International Workshop

AGING PHENOMENA IN GASEOUS DETECTORS

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The Basics on Aging and the Early Developments since the 1986 Workshop

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New Insights into Aging Phenomena from Plasma Chemistry

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Plasma polymerization (deposition of solid materials in plasma) is reviewed with respect to the following aspects:

- Mechanisms of polymer formation in conventional free radical chain-growth polymerization and in plasma polymerization
- Competitive Ablation & Polymerization (CAP) principles
- Plasma sensitivity of elements based on the electro negativity of atoms
- DC discharge polymerization; dark polymerization in the cathode region and glow polymerization in the negative glow
- Effect of electrical field on sputtering & deposition on cathode and anode
- Effect of wall contamination on plasma polymerization.

Summary of Talk: The mechanisms of material formation in plasma polymerization, or plasma chemical vapor deposition (CVD), are completely different from those for conventional polymerizations. Polymeric materials are formed via recombination of free radicals that are formed by fragmentation of molecules caused by the bombardment of energetic species in plasma. Organic compounds can be classified in the following types with respect to polymerization characteristics in plasma: Type 1 monomers are molecules with triple bond and/or aromatic-, hetero-aromatic structures. Type 2 monomers are double bond and/or cyclic structure containing compounds. Type 3 monomers are aliphatic compounds that do not contain structures mentioned in Type 1, and Type 2 monomers. Type 4 monomers are oxygen-containing compounds such as alcohols, ethers, and esters. Plasma polymerization and plasma ablation of materials occur simultaneously in a competitive manner according to the 'Competitive Ablation and Polymerization' (CAP) principle. The balance of these two processes is dependent on conditions of the plasma and on factors of the reactor as well as the types of monomers. DC discharge polymerization consists of dark polymerization in the cathode region and glow polymerization in negative glow. More than 85% of polymerization is due to the dark polymerization, which deposits on the cathode, and polymers formed by the glow polymerization deposits on any surface, including cathode and anode. The anode is a passive surface as far as plasma polymerization is concerned. Characteristics of the cathodic polymer and the glow polymer are significantly different; i.e. cathodic polymers are much tighter networks than the corresponding glow polymers. The deposition mechanisms for glow polymerization and for the dark polymerization are also different. The most important operational parameter for the glow polymerization is W/FM, where W is discharge wattage, F is volume or molar flow rate, and M is the molecular weight of the monomer used, which represents the energy input per mass of monomer gas (J/kg). Most glow discharge polymerizations are carried out in the range of 1 – 1,000 MJ/kg using monomers, which have a total bond energies per mass in the range of 10 – 100 MJ/kg. An overview of plasma polymerization based on the difference of the dark polymerization and the glow polymerization is presented to illustrate the role of electrode surfaces in alternating high frequency discharge (40 kHz and 13.5 MHz). Plasma sensitivity of elements seems to follow the electro negativities of atoms. For example, whether or not F atoms (high electro negativity) of Teflon could be liberated when Teflon is exposed to plasma is determined by the electro negativity of the atom but not by the bond energy of C–F bond. Contrary to the widely spread concept that Teflon is stable even in plasma due to the strong C–F bond, F atoms are liberated from Teflon easily and spread over the entire reactor causing serious problems in certain cases. Since an F atom in a plasma state is reactive, it reacts with surfaces, but the fluorine atoms in the fluorinated surface is labile to plasma and tends to come out of the surface again. Thus, F atoms recycle between solid surface and plasma phase repeatedly. An example of the damaging effect of wall contamination by F-containing fragmented material on the adhesion of nano-film, which is used for corrosion protection of aluminum alloys, is presented to illustrate the importance of the CAP principle and the influence of reactor wall contamination.

Aging Phenomena in Large Detector Systems

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Experience with the L3 Vertex Drift Chamber at LEP

L3 Vertex Chamber Group

presented by **Botio Betev**

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The design, performance, running parameters, infrastructure and operational history of the pressurized, high resolution drift chamber, based on the time expansion principle, is described. This cylindrical chamber with an outer diameter of 93.7 cm and sense wires with length of 98.0 cm was the tracking device of the L3 Experiment during 11 years of LEP operation. The total received radiation dose in the central region during this period, measured by the L3 radiation monitor is about 2300 rad. The radiation received on the wires, estimated from their integrated counting and tracks rate, amounts to $8.0 \cdot 10^{-6}$ C/cm.

Summary of Talk: The tracking chamber of the L3 Experiment at LEP, based on the time expansion principle, its design, running parameters, performance and operational history, as well as its gas system and gas test chamber are described. The chamber is a cylinder with outer diameter of 93.7 cm and sense wires with length of 98.0 cm. The volume is divided into two concentric cylinders. The inner cylinder is subdivided into 12 sectors, and the outer into 24 sectors. The wire configuration of each sector divides the volume into detection gap and drift region. These are separated by the grounded grid planes, made out of 100 micron gold-plated copper-beryllium wires. The sense anode wires, 8 in each inner sector and 54 in each outer sector, are made of 20 micron gold- plated tungsten. The voltage gradient between the anodes and the grid (3mm distance) is 2.9 kV. The gas mixture used is carbon dioxide/isobutane 80:20 at an absolute pressure of (1.200 +- 0.1%) bar. The gas flow refreshes the chamber gas volume in about five hours. The gas components are monitored by a mass spectrometer and a test chamber, based also on the time expansion principle. The long-term stability of the gas parameters was at the 0.1% level. The average number of electrons seen by an anode acceptance region is about 30 and the gas gain in the detection gap is on the order of 50,000. During the 11 years of operation at LEP, the total received radiation dose in the central region measured by the L3 radiation monitor is about 2300 rad. The pulse amplitude on the anodes, induced by the electron clusters remained unchanged during all 11 years of running the chamber at LEP. Unchanged remained also the single wire resolution, which was in the order of 50 microns.

Experience with the ZEUS Central Tracking Detector

(title assigned)

presented by **David Bailey**

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The Central Tracking Detector (CTD) of the ZEUS experiment has been in operation since 1992. It is a cylindrical drift chamber of length approximately 2 meters with a diameter of about 1m. The CTD has operated reliably in a magnetic field of 1.4T using a gas mixture of $Ar/CO_2/C_2H_6$ 90:8:2. Age related effects in the CTD are reported, with particular attention paid to the necessary addition of H_2O to the gas mixture during operation in 2000 to cure repeated trips of the high voltage.

Summary of Talk: The ZEUS Central Tracking Detector is a cylindrical drift chamber, built to a similar design as the CDF tracker. Its 4608 sense wires are arranged into 9 superlayers of eight wires each. Five of these superlayers have wires parallel to the chamber axis whilst the other four have small stereo angles (about 5 degrees). Originally developed for use in a 1.8T field with a Ar/C_2H_6 50:50 gas mixture, it has operated reliably from 1992 to the present in the ZEUS environment of 1.4T and a gas mixture of $Ar/CO_2/C_2H_6$ 90:8:2 bubbled through ethanol. The properties of this gas (Lorentz angle, drift velocity and gain) are similar to Ar/C_2H_6, but it offers safety against whisker growth and is quieter in operation. Until 1997 the CTD had shown no signs of aging. However, towards the end of that year there were several instances of non-beam induced trips of the high voltage (HV) that could only be cured by disconnecting the affected section of the chamber from HV for a number of days. This problem became more serious during the 2000 data-taking period and so, after a short study, the gas mixture was changed to add a small quantity of distilled water. This addition of water had some undesirable effects, notably large changes in the electron drift velocity and Lorentz angle, but to date has completely cured the problem of trips of the HV. The CO_2/C_2H_6 composition of the gas was subsequently adjusted to return the drift velocity and Lorentz angle to acceptable values. This change was motivated by use of the Garfield program to predict relative changes in the Lorentz angle due to variations in the gas composition.

Observations on Cathode Aging (Malter effect) in High–Irradiation–Load Drift Tubes

presented by **Gerhard Bohm**

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The 'Malter' effect (ignition of self-sustaining discharges) in honeycomb drift chambers with cathodes of conductive plastics, using CF_4–containing drift gases, as observed in prototypes of the outer tracker in HERA–B, is reviewed. In addition to the observations from irradiation tests, the results of additional studies of cathode surface properties are presented.

Summary of Poster: The main observations discussed here are connected to a form of cathode aging known as 'Malter' effect, with special attention to the following influencing factors:

- Surface properties: The presence of an isolating, irradiation-dependent surface layer could be demonstrated by various methods (electron- and X-ray spectroscopy, among others).
- Beam conditions: According to observations of striking differences in aging effects for various beams, the decisive role of local peaks in ion current densities, as caused by heavily ionizing particles ('HIPS'), became very likely.
- Influence of quencher: The use of CH_4 as quencher in CF_4 containing gases was found responsible for enhanced plasma polymerization on both electrodes.

Some semi-quantitative estimates are included, in order to promote some discussion on the physical explanation and systematization of the often not-easy-to-interpret observations.

A Clean Gas System with Closed Loop for a Large Gaseous Detector Operating at High Rates

presented by **Marcus Hohlmann**

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The gas system of the Outer Tracker (OTR) of HERA–B produces the desired gas mixture (standard mix is Ar/CF_4/CO_2 65:30:5) and circulates the counting gas through the detector at a flow rate of 22 m^3/h, i.e. 1 vol/h. It controls flows and regulates pressures in all 26 OTR half–superlayers, purifies the gas upon return from the detector, and automatically performs a quantitative analysis of main and trace (O_2, N_2, H_2O) gas components for the common input and the outputs of all half–superlayers. We report on constructing such a large system with major gas purification stations ($\approx$ 60 kg of purifying agent per station) using only non–outgassing, "clean" materials and devices, e.g. stainless steel, PEEK, baked Viton, and metal bellows pumps; the experience of running the system for over a year is also discussed. We review the extensive use of an epoxy glue as a non–outgassing sealing material in applications with up to 100 bar pressure.

Summary of Poster: The system has been supplying all OTR chambers with gas since the beginning of the HERA–B commissioning run in January 2000. Fresh gas has been continuously added at rates of 0.5 – 2%/h by the mixing station. The monthly gas consumption of CF_4 – by far the most expensive gas component at about 70 DM/kg – was about 400 kg/month. The pressure regulation of the chambers worked well keeping them at slight over-pressures of 0.3 – 0.6 mbar relative to ambient air pressure. A system of safety valves successfully prevented all chambers from becoming dangerously over-pressurized or under-pressurized while preventing air from entering the chambers during pressure alarms. For most of the run period the gas system was able to keep the variation of the main gas concentrations within the range allowed by design: (65$\pm$1)% for Argon, (30$\pm$1)% for CF_4, and (5$\pm$0.2)% for CO_2. A variation of Argon concentration by 1% corresponds to a change in gas gain of $\approx$15% under nominal operating conditions. The purification system for removal of oxygen and water was commissioned by mid-April 2000. During commissioning it was observed that the regenerable oxygen purifier absorbs not only oxygen, but also significant amounts of CO_2 and water. Appropriate CO_2 conditioning procedures after regeneration were successfully established to ensure a stable CO_2 concentration in the counting gas. Due to the water absorption by the oxygen purifier the detector was operated with very dry gas (c(H_2O)$<$ 20 ppm) for most of the 2000 run even after the water purifier had been excluded from the system. One regenerated purifier could keep the oxygen content at levels below 200 ppm for about 10 days giving the gas crew considerably more than the needed minimum of 3 days to regenerate the second oxygen purifier in parallel. An operational problem was that leaks occurred repeatedly in the bellows of the metal bellows pumps that circulate the gas. The leakage is most likely due to grease, metal shavings and/or dust getting wedged in the outside of the moving bellows and finally causing a rupture; the possible influence of fluorine compounds or radicals in these ruptures is currently under study. To prevent further leaks 5 pumps were lifted up from the floor of the pump house and an air filter was installed. A leak detection system is being installed for the pumps using an oxygen meter and valve system to pinpoint any future pump leaks very quickly.

Space Distribution of Streamers in Straw Drift tubes

G. Gavrilov, A. Krivchitch, E. Kouznetsova, V. Maleev

presented by **Ekaterina Kouznetsova**

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The appearance of the limited streamer mode in straw drift-tubes operating with a $Xe/CO_2/CF_4$ gas mixture has been investigated. Space distributions of the streamer mode across the straw with different gas gains and wire offsets in the straw have been measured. It has been found that the streamers are generated in the narrow zone (FWHM = 400 μm) surrounding the anode wire. It was shown that the streamer contribution sharply increases with high voltage and that it reaches practically 100% at a gas gain of about 10^5. The number of streamers was observed to increase a few times when the wire is offset by 300 μm, even at a not too high gas gain of $3.5{\cdot}10^4$. This can greatly boost the aging of anode wires because the streamer mode is an additional noticeable source of oxygen ions and active radicals generated in the gas discharge since the total charge produced per streamer may be a hundred times larger than that of a proportional pulse. The results of a corresponding aging investigation of straws with an accumulated charge of 9 C/cm are presented.

Summary of Poster: The data were obtained during investigations of the appearance of limited streamer mode in straw-tubes with a working gas mixture of $Ar/CO_2/CF_4$ 70:10:20. This test was carried out using a ^{55}Fe-source. The straw-tubes used in our investigations are being designed for the TRT in the ATLAS experiment. They have a diameter of 4 mm. The cathode consisted of a 50 μm carbon-coated Kapton film and the anode wire was made of gold-coated tungsten with a diameter of 35 μm. In order to be as close as possible to the real experimental conditions, the high voltage was chosen to compensate the space charge effect that decreases the gas gain at intense irradiation. This resulted in a gas gain that was too high for the non-irradiated parts of wire because at the edges of the irradiated zone the gas gain was 50% higher than nominal. It was shown that the first signs of aging were observed at both edges of the irradiated zone. This effect is due to the higher gas gain and streamer mode contribution observed in these areas. The contribution of Limited Streamer Mode (LSM) in the straw-tubes quickly increases as a function of the high voltage applied to the straws. Thorough studies of the LSM appearance across the straw were performed. It is shown that the LSM has a space distribution with a width and an intensity that strongly depend on the gas gain and anode wire offset. It was shown that the contribution of the streamer mode is so large that it reaches more than 20% even at a moderate gas gain of $5 \cdot 10^4$. It is necessary to note that the limited streamer mode could be one of the very important reasons for anode wire aging since the total charge produced per streamer is around 10 – 20 times larger than that from a proportional pulse. Preliminary calculations for both the multiplication and attachment coefficients were performed with the "MAGBOLTZ" program. It was shown that an electronegative zone exists around the anode wire that has dimensions that match the space distribution of the LSM.

Manifestation of Aging Effects in Gas Proportional Counters

presented by **Tadeusz Kowalski**

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The influence of aging on energy resolution, length of energy resolution plateau, decrease of gas gain and on the so-called count rate effect has been measured. Special attention has been paid to the performance of aged counters under high gas gain and high count rate. Longitudinal and azimuthal distributions of anode deformation were also determined.

Summary of Poster: The aged counters were filled with Ar/isopentane and Ar/CO_2/N_2/isopentane mixtures. Isopentane was selected as an additive to accelerate the aging at normally encountered anode current. The detectors were exposed to radiation coming from ^{109}Cd and ^{90}Sr sources. The aging currents were: 20nA, 85nA and 1000nA, respectively. Results:

- strong degradation of energy resolution and shortening of energy resolution plateau were observed; the effect is much stronger for higher gas gain and higher intensity of measured radiation,
- the decrease in gas gain is a linear function of collected charge; for fixed collected charge it is a linear function of applied high voltage,
- the count rate effect strongly depends on collected charge; for fixed collected charge it depends on the applied high voltage, i.e. for low gas gain and low intensity of radiation a good spectrum for ^{55}Fe is observed, whereas for high gas gain and high count rate a double-peak structure is observed.

It should be underlined that all aging tests were done at normally encountered anode current. The main scope of this work was to determine which parameter of the detector is most sensitive to aging.

A Study of Aging Effects in Gas–Monitoring Proportional Counters of the BAC Calorimeter of the ZEUS Experiment

presented by **Tadeusz Kowalski**

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The multi-cell proportional chambers at the backing calorimeter of the ZEUS experiment at the storage ring HERA are supplied with an Ar/CO_2 gas mixture by an open gas system. Flushed proportional counters with built-in ^{55}Fe sources are used as gas system monitoring detectors. The results of measurements of aging effects for the gas–monitoring counters will be presented.

Summary of Poster: Due to the structure of the ZEUS detector the whole BAC calorimeter gas system has been divided into 79 branches. Each branch consists of about 65 proportional chambers connected in parallel. There are monitoring proportional counters both at the input of each branch and at the output of "the last chamber" of the branch, i.e. the chamber placed at the longest distance from the gas inlet. For these chambers the worst conditions of gas exchange occur. Overall, in the BAC calorimeter there are 79 input- and 79 output counters. For all these counters the pulse height distributions of a ^{55}Fe line were measured during the counter operation. The characteristic behavior of degradation for the OUTPUT counters is dramatically demonstrated by the deterioration of the ^{55}Fe X-ray spectrum on the lower energy side of the main peak. These observations are in a good agreement with those presented by others. However, it should be strongly pointed out that for the INPUT counters the degradation behavior is in contradiction to that for the OUTPUT counters: An unexpected peak degradation is measured. The undesirable changes in pulse height distribution appear in this case on the higher energy side of the main peak. An increase in gas gain is observed. Some idea of explanation of this phenomenon will be given. The BAC gas system is open so that the working gas pressure follows the atmospheric pressure. The response of aged counters to pressure variation will also be presented.

Study of Aging Properties of a Wire Chamber Operating with High–Pressure Hydrogen Designed for a Precision Measurement of the μp–Capture Rate.

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presented by **Evgeny Maev**

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The project for high precision studies of muon capture in hydrogen is based on the application of a multi-wire proportional chamber (MWPC) operating in ultra pure deuterium-depleted hydrogen (protium) at high pressure. A special test setup was constructed at PNPI to investigate the MWPC performance at the expected experimental conditions. The chambers were tested inside a vessel filled with clean hydrogen at 10 bar pressure. The aging studies of the MWPCs were performed under intense irradiation from an alpha-source (^{241}Am) and a beta-source (^{90}Sr). For example, after 45 days of continuous irradiation by alpha-particles with four intermediate gas re-fillings we did not see any changes in the currents, in the signal shapes, and in the counting rates. It was demonstrated that the MWPCs can operate without degradation at least up to accumulated charges of 0.1 C/cm of wire. These irradiation conditions are much more severe than in the real experiment. The electron microscopic and X-ray analysis of the anode and cathode wires revealed no serious signs of destruction of the wire surfaces. However, in several radiation tests an appearance of dark currents was observed (up to 10 μA), the nature of which is not yet clearly understood. During the study of the MWPC we have observed the appearance of short duration (about 20 ns) signals with amplitudes an order of magnitude larger than for normal signals from the alpha particles. The number of such signals ("streamers") strongly depends on HV. We shall continue these tests in the future with the goal to obtain more detailed information about aging properties of the MWPCs operating with high-pressure hydrogen.

Summary of Poster: A new experiment for high precision studies of muon capture in hydrogen is based on the application of a special Time Projection Chamber (TPC) for detection of the incoming muons and the outgoing decay electrons. The TPC contains four multi-wire planes. The idea of using the TPC as an active target for this experiment is based on ten years of working experience with a TPC operating in ionization mode. The switch to the proportional regime was prompted by the necessity to simultaneously register the heavily ionizing particles (slow muons) and weakly ionizing particles (the decay electrons). This is possible with a gas gain above 10,000. The target pressure was chosen to be 10 bar. As the world-wide experience with using multi-wire proportional chambers (MWPCs) in hydrogen at such conditions was very limited we had to carry out detailed studies of their performance. The MWPCs were tested in a special setup filled with clean hydrogen at 10 bar pressure with gas contamination (N_2, O_2, H_2O) of about 10 ppm. After design optimization, the following basic parameters of the MWPCs have been chosen: cathodes- Fe wires, 50 μm diameter, 0.5 mm spacing; anode-W(Au) wires, 25 μm diameter, 4 mm spacing; the anode-cathode gap is 3.5 mm. The MWPCs showed stable operation up to HV=7.0 kV providing a gain of up to 20,000 and 5,000 while detecting relativistic electrons and alpha-particles, respectively. The difference of the gains is a result of the space charge effect. The aging studies of the MWPCs were performed under intense irradiation from the alpha source (^{241}Am, energy 5.5 MeV). The nominal HV was 6.5 kV. The current from the chamber (determined by the source intensity) was 360 nA. The maximum current from a single wire was 50 nA. These currents are comparable to the currents in the real experiment with a 50 kHz muon beam. For example, the current in the entrance muon chamber will be 5 nA per wire (i.e. an order of magnitude less than in our tests) and in the TPC the current per wire will be about 20 nA. Note that the signals from alpha particles have much higher amplitudes than even the muon signals from the muon-stop wires. Some preliminary results: after 45 days of continuous irradiation by alpha-particles with four intermediate gas refilling we did not see any changes in the currents, in the signal shapes, and in the counting rates. The maximum collected charge per 1 cm of wire was 0.1 C/cm. So we may conclude that MWPCs can operate reliably in hydrogen with life times considerably exceeding the running time of the experiment. Note that these studies have been done with contaminations of the hydrogen of 1ppm just after the filling up to about 10ppm several days after the filling. We plan to repeat these studies with ultra-clean hydrogen (with the concentration of impurities less than 0.1ppm) using a special circulation system.

Gas Gain and Space Charge in Quick Aging Tests of Gaseous Detectors

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presented by **Victor Maleev**

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We present the results of investigations into the gas gain of straw drift-tubes under different irradiation intensities from a ^{90}Sr beta-source. Tests were performed with a gas mixture containing Xe, CO_2 and CF_4. The goal of this investigation was to show how to optimize the choice of the high voltage for quick aging studies of modern gaseous detectors. In order to perform the aging investigation within a reasonable time period, the rate of accumulated charge should be at least 10 times more than what is expected in a real experiment. This forces us to choose a reasonably quick charge accumulation of about 0.1 – 0.2 C/cm per day (1 – 2.5 μA/cm). In order to be as close as possible to the real experimental conditions, the high voltage should be chosen so that it compensates the space charge that affects the gas gain in such quick aging tests. It was shown that performing aging tests without such compensation prevents any sufficiently reliable extrapolation of the obtained results to the real experimental conditions.

Summary of Poster: The main goal of this work was to investigate the influence of space charge on the gas gain for different irradiation rates. These investigations were performed with straw drift-tubes, designed for the ATLAS TRT, and operating with a $Xe/CO_2/CF_4$ 70:10:20 gas mixture. The straw tubes used in our investigations had a diameter of 4 mm. The cathode was made of 50 μm carbon-coated kapton film and the anode wire was made of gold-coated tungsten wire with a diameter of 35 μm. The gas gains have been measured for different irradiation intensities from a ^{90}Sr beta-source, which correspond to the ionization plateau of the current densities in the range of 2 – 60 pA/cm. It was shown that the limited streamer mode, which is an additional strong source of the space charge production, became quite noticeable starting from a gas gain of about $4.5 \cdot 10^4$ and quickly rose depending on the increase in the high voltage. It is possible to point out two options how to choose the applied high voltage to perform the quick aging test. The first one is to fix the gas gain under definite high voltage and to carry out the aging test under intense irradiation. In this case, the space charge decreases the gas gain and therefore reduces the electron component of the negative charge flow to the anode. The second one is to perform the aging investigations with increased high voltage to compensate the space charge influence on the gas gain in the irradiated zone. It was shown that even under a moderate rate of charge accumulation (1.5 μA/cm) the gas gain drops by about 40% due to the space charge effect. Such a strong space charge contribution to the gas avalanche development causes inadequate extrapolation of results obtained in quick aging tests to the real experiment conditions. In order to be as close as possible to the real experimental conditions the high voltage could be chosen to compensate the space charge under intense irradiation. This would put the non-irradiated part of a wire at a too high gas gain. As a result, the gas gain was about 50% higher than nominal gain ($2.5 \cdot 10^4$) at the edges of the irradiated zone. This should be taken into account in the analysis of the obtained data. As a result of our investigations we propose a method which achieves a proper balance between reasonable irradiation rate and minimizing the gas gain drop due to the space charge effect in quick aging tests.

Design and In–Orbit–Performance of the Position–Sensitive Proportional Counter on Board the X-Ray Astronomy Satellite ROSAT

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presented by **Elmar Pfeffermann**

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The Position Sensitive Proportional Counter (PSPC) was the prime focal plane instrument on board ROSAT. It was a conventional multiwire counter, operating in an energy range from 0.1 to 2.4 keV. The counter gas was a mixture of Ar/Xe/CH_4 65:20:15 at a pressure of about 1.5 bar, replenished at a flow rate of 2.5 stcm^{3}min^{-1}. At 1 keV the detector had an energy resolution of $\delta E/E = 0.41$ FWHM, a position resolution of 230 μm FWHM and a quantum efficiency of 50%. The background rejection capability of the detector in a space environment was 99.85%. Within the first four years of the mission the PSPC has been used for 80% of the observing time. Thereafter the gas supply was nearly exhausted and the PSPC was used only for special observations. The drop of the gas gain of the detector during the whole mission was 10%. After eight years a final observation with the PSPC has been carried out with an extremely reduced gas flow and at the border of the radiation belts with a very high particle background. During this observation the detector probably suffered a discharge and within several days an increasing area with 50% gain loss developed. We will report on the detector design, the in–orbit–performance of the PSPC and some results of the ROSAT mission.

Summary of Poster: ROSAT is a German X-ray satellite with major contributions from the UK (UV-telescope) and the USA (HRI-detector and satellite launch). The satellite was launched in 1990 and operated for more than eight years in orbit. The main scientific objective of the ROSAT mission was to perform the first all–sky–survey in the energy band from 0.1 to 2.4 keV with an imaging telescope. After completion of the survey ROSAT was used in pointed mode for detailed observations of selected objects. The main scientific payload of ROSAT was an imaging X-ray telescope with a fourfold nested Wolter type 1 mirror system with a maximum aperture of 83 cm and a focal length of 2.4 m. The focal plane instrumentation carried two different types of X-ray image detectors, which complemented one another: two redundant Position Sensitive Proportional Counters (PSPC) with a sensitive area of 8 cm diameter, and one High Resolution Imager (HRI) based on micro channel plates, with a sensitive area of 2.5 cm diameter. The detectors are mounted on a carousel, which allows the positioning of the desired detector in the focus of the mirror system. Except for the HRI, the whole focal plane instrumentation was developed and built in our institute. The PSPC includes two multiwire proportional counters. The upper one, below the entrance window and a drift region of 8 mm, is the position and energy sensing X-ray detector. The lower one is an anti-coincidence counter, to distinguish between X-ray events and background events. We used 10 μm tungsten wires for the anode grids with a wire spacing of 1.5 mm for the X-ray detector and 2 mm for the anti-coincidence counter. For the cathode grids 50 μm Pt–Ir wires had been used with a wire spacing of 0.5 mm. The two cathode grids of the X-ray detector are electrically subdivided in strips of 3.5 mm width for the position readout of the x-ray events by the center–of–gravity method. The grids were manufactured on a winding machine and glued on glascermic frames. Due to a very precise spacing of the wires ($\pm 2\mu m$) and the grid gaps ($\pm 5\mu m$), we obtained a very homogeneous gas gain over the sensitive area (variation 3%). All grids of the flight units were checked for wire spacing and wire tension. The resonance frequencies of the wires had to be above 400 Hz to survive the rocket launch. The PSPC is operated with a gas mixture of Ar/Xe/CH_4 65:20:15 at a pressure of 1466 mbar at 22^{o}C. The detector window is a 1 μm thick polypropylene foil coated with carbon and Lexan. The foil is supported by wire grids and aluminum struts. The differential diffusion and the leakage of the window foil as well as the cleaning of the detector gas from crack products of the quench gas required a gas flow system. The detector gas was density controlled with a selectable flow rate between 2 to 5 stcm^{3}min^{-1}. A filter wheel in front of the detector window included a vacuum door with three calibration sources for ground checkout and in orbit calibration. Several watch dog functions were implemented in the on-board software of the experiment computers to ensure the nominal function of the PSPC: Limit checks of housekeeping values like gas pressure, high voltage and count rates were carried out continuously and in case of an overshoot the detector was switched off. The ROSAT orbit (circular, 580 km, inclination 58 deg) touches at its northern and the southern part the inner radiation belt and crosses the South Atlantic Anomaly, regions with extremely high particle fluxes. Within these parts of the orbit the detector was switched off. During the mission we found two degradation features. We had a gas gain loss of about 3% year^{-1}. In addition, we found a slight increase of background in the energy channels below 180 eV. These low energy events were after-pulses of high energy events with a time delay of about 1 ms. At the end of the mission, with nearly no gas flow, high particle rates, and watch dogs switched off the detector had a corona discharge. After that, an area increasing from 1 mm^2 to several

cm^2 developed with a factor of two lower gas gain. The ROSAT mission increased the number of known celestial X-ray sources from several 10^3 to more than 10^5. But ROSAT not only contributed to the number of known X-ray sources. Due to the high background rejection efficiency and the good energy resolution of the PSPC four-color X-ray images of all types of objects like the near moon, comets, normal stars, neutron stars, binary systems, supernova remnants, galaxies, clusters of galaxies and the most distant quasars could be measured with high contrast.

The Performance of a Wire Chamber with a Light-Sensitive Methane/TMAE Gas Mixture at High Counting Rates

presented by **Damijan Skrk**

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A multiwire photon detector with the addition of TMAE vapor to achieve photo-sensitivity was tested as a possible candidate for the HERA–B RICH detector. The main obstacle for use of such a methane/TMAE filled gas detector in a high rate experiment, appears to be prohibitive aging in the form of rapid loss of chamber gas gain and thus of efficiency. The lower efficiency in turn reduces the number of detected photons per Cherenkov ring and thus the velocity resolution. The gain reduction is attributed to polymer deposits on the anode wires. In order to remove these deposits, a special circuit was constructed, which enabled heating of the anode wires in-situ with elevated currents. An almost complete recovery of the gain was achieved. Unfortunately, this recovery is not of long duration, but is followed by a quick drop in gain. With periodic short heat treatments, an average gain considerably higher than for the non-heated wires could be achieved. Although this rejuvenation of the aged wires does not seem to be sufficient for HERA–B, it could hopefully be useful in experiments with somewhat lower rates.

Summary of Poster: One of the candidates considered as a photon detector for the HERA–B RICH was a multiwire proportional detector with the addition of TMAE vapor to achieve photo-sensitivity. The test module, inspired by the JETSET chamber, consisted of 64 (8×8) cells with 8×8 mm^2 cross section and 10 cm length. It was made of 0.2 mm thick slotted, gold-plated bronze plates. A 50 μm diameter gold-plated tungsten anode wire was stretched along the axis of each cell, being soldered to an end-plate on one end and to a ceramic bridge on the other. The module was closed on the top and bottom by the end-plate and by a quartz window respectively. Such a design ensured short drift times, required by the 96 ns bunch crossing time in HERA. It also permitted operation with the TMAE vapor pressure below saturation, thus avoiding condensation, while conserving high quantum efficiency. The signals were read out by charge sensitive preamplifiers. They were then led through amplifiers (EG&G Mod.574) to CAMAC discriminators (Philips Mod.7106) and to CAMAC scalers (CAEN, Mod.$C_2$57). The discrimination threshold could be set by the computer programme, which enabled quick scans of the individual cell count rates versus their threshold voltage setting. With -2650 V on the cathodes and the anodes at ground potential, an exponential pulse height distribution, due to single photons from a UV lamp, was obtained. Thus, the distribution of count rate versus threshold voltage should also be exponential, with the logarithmic derivative inversely proportional to the average pulse height and thus to the chamber gas gain. A small UV light source and a spherical mirror gave a parallel beam with which 8 cells were illuminated resulting in an event rate of about 2.5 MHz per cell. As may be seen from the threshold scans of cells at the beginning and towards the end of illumination, the gain has been considerably reduced which is indicated by the increased slope. On the other hand, the rate extrapolated to zero threshold, has not changed, indicating no change in quantum efficiency. The gain reduction is attributed to polymer deposits on the anode wires. The ratio of average responses of illuminated and non-illuminated cells showing a gain reduction to about 30% of the initial value in 300 hours of illumination. This illumination corresponds to $\sim$ 55 mC of accumulated charge per cm^2 of the detector surface. In order to remove these deposits, a special circuit was constructed, which enabled heating of the anode wires with elevated currents. A mass-spectrometric analysis showed no changes in composition of evaporated components above a temperature of 200^0C, which was the limit set also by possible loosening of the solder bonds. The threshold scan immediately after heating shows that the gain has increased to approximately the value it had at the beginning of illumination. In other words, the rejuvenation with heating almost compensates the aging due to illumination. Unfortunately, this rejuvenation is of short duration. The gain falls more quickly after heating. Nevertheless, the heating of anode wires has an overall beneficial effect. With periodic short heat treatments, an average gain considerably higher than for the non-heated wires could be achieved. Although this rejuvenation of the aged wires does not seem to be sufficient for HERA–B, it could hopefully be useful in experiments with somewhat lower rates.

Aging in the Central Jet Chamber of H1

(title assigned)

presented by **Carsten Niebuhr**

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The track detectors of the H1 experiment are in operation since 1992 at the HERA *ep* collider. Various aging effects which have been observed in the period 1993 – 1997 in the Central Jet Chamber of H1 (CJC) are described.

Summary of Talk: The track detectors of the H1 experiment are in operation since 1992 at the HERA *ep* collider. In the central region charged particle tracks are measured with two cylindrical jet drift chambers which are mounted concentrically around the beam pipe. The inner ring, CJC 1, has 24 layers of sense wires strung parallel to the beam axis and covers the radial range $20 < r < 45$ cm, whereas the outer ring, CJC 2, consists of 32 layers covering the range $53 < r < 85$ cm. For most of the running period from 1992-1998 an Argon/Ethane 50:50 gas mixture with 0.1% H_2O as additive was used. Both CJC rings were connected to the same gas circuit. Already after the first few month of operation at HERA a number of wires broke in CJC 1. In total, 48 wires broke in CJC 1 over a period of 7 months while no damage was observed in CJC 2. Corrosive remnants from the gilding process were found on the crimp parts of CJC 1 which induced brittle fracture of the tungsten wires. After changing the design and manufacturing process of the crimp parts of CJC 1 the chamber was rewired in the shutdown 1993/94. Starting in 1996 a significant degradation of the performance in the lower part of CJC 2 was observed. By the end of 1997 a local gain drop of up to a factor of 4 had developed showing a clear dependence on the height of the affected sense wire in CJC 2. Investigations of several of those wires with an electron microscope revealed a correlation between deposits observed on the wires and the measured gain loss. As a consequence all sense wires in CJC 2 have been replaced in the shutdown 1997/98. Another problem occurred in 1998/99 when HERA was operated with electrons instead of positrons leading to increased background levels in the H1 interaction region. In several cells of CJC 1 and CJC 2 higher chamber currents started to develop which after some time led to local HV instabilities, most likely due to the Malter effect. By replacing 0.1% H_2O with 0.8% Ethanol as additive most of the affected regions could be recovered and behaved normally afterwards.

Restoring Contaminated Wires, Removing Gas Contaminants and Aging Studies of Drift Tube Chambers

D0 Collaboration

presented by **Tom Marshall**

Indiana University, Bloomington, IN, USA

The original muon detection system of the Fermilab D0 colliding beam experiment contained 12,000 drift cells 5 cm by 10 cm in cross section and up to 580 cm in length. There was one recycling gas system for all the chambers. During the first year of running, it was discovered that inefficient cells, all in regions of high radiation, had a contaminating shell of crud coating their wires. The source of the contaminant was found to be outgassing of the cathode pads which were made from a laminate of fiberglass and epoxy/polyester resin, with a copper cladding on one surface. The vapor formed a brittle sheath on the wires, but only in regions of high current discharge due to radiation from the accelerator and colliding beams. A method for cleaning the wires in place was devised. By heating the wire quickly to a temperature close to the melting temperature of gold, the sheath was ripped to shreds and blown away. The procedure for "zapping" wires and for removing the contaminating vapor will be presented. The upgraded D0 experiment now uses Iarocci-type mini-drift tubes for the forward muon system. The results of aging tests for these chambers will also be presented.

Summary of Talk: The Fermilab D0 experiment is a large, general-purpose collider detector. It consists of three systems: tracking, calorimetry and muon detection. The central muon detection system (WAMUS) is made up of a set of proportional drift tube chambers which surround large magnetized iron toroids. All of the WAMUS PDT chambers are made of the same 10 cm by 5 cm aluminum tubes, but vary from 330 cm to 580 cm in length. Each drift cell has top and bottom cathode pads, which are made of either G-10 (25%) or Glasteel (polyester and epoxy based plastic sheets with a glass fiber mat)(75%). Only the cathode surface has copper cladding. The aluminum tube is grounded while the potentials of the sense wire and pads are kept at +4.6 and +2.3 kV respectively. The gas mixture was Argon/Freon/CO_2 90:6:4 during the first run, and is Argon/Freon/Methane 84:8:8 for the upgraded detector. All PDTs share a recycling gas system. The forward muon tracking detector (FAMUS) consists of three layers of Iarocci-type mini-drift tubes (MDTs) covering large toroid magnets. Each tube has eight 1 cm by 1 cm cells up to 583 cm in length, with a 50 micron (W-Au) anode wire in the center. The tubes are made from aluminum extrusion combs with stainless steel cover foil and inserted into plastic (PVC) sleeves. The anode wire is grounded at the amplifier while the cathode potential is -2.3kV. The fast gas mixture is CF_4/CH_4 90:10. The MDTs also have their own gas recycling system. Although most of the hadrons and electrons are filtered out by the calorimeters before they reach the muon system, at small angles the background particle flux is rather high. Another large source of radiation during the first run was from the main ring accelerator, which passed, with very little shielding, right through the detector. During the first year of running we realized that the drift cells in regions of high level radiation were becoming very inefficient. We extracted and replaced several wires that were in the region of high radiation. The bad news was that the exposed wires were covered with a thick brittle sheath of crud. The good news was that the wall and pads of the drift cells were not damaged. Since changing the 500 plus wires that were affected was not a possibility, we searched for a cure that would clean the wires in place, and could be completed in a matter of days during an extended shutdown. A sample of the wire crud was taken to Argonne's chemical physics lab. Meanwhile, we performed our own studies and discovered a number of crud facts and attributes:

- The crud scrapes off easily, and dissolves in ammonia and in water.
- The source of the crud is from the vapors of the Glasteel of the cathode pad. The crud can be created quickly by flowing gas through Glasteel ground up into a powder and then into a test cell running at 1 microamp per inch of wire. The test cell has the same geometry as the PDTs. Crud formation is not dependent on the percentage of Freon in the gas mixture.
- The crud can be removed by increasing the cell voltage to create currents of 10 microamps/inch, but this process takes several days and is not a practical way to clean thousands of 500 cm or longer wires.

The Argonne analysis seemed to confirm our results, identifying the crud as similar to CASCAMITE 14, a powdered resin glue, using styrene. We made several attempts at renewing dirty wires inside drift cells, but only succeeded in forming an insulating layer of aluminum oxide on the cell walls and copper oxide on the pad surfaces. In our attempt to exploit the high current cleaning effect, however, we discovered that if the wire is heated quickly to a temperature close to the melting point of gold, the sheath of crud shatters and blows away! If the heating is too slow, the crud cooks into a coating which is hard to remove and is insoluble. If the temperature is too high, the gold melts and beads up (later tests showed that drift cells still worked if the gold was beaded up or even completely removed from the Tungsten wire). We were able to clean over 5000 wires during a two week shutdown using a "zapping" probe. One end of a cell sense wire was grounded to the chamber. A 1.55 microfarad capacitor is charged up between 3500 volts for a 190 cm long wire and 6300 volts for a 580 cm wire. This corresponds to a stored energy of 9.5 to 31 joules. The zapping probe is touched to the other end of the grounded wire and the capacitor is discharged through it in less than 2 millisec. The signals from the "zapped" wires are as good as newly replaced wires. We also discovered two ways to trap out the evil vapor. During the first run a cold trap operating slightly above the freezing point of CO_2 (Argon and CF_4 have even lower liquification temperatures) was added to the gas recycling system, and reduced the aging rate by a factor of ten. For the present run we are simply using a large activated charcoal filter. It has removed the contaminants without changing the gas mixture ratio. The famous MDT's have replaced the forward PDTs which would not have survived the present run which will reach an integrated luminosity of 2 inverse femtobarns. Aging tests of MDTs have been performed at Dubna, where the tubes were built. Several detectors made in the style finally used in the D0 detector were illuminated by a ^{90}Strontium source. A comparison was done between the radiated MDT and a non-irradiated MDT, using the signals from an ^{55}Fe source. All studies were performed with the CF_4/CH_4 90:10 mixture. No deterioration in the detector performance was seen with an accumulated charge up to 5 C/cm. The estimated charge accumulated on the anode wires during Run II is about 0.02 C/cm. These studies demonstrate that the MDTs can run for many years at expected Tevatron luminosities without aging.

Experiences with the Central Tracking Chambers of CDF

(title assigned)

presented by **Morris Binkley**

Fermi National Accelerator Lab (FNAL), Batavia, IL, USA

The experience of CDF with the aging of gaseous wire tracking chambers located in the central region of the detector is presented. The primary chamber is a large axial drift chamber that is roughly 3 meters long and 3 meters in diameter. This large detector includes the gas mixing and delivery system and the small monitoring chambers required for its operation. The primary gas is a mix of Argon/Ethane 50:50 with a small addition of alcohol. The first large axial chamber accumulated a dose of about 0.05 Coulombs/cm on the inner layers during 'Run I'. Aging in the large chamber is compared to results from small prototype chambers.

Summary of Talk: At the heart of CDF, a large magnetic detector built to study 2 TeV $\bar{p}p$ collisions at the Fermilab collider, is a cylindrical drift chamber coaxial with the beam. The chamber is roughly 3 meters long and 3 meters in diameter. The chamber is filled with a mix of Argon/Ethane 50:50 with a small addition of alcohol (roughly 1%), primarily to reduce the effects of aging. The initial chamber (CTC) accumulated a dose of about 0.05 Coulombs/cm on the inner layers during 'Run I' and experienced significant aging. The CTC has recently been replaced by a new chamber (COT) with smaller cell sizes to accommodate higher interaction rates. Both chambers have 40 micron gold-plated tungsten sense wires. For the CTC, the potential and cathode wires were 140 micron or larger stainless steel 304. For the COT, the potential wires (that alternate with the sense wires) are also 40 micron gold-plated tungsten, but the cathode wires have been replaced by a mylar sheet with 350 angstroms of vapor-deposited gold. The endplates and outer cylindrical cans are aluminum and the inner support cylinder is carbon fiber covered with aluminum foil. Prior to most of the accumulated luminosity in Run I, aging tests were done using a realistic prototype of the inner wires in the CTC using gas directly from the CDF gas tanks. No aging effects were found for for an accumulated dose equivalent to 0.4 Coulombs/cm (to an accuracy of $\pm$4%). In the middle of Run I it was found from the data that there were aging effects in the CTC at a much lower accumulated dose. The gain decrease was linear with integrated luminosity and corresponded to about 1000%/Coulomb/cm. In June 1994, CDF started using ethane from a new supplier and at about the same time the luminosity increased dramatically. The new supply of ethane had significantly larger amounts of ethylene; apparently naturally occurring ethylene-free ethane was no longer available. Tests indicated that the increased ethylene should have no effect on aging. Attempts were made by the vendor to convert the ethylene to ethane, but the new gas typically did have a few thousand ppm ethylene and propylene. There was not enough data to reliably measure what the aging rate was before the change in ethane supply in June 1994. Some cleaning of the gas lines, valves, and alcohol bubbler and the addition of copper wool filters were done during 1995, but there was not enough data after these actions to tell if any of them had a significant effect on the aging of the CTC. Gas monitor chambers with ^{90}Sr sources to measure aging effects were introduced into the system in 1995. The charge accumulation in these chambers was large enough to get a measure of the effect of the various changes to the system. From these we know the following: April 1995: Measure aging directly after alcohol bubbler on the gas platform to be about 100k%/Coul/cm. Cleaning the system components (bubblers, valves, lines on gas platform) had no measurable effect. May – June 1995: Measure aging rate at input to the large CTC chamber (about 50 meters from the gas platform) to be (10k – 20k)%/Coul/cm. June 1995: Suspect aerosols from alcohol bubbler may contribute to accelerated aging. Add one copper wool filter after bubbler. Measure aging at the CTC input to be about (10 ± 1)k%/Coul/cm. Measure aging rate at the CTC exhaust to be $<$ 0.5k%/Coul/cm. July 1995: Using a new monitor chamber, measure aging after bubbler but before Cu wool to be still (100 ± 7)k%/Coul/cm. After Cu wool aging is (48 ± 7)k%/Coul/cm. August 1995: Add second Cu wool filter to canister and add a heater. Measure aging after Cu wool canister to be (16 ± 4)k%/Coul/cm. November 1995-February 1996: Add third and fourth Cu wool filters in a 2nd canister with heater. Increased alcohol temperature so that it was necessary to flow only 1/6 of the gas through the bubbler. Aging was measured after heated Cu wool filters to be (50 ± 30)%/Coul/cm. Aging at the input to the large CTC chamber was measured to be (12 ± 29)%/Coul/cm. The aging at the output of the large CTC chamber was measured to be (76 ± 21)%/Coul/cm. To help interpret the above results, sample wires were scanned using electron microscopes. Energy and Wave Dispersive Spectroscopy (EDS and WDS) gave a spatial resolution of a few nanometers and good automated elemental spectroscopy. Additional Fourier Transform Infrared Spectroscopy (FTIR) gave the capability of measuring molecular bonds. Before implementing the full Cu wool filtering and reducing the gas flow through the alcohol bubbler, the wires aged in test chambers on the gas platform and at the CTC input showed carbon-dominated deposits with aliphatic hydrocarbon chains. Pictures showed a smooth coating with occasional "nodules." Findings on an aged CTC wire were similar although the coating was thinner and the "nodules" more sparse. Wires from a bench test chamber using standard CDF gas with no alcohol had significantly different deposits that were rich in silicon and oxygen in the form of amorphous SiO_2. Pictures showed a landscape of thin fibers that resemble a burnt out, dense forest. The results for the CTC are consistent with aging due to a long-lived aerosol generated by a large flow rate through the alcohol bubbler. After the improvements, monitor chambers indicated that the aging rate due to the CDF gas system was less than 100%/Coul/cm. Subsequent bench tests on small COT prototype chambers measured an aging rate for Argon/Ethane with alcohol of less that 5%/Coulomb/cm. The CDF gas system has received more cleaning and new filters (mostly carbon). After the first few months of COT operation, monitor chambers after the Cu wool canister, at the COT input, and at the COT exhaust all measure aging rates less than 5%/Coul/cm.

Aging & Materials: Lessons for Detectors and Gas Systems

Mar Capeáns

CERN, CH-1211 Geneva 23, Switzerland

Effect of Materials on Aging Rates in Wire Chambers Operated with DME

(title assigned)

presented by **Robert Openshaw**

TRIUMF, Vancouver, B.C., Canada

The effects of various materials on aging rates of wire chambers filled with dimethylether gas (DME) have been investigated. Silicone compounds and some urethane polymers were observed to dramatically increase aging damage in test chambers. All other materials tested did not appear to significantly affect the measured damage rates.

Summary of Talk: The TWIST drift chambers (TRIUMF E614) are expected to make precise and efficient position measurements of both the polarized surface muons which stop in a target in the middle of the detector stack, and the resulting decay electrons which spiral out in the 2 Tesla magnetic field. Dimethylether (DME) was chosen as the filling gas due to its small Lorentz angle, high primary ionization, low Z, and wide efficiency plateau. Because of concerns about DME aging and attack, materials and devices proposed for use in the drift chambers and gas system which would be in contact with the gas stream were subjected to laboratory aging tests. Single-wire wire chambers (SWC's) were used to measure aging damage. Two adjacent independent SWC's were milled out of a single piece of 1.2 cm thick aluminum bar stock. The active volume of each SWC was 20 cm long, 1.2 cm square cross section, with a central 20 μm gold-plated tungsten anode wire and aluminised mylar cathode foils. Five pairs of SWC's were placed in a stack separated by 6 mm thick lead collimator sheets and illuminated by a single 10 mCi ^{90}Sr source, such that only the central 2 cm of each SWC was directly exposed to the source. Typical aging current densities ranged from approximately 100 nA/cm-wire at the top of a stack to 10 nA/cm-wire for the SWC's at the bottom. Materials to be tested were put inside copper canisters which were then inserted in the input gas line approximately 20 cm from the input port of each SWC. Devices to test, such as valves, flowmeters, etc., were inserted at similar locations. A few SWC's in each stack had no test materials inserted and one of these was left with zero high voltage during aging to allow "null" comparisons. The SWC's were aged at a nominal gasgain of $5 \cdot 10^4$ for 3 to 6 months to total accumulated charges ranging from 0.10 to 1.8 C/cm-wire. Once each week the ^{90}Sr source would be removed and the gas changed to Argon/Ethane 50:50 to provide more precise pulse height spectra. An ^{55}Fe x–ray source collimated to 1 mm was then used to measure the average pulse height at the centre of the irradiated region and at locations 4 cm upstream and 5.5 cm downstream of the centre for each SWC. Detailed pulse height profiles at 1 cm intervals along the anode wire were then measured for 3 or 4 of the SWC's. These measurements were used to reveal changes and estimate damage rates in the SWC's. After completion of the measurements the gas flow was changed back to DME, and the ^{90}Sr source installed for further aging. Materials being tested were inspected for any obvious visual or functional changes at the end of the entire aging period. Various epoxies, adhesives, sealants, elastomers, plastics, valves, and other devices were tested. Of the 49 tests completed, 25 revealed pulse height loss of less than 10%/C/cm-wire and most of these were consistent with zero apparent damage. Another 7 tests caused damage rates from 10% to 50%/C/cm-wire. The remaining 17 tests resulted in damage rates ranging from 70% to 5600%/C/cm-wire. This latter group was dominated by materials or devices containing silicone rubbers, adhesives or lubricants. Urethane rubbers and UV activated urethane methacrylate glues also caused extremely high damage rates. There was no convincing evidence of enhanced damage rates with any of the other materials tested, with the possible exception being Buna-N, where damage rates of 14% and 43%/C/cm-wire were recorded in two separate tests. A discolouration of the internal surface of the zinc body of a pressure regulator was the only observed evidence of changes to materials tested caused by prolonged exposure to DME. A 40 cm^2 area of a complete drift chamber module constructed with "approved" materials was aged at a 60 nA/cm-wire rate to a total accumulated charge of 0.311 C/cm-wire. No aging damage was observed in the irradiated area.

Influence of Materials and Sense Wire Surface Quality on Aging with DME and Other Gases

(title assigned)

presented by **Vladimir Blinov**

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Different methods of aging-rate measurements for wire chambers were analyzed and a more correct procedure was proposed. Using this procedure the gain and gas flow rate dependence of the aging rate with dimethylether (DME) was measured. A study of aging with DME argon/carbon dioxide and carbon dioxide/isobutane was performed. The influence of the drift chamber construction materials, gas seal pastes and tubes on the aging rate has been investigated. The radiation hardness of the KEDR drift chamber cell with DME was increased by an order of magnitude by careful selection of drift chamber and tubing materials. The influence of preliminary irradiation of the counter with pure DME gas in relatively clean conditions on the aging rate was studied. Under continued irradiation of the same part of the sense wire with contamination in the gas from certain materials a zero aging rate was observed up to a charge collected per unit length equal to 0.2 – 0.3 C/cm depending on the dose of the preliminary irradiation. Then the amplitude started to drop but the aging rate measured for this part of the sense wire is smaller in comparison with non-irradiated one. The influence of the sense wire surface quality on aging properties was investigated; a model for the creation and growth of films is proposed to explain these results.

Summary of Talk: It was found that the commonly used procedures for aging rate measurement have big systematic errors. A new, more correct procedure for aging rate determination was proposed. Using this procedure DME gas as a candidate for the drift chamber of the KEDR detector has been tested under laboratory conditions, with control of purity, materials, plumbing, etc. Also some previously known gases have been investigated compared with DME under the same conditions. Special emphasis has been given to the test of our DME gas, and the conditions necessary to maintain good stability. Under relatively clean conditions, very good stability against aging was found with the proportional tube. It is found that the aging rate of this gas is very sensitive to contaminations from the materials in the gas stream. The influence of the different DC construction materials and gas seal pastes on the aging rate has been investigated. Studies were made of the various types of tubing commonly used for the plumbing. Teflon and two type of PVC tubing were tested, and only the PVC tubing used in medicine did not exhibit aging effects. An investigation of two types of oil vapors showed negligible influence on aging. The gain and gas flow rate dependence of the aging rate with DME was measured. The influence of preliminary irradiation of a counter with pure DME gas in relatively clean conditions on the aging rate was obtained. Under continued irradiation of the same part of the sense wire with contamination in the gas from some materials zero aging rate was observed up to a collected charge of 0.2 – 0.3 C/cm depending on the dose of preliminary irradiation. Then the amplitude started to drop but the aging rate measured for this part of sense wire is two times smaller in comparison with the non-irradiated one. The influence of the sense wire surface quality on aging properties was investigated and a model for the creation and growth of films is proposed for the explanation of these results.

Application of a Nuclear Reaction Analysis for Aging Investigations

G. Gavrilov, A. Krivchitch, V. Lebedev

presented by **Victor Lebedev**

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In order to provide precise measurements of the concentration and depth distribution of the light elements (fluorine, oxygen, carbon, nitrogen, etc.) which come from the gas avalanches and penetrate inside the wire, a 'Nuclear Reaction Analysis' (NRA) was applied. For aging investigations nuclear reactions such as 16O(dp)17O, 12C(d,p)13C, 14N(d,p)15N, 14N(d,X)12C, 19F(p,X)16O can be used. Some of them have already been performed in our aging investigations with deuterons and protons in the energy range of 1 MeV. The sensitivity of the NRA to carbon, oxygen and nitrogen is better than $5{\cdot}10^{-2}$ %. The precision of the quantitative evaluation of the element content depends on the accuracy of the knowledge of the differential cross section for the considered nuclear reaction and is 5%. Using NRA in combination with a SEM/XEM analysis, aging studies of straw drift-tubes operating with a $Xe/CO_2/CF_4$ gas mixture were performed. The concentration of oxygen along the wire was measured. It was shown that after irradiation the amount of oxygen and carbon noticeably increased. It is determined that deposits containing tungsten, oxygen and carbon are distributed along the wire corresponding to the gas flow direction. The concentration of oxygen and carbon as a function of depth within the wire has also been investigated using NRA.

Summary of Talk: It is clear that the new generation of wire chambers will need a higher level of radiation hardness. Thus, the study of aging effects for these new detectors is especially important. Usually, aging effects result in a surface degradation of both the anode and cathode electrodes, which occur in the form of "deposits". An SEM/XEM analysis yields qualitative information on the morphology of the wire surfaces, by imaging with scattered and secondary electrons, and on the atomic composition of the surface material by X-ray fluorescence spectroscopy. This analysis is good for the wire surface deposit investigations. However, in order to complete the evidence for the aging mechanism and to establish the fact that the elements penetrate into the gold of the wires, a nuclear reaction method is proposed. For the detection and quantitative evaluation of the oxygen, carbon, fluorine and nitrogen content as a function of depth in the gold, we propose to use the following nuclear reactions with deuterons and protons in the energy range of 1 MeV:

- 12C + d $\rightarrow$ 13C + p + 2.722 MeV
- 16O + d $\rightarrow$ 17O + p + 1.049 MeV
- 14N + d $\rightarrow$ 15N + p + 1.305 MeV
- 14N + d $\rightarrow$ 12C + α + (9.146 or 13.579) MeV
- 19F + p $\rightarrow$ 16O + α + γ + 8.144 MeV

As one can see from these nuclear reactions, the energy and type of emitted particle is characteristic of a specific element. The (dp) reactions are exothermic and thus the exiting protons and α-particles have higher energies relative to the incoming deuterons scattered on the target. This allows us to completely absorb the deuterons with a few microns of aluminum foil placed in front of the semiconductor detector, which is used in detecting the final state particles. The energy of the bombarding deuterons (E_d = 0.9 MeV) is not sufficient for nuclear interaction with higher atomic number elements due to the Coulomb barrier. Hence, the protons and α-particles produced in the interaction with light elements are detected practically without background. One of the advantages of the nuclear reaction analysis method is that it gives us an opportunity to investigate the depth profile of atomic composition for thin film without etching. Thanks to ion braking the energy of the exiting particle gives information on the depth where that reaction occurs. The thickness of the investigated layer depends on the absorption range of the particles, and amounts to about a few microns. Thus, this technique allows us to evaluate the light element content not only in the gold coating of the wire ($\approx$ 1 mm) but also in the tungsten with a depth resolution of 0.1 mg/cm^2. This proposed method looks very promising and unique due to the above mentioned advantages of high sensitivity, the lack of etching, quantitative evaluation of the light element content, and the large depth of analysis. This method has been developed by us considering first the needs of the aging investigation. It is very probable that this nuclear reaction method will become a customary technique for aging investigations of the new generation of gas-filled chambers. Using NRA in our aging investigations it was reliably confirmed that the role of oxygen in the wire swelling mechanism is important and that the oxygen transportation into the depth of the gold coating really exists. Some of these results are presented in this report.

Gas-Chromatographic Analysis of Organic Compounds Formed in Avalanches Around Wires

(title assigned)

presented by **Kari Kurvinen**

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Some organic chemical compounds formed in electron avalanches have been analyzed by using a tandem gas chromatograph equipped with a cryogenic sample concentration unit. The characteristics of the analyzer are described. An analysis of compounds created in a single-wire proportional counter filled with Ar/C_2H_4 50:50 gas mixture is presented. Simple reaction kinetics for some of the compounds observed is discussed. Examples of using the system for studying outgassing of various materials and effects of additives are given as well.

Summary of Talk: A large amount of organic compounds and radicals are involved in the chemical processes occurring in gaseous radiation detectors. Some of these reactions produce large molecular chains forming polymer structures on anode or cathode surfaces. Identification of organic compounds being formed in electron avalanches may help us to understand the basic chemical processes causing these aging effects. We have assembled a gas analyzing system consisting of two gas chromatographs and a cryogenic sample concentration unit. The sample is taken from the gas output flow of the gaseous radiation detector under investigation. It is concentrated in a cryotrap cooled by gaseous nitrogen that is itself cooled by liquid nitrogen. To be able to analyse small concentrations of organic compounds in a gas mixture where a significant part of the mixture is an organic compound itself, a precise temperature control of the cryotrap is needed. A heated single wire counter with a continuous gas flow was used in the study. The counter was filled with a Ar/C_2H_4 50:50 gas mixture working in proportional mode. An X–ray tube with Cu target was utilised as a radiation source. The anode current of the counter, which was measured continuously during the irradiation, was typically a few hundred nanoamps. The sample trapping time and the irradiation time varied from a few minutes to three hours resulting in an integrated charge of a few millicoulombs at maximum. Fifteen new organic compounds were identified in the gas mixture. Production of most of them may be explained by simple chemical reactions. Some of these compounds have double or even triple bonds, which are easily opened and may start to form longer molecular chains. Literature survey revealed that the triple bond compound found is known to polymerize very aggressively. In the accelerated aging tests, a presumption is made that the chemical environment in electron avalanches is independent of the irradiation rate. Validity of this presumption is studied by measuring the production rate of the avalanche compounds as a function of the irradiation rate.

Gas support systems for New High–Rate Detectors: The Example of the Inner Tracker of HERA–B

(title assigned)

presented by **Hans-Bernd Dreis**

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The challenge to avoid aging in the new generation of hadronic high-rate detectors at DESY and CERN does not only need adequate and partly new detector materials but also force the gas support systems to be of previously not needed material qualities and cleanliness. The effort which is necessary to test materials for detectors must be extended to all parts which are touched by gas; detailed and critical investigations also in a lot of traditionally used parts are necessary. It turned out that some of these contain small parts of out-gassing material, which were so far negligible, but can cause fast aging under high rate conditions. In addition, for some detectors new quenchers that are chemically reactive were proposed, which caused the number of usable gas system components to shrink even further. Finally, the traditional way of mounting gas systems in workshop-like environments is history by now; in the future clean-room-like environments become more and more necessary.

Summary of Talk: HERA–B – recently started – is the first of a number of hadronic high-rate experiments which will be operated or will start in the next ten years. As well as for detector technology, HERA–B was also a pioneer in gas system technology; not only for gas system automation and flow regulation but in particular also for investigations into pipes and other parts related to gas systems that are usable at high detector rates, for which approximately three man years were necessary. The work was done in parallel with the detector development and frequent aging tests could also be used for excluding inadequate gas system components. All potential candidates for parts such as valves, flow controllers and pressure transducers etc. were completely dismantled and the origin and material of their parts were determined and checked up to traces of glue used somewhere. Only the small number of accepted types of materials which had passed the aging tests could be accepted to be used inside the parts and everything else had to be replaced if possible. Consequently, those candidates for which this didn't work had to be rejected. It was interesting to learn that also parts which had a so-called 'complete material list' contained often surprises neglected in the documents. The list of gas system compliant components for HERA–B was split into two branches; one being the inner tracker gas components and the other outer tracker, muon system and high–P_T chambers components (The RICH gas system with completely different purpose is neglected here). Originally, the list for the inner tracker was especially small because the inner tracker gas system was completely designed for the use of DME which is known to be reactive and aggressive, e.g. when used with many sealing elastomers. The use of DME had finally to be canceled after a last minute discovery which proved gas aging caused by the DME itself. Another discovery independent from the use of DME had big influence on the gas system design, namely the fact that CERN tests showed in 1997 that Teflon somewhere in the system even if touched by gas only at small surfaces starts aging in MSGC's. As a consequence, all Teflon parts had to be removed from the inner tracker system (and as a preventive measure also from the rest of the tracker). The bad thing here was that Teflon is used more or less everywhere in commercial products. Concerning the pipes with their big surfaces a special cleaning procedure with acetone and ethanol was done routinely. This was also applied to the outer surface because this is usually covered with suppliers inscriptions which can accidentally have contact with the gas inside fittings. This cleaning procedure fails of course for ring corrugated tubes which cannot be easily cleaned. In HERA–B, approximately 2.5 km of ring corrugated tubes are used for gas support and a suitable oil-free method of production and chemical-free method of cleaning had to be found which took several month. At least one company was able to do so but nevertheless the inner tracker ring corrugated tubes were in addition cleaned and dried with some hundred cubic meters argon before use. The meaning of pumps gets also a new quality when trying to build a closed loop system for high hadronic rates. In HERA–B, large gas flows of up to 22 m^3/h have to be compressed to a pressure of 2.5 bar (abs). Elastomer membrane pumps as well as rotary slide pumps were excluded a priory because they enforce the contact of gas with rotating sealing material or elastomer membranes. The finally chosen metal bellow pumps tend to develop leaks at the bellows, which is still a subject of investigation. The mounting of gas system components finally was performed under stricter conditions compared to the usual practice. To avoid grease from hands on fittings and pipes the mounting was performed with latex gloves and fittings were routinely or especially if potentially contaminated with dirt severely cleaned in ultra-sonic acetone and ethanol baths and afterwards stored in special dust-free clean boxes. It should be pointed out that such precautions need an enormous amount of discipline on part of the technical personnel because the meaning of clean environment and parts in all areas not directly related to detector production are usually underestimated. In addition, it can never be avoided that some of the work has to be done on the fly in the experimental hall where conditions are worse than in the labs. Finally, it should be mentioned that the cost of the HERA–B gas systems due to the tough conditions exceed by far what is known from the other experiments at HERA. In the end, one can only hope that the effort was sufficient because it is clear that aging coming from impurities in the gas support systems can take some time. What we can say so far is that we have put an enormous effort into the attempt to avoid it and that after one year of HERA–B running we have absolutely no indications for gas aging and we have hopes for this condition to stay.

A Long-term Aging Study of the Honeycomb Drift Tubes of HERA–B Using a Circulated and Purified CF_4–Gas Mixture

M. Capeáns, K. Dehmelt, M. Hohlmann, B. Schmidt

presented by **Klaus Dehmelt**

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The Outer Tracker (OTR) of HERA–B uses a gas mixture containing CF_4 to obtain high electron drift velocities. The high cost of this gas makes it necessary to circulate the gas mixture which must then be purified to avoid accumulation of air and pollutants. However, any gas purifier presents the danger of outgassing pollutants into the gas stream. Furthermore, in this application the purifiers could be attacked chemically by the aggressive products from the cracking of CF_4 molecules in the plasma avalanches of the detector. This could potentially release further harmful pollutants into the gas stream. Consequently, a long–term irradiation study of about 3000 hours was carried out for the Honeycomb Drift Tubes that are used in the OTR. This provided a test of the long–term stability of the gas purifiers before putting them into operation for the full–size detector. We report on the experimental setup, procedures and obtained results.

Summary of Talk: In a small–scale setup built for simulating the OTR of HERA–B and its gas system as closely as possible, honeycomb test modules underwent long–term irradiation with 8.6 keV photons from an X–ray tube. The setup had two gas purifiers (a 3$\overset{o}{A}$ molsieve for removing water and a copper–based catalyst for binding oxygen) running in series. These purifiers were chosen because the same types have been used successfully for years – albeit at much lower irradiation rates – in other track detectors, e.g. in the H1 and HERMES experiments. Special attention was paid to the choice of clean, non-outgassing materials for chamber and gas system construction. The aging test test was conducted with a gas mixture of $Ar/CF_4/CO_2$ 65:30:5 as used in the OTR. The development of gain in time as well as the gas composition and ambient parameters (temperature, pressure etc.) were monitored. A total charge of 2.3 C/cm was accumulated over $\sim$ 3000 hours of irradiation, which is equivalent to more than three years of nominal HERA–B operation in the hottest region of the OTR at 40 MHz interaction rate. All observed gain changes could be explained by changes in gas composition and/or ambient parameters. The results show the reliability of the gas purification scheme for at least three high–rate HERA–B years.

Humidity Dependence of Dark Currents and Anode Etching

presented by **Alexander Schreiner**

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The intense radiation environment in the HERA–B experiment, being comparable to that of LHC experiments, requires that the detector be very resistant to high radiation loads. The Outer Tracker of HERA–B consists of drift tubes folded from gold-coated polycarbonate foils (honeycomb) and is operated with a mixture $Ar/CF_4/CO_2$ 65:30:5. The choice of the mixture (no hydrocarbons) and the gold-coating of the foil was the result of research on how to avoid anode aging (gain loss) and cathode aging (Malter effect). However, other, relatively less known aging effects appeared: rising conductivity of the wire-supporting strips and wire corrosion. These two aging effects could be prevented by keeping water at a proper concentration. In an attempt to interpret the test results, plasma phenomena such as production of certain molecular species, concentration of long-lived HF produced via CF_4 dissociation in the avalanche were semi-quantitatively estimated. The results of the aging investigations will be presented in the talk.

Summary of Talk: Aging tests of the Outer Tracker honeycomb chambers with gold-coated polycarbonate cathode using the mixture $Ar/CF_4/CO_2$ 65:30:5 did not show significant gain loss or Malter effect up to 5 C/cm of accumulated charge. However, other effects showed up: high dark current and anode etching. Strong dark currents (>0.3 μA/cell) were observed in honeycomb chambers when the humidity of the gas was rather high (>1000 ppm). These dark currents are characteristic for the specific design of the chamber since they are caused by increased conductivity of the wire-supporting FR4 strips, which are indispensable components of the chamber construction. The dark currents increased at the beginning of the irradiation and saturated typically after 0.3 C/cm. The effect can be explained by the production of HF which reacts with water forming slightly conductive hydrofluoric acid. Another effect, anode etching, caused wire rupture when the counting gas $Ar/CF_4/CO_2$ was very dry (humidity below 100 ppm). Electron microscopy showed that wires swell (the diameters increase by several percent) and the gold-coating on the wires peels off. Each investigated broken wire ruptured approximately in the center of the irradiated zone of the corresponding cell. The X–ray spectroscopy of heavily etched wires did not reveal the presence of any other species except tungsten (and gold) on spots where the gold coating was removed by plasma etching. However, oxygen usually accompanied tungsten if it was deposited (for example, in form of whiskers) above the gold surface of the anode or the cathode. It is concluded that fluorine is responsible for anode etching since this effect was effectively suppressed by water. The anode etching correlated with another effect, "transient aging" (which is not related to damage of chambers, in fact). The latter effect is a non-permanent drop of the gain during high rate operation which recovers after a short relaxation time. The "transient aging" was also considerably reduced when water was added in concentrations of more than 200 ppm. The effect probably arises due to the avalanche production of F_2, a very electronegative gas.

Aging Studies for the Outer Tracker of HERA–B

HERA–B Outer Tracker Group

presented by **Cristóbal Padilla**

Deutsches Elektronensynchrotron (DESY), 22603 Hamburg, Germany and *CERN, Geneva, Switzerland*

The experimental conditions at HERA–B resemble, in terms of radiation and particle flux, those expected in the LHC. Prototypes of the HERA–B Outer Tracker experienced several aging effects, sometimes after only 10 mC/cm of integrated accumulated dose: Malter effect, anode aging, permanent dark currents, and anode etching. The detector requirements and conditions are summarized. Results of the R&D experiments to find solutions to these problems are given. The conclusions and changes subsequently implemented in the original construction techniques are explained.

Summary of Talk: The HERA–B Outer Tracker is one of the largest trackers ever built. It has in total 8 km^2 of cathode surface and 22 m^3 of gas are flowing through the detector every hour. The experiment collides a proton bunch at an energy of 920 GeV with a fixed target wire at a frequency of 10 MHz and it is designed to produce an average of four proton–Nucleon interaction in every bunch crossing. The high interaction frequency requires a fast drift gas containing CF_4. A high tracking efficiency, together with the noise conditions of the densely packed electronics require the effective gas gain to be at least $2 \cdot 10^4$. This fact, together with the high charged particle flux in the experiment, imposes very strong requirements on the detector, which is designed to receive a maximum accumulated dose of 500 mC/cm of wire per year in the hottest areas. The Outer Tracker has a honeycomb drift tube geometry. The cathode is made from carbon-loaded polycarbonate foil (trademark 'Pokalon-C') that is glued together to form the drift tubes. Gold-plated tungsten wires are soldered into supporting bridges made of bromine-free FR4 material that are installed inside the drift tubes. Material and construction techniques lead to the appearance of different aging effects, some of them after only 10 mC/cm integrated radiation dose: Malter effect, very fast wire aging, permanent dark currents and wire etching were observed. In particular, the Malter effect was observed only in chambers that were irradiated with a hadronic beam. After an intense R&D effort in different radiation facilities, from X-rays to α-beams, solutions have been found for the different problems: the problem of anode aging was solved by exchanging the CH_4 quencher in the originally planned gas mixture ($Ar/CF_4/CH_4$) by CO_2 and carefully selecting "clean" materials and non-outgassing glues. The Malter effect was avoided by coating the cathode foil with a copper-gold layer. The origin of permanent dark currents was traced back to the hygroscopic nature of the FR4 and the wire etching effect can be alleviated by avoiding a gas mixture that is too dry. The last two conditions impose some constraints on the gas system that has to carefully control and monitor the water content inside the drift gas. Long-term aging experiments performed with prototypes that were produced in the same way as the final chambers demonstrated that, after the above mentioned changes, the detector can stand up to 2 C/cm of integrated radiation dose (up to 5 C/cm for some of the effects).

Aging Studies for the Transition Radiation Tracker of ATLAS

(title assigned)

presented by **Anatoli Romaniouk**

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Studies of aging effects carried out in the framework of the ATLAS Transition Radiation Tracker (TRT) collaboration are presented. Aging effects such as damage to wire gold, cathode material degradation, Si-polymerization, and possible processes leading to these effects are discussed in detail. Some recommendations and remedies are presented.

Summary of Talk:

1. The main agent responsible for the gold-damage effect is H_2O. To avoid this effect the H_2O concentration must be below 1000 ppm. In this case, no damage to the gold is observed up to 20 C/cm of accumulated charge.
2. The most complicated problem is Si-polymerization. There are many external sources of Si; a careful choice of components and cleaning of components is necessary.
3. If the gas system components contain small traces of Si, they can be removed by flushing with dimethylether (DME).
4. Straws can be easily polluted by Si which then stays in the straws for a long time and can produce aging effects at a later time under certain conditions.
5. The straw material itself contains Si which under certain conditions polymerizes on the wire. It can be removed by special cleaning procedures.
6. Active radicals produced in avalanches react with the detector material but no aging effect is observed if this material does not contain Si.

Laboratory Aging Tests for the BaBar Drift Chamber

(title assigned)

presented by **Adam Boyarski**

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Noise and Malter breakdown have been studied at high rates in a small drift chamber. The test chamber has the same small-cell structure and gas (He/Isobutane 80:20) as the BaBar drift chamber, and uses a 100mCi ^{55}Fe source. Exposing it to a high radiation level at an elevated high voltage purposely damaged the test chamber. Breakdown was then seen at low source levels (≈ 0.5 nA/cm). Additives such as H_2O and alcohol were shown to suppress breakdown in a damaged chamber, but not cure it. The most interesting additive was oxygen. When $200 - 500$ ppm of O_2 was added, a damaged chamber could operate at high currents, and when the oxygen was removed, the chamber could still operate at higher currents (25 nA/cm). This shows for the first time that running with an O_2 additive at higher rates can cure a damaged chamber. This may be important for factory type chambers that operate at high rates for long periods of time.

Summary of Talk: The BaBar drift chamber uses small cells and a gas mixture of Helium/Isobutane 80:20. The chamber soon ran into current-draw problems at high rates, and water was added to alleviate the problem. A small test chamber was built with a similar hexagonal cell structure to measure the safety factor that water provides at higher chamber currents. BaBar currently operates at 0.3 nA/cm of anode wire. The test chamber has a single anode wire (20 μm gold-coated tungsten-rhenium) surrounded by six cathodes (120 μm gold-coated aluminum) spaced 1 cm apart, and six bias wires further out that are biased to provide a 20 kV/cm field on the cathodes and 239 kV/cm on the anode wire. A 100 mCi ^{55}Fe source and attenuation foils provided any desired chamber current up to 25 nA/cm on the anode wire. A picoampmeter and a multi-channel analyzer measured the chamber current and pulse spectrum respectively. The flow rate of the gas mixture was 125 cc/min, which gave one volume change every 24 minutes. The exhaust gas passed through a bubbler and was vented to the atmosphere. With only the He/Isobutane 80:20 gas, the chamber could operate up to approximately 1 nA/cm of chamber current. Beyond that, the chamber current suddenly jumps by more than an order of magnitude, and remains elevated even if the source is removed until the voltage is lowered. This is the Malter effect. Just prior to the current jump, the pulse spectrum shows an increase in the number of small pulses that grow with time. Several additives were found that allow operation beyond 5 nA/cm. These were methylal(4%), 2–propanol(1%), and H_2O(0.35%). All these additives showed immediate improvement. Of these, H_2O was best in that it had no visible increase in small pulses, and could operate up to 25 nA/cm of chamber current. Propanol does nearly as well, but showed a slight increase of small pulses at high currents, while methylal could only reach 5 nA/cm and showed the smallest pulses. Oxygen was found to be a most interesting additive: At 500 ppm of O_2, it was possible to slowly bring up the chamber current to 25 nA/cm. If brought on too quickly, the chamber would ignite in Malter mode, but after repeated attempts would become stable. But the most important result is that when the oxygen is removed, the chamber was still able to operate at 25 nA/cm. The oxygen had cured what was a damaged chamber. The chamber was cycled through a damage step (by raising high voltage with maximum source) and cure step several times to verify the result. Also, a lower amount of oxygen (200 ppm) was shown to cure the chamber as well, but the training time was longer (a day rather than two hours). The fact that the chamber could not operate immediately at high currents with oxygen but had to be slowly trained is indicative that the oxygen reacts with and removes ingredients on the wires over a period of time. It requires both oxygen and a high current to cure the chamber. The high ionic current passing through the high electric field near the wire surface heats up the local gas, which allows reaction of oxygen with the carbon-based deposits on the wire surface. The CO, CO_2, etc. combustion products are removed from the chamber by the flowing gas. This talk shows the pulse spectra, the growth of small pulses before Malter ignition, the chamber current history during a curing cycle, as well as an understanding of the small pulse spectrum from ^{55}Fe.

Aging Tests of Micro–Strip Gas Chambers for the CMS Forward Tracker at Mons University

presented by **Evelyne Daubie**

Service de Physique Générale et Physique des Particules, B-7000 Mons, Belgium

Our group performed a systematic study of MSGC aging effects aiming at the determination of their optimal performances in the framework of the design of the CMS forward tracker. A series of tests was conducted on prototypes under various operating conditions (glass substrates, Ar/DME or Ne/DME gas mixtures, gas set-up purity-8230). Irradiation was performed using an X-ray generator. The different steps of our investigations will be summarized and commented on.

Summary of Talk: Our group performed a series of tests on MSGC's which were conducted in the framework of the design of the CMS forward tracker. The main research effort was oriented towards testing the rate capability of MSGC's and studying aging effects. It included prototype work and morphological studies of the surface of substrates before and after exposure to X-ray radiation. The investigations were done on MSGC prototypes in the cleanest operating conditions possible: use of a custom-built gas system made of all metal components (tubing, connectors, mixer, and flowmeters), chamber mounted in a stainless steel or PEEK box with a thin-foil aluminum front window and metal-glass feed-through. Irradiation was done using an X-ray generator equipped with a collimator with either a thick absorber in front (for preliminary tests : plateau - gain - energy resolution) or a thin absorber in front for long-term high-rate measurements The tests were performed under various conditions of glass substrates (ionic or electronic conductivity, semi-conductive coatings), employing a geometry of anode and cathode strips alternating with 200 – 956 μm pitch (Au or Cr metal). The anodes were connected together to the voltage supply while the cathodes were ganged in 3 groups of around 50 strips each and set to ground potential, allowing the recording of pulse height with a charge sensitive amplifier or the measurement of the current with a electrometer. The gas mixtures used were Ar/DME 50:50 or Ne/DME 50:50. The experimental set-up will be described with emphasis on the different steps aiming at improvements of MSGC aging behavior. The morphological study of substrates performed by means of specific instruments (polarizing microscope, profilemeter) will be presented. The results obtained in our systematic study of aging effects will be summarized and commented on.

Aging Studies for the Muon Detector of HERA–B

M. Danilov, Yu. Gilitsky, T. Kvaratschellia, L. Laptin,
I. Tichomirov, M. Titov, Yu. Zaitsev

presented by **Maxim Titov**

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Experimental conditions at the HERA–B experiment impose very strong requirements for gaseous detectors. The charged particle flux through the HERA–B tracking system, varying with the radial distance R from the beam line, is about $2 \cdot 10^7/R^2$ particles per second, i.e. comparable to what will be encountered by LHC experiments.

The severe radiation environment of the HERA–B experiment leads to a maximum charge accumulation by a wire in the muon detector of 200 mC/cm per year. We report recent results of aging studies performed by irradiating proportional wire chambers filled with $Ar/CF_4/CH_4$ 74:20:6, $Ar/CF_4/CH_4$ 67:30:3, $Ar/CF_4/CO_2$ 65:30:5, Ar/CF_4 70:30, CF_4/CH_4 90:10, and CF_4/CH_4 80:20 mixtures in three different experimental setups: laboratory conditions (^{106}Ru and ^{55}Fe sources), a 100 MeV α-beam and the high-rate HERA–B environment. The size of the irradiation zone varied in the tests from 1 cm up to 500 cm. Our experience shows that the aging rate depends not only on the total collected charge, but, in addition, on the mode of operation and area of irradiation. The possible application of these results to the construction of a large-area gaseous detectors for operation in high-rate environments will be presented.

Summary of Talk: The aging performance of aluminum proportional chambers has been investigated for six different CF_4-containing mixtures in three different experimental setups: laboratory conditions (^{106}Ru and ^{55}Fe sources), a 100 MeV α-beam and the high-rate HERA–B environment. The size of the irradiation zone varied in the tests from 1 cm up to 500 cm. The aging studies can be summarized as follows:

1. The aging rate of aluminum proportional chambers filled with $Ar/CF_4/CH_4$ 74:20:6 or 67:30:3 mixtures was found to be more than two orders of magnitude higher in tests conducted in a high-rate radiation environment than in laboratory tests with radioactive sources.

2. Aging effects in tube proportional chambers filled with $Ar/CF_4/CH_4$ 74:20:6, $Ar/CF_4/CH_4$ 67:30:3 mixtures were observed after irradiation in a 100 MeV α-beam and in the high-rate HERA–B environment. For operation in HERA–B, the aging behavior of the $Ar/CF_4/CH_4$ 67:30:3 mixture was found to depend on the high voltage and the size of the irradiation area. SEM analysis of the aged anode wires, operated with a gas gain $> 10^4$, revealed a polymer matrix, consisting of C and F elements (H was not detectable). Anode aging was also accompanied by the appearance of a thin layer of polymers on the cathode, consisting of C, F, and O. These surface deposits on the electrodes resulted in a gain reduction and in the appearance of a dark current during operation in HERA–B. In contrast to deposits formed at a gas gain $> 10^4$, one of the anode wires operated at a gas amplification of $< 10^4$ had only traces of carbonaceous deposits, without incorporation of F into the polymer structure. Although the addition of H_2O results in the suppression of the polymerization effects in the $Ar/CF_4/CH_4$ 67:30:3 mixture, our results clearly indicate a problem for the use of $Ar/CF_4/CH_4$ mixtures in the muon detector of the HERA–B experiment.

3. Using a mixture of $Ar/CF_4/CO_2$ 65:30:5 + 1000 ppm H_2O, no loss in performance of aluminum proportional chambers was observed up to a collected charge of $\sim 700 \frac{mC}{cm \cdot wire}$, when irradiating with different gas gains. Analysis of cathode surfaces revealed trace amounts of C, O, and F for tubes operated at a high gas gain of $\sim 10^5$, while for a baseline gain of $3 \cdot 10^4$, exposed cathodes were almost indistinguishable from reference cathodes. Consequently, this $Ar/CF_4/CO_2$ 65:30:5 + 1000 ppm H_2O mixture is currently used for operating the muon chambers in HERA–B.

4. No loss in performance of aluminum proportional chambers operated with Ar/CF_4 70:30 without water has been observed up to a collected charge of $\sim 70 \frac{mC}{cm \cdot wire}$.

5. In contrast to the $Ar/CF_4/CH_4$ mixture, aging tests of aluminum proportional chambers filled with CF_4/CH_4 90:10 and CF_4/CH_4 80:20 showed neither rapid gain reduction at a level of accumulated charge of $\sim 30 - 100 \frac{mC}{cm \cdot wire}$, nor the appearance of dark current. No dependence of lifetime on water addition and size of irradiation area was observed for CF_4/CH_4 gases.

6. Using CF_4/CH_4 90:10 + 600 ppm H_2O, a stable lifetime of up to 370 $\frac{mC}{cm \cdot wire}$ was achieved for two wires, except for one wire specimen ($\sim$ 4 cm out of 50 cm), where a significant gain reduction was detected. The origin of this aging is not understood.

7. Using CF_4/CH_4 80:20 + 600 ppm H_2O, a gain reduction was observed after a radiation dose of 170 $\frac{mC}{cm \cdot wire}$ for all three irradiated wires. SEM analysis confirmed the presence of a thin layer of carbonaceous deposit on the anode wires. At the same time, no loss in performance was observed for three wires operated with a CF_4/CH_4 80:20 mixture without water up to 40 $\frac{mC}{cm \cdot wire}$.

Finally, many chemical processes are expected to occur simultaneously in the gaseous discharges surrounding the wire and therefore a quantitative description of aging effects, which would require as a minimum, a detailed analysis of all gas phase and gas surface reaction products, is not possible. In addition, many of the reactions may be extremely sensitive to the nature and purity of the gas mixture, different additives and trace contaminants, construction materials, the actual geometry of the electrodes, the gas flow, the irradiation intensity, the size of the irradiation area, the particle species... Since the present state of knowledge does not allow one to formulate a complete set of recommendations of how to prevent the aging effects in wire chambers, it is important to study the aging performance of the mixture under conditions as close as possible to real ones. In view of the aging results discussed here, one can also see that in wire chamber operation, the presence of large amounts of CF_4 in the mixture does not necessarily ensure good aging performance.

First Results of an Aging Test of a Full–Scale MWPC Prototype for the LHCb Muon System

presented by **Vsevolod Souvorov**

CERN, CH-1211 Geneva 23, Switzerland

A four-gap MWPC designed for the LHCb muon is undergoing an aging test at the CERN Gamma Irradiation Facility. The first results of this study are reported. The results are based on the analysis of the chamber behavior after accumulating a linear charge density of about 0.25 C/cm, corresponding to approximately 5 years of operation in LHCb under the worst conditions expected for this chamber type (about 37 kHz/cm^2 counting rate). The chamber showed some increase in dark current during the irradiation, although less than what would affect the proper operation of the chamber.

Summary of Talk: Multiwire proportional chambers (MWPC's) with anode wire and cathode pad readout are being developed as a substantial part of the LHCb muon detector. The maximally expected counting rate for these chambers is about 37 kHz/cm^2, which includes a safety factor of 5 on the best estimate of the particle flux. The accumulated charge density for 10 years of LHCb operation under these conditions would be 0.5 C/cm on the anode wires and 1.7 C/cm^2 on the cathode pads. To collect similar charge densities, the chamber has been exposed to the very intense ^{137}Cs source (675 GBq in February 2001) in the Gamma Irradiation Facility (GIF) at CERN. The photon counting rate produced by the source is about 30 kHz at the chamber. The test is scheduled to last for 1 year and began in February 2001. The MWPC under irradiation is a full-scale four-gap chamber with a gas volume of 3 liters and a total irradiated area of 1500 cm^2. A three component gas mixture $Ar/CF_4/CO_2$ 40:10:50 is used. The gas pipes are made from stainless steel (supply) and copper (exhaust). The gas flow rate is one chamber volume per hour, which is the normal flow rate used in high-irradiation conditions. One of the four gaps of the chamber is only under high voltage during measurements and is used as reference gap to measure the relative gas gain variations. All of the cathode surfaces are gold plated in order to minimize the effects of cathode aging. Gold-plated cathodes will be used for the chambers situated in the locations of highest irradiation. Aging effects on the cathodes are checked by regular measurements of the resistances between the cathode-pads and ground. The anode status is checked by current monitors with a current resolution of about 1 nA. The current is monitored both during irradiation and without irradiation. The currents in the gaps are in the range of 150 – 250 μA under irradiation. The pressure, temperature and humidity around the chamber are monitored as well. An Americium source was used to measure the source-induced current over the full area of the chamber before the irradiation. The performance has also been studied with a 3 GeV pion beam. Analysis of the data obtained after a radiation dose corresponding to about 5 years of LHCb operation did not show any deterioration which could prohibit the use of these chambers in LHCb. To achieve a charge equivalent to 10 years of LHCb operation the test will continue until the beginning of 2002.

Aging Tests for the ATLAS Muon Drift Tubes

presented by **Michael Kollefrath**

Universität Freiburg, Freiburg, Germany

The aluminum drift-tubes (MDT's) of the ATLAS muon spectrometer are expected to accumulate charges of up to 0.6 C/(cm of wire) during ten years of operation. Therefore aging tests are in progress. In five setups up to 80 tubes can be irradiated simultaneously. The influence of the drift gas on the aging performance was studied. The amount of gas flow, different additives to the drift-gas, different cathode coatings, the cathode cleanliness, the irradiation rate, the length of the irradiation zone, the gas gain (high voltage) and the construction material in the gas volume were varied to determine their influence on the aging performance.

I will focus my talk on two aspects. In the first place, on the dependence of aging on the irradiation rate, on the length of the irradiation zone, and on the applied high voltage (gas gain). These dependencies dictate which gas to choose. They make extrapolation from the laboratory conditions to the full experiment difficult. Secondly, I will speak on the choice of the gas for the MDT's.

Summary of Talk: The requirements for the ATLAS Monitored-Drift-Tubes (MDT's) are hard to meet. At the rather high irradiation rate of up to 100 Hz/cm^2 (without safety factor of 5) a single-wire resolution in space of 80 μm has to be achieved. As under these conditions already small changes in pulse height or shape degrade the resolution, we consider the end of the lifetime of a tube at the point when the original pulse height is reduced to 70%. The target value is an accumulated charge of 600 mC/cm at a gas gain of $2 \cdot 10^4$. We started in 1995 with aging tests and in this talk I want to concentrate on what we think to be some of the most important issues. Using a set of short drift-tubes we managed to find a gas that could collect more than 5 C/cm without any sign of aging and yet had good performance concerning the drift properties. This mixture: $Ar/CH_4/N_2/CO_2$ 94:3:2:1 has a very linear r–t relation and a short enough maximal drift time for the high-rate environment. When we tested this gas in full-length tubes at the high irradation facility in CERN, the tubes became inefficient at 80mC/cm. In order to understand this, we made detailed studies on the dependence of aging on the following parameters: cathode cleanliness, amount of gas flow as well as irradiation rate, length of irradiation zone and the applied HV. If the life time depended only on the amount of collected charge/(cm of wire), the last three parameters should not effect aging. On tubes made as identical as possible we measured that the accumulated charge at the end of the lifetime decreases from 5 C/cm at 3350 V to less than 0.2 C/cm at 3505 V. (The pulse charge was doubled under the latter condition.) Increasing the irradiation rate from 0.350 kHz/cm to 12.5 kHz/cm reduced the lifetime by a factor of five. By nearly doubling the irradiation zone from 25 mm to 45 mm the lifetime was reduced by a factor between two and three. These results illuminate the problems with aging tests that are meant to give reliable results for the final detector in a short time and on a small scale. As we do not understand how to extrapolate from the laboratory conditions to the final experiment, we propose to use Ar/CO_2 93:7 as drift-gas. With this gas the tubes did not age, even if all parameters are varied to values above the design limits. Nevertheless, we observed that small impurities in the gas immediately cause aging.

Aging Studies of CMS Muon Chamber Prototypes under High Doses

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presented by **Gennady Gavrilov**

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The aging of prototypes for the CMS muon cathode strip chambers under sustained irradiation was studied. The tests were performed with three prototypes with different gas seal designs and for three gas mixtures ($Ar/CO_2/CF_4$ 30:50:20, Ar/CO_2 30:70, and $Ar/CO_2/CF_4$ 40:50:10). The CF_4-containing mixtures showed no or little aging for an accumulated charge per unit of wire length exceeding the high dose of $\approx$ 13 C/cm. Results of SEM/XEM examinations of the anode wire surfaces for different gas mixtures are presented. In comparison, the performance deterioration in the Ar/CO_2 mixture proved to be very dramatic: the gas gain was falling by a factor of two for each 0.25 C/cm of accumulated charge. The correlation between accumulated charge and the amount of oxygen collected in the anode wire was observed using a Nuclear Reaction Analysis. Aging studies of a full-size CMS Muon Cathode Strip Chamber under global irradiation at the GIF facility at CERN are also presented.

Summary of Talk: The irradiation tests were conducted with three prototypes that were fabricated using materials intended for production chambers. The active area of the prototype chamber was 175 $\times$ 240 mm^2 and reproduced the major local details of the final design. The typical rate of the charge accumulation per day was as follows: about 0.3 C per cm of wire at the center spot, and about 0.004 C/cm^2 for the total charge per entire cathode plane averaged over its surface. The first chamber was tested with $Ar/CO_2/CF_4$ 30:50:20 which was the baseline gas mixture at the time of the test. The CF_4 component is added primarily for its aging-preventing abilities. Indeed, as described below, even in a case of negative influence from the RTV sealing the aging resistance of a chamber with 20% CF_4 mixture did not change up to 13.6 C/cm of accumulated dose. The $Ar/CO_2/CF_4$ 40:50:10 gas mixture was used to see whether this gas is still capable of preventing aging. An SEM/XEM surface examination of the anode wire was done in a few points of the irradiated zone. At the center of the irradiated zone, the gold coverage looked damaged and the wire surface became dark. Although having drastically damaged the gold coverage of the wire with the longtime discharges, we found neither silicon nor carbon-based deposits on the surface. Both $Ar/CO_2/CF_4$ 40:50:10 and $Ar/CO_2/CF_4$ 30:50:20 gas mixtures showed very little signs of aging besides an increase in dark current. The gas gain remained virtually constant up to the end of the test (13 C/cm). Opening of the chambers revealed layers of deposits on the cathode surface. Chemical analysis showed presence of Si, F, and O elements. The intensity of the cathode coating in the test with 10% CF_4 was substantially smaller; however, this is likely due to the change in the chamber sealing design. Wires tested with mixture containing 20% CF_4 appeared to have an etched gold-plated surface. This observation is different from that with 10% CF_4: here the gold plating of wires was observed to crack and the wires were damaged more. However, these damages apparently did not affect the chamber performance. On the outlet edge of the wires we found some tin flakes on the wire surface, very similar to those formed in the 20% CF_4 gas mixture. The tin may come from solder interacting with fluoride. To confirm the crucial role of CF_4, we conducted the second test with Ar/CO_2 30:70 and saw a truly dramatic deterioration. A Nuclear Reaction Analysis was applied to investigate how the light element (oxygen, nitrogen and carbon) distribution along the wire and the depth distribution into the wire surface depend on the accumulated dose. Aging properties of a full-size CMS muon cathode strip chamber (2$\times$1 m^2) were studied at the CERN Gamma Irradiation Facilities (a 0.7 TBq ^{137}Cs source that provided a high flux of 0.66 MeV photons). The chamber studied was from the production line and was flushed with the nominal gas mixture $Ar/CO_2/CF_4$ 40:50:10 at the baseline gas flow rate of 1 chamber volume per day. The total charge per unit of wire length accumulated over the period of 4 months was about 0.4 C/cm, which would correspond to approximately 40 LHC years. The chamber successfully passed the test. A number of chamber parameters was monitored during these studies. The chamber gas gain, efficiency plateau, and anode wire noise did not change. The dark current and resistivity between strips did show signs of deterioration, but still remained well within the specifications throughout the tests.

Aging Studies for the Cathode Strip Chambers of the CMS Muon Endcap Detector

(title assigned)

presented by **Oleg Prokofiev**

Fermi National Accelerator Lab (FNAL), Batavia, IL, USA

The CMS Endcap Muon system will consist of 540 six-plane cathode strip chambers with an overall area of a thousand meters square and about 2.5 million wires. Given the scale of the detector the primary concern is obviously the reliability and chamber aging is one of the critical points of the system operation. Two CMS ME1/2 production Cathode Strip Chambers were tested to study chamber performance and aging effects in the high-radiation environment at the Gamma Irradiation Facility (GIF) at CERN. At an accumulated dose of 0.3 C/cm, equivalent to about 40 years of LHC operation at full luminosity, no evidence of dramatic chamber deterioration was observed. There was no significant change in gas gain and chamber efficiency, and the dark counting noise rate remained within the acceptable range. Only one sign of aging phenomena was found in the decrease of the strip-to-strip resistance, which indicates accumulation of deposits on the cathode planes but it did not affect the chamber performance.

Summary of Talk: Two sets of aging test with EMU Cathode Strip Chamber were performed at GIF. The 6-plane ME1/2 production chambers of 0.8 m $\times$ 1.8 m were irradiated over 0.4 m^2 at a rate of 18 kHZ/cm^2 for 4–5 months. Chambers were tested with an $Ar/CO_2/CF_4$ 40:50:10 gas mixture using a prototype of the closed-loop circulation system where oxygen and water were being removed by purifiers. The prototype contained the same materials (including all piping) and components that will be used in the final CMS gas system. The flow rate was about 1 chamber volume per day in purging mode and 4 volumes/day with the closed-loop circulation system. The impurity levels in the gas system were monitored with oxygen and water sensors and a gas chromatograph. In both experiment – with and without circulation system – we did not find any indication of aging which could cause a deterioration of chamber performance under realistic LHC conditions. Chamber parameters like gas gain and chamber efficiency did not change up to 0.3 C/cm. The dark current and wire noise rate remained at the same level as at the beginning of the test, about 1-10 nA per plane and 8-10 Hz per anode wire group ($\sim$120 cm^2). Only one evidence of an aging effect was discovered in form of a drop of strip-to-strip resistance by two orders of magnitude (from 1000 GOhm to 10 GOhm) but it stayed at a level about two orders above the safety limits. After the chamber was disassembled some deposits were observed on the cathode planes. From the previous aging test with a CSC prototype the deposit was mostly connected to a silicone coating which came from the machined FR-4 material existing in the chamber gas volume and silicone RTV used for chamber sealing. The gas-chromatographic analysis showed that within errors ($\pm$ 200 ppm) we do not see any difference between premixed gas and working gas mixture in the circulation system. The oxygen in the system was found to be at the level of 140 ppm and the water at about 10 ppm. All tests showed that EMU chambers operated with a $Ar/CO_2/CF_4$ gas mixture can be run in the LHC environment without appreciable aging effects.

Irradiation Response of Straw Drift Tubes

presented by **Wolfgang Dünnweber**

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Drift tubes filled with mixtures of $Ar/CF_4/CO_2$ were exposed to proton beams to study the radiation effects and operation characteristics expected for the COMPASS experiment at CERN. Stable operation is possible for charge accumulations on the anode wire up to 1.2 C/cm, in contrast to the aging effects that we observe for Ar/CH_4 mixtures. In addition to the aging characteristics, we also studied gas gains and spatial resolutions for various operation parameters.

Summary of Talk: The straw drifttime detectors of the COMPASS experiment at CERN consist of metallized kapton tubes of 6 or 10 mm diameter and 30 μm Au/W anode wires. We have studied the radiation effects and operation characteristics using 24 MeV proton beams from the Munich Tandem accelerator with broad and homogeneous profiles. Gas gains in the 10^4 range were determined by comparing the measured integrated electrical currents and proton doses. Pulse height spectra for 5.89 keV photons from a ^{55}Fe source allowed sensitive monitoring of gain variations. An Ar/CH_4 70:30 gas mixture was used to demonstrate the sensitivity of our methods. A gain loss of 23% per C/cm was measured and the onset of Malter current was observed for accumulated charges below 0.1 C/cm. With a mixture of $Ar/CF_4/CO_2$ 74:20:6, considered for COMPASS operation, no significant loss of gain ($< 1\%$) was found up to an integrated current of 1.2 C/cm. Electron microscopy shows formation of a layer of fine grain of about 0.1 μm thickness. Some light element enrichment in the deposit are indicated in an Elastic Recoil Detection Analysis. The accumulated charge of 1.2 C/cm corresponds to about 20 (4) years of COMPASS (muon halo at 10 cm from beam axis) for a gas gain of $2{\cdot}10^4$ ($1{\cdot}10^5$).

Aging Problems of the Inner Tracker of HERA–B: How to Develop Micro Pattern Gaseous Detectors for High–Rate Experiments

presented by **Thomas Hott**

University of Heidelberg, Heidelberg, Germany

Aging Measurements with the Gas Electron Multiplier (GEM)

presented by **Steffen Kappler**

IEKP, Karlsruhe University and *CERN, Geneva, Switzerland*

Continuing previous measurements, we have made long-term, high-rate exposures of production GEM detectors – built for the COMPASS experiment – to radiation to study aging properties. In standard operating conditions, with Ar/CO_2 filling, no change in gain is observed after a total collected charge of 5 mC/mm^2, corresponding to 5 years of normal operation. The observation confirms previous results demonstrating the relative insensitivity of GEM detectors to aging, even when manufactured with common materials.

Summary of Talk: Due to the absence of thin anodes, the GEM multiplier seems a priori much less sensitive to aging than other micro-pattern devices. Indeed, since the gain is determined by the field strength in the central region of the holes, far from electrodes and walls, it is very little affected by possible polymerization deposits. This has been already confirmed experimentally by us and various authors. As a necessary complement of our previous measurements, made with small detectors under somewhat ideal conditions, we have exposed a standard large-area production model of the triple-GEM detectors built for the COMPASS experiment at CERN. In this case, because of practical constraints, the choice of the materials, epoxies and sealants is somewhat less optimal. Nevertheless, a long-term exposure to X-rays, made over a substantial area of a detector (about 100 cm^2) has shown no sign of degradation of gain up to a total collected charge of 5 mC/mm^2. This corresponds to 5 years of operation in the experiment. The chamber is operated in a mixture of Ar/CO_2 70:30. Measurements continue to assess the possible effects of contaminants, the most likely one being water permeating through the windows or the gas tubes.

Aging Studies for the Inner Tracker of HERA–B

(title assigned)

presented by **Malte Hildebrandt**

Physik–Institut Universität Zürich, CH - 8057 Zürich, Switzerland

The Inner Tracker of the HERA–B experiment at the Deutsches Elektronensynchrotron (DESY) is a position-sensitive detector which was designed to be exposed to a particle flux density up to $2 \cdot 10^4$ MIPs/mm^{2}s and to a radiation dose up to 1 Mrad/year (10 kGy/year). The system consists of Microstrip-Gas-Chambers (MSGC) using a Gas Electron Multiplier (GEM) as preamplifier structure in the gas volume. During the R&D phase, long term aging measurements with X-rays were performed to study which materials and glues do not lead to aging of the detector over long running periods.

Summary of Talk: Aim of measurements: The aim of the high rate and long term aging measurements with X-rays described here was to study which materials and glues do not lead to aging of the GEM-MSGC detector with Ar/DME 50:50 as counting gas over long running periods. The typical running time at HERA–B is 10^7 s/year. For a GEM–MSGC which is operated at a gas gain of 4000 and which is exposed to an average particle flux of $1 \cdot 10^4$ MIPs/mm^{2}s the total accumulated charge amounts to 5 mC/cm per year. The aging measurements were performed within the scope of the development of the detectors for the Inner Tracker at HERA–B and took place at the high rate test setup at the Physikalisches Institut of the University Heidelberg.

Test setup: The detectors were irradiated with a particle flux up to $20 \cdot 10^3$ γ/mm^{2}s (Cu-K$_\alpha$). A very clean gas system was used for the gas supply, with components made of stainless steel and sealing rings made of Kalrez. Several bypass devices furthermore allowed to add α-particles as well as 0.3 % water to the counting gas and to direct the gas over additional samples of materials or glues.

Results: Aluminum and gold as electrode material for the MSGC structure were tested. For aluminum a significant decrease in the pulse height was observed for a total accumulated charge of much less than what is expected after one year of running at HERA–B. The aging was observed both for Ar/CO_2 70:30 and Ar/DME 50:50 as counting gas. The cathode strips showed large and small bubbles after running with Ar/CO_2, whereas after the operation with Ar/DME the cathode strips were covered with small craters. No aging effects and no damages of the cathode were observed for MSGC's with an electrode structure made of gold. Adding 0.3 % water to the counting gas led to a more stable detector operation but also to massive aging of the anode strips and in consequence to a strong decrease of the pulse height and energy resolution. A thick coating on the anode stripes was visible with the microscope. In addition some anode strips showed 'worm-like' growths in the plane of the MSGC substrate.

An aging study of a MICROMEGAS + GEM detector

J. May, S. Kane, J. Miyamoto, I. Shipsey

presented by **Jun Miyamoto**

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We are studying the aging behavior of a micromegas detector with GEM preamplification. Because of minimal insulation materials and its inherent parallel E-field in the amplification gap, superior radiation hardness was previously reported in Ar-Isobutane gas mixture in a micromegas detector with no preamplification. It is expected to tolerate even a larger amount of radiation in cleaner gas mixture like Ar/CO_2. However, using it as a stand-alone device in this mixture (low gas gain) could increase its discharge probability and it could lead to faster degradation of detector performance. To circumvent this problem, small preamplification with a GEM was added to extend the life time of the main detector. It is well known that the GEM itself tends to age if too much gain requirement is imposed on it, thus a good balance of gain sharing between the micromegas and the GEM should make it possible to build a very radiation-hard gas detector. We will report on the aging behaviors of both devices when the two devices are combined to achieve high gas gain and operated under safe conditions.

Summary of Talk: A micromegas detector consists of an anode plate and micro-mesh separated by only 50 – 100 microns [1]. Unlike typical micro-patterned gaseous devices, its electric field is similar to that in a parallel plate chamber. This parallel structure may have distinct advantage in terms of radiation hardness. From our experience, trying to achieve high gas gain in an extremely narrow gap with an insulator in-between (e.g. near anodes of MSGC and MGC) could accelerate aging and its effect is more pronounced in the form of dark deposit accumulated on the strips of these devices [2]. Accumulation of deposits on very thin strips could change the detector properties irreversively. The parallel structure of the micromegas allows the use of anode strips on the electron collector that are wider by an order of magnitude so that very fragile thin anode strips are not needed to achieve the same gas gain. The elimination of the thin strips can minimize aging effects significantly even if some deposit is formed on the metal surface because some surface will be always available for charge collection.

A Micromegas detector has another advantage in that it has very little insulating materials between the anode and the cathode. The only insulating material near the avalanche region is the small pillars made of Kapton separated by a few millimeter pitch and the area obstructing the active detector area is almost negligible. This feature was not available in the MSGC and a large insulator often becomes an origin of discharge.

For the reasons above, the first aging study of the detector was very encouraging and 16 mC/mm^2 was accumulated in an Ar/Isobutane mixture by the Saclay group [3]. Because of the high gas gain that such a gas mixture allows, the micromegas was used as a stand-alone detector with no preamplification. In order to build a more radiation-hard detector, cleaner gas like Ar/CO_2 must be used but this gas mixture does not yield gas gain high enough to be of practical use and preamplification is necessary. In our work a GEM (gas electron multiplier) was used to add preamplification and the gain was shared by both the GEM and the micromegas. This gain sharing mechanism usually works favorably assuming that both devices are quite radiation hard but the radiation hardness of GEM's was already confirmed by our previous work [4]. We will report on the radiation hardness of the combined system in our talk.

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Anode Wire Swelling – a New Phenomenon for Anode Wire Aging at High Doses

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presented by **Anatoli Krivchitch**

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We present results from an aging investigations of straw drift tubes placed under sustained irradiation from a 2 Ci ^{90}Sr β-source. Aging tests were performed with two different gas mixtures $Xe/CO_2/CF_4$ 70:10:20 and $Ar/CO_2/C_2H_2F_4$ 40:40:20. A thorough study of the aging phenomenon of gold-coated tungsten wires with a diameter of 35 μm was done with accumulated charges of 3.6 C/cm and 1.6 C/cm. As a result of the aging process, the gold coating on the wires was damaged, and the wire diameter increased about 5.6%. Using Nuclear Reaction Analysis (NRA), in combination with an SEM/XEM analysis, we determined that a direct correlation between the amount of oxygen inside the gold coating and the anode wire diameter exists. This anode-swelling effect can be explained as a result of tungsten oxidation underneath the wire coating. This phenomenon of anode wire swelling by forces applied from within the anode wire is a new phenomenon in anode aging.

Summary of Talk: In this talk, we propose another possible mechanism for anode wire aging, which starts from dissociation reactions in the avalanches and finally causes the oxidation of the wire's tungsten under the gold coating. It should be noted that in the center of the irradiation zone the total amount of oxygen collected in the gold has increased more than 20 times in comparison to the non-irradiated wire. Moreover, the peak oxygen concentration increased up to 10 times, achieving a very high value of $1 \cdot 10^{22}$ at/cm^3. An analysis of this phenomenon, including data obtained earlier and the data presented in this report, leads us to propose a new mechanism for anode wire aging. We attempt to describe this phenomenon in general terms, but have no pretensions that this process is entirely understood. Our goal is to show the interconnection between the main factors causing both the anode-wire swelling and the development of aging. It has been found that atomic oxygen plays a very important role in this anode-wire aging process and greatly speeds up the aging of anode wires under a high irradiation dose. We believe that measurements performed using NRA of the oxygen concentration and the depth of its penetration into the gold coating after irradiation provide an excellent method to compare the aging resistance of different wires. The presence of both xenon and water vapor in the gas causes additional pathways for the creation of chemically active radicals. Xenon and xenon fluorides amplify the etching process and provide an easy path for the oxygen to reach the tungsten. Traces of water vapor may stimulate the process of wire swelling due to the creation of hydrofluoric acid in the gas discharge. We do not have direct evidences that tungsten oxide plays the main role in the wire swelling. This is our assumption and is based on two facts. Firstly, a large amount of oxygen has been observed directly on the tungsten surface of the wire. Secondly, neither carbon nor fluorine are observed in noticeable amounts in the XEM spectra. Consquently, oxygen appears to be the important element. Many compounds are created by etching the gold and from reactions with the tungsten in the wire. Some of them are in the solid phase and their densities are lower than that of tungsten or gold. Thus, the swelling phenomenon can take place in the wire material. How many and what types of compounds form in the tungsten are still unknown and more studies are needed.

Aging in Gaseous Photodetectors

(title assigned)

presented by **Vladimir Peskov**

Royal Institute of Technology, Stockholm Physics Centre, Stockholm, Sweden

Aging Studies of Large–Area CsI Photocathodes

ALICE collaboration

presented by **Antonio Di Mauro**

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The ALICE High-Momentum-Particle-Identification (HMPID) RICH detector is equipped with CsI photocathodes in a MWPC for the detection of Cherenkov light. The stability of large-area CsI photocathodes has been investigated over long periods with beam tests. A quantum efficiency drop of less than 10% over 6 years has been observed. In addition, dedicated studies have shown that the exposure to oxygen and water vapor with limited contamination has no influence on the photocathodes response.

Summary of Talk: The ALICE High-Momentum-Particle-Identification (HMPID) system is based on a CsI-RICH detector, having a liquid C_6F_{14} radiator coupled, in a proximity-focusing geometry, to a MWPC and a CsI photocathode (PC) segmented into pads with 2D analog multiplexed readout. A procedure has been established to deduce the differential quantum efficiency of PC's through the analysis of Cherenkov rings obtained from beam tests, with the support of Monte Carlo simulation. The main sources of the quantum efficiency degradation for CsI PC's are: humidity, photon impact (at very high fluxes) and, for PC's operated under gas multiplication, ion bombardment. Several CsI PC's, of area up to 65×40 cm^2, have been produced in the last 6 years and checked periodically in a test-beam. Humidity resulted to be a critical parameter during the PC preparation and in all the subsequent phases of handling, storage and operation. The influence of the exposure to oxygen and water vapor was studied under stagnant conditions, through increased levels of O_2 and H_20 due to outgassing, and under gas flow, with large concentrations of O_2 in the detector gas mixture. No degradation of the photoemission has been observed under the experimental conditions of the test. The results of this study found a direct application for the storage of CsI photocathodes during the shipment of the HMPID prototype-2 to the STAR experiment at BNL. A decay of the photoemission could be determined by the impacts of ion clouds on the PC's surface at each avalanche. Several PC's exposed to an integrated charge larger than 0.05 mC/cm^2, corresponding to one year running with lead ions at ALICE, have shown very limited degradation, and a quantum efficiency drop of less than 10% has been observed in PC's 6 years old.

Test-beam Aging Studies of a TMAE Prototype for the HERA–B RICH

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presented by **Kwong Lau**

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We report on aging measurements of a 64-cell proportional chamber Cherenkov photon detector prototype operating in a methane/TMAE gas mixture. The cells of the chamber, 100 mm long and 8×8 mm^2 in area, were constructed with brass cathode and 45 μm gold-plated tungsten anode wire. Aging was achieved by exposing the chamber to UV light from a deuterium lamp up to photon rates of 3 MHz/cm^2 for several weeks while the chamber was being studied in a DESY electron test beam. The photon-detection efficiency of the chamber was determined by measuring the number of Cherenkov photons emitted by 3 GeV electrons in a radiator consisting of 5 m of Argon. The pulse height distribution of the chamber was continuously monitored during the aging process. We found significant loss of chamber gain after an exposure equivalent to about 2 mC of charge deposited on the cell.

Summary of Talk: This talk reports on the aging measurements of a prototype TMAE photon detector for the HERA–B RICH. The HERA–B experiment was designed to operate at interaction rates up to 40 MHz. The particle identification system, a Ring Imaging Cherenkov (RICH) detector consisting of a 2.75 m long C_4F_{10} radiator, is expected to reach peak photon rate of 3 MHz/cm^2. Aging of TMAE-based proportional chambers has been observed at OMEGA and SLD. A first HERA–B photon detector prototype chamber, consisting of 1024 8×8 mm^2 cells using 25 μm wire operated with a TMAE/methane mixture at room temperature, indicated a 50% loss of gain after being exposed to a dose equivalent to about one HERA–B day. To find out if this rapid aging of TMAE-based proportional chambers can be slowed down, a second-generation 64-cell prototype was built with 45 μm wires and tested in an electron beam at DESY. The goal was to expose the chamber to radiation conditions as close as possible to those of HERA–B and to measure the Cherenkov photon detection efficiency during this aging process. We have monitored all the relevant environmental factors so that they can be corrected for in the analysis. The chamber assembly was housed in a 90 mm^2 square stainless steel tube fitted with a quartz window on one side and a flange to hold and seal the backplane on the other. An all stainless steel gas system has been built to vacuum specifications. Methane of 99.99% purity was first passed through an Oxisorb filter to remove residual water and oxygen. Regulated by electronic mass flow controllers, part of the flow was then forced through a TMAE-filled bubbler at room temperature and, mixed with the other part, was fed into the chamber. Prior to using this TMAE in the prototype chamber, the TMAE was washed with nitrogen until about 5% of the liquid was evaporated. For the normal operation of the chamber, we choose a flow rate of 10 cm^3/min through the bubbler and the bypass, yielding a TMAE/CH_4 mixture with a photon absorption length of approximately 5 cm. About one chamber volume of gas was exchanged per hour. We applied negative high voltage through a 1 MΩ resistor to the cathode planes; the wires were at ground potential. An operating point of 2650 V was used to achieve a gain of 200,000, determined from the measured current and the count-rate projected to 0 V threshold. The chamber was mounted on the upper quartz window of a 5 m long radiator tank, filled with argon, situated at the T24 3 GeV electron test beam at the DESY synchrotron. To achieve an even photon flux comparable to that in the HERA–B RICH, a UV light source was placed at the focus of the mirror on the outside of the radiator tank. The source consisted of a variable pin hole in front of a matte quartz plate illuminated by a deuterium lamp (Hamamatsu L5499-50). The light input to the chamber was monitored continuously by a UV PMT (Hamamatsu R2059) placed next to the chamber. The PMT was fitted with an interference-type filter (Oriel

200-N-2D) to limit the sensitivity to 200±11.3 nm. To test different exposure rates the chamber was divided into four equal quadrants Q1–Q4 by a removable mask (an aluminum plate with different size hole patterns) with transmissions of 100% (Q4), 64% (Q1), 32% (Q2) and 0% (Q3). The charge deposited on the wires, added by quadrant, was measured directly by an electrometer (Keithley 6517). The AC part of the signal was read by four 16-channel low noise charge sensitive preamplifiers. The pulse-height spectrum was determined automatically about every half hour, by taking a threshold curve for all 64 channels with a programmable discriminator. Every 1–3 days, aging was interrupted for about an hour by turning the deuterium lamp off. The electron beam was turned on. Runs of about 10,000 triggers with counting rates and TDC information for all 64 wires were taken. The triggers were created by a 3-fold coincidence of a beam scintillator and two small tracking chambers. The two sets of data were used to collect as much information as possible during the aging process of the TMAE chamber. First, the number of detected Cherenkov photons produced by relativistic electrons in an argon radiator is an absolute measure of the chamber efficiency. The number of detected photons in the prototype chamber in the wavelength range 150–220 nm was estimated with a model to be 11.2±1.5 photons per track, which agrees well with the measured number of 11.5 photons before aging. Second, the continuously monitored environmental parameters and the frequently measured charge distribution of each wire allow an easy detection of changes in the gain of the wire. Both efficiency and gain of the exposed chamber quadrant Q4 dropped during the first two days to less than half of their initial values. After two days the drop in gain and efficiency of Q4 slowed to about 10% per week. The gain of the unexposed quadrant Q3 dropped to about two-third of its initial value during the first day, then continues to fall at about 3% per week. The efficiency of Q3, with larger uncertainty, also dropped to two-thirds of its initial value after the first day of exposure.

Recent Experiences with Aging in Systems of Resistive Plate Chambers (RPC's)

(title assigned)

presented by **Daniel Marlow**

Princeton University, Princeton, NJ 08544, USA

Aging effects in the RPC's of the BaBar Experiment

(title assigned)

presented by **Davide Piccolo**

INFN Napoli, Napoli, Italy

The performance of the RPC's working at the BaBar experiment will be reported in this talk. Results from 1999 up to now will be described focusing on the problems (high dark current, detection efficiency reduction) affecting the operation of the detector. A brief report from the R&D activities to explain the anomalous behavior of the detector will be given.

Summary of Talk: The RPC's have been employed in the BaBar experiment to instrument the iron plates used to return the magnetic flux. The system is used to discriminate muons from pions and to identify neutral hadrons. The RPC's produced between 1996 and 1998 have been tested in Italy and at SLAC showing satisfying performances before the installation in the detector. Data taking of the BaBar experiment started in summer 1999 and the RPC system worked during the first months at high temperature (greater than 36^o C). Very soon after, a big fraction of the chambers showed anomalously high currents (about 10 times the initial value) and a continuous reduction of the detection efficiency. Systematic investigations of the peculiar behavior of these RPCs has been carried out both with data coming from the RPCs installed in the detector and on chambers in the laboratory. Preliminary conclusions seem to relate the problems to the correlated actions of high temperature, high voltage, and abundance of linseed oil.

Results of Long-Term Performance and Laboratory Tests on the L3 RPC Trigger System at LEP

presented by **Gianpaolo Carlino**

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The L3 experiment has been equipped with a forward–backward spectrometer triggered by an RPC system made of 192 double-gap chambers working in streamer mode. We monitored the behavior of the system over seven years of L3 activities. After the end of the LEP run, a small number of the chambers have been tested and analysed in our test site in Napoli. In this talk, we report on the long-term performance and the laboratory results.

Summary of Talk: In this talk, we aim at showing the behavior of the RPC chambers after 7 years of LEP running. The L3 muon trigger system as well as the RPC chamber characteristics will be described in the first part of the talk. The RPC's that were monitored during the LEP activities show a small reduction of performance in some chambers. In order to determine with good precision the RPC performance, some chambers have been tested with cosmic rays in our laboratory in Napoli during the L3 dismantling. The results of these tests show an average detector efficiency greater than 90%, even if the efficiency of a very small number of this sample is quite low. This could be due to mechanical deformations even if other effects could be responsible for this efficiency reduction. Further investigations are needed.

Further Advances in Aging Studies for RPC's

presented by **Giulio Aielli**

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Aging phenomena in RPC's have been studied in the framework of the ATLAS experiment since 1997 on small size prototypes, irradiated with a ^{60}Co source. The early results evidenced a decrease of the detector's rate capability at fixed electric field due to an increase of the total resistance of the electrodes. This behavior was recently confirmed by an extensive aging test performed on the ATLAS RPC 8220 (module-08221) at the GIF-X5 facility of CERN, that showed a residual rate capability of 300 Hz/cm^2 after the equivalent of 12 years of the ATLAS experiment, the initial value being 2 kHz/cm^2. The primary cause of this effect was clearly attributed, with the help of systematic laboratory tests, to a degradation of the anodic graphite coating, which distributes the electric field on the Bakelite electrode. We present here a systematic test of an improved graphite coating, carried out on single Bakelite electrodes as well as on fully assembled RPC's irradiated at the GIF. The test results indicate an improvement of at least a factor of 2 in the detector aging.

Summary of Talk: Aging phenomena in RPC's have been studied in the framework of the ATLAS experiment since 1997 on small size prototypes, irradiated with a ^{60}Co source. The early results evidenced a decrease of the detector's rate capability at fixed applied electric field due to an increase of the total resistance of the electrodes. Due to the detector working current, the resistance increase produces an increase of voltage drop on the resistive electrodes, thus reducing the effective electric field applied to the gas. This behavior was recently confirmed by an extensive aging test performed on the ATLAS RPC 8220 (module-08221) at the GIF-X5 facility of CERN. The test consisted in irradiating the detector at working point conditions in order to integrate 10 years of working at the LHC under the conditions expected for the ATLAS experiment, including a safety factor of 10 (10^{10} counts/cm^2). This can be expressed in terms of total integrated charge, knowing the average charge per count (30 pC) delivered in the gas at full efficiency. This number depends of course on the front-end electronics threshold. Both the total counts and the current were monitored during the test, to estimate the aging progress. Periodically, both the detector performances with the X5 muon beam and the electrodes' total resistance were measured. The latter was obtained by measuring the average charge per count vs. the applied electric field for different source intensities. Representing the previous quantities vs. the effective field (i.e. the applied field decreased by the unknown ohmic drop) it is possible to fix the electrodes' resistance left as a free parameter. These measurements showed a residual rate capability of 300 Hz/cm^2 after 12 ATLAS years equivalent, the initial value being 2 kHz/cm^2, while the electrodes' total resistance increased by a factor of 12. The primary causes of this effect were clearly attributed, with the help of systematic laboratory tests, to some initial evolution of the Bakelite resistivity, but mostly to a degradation of the anodic graphite coating, which distributes the electric field on the Bakelite electrode. We present here the results of these tests by comparing the behavior of the previous graphite coating with an improved one. The test is carried out on single Bakelite electrodes, small detectors operating in pure Argon as well as fully assembled RPC's irradiated at the GIF and equipped with the standard front end of ATLAS. The laboratory tests were carried out on Bakelite samples of different resistivities to study the aging process which is of purely electro-chemical nature, and to compare the different performances. This was done by applying 400 V on 2 mm thick Bakelite slabs coated with graphite on both sides, in order to integrate the desired amount of charge. The test on the fully assembled detector was performed at GIF-X5, similarly to the test cited above, to check under realistic conditions the effective gain, in terms of aging, of the new setup. The test results indicate an improvement of at least a factor of 2 in the detector aging.

Aging Studies for the Resistive Plate Chambers (RPC's) of the CMS Muon Trigger Detectors

(title assigned)

presented by **Gabriella Pugliese**

Department of Physics, University of Bari, 70126 Bari, Italy

The CMS Resistive Plate Chambers (RPC's) of the muon trigger detectors will work in presence of an intense gamma and neutron background. The total accumulated dose and charge for 10 years of LHC operation have been estimated to be about 1 Gy and 0.05 C/cm^2 per gap, respectively. In order to study possible aging effects, dedicated irradiation tests have been performed both with gamma fluxes and neutron fluxes. These tests were performed with the final detector geometry and readout electronic chain at the CERN Gamma Irradiation Facility and Louvain-la-Neuve neutron facility.

Summary of Talk: The RPC's are well known gaseous ionizing detectors. They will be used as dedicated detectors for the CMS muon trigger system at the future Large Hadron Collider (LHC). At the maximum LHC luminosity (10^{34} cm^{-2}s^{-1}) the expected background fluxes in the barrel region of CMS due to low energy photons (up to about 100 MeV) and neutrons (up to 1 GeV) will be about $4 \cdot 10^2$ cm^{-2}s^{-1} and 10^3 cm^{-2}s^{-1}, respectively. Monte Carlo simulations have estimated that the corresponding integrated dose in ten years of LHC operation will be about 1 Gy. Moreover, a total charge of about 0.05 C/cm^2 per gap will be integrated in the active area of the detector. It has been extensively verified that double-gap RPC's, operated in avalanche mode, have a time resolution better than 2 ns, an efficiency above 95% and a rate capability of $\approx$ 1 kHz. However, aging tests are necessary to realistically reproduce the background conditions of the CMS experiment. This talk summarizes the experimental results obtained during the past years on CMS-RPC's irradiated with gamma and neutron fluxes at the CERN Gamma Irradiation Facility and the Louvain-la-Neuve neutron facility, respectively. These tests were performed with the final detector geometry and electronic readout chain. It is well known that a thin layer of linseed oil on the Bakelite surface has the effect of reducing the RPC noise and dark current. Therefore, detectors with and without linseed oil treatment have both been tested, in order to verify a possible different behavior from the aging point of view. To investigate possible aging effects the current, the counting rates, and the efficiency of the chambers have been monitoring during the irradiation. Concerning the gamma irradiation, the results show no significant variation of the RPC efficiency with cosmic muons. No variation of the gamma sensitivity of the detector has been observed. However, an increase of the counting rate and of the current have been measured. For the neutron test, very preliminary results will be available. Finally, the RPC front-end chips have been also tested during the irradiation to measure the S.E.U. (Single Event Upset) rate. No degradation both in their timing characteristics and in drawn current have been observed.

First Results from an Aging Test of a Prototype RPC for the LHCb Muon System

presented by **Giovanni Passaleva**

INFN Florence, Florence, Italy

We present the first results of an aging test being performed at the CERN Gamma Irradiation Facility on a single-gap RPC, a prototype of those foreseen for the LHCb muon system. The results are based on an accumulated charge of about 0.4 C/cm^2, corresponding to about 4 years of LHCb running at worst conditions. We have measured regularly the performance of the chamber with test beam facilities. We observed the expected degradation of the rate capability above 1 – 2 kHz/cm^2. We also found that the dark current and the noise increased after irradiation. However, the chamber still meets the LHCb operation requirements.

Summary of Talk: RPC detectors have been chosen for equipping a large fraction of the LHCb muon system. The maximally expected rate, after application of all safety factors, depends mainly on the polar angle and varies between 250 and 750 Hz/cm^2. The corresponding expected integrated charges for ten years of operation are 0.35 and 1.1 C/cm^2, respectively. These are significantly larger than those expected in ATLAS and CMS, whose aging studies reached accumulated studies of at most 0.3 C/cm^2. The LHCb aging study started in January 2001 at the CERN Gamma Irradiation Facility, where a ^{137}Cs photon source of about 675 GBq is installed, and is expected to last until December 2001. The tested chamber is a single-gap RPC of dimensions 50 × 50 cm^2. A second chamber is operated under the same conditions (gas composition and exchange rate, temperature, pressure) except for the irradiation. The comparison between the two chambers allows disentangling the effects solely due to irradiation. During the test, the currents drawn by the two chambers are continuously monitored. To accelerate the test the chambers are operated at a voltage such that the current density in the irradiated chamber is about 60 nA/cm^2. The resulting charge integration rate is about 0.08 C/cm^2/month, and the charge collected so far is about 0.4 C/cm^2. At this rate, it should be possible to collect 0.8 – 0.9 C/cm^2 by the end of 2001, close to the 'ten-LHCb-years-operation' target. An overall decrease of the current drawn by the irradiated chamber is observed. The performances of the two chambers have been regularly measured with test beams. The irradiated chamber is behaving as the reference one up to rates of 1 – 2 kHz/cm^2, well within the LHCb requirements. Aging effects are observed at larger rates. We also observe an increase in noise and dark currents, which remain, however, well below the maximum acceptable values.

Review of Workshop Results on the Fundamental Understanding of Aging Processes

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Recommendations for Building and Testing the Next Generation of Gaseous Detectors

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