Aging Studies for the Muon Detector of HERA–B

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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.