International Workshop on
Aging Phenomena in Gaseous Detectors
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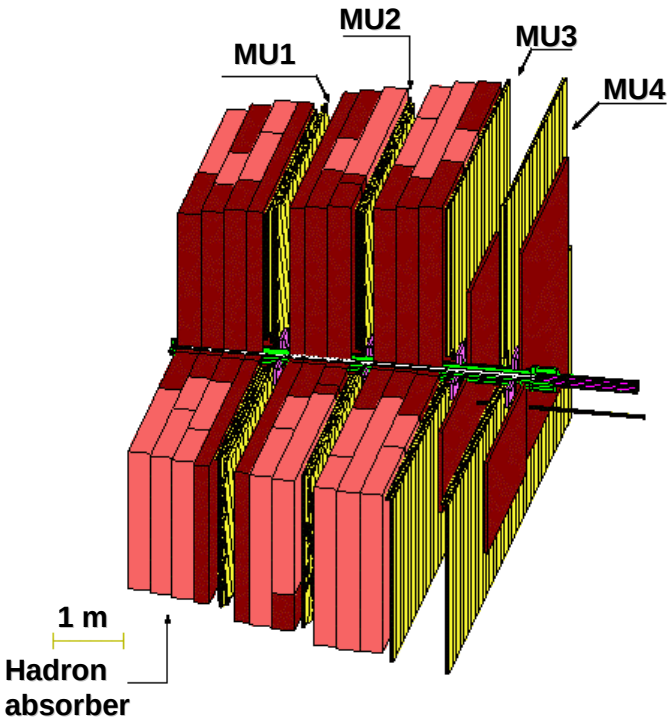
Aging Studies for the MUON Detector of HERA-B

M. Titov
ITEP, Moscow

- Introduction
- Aging results from laboratory tests
- Aging studies in a 100 MeV α-beam
- Aging studies in a high-rate HERA-B environment
- Summary and Outlook

HERA-B MUON Detector



4 muon superlayers consist of tube, pad, pixel gas proportional chambers:
~ 1000 chamber modules
~ 30000 readout channels

The total area covered by chamber modules ~ 800 m²

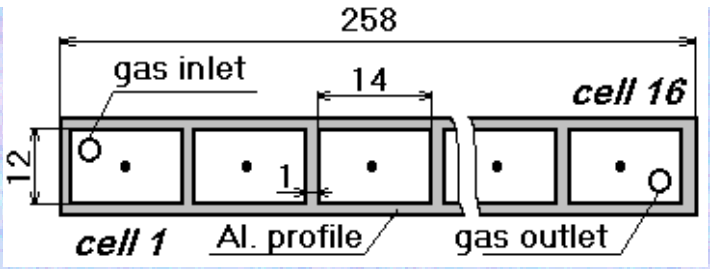
Muon Detector has been running continuously since November'99

HERA-B: Operating conditions

High track densities comparable
to LHC-conditions:
particle-flux/year/area 2 * 10^{14} / R^2 [cm^2]

MUON System

Detecting element: tube chamber



Radiation dose, estimated from
chamber currents in MU1:
up to 200 mC/cm wire per year

Criteria for the gas choice

(total muon gas volume ~ 8 m^3)

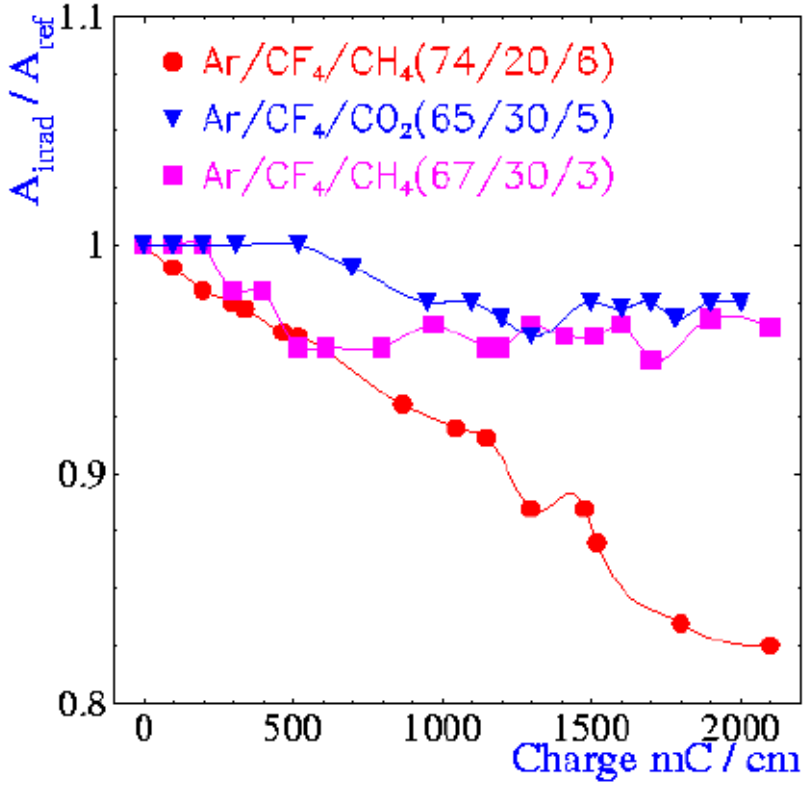
- High resistance to sparking
- Good transport properties
  (high drift velocity, convenient operating electric field E/P)
- Good chemical properties
  (non-flammable, non-poisonous)

Ar/CF4/CH4(74:20:6),
Ar/CF4/CH4(67:30:3),
Ar/CF4/CO2(65:30:5)

Main requirement -
Extremely low aging

Aging Studies with Fe55 and Ru106 sources

Status at collected charge ~ 2 C/cm wire:



3 cm of the wire irradiated by Fe^{55}

Ar/CF4/CH4 (74:20:6)

current density up to 700 nA/cm

Gas gain loss: R=-(1/G)(dG/dQ) ~8%/C/cm

After ~1 C/cm self-sustained dark current

1 cm of the wire irradiated by Ru^{106}

Ar/CF4/CH4 (67:30:3)

current density up to 1200 nA/cm

Ar/CF4/CO2 (65:30:5)

current density up to 900 nA/cm

Negligible loss in performance observed

Aging rate in the laboratory setup **? ? ?** → Irradiation of the large area detectors in high intensity environments

Aging Studies in a 100 MeV alpha-beam
Ar/CF4/CH4(74:20:6)

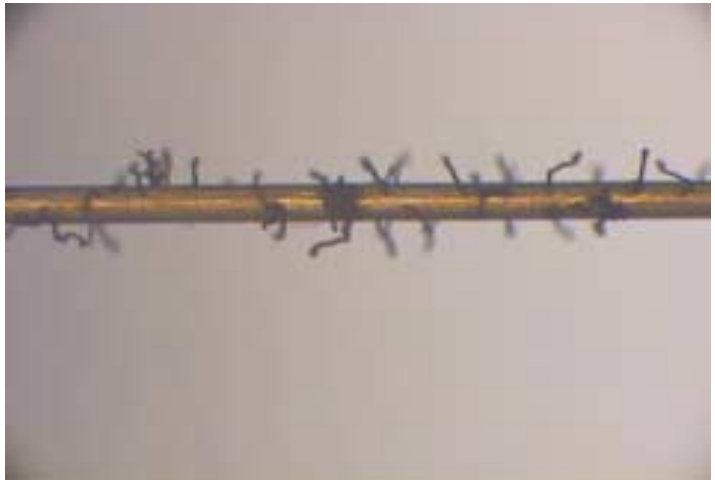
Operating conditions:

- α-beam area 8 * 8 cm²

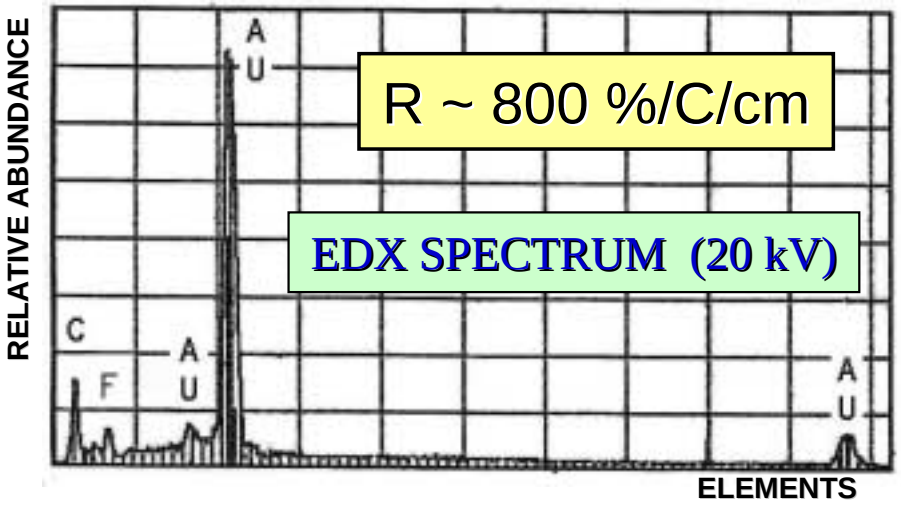
(Irradiation of 4 wires fully, 2 wires exposed over half of their cell width)

- HV=2.35 kV, gas gain ~4 *10⁴
- current density ~ 250 - 750nA/cm
- Gas flow ~5 l/h

Total collected charge ~280 mC/cm:

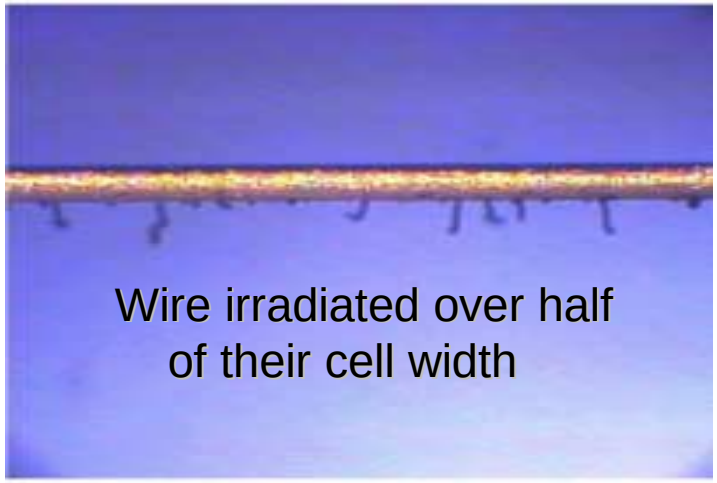


Gain reduction was observed after ~60 mC/cm



R ~ 800 %/C/cm

EDX SPECTRUM (20 kV)



Fe⁵⁵ source
R ~ 8 %

?

HERA-B
environment

?

100 MeV α's
R ~ 800 %

Aging Studies in a HERA-B environment

Conditions:

1) Ar/CF4/CH4 (67:30:3)
5 different HV (2.25 kV-2.65kV)
gas gains ($8*10^3$ - $2*10^5$)
current density (40 nA/cm - 200 nA/cm)

2) Ar/CF4/CO2 (65:30:5)
5 different HV (2.25 kV-2.65 kV)
gas gains (10^4 - $3*10^5$)
current density(50 nA/cm - 270 nA/cm)

3)Ar/CF4 (70:30)
HV=2.6 kV, current density ~ 150 nA/cm

4) CF4/CH4 (90:10)
HV=3.0 kV, current density ~ 200 nA/cm

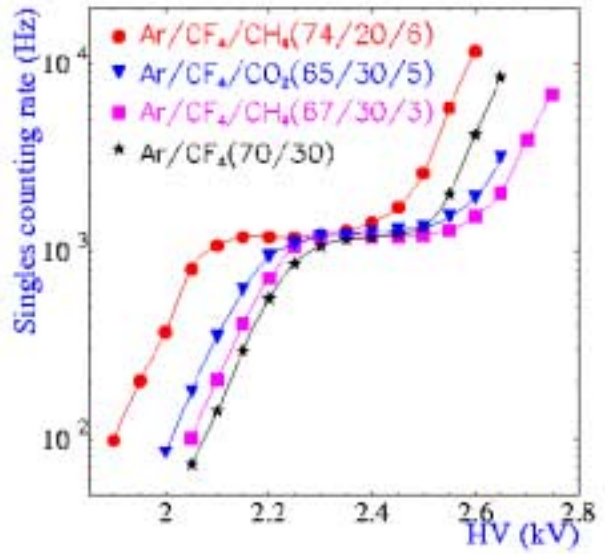
5) CF4/CH4 (80:20)
HV=3.0 kV, current density ~150 nA/cm

6) Ar/CF4/CH4 (74:20:6)
HV~2.45 kV, current density~200 nA/cm

- Radiation intensity varied during aging tests by factor of 4
- Gas flow ~1.5-3 l/h (1-2 Vol/hour)
- Size of irradiation area ~1000 cm^2

!!! Maximum current density in the muon system: ~20 nA/cm

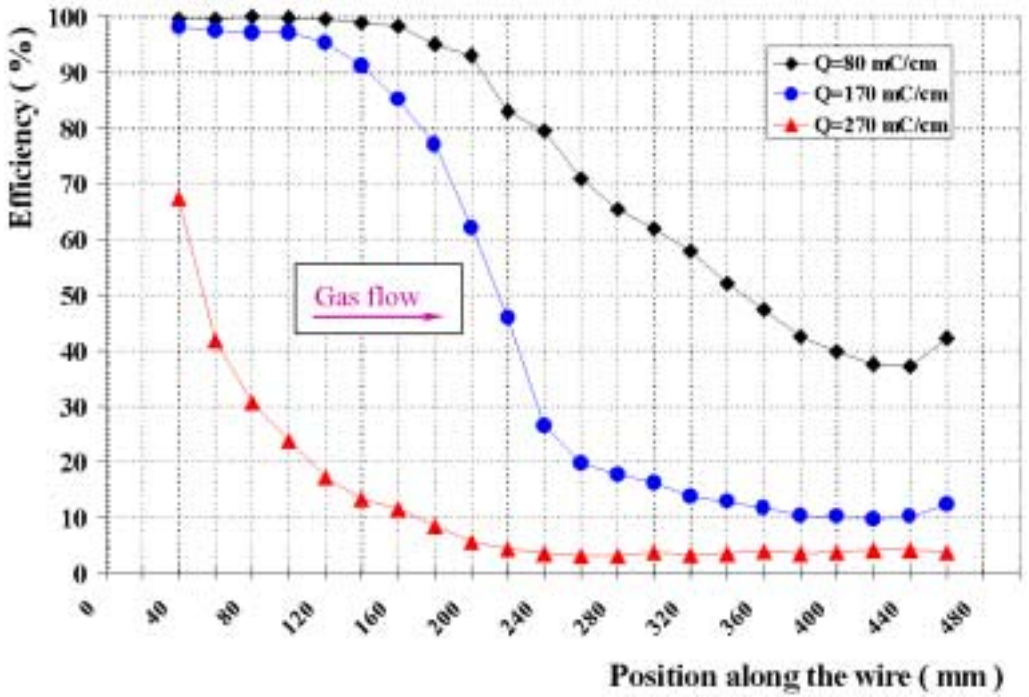
Counting rate vs HV (3 GeV e^+):



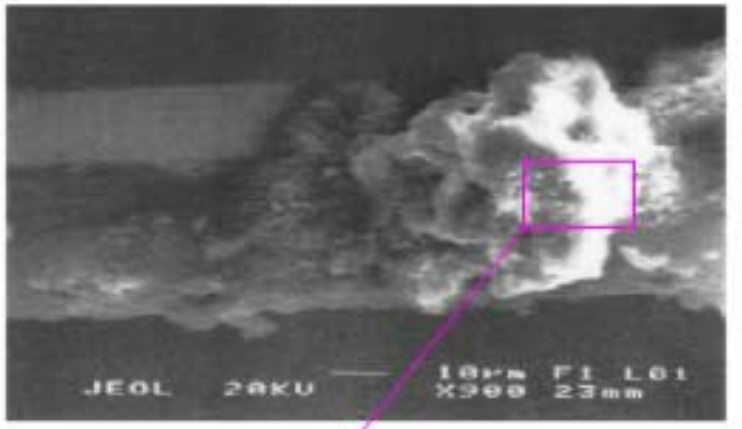
Ar/CF4/CH4(67:30:3) + 500 ppm H2O

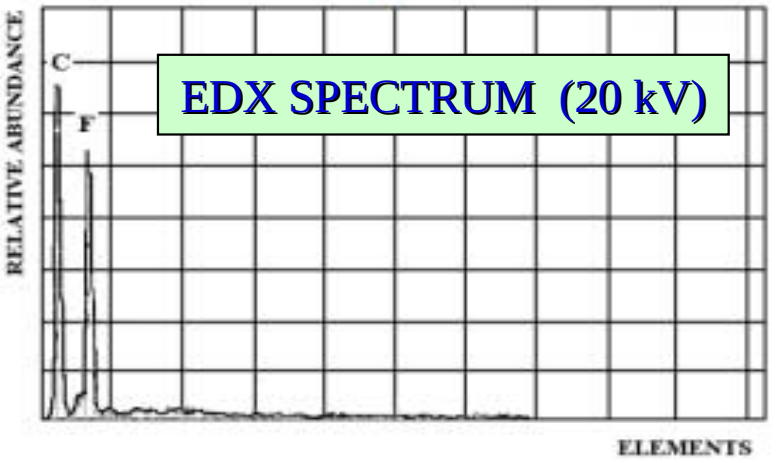
Wires irradiated at 2.65 kV (2.6 kV, gain ~10^5) started to show gain reduction and dark currents above a collected charge of 25 mC/cm (80 mC/cm):

Wire irradiated at 2.6 kV:



Total collected charge ~400 mC/cm:

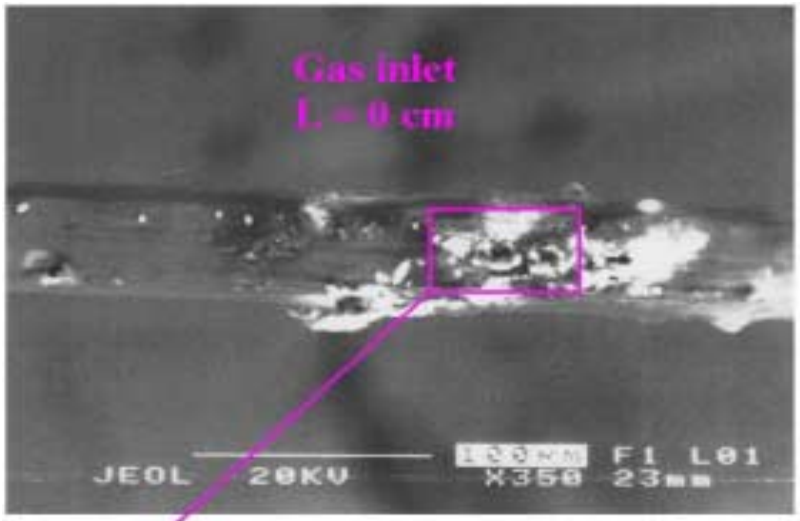


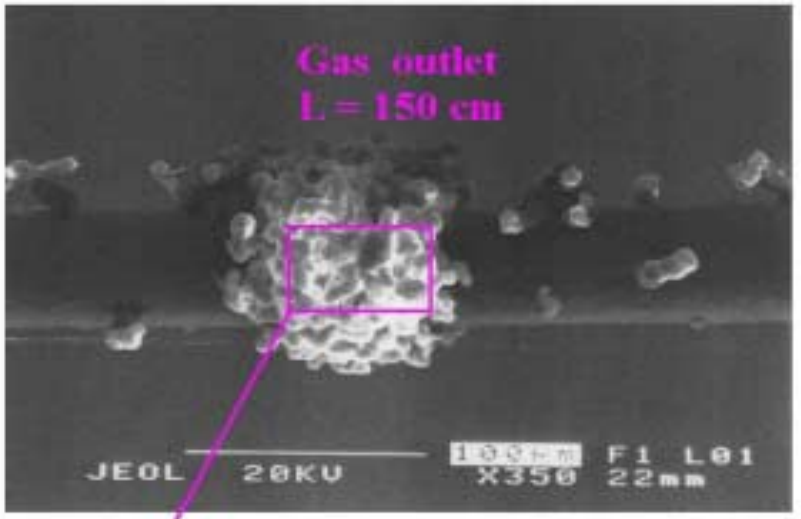


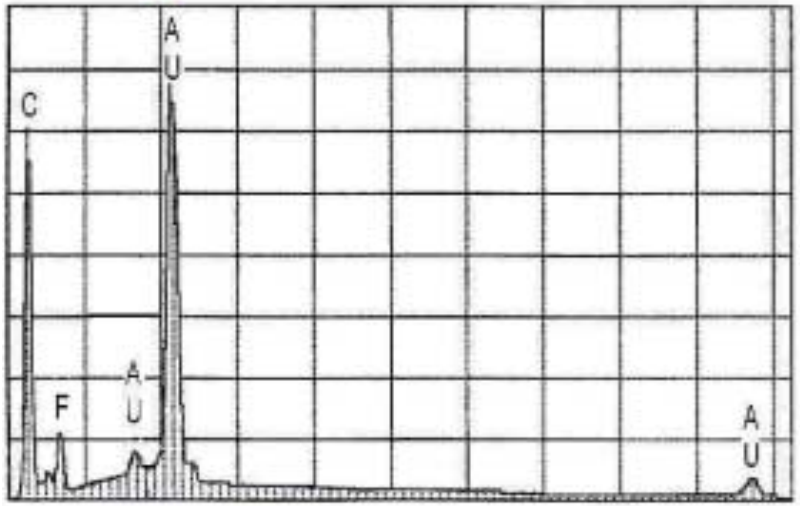
- Efficiency decreases in the direction of the serial gas flow
- Wire deposits, containing only C and F elements (H is not observable)

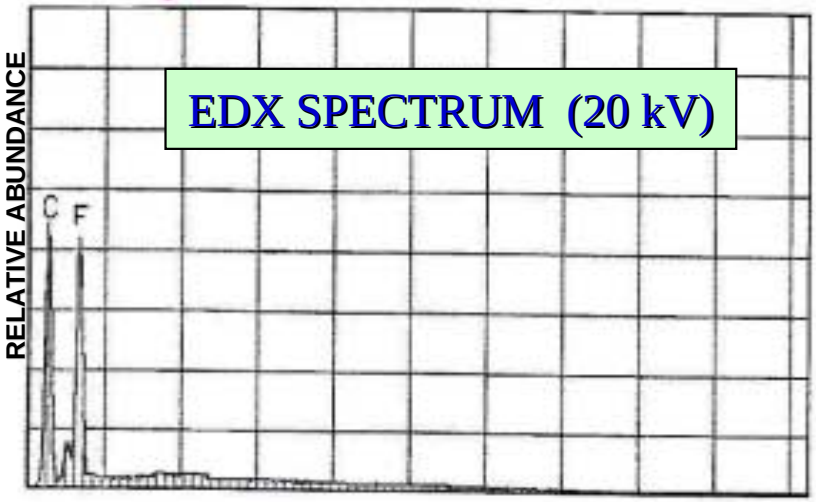
Ar/CF4/CH4(67:30:3) + 500 ppm H2O

Wires irradiated at 2.65 kV: Total collected charge ~ 200 mC/cm







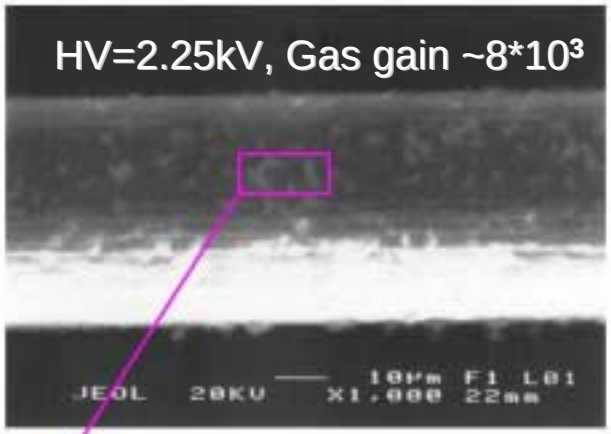


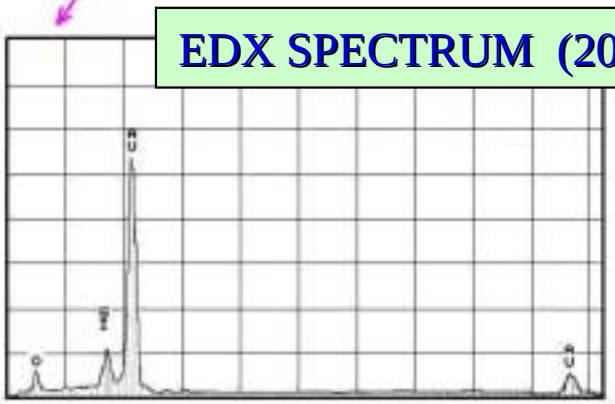
F/C ratio in the polymer increases in the direction of the serial gas flow

Ar/CF4/CH4(67:30:3)

Two wires irradiated at 2.25 kV up to:
100 mC/cm Ar/CF4/CH4+500 ppm H2O
100 mC/cm Ar/CF4/CH4+1400 ppm H2O

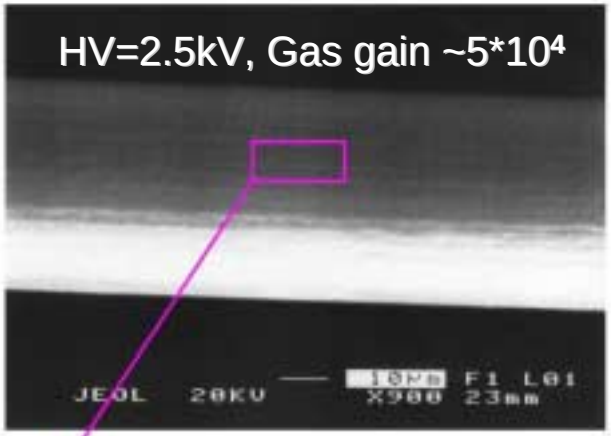
No gain reduction for one wire,
Si-based deposits on the other
(maximum gain reduction is in the region of lowest radiation intensity)

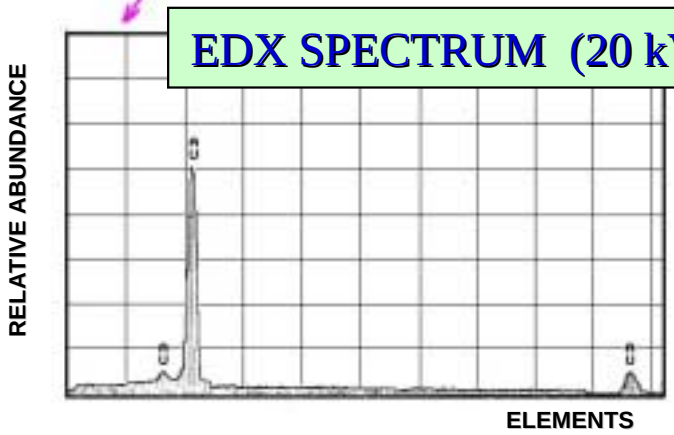




Four wires irradiated at 2.5 kV,2.55 kV up to:
400 mC/cm Ar/CF4/CH4+500 ppm H2O
400 mC/cm Ar/CF4/CH4+1400 ppm H2O

No gain reduction for all wires after 800 mC/cm, several distinct spots on the wires with gas gain loss after 400 mC/cm, which afterwards vanished

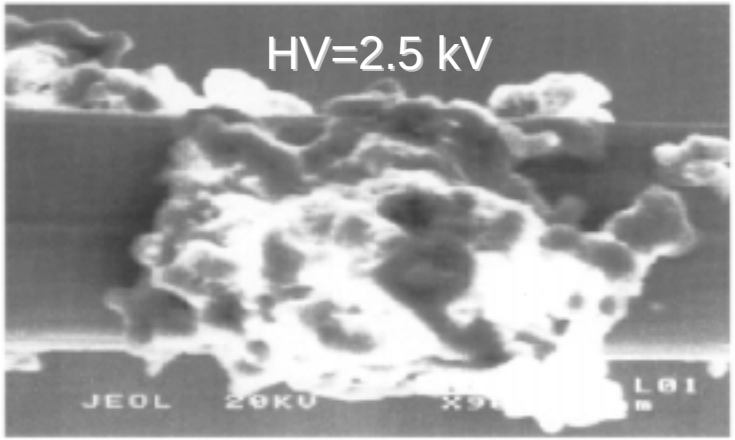


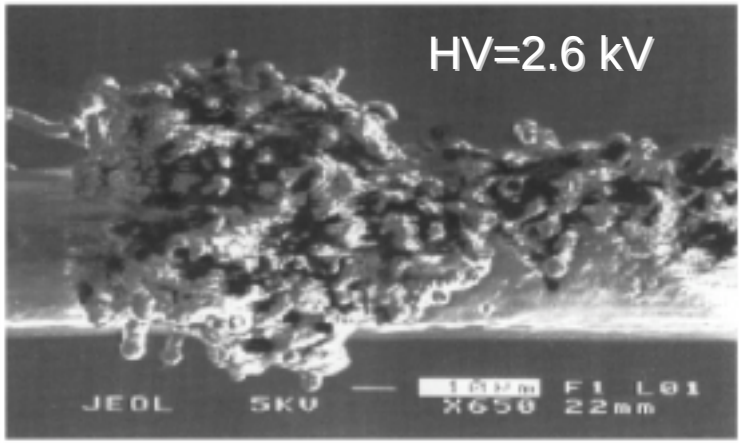


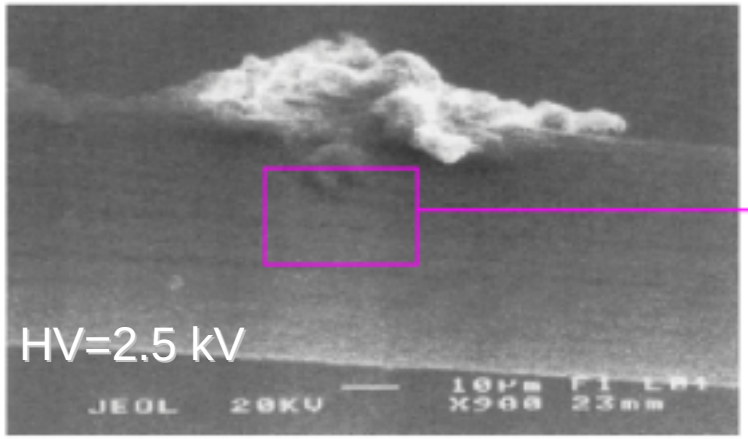
Ar/CF4/CH4(67:30:3)

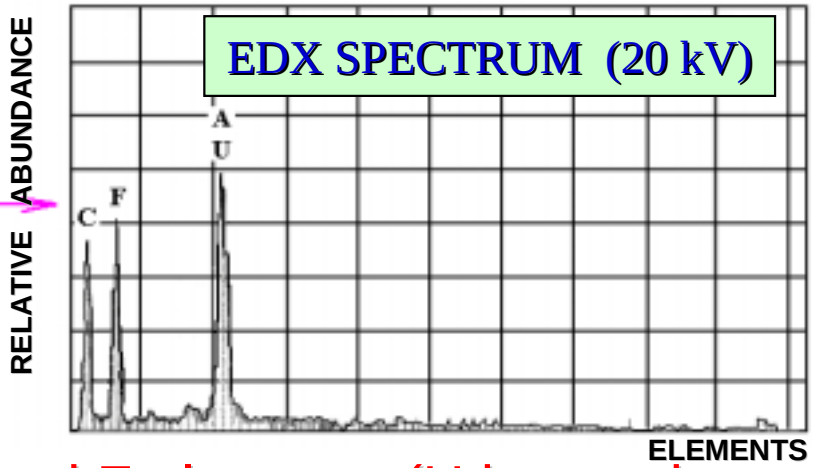
New aging studies: several new tube chamber cells and cells previously operated at 2.25 kV, 2.5 kV, 2.55 kV (restrung with the new anode wires)

For all wires irradiated at 2.5 kV and 2.6 kV (current density ~150 nA/cm):
Ar/CF4/CH4+1400 ppm H2O: ~ 80 mC/cm (no dark current, stable anode current)
Ar/CF4/CH4(no H2O): after 20-30 mC/cm (dark current, steadily decreasing anode current)





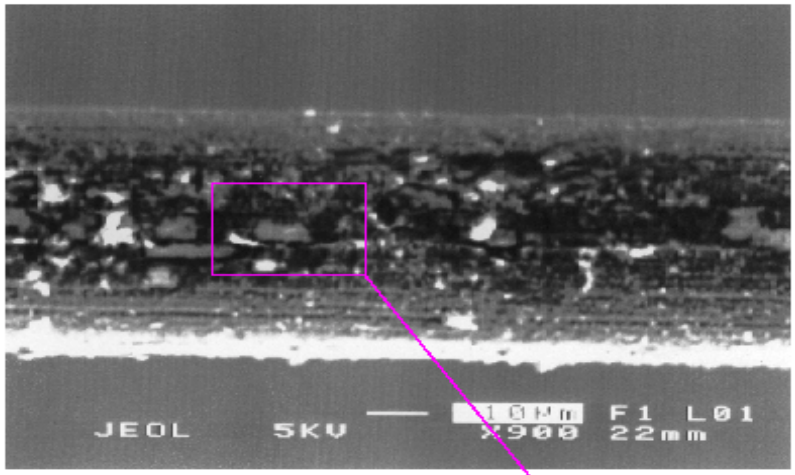


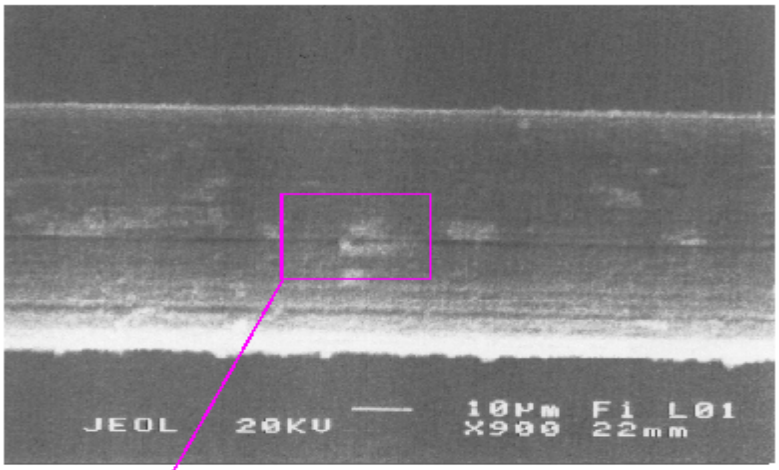


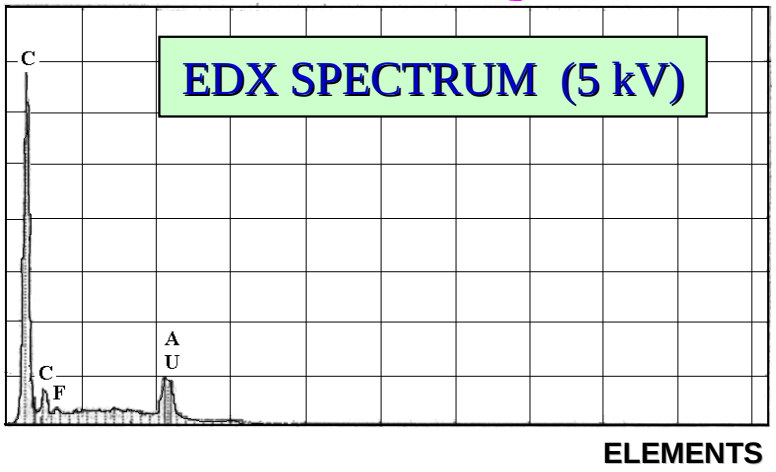
Wires deposits, containing only C and F elements (H is not observable)

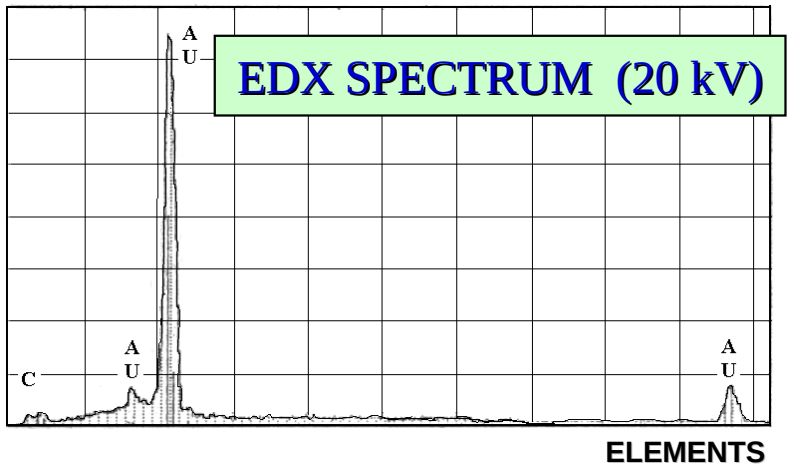
Ar/CF4/CH4(67:30:3)

Two wires irradiated at 2.25 kV (current density ~40 nA/cm) :
Ar/CF4/CH4 with 1400 ppm H2O: ~ 40 mC/cm (no dark current, stable anode current)
Ar/CF4/CH4 (no H2O): ~ 20 mC/cm (no dark current, stable anode current, one of the wires shows gain reduction in the region, where the radiation intensity was the largest)







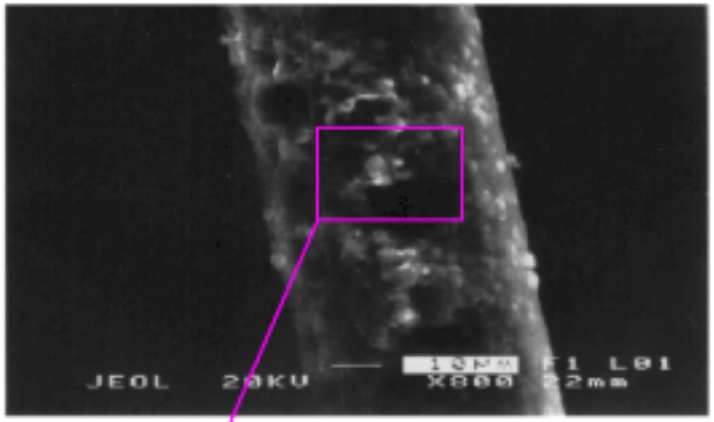


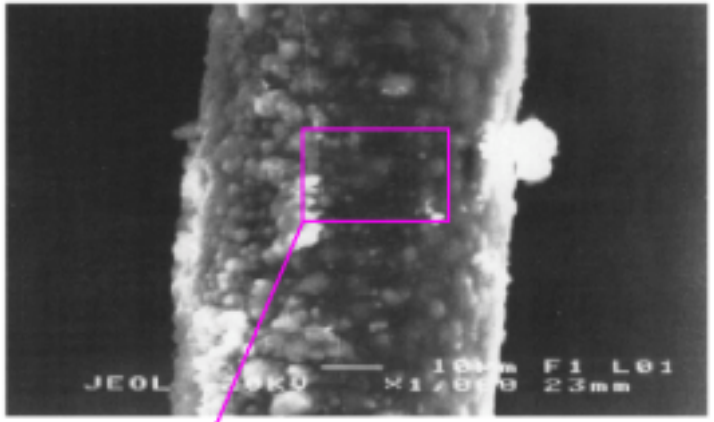
Deposits are carbonaceous, without incorporation of F into the polymer

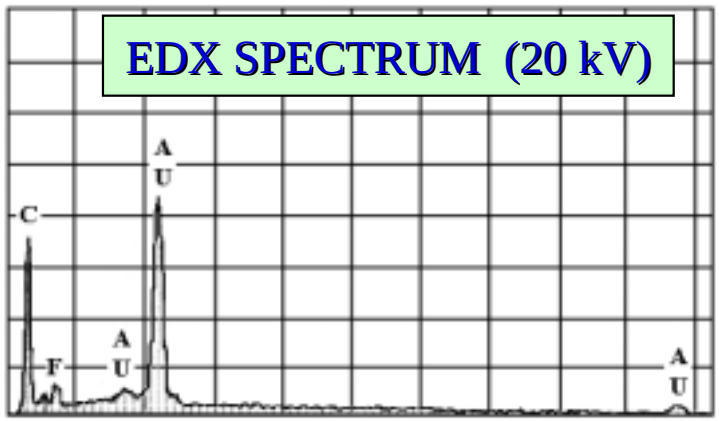
Ar/CF4/CH4(74:20:6)

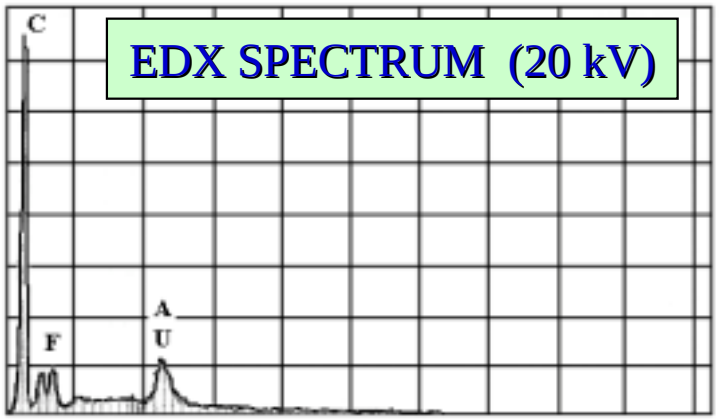
No systematic studies in HERA-B (poor aging properties in a 100 MeV α-beam)

Operating conditions: HV=2.3kV-2.5kV, average currents - 50-500 nA/cm, gas flow 3l/h-16 l/H, no control of H2O,N2,O2 species in the effluent gas stream





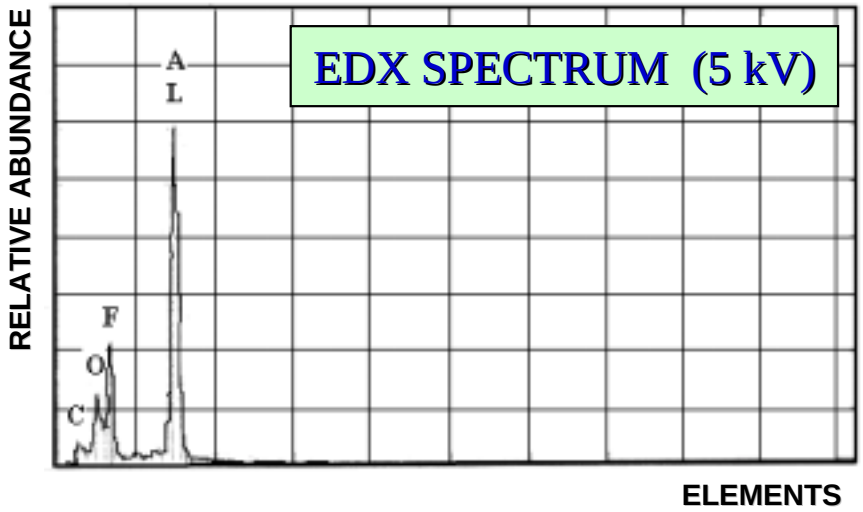




Polymer coating, consisting of C, F (and most probably O) elements

Cathode effects in Ar/CF4/CH4(67:30:3)

A thin layer of deposits, consisting of C,O,F was identified on the Al cathodes in the aged cells, operated with gas gains >10^4



- Free radicals produced in CF4 discharges could react violently with nongold wires to form metal fluorides
- The appearance of fluorocarbon deposits on the irradiated cathodes in CF4-containing mixtures has been reported in the literature:

(J.Wise et al., J.Appl.Phys.74(9)(1993)5327,
V. Paschoff, Dissertation,University Freiburg, October (1999),
D.Denisov, NIMA 306(1991)200,
T.Ferguson et al., CMS Note 1999/011)

Summary of aging experience in Ar/CF4/CH4

Despite the negligible gas gain loss measured after the long-term irradiation with radioactive sources, rapid aging effects were observed during irradiation in a 100 MeV alpha-beam and in the high-rate HERA-B environment.

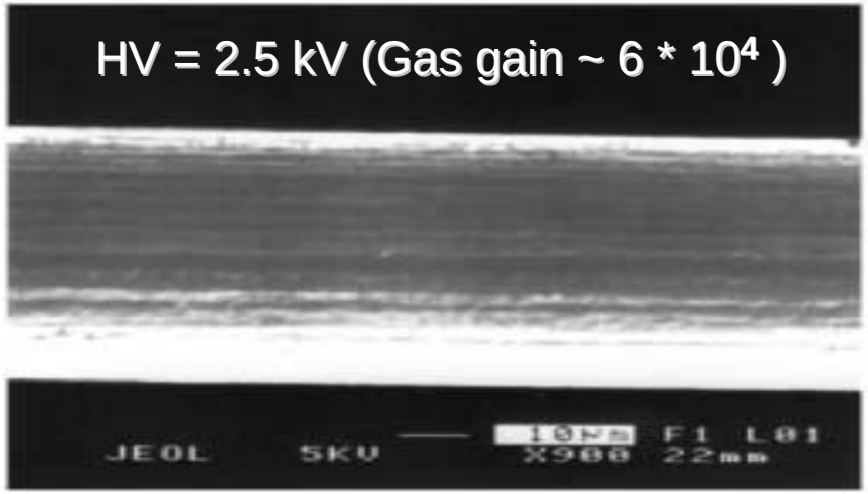
- Gain reduction for the anode wires (operated with a gas gain >10^4 and current densities ~150-200 nA/cm) was caused by the appearance of 'whiskers' type deposits, consisting of C and F elements (H is not detectable).
- Anode aging was also accompanied by the appearance of thin layer of C,F,O on the cathode, which resulted in a dark current.
- Addition of H2O resulted in suppression of polymerization effects in Ar/CF4/CH4

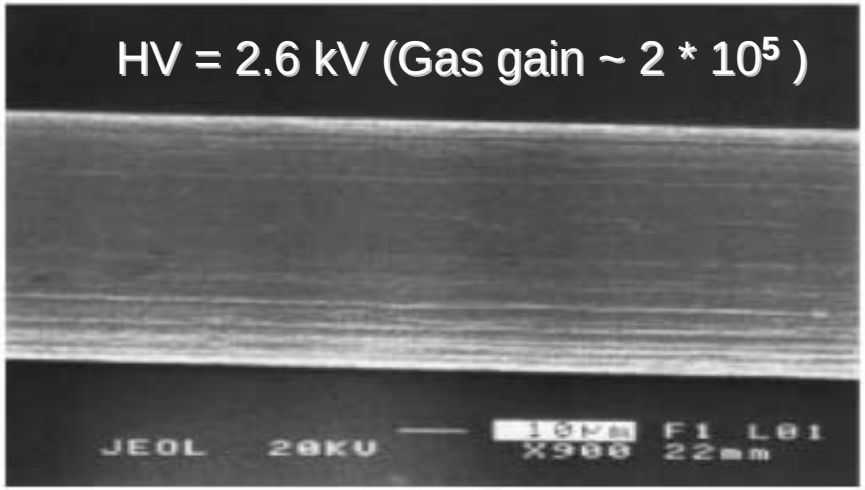
Si-polymerization was not a dominant aging process in our tests
Gaseous discharges in Ar/CF4-mixtures could provide an additional resistance against Si-deposits in wire chambers (Si-deposits in our tests were found only on 1 wire, irradiated with the lowest current density ~20 nA/cm, out of 25 wires)

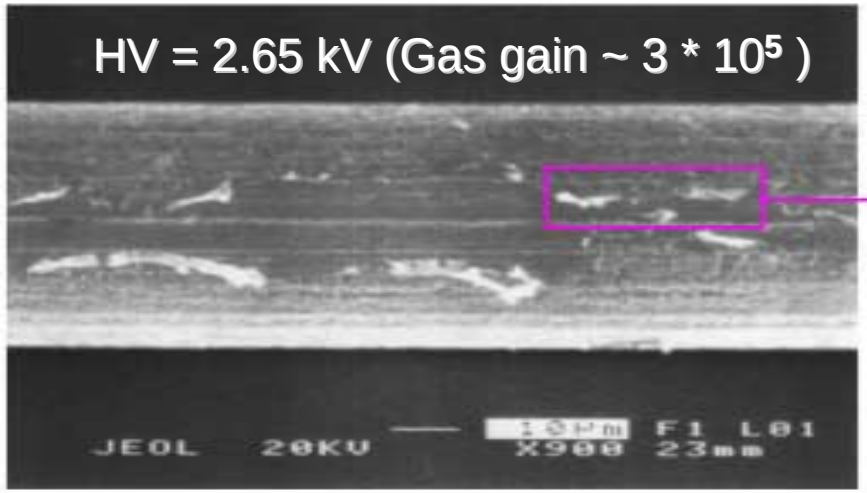
Since long time plasmas based on CF4 have been used for Si, SiO2 etching:
(H.Winters et al., J.Appl.Phys.48(12)(1977)4973,
C.J.Mogab, J.Appl.Phys.49(7)(1978)3796
M.Kushner, J.Appl.Phys.53(4)(1982)2923).
H2 added to CF4 → decreases F/CF2 → etching SiO2
O2 added to CF4 → increases F/CF2 → etching Si

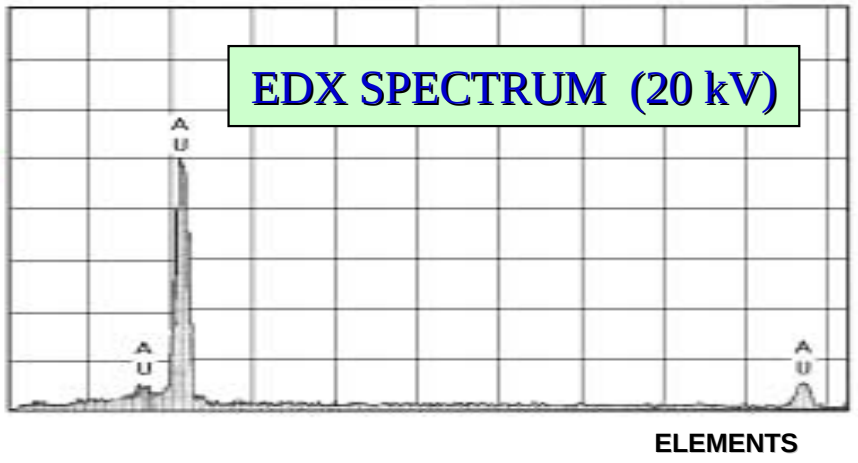
Ar/CF4/CO2 (65:30:5) + 1000 ppm H2O

No gain reduction was observed for all irradiated wires up to ~ 700 mC/cm





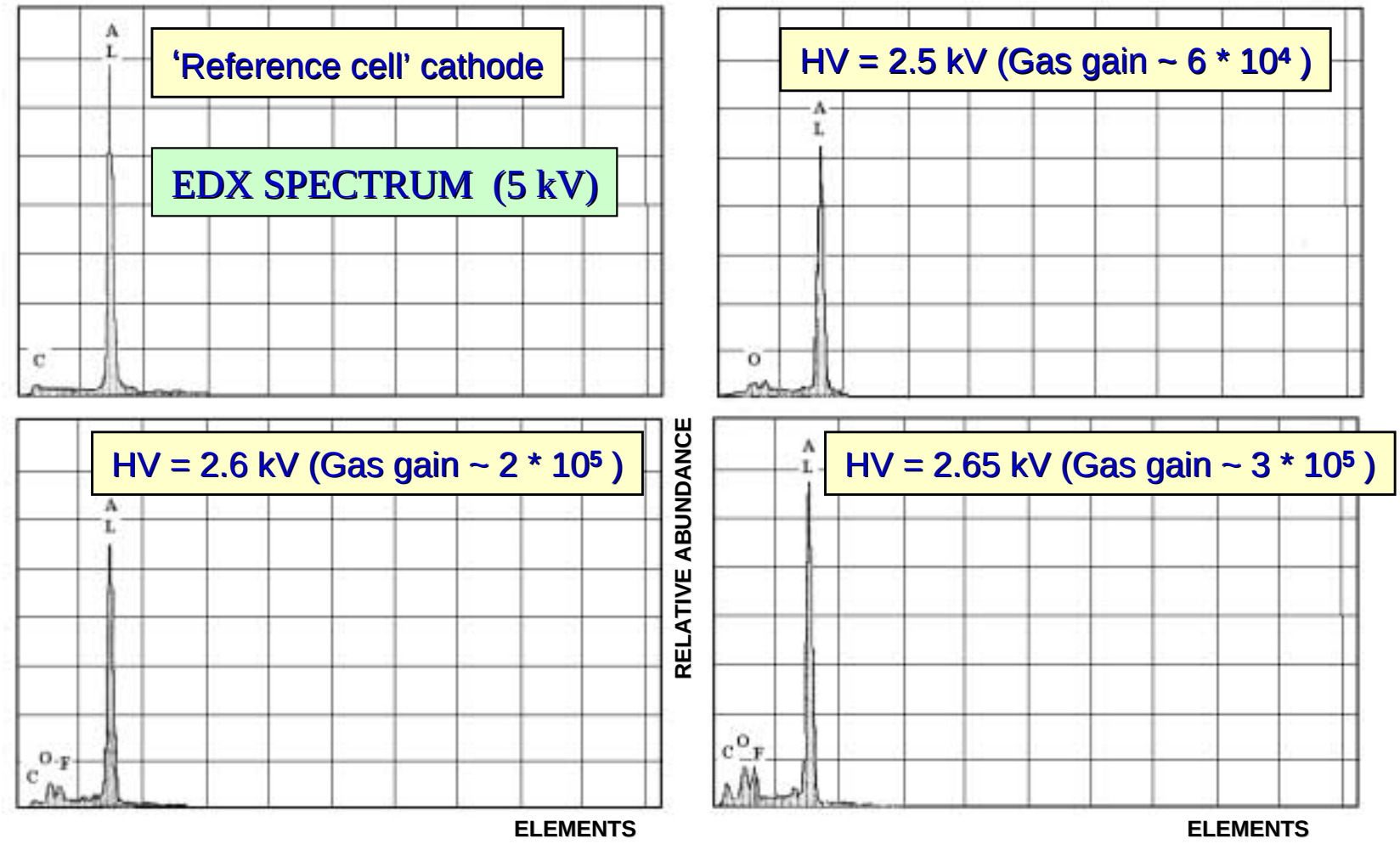




A few point-like deposits (Si,Al;~1-2 μm) on the wires didn't result in local inefficiencies

Ar/CF4/CO2 (65:30:5) + 1000 ppm H2O

- C,O and F were observed on Al cathodes in cells operated at gains > 10^5 (these deposits did not lead neither to dark current, nor to gain reduction)
- No F-based deposits on the cathodes in reference cells and operated at gains($<10^5$)



Ar/CF4/CO2(65:30:5)+1000 ppm H2O is currently used in the muon detector

Motivation for further aging tests

Ar/CF4/CH4 (74:20:6) (67:30:3) aging effects at 25-100 mC/cm

Ar/CF4/CO2 (65:30:5) stable operation up to 700 mC/cm

Under certain conditions, the tubes survive a high-rate irradiation in HERA-B, even with Ar/CF4/CH4 mixture

Plasma Polymerization

Competitive ablation and polymerization (Yasuda, Plasma polymerization, p.180)

The main effect of the CF4 plasma can be shifted from etching to polymer deposition by the addition of H2(CH4) into the plasma and that depending upon the amount of H2 added to CF4, the balance between polymerization and ablation can be controlled (Yasuda, Plasma polymerization, p.178)

Addition of oxygenated species shifts the chemistry of CF4 toward etching, addition of hydrogenated species shifts the chemistry toward polymerization

Ar/CF4 (70:30)

- aging in Ar/CF4/CH4 appears only when CH4 added to Ar/CF4
- The operating voltage was set to 2.6 kV, where the rate of afterpulses is very large

Study of aging dependence from:

- Cathode cleanliness of Al tubes (surface cleanliness has a strong influence on aging, M.Koleffrath et al. NIM A419(1998)351)
- Trace contaminants in the gas system, sparks,...

CF4/CH4 (90:10), CF4/CH4(80:20)

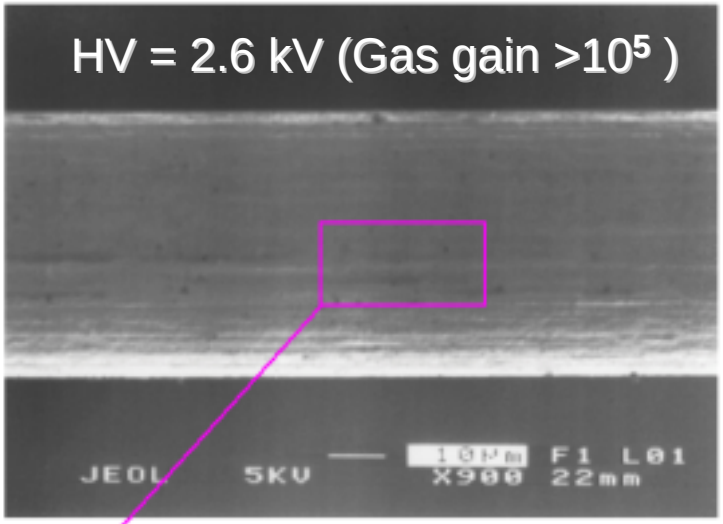
Attempt to compare aging performance of Ar/CF4/CH4 and CF4/CH4 mixtures

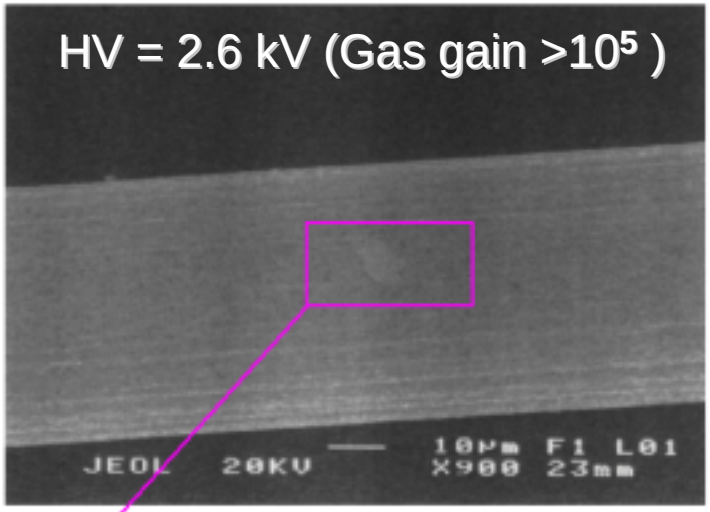
Chemical model for wire aging in CF4/iC4H10: (J.Wise et al., J.Appl.Phys.74(9)(1993)5327). Excellent aging properties in CF4/iC4H10(80:20) Wire deposits in CF4/iC4H10(20:80), (95:5).

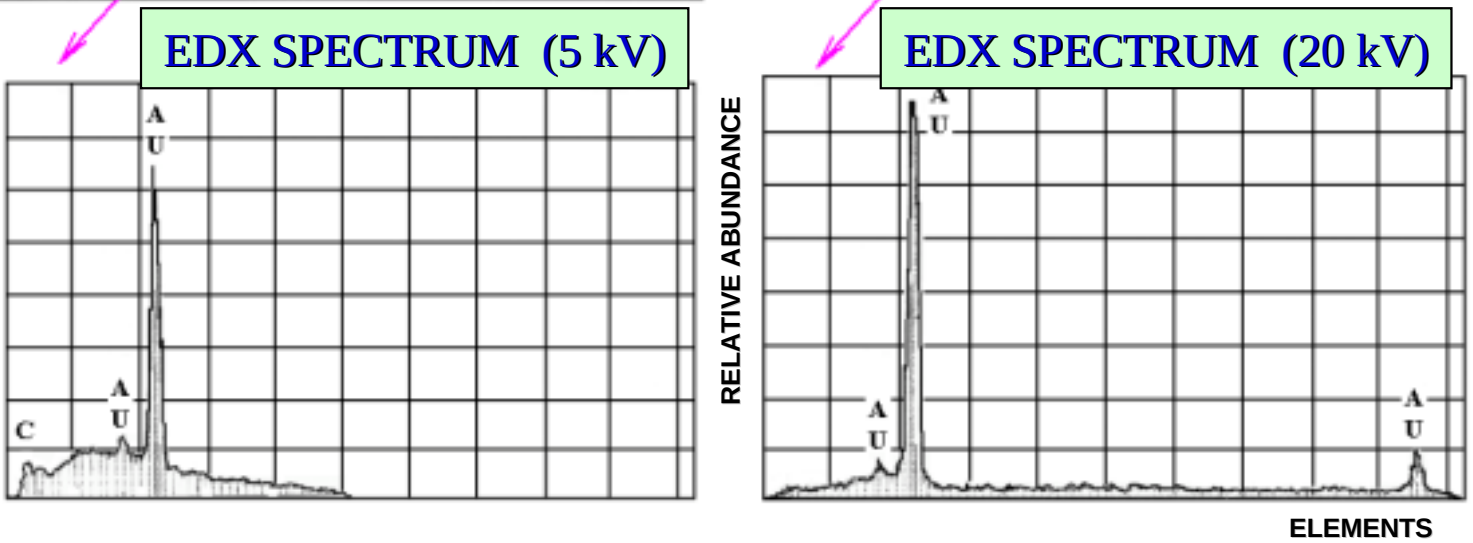
Aging studies in CF4/CH4 have been reported: (see talks by C.Padilla, T.Marshall)

Ar/CF4/ (70:30) without H2O

The gas gain remained constant for both irradiated wires up to ~ 70 mC/cm





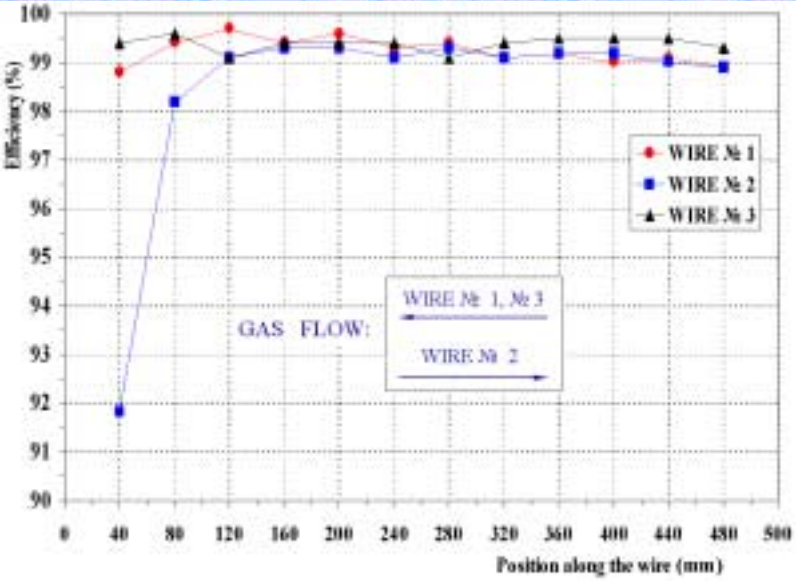


- Small traces of C, F observed on the cathodes (these deposits did not lead neither to dark current, nor to gain reduction

CF4/CH4 (90:10)

with 600 ppm H2O

Efficiency profile along irradiated wires (N1,N2) after the total collected charge 370 mC/cm and along reference wire (N3)

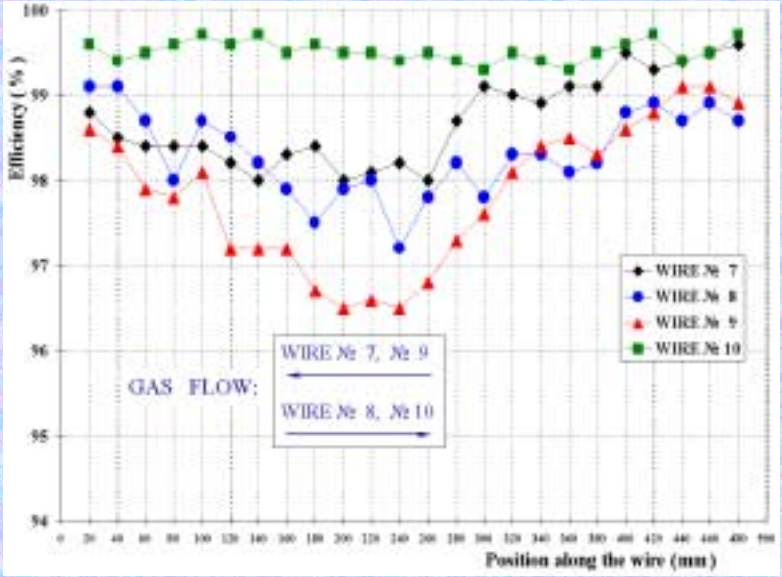


No gain reduction except one wire (N2) specimen near the chamber endcup, where gain reduction (dG/G ~ 50%) was detected.

CF4/CH4 (80:20)

with 600 ppm H2O

Efficiency profile along irradiated wires (N7,N8,N9) after the total collected charge 160 mC/cm and along reference wire (N10)



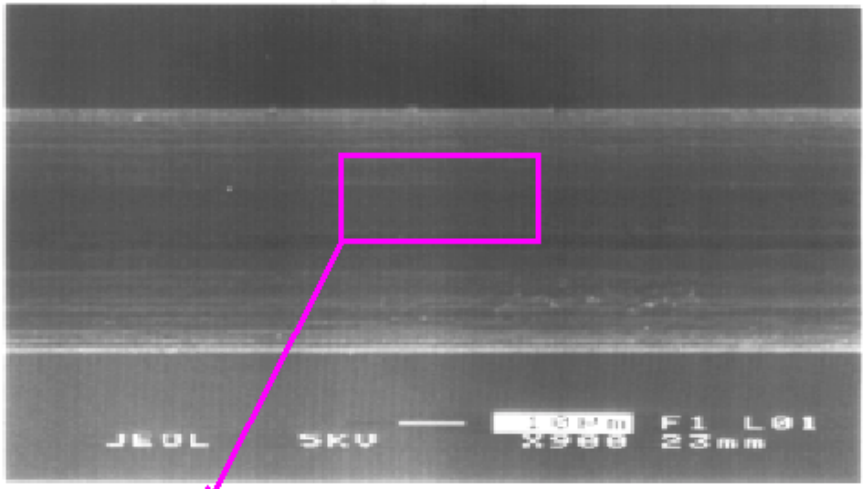
Gain reduction was observed for all three irradiated wires

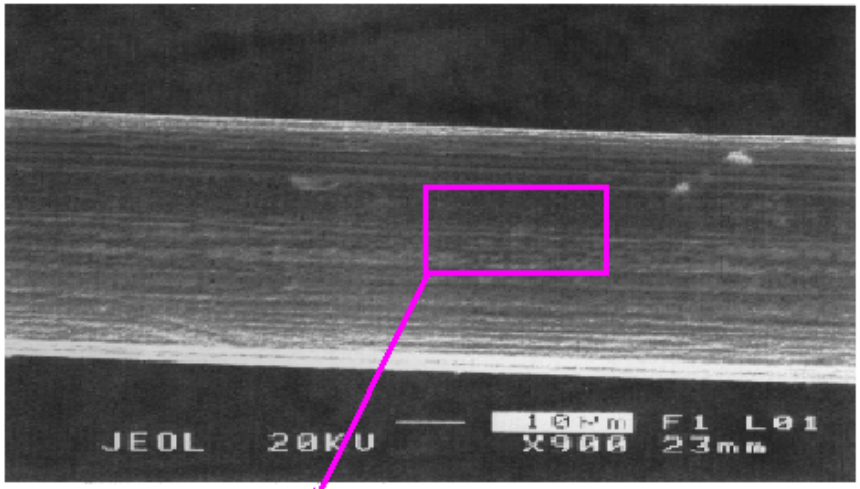
without H2O

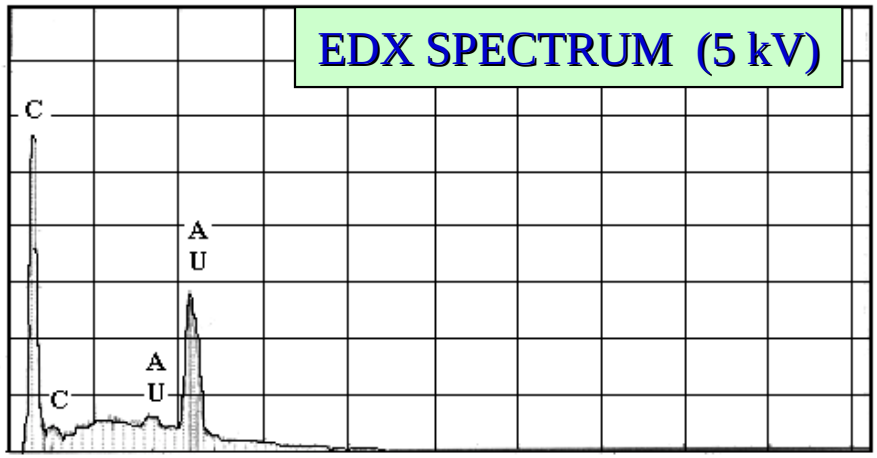
No loss in performance for three wires up to 40 mC/cm

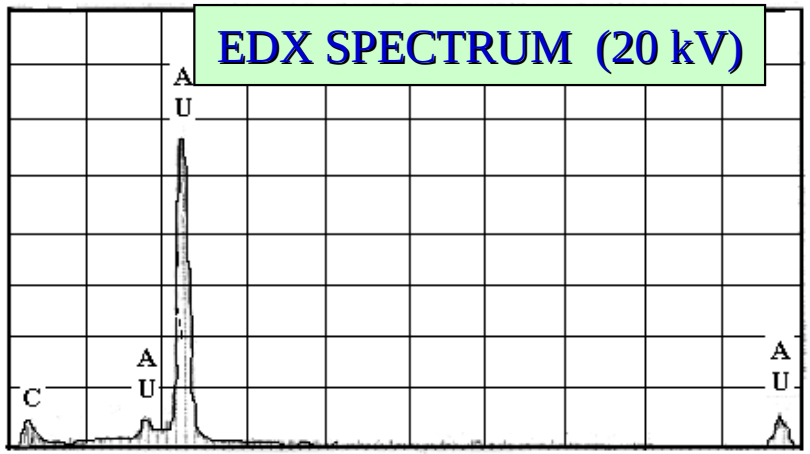
CF4/CH4 (80:20)+600 ppm H2O

Gain reduction was observed for all three irradiated wires after ~ 160 mC/cm





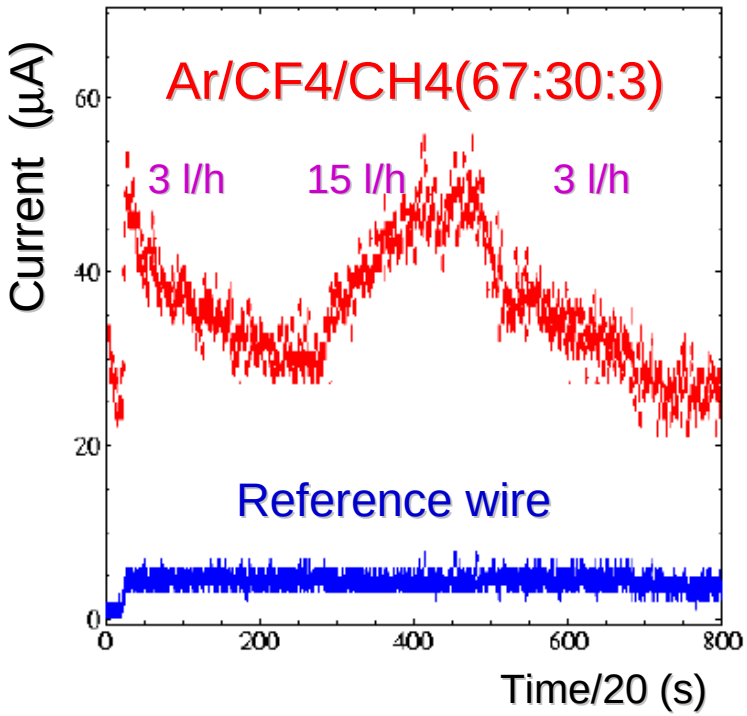


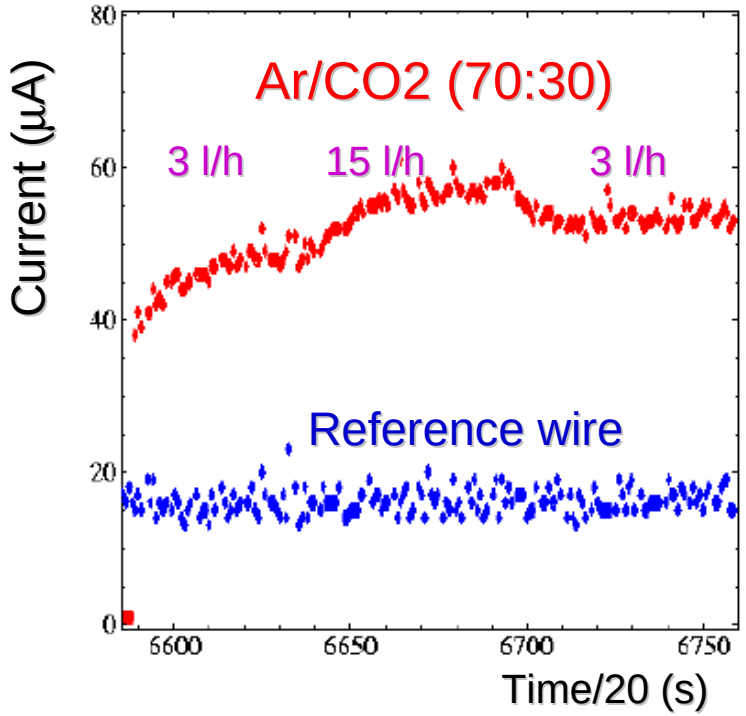


- Structure of wire deposits is different from that in Ar/CF4/CH4 (only C is detected in deposits)
- No cathode effects (dark currents, deposits on Al surface) have been observed

Electronegative radical production

For partially aged wires operated with Ar/CF4/CH4 mixtures in the HERA-B environment: the anode current was dependent upon gas flow rate





Evidence for generation of highly electronegative species in Xe/CF4/CO2

(M.Capeans et al., NIM A337 (1993)122, V.Bondarenko et al., Nucl.Phys.B 44(1995)577)

Ar/CF4/CO2 (65:30:5)

Output flowmeter from irradiated chamber became covered by white residue → reactive and long-lived species produced in the avalanches

Ar/CF4/CH4

- C,F-based deposits on the wires
- Dark currents and traces of C,O,F on Al cathodes
- Aging is more pronounced in the direction of gas flow
- Addition of H2O helps to suppress polymerization

CF4/CH4

- Only C-containing deposits on the wires
- No cathode-related effects have been observed
- Aging effects are more severe in the regions, where the radiation intensity was the highest
- No aging dependence from H2O content

Possible differencies in aging properties between Ar/CF4/CH4 and CF4/CH4:

- The role of argon can be explained by the effect of adding energy-carrying species, which increases the effective electron energy distribution in the avalanche (initiates new chemical reactions) and could lead to the apperance of streamers, sparks.
- Polymer deposition mechanism ➔ chemistry of gaseous discharges and nearby electrodes (radicals with large dipole moments will stick easily to electrodes)

Plasma Polymerization:

In CF4, CF3H, C2F6 plasmas the residence time and the energy density control the amount of conversion of a starting material to gas products (E.Truesdale et al.,J.Appl.Phys.50(11)(1979)6594, E. Truesdale et al.,J.Appl.Phys.51(5)(1980)2909).

Summary and outlook

The initial stage of radiation tests usually performed in the laboratory may not offer full information, needed to give an estimation about the lifetime of the real detector (accumulated charge alone can not explain the data consistently)

Strong dependence of the aging rate on high voltage (gas gain, total charge of the avalanche) and the size of irradiation area (see also talk by M.Kollefrath)

- Difference in aging performance of Ar/CF4/CH4 and CF4/CH4:
  → the aging properties could depend not only on the chemical nature of the mixture, but also on the actual discharge conditions.
- No loss in performance was observed for the CH4-free gases

Since the present state of knowledge does not allow to formulate a complete set of recommendations of how to prevent the aging in wire chambers, it is important to study the aging properties in the conditions as closely as possible to real ones.

The presence of large amounts of CF4 in the mixture does not necessary ensure good aging properties

The results obtained in a framework of these studies have been published in:
1) Preprint ITEP43-00, hep-ex/0107080; 2) Preprint ITEP15-01