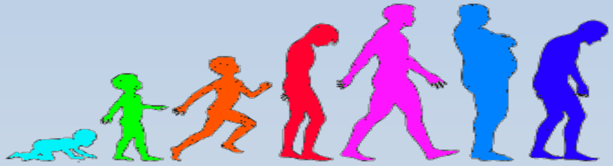


GAS COUNTERS AGING FOR DUMMIES

MAJOR REFERENCES

John Kadyk: Proceedings of the Workshop on Radiation Damage to Wire Chambers. LBL-21170 (1986).

John Kadyk: Wire Chamber Aging. Nucl. Instr. Meth. A300 (1991) 436

Marcus Hohmann: Aging phenomena in gaseous detectors-perspectives from the 2001 workshop. Nucl. Instr. Meth. A494 (2002)494.

Mar Capeáns: Aging and materials: lessons for detectors and gas systems. Nucl. Instr. Meth. A515(2003)73.

Maxym Titov: Radiation damage and long-term aging in gas detectors. Proc. 42nd Workshop of the INFN ELOISATRON Project (2003)

Fabio Sauli: Gaseous Radiation Detectors: Fundaments and Applications. Cambridge University Press (2014).

RD10: A study to improve the radiation hardness of gaseous detectors for use at very high luminosity

RD28: Development of microstrip gas chambers for high-rate applications

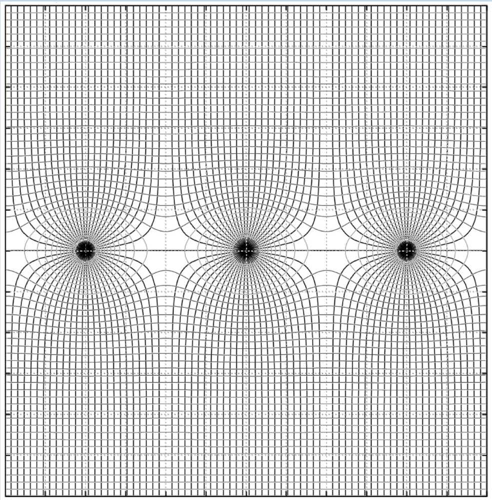
RD51: Development of Micro-Pattern Gas Detectors Technomogies

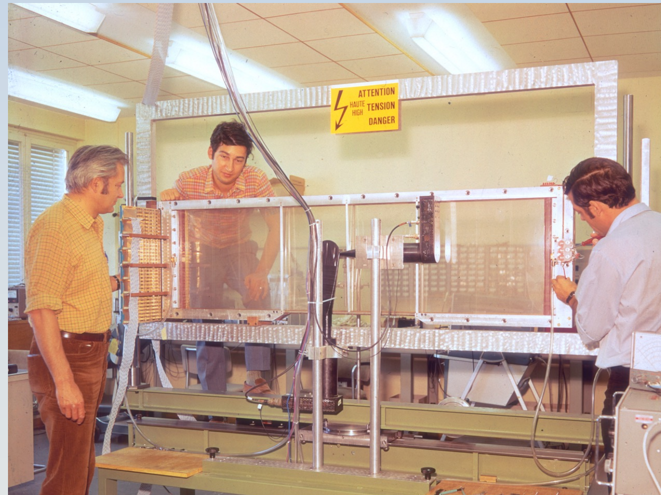
GDD: Gas Detectors Development Group (CERN)

☛ **Special Thanks to Eraldo Oliveri**

Limited to MWPCs & MPGDs

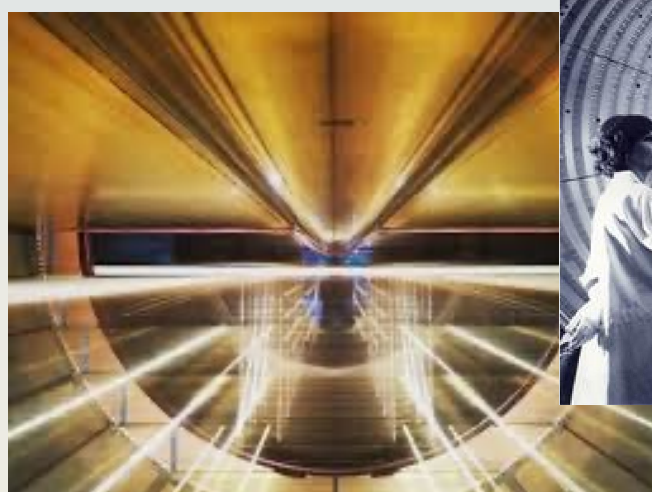
1968: Multiwire Proportional Chamber

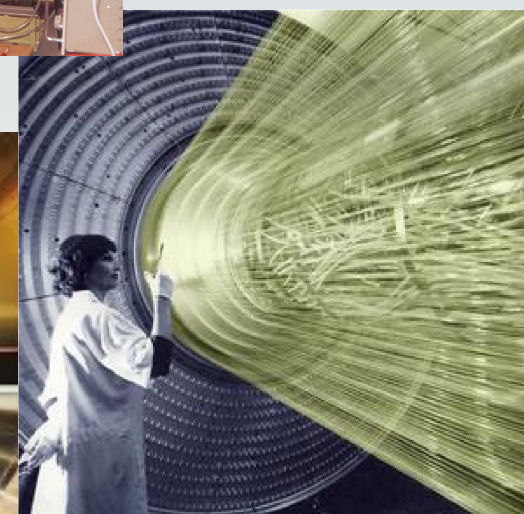




Drift Chambers
Time Projection
Jet Chambers
....

G. Charpak et al,
Nucl. Instr. Meth. 62(1968)282

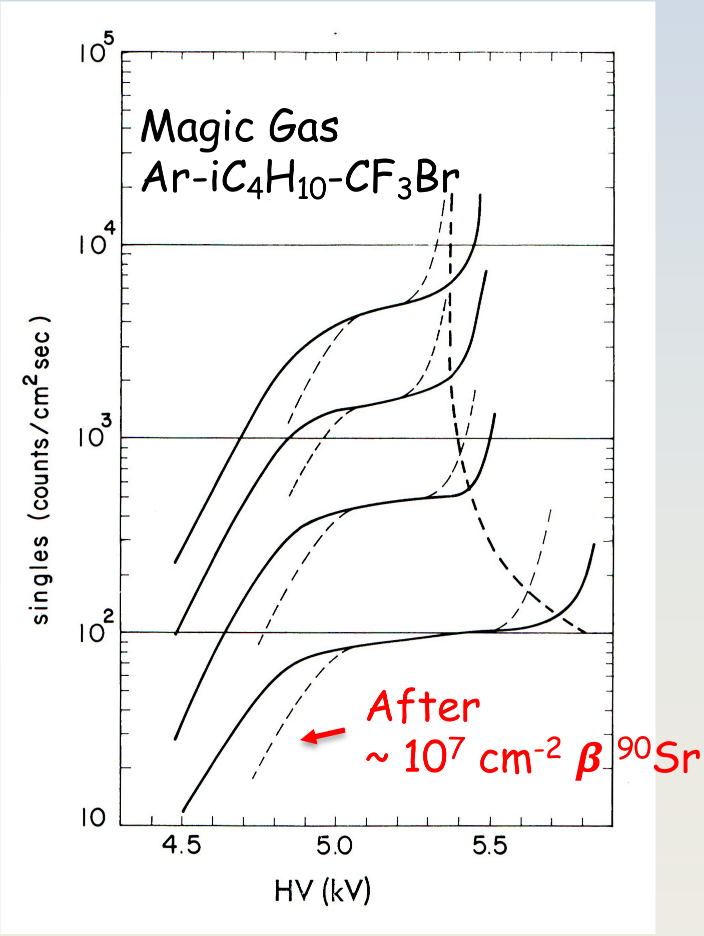


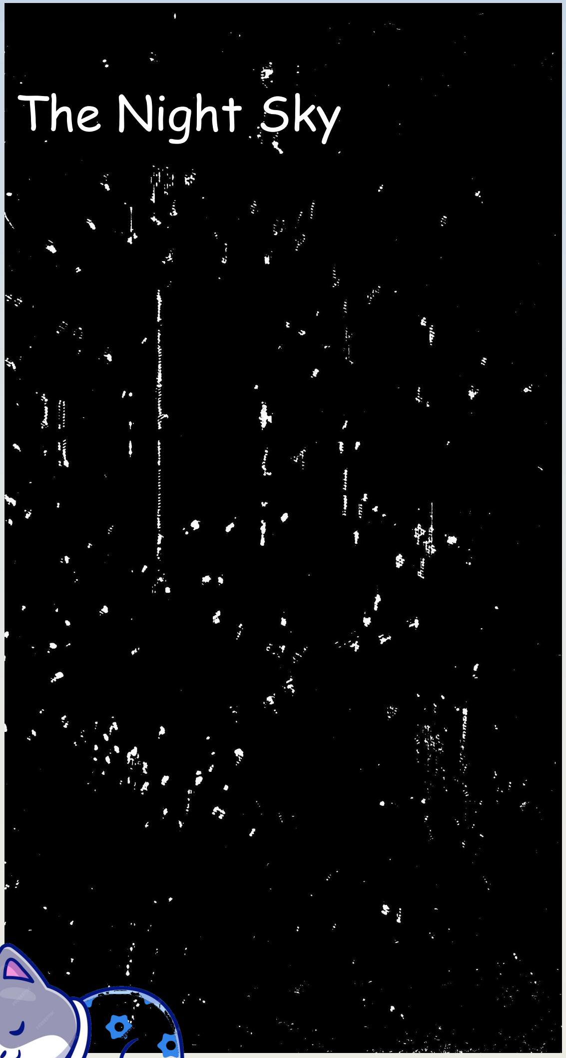


AGING OF MWPCs

Deterioration of Performances under Irradiation:

- Rate Dependence of Gain
- Higher Noise



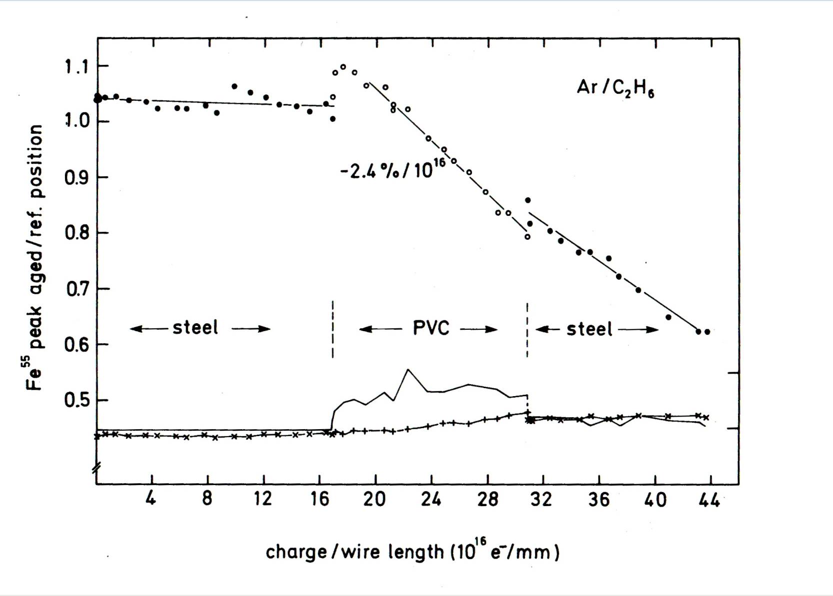


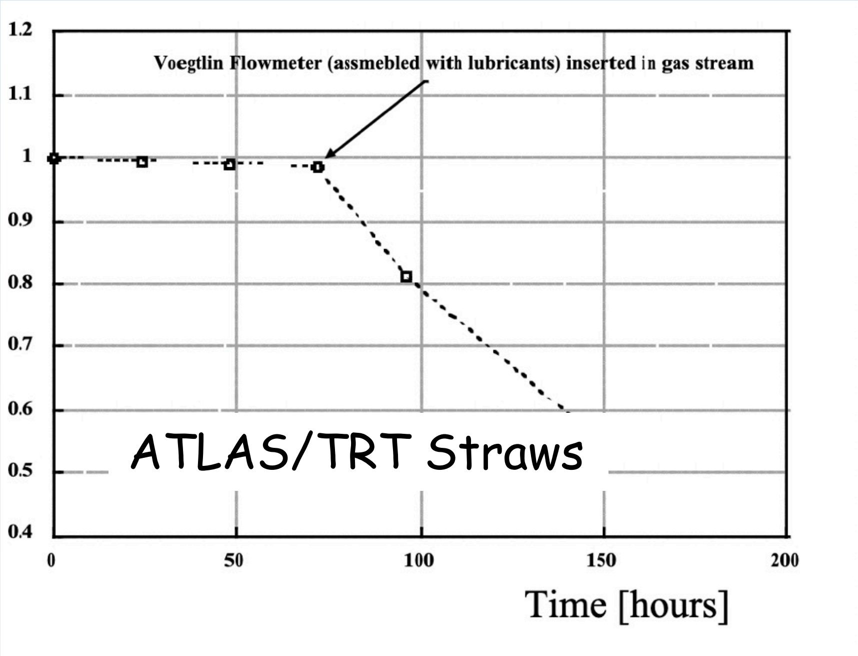
G. Charpak et al, Nucl. Instr. Meth. 99(1972)269

Examples of the Effect of Trace Pollutants in the Gas

Adding a Short PVC Tube

Change of a Gas Flowmeter





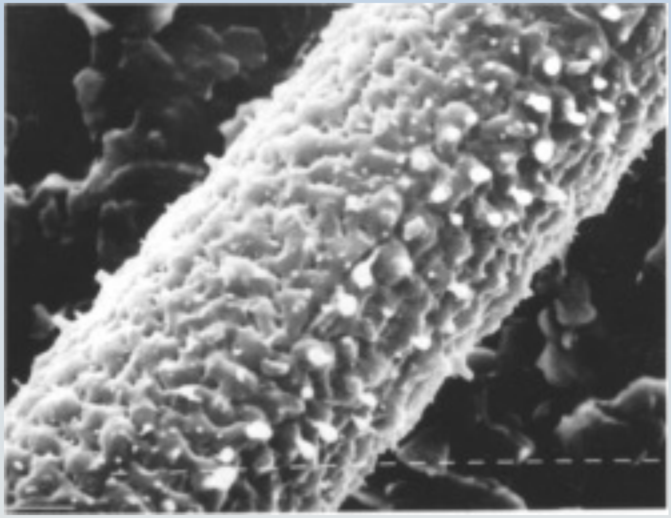
R. Kotthaus,
Nucl. Instr. Meth. A252 (1986) 531

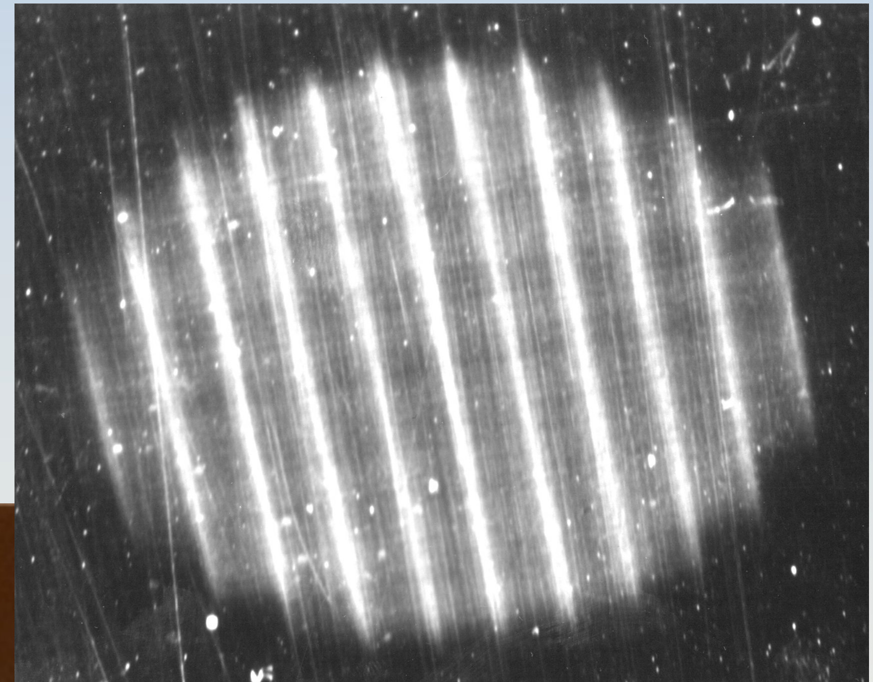
M. Capeáns,
ICFA Instr. Bull. (2002)

PLASTICIZERS

SILICON COMPOUNDS

Deposit on Anodes and Cathodes

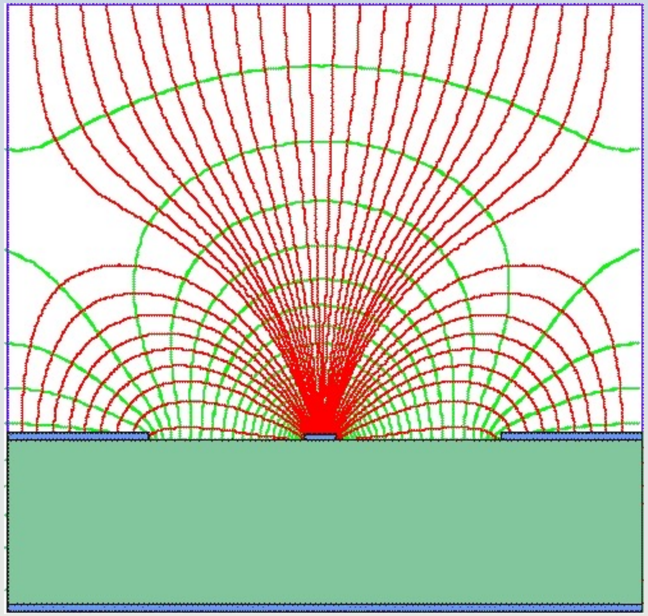




Polymers of organic quencher
Pollutants
Materials Outgassing

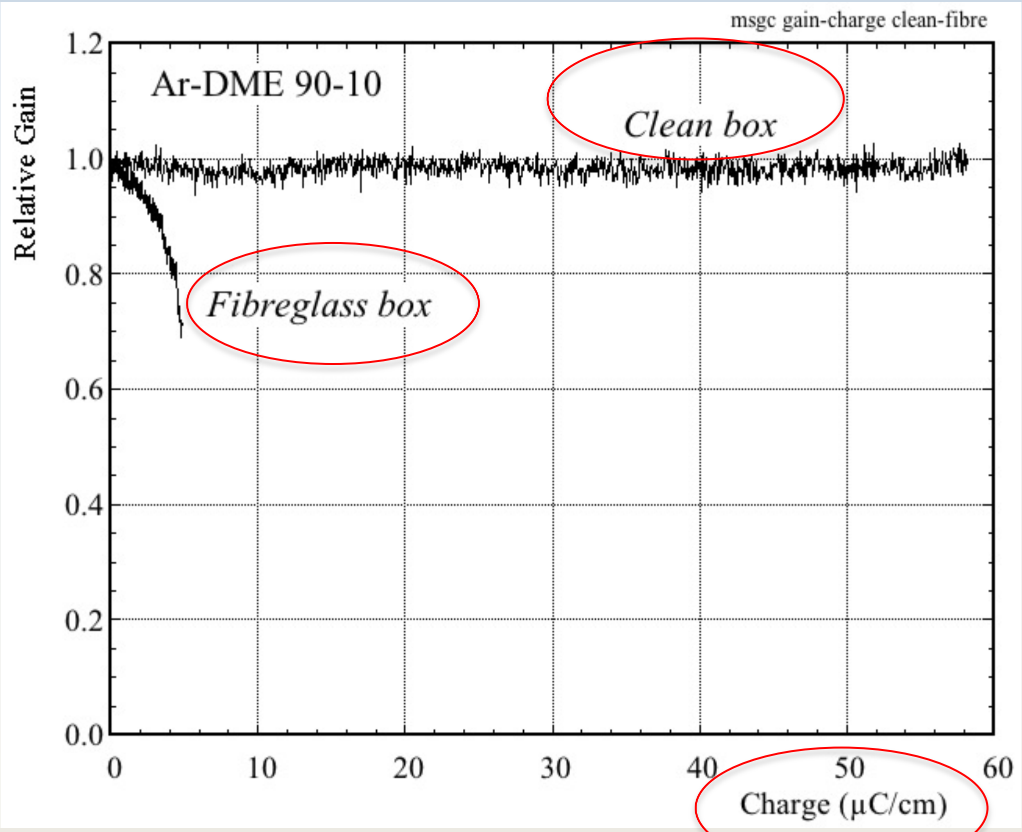
SILICONE Deposits
(see Later)

1988: Micro-Strip Gas Counter (MSGC)



A. Oed,
Nucl. Instr. Meth. 263(1988)351

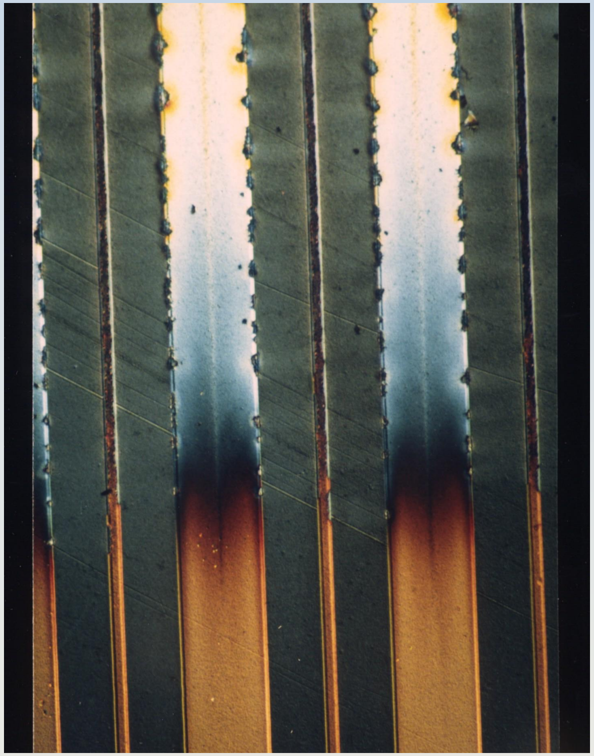
Extreme Dependence on Gas Purity



R. Bouclier et al, Nucl. Instr. Meth. A348(1994)109

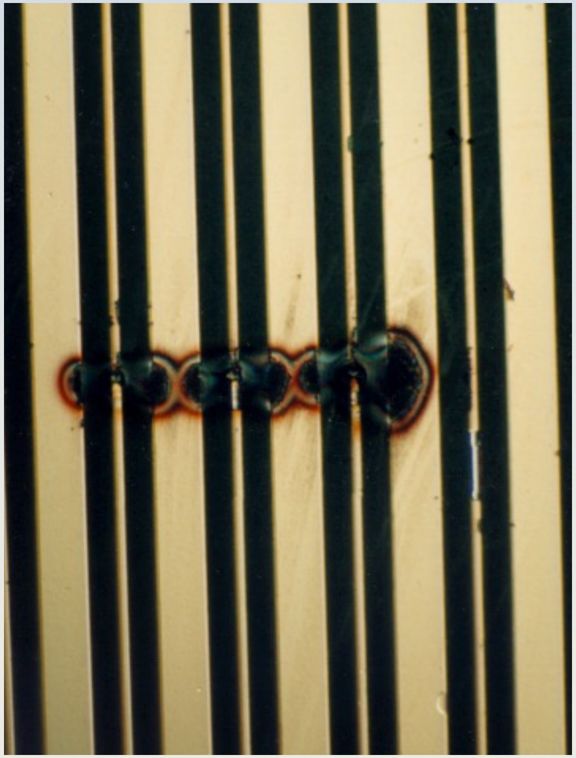
MSGC: Aging and Discharges

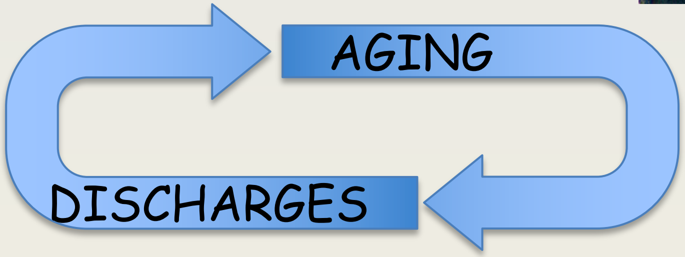
Discolorations (Deposits?)



Pitting (Micro-Discharges)

Full Discharge





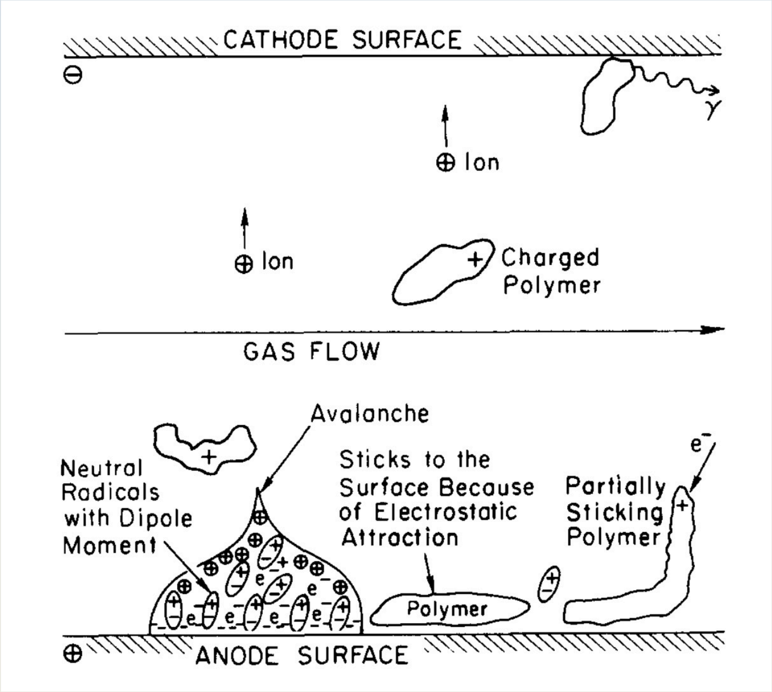
☛ Discharges: See Piotr Gasik Talk

Mechanisms of Polymer Formation

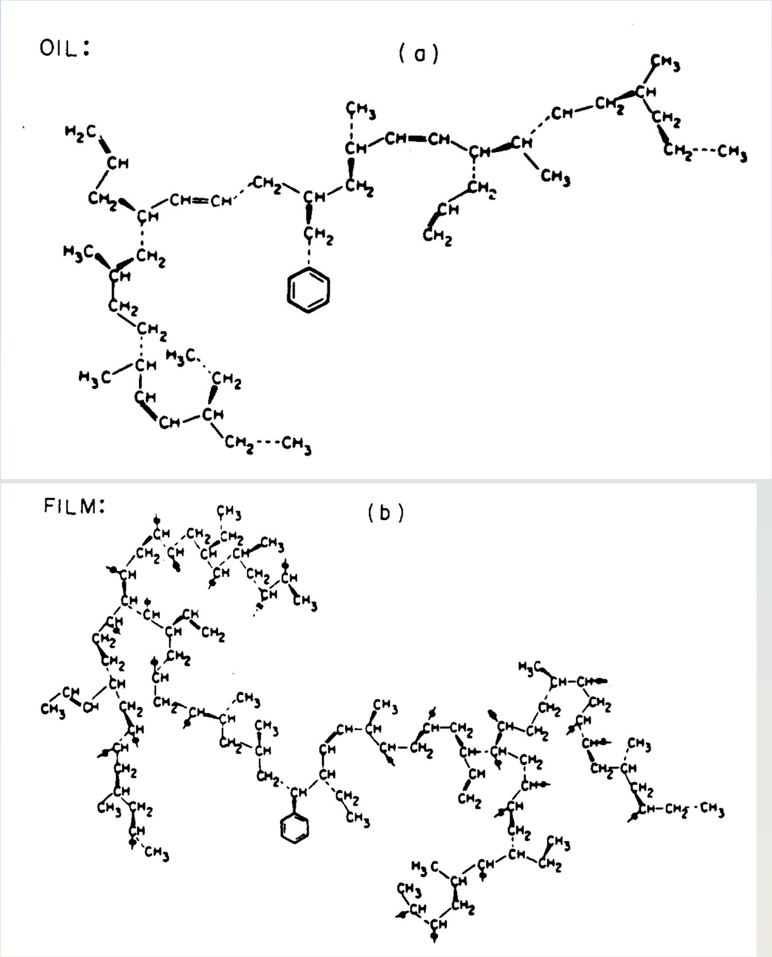
Plasma Chemistry

$e + CH_4 \rightarrow CH_2{:} + H_2 + e$

Production of CH_2: radicals
(precursors of Polyethylene)



Polyethylene Compounds

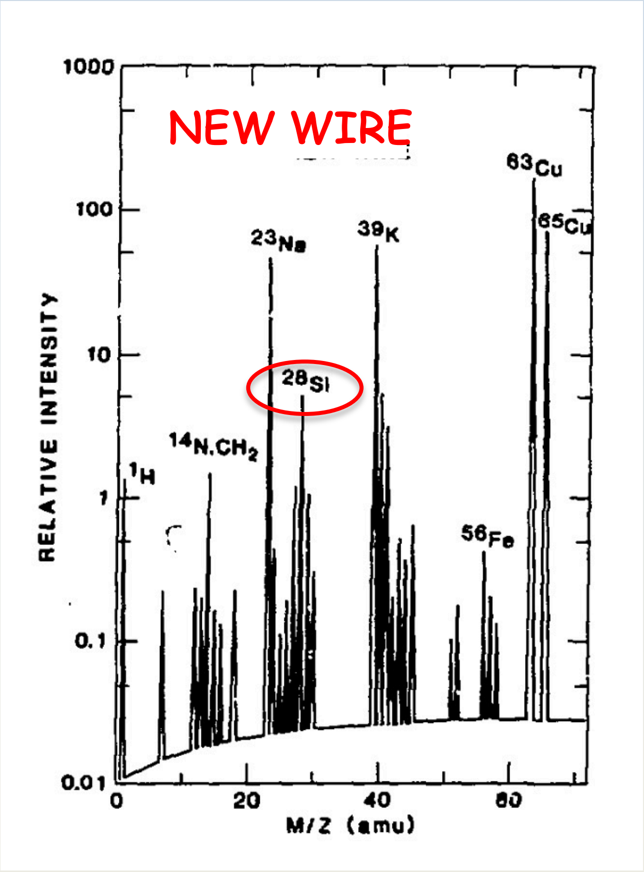


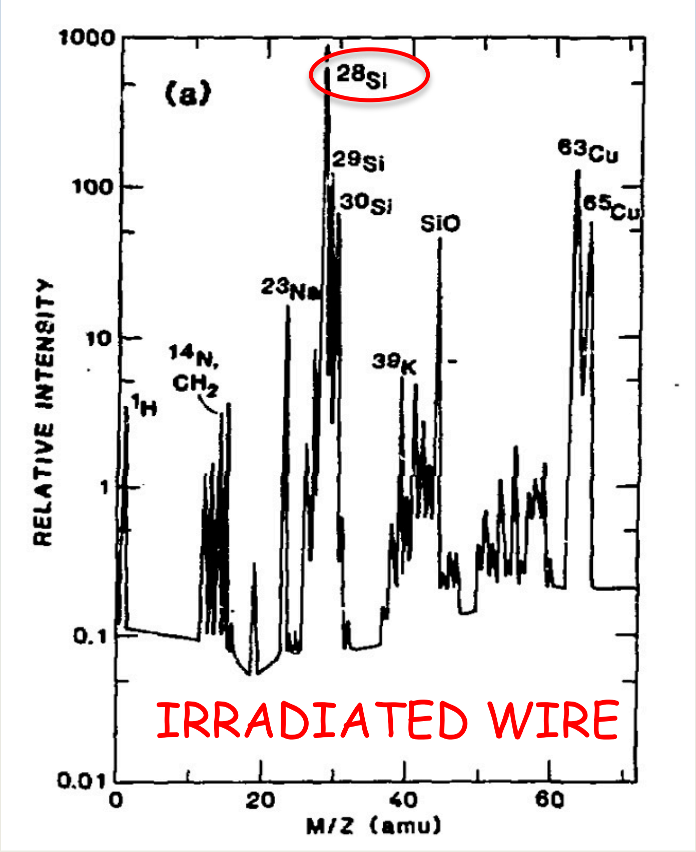
J. Va'vra,
Nucl. Instr. Meth. A252(1986)547

☛ Plasma Chemistry See Katerina Kudnetzova

Silicone Compouds Deposits

Anode Wire Surface Analysis with Ion Microprobe Mass Analysis





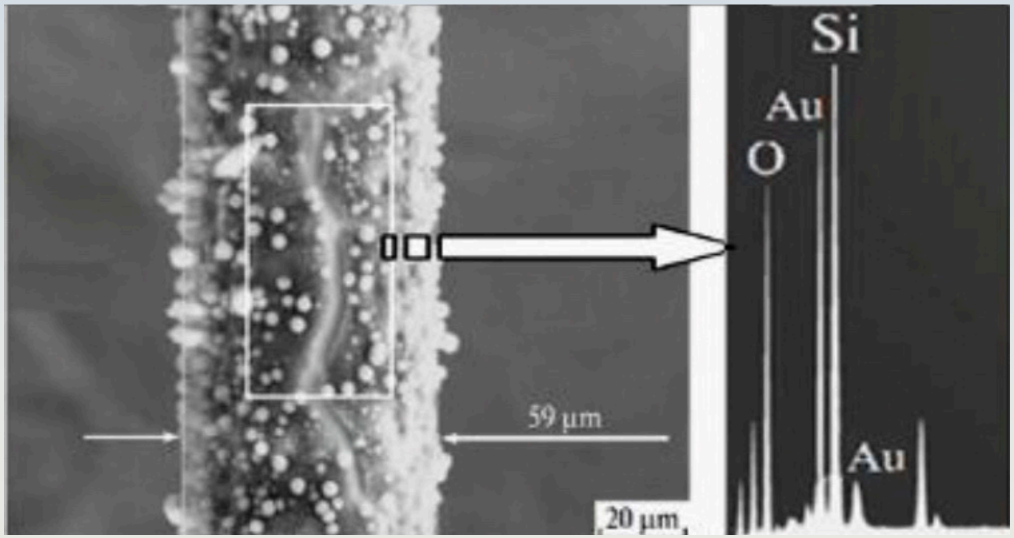
W. Haberichter and H Spinka, AHL-HEP-CP-86-10

Silicone from Materials→ J. Kadyk, Nucl. Instr. Meth. 300A(1991)436

Very Effective Formation in the Avalanche of Silicone Polymers

Polysilicon $[-\overset{\displaystyle R}{\underset{\displaystyle R}{\mathrm{Si}}}-\mathrm{O}-]_n, \quad (\mathrm{R} = \mathrm{CH_3})$

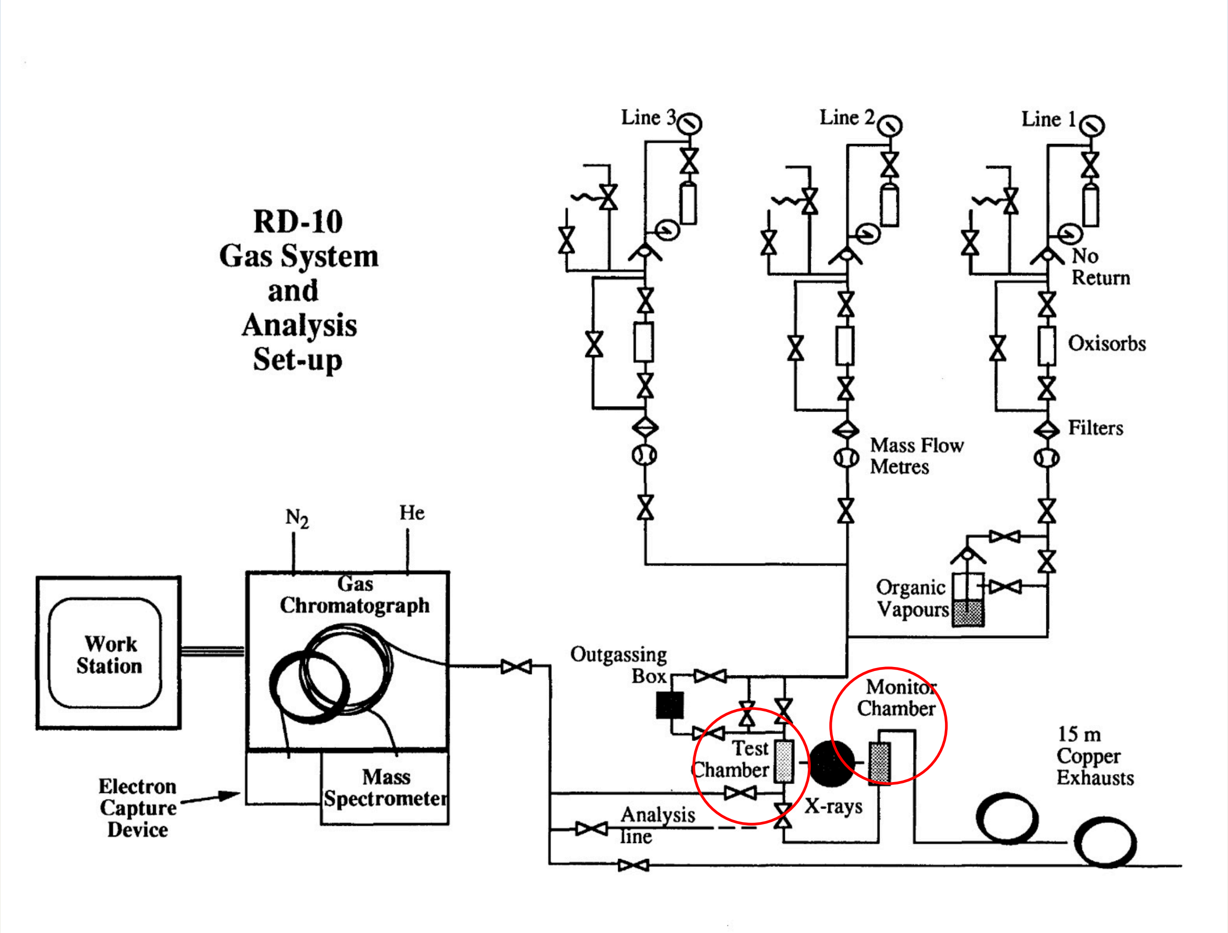
Silicate $[-\overset{\displaystyle O}{\underset{\displaystyle O}{\mathrm{Si}}}-\mathrm{O}-]_n.$



AVOID:
Plasticizers (Phtalates)
Sealant: RTV
Vacuum Grease
Oil Bubblers
Silicone oil (Dow 704)
Duo-Seal
Epoxies: G10
…. and many others

G. Gavrilov et al. Phys. Part. Nuclei 49(2018)33

RD10-RD28 Setup at CERN:
Study of Aging of Detectors Under Irradiation



M. Capeáns: Nucl. Instr. Meth. A515(2003)73.

Units Used for Long-Term Aging Studies:

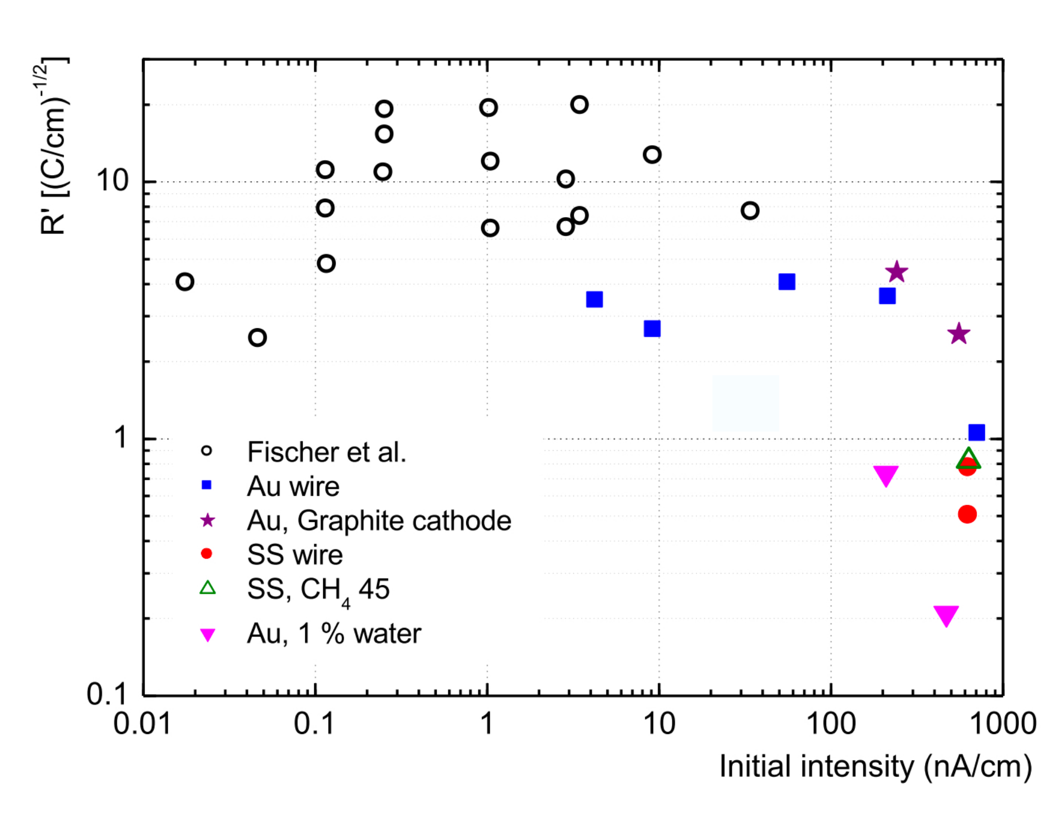
- Irradiation Time
- Radiation Flux :   Counts/cm^2
- Charge per unit Surface: Coulomb/cm^2
- Charge per unit Wire Length: Coulomb/mm
- LHC Years

Accelerated lifetime measurements:

- High source intensity
- High charge gain
- Both   → Local Charge Density 10 to 100 times than normal

CAVEAT: HIGH-RATE MEASUREMENTS ARE OPTIMISTIC !

Effect on Ageing Rate of Irradiation Current Density:



M. Capeáns Nucl. Instr. Meth. A515(2003)73

Materials Outgassing and Effects on Detectors

Table 3
List of investigated epoxy compounds curing at temperatures above 50°C

Source	Epoxy	Curing T (°C)	Outgas	Effect in detector	Global result
CERN/GDD	EPOTECNY E505 SIT	50	YES	NO	OK
HERA-B/ITR	EPOTEK H72	65	YES*	NO	OK*
CERN/GDD	AMICON 125	85	NO	—	OK
CERN/GDD	POLYIMIDE DUPONT 2545	65	NO	—	OK
ATLAS/TRT	RUTAPOX L20	60	NO	—	OK
CERN/GDD	ARALDITE AW 106	70	YES	—	BAD
CERN/GDD	LOCTITE 330		YES	YES	BAD
CERN/GDD	EPOTECNY 503	65	YES (Silicone)	—	BAD
CERN/GDD	NORLAND UVS 91	50	YES	—	BAD

Table 6
Outgassing tests carried out for some sealants used for fixing small gas leaks in chambers and gas systems

Source	Material	Type	Outgas	Effect in detector	Global result
CERN/GDD	VARIAN Torr-Seal	Solvent-free epoxy resin	NO	NO	OK
CERN/GDD	RHODORSIL CAF4	Caoutchouc Silicone RTV	NO	NO in very small quantities	OK ?
CERN/GDD	DOW CORNING R4-3117 RTV	Silicone based	YES	NO in very small quantities	OK ?
HERA-B/OTR	LOCTITE 5220	Polyurethane-based	YES	—	BAD

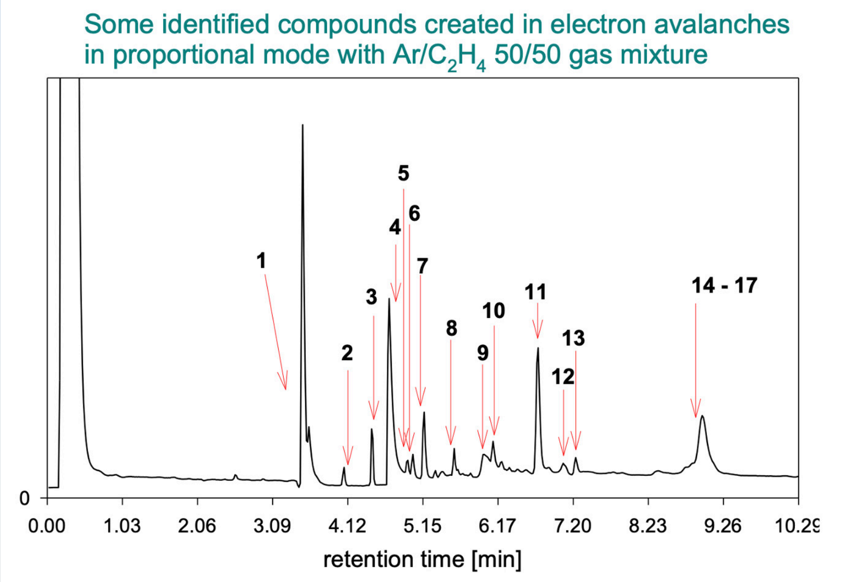
Table 9
Outgassing properties of some plastic pipes

Material	Type	Outgas	Effect in detector	Global result
PP	Polypropylene	NO	NO	OK
RILSAN NYLON	Polyamide	Water	NO	OK*
PEEK Crystalline	Polyetherether ketone	NO	NO	OK
PEEK Amorphous	Polyetherether ketone	YES	—	BAD
PEE		YES	—	BAD
PUR	Polyurethane	YES	—	BAD

M. Capeáns: Nucl. Instr. Meth. A515(2003)73.

☛ ***Maxym Titov: Gaseous Detectors and Radiation Hardness***

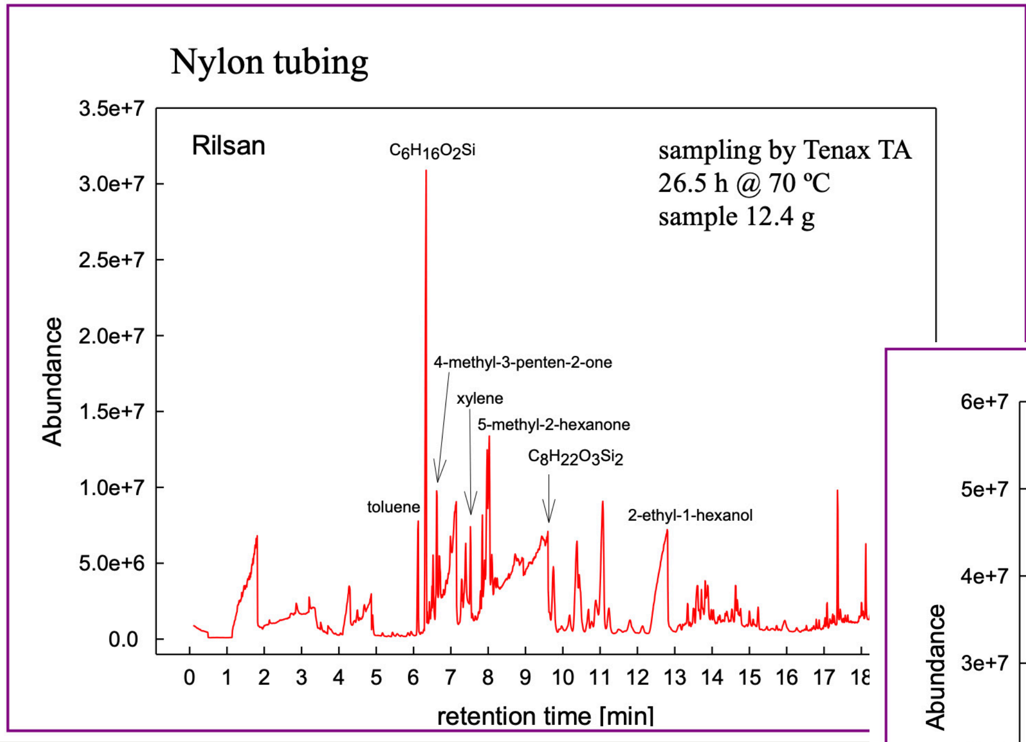
More Studies on Wire Chamber Chemistry

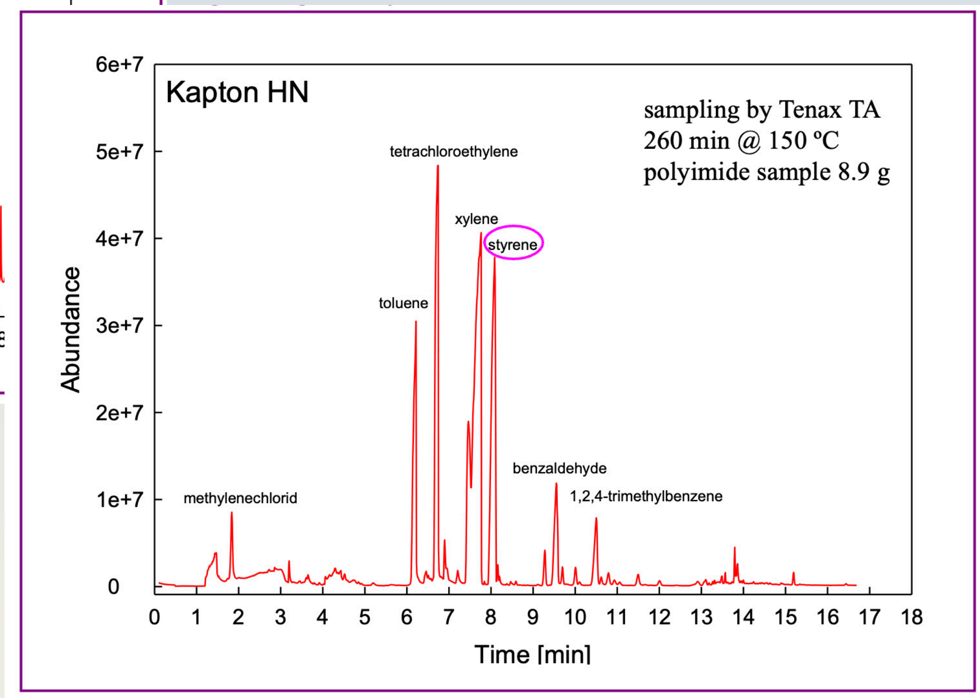


PEAK	COMPOUND	SOURCE	REMARK
1	Asetaldehyde	Electron aval.	Polymerising improbable.
2	1,3-butadiyne	Electron aval.	Explosively polymerising.*
3	Ethanol	Electron aval.	Polymerising improbable.
4	1,3-pentadiene	Electron aval.	Able to polymerise.
5	2-methyl-2-propanol	Electron aval.	Polymerising improbable.
6	Methoxy-asetaldehyde	Electron aval.	Polymerising improbable.
7	2-ethoxy-2-methylpropane	From system.	Polymerising improbable.
8	2-methyl-1,3-dioxolane	Electron aval.	Polymerising improbable.
9	2-methoxy-ethanol	Electron aval.	Polymerising improbable.
10	1,3-hexadien-5-yne	Electron aval.	Able to polymerise.
11	3-methyl-1,3-pentadiene	Electron aval.	Able to polymerise.
12	4-methyl-1,4-hexadiene	Electron aval.	Able to polymerise.
13	2,4-heptadiene	Electron aval.	Able to polymerise.
14	Tetracloroethylene	From gas bottle.	Contaminant in ethylene bottle.
15	1-ethenyl-4-ethylbenzene	Electron aval.	Able to polymerising.
16	2,3-dihydro-1-methylindene	Electron aval.	Polymerising improbable.
17	4-ethylbenzaldehyde	Electron aval.	Polymerising improbable.

K. Kurvinen, RD-51 WG2 meeting 10 Dec. 2008

Outgassing of Nylon Tubing





K. Kurvinen, RD-51 WG2 meeting 10th Dec. 2008

The CF_4 Case: Benefits and Harms

Very Fast Drift Velocity and Low Diffusion

Dissociates to Reactive Species uner Avalanche Conditions

$CF_4 + e \dashrightarrow CF_3^* + F^* + e$

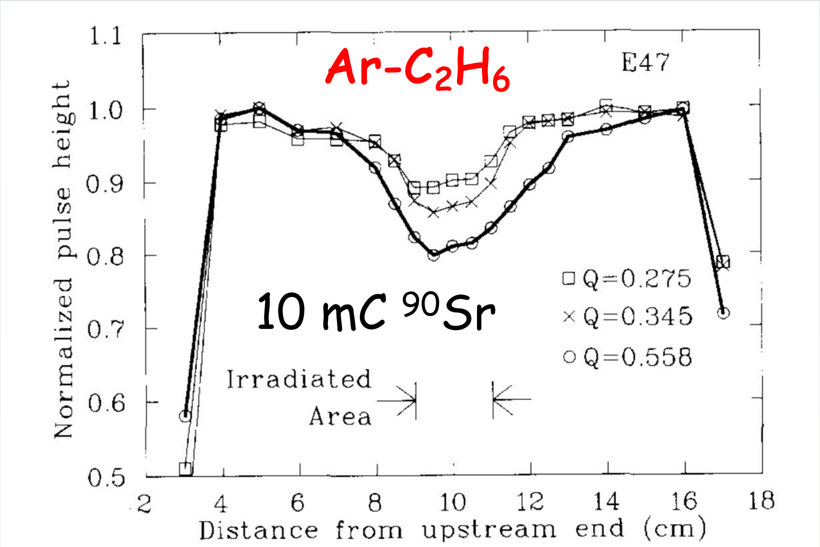
$CF_4 + e \dashrightarrow CF_2^* + 2F^* + e$ $F + H_2O \rightarrow HF$

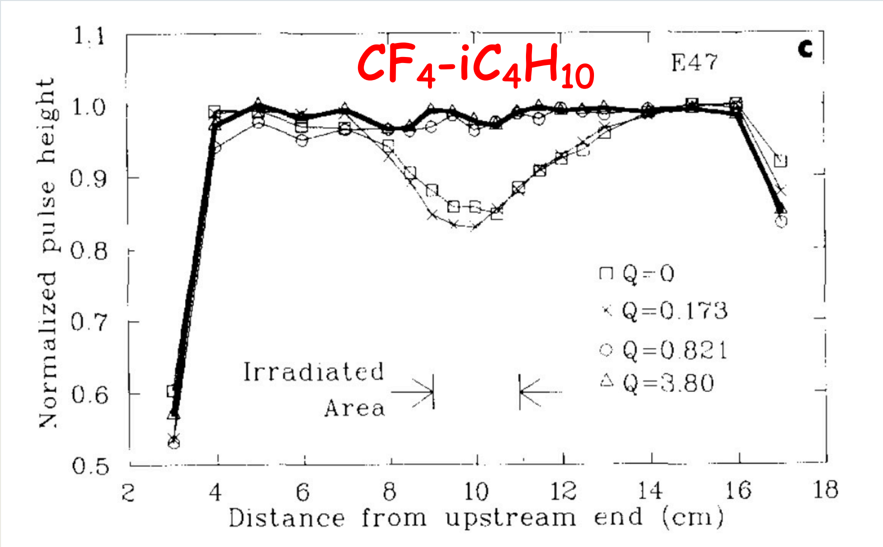
$CF_4 + e \dashrightarrow CF_3^- + F^*$

Efficient Etching of Deposits on Wires

Wire Chamber Aging

Recovery With CF_4





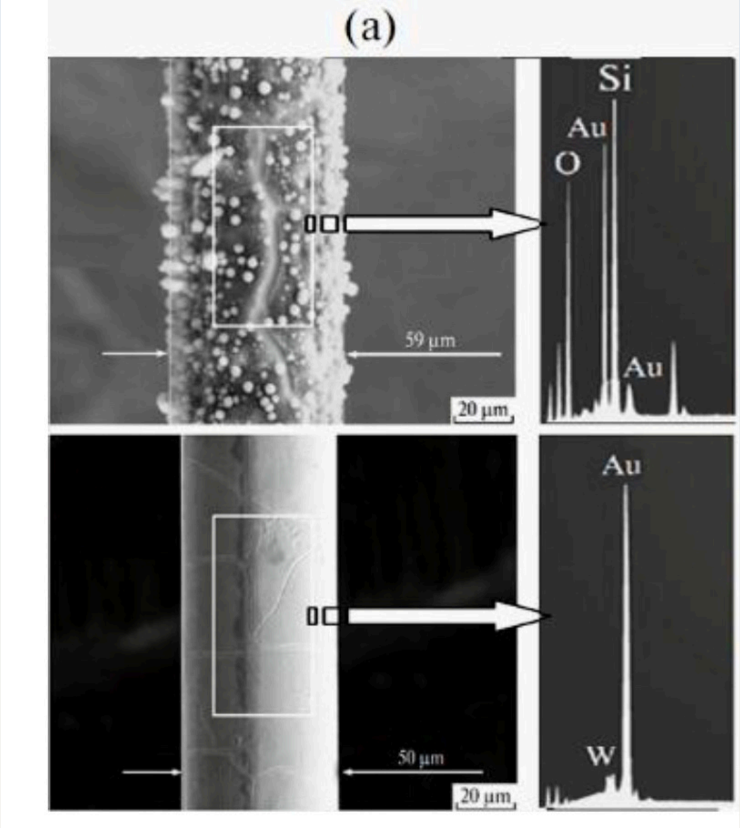
R. Openshaw et al, Nucl. Instr. Meth A307(1991)298

CAVEAT:

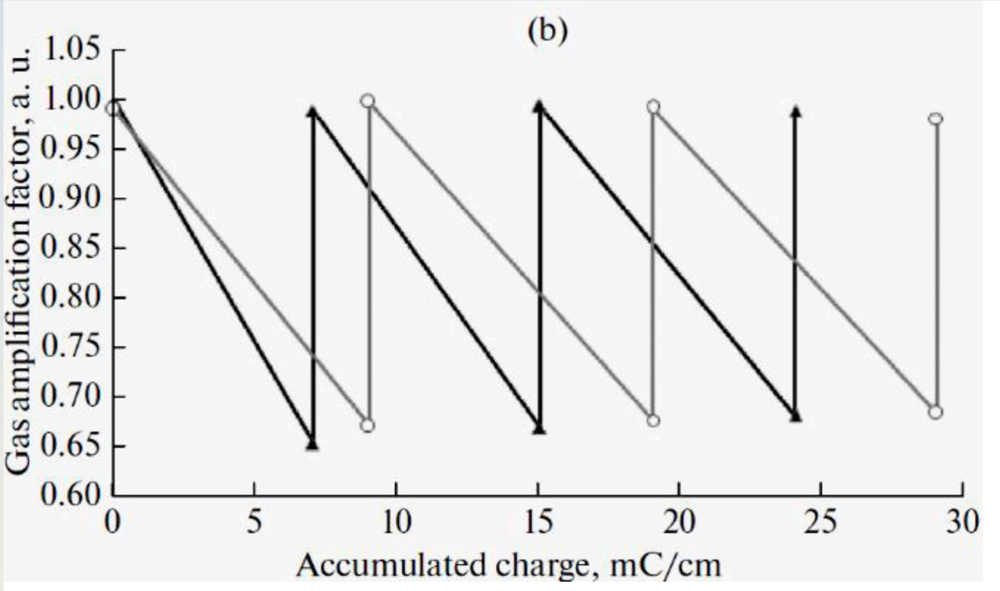
CF_4 dissociation products react also with the detector building materials !

Anode Wire Aging Recovery in CF_4

Aged Wire Irradiated with ^{55}Fe source in Ar-CO2 + 10% CF4

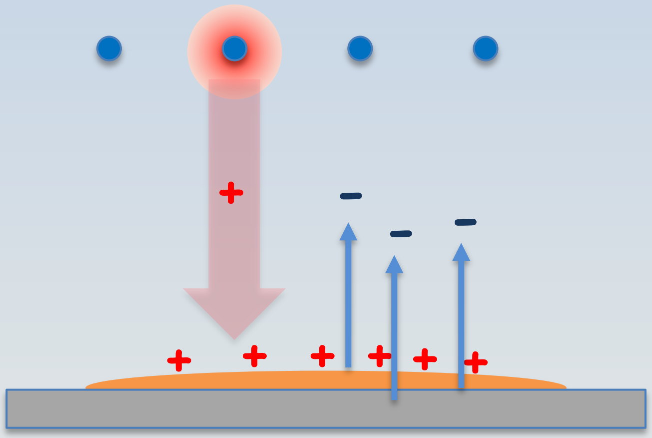


"Training": Cyclic Exposure to ^{90}Sr Source in 80% CF_4-20% CO_2



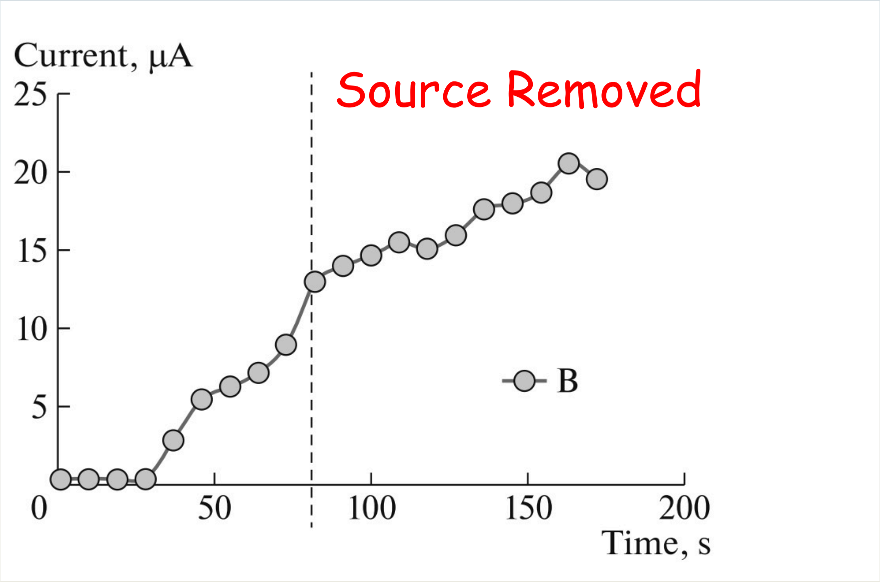
G. Gavrilov et al, Physics of Particles and Nuclei49(2018)33

Cathode Field Emission - Malter Effect



The Current Increase due to Malter Effect continues after removal of source

LHCb Muon MWPC:



Positive Ions Deposit on the Thin Insukating Layer and Create an Electric dipole Field Extracting Electrons
Self-Sustained Effect Leading to Current Increase and Discharge

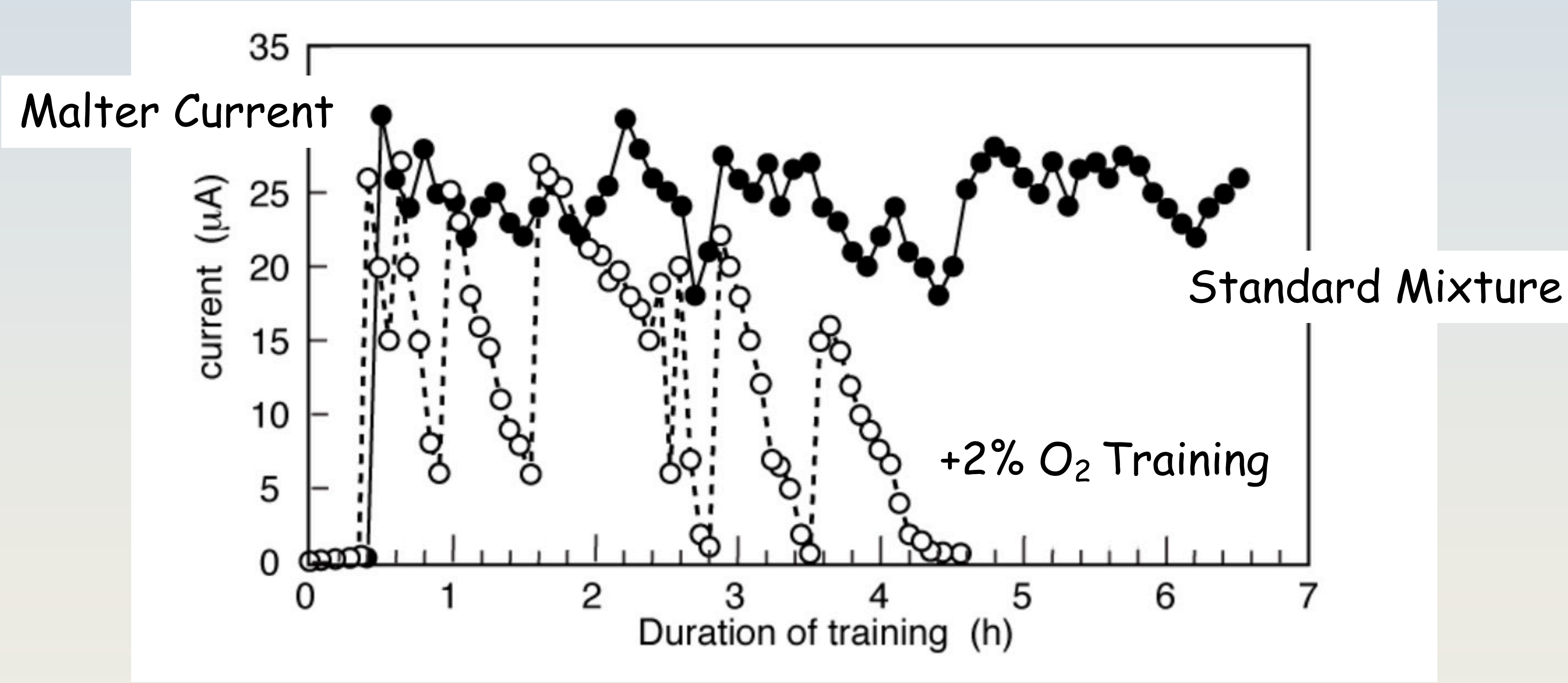
- Rate Dependent
- Enhanced Sensitivity to Light

G. Gavrilov et al,
Phys. Atomic Nuclei 82(2019)1273

LHCb Muon Chambers : ~ 1400 MWPC with Ar-CO_2-CF_4

Operated for 9 years without gain reduction
~ 20% MWPC developed high current and HV trips, attributed to Malter effect on Cathodes

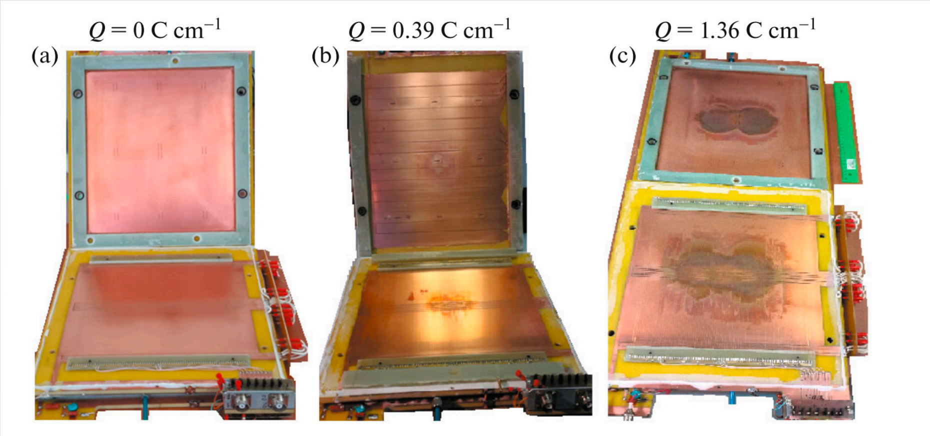
TRAINING : Reduction of Mather CurrentAdding O_2 to Ar-CO_2-CF_4

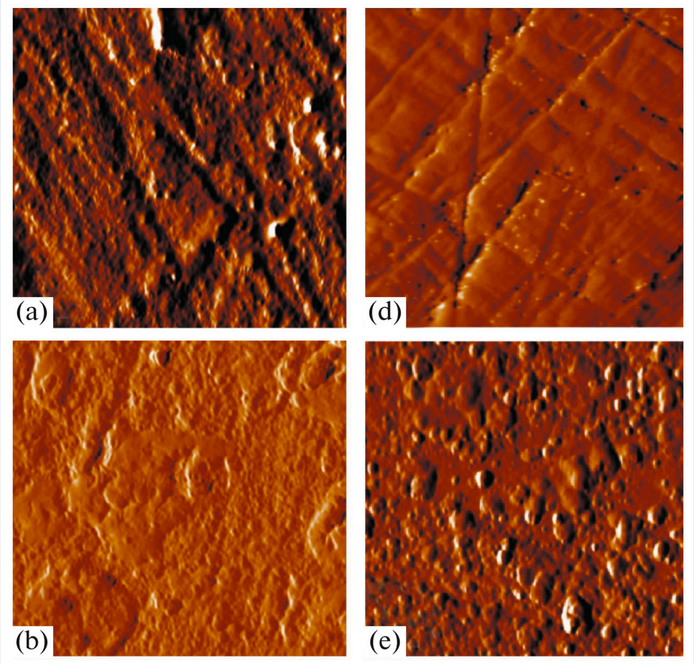


F. P. Albicocco et al, JINST 14(2019)P11031

Catode Plane Damage in CMS CSC Chambers

The gas mixture used, (Argon-CO_2–CF_4) prevents the formation of anode and cathode deposits; damages to electrodes under sustained irradiation are attributed to CO_2 dissociation products (O^* , CO^* O_2 , O_3).





M. A, Buzoveria et al, Phys. Atomic Nuclei 82(2019) 1252

CAVEAT: CF_4 is Expensive, Difficult to Procure and Greenhouse Gas

Search for Eco-Friendly Replacements:

☛ Beatrice Mandelli, Maxym Titov + Many Presentations

GOLDEN RULES OF AGING PREVENTION

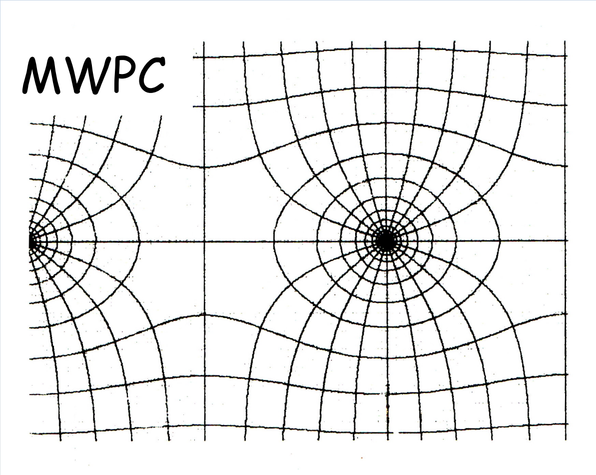
- Ultra-Pure gases
- Non-Organic Quenchers (CO_2)
- Choice of non-Outgassing Building Materials
- Non-Polymerizing Additives: Methylal, Propilic Alcohol
- Improved Cleaning Protocols
- Avoid Silicon-Containing Materials: Tubing, Sealings, ...

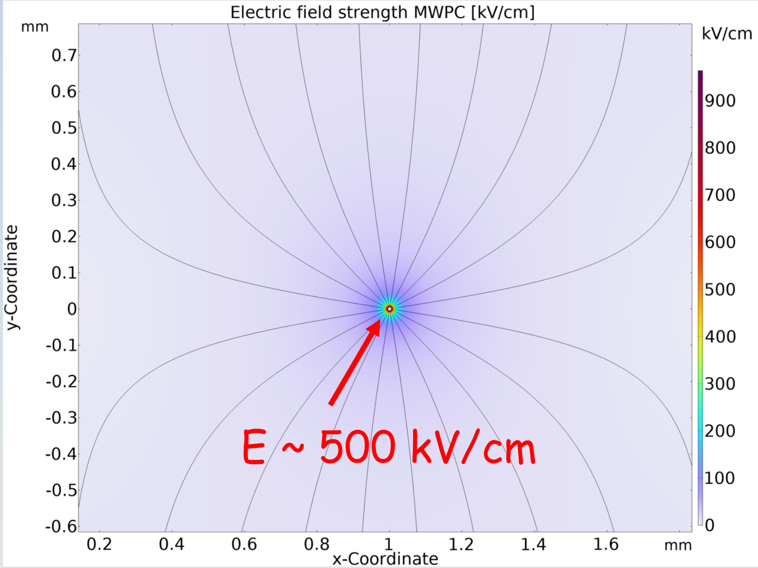
- Zapping: Burning Deposits with High Current on Anodes

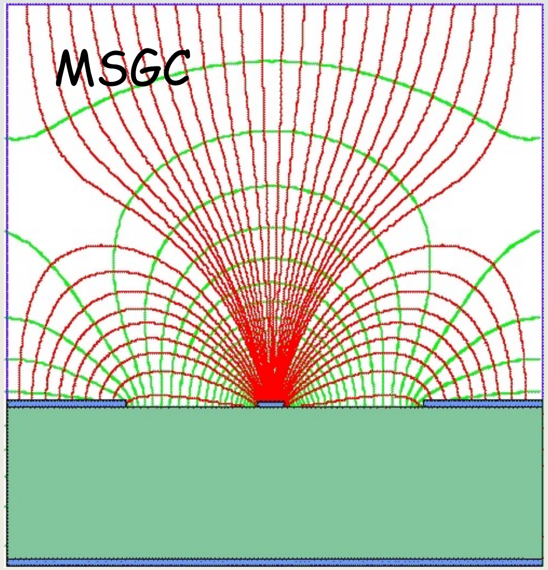
- Addition of Compounds with Etching Properties (O_2 , CF_4)

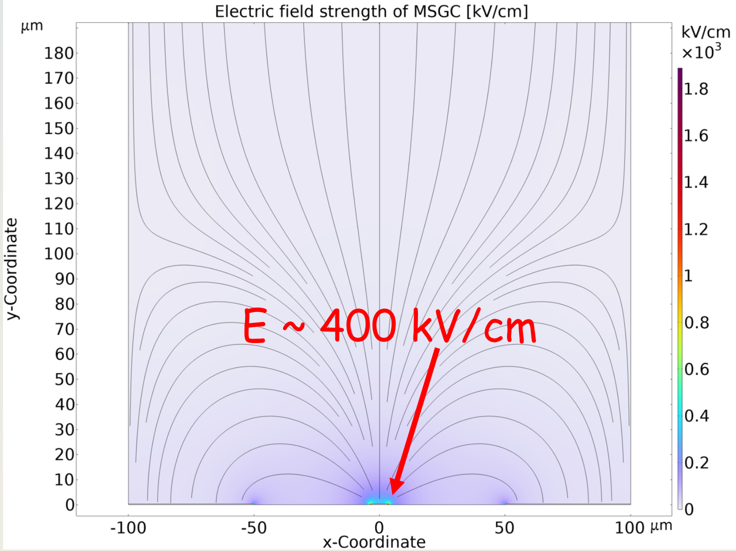
- THE CREATION OF REACTIVE SPECIES IS ENHANCED AT HIGH VALUES OF THE ELECTRIC FIELD

Maximum Electric Field in MWPC & MSGC:







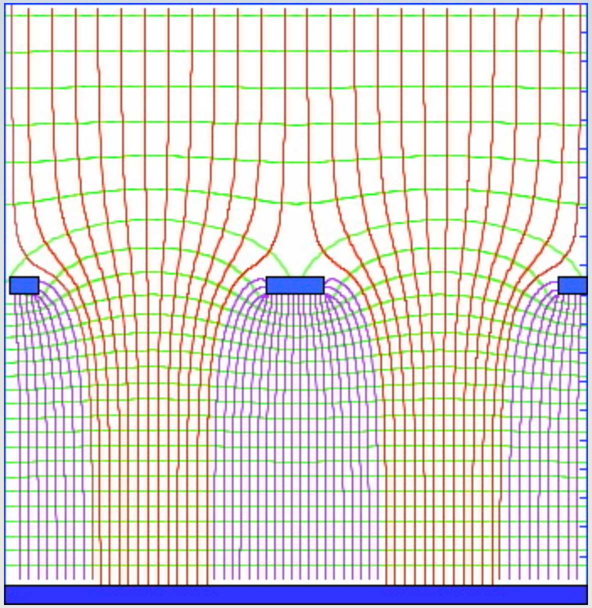


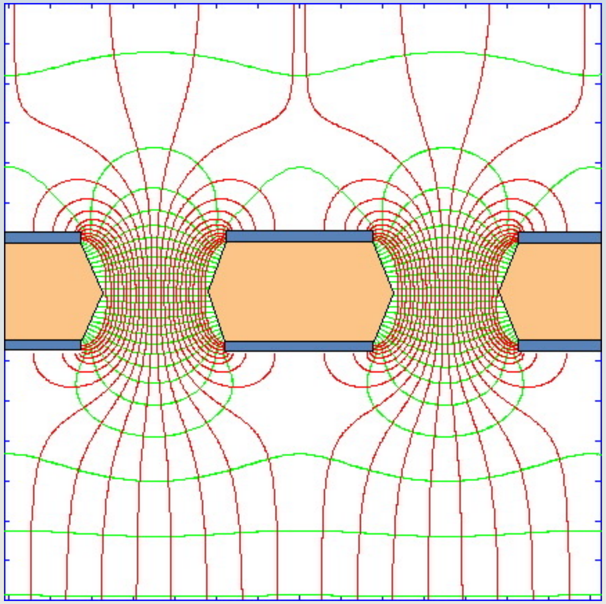
Computed by Djunes Janssens (CERN-GDD)

The Solution: Get Rid of Thin Wires and Strips
➽ Micro-Pattern Gas Detectors (MPGD)

MICROMEGAS

Gas Electron Multiplier (GEM)



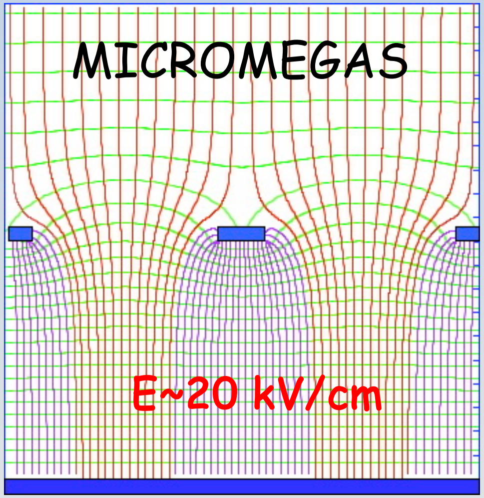


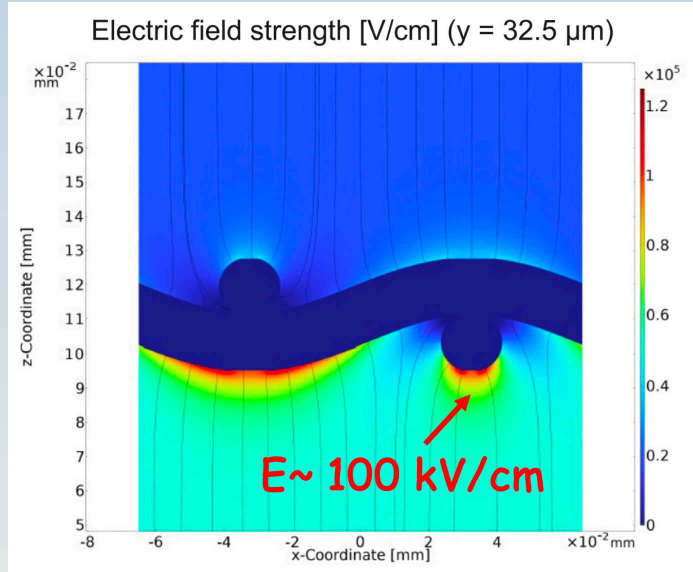
Y. Giomataris et al,
Nucl. Instr. Meth. A376(1996)29

F. Sauli,
Nucl. Instr. Meth. A386(1997)531

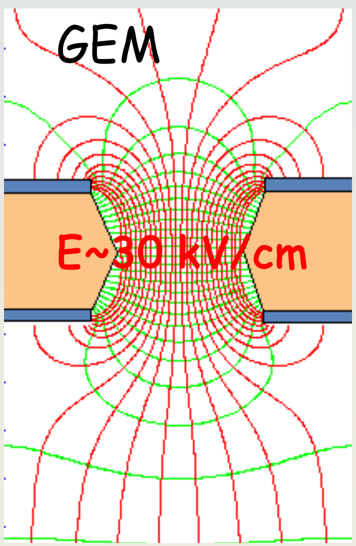
+ MiroGroove, MicroGap,MicroPixel
  Resistive Plate Well ……….

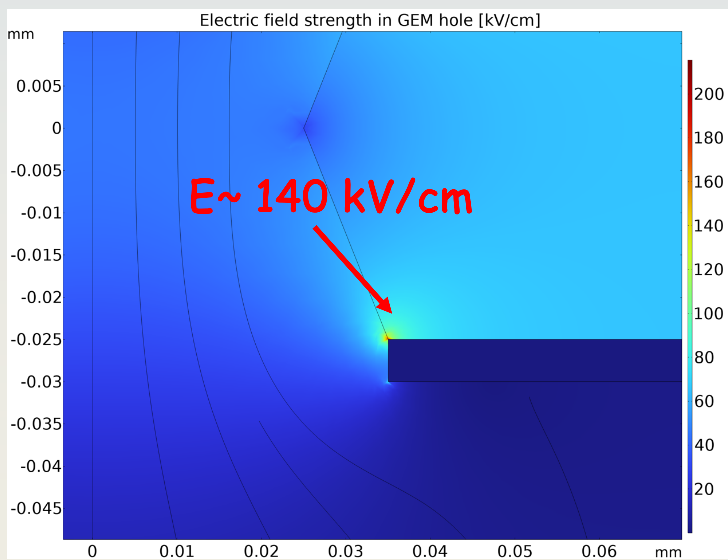
Electric Field Strength: MICROMEGAS & GEM





Interwoven Micromesh



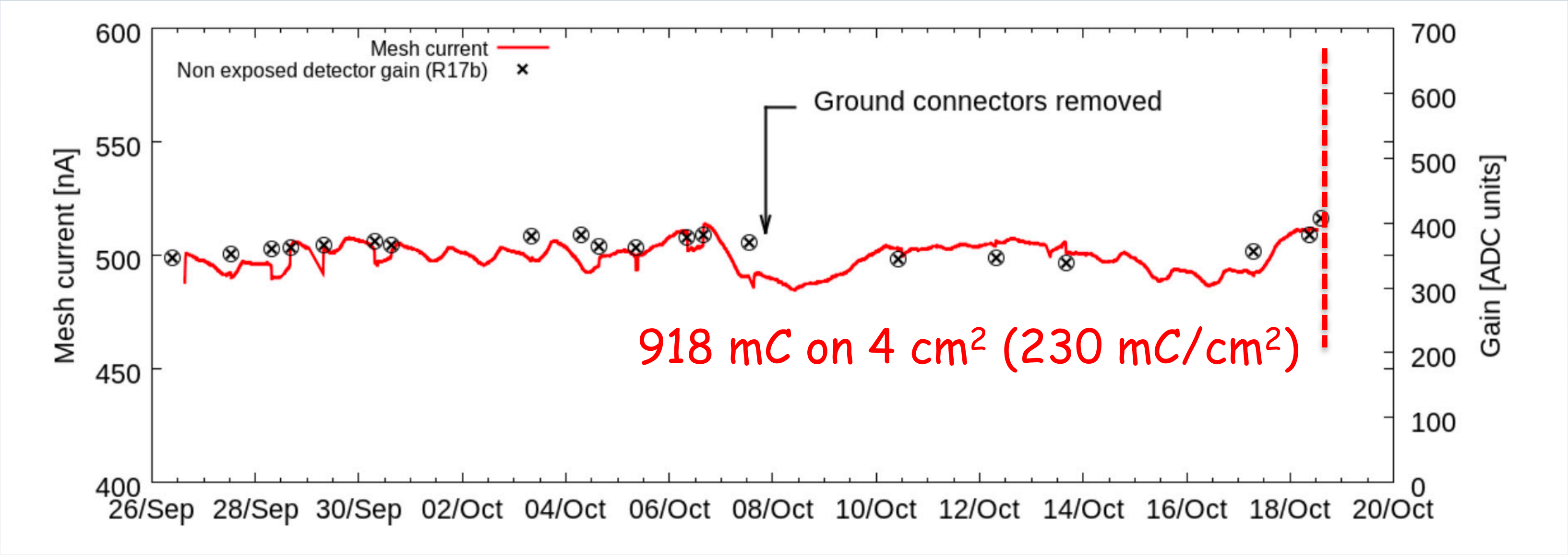


Lower GEM Hole Edge

Computed by Djunes Janssens (CERN-GDD)

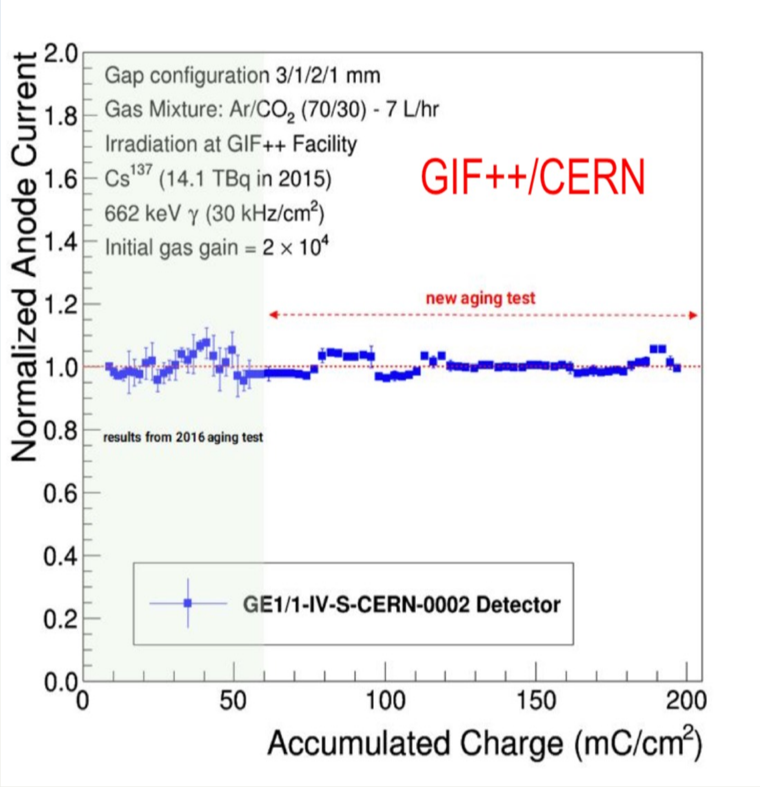
Long-Term Aging Measurements: MICROMEGAS HL-LHC ATLAS Upgrade

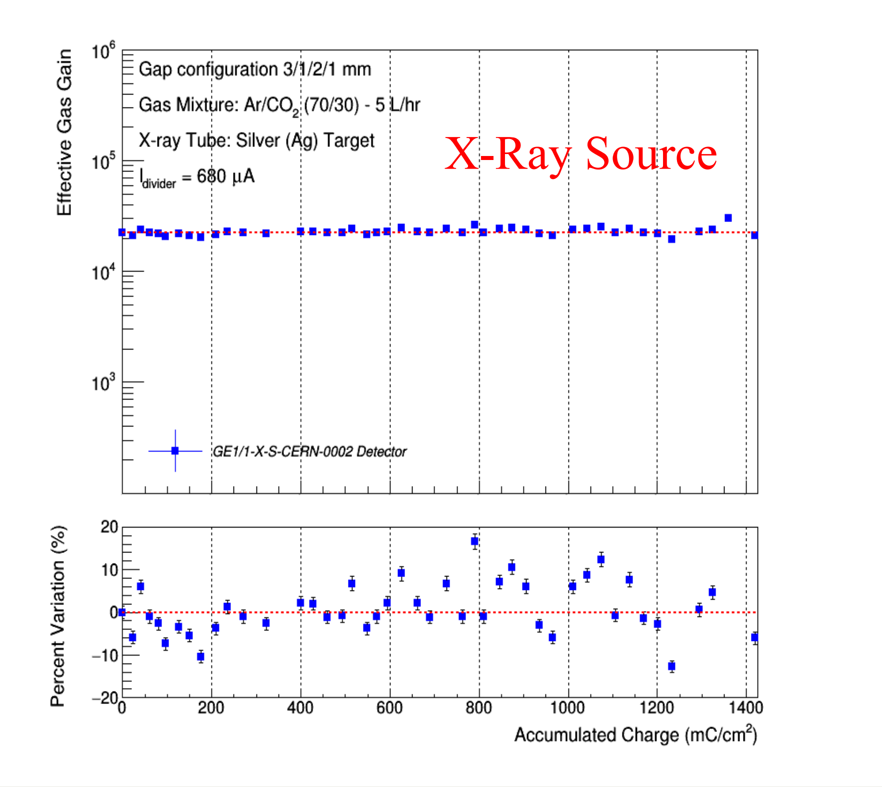
X-Ray Generator 11 kV
Ar-CO_2 (90-10)



J. Galan et al, JINST7(2012) C01041

Long-Term Aging Mesurements
CMS Forward Muon Triple-GEM Upgrade
Ar-CO_2(70-30)



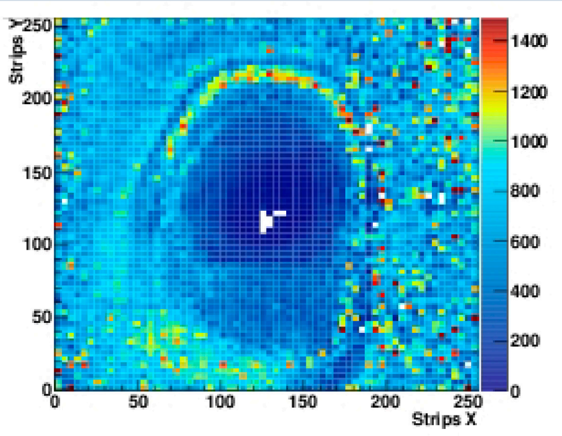


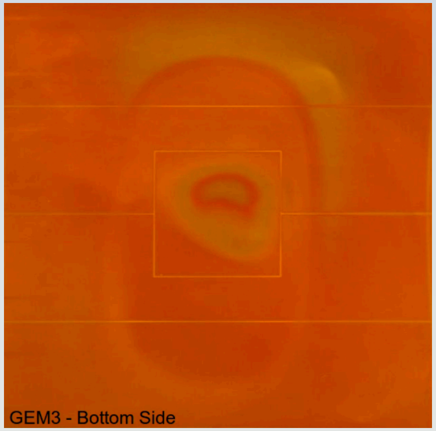
F. Fallavollita, PhD Theses Pavia Univ. (2019)

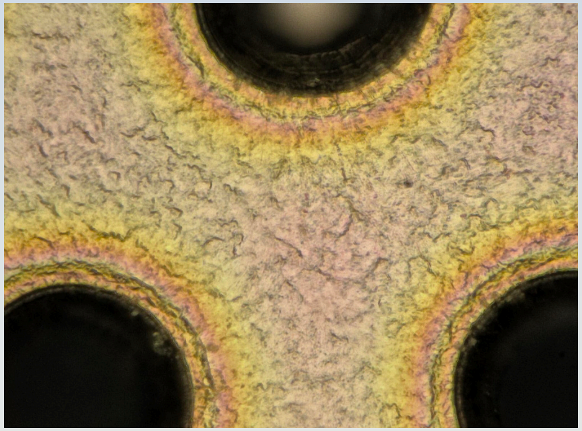
CAVEAT:

MPGD ARE ALSO SENSITIVE TO POLLUTANTS!

COMPASS Pixel GEM– After Four Years of Operation (165 mC/cm^2)







Silicon Coating: (R_2SiO) - Sulphur: Sulphuric Acid (H_2SO_4)

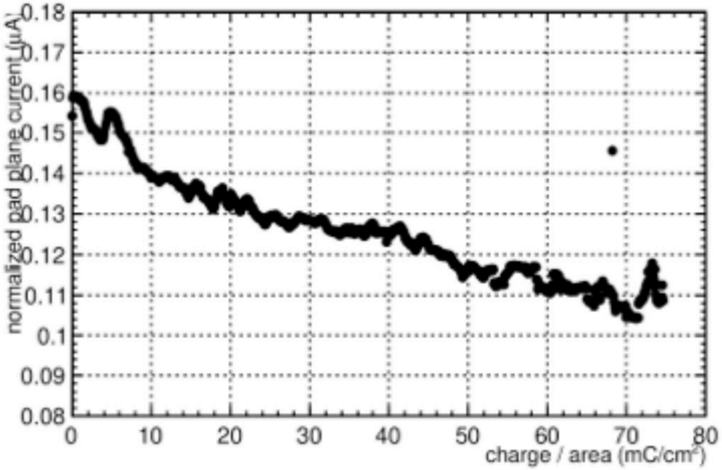
The Culptit: External Sealant DowCorning 1-2577

C. Dreisbach, MPGD Conf. Zaragoza (2013)

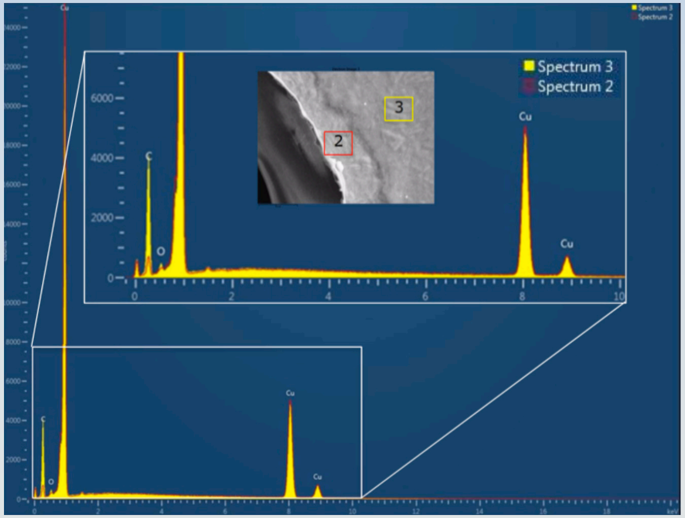
ALICE TPC AGING in Ar-CH_4

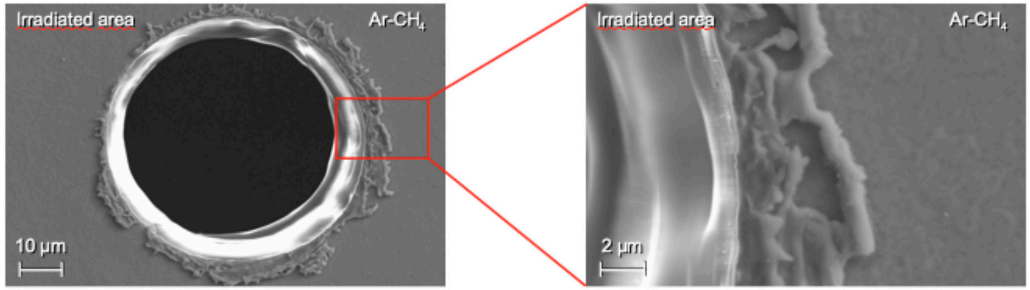
Hydrocarbon Deposits on Copper

Gain = 7200
Currrent density = 35 nA/cm^2



30 % gain drop after 75 mC/cm^2





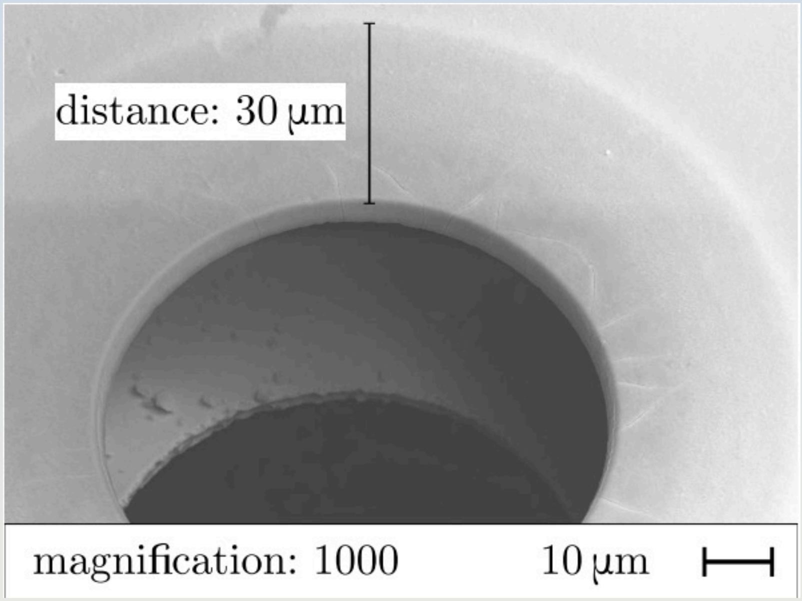
Magnification: 1000 Magnification: 5000

M. Jung, Ch. Garabatos and R. Negrão, RD51 Coll. Meeting Munich 19/06/2018

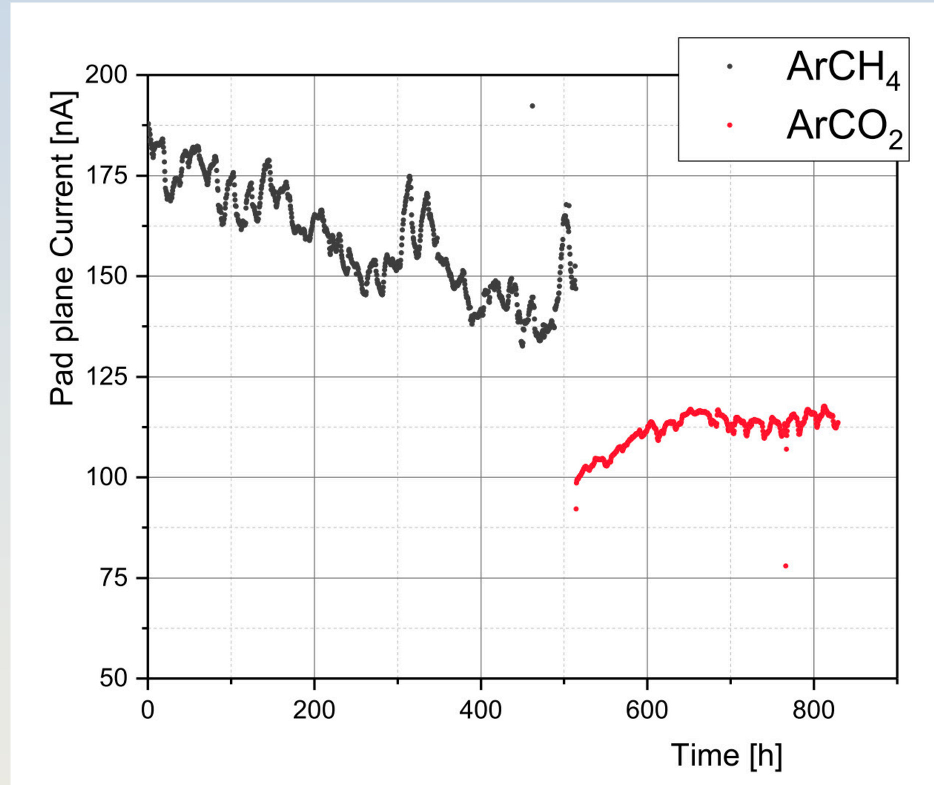
ALICE TPC AGING in Ar-CH_4

Circular Halo Around Holes

Kapton Ablation? Outgassing from Epoxy?



Recovery after Replacement of CH_4 with CO_2

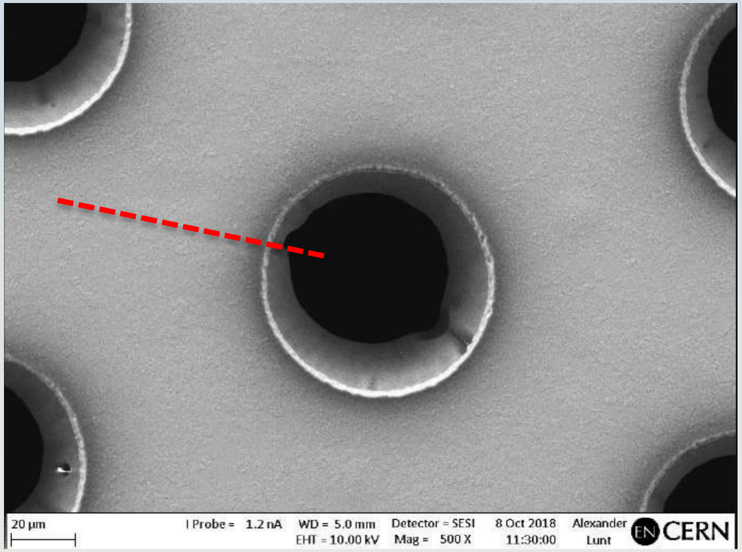


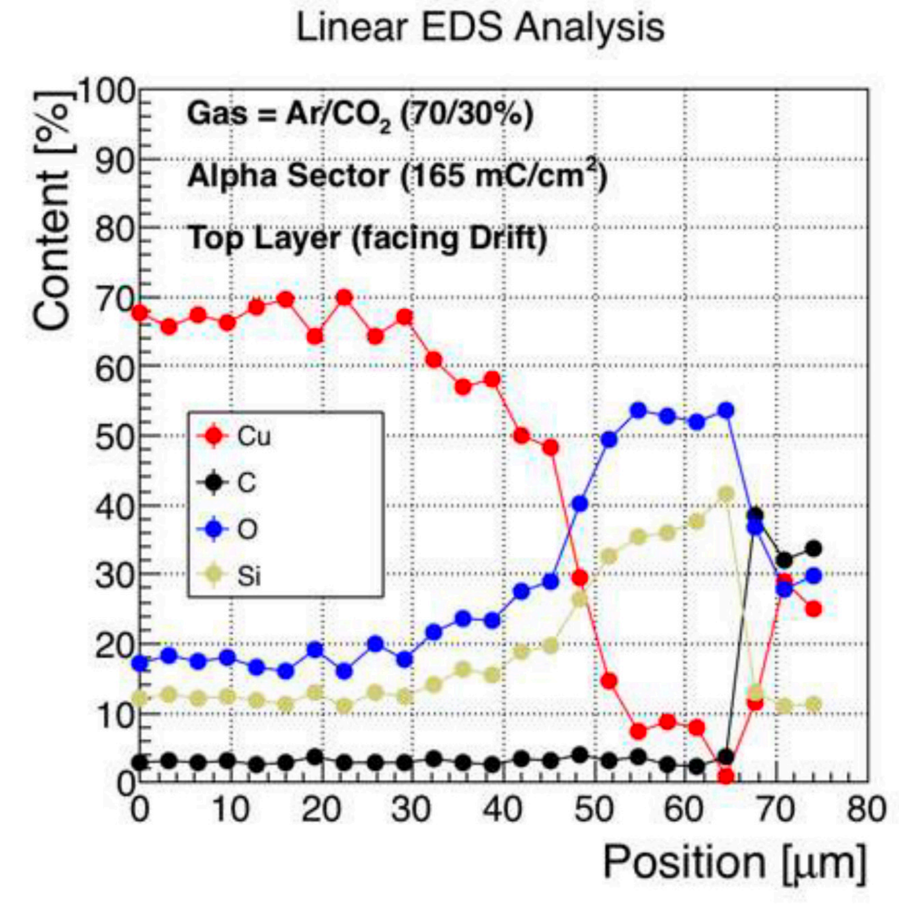
M. Jung, Master Thesis, Univ. Frankfurt (2019)

For Updates: ☛ See Other Presentations at this Conference

GEM: Silicon Deposits on Rim

SEM Analysis after long-Term Irradiation

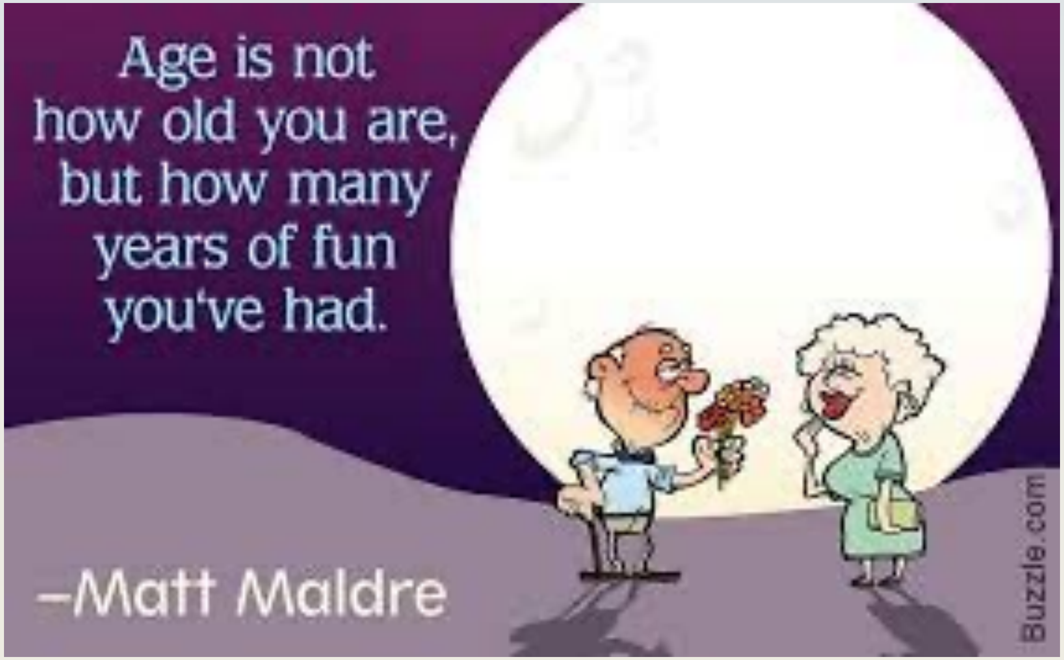




J.A.Merlin
RD51 Miniweek CERN 4-7 Dic 2018

CONCLUSIONS (IF ANY!)

Despite many problems, wire-based detector systems have been successfully operated for over two decades
The development of novel MPGD devices and a better understanding of the aging processes have extended the lifetime of existing systems, as amply documented by the work discussed at this conference
A continuing development effort is needed to ensure operation at the ever increasing luminosity of colliders



Everybody's Dream