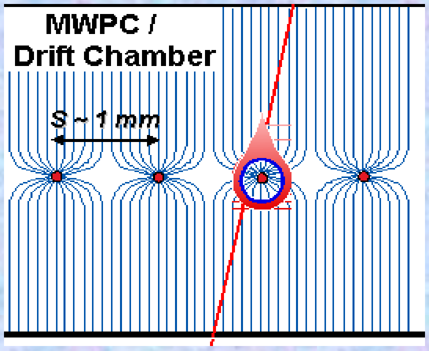
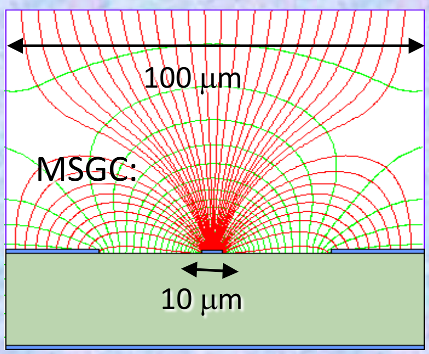
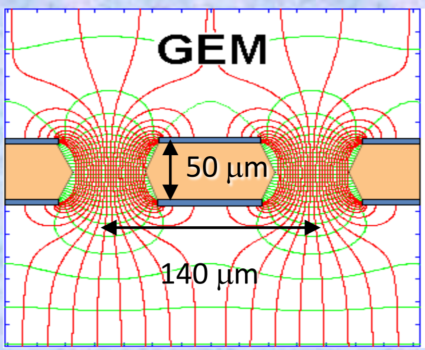
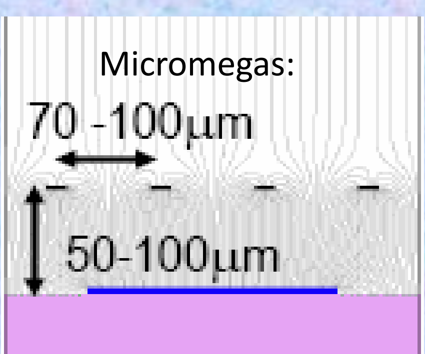
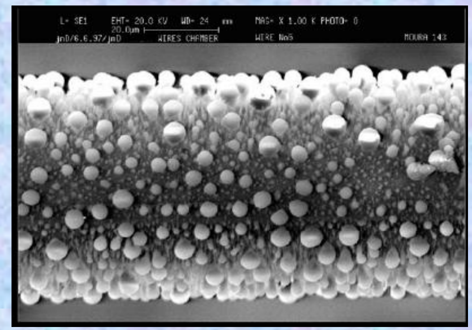
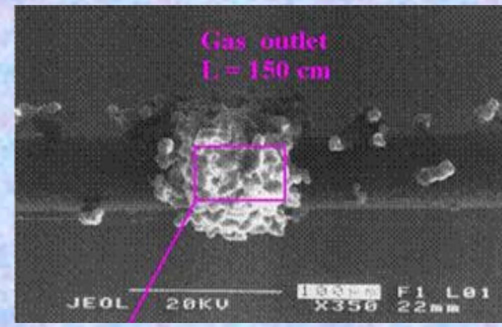


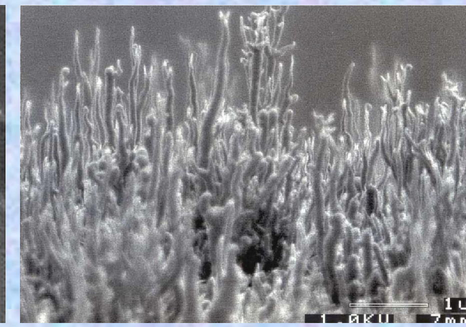


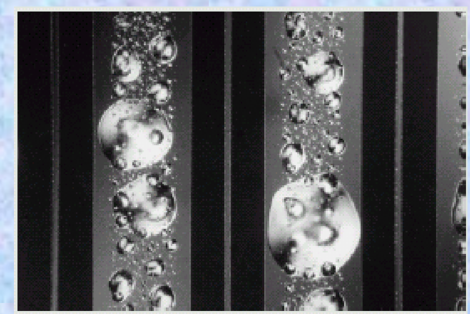


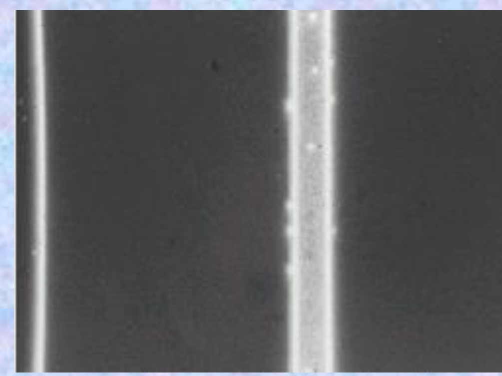


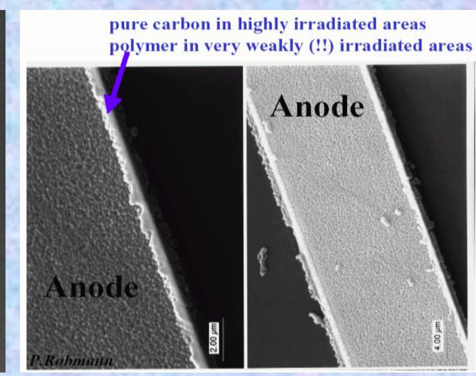







bubbles on cathodes





Radiation Damage and Long-Term Aging in Gas Detectors

Maxim Titov,
CEA Saclay, IRFU/SPP, France

"Workshop on TPCs at High Rate Experiments"
Bonn, Germany, February 27 - March 1, 2013

Aging Phenomena in Wire Chambers: 40 Years Ago

A permanent degradation of operating characteristics under sustained irradiation was found to be the main limitation of long-term wire chamber use in experiments

NUCLEAR INSTRUMENTS AND METHODS 99 (1972) 279–284; © NORTH-HOLLAND PUBLISHING CO.

TIME DEGENERACY OF MULTIWIRE PROPORTIONAL CHAMBERS

G. CHARPAK, H. G. FISHER, C. R. GRUHN, A. MINTEN, F. SAULI and G. PLCH

CERN, Geneva, Switzerland

and

G. FLÜGGE

II. Institut für Experimentalphysik, Hamburg, Germany

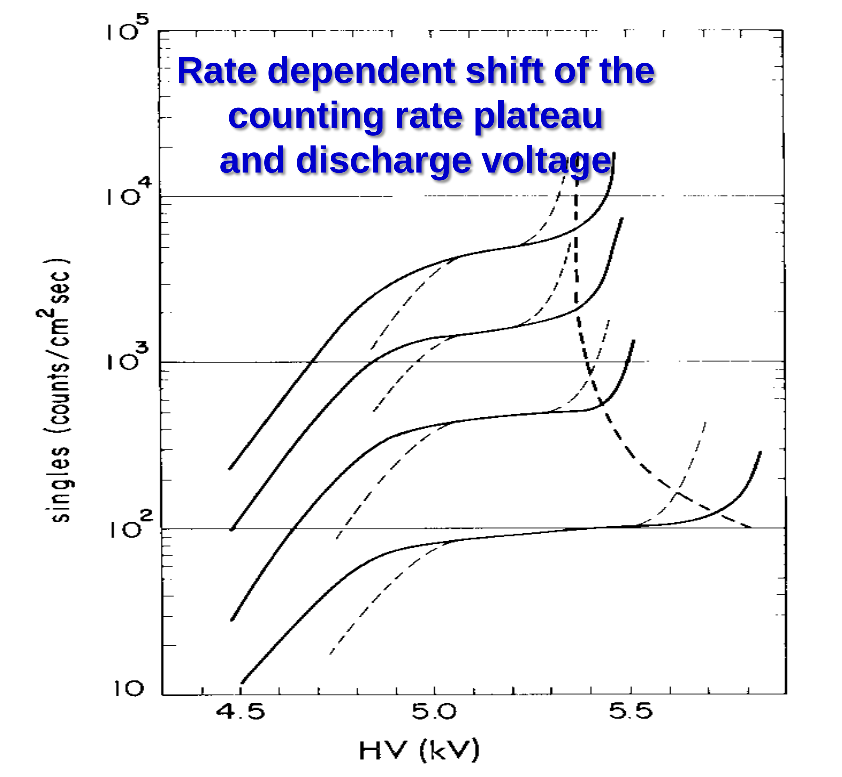
Received 28 May 1971

The deterioration with time of multiwire proportional chambers using isobutane as one component of the gas mixture is studied. It is shown that by addition of methylal among others, a long lifetime can be obtained without changing the properties of the gas mixture. Irradiation tests of $5 \times 10^{10}/\text{cm}^2$ have not shown any alteration in the chamber performance.

1972

'Classical Aging Effects' lead to deposition of polymers on the anode (and/or) cathode surfaces and manifest themselves as:

- **Loss of gas gain**, energy resolution and reduction of the plateau region
- Electron emission (**Malter currents**)
- Sparking
- Self-sustained current discharge



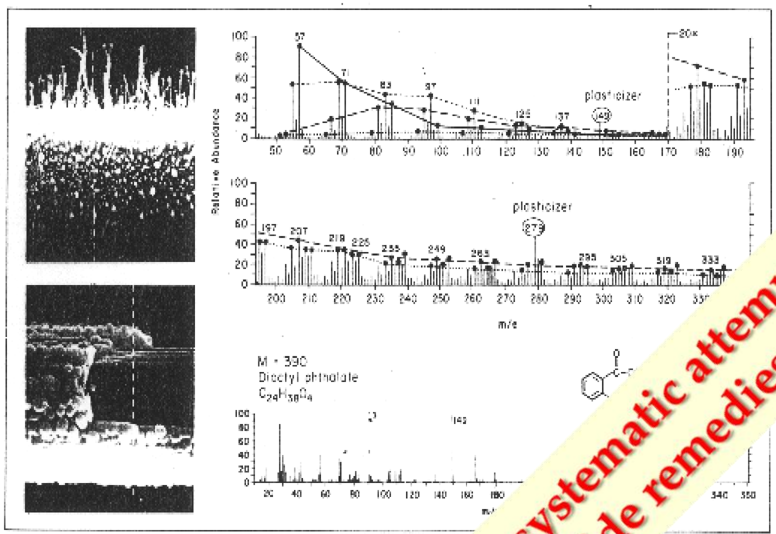
Aging Phenomena in Wire Chambers: 30 Years Ago

Proceedings of the
Workshop on Radiation Damage to
Wire Chambers

Lawrence Berkeley Laboratory, Berkeley, California

January 16-17, 1986

1986



April 19…

Lawrence Berkeley …
University of Califo…
Berkeley, California 94…20

Nuclear Instruments and Methods in Physics Research A252 (1986) 547–563
North-Holland, Amsterdam 547

REVIEW OF WIRE CHAMBER AGING *

J. VA'VRA

Stanford Linear Accelerator Center, Stan… California 04305, USA

This paper makes an … hamber aging problems as a function of various chamber design parameters. It emphasizes the chemi… any examples are drawn from the plasma chemistry field as a guidance for a possible effort in the wir… per emphasizes the necessity of tuning of variables, the importance of purity of the wire chamber env… ovides a practical list of presently known recommendations. In addition, several models of the wire ch… vely discussed. The paper is based on a summary talk given at the Wire Chamber Aging Workshop held… nuary 16-17, 1986. Presented also at Wire Chamber Conference, Vienna, February 25-28, 1986.

First systematic attempts to summarize aging results and to provide remedies minimizing wire chamber aging

Nuclear Instruments and Methods in Physics Research A300 (1991) 436–479
North-Holland

Wire chamber aging *

John A. Kadyk

Lawrence Berkeley Laboratory, 1 Cyclotron Road, Berkeley, CA 94720, USA

Received 27 June 1990

An overview of wire chamber aging is presented. A history of wire aging studies and the manifestations of wire aging are reviewed. Fundamental chemical principles relating to wire chamber operation are presented, and the dependences of wire aging on certain wire chamber operating parameters are discussed. Aging results from experimental detectors and laboratory experiments are summarized. Techniques for analysis of wire deposits and compositions of such deposits are discussed. Some effects of wire material and gas additives on wire aging are interpreted in chemical terms. A chemical model of wire aging is developed, and similarities of wire chamber plasmas to low-pressure rf-discharge plasmas are suggested. Procedures recommended for reducing wire aging effects are summarized.

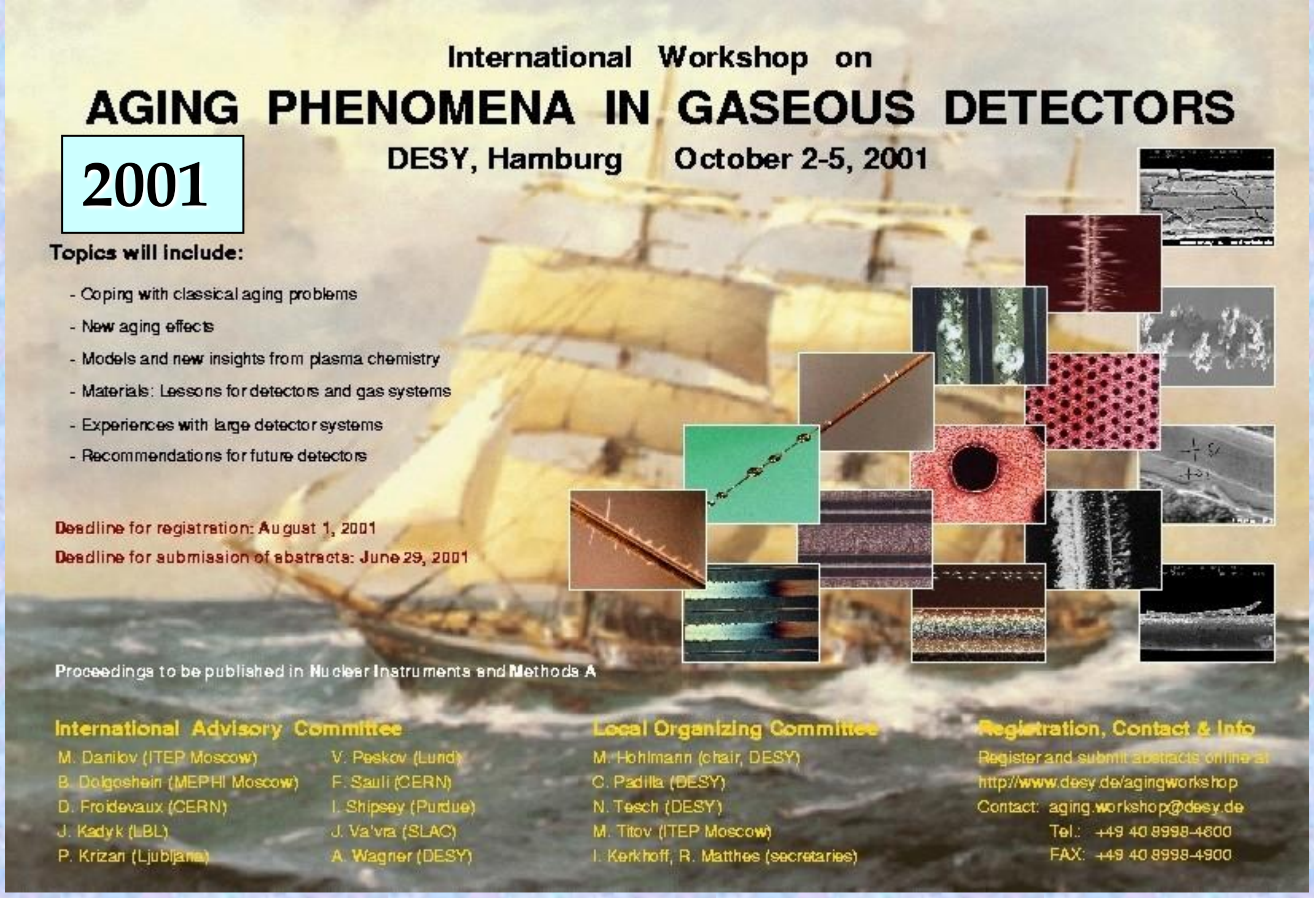
It is difficult to understand truly any present aging measurement and extrapolate it to other operating conditions → reality is a complex mixture of many processes

Aging Phenomena in Gaseous Detectors: 15 Years Ago

High Energy Physics Experiments entered a new era which required operation of gaseous particle detectors at unprecedented high rates and integrated particle fluxes

(… a lot of "new and unexpected experience " from HERA-B @ DESY)

Workshop contributions appear in NIMA Vol.515



IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 49, NO. 4, AUGUST 2002 1609

Summary and Outlook of the International Workshop on Aging Phenomena in Gaseous Detectors (DESY, Hamburg, October 2001)

M. Titov, M. Hohlmann, C. Padilla, and N. Tesch

arXiv:physics/0403055 v1 9 March 2004

RADIATION DAMAGE AND LONG-TERM AGING IN GAS DETECTORS[1]

MAXIM TITOV

Institute of Physics, Albert-Ludwigs University of Freiburg, Hermann-Herder Str. 3, Freiburg, D79104, Germany and

Institute of Theoretical and Experimental Physics (ITEP), B. Cheremushkinskaya, 25, Moscow, 117259, Russia

Aging Phenomena in Gaseous Detectors: 10 Years Ago

Summary of aging results from high-rate laboratory tests and experiments

Wire-type detectors: **2004** **Micro-Pattern Gas Detectors:**

Table 1. Aging results with wire detector prototypes for the use at high energy physics facilities.

Experiment, Detector, Reference	Gas Mixture	Gain reduction/ etching	Cathode aging	Charge C/cm	Gas gain(G); Current density(I); Rate (R); Irradiated area (S)
HERA-B OTR [34]	$Ar/CF_4/CO_2$ (65:30:5)	No/Au damage	No	0.6	G~3*10^4; I~0.4-0.9μA/cm; 100MeV α-beam; S~50cm^2
HERA-B MUON [35]	$Ar/CF_4/CO_2$ (65:30:5)	No	No/F-film on Al cath.	0.7	G~10^4-10^5; I ~ 0.3μA/cm; R<10^5 Hz/cm^2; S~1200cm^2
HERA-B MUON[35]	Ar/CF_4 (70:30)	No	No	0.07	G~10^5; I ~ 0.15μA/cm; R~10^4 Hz/cm^2; S~150cm^2
ATLAS TRT [15,48]	$Xe/CF_4/CO_2$ (70:20:10)	No	No	20	G~ 3*10^4; I ~ 0.7 μA/cm; S~24 cm^2
Straw R&D[45]	$Xe/CF_4/CO_2$ (70:20:10)	No/Au cracks	No	9	G~3*10^4; I ~ 1.7μA/cm; R~2*10^6 Hz/cm^2; S~1cm^2
Straw R&D[45]	$Ar/CF_4/CO_2$ (60:10:30)	No/Au cracks	No	15	G~10^5; I ~ 1.7μA/cm; R~10^6 Hz/cm^2; S~1cm^2
CMS MUON [14]	$Ar/CF_4/CO_2$ (40:10:50)	No/ Au cracks	Si-F film on Cu cath.	13.4	G~6*10^4; I ~ 2μA/cm; R~2*10^6 Hz/cm^2; S~1cm^2
CMS MUON [46]	$Ar/CF_4/CO_2$ (40:10:50)	No	Si-F film on Cu cath.	0.4	G~10^5; I < 0.05 μA/cm; R~2*10^4 Hz/cm^2;S~21000cm^2
LHC-B MUON [52]	$Ar/CF_4/CO_2$ (40:10:50)	No	Etching of FR4 bars	0.25	G~10^5; I < 0.03 μA/cm; R~3*10^4 Hz/cm^2; S~1500cm^2
COMPASS Straws [53]	$Ar/CF_4/CO_2$ (74:20:6)	No/ Si-traces	No	1.1	G~4*10^4; I ~ 4 μA/cm; R~2*10^5 Hz/cm^2; S~3 cm^2
HERMES FD [47]	$Ar/CF_4/CO_2$ (90:5:5)	No	Al etching/ Cl deposits	9	G~5*10^5; I ~ 1 μA/cm; R~10^5 Hz/cm^2; S~7 cm^2
ATLAS TRT[16]	$Xe/CO_2/O_2$ (70:27:3)	No	No	11	G~ 3*10^4; I ~ 1-3 μA/cm; S~1 cm^2
ATLAS TRT[16]	$Xe/CO_2/O_2$ (70:27:3)	No/Si-deposits	No	0.3	G~3*10^4; I ~ 0.1 μA/cm; S~1 cm^2
ATLAS MDT[55]	Ar/CO_2 (90:10)	No	No	0.7	I ~ 0.1μA/cm; R~4*10^2 Hz/cm^2;S~7500cm^2
ATLAS MDT[56]	Ar/CO_2 (93:7)	No	No	>1.5	G~2*10^4; I ~ 0.05-0.2μA/cm; R~8*10^2-10^{4}Hz/cm^2;S~90cm^2
ATLAS MDT[57]	Ar/CO_2 (93:7)	Yes/Si-deposits	No	0.2	G~9*10^4; I ~ 0.02μA/cm; R~5*10^2 Hz/cm^2;S~15000cm^2
CMS MUON[14]	Ar/CO_2 (30:70)	Yes/ Si-deposits	No	0.76	G~6*10^4; I ~ 2 μA/cm; R~2*10^6 Hz/cm^2; S ~ 1 cm^2

Table 2. Summary of aging experience with Micro-Pattern Gas Detectors.

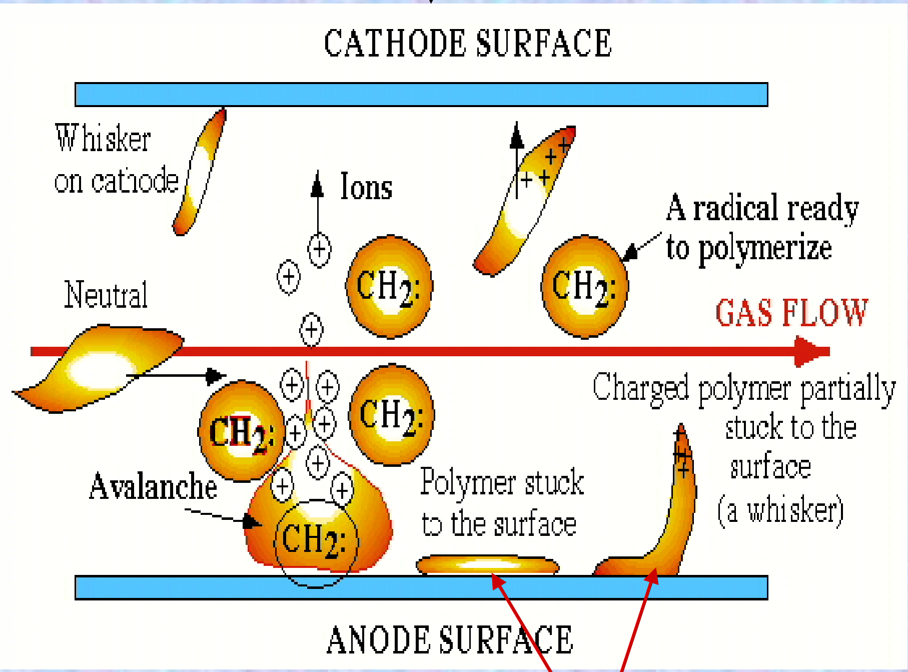
Detector type	Mixture	Gain reduction ΔG/G	Charge mC/mm^2	Current density, nA/mm^2	Irradiated area; Irradiation rate	Irrad. source
MSGC [65,104]	Ar/DME (90:10)	No	200	10	3 mm^2; 10^5 Hz/mm^2	6.4 keV X-rays;
MSGC [66]	Ar/DME (50:50)	No	40	63	0.3*0.8mm^2; 8*10^5 Hz/mm^2	5.4keV X-rays
MSGC [66]	Ar/DME (50:50)	Anode deposit	50	9	0.3*0.8mm^2; 2*10^4 Hz/mm^2	5.4keV X-rays
MSGC+GEM [66]	Ar/DME (90:10)	No	70	63	0.3*0.8mm^2; 2*10^6 Hz/mm^2	5.4keV X-rays
MSGC+GEM [51]	Ar/DME (50:50)	No	5	2	~ 113 mm^2; 2*10^4 Hz/mm^2	8keV X-rays
MSGC+GEM [51]	Ar/DME (50:50)	Yes	0.5	1	~ 900 mm^2; 10^4 Hz/mm^2	8keV X-rays
MSGC+GEM [51]	Ar/CO_2 (70:30)	No	10	2	350 mm^2 2*10^4 Hz/mm^2	8keV X-rays
Double GEM [67]	Ar/CO_2 (70:30)	Slight gain loss	25	6	2 mm^2; 7*10^4 Hz/mm^2	5.4keV X-rays
Triple GEM [68]	Ar/CO_2 (70:30)	No	27	13	15 mm^2; 6*10^4 Hz/mm^2	5.4keV X-rays
Double GEM [69]	Ar/CO_2 (70:30)	No	12	4	200 mm^2; 5*10^4 Hz/mm^2	6keV X-rays
Triple GEM [70]	Ar/CO_2 (70:30)	No	11	10	1260 mm^2; 2*10^4 Hz/mm^2	8.9 keV X-rays
Triple GEM [71,72]	$Ar/CF_4/CO_2$ (60:20:20)	< 5 %	230	270	1 mm^2; 5*10^6 Hz/mm^2	5.9 keV X-rays
Triple GEM [72]	$Ar/CF_4/CO_2$ (45:40:15)	< 5 %	45	160	1 mm^2; 5*10^6 Hz/mm^2	5.9 keV X-rays
Triple GEM [73]	$Ar/CF_4/CO_2$ (45:40:15)	Yes/ 55%	20	20	200*240 mm^2	25 kGi ^{60}Co
Triple GEM [72]	$Ar/CF_4/C_4H_{10}$ (65:28:7)	~ 10 %	110	160	1 mm^2; 5*10^6 Hz/mm^2	5.9 keV X-rays
Triple GEM+ CsI [88]	CF_4 (100)	No	0.1	3	100 mm^2; 10^7 Hz/mm^2	Hg UV Lamp
Micromegas [74]	Ne/C_2H_6 (91:9)	Yes/ 35 %	10	50	16 mm^2; 33Hz spark rate	5.3 MeV α's
Micromegas [75]	Ar/CF_4 (95:5)	No	2	10	--------	8keV X-rays
Micromegas [76]	CF_4/C_4H_{10} (94:6)	No	1.6	25	20 mm^2; ~10^5 Hz/mm^2	8keV X-rays
Micromegas [76]	Ar/C_2H_6 (94:6)	No	18	20	20 mm^2; 2*10^6 Hz/mm^2	8keV X-rays
Micromegas+ GEM[77]	Ar/CO_2 (70:30)	No	23	17	3 mm^2	5.4keV X-rays
MSGC+GEM DIRAC [64]	Ar/DME (60:40)	10% eff. drop	0.01	0.05	100*100 mm^2; 3*10^4 Hz/mm^2	24 GeV protons
3-GEM [78] COMPASS	Ar/CO_2 (70:30)	No	2.3	--	310*310 mm^2; 2*10^4 Hz/mm^2	Compass Beam

Mechanism of Polymerization in Wire Chambers

Free-radical polymerization is the dominant mechanism of the wire chamber aging

During gaseous discharges many molecules break up due to collisions with electrons, de-excitation of atoms, and UV-absoprtion processes

Whereas most ionization processes require electron energies > 10 eV, the breaking of chemical bonds and formation of free radicals requires ~ 3-4 eV



Modification of electric field

Polymer deposition mechanism → chemistry of gaseous discharges and nearby electrodes:

- Chemical reactions between polymer atoms and atoms of the electrode material
- Electrostatic attraction to the electrode (many chemical radicals are expected to have permanent or induced dipole moments)

Aging Phenomena in Gaseous Detectors

Implicit assumption:

- **aging rate is proportional only to the total accumulated charge**

R = - (1/G)(dG/dQ)   (% per C/cm)   (Kadyk’ **1985**

This model was not proven …

Aging phenomena depends on many highly correlated parameters:

Microscopic parameters:

- Cross-sections
- Electron or photon energies
- Electron, ion, radical densities
- …

Macroscopic parameters:

1985

CLASSICAL AGING:

- Gas mixture (nature of gas, trace contaminants)
- Gas flow & Pressure
- Geometry/material of electrodes & configuration of electric field

‘NEW AGING’ EFFECTS:

2000

- Construction materials
- Radiation intensity
- Gas gain, ionization density
- Size of irradiation area

There are simply too many variables in the problem →

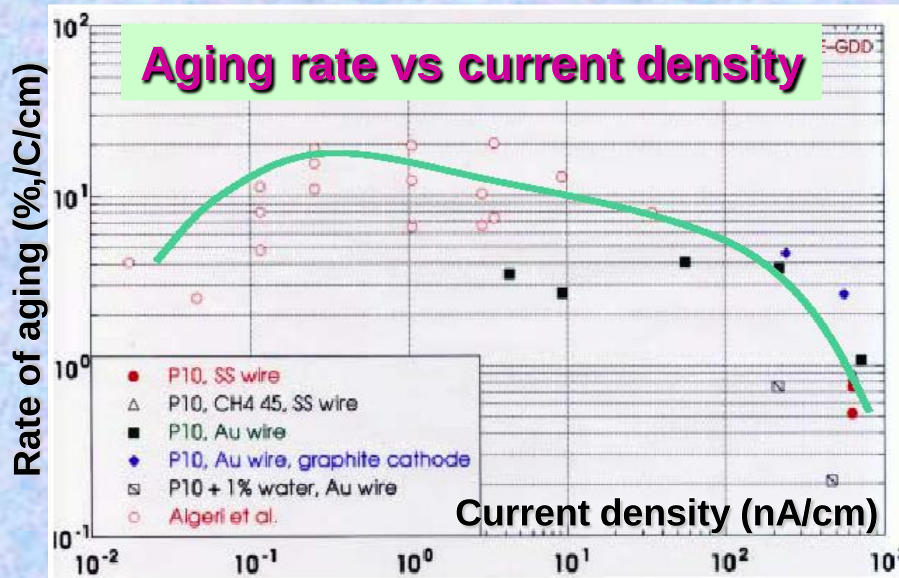
would be too naive to expect that one can express the aging rate using a single variable (C/cm)

1. Classical Aging Effects: Polymerization of hydrocarbons

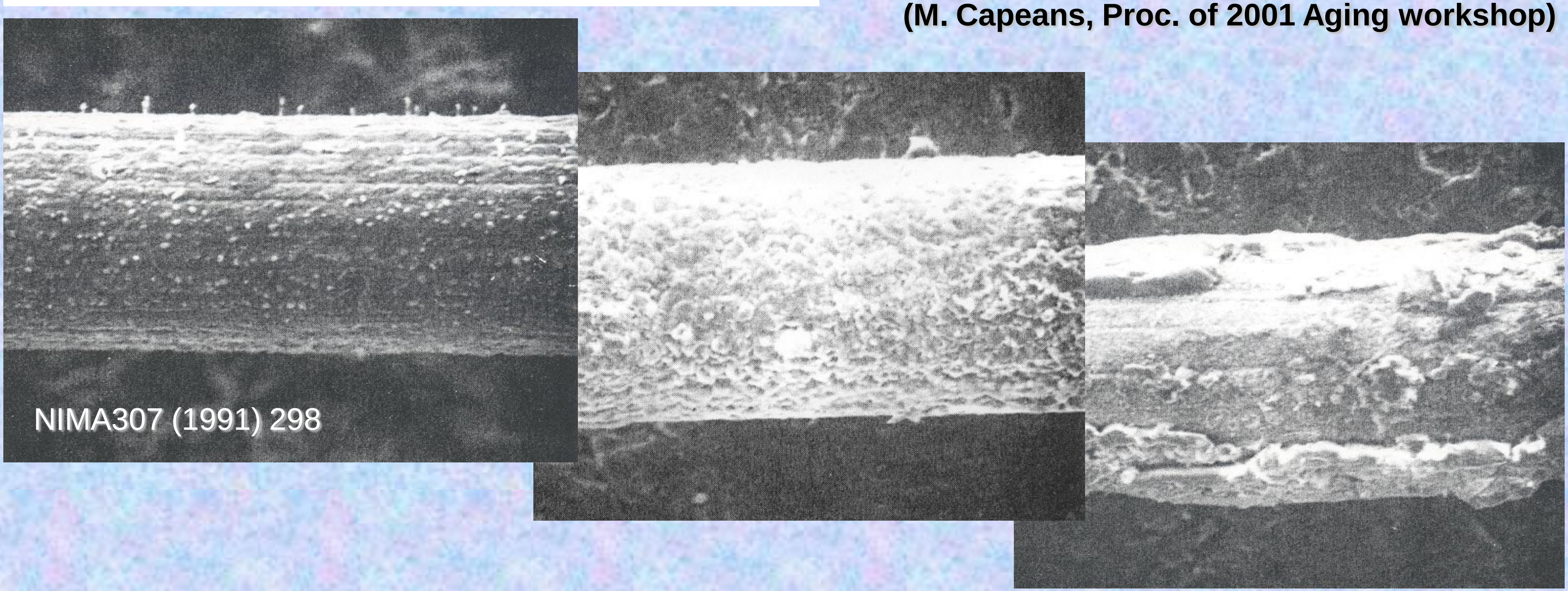
- **All hydrocarbons, including the simplest CH_4, polymerize.**

➢ **Mechanism of CH_4, C_2H_6,… polymerization is relatively well understood (hydrogen deficiency of radicals and their ability to form longer molecular chains)**

➢ **Pollutant molecules/trace contaminants may trigger and/or accelerate hydrocarbon polymerization**

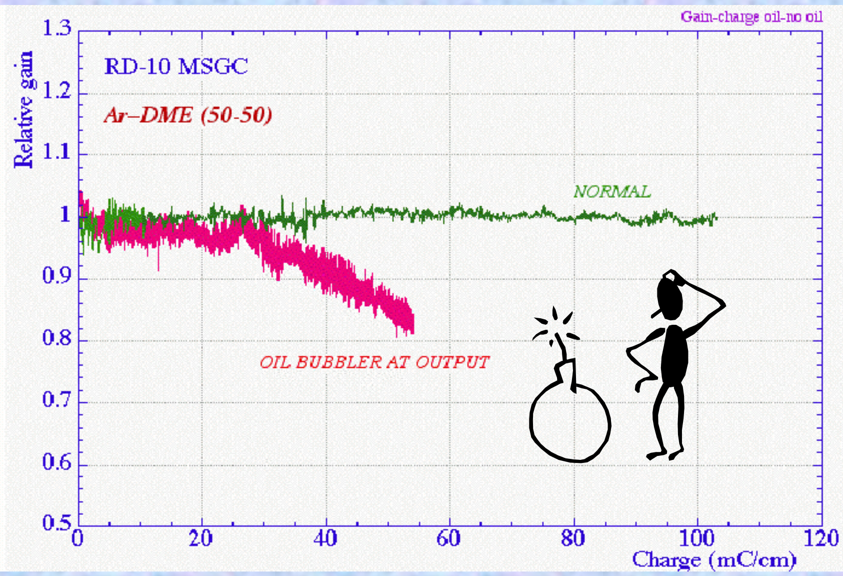


(M. Capeans, Proc. of 2001 Aging workshop)

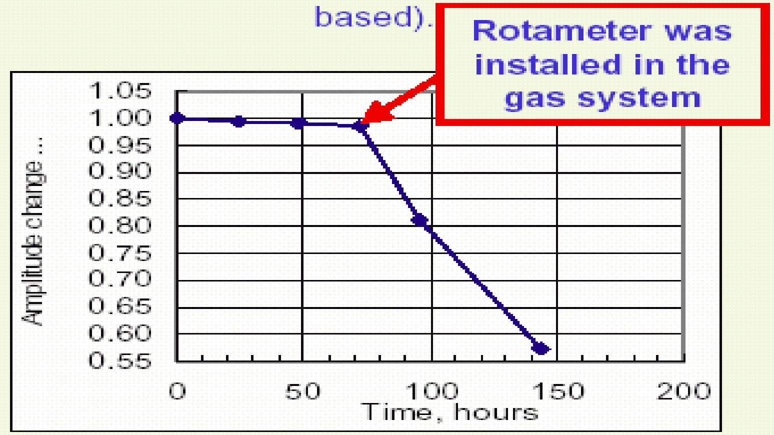


2. Classical Aging Effects: Silicon contamination

The silicon contamination is one of the most serious problem for gaseous detectors



Example: "Vogtlin" flow regulator (rotameter) specially produced by company and claimed to be free from any lubricants (particularly Si-based).



Examples of silicon-based pollutants:

- Silicon rubber sealants and adhesives
- Silicon potting and encapsulation compounds
- Silicon vacuum grease (O-rings, mould-release agents) and various oils
- Detergent residues (sodium metasilicate)
- Glass and related products
- Fine dust, polluted gas cylinders, diffusion
- pumps, standard flow regulators, molecular sieves

Si molecules should be avoided in the system at all cost:

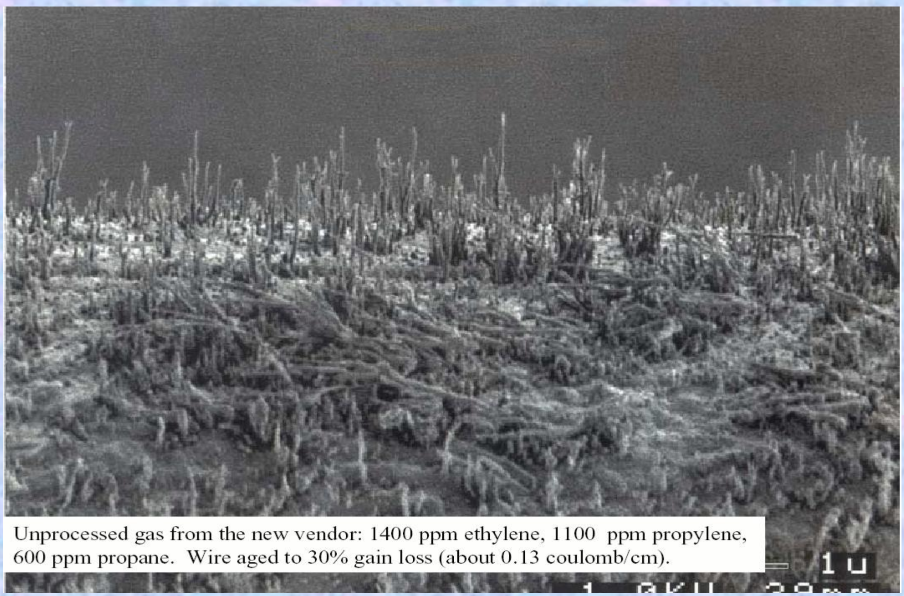
- If there is a question if some device may incorporate Si

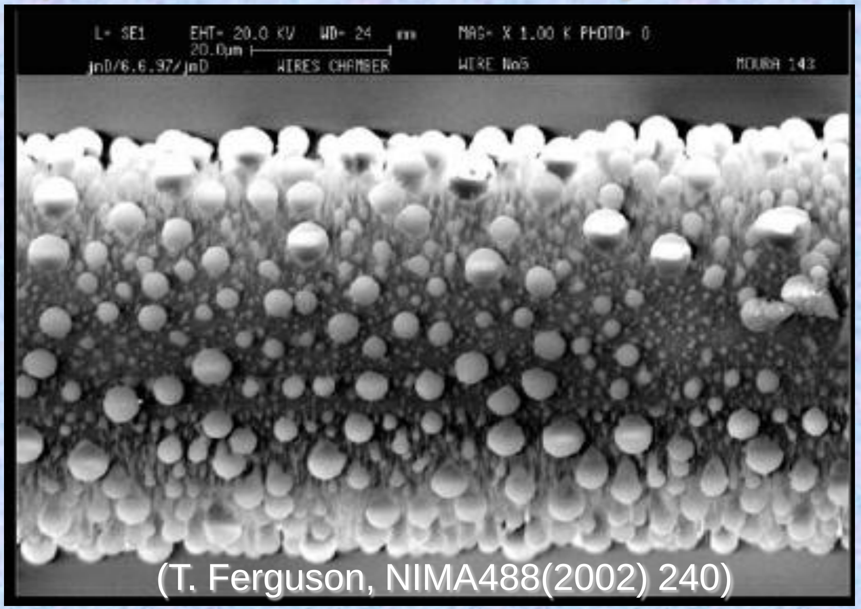
→ IT SHOULD BE SUBJECT TO ADDITIONAL ACCEPTANCE AGING TESTS

(J. Va'vra, NIMA252(1986)547; J. Kadyk NIMA300(1991) 436,
M. Capeans, A. Romaniouk, F. Sauli, Proc. of 2001 Aging Workshop)

2. Classical Aging Effects: Silicon contamination

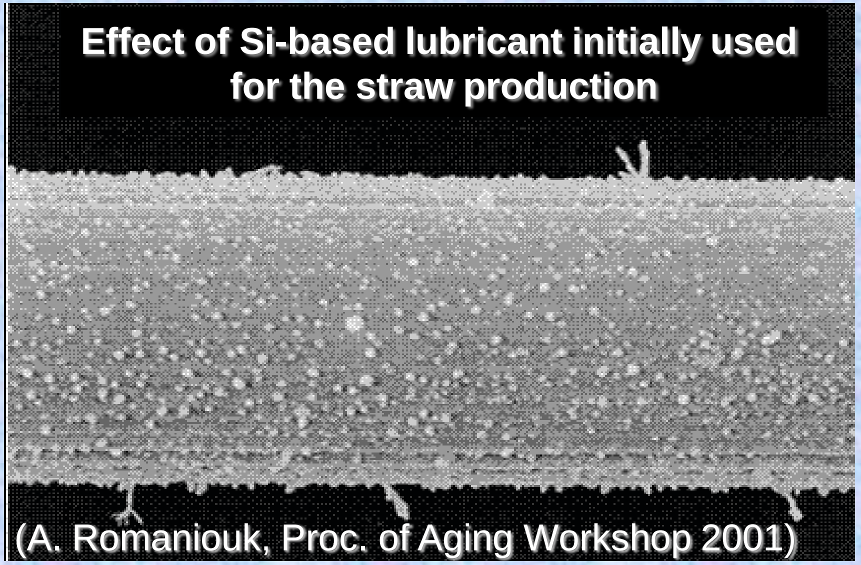
Silicon has been systematically detected in analysis of many wire deposits, although in many cases the source of Si-pollutant has not been clearly identified





(T. Ferguson, NIMA488(2002) 240)

(M. Binkley, Proc. of Aging Workshop 2001)



(A. Romaniouk, Proc. of Aging Workshop 2001)

3. Classical Aging Effects: Malter Effect

- **Malter effect is induced by insulating deposits on the cathode**

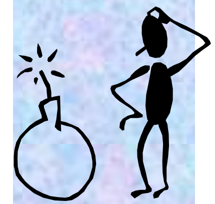
Ions are not neutralized at the cathode

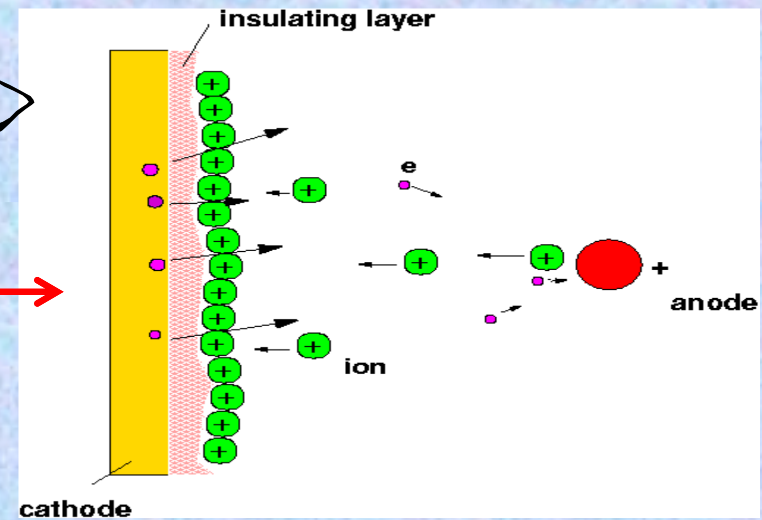
↓

Large electric field across the insulating layer

↓

Electrons are 'pulled out' from the cathode



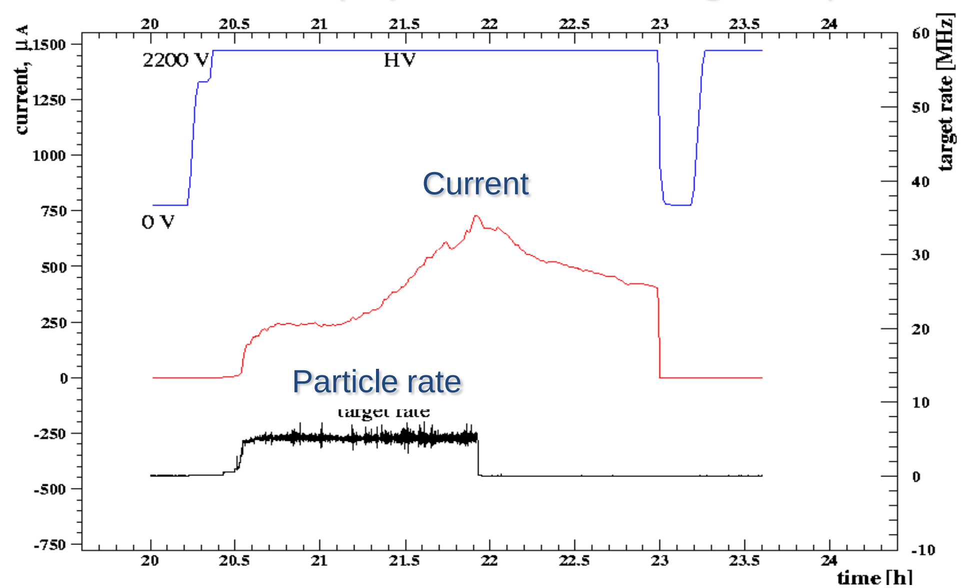


The RICH-GRID Detector
(First imaging of Malter effect):

sporadic bursts of single electrons from a localized cathode spot.

J. Va'vra – NIMA367(1995) 353

The microscopic non-conductive layer on the cathode will impede the ion flow (appearance of the dark current), in some cases it can lead to classical Malter effect (exponential current growth)



Factors which facilitate an ignition:

- **Poor cathode conductivity and/or microscopic dielectric insertions**
- **Highly ionizing particles, sparks, discharges**

Large area Gaseous Detectors: what has changed since 1980 ?

Radiation levels not even thought in '1980: (from mC/cm ⟶ many C/cm)

'Low & Standard radiation levels'
(LEP,HERA ep, BaBar,Belle,CDF,D0...)

- Basic rules for construction are known and tested
- Detectors are built and demonstrated to work
- Huge variety of gases are used
- If aging is nevertheless observed : add oxygen-containing additives (to suppress CH_4 polymerizaion/ and/or Malter effect) (and/or) having identified the source of pollution, try to clean the gas system

'High radiation levels'
(LHC, HERA-B,…)

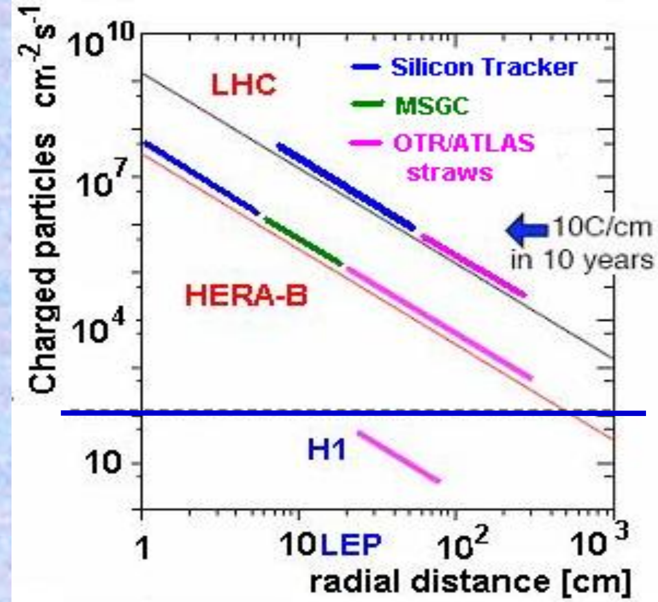
- Enormous R&D done (RD-10, RD-28, RD-6, HERA-B, ATLAS, CMS, LHC-b, ALICE, …)
- Some basic rules are found
- List of clearly 'bad' materials
- Only a few gases can be used at high rates
- New classes of gas detectors – straws, MSGC, MPGD, CsI, RPC with their own specific aging effects evolved

Aging Experience with High-rate Detectors of the LHC Era

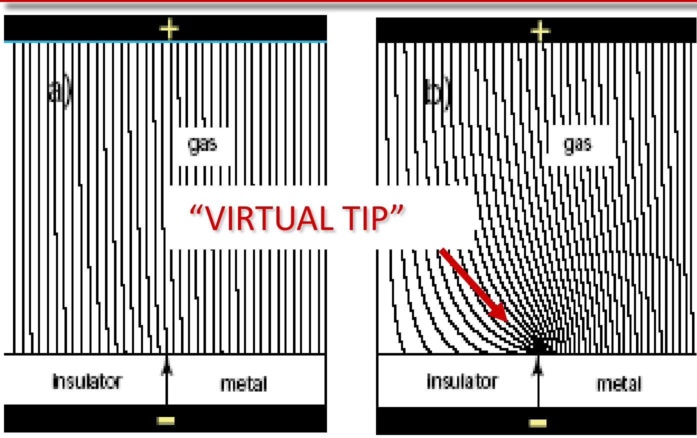
New Class of Gas Detectors (HERA-B, LHC, Micro-Strip Gas Chambers):

Radiation hardness is of a primary importance

- Use of NASA & RD28 experience to select materials
- Gas choices are extremely limited
- Outgassing is serious (normal & radiation-induced)
- Extraordinary ultra-clean system quality (assembly materials/procedures, quality checks)



AVOID "TRIPLE JUNCTIONS" at HIGH FIELDS:

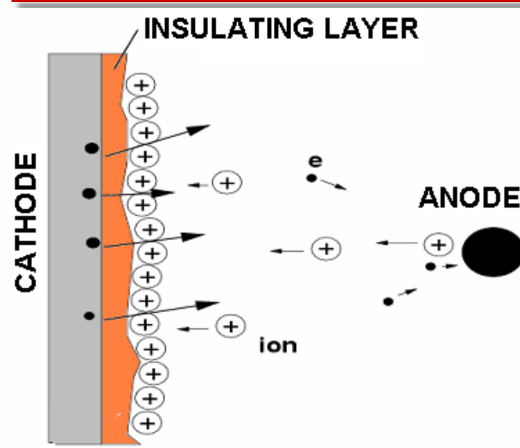


If conductivity of the gas becomes higher than insulator (under Irradiation)

ELECTRIC FIELDS ARE DETERMINED BY CAPACITIES AND CURRENTS

Proceedings of 2001 Aging Workshop, NIMA515

ADD INSULATORS WITH GREATEST CARE



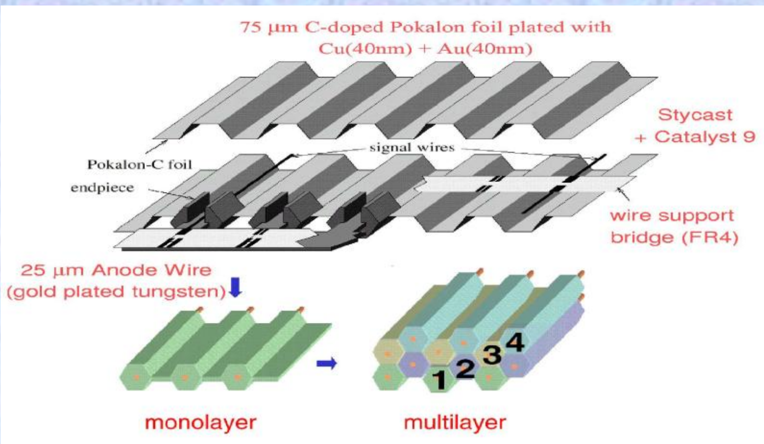
Maximum Rate Capability: (to prevent charge build-up):

$R_{max} \sim 1/(10RC) = 1/(10\ \varepsilon_r\ \varepsilon_0\ \rho_V)$

DETECTOR WHICH USE INSULATORS MAY FACE RADIATION-INDUCED INCREASE OF SURFACE RESISTIVITY

Aging Studies for the HERA-B Outer Tracker

Honeycomb Drift Chambers with carbon-loaded polycarbonate foil (Pokalon-C) used as a cathode:



AGING RATE DEPENDS:

- **PARTICLE TYPE**
- **PARTICLE ENERGY**
- **IRRADIATION AREA**

Facility Radiation Type	Radiation Density	Radiation Density	Irradiation area	Gas Mixture	Effect seen?
Zeuthen X-Ray Mo (35 keV)	5 C/cm	1.5 µA/cm	~1x3 cm^2	CF_4/CH_4	NO*
Dubna X-Ray Cu (8 keV)	6 C/cm	5 µA/cm	~0.5x1 cm^2	$Ar/CF_4/CO_2$	NO*
HMI Electron 2.5 MeV	10 mC/cm	0.1-3 µA/cm	~100x 30 cm^2	$Ar/CF_4/CH_4$	NO*
HD X-Ray Cu (8 keV)	~ mC/cm	~0.1 µA/cm	~46x 30 cm^2	$Ar/CF_4/CH_4$	NO*

Facility Radiation Type	Radiation Density	Radiation Density	Irradiation area	Gas Mixture	Effect seen?
Rossendorf Protons 13 MeV/c	5 mC/cm	0.3 µA/cm	~9x9 cm^2	$Ar/CF_4/CH_4$	NO
Rossendorf α-part, 28 MeV/c	3 mC/cm	0.6 µA/cm	~1x3 cm^2	$Ar/CF_4/CH_4$	NO
PSI p 70 MeV/c	~ mC/cm	0.2 µA/cm	~0.5x0.5 cm^2	$Ar/CF_4/CH_4$	NO YES*
PSI π/p 350 MeV/c	~ mC/cm	0.02 µA/cm	~12x22 cm^2	CF_4/CH_4	YES
Karlsruhe α-part, 100 MeV/c	~ mC/cm	0.02 µA/cm	~7x7 cm^2	$Ar/CF_4/CH_4$	YES
HERA-B P(920 GeV)-N	~ mC/cm	0.03 µA/cm	100x30 cm^2	All gas mixures	YES

X-rays or e$^-$ can not trigger Malter effect independently of their energy or radiation intensity

Hadrons above certain energy produce Malter effect at ~mC/cm as in HERA-B
(Irradiation area above certain limit is necessary for ignition of Malter effect)

Aging Studies for the HERA-B Outer Tracker

Initiated Intense R&D program:

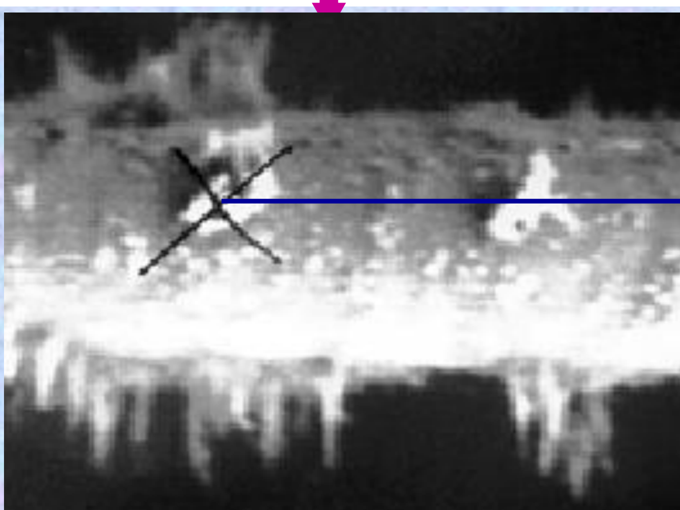
All building materials (glues, plastics, wires) and technique were tested and validated:
use only ‘allowed’ consruction materials and gases, carefully check the way detectors are built

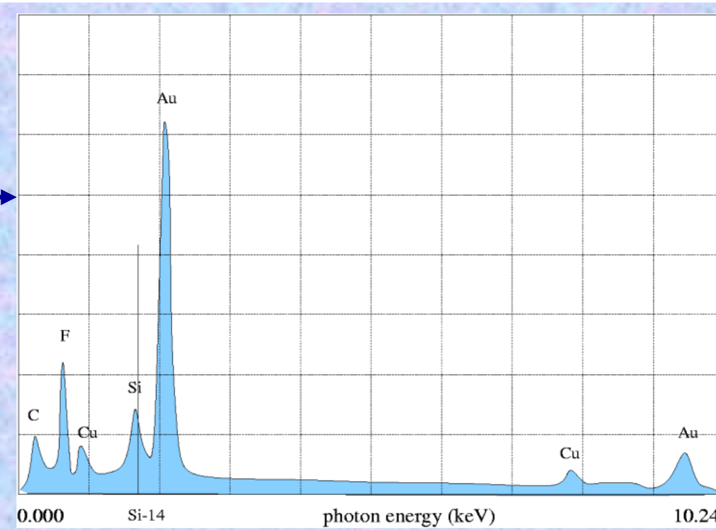
Chamber would not operate in HERA-B longer than 10 hours

- Indications that the pokalon-C is responsible for Malter effect and impede the ion flow at high rates
- Fast anode aging is due to $Ar/CF_4/CH_4$ (74:20:6)

Stable gain for more than 2 HERA-B years (~ 1C/cm)

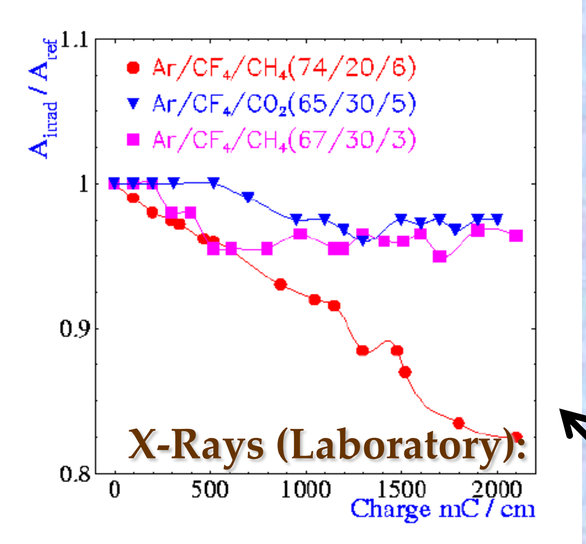
- Coat 1200 cathode foils with 40 nm Cu (good adhesion to plastics) + 40 nm Au (gas contact)
- Change to $Ar/CF_4/CO_2$(65:30:5)

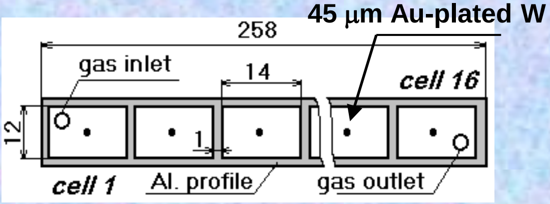


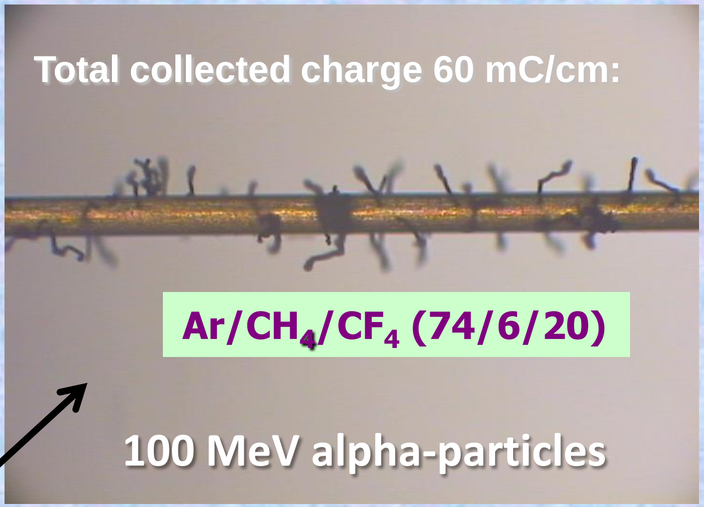


C. Padilla, Proc. of Aging Workshop 2001

Aging Studies for the HERA-B Muon Detector



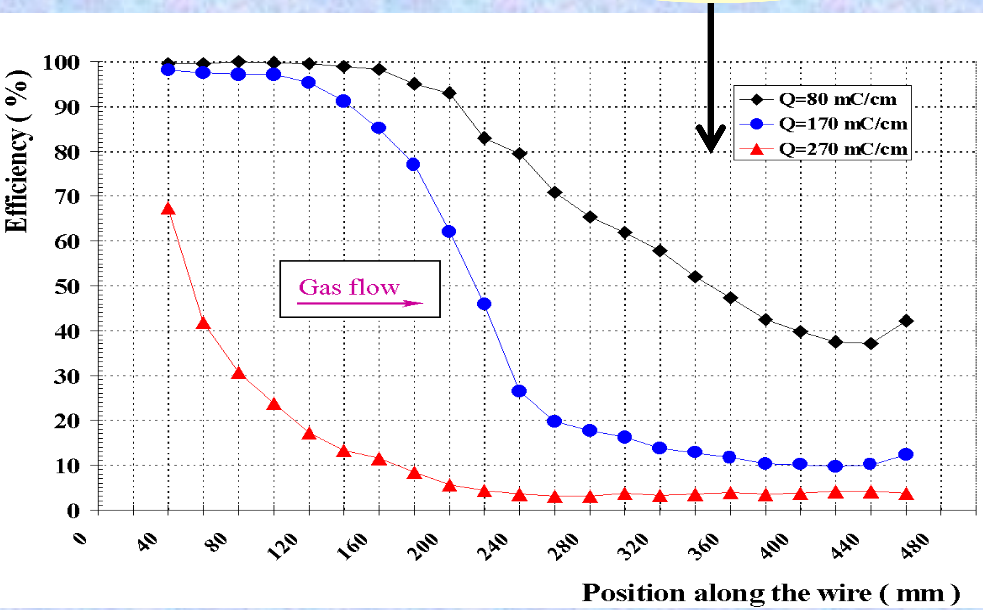


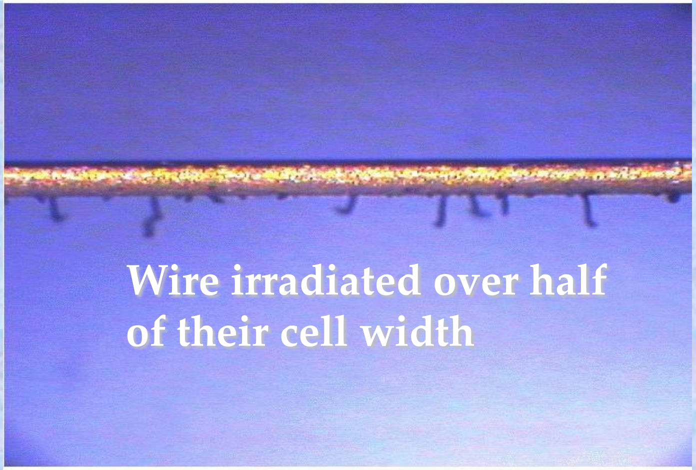


➢ PARTICLE TYPE

AGING RATE DEPENDS:

M. Titov et al.,
Proc. of Aging Workshop 2001

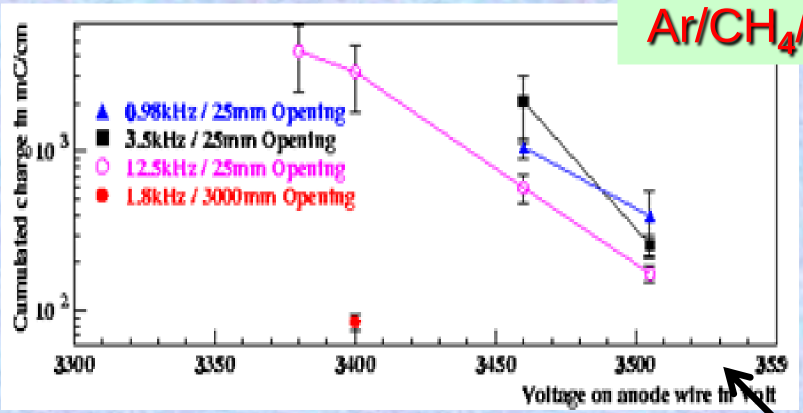


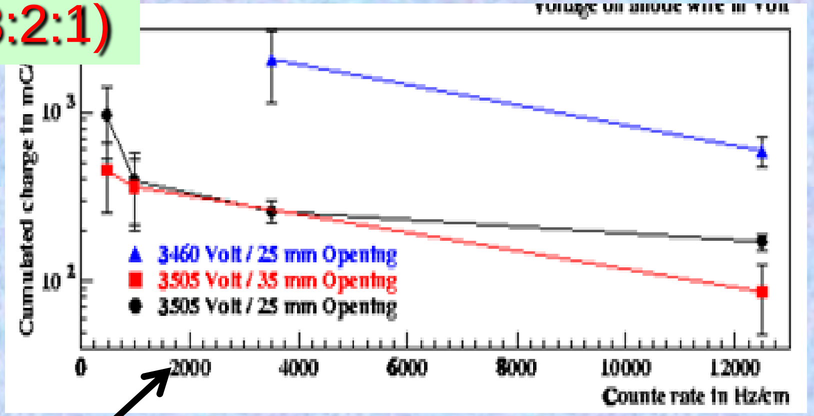


➢ IRRADIATION AREA
➢ HIGH VOLTAGE

Aging Studies for ATLAS Muon Drift Tubes (MDT)

$Ar/CH_4/N_2/CO_2$ (94:3:2:1)





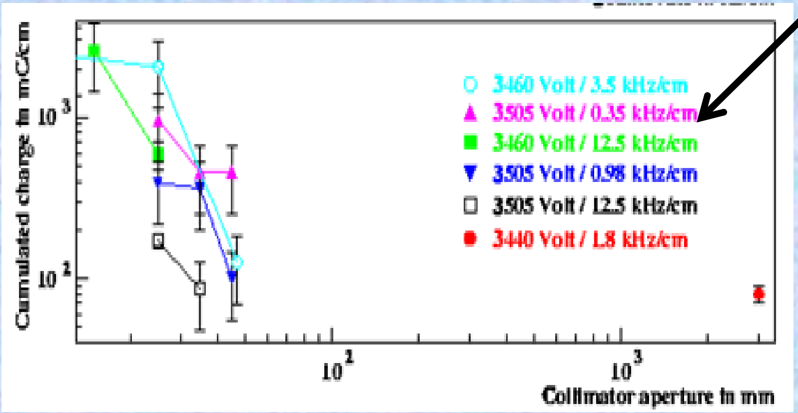
➢ HIGH VOLTAGE

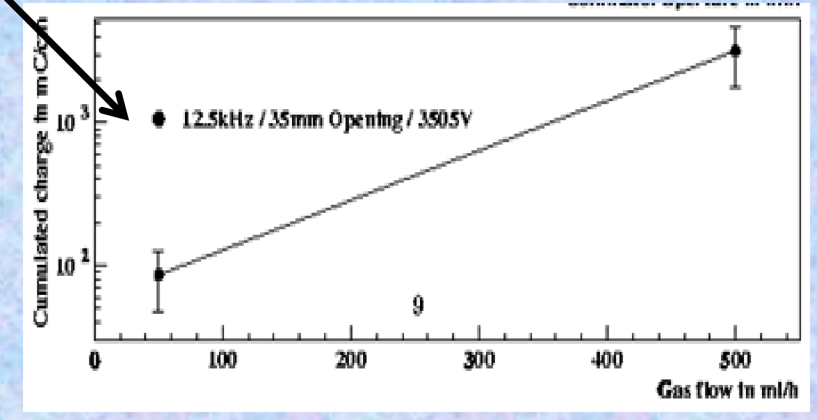
➢ IRRADIATION RATE

AGING RATE DEPENDS:

➢ GAS FLOW

➢ IRRADIATION AREA



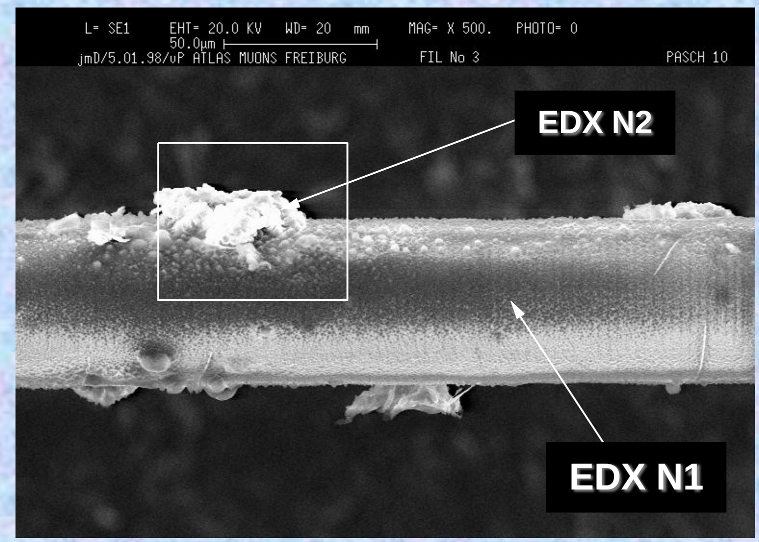


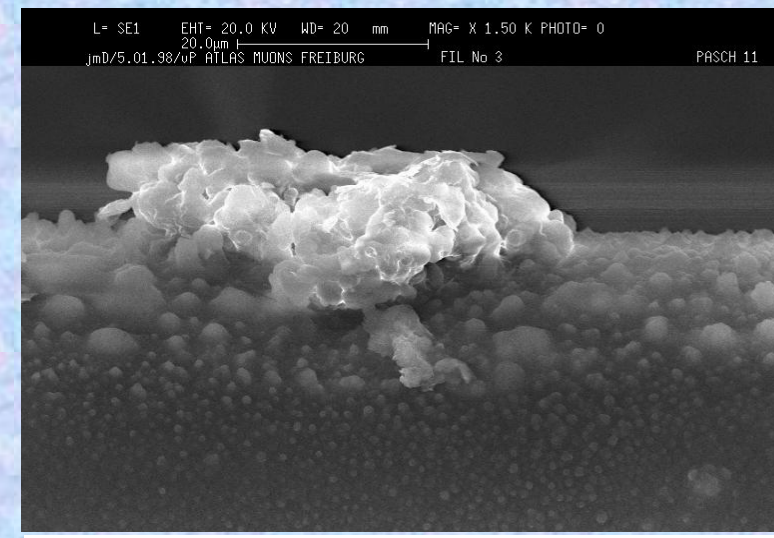
M. Kollefrath et al., ATLAS MUON-NO-012 (2001)

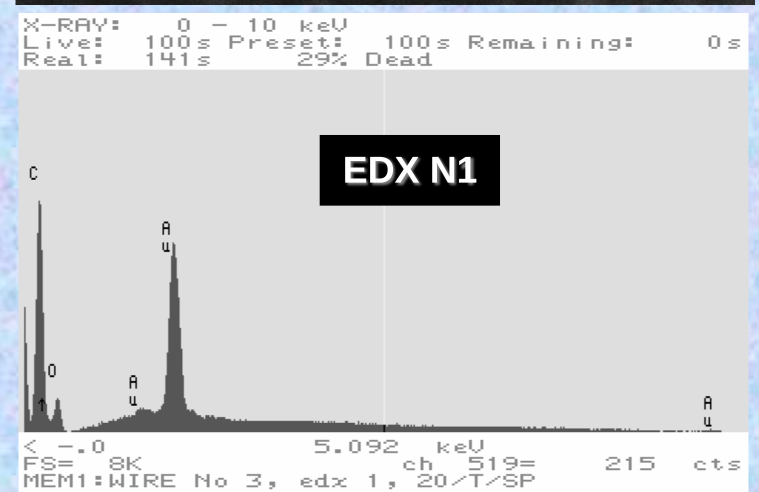
Aging Studies for ATLAS Muon Drift Tubes (MDT)

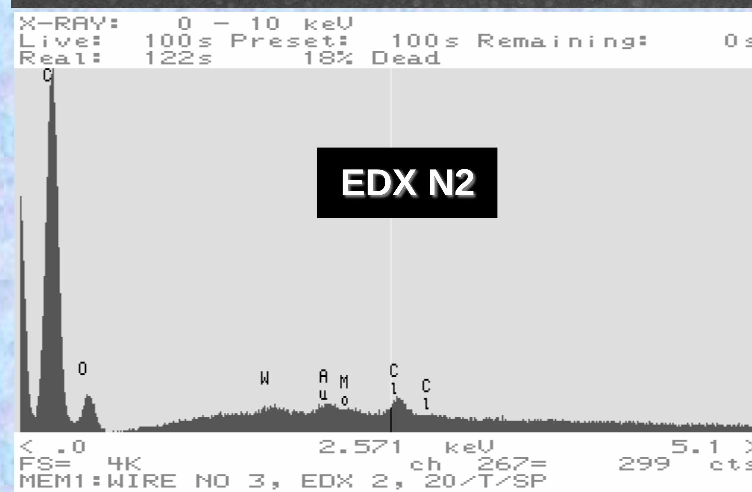
$Ar/CH_4/N_2/CO_2$ (94:3:2:1): Most likely polymerization of hydrocarbons

(no indication that impurity/contamination caused aging effects)







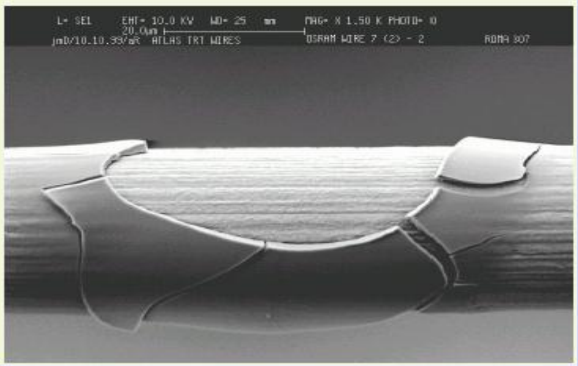


M. Kollefrath, Dissertation, Freiburg University (1999)

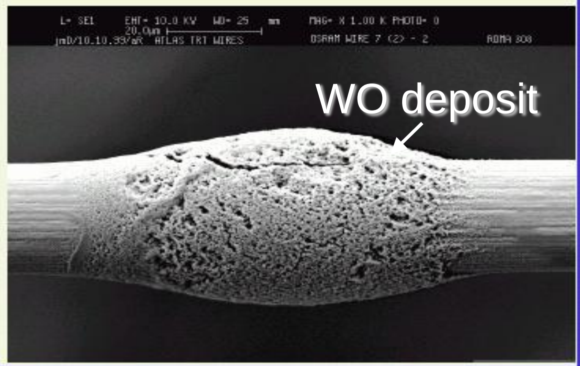
Damage of the gold-plating of wires in Xe/CF4/CO2 (70:20:10)

- **Main components responsible for anode wire damage (current densities ~5mA/cm) are reactive species produced in CF_4 avalanches (effect depends on type of wire)**
- Neither gold wire damage nor cathode surface degradation in ATLAS TRT straws were observed for H_2O concentrations below 0.1% in $Xe/CF_4/CO_2$ up to 20 C/cm

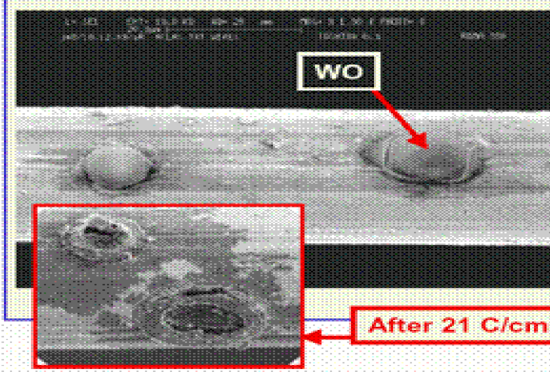
OSRAM wire, 3 % Au
Standard mixture +1.2% H_20 and 1.5%O_2
0.5 C/cm



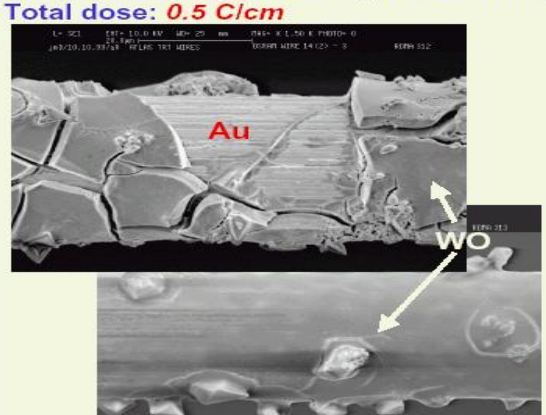
OSRAM wire, 3 % Au
Standard mixture +1.2% H_20 and 1.5%O_2
0.5 C/cm



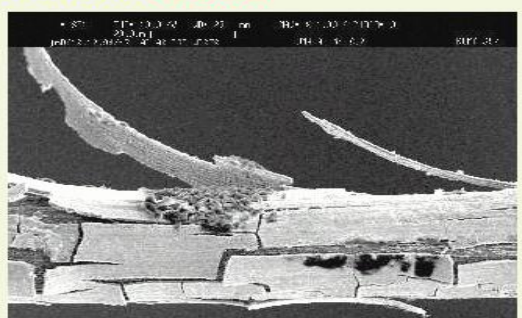
Toshiba wire, 7% Au,
Standard mixture +~0.4% H_2O (NO O_2),
5 C/cm



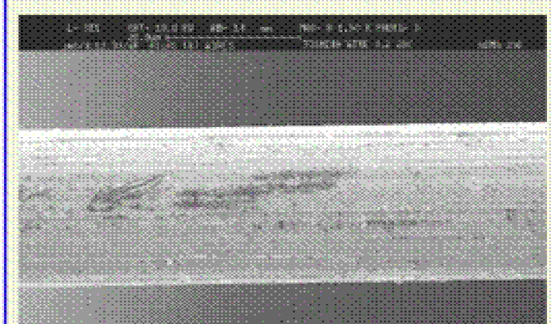
OSRAM wire, 3 % Au
Standard mixture +1.2% H_20 and 1.5%O_2
Total dose: *0.5 C/cm*



Luma wire, 5 % Au,
Ni-substrate
Standard mixture +1.2% H_20 and 1.5%O_2
Total dose: ~3 C/cm



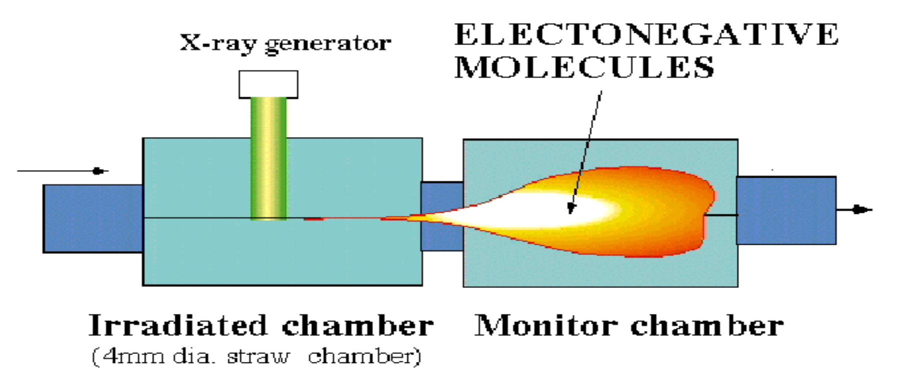
Toshiba wire, 7% Au,
Standard mixture + <0.1% H_2O (NO O_2),
20 C/cm



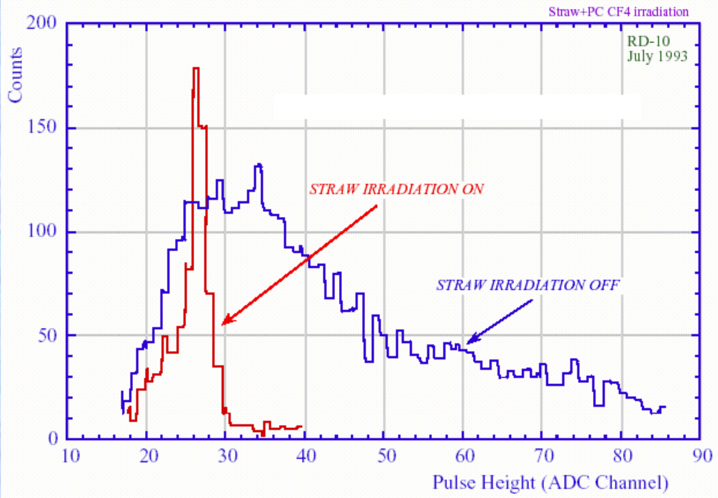
A. Romaniouk, Proc. of Aging Workshop 2001

Electronegative radical production in CF4-based mixtures

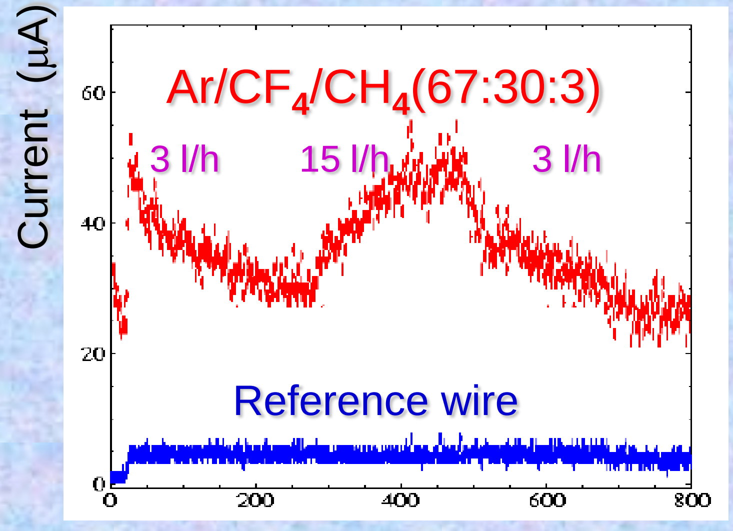
Evidence of long-lived and highly electronegative radical production in the `monitor chamber' downstream the strongly irradiated straw in $Xe/CF_4/CO_2$ (50:30:20):

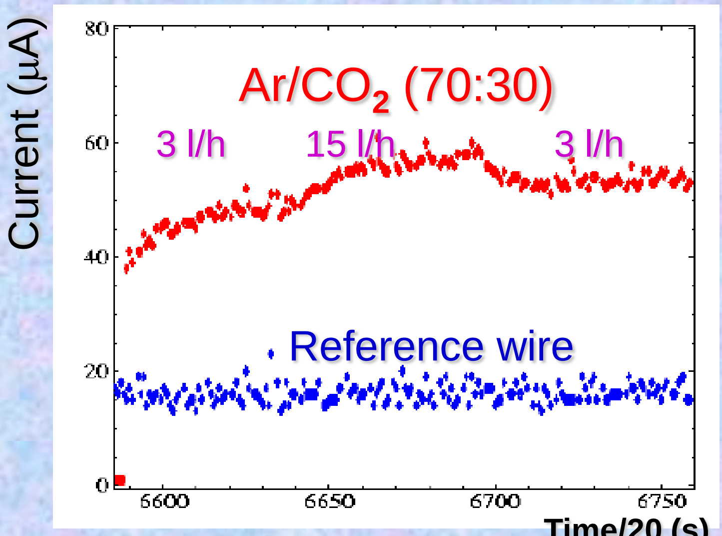


(M.Capeans et al., NIMA337 (1993)122, V.Bondarenko et al., Nucl.Phys.B 44(1995)577)



Gas flow dependence of the current for the 'partially' aged wires in $Ar/CF_4/CH_4$ (67:30:3):





A few intermediate remarks on aging phenomena:

Description of aging rate by a single parameter: R=-1/G(dG/dQ) is not adequate

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

Clear evidence for aging dependence on:

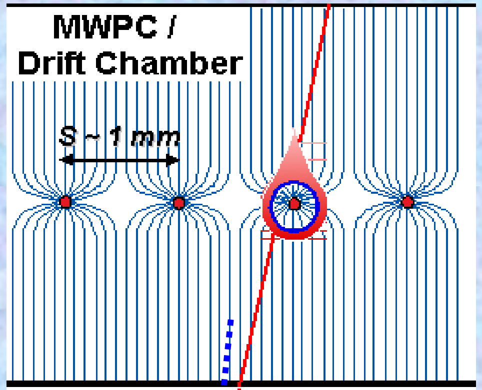
- size of irradiated area → aging as non-local phenomena
- irradiation rate
- ionization density
- high voltage (gas gain)
- particle type and energy
- gas exchange rate

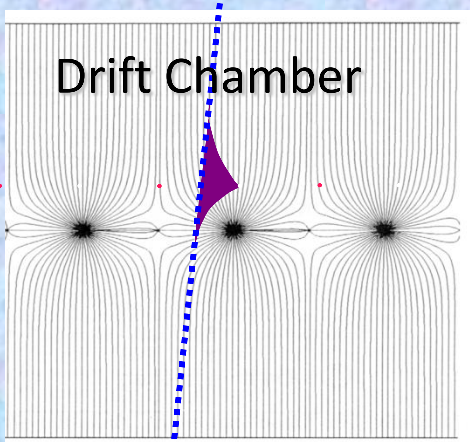
(irradiation rate, ionization density, high voltage) → Effect of microdischarges & Malter currents: increase in polymer production rate or production of new reactive species

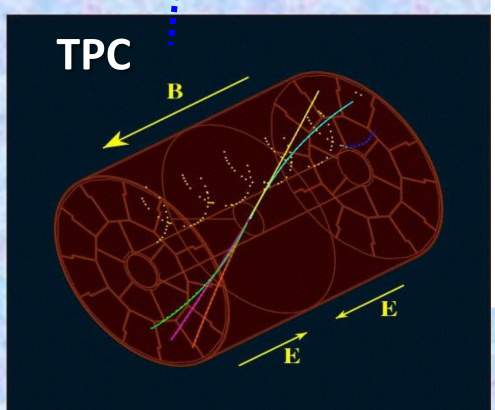
- The aging performance can not be predicted only based on the gas mixture composition (it can work at low intensities and fail at the high-rates)

- The counting gas under self-sustained discharge is much better conductor than many insulators

Advanced Concepts: Detectors @ High Luminosity



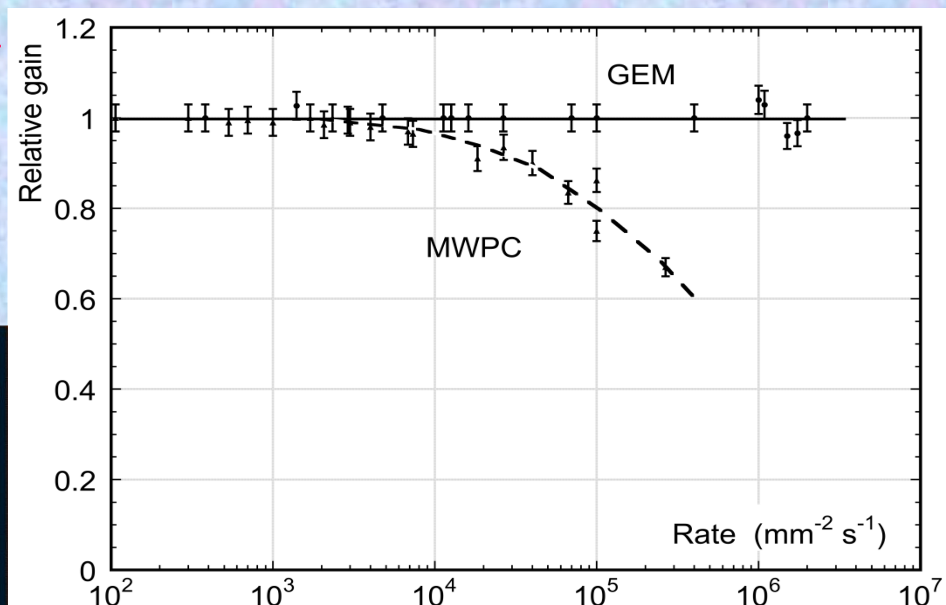




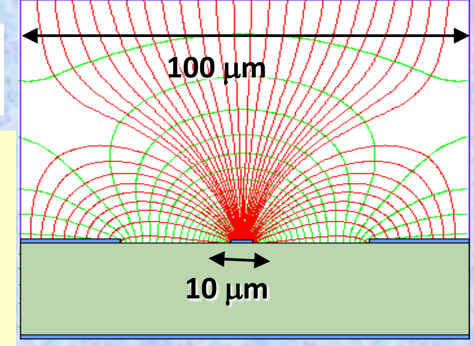
Higher Rate, enormous occupancy:
1D easily saturated → 2D → 3D

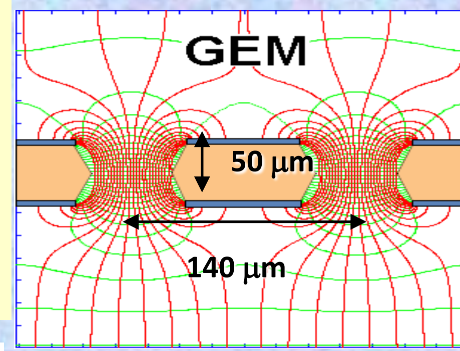
➢ **Silicon detectors:**
Strips →Pixels (2D)→ 3D-Si det.
& 3D electronics integration

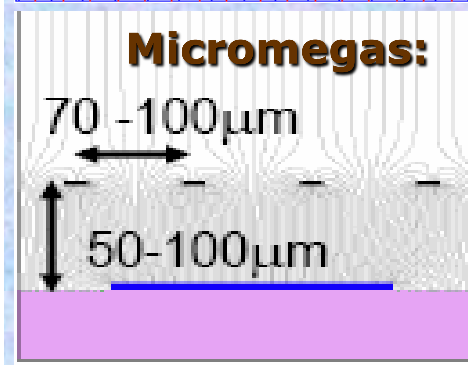
➢ **Gaseous detectors**
Wire Chamber → Wireless MPGD (2D)
→ InGrid/Timepix (3D)

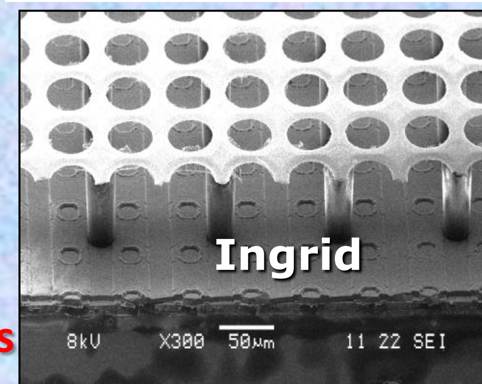


Advances in Micro-electronics & Etching Technology → Micro pattern Gaseous Detectors



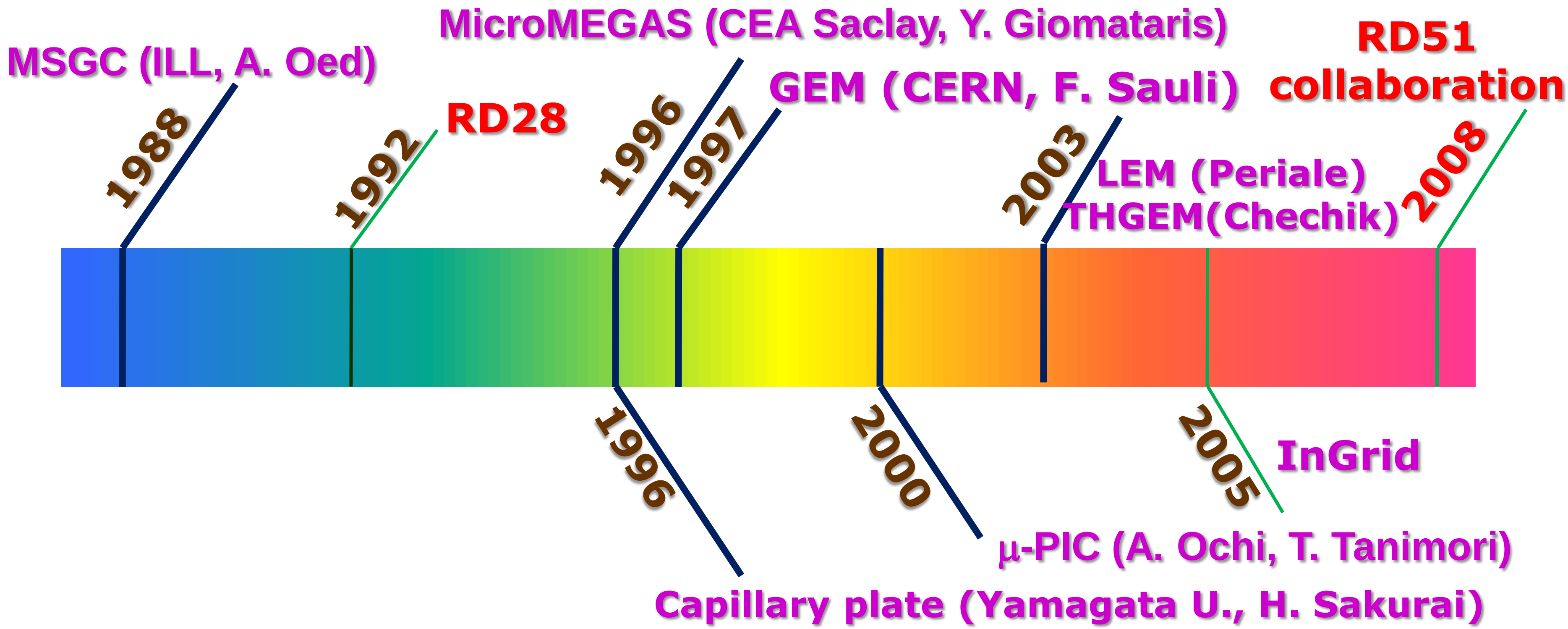






MPGD Developments: Historical Roadmap*

(*Many more micro-pattern structures were developed; only widely spread technologies are shown)



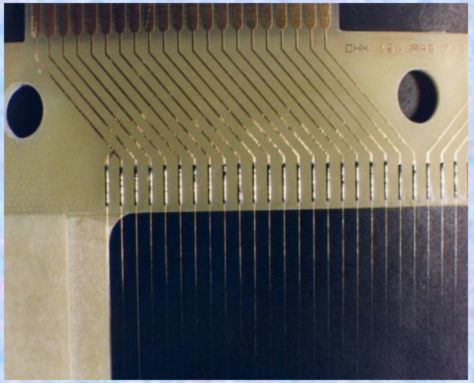
From A.Ochi ADA2012@Kolkata (updated)

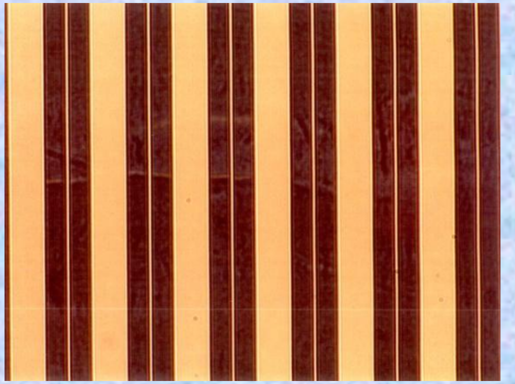
- ❖ What do we know about aging effects in wireless-type detectors ?
- ❖ What is the radiation hardness of the Micro-Pattern Gaseous Detectors ?

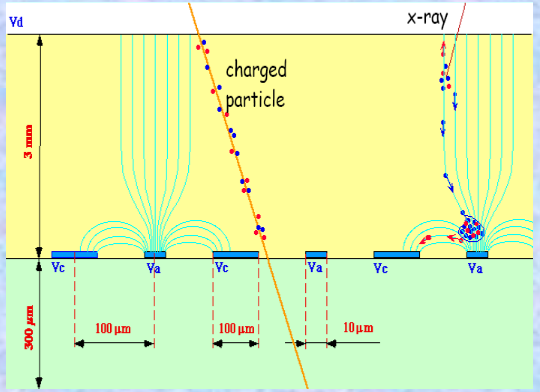
Micro-Strip Gas Chamber (MSGC)

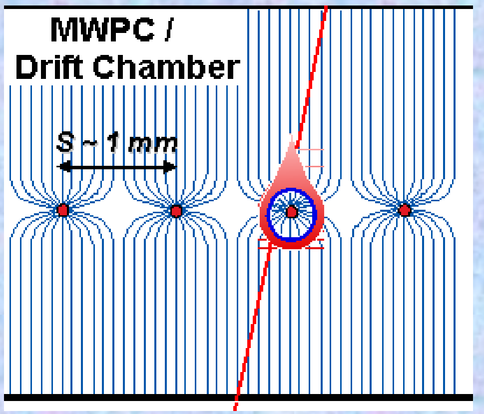
MWPC

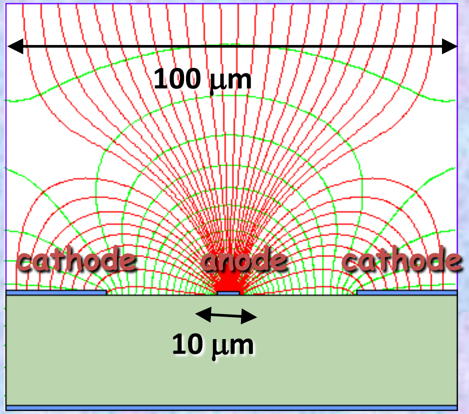
MSGC



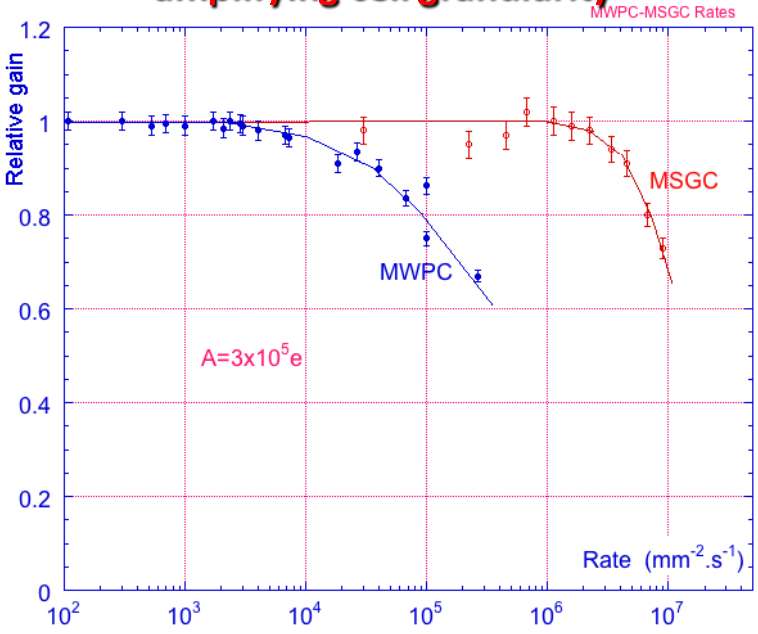








Rate capability limit due to space charge overcome by increased amplifying cell granularity



Typical distance between wires limited to 1 mm due to mechanical and electrostatic forces

Typical distance between anodes 200 µm thanks to semiconductor etching technology

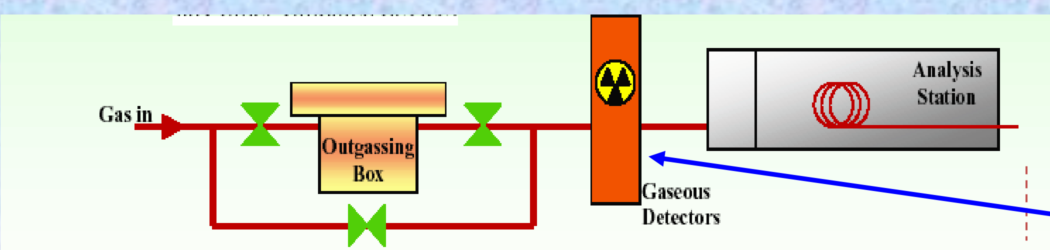
A. Oed, Nucl. Instr. and Meth. A263 (1988) 351.

Micro-Strip Gas Chambers: Findings and Solutions (I)

MSGC has entered a new dimension of sensitivity compared to MWPC due to the filigree nature of the MSGC structure and catalytic effects on the MSGC substrate

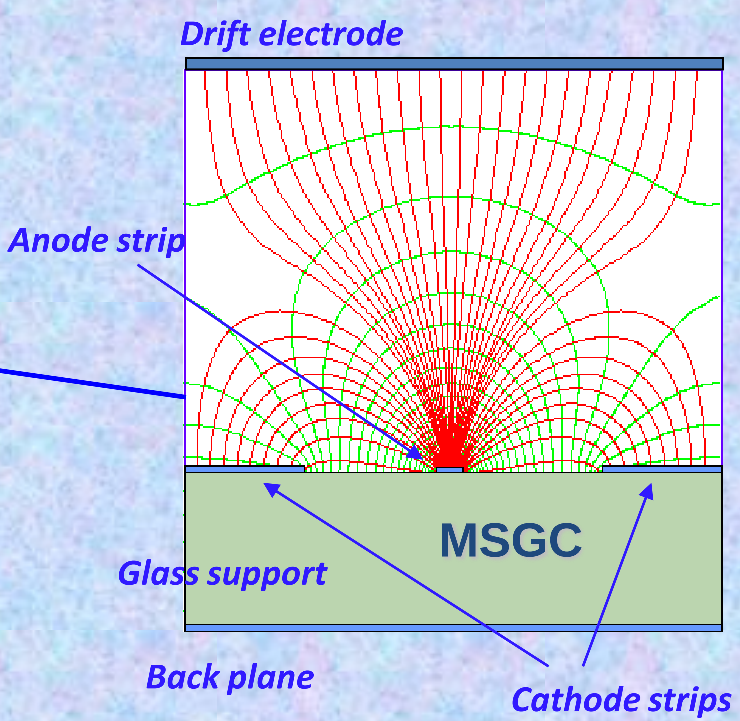
The lifetime studies of Micro-Strip Gas Chambers (MSGC) in high intensity environments, which had also the greatest impact on the understanding of aging phenomena in all the types of gaseous detectors, demonstrate that the amount of pollutants in the gas system plays a major role in determining the aging properties of the detector; outgassing from materials, epoxies, joints, tubing has to be carefully controlled and kept at ppm level or better

RD28: aging results from MSGC community

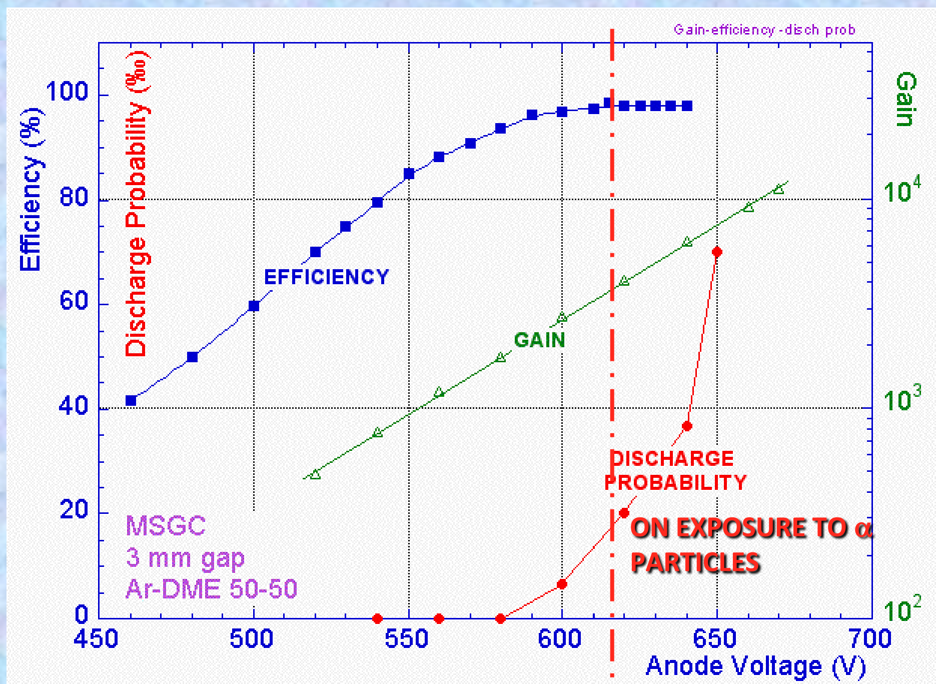


(R. Bouclier et al., NIMA381(1996) 289,
M. Capeans, ICFA Instrum. Bull.24(2002)85-109)

(NASA DATABASE - Outgassing Data for selecting Spacecraft Materials
http://epims.gsfc.nasa.gov/og/index.cgi)



Micro-Strip Gas Chambers: Findings and Solutions (II)

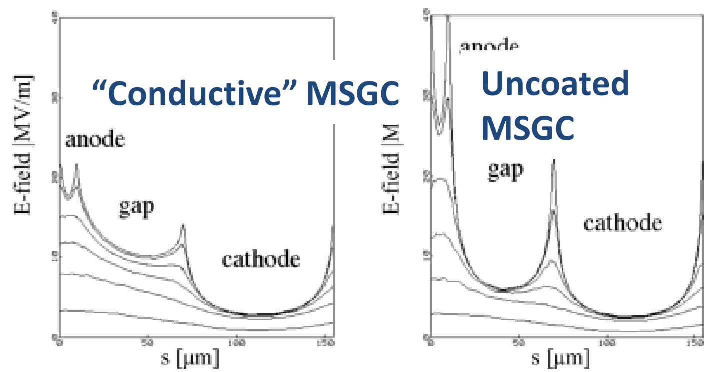


A. Bressan et al, NIMA A424 (1999) 321.

Major processes leading at high rates to MSGC operating instabilities:

- **Substrate charging-up and time-dependent modification of the E field**

→ slightly conductive support



- **Deposition of polymers (aging)**

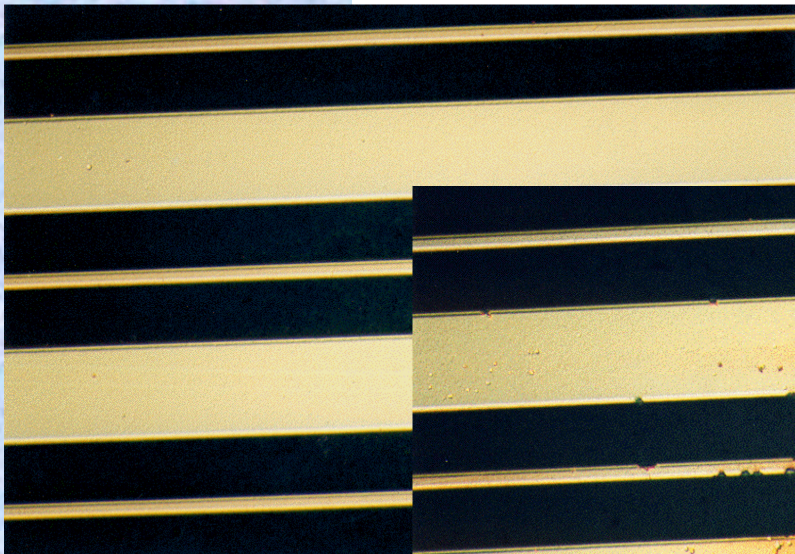
→ validation of gases, materials, gas systems

- **Discharges under exposure to highly ionizing particles**

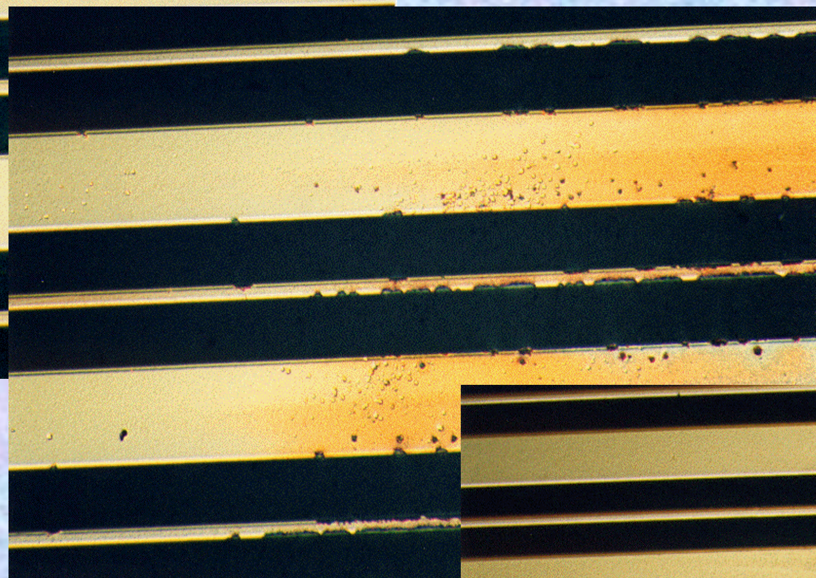
→ multistage amplification, resistive anodes

Induced discharges are intrinsic property of all single stage micropattern detectors in hadronic beams (MSGC turned out to be prone to irreversible damages)

MSGC Discharge Problems



Discharge is very fast (~ns)
Difficult to predict or prevent



MICRODISCHARGES

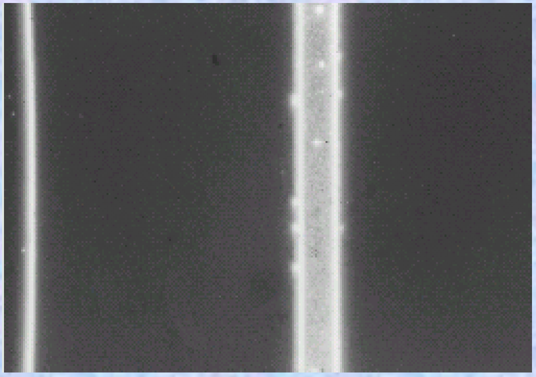
FULL BREAKDOWN

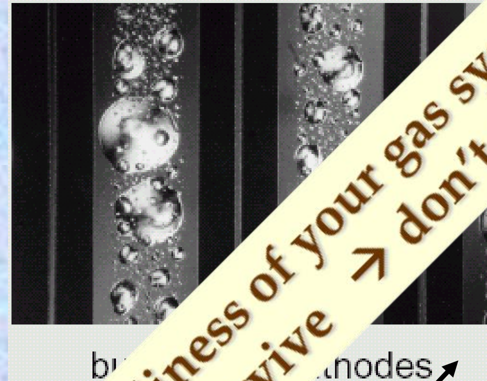
Owing to very small distance between anode and cathode the transition from proportional mode to streamer can be followed by spark, discharge, if the avalanche size exceeds
RAETHER'S LIMIT
Q ~ 10^7 – 10^8 electrons

F. Sauli, http://www.cern.ch/GDD

Micro-Strip Gas Chambers: Findings and Solutions (III)

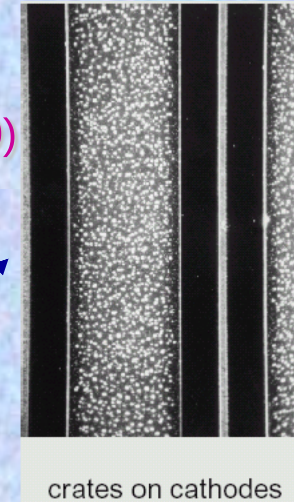
Increased stability but severe anode aging in Ar/CO_2 & Ar/DME (0.3% H_2O)





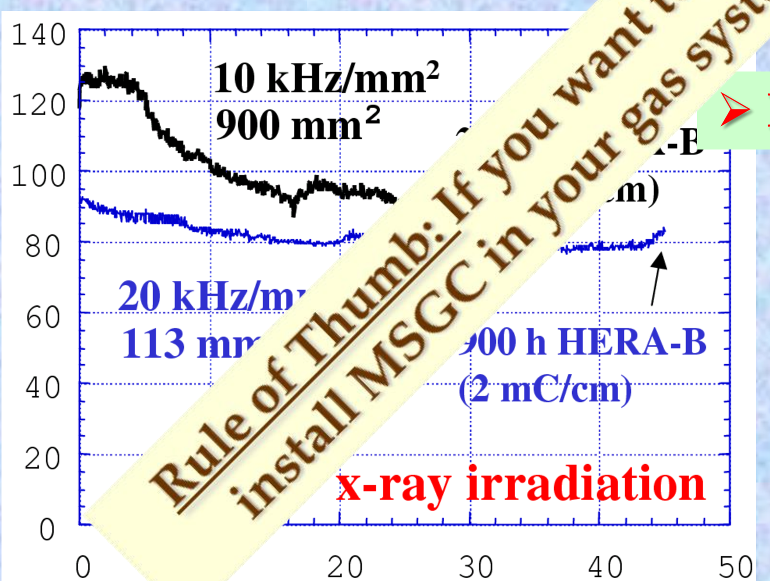
CO_2 (70:30)
2.7 mC/cm

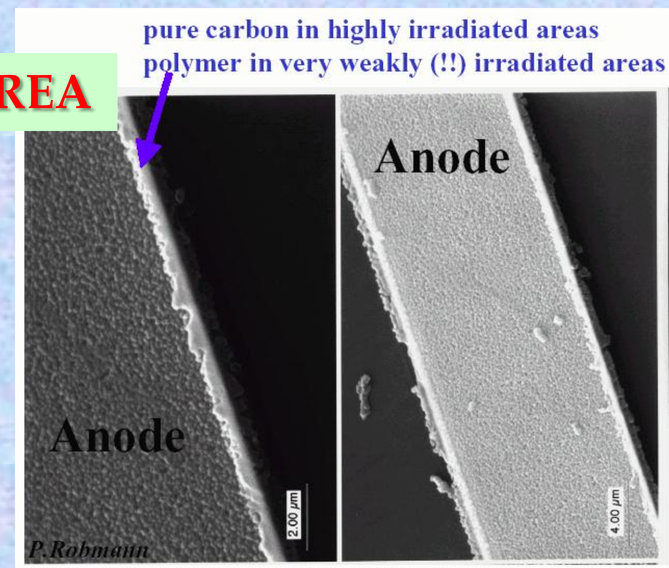
Ar/DME(50:50)
+ 0.3% H_2O
0.8 mC/cm



RATE
ENDS:

- WATER CONTENT
- STRIP MATERIAL
- IRRADIATION AREA





Rule of Thumb: If you want to test the cleanliness of your gas system: install MSGC in your gas system, if it will survive → don't worry

Choice of Materials for High-Rate Detectors of the LHC Era

Outgassing Tests of Some Materials

- Epoxy Compounds
- Adhesive Tapes
- Leak Sealers
- Rigid materials
- Contamination:
  - User-generated
  - Silicone

Outgassing of Epoxy Compounds

- Material itself
- User-generated
  - Pollution
  - Incorrect ratio of hardener to resin
  - Insufficient curing time & temperature

Low Outgassing Epoxy Compounds (Room T-curing)

Source	Product	Outgas	Effect in G.D.	Note
CERN/GDD	STYCAST 1266 (A+B)	NO	NO	Long curing time
HERA-B/OTR	STYCAST 1266 (A+Catalyst 9)	NO	NO	In Use
CERN/GDD	HEXCEL EPO 93L	NO	NO	Out of production
HERA-B/ITR	ECCOBOND 285	NO	NO	In Use
CERN/GDD ATLAS/TRT	ARALDITE AW103 (Hardener HY 991)	NO	NO	In Use
ATLAS/TRT	TRABOND 2115	NO	NO	In Use

'Rejectable Epoxy Compounds' (Room T-curing)

Source	Product	Outgas	Effect in G.D.	Result
CERN/GDD ATLAS/TRT	ARALDITE AW 106 (Hardener HV 935 U)	YES		BAD
CERN/GDD	DURALCO 4525	YES	YES	BAD
CERN/GDD	DURALCO 4461	YES	YES	BAD
CERN/GDD	HEXCEL A40	YES	-	BAD
CERN/GDD	TECHNICOLL 8862 + (Hardener 8263)	YES	-	BAD
CERN/GDD	NORLAND NEA 155	YES	-	BAD
CERN/GDD	EPOTEK E905	YES	-	BAD
CERN/GDD	NORLAND NEA 123 (UV)	YES	-	BAD

(M. Capeans - Aging Workshop 2001, DESY)

Choice of Materials for High-Rate Detectors of the LHC Era

Full evidence of suitability (long-term MSGC aging test) ←

Epoxy Compounds Curing at T > 50 C

(in order to increase the sensitivity of the system, samples warmed up)

Source	Product	Curing T (ºC)	Outgas	Effect in G.D.	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

Conductive epoxy Compounds

Source	Name	Outgas	Effect in G.D.	Result
CERN/GDD	TRADUCT 2922	NO		OK
HERA-B/OTR	SILBER LEITKLEBER 3025 (A+B)	NO	NO	OK
ATLAS/TRT	TRABOND 2902	NO	NO	OK

Adhesive Tapes

Source	Name	Outgas	Effect in G.D.	Result
HERA-B/OTR	SCOTCH 467 MP	YES	-	BAD
HERA-B/OTR	TESAFIX 4388	YES	-	BAD

(M. Capeans - Aging Workshop 2001, DESY)

Choice of Materials for High-Rate Detectors of the LHC Era

Outgassing Tests of Leak Sealers

Source	Material	Type	Outgas	Effect in G.D	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

Rigid Materials

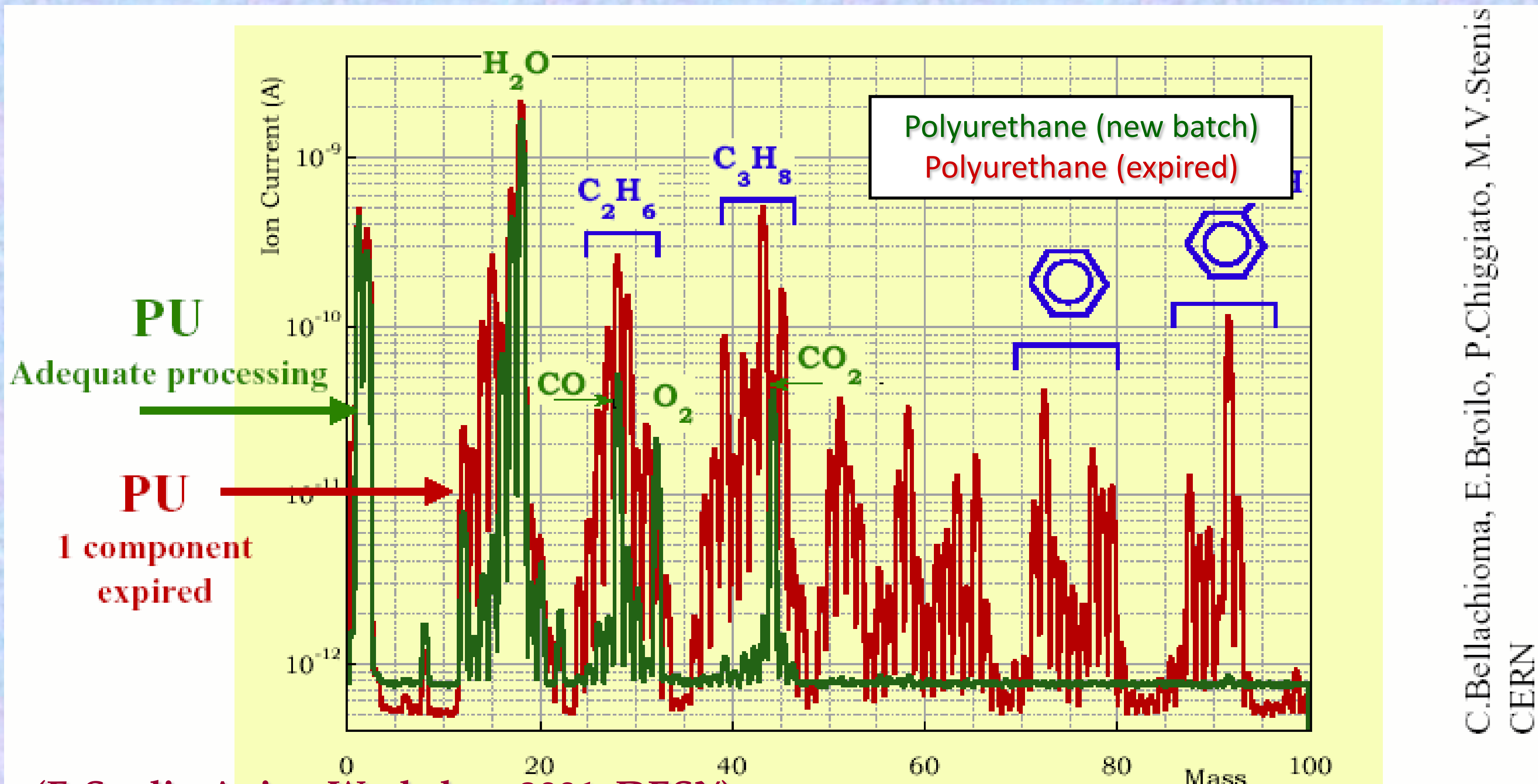
Full evidence of suitability (long-term MSGC aging test) ←

Source	Name	Type	Outgas	Effect in G.D.	Result
CERN/GDD	STESALIT 4411W	Fiberglass	YES	NO	OK
CERN/GDD	VECTRA 150	Liquid Crystal Polymer	YES	NO	OK
CERN/GDD	PEEK Crystalline	Polyeteherether ketone	NO	NO	OK
ATLAS/TRT	ULTEM	Polyetherimide	NO	-	OK
ATLAS/TRT	C-Fiber	C-fiber	NO	-	OK
ATLAS/TRT	POLYCARBONATE	C-fiber	NO	-	OK
HERA-B/ITR	FIBROLUX G10	Fiberglass	YES	-	BAD
HERA-B/ITR	HGW 2372 EP-GF	Fiberglass	YES	YES	BAD
CERN/GDD	RYTON	Polysulphur phenylene	YES	YES	BAD
CERN/GDD	PEEK Amorphous	Polyetherether ketone	YES	-	BAD

(M. Capeans - Aging Workshop 2001, DESY)

User-generated Outgassing

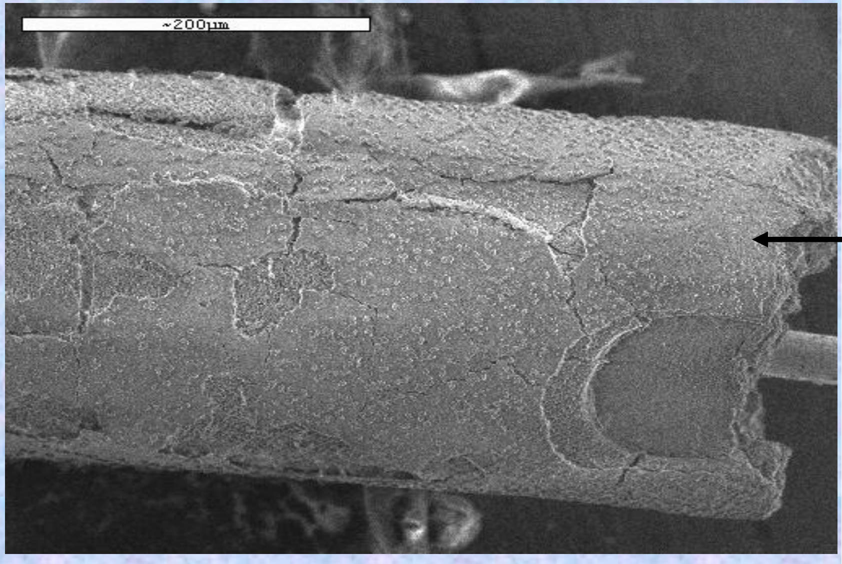
NEW vs EXPIRED: NUVOVERN LW -HARDNER PUR LW (Mader Lucke AG)



(F. Sauli - Aging Workshop 2001, DESY)

Aging effects in prototype LHCb straw tubes → "too low temperature" during glue curing → non-polymerized glue → significantly increased outgassing rate → gain reduction and wire deposits

Choice of materials: etching of glass wires joints in Xe(Ar)/CF4/CO2 (70:20:10)

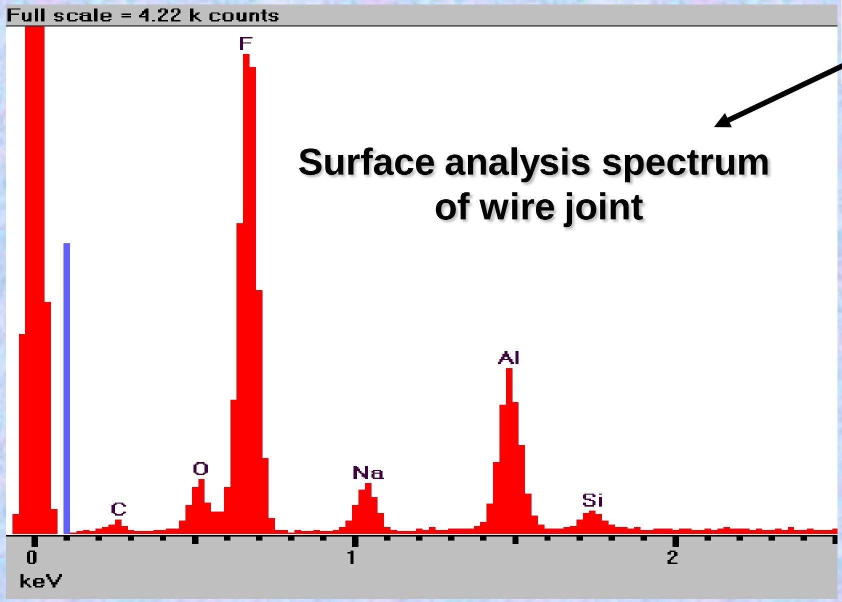


The ATLAS TRT glass wire joint separates electrically the barrel wire into two parts

- **Much of the glass has been etched away and wire joints showed heavy cracks after irradiation in Xe(Ar)/CF_4/CO_2 at high dose rates**

- No gain change due to Si etching from the glass wire joints (it seems that etched Si is in stable gas form and exits the system)

- **Surface analysis of wire joints showed fluorine deposits while much of Si has disappeared**



Baseline gas for the ATLAS TRT operation:

$Xe/CO_2/O_2$ (70:27:3)

(no indication of wire joint damage)

+

Run for short periods with CF4-cleaning gas:

$Ar/CF_4/CO_2$ (70:3:27)

(Si-deposits on sense wires are of major concern)

M. Capeans, ATLAS week, June(2002) and will be presented at 2003 IEEE NSS/MIC; DUKHEP Note 08-02-02

Choice of Materials for High-Rate Detectors of the LHC Era

Plastic pipes: PTFE, NYLON,PVC, PU — high gas permeability, possible outgassing, cheap
Metal pipes: copper, stainless stell — 0 gas permeability, 0 outgassing, expensive

Outgassing Tests of Plastic Pipes

GDD Group
CERN

Material	Type	Outgas	Effect in Gaseous 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

20 m of Nylon Pipe
on the chamber inlet
~ 1700 ppm H_2O

↓

Extremely dangerous
for MSGC, straws, GEMs

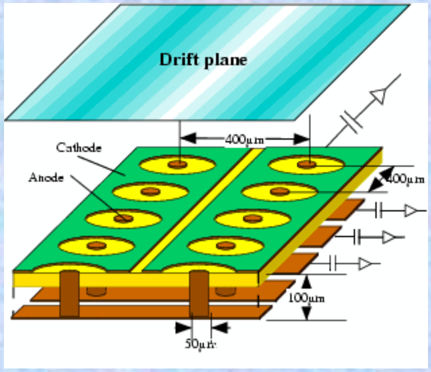
There are clearly many 'bad' and a lot of 'usable' materials

A material is adequate or not for a very particular detector type and operating conditions → test to match your specific requirements

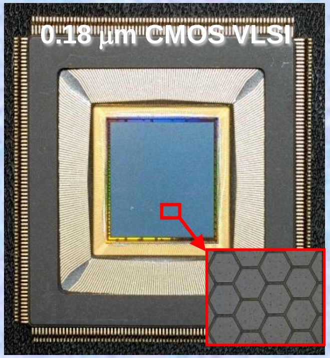
Micro-Pattern Gaseous Detectors: Technologies for Future Projects

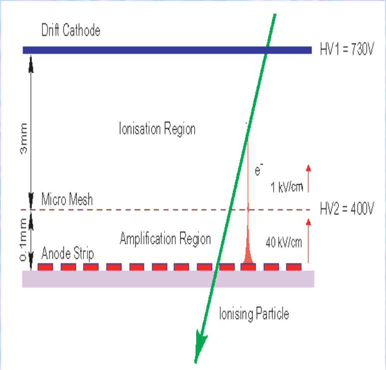
- Micromegas
- GEM
- Thick-GEM, Hole-Type Detectors and RETGEM
- MPDG with CMOS pixel ASICs (“InGrid”)
- Micro-Pixel Chamber (μPIC)

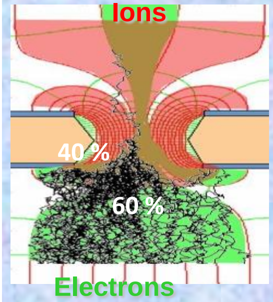
μPIC

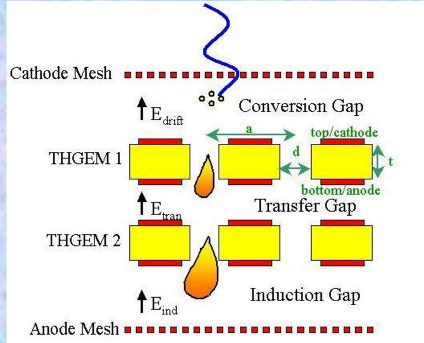


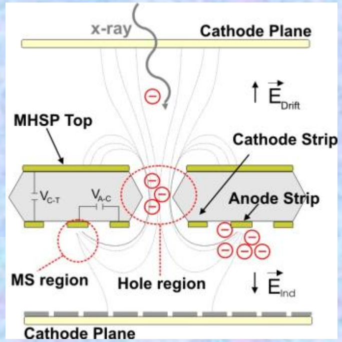
CMOS high density readout electronics

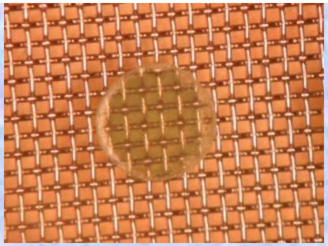




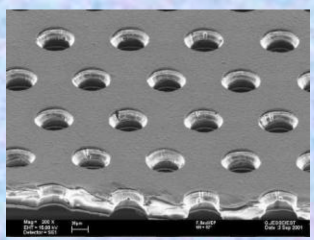




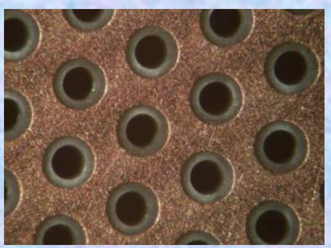




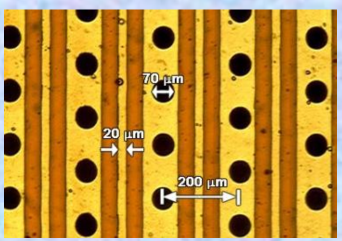
Micromegas



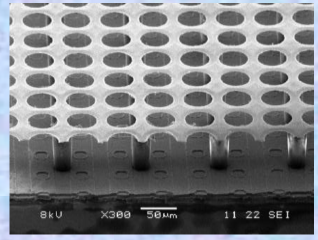
GEM



THGEM



MHSP



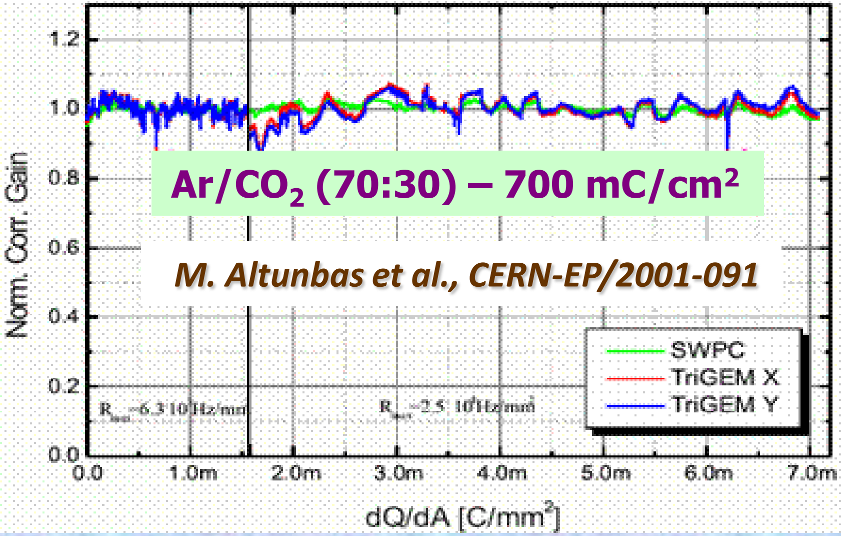
Ingrid

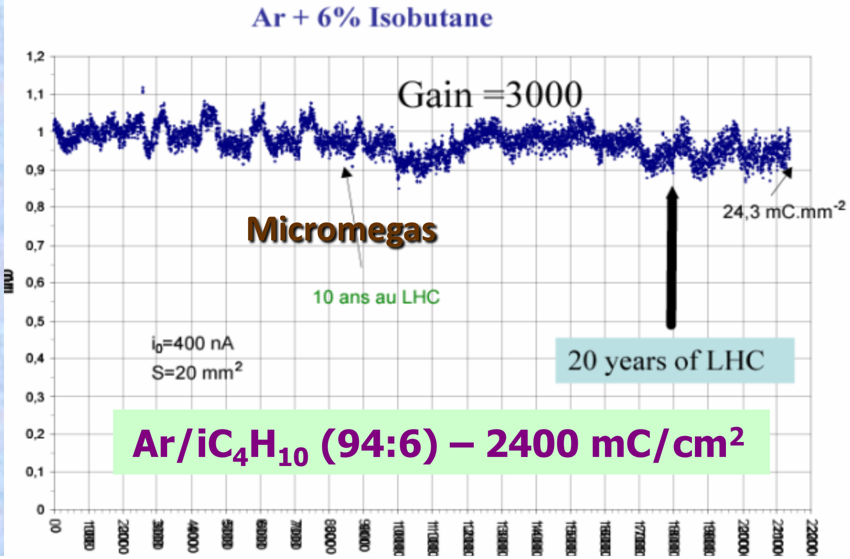
Laboratory Aging Studies with Micro-Pattern Gas Detectors

More robust devices (MICROMEGAS, multi-GEM) can tolerate certain sparking rate and better suited for the harsh environments than MSGC based systems

Table 2. Summary of aging experience with Micro-Pattern Gas Detectors.

Detector type	Mixture	Gain reduction ΔG/G	Charge mC/mm^2	Current density, nA/mm^2	Irradiated area; Irradiation rate	Irrad. source
MSGC [65,104]	Ar/DME (90:10)	No	200	10	3 mm^2; 10^5 Hz/mm^2	6.4 keV X-rays;
MSGC [66]	Ar/DME (50:50)	No	40	63	0.3*0.8 mm^2; 8*10^5 Hz/mm^2	5.4 keV X-rays
MSGC [66]	Ar/DME (50:50)	Anode deposit	50	9	0.3*0.8 mm^2; 2*10[illegible] Hz/mm^2	5.4 keV X-rays
MSGC+GEM [66]	Ar/DME (90:10)	No	70	63	0.3*0.8 mm^2; 2*10^6 Hz/mm^2	5.4 keV X-rays
MSGC+GEM [51]	Ar/DME (50:50)	No	5	2	~ 113 mm^2; 2*10[illegible] Hz/mm^2	8 keV X-rays
MSGC+GEM [51]	Ar/DME (50:50)	Yes	0.5	1	~ 900 mm^2; 10[illegible] Hz/mm^2	8 keV X-rays
MSGC+GEM [51]	Ar/CO_2 (70:30)	No	10	2	350 mm^2 2*10[illegible] Hz/mm^2	8 keV X-rays
Double GEM [67]	Ar/CO_2 (70:30)	Slight gain loss	25	6	2 mm^2; 7*10[illegible] Hz/mm^2	5.4 keV X-rays
Triple GEM [68]	Ar/CO_2 (70:30)	No	27	13	15 mm^2; 6*10[illegible] Hz/mm^2	5.4 keV X-rays
Double GEM [69]	Ar/CO_2 (70:30)	No	12	4	200 mm^2; 5*10[illegible] Hz/mm^2	6 keV X-rays
Triple GEM [70]	Ar/CO_2 (70:30)	No	11	10	1260 mm^2; 2*10[illegible] Hz/mm^2	8.9 keV X-rays
Triple GEM [71,72]	$Ar/CF_4/CO_2$ (60:20:20)	< 5 %	230	270	1 mm^2; 5*10^5 Hz/mm^2	5.9 keV X-rays
Triple GEM [72]	$Ar/CF_4/CO_2$ (45:40:15)	< 5 %	45	160	1 mm^2; 5*10^5 Hz/mm^2	5.9 keV X-rays
Triple GEM [73]	$Ar/CF_4/CO_2$ (45:40:15)	Yes/ 55%	20	20	200*240 mm^2	25 kGi ^{60}Co
Triple GEM [72]	$Ar/CF_4/C_4H_{10}$ (65:28:7)	~ 10 %	110	160	1 mm^2; 5*10^5 Hz/mm^2	5.9 keV X-rays
Triple GEM+ CsI [88]	CF_4 (100)	No	0.1	3	100 mm^2; 10^7 Hz/mm^2	Hg UV Lamp
Micromegas [74]	Ne/C_2H_6 (91:9)	Yes/ 35 %	10	50	16 mm^2; 33Hz spark rate	5.3 MeV α's
Micromegas [75]	Ar/CF_4 (95:5)	No	2	10	--------	8 keV X-rays
Micromegas [76]	CF_4/C_4H_{10} (94:6)	No	1.6	25	20 mm^2; ~10^5 Hz/mm^2	8 keV X-rays
Micromegas [76]	Ar/C_4H_{10} (94:6)	No	18	20	20 mm^2; 2*10^5 Hz/mm^2	8 keV X-rays
Micromegas+ GEM [77]	Ar/CO_2 (70:30)	No	23	17	3 mm^2	5.4 keV X-rays
MSGC+GEM DIRAC [64]	Ar/DME (60:40)	10% eff. drop	0.01	0.05	100*100 mm^2; 3*10[illegible] Hz/mm^2	24 GeV protons
3-GEM [78] COMPASS	Ar/CO_2 (70:30)	No	2.3	--	310*310 mm^2; 2*10[illegible] Hz/mm^2	Compass Beam



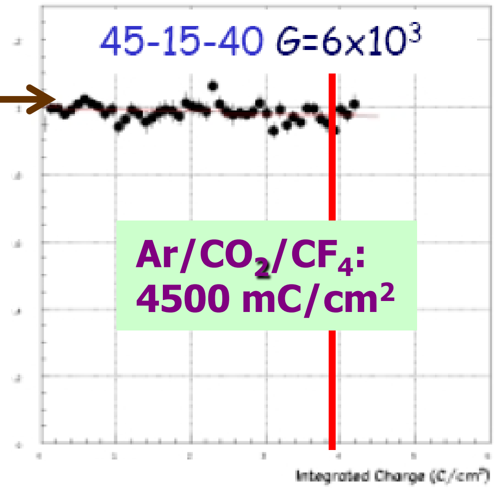


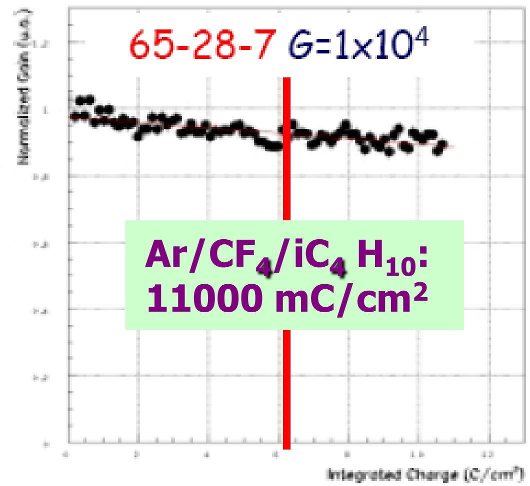
G. Puill et al., *IEEE Trans. Nucl. Sci. V.46(6), 1894 (1999).*

Laboratory Aging Studies during R&D for LHC-b Muon System

Many aging tests performed, exceeding the LHCb integrated charge

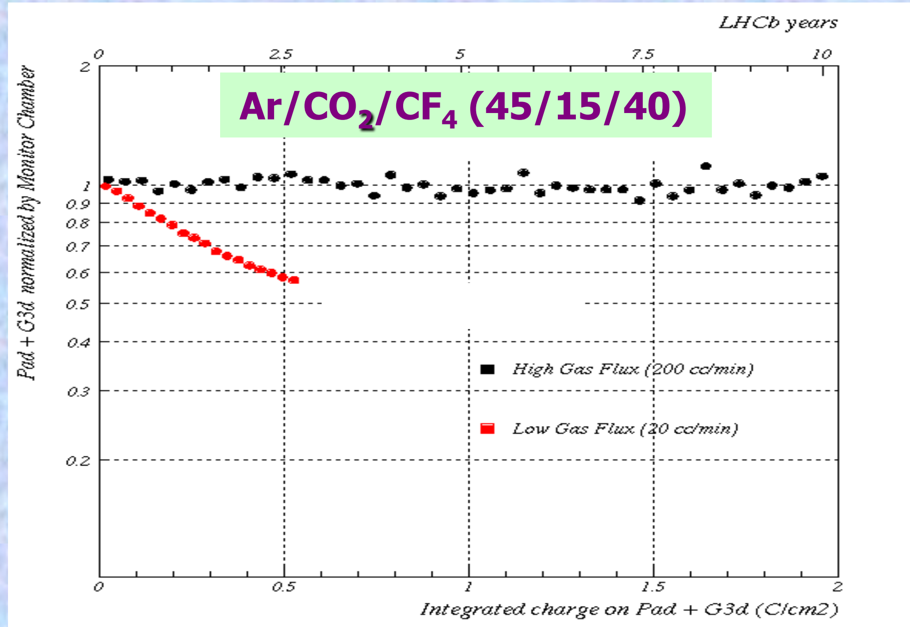
- **Local (~ 1 cm2):** 6 keV X-Rays,
- **Large Area (~15cm2):** PSI πM1 hadron beam
- **Full detector: (20*24 cm2):** Enea-Casaccia 25 kCi ^{60}Co source, 0.5 ÷ 16 Gray/h





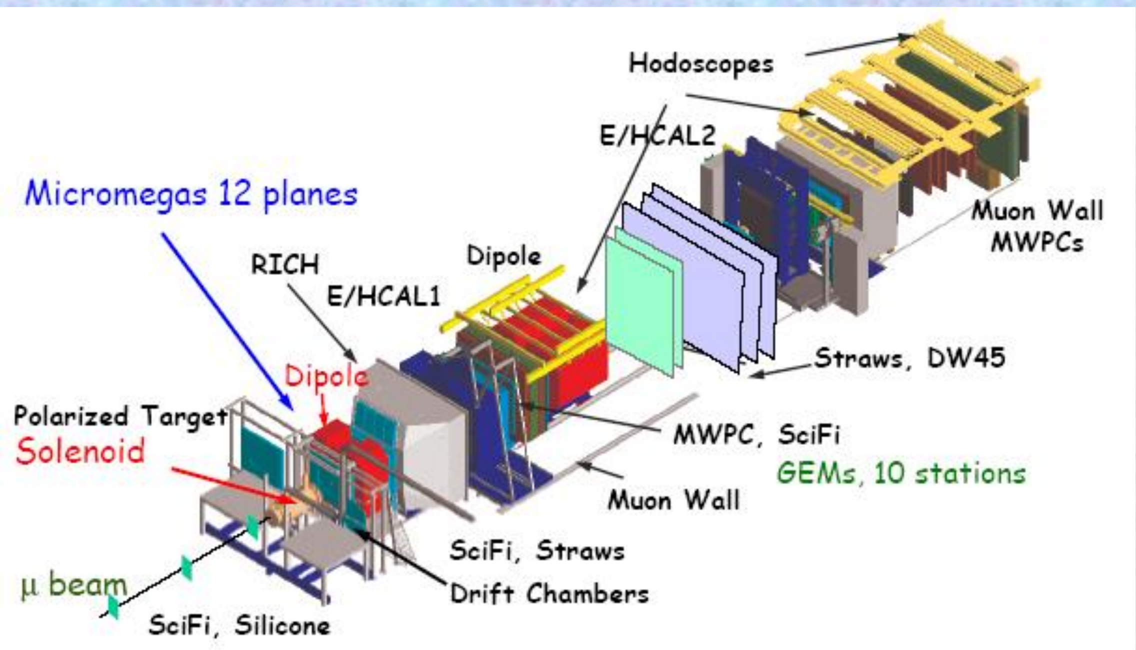
❖ **No aging observed, except high- rate Casaccia tests**

❖ **High-rate Casaccia studies →** **gain reduction effects at low ratio of gas flow/irradiation rate** (CF4 etching of copper and kapton in proximity of GEM holes)



❖ **Fixed by increased gas flow**

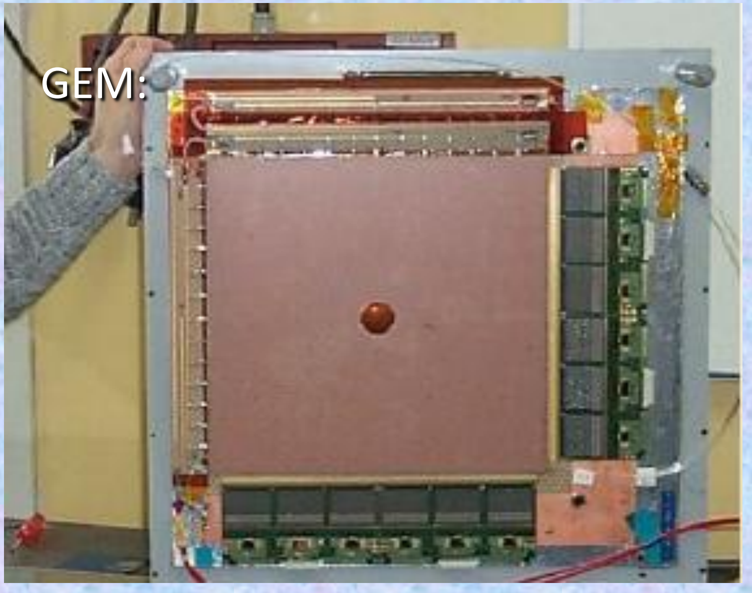
GEM / Micromegas in COMPASS - Textbook of Modern Physics



22 TRIPLE GEM DETECTORS
($31*31\ cm^2$)
& 12 MICROMEGAS PLANES
($40*40\ cm^2$)

High Rate /
High Precision /
Low Mass Detectors:

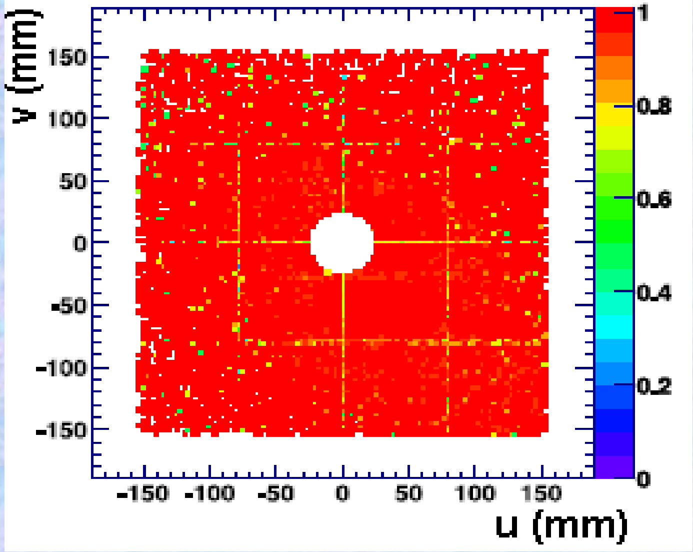
~ 25 kHz/mm^2



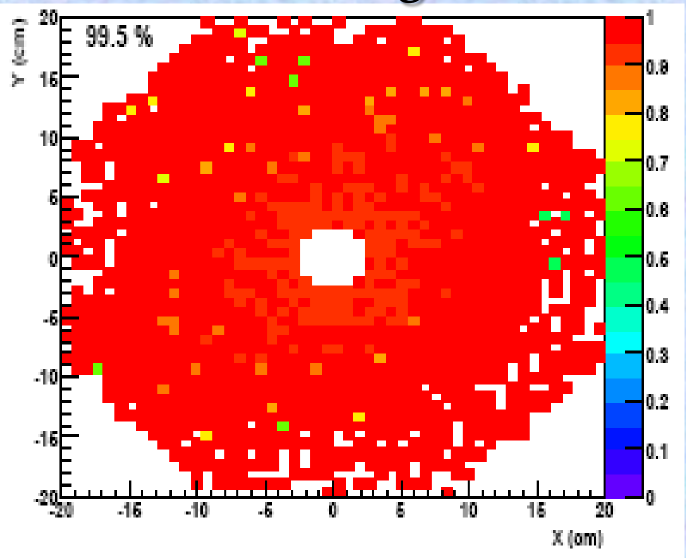
P. Abbon, et al., NIM A 577 (2007) 455-518

GEM / Micromegas in COMPASS - 5 Years of Experience

GEM:



Micromegas:

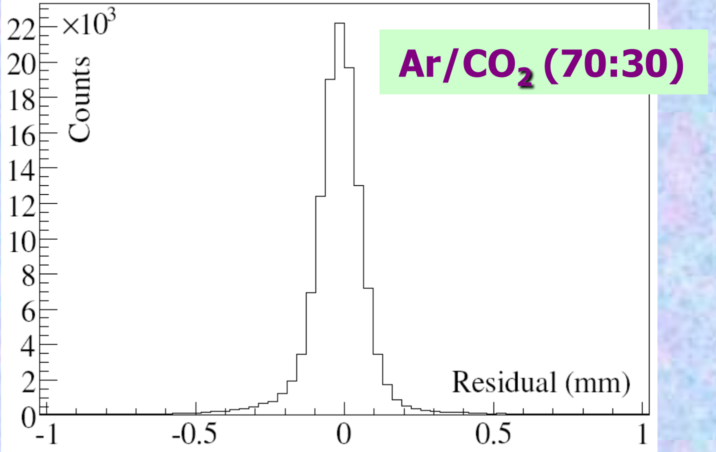


Reliable Operation in 2002-2007:

UNIFORMITY OF TRACKING EFFICIENCY: (ε > 95 %)

- **GEM spatial resolution $\sigma \sim 70\ \mu m$**
- **Time resolution ~ 12 ns**

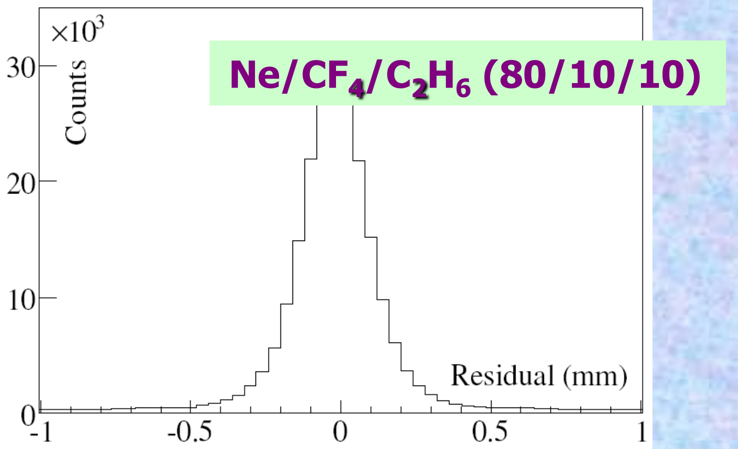
- **Micromegas spatial resolution $\sigma \sim 90\ \mu m$**
- **Time resolution ~ 9 ns**



Total charge during 2002-2007: up to 200 mC/cm²

NO SIGN OF AGING

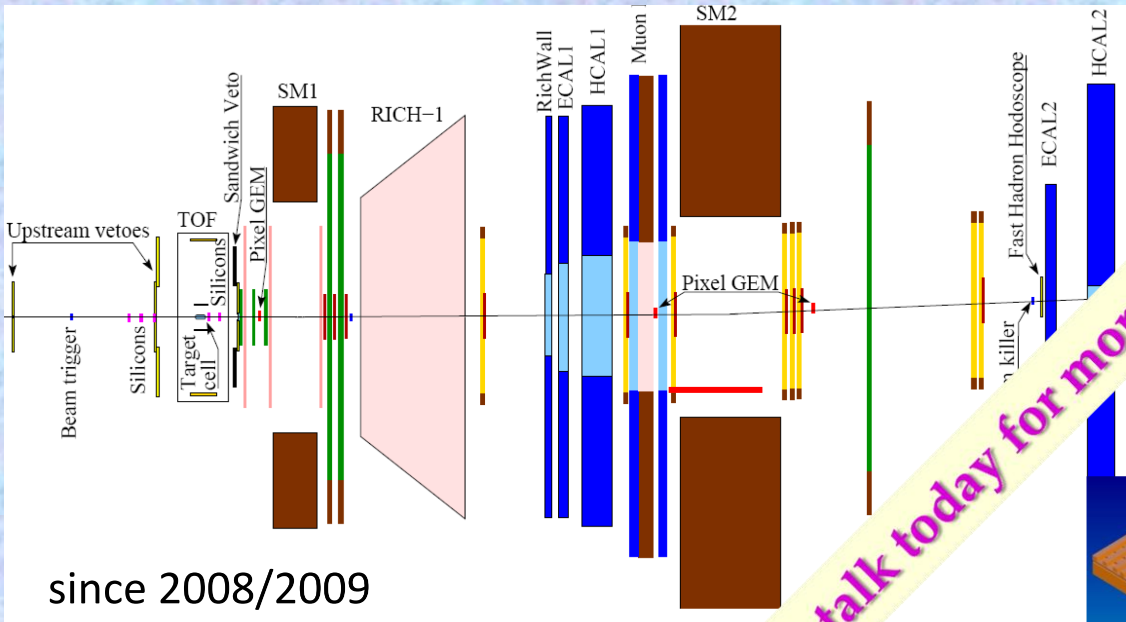
(NO GAIN DROP)



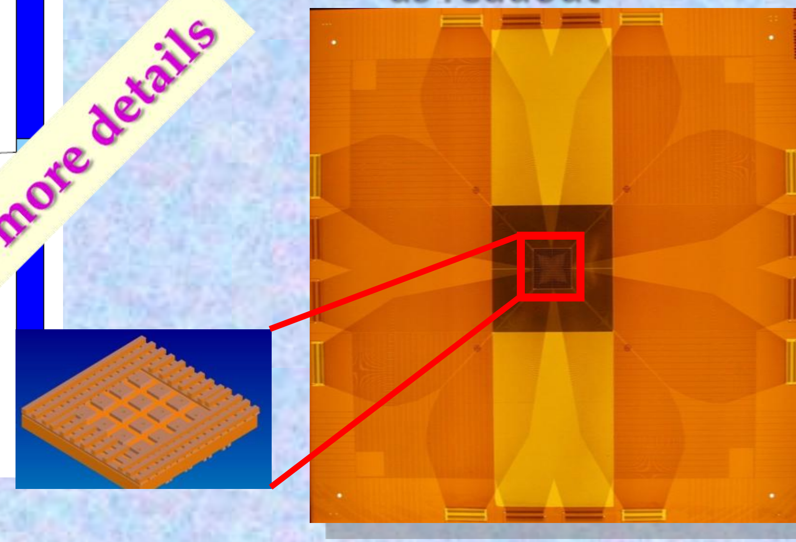
Total charge during 2002-2007: up to 100 mC/cm²

Pixel GEM Tracker @ COMPASS

B. Ketzer (TU Munich), 2011



Triple-GEM with central pixels as readout



See B. Ketzer talk today for more details

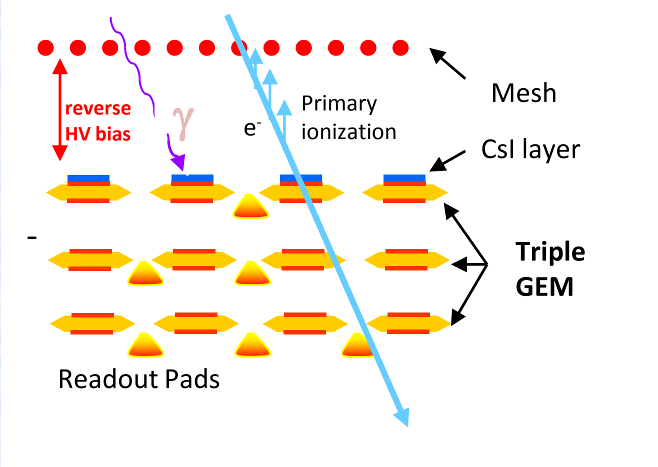
- **Triple-GEMs w/ pixel & strip re[illegible], center: 32×32 1mm² pixels; outside: 2 × 512 strips (2D)**
- **Rates up to 12 MHz/cm² (1[illegible] spatial and 7.2 ns time resolution achieved)**

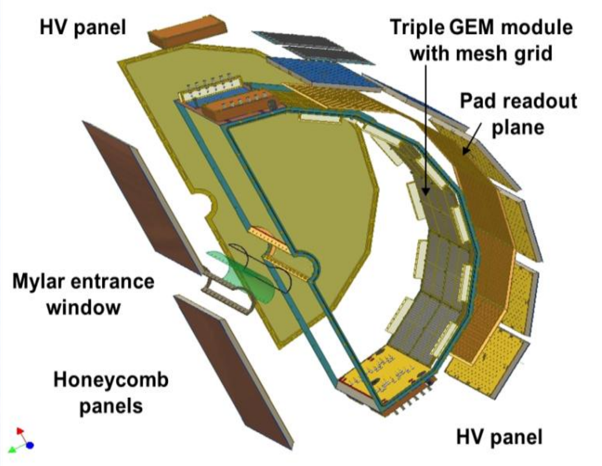
❖ Detection inefficiencies in central area for two GEMs at the end of 2009

→ Tracked down to Si deposits on GEM; culprit were gas leaks that allowed Si from an outside sealant to migrate into chamber → Lesson: Never, ever use materials containing Si

❖ Accumulated charge during 4 years (2008-2011): ~ 1600 mC/cm²

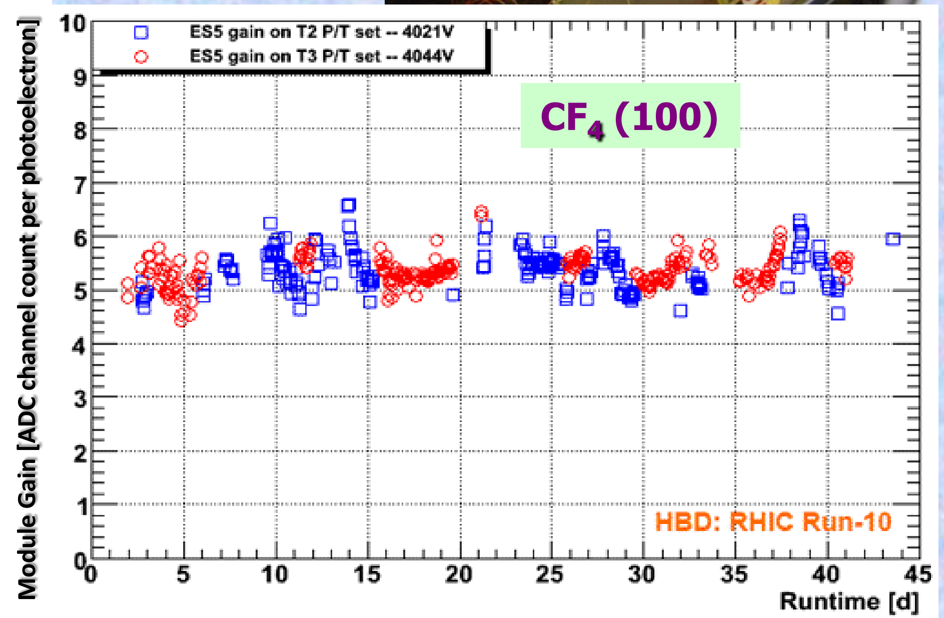
PHENIX Hadron Blind Detector @ RHIC





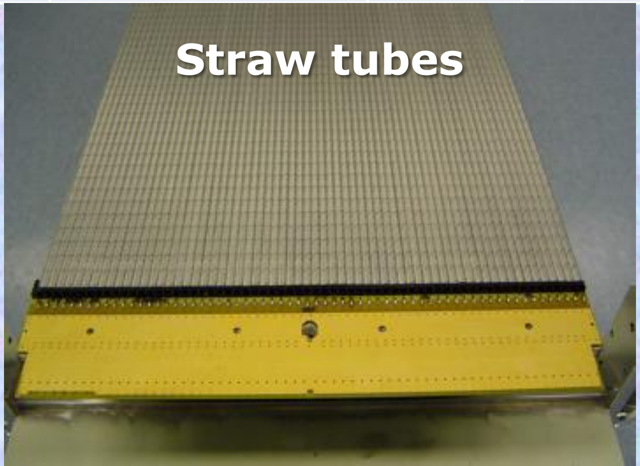
- **Low-rate detector by design (HBD)**
- **Initial problems with sparking during commissioning phase**
  - **Dust during GEM construction caused inter-GEM sparking**
  - **These in turn cause stronger sparks between drift mesh & top GEM; tracked down to oversize HV filtering capacitors**
- **Required HV circuit redesign & full rebuild of the detector in lower-dust environment (laminar flow-hoods)**
- **After rebuild, HBD performed as designed in 2010 run**
- **Gain (3-5 × 10^3) remained stable to within ± 10% during 2010 run**
- **Accumulated charge: 10-20 μC/cm^2 per year**

C. Woody (BNL), RD51 Coll. Meeting, Freiburg, May 2010



Gaseous Detectors in LHC Experiments

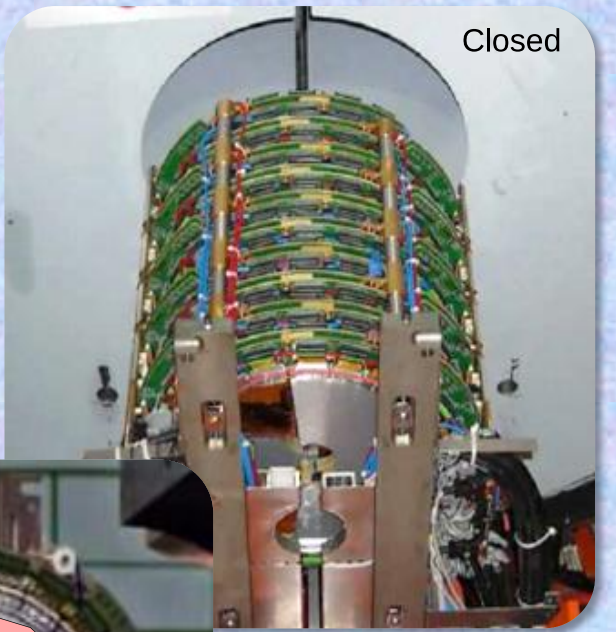
	Vertex	Inner Tracker	PID/ photo-det.	EM CALO	HAD CALO	MUON Track	MUON Trigger
ATLAS	-	TRD (straws)	-	-	-	MDT (drift tubes), CSC	RPC, TGC (thin gap chambers)
CMS ----- **TOTEM**	-	-	-	-	-	Drift tubes, CSC ----- GEM	RPC, CSC ----- GEM
LHCb	-	Straw Tubes	-	-	-	MWPC	MWPC, GEM
ALICE	-	TPC (MWPC)	TOF(MRPC), PMD, HPMID (RICH-pad chamber), TRD (MWPC)	-	-	Muon pad chambers	RPC

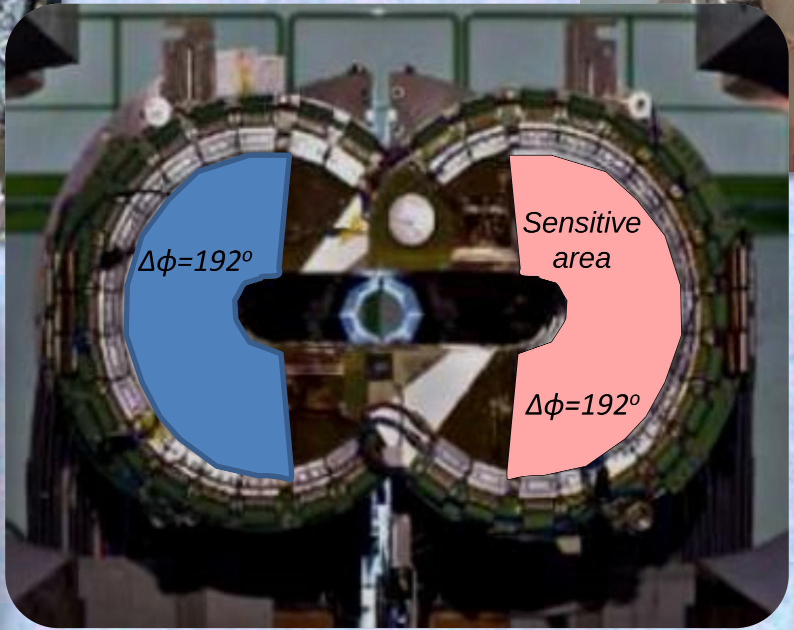


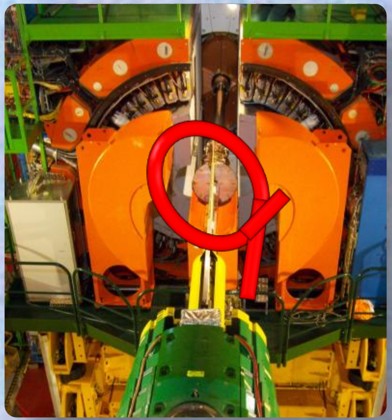
TOTEM GEM Tracker Performance @ LHC

Ar/CO_2 (70:30)

- **Stable operation at very high rates up to 12 MHz/cm^2**
- **Achieved spatial (time) resolution: 135 μm (7 ns) at high intensity 2* 10^8 s^{-1}**

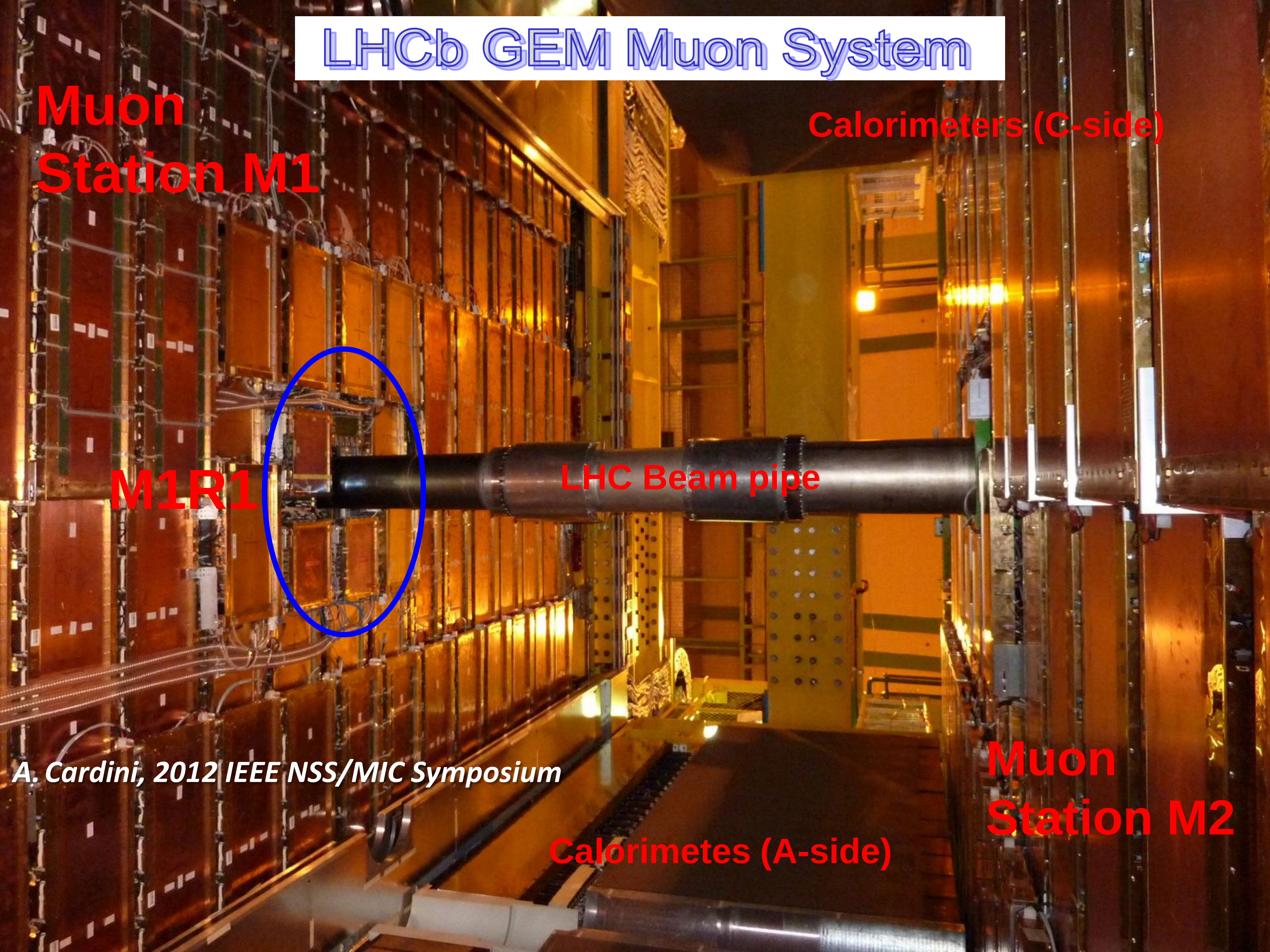






E. Oliveri (INFN Pisa), 3rd CMS GEM Upgrade Workshop, April 2012
M. Hohlmann, 2013 GEM CMS Technical Review, 18/02/2013

LHCb GEM Muon System



LHCb GEM Performance @ LHC

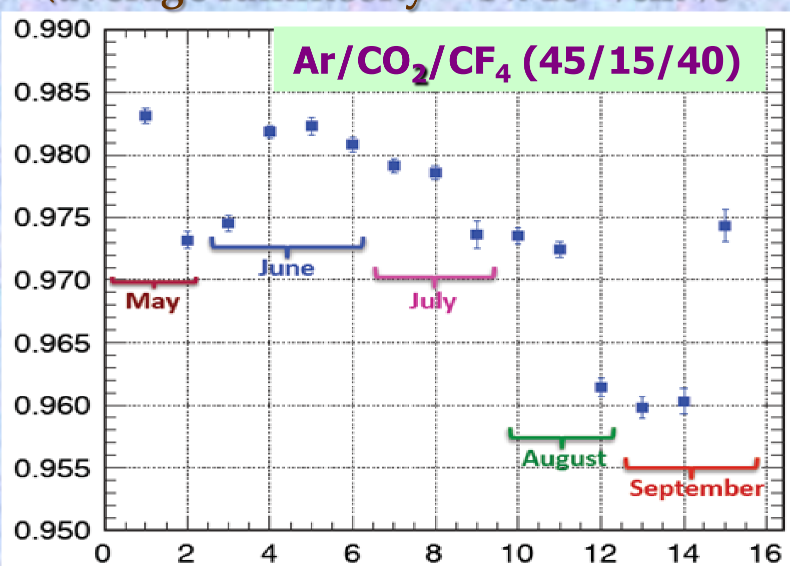
Integrated charges in 2012:

A18A2L: 18 mC/cm^2	A18A1L: 34 mC/cm^2	C18A1L: 31 mC/cm^2	C18A2L: 13 mC/cm^2
A18A2R: 12 mC/cm^2	A18A1R: 23 mC/cm^2	C18A1R: 17 mC/cm^2	C18A2R: 21 mC/cm^2
A17A2L: 50 mC/cm^2	Beam Pipe		C17A2L: 42 mC/cm^2
A17A2R: 59 mC/cm^2			C17A2R: 60 mC/cm^2
A16A2L: 35 mC/cm^2			C16A2L: n/a
A16A2R: 35 mC/cm^2			C16A2R: 35 mC/cm^2
A15A2L: 30 mC/cm^2	A15A1L: 33 mC/cm^2	C15A1L: 33 mC/cm^2	C15A2L: 34 mC/cm^2
A15A2R: 29 mC/cm^2	A15A1R: 36 mC/cm^2	C15A1R: 41 mC/cm^2	C15A2R: 18 mC/cm^2

Triple-GEM Efficiencies in 2012:

(average luminosity ~ 4 x 10^{32} /cm^2/s^{-1})

A. Cardini, 2012 IEEE NSS/MIC Symposium



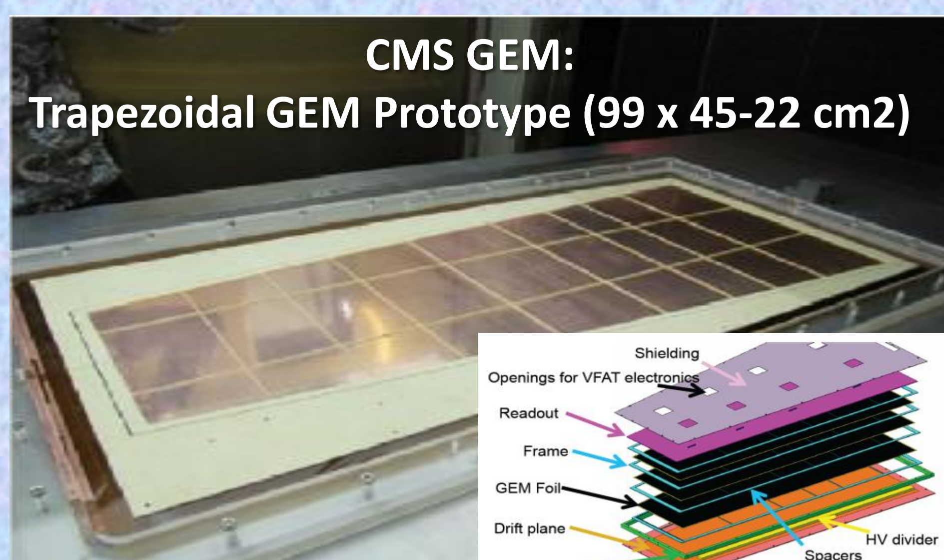
Integrated Luminosity 2012 (to October 15th)~1.5 /fb^{-1}:

- 120 mC/cm^2 total integrated charge (average) (2010 + 2011 + 2012 data taking periods)
- 60 mC/cm2 in 2012 (max) - until Oct. 2012
- No indications of “classical” aging

MPGD Technologies for Energy Frontier (sLHC, LC)

Ongoing R&D Projects using MPGDs in the framework of HEP Experiments

	Vertex	Inner Tracker	PID/ photo-det.	EM CALO	HAD CALO	MUON Track	MUON Trigger
ATLAS	GOSSIP /InGrid	GOSSIP /InGrid				Micromegas	Micromegas
CMS						GEM	GEM
ALICE		TPC (GEM)	VHPMID (CsI-THGEM)				
Linear Collider		TPC(MM, GEM, InGrid)			DHCAL (MM,GEM, THGEM)		



Advancing MPGD Technologies for Nuclear and Hadron Physics

… **MPGD are mostly used/proposed for** <u>**high-rate tracking**</u> **and** <u>**ph… detectors**</u>

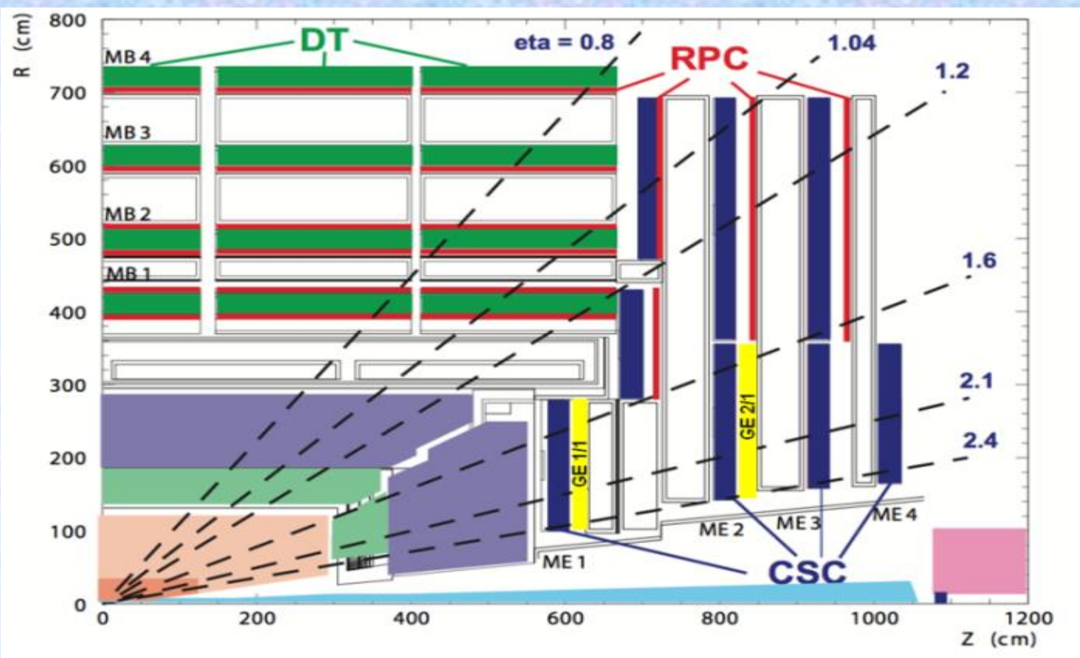
… not even a complete list …

- **COMPASS Upgrade:**
  - Micromegas and GEM detectors for high-rate tra…g
  - Photon Detectors Using THGEM technology fo… …CH 1
- **KLOE2 Upgrade:**
  - Large-area cylindrical GEMs for Inner T…ker
- **RHIC Upgrades:**
  - GEM Tracking for STAR Experime…
  - GEM Tracking for PHENIX Expe…ent(+ drift micro-TPC); development of Ring Imagin… …rsion of HBD for particle ID
- **Future JLAB Projects:**
  - Thin-Curved Microme… …or JLAB/CLAS12
  - GEM Tracker for JL… …all A High Luminosity (SBS) experiments
- **Future FAIR F…ity:**
  - GEM Tracker … GEM TPC for the PANDA Experiment
  - GEM/Micro…gas tracking in CBM Muon Chamber (MUCH)
- **Future …ctron - Ion Collider Facility:**
  - Trac…g and particle ID detectors based on MPGD-technology

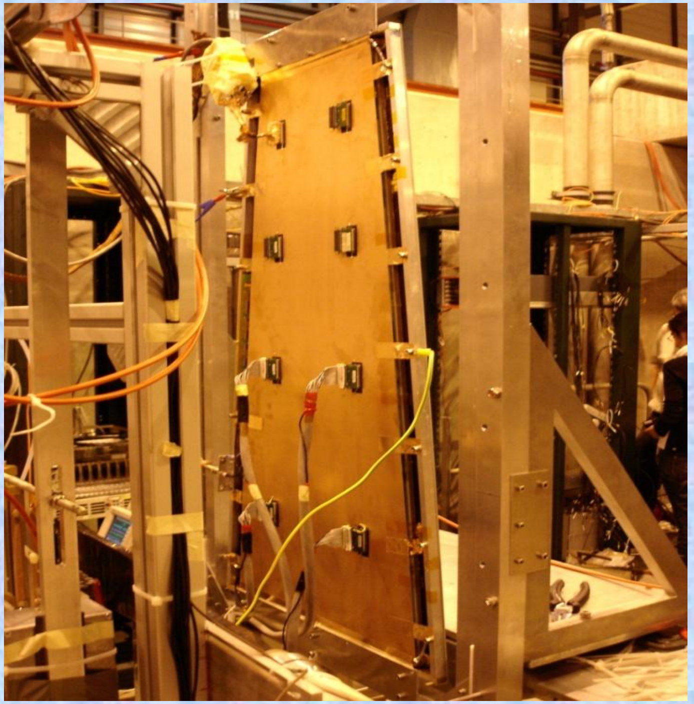
See J.Ball talk yesterday - Aging results with resistive MM for CLAS12

GEMs for CMS High Eta Project ($1.6 > \eta > 2.1$)

CMS missing redundant tracking capability in high h-region (in particular, ME1/1-2/1):



Large Prototype: GE1/1
Beam Test @ RD51 setup

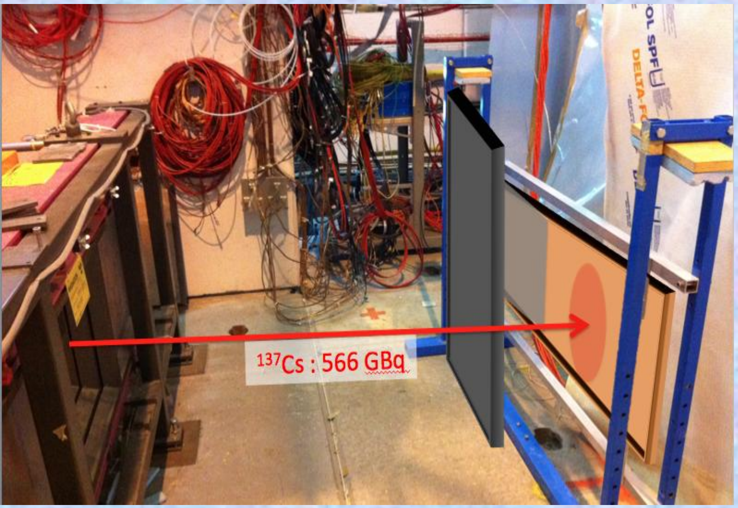


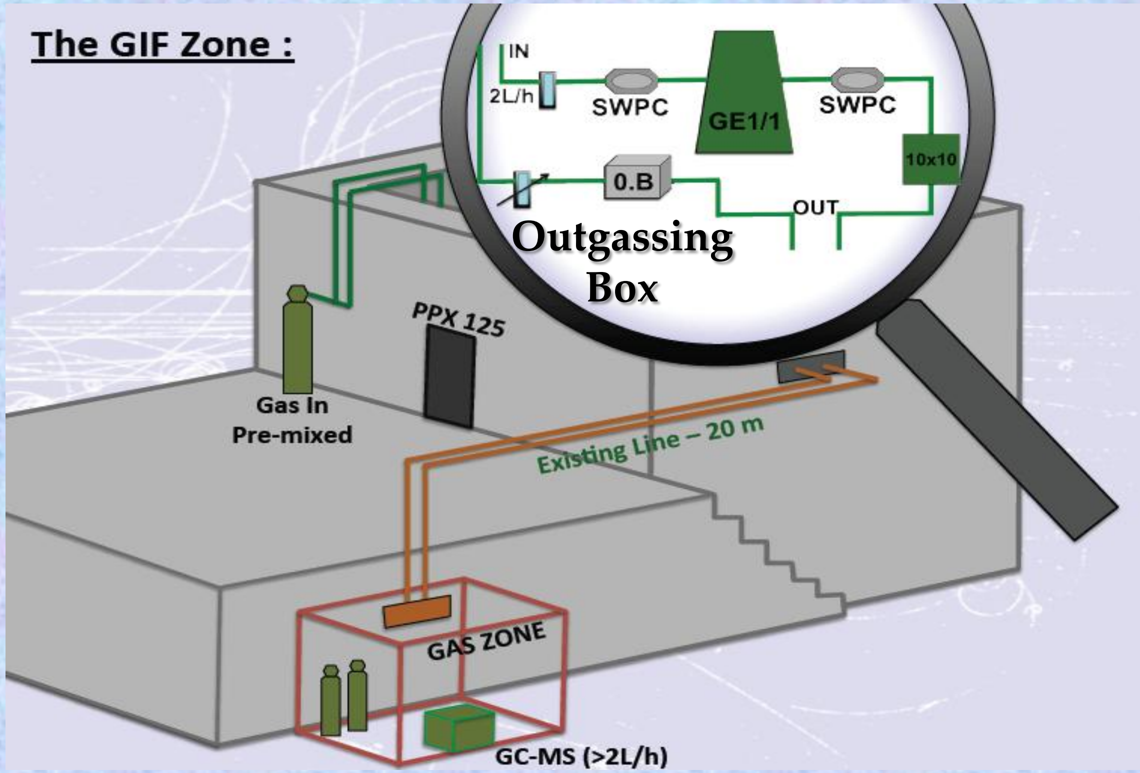
Formally approved as a CMS R&D project of interest (April 20, 2012)

About 1000 m^2 ;
216 triple-GEM detectors

Station	Nbr of modules	Module area (containing rectangle)	Total Nbr of modules (w/o spares)	Total GEM foil area (3ple GEMs)	Manufacturing plan (preliminary)
1	18x2x2=72	~0.43m^2 (440x990)	72	0.43x72x3= 93m^2	Yrs 2014+2015
2	36x2=72 (long) 36x2=72 (short)	~2.4m^2 (1251x1911) ~1.6m^2 (1251x1281)	144	(2.4+1.6)x72x3= 864m^2	Yrs 2015+1016

Future Aging Tests of CMS GEMs at GIF / CERN





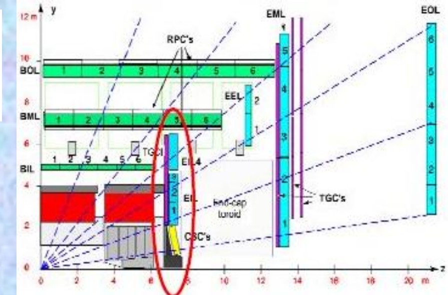
Jeremie Merlin
(Strasbourg/CERN)

$Ar/CO_2/CF_4$ (45/15/40)

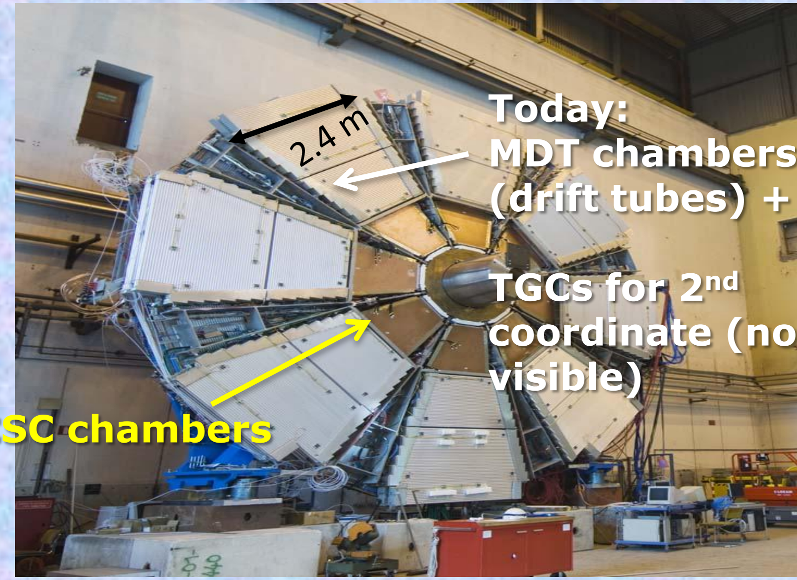
Plan

- 2013-2014 : Ageing test at the Gamma Irradiation Facility (GIF,CERN)
- 2013 : Outgassing tests (GIF,CERN)
- 2013 : Temperature test (RD51 lab,CERN)
- 2014 : Neutron background test (Dubna and/or Ljubliana)
- 2014 : Neural Network based on 2013 results
- 2014 : Propose a set of recommendations to operate GE1/1 Detectors for CMS

Resistive MM for the ATLAS Muon System Upgrade

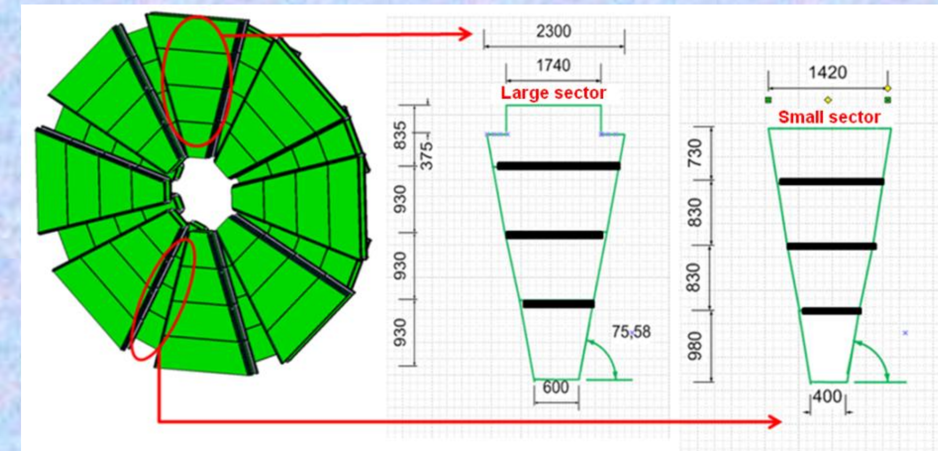


The ATLAS Small Wheel Upgrade:



Equip Small Wheels with 128 MM (0.5–2.5 m²):

→ Combine precision and 2nd coordinate meas. and trigger functionality in a single device



Resistive strip Micromegas has been chosen as the baseline option for the upgrade of the Small Wheel:

~ 1200 m² of Resistive MM

Sector	Nbr sectors Nbr chambers/sector MM layers/chambers	MM layer area (containing rectangle)	Total Nbr MM layers (w/o spares)	Total MM PCB area	Manufacturing plan (preliminary)
Small	8x2=16 4 4x2=8	From ~0.68m² (696x980) To ~1m² (1420x730)	512	0.88x512 = 450m²	Yrs 2015 +2016
Large	8x2=16 4 4x2=8	From ~0.96m² (1036X930) To ~1.9m² (2300x835)	512	1.5x512= 768m²	Yrs 2015 +2016

Resistive Micromegas Technology for the ATLAS Muon System Upgrade

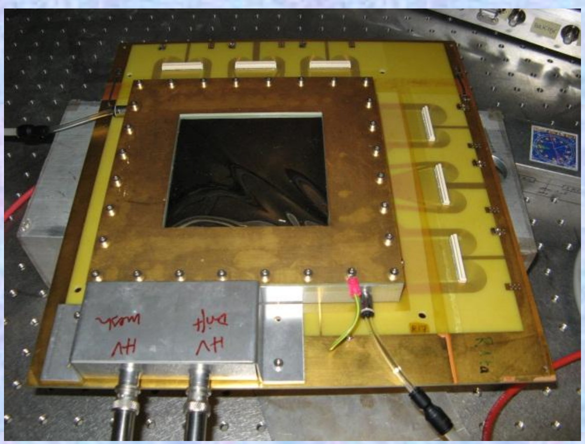
Two resistive prototypes (R17) were sent to Saclay for performing aging tests

17A
Resistance to GND: 80-140 MOhm
Resistance along strips: 45-50 MOhm/cm

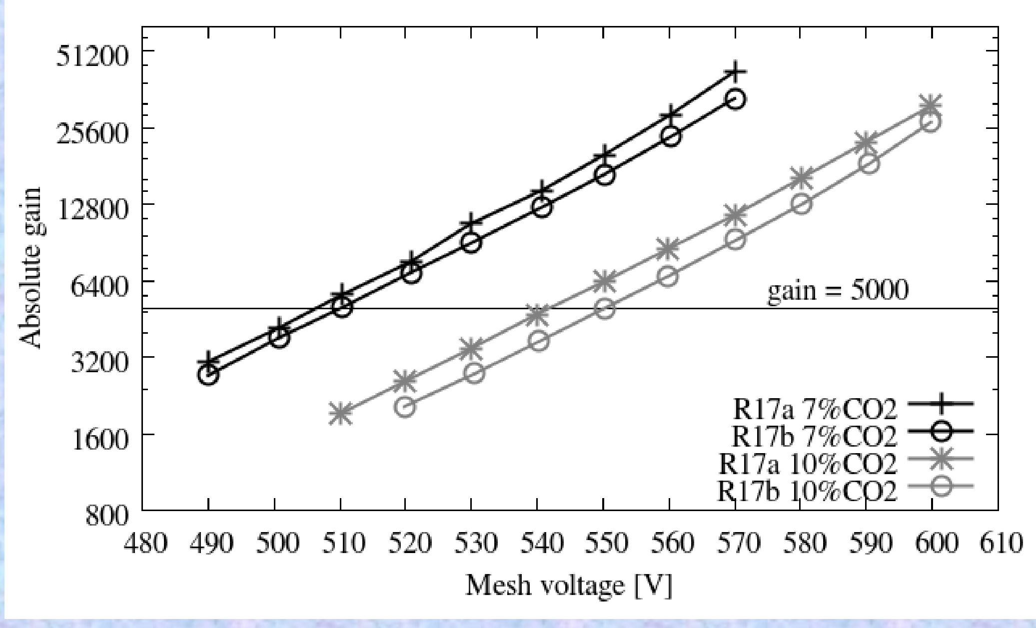
17B
Resistance to GND: 60-100 MOhm
Resistance along strips: 35-40 MOhm/cm

Geometrical properties

Strip pitch/width for all: 250 µm/150 µm
Top layer (Resistive strips): 35 µm thick
Insulation (coverlay): 60 µm
Y strips (90 degrees to R strips):9 µm Cu
Insulation (FR-4): 75 µm
X strips (same direction as R strips): 9 µm Cu



Both detectors show similar gain properties
Re-characterized at CEA for different gas mixtures



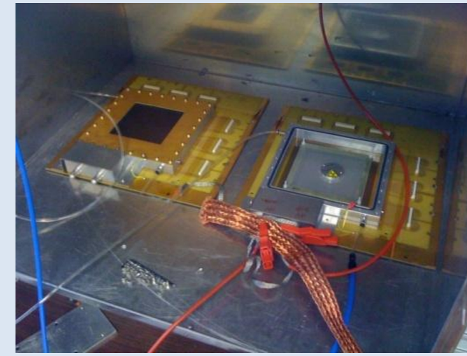
J. Galan, 2013 Vienna Chamber Conference, 12/02/2013

Resistive Micromegas: Summary of Aging Studies

X-ray beam

Cold neutron beam

Alpha source



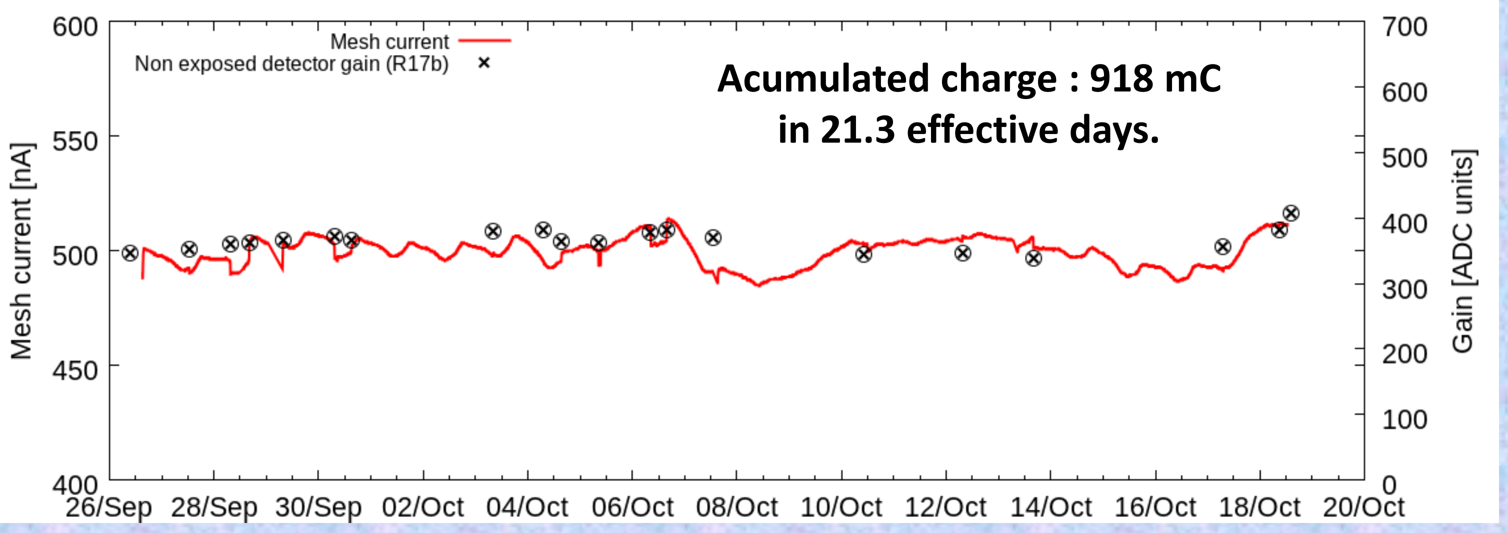
Gamma source

Ar/CO_2 (90/10)

- R17a detector is exposed to different radiation natures.
- R17b detector is kept unexposed.
- Gain control measurements are performed before and after each exposure.
- After the ageing both detectors are taken to the H6 CERN-SPS pion beam line.
- The goal to accumulate an integrated operation charge equivalent to the one would be obtained at the HL-LHC for 10 years for each type of radiation.

J. Galan, 2013 Vienna Chamber Conference, 12/02/2013

Resistive Micromegas: X-Ray Aging Studies



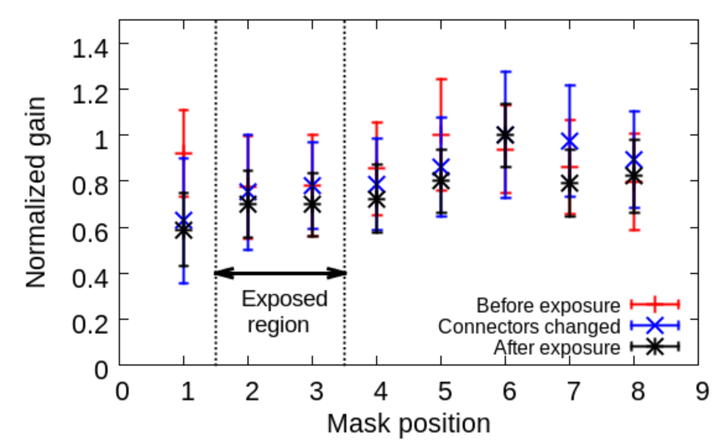
225 mC/cm2

versus

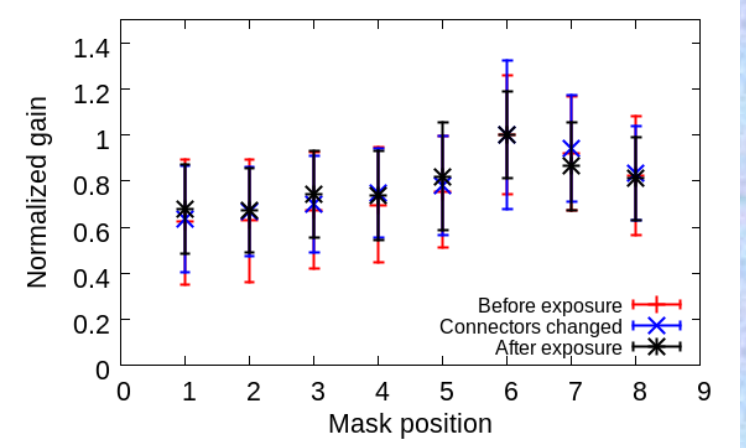
32 mC/cm2

Estimated per HL-LHC year (ATLAS Muon)

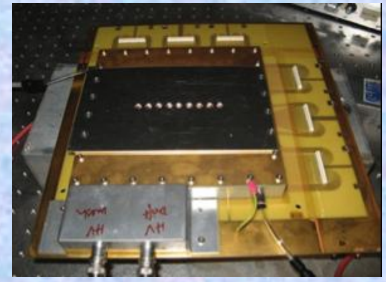
R17a irradiated detector



R17b non-irradiated detector

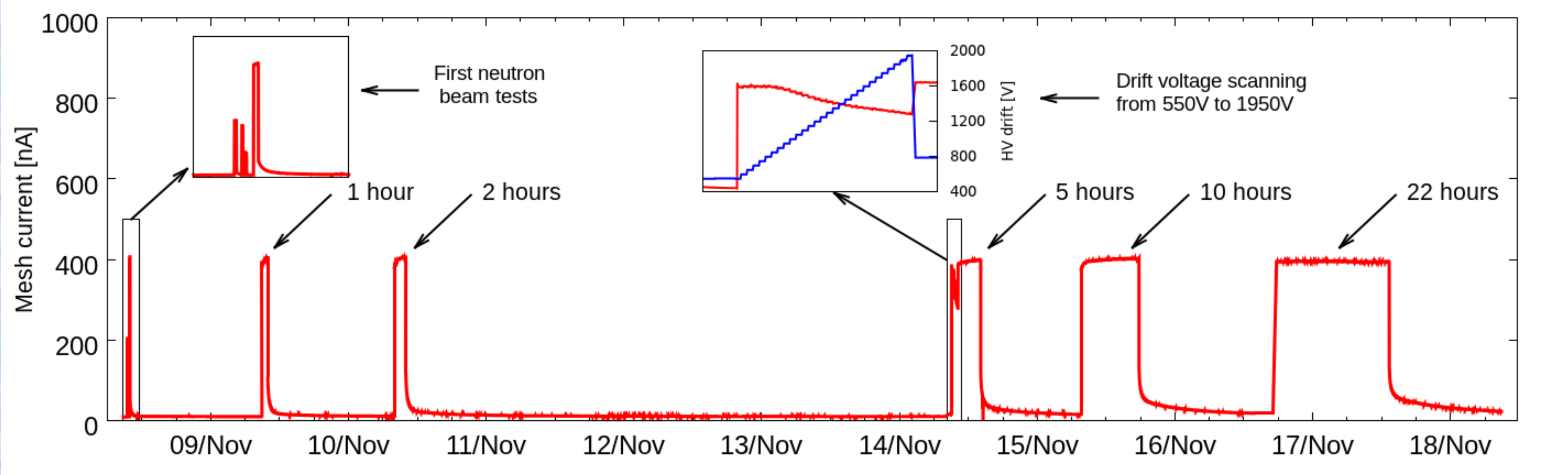


9-holes mask



Resistive Micromegas: Neutron Irradiation

High intensity thermal neutron irradiation had place at C.E.A. Orphee reactor.

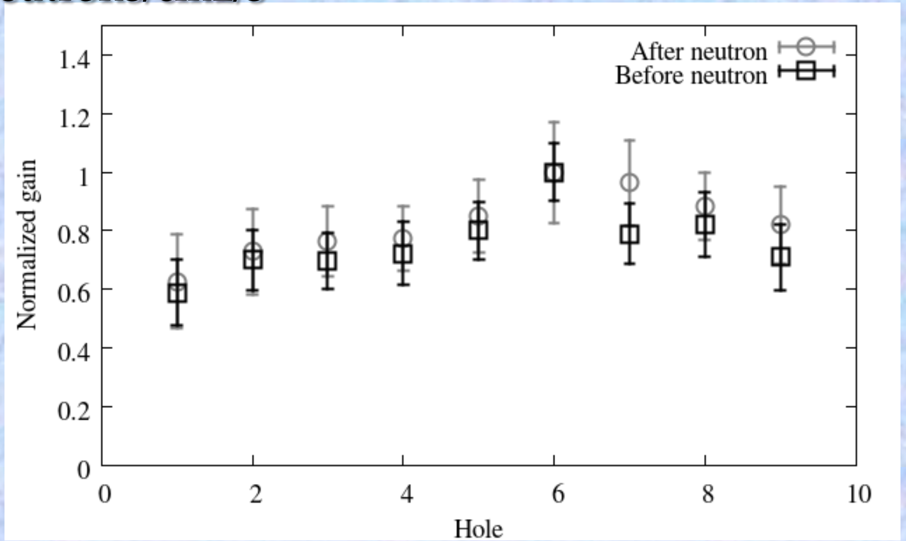


Neutron flux at the level of ATLAS Muon ~3.10^4 neutrons/cm2/s

10 years at HL-LHC (=> x10.10^7 sec) with a security factor : x3

At the HL-LHC, we will accumulate 1,5.10^{13} n/cm2

At Orphee we have ~8.10^8 n/cm2/sec so in 1 hour we have : 8.10^8 x 3600 ~ 3.10^{12} n/cm2/hour which is about 2 HL-LHC years (200 days year).



J. Galan, 2013 Vienna Chamber Conference, 12/02/2013

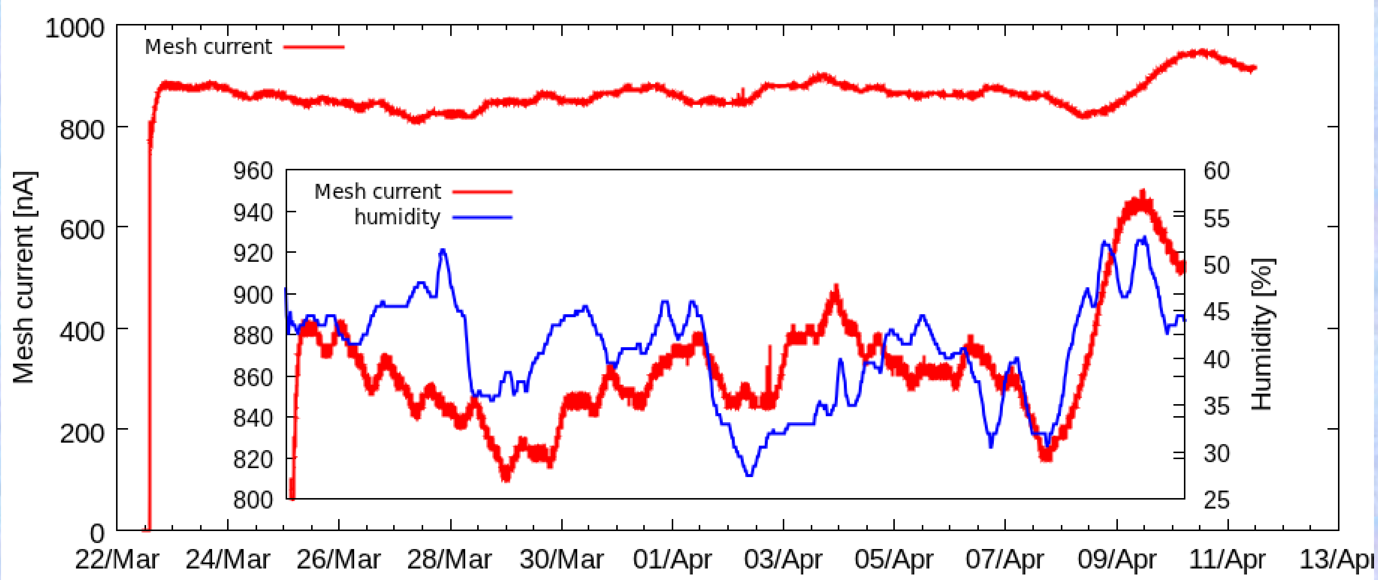
Resistive Micromegas: Gamma Irradiation

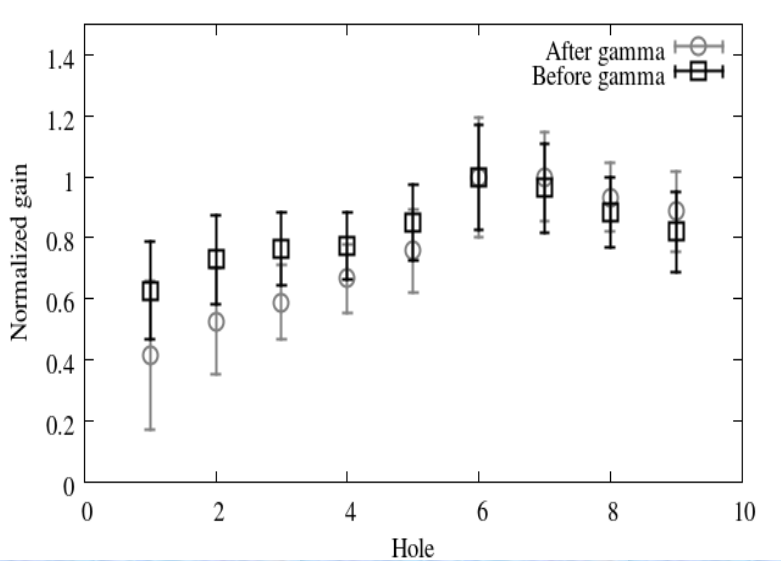
Gamma exposure between 22nd of March and 11th of April (2012).

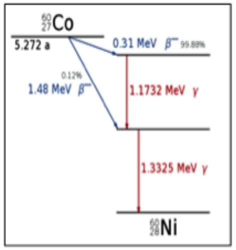
Total exposure time : 480 hours

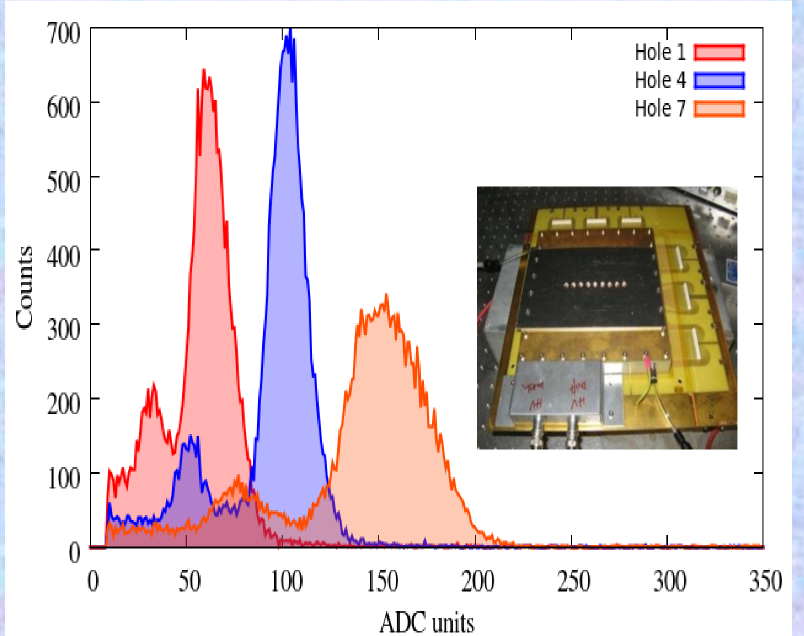
Total integrated charge : 1484 mC

Mean mesh current : 858.4 nA



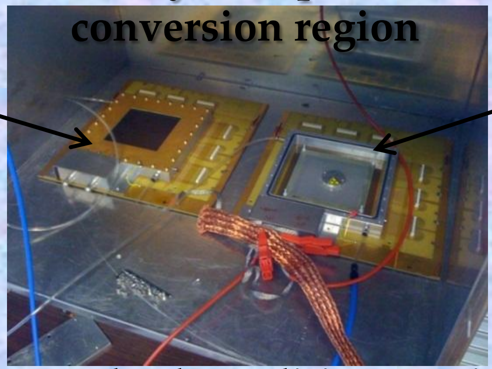




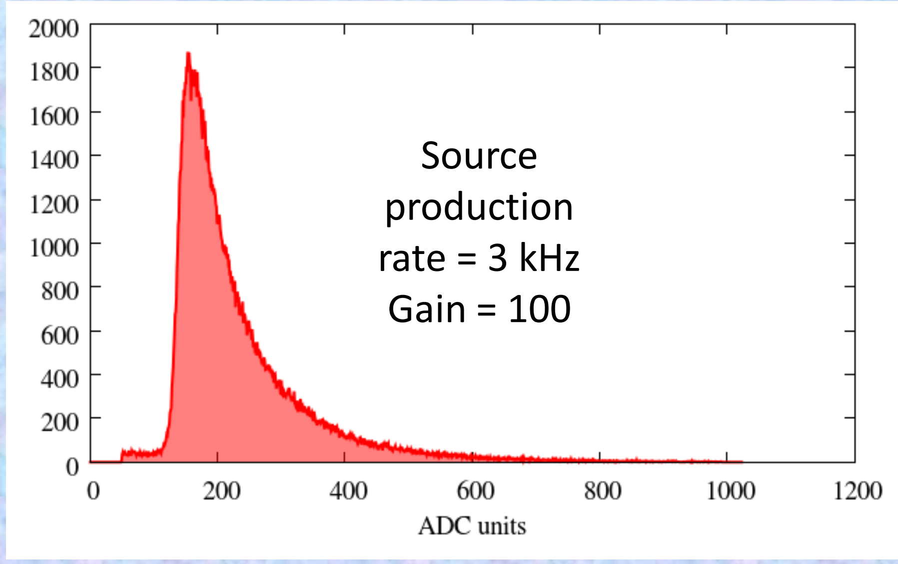


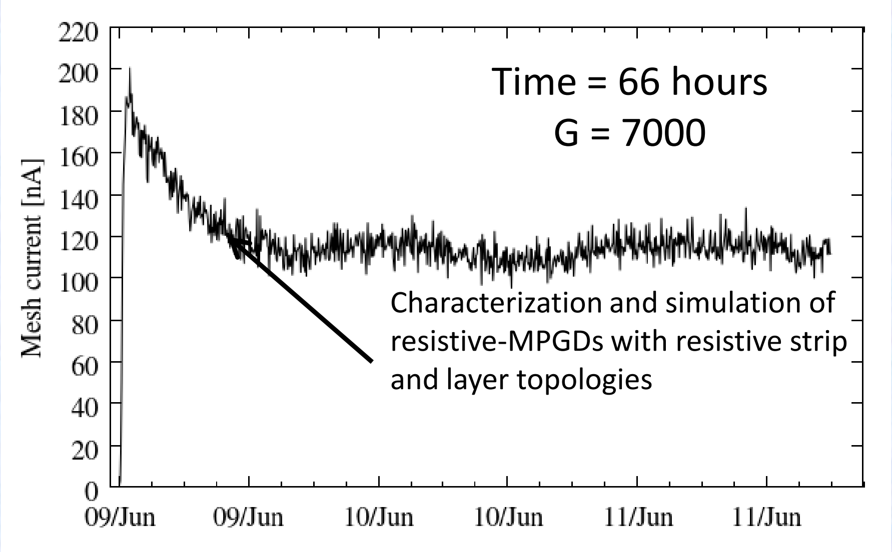
Resistive Micromegas: Alpha Irradiation (241 Am Source)

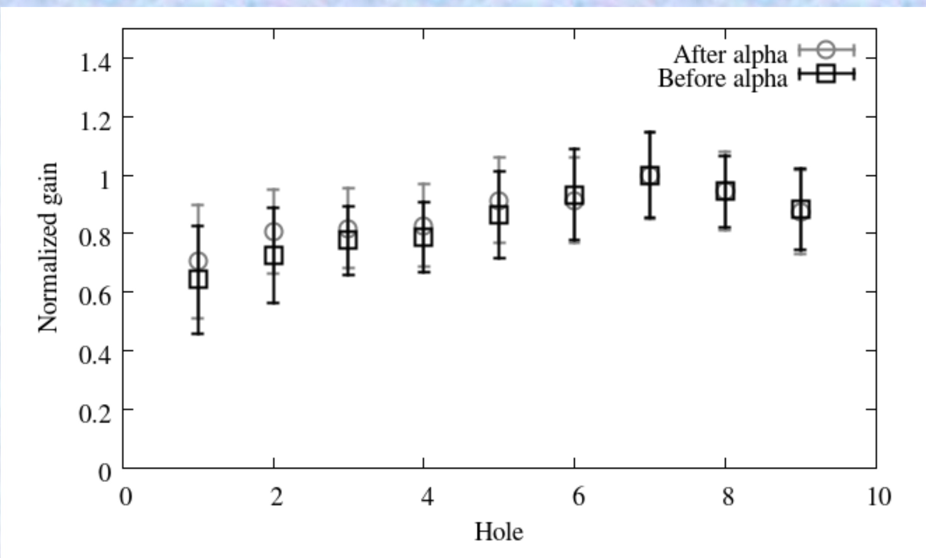
About 30000 primaries are produced by an alpha in 0.5cm conversion region



In standard conditions, gains higher than 100 produce a spark on every alpha (Raether's)







Final Remarks: how to plan systematic aging studies…

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

The fundamental problem: you can not do a 'real time test'
How is it possible to learn in a reasonable time about the long-term aging behaviour?

- **Build a 'full size prototype detector' (the smallest full size independent element of your detector)**

- **Expose full area of detector to real radiation profile (particle types)**

- **Choose your gases and materials very carefully**

- **Vary all parameters systematically (gas gain, irradiation intensity, gas flow, …) and verify your assumptions…**

- **Do not extrapolate your results for any given set of parameters by more than 1 order of magnitude**

- **If you observed unexpected result - understand the reason – and reproduce results**

Radiation Damage and Long-Term Aging can be minimized by:

1. Careful choice of construction materials: radiation hardness and outgassing properties are of a primary importance
(There are clearly many ‘bad’ and a lot of ‘usable’ materials.
A material is adequate or not for a very particular detector type and operating conditions ⟶ test to match your specific requirements)

2. Use of aging resistant gases: noble gases, CF_4, CO_2, O_2, H_2O, alcohols are the most attractive candidates for the high-intensity environments;
(Hydrocarbons are not trustable for long-term high rate experiments; operational problems could be aggravated by CO_2 as a quencher and by the very high aggressiveness of dissociative products of CF_4)

3. Adequate assembly procedures, maximal cleanliness for all processes and quality checks for all system parts (personnel training, no greasy fingers, no polluted tools, no spontaneously chosen materials installed in the detector or gas system in the last moment, before the start of real operation)

4. Careful control for any anomalous activity in the detector: dark currents, variation of anode current, remnant activity in the chamber when beam goes away.
(Use oxygen-based molecules to inhibit/relief/cure polymerization of hydrocarbons, operation with CF_4 decreases a risk of Si polymerization)

Radiation Damage in Gas Detectors: Summary and Outlook (I)

- **Stable and reliable operation of fast gaseous detectors at large scale for high rate tracking in hostile environments has been demonstrated by many experiments**

- **With the increasingly stringent requirements of modern experiments, geometry, configuration of electric field, construction and electrode materials and operating gases have been the subject of extensive studies and optimization efforts**

- **New micro-pattern detectors (MICROMEGAS, GEM) are rather insensitive to aging compared to MSGC and MWPC (separation of multiplication and readout stages, lacking fragile thin anodes, gain being obtained by avalanche multiplication along an extended high field region)**

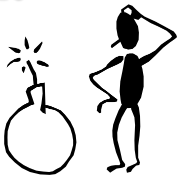
It is widely believed that gas detectors are less radiation resistance than Si-detectors ☹

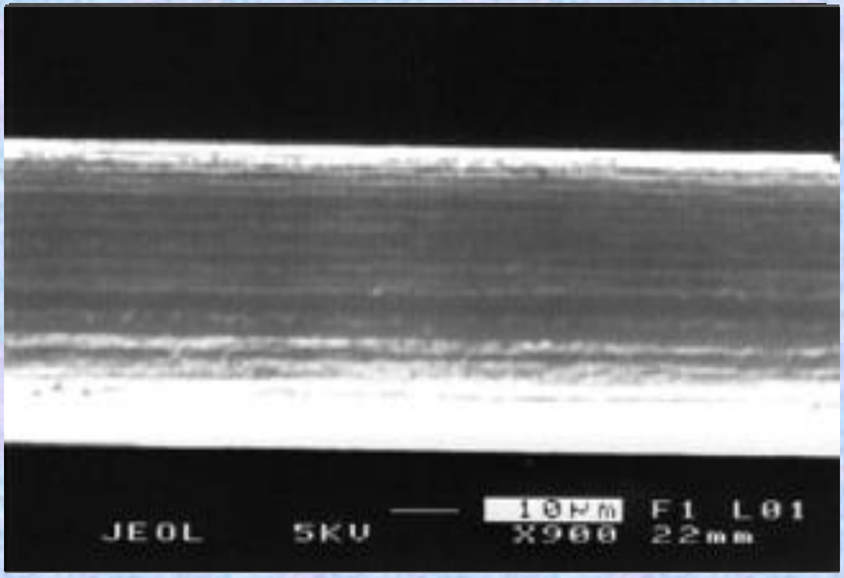
THIS IS NOT ACTUALLY CORRECT, EVEN for LHC (SLHC)-like CONDITIONS ☺

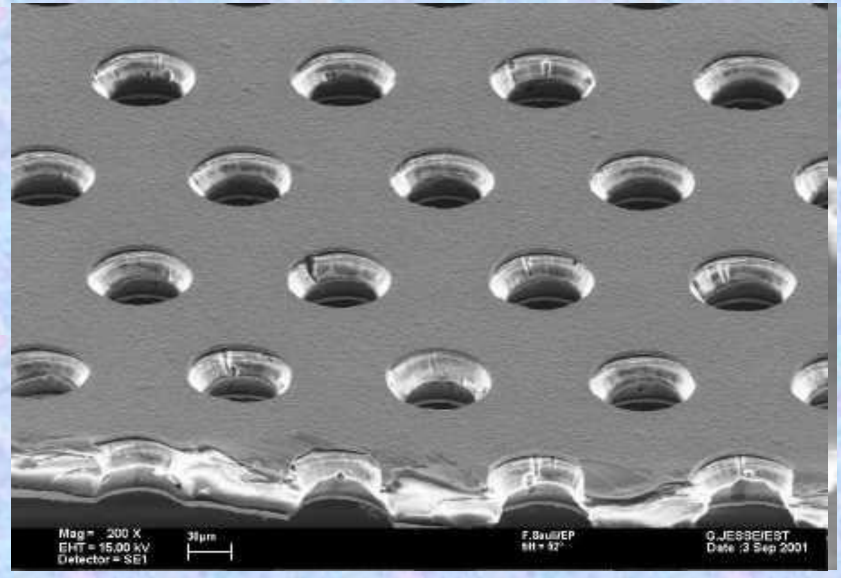
Radiation Damage in Gas Detectors: Summary and Outlook (II)

Many problems in HIGH RATE GAS DETECTORS were due to casual selection of chamber designs, gas mixtures, materials and gas system components, which worked at "low rates", but failed in harsh radiation environment

Benefit from > 20 years of R&D Experience







If properly designed and constructed, gas detectors (especially Micro-Pattern Gas Detectors) can be robust and reliable in the high-rate environment