# Radiation Hardness of Gaseous Detectors

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**4th MC-PAD Network Training Event**

**Gaseous Detectors**

CERN, 16-18/3/2011

# Outline

- Radiation Damage of Gas Detectors: AGING
- Particle Rates at LHC
- Aging Phenomena
- Factors Affecting the Aging Rate
- Strategies to Build Radiation-Hard Gas Detectors

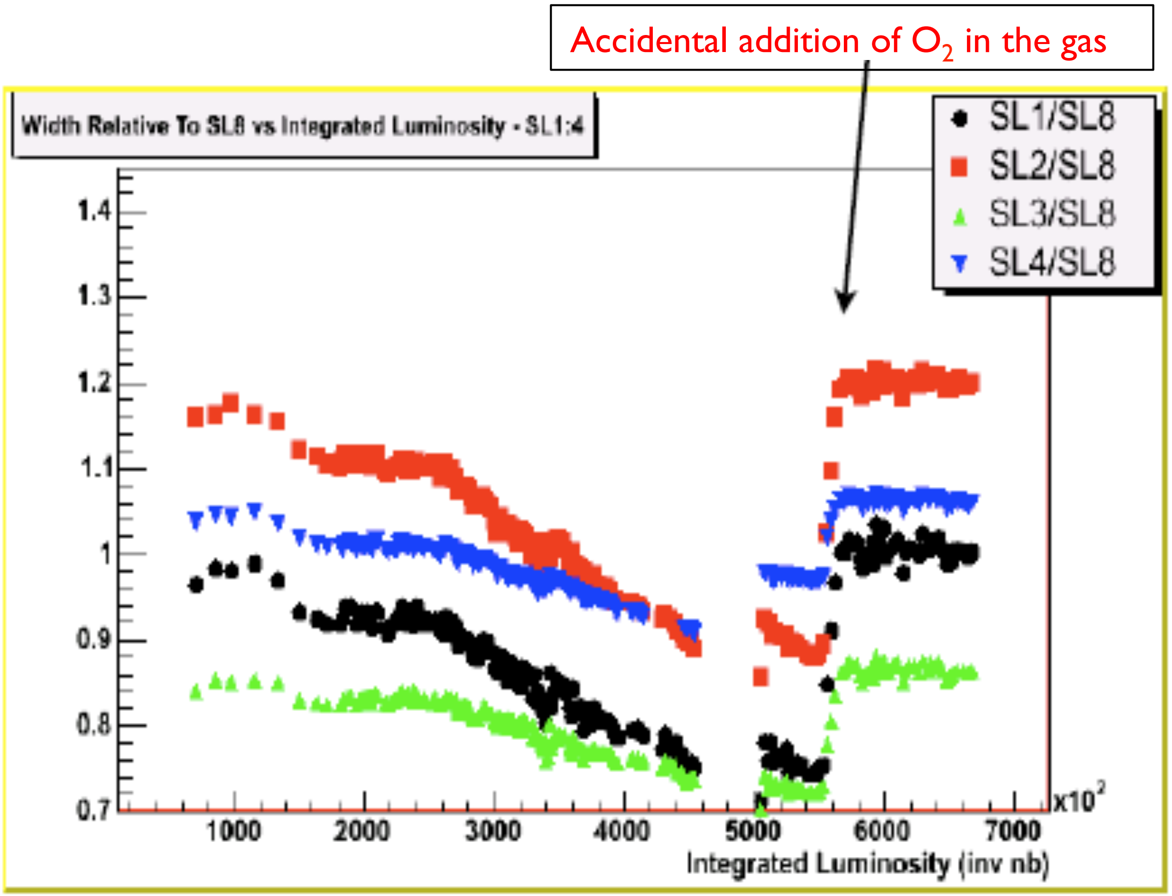
# Radiation Damage of Gas Detectors

- **Deterioration of performance under irradiation** has been observed since development of Geiger and proportional counters (~100 years) and yet it remains one of the main limitations to use Gas Detectors in high rate experiments.
- Deterioration in Performance:
  - loss of gas gain
  - loss of efficiency
  - worsening of energy resolution
  - excessive currents
  - self-sustained discharges
  - sparks
  - loss of wires
  - changes of surface quality…

# Aging of Gas Detectors in Experiments

**Aging in the Central Outer Tracker of CDF Fermilab** (D.Allspach et al.)

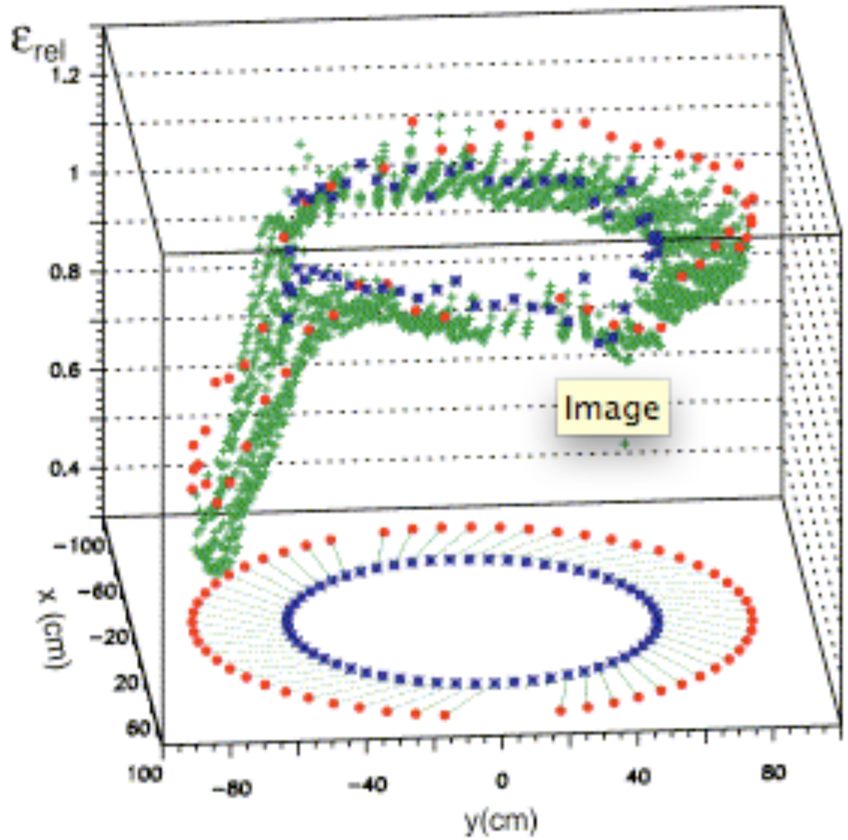
Drift chamber Ar-$C_2H_6$ [50-50] + 1.7% isopropanol



# Aging of Gas Detectors in Experiments

**Aging in the Central Jet Chamber of H1 DESY** (C.Niebuhr)

Radial Wire Chamber Ar-$C_2H_6$ [50-50] + water



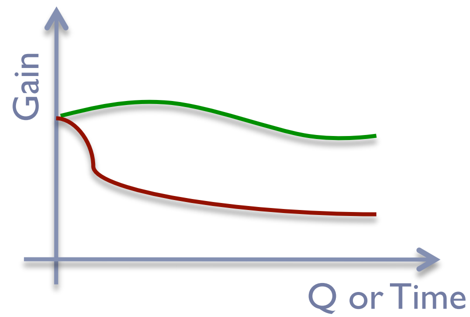
# Rate of Aging

- **Ageing depends on the total collected charge Q:**

Q [C] = Gain x Rate x Time x Primaries

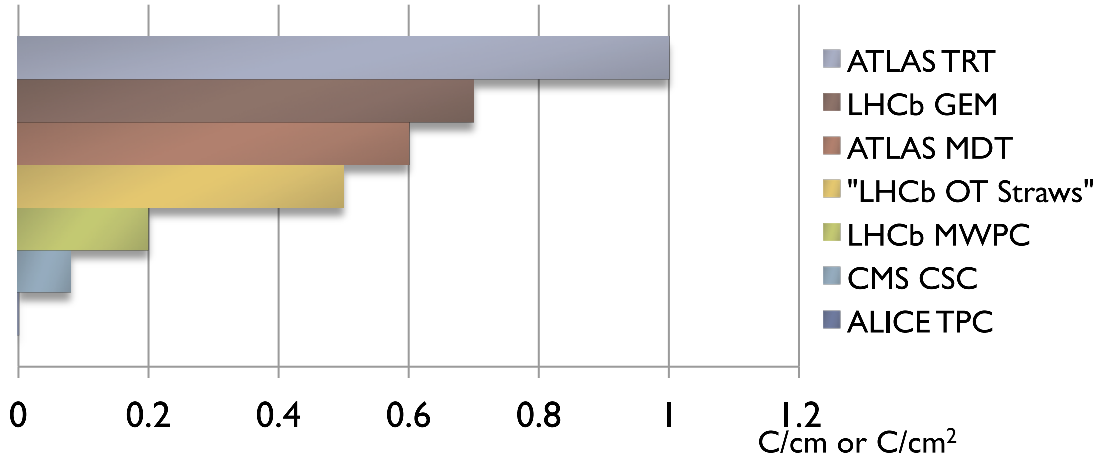
- Rate of Aging: R(%) ~ slope of **Gain vs. Q**

  where Q is expressed in [C/cm] for wire detectors and [C/cm$^2$] for strips or continuous electrodes.



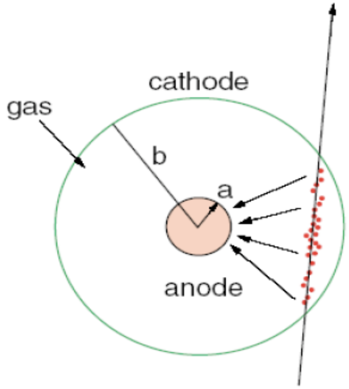

- **Accumulated charge per LHC year:**

- 1 LHC year = $10^7$ s
- Different safety factors
- Detectors operating at nominal conditions

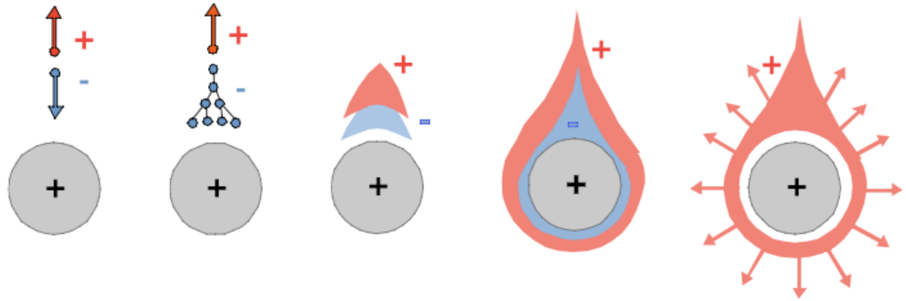


# Gaseous Detectors - Principle

$$E(r) = \frac{CV_0}{2\pi\varepsilon_0}\frac{1}{r}$$




Principle of Gas Multiplication ~ Signal development



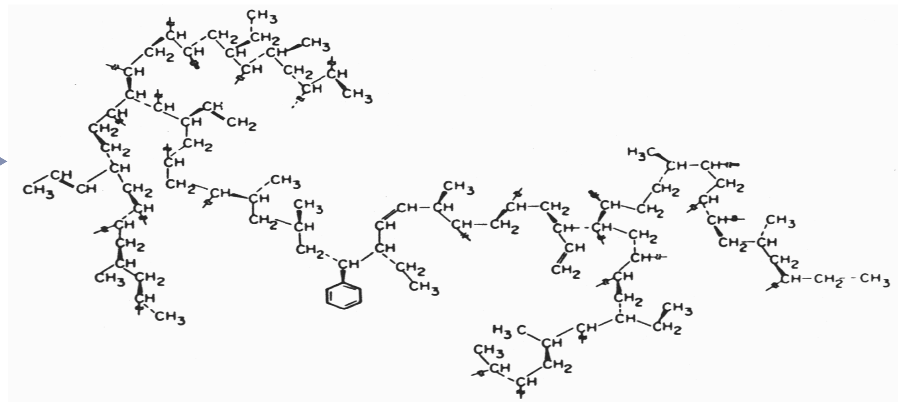
1. Gas mixture → $Ar + CH_4$

2. Initial Reaction → $e^- + CH_4 \Rightarrow CH_2: + H_2 + e^-$

3. Creation of radicals → $CH_2:$

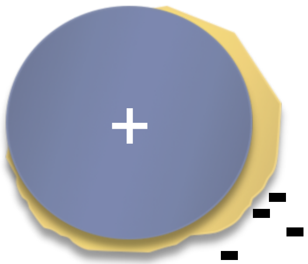
4. Polymer Formations →

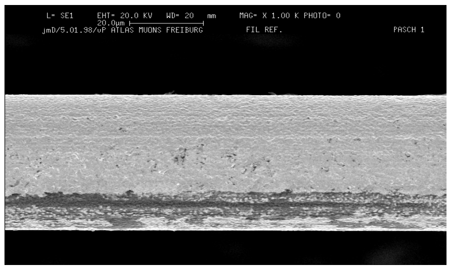
- Solid, highly branched, cross linked
- Excellent adhesion to surfaces
- Resistant to most chemicals
- Insoluble in most solvents

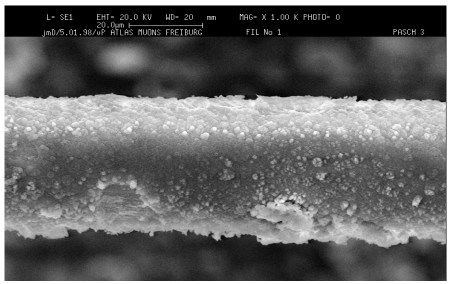


# Aging Phenomena

- Anode Aging: deposits on wire







## Effect of Deposits

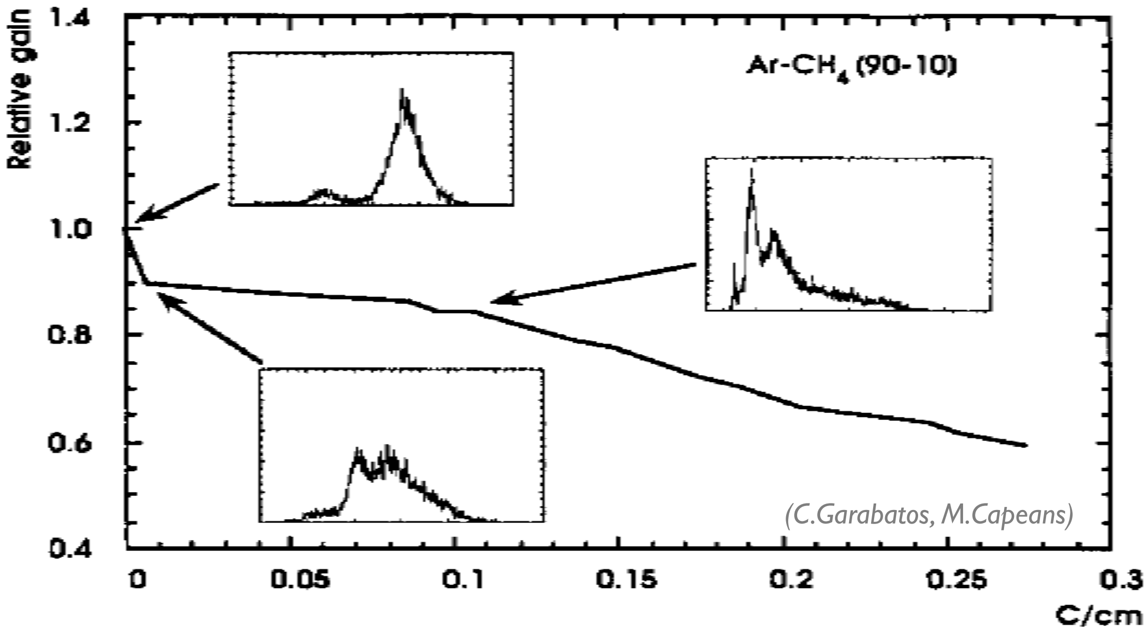
- If deposit is **conductive**, there is a direct effect: the electric field weakens (~thicker wire)
- If deposit is **insulating**, there is indirect effect due to dipole charging up: the field close to the anode will be screened as new avalanches accumulate negative charges on the layer

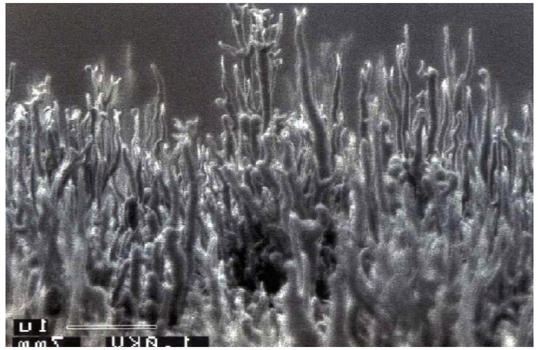
## Consequences on the detector

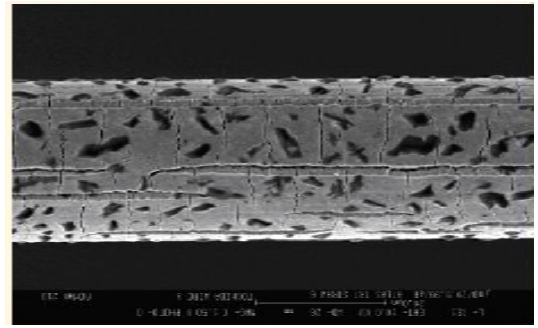
- Decrease of gain
- Lack of gain uniformity along wires
- Loss of energy resolution

# Anode Aging

SWPC
Aging Test in Laboratory

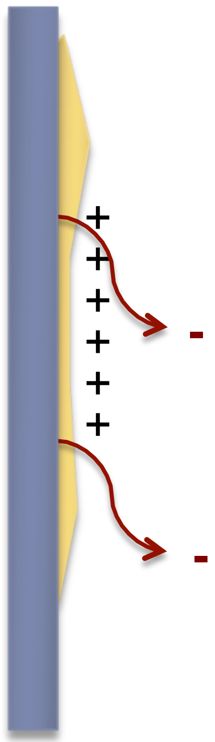




# Aging Phenomena

- Cathode Aging: layers on surfaces



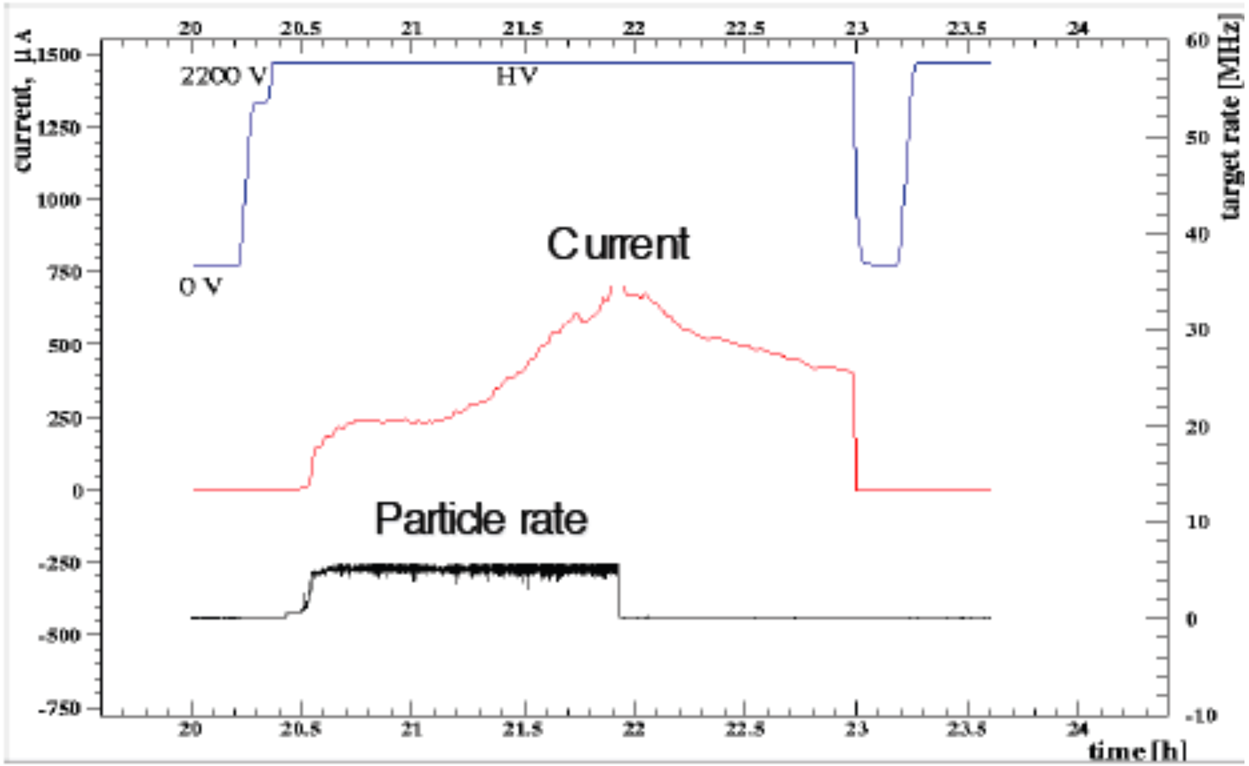

### Effect of Layers

- Charges do not reach the cathode and layer becomes positively charged. This produces a large dipole electric field which can exceed the threshold for field emission and $e^-$ are ejected from the cathode producing new avalanches
- Malter effect (self-sustained currents, electrical breakdown)

### Consequences on the detector

- Noise, dark currents
- Discharges

# Cathode Aging




**Malter effect**

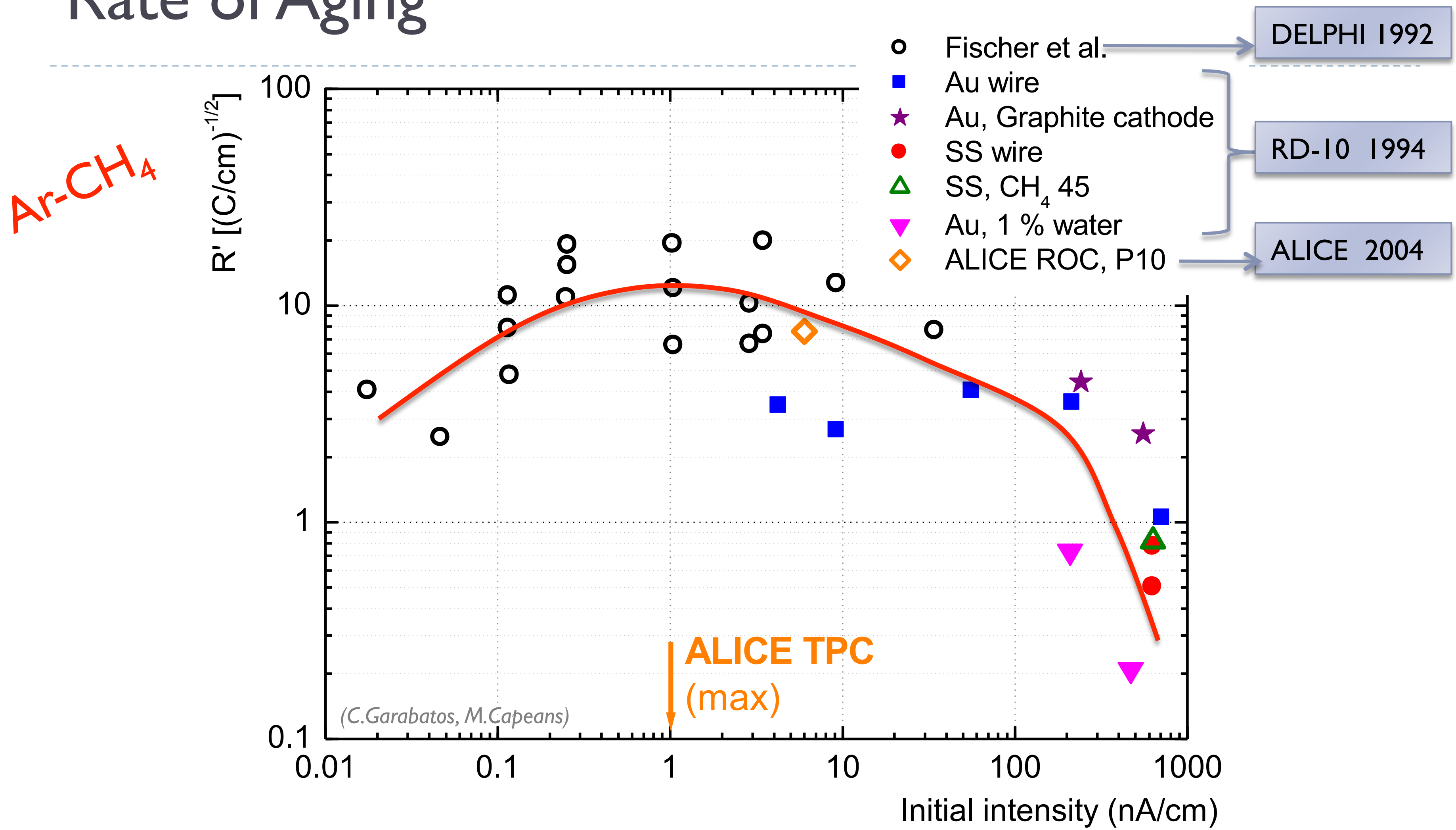
# Accelerated Aging Tests

- Needed in order to asses lifetime of a detector under irradiation in a limited amount of time
- How much can we **accelerate** the tests in the lab with respect to the real conditions?
- …Aging depends on:

Q [C] = Gain x Primaries x Rate x Time

| Gain | Rate |
| --- | --- |
| • HV<br>• Gas mixture<br>• Pressure<br>• Gas exchange rate<br>• Electrical field strength<br>• Detector geometry<br>• … | • Dose rate<br>• Ionization density<br>• Particle type<br>• … |

# Rate of Aging



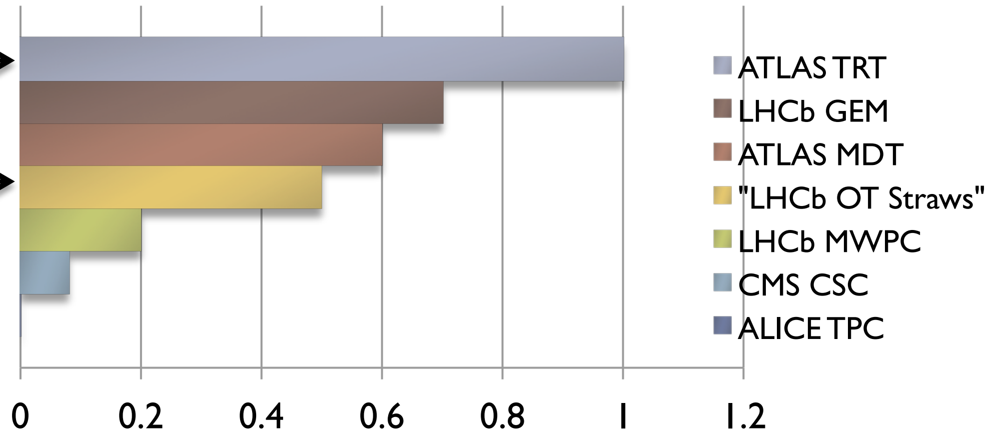

- Space charge gain saturation can decrease the polymerization efficiency
- Gas flow insufficient to remove reaction products created at high rate

# Acceleration Factors in Aging Tests of LHC Detectors

<u>Acceleration Factor in Lab Tests</u>

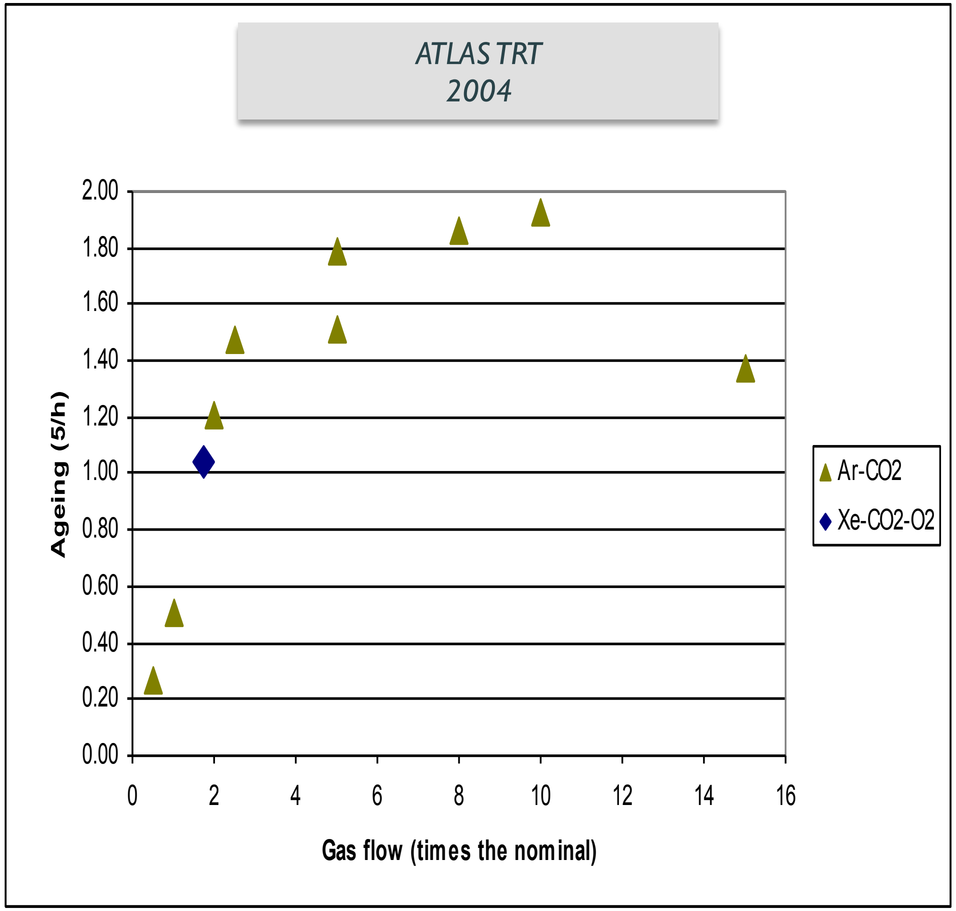
| | |
|---|---|
| **Atlas TRT** | x 10 |
| **LHCb OT (Straws)** | x 20 |
| **CMS RPC** | x 30 (and much larger) |

<u>Accumulated charge in 1 year at LHC</u>



# Aging Rate, for different Gas Flows

*(S.Konovalov, A,Romaniouk)*



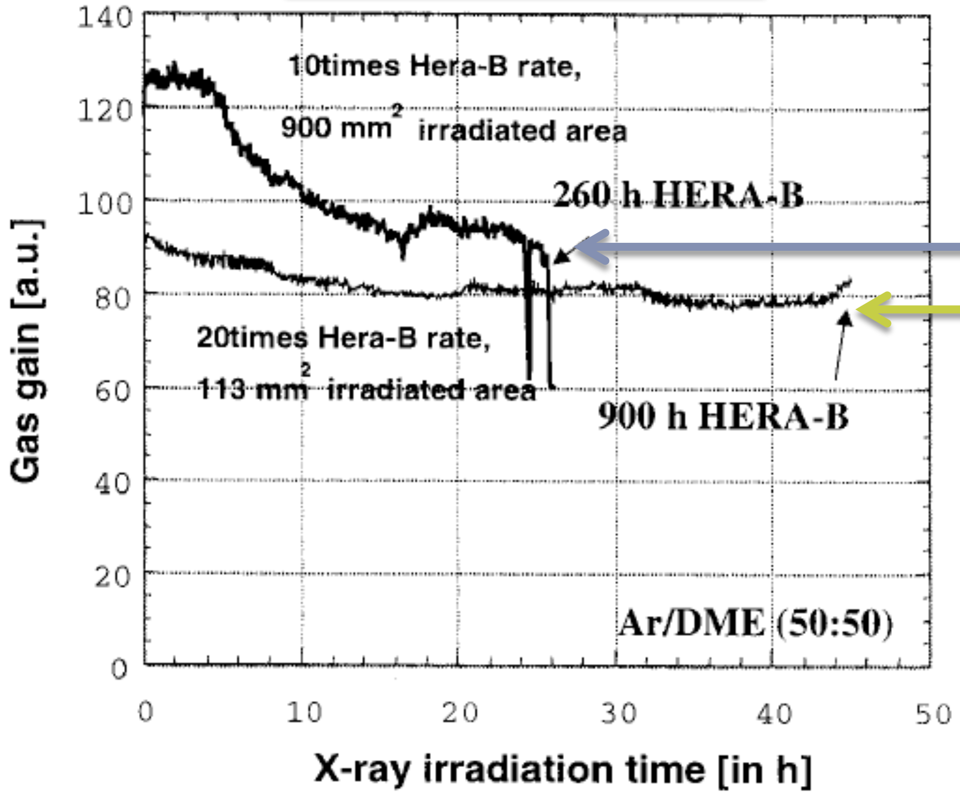

## ATLAS TRT Validation Tests

Lab test to measure rate of aging of TRT straws when the **mixture is contaminated intentionally**

LHC Nominal Gas Flow: < 0.15 $cm^3$/min/straw

# Aging Rate, for different sizes of the beam

Hera-B Inner Tracker (MSGC)
C.Richter et al.




*Lab test to measure rate of aging in the Hera-B MSGCs with X-rays beams of different areas*

**Irradiated area: 900 mm²**
Acceleration factor x 10

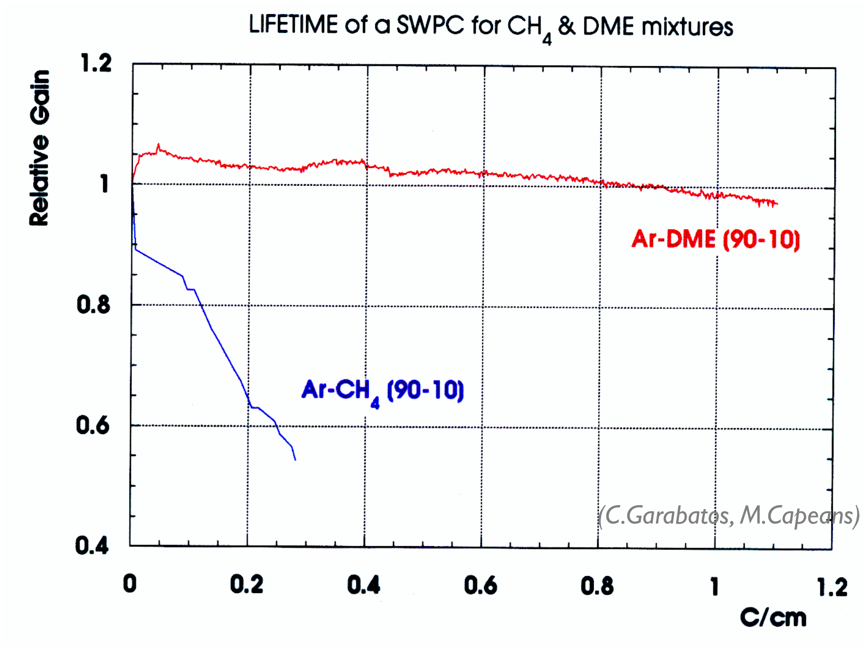
Aging Rate: 28%

**Irradiated area: 100 mm²**
Acceleration factor x 20

Aging Rate: 11%

# Influence of the Gas Mixture on Aging

- Hydrocarbons: polymerization (so, aging) guaranteed.
  - Polymer formation directly in the avalanche process.
  - Effect is more pronounced under spark/discharges




**DME**

- Flammable >3%
- Solvant
- Vulnerable to gas pollution

**$CO_2$**

- Increased HV
- More energetic discharges

# $CF_4$

high e⁻ drift velocities, low diffusion constant, high primary ionization, good ageing properties

**Deposition**

In hydrogenated environments – $CH_4$

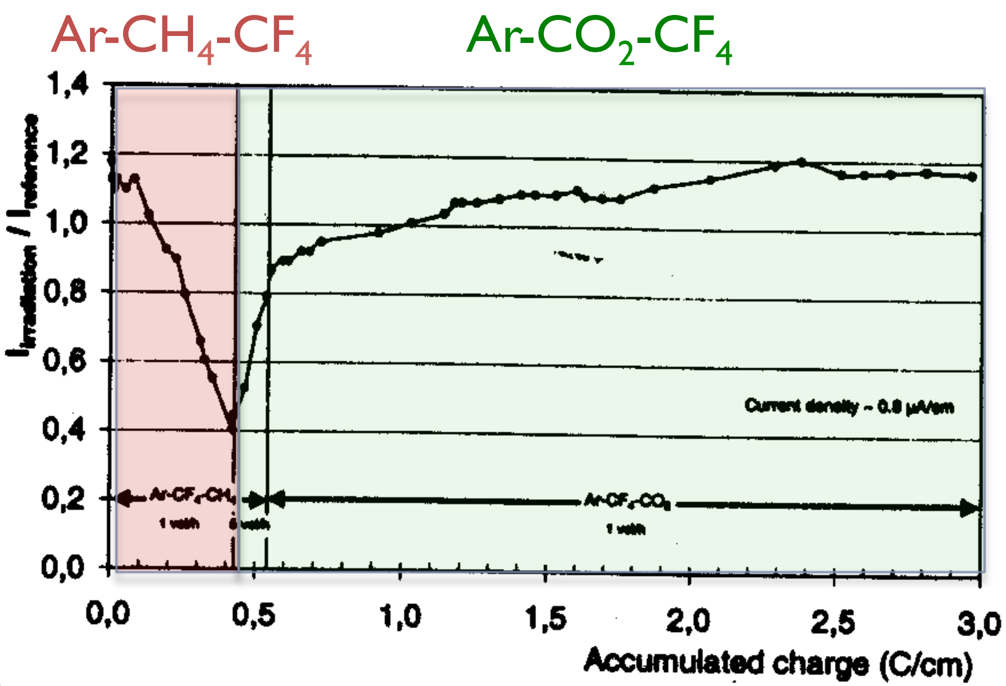
Deposits on wires

**Etching**

If oxygenated species are added – $CO_2$

Wire cleaning

Can also be aggressive to some detector assembly materials, can accumulate

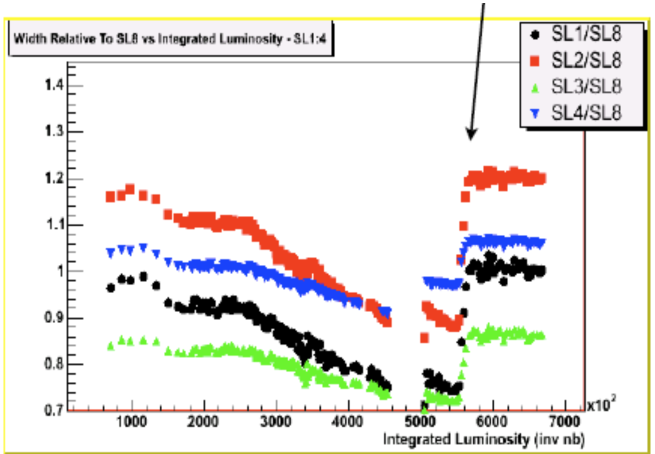


# Additives, Emergencies

- Small concentrations of some components can restore aged chambers or prevent effectively the aging process to significant accumulated charges

- **$O_2$**
  - Etching of HC-deposits
  - Reacts with HC, and end products are stable and volatile
- **$H_2O$**
  - Reduces the polymerization rate in plasma discharges
  - Makes all surfaces slightly more conductive, thus preventing the accumulation of ions on thin layers responsible for the gain degradation and Malter effect
  - But, modification of the electron drift parameters or change in rate of discharges are not always acceptable
- **Alcohols**
  - Reduction of polymerization rate
  - Large cross section for absorption of UV photons

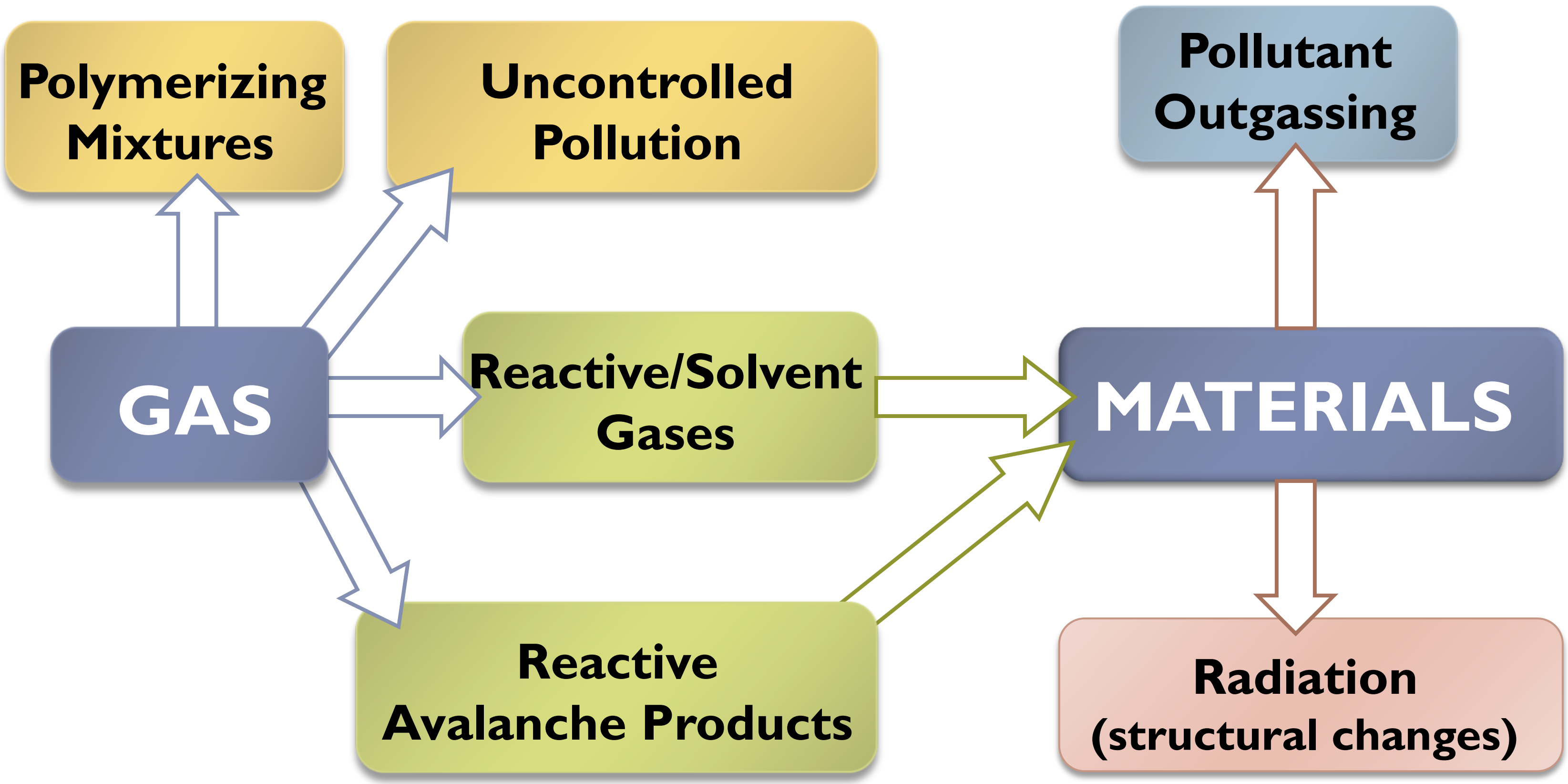
Addition of **$O_2$** in the gas mixture Ar-$C_2H_6$ [50-50]



# Gas Mixtures in LHC detectors

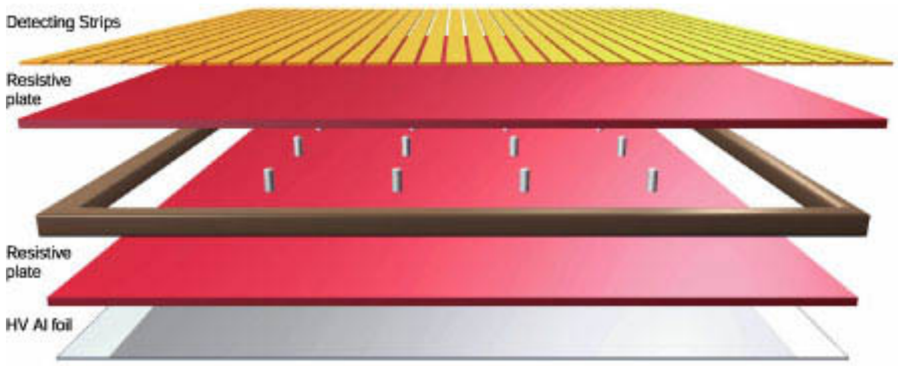
| Experiment | Sub- Detector | Gas Mixture |
|---|---|---|
| ALICE | TPC, TRD, PMD | Noble Gas + $CO_2$ |
| ATLAS | CSC, MDT, TRT | |
| CMS | DT | |
| LHCb | OT straws | |
| TOTEM | GEM, CSC | |
| LHCb | MWPC, GEM | Ar - $CF_4$ - $CO_2$ |
| CMS | CSC | |
| | RPC<br>TGC<br>RICH | $C_2H_2F_4$ - $iC_4H_{10}$ - $SF_6$<br>$CO_2$ – n-pentane<br>$CF_4$ or $C_4F_{10}$ |

# Contributions to the Aging Process

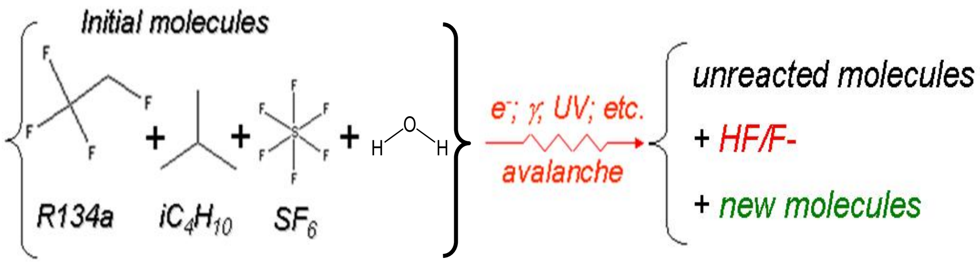


# Non Classical Aging, Ex: RPC systems

- **Resistive Plate Chambers (RPCs) at LHC:**
  - Relatively low production cost
  - High time resolution (~1 ns)
  - Suitable spatial resolution (~1 cm)



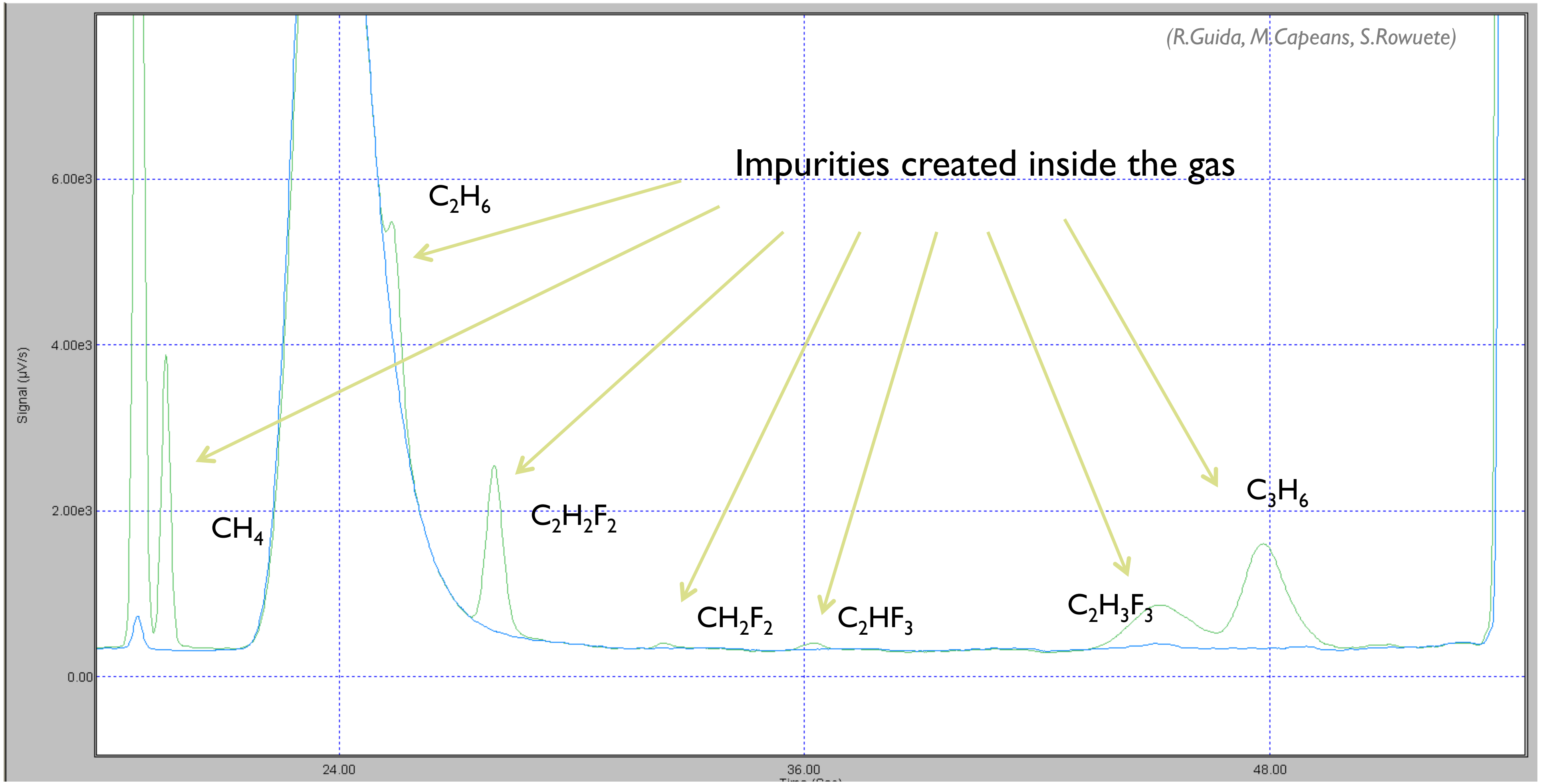

- **Gas mixture:**
- **$C_2H_2F_4$ - $iC_4H_{10}$ - $SF_6$ [95-5-0.3 %] +0.1% water vapour**
- The large detector volume (~16 $m^3$ in ATLAS and CMS) and the use of a relatively expensive gas mixture make a closed-loop circulation system unavoidable.



# Non Classical Aging, Ex: RPC systems

- RPC gas mixture under irradiation

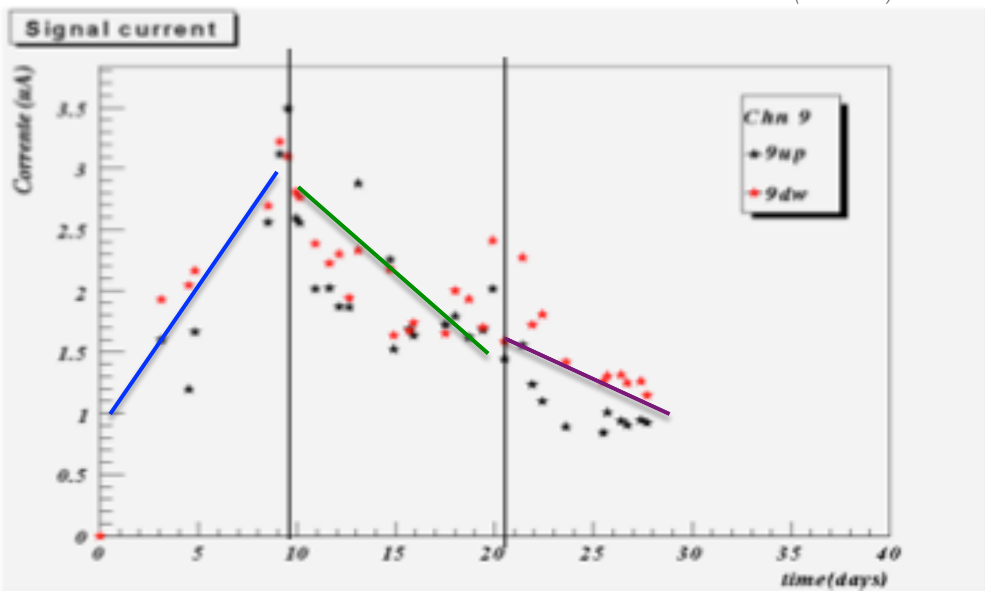
GC/MS signal: Fresh gas mixture (blue) and a sample of gas after the irradiated RPC chambers (green)



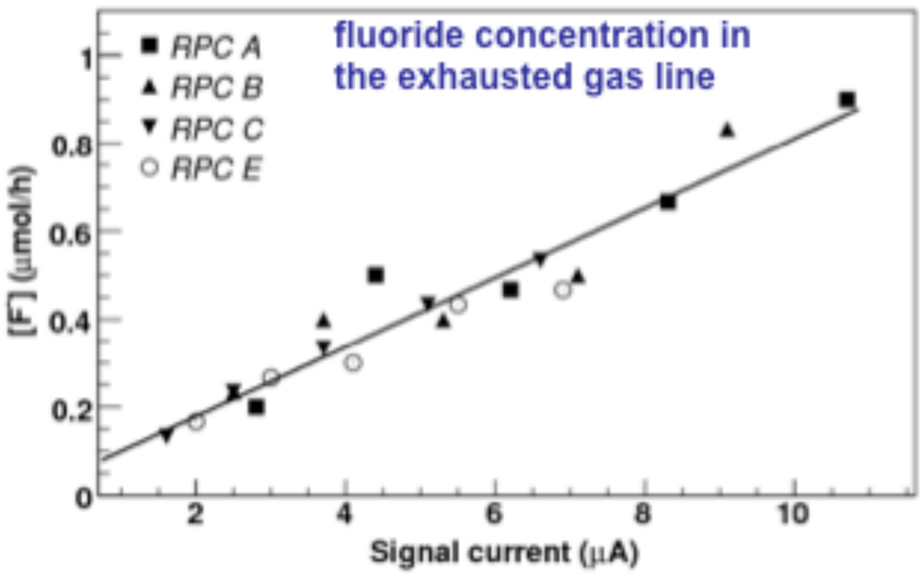
# Non Classical Aging, Ex: RPC systems

RPCs under irradiation at GIF, effect of impurities on chamber currents

(R.Guida)




(R.Guida)



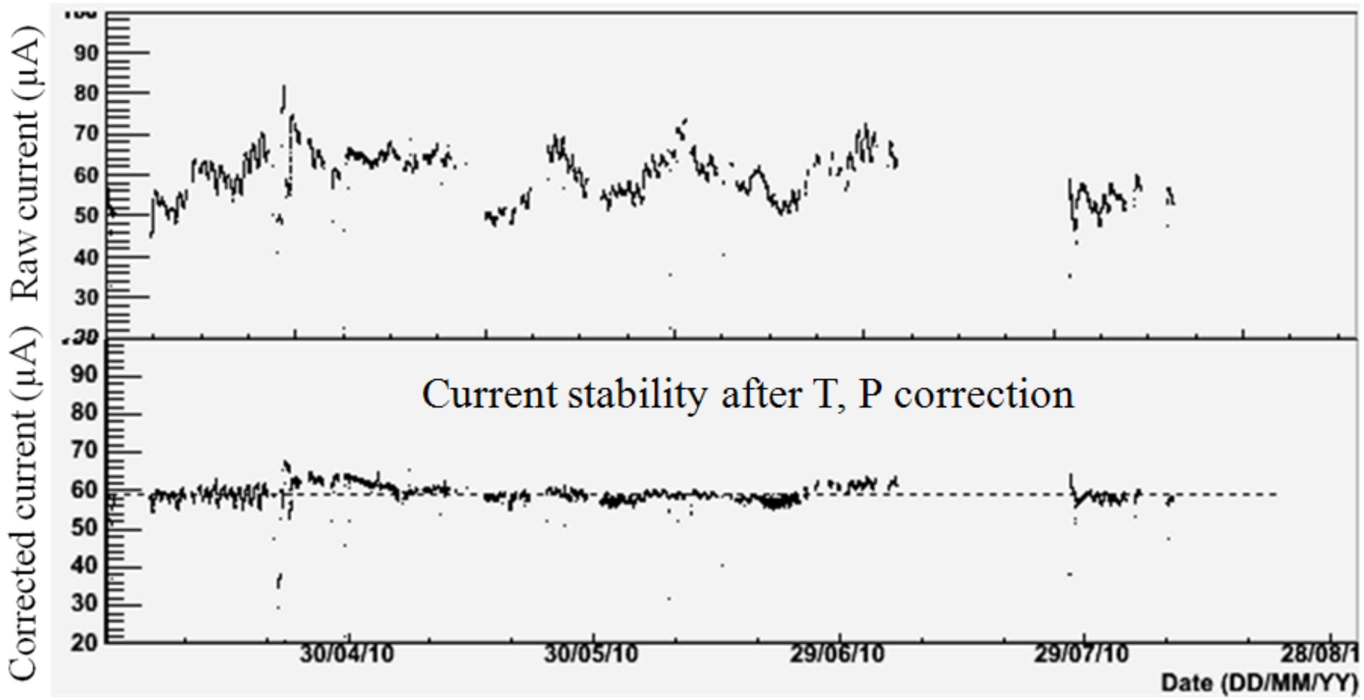

Closed-loop gas system

Open-loop gas system

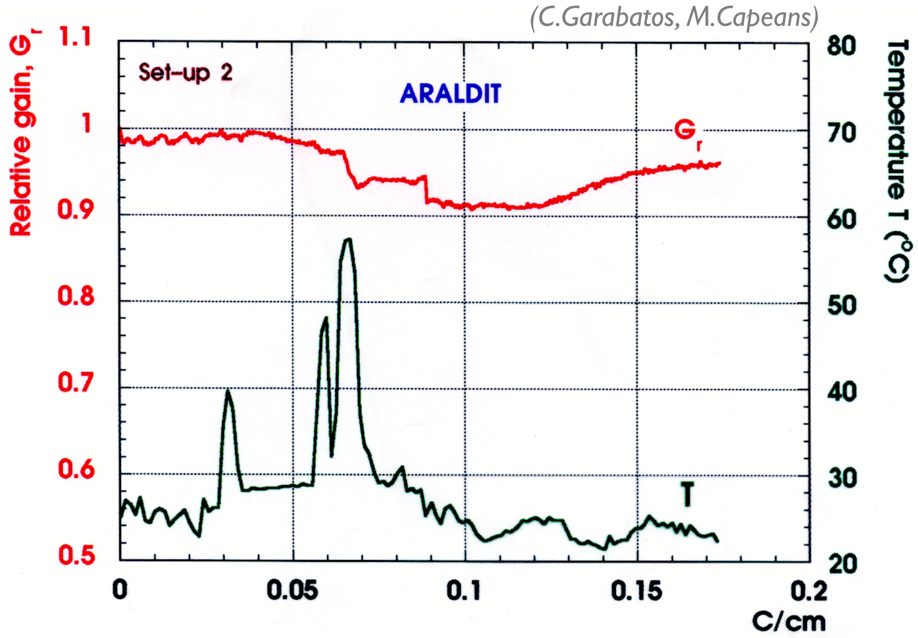
Closed-loop gas system with PURIFIERS

# Radiation Hard Detectors, Ex. RPCs

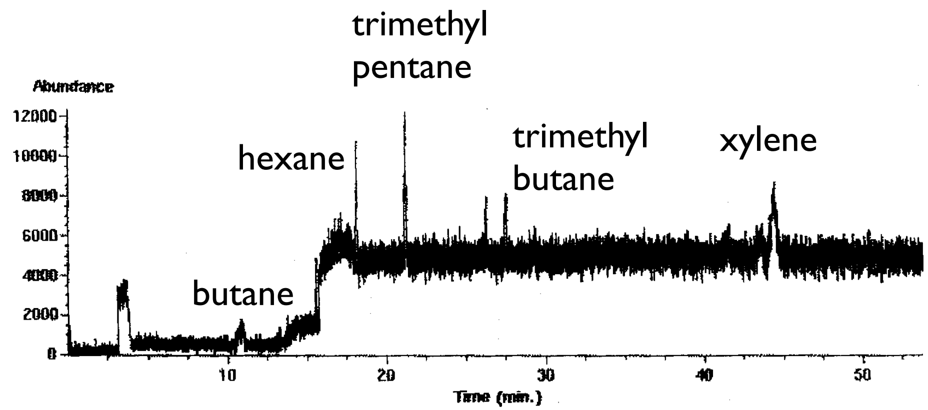
- **RPC irradiated at GIF in a closed loop gas system equipped with a set of optimal purifiers that keep the gas mixture clean at 1000 ppm level**
- Accumulated charge: ~ 50 mC/cm$^2$, that is equivalent to 1.3 y in ATLAS, 7.6 years in the CMS Barrel and 0.8 years in the CMS end-cap regions (at LHC nominal luminosity)



# Effect of Materials

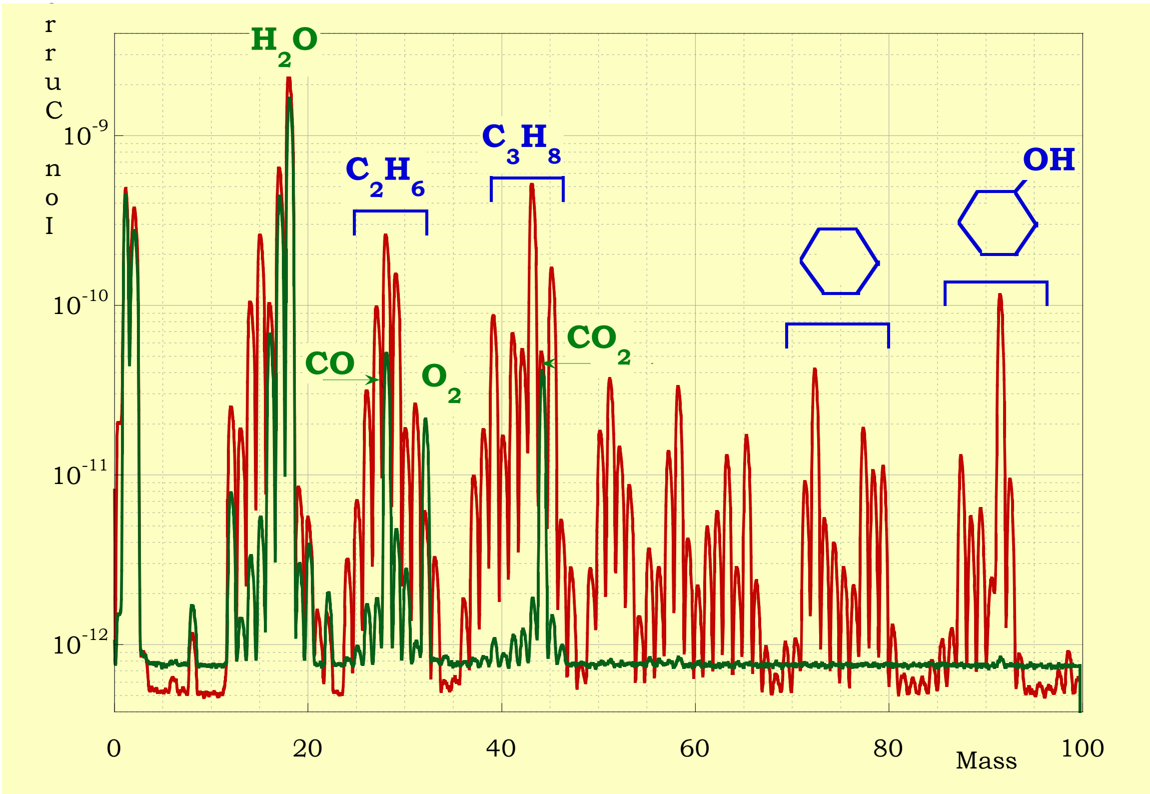



Aging test of a SWPC counter
Epoxy Araldite 106 inserted in gas stream




GC/MS analysis of the gas mixture
Outgassed components of Araldite 106

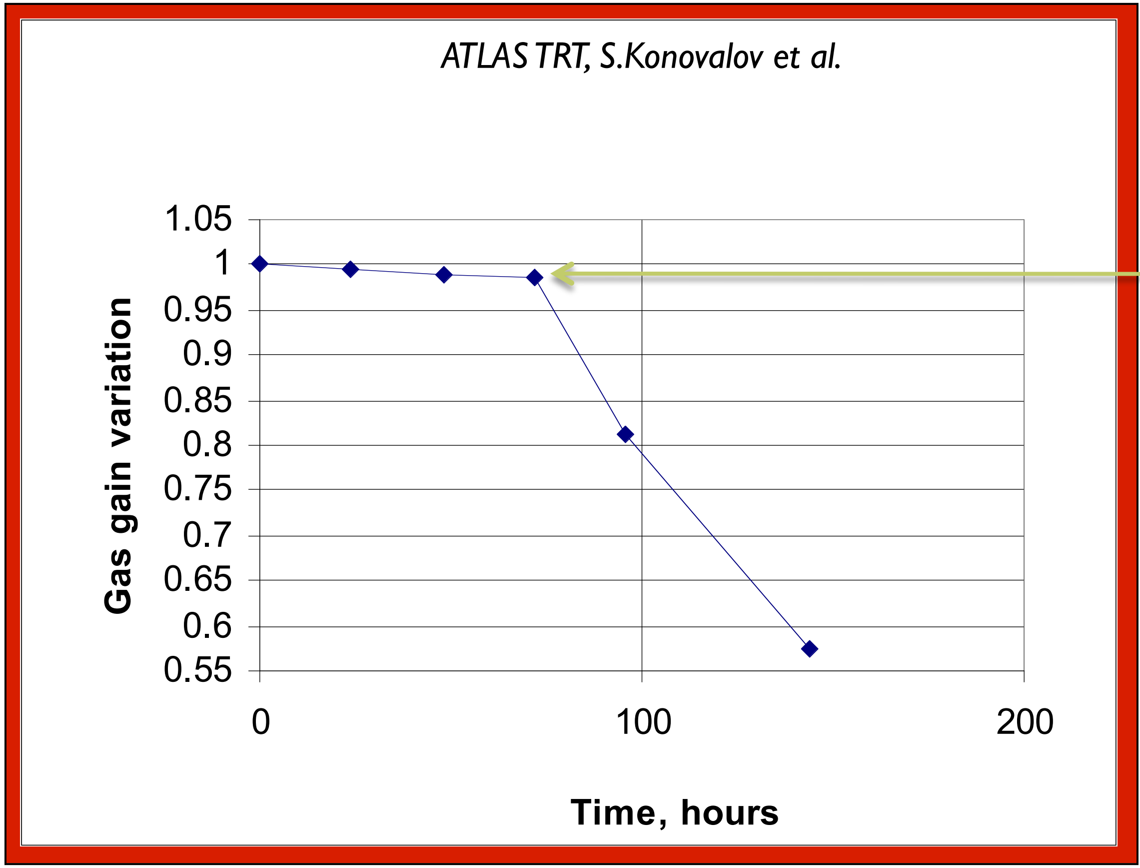
# Material Outgassing




Analysis of outgassed components of a 2-component Polyurethane

1. Green: sample treated correctly
2. Red: one component expired

# Pollution of the Gas Mixture




**Inserted a new flowmeter in the gas system, and gas gets polluted by minute amounts of Silicone-based lubricant**

# Materials

- Minor changes, big impact
- Difficult to control all parameters in large systems, at all stages
- Need validation of materials (detector assembly materials and gas systems' components), with an efficient strategy

http://www.cern.ch/detector-gas-systems/Equipment/outgassing.htm

Rigid Materials

| 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 |

Epoxies

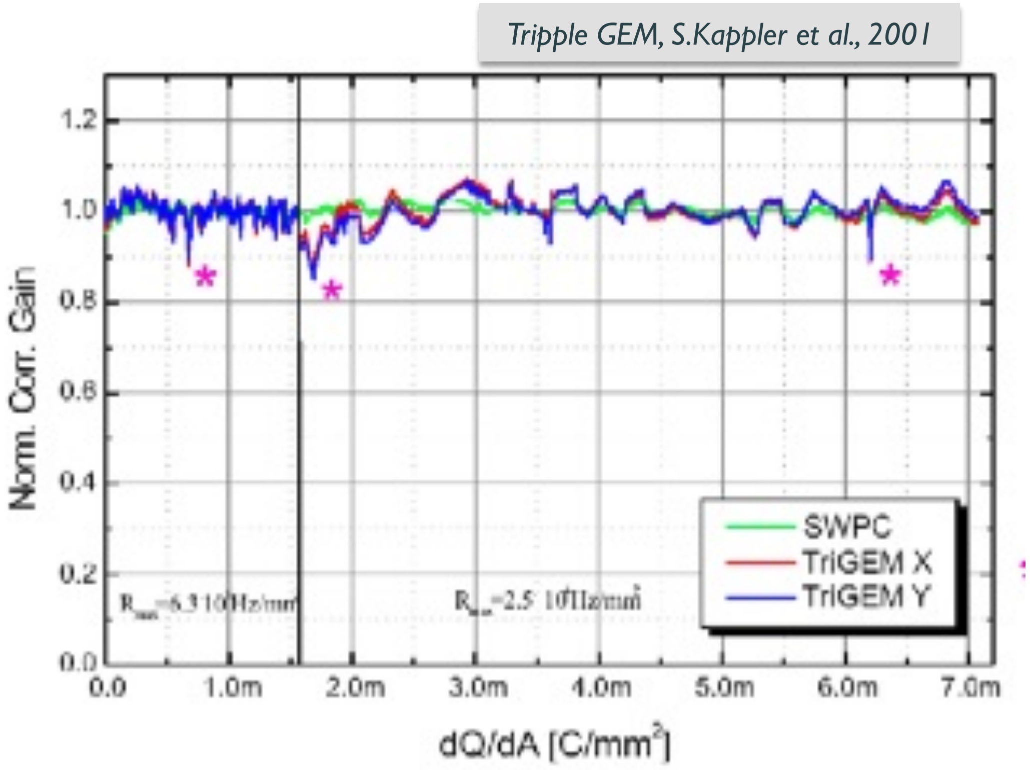
| Source | Product | Curing T (ºC) | Outgas | Effect in G.D. | Result |
|---|---|---|---|---|---|
| CERN/GDD | EPOTECNY E505 SIT | 50 | YES | NO | OK |
| HERA-B/ITR | EPOTEK H72 | 65 | YES* | NO | OK* |
| CERN/GDD | AMICON 125 | 85 | NO | - | OK |
| CERN/GDD | POLYIMIDE DUPONT 2545 | 65 | NO | - | OK |
| 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 |

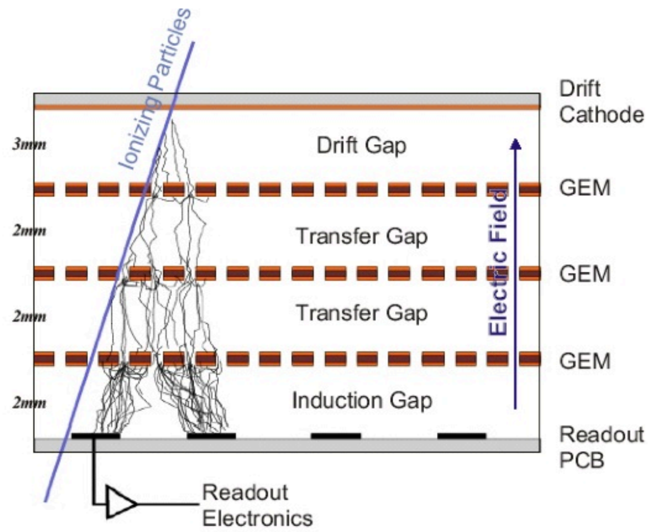
*(C.Garabatos, M.Capeans)*

# Rad-Hard Gaseous Detectors

- **Use good gases**: noble gas with $CO_2$ and maybe a small concentration of $CF_4$ or small amounts of additives like water, $O_2$…
- **Avoid contaminating the gas**:
  - Use outgassing-free detector assembly materials
  - Control all components in contact with the gas (gas system, piping, etc).
  - Do careful quality assurance during detector production
  - Review existing knowledge!
- **Test well:** select carefully the operating conditions in the lab (gas mix, gas flow, gain, rate, beam size, etc.). Keep in mind that accelerated Lab Tests may not be fully extrapolate to real conditions. We need to add to same **safety factors**.
- **Monitor anomalous behaviour of detectors.** If aging is detected soon enough, detector can probably be recovered (using additives in the gas, varying the gas mixture, reversing HV for some time, flushing with large amounts of clean gas…)

# Radiation Hard detectors, Ex. GEM




- ‘Good’ gas mixture: Ar-$CO_2$ 70-30
- Absence of thin anodes
- Gas amplification inside holes, rather far from signal electrodes and walls
- Field shape and strength possibly not affected by polymerization deposits, if any

# Concluding remarks

- Gaseous detectors are still the first choice whenever large area particle detection and medium space resolution is required.
- New gas detector developments (the MPGD family) extend the capability of gas detectors to applications where very high rate capabilities are required.
- Long-term operation in the high-intensity experiments of the LHC-era not only demands extraordinary radiation hardness of construction materials and gas mixtures but also very specific and appropriate assembly procedures and quality checks during detector construction and testing.
- Intensive research in this field has demonstrated that **when properly designed, constructed and operated, gaseous detectors are robust and stable.**

# Compilations

- Aging:
  - Wire chamber aging, J.A. Kadyk (LBL, Berkeley)

    Nucl. Instrum. Meth. A300:436-479 (1991)
  - Proceedings of the International Workshop on Aging Phenomena in Gaseous Detectors, M.Holhman et al. (DESY)

    Nucl. Instrum. Meth. 515, Issues 1-2, (2003)
  - Aging and materials: lessons for detectors and gas systems, M.Capeans (CERN)

    Nucl. Instrum.. and Meth. A515:77-88 (2003)

- Materials Properties for Gas Detectors and Gas systems:
  - http://cern.ch/detector-gas-systems/Equipment/componentValidation.htm