LHC Muon Detectors:

Longevity and aging issues

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Outline:

- The ID card of the present detectors (with italian contribution)
- Aging by technologies (some examples)
- An overview of the previuos aging campaign (with comments)
- Priority aging tests
- Summary and recommendations

The ID card of the <u>present</u> LHC ***Muon Detectors*** with Italian contribution

- ALICE: RPC, CPC, (MRPC)
- ATLAS: MDT, RPC (***uMegas***)
- CMS: RPC, DT, (**GEM, iRPC**)
- LHCb: MWPC, GEM

In red Future Detectors

- **Most** of the Experiments started **Mass Production** in early **2000**
- Detector' s **Installation** from **2004 to 2008**
- The **oldest** Detectors are about **10 years old**
- By the end of LS3 (**HL-LHC**) detectors will be **20 years old** and be required to operate **beyond** the **design specification** and after 20 years from the construction (14 years of operation).
- **Where** detectors **can not be replaced** actions should be taken **to improve** their longevity (i.e. further layers can be added)
- Increasing the **redundancy** (i.e. with new layers) **could** also **help** to overcome the danger of aging effects
- ***All*** the detectors are ***gaseous*** (wire/parallel plate)

The rationale

- PREVIOUS R&D STUDIES ON DETECTORS' AGING AIMED AT ASSESSING THEIR «10 LHC YEAR» LONGEVITY
- BY THE END OF PHASE 1 THE SAFETY FACTORS WILL BE ALMOST FULLY USED
- FOR HL-LHC A NEW CAMPAIGN OF AGING STUDIES IS NEEDED
- MOREOVER, THE REQUEST FOR ECOLOGICAL GAS MIXTURES REQUIRES STUDIES OF AGING PROPERTIES OF NEW GREEN GASSES AND DETECTORS
- ALSO IMPORTANT THE STUDY OF NEW MIXTURES THAT CAN HELP MITIGATING THE AGING
- NEW DETECTORS FORESEEN
- THE GAS MIXTURES CURRENTLY USED HAVE BEEN STUDIED WITHIN THE PREVIOUS AGING CAMPAIGN

Muon System lifetime

Muon system lifetime at LHC depends on

Detector lifetime

- Technology, aging properties (wire chambers /parallel plates)
- Location (background level)
- Sensitivity to neutrons and photons (the main sources of bkg)
- Accumulated charge per hit (according to working regime)

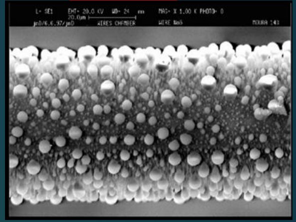
Frontend electronics lifetime

- Resistance to irradiation
- Aging of components
- Components obsolescence (spares unavailability)

Aging by technologies

Drift/Wires

«Classical aging» (and most studied from plasma physics): chemical reactions near anodes during avalanche formation leading to (conducting/insulating) deposits on electrodes surfaces



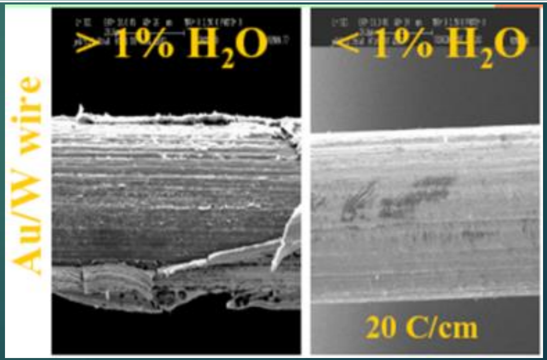
Nucl. Instr. and Methods **A515**, 53 (2003).
Nucl. Instr. and Methods **A488**, 240 (2002).

Potential aging effects:

- Loss of gas gain and reduction of the plateau
- Loss of energy resolution
- Increase of dark current
- Distortion of the pulse height distribution
- Electron emission (Malter Effect)
- Sparking
- Self-sustained discharges
- Etching of the surfaces

Preventing ageing:

- Clean procedures during chamber assembly
- Very clean gas system
- No hydrocarbons in gas mixtures
- No use of silicone
- ...and other (use of water, few percent of O_2...) but some controversial



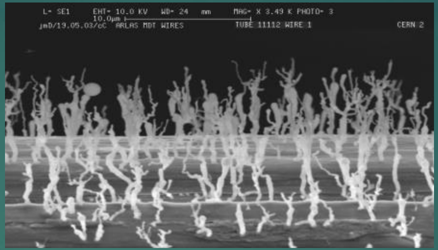
M.Capeans MPGDWorkshop Sept07

Example: MDT (ATLAS)

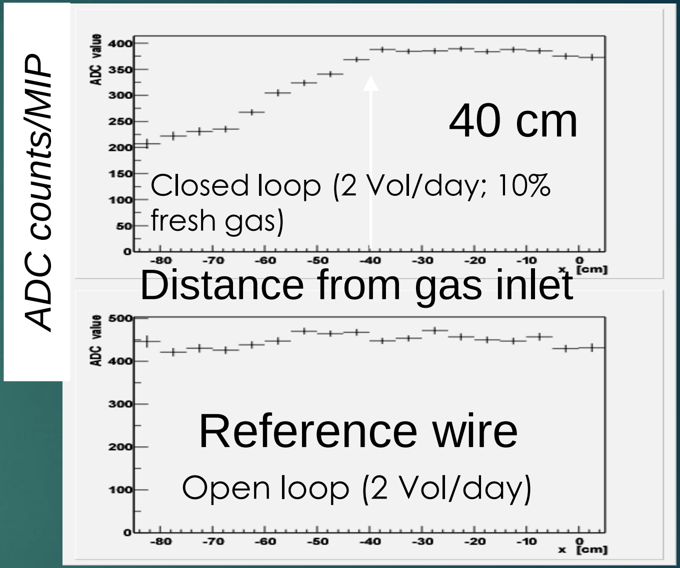
- ^{137}Cs@GIF + 100 GeV μ beam (2001-03/2006)
- γ rates up ~1kHz/cm^2 → Int.charge 300 mC/cm

30 mm diameter tubes
Ar/CO2 @ 3 Bar

- Effects due to gas pollution



Nuclear Physics B (Proc. Suppl.) 150 (2006) 168–171
S.Zimmernmann, CERN-THESIS-2004-018



From M. Iodice (ATLAS)

- Use of gas filters led to a complete recovery.

Full Size Detectors used

- Now: recent studies on higher rate zones show no ageing effects up to now → expected to sustain HL-LHC following some consolidation works

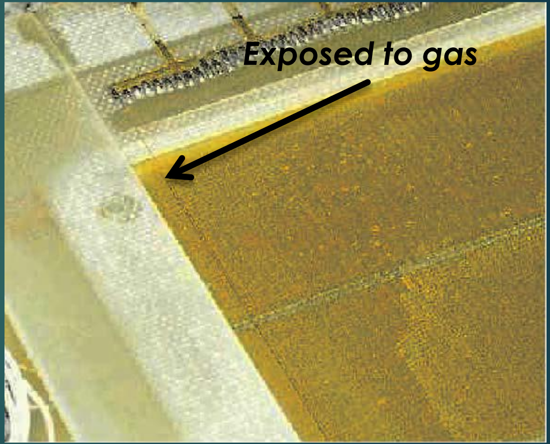
Example: MWPC (LHCb)

- *^{137}Cs@Gif (2003) γ rates up ~30 kHz/cm^2*
- *^{60}Co@Calliope -ENEA (2009) γ rates up ~1kHz/cm^2*

Ar/CO2/CF4

NIM A 515 (2003) 220–225, NIMA 599 (2009) 171–175, NIM A 593 (2008) 319-323

- Effects of the gas on to the materials (etching of RF4)



- Good time resolution and eff up to 28nA/cm^2
- Front-end dead time → expected to sustain HL-LHC following some consolidation works (electronics …)

Full Size Detectors used

Integrated Charge 0.25 C/cm to 0.4 C/cm (wires) and 0.8 C/cm^2 (cathode)

Aging by technologies

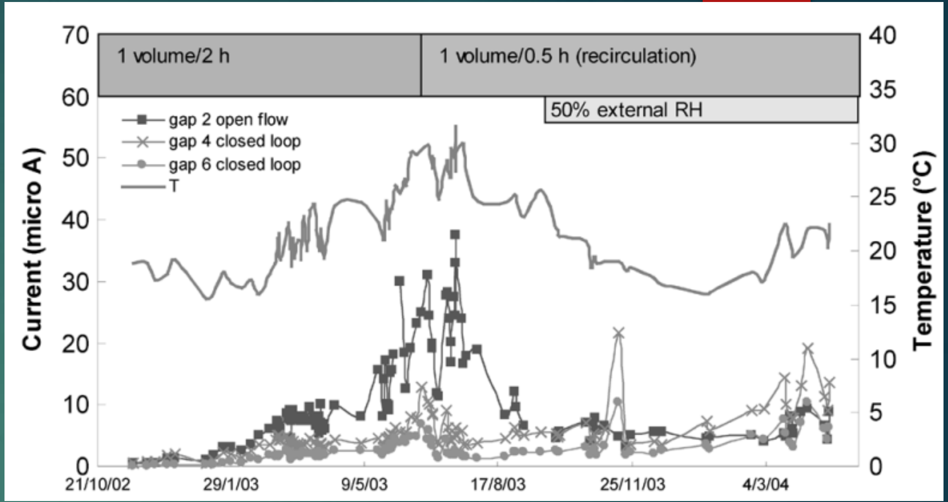
RPC

- Given an amount of integrated charge it gives a very different effect depending on how it is generated and depending on:
  - **Working point**: the lower the better
  - **Temperature**: the lower the better
  - **Relative humidity**: best value 40-45% for stable resistivity around $5*10^{10}\ \Omega$ cm
  - **Resistivity**: the higher the better compatibly with the rate expectations
  - **Coating**: a stronger coating increase the detector endurance
  - **Gas composition**: HF production, the lower the better
  - **Gas change rate**: the higher the better

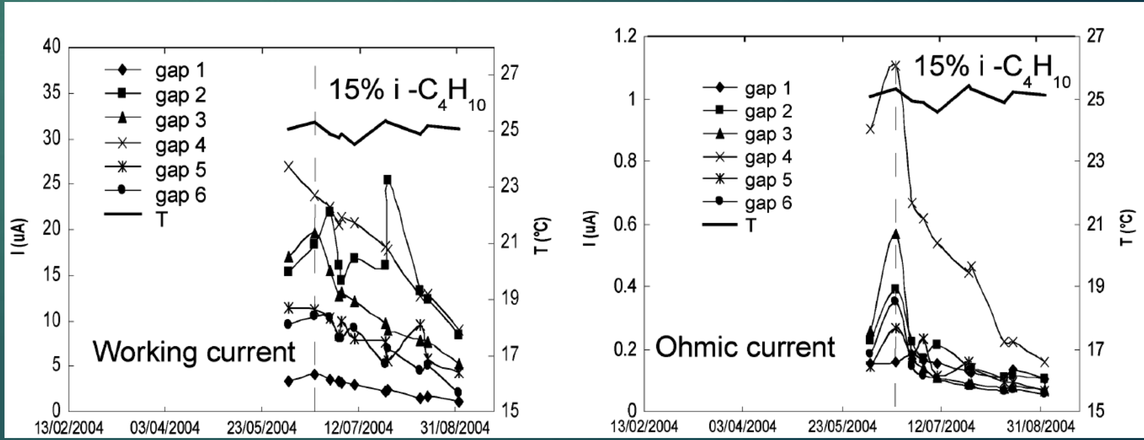
- It turned out that in case of detector internal damage a current generated in ideal condition can heal the problem instead of worsening it!

The atlas RPC ageing case (@ GIF)

- Recovery after extreme damage due to the recirculation (and dcs) failure
- Increase of the noise current up to 20 μA source off. Also the ohmic current increased



- Recovery monitored at constant temperature
  - Deep cleaning with pure argon discharge
  - Operation at reduced voltage (7000V)
  - 15% C4H10
  - 2 change/h
- Extra current disappeared completely and the detector performance was as before

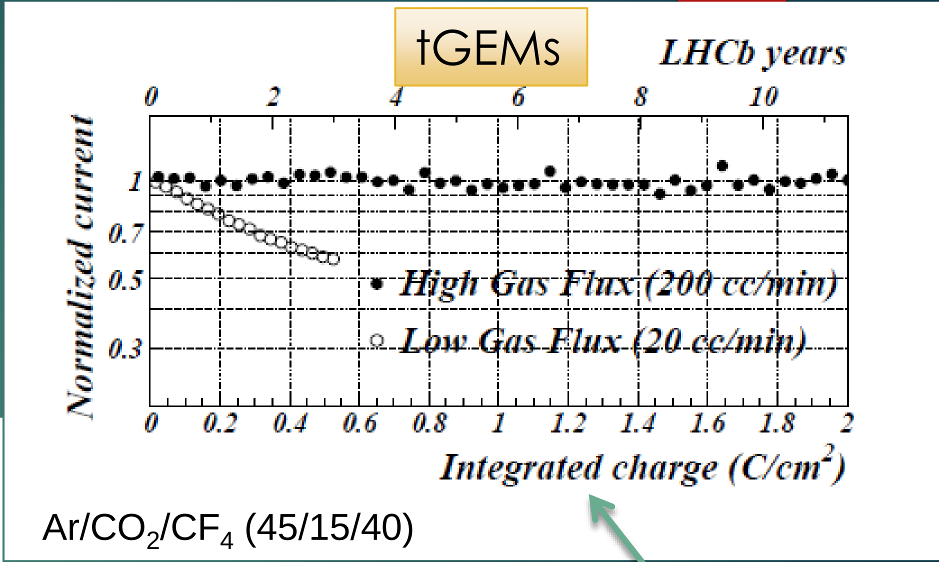


Aging by technologies

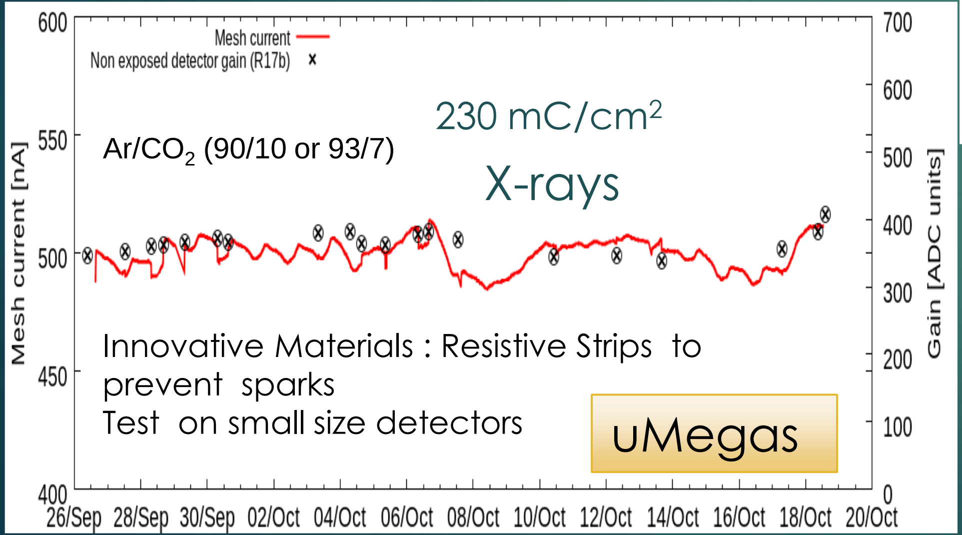
Nuc Phys. B (Proc. Suppl.) 150 (2006) 159–163

GEMs, μMEgas

Usually "Not expected" …provided that the gas flow is adequate, as well as other recommendations (clean assembly material, clean gas systems, gas flow …)



0.3 Vol. change/min
vs
3 Vol. Change/min



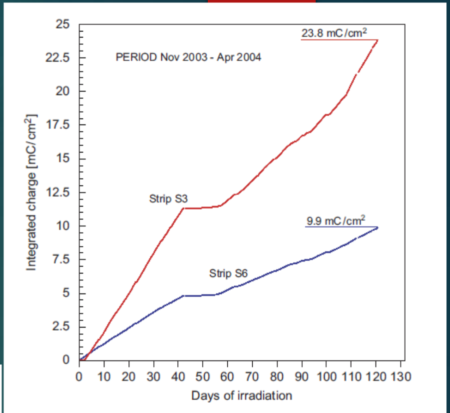
Small size detectors used

arXiv:1301.7648v1 [physics.ins-det] 31 Jan 2013

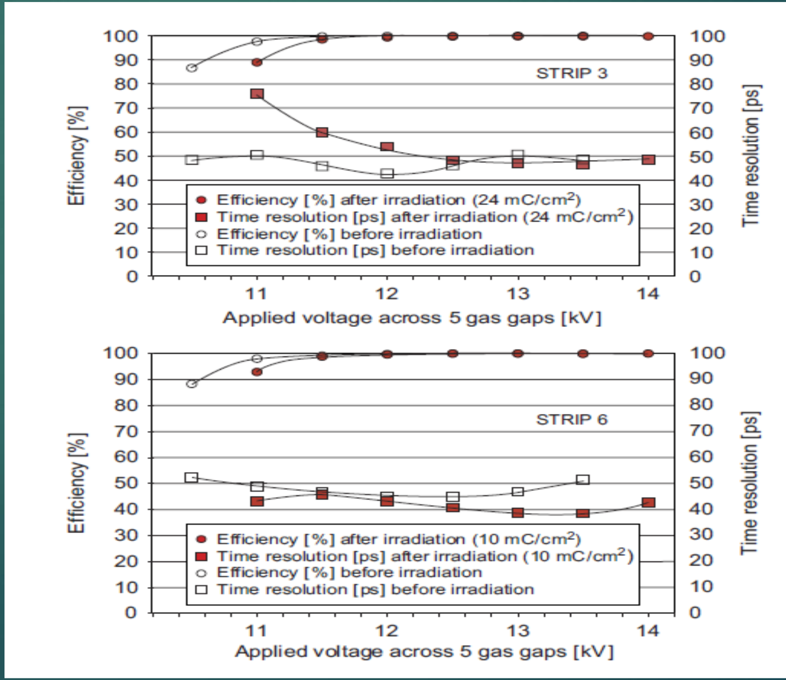
Aging by technologies

MRPC

- No aging effects up to 24 mC/cm² (and not expected)
- Rate capability up to 2.5 kHz/cm² (well above the ALICE requirement) but can be much higher (→low resistivity glass)



Efficiency, time resolution
Not affected after 24 mC/cm²



NIM A 579 (2007) 979-988

Full size
detectors used

Some general parameters to be studied for an aging test:

- ❑ Material : aging (after rad exposition) and gas pollution due to outgassing

- ❑ Detector:

- Dark current, Gain (integrated Lumi effects)
- Resistivity, Strip to strip capacitance, Shielding (at Design level)
- T,RH,P (for normalization)
- Efficiency, Rate capability, Plateau stability , Cl.Size (istant. Lumi effects)
- Sensitivity to neutrons and gammas
- Gas composition, Gas flow, Working point (aging mitigation)

- ❑ Size of the detector/irradiated zone : full size , fully equipped

- ❑ Electronics: Single Event Effects, Total Dose damage

An overview (not complete) of the previous aging campaign....

EXP	Detector	IntCharge (mC/cm2)	Full Size? YES/NO	Counting Rate (Hz/cm2)	Aging/Comments	Number of Detectors	Particle	Facility	Use of Fluorine in the mixture
ALICE	RPC	23	NO	60	*After 15mC/cm2 current instability (due to high working point)*	3	g	GIF	
ALICE	RPC	50	NO	60	*NO*	3	g	GIF	YES
ALICE	MRPC	24	YES		*NO*	5	g	GIF	
ATLAS	MDT	4.8C/cm	YES		*NO*	2	g/n	ENEA	NO
ATLAS	RPC	300	YES	700	*Incr. of rho, recover with RH, incr. of current recover with iC4H10, good eff*	3	g	GIF	YES
LHCb	GEM	2200	YES	2E+07	*Etching of gem's hole due to low gas flow, recovered, NO overall*	3	g/pi	ENEA/CERN	
LHCb	GEM	1800	NO	5E+07	*50% gain reduction, 20 V shift of the wp but still inside specs*	3	Xray/pi	ENEA/PSI	YES
LHCb	MWPC		YES	3.5E+04	*Good time res, eff up to 28 nA/cm2 but FEE dead time when full source on*	1/3	g	GIF/ENEA	
CMS	RPC	50	NO	200	*NO, small increase of op. Voltage at 90% eff,small decrase of counting rates*	11	g	GIF	
CMS	RPC	25	YES	200	*NO, use of wet mixture to control electrode resistivity*	2	g	GIF	
CMS	RPC	230	NO	800	*NO*	4	g	Korea	YES
CMS	RPC	500	NO	3000	*YES, dark current increase, bulk damage by HF, dark rate increase*	3	g	Korea	
CMS	RPC		NO	2500	*NO (d@50 MeV on Beryllium target) (some activation)*	2	n	UCL	
CMS	DT		YES	1E+04	*NO*	2	g	GIF	NO

How much time an aging test may last (given a safety factor and acceleration factor)

SF = x5 (Safety Factor)
AAF= 10 ÷100 (Acceleration Aging Factor)

Tecnology | LHC | Experiment

$$\text{Expected int charge}\left(\frac{C}{cm^2}\right) = \left[\varepsilon\frac{Charge}{hit}\right] \times \left[\frac{0.5\times10^7}{LHCy}s\right] \times \phi_{particle}^{Experiment} \times SF \times [n°LHCy]$$

Fixed

$$\text{Aging test int charge}\left(\frac{C}{cm^2}\right) = \left[\varepsilon\frac{Charge}{hit}\right] \times [T\_test] \times AAF \times \phi_{particle}^{Experiment}$$

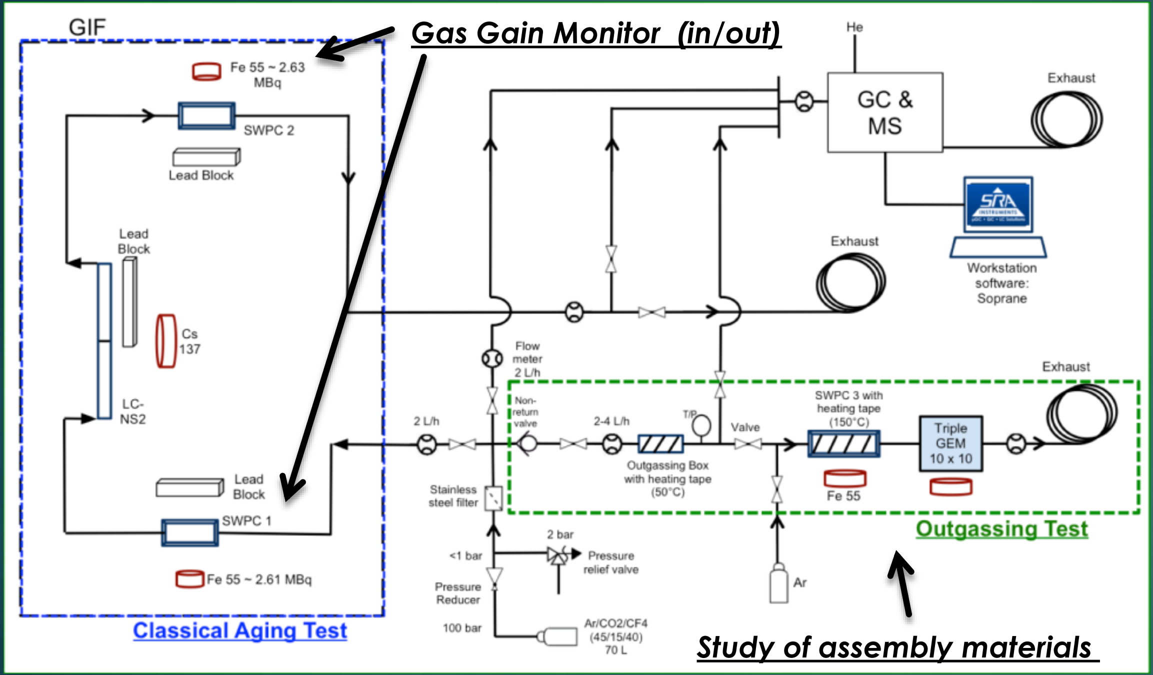
If *Aging test integrated charge = Expected integrated charge*

$$[T\_test] = \left[\frac{SF}{AAF}\right] \times \left[\frac{0.5\ \times 10^7}{LHCy}s\right] \times [n°LHCy] = 0.1 \div 1\ \frac{months}{LHCy} \times [n°LHCy]$$

Common Test Facilities

Typical test stand for detector aging studies :

NB: For Gas Aging Studies a small cosmic stand (lab size) may be enough. After optimization a full test ot a facility can be foreseen.



+ Beam (beam trig) + Cosmic (cosm trig)

Used Tecnologies to study gas aging

- Infrared Spectroscopy → Gaseous, Liquid, Solid samples
- EDX (Energy Dispersive X-ray spectroscopy with electrons) → solids samples
- GS (Gas Cromatography)
- MS (Mass Spectrometry)

Synergy tests at work at GIF/GIF++

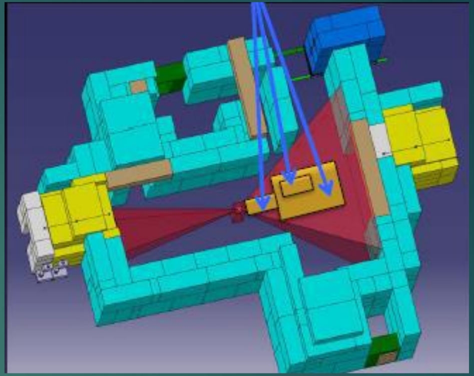
Common efforts already started between:

ALICE, ATLAS ,CMS / RPC HPL and glass (but other detectors are welcome)

- "Standard" tests:
  1. Measure and monitor chamber ageing Current monitoring stability
  2. RPC radiation sensitivity
  3. RPC rate capability
  4. Performance under irradiation
- Comparison among different FE proposed

  Performance assessment under stress
- Set-up for HF measurements

  function of chambers parameter, irradiation and gas mixture composition
- RPC consolidation (improved chambers for the existing system)



- Infrastructure being developed (for GIF++) at the old GIF including:
- DCS and DAQ (by ATLAS)
- Fluoride measurement tools (by CMS)
- Dedicated gas system (by Alice)
- Gas humidification and distribution (CERN gas Group)
- Test on both prototypes and production chambers

Single Event Effects measurement (**SEE**) – ***Active test*** –
Goal: ***SEE cross section estimation***
Procedure: supplied boards exposed to the beam , open inputs
→ number of events (due to interactions of particles with chips) counted
→ $\sigma = R/\phi$
Acquisition time: from particles flux and interactions cross sections with Si
→ obtain a statistically significant number of events
→ **NO** need for a lot of fluence
Particles: Neutrons: thermal (interactions with boron), fast (E > MeV) and Ions

Cumulative Effects measurements – ***Passive test*** -
Goal: maximum tolerated fluence estimation
Procedure: non supplied boards exposed to the beam
→ comparison between board's parameters before and after the irradiation
Acquisition time: need to accumulate the right FLUENCE (1 year LHC…)
Particles: Neutrons, Gammas

Priority Aging Tests …

- ***Single Event Effect and Total Ionizing Dose on New electronics***
  → Neutrons (to study Single Event Effects): from thermal up to 100 MeV (from 20 MeV up protons can «simulate» neutrons since inelastic cross section on Si almost equal)
  → Photons (to study dose damage) : <energy> 1 MeV and up to 10 MeV

- ***New gas (green) mixtures and their aging properties***

- ***Aging and outgassing of new materials*** (especially for Upgrade detectors)

- ***Detector Sensitivity to gammas and neutrons***

- In case ***spares*** from the ***mass production*** (that are getting old naturally) are ***available*** , aging test on them could infer some information on the ageing factor due to only the running life so far

Summary/Recommendations

- ***Longevity expectations*** are quite good and existing detectors are expected to safely operate at HL-LHC ....***provided that***
- ✓ ...some ***additional changes*** (electronics, gas regime) ***will take place***
- ✓ ...the **continuous monitoring** of the working parameters and possibly their ***modification*** (gas flow, working points, etc..) ***will be assured*** (aging mitigation)
- ✓ ... a **consolidation** , when required, will be ***planned*** and ***resources allocated***
- ✓ ...the ***maintenance*** of the systems can be ***guaranteed***

- ***New aging tests*** on existing and new detectors, electronics and new green gas mixtures are ***necessary***
- ✓ ...***Spare detectors*** (naturally aged so far) ***may be used***
- ✓ ...***Common efforts*** to ***share costs*** and to ***optimize facilities*** time sharing should ***be organized*** [Already ***good example*** of synergies among groups and detectors (Atlas,CMS,ALICE) (RPC,GEM,iRPCs) at GIF/++ ***to be sustained and expanded***]
- ✓ ...***In view*** also of the experiment's Technical Proposals for Phase 2 → ***short timescale*** (about 4 years)

Backup

Where?

Facilities considered for the irradiation

Facility	Beam
LENA Pavia	Neutrons
ENEA Casaccia	Neutrons
PSI Villigen (Svizzera)	Neutrons
Louvain la Neuve (Belgio)	Neutrons , Ions
ENEA Frascati	Neutrons, gamma
TSL Uppsala	Neutrons
LNL Legnaro	Neutrons , Ions, Gamma
CNAO Pavia	Carbon Ions
GIF (++)	Gamma

Thermal (LENA Pavia, ENEA Casaccia, PSI Villigen)

Fast (Louvain la Neuve, ENEA Frascati, TSL Uppsala)

..and others in Italy and Europe..

Example of a planned aging test at UCL with neutrons (CMS - RPC/GEMs) (Detector&Electronics)

13 h of beam time:

Measurement A: ***Detector irradiation***:

6 h of beam time at 10^{7} n/cm²s

Constantly measure the chamber's sensitivity to neutrons.

→ After the irradiation, ***a recovery time*** of at least an hour without beam,

→ Followed by 1 h of irradiation, always with the same flux, : verification of possible irreversible aging

Measurement B: ***Front-End electronics irradiation***:

6 h of beam time at 10^{7} n/cm²s,

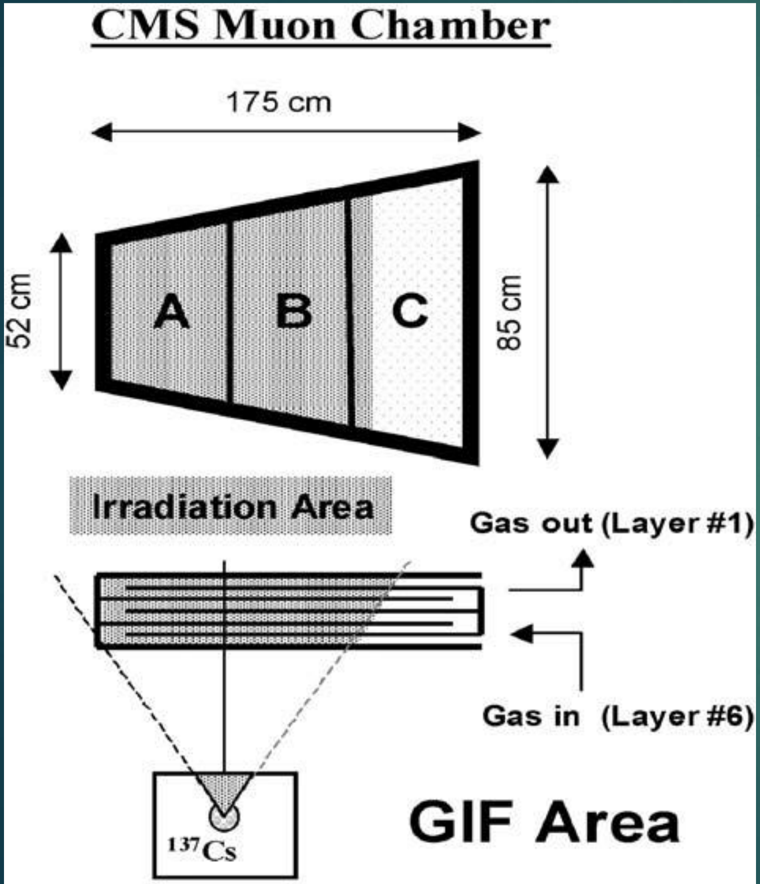
→ measurement of the SEE cross section as a function of the signal ***discrimination threshold***

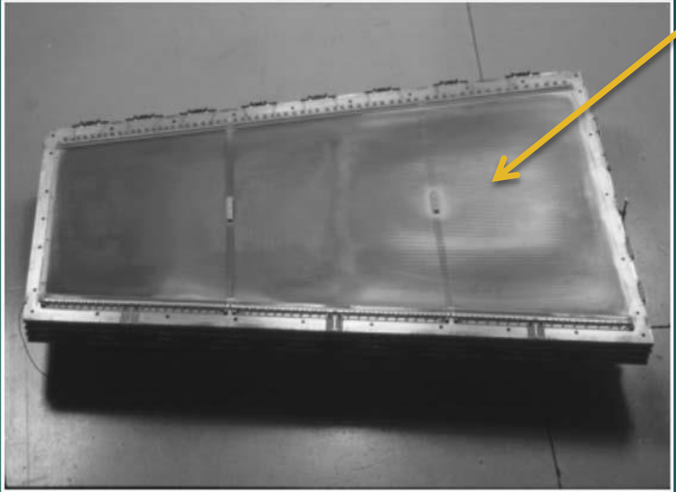
→ 50 min/run (divided in 5 acquisition intervals of 10 min, necessary in order to obtain a statistically significant number of events) for 7 different thresholds.

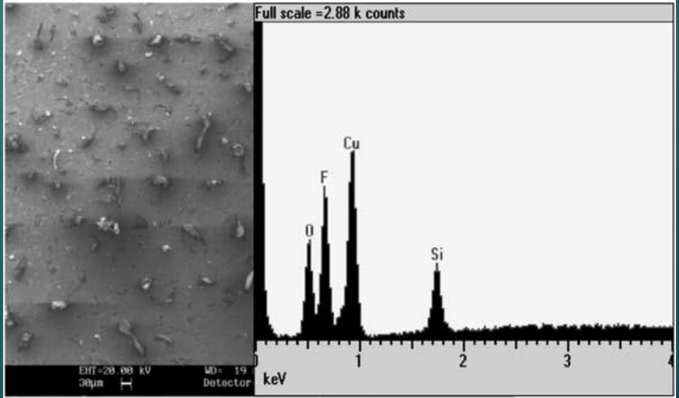
→ During all the 6h, the number of events induced by neutrons will be registered and the threshold values will be changed via software without the need of switching off the beam.

Why full scale detectors are necessary in aging tests

Deposits on Non supplied and Non irradiated area



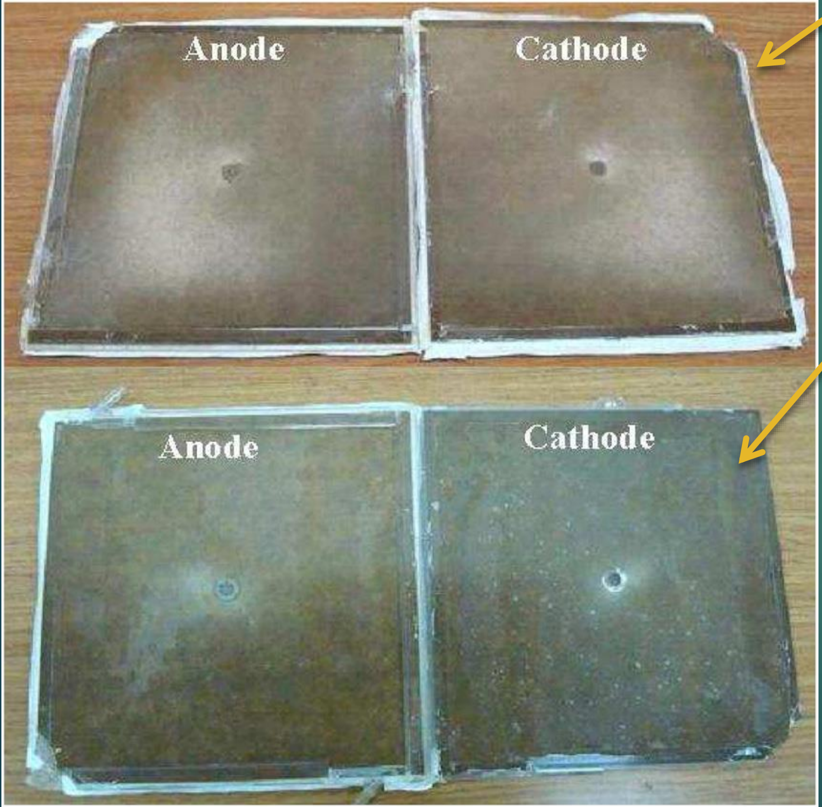




CMS-CSC

NIM A 515 (2003) 226–233

CMS RPC Aging induction test - post mortem analysis



NIMA 602 (2009) 771-774

Oiled ; gamma rate= ***5 kHz/cm²***
Integrated Charge = 578 mC/cm²

Non Oiled ; gamma rate= ***3 kHz/cm²***
Integrated Charge = 248 mC/cm²

Small size detectors

After/Before Ratio

10-180 in current and dark rate

Extrapolation Summary (from WG1)

	ATLAS		CMS	
Extrapolation @	RPC (barrel)	MDT	RPC (endcap)	DT
L = 3 * 10^{34} $cm^{-2}s^{-1}$ Lint = 500 fb^{-1}	120 Hz/cm^2 60 mC/cm^2		180 Hz/cm^2 67 mC/cm^2	25 Hz/cm^2
L = 7 * 10^{34} $cm^{-2}s^{-1}$ Lint = 3000 fb^{-1}	280 Hz/cm^2 **360** mC/cm^2	140 kHz/tube	390 Hz/cm^2 **495** mC/cm^2	55 Hz/cm^2
Detector certified for	300 mC/cm^2		100 mC/cm^2	

RPC aging will exceeds the certified values

GIF++ aging tests needed

LHCb		GEM			MWPC		ALICE	RPC		MRPC	
	Zone	Charge mC/cm^2	Max Rate **kHz/cm^2**	Zone	Charge **mC/cm**	Max Rate **kHz/cm^2**		Max Rate Hz/cm^2	Charge mC/cm^2	Max Rate Hz/cm^2	Charge mC/cm^2
Run 1 (2010-12)	M1 R1	***120***	***350***	M2 R1	***30***	***120***	Run 1 (2010-12)	***15***	***7***	***14***	***0.2***
Run 2 (2015-17)	M1 R1	***450***	***600***	M2 R1	***100***	***200***	Run 2 (2015-17)	***15***	***29***	***14***	***1.1***
Run 3 (2019-21)	M2 R1	***100***	***300***	M2 R2	***200***	***50***	Run 3 (2019-21)	***55***	***40 ****	***95***	***1.9***
Run 4 (2024-26)	M2 R1	***250***	***600***	M2 R2	***400***	***100***	Run 4 (2024-26)	***55***	***50 ****	***95***	***2.8***

**** Without FEE upgrade***