“Aging studies for the Resistive Plate Chambers (RPCs) of the CMS Muon Trigger Detector”

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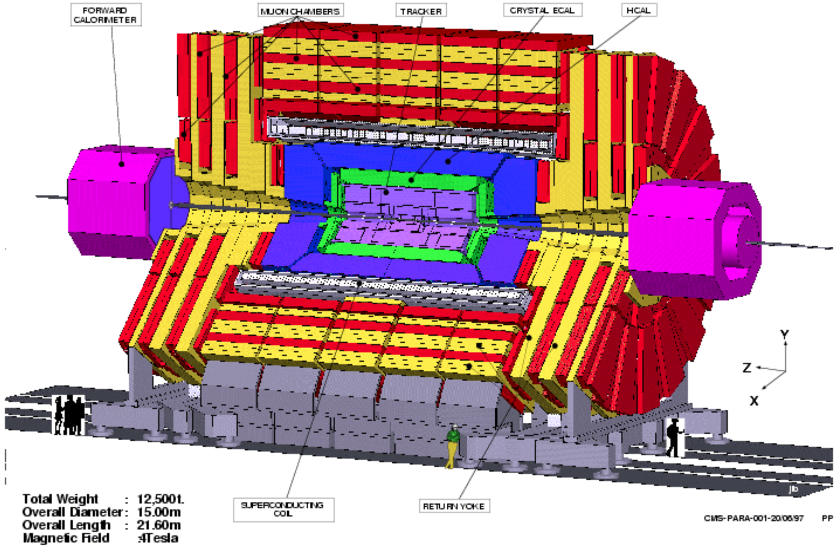
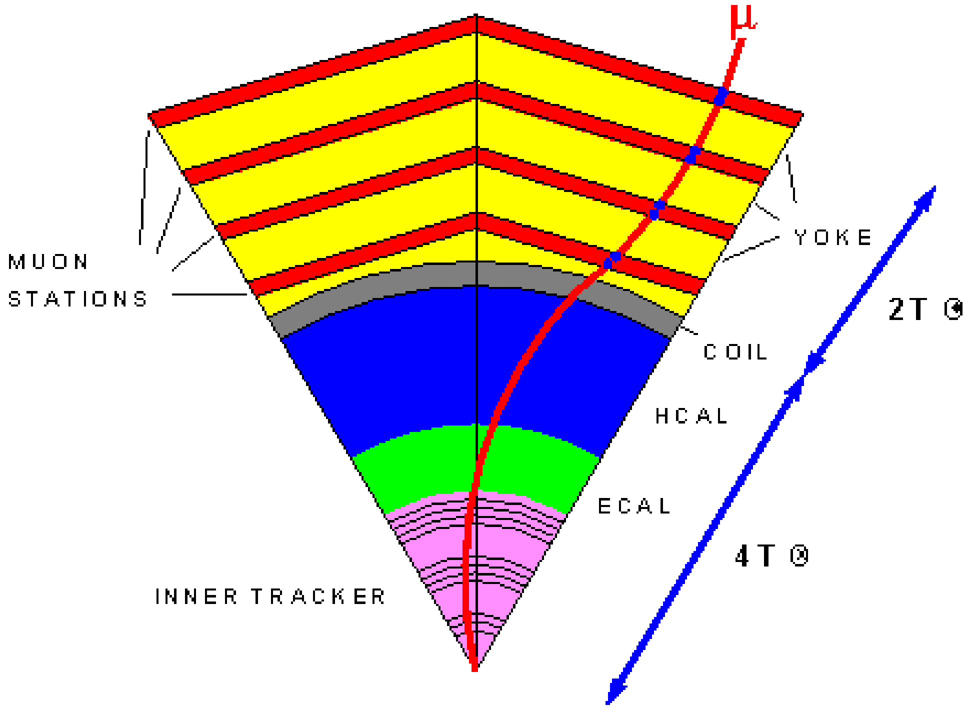
for the CMS-RPC Bari Pavia collaboration

The CMS Muon System





2 complementary and independent systems for a redundant and robust muon trigger:

RPC — **fast dedicated trigger detectors**

DT + CSC — **wire chambers for precise muon p_T measurement**

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The CMS RPCs

In the last 5 years an extensive R&D program has been carried out by the CMS-RPC collaboration to reach the final detector design.

Required performance

Cluster size	< 2 strips
Noise	< 10 Hz/cm^2
Efficiency	≅ 95%
Time resolution	≅ 2.5 ns
Rate capability	≅ 1 kHz/cm^2

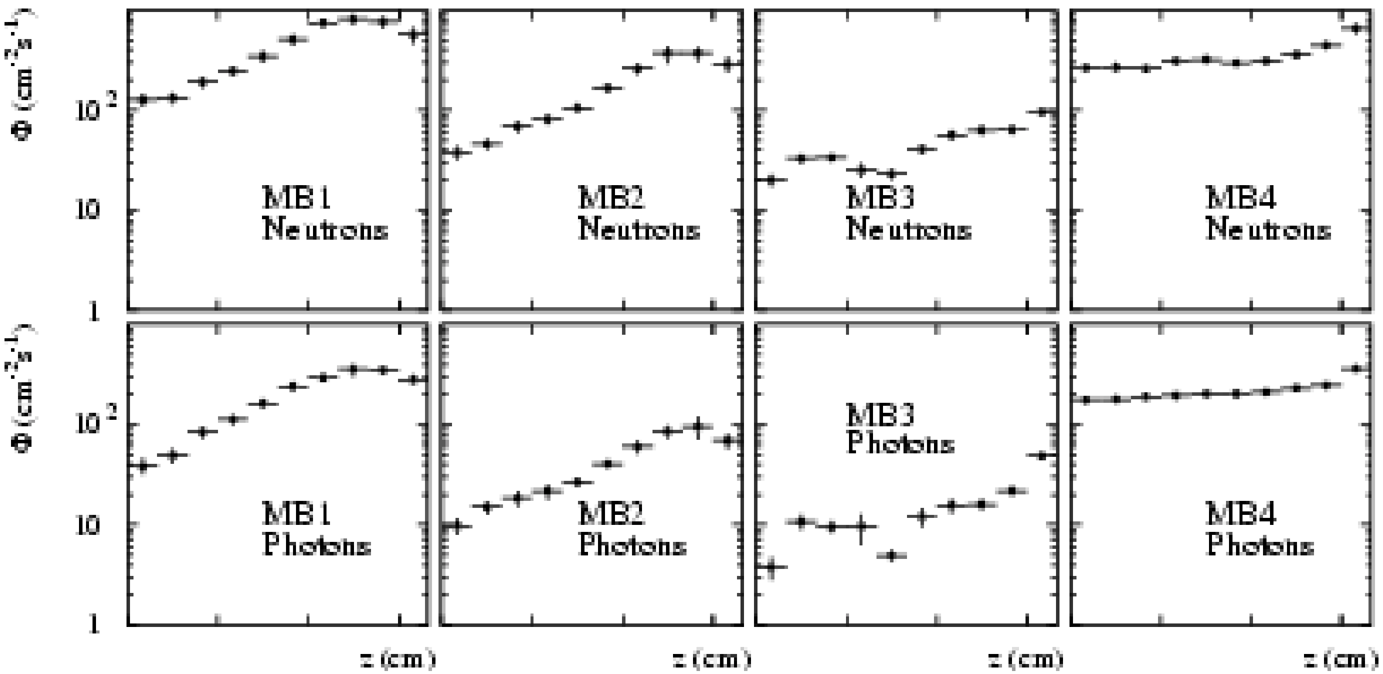
CMS RPC design

- avalanche mode
- 2 mm double gap
- bakelite resistivity: 2-5 x 10^{10} Ωcm
- bakelite thickness: 2 mm
- gas mixture: 96.5% $C_2H_2F_4$
  3.5% isoC_4H_{10}
- operating voltage: ~ 9.0 - 9.2 kV

Latest decision: linseed oil coating of the electrode

Radiation environment in CMS

CMS-Barrel region:



Max. Barrel flux:

$\phi_\gamma = 3{\cdot}10^2\ \mathrm{cm^{-2}s^{-1}}$

$\phi_n = 10^3\ \mathrm{cm^{-2}s^{-1}}$

Energy spectrum:

γ up to 100 MeV

n up to 1GeV.

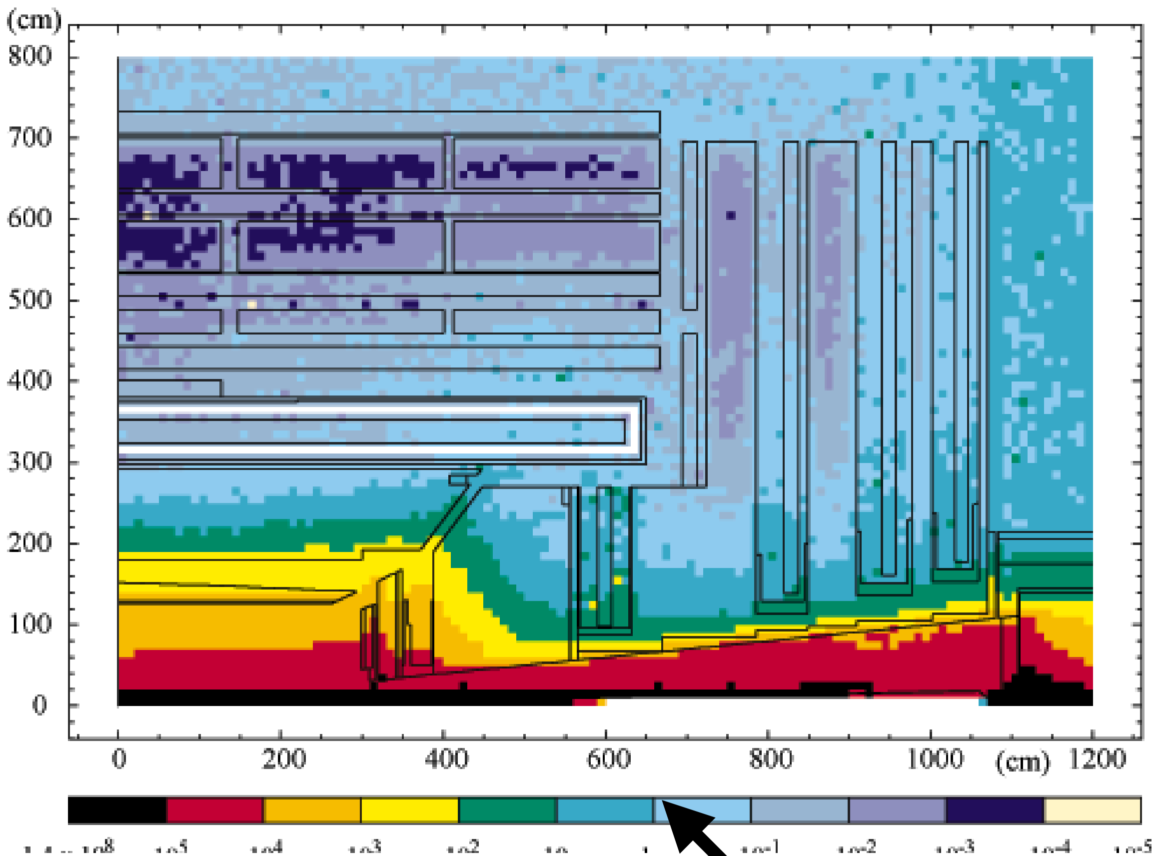
Total max. Barrel fluence in 10 years of CMS operation :

$$\Phi_\gamma \approx 5 \bullet 10^{10}\ \mathrm{n/cm^2}$$

$$\Phi_n \approx 10^{11}\ \gamma/\mathrm{cm^2}$$

10 CMS years = T_{eff}=5 •10^7s

Total Dose and charge in CMS



The **total charge** accumulated by RPCs in the Barrel region is

$$\langle q \rangle \cdot R_{tot} \cdot T_{eff} = 0.05 \ \mathrm{C/cm^2 gap}$$

R_{tot}= rate of charged particle

$\langle q \rangle$= 20 pC

The integrated **dose** in 10 years of CMS operation is below 1 Gy in the Barrel and 10 Gy in the Endcap.

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Aging test

RPCs with oil coated and non coated electrodes were tested under gamma and neutron irradiation :

Gamma Irradiation Facility @ CERN

^{137}Cs γ source, activity = 740 GBq

E_{γ} = 0.662 MeV

Accumulated dose = 100 Gy

Accum. charge/gap = 0.05 C/cm^2

Total fluence = 10^{13} γ/cm^2

Centre de Recherches du Cyclotron @ Louvain la Neuve

Reaction: ^{9}Be (d,n)

d (50 MeV) on a Be target

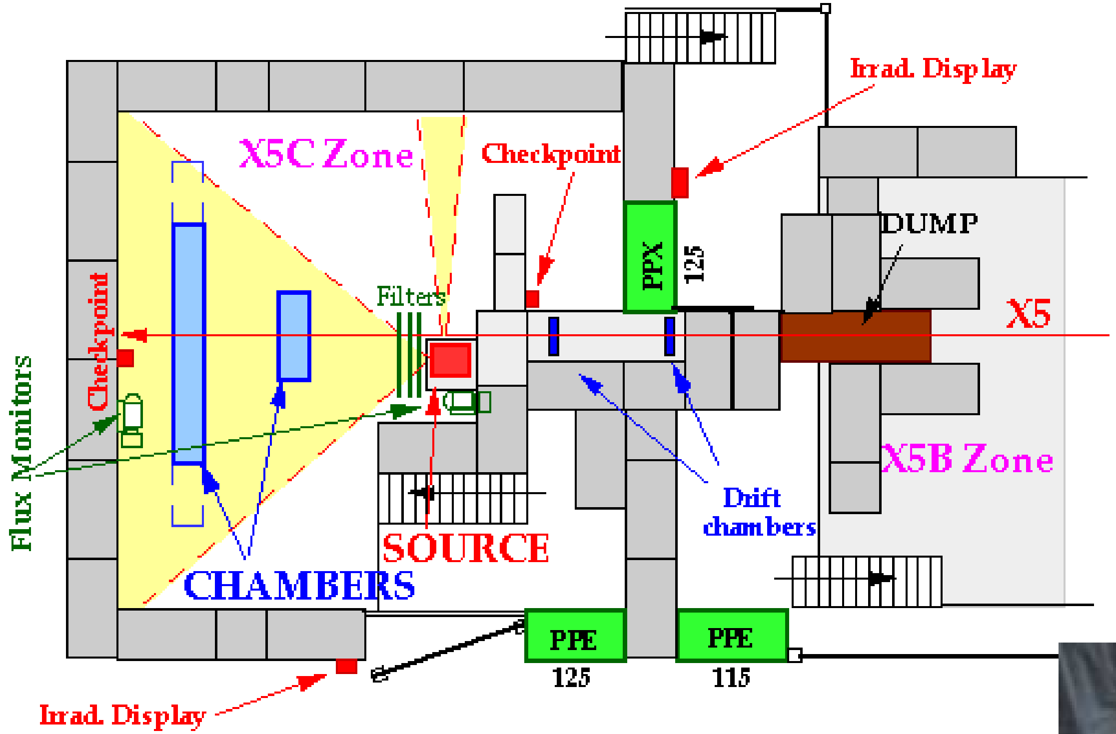
E_n < 50 MeV

Accumulated dose = 50 Gy

Accum. charge/gap = 0.002 C/cm^2

Total fluence = 10^{12} n/cm^2

γ Irradiation @ GIF



Electrodes coating with oil

29 front-end channels

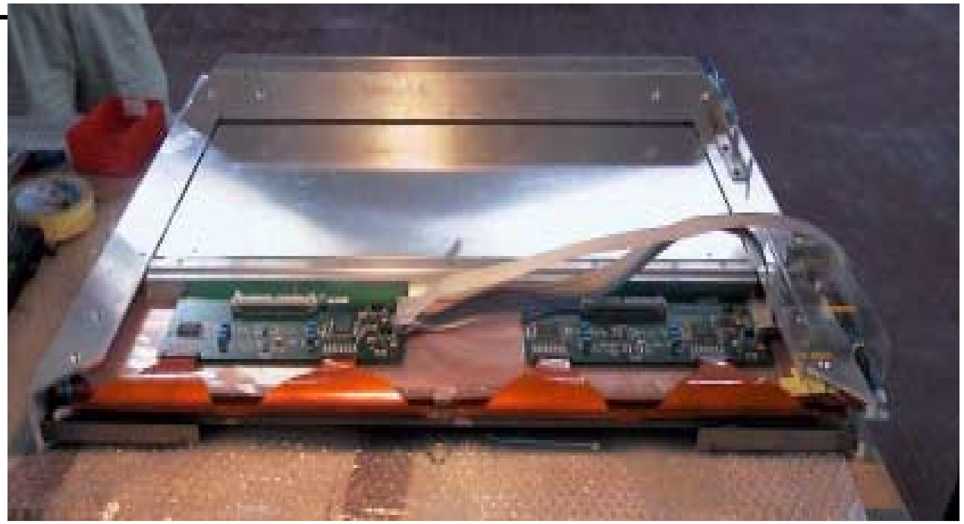
Resistivity: $\approx 8.1\ 10^9\ \Omega$ **cm**

Gas mixture: 96.5 % $C_2H_2F_4$
3.5 % $i\text{-}C_4H_{10}$

The chamber has been placed at 50 cm away from the source:

Max. Flux = 0.12 • $10^8\ \gamma/cm^2s$

Filters may be interposed to reduce flux (ABS 100-50-10-1).



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Irradiation schedule

# Measurements	Dose (Gy)	Charge (C/cm^2 gap)	
1	0	0	
2	30	0.02	
3	100	0.05	
4	100	0.05	← Two months after irradiation

Monitor with source Off:

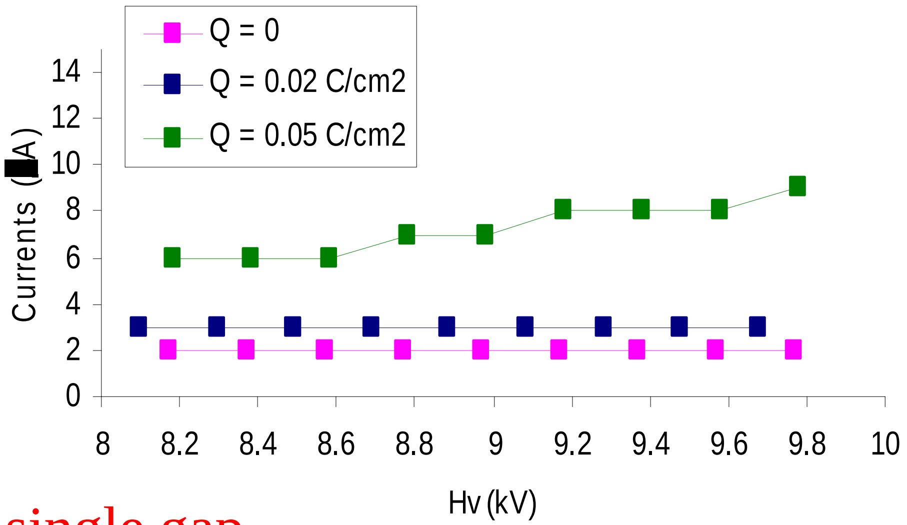
- current
- noise
- efficiency

Monitor with source On:

- counting rate

Between measurements #1- #2 and #2 - #3 the chamber was continuously irradiated under high gamma flux (high voltage ON).

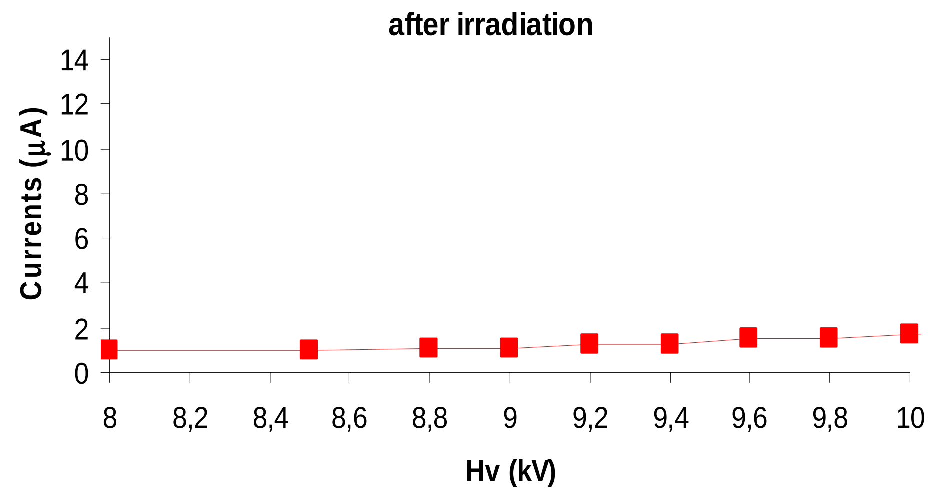
Current Monitoring



single gap

Currents measured during the irradiation (# 1, #2, #3)…..

……. and after the irradiation (#4)



The previous increase of current is not permanent.

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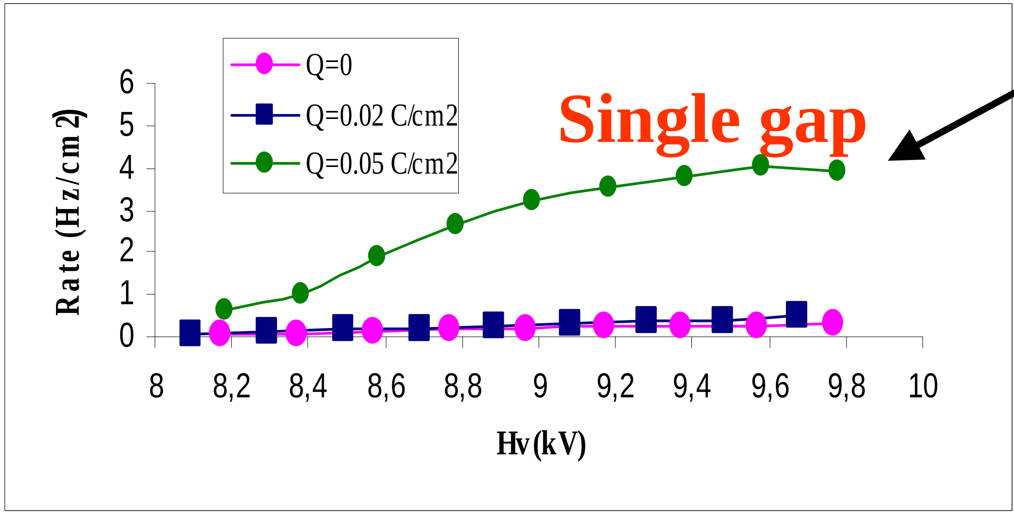
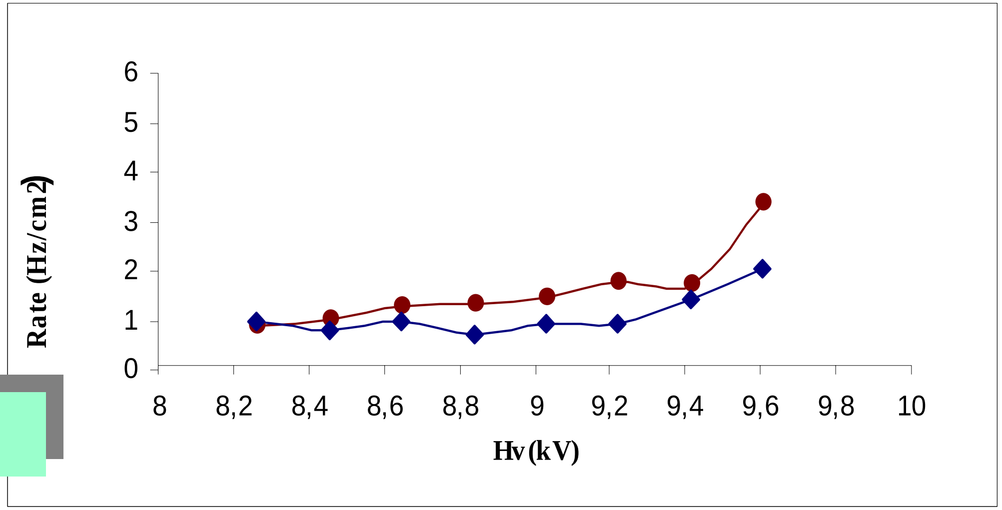
Noise during and after irradiation

The chamber noise is measured as the average of 4 ORs (1 OR for each 8 channels, VLSI modularity)



Increase of the noise rate during the irradiation. Nevertheless the value remains below 10 Hz/cm^2.



After the irradiation (#4)

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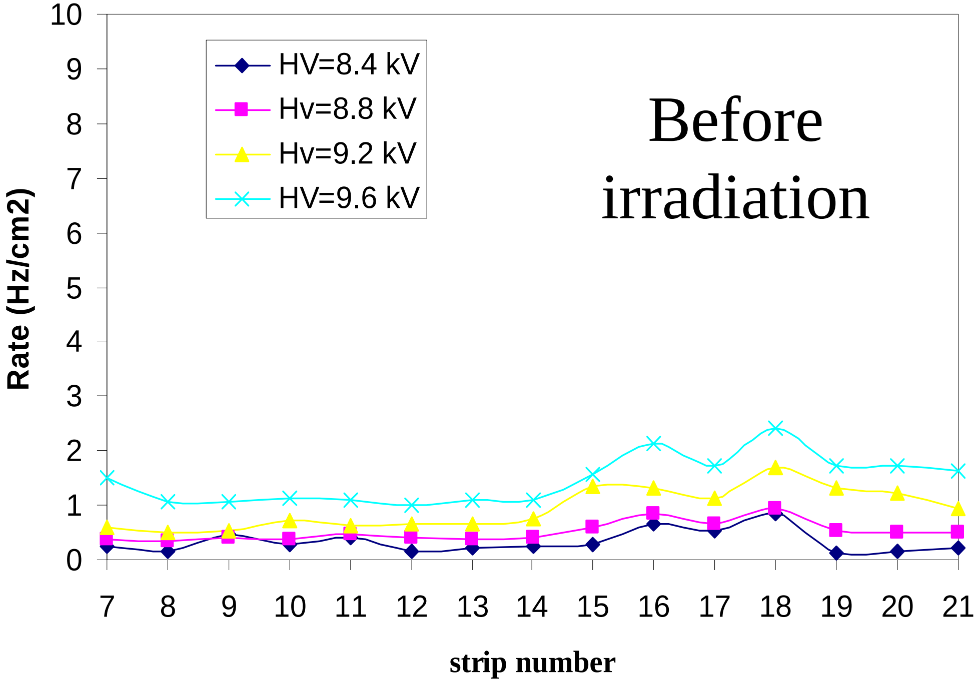
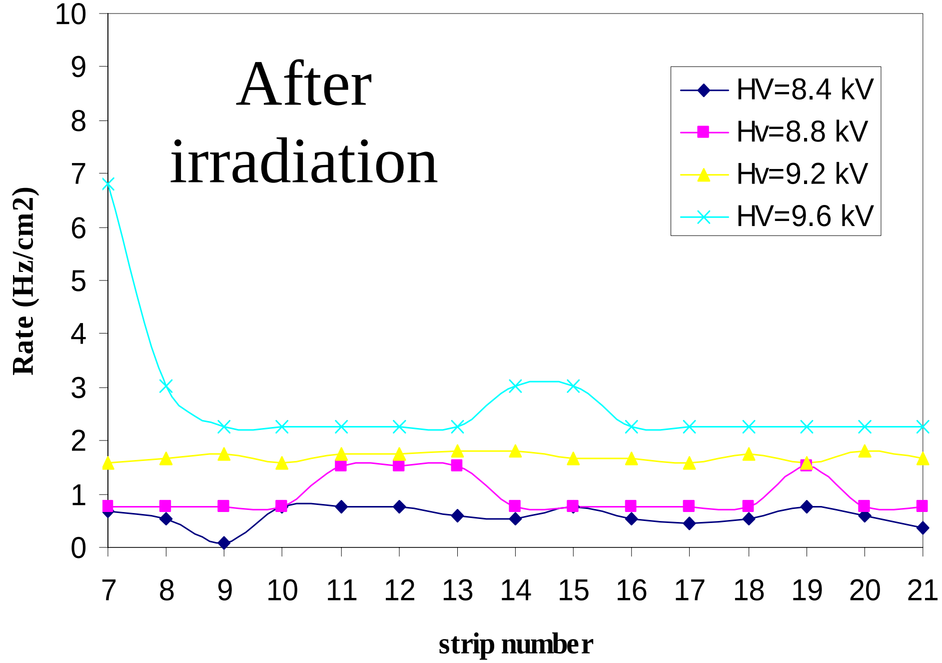
Noise Strip Profile: before and after irradiation

To verify possible local aging effect the strip profile in the central region has been considered.





- No dead strip
- No sensible variation of strip noise

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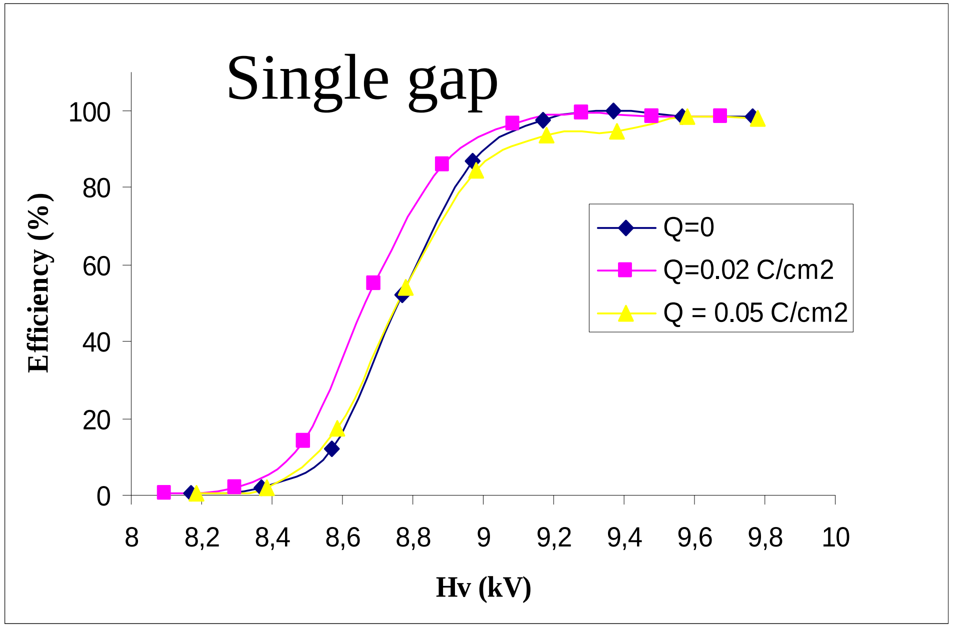
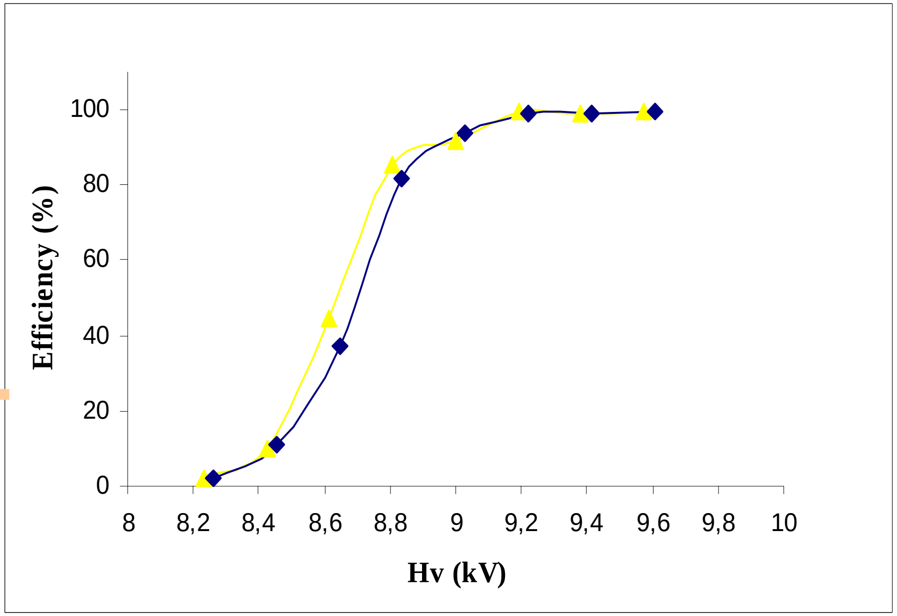
Efficiency during and after irradiation



The chamber efficiency in the central region was measured using cosmic muon triggers (measurements # 1, #2, #3)….

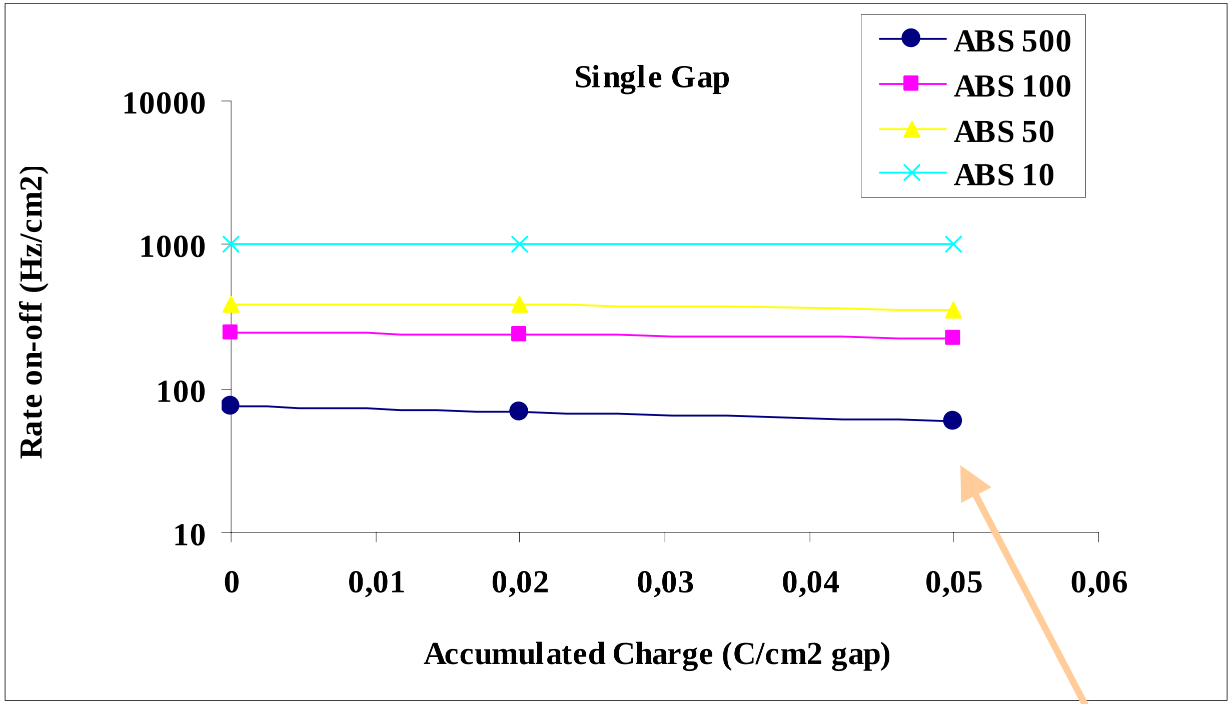
…after the irradiation (#4)



During and After irradiation

No relevant differences on the plateau value are observed.

Chamber rate at different γ fluxes



Absorption factor* (ABS)	γ flux (cm^{-2} s^{-1})
500	$5.4\ 10^{4}$
100	$2.3\ 10^{5}$
50	$4.4\ 10^{5}$
10	$1.5\ 10^{6}$

**Ref. S.Altieri, CERN EP 2000-031*

The rate off has been subtracted

No sensible variation of the irradiated chamber rate up to very high γ flux has been observed (at HV = 9.6 kV).

Conclusion: γ Aging test

Two years ago*

After a long term irradiation test on one RPC without oil coating: a dose and a charge equivalent to 10 years of CMS operation was integrated.

The perfomance of the irradiated detector remained unchanged. No relevant aging effect.

One RPC with oil coating has been exposed to a hight γ flux: a dose and a charge equivalent to 10 years of CMS operation was integrated.

The RPC efficiency remained almost unchanged during and after the irradiation.

Although an increase of the counting rate during the irradiation has been observed the value remains below 10 Hz/cm^2.

**Inter. Conference On Position sensitive Detector, London 1999, Conference Proceeding in print NIM*

n irradiation @ Louvain

Centre de Recherches du Cyclotron
(Louvain la Neuve)

1 gap with oil coating
(Resistivity: ≈ 1.4 10^{10} Ω cm)

1 gap without oil coating
(Resistivity: ≈ 3.2 10^{9} Ω cm)

Gas mixture: 96.5% $C_2H_2F_4$
3.5% i-C_4H_{10}
15 front-end channels

The Neutron Flux can be adjusted by tuning the current of the beam:

at 90 cm **ϕ = 8.15 10^7 n/cm^2 s μA**

Beam spot of about 330 cm^2

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Irradiation schedule

# Measurements	Dose (Gy)	Charge (C/cm^2 gap)	*n* fluence (n/cm^2)
1	**0**	**0**	before irradiation
2	**4**	**$7 \cdot 10^{-4}$**	$2\ 10^{11}$
3	**50**	**0.002**	$1\ 10^{12}$
4	**50**	**0.002**	To be done

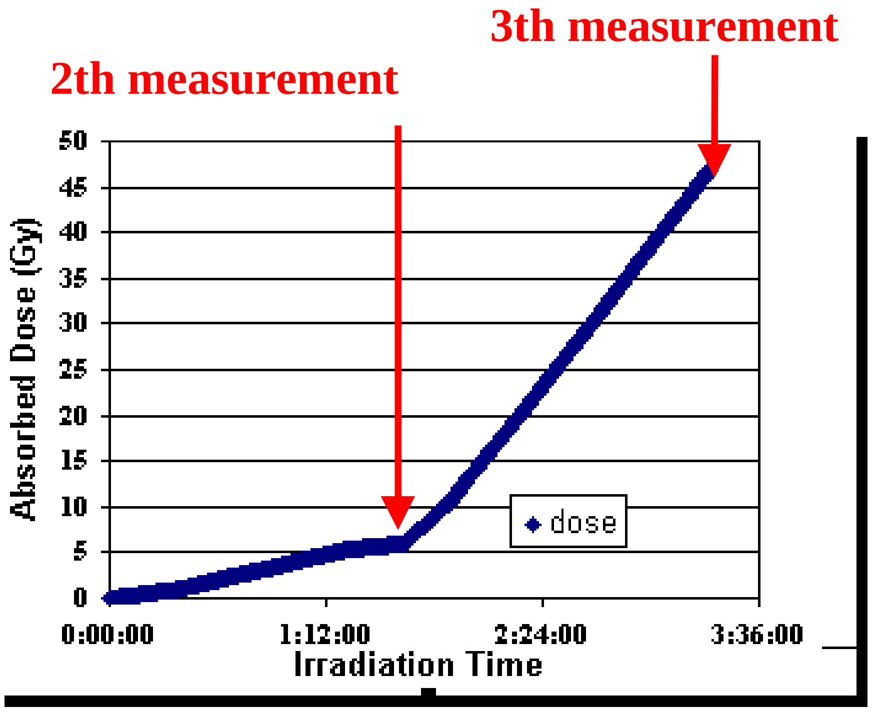
Neutron irradiation

Measurements done with beam off:

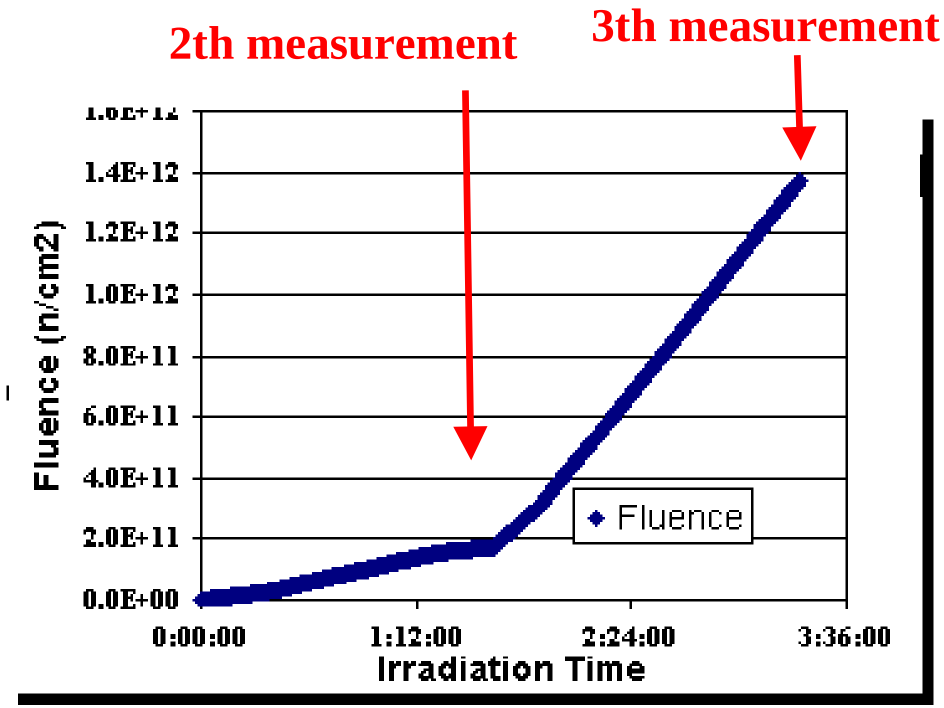
- current
- noise
- efficiency (only before the irradiation)

Total Dose, fluence and charge

Total absorbed dose



Total Fluence



Dose evaluation*:

$$(2.8\ 10^{-3}\ \mathrm{Gy/s\ \mu A}) \cdot I_{beam} \cdot T_{irr}$$

Total charge accumulated:

$$Q_{tot} = 0.002\ \mathrm{C/gap\ cm^2}$$

**Ref. K.Bernier, http://www.fynu.ucl.ac.be*

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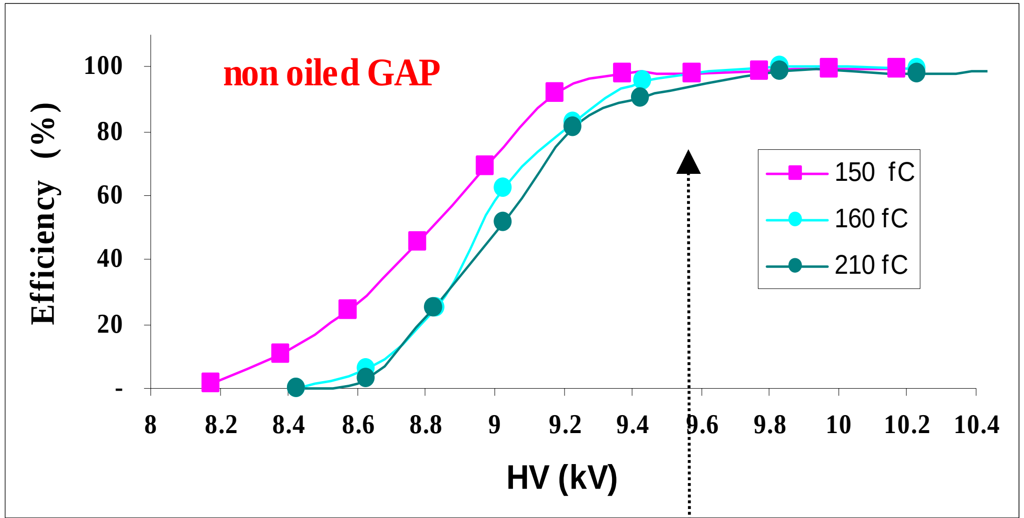
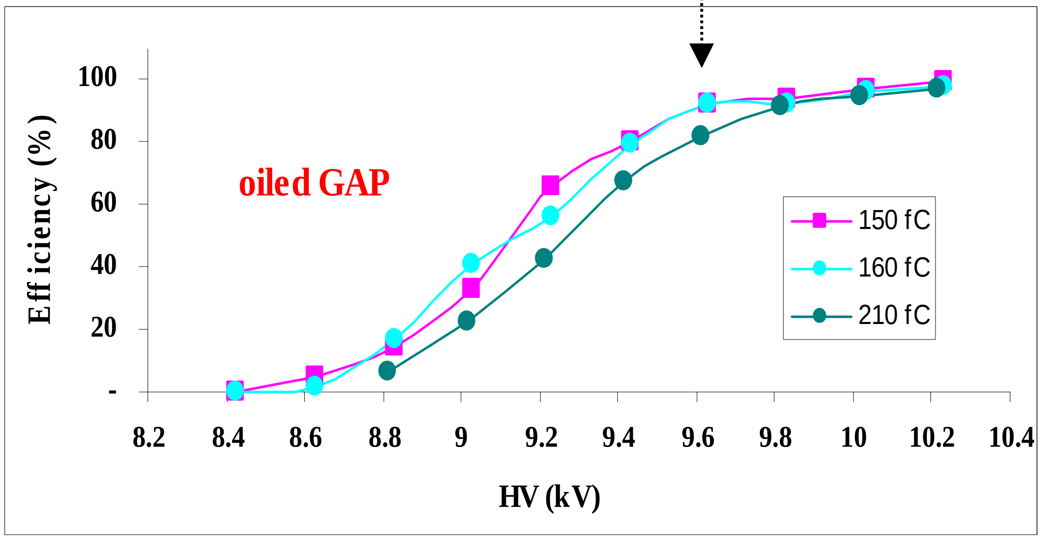
Before irradiation

The chamber **efficiency** has been measured with atmospheric muons. Different thresholds have been considered.



Efficiency plateau

Efficiency plateau



For the irradiation test the threshold has been fixed at Th = 160 fC.

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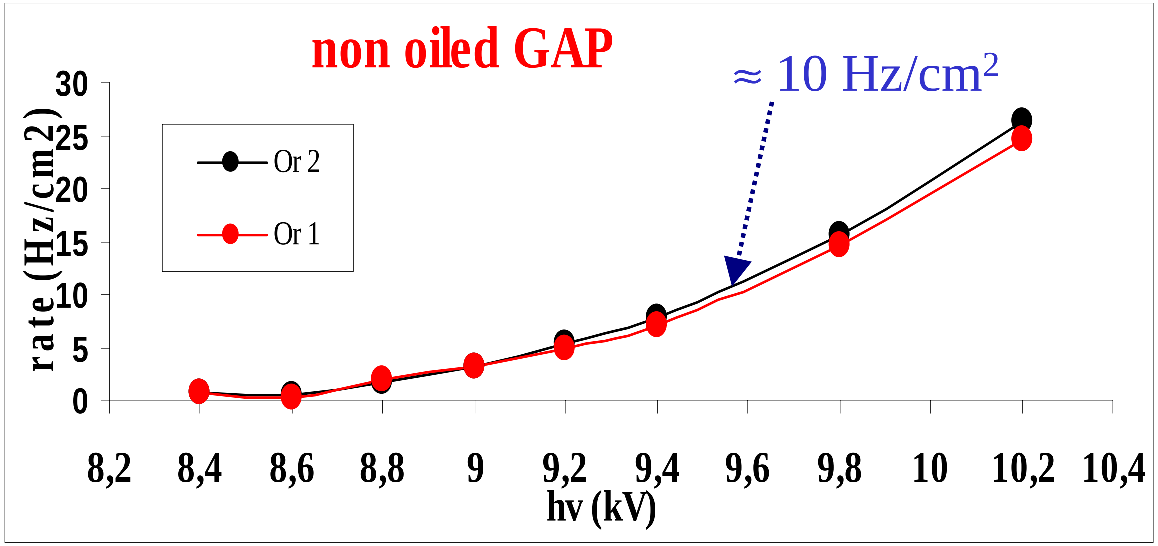
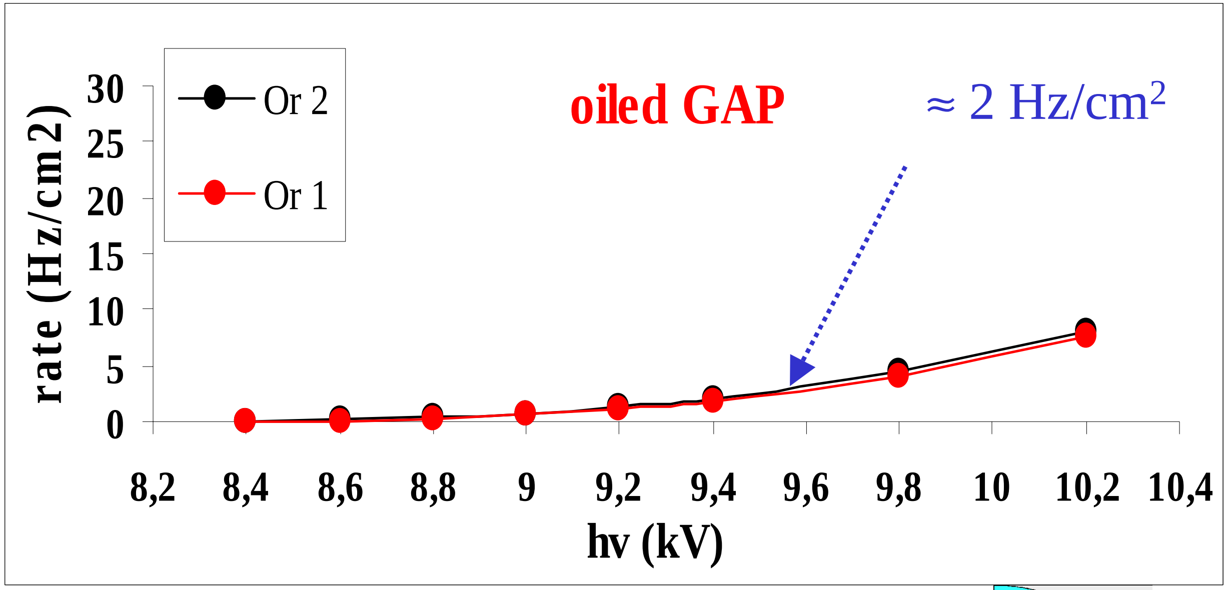
Before the irradiation



Chamber noise:

ORs of 8 channels



Reduction of the noise level with linseed oiled coating

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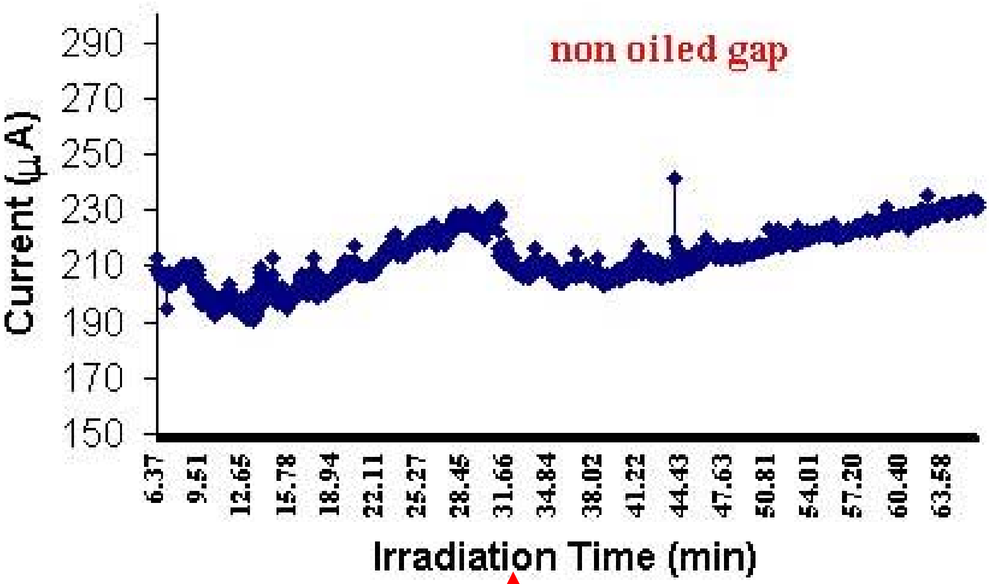
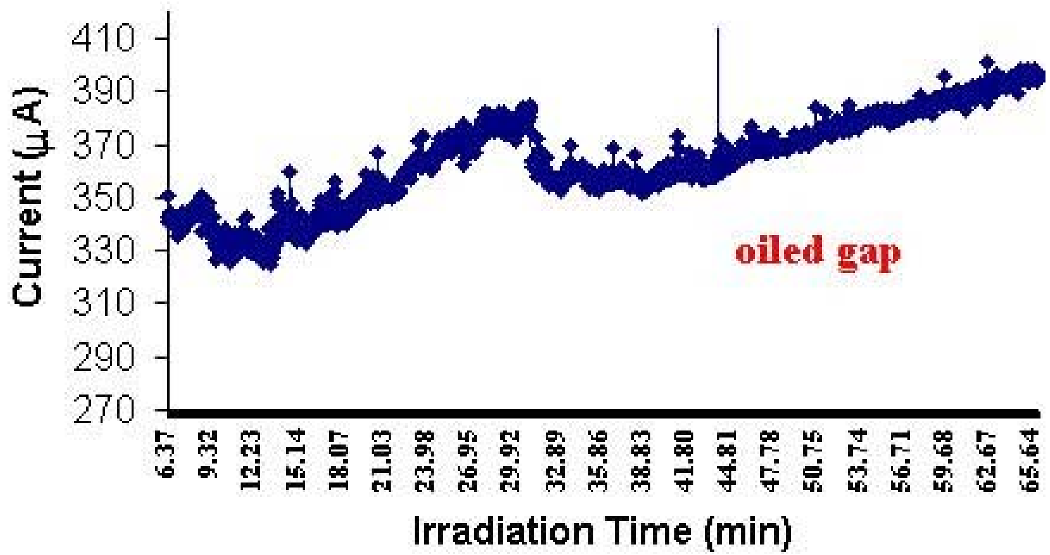
Irradiation with high flux (first period)

Preliminary results

To accumulate a value of dose and fluence equal to the one expected in 10 CMS years, the chambers are irradiated with a high neutron flux: $3 \bullet 10^7$ n/cm^2 s (I_{beam} = 0.4μA)



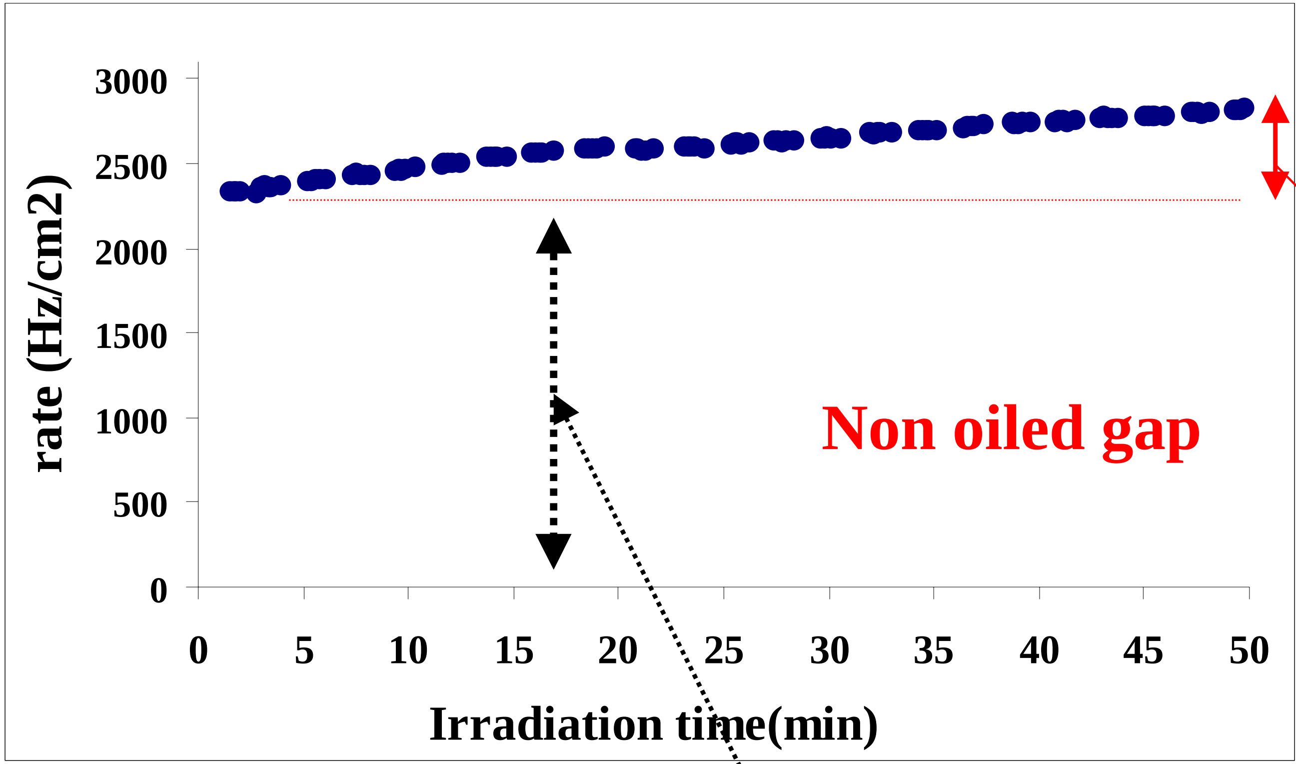
Monitor with beam ON: current



Sensible increase of the chamber current

Irradiation with high flux (first period)

Preliminary results



Monitor with beam ON: Chamber rate at constant HV = 9.4 kV

Increase of the chamber rate at the end of the irradiation:

$R_{att} \approx 530$ Hz/cm^2

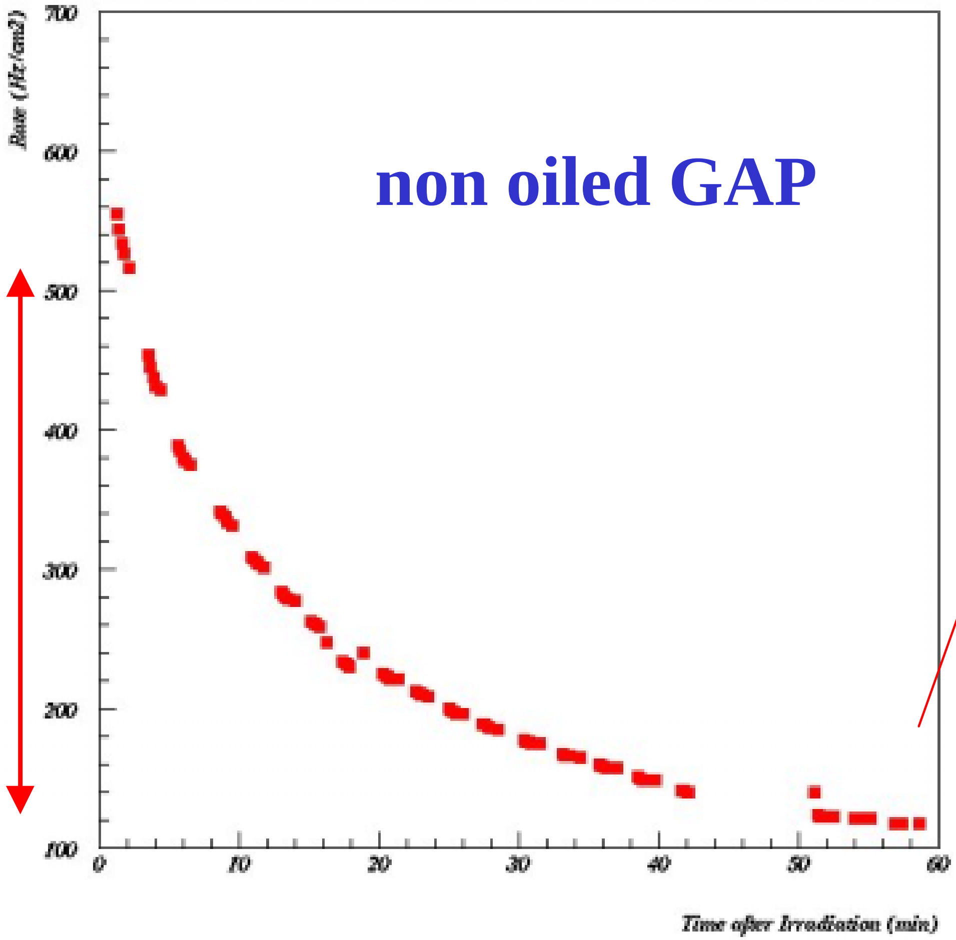
At constant neutron flux (about $3 \bullet 10^7$ n/cm^{2}s) the contribution of the neutron activation must be added.

Chamber noise (measurement # 2)

Preliminary results

Beam off: the chamber was monitored (at HV constant) for about 1 hour after the first period of irradiation.

$R_{att} \approx 550\ Hz/cm^2$



The chamber noise is decreasing following the decay law:

After 1 h $R_{att} = 110\ Hz/cm^2$.

However the contribution of the isotopes with longer time decay must be take into account:

- $^{63}Cu(n,2n)^{62}Cu$ $T_{1/2} = 9.8$ min
- $^{65}Cu(n,2n)^{64}Cu$ $T_{1/2} = 12.7$ h ←
- $^{27}Al(n,p)^{27}Mg$ $T_{1/2} = 9.4$ min
- $^{27}Al(n,\alpha)^{24}Na$ $T_{1/2} = 15$ h ←

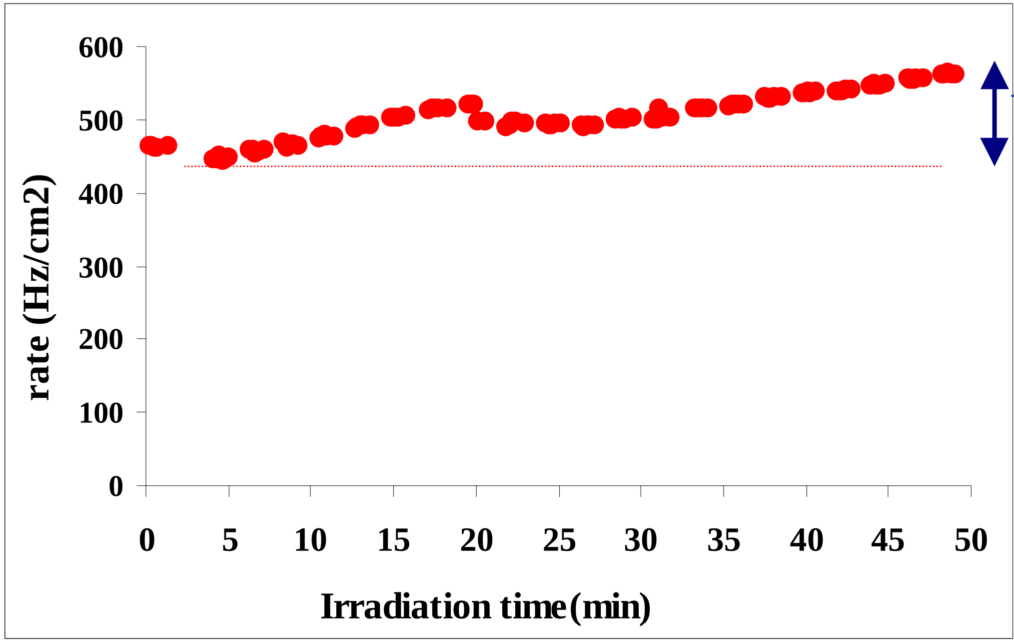
Chamber noise (measurement # 3)

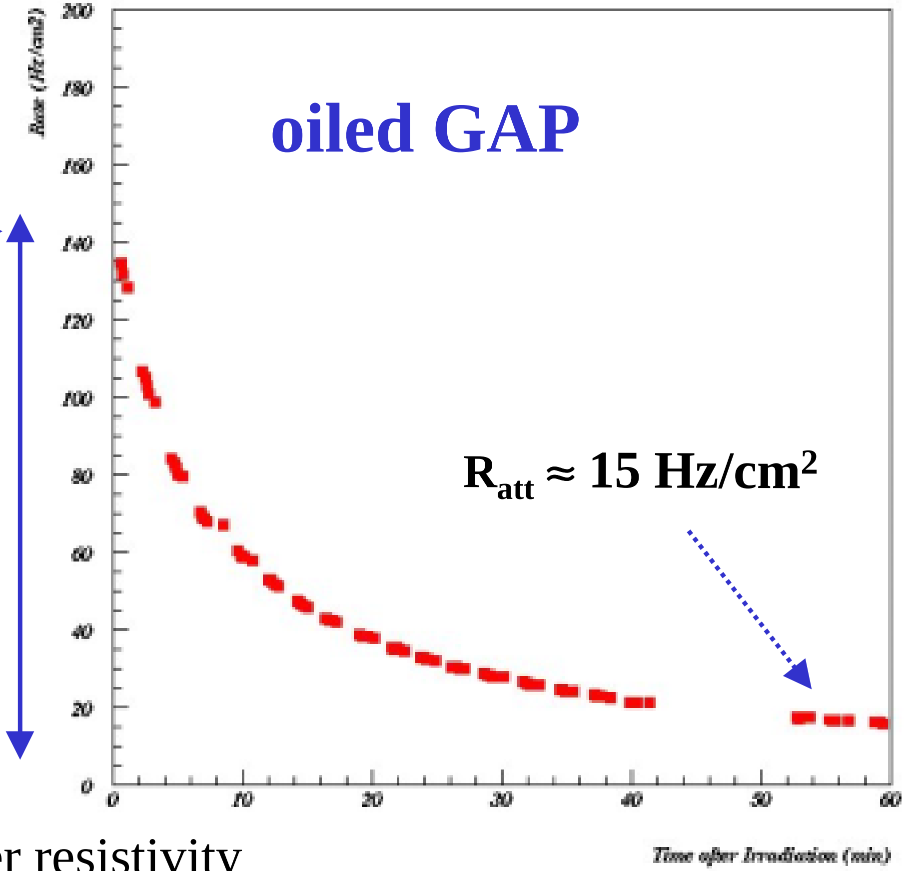
Preliminary results

Increase of the chamber rate at the end of the irradiation:

$R_{att} \approx 120\ Hz/cm^2$

After 1 h the chamber noise is about 15 Hz/cm^2.





Reduced neutron flux - Higher resistivity

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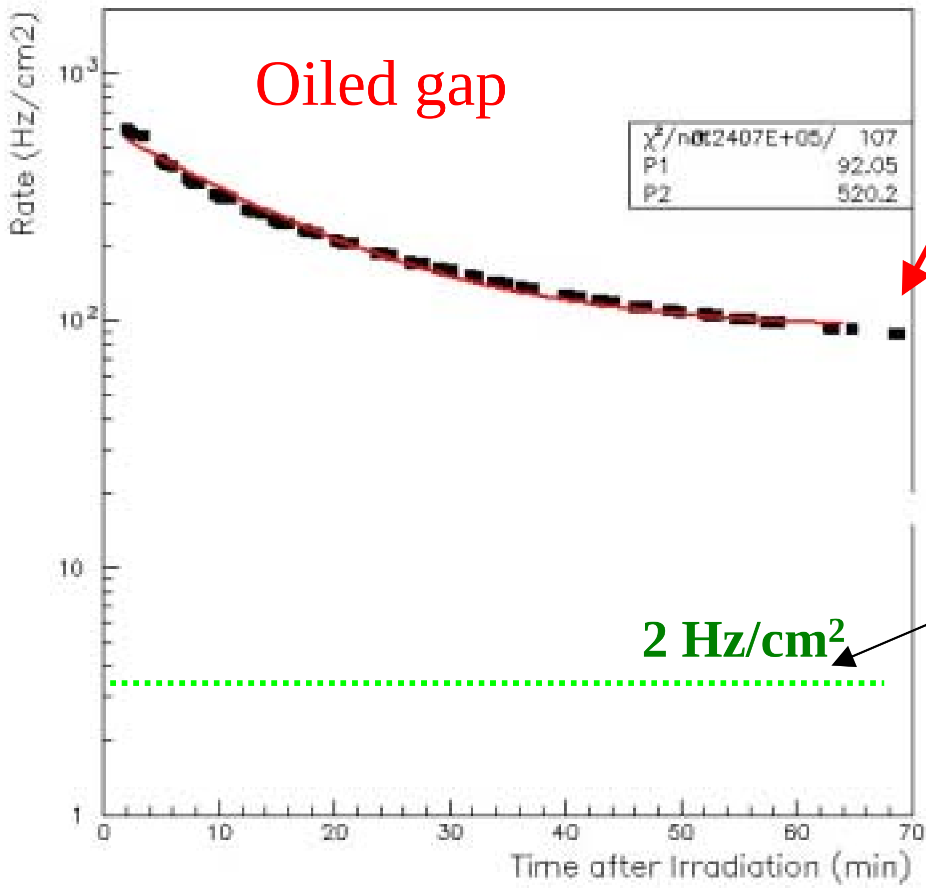
Measurement #4: second irradiation with high flux

Preliminary results

Last irradiation: 100 min at 1.6 10^8 n/cm^{2}s (I_{beam} = 2 μA).
The current and rate are monitored.

END of irradiation test



- The value is compatible with the expected hits due to the contribution of the activated isotopes, about 2 10^9 Bq.

Noise chamber recovery time

Time necessary to reduce the hits, due to the activation, less than 1% of chamber noise before irradiation.

It has been estimated as about 180 h.

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Future Planning

Verify no irreversible changes

RPC Performance

- Efficiency: at cosmic muon and at muon beam
- Noise chamber level

RPC Autopsy

- Visual inspection of the bakelite plate with an optical microscope: surface qualities and no presence of pimples…
- Chemical analysis of the bakelite plate: degradation of the linseed oil.
- Measurement of the bakelite bulk resistivity.

Front-end Neutron irradiation tests

The RPC front end chips have been also tested in two neutron facilities:

Louvain la Neuve

E_n < 65 MeV

p(65MeV) on a Be target

Neutron fluence: $1 \bullet 10^{12}$ n/cm^2

LENA Irradiation Test

E_n up to 10 MeV

Neutron Fluence = $1.7 \bullet 10^{11}$ n/cm^2

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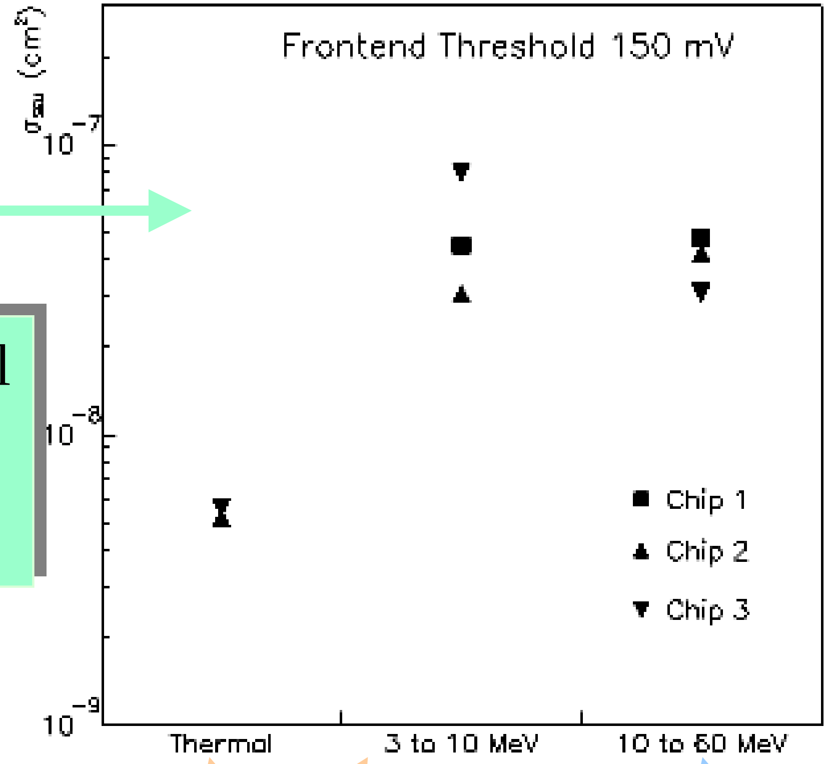
Single Event Upset

The neutron induced Single Event Upset (SEU) has been measured as a function of the fluence in both irradiation facility. Each OR of 8 channels (1 chip) was counted (with open input) at neutron beam ON and OFF.

SEU Cross Section

$$\sigma_{SEU} = \frac{SEU_{counts}}{Fluence(cm^{-2})}$$



LENA *n* energy

Louvain *n* energy

Assuming a neutron flux in the CMS barrel region of about 10^3 n/s cm^2 the SEU rate is:

$SEU_{rate}(s^{-1}) = \sigma_{SEU} \bullet Flux = 8.5\ 10^{-5}$ Hz/chip

The behavior of the CMS front-end chip is satisfactory at the expected experimental condition.

Conclusion

γ Aging test

One RPC with oil coating has been exposed to a high γ flux: a dose and a charge equivalent to 10 years of CMS operation was integrated.

The RPC efficiency remained almost unchanged during and after the irradiation.

Although an increase of the counting rate during the irradiation has been observed the value remains below 10 Hz/cm^2.

n Aging test

Two RPC with and without oil coating have been irradiated at high neutron flux. A dose and a fluence comparable with the expected values at CMS have been accumulated.

A noise increase has been observed ascribable to the neutron activation.

To verify no irreversibile changes of the noise and of chamber performance new tests are in progress.