Development of a gaseous detector based on Gas Electron Multiplier (GEM) Technology

F.Murtas (LNF-INFN)

- Introduction
- Gas mixture choice
- Performance: gain, time resolution, efficiency
- Aging and discharges
- Chamber 20x24 cm^2
- Other possible applications
- Conclusions

Gas Electron Multiplier

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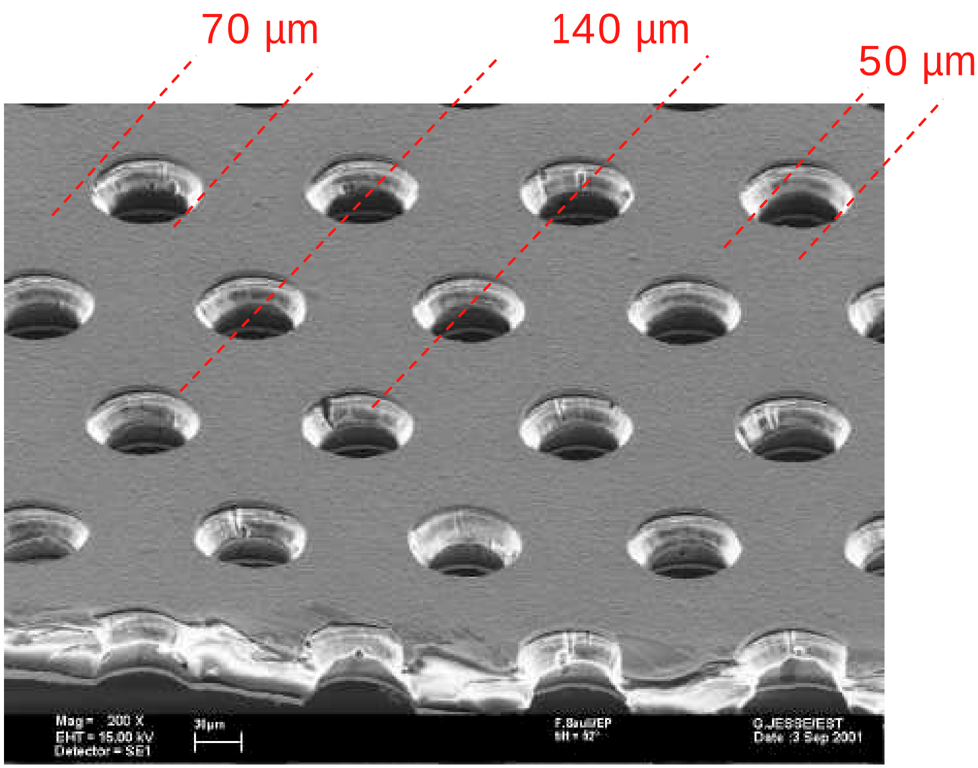
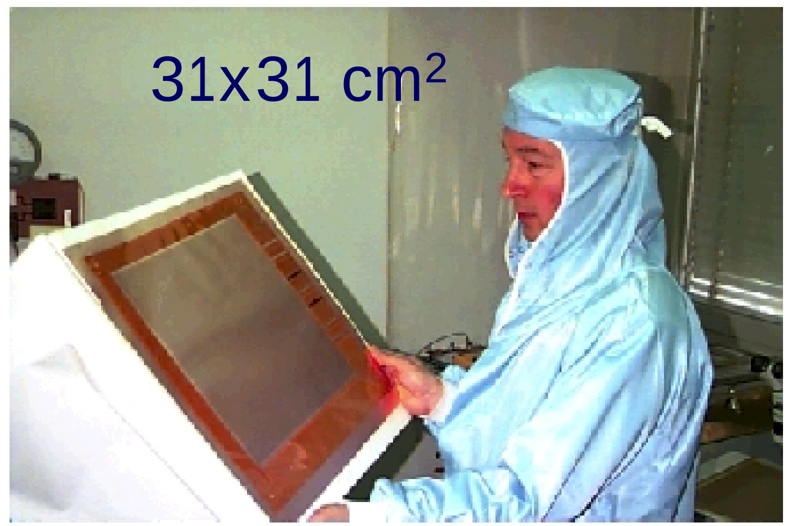
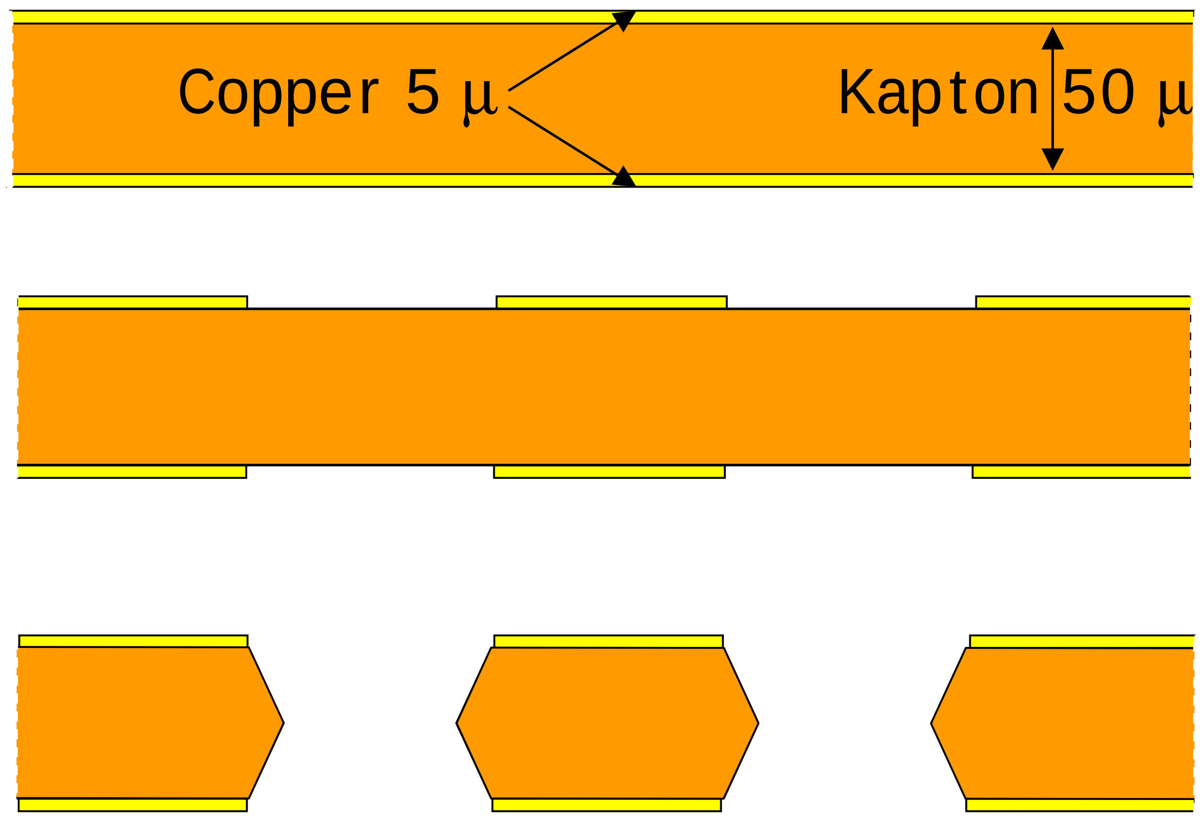
A Gas Electron Multiplier (F.Sauli, NIM A386 531 **1997**) is made by 50 μm thick kapton foil, copper clad on each side and perforated by an high surface-density of bi-conical channels;





GEM foil construction (CERN)

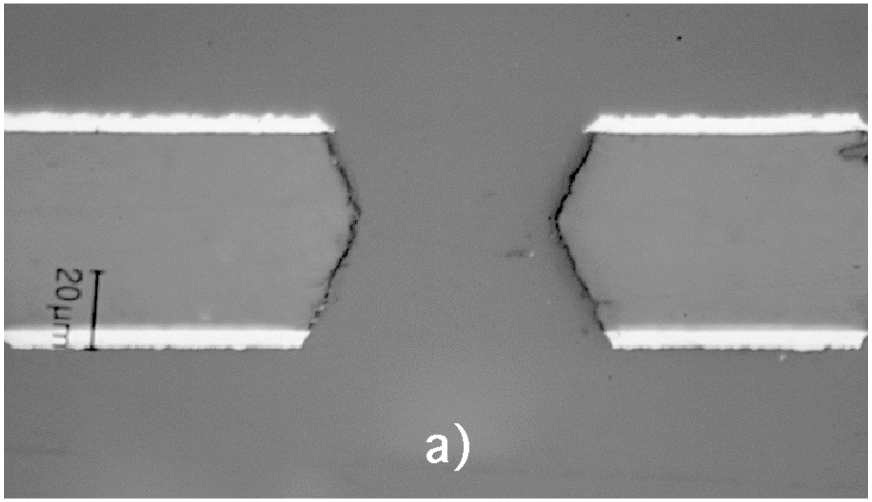
Photolithographic technology used
for printed circuit board construction



Copper etching by chemical solution

Kapton etching using the copper mask

GEM different geometries



DOUBLE-CONICAL (Optimized)
50 μm kapton width
70 μm holes and
140 μm pitch

Other hole densities developed at CERN
with a Double Conical structure :
50 μm kapton, 140 μm holes at 280 μm
25 μm kapton, 70 μm holes at 140 μm

Other hole geometries are under studies:

CONICAL
50 μm kapton, 60/120 μm holes

CYLINDRICAL
50 μm kapton, 70 μm holes

Gas Electron Multiplier

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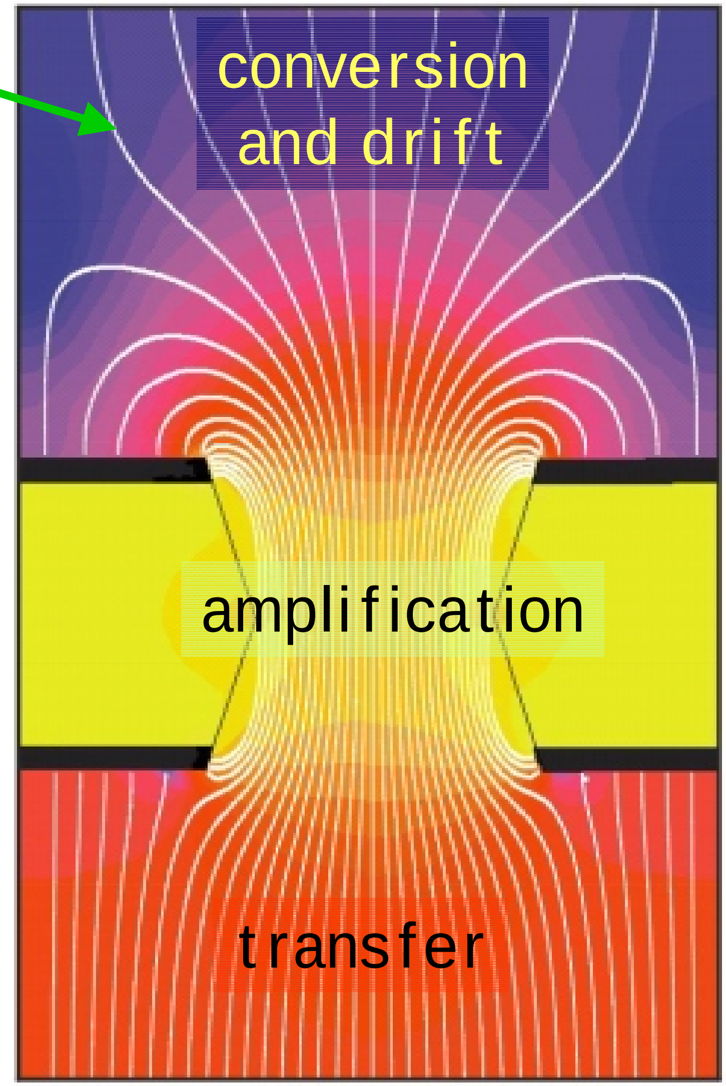
Filed lines

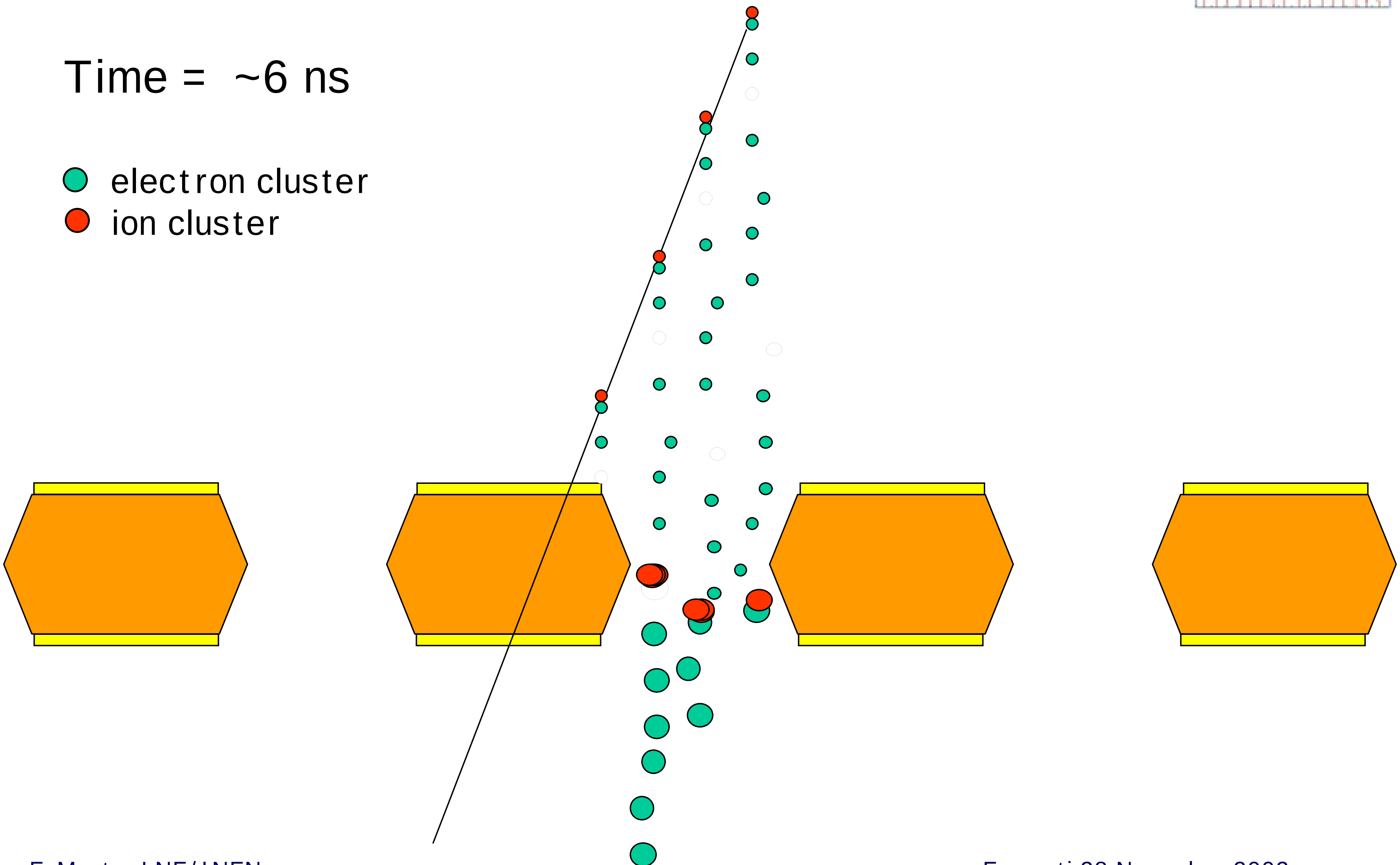


By applying a potential difference between the two copper sides an electric field as high as 100 kV/cm is produced in the holes acting as multiplication channels.

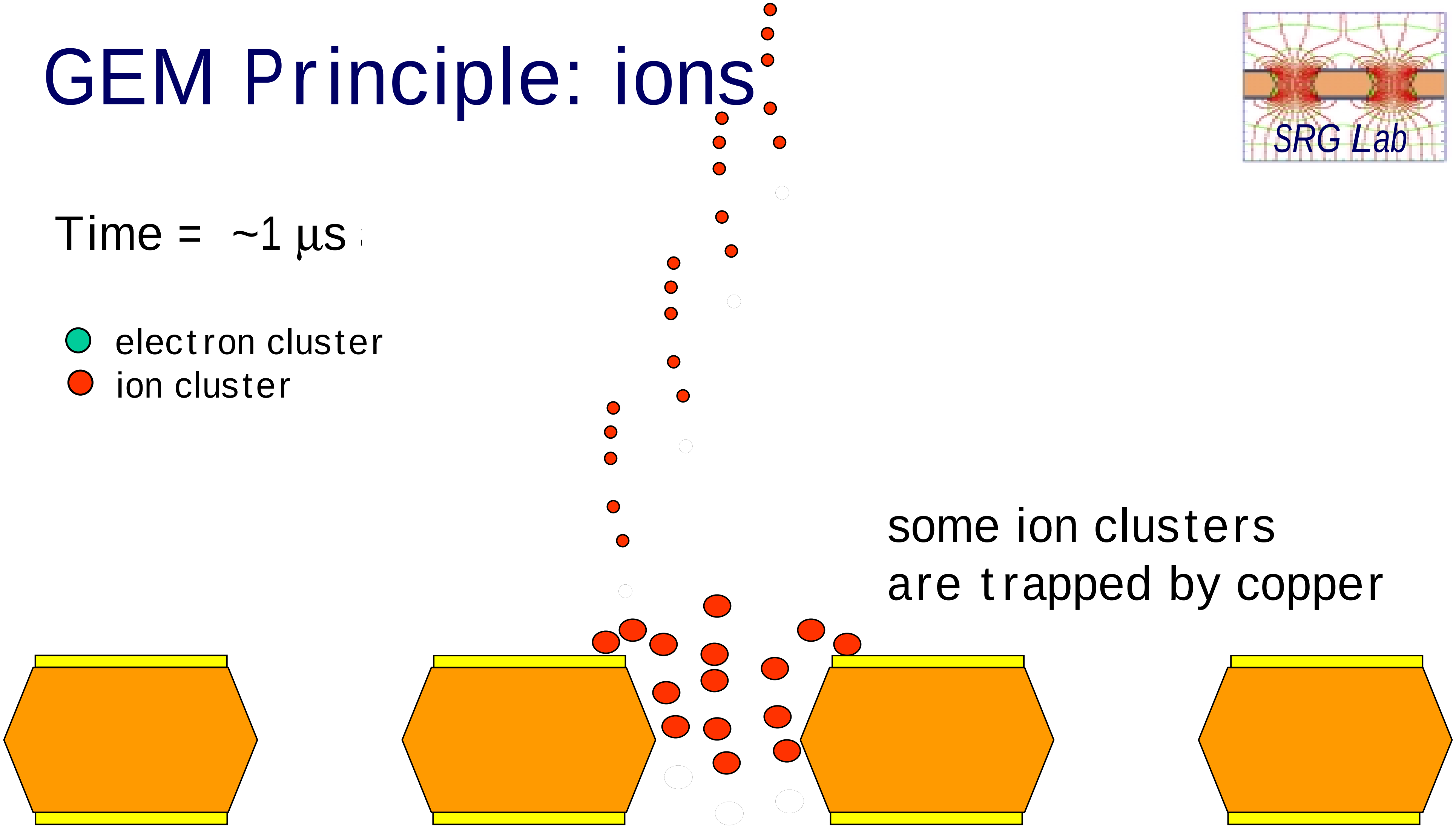
Potential difference ranging between 400 - 500 V

GEM principia: electrons

Time = ~6 ns



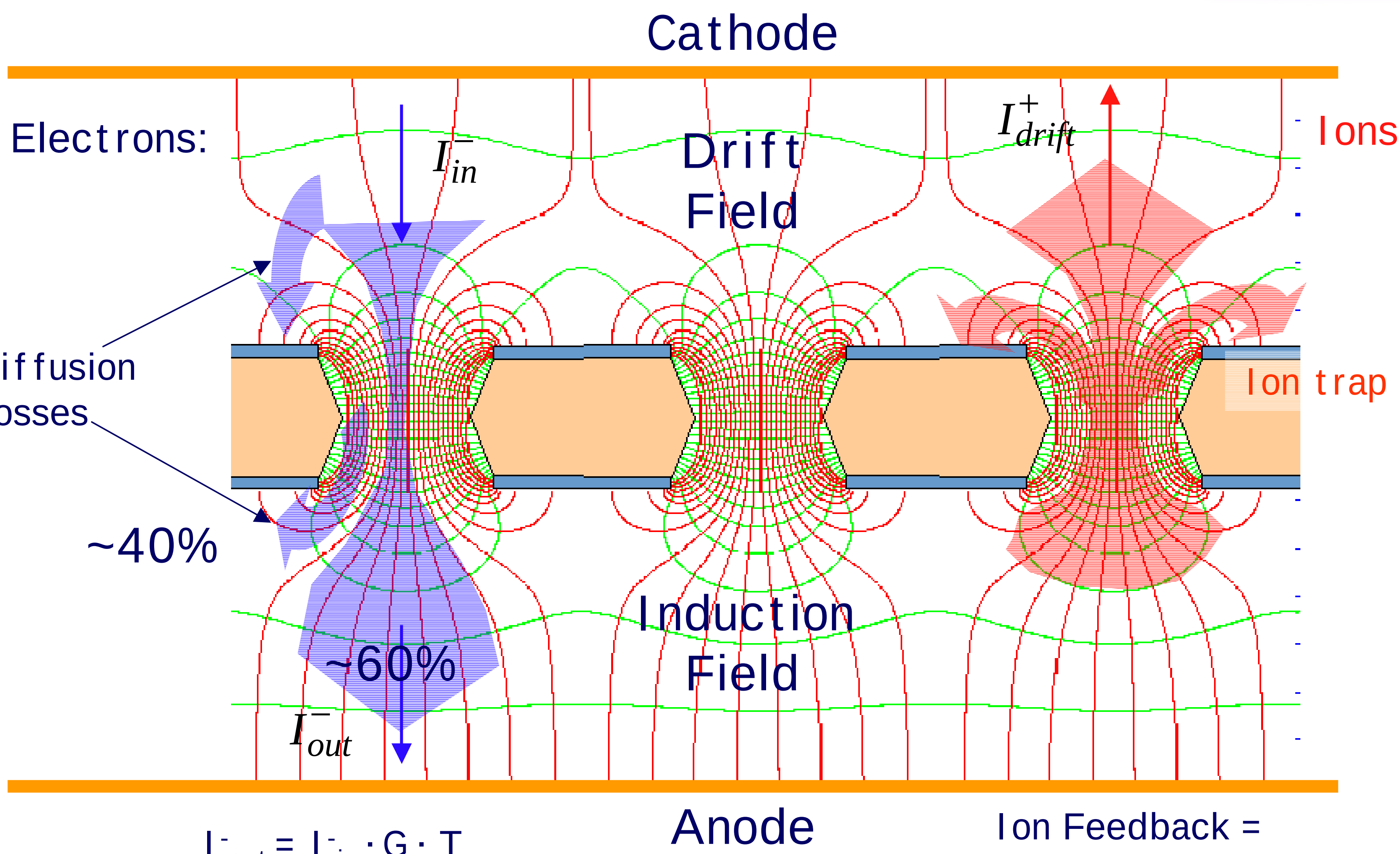
GEM Principle: ions



The hole are completely ion free after 1 μs

high rate capability

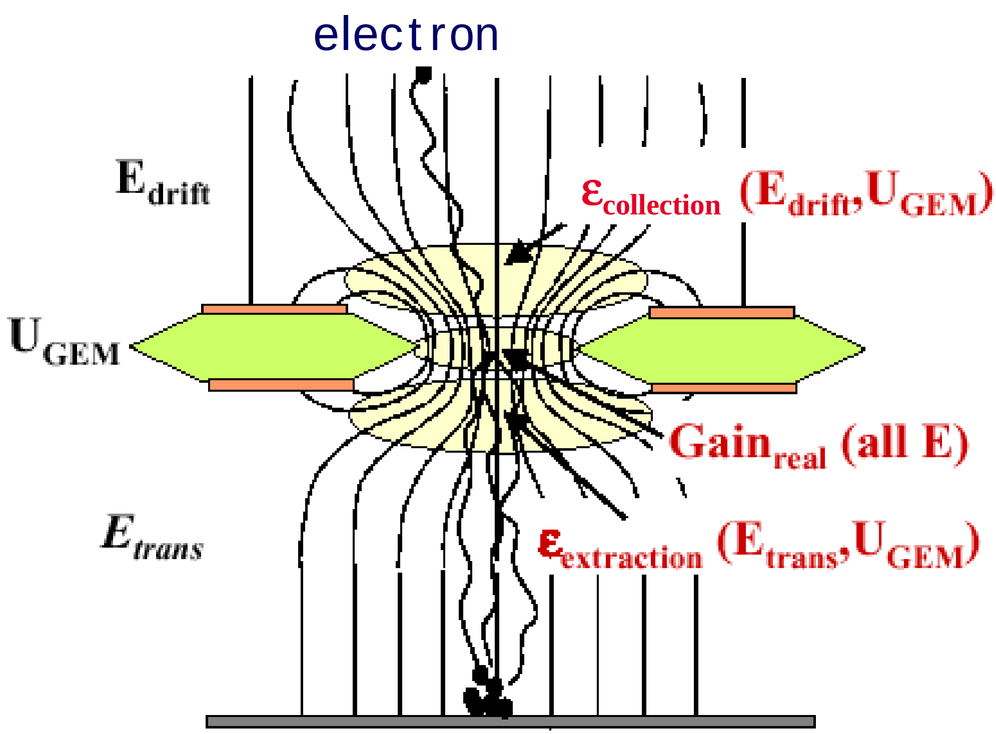
Single GEM detector



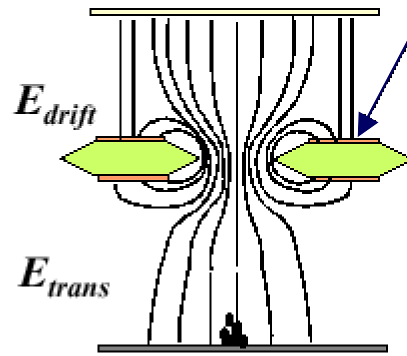
$I^{-}_{out} = I^{-}_{in} \cdot G \cdot T$
(gain x transparency)

Ion Feedback = I^{+}_{drift} / I^{-}_{out}

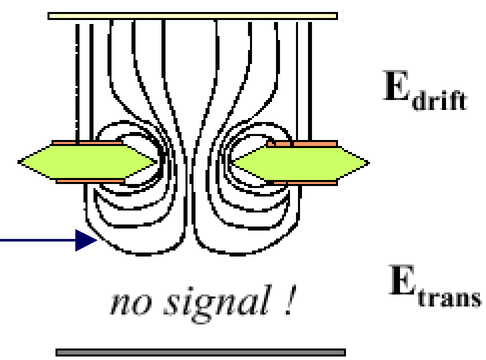
Working with Fields



Collection efficiency
decrease at high drift field values due to defocusing of field lines above the GEM

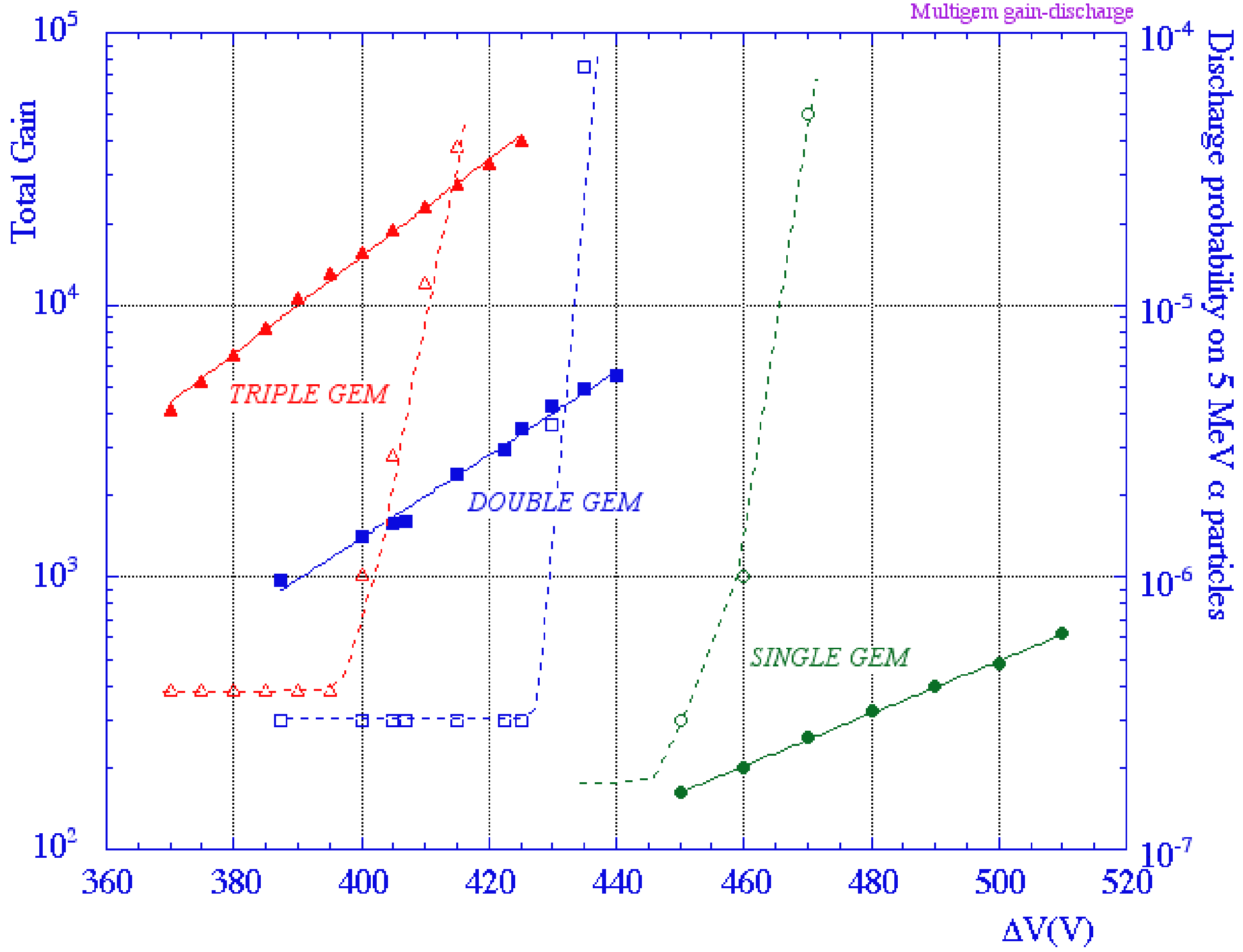


Extraction efficiency
decrease at low transfer fields values due to a worst electron extraction capability from the lower side of the GEM

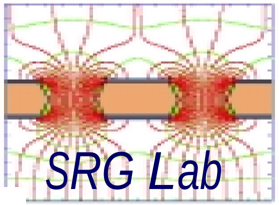


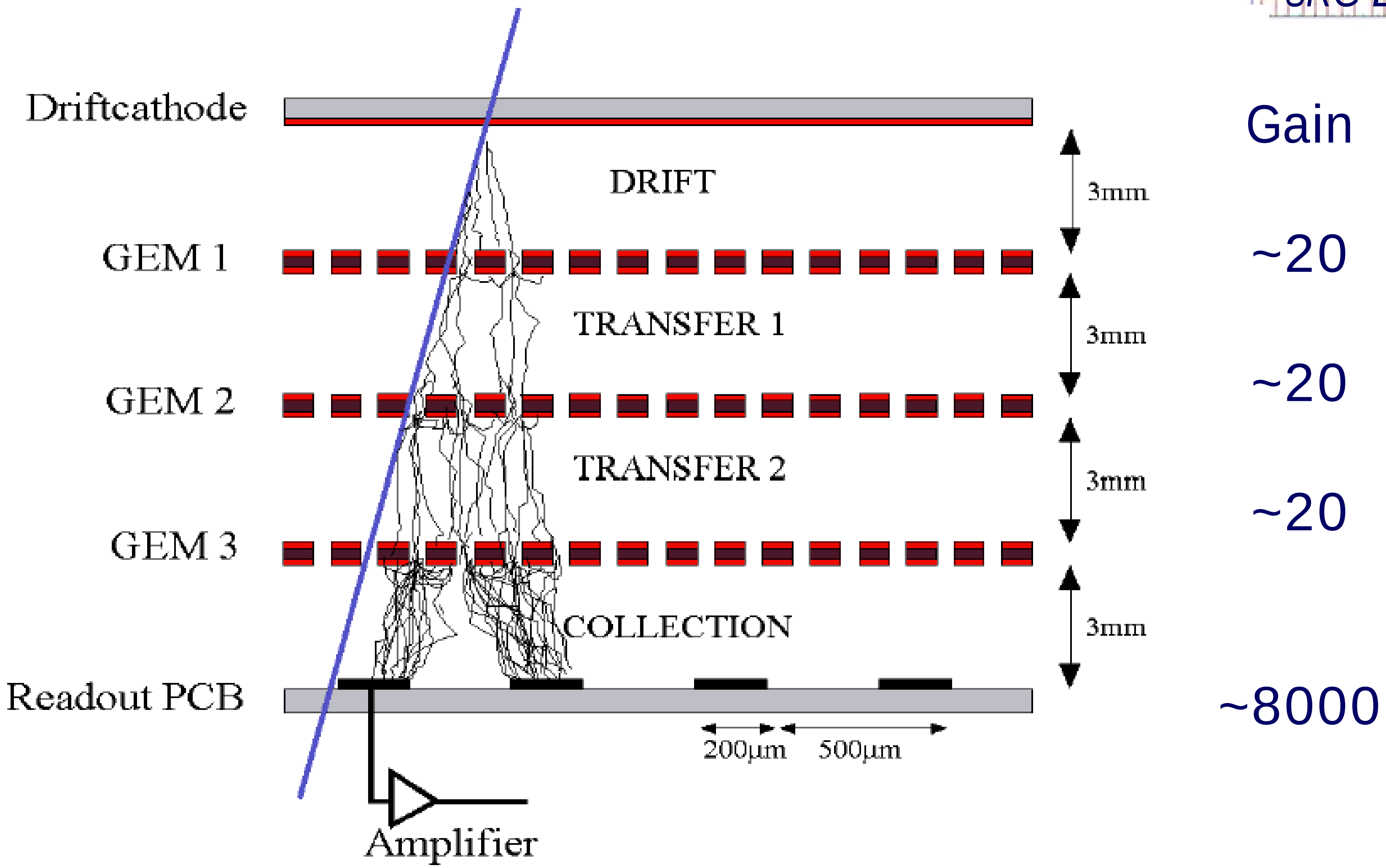
Single vs triple GEM

Measurements with alfa particle



Triple GEM geometries





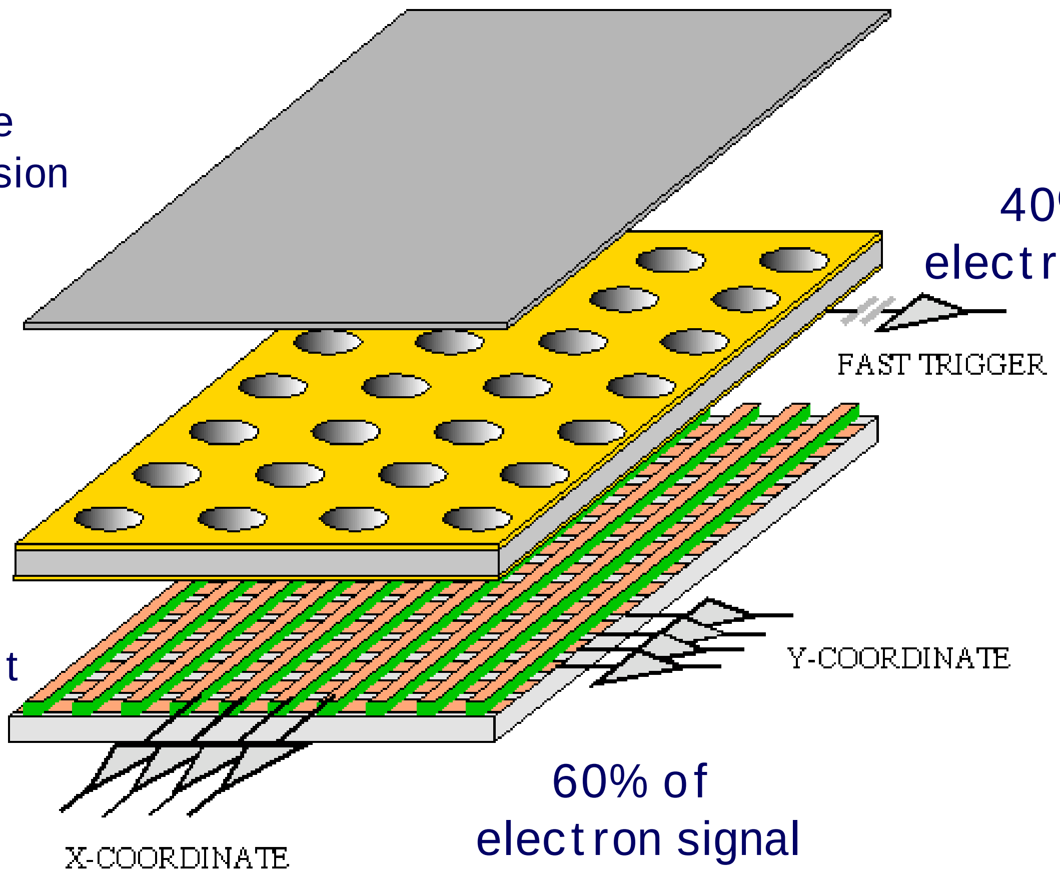
GEM Readout

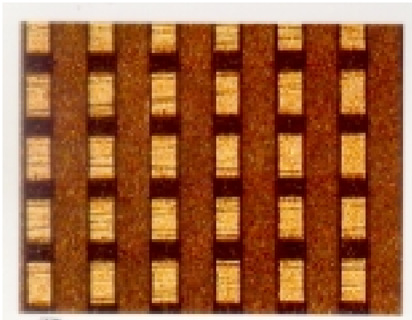
- Gain and readout functions on separate electrodes
- Fast electron charge collected on patterned anode
- Energy signal detected on lower GEM electrode

Particle conversion

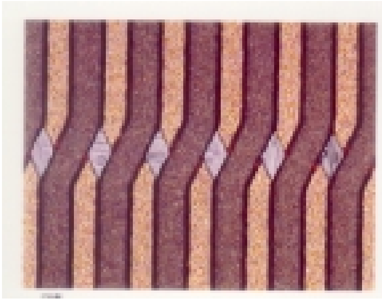
Gain

Readout

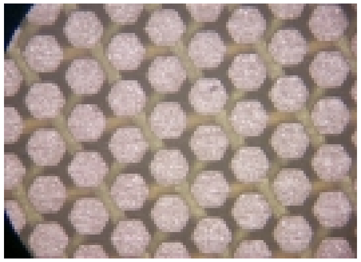




Cartesian



Small angle



Pads

GEM Group

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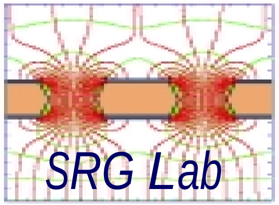
With the technical support of :

SSCR /SPAS (LNF)

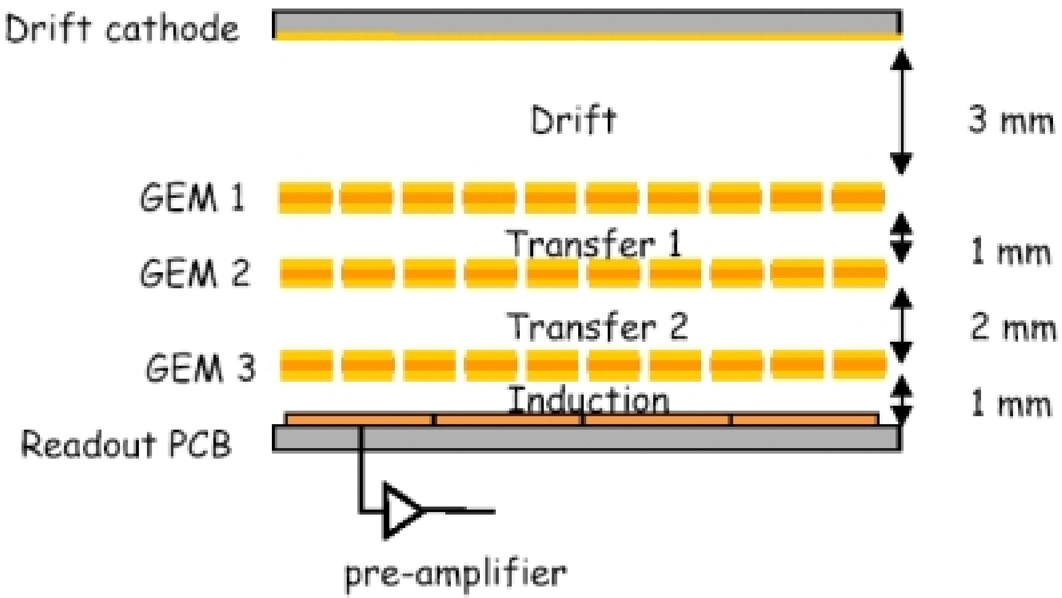
Electronic Pool Service (LNF)

Electronic Pool Service (CA)

The triple-GEM detector



- Multiple GEM structures allow to reach high gain in safe operating conditions;
- Several 3-GEM detector prototypes have been built and tested in last two years by our group;



3-GEM detector layout together with the labeling of different geometrical parameters

- We propose this kind of detector for equipping the central region (R1) of the first station (M1) of the LHCb muon system.

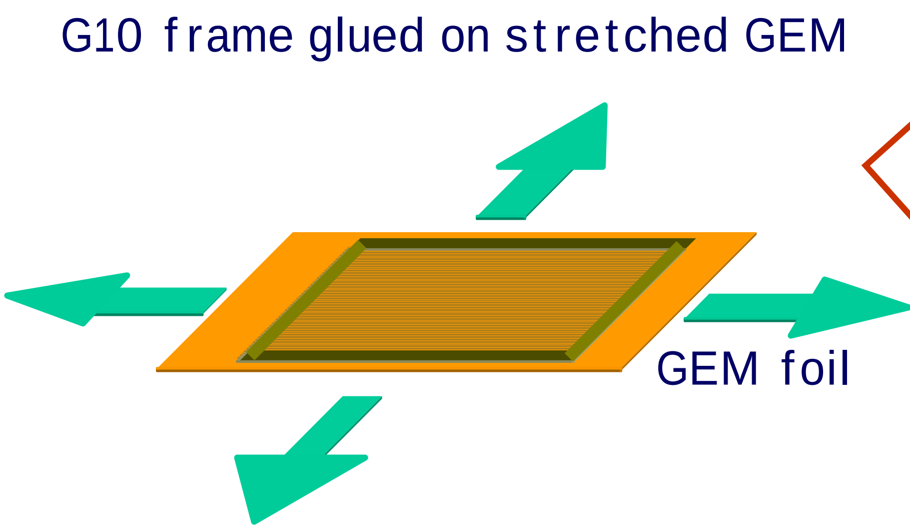
Detector Requirements

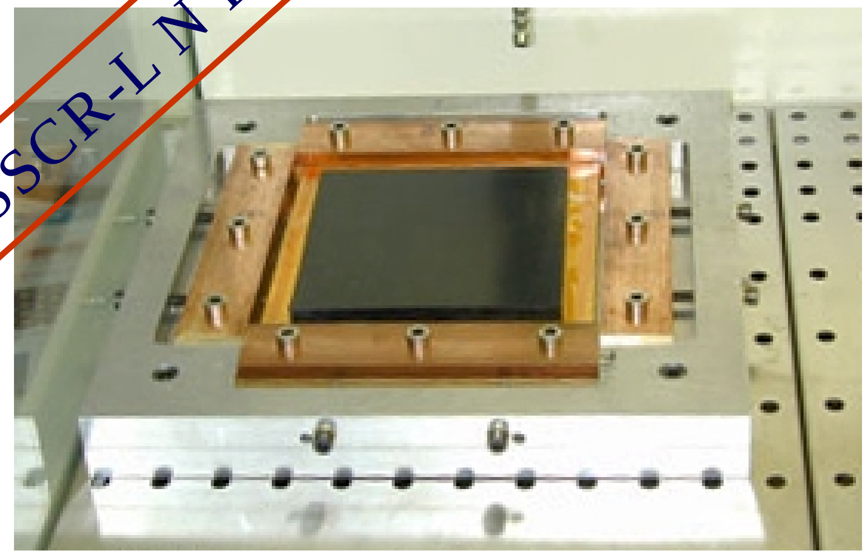
A triple-GEM detector is being proposed for the Central Region of the first Muon Station of the LHCb experiment at CERN, for which the requirements are:

- Rate Capability ~ up to 0.5 MHz/cm^2
- Station Efficiency ~ 99% in a 25 ns time window **(*)**
- Cluster Size ~ 1.2 for a 10x25 mm^2 pad size
- Radiation Hardness ~ 6 C/cm^2 in 10 years (for G ~ 10^4)

(*) A station is made of two detectors "in OR", pad by pad.
This improves time resolution and provides some redundancy.

GEM stretching



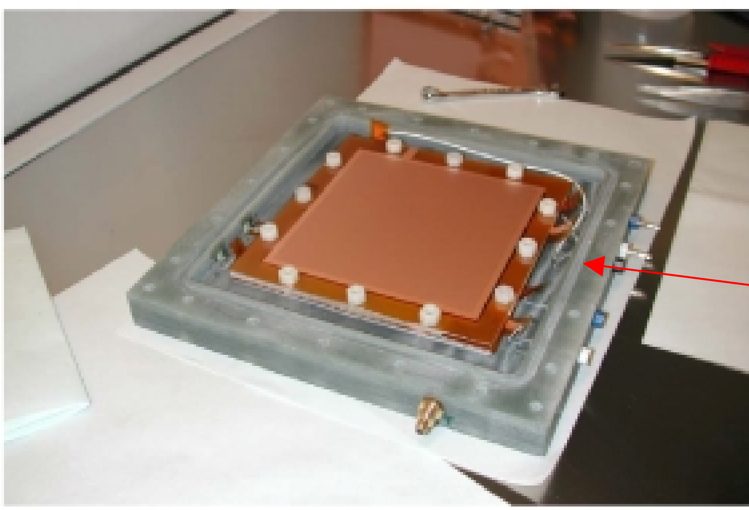


GEM stretcher

The frame is glued on GEM with a CIBA 2012 :
~2 h for epoxy polymerization with 50% of final curing
All operations in clean room !

Prototype construction

10x10 cm^2 GEM stretched and glued on frames

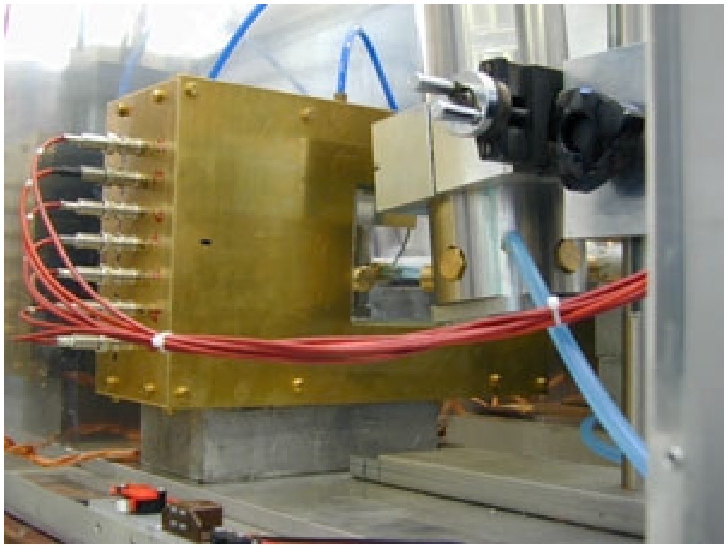


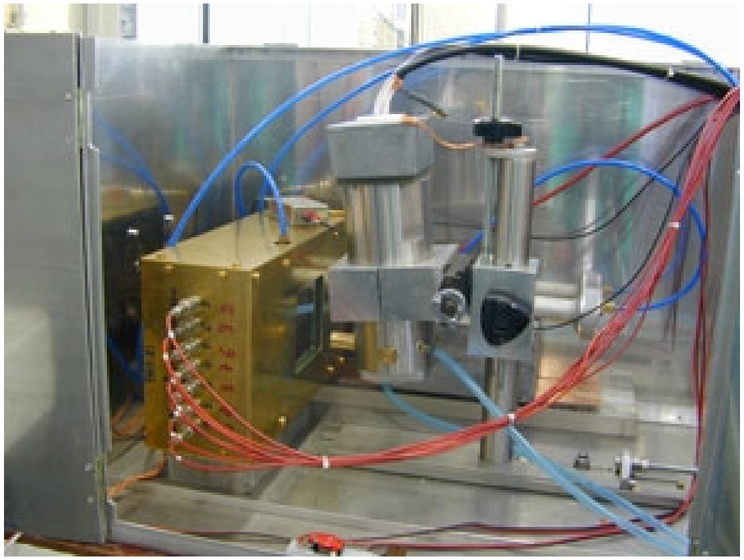
The triple-GEM prototype assembled inside a gas tight box

X-Ray System @ LNF

- E = 5.9 keV monochromatic X-ray beam
- Flux = 50 MHz/cm^2 (10^2 times max LHCb rate)
- Spot size = π mm^2

With this setup we have measured vs Gas mixture :
Gain , Plateau , Rate Capability and Aging





The gas mixtures

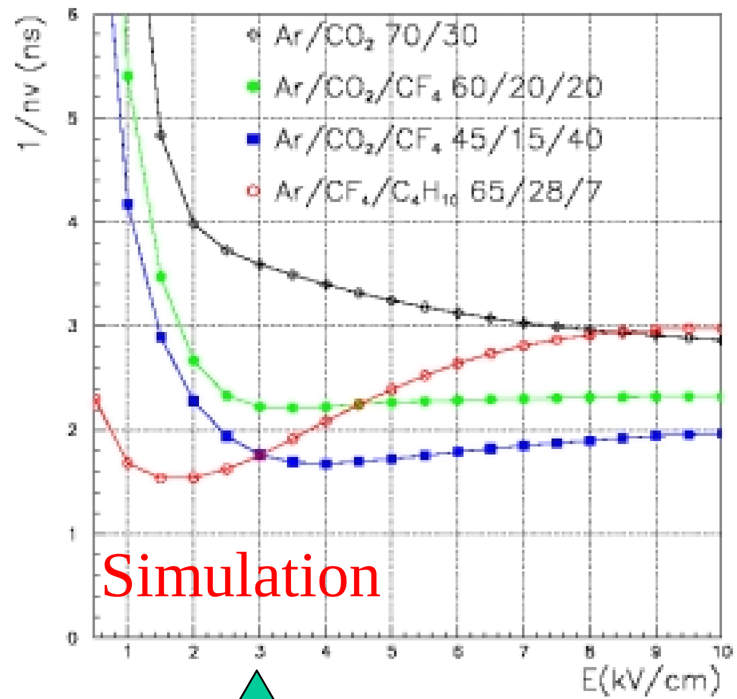
In the beam tests we studied 4 different gas mixtures:

1. Ar/CO_2 70/30;
2. $Ar/CO_2/CF_4$ 60/20/20;
3. $Ar/CO_2/CF_4$ 45/15/40;
4. $Ar/CF_4/C_4H_{10}$ 65/28/7;

Given

- n: the number of clusters per unit length;
- v: the electron drift velocity in the drift gap;

The 1/nv term is the main contribution to the intrinsic time resolution of this kind of detector.



Drift field 3 kV/cm

The $Ar/CO_2/CF_4$ 45/15/40 gas mixture should give the same time performance as the $Ar/CO_2/C_4H_{10}$ 65/28/7.

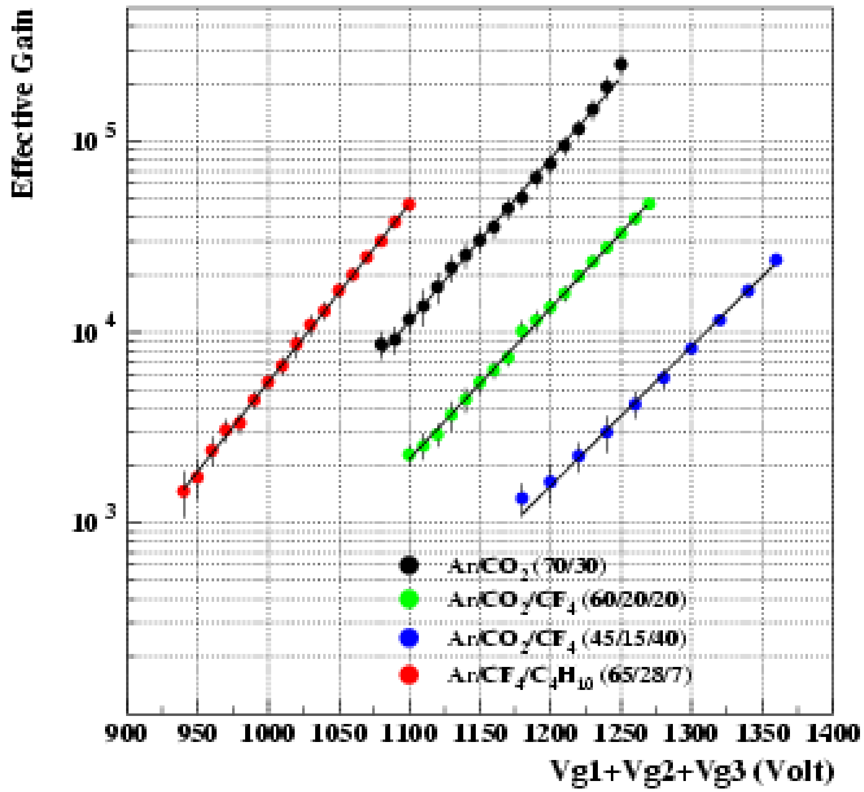
The gas gain

The GEM detector gain was measured by using X-rays for the different gas mixtures;

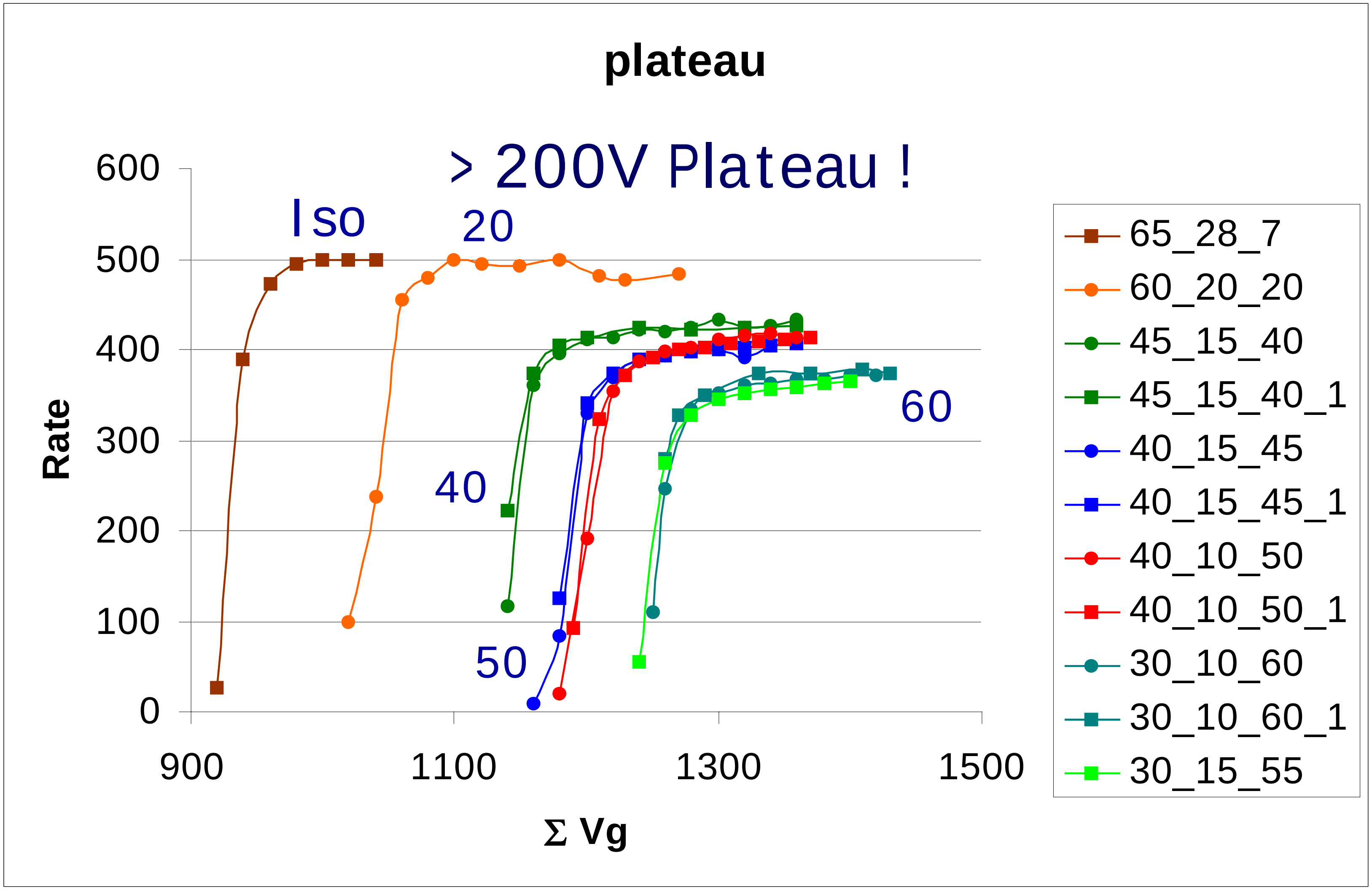
The detector gain is an exponential function of the sum of the 3 GEM supply voltages :

$$G = A\, e^{\alpha(Vgem1+Vgem2+Vgem3)}$$

A and α depend on the gas mixture.

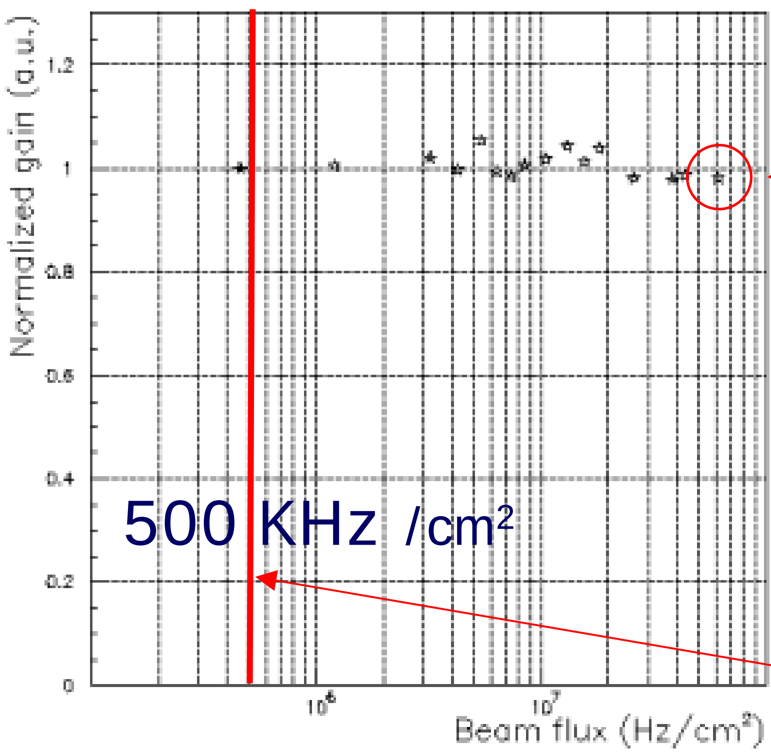


Plateau with Xray



Rate capability

- The rate capability was measured with X-ray;
- The detector was operated with an $Ar/CO_2/CF_4$ (60/20/20) mixture at a gain of about $2x10^4$;



A very good gain stability was found up to a photon flux of about 50 MHz/cm^2

LHCb R1-M1 maximum rate

Aging test

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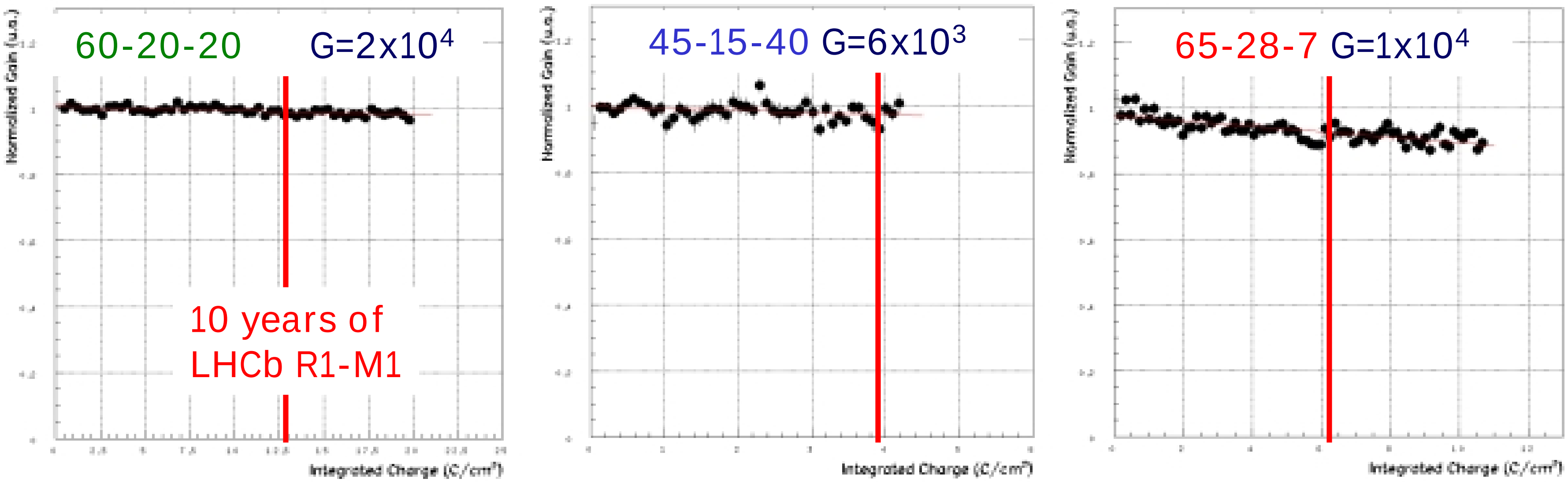
By irradiating the detector with an X-rays flux of 50 MHz/cm^2 :

~ 20 C/cm^2 was integrated with 60-20-20 @ Gain 2×10^4 (15 LHCb Y)

~ 4.5 C/cm^2 was integrated with 45-15-40 @ Gain 6×10^3 (10 LHCb Y)

~ 11 C/cm^2 was integrated with 65-28-7 @ Gain 1×10^4 (17 LHCb Y)

ΔG/G < 5% ΔG/G < 10%



P and T variations are corrected by using a low irradiated 3-GEM chamber

The time performance

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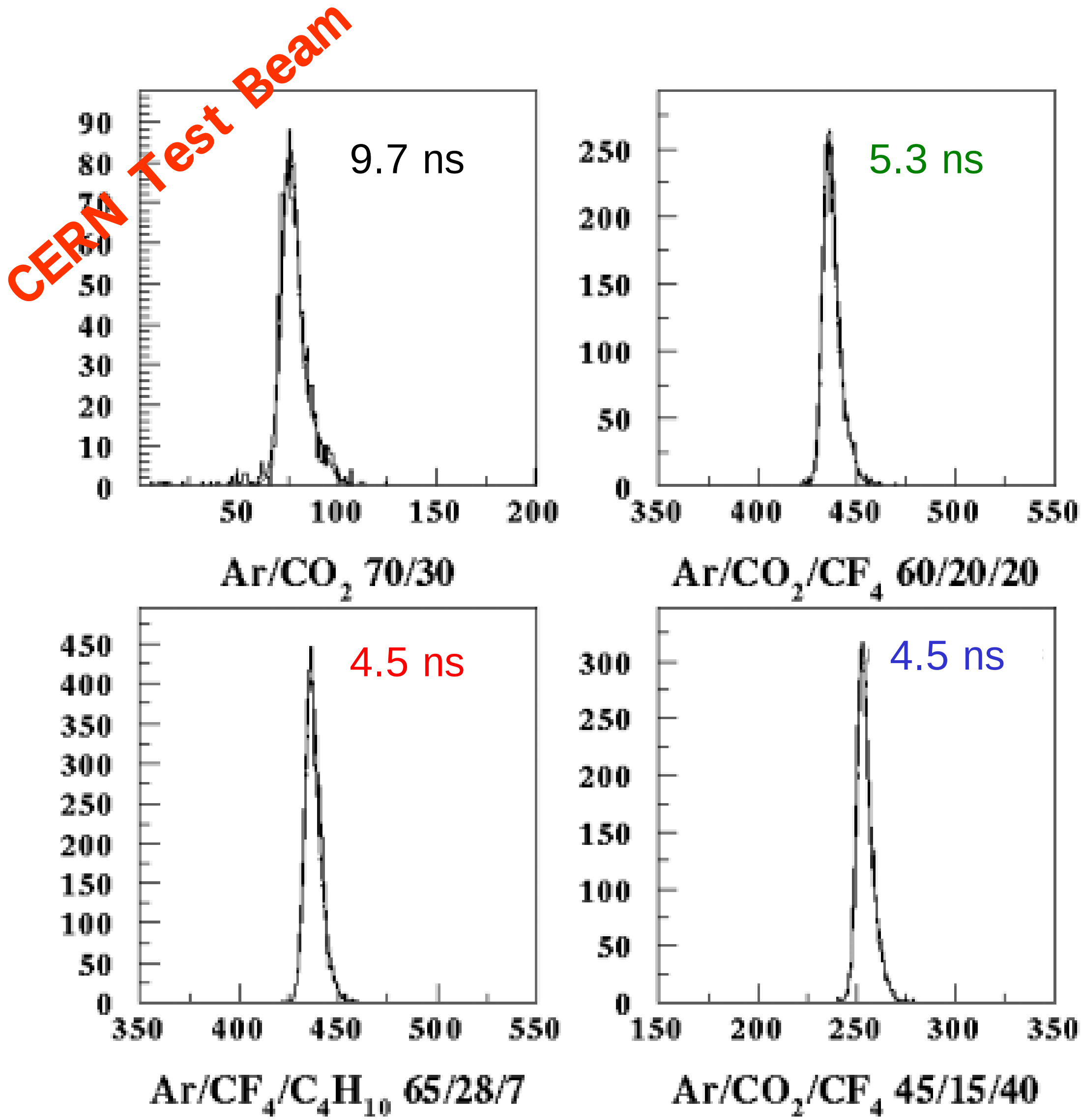


Considerable improvement with respect to the Ar/CO_2=70/30 mixture, which exhibits a poor time resolution of about 10 ns (r.m.s.), is obtained with the new CF_4 and iso-C_4H_{10} based gas mixtures, which allow to reach time resolutions better than 5 ns (r.m.s.)

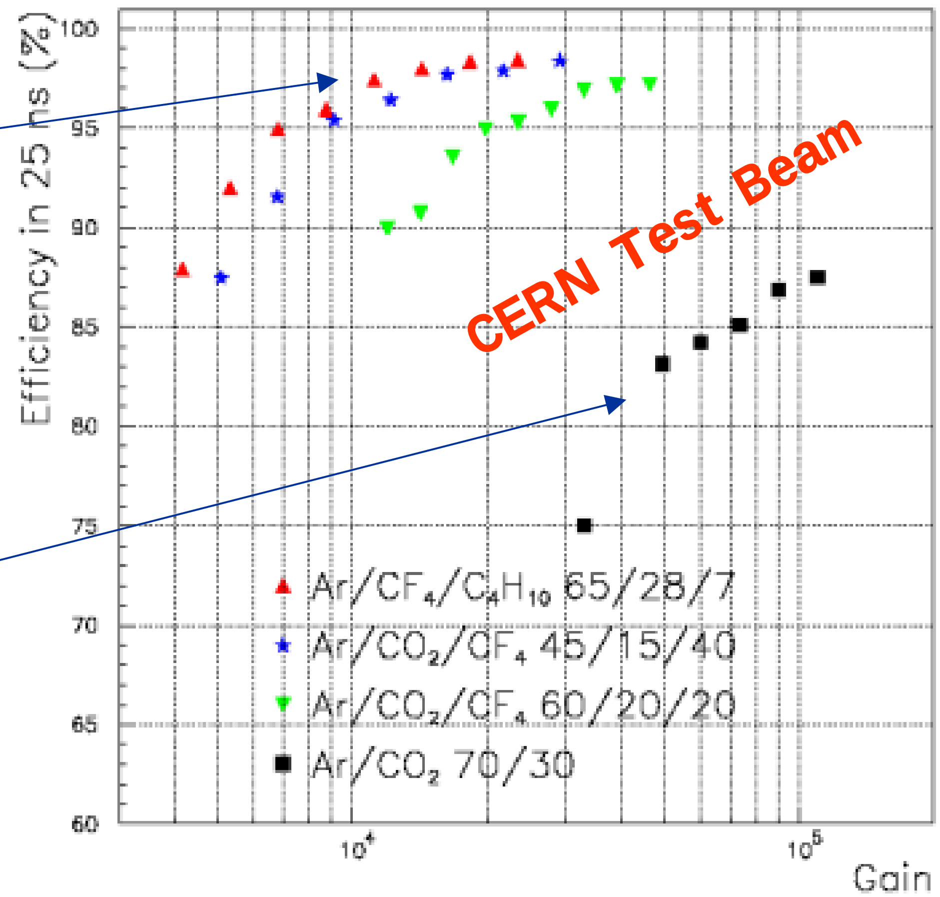
The efficiency in 25 ns

A very important requirement for triggering in LHC experiments is to ensure an high efficiency in a 25 ns time window for a correct bunch crossing identification;

Fast mixtures give an ε_{25} of 98% also at moderate gain values

Slow mixture ε_{25} less than 88% also for high gain values

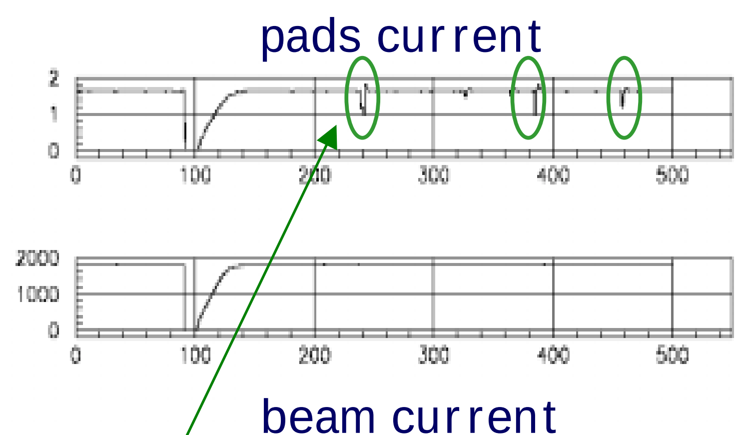
Single detector efficiency in 25 ns



Discharge studies @ PSI

With X ray NO discharges !

- The occurrence of discharges in gas detectors is correlated with the transition from avalanche to streamer.
- The transition depends on the voltage and ionization density.
- In this case the total charge created by the multiplication processes could exceed the threshold value (Raether limit, 10^7-10^8 e-I$^+$ pairs) for the transition from avalanche to streamer.
- Due to the very small anode-cathode distance in GEM detectors, the transition from avalanche to streamer is most of the time followed by discharges.



A discharge is seen on the read-out pads as a current drop

Discharge Results (@PSI)

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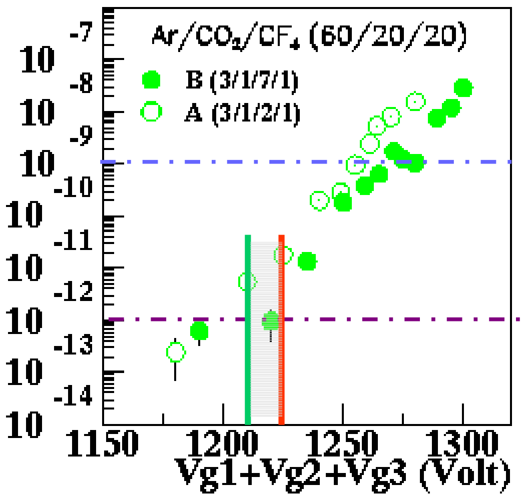
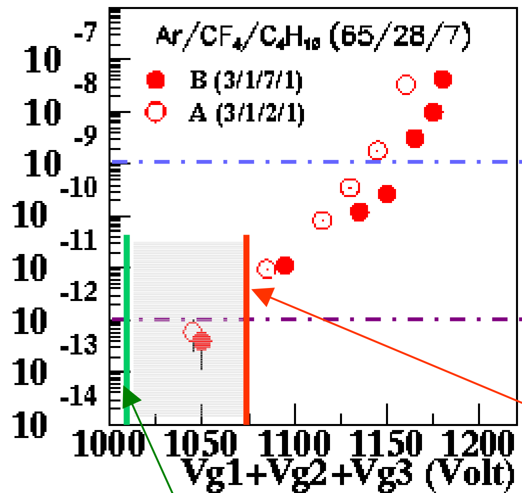
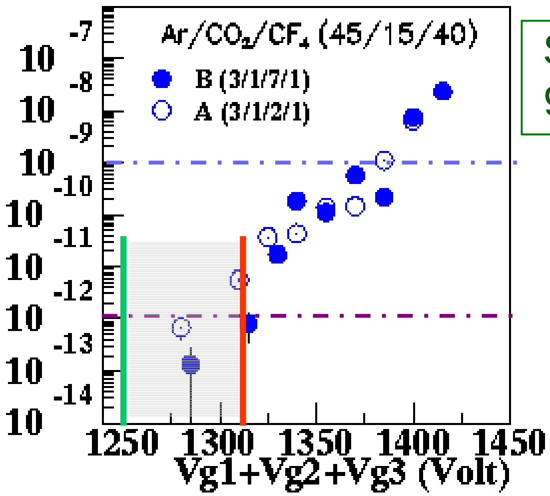
Discharge probability per incident particle







1 % inefficiency due to re-charging time

Discharge probability < 10^{-12}

End of efficiency plateau given by the limit on the discharge probability of 10^{-12}

Start of efficiency plateau: 99% in 25 ns per station

During the PSI test each detector integrated without any damage or aging effect about 5000 discharges, corresponding to a discharge probability per incident particle of 10^{-12} in 10 years at LHCb.

Results: $Ar/CO_2/CF_4$ 45/15/40

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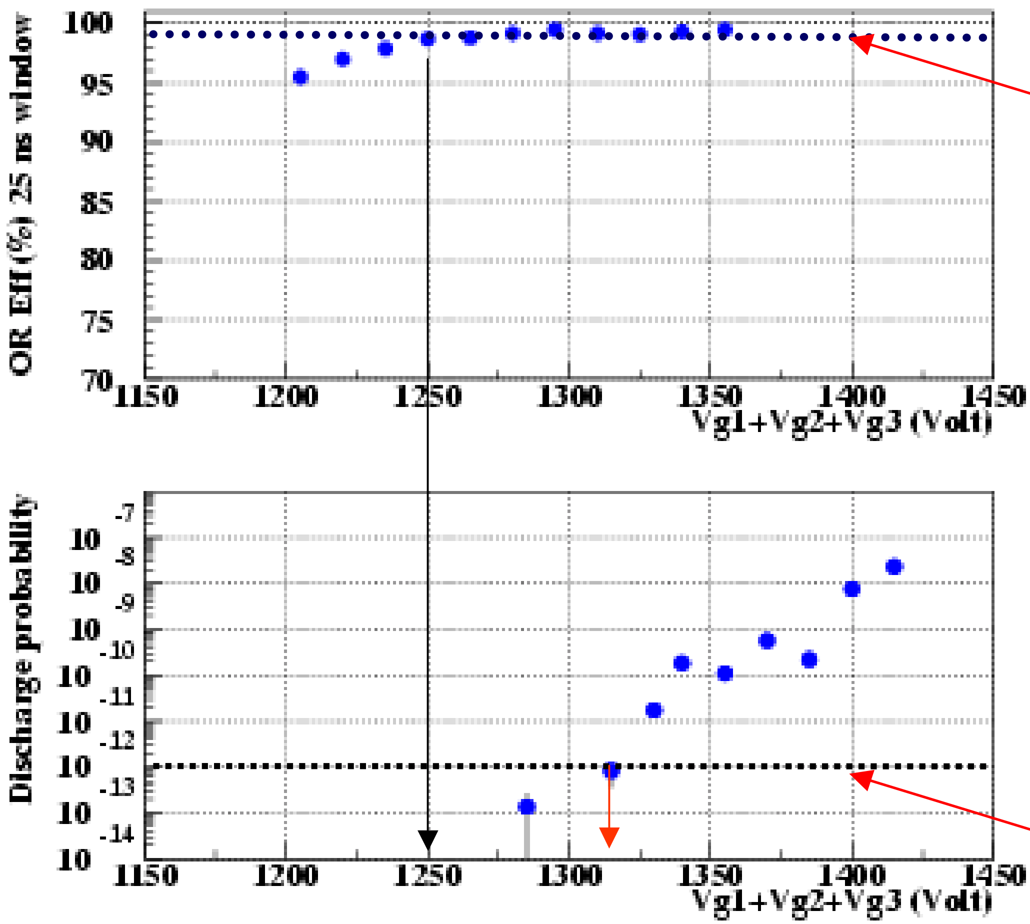


99% efficiency in 25 ns of two chambers in OR

(measured after 10 years LHCb equivalent)

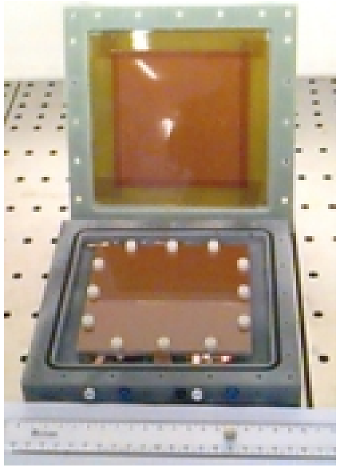
Discharge probability < 10^{-12}

1250 V 1315 V

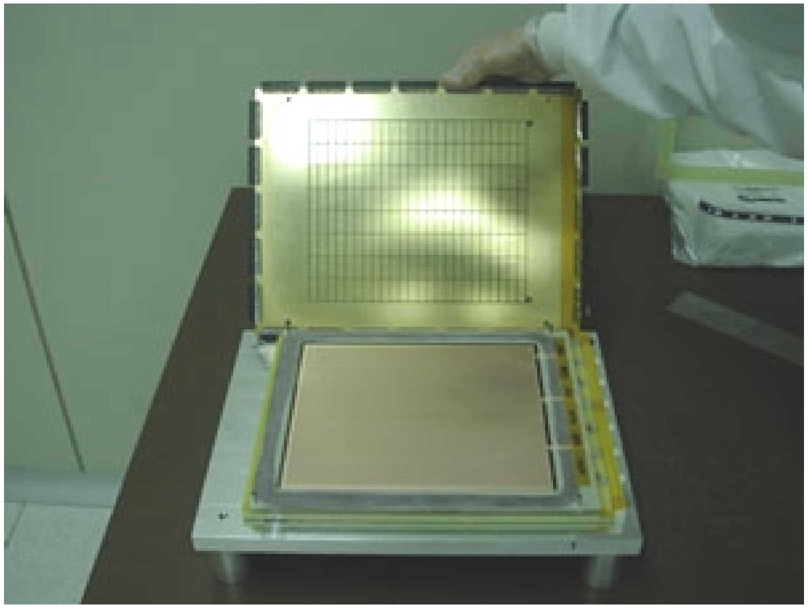
65 V wide working region

Chamber 20x24 cm^2

All the measurements shown until now are performed with 10x10 cm^2 prototype



In the last months we have started the construction of 20x24 cm^2 chamber



Load Measurements

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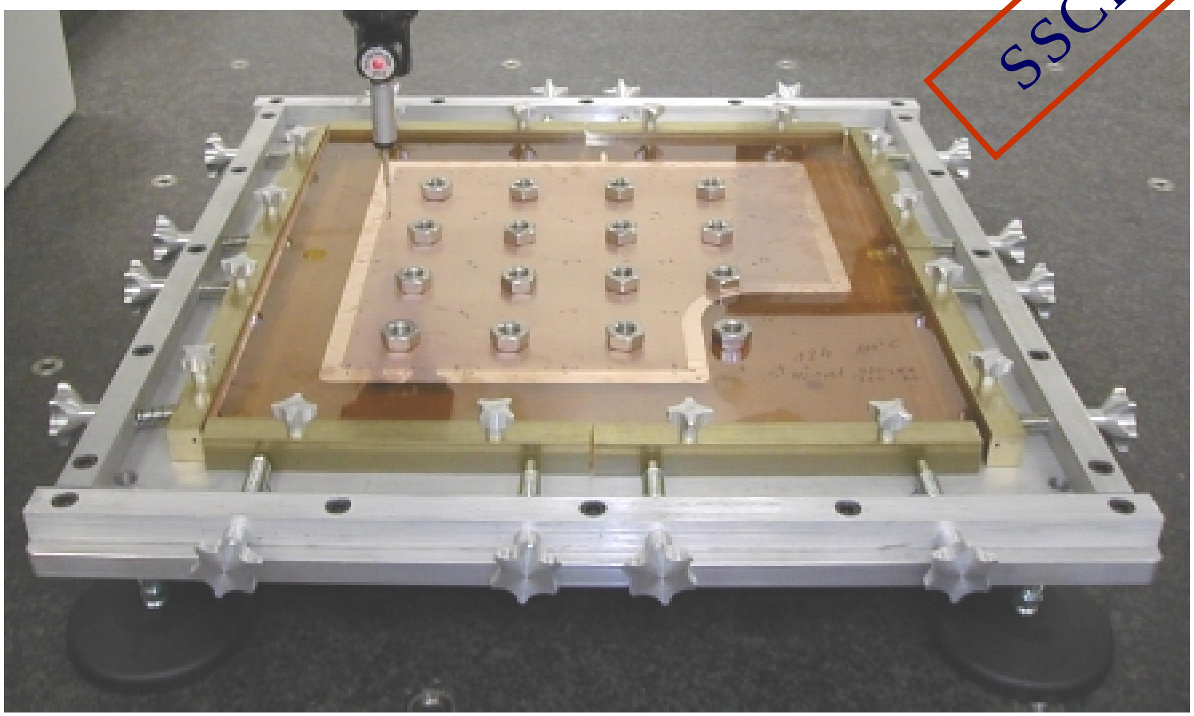
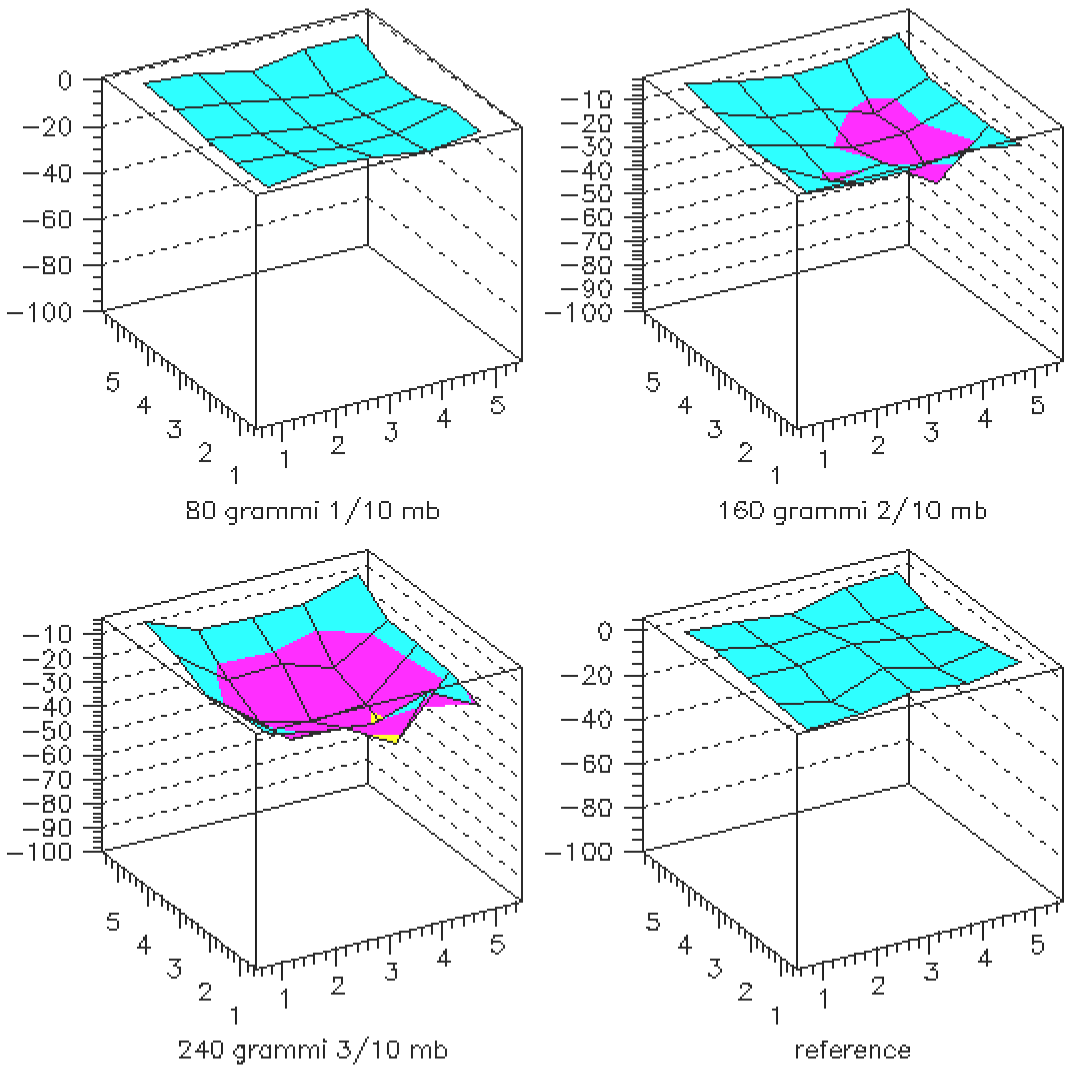
We have built a new gem stretcher
for GEM foils 30x30 cm^2.

Sag measurements have been performed
as a function of different loads

SSCR-LNF



Load measurements results



The GEM with a tension of
30 Kg per side (~1Kg/cm)
shows a sag of 100 μm
(central region) for a distributed load
of 100 gr (equivalent to 0.1 mbar).

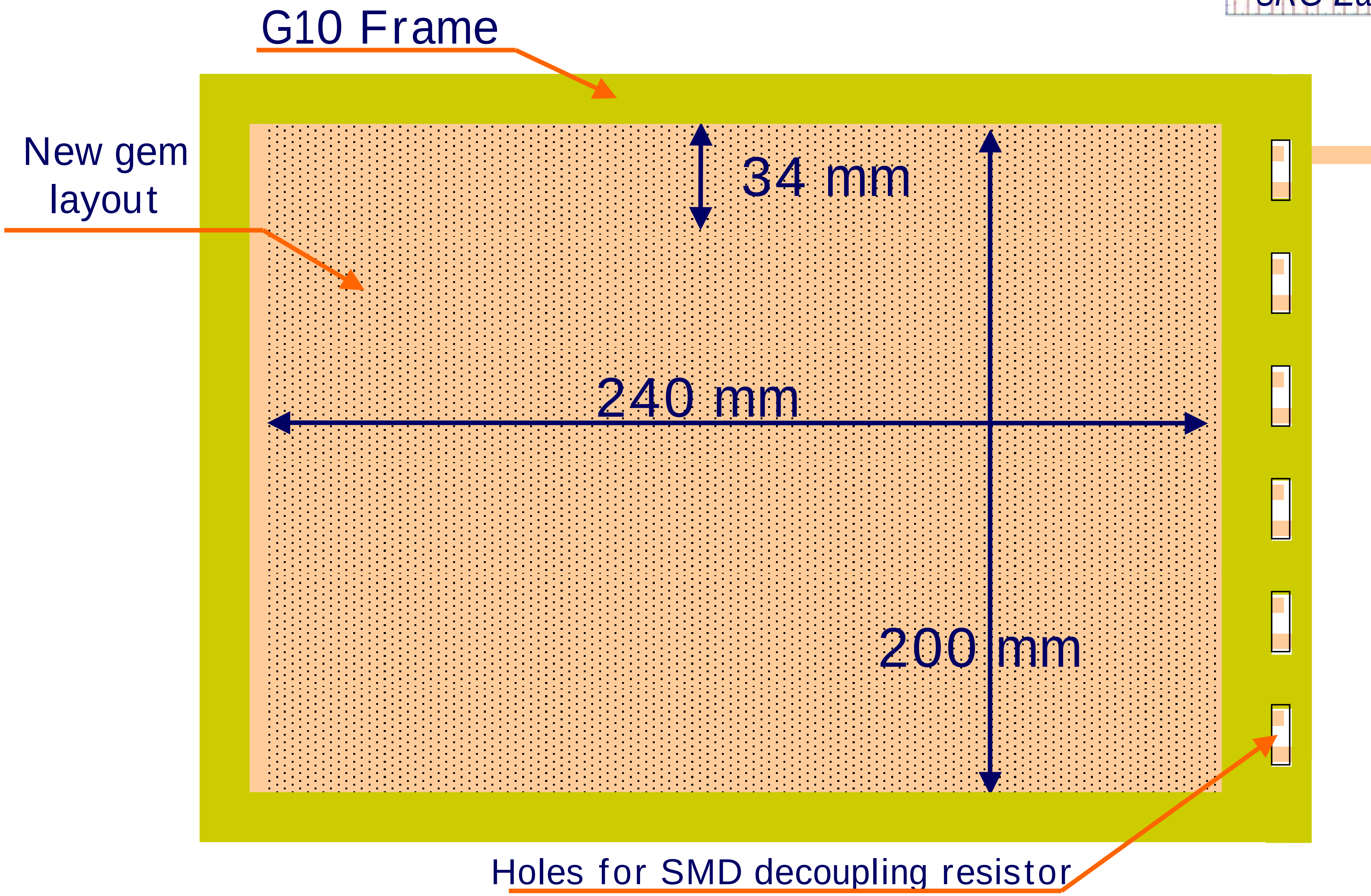
The electric field corresponds to
a force of ~ 0.01 mbar.

The total sag due to the electrostatic
force should be of the order 10μm.

⬇

Large size triple GEM detector
without spacer

New GEM Foil



G10 Frame
New gem layout
34 mm
240 mm
200 mm
Holes for SMD decoupling resistor

Module-0 construction

Few months ago we started to built the first chamber 20x24 cm^2

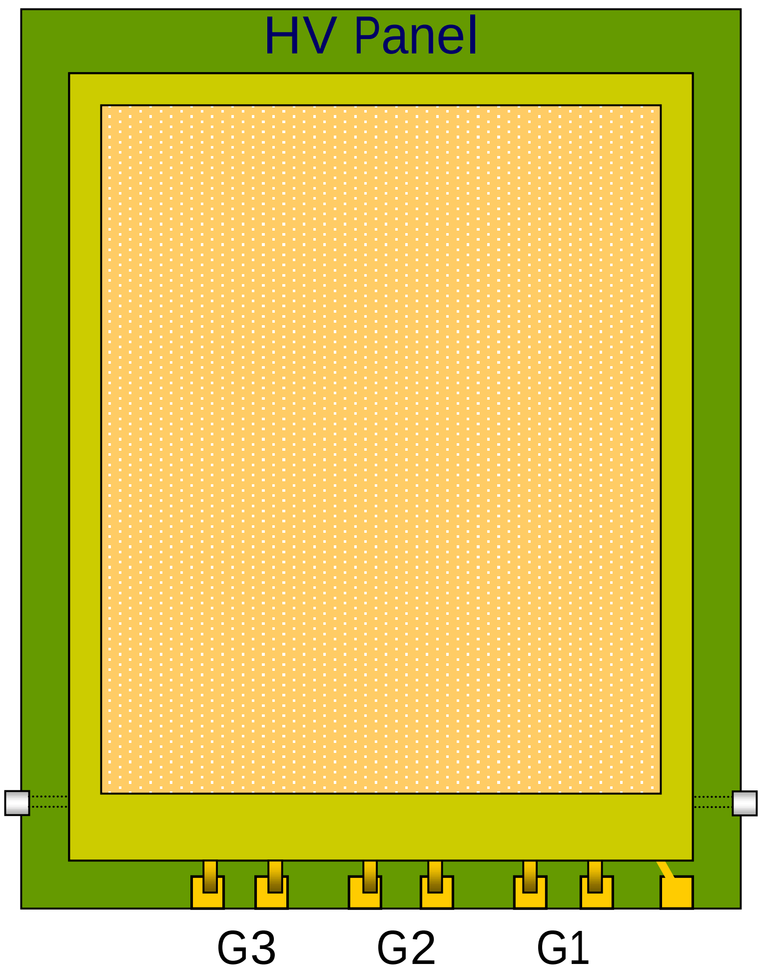
The GEMs are stretched.

The G10 frames glued on the GEM foil

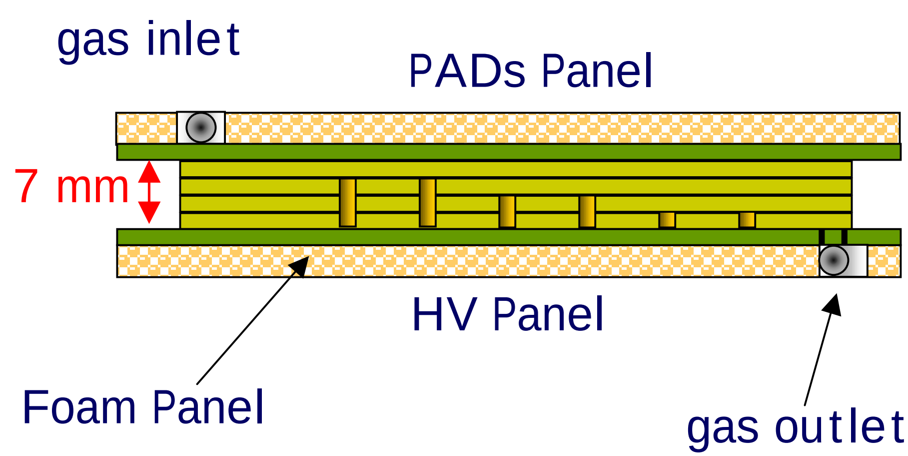
In the frames 6 holes house
1MΩ SMD resistors for HV decoupling

GEM Chamber Layout

GEM Chamber top view

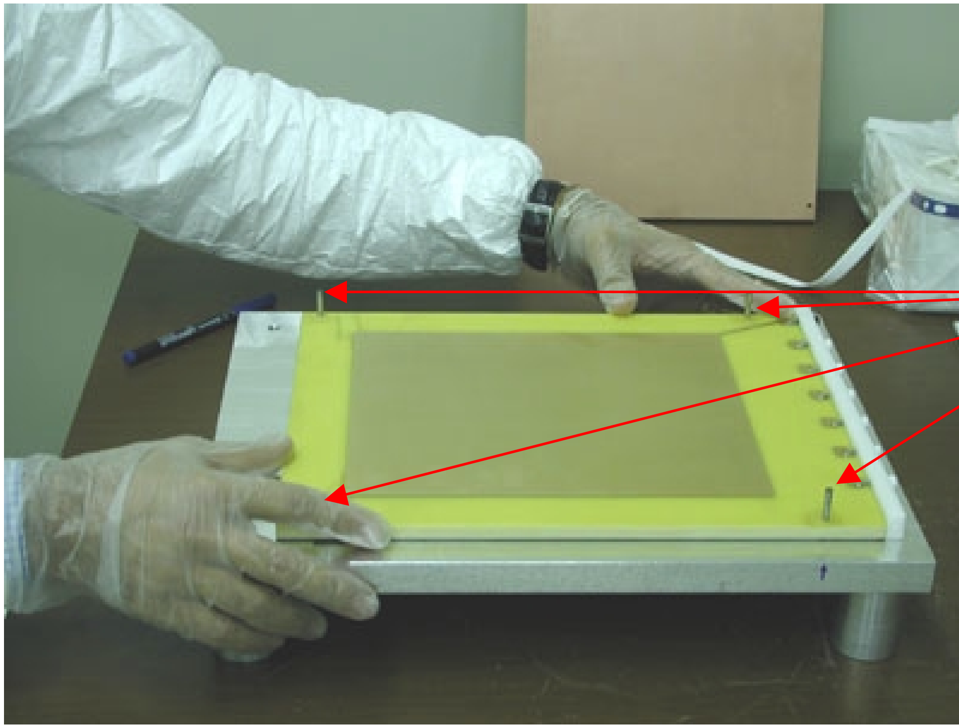


One day for assembling !



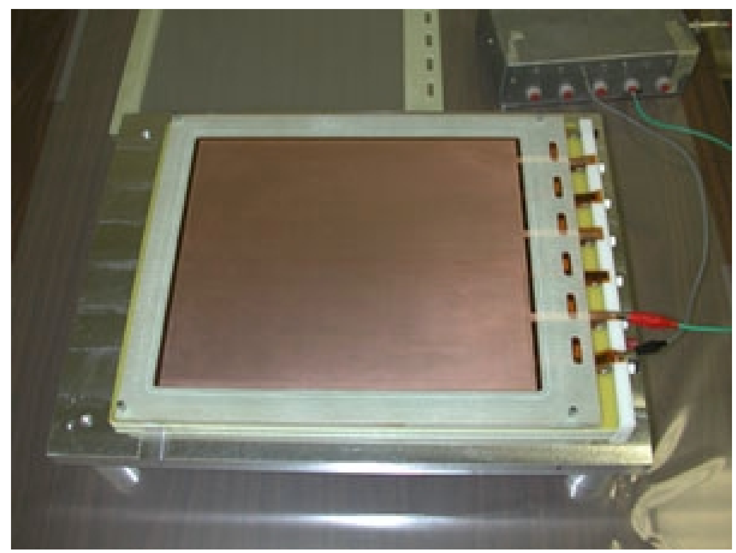
GEM Chamber side view

Module 0 assembling

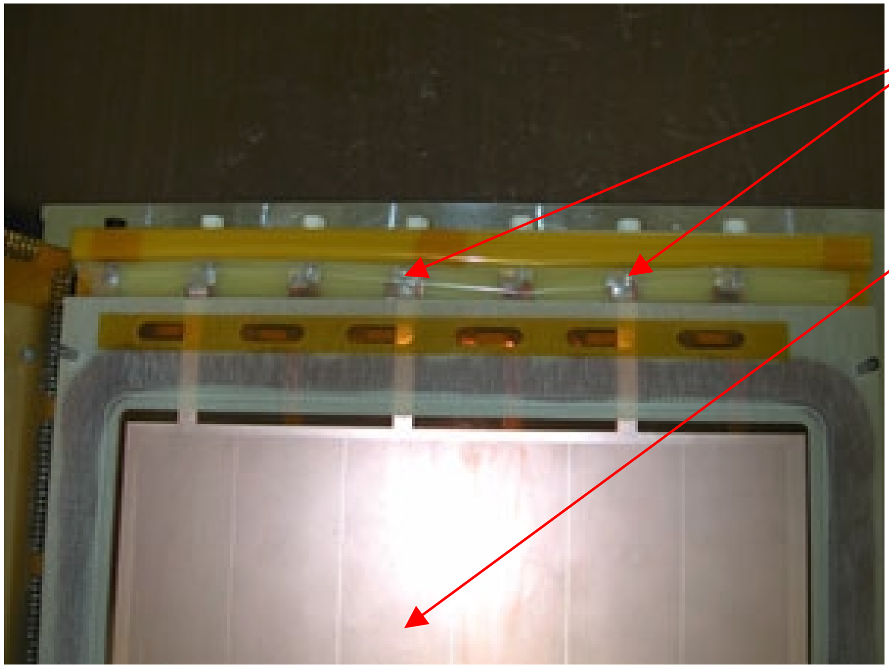


The assembling starts with the HV panel placed on top of a reference plane with 4 reference pins

The three GEM frames are glued on top of the others and tested with HV each time.

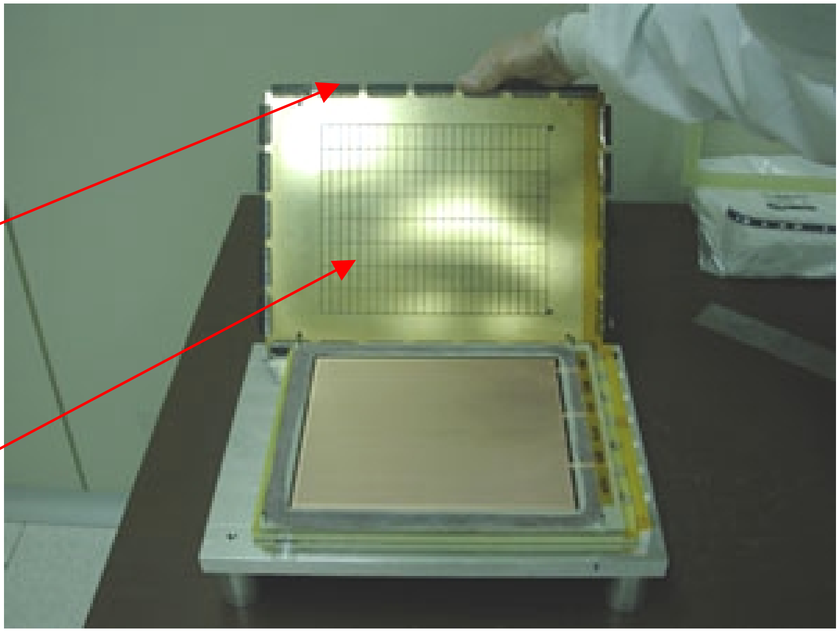


Module 0 assembling



The HV GEM contacts are soldered on the Drift Cathod Panel

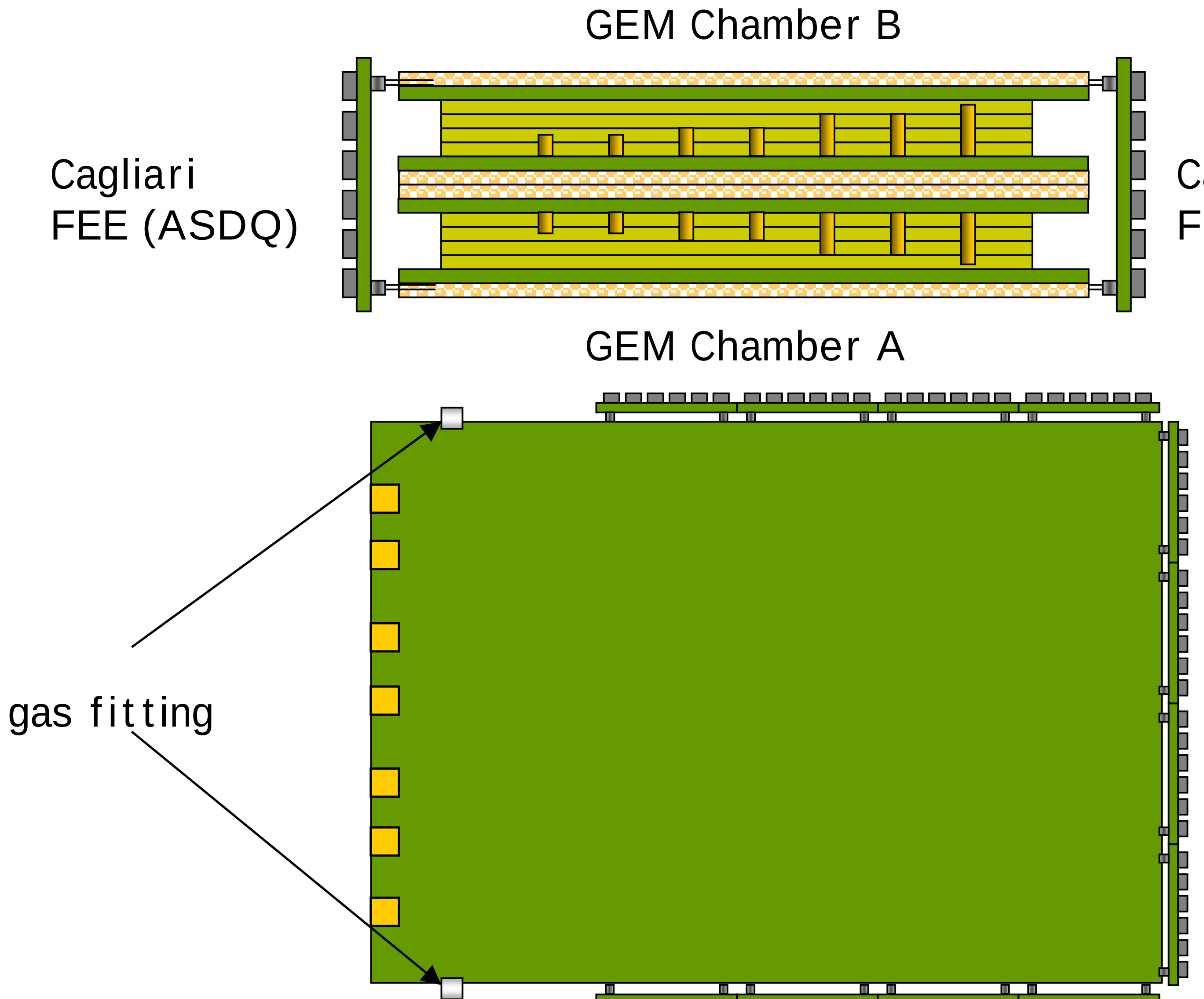
The GEM are assembled without internal spacers



Connector for FEE (ASDQ 25 mV/fC)

The GEM stack is closed with the Readout Pad Panel

Module 0 Layout



The Module 0
has been equipped
with 17 ASDQ cards
(instead of 24)

272 channels

Module 0 tests beam results

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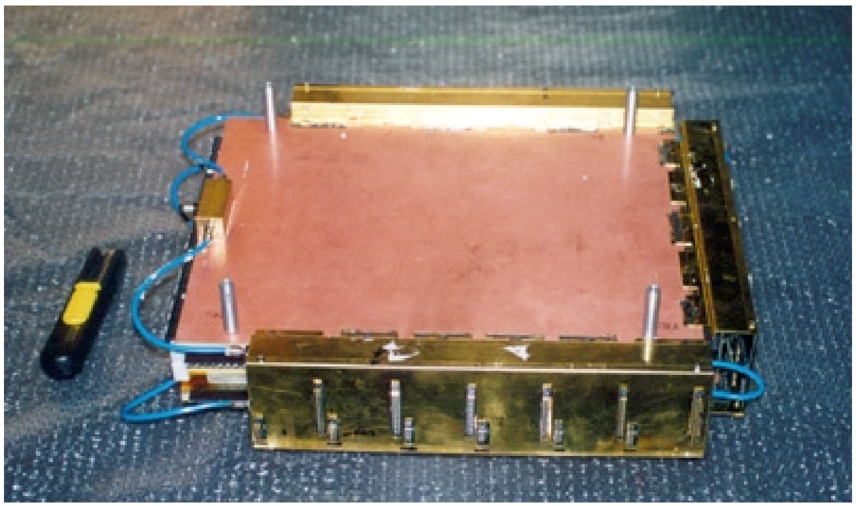
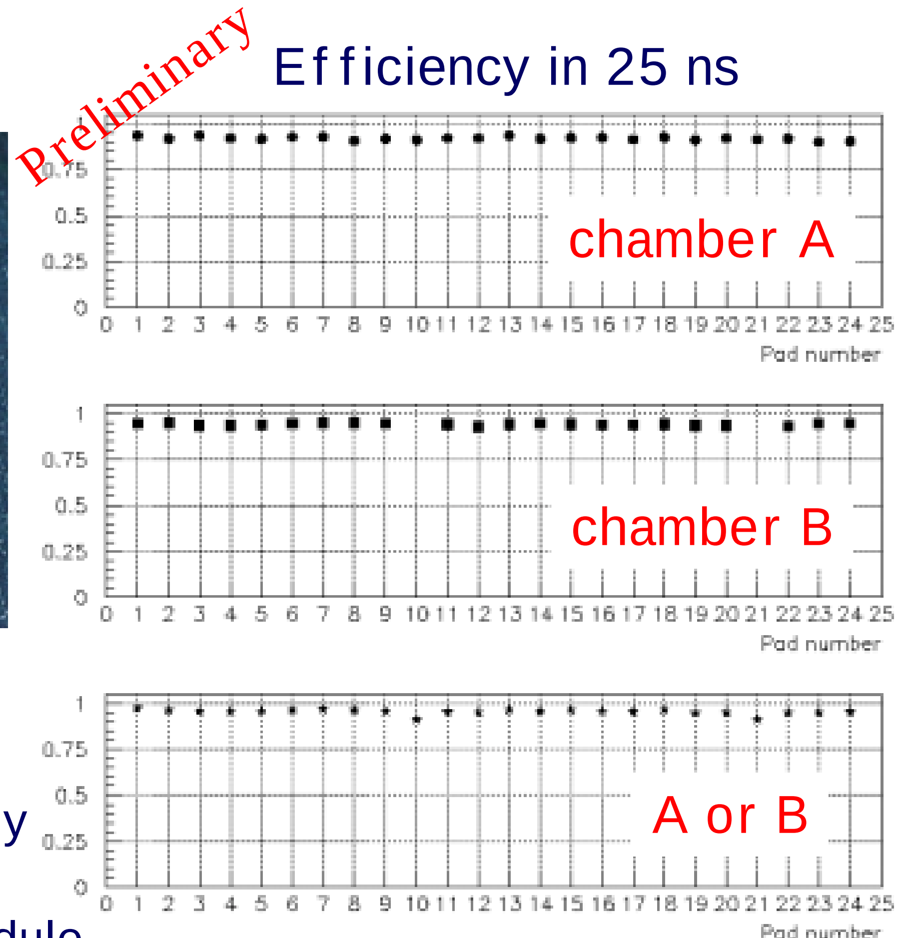
Both chambers reach the operating Voltage with few nA of dark current





At the first test beam@ CERN
the Module 0 shows a good uniformity

Only a portion 10x6 cm^2 of the Module

Material budget & cost

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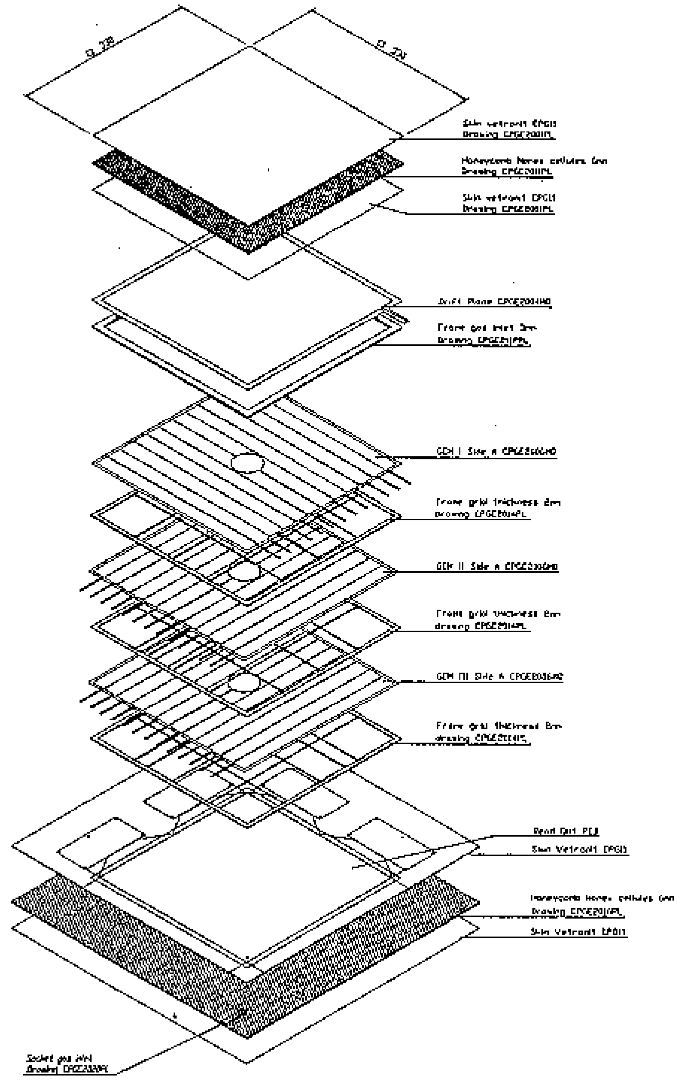
One triple GEM chamber	Active area	Border
3 Frames of 22 mm wide 1-3 mm thick		4.0 % X_0
3 GEM Foils 50 µm Kapton and 5+5 µm Cu	0.2 % X_0	0.1 % X_0
Honeycomb + Cathode and Anode 5+5 µm Cu	0.6 % X_0	0.5 % X_0
Total	0.8 % X_0	4 .6 % X_0

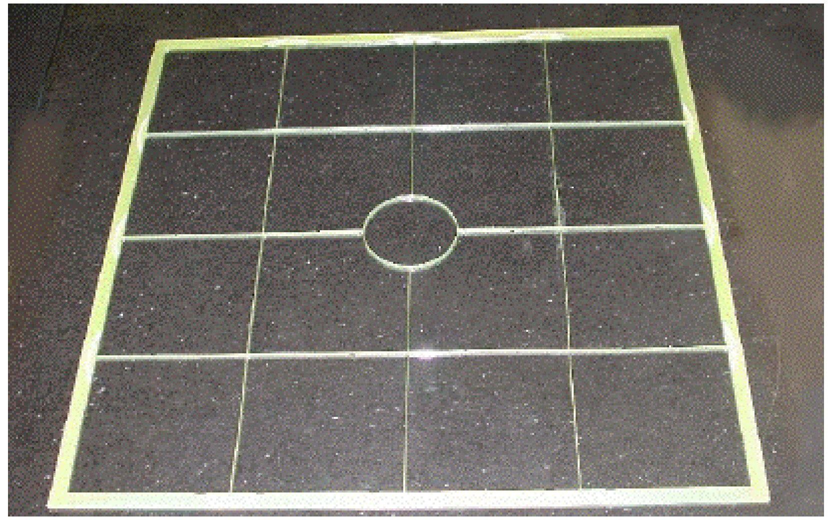
Actually only the CERN is able to built different type of GEM foil ...
you have to decide only the HV sectors organization and HV road...

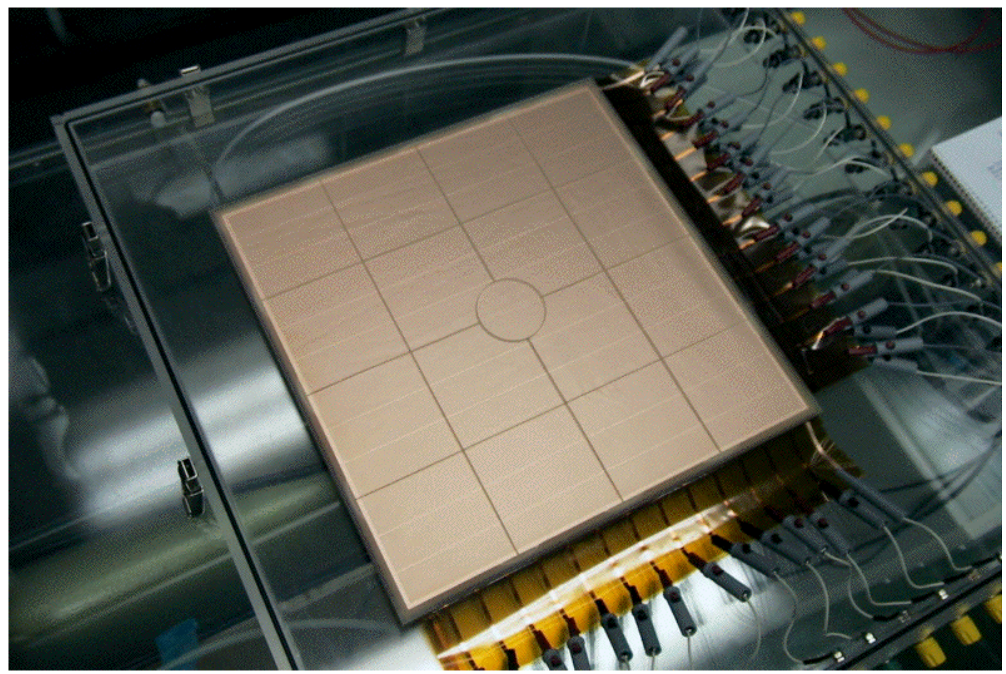
One GEM foil 20x24 cm^2 have a cost of ~ 300 €.

Other GEM Applications

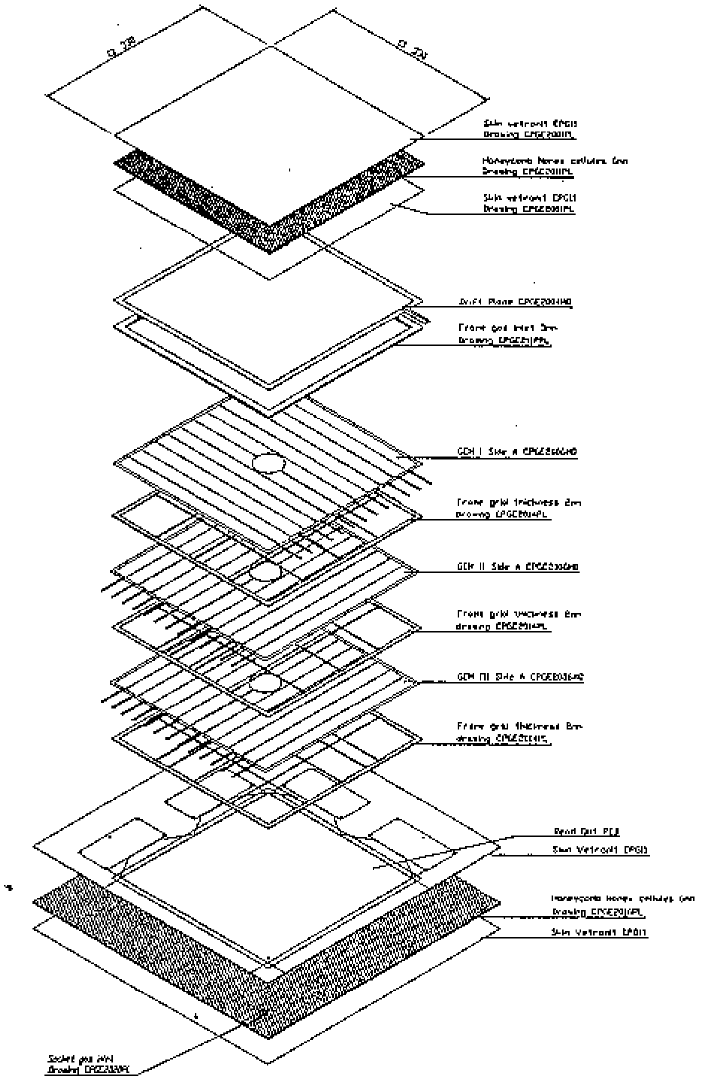
Compass experiment

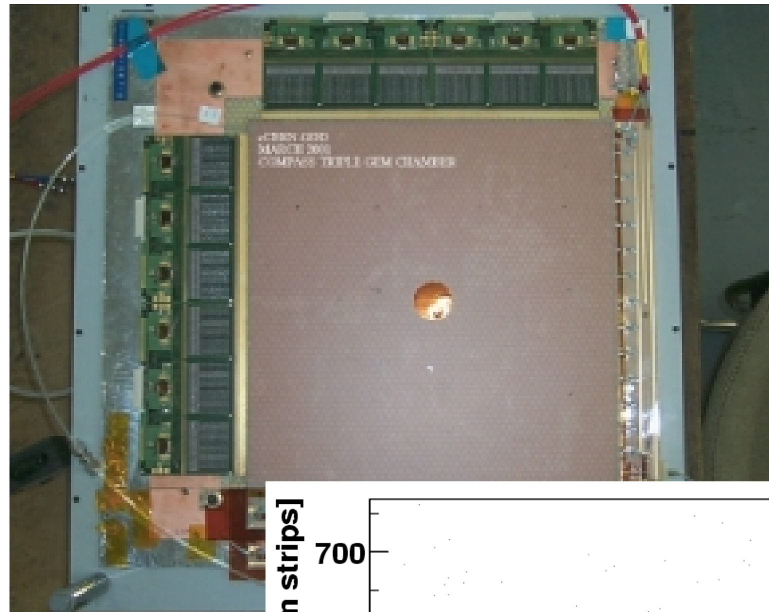


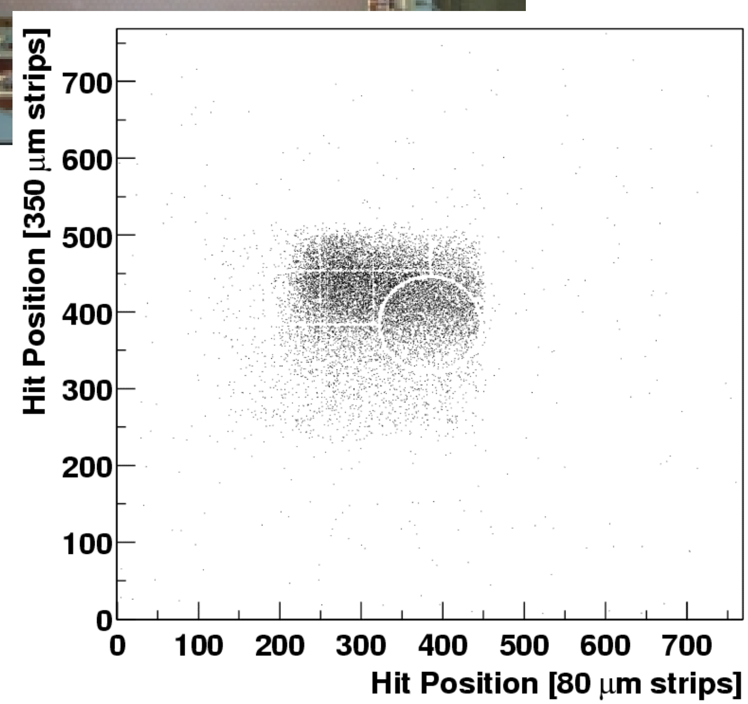




Compass experiment







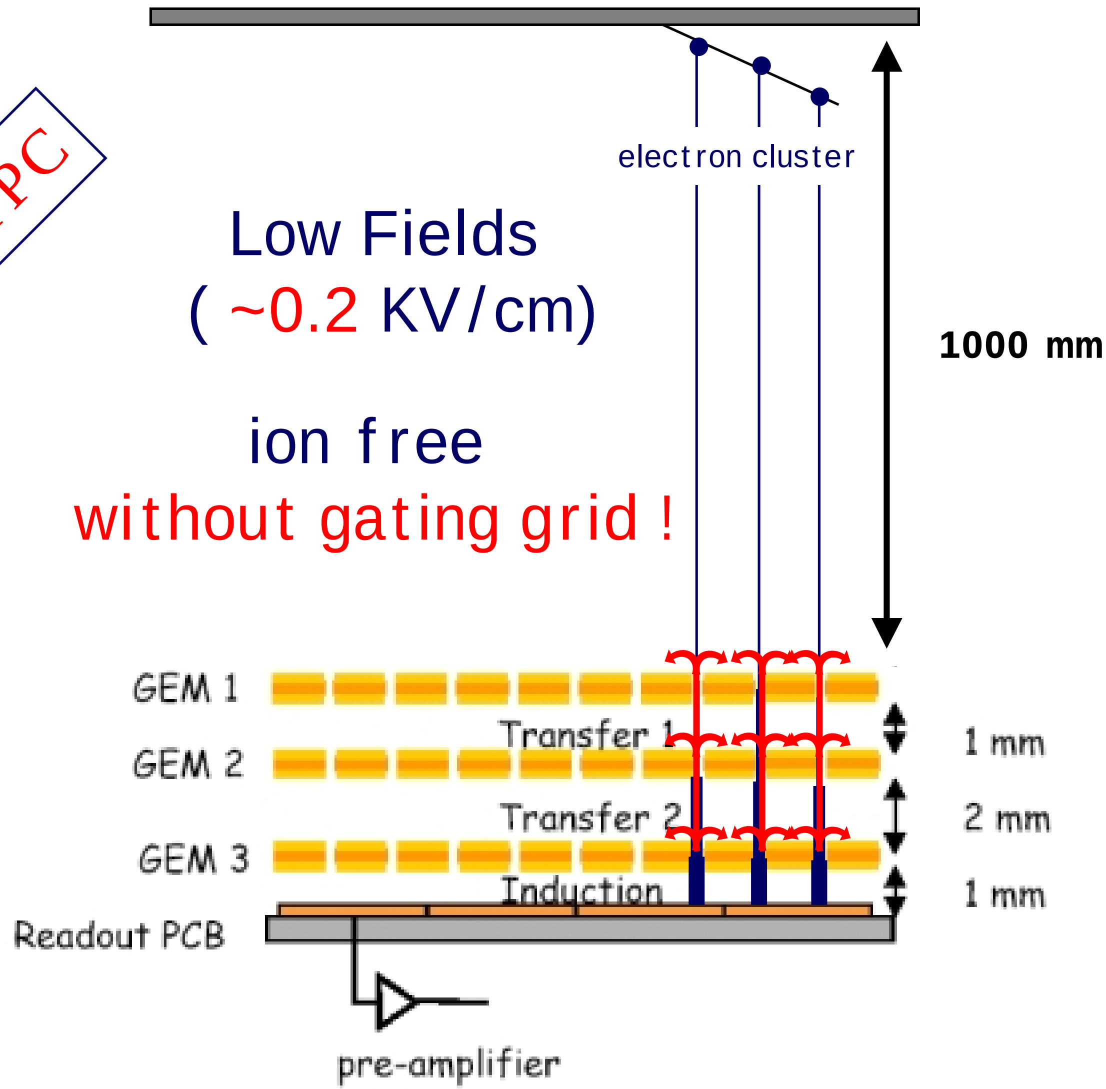
TPGC: TPC with GEM

SRG Lab

GEM is a TPC

Low Fields
(~0.2 KV/cm)

ion free
without gating grid !

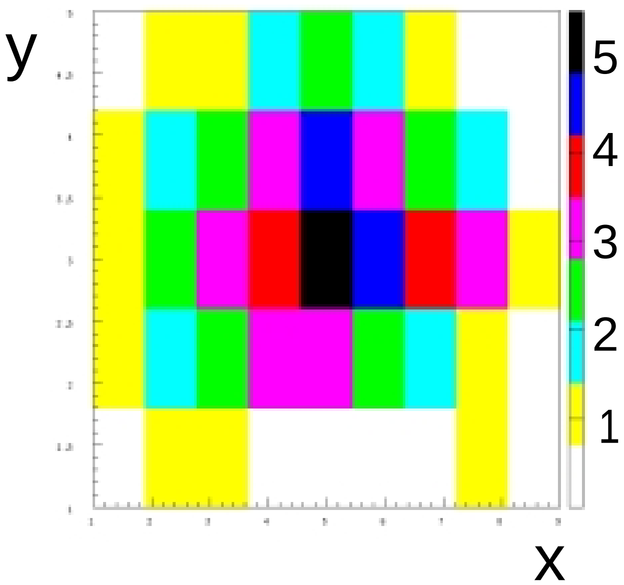


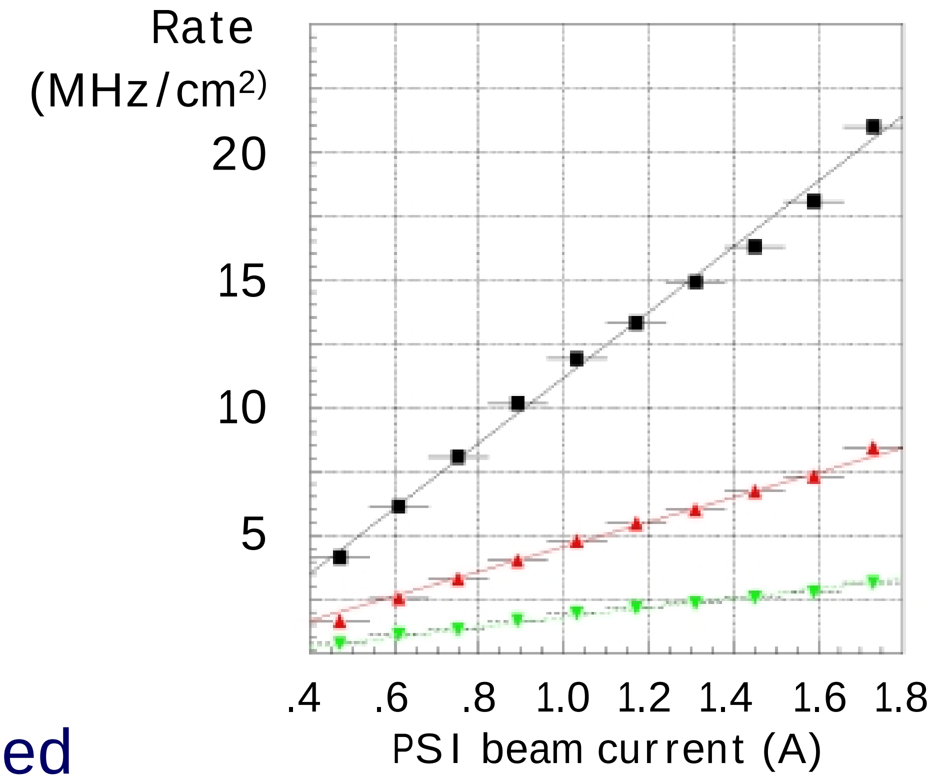
F. Murtas LNF/INFN

Frascati 28 November 2002

Beam Monitor @ PSI

SRG Lab





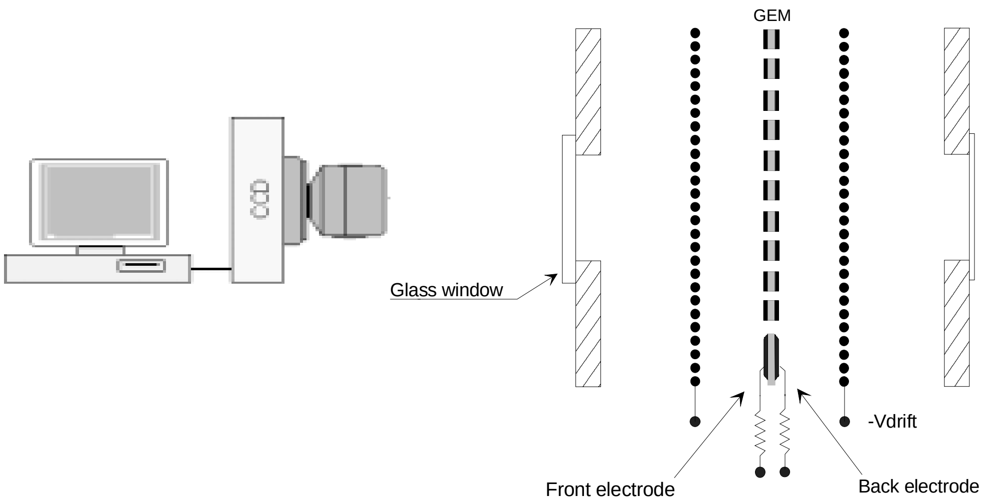
Beam spot at PSI measured with a triple gem 10x10 cm^2 and the LNF nano-amp

GEM and CCD Cameras

T.L. van Vuure[∇], R. Kreuger[∇], C.W.E. van Eijk[∇] and R.W. Hollander[∇], L. M. S. Margato[*] , F. A. F. Fraga[*], M. M. F. R. Fraga[*], S. T. G. Fetal[*], R. Ferreira Marques[*], A. J. P. L. Policarpo[*]

[∇]Radiation Technology Group TU Delft

[*]LIP Coimbra Universidade de Coimbra

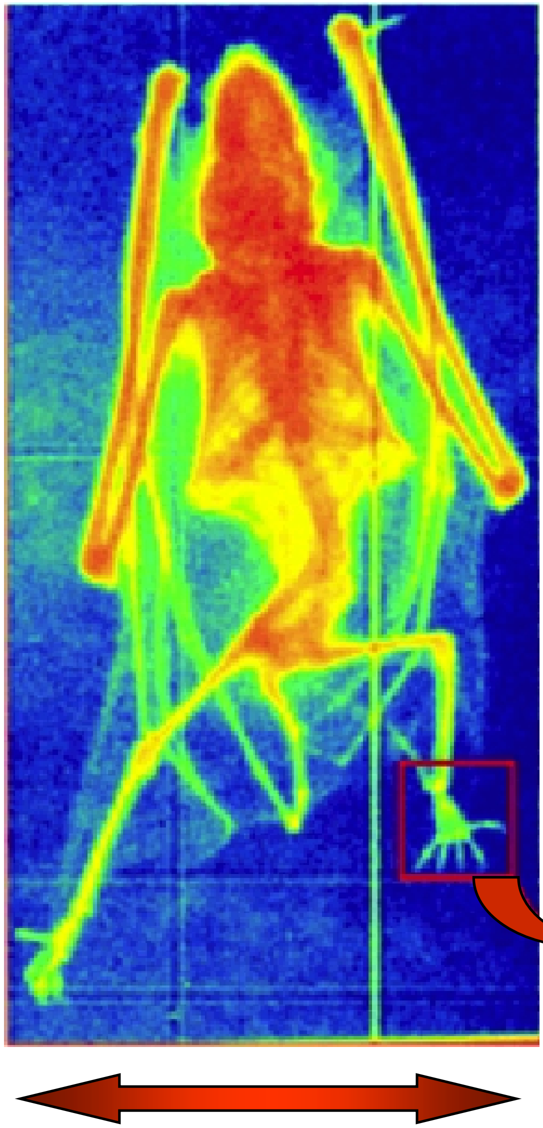


Tracks of 5.5 MeV alphas from a Am source, stopped in 1 bar of Ar/CF 60/40.

The light was produced using a triple GEM and measured with a CCD camera

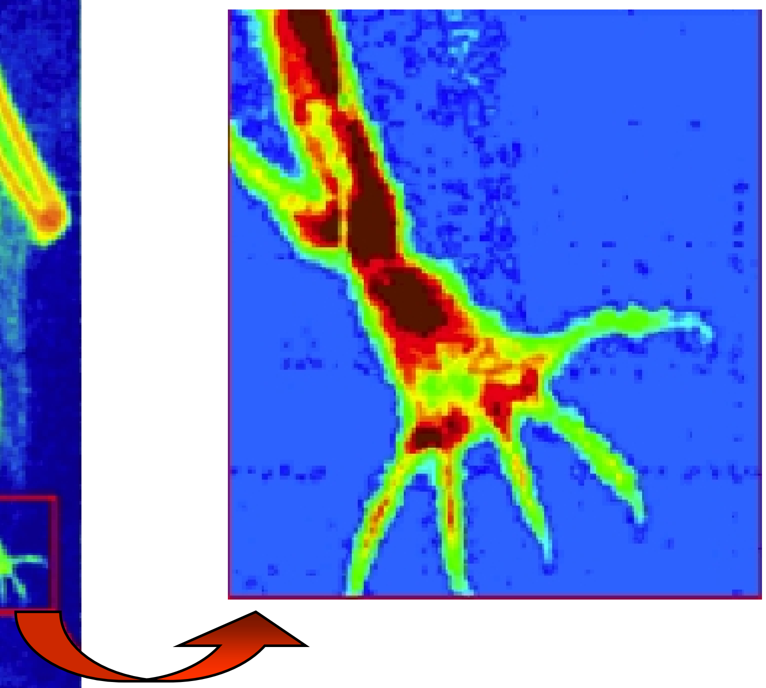
The range is 3.4 cm.

Radiography with GEM



32 mm

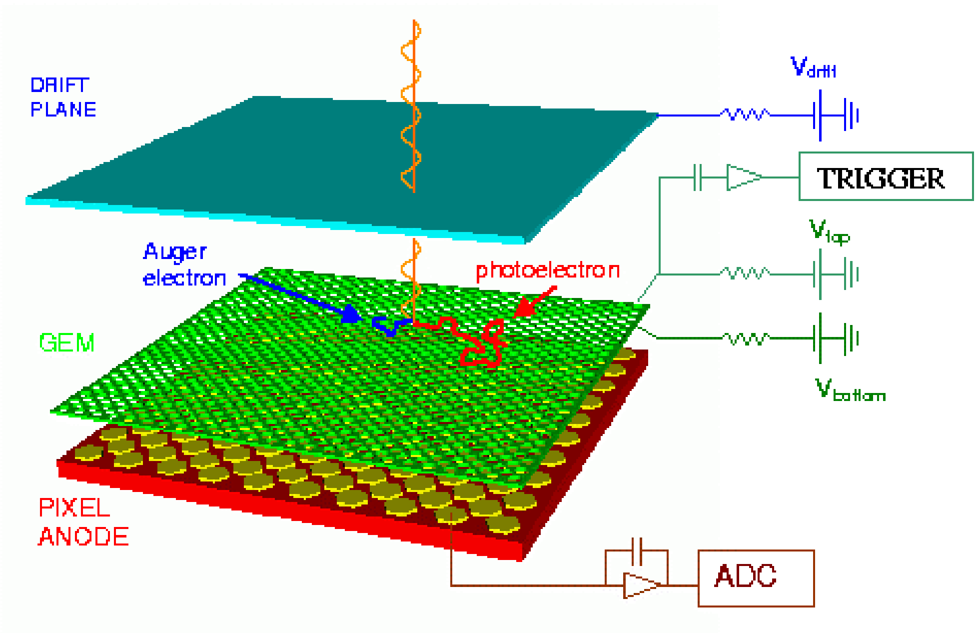
Radiography with Xray at 8 KeV of a small mammal (1200 x 640 Pixels)

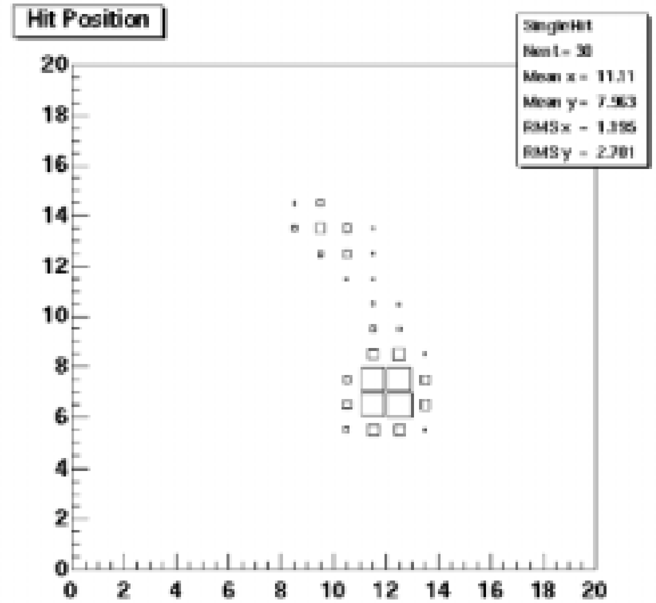


Pixel size of $50x50\ \mu^2$

X-ray polarimeter

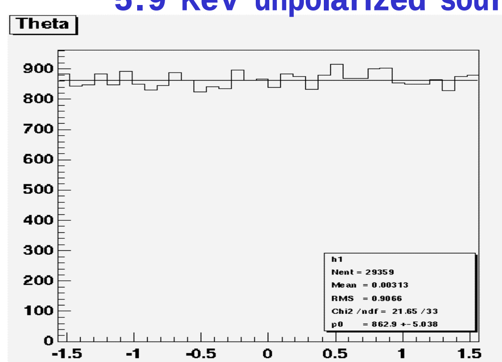
GEM chamber with pad readout to detect the direction of the photoelectron produced by X-rays



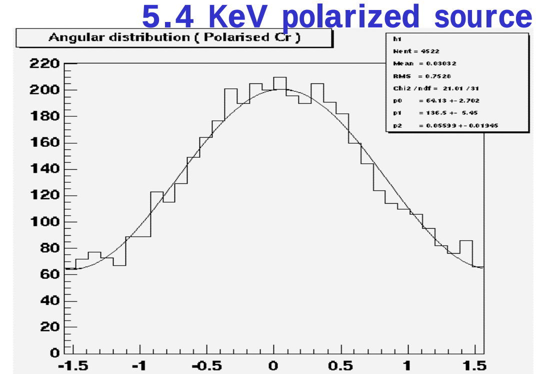


Charge asymmetry:

5.9 KeV unpolarized source



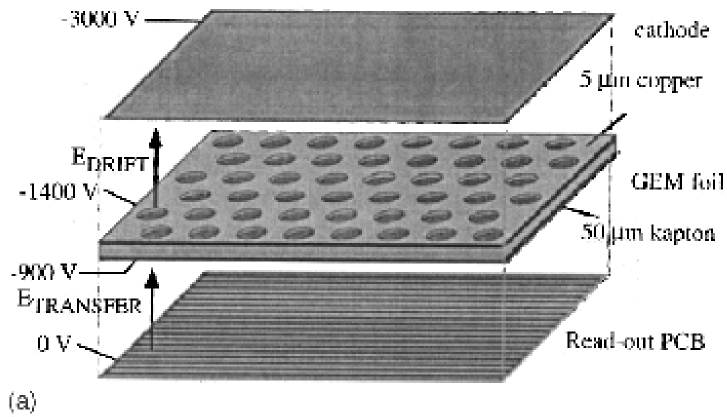
5.4 KeV polarized source

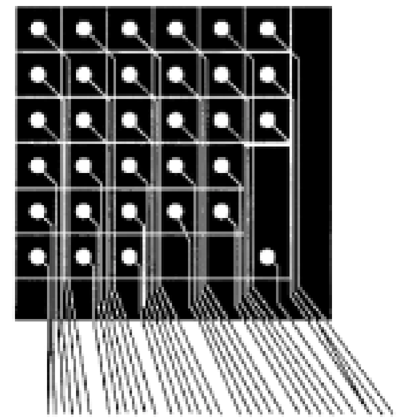


E. Costa et al,
Nature 411(2001)662
R. Bellazzini et al
Nucl. Instr. and Meth.
A478(2002)13

Fast X-ray plasma diagnostics

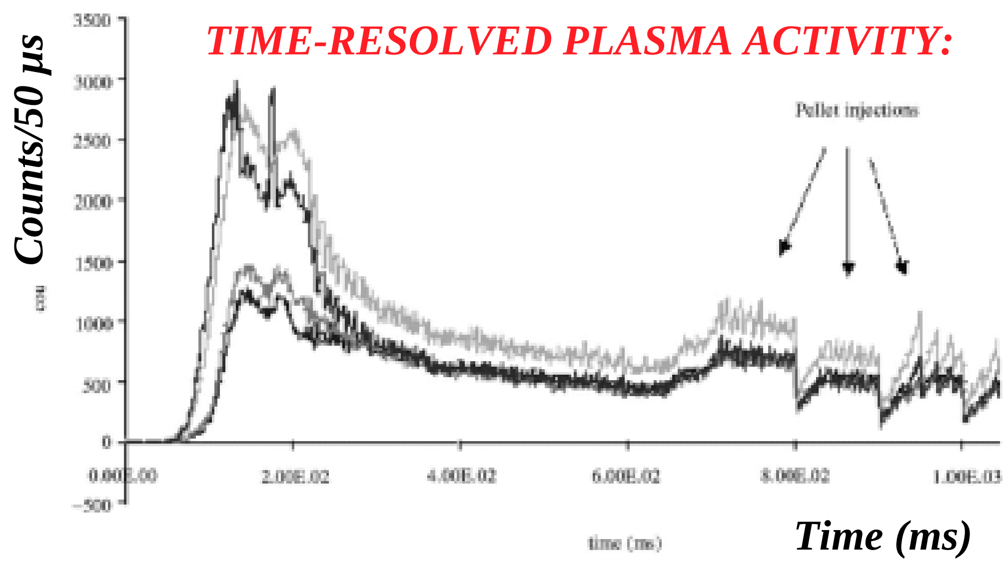
Readout: 32 2 mm^2 pixels



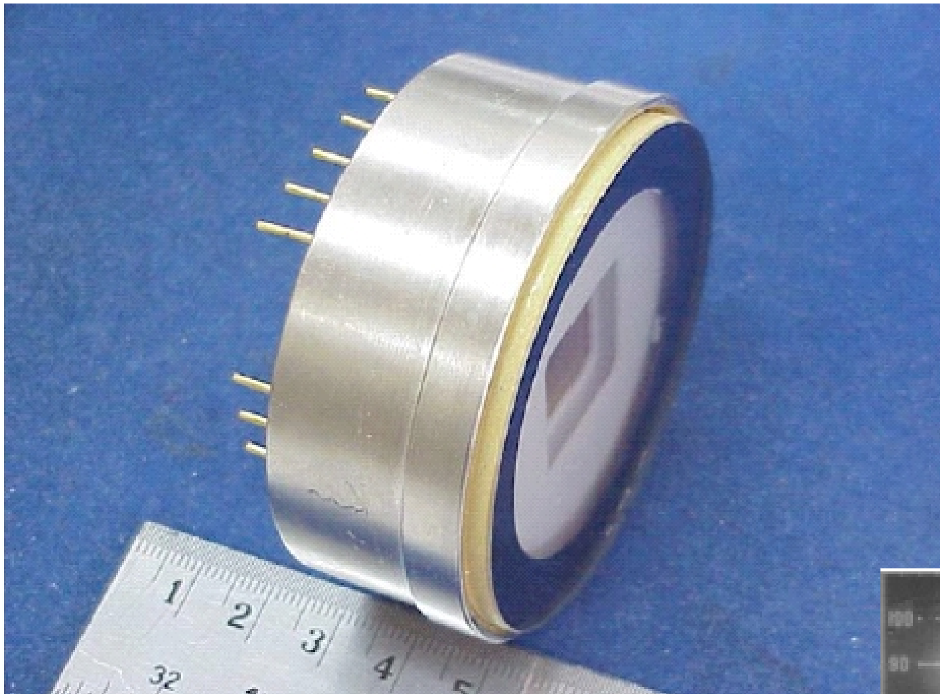


(ENEA Frascati, Italy)

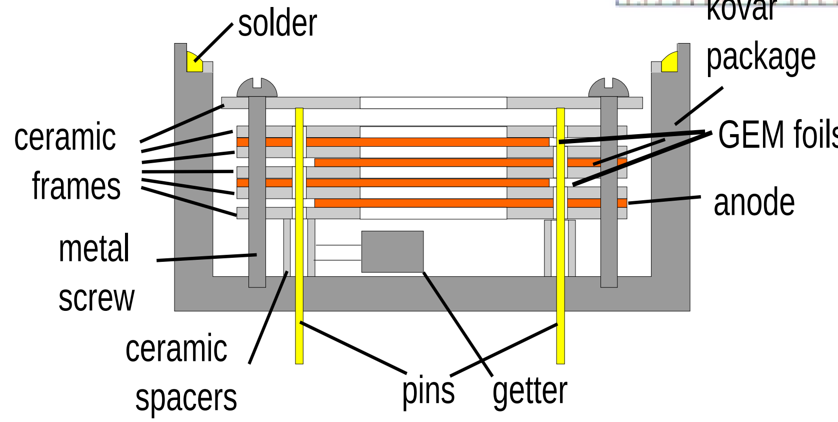
D. Pacella et al,
Rev. Scient. Instrum. 72 (2001) 1372
R. Bellazzini et al,
Nucl. Instr. and Meth. A478(2002)13



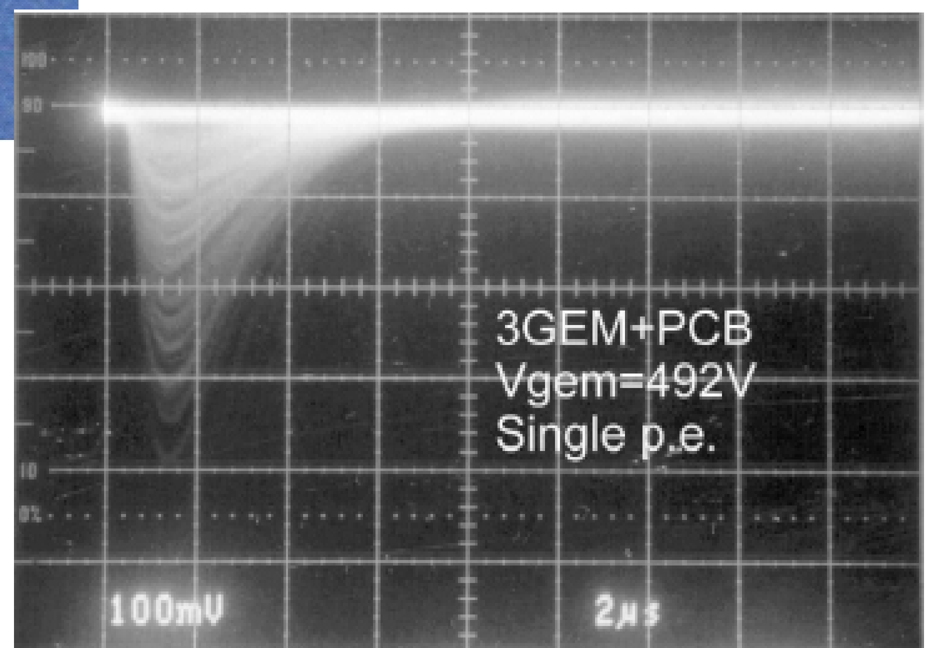
Sealed GEM Photomultiplier



Semi-transparent CsI photocathode

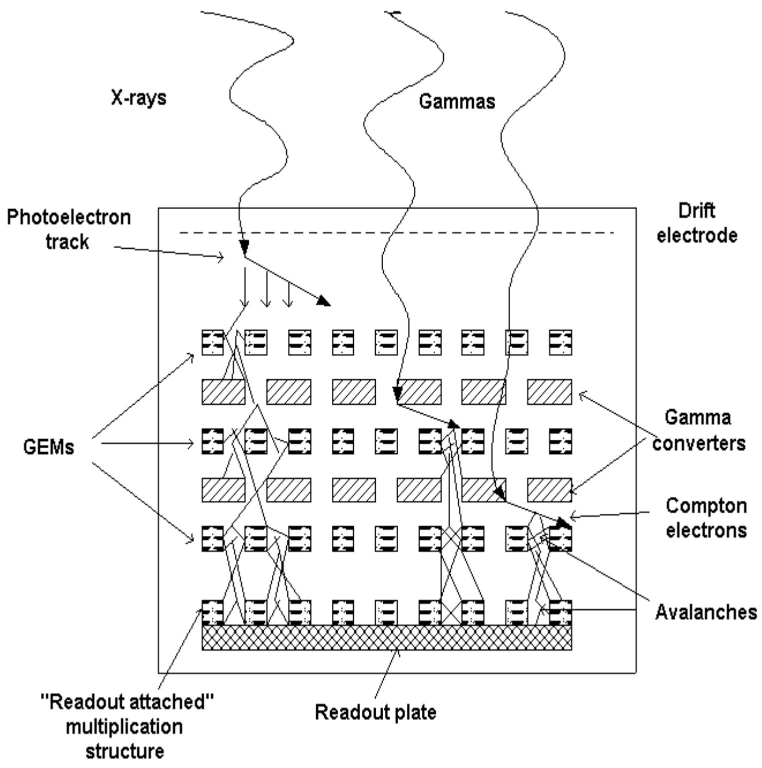


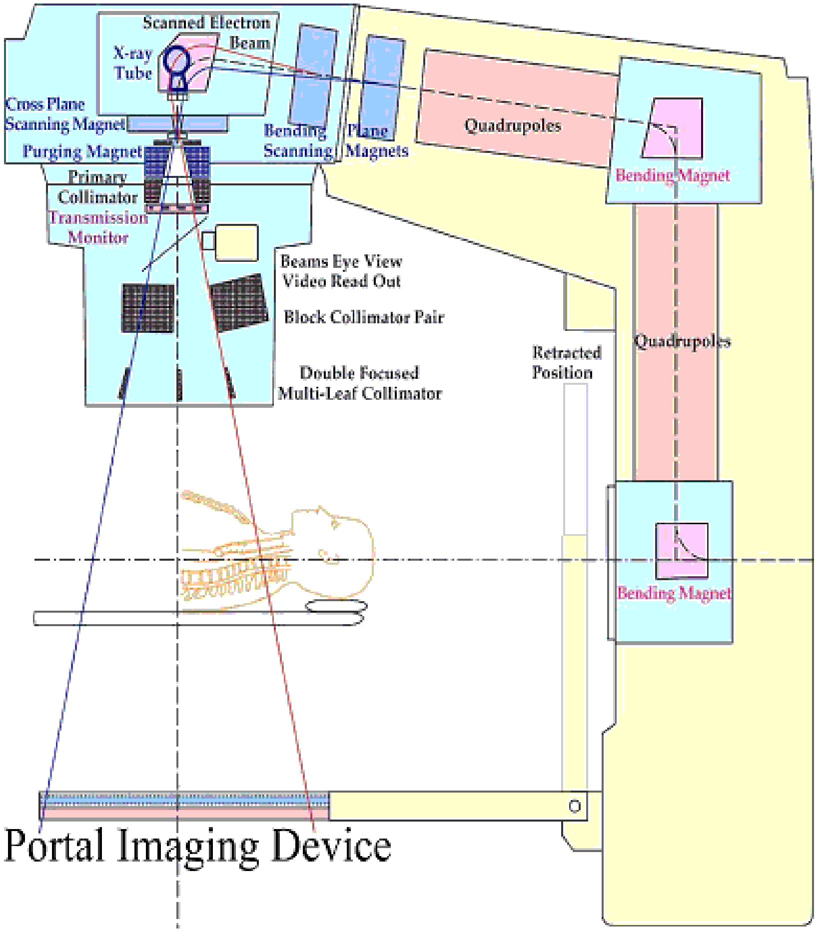
Single photo-electron signals:



A. Breskin et al,
Nucl. Instr. and Meth. A478(2002)225

GEM on medical imaging





GEM on medical image

Radiation: ^{241}Am-source

Setup: Pad-type readout + GEM (gain 30)+ drift

Gas: $ArCO_2$ (80-20) at 1 atm

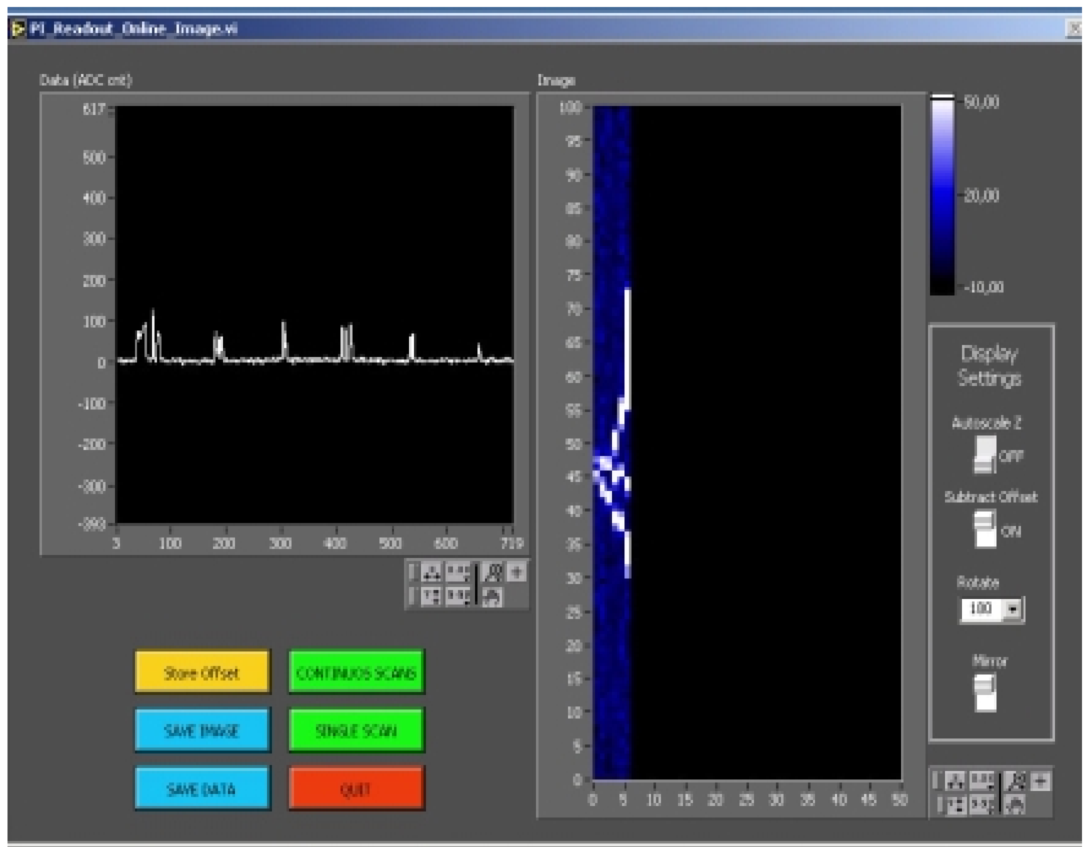
Readout: 6 x 100 pads, pixel size of 1.27 x 1.27 mm^2

Sensitivity: 3.7 mV/fC

Integration time: 1 ms

Readout time: 10 μs per pixel

Peskov (Upsala University)



Conclusions

The triple-GEM detector operated with iso-C_4H_{10} and CF_4 gas mixtures fulfills all the requirements for the High Flux region of LHCb muon system.

Requiring 99% efficiency in 25 ns and $P_{dis} < 10^{-12}$:

- $Ar/CO_2/CF_4$ 60/20/20 ⇒ narrow working region 10 V;
- $Ar/CF_4/C_4H_{10}$ 65/28/7 ⇒ wide working region ≈ 45 V;
- $Ar/CO_2/CF_4$ 45/15/40 ⇒ wide working region ≈ 65 V;

– Good rate capability (up to 50 MHz/cm^2);

– Good radiation hardness (>10 LHCb equivalent years);

– Very good results also for the large size detector.

The GEM community is working on other detector applications : Xray Astronomy , Medical Imaging , TPGC , Plasma monitoring , Neutron detector , and many other R&D.