TRAINING COURSE ON RADIATION DOSIMETRY:

Micro Dosimetry with GEM (Gas Electron Multiplier) and GEMpix

F. Murtas, CERN-INFN

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- Introduction: GEM principia
- Performance: gain, time resolution, efficiency
- Detector Construction
- GEM application in dosimetry
- GEMpix
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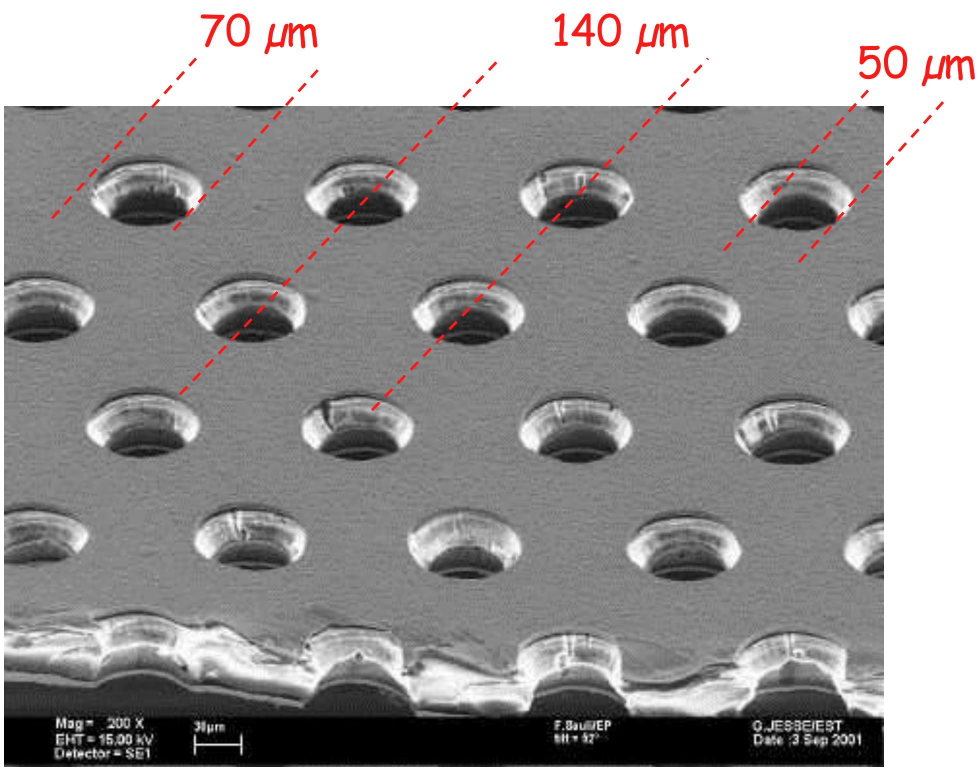
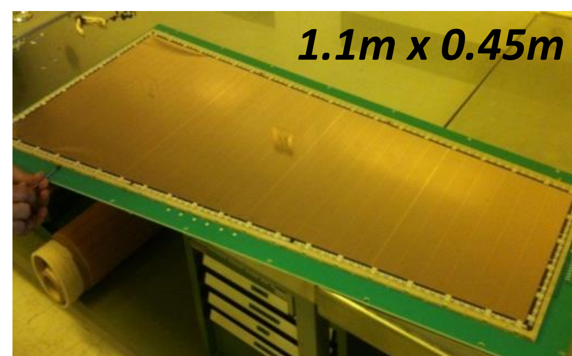
Gas Electron Multiplier

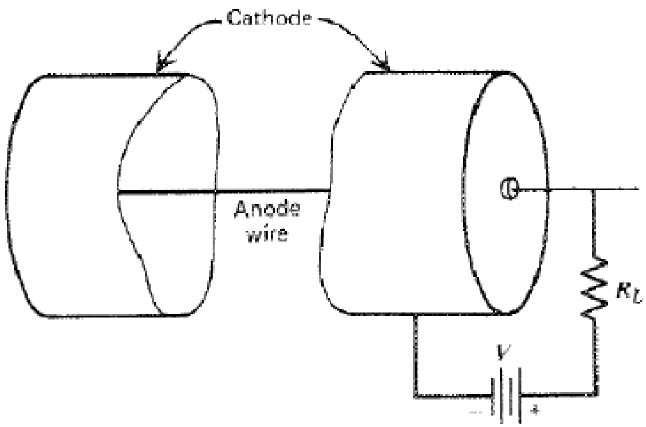
A Gas Electron Multiplier (F.Sauli, NIM A386 531 **1997**) is made by 50 μm thick kapton foil, copper clad on each side and perforated by an high surface-density of bi-conical channels;

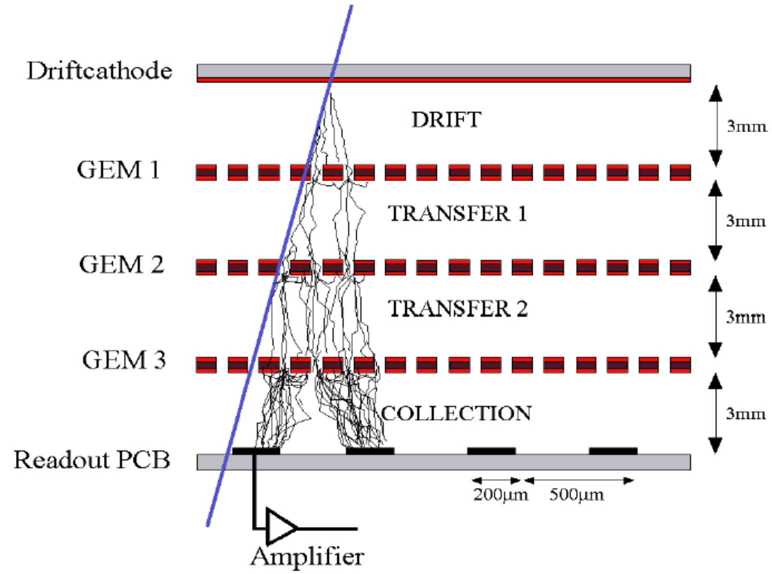


different shapes

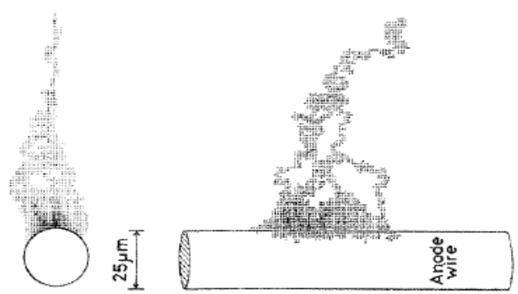


WPC vs GEM





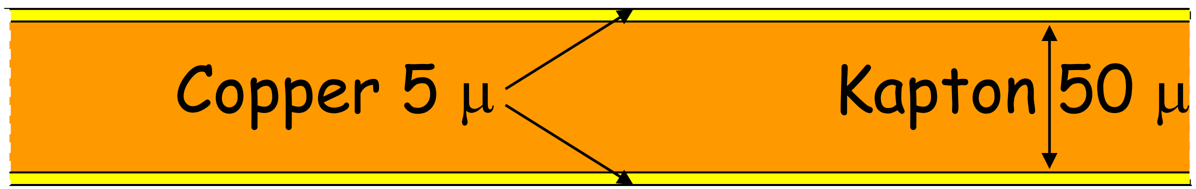
Effective Gain
~20
~20
~20
~8000

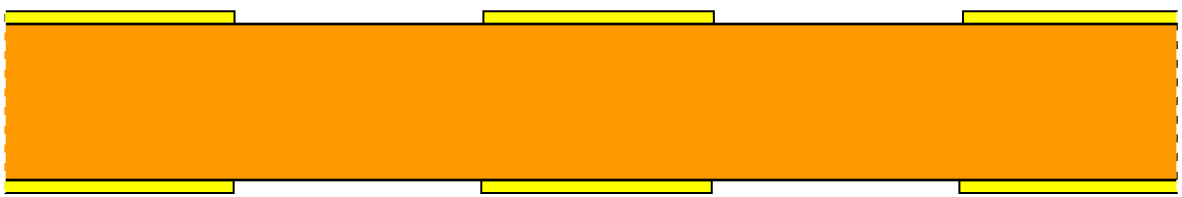


Advantage :
- faster signal (electrons)
- higher rate capability
- higher space resolution
- radiation hardness
- lower electric fields
- no after pulses
- low level of ions in the active area

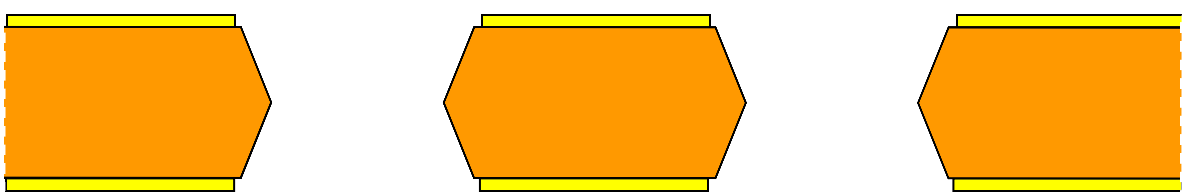
GEM foil construction (CERN)

Photolithographic technology used
for printed circuit board construction





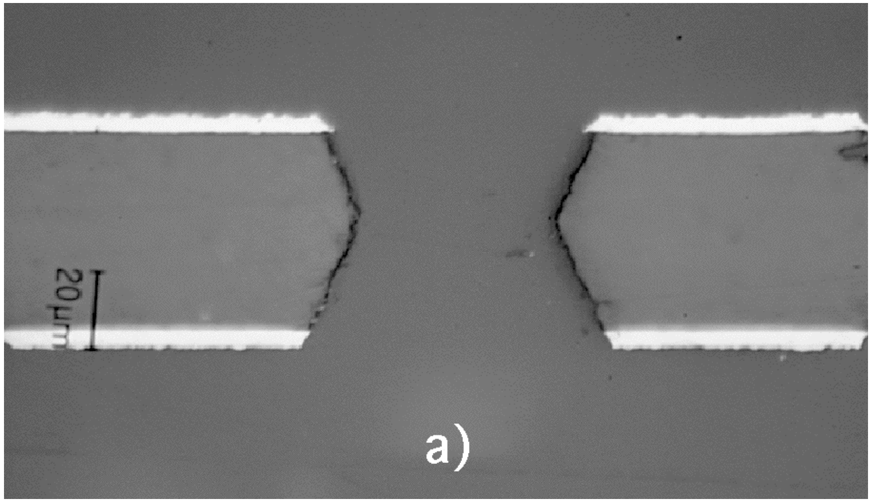
Copper etching by
chemical solution

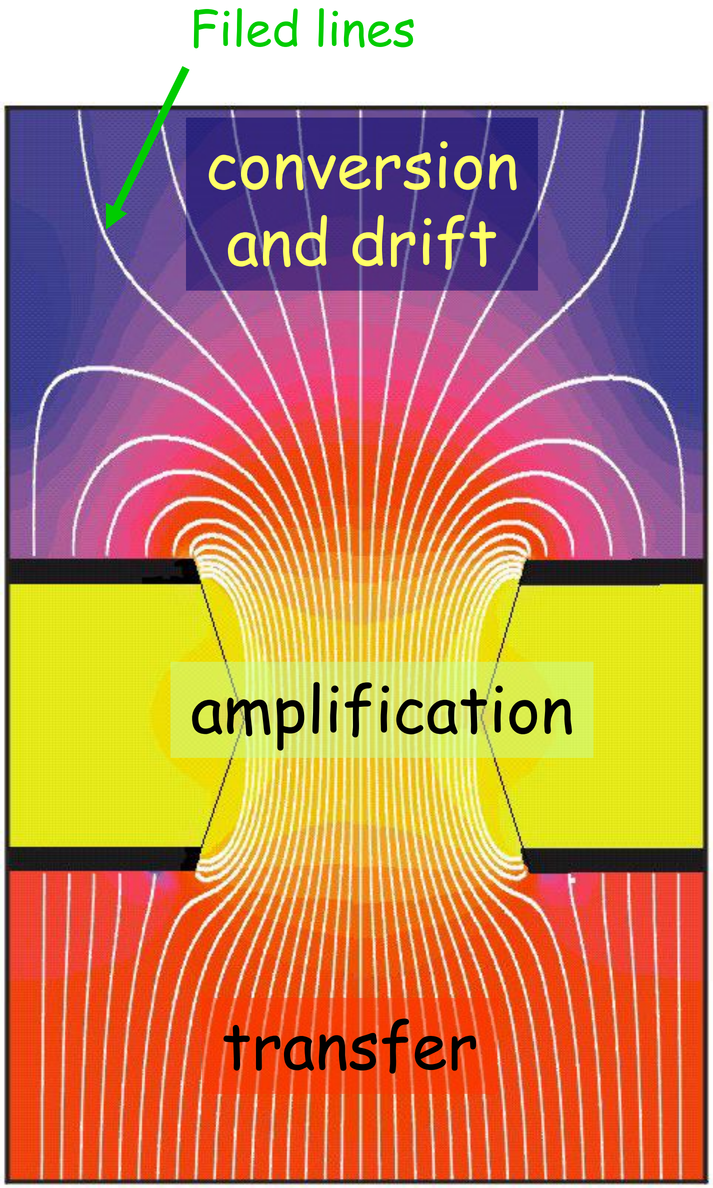


Kapton etching using
the copper mask

now also with laser !

Gas Electron Multiplier

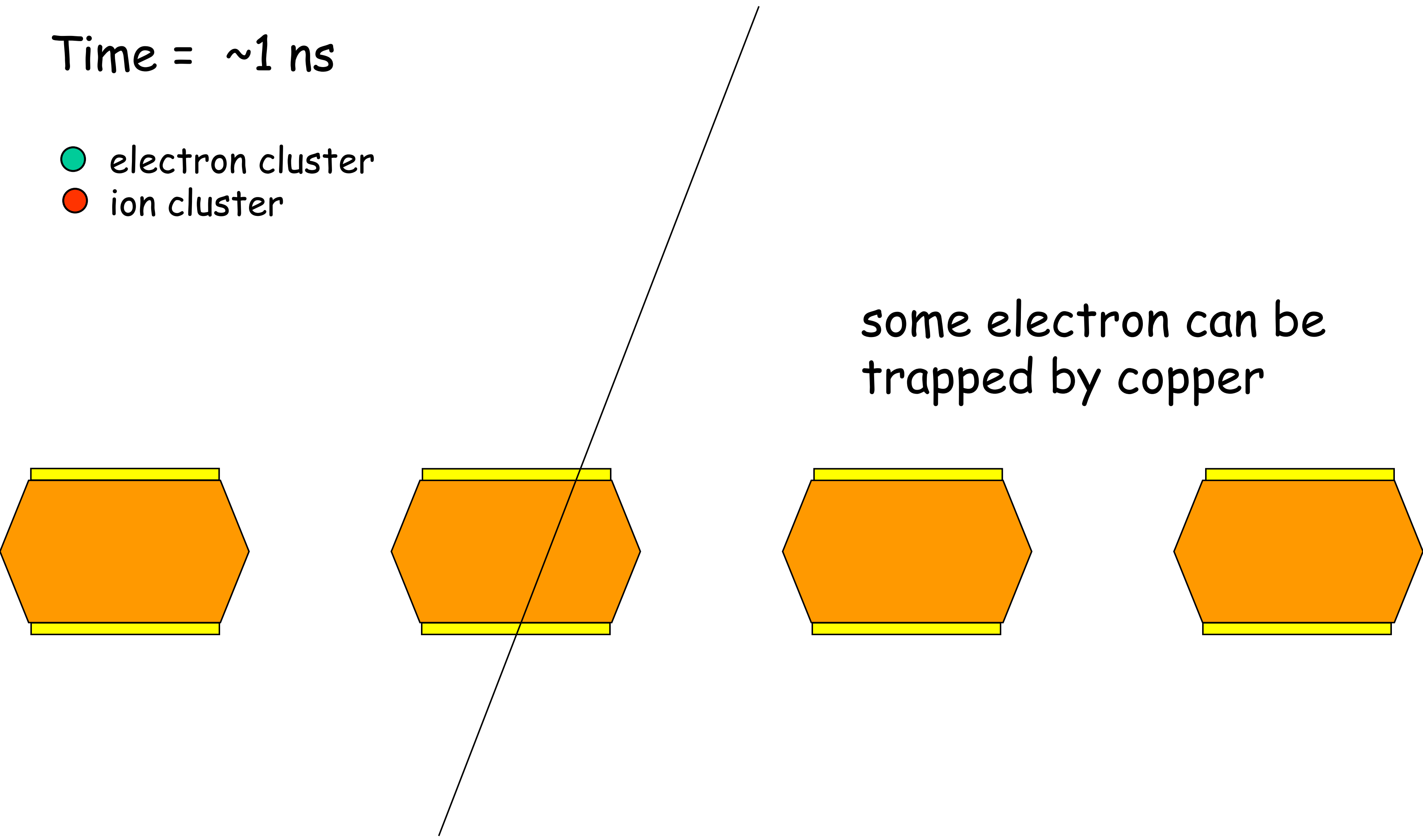




By applying a potential difference between the two copper sides an electric field as high as 100 kV/cm is produced in the holes acting as multiplication channels.

Potential difference ranging between 400 - 500 V

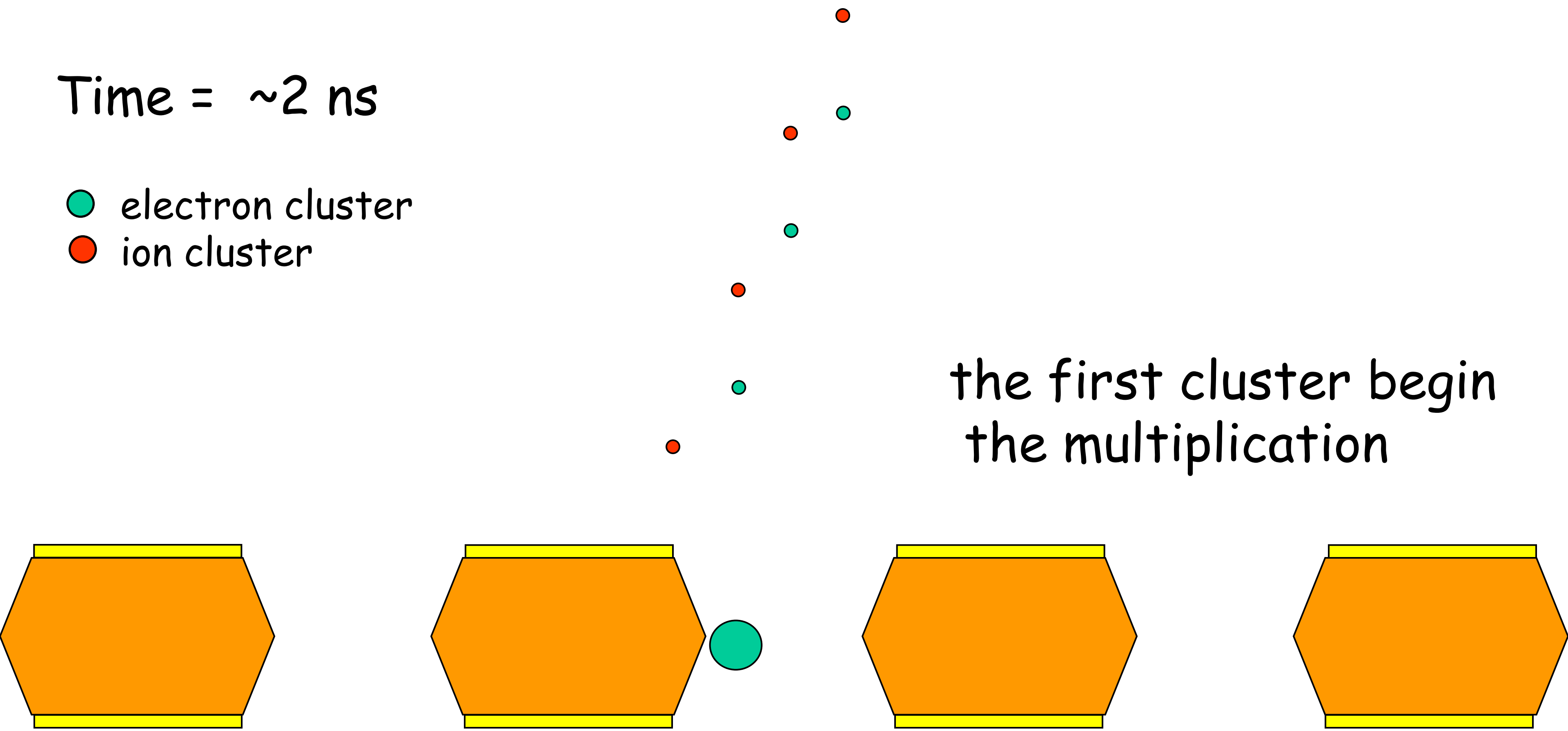
GEM principia: electrons



GEM principia: electrons

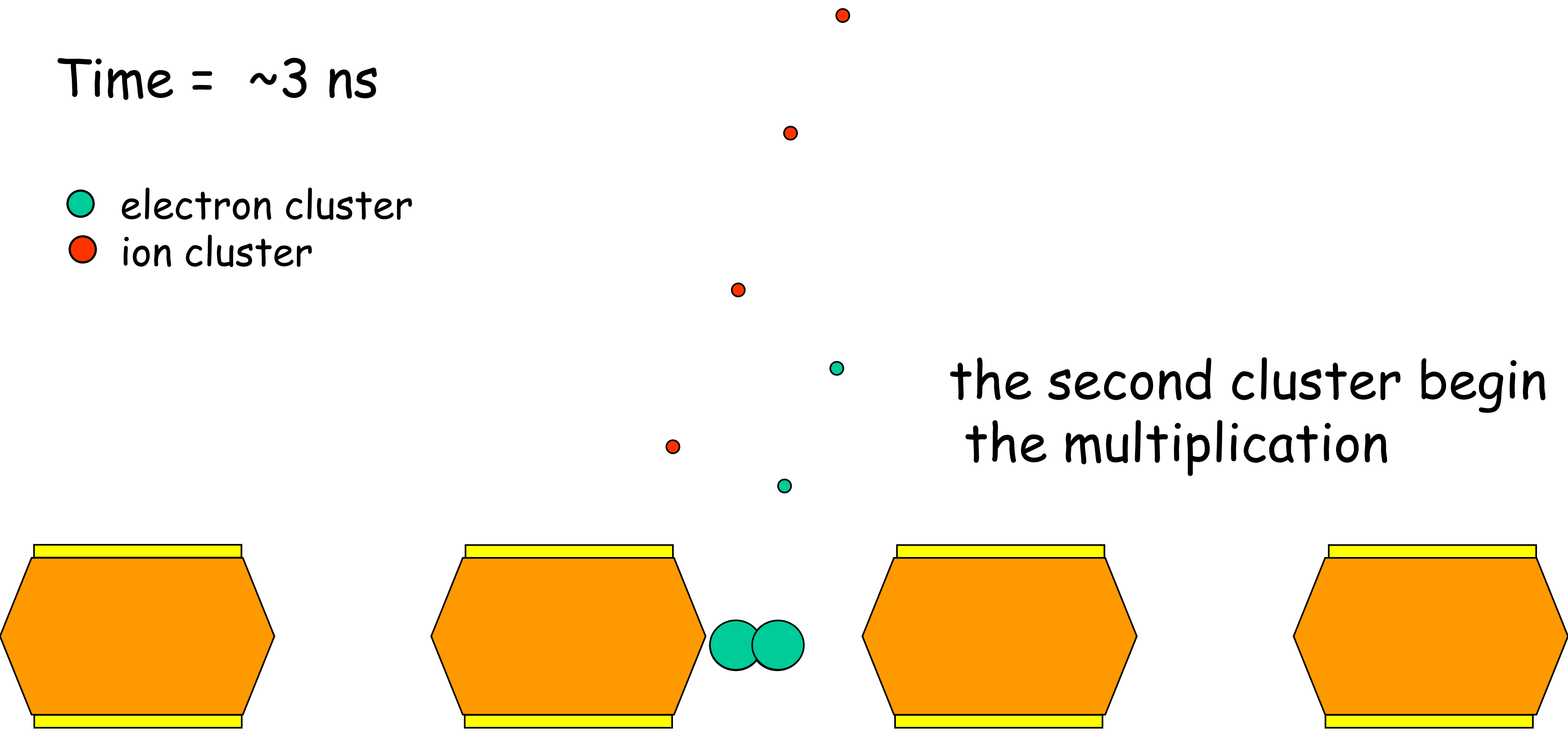
Time = ~2 ns

- electron cluster
- ion cluster



GEM principia: electrons

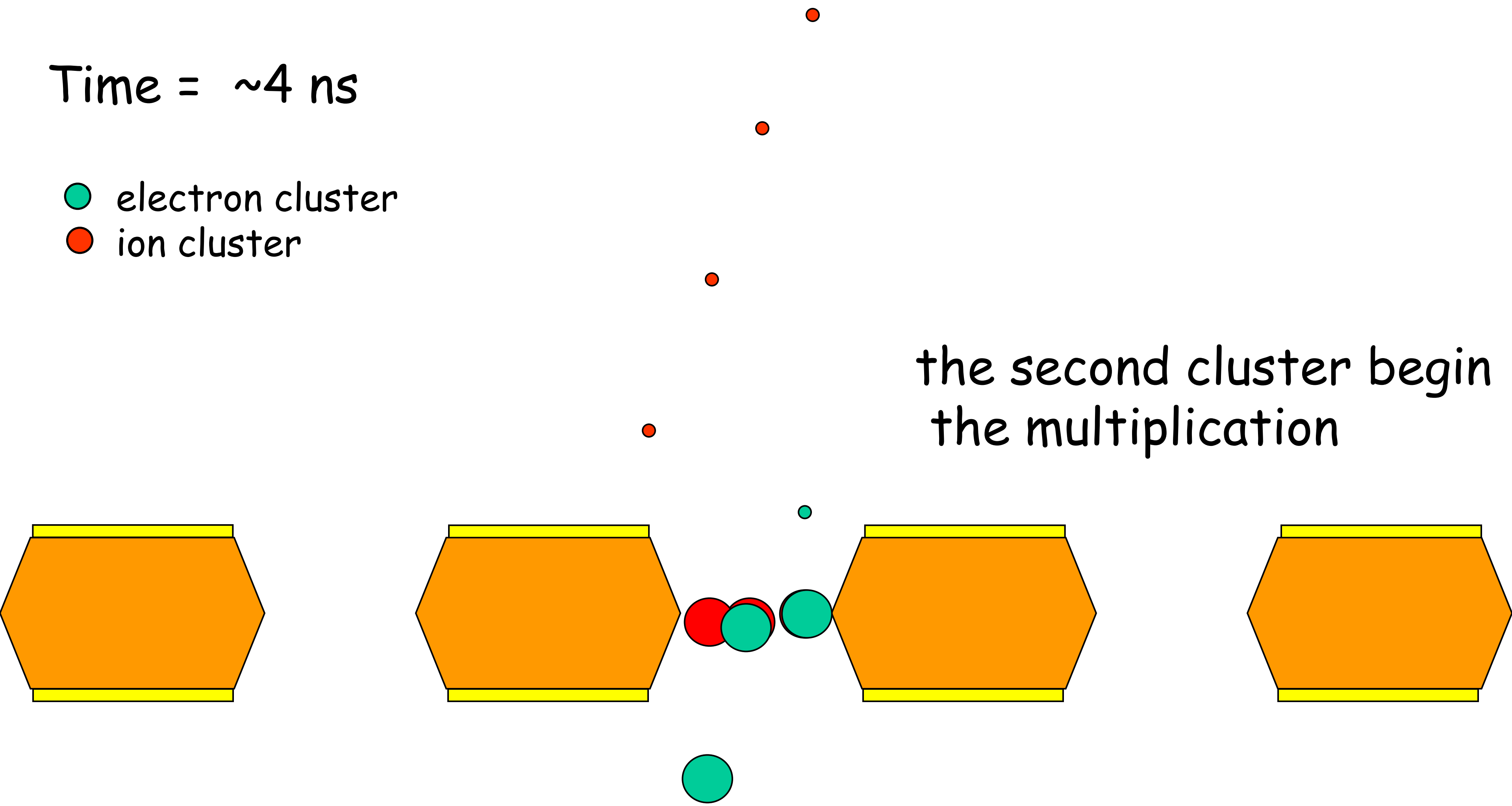
Time = ~3 ns



GEM principia: electrons

Time = ~4 ns

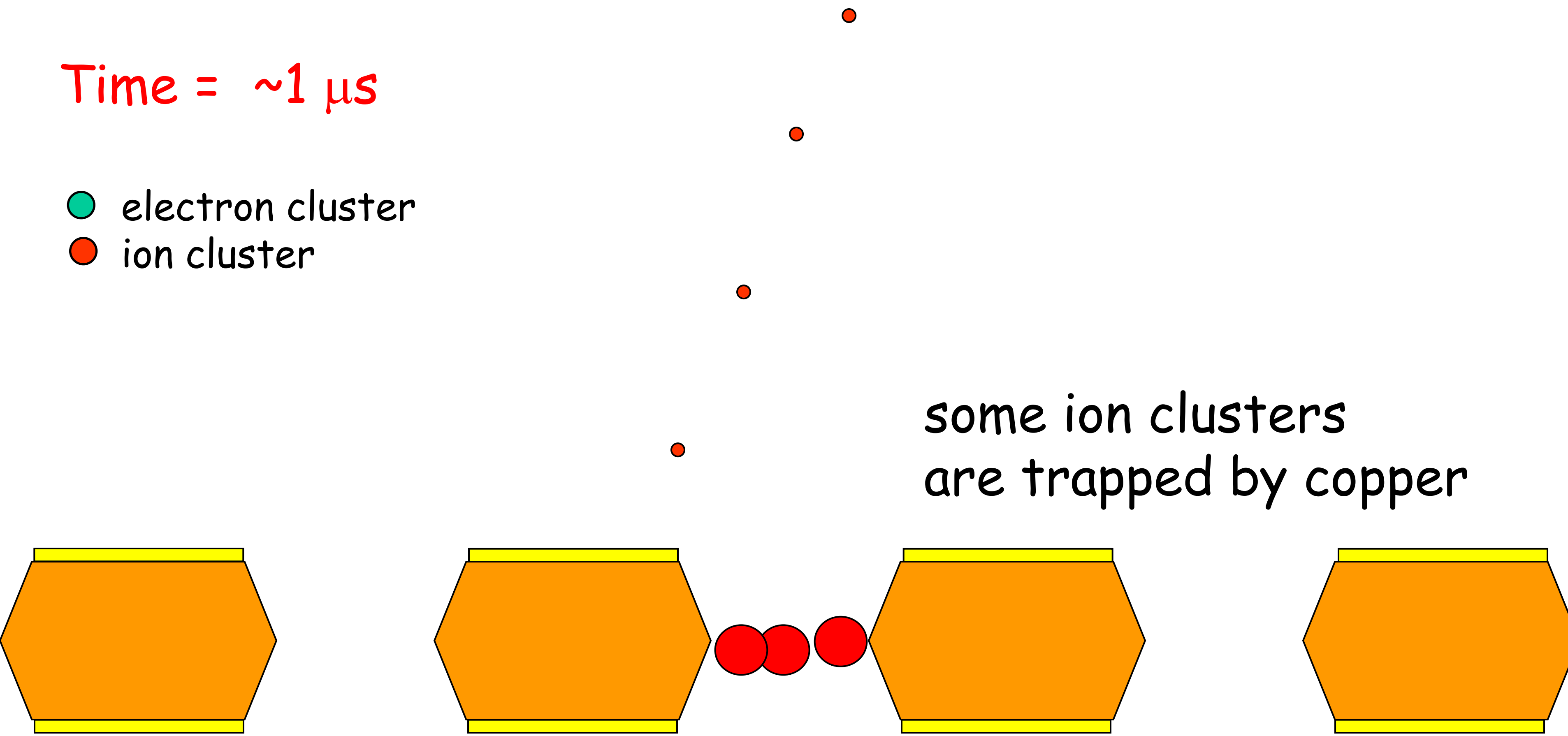
- electron cluster
- ion cluster



GEM principia: ions

Time = ~1 μs

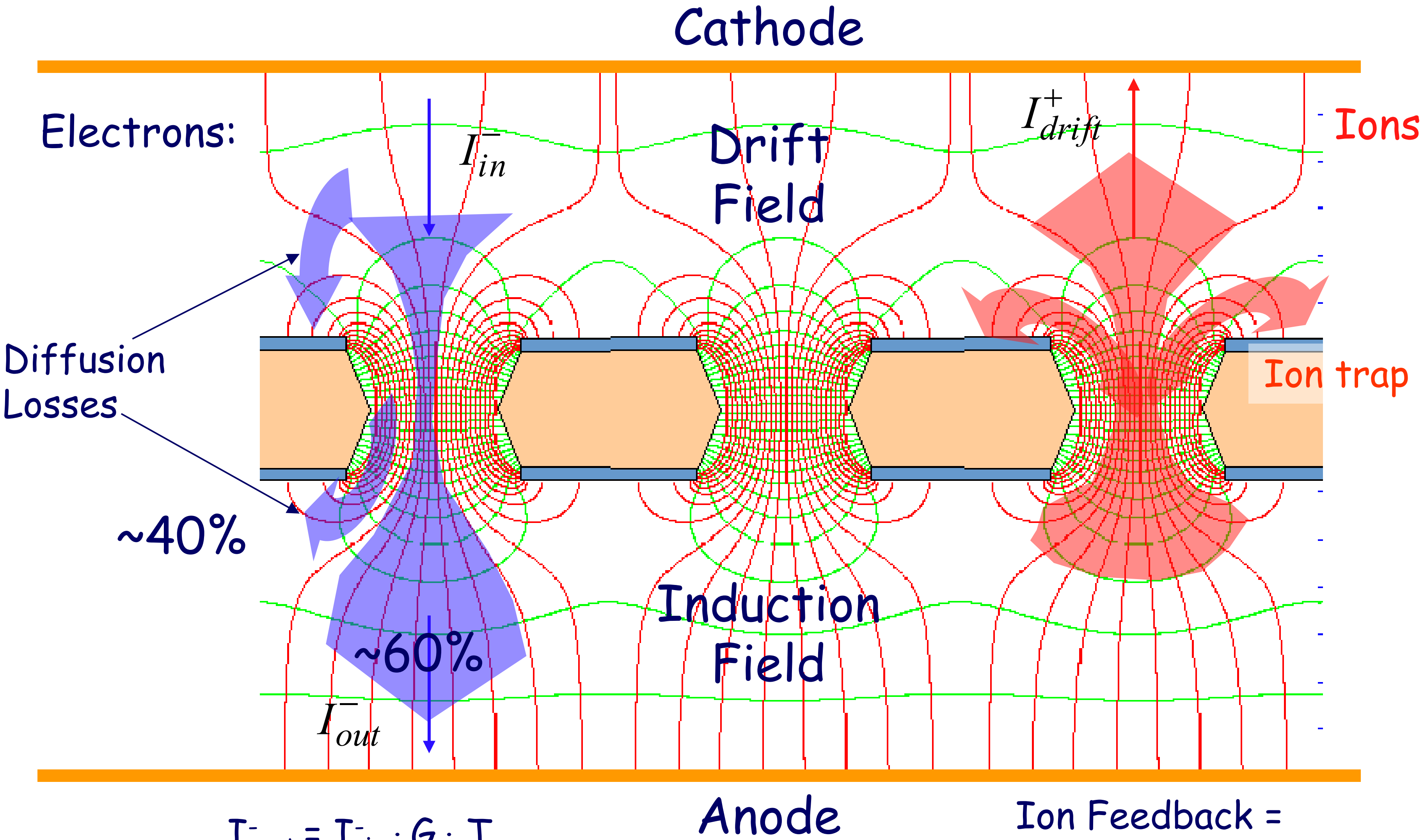
- electron cluster
- ion cluster



The hole are completely ion free after 1 μs

high rate capability

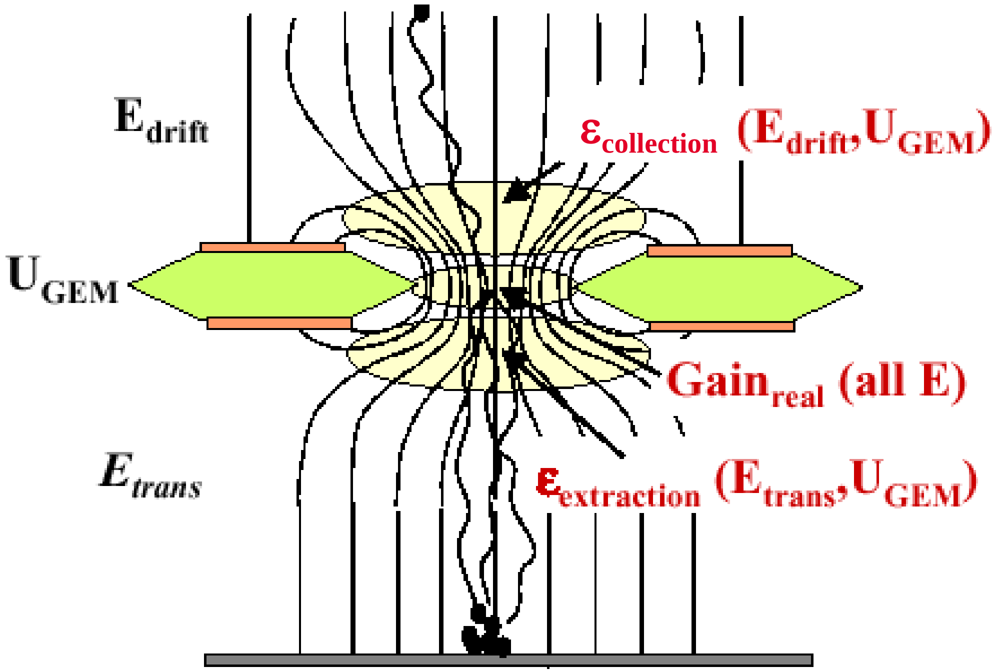
Single GEM detector



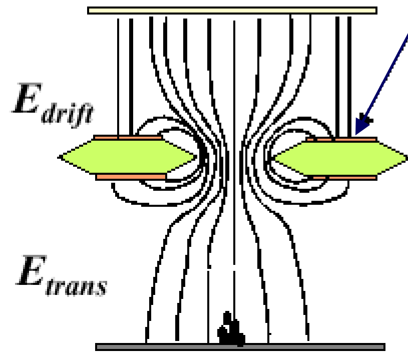
$I^{-}_{out} = I^{-}_{in} \cdot G \cdot T$
(gain x transparency)

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

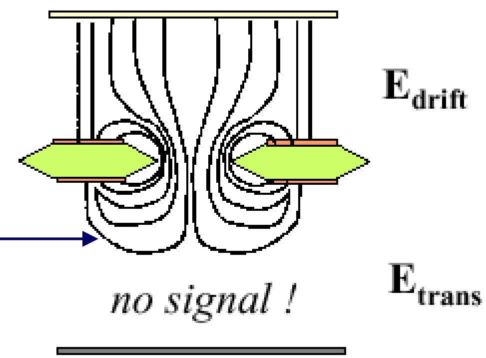
Working with Transfer Fields



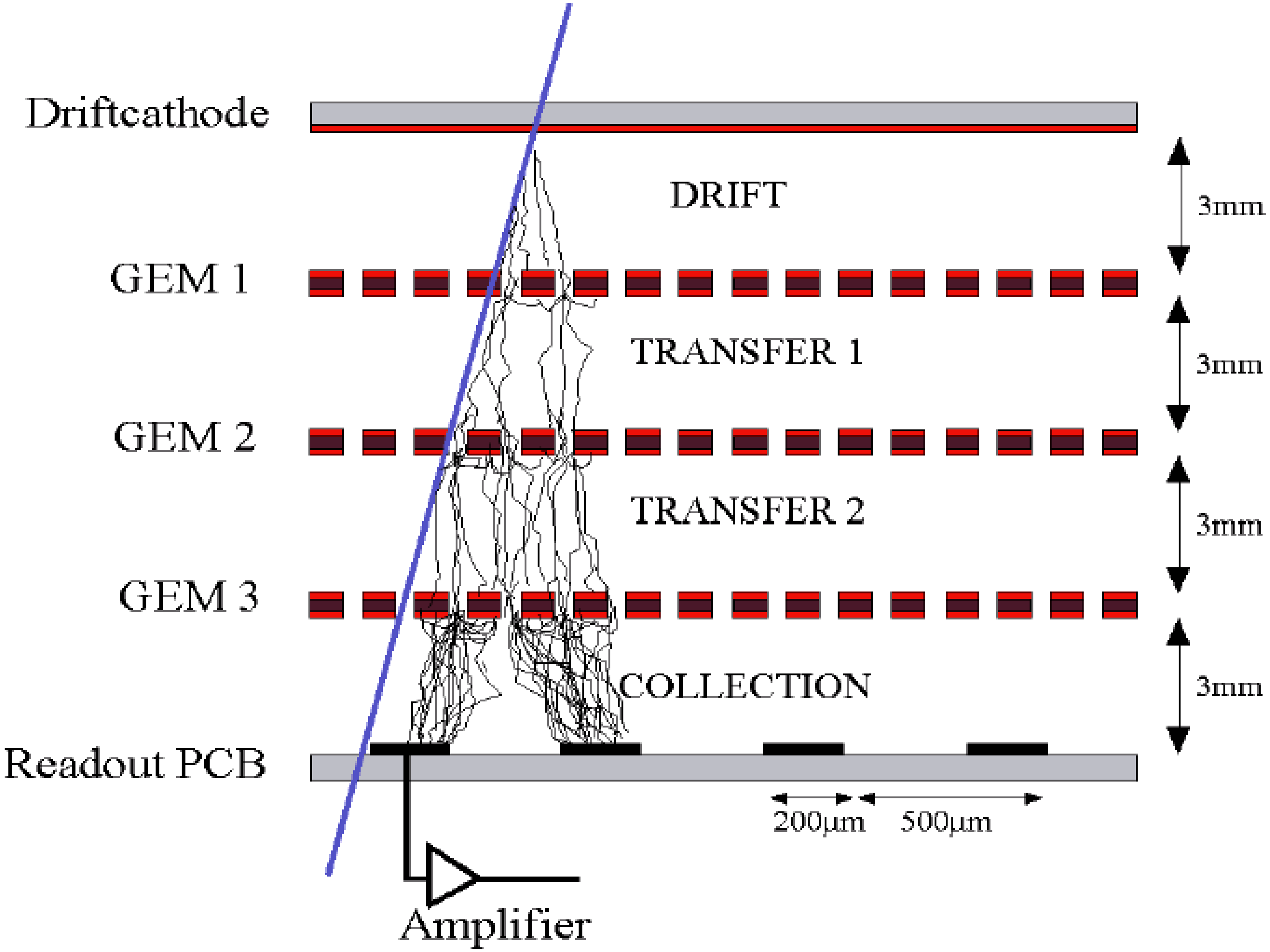
Collection efficiency decreases at high drift field values due to defocusing of field lines above the GEM



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



Triple GEM geometries



Effective Gain

~20

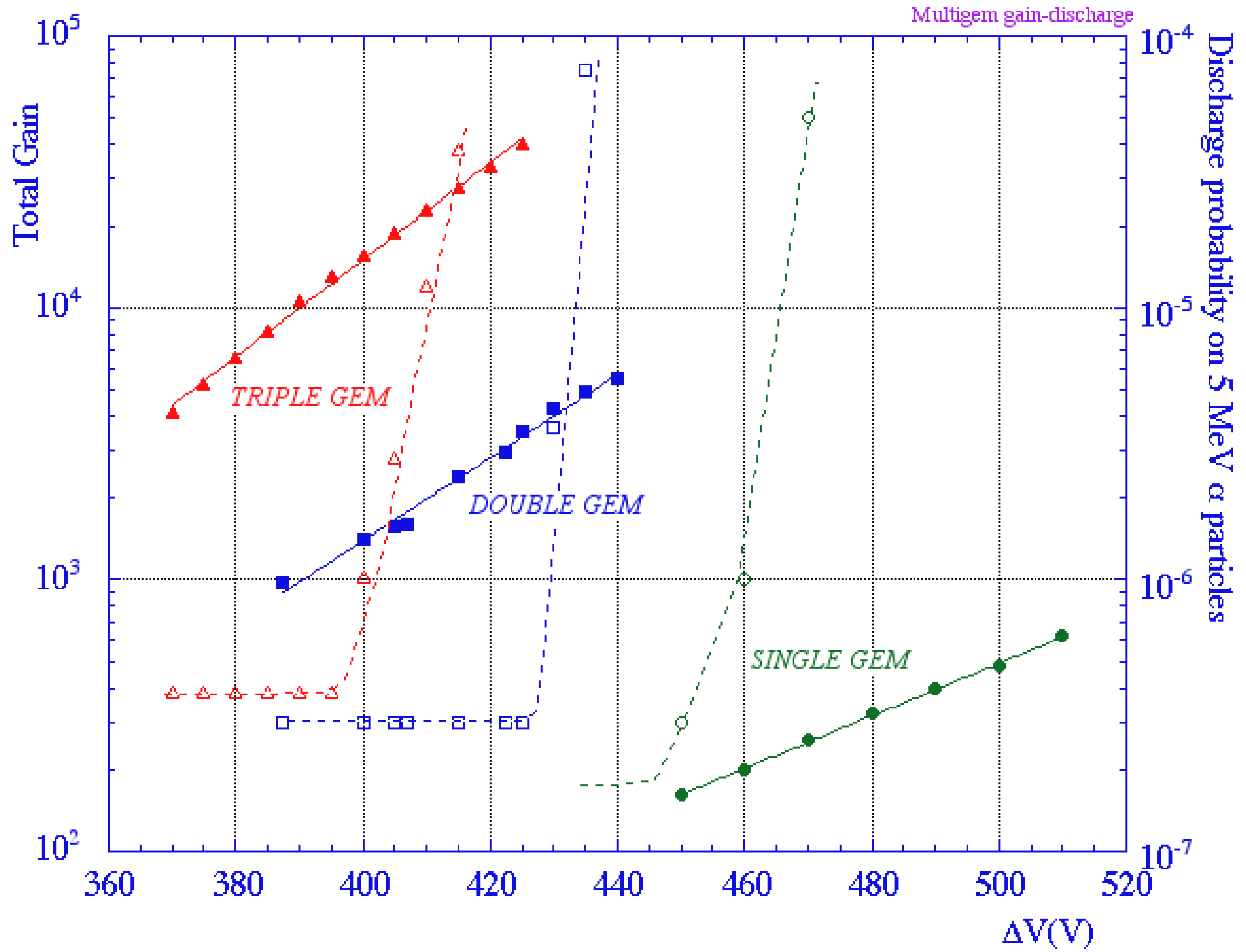
~20

~20

~8000

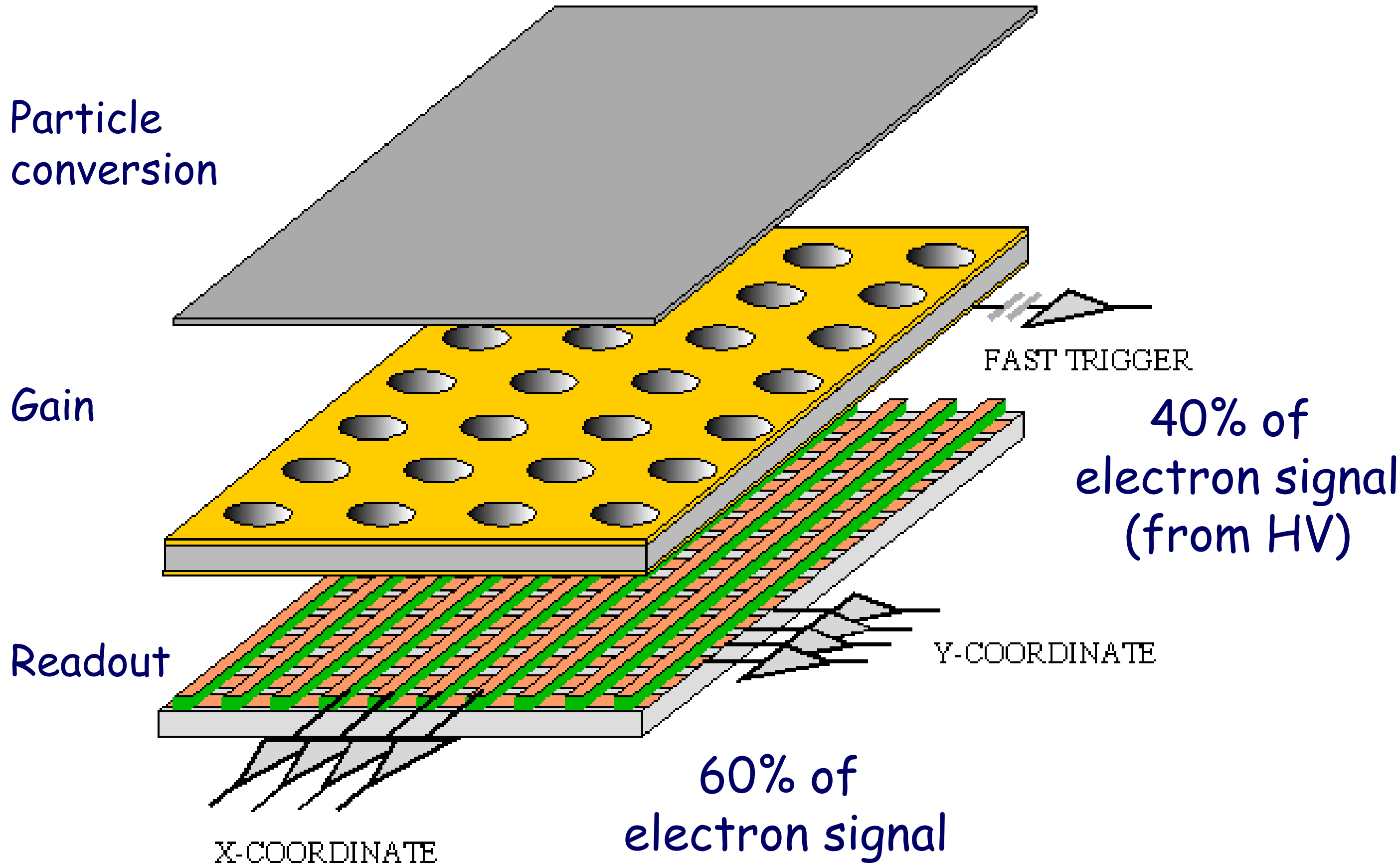
Single vs triple GEM

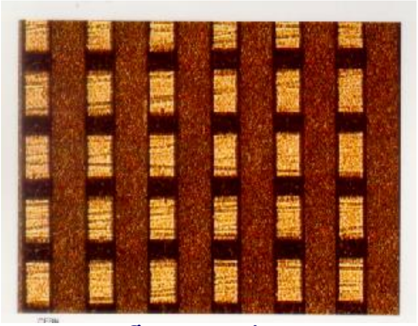
Measurements with alfa particle



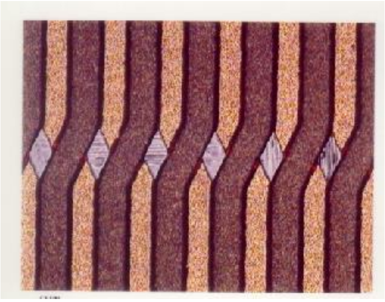
GEM Readout

- Gain and readout functions on separate electrodes
- Fast electron charge collected on patterned anode

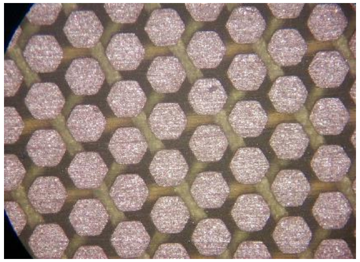




Cartesian



Small angle



Pads

GEM Performances

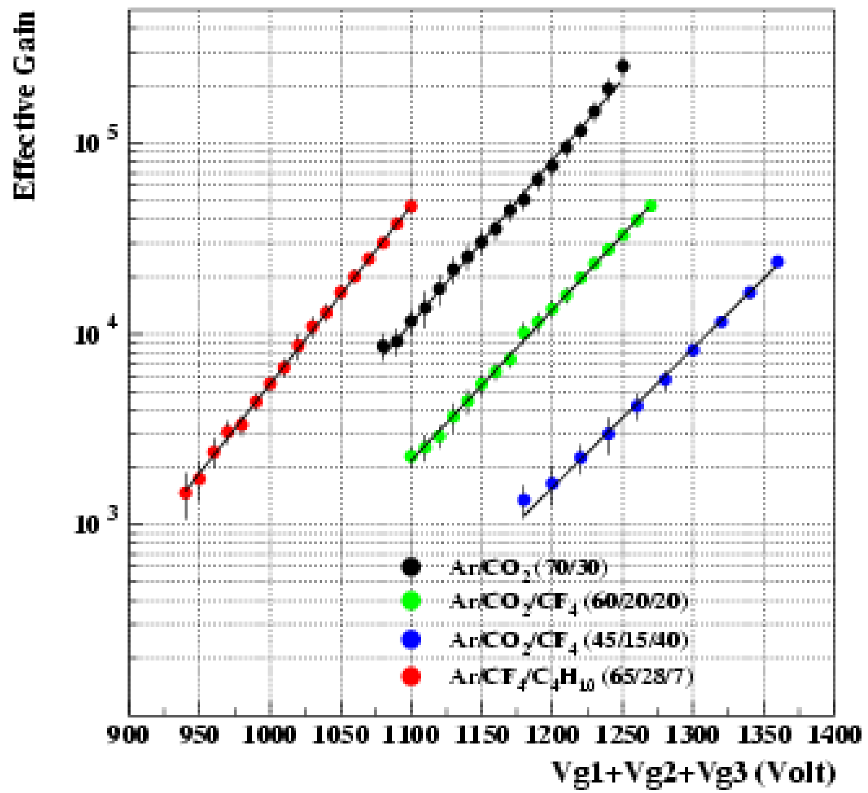
The gas gain vs HV

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

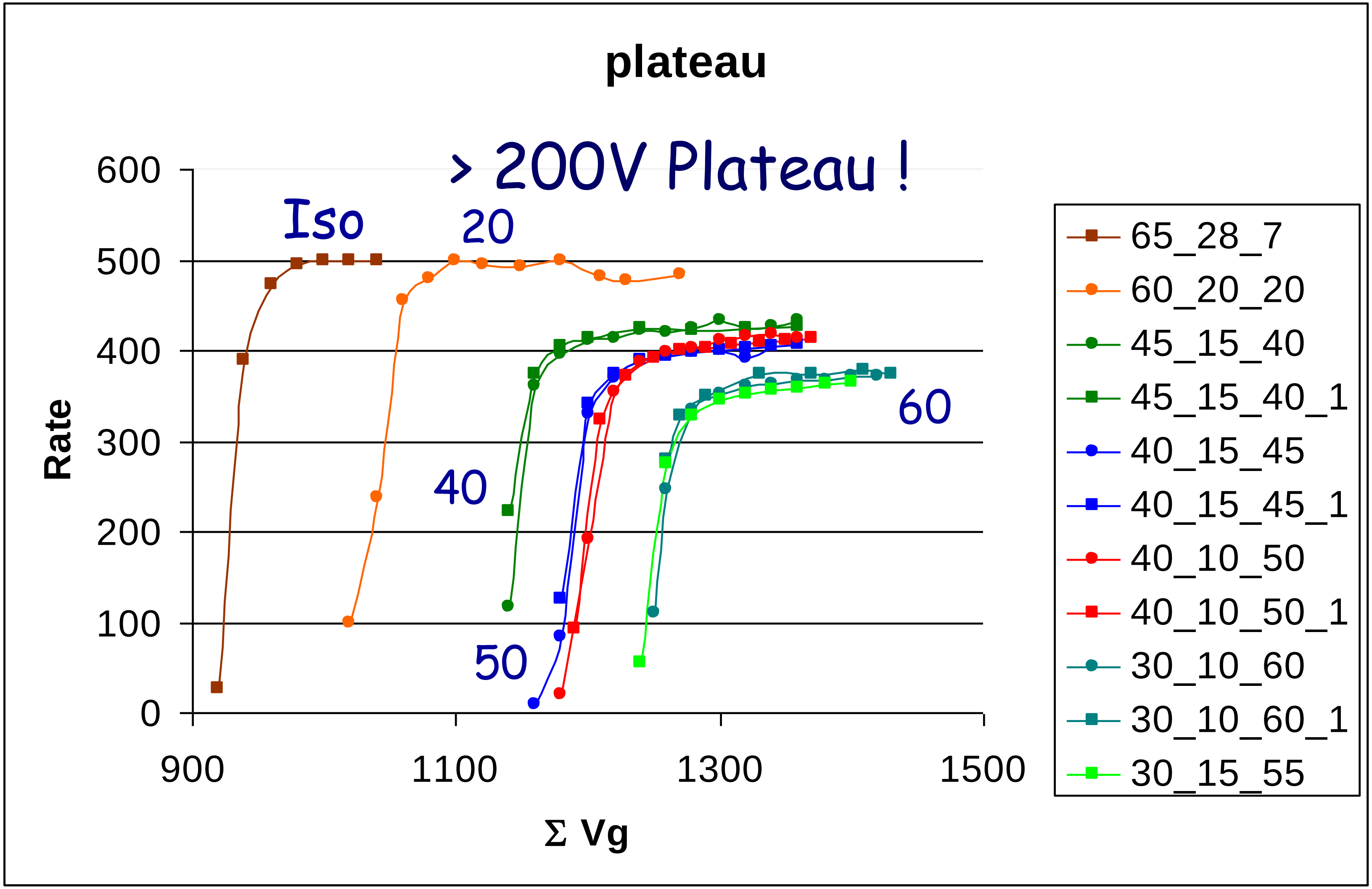
The detector gain is an exponential function of the sum of the 3 GEM supply voltages :

$$G = A\, e^{\alpha(V_{gem1}+V_{gem2}+V_{gem3})}$$

A and α depend on the gas mixture.

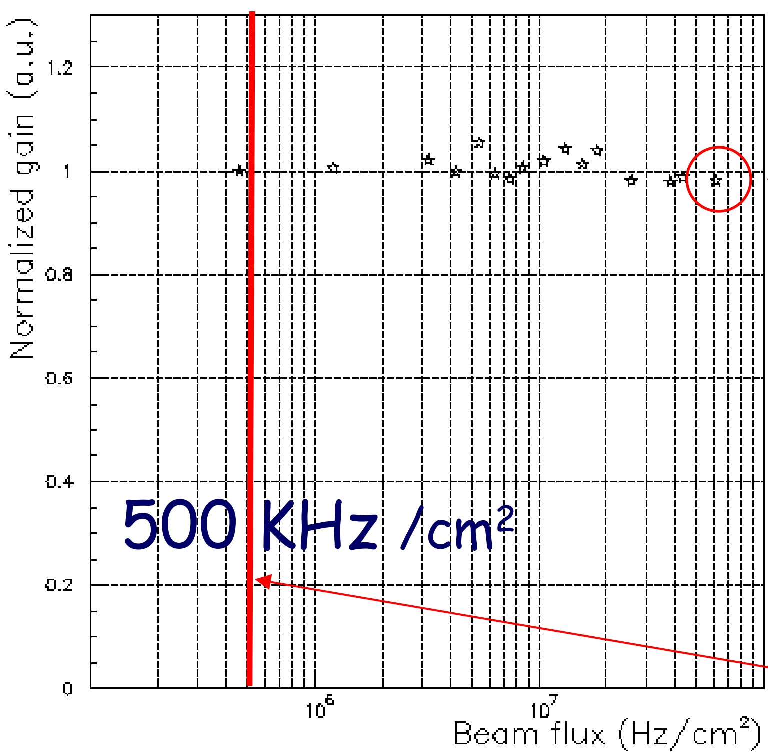


Efficiency vs HV with X-Ray



Rate capability

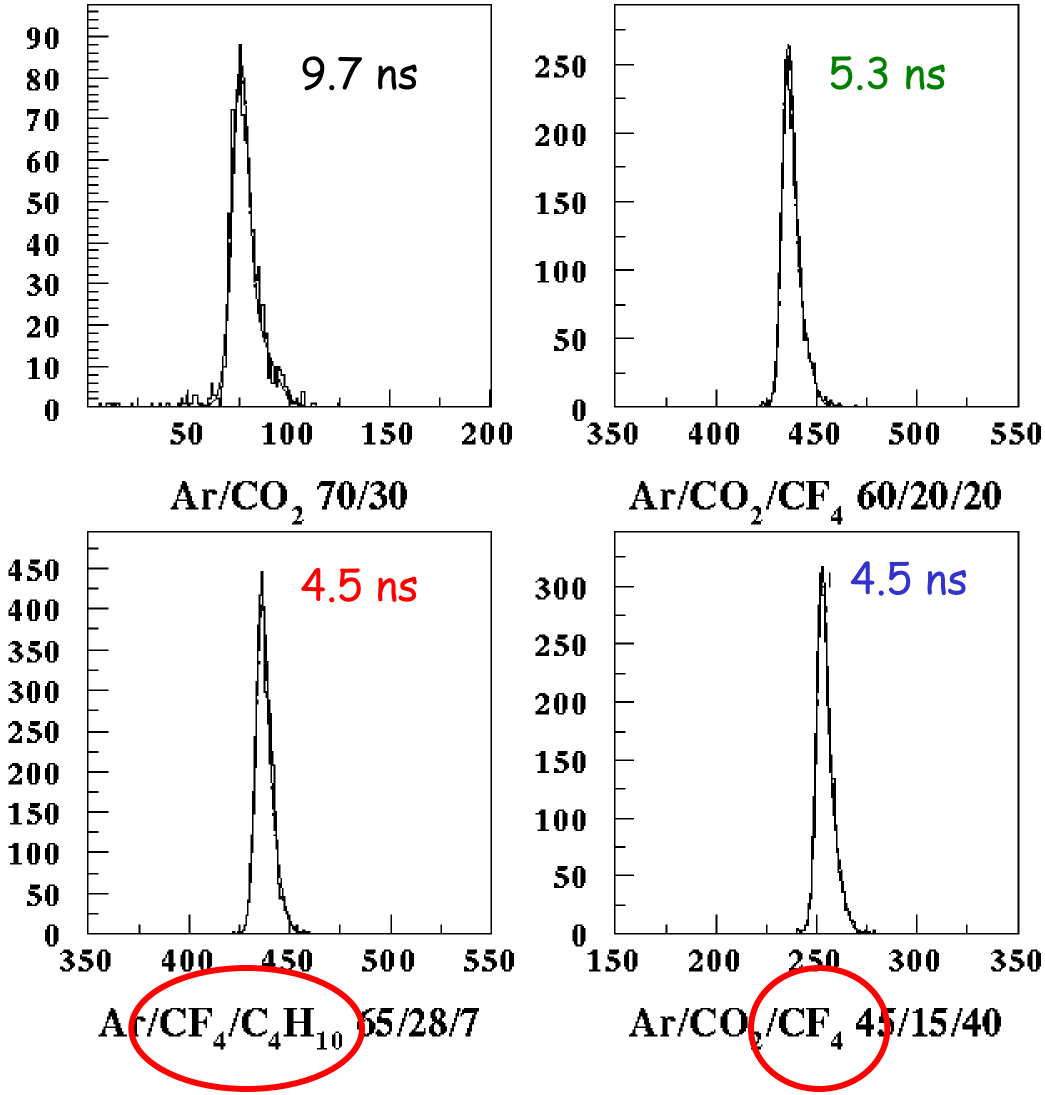
- The rate capability was measured with X-ray;
- The detector was operated with an $Ar/CO_2/CF_4$ (60/20/20) mixture at a gain of about $2x10^4$;



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

LHCb R1-M1 maximum rate

The time performance



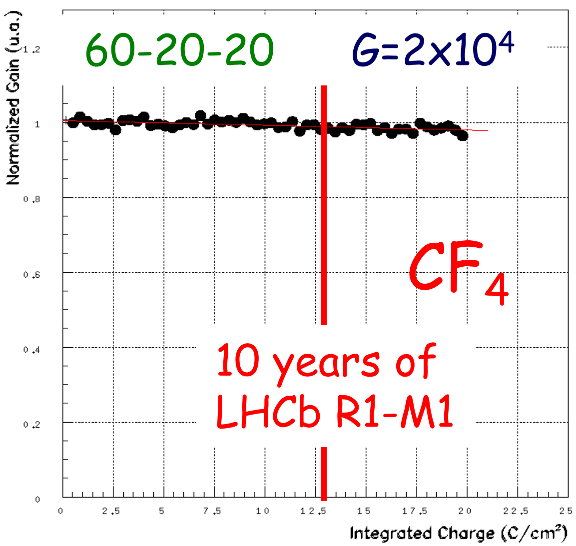
Considerable improvement with respect to the Ar/CO_2=70/30 mixture, which exhibits a poor time resolution of about 10 ns (r.m.s.), is obtained with the new CF_4 and iso-C_4H_{10} based gas mixtures, which allow to reach time resolutions better than 5 ns (r.m.s.)

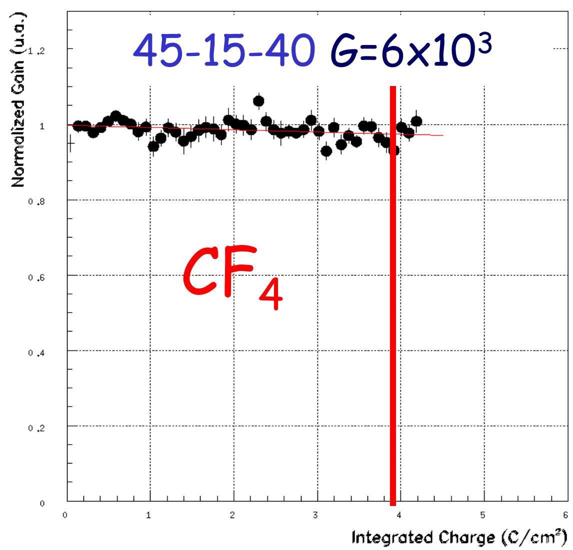
Aging Tests made for LHCb

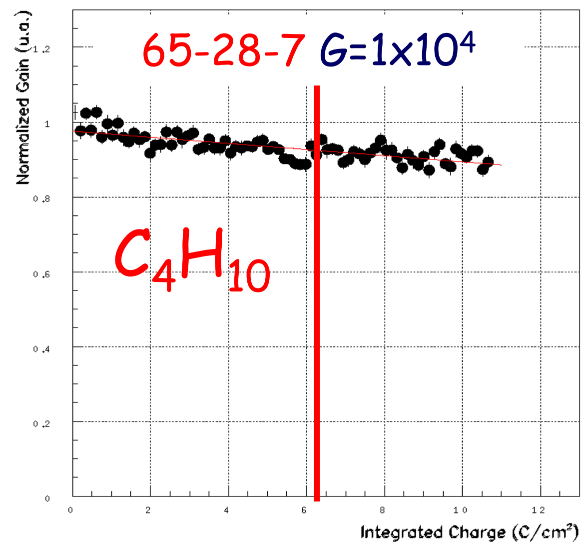
By irradiating the detector with an X-rays flux of 50 MHz/cm^2 :

- ~ 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)

$\Delta G/G < 5\%$ $\Delta G/G < 10\%$

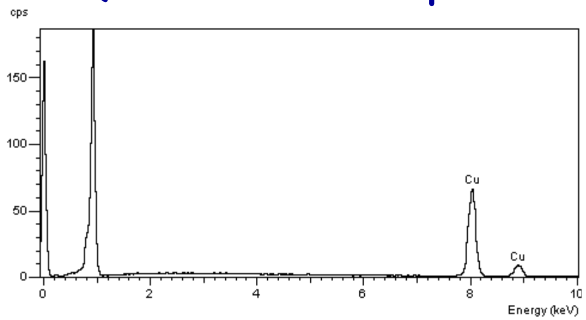




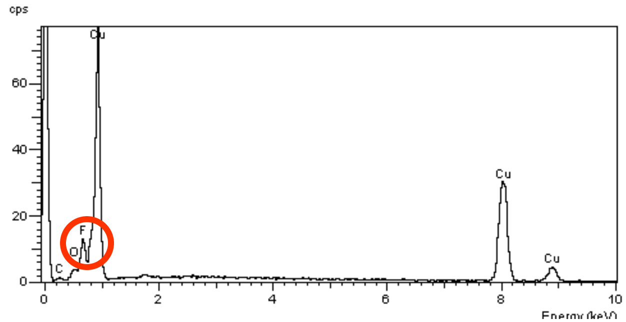


SEM analysis after ageing with ^{60}Co (15MHz/cm^2)

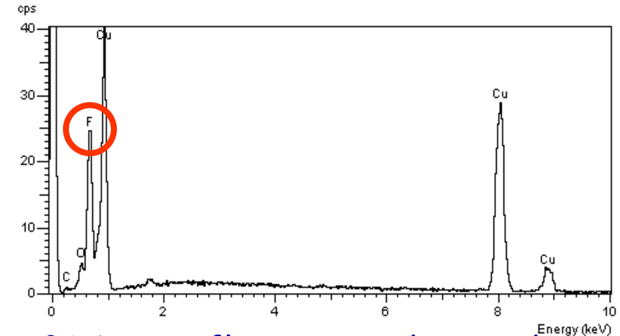
- No damage on gold plated drift cathode and Pad PCB. They are perfectly clean.
- Fluorine found on G2 and G3 could be present as some Cu-F compound, forming a thin insulating layer (no carbon deposits observed on the surfaces).



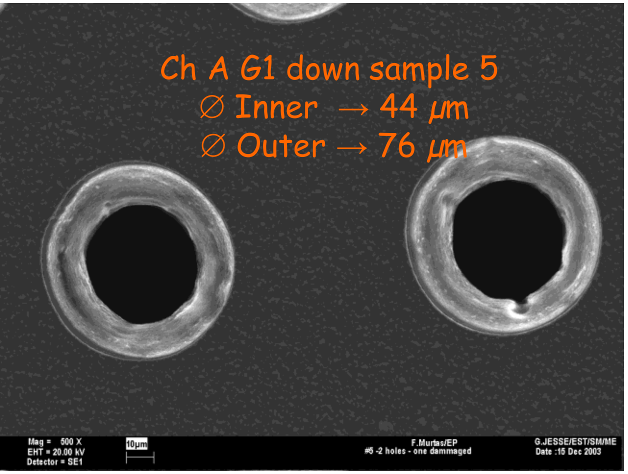
G1: No fluorine No etching

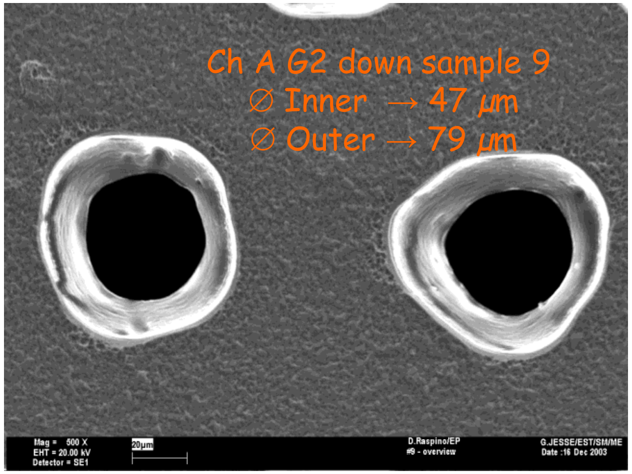


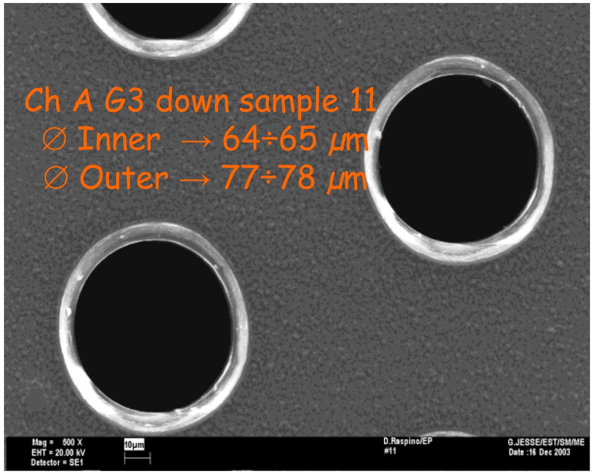
G2: Small fluorine,etching started



G3: Large fluorine etching enhanced





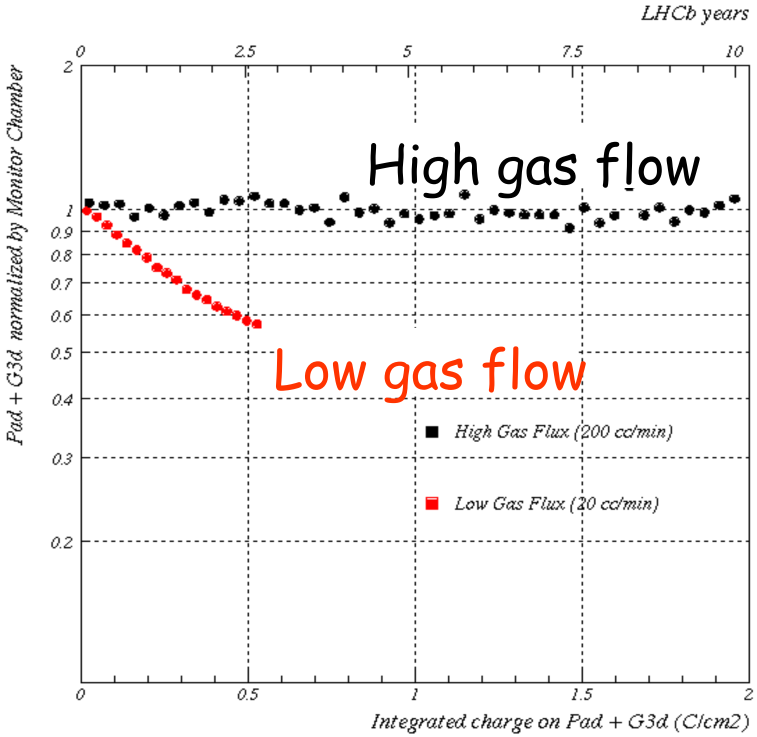


Aging induced by low gas flow

We tried to reproduce 11 years ageing test results, irradiating with X-rays a 10x10 cm^2 chamber (total current ~2 μA on ~ 1 cm^2 irradiation spot) flushed with a low gas flow (20 cc/min).

A current drop of ~ 40% for a 0.55 C/cm^2 integrated charge (~3 LHCb years) is found on the low gas flow measurement.

NO current drop is observed on the high gas flow measurement.



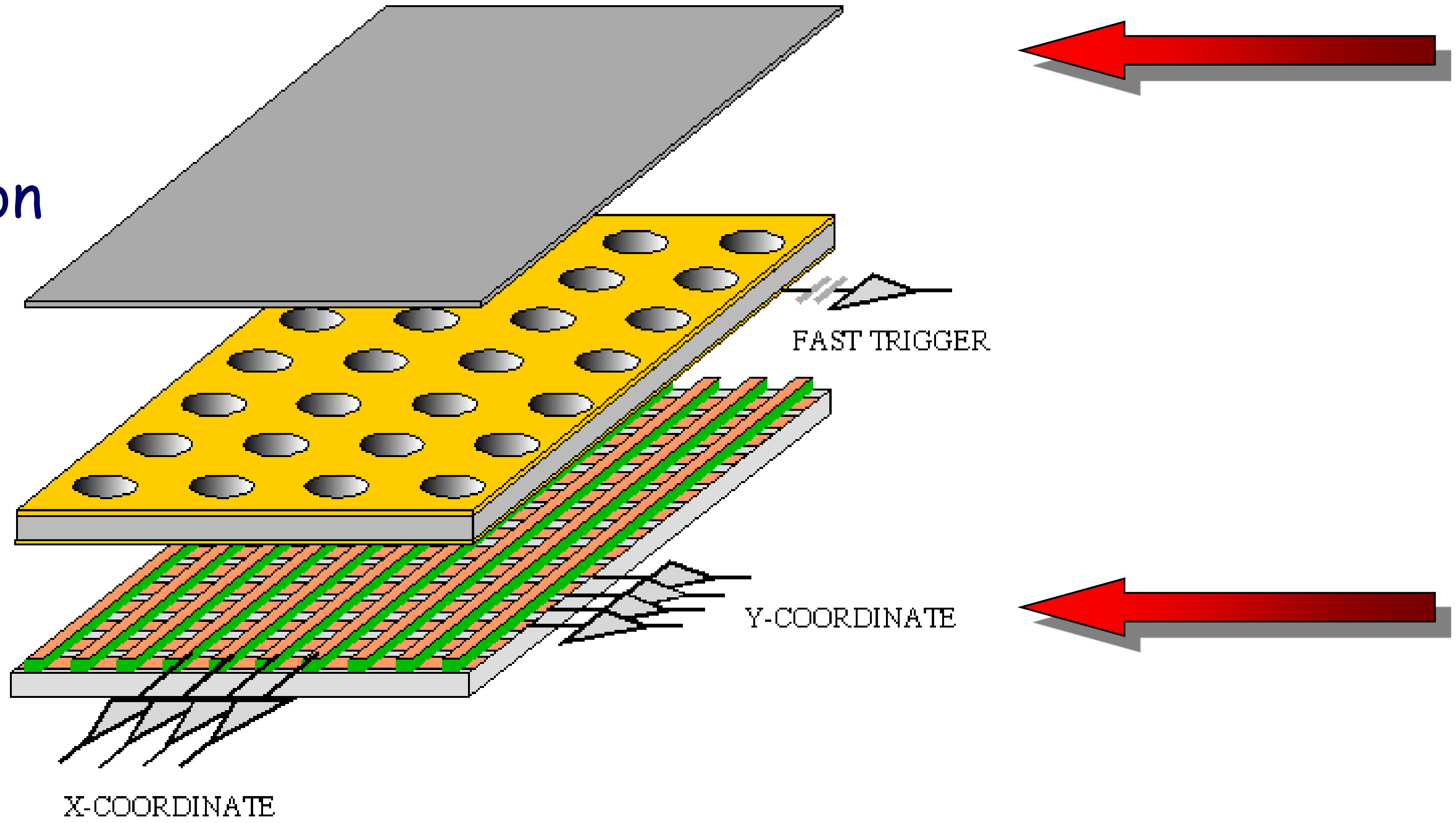
What would happen to sealed chambers ?

Where we are working now

Particle conversion

Gain

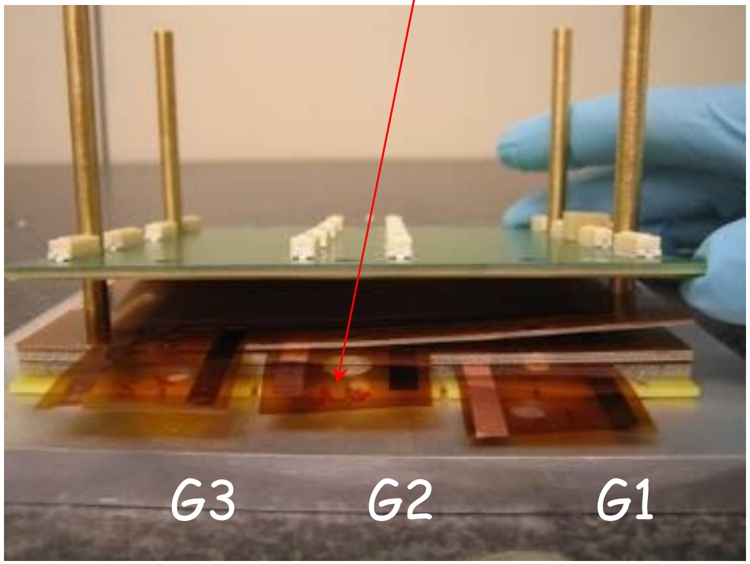
Readout



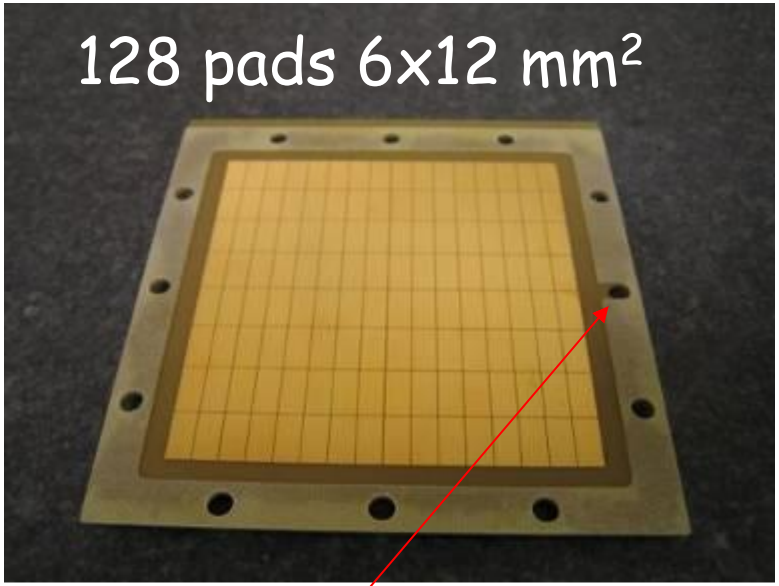
GEM Detector construction

A Sealed Triple GEM construction

The glued detectors described in this seminar are built starting form the standard 10x10cm^2 :
only one GEM foil has been modified to have central electrodes.



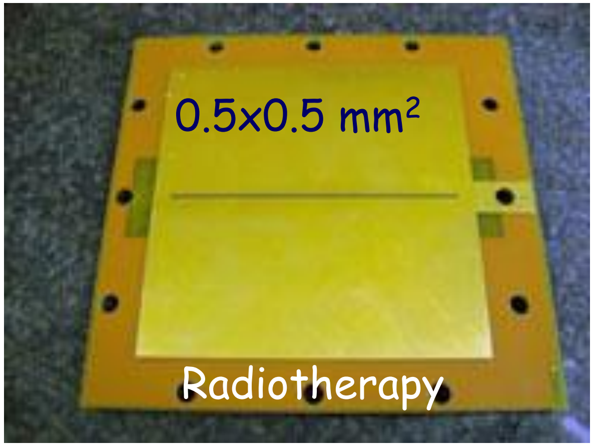
The GEM are stretched and a G10 frame is glued on top

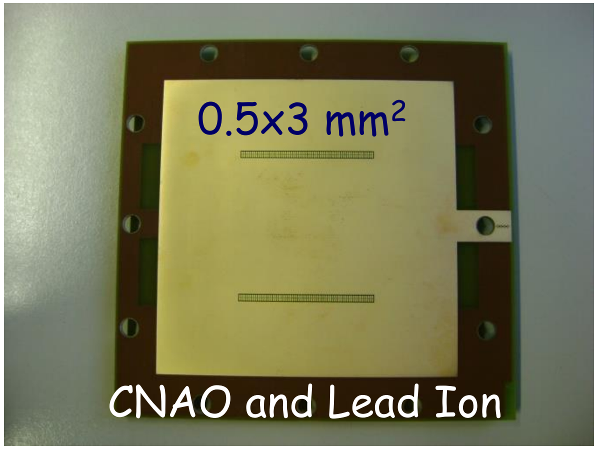


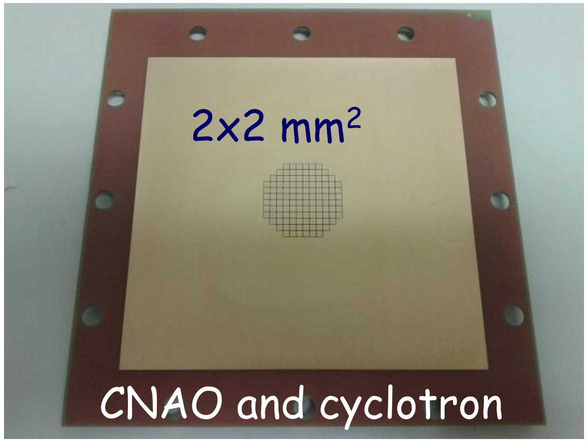
The frame for the G3 foil has been modified for the gas inlet

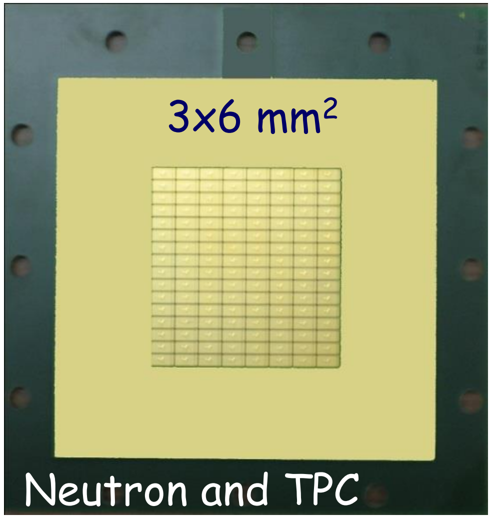
Pad readouts

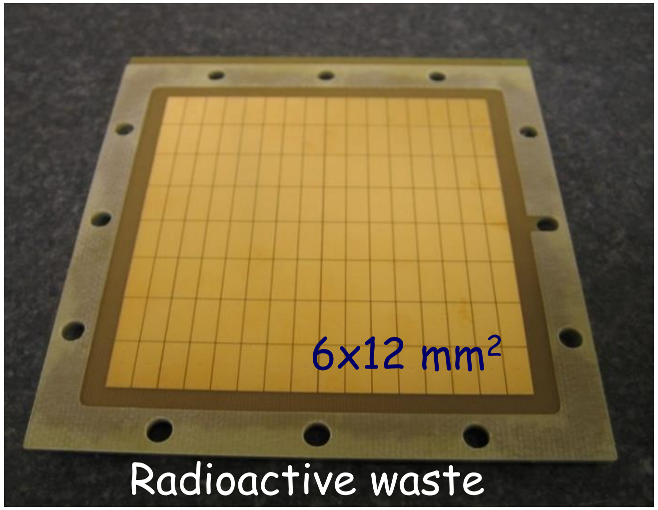
Different pad geometry but always with 128 channels

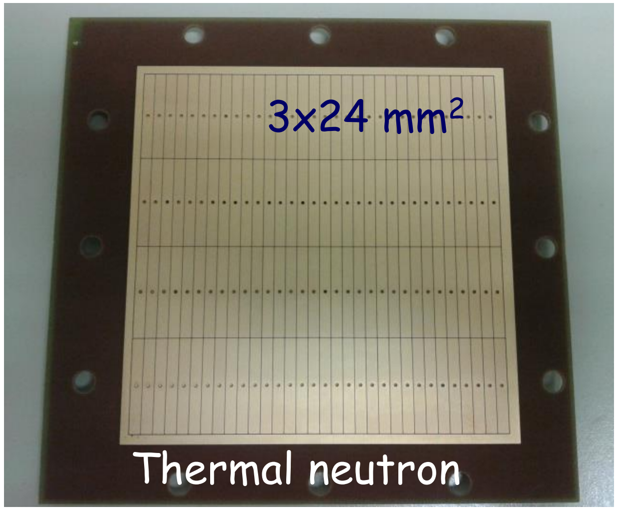












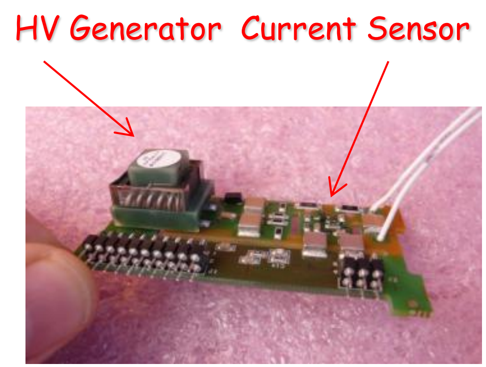
DAQ System and Power Supply

Two important devices have been developed in Frascati during 2010 :

A compact DAQ board, FPGA based :
with 128 Scalers readout and
with 128 TDC channels

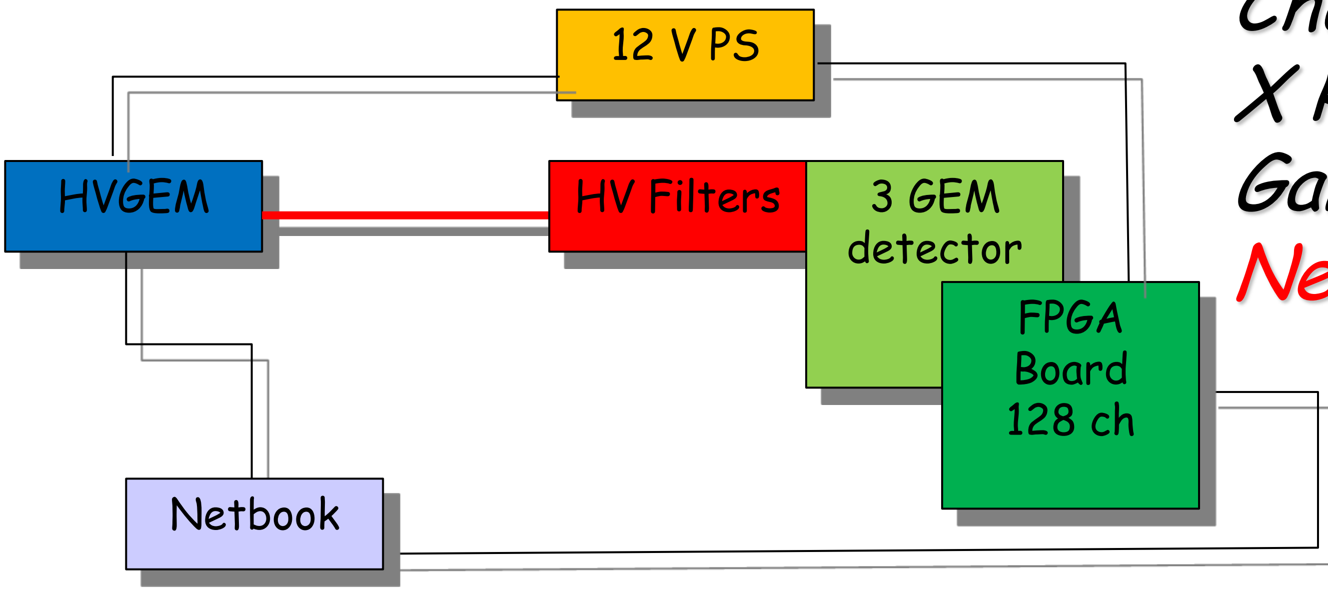
1 power supply (12V)
2 input channels: gate and trigger
3 data outputs : ethernet and USB
8 acquisition modes
(made by Athenatek)

HVGEM : a power supply for
triple GEM detectors:
7 HV channels (0.5 V ripple)
with 7 nano-ammeters (10 nA)

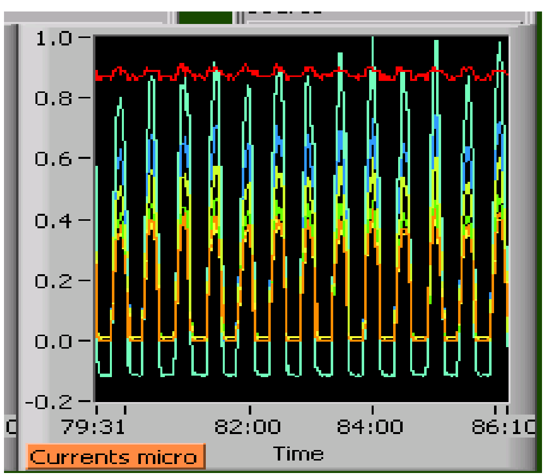


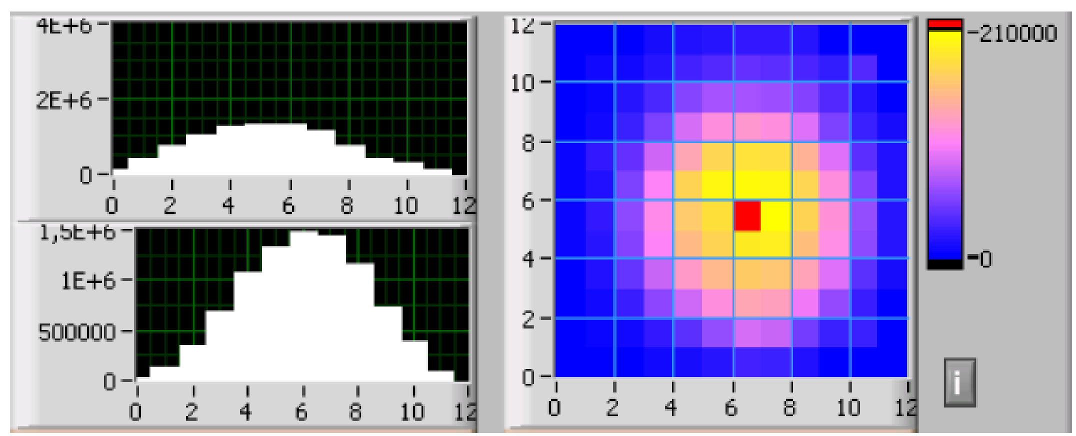
Two slot NIM Module CANbus controlled
(made by MPelettronica)

A triple GEM detector system



Charged particles
X Ray
Gammas
Neutrons





GEM Detector applications in dosimetry

Why GEM Detectors ?

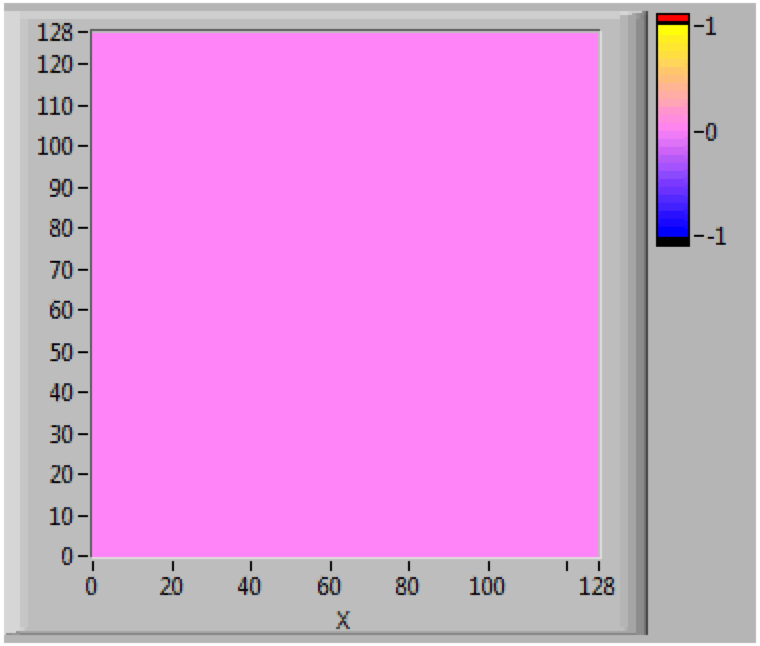
GEMs offer the following advantages :

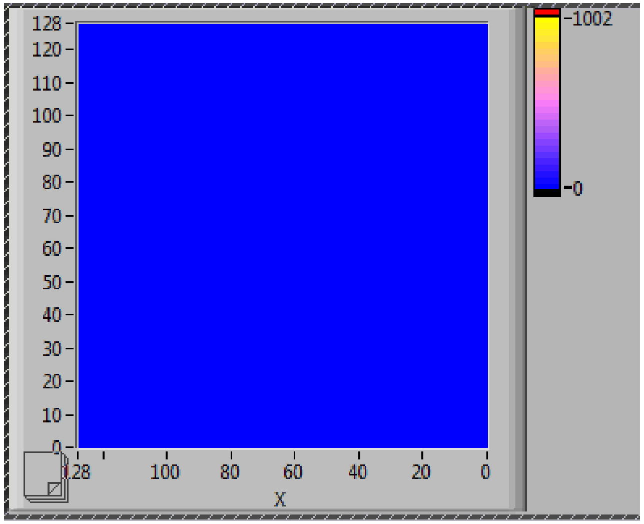
- Sensible to single particle
- Very high rate capability (MHz/mm^2)
- Submillimetric space resolution (50-200 μm)
- Time resolution from 5 ns
- Possibility to be realized in large areas and in different shapes
- Radiation hardness and very low discharge probability
- Insensitivity to gamma rays (with appropriate gain)

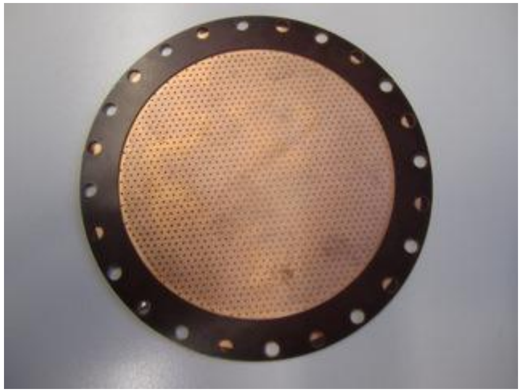
X-Ray Images

X-Ray 6 KeV
With a mesh of 600 micron holes
Pitch of 2 mm

X-Ray beam of 6 KeV



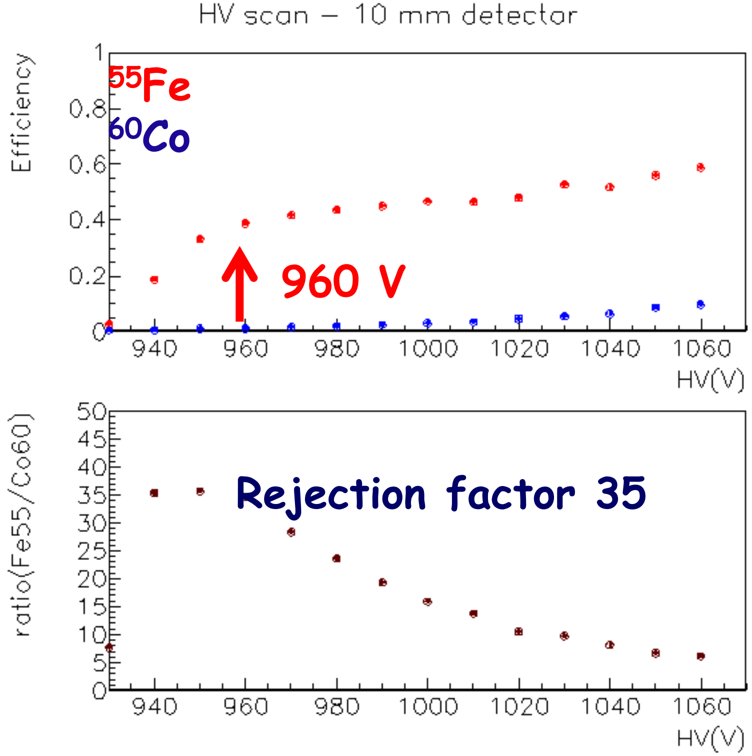


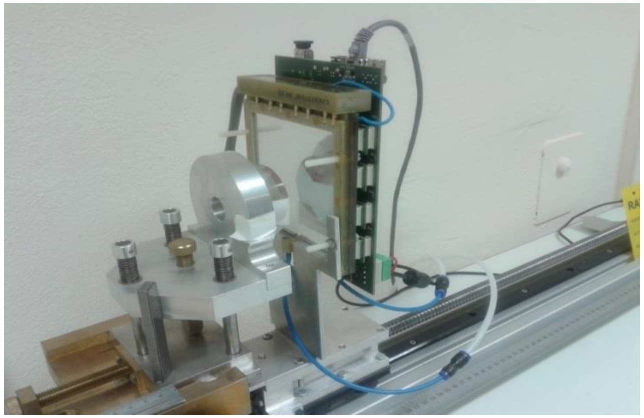


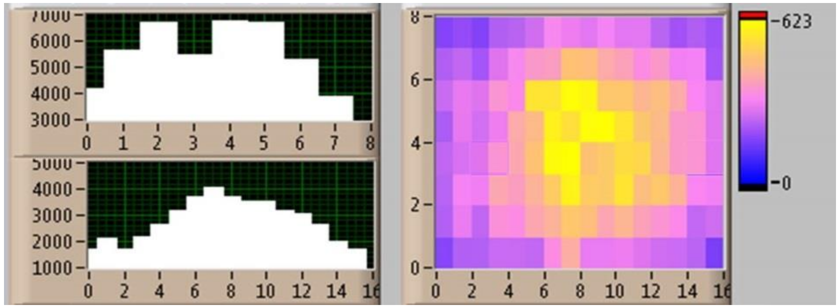
The detector is limitated by the electronics channel density

Radioactive waste : ^{55}Fe vs ^{60}Co

At CERN, there are cavities and beam pipes from LEP with residual radiactivity
Some one are candidate for a free release but there is a really stringent limit on ^{55}Fe activity .... The chemical analysis is slow ...
Gas chambers could be a good monitor for this type of radioactivity

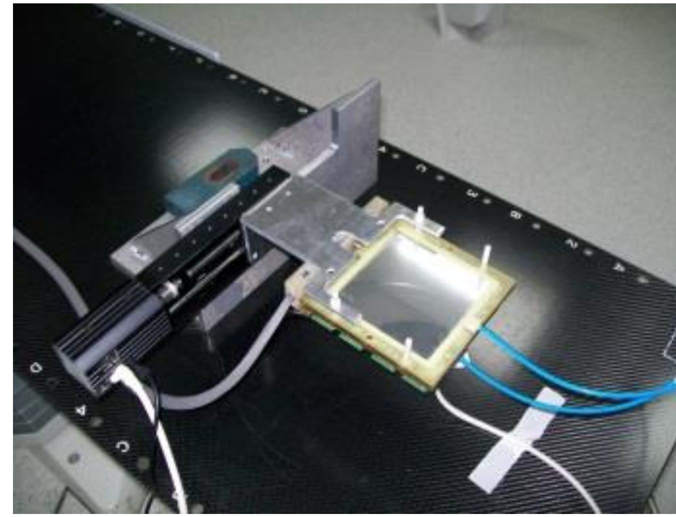




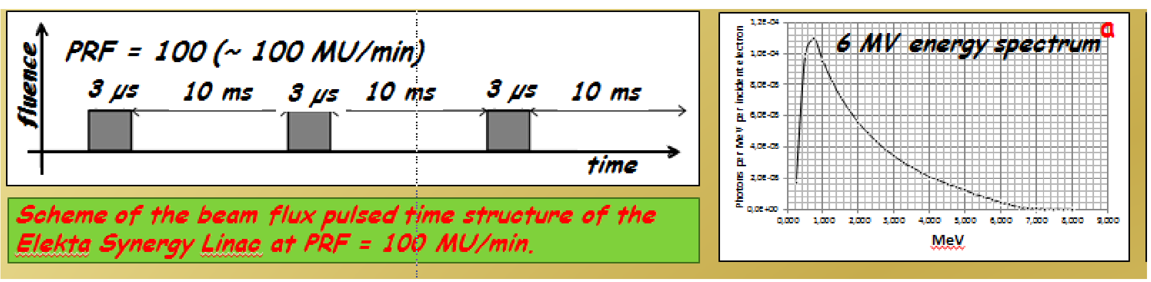


Possibility to find the hot spot

Gamma flux measurements at PTV

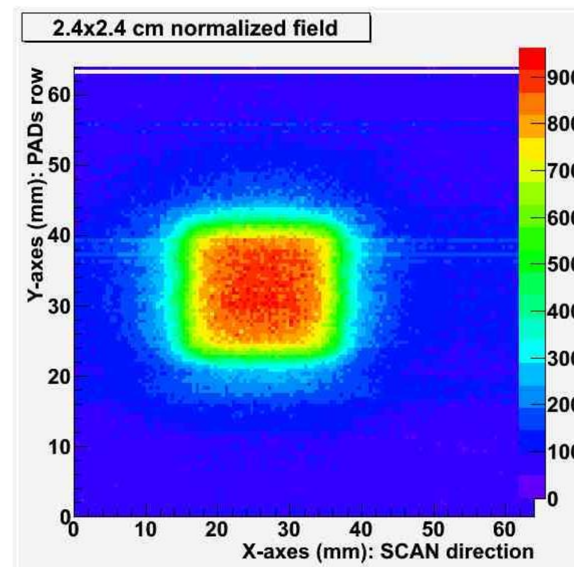


Gamma flux of 10^8 Hrz/cm^2 6-1 MeV



The flux of gamma in radiotherapy is composed by several 3 μs bunches

With a scan, a triple GEM with a row of 128 pad of 0.5x0.5 mm is moved crossing the beam. Each line is aquired in 200 ms

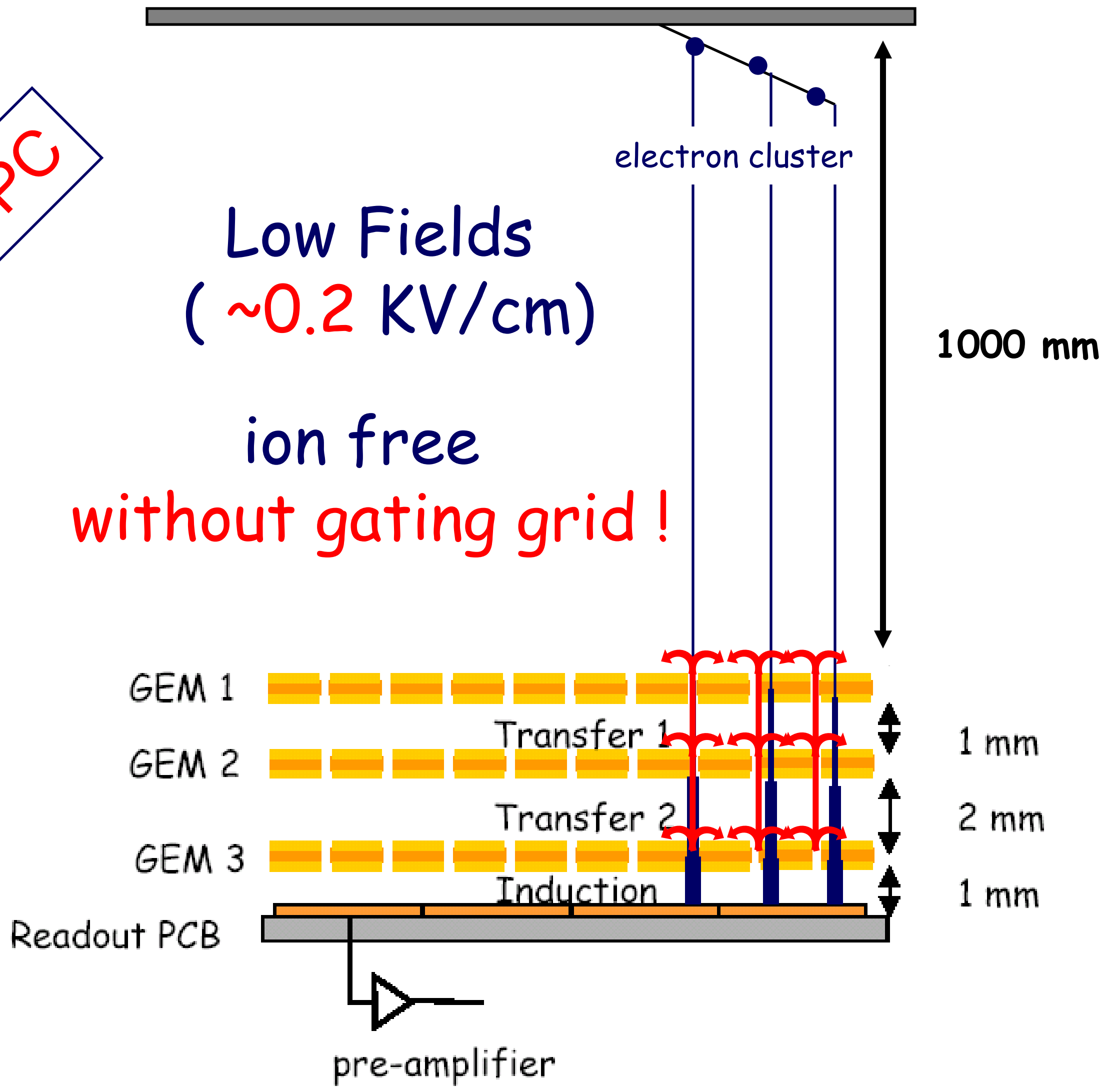


TPGC: TPC with GEM

GEM is a TPC

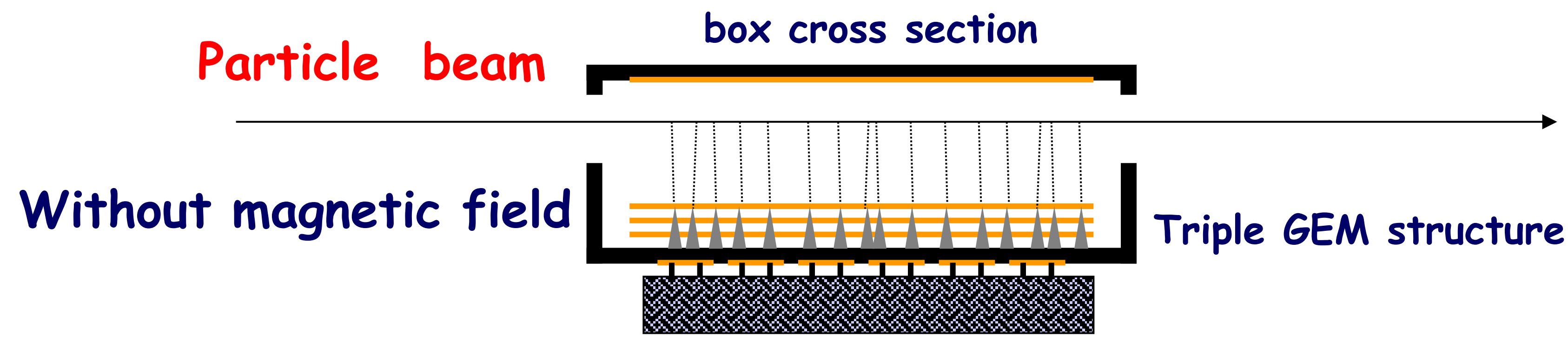
Low Fields
(~0.2 KV/cm)

ion free
without gating grid !

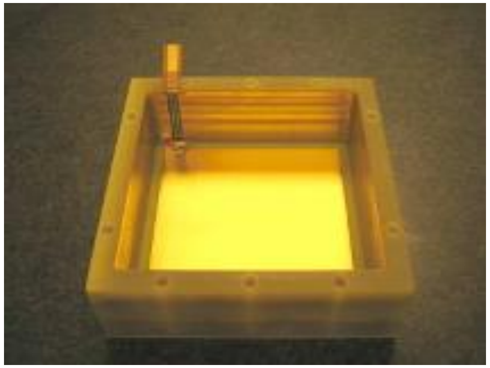


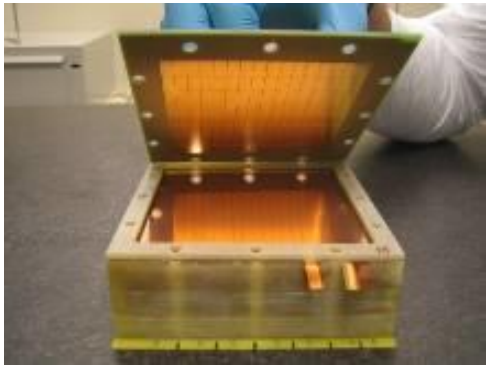
A Triple GEM beam monitor

It's essentially a small TPC with a 4 cm drift and readout with triple GEM
With this detector also high current beam can be monitored in position



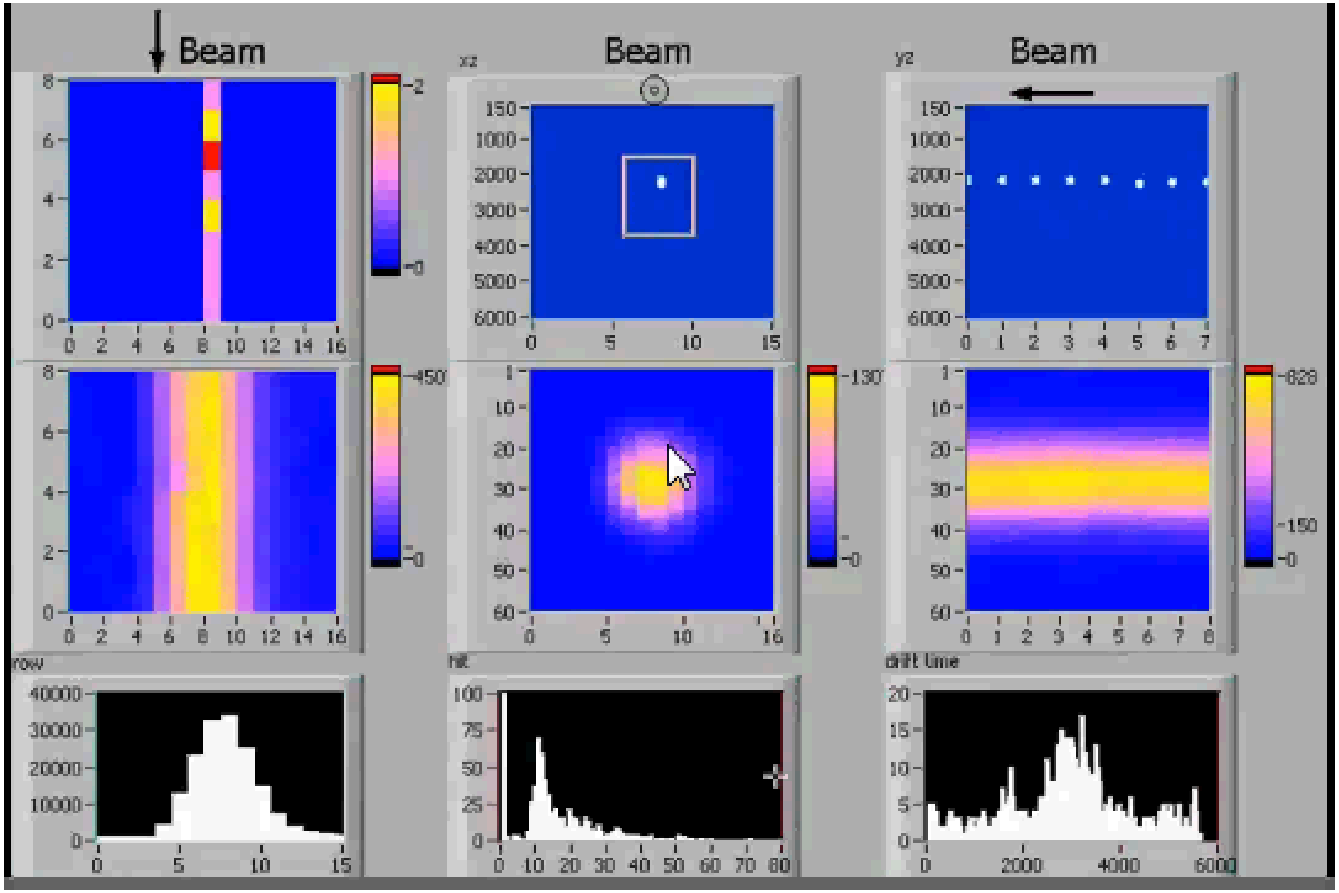
The material budget crossed by a particle is only two kapton foils (<0.2%X_0) used for the field cage necessary for the drift field uniformity





Real time track reconstruction

... thanks to this good efficiency ....



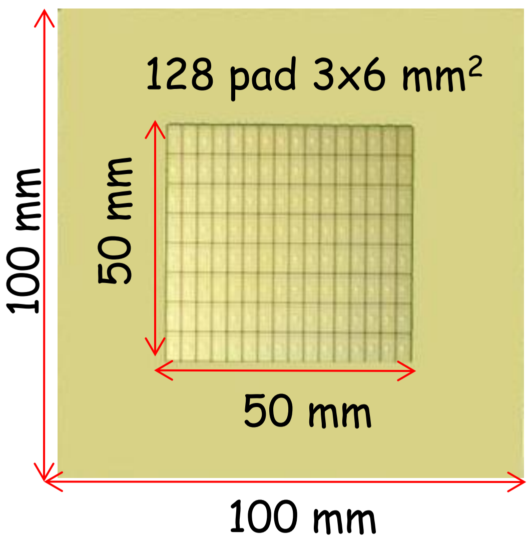
Single event

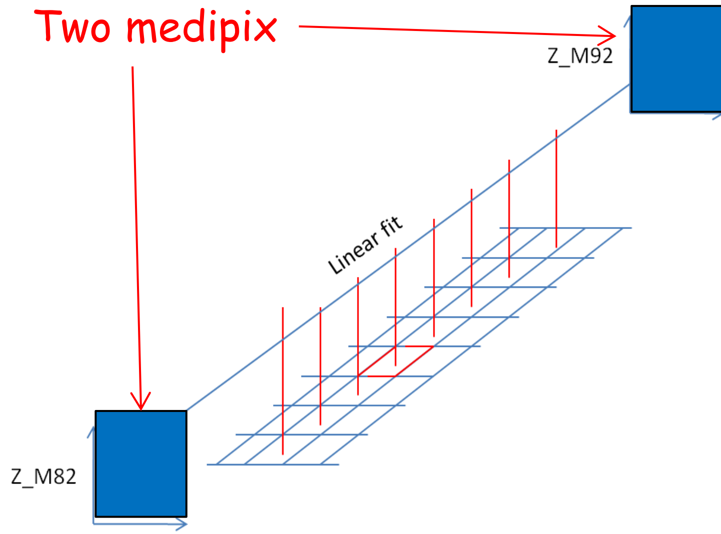
History

Profiles

This is a screen shot of the TPC GEM Online Console

3D track reconstruction

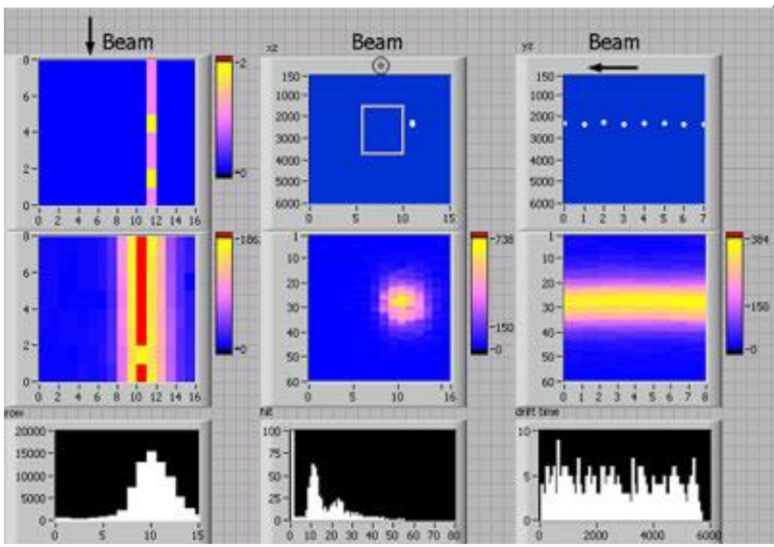




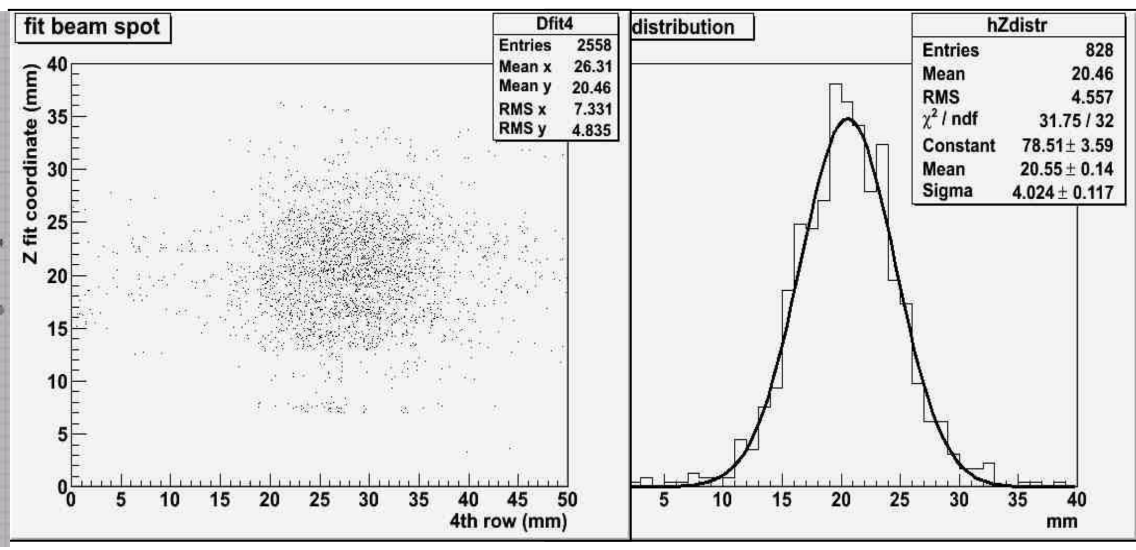
Z coordinate is measured from the drift time of the electrons produced by the particle track.

80 microns resolution

Beam Z profile



ONLINE CONSOLE



The hits are linearly fitted, and the beam spot at the center of the chamber is recostructed

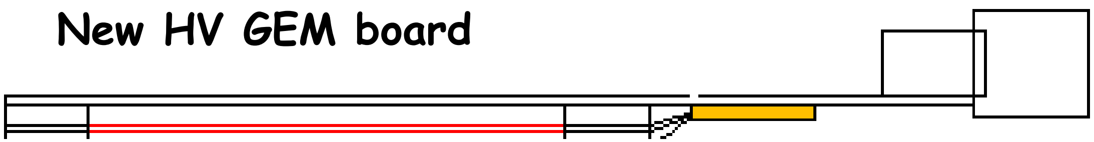
GEMPIX detector

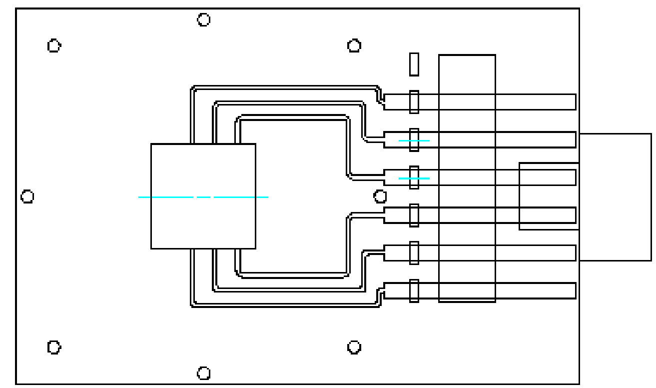
Assembling

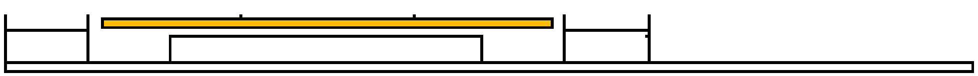
The detector has two main parts :

- The quad medipix with a naked devices
- The triple gem detector with HV filters and connector

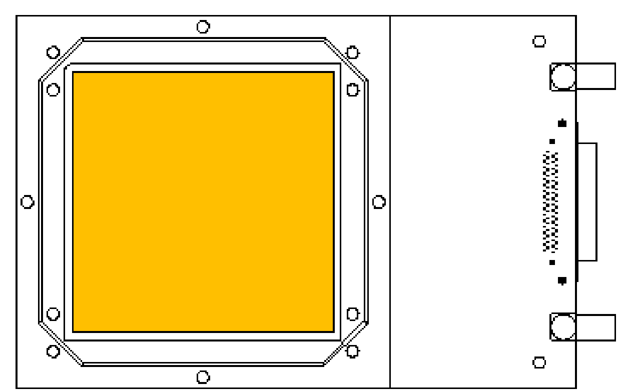
New HV GEM board







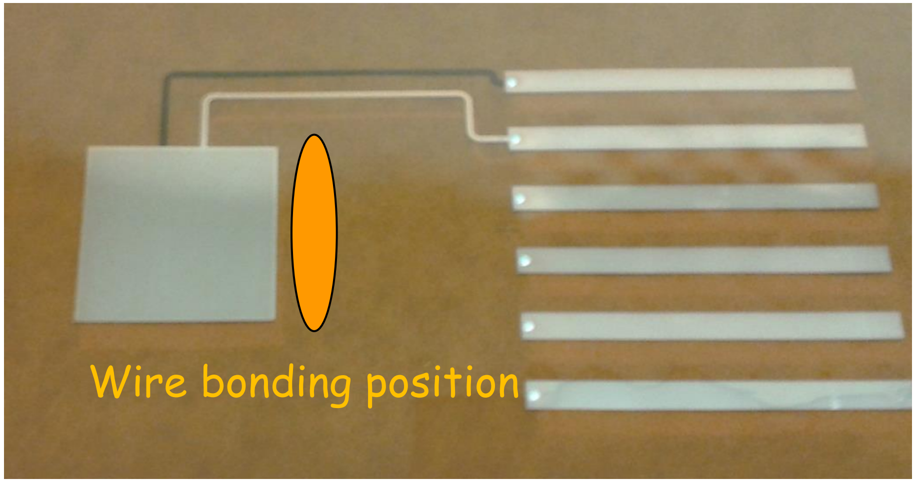
Quad medipix board



Top view

M.Campbell, J.Alzoy

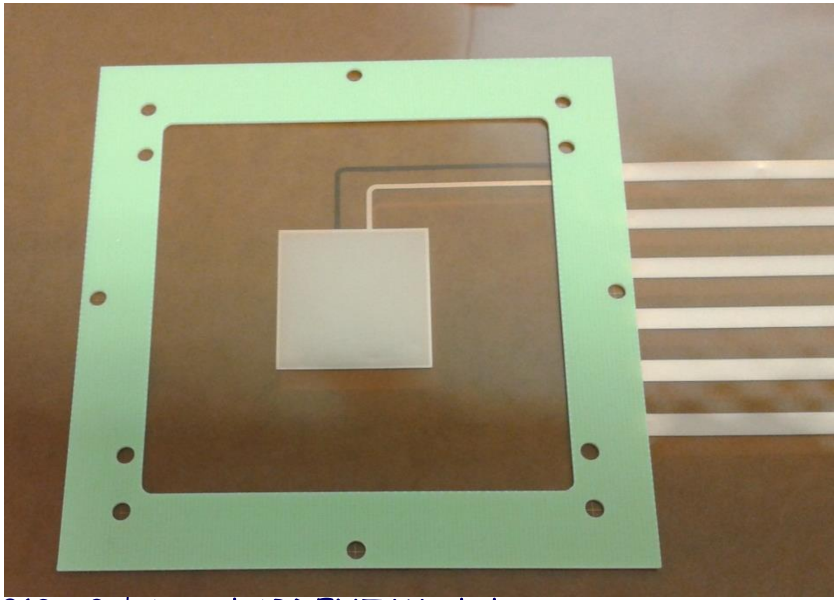
Gem foils and frame



A new GEM layout has been designed
Active area of 28x28 mm^2
The electordes path have been designed to avoid the medipix wire bonding.
Produced by Rui De Oliveira.

New frames were designed 10x10 cm^2 to fit the Quadmedipix board

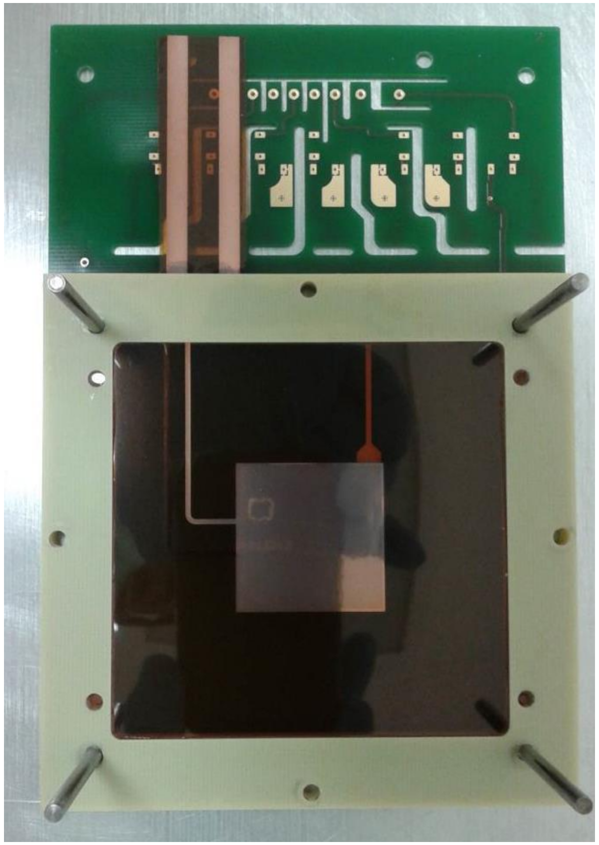
5 different thickness (from 1 to 5 mm)

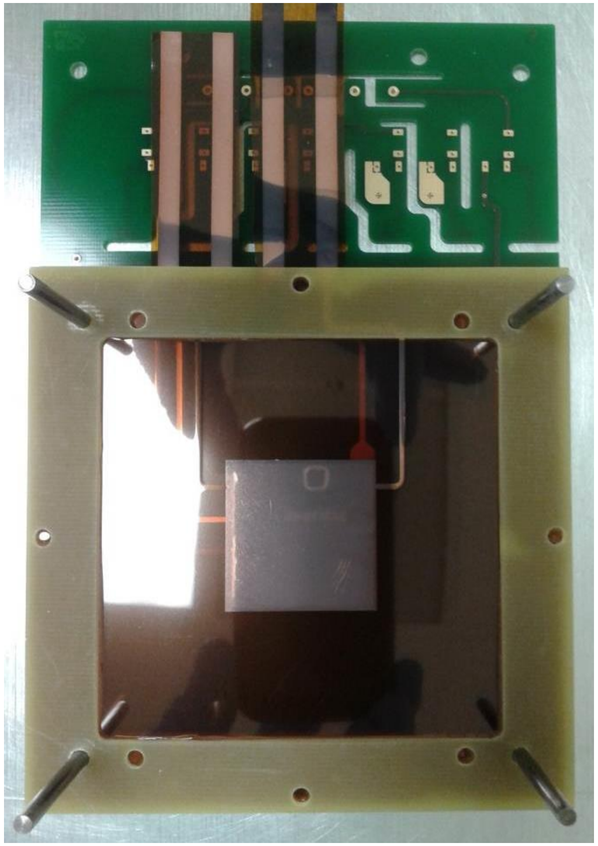


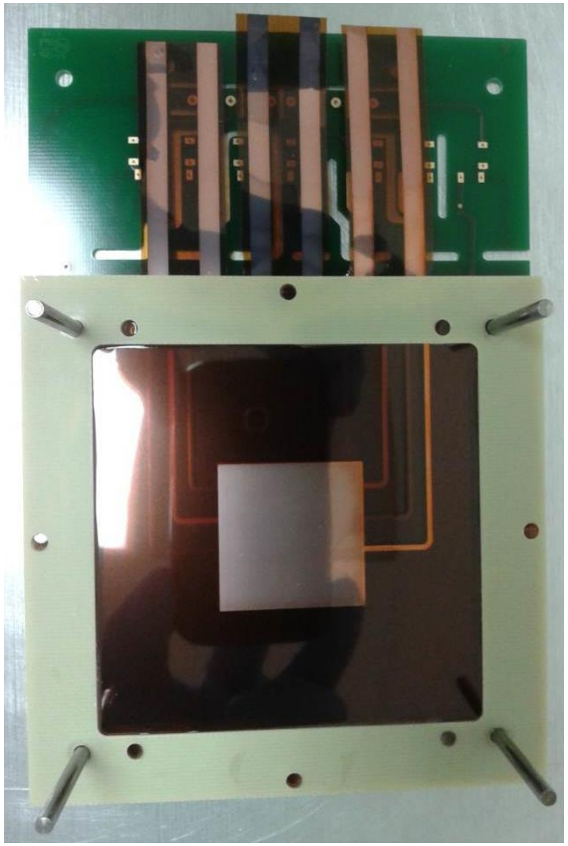
Assembling the GEM foils

A new board for HV power supply as been designed and made in Frascati (D.Tagnani)

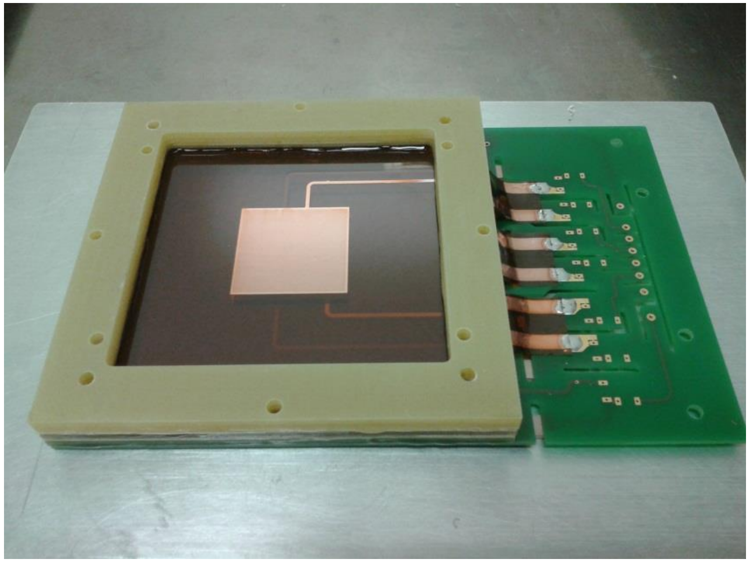
The three GEM foils are assembled on top of HV GEM board

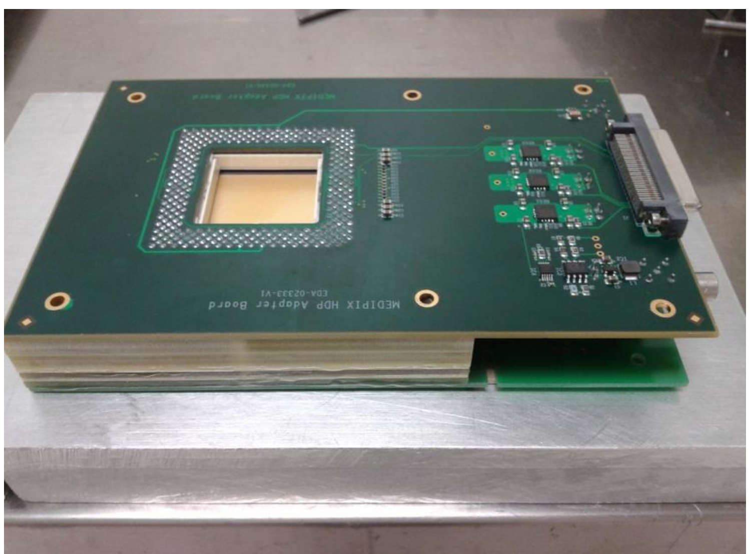




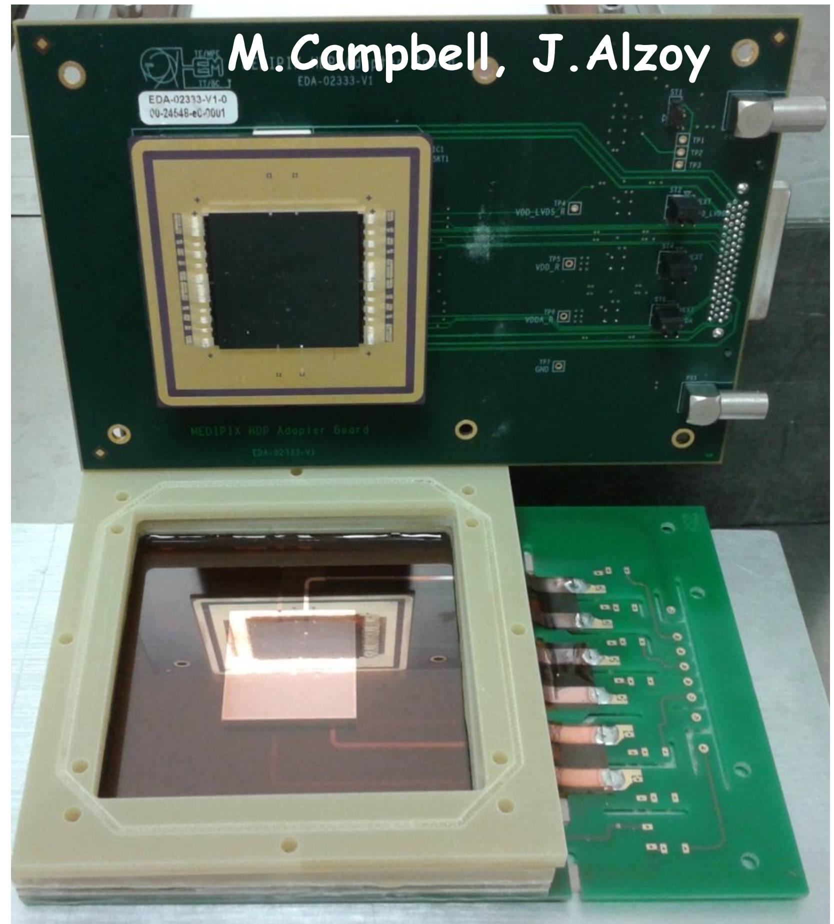


Final detector and assembly



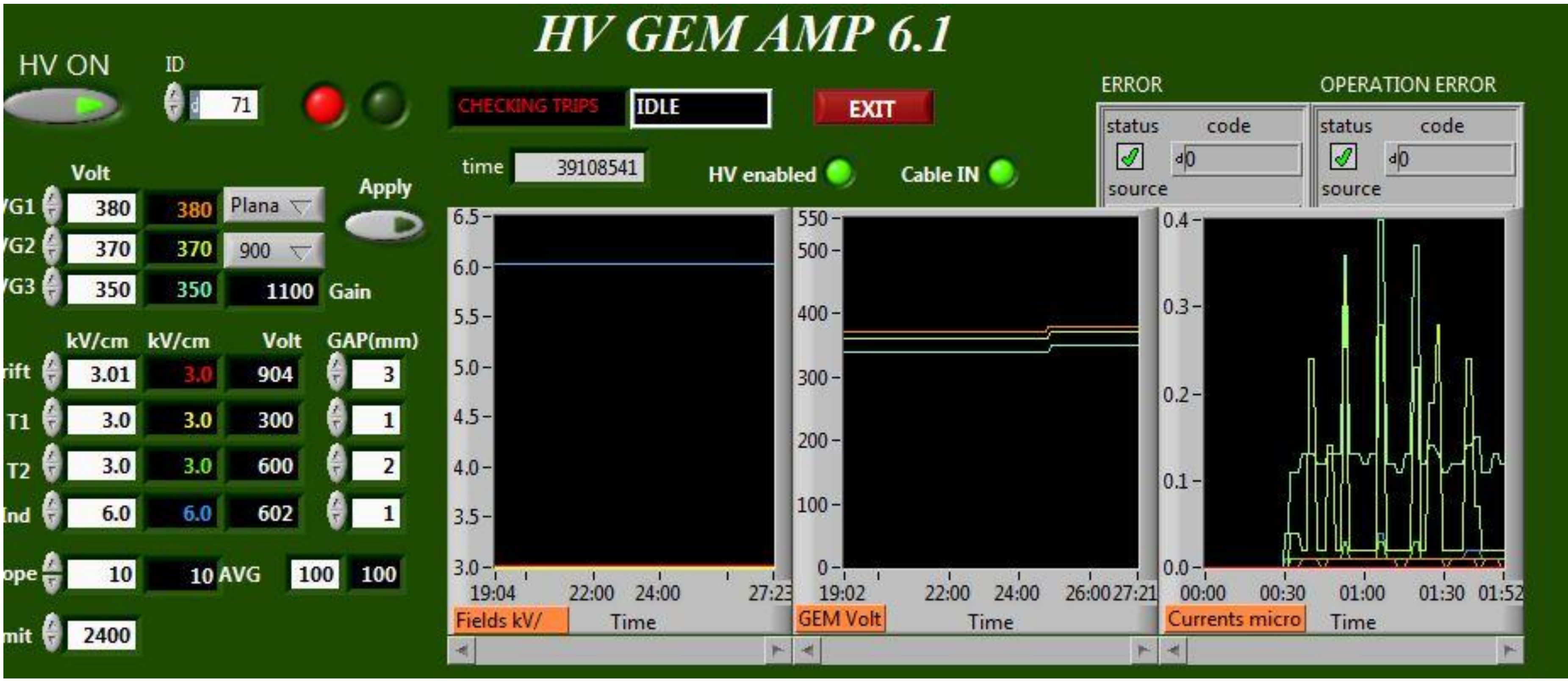


The detector could be open again
and the ceramic board with 4 medipixes
could be changed at any time



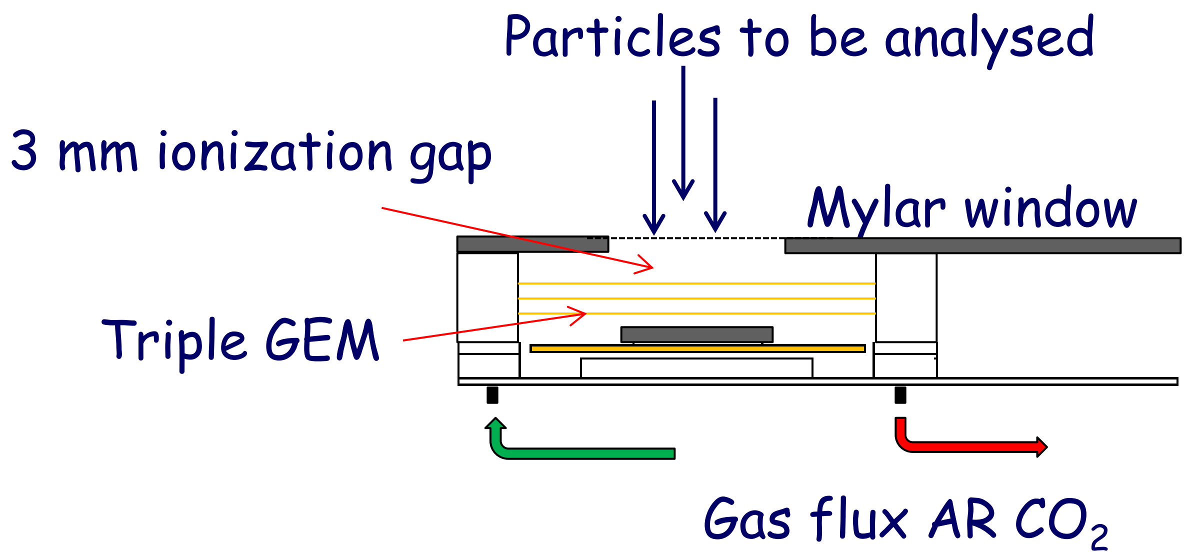
Induced sparks

The chamber gain has been increased to produce small sparks on GEM foils:
no effect on medipix chip



Previous attempts (2004-2010) have burned a number of chips

Head on detector

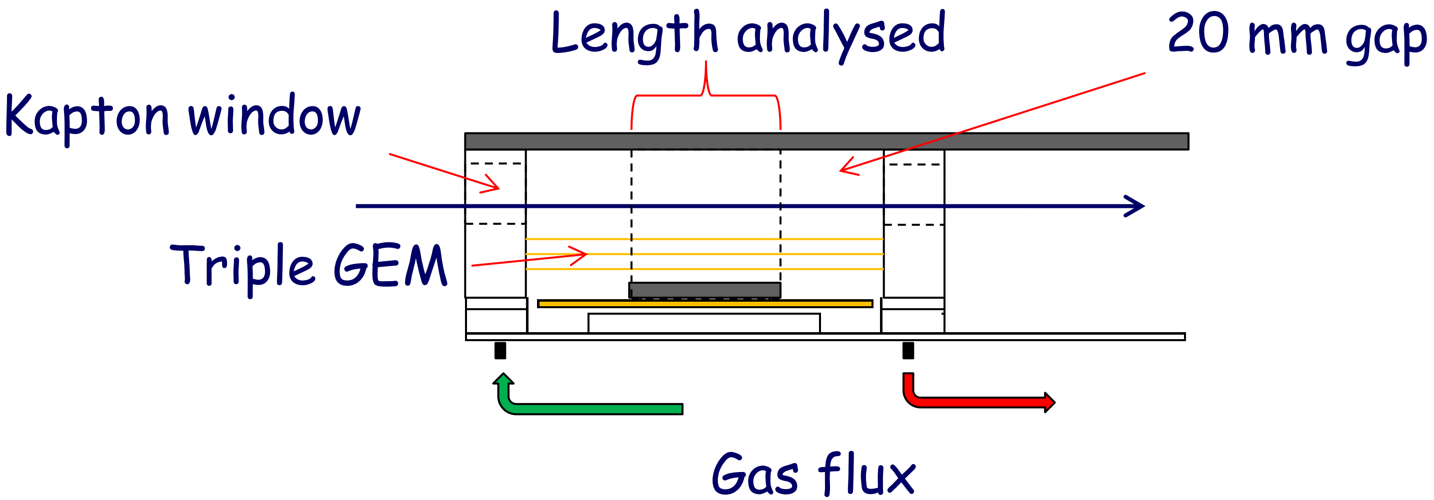


The detector is a quad naked medipix :
The active area is 9 cm^2

This type of detector can be used for the ^{55}Fe activity in radioactive waste if we need an higher rejection to gamma and electrons

Detector for TEPC

This is a tissue equivalent proportional chamber useful to reproduce and measure the energy released of ionizing particle in human tissue

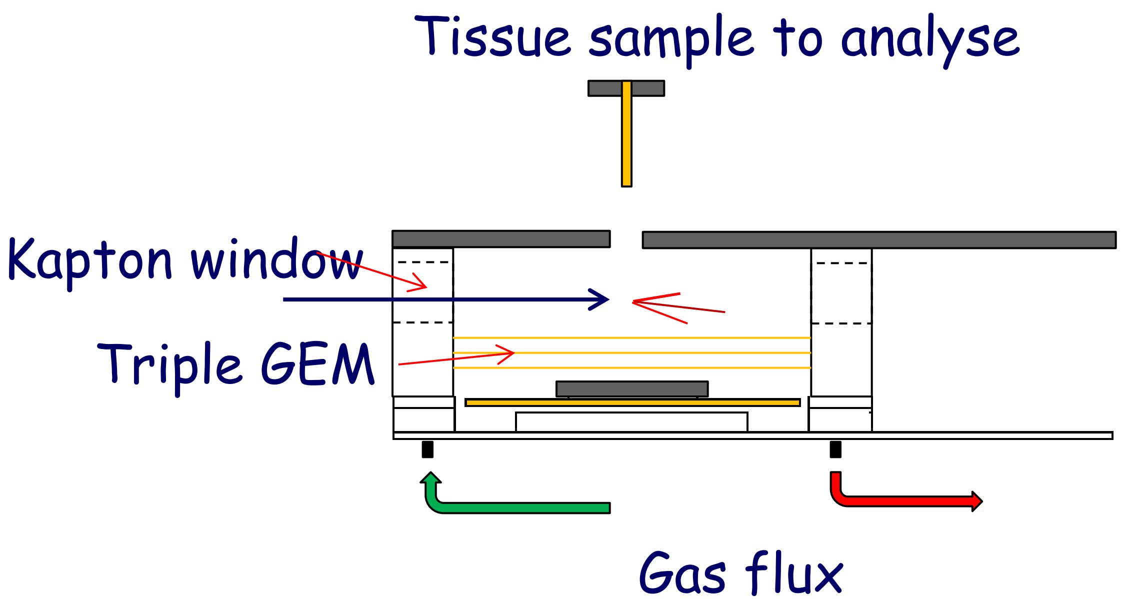


The particle track is analysed with 512 pixel in 3 cm length

This is equivalent to 30 microns of tissue …
with 17 samples/per cell …
Really a new device for microdosimetry

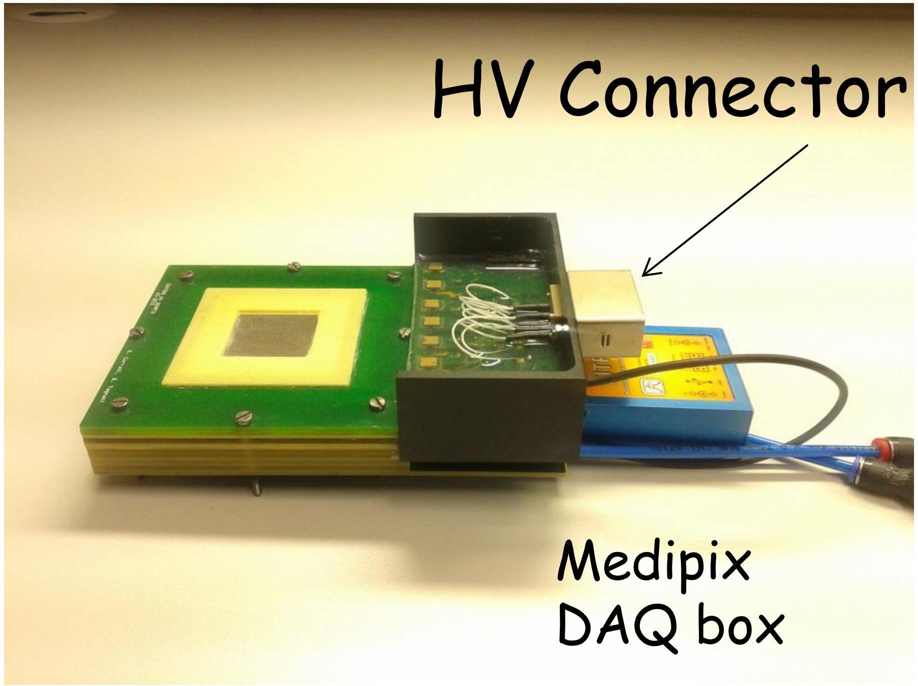
Detector for tissue sample

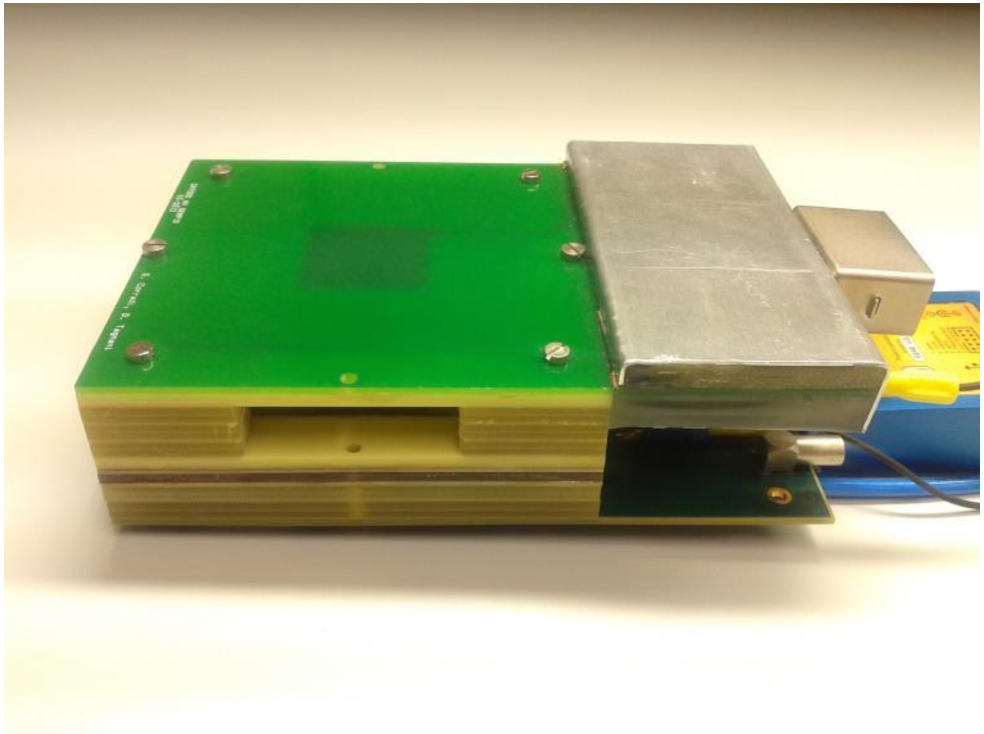
There is the necessity to analyse the interaction products of proton and ion beam in hadrotherapy with real tissue samples



This prototype will be built on november

Two prototype of GEMPIX





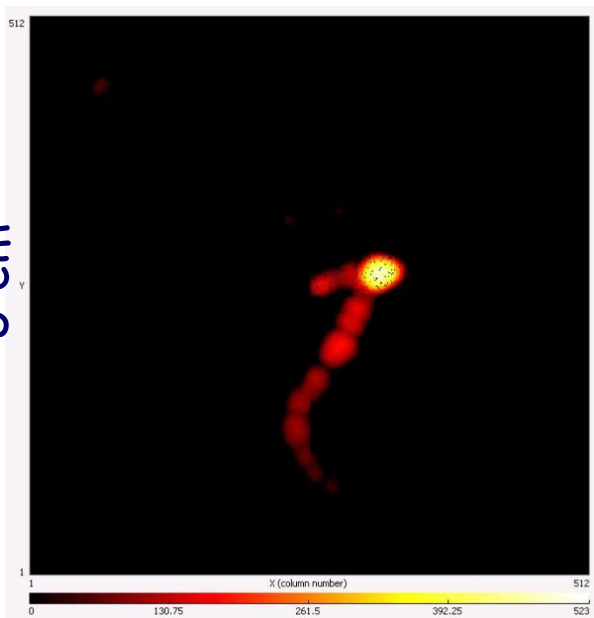
Head-on detector

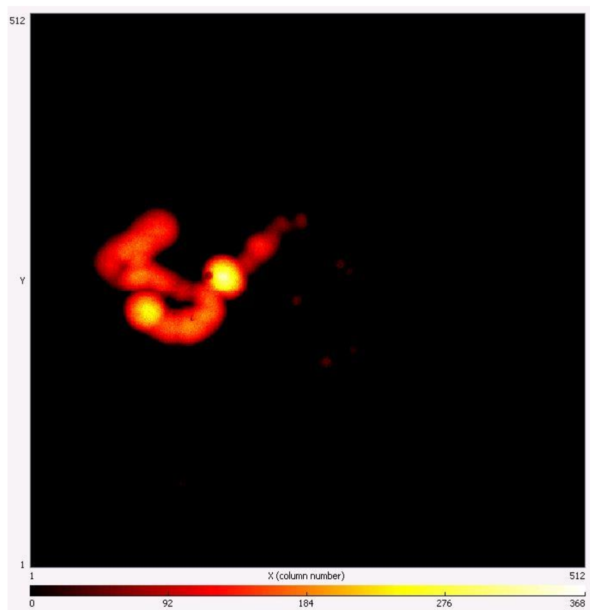
Side-on detector

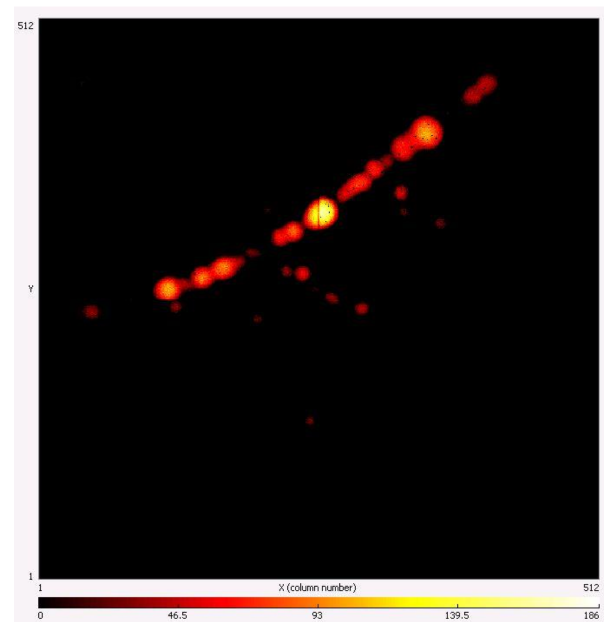
Cosmic rays with a gas AR/CO_2 70:30

These are the first pictures taken with the GEMPIX

3 cm





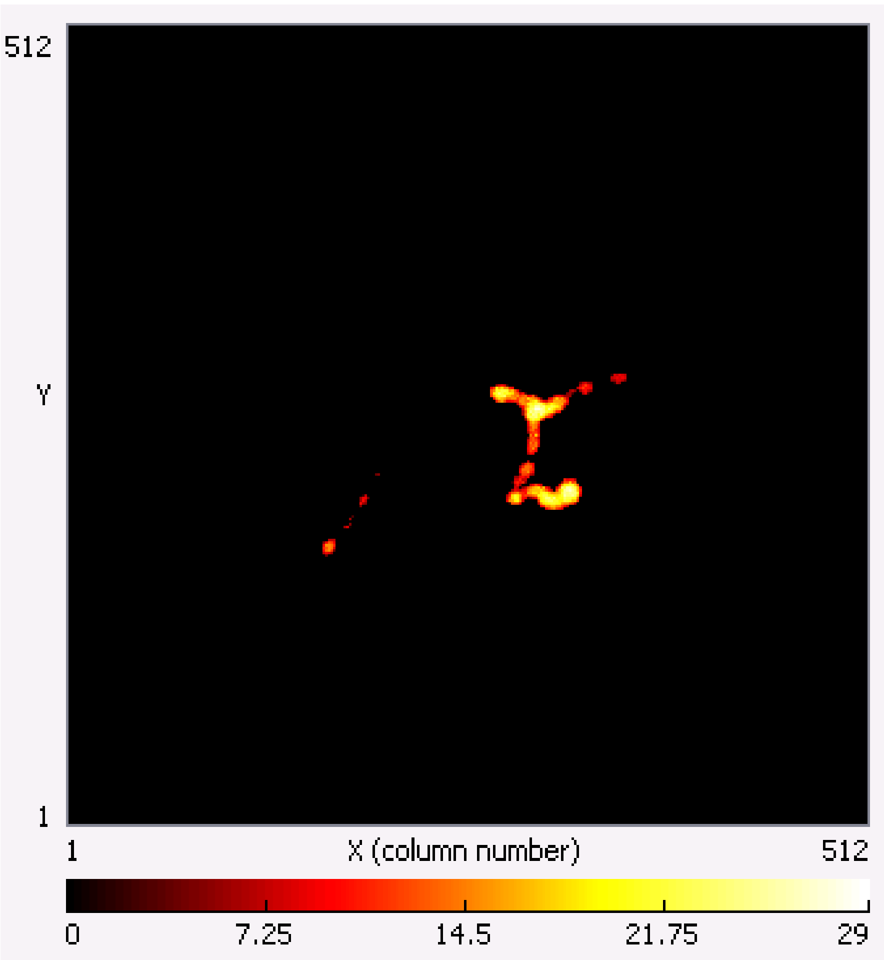


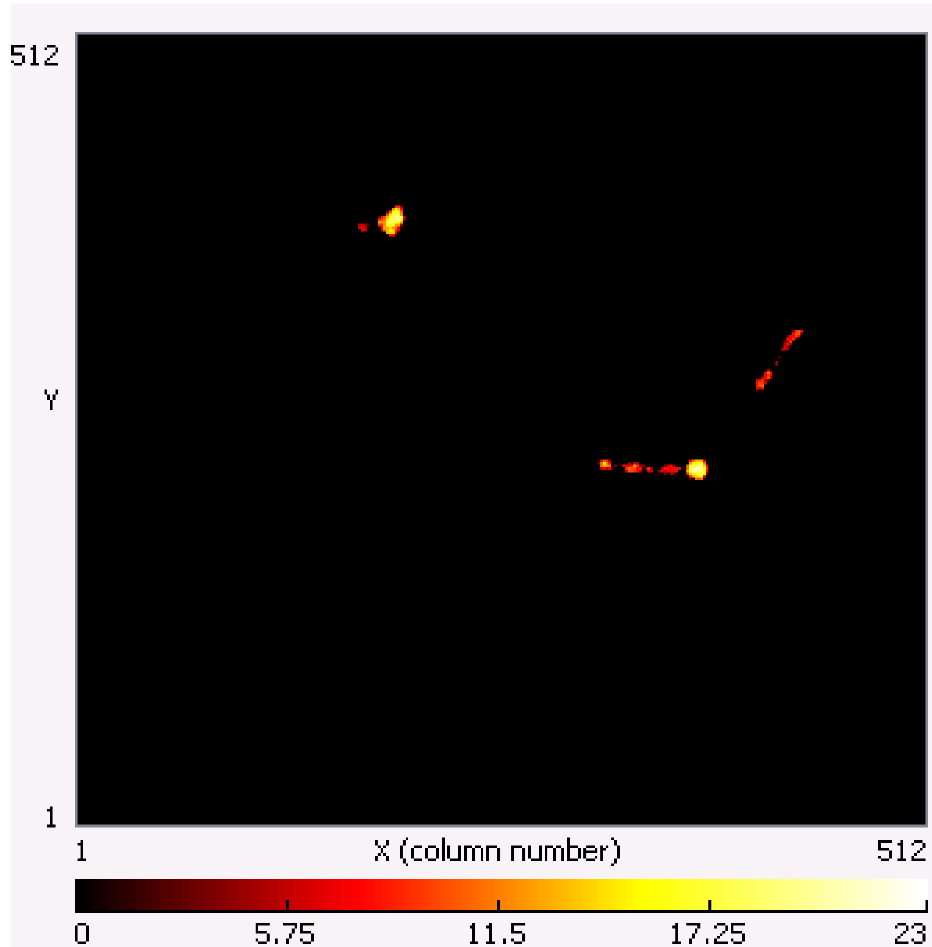
3 cm

With this type of gas mixture to high diffusion

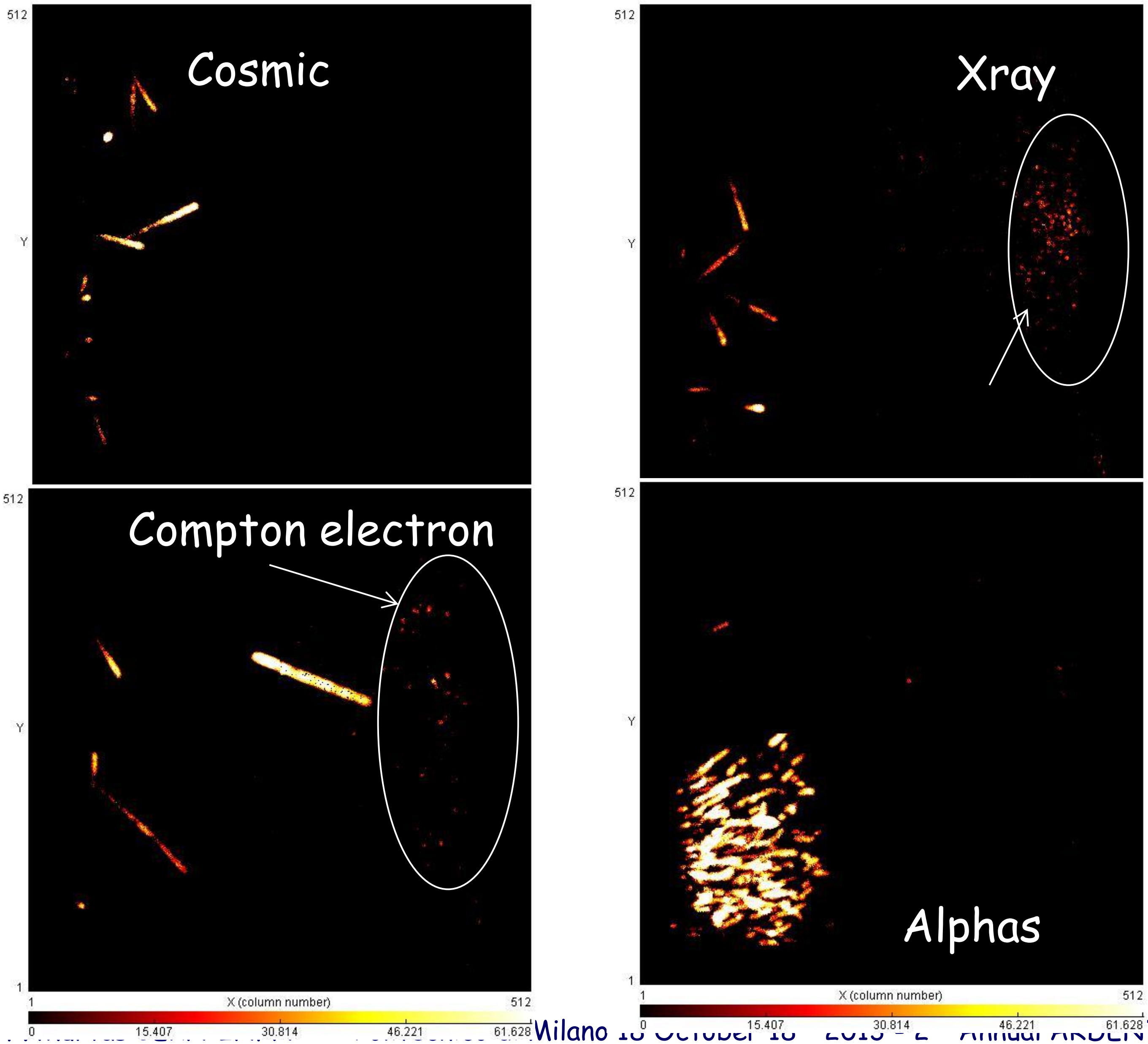
Other gas mixture : AR CO_2 CF_4

Compton electrons from ^{60}CO source (@1220 V)





Signals from radioactive source

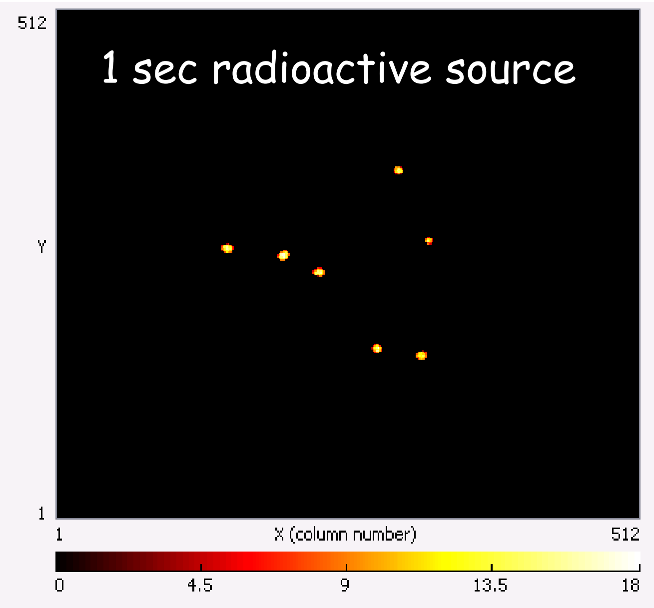


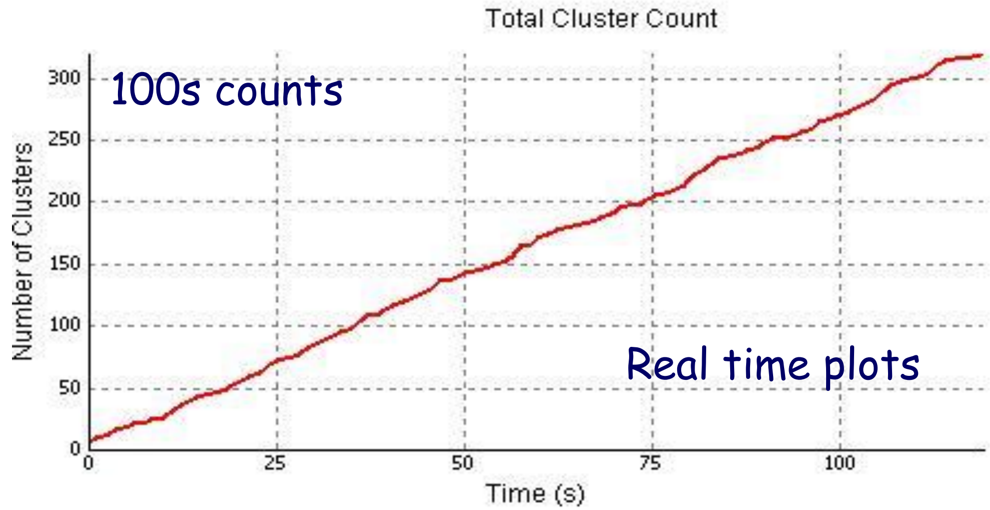
These pictures were taken with radiactive sources of ^{55}Fe Cesium and Americium

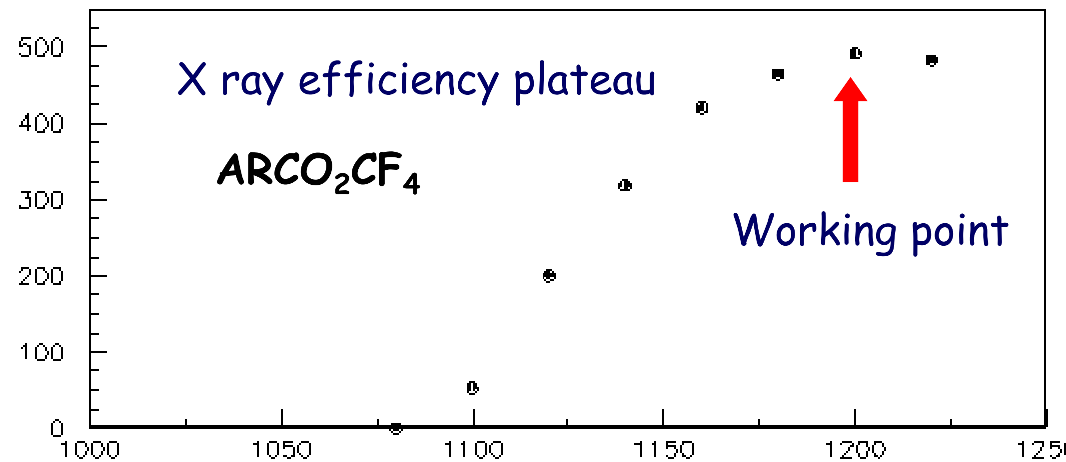
Using a gas mixture of $Ar/CO_2/CF_4$ 45/15/40

With a gain of 6000 and an induction field of 2 kV/cm

Cluster counting ^{55}Fe





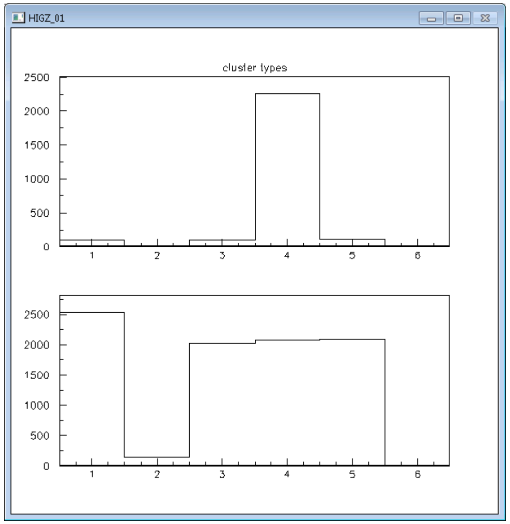


With this device it is possible to use all the patern recognition already developed for medipix by Praga group.

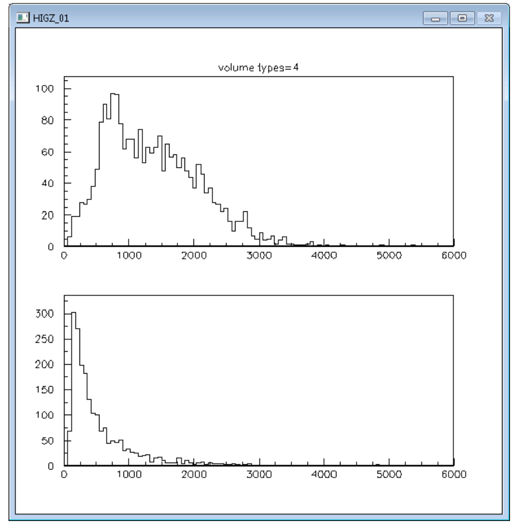
With timepix3 will be possible the 3D track reconstruction and dE/dX measurements at the same time

Cluster Analysis Xray(^{55}Fe) vs Gammas (^{60}Co)

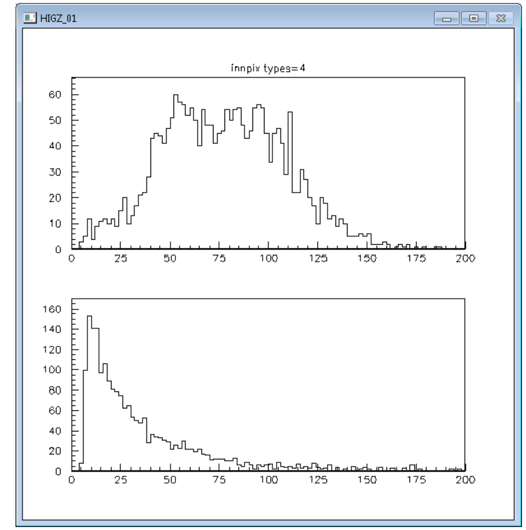
Cluster type

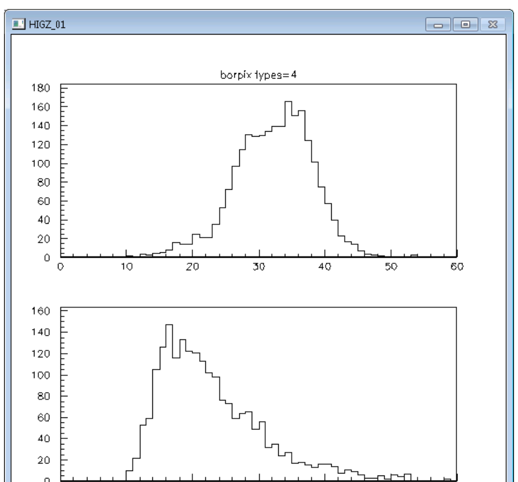


Cluster volume

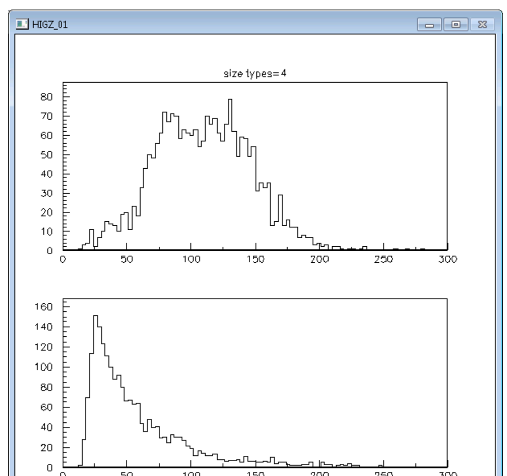


Inner size

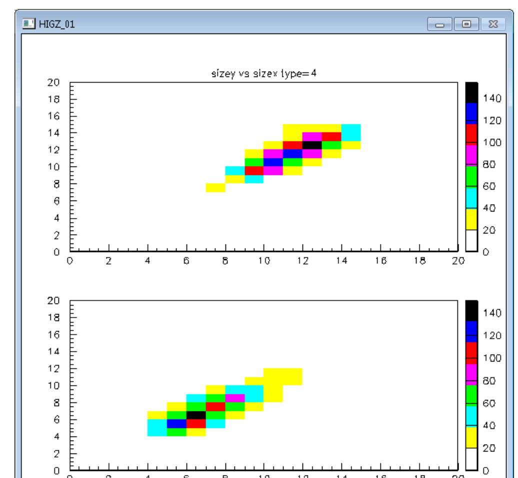




Border size



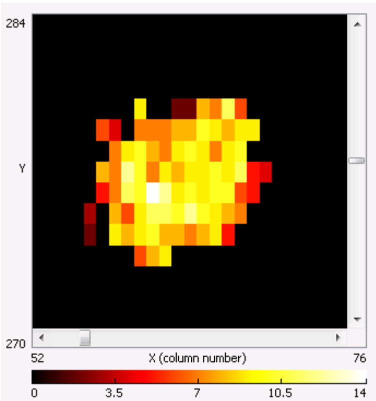
Size

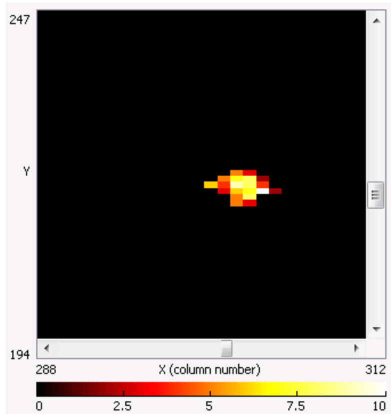


Size y vs size x

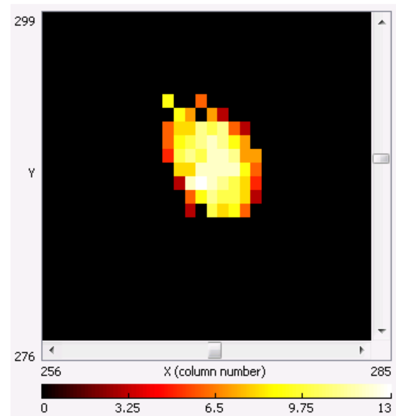
Detailed energy deposition

Cobalt (compton electron) 1100V

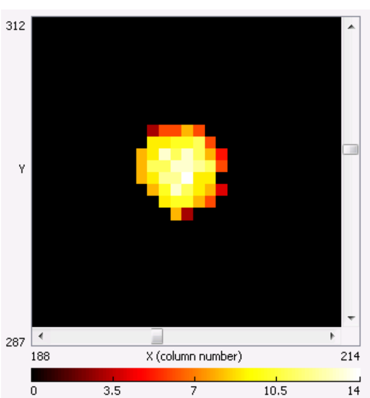


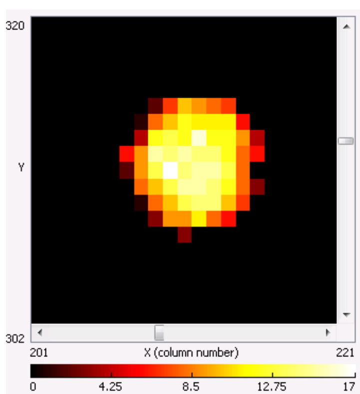


1120V

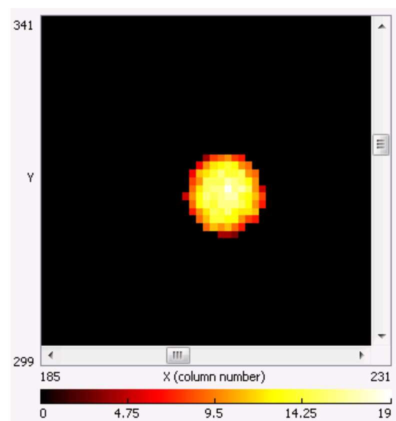


X Ray 1100V





1160V



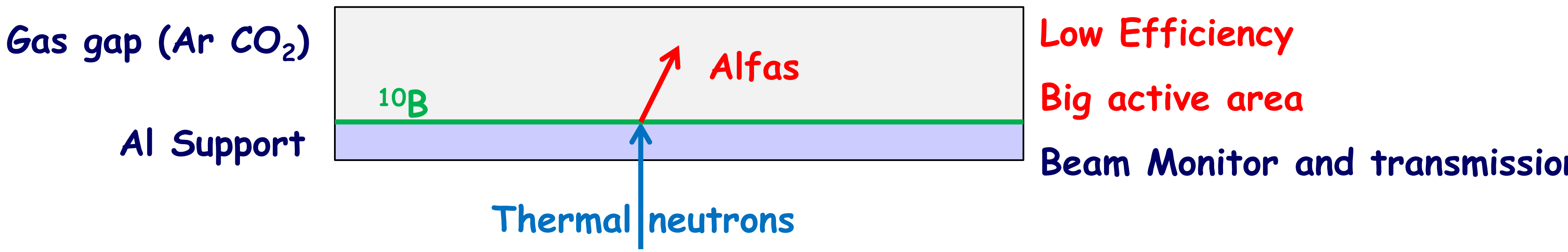
Still a lot of work to do .... but a really promising detector

Summary

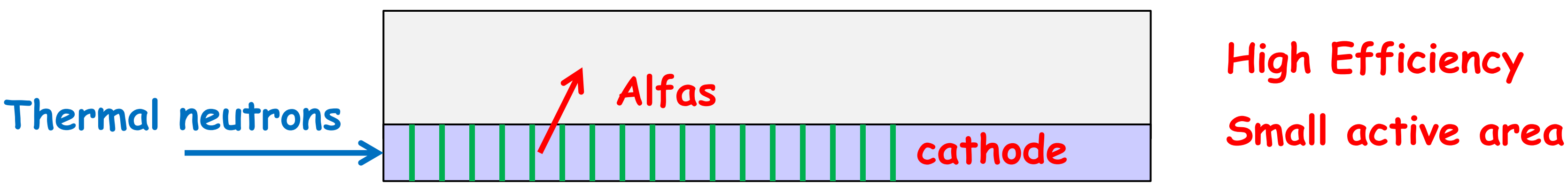
- ✓ The triple GEM tecnology is very relayable and usefull for different applications in different science and technology fields;
- ✓ Particular interesting the dosimetry thanks to the high dinamic range
- ✓ We developed a compact and complete system
- ✓ The FPGA based Mather Board semplifies the Data Acquisition and the HVGEM allow a very fine tuning of a GEM detector.
- ✓ Two GEMpix detector have been built and they show good performances in cluster analysis also thanks to the Fitpix software pakage
- ✓ Other software tools and detector tuning need for the cluster analysis in gas (dE/dX, particle id, 3D track reconstruction....)
- ✓ Another GEMpix will be mounted for the studies of interaction of particles with real tissue samples

^{10}B Cathode for thermal neutron

Thermal Neutrons interact with ^{10}B, and alfas are emitted entering in the gas volume generating a detectable signal.



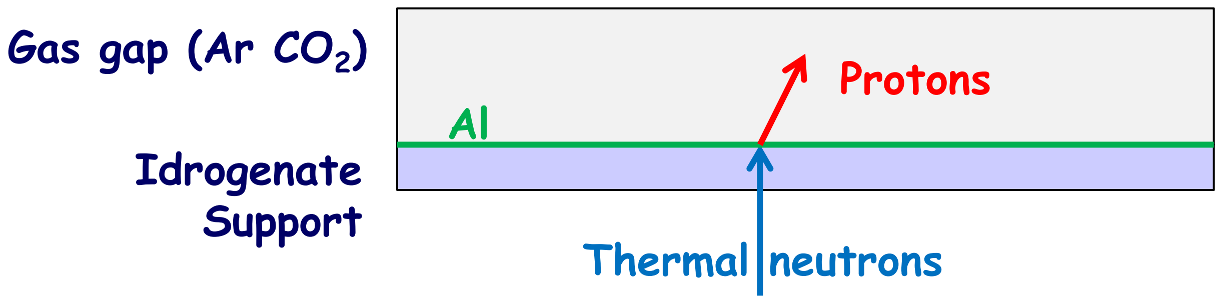
Side-On detector



Actually 4% efficiency … working to obtain 70%.
Good candidate as ^{3}He replacement detector

Polyethilene for fast neutron

Fast Neutrons interact with H, and protons are emitted entering in the gas volume generating a detectable signal.

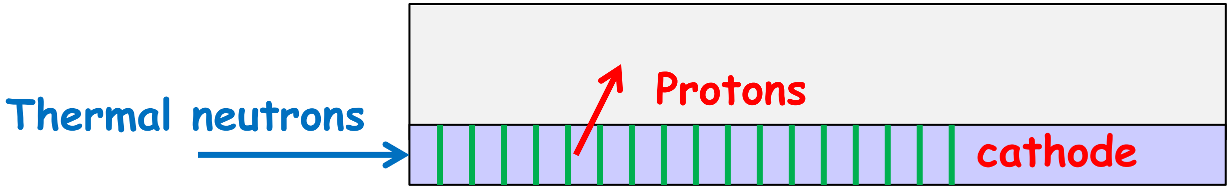


Low Efficiency

Big active area

Beam Monitor and transmission

Side-On detector



High Efficiency

Small active area

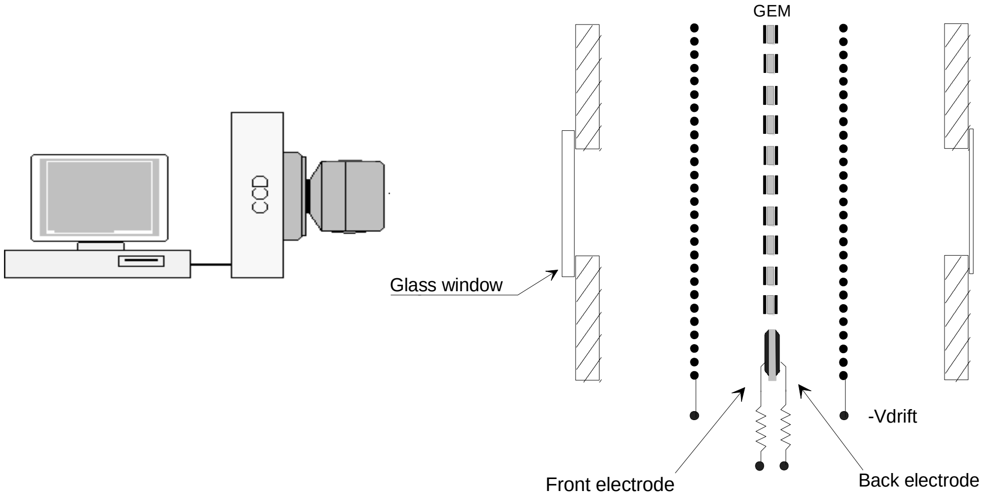
Actually 0.1% efficiency ... working to obtain few %.

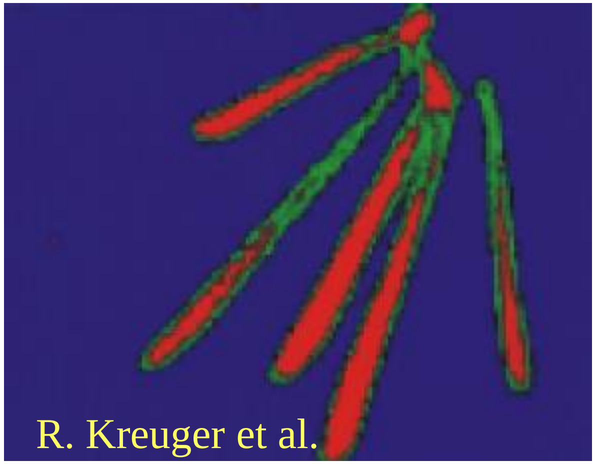
GEM and CCD Cameras

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.

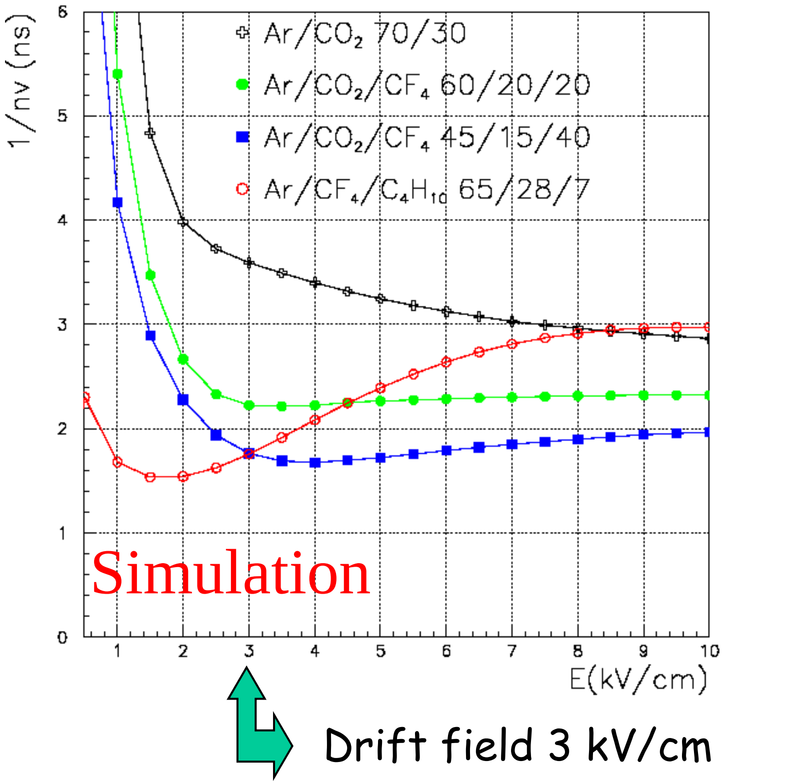
The light was produced using a triple GEM and measured with a CCD camera

The range is 3.4 cm.

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.

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.