Developments of Advanced Detectors for Radioprotection and Radiation Dosymetry

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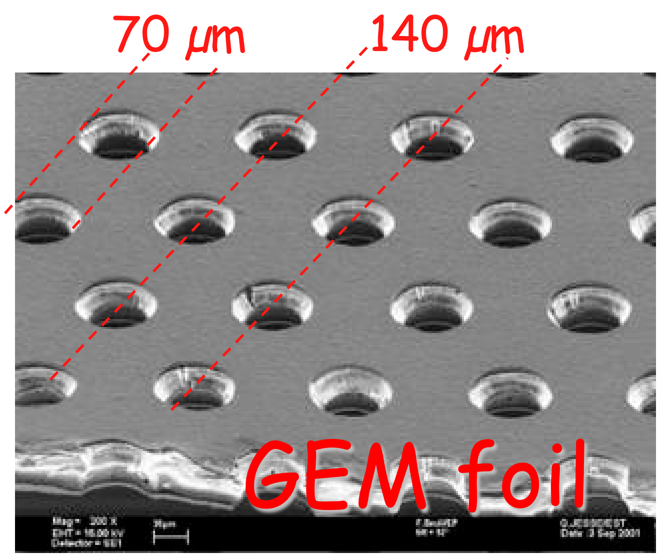
ARDENT Marie Curie ITN Project

- Application fields with GEM detectors
- A portable system
- Gamma and XRay detectors
- Beam monitor for Hadrotherapy
- GEMPIX for microdosimetry
- Conclusions

A triple GEM Chamber

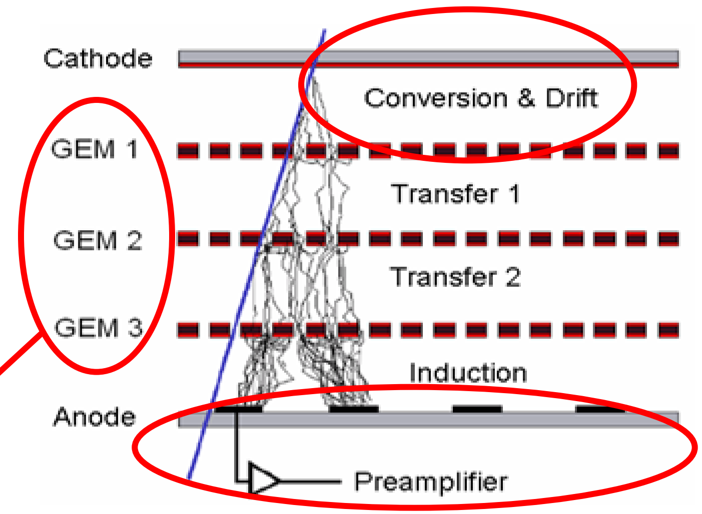
A Gas Electron Multiplier (F.Sauli, NIM A386 531) is made by 50 μm thick kapton foil, copper clad on each side and perforated by an high surface-density of bi-conical channels;



A GEM detector has the three function

Conversion, Amplification, & Readout

well separated and decoupled



Working with different levels of gain it is possible to obtain high level of particle discrimination

Radioprotection and Dosimetry with GEM

Low energy Xray

Radioactive waste
Xray immaging

Fast and Thermal Neutron
Neutron monitors

Neutron production in hadrotherapy

Pixelated GEM

Microdosimetry
Tissue Equivalent chamber
Direct measurements with real tissue
Radon Monitor

Gamma High fluxes

Radiotherapy

High Intensity Beam Monitors
Hadrotherapy
Ions Beam Monitor

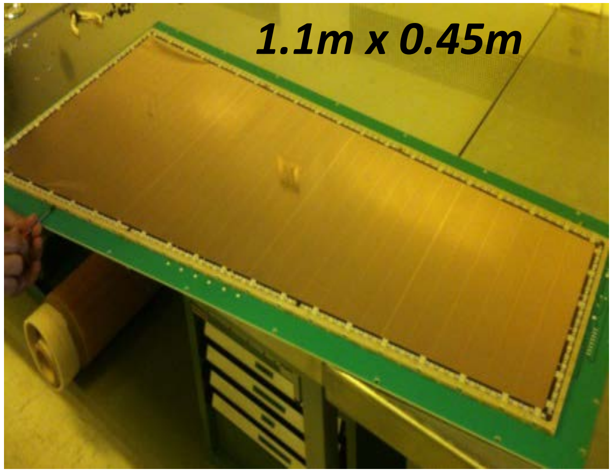
But you need a portable system ...

Different shapes and dimension

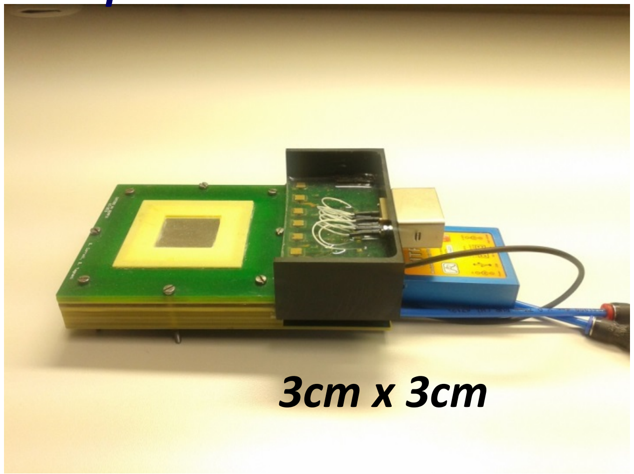
In 15 years of R&D different detectors have been built in shapes and dimensions

Cylindrical GEM tracker

CMS chambers



GEMpix



Several GEM detectors in construction
both for HEP and for industrial and medical applications

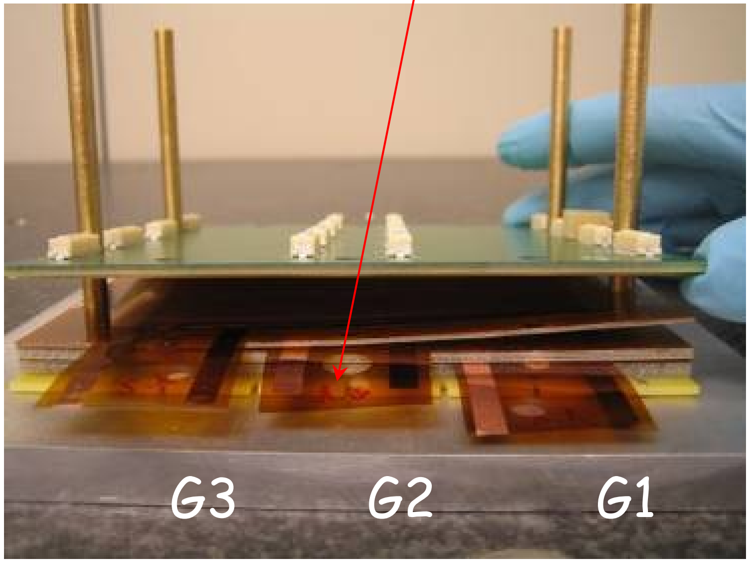
Why GEM Detectors ?

GEMs offer the following advantages :

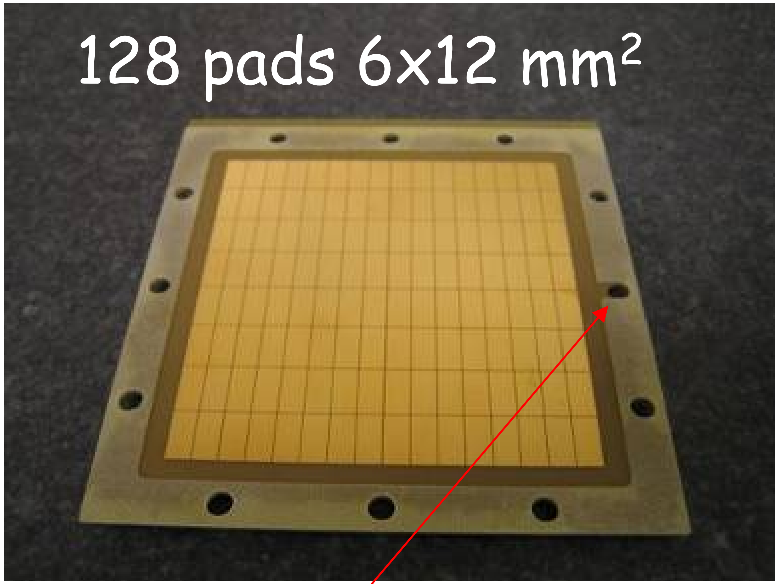
- Sensible to single particle
- Very high rate capability (few MHz/mm^2)
- Submillimetric space resolution (50-200 μm)
- Time resolution from 5 ns
- Possibility to be realized in large areas and in different shapes
- Radiation hardness and very low discharge probability
- Insensitivity to gamma rays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

A Sealed Triple GEM construction

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



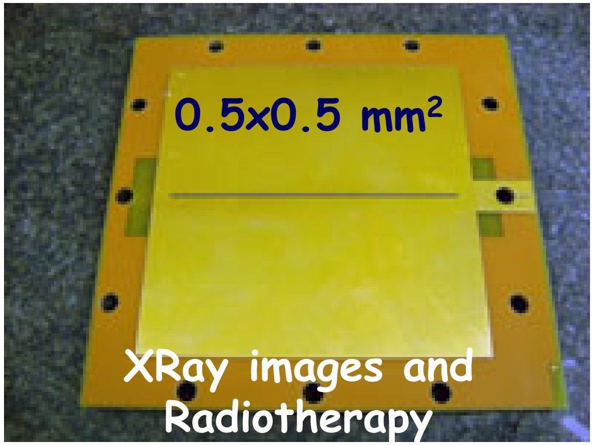
The GEM are stretched and a G10 frame is glued on top

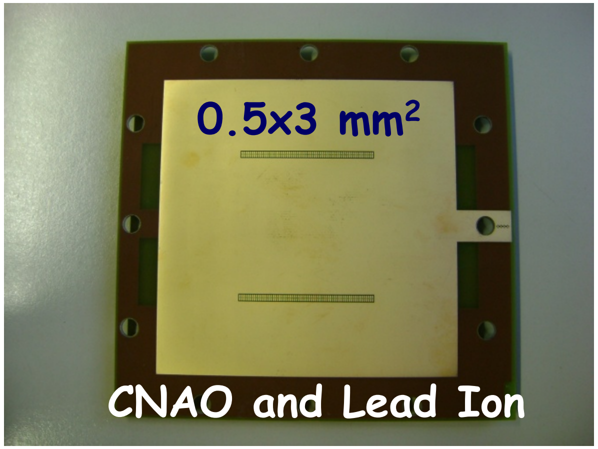


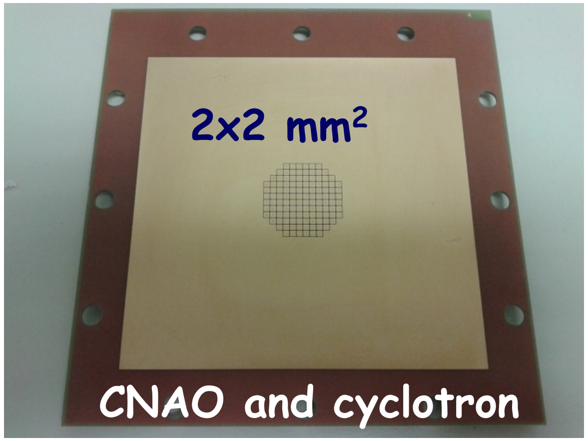
The frame for the G3 foil has been modified for the gas inlet

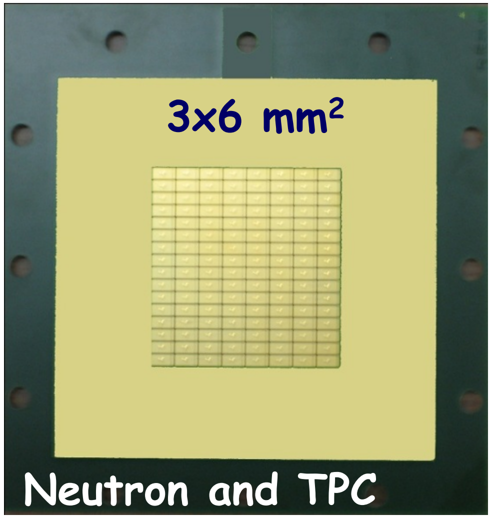
Pad readouts

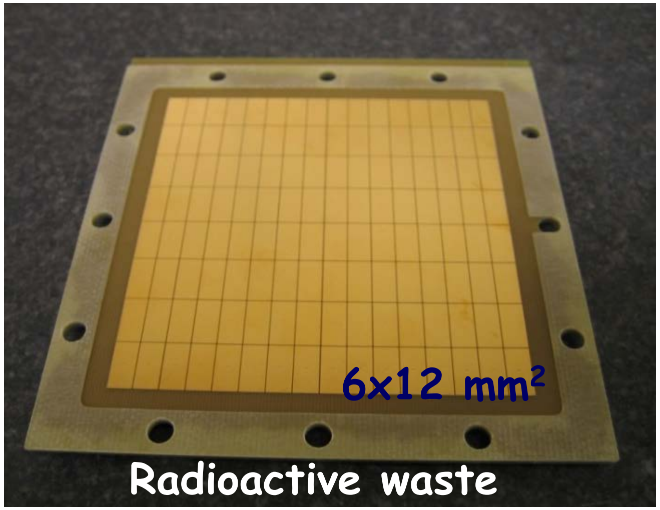
Different pad geometry but always with 128 channels

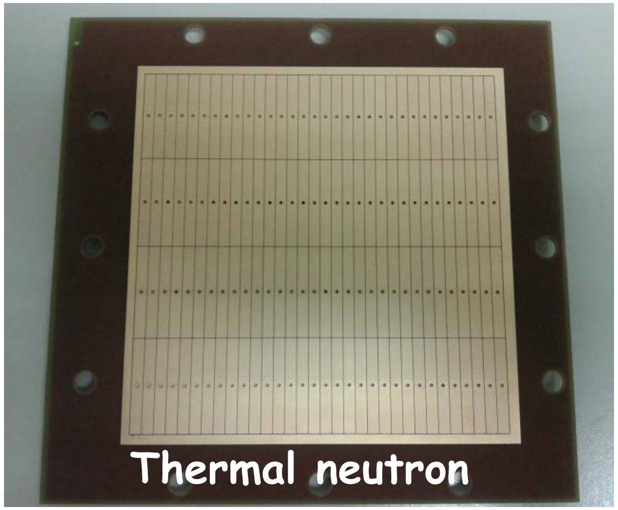








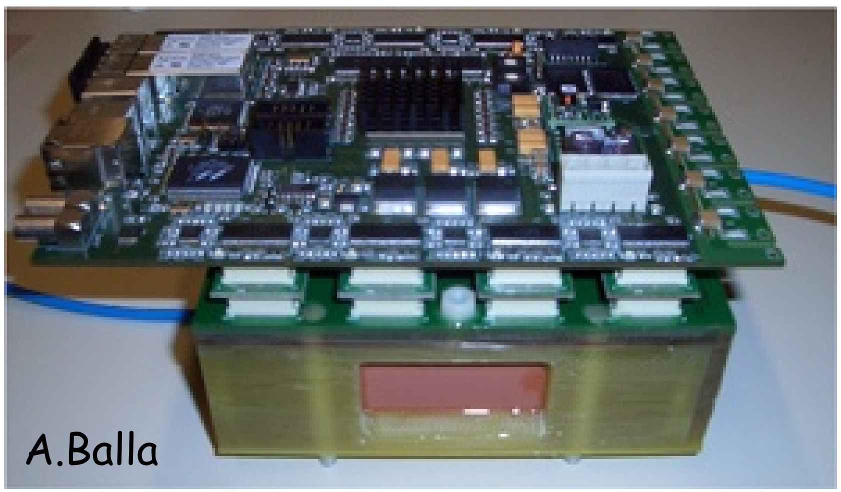




DAQ System and HV Power Supply

Two important devices have been developed in Frascati during 2010 :

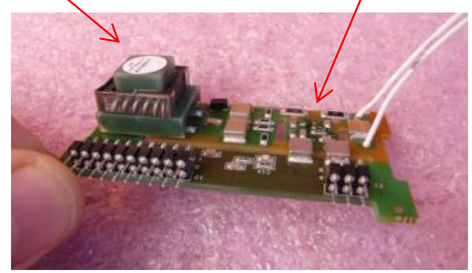
A compact DAQ board, FPGA based :
with 128 Scalers readout and
with 128 TDC channels



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

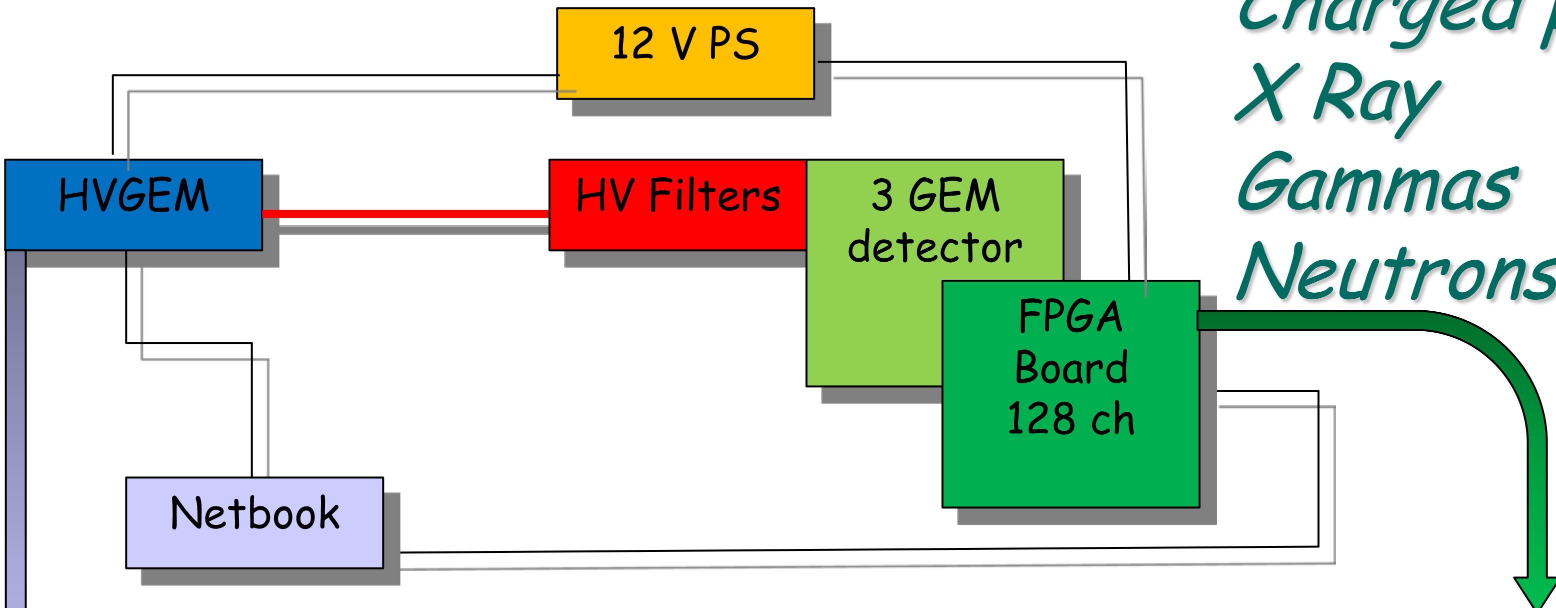
HVGEM : a power supply for
triple GEM detectors:
7 HV channels (0.5 V ripple)
with 7 nano-ammeters (10 nA)

HV Generator Current Sensor

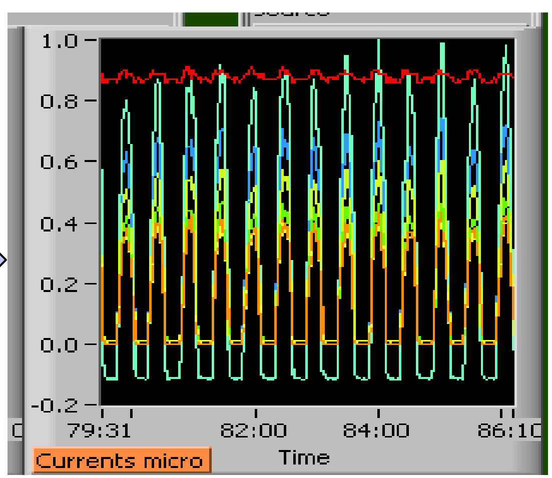


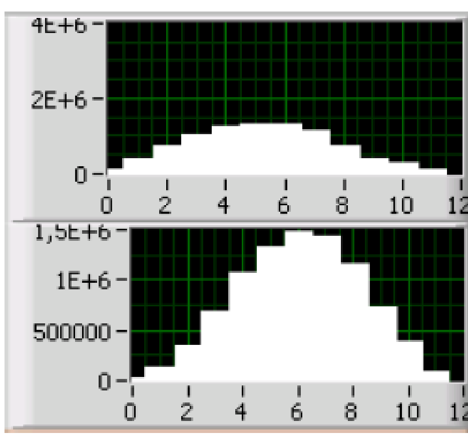
Two slot NIM Module CANbus controlled
(made by MPelettronica)

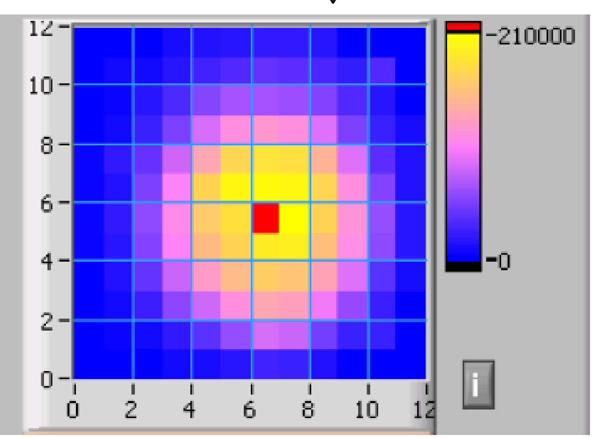
A triple GEM detector system



Charged particles
X Ray
Gammas
Neutrons



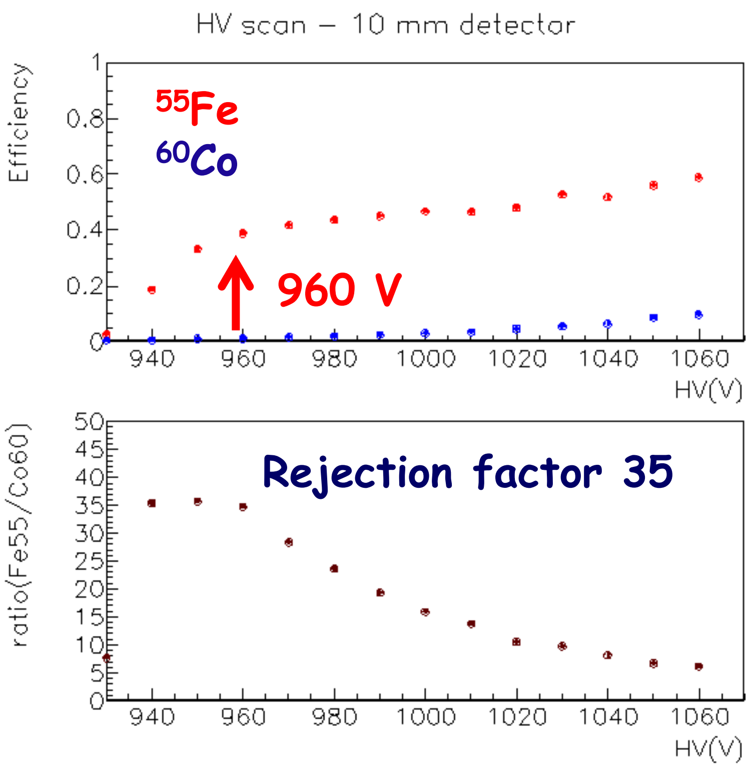


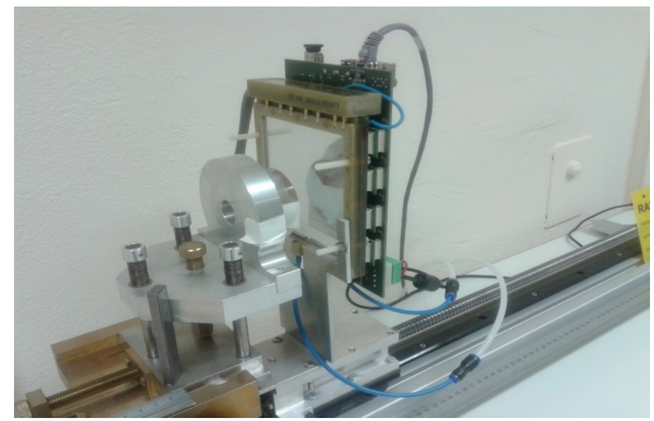


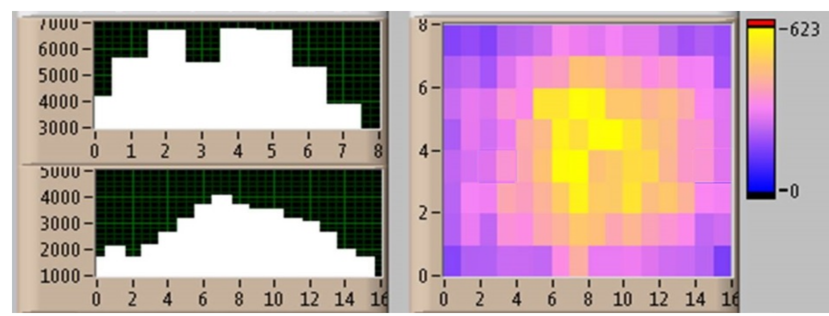
GEM Detector applications in dosimetry

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.





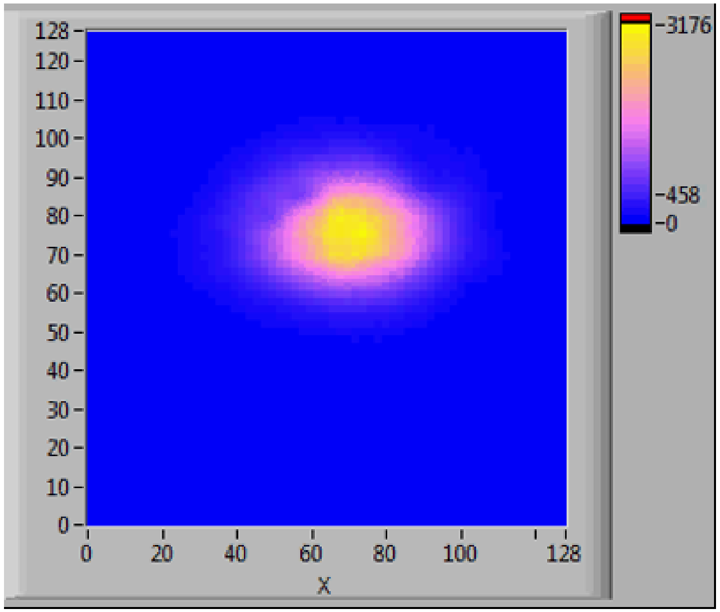


See S.Puddu talk

Capability to find out a radioactive hot spot

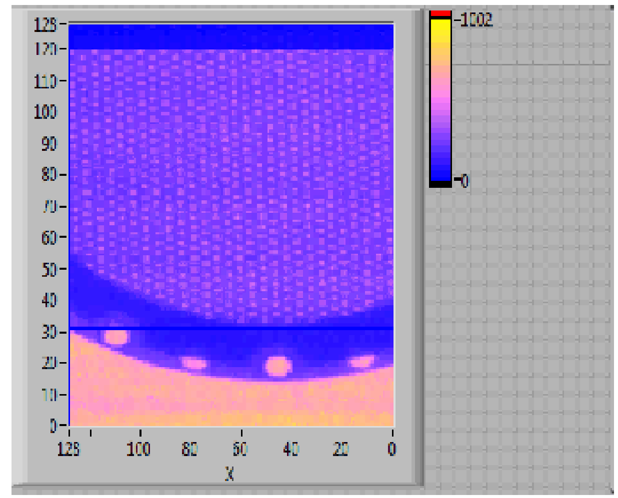
Low energy X-Ray Images with scan

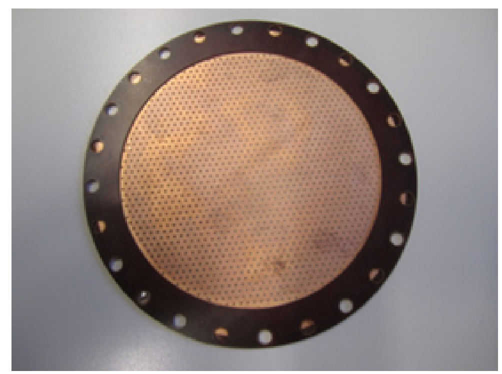
X-Ray beam of 6 KeV



Scan images
$9 \times 9\ cm^2$

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

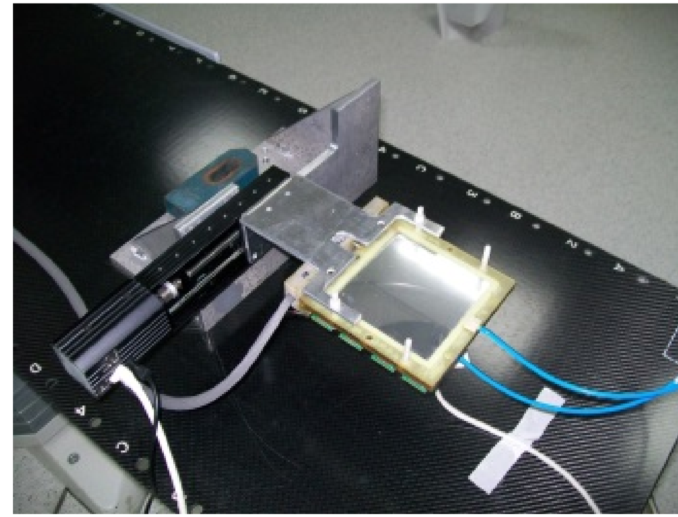




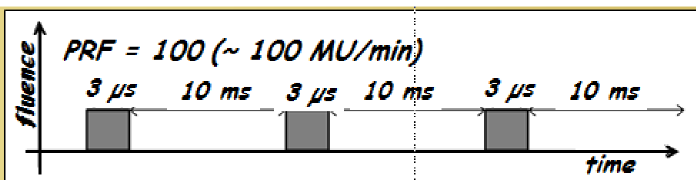
These images was realized in real time moving a triple gem with an array of 128 pads $0.5 \times 0.5\ mm^2$ crossing the beam

The detector is limitated by the electronics channel density

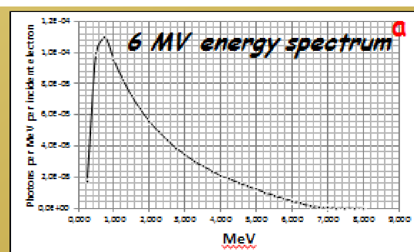
Gamma dosimetry measurements

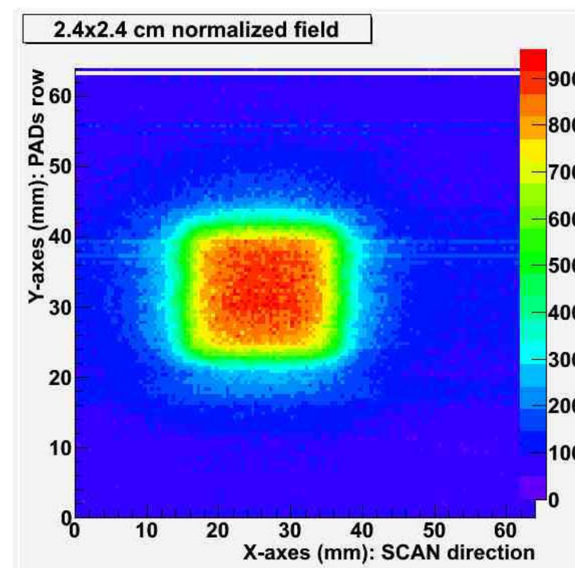


Gamma flux of 10^8 Hz/cm^2 6-1 MeV



Scheme of the beam flux pulsed time structure of the Elekta Synergy Linac at PRF = 100 MU/min.



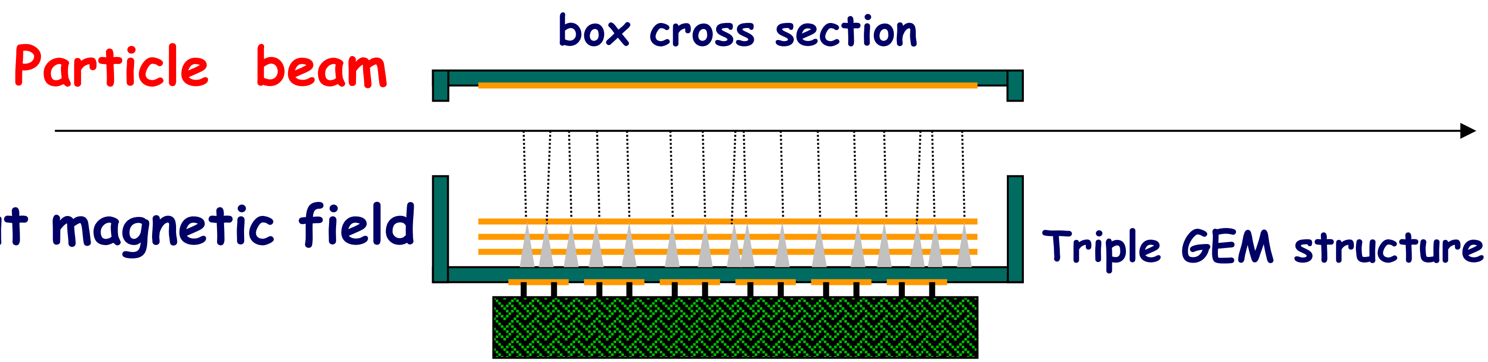


The flux of gamma in radiotherapy is composed by several 3 μs bunches

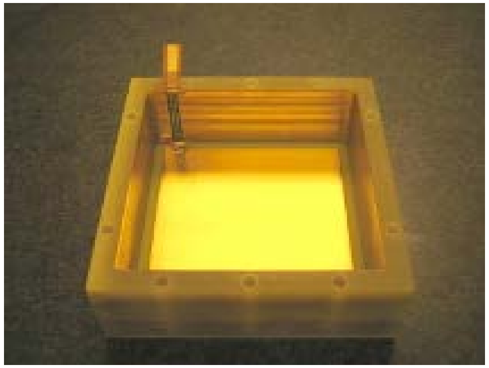
With a scan, a triple GEM with a row of 128 pad of 0.5x0.5 mm is moved crossing the beam. Each line is acquired in 200 ms

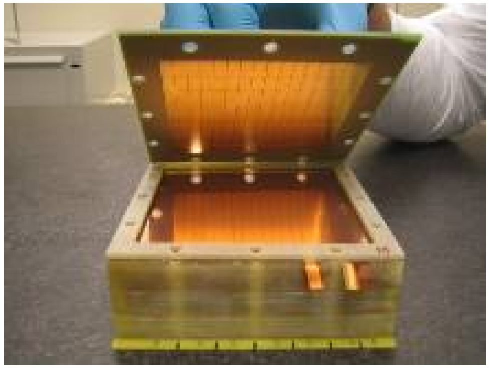
A Triple GEM beam monitor

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



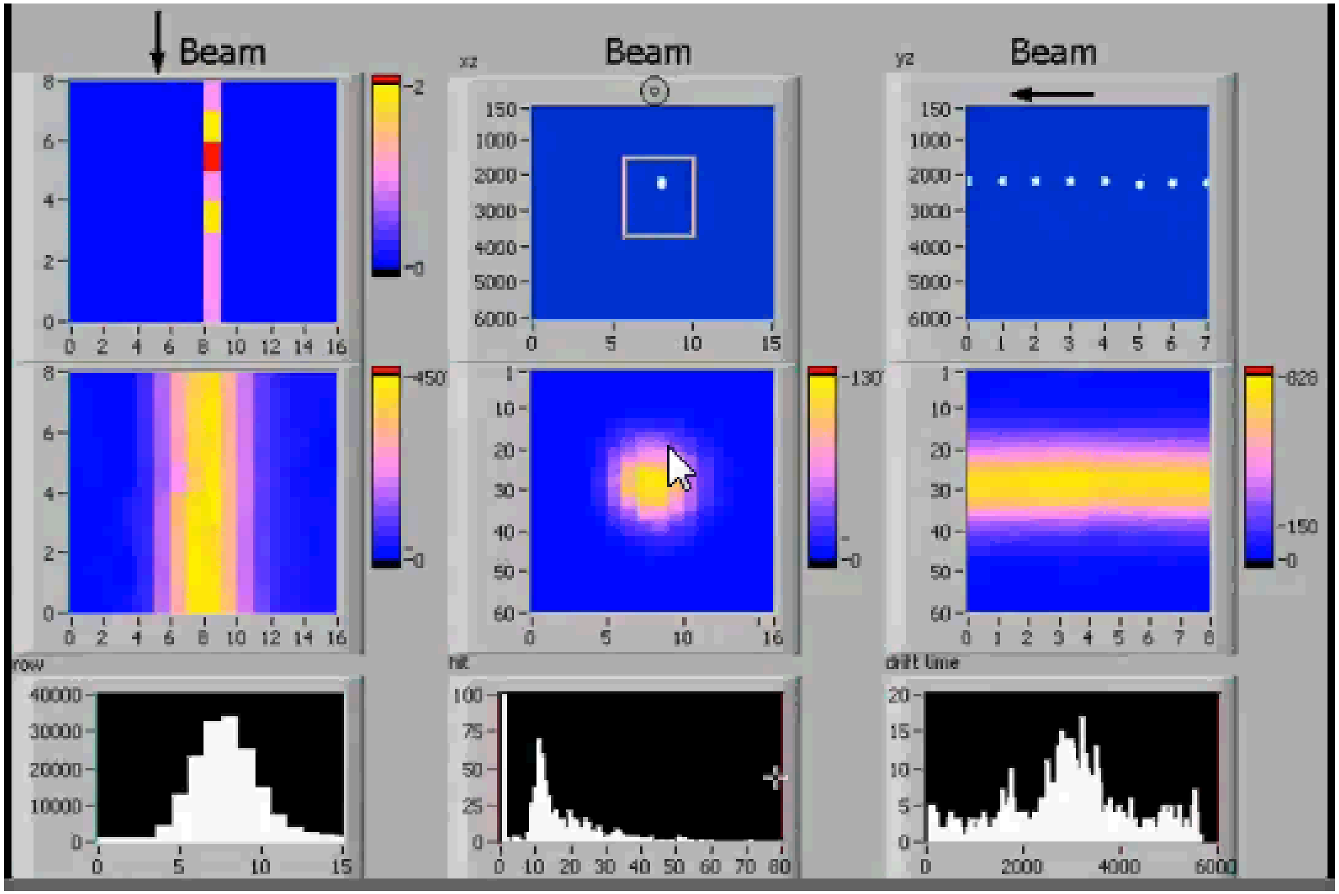
The material budget crossed by a particle is only two kapton foils ($<0.2\%X_0$) used for the field cage necessary for the drift field uniformity





Real time 3D track reconstruction

... thanks to a good efficiency ....



Single event

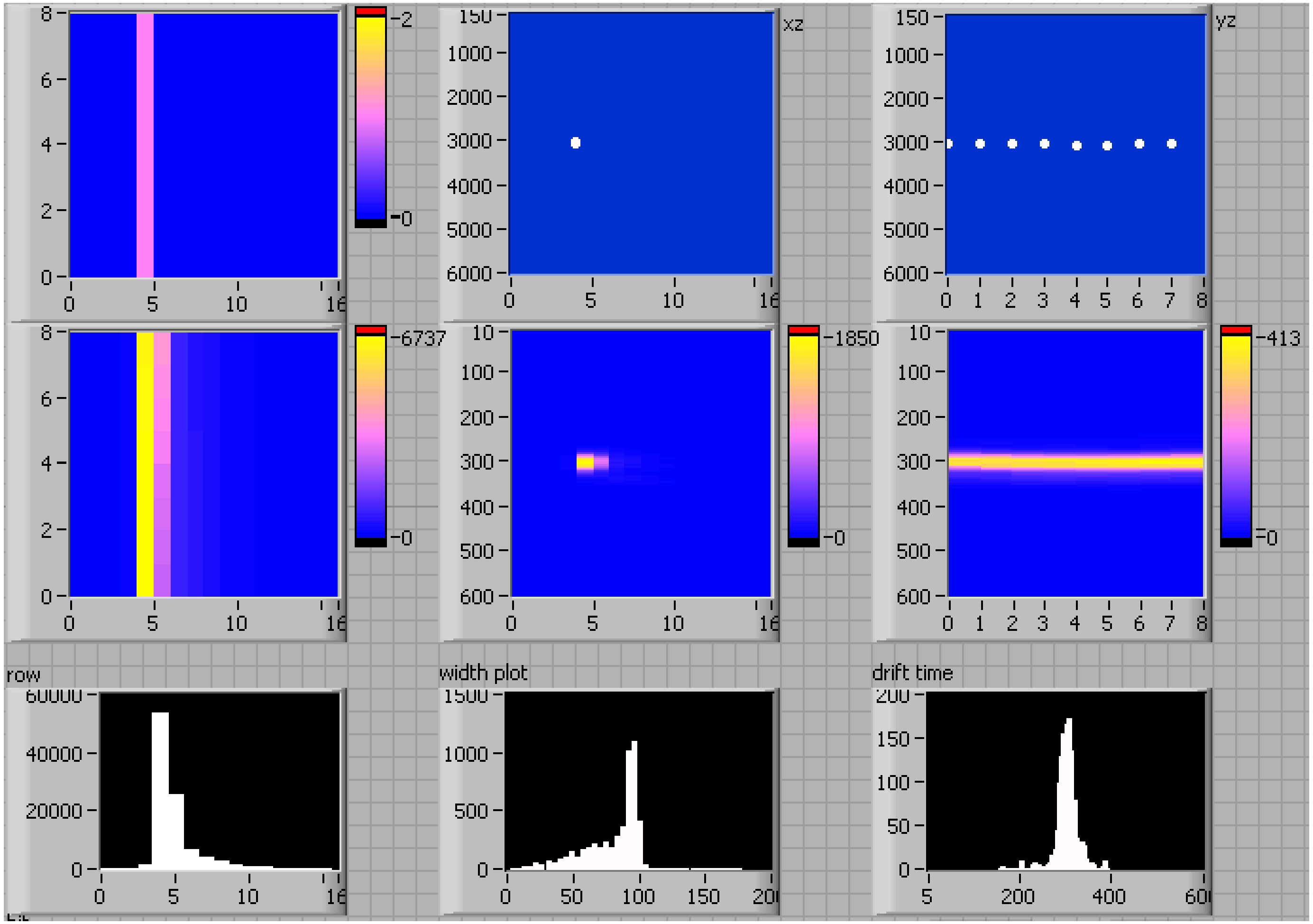
History

Profiles

This is a screen shot from real time console

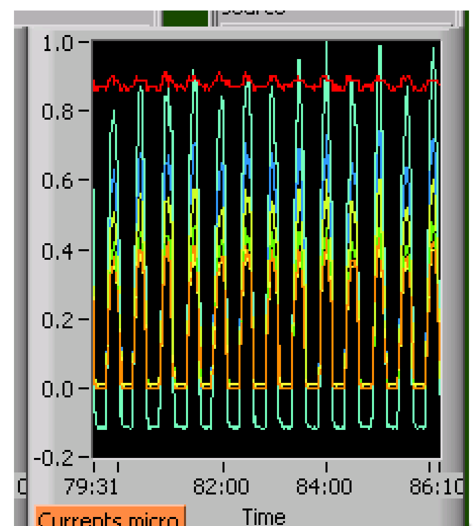
Lead Ions at CERN H8

The test was performed in November 2011



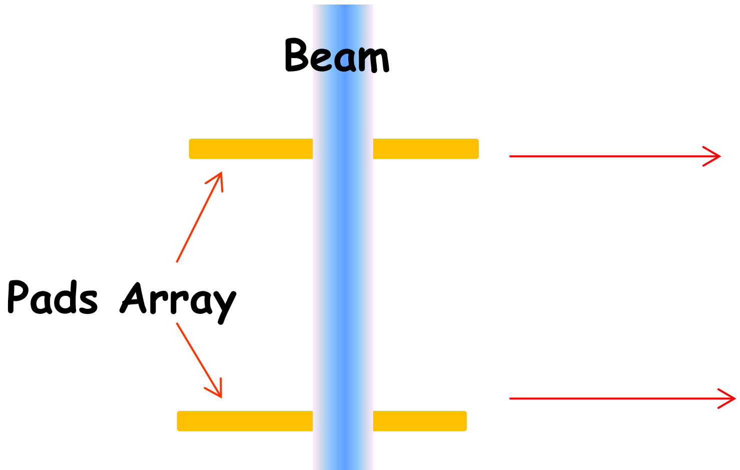
Real time
3D track
reconstruction

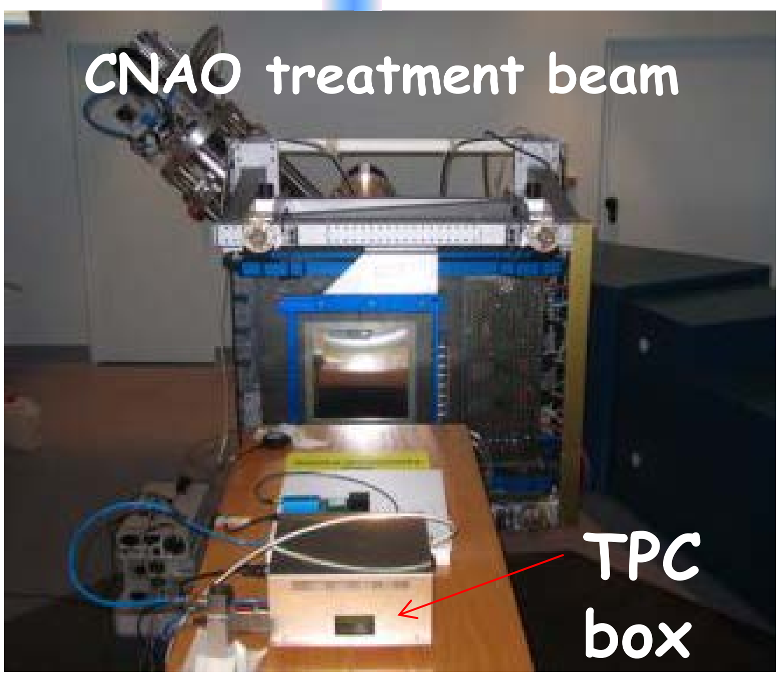
The ion beam is
spilled in 12-17 sec
(currents from HV)

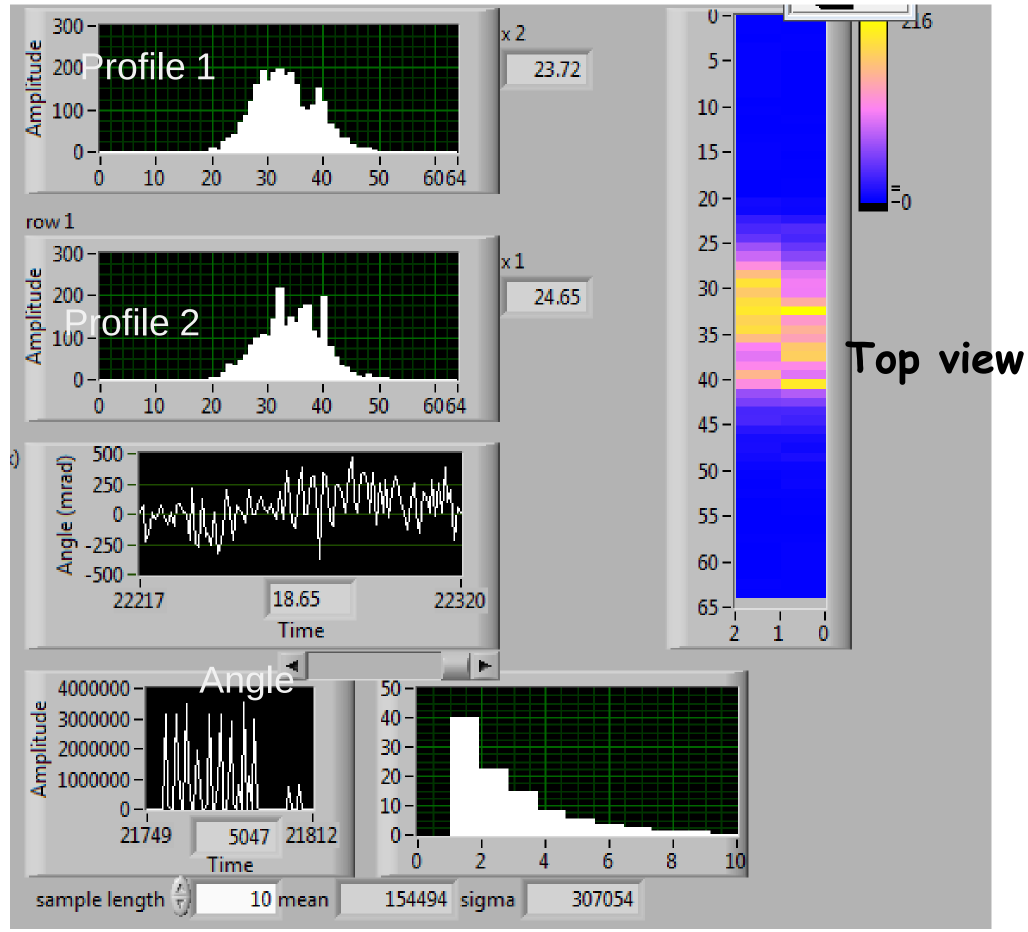


Test at CNAO: 10^8 protons/sec

Centro Nazionale di Adroterapia Oncologica (Pavia Italy)







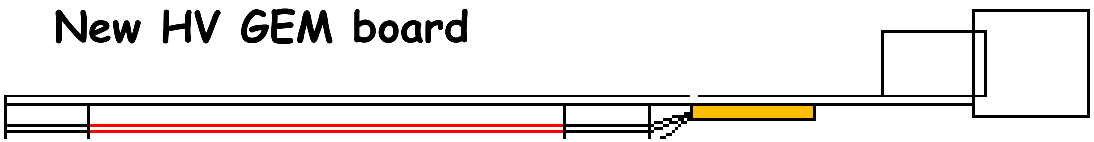
Issue of ion pollution …
studies with low pressure chambers ongoing

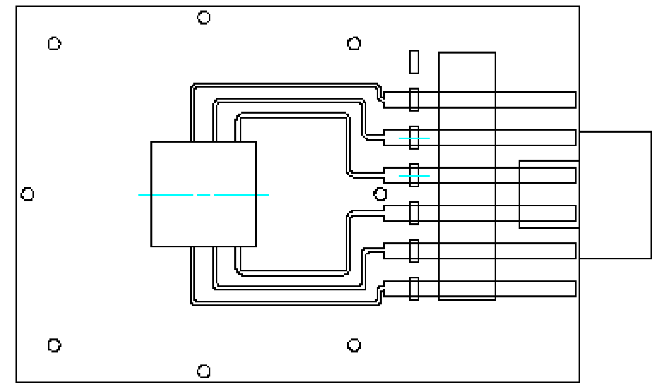
GEMPIX detector

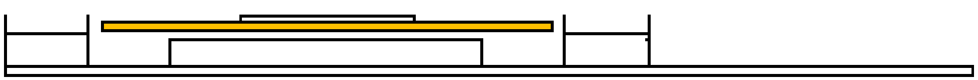
GEMpix Assembling

The detector has two main parts :
- The quad medipix with a naked devices
- The triple gem detector with HV filters and connector

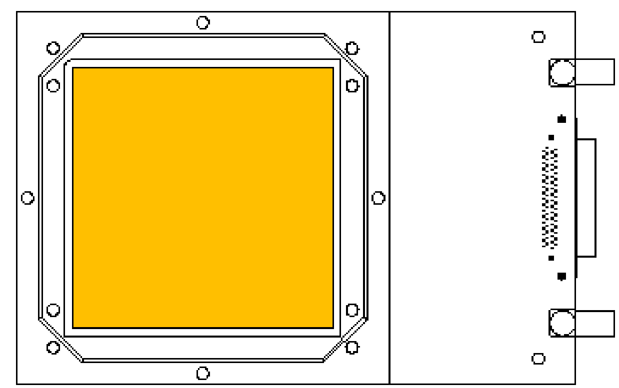
New HV GEM board







Quad medipix board

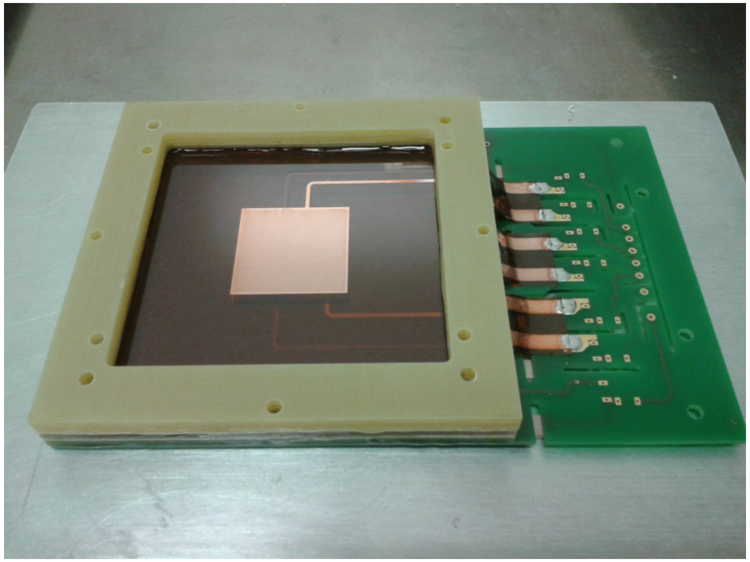


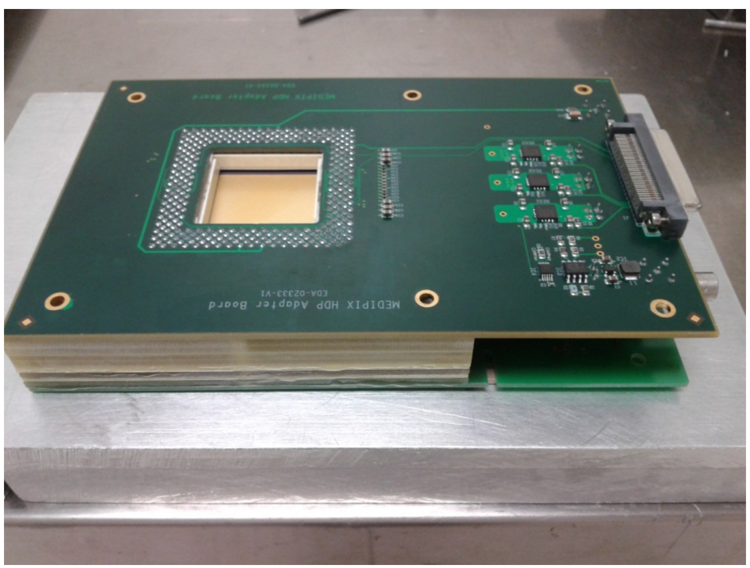
M.Campbell, J.Alzoy

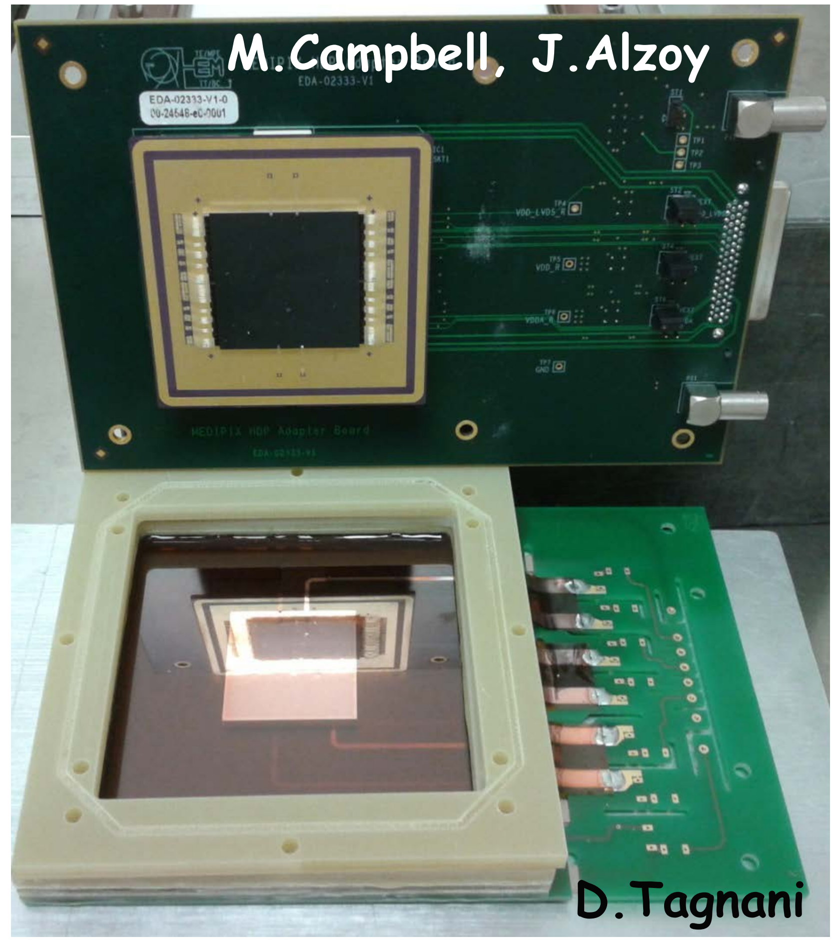
Top view

Final assembly

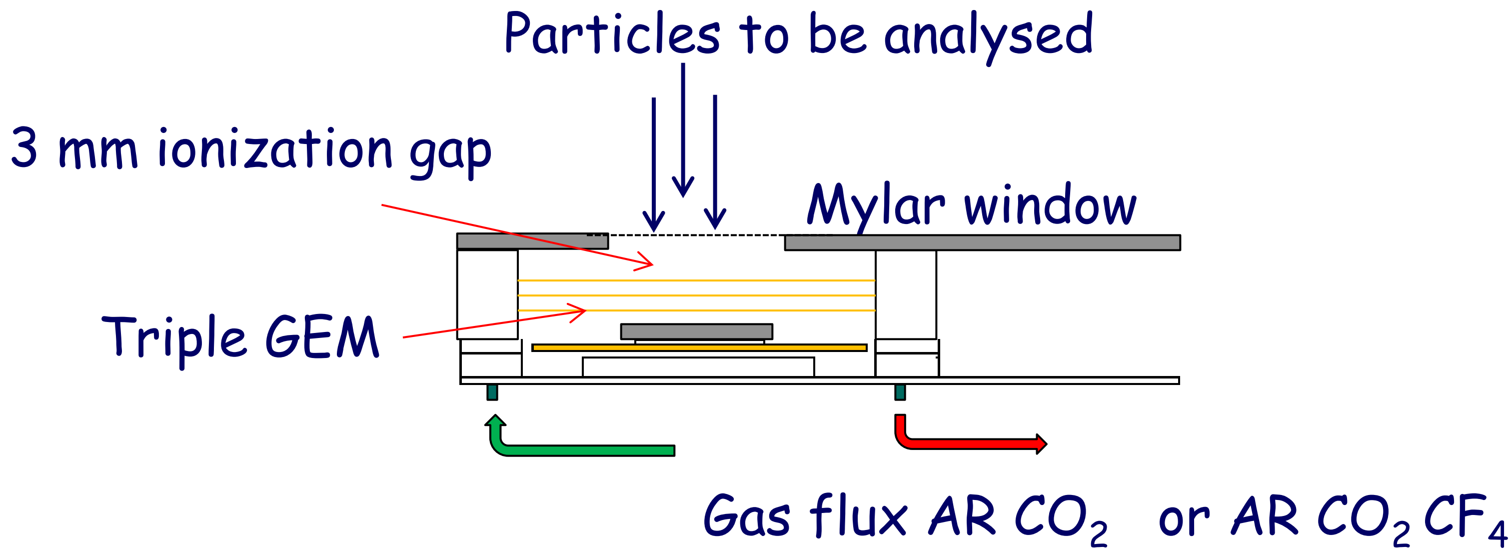
The detector could be open again
and the ceramic board with 4 medipixes
could be changed at any time







Head-on detector



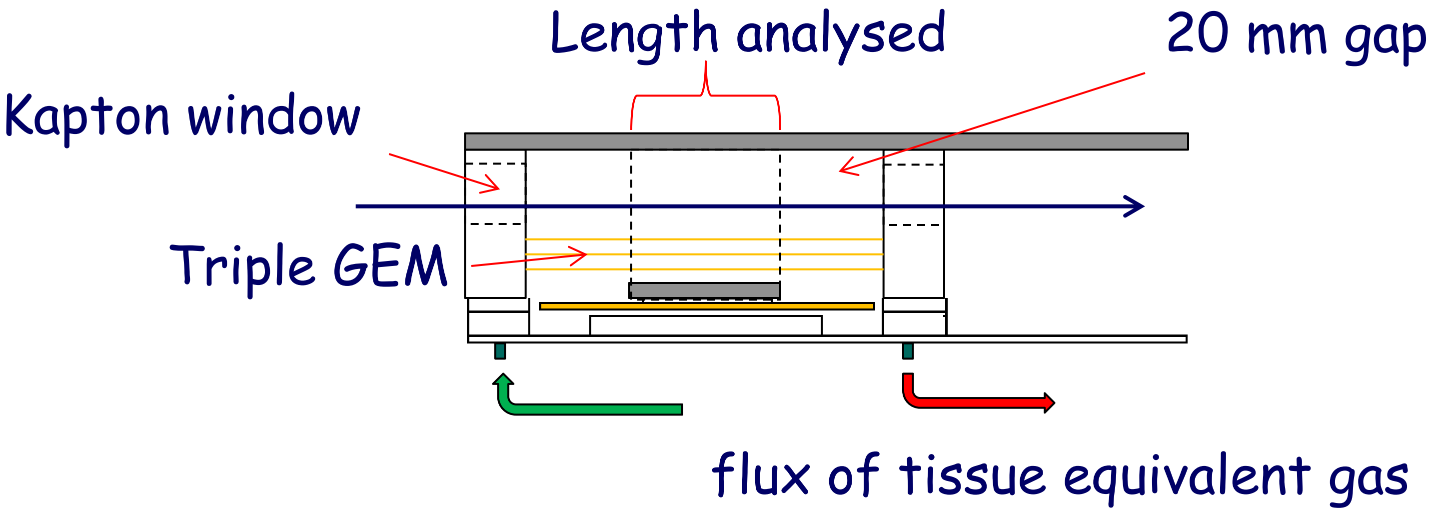
The readout is made by naked quad medipixes :
The active area is 9 cm^2 512x512 pixels 50x50 $microns^2$

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

But also for high intensity proton beam monitor in hadrotherapy
Reduced ion pollution … only 3 mm ionization gap
Tests at CNAO beam already scheduled

Detector for TEPC

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



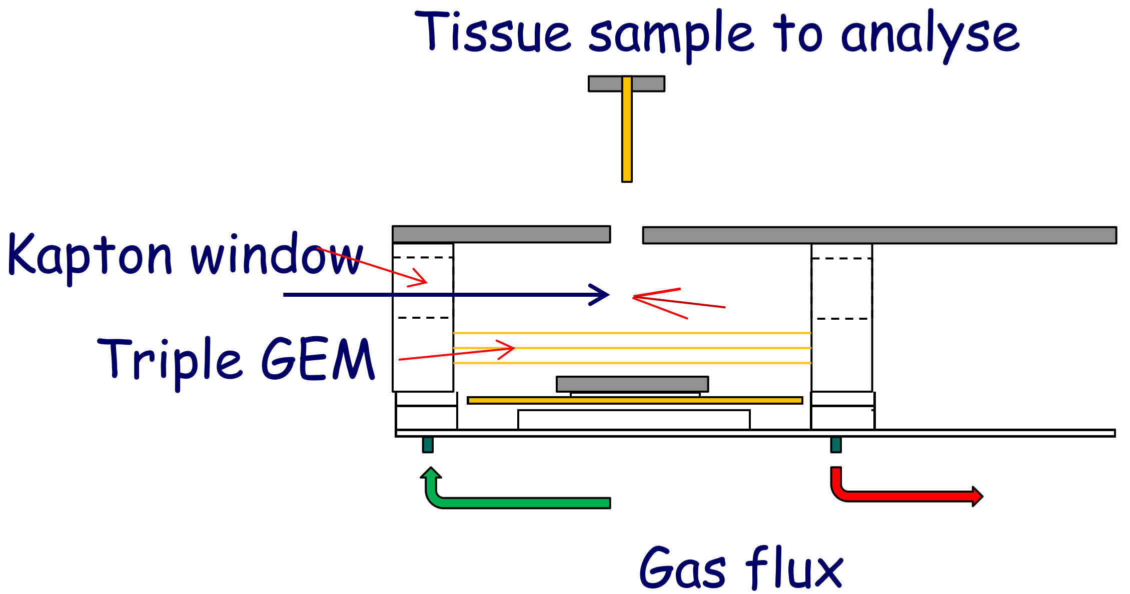
The particle track is analysed with 512 pixel in 3 cm length

This is equivalent to 30 microns of tissue … with 17 samples/per cell …

Really a new promising device for microdosimetry

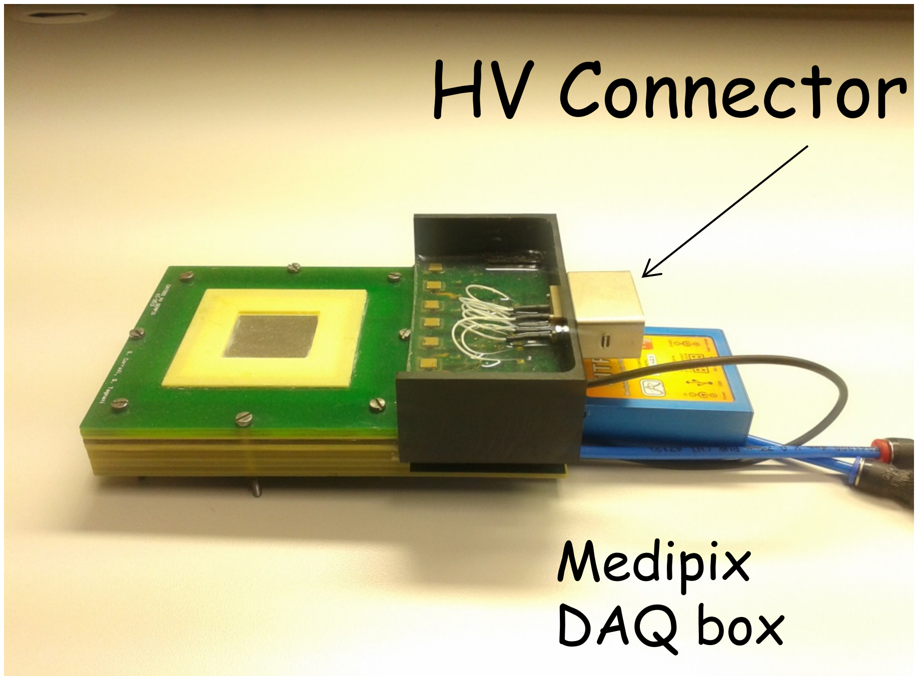
Detector for tissue sample

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

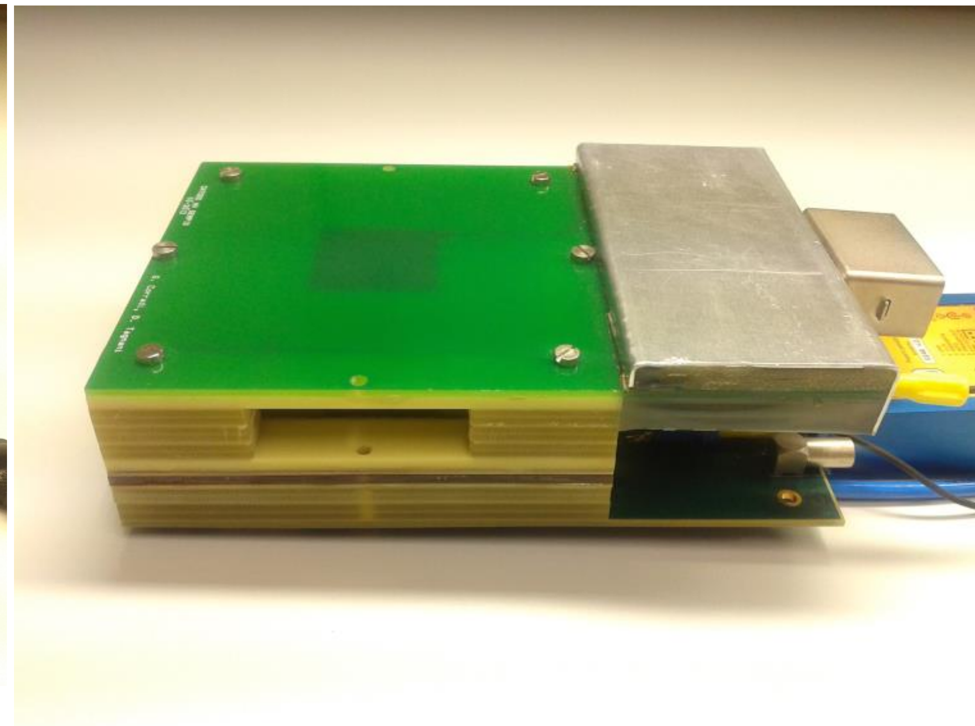


Capability of 3D track reconstruction of secondary products

Two prototypes of GEMPIX



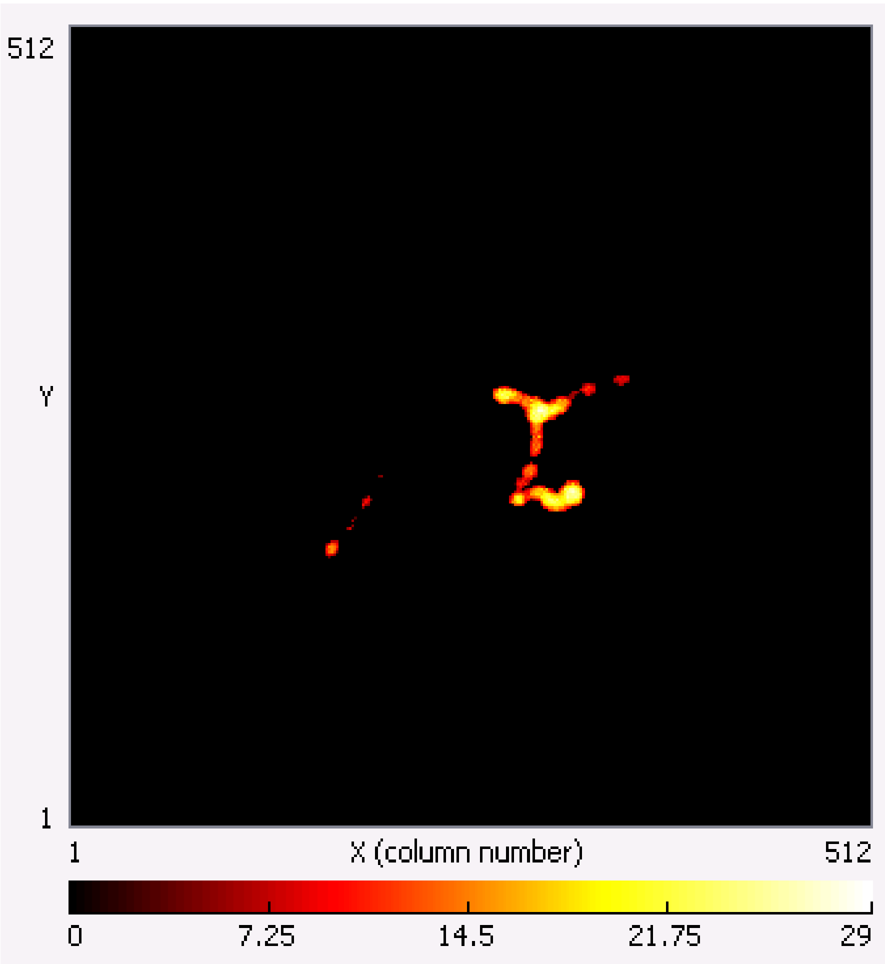
Head-on detector

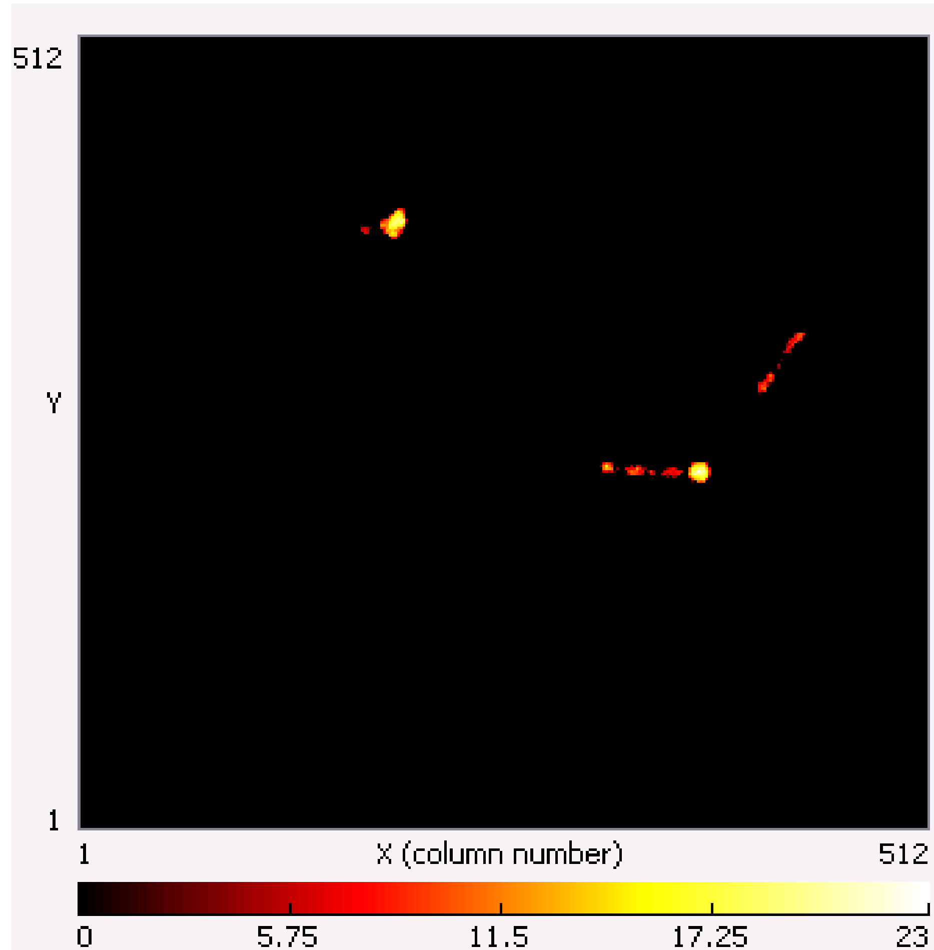


Side-on detector

Tracks on GEMpix

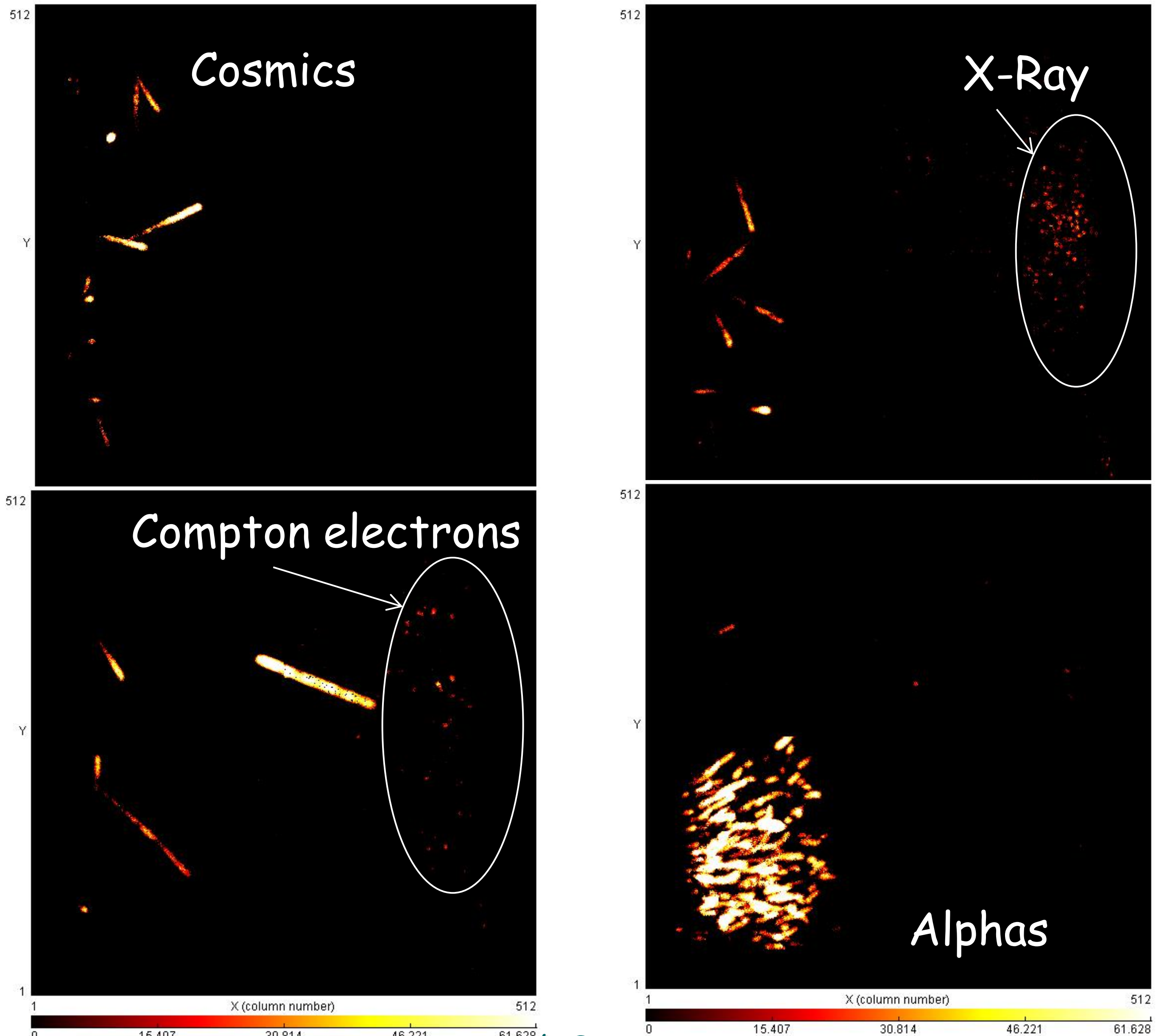
Compton electrons from ^{60}CO source 3x3 cm^2 images





3D track reconstruction

Signals from radioactive source



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

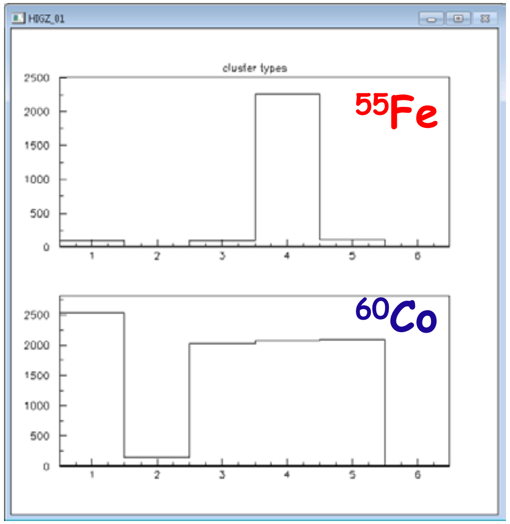
Using a gas mixture of $Ar/CO_2/CF_4$ 45/15/40

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

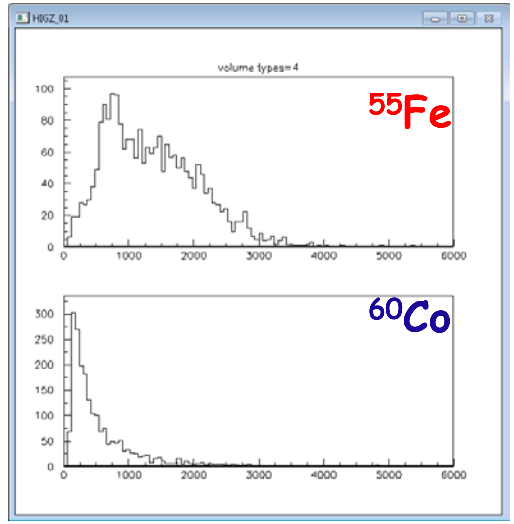
See S.P.George talk on pattern recognition

Cluster parameters measurements

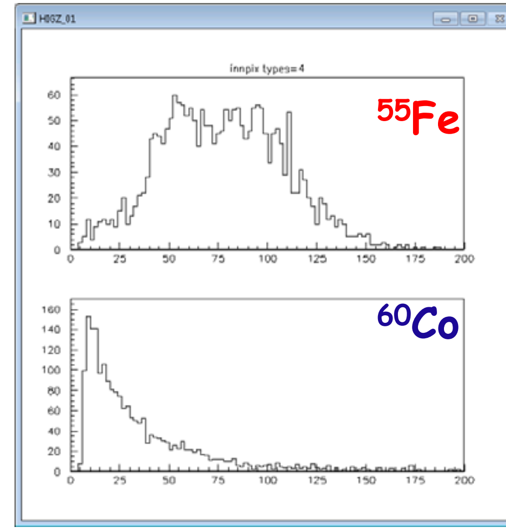
Cluster type

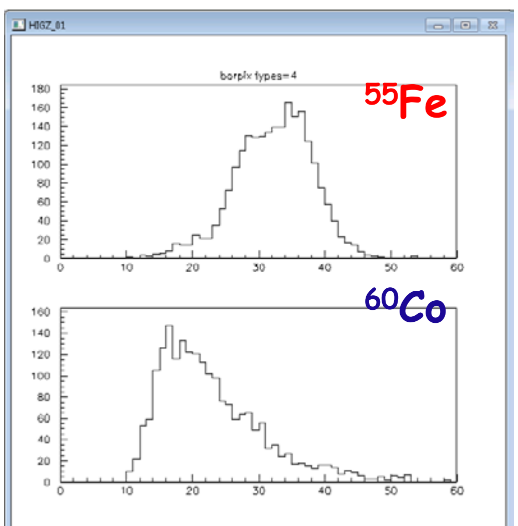


Cluster volume

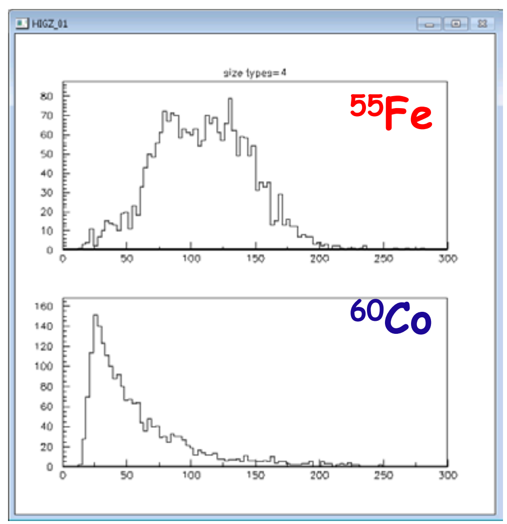


Inner size

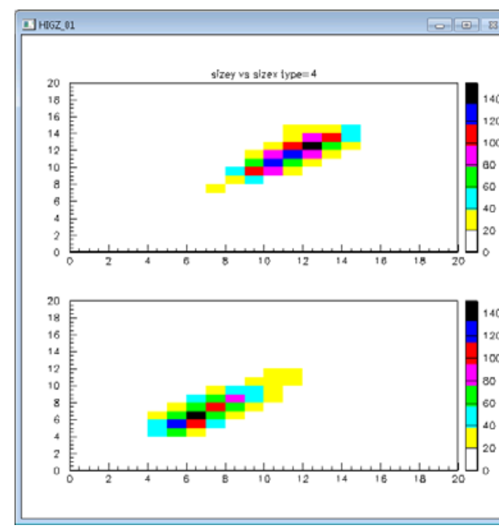




Border size



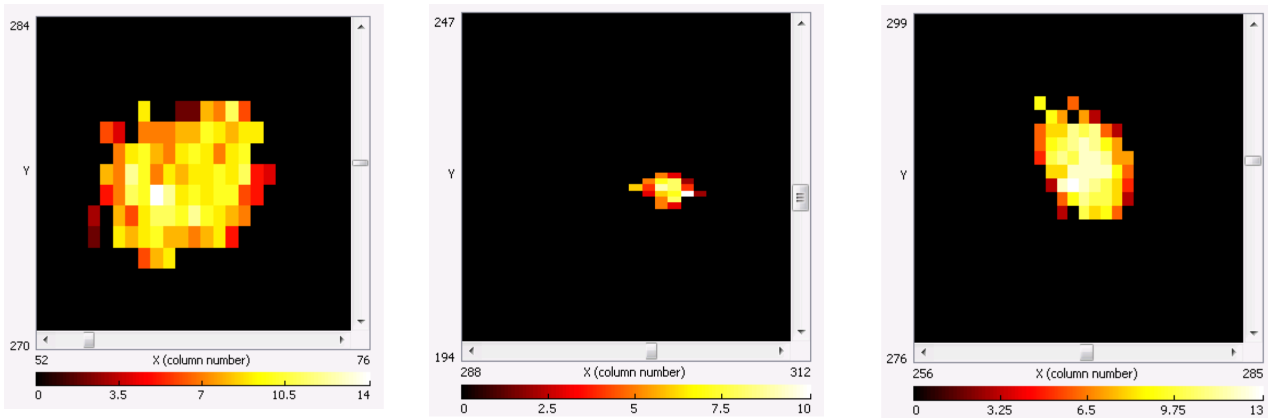
Size



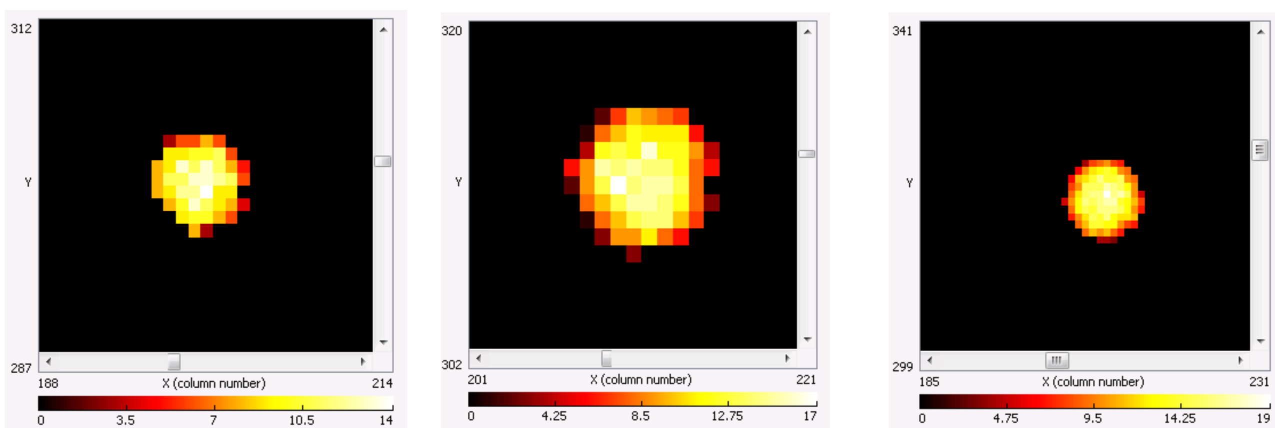
Size y vs size x

Detailed energy deposition

Cobalt (compton electron)



X Ray



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 compact and complete systems with the FPGA based Mather Board and the HVGEM that allow a very fine tuning of a GEM detector.
- ✓ Two GEMpix detectors have been built and they show good performances in cluster analysis also thanks to the Fitpix software pakage
- ✓ Other software tools and detector tuning are needed 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