Applications of MPGD beyond particle and nuclear physics

F.Murtas
Frascati INFN & CERN
The ARDENT Marie Curie ITN project

- A triple GEM detector system
- Fast neutron beam monitor
- Thermal neutron detectors
- Low energy XRay detector
- Application in Radiotherapy and Hadrotherapy
- GEMPIX for microdosimetry

E,Aza, A.Balla, G.Claps, G.Corradi, G.Croci, A.Pietropaolo, S.Puddu, L.Quintieri, D.Raspino, M,Silari, P.Stuart, D.Tagnani (INFN, ENEA, CERN, RAL, U.BICOCCA)

Non HEP Research activity

Fast and Thermal Neutron
Non destructive diagnostic
Biology
Nuclear Energy Plant
Tokamak Diagnostics
Chip Irradiation

Xray Low energy

Tokamak diagnostics
Radioactive waste

Pixelated GEM

Microdosimetry
Tissue Equivalent chamber
Direct measurements with real tissue
Radon Monitor

High Intensity Beam Monitors

Hadrotherapy
Ions Beam Monitor

Gamma High fluxes

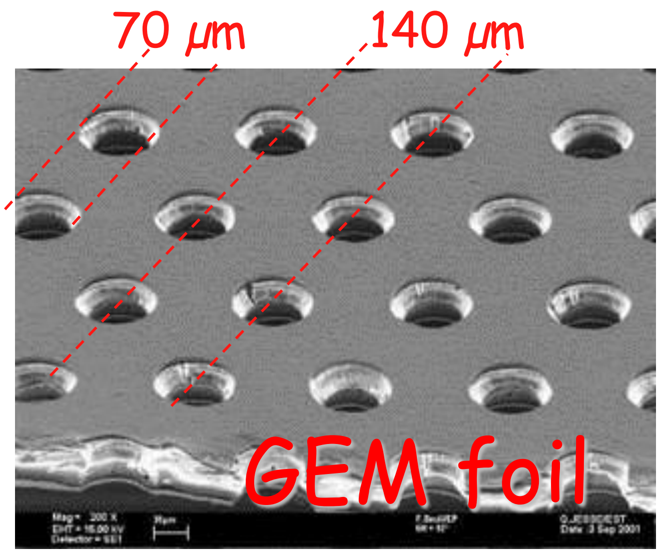
Radiotherapy

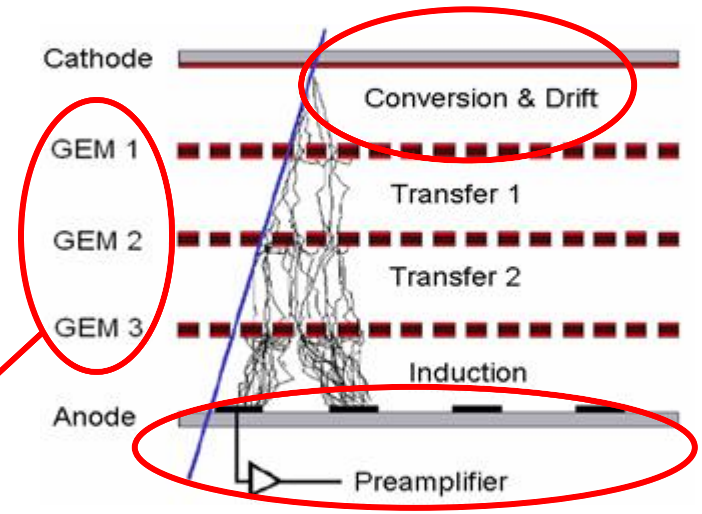
You need a portable system ...

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;

Several triple GEM chambers have been built in Frascati since 2001 …LHCb, Dafne Upgrade, KLOE2, UA9, IMAGEM, GEMINI, AIDA/BTF …

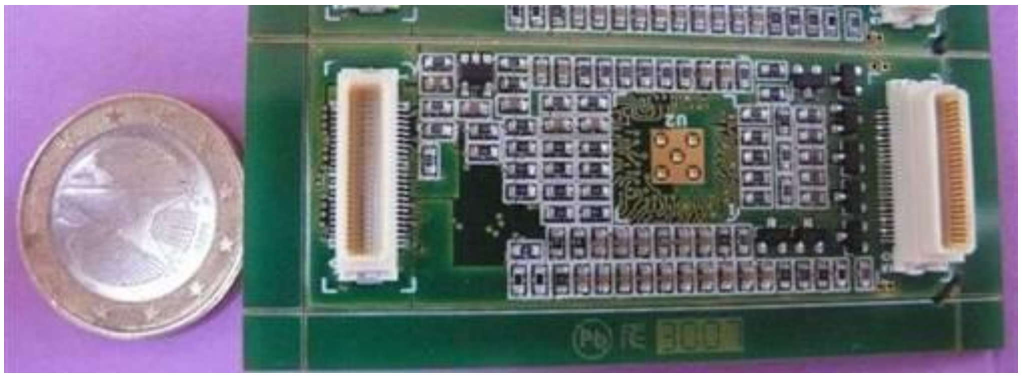


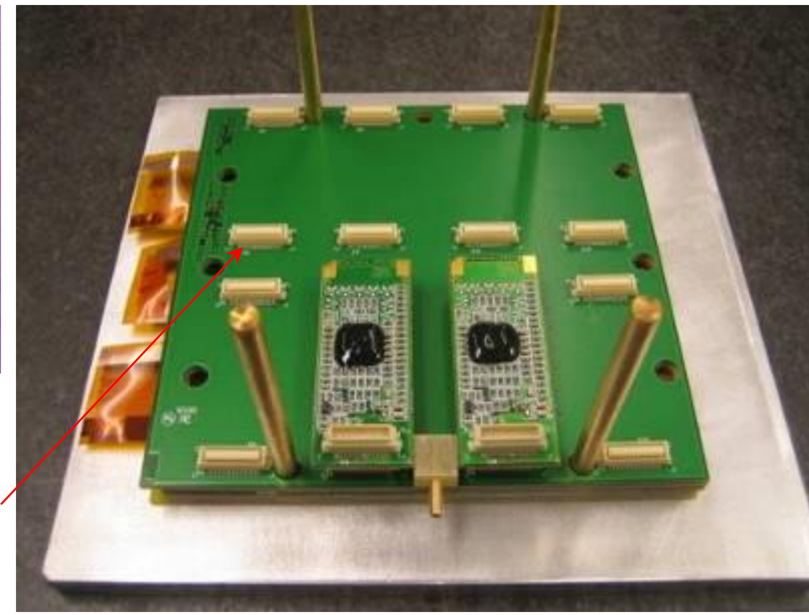


Working with different levels of gain it is possible to obtain high level of particle discrimination

The Front End Electronics Board

The card is based on Carioca Chip (LHCb) and has been designed and made in Frascati by Gianni Corradi ; Total dimension : 3x6 cm^2



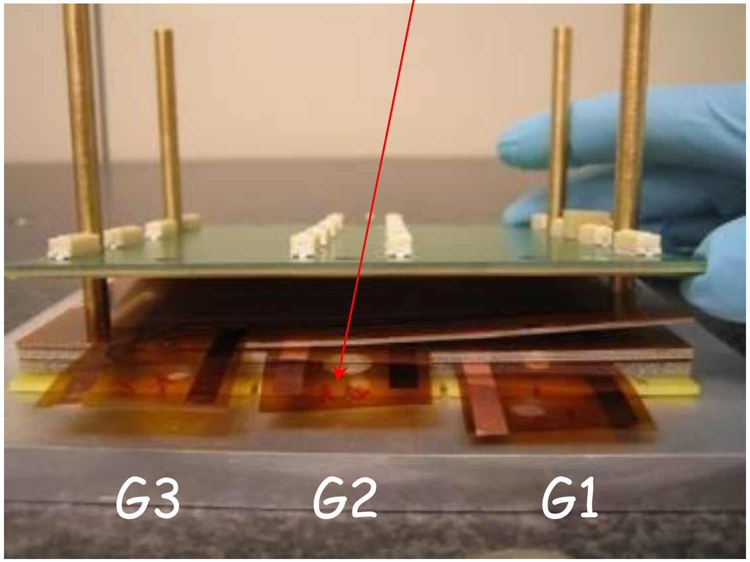


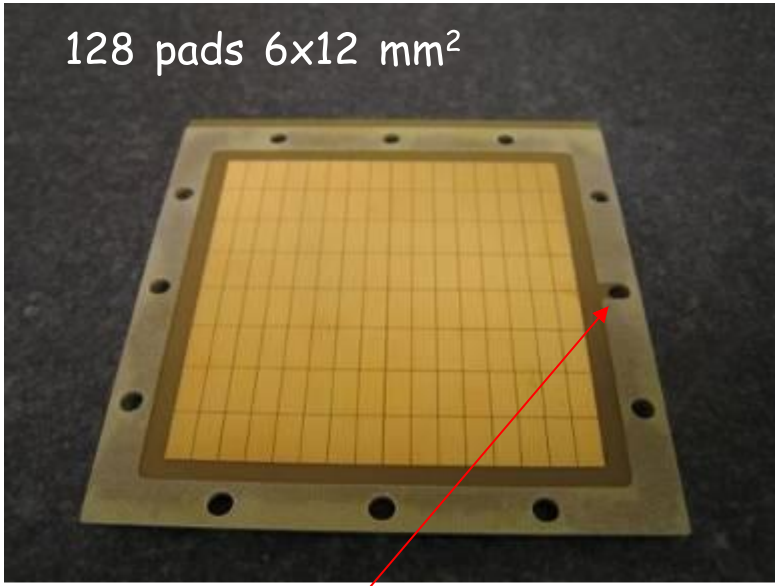
All the anode PCB have been designed with the same connector layout for a total of 128 channels (1ch/cm^2)

Now we are working with a Milano Bicocca electronic group (A. Baschirotto) for the design and construction of a chip GEMINI with 8 channels able to measure also the charge released in the drift gap;
The aim is to reach an high density pixel readout (32 ch chip .. 1 ch/mm^2)
ST Microelectronics

A Standard Triple GEM construction

The detectors described in this talk are built starting form the standard 10x10cm^2 :
only one GEM foil has been modified to have central electrodes.
The gas mixture used is Ar CO_2 70-30 atmospheric pressure



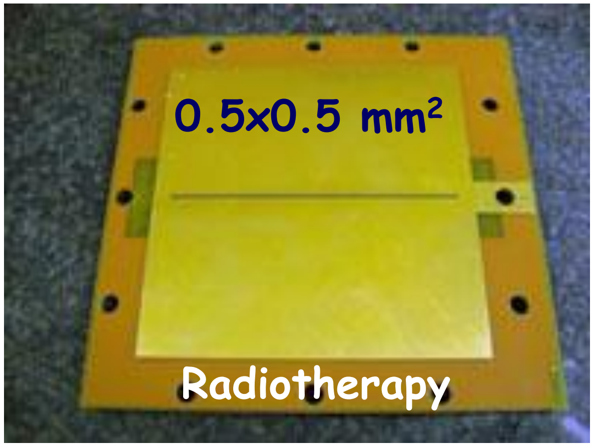


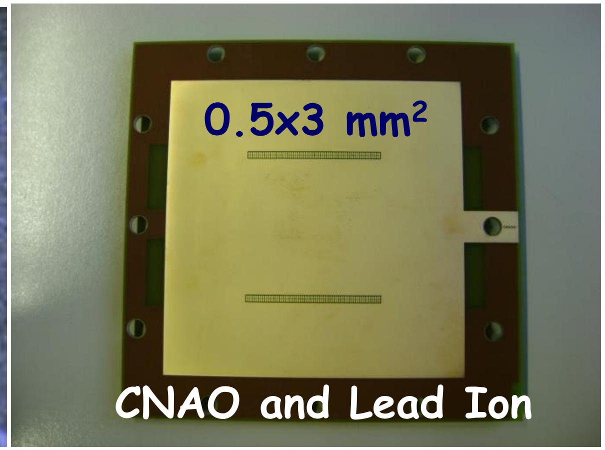
The GEM are stretched and a G10 frame is glued on top

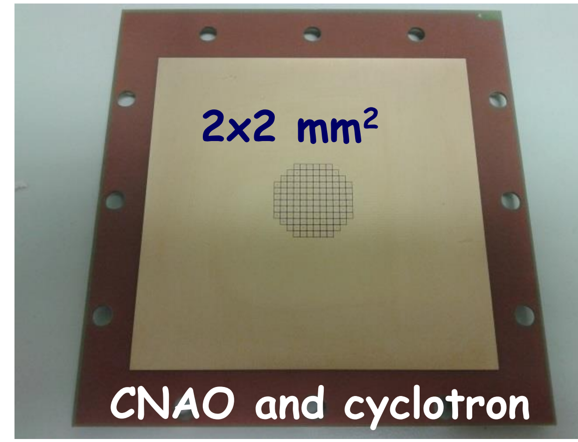
The frame for the G3 foil has been modified for the gas inlet

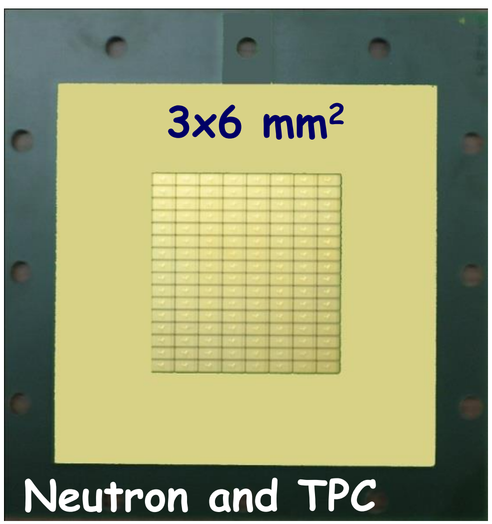
Pad readouts

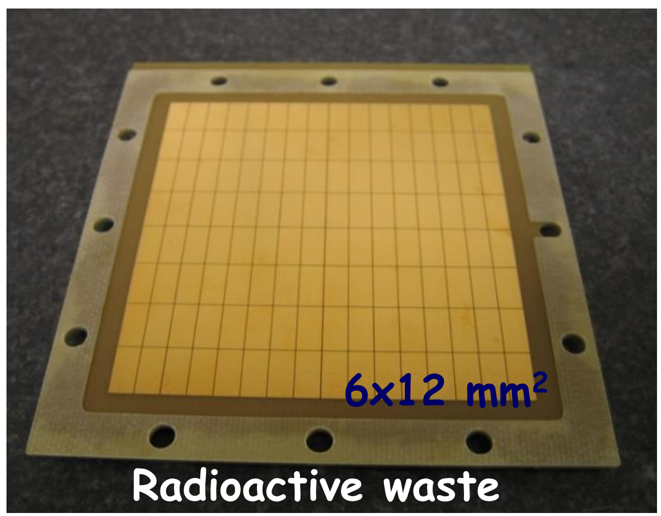
Different pad geometry but always with 128 channels

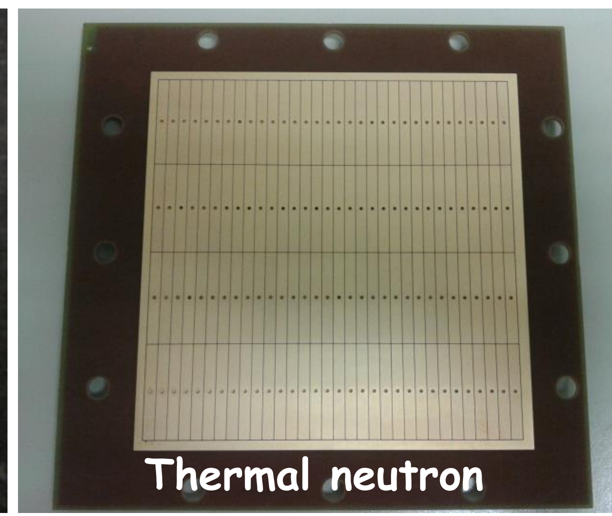












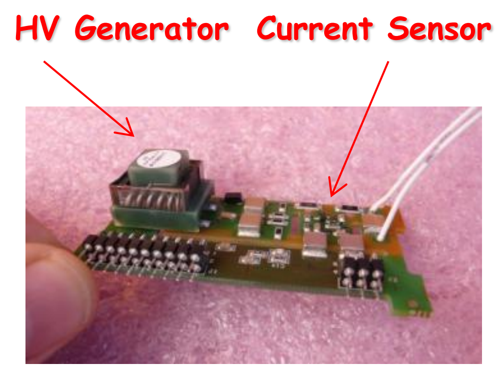
DAQ System and Power Supply

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

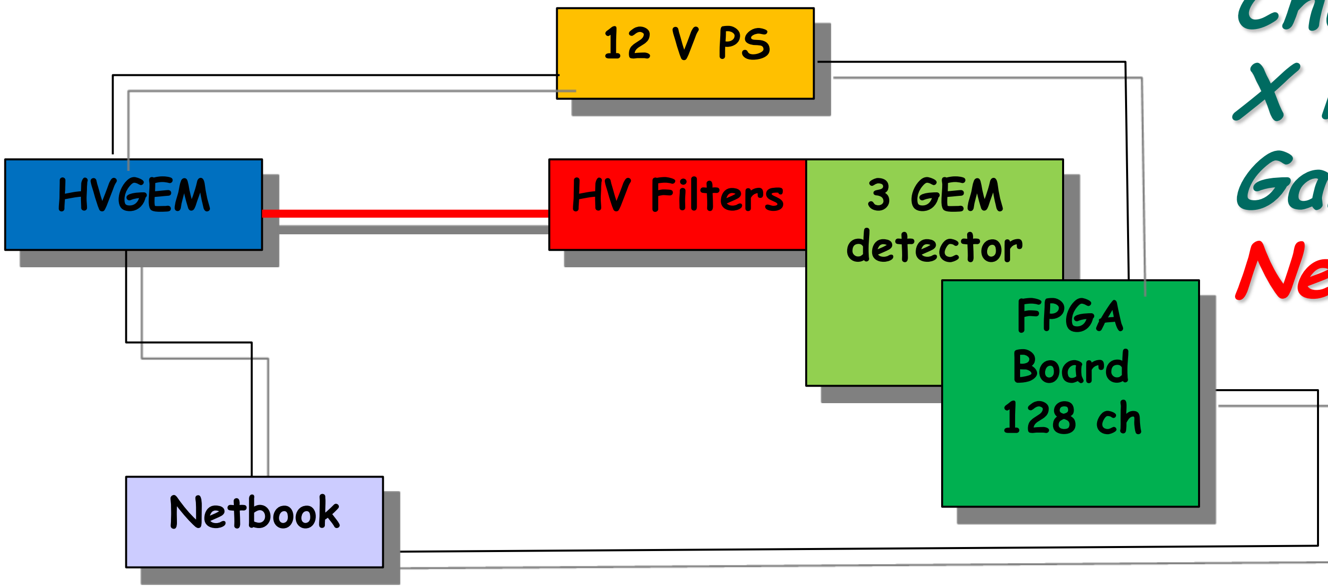
1 power supply (12V)
2 input channels: gate and trigger
3 data outputs : ethernet and USB
8 acquisition modes
(made by Athenatek)

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

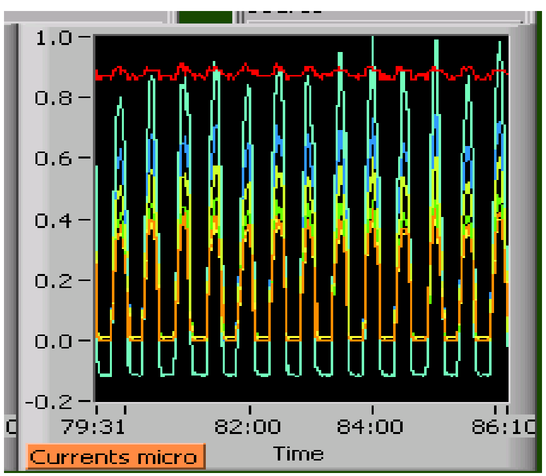


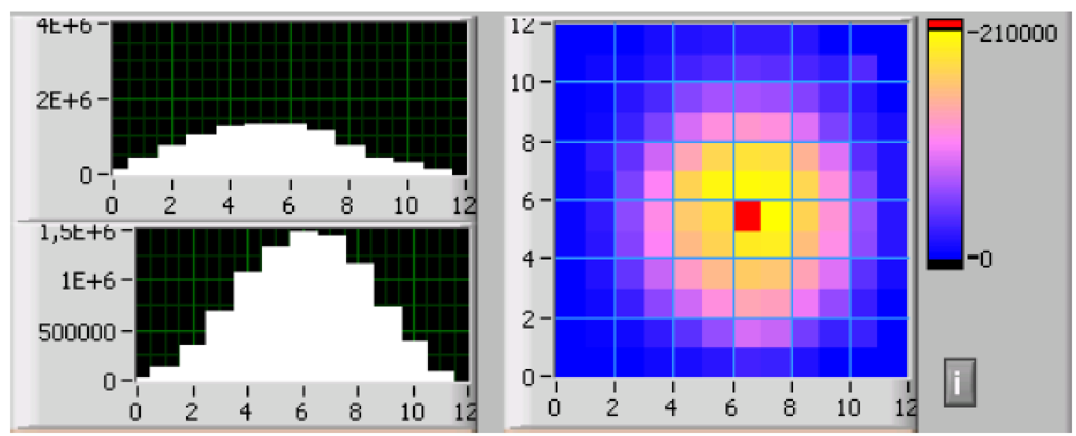
Two slot NIM Module CANbus controlled
(made by MPelettronica)

A triple GEM detector system



Charged particles
X Ray
Gammas
Neutrons





Fast Neutron detection at

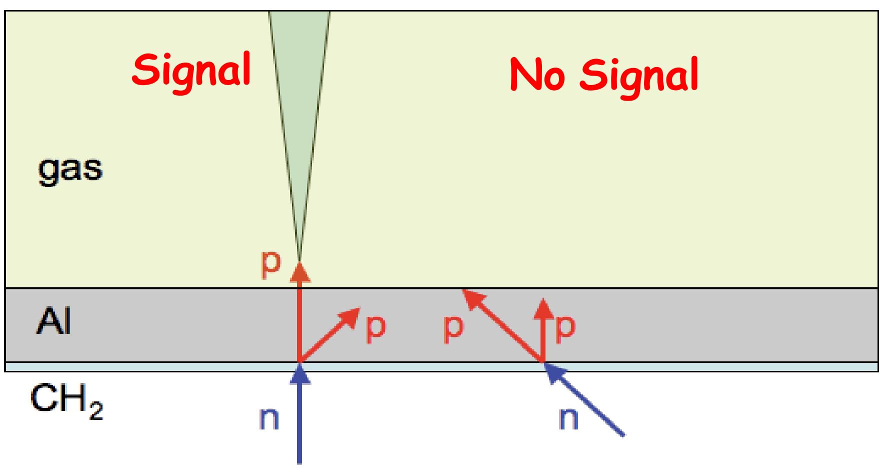
Frascati Neutron Generator (ENEA)
Neutron Spallation Source ISIS (UK)
and
n-TOF (CERN)

Polietylene Converter Cathode

2.5 MeV Neutrons interact with CH_2, and, due to elastic scattering processes, protons are emitted and enter in the gas volume generating a detectable signal.

Aluminum thickness ensures the directional capability,

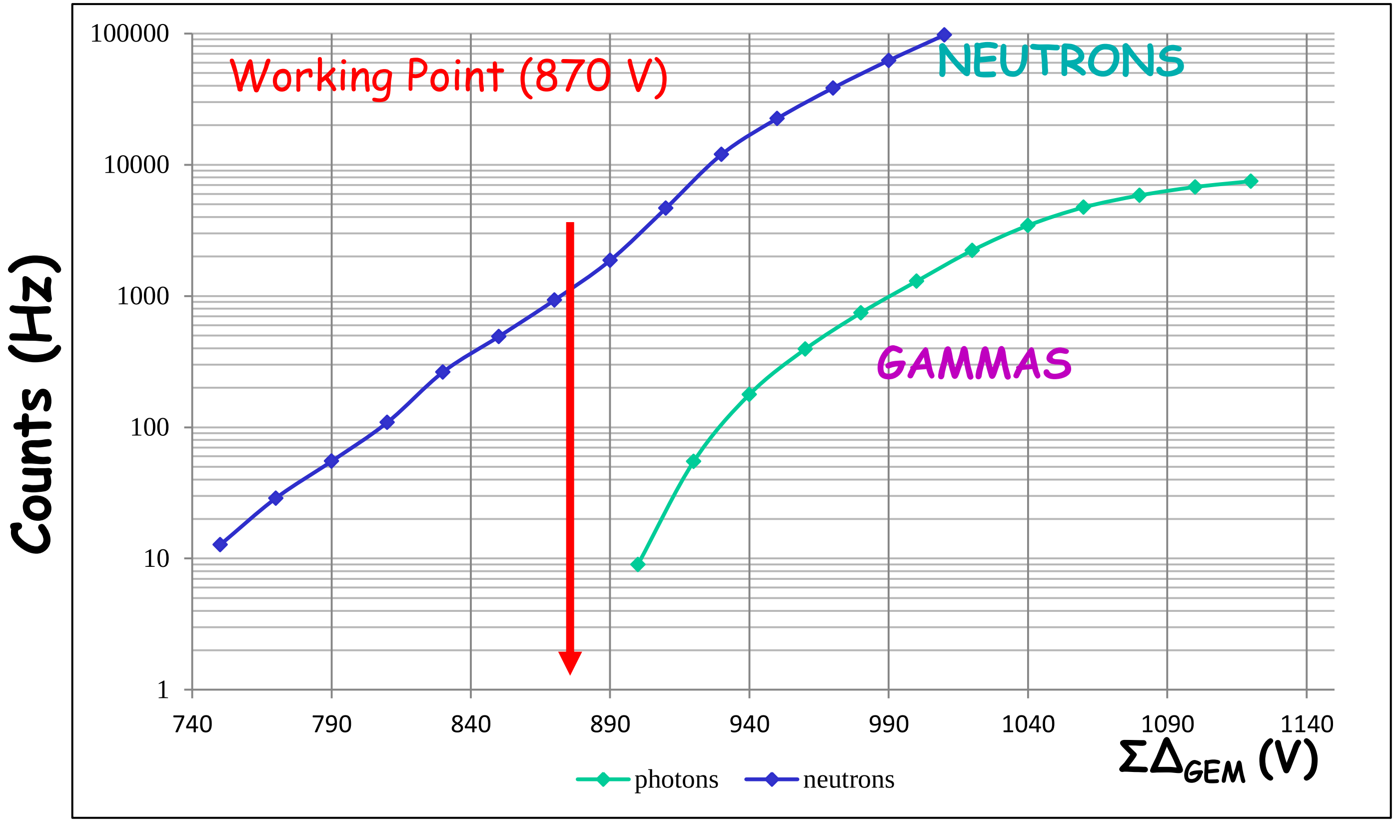
stopping protons that are emitted at a too wide angle.



Optimized CH_2–Al thicknesses (50 μm-50 μm) determined by simulations (MCNPX-GEANT4)

Efficiency of 4 10^{-4}

Detector Working Point

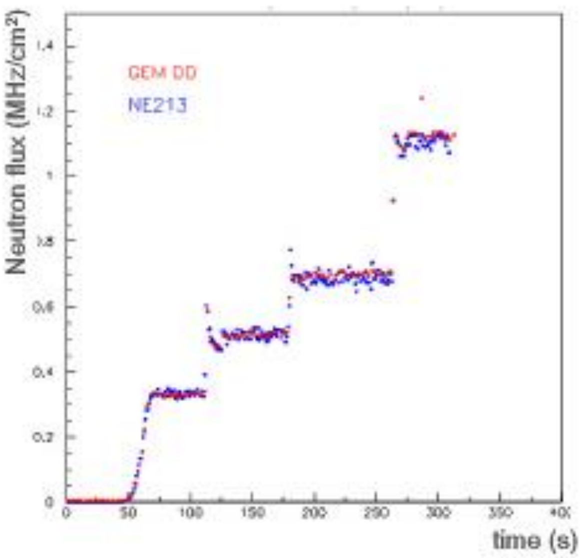


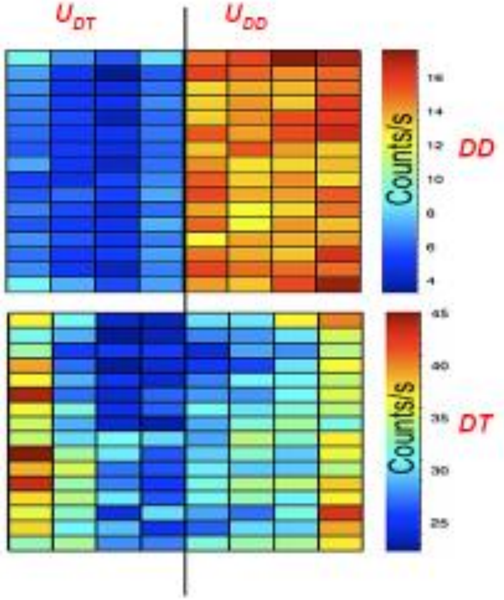
Counting rate Vs chamber gain: up **to 890 V** the chamber is sensitive to fast neutron but not to gamma rays.

Neutron diagnostics at Frascati Tokamak

The active area of this neutron monitor has been divided into two parts with the polyethylene converter optimized for the two energies (2.4 and 14 MeV from DD and DT nuclear interaction respectively)

Measurements at Frascati Neutron Generator (ENEA)

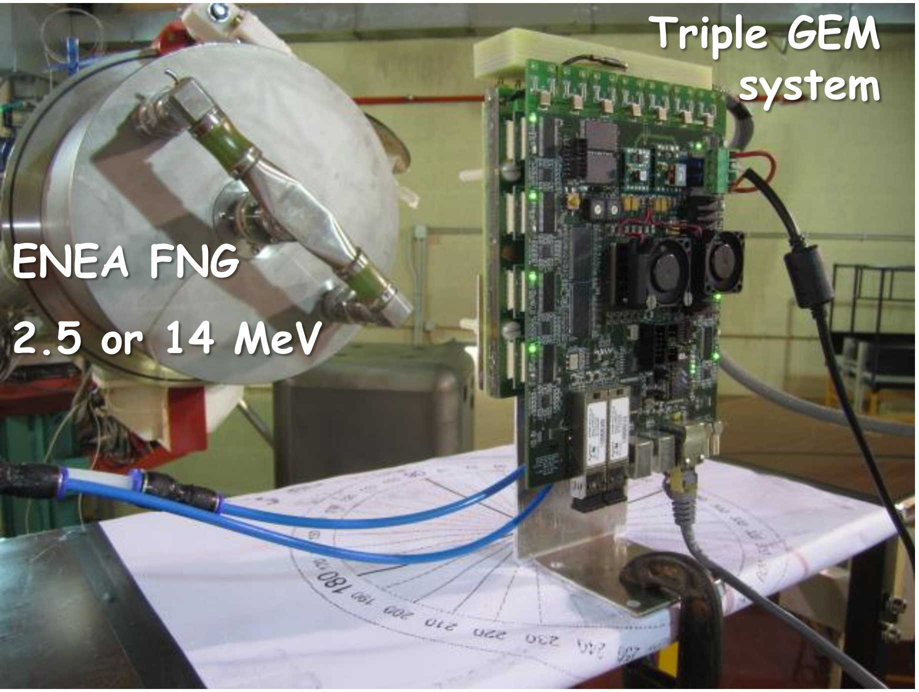


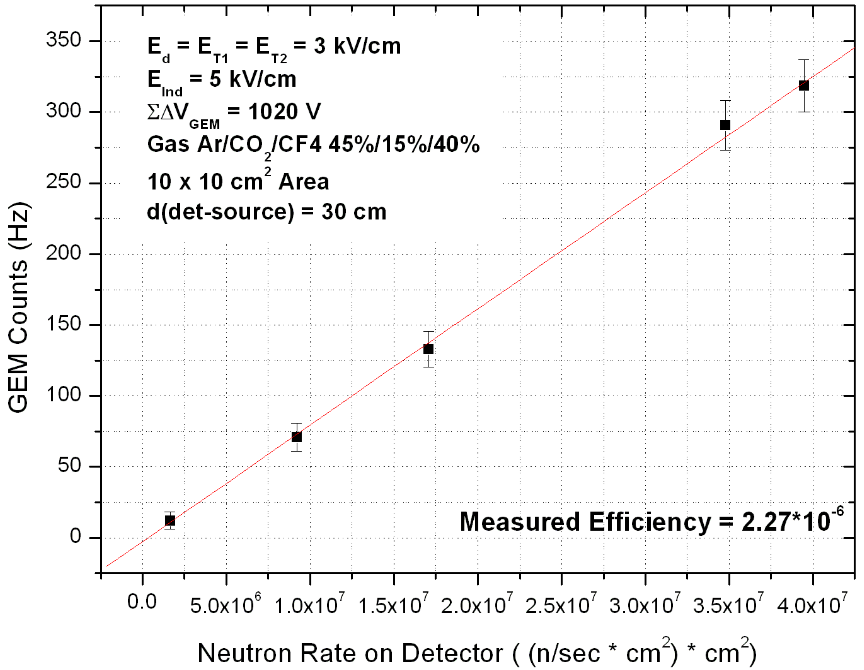


Design of a GEM-based detector for the measurement of fast neutrons
B.Esposito et al NIM A, Volume 617, Issues 1–3, 11–21 May 2010, Pages 155-157

Test at Frascati Neutron Generator

Measurement of the PH spectrum acquired under 2.5 MeV neutron irradiation at different angles with respect to beam direction and comparison with MCNP. As expected the integrated PH counts decrease when increasing the angle.



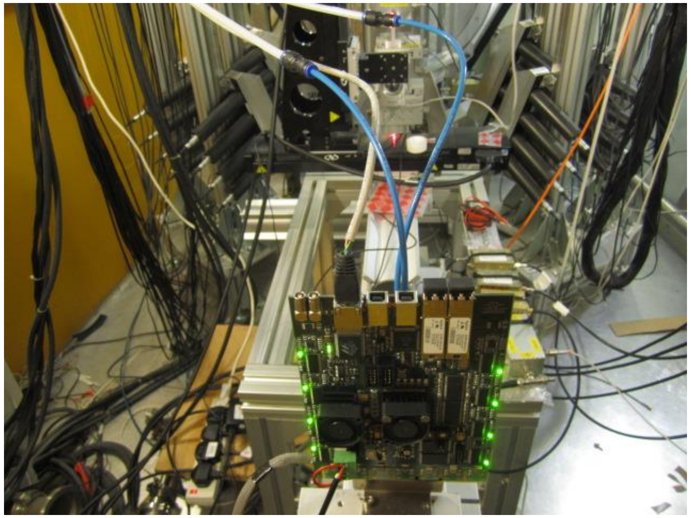


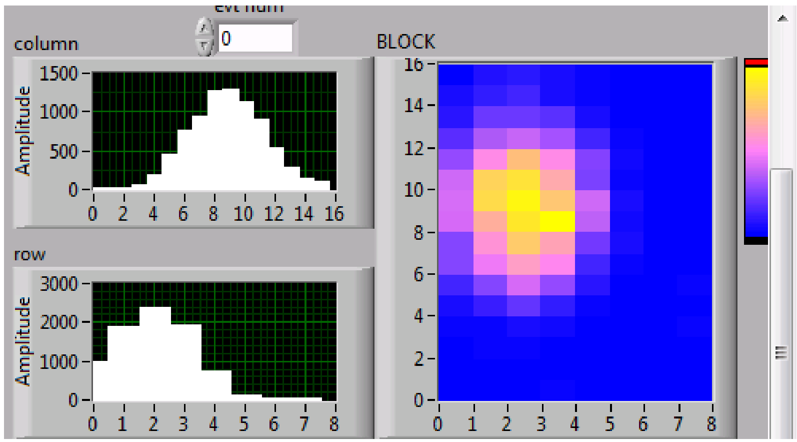
Good linearity measured up to $4x10^7$ neutron/sec cm^2 the maximum rate reached by this facility

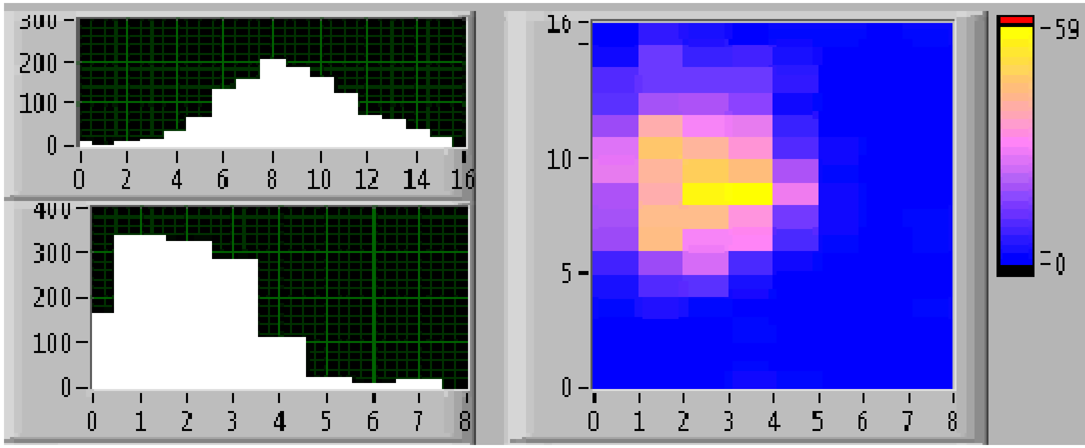
Fast Neutron Monitor (ISIS)

Monitor for a fast neutron beam with energies ranging from a few meV to 800 MeV

Tested at neutron beam of the Vesuvio facility at RAL-ISIS.



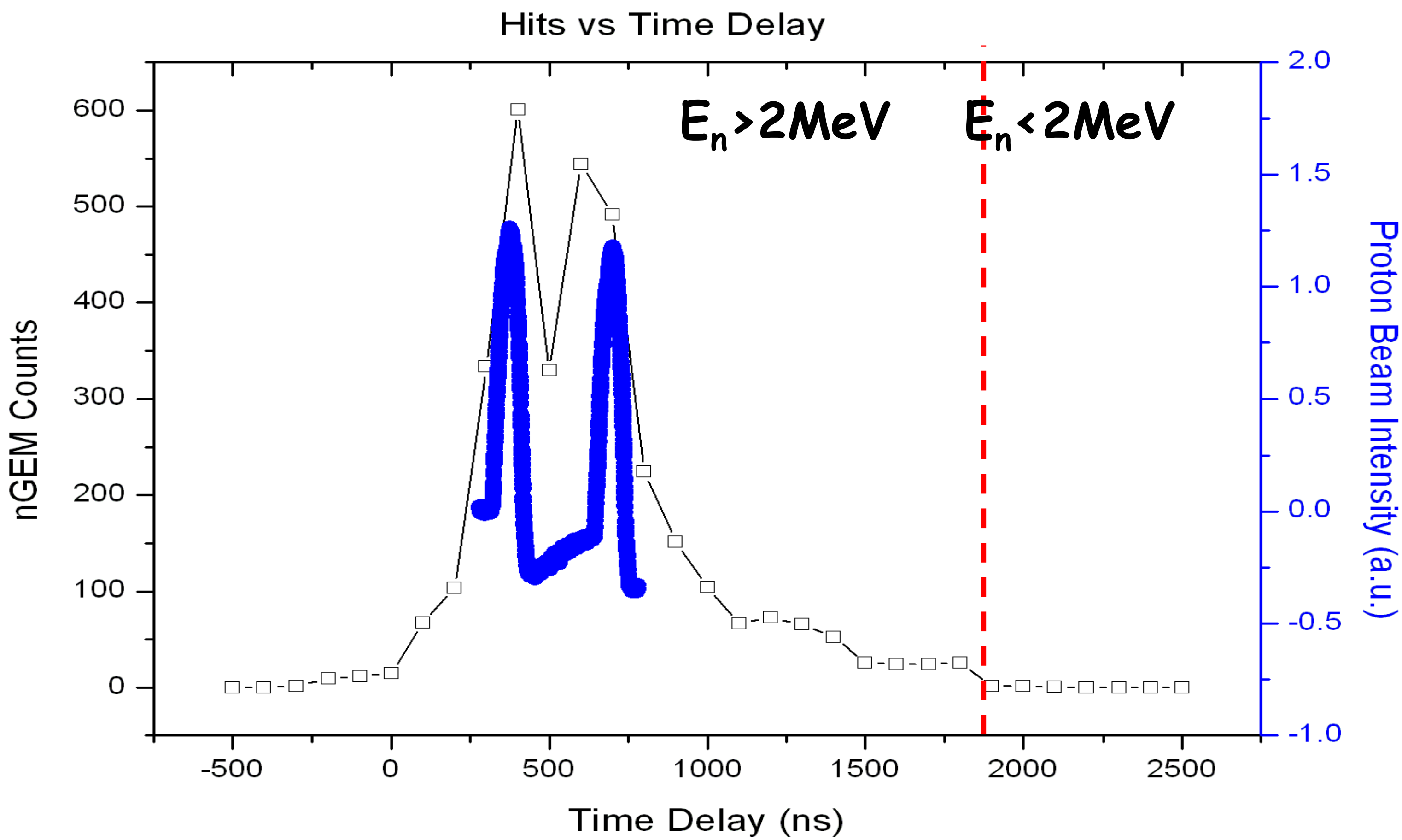




Beam profiles and intensity in real time

Neutron beam monitorig during the shutter opening

Fast Neutron time line

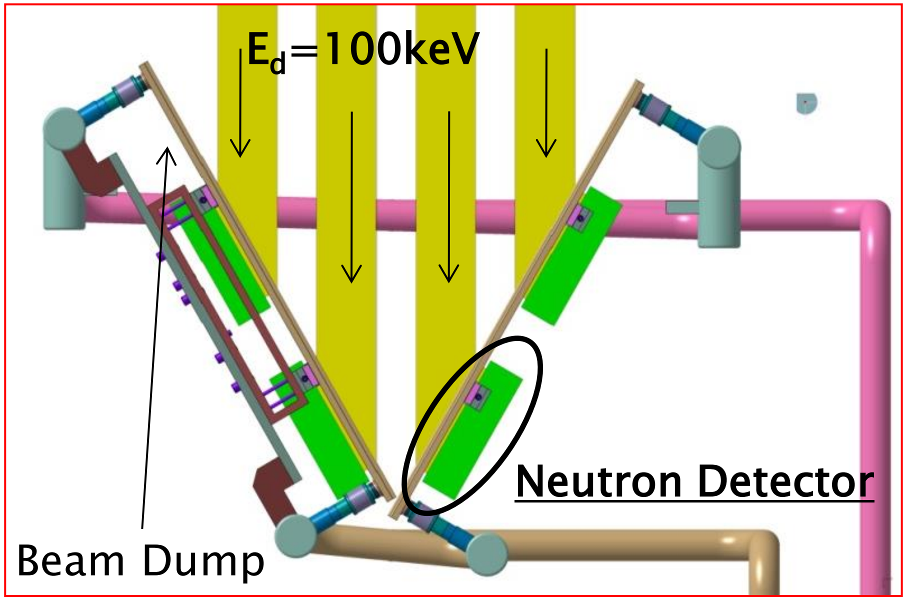


Rate measurement scan on time delay from beam T_0 using GEM detector with 100 ns gate.

Comparison with proton beam profile intensity

Chambers for Spider at RFX (Padova)

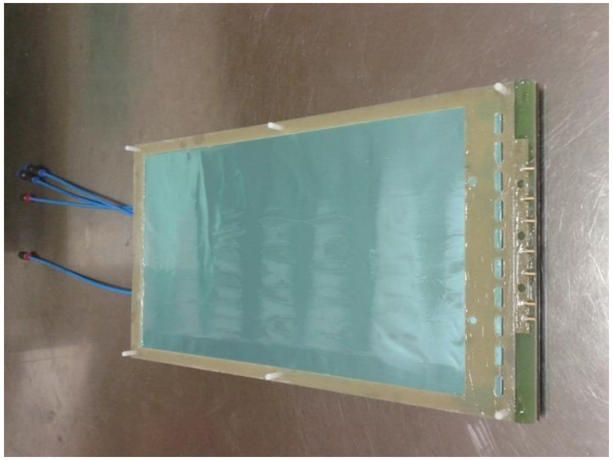
Deuterium beam

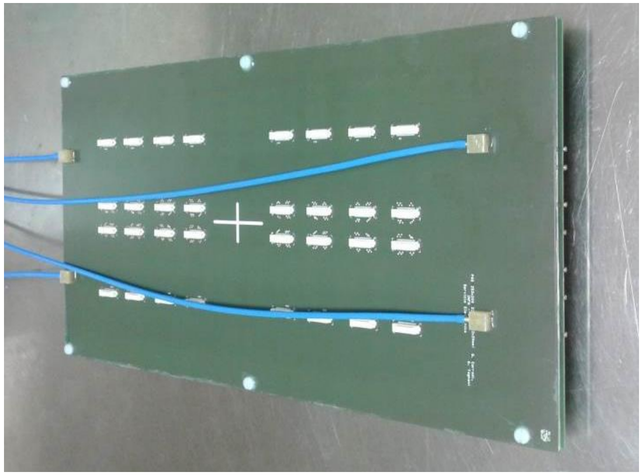


Neutrons are emitted via the reaction:

$$d + d \rightarrow He^3 + n + 3.27MeV$$

The proposed detection system is called Close-contact Neutron Emission Surface Mapping (CNESM).





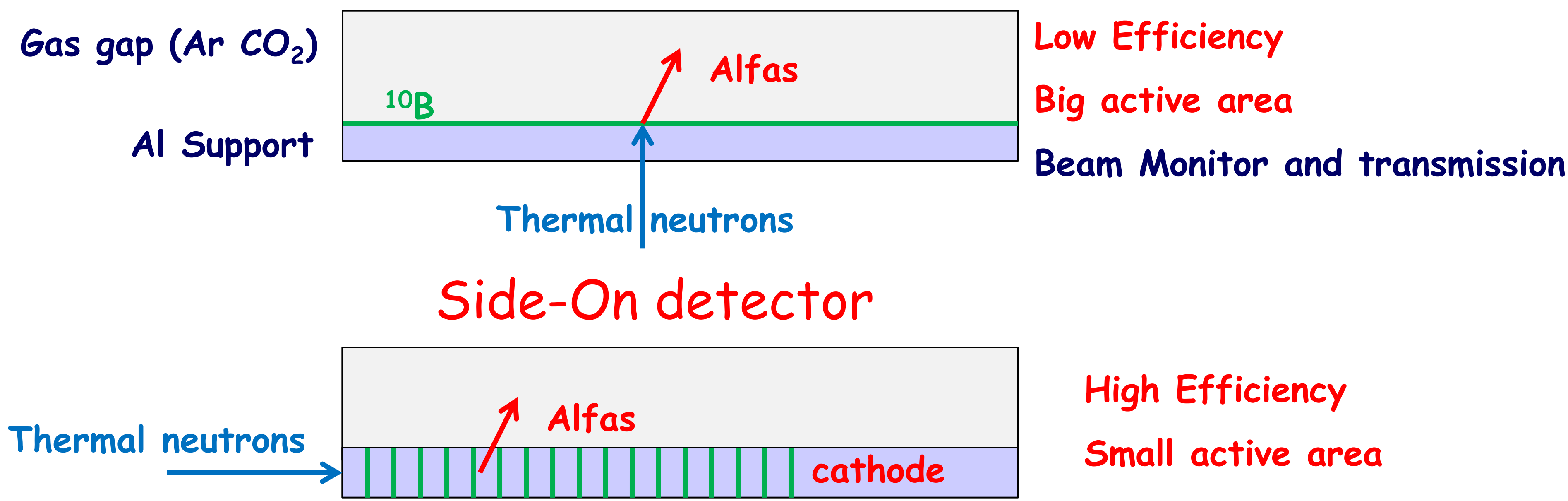
Prototypes build in Frascati in May and in test now at ISIS

Thermal Neutron detection at

Triga Casaccia (ENEA)
Neutron Spallation Source ISIS (UK)
and
n-TOF (CERN)

^{10}B Cathode for thermal neutron

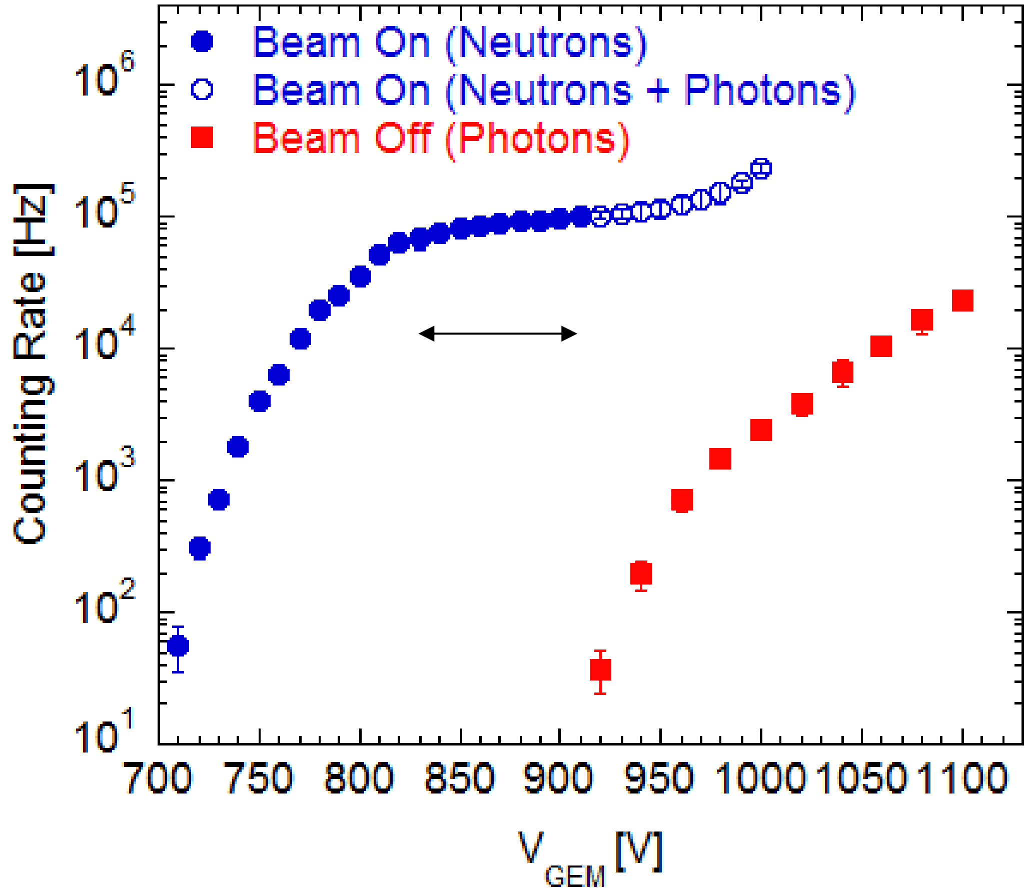
Thermal Neutrons interact with ^{10}B, and alfas are emitted entering in the gas volume generating a detectable signal.



Actually 4% efficiency ... working to obtain 50%.
Good candidate as ^{3}He replacement detector

Workin point

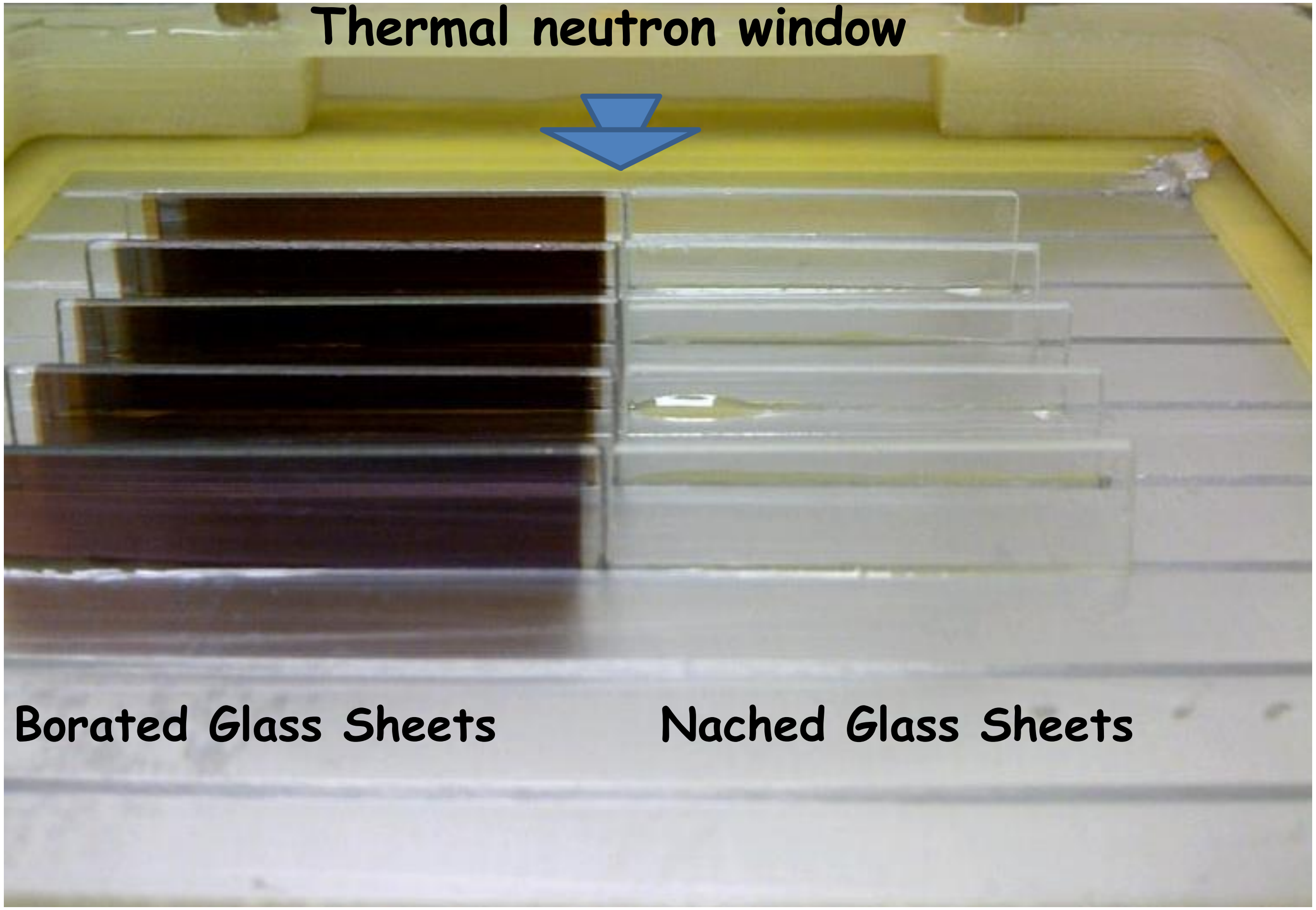
The alfas produce an higher ionization respect to protons that allow a wider plateau before the gamma background



G.Croci *et al*: GEM-based thermal neutron beam monitors for spallation sources Vienna Conference 2013

Boron multilayer cathode

First prototype made in 2012

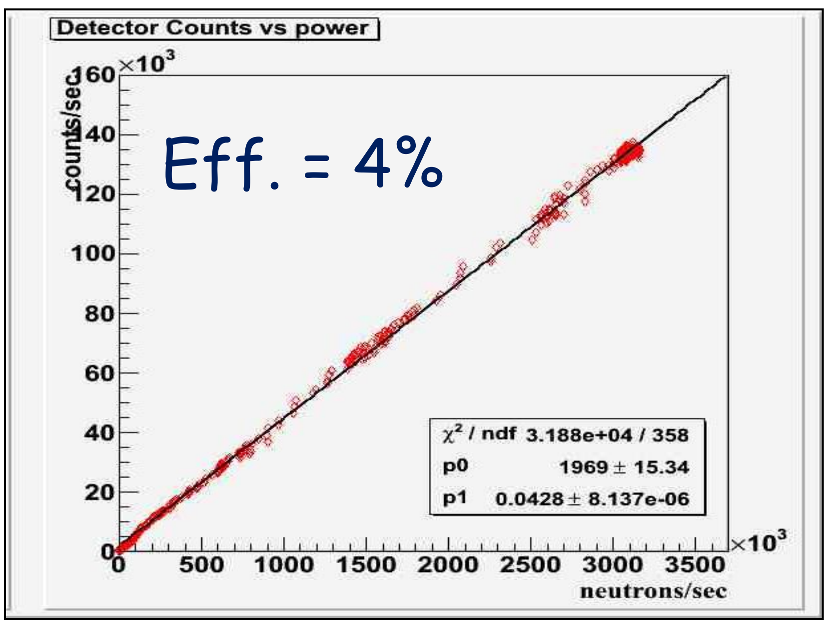


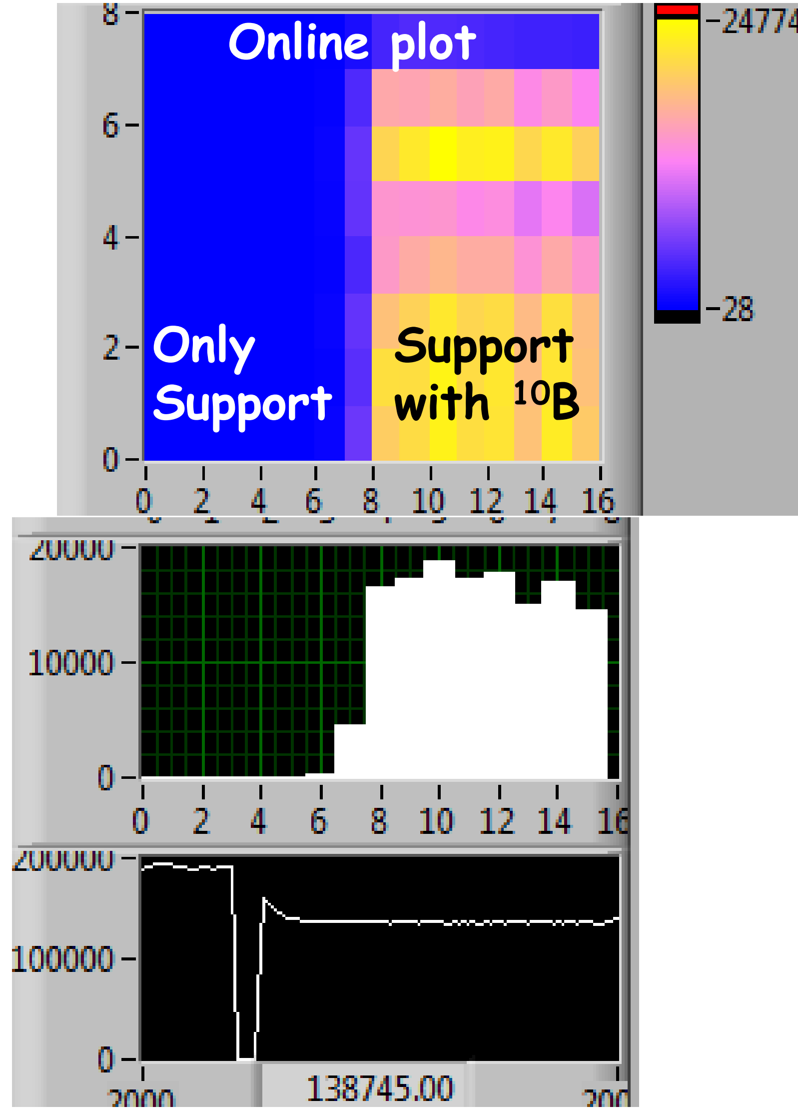
Neutron Monitor applied to fission reactor

Measurements at Triga (ENEA)
Power of 1 MW

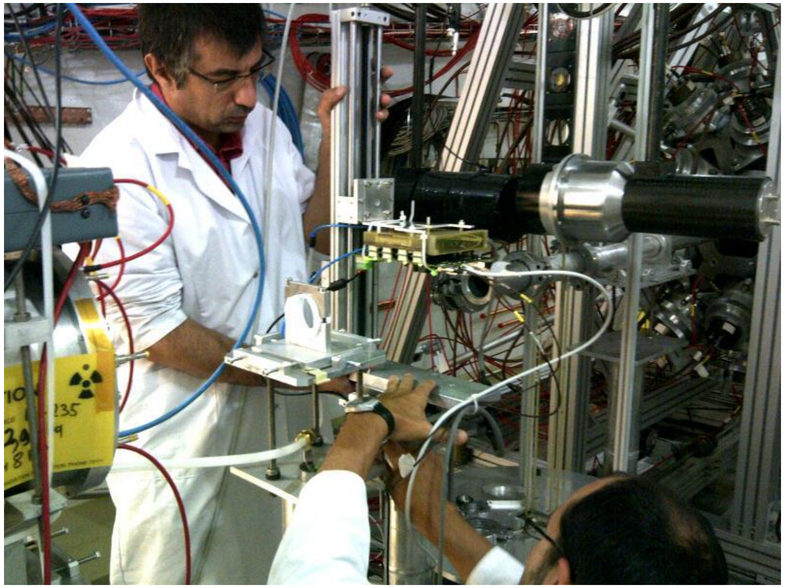
Gamma background free
Without electronic noise

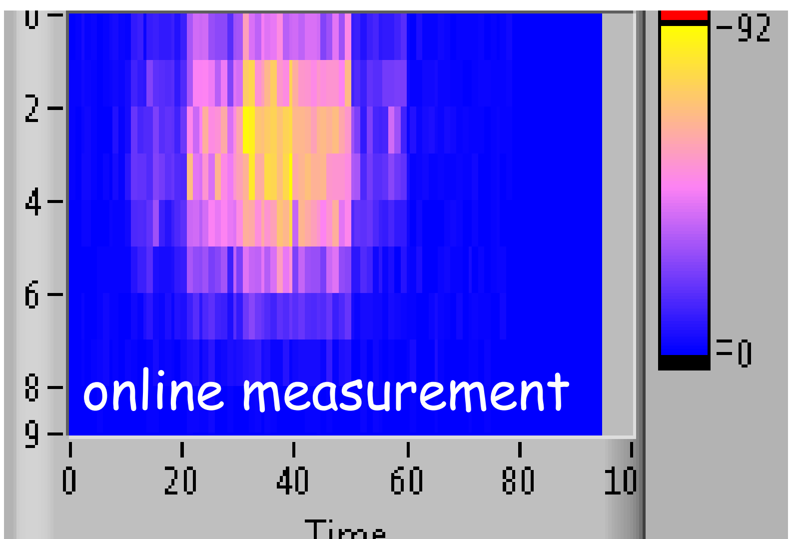
Good linearity up to 1 MW



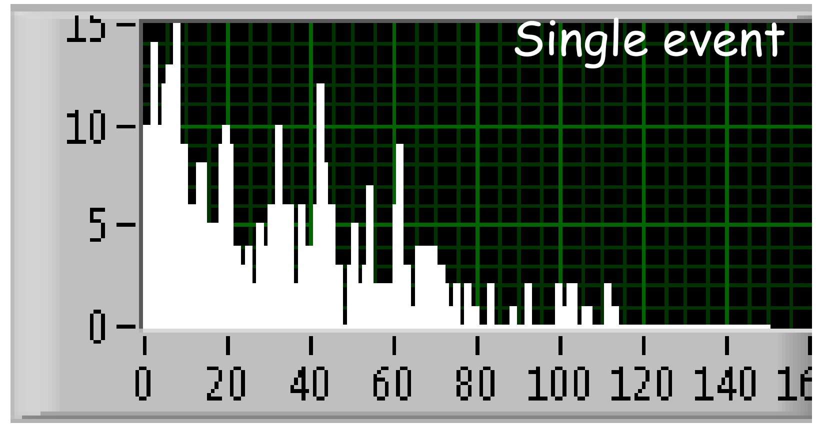


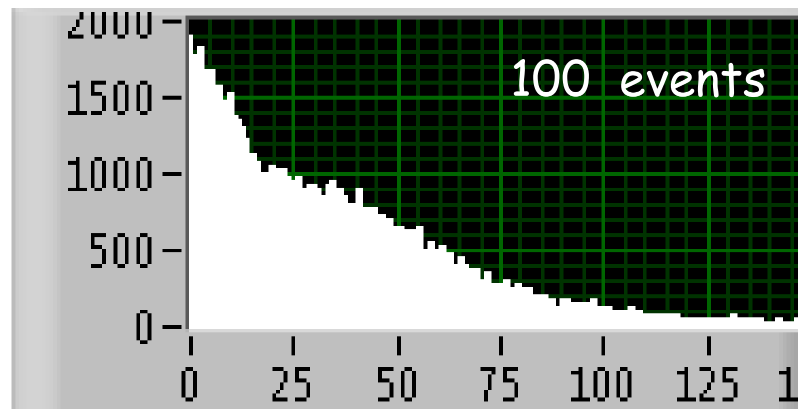
N-TOF thermal neutron beam spot





Real time plots

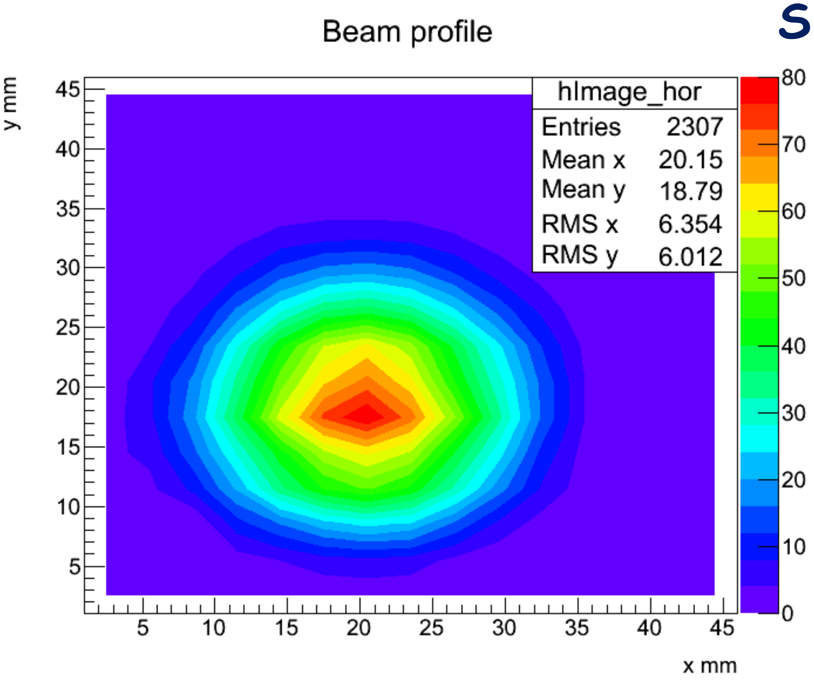


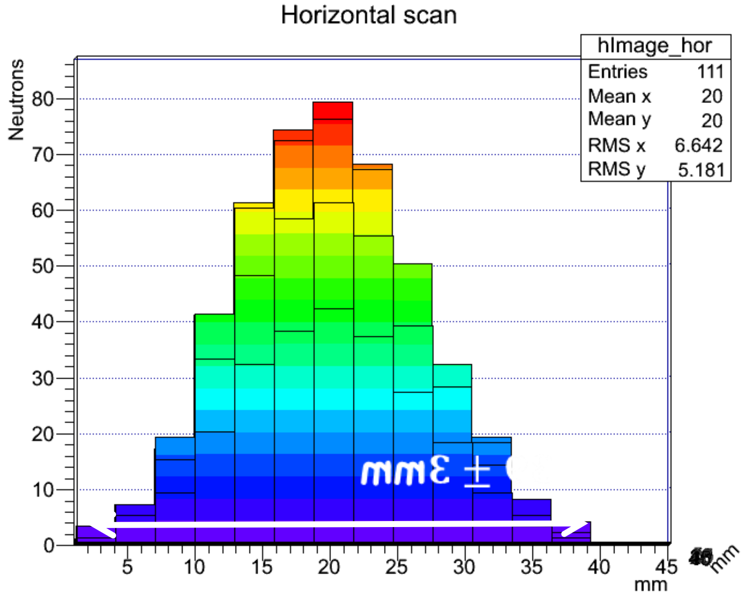


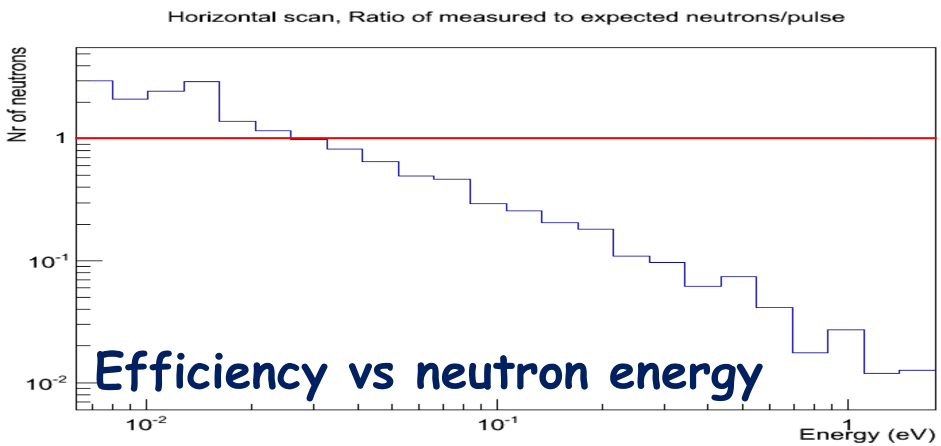
Time spectrum (1ms/bin)
150ms total gate

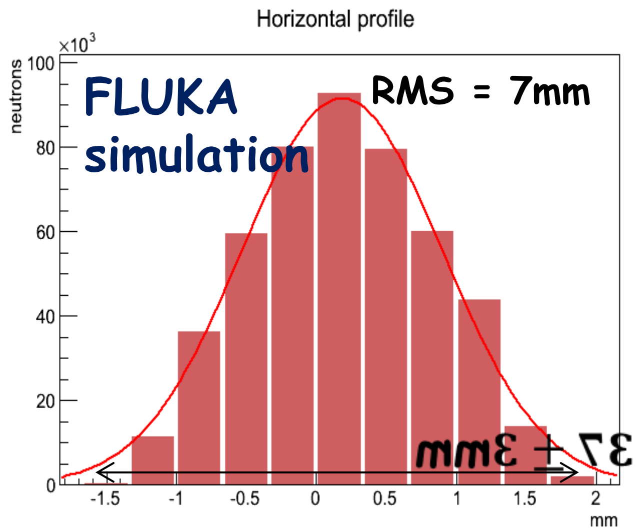
N-Tof Beam profile

S. Puddu E.Aza









Imaging of Thermal Neutron beam through a cadmium grid (ISIS)

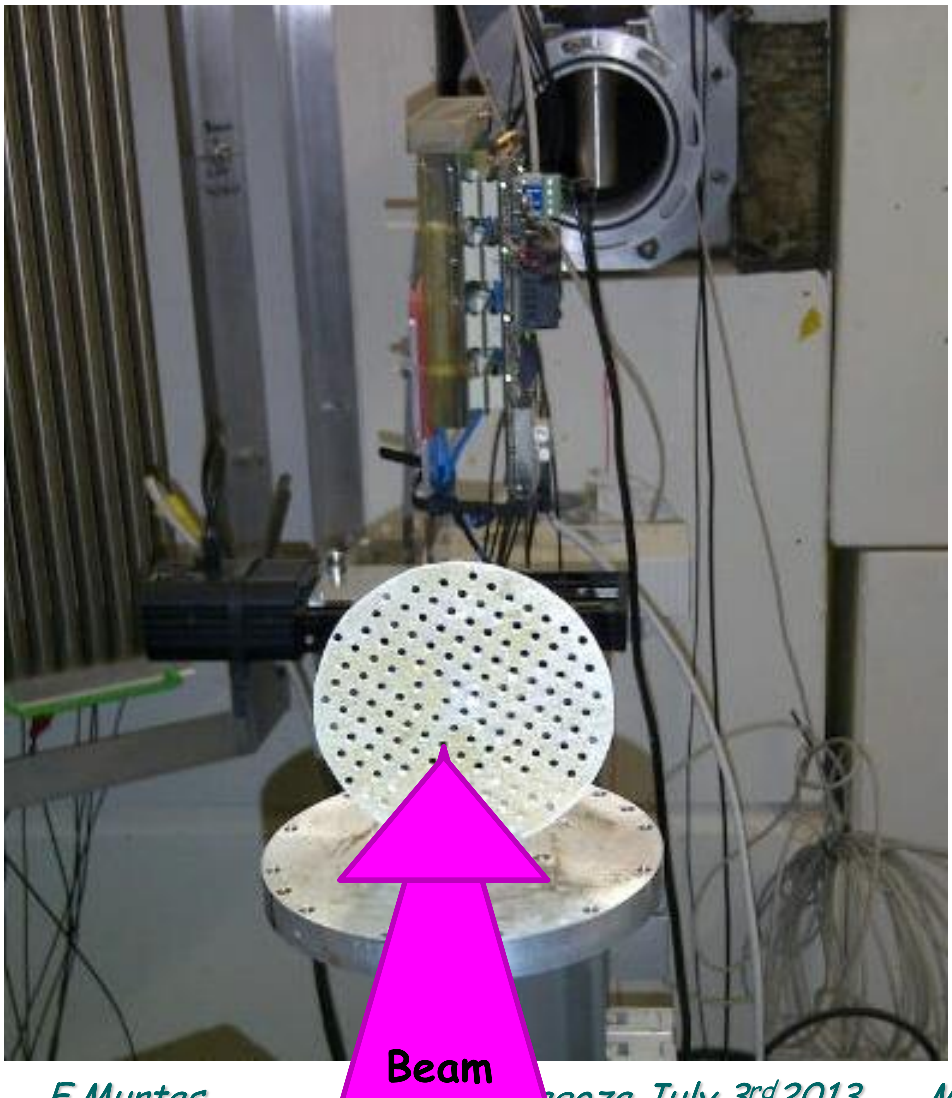
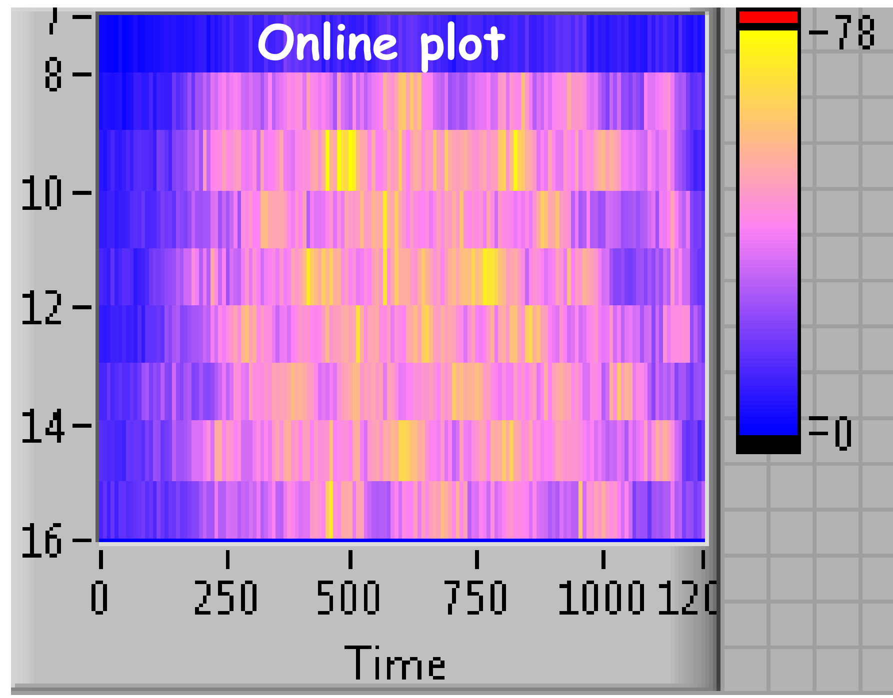
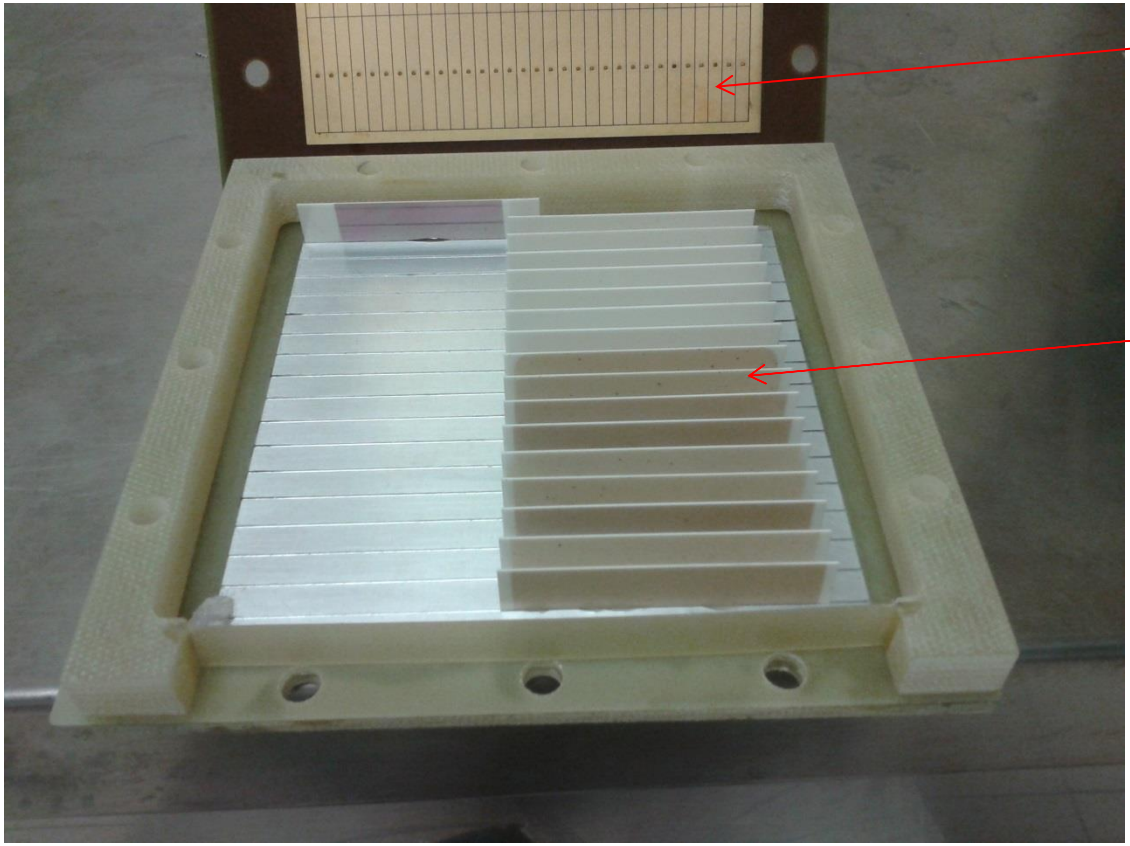


Image realized with a scan through the beam



New prototype for higher efficiency

Second prototype made in May 2013



Pad dimension 3x24 mm
millimetric resolution

17 allumina supports
10 x 50 x 0.4 mm

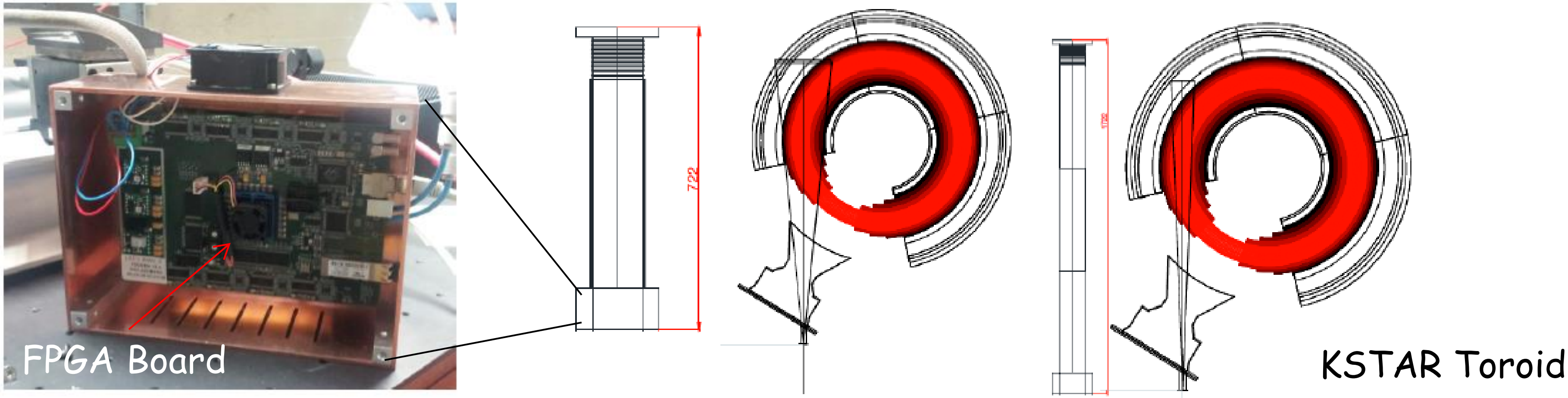
34 Born depositions (1 micron)
made by G.Celentano (ENEA)

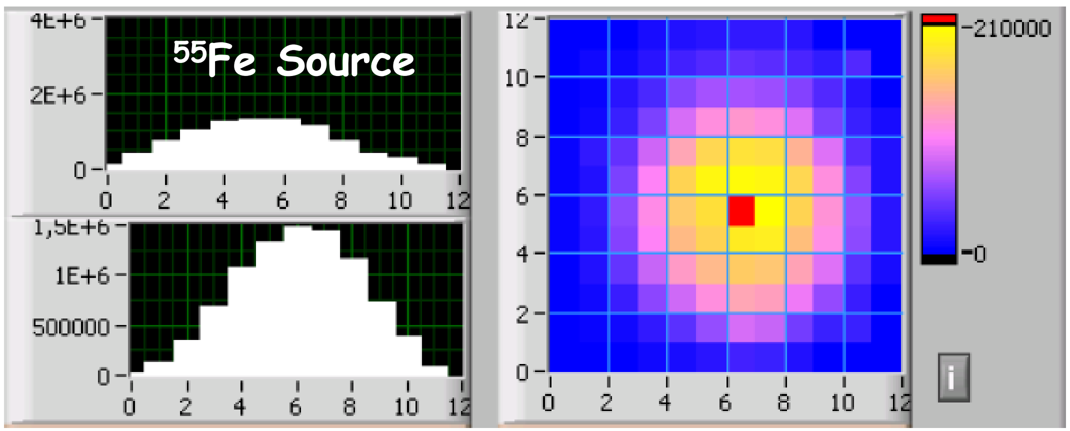
Some problems on depositions

Designed optimised with Fluka simulation (L.Quintieri)
Now on characterization measurement at Oak Ridge (G.Claps)

XRAY Detector
for
Tokamak Plasma Diagnostics
Radioactive Waste

Tokamak diagnostics at KSTAR (KOREA)



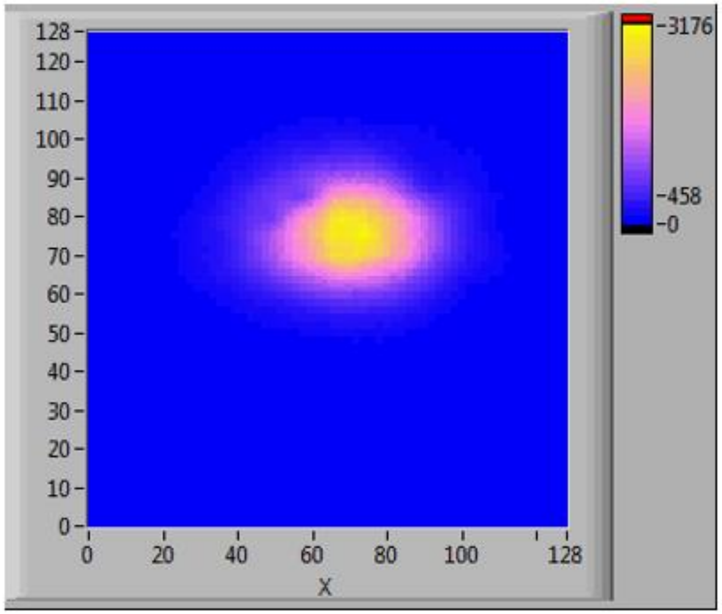


The system firmware is able to produce a movie of 65000 frames of 1 ms.
The 2013 KSTAR data taking will start in few weeks.

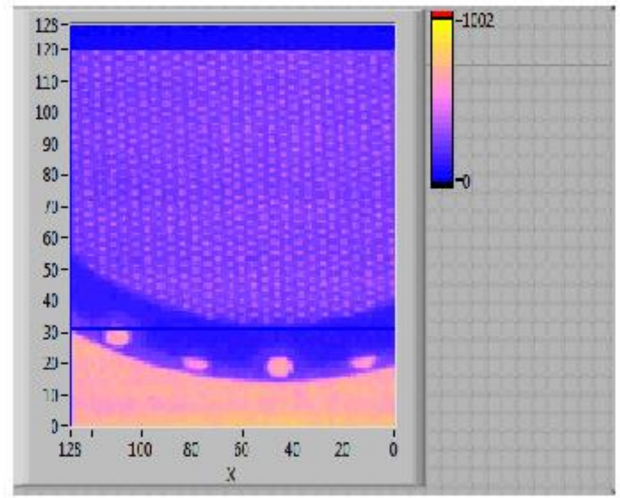
D. Pacella et al. :
GEM-based Energy Resolved X-ray Tangential Imaging System at KSTAR

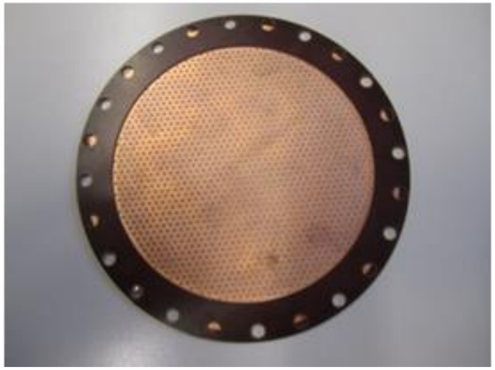
Low energy X-Ray Images

X-Ray beam of 6 KeV



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

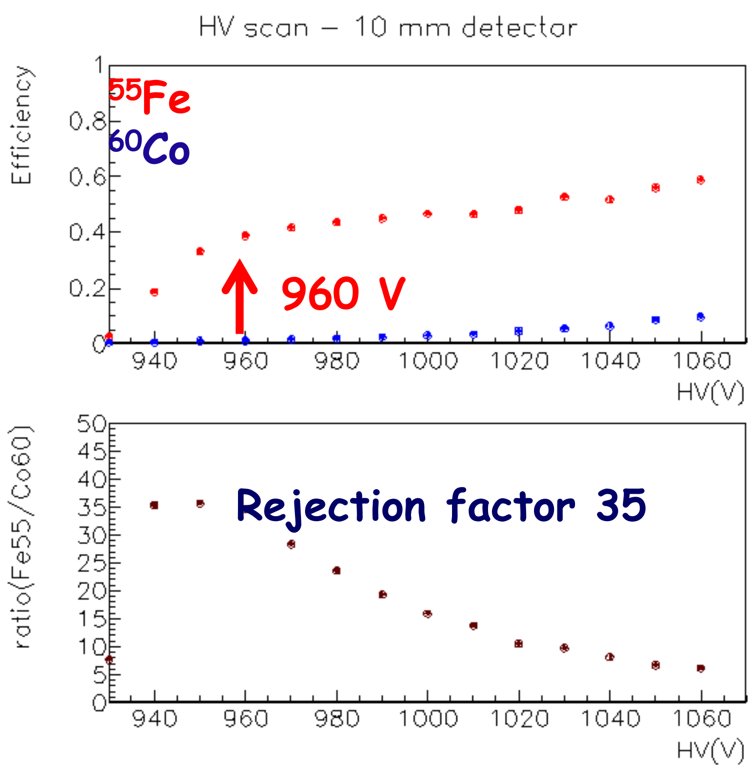


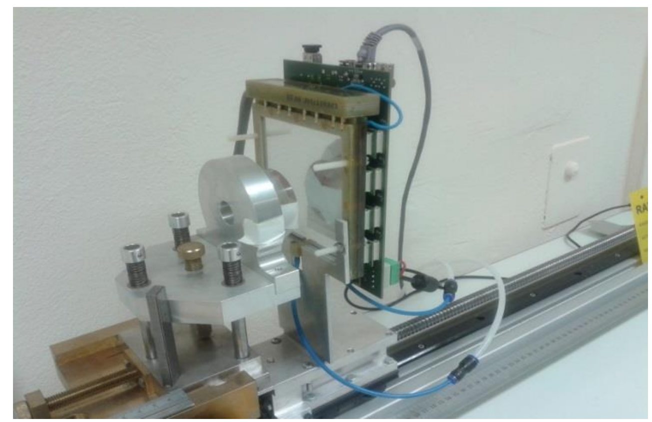


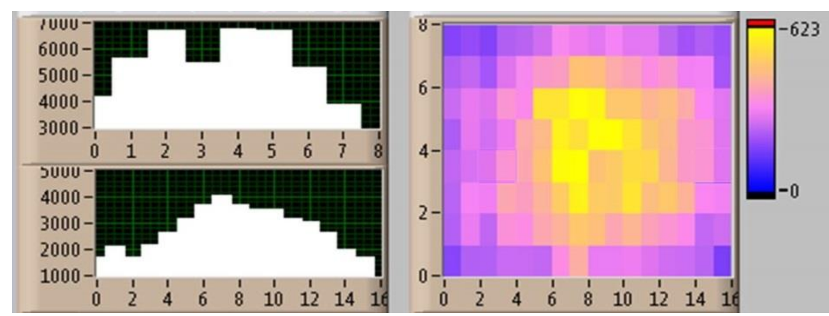
These images was realized in real time moving a triple gem with an array of 128 pads 0.5x0.5 mm crossing the beam

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



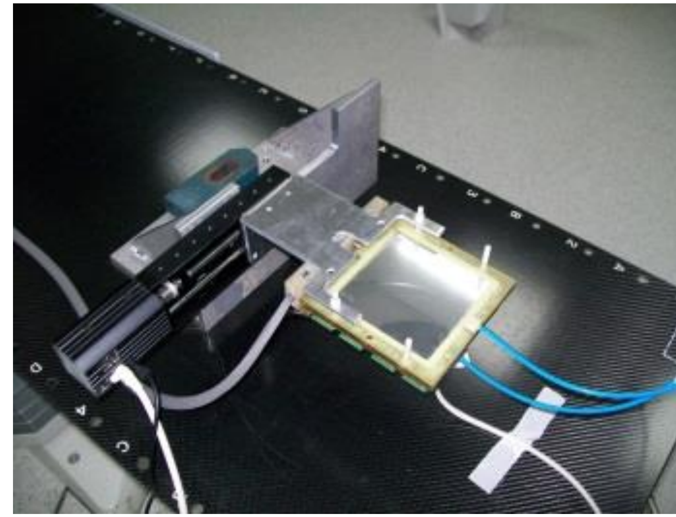




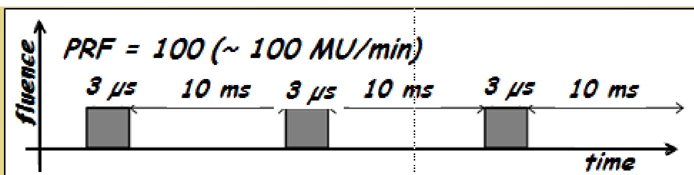
Possibility to find the hot spot

Radiation monitor in radiotherapy and hadron therapy

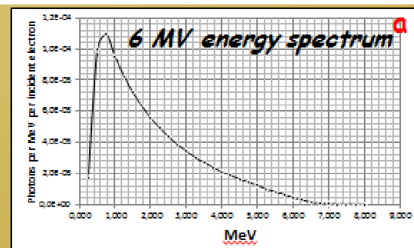
Gamma flux measurements at PTV

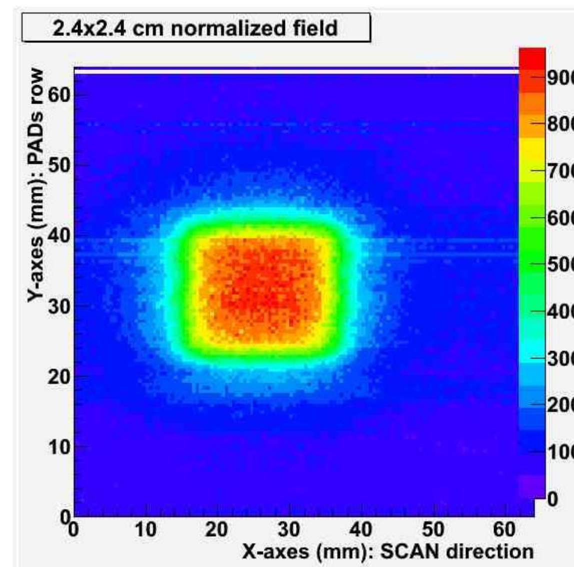


Gamma flux of 10^8 Hrz/cm^2 6-1 MeV



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



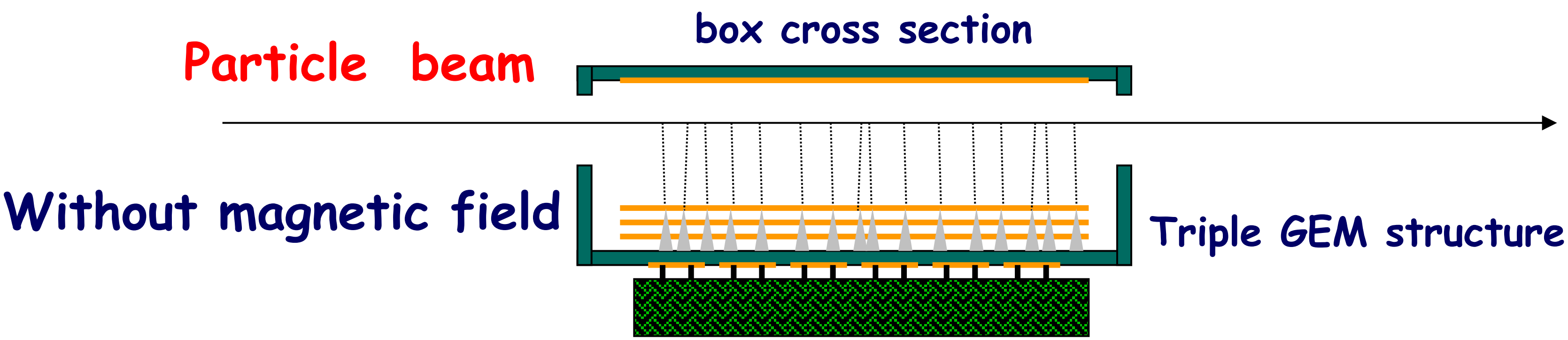


The flux of gamma in radiotherapy is composed by several 3 μs bunches

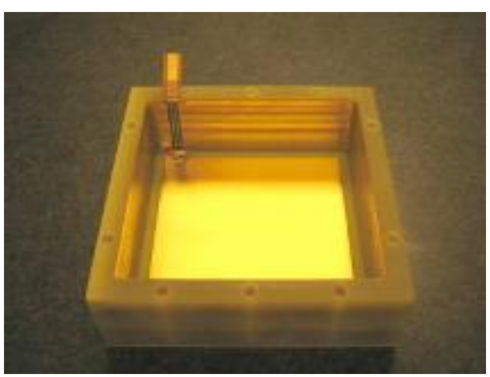
With a scan, a triple GEM with a row of 128 pad of 0.5x0.5 mm is moved crossing the beam. Each line is aquired in 200 ms

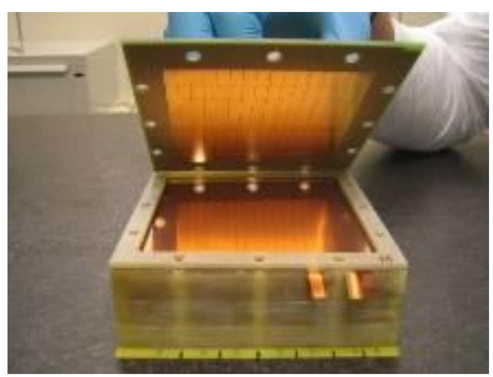
A Triple GEM beam monitor

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



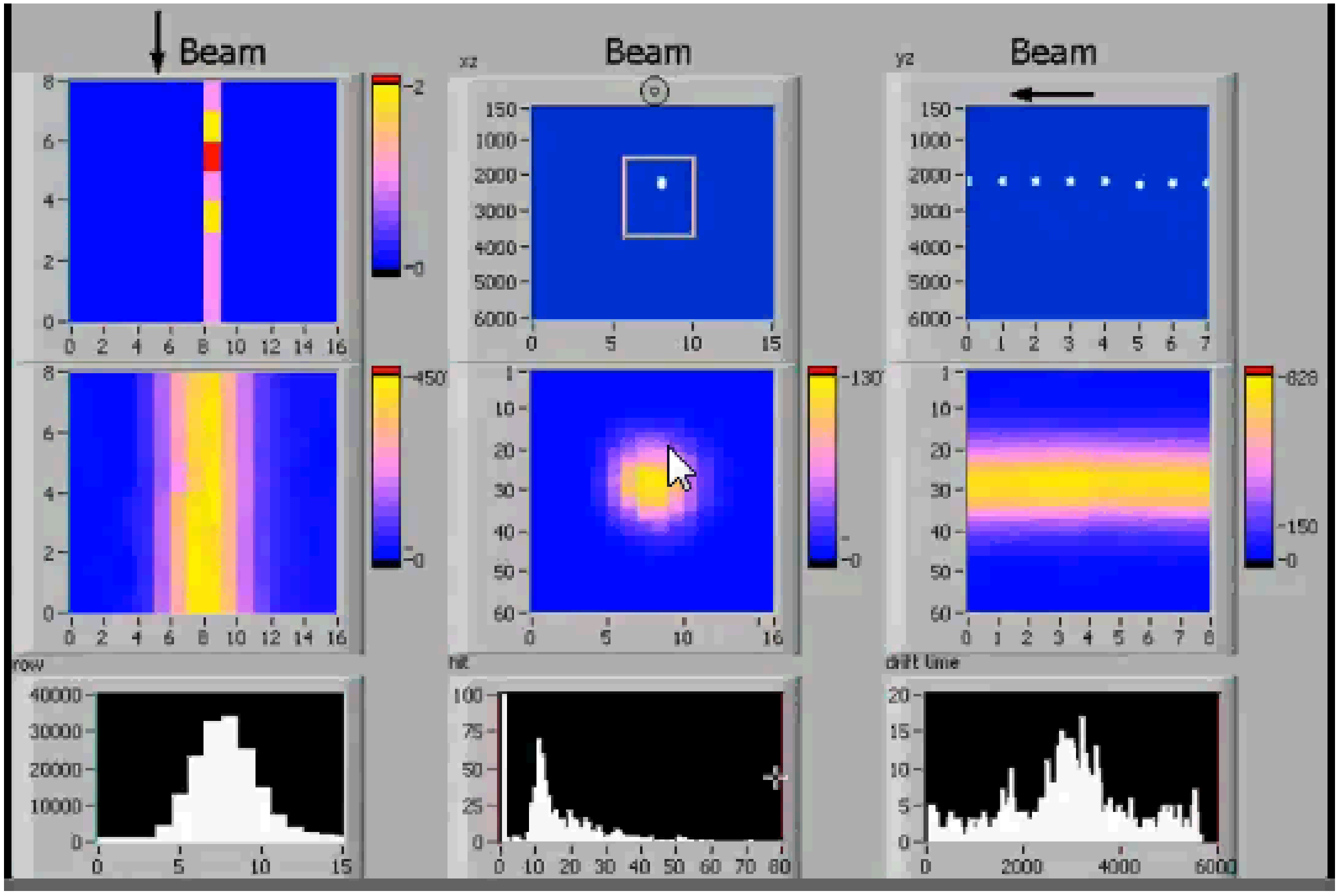
The material budget crossed by a particle is only two kapton foils (<0.2%X_0) used for the field cage necessary for the drift field uniformity





Real time track reconstruction

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



Single event

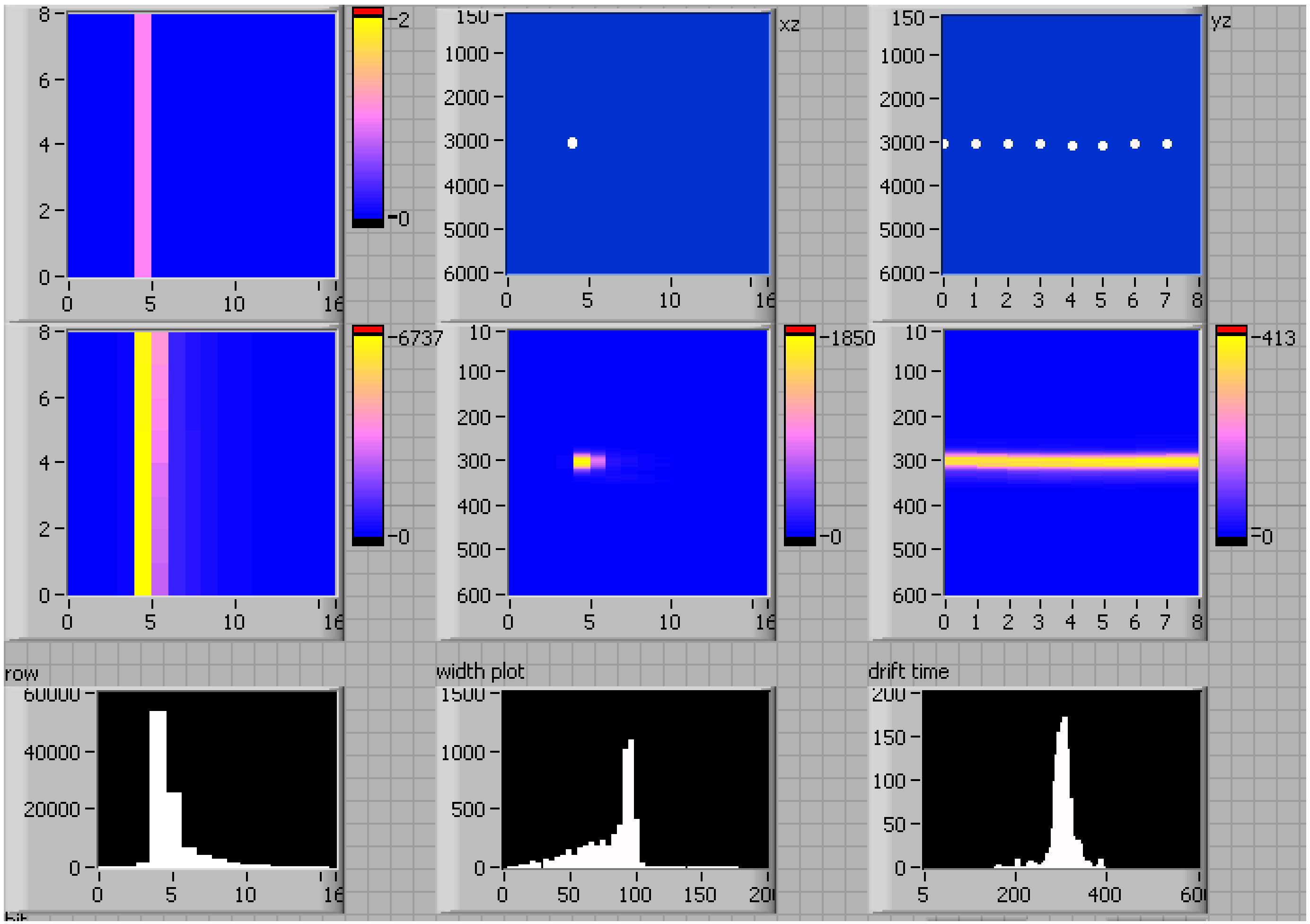
History

Profiles

This is a screen shot of the TPC GEM Online Console

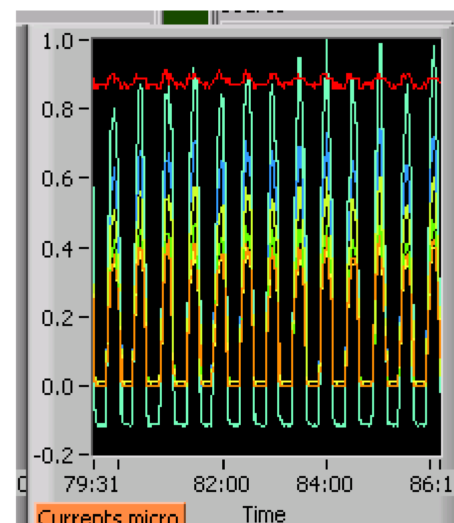
Lead Ions at CERN H8

The test was performed in November 2011



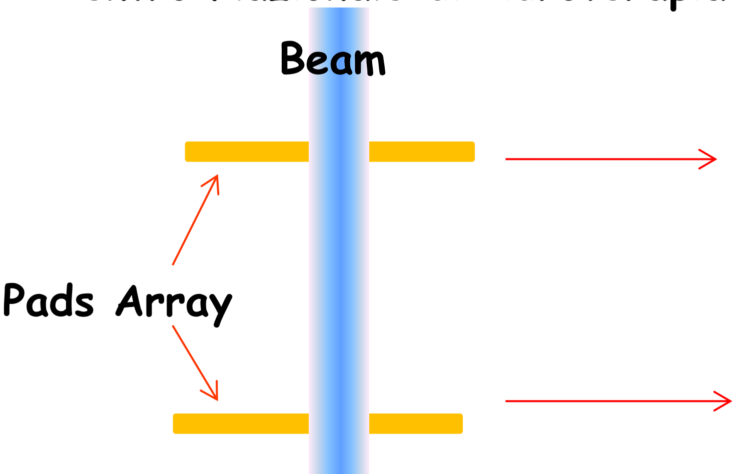
Time zero for 3D reconstruction taken with a Scintillator

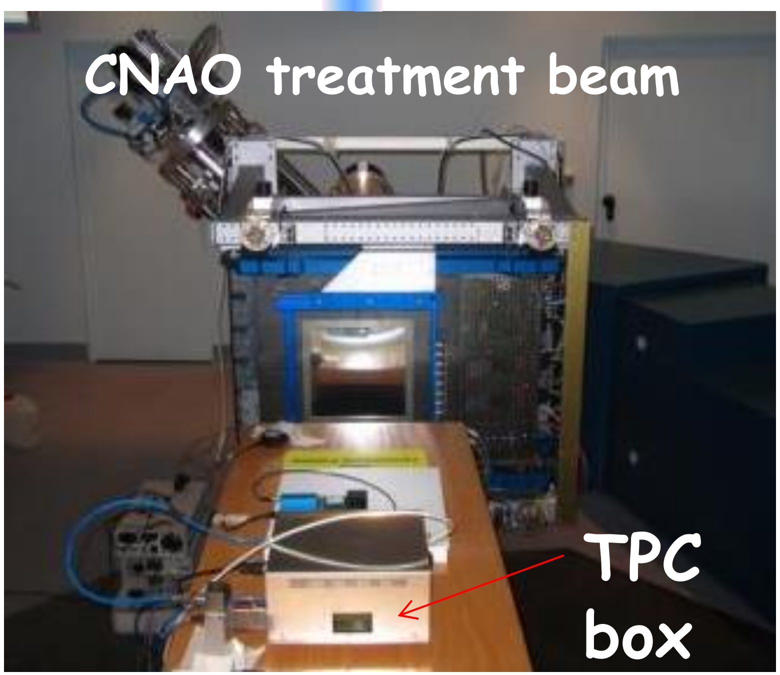
The ion beam is spilled in 12-17 sec (currents from HV)

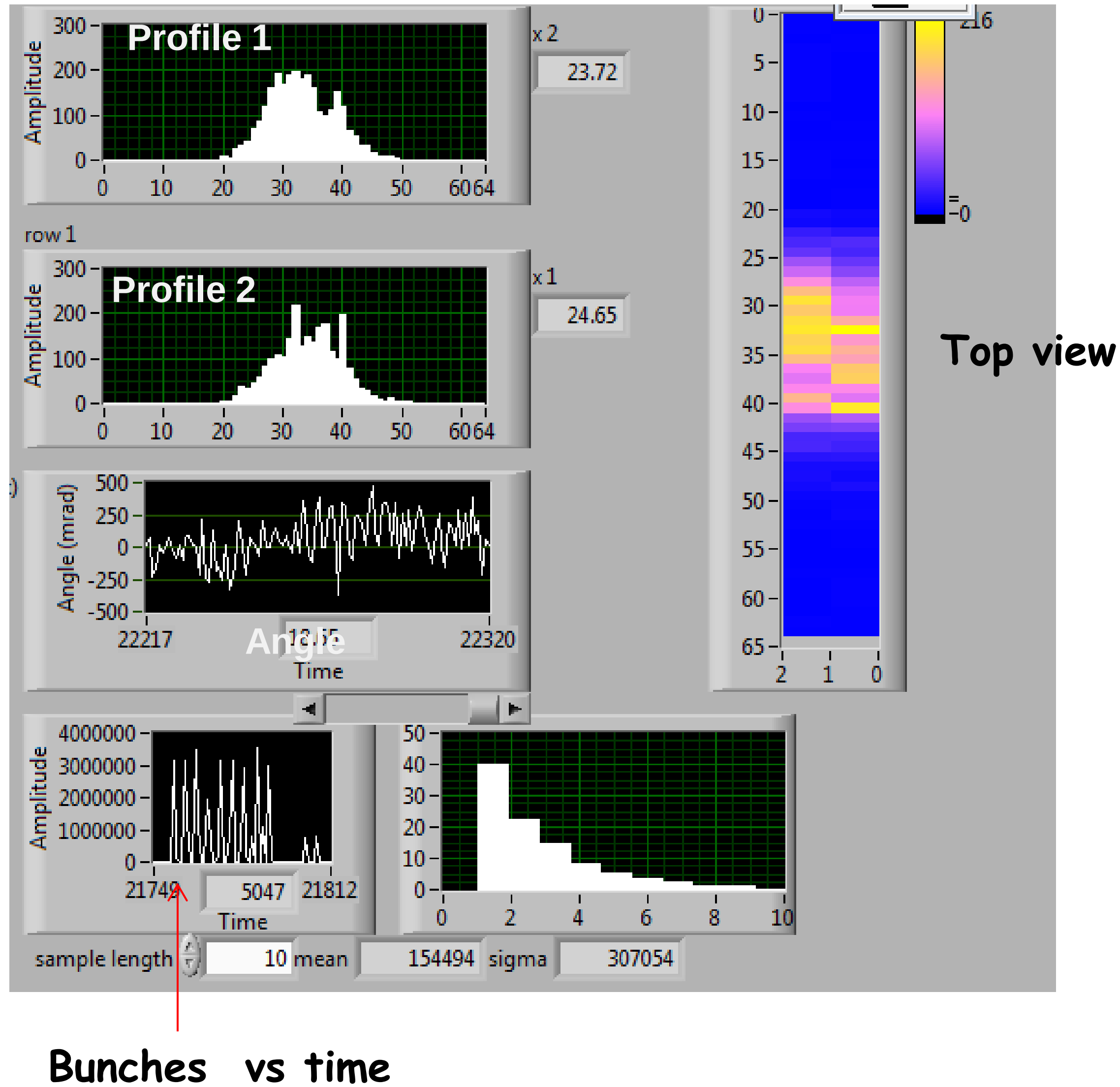


Test at CNAO: 10^8 protoni/sec

Centro Nazionale di Adroterapia Oncologica (Pavia)





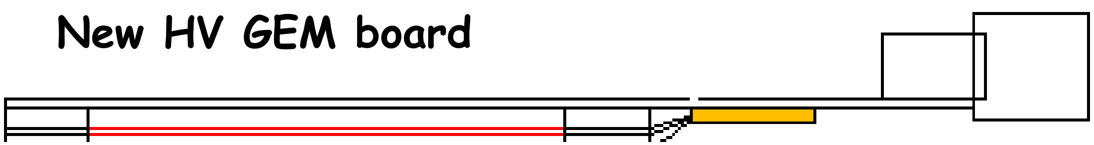


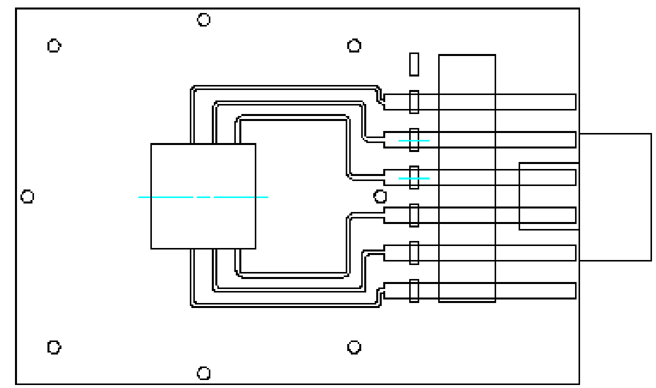
GEMPIX detector

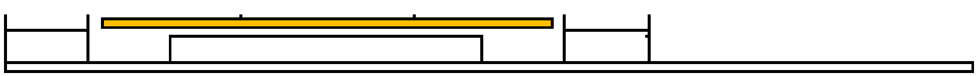
Assembling

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

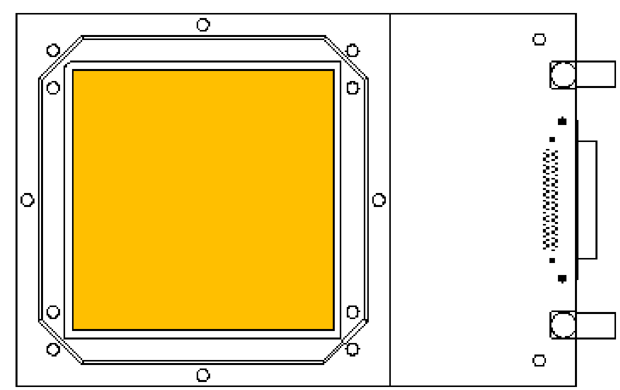
New HV GEM board







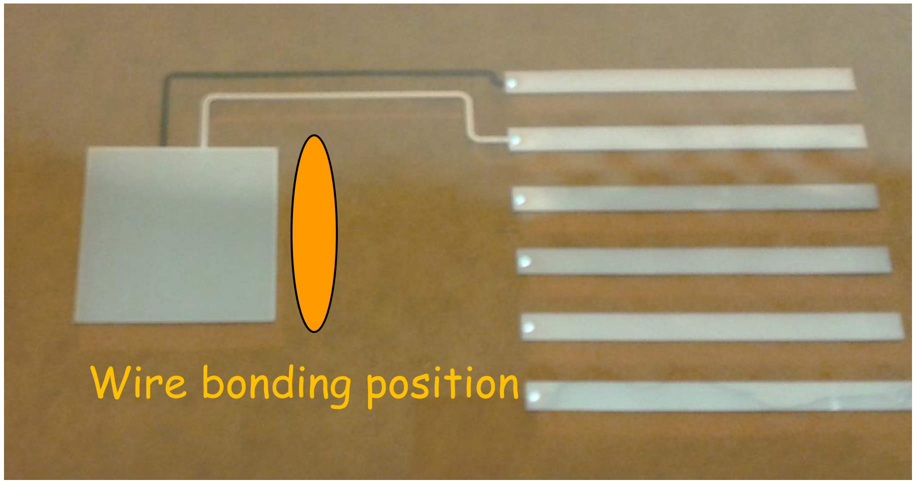
Quad medipix board



M.Campbell, J.Alzoy

Top view

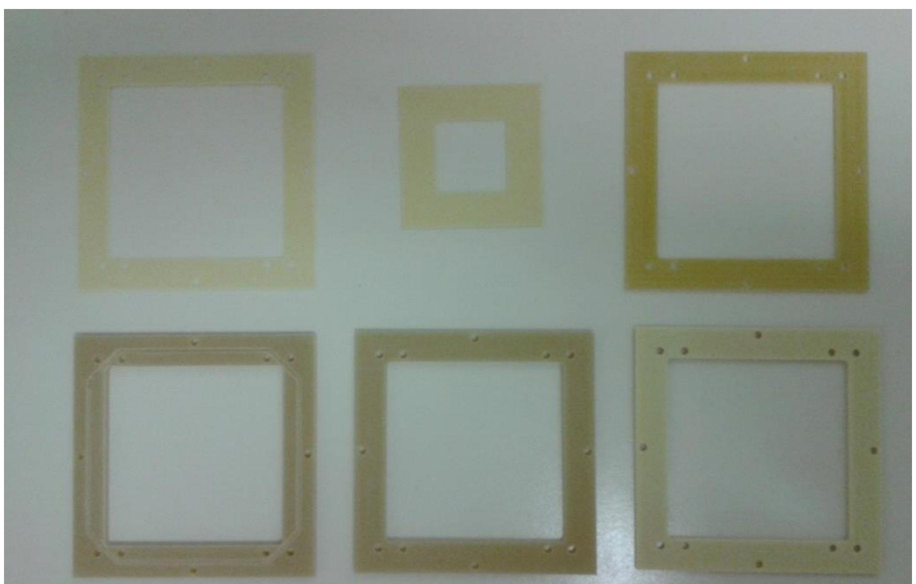
Gem foils and frame

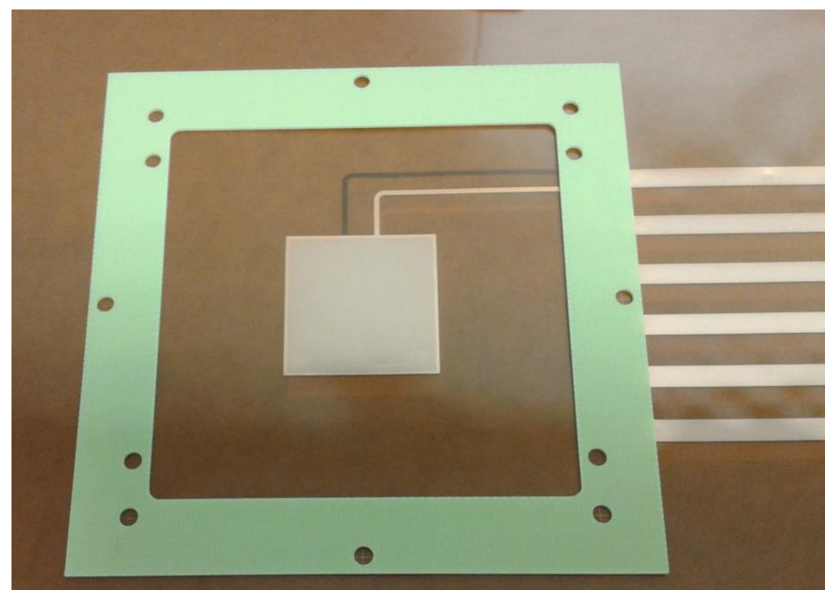


A new GEM layout has been designed
Active area of 28x28 mm^2
The electordes path have been designed to avoid the medipix wire bonding.
Produced by Rui De Oliveira.

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

5 different thickness (from 1 to 5 mm)

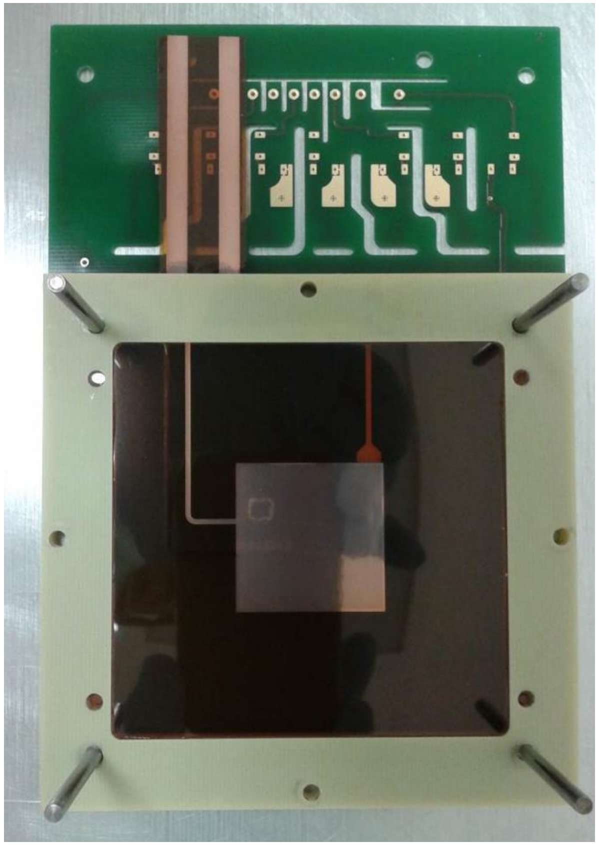


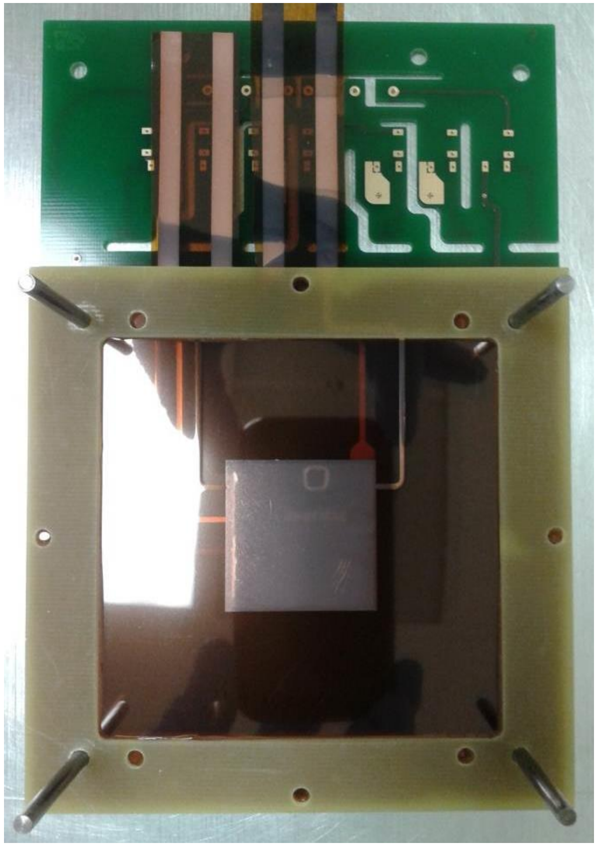


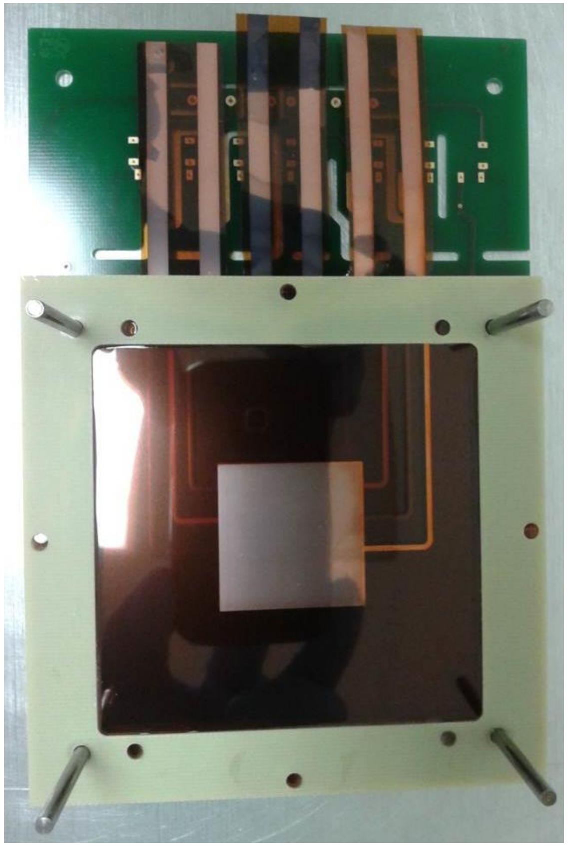
Assembling the GEM foils

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

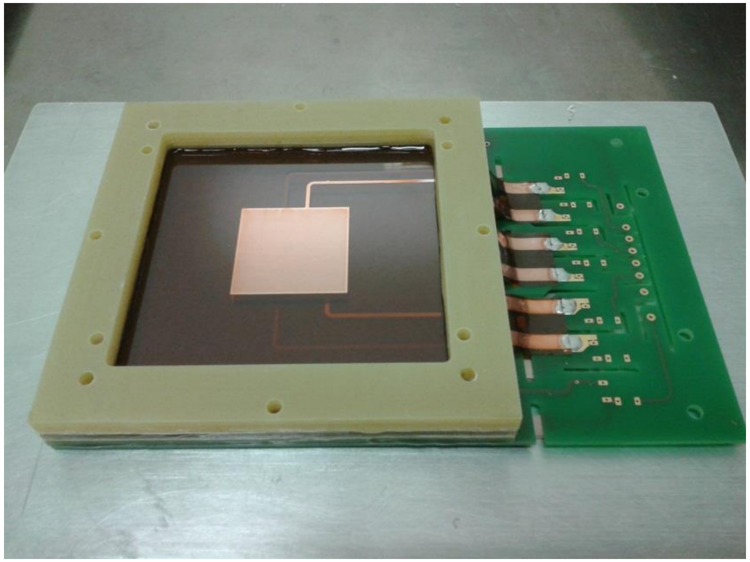


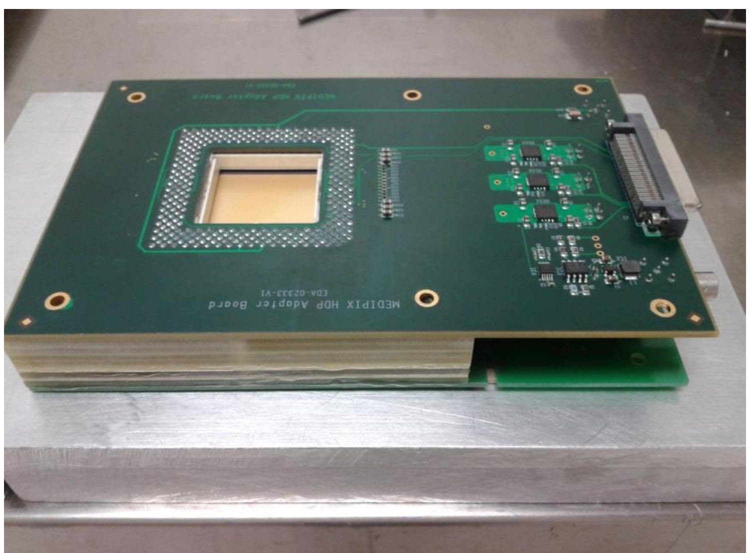


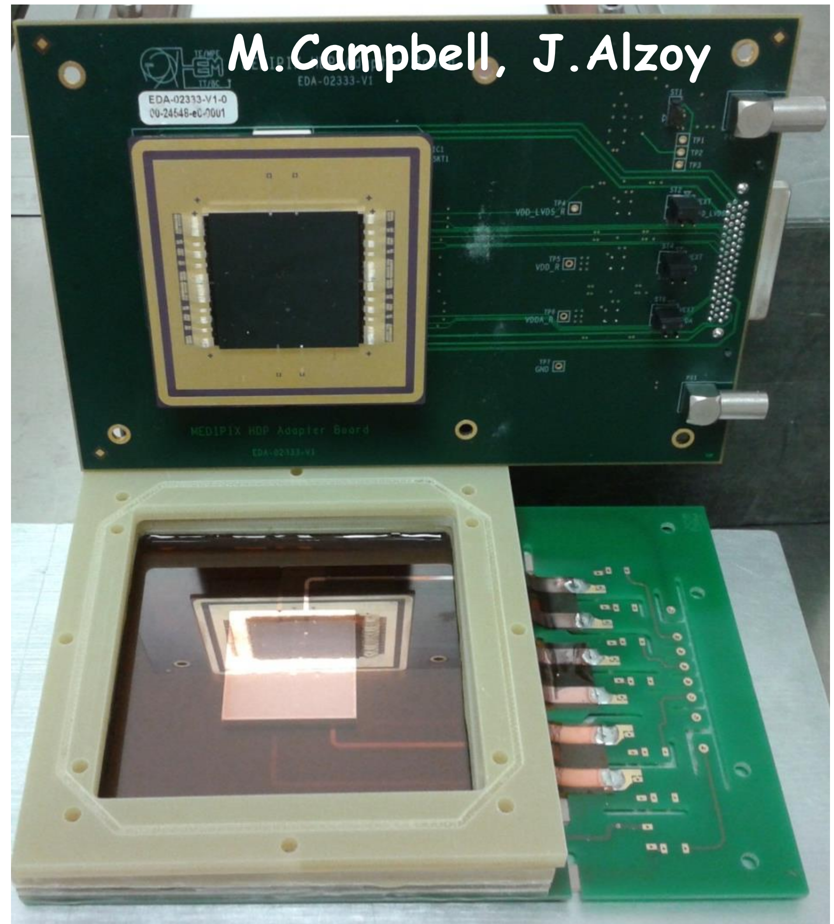


Final detector and assembly

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

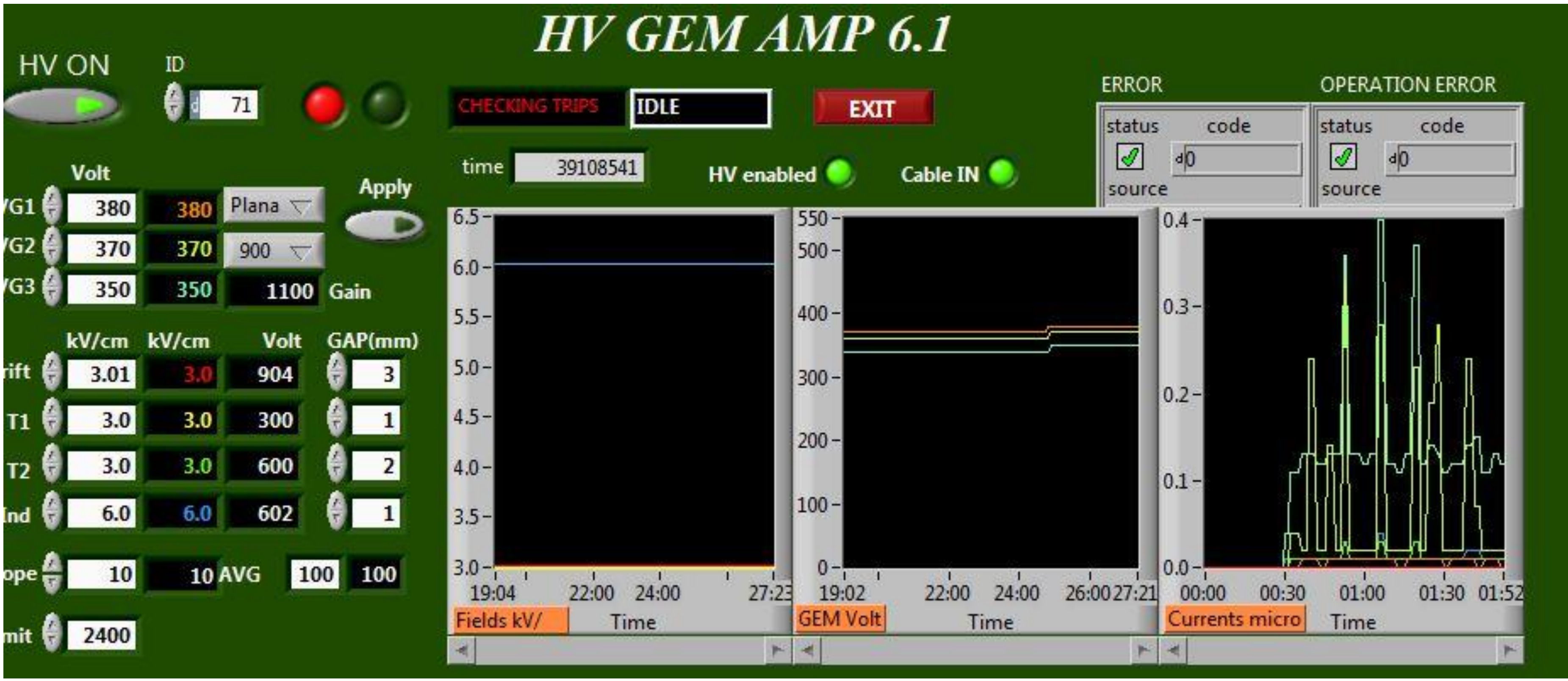




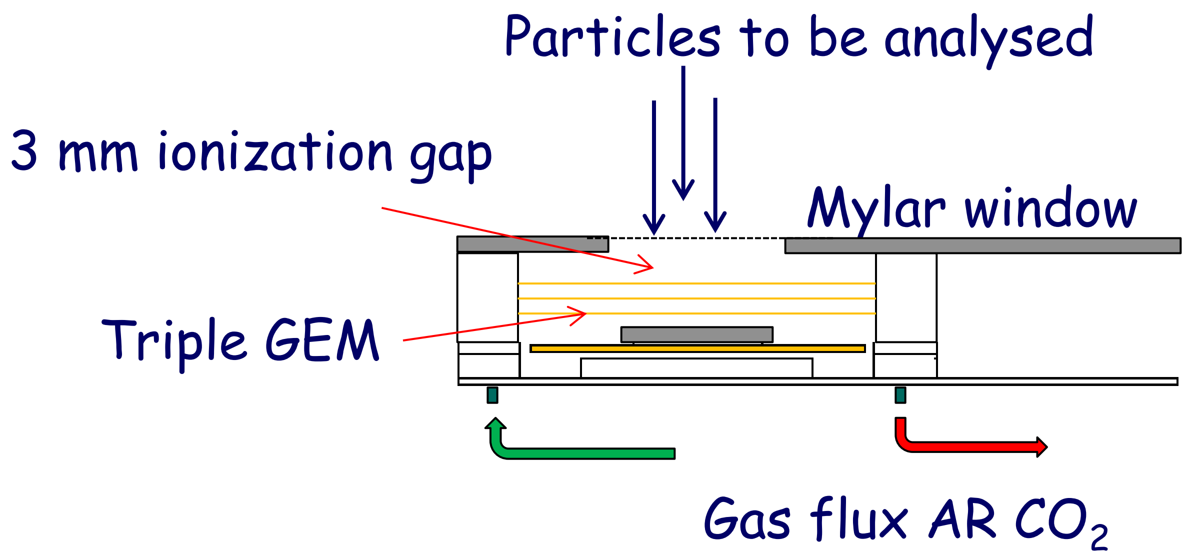


Induced sparks

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



Head on detector

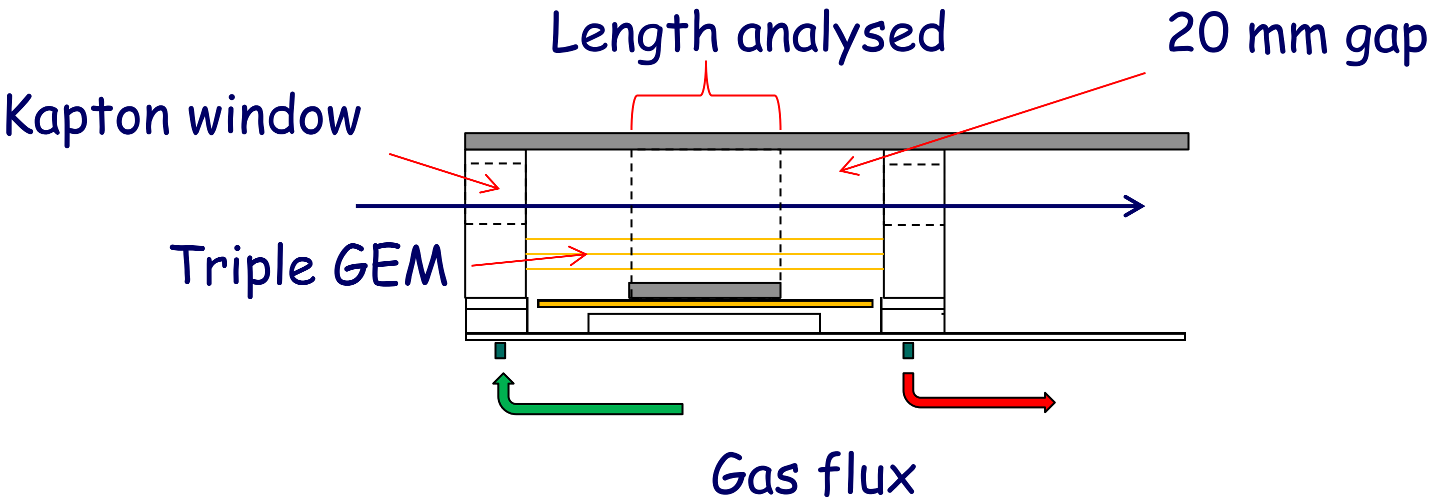


The detector is a quad naked medipix :
The active area is 9 cm^2

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

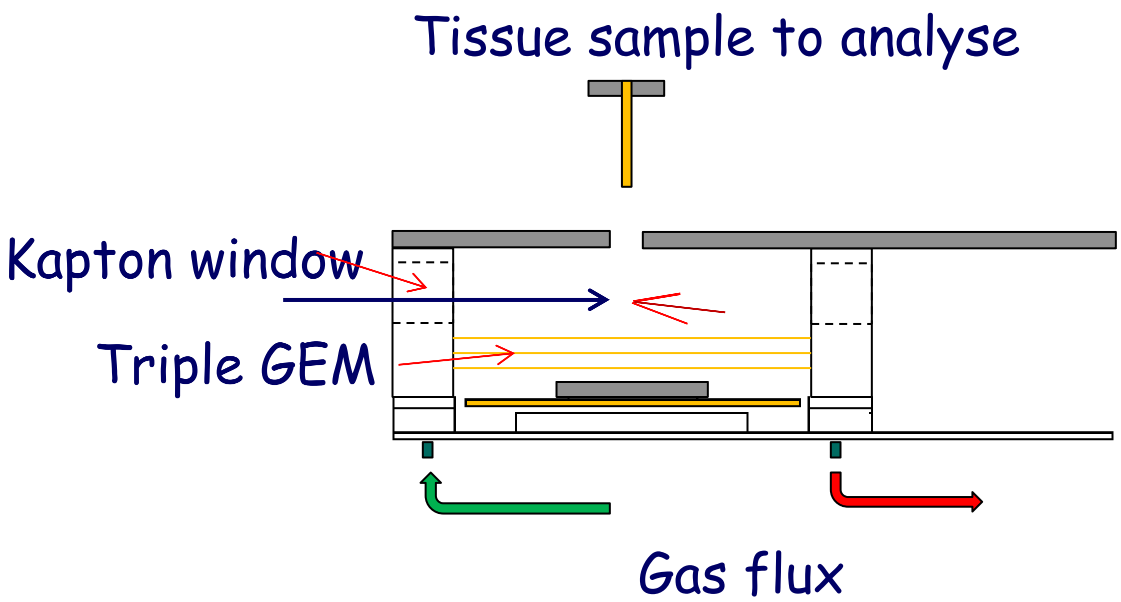


The detector is a quad naked medipix :
The active area is 9 cm^2
The particle track is analysed with 512 pixel in 3 cm length

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

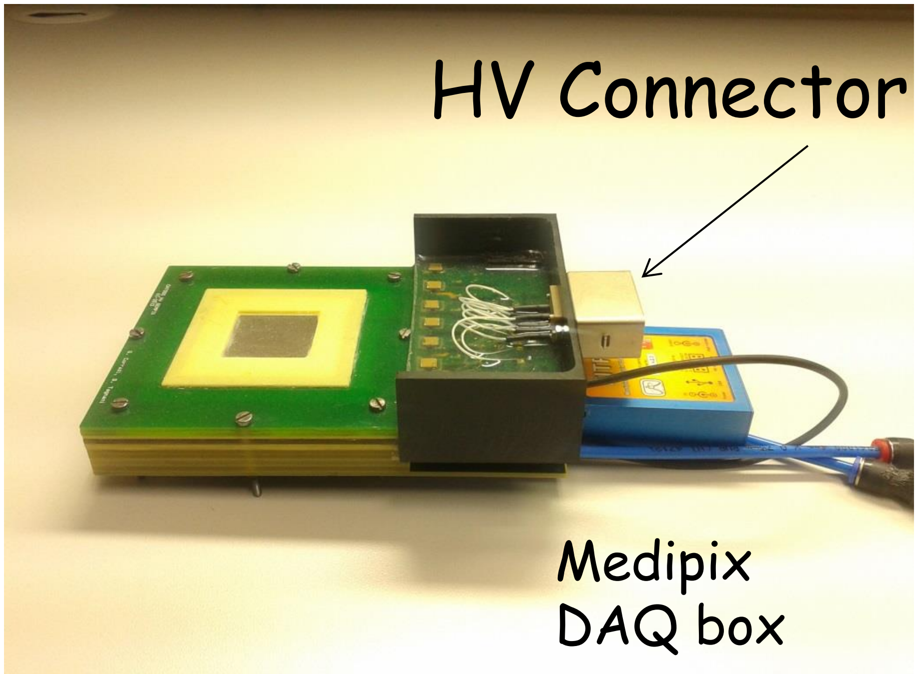
Detector for tissue sample

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

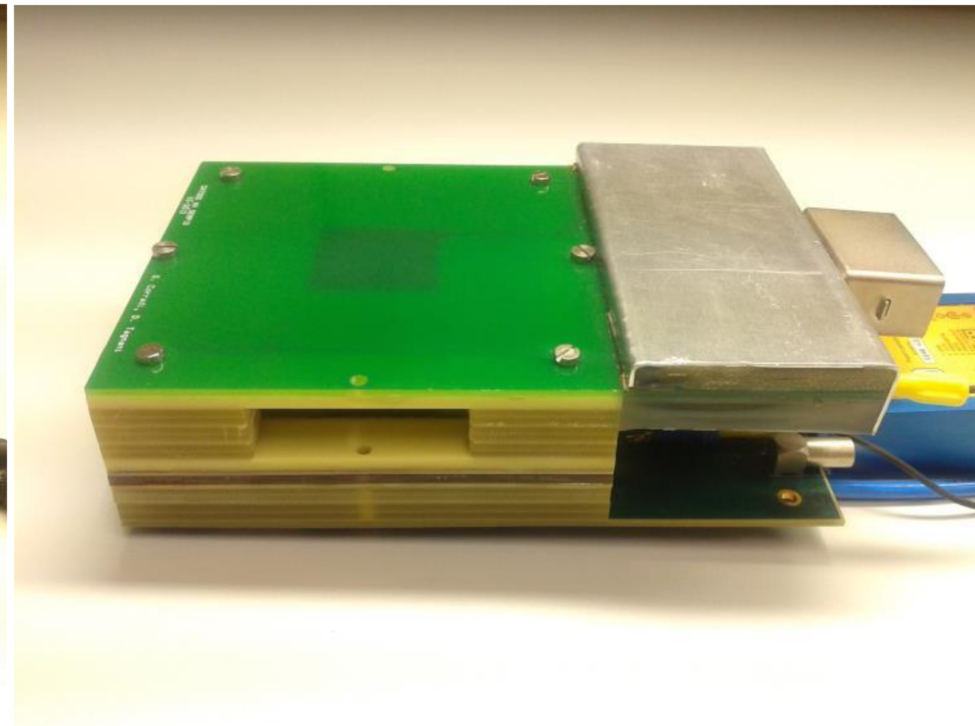


This prototype will be built on september

Two prototype of GEMPIX



Head-on detector

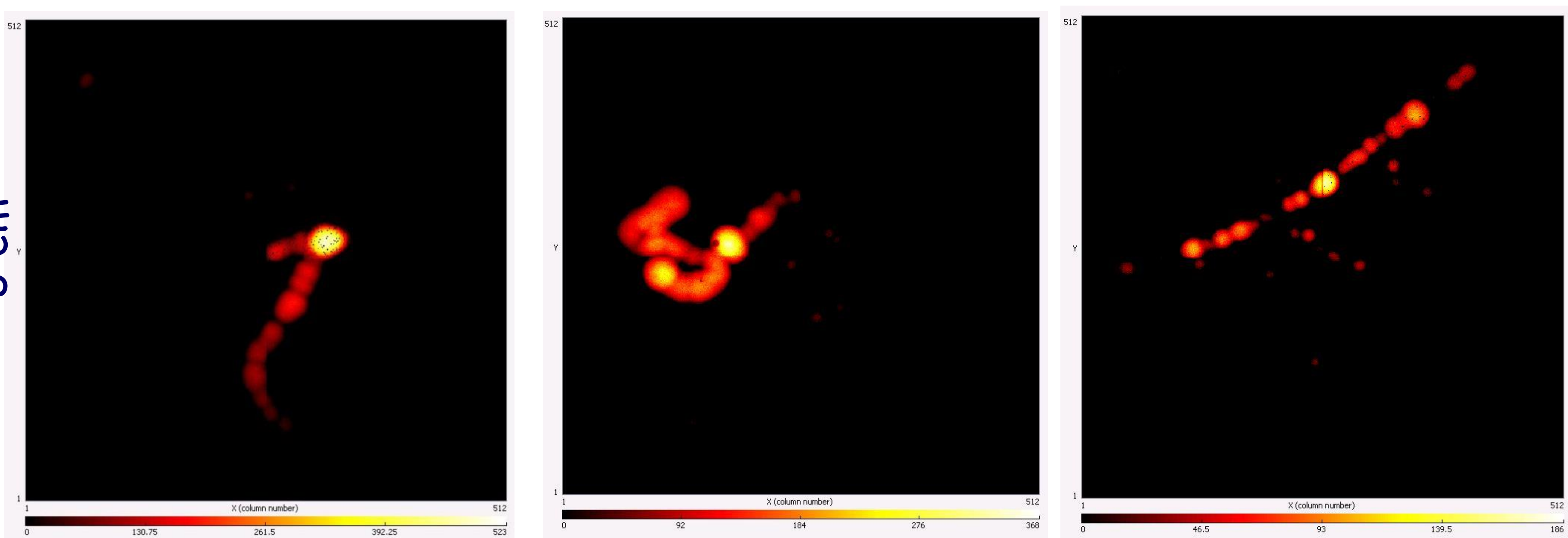


Side-on detector

Cosmic rays with a gas AR/CO_2 70:30

These are the first pictures taken with the GEMPIX

3 cm

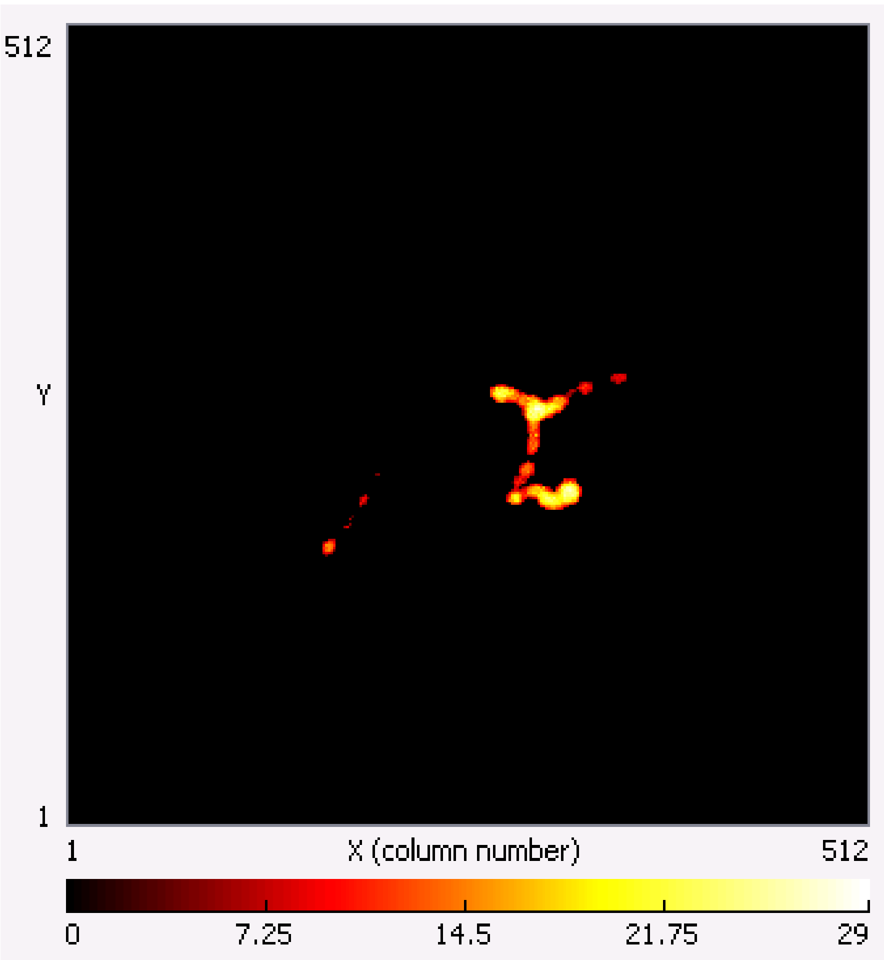


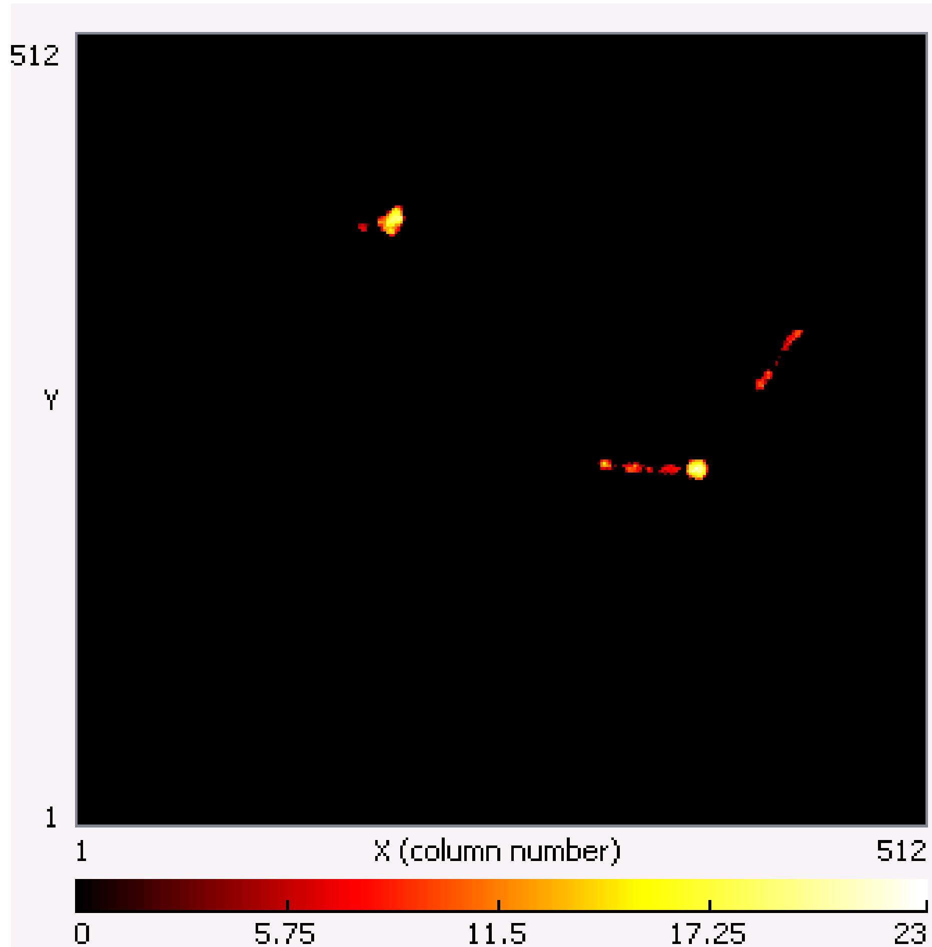
3 cm

With this type of gas mixture to high diffusion

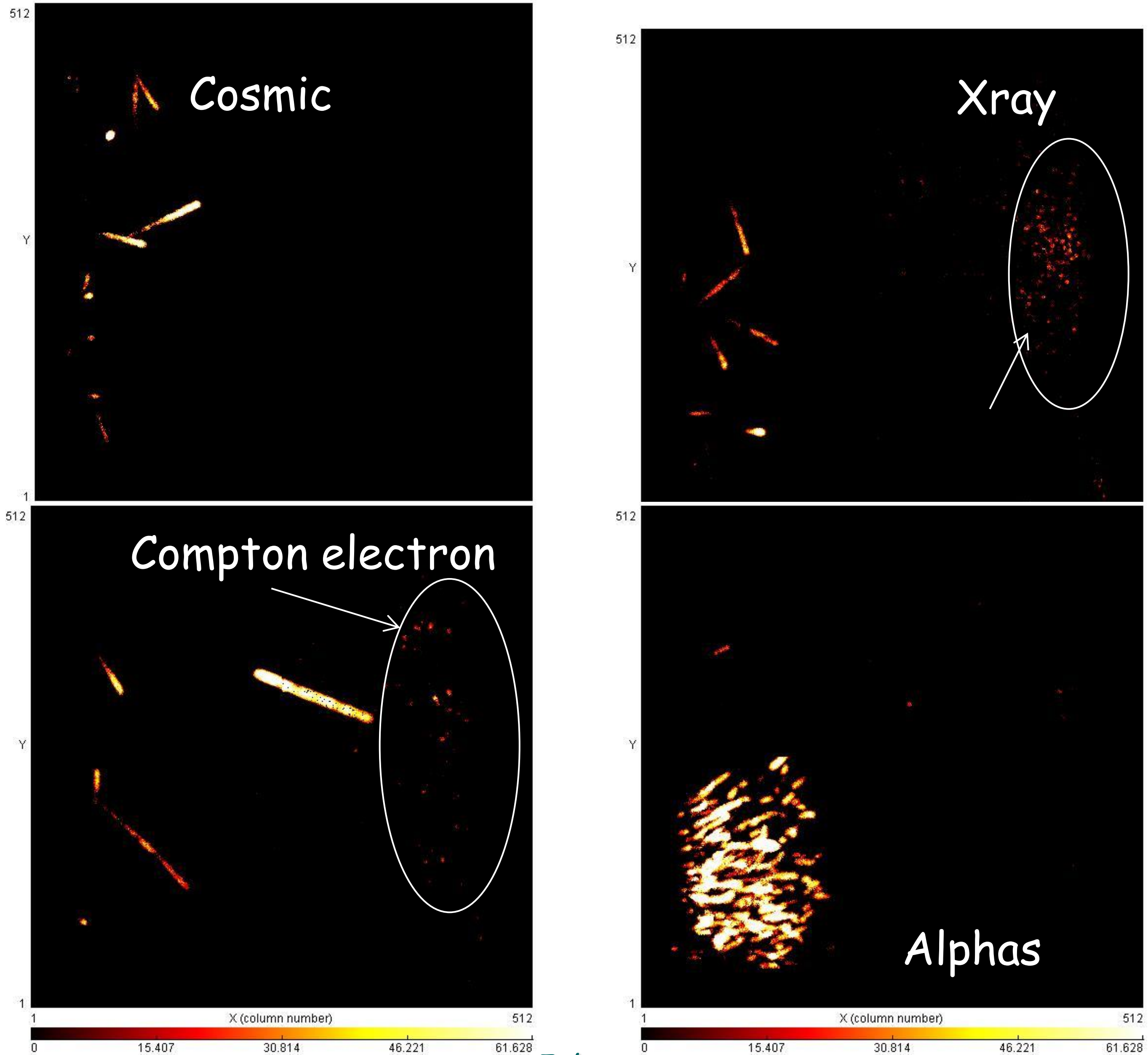
Other gas mixture : AR CO_2 CF_4

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





Signals from radioactive source

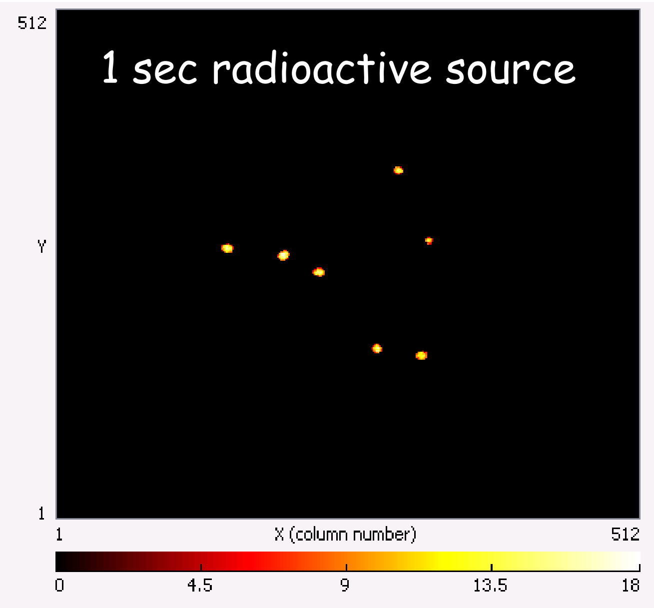


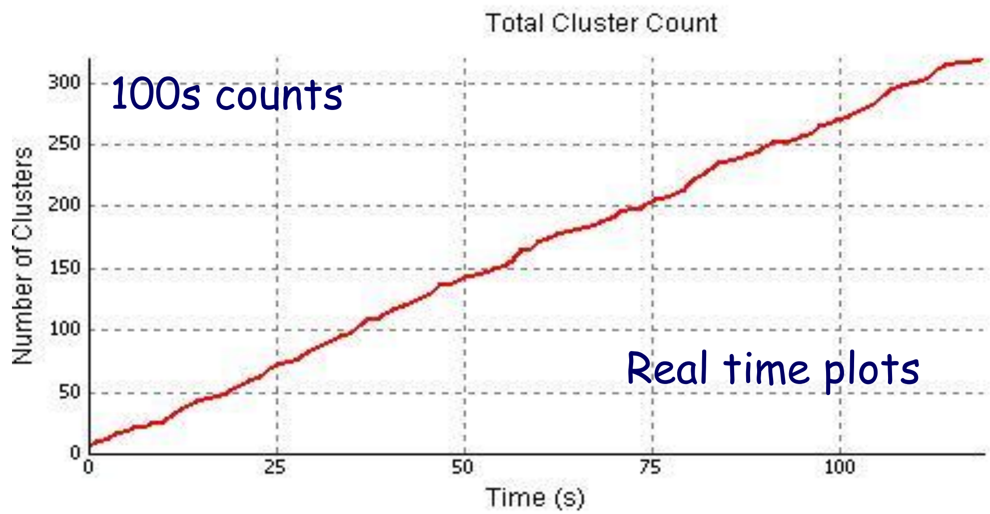
These pictures were taken with radiactive sources of ^{55}Fe Cesium and Americium

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

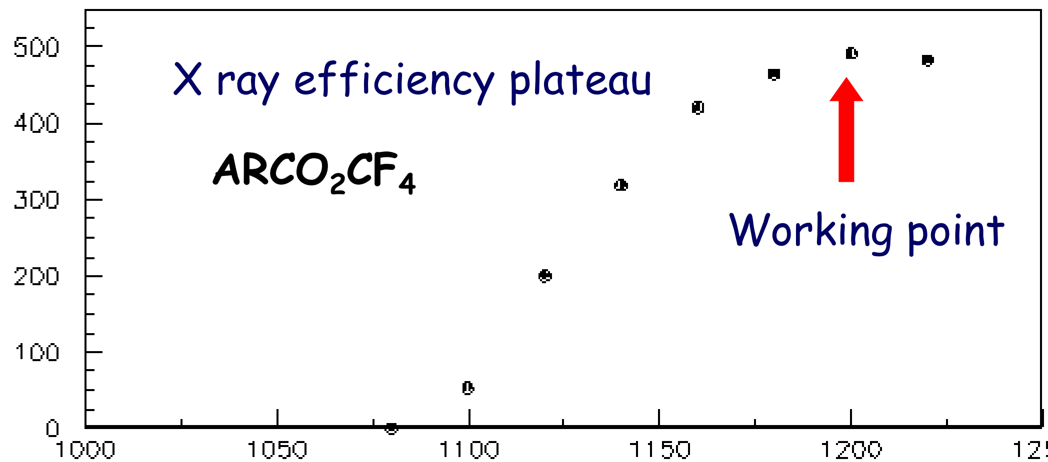
With a gain of 6000 and an induction field of 2 kV/cm

Cluster counting ^{55}Fe





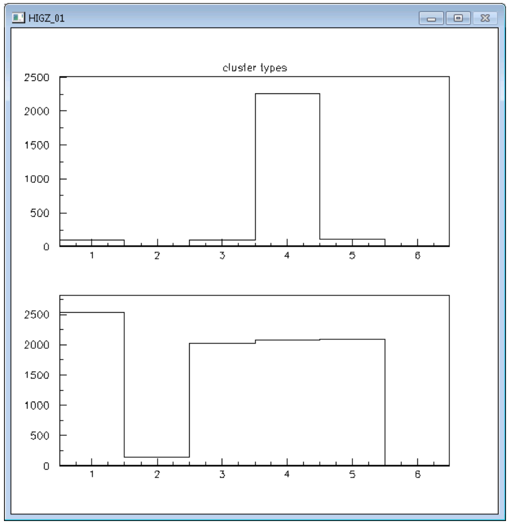
With this device it is possible to use all the patern recognition already developed for medipix by Praga group.



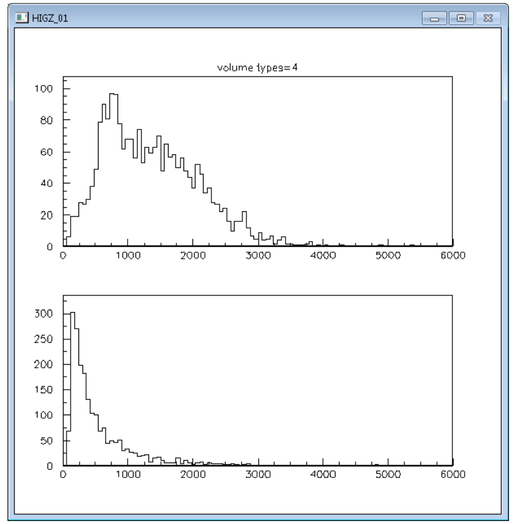
With timepix3 will be possible the 3D track reconstruction and dE/dX measurements at the same time

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

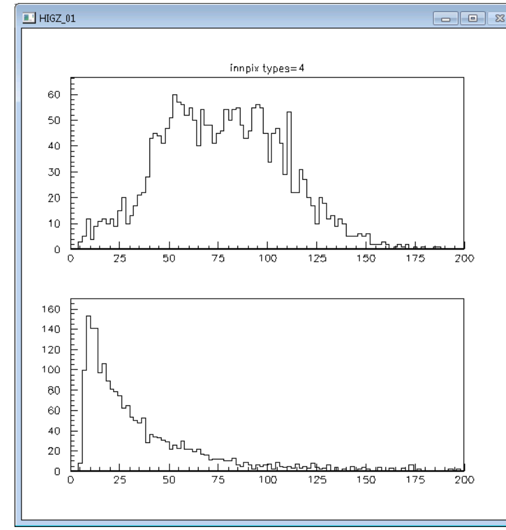
Cluster type

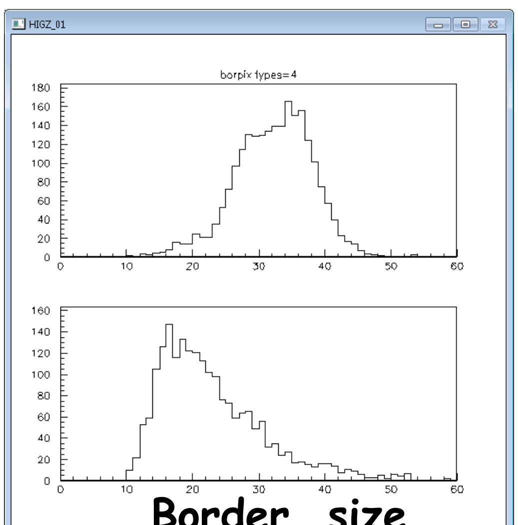


Cluster volume

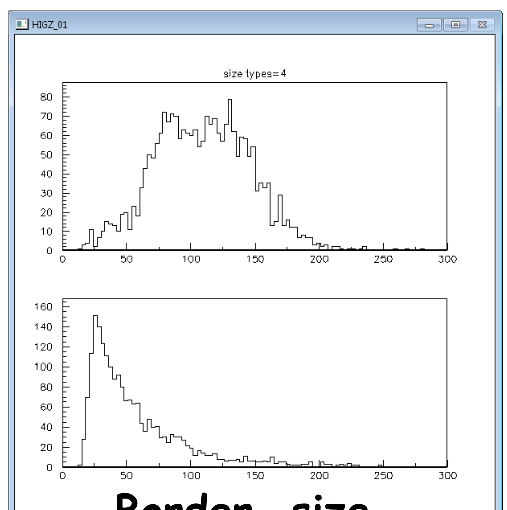


Inner size

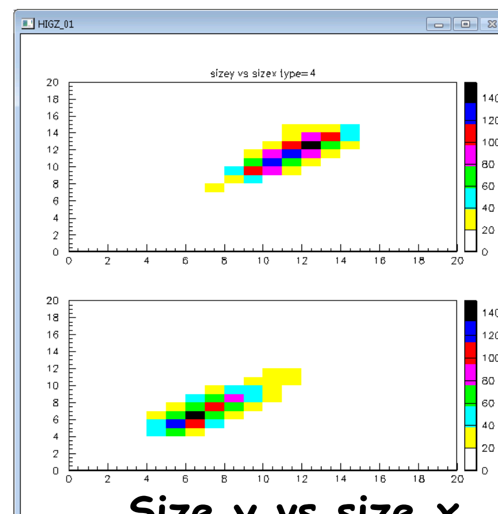




Border size



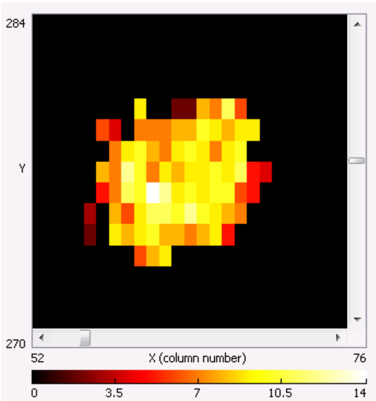
Border size

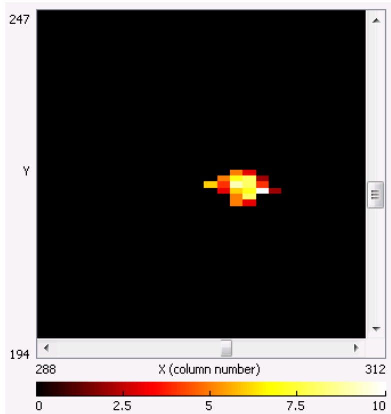


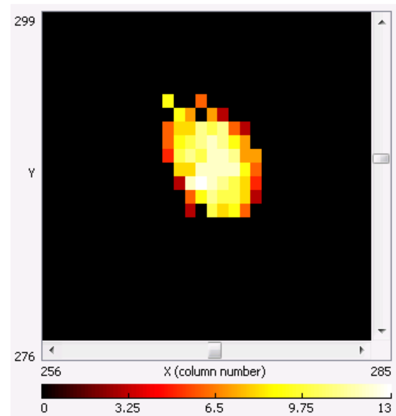
Size y vs size x

Detailed energy deposition

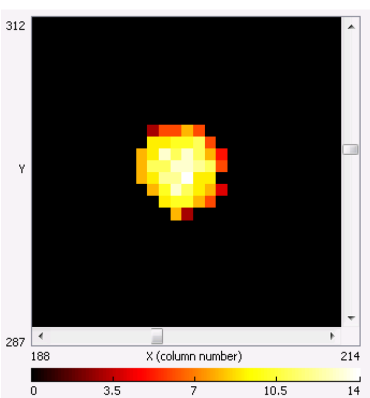
Cobalt (compton electron) 1100V — 1120V

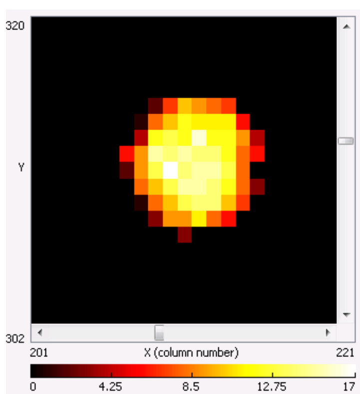


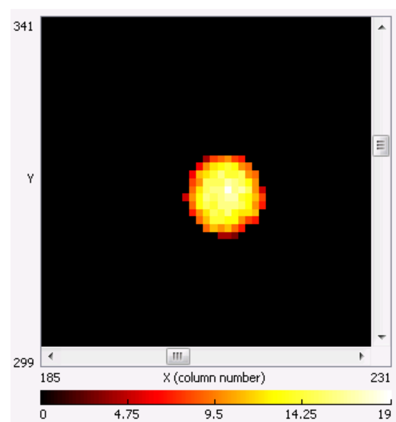




X Ray 1100V — 1160V





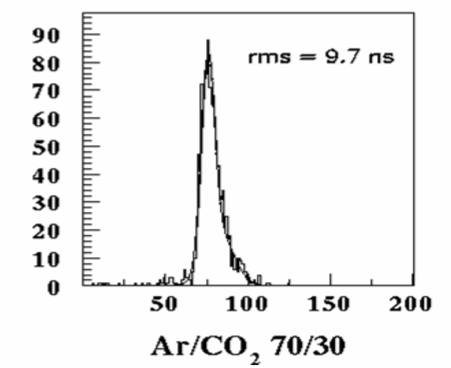


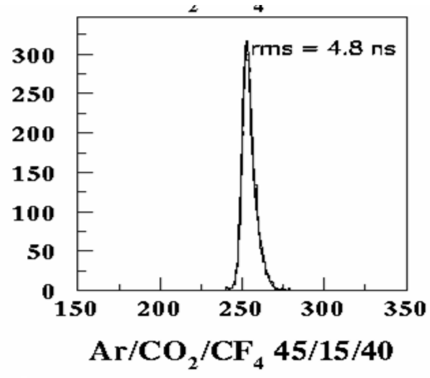
Still a lot of work to do .... but a really promising detector

Summary

- ✓ The triple GEM tecnology is very relayable and usefull for different applications in different science and technology fields
- ✓ Non HEP applications require a compact and quasi portable system.
- ✓ Recently very good results have been obtained for a real time fast and thermal neutron detectors with spatial and time high resolution
- ✓ High dinamic range in rate measurements with very low background from few X ray up to MHz of gamma in radio therapy.
- ✓ Working in progress for high efficiency thermal neutron detector
- ✓ New progress on high pixelated detector with GEMPIX and really interesting application in microdosimetry
- ✓ Other applications under studies in the framework of ARDENT project

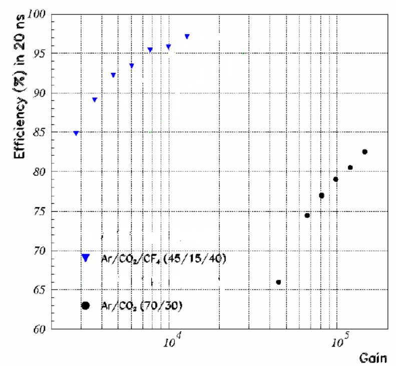
GEM Performances (2002-2006)





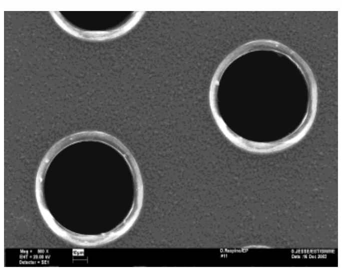
The results of several tests* on 10x10 cm^2 prototype allowed us to select the $Ar/CO_2/CF_4$ with geometry 3/1/2/1 mm

→ better time resolution 4.8 ns in respect of Ar/CO_2



→ higher efficiency at lower gas gain : 96% in 20 ns

Max space resolution O(100 μm)



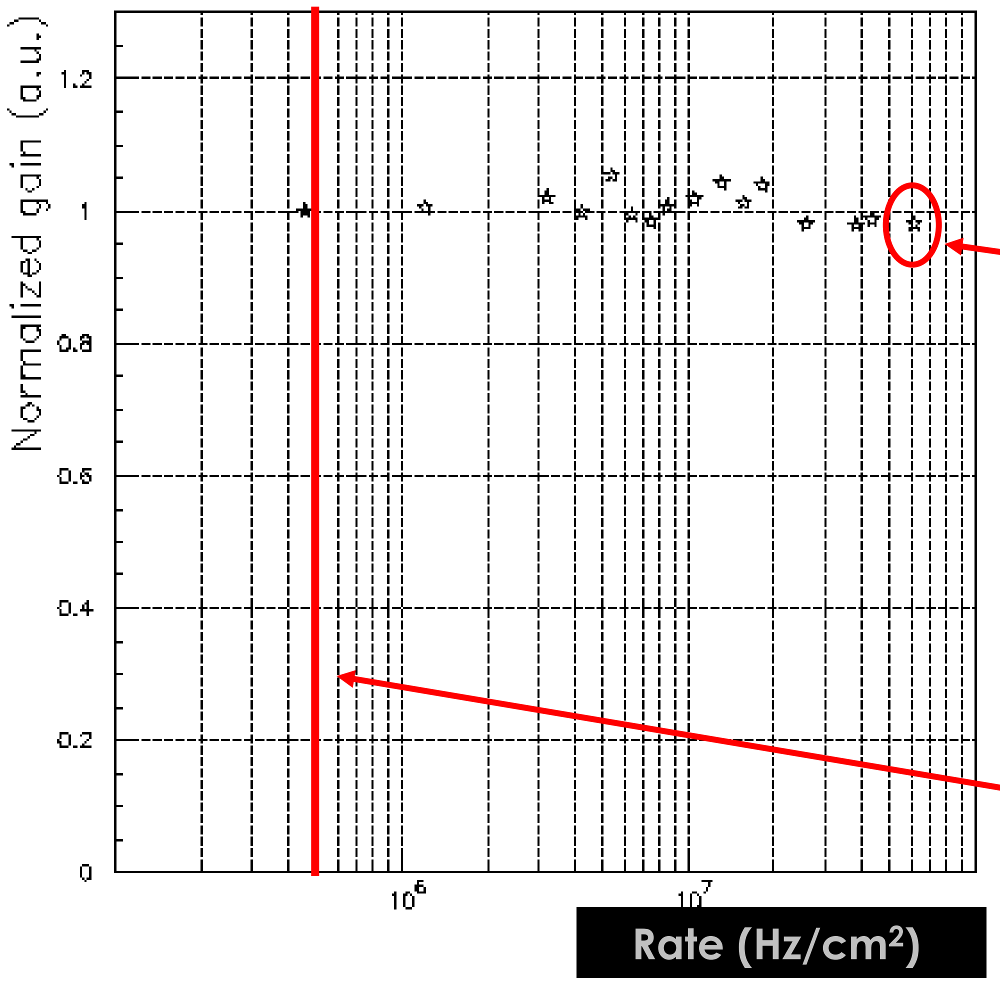
Ageing studies on whole detector area 20x24 cm^2:
25 kCi ^{60}Co source at 10 MHz/cm^2 on 500 cm^2
Integrated charge 2.2 C/cm^2

Detector performance recovered with a 15 V shift on HV

G.Bencivenni et al., NIM A 518 (2004) 106
P. de Simone et al., IEEE Trans. Nucl. Sci. 52 (2005) 2872

Linearity at very high rate

- The rate capability was measured with an X-ray (5.9 keV) tube over a spot of ~ 1 mm²
- The detector was operated at a gain of ~ $2x10^4$



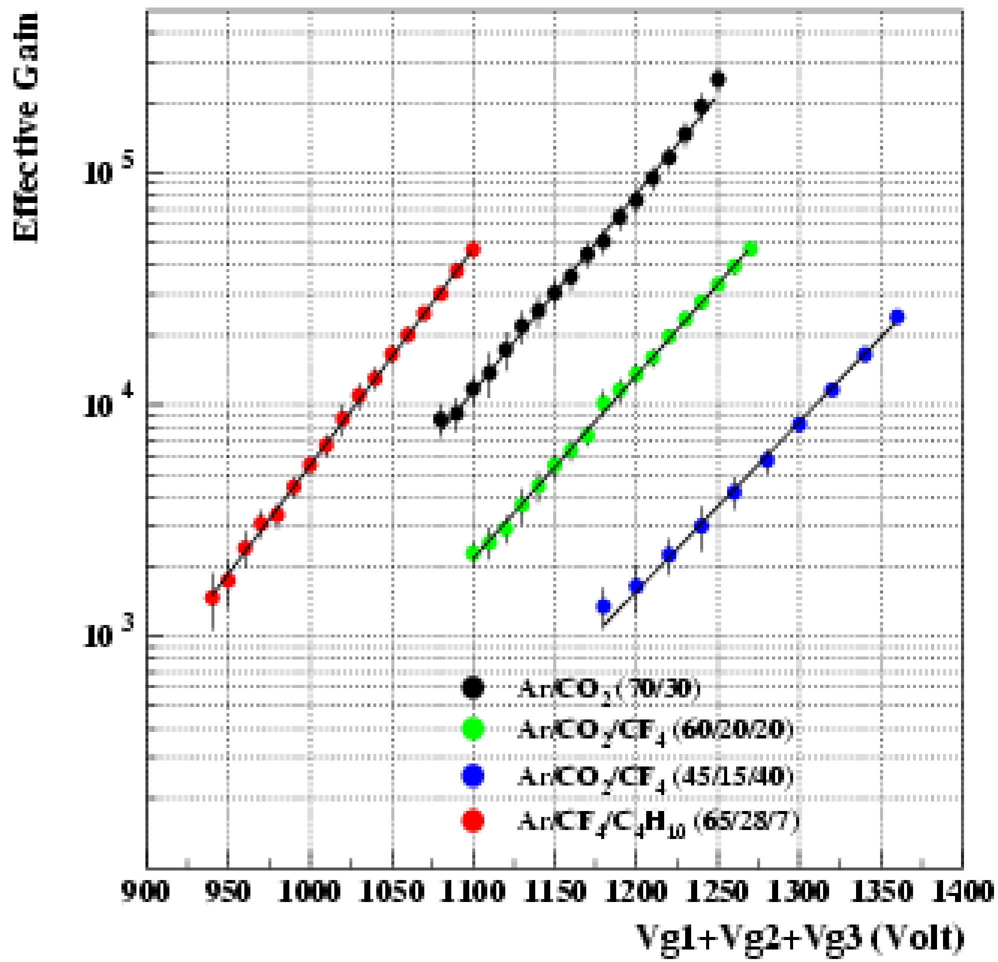
A very good gain stability was found up to a photon counting rate of 50 MHz/cm²

LHCb M1R1 maximum rate (460 kHz /cm²)

Gas Gain

The effective GAIN G_{eff} of the detector has been measured using a 5.9 keV X-ray tube, measuring the rate R and the current i, induced on pads, by X-rays incident on the GEM detector.

$G_{eff} = i / eNR$



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

A and α depend on the gas mixture.

Discharge probability

At PSI we exposed three detectors to a particle flux up to 300 MHz.

Each detector integrated, without any damage, about 5000 discharges.

In order to have no more than 5000 discharges in 10 years in M1R1 the discharge probability has to be kept below 2.5 10^{-12} (G < 17000).

This limit is conservative because up to 5000 discharges no damage was observed.

Working region