Front End Electronics for Gas Detectors
Pixel Integration - GEMPix

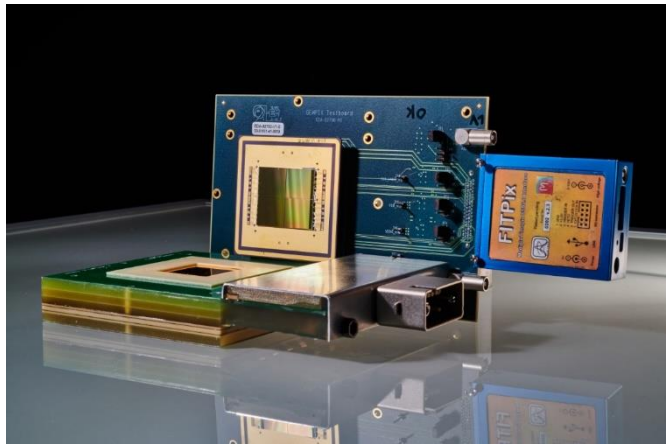
Fabrizio Murtas (CERN & INFN-LNF)

- **Pixel readout for GEM detectors**
- **GEMPix Detector**
- **GEMPix applications :**
  - **Nuclear Fusion studies on Laser Facility**
  - **Medical applications**
  - **Radiactive waste**
  - **Neutron detectors**
- **Large Area GEMPix**

Pixelated GEM Detector Readout

For any possible application you need hopefully a portable DAQ system → FPGA

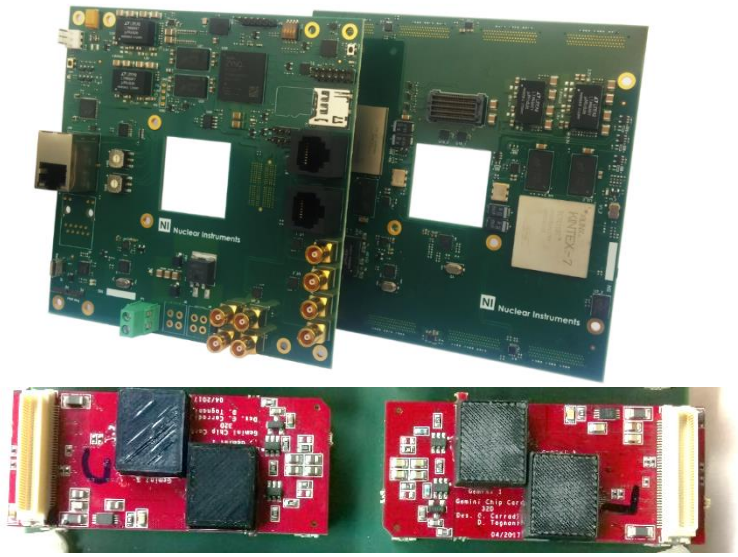
GEMPix



Timepix (1, 3 or 4) Chip
Up to 512x512 pixels = 262 kch
55x55 um^2 pixels
FPGA FITPIX (USB)

I'll show you this one

GEMINI + FPGA

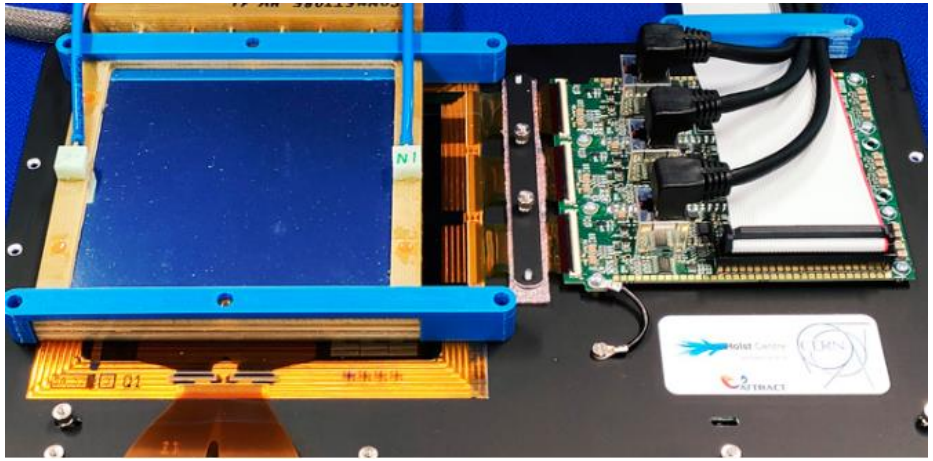


Gemini Chip 16 ch
Gemini Board 32 or 64 ch
FPGA 256 ch (Ethernet or optical)

NI Nuclear Instruments

Abba talk tomorrow

TNO TFT



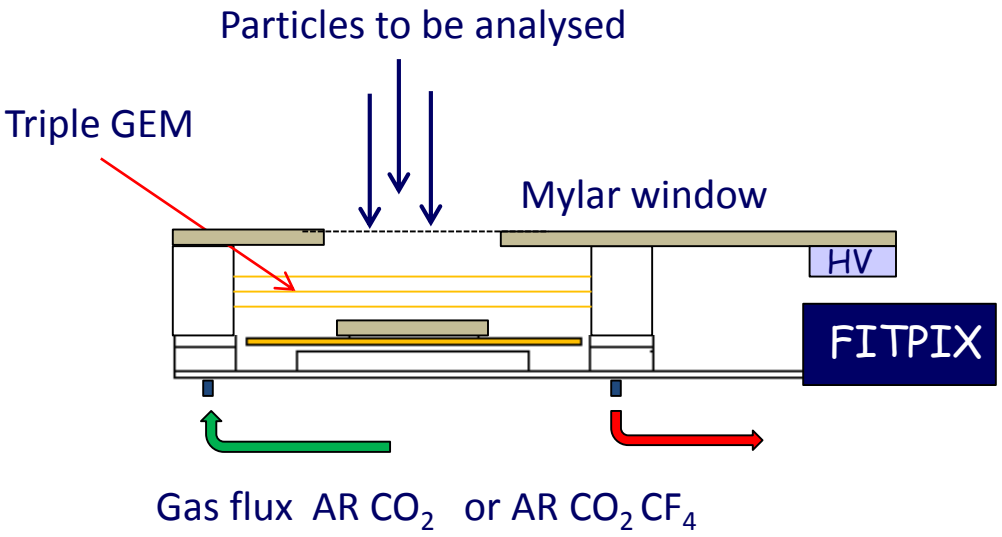
Thin Film Transistor
480 x 640 pixels
126x126 um for each pixel
FPGA (Ethernet)

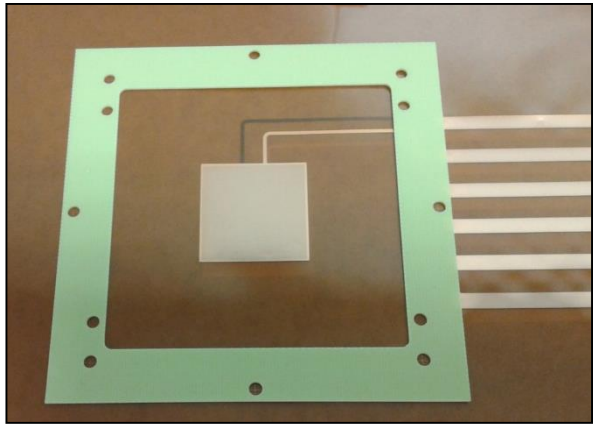
TNO innovation for life

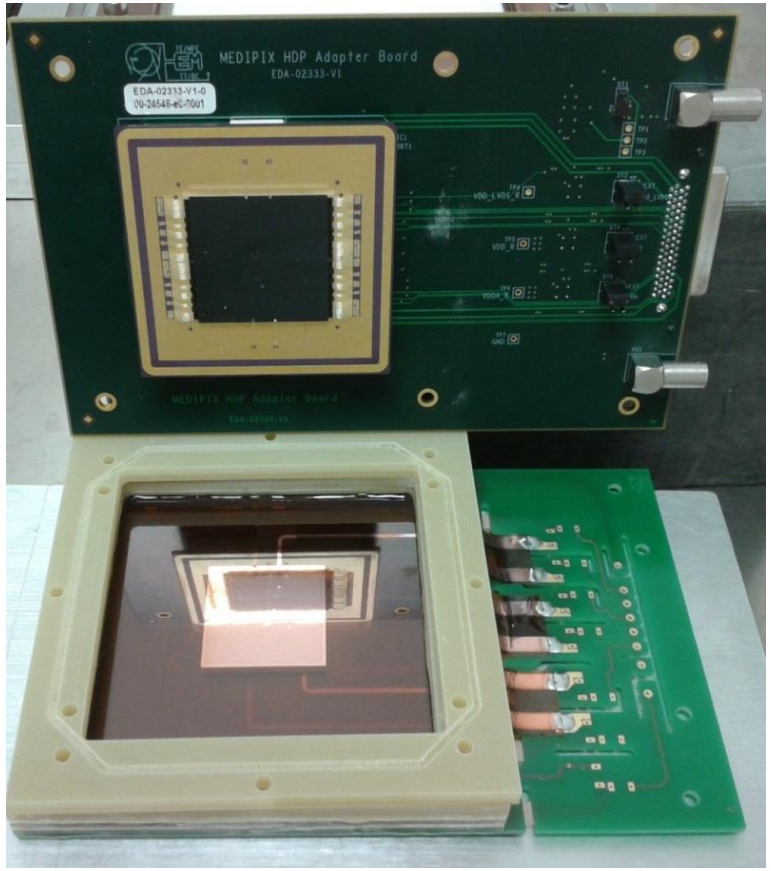
One slide at the end

GEMPix detector: head on version

The detector is composed by a small triple GEM chamber and a Quad Timepix1
Both technologies were developed at CERN



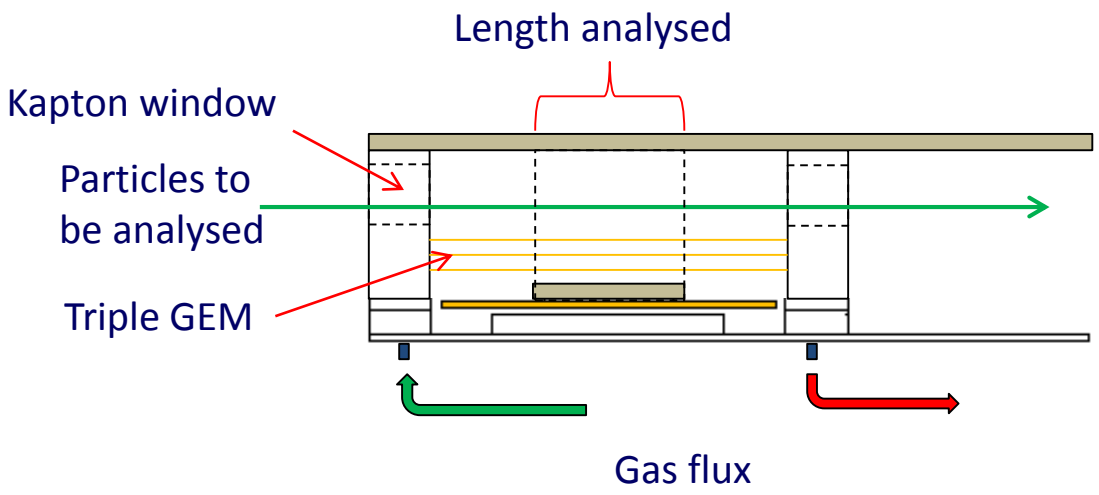


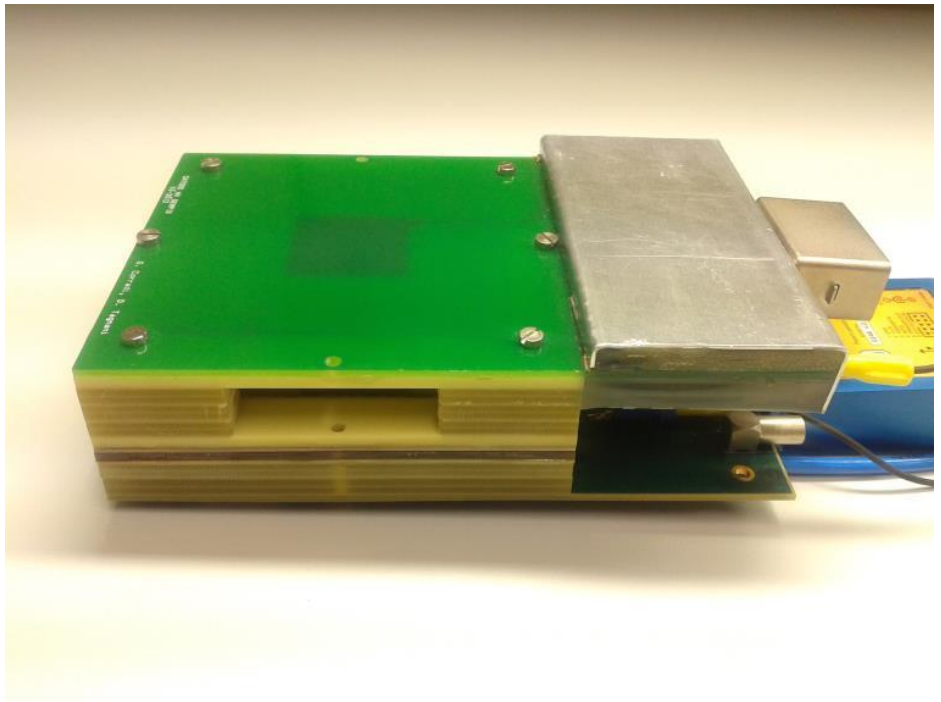


F.Murtas, The GEMPix detector. Radiation Measurements Vol. 138, Nov. 2020, 106421

The triple GEM detector and the board readout are mechanical coupled and gas sealed with O-ring
The anode is a quad naked Timepix1 (without silicon sensor) mounted on a ceramic board.
The active area is 30x30 mm^2 with GEM foils specifically designed and realized at CERN (R. De Oliveira)
The readout is performed with Fitpix (FPGA) through a USB cable and PIXELMAN software

A small TPC

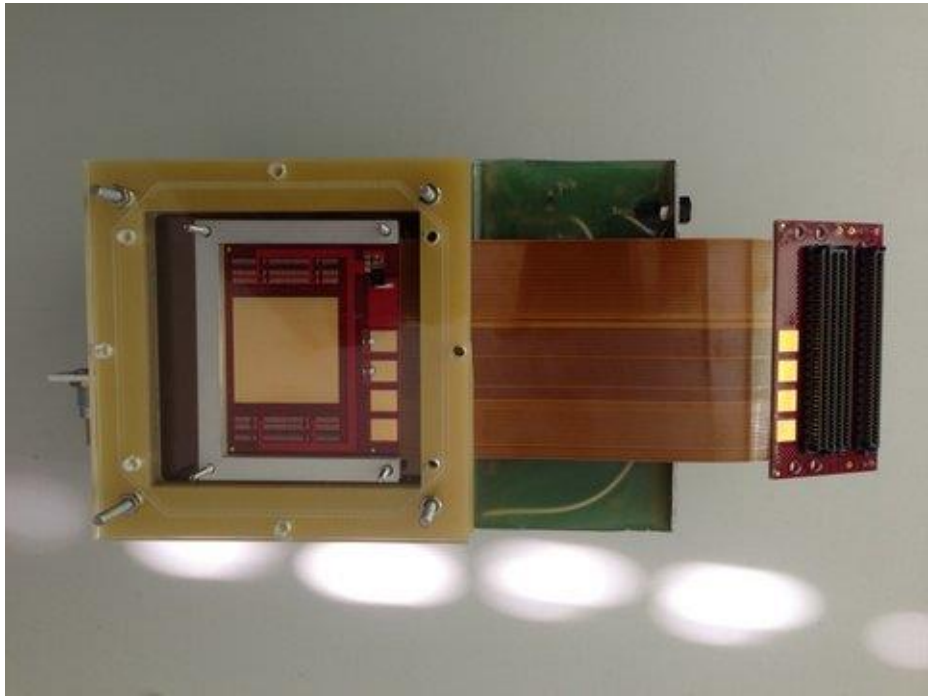


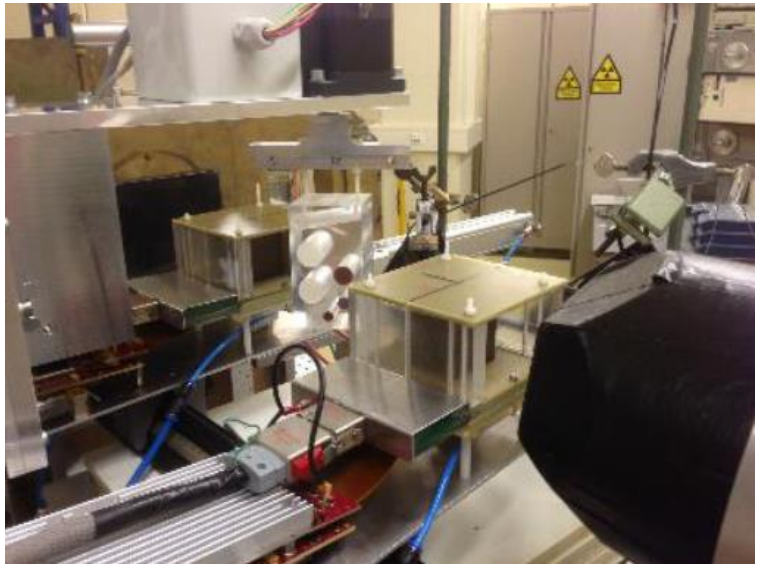


The particle track is analysed with 512 pixels in a length of 3 cm

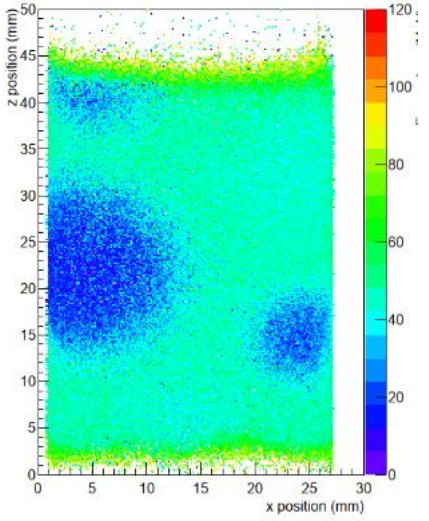
This detector could be used also as Tissue Equivalent Proportional Chamber
The track path is equivalent to 30 microns of tissue … with 17 samples/microns

Timepix3 setup





In 2016 we changed the Timepix1 with a Timepix3 quad and read by Spider DAQ (Nikef).
It was used for studies on proton tomography (I.Visser and P. Radaelli)

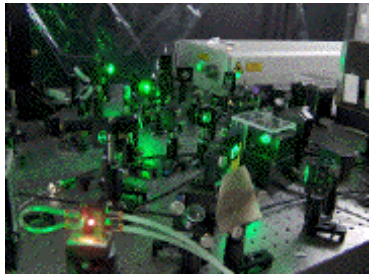


We are waiting the Timepix4 for next step
(but we have to design the new GEM foils with the new chip dimensions)

NOW SOME APPLICATIONS : NUCLEAR FUSION WITH LASER FACILITIES

Experimental tests of GEMpix on laser facilities

ECLIPSE (Bordeaux)



2015-2017

175 mJ 39 fs

$4.5\ 10^{12}$ W

Spot 10μm

G_{GEM}= 900 V

VEGA-2 (Salamanca)

2018

6,5 J 35 fs

$1.8\ 10^{14}$ W

Spot 30μm

G_{GEM}= 620 V

Gekko XII (Japan)

Sep. 2019

1,5 KJ 5 ns

3×10^{11} W

Spot 300 μm

G_{GEM} = 200 V

No EMP noise

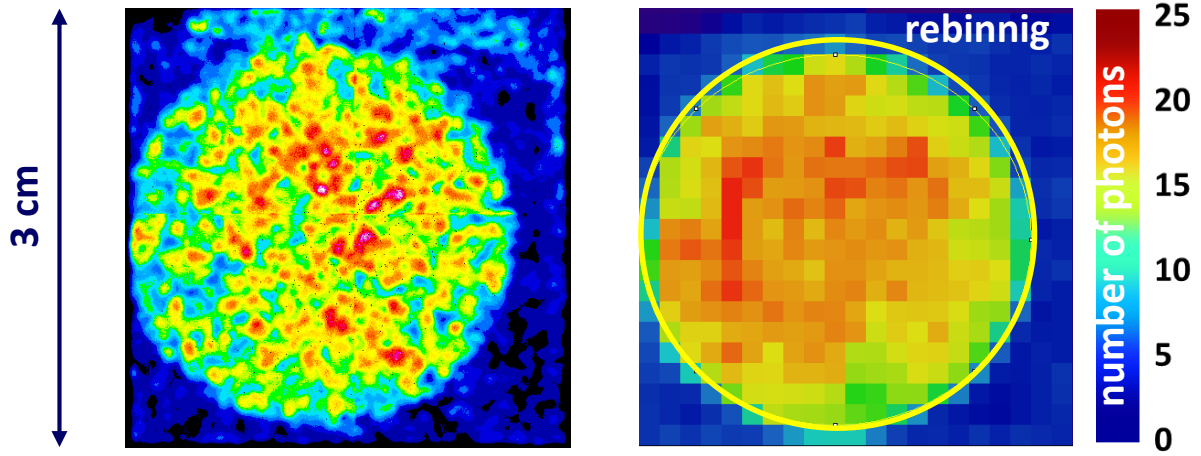
No EMP noise

Small EMP noise

Same signal !

GEMpix detector at ECLIPSE laser facility (Bordeaux)

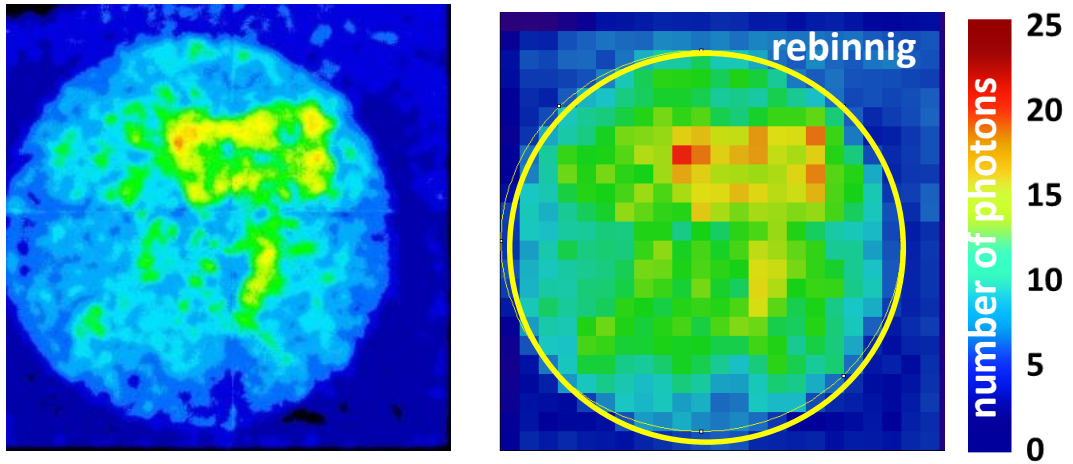
Cu target, 10 shots (1 Hz) at 1060 V gain



Estimate of the detected photon number:

Cu
Mean blob diameter = 25 pxs
Mean blob integral = 21300 ToT counts
measured ph/shot = 5500
(expected value ~ 3500 ph/shot)

Fe target, 10 shots (1 Hz) at 1060 V gain

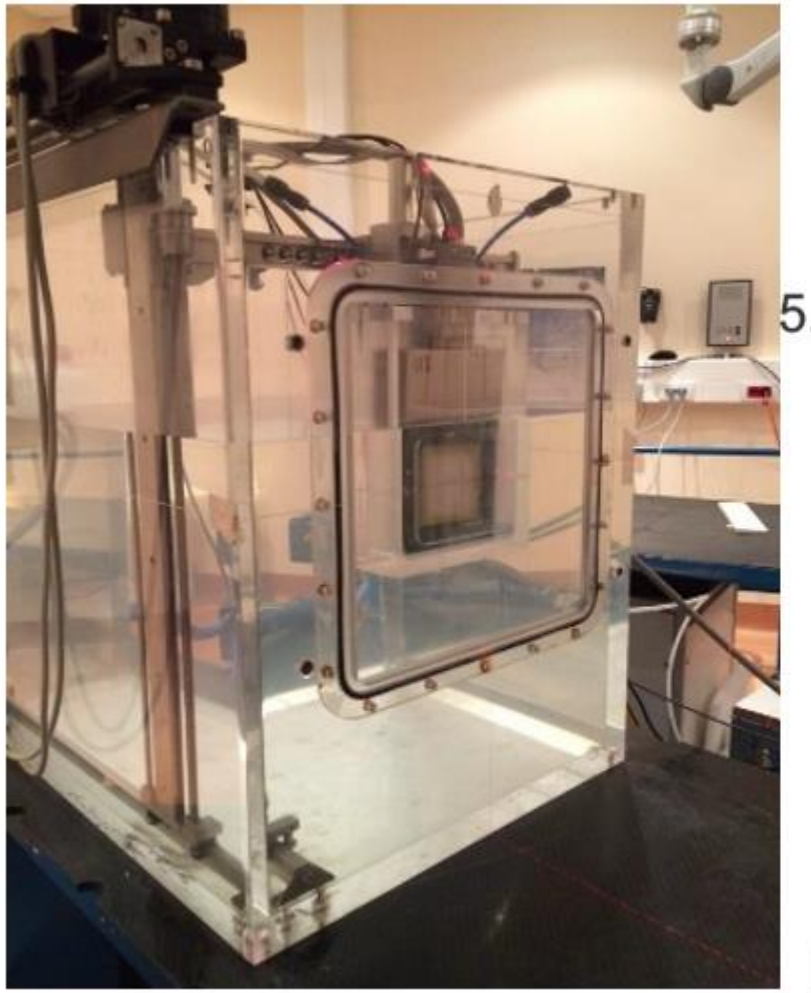


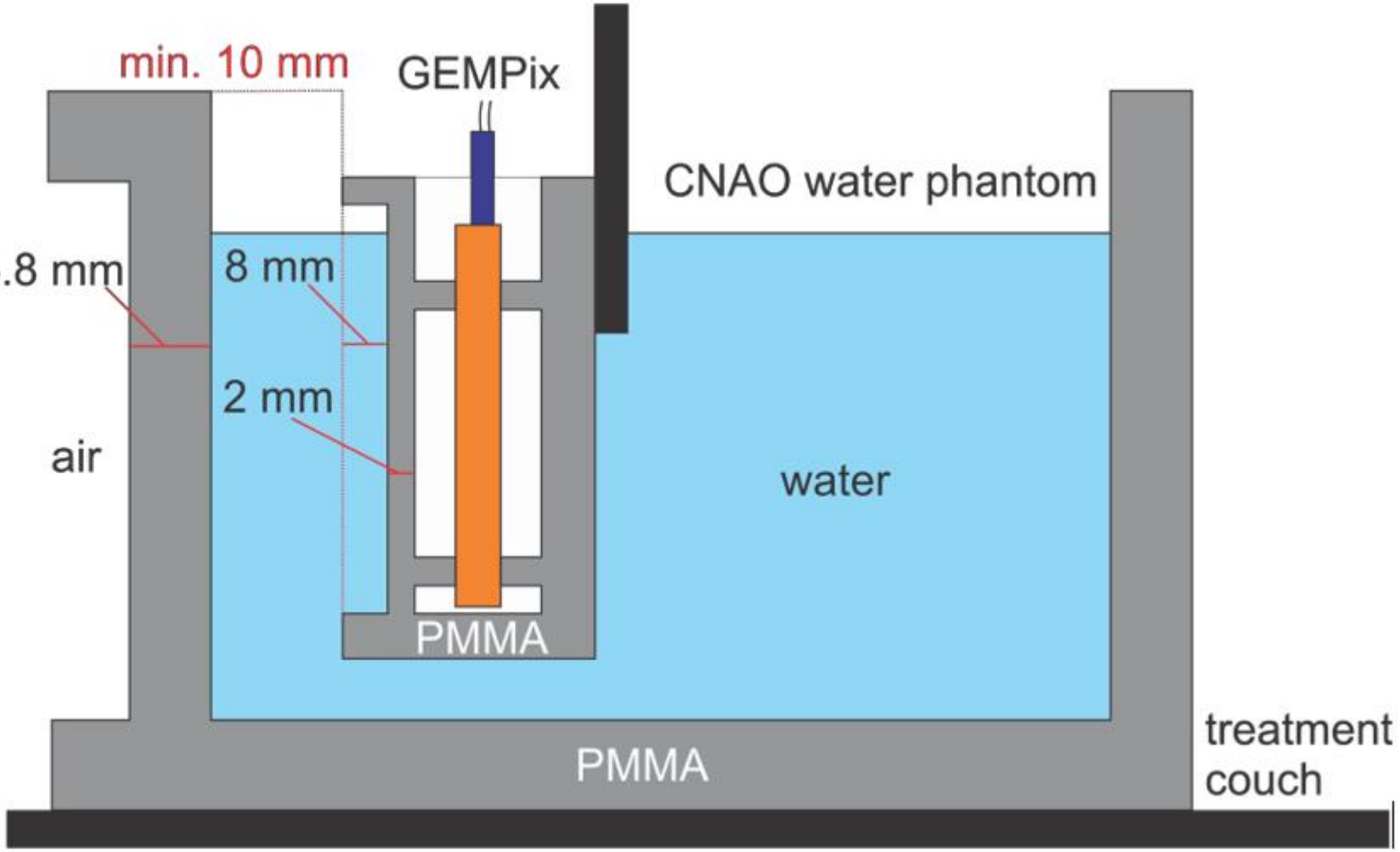
Fe
Mean blob diameter = 21 pxs
Mean blob integral = 15100 ToT counts
measured ph/shot = 3200
(expected value ~ 3900 ph/shot)

G. Claps et al., The GEMpix detector as new soft X-rays diagnostic tool for laser produced plasmas, Review of Scientific Instruments 87, 103505 (2016)

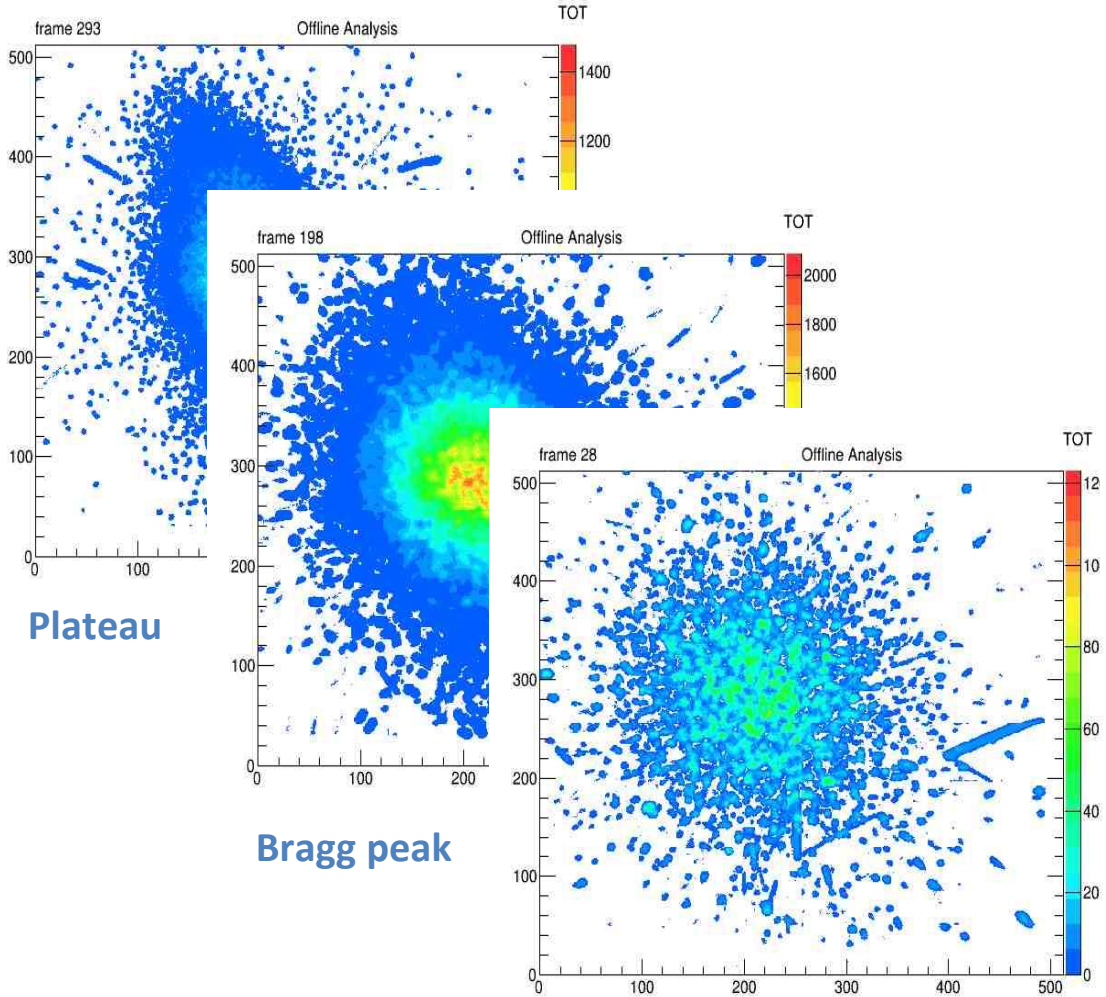
MEDICAL APPLICATIONS

Verification of treatment plan in hardon therapy





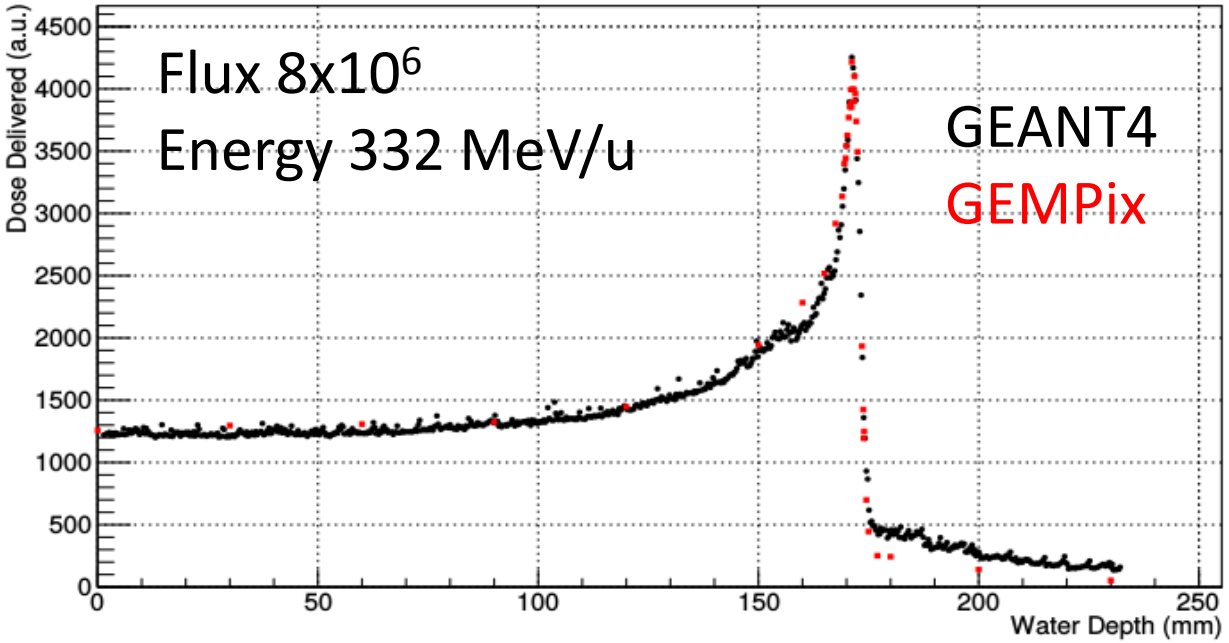
3D reconstruction of Bragg peak Carbon Ion Beam

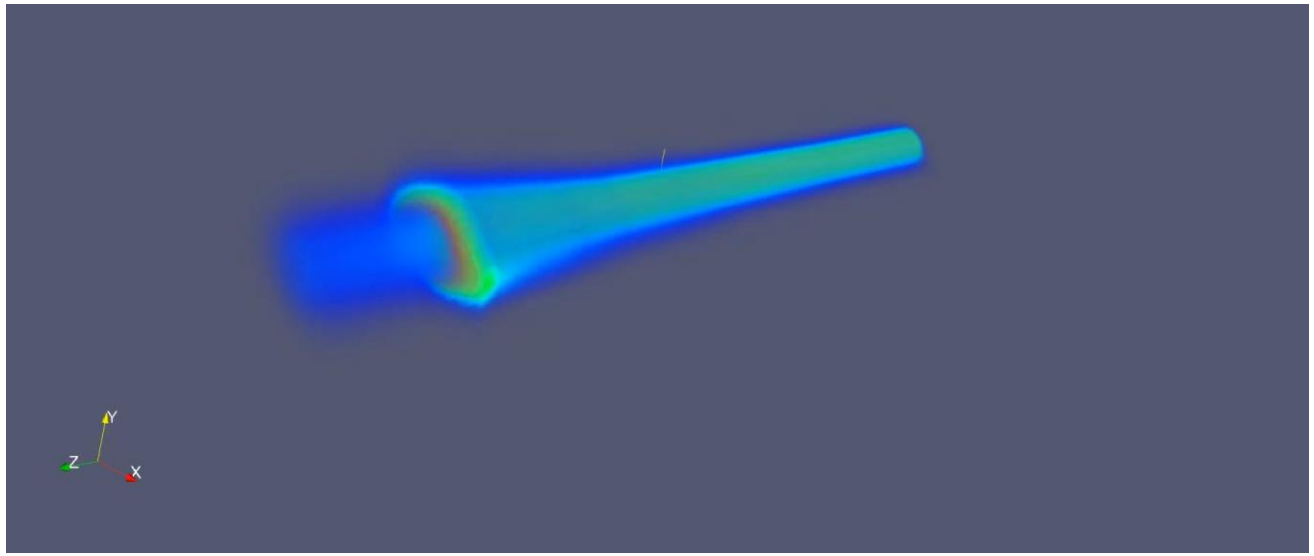


Plateau

Bragg peak

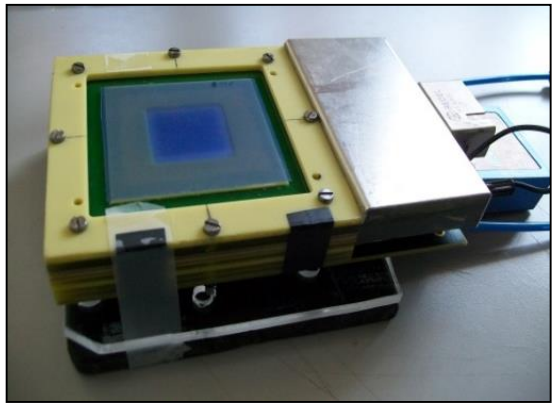
Tail

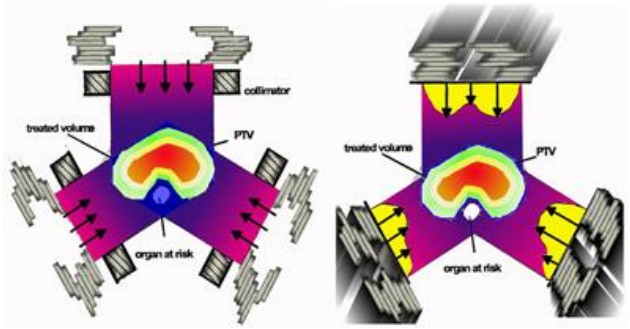




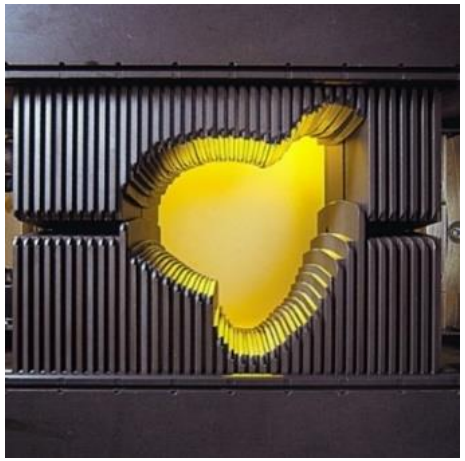
GEMPix for Radiotherapy

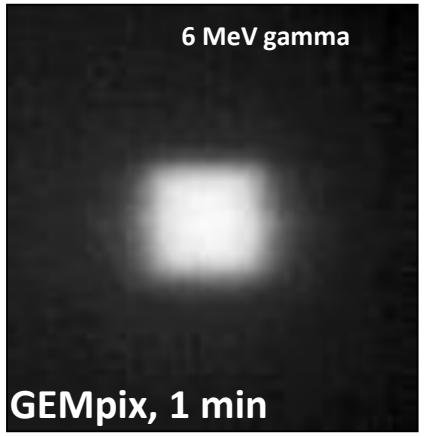
2D measurements of energy released in IMRT (Policlinico Tor Vergata Roma)

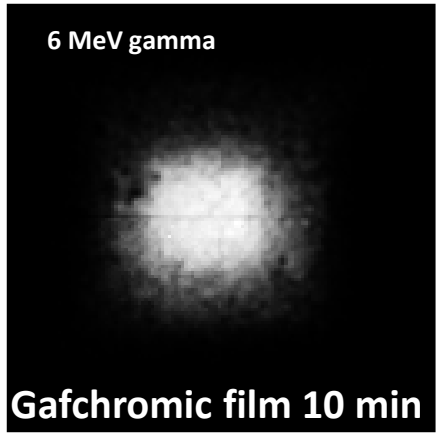


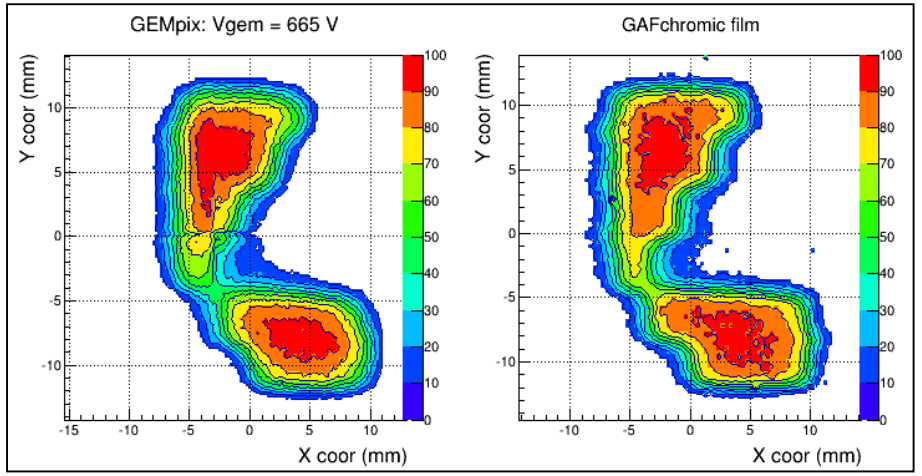


Intensity Modulated Radiation Therapy (IMRT)









G.Claps

Real-time measurements with GEMPix allows fast Quality Assurance procedure

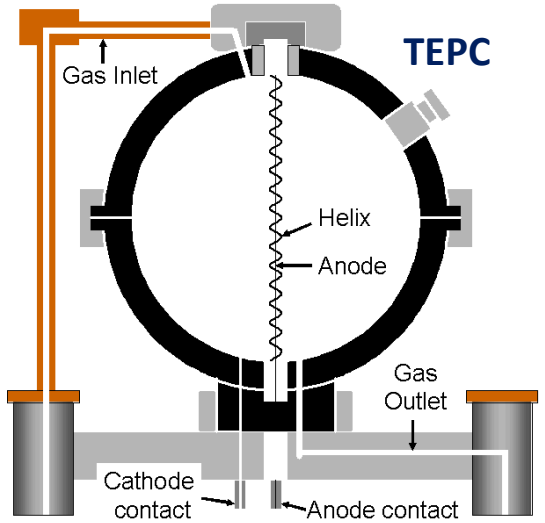
Microdosimetry with the GEMTEQ

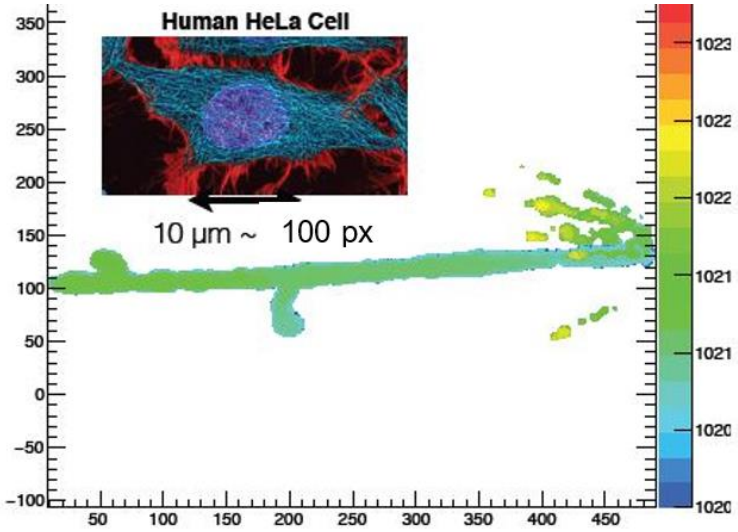
Microdosimetry:

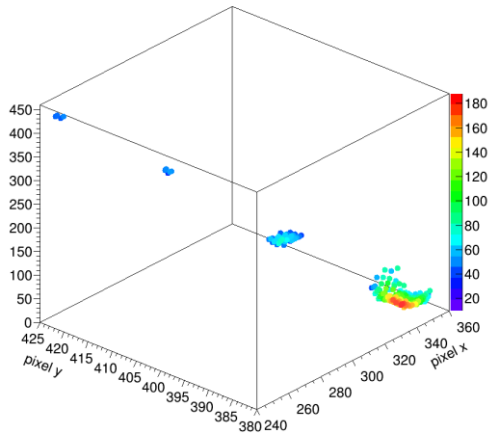
- Statistical fluctuations of energy deposition become important at small scales (e.g. human cell)
- Important e.g. to qualify radiation fields for cancer therapy

Measurements in gas detectors:

1. Use tissue-equivalent (TE) gas: propane + CO_2 + N_2
2. (Low pressure) gas volume scales with density to tissue volume, standard detector: single channel TEPC
3. **GEMPix: operated with TE gas, pixel pitch equivalent to 100nm in tissue**

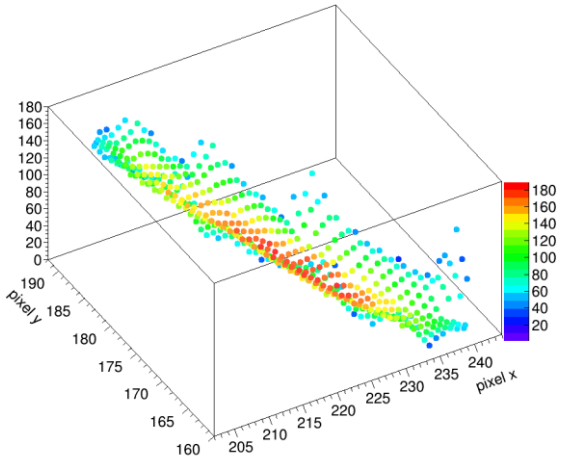






Cs-137: electron

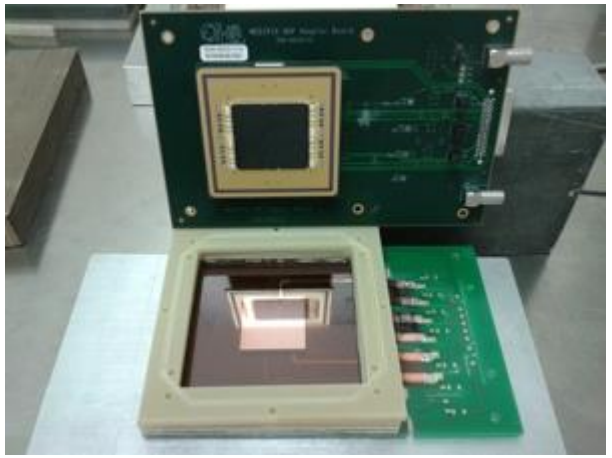
Am-241: alpha



RADIOACTIVE WASTE

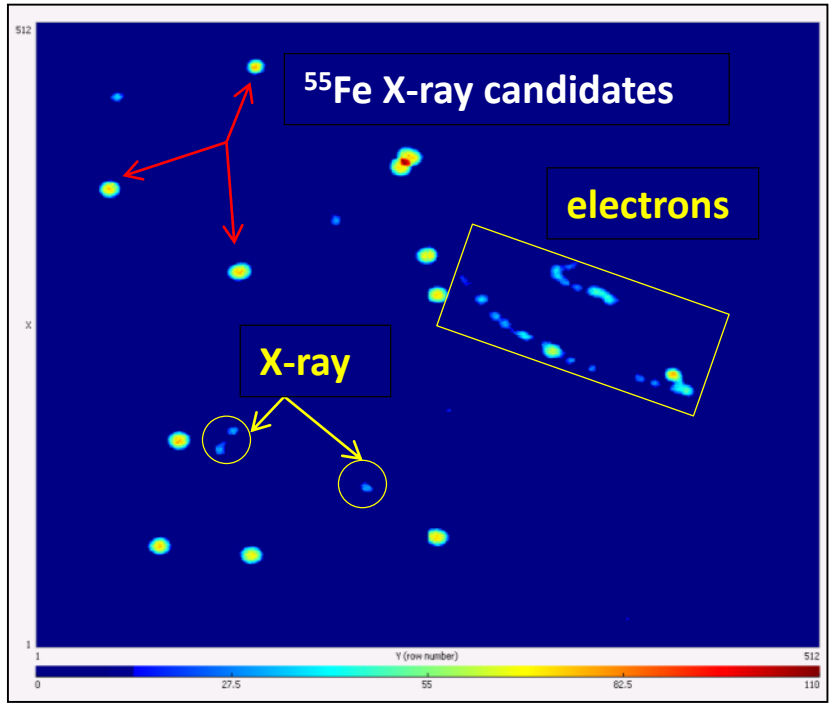
GEMPix for radioactive waste ^{55}Fe

Silicon sensor has some difficulties to detect low energy Xrays coming from iron radioactive waste



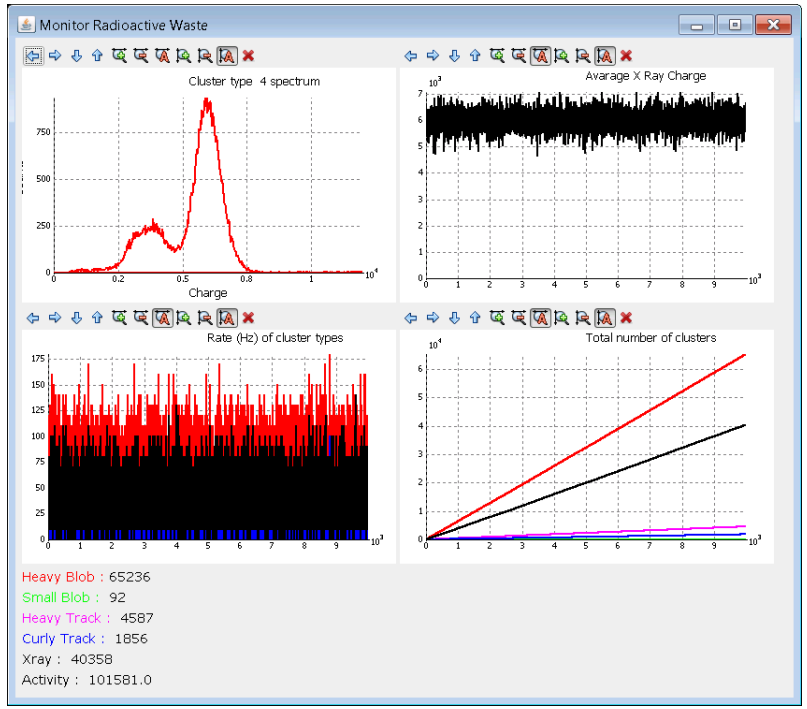
3x3 cm^2 active area

Data acquired in one second



Very good pattern recognition and real-time particle identification

X-ray Energy real-time measurement



Activity higher than 10 Bq/g of ^{55}Fe
GEMPix : 2 hours of data acquisition
Medipix :10 hours of data acquisition
External companies : days …

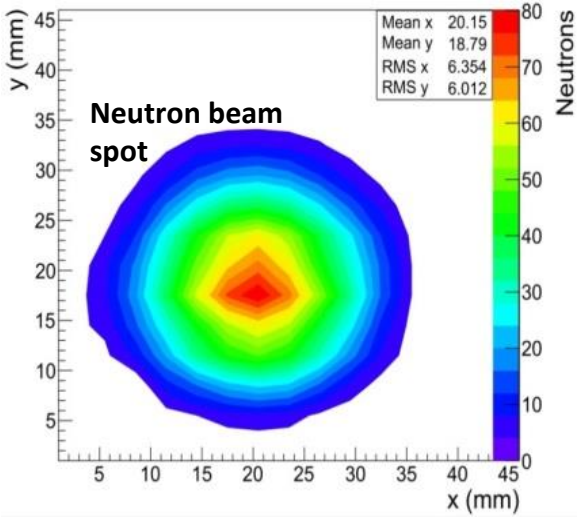
With the new Gemini readout we'll be able to visualize the ^{55}Fe radiation hot spot with a 10x10 GEM detector

NEUTRON DETECTORS

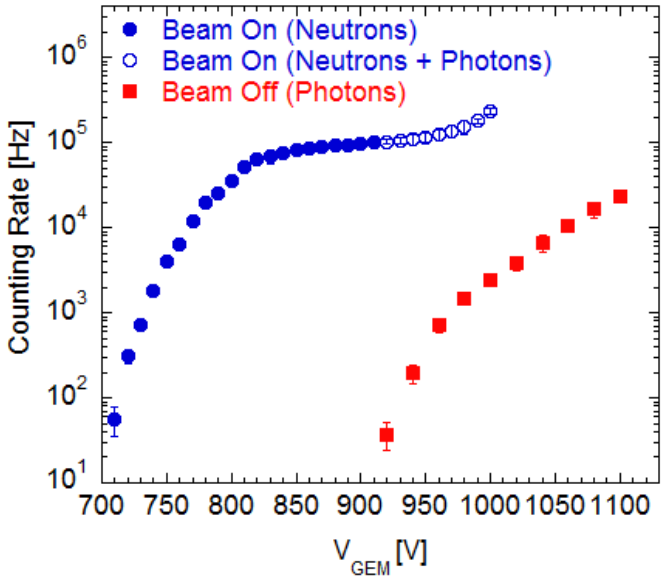
GEM detector for Neutrons

GEM detectors for neutrons, conversion on Boron coated cathode
(good candidate for He^3 detector replacement):

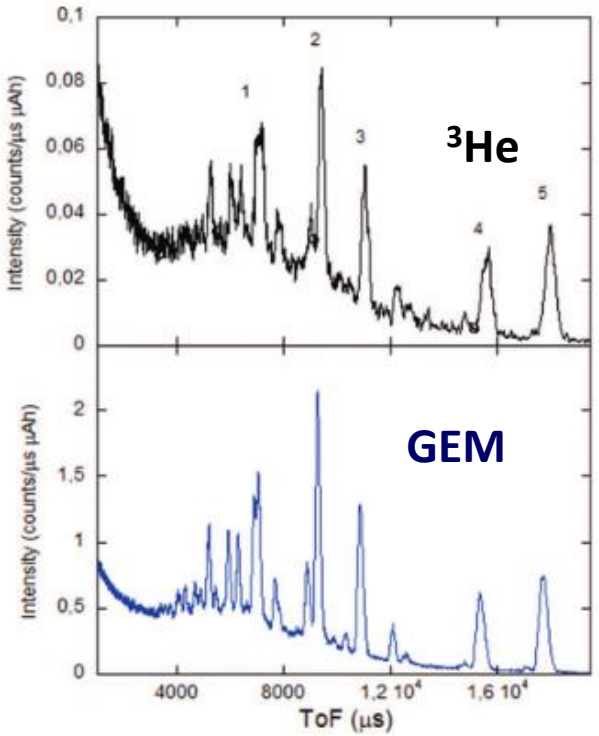
- **Imaging capability**
- **good time resolution (5 ns),**
- **high gamma rejection (>10^5)**
- **high rate capability O(10 MHz/cm^2)**
- **good spatial resolution O(mm)**



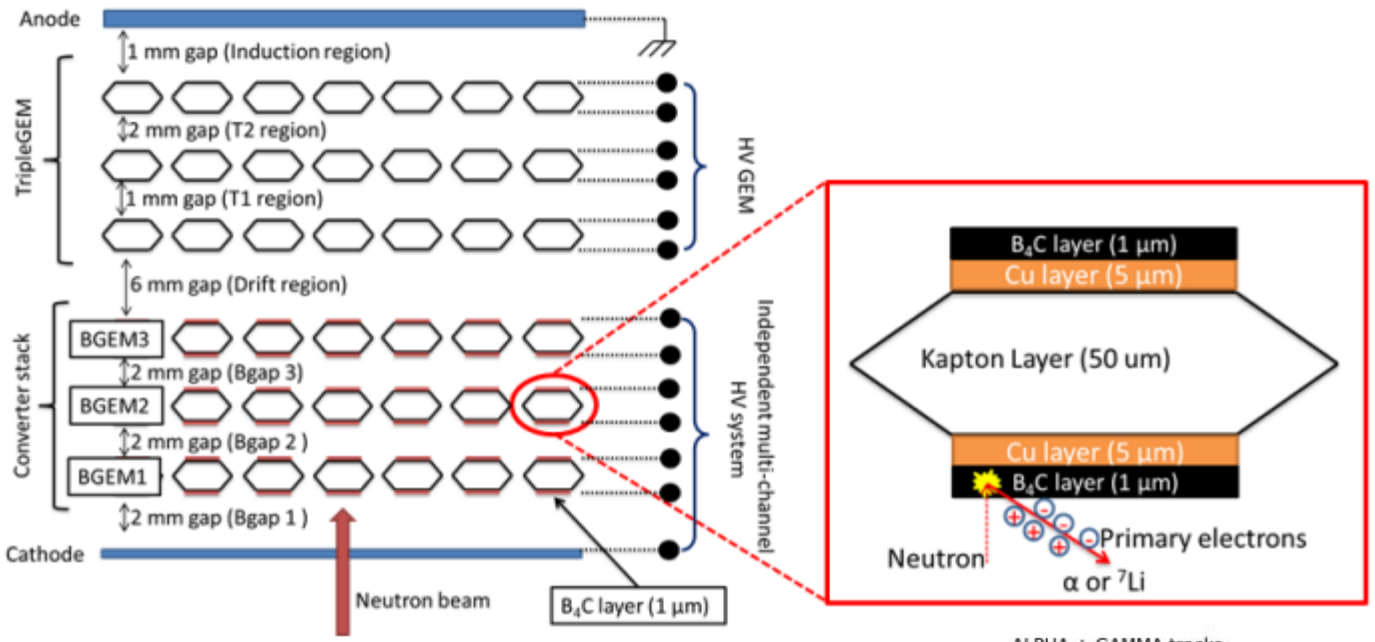
Gamma Neutron rejection

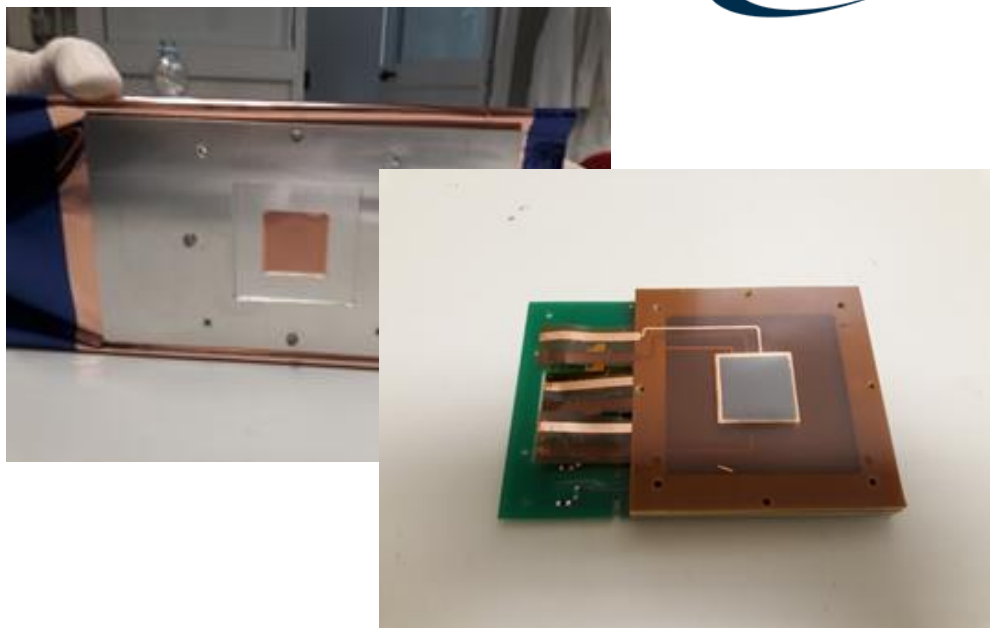


Diffraction Measurement

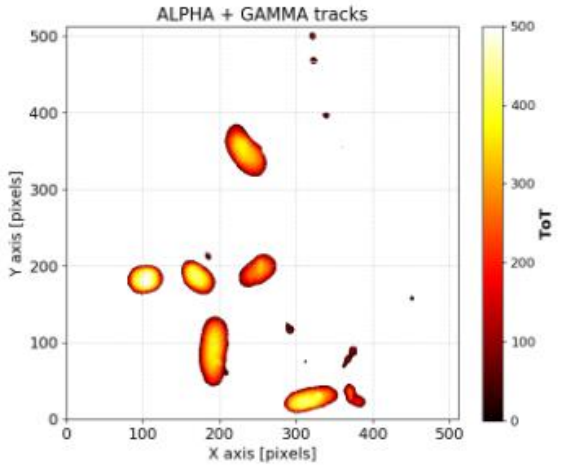


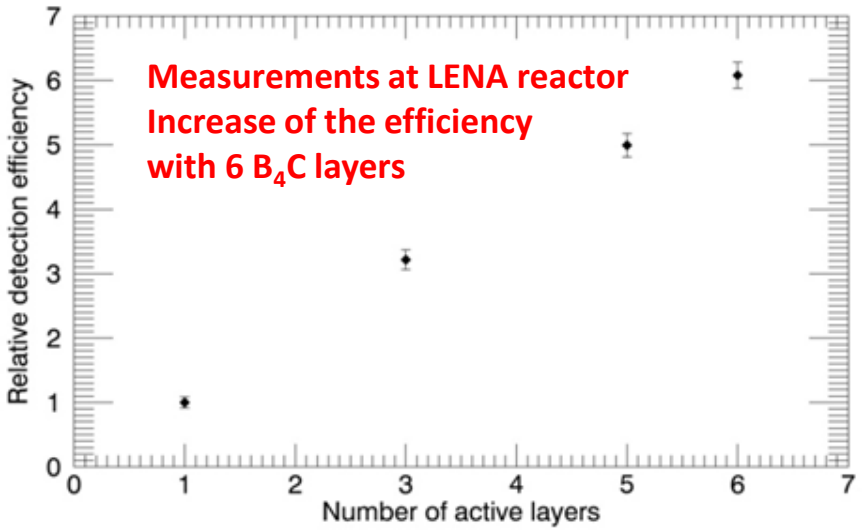
Multi Borated GEM detector: studies with GEMPix



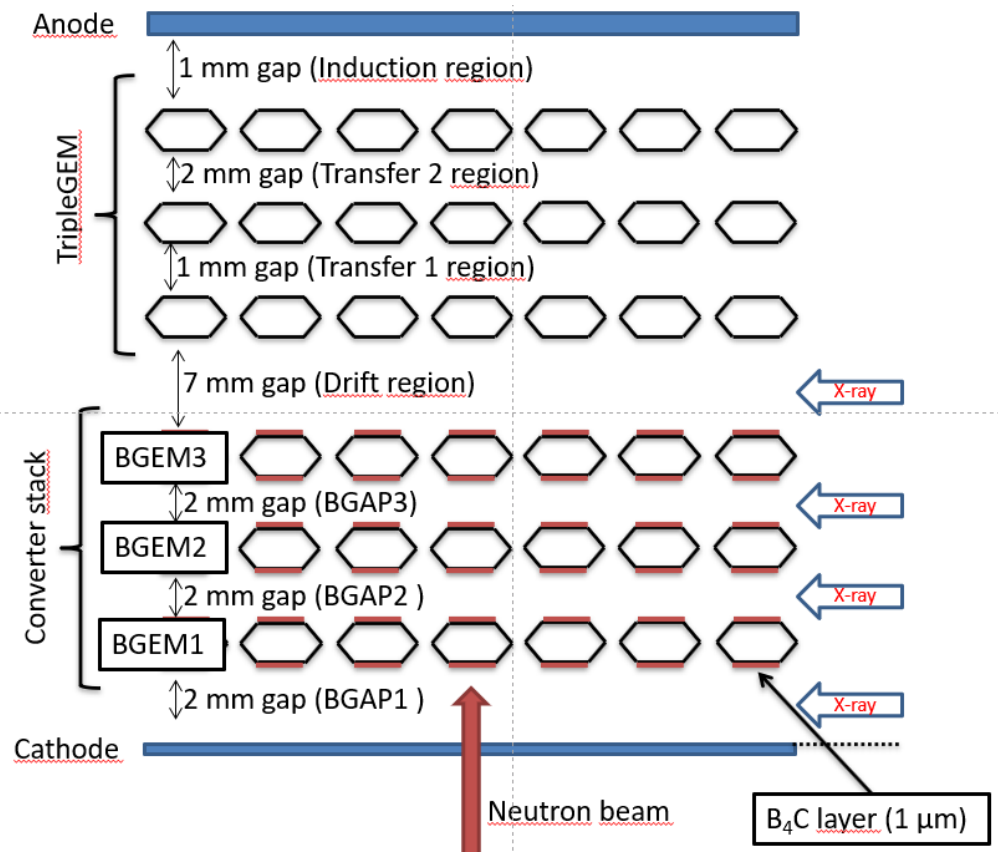


The idea is similar to the Cascade detector but recently with R.De Oliveira and ESS (C.Lai we developed B_4C deposition procedure on both GEM sides

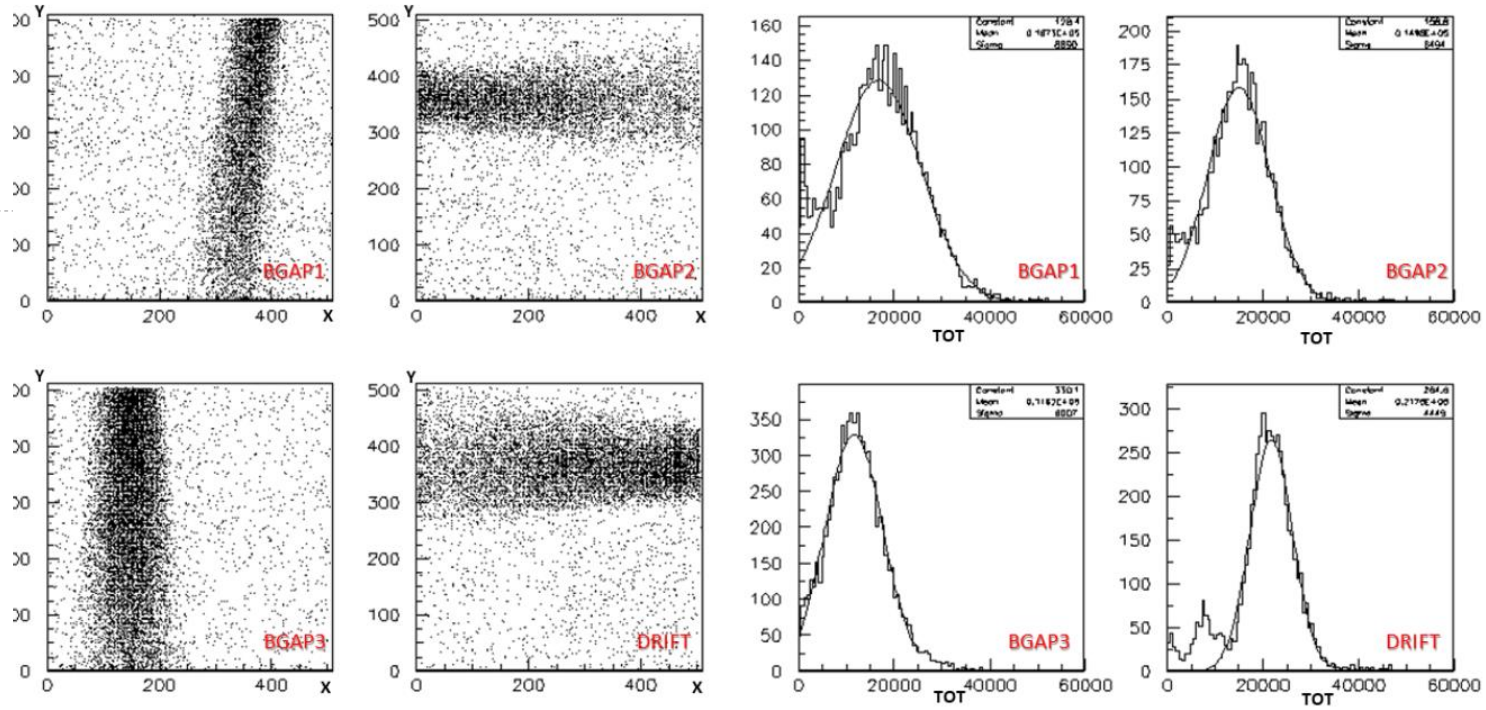




Multi Borated GEM detector: studies with GEMPix



One of the best advantage of a highly pixelated GEM detector is to have the possibility to select the single electron cluster and optimize the parameters of each neutron converter stage



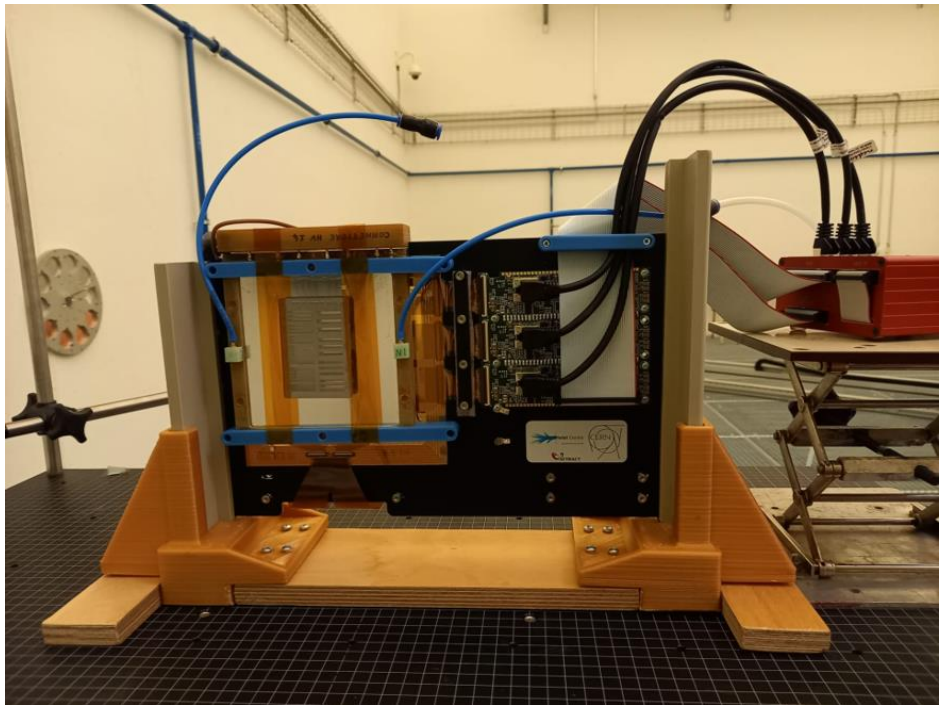
2D X-ray beam image

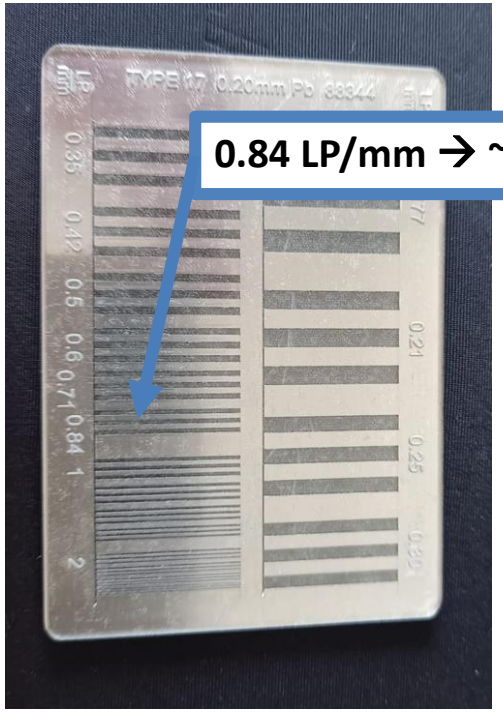
6 KeV X-Ray spectrum

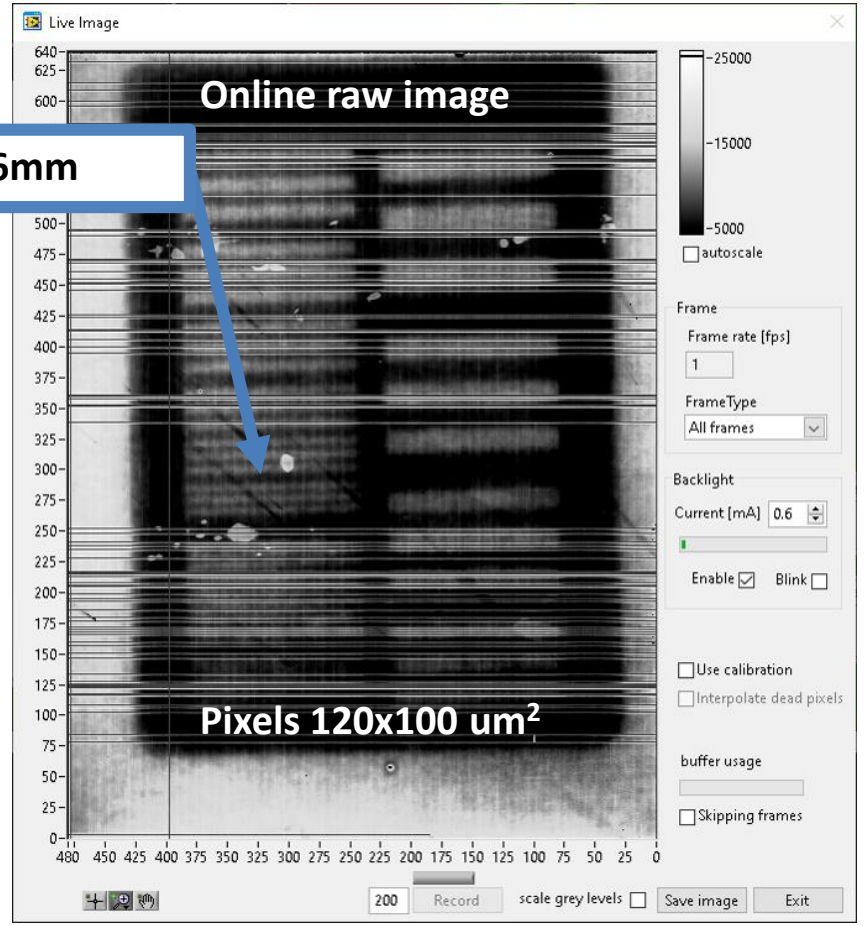
Successful test with 10x10 cm^2 GEM at LENA in Pavia ➡ Abba talk

Large Area GEMPix : TFT readout

Recently we try to read the GEM with TFT without OPD sensor, with the aim to observe directly the electrons







Better spatial resolution reaching the target for some medical applications

Studies for the radiation tolerance characterization are ongoing

Improvements on TFT readouts in collaboration with TNO are foreseen

X-Ray 30 kV, Ar:CF4

Integration time: 50 ms

Conclusions on GEMPix

The GEMPix allows to studies in deep details the interaction of particles with a gas detector

This can help to optimize the performance of some new detectors like Borated GEM foils

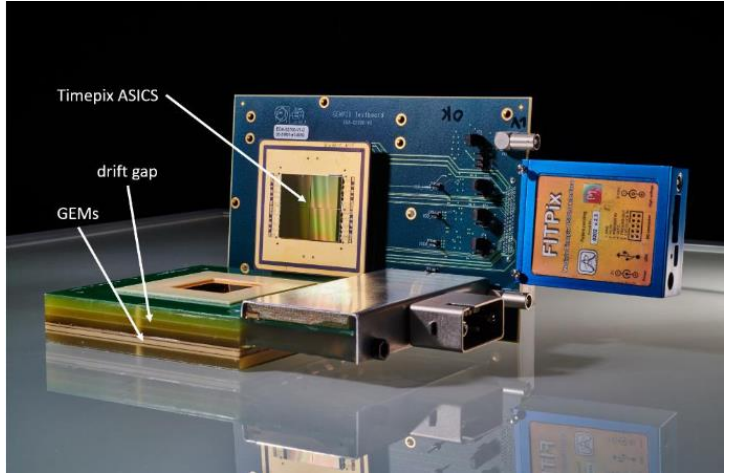
With its portability GEMPix can be used in several applications beyond the High Energy Physiscs.

Some interesting use in medical application have been demonstrated

The microdosimetry is one of the most interesting one

The use of TIMEPIX 4 and TFT readout will increase the active area of this pixelated gas detector

The GEMPix bibliography



General overview:

Murtas, F. The GEMPix Detector, https://doi.org/10.1016/j.radmeas.2020.106421

Leidner, J.; Murtas, F.; Silari, M. Medical Applications of the GEMPix. Appl. Sci. 2021,11, 440. https://doi.org/10.3390/app11010440

For quality assurance in hadron therapy:

Leidner, J., Ciocca, M., Mairani, A., Murtas, F. and Silari, M. (2020), A GEMPix-based integrated system for measurements of 3D dose distributions in water for carbon ion scanning beam radiotherapy. Med. Phys., 47: 2516-2525. https://doi.org/10.1002/mp.14119

Leidner, J. et al, 3D energy deposition measurements with the GEMPix detector in a water phantom for hadron therapy, 2018, JINST13 P08009, https://doi.org/10.1088/1748-0221/13/08/P08009

For measurements of ^{55}Fe in radioactive waste samples:

Curioni, A., et al, Measurements of ^{55}Fe activity in activated steel samples with GEMPix, 2017, https://doi.org/10.1016/j.nima.2016.12.059

Particle tracking:

George, S.P. et al, Particle tracking with a Timepix based triple GEM detector, 2015, JINST10 P11003, http://dx.doi.org/10.1088/1748-0221/10/11/P11003