Application beyond fundamental research

Fast and Thermal Neutron

Neutron diffractometers at NSS
Tokamak neutron Diagnostics

Low energy Xray

Tokamak diagnostics
Radioactive waste

Pixelated MPGD

Microdosimetry
Treatment plan verification in Hadrontherapy

High Intensity Beam Monitors

Hadrontherapy
Ion Beam Monitor

High Intensity Gammas
Radiography
Radiotherapy

We need a portable system ...

Major consideration

Gas detectors for sure are not portable devices like Timepix. Timepix Family is one of the best example of detector with wide applications beyond fundamental research

Courtesy NASA

But when you need :

- big detection areas,
- high radiation tolerances
- measure high intensity particle fluxes,
- medical imaging (big areas)
- detect thermal neutrons with high efficiency
- study on micro dosimetry
- low energy Xrays

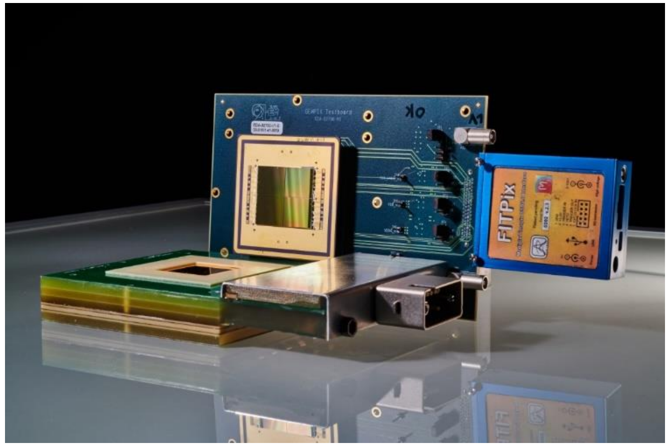
then you need gas detectors !

Typically you need High Voltage and Gas Supply systems that limits the possible applications :
Also if you have portable HV Power supply
it is not easy to produce sealed gas detectors

Gas Detector Readout

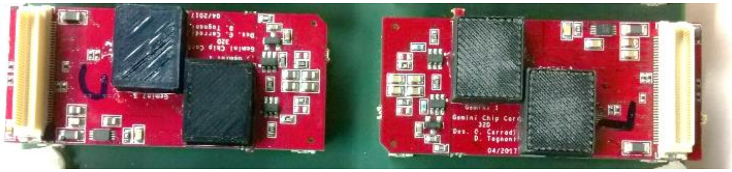
For any possible application you need hopefully a portable DAQ system → FPGA

FITPix



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

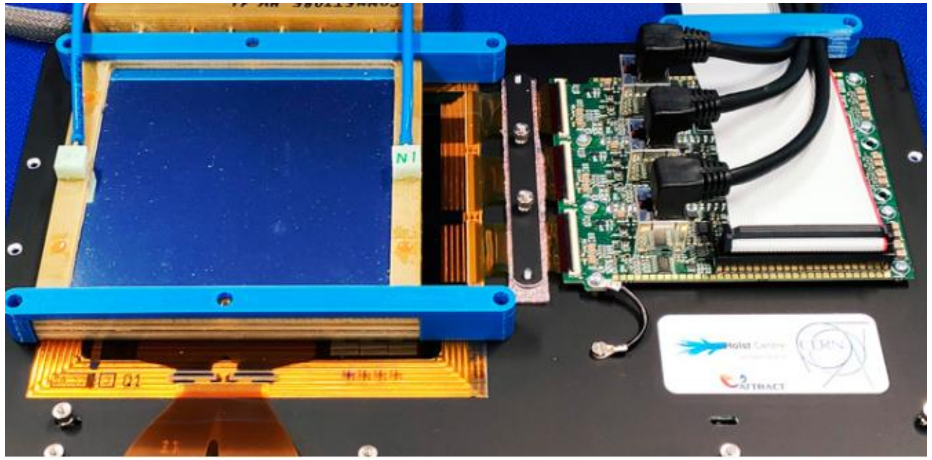
GEMINI + FPGA



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

NI Nuclear Instruments

TNO TFT



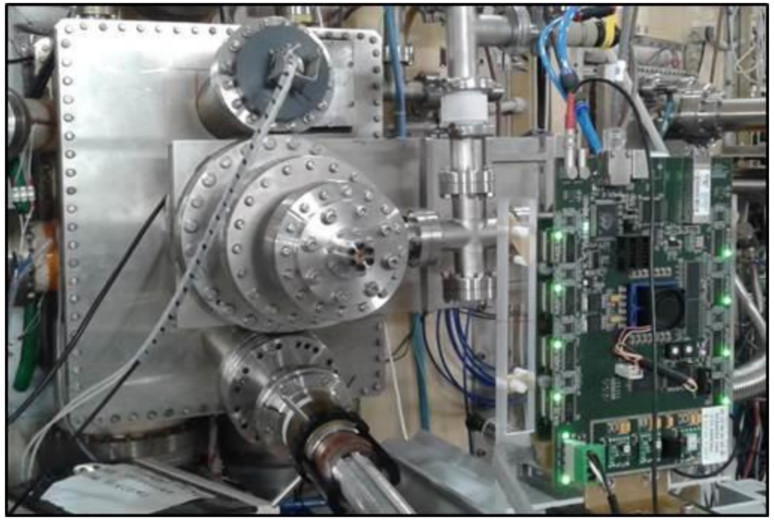
Thin Film Transistor
480 x 640 pixels
126x126 um for each pixel
FPGA (Ethernet)

TNO innovation for life

I'll show you only few examples of possible applications

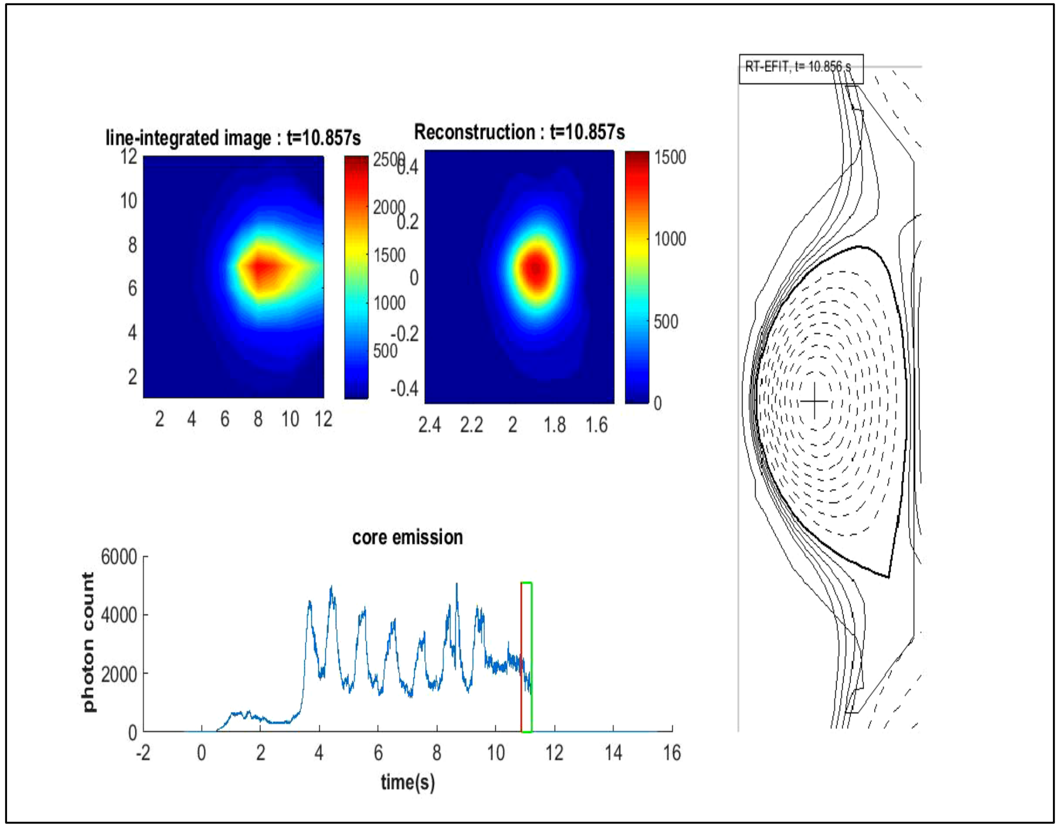
FUSION REACTORS
TOKAMAK

2D GEM pin-hole camera: plasma imaging on KSTAR Tokamak

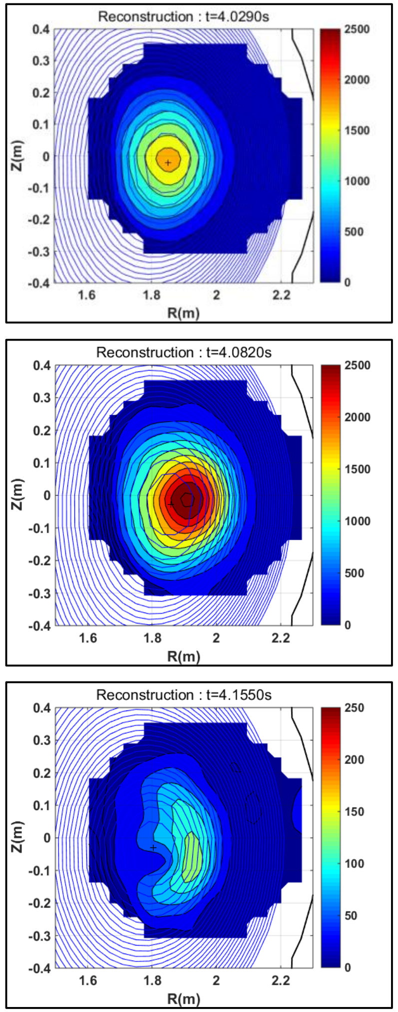


2014

2016



2017

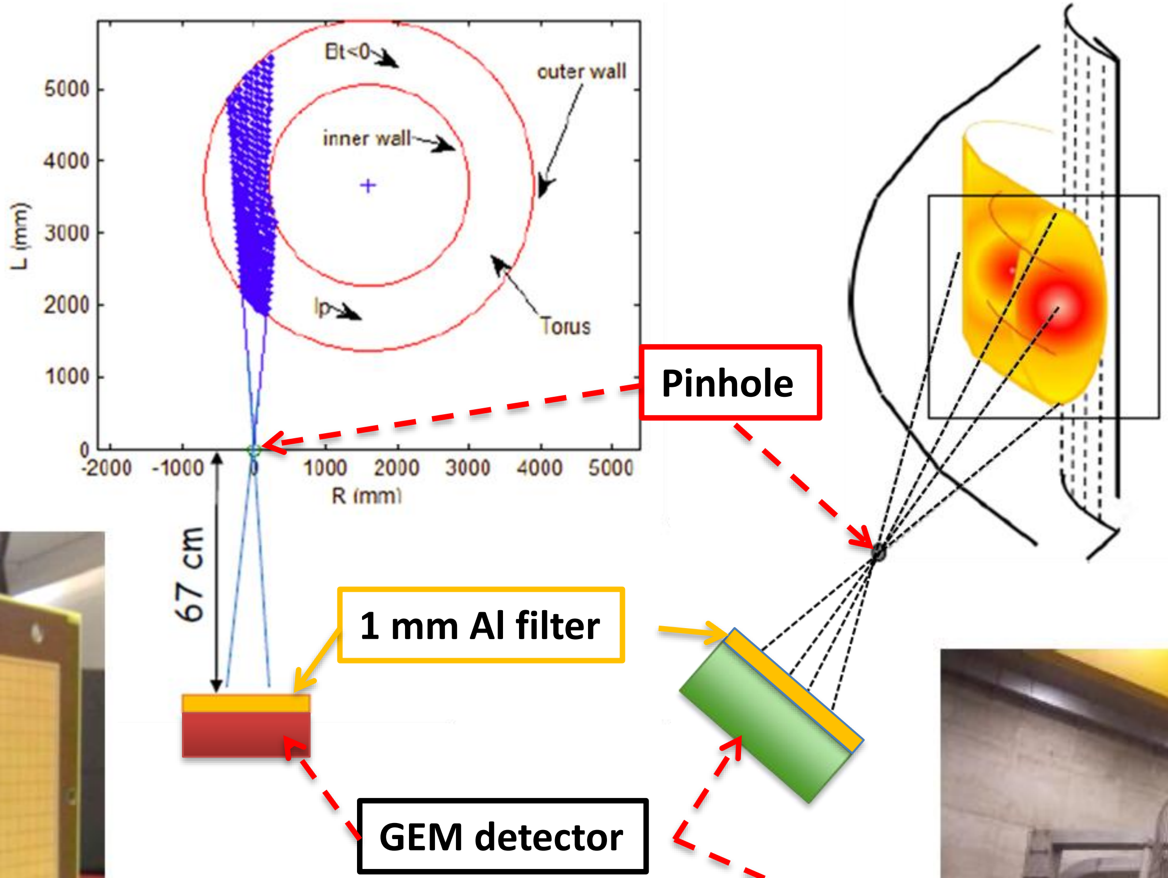


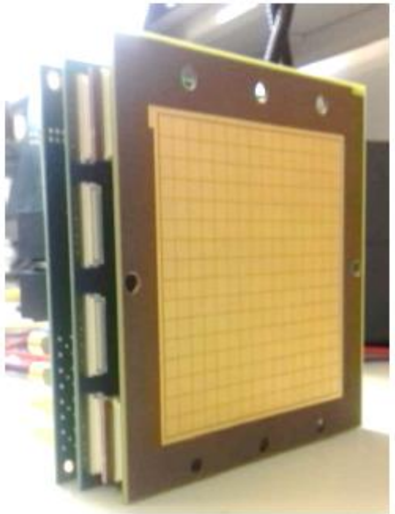
time resolution : 2ms

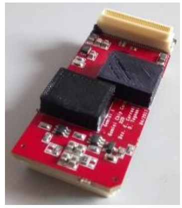
colormap is normalized to the maximum counts in the time interval

Carioca Chip (the same used in LHCb muon chamber) has been used

New GEM monitor: installation @ EAST (China) in 2019







16 x 16 PADs, each with an area of 6 x 6 mm^2

Readout with GEMINI chip → X ray energy measurements and 5 ns time resolution

New GEM prototype: preliminary results @ EAST

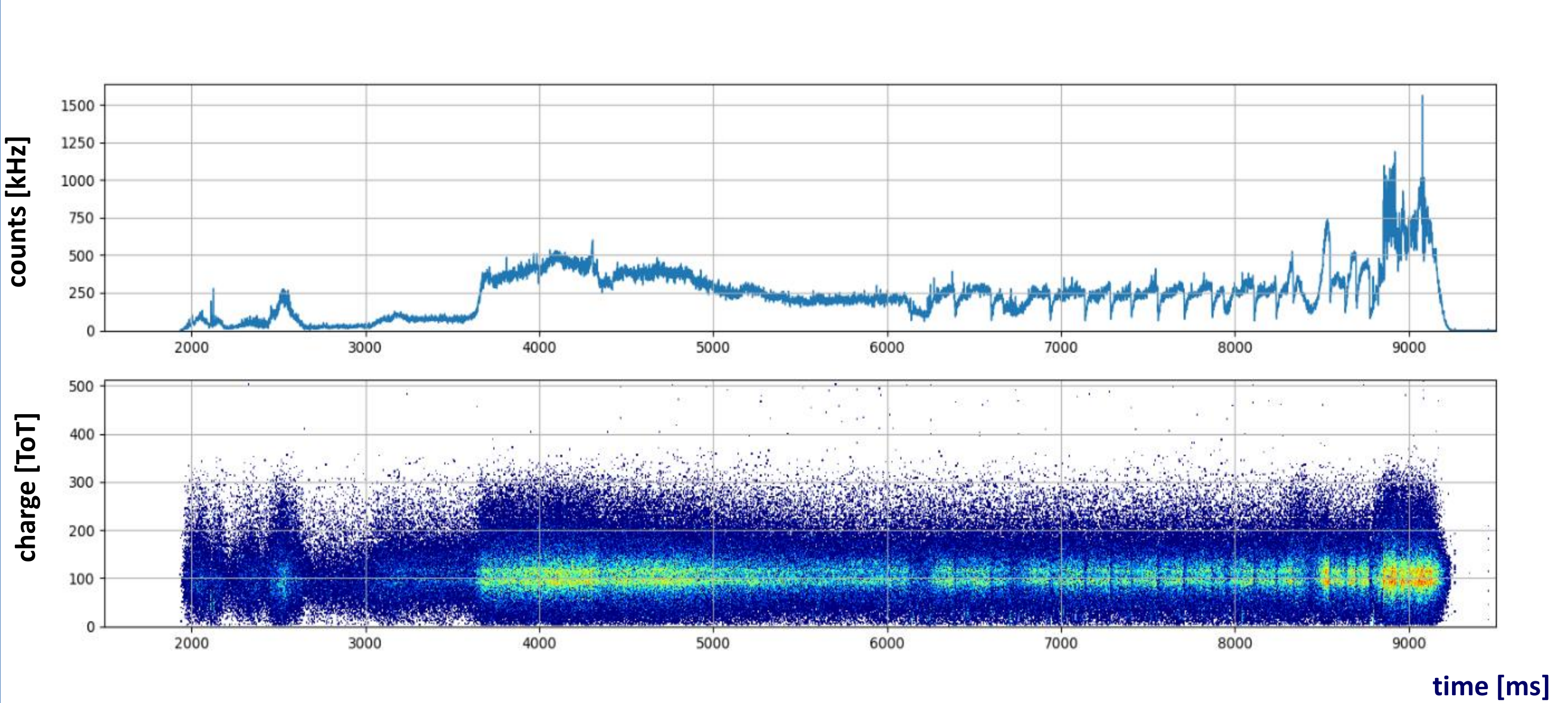
Data taken in the first week of April 2019

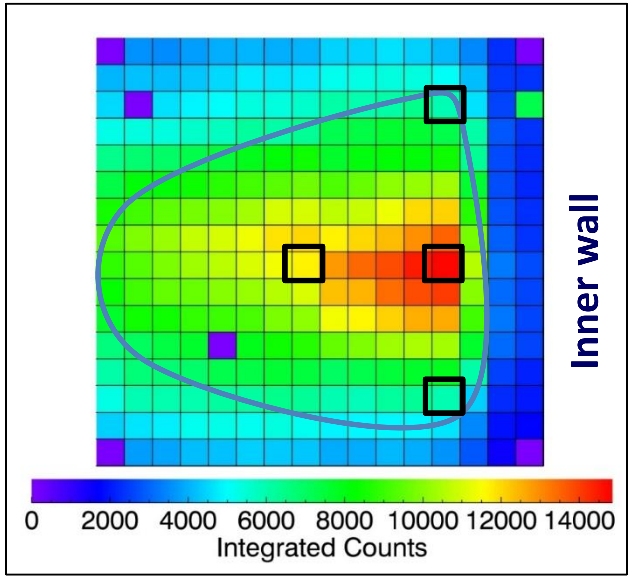
Strong limitations in timing resolution due to the limited bandwith of the ethernet comunication

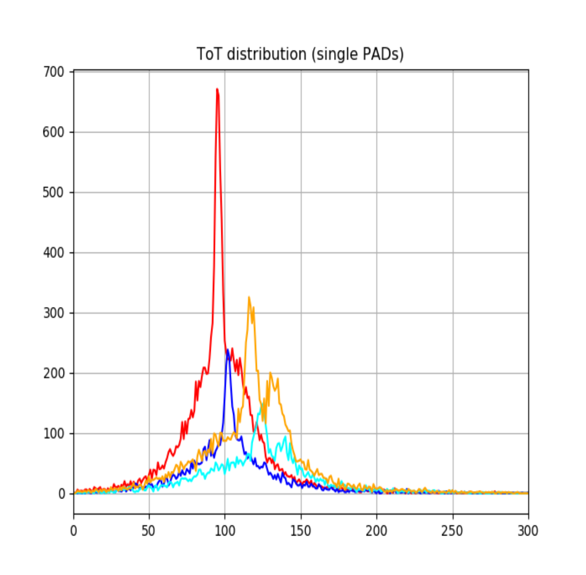
1mm thick Al filter in front of the detector is needed in order to reduce the incoming flux

Shot n° 83874

Space emission integrated for all the pulse duration e for all x-rays energies.



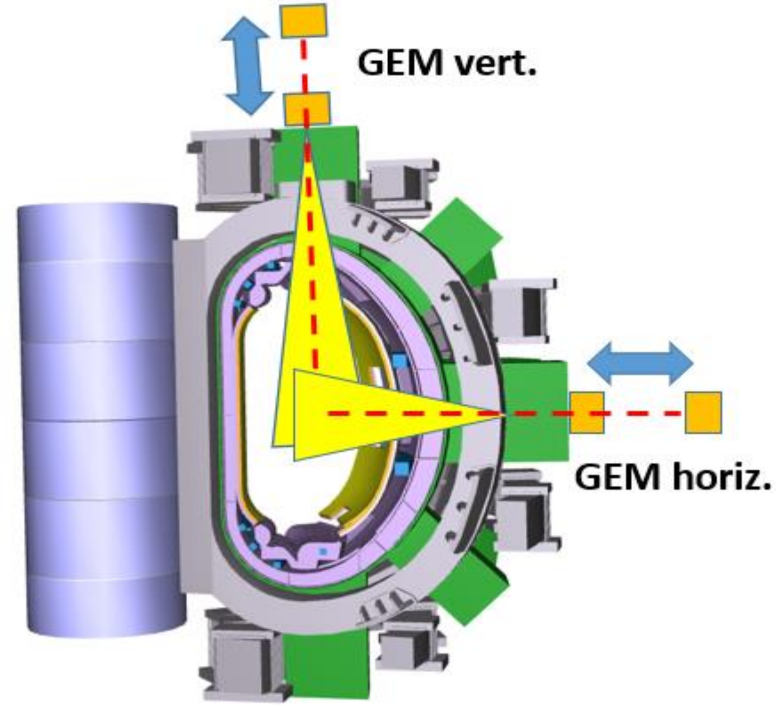




energy spectra pad by pad

DIAGNOSTICS FOR DIVERTOR TOKAMAK TEST facility

- An Italian 6 T magnetic field, 5.5 MA Superconducting Tokamak
- To be built in the ENEA Frascati Research Centre within the European roadmap to the realization of fusion energy
- Designed to study the power exhaust problem in:
  - An integrated environment within a high performance Tokamak
  - DEMO relevant conditions



Already allocated:

- X-ray imaging/tomography with GEM (10cm x 10cm) 256 channels
- X-ray imaging con GEMpix (3cm x 3cm) 256000 pixels

To be assessed

- Pixellated diamond (n, alpha, Hard-X, gamma)
- Side-on Silicon C-MOS (gamma)
- GEM for fast neutrons

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

No EMP noise

VEGA-2 (Salamanca)

2018

6,5 J 35 fs

$1.8\ 10^{14}$ W

Spot 30μm

G_{GEM}= 620 V

No EMP noise

Gekko XII (Japan)

Sep. 2019

1,5 KJ 5 ns

3×10^{11} W

Spot 300 μm

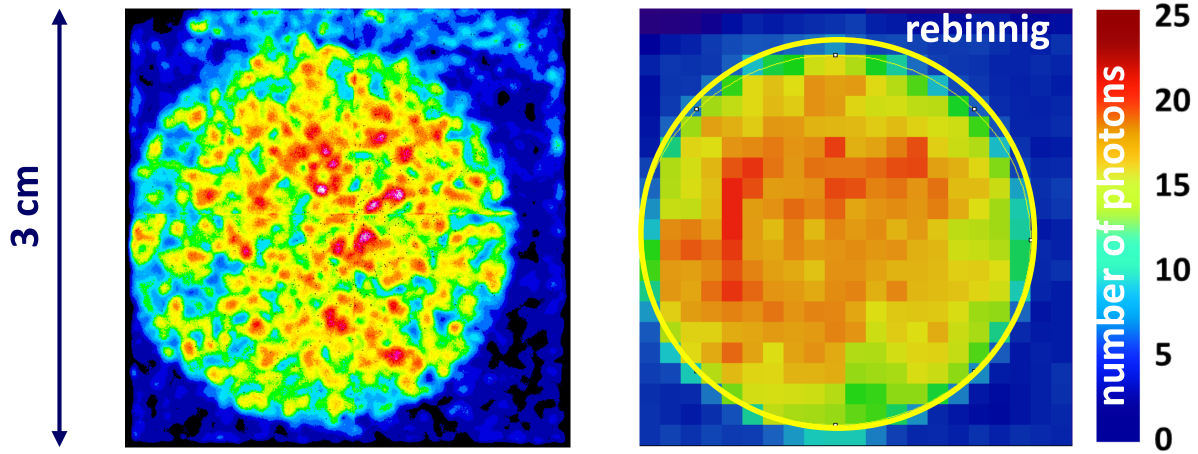
G_{GEM} = 200 V

Small EMP noise

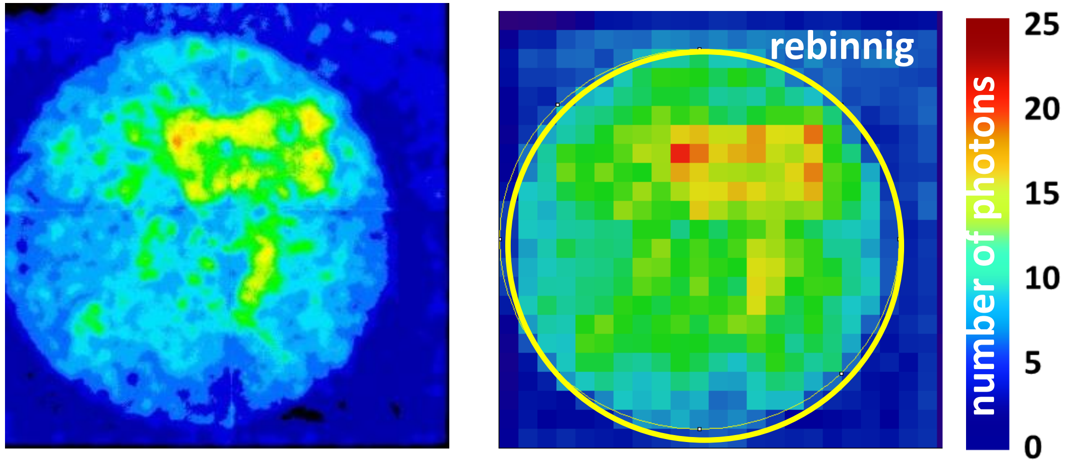
Same signal !

GEMpix detector at ECLIPSE laser facility (Bordeaux, France)

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



Fe 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
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

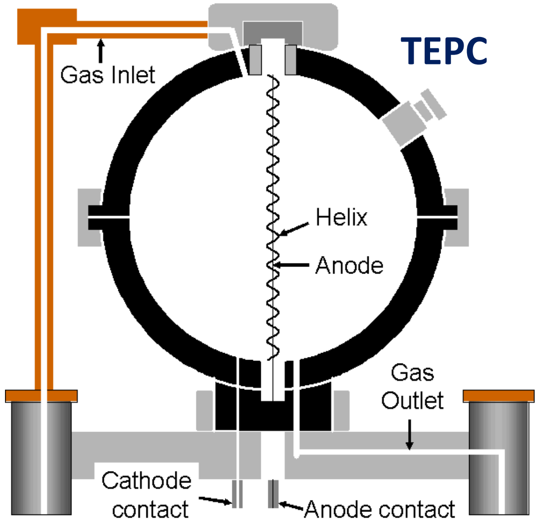
Microdosimetry with the GEMTEQ

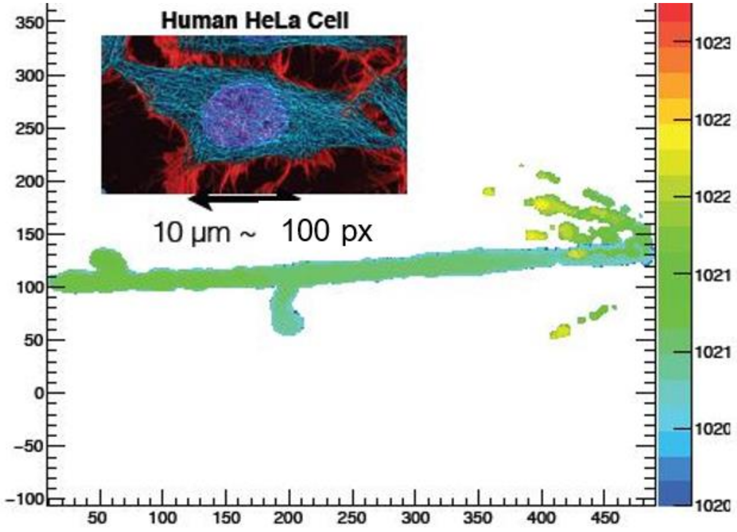
Microdosimetry:

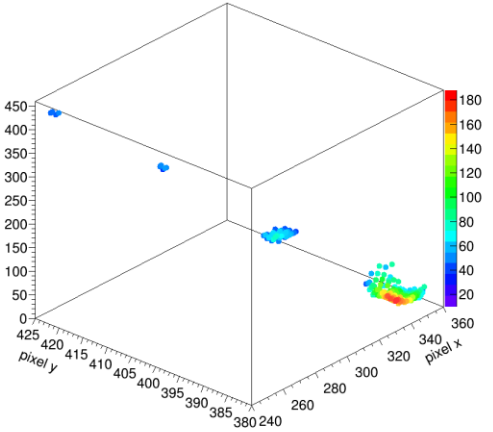
- Statistical fluctuations of energy deposition become important at small scales (e.g. human cell)
- Important e.g. to qualify radiation fields for cancer therapy

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**

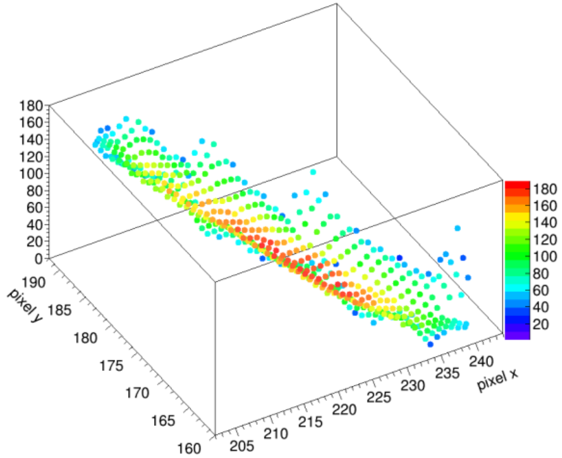




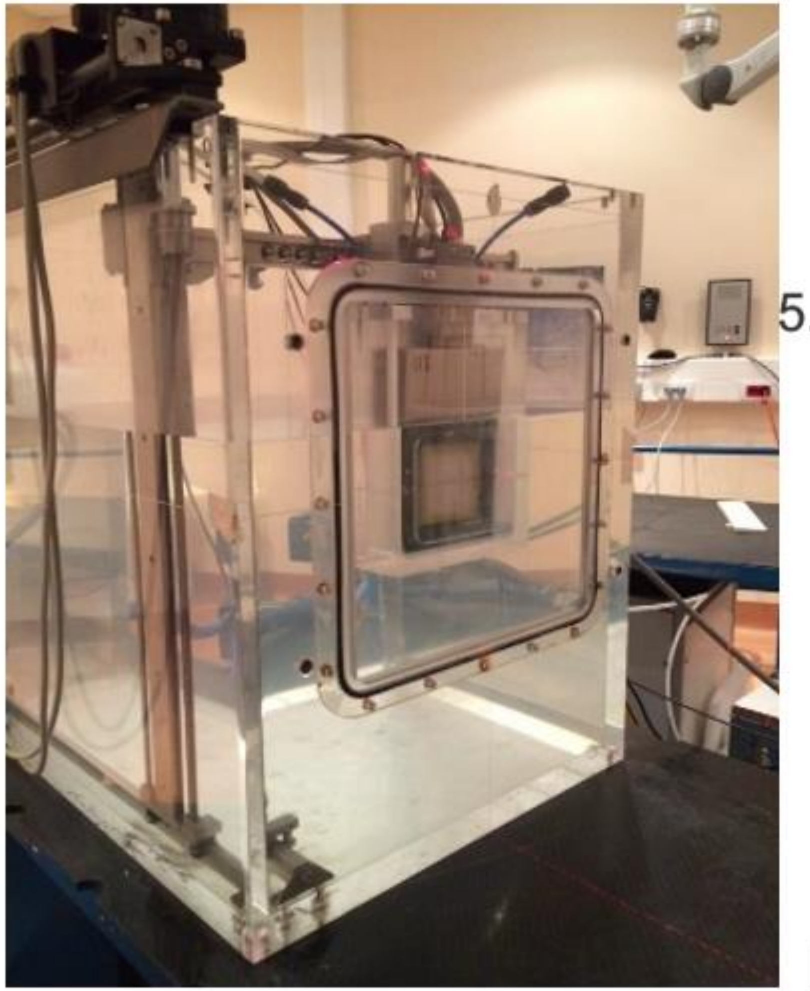


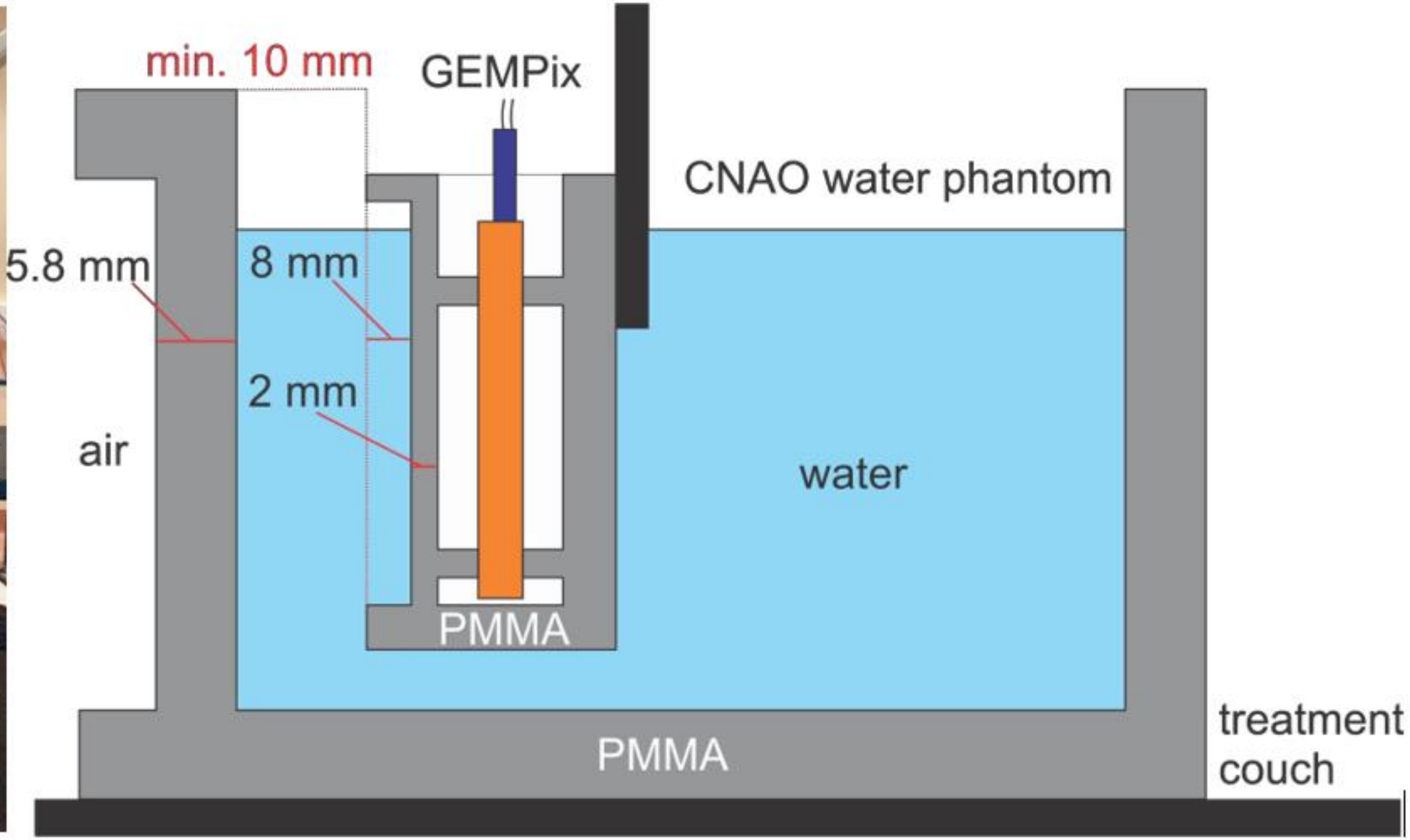
Cs-137: electron

Am-241: alpha

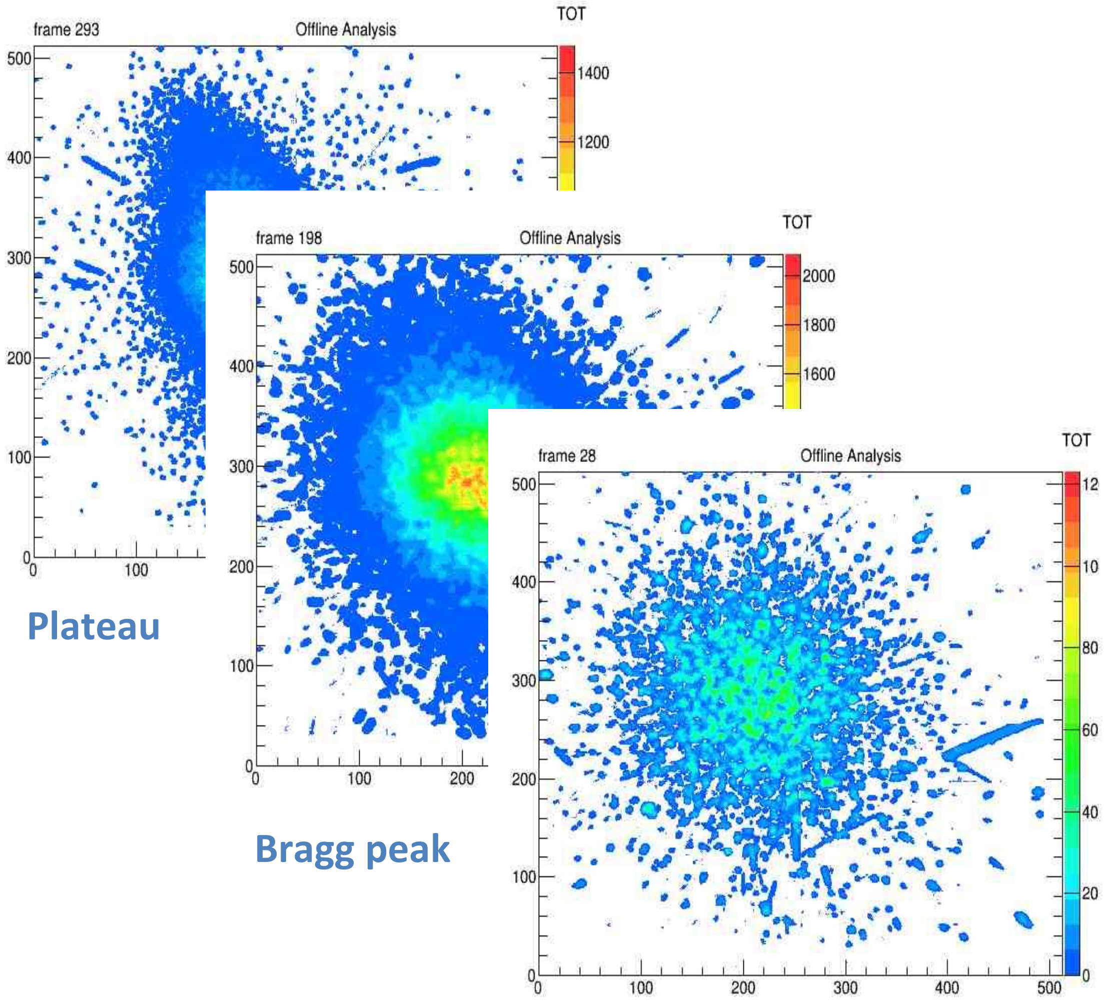


Verification of treatment plan in hardon therapy





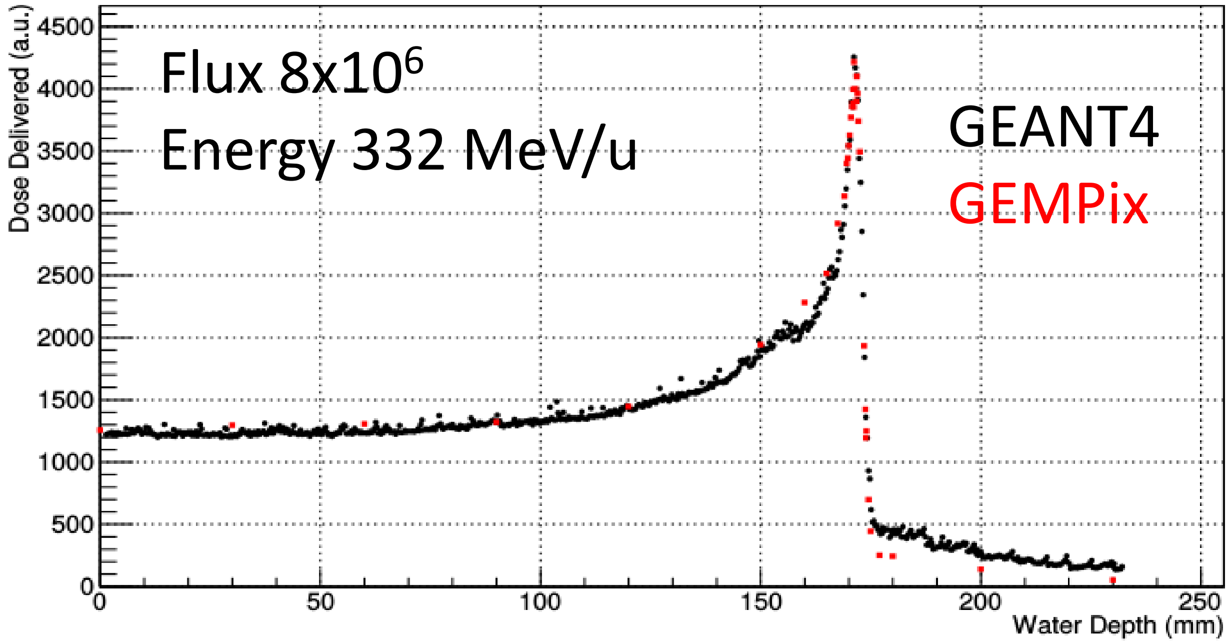
3D reconstruction of Bragg peak Carbon Ion Beam

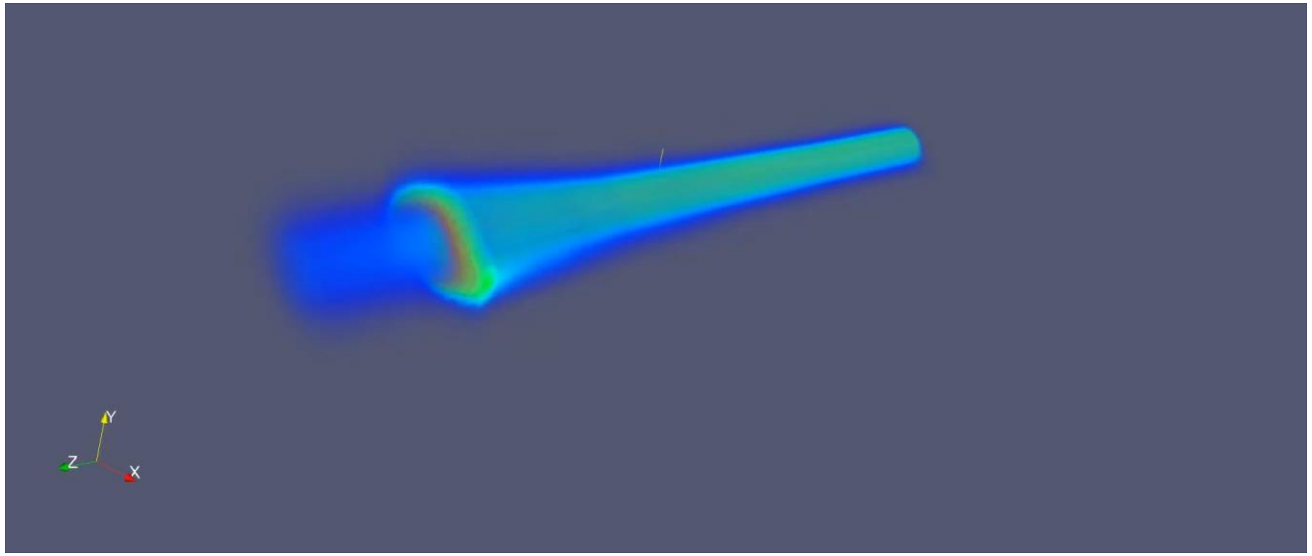


Plateau

Bragg peak

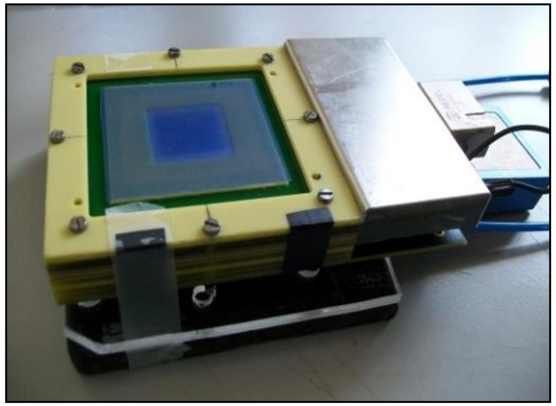
Tail

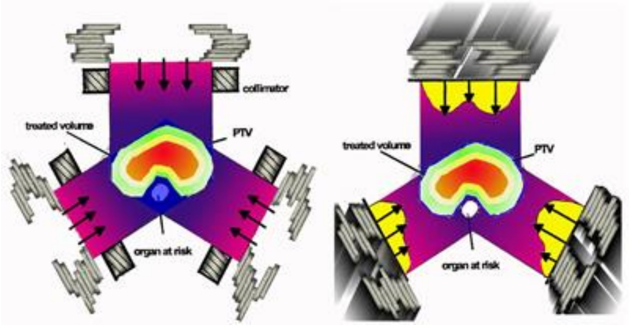




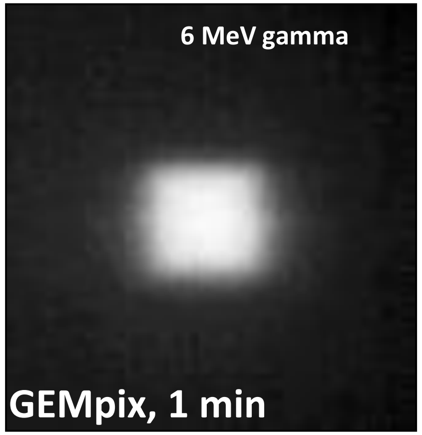
GEMPix for Radiotherapy

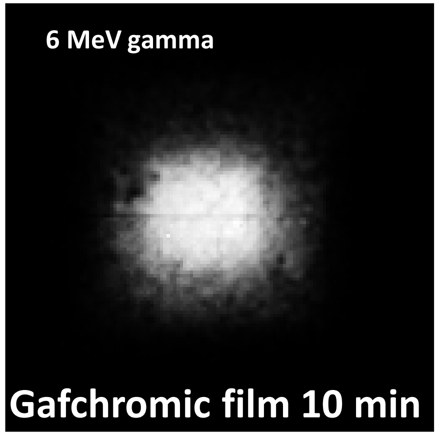
2D measurements of energy released in IMRT (Policlinico Tor Vergata Roma)

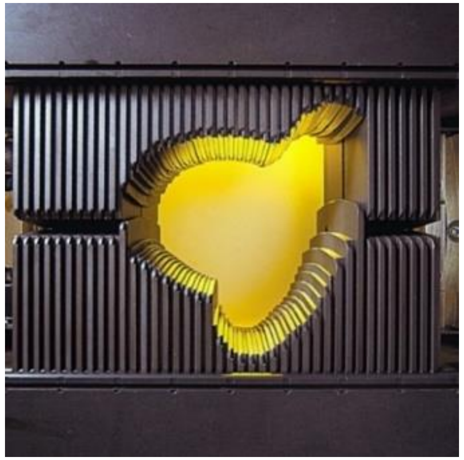


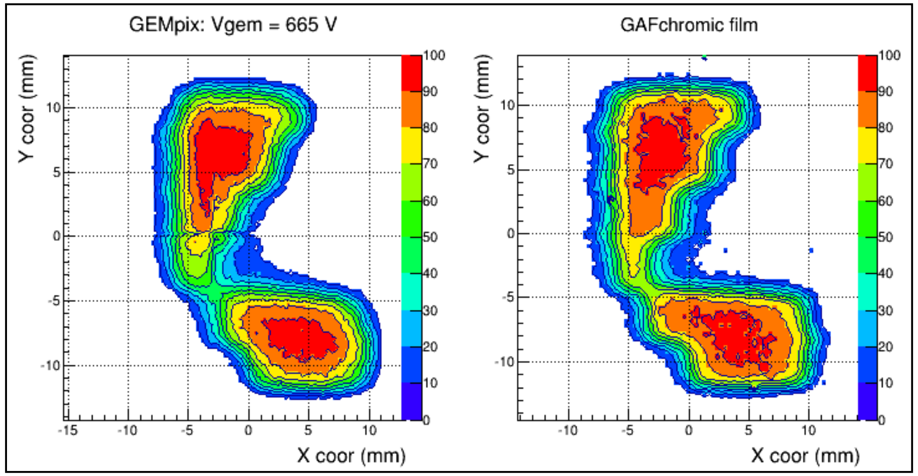


Intensity Modulated Radiation Therapy (IMRT)









G.Claps

Real-time measurements with GEMPix allows fast Quality Assurance procedure

LaGEMPix: Optical Readout

Why a Large Area GEMPix?

Underestimation of the dose of a pencil beam in the GEMPix:

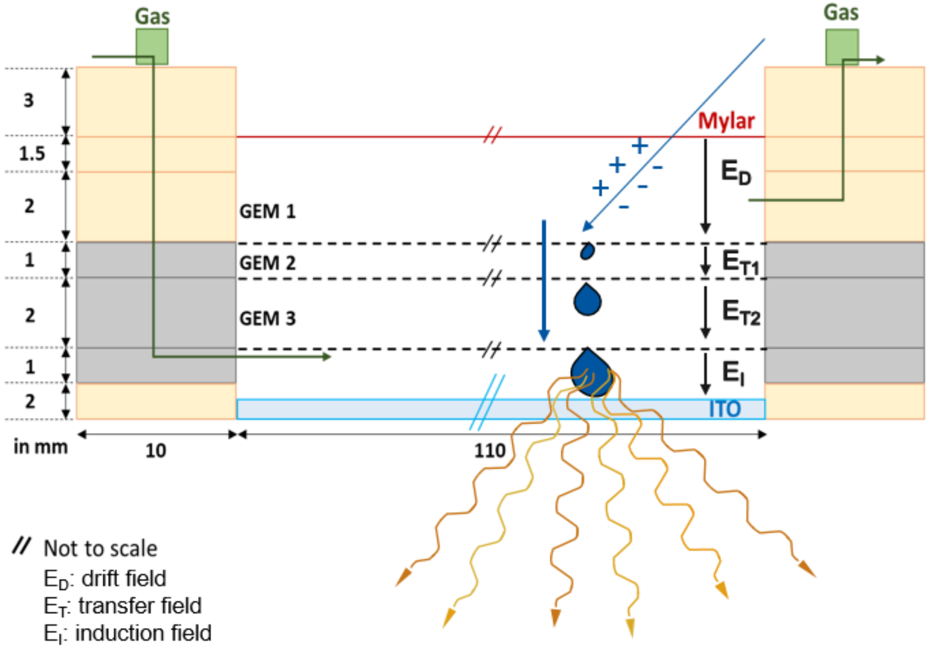
- The beam is spread out with increasing depth in water

Larger detector area of 20 cm x 20 cm needed to:

- cover typical maximum radiation field size for scanned beams
- avoid losses due to beam spread out

On-going work focused on larger sensitive area readout:

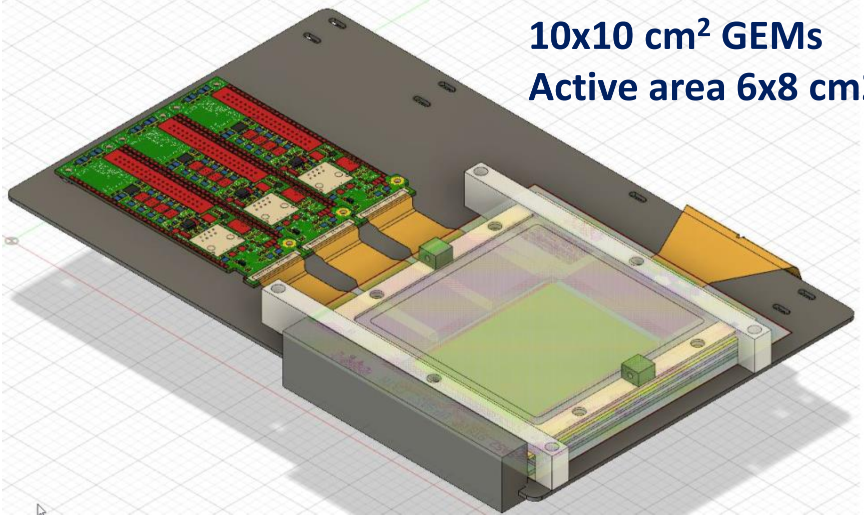
- Large area GEMs already exist
- Check new readout possibilities



Goal: 20 cm x 20 cm, spatial resolution better 1 mm!

LaGEMPix: Optical Readout

A possible solution is
the **Organic Photo Diodes** coated
on an organic TFT backplane



10x10 cm^2 GEMs
Active area 6x8 cm2

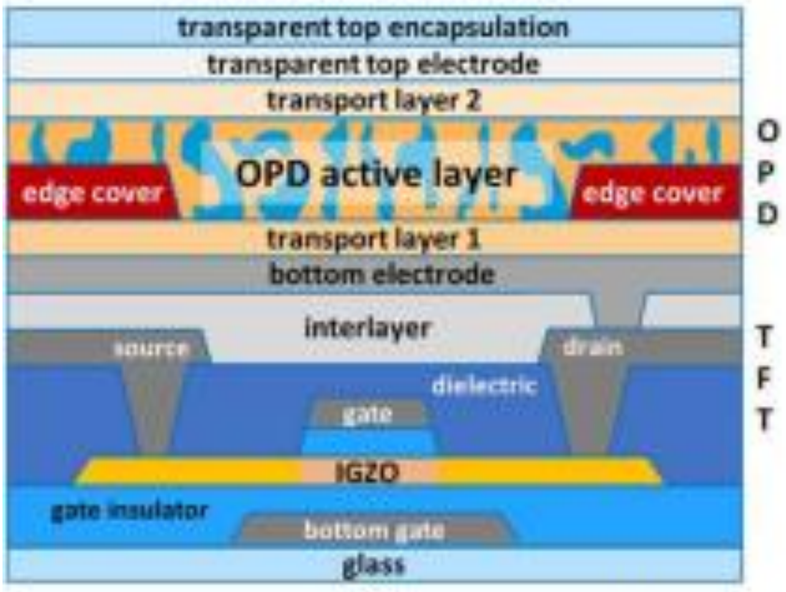
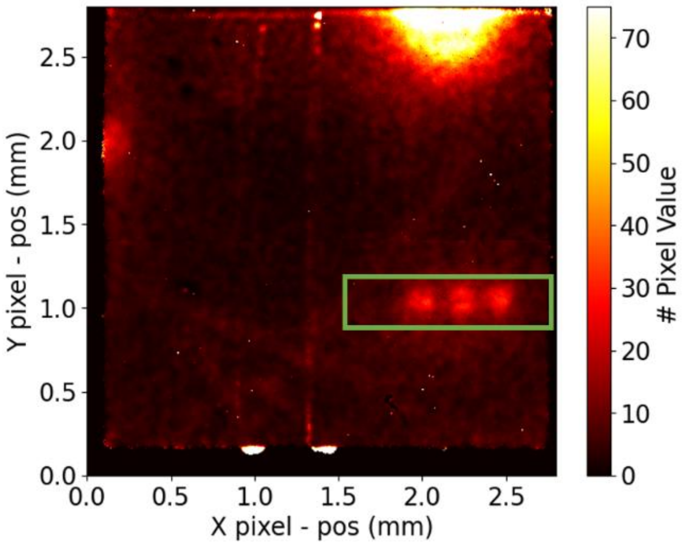
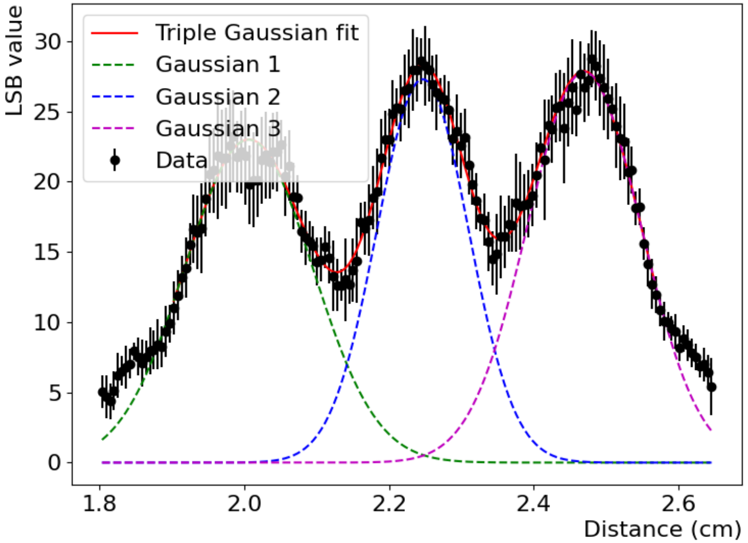


Image sensor used in LaGEMPix

Image realized with 40kV X-rays, with a copper plate with holes.

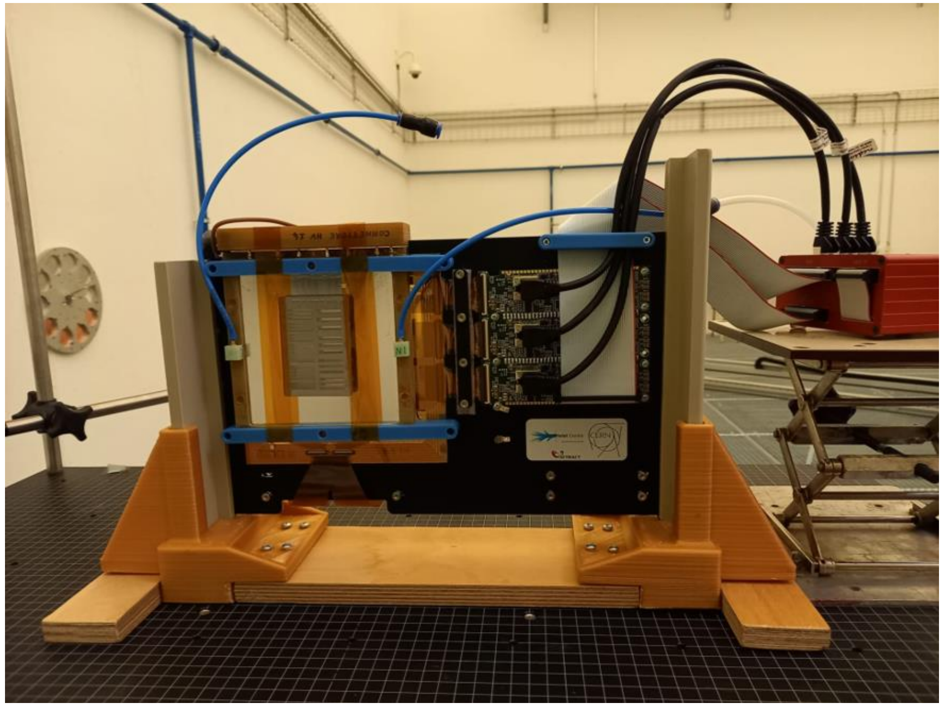


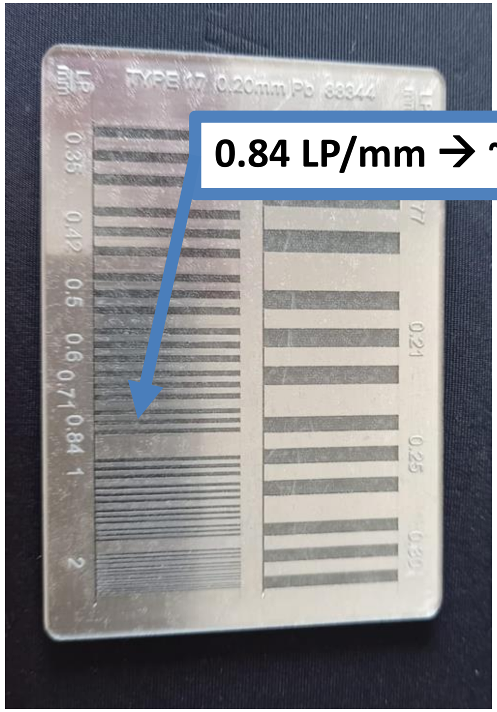
1.6mm diameter holes with a spacing of 1mm can be resolved

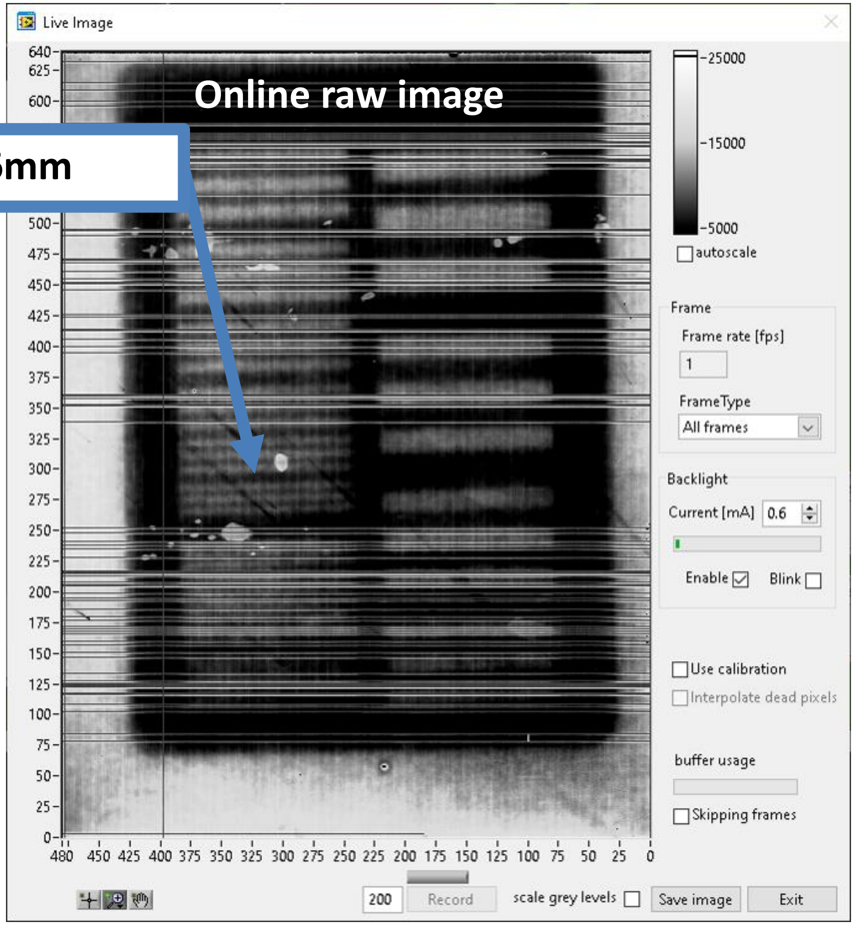


TFT without OPD sensor

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







X-Ray 30 kV, Ar:CF4

Integration time: 50 ms

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

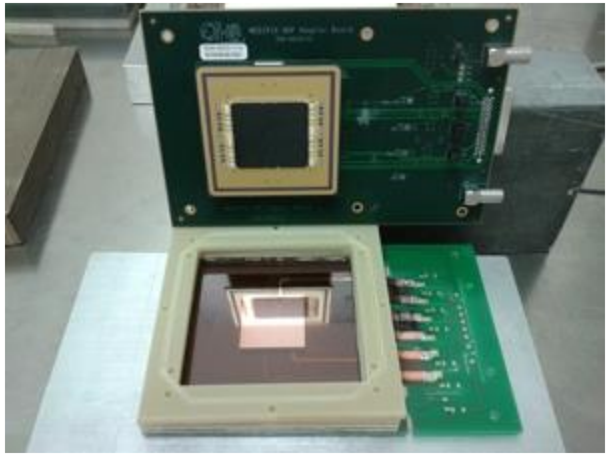
RADIOACTIVE WASTE

GEMPix for radioctive waste ^{55}Fe

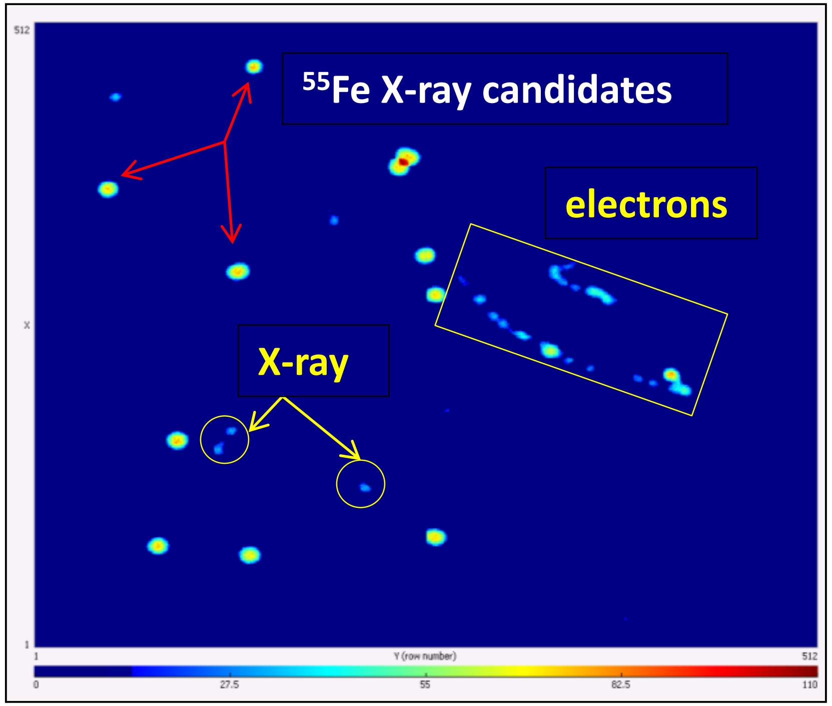
Data acquired in one second

X-ray Energy real-time measurement

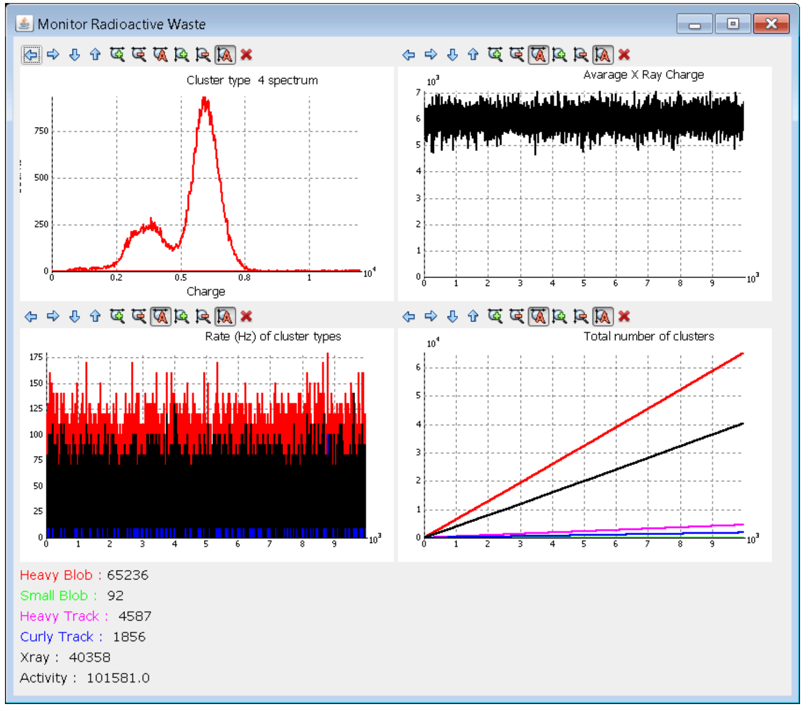
Silicon sensor has some difficulties to detect low energy Xrays coming from iron radioactive waste



3x3 cm^2 active area



Very good pattern recognition and real-time particle identification



Activity higher than 10 Bq/g of ^{55}Fe

GEMPix : 2 hours of data acquisition

Medipix :10 hours of data acquisition

External companies : days …

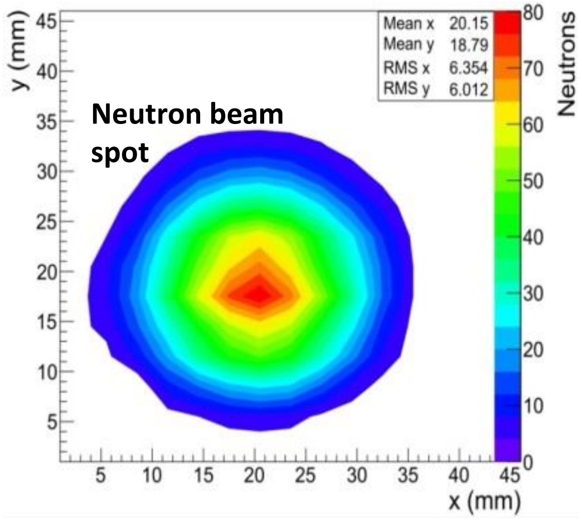
With the new Gemini readout we'll be able to visualize the ^{55}Fe radiation hot spot with a 10x10 GEM detector

NEUTRON DETECTORS

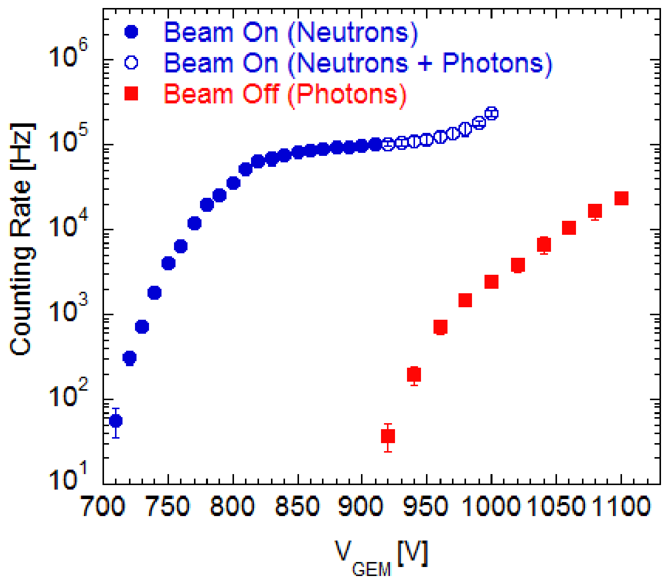
GEM detector for Neutrons

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

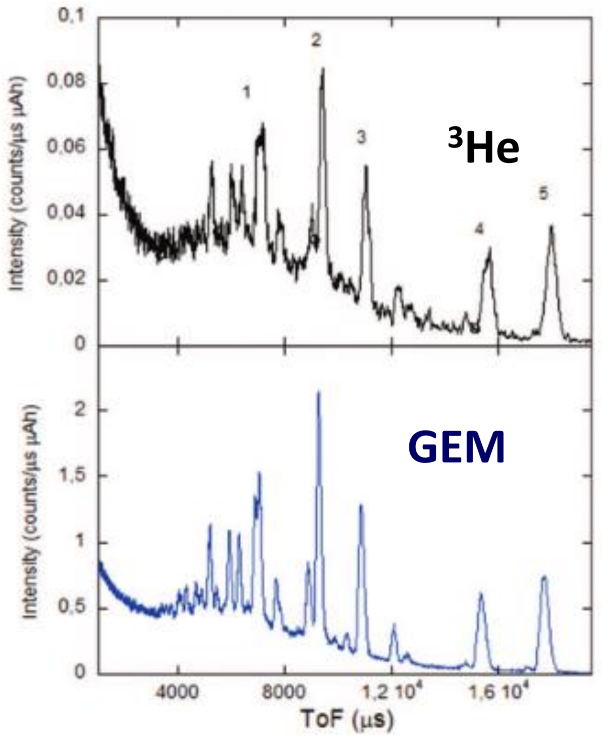
- **Imaging capability**
- **good time resolution (5 ns),**
- **high gamma rejection (>10^5)**
- **high rate capability O(10 MHz/cm^2)**
- **good spatial resolution O(mm)**



Gamma Neutron rejection

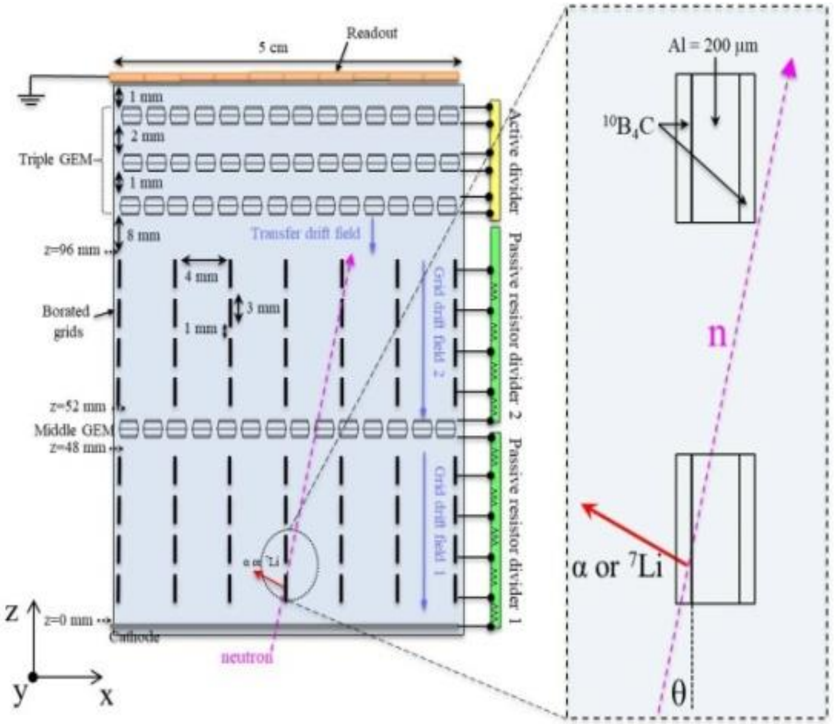


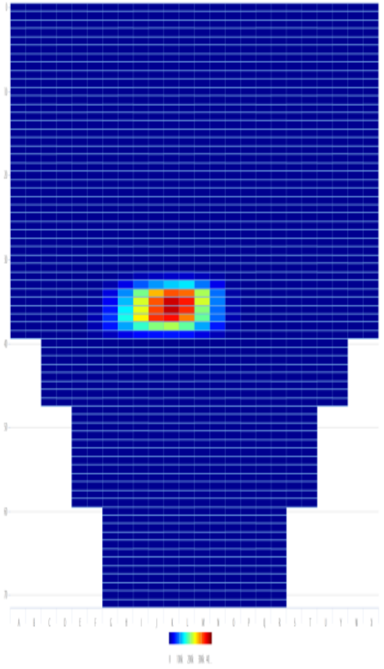
Diffraction Measurement



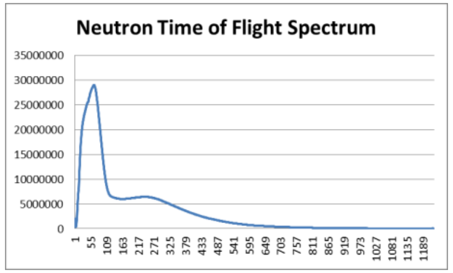
Band GEM for thermal neutron detection at ESS

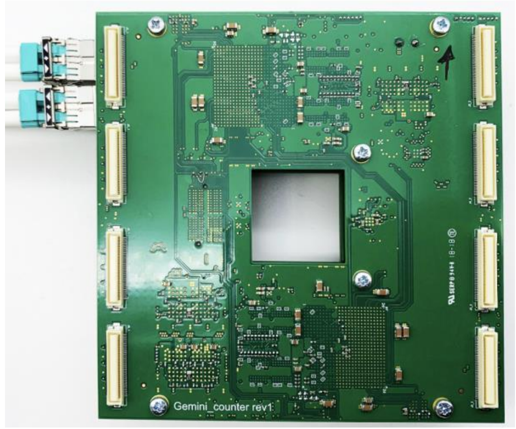
Trying to increase the efficiency in thermal neutron detection some borated grid has been placed hortogonally to the GEM foils





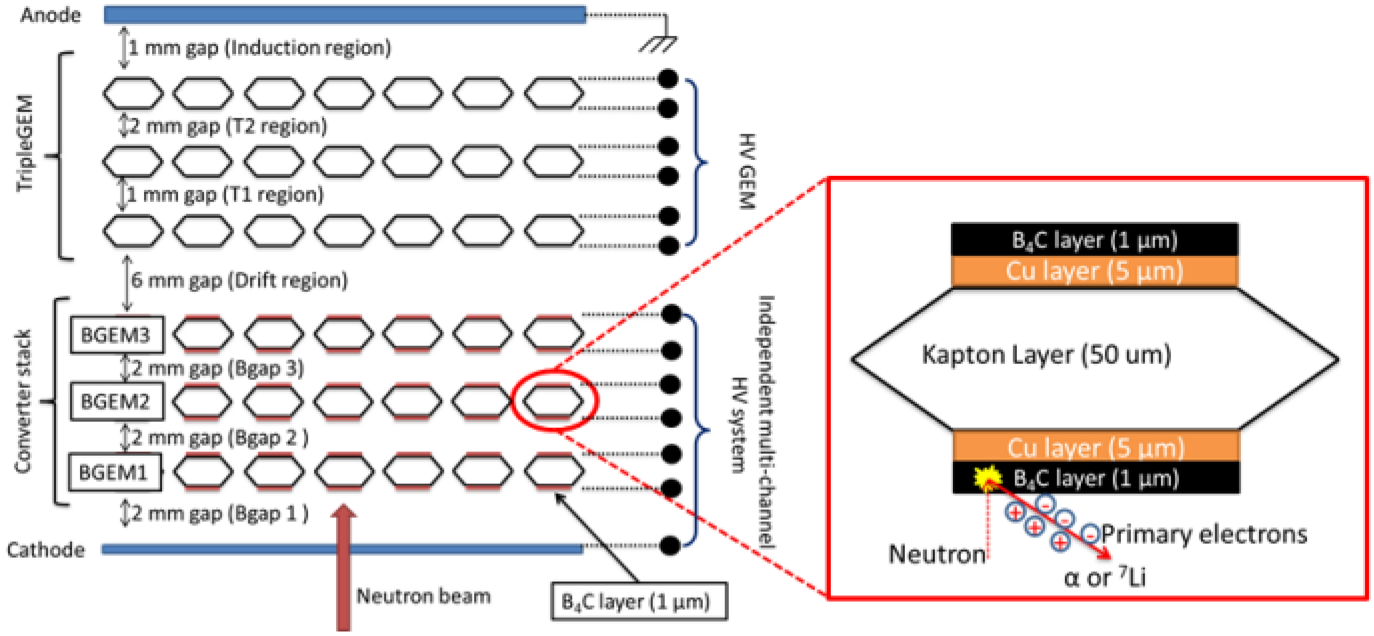
Real time Image of the neutron beam

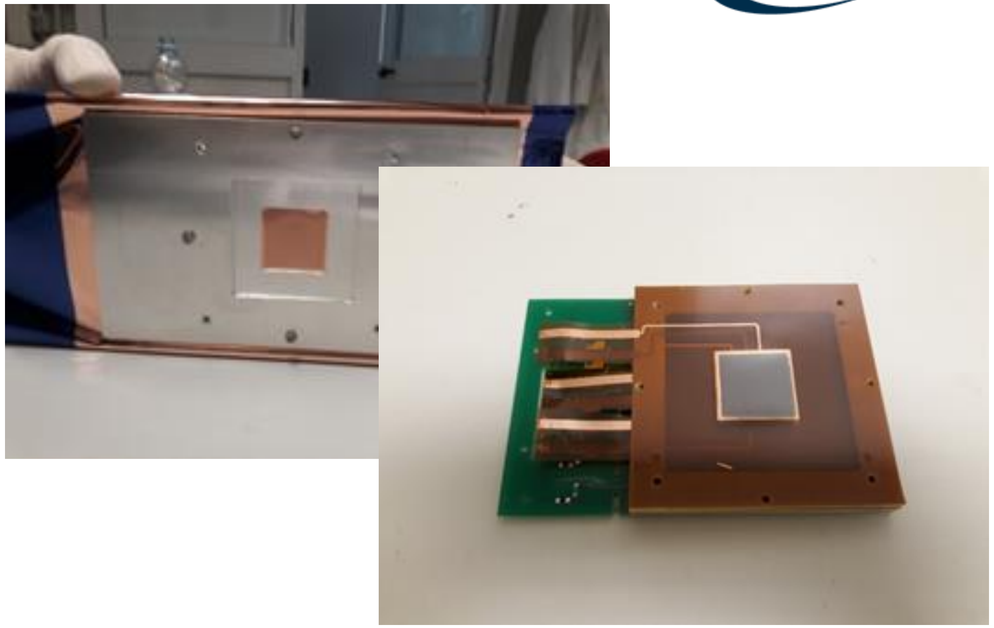


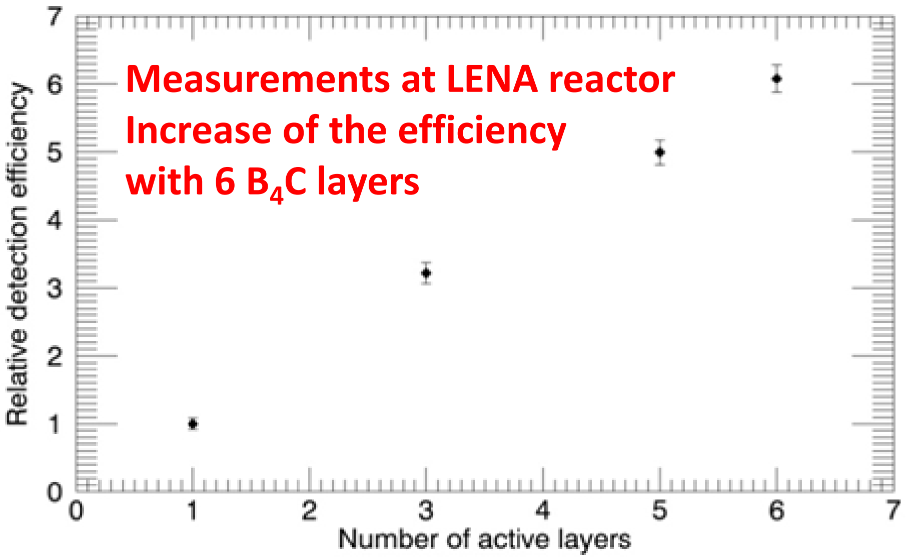


Readout electronics developed by Nuclear Instruments

Multi Borated GEM detector







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

Test ongoing with 10x10 cm^2 GEM at LENA in Pavia

Conclusions

In a short time obviously is really hard to do a complete review of applications beyond fundamental research.

I hope I gave you some issues on which our funding agencies must invest if we want that our research has some effects also on other social fields

What I've shown has been funded by :

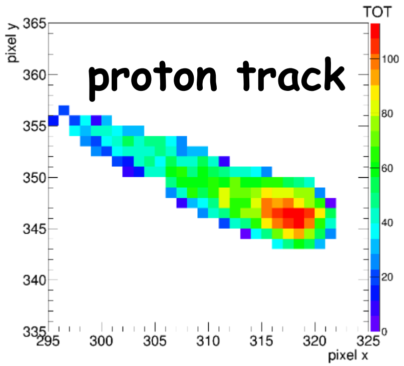
- INFN-ENERGY
- ATTRACT EU
- MAPF@CERN
- Radio Protection Special Project @ CERN
- ARDENT EU
- ENEA
- European Spallation Source
- Universita' Milano Bicocca

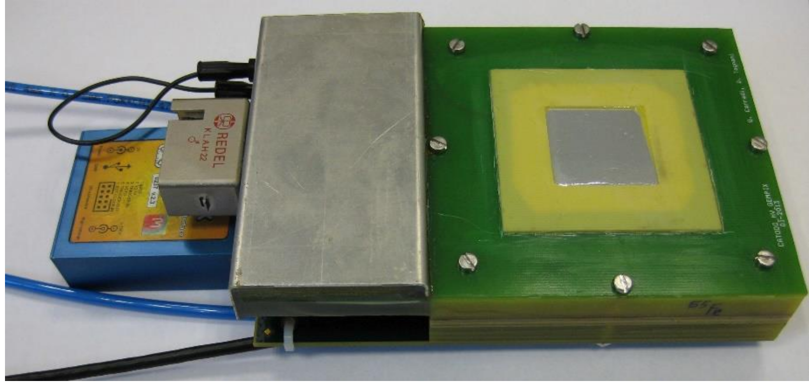
…with the invaluable help of some HI TECH companies :

I think that we have to improve the relationship with these companies for the future

1

The GEMPix II





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

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