GEMpix detector: a new diagnostic for Laser Produced Plasmas monitoring

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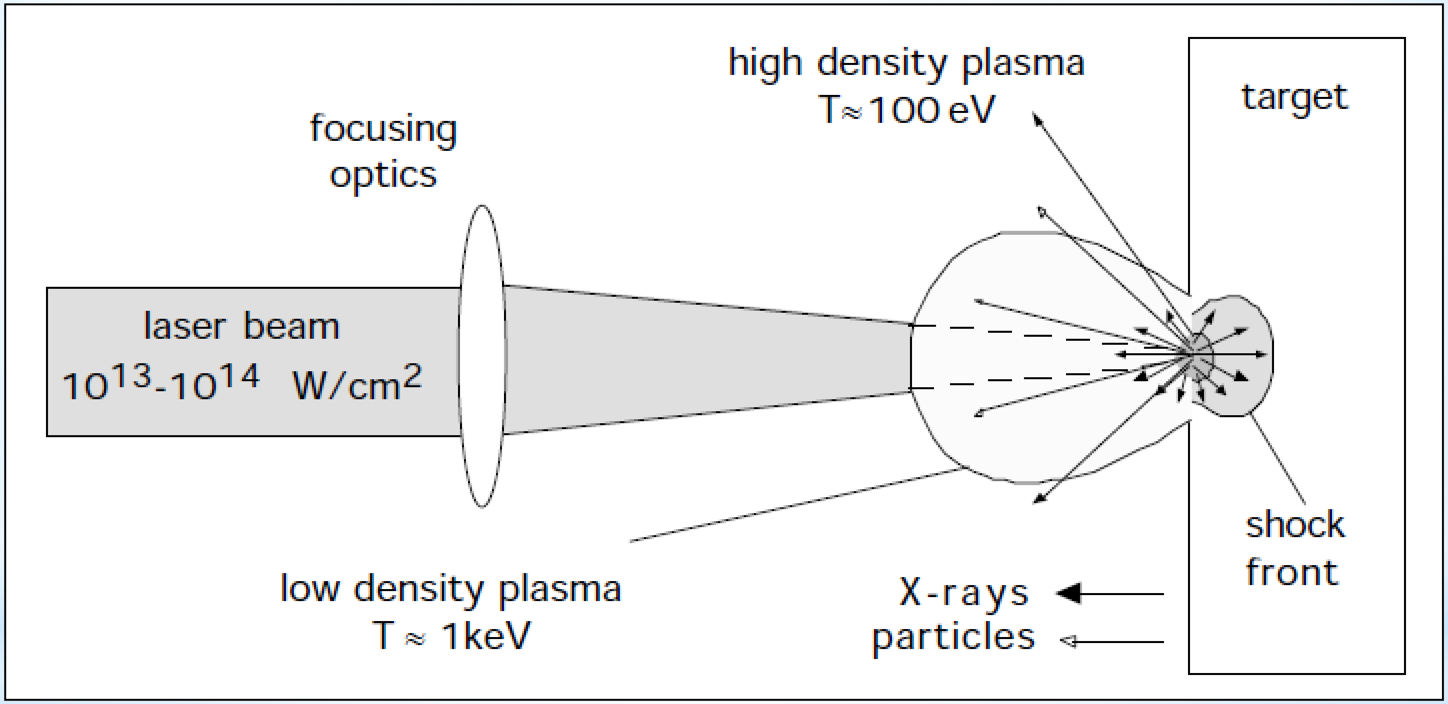
RD51 Academia-Industry Matching Event
Special Workshop on Photon Detection with MPGDs

10 - 11 June 2015

Laser Produced Plasma (LPP)

When an high intensity LASER is sent on a solid target, a plasma on its surface is generated. It is referred to as ***Laser-Produced Plasma*** (***LPP***).



The high intesity Laser is a ***pulsed Laser*** (ns or fs pulses). It is a Laser device on which Q-switch or mode Locking techniques are applied, eventually together with a final stage in which the pulse is subsequently amplified and further compressed in vacuum by a second pair of gratings.

Laser Produced Plasma (LPP)

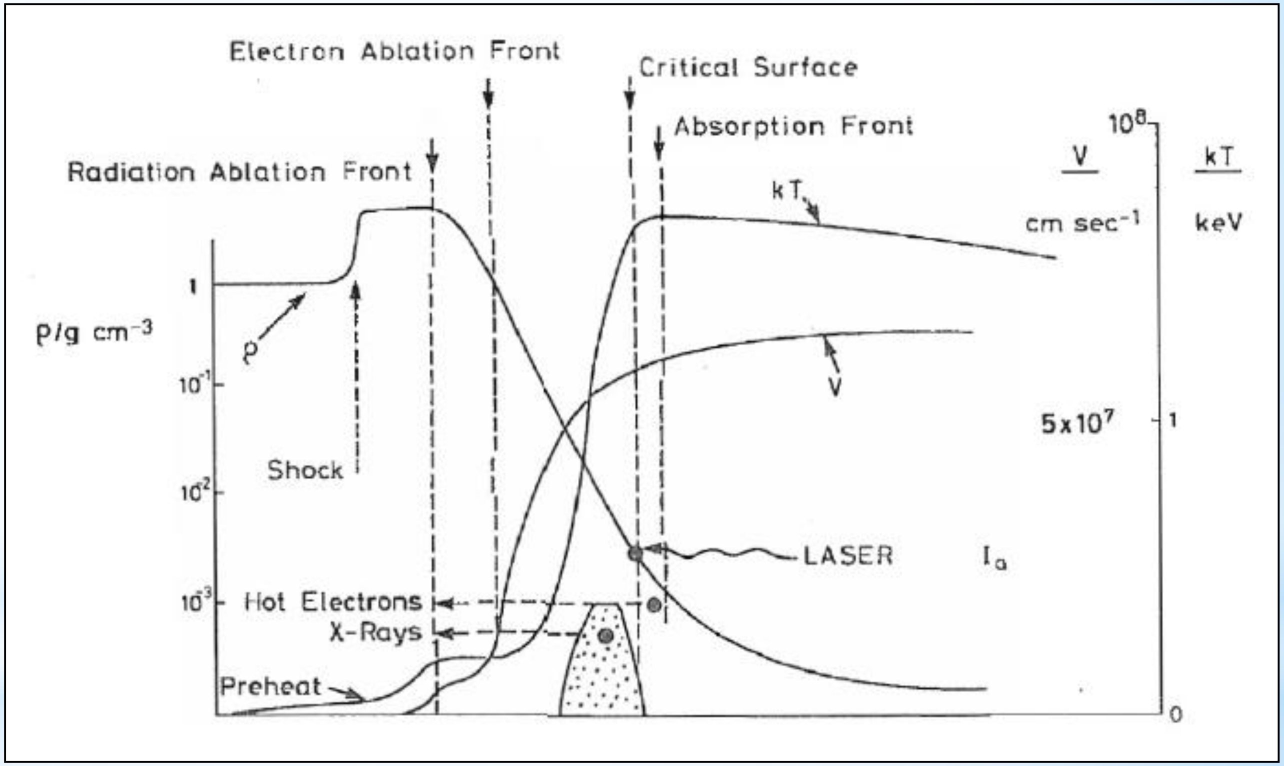
LASER-produced plasma is a matter state, in which partial or even total ionization is induced by LASER irradiation. It's a fluid state composed by electrons and ions; plasma as a whole, is neutral, but for it's made up by charges.

Plasma frequency

$$\omega_p = \sqrt{\frac{n_e e^2}{m \varepsilon_0}}$$

n_e number of electrons per unit volume

e electronic charge
m electronic mass



Typical temperature, density and expansion velocity proles of a plasma generated by irradiation of a solid target by a nanosecond LASER pulse focused on target at an irradiance of 10^{14} W/cm^2.

Laser Produced Plasma (LPP)

A common characteristic of Laser produced plasmas (LPPs) is their ***intense emission*** in the ***X-ray spectral region***. For this reason, they are considered also as ***bright sources of X-rays***.

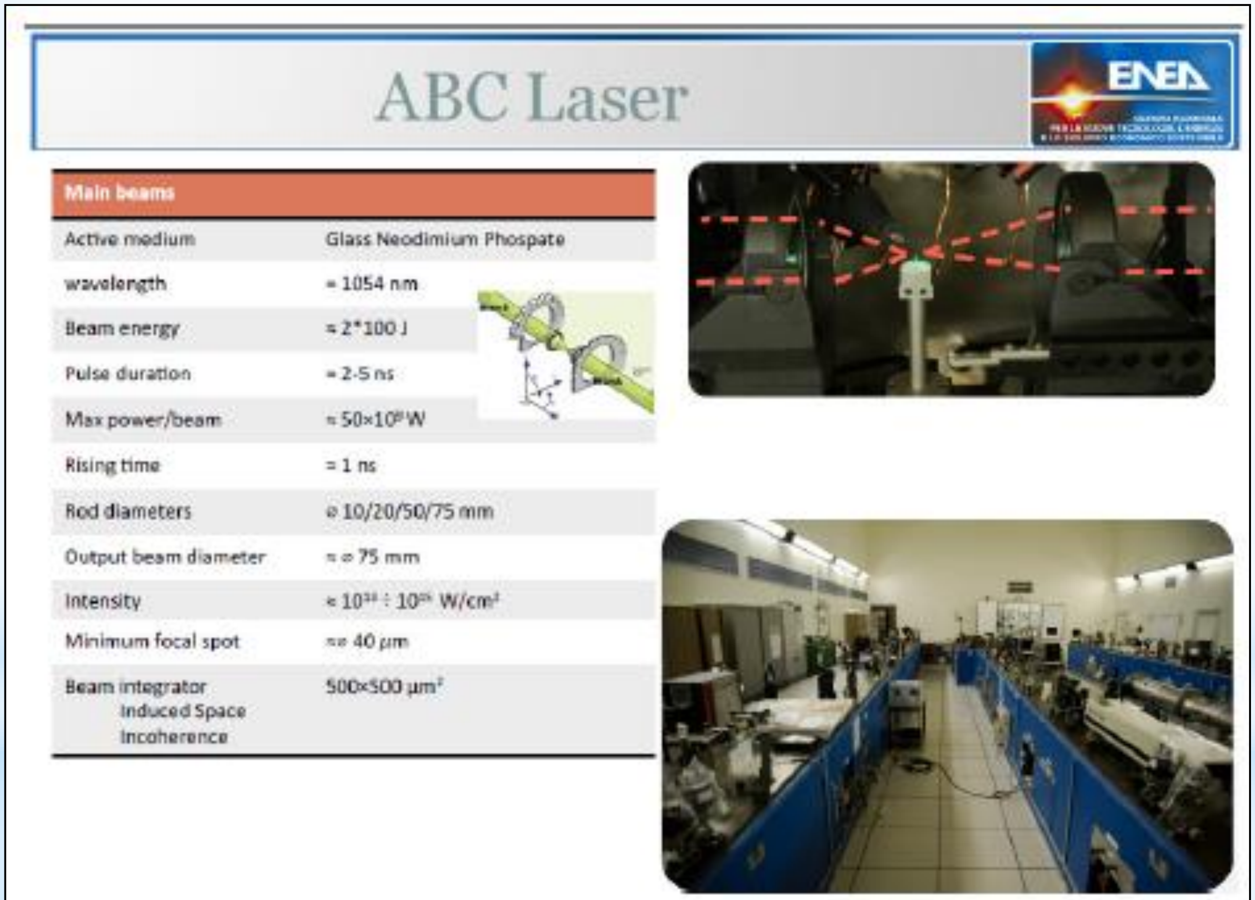
When plasma is the thermal relaxing phase, it emits X-rays throught three physical mechanisms which does not depent direclty on the interaction with the Laser field :

- ***Bremsstrahlung***: electron can move in the ionic environment with a sufficient thermal velocity so that it does not return in a bound state, but experience a friction force with a consequence deceleration and radiation emission.
- ***Electron-atom recombination*** radiation: electrons recombine in the lower atomic states of the free ions; when their initial kinetic energy is , typical spectral edges are observed.
- ***Atomic de-excitation transition*** lines: emission lines are due to transitions of electrons from upper to lower bound states.

Contribution from electron-atom recombination and atomic de-excitation transitions becomes becomes predominant with ***high-Z materials***.

ABC LASER facility

ABC LASER facility, at the ENEA Research Center in Frascati, is the most important facility in Italy dedicated to the studies about the ICF (Inertial Confinement Fusion).



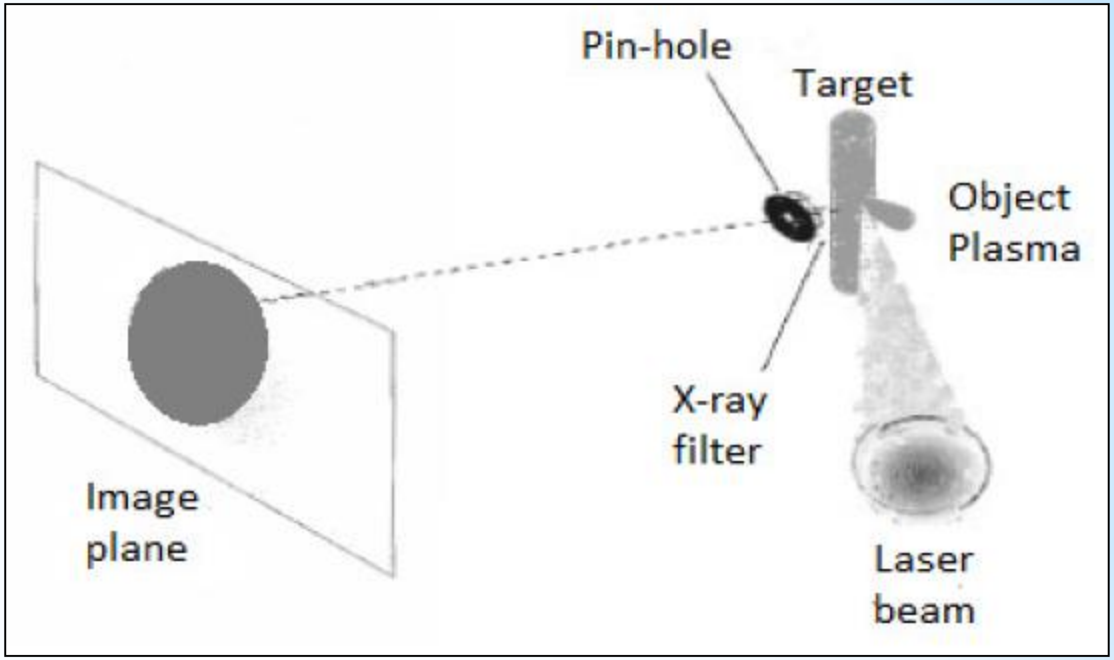
Main beams	
Active medium	Glass Neodimium Phospate
wavelength	≈ 1054 nm
Beam energy	≈ 2*100 J
Pulse duration	≈ 2-5 ns
Max power/beam	≈ 50×10[illegible] W
Rising time	≈ 1 ns
Rod diameters	⌀ 10/20/50/75 mm
Output beam diameter	≈ ⌀ 75 mm
Intensity	≈ 10[illegible] ÷ 10[illegible] W/cm²
Minimum focal spot	≈⌀ 40 μm
Beam integrator Induced Space Incoherence	500×500 μm²

ABC LASER is based on Nd:glass (1.054 μm) active medium and can be splitted two beam lasers which can deliver up to 100 J in pulses few nanoseconds long (2-5 ns).

ABC LASER facility: X-ray imaging

Typically, X-ray imaging is realized through a pin-hole camera (PHC). The images are recorded using:

- X-ray sensitive detectors (film and CCD)
- Phosphor screens coupled to optical image intensifiers, like Multi-Channel-Plates (MCP).



With a plasma transverse size of 100 µm and assuming an image magnification of 10 with a pin-hole diameter of 10 µm and a pin-hole to image distance of 50 cm, at the 1 keV region, a photon flux from ***10^5 to 10^8 photons/cm^2*** is expected according to the variation of the absorbed laser energy. ***X-ray emission is concentrated in few ns***.

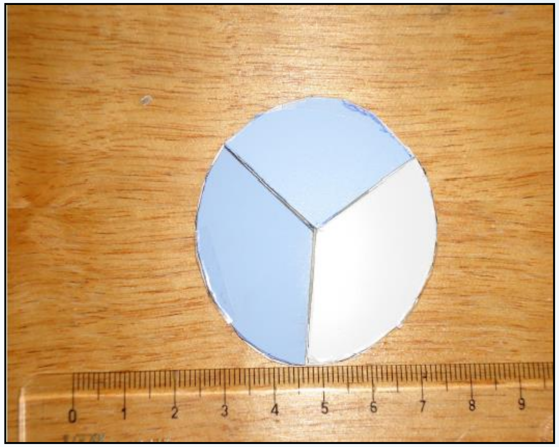
Photon fluence can be changed working at longer distance in order to have a lower number of photons per unit area.

ABC LASER facility: X-ray imaging

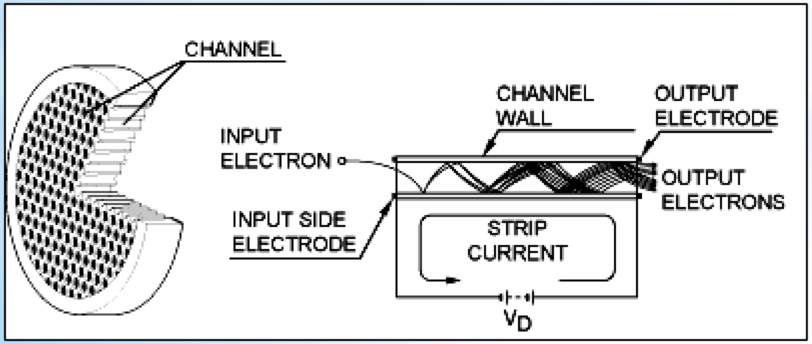
Image Plates: they are two-dimensional X-ray detectors which are photo-stimulated by X-rays.

They are composed of rare-earth-doped alkaline-earth halide (BaFBr: Eu^{2+}).
They contains F-centers, namely a type of crystallographic defect in which an anionic vacancy is capable of attracting and binding one (or more) free or quasi-free electron into a metastable atomic-like state.

Then photo-luminescence is stimulated red Laser (HeNe).

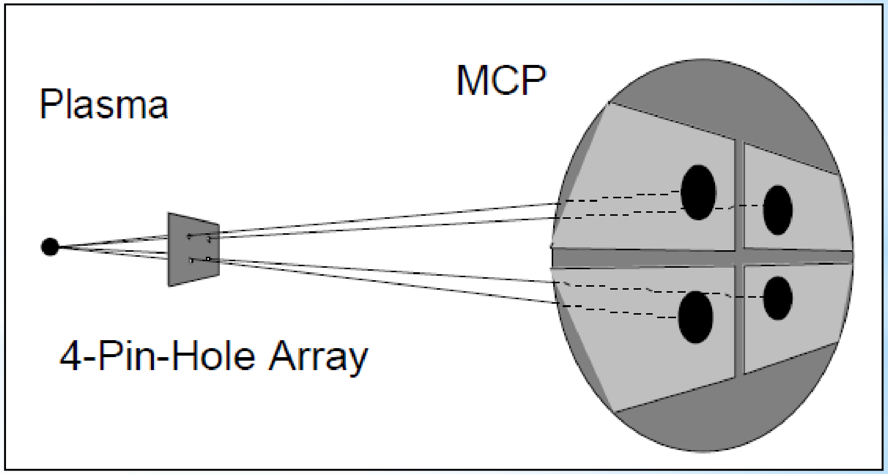


A mosaic of three different image plates.



In alternative MCP + CCD

Spectral selection in X-ray imaging



Schematin arrangement of a pin-hole camera fitted with a 4-pin-hole array to perform 4-channel imaging of laser produced plasmas.

X-ray imaging: Image Plate and CCD

Image plate advantages:

- High dynamic range
- High spatial resolution
- Linear response to radiation dose
- They can be reused

Image plate disvatages:

- Low efficiency
- Detector noise
- Complex and long post-processing

CCD advantages:

- Good quantum efficiency
- Medium to high dynamic range

CCD disvatages:

- Small detector size
- Detector noise
- Need to be cooled to reduce noise

Often CCD are used with MCP: the signal is amplified, but imaging bocomes worse and information on the energy is lost.

MCP are used also with a fast gate potentials and a consequent gain up to 1000.

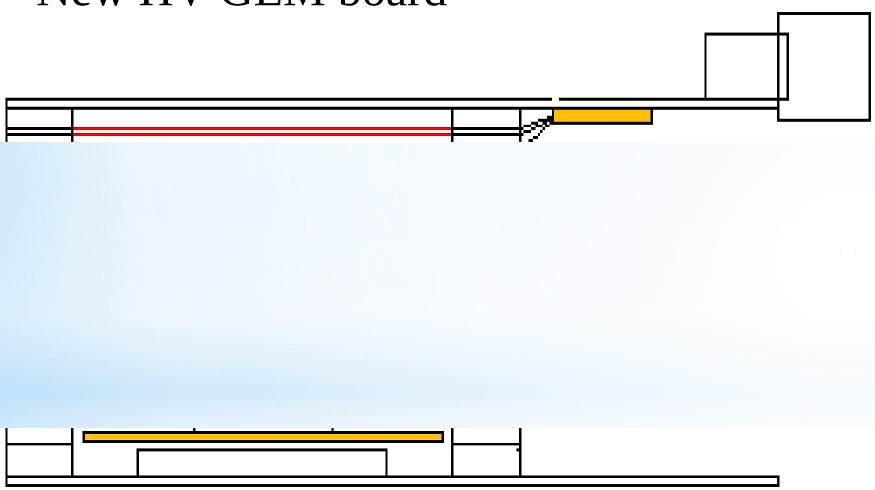
The GEMpix detector

The detector was conceived within the ARDENT project for the hadron high intensity beam monitor.

Detector has two main components:

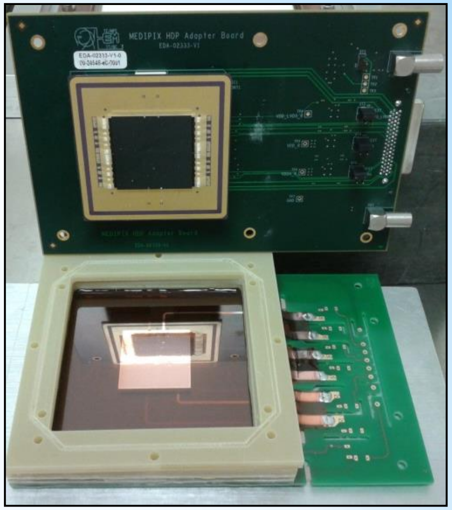
- A quad medipix without silicon layer
- A triple-GEM with filter and HV connectors

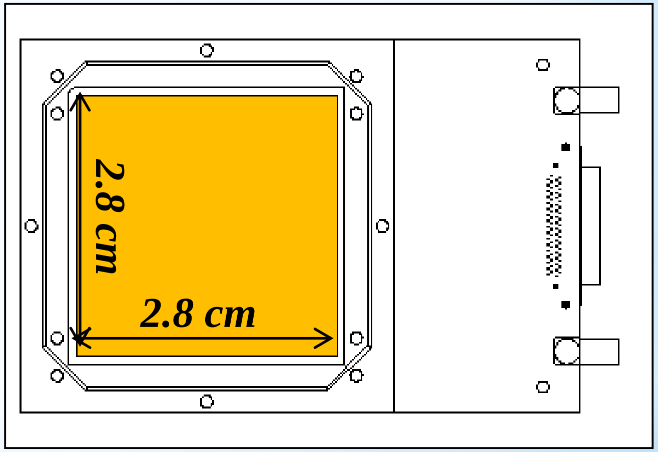
New HV GEM board

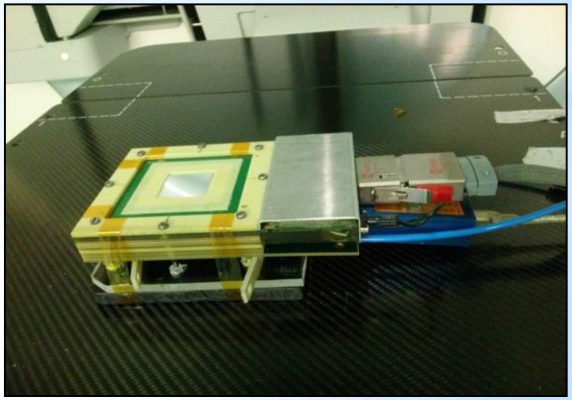


Quad medipix board (M.Campbell, J.Alzoy)

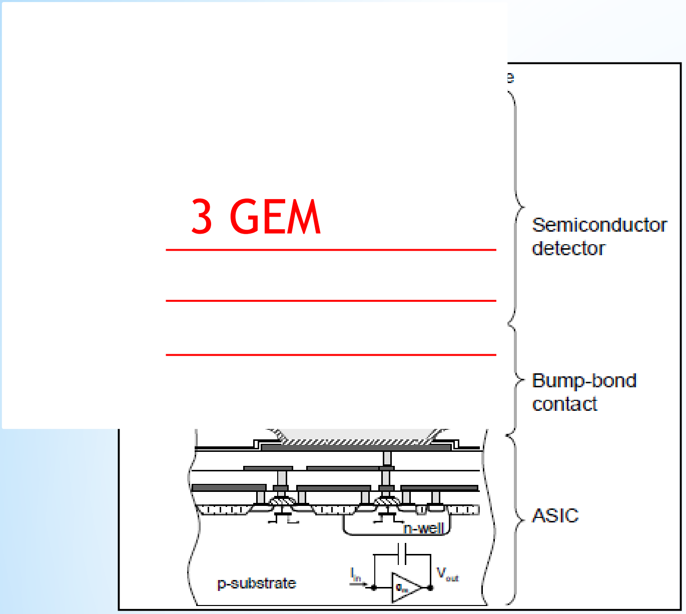
A Medipix chip has 256 x 256 pixles, each having an area of 55 x 55 μm². Quad Medipix is made of 4 medipix chip hold together (512 x 512 pixles).



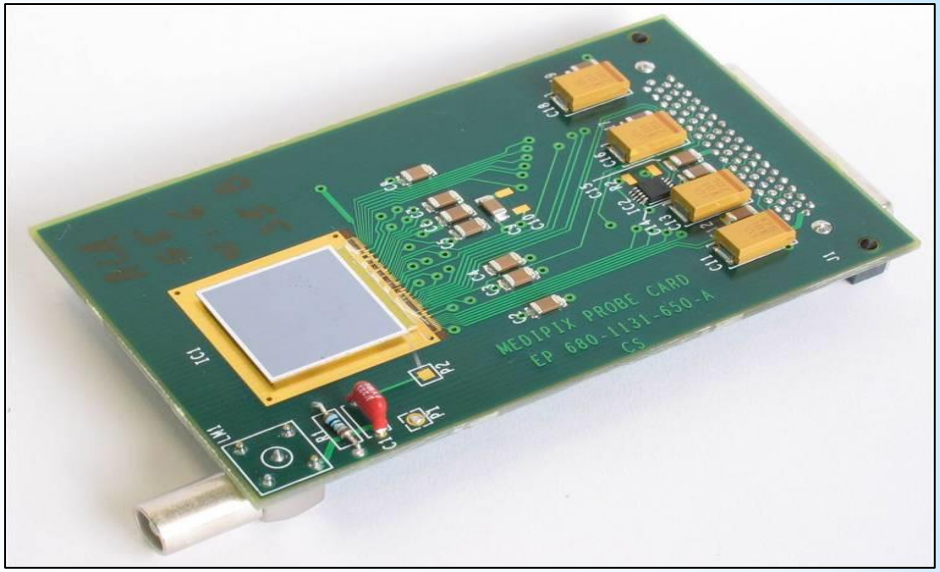




The GEMpix detector: front-end-electronics

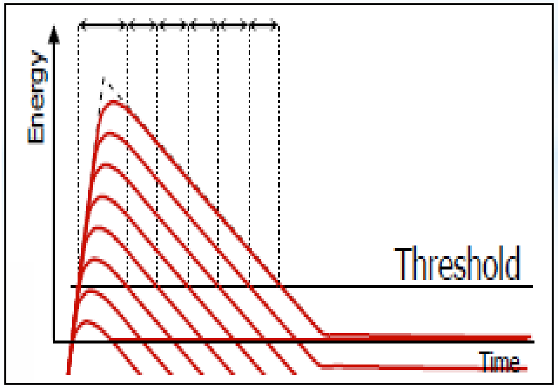


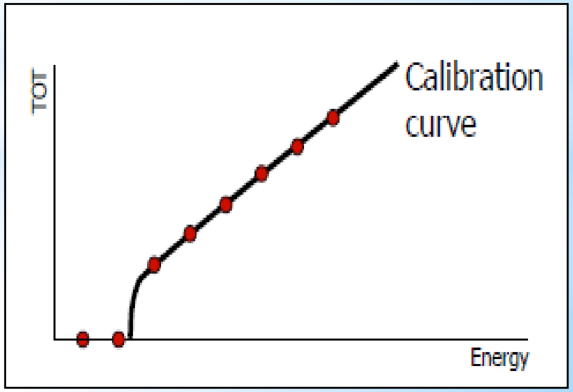
A Medipix detector with its electronic.



Physical dimensions	***14.08 x 14.08 mm²***
PADs	*55 x 55 μm²*
Charge collection	*e⁻, h⁺*
Pixel functionality	*Counting, ToT, Timepix*
Amplifier gain	*~ 18 mV/ke⁻*
Noise	*~ 75 e⁻*
Linearity	*Up to 50 ke⁻*
Minimum threshold	*~ 500 e⁻ (expected)*
Counter depth/overflow	*14-bit/yes*
Max Analog Power	*6.5 μW/pix; 190 mA/Chip*
Static digital power	*200 mA @ 100 MHz*
Read out	*Serial/Parallel*

Time over Threshold Mode

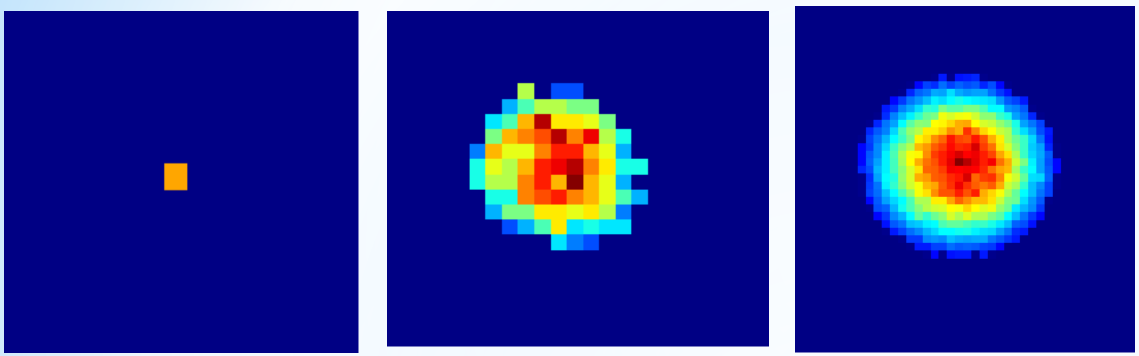




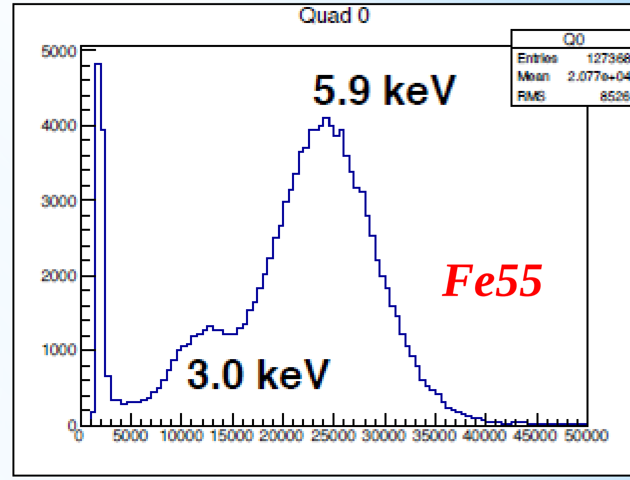
The «GEMpix» detector: characterization @ NIXT Lab (ENEA)

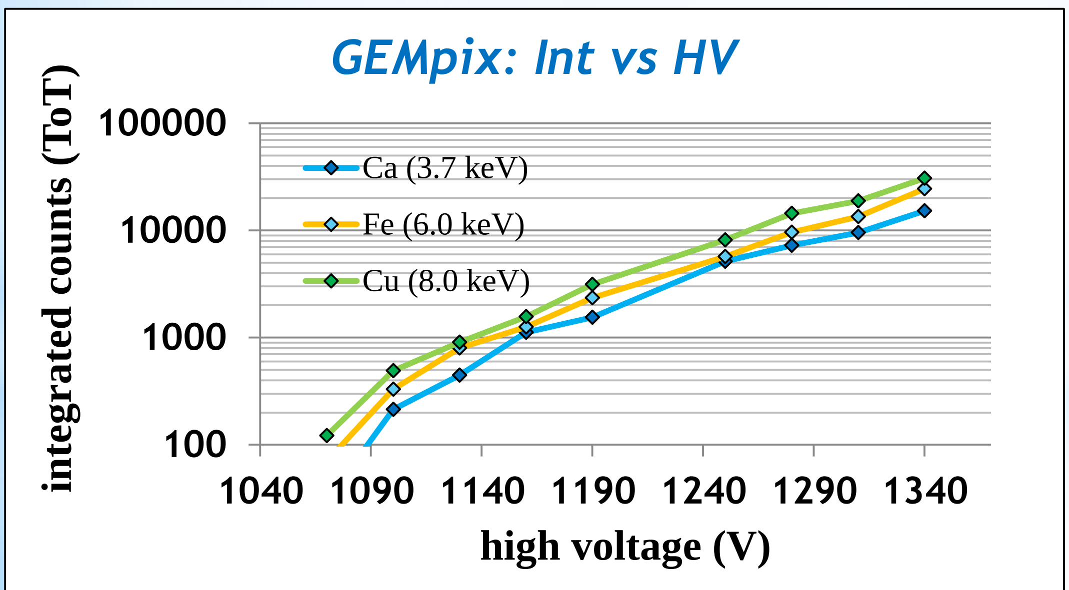
single photon at 6 keV

Vgem = 930 V **Vgem 1000 V** **Vgem 1150 V**

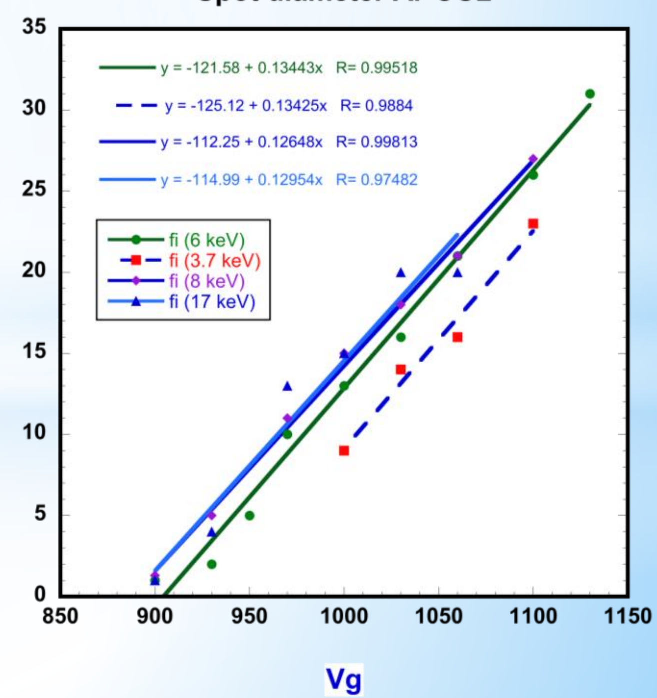


Increasing gain, the charge cloud becomes larger.



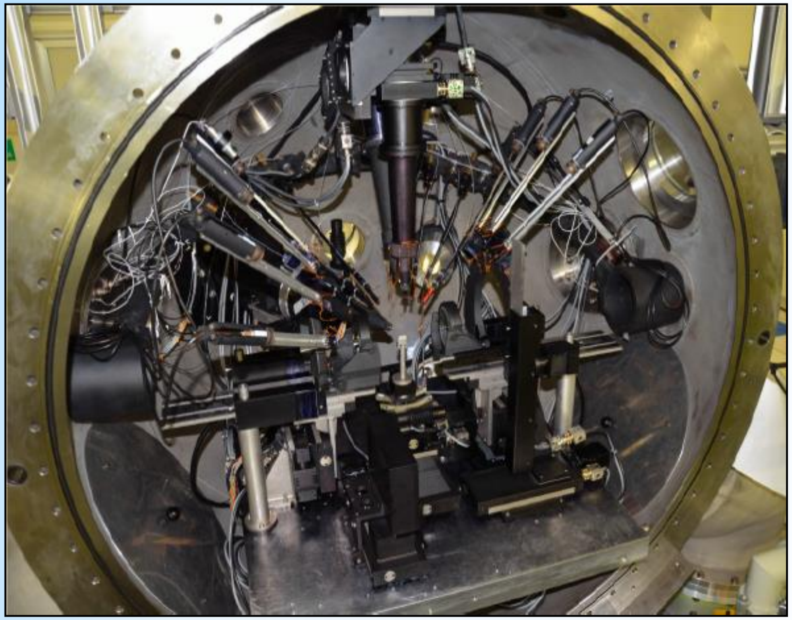


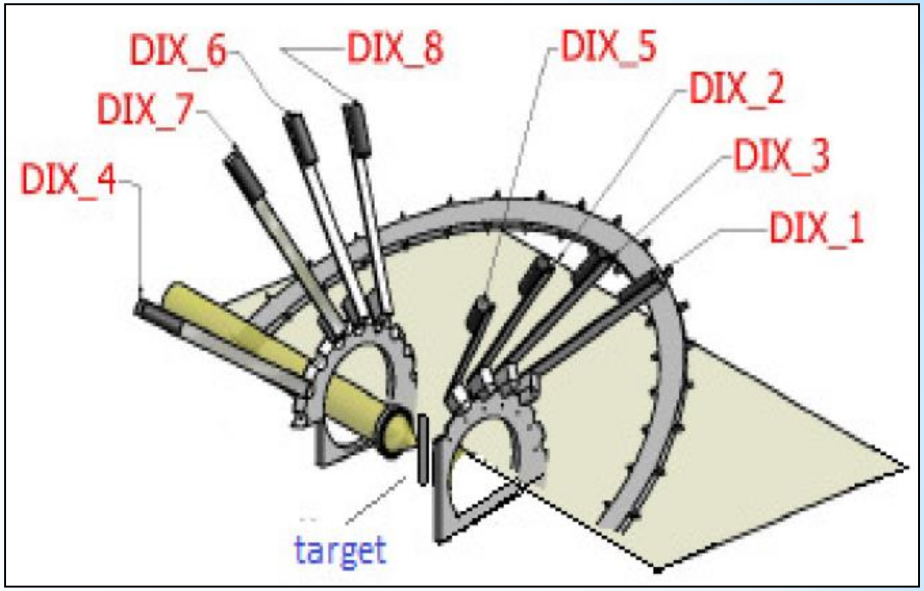
Spot diameter Ar-CO2



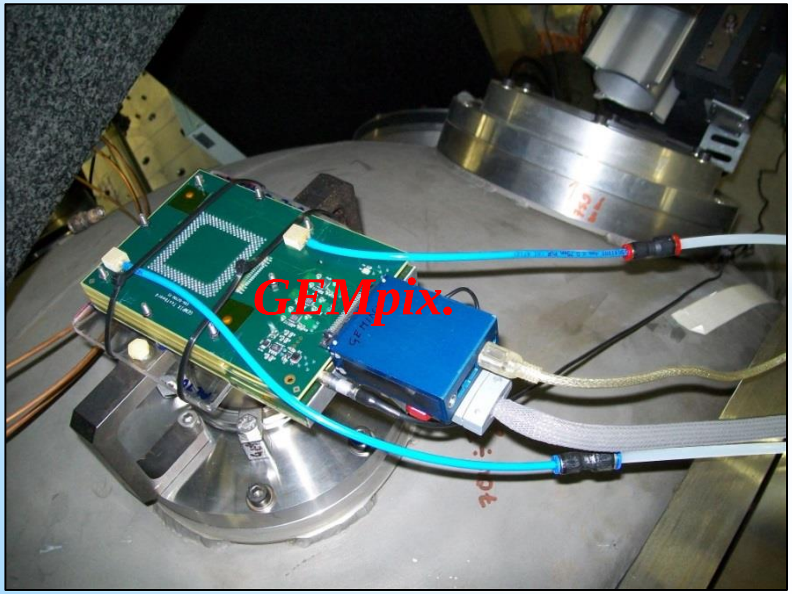
Sensitivity can be adjusted over 3 orders of magnitude.

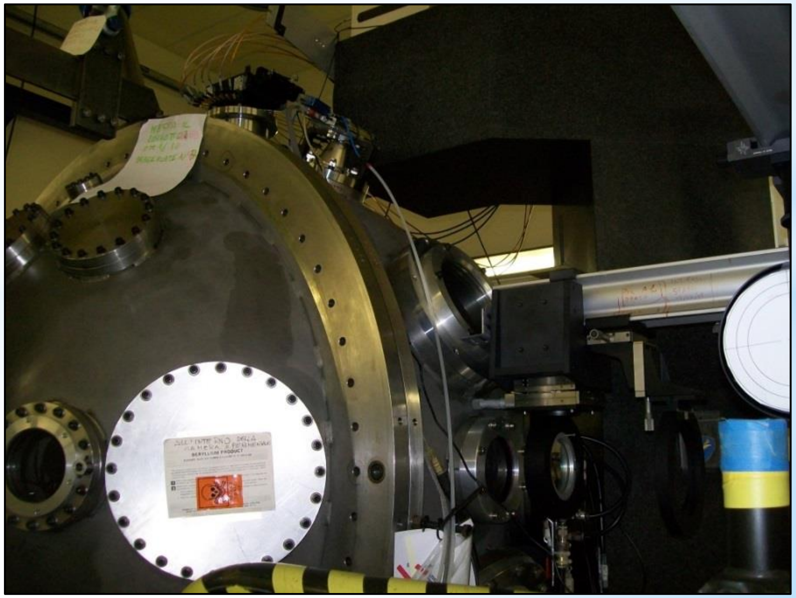
The GEMpix detector @ the ABC Laser facility





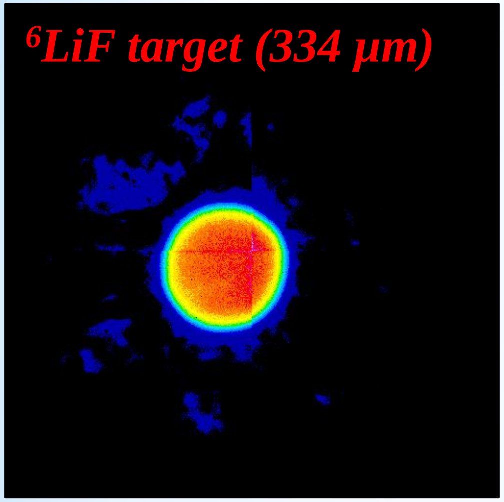
Arrangemets of pin-diodes in the camera.

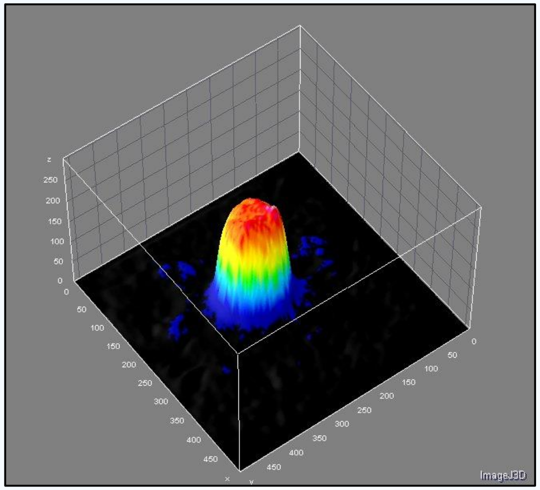




Measurements at Lab ABC tests

GEMpix was mounted on a port with a berillium window 5 mm in diameter and 50 μm thick (no imaging)

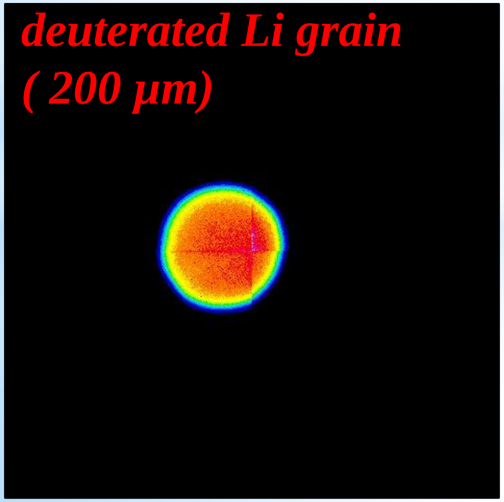


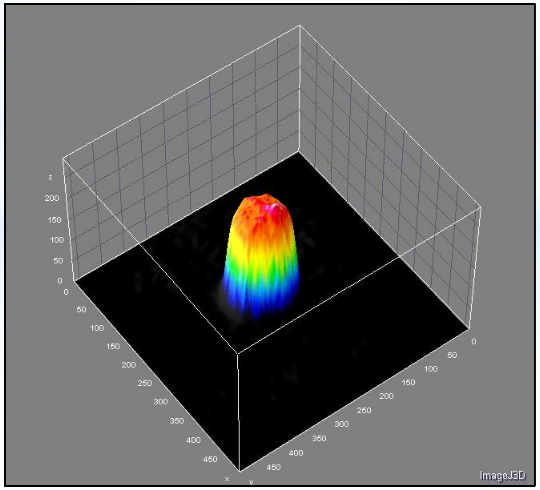


High Voltages on GEMs:
Drift = 3.0 kV/cm
T1 = T2 = 3.0 kV/cm
Ind = 5.0 kV/cm

Vg1 = Vg2 = Vg3 = 300 V
Vgain = 900 V (gain = 440)

GAS: Ar/CO2 (70/30)
Gas flux = 1.0 LPM

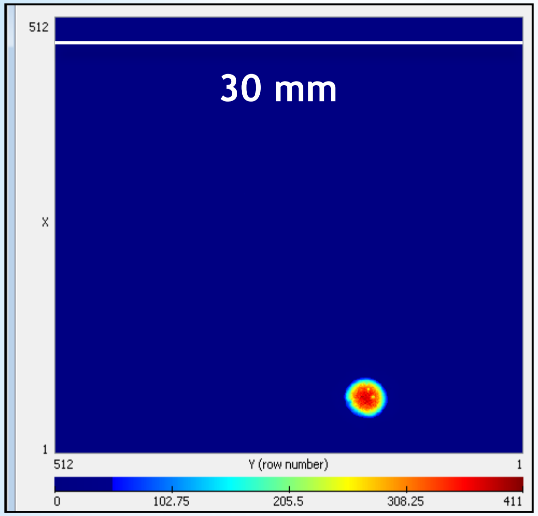


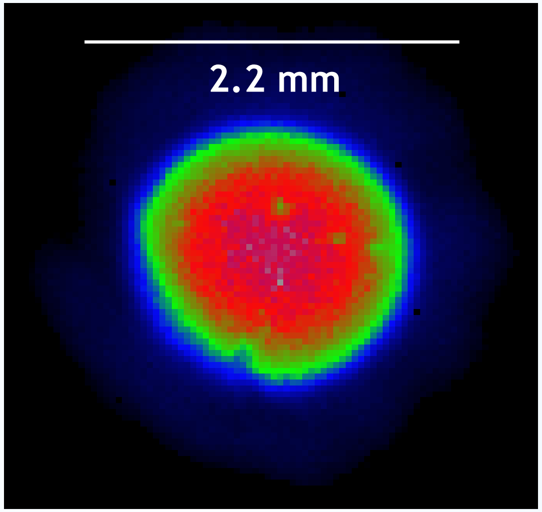


GEMpix can work well in ToT mode with high photon fluence and good uniformity is observed (flat field).

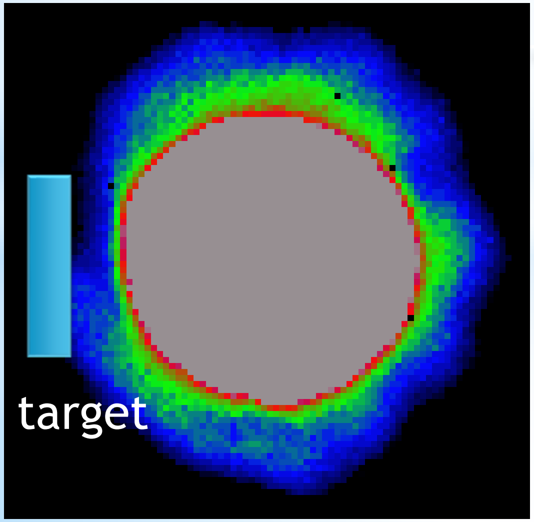
Measurements at Lab ABC tests

GEMpix was mounted on a port with a pin-hole with a magnification of 1.5. The target was an aluminium foil 7 µm thick.





The shaping of the core emission is visible and the estimateted dimension is comparable with that expected from other observations.



Changing the intensity scale (colors) the core is saturated and becomes visible the presence of a corona around the plasma core. This corona exhibits clearly ***poloidal modulations***, imaged with a spatial resolution of about 50 mm. On one side it is possible to observe a cut which identifies the ***target***, from which plasma plume comes out.

Conclusions

GEMpix inherits some of the main advateges of GEM gas detector an C-MOS techcnology and from these preliminary tests on LPPs, some advatage are clear:

- ***High and adjustable sentitivity (Vgem) over 4 orders of magnitude***
- ***High dynamic range***
- ***High spatial resolution***: in the case of LPPs, working at low gain it is possible to separate different burst of photons up to 55 μm.
- ***Absence of noise***.
- Possibility to operate with different threshold so that to ***separate different energy bands***. No need of filter. GEMpix ***can be adapted for X-ray spectral*** selection measurements.
- ***Measurements*** are ***fast*** and can be followed in ***real-time***.
- ABC test have demostared that detector can work in the ***imaging of LPPs***. It work in a ***«pile-up» mode*** and is able, for example, also to describe details on the poloidal variaton of plasma corona.

In the future a series of sistematic characterization tests will be performed on the Eclipse Laser Facility (Bordeaux). A series of reproducible laser-target interactions will be available and this is importat for the charactrization of GEMpix performances.

Thanks
for your attention!!!