Our team

Head of

COMPACT DIAGNOSTIC SYSTEMS FOR X-RAYS, GAMMAS, AND NEUTRONS: A "SWISS-KNIFE" DETECTORS PORTFOLIO RANGING BETWEEN MAGNETIC CONFINEMENT FUSION, THERMAL AND FAST NEUTRONS DETECTION, AND LASER PRODUCED PLASMAS EXPERIMENTS

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ITER site, ITPA – TG, 29/10/2021

Lab NIXT DETECTORS PORTFOLIO

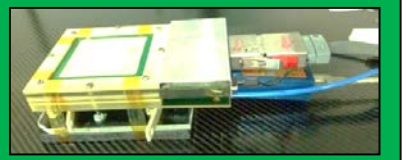
in collab. with:

INFN Istituto Nazionale di Fisica Nucleare — F.Murtas

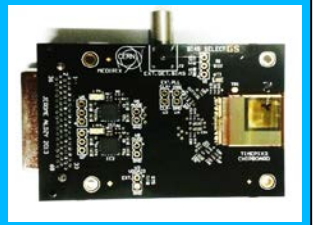
Consiglio Nazionale delle Ricerche — A.Muraro, M.Tardocchi

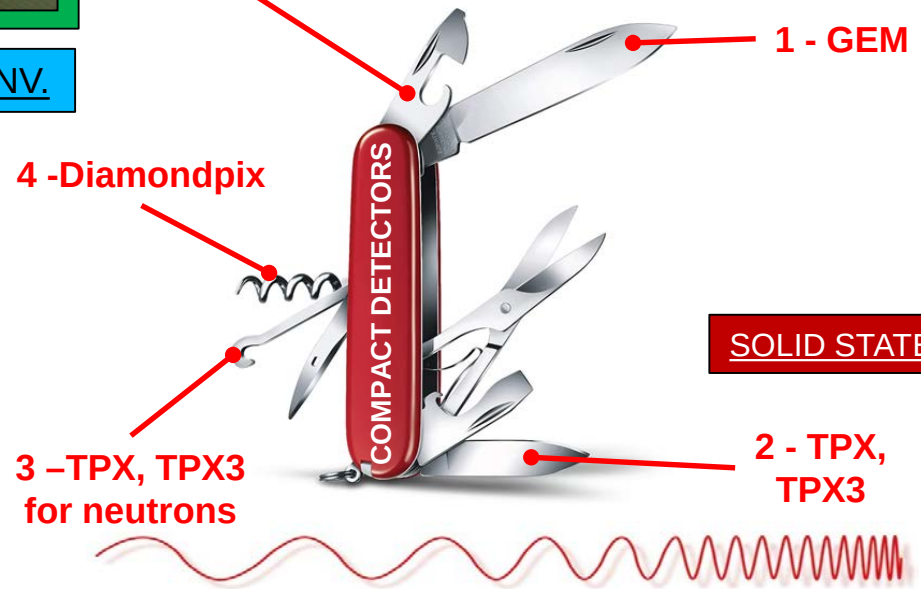
Università degli Studi di Milano Bicocca — S.Cancelli, G.Croci, G.Gorini

HYBRID ASIC-GAS



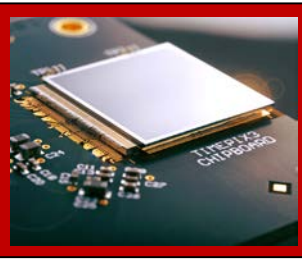
HYBRID ASIC-DIAM./CONV.





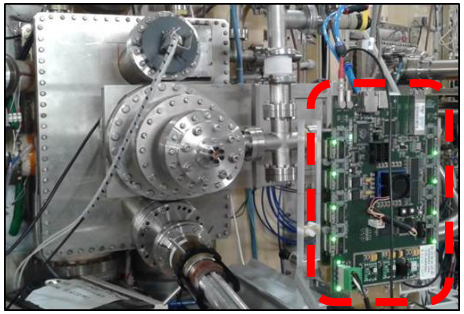
GAS

SOLID STATE



1 - GEM DETECTORS (1997-2019)

Gas **E**lectron **M**ultipliers (GEM), initially developed at CERN in 1997 by F. Sauli as particle detectors, were used for the first time as 2D imaging cameras by D. Pacella in 2000 (*). They were successfully tested for **soft X-ray plasma imaging** on NSTX (2000-2004)



GEM installed outside port 5 on **FTU** (2016)

GEM ADVANTAGES:

- **high sensitivity (4 orders of magnitude higher than diodes)**
- **noise-free (only shot noise)**
- **high contrast**
- **single-channel energy range and time of arrival**
- **optical flexibility (tilting and zooming)**
- **adjustable sampling rate (1 kHz, 100 kHz or better for short time intervals)**
- **absolute calibration**
- **works in a radiative environment**

OBSERVABLE PLASMA PHYSICS PHENOMENA :

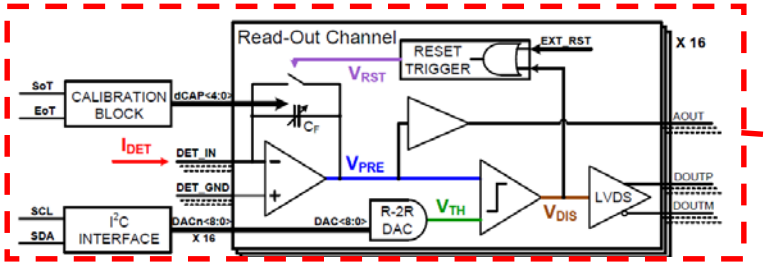
TOPIC	FREQUENCY [kHz]
SAWTOOTH PERIOD	0.1
IMPURITY TRANSP. STUDY	1
MHD MODES (TEARING)	10
SAWTOOTH CRASHES	10
OTHER MHD (TAE, BAE)	100

A triple GEM is a proportional gas chamber based on the gain produced by three foils of 50 um thick Kapton foil, with copper cladding on each side and perforated by a high surface-density of bi-conical channels, which multiply the ionization charge in three subsequent steps to detect radiation (photons or particles). They are intrinsically digital detectors; it is possible always to acquire data at the max possible sampling rate and then operate with post-processing.

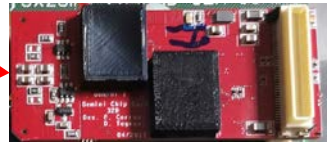
(*) D. Pacella et al., *Ultrafast soft x-ray two-dimensional plasma imaging system based on gas electron multiplier detector with pixel readout*, Volume 72, Issue 2, February 2001, Pages 1372-1378

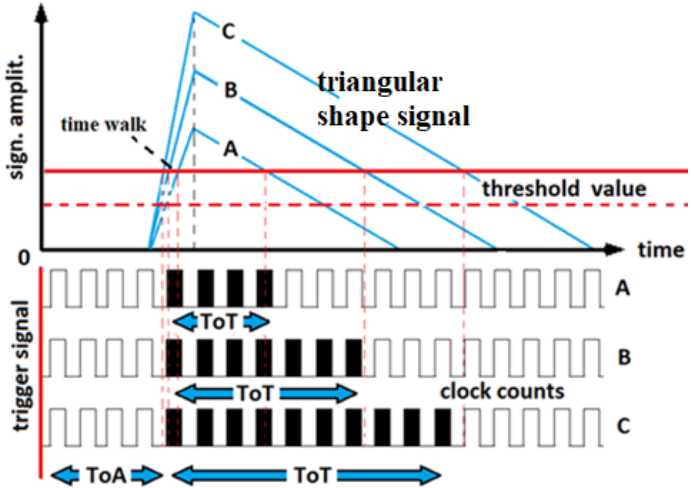
1- NEW GEM DETECTORS (2019)

The new ASIC (**GEM INtegrated Inter-face**) (*) was developed thanks to the collaboration **INFN – *Univ. of Milano Bicocca.*** The reading board thanks to the collaboration between INFN ARTEL and Nuclear Instruments.



GEMINI card:





New management !

With this new system, it is now possible to get the **energy** proportional to the **Time over Threshold** (**ToT**) **,** and the **Time of Arrival** (**ToA**) in the detector by the incoming radiation on **each detector channel**. The readout type is now **data driven** instead of frame-based. This new acquisition system hence integrates **photon counting**, **energy**, and **time resolution**. This fact opens new investigation scenarios to assess continuous phenomena at high time resolution (**Tokamak**) or pulsed (**laser-plasma experiments**).

(*) A. Muraro et al., *Development and characterization of a new soft x-ray diagnostic concept for tokamaks*, 2019 JINST **14**

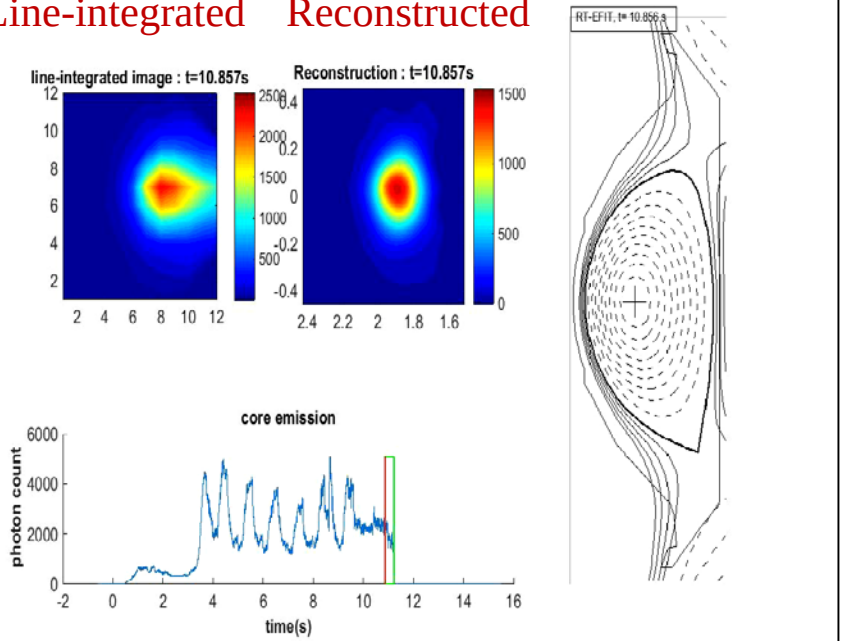
Plasma imaging on KSTAR Tokamak (2016)

Current ramp down : 10.824 - 11.224 s

time resolution : 2ms
colormap is normalized to the maximum value in the interval

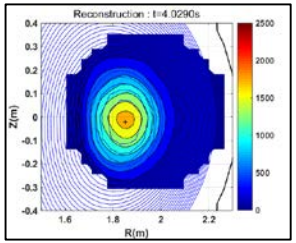
Shot #13544

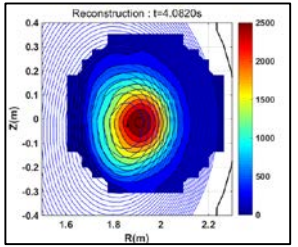
Line-integrated Reconstructed



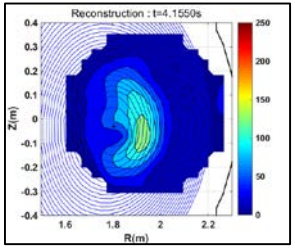
2016

Accumulation of
Tungsten impurities





2017

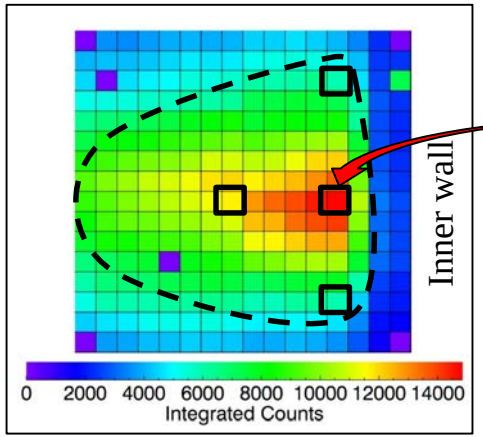


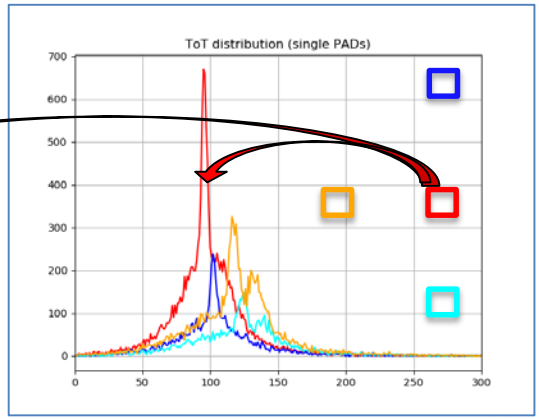
1- NEW GEM DETECTORS RESULTS

Thanks to the collaboration between **ENEA Frascati** and the **Inst. of Plasma Physics, Chinese Acad. Of Science:**

- Data taken on **EAST Tokamak** in the first week of April 2019
- **Strong limitations in timing resolution due to the limited bandwidth of the Ethernet communication (now overcome using an Optical-link)**
- 1mm thick Al filter in front of the detector was needed in order to reduce the incoming flux

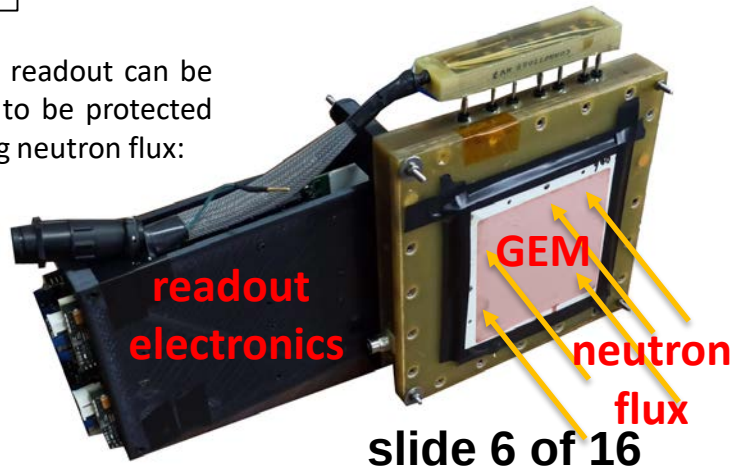
EAST shot n° **83874**





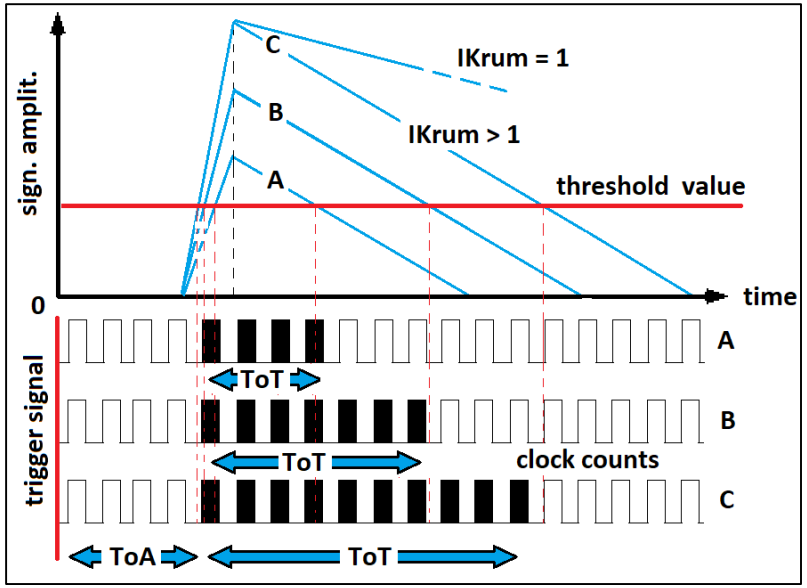
Neutrons hardness: **old** GEM detectors have a measured limit of **10^7 n/s cm^2** . With the **new** GEM detectors, offering also a side-on electronics, a **higher flux** will be reached (for ITER and DEMO) . For DTT, we are already close.

All the electronics readout can be **shifted on a side** to be protected from the impinging neutron flux:

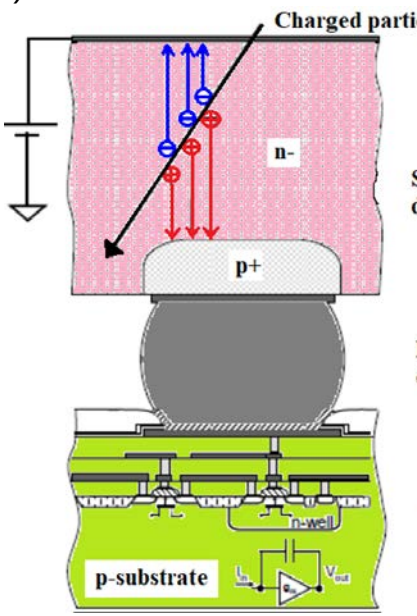


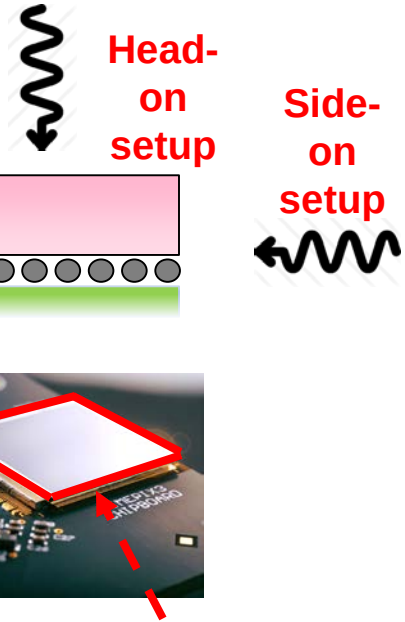
2- CMOS IMAGER: Timepix, Timepix3

After the appearance of **Timepix1** (TPX1) in 2006, the **Timepix3** (TPX3) is a commercial chip of 2013 (developed by the Medipix collaboration; in particular, **INFN** is a member of **Medipix4**)



ToT and ToA



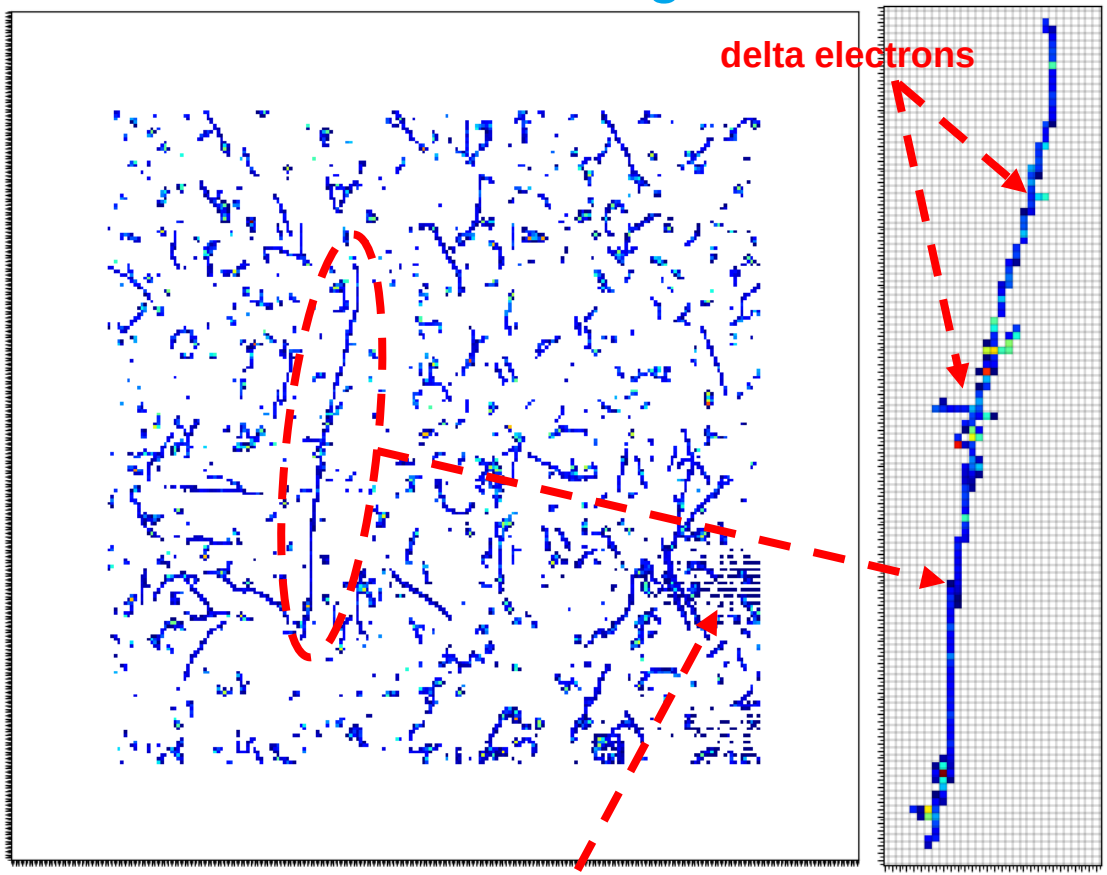


TPX1 vs. TPX3 main difference:
TPX3 can acquire **ToT and ToA at the same time**

Each pixel is connected to its own **readout circuit** so that the signals can be collected and amplified and the data can be stored.

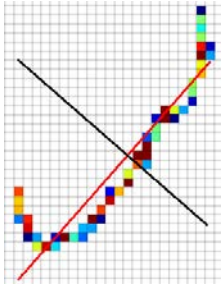
- 14 x 14 mm, **300** ÷ **1000** um thick.
- **Silicon/GaAs/CdTe** active volume

2- TPX3 in side-on configuration:



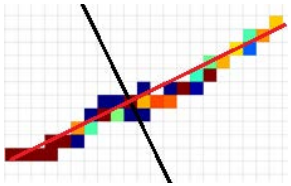
Ionizing particles release their energy with different **morphological shapes** of the **cluster** here defined as a region of adjacent pixels. The first step in the analysis is the **connected component labeling** or "**clusterization**" process: assigning a unique label to each cluster in a frame of data.

cluster's morphology:

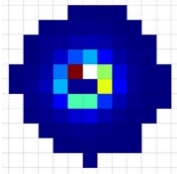


linearity: 0.71

<

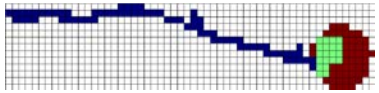


linearity: 0.89



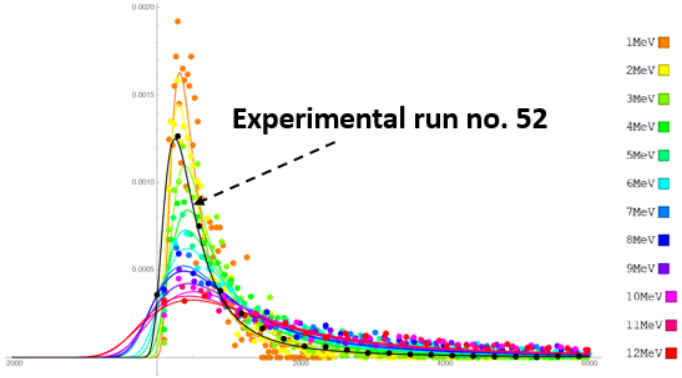
roundness: 0.89

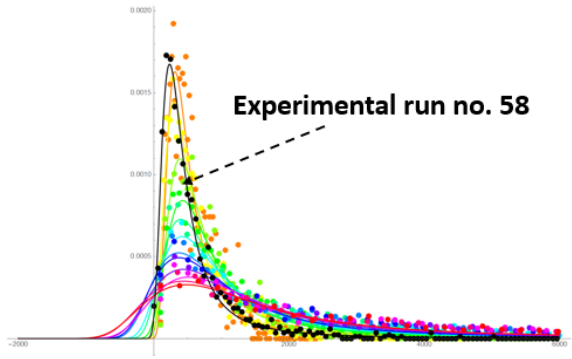
>



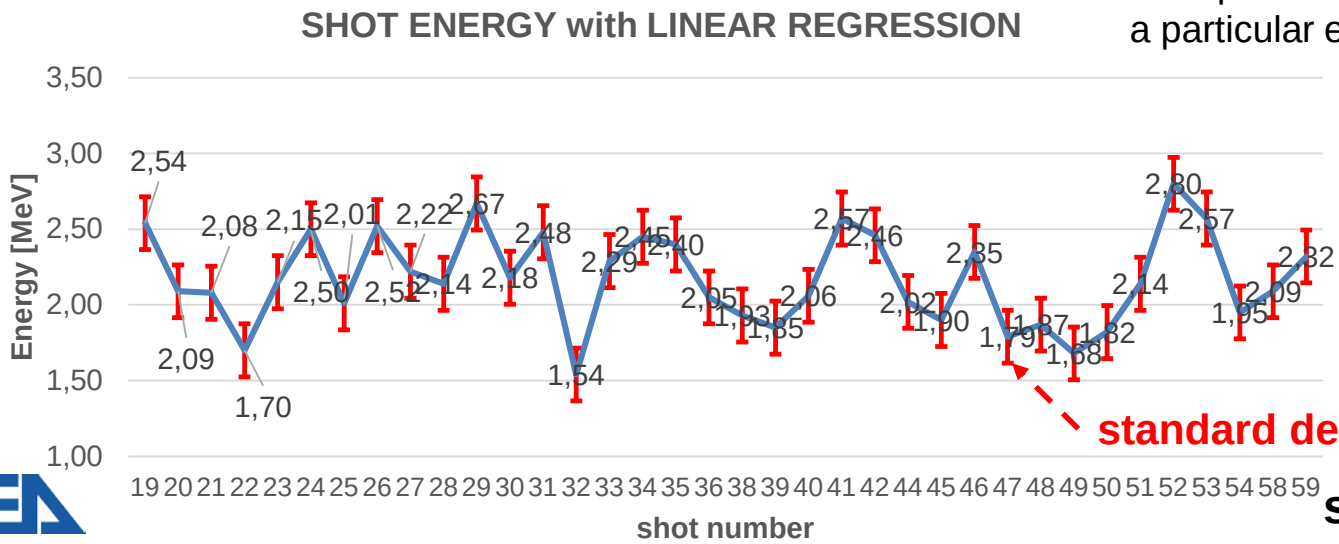
roundness: 0.59

2-TPX3 on LPP: Energy through Machine Learning





Since every Landau distribution is parametrized by a location parameter **μ** and a non-negative scale parameter **σ**, we can use these two parameters of the preceding simulations to train a predictor function on the correspondent energies and then predict the energy value of a particular experimental run.

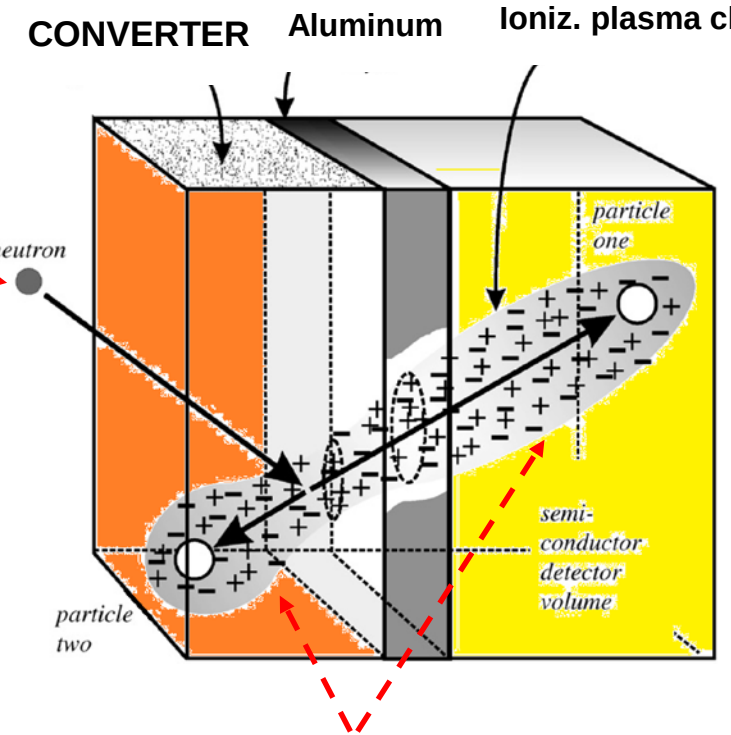


3- TPX, TPX3 with thermal neutron converter

Possible materials for the neutron converter layer:
B_4C, **^6LiF**, or **H_3BO_3** with different efficiencies.

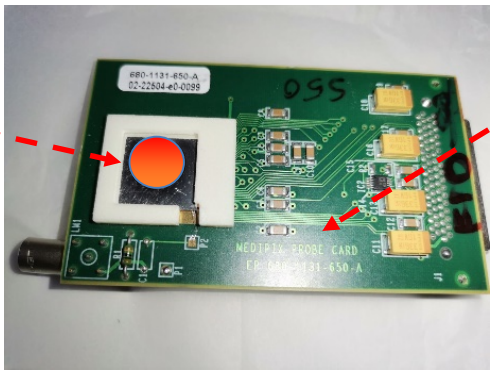
Thermal neutrons: **~ 25 meV**

With a thin-film-coated semiconductor neutron detector, the film thickness should not exceed the maximum range of the "long-range" reaction product.



The reaction products (e.g. **tritons** and **alphas**) are emitted in **opposite directions**.

^6LiF film (*)



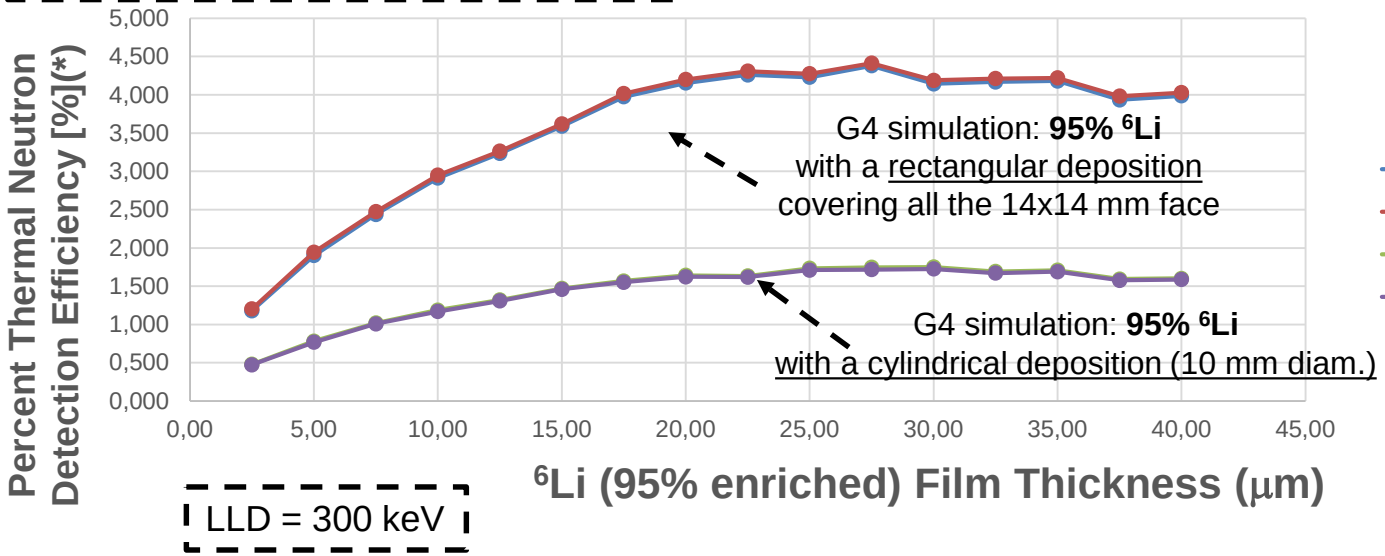
TPX1

(*) The ^6LiF film was thermally evaporated directly on the TPX1 at ENEA C.R. Frascati, **FSN-TECFIS-MNF laboratory** (R.M. Montereali, V. Nigro, M.A. Vincenti)

3- TPX, TPX3 with neutron converter

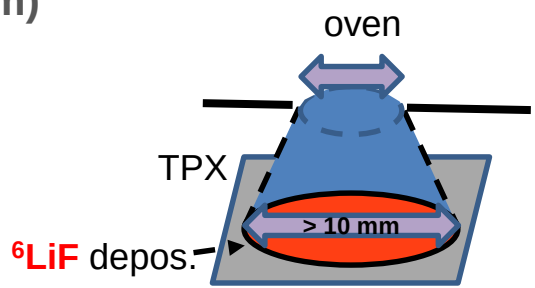
Parallel beam of **10^5** neutrons, 25 meV
incident on the front face of the detector

TPX + ^{6}LiF



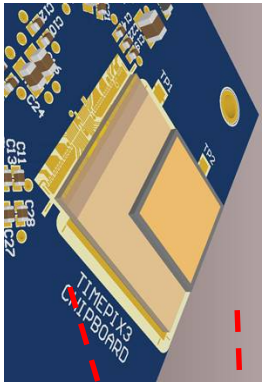
LLD = 300 keV

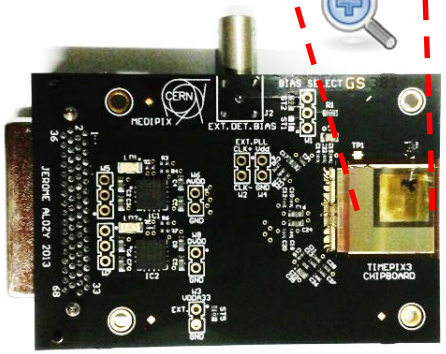
The efficiency of the TPX + ^{6}LiF was calculated using **HOTNES** (**HO**mogeneous **T**hermal **NE**utron **S**ource) within the **INFN-LNF** / **ENEA-Frascati collaboration** (A. Pietropaolo, Frascati Neutron Generator and R.Bedogni INFN-LNF).

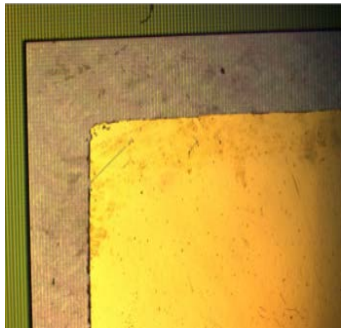


4- Diamondpix

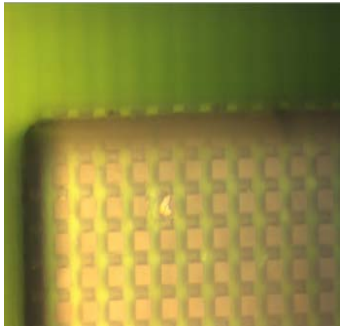
The “**Diamondpix**” (*) is the product of the collaboration of **INFN**, **CERN**, and **ERC Crystal** (the bump bonding of the diamond thanks to the **IZM** experience)



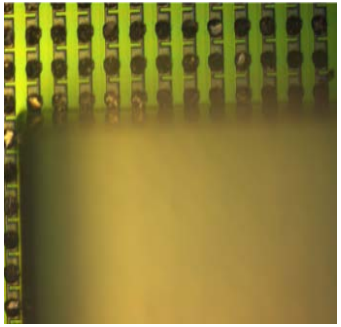




Gold cathode on diamond upward surface

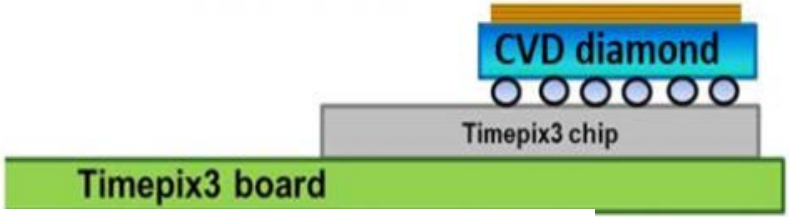


Pads on diamond downward surface



Timepix3 Pads

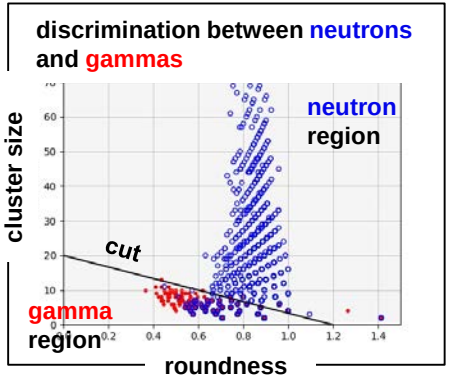
This new diamond-based detector has been realized by coupling a Timpix3 chip and a **CVD diamond** through a **bump-bonding connection**. This new detector has been successfully tested with different types of radiations: X-rays, fast neutrons, and electrons



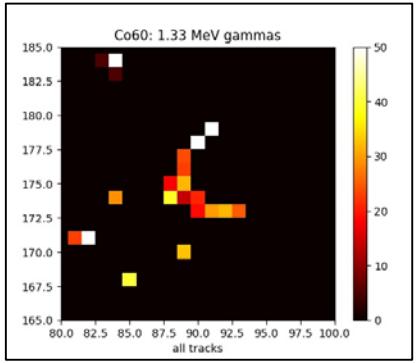
(*) G.Claps et al., *Diamondpix: A CVD diamond detector with Timepix3 chip interface*, IEEE Trans. Nucl. Sci., (2018)

4- Diamondpix

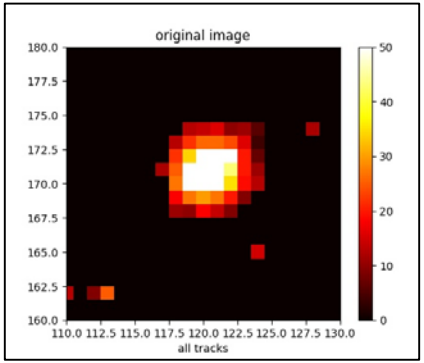
neutron / gamma discrimination

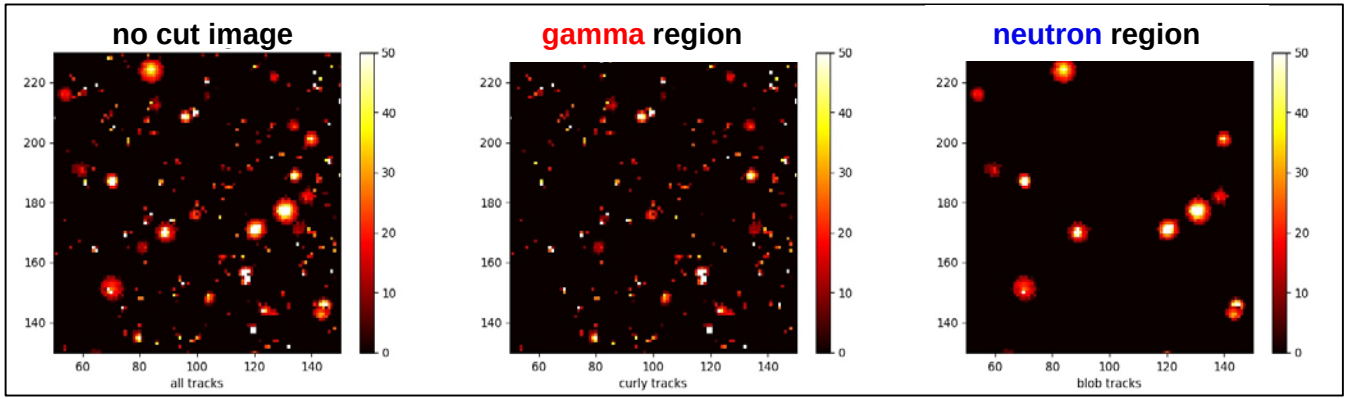


gammas



neutrons

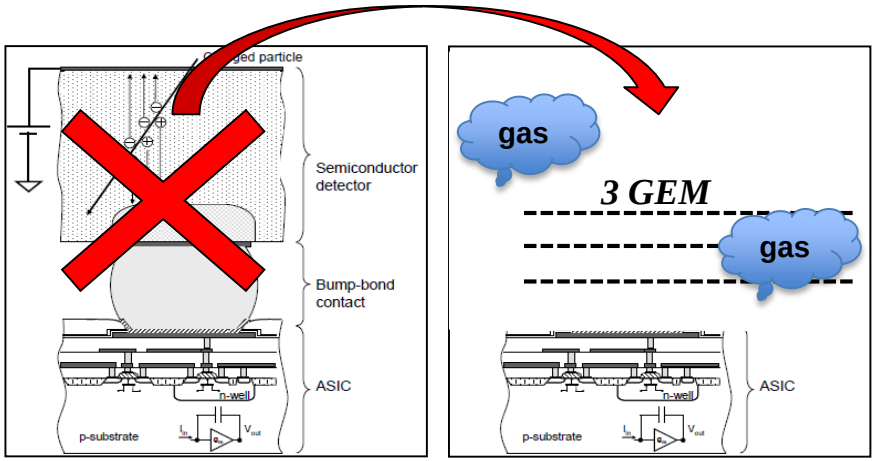




neutrons, gamma, electrons, and **X-rays** can be detected and discriminated

5- GEMpix

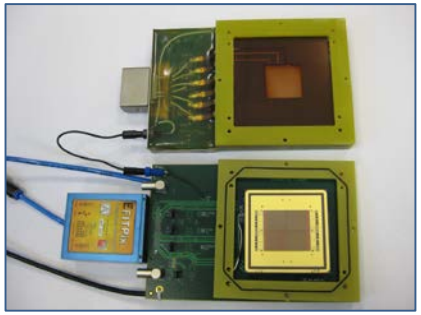
The **GEMpix** detectors (*) were developed initially in **ERC ARDENT** and are at the moment in the **CERN KT** portfolio (they have been proposed for the first time for micro-dosimetry applications in hadron therapy)



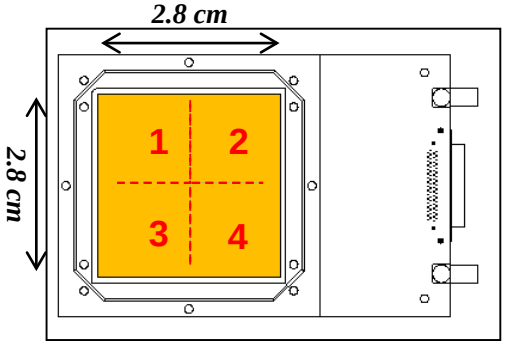
Merging the advantages of a **gas detector** with an **high density pixel read-out** (ASICs)

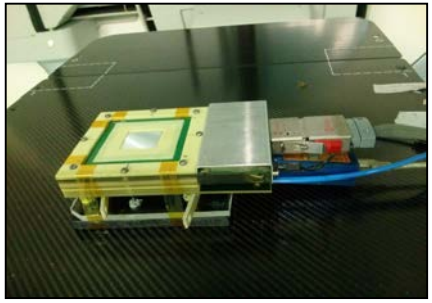
This kind of detector has two main components:

- A **quad medipix** (TPX) without silicon layer
- A **triple-GEM** with filter and HV connectors



512 × 512 pixels



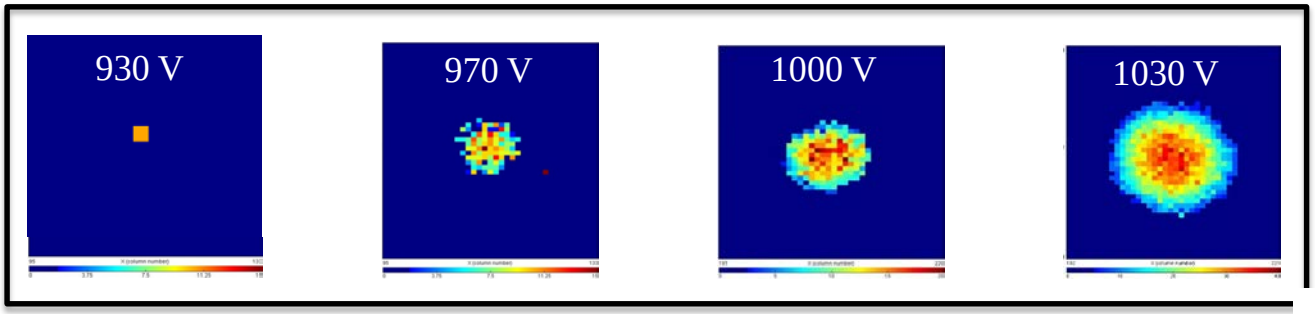


A single Medipix chip has 256 x 256 pixels, each having an area of **55 x 55 μm²**. Quad Medipix is made of **4 medipix chip** (TPX) held together.

(*) F.Murtas, *The GEMPix detector*, Radiation Measurements 138 (2020) 106421

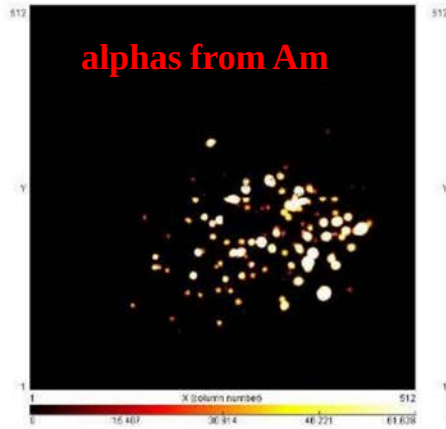
5- GEMpix

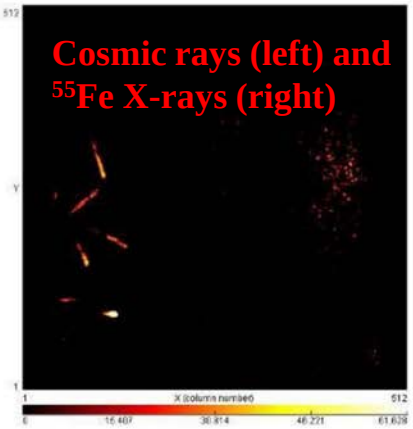
Signal from a single photon as a function of the applied gain

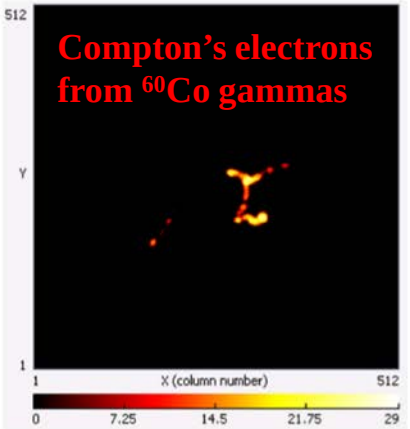


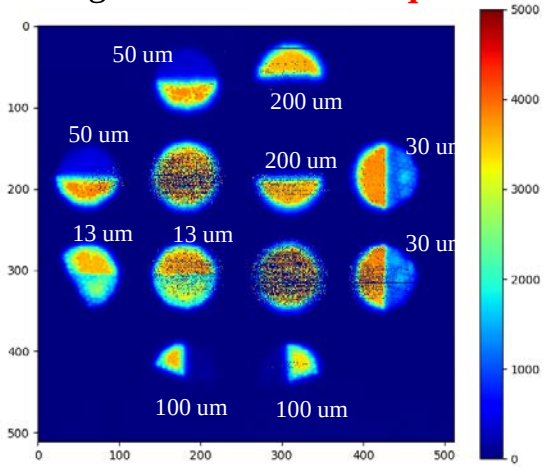
Increasing the **gain**, the interaction of a **single photon** releases a cluster of charges with **increasing diameter** and **volume** (*).

GEMpix with an **Al mask** for energy distribution measurement using a **multi-foil technique**.









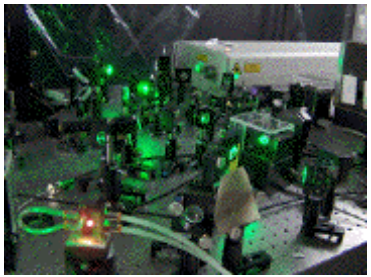
GEMpix on Gekko XIII

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

5 –GEMpix TEST DRIVE (2015-2019)

very different Laser Produced Plasmas experiments

ECLIPSE (Bordeaux)



2015-2017

175 mJ / 39 fs
4.5×10^{12} W
Spot size 10μm

G_{GEM}= 900 V

VEGA-2 (Salamanca)

2018

6.5 J / 35 fs
1.8×10^{14} W
Spot size 30μm

G_{GEM}= 620 V

Gekko XII (Japan)

Sep. 2019

1.5 kJ / 5 ns
3.0×10^{11} W
Spot size 300 μm

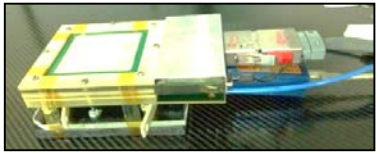
G_{GEM} = 200 V

No EMP noise

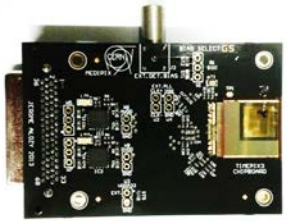
No EMP noise

No EMP noise

Same signal !



5- GEMpix



4- Diamondpix

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1- GEM

3- TPX, TPX3 with convert.

2- TPX, TPX3