Gamma photons energy measurement in Laser Produced Plasmas: a novel approach using a Timepix3 detector and Geant4-based simulations

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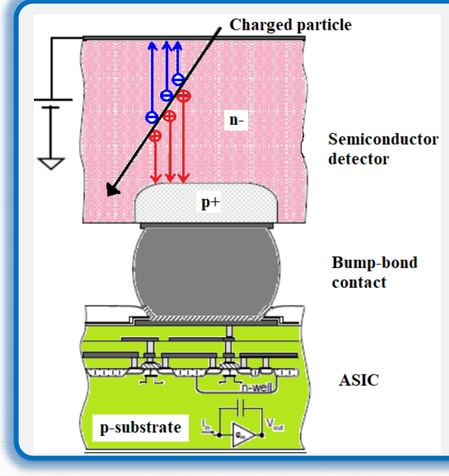
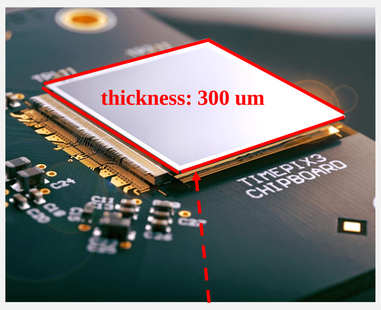
ABSTRACT

The plasma's X-ray monitoring in Laser Produced Plasmas (LPPs) experiments is troublesome since the X-ray emissions impinge the detector in a too short time window (from a few tens of ps to few ns,) depending on the power and pulse time width of the laser. Hence the measure of the non-integrated photon flux is a problem hard to handle. To this end, we have used the Timepix3 (TPX3) chip [1], in a side-on configuration, in order to get a quick estimate of the gamma photons energy. TPX3 is a single chip detector, silicon-based, 256 x 256 pixels bump-bonded with 300 µm thick silicon layer and long side of 14 mm. Using the long side for the interaction of gammas, it is possible to obtain some characteristic tracks or pixels clusters mainly due to Compton electrons. Thanks to many different parameters that can be defined as Cluster Size (CS), Time over Threshold (ToT), Linearity, Roundness, etc. the detector response was studied and compared with some known gamma sources and some Geant4 simulations in the energy range of interest. This new approach (see [2]), through a Landau distribution comparison between simulations and experimental data, allows discriminating the various energy bands for the gamma photons (also with a single experimental run provided it produces enough statistics).

TIMEPIX3 SILICON DETECTOR, MAIN FEATURES



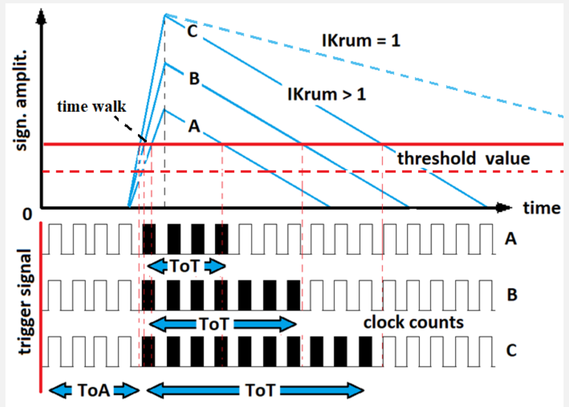


14 x 14 mm, 300 um silicon active volume

Main Features

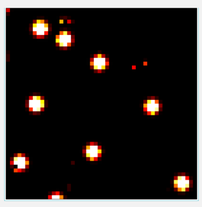
- **Pixel Arrangement**: 256 x 256
- **Pixel Size**: 55 x 55 um
- **Technology**: 130 nm CMOS
- **Acquisition modes:**
  - Time of Arrival (ToA)
  - Time over Threshold (ToT)
  - Event Counting
- **Readout modes**: Data Driven
- **Minimum Timing resolution**: 1.56 ns
- **Minimum detectable charge**: 500e-

ToT counts are proportional to the released charge. In addition, the charge sensitivity can be increased changing the Ikrum parameter.

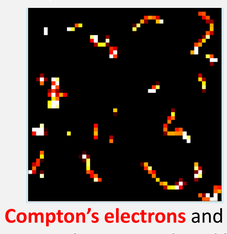


With TPX3, space, charge and time information can be measured simultaneously.

Timepix has been successfully used to identify different kinds of particles: tracks released by x-rays, gamma and electrons ([3]) and ions have a different morphology on the pixel matrix.



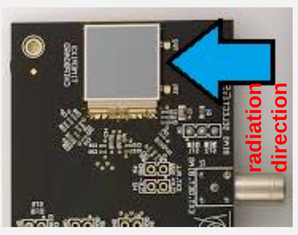
alpha particles clusters produced by an Am241 lab source



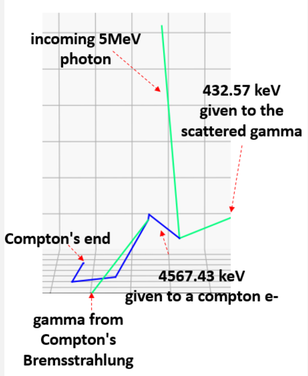
Compton's electrons and gammas clusters produced by a Cs137 lab source

ENERGY CALIBRATION, AFFINE TRANSFORMATIONS, LANDAU DISTRIBUTIONS FIT

Gamma photons interact with silicon through the **photoelectric effect**, the **Compton scattering** and **pair production** depending on their impinging energy. Ionizing particles release their energy with different **morphological shapes** of the **cluster** here defined as a region of adjacent pixels (here defined as 8 possible adjacent pixels to one particular pixel). The first step in the analysis is the **clusterization** process: a recursive procedure for assigning a unique label to each cluster in a frame of data.



side-on configuration

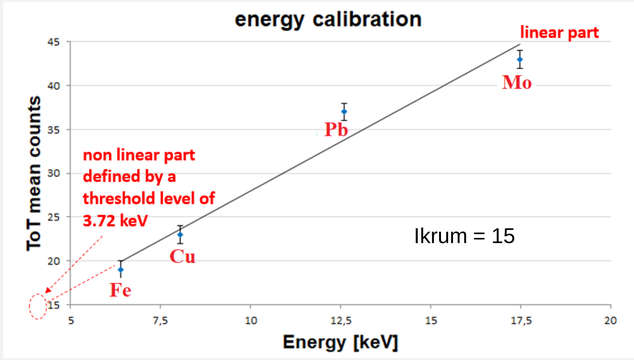


example of gamma interaction

To characterize the produced clusters on the Timepix3, some **laboratory sources** have been used and simulated:

- BaCs (81 keV photons)
- Cs137 (662 keV photons)
- Co60 (1.17 and 1.33 MeV photons)
- Sr90 (546 keV electrons)

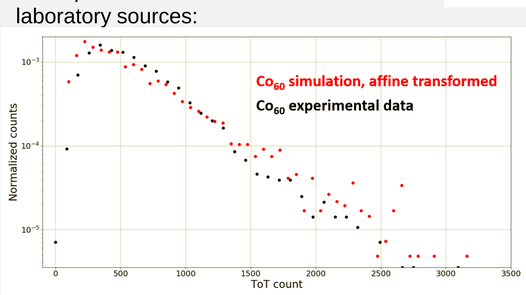
Using **affine transformations**, the free parameters of the simulations have been found in order to match the simulations with the experimental data of the with the laboratory sources:



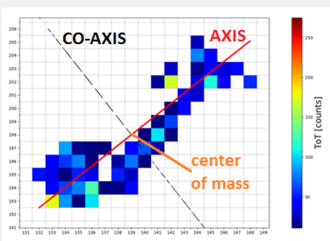
The TPX3 calibration function can be found using known **fluorescence sources** (Fe, Cu, Pb, Mo) and averaging over all pixels. Here the Ikrumm value is 15. The linear part is given by the linear fit:

$$ToT \sim 2.24 \cdot E + 5.59$$

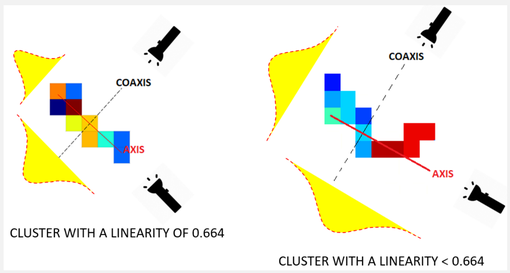
ToT distributions are obtained from the experimental data run setting a **lower linearity limit of 0.8** and a **minimum cluster size of 6 pixels**. As a result, normalized ToT distribution can be fit through Landau distribution functions.



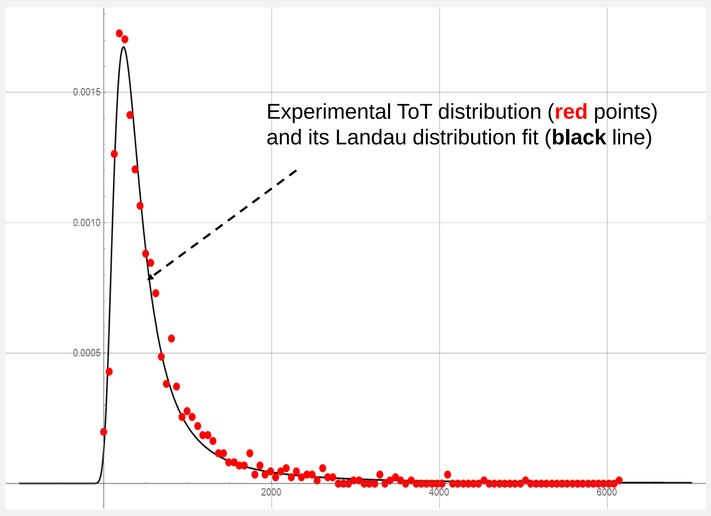
affine transformation



co-axis, axis, centre of mass

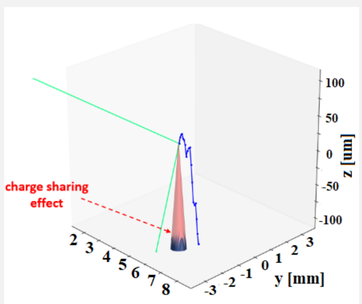


linearity

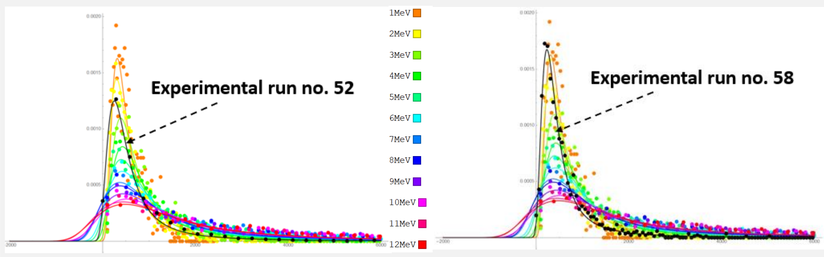


Landau distribution fit

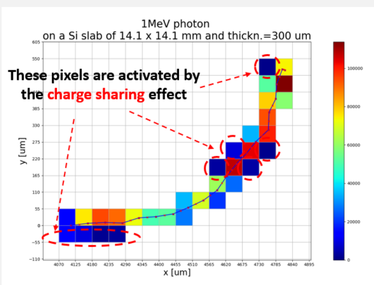
GEANT4 SIMULATIONS AND MACHINE LEARNING TECHNIQUES



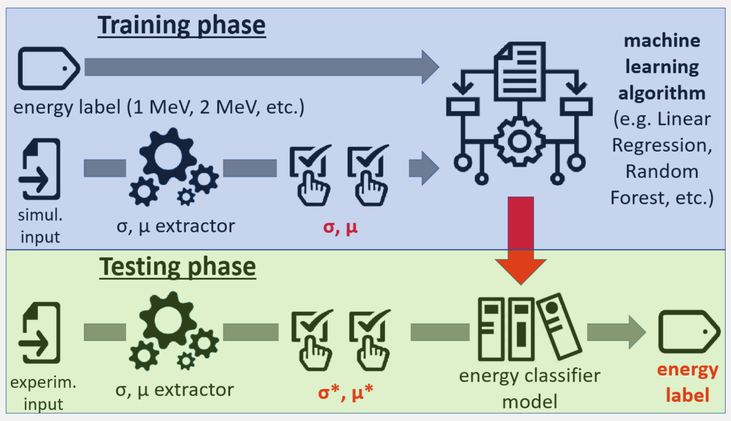
Geant4 simulation of 1 MeV gamma photon interacting with the TPX3 Si layer



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.

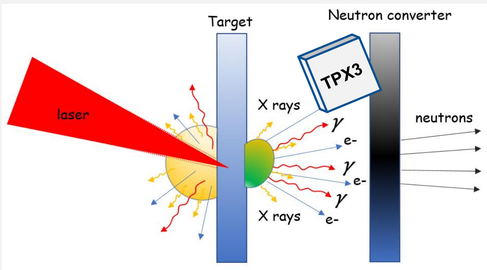


2D projection of the above 3D figure: **charge sharing** and **ToT values building**



In a **supervised machine learning approach**, after a **training phase**, we first produce a Landau fit of the experimental data, then we extract (**µ***, **σ***) and in the **testing phase** we finally compare them to the **µ, σ** of the simulated Landau fits through a specified machine learning algorithm (e.g. **Linear Regression**, **Random Forest**, **Neural Network**, etc.)

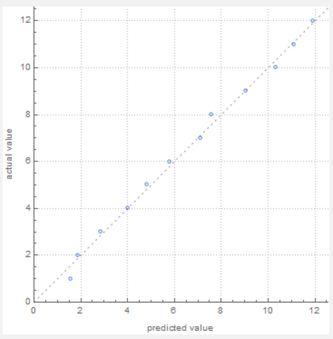
PHOTO-NEUTRON PRODUCTION EXPERIMENT



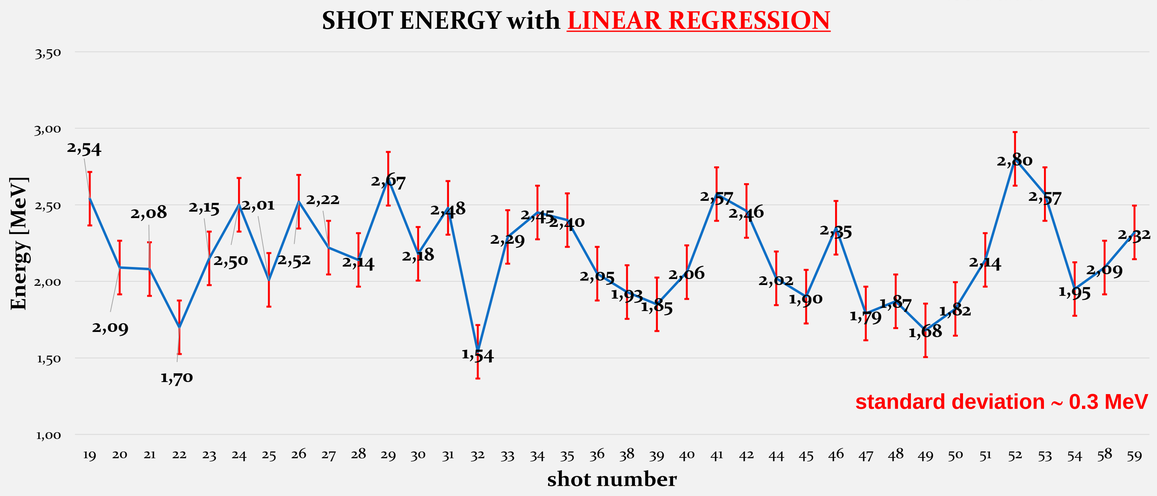
A Timepix3 has been mounted on the VEGA-2 laser facility during an experiment aimed to produce neutrons through **GAMMA PHOTO-PRODUCTION** on different solid targets [4].

VEGA-2 laser facility:

- laser wavelength: ***800 nm***
- laser Energy: ***4.5 J***
- pulse width: ***35 fs***
- laser Power: ***130 TW on target***
- beam diameter: ***~ 10 um***
- TPX3 – target distance***: 390 cm***



plot of predicted values versus test values



CONCLUSIONS

- The **Timepix3** has been used in a **side-on configuration** and calibrated to work as a gamma monitor in order to provide a fast and a **reasonable estimate of gamma energy**
- A **clusterization** algorithm has been realized in order to identify some characteristic parameters of the tracks. Using **GEANT4 simulations** of known laboratory sources and affine transformations a **training set was constructed**
- **Machine learning techniques** were then applied in a supervised learning approach to get an **estimate of the gamma energy**
- Preliminary work has been realized on the **VEGA-2** laser facility during a **photo-neutron production experiment** and the obtained results are satisfying

REFERENCES

[1] T. Poikela et al., *Timepix3: a 65K channel hybrid pixel readout chip with simultaneous ToA/ToT and sparse readout*, 15th international workshop on radiation imaging detectors 23–27 June 2013, Paris, France
[2] G. Claps et al., *Timepix3 detector and Geant4-based simulations for gamma energy detection in Laser Produced Plasmas*, being published on JINST
[3] C. Granja et al., *Energy loss and online directional track visualization of fast electrons with the pixel detector Timepix*, Radiation Measurements 59 (2013) 245-261
[4] Y. Arikawa et al., *Efficient and Repetitive Neutron Generation by Double-Laser-Pulse Driven Photonuclear Reaction*, Plasma and Fusion Research, Volume 13, 2404009 (2018)

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