Timepix chip interface detectors for X-rays, gammas and electrons monitor on LPPs

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1. Introduction

In the last years, Laser Produced Plasmas (LPPs) offered a lot of new applications: in addition to particles acceleration and inertial fusion, they can be used also to realize new X, gamma and neutron sources. Laser beams are pulsed devices and the pulse time width can range from few ns down to few tens of fs, according to the requested power. As a consequence, production of these particles is concentrated in bursts lasting about as the laser pulse. In these conditions, a measure of the particle flux and energy becomes a very difficult task with conventional methods. Our work focuses mainly on the detection of soft-X and gamma rays coming from LPP sources. We used two types of detectors, both based on the Timepix chip. For soft-X rays, we realized a triple-GEM gas detector with a Timepix quad electronic front-end ("GEMpix" detector [1]). Measurements on soft-X rays have been performed on the ECLIPSE laser facility (CELIA, Bordeaux, France) and results are presented in [2]. For gamma rays we have used a Timepix3 chip silicon detector [3] and, in this paper, we focus on the more recent results obtained for gamma detection on the VEGA laser facility (Salamanca, Spain). It is consists of a single chip of 256 x 256 pixels bump-bonded to a 300 um thick silicon layer with a single pixel size of 55x55 μm^2. Measurements were performed during an experiment for which an estimate of the energy gamma spectrum was required. Interaction of gammas with detector releases some characteristic tracks due mainly to the Compton scattered electron. For each track we have defined some track parameters by which we can identify different energy bands for gamma photons.

2. Experimental set-up on VEGA laser facility

The main goal of the experiment was the study of an efficient repetitive neutron generator via laser driven photonuclear reactions.

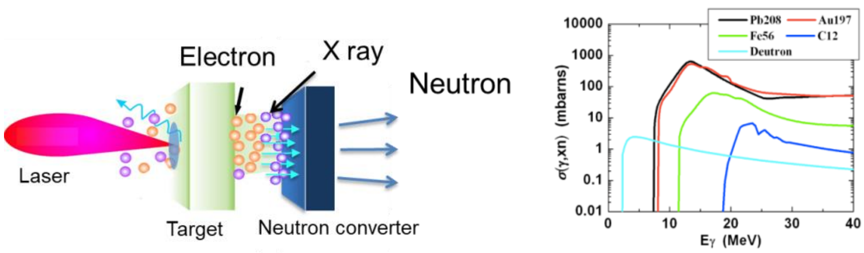

Figure 1. LEFT: an explanatory scheme of the neutron photo-production through the gamma produced by laser plasma; RIGHT: neutron photo-production cross section for different types of target materials.

The energy provided by the main laser was 4.5 J, while the spot size was less than 7 μm in diameter. The pulse time width of the laser is 35 fs so that the released power on target was about 130 TW. Different targets have been used: deuteron, steel, lead, iron and so on. After the laser-target interaction, electrons inside the plasma have enough energy that, when a fraction of them reaches the target, they are stopped (or partially stopped) producing in this way bremsstrahlung photons. With this kind of laser (hundreds of terawatts), the energy expected for photons can be in the range of hard-X and gamma radiation. For this experiment, the production of gammas was particularly important since they must reach the energy required to produce neutrons by photonuclear reactions on a secondary target (figure 1). As can be observed, the cross section for neutron photo-production depends on the used material. Then it is necessary to provide a measure of the gamma energy and we have proposed the Timepix3 silicon detector which has the peculiarity to work in Time over Threshold (ToT) and Time of Arrival (ToA), simultaneously. In this case ToA time was important to identify the signal arrival with respect to a given hardware trigger. The Timepix3 was used in a side-on configuration (figure 3). In the gamma range, the main photon interaction mechanism is the Compton scattering. The result of gamma interactions produces tracks in silicon due to Compton scattered electrons. Due to the very high gamma and hard-X flux, the detector was placed at about 4 m from the target and screened from hard-X rays background.

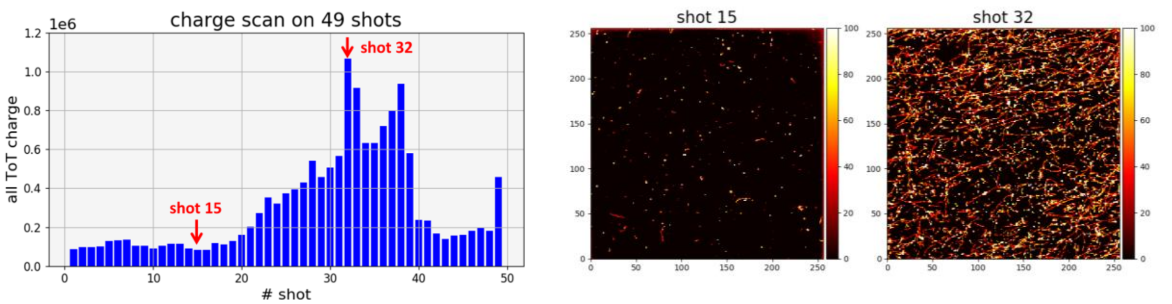

Figure 2. LEFT: a measure of the total ToT charge collected during a sequence of 49 laser shots. RIGHT: frame acquisition for the lower charge shot and the higher charge shot.

When the laser reaches an optimal focalization, not only the number of tracks increases, but also their length, which corresponds to photons of higher energy (figure 2).

3. Calibration and analysis

The first step was a calibration work done in the NIXT lab (ENEA, Frascati) using known sources (BaCs, ^{137}Cs, ^{60}Co and ^{90}Sr). The subsequent step was to define some characteristic tracks parameters:

- *Cluster size (CS)*: the number of adjacent pixels in a single cluster
- *ToT charge*: the sum of all ToT counts in a single cluster

- *Linearity*: once defined a best fit line for the cluster, it is defined as one minus the ratio between the sum of the weighted squared distances of all pixels from the best fit axis and the same weighted sum computed for the line perpendicular to this in the center of gravity.

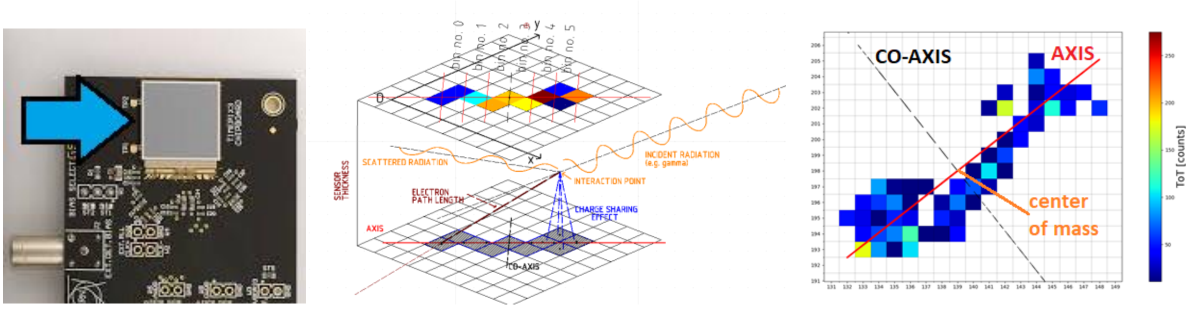

Figure 3. LEFT: a photo of the Timepix3 detector: it has been used in side-on configuration; CENTER: scheme of a gamma interaction in the silicon layer: charge sharing effect is higher where the Compton electron is far from the pixel readout; RIGHT: a typical curly-like track with the fitted axis and the corresponding co-axis.

After gamma interaction, the expected "curly" tracks have a given linearity that ranges from 0 (no linearity) to 1 (optimal linearity). For gamma and hard-X rays interactions, long tracks are expected and, when the photon energy increases, the electron track will have a linearity near to 1. Then when cluster size is high and linearity tends to 1, a photon of higher energy is expected. Figure 4 reports the correlation plots between cluster size and linearity, cluster size and ToT charge and the normalized distribution of ToT charge for the ^{60}Co calibration source and a 50 shot run during the VEGA experiment.

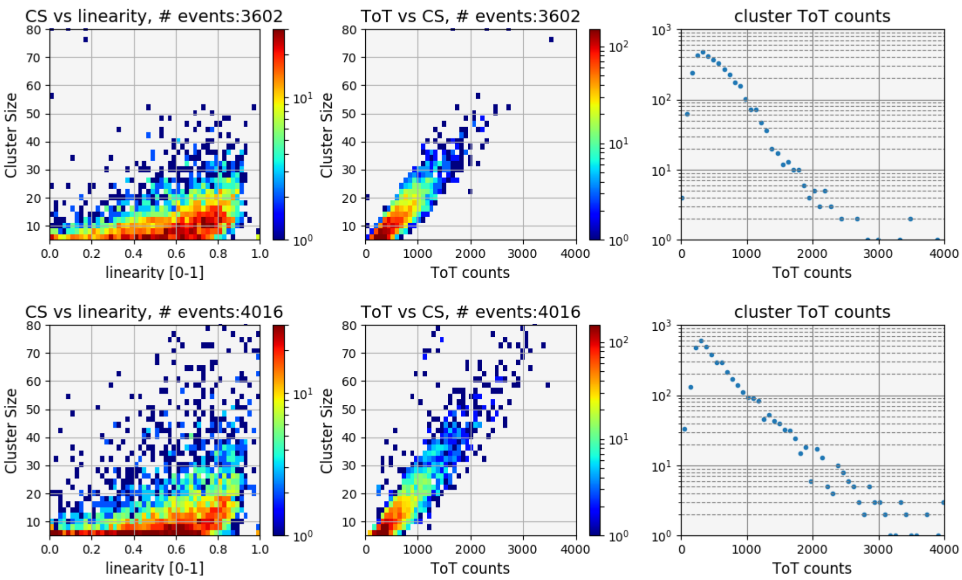

Figure 4. 2D histogram plots of Cluster Size vs Linearity and normalized ToT counts distribution for the ^{60}Co laboratory source and a 50 shots run in the VEGA experiment.

It can be observed that, with respect to the calibration source, the ToT charge distribution has a longer tail which extends towards higher values. In order to quantify these observations, we have compared the ToT charge distributions considering all the clusters with a cluster size between 5 and 200 and a minimum linearity of 0.6. Figure 5 shows the comparison in a semi-logarithmic plot for the BaCs (80 keV), ^{137}Cs (660 keV) and ^{60}Co (1.17 and 1.33 MeV) calibration sources and the VEGA run. We have defined a reference dashed gray line at the value of 10^{-5}. The straight lines are the best exponential decay fits using the fitting function $a \cdot e^{(-1/b)(x-c)}$. The x coordinate intercept of the extension lines with the gray line are: 1850 for BaCs, 2300 for ^{137}Cs, 2560 for ^{60}Co and 3300 for the gammas detected during the VEGA run. This is a clear indication that the observed gammas have a high energy respect to the ^{60}Co line. The same type of analysis has been performed for other shot sequences. We have selected only those runs for which clusters can be distinguished and analyzed.

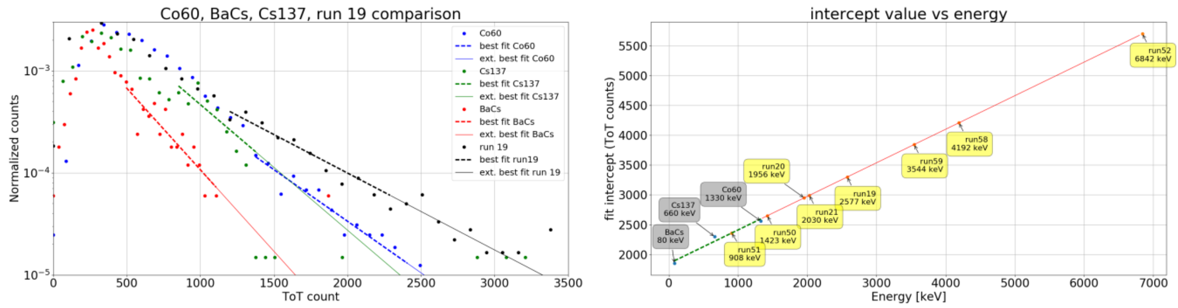

Figure 5. LEFT: ToT distributions for BaCs, ^{137}Cs and ^{60}Co sources, RIGHT: ToT best fit as a function of energy.

Exception made for run 51, all the other runs fall behind the three calibration points and a wide linear extrapolation must be applied. Since we can't use sources of energy higher than ^{60}Co (in order to obtain calibration points for higher energies), at the moment we are writing a Fluka/GEANT4 simulation program in order to estimate the gamma tracks at higher energies and to validate the experimental results.

References

[1] F. Murtas, 3rd INTERNATIONAL CONFERENCE ON MICROPATTERN GASEOUS DETECTORS, 1–6JULY, 2013, Zaragoza, Spain.

[2] Claps G., Pacella D., Murtas F., Jakubowska K., Boutoux G., Burgy F., Ducret J.E., Batani D. *The GEMpix detector as new soft X-rays diagnostic tool for Laser Produced Plasmas* (October 2016) Review of Scientific Instruments, Volume 87, Issue 10

[3] 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