Characterization and first tests of an i-TED prototype at CERN n_TOF

Babiano Suárez, Víctor; Caballero Ontanaya, Luis; Domingo Pardo, César; Ladarescu Palivan, Ion;
Instituto de Física Corpuscular (CSIC – Universitat de València)

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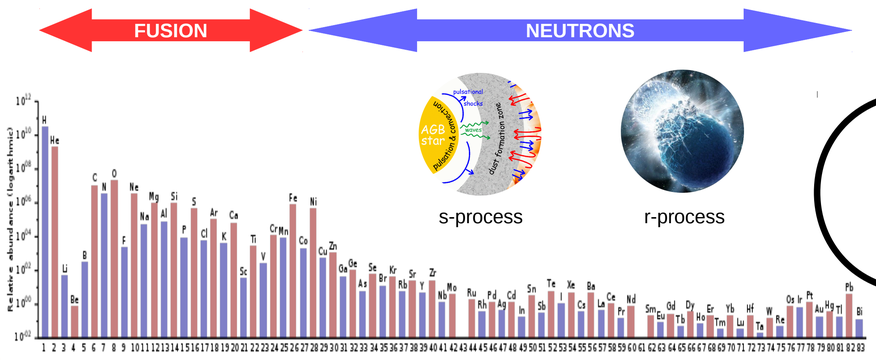
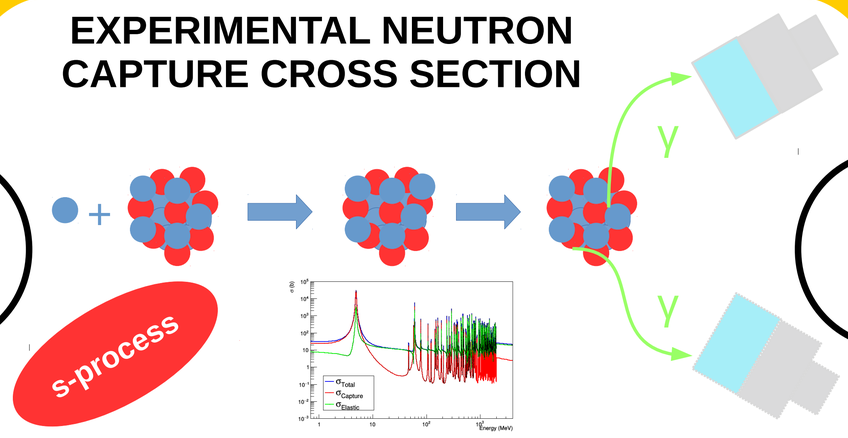
SOLAR SYSTEM ABUNDANCES



From the natural abundances of the elements of the periodic table…

EXPERIMENTAL NEUTRON CAPTURE CROSS SECTION



… and precisely measuring the neutron capture cross sections of the s-process...

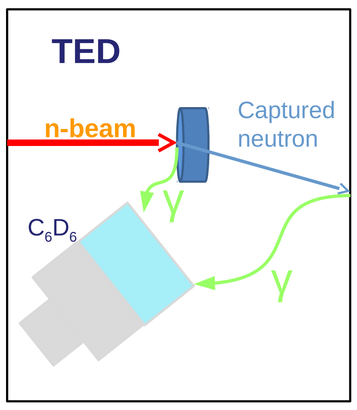
QUESTIONS OF INTEREST

…one can answer important questions like:

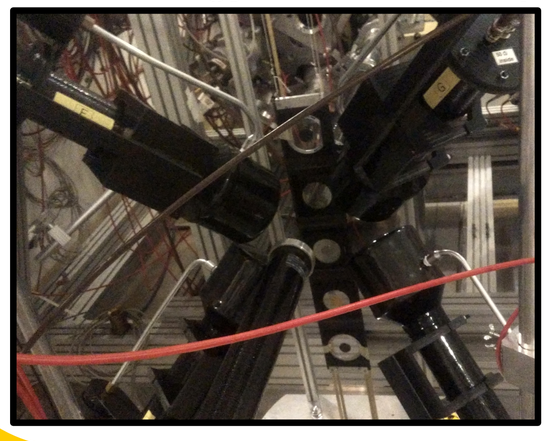
- Thermal conditions in core He-burning and shell C-burning evolutionary stages of red giant stars.
- Evolutionary time-scales.
- Reliable r-process constraints.

Nowadays the most interesting experiments concern the measurement of long-lived radioactive nuclei, which act as branching points along the s-process path and are particularly sensitive to the physical conditions of the environment.

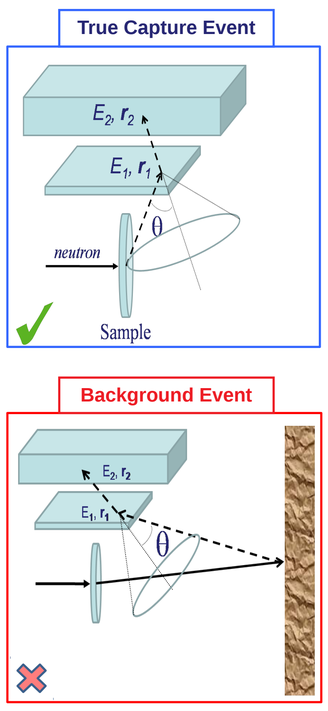
A common technique for the measurement of the neutron capture CS is the detection of the prompt capture gamma-ray cascade using C_6D_6. But, neutrons captured in the surroundings (walls) cannot be distinguished from capture events in the sample



Total Energy Detector (TED)

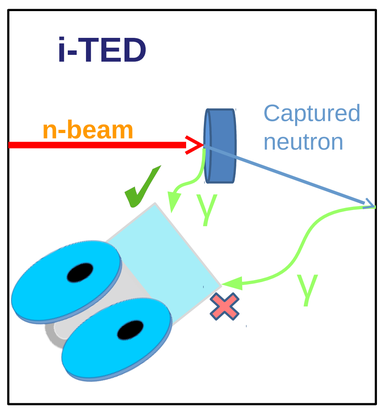


Novel idea for enhanced sensitivity (n,γ) measurements: COMPTON IMAGING



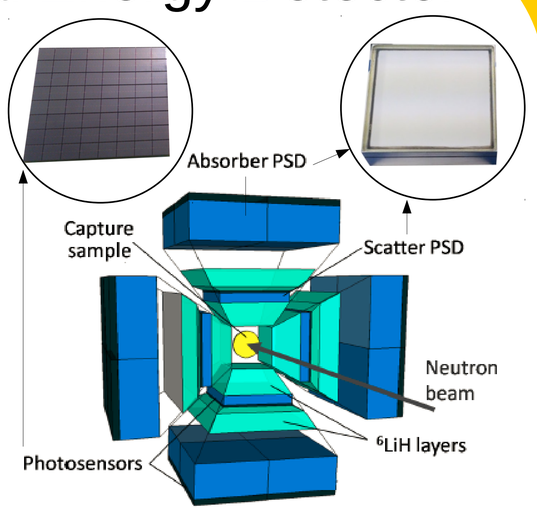
One can use two stages of detection in time coincidence, and knowing the energy and the place of each interaction, find out the original gamma ray direction using the Compton principle [1]...

$$\theta = arcos\left[1 - m_e c^2\left(\frac{1}{E_1} - \frac{1}{E_1 + E_2}\right)\right]$$



imaging – Total Energy Detector

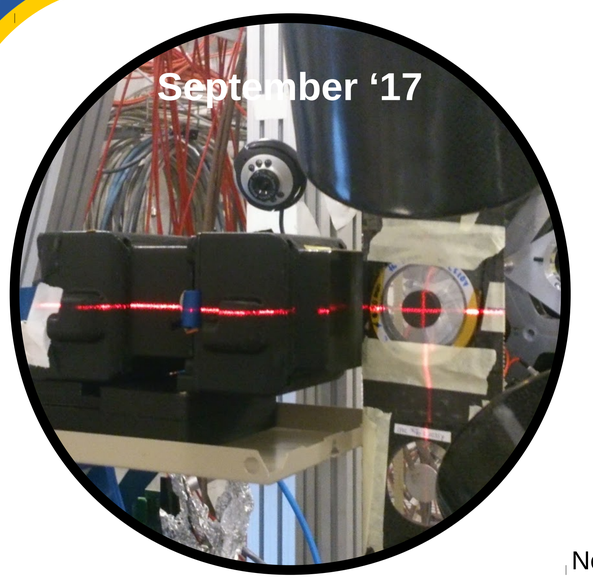
- With Compton imaging, one can distinguish true capture events in the sample from contaminant background events from the surroundings. After careful characterization of intrinsic spatial resolution, depending on the crystal thickness we have obtained average resolutions between 1.5 ± 0.6 mm and 2.1 ± 0.6 mm FWHM [2].
- With good energy resolution, one can discriminate contaminant gamma-rays from activated impurities in the sample. Using $LaCl_3$ monolithic crystals coupled to 8x8 pixelated SiPMs we have obtained an average energy resolution of 4% FWHM at 662 keV [3].



i-TED conceptual design:

- It has four Compton modules surrounding the sample.
- Each module consists of two stages of detection: scatter + absorber.
- Both, scatter and absorber are formed by pixellated SiPMs optically coupled to monolithic crystals of $LaCl_3$.

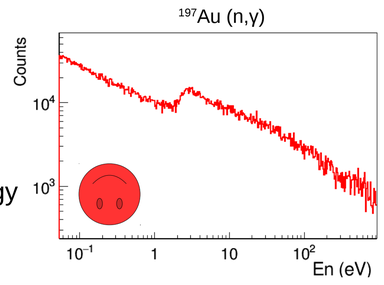
FIRST TESTS @n_TOF

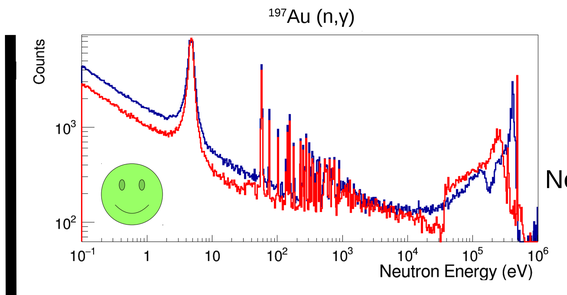


In order to technically validate the instrumentation, we developed an i-TED prototype (image on the left). It consist of one scatter and one absorber stage. Both connected to a frontend readout electronics by PETSyS [4], and the latter connected to a PC by Ethernet.

First tests were performed in September of 2017 at n_TOF (CERN). Since we had problems to identify the start of each bunch, we could not obtain histograms of time of flight and energy. For the second tests in November of 2017 the electronics were modified and we could implement an external trigger signal from the CERN proton-synchrotron (PS), which enabled a good timing and hence to obtain proper neutron energy spectra.

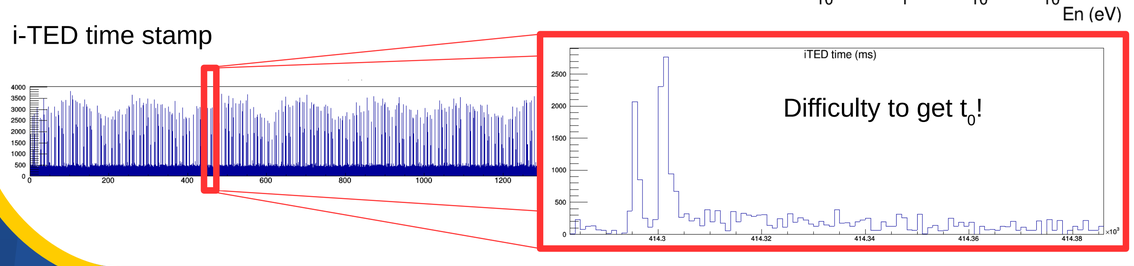
Neutron energy spectra



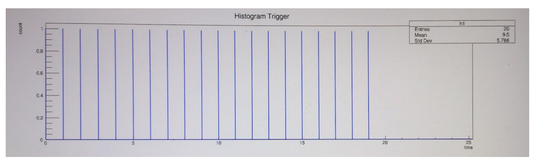


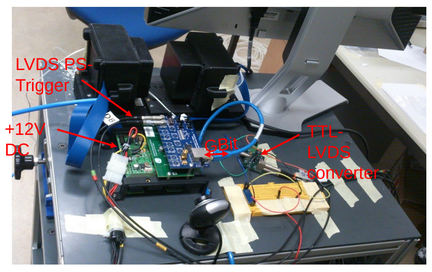
Neutron energy spectra

i-TED time stamp



External trigger use from PS fed into i-TED electronics

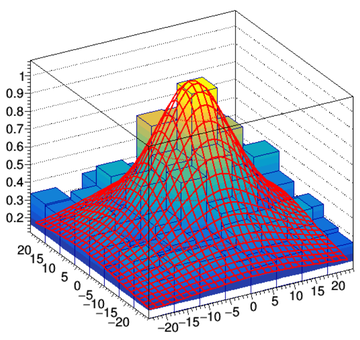




Ongoing work… Position reconstruction!

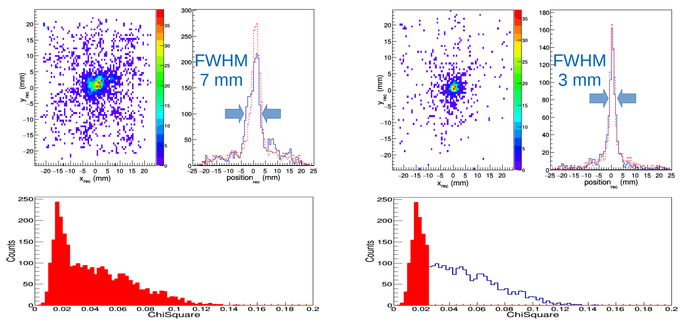
In order to know the interaction location of the gamma ray in each of the detection stages, we adjust an analytical formula [5] to the charge distribution obtained with the SiPM sensors:

$$L(\vec{r}) \approx \frac{L_0}{(\vec{r} - \vec{r}_0)^2} \alpha e^{-\alpha|\vec{r} - \vec{r}_0|}$$

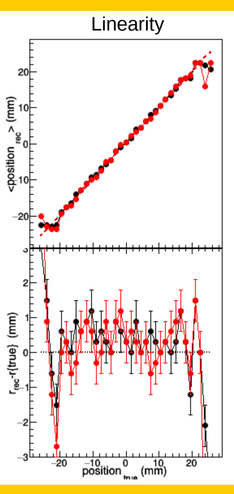


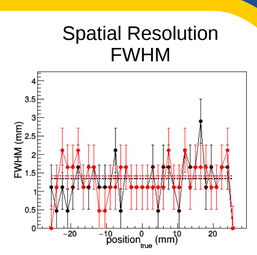
Accumulating the reconstructed positions in a 2D histogram we obtain the following graphs.

During reconstruction we can use the Chi parameter as goodness of fit and reject events that do no fit well.



Scanning all the surface of the crystal one can check the linearity, as can be seen in the final figures on the right: on top, reconstructed positions are compared to real ones; in the bottom, its differences are plotted.





Average Results

FWHM	1.8 ± 0.6 mm
Field of View	45x45 mm²
$r_{rec} - r_{true}$	0.7 ± 0.6 mm

[1] Domingo Pardo, C., "*i-TED: A novel concept for high-sensitivity (n,γ) cross-section measurements*", Nuclear Instruments and Methods in Physics Research A, vol. 825 , p. 78-86, 2016.
[2] Babiano Suárez, V. et al., in preparation.
[2] Olleros Rodríguez, P., et al., *"On the performance of large monolithic $LaCl_3$(Ce) crystals coupled to pixelated silicon photo-sensors"*, Journal of Instrumentation, 13 P03014, 2018.
[3] Available online: "http://www.petsyselectronics.com/web/"
[4] Lerche, Ch. W., et al., *"Depth of interaction detection with enhanced position-sensitive proportional resistor network"*, Nuclear Instruments and Methods in Physics Research A, vol. 537, p. 326-330, 2005.