i-TED spatial calibration

Detectors using monolithic crystals and pixelated photomultipliers need an energy and spatial calibration. This characterization will improve the position determination of the gamma-ray hit.

HYMNS

High-sensitivity Measurements of key stellar Nucleo-Synthesis reactions

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n_TOF Collaboration Meeting Granada 2018
i-TED is the system for acquiring, monitoring, analysing and processing data.
Energy calibration and Spatial calibration

For good results of data processing we need a energy calibration and a spatial calibration.

→ **Spatial calibration**
characterization of each detector using a pointer source collimated that points to many defined positions along the detector surface.

→ **Energy calibration**
we are using known radioactive sources as Na22, Cs137, Eu152, Ba130
Spatial calibration

Pixelated crystals
Using pixelated crystals and SiPM, we would get one pixel fired, no matter the position of the gamma-ray hit within the pixel. The best spatial resolution that one can get is conditioned by the size of the pixel.
Spatial calibration

- **Monolithic crystals**
  Using monolithic crystals and SiPM, we get more than one pixel fired. Depending on the position where the gamma-ray hits, and analysing the scintillation-light distribution, we can get a sub-pixel position accuracy.
Spatial calibration

→ Monolithic crystals and pixelated SiPM
Spatial calibration is 1225 distributions for 35x35 symmetric positions with 1.5mm spacing covering entire surface of the detector.

Eg: Analysing the 35 acquisitions scanned in the middle horizontal line, we can observe how the distribution changes.
Spatial distribution

Each frame of this animation is an acquisition for one position and represents the energy sum of all events that has been fired.
Systematic scan with a series of collimated gamma-ray source measurements in many positions (35x 35y) covering the full detection surface

Get data acquisition and calculate the accumulated distribution of each scan-position

Use analytic and artificial neural network techniques to correlate the position of the gamma-ray hit with the measured scintillation-light distribution
Mounting i-TED Detectors

- pixelated SiPM matrix of 8x8 px - 6x6mm/pixel.

- Detectors have LaCl3 crystals and SiPM photomultipliers

- LaCl3 CONTINUOUS crystals
  thicknesses: 10, 20 and 30mm 50x50mm,
Characterization

- PETSys acquisition system
- Cooling system control
- XY table control
- Detectors
Characterization

PETSys acquisition system

Detectors

Cooling system control

XY table control

Y axis

X axis
The XY Table is an old one with an obsolete communication by parallel port under windows 3.1. Now is updated with a new USB control under CentOS 7, W10, MacOS.
xy table

Detector to be characterized is placed here

Digital microscope 400x to check the precision

X axis

Y axis
load_xy_positions_in_list();
for each xy_position{
    move_detector_to xy_position();
    start_acquisition_400s();
    //process raw data -> singles data
    open_new_thread_for_data_processing();
}

load_singles_processed_data_files_list();
for each single data file{
    calculate_events();
    apply_algorithm_for_xy_accurate_position();
    print_results();
}
Position Reconstruction Techniques Researched

→ Anger (centroid-method)
  fast, conventional approach

→ Artificial Neural Networks
  fast and accurate

→ Analytical Fit
  Lerche, Li

\[
L(\vec{r}) \approx \frac{L_0}{(\vec{r} - \vec{r}_0)^2} e^{-\alpha |\vec{r} - \vec{r}_0|} + \tau, \quad \vec{r} \neq \vec{r}_0
\]

\[
f = A_0 \times \frac{z}{(x-x_i)^2 + (y-y_i)^2 + z^2}^{3/2} \times \frac{1}{1 + e^{-\beta \times (\theta - \theta_0)}}
\]

\[
\theta = \arctan \left[ \frac{\sqrt{(x-x_i)^2 + (y-y_i)^2}}{z} \right]
\]
Anger

Centroid of the distribution

FWHM 8mm
Analytical Fit Lerche

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

where $\vec{r}$ is the position vector, $L_0$ is the amplitude, $\alpha$ is the attenuation coefficient, $\tau$ is the background, and $\vec{r}_0$ is the center of the distribution.
Analytical Fit

FWHM 1mm

\[ f = A_0 \times \frac{z}{((x-x_i)^2 + (y-y_i)^2 + z^2)^{3/2}} \]
Artificial Neural Network  FWHM 3mm
Anger

Linearity diagrams: reconstructed position versus true position

ANN

Li

Lerche
We have developed a characterization method for spatial reconstruction for \textit{iTED}

\textsc{HYMNS, 2018}

V. Babiano et al. “γ-Ray position reconstruction in large monolithic LaCl₃(Ce) crystals with SiPM readout”, submitted to NIM-A, \url{https://arxiv.org/abs/1811.05469}
We have developed an instrumentation (XY-scan table integrated with DACQ) and methodology to perform an accurate and systematic spatial characterization of the i-TED detectors.

We have explored both analytical and machine-learning based methods.

Analytical methods provide the best spatial resolution (~1mm FWHM) and high-linearity and largest field-of-view (<25cm2), but suffer of very low reconstruction efficiency (30-50%).

Neural-Network methods provide a sufficiently good spatial resolution (~3mm FWHM), a high linearity too and large field-of-view (<25cm2) and 100% reconstruction efficiency.

Presently NN-based methods are preferred for i-TED because the Compton imaging resolution is still limited by the energy resolution (5% at 662keV) rather than by the spatial resolution.

We plan to further improve position reconstruction by means of more sophisticated NN-methods.

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