Reconstruction of photon interactions in plastic scintillators in J-PET detectors

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Is Quantum Theory exact? From quantum foundations to quantum applications
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Outline

- Compton scattering in plastic scintillators
- J-PET detector prototypes
- Software Framework
- Reconstruction steps
- Usage examples
- Summary
Compton scattering in plastic scintillators

- The goal is to reconstruct particle interactions in plastic scintillators
- Gamma quanta is scattered via Compton effect
- Absorbed energy is emitted via fluorescence
- Light travels like in an optical link through the scintillator
Big Barrel
192 scintillators
384 vacuum tube PMs
probing on 4 thresholds

Modular Detector
24 modules x 13 scintillators
2496 SiPMs (8 per scintillator)
probing on 2 thresholds
Members of the J-PET collaboration develop software project for the data reconstruction and analysis in our experiment.

Repository is maintained on GitHub, contains the set of data reconstruction procedures.

As well as other programs to perform calibrations, basic data selection for event reconstruction, analyze data from different setups.

www.github.com/JPETTomography/j-pet-framework-examples
Reconstruction steps (1)

▶ Triggerless DAQ \implies \text{Time Slots} \ni \text{data points} (\text{time, edge, channel})


▶ Procedure iterates over data points from connected channels and matches them into signals
Procedure matching signals from the photomultipliers on the opposite sides into scintillator hits - points of interaction of the particle with the material.

\[ \text{time difference } \Delta t = |t_{\text{signalB}} - t_{\text{signalA}}| \]

\[ \text{interaction z-position } = \Delta t \cdot c_{\text{eff}} / 2 \]

\[ \text{interaction time } = (t_{\text{signalA}} + t_{\text{signalB}}) / 2 \]
Reconstruction steps (3)

Additional elements:

- reading the detector configuration
- noise filtering
- time synchronization of channels across the whole detector
- effective velocity of light in scintillators

The results of reconstruction procedures:

- 3-dimensional position in the detector
- interaction time
- Time-over-Threshold
Reconstruction steps (4)

- Time-over-Threshold can be used as a measure of energy deposited in the scintillator by some particle

- Analysis of TOT and deposited energy relation [work by S. Sharma - publication in preparation]
Examples (1)

Measurement description:

▶ Vacuum chamber was inserted into the detector
▶ Radioactive source \(^{22}\text{Na}\) of activity of 1 MBq was used,
▶ It was surrounded with porous material XAD4 - enhancing rate of positronium creation
▶ Time slot parameter: 300 \(\mu\text{s}\)
▶ Measurement lasted 22 days - 3590 files were written on disk

Reconstruction performance:

▶ 40 cores of 2.7 GHz were utilized
▶ Average execution time for one file: 18 minutes
▶ Elapsed time: 28 hours
Examples (2)

Examples of data points matched into signals - event display software
Examples (3)

Examples of data points matched into signals - event display software
Examples of reconstructed hits - multiplicity in time slots and 3D position
TOT spectrum has a structure of Compton edges. Left is a TOT spectrum of all the hits reconstructed in the measurement (one file). Right is a simulation of deposited energy in a scintillator by photons of different energies (derived from Eur. Phys. J. C (2016) 76:445)
Data analysis Framework for J-PET experiment is a flexible environment for offline data reconstruction.

Series of procedures within the J-PET Framework reconstructs interactions of photons in plastic scintillators from raw binary data to the level of data structures with physical interpretation.

Our collaborators are using Framework for data analysis from measurements with Big Barrel Detector and after slight modifications - the procedures can be used with the data from next prototypes.

Results of reconstruction procedures is a starting point for variety of investigations in physics analyses, medical imaging, detector calibration - applications that are based on physical phenomena occurring on a quantum level.
Thank you for your attention
Backup slides (1 - matching data points)
Backup slides (2) - noise filtering

Noise filtering

<table>
<thead>
<tr>
<th>good_v_bad_raw_sigs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Std Dev</td>
</tr>
</tbody>
</table>

Number of Raw Signals

0 2 4 6 8 10 12 14 16

<10^6

GOOD

> 2%

CORRUPTED
Backup slides (3) - z position reconstruction

Hit Position per Scintillator ID

~ 2% hits loss

ID of Scintillator

Entries 5377937
Mean x -0.1194
Mean y 84.16
Std Dev x 13.92
Std Dev y 54.9

Hit z position [cm]
Backup slides (4) - time synchronization