Real-time detection of alpha-particles and gammas using a fast optical camera

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SETUP

Optical detection scheme of $\alpha$-particles

- Real-time detection of alpha-particles essential for nuclear medicine, nonproliferation, security applications, ...
- $^{241}$Am source decay: 59 keV x-ray emission + 5.49 MeV $\alpha$-particle emission
- $\alpha$ in LYSO produces localized flash of light
- Light collected with lens onto intensified optical camera (ASI TpxCam3) with single photon sensitivity
- TPXCam3: Timepix3 readout chip + 256×256 pixels (55×55 $\mu$m$^2$ each) optical sensor

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1 G.D’Amen et al., Novel imaging technique for $\alpha$-particles using a fast optical camera
2 TimePix3 project: https://kt.cern/technologies/timepix3
Reconstruction using Centroiding Algorithm
Centroiding Algorithm

Occupancy

- Each $\alpha$ produces multiple photons in LYSO
- Single photon ID essential for alpha detection
- Reconstructed photons with high (≥20) hit-multiplicity clearly identify source position
- LYSO reflections visible from low hit-multiplicity photons
Centroiding algorithm relies on **Time of Arrival (ToA)** and **Time over Threshold (ToT)**

- Reconstructed "photons" from alpha particle interaction in LYSO can be resolved
- Limits in the approach; does not account for **photon blending**

### Resolved α candidate

### Blended α candidate
Reconstruction using Clustering Algorithm
Centroiding Algorithm  Clustering Algorithm

Clustering Algorithm
Hits, Clusters, Events

- **Hit**: $x, y, \text{ToA}, \text{ToT}$ information of photon on pixel
- **Event**: "temporal slice" of hits, no two registered more than $\Delta T = 20$ ns apart
- **Cluster**: subset of an Event; hits within $R = 3$ pixels from cluster center and temporally close
- Cluster center iteratively re-computed via non-weighted center-of-mass method to minimize exclusion of outliers
Clustering Algorithm

Cluster reconstruction

- 3D visualization of events \((x, y, \text{ToA})\) shows separate clusters (+ ToT for dot size)
- Some events have \(\geq 2\) clusters (multi-clusters event), others a single cluster
- ToA information corrected to minimize time-walk effect
- Are "clusters" good approximation of "single photons"?
Results compared to single-cluster test dataset: thermal photo-electrons from photocathode with blinded intensifier, indistinguishable from single photons.

Populations correspond to the $^{241}\text{Am}$ productions of x-ray (Single-cluster events) and $\alpha$-particles (Multi-cluster events), once reconstruction efficiencies of the algorithm are taken into account.
Centroiding Algorithm  Clustering Algorithm

Clustering Algorithm

**Flux** \((\sum \text{ToT})\)

- Distribution of **total ToT** and **number of hits** in each **event** or **cluster**
- Event distributions peak at low value; shape compatible to cluster distributions (single-photon events)
- Hypothesis: **peak regions populated by single-cluster events** (x-ray photons); tails populated by multi-cluster events \((\alpha)\)

**Hit multiplicity**
Imaging of $\alpha$-particles using fast optical camera by collecting photons produced by $\alpha$ in thin layer of LYSO is a viable approach.

Developed a clusterization algorithm to exploit spatial and temporal information.

Optical technique suitable for x-rays or other ionizing radiation with $\sigma_t \sim 10$ ns.

Sensitivity to x-rays in energy range 10 - 100 keV, where conventional solid-state x-ray detectors have limited sensitivity.

Main detection techniques for neutrons ($^{10}$B or $^6$Li), result in emission of $\alpha$-particles; the proposed approach may be exploited.

Allows for free-space light collection from large distances/large field using appropriate lens (for sufficiently strong $\alpha$ emitters).

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$^3$J.Yang et al., *A novel energy resolved neutron imaging detector based on TPX3Cam for the CSNS*
Backup
**Hotspot Masking**

- Compute Average number of entries per pixel
- Check for pixels with height > average
- If less than N additional neighbouring bins are > (pixel height * M%), pixel gets masked

![Example](image)

**Example:**

- N=2, M=50%
  - Required:
    - N = 3, kept
    - N = 1, masked
HOTSPOT MASKING

- Compute Average number of entries per pixel
- Check for pixels with height > average
- if less than N additional neighbouring bins are > (pixel height * M%), pixel gets masked
Clustering Algorithm

Stacked duration

Single photons  

Americium