Development of a pixelated BaF₂ test bed for timing applications

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This material is based upon work supported in part by the Department of Energy National Nuclear Security Administration through the Nuclear Science and Security Consortium under Award Number DE-NA0003996.

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Nuclear Science & Security

Time-of-flight positron emission tomography (TOF-PET)

- Conventional PET uses timing information only to establish a line of response (LOR)
- TOF-PET uses TOF to localize the annihilation position along the LOR
- Improves signal to noise ratio
- 10 ps FWHM coincident time resolution enables direct source localization instead of reconstruction from multiple LOR

![Figure 1. Relationship between relative annihilation photon TOF and annihilation position along the line of response [1].](image1)

Conventional PET

TOF-PET

Figure 3. (Top) Conventional PET: each event is equally attributed to all image elements along the LOR. (Bottom) TOF-PET: each event is attributed only to those image elements along the LOR that are compatible with the relative annihilation photon TOF [2].

BaF₂ for sub-nanosecond timing

- Pure BaF₂ crystal exhibits two scintillation mechanisms with distinct emission characteristics
  - Self-trapped exciton luminescence: slow emission peaked at 310 nm, 600 ns decay
  - Cross luminescence: fast emission peaked at 195 nm & 220 nm, sub-nanosecond decay

![Figure 1. (Top) Schematic of BaF₂ band structure and two scintillation mechanisms [3]. (Bottom Center) Time resolved BaF₂ emission spectrum [4]. (Bottom Left) Time distribution of fast emission [4]. (Bottom Right) Time distribution of slow emission [4].](image2)

Detector design

Goal: to develop a pixelated BaF₂ test bed to characterize the performance of various configurations for timing applications.

- Timing applications are characterized by high time resolution and/or count rate
- High count rates require slow component suppression
- Primary design motivation: time-of-flight positron emission tomography (TOF-PET)
- Deployable form factor
- Variable system geometry

![Figure 4. A stack of acetal sheets forms the frame for an 8x8 array of 4.5 mm x 4.5 mm x 30 mm pure BaF₂ crystals. Each pixel slot has rounded corners which enforce an airgap around the pixel; the top of the array reflects the color of the surface it sits on.](image3)

![Figure 5. The BaF₂ array is air coupled to an 8x8 Photonis Planacon MCP-PMT (35 ps transit time spread).](image4)

![Figure 6. Four detectors have been assembled and tested under x-ray (> 500 keV) excitation.](image5)

Next steps

1. TOF-PET system performance
   - Custom brackets to mount detectors to ring stands, already in hand
   - TDC for timing, waveform digitizer for spectroscopy
   - Rather than using anode signals for timing, pick off signal from HV divider

![Figure 7. Proposed PET-like experimental setup [1].](image6)

2. Optical filter characterization
   - Slow emission component suppression via optical filtering makes high count rate applications viable by avoiding pile up
   - Interference filter transmission is angle-of-incidence dependent, so long wavelength transmission cutoff must be optimized for fast emission collection
   - Simultaneous collection of filtered and unfiltered light enables absolute pulse shape comparison for filter performance assessment
   - Feasibility study for filtered spectroscopy

![Figure 8. (Top) 1" x 1" cylindrical pure BaF₂ crystal. (Top Right) Omega 227 SP optical filter. (Bottom) Proposed dual PMT readout for filtered pulse shape characterization.](image7)

References