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Office of Nonproliferation and Verification Research & Development

SNM Movement Detection / Radiation Sensors and Advanced Materials Portfolio Review

RadSensing2010

Neutron Imaging Using Crystalline Organic Scintillators and Pulse Shape Analysis

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Project Overview

Neutron Imaging Using Crystalline Organic Scintillators and Pulse Shape Analysis

Sandia National Laboratories, CA

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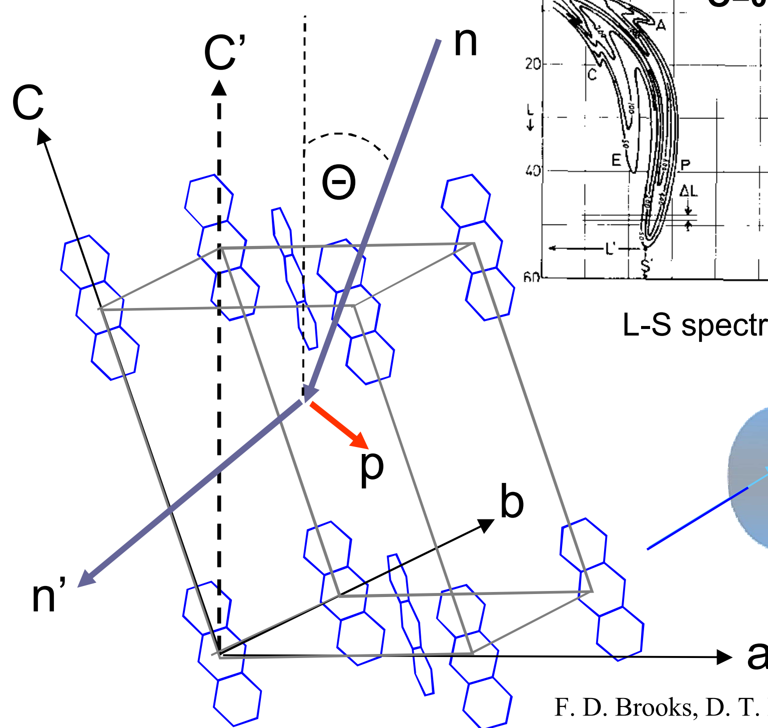
Team: John Steele, Peter Marleau

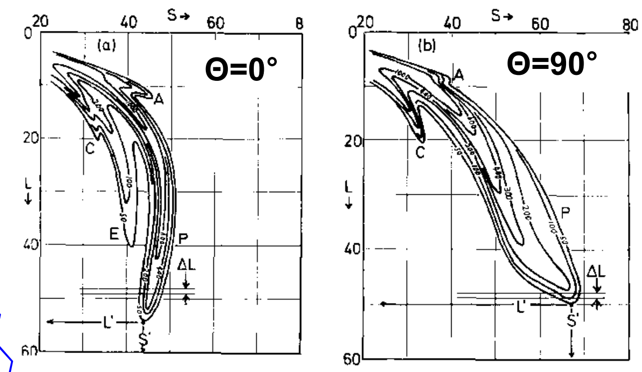
Budget: $200k FY09, $200k FY10

Summary: We are investigating the feasibility of a new class of compact, efficient neutron detectors with directional sensitivity. The detectors would exploit an anisotropy in the neutron response of crystalline organic scintillators, specifically in the scintillation pulse shape. We need to characterize the pulse shape anisotropy, and determine how best to use the pulse shape information for neutron imaging.

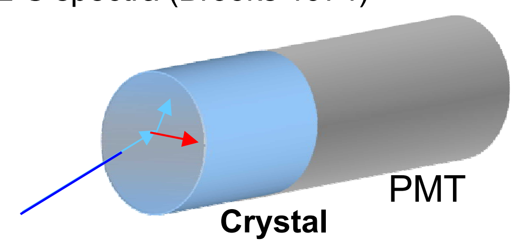
The Principle

- Crystalline organic scintillators (e.g. anthracene, stilbene) exhibit pulse height and pulse shape dependence on incident neutron direction, via an anisotropy in the scintillation response to the proton recoil.
  - First observed in 1960s-1970s
- In principle, the anisotropy could be employed in a new class of compact and efficient neutron detectors with directional sensitivity.
  - Complements scatter camera, TPC, other techniques





L-S spectra (Brooks 1974)

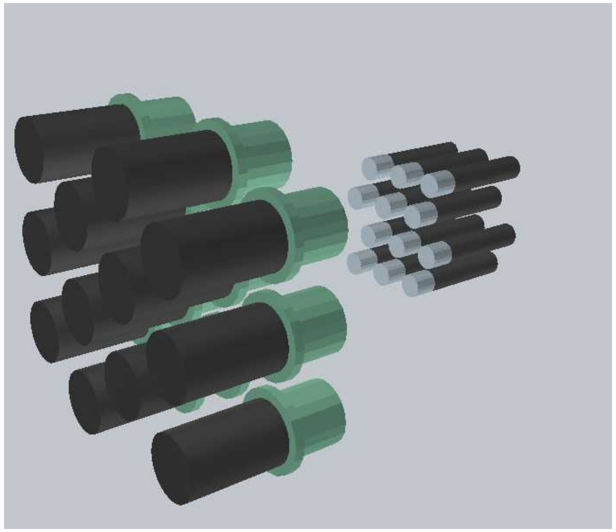


F. D. Brooks, D. T. L. Jones, "Directional Anisotropy In Organic Scintillation Crystals", Nuclear Instruments And Methods 121 (1974) 69-76.

Goal and Technical Approach

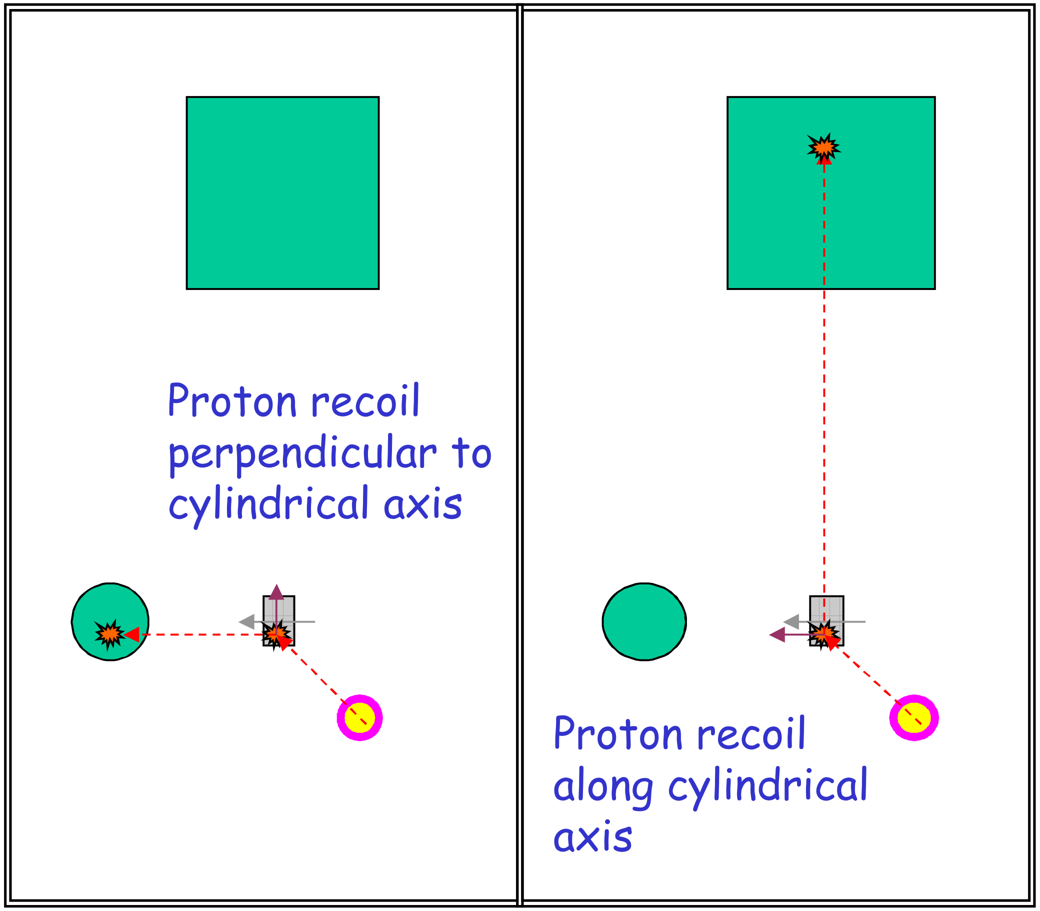
- **Our goal: Determine the feasibility of using this directional effect to create a novel, compact, imaging fast neutron detector.**
- **Potential payoff: Hand-held direction-sensitive neutron detectors, suitable for SNM search in buildings, aircraft, maritime vessels, etc.**
- **Three threads to the technical work:**

1. **THE PHYSICS:** Measure the directional effect in crystalline organic scintillators, especially in the fission energy region, where it has not been well characterized.
2. **THE TECHNOLOGY:** A key to successfully exploiting the effect is high-quality pulse shape discrimination (PSD). Explore different methods to reach and improve on the state of the art.
3. **THE ANALYSIS:** Determine how best to use the PSD information to detect a point neutron source above smoothly varying background.

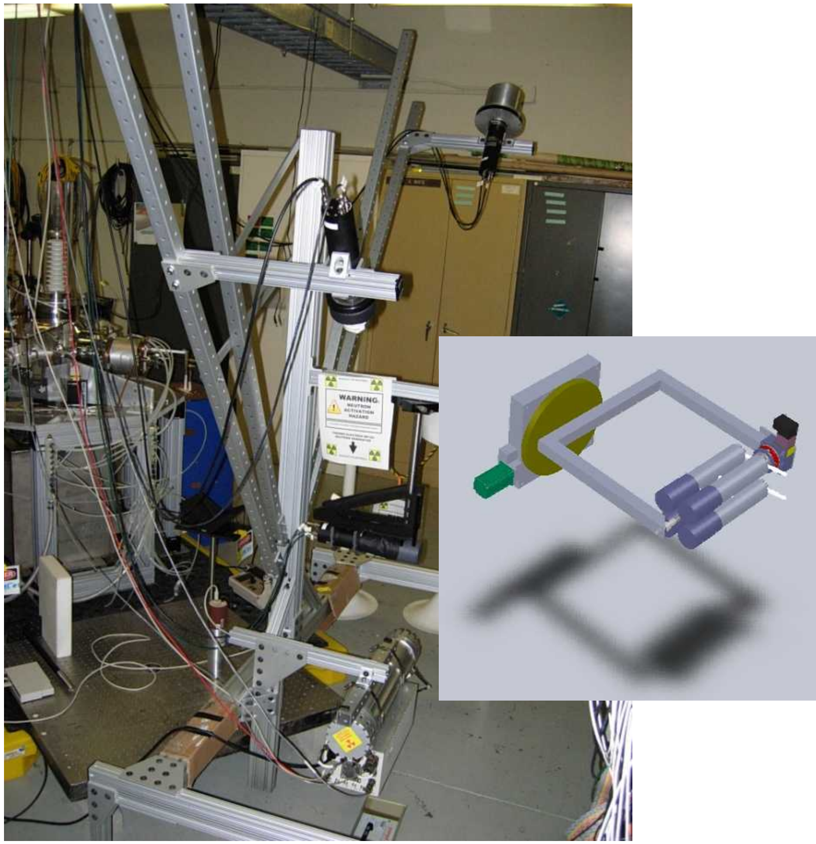


Measurement Strategy

- **To measure the physical effect:**
  - Fix proton recoil energy.
  - Fix proton recoil direction.
  - Accumulate statistics for pulse height, pulse shape.
- **Double scatter configuration fixes proton recoil direction.**
- **Monoenergetic neutrons from D-T generator fixes proton recoil energy.**
  - And provides high n flux.



Measurement Apparatus

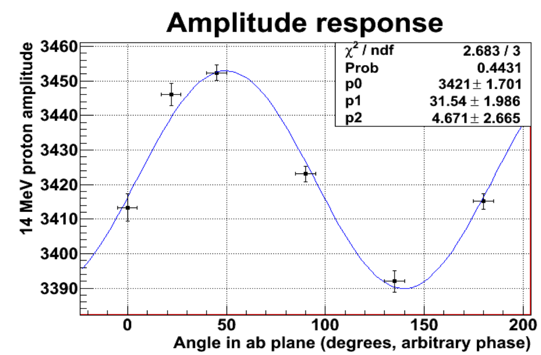


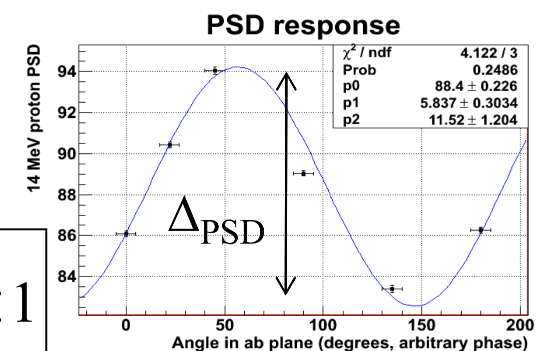
- **Built a custom crystal characterization rig.**
  - Thermo MP320 NG.
  - Adjustable double-scatter angles, distances.
  - Two-axis remotely controlled rotation of the crystal detector.

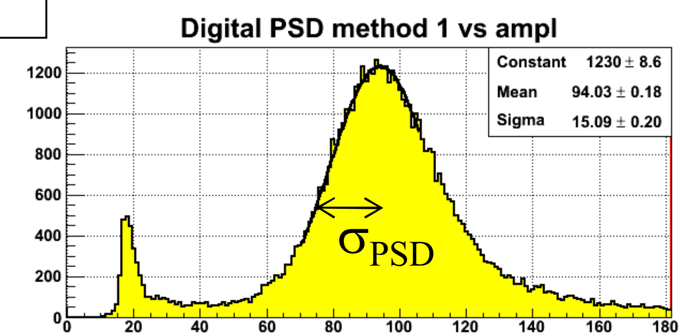
Experimental Results

- **Double scatter events probe E_n<14 MeV.**
  - Difficult tradeoff between statistics and systematics.
  - So far double scatter data is not well understood.
- **Events with ~14 MeV also define a unique proton direction and energy.**
  - Abundant and relatively easy to analyze.
  - First measurements of stilbene anisotropic response to 14 MeV proton recoils.
  - Similar measurement on anthracene.

$$\frac{\Delta_{PSD}}{\sigma_{PSD}} < 1$$





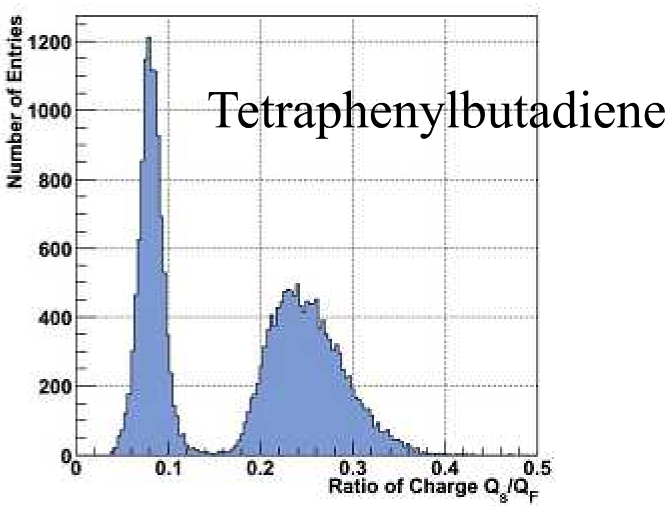


Stilbene, 14 MeV proton recoils

Experiment Conclusions

- Pulse height and shape anisotropies are present in anthracene and stilbene.
- The effect is quite subtle in stilbene, less so in anthracene.
- Double-scatter experiments to characterize at lower energy very challenging.
  - Further effort needed in simulation and analysis.

- We would like to use our apparatus to look for more striking anisotropies in new crystalline organic scintillators.
  - Plan to work with LLNL group to characterize promising materials.

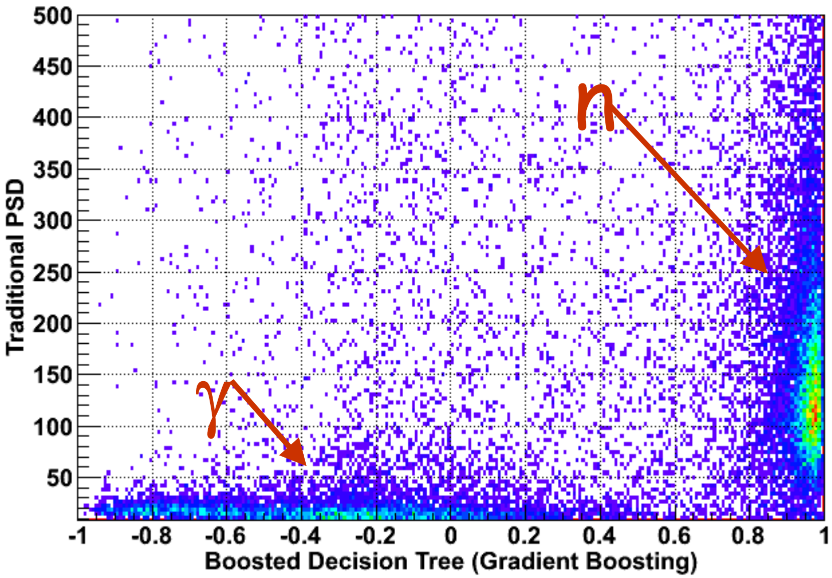


Hull, Zaitseva, Payne, et al.,
IEEE T Nucl Sci **56**, 899 (2009).

Pulse Shape Analysis

- **Early work explored analog PSD techniques.**
  - Ortec PSA module most sensitive.
- **Implemented digital pulse acquisition and analysis.**
  - Simple algorithm provides good performance.
  - Flexibility to try various offline techniques!
- **Expect to improve PSD resolution with more effort on this front.**
  - Various approaches in the literature.

- **Work in progress to apply multivariate techniques to digitized pulses.**
  - E.g. this preliminary result implies boosted decision tree provides independent information on n-γ separation in stilbene.



Using the Anisotropy

- **Using the directional information is not trivial:**
  - Statistical/experimental resolution on PSD.
  - PSD does not uniquely encode a single direction.
  - Inherent ambiguity in incoming neutron energy, angle.
  - Parity symmetry!
- **Broadly, two approaches to using directional detector:**
  - Require another interaction to gather more information.
    - Neutron Scatter Camera with organic crystals in the front plane.
  - Statistical reconstruction (imaging) of source location by making some assumptions about incoming neutron spectrum.
    - Allows simple detector designs, but more complicated analysis.

Image Reconstruction I

- **Toy Monte Carlo includes n-p elastic scattering, but no anisotropy.**
  - i.e. assumes we measure proton energy, direction directly.
- **Compare various reconstruction methods:**

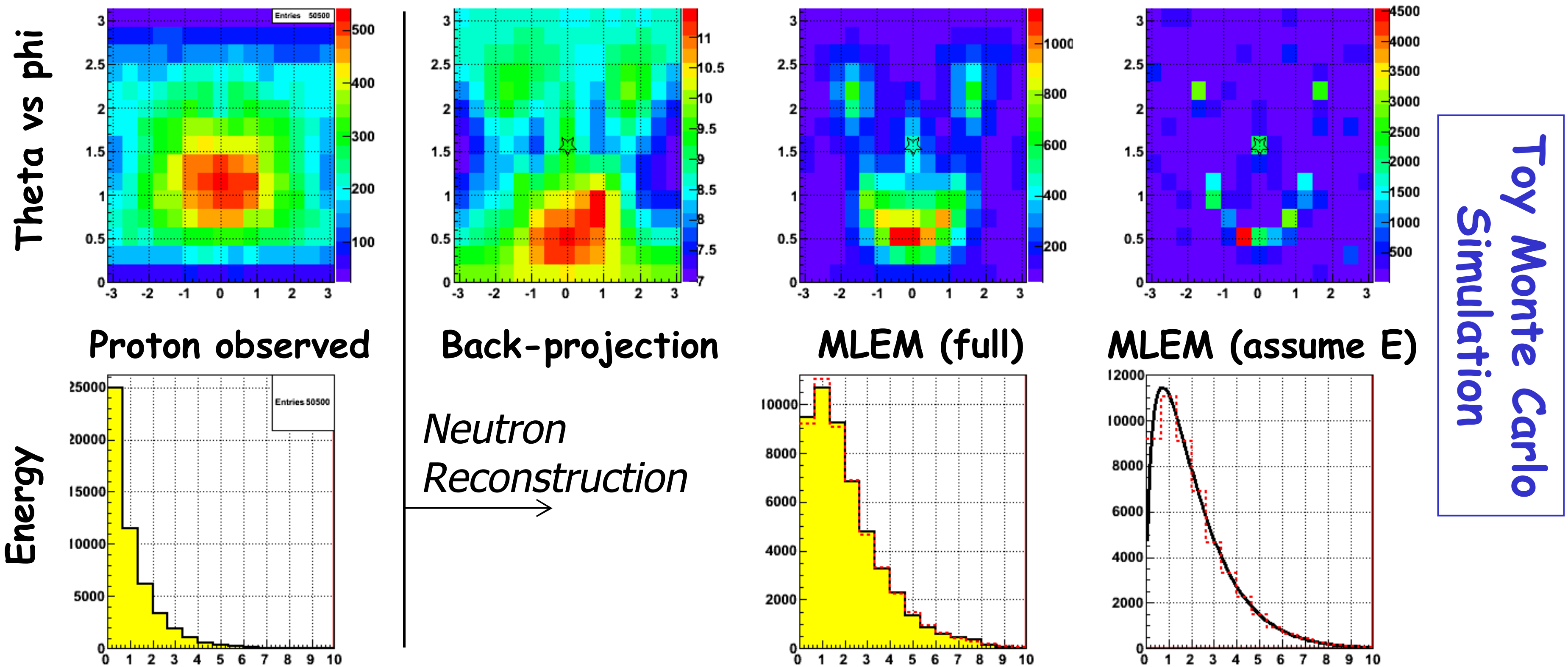
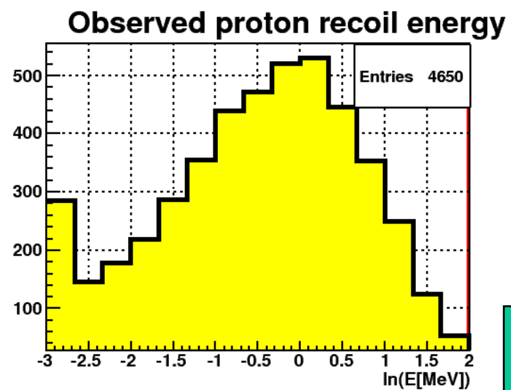
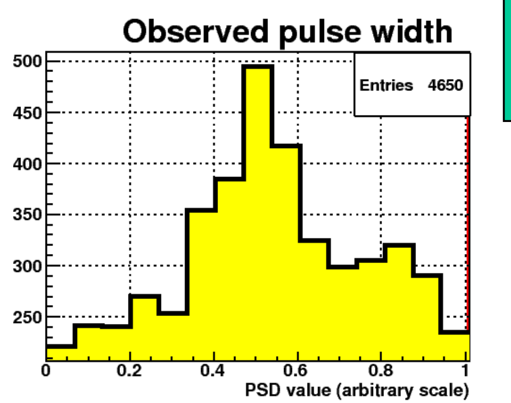


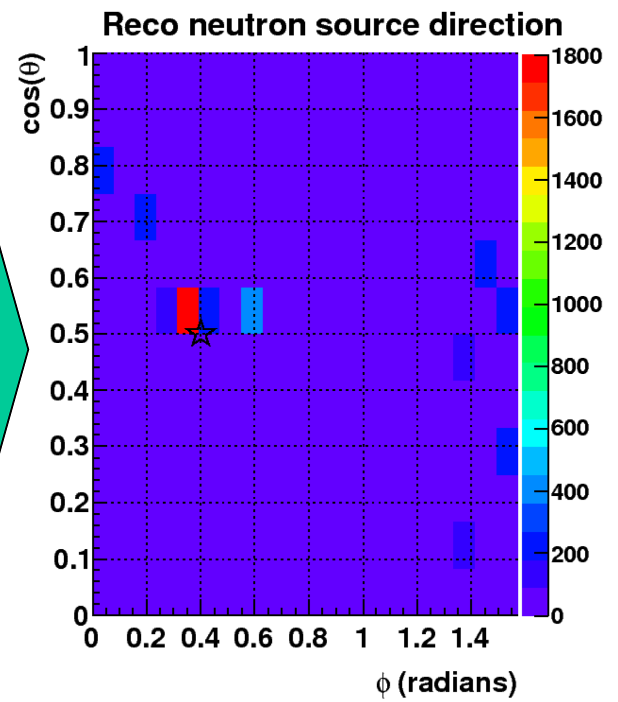
Image Reconstruction II

- **Toy Monte Carlo simulation includes n-p scattering physics *and* anisotropy physics**
- **Acquire pulse height, pulse shape for each event**
  - Assume optimistic pulse shape resolution
- **Reconstruction of point source location is possible using MLEM.**
- **NB: Eight-fold directional ambiguity can be broken to two-fold using multiple crystals with varying orientation**





Toy Monte Carlo Simulation



Unclassified

Summary and Conclusions I

- **Determining the physical effect:**
  - We have built an experimental apparatus for characterizing the anisotropic neutron response of crystalline organic scintillators.
  - Initial experiments confirm the presence of anisotropies in anthracene and stilbene, with relative magnitudes as expected.
  - Double-scatter data to probe energies relevant to fission-energy neutrons are difficult; for successful measurements we need more data and control of systematics.
  - A wide range of organic crystals should be searched for potentially useful anisotropies.
- **Optimizing the PSD measurement:**
  - We have implemented digital pulse acquisition and analysis for the measurements presented here.
  - There are indications that sophisticated pulse analysis techniques can provide improved PSD resolution.
- **Using the PSD information to image neutrons:**
  - We have shown that using maximum likelihood techniques, we can statistically reconstruct a neutron source from pulse height/shape data.

Summary and Conclusions II

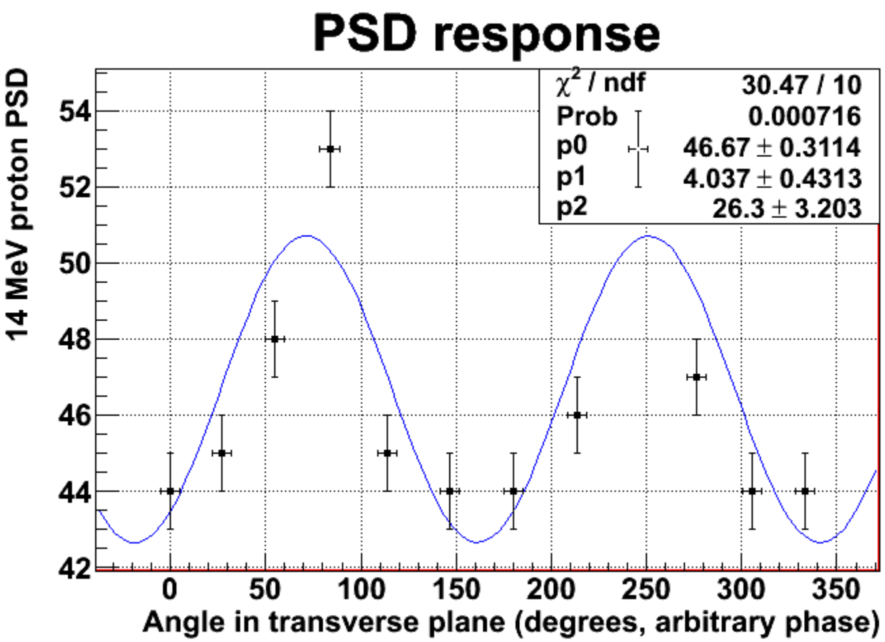
- **Our conclusions:**
  - There are no evident barriers to exploiting this effect in a new class of directional neutron detector.
  - More sensitive PSD will be needed.
  - Larger anisotropies in new scintillators would help; we will work with LLNL to explore new organic scintillators produced there.
  - If reasonable resolution can be reached, we have shown that the information can be used to image a neutron source.

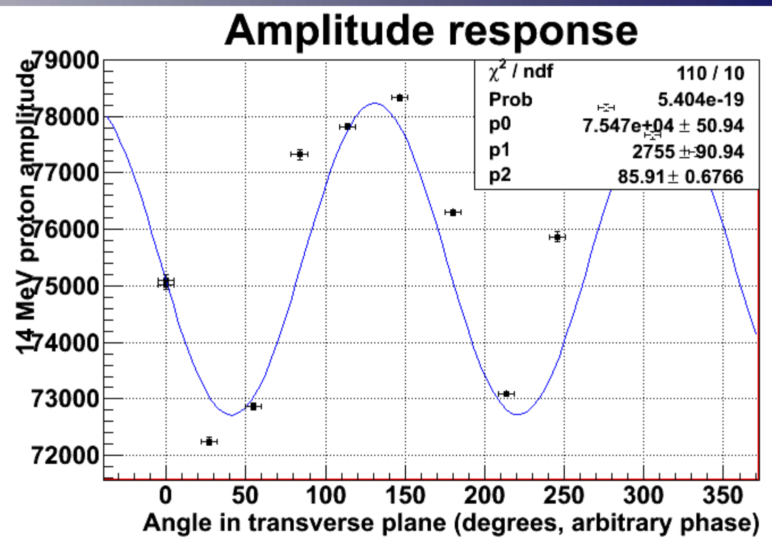
ADDITIONAL MATERIALS

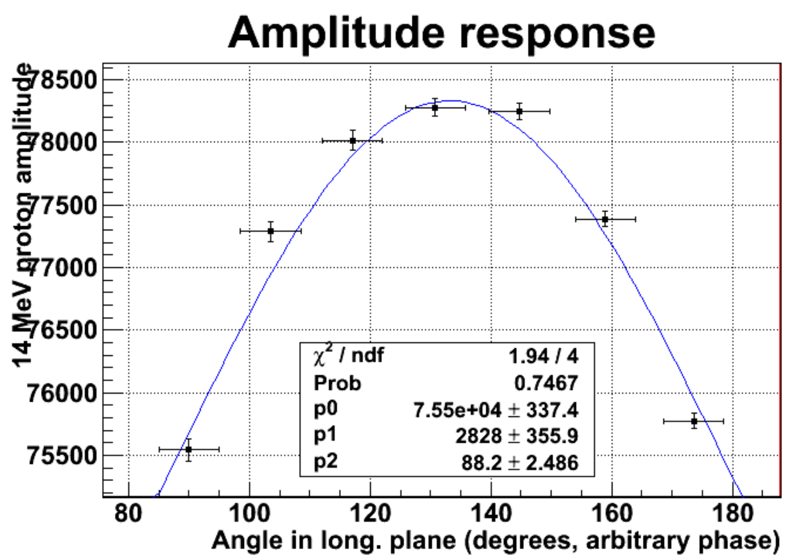
Anthracene measurements

National Nuclear Security Administration

Anthracene, 14 MeV proton recoils







Crystalline axes do *not* coincide with the macroscopic shape!

$$\frac{\Delta_{PSD}}{\sigma_{PSD}} >\sim 3$$