Investigation of Directional Dependence in Anthracene and Stilbene Detectors

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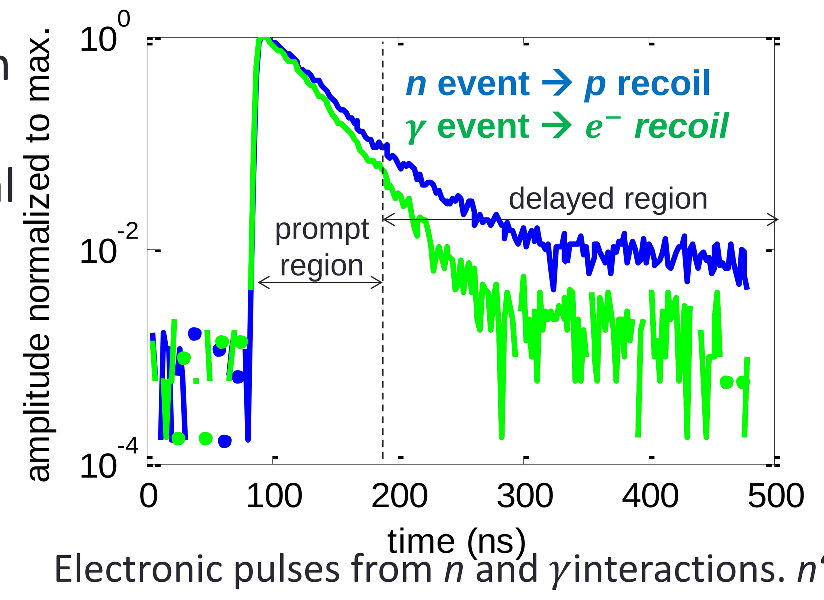
Abstract

- Organic scintillator materials are becoming increasingly valuable as radiation detectors in nuclear safeguards and security. They offer simultaneous detection of fast neutrons and gamma-rays, provide information about the neutron energy, can be made in large sizes, and are relatively inexpensive.
- Organic crystal scintillators offer minimal thermal expansion compared to liquids and can be made in large sizes with excellent performance. However, a directional dependence that degrades the energy resolution has long been observed in heavy charged particle interactions in organic crystal scintillators.
- This directional dependence is generally seen as a problem, but may be an opportunity to learn more about the material properties in organic crystal scintillators or use them as directional neutron detectors.

Organic Scintillator Output Depends on Particle Type

- Interactions by neutrons and gamma-rays in organic scintillators produce different distributions of light vs. time. Both the total light output per energy deposited and the shape of the time distribution differ.
- The pulse shape is quantified by measuring the fraction of delayed light, calculated as the tail-to-total (TTT) value:

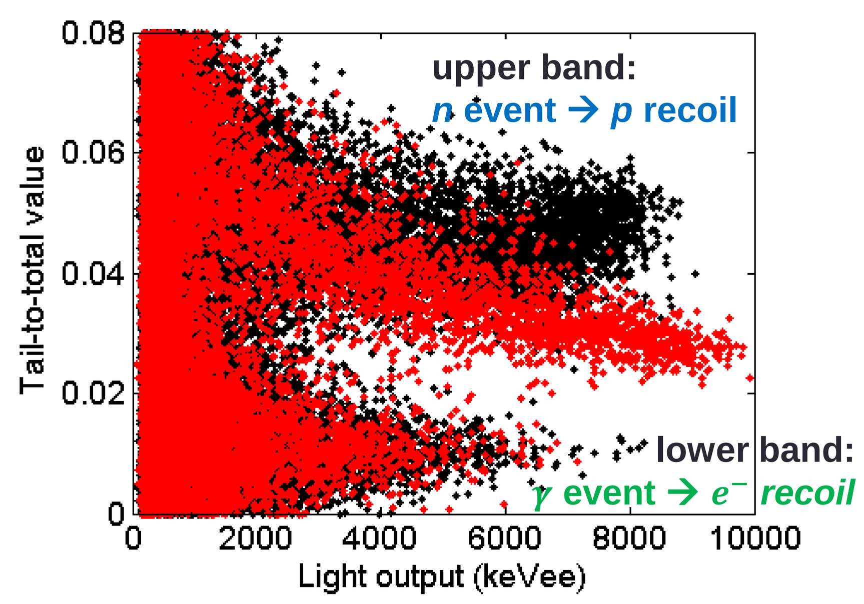
$$TTT = \frac{\text{delayed light}}{\text{prompt+delayed light}}$$



Electronic pulses from n and γ interactions. n's produce more relative delayed light

Crystal Organic Scintillator Output Also Depends on Heavy Charged Particle Direction

- In crystalline materials, the light output and pulse shape also depend on the direction of the heavy charged particle recoil with respect to the crystal axes.
- A measurement of events from a dT neutron generator at two different orientations (red and black data) produce different TTT vs. Light Output distributions as shown on right.



- The magnitude of change in the light output is greater at lower proton recoil energies, and the magnitude of change in the tail-to-total value is greater at higher proton recoil energies.
- While the light output changes by a similar factor in both materials, the tail-to-total value changes much more in anthracene than in stilbene.

Anthracene		
E_p	L.O. Max/Min	TTT Max/Min
$14\ MeV$	1.155 ± 0.006	1.798 ± 0.006
$2.4\ MeV$	1.396 ± 0.036	1.317 ± 0.007
Stilbene		
	L.O. Max/Min	TTT Max/Min
$14\ MeV$	1.191 ± 0.004	1.076 ± 0.001
$2.4\ MeV$	1.320 ± 0.020	1.031 ± 0.003

Hypothesis For Explaining Directional Dependence

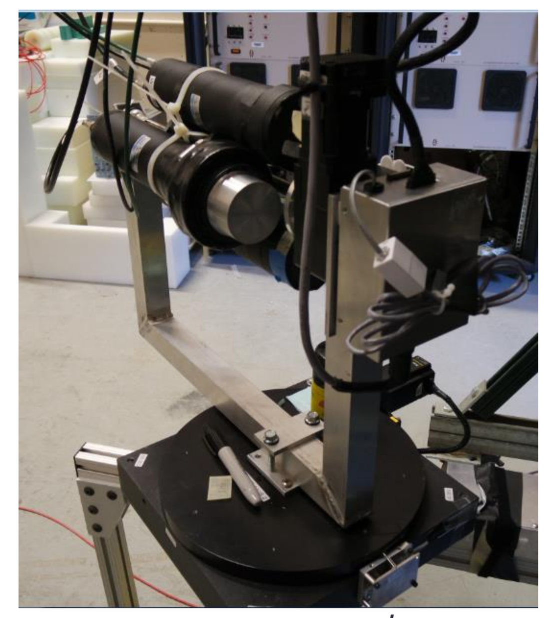
Why is there a directional dependence in heavy charged particle events?

- The light output depends in part on interactions between excitations. If the ability of the excitations to move in the material and interact changes, the light output will change.
- There are preferred directions of excitation transport in the crystals. Depending on the direction of the proton recoil, the excitations may be distributed along a direction with easy transport and meet other excitations as they move during their lifetime. If they are distributed along a direction with difficult transport, the excitations will instead diffuse away from the other excitations, reducing the number of interactive processes and affecting the light output.

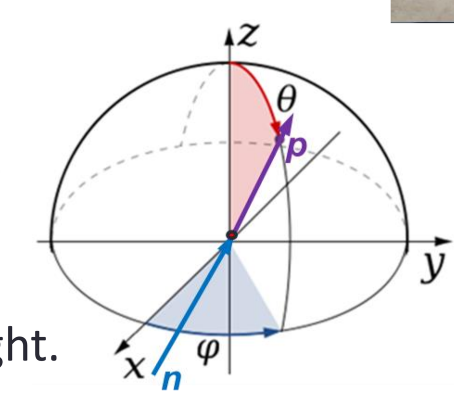
Why is there no directional dependence observed in electron recoil events?

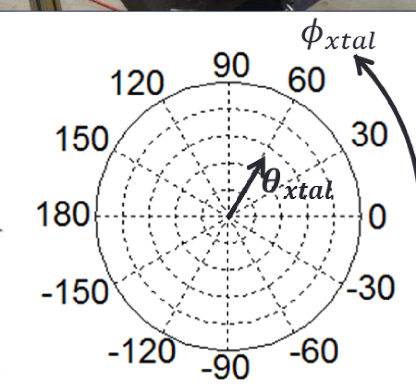
- Electrons deposit a much lower dE/dx than protons, so the excitations are farther apart in the material. While there are still preferred directions of excitation transport, the excitation interaction likelihood does not change significantly because the excitation density is still so low. Thus, there is no observable change in the light output.
- Muons, which interact with low dE/dx like the electron recoil, were shown to not produce a directional dependence, which is consistent with the hypothesis that a large dE/dx is required for producing the effect.

Characterizing Light Output and Pulse Shape vs. Proton Recoil Direction



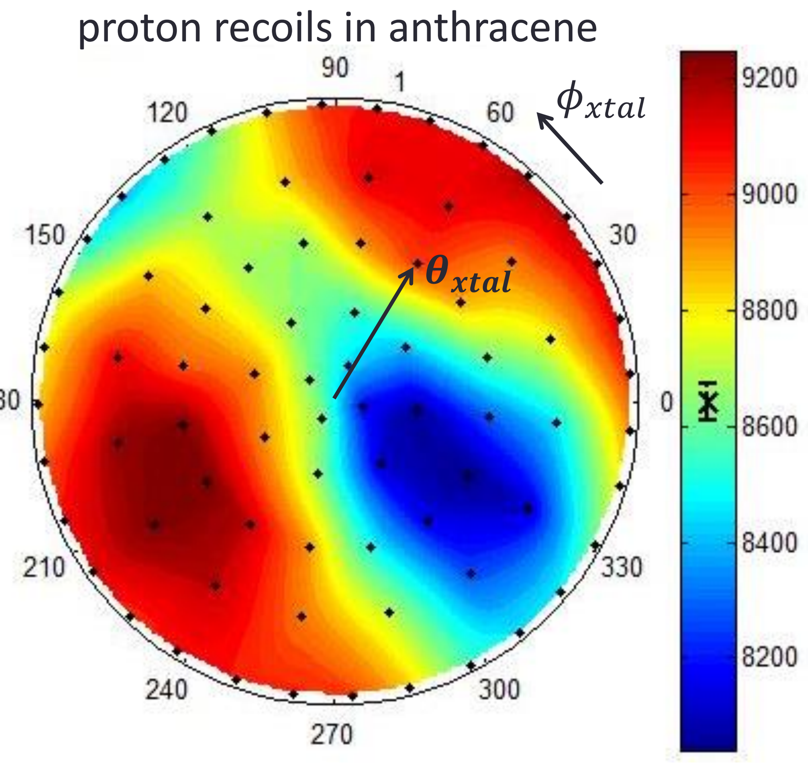
- To control the proton recoil direction and energy, full energy interactions from monoenergetic neutrons are used in which the proton travels in a single known direction. The proton recoil direction is adjusted by rotating the detector with respect to the neutron source.
- A motor-driven rotational stage can position four detectors at all possible proton recoil directions in the crystal axes.
- Proton recoil directions are expressed in spherical coordinates as (ϕ, θ) in an arbitrary axes system, with a 2D representation for plotting purposes shown on right.



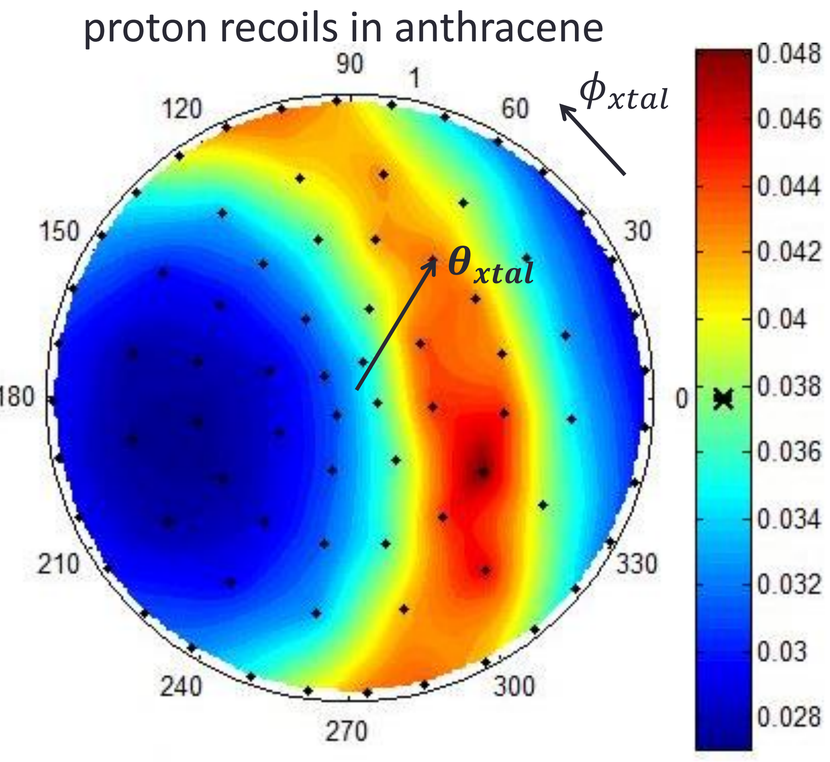


- The following figures show the light output and tail-to-total value as a function of proton recoil direction at 14 MeV in anthracene and stilbene.
- In anthracene, the direction of maximum light output corresponds to that of minimum tail-to-total value. In stilbene, that relationship is reversed.

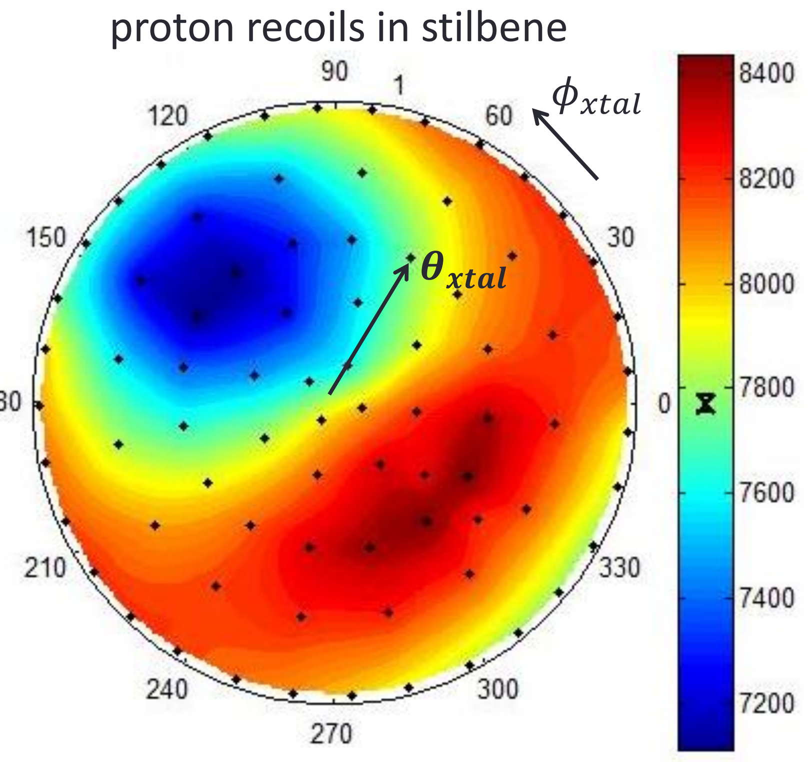
Light Output (keVee) for 14 MeV proton recoils in anthracene



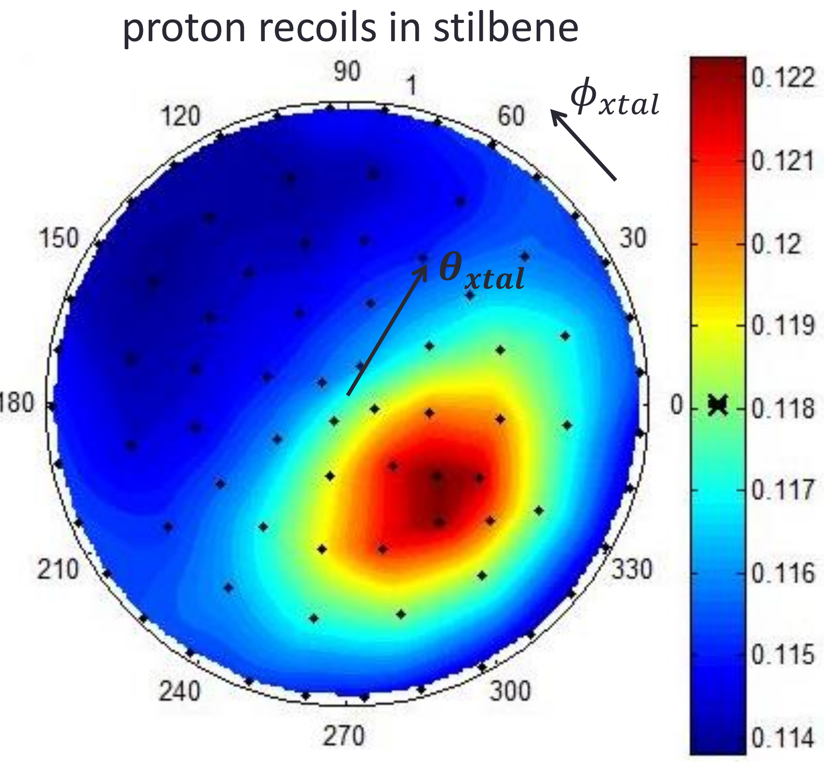
Tail-to-total values for 14 MeV proton recoils in anthracene



Light Output (keVee) for 14 MeV proton recoils in stilbene



Tail-to-total values for 14 MeV proton recoils in stilbene



Conclusion and Future Work

- Measurements of proton recoils from neutron interactions have demonstrated that the light output and pulse shape depend on the direction of the proton recoil. The observed directional dependence is significant and complex in anthracene and stilbene.
- Future work aims to characterize additional materials of different crystal quality, *n-g* separation, and with known crystal axes to better understand the mechanism that produces the effect.
- A deeper understanding may make it possible to correct for the effect in order to improve energy resolution, or produce new materials that eliminate or enhance the effect.
- These materials offer the potential for a compact directional neutron detector. A hand-carryable, relatively robust system could be constructed with a single detector whose material properties provide internal directionality.

Acknowledgements

The author would like to thank Erik Brubaker, Stan Prussin, and Kai Vetter for their mentorship, and Natalia Zaitseva for providing the stilbene sample.

This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0000979. This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. DGE 1106400.