Exploiting the anisotropic scintillation response of stilbene for directional neutron source information

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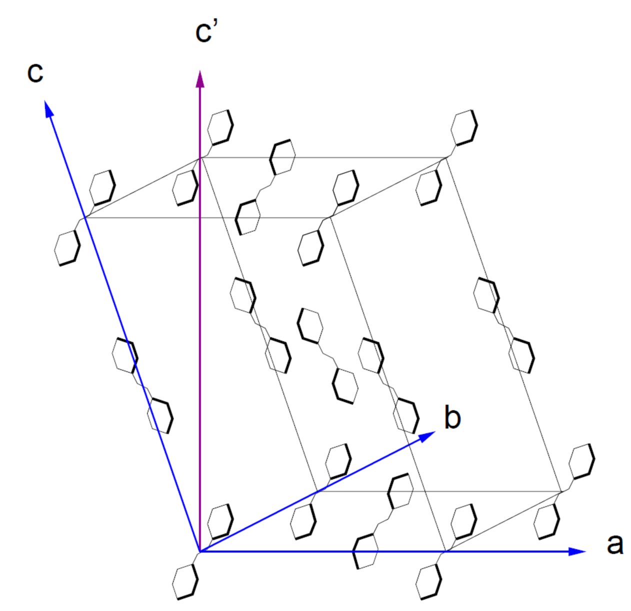
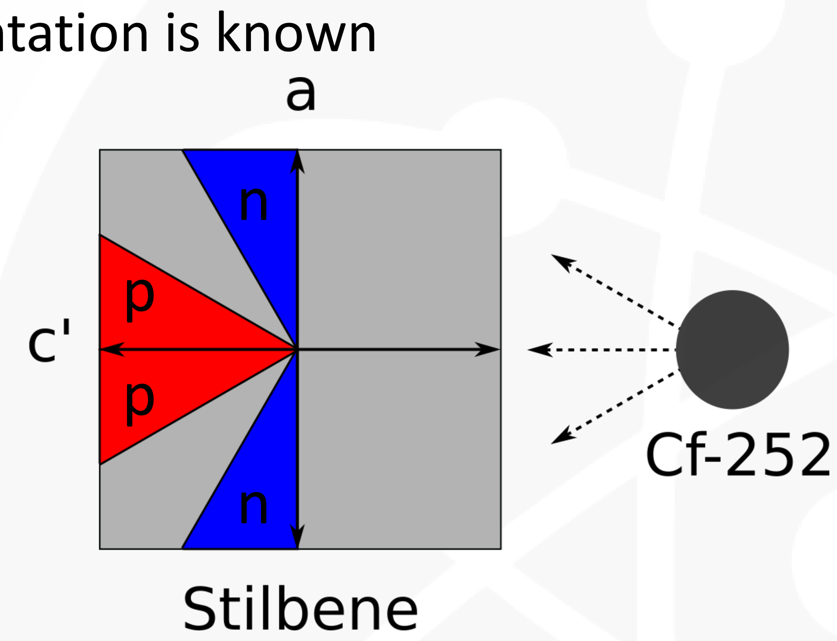
Introduction

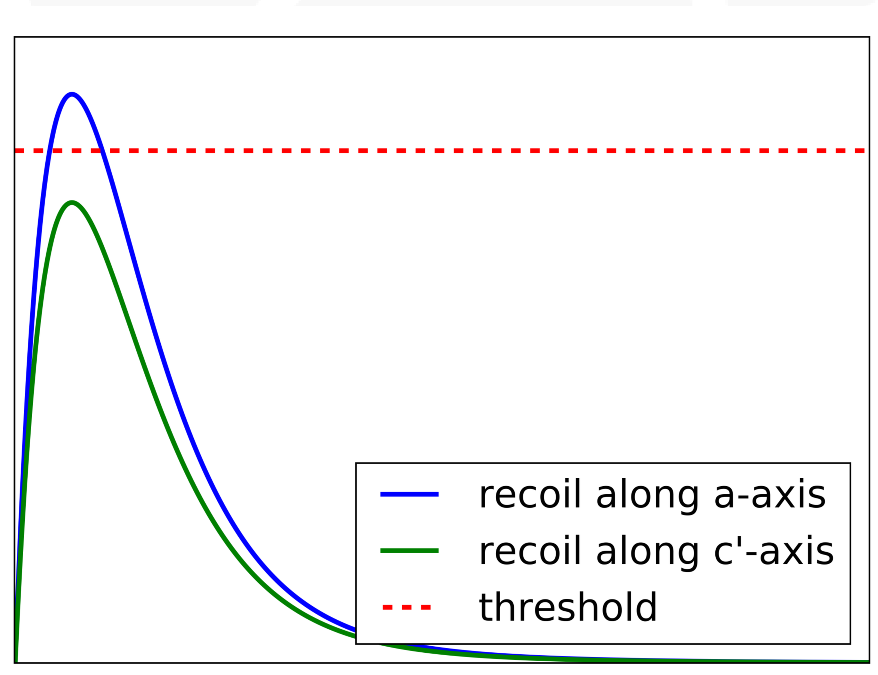
- Locating and tracking Special Nuclear Material (SNM) is a primary concern for nuclear nonproliferation
- **Research goals**:
  - Design a directionally sensitive neutron source detection system by exploiting the scintillation anisotropy of stilbene
  - Supports the NNSA mission of nuclear nonproliferation and treaty verification
- **Measurement presented here**: simple bench-top experiment that demonstrates using the scintillation anisotropy of stilbene to obtain directional information from a fission neutron source



Theory

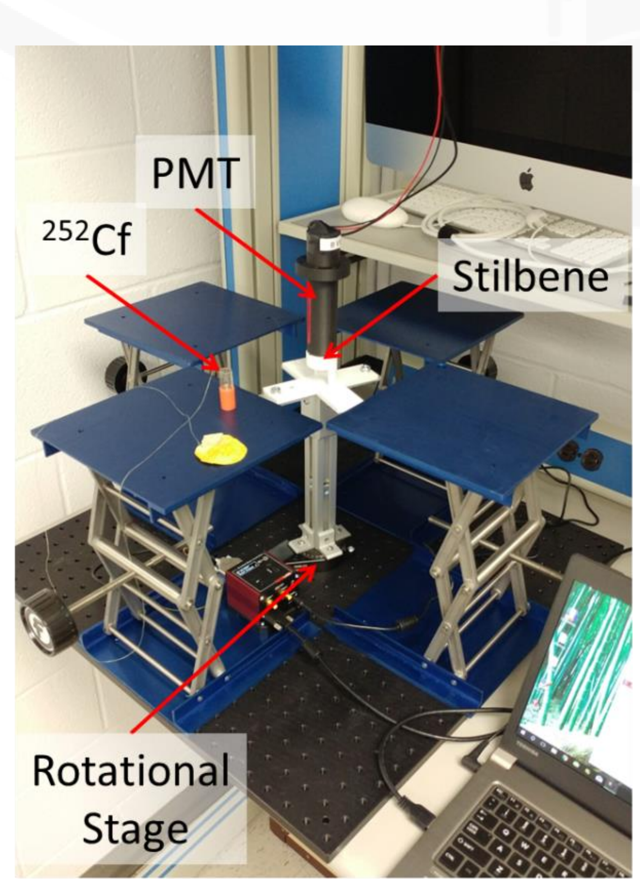
- Light output anisotropy: for a proton recoil with energy E_p the light output will be at a maximum if its trajectory is along the crystalline *a*-axis and a minimum if it is along the *c′*-axis
- This anisotropy can be exploited for neutron directional detection using threshold effects if the crystalline orientation is known
- The detector threshold constrains the accepted proton recoil directions by placing a lower limit on the recoil energy recorded
  - Recoil energy: $\boldsymbol{E_p = E_n \sin^2 \theta_n}$
  - Recoil direction: $\boldsymbol{\theta_n + \theta_p = 90°}$
- In this way, the threshold restricts detected protons to a cone about the axis that is collinear with the source-detector axis
- In addition, recoiling protons with energies near the threshold and traveling in the direction of the maximum light output will produce enough scintillation photons to cross the threshold while recoils along other directions will not
- Result: change in the count rate dependent on the orientation of the detector relative to the source





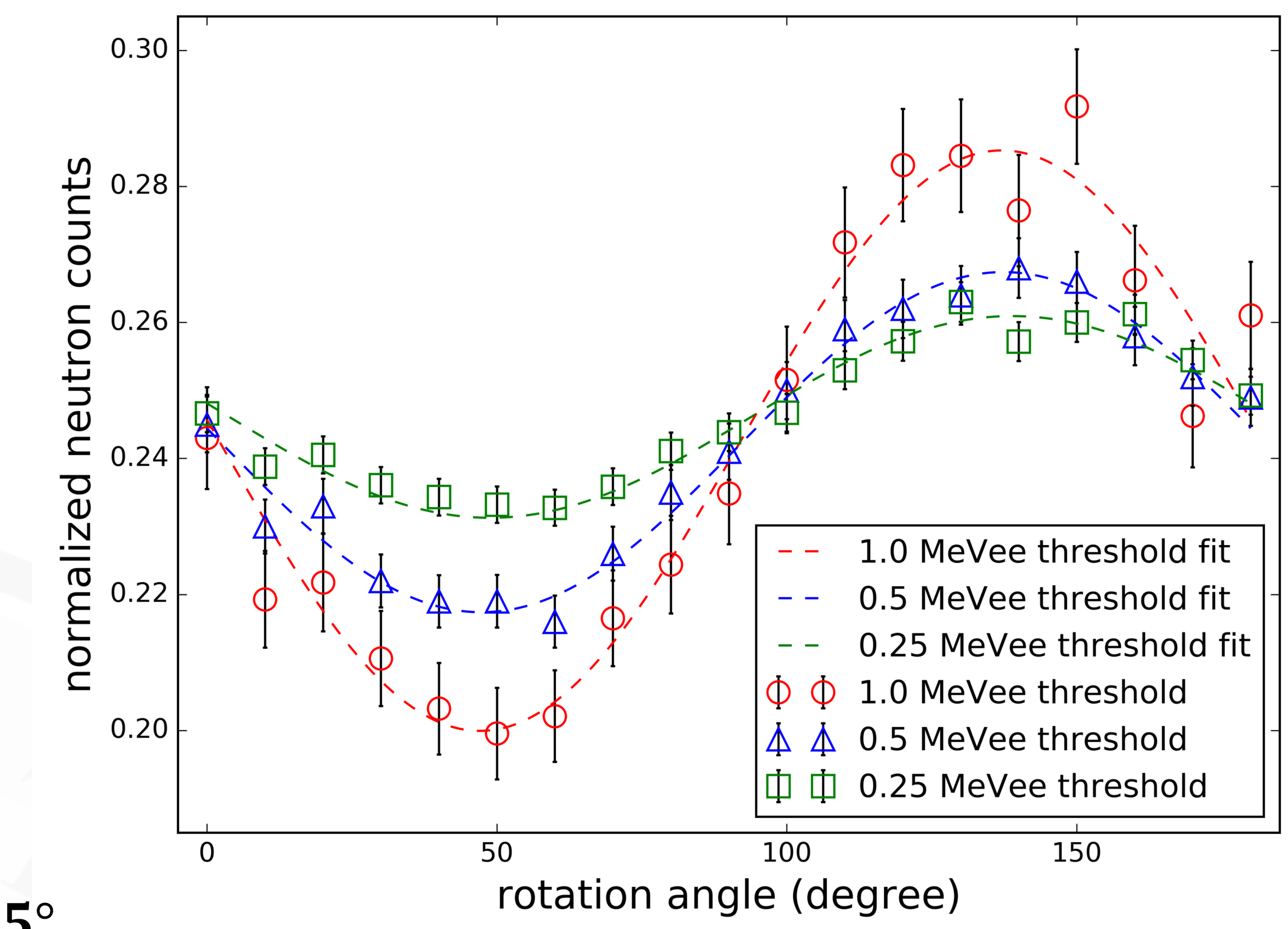
Experiment setup

- 1 cc stilbene detector with known crystalline axis orientation placed on a 360° rotational stage
- ^{252}Cf source positioned coplanar with the stilbene crystal
- Stilbene was rotated through 180° in 10° increments (mirror symmetric)
- Count rate was recorded at each orientation
- Uncertainty on source position: ±3°



Results with source at 45°

- ^{252}Cf source was positioned at 45° relative to rotational stage
- Stilbene detector was oriented with the c′-axis (direction of minimum response) at 0° relative to the rotational stage
- **True minimum: 45°**
- **True maximum: 135°**
- Neutron count rate normalized using the gamma count rate – accounts for changes in the source-detector distance
- 1.0 MeVee threshold
  - Smaller solid angle for recoiling protons
  - Low number of counts – high statistical uncertainties
- 0.25 MeVee threshold
  - Larger solid angle for recoiling protons
  - High number of counts – low statistical uncertainty



Threshold (MeVee)	Maximum Count Rate Angle	Minimum Count Rate Angle	σ_{fit}
0.25	138.9°	48.9°	2.5°
0.5	137.3°	47.3°	1.8°
1.0	137.1°	47.1°	3.7°

- Agreement between true direction and measured direction for each threshold is within $2\sigma_{fit}$
- Results contain a bias of ~2°–2.5°
  - Due to uncertainty on the position of the source
  - Correcting for the bias results in agreement between the measured and true directions within σ_{fit} for each threshold
- **Conclusion**: scintillation anisotropy can be exploited using threshold effects to obtain the neutron source direction within the uncertainty of the fitted measurements

Conclusions and future work

- A stilbene detector was used to obtain the direction of a ^{252}Cf source within the uncertainty of the measurement
  - This is the first experimental demonstration of the viability of exploiting scintillation anisotropy for the directional detection of fission neutron sources
  - While the results are promising, the measurement is merely proof of concept and is only applicable if the source and detector are coplanar
- Future work
  - Extension from a coplanar measurement to 4π using a high-precision response characterization of stilbene's anisotropic scintillation response
  - Test the measurement system with SNM sources in collaboration with scientists at the Nevada Test Site

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