SANDD: A directional antineutrino detector with segmented ^{6}Li-doped pulse-shape-sensitive plastic scintillator

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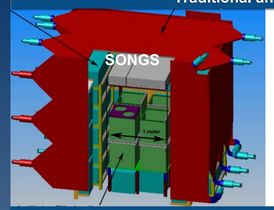
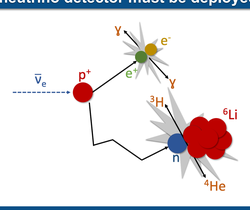
We present a complete characterization of a small (9-liter) and mobile 0.1% ^{6}Li-doped pulse-shape-sensitive plastic scintillator antineutrino detector called SANDD (Segmented AntiNeutrino Directional Detector), constructed for the purpose of near-field reactor monitoring with sensitivity to antineutrino direction. A detailed Monte Carlo simulation code was developed and validated to model the performance of each of the detector elements, as well as the performance of the entire detector. Analysis cuts were developed to maximize the sensitivity to the inverse beta decay (IBD) and minimize the background. The neutron and positron detection efficiencies are estimated to be 34% and 78%, respectively, resulting in antineutrino detection efficiency of 19%±1.0%(stat.)±2.0%(syst.). An uncertainty of 25^0 in the direction of the reactor antineutrino flux is predicted from 100 detected antineutrino events.

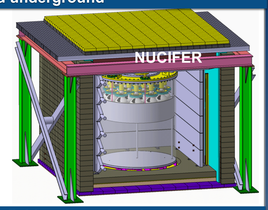
Motivation and antineutrino detection

6 antineutrinos per fission **x** ~10^{21} fissions per second in a 3,000-MWt reactor **=** ~10^{22} antineutrinos per second unattenuated and in all directions

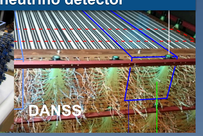
Traditional antineutrino detector must be deployed underground



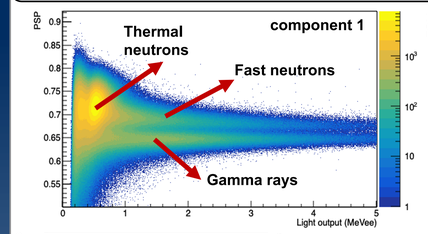


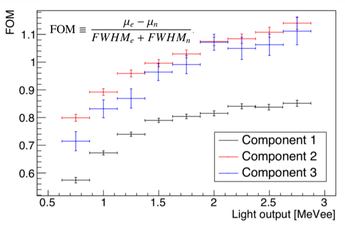


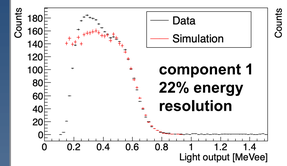
There are many efforts underway to develop aboveground near-field antineutrino detector

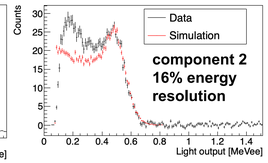


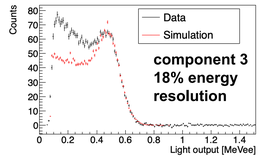
Pulse shape discrimination and energy resolution







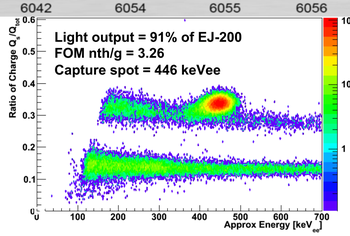


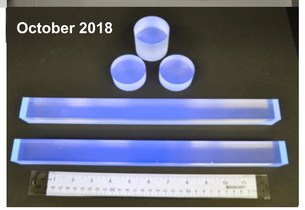


$\sqrt{E_A E_B} = \sqrt{(Ee^{-z/a_{eff}})(Ee^{z/a_{eff}})}$

Geant4-based simulation framework is validated by comparing the simulated responses to the measured responses

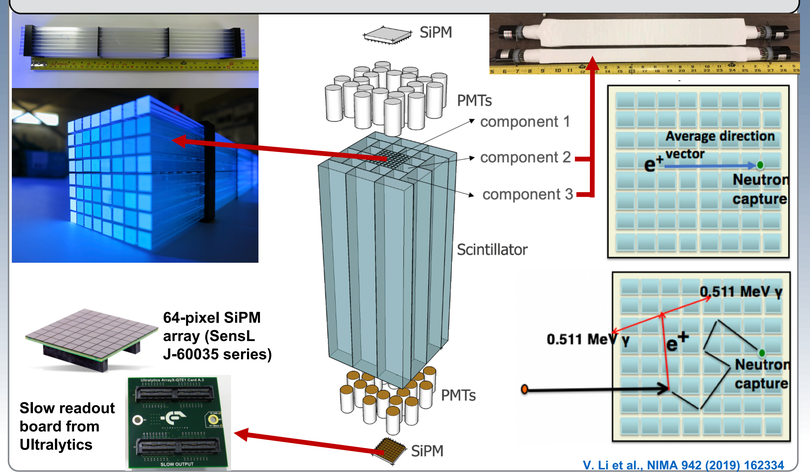
Status of Li-doped PSD plastic development





- PSD requires high (~30%) content of PPO
- Lithium compounds tend to absorb light at the polymer emission wavelengths
- Polymerization is exothermic (produces heat); therefore careful temperature control is required for larger volumes
- Can now make 40 cm long (1 liter) samples

SANDD (Segmented AntiNeutrino Directional Detector)



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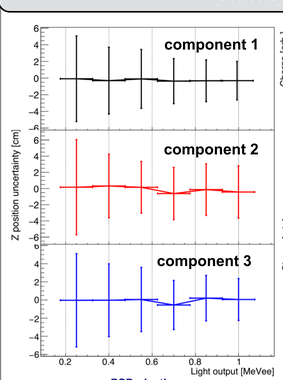
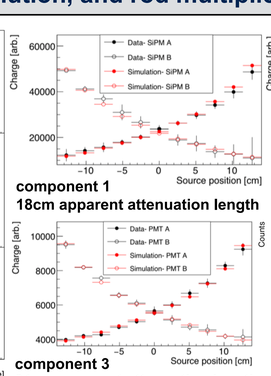
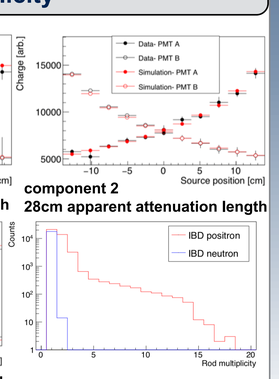
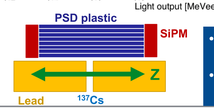
Apparent attenuation length, Z-position resolution, and rod multiplicity



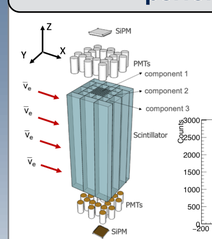




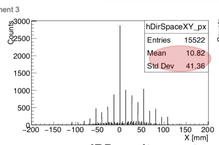


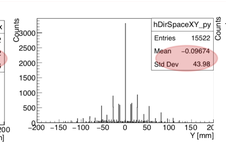
- Apparent attenuation length of the plastic material is comparable to the length of SANDD components
- Additional discrimination for/against neutron scattering can be achieved by analyzing the particle range from segment multiplicity

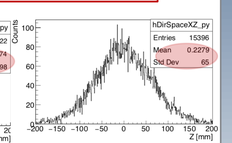
Simulated antineutrino detection efficiency, directional performance, and potential deployment sites



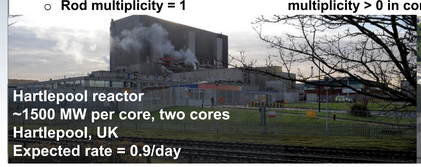
Average displacement = $\sqrt{(11\,mm)^2+(0.1\,mm)^2+(0.2\,mm)^2} = 11\,mm$
Average position spread = $\frac{1}{3}(41\,mm + 44\,mm + 65\,mm) = 50\,mm$
Angular spread = $\operatorname{atan}\left(\frac{50mm}{11mm\sqrt{100\ IBD\ events}}\right) = \pm 25°$ for 100 IBD event

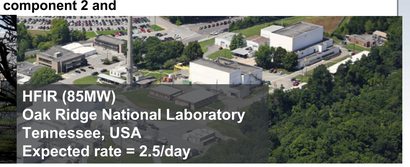






- **IBD neutron cuts:**
  - 0.37 MeV < E < 0.64 MeV
  - PSP, 1% particle misclassification probability
  - Rod multiplicity = 1
- **IBD positron cuts:**
  - 1 MeV < E < 7 MeV
  - PSP, 1% particle misclassification probability
  - Rod multiplicity > 1 in component 1 or Rod multiplicity > 0 in component 2 and
- Coincidence time < ~45 μs
- Antineutrino detection efficiency = ~19%





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