Small and Mobile AntiNeutrino Detectors for Safeguards?

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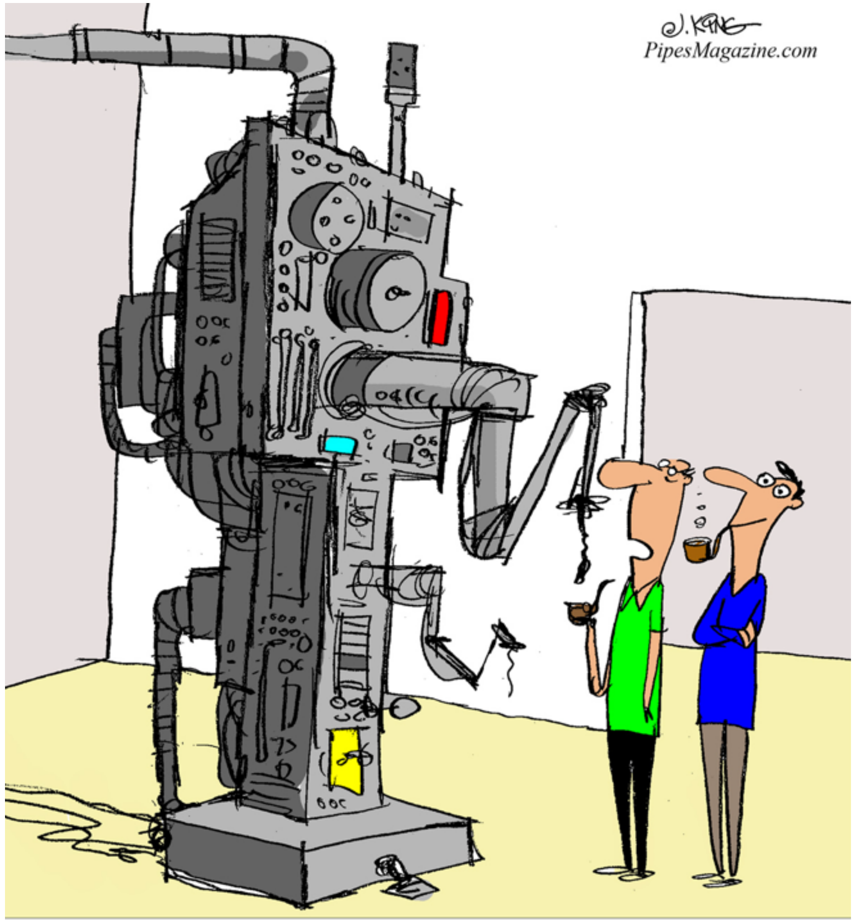
What is an antineutrino detector, and how do I know if I want one?

<u>These statements were once true. Less true now:</u>

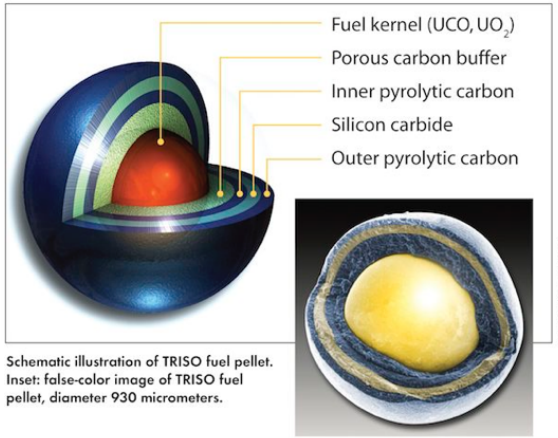
- A huge complex thing that costs a fortune and detects very few of these very difficult to detect particles.
- Requires an underground location
- Is going to cost the reactor operator time and money
- Is not needed – already safeguards verification techniques (item accountancy) are good enough



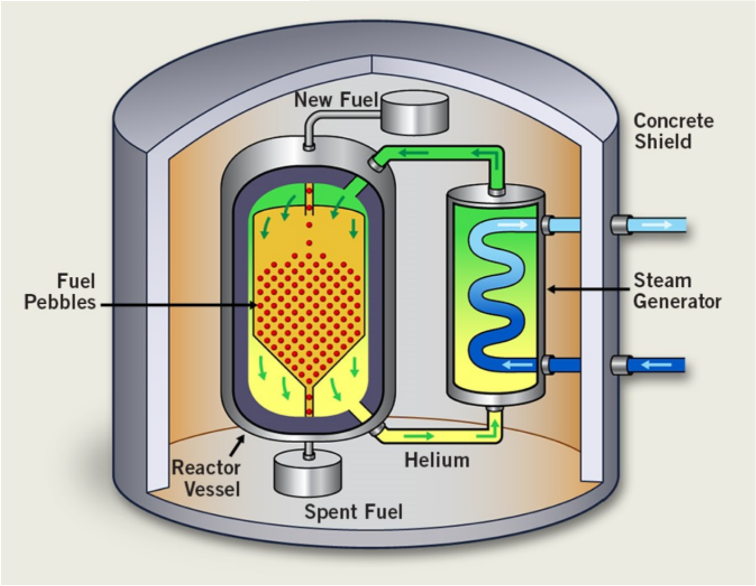
"It works great, but for a pipe cleaner, you may have over designed it."

New reactor designs:
May not be well suited for present day safeguards techniques

- May be safer, more efficient and mobile
- Reduced cost of entry
- Can envision a scenario where a single site can house many small reactors, accumulated over time. Reducing capital requirements



Schematic illustration of TRISO fuel pellet. Inset: false-color image of TRISO fuel pellet, diameter 930 micrometers.



<u>But:</u>

- Some new designs use small “pebbles” of fuel, some use multitudes of tiny (~mm) fuel units (triso). Some use liquid fuels
  - Item accountancy verification is difficult for these designs

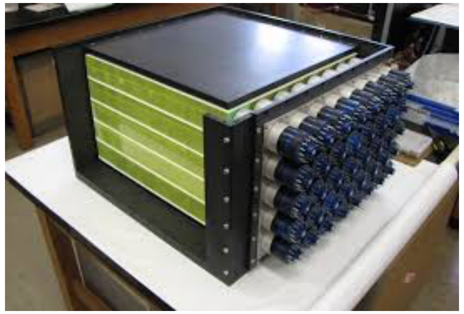
The Need

- Where item accountancy is <u>not</u> possible or difficult, real time fission monitoring might be useful.

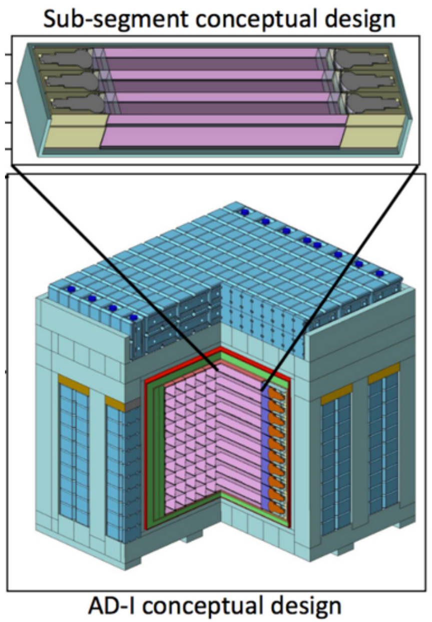
- Would a small autonomous detector about the size of a fridge be useful in this context?
  - Capable of measuring ON/OFF status and power level, integrated fuel burnup
  - Few hundred kg
  - Safe, no liquids, no high voltage
  - Little to no calibration required (set it and forget it)
  - High signal to background, even if operated above ground

Is technology up to producing such a detector?

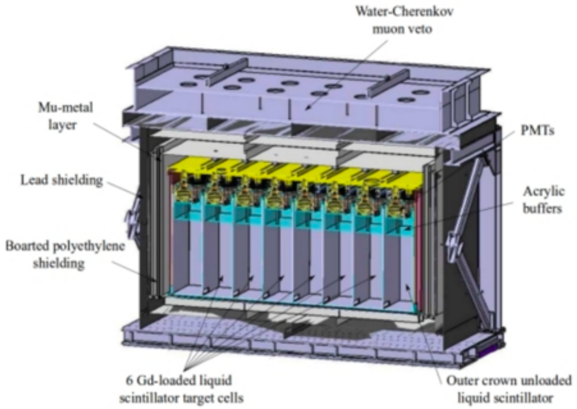
CHANDLER



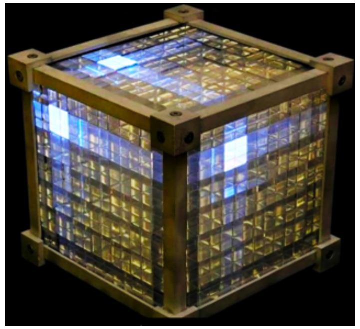
PROSPECT



STEREO



NULAT



<u>No. Technology is not where it needs to be yet</u>

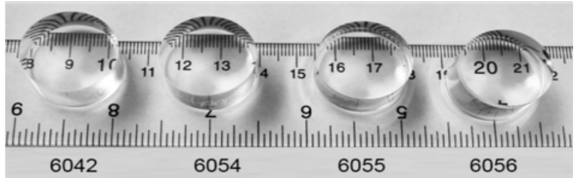
- Only liquids offer homogeneous volume PSD. However, liquid performance not yet stable and can be chemically aggressive
- Plastic scintillator detectors require nonhomogeneous wrapping neutron capture layers
- Both technologies have dead non scintillating volumes, which reduce efficiency, impact energy sensitivity
- Best detectors are still multi-ton, and complex. Need to build on site.

Immediate future – Some of the technology improvements on offer

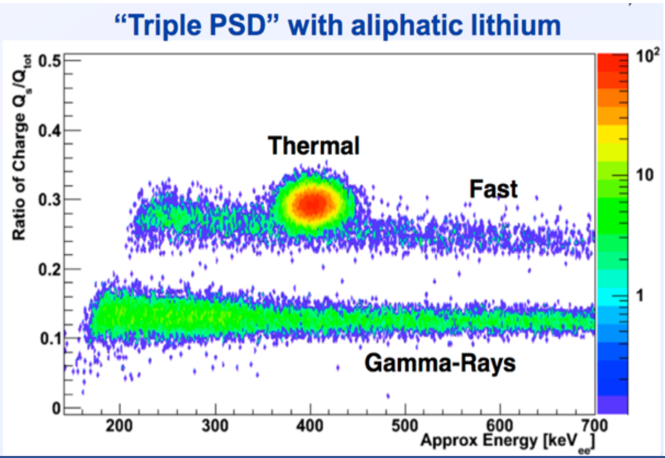
- ^{6}Li-doped PSD plastic
  - Homogeneous volumes (no dead material)
  - Smaller segments → better position resolution
- Solid state photodetection → high QE, smaller segments, no HV. <u>Need PSD readout</u>
- Miniaturized ASIC-based DAQs

<u>e.g. ^{6}Li-doped PSD plastic</u>

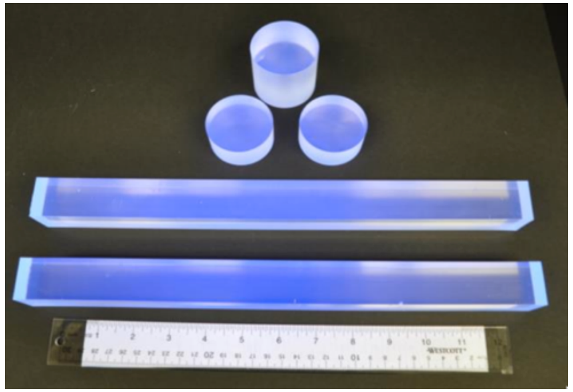
Note: Early samples were ~1” scale



Formulation with aliphatic lithium
Light Output = 80% of commercial plastic

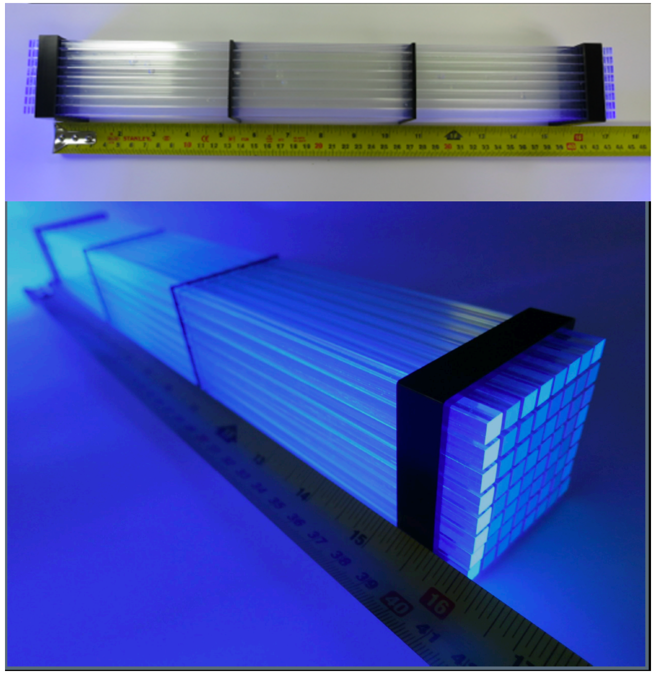


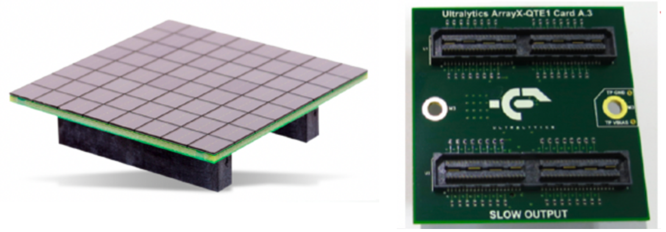
New ^{6}Li-doped PSD plastic
At ~40cm scales (1 liter)



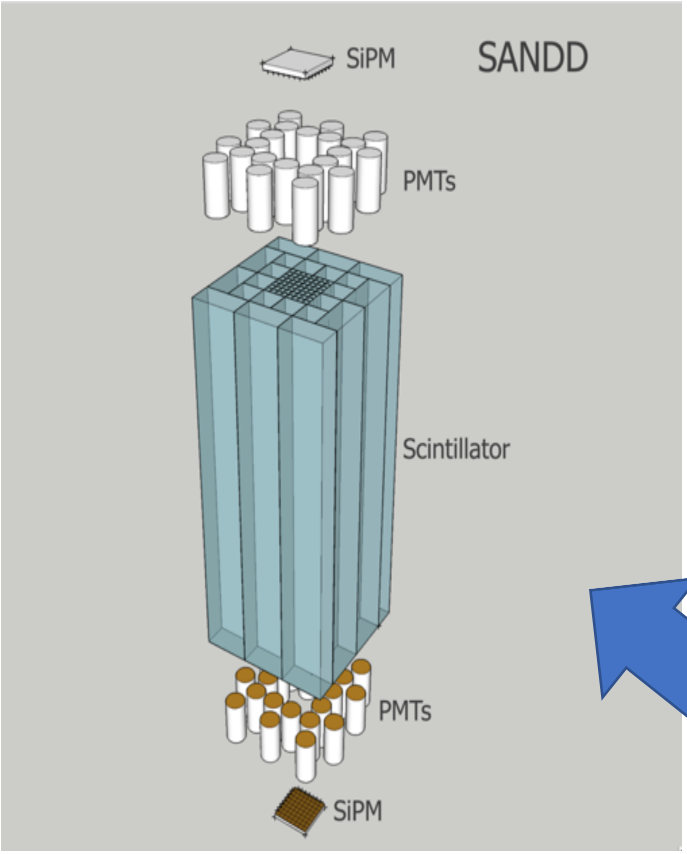
An Example:
SANDD – Segmented AntiNeutrino Directional Detector

Central module of SANDD





Solid state SiPM photon readout



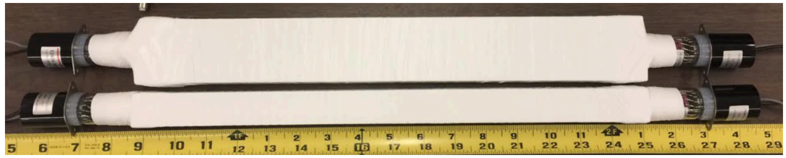
The aim of SANDD was to develop a detector sensitive to directionality.

To do this it must be sensitive to the kinematic features of IBD events with a minimum of dead (non scintillating) material

Kinematic features offer new potential signal to background improvements

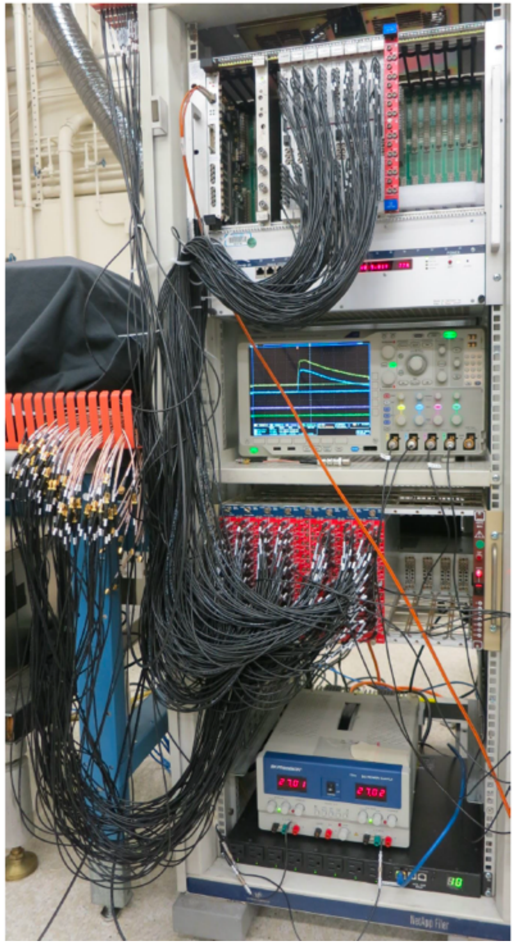
We hope to reach these goals via segmentation

Outer Segments

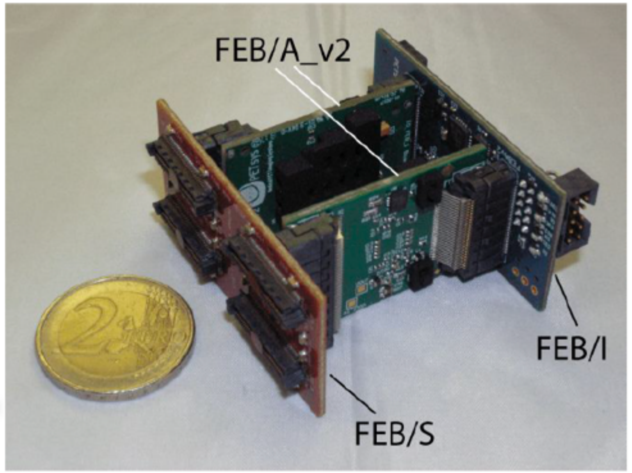


Modern trends in electronics
(This is an oversimplification, but still...)

SANDD electronics



Proposed iSANDD electronics
A neutron imager proposed by V. Li



1,000s of channels
100-ps timing
~5 mW/channel
<$20/channel

There is a commercial need for modern multi-channel fast timing PET scanners. This need has accelerated shrinking fast electronics in DAQ systems

This trend can be extended to antineutrino detection

Summary:

The future of reactor designs:

- Future directions in reactor technology are designed for reducing capital costs, safety, efficiency, mobility in mind. Not necessarily ideal for safeguards
- Safeguards techniques focused on item accountancy (accounting for assemblies) are not ideal for some of the new reactor technologies
- Are the lack of safeguards solutions holding these technologies back?
- Antineutrino detectors (in principle) offer real time verification of fissions and integrated burnup
- Antineutrino detectors must become smaller and simpler in order to fulfill a safeguards role

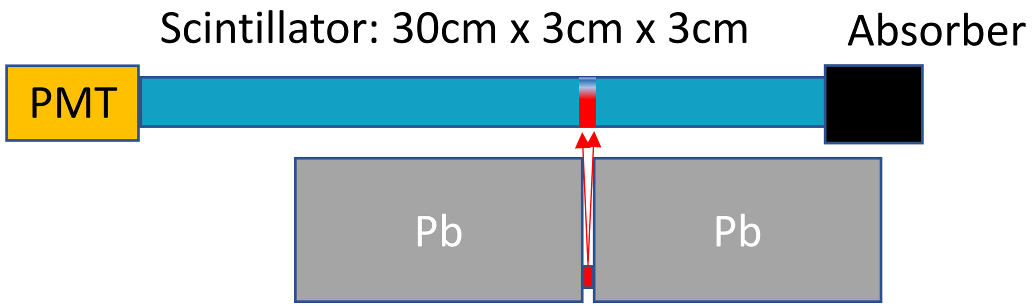
Technology Trends:

- Shrinking high speed electronics
- modern scintillators offer potential paths to smaller and simpler detectors with better light production, PSD and kinematic feature based particle ID (better signal to background)

SANDD Backups

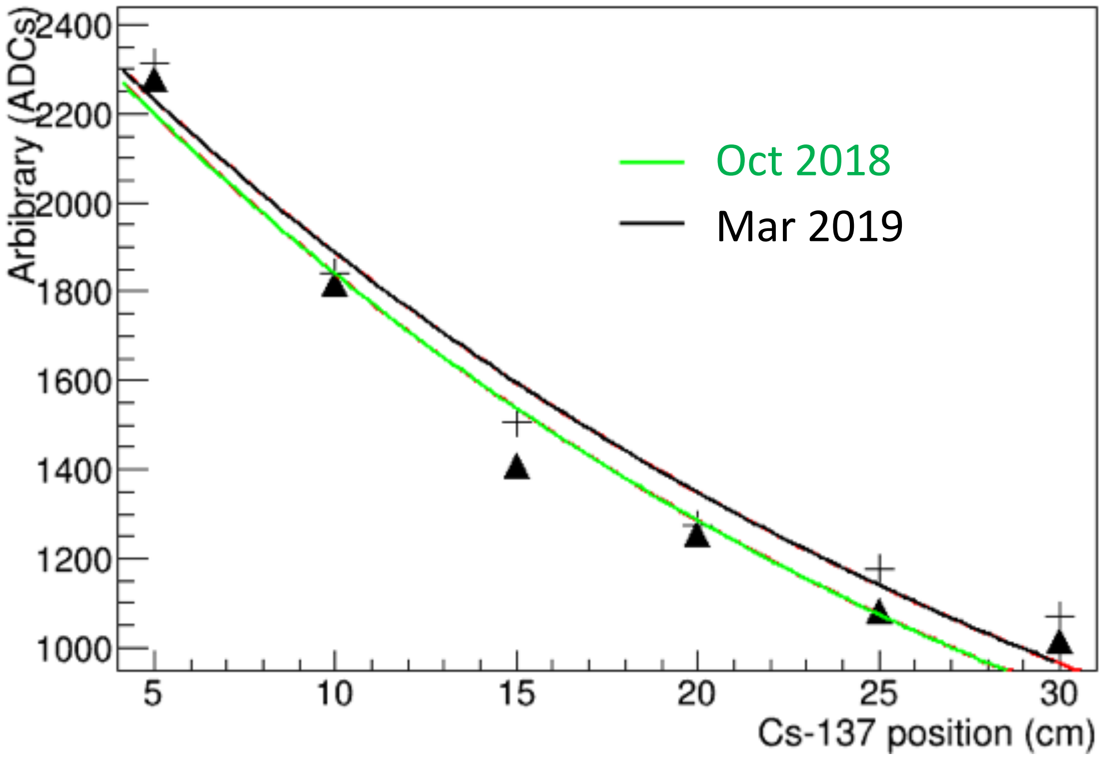
^{6}Li-doped plastic – Apparent attenuation length

Attenuation setup



- The apparent attenuation length includes effect of plastic transparency and reflectivity off walls.
- Apparent attenuation length → 25-27 cm
- Two samples stable performance for 6 months

- GEANT4 simulation is used to estimate the intrinsic attenuation length

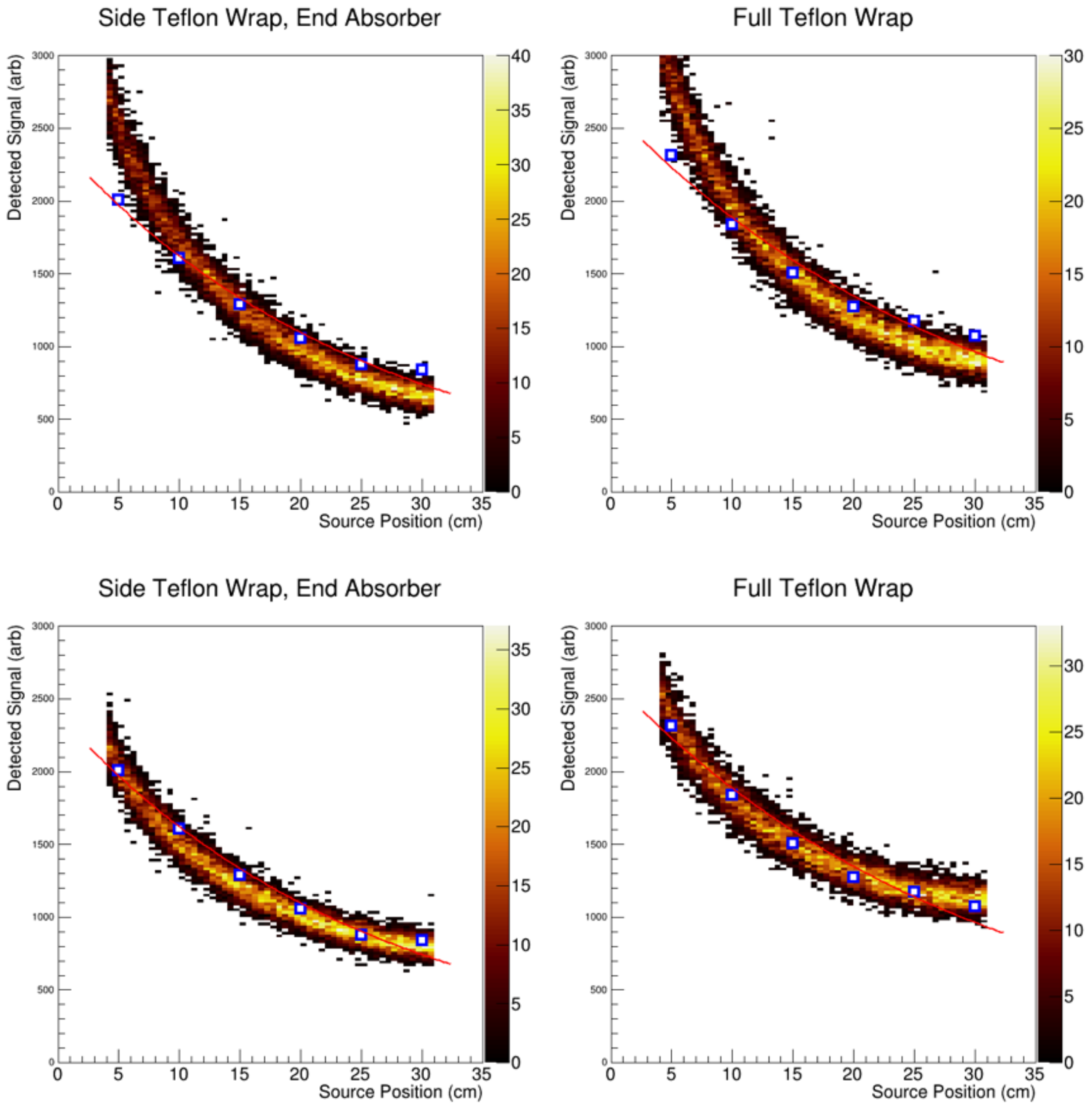


Note: single exponential is not a great fit here
Better is a double exponential – maybe some wavelength dependence? Or reflections?

Intrinsic attenuation length (Preliminary!)

GEANT4
30 cm
intrinsic

GEANT4
50 cm
intrinsic

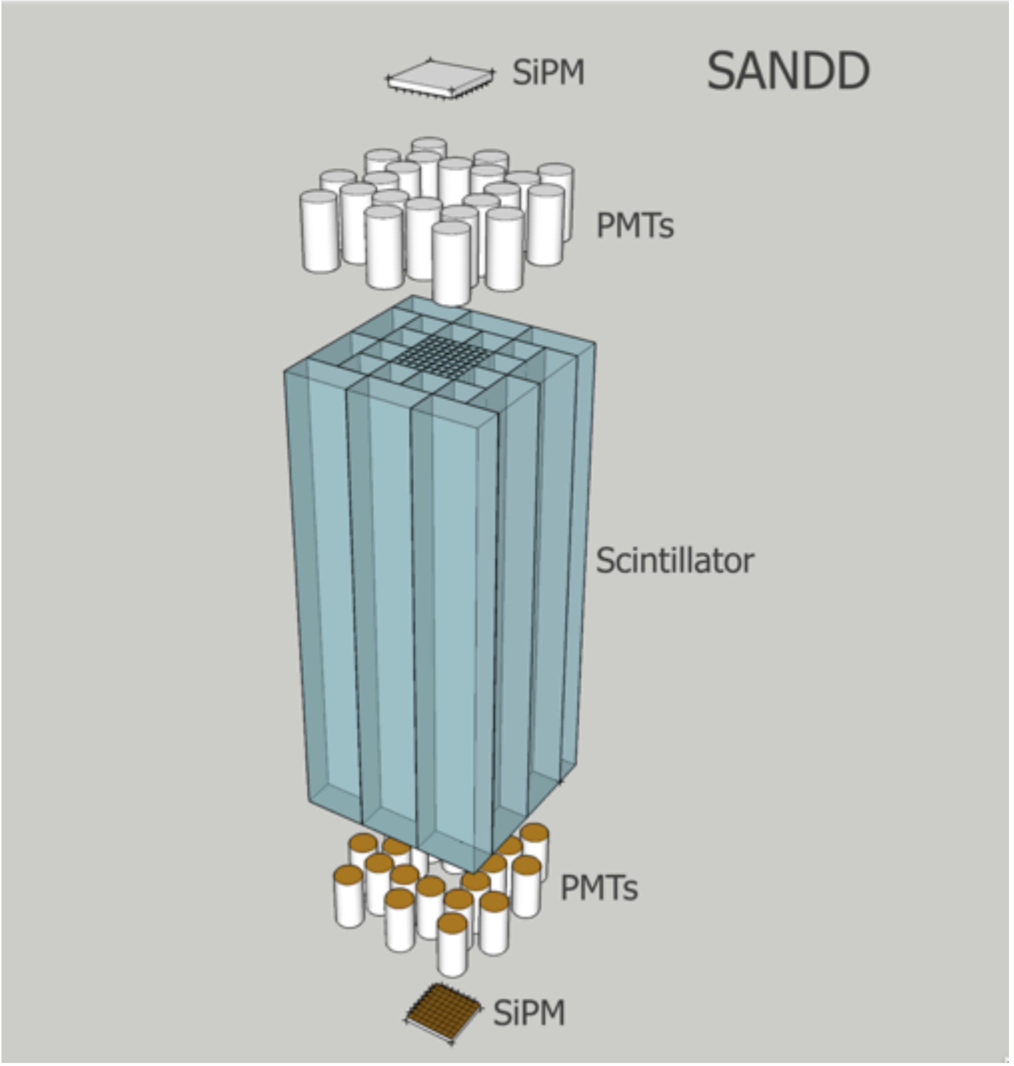


- We have the apparent attenuation length – includes intrinsic + reflectivity
- Attenuation results compared with GEANT4 simulation to get rough idea of the intrinsic attenuation length
- Best fit 50 cm
- <u>VERY preliminary</u>. We will be following up with more measurements soon. Grain of salt must be taken here….

- <u>Take away – intrinsic appears to be > 30 cm</u>

SANDD
(a small directionally sensitive detector prototype)

- full detector → central module surrounded by 1” x 1” ^{6}Li-doped segments, surrounded by 1” x 2” segments
- Total volume ~10 liters → ~4 ev/day at HIFR, ~1 ev/day at Boulby @ 50m
- IDB (positron and neutron capture efficiency ~40% to 50%)
- Inner detector placed inside ~30 → 40 cm boron doped poly shielding, surrounded by a muon veto.
- Whole detector (including shielding) should be large refrigerator size



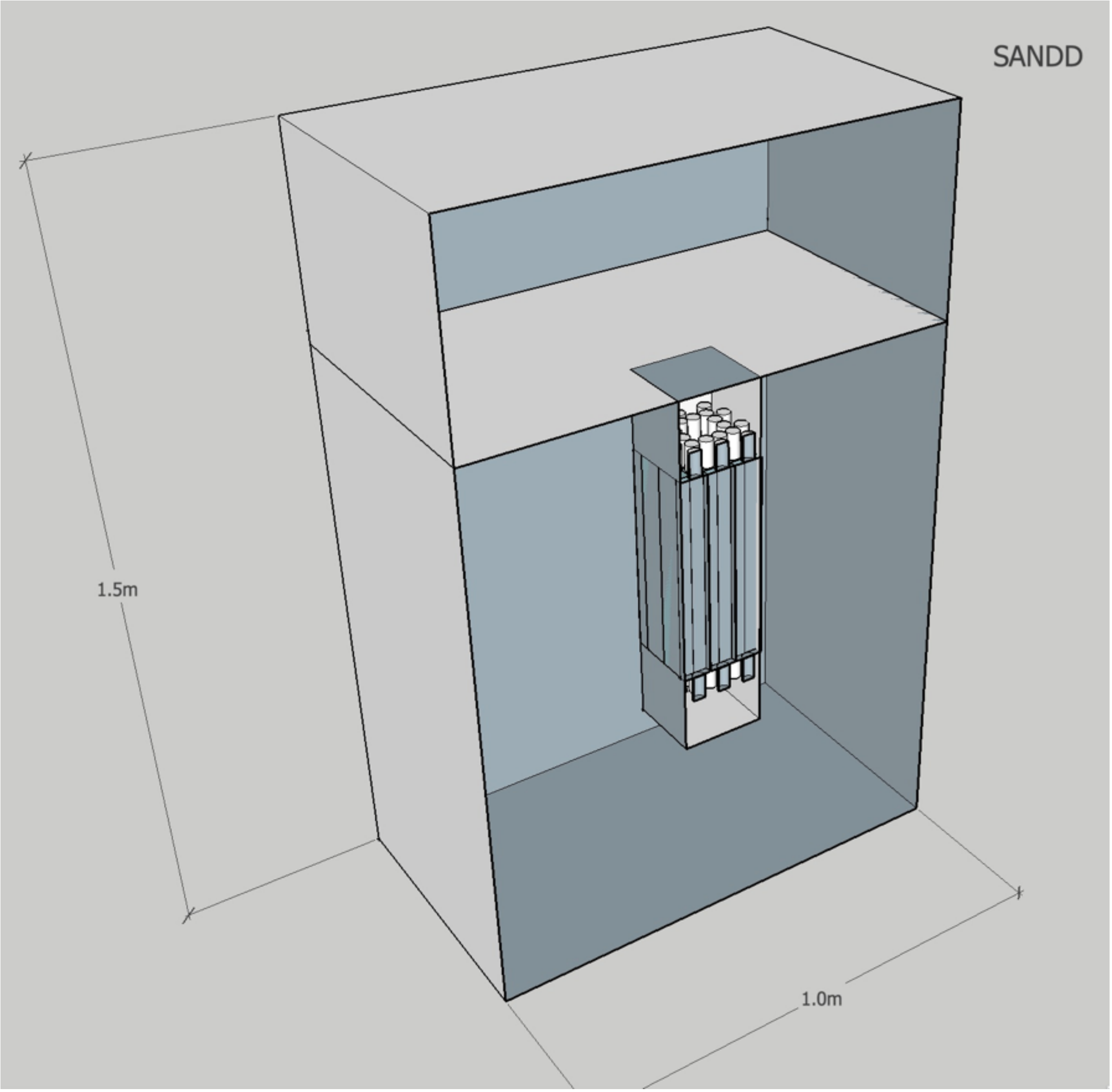
Deployment logistics
Materials/hazards

Hazards:

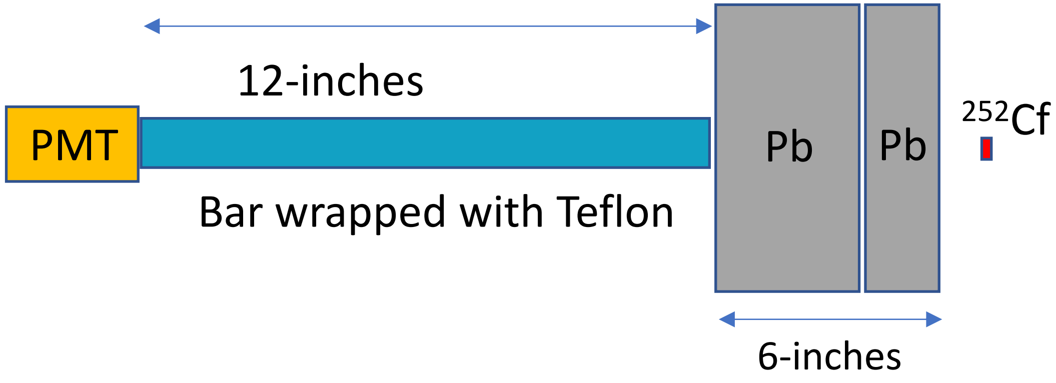
- Note: no liquids, no hazardous materials.
- HV – PMT high voltage only
- Materials
- 10 liters Li-doped plastic scintillator
- ~1.5 tonnes poly shielding
- 50 PMTs, 2 SiPMs
- 1 x rack containing 2 VME crates + 1 NIM

  (~1 kW)

Upright orientation shown

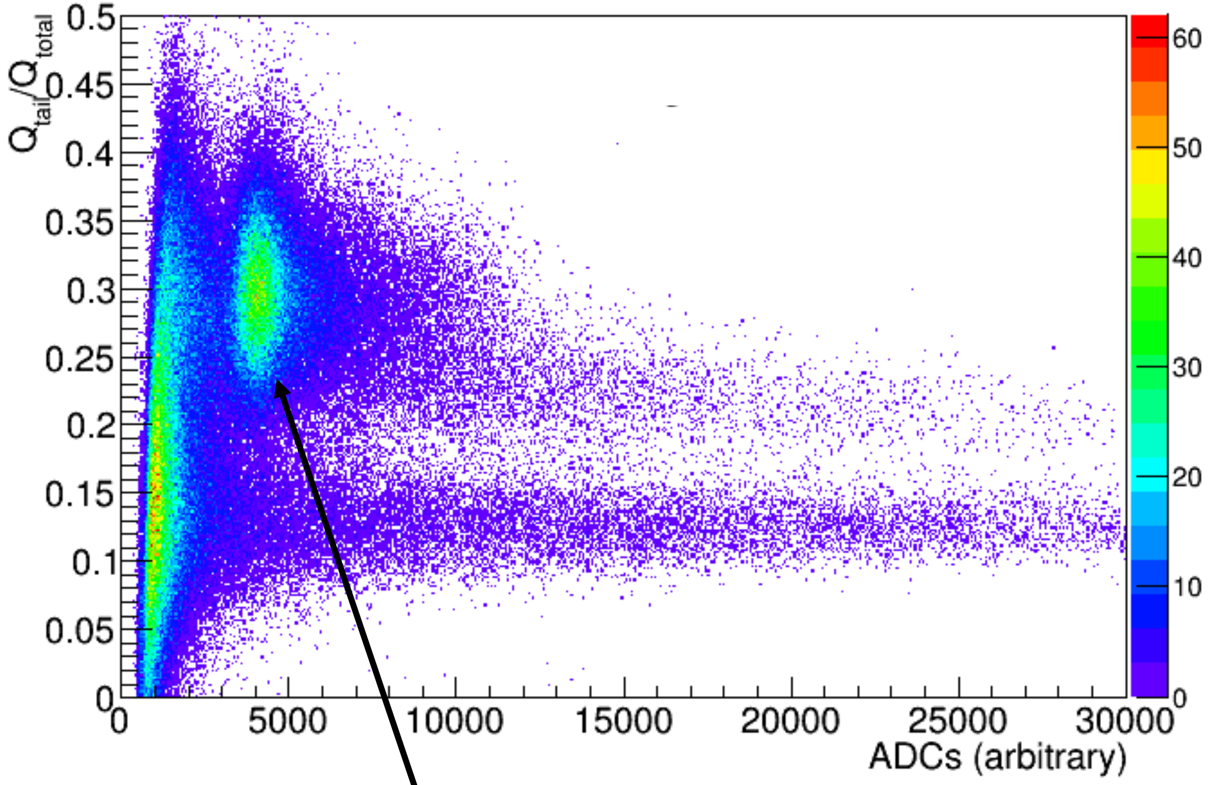


PSD tests of the 30cm long ^{6}Li-doped bar



Note:

- Single PMT, no energy calibration
- Captures mostly at end of bar → light must travel ~25 cm to the PMT.
- SANDD Detector will have a better setup with 2 PMTs (one each end)

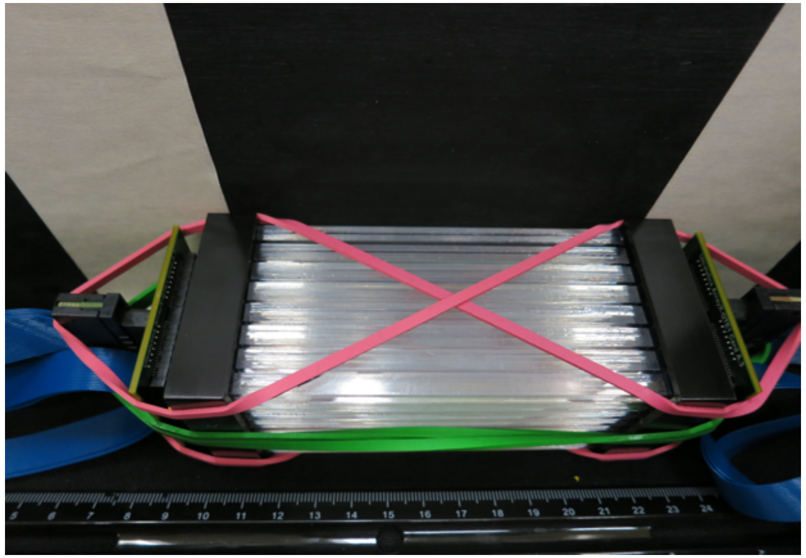


^{6}Li capture → ~400 keV$_{ee}$

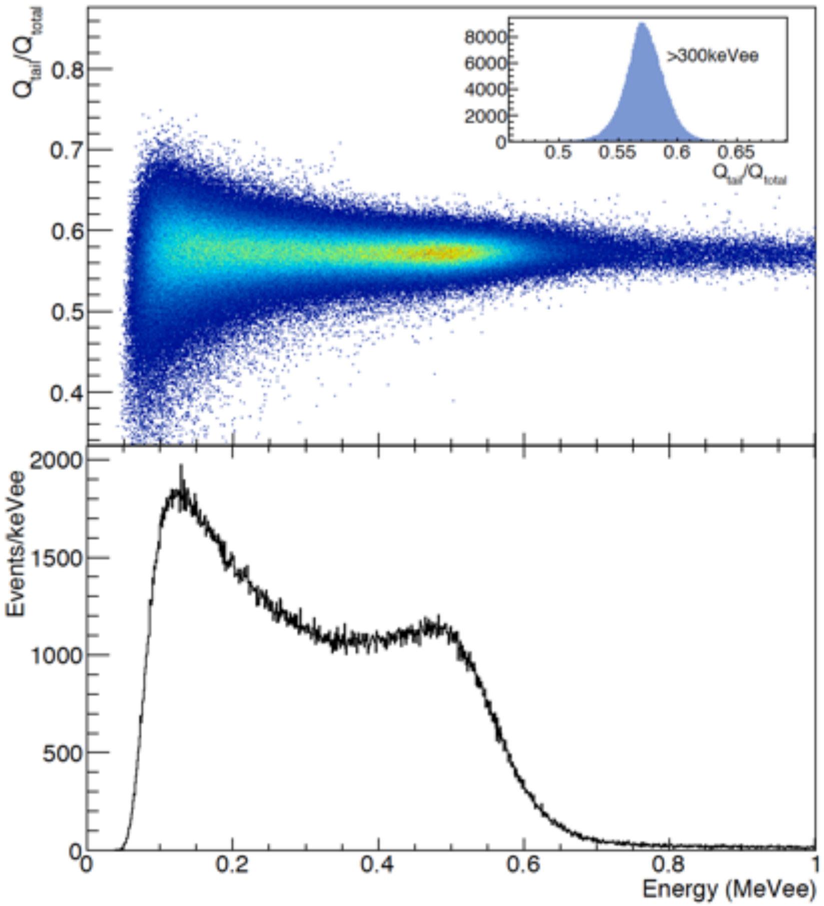
First prototype

Pulse Shape Sensitive Plastic plus 64 Channel SiPM Slow Signal Readout……

The Prototype

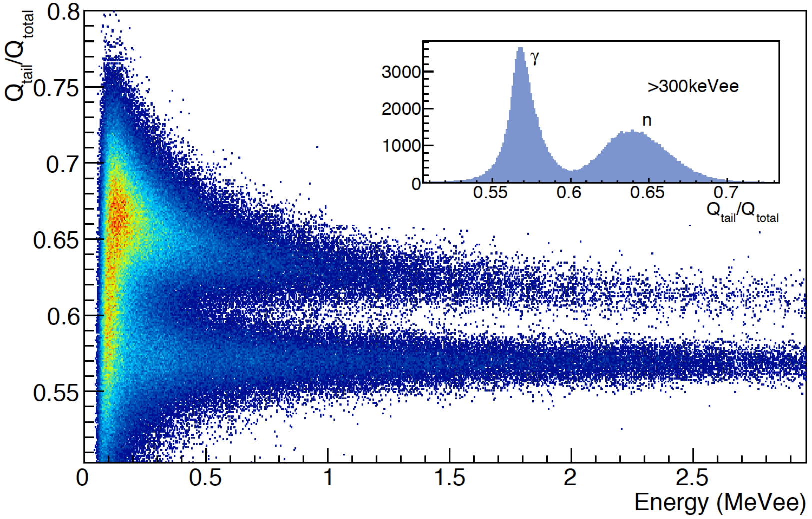


Cs-137 PSD and spectrum

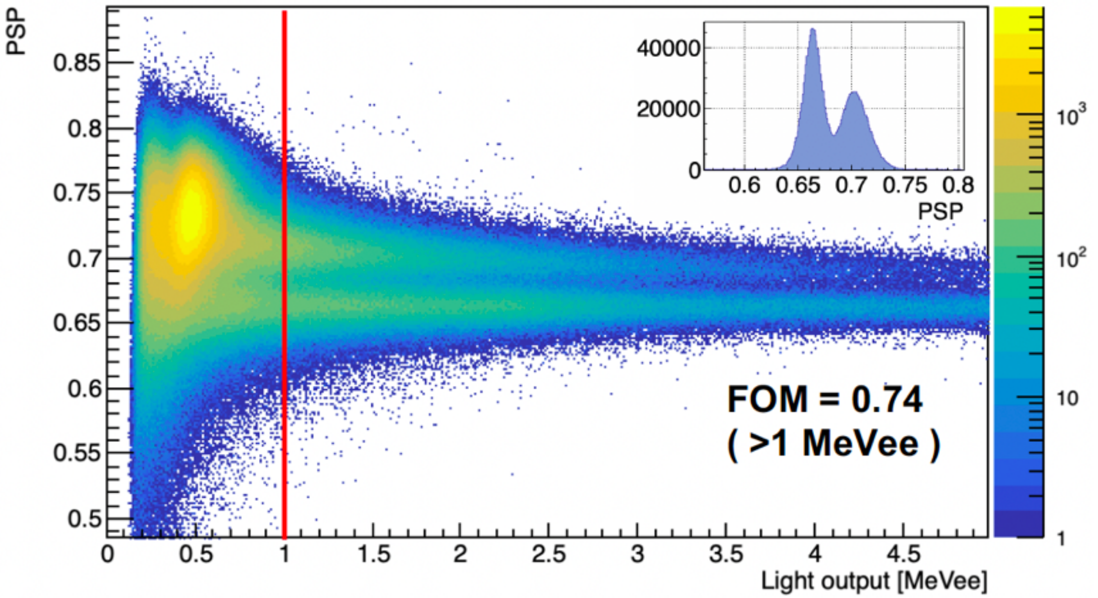


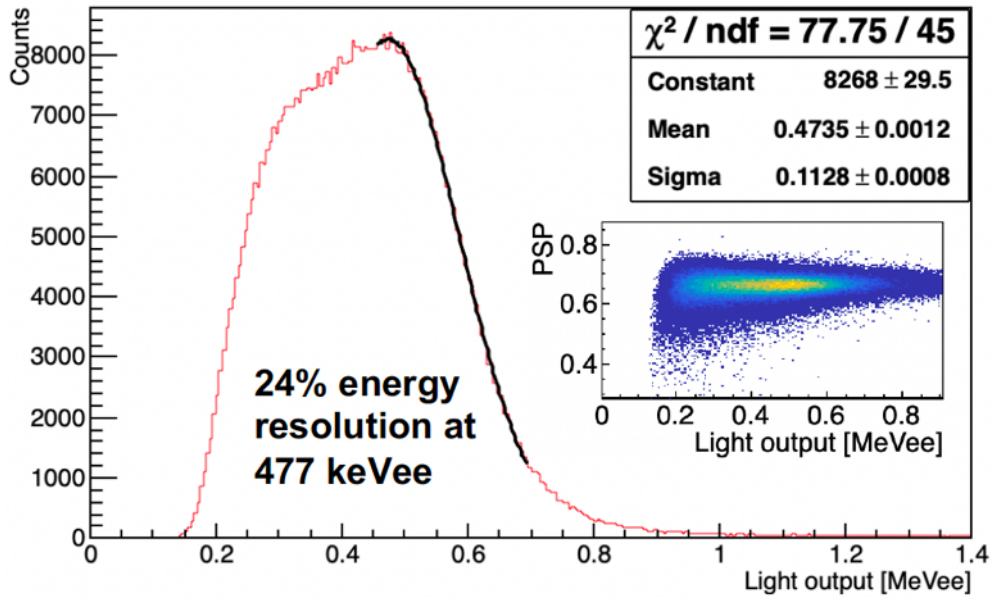
Cf-252

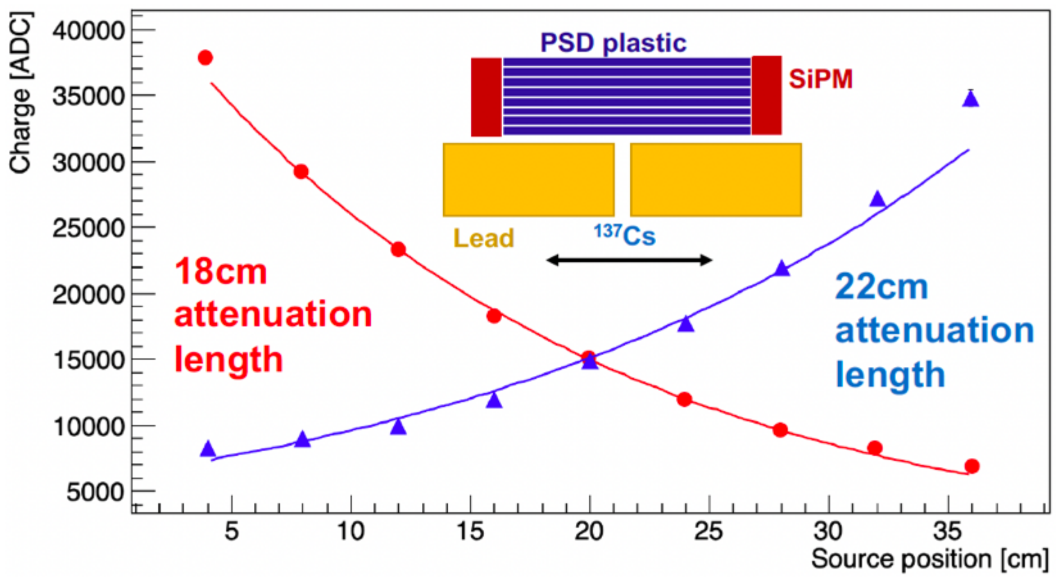
Pulse shape sensitivity with prototype

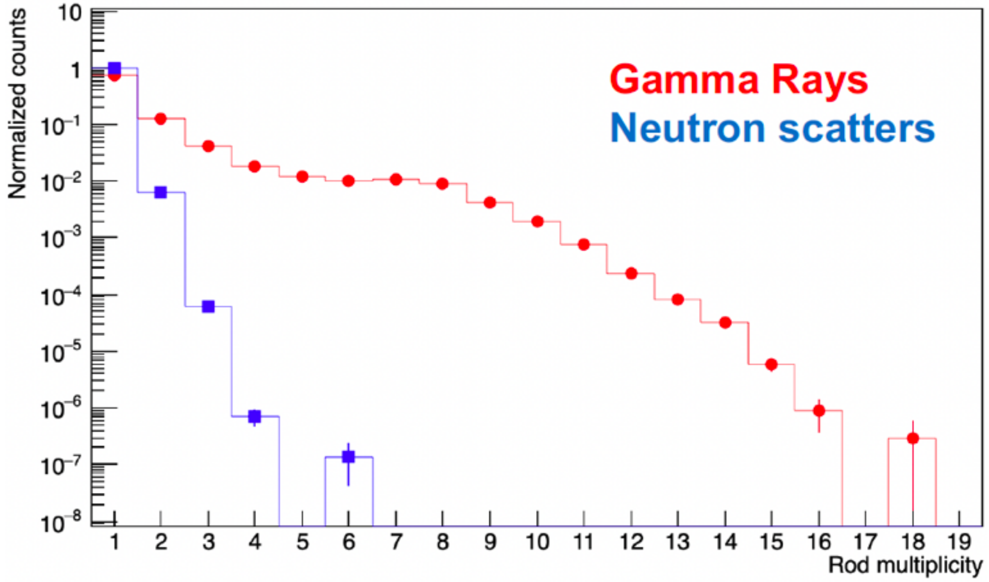


Characterization of detector performance

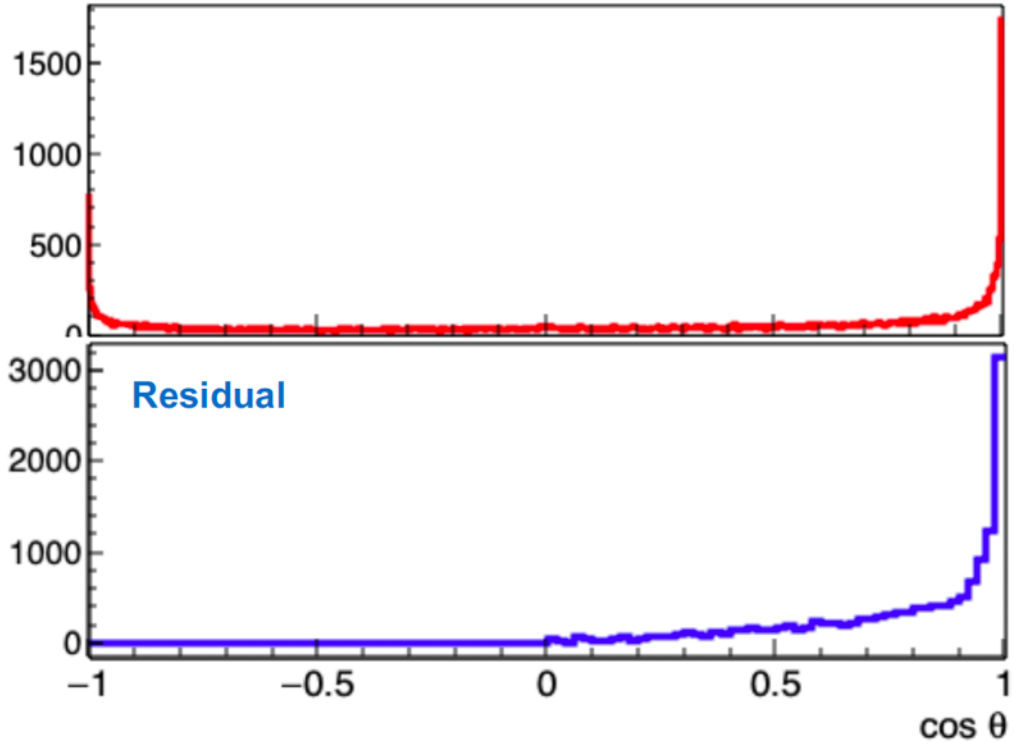








Simulated antineutrino directionality and IBD neutron capture time



- Positrons and neutrons are simulated uniformly in the scintillator volume
- Antineutrinos are generated with <1,0,0> direction