CHANDLER: New Technology for Short-Baseline Reactor Experiments

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Keys to a Short-Baseline Reactor Experiment

1. Sensitivity to the higher Δm^2 range (2 eV^2 and above) requires a compact reactor core and good energy resolution.

2. Relatively small detectors require careful consideration of isotope used for neutron capture and tagging.

3. Background is important, needs to be characterized

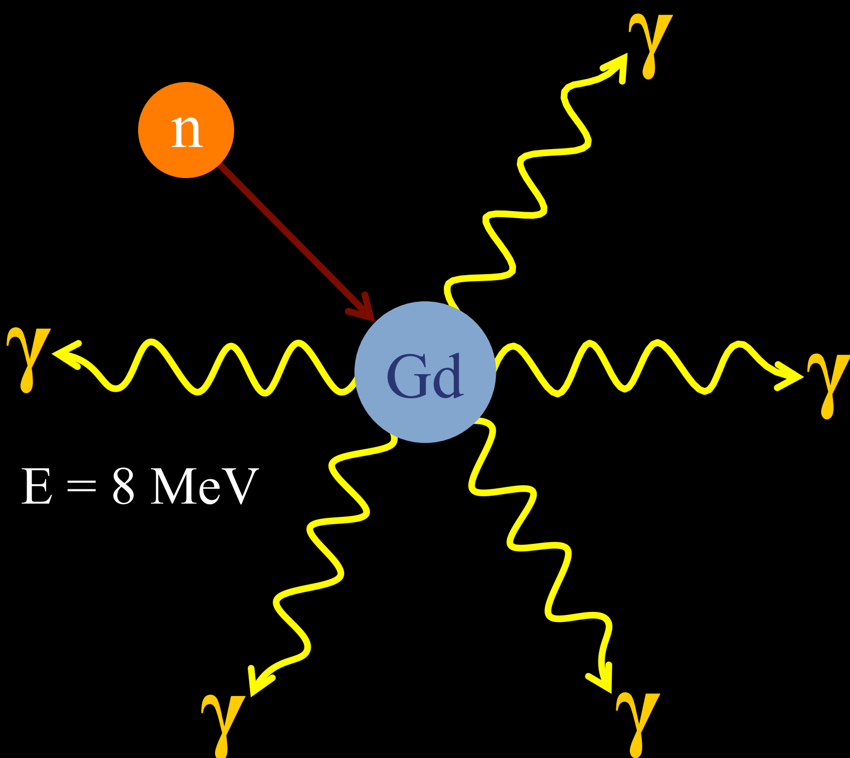
4. Detector should be able to work on the surface or with very small overburden

5. Detector should be portable, cannot use tons of shielding material

Neutron Capture Options

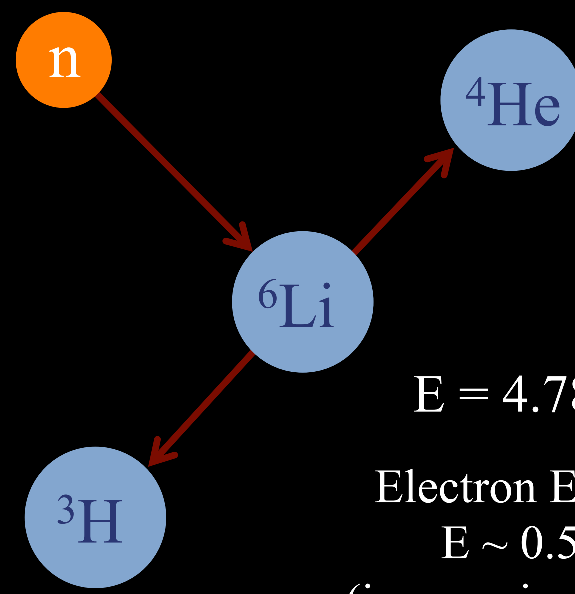
- Not the same as in a reactor experiment
- Similar backgrounds but different overburden
- Detector dimensions and event containments are very different

Neutron Capture on Gadolinium



Poorly contained in small detectors

Neutron Capture on Lithium-6



E = 4.78 MeV

Electron Equivalent
E ~ 0.5 MeV
(in organic scintillator)

Contained in a few micrometers

Backgrounds

Backgrounds, particularly from cosmic induced neutrons are the most significant challenge.

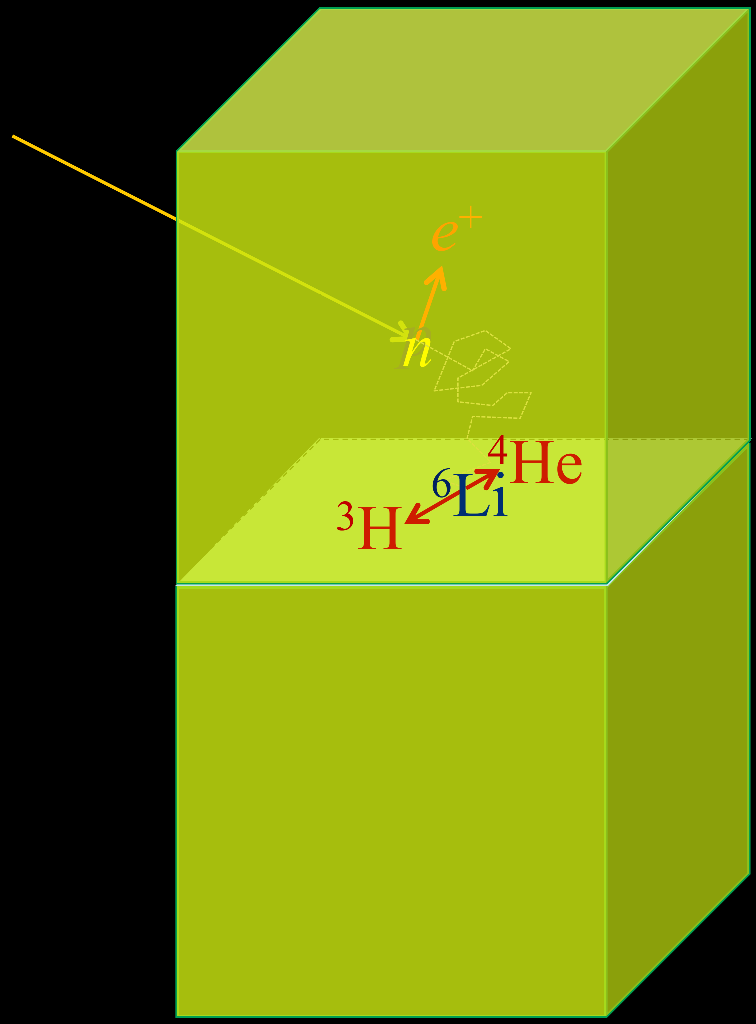
Difficult to shield muons, and shielding will contribute to enhance the number of neutrons produce by muons.

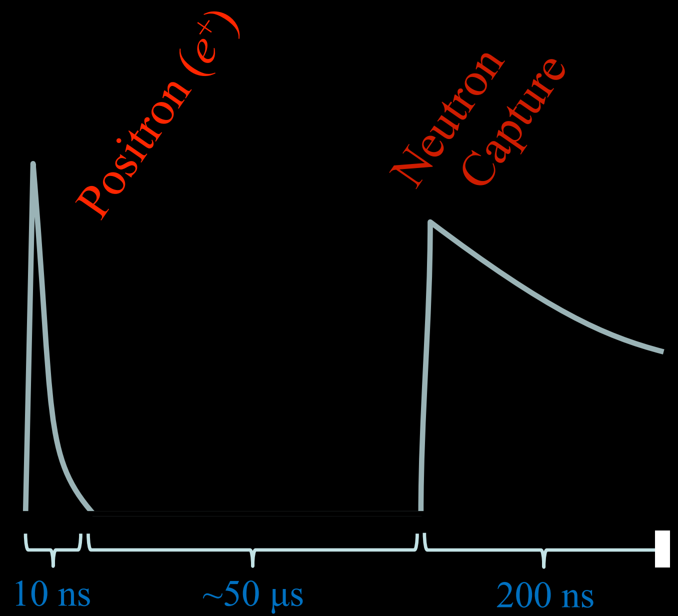
Multiple neutrons in particular will constitute a problem. Need to measure this on reactor site with a sizable detector.

Random coincident backgrounds is also a problem but can be mitigated by:

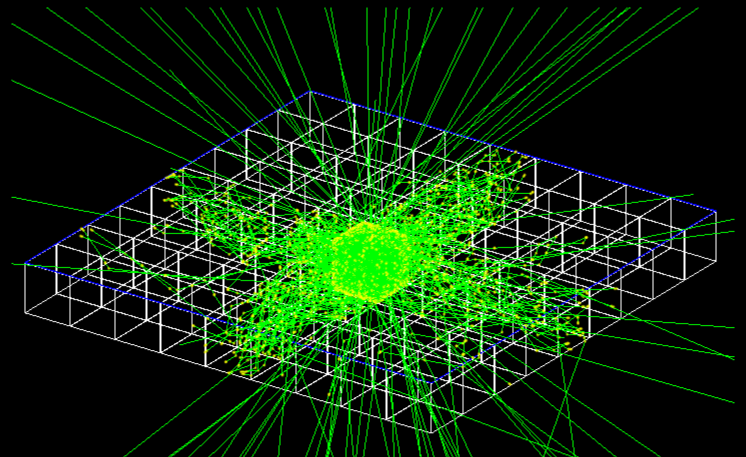
a. Reducing background rates (shielding)
b. Improving signal pattern recognition, and
c. Tightening coincidence criteria

The CHANDLER Detector





Light is transported by total-internal-reflection

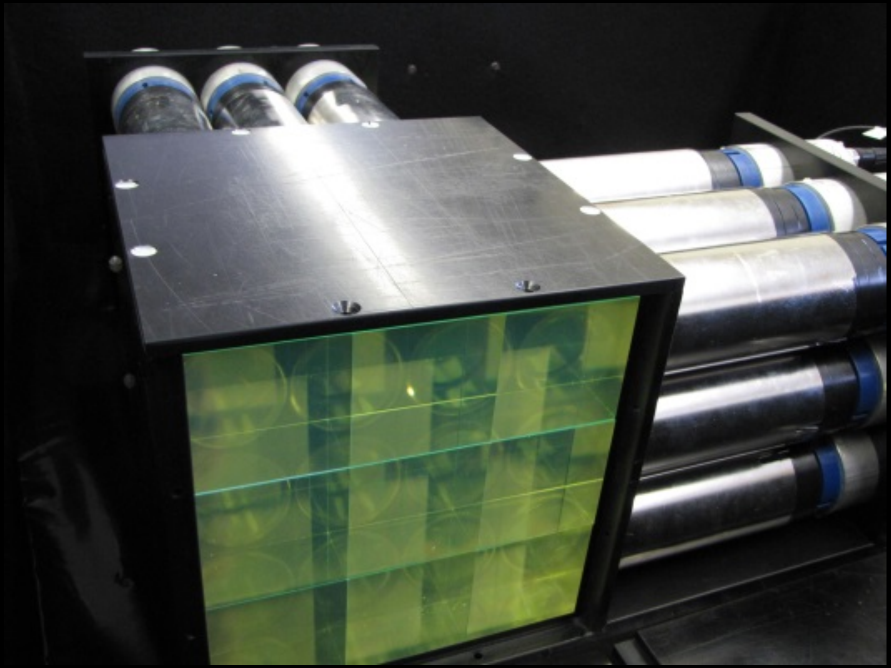


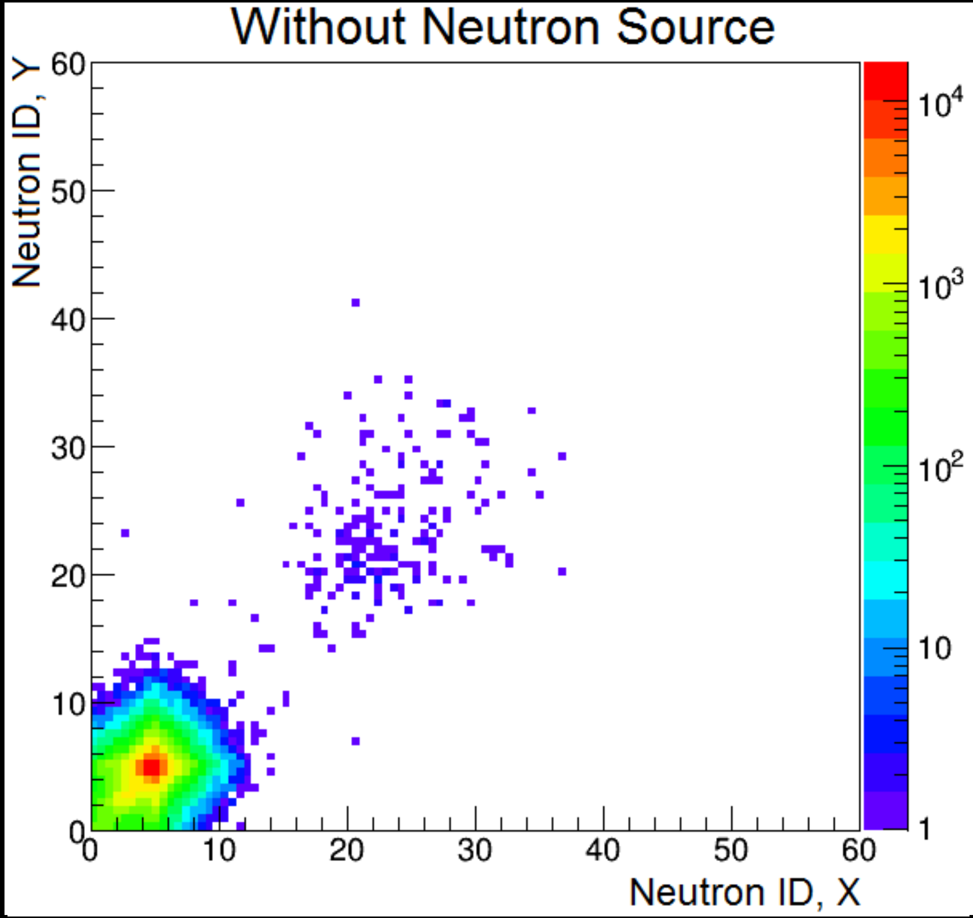
Photon Ray Tracing in GEANT4

Neutron Capture in MicroCHANDLER

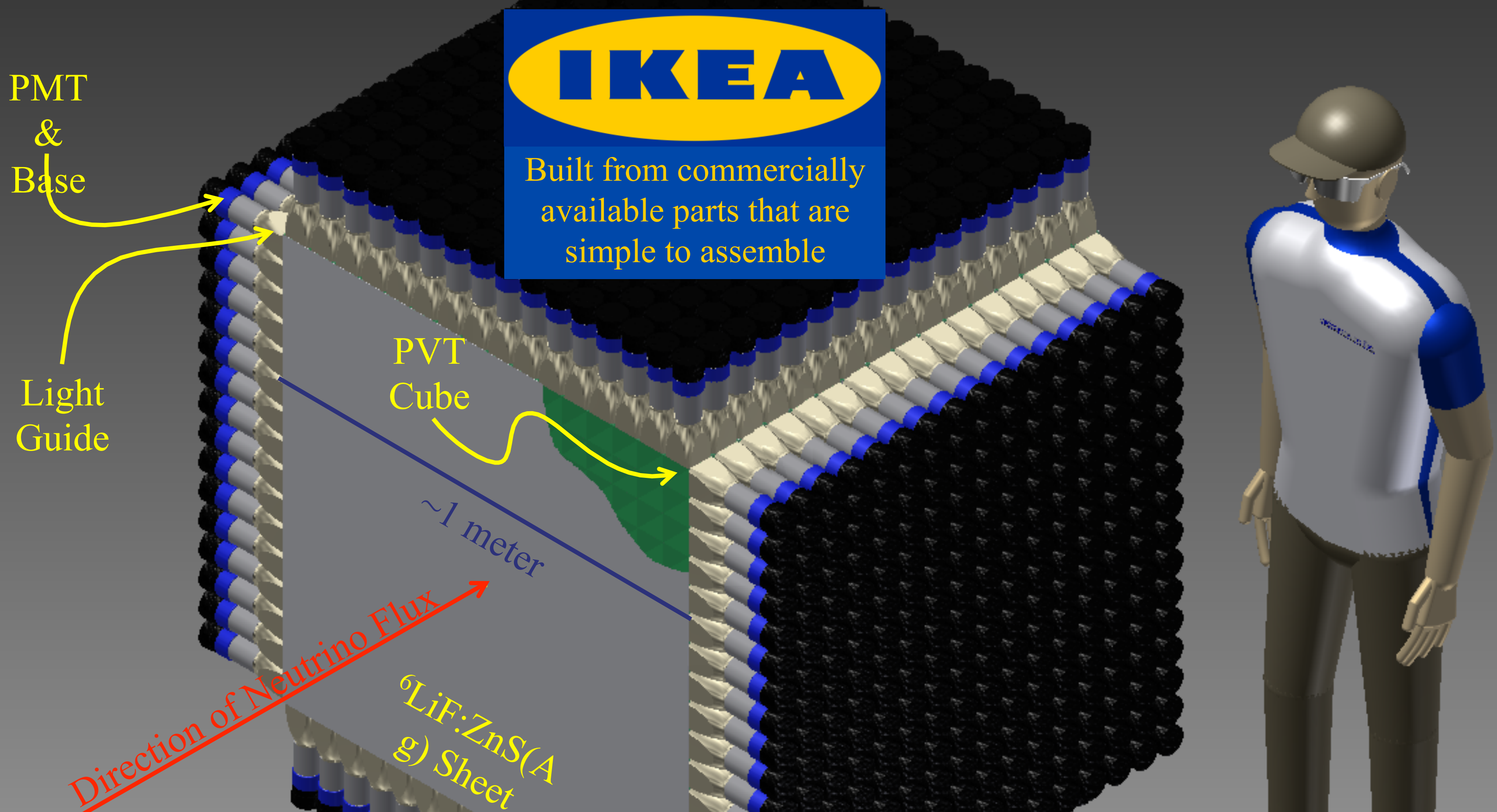
The 18-channel MicroCHANDLER prototype is idea for testing neutron tagging.

For each hit cell, we compute the neutron ID variable as the ratio of the integral of the pulse to the pulse peak value.





CHANDLER

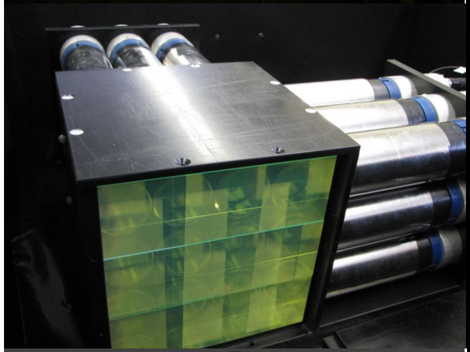


VTIP 15-048 | CONFIRMATION OF RECEIPT | NEW IP DISCLOSURE

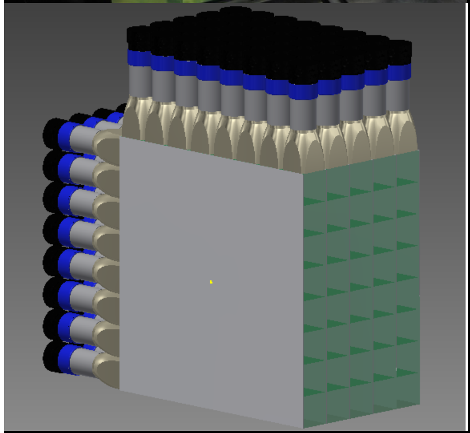
IP Disclosure: VTIP 15-048
Disclosure Date: November 12, 2014
Title: Antineutrino Dection Based on Heterogeneous Scintillation Lattice
Inventors: Patrick Huber; Jonathan Link; Camillo Mariani
VTIP Manager: Mike Miller | (540) 443-9228 | mmiller@vtip.org

Research and Development Effort

Cube String Studies have been used to study light production, light collection, light attenuation, energy resolution and wavelength shifter concentration.



MicroCHANDLER is a 3×3×3 prototype which we are using to test our full electronics chain, develop the data acquisition system, study neutron capture identification and measure background rates.



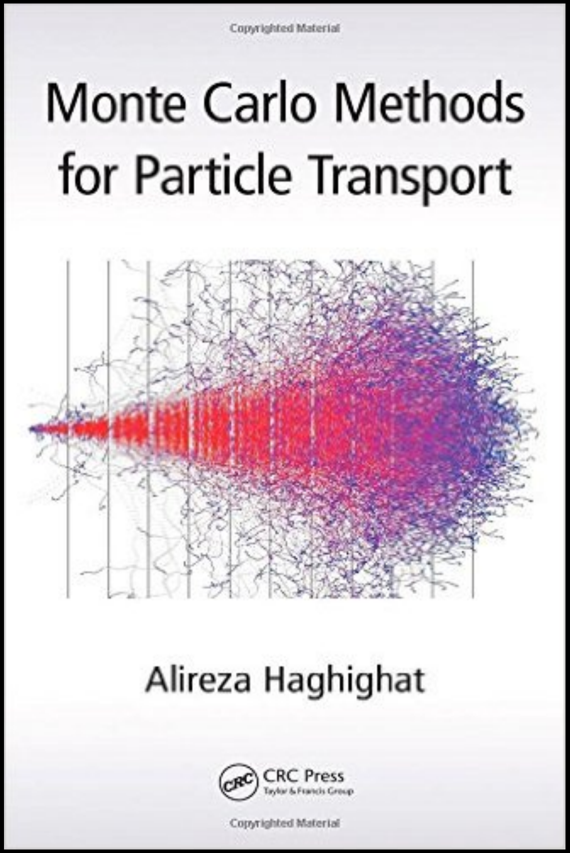
MiniCHANDLER is a **fully funded** systems test (8×8×5) which is currently under construction and will be deployed at a commercial nuclear power plant. It will be used to test any remaining options and optimizations. It will be operational by winter 2016.

Detector Simulation

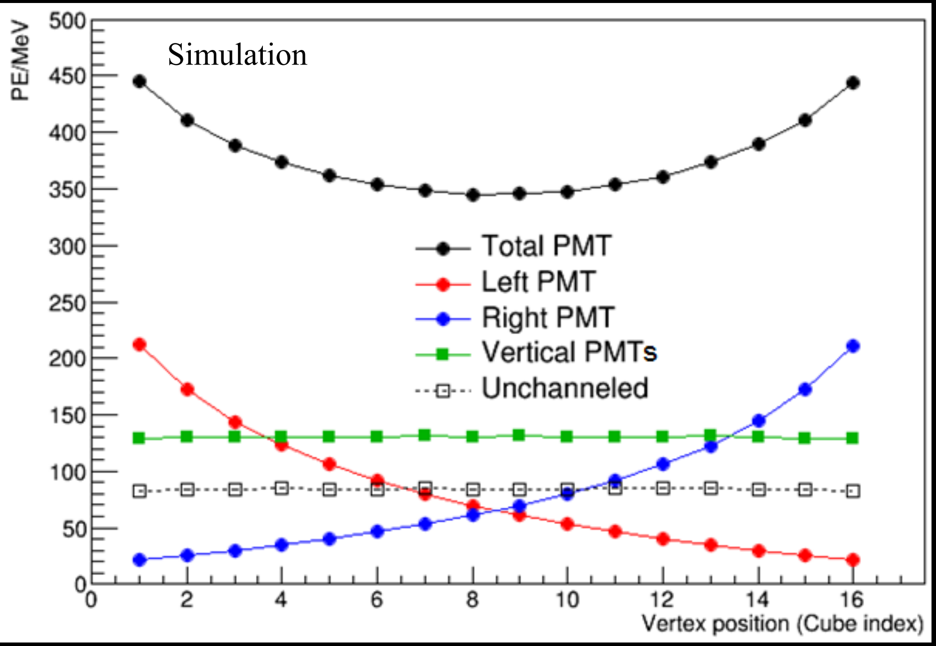
We have a full-scale GEANT4 simulation, developed by Jaewon Park, which we are using to study light transport and collection, and neutron transport and capture.

We also have a full-scale MCNP6 simulation, developed by William Walters and Alireza Haghighat, which we are using to study neutron transport and capture (see talk from Ali).

The neutron transport models in GEANT4 and MCNP6 are in very good agreement.



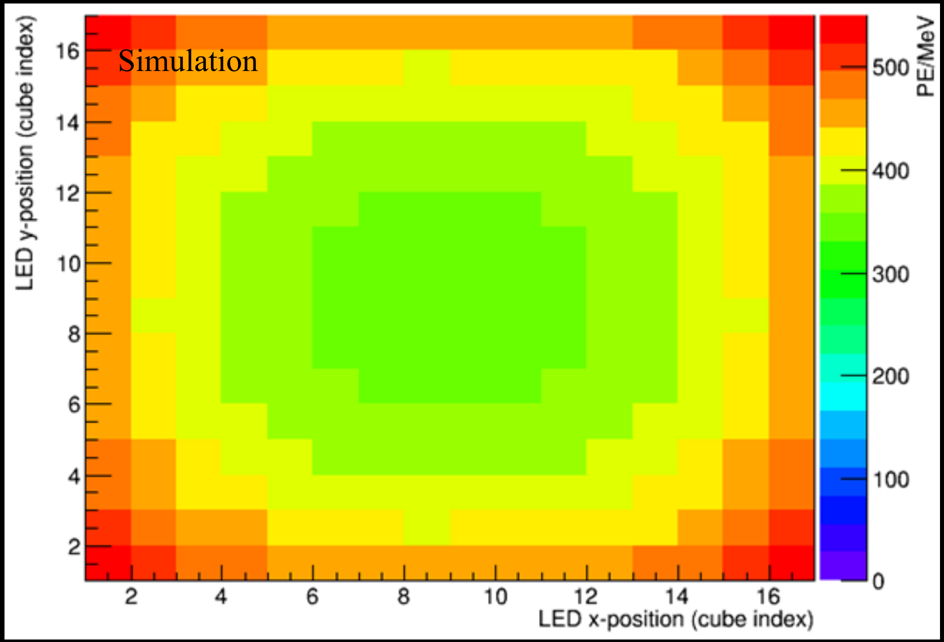
GEANT4: Detector Response vs. Cube Position



Most of the light is collected in the 4 PMTs in the TIR channel directions.

About 20% of light is unchanneled, with the largest share in the adjacent PMTs.

Collected light falls off as you move away from the PMT.

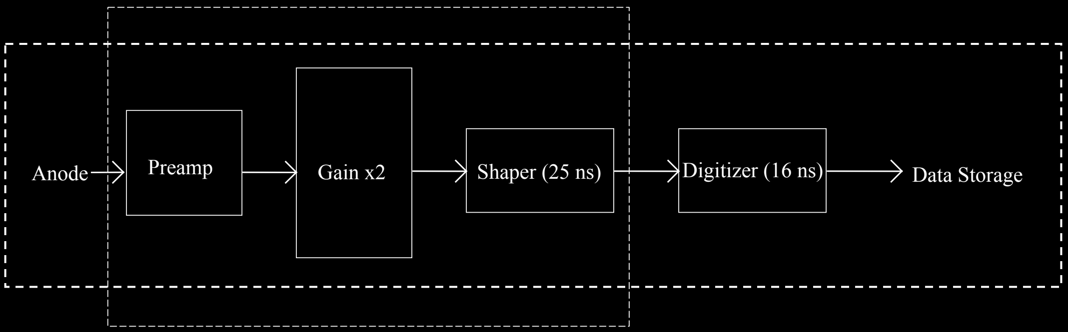


The largest excursion from the mean is in the corner cells.

The conversion to p.e./MeV assumes light guides, and a PMT with quantum efficiency of 25%.

Electronics and DAQ

VME Shaper module 16 ch

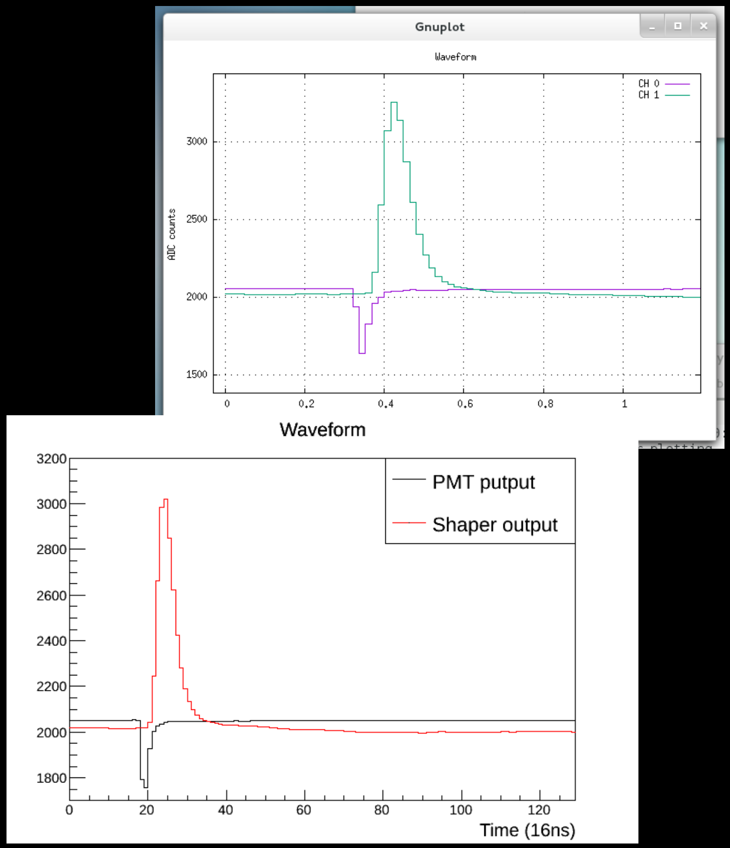


CHANDLER Readout Electronics

- 2 inch high quantum efficiency PMT (R6231-100)
- VME 16 ch - Analog Pre-amp and shaper circuit (VT+CREMAT)
- VME 64 ch, 16 ns, 12 bit digitizer card (CAEN V1740)

Readout Software

- VT customized readout system (based on CAEN WaveDump)
- Each digitizer connected by dedicated single optical link to the optical card in the computer
- Each link speed up to 80 MB/s
- Multi-Board readout via parallel processing
    - Each DAQ processes run on a separate core
- DAQ reads out each link as a separate data stream via optical card
- Data streams are combined and sorted to identify events via event builder process running on raw data

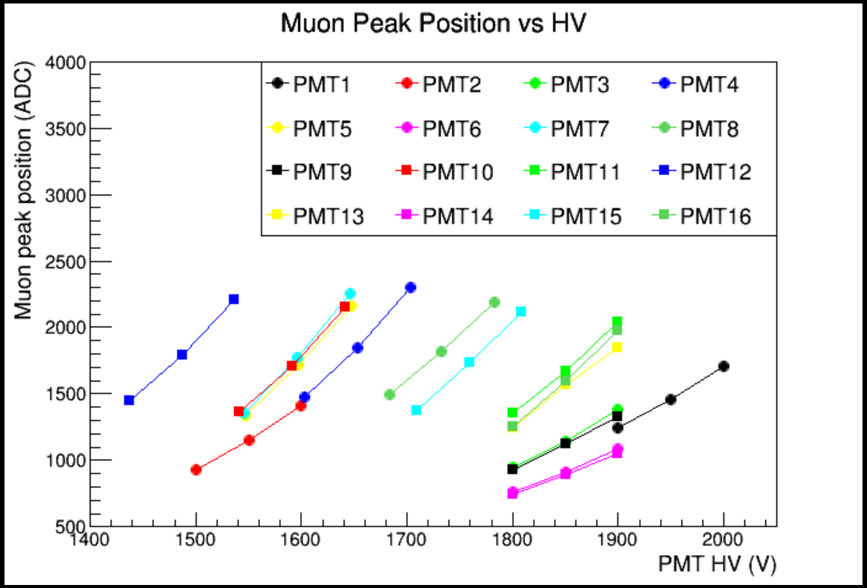


HV system

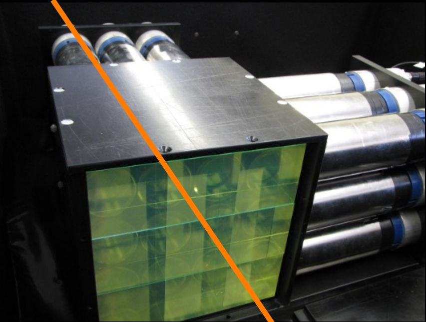
High Voltage

- CAEN SY527 HV Mainframe
- 3-5 CAEN A734N HV cards
- HV Software developed at VT

Possibility to fine control each HV channel
good for calibration and monitoring

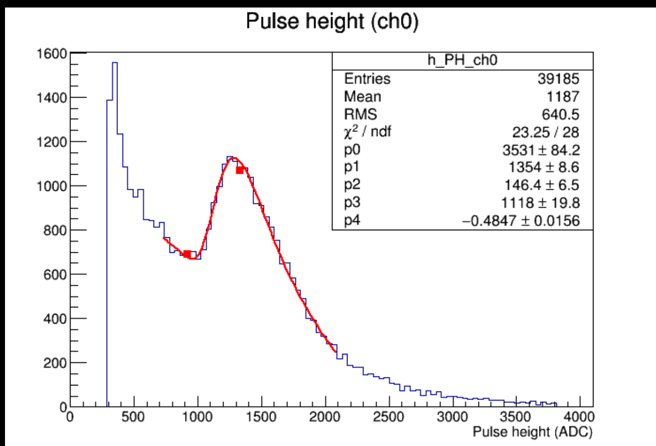


Calibration scheme

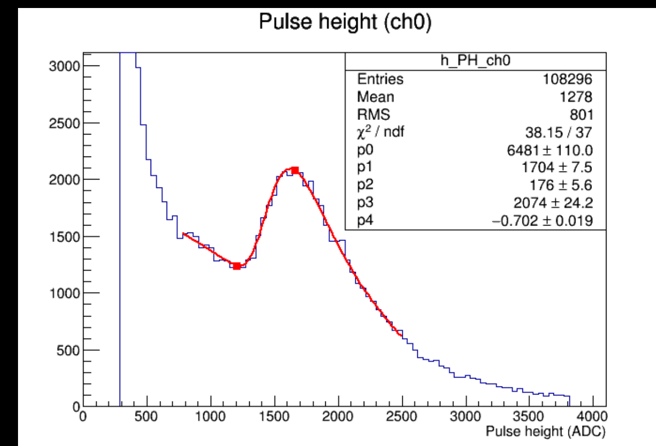


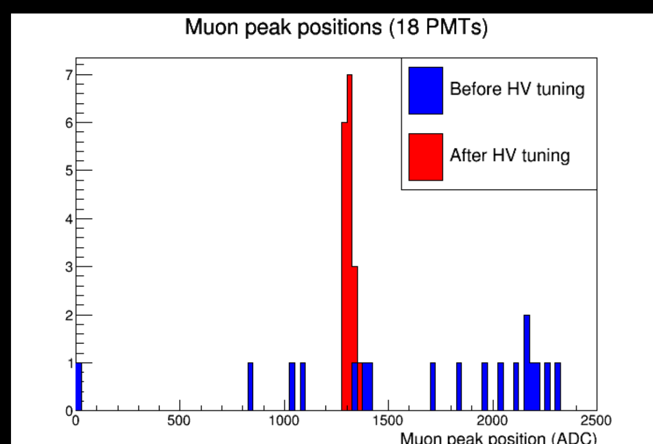
μ

Use muons, simple and they are present in the detector, avoiding complicated calibration scheme (not so effective in past experiments while considering the complication of the calibration system and of the risk of the deployment.



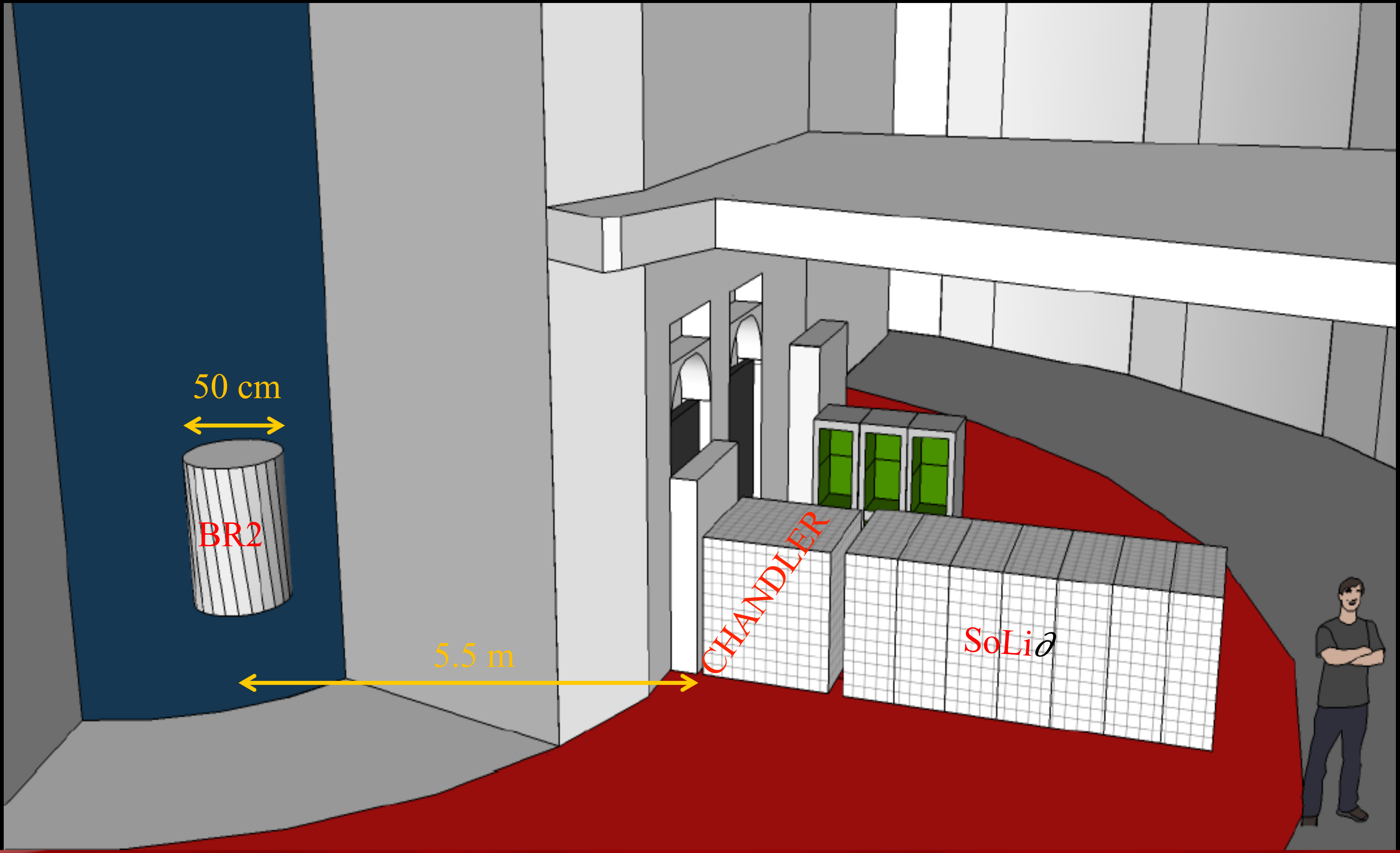
Fit model Landau
+
Exponential





CHANDLER and SoLi∂

The two detectors will be deployed at the BR2 reactor operating as a single experiment.

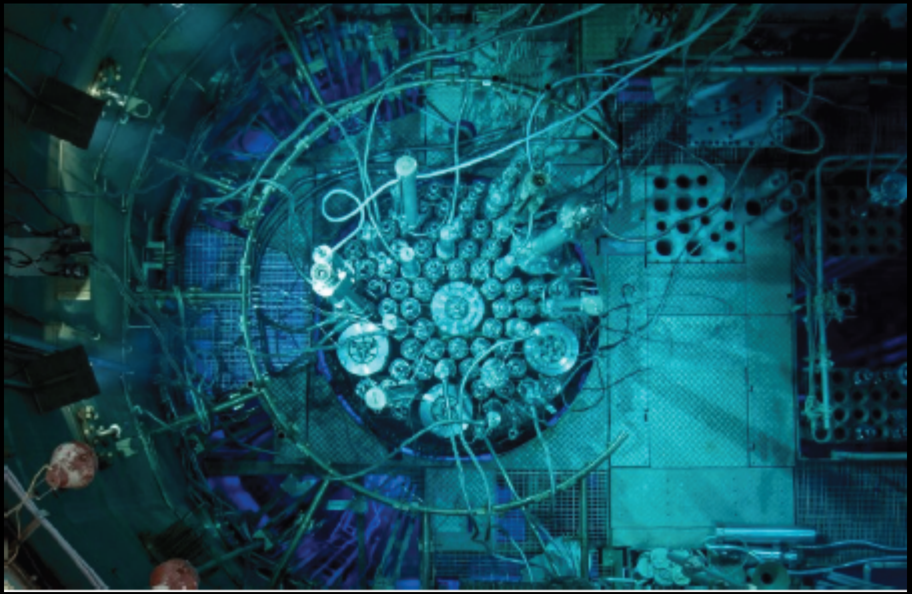


The BR2 Reactor

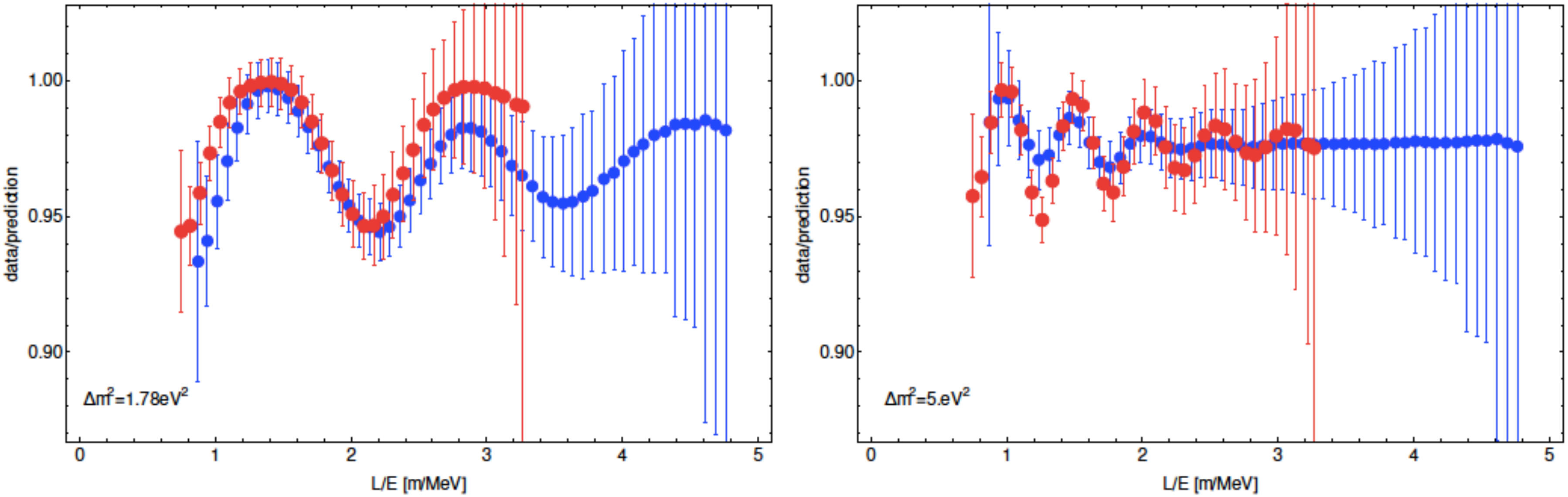
The 60 MW BR2 reactor is a facility at the Belgian National Nuclear Lab, SCK•CEN.

With a 5.5 meter closet approach this site has the highest reactor antineutrino flux of any publically knowable compact reactor site.

The absence of any beam portals makes for a relatively low-background site with backgrounds dominated by the typical environmental sources.



SoLi and CHANDLER Sensitivity



Distribution of events as a function of L/E for two different values of Δm^2 .
The red data points are for CHANDLER and the blue data points are for SoLid.
Resolutions are fully included and the error bars represent the statistical errors after background subtraction.

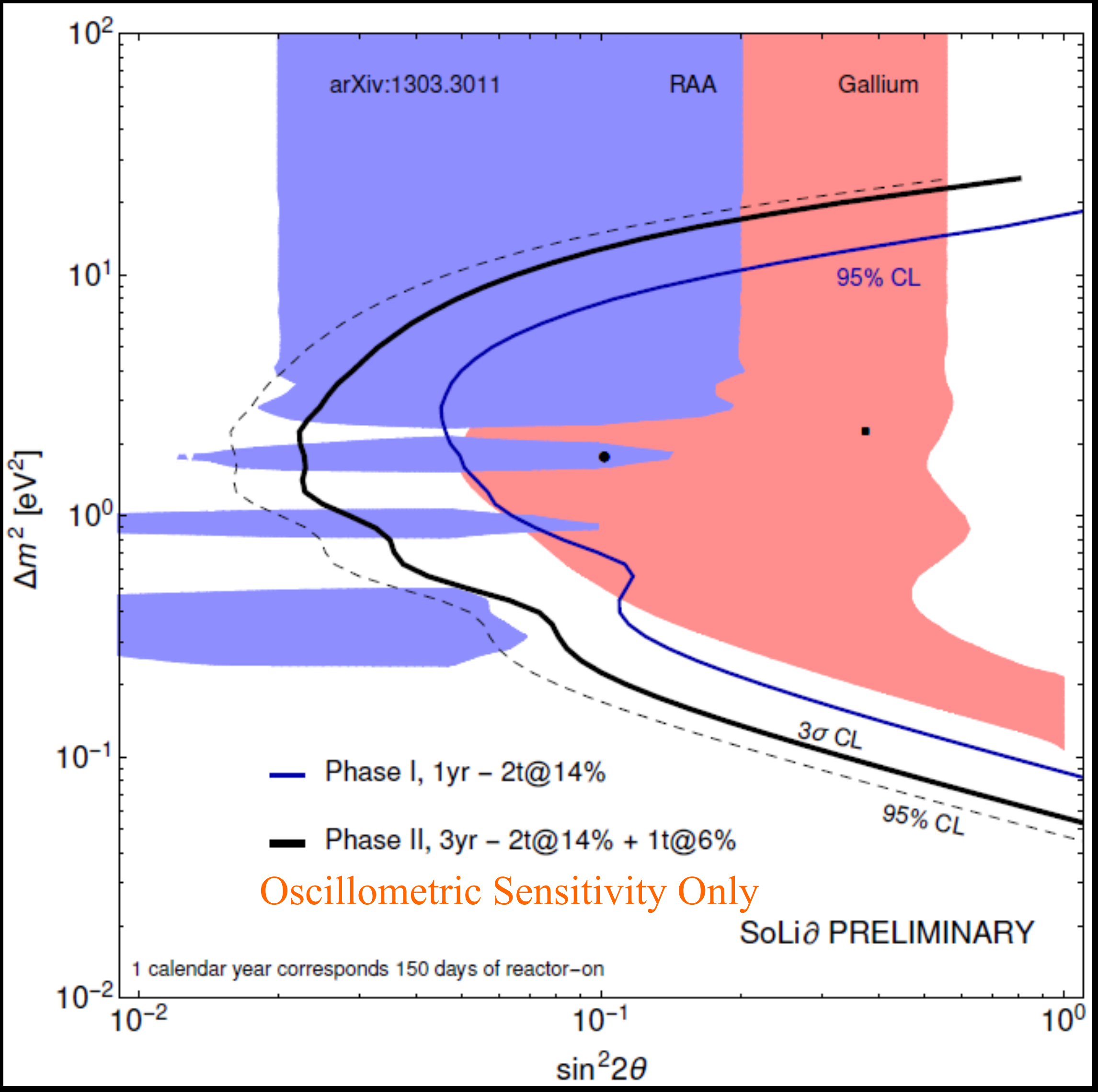
SoLi∂ and CHANDLER Sensitivity

The combined sensitivity for the SoLi∂/CHANDLER deployment at BR2 is compared to the Gallium and Reactor Anomalies.

The one-year, Phase I SoLi deployment covers most of the low Δm^2 part of the Gallium Anomaly at 95% CL.

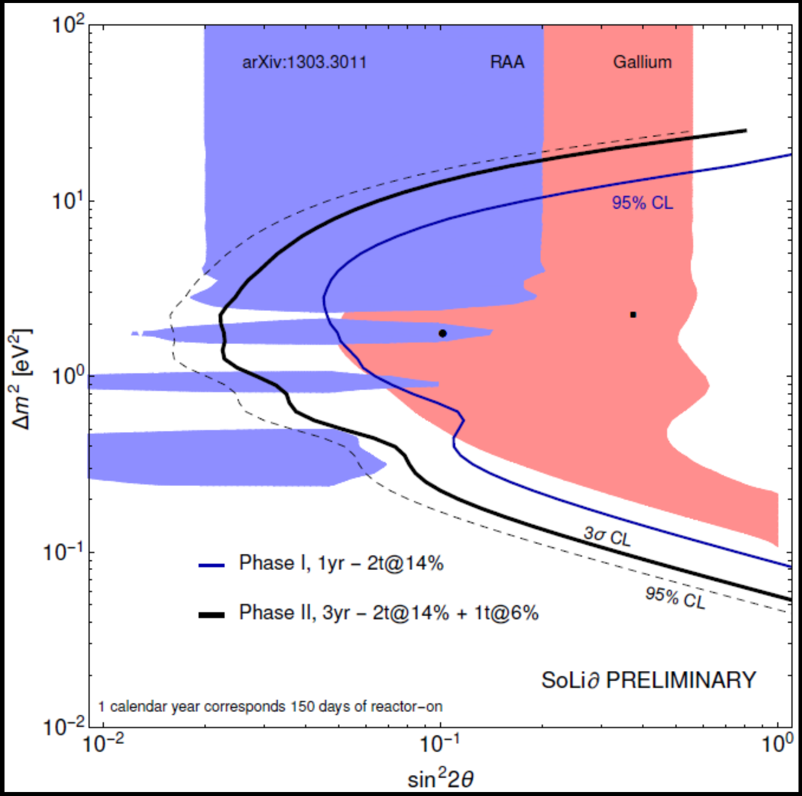
Adding CHANDLER to the three-year Phase II extends the coverage to higher Δm^2 and pushes the reach well into the Reactor Anomaly.

These sensitivities are purely oscillometric, based on energy spectrum and baseline information alone.



Conclusions

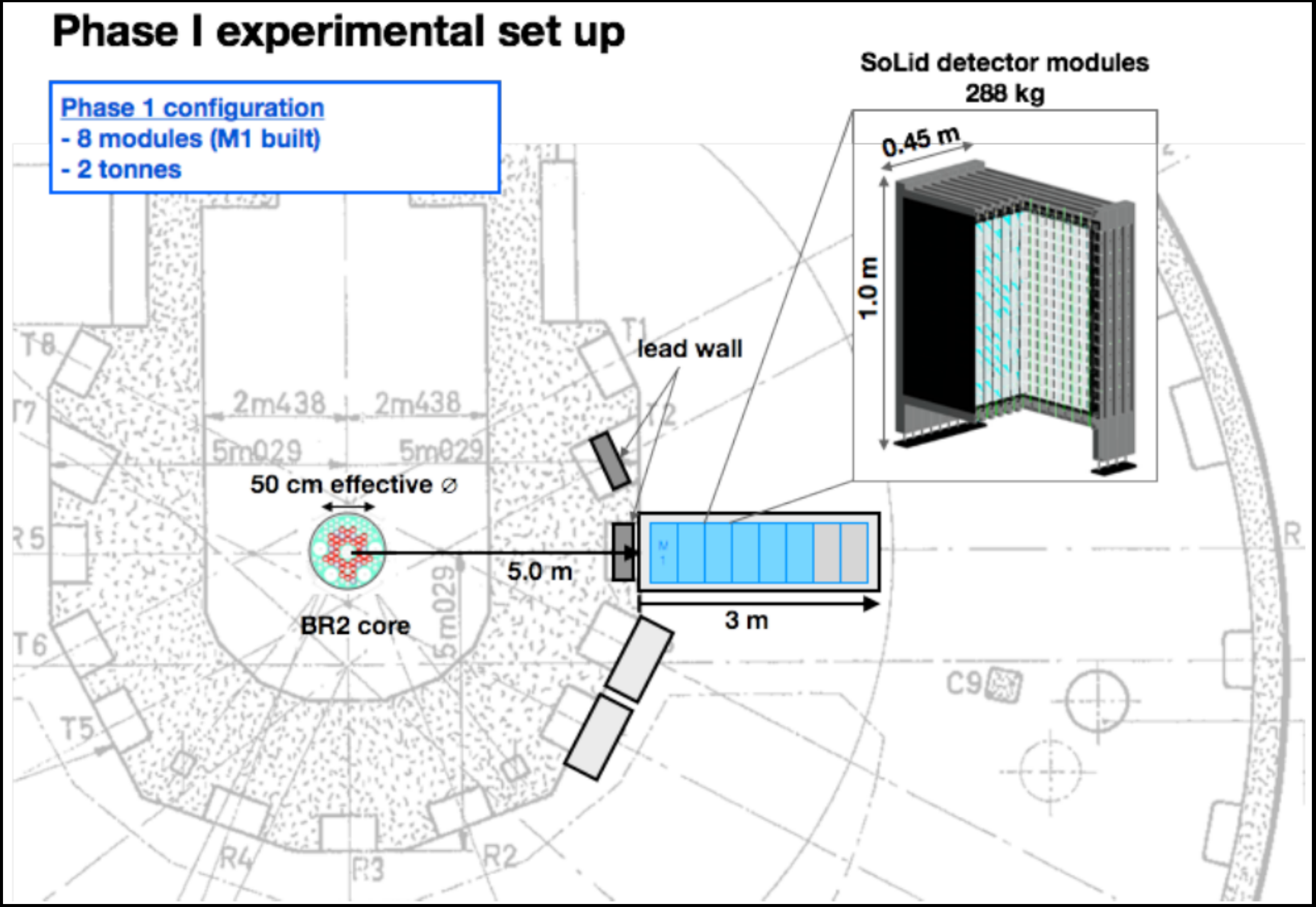
1. The evidence for a 1 eV^2 sterile neutrino is persistence but inconclusive.
2. Electron neutrino disappearance, which must exist if any of the oscillation hints are true, is the most promising way to resolve the sterile neutrino question.
3. Radioactive source and reactor neutrino experiments will soon be operating to search for short-baseline oscillations.
4. CHANDLER is a new detector technology with high purity, high efficiency neutron tag and good energy resolution.
5. Together CHANDLER and SoLid cover most of the ν_e disappearance allowed space.



Thank you

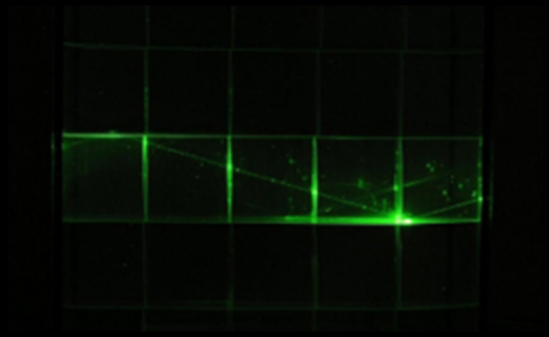
Backup

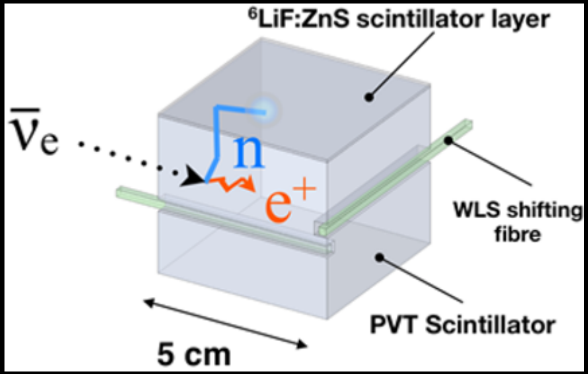
SoLi∂ at the BR2 Reactor in Belgium

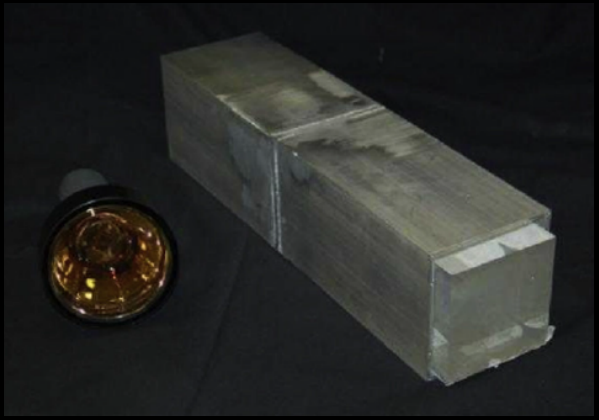


Technological Convergence

SoLid







The **Raghavan Optical Lattice** (ROL), invented by the late Virginia Tech professor, Raju Ragahvan, divides a totally active volume into cubical cells that are read-out by total internal reflection. LENS was designed for solar neutrino detection and not optimized for reactor antineutrino detection.

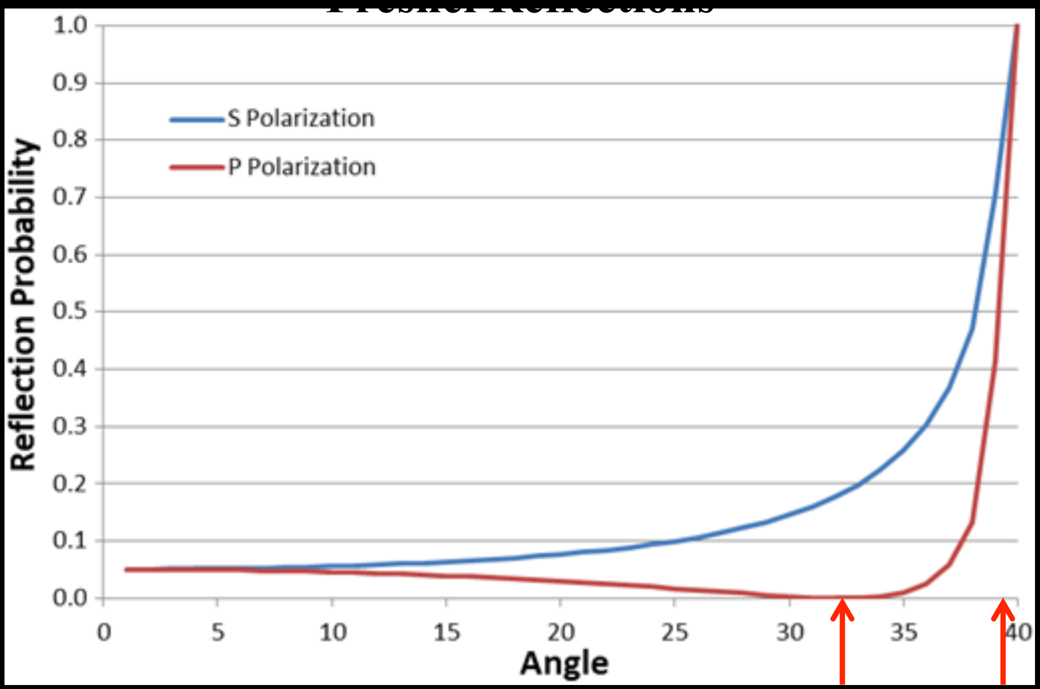
Optically isolated cubes, mated to **^{6}LiF:ZnS(Ag) sheets**, are used to tag IBD. Light is read-out by wavelength shifting fibers in orthogonal directions. It has the spatial resolution of the ROL optimized for reactor antineutrino detection. The small cross-sectional area of the fibers limits the light collection, dilutes the energy resolution and lowers the efficiency.

Used ^{6}LiF:ZnS(Ag) sheets mated to a **solid bar of wavelength-shifting plastic scintillator**. This prototype demonstrated the feasibility of pairing the sheets to wavelength shifting plastic, but the long bars do not have the spatial resolution required for good background rejection

CHANDLER

Carbon Hydrogen Anti-Neutrino Detector with a Lithium Enhanced ROL

Optics of the Raghavan Optical Lattice



The optics are based on the interface of PVT (n=1.58) and air (n=1).

The critical angle (θ_c) is 39.27°

The Brewster angle is 32.22°

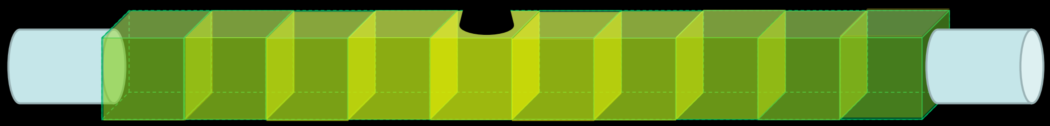
Because $\theta_c < 45°$ any light capable of passing between cubes will necessarily fall into the total-internal-reflection (TIR) channel in that direction.

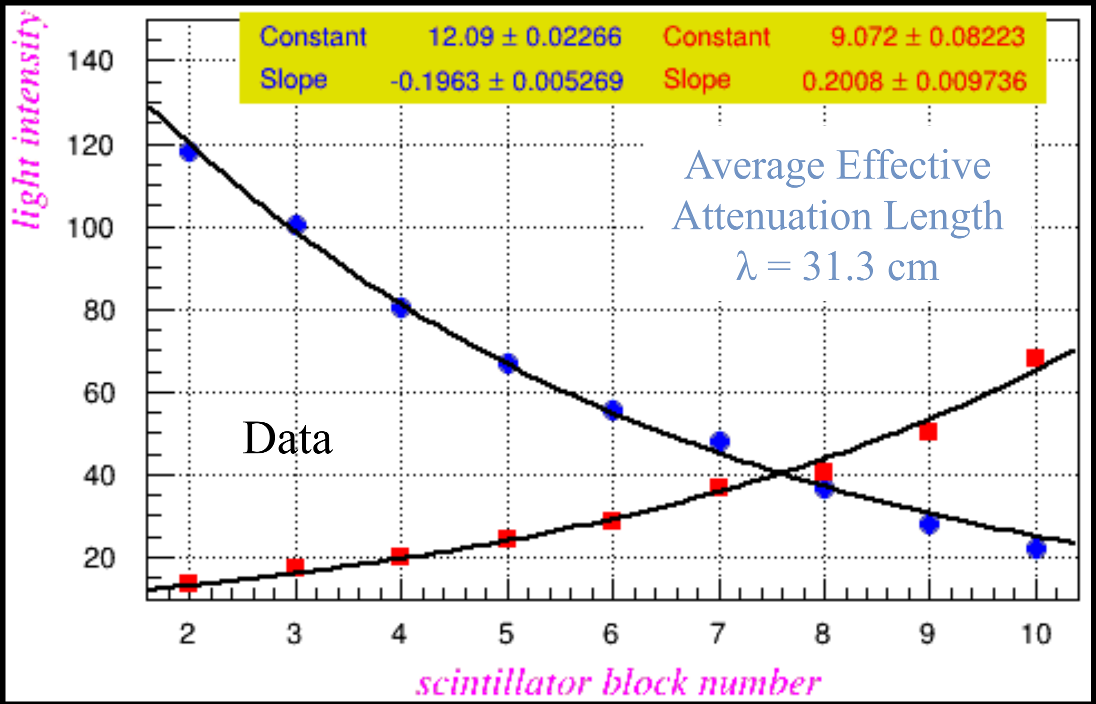
Each of the four TIR channels is open to 11.3% of the light produced in a cube.

54.8% of all light can not be channeled.

Some channeled light that gets reflected off of a cube surface perpendicular to the channel direction will reach the PMT in the opposite direction.

Effective Attenuation Length Study



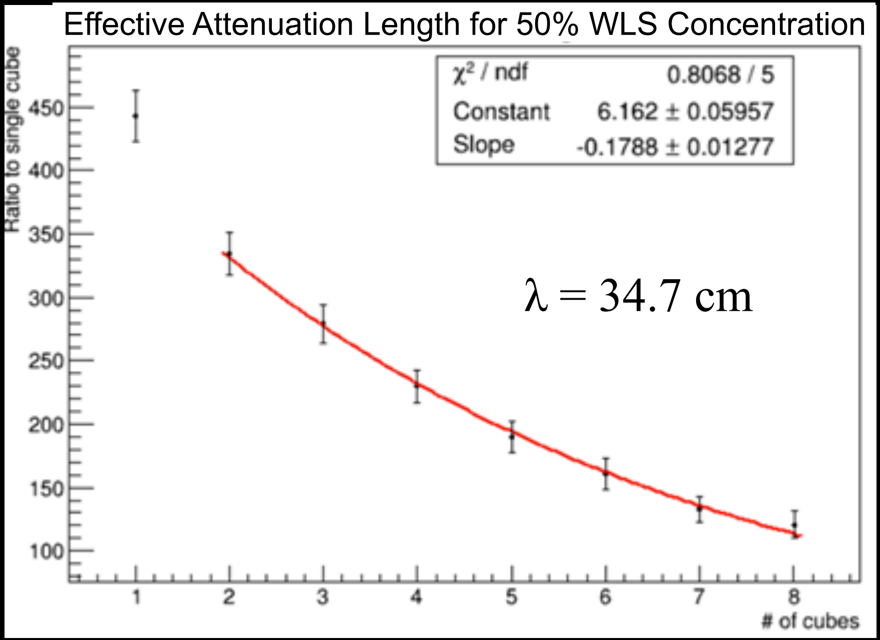


There are two contributions to the effective attenuation:

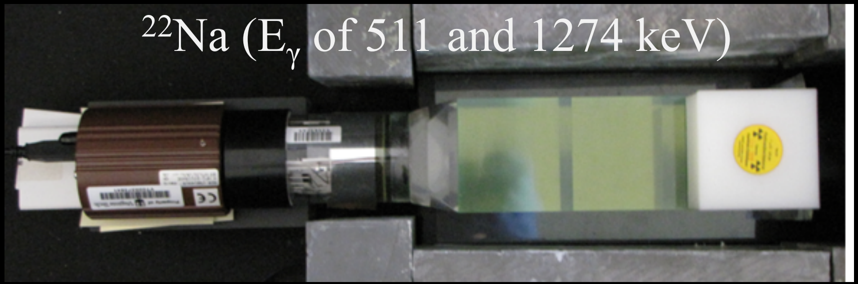
1) bulk attenuation in the PVT and
2) Fresnel reflection at the cube interfaces.

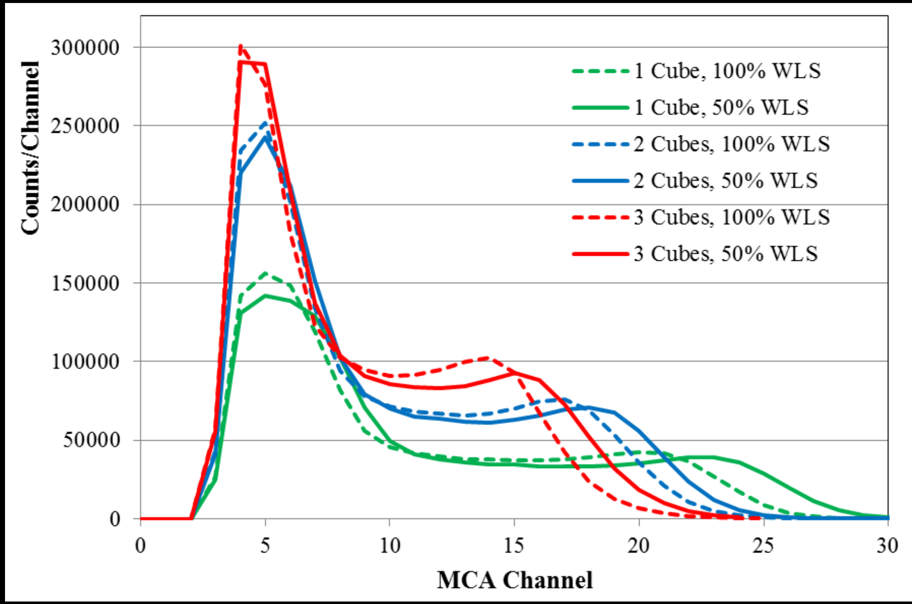
Wavelength Shifter Concentration

The wavelength shifter (WLS) dopant can be a significant source of attenuation.



The Compton edge of ^{22}Na was used to study the relative light output.



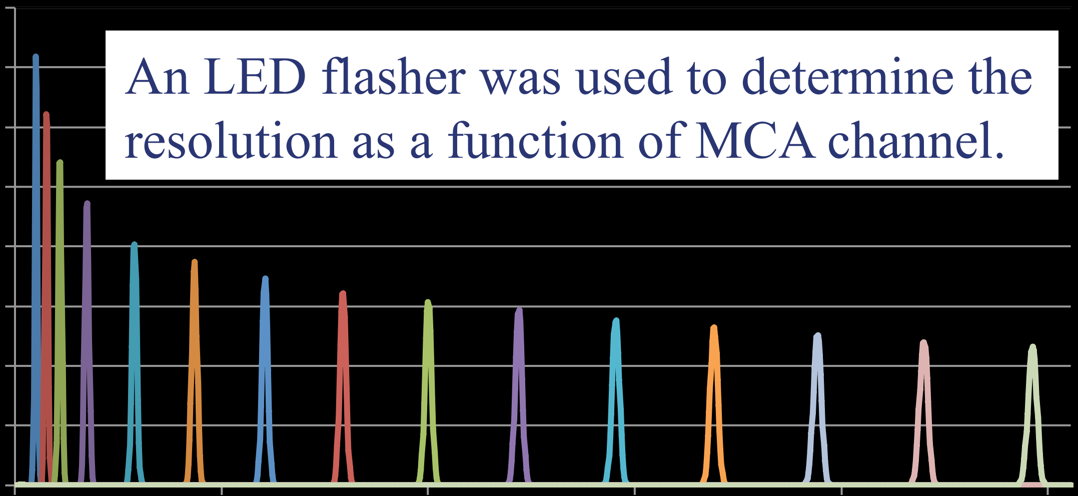


Halving the WLS concentration increases the attenuation length by 10%.

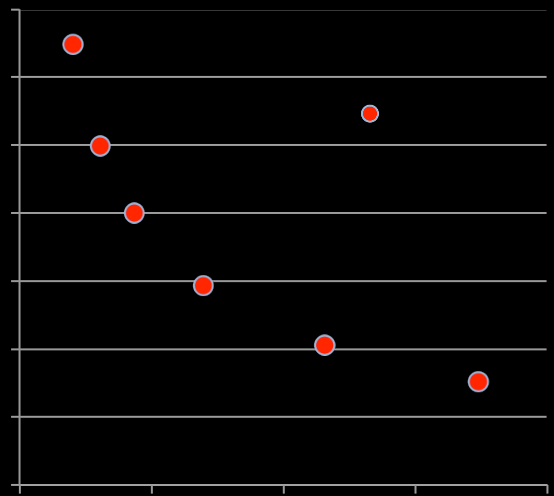
The light collection with lower WLS is greater at each position.

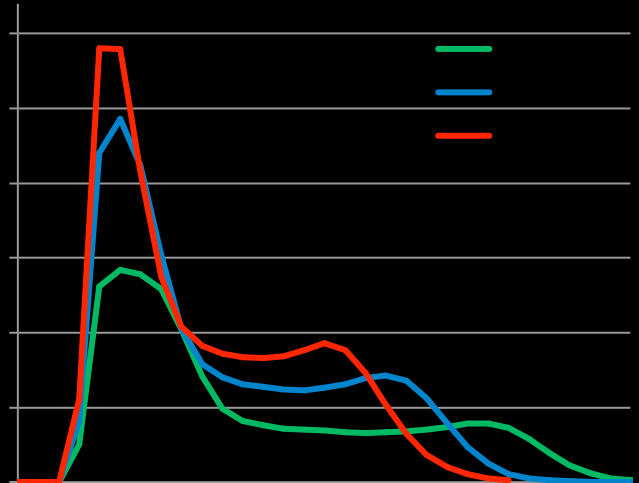
We will also be studying WLS concentrations of 75% and 25%.

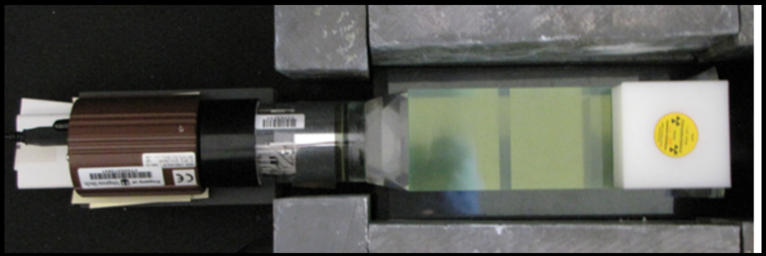
Light Output and Collection



An LED flasher was used to determine the resolution as a function of MCA channel.







The ^{22}Na Compton edge is at 1.06 MeV, and at two cubes from the PMT it reconstructs at channel 20, which corresponds to an energy resolution of 6.5%.

MCNP6: Neutron Transport and Capture

	^{6}Li Capture	Time for 90% Capture	Volume for 90% Capture
Full Cube, 350 μm Sheet	51%	229 μs	37 cubes
Full Cube, 500 μm Sheet	55%	209 μs	35 cubes
Half Cube, 350 μm Sheet	69%	120 μs	24.5 cubes
Half Cube, 500 μm Sheet	73%	103 μs	23 cubes