Reactor Antineutrino Spectrum and Anomaly Measurements: Homogeneous Scintillator

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Outline

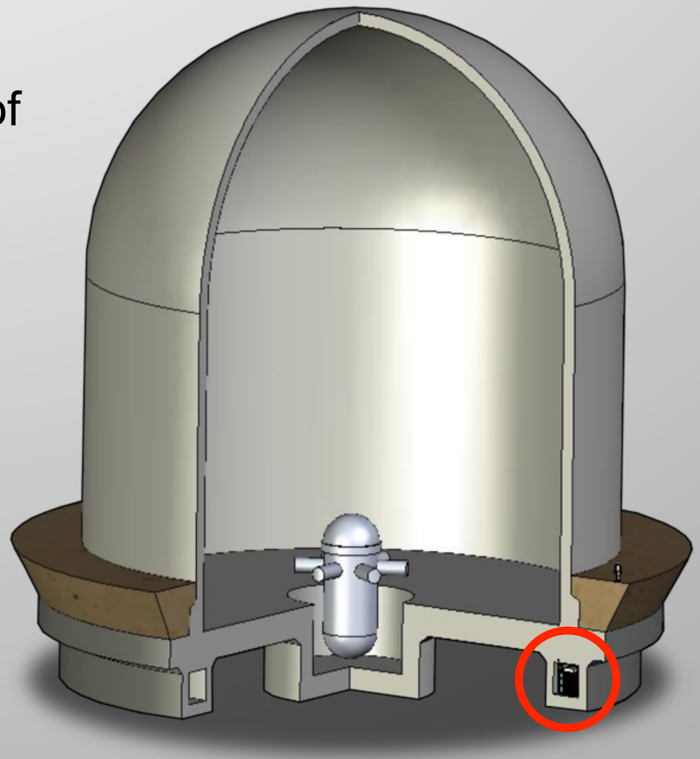
- Motivation
- Base Detector Design
- Variations
  - Position Resolution
  - Energy Resolution
  - Neutrons
- Conclusion

Motivation

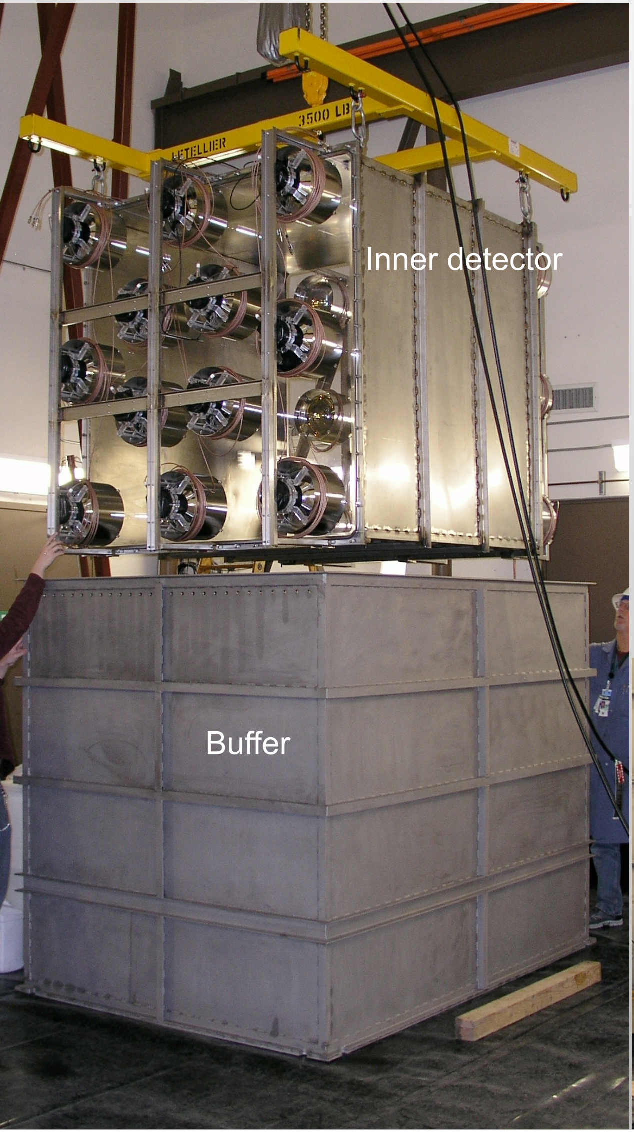
The motivation for these designs was the possibility of taking the measurement as quickly as possible at the SONGS facility. This facility would have provided a high flux of neutrinos and the deployment would have been facilitated by a longstanding working relationship between LLNL and SONGS

The geometry of the tendon gallery was the driver of The initial geometry tested. An emphasis on light collection uniformity throughout the volume further Constrained the geometries and materials tested.

- High Flux: ~10^{17} **ν**/m2/s
- 130 - 180m to other reactor
- Good working relationship with operator
- Familiar with work environment and backgrounds



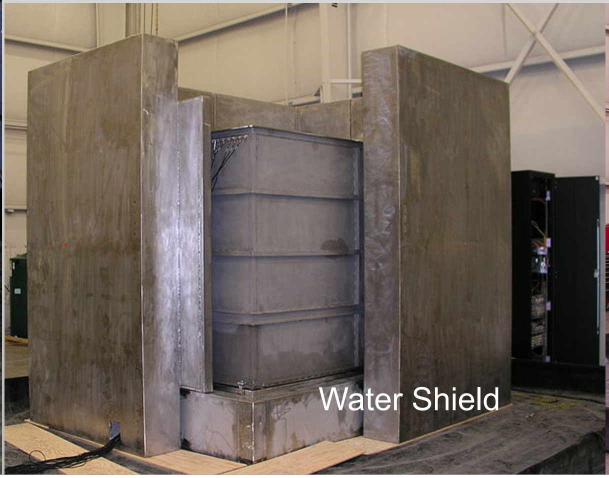
Motivation: Detector Design



The dual-ended readout for the recently completed CANADA detector significantly improved energy and position resolution over our previous detectors.

The lack of a gamma catcher meant there was leakage of Gd capture gammas near the edge of the detector.

The mechanical design was well validated at LLNL, no leakage between volumes was detected.



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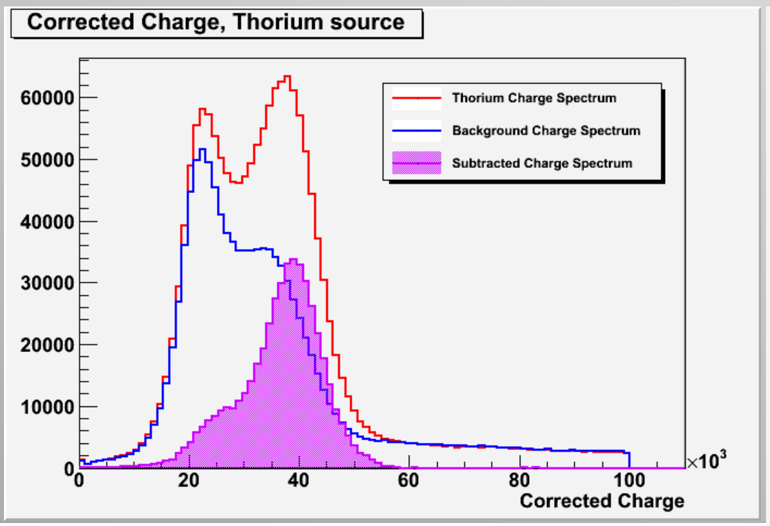
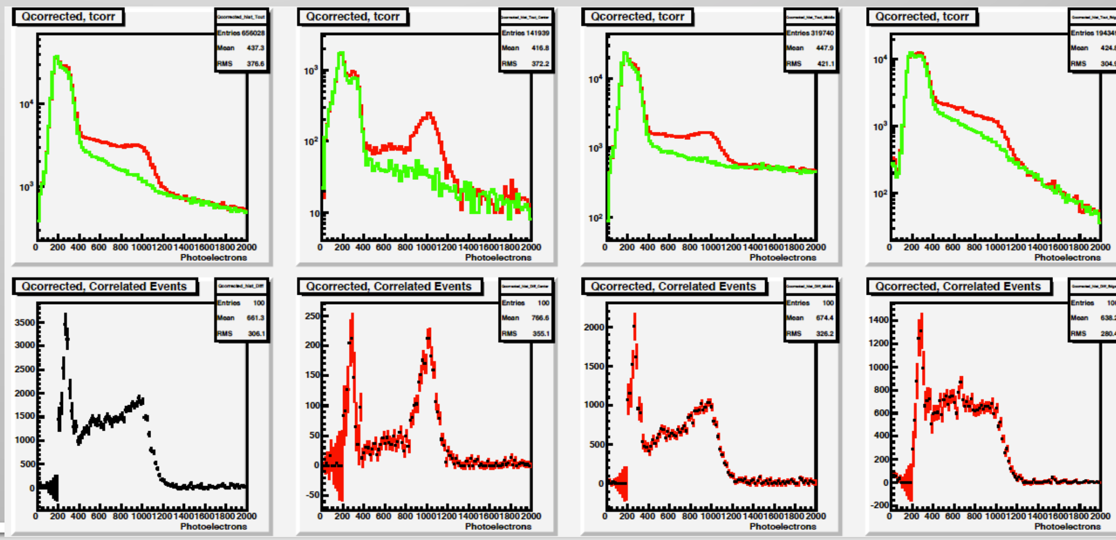




Basic Simulation Features

- A target volume surrounded (fully or partially) by a gamma catcher volume.
- Gd-doped Target Scintillator (0.1% by mass)
- Gamma catcher scintillator light output matched to target scintillator
- Optical readout through 10" Hamamatsu R7081 PMTs
- Dual ended readout provides position sensitivity along one axis.
- Detector length ~3.6m, width ~2.1m
- Detected photoelectrons smeared by a realistic PMT response

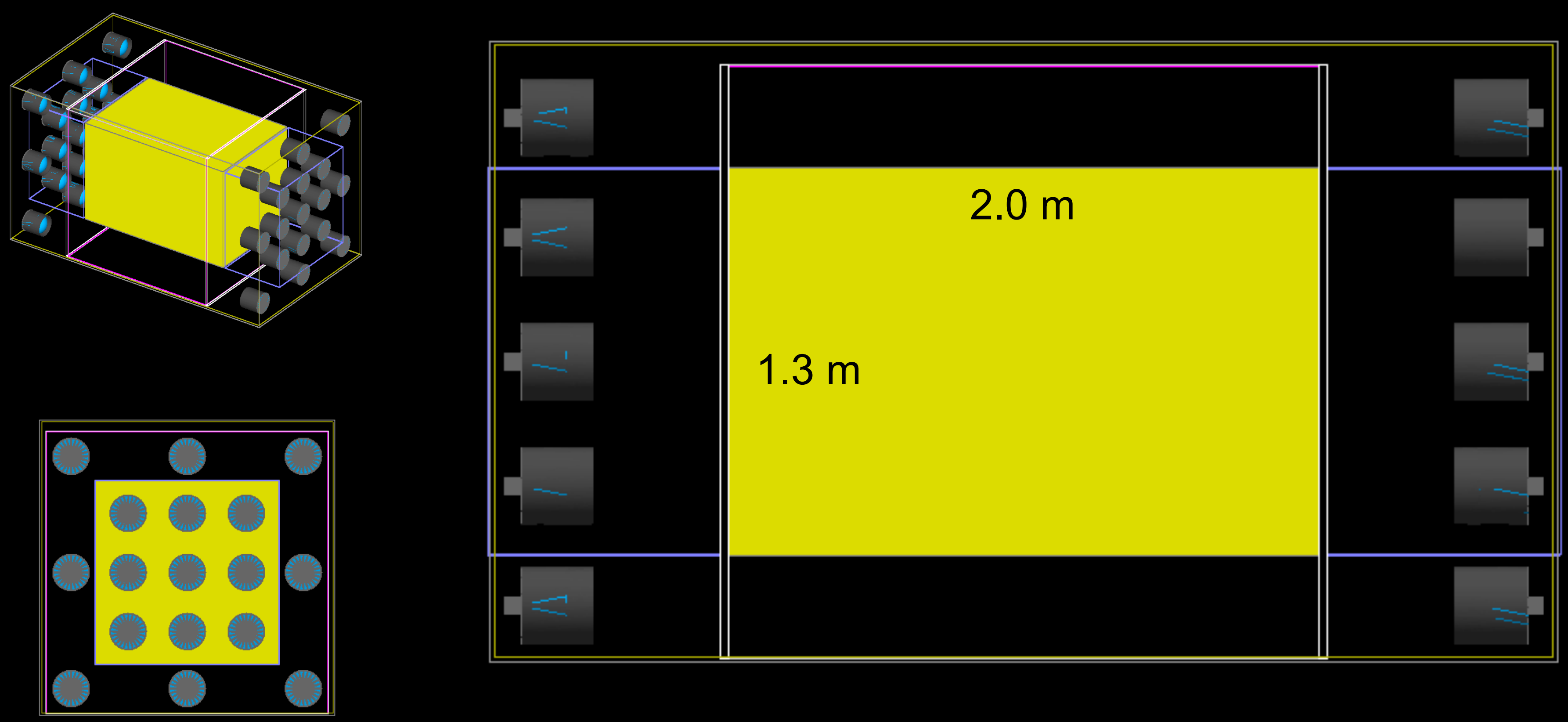
Advantages / Disadvantages

- Homogenous may be the simplest and most cost effective way to achieve a given detector mass
- In compact spaces, optical readout on at most two ends is probably the most that can be achieved
- Two-ended readout can provide decent position resolution along that axis – convenient (at least for ATR) that axis is away from reactor, providing handle on L (as well as E) for oscillation.
- Resolution achievable appears well matched to inherent spread due to core size - I.e very fine resolution may not provide a large advantage.

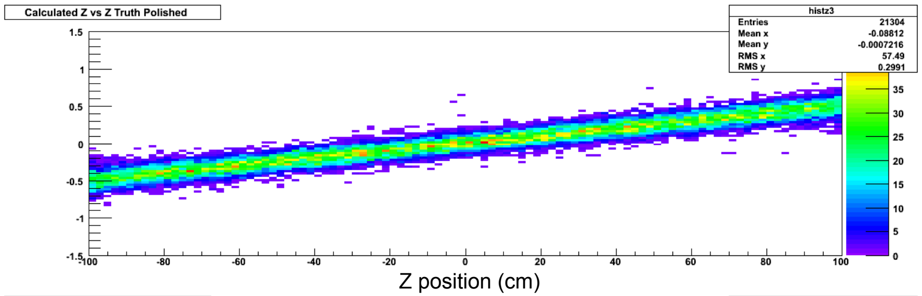
- Uncertain how good PSD could be for background rejection in large volume (if scintillator supports PSD in the first place)
- The dispersed nature of the Gd shower results in a reduction in efficiency and selectivity
- Gd-doping provides no definitive indication of neutron, meaning you must rely on thresholding and accept loss of efficiency
- Liquid handling in a reactor complex (spill protection, liquid transfer, etc).
- Material flammability is an important consideration too, but secondary (within reason – no 100% xylene!) so far in our reactor experience.

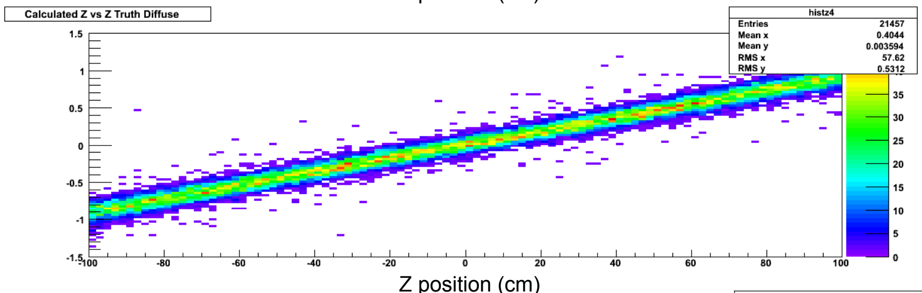
Variation 1:

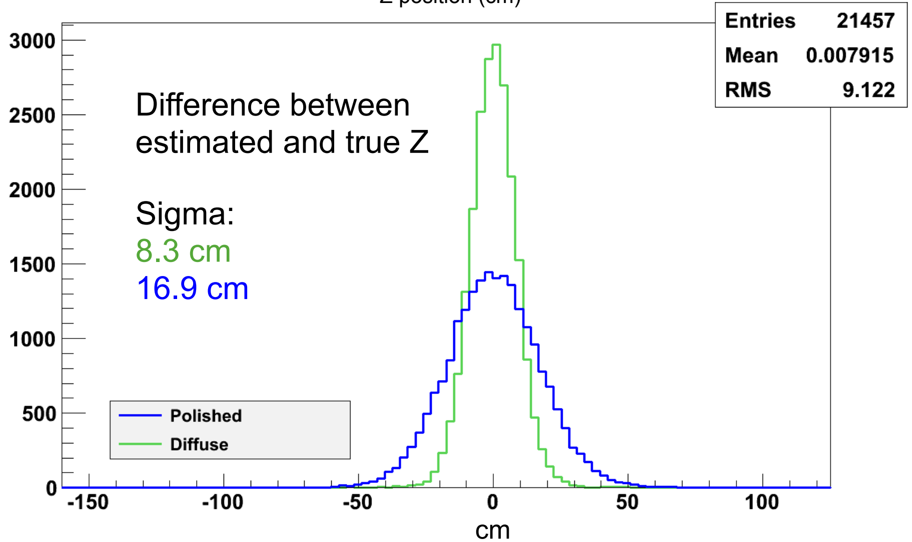
- Partial 35cm Gamma Catcher (no Z-containment)
- Wall between the gamma catcher and target is stainless steel (both diffusely reflective and polished walls were tested)
- Gamma catcher and target share a single acrylic window on each side
- Optical separators segregate gamma catcher and target PMTs



Position Sensitivity



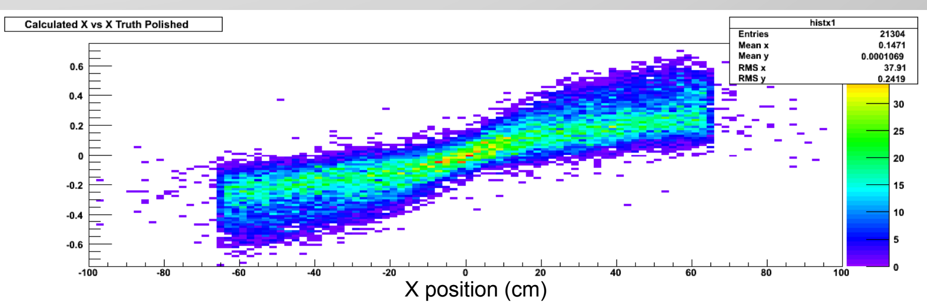


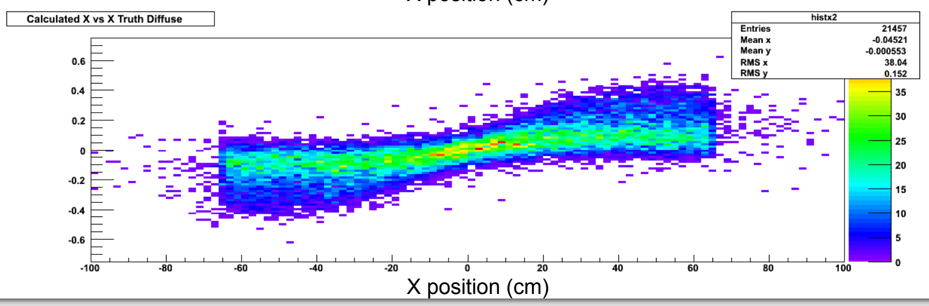


This style of detector offers good Z resolution. This means the detector can be artificially segmented in the analysis if it is oriented with the neutrino flux along Z.

X and Y resolution is poor however.

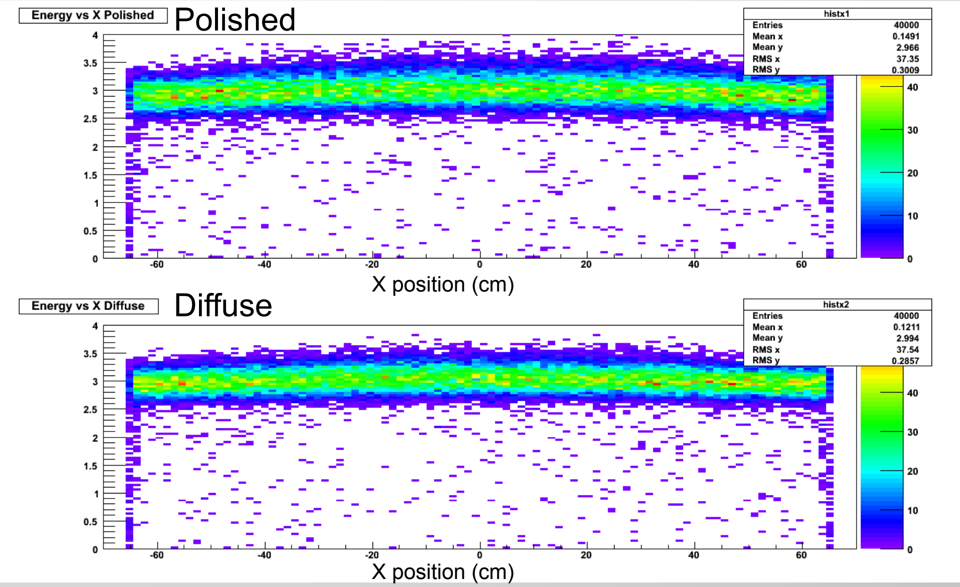
Position is based on charge sharing, not timing.



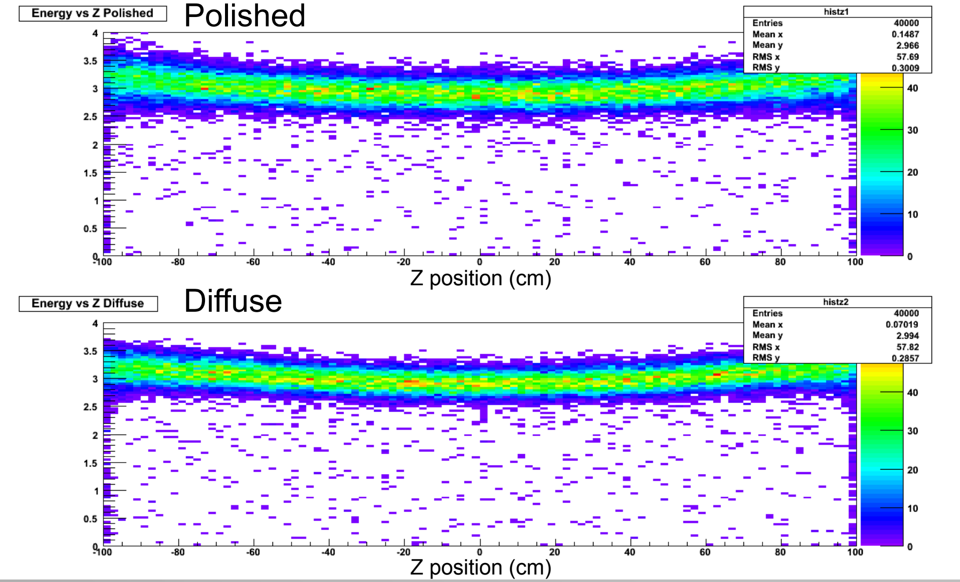


Energy Uniformity

The energy response of the detector is fairly uniform in both the transverse (X) and longitudinal (Z) dimensions. There is also not a major difference between the Polished and Diffusely reflecting walls.



Energy vs X(cm)

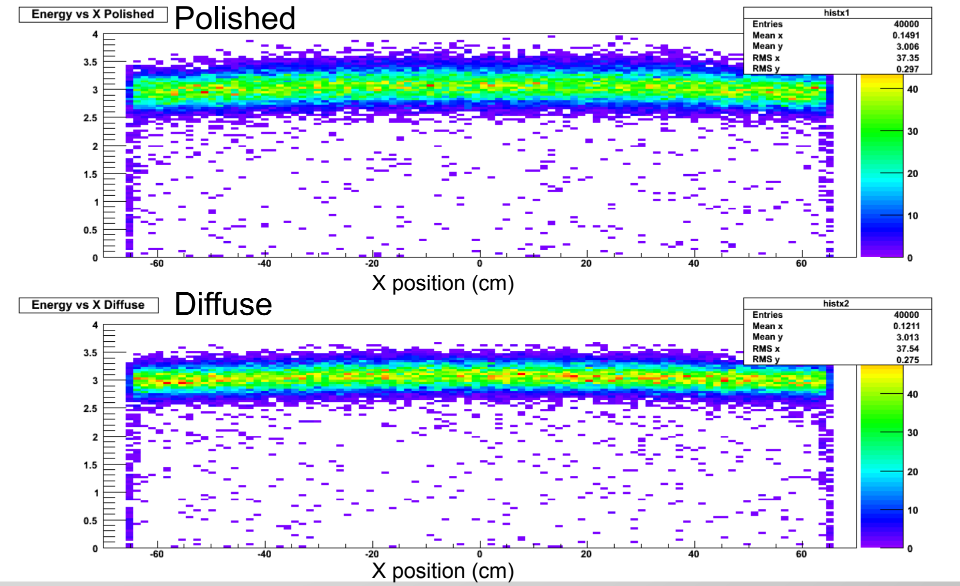


Energy vs Z(cm)

The correction function removes geometrical acceptance differences in Z, giving a much tighter energy response.

Corrected Energy Uniformity

The energy response of the detector is fairly uniform in both the transverse (X) and longitudinal (Z) dimensions. There is also not a major difference between the Polished and Diffusely reflecting walls.



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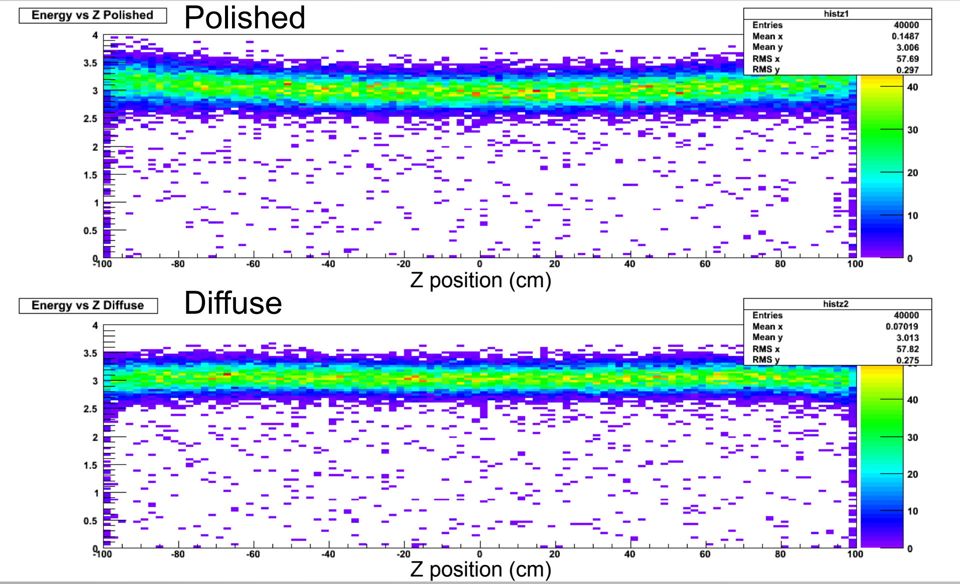

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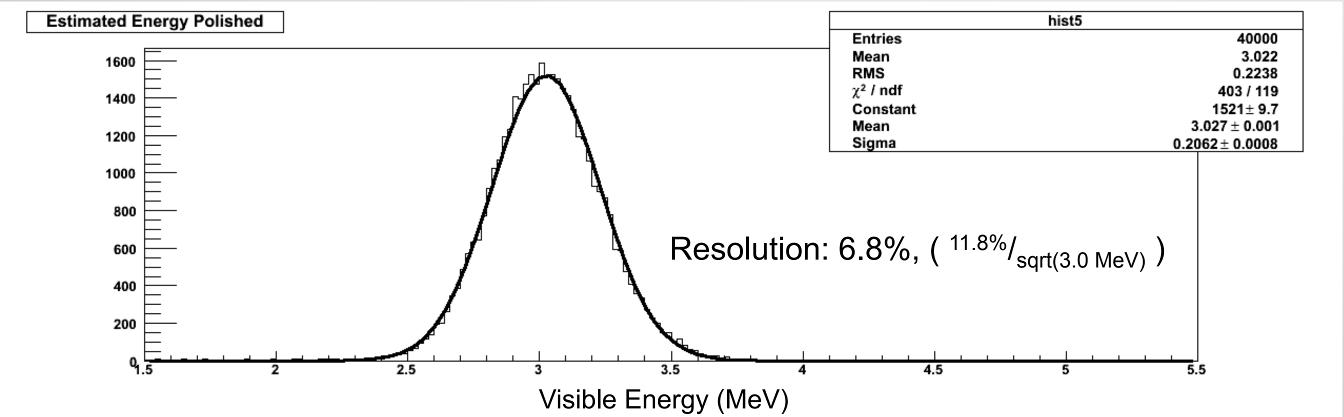
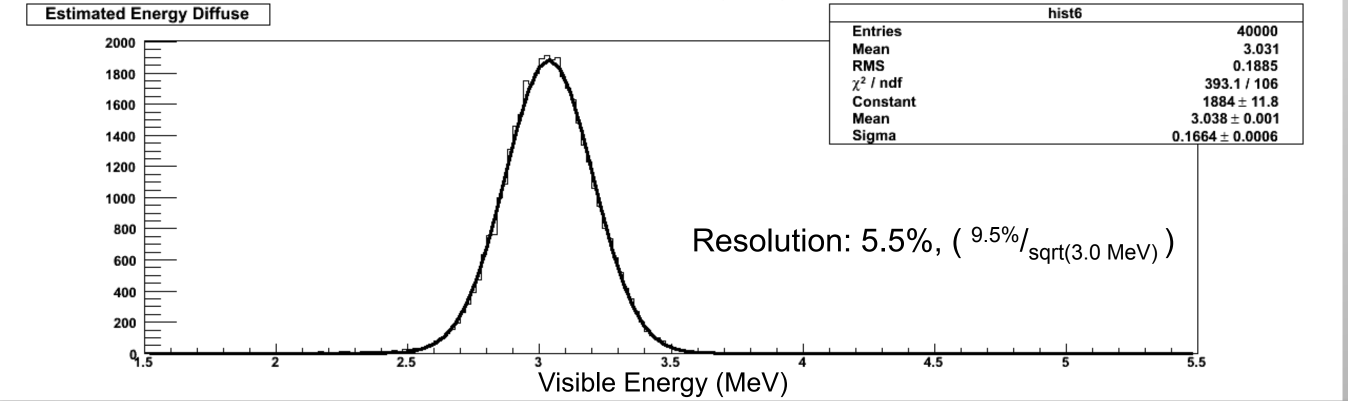
Energy Resolution

Input: 40,000 3.0 MeV electrons uniformly distributed throughout the target volume



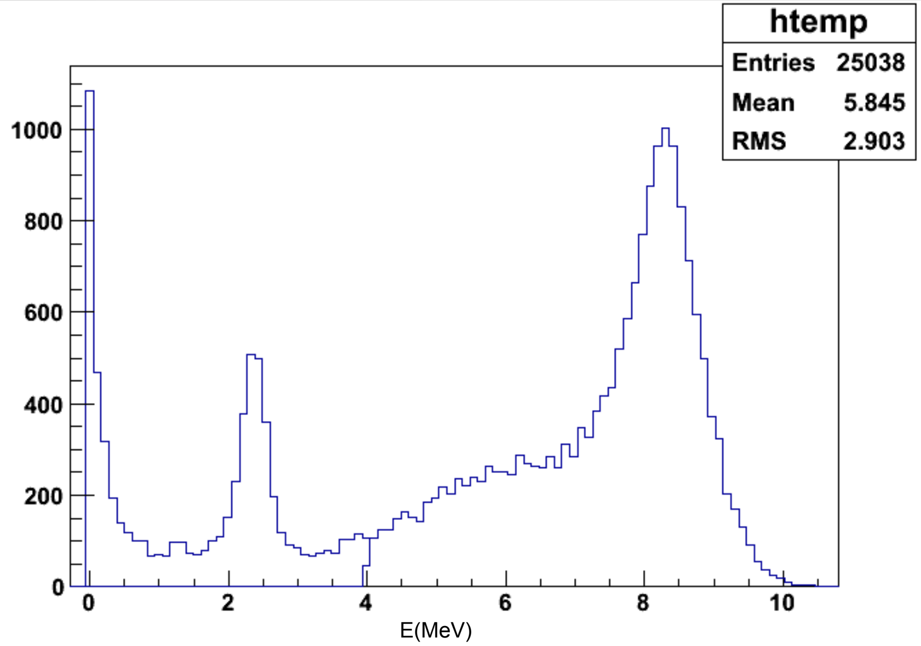


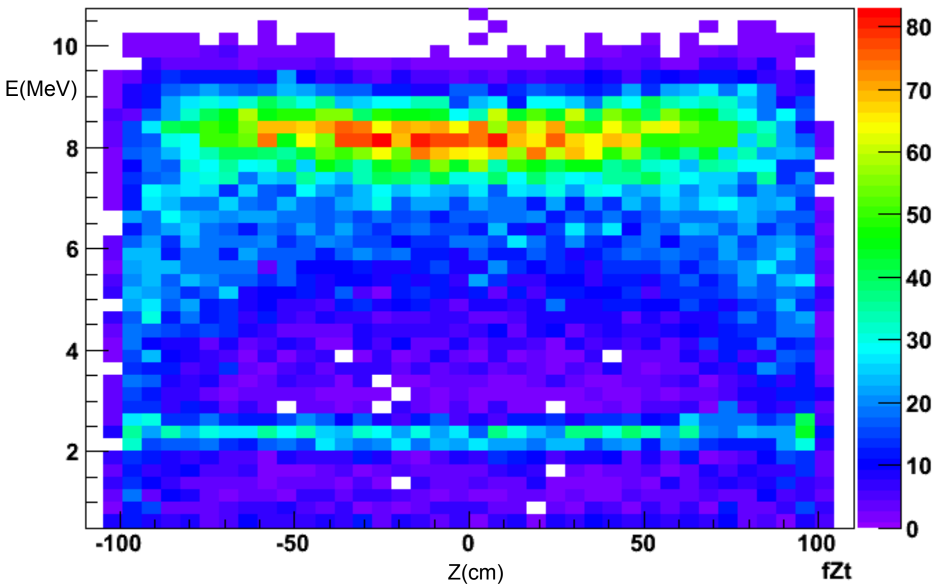
The energy is estimated using a correction function that reduces the position dependence of the light collection. The correction function is not based off any Monte Carlo truth information

Neutrons

The neutron capture energy spectrum for all neutrons captured within the target shows good containment of the ~8 MeV gamma cascade for Gd capture. Cutting at a visible energy of 4.0 MeV results in a 73% efficiency.

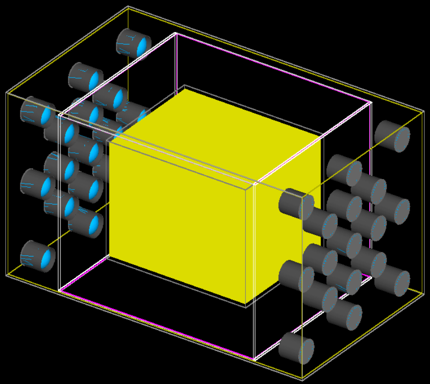
Looking at the neutron capture energy vs Z shows a clear dropoff in containment near the ends of the detector where there is no gamma catcher

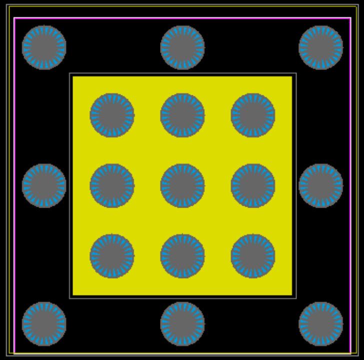


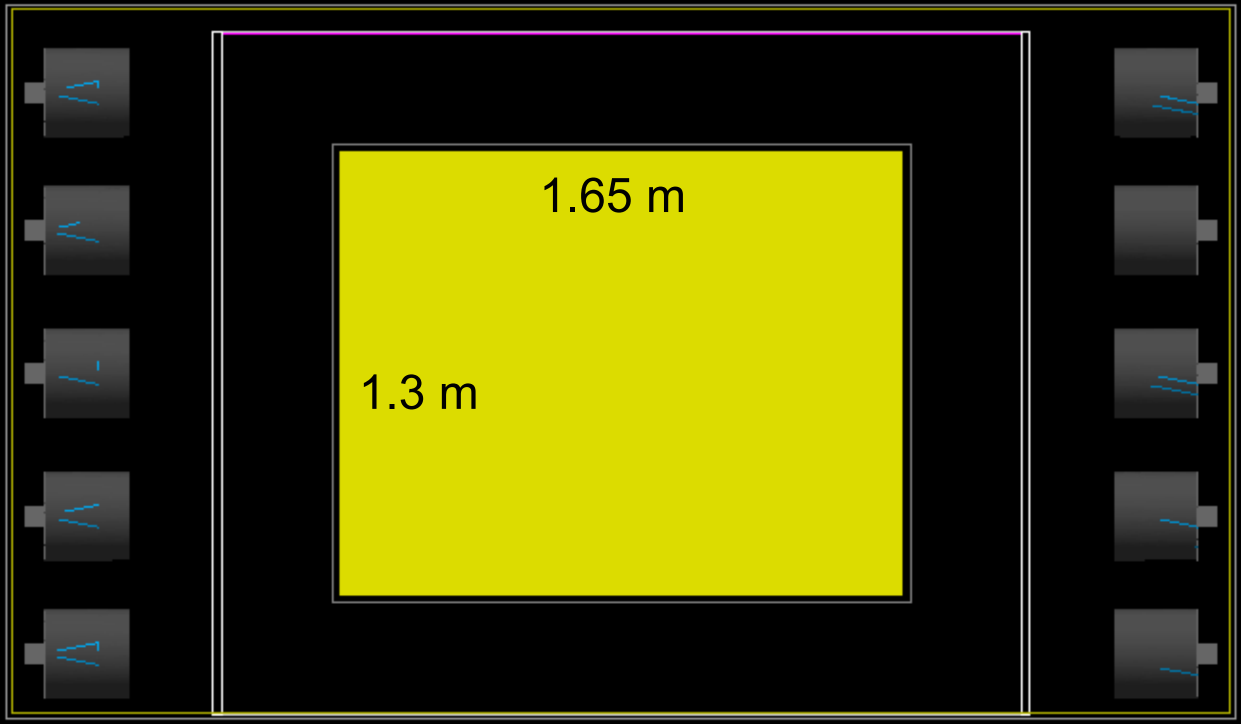


Variation 2

- Full 35cm Gamma catcher
- The target is contained within an acrylic vessel
- No optical separators, meaning no distinct gamma catcher and target readout



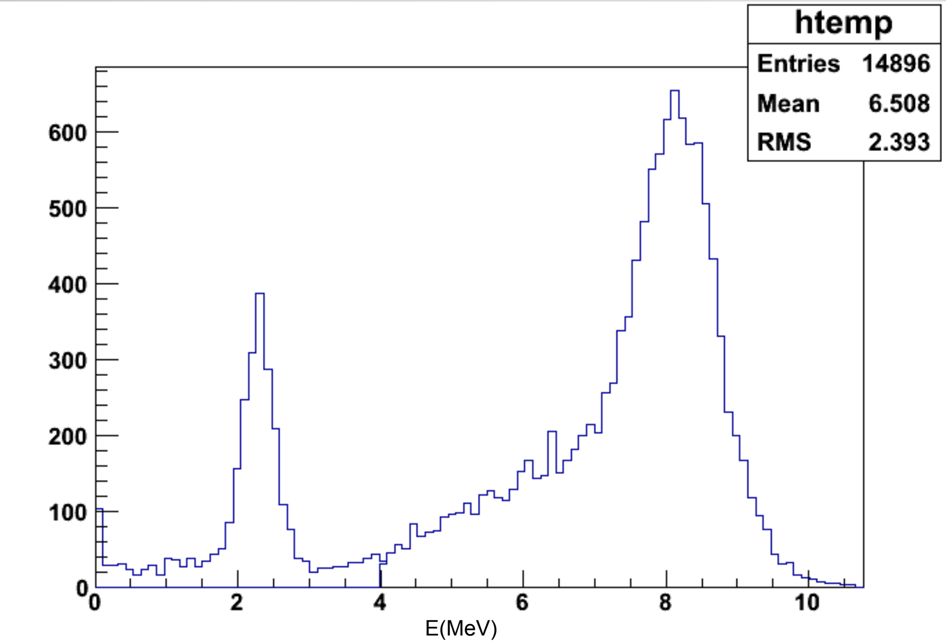


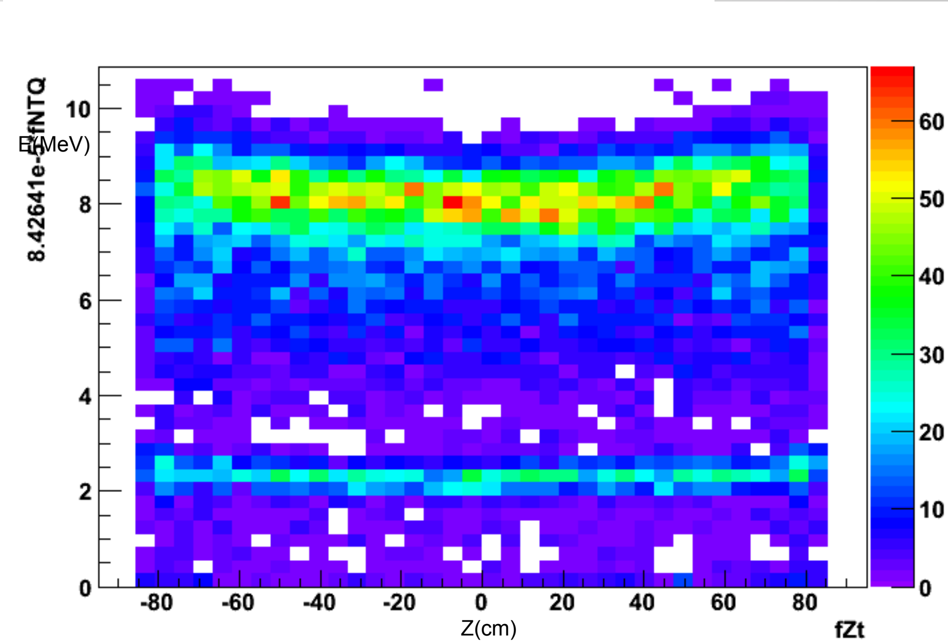


Neutrons

The neutron capture energy spectrum for all neutrons captured within the target shows good containment of the ~8 MeV gamma cascade for Gd capture. Cutting at a visible energy of 4.0 MeV results in a 81% efficiency.

The addition of the full gamma catcher results in an improvement in the full absorption peak from the Gd-capture, though this comes at a slight cost of overall energy resolution and a 17.5% drop in target mass.





Conclusion

- These detector concepts represent what we could do with current technology to deploy a detector as quickly as possible
- The designs were motivated by a deployment in the SONGS tendon gallery, so would need to be adjusted to fit alternate deployment sites.
- The technology presented here is likely the least sophisticated but best understood being considered for this project (i.e. simplest and cheapest)
- The performance of this style of detector could be sufficient to make the desired measurement, with energy resolution $\sim ^{10\%}/_{\mathrm{sqrt(E)}}$ and the possibility of artificial segmentation of the detector in Z.

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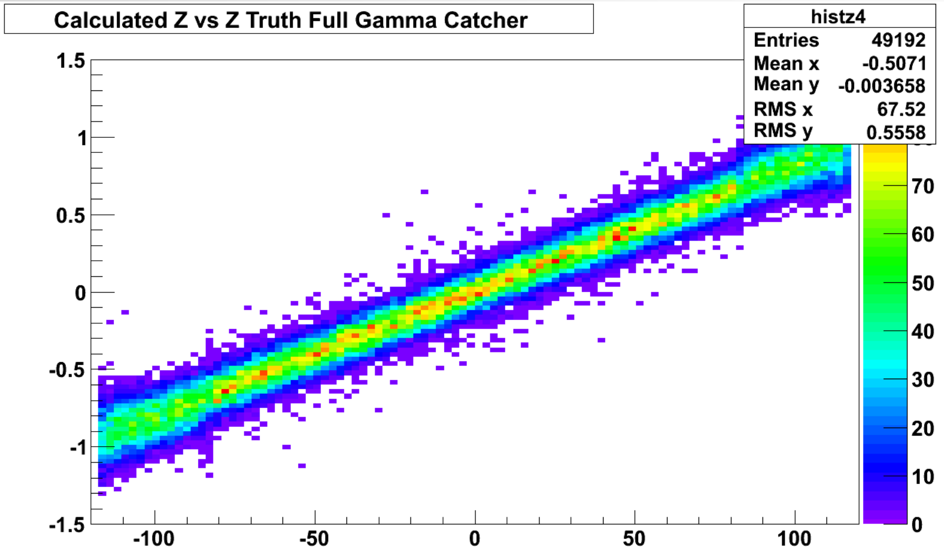
Position Sensitivity



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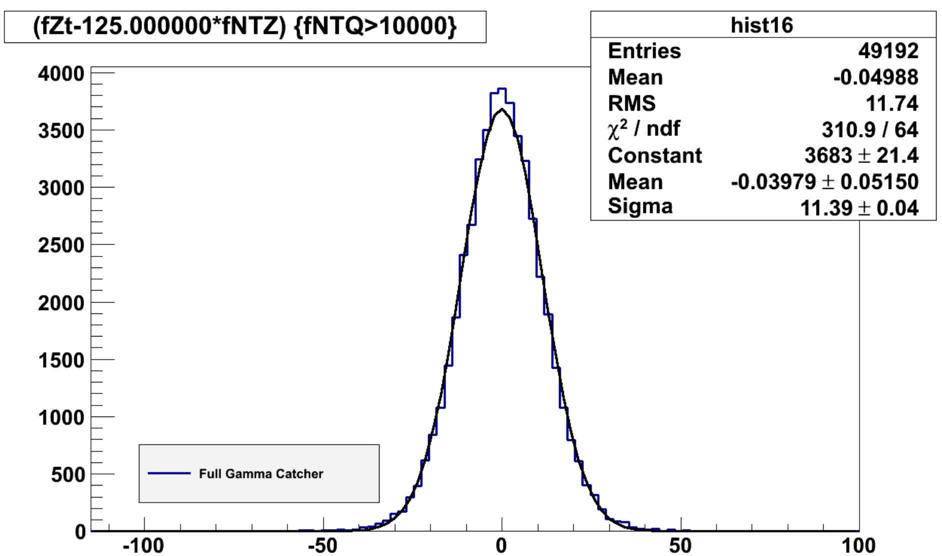

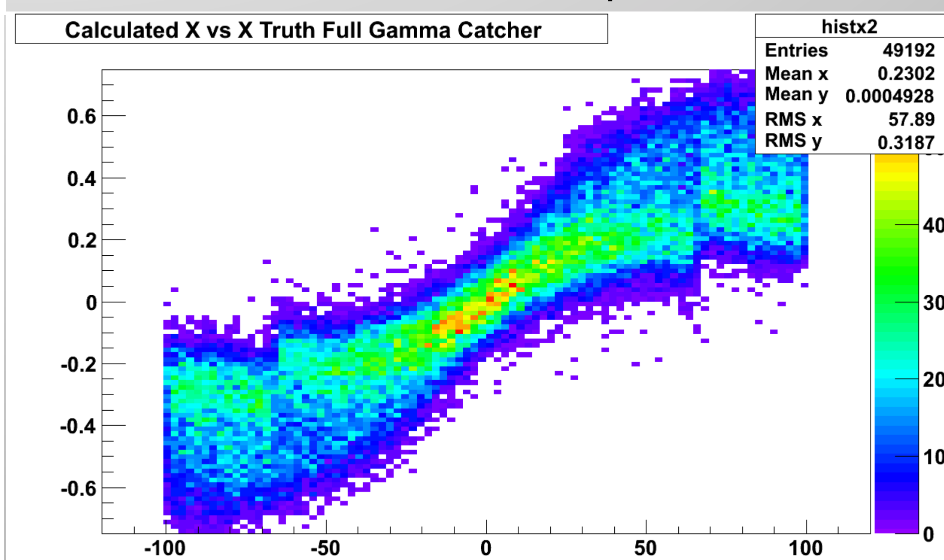

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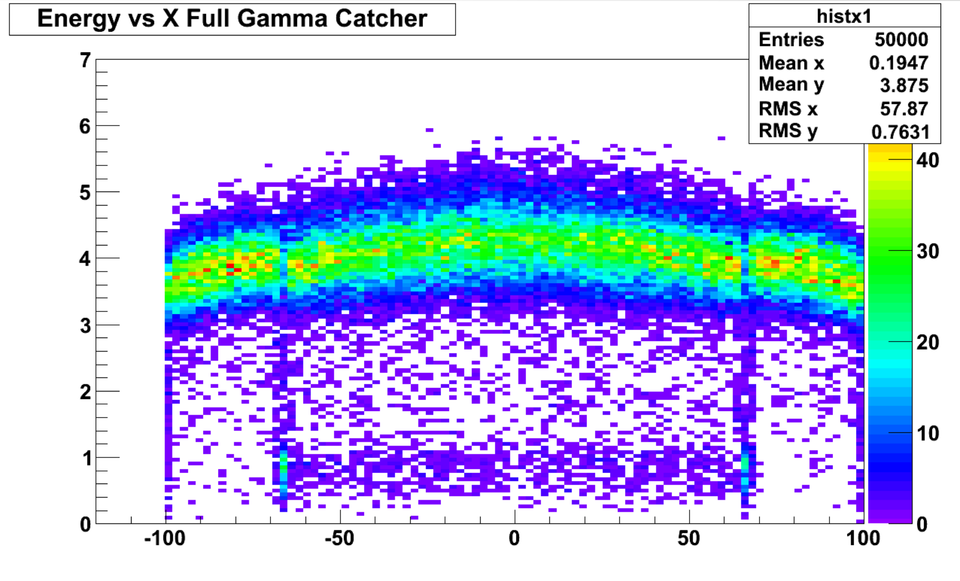

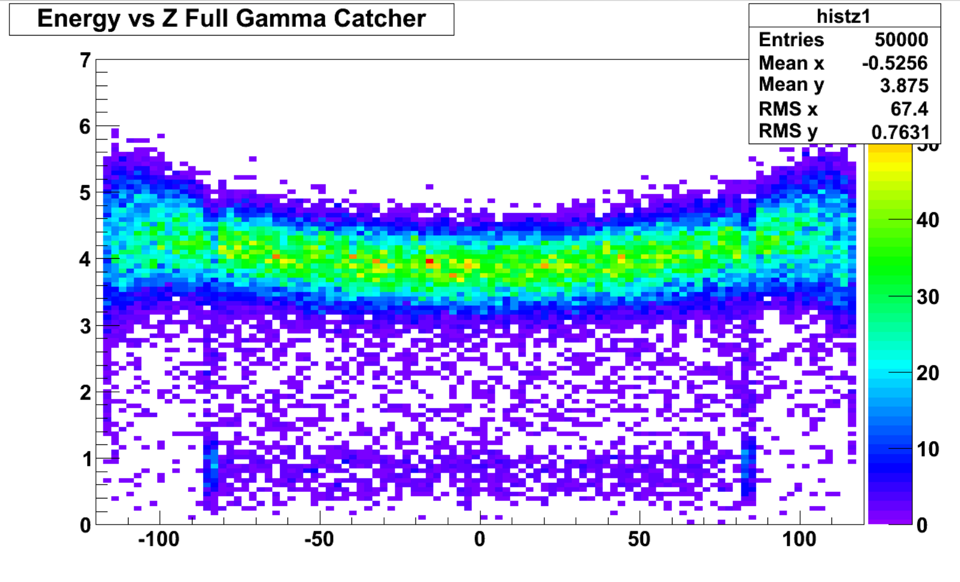

Energy vs X(cm)

The full gamma catcher with this design means that there is no falloff in energy near the ends of the target. Behavior in X and Y becomes worse. Calibrations within the gamma catcher may improve this.