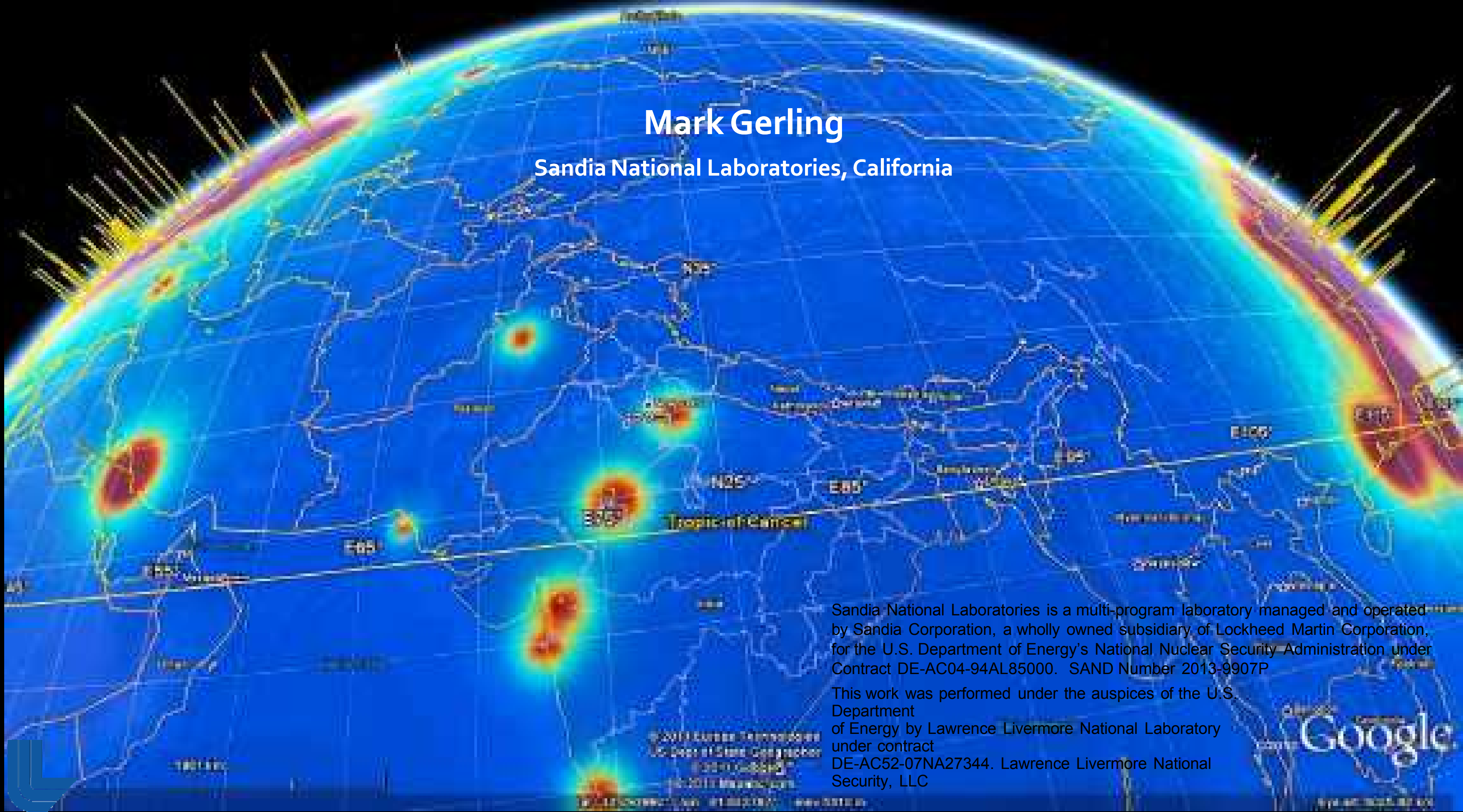
SAND2014-2231C

WATCHMAN

WATer CHerenkov Monitoring of Anti-Neutrinos

MARS Measurements of the Fast Neutron Background at Depth



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Outline

- **WATCHMAN Overview**
- **Neutron Backgrounds at Depth**
- **Multiplicity And Recoil Spectrometer Design (MARS)**
- **System Testing and Deployment**
- **Deployment and Results**

The WATCHMAN Collaboration

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Virginia Tech

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25 collaborators
2 National Laboratories
6 Universities
15 physicists
5 engineers
2 Post-docs
3 Ph.Ds

- **Many person-decades of experience with large neutrino detector design and use**
- **Will add ~2-4 more groups for full project**

SuperKamiokande
SNO
IMB
KamLAND
Double Chooz

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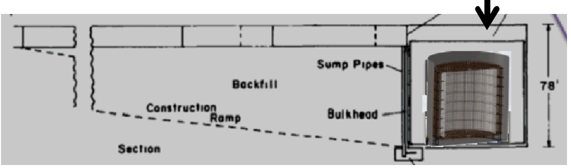
Goal: Remote Detection

Reactor power and duty cycle (signal)

Stand-off distance ($1/r^2$)
Generally closer is better

Depth
(shielding from muogenic backgrounds)
- Existing holes in ground preferred
- Existing infrastructure desirable



- Detector scale (mass and efficiency)
- Cavern composition

- **"Remote" detection must be defined:**
  - ✓ Outside of facility.
  - ✓ Prove scalability for larger stand-off.
- **"Detection" must be defined:**
  - ✓ Reactor state through one fueling cycle.

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WATCHMAN Design

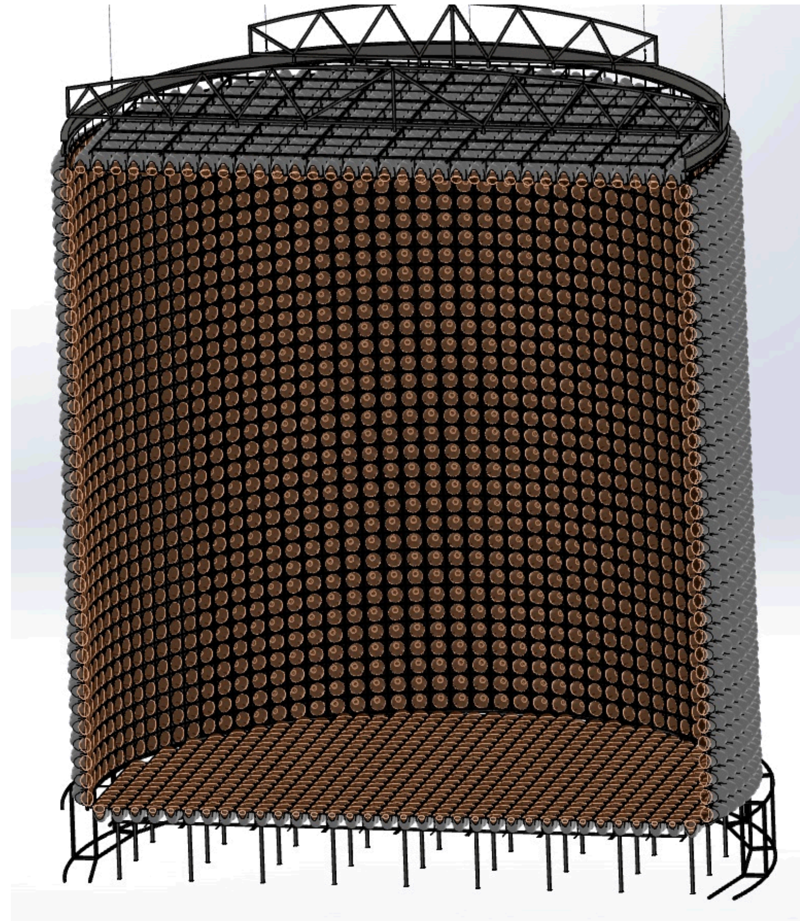
WATer CHerenkov Monitoring
of Anti-Neutrinos:

Detector has target volume of 10.8x10.8 meter right cylinder of 0.1 % gadolinium-doped water (1 kton).

Capture locations can be resolved with 1 meter vertex resolution (sigma) for optically coupled fiducial region.

2.0 meter buffer+veto volume outside of fiducial.

Previous reactor monitoring measurements relied on being situated in close (~25 m) proximity to the reactor to utilize inverse beta decay to detect antineutrinos.



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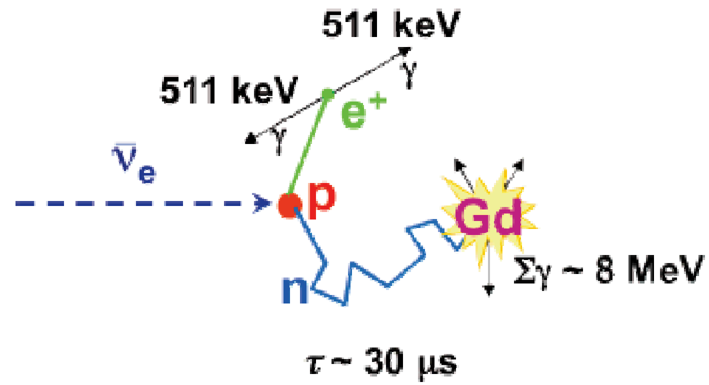
WATCHMAN Signal

Anti-neutrino undergoes inverse-beta decay.

Observe positron annihilation, 30us later observe the Gd shower.

- **Exactly two** Cerenkov flashes
- within ~100 microseconds
- Within a ~ 1 cubic meter voxel



Detector Fiducial Mass	1000	ton
Reactor Power	3875	MWt
Standoff	13	km
Overburden	1434	meters water equiv.
Perry reactor antineutrino rate	12	antineutrino or antineutrino-like events per day
Total background (RMSIM,prelim.)	~2	
Days to 3 sigma detection of change in power (ON/OFF)	~2	<30 days is our target

Preliminary Background/Signal Estimates

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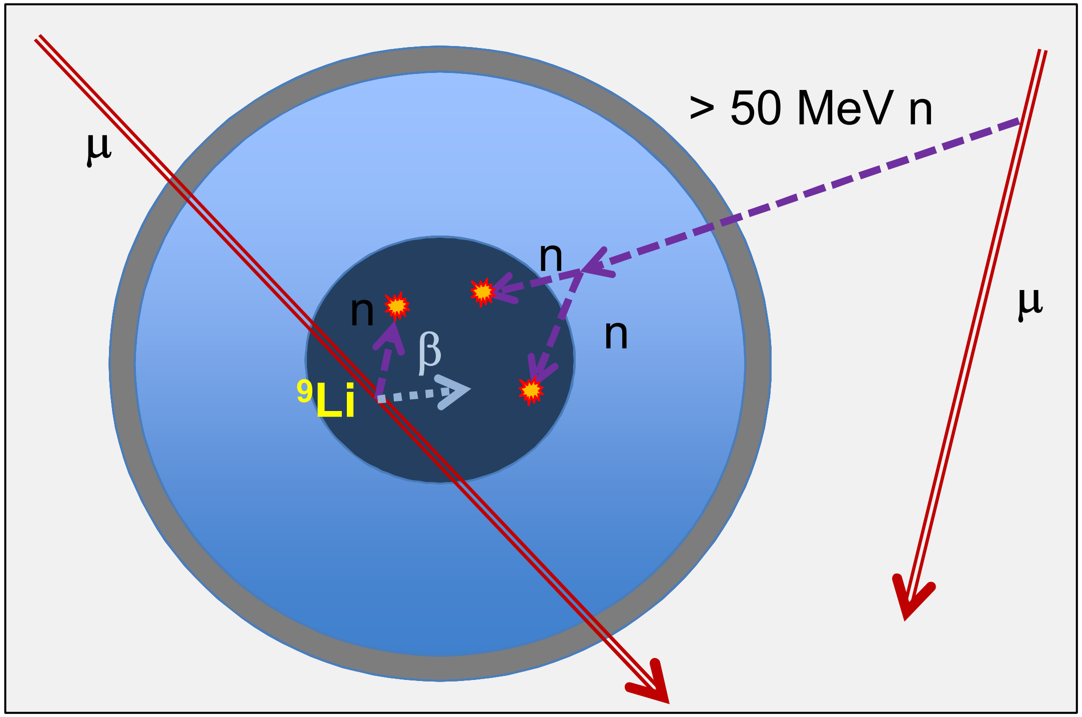
WATCHMAN Background

Scaling up the detector in order to remotely monitor a reactor from kilometer distances requires an increased understanding of the backgrounds:

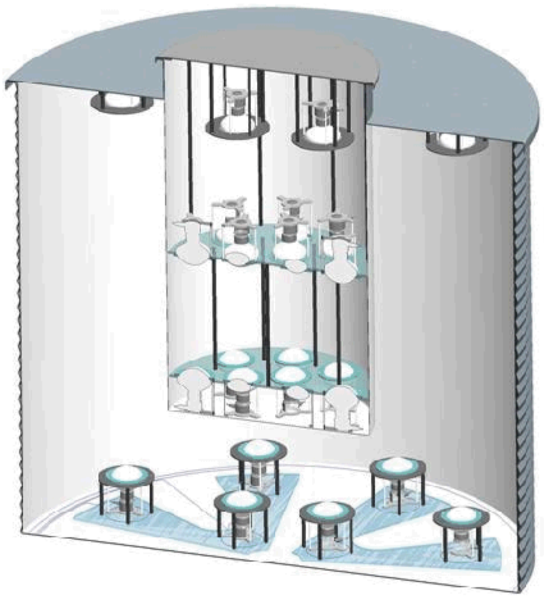
Muongenic beta delayed precursors

Fast neutron rate capable of producing two correlated events in a detector.



Two Backgrounds, Two Detectors

WATCHBOY: Radionuclide Detector



MARS: Fast Neutron Spectrometer

Neutron Backgrounds at Depth

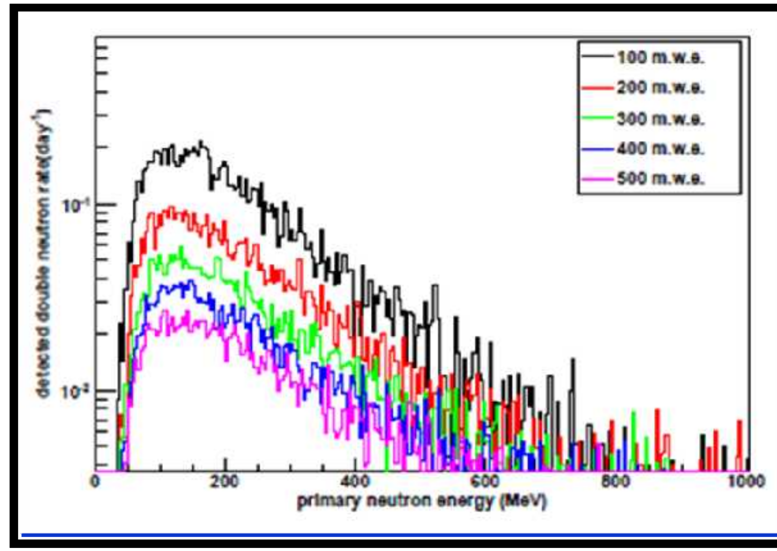
Preliminary kTon water detector simulations

Correlated di-neutron events mimic an antineutrino signal.

μ – Nuclear interactions in the rock produce several 100+ MeV neutrons.

(n,kn) reactions in the rock (and/or detector) create a neutron shower.

Simulations indicate that 50+ MeV neutrons are most likely to produce di-neutron signatures through 2 meters of water shielding.



Rate of double neutrons as a function of incident neutron energy (2m. shield)

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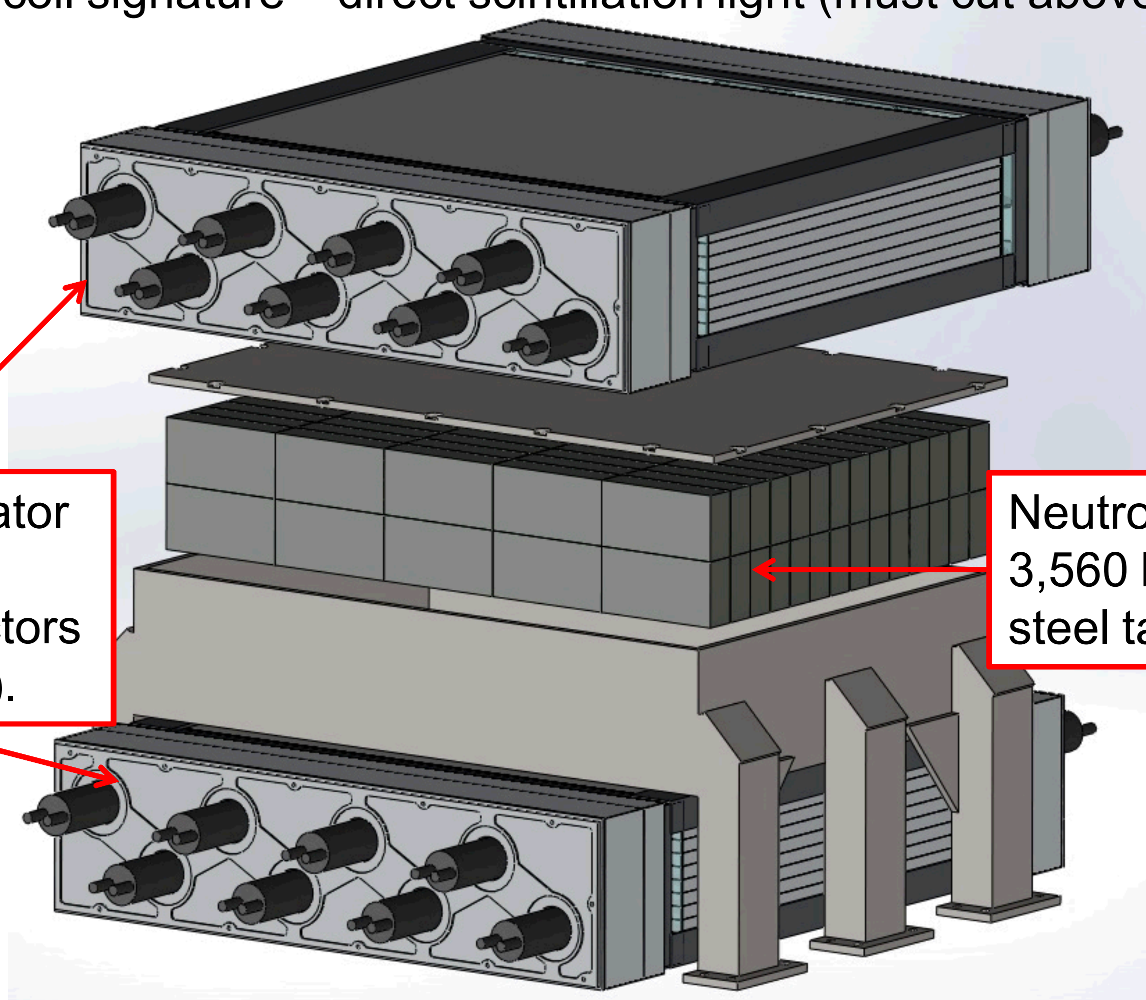
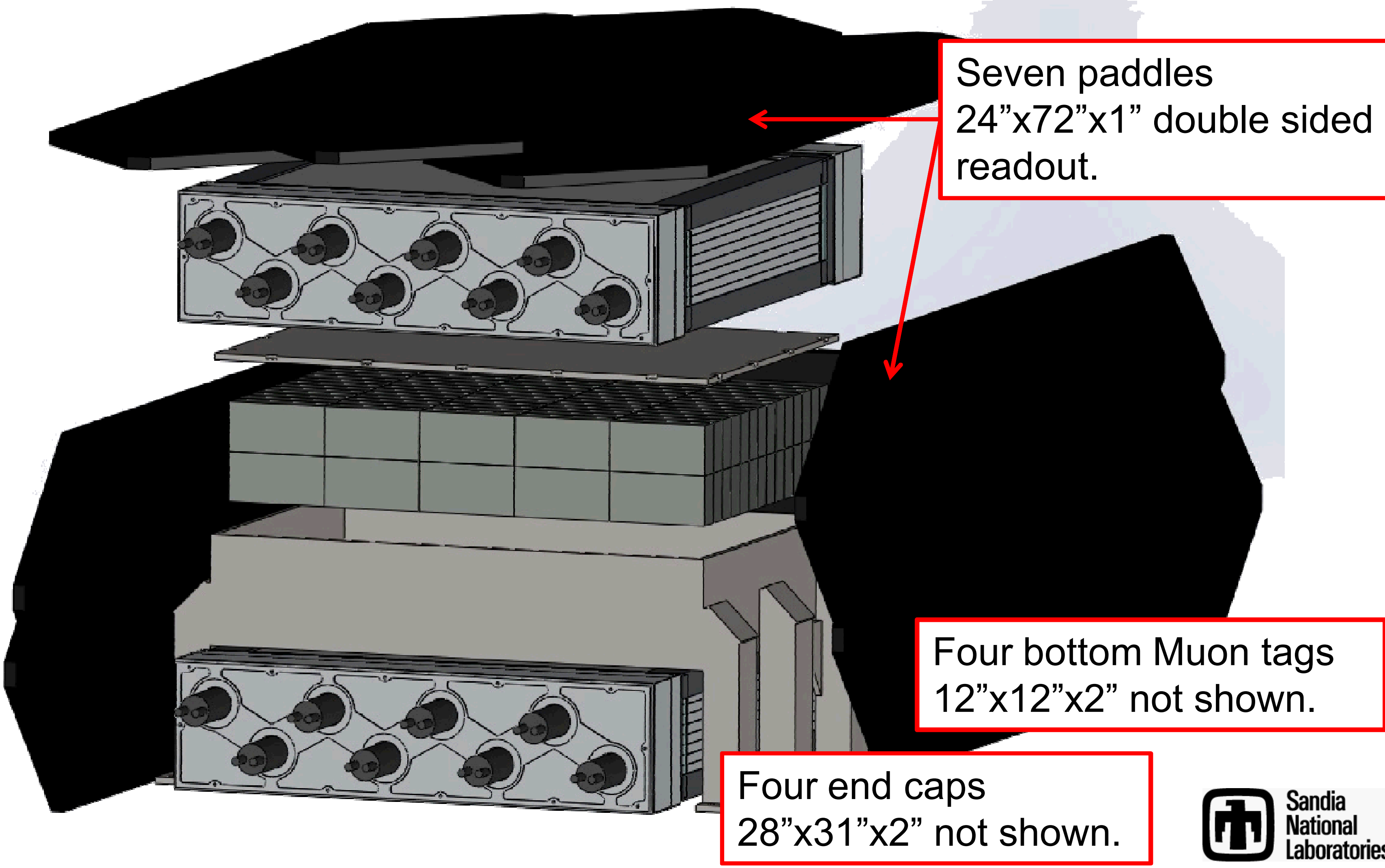
Multiplicity And Recoil Spectrometer (MARS)

- Design based on the Neutron Multiplicity Meter (NMM) deployed at Soudan
  - “Sandwich” designed to captured more neutrons
  - Capture signature - ~8 MeV of gammas from Gd capture.
  - Recoil signature – direct scintillation light (must cut above ~8 MeV).

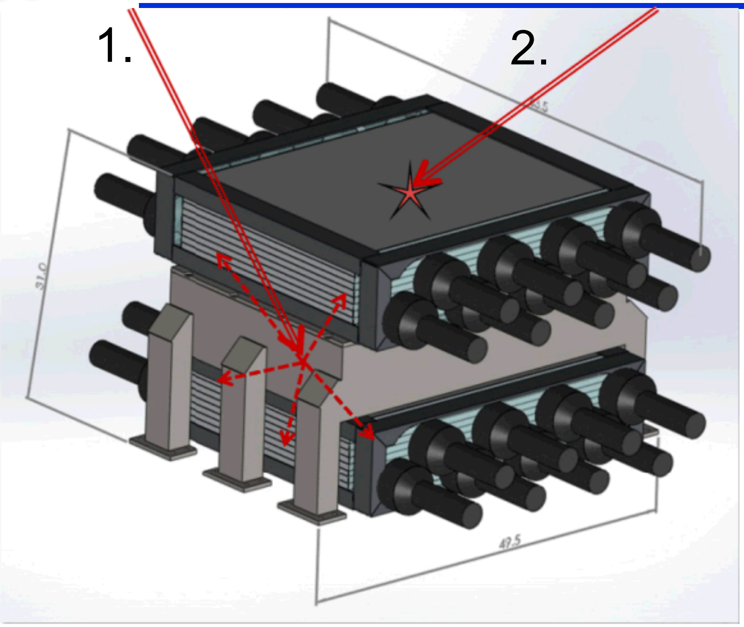


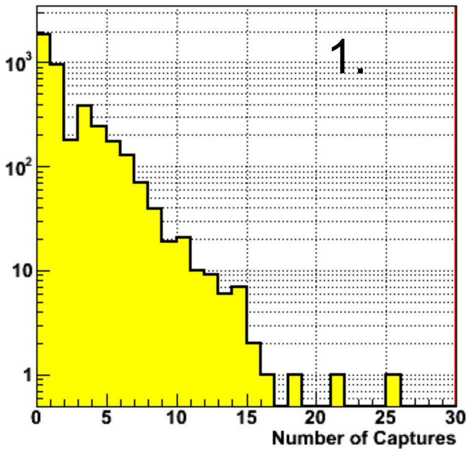
MARS Detector Configuration

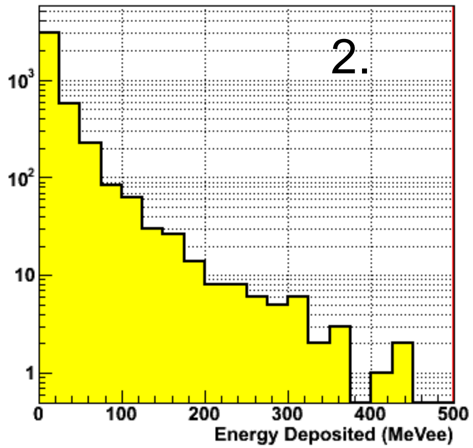
- Muon veto to reject muogenic neutron production within MARS, tagging muon spallation interactions in the lead.



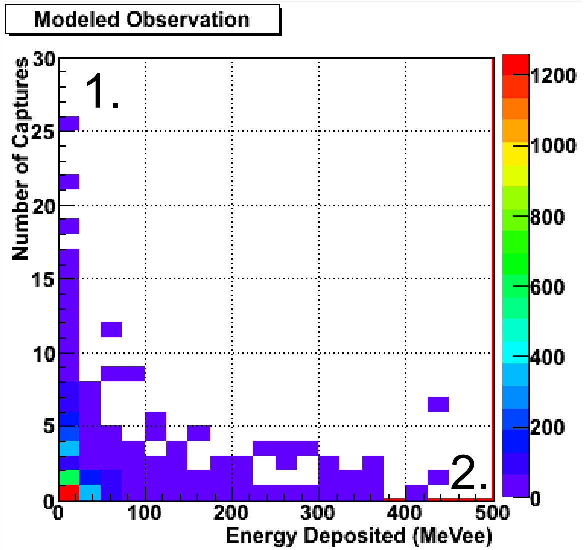
MARS Design







Early Simulation Results



Two Classes of Events:

1. **Multiplicity: (n,kn) in lead converts >30 MeV neutrons into multiple ~1 MeV neutrons. Number of captures incident ∝ energy.**
2. **Recoil: Direct "Prompt" Energy Deposition scintillation light ∝ incident energy (sensitive to ~10 MeV – 100+ MeV)**

Data Acquisition

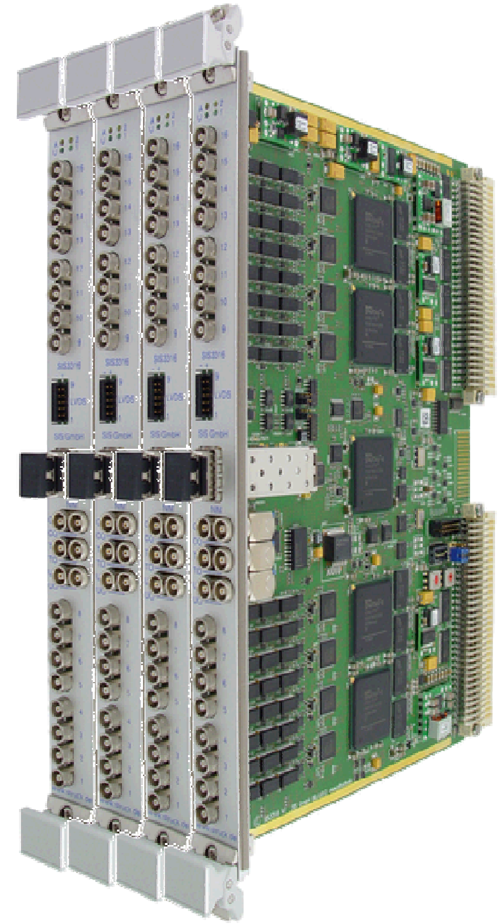
Data Acquisition utilizes 4x Struck 3316 250MSPS 14-bit VME cards controlled by an external FPGA for synchronized timing and control.

All data written out in list mode, with 16x PMT’s from each detector in a dedicated 3316 card. The remaining 22 muon paddle veto channels are distributed through the remaining 2x 3316 cards groups of 4.

This logic setup allows for paddle pairs to be controlled with a common threshold.

Each 16x detector is triggered if the sum of one of its group of 4 goes above threshold.

Veto are arranged to trigger if detectors in the same volume trigger above a threshold, only those channels are read out (pairs and singles only).



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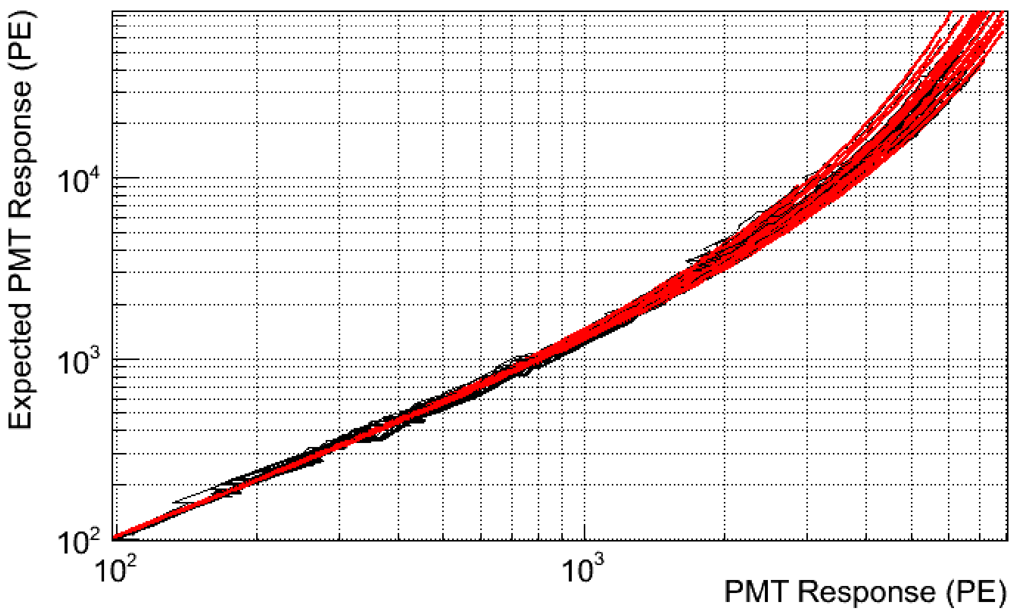
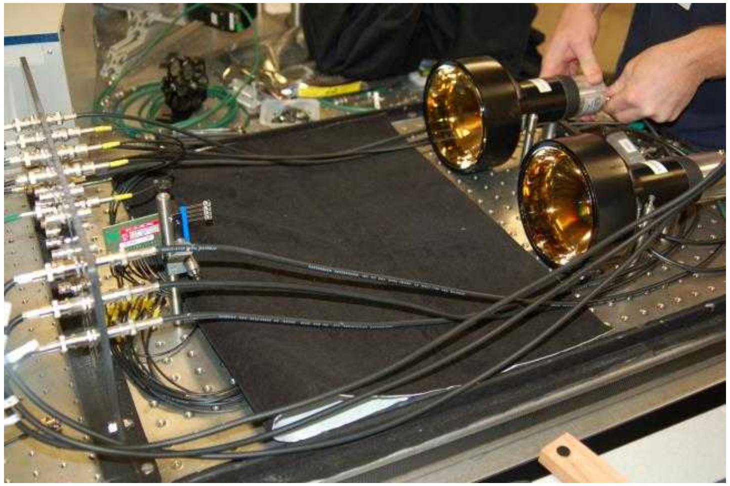
System Testing (early 2013)

- Detector testing was done in several stages:
  - PMT on scintillator cell to set gain.
  - Dark box with LED's to gauge PMT single PE response and non-linearity.
    - Single photoelectron response found for each PMT.
    - Response measured using 4 LEDs over a large dynamic range to quantify non-linearity.
    - 20% non-linearity at ~1000 p.e.
  - Full detector geometry with fixed sources to map position sensitivity.





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Deployment Location: KURF

Kimballton Underground Research Facility (KURF)
Located inside limestone mine.

Drive-in access to multiple levels from 300 – 1500 meters water equivalent (m.w.e.).

Scientific research facility (at ~1450 mwe) managed by Virginia Tech.

Numerous experiments currently operated by V. Tech. and other institutions (local support).

Expected rates from models were used to estimate dwell times at different KURF locations.

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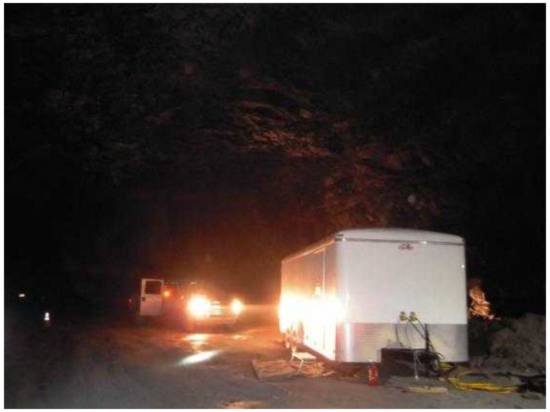
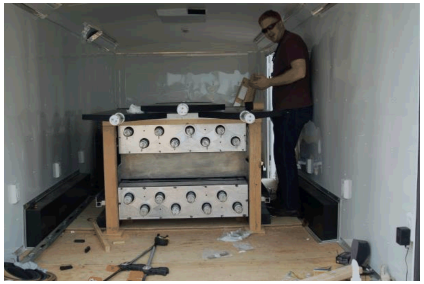
Deployment Depths

- Initially deployed to level 6 at 600 m.w.e. for ~6 months.
- Moved to level 2 at 380 m.w.e. (late 2013, early 2014) for ~3 months.
- Will Deploy at KURF research site at 1,450 m.w.e. for 6-9 months.

Locations chosen to map out low overburden (300-600 m.w.e) as well as the now likely WATCHMAN deployment location for Perry (1,500 m.w.e.).

Deployed June 2013





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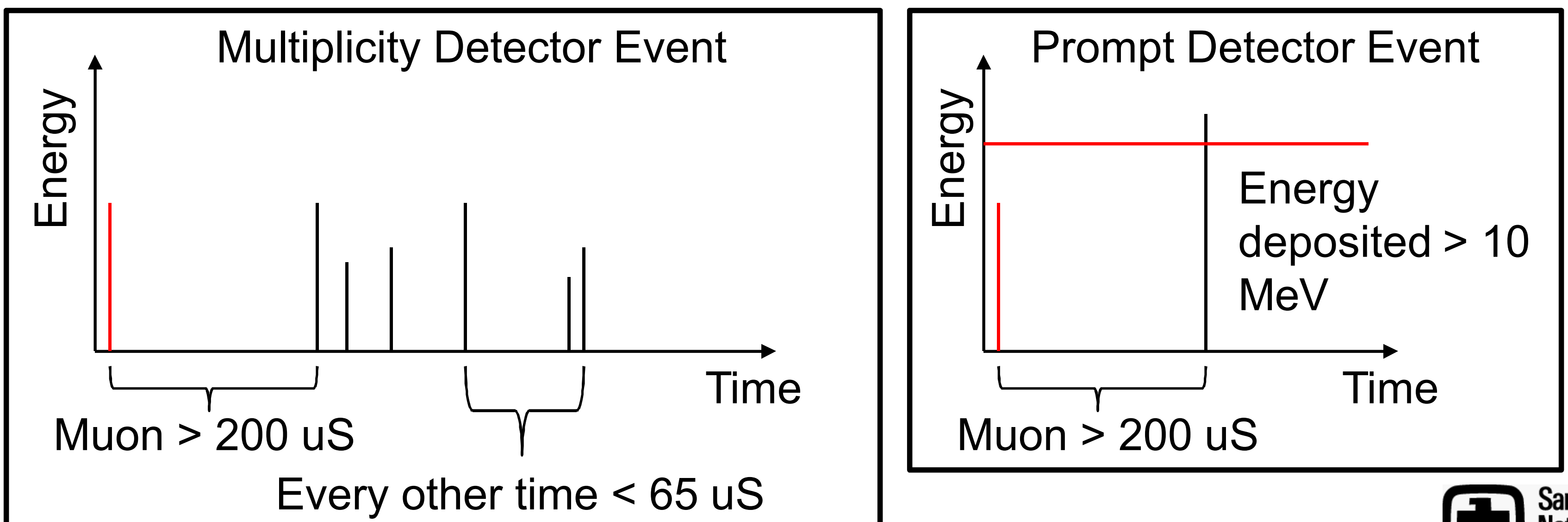
Data Analysis

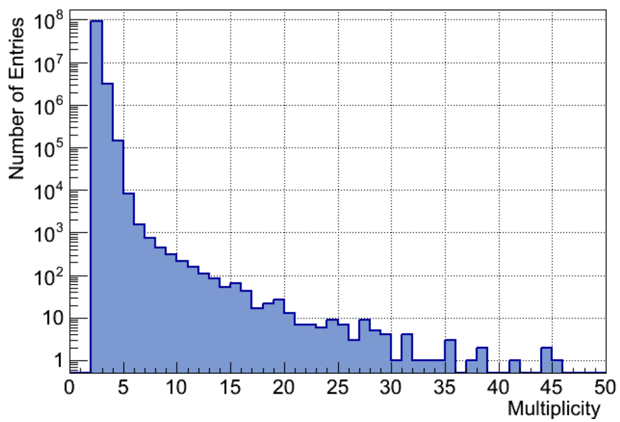
- Filter prompt and multiplicity events out from data using a sliding window that collects detector events where the time between every other event is less than 65 uS.
- Prompt events: Larger than 10 MeV energy deposition in the first event, without an associated multiplicity.
- Multiplicity events: More than 5 events with more than ~660 keV and less than 10 MeV in each event.
- Reject events where a muon paddle registered within 200 uS of the main event, or when a muon interrupts a detector multiplicity.

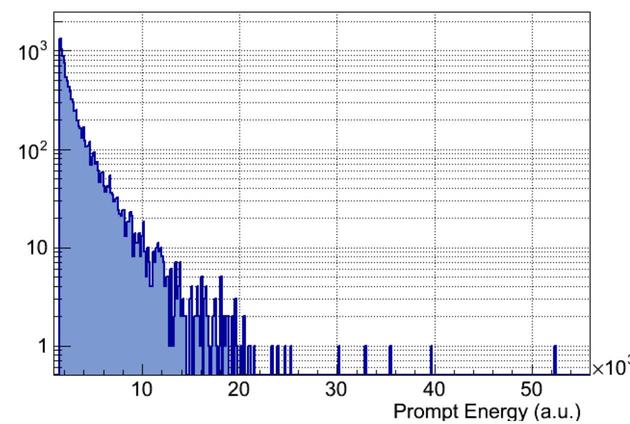


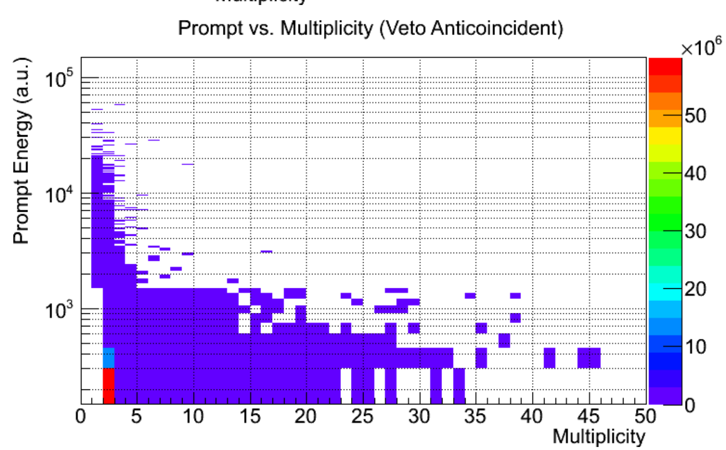
Preliminary Processed Results

Level 6 (600 m.w.e.)
Live time ~16.5 days

Multiplicity (prompt energy ~1-10 MeV) above 5: 3,894 = ~7,080/month (30days)
Prompt (Multiplicity 1-2) and energy above 1 MeV: 9,763 = ~5,370/month



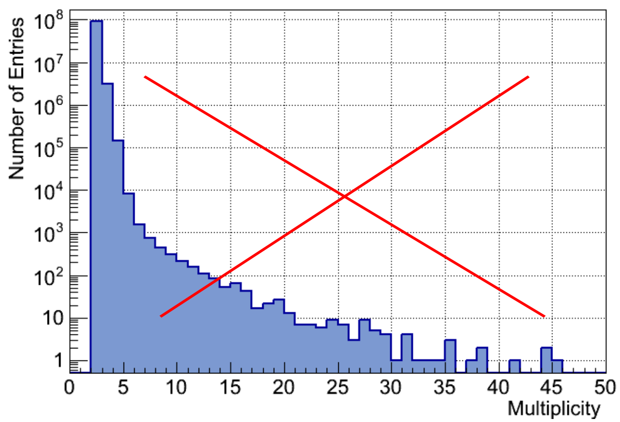


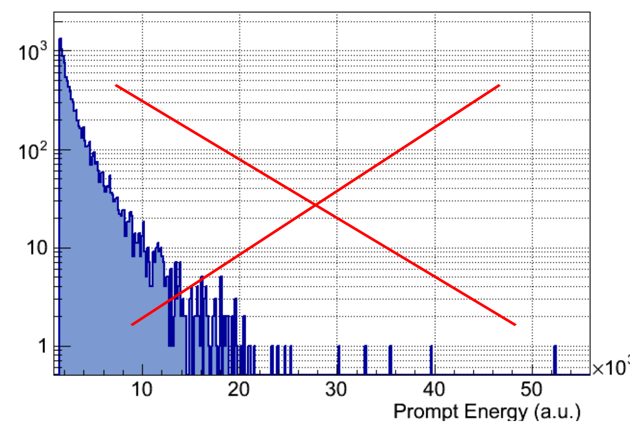


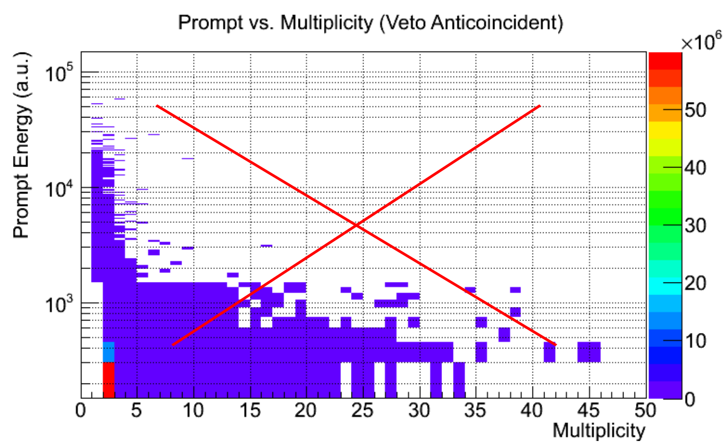
Preliminary Processed Results

Level 2 (380 m.w.e.)
Live time ~x days

Multiplicity (prompt energy ~1-10 MeV) above 5: x = ~x/month (30days)
Prompt (Multiplicity 1-2) and energy above 1 MeV: x = ~x/month







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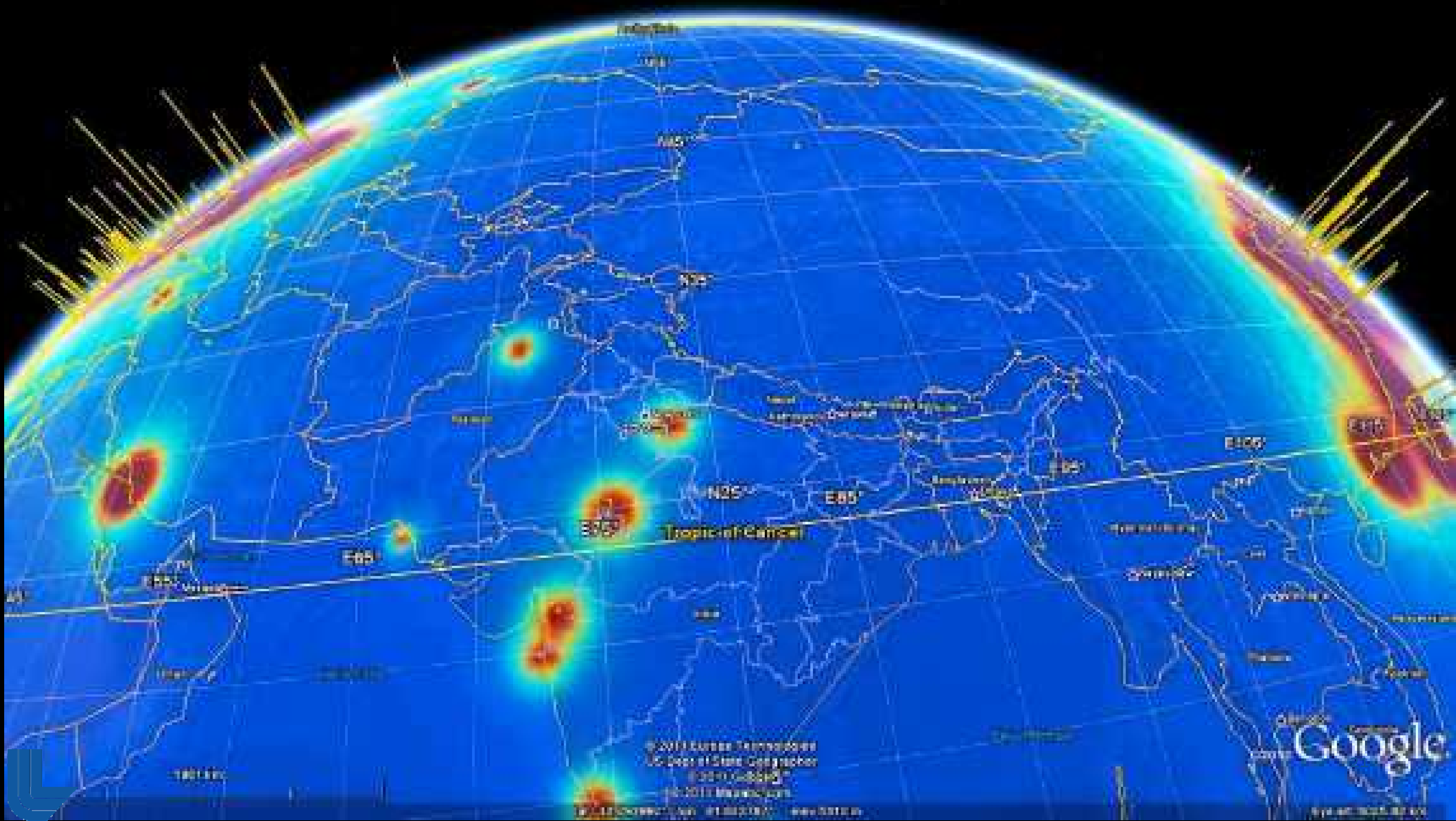
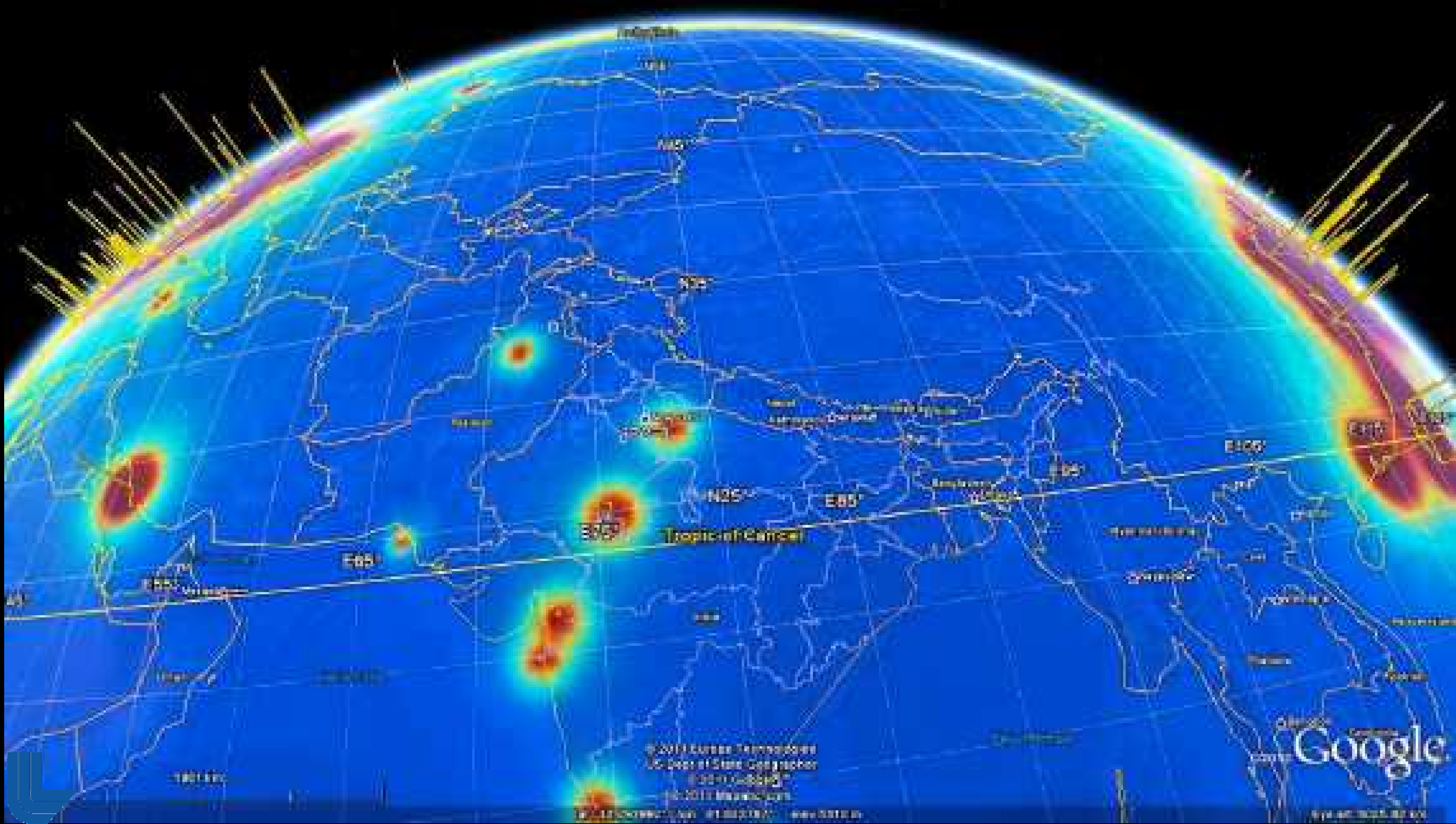
Conclusions

- Wrapping up deployment on level 2 soon and moving to the final location at ~1,500 m.w.e.
- Further analysis needed to unfold true neutron spectrum utilizing simulations.
- Current rates seem to match early estimates.

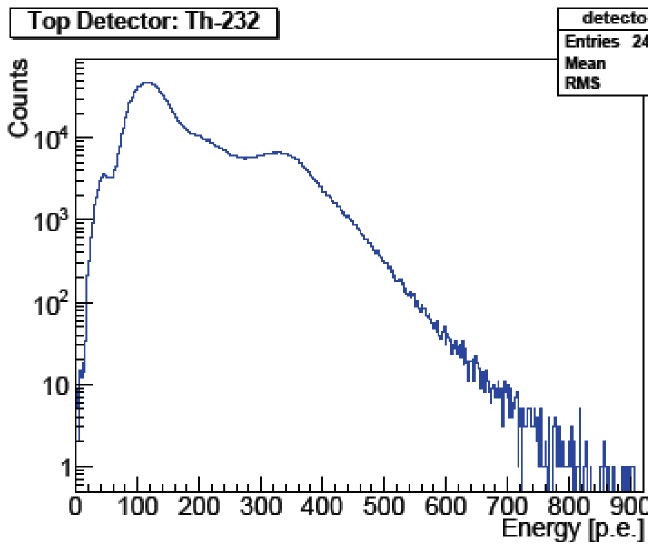
Thank you!

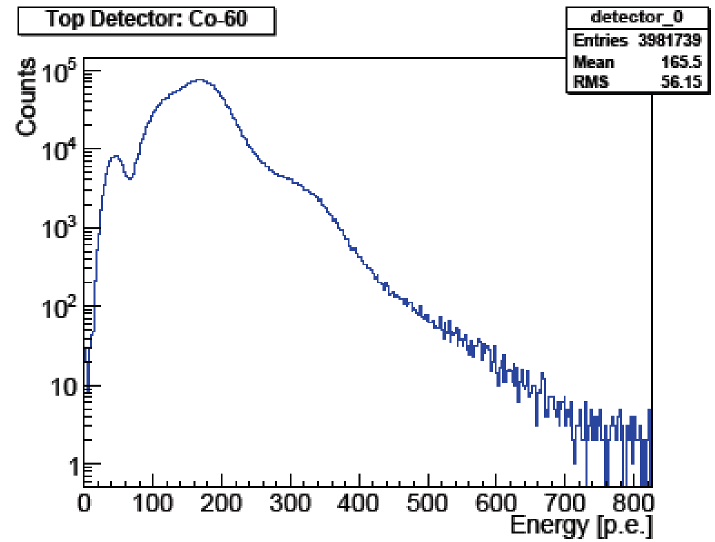


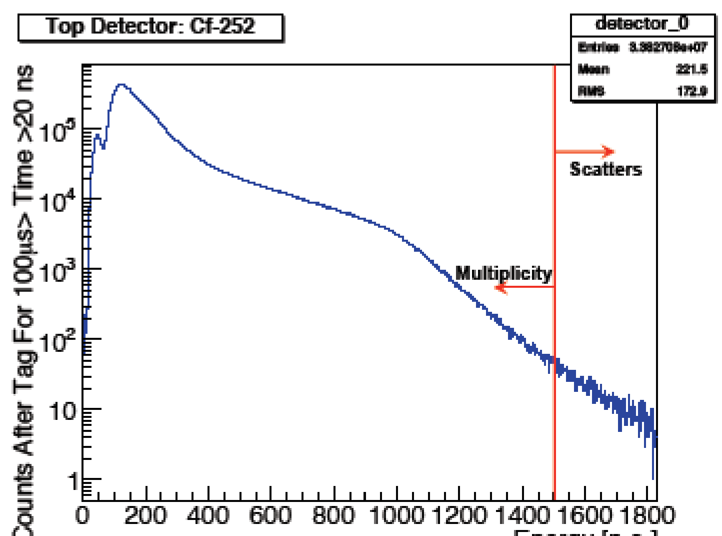
Backup Slides…



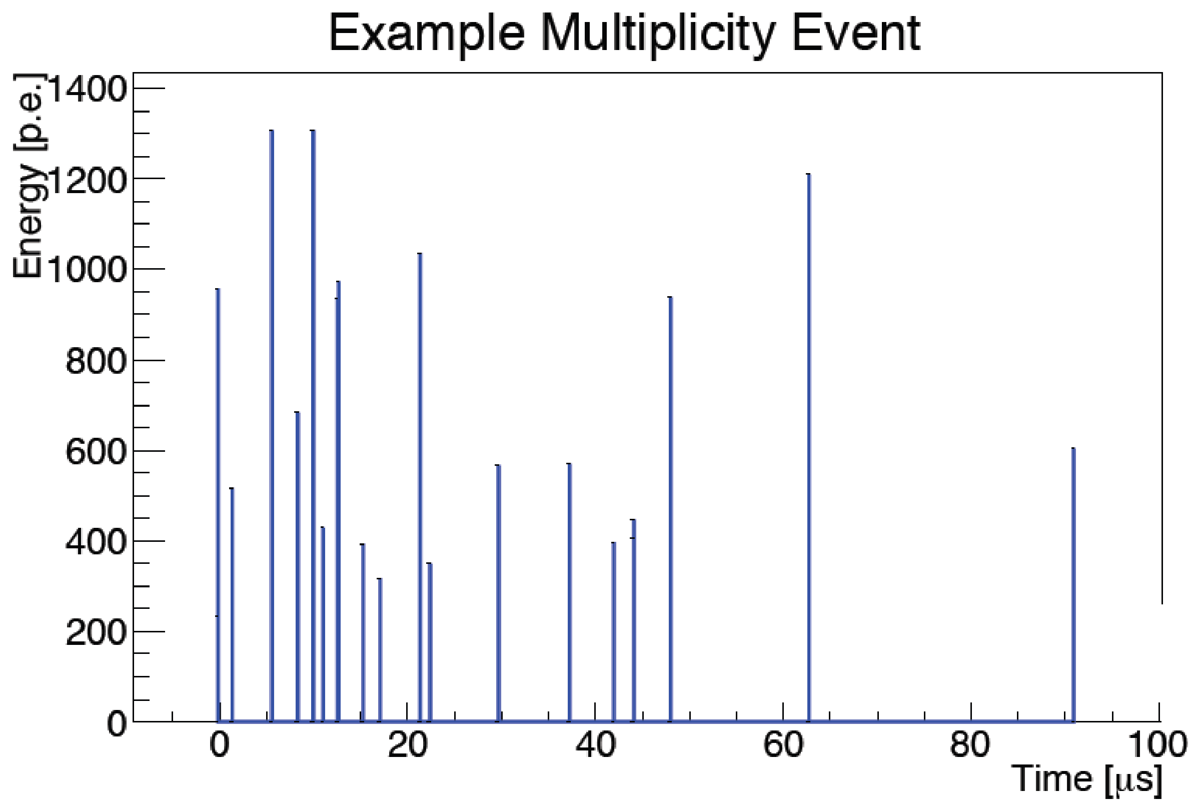
Calibrations







Example Events



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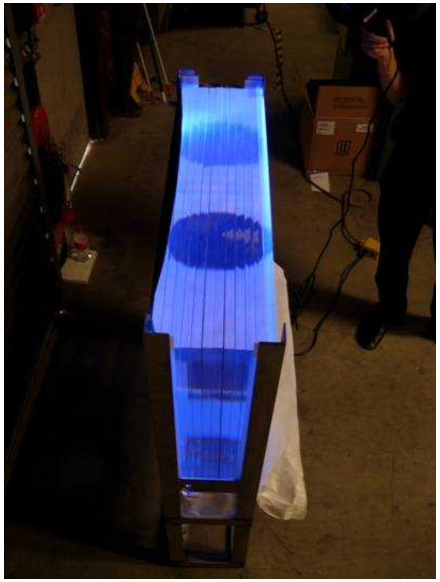
Scintillator Detectors

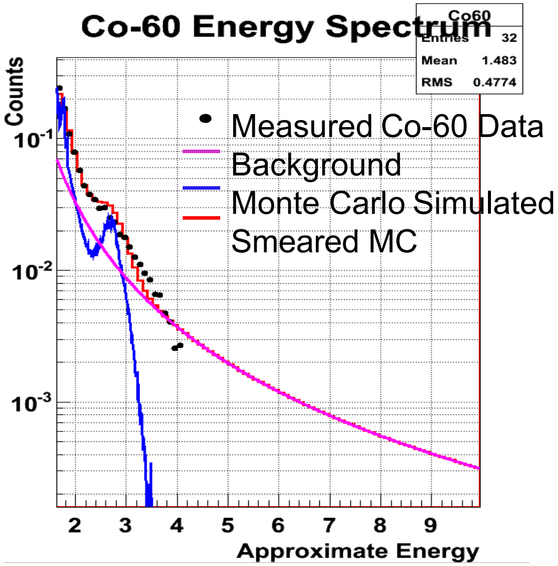
- **Utilized existing detector components to mitigate uncertainty.**
  - **SONGS detector panels: Sheets of 1% Gadolinium paint between layers of 2 cm thick EJ-200 plastic scintillator.**
  - **12 layers total (75 cm x 100 cm)**
  - **Previous deployment utilized four 9" PMT's with acrylic cookies and 4" light guide.**

~ 24% energy resolution at 1 MeVee

~10% light collection efficiency

~1.5 MeVee threshold





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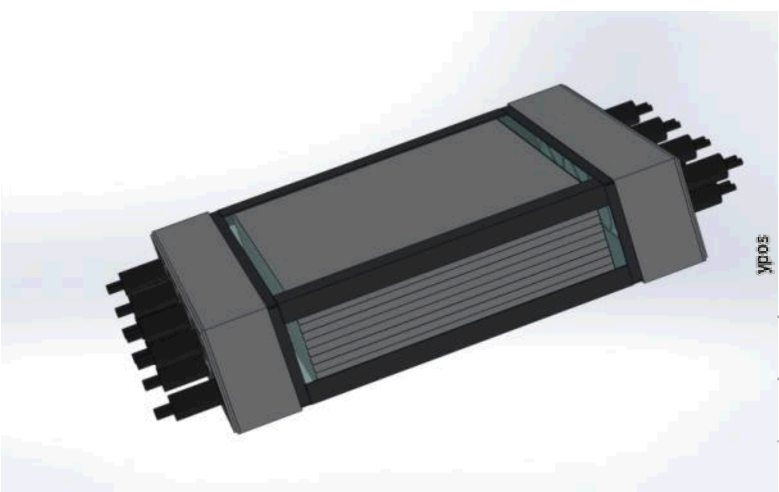
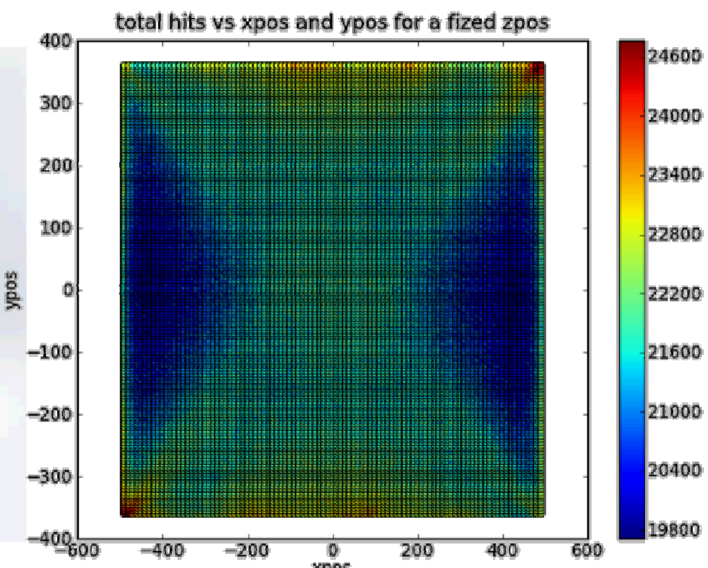
Design Modifications for MARS

- **Converted to utilize 16 - 5" ADIT PMT's on each detectors to improve uniformity of photocathode coverage and linearity at high energies.**
  - **Initial Photon Simulation Results:**
    - **100,000 optical photon simulation (~10 MeVee)**
    - **~22% light collection efficiency**
    - **~10% position variation**
    - **~10% non-linearity at ~1000 PE**
    - **Expected linear response up to ~36 MeVee at the center and ~10 MeVee at the edges.**



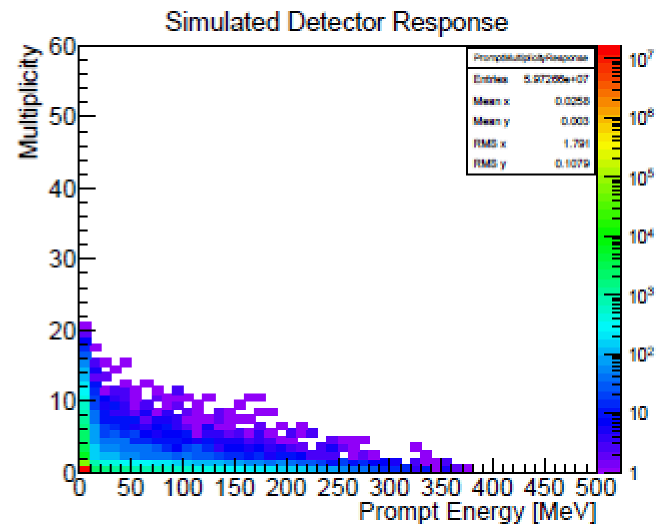


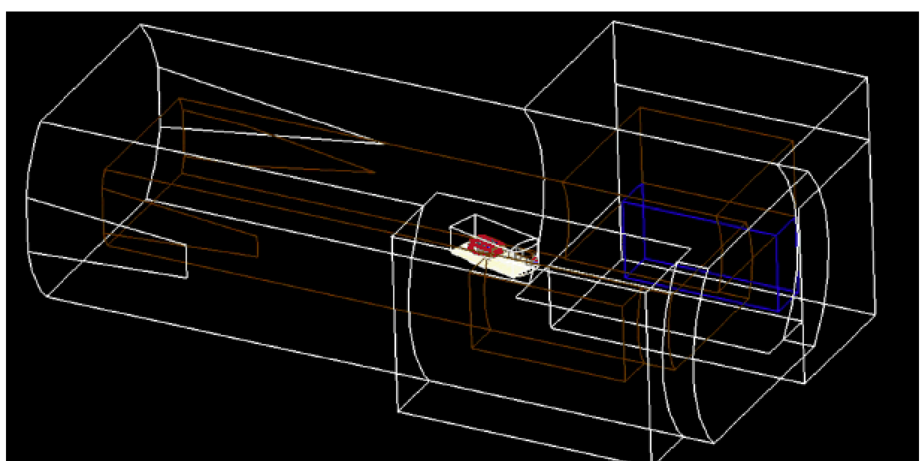
Geant4 Simulation

Initially simulate flat energy distribution of fast neutrons from cavern walls

In the future simulate muon propagation through rock layer around cavern folding in overburden

Model response will be used to unfold energy spectra using experimental data using Maximum Likelihood Estimation Maximization (MLEM).





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