SAND2015-2055PE

# Fast Neutron Backgrounds As A Function Of Depth Underground

## LRT 2015

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For The WATCHMAN Collaboration

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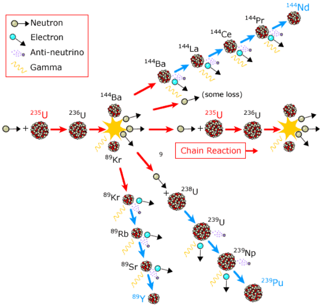
# Outline

1. Motivation
2. Measurement concept
3. Detector design
4. Detector characterization
5. Preliminary results
6. Conclusions + Future Work

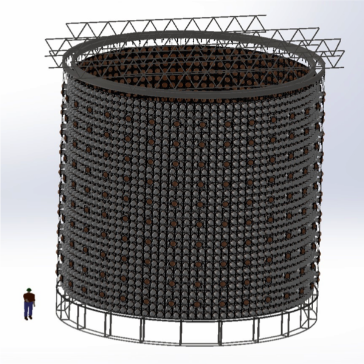
# Monitoring Weapons Usable Material in Reactors

# WATer CHerenkov Monitor of AntiNeutrinos



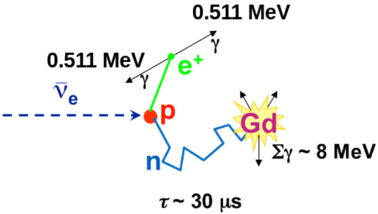

1. $\sim$6 antineutrinos per fission
2. $\sim$2x$10^{17}$ antineutrinos per second per MegaWatt thermal

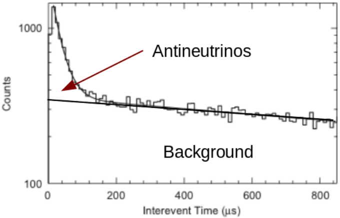
1. 16m x 16m 304 SS tank
2. Optically clean water
3. 0.1% Gd by weight



# If It Barely Interacts How Do We Detect It?

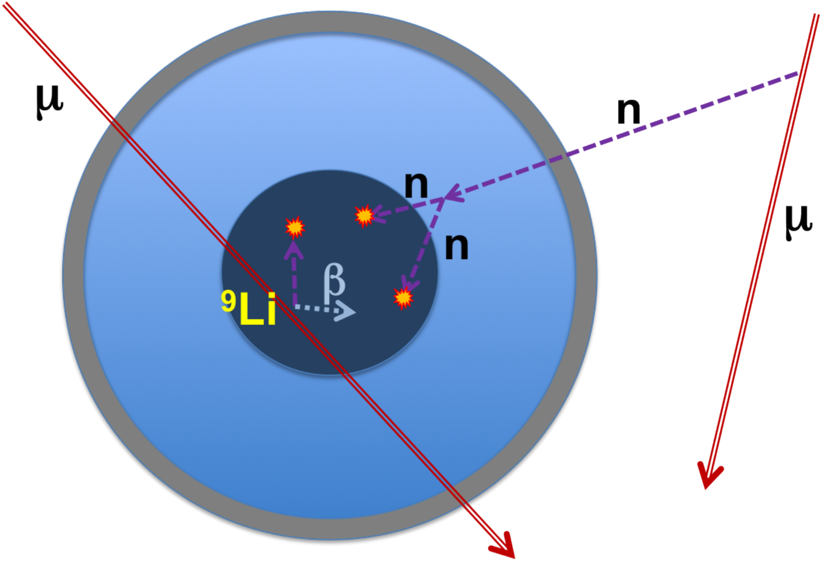
1. Antineutrino occasionally undergoes inverse-beta decay
2. Positron then the neutron each produce a short pulse of light
3. Light is detected with a sensor in the detector
4. Coincident light pulses are a nearly unique signature of an antineutrino interaction



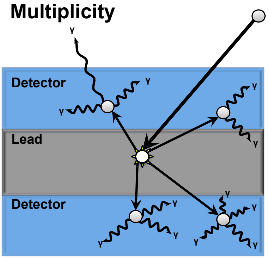

*N.S. Bowden et. al, NIM A* **572** *(2007) 985-998*

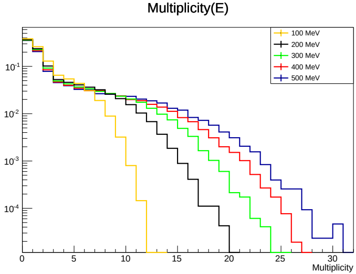
# Time Correlated Backgrounds Are Initiated From Nearby Or Through-Going Muon



# Measurement Concept For The Neutron Energy

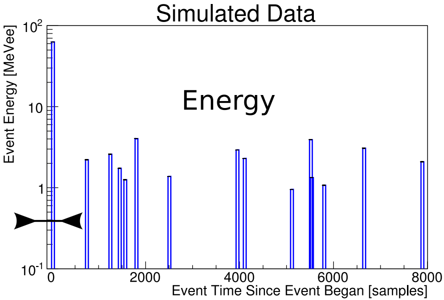
1. Use spallation reaction (n,kn)
2. k $\propto$ Energy of neutron
3. Use hydrogenous media to quickly thermalize neutrons
4. Neutrons capture on Gd dopant



# Unfolding Requires More Information Than Just Multiplicity

1. Initial elastic scatter energy



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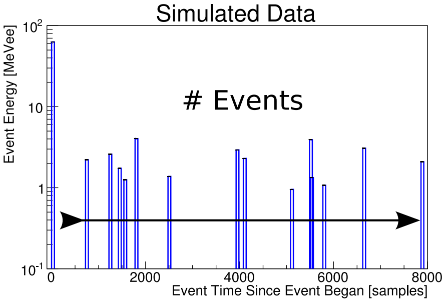
1. Initial elastic scatter energy
2. Gd captures and showers ($\sim$8 MeV) "multiplicity"



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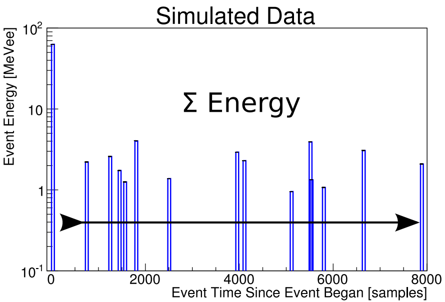

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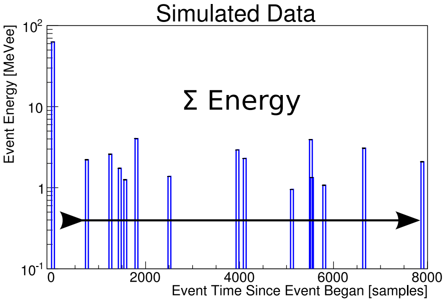
4. Solve using MLEM approach



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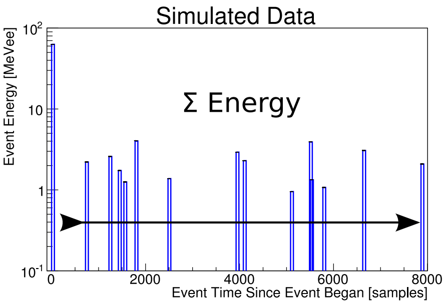
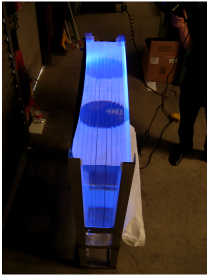
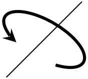
2. Gd captures and showers (∼8 MeV) "multiplicity"
3. Total energy from Gd shower in multiplicity sequence
4. Solve using MLEM approach
5. Detector response from simulation+calibrations

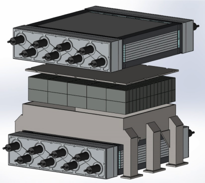


# MARS Design: Capture-Gated Spectrometer and Multiplicity Meter

1. 12 1.0x0.75x0.025$m^3$ plastic scintillator sheets
2. Plastic sheets coated with white Gd doped paint
3. 16 PMTs split between 2 sides per detector
4. Lead neutron amplifier between two detectors

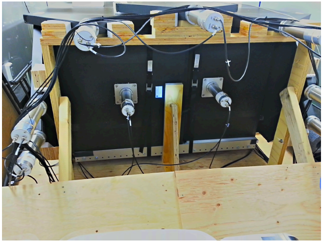






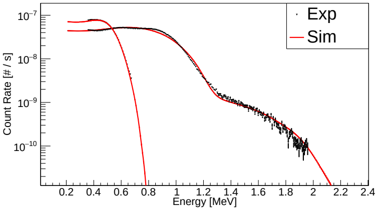
# MARS Neutron Measurement Campaign at KURF

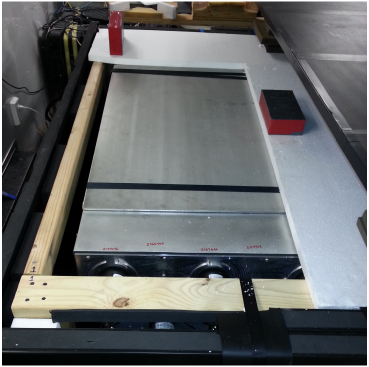
1. Measurements taken at 380 and 600 m.w.e.
2. Several thousand high energy neutron events at both 380 and 600 m.w.e.
3. Ongoing measurement at 1450 m.w.e.

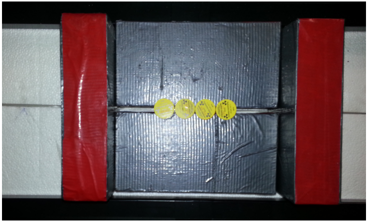


# Measuring The Position Dependent Response

1. Mapped response
   - 5x5 grid on the top detector
   - 3 positions in the long 2 PMT vetoes
   - 2 positions in the square 1 PMT vetoes
2. Collimated Cs137/Co60 source
3. Smear simulated response
4. Minimize $\chi^2$

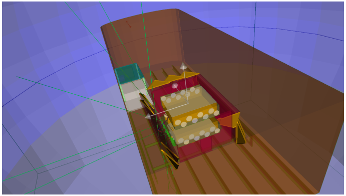


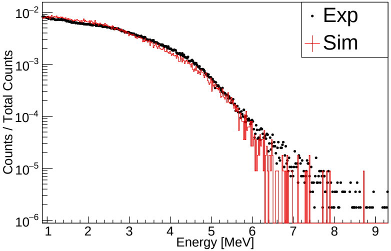





# Detector Characterization Of Tagged Cf252 Source

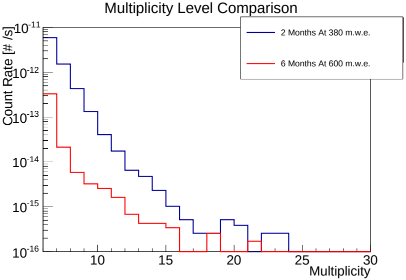
1. Apply detector response to simulation
2. Require >3 events between 100$ns$ and 100$\mu s$ after tag
3. Calculate total efficiency based upon ratio of higher order multiplicity events
4. Able to tune Gd concentration based upon capture time and total efficiency

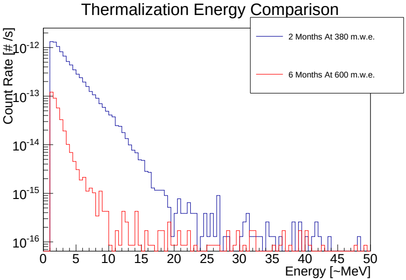


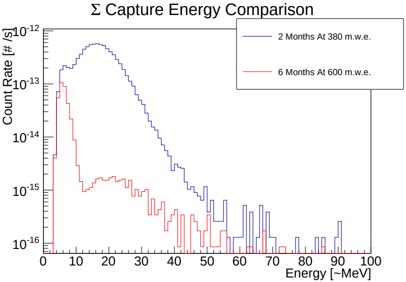


# Experimental Results At KURF

1. Require 6 multiplicity, 500 keV per deposition
2. Count rate decreases as a function of depth

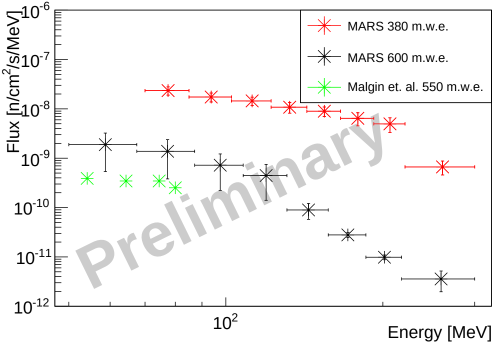


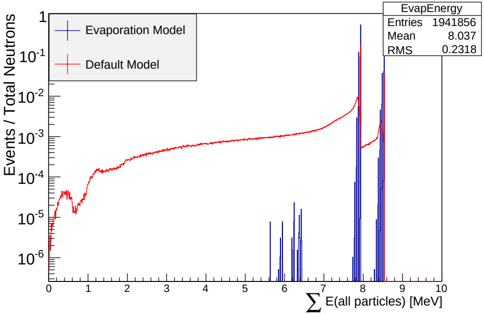
# Preliminary Results

1. Assume one neutron per interaction
2. Assume smooth result
3. Use MLEM to reconstruct spectra
4. Generate error bars from different multiplicity requirements



# Why The Preliminary Results Are Wrong

1. Uncertainty in depth at 600 m.w.e. measurement
2. Poor background rejection at 600 m.w.e.
3. Default Geant4 Gd capture model does not conserve Q value
4. Geant4 evaporation model changes tuned capture time $\rightarrow$ different Gd loading



# Conclusions

1. A spallation based multiplicity detector has been constructed to measure the high energy neutron flux as a function of depth underground
2. The detector response has been characterized by gamma ray sources and thermal neutrons
3. MLEM has been used to unfold preliminary results

# Future Work

1. Tune Gd loading based upon Cf252 response
2. Re-simulate detector response with correct Geant4 models
3. Use detector singles data to simulate background contamination
4. Unfold results with updated model at all 3 levels
5. Perform surface measurement next month to validate underground results

# Institutions And Disclaimer

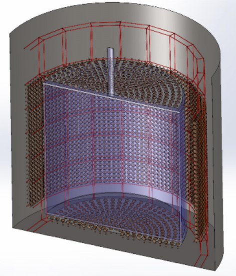
This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number: DE-NA0000979 through the Nuclear Science and Security Consortium.

# Backup Slides

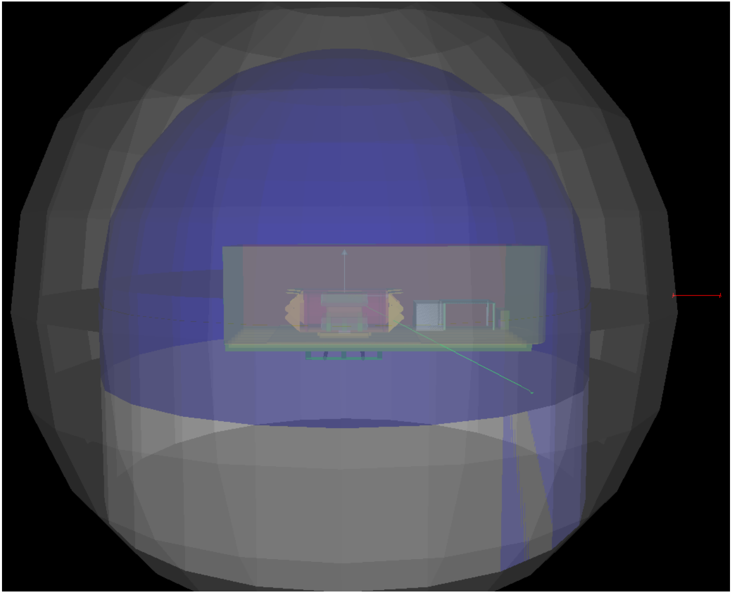
# WATCHMAN Deployment Options

## 1 kton fiducial Gd-water detector

1. Low Power Reactor
   - Relatively shallow depth (100 meter)
   - Relatively high background
   - Relatively close (1 km)
2. High Power Reactor
   - Relatively deep depth (500 meter)
   - Relatively low background
   - Relatively far (10 km)



# Geant4.9.6.p02 Simulation



# How To Unfold A Signal That Is Not Directly Measured

**Solve** $g(\vec{y}) = \int A(E, \vec{y}) f(E)\, dE + b(\vec{y})$

1. g($\vec{y}$) is the measured data space
2. f(E) is the energy spectrum we want
3. A(E,$\vec{y}$) is the kernel from simulation: predicted relationship between energy and the measured data space
4. b($\vec{y}$) is the background, typically measured

# Neutron Energy Spectrum Unfolding - MLEM

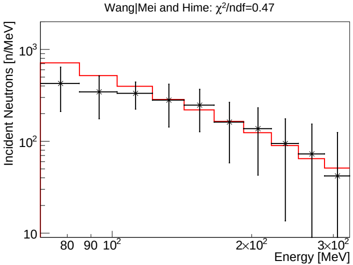
**General Algorithm: Solve** $g(\vec{y}) = \int A(E,\vec{y}) f(E)\; dx + b(\vec{y})$

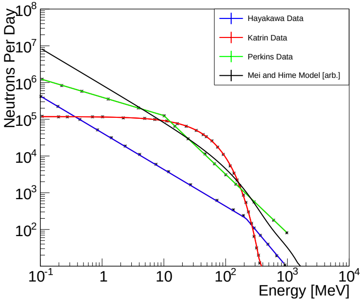
1. Discretize $\vec{g}_{meas} = \mathbf{A}\vec{f} + \vec{b},\;\; \vec{g}^{k}_{pred} = \mathbf{A}\vec{f}^{k}$
2. Likelihood $L^{k}(f) = \prod_{i=1}^{n} P(g_{meas,i} | g^{k}_{pred,i})$
3. Find $Min\Big(-ln[L^{k}(f)]\Big)$ or $Min\left(-ln[L^{k}(f)] + \beta R(E)\right)$

$$f^{k+1}_{j,unreg} = \frac{f^{k}_{j}}{\sum_{i=1}^{n} \mathbf{A}_{ij}} \sum_{i=1}^{n} \mathbf{A}_{ij} \frac{g_{meas,i}}{g_{pred,i}},\;\; iff\;\; \beta = 0$$

# Simulation Test Case Of Algorithm

1. Simulate kernel **A**
2. Separate simulation of expected spectrum
3. Require 6 multiplicity, 500 keV per deposition
4. Other spectra from Palo Verde paper



# Simulated Unfolding Results

1. Initial kernel had sparse statistics at lower neutron energy
2. Good agreement above 100 MeV
3. No background in model