Lawrence Livermore National Laboratory

Water-based Antineutrino detector at SONGS

Steven Dazeley Oct 11, 2011

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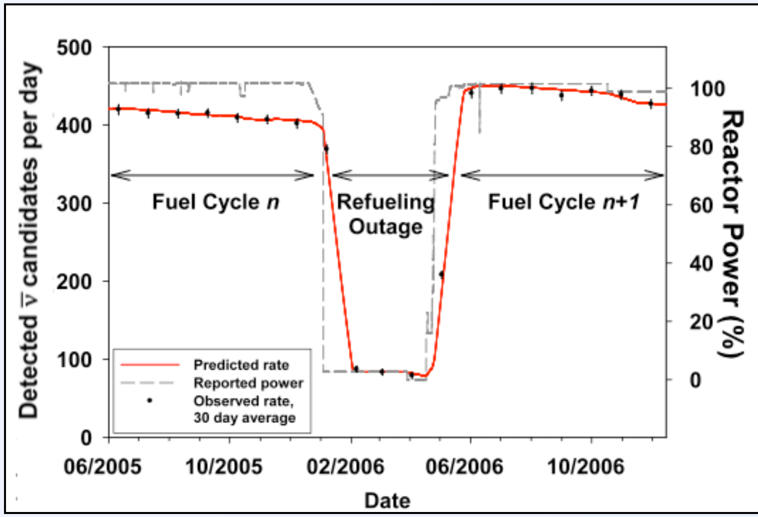
LLNL-PRES-503991

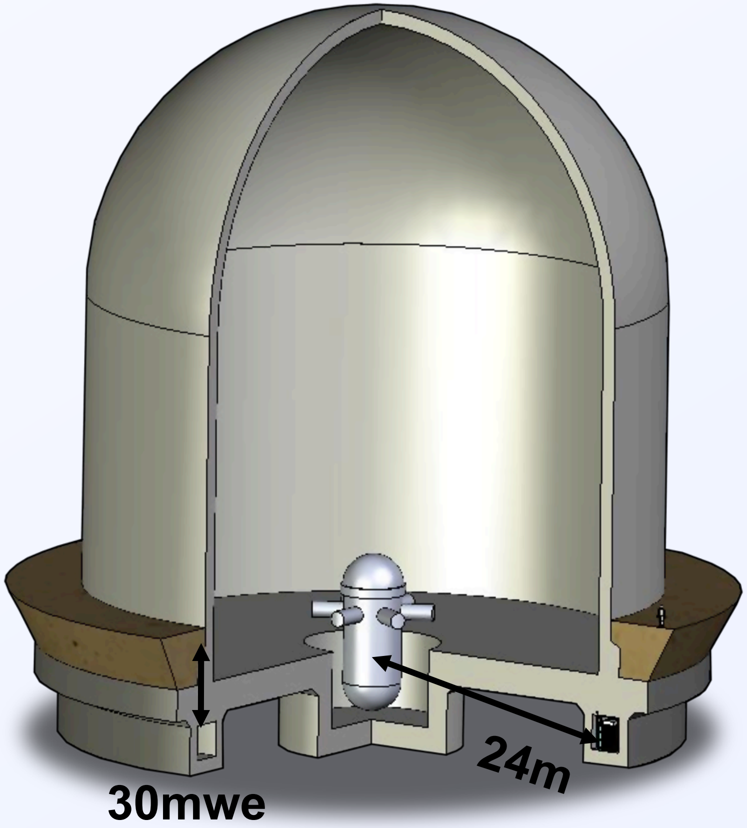
The San Onofre Nuclear Generating Station: Our (nonproliferation) laboratory for over a decade

Direct Observation of reactor fuel burnup via antineutrino counting



- We have cultivated an exceptionally strong and trusting relationship with SONGS:
  - A multitude of access requests have been readily granted since 1999
  - Provide unescorted reactor access, deployment assistance, commercially sensitive fueling data, introductions to other operators, …..
- We possess unparalleled operational experience in this industrial environment:
  - **Five** detector deployments since 2003

Tendon Galleries are Ideal Deployment Locations



- High Flux: ~10^{17} $\nu/m^2/s$
- 130-180m to other reactor
- Gallery is annular – unfortunately no possibility to vary baseline

SONGS Signal and Backgrounds

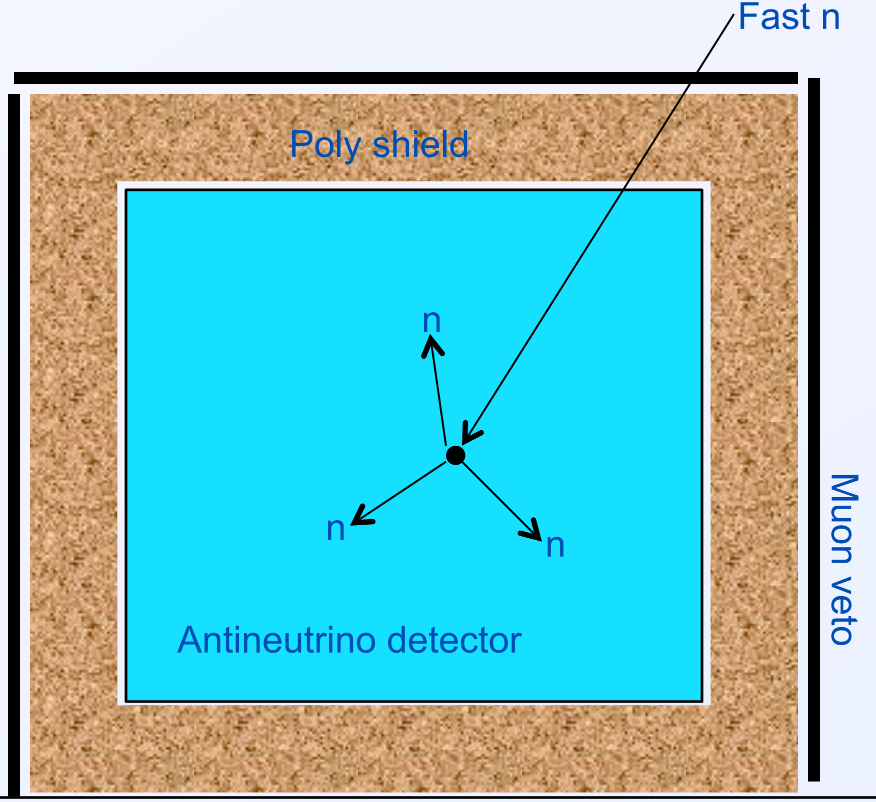
- Our SONGS1 detector (20 meters water equiv. underground, 25 meters from core) had S/B of ~4/1
- Background was primarily:
  - Fast neutron recoil followed by capture
  - Multiple neutron capture

- Above ground possible?
  - Many more potential deployment sites
  - There may not be a tendon gallery at every reactor

- Water SONGS particulars
  - Technology choices driven by need to defeat cosmogenic fast neutrons,
  - Neutron flux ~ up to 10^3 x below ground site
  - Antineutrino flux (50 meters from core) ~¼ SONGS1 flux

Above-Ground Water-Detector backgrounds

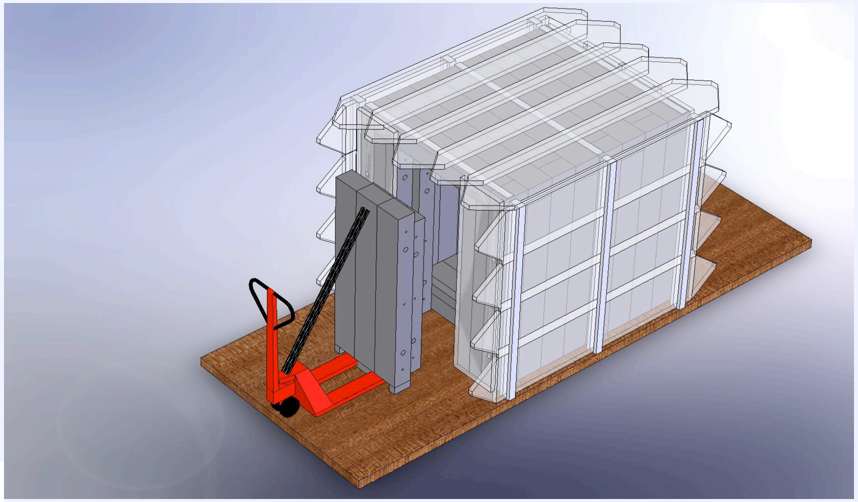
- Major background is now – fast (100s MeV) neutron spallating inside an oxygen (say) nucleus inside detector → multiple neutron captures
  - Fast neutrons are missed by the muon veto surrounding the detector

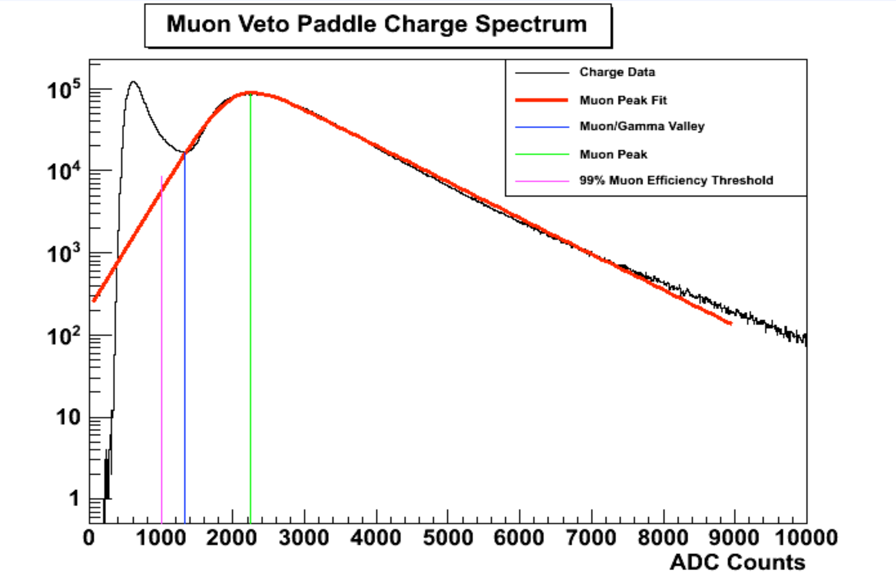


Cosmogenic shielding and Muon veto

Fast neutron shield

- Between 40cm and 60cm poly shielding on all sides
- Inner 2.5cm is borated poly



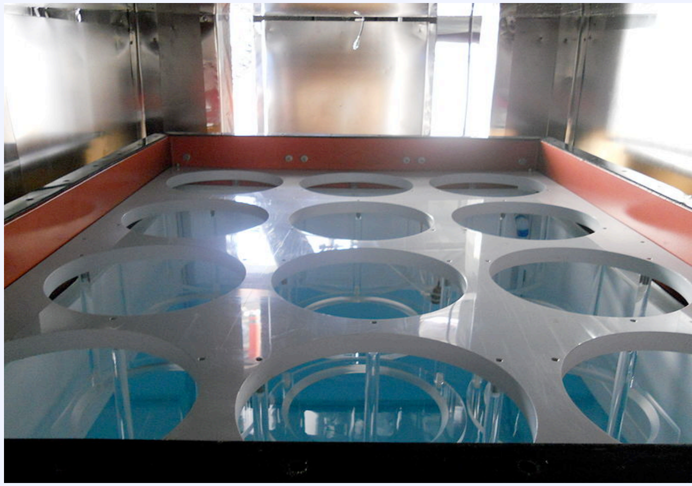


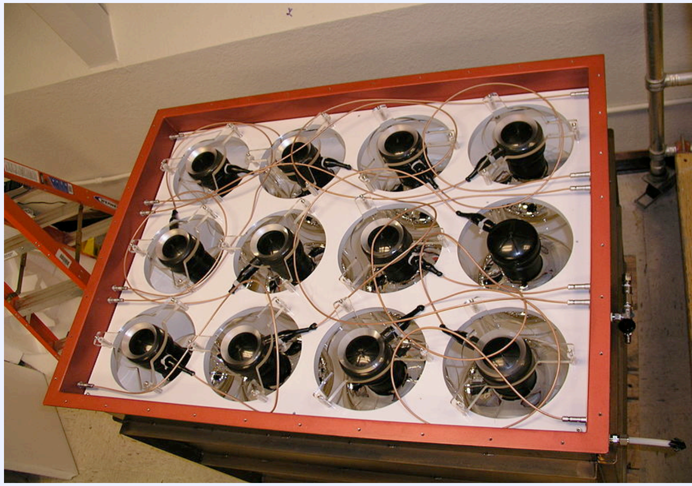
Muon Veto

- Muon paddles – 5cm thick overlapping plastic scintillator paddles
- Muon peak generally fits to a sigmoid multiplied by an exponential. We use the low energy tail to predict approx efficiency versus energy cut
- 99% analysis threshold used
- Veto time – 100 microseconds – 20% dead time
- Estimated efficiency (from data) → 98.5%

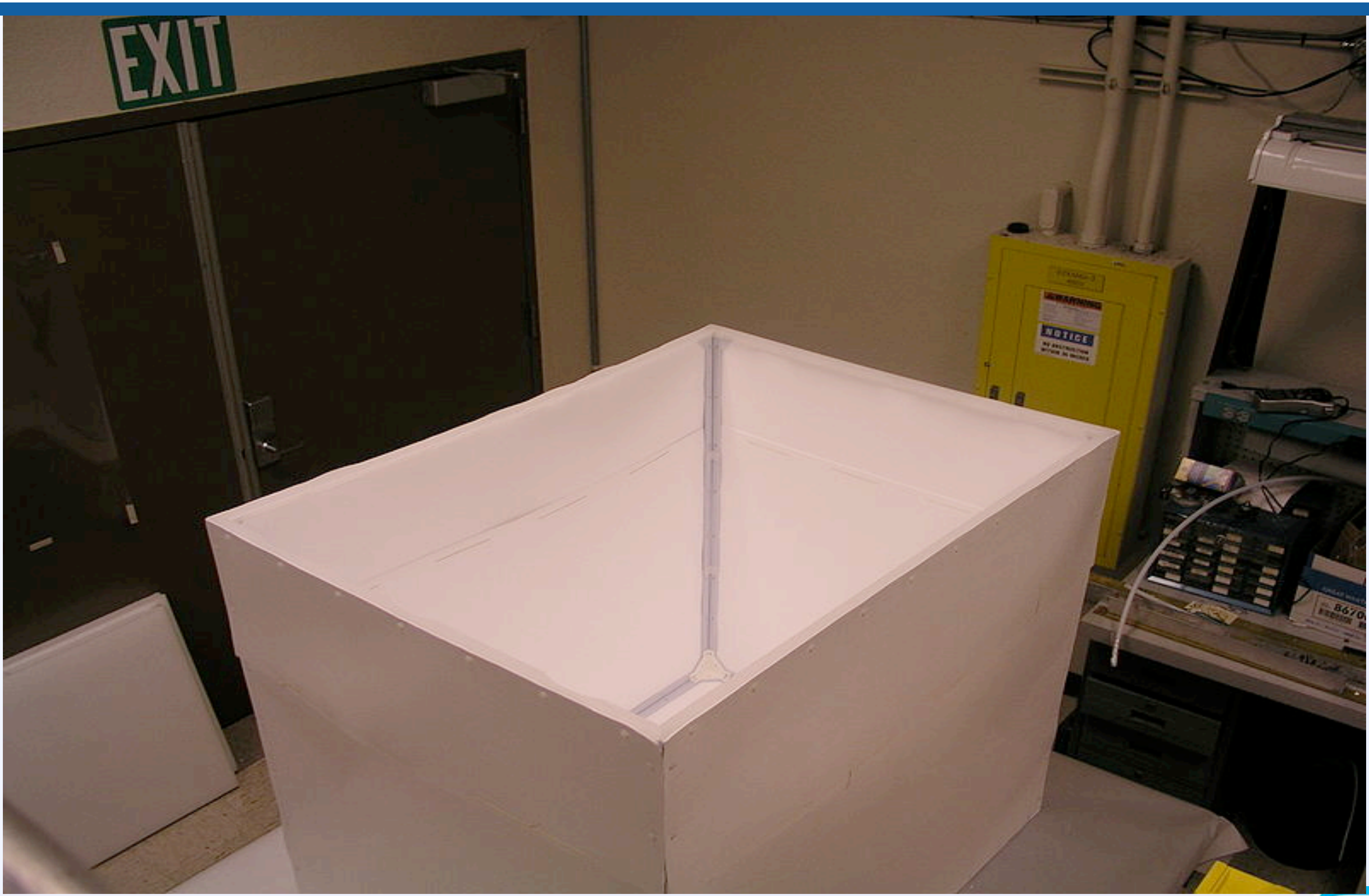
Inner (Water) Detector

- ~ 1-tonne pure DI water + 0.2% $GdCl_3$
- 12 x 10-inch Hammatsu PMTs arranged on top of water looking DOWN
- Stainless steel tank with baked Teflon interior
- GORE-DRP diffuse reflective (99%) walls
- DAQ – PMT signals 23 MHz low-pass filters → CAEN V975 x10 fast amps → Struck 200MHz SIS3320 waveform digitizers
- Trigger rate ~ 700Hz inside poly shield (300Hz of that from muons)
- Excellent single PE resolution





Few words about the (important) details



Shield Construction (Designed and built at Sandia Natl. Lab.)

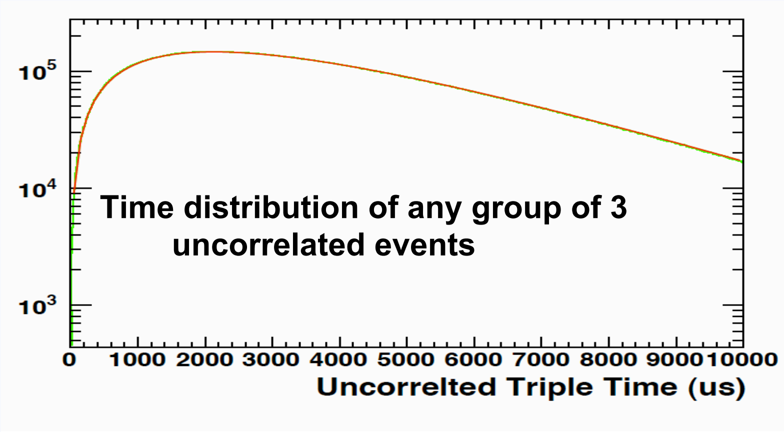
Shield Construction

Installing Inner detector

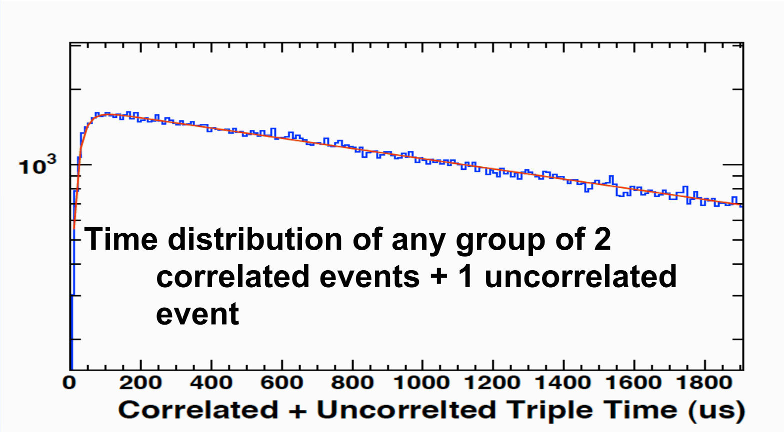
Cosmogenic neutron backgrounds

Antineutrino signature is a simple correlated two events - how many correlated neutron pairs are part of a triple? Quadruple? etc

Distributions of event times are well understood – simple analytical function fits are very good

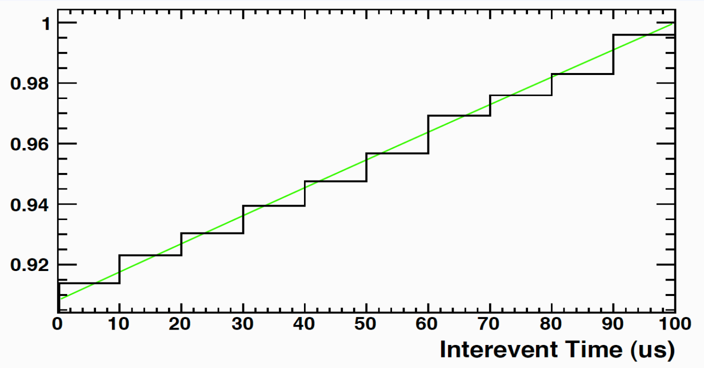


Time distribution of any group of 3 uncorrelated events



Time distribution of any group of 2 correlated events + 1 uncorrelated event

Correlated event pair efficiency as a function of inter-event time after multiple neutron cut

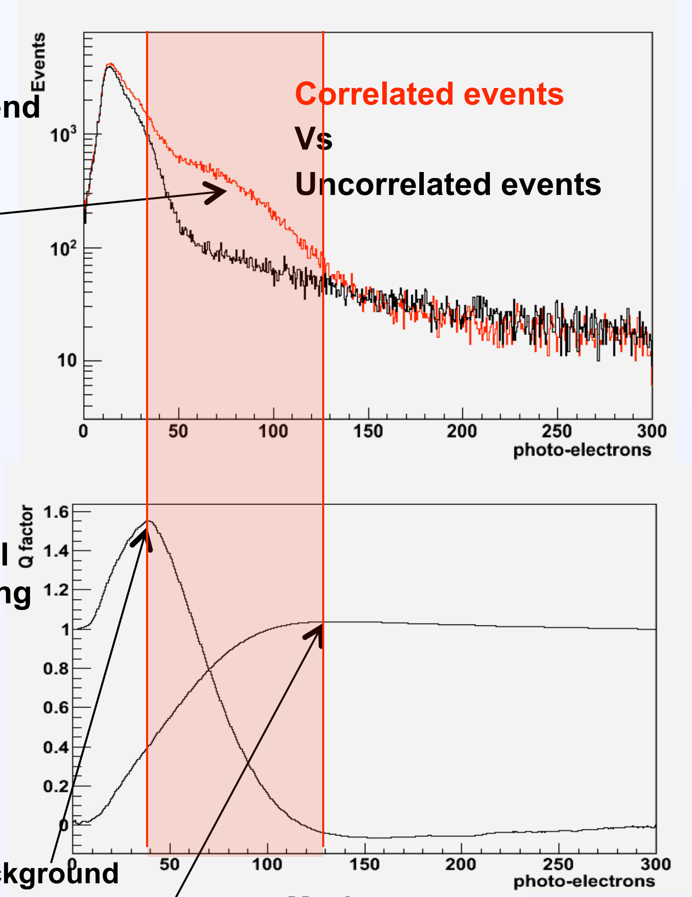


Neutron Selection, rates

Selecting Neutrons – detector response

Correlated events tend to have a higher neutron capture component

- higher detector response



Q factor – statistical advantage of applying an analysis cut at some value.

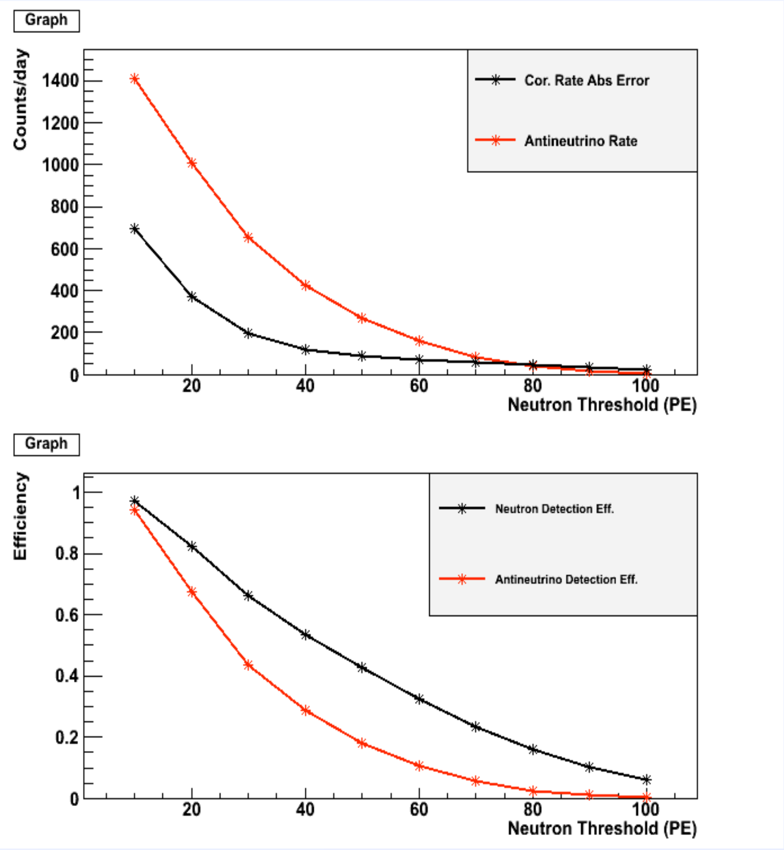
Q Factor = $\frac{S_c/\sqrt{B_c}}{S_b/\sqrt{B_b}}$

S_c, B_c =signal and background after applying cut

S_b, B_b = signal and background before applying cut

Maximum neutron sensitivity between 38 and 130 PE

Absolute correlated rate uncertainty versus Expected antineutrino interaction rate (scaling from SONGS1 interaction rate)



Initial look at data quality…. (ongoing)

- May 3 2010 – start taking data

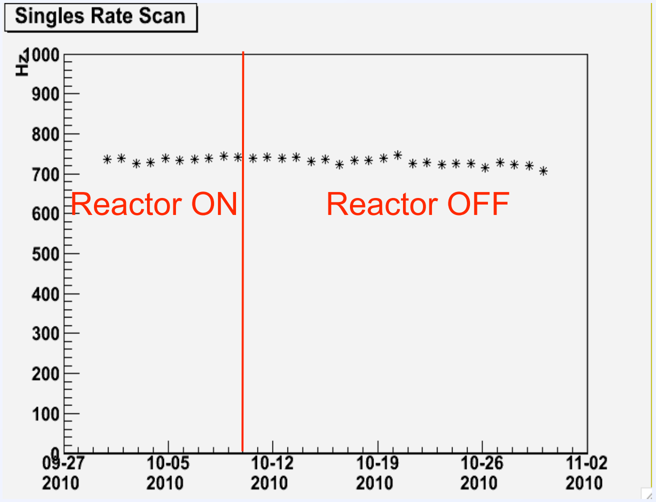
  …. Some months of inconsistent data quality

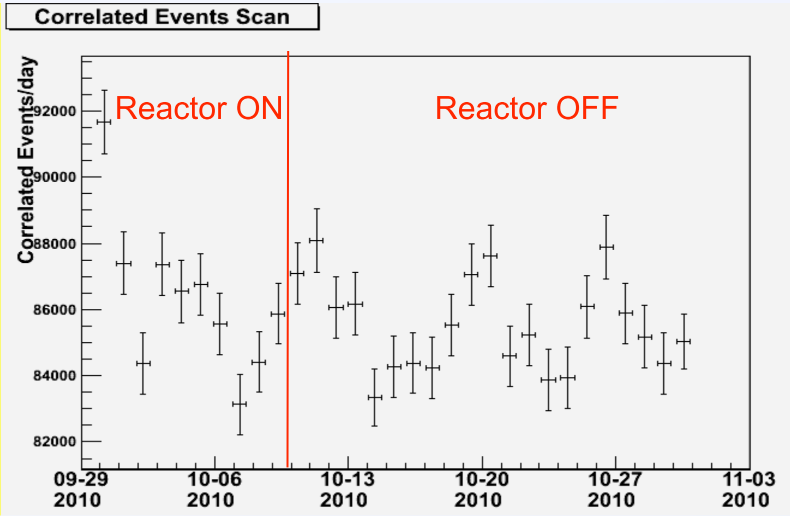
  ….
- Early July 2010 (1 week) – good physics data

  More inconsistencies, temperature troubles, humidity, DAQ…
- Late August to early Dec 2010 – good data
- Reactor turns OFF on Oct 10 2010 until mid February 2011
- Appears to be ~ 5 to 6 weeks good reactor ON/OFF reactor data. But it remains to be seen how well it stands up to scrutiny/analysis

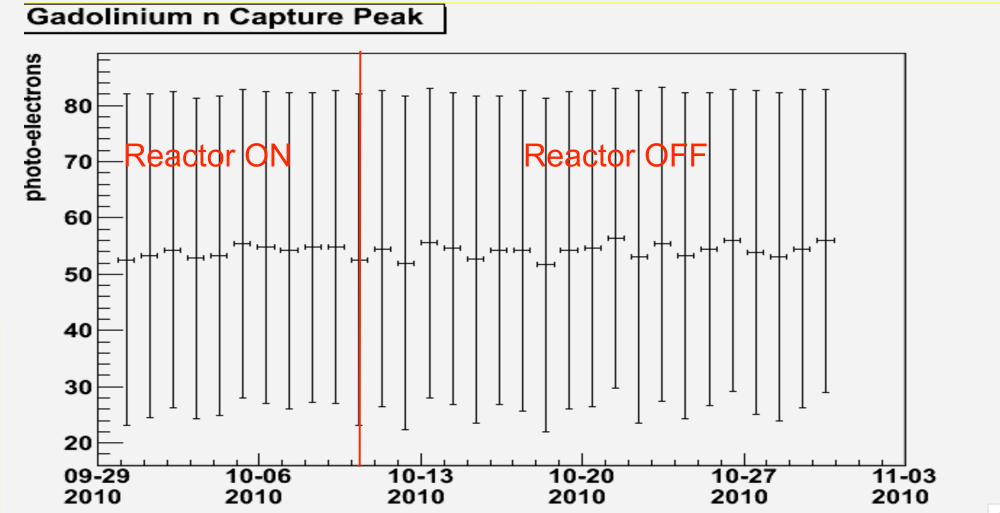
Detector Stability
(near Reactor shutdown, October time frame)

Reactor ON/OFF transition Period





Gaussian fit to Gd Peak (mean position and width of peak)



We see no evidence of any systematically unstable detector response that might lead to fake signals

(during this data period (Oct 2 to Oct 17)

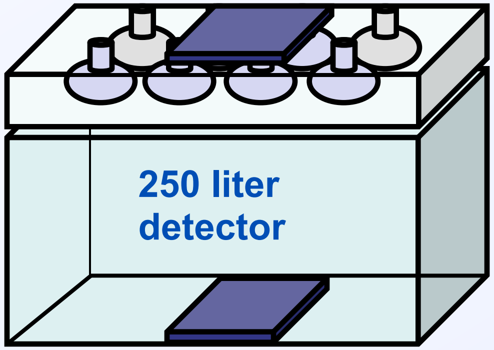
Results: (8 days Reactor ON/OFF)

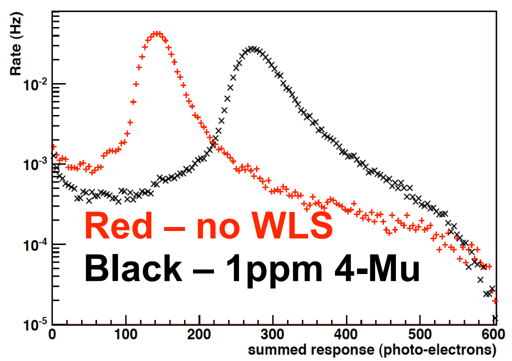
- Applying detector response cuts (38 PE to 130 PE), eliminating all triples and quadruples, etc, get
    - 43768 ± 127.8 Reactor ON per day (October 2 to October 9 2010)
    - 43453 ± 125.7 Reactor OFF per day (October 10 to October 17 2010)

Future Improvements

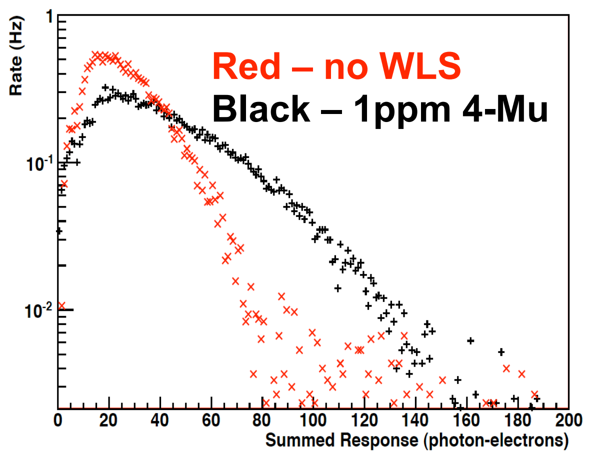
- Wavelength shifting – UV Cherenkov light shifted to blue → Light output ~ x2. Stable over ~ 2 months

Muons



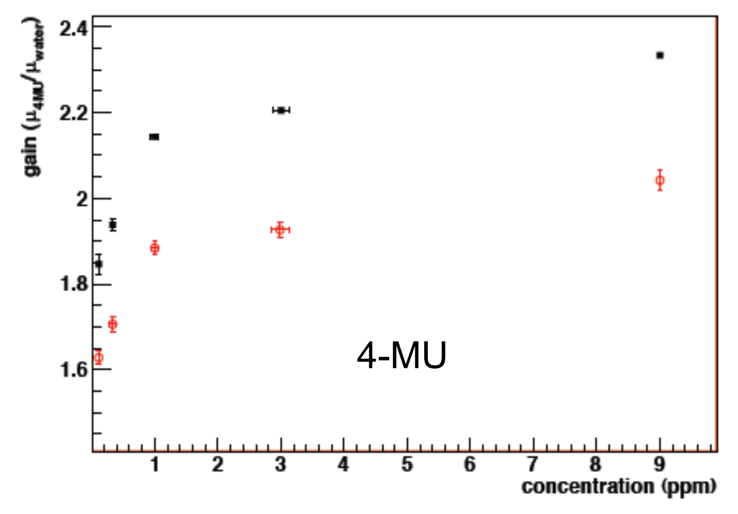


neutrons

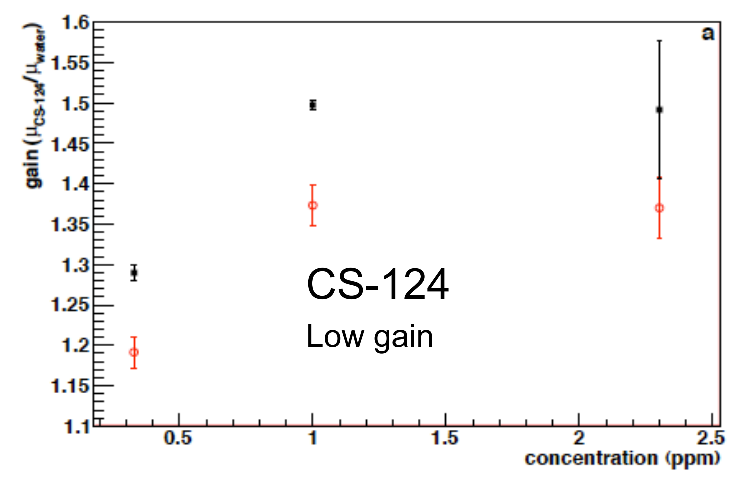


One gives up Cherenkov rings to some extent – which may be a problem in large science experiments

Gain of CS-124 and Amino-G

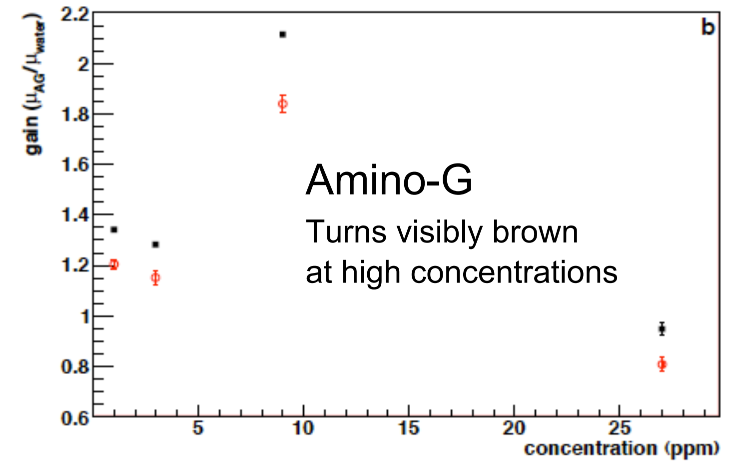


4-MU



CS-124

Low gain



Amino-G

Turns visibly brown
at high concentrations

Summary – Preliminary Water Detector results

- In order to determine the best detector response cuts for positrons, we will use a MC simulation of the detector response, tuned to match our neutron capture spectrum – in progress…

- For now, we use the n capture cuts as a proxy for position energy cuts (since the detector response to positrons (from antineutrinos) is probably higher than for background gamma-rays)

- Applying detector response cuts (38 PE to 130 PE), eliminating all triples and quadruples, etc, get
  - 43768 ± 127.8 Reactor ON per day (October 2 to October 9 2010)
  - 43453 ± 125.7 Reactor OFF per day (October 10 to October 17 2010)

- More data to be analyzed (OTHER 5 weeks ON and OFF data has not been analyzed yet…watch this space). Conclusion – at these background levels getting a statistically significant positive detection above ground with water detector will be difficult
- Future improvements – wavelength shifting x2 improvement in light detection

Bonus Pictures: Shield Construction (Designed and built at Sandia Natl. Lab.)

Shield Construction

Shield Construction

Shield Construction

Shield Construction

Filling

Packing up

Near the Reactor

Near The Reactor