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Progress on Developing a Segmented Detector using $ZnS:Ag/^{6}Li$

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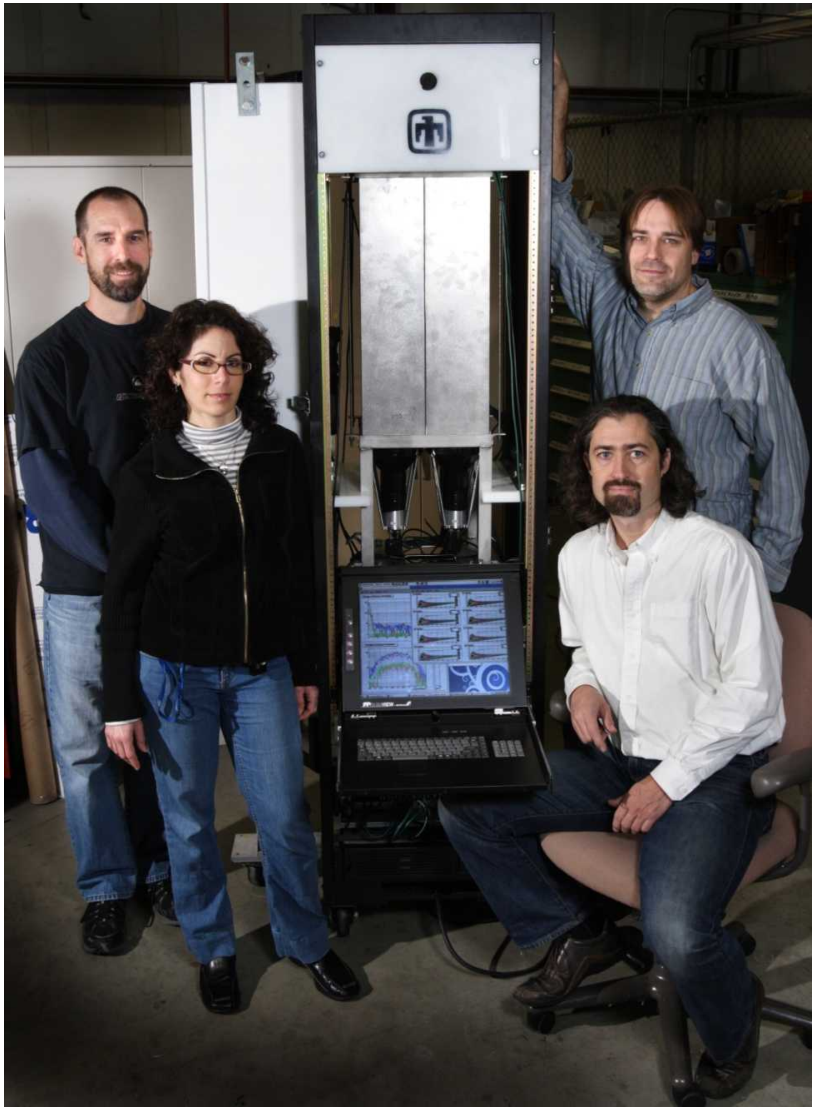
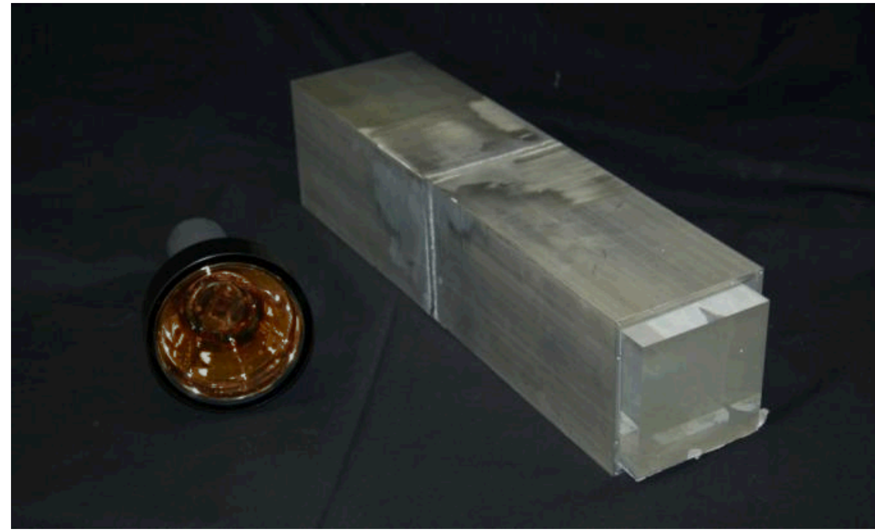
Previous Prototype Deployment

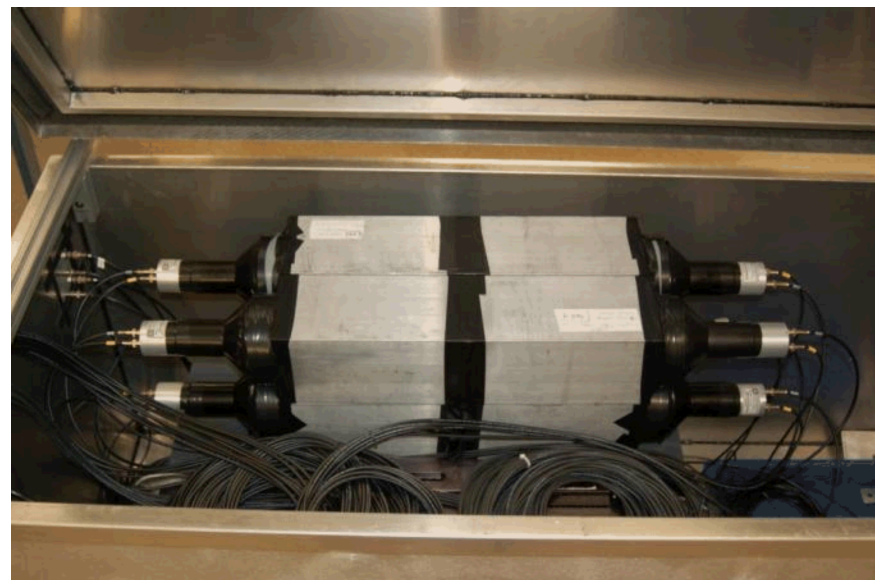


- As part of a joint SNL/LLNL project to develop aboveground detector technology, we deployed a 4-cell prototype segmented scintillator system
  - Aboveground shielded and unshielded runs in 2011
  - Belowground deployment in 2012-2013
- Very encouraged by performance of Segmented Scintillator prototype
  - This technology is focused on reducing the overall footprint and enabling a transportable detector that can be deployed in high-background or unshielded locations
  - Demonstrated rejection of backgrounds of 5 orders of magnitude even without an external shield

Segmented Scintillator Detector

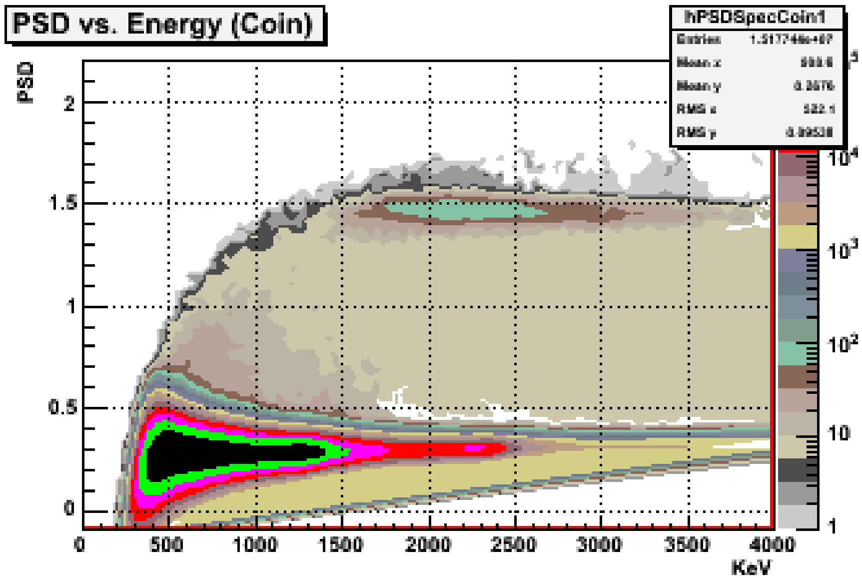
- Individual Segments contain organic scintillator with ZnS:Ag/^{6}LiF screens on outer surface
  - Tested cells with both plastic and liquid scintillator (plastic preferred)
- Use of ZnS:Ag with ^{6}LiF allows identification of neutron capture
  - ZnS:Ag is sensitive to alpha from n-capture on Li
  - Very slow scintillator time constant (~100ns) allows pulse shape discrimination to separate n-capture from γ events
- This 4-cell prototype was intended for first testing background rejection only





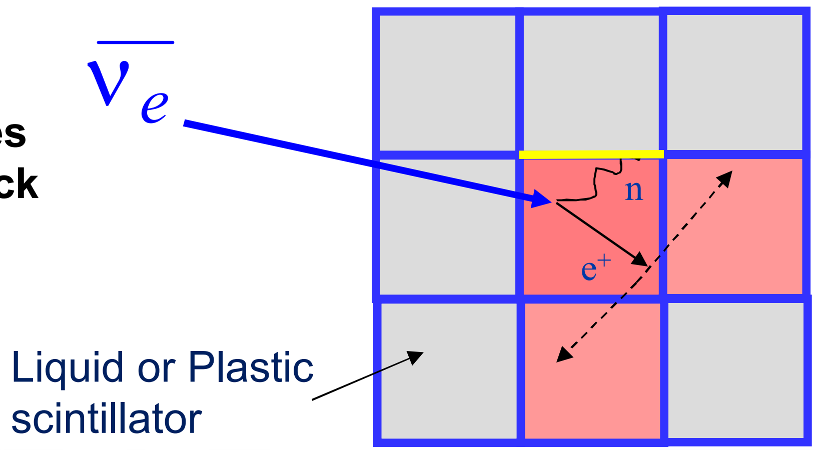
Particle Identification (PID)

Neutron identification through Pulse Shape Discrimination (PSD)



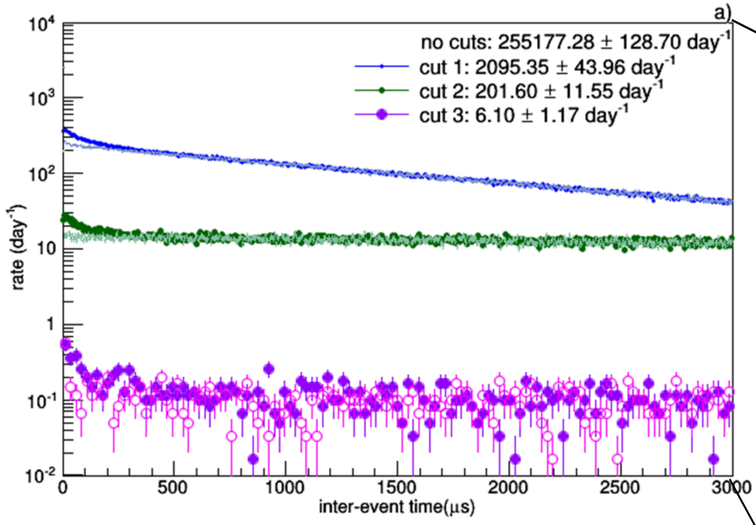
Positron Identification through Topology

- Positrons are rare in nature
  - Deposit most of their kinetic energy very quickly through standard ionization losses
- Positrons will annihilate into two back-to-back 511 keV gammas
  - Very distinctive signature
  - Gammas will travel ~2-5” through most scintillators

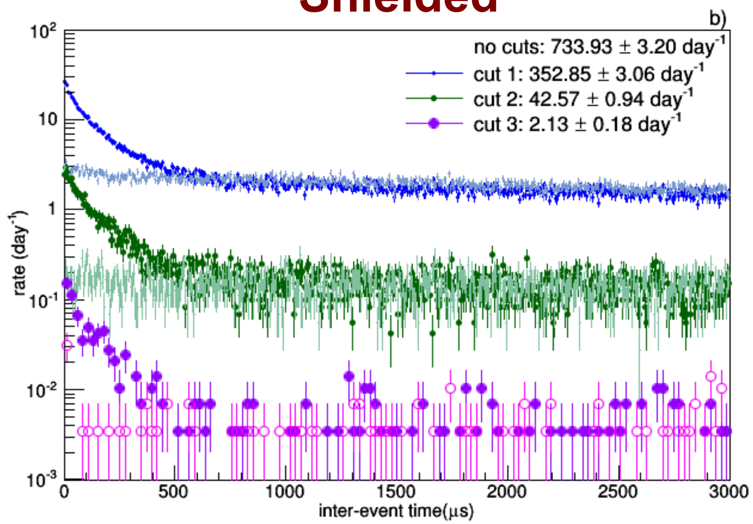


Aboveground Data

Unshielded



Shielded



No PID cuts
225,177 ev/day

Cut 1 = neutron PID only
2095 ev/day

Cut 2 = neutron PID +
Loose positron topology
202 ev/day

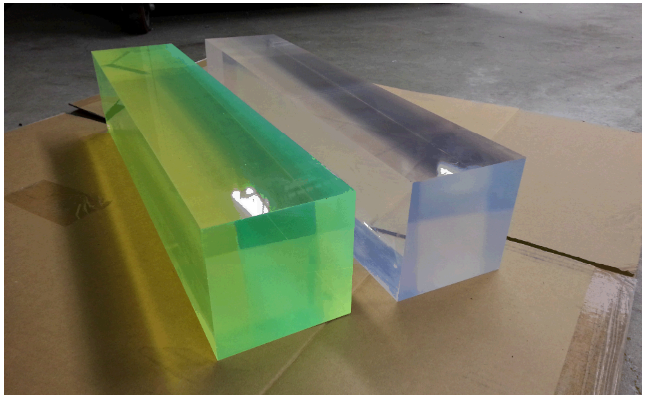
Cut 3 = neutron PID +
Strict positron topology
6 ev/day

Expectation ~ 0.5 ev/day (cut 3)

D. Reyna et al. INMM proceedings (2012)

WLS Allows Extended Length

Test Bar	Attenuation length	Normalized neutron efficiency §
Original grease coupled 60cm	35.6 +- 1.2 cm	10.1 +- 0.9 %
WLS, air gap, 60 cm	118 +- 7 cm	10.8 +- 0.9 %
WLS, air gap, 120 cm	154 +- 11 cm	12.6 +- 1.2 %
WLS, air gap, 180 cm	200 +- 20 cm	10.9 +- 1.1 %

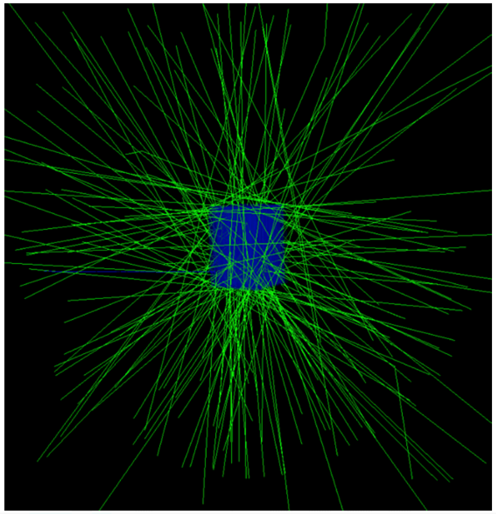


§ Efficiency calculated relative to a calibrated ^{3}He detector and normalized to detector area

More details can be found in *Sweany et al, NIM A Volume 769, 1 January 2015, 37–43z*

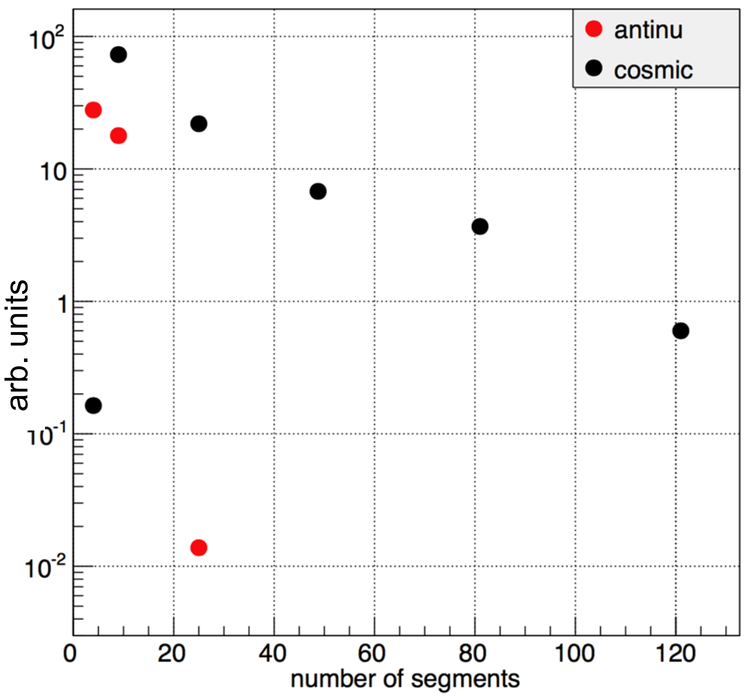
This Study – Investigate Performance vs. Size Scaling

- Simulated detector configurations
  - Configurations of 3x3 to 11x11 (9 to 121 segments)
  - WLS segments of 180cm length
    - Position and energy smearing applied in post-processing
    - Low energy (100 keV) threshold applied for trigger
- Simulation of fast neutron backgrounds
  - Geant 4.10.1.p01 with QGSP_BERT_HP physics list
    - Older 4.9.5.p02 showed unphysical transitions in neutron spectra that made ~30% reduction in background events
  - Cosmic neutron generator from Gordon et al. (2004)
    - Distributed azimuthally like muons
- Simulation of antineutrino events
  - Coincident positron and 200 keV neutron
  - Uniformly distributed throughout



Gut-Check: Neutrons

Skin Depth:

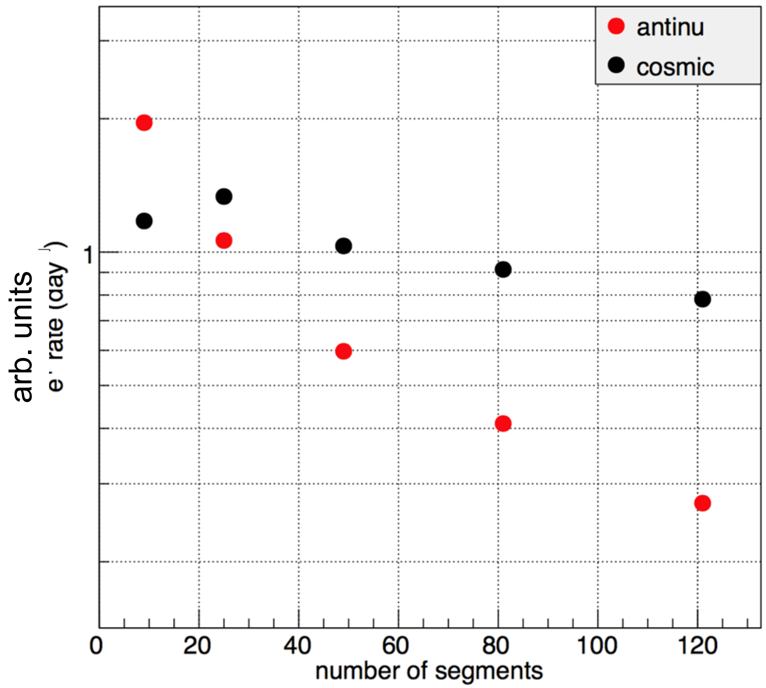


Neutron Captures in outer most segments

- antinu: neutrons started at center
- cosmic: pencil beam pointed at center

Rate normalized to total number of events

Neutron Wander:



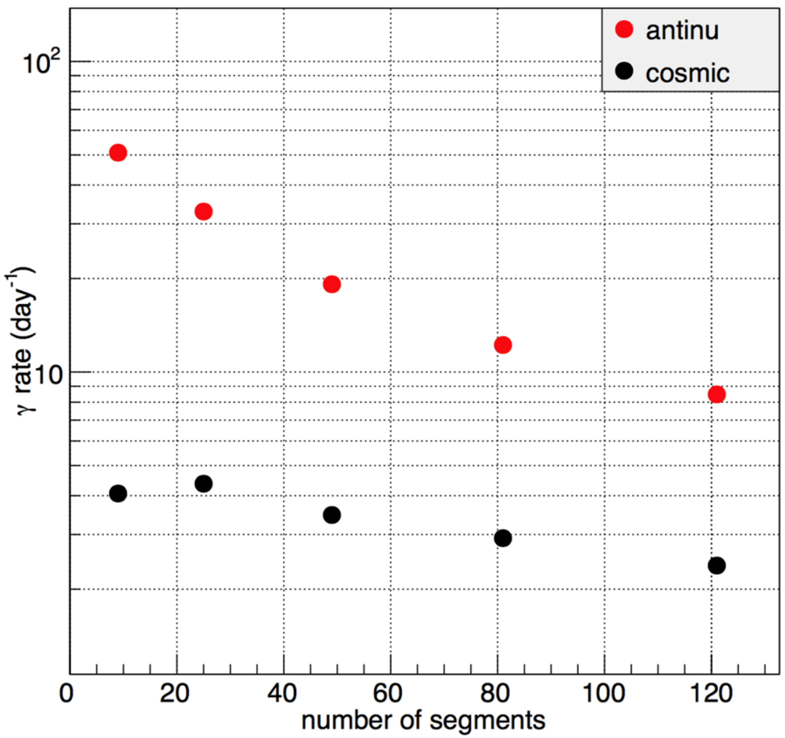
Neutron Captures outside of e+ neighbors

- antinu: uniformly distributed
- cosmic: cosmogenic distribution

Rate normalized to total number of events

Suggests a neutron / e+ co-location cut will improve with size

Gut-Check: Positrons



Number of events for which the annihilation gammas are not in the 8 surrounding segments from the identified core e+ deposition

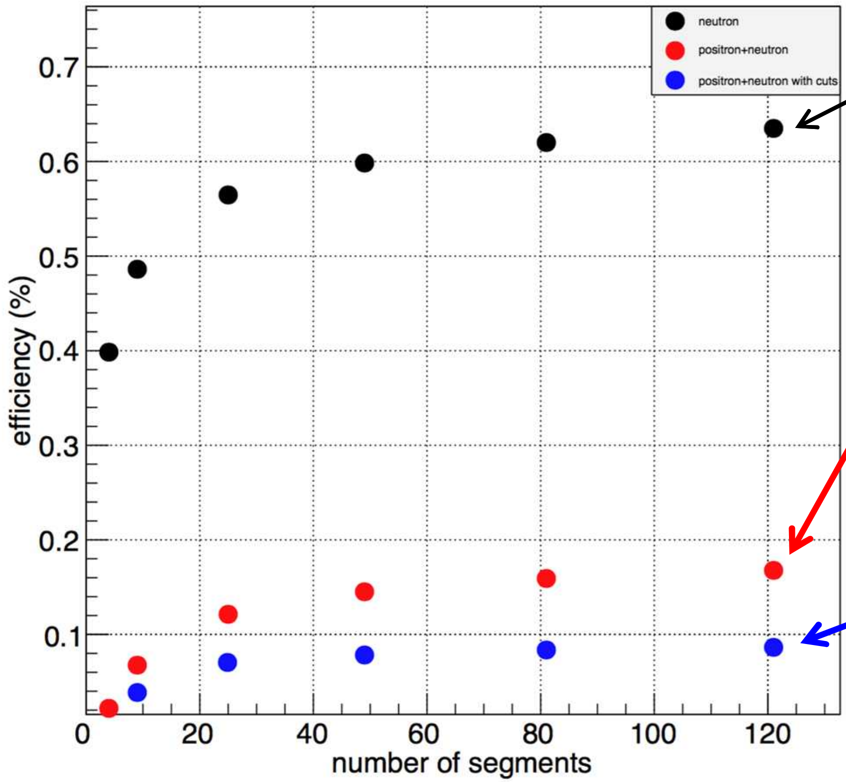
- antinu: uniformly distributed
- cosmic: cosmogenic distribution

Rate normalized to total number of events

Suggests a full e+ topology cut will improve with size

Impact of Antineutrino Event Selection

Overall efficiency for uniformly distributed antineutrino events passing an event definition



Events with a neutron and single e+ deposition coincident in time

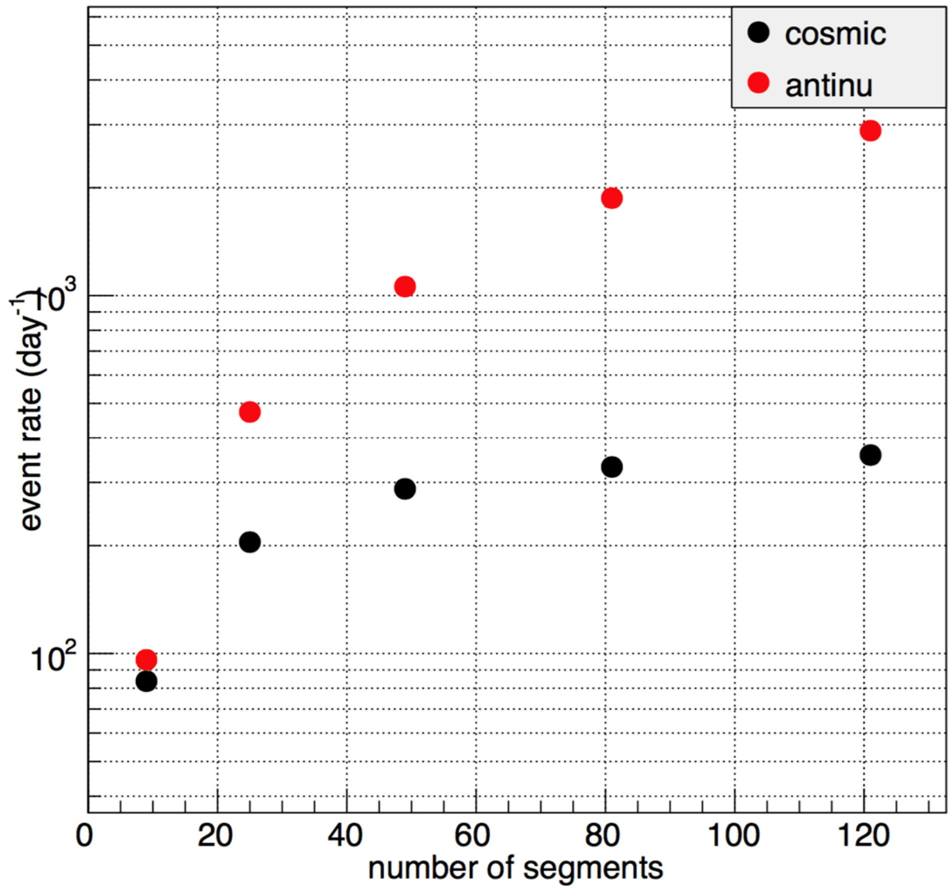
Events with a neutron and single e+ deposition coincident in time and within a 9-segment box

Events with a triple positron deposition (within 9 segments) coincident in time with a neutron that's within a 9-segment box around the central e+ deposition

For large detectors, the most restrictive cut yields ~10% efficiency

Realistic Expectations

Expected Rates 25m from SONGS



Sanity Check

Approximate duplication of 50m deployment at SONGS

- **4-segments (60 cm)**
- **Reduced efficiency (non-WLS)**
- **No proximity selection**

Cosmic: 7 events/day

Antinu: 1 events/day

Compares favorably with measured 6 events/day

Signal scales like mass but background rejection improves quicker

Conclusion

- This technology appears to be robust and scalable
  - Simulations agree with current measurements and confirm expectation that background rejection improves with size
- A 20’ shipping container could be a functional system
  - Contain 520 2m-long segments
  - Total mass ~20 tons
  - Overall efficiency ~10% ➔ ~ 2 tons “ideal”
    - Almost reach Huber’s “ideal 5t detector”
  - Expected rates would be reasonable
    - Background rate ~400 events/day
    - Signal rate ~5 events/day/MW_{th} at 20m

- Now we just need to build one and validate