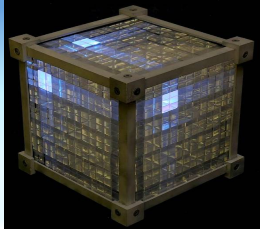
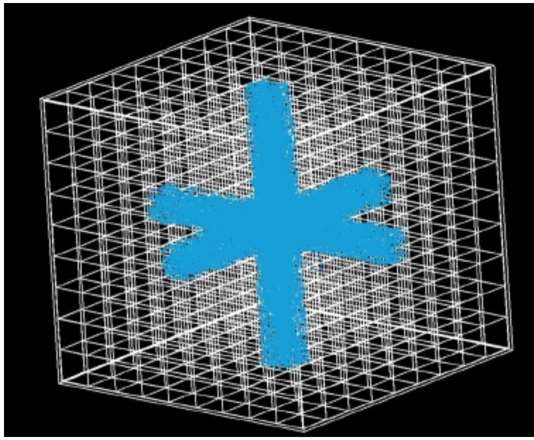


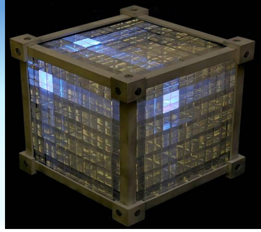
Neutrino Lattice

NuLat – Novel Detector for Sterile Neutrino Search with Reactor Neutrinos

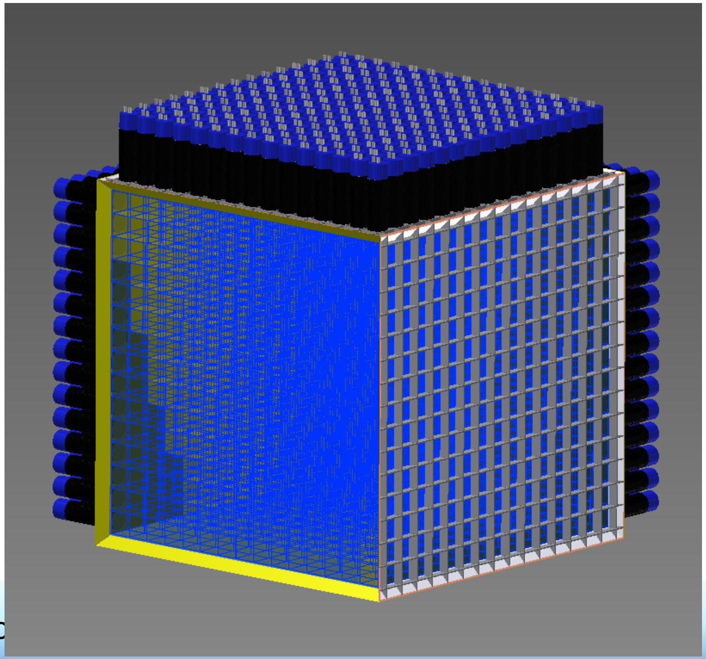
- **Hawaii**: M. Duvall, **J. G. Learned**, V. Li, **J. Maricic**, S. Matsuno, R. Milincic, S. Negrashov, M. Rosen, G. Varner
- **Virginia Tech**: M. L. Pitt, M. Pierson, S. D. Rountree, **R. B. Vogelaar**, T. Wright, Z. W. Yokley
- **Drexel**: C. E. Lane, C. Peters
- **HPU**: S. Dye
- **Johns Hopkins**: S. M. Usman
- **LSU**: J. C. Blackmon, J. Matthews, B. C. Rasco
- **NCCU**: D. M. Markoff
- **NIST**: H. P. Mumm
- **Ultralytics**: G. R. Jocher, K. Nishimura
- **University of Maryland**: W. McDonough



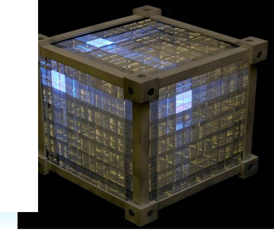
Outline

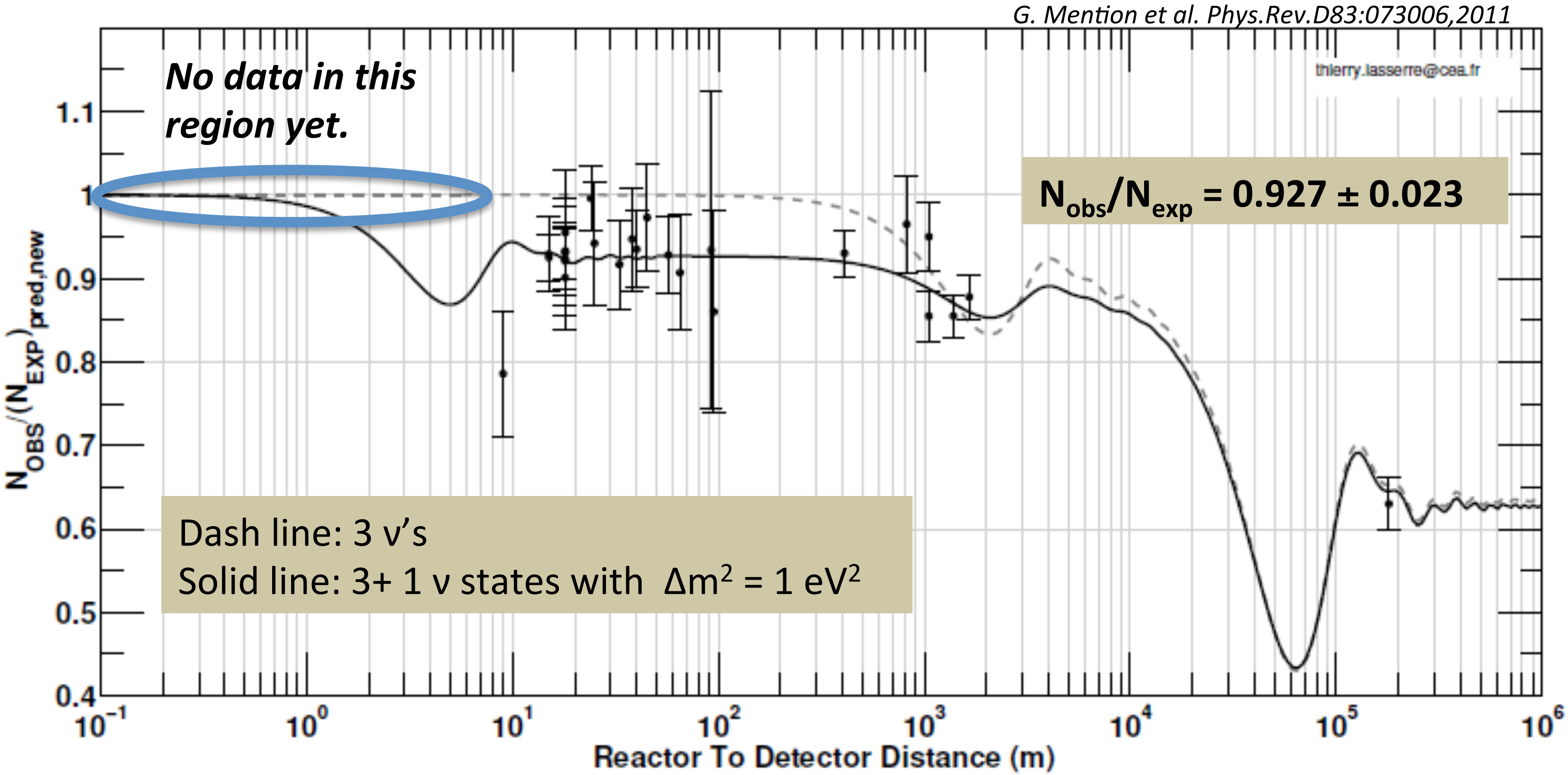


- Science Motivation
- NuLat Detector Design
- Site Development
- Sensitivity to sterile neutrinos
- Summary and Outlook



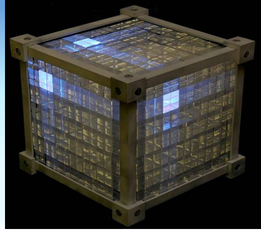
Motivation for the short baseline antineutrino search





- Reactor Antineutrino Anomaly → existence of 4th neutrino $\Delta m^2_n \sim 1\ eV^2$?
- Galium anomalies – 2.7 σ detected neutrino deficit observed in deployment of ^{51}Cr and ^{37}Ar sources in GALEX and SAGE solar neutrino experiments

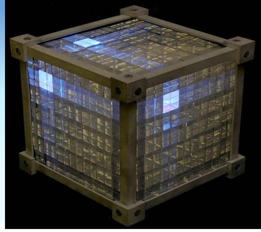
Challenges & Requirements of Detecting Neutrinos Next to Reactors and Observing Neutrino Oscillations



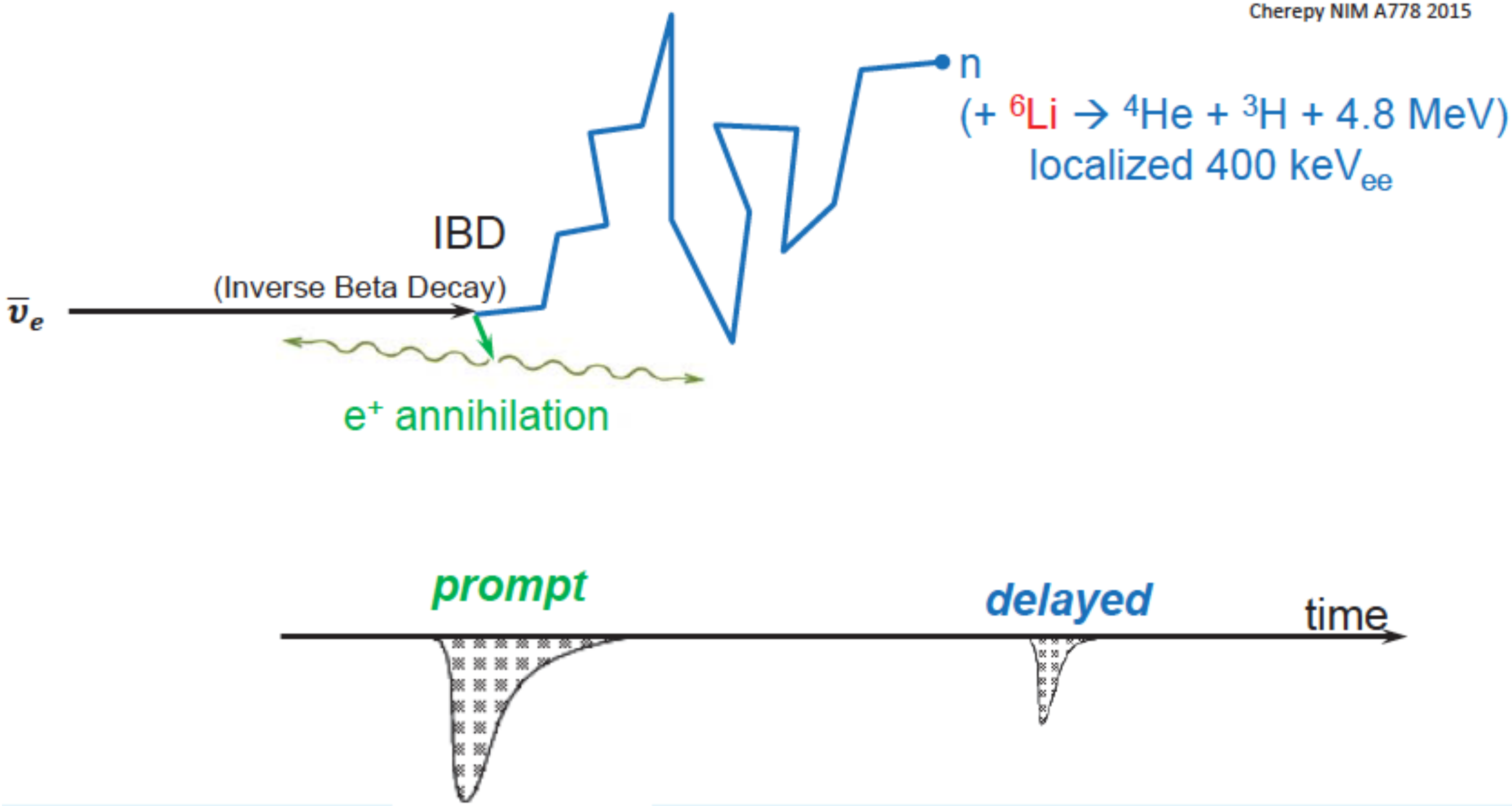
- Difficult measurement:
  - Small/no overburden (high cosmic ray background)
  - High neutron/gamma background flux from reactor
  - Good energy resolution needed → spectral distortions
  - Good vertex resolution → reject backgrounds & observe L/E pattern

- Challenging detector design
  - Detector target segmentation → discern signal from background
  - Well localized signal → better antineutrino event tagging → distinguish from backgrounds

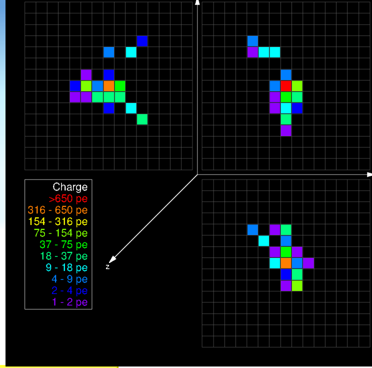
NuLat's Neutrino Detection Concept

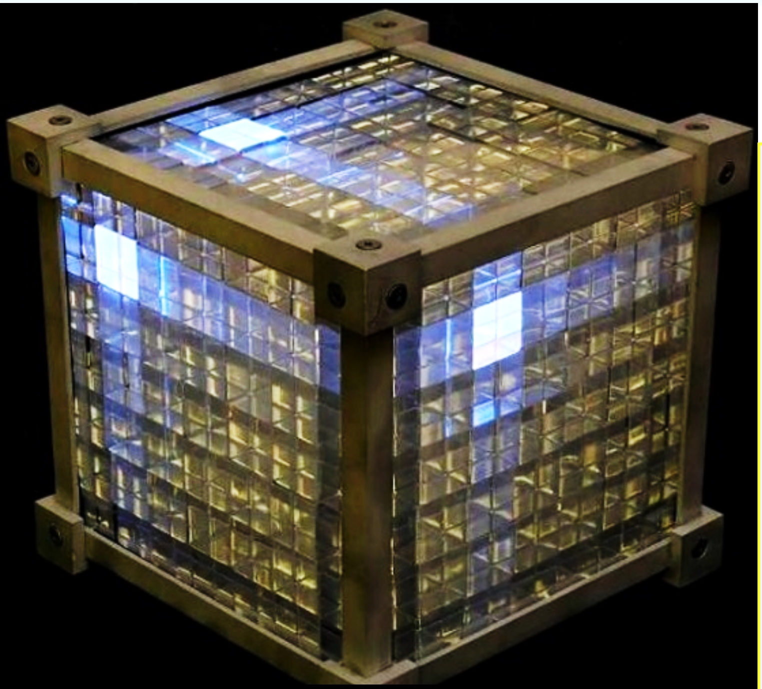


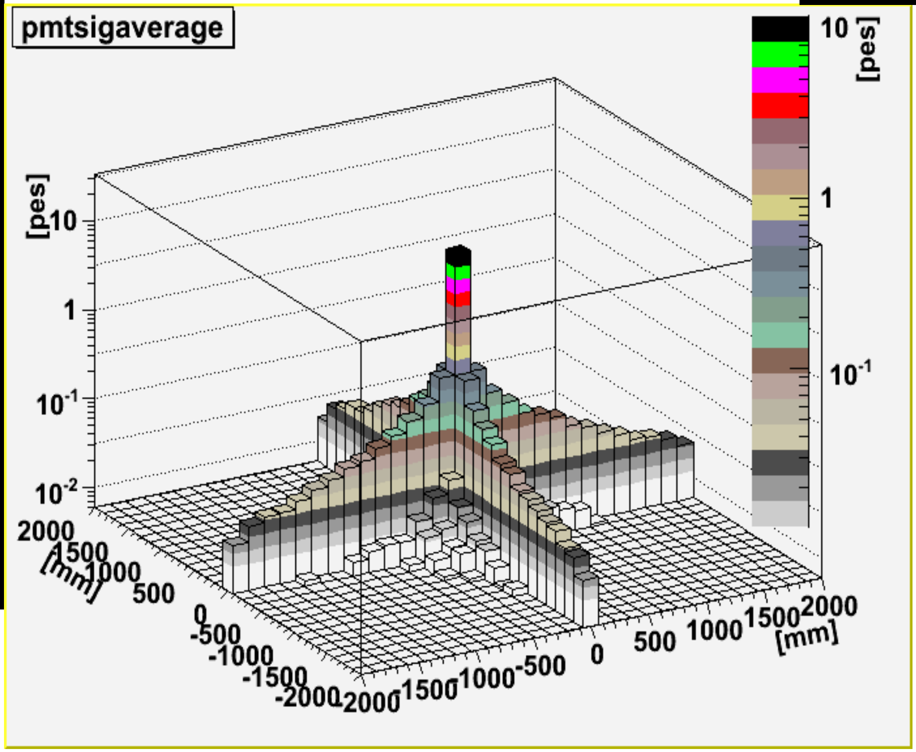
Inverse Beta Decay reaction with neutron capture on ^{6}Li.
Distinguished reaction with very localized prompt and delayed signal.

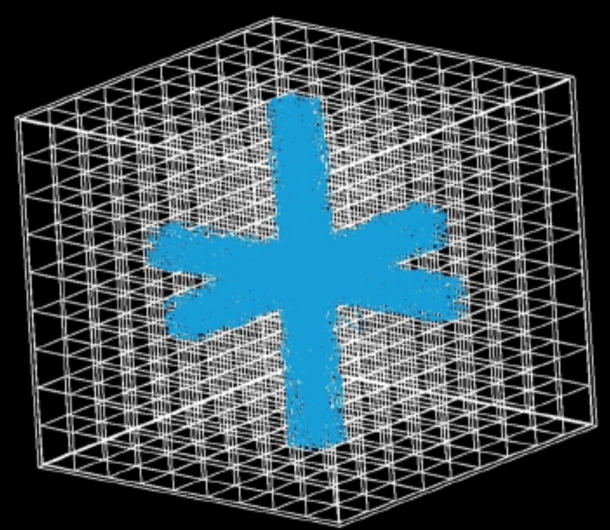


NuLat: based on a Raghavan Optical Lattice



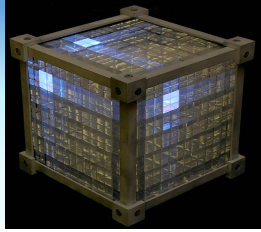




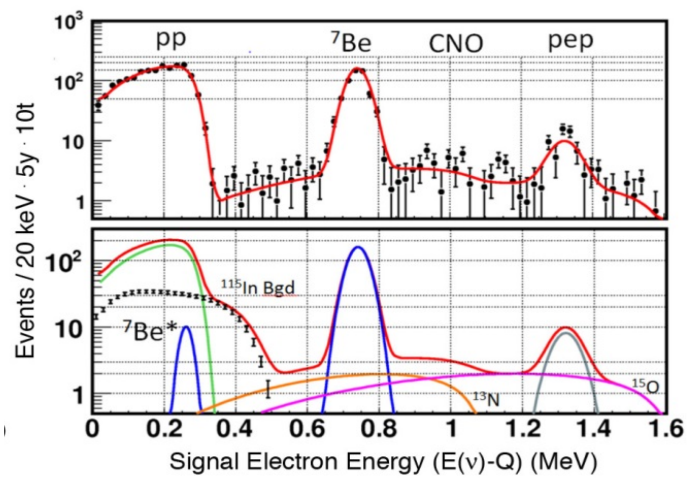


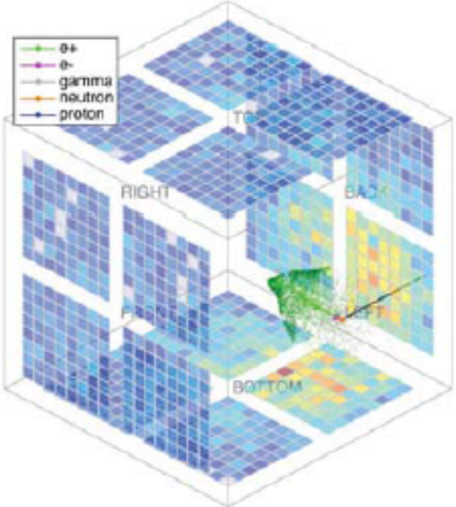
- Li-6 doped plastic scintillator
- light channeling via total internal reflection
- full 3D light collection along principle axes
- increasing # of cells doesn't degrade event topology

Merger of Existing Work

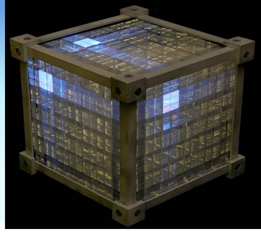


- LENS
  - solar neutrino spectrum
  - low-energy, high resolution & segmentation
  - 125 tons → 1 ton
- TimeCube
  - neutrino detection and fission neutron directional detection
  - very fast (< 0.1 ns) electronics
  - 0.002 tons → 1 ton



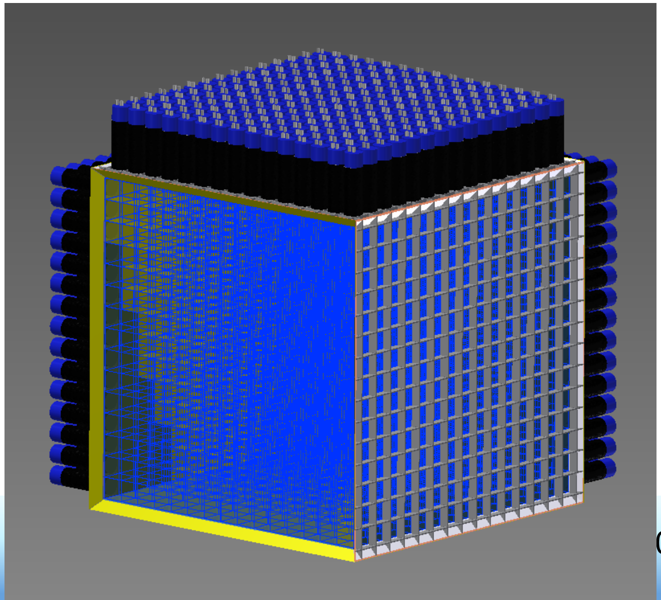


Segmentation



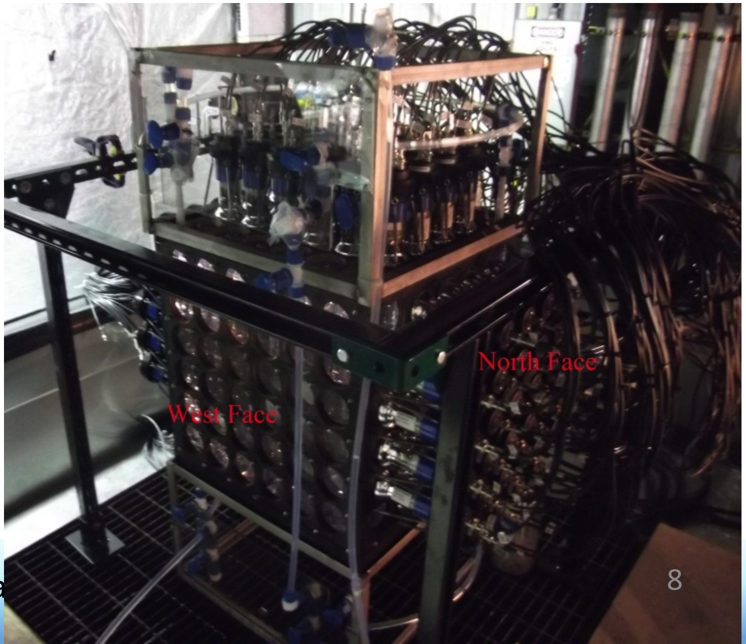
NuLat (solid scintillator)

- 2.5 inch polished scintillator cubes
- 0.5% ^{6}Li loaded scintillator (Eljen)
- 15X15X15 CUBES
- VM2000 reflective film ‘dots’ for <u>optical air-gap</u>
- ***total*** light channeling
- ‘true zero-mass wall’



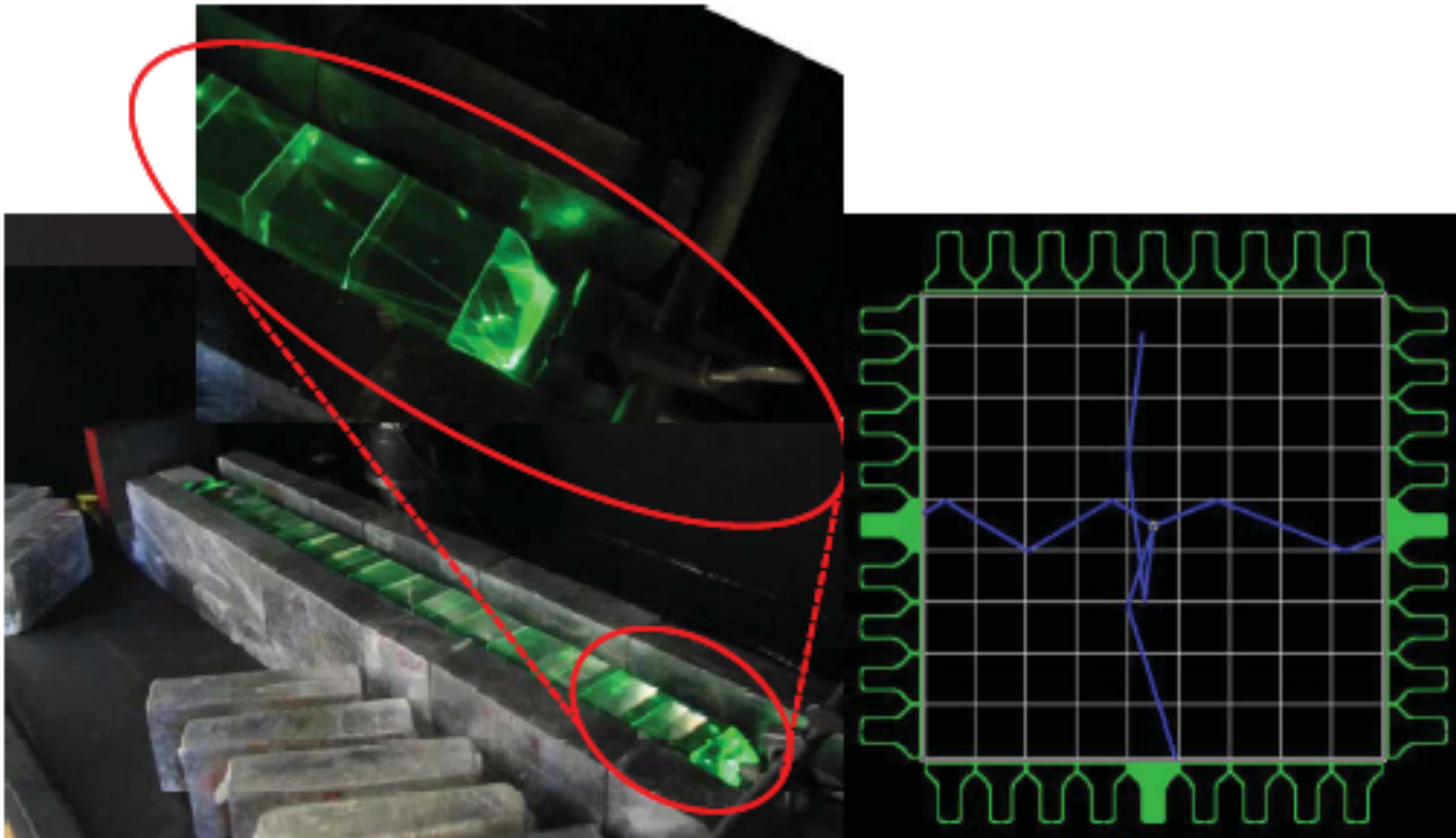
- Proven technique: micro-LENS
  - operational liquid scintillator prototype)
  - 3-axis film strips (double-wall if needed)
  - thin Teflon walls (0.002”)
  - incomplete light channeling

6x6x6 micro-LENS

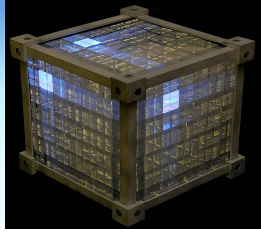


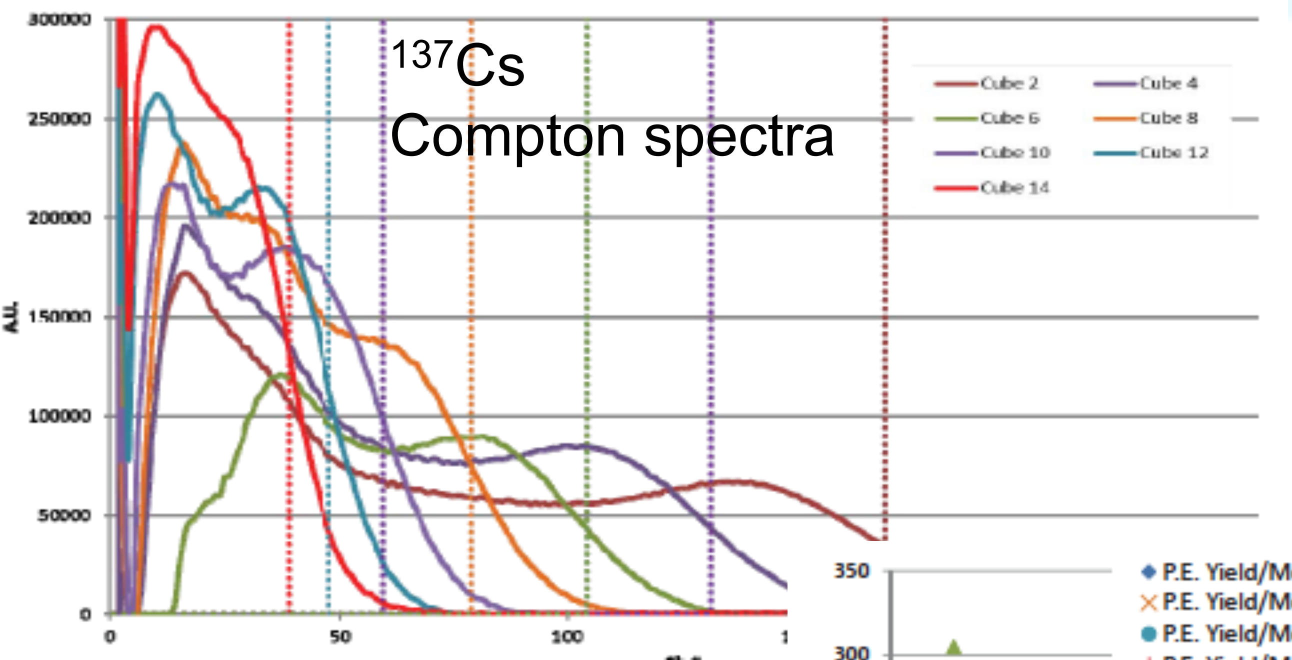
NuLat Full Length Channel Module Testing

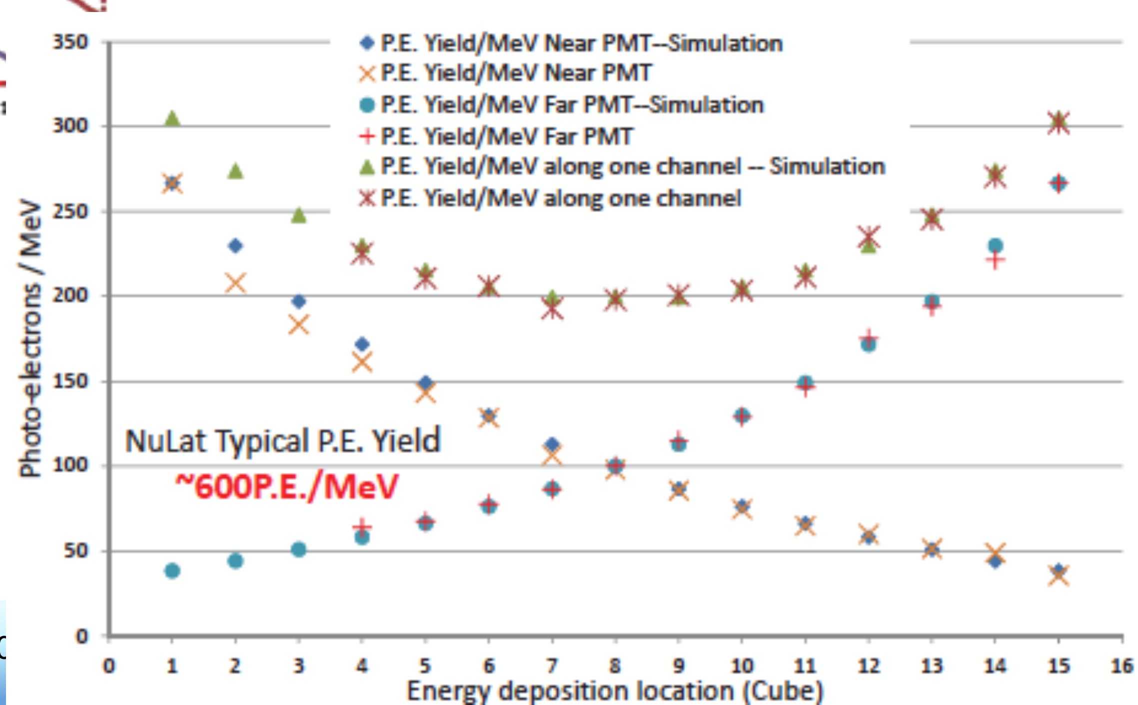
- 1x15 cube demonstrator built



Results of One Channel Module Testing

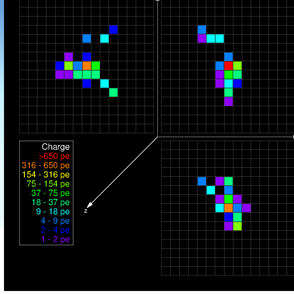


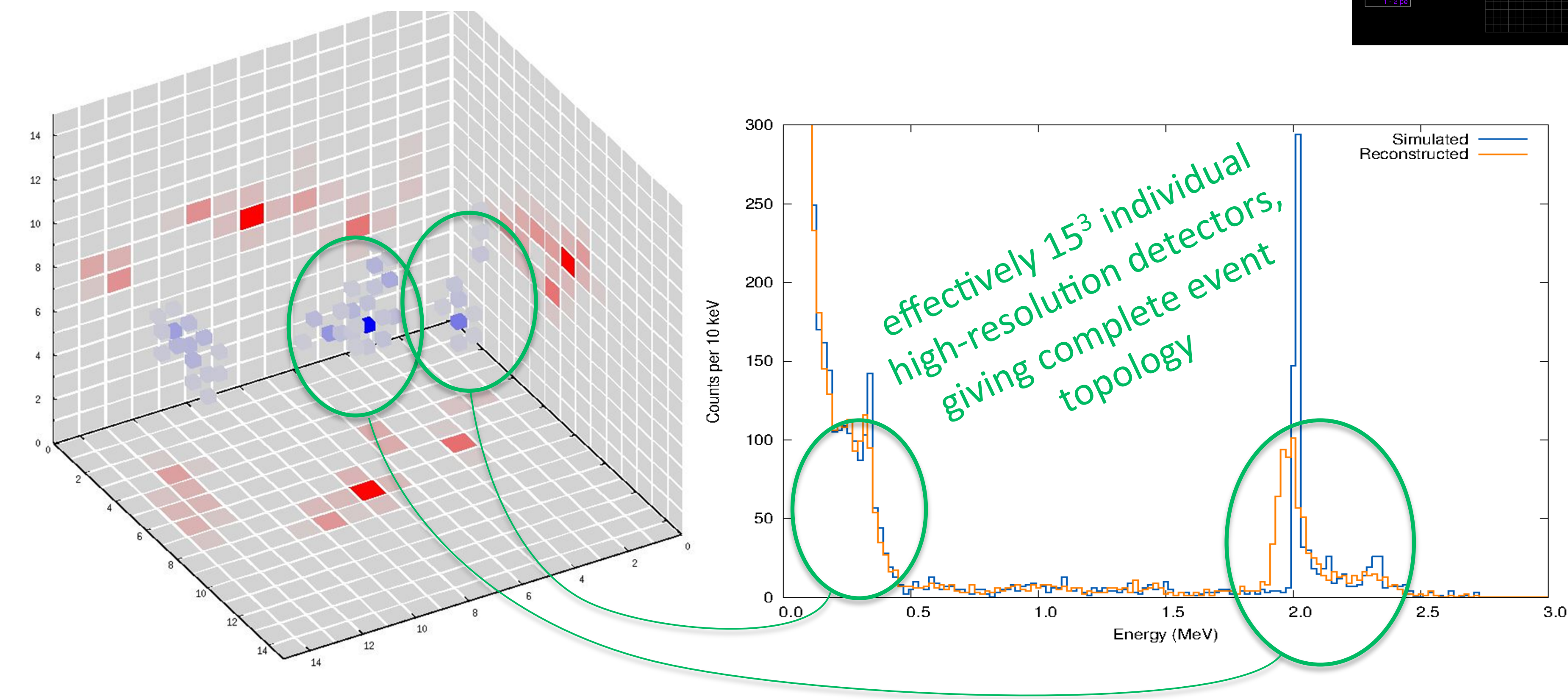




600 P.E./MeV L.Y. confirmed!

Event topology





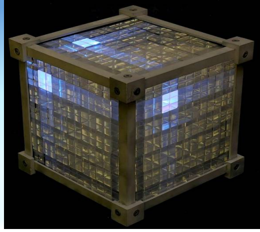
Reconstruction of a typical 2 MeV positron event.

Note: 3D allows digital separation of events *along* channel.

< 4%/√E (>600 p.e./MeV)

Single cell position (< 3 cm w timing)

ν-Signal: Prompt



→ **full positron energy in one cell (or at most two)**

→ **minimal contamination by annihilation gammas in positron cell**

→ **allows excellent neutrino energy resolution throughout complete detector**

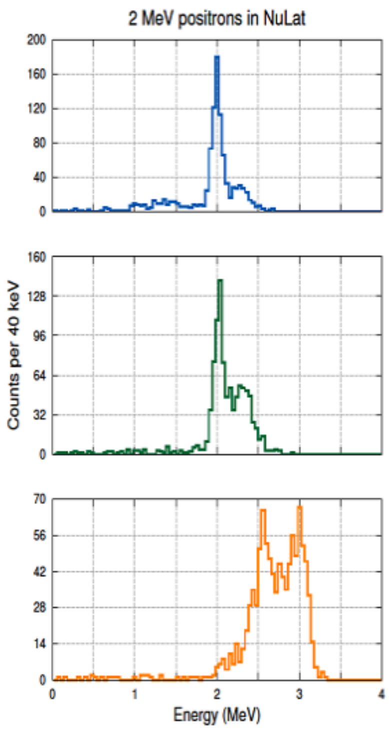
unique to NuLat →

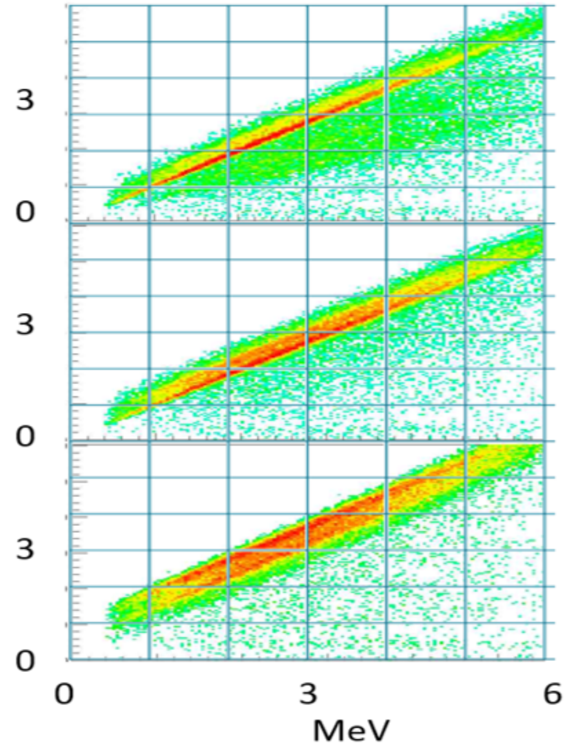
Largest Cell Only

Largest Cell and nearest max cell

typical for integrating small detectors →

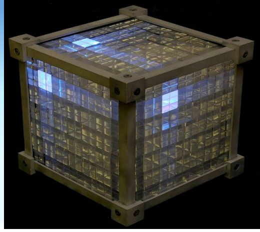
Total Energy in Detector



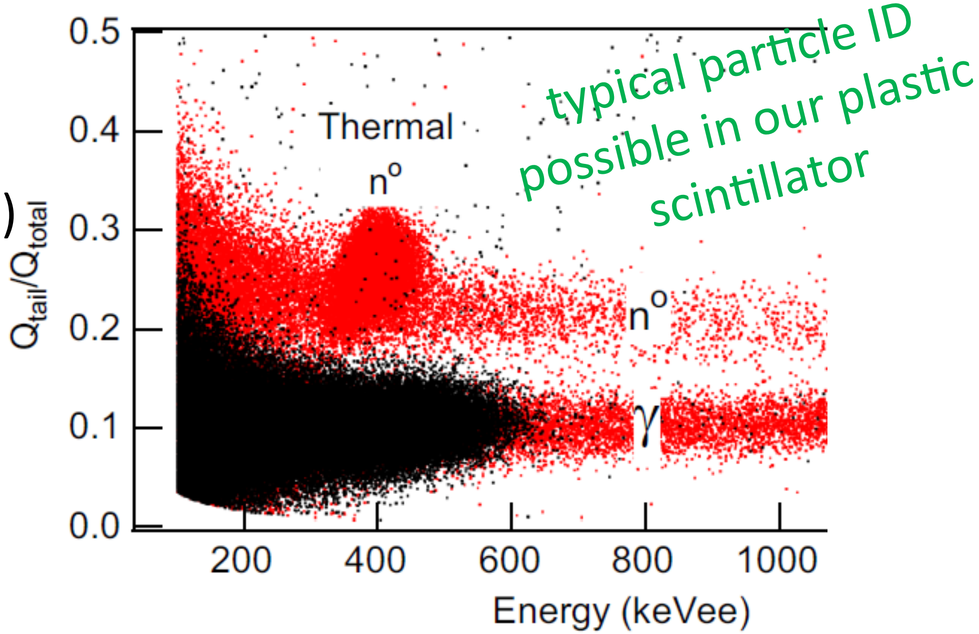


(*left*) reconstructed response to 2 MeV positrons; (*right*) response to a reactor neutrino spectrum (with statistics reflecting only a one-day exposure).

ν-Signal: Delayed (neutron capture)



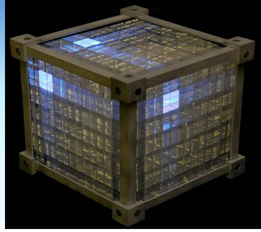
- Power of Lithium-6
  - $^{6}Li + n \rightarrow {}^{3}H + \alpha$
  - 15 µs time correlation (0.5% ^{6}Li)
  - 940 barn
  - Mono-energetic ~400 keV_{ee}
  - Single cell delayed signal
  - n/gamma separation
  - 23% n capture in same cell as positron
  - 60% n capture in same cell as positron + six facing cells
  - potential for sub-cell position resolution due to light channeling and fast electronics



Cherepy NIM A778 2015

Better energy resolution results gives better background rejection.

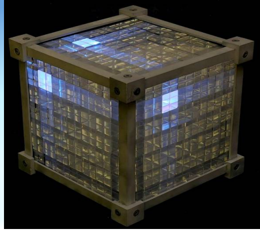
Background Rejection



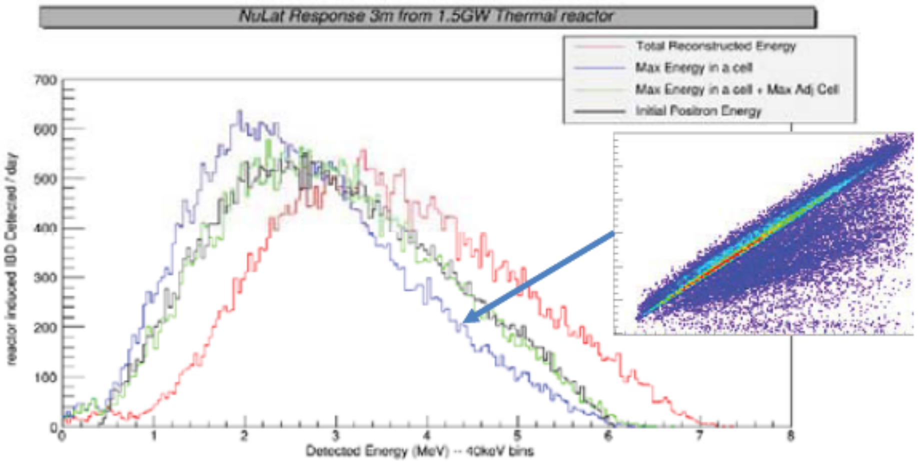
- Primary Coincidence Timing
  - start: positron and annihilation
  - stop: neutron capture (trigger: single cell, ~400 keV)
  - 15 μs window typical (0.5% ^{6}Li loading)

- Segmentation
  - 256 cm^3 cells (1/4 liter)
  - 23% n capture in same cell as positron
  - 60% n capture in same cell as positron plus the six facing cells
  - potential for sub-cell position resolution due to light channeling and fast electronics

Systematic Errors

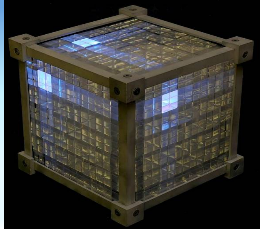


- ***Precision*** wall-free isotropic segmentation
  - uniquely allows digital ratios to benchmark detector response
  - critical for quantifying spectra features



- Readily Movable
  - allows multiple baselines on short time-scale
  - allows easy transport to multiple reactor sites

Deployment Sites

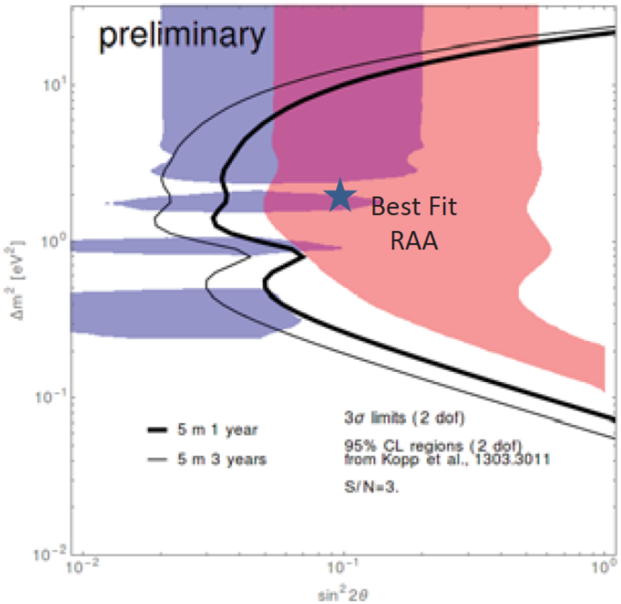


- Research reactor: NIST 20 MW_{th}(confirmed), MD (HFIR, ATR similar)
  - Compact, HEU, close to core (3.8 m), good access, but low power
- Commercial power reactor: Hope Creek, NJ – 3 GW_{th}
  - Large core (smearing), LEU, far from core (30 m), good access, high power → candidate testing site
- Naval reactor: Knolls Atomic Power Lab (KAPL), NY – 500 MW_{th} or US Navy reactor on aircraft carrier 1.5 GW_{th}
  - Compact, HEU, close to core, high power, but difficult access

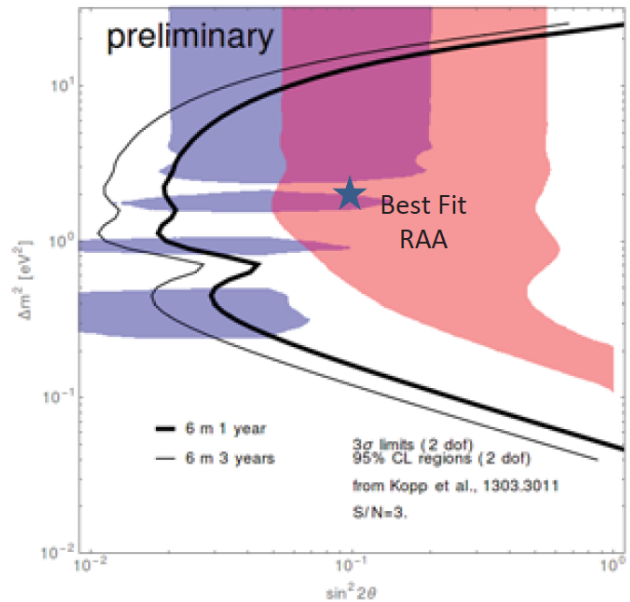
- Detector portability: NuLat may use more than one site, or even multiple locations at a single site.
- We are in contact with all three sites, access negotiation in progress (NIST has confirmed availability).

Sensitivity to RAA

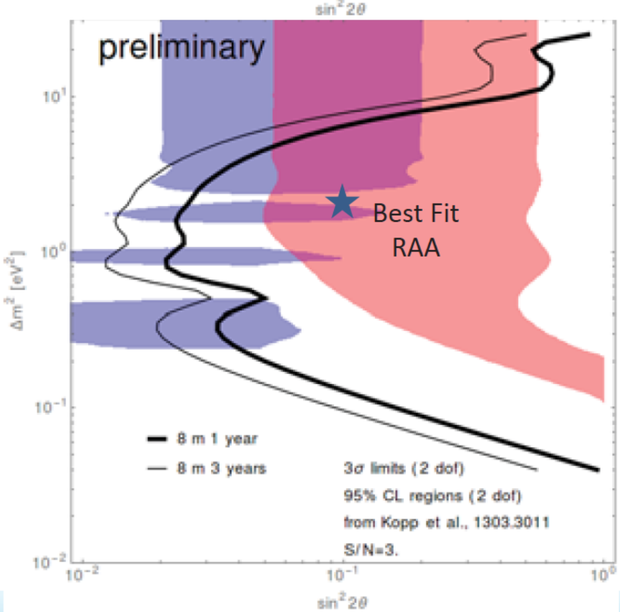
NIST



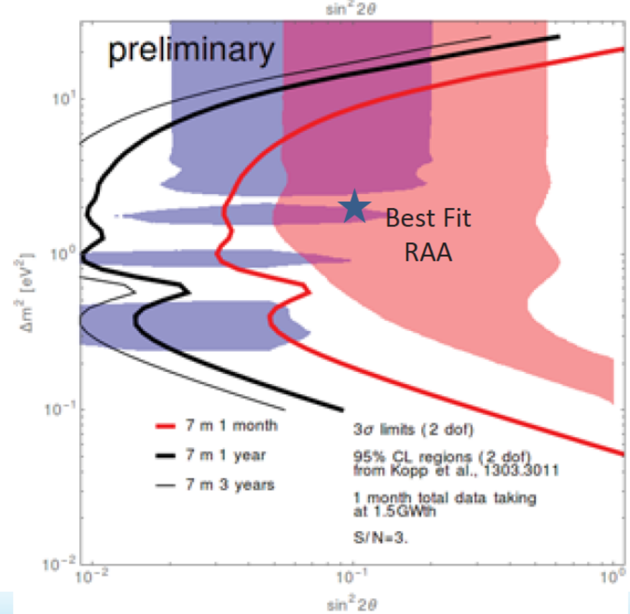
HFIR



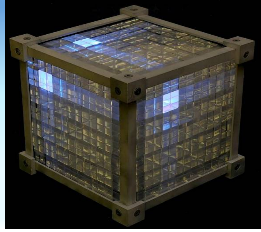
ATR



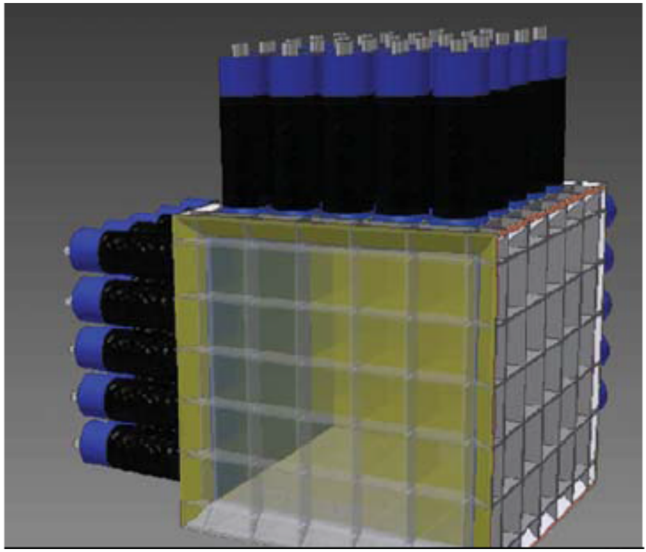
USN



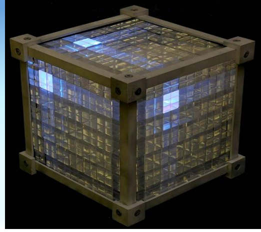
NuLat Summary and Outlook



- credible avenue towards using naval reactor
  - highest neutrino flux (52,000 ν interactions per day)
  - simple and compact
    - minimal loss to ‘fiducial’ cuts
    - small shielding mass
  - no liquids or problematic gasses
  - true real-time portability
- exceptional background rejection
  - **full 3D** ***precision*** segmentation (256 cc)
  - complete event ‘topology’ (dE,x,y,z,t)
  - exceptional light collection (600 pe/MeV)
  - sub-nanosecond timing



- science within two years of funding (< $3M hardware - shared amongst agencies)
- lattice design has other immediate applications
- 5x5x5 demonstrator in construction – deployment at NIST and Hope Creek in early 2016



Thank you

THE END