Majorana Monte Carlo & Simulations

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For the Majorana Simulation Group

Outline

1. "MaGe" Simulation Framework
2. Majorana Reference Design Simulations.
   - Majorana Background Model
   - Bulk contamination
   - Surface Alpha Contamination
3. Continuing/Future work:
   – Cosmic-ray induced neutrons
   – Pulse shape simulation

Charge Addressed:

b. The status of the technical design, including completeness of technical design and scope, feasibility and merit of technical approach; feasibility and effectiveness of technical performance delivering the science;

Goals of Simulation Package

Jan. 2004. Majorana decided to develop integrated simulation package.

Oct. 2004. Majorana and GERDA joined simulation efforts.

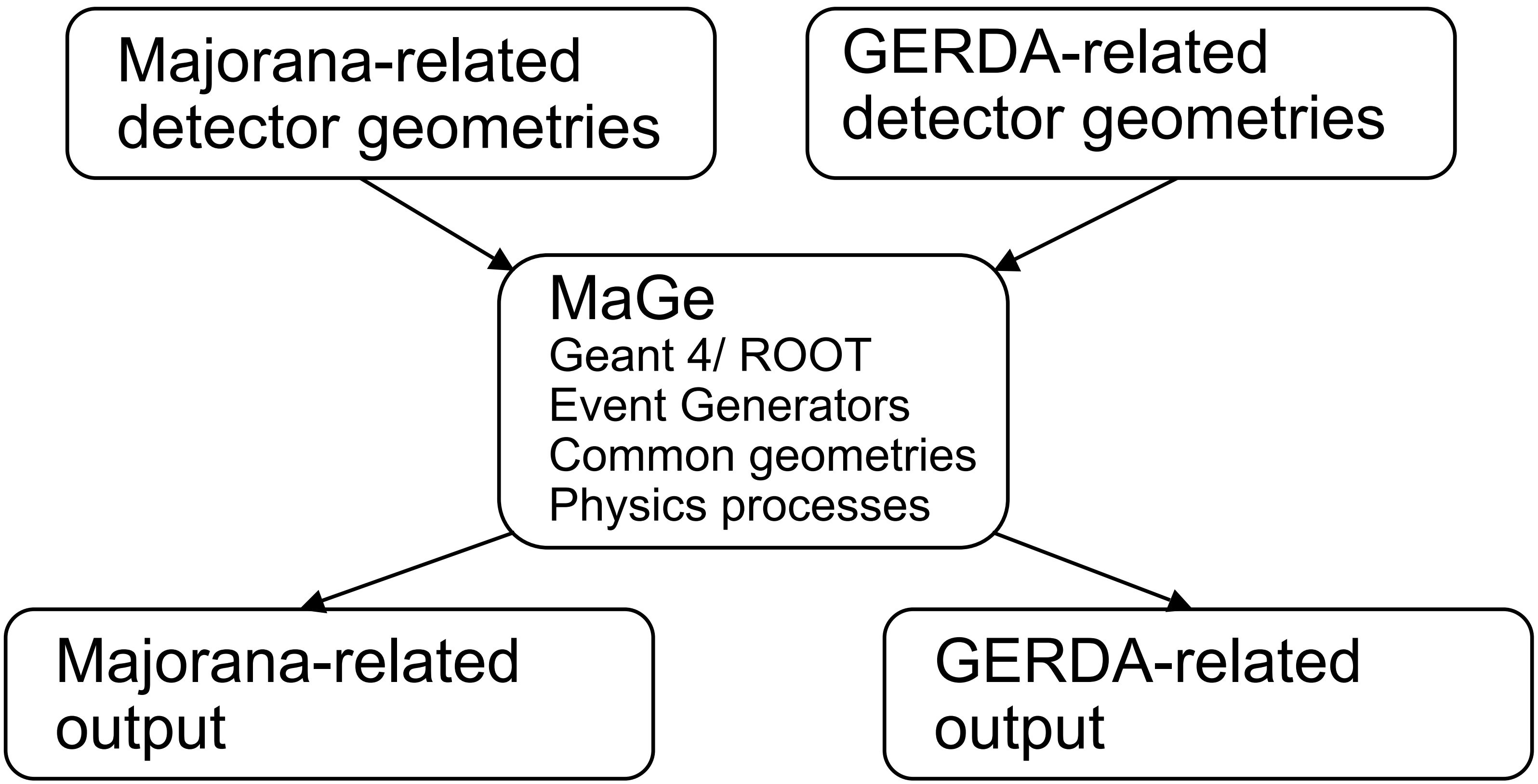
1. To provide the collaboration with a physics simulation package to aid in the optimal design, operation and analysis of data from the Majorana experiment.
2. The package must persist over the long lifetime of the experiment.
3. The package must be well-maintained, documented, and robust.
4. Maintain record of results.

Many different aspects

1. Energy deposition of particles from radioactive sources, cosmic rays, and signal sources. Low-energy electromagnetic and neutron interaction packages are critical.
2. Pulse-shape formation in crystals, different segmentation schemes, and crystal geometries. Use expertise from GRETINA collaborators.
3. Electronics.
4. Shielding (neutron absorption and muon tagging).
5. Radioactive decay chains and emissions.
6. Signal: double-beta decay
7. Activation in detector material.
8. Different crystal packing arrangements.
9. …….

“MaGe” Simulation Package

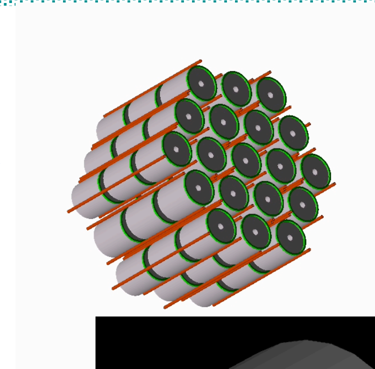
Framework uses powerful object-oriented and abstraction capabilities of C++ and STL for flexibility



Previous Majorana MaGe Activities

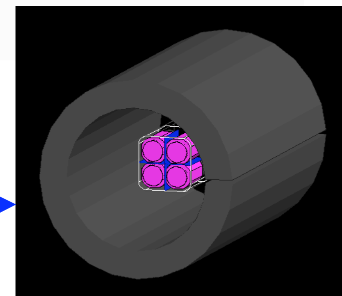
Previous Activities:

Characterization of radioactive backgrounds in conceptual design for NuSAG proposal.

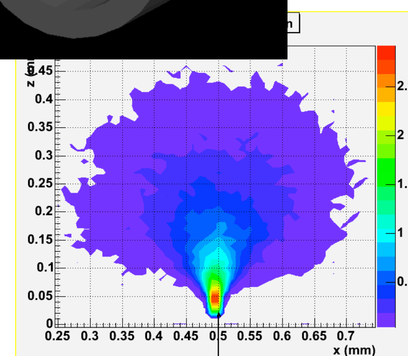


Interpretation of results from highly segmented detector at MSU.

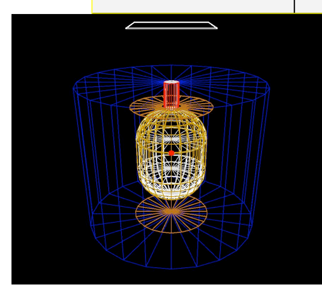
TUNL-Free Electron Laser Run



Charge Distribution in $0\nu\beta\beta$-decay



GERDA (muons and segmentation)

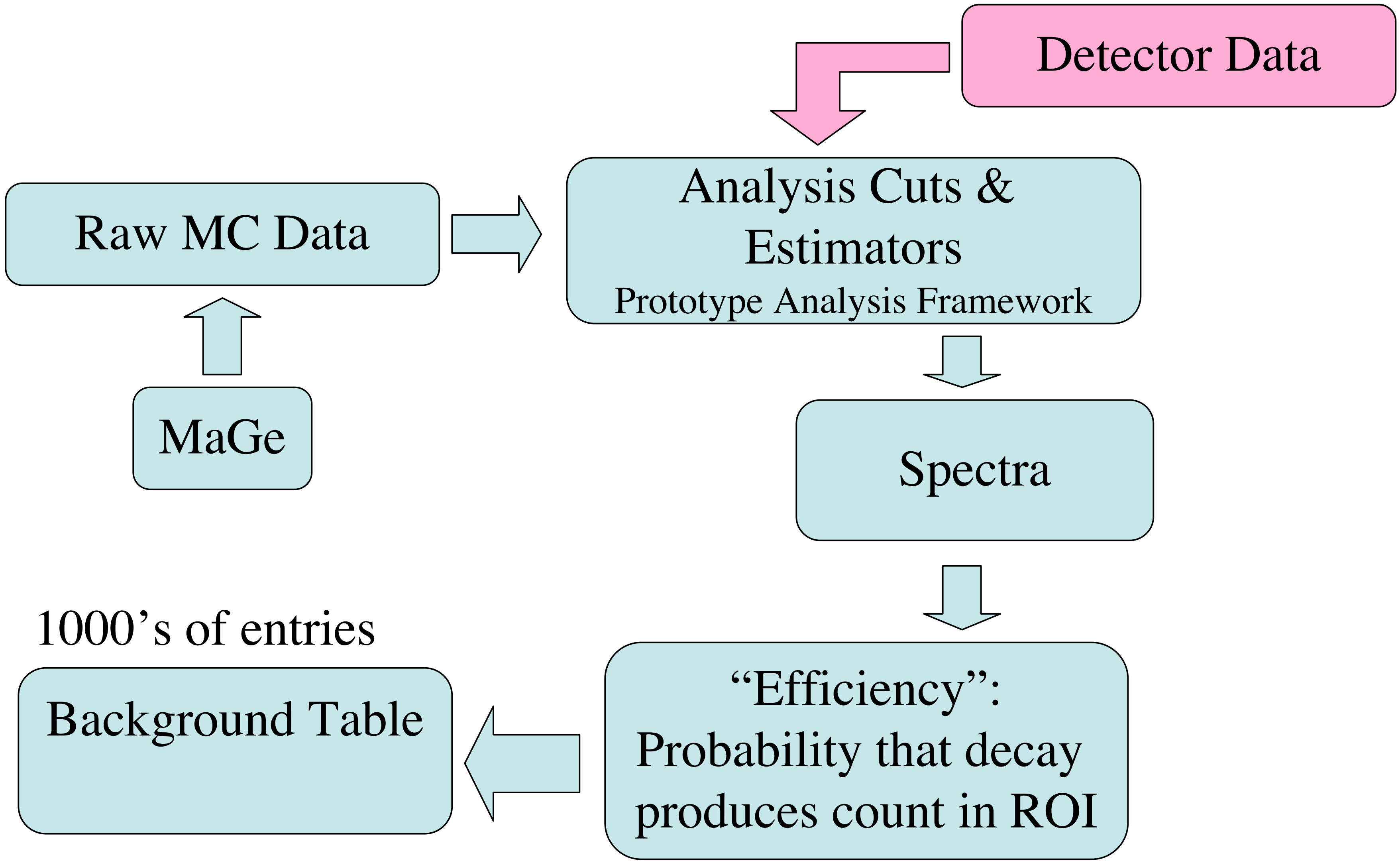


Posters at Neutrino04,
TAUP05, Neutrino 2006
IEEE San Diego 2006

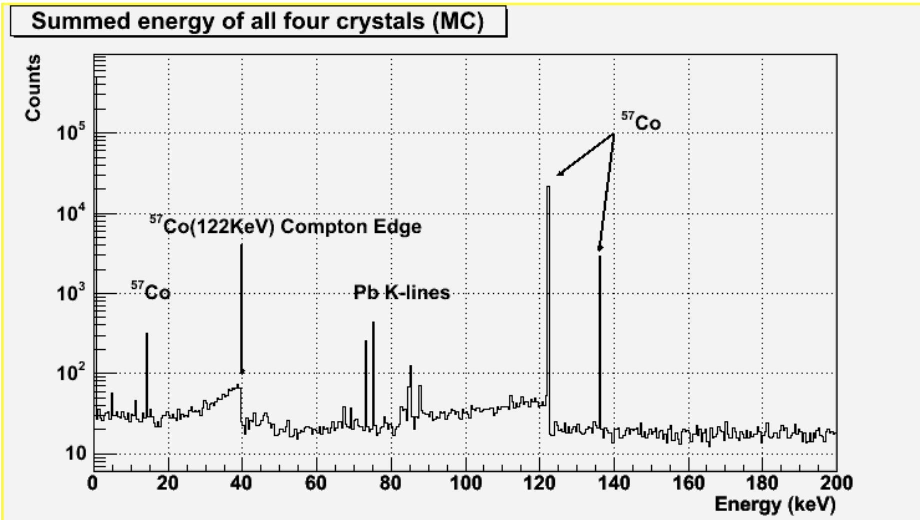
Two GERDA publications In NIM

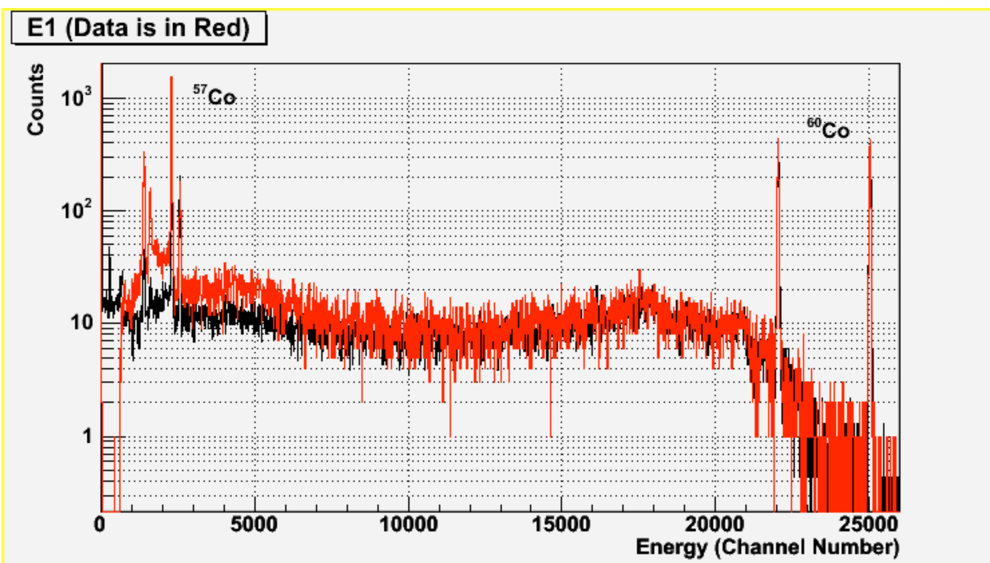
Majorana publications in preparation

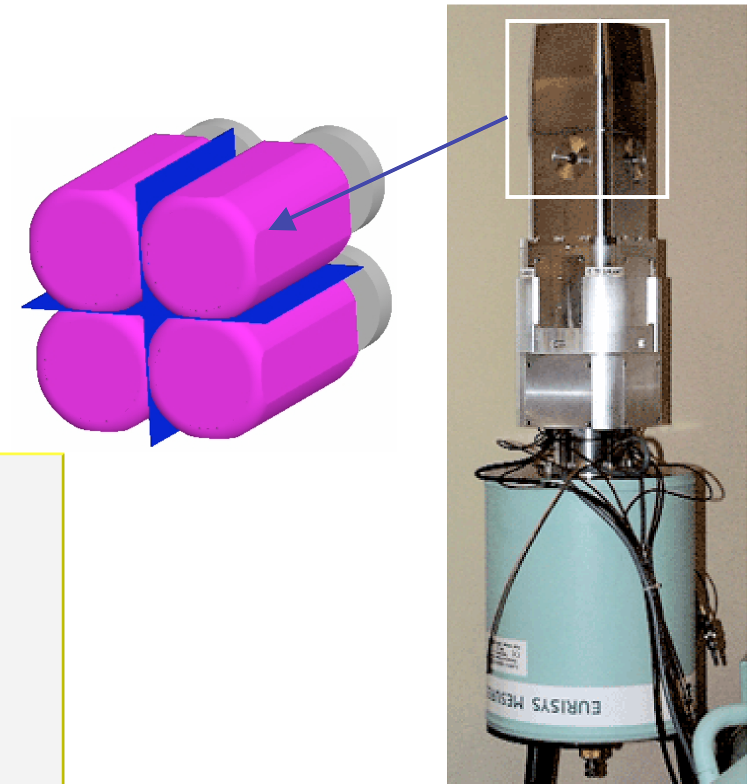
Simulations for Majorana Background Model



Validation: Canberra Clover Detector Simulation







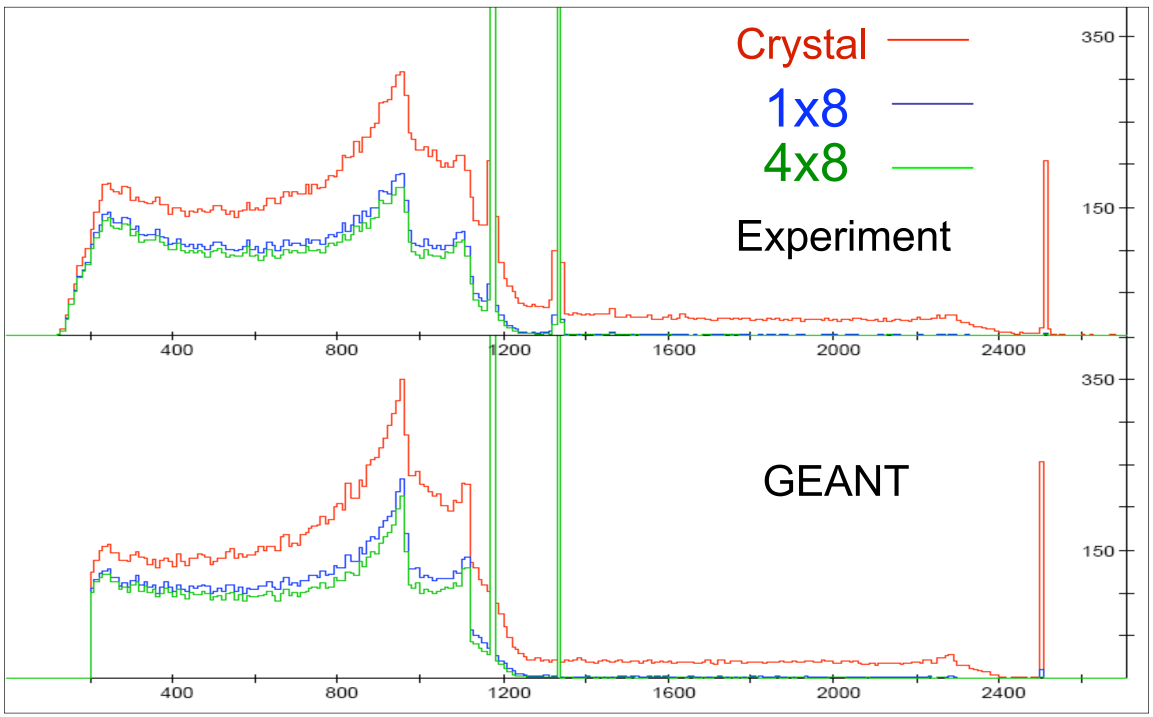
External Combined ^{57}Co ^{60}Co Source measured at LANL

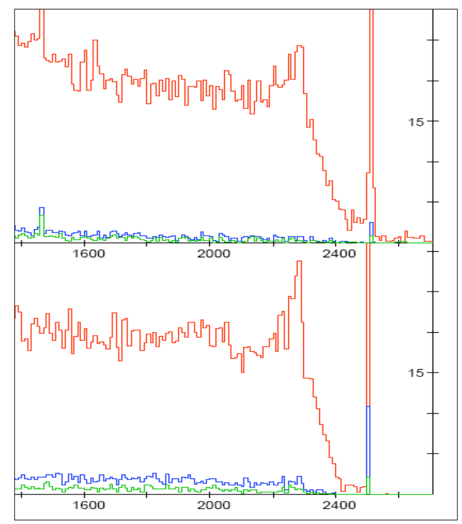
Segmentation test & simulation comparison

Experiment with MSU/NSCL Segmented Ge Array

- 4x8 segmentation scheme: 4 angular 90 degrees each, 8 longitudinal, 1 cm each
- ^{60}Co source
- Segmentation successfully rejects backgrounds.
- Data agrees well with simulations

•Example: Reduction in Compton edge 820-920 keV:
•1x8/xtal Exp: 0.62 MaGe: 0.65
•4x8/xtal Exp: 0.56 MaGe: 0.58

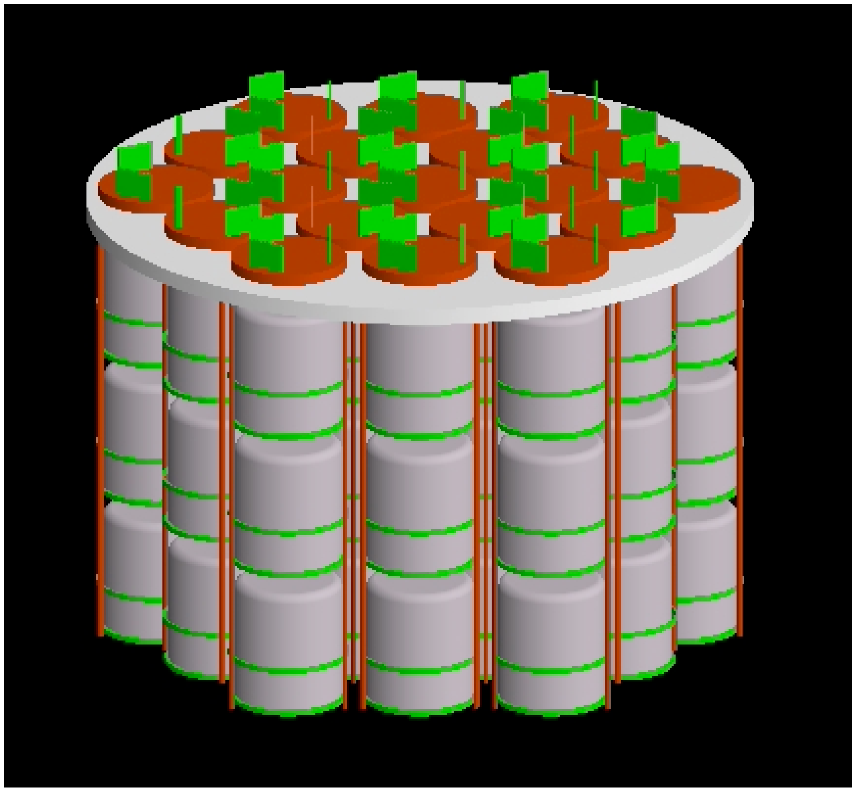




Counts / keV / 10^6 decays

Majorana Reference Design Simulation

Simulated Geometry
Shields & Cryostat Removed



Simulation Includes:

- 57 Enriched crystal w/ deadlayers.
- LFEPs
- Support Rods
- Ge Trays
- Contact Rings
- Cryostat
- Shields:
  - Inner, Outer Cu
  - Inner, Outer Pb
  - Neutron shield.
  - Room, rock wall.
- 45,000 CPU hours, 12,000 jobs, 2TB of data.
- Thanks to PDSF:

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Bulk Contamination Study

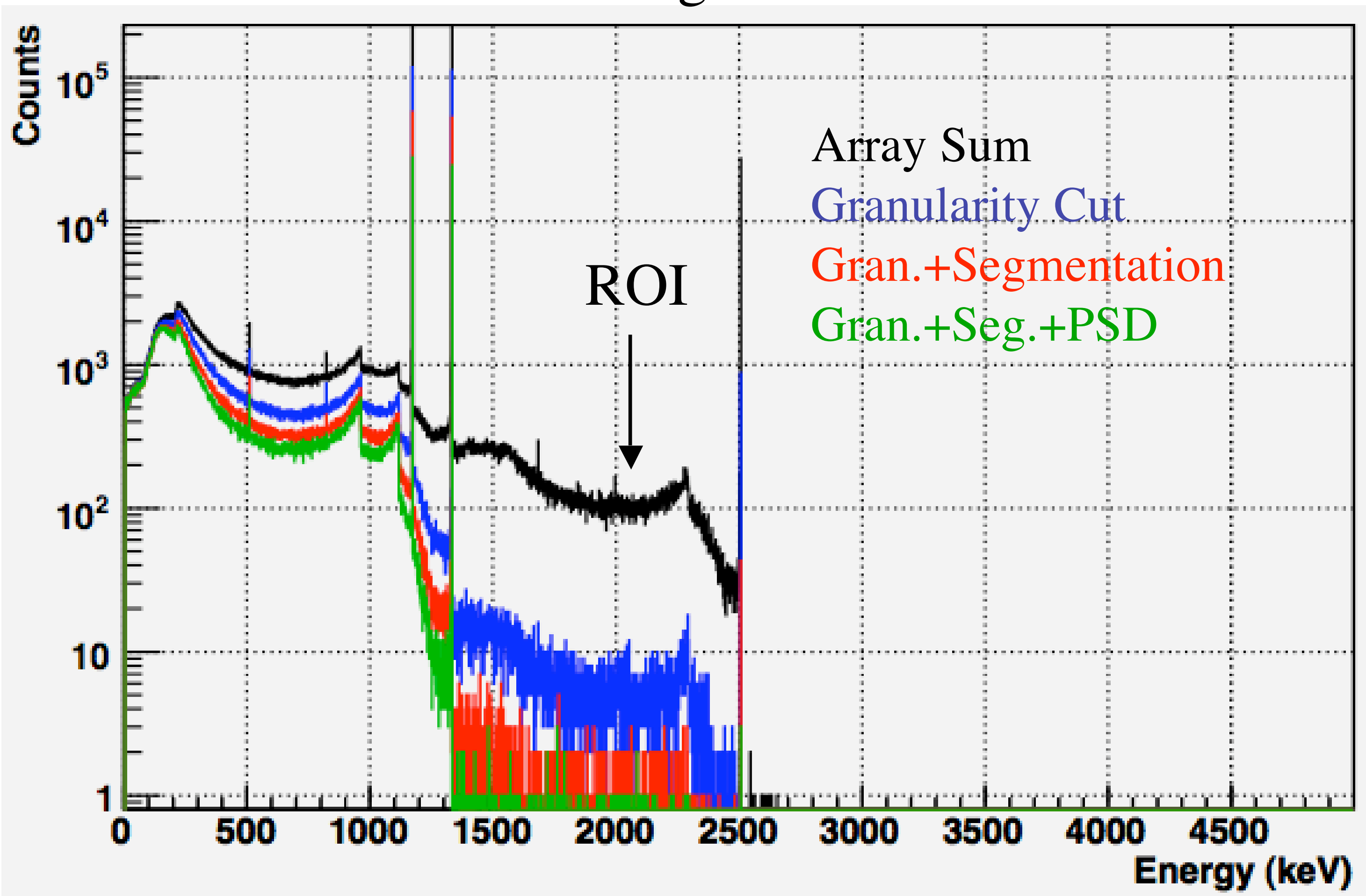
- Simulate spectrum from sources in all detector components.
- Apply heuristic analysis cuts:
  - Granularity
  - Segmentation (~20 schemes).
  - Pulse shape discrimination estimator
  - 3D Reconstruction (highly-segmented detectors).
  - Use clustering of energy deposits
  - Modified electrode
- ^{208}Tl in Copper
- "Small parts"

Sources

- Crystals Internal:
  - ^{68}Ge, ^{60}Co, ^{214}Bi, ^{208}Tl :
  - $2\nu\beta\beta$, $0\nu\beta\beta$:
- Support Rods: ^{208}Tl, ^{214}Bi, ^{60}Co.
- Ge Trays: ^{208}Tl, ^{214}Bi.
- Contact Rings: ^{208}Tl, ^{214}Bi.
- Cabling: ^{208}Tl, ^{214}Bi.
- LFEPs: ^{208}Tl, ^{214}Bi, ^{60}Co.
- Cryostat, ^{208}Tl, ^{214}Bi, ^{60}Co:
- Crystals Surface: Rn daughters (alphas). U/Th dust
- Inner Cu shield: ^{208}Tl, ^{214}Bi, ^{60}Co.
- Other Shielding.
- …. WIP

Example spectra: ^{60}Co in Cryostat

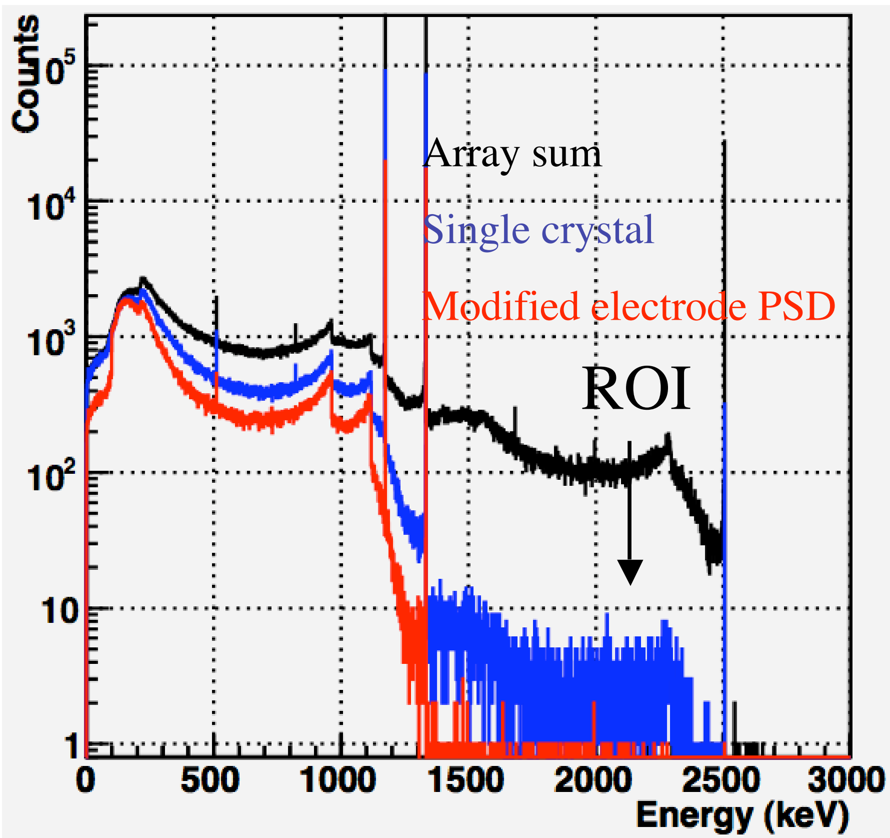
2x3 Segments



Cuts very effective against ^{60}Co (inherently multi-site event)

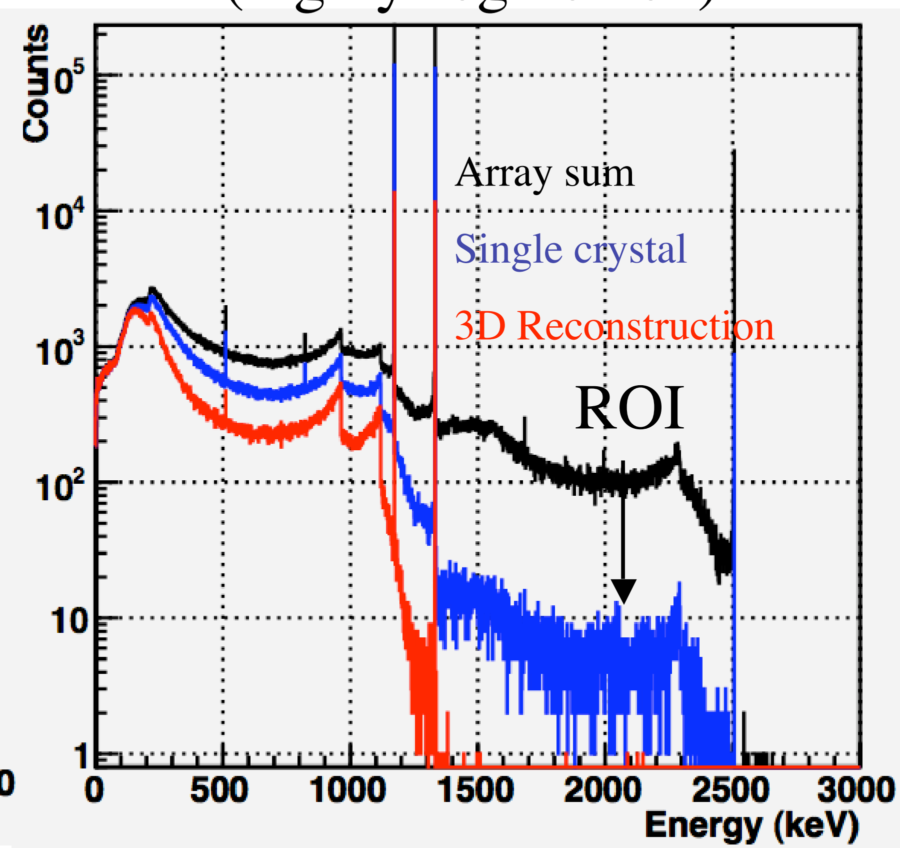
Example spectra: ^{60}Co in Cryostat (2)

Modified Electrode



3D Reconstruction

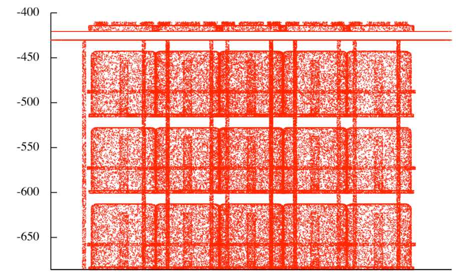
(highly segmented)

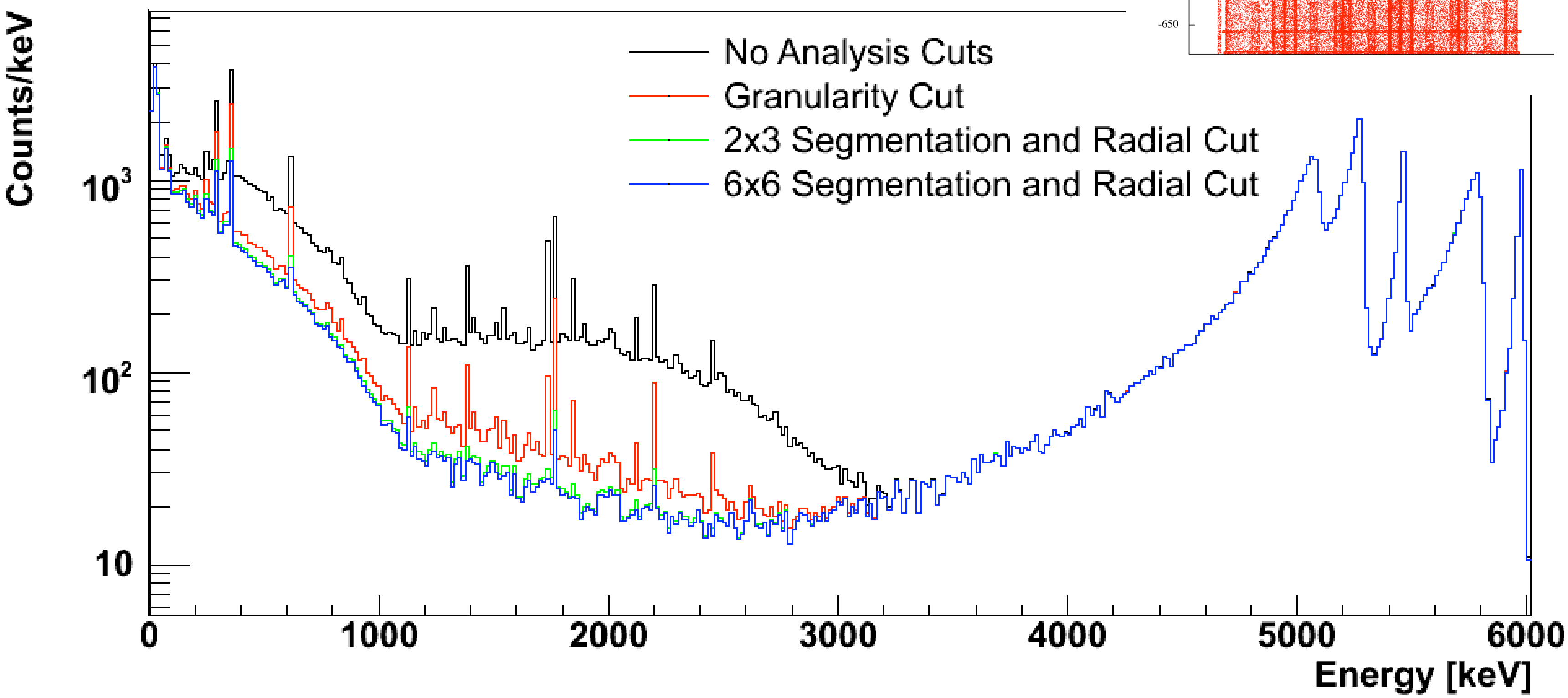


Surface Alpha Contamination

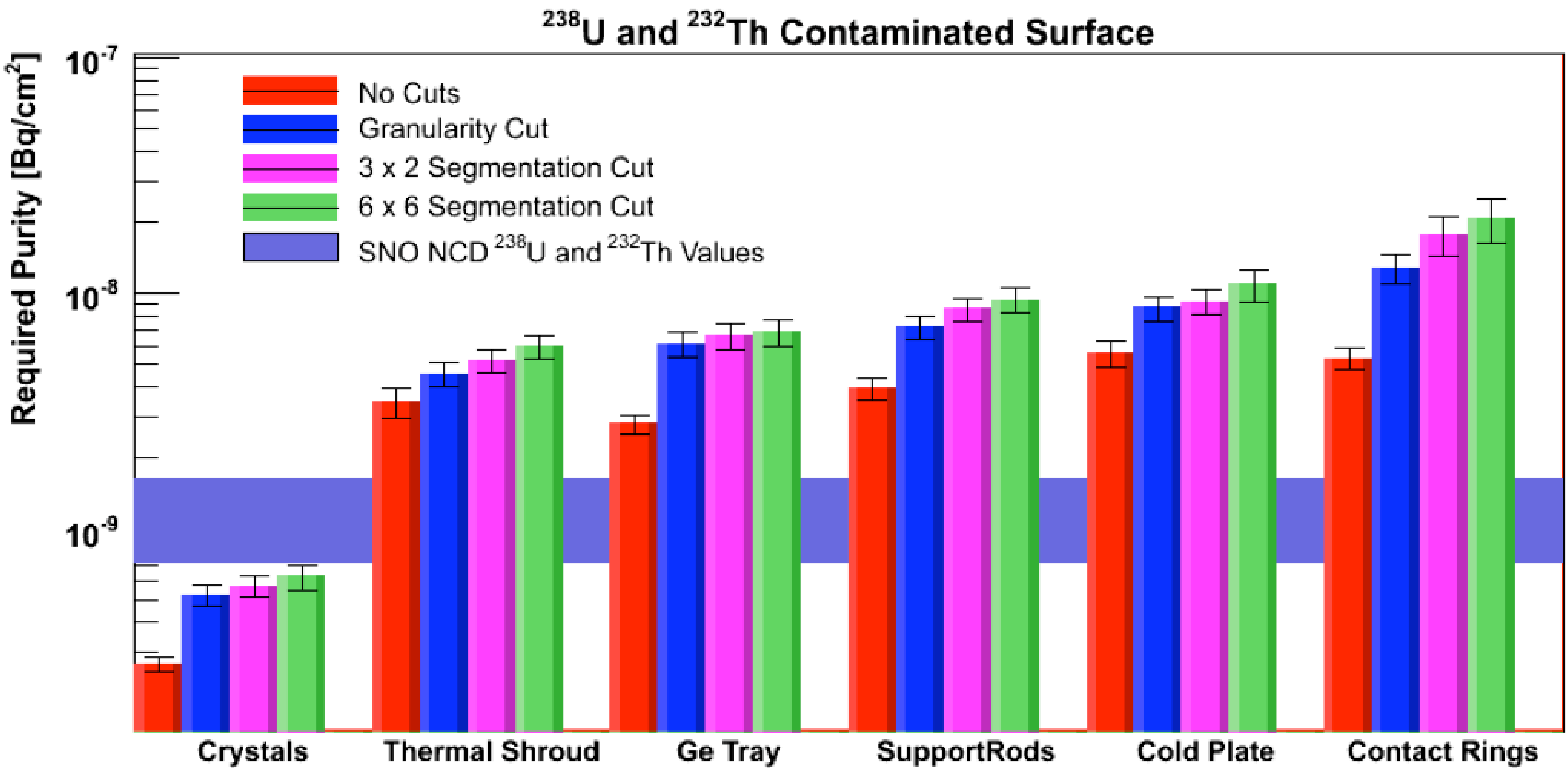
Studied several chains
Example Spectrum in Reference Design
(^{222}Rn to ^{206}Pb):

Generic Surface Sampler



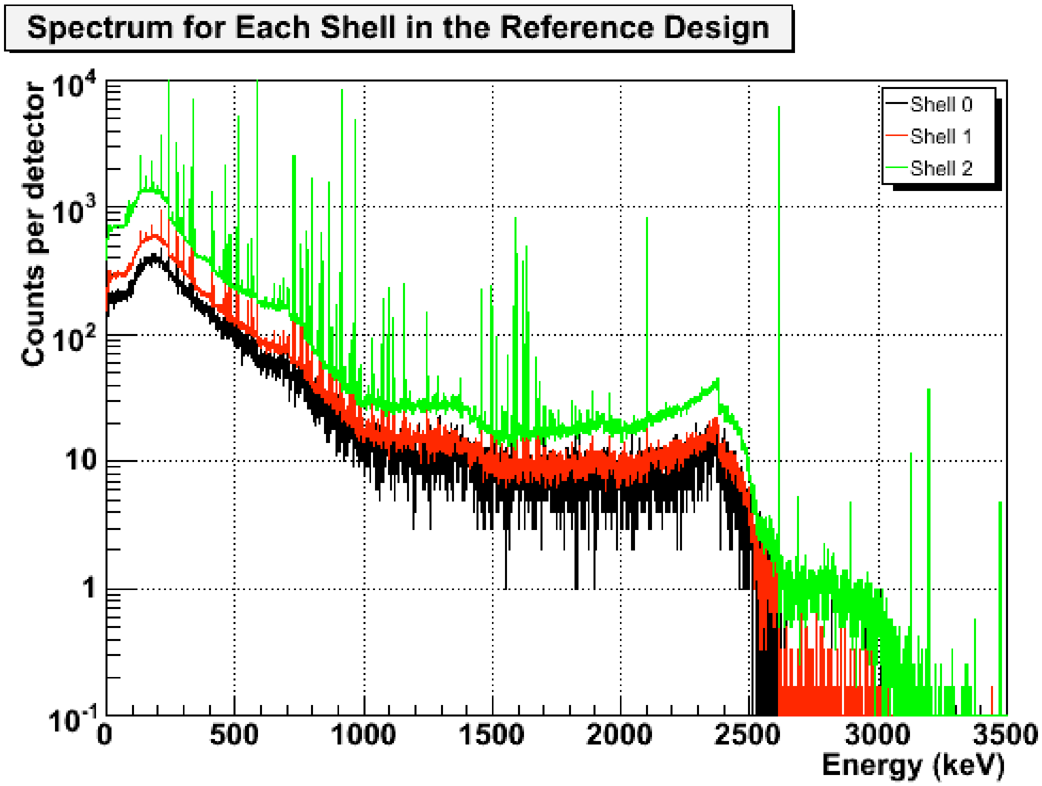


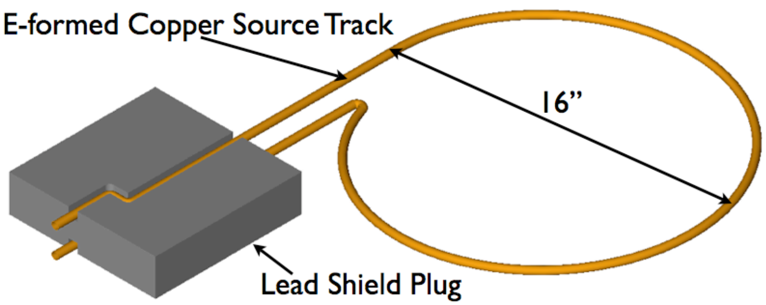
Surface Cleanliness Requirements



Cleanliness requirements for inner surfaces similar to Sudbury Neutrino Observatory Neutral Current Detectors.

Additional R&D:
Reference Design Calibration Simulation



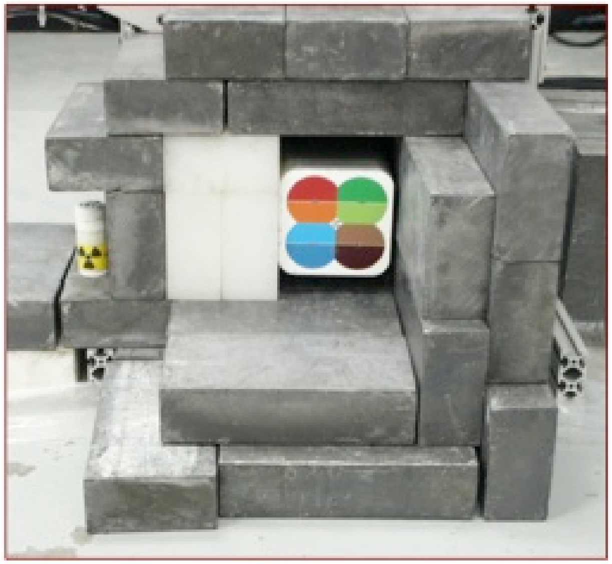


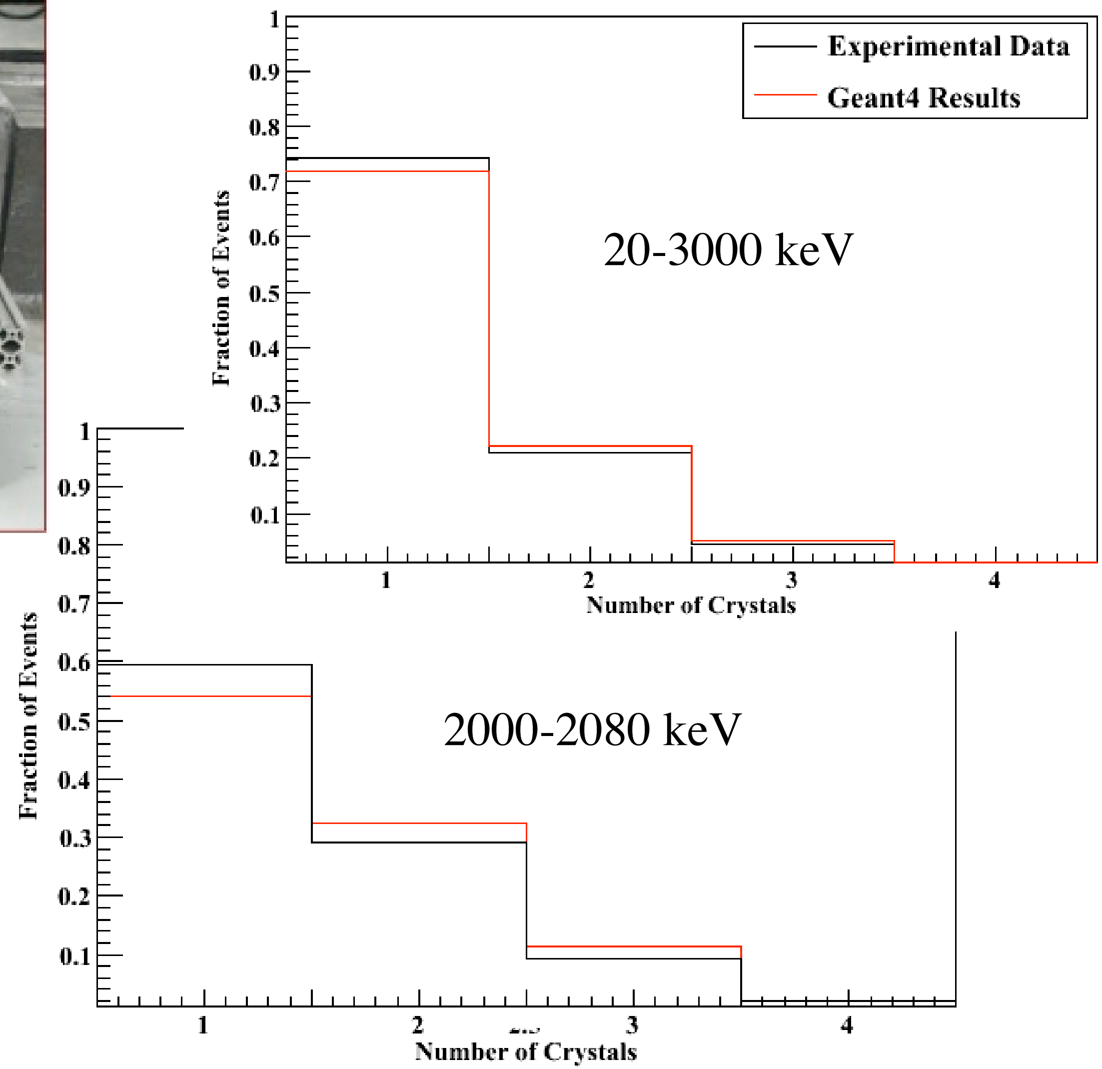
- Simulation of ^{232}Th wire source wrapped 315° around RD cryostat..
- Constructed spectra per concentric shell in the RD array to understand calibration rate requirements
- This spectrum corresponds to roughly 19 hours of runtime with 0.22 mm diameter Thorium wire available commercially from Goodfellow.
- Will provide additional validation with LANL Clover.

Cosmic-ray induced background.

- In Progress
- Complex simulation. Requires Physics from 100's of GeV to 4 keV window. Complex inelastic neutron processes.
- Current result from Mei & Hime (2006) and others indicate Majorana requires ~ 4500 mwe.
- Depends on Geometry, ie. shielding
- Goal: confirm Mei & Hime results with Majorana Reference Design
- Baseline Monte Carlo against data first.
  - **Quantify Uncertainties**
- Two aspects under investigation:
  - Simulation of neutron production from cosmic-rays and neutron propagation through rock
  - Neutron interactions in detector material.
- Status: Identified and corrected many shortcomings in Geant4. Active discussion with Geant 4 collaboration.
- Anticipate production running early next calendar year.

Example of Validation: AmBe source with LANL clover





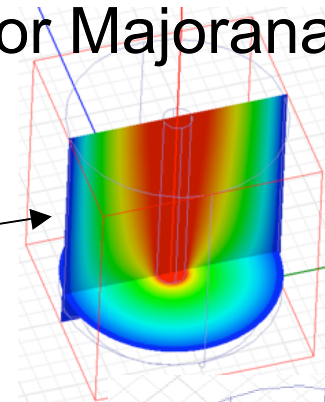
- Simulation of effect of granularity cut in ROI for neutrons source
- Effect of granularity cut accurate to 5-10%.
- More detailed analysis of spectral features in progress.

Waveform Simulation for Majorana

- Based on Ramo's Theorem
- Well tested for Ge detector applications
- Rely on GRETINA Development
- Implementation Under Development for Majorana/MaGe

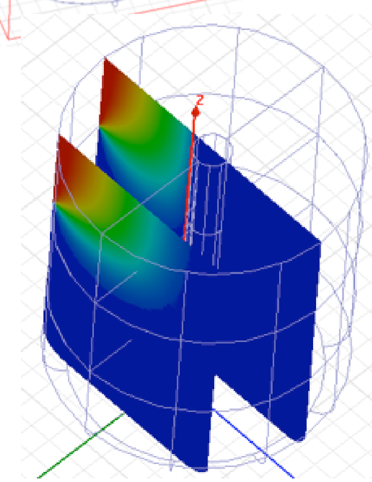
Electron-Hole Trajectory

-E-Field (Geometry, Bulk material permittivity, charge impurity profile)
-Velocity Model (Anisotropy)



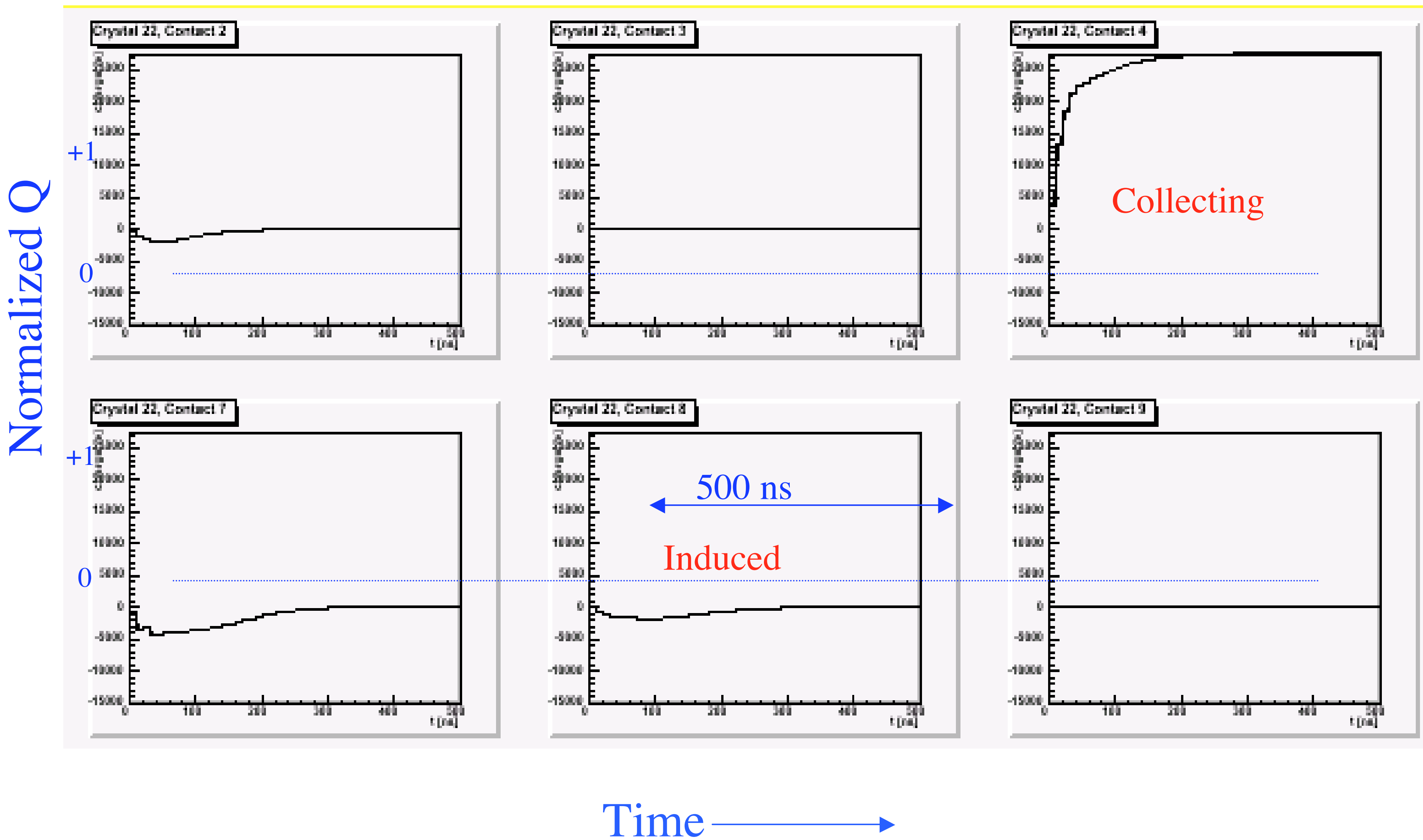
Pulse Formation

-Weighting Potentials (Electrode configuration)



Software tools - Both commercial (COMSOL, Maxwell3D and internal to the collaboration).

Example single hit waveform simulation using MaGe implementation of GRETINA m3d2s package



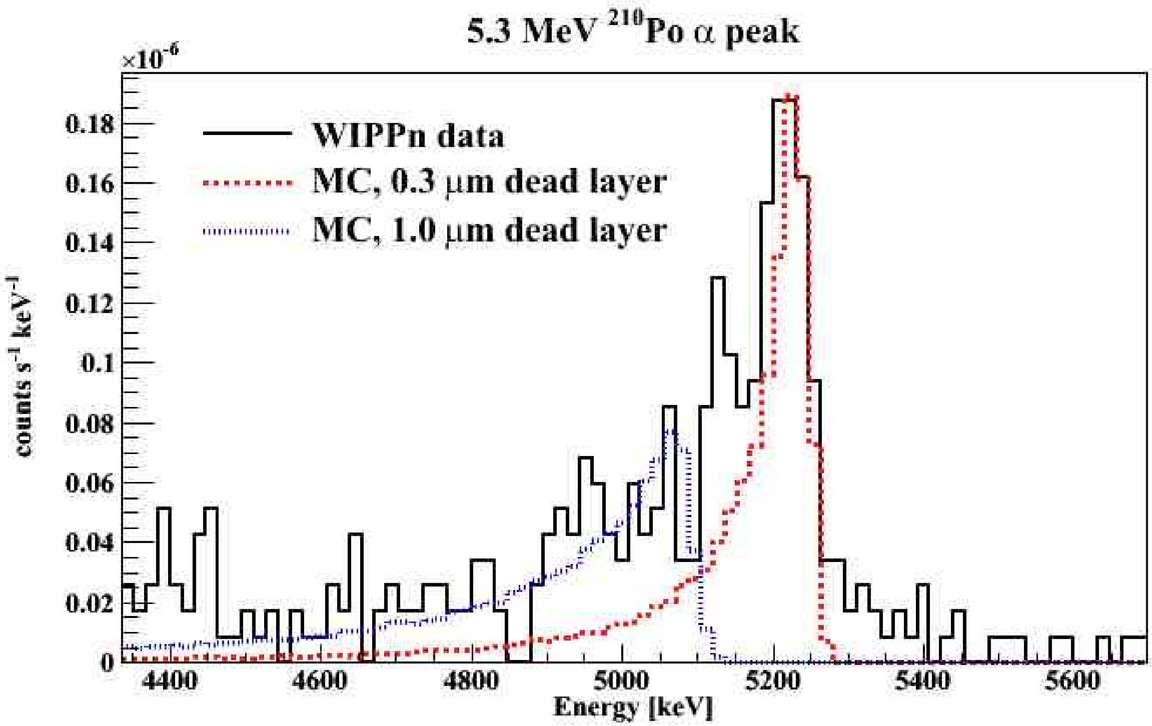
Conclusions & Outlook

- Completed significant effort to quantify purity requirements for Reference Design with heuristic analysis cuts.
- Collaboration w/ Gerda extremely valuable.
- Future/ongoing work:
  - Additional validation: Highly-segmented HPGe detector at Oroville, LANL Clover with ^{232}Th source, …
  - Muon-induced background --> Depth and shielding requirements.
  - Pulse shape simulation. Interface w/ GRETINA.
  - Phased startup.
  - Additional cryostats
  - Pulse shape analysis
  - Detector characterization requirements
  - Full spectra analysis and background model.
  - Analysis framework and tools.

Backup slides

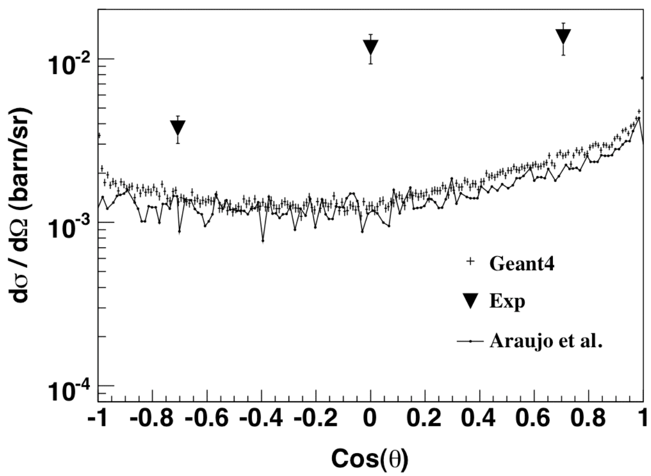
Surface Alpha Contamination

Comparison to data
Indicates varying thickness
of deadlayer

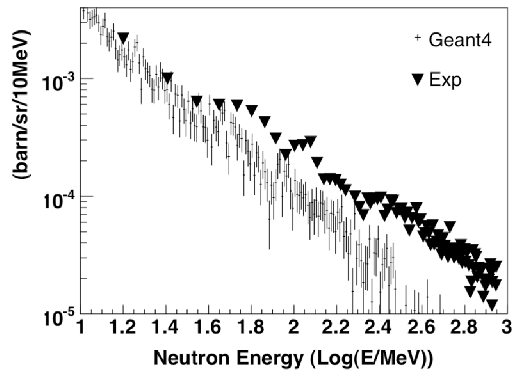


Muon-induced neutrons

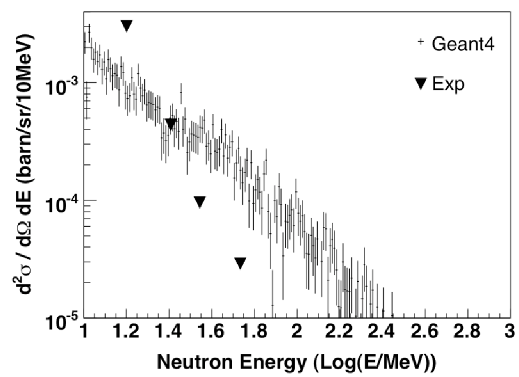
High Z material
(Pb) results

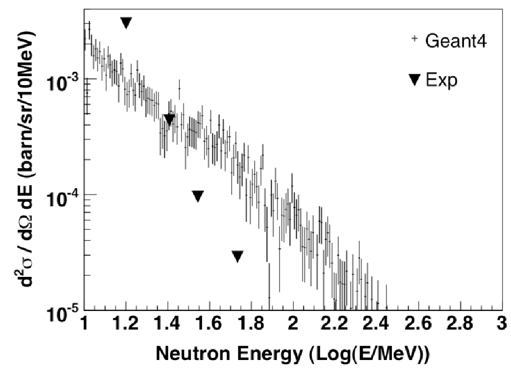


45 Deg



90 Deg

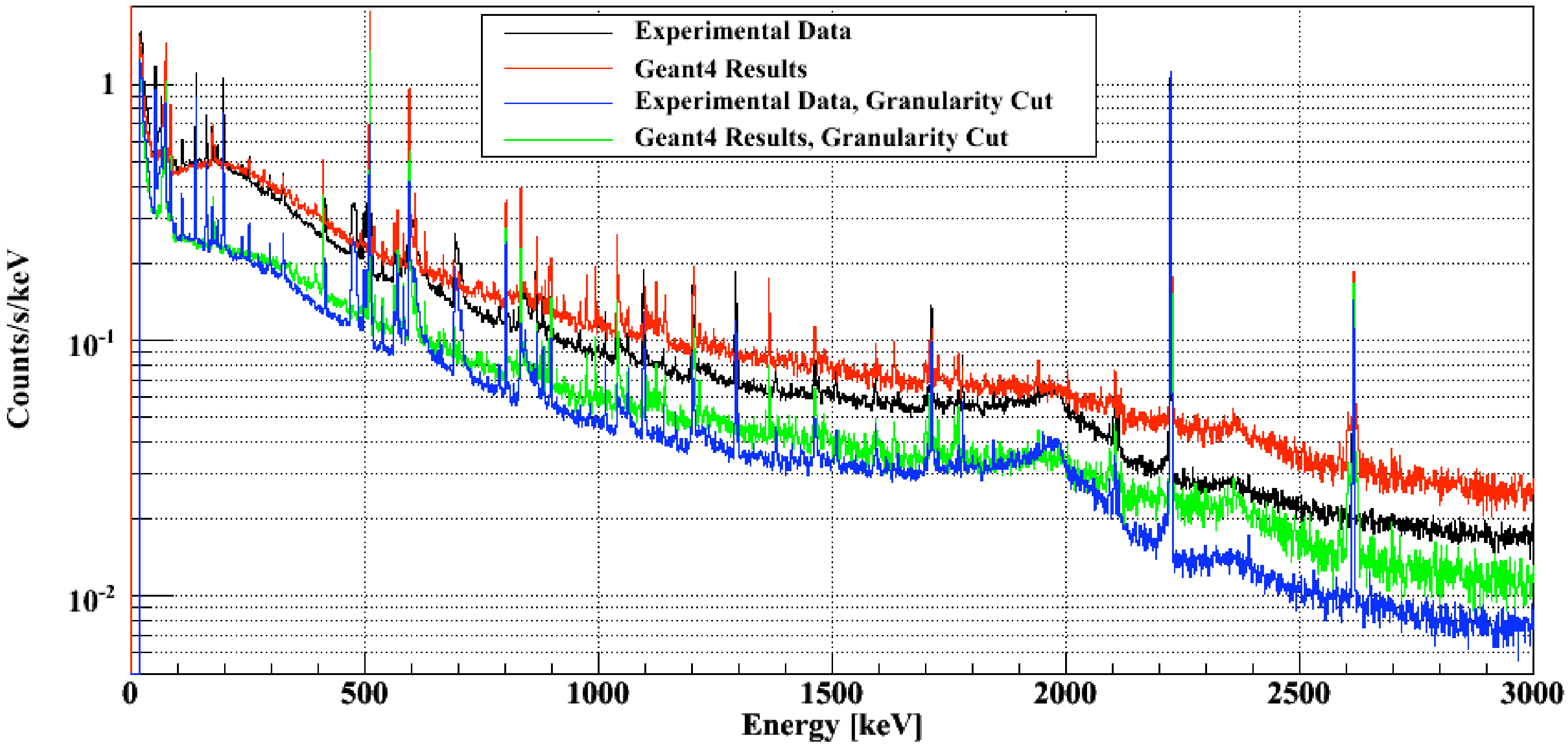




135 Deg

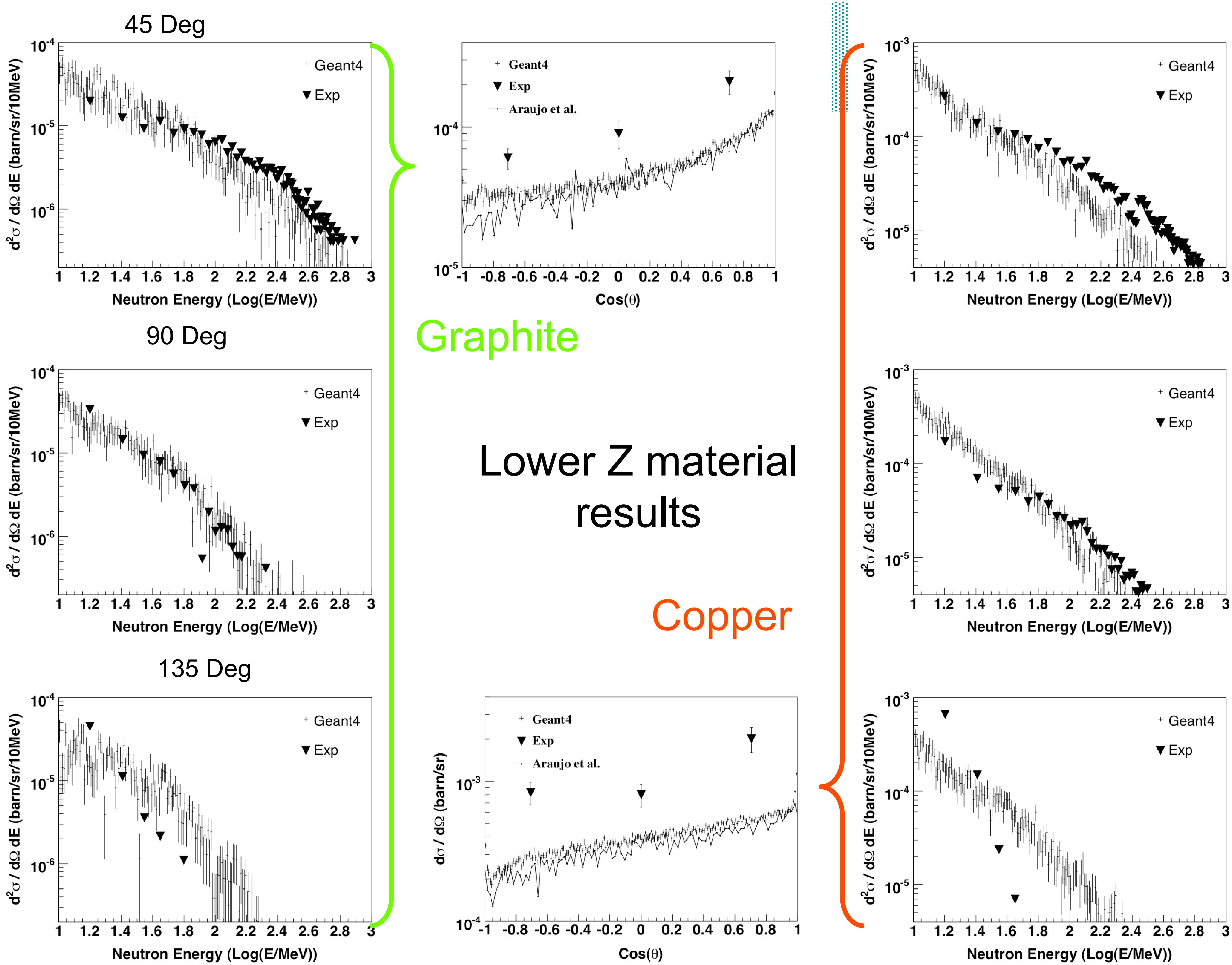
The total production agre
within a factor of ~6.

AmBe Source Spectra



- Added nuclear quenching.
- Comparison identified issues with cross section data, metastable states, and internal conversion electrons. --> Corrected for.
- Effect of granularity cut captured.

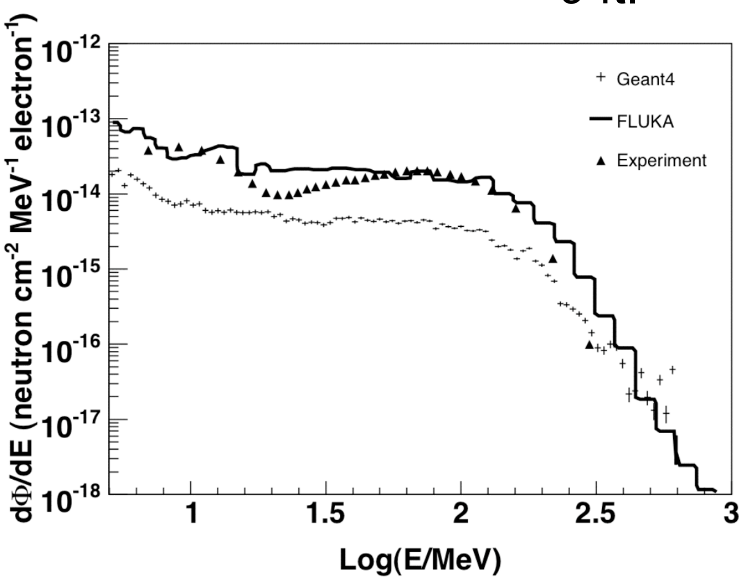
Lower Z material results

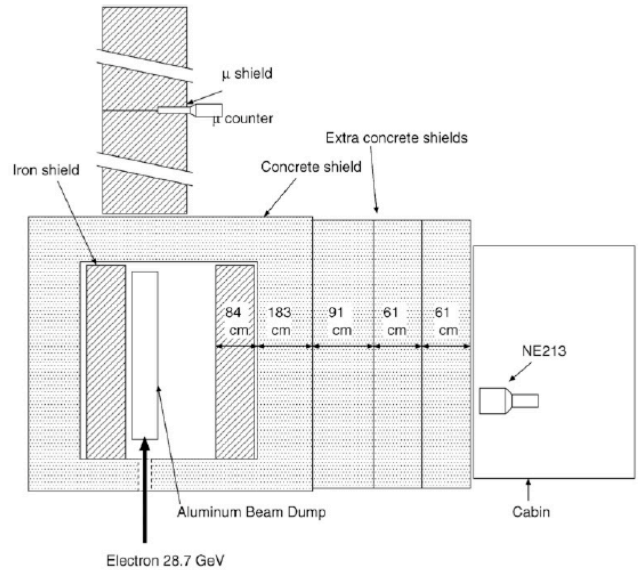


Neutron Transport

- SLAC electron beam-dump
  - 28.7 GeV e^- on Al
  - Measured neutron flux through steel and concrete

9 ft.

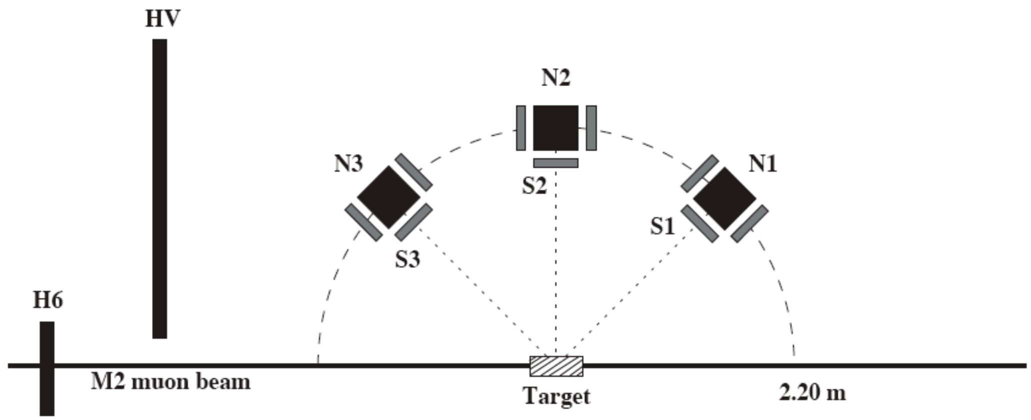




NIM A **503** (2003) 595ff.

Muon-induced neutrons

- CERN NA55 - measured neutrons generated from 190 GeV muon incident on C, Cu, and Pb.
- Low-Z (Z<~ 29) materials provide good agreement with previous results. Geant-4 reproduced results from Araujo et al.



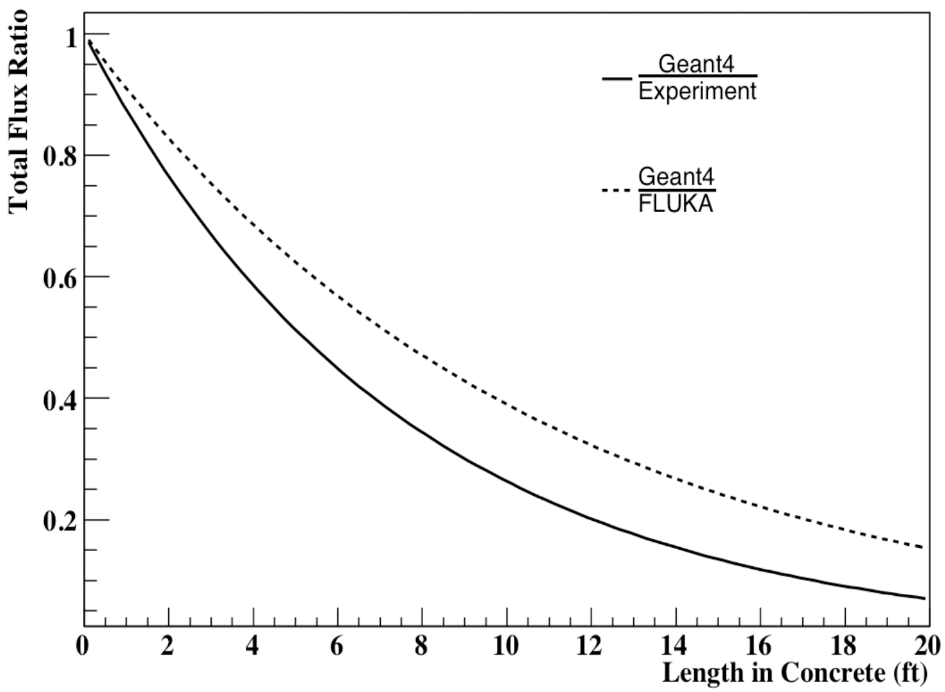
Chazal, et al. NIM A **490** (2002)

Material	Measured Fluence (n/μ/g/cm^2)	Calculated Fluence	Ratio
Graphite	6.83E-05	3.28E-05	2.08
Copper	1.19E-04	4.82E-05	2.47
Lead	3.48E-04	5.87E-05	5.93

Not as good agreement for high-Z Pb

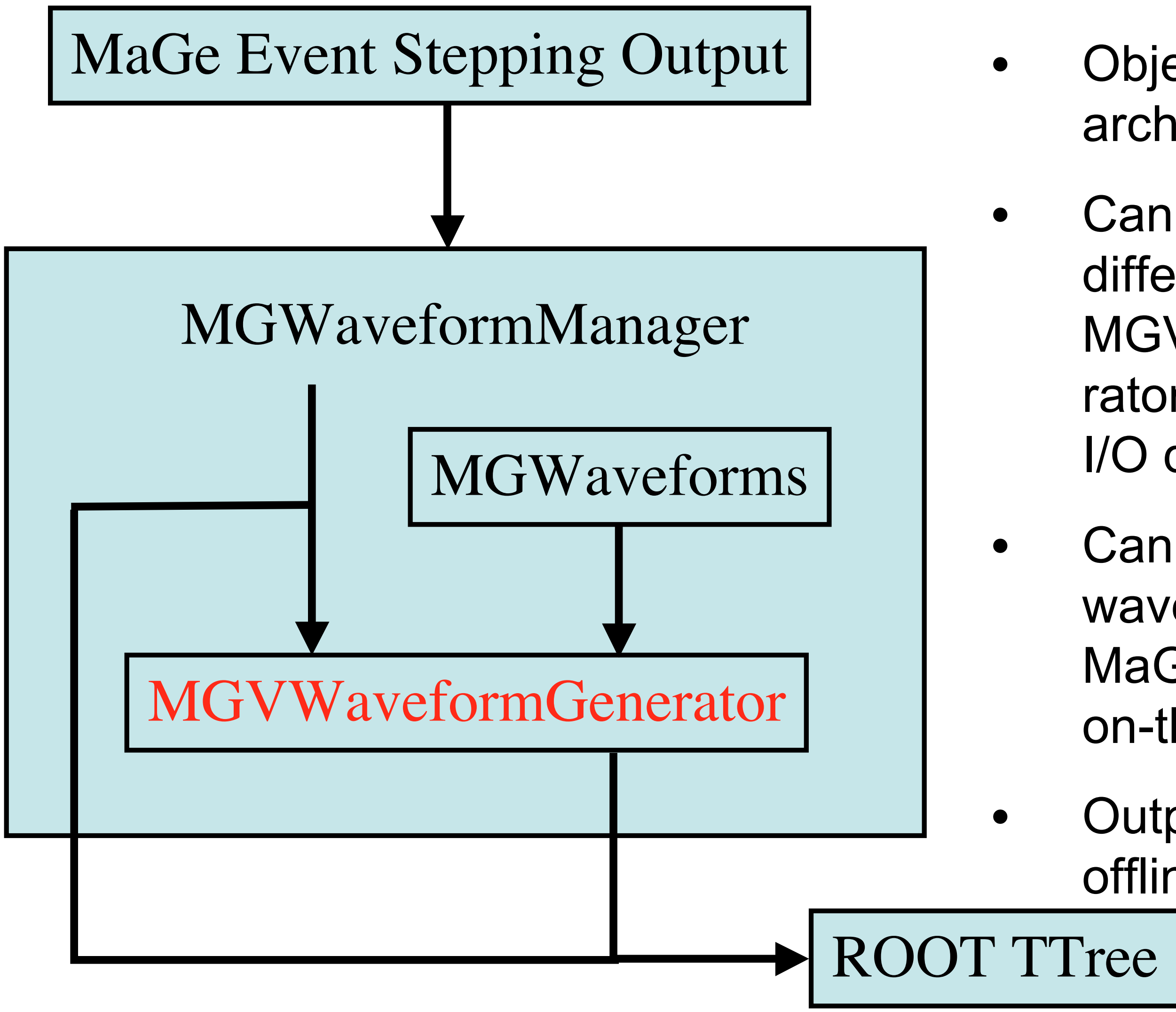
Neutron Transport

Total neutron Φ (>6 MeV)



- Problems identified:
  - Under production of primary neutrons
  - Over attenuation of neutrons
- Working with Geant 4 to resolve this.
- Possible Solutions:
  - Include correction in Monte Carlo.
  - Interface with FLUKA

Waveforms in MaGe



- Object-oriented architecture
- Can implement different MGVWaveformGenerators while ignoring I/O details
- Can generate waveforms from MaGe output files or on-the-fly
- Output to ROOT for offline processing

MJM3D2S - Primary Waveform Generator

- MJ Monte Carlo Default Crystal @4500V Bias
- 1x1 (non-segmented), 3x2, … ,6x6
- Finite Element Analysis code for field and potentials
- GRETINA (m3d2s) code for pulse generation
- Impurity charge density r(z) = 0.0016*(1.+20.*z(m)) C/m^3

Weighting Potential examples (Ver. 11.1)