1. Monte Carlo Studies for the Gerda/Majorana Experiments and 2. Highly Segmented HPGe Detectors for DBD

Reyco Henning

The Majorana Collaboration

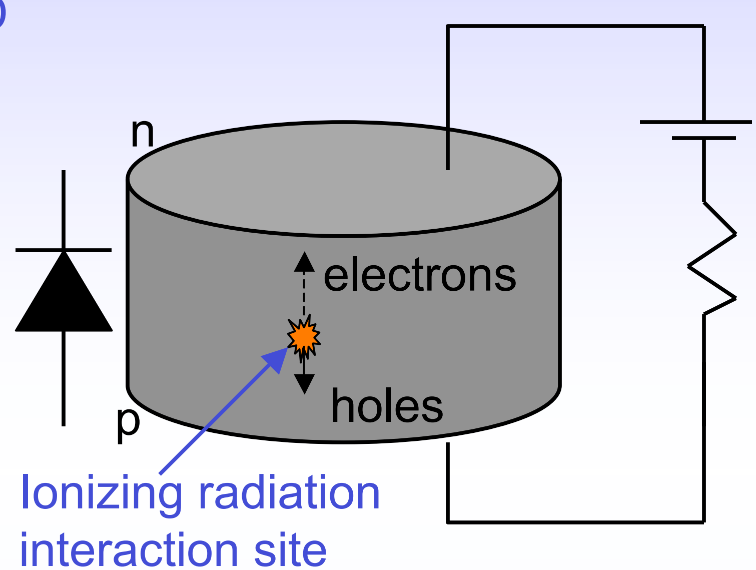
1. Monte Carlo Studies for Majorana/Gerda

1. The Majorana and Gerda Experiments
2. The Joint Majorana/Gerda Simulation Package Framework-- MaGe
3. Majorana Results

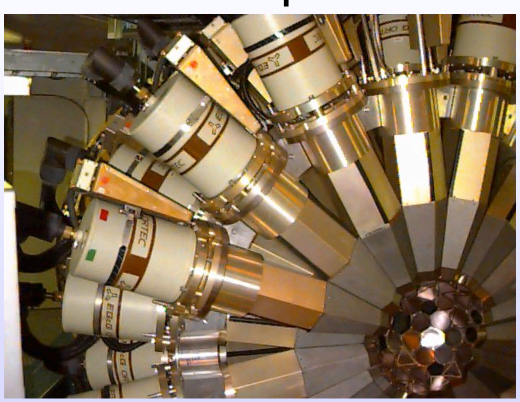
Ge Detection Principle

- Majorana and Gerda search for DBD in ^{76}Ge.
- Ge is semiconductor -- Diode.
- Ionizing radiation creates electron-hole pairs.
- Signal generated by collecting electrons and holes.
- Gamma-ray spectroscopy

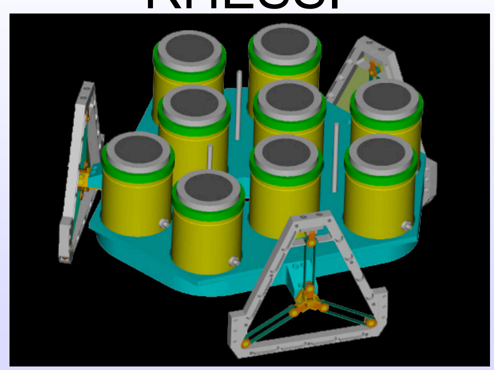
Mature Technology



Gammasphere



RHESSI



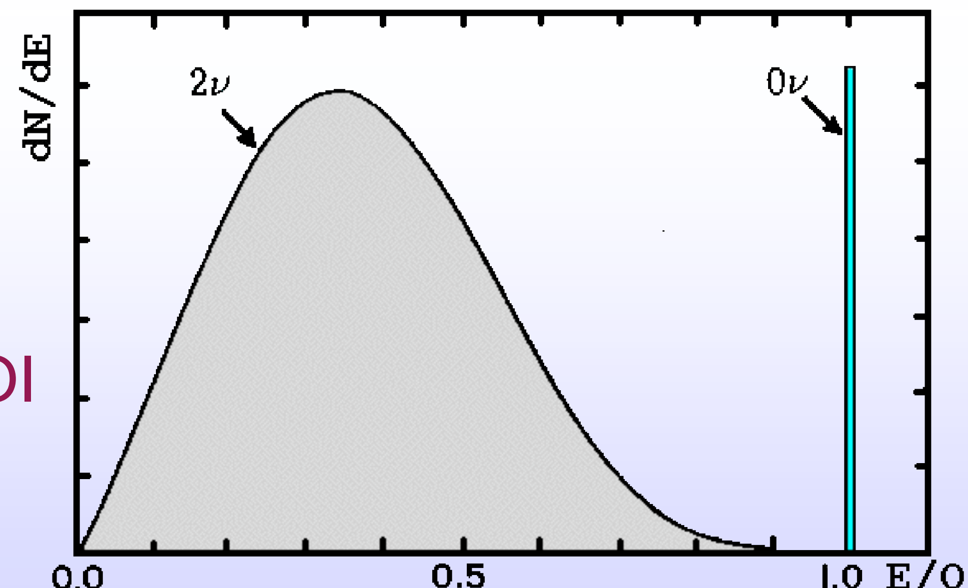
Eurisys (Commercial)

Experimental Considerations for DBD

- Measure *extremely* rare decay rates :

  $T_{1/2} \sim 10^{26}$ -10^{27} years
- Large, highly efficient source mass.
- Extremely low (near-zero) backgrounds in the $0\nu\beta\beta$ peak region-of-interest (ROI) (1 count/t-y)

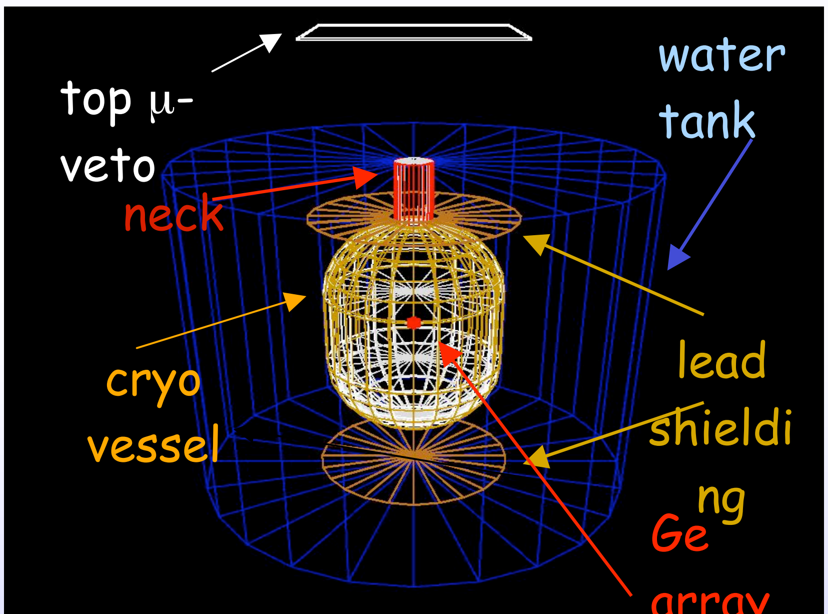
- High Q value
- Best possible energy resolution
  - Minimize $0\nu\beta\beta$ peak ROI to maximize S/B
  - Separate $2\nu\beta\beta/0\nu\beta\beta$



U. Zargosa

GERDA

GERDA is a new experiment for the search of ^{76}Ge neutrinoless double-beta decay at LNGS. The principle of GERDA is to operate germanium detectors made out of isotopically enriched material inside a cryogenic fluid shield.

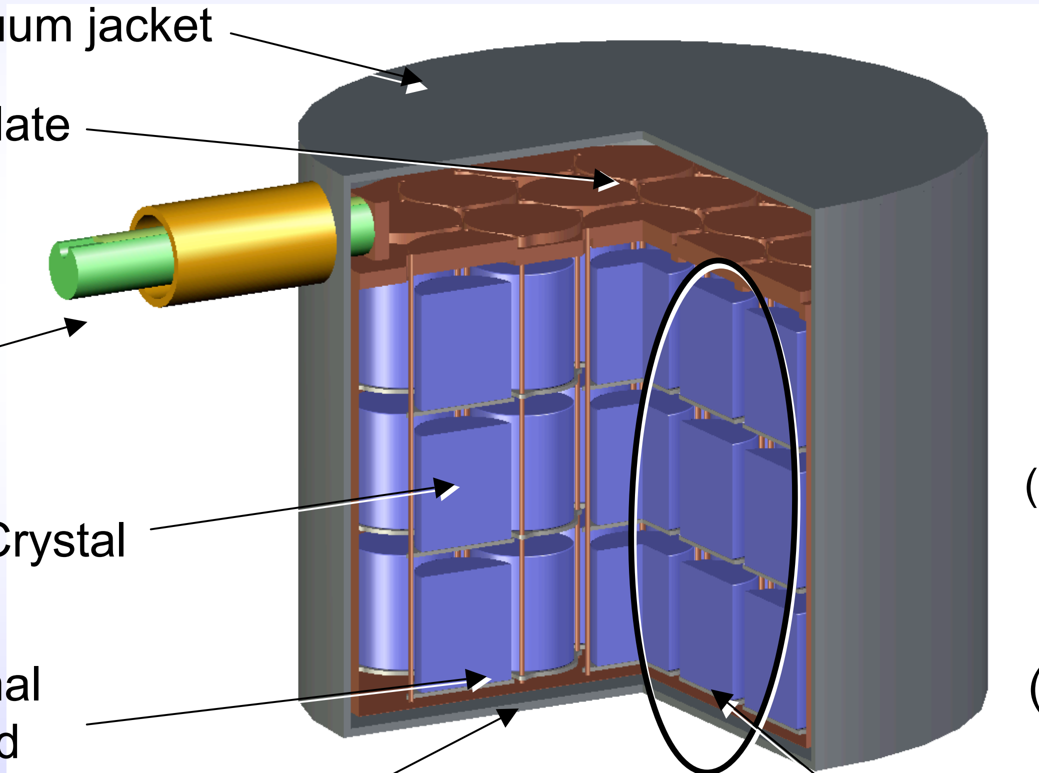


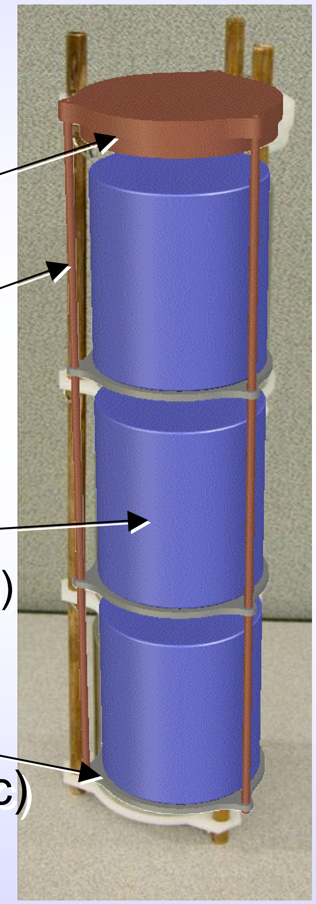
- The facility will be located in HAll A of LNGS and will serve a dual purpose:
- It will probe the neutrinoless double beta decay of ^{76}Ge with a sensitivity of $T_{1/2} > 10^{24}$ y at 90% confidence level, corresponding to a range of effective neutrino mass < 0.09 - 0.20 eV within 3 years.
- It will be a pioneering low-level facility which will demonstrate the possibility of reducing backgrounds by 2-3 orders of magnitude below the current state-of-the-art.

The Majorana Modular Approach

57 crystal module

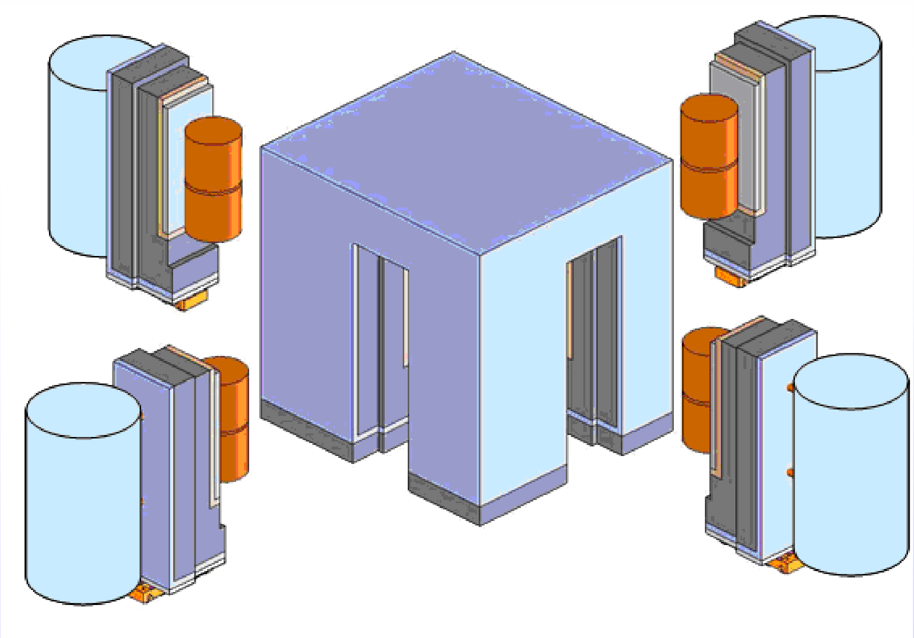
- Conventional vacuum cryostat made with electroformed Cu.
- Three-crystal stack are individually removable.



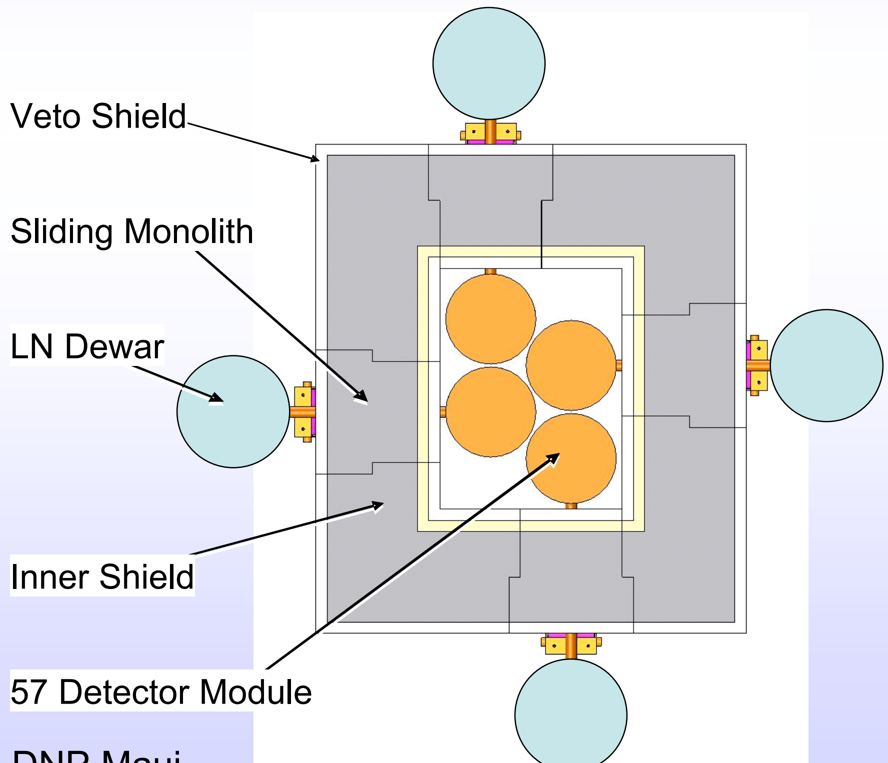


The Majorana Conceptual Design

- Allows modular deployment, early operation
- Contains up to eight 57-crystal modules (M180 populates 3 of the 8 modules)
- Four independent, sliding units
- Use 180-Kg of material to probe degenerate mass region.



Top view



History & Goals of Simulation

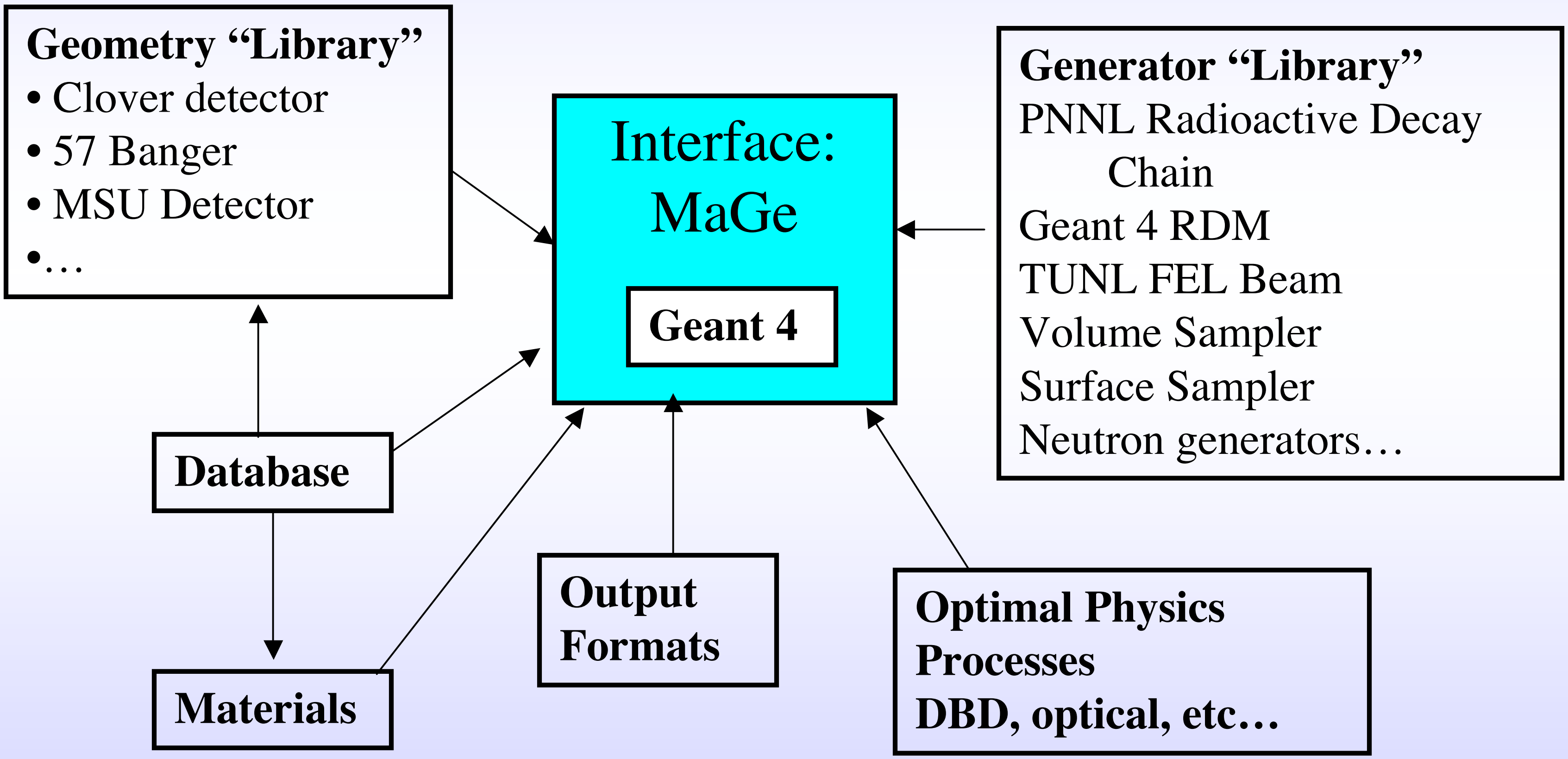
- Much previous work from PNNL, NCSU, U.W. & others.
- Jan. 2004. Decided to develop integrated software package using professional programming techniques.
- Philosophy: Use Geant4. Improve where needed. Create Framework first

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, upgradable, documented, and robust.
4. Maintain record of results.

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/GRETA collaborators.
3. Electronics.
4. Shielding (neutron absorption and muon tagging).
5. Radioactive decay chains and emissions.
6. Signals (double-beta decay, dark matter, axions…).
7. Activation in detector material.
8. Optimization of close-packed crystal packing arrangements for self-vetoing
9. …….

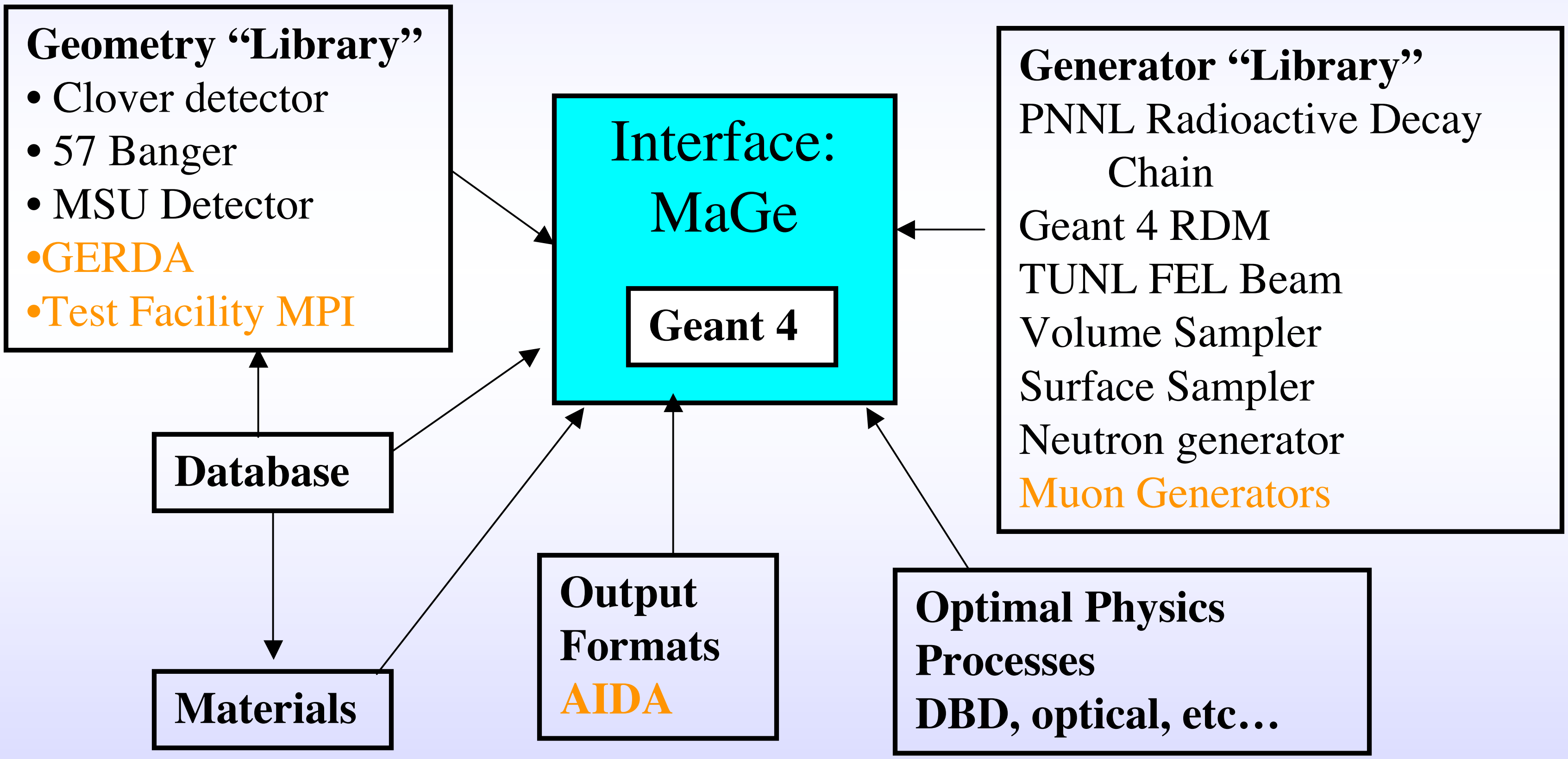
Framework

Build common interface using powerful object-oriented capabilities of C++



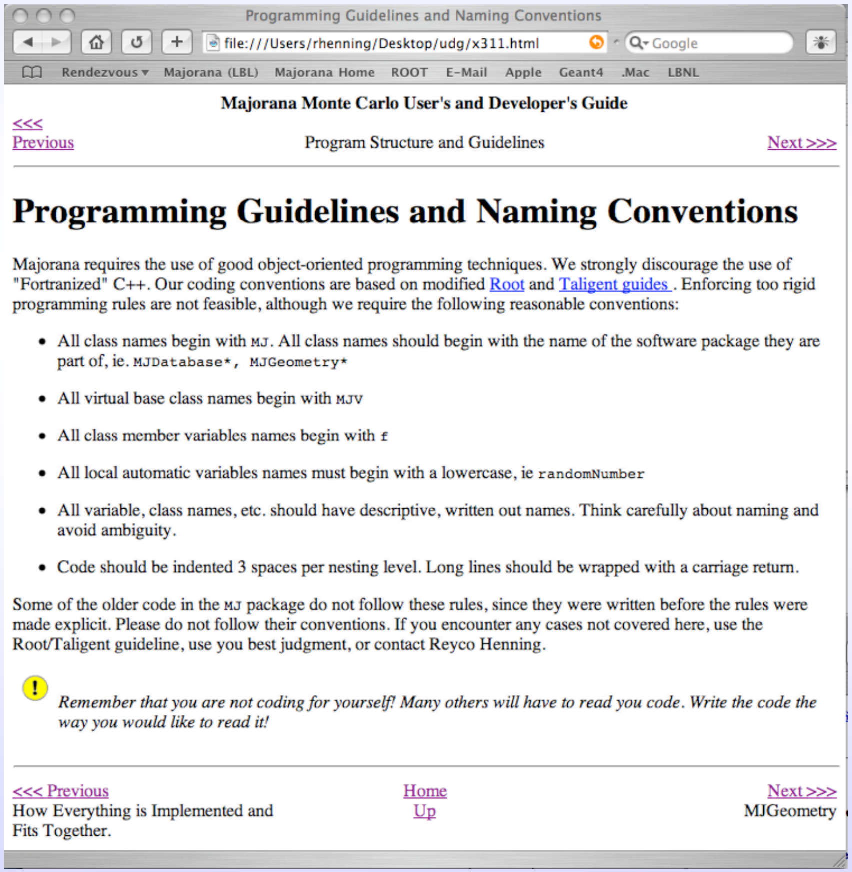
The Majorana/Gerda Collaborative Effort

- Started Oct. 2004, Gran Sasso
- Twice as many developers, test cases, etc…
- Very Sucessful



Example Documentation

User's Guide



Programming Guidelines and Naming Conventions

file:///Users/rhenning/Desktop/udg/x311.html

Rendezvous Majorana (LBL) Majorana Home ROOT E-Mail Apple Geant4 .Mac LBNL

Majorana Monte Carlo User's and Developer's Guide

<<< Previous | Program Structure and Guidelines | Next >>>

Programming Guidelines and Naming Conventions

Majorana requires the use of good object-oriented programming techniques. We strongly discourage the use of "Fortranized" C++. Our coding conventions are based on modified Root and Taligent guides . Enforcing too rigid programming rules are not feasible, although we require the following reasonable conventions:

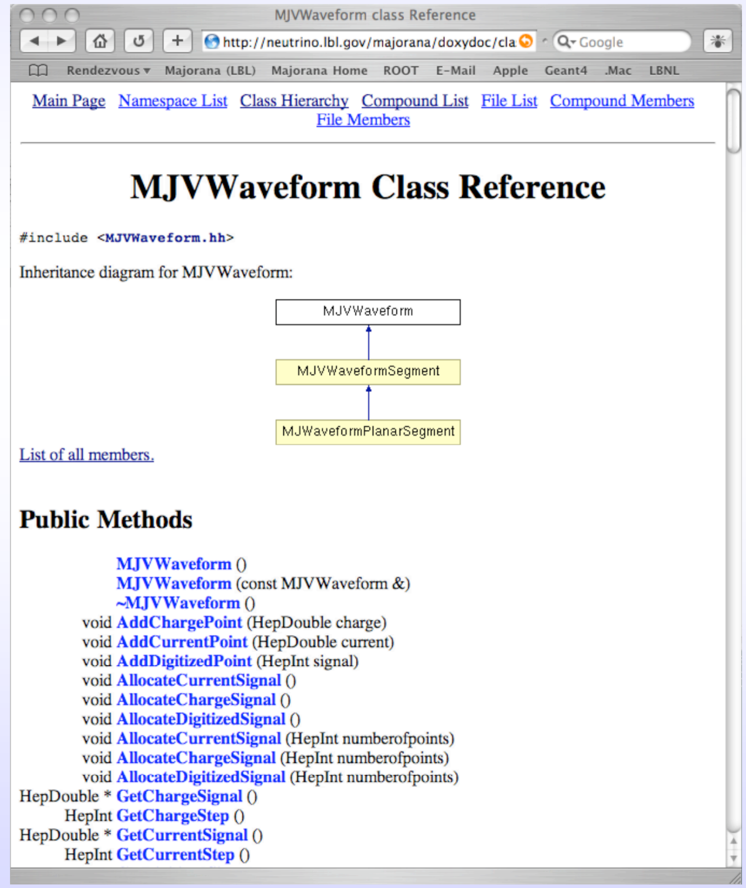
- All class names begin with `MJ`. All class names should begin with the name of the software package they are part of, ie. `MJDatabase*, MJGeometry*`
- All virtual base class names begin with `MJV`
- All class member variables names begin with `f`
- All local automatic variables names must begin with a lowercase, ie `randomNumber`
- All variable, class names, etc. should have descriptive, written out names. Think carefully about naming and avoid ambiguity.
- Code should be indented 3 spaces per nesting level. Long lines should be wrapped with a carriage return.

Some of the older code in the `MJ` package do not follow these rules, since they were written before the rules were made explicit. Please do not follow their conventions. If you encounter any cases not covered here, use the Root/Taligent guideline, use you best judgment, or contact Reyco Henning.

Remember that you are not coding for yourself! Many others will have to read you code. Write the code the way you would like to read it!

<<< Previous | Home | Next >>>
How Everything is Implemented and Fits Together. | Up | MJGeometry

Reference Guide



MJVWaveform class Reference

http://neutrino.lbl.gov/majorana/doxydoc/cla

Rendezvous Majorana (LBL) Majorana Home ROOT E-Mail Apple Geant4 .Mac LBNL

Main Page Namespace List Class Hierarchy Compound List File List Compound Members File Members

MJVWaveform Class Reference

`#include <MJVWaveform.hh>`

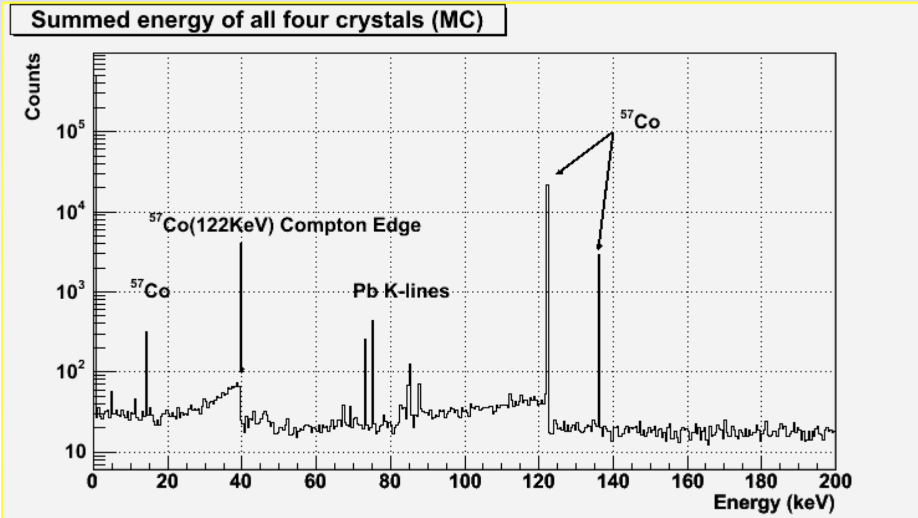
Inheritance diagram for MJVWaveform:

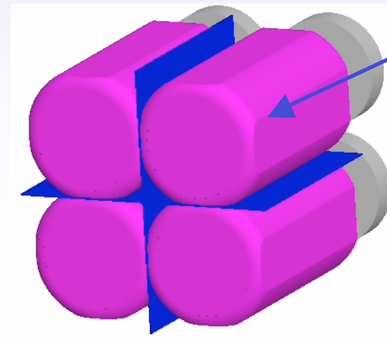
List of all members.

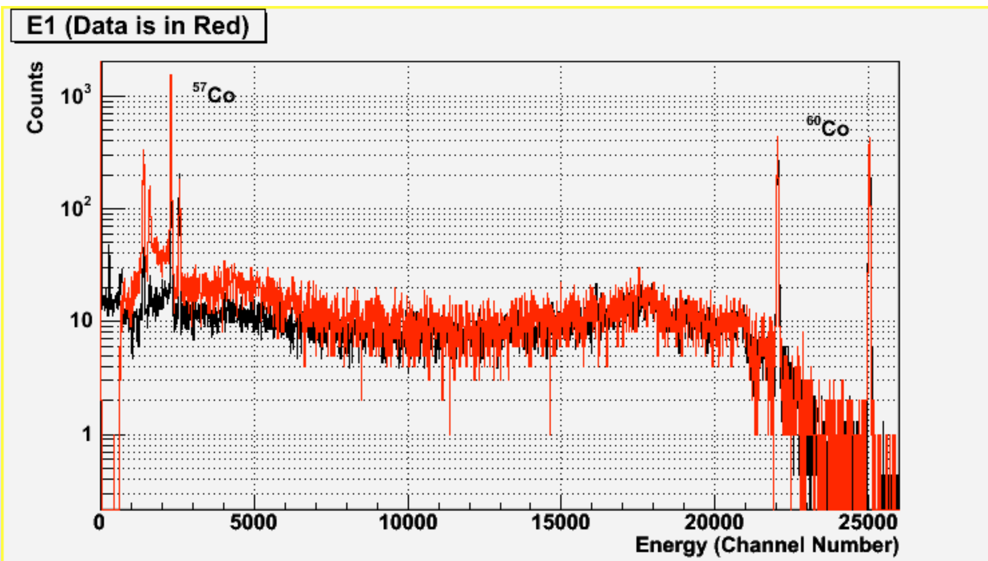
Public Methods

```
          MJVWaveform ()
          MJVWaveform (const MJVWaveform &)
          ~MJVWaveform ()
     void AddChargePoint (HepDouble charge)
     void AddCurrentPoint (HepDouble current)
     void AddDigitizedPoint (HepInt signal)
     void AllocateCurrentSignal ()
     void AllocateChargeSignal ()
     void AllocateDigitizedSignal ()
     void AllocateCurrentSignal (HepInt numberofpoints)
     void AllocateChargeSignal (HepInt numberofpoints)
     void AllocateDigitizedSignal (HepInt numberofpoints)
HepDouble * GetChargeSignal ()
   HepInt GetChargeStep ()
HepDouble * GetCurrentSignal ()
   HepInt GetCurrentStep ()
```

Canberra Clover Detector Simulation

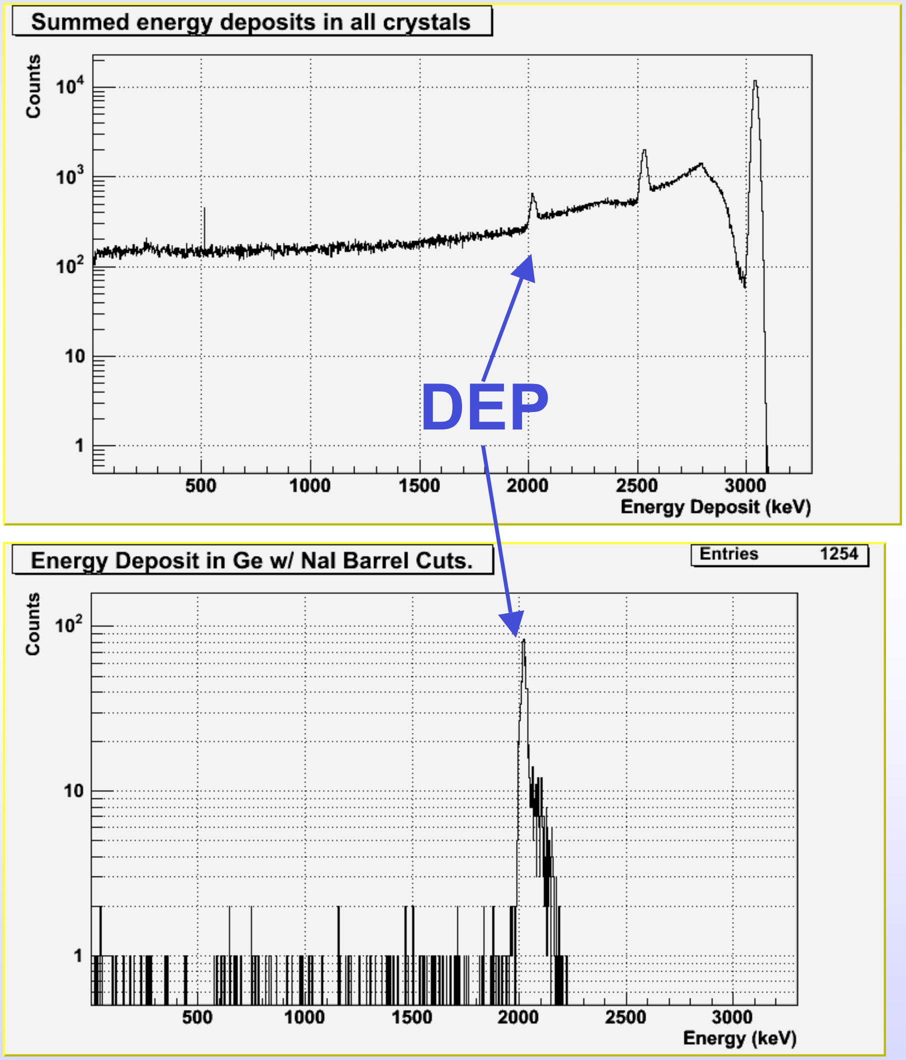




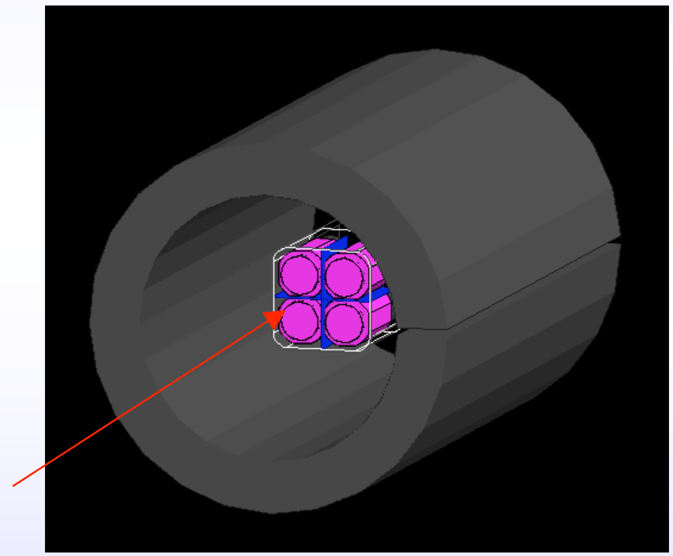


External Combined ^{57}Co ^{60}Co Source measured at LANL

Clover at TUNL-FEL



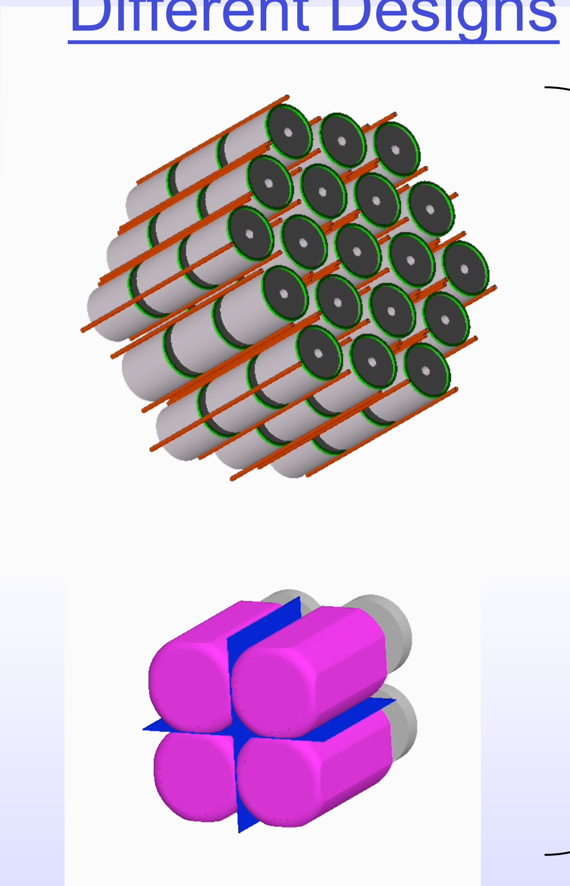
Segmented NaI Barrel to Tag DEP Events.



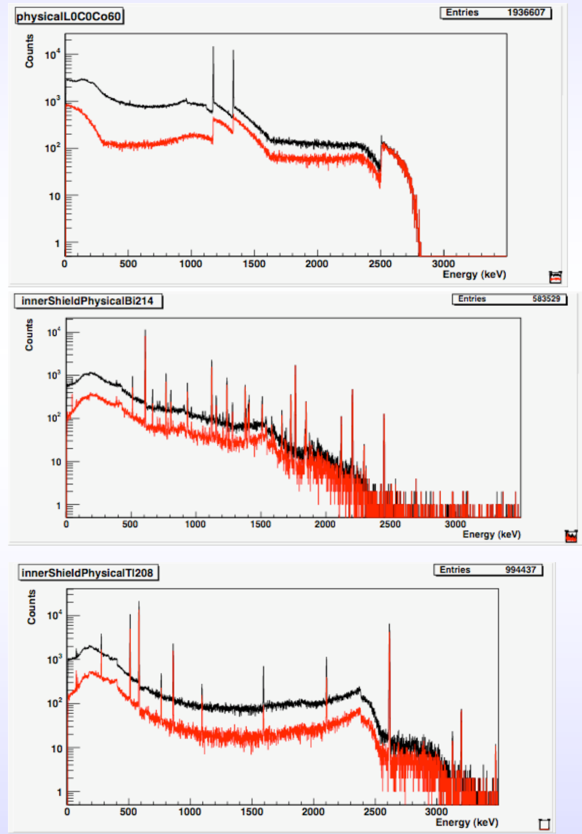
DEP Events are Single-Site: Useful for PSD Studies

Background Models

Different Designs

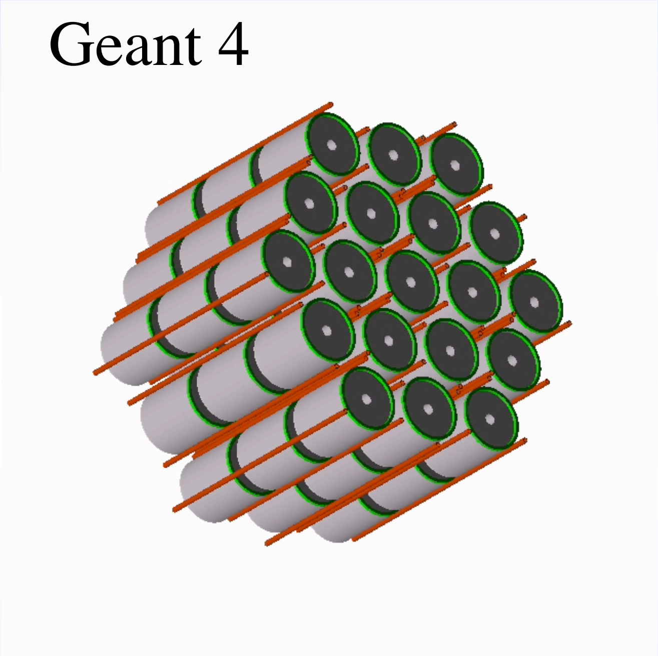


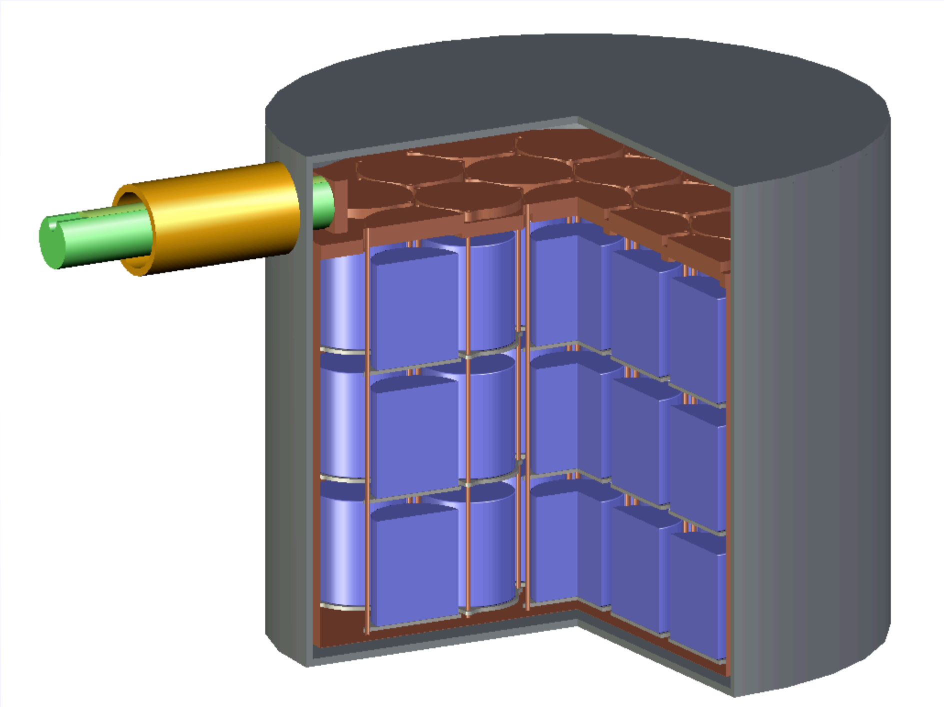
Potential Backgrounds



Background Models

Example: 57 Banger for Majorana Background Model





- Cu Cryostat: 5mm, 37-kg.
- Lead Shield (20, 50) cm
- Cu Rod, 1-gm/cm
- Polypropylene Support Rings

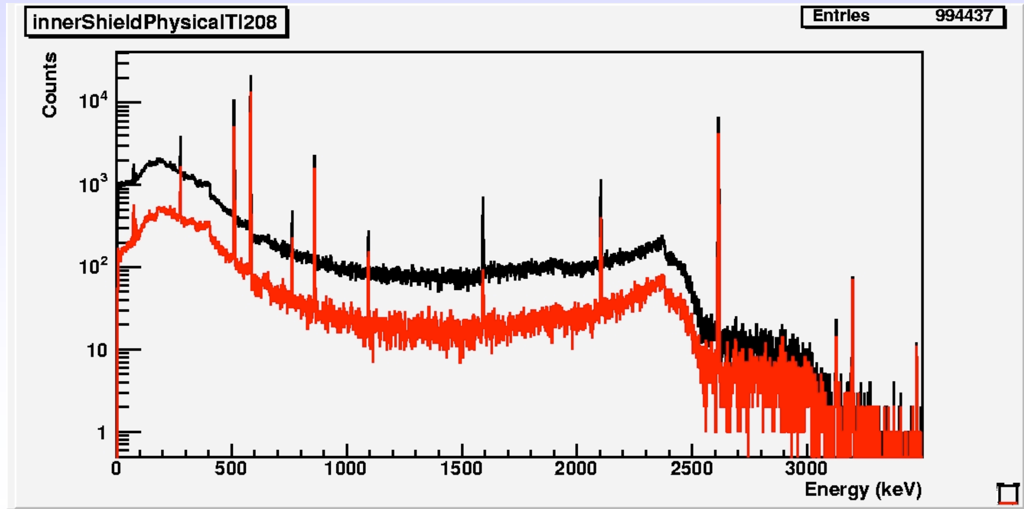
Radioactive Contaminants in 57 Banger Design

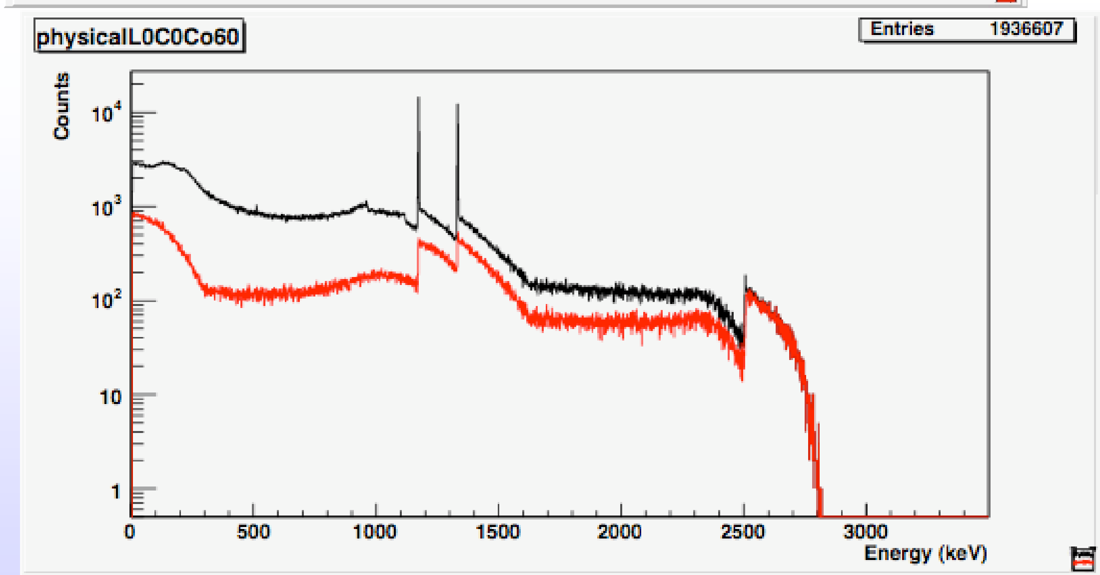
Isotopes	Simulated Modes	Q (keV)	Half-life
Simulated			
^{56}Co	$EC/\beta^+ + \gamma$	4566	77 d
^{60}Co	$\beta^- + \gamma$	2823.9	5.27 y
$^{68}Ge \rightarrow ^{68}Ga$	$EC + \beta^+ + \gamma$	2921.1 (^{68}Ga)	270 d
$^{194}Hg \rightarrow ^{194}Au$	$EC + \beta^+ + \gamma$	2492 (^{194}Au)	^{194}Hg: 520 y
^{208}Tl (^{232}Th)	$\beta^- + \gamma$	5000.9	3.053 m
^{214}Bi (^{238}U)	$\alpha(0.02\%), \beta^-(99.979\%) + \gamma$	$\alpha : 5617, \beta : 3272$	19.9 m
To Be Simulated			
^{22}Na	$EC/\beta^+ + \gamma$	2842.1	2.60 y
^{46}Sc	$\beta^- + \gamma$	2366.7	83.8 d
^{48}V	$EC/\beta^+ + \gamma$	4012.3	16.0 d
^{54}Mn	$EC + \gamma$	1377.1	312.3 d
^{57}Co	$EC + \gamma$	836.1	271.79 d
^{58}Co	$EC/\beta^+ + \gamma$	2307.4	70.82 d
^{65}Zn	$EC/\beta^+ + \gamma$	1351.4	244.26 d
^{228}Ac (^{232}Th)	$\alpha(5.5 \times 10^{-6}\%), \beta^- + \gamma$	$\alpha : 4830, \beta : 2127$	6.15 h
^{234}Pa (^{238}U)	$\beta^- + \gamma$	2197	6.70 h

Table 1: Isotopes and decay modes considered in current and future simulations. All decays include applicable atomic de-excitations.

Counts in ROI

- Cryostat
- Shield
- Cu Tubes
- Plastic Rings
- Active Regions
- Dead Layers
- “Small Parts”
- Attic





Region	Isotope	ϵ_{ROI} 2032.5 – 2043.5 keV	R_{ROI}	Initial Activity (μBq/kg)	Equilibrium Activity (μBq/kg)	Counts in ROI after 3 y (2032.5 – 2043.5 keV)	Counts in ROI after 3 y (2037 – 2041 keV)
Active Regions of Crystals						**Total: 8.0**	**Total: 2.9**
	^{68}Ge + ^{68}Ga	$(1.03 \pm 0.02) \times 10^{-3}$	5.1 ± 0.1	3	0	6.0	2.2
	^{60}Co	$(4.25 \pm 0.09) \times 10^{-4}$	10.5 ± 0.5	1	0	2.0	0.73
External Cryostat						**Total: 8.1**	**Total: 3.0**
	^{56}Co	$(1.61 \pm 0.04) \times 10^{-3}$	2.52 ± 0.07				
	^{60}Co	$(3.00 \pm 0.55) \times 10^{-5}$	16 ± 3	18	0	1.6	0.57
	^{208}Tl	$(3.02 \pm 0.17) \times 10^{-4}$	2.30 ± 0.16	0	3	3.2	1.2
	^{214}Bi	$(5.8 \pm 0.8) \times 10^{-5}$	2.8 ± 0.4	0	16	3.3	1.2
External Lead Shield (20 cm)	^{208}Tl	$(1.27 \pm 0.08) \times 10^{-5}$	2.0 ± 0.2	0	1	3.8	1.7
	^{214}Bi	$(1.0 \pm 0.2) \times 10^{-6}$	2.4 ± 0.6	0	1	0.3	1.3
	^{194}Hg $\rightarrow$ ^{194}Au	$(8.4 \pm 1.1) \times 10^{-6}$	2.45 ± 0.25	0	1	2.6	~ 0.1 [a]
“Attic”	^{60}Co	$(9.8 \pm 1.4) \times 10^{-6}$	28 ± 4				
	^{208}Tl	$(2.52 \pm 0.07) \times 10^{-4}$	2.29 ± 0.08				
Cryostat “Vacuum”	^{208}Tl	$(1.96 \pm 0.14) \times 10^{-4}$	5.4 ± 0.4				
	^{214}Bi	$(2.50 \pm 0.16) \times 10^{4}$	3.8 ± 0.3				
Copper Support Tubes						**Total: 0.59**	**Total: 0.22**
	^{60}Co	$(8.8 \pm 0.7) \times 10^{-5}$	37 ± 3	18	0	0.18	0.07
	^{208}Tl	$(2.1 \pm 0.1) \times 10^{-4}$	7.1 ± 0.4	0	3	0.09	0.03
	^{214}Bi	$(1.47 \pm 0.09) \times 10^{-4}$	5.4 ± 0.3	0	16	0.32	0.12

Table 3: Summary of simulated radioactive backgrounds efficiencies with a crystal-to-crystal veto applied for the 57 banger detector with “fuelrod” support structures. R_{ROI} is the rejection factor due to the granularity of the detector in the 2032.5 – 2043.5 keV ROI. The counts shown in the ROI were integrated for 3 years, starting at the initial levels of activity given in the table. Only the dominant contributions are given here, the rest are described in the text. Quoted uncertainties are Monte Carlo statistical only.

[a] ^{194}Au has a peak at 2043.67 keV, making the counts in the ROI very sensitive to the size of the ROI.

Conclusions

- Other Majorana: Neutron background,

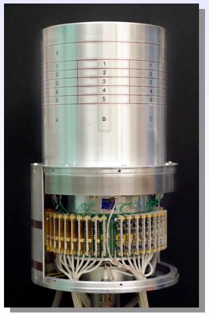
  See K. Hudek, FR 53, CEU Poster Session, 13:00 Wednesday
- MaGe Framework successful
- Collaboration with Gerda ongoing and lucrative.
- Simulations critical for background model (See following talk by C. Aalseth).
- Provides input for waveform simulations.

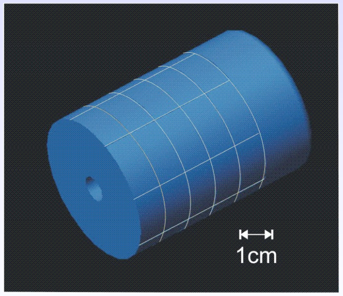
2. Highly Segmented Ge Detectors for DBD

1. Germanium detector segmentation
2. Underground test facility at Oroville

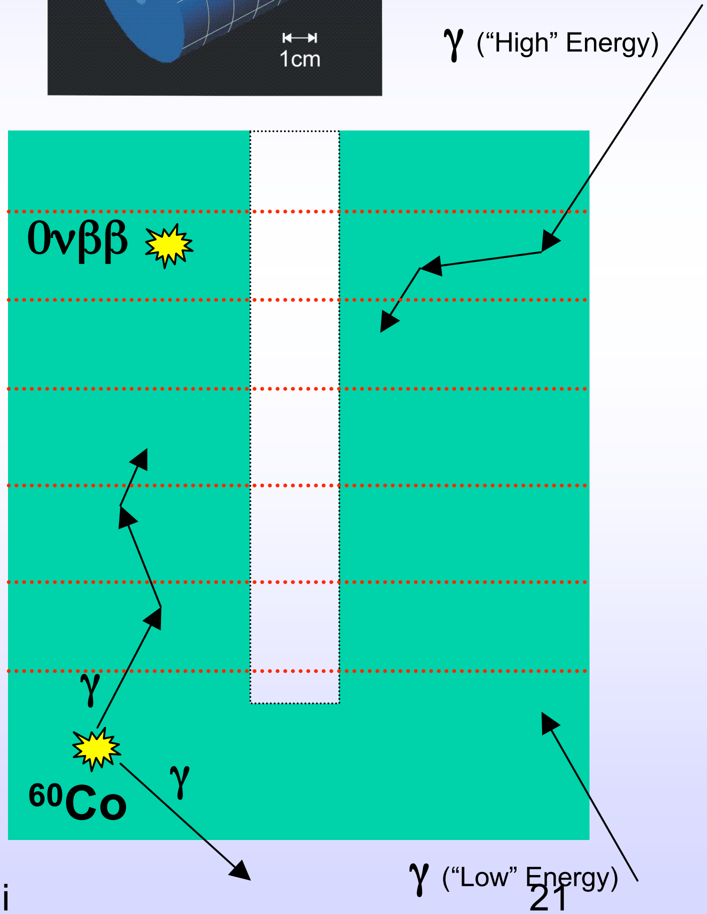
Crystal Segmentation

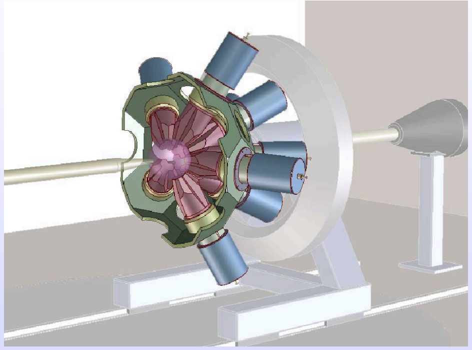
- Multiple conductive contacts
- Additional electronics and small parts

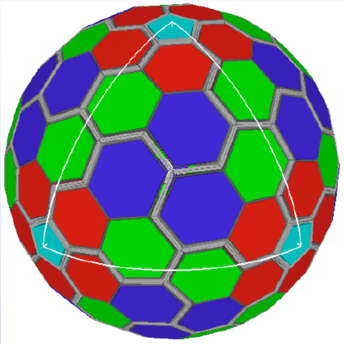




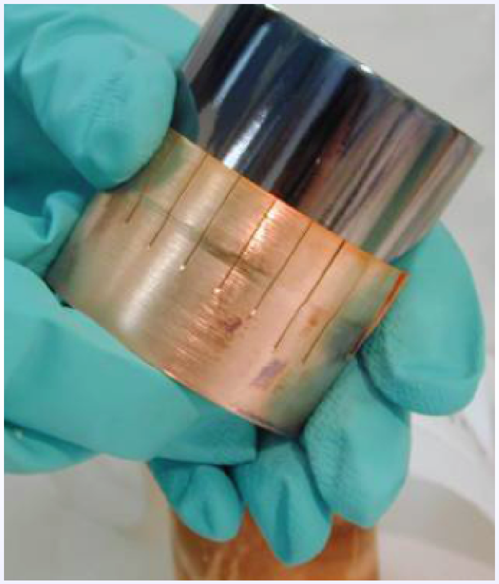
- Examples
  - MSU experiment (4x8 segments)
  - LANL Clover detector (2 segments)
  - LLNL+LBNL detector (8x5 segments)
  - Gretina Prototype + AGATA

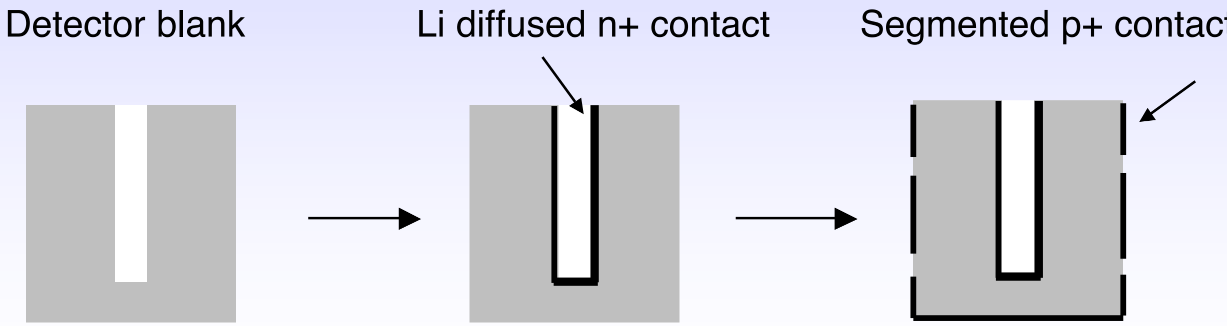


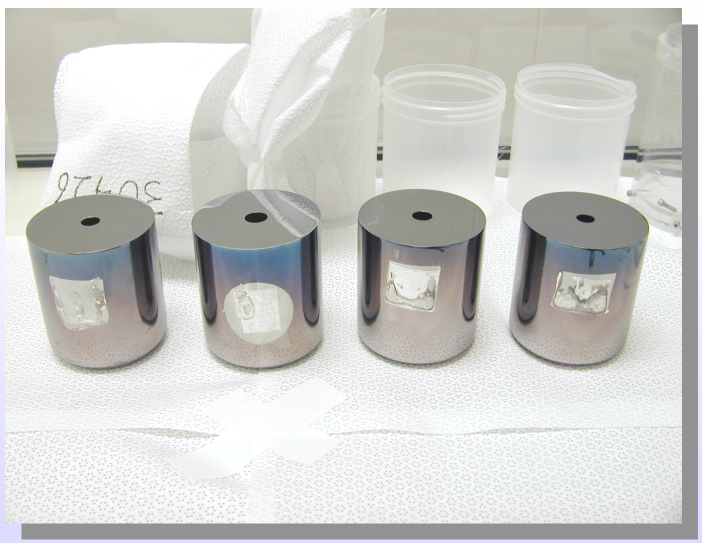




Detector Fabrication



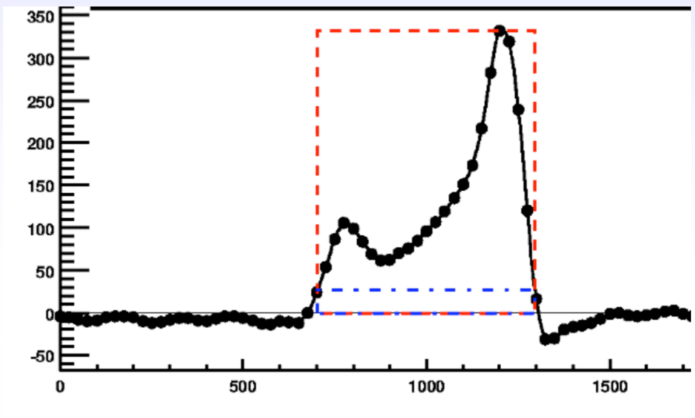


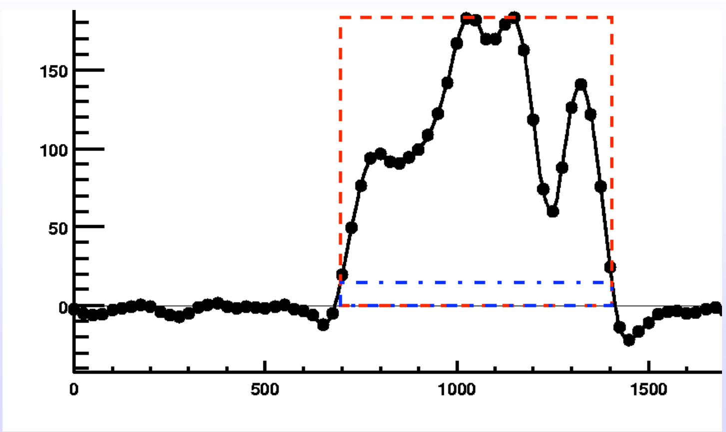


Surface Exposure time
has to be minimized

Pulse Shape Discrimination (PSD)

Central contact (radial) PSD



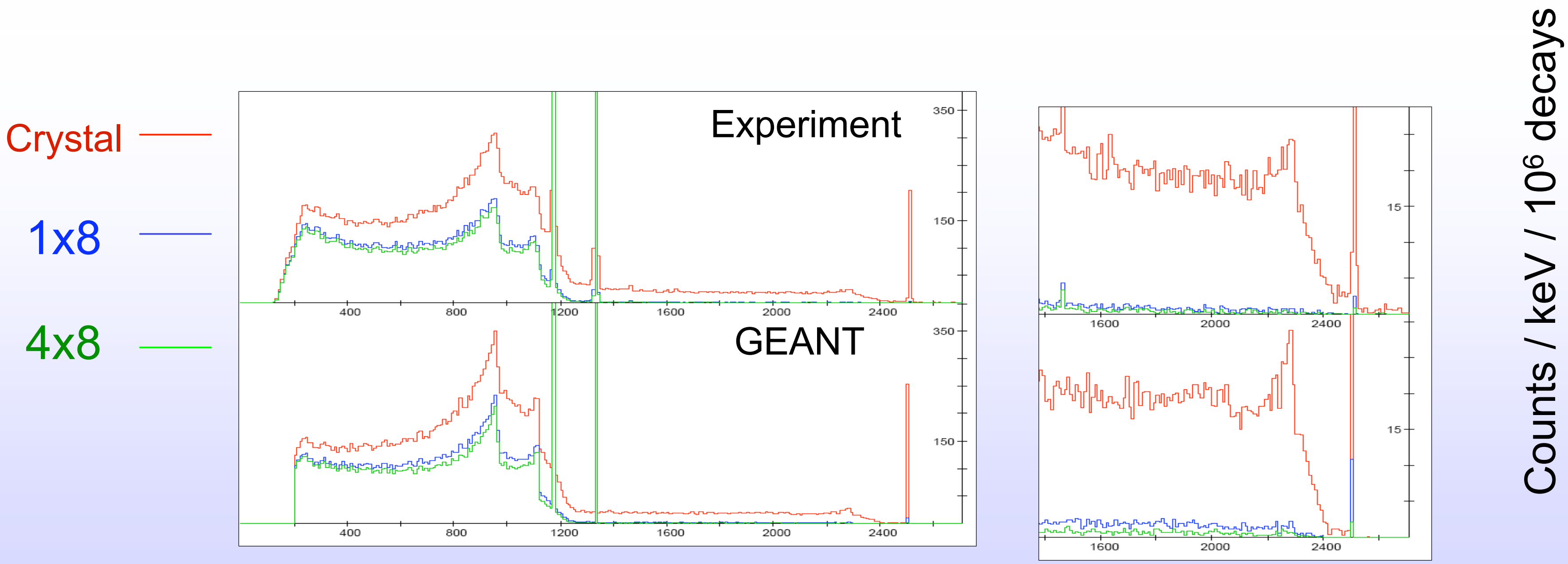


- Excellent rejection for internal ^{68}Ge and ^{60}Co (x4)
- Moderate rejection of external 2615 keV (x0.8)
- Shown to work well with segmentation

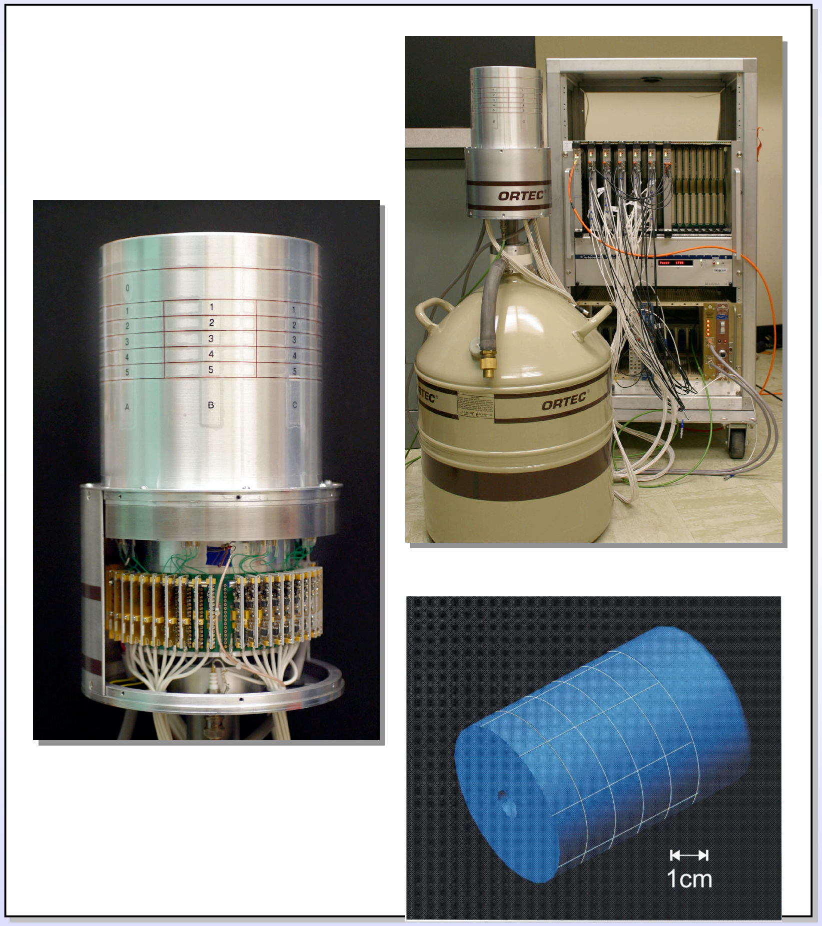
Segmentation test & simulation comparison

Experiment with MSU/NSCL Segmented Ge Array

- N-type, 8 cm long, 7 cm diameter
- 4x8 segmentation scheme: 4 angular 90 degrees each, 8 longitudinal, 1 cm each
- ^{60}Co source
- Segmentation successfully rejects backgrounds.
- Data are in good agreement with the simulations

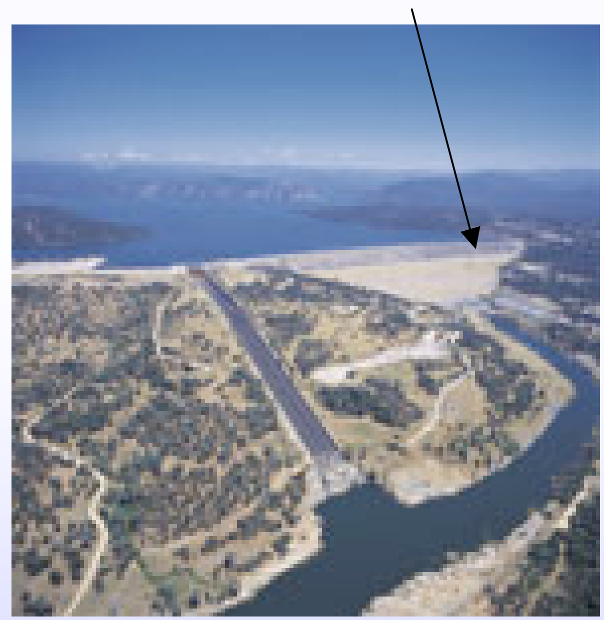


LLNL Detector at Oroville



Kai Vetter, David Campbell (LLNL)

Kevin Lesko, Yuen-Dat Chan, Reyco Henning, Donna Hurley,Michelle Perry, Alan Poon, Al Smith (LBNL)



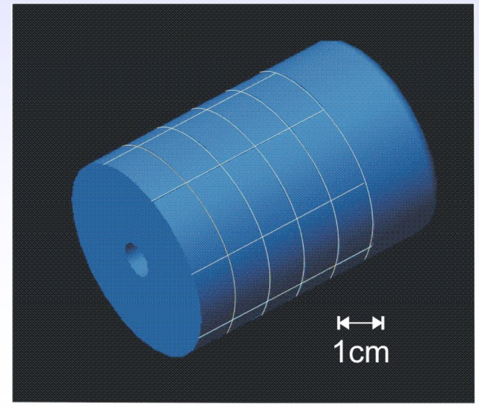
~200 mwe

Goals

- First Highly Segmented Detector with Pulse Digitization in Low Background Environment.
- Determine Background rejection for natural radioactivity for a detector in the field.
- Additional Data to Verify MC against.
- Access to Low Background Counting Facility.

The Detector System

40-fold segmented, closed-ended coaxial HPGe detector (built by ORTEC in summer 2002)

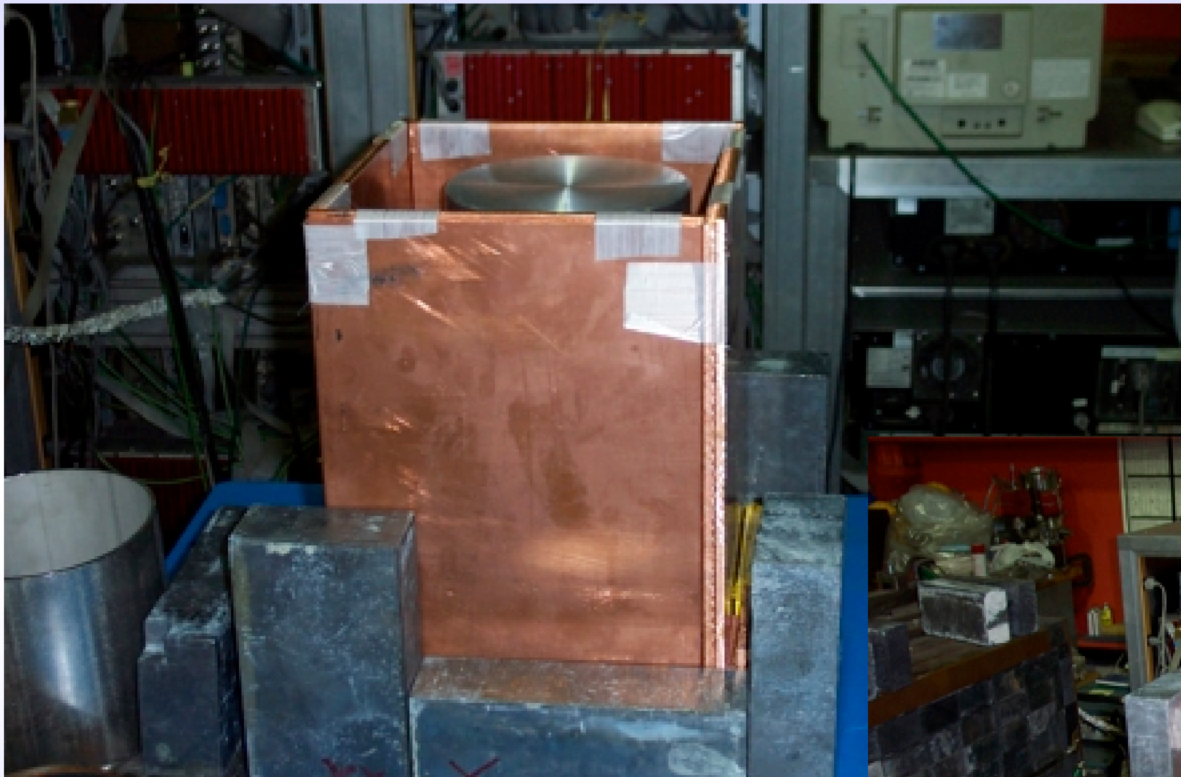


- N-type HPGe crystal: 8cm length and 5cm diameter
- 5 Transversal segments with Dz=1cm
- 8 Longitudinal segments with Df=45deg.
- Custom-made, compact preamplifiers mounted on circular motherboard close to feedthroughs equipped with warm FETs.
- Energy resolution: 0.9keV at 60keV and 1.9keV at 1332keV
- Data acquisition: Six 8-channel waveform digitizer modules built by Struck Innovative Systems (optical VME-PCI readout)

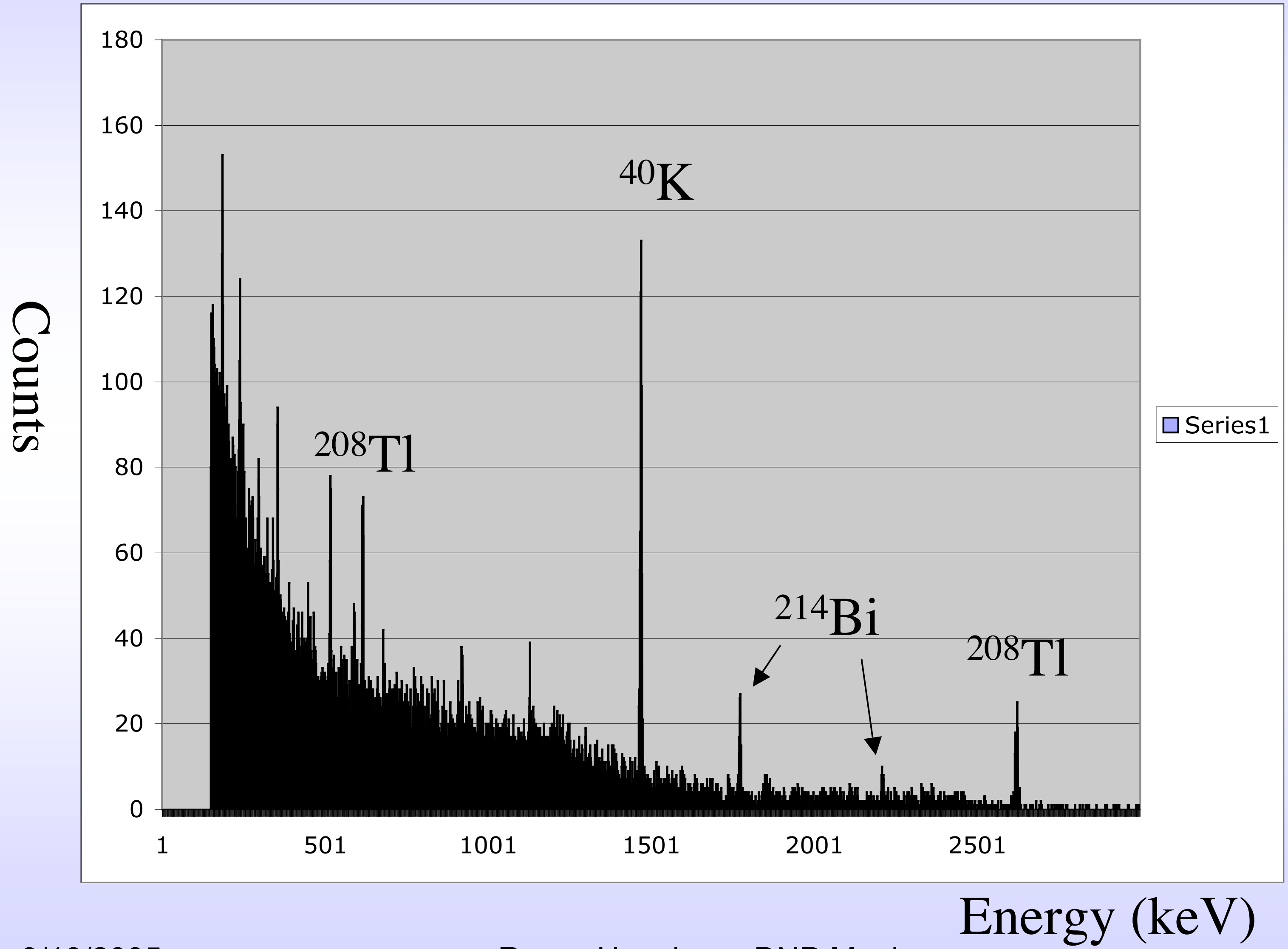
Installation

- Installed 6/14-15
- All Segments Survived 3 hr. drive!
- Replenish Disk Drives Every Two Weeks. ~20 GB/day
- 2” Pb Shield + 400lb Table.

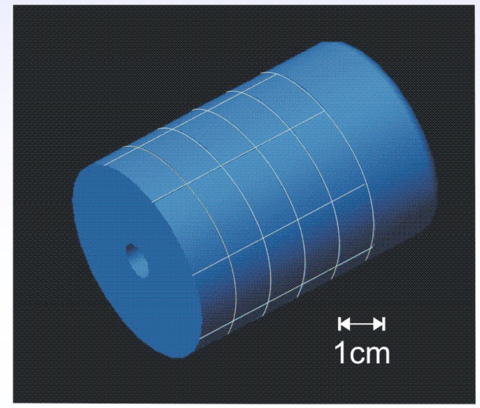
Installation



First Day's Spectra



Initial Pulse shapes



See poster by

M. Perry, FR 47, CEU Poster Session

Conclusions

- First highly segmented detector operating at low background facility.
- Quantitative measurement of background reduction efficiency from segmentation, PSD and gamma-tracking.
- Neutron response measurements.
- Have first publishable results in 6 months.
- Session JG, Thursday, 9:00, Techniques for Neutrino Science
- Session KD, Thursday 14:00, Mini-symposium on New Technology in Gamma Ray detection