Majorana Update

Harry Miley

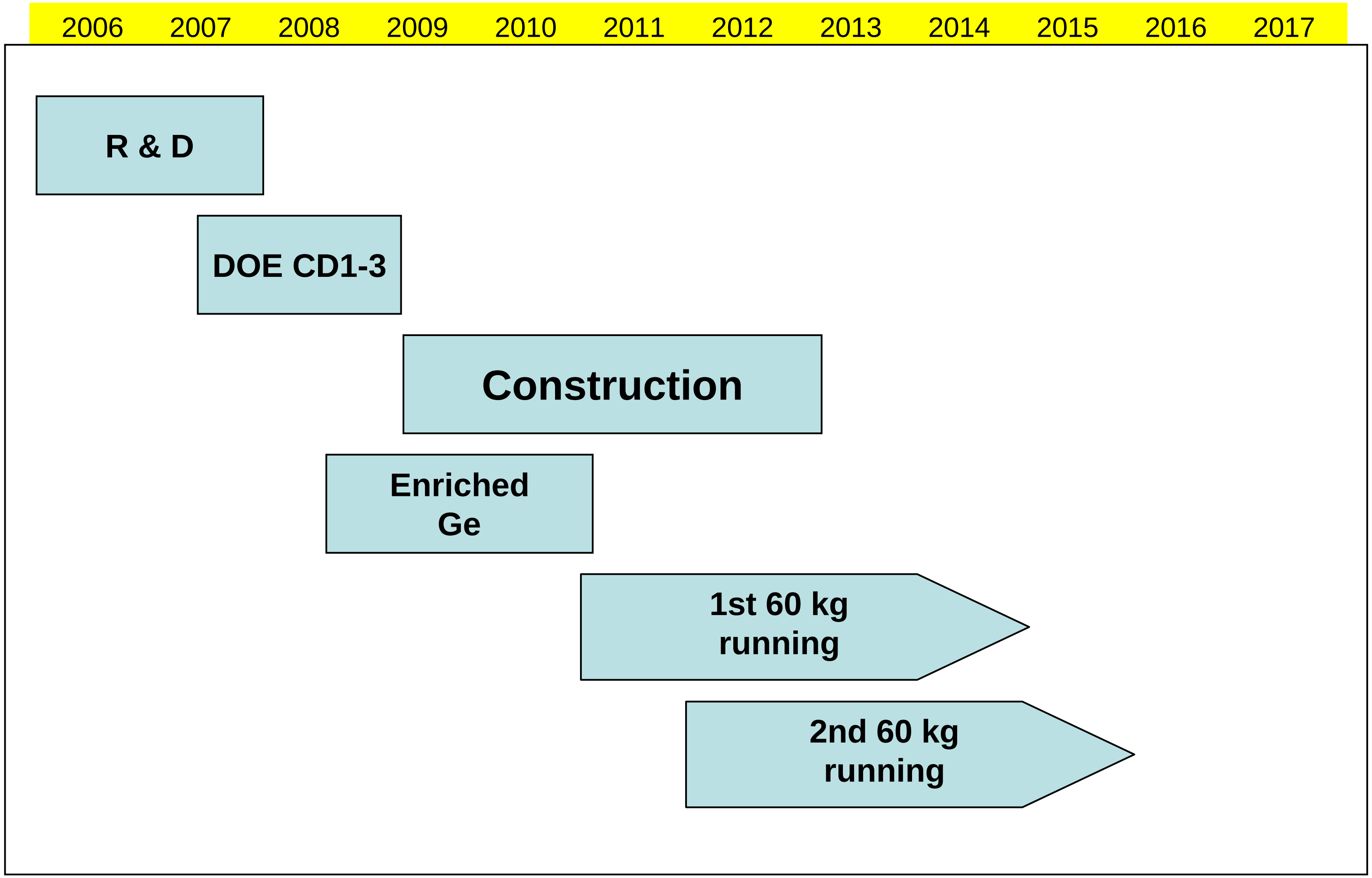
Majorana Organization Developments

- Summer ’05: NUSAG review (☑)
- November ’05: CD-0 (☑)
- March ’05: Internal Review (☑)
  - GO faster, concentrate on M60F
- November ’06: DOE review (☐)
  - To construct sponsor ββ program
- Maybe August ’07: CD-1 review (☐)

- GERDA Meeting LNGS June 2006
  - Chance to become more familiar with Italy


d'andrea & d'andrea
CITTASOLARIA
NISSAN

Schedule (assuming two 60 kg modules)



Contingent on funding and funding profile

Neutrino Scientific Assessment Group - Fall 05

Recommendation: *The Neutrino Scientific Assessment Group recommends that the highest priority for the first phase of a neutrino-less double beta decay program is to support research in two or more neutrino-less double beta decay experiments to explore the region of degenerate neutrino masses* ($\langle m_{\beta\beta} \rangle > 100$ meV)*. The knowledge gained and the technology developed in the first phase should then be used in a second phase to extend the exploration into the inverted hierarchy region of neutrino masses* ($\langle m_{\beta\beta} \rangle > 10-20$ meV) *with a single experiment.*

Majorana: The excellent background rejection achieved from superior energy resolution in past ^{76}Ge experiments must be extended using new techniques. The panel notes with interest the communication between the Majorana and GERDA ^{76}Ge experiments which are pursuing different background suppression strategies. The panel supports an experiment of smaller scope than Majorana-180 that will allow verification of the projected performance and achieve scientifically interesting physics sensitivity, including confirmation or refutation of the claimed ^{76}Ge signal. **A larger ^{76}Ge experiment is a good candidate for a larger international collaboration due to the high cost of the enriched isotope.**

Pre-CD-1 Review

- Majorana and CUORE will be reviewed
  - November ’06 time frame
  - SC-NP and NSF will participate
- Review team will construct double-beta decay program, set R&D priorities
  - Under several hypothetical funding scenarios
  - Projects will be selected
- Positions SC-NP to take advantage of funding opportunities as they arise, sets out year expectations (’08 and beyond).

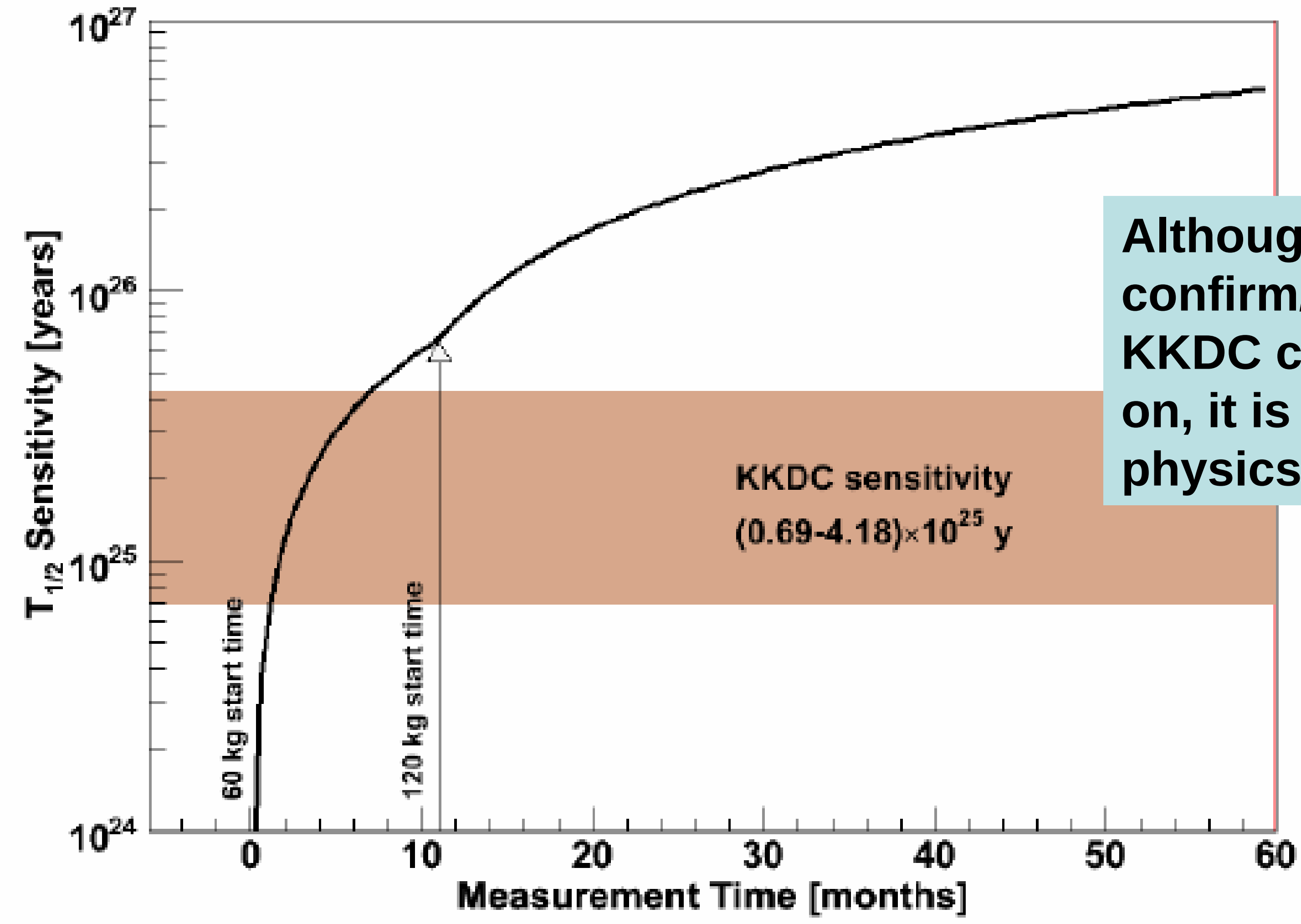
Technical Progress

- Key issue: Copper purity
  - Electroplating developments
  - Assay improvements
- MEGA installation this summer
- Ge processing update: loss estimates
- Simulation results, background model
- Surface analysis
- Shielding: Pb test and Veto
- Test with segmented detector

Background mitigation

- Sensitivity to $0\nu\beta\beta$ decay is ultimately limited by S-to-B.
  - Goal: ~ 150 times lower background (after analysis cuts) than previous ^{76}Ge experiments.
- Approach
  - Shielding the detector from external natural and cosmogenic sources
  - Ultra-pure materials used in proximity to the crystals
    - electroformed Cu
    - development of ultra-senstive ICPMS methods for materials assay
  - Optimizing the detector energy resolution
  - Granularity
  - Time correlation analysis
  - Pulse shape analysis
  - Segmentation

Sensitivity with respect to mass

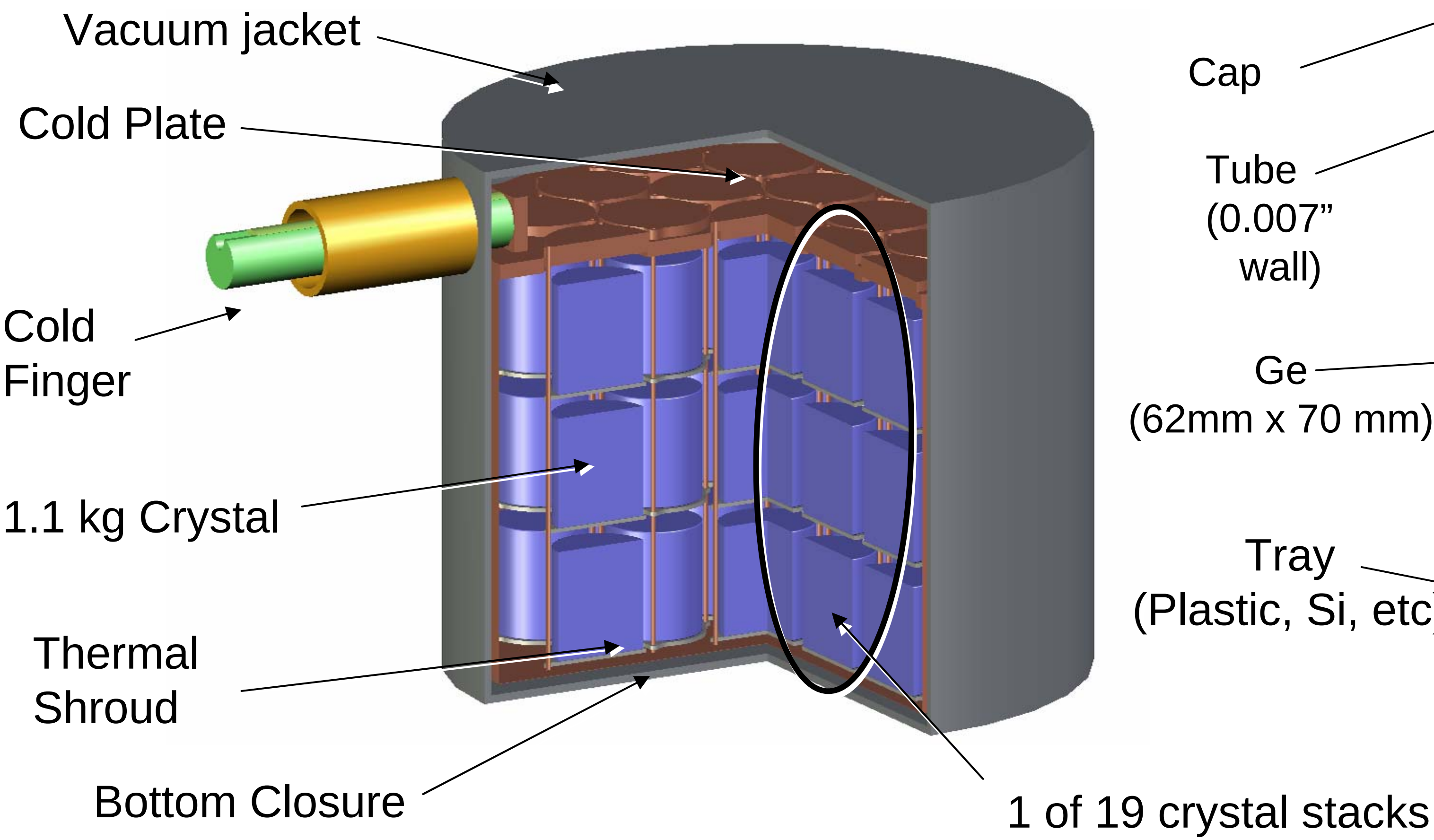


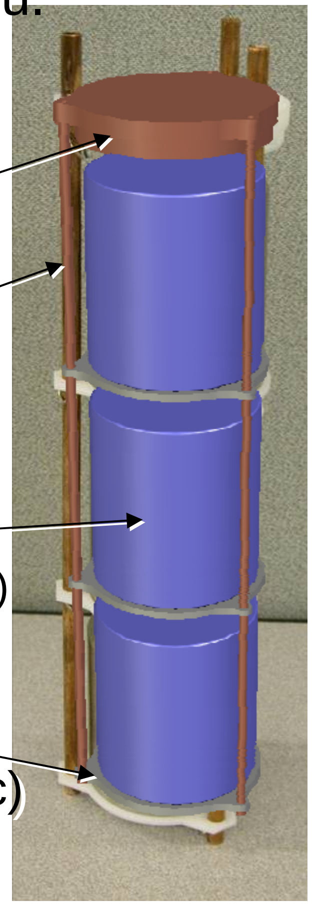
Although we will confirm/refute the KKDC claim early on, it is not driving physics goal.

0.46 t-y

The Majorana Modular Approach

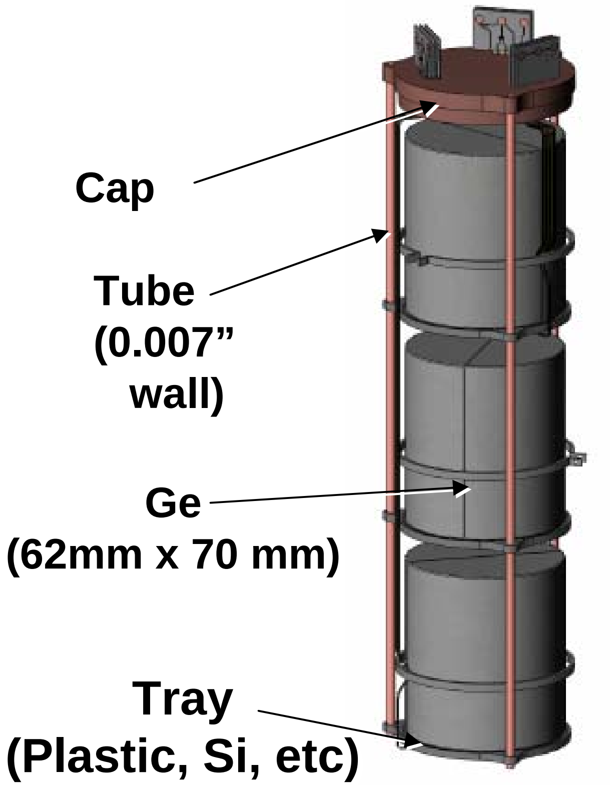
- 57 crystal module
  - Conventional vacuum cryostat made with electroformed Cu.
  - Three-crystal stack are individually removable.

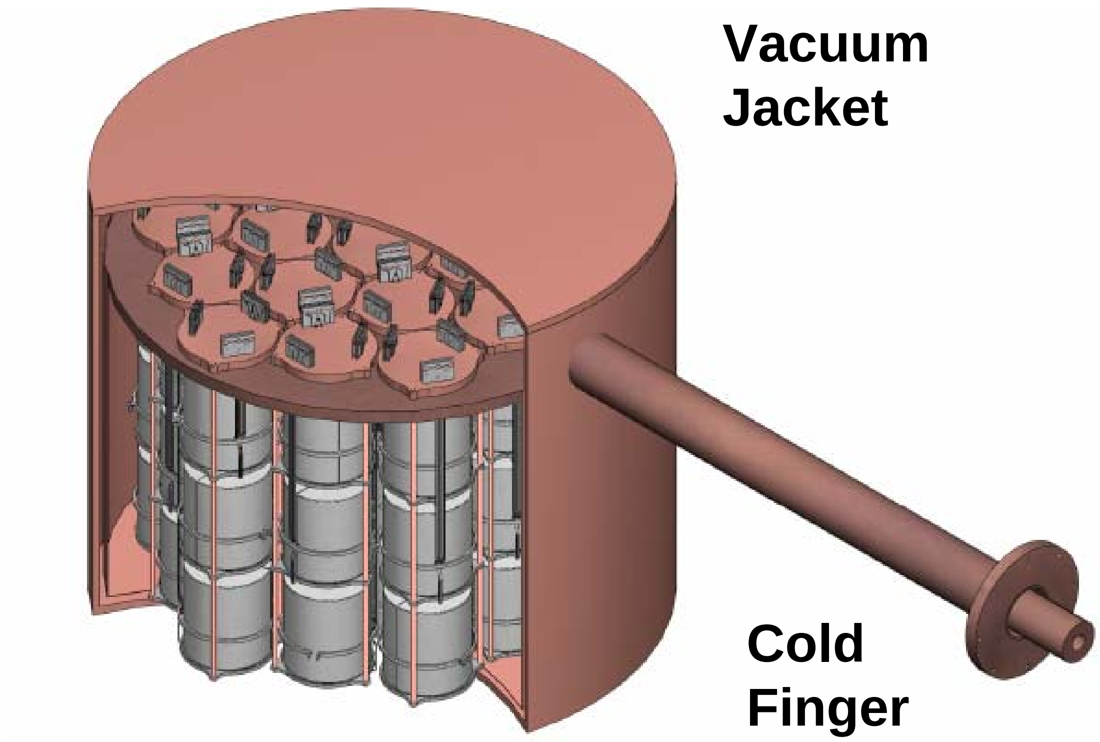




The Majorana Modular Approach

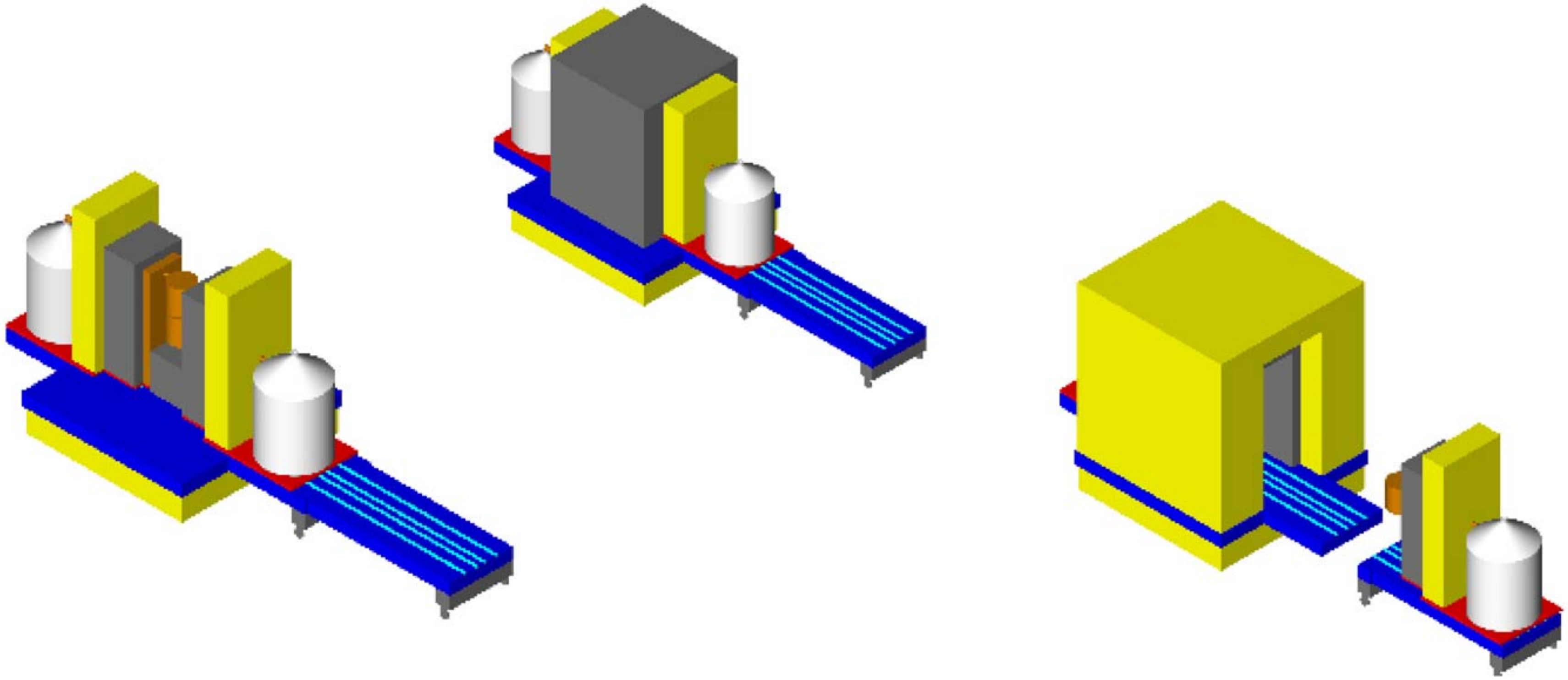
- **57 crystal module: 60 kg of Ge per module**
  - –**Conventional vacuum cryostat made with electroformed Cu.**
  - –**Three-crystal stacks are individually removable.**





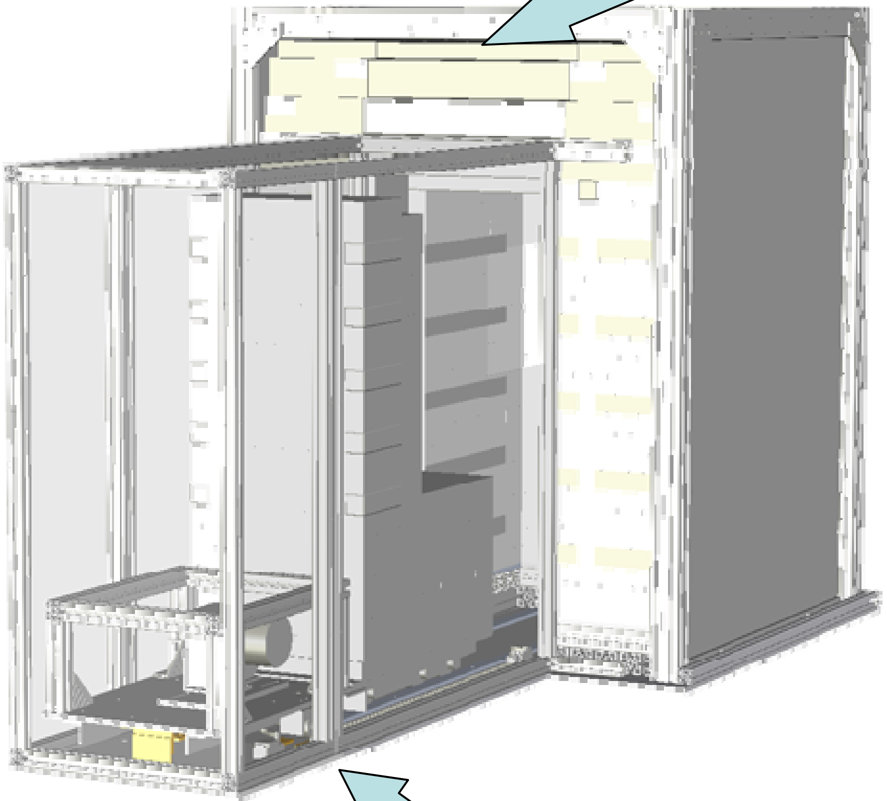
The Majorana Shield - Conceptual Design

- Inner liner: 10 cm ultra-low background e-formed Cu
- Bulk shield: 40 cm Pb, two detector modules shown
- Active 4π veto detector
- Outer sheath: 30 cm polyethylene layer



Concept shield under construction

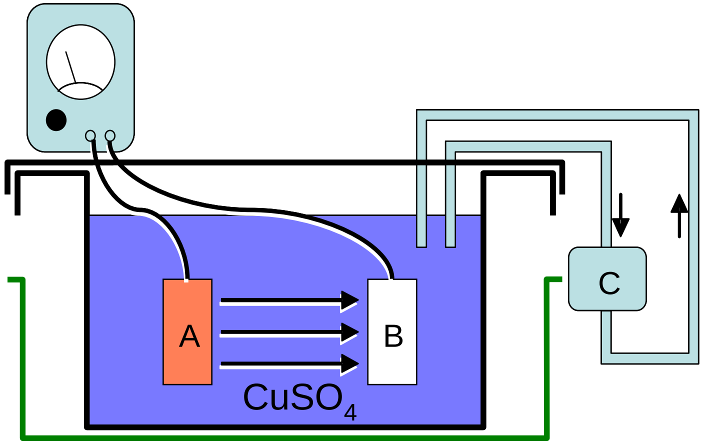
Special bricks
span cavity



Monolith
mover

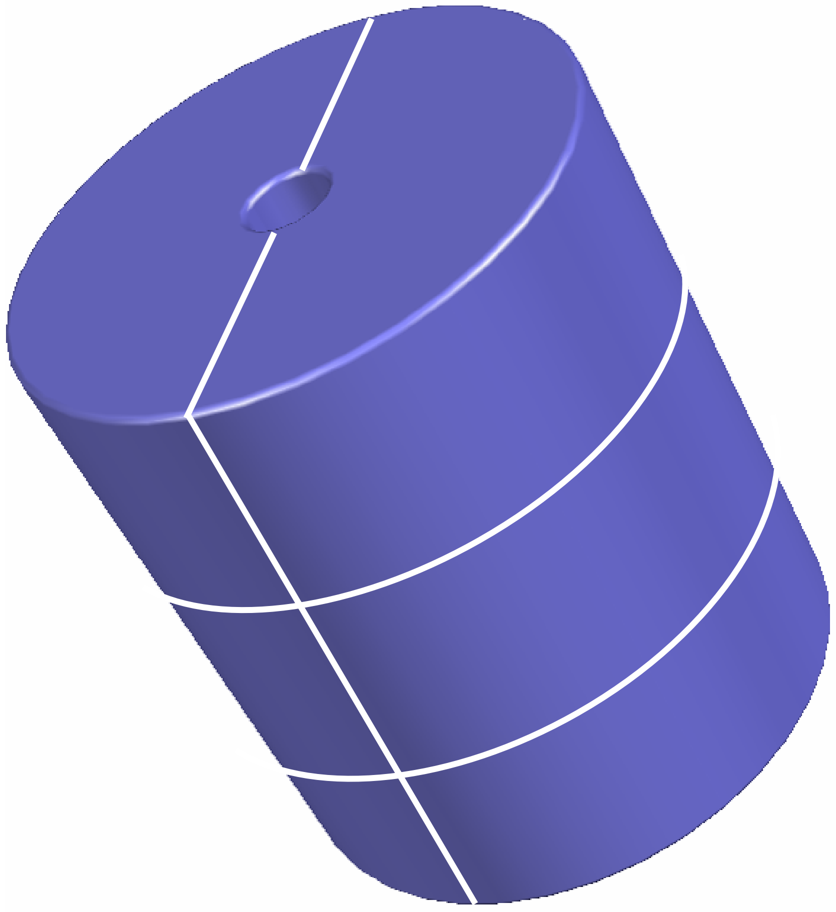
Electroforming copper - key elements

^{232}Th < 1µBq/kg



- Semiconductor-grade acids
- Copper sulfate purified by recrystallization
- Baths circulated with continuous microfiltration to remove oxides and precipitates
- Continuous barium scavenge removes radium
- Cover gas in plating tanks reduces oxide formation
- Periodic surface machining during production minimizes dendritic growth
- H_2O_2 cleaning, citric acid passivation

Crystal Segmentation



Reference Plan:

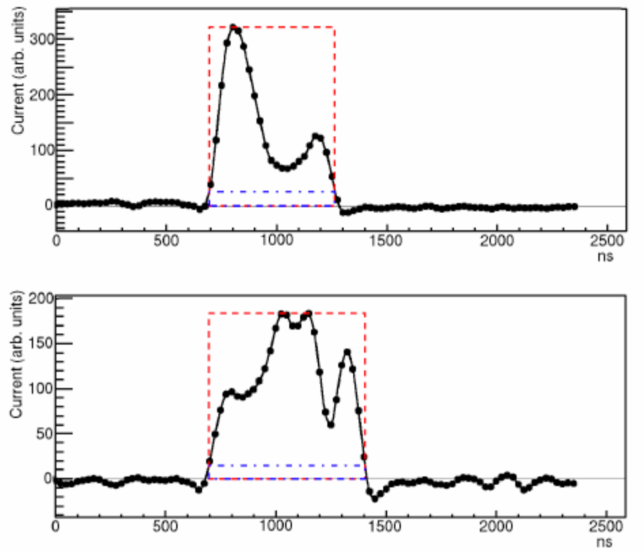
- 1.1 kg detector
- 62 mm diameter/70 cm high
- 2 x 3 segmented n-type detector

Considerations underway:

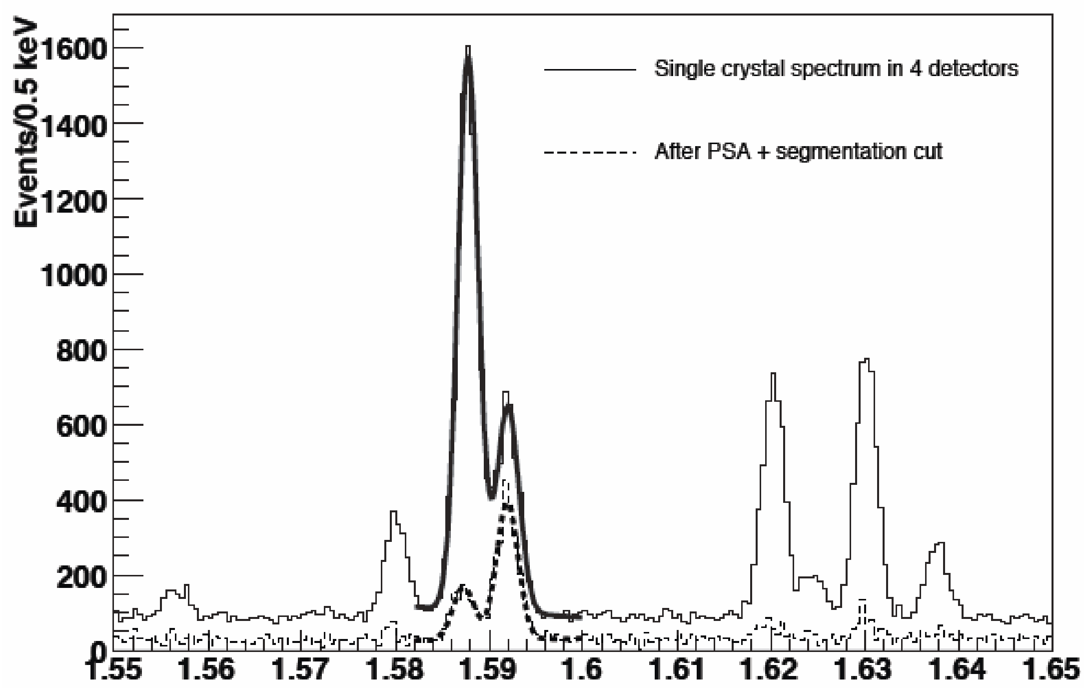
- Monte Carlo design R&D
- Alternatives R&D
- Costing analysis
- Surface preparations
- Cabling and small parts

Pulse shape analysis

CEA Thesis, 2000



Similar results obtained from center and outer contacts



Aalseth, et al, Elliott, et al, Radford, et al, Collar, et al

Very effective against internal activities and multiply scattered γ rays

Ultra-pure materials

Table 4.1: Component material radioactivity goals for the major contributors to backgrounds in the $0\nu\beta\beta$ - decay region of interest. Note that the column Equivalent Achieved Assay specifies the goal for the component's activity in ^{208}Tl to the measured quantity of ^{232}Th. An activity of ^{208}Tl of 0.3 μBq/kg would correspond to an activity of ^{232}Th of 1.0 μBq/kg. We have focused on the Th contamination levels, since it has the more complex chemistry and hence is more difficult to remove.

Location	Purity Issue	Exposure	Activation Rate	Equiv. Achieved Assay	Reference
Germanium	^{68}Ge, ^{60}Co	100 d	1 atom/kg/day		[Avi92]
		Component Mass	Target Purity		
Inner Mount	^{208}Tl in Cu ^{214}Bi in Cu	2 kg	0.3 μBq/kg 1.0 μBq/kg	0.7-1.3 μBq/kg	Current work also [Arp02]
Cryostat	^{210}Tl in Cu ^{214}Bi in Cu	38 kg	0.1 μBq/kg 0.3 μBq/kg	0.7-1.3 μBq/kg	Current work also [Arp02]
Cu Shield	^{208}Tl in Cu ^{214}Bi in Cu	310 kg	0.1 μBq/kg 0.3 μBq/kg	0.7-1.3 μBq/kg	Current work also [Arp02]
Small Parts	^{208}Tl in Cu ^{214}Bi in Cu	1 g/crystal	30 μBq/kg 100 μBq/kg	1000 μBq/kg	

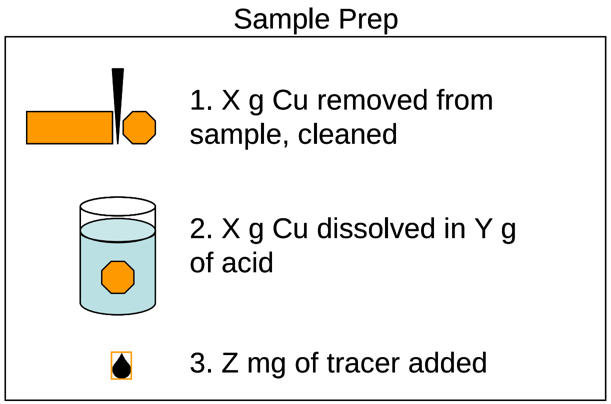
ICPMS studies

Background model summary

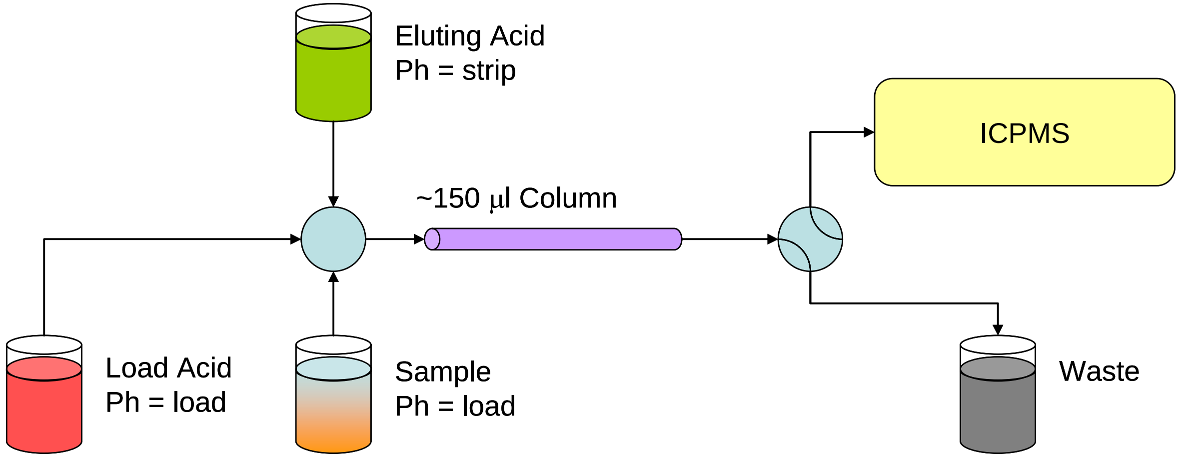
Background Source		Rates for Important Isotopes cnts/ROI/t-y				Total Est. Background cnts/ROI/t-y
		^{68}Ge	^{60}Co			
Germanium	Gross:	2.54	1.22			
	Net:	0.02	0.06			0.08
		^{208}Tl	^{214}Bi	^{60}Co		
Inner Mount	Gross:	0.12	0.03	0.26		
	Net:	0.01	0.00	0.00		0.01
Cryostat	Gross:	0.49	0.48	0.58		
	Net:	0.14	0.12	0.00		0.26
Copper Shield	Gross:	1.39	0.55	0.02		
	Net:	0.39	0.11	0.00		0.50
Small Parts	Gross:	0.45	0.68	0.34		
	Net:	0.05	0.17	0.00		0.22
Surface Alphas	All surfaces:					0.36
		muons	cosmic activity	gammas	(α, n)	
External Sources	Gross:	0.03	1.50	0.05	0.06	
	Net:	0.003	0.21	0.05	0.06	0.32
$2\nu\beta\beta$						<0.01
Solar ν						0.01
Atm. ν						0.02
		TOTAL SUM				1.75

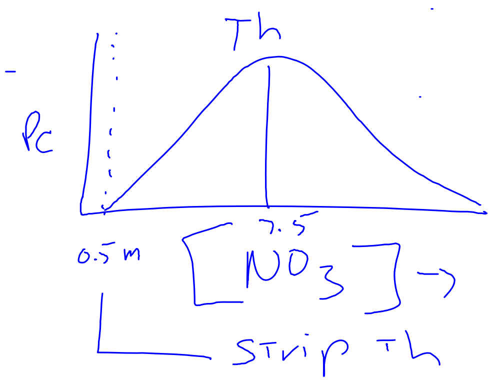
Copper Assay Developments (1)

- Recent assay campaign 2.7-3.7 μBq/kg ^{232}Th
  - Too high, variable
- Analysis of ^{229}Th tracer
  - contained 6% ^{232}Th contamination
  - was of a form (chloride) that caused poor yielding (x1/3)



4. Wash w/loading acid, eluent to waste
5. Clean w/eluting acid, to waste
6. Condition w/loading acid, to waste
7. Load sample, eluent to waste
8. Elute w/eluting acid, eluent to ICPMS

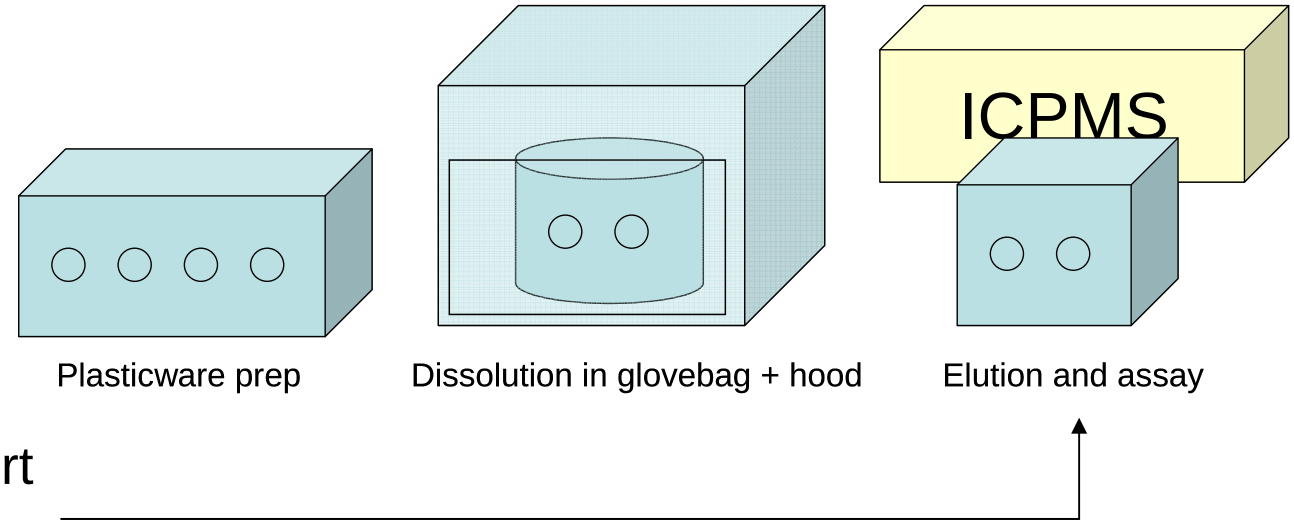




Copper Assay Developments (2)

- New ^{229}Th tracer obtained
  - Much lower ^{232}Th contamination (<0.3%, or 20x lower)
  - Proper chemical form
    - Could have been corrected by ashing and redissolution
  - Quantitative results obtained in preliminary measurements

- New method of handling assay planned
  - Clean boxes, glove bags for sample prep
  - Automatic 6 port valves column handling
  - Column flush with oxalic and bypass



Copper Plating

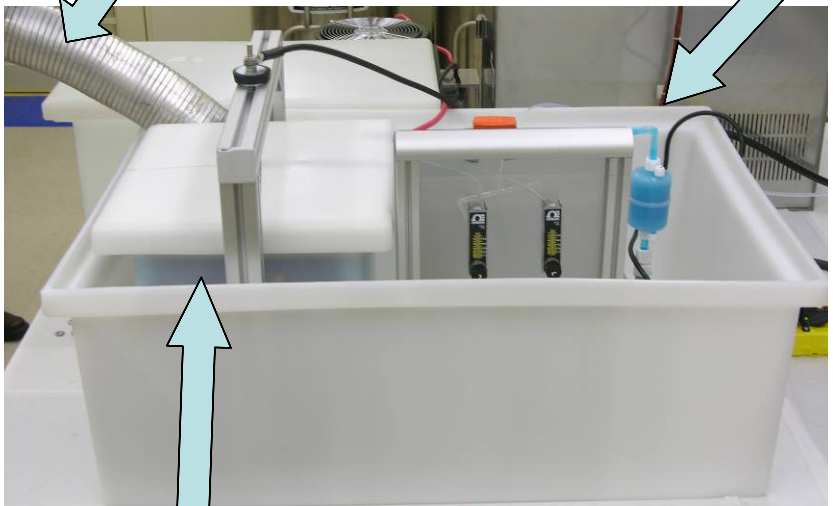
- New test lab: class 2000 (frequently class 1300)
- Improved bath chemistry requires less surface finishing (less machining and handling)
- Improved starting stock quality and handling

Corrosive aerosol
& gas removal

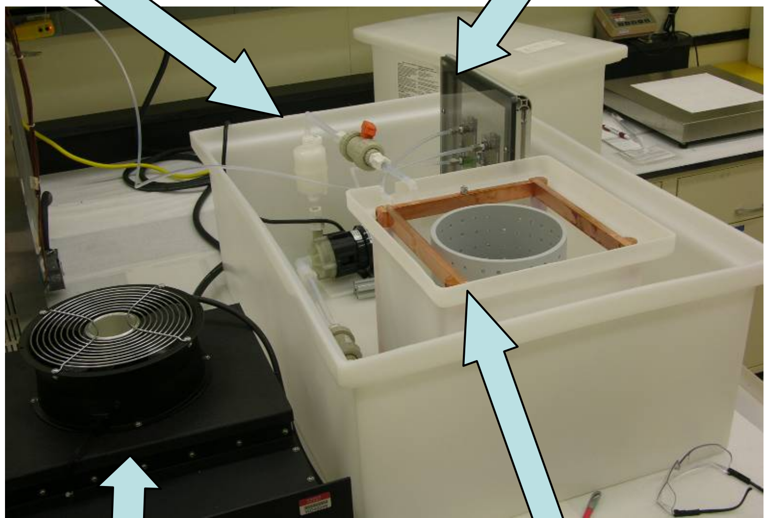
Radium & particulate filtration
and chemical scavenge

N2 sparge gas
flow control

Front view



Side view



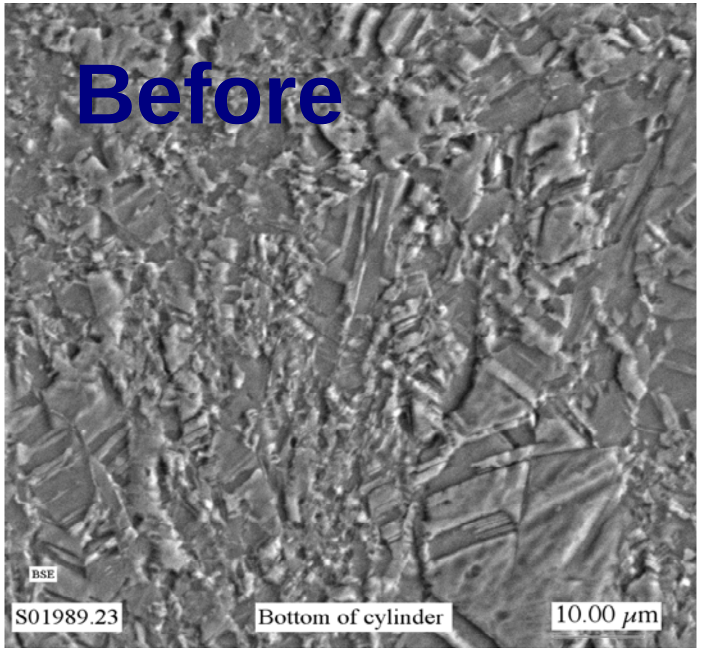
Cu sulfate bath with cover
gas, mandrel, current

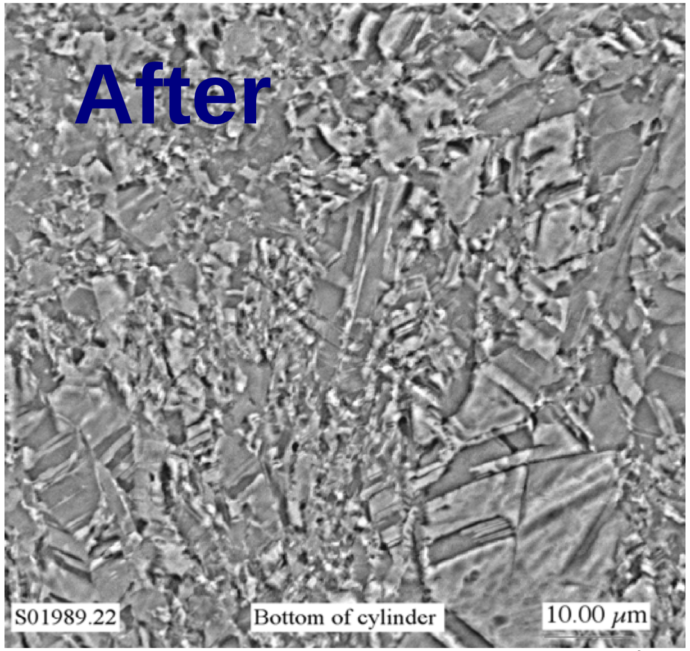
Programmable
power supply

Inner bath containment
& Cu bus

Copper quality

- New recipe does not require daily machining, at least on small parts
- New parts built up to near 1 cm thickness
- Proper recipe and voltage result in low plating rate, high quality copper
  - Small grain size
  - Each sample tested for hardness
    - “The average hardness is 105-108 vickers using a 100 grams of force. This translates to approximately 300-340 Mpa tensile strength. ”
- Surface cleaning study done



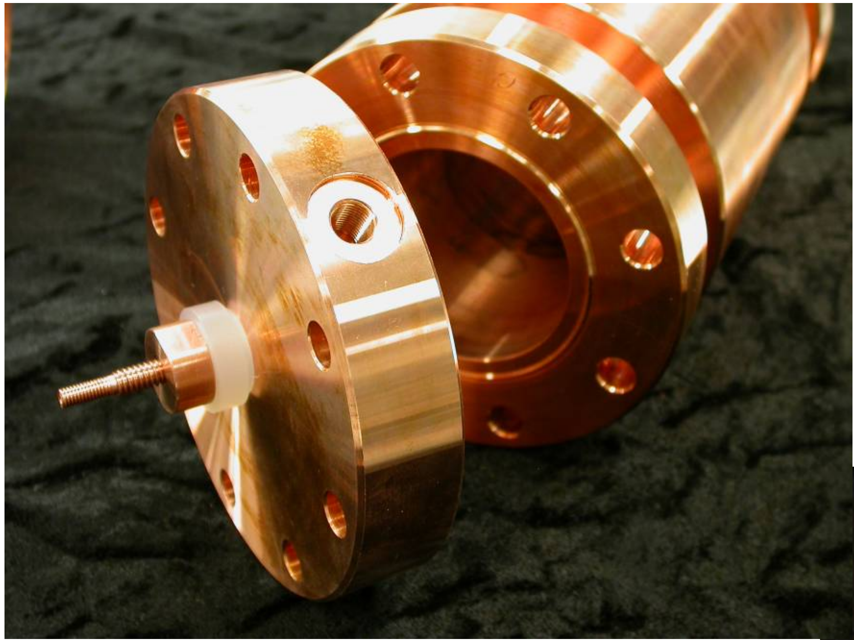


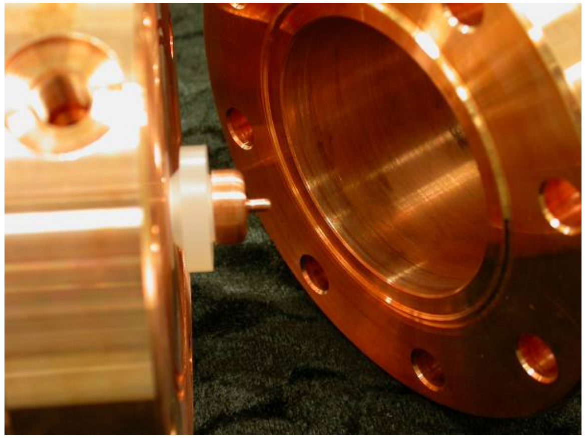
Preliminary Dust vs Rn study

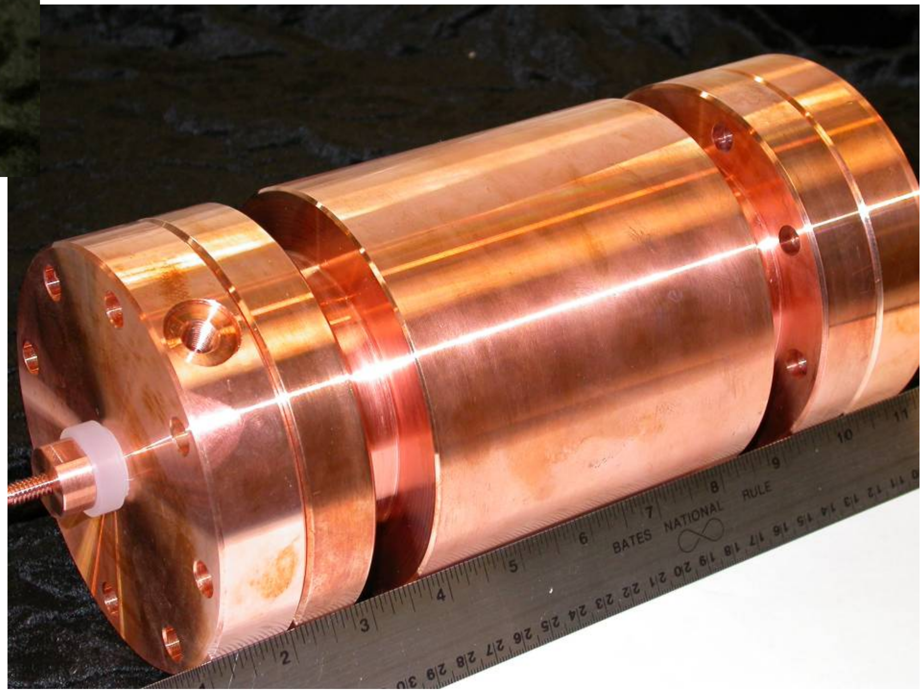
- Screening scheme for surface alphas devised using witness plates and large proportional counter
  - Counter under development currently
  - Size of witness plate ~ 20x20 cm (?)
  - Prototype proportional counter planned sensitivity of about 10^{-8} Bq/cm^2
  - Further development to 5×10^{-10} Bq/cm^2 planned

- Dust appears to be more significant than Rn
  - ^{210}Pb chain, from ^{222}Rn
    - 1 year in air yields ~ 10 decays/day for prototype counter
  - ^{238}U and ^{232}Th chains in crustal abundance in dust
    - 1 mg of dust yields ~ 100 decays/day for prototype counter
    - Class 2500 clean room measured 0.1-1.0 μg/cm^2/month (SNO)

Gas Proportional Counter Prototype

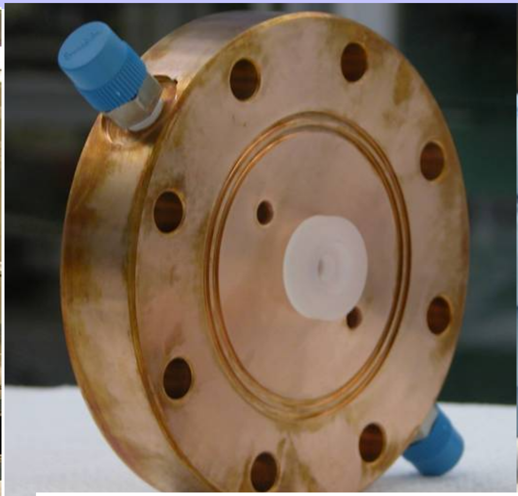


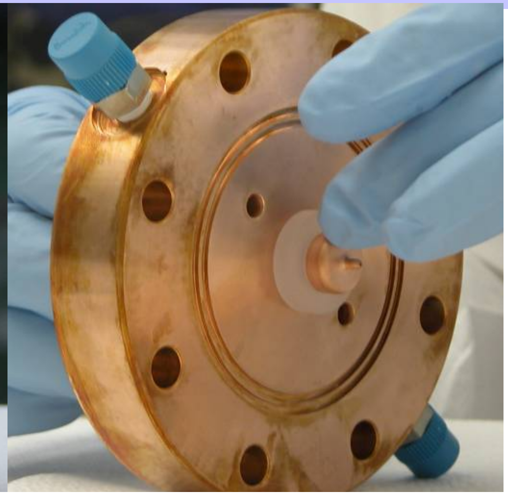




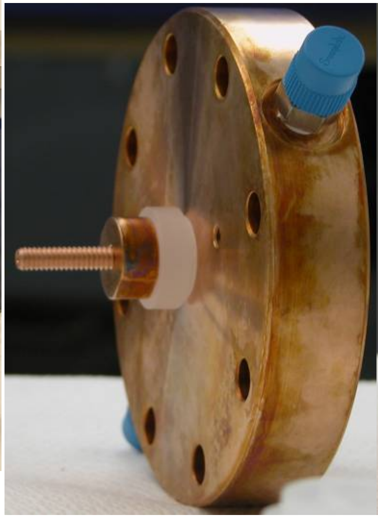
Parts are test-fit prior to cleaning and vacuum bake

Prototype 1 Assembly





Results to date: Counter in testing



Majorana Facility Estimates

Currently we are refining the ocupancy estimates based on the WBS and safety reviews

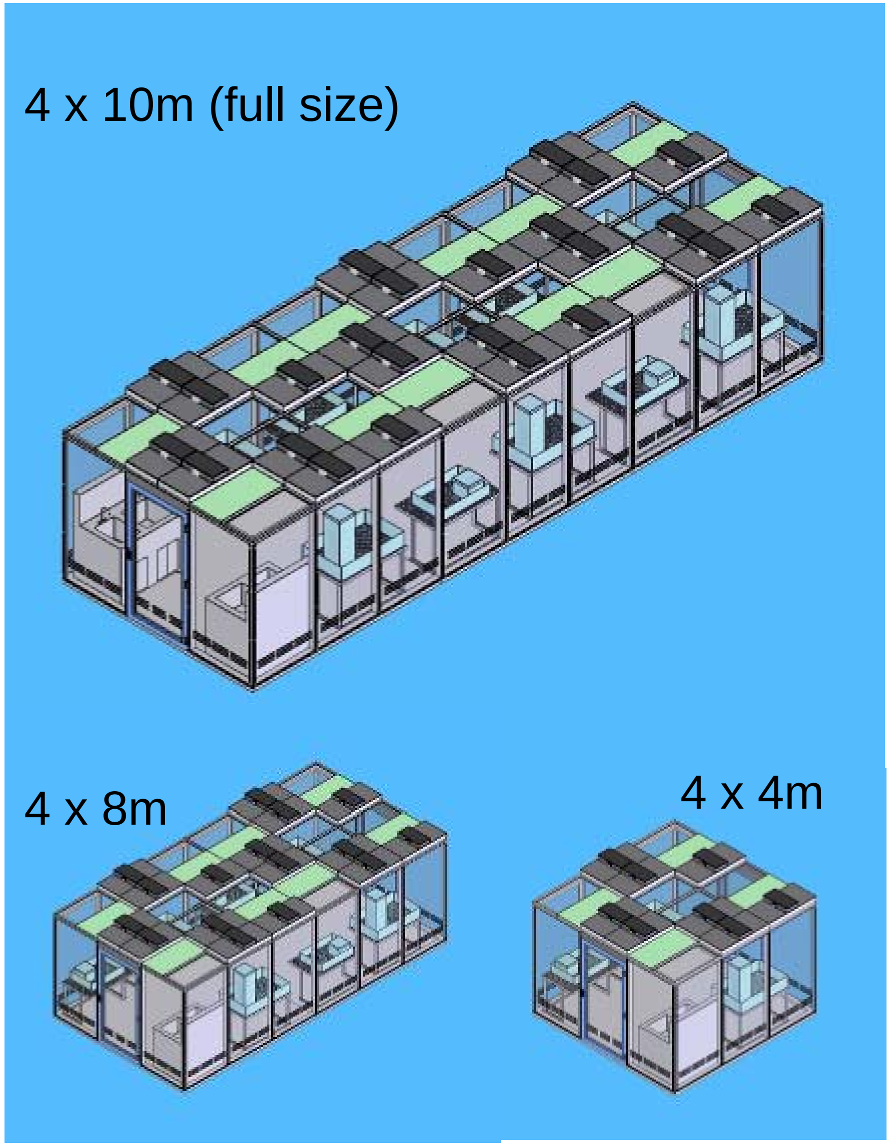
Location	Space (m)	Power (kW)	Air Quality	Occupancy (People/shift)
control room	5x4x3	30 (ups)	regular lab	2 (2 shifts)
detector	5x5x3	2 (ups)	class 100, radon free	0-2 (2 shifts)
assembly	5x5x3	8 (ups)	class 100, radon free	0-4 (2 shifts)
entry	4x4x3	1	HEPA	-
storage (dirty)	4x4x3	1	regular lab	-
storage (clean)	4x4x3	1	class 100, radon free	-
electroforming	4x10x3	40	class 2,000, radon free	0-4 (2 shifts)
shop	4x10x3	24	class 2,000, radon free	0-4 (2 shifts)
entry	4x10x3	1	HEPA	-
Total	214 m^3	108		20-40*

We have not yet defined what “radon free” means

*Peak year estimate.

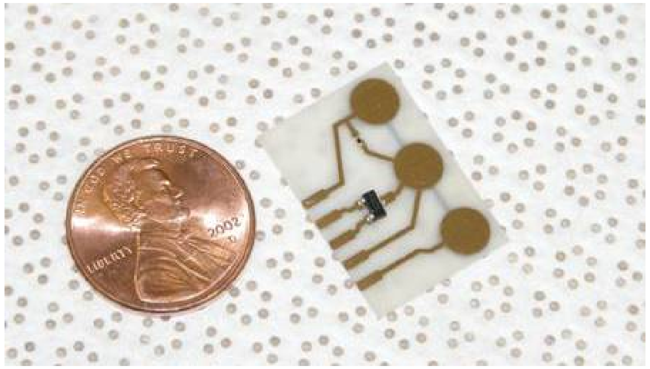
Example: Electro-Plating Lab

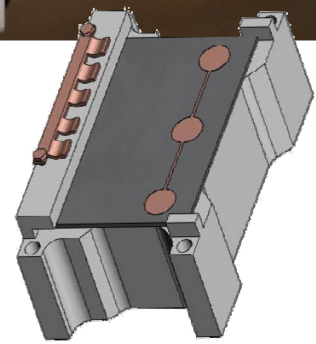
- Collecting site selection and build out criteria
- Modular underground spaces in design
- Example: Electro-Plating Lab
  - Class 100-1000 Clean Room, scalable in size
  - Radon reduced air
  - Directly adjacent to Machine Shop
  - Clean storage for supplies
  - Wash-down sink, DI water

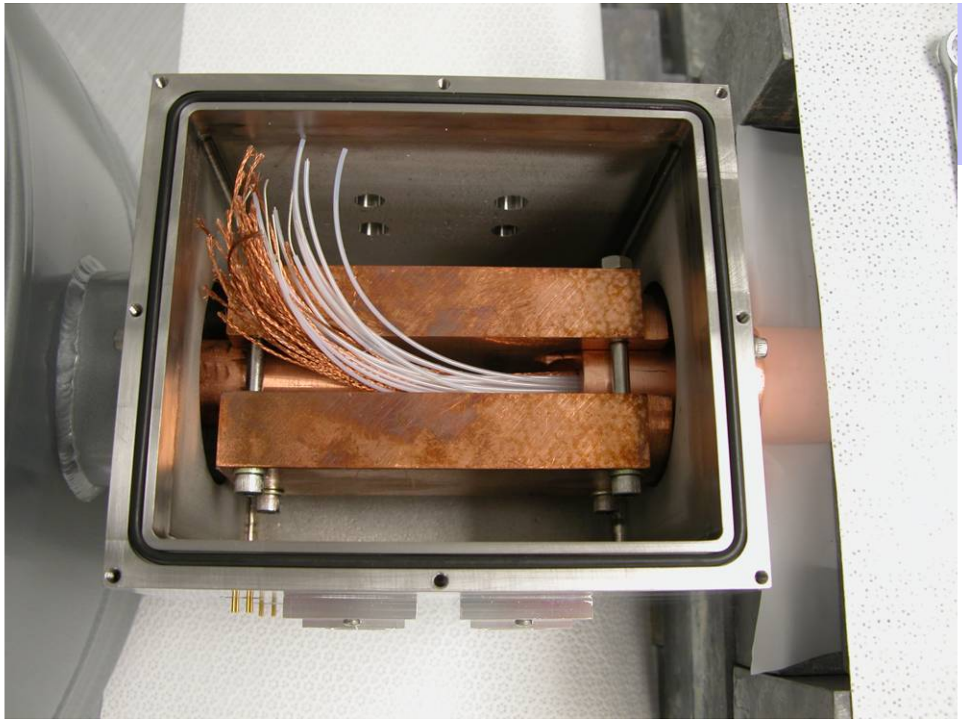
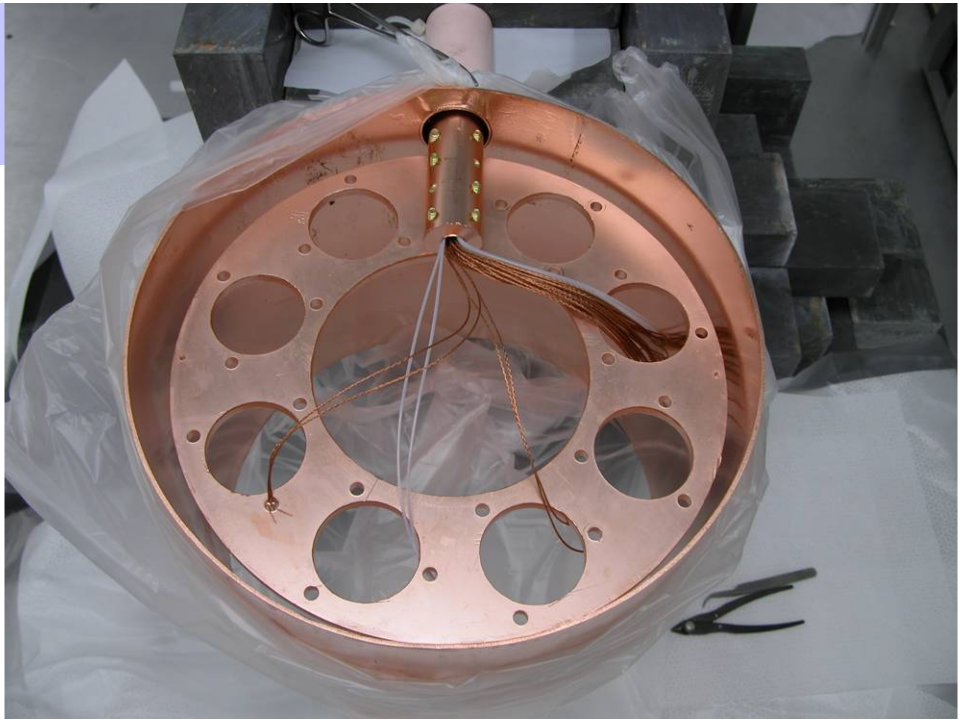
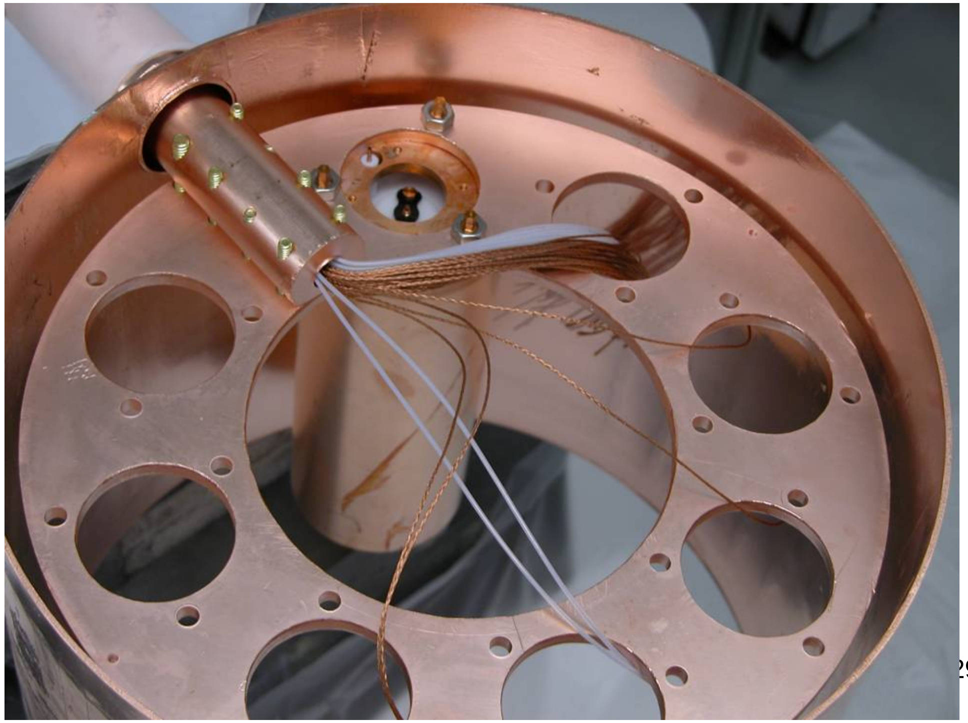
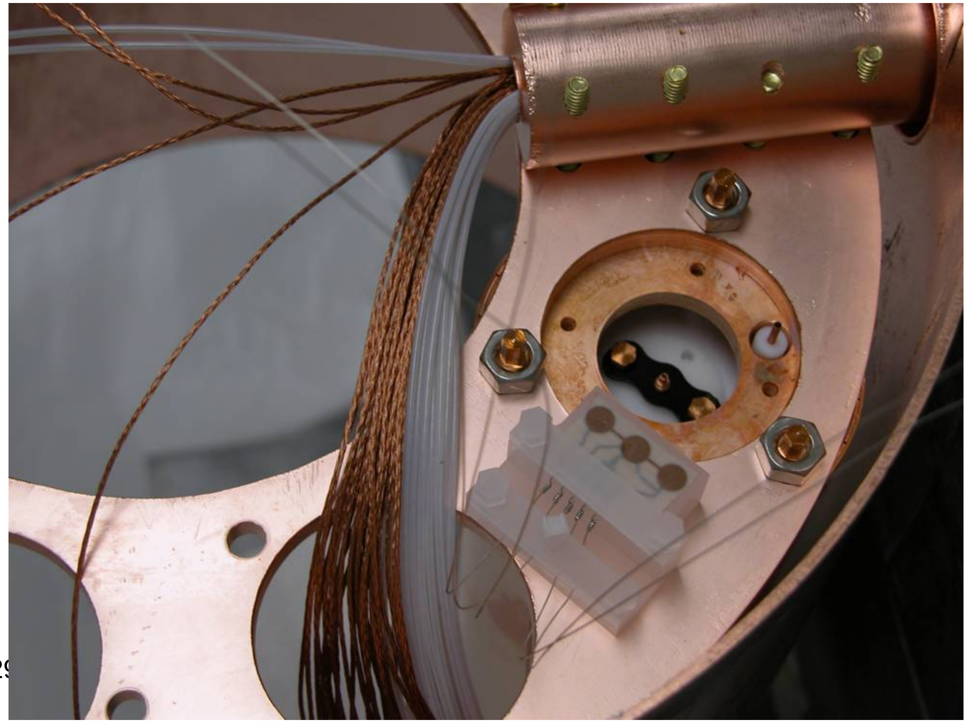


MEGA progress

- Cool down test at WIPP
  - ~12W thermal load, allow 1w dewar, then 2% emmissivity likely
- Cool down test at PNNL
  - Cooled 2-pack to 80K in one day, mostly in 4 hours
- Electronics testing
  - Student training
- Encapsulation redesign
  - Better reliability of package, lower plastic mass
- Summer installation campaign planned



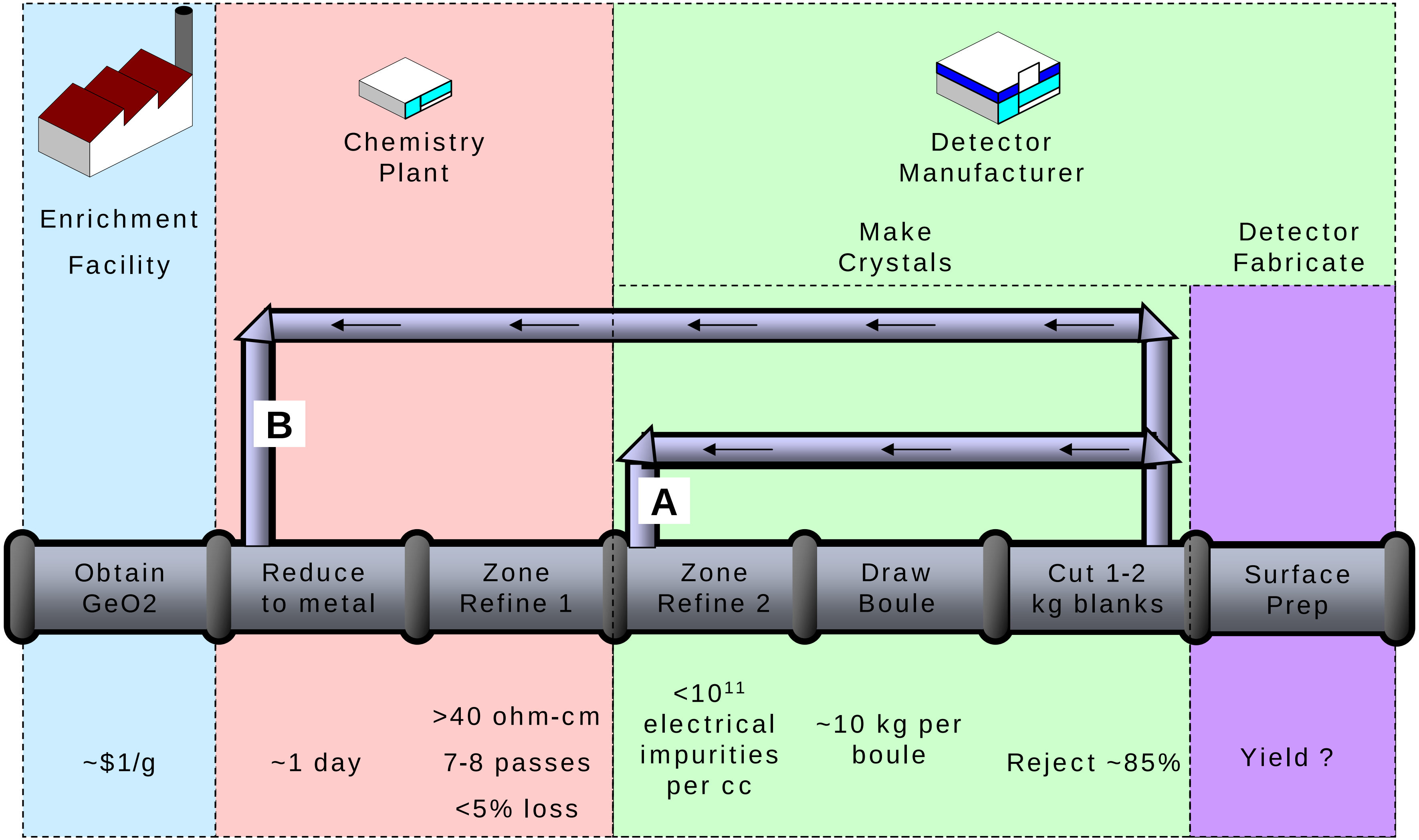


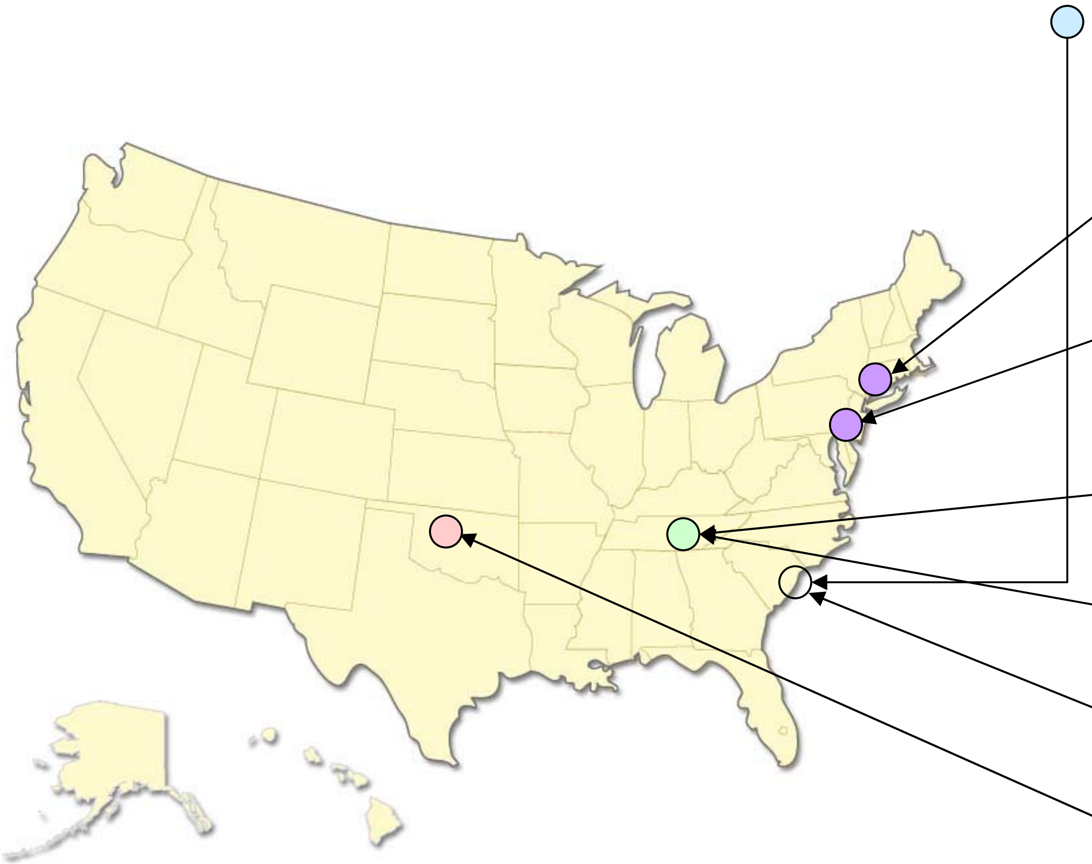
Chemical Processing: Work to date

- Two surveys of losses in process
  - Paul Luke et al
  - FTA IGEX experiences
- Both fairly detailed and documented
- Neither may accurately reflect a dynamic situation
  - Radiopurity process changes
  - Difference in cost vs. schedule/exposure emphasis from IGEX to Maj
- Toy model created to explore impact of losses
  - Loss type, loss location, affect on Ge yield, exposure

Basic Processing Steps



Likely Locations



ECP, Enrichment

Canberra, Detector Fab

PGT, Detector Fab

Canberra, Xtal Growth

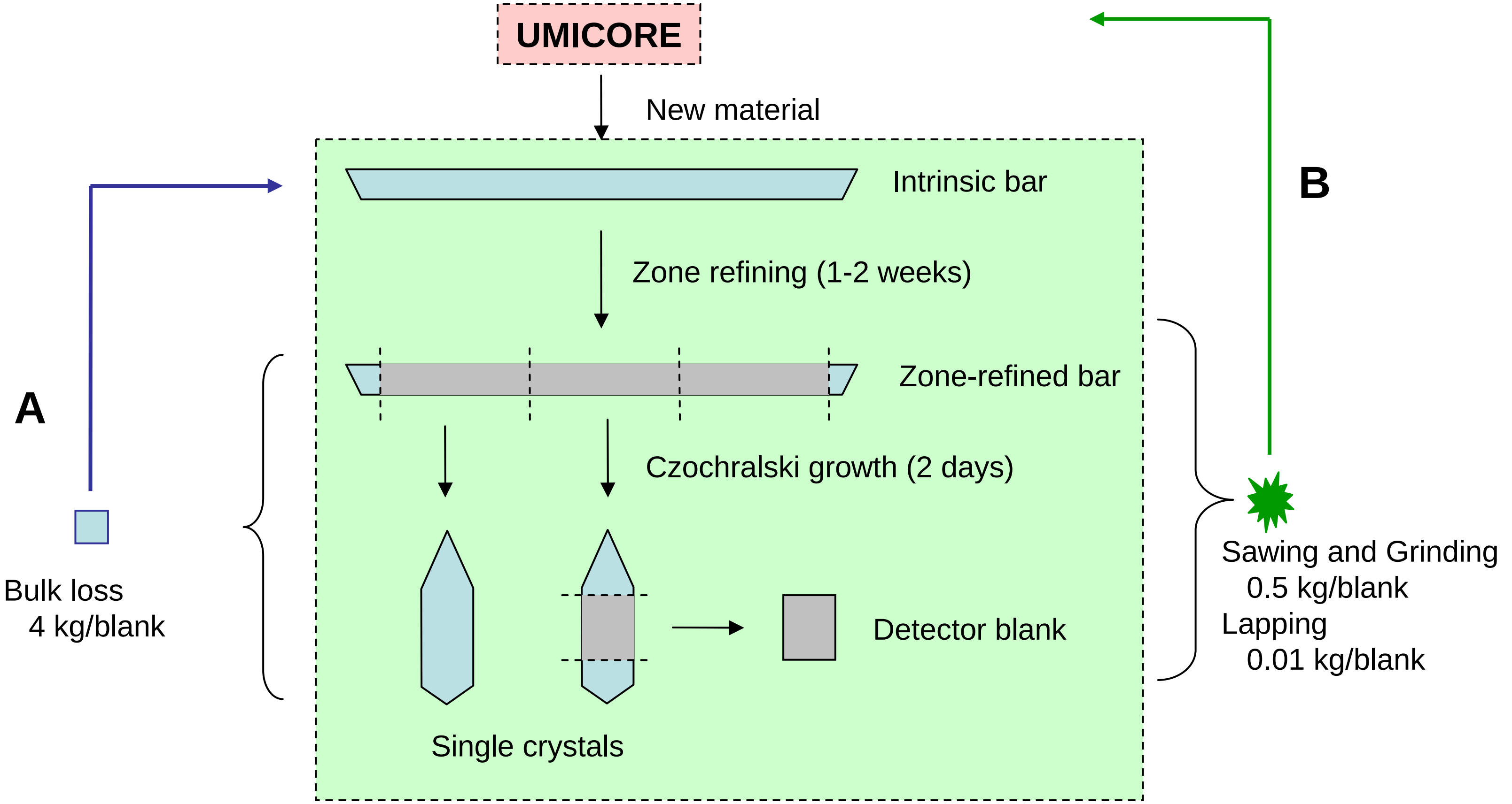
ORTEC, Xtal Growth

ORTEC, Detector Fab

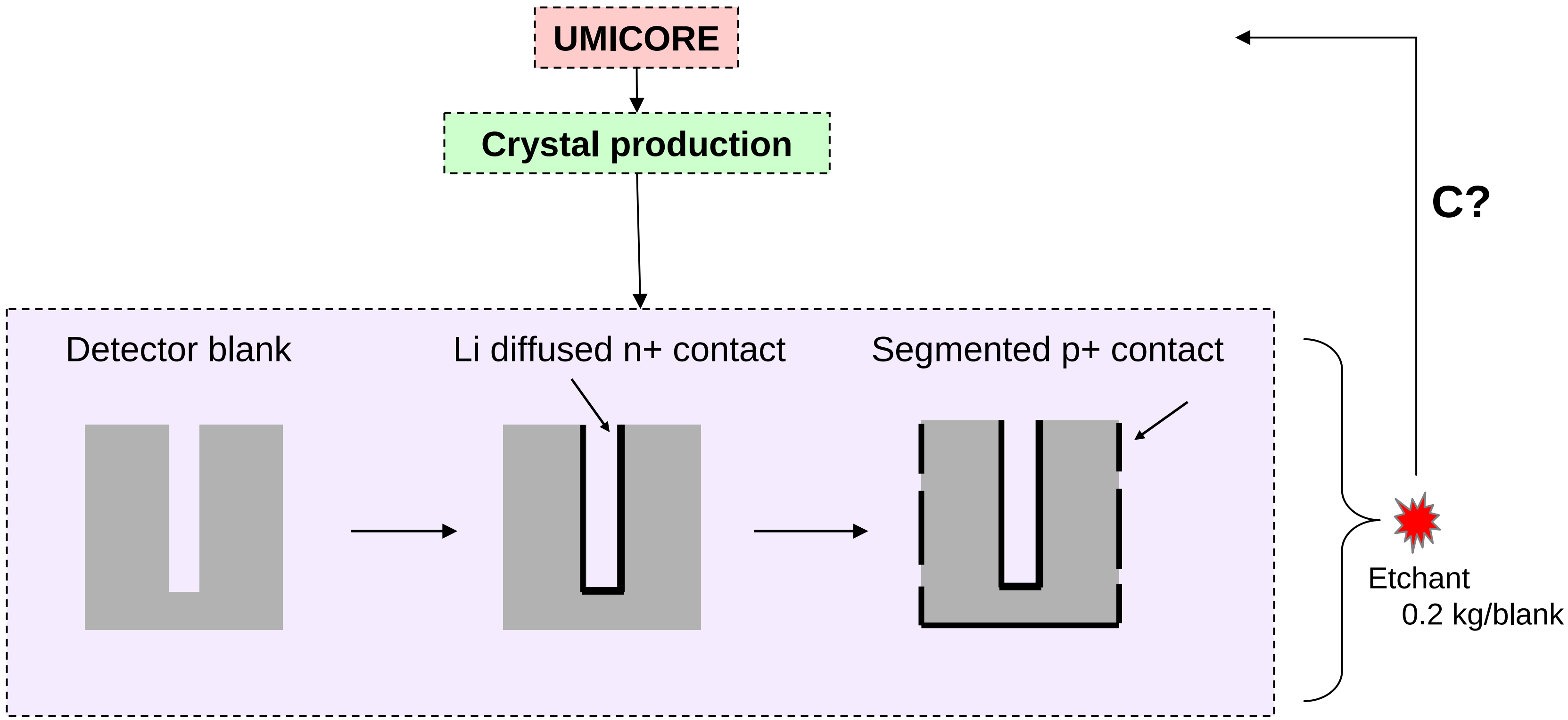
Ge receipt, Charleston?

UMICORE, Chem Purification

Crystal production process

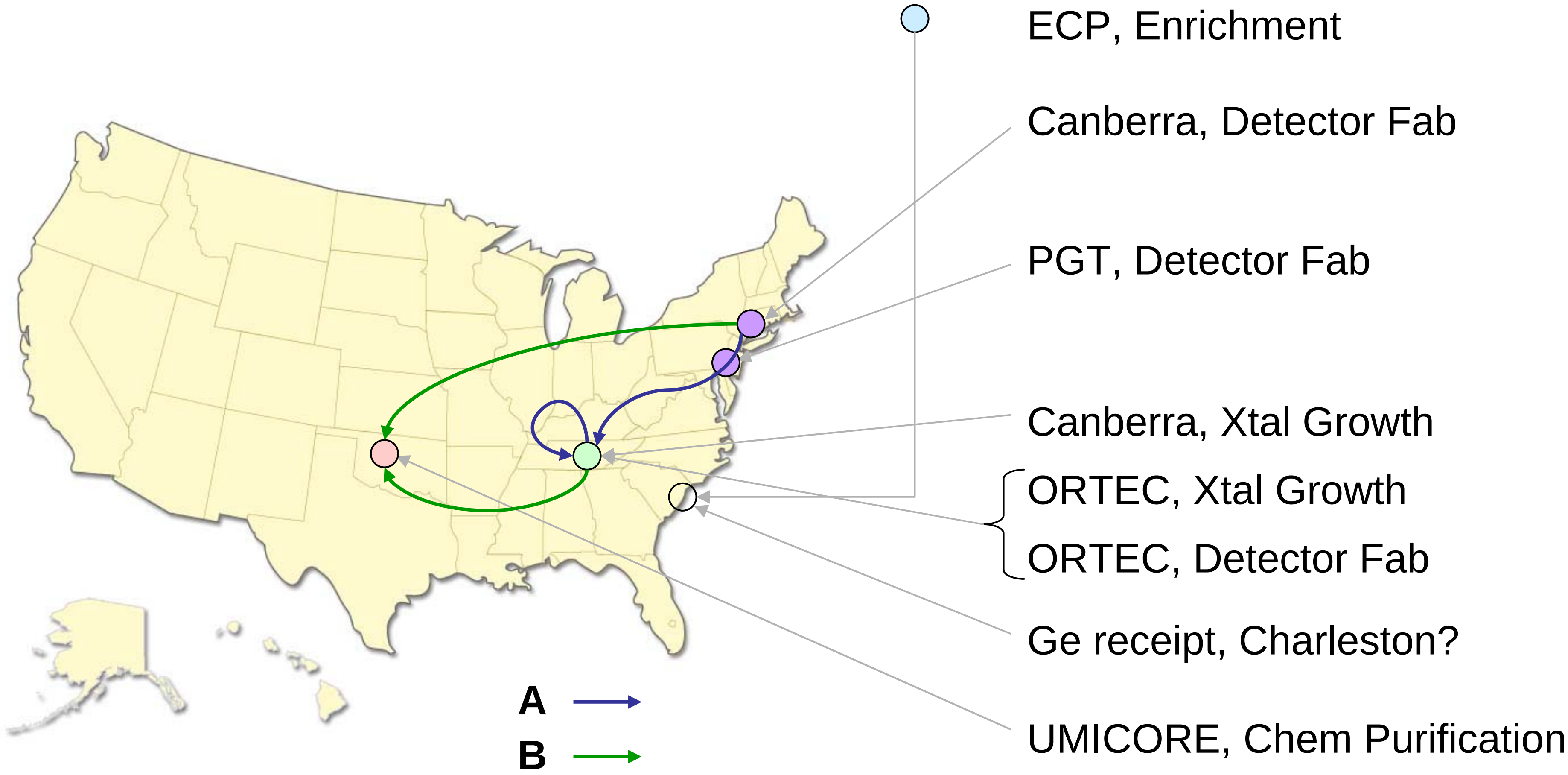


Detector fabrication



Machining, surface etching, other losses…

Logistics of losses



Process Background

- Chemical preparation
  - UMICORE, Quapaw,OK
  - Receives raw Ge oxide
  - Converts to metal
  - Purifies in up to 8 zone refinement steps
  - Quoted numbers
    - 85% yield on first batch
    - 96% yield thereafter
    - ~2% is truly “lost”
    - Rest may be recoverable (B)
- Detector manufacturing
  - Detector blanks
    - Additional zone refinement
      - Ears removed (A)
    - Crystal pull
      - Top/bottom removed (A)
    - Sawing, grinding, lapping (B)
  - Detector fabrication
    - Machining (B)
    - Etching (**C**)

Model results

- Changing "B" losses is not very effective at improving efficient use of Ge as the material only suffers a little real loss in the recycle.
- Changing "**C**" losses can have a real effect. In this case where input is fixed at 170 kg (or at $52/g, $8.84M) about 15kg of finished detectors are the result, or about 13% more efficiency (saving ~$1.15M and lots of exposure and transportation cost.)

B/blank kg	C/blank kg	GeO2 kg	det_kg kg	orphan kg	lost/dets	total/dets
0.6	0.2	170	127.8	5.6	0.288	1.332
0.4	0.2	170	127.6	6.5	0.281	1.332
0.2	0.2	170	127.6	7.47	0.274	1.332
0.6	0.1	170	137.5	6.2	0.191	1.236
0.6	0.05	170	141.9	7.75	0.143	1.198

Experiment with MSU/NSCL detector

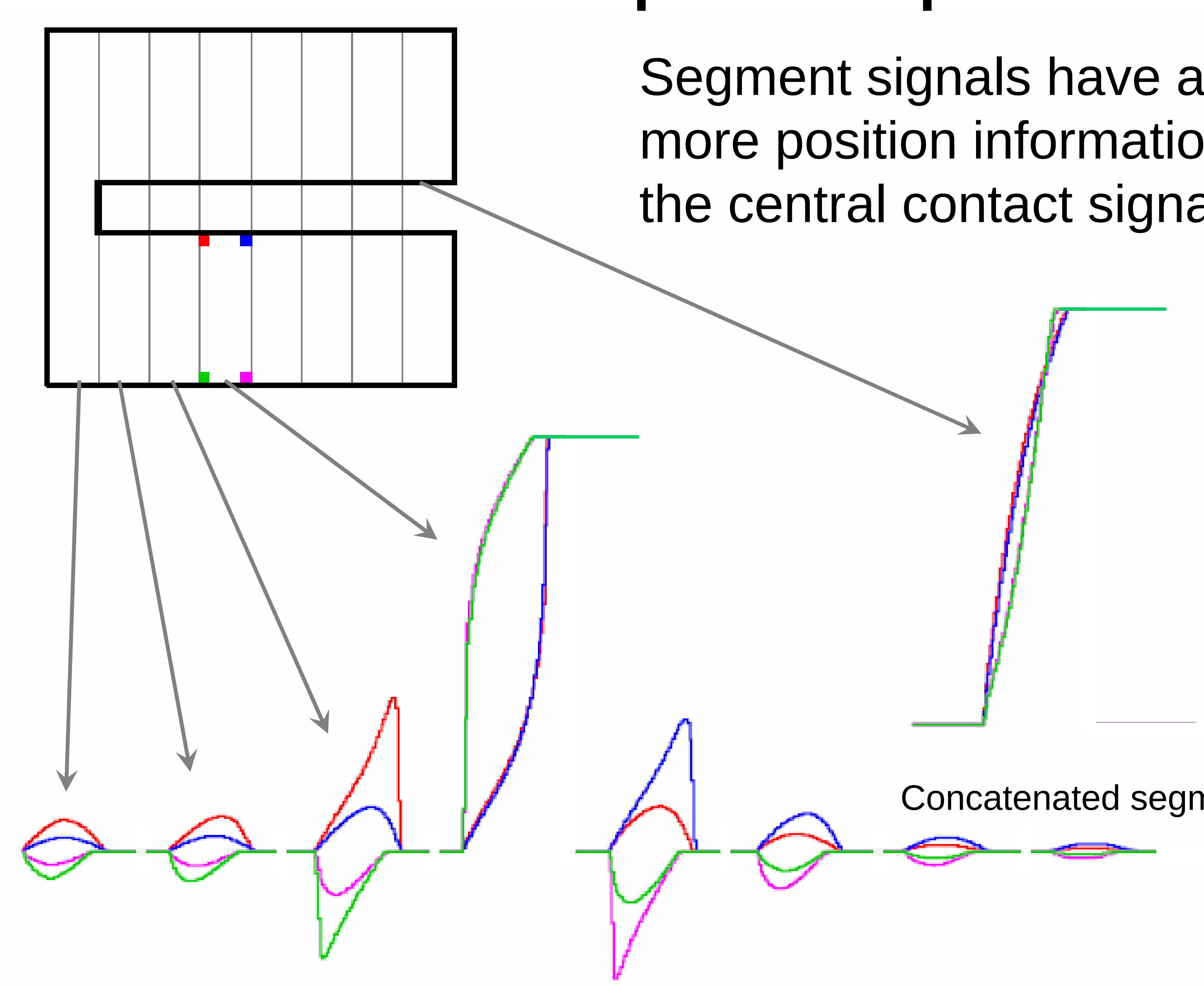
SeGA : Segmented Ge Array

- N-type, 8 cm long, 7 cm diameter
- 4x8 segmentation scheme
  - 4 angular segments, 90 degrees each
  - 8 longitudinal segments, 1 cm each
  - Digitally summed to give 1x8 configuration
- All but one of the segments, plus the central contact, were digitized
  - 32 channels of 100 MHz Struck ADC
  - Can treat as 4x8 = 32 segments, or sum to make 8 slices
- ^{60}Co and ^{56}Co sources on the side of the detector
  - Simulates ^{60}Co in the can; ^{56}Co gives double-escape peaks
- Collected several million events, 40 GB of data

Position sensitivity

of pulse shapes

Segment signals have a lot more position information than the central contact signal.

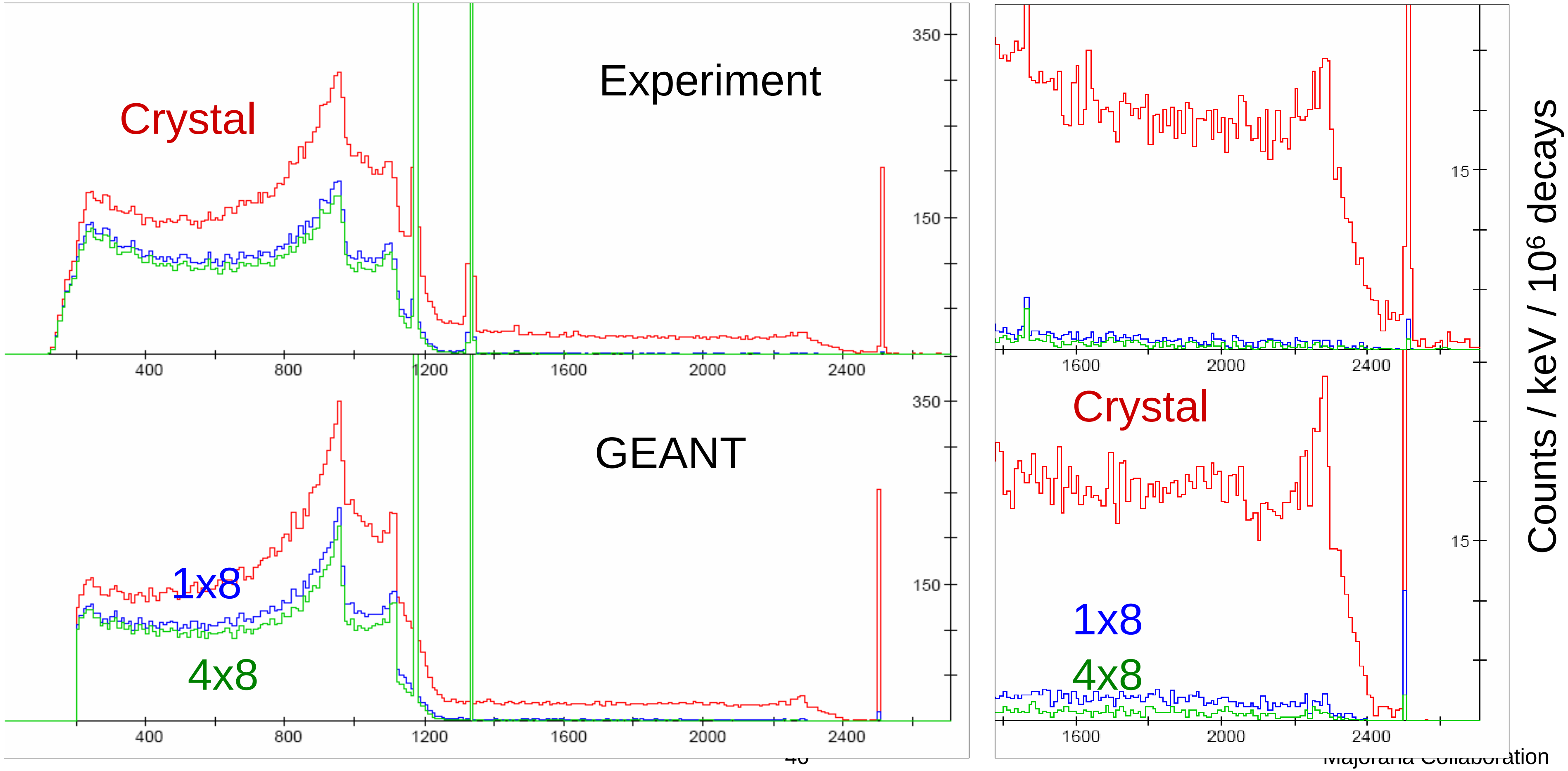


Majorana Collaboration

Spectra from MSU / NSCL detector compared with GEANT simulations

^{60}Co on the side of the detector

Simple multiplicity cuts – No PSA

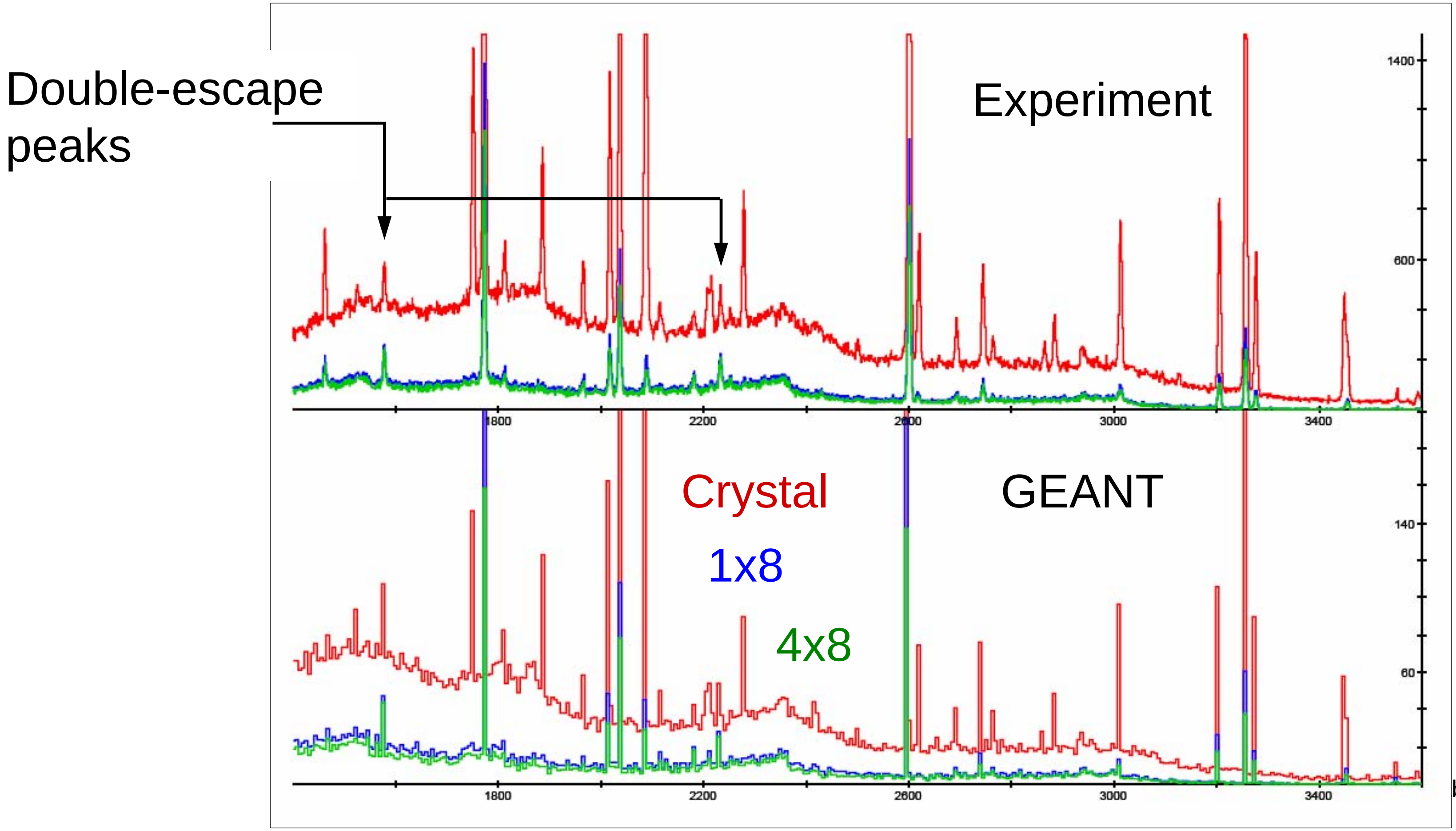


Spectra from MSU / NSCL detector

compared with GEANT simulations

^{56}Co on the side of the detector

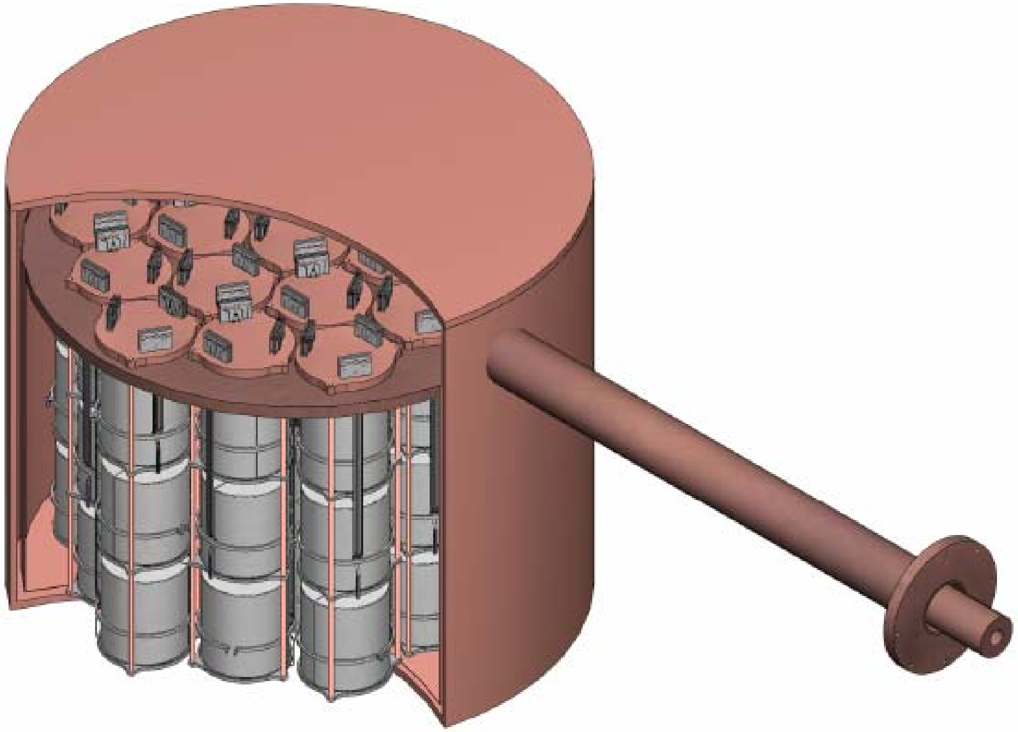
Simple multiplicity cuts – No PSA



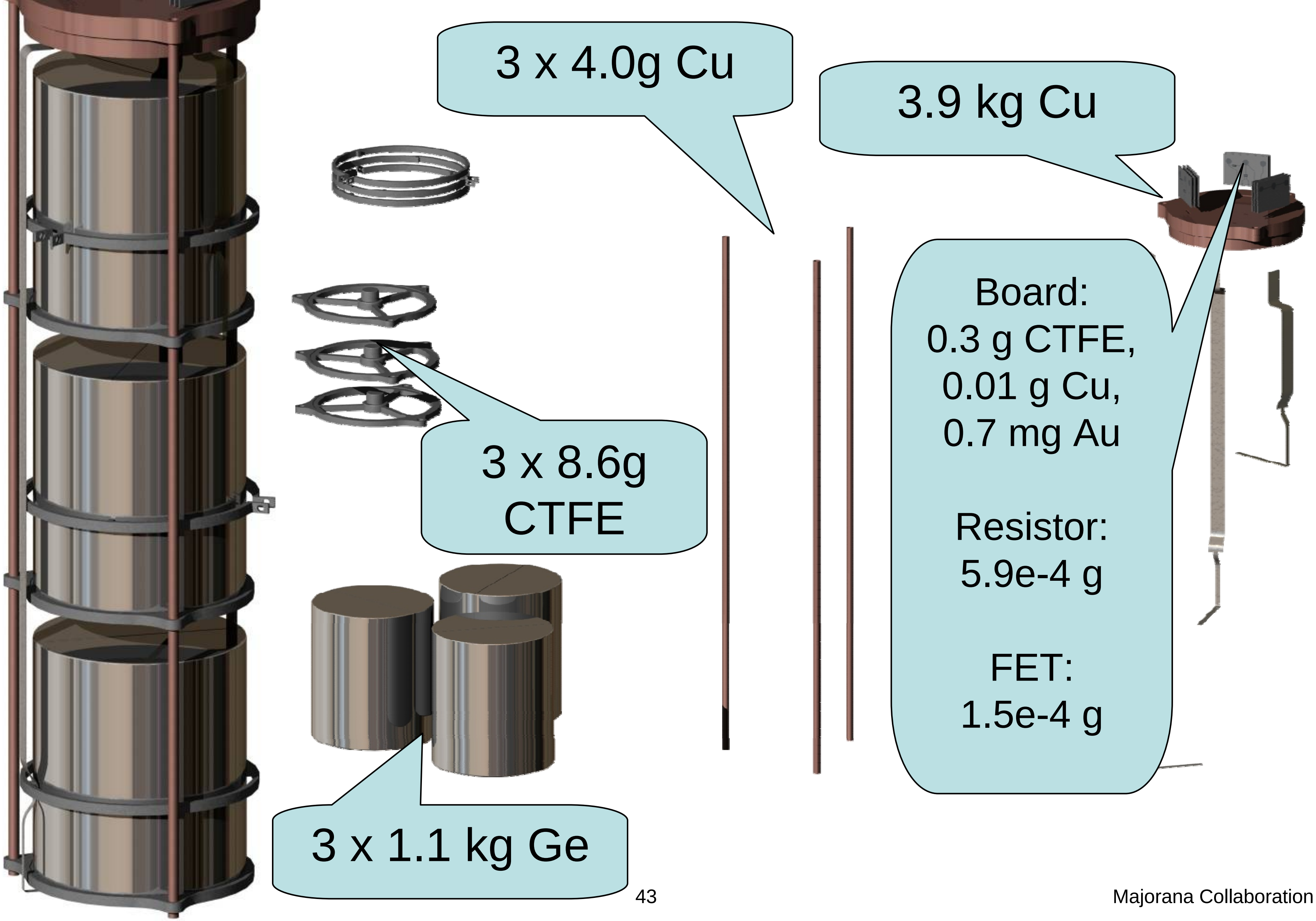
boration

Simulation progress

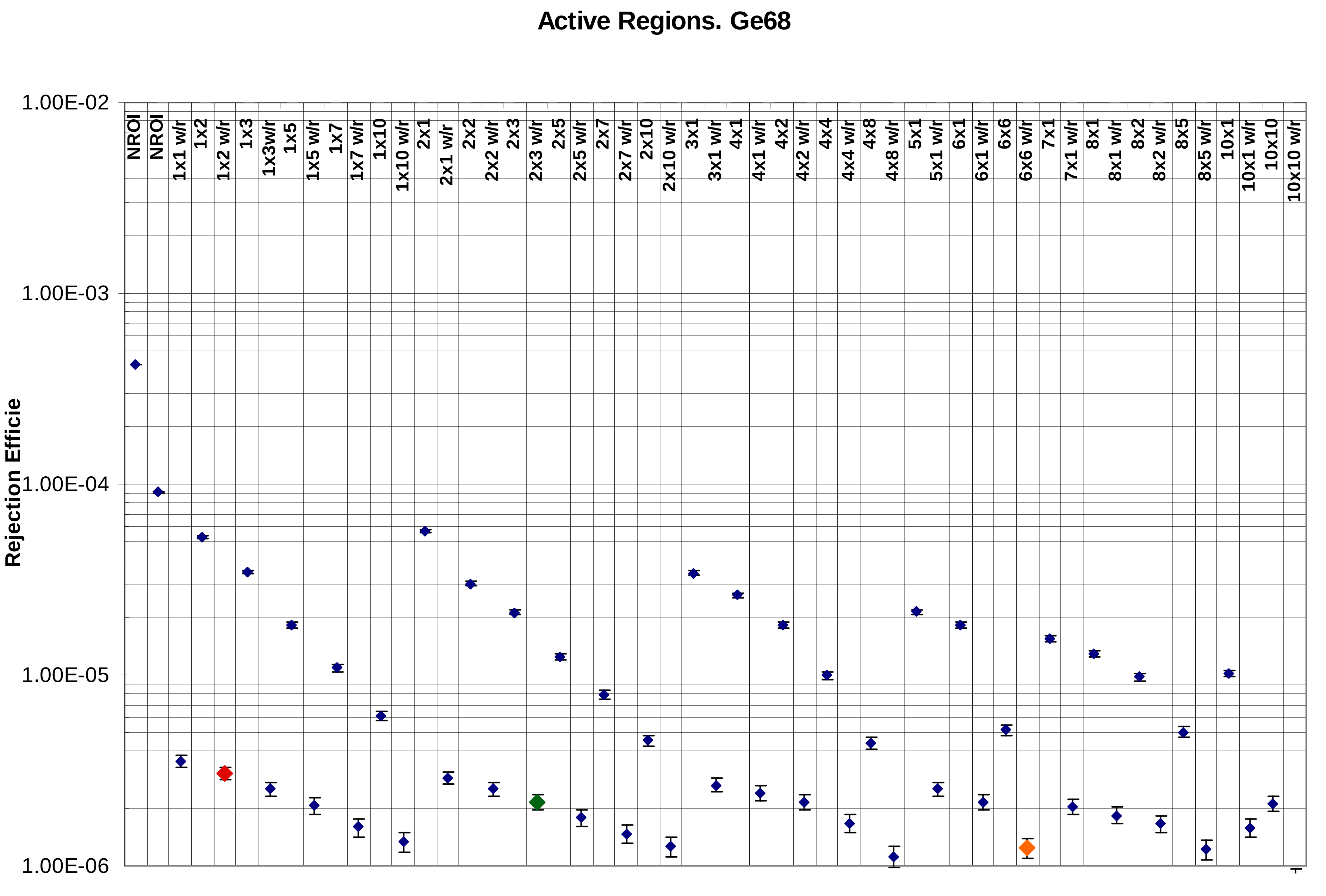
- Simulation group performing various simulations
  1. Detector materials
  2. Muons/neutrons
  3. Surface alphas
  4. ….
- Matrix of materials and sources vs. segmentation
  – Energy
  – Xtal-to-xtal
  – Segmentation



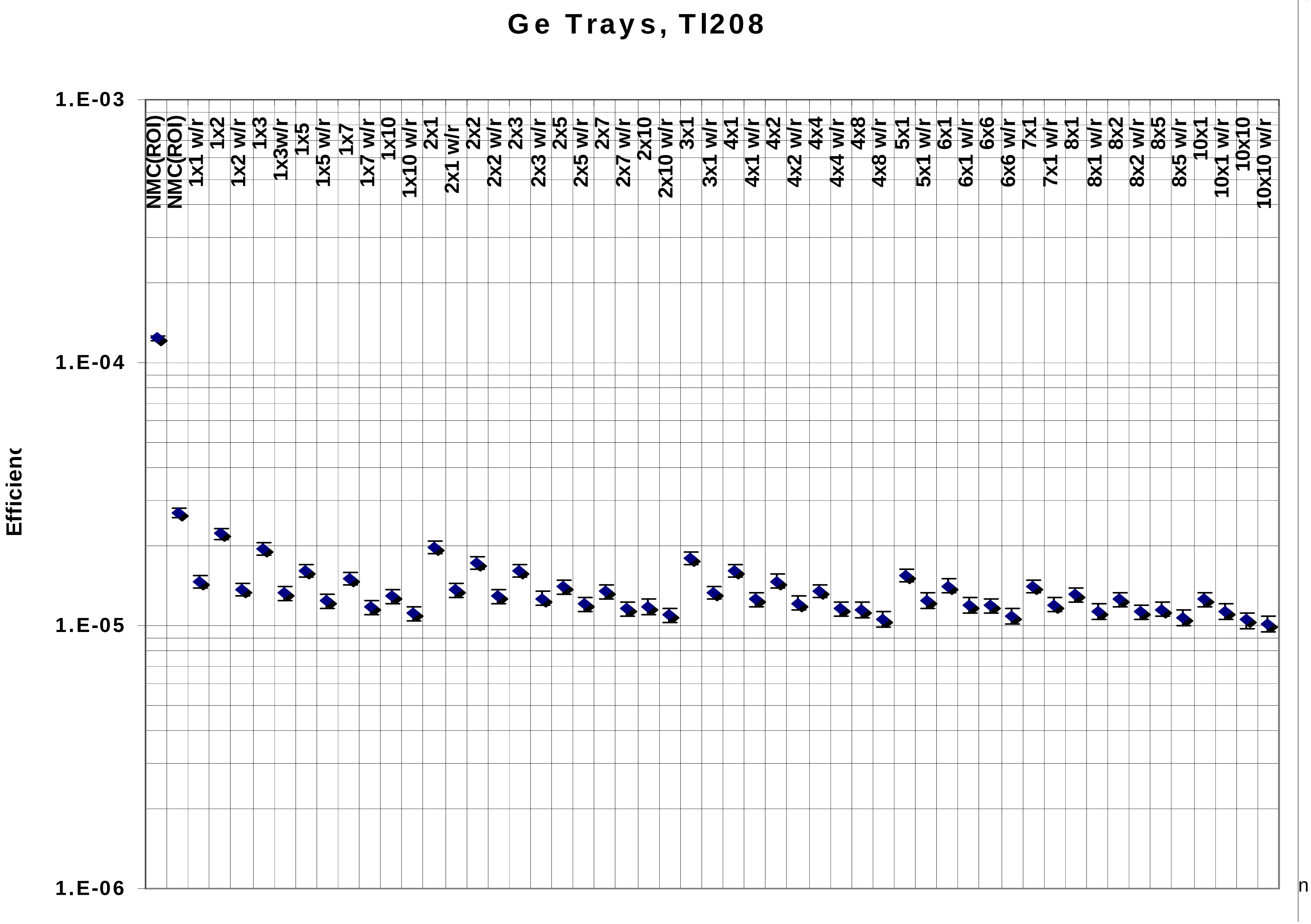
Detector String Breakdown



Example Simulation: 68Ge

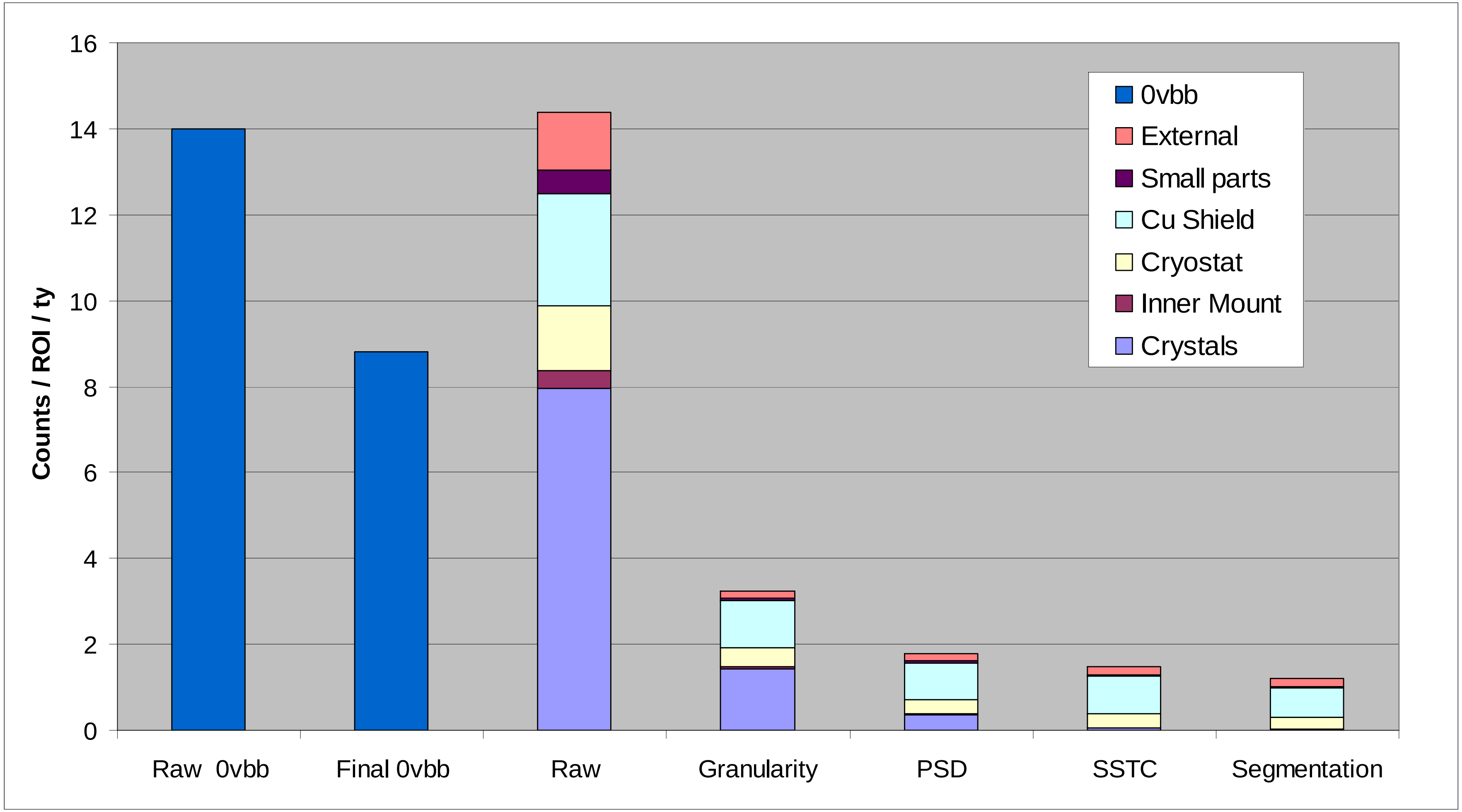


Simulation Example: 208Tl

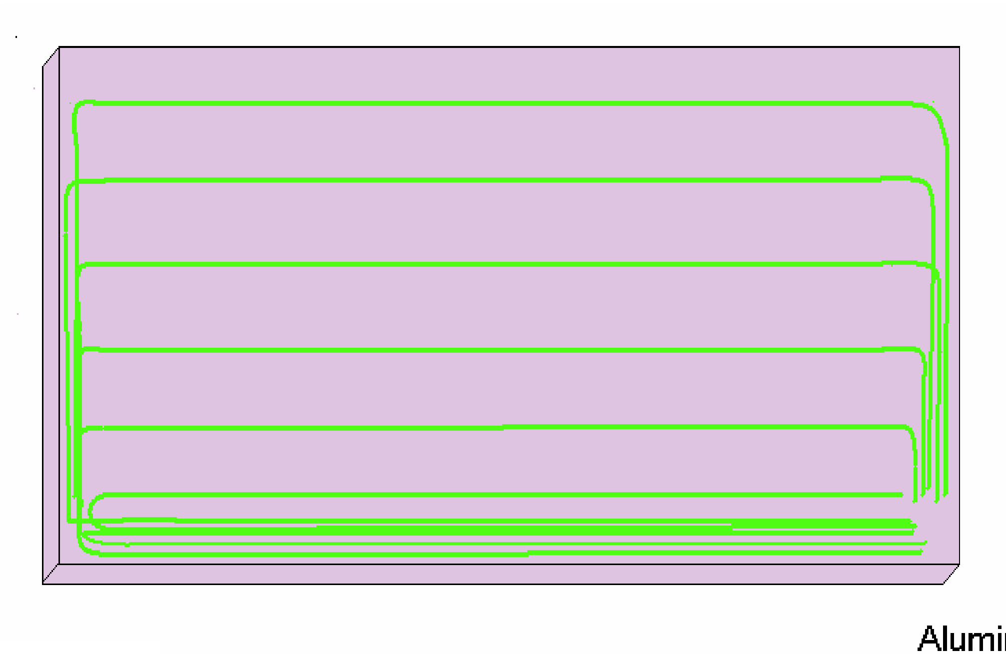


An (old) example background model

Important to consider the sources and the suppression methods

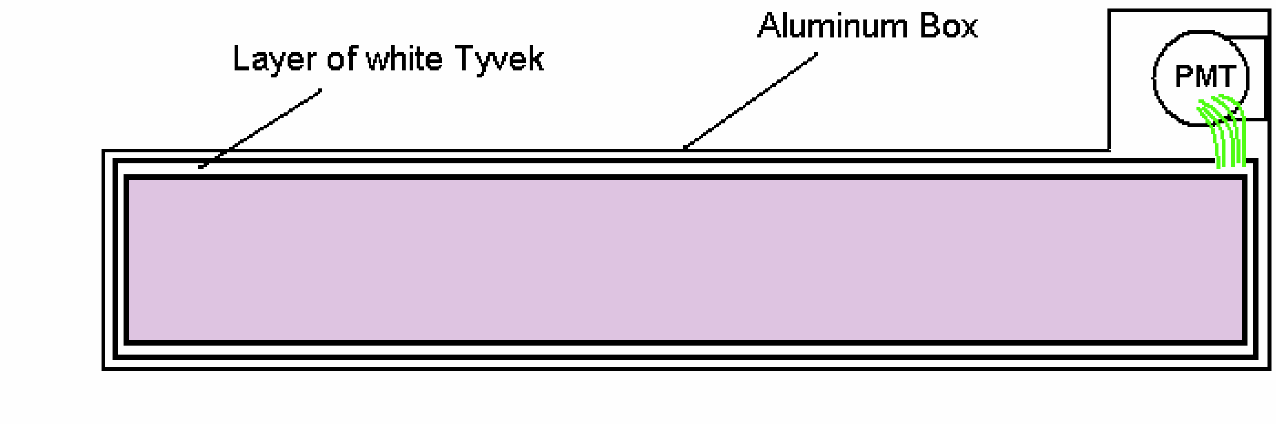


MEGA Veto Panel Design, Test, Status



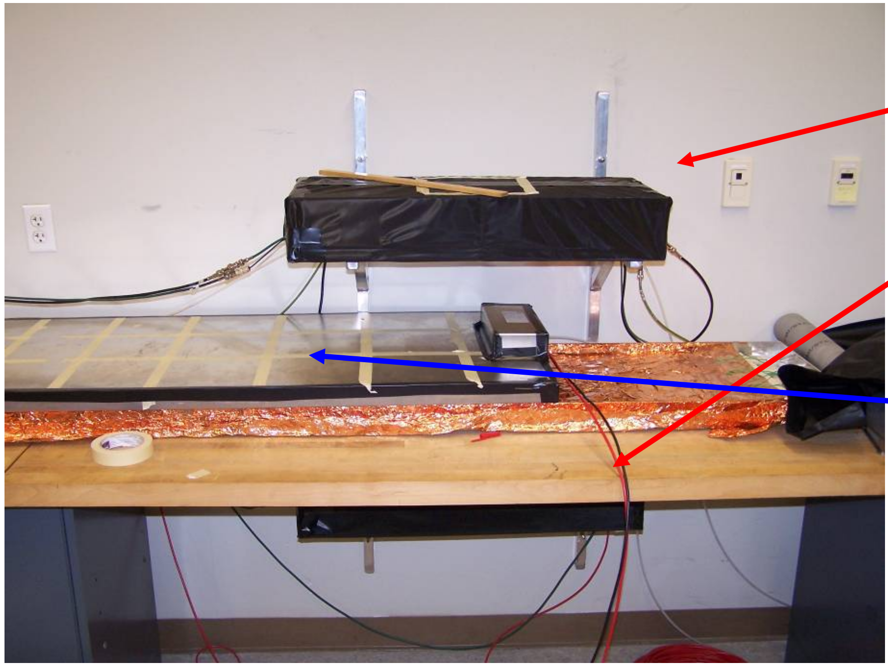
Panels use scintillator plastic with wls fibers secured in uniform groves.

The uniformly spaced fibers will provide complete coverage of panel.



Panel Testing

Panel dimensions 51.5” by 23.5”



To test panel efficiency, two triggering 8x8” muon detectors were used.

The panel was divided into sections and the triggering detectors were placed above and below the panel

Design Goals, Veto Status

–High efficiency **Average efficiency ~99.9%**

–Uniformity **Amplitude range 242.7-244.4**

–Hermetic **Only gaps occur for utilities**

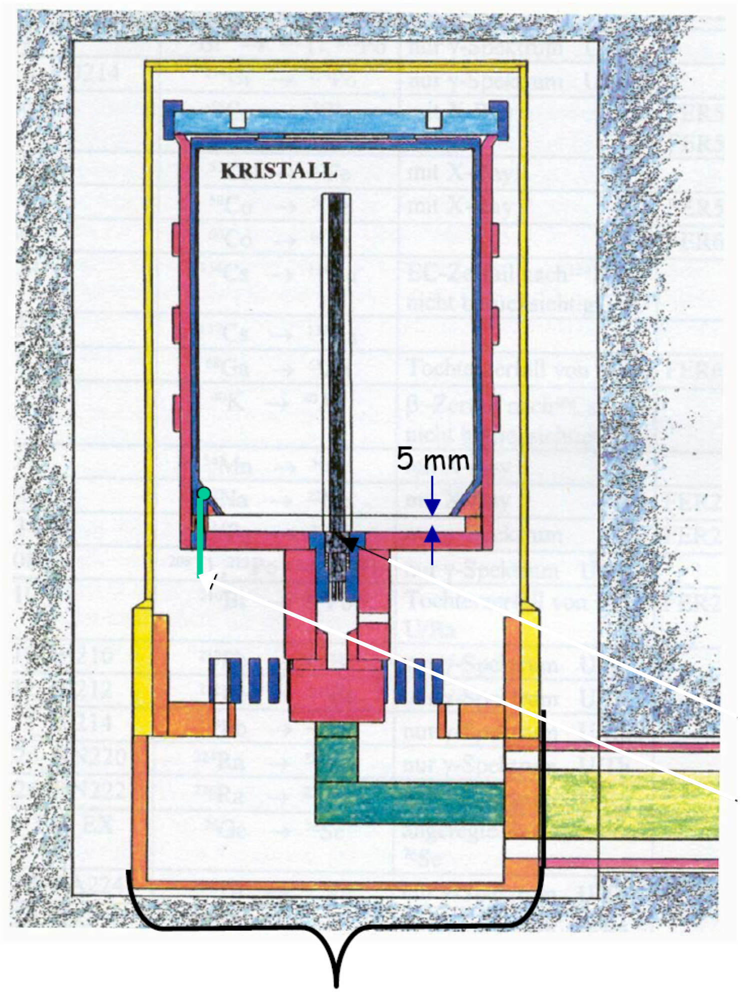
–Compact and modular for inner adjustment

Each panel can be handled by two people

Delivered to WIPP site in conjunction with other MEGA components for summer installation campaign

Past use of structural materials

HDM detectors



PNNL-Built Detectors

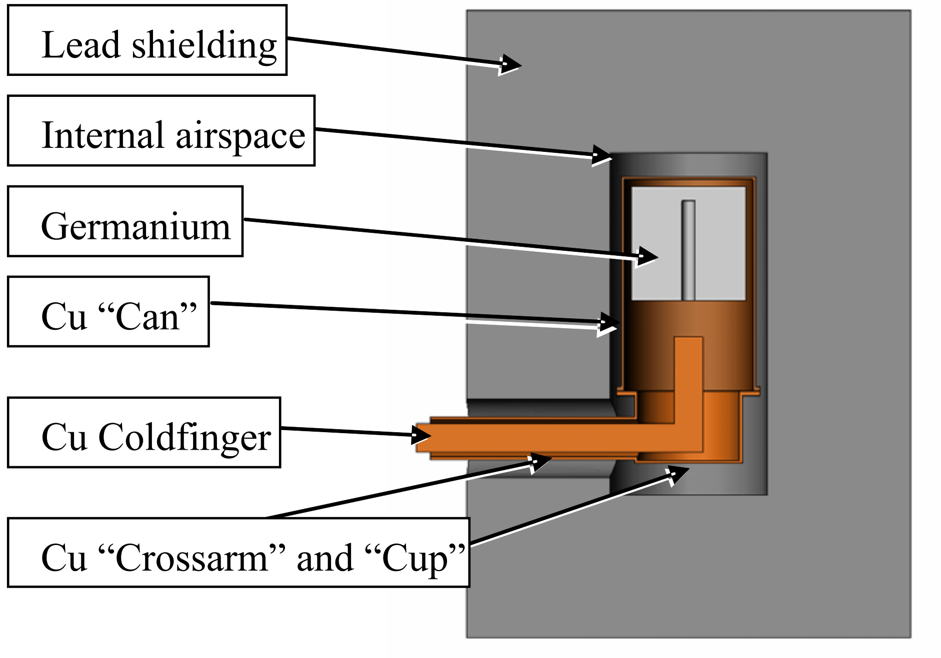


Figure 3-1 Typical germanium detector arrangement. The volume of Ge is about 400 cc (2.1 kg) and the volume of Cu is Can: 97 cc (0.8 kg); Crossarm + Cup: 63 cc (0.6 kg) + Coldfinger: 82 cc (0.7 kg); Total: 242 cc (**2.1 kg Cu**).

Conclusions

- Progress on main DOE funding is occurring
  - Perhaps not the schedule I'd like, but I can't complain
- Technical progress occurring
  - Continuing development of synergies
- Continued technical interchange should be mutually beneficial