Majorana project

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For the Majorana group.

Power point sheets provided by Dr. Craig Aasleth

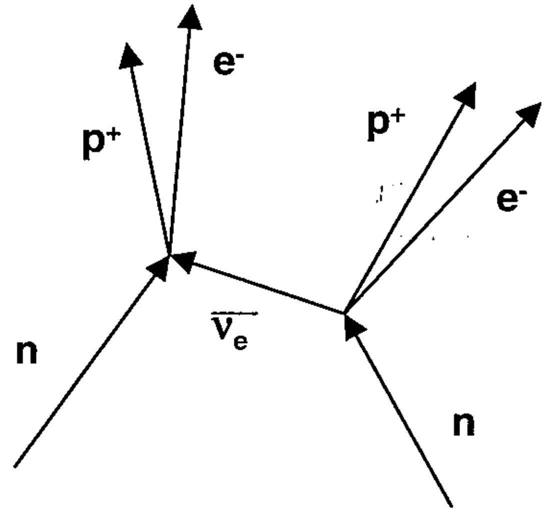
The *Majorana* Project

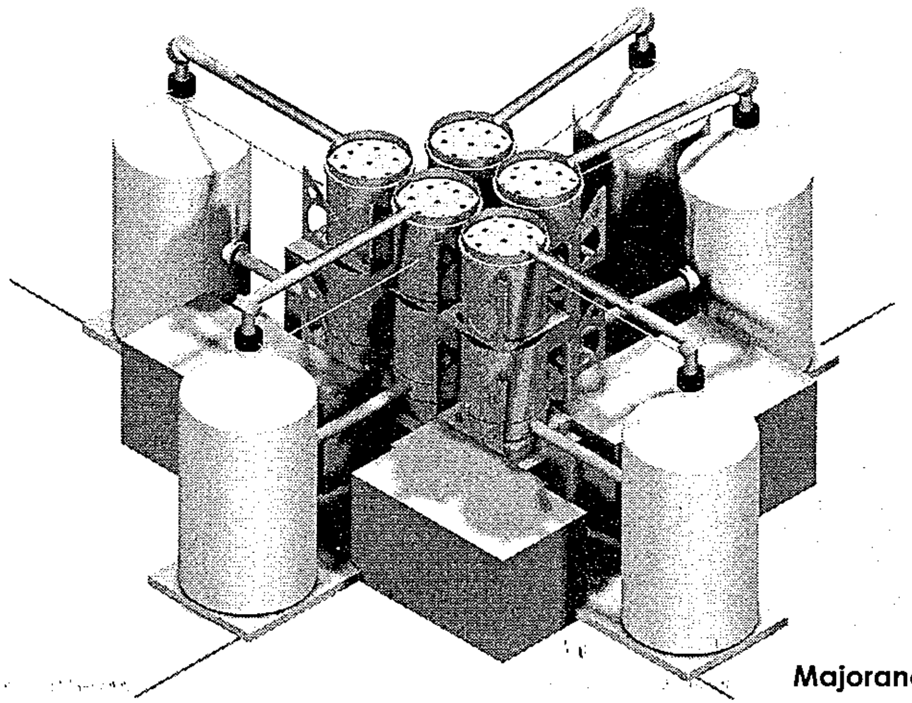
- Collaborators
  - PNNL
  - U of South Carolina
  - TUNL
  - ITEP
  - Dubna
  - NMSU
  - U of Washington
- Industrial Partners
  - ORTEC
  - Canberra
  - XIA
  - MOXTEK
  - ECP

See http://majorana.pnl.gov for latest project info

Ready to begin now

Majorana Highlights





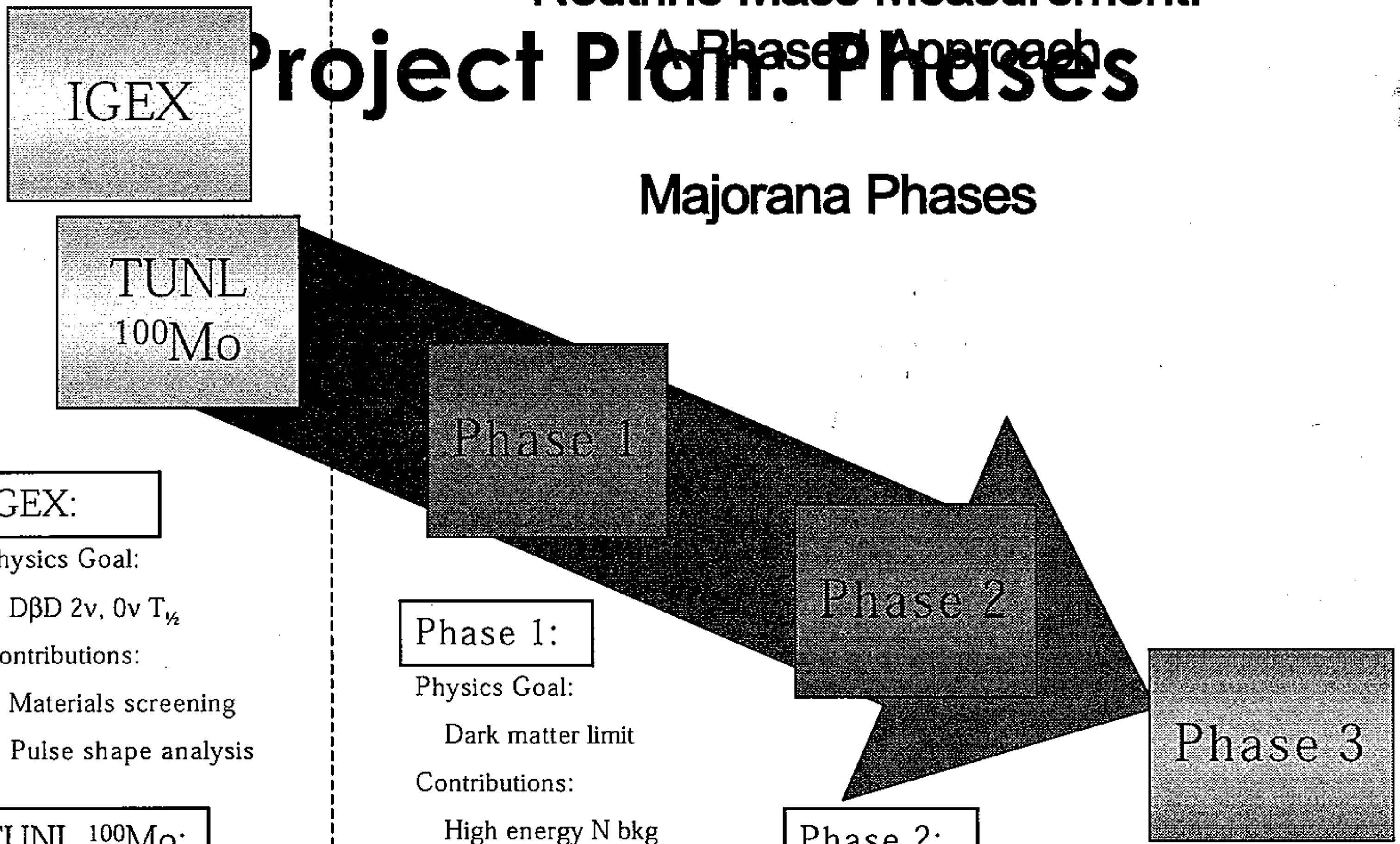
- Neutrinoless double-beta decay of ^{76}Ge potentially measured at 2038.6 keV
- Rate of 0ν mode determines "Majorana" mass of ν_e
- $< m_{\overline{\nu}_e} >$ as low as 0.02-0.07 eV
- Requires:
  - Deep underground location
  - ~$20M enriched 85% ^{76}Ge
  - 210 2kg crystals, 12 segments
  - Advanced signal processing
  - ~$20M Instrumentation
  - Special materials (low bkg)
  - 10 year operation

Project Plan: Phases

Neutrino Mass Measurement: A Phased Approach

Majorana Phases

Past | Future



IGEX:

Physics Goal:

- DβD 2ν, 0ν $T_{1/2}$

Contributions:

- Materials screening
- Pulse shape analysis

TUNL ^{100}Mo:

Physics Goal:

- Excited state DβD $T_{1/2}$

Contributions:

- Coincidence method
- Background suppression

Phase 1:

Physics Goal:

- Dark matter limit

Contributions:

- High energy N bkg
- Pulse analysis test
- Materials screening

Phase 2:

Physics Goal:

- Excited state DβD $T_{1/2}$

Contributions:

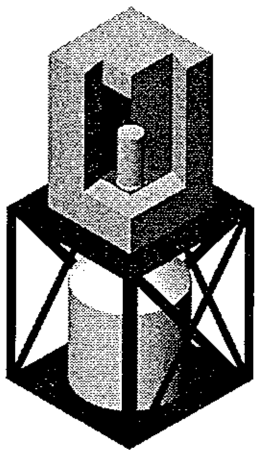
- Segmentation test
- Materials test
- Design test
- Geometry test

Phase 3:

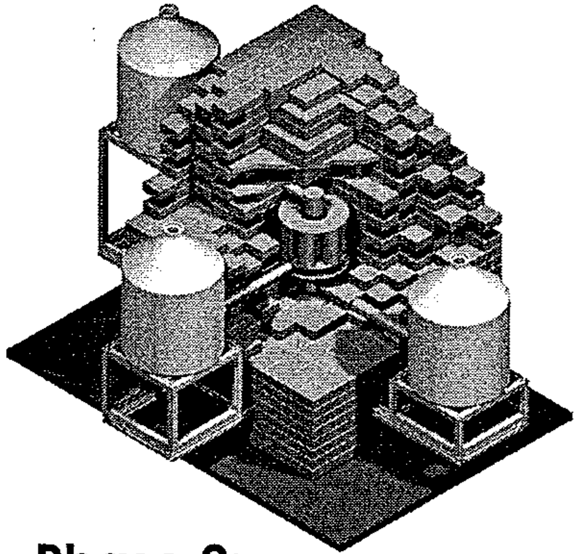
Physics Goal:

- *Measure neutrino mass*
- Majorana vs. Dirac Character
- High dark matter sensitivity

Phased Approach:
Baseline Conceptual Approaches

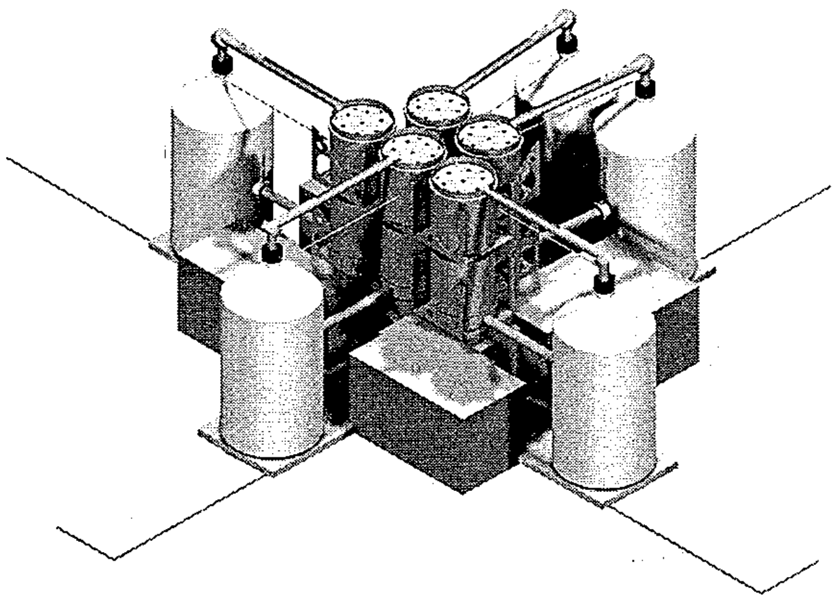


Phase 1:
1 Ge crystal



Phase 2:
14-18 Ge crystals

Phase 3: Majorana
210 Ge detectors
All enriched/segmented
Ten 21-crystal modules



Addressing the Backgrounds

- Materials
  - Radiological screening
  - New materials (clean chem processes)
- Cosmic
  - Depth
  - Shield design
- Cosmogenics in Ge (^{60}Co, ^{68}Ge)
  - Pulse Shape Discrimination (PSD)
  - 6 x 2 crystal segmentation
  - Self shielding

Depth: Direct Cosmic

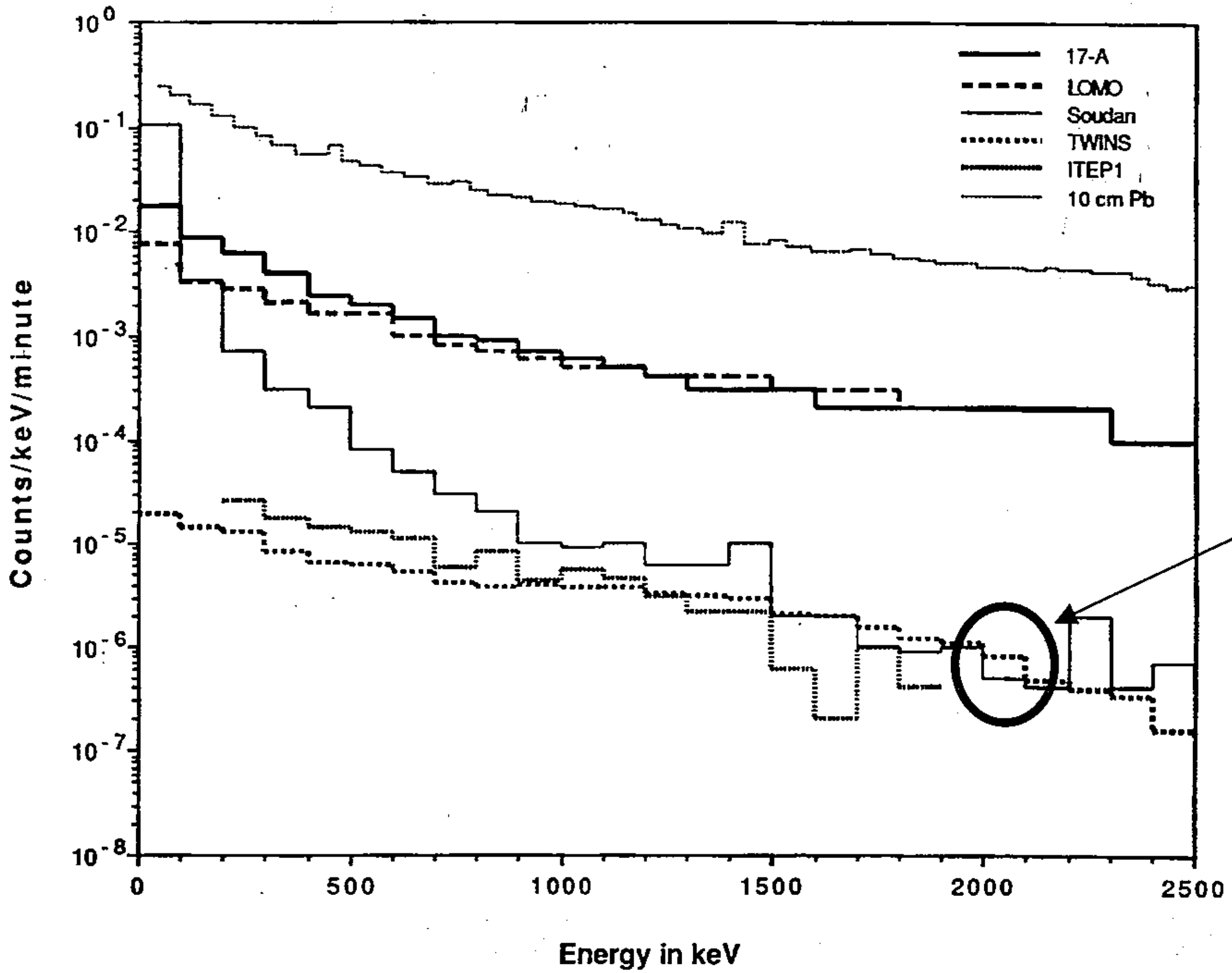


Figure 6. Background rates of all detectors compared. A typical aboveground detector with a 10-cm thick Pb shield is included for reference.

10 cm Pb = rebuilt surface
17-A = surface 4-π shield
LOMO = ~100 mwe dam
Soudan = 2000 mwe
TWINS, ITEP1 = 4000 mwe

At IGEX background level (0.2 cts/keV/kg/y), cosmogenic activity in the germanium dominates direct cosmic

Cosmogenic Composition

Early IGEX Data (Computed)

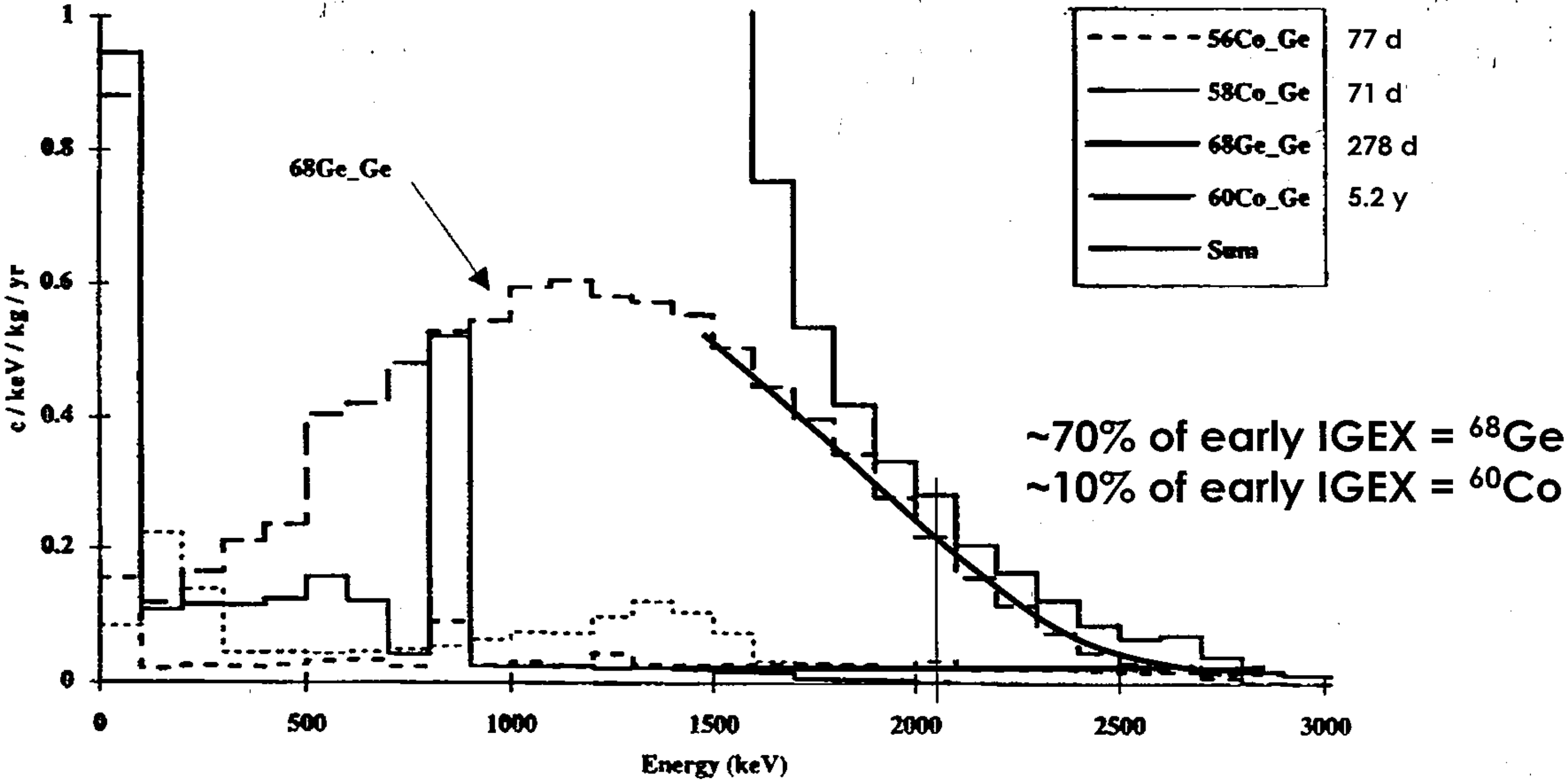
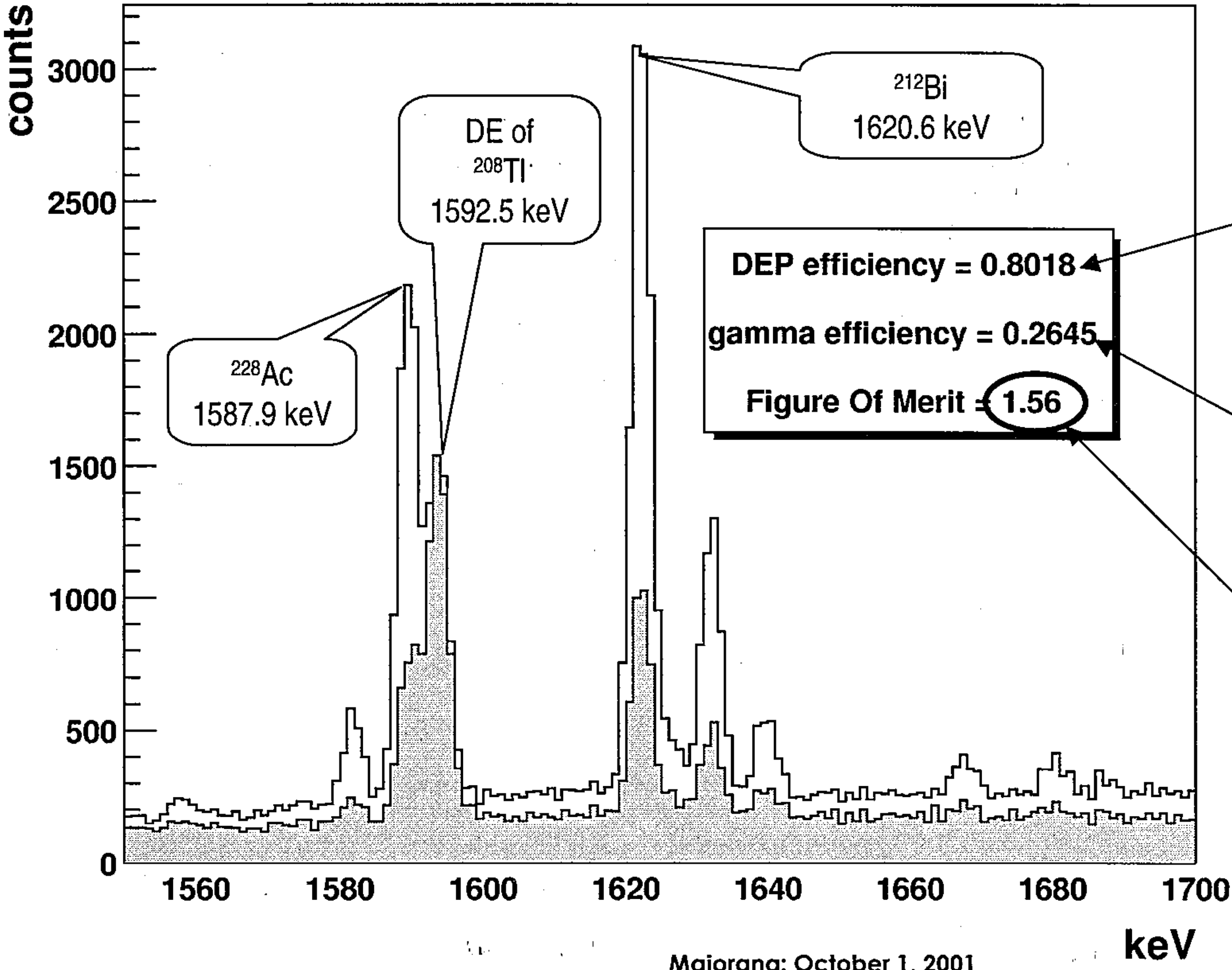


Fig. 3 Calculated absolute response functions for those isotopes from Figure 2 which make contributions to the spectrum above 2 MeV. The vertical scale is expanded by a factor of 10

Pulse-Shape Discrimination and Segmentation for 0ν ββ-Decay

- Major cosmogenic backgrounds (^{60}Co, ^{68}Ge) require multiple depositions to reach ~2 MeV
- 0ν ββ-decay is essentially a single-site process
- Pulse-Shape Discrimination (PSD) radial
  - Single-site depositions create current pulses populating a small area of a well-chosen parameter space.
  - Multiple-site depositions are linear combinations of single-site current pulse-shapes and populate a larger area of this experimentally verified parameter space.
- Segmentation axial and azimuthal
  - Single-site depositions are nearly always contained in a single detector segment.
  - Multiple-site depositions usually leave energy in more than one segment, with a probability depending on segment geometry.

Experimental PSD Result



Keeps 80% of the single-site DEP (double escape peak)

Loses 74% of the multi-site backgrounds

FOM applies directly to $T_{1/2}$

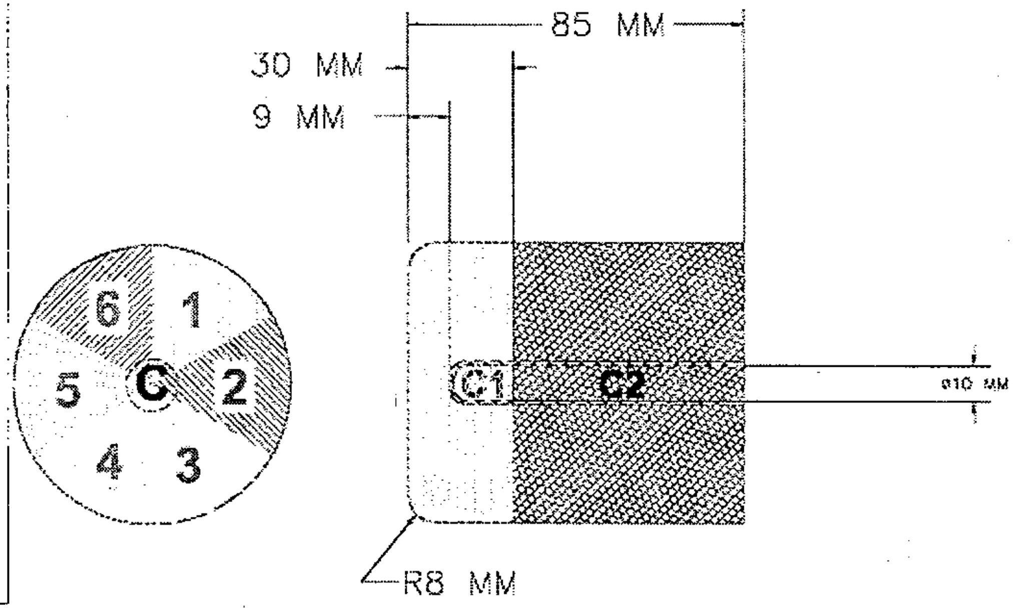
Majorana: October 1, 2001

Detector Segmentation

- Sensitive to axial and azimuthal separation of depositions
- Perkin-Elmer design with six azimuthal and two axial contacts has low risk
- Projected efficacy of this design is excellent with expected backgrounds

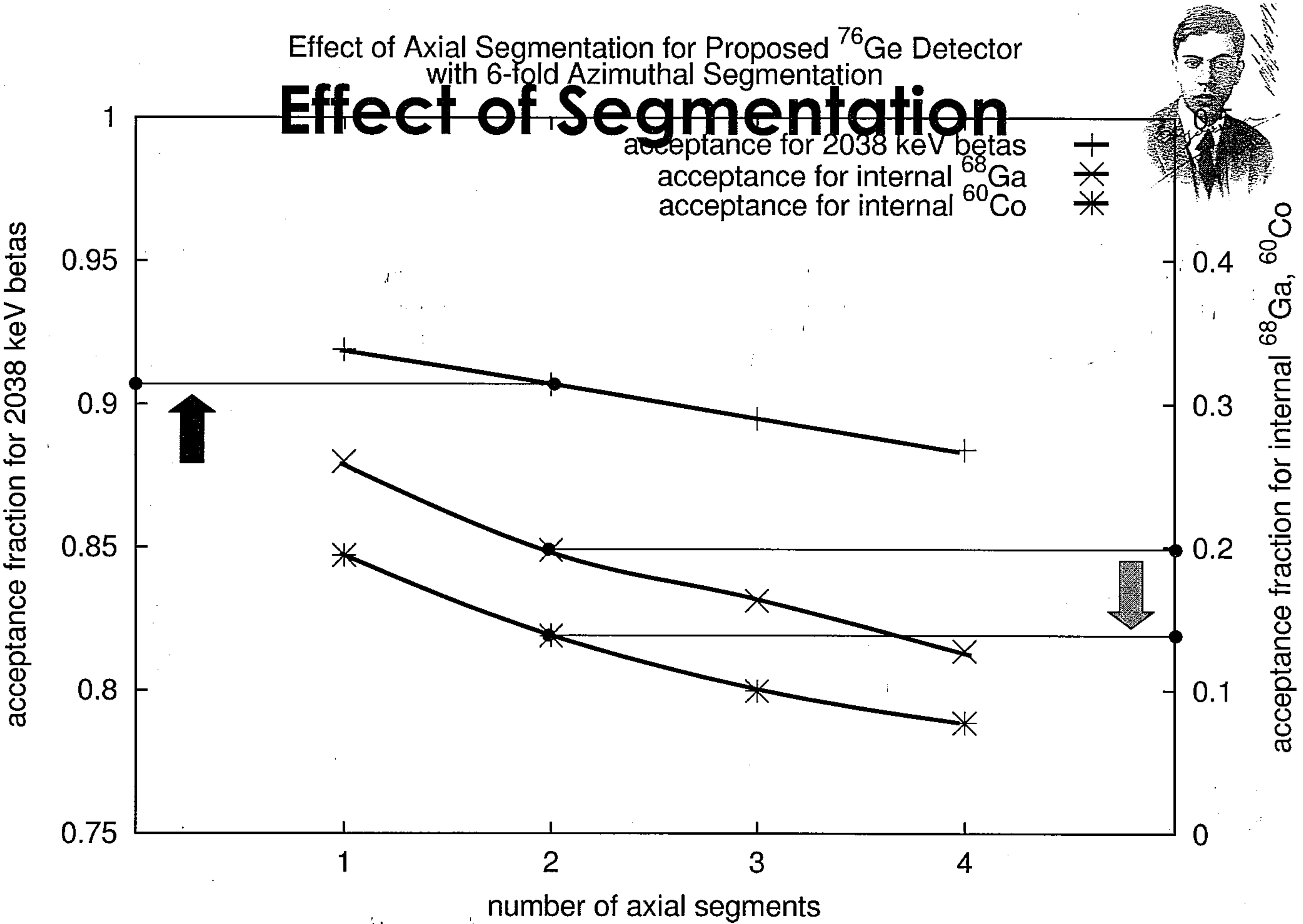
PT6X2

12-SEGMENTS
SEGMENTED DETECTOR
(6-EXTERNAL X 2-INTERNAL)



6 SIDE CHANNELS
2 CENTER CHANNELS
TOTAL = 8 PREAMPLIFIERS

Effect of Segmentation



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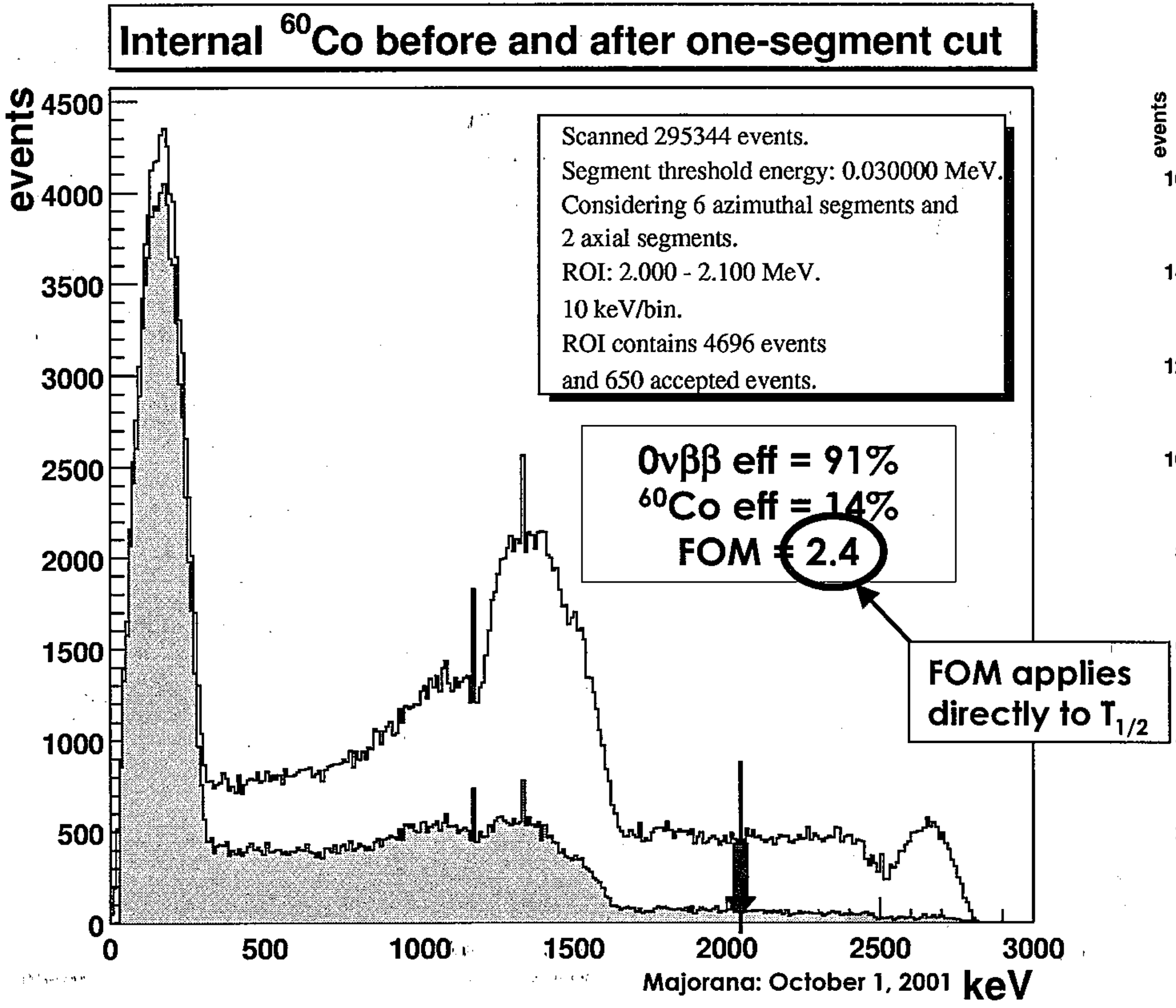
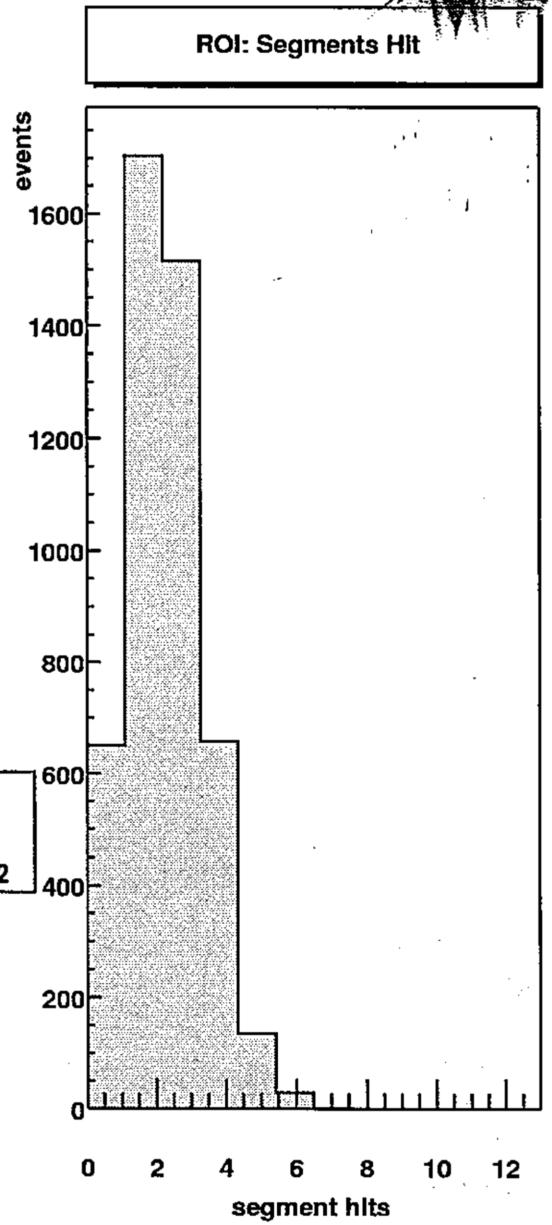
A Monte-Carlo Example





Projected Sensitivity

Ground State

GIVEN:

- Background at 2038 keV = 0.2 cts/keV/kg/y
  - ^{68}Ge decay *10x reduction*
  - ^{60}Co decay/self shielding/less copper mass *2x reduction*
- 500 kg 86% ^{76}Ge x 10 years
- PSD+Segmentation FOM = 1.6 x 2.4 = 3.8

RESULT:

- $T^{0\nu} = 4.0 \times 10^{27}$ y
- $\langle m_\nu \rangle = \{ 0.020 - 0.068 \}$ eV

What is background was 'zero'? (4.8 counts less)

- $T^{0\nu} = 2.0 \times 10^{28}$ y
- $\langle m_\nu \rangle = \{ 0.009 - 0.031 \}$ eV

Matrix Elements

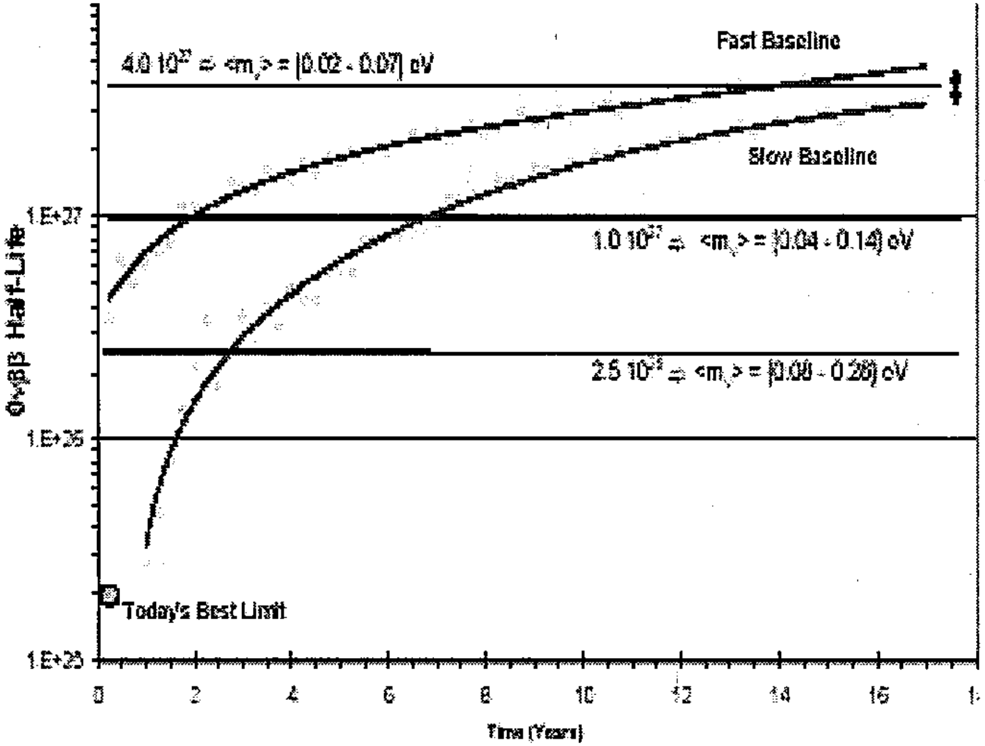
$$\langle m_\nu \rangle = m_e \frac{1}{\sqrt{T^{0\nu}_{1/2} F_N}}$$

F_N (yr^{-1})	Model	$\langle m_\nu \rangle$ eV*	Reference
1.56×10^{-13}	Weak coupling shell model	0.020	[Hax84,Hax93]
9.67×10^{-15}	QRPA	0.082	[Vog86,Eng88, Moe94]
1.21×10^{-13}	QRPA	0.023	[Civ87,Tom91]
1.12×10^{-13}	QRPA	0.024	[Mut88,Sta90]
1.41×10^{-14}	Shell model	0.068	[Cau96,Rad96]

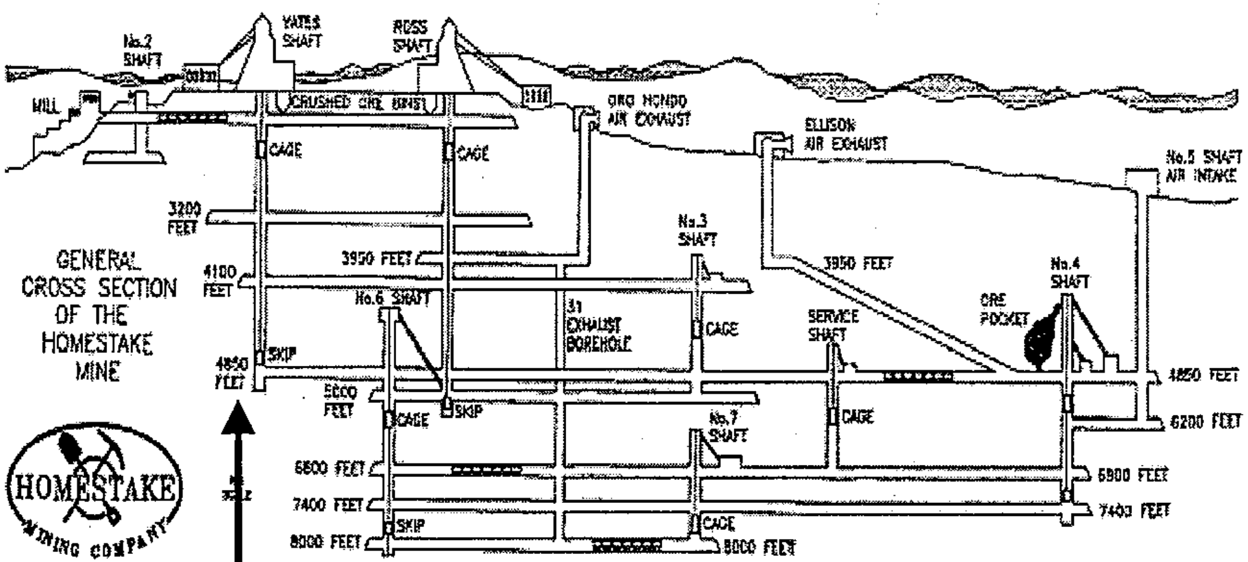
* Assumes $T^{0\nu}_{1/2} = 4 \times 10^{27}$ years

Sensitivity

- Gradual ramp to 100 kg/y - total 500 kg 85% ^{76}Ge
- Fast Baseline: (No ramp) 200 kg/y
- Present $0\nu\beta\beta$ ^{76}Ge $T_{1/2}$ limit rapidly surpassed ($T_{1/2} > 1.9\ 10^{25}$ y)

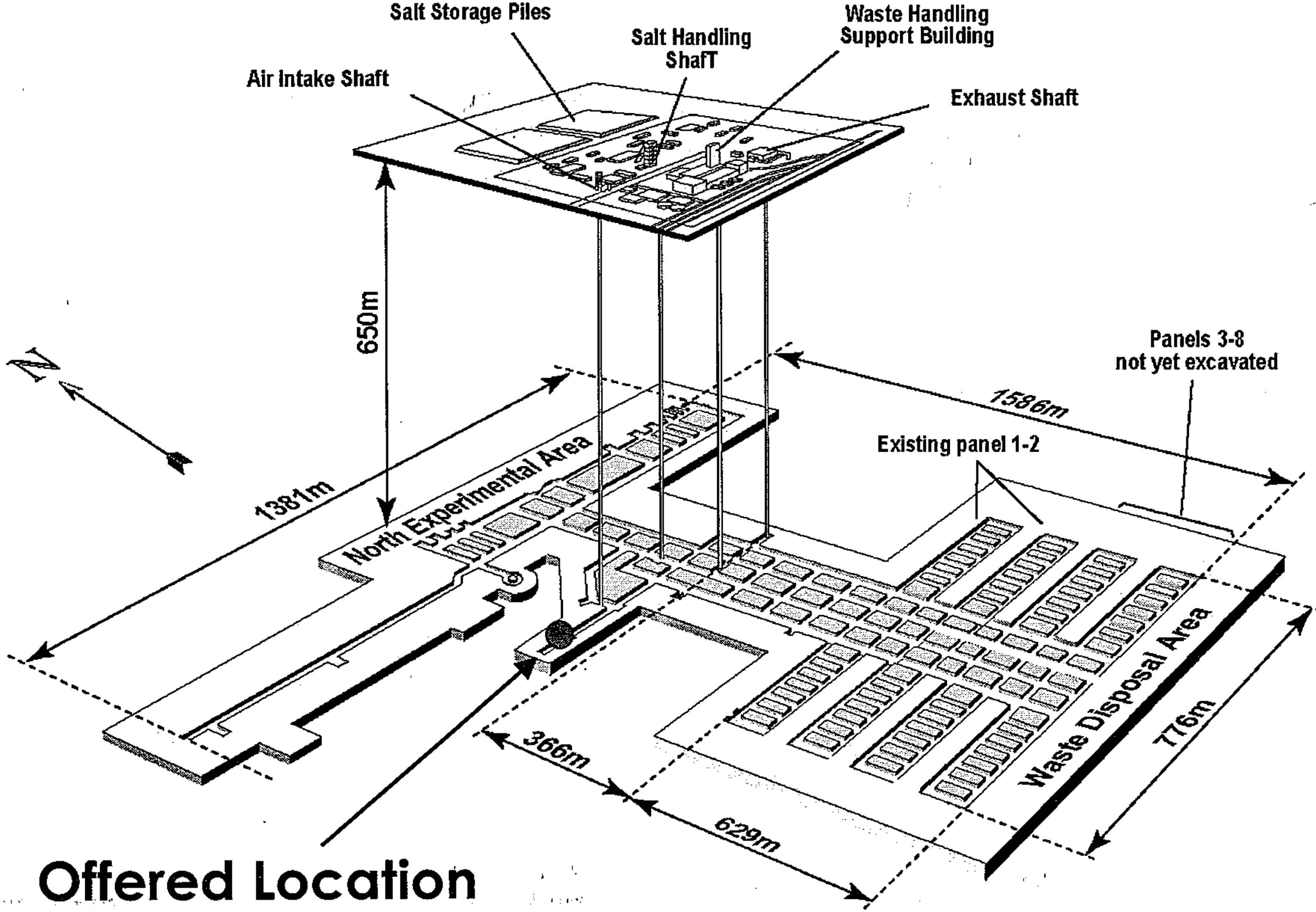


Homestake Layout

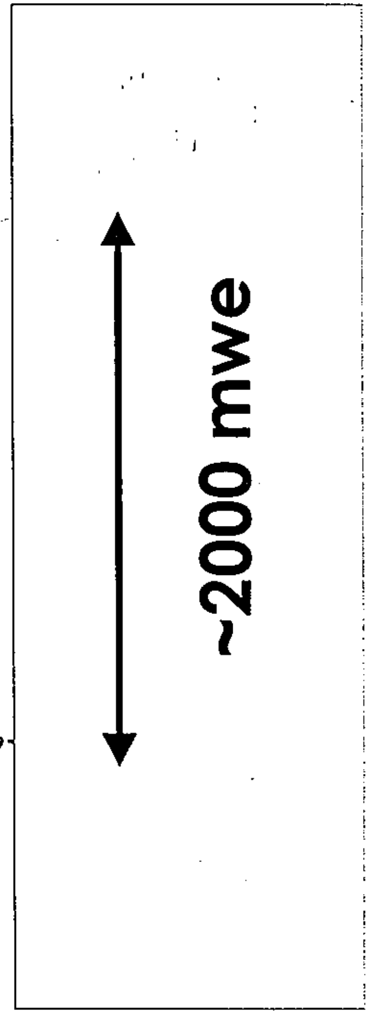


Location of previous experiments

WIPP Layout



Salt Storage Piles
Salt Handling ShafT
Waste Handling Support Building
Air Intake Shaft
Exhaust Shaft
650m
1586m
Panels 3-8 not yet excavated
Existing panel 1-2
North Experimental Area
1381m
Waste Disposal Area
776m
366m
629m
Offered Location



~2000 mwe

Conclusions

- **Unprecedented confluence:**
  - *Krasnoyarsk availability/Neutrino mass interest/ Underground development/crystal capacity*
- **High Density:**
  - *reduced shielding and footprint*
- **Low Risk:**
  - *proven technology/ modular instrument / relocatable*
- **Experienced Collaboration**
  - *long DβD track record*
- **Neutrino mass sensitivity:**
  - *potential for discovery*

Collaboration

- **Majorana-MOON**

- **Thank you for attention**

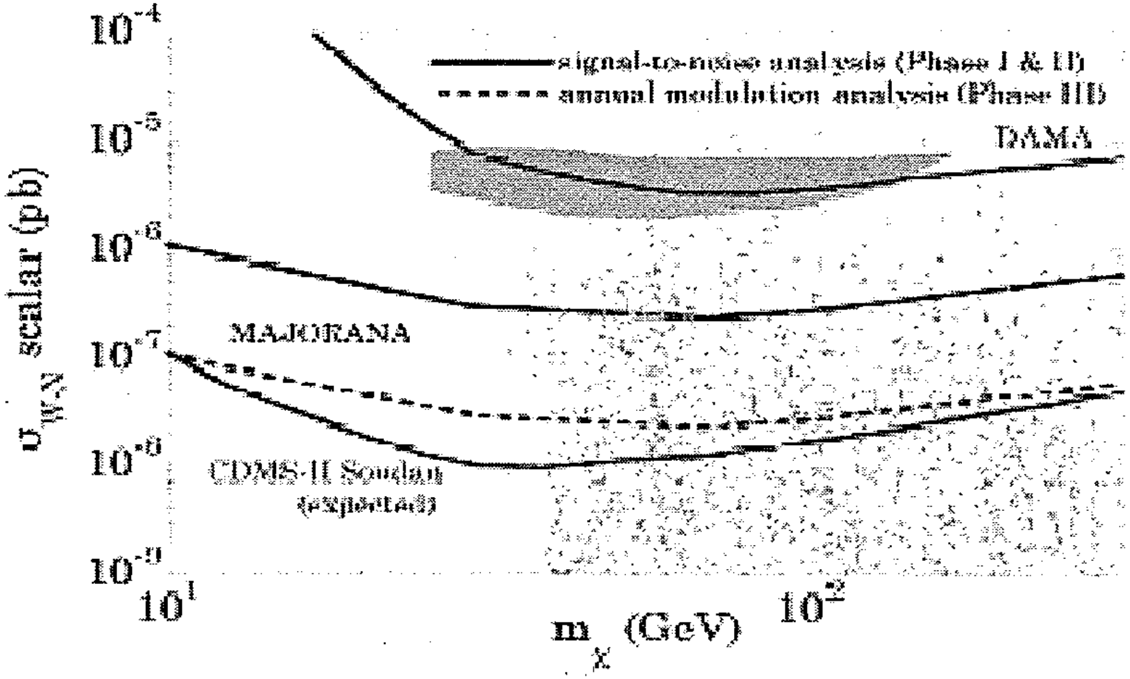
Majorana Overview

- $0\nu\beta\beta$ decay of ^{76}Ge potentially measured at 2039 keV
- Sensitive to effective Majorana ν mass as low as 0.02-0.07 eV
- Based on well known ^{76}Ge detector technology plus:
  - Pulse shape analysis
  - Detector segmentation
  - *Ready to begin now*
- Requires:
  - Deep underground location
  - 500 kg enriched 85% ^{76}Ge
  - 210 segmented crystals
  - Advanced signal processing
  - Special materials (low bkg)

Dark Matter

Majorana dark matter sensitivity similar to and complementary with CDMS-II

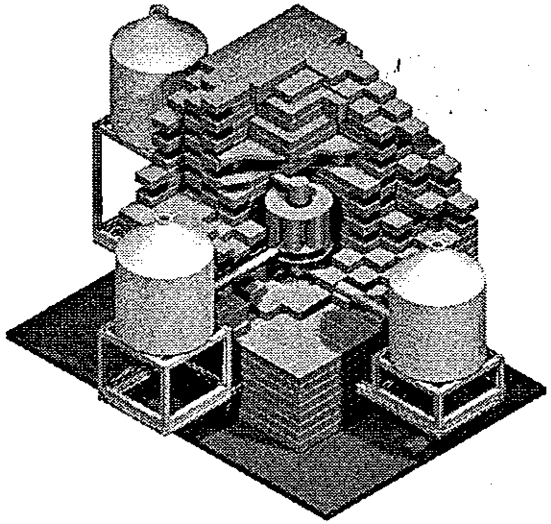
- Projected 95% C.L. Majorana for an assumed low-energy background of 0.005 counts/keV/kg/day, one order of magnitude lower than in present detectors
- Assumes ionization threshold of 1 keV, Phase 1 and 2 limits are < 1 kg-y
- Phase 3 limits are calculated for the total exposure of 5000 kg-y
- Dots represent plausible supersymmetric neutralino WIMP candidates

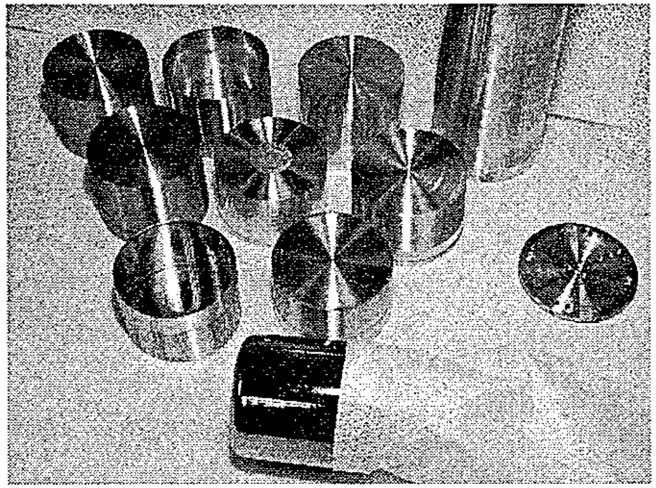


Phase 1 and 2 Requirements

- Apparatus:
  - 4 x 4 m footprint
  - Cleanable walls
  - Airlock + HEPA air
  - Temperature: ~20C, < ±1C/day
- Counting House:
  - 3 x 3 m footprint
  - 1 Rack + Control Station
  - Temperature: ~20C, < ±1C/day
  - Power: TBD (<10kW)
    - Conditioned
    - Some UPS
- Storage/Staging:
  - 2 x 3 m

Phase 2 Instrument Gallery





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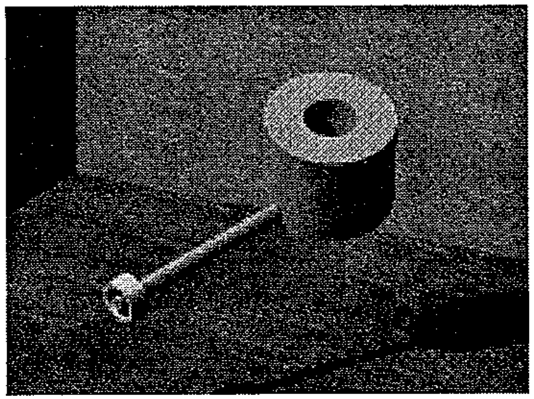
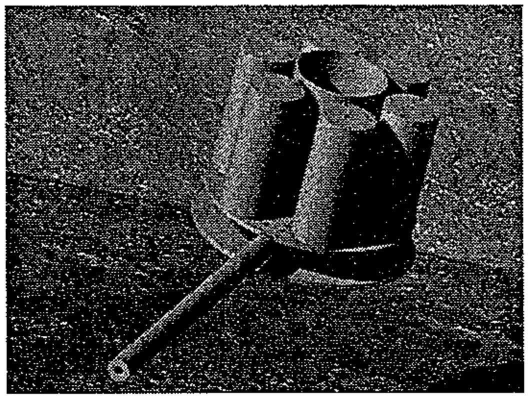
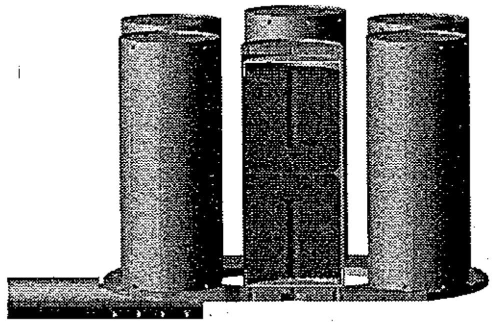






New design: 12-16 crystals

Phase 3 Infrastructure: Electroforming

- Electrochemical
  - 4 x 8 m footprint
    - Plating baths
    - Material prep area
  - Cleanable surfaces
  - <15 kW
  - Airlock + HEPA air
  - Hood/Fume Extractor
  - Ultra clean water
  - Chemical storage
- Clean Machining
  - 4 x 8 m footprint
  - Cleanable surfaces
  - ~24 kW
  - Airlock + HEPA air
  - Pass-thru to E-chem
  - Lubricant storage

Phase 3 Requirements

- Apparatus
  - 5 x 4 m footprint
  - Cleanable surfaces
  - Airlock + controlled air
  - Temperature
    - Same as Phase 2
- Staging
  - 4 x 4 m footprint
- Counting House
  - 24 crates, 4 racks
  - Monitoring Station
  - 4 x 4 m footprint
  - Controlled temp for electronics
  - Broadband connectivity
  - Power: TBD (<20kW)
    - Conditioned
    - Some UPS capability

Phase 3 Infrastructure:
Detector Manufacturing

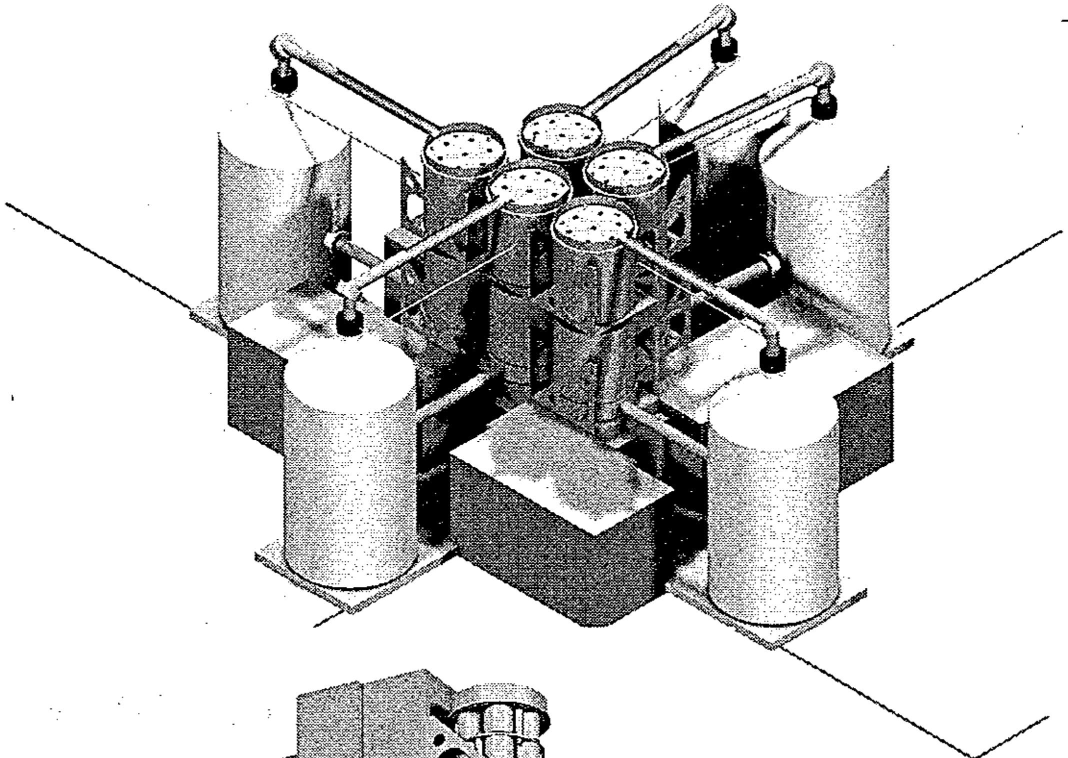
- Requires
  - Zone refining
  - Crystal growth
  - Crystal handing and preparation

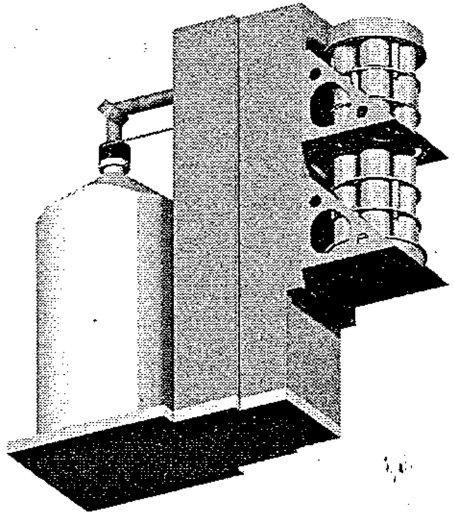
- Lots of power
- ~30x15 m footprint
- Chemical storage

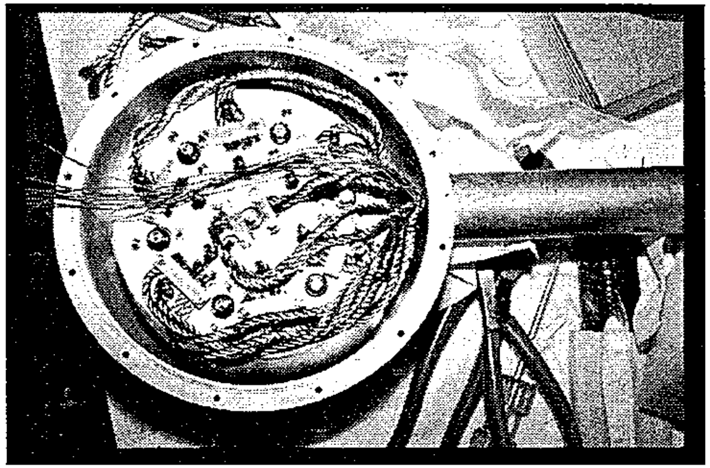
Controls on:

- Temperature
- Air Quality

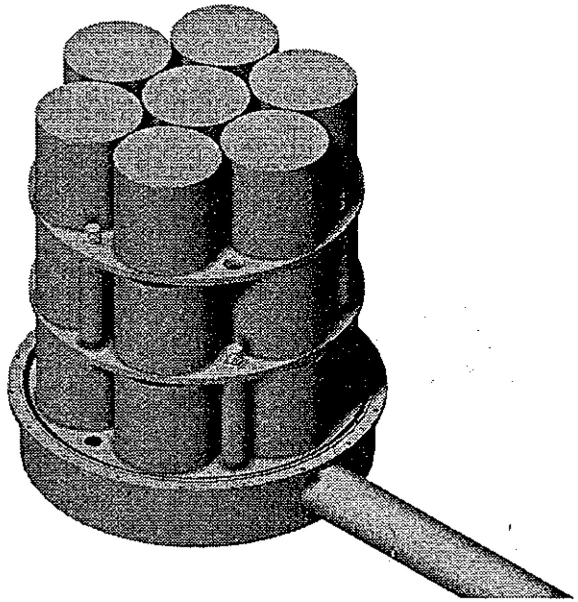
Phase 3 Instrument Gallery







PNNL 7-Crystal Prototype



Projected Sensitivity

Excited State

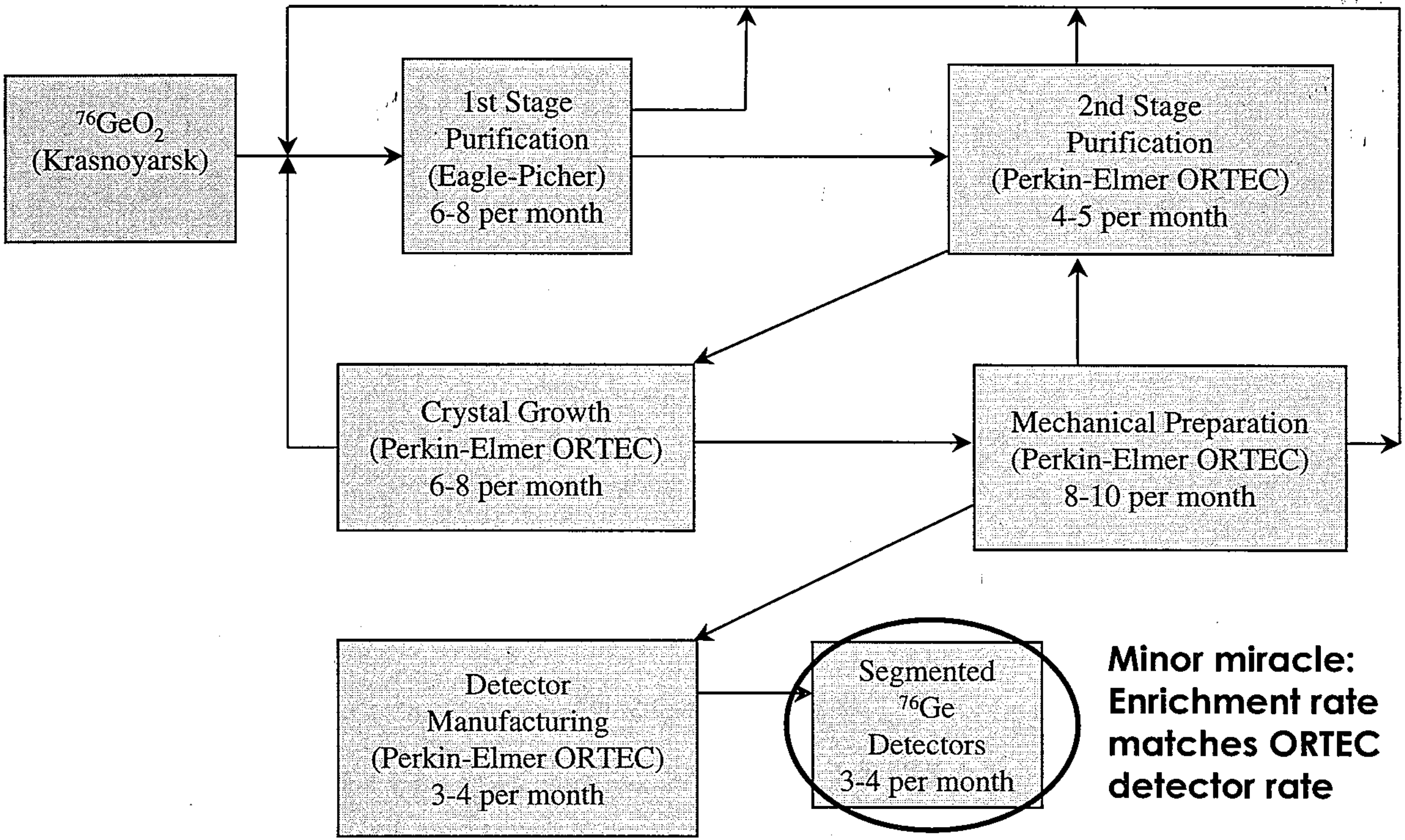
GIVEN:

- Background ~0 counts *coincidence*
- 500 kg 86% ^{76}Ge x 10 years

RESULT:

- $T^{0\nu} = 9.9 \times 10^{27}$ y
- $\langle m_\nu \rangle = \{ 0.049 - 0.162 \}$ eV

Production Capacity Adjustment For 3-4 Detectors Per Month



Minor miracle: Enrichment rate matches ORTEC detector rate

Materials

~1980 →

~1990 →

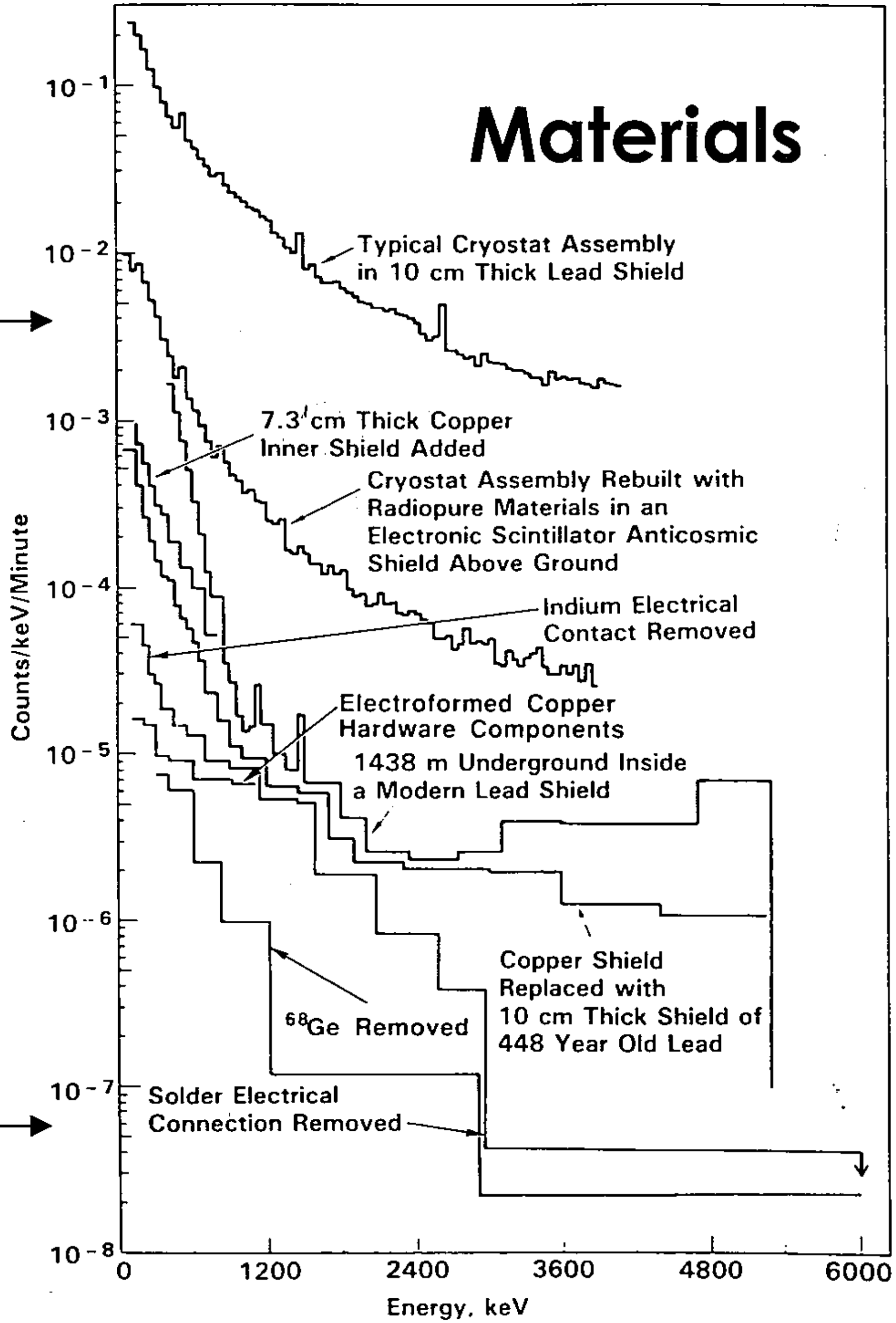


Fig. 1. Improvements in low-background technology.

~1995

Radiochemistry gains:

- H_2SO_4 Purity
- Recrystalized $CuSO_4$
- Barium scavenge

Results:

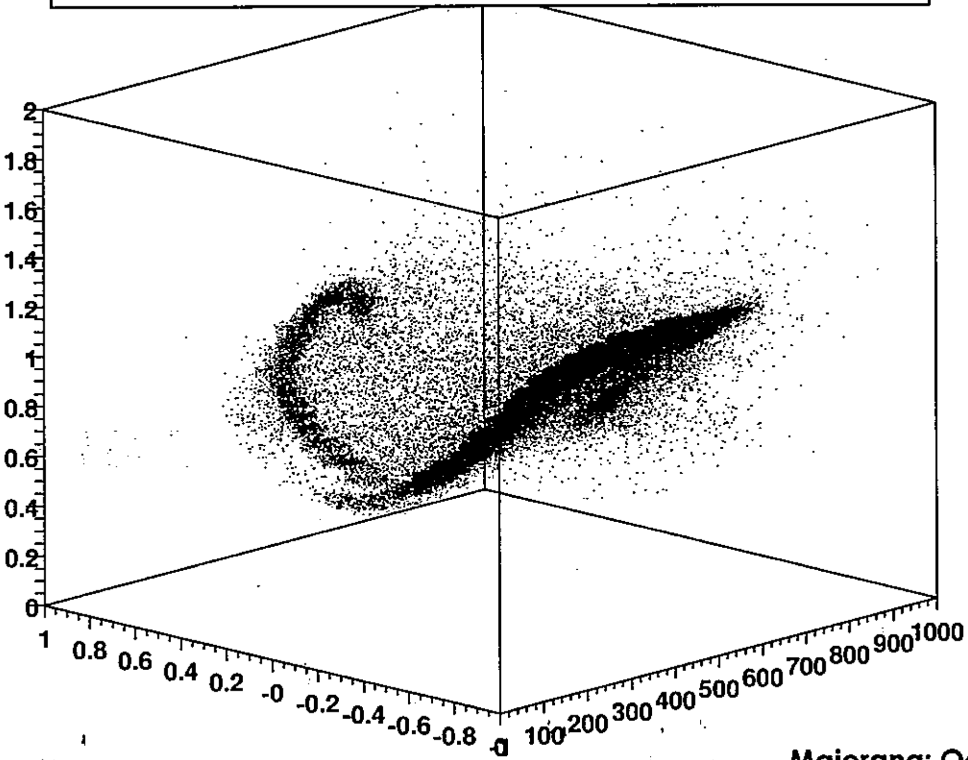
^{226}Ra	<25 μBq/kg (<1 part in 7E19)
^{228}Th	9 μBq/kg (1 part in 3E21)

(From Brodzinski et al, Journal of Radioanalytical and Nuclear Chemistry, 193 (1) 1995 pp. 61-70)

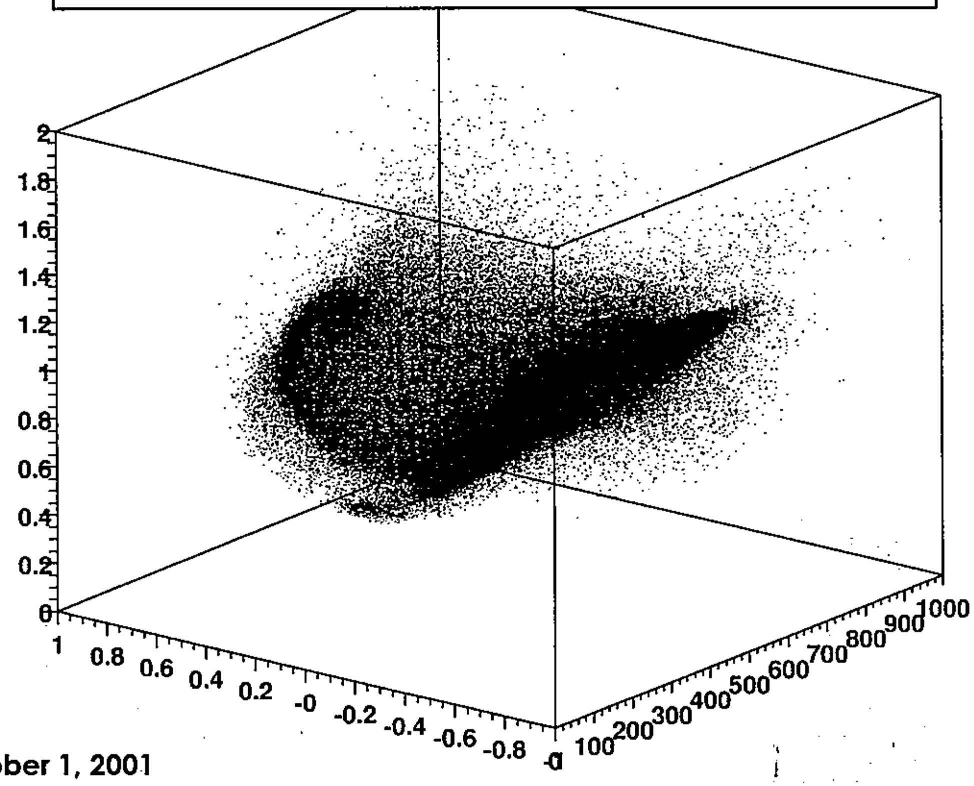
Parameter-Space Pulse Shape Discrimination

- Sensitive to radial separation of depositions
- Self-calibration allows optimal discrimination for each detector
- Discriminator can be recalibrated for changing electronic variables
- Method is computationally cheap, no computed pulse libraries needed

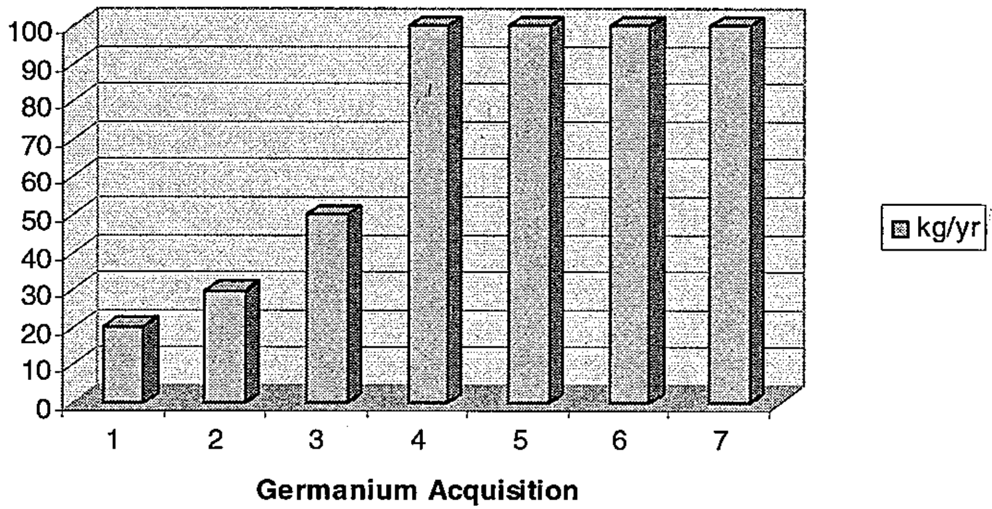
Single site distribution

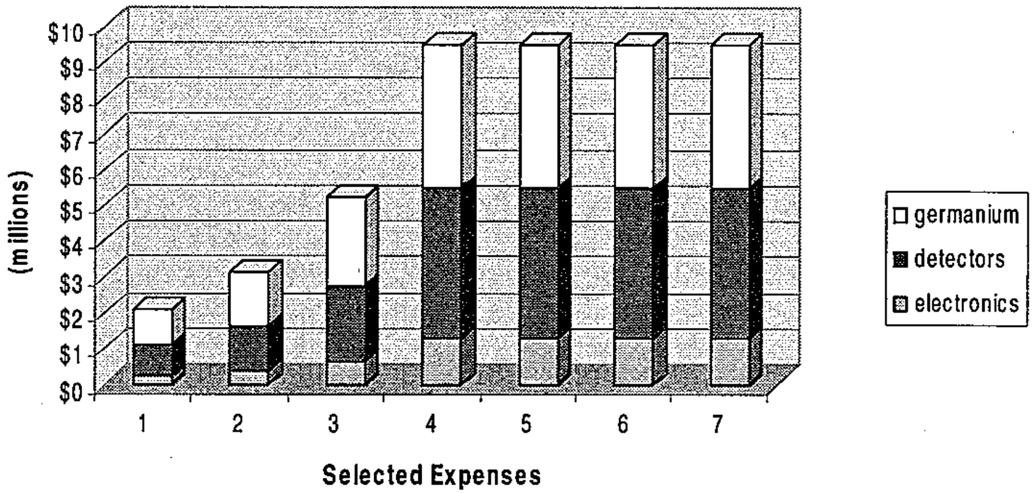


Multiple site distribution



Majorana Deployment

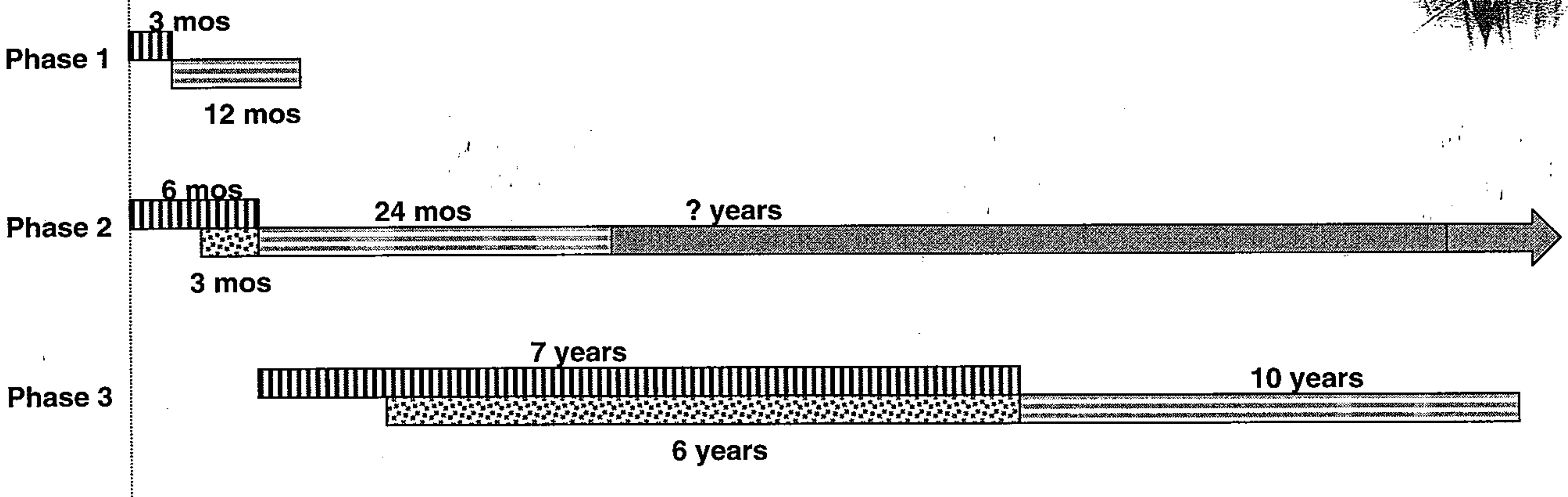




Estimates from:

- Krasnoyarsk Ge production
- Commercial Ge detector segmentation
- Commercial waveform digitizers

Anticipated Schedule



Legend:

- Build
- Test run: System partially built
- Main Run
- Repurposed use