The Majorana R&D Project

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and

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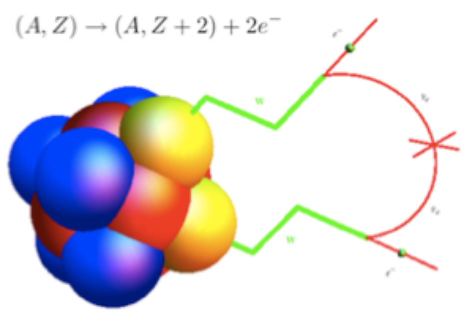
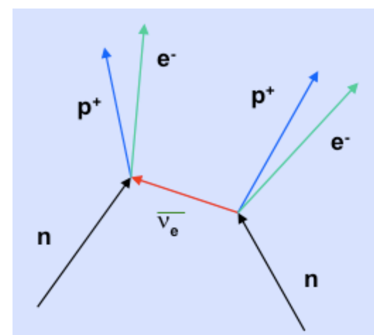
Neutrinos in Cosmology,in Astro, in Particle and in Nuclear Physics

ERICE, Trapani, Sicily, Italy

16-24 September 2009





I was 4 years old when Majorana started this ball rolling


Majorana

The idea of double-beta decay is almost as old as neutrinos themselves:

The possibility of neutrinos-less decay was first discussed in 1937:

E. Majorana, Nuovo Cimento 14 (1937) 171

G. Racah, Nuovo Cimento 14 (1937) 322

Even earlier the study of nuclear structure led to the conclusion that the 2 neutrino mode would have half lives in excess of 10^{20} years

M.Goeppert-Mayer, Phys. Rev. 48 (1935) 512

 From Giorgio Gratta

$0\nu\beta\beta$ Rate and Neutrino Mass

$$\left[T_{1/2}^{0\nu}\right]^{-1} = G^{0\nu}(E_0, Z)\left|\langle m_{\beta\beta}\rangle\right|^2 \left|M^{0\nu}\right|^2$$

$$\left|< m_{\beta\beta} >\right| = \left|\sum_i \left|U_{ei}\right|^2 m_{\nu_i} e^{i\alpha_i}\right|$$

- $0\nu\beta\beta$ decay probes the **absolute** neutrino mass scale and mixing.

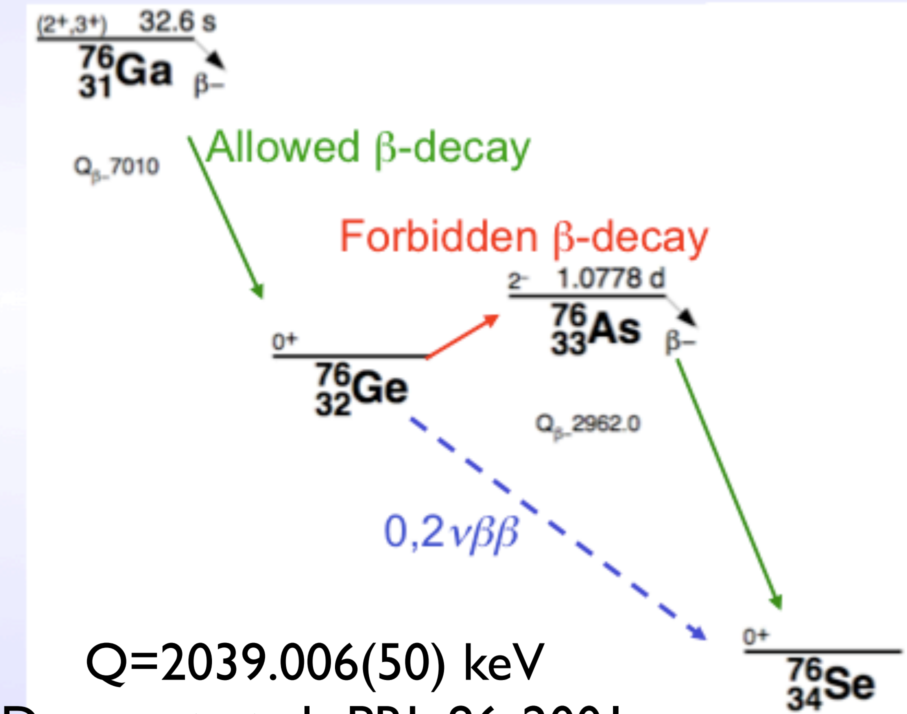
Taken from Reyco Henning, CIPANP 09, San Diego, CA

Neutrinoless double-beta decay of Ge-76 and Majorana

$$^{Z}A \Rightarrow {}^{Z+2}A + 2e^{-}$$

Violates Total Lepton Number Conservation

Existence implies Neutrino is a Majorana Particle



Q=2039.006(50) keV
Douysset et al., PRL 86, 2001

$2\upsilon\beta\beta$: Observed 2nd order weak process.

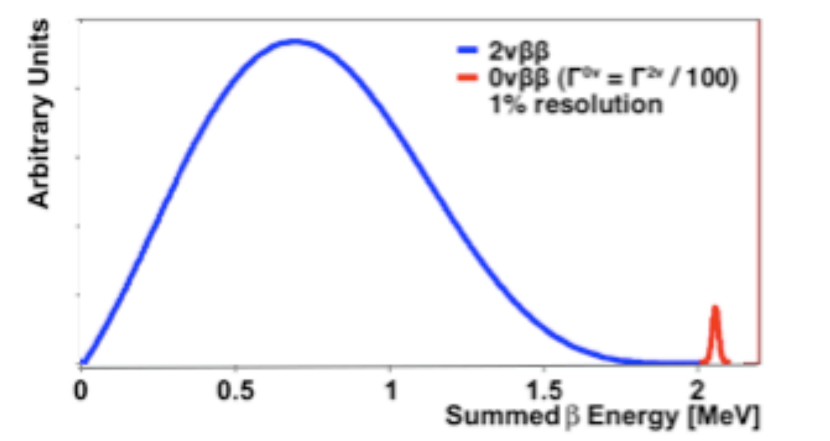
$$^{Z}A \Rightarrow {}^{Z+2}A + 2e^{-} + 2\overline{\nu}_{e}$$

Taken from Henning, CIPANP 09, San Diego, CA

Experimental Considerations

- Measure ***extremely*** small 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 after analysis cuts.



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

MAJORANA Collaboration Goals

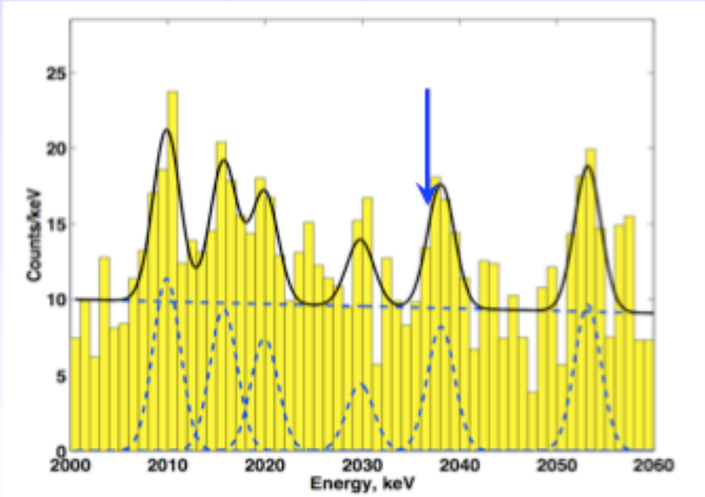
Actively pursuing the development of R&D aimed at a ~1 ton scale ^{76}Ge $0\nu\beta\beta$-decay experiment.

- Technical goal: Demonstrate background low enough to justify building a one-ton scale Ge experiment.
- Science goal: build a prototype module to test the recent claim of an observation of $0\nu\beta\beta$. This goal is a litmus test of any proposed technology.
- Work cooperatively with GERDA Collaboration to prepare for a single international ton-scale Ge experiment that combines the best technical features of MAJORANA and GERDA.
- Pursue longer term R&D to minimize costs and optimize the schedule for a 1-ton experiment.

We have been guided by advice from NuSAG, an independent external panel review (Mar. 06), and a DOE NP $0\nu\beta\beta$ pre-conceptual design review panel (Nov. 06). Endorsed by Nuclear Physics Long Range Plan.

The Recent Claim

Klapdor-Kleingrothaus H V, Krivosheina I V, Dietz A and Chkvorets O, *Phys. Lett.* B **586** 198 (2004).



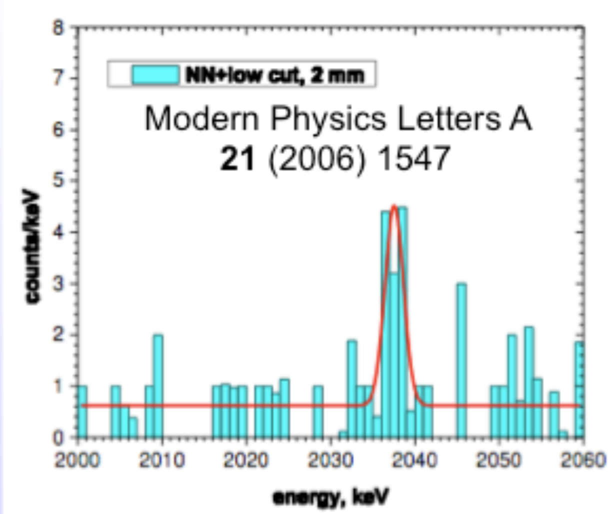
Five ^{76}Ge crystals, with a total of 10.96 kg of mass, and 71 kg-years of data.

$T_{1/2} = 1.2 \times 10^{25}$ y

$0.24 < m_\nu < 0.58$ eV (3 sigma)

A More Recent Claim

6.8 sigma. This claim can not be refuted except experimentally



Neural Net Analysis

Taken from Henning, CIPANP 09, San Diego, CA

BACKGROUND REDUCTION,HOW?

MATERIAL SELECTION

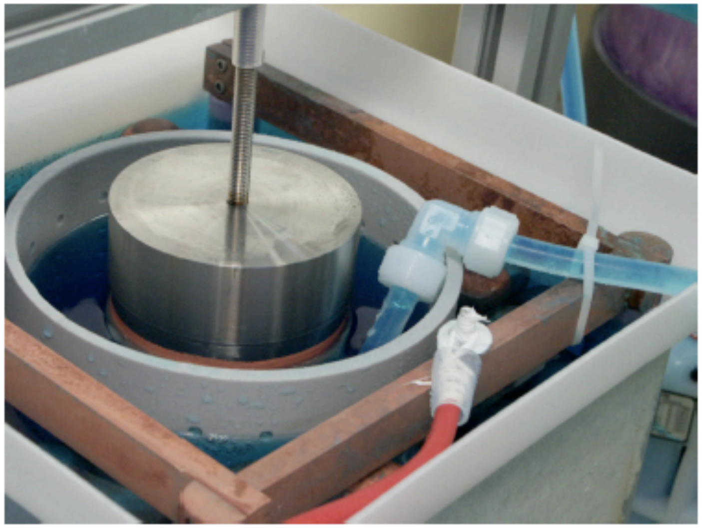
GRANULARITY

SEGMENTATION

(See Bela Majorovits talk)

PULSE SHAPE ANALYSIS

Underground electroforming at WIPP



Electroform a part underground

Electroformed Cu is extremely pure, very little Th/U. By electroforming UG, the cosmogenic isotope Co-60 should be eliminated also

1. Demonstrate that one can safely form a part underground in a highly regulated environment
2. WIPP follows a strict safety protocol directed by DOE and MSHA Presently in the sanford Lab
3. Low voltage system to plate Cu from xxx M acid solution onto SS mandrel

Test Part

Copper "Beaker" fabricated

660 gm

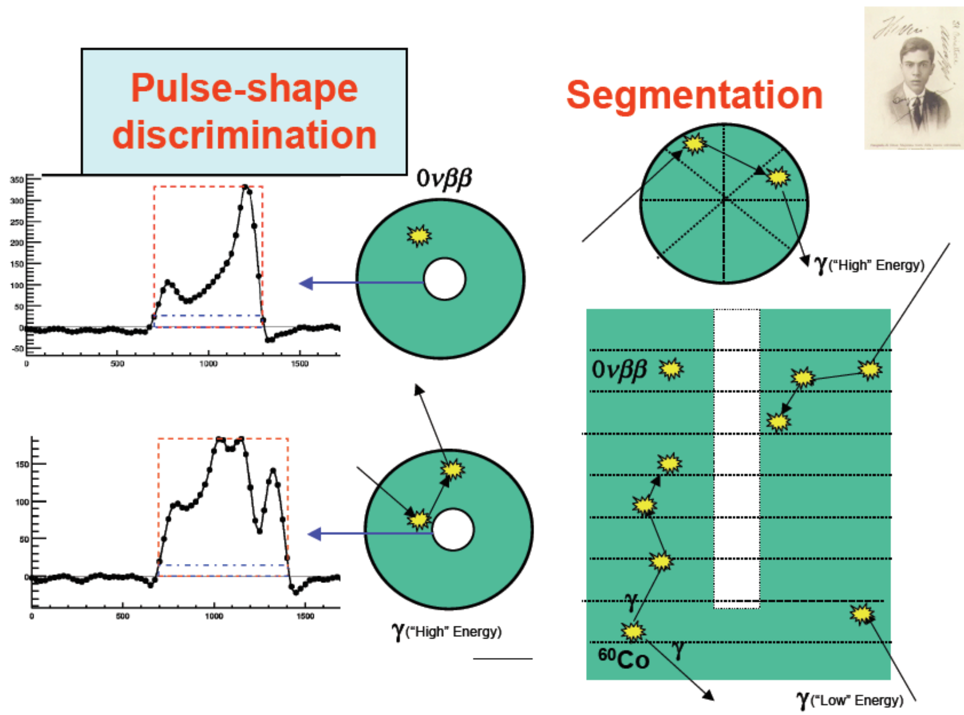
160 mm high, 110 mm diameter

Wall thickness ~1 mm

~10 days of UG electroforming in two stretches

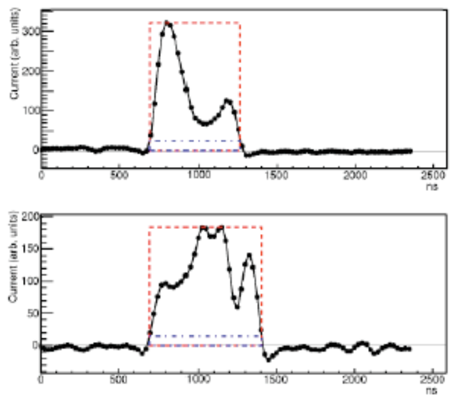
Solution is 1.5 kg copper sulfate dissolved in 16 L DI water

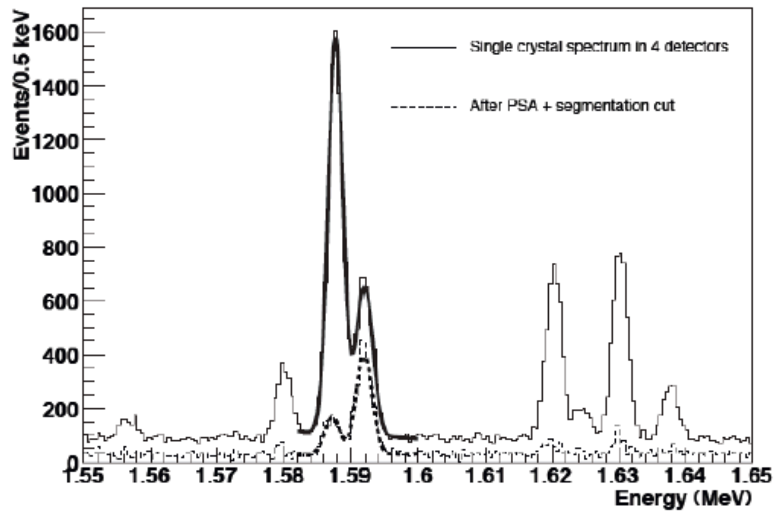
Part removed from mandrel by successive dunks in boiling water and liquid nitrogen



Pulse-shape discrimination
Segmentation
$0\nu\beta\beta$
γ ("High" Energy)
γ ("High" Energy)
$0\nu\beta\beta$
γ
^{60}Co
γ
γ ("Low" Energy)

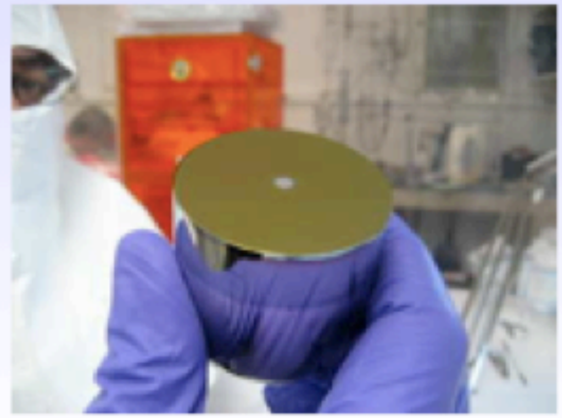
Pulse shape analysis





Very effective against internal activities and multiply scattered γ rays

Detectors for the MAJORANA DEMONSTRATOR



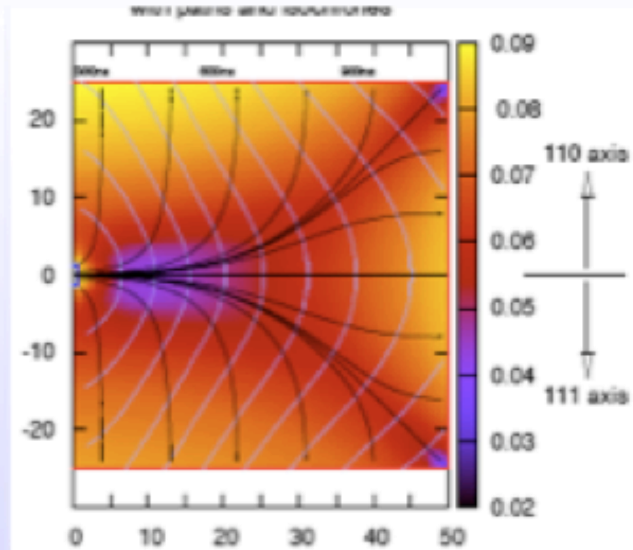
–Concentrate on P-PC Detectors.

- Advantages of cost and simplicity, with no loss of physics reach.

–Additional physics opportunities with low-energy P-PC detectors.

- Exploits low-energy thresholds (~100 eV threshold) of P-PC

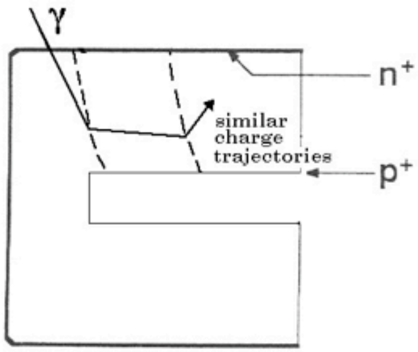
–Several Prototypes in hand. 18 Additional natGe detectors ordered (LANL).



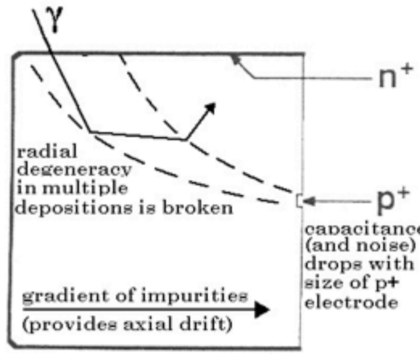
From Recvo Henning, CIPANP 09, San Diego, CA

P-type point contact (PPC) detectors

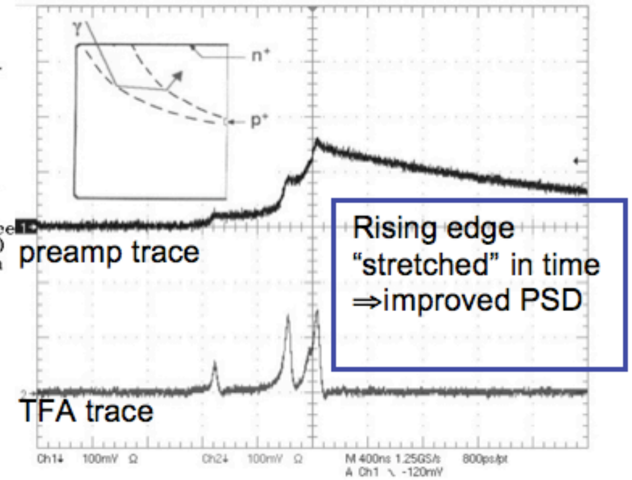
Barbeau et al., JCAP 09 (2007) 009; Luke et al., IEEE trans. Nucl. Sci. 36 , 926(1989)



standard coaxial HPGe

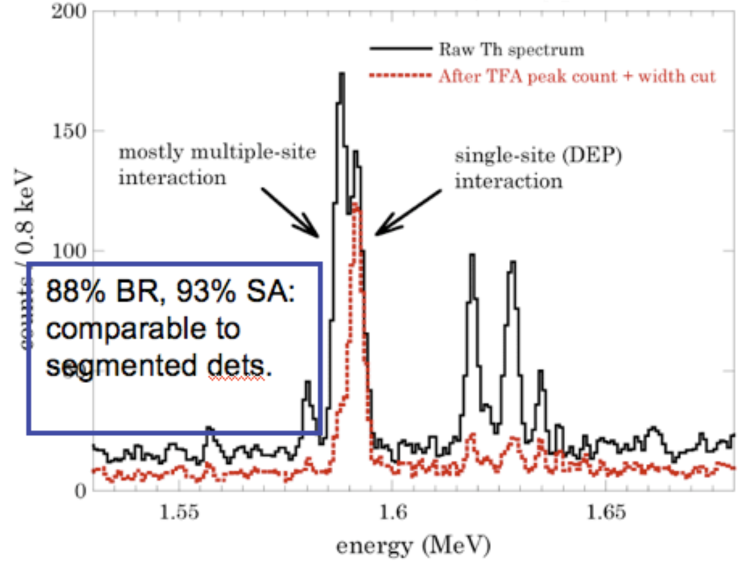


P-type modified electrode



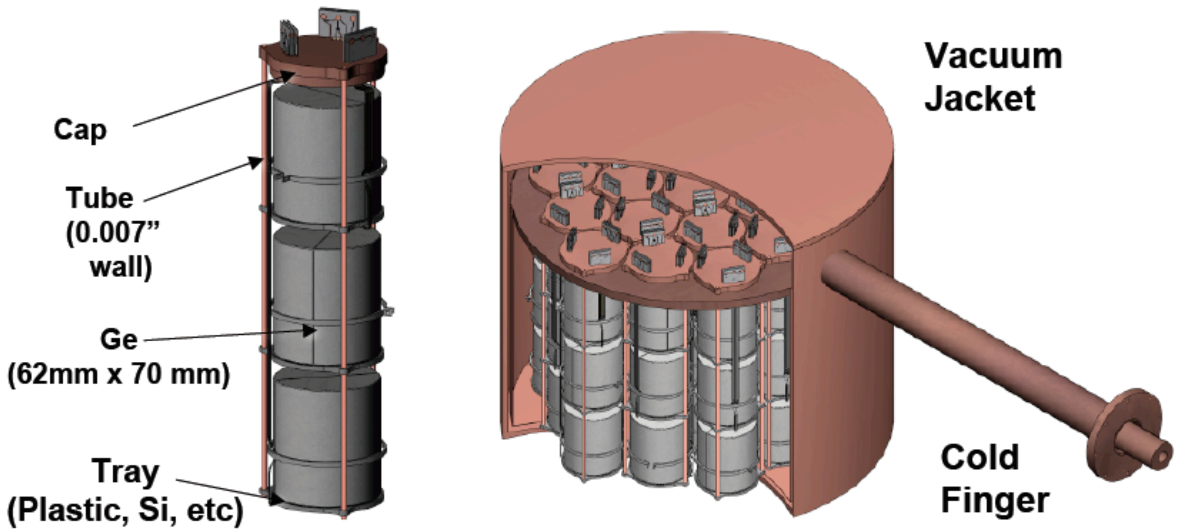
P-type point-contact detectors (PPC)

- P-type Ge detectors are easier to handle.
- Single-channel devices, reduce background, thermal load due to front-ends and cabling.
- Due to longer drift distance, pulse is "stretched". Excellent separation of multiple- & single-site interactions.
- Most surface area insensitive to alphas: configurations with facing passivated surfaces may lead to abatement of this background.
- Must demonstrate reproducibility and low-cost. Required impurity gradient understood via simulation.
- 1st prototype(UC):~450g, 1.8keV FWHM (^{60}Co), E_{thr}=330eV
- 6 more in progress (LANL, LLNL, PNNL, ORNL, UC). Lab., DOE and NSF funding. 3 vendors (Canberra, Ortec, PhDs)

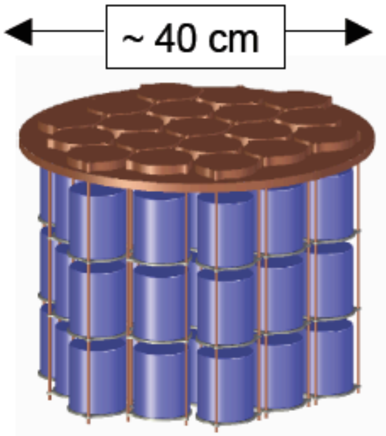


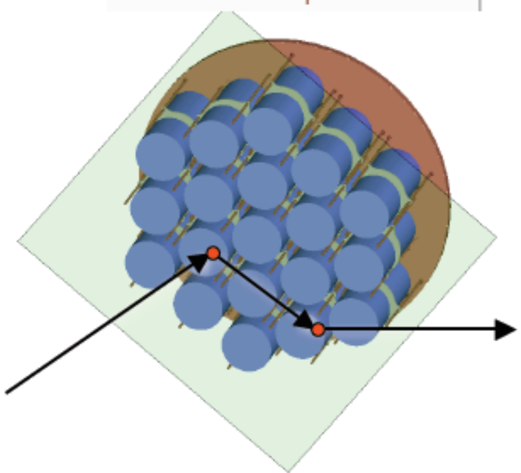
The Majorana Modular Approach

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



Granularity and segmentation



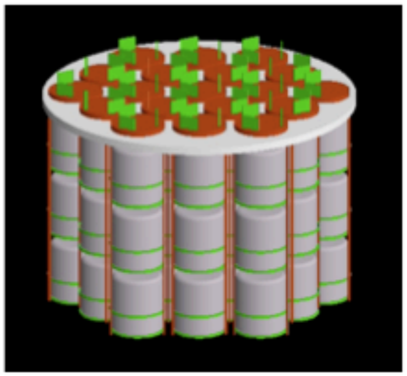


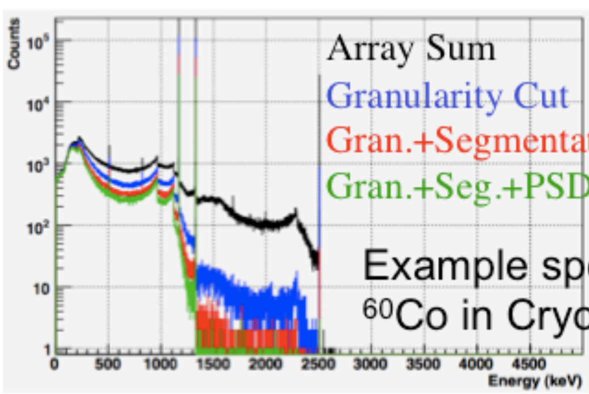
- Granularity cut: Simultaneous signals in two detectors cannot be 0nbb
- Requires tightly packed Ge
- Successful against:
  - ^{208}Tl and ^{214}Bi
    - Supports/small parts (~5x)
    - Cryostat/shield (~2x)
  - Some neutrons
  - Muons (~10x)
- Segmentation cut: similar idea but for segments of a single crystaldetector
- Simulation and validation with a number of segmented detectors

Granularity is intrinsic to the design and a powerful background suppressor.

MAJORANA Simulation

Simulated Geometry
Shields & Cryostat Removed





Array Sum
Granularity Cut
Gran.+Segmentation
Gran.+Seg.+PSD

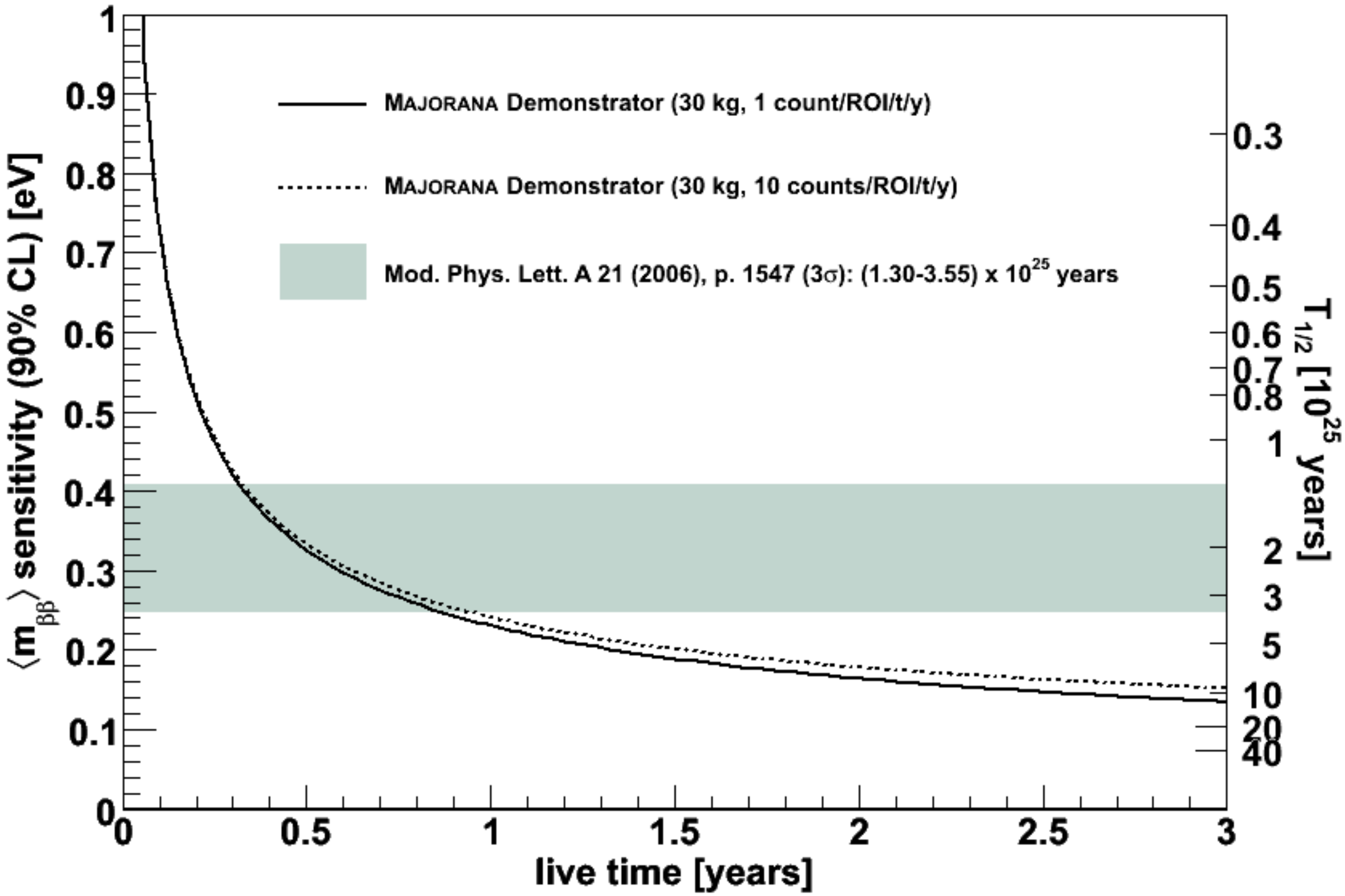
Example spectra:
^{60}Co in Cryostat

Simulation Includes:

- 57 Enriched crystal w/ deadlayers.
- LFEPs
- Support Rods
- Ge Trays
- Contact Rings
- Cryostat
- Surface Alphas
- Shields:
  - Inner, Outer Cu
  - Inner, Outer Pb
  - Neutron shield.
  - Room, rock wall.
- 45,000 CPU hours, 12,000 jobs.

NERSC
NATIONAL ENERGY RESEARCH SCIENTIFIC COMPUTING CENTER
Advancing Computational Science of Scale—Producing Real Results

HOW WELL WILL WE CONFRONT THE CLAIM?



GERMANIUM PURIFICATION AND ZONE REFINEMENT

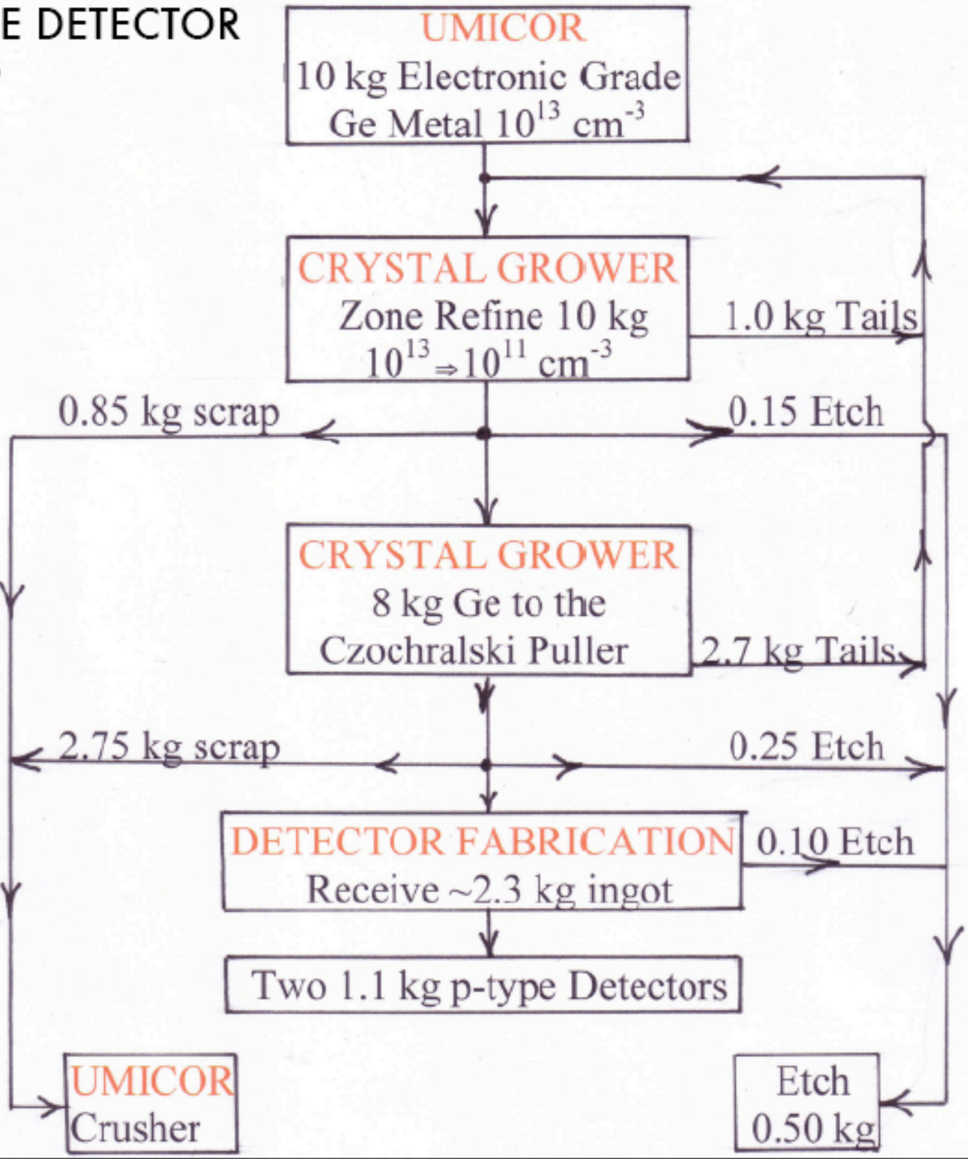
THE IGEX AND HEIDELBERG-MOSCOW EXPERIMENTS Ge WAS PURIFIED AND GIVEN THE FIRST ZONE-REFINEMENT BY EAGLE PICHER. THIS COMPANY WAS BOUGHT BY UMICORE, BELGIUM;THEY HAVE DECIDED NOT TO ACCEPT ANY CONTRACTS TO PURIFY ISOTOPICALLY ENRICHED Ge

SO WE MUST DO IT OURSELVES!!!

THE TASK:

1. PURCHASE Ge ENRICHED TO 86% IN Ge-76
2. BUILD AND OPERATE A FACILITY TO PURIFY AND ZONE REFINE THE Ge TO THE PURITY SPECIFICATIONS OF THE DETECTOR MANUFACTURERS.
3. DESIGN AND EXECUTE A QUALITY ASSURANCE PLAN TO INSURE SUCCESS.
4. DELIVER THE ZONE REFINED MATERIAL.
5. RECYCLE THE SCRAP MATERIAL AND RETURN IT FOR THE NEXT ROUND OF DETECTORS.
6. REFINE ENOUGH Ge TO BUILD 30 kg OF ENRICHED DETECTORS.
7. DEVELOP RECYCLING OF ETCH SOLUTION.

AT THE DETECTOR SHOP

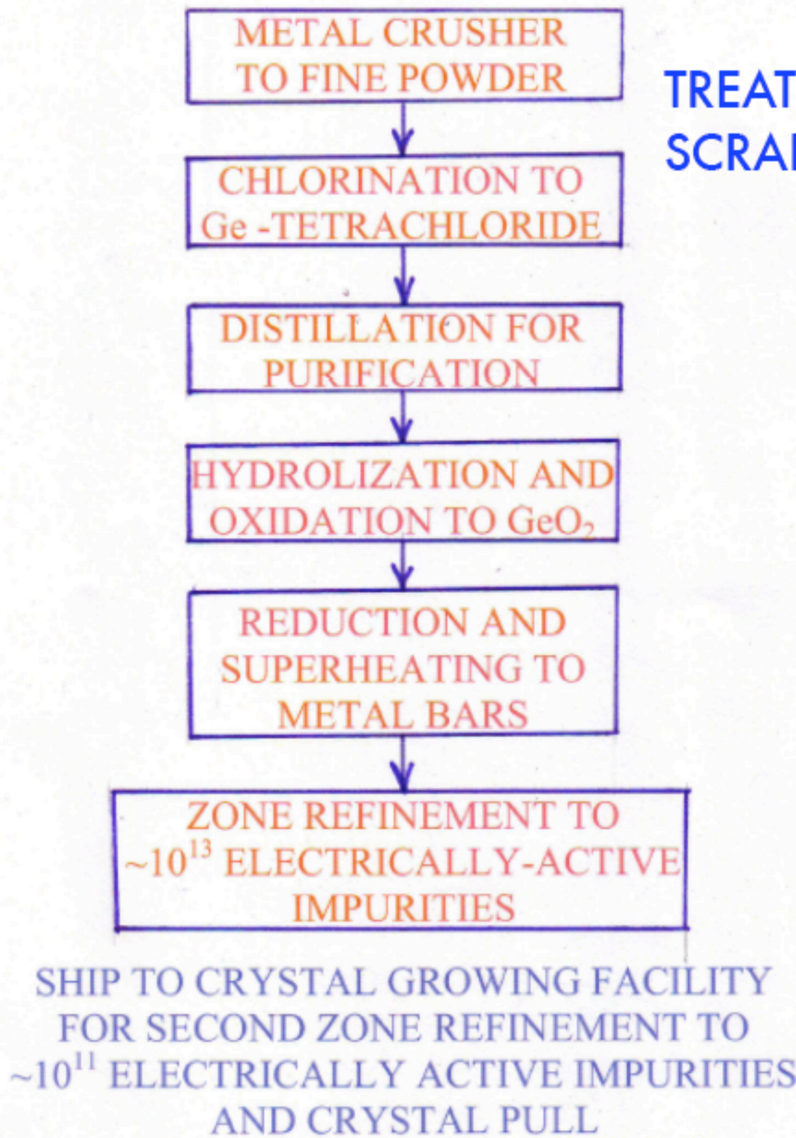


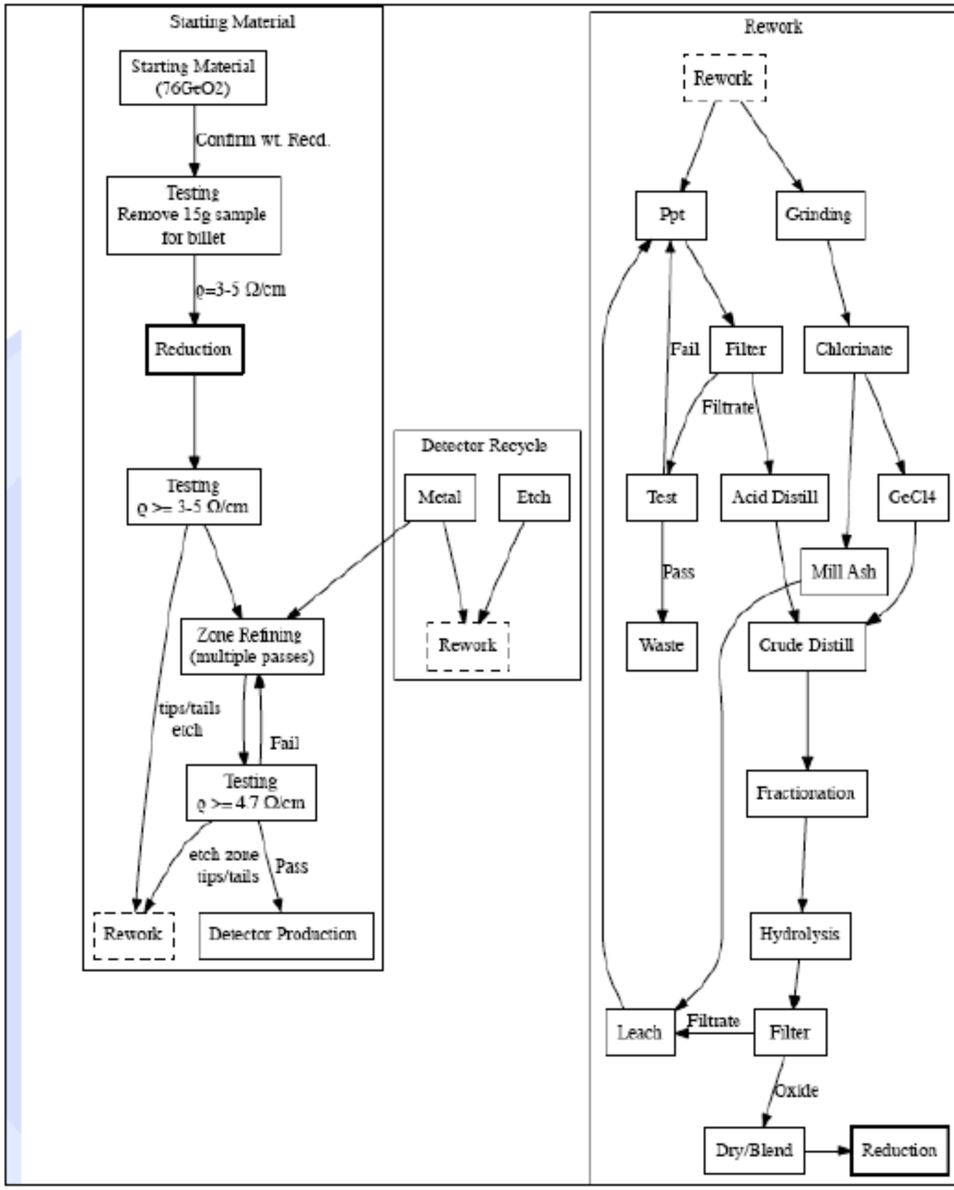
THIS DIAGRAM WAS PUT TOGETHER BY LARRY DARKEN AND FTA BASED ON DL'S EXPERIENCE WITH NORMAL P-TYPE PRODUCTION DETECTORS.

HOW DO WE GET 30 kg IN DETECTORS IN CYCLES?

INPUT kg	#BARS	#XTALS	LOSSES kg	ETCH kg	UNUSED kg	DIRECT to zoner kg	RECYCLED kg
56.00	5	10	2.25	2.50	6.00	18.0	16.25
40.25	4	8	1.80	2.00	0.25	14.4	13.00
27.65	2	4	0.90	1.00	7.65	7.20	6.50
21.35	2	4	0.90	1.00	1.35	7.20	6.50
15.05	1	2	0.45	0.50	5.05	3.60	3.25
11.90	1	2	0.45	0.50	1.90	3.60	3.25
TOTALS	30	Detectors	6.75 kg	7.50 kg			48.75 kg

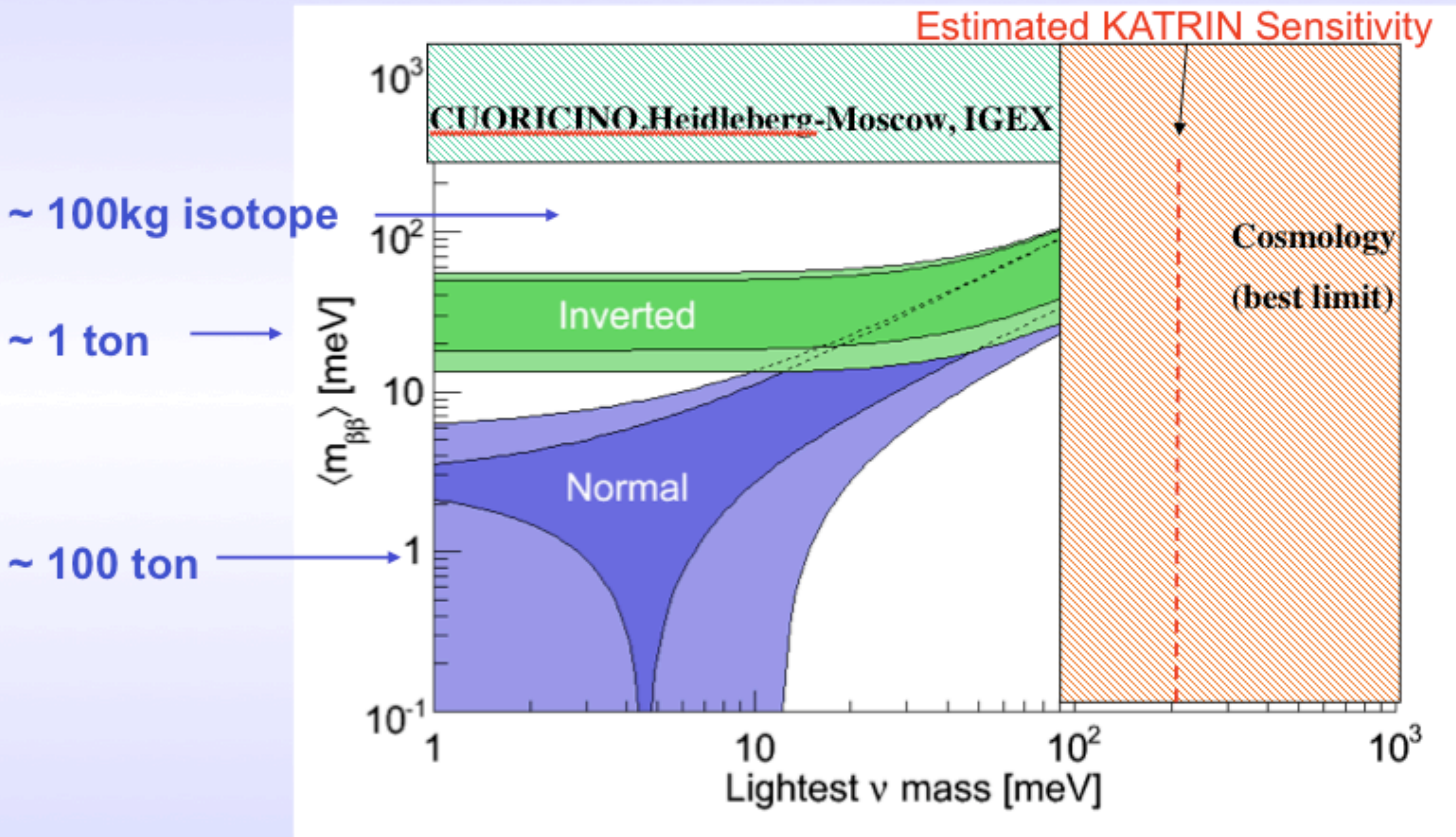
TREATMENT OF SCRAP Ge METAL





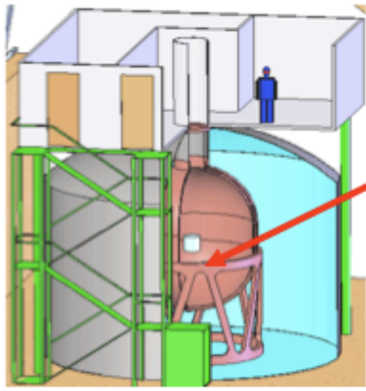
THIS IS A DETAILED PROCESSING PLAN BEGINNING WITH OXIDE, REDUCING, ZONE REFINING, PRODUCING HIGH PURITY Ge AND RECYCLING

Combined Mass Limits



Taken from Reyco Henning, CIPANP 09, San Diego, CA

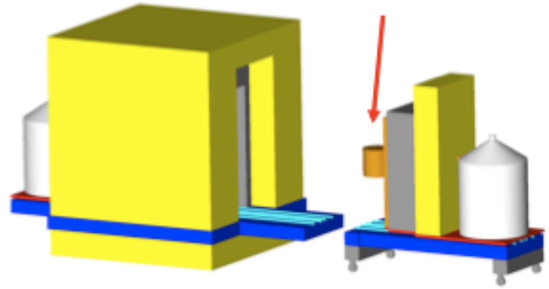
GERDA



- 'Bare' ^{enr}Ge array in liquid argon
- Shield: high-purity liquid Argon / H_2O
- Phase I (mid 2008): ~18 kg (HdM/IGEX diodes)
- Phase II (mid 2009): add ~20 kg new detectors

Total ~40 kg

MAJORANA



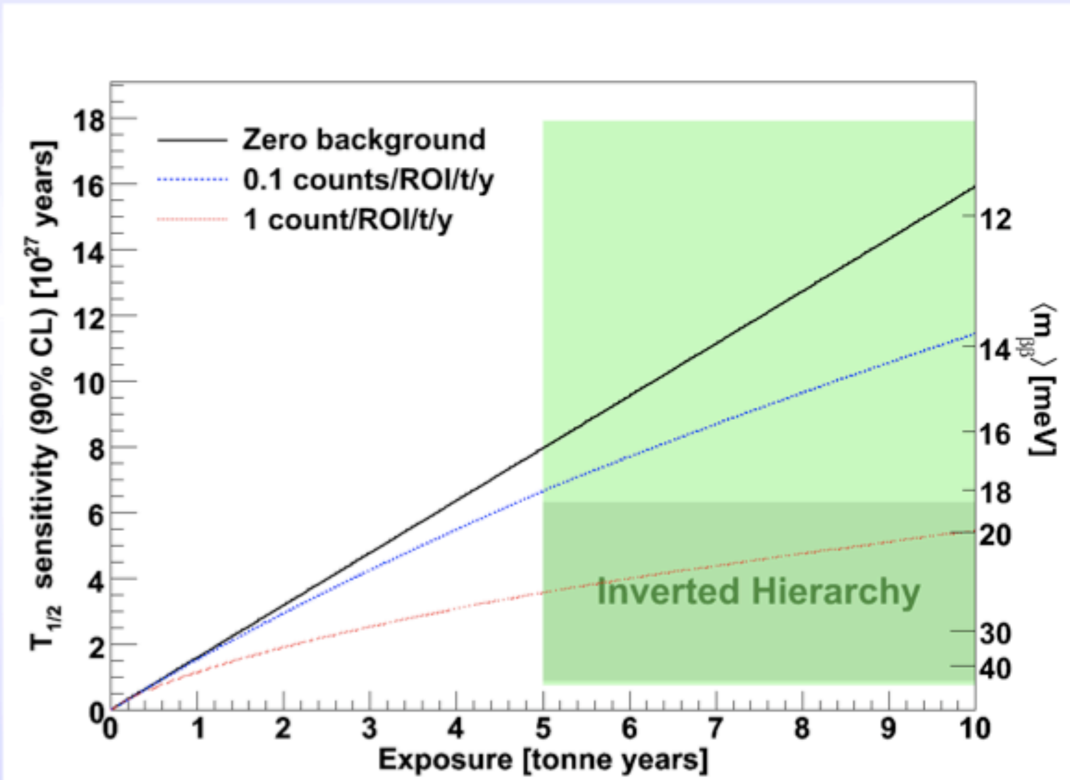
- Modules of ^{enr}Ge housed in high-purity electroformed copper cryostat
- Shield: electroformed copper / lead
- Initial phase: R&D prototype module

Total 60 kg (30 enriched)

Joint Cooperative Agreement:

- Open exchange of knowledge & technologies (e.g. MaGe, R&D)
- Intention to merge for 1 ton exp. Select best techniques developed and tested in GERDA and MAJORANA

1-ton Ge-76 Projected Sensitivity vs. Background



Revco Henning, CIPANP 09, San Diego, CA

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Note: Red text indicates students


IL LAVORO MI PERSEGUITA,
MA IO SONO PIU' VELOCE!