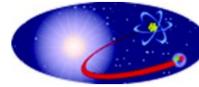




U.S. DEPARTMENT OF
ENERGY

Office of
Science

Office of Nuclear Physics



APS | DIVISION OF
PARTICLES & FIELDS



Status Update of the MAJORANA DEMONSTRATOR Neutrinoless Double Beta Decay Experiment

Julieta Gruszko

University of Washington

On behalf of the MAJORANA Collaboration

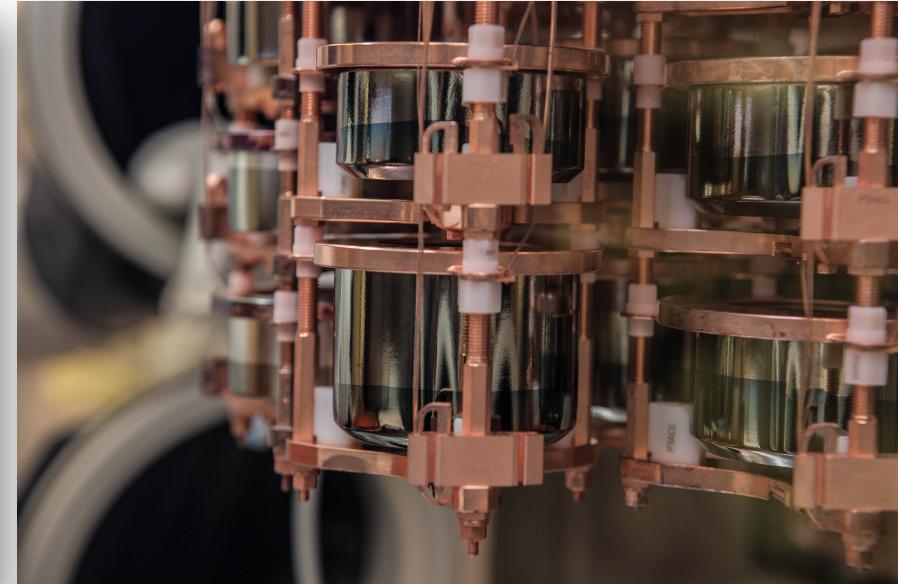
APS DPF 2015, Aug. 4-8, 2015





Outline

- Searching for $0\nu\beta\beta$
- MAJORANA DEMONSTRATOR Overview
- Status of the DEMONSTRATOR



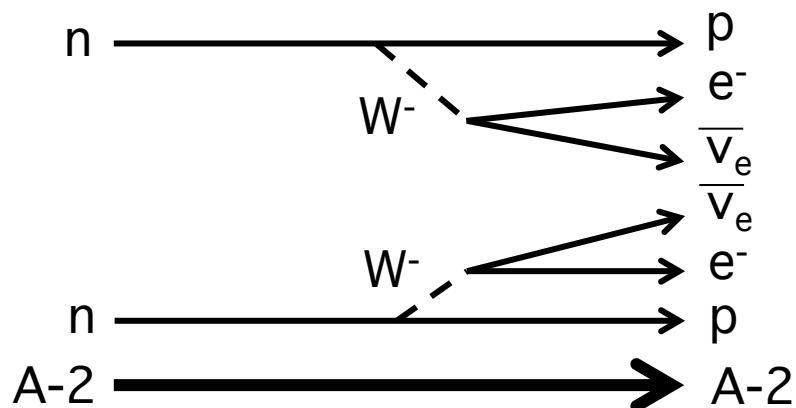
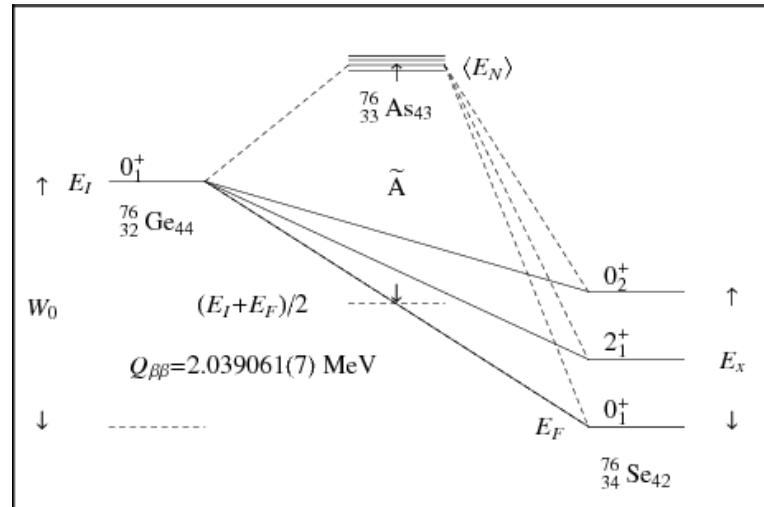
SEARCHING FOR $0\nu\beta\beta$





Double Beta Decay

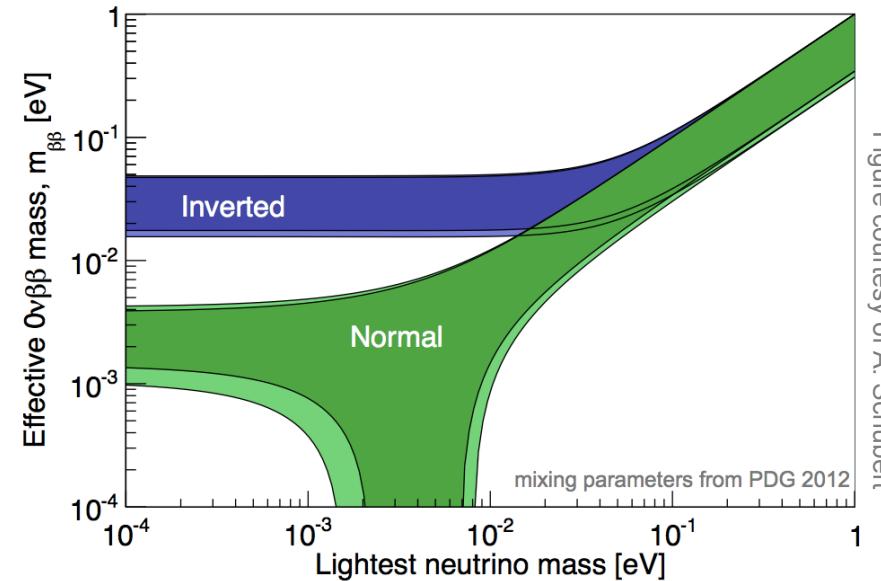
- For some isotopes, single beta decay is disallowed by energy considerations
- Double beta decay becomes favorable
- In the SM, two electron antineutrinos are emitted
- $T_{1/2} \sim 10^{19}$ to 10^{21} years





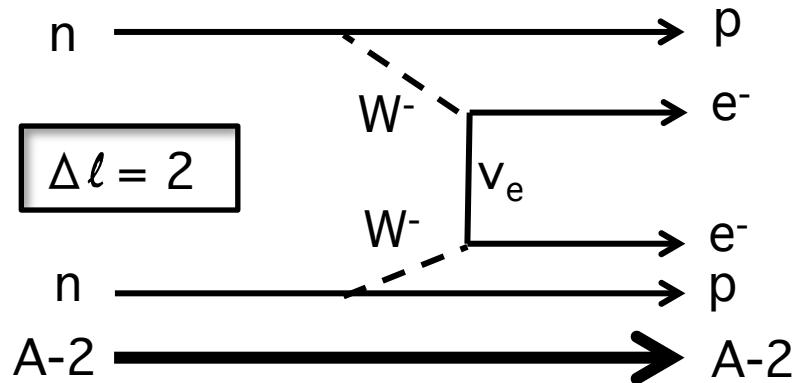
Neutrinoless Double Beta Decay

- If neutrinos are majorana, $0\nu\beta\beta$ could occur
- Rate depends on neutrino mass and mass hierarchy



$$(T_{1/2}^{0\nu})^{-1} = G^{0\nu} |M_{0\nu}|^2 \left(\frac{\langle m_{\beta\beta} \rangle}{m_e} \right)^2$$

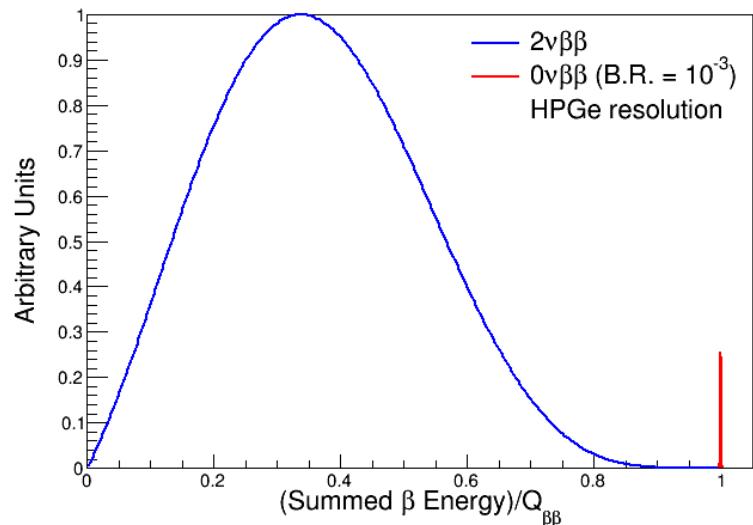
$$\langle m_{\beta\beta} \rangle = \left| \sum_{i=1}^3 U_{ei}^2 m_i \right|$$



Backgrounds and $0\nu\beta\beta$



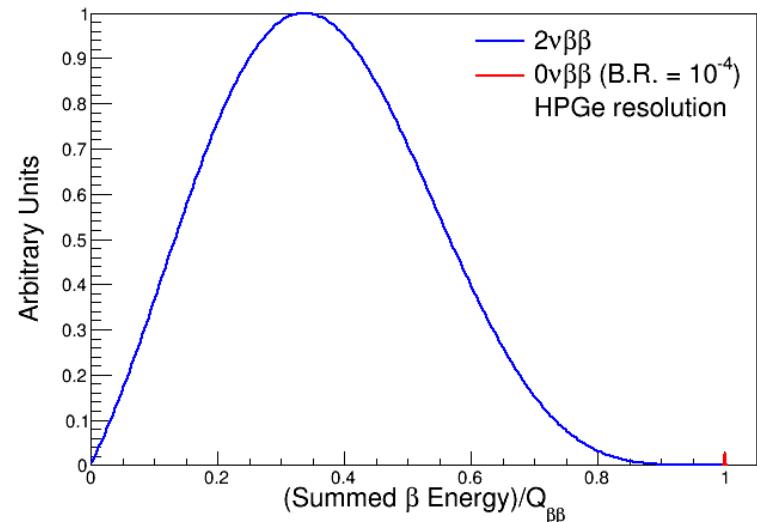
- Current limits: $T_{1/2} > 10^{25}$ years
- Excellent resolution and extremely low backgrounds in the signal region are key
- Need a large mass, high efficiency



Backgrounds and $0\nu\beta\beta$

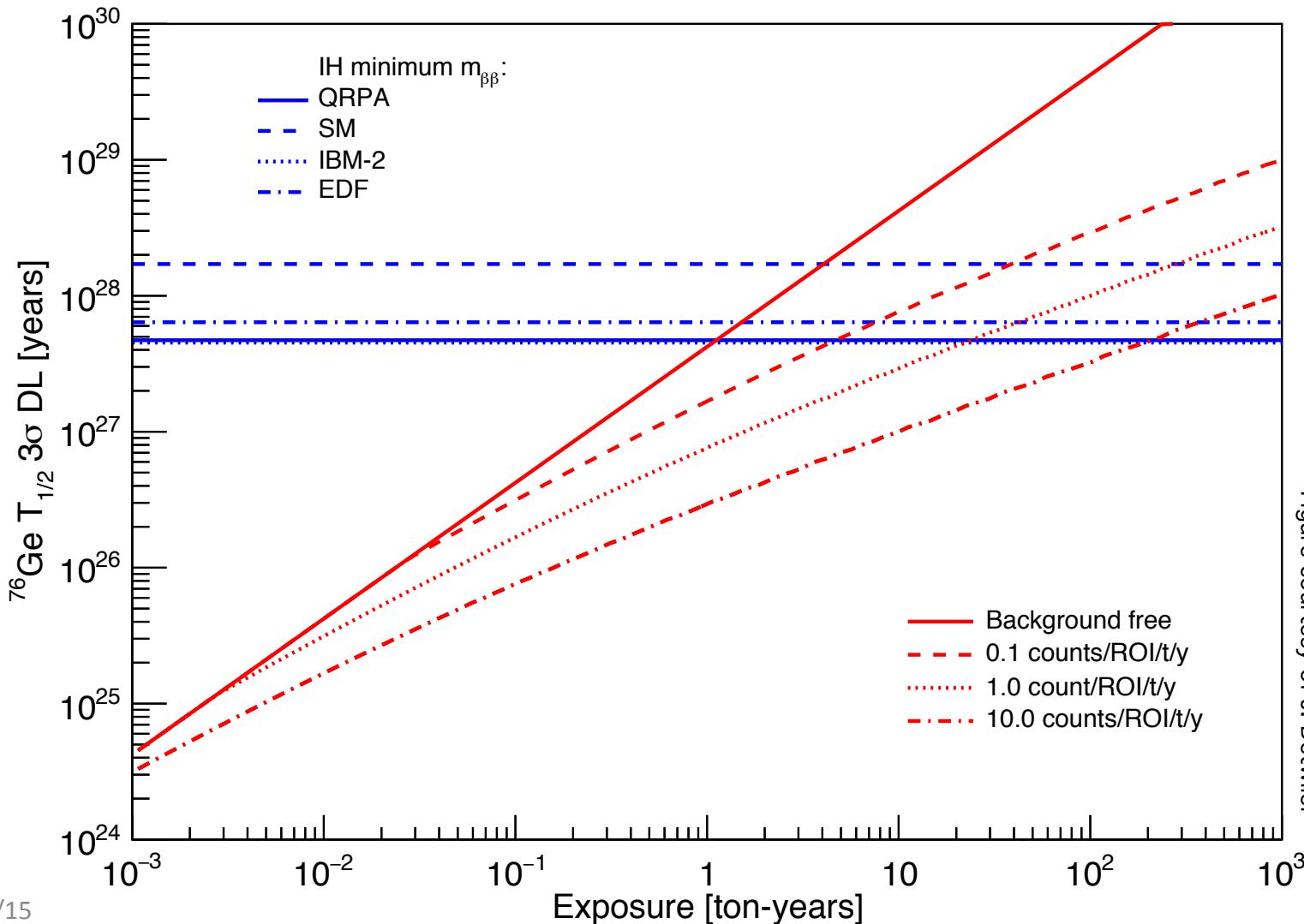


- Current limits: $T_{1/2} > 10^{25}$ years
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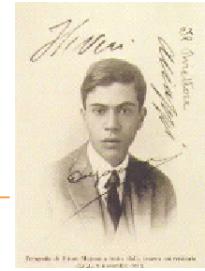


Need to have independent observations in multiple isotopes

Discovery, Background, and Exposure



MAJORANA DEMONSTRATOR OVERVIEW





The MAJORANA Collaboration



OAK RIDGE NATIONAL LABORATORY



Pacific Northwest
NATIONAL LABORATORY



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Duke University, Durham, North Carolina , and TUNL

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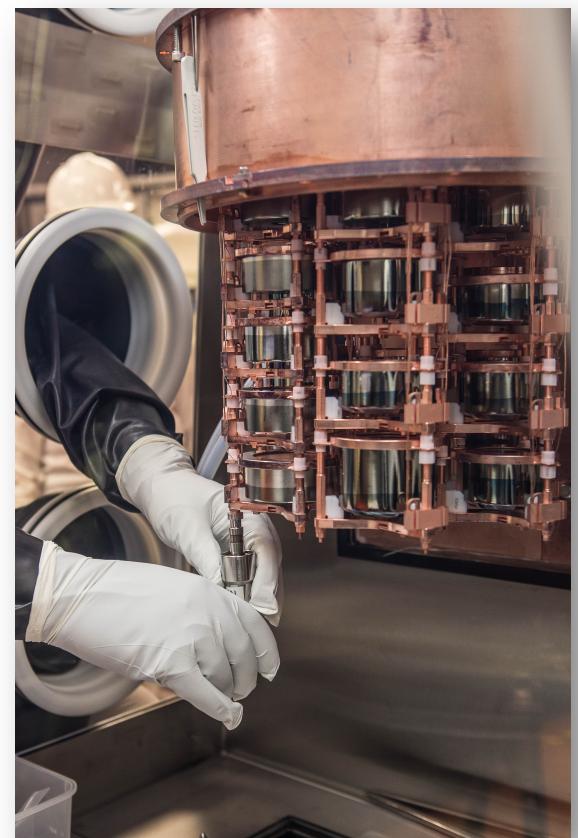
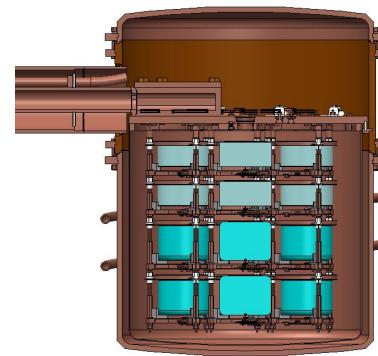


The MAJORANA DEMONSTRATOR

The MAJORANA DEMONSTRATOR (MJD) is an array of enriched and natural germanium detectors that will search for the $0\nu\beta\beta$ -decay of ^{76}Ge .

Goals:

- Demonstrate backgrounds low enough to justify building a tonne scale experiment.
- Establish feasibility to construct & field modular arrays of Ge detectors.
- Searches for additional physics beyond the standard model

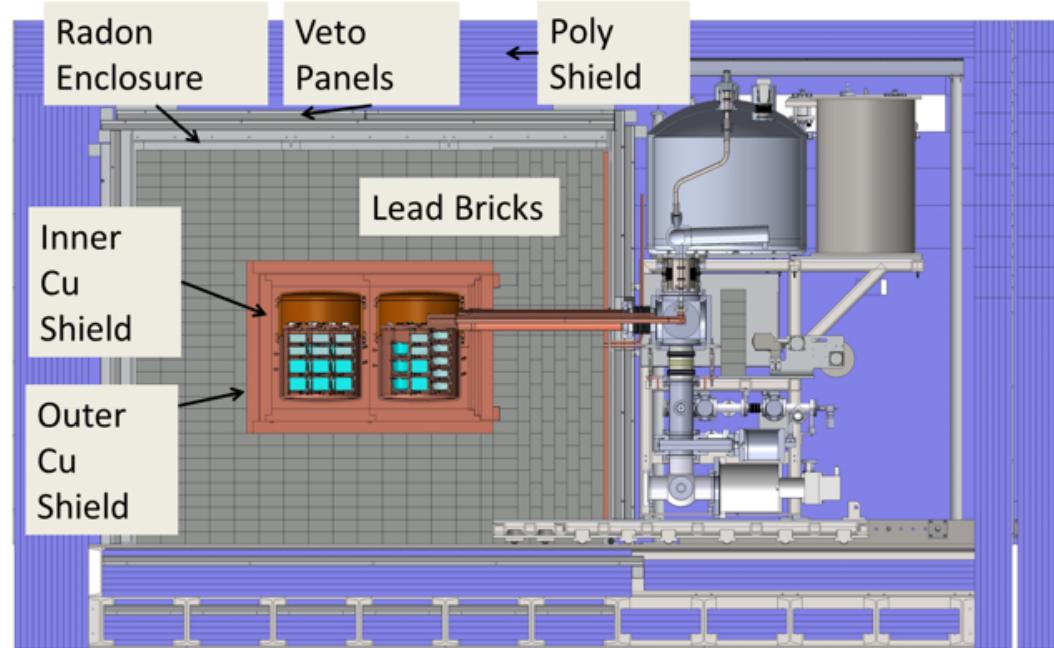


The MAJORANA DEMONSTRATOR

Funded by DOE Office of Nuclear Physics and NSF Particle Astrophysics,
with additional contributions from international collaborators.



- Located underground at 4850' Sanford Underground Research Facility
- Background Goal in the $0\nu\beta\beta$ peak region of interest (4 keV at 2039 keV)
 - 3 counts/ROI/t/y (after analysis cuts) Assay U.L. currently ≤ 3.5
 - scales to 1 count/ROI/t/y for a tonne experiment
- 44-kg of Ge detectors
 - 29 kg of 87% enriched ^{76}Ge crystals
 - 15 kg of $^{\text{nat}}\text{Ge}$
 - Detector Technology: P-type, point-contact.
- 2 independent cryostats
 - ultra-clean, electroformed Cu
 - 20 kg of detectors per cryostat
 - naturally scalable
- Compact Shield
 - low-background passive Cu and Pb shield with active muon veto





Modular Design



PPC HPGe
Detector

Low-Mass
Mount

String

7-String Array

Cryostat

Shield

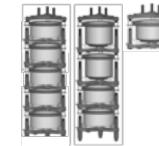
- Makes MJD design scalable for tonne-scale experiment



3 Stage Implementation

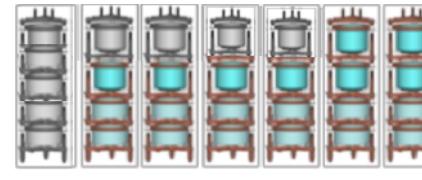
Prototype cryostat: 7.0 kg (10) ^{nat}Ge

Same design as Modules 1 and 2, but fabricated using OFHC Cu Components



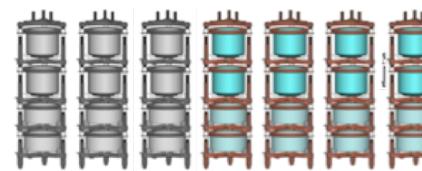
July 2014 –
June 2015

Module 1: 16.8 kg (20) ^{enr}Ge
5.7 kg (9) ^{nat}Ge



May 2015 –

Module 2: 12.6 kg (14) ^{enr}Ge
9.4 kg (15) ^{nat}Ge



End 2015

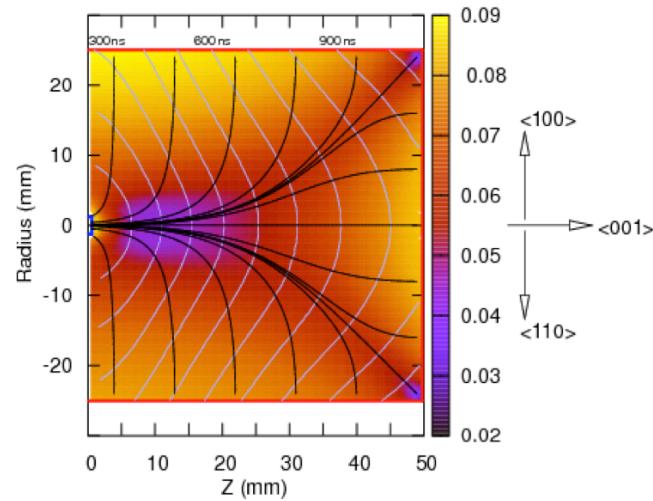
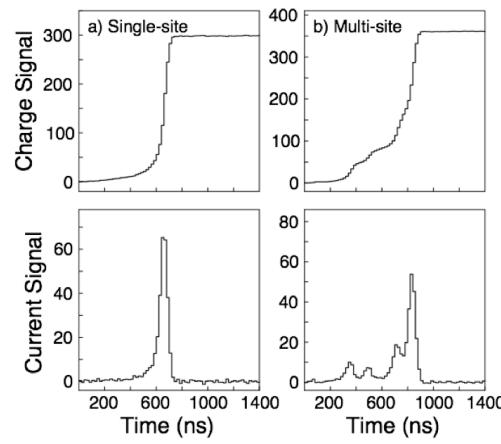


PPC Detectors

- P-type Point Contact Germanium Detectors
- Mix of enriched and natural-abundance detectors
- Small capacitance ($\sim 1\text{ pF}$), good energy resolution, low threshold
- Localized weighting potential allows multi-site event rejection



Photo by James Loach

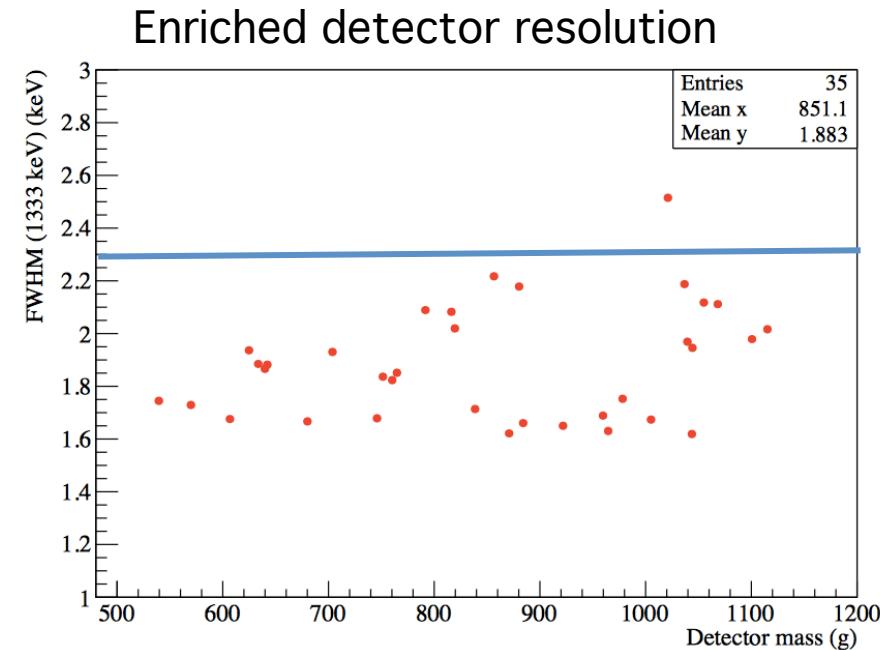


Luke et al., IEEE trans. Nucl. Sci. 36 , 926 (1989); P. S. Barbeau, J. I. Collar, and O. Tench, J. Cosm. Astro. Phys. 0709 (2007).



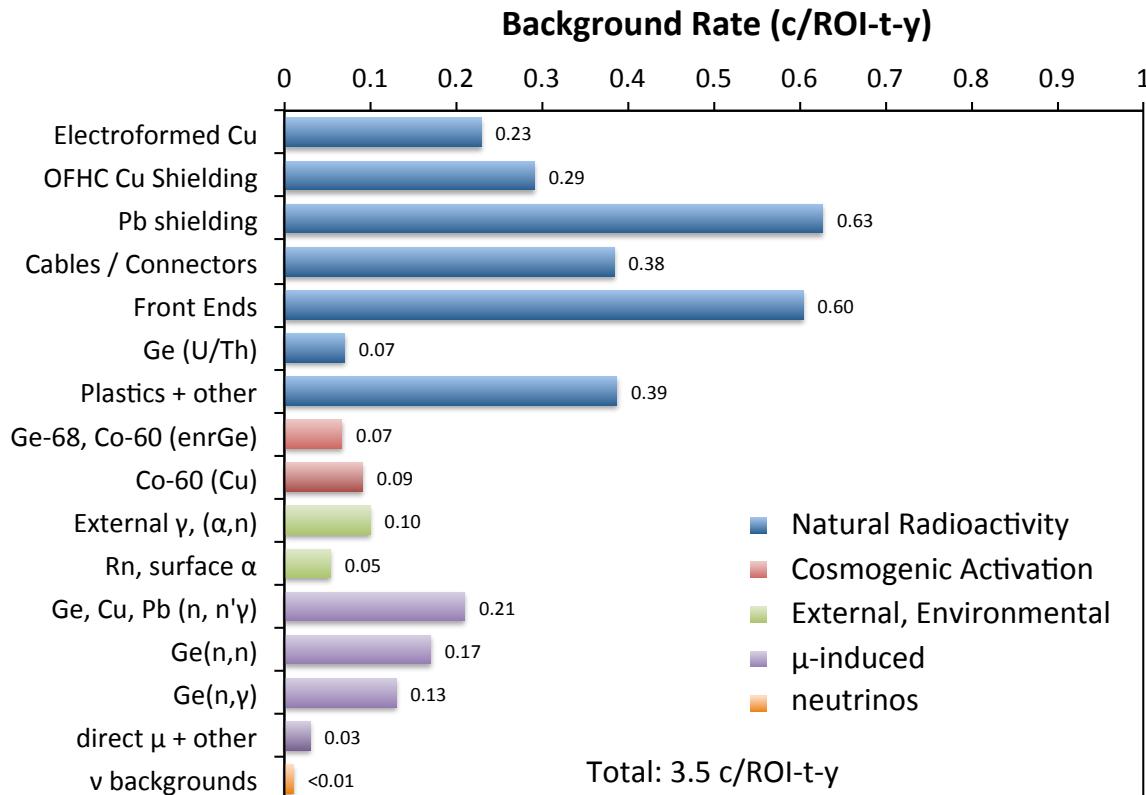
Enriched Detectors

- All material stored underground, delivered via ground
- 35 enriched detectors from ORTEC
 - Average of 850g each
 - 29.7 kg, 87% ^{76}Ge
- 33 natural-Ge BEGe detectors from Canberra
 - 20 kg





Background Reduction



- Low-mass, low-background components
- Extensive assay campaign
 - NAA, ICPMS, γ counting, GDMS
- Underground electroformed copper
- SURF 4850' level
- Compact shield, active muon veto

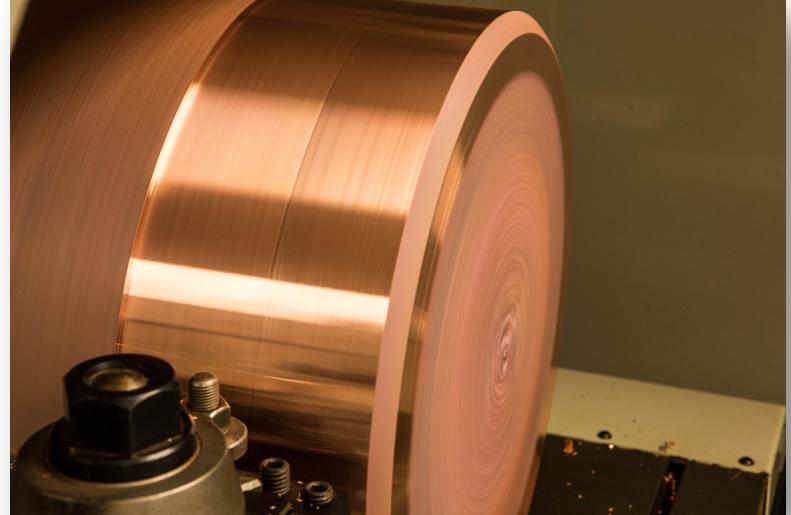
Underground Electroforming



- Copper was electroformed at PNNL and SURF 4850' level
- MJD e-forming is complete, baths still operating
- Th decay chain $\leq 0.1 \mu\text{Bq/kg}$
- U decay chain $\leq 0.1 \mu\text{Bq/kg}$

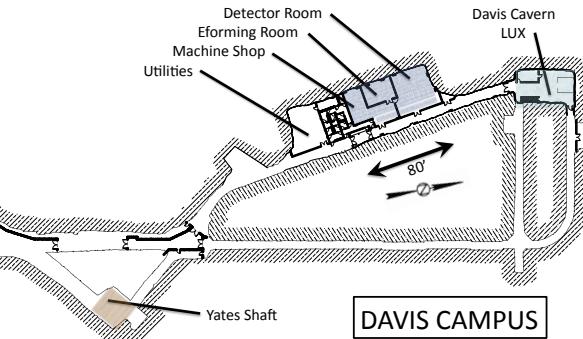


Photos by Matt Kapust





Background Reduction



Photos by Matt Kapust

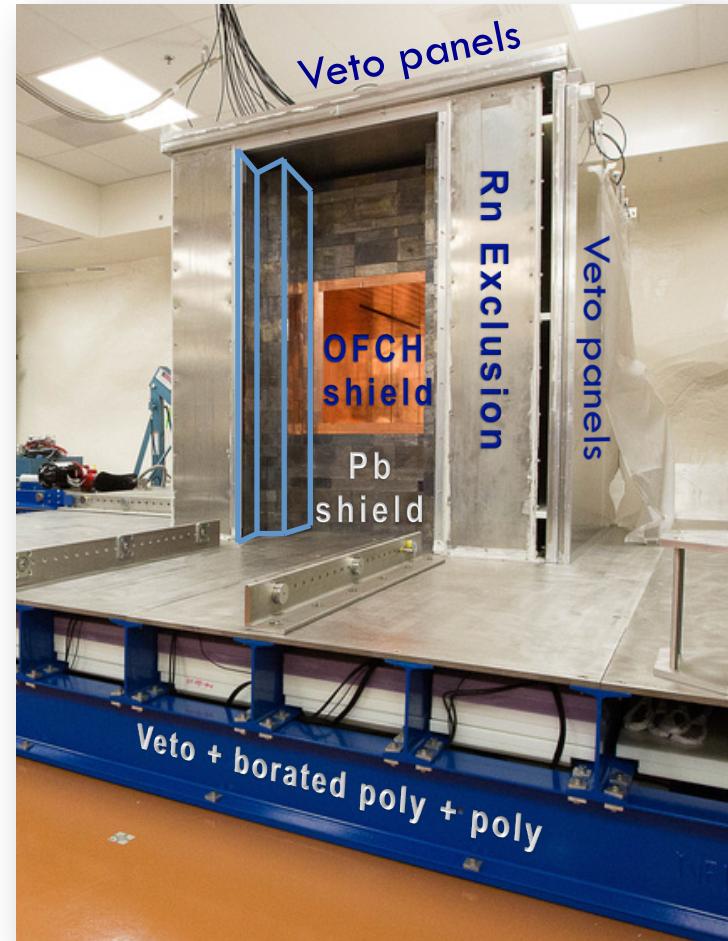
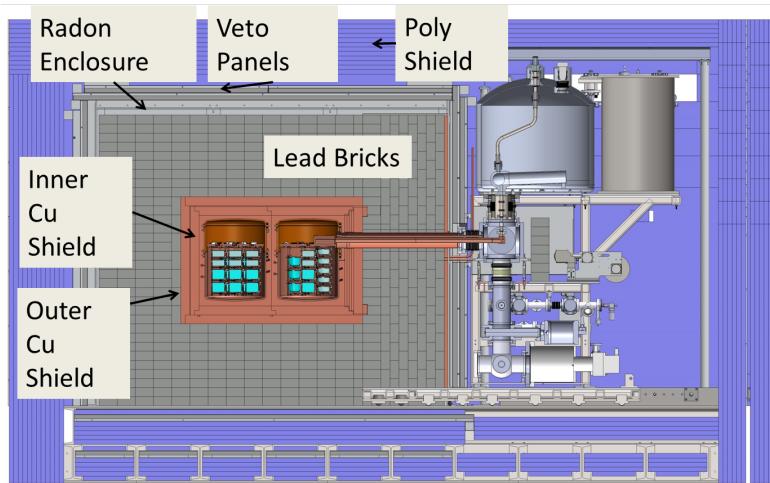
8/5/15

- Construction at SURF Davis Campus – 4850' level
- Class 1000 cleanroom for all work, class 10 glovebox for ultra-low background work
- Clean machine shop
- Parts and material tracking
 - for details see: The MAJORANA Collaboration, Nucl. Instrum. Meth. in Phys. Res. Sec. A, Volume 779, 11 April 2015, Pages 52-62; doi:10.1016/j.nima.2015.01.0



Shielding and Active Veto

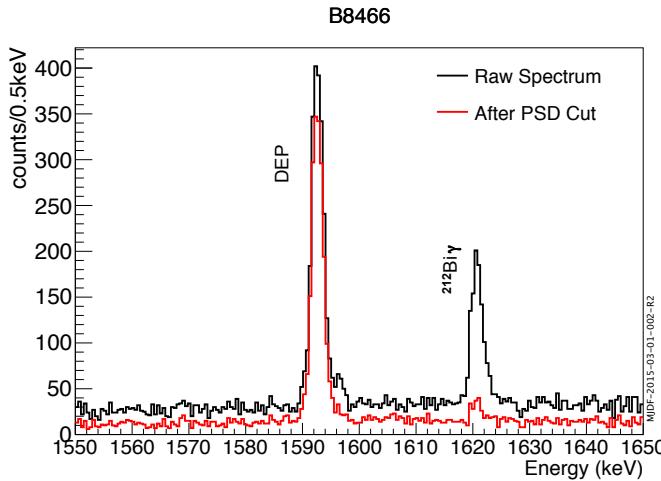
- Compact passive shield:
 - Lead, commercial copper, and electroformed copper
- Nitrogen-purged radon exclusion box
- Veto panels surrounding all sides
- Borated poly and poly neutron shielding
- Calibration system in use



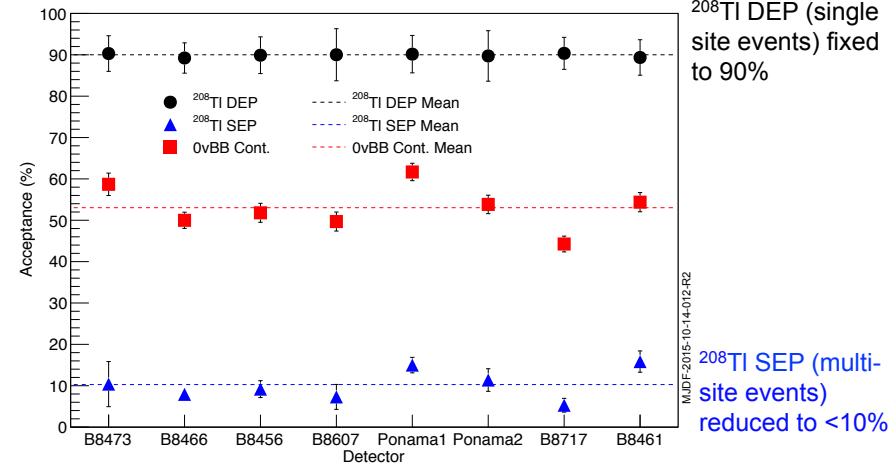


Background Rejection

Natural BEGe detector in Prototype Cryostat

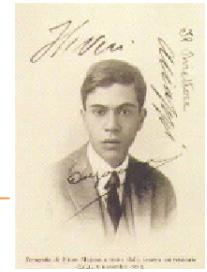


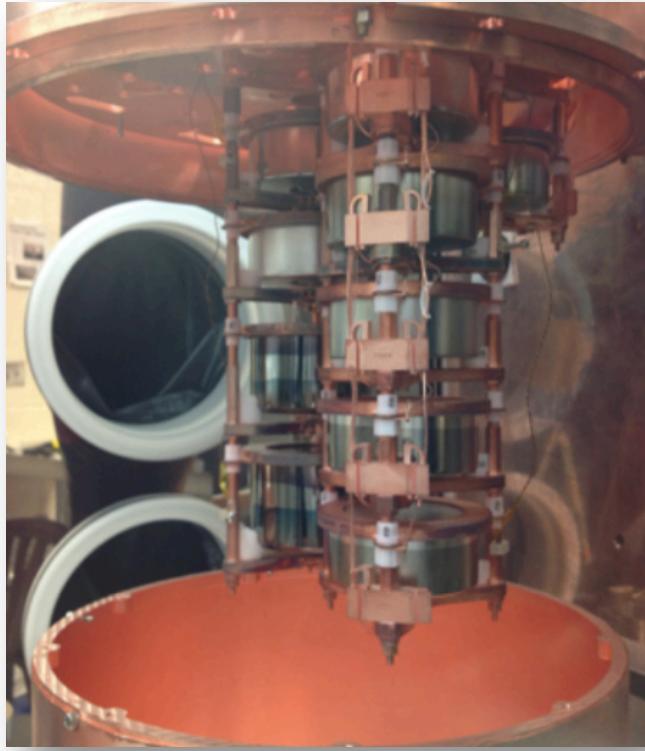
PSD in Prototype Cryostat



- Analysis cuts: multi-site event rejection, granularity, timing correlations
- Energy resolution: $<0.2\%$ at $Q_{\beta\beta}$
 - 4 keV ROI
 - $2\nu\beta\beta$ background is negligible

STATUS OF THE DEMONSTRATOR





Prototype Cryostat



- Used for R&D:
 - Mechanical systems
 - Fabrication and cleaning processes
 - Assembly procedures
- Commercial copper cryostat, some higher background components
- 3 strings of natural detectors
- Took data in shield July 2014 - June 2015
- Just finished decommissioning



Module 1

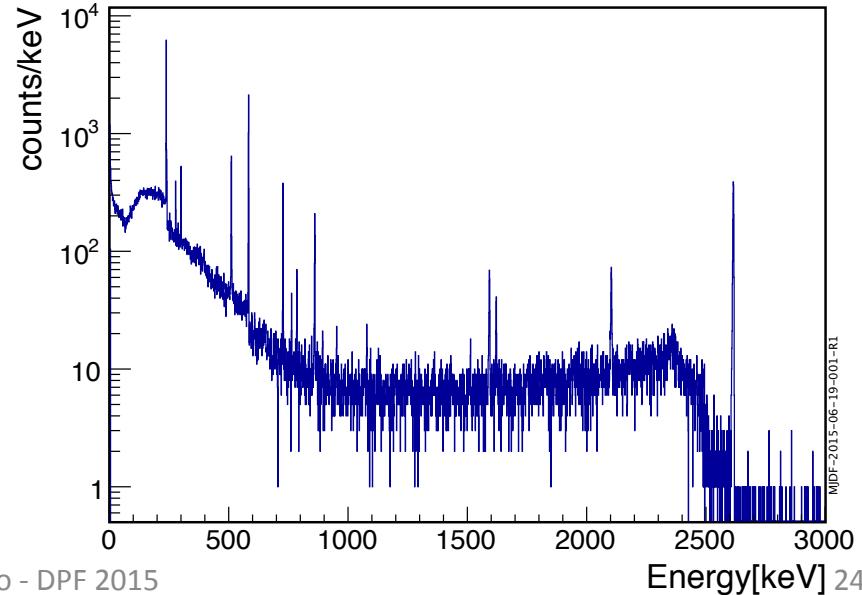
- Ultraclean cryostat, electroformed copper
- Operating 23 of 29 detectors
 - 14 kg enriched, 3.7 kg natural
- Moved into shield end of May 2015, inner copper shield is not in place
- In commissioning



Photo by Matt Kapust

^{228}Th Calibration – Module 1

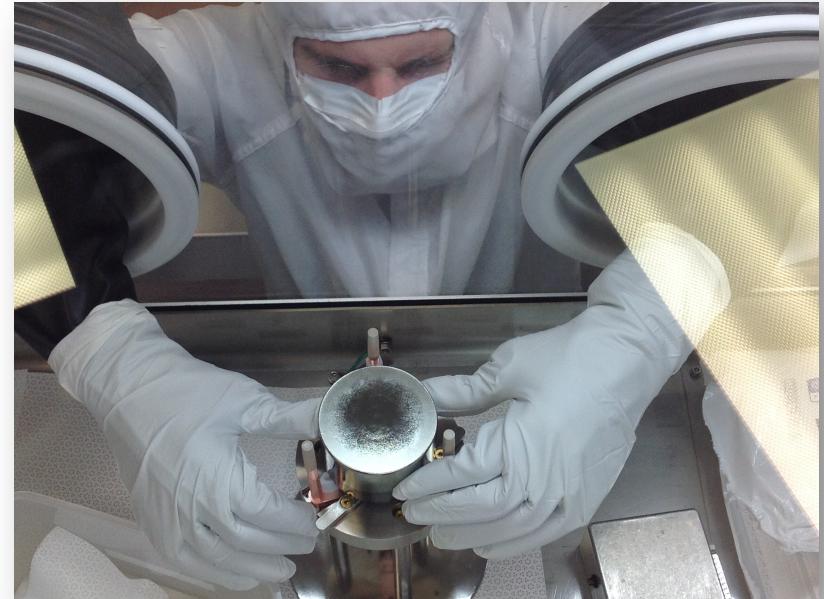
One enriched detector spectrum within a string mounted in Module 1 and inside shield. FWHM 3.6 keV at 2.6 MeV





Module 2

- First strings built, more to come
- Vacuum system under construction
- Will be in commissioning by end of 2015





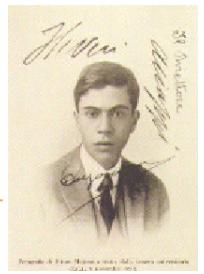
Summary

- Based on assays, MJD is projected to meet background goal of < 3 counts/ROI/t/y
- E-formed copper production complete, shielding nearly complete
- Module 1 complete, being commissioned
- Module 2 assembly and construction proceeding at SURF
- Nearing the start of blinded data-taking



Photo by Matt Kapust

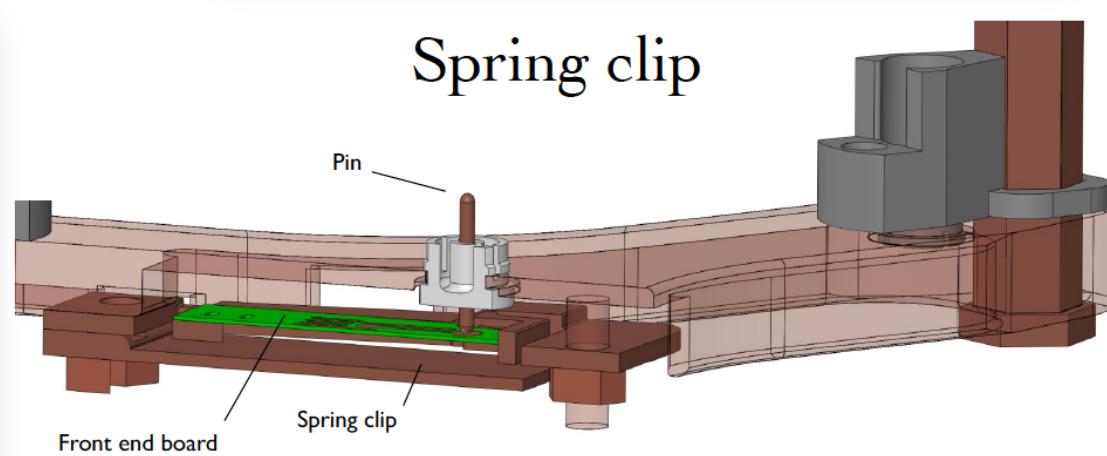
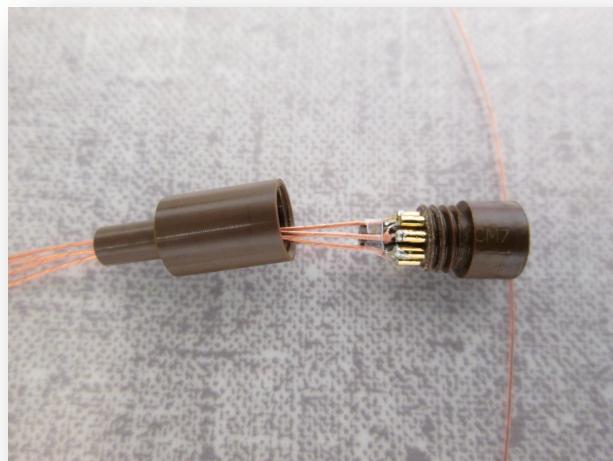
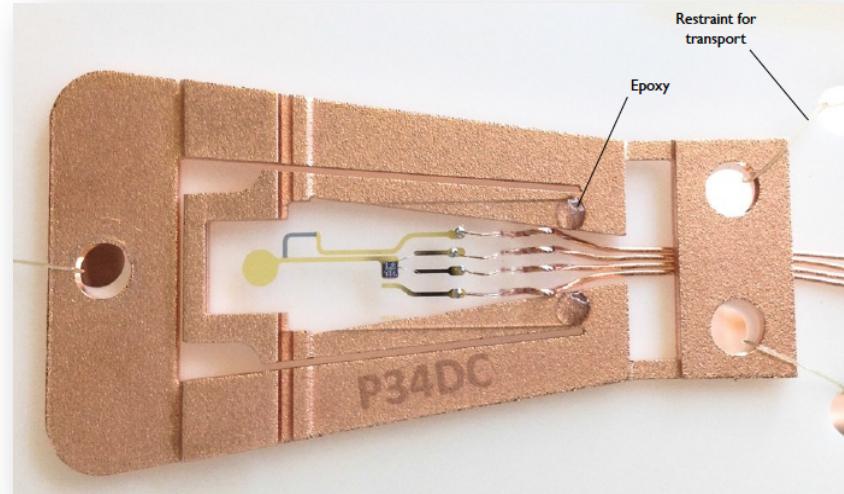
SUPPLEMENTARY SLIDES



Low-Background Electronics



- Low background LMFE is mounted on each detector unit
- Axon pico-coax cables for signal and HV
- Signal connectors are Vespel with low background solder and flux





Sensitivity, Background, and Exposure

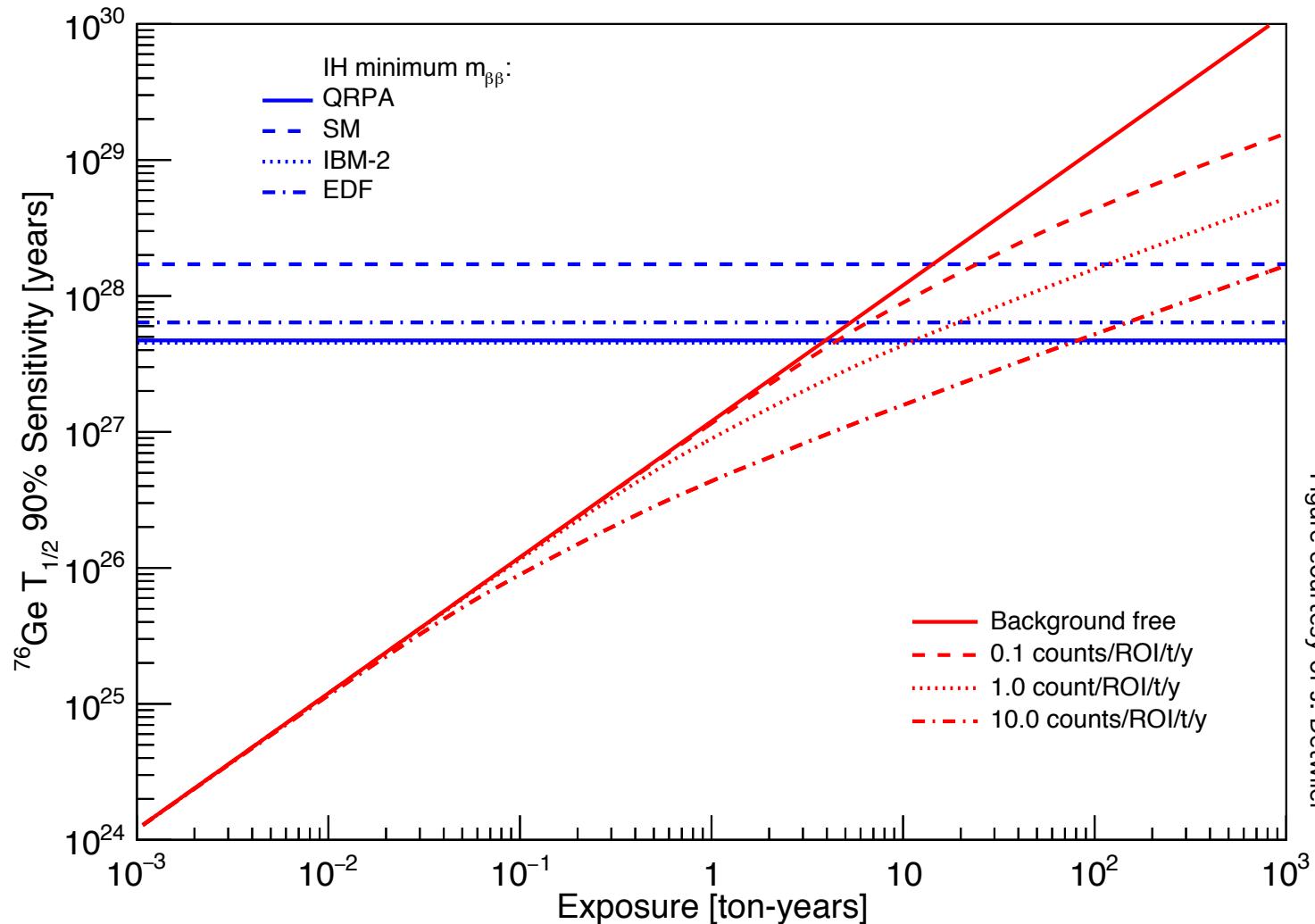


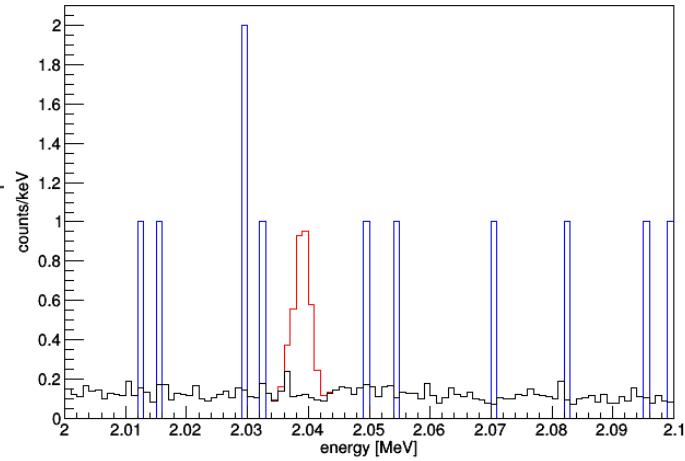
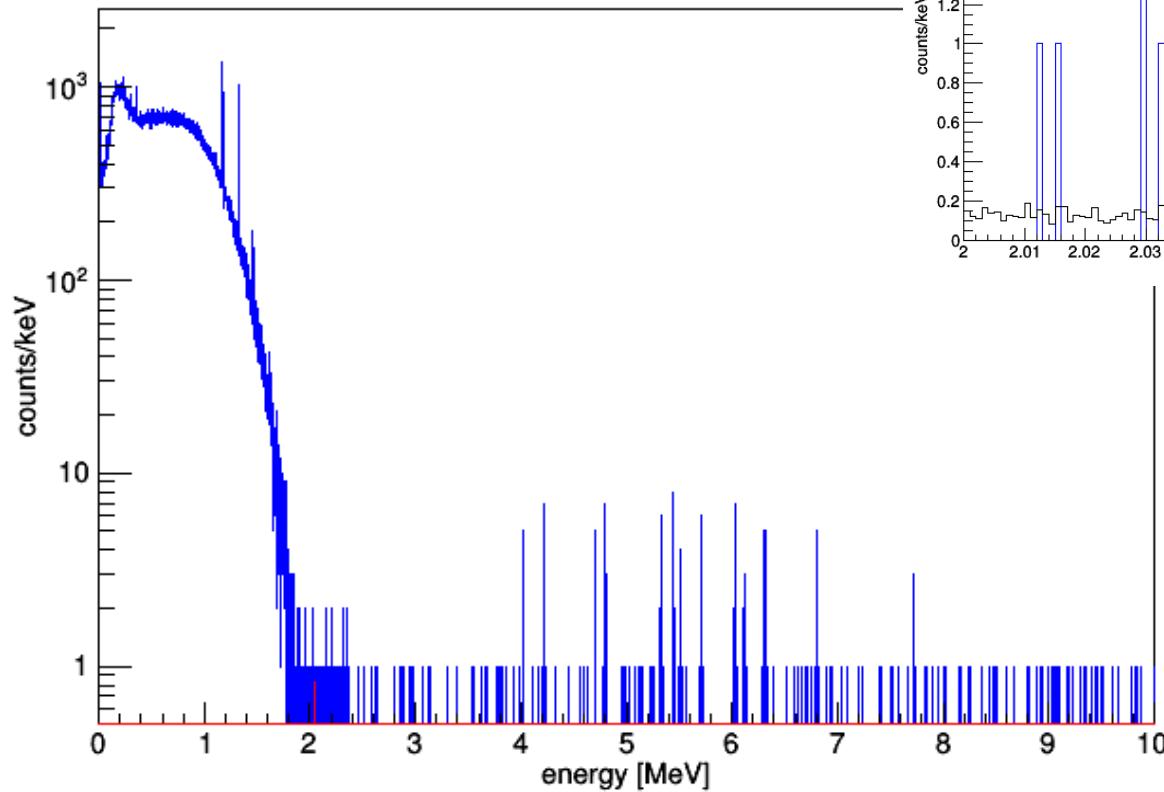
Figure courtesy of J. Detwiler



MJD Simulations

- Model built in MaGe

MJD, 5-year exposure





Ge Surface Exposure

