The MAJORANA Demonstrator Neutrinoless Double-Beta Decay Experiment

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OAK RIDGE
National Laboratory

On Behalf of The MAJORANA Demonstrator Experiment

Outline

- Neutrinoless $\beta\beta$ decay
- MAJORANA Demonstrator
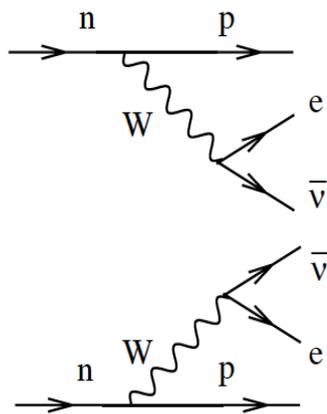- Experiment Status

Outline

- **Neutrinoless $\beta\beta$ decay**
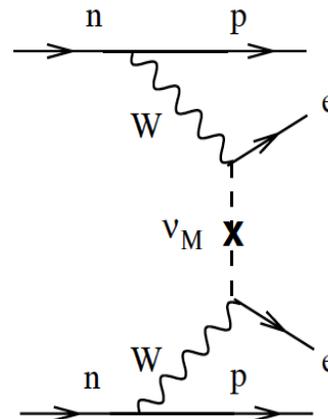- MAJORANA Demonstrator Design
- Experiment Status

Neutrinoless $\beta\beta$ decay

This rare decay in which a nucleus (Z, A) decays to a new nucleus (Z + 2, A).
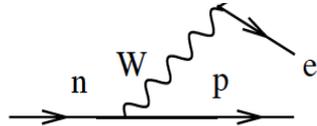
2ν case.

0ν case.

Neutrinoless $\beta\beta$ decay

This rare decay in which a nucleus (Z, A) decays to a new nucleus (Z + 2, A).
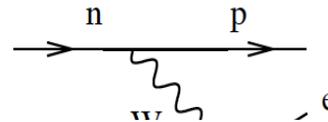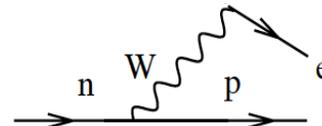
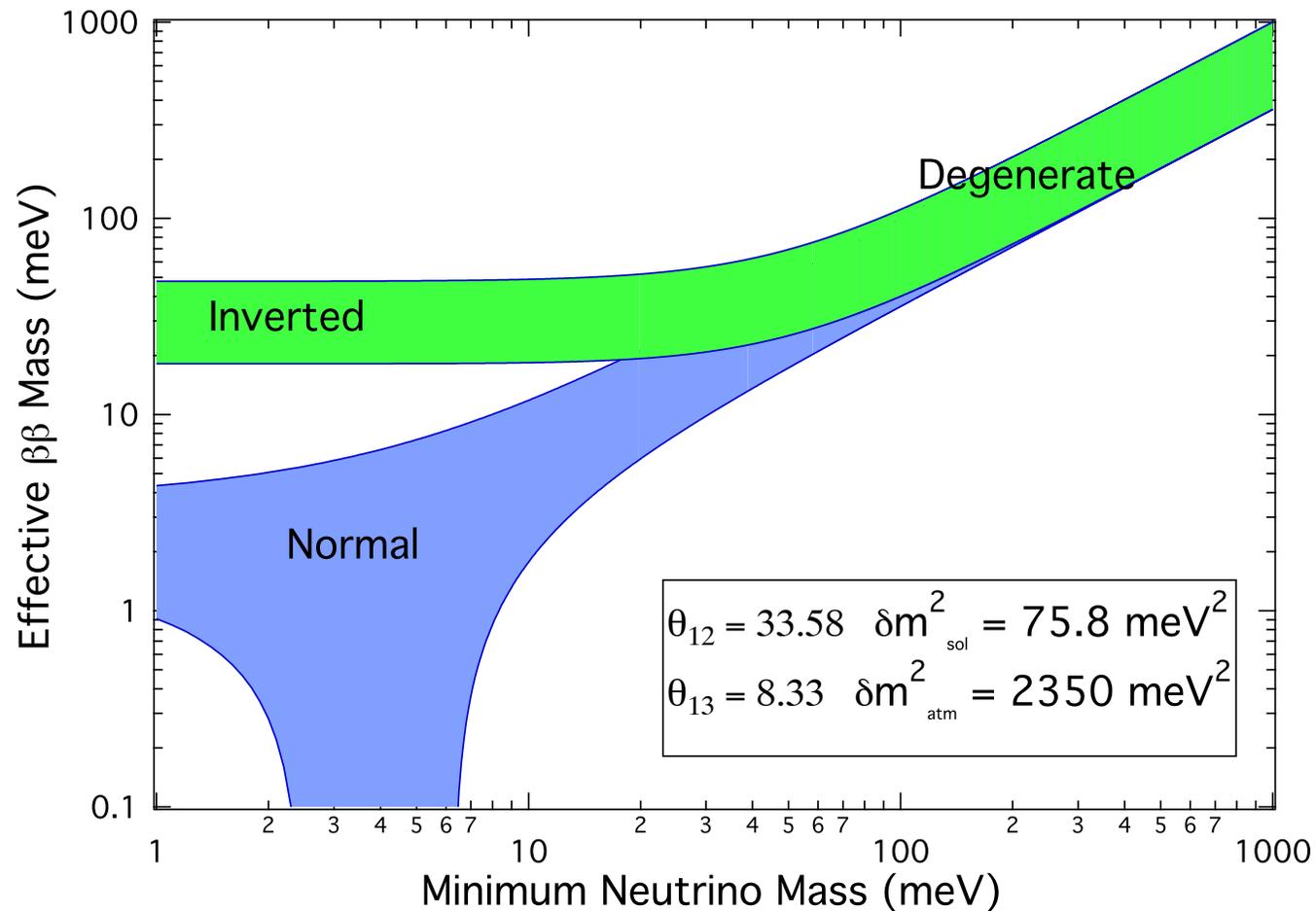2ν case.

Measured In several Isotopes

0ν case.

Only limits for half-life of decay

Conditions for the zero neutrino case to occur include lepton number violation, massive neutrinos, and the neutrino must be its own antiparticle.

Neutrinoless $\beta\beta$ decay

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

Neutrinoless $\beta\beta$ decay

| Isotope	$2\nu\,\beta\beta$ decay half-life [yr]
^{48}Ca	~4.3 x 10^{19}
^{76}Ge	~1.5 x 10^{21}
^{82}Se	~9.2 x 10^{19}
^{96}Zr	~2.0 x 10^{19}
^{100}Mo	~7.0 x 10^{18}
^{116}Cd	~3.0 x 10^{19}
^{130}Te	~9.1 x 10^{20}
^{136}Xe	~2.1 x 10^{21}
^{150}Nd	~7.8 x 10^{18}

Some Considerations for Isotope Selection:

- Q value of the decay
- Nuclear matrix element
- Availability and abundance of isotope
- Detector design

Detection Requirements

Basic requirements for detecting such rare decay:

- Large source mass of desired isotope
- Low background to reach acceptable signal to background ratios
- High resolution to separate 0ν detection from tail of 2ν energy spectrum

Rev.Mod.Phys.
80:481-516,2008
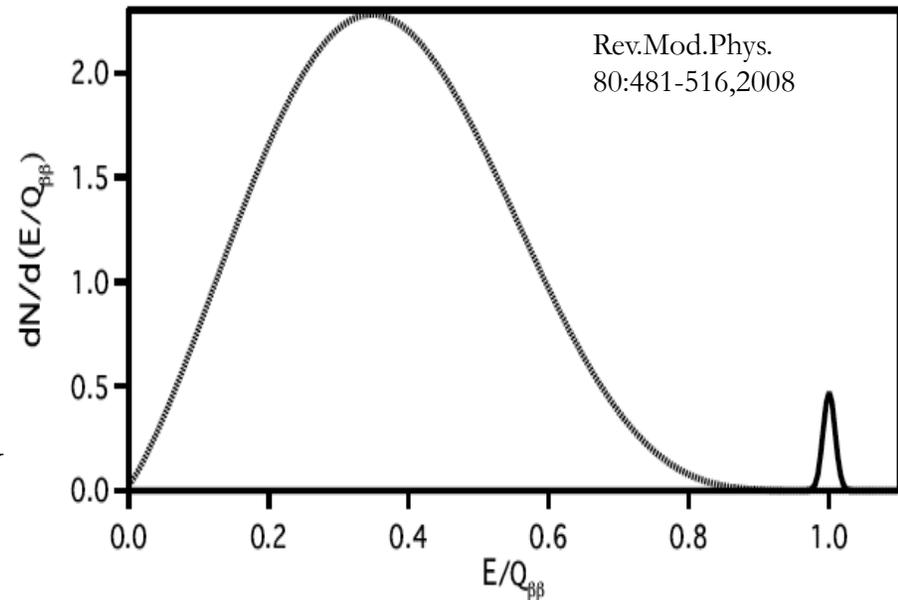
Neutrinoless $\beta\beta$ decay

^{136}Xe

^{116}Cd

^{82}Se

^{130}Te

^{76}Ge

IGEX

Sensitivity, Background and Exposure

Fig: Courtesy J. Detwiler
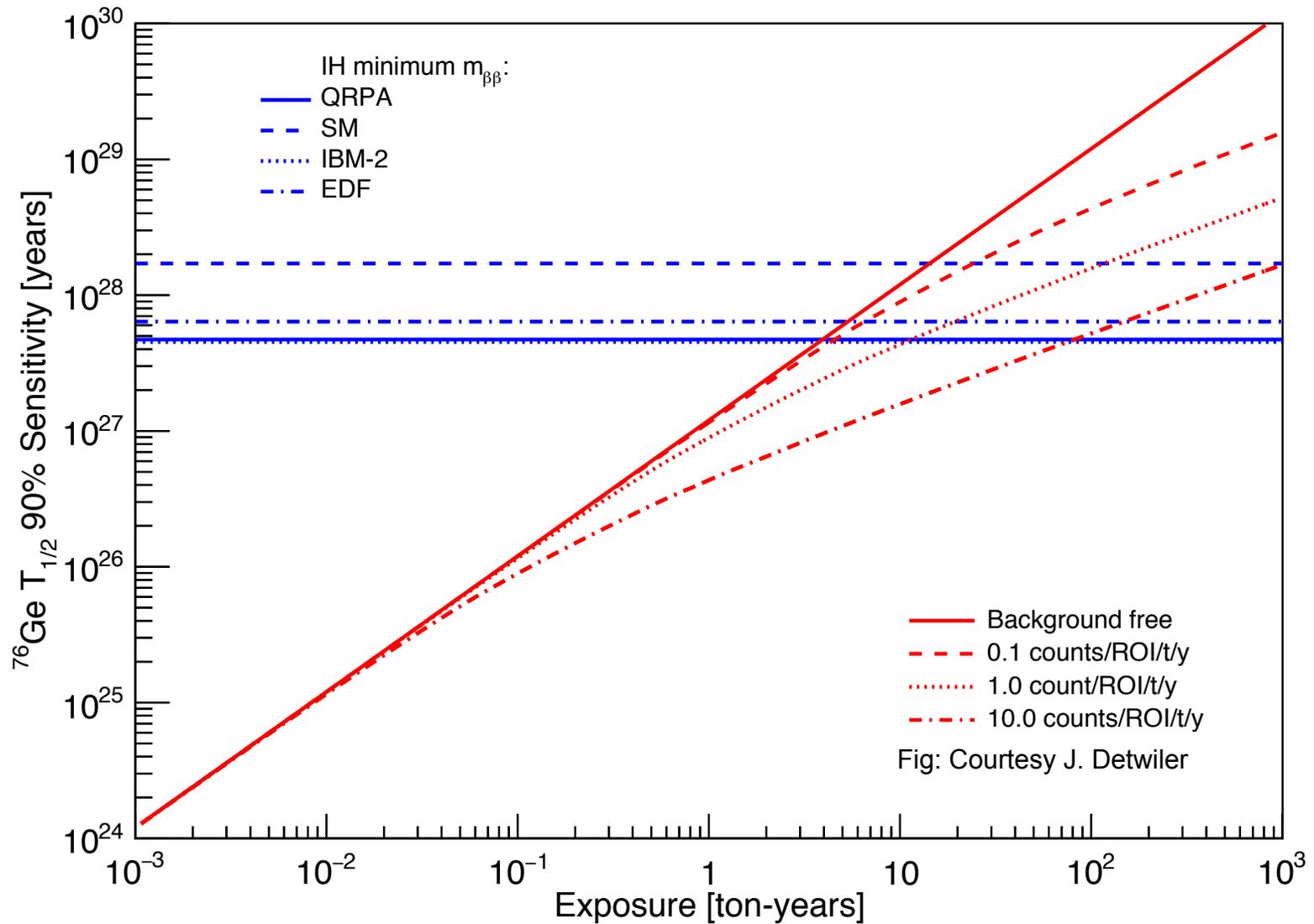
Discovery, Background and Exposure

Fig: Courtesy J. Detwiler
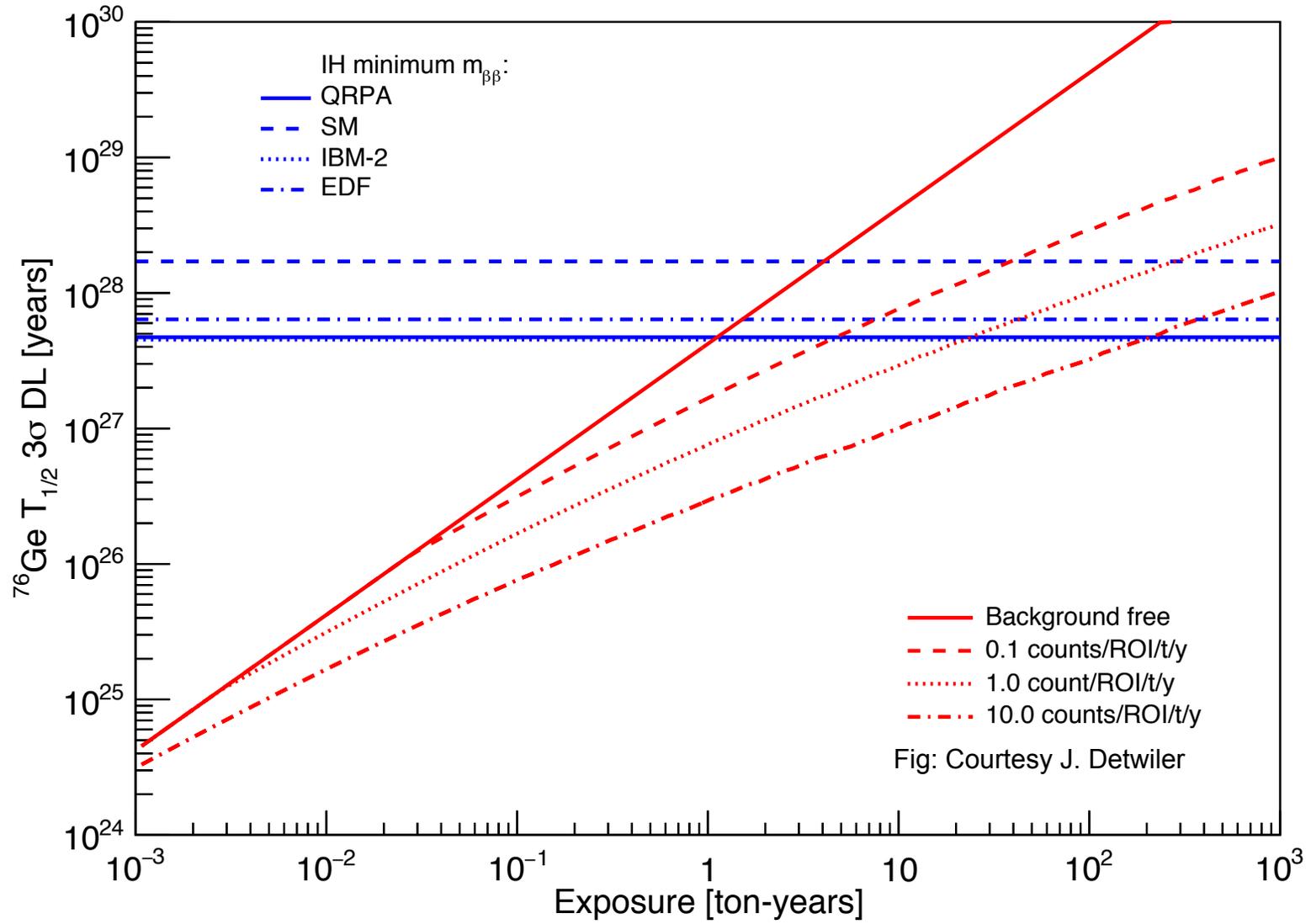
Outline

- Neutrinoless $\beta\beta$ decay
- **MAJORANA Demonstrator**
- Experiment Status

The MAJORANA Collaboration

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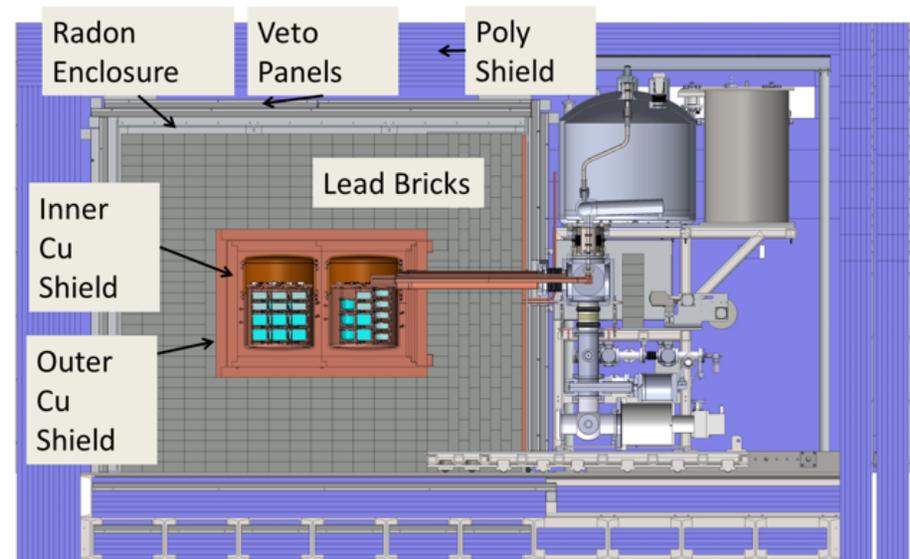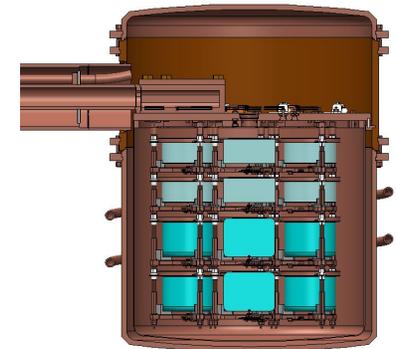Tim Van Wechel

The MAJORANA DEMONSTRATOR

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

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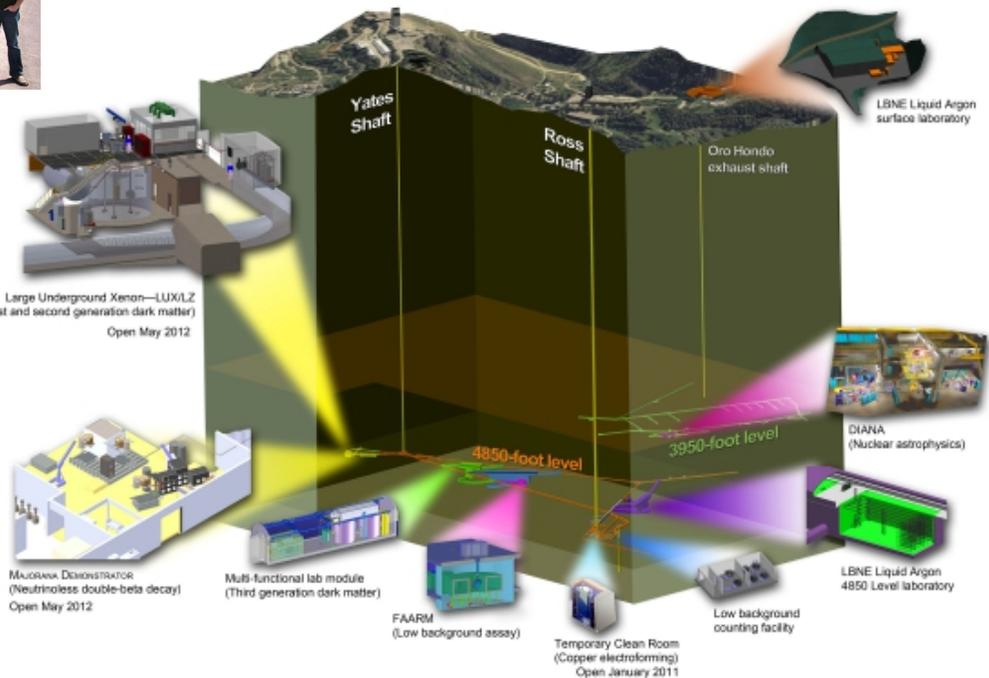- Searches for additional physics beyond the standard model.

- **Located underground at 4850' Sanford Underground Research Facility**

- **Background Goal in the 0νββ 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**
  - **29.6 kg of 87% enriched ^{76}Ge crystals**
  - **15 kg of ^{nat}Ge**
  - **Detector Technology: P-type, point-contact.**

- **2 independent cryostats**
  - **ultra-clean, electroformed Cu**
  - **20 kg of detectors per cryostat**
  - **naturally scalable**

- **Compact Shield**
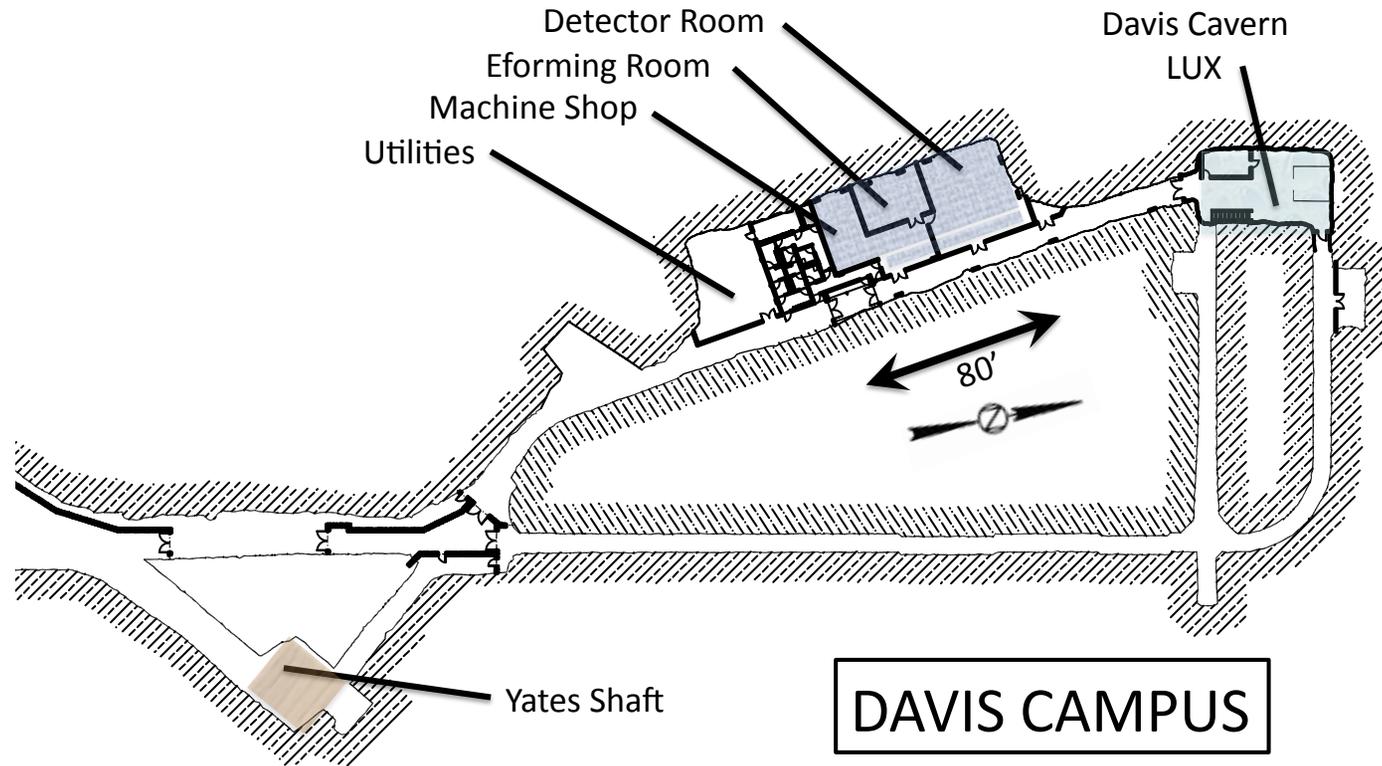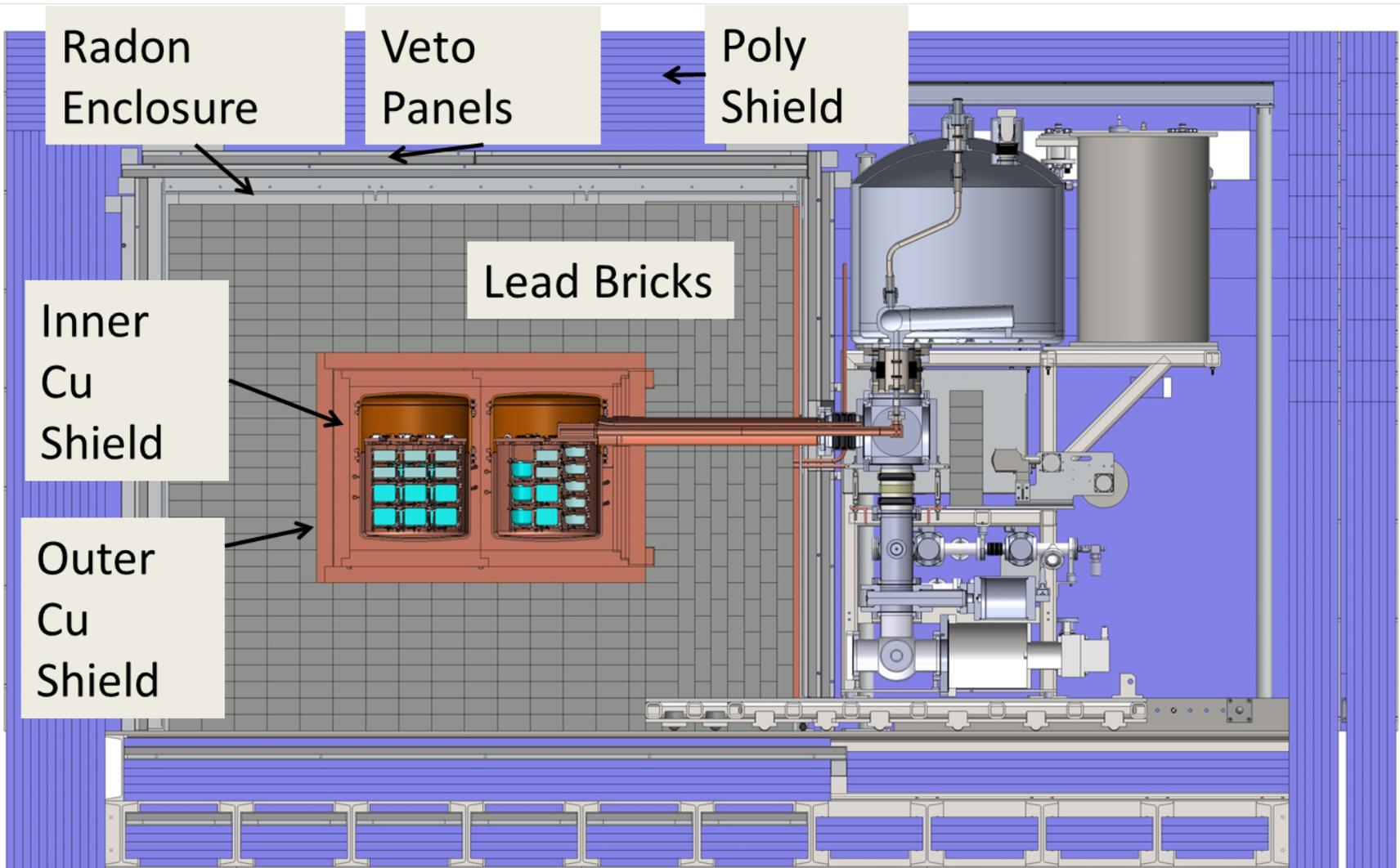 - **low-background passive Cu and Pb shield with active muon veto**

Underground Laboratory

Located at the former Homestake Mine in Lead, SD.

Sanford Underground Research Facility

Underground Laboratory

Detector Room
Eforming Room
Machine Shop
Utilities

Davis Cavern
LUX

80'

Yates Shaft

DAVIS CAMPUS

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Apparatus Overview
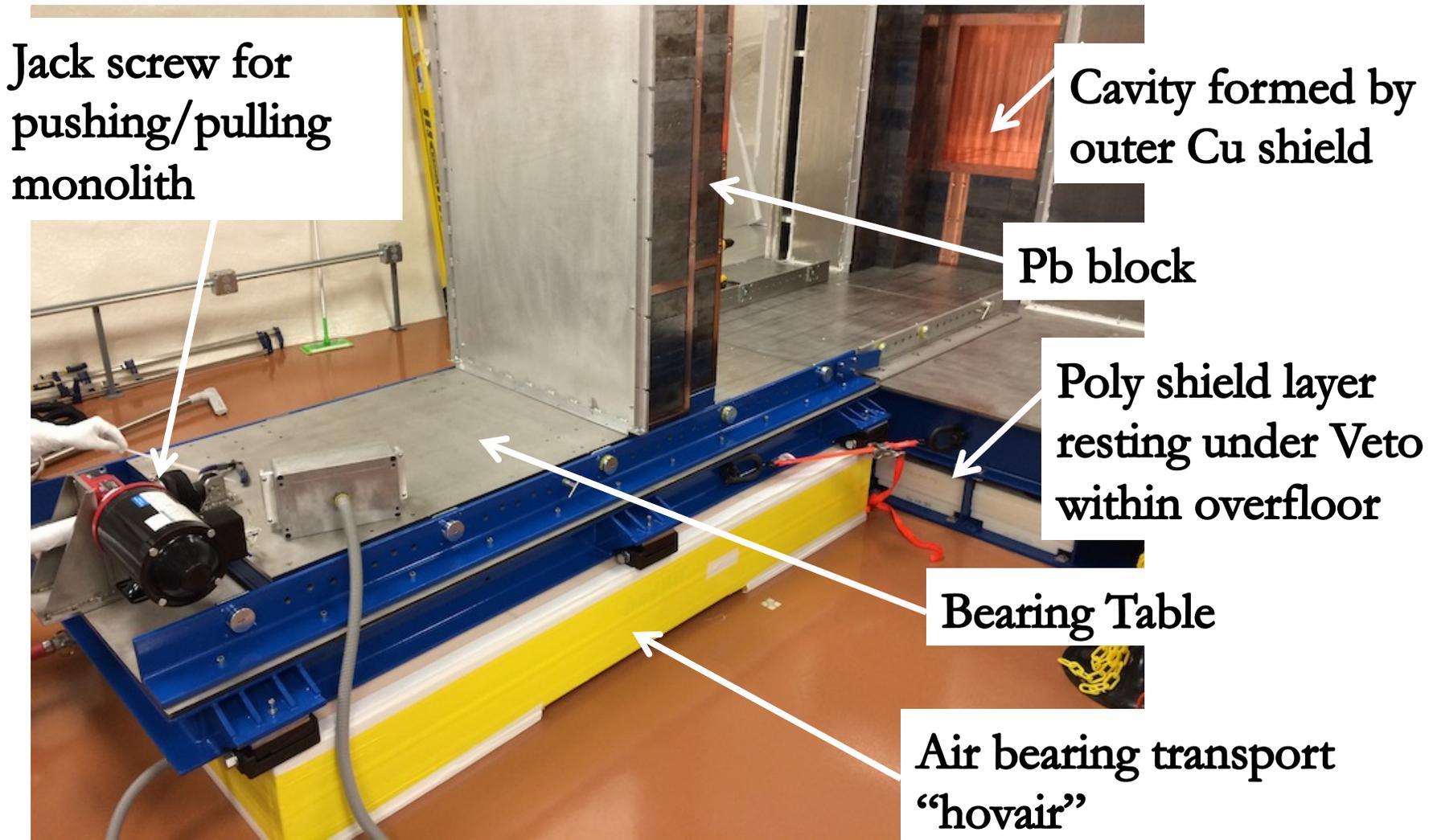
The Shield

Veto + borated poly + poly

The Shield

Note keyed structure of shield

- Inner shield is made of underground electroformed copper surrounded by clean commercial copper.
- Cleaned Lead structure surrounds the inner copper shield.

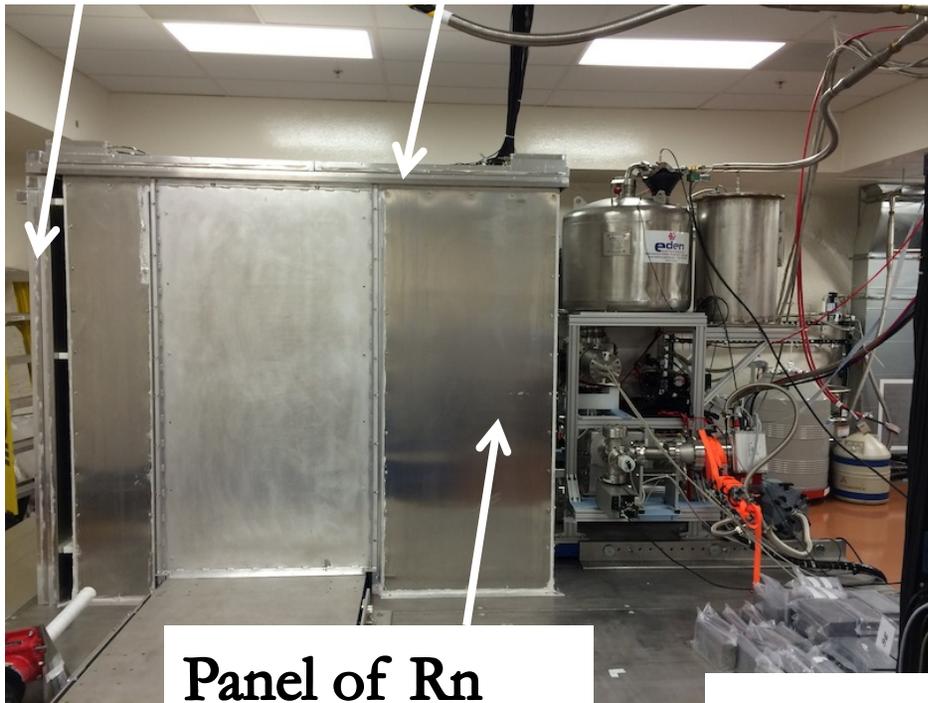# Blank Monolith, when running only one cryostat of detectors

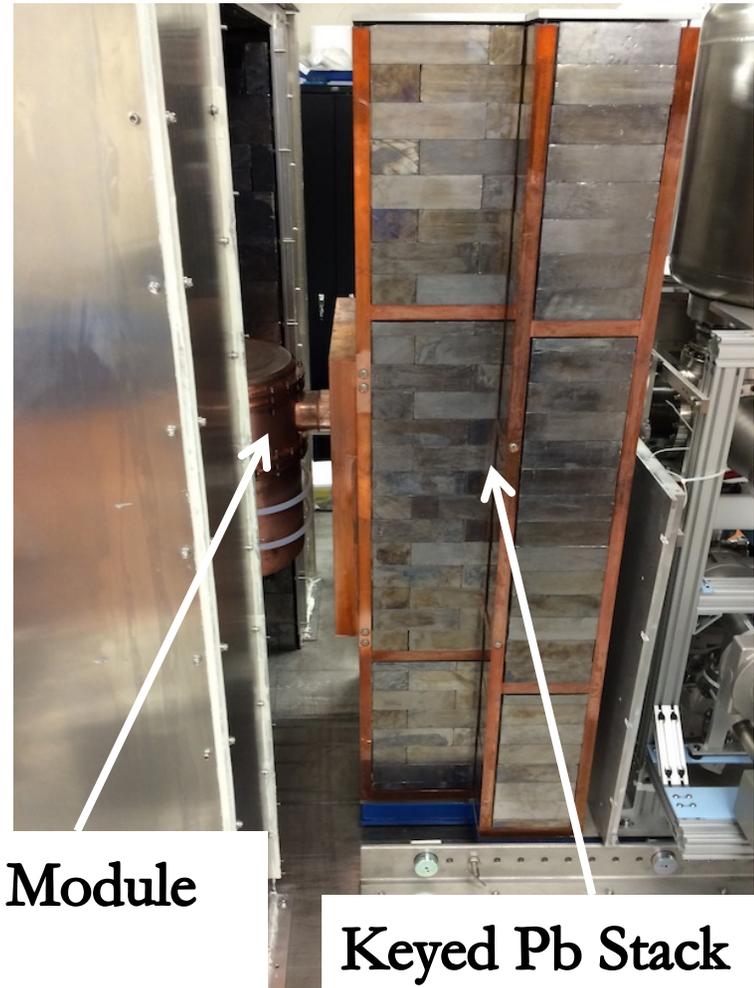Jack screw for pushing/pulling monolith

Cavity formed by outer Cu shield

Pb block

Poly shield layer resting under Veto within overfloor

Bearing Table

Air bearing transport "hovair"

Shield Details

Side Veto

Upper Veto
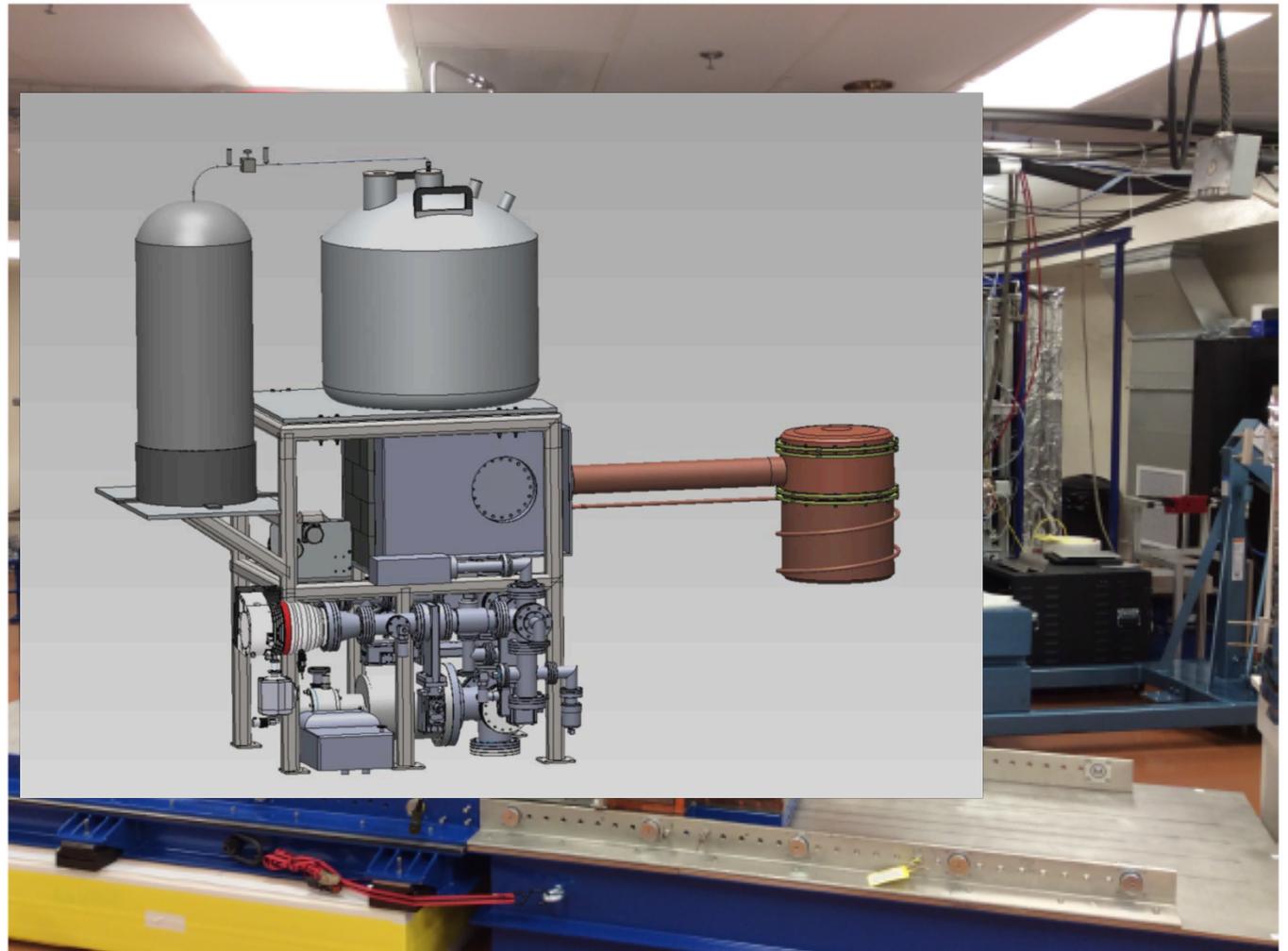
Panel of Rn exclusion box
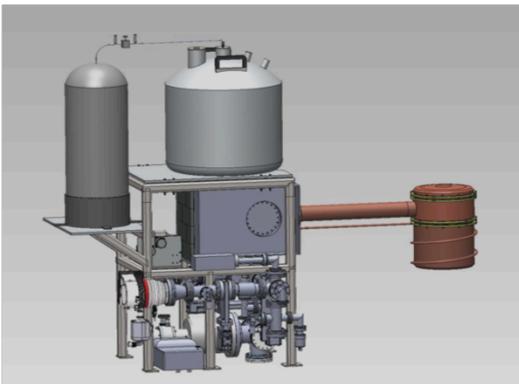
Prototype Module Cryostat

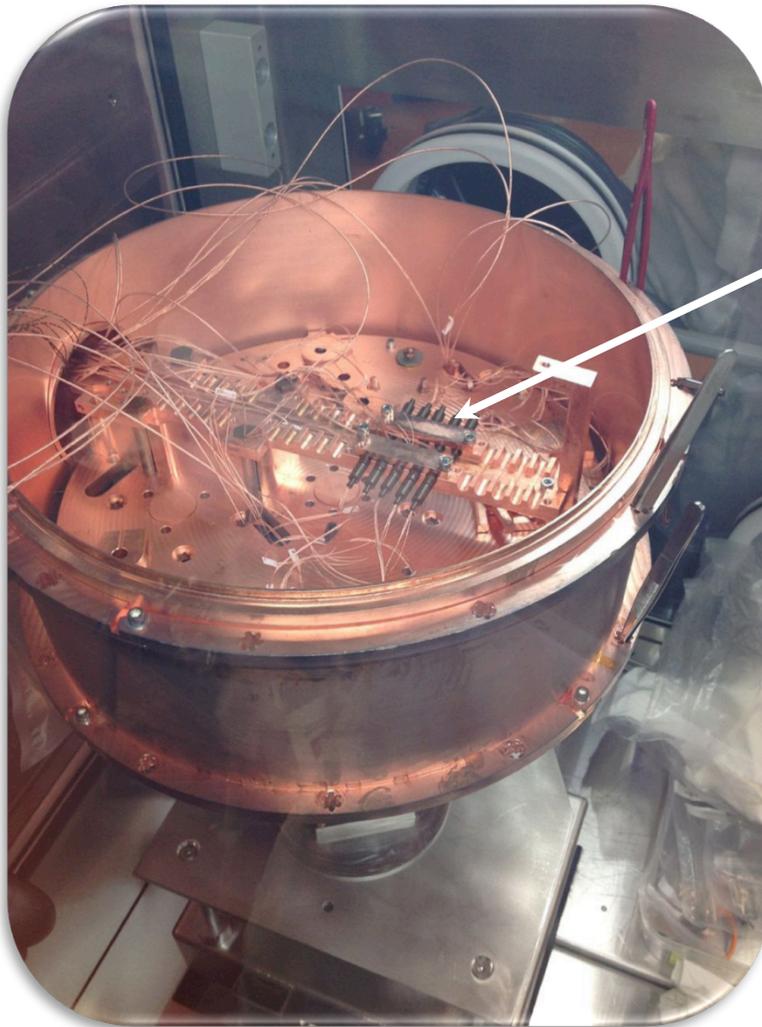Keyed Pb Stack

Modules

A Module is:

- Cryostat
- Thermosyphon
- Vacuum
- Shield Section
- All resting on a movable bearing table

Modules

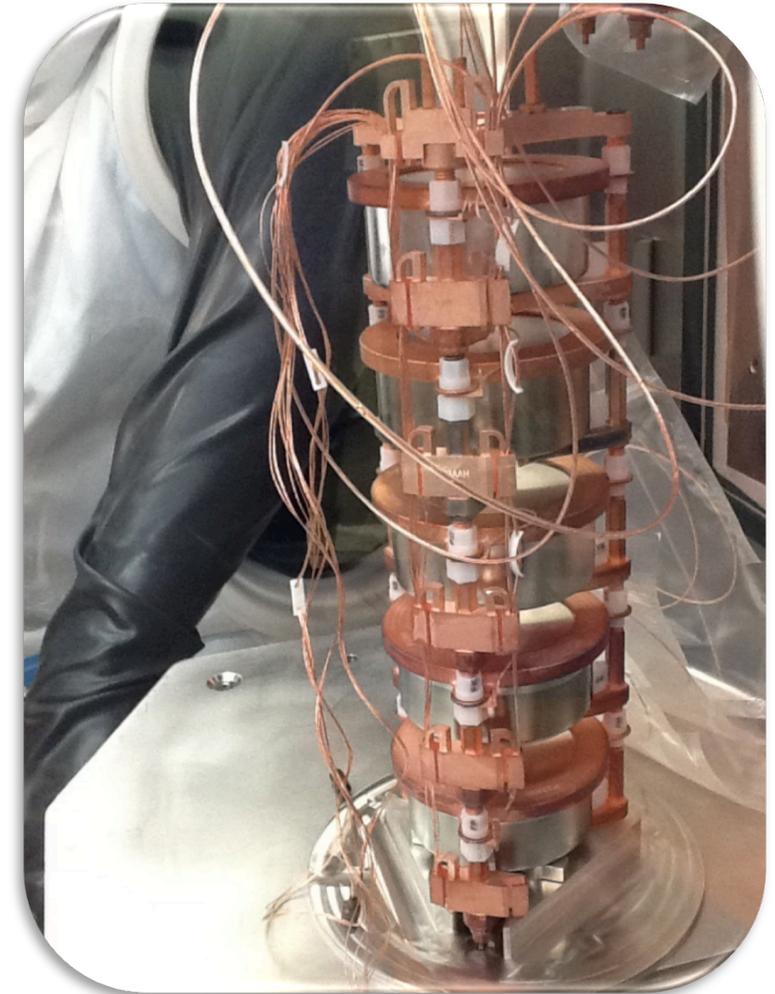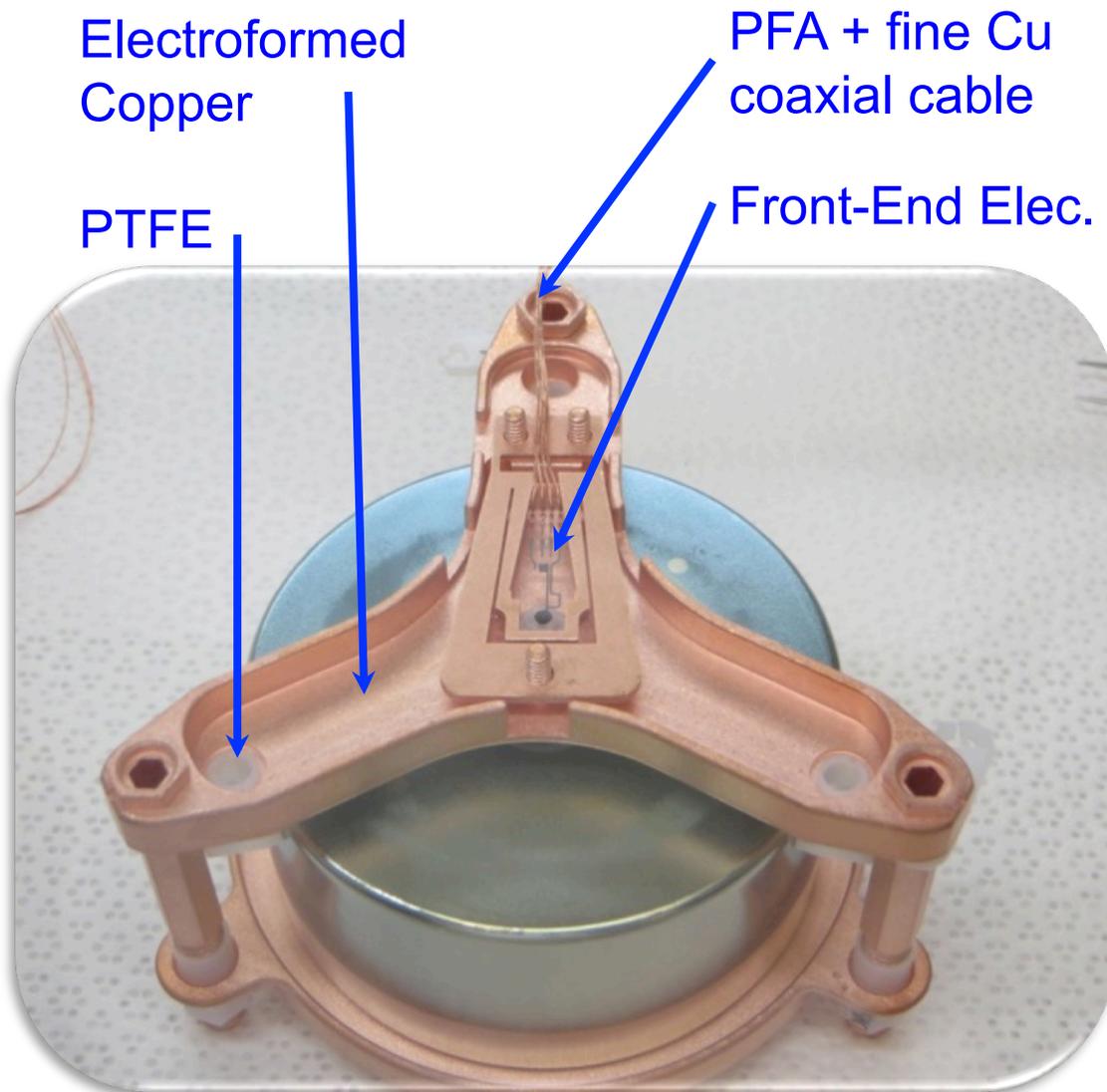# Top of the Cold Plate

Vespel connectors

HV cables are run from vacuum feed-through to detector.
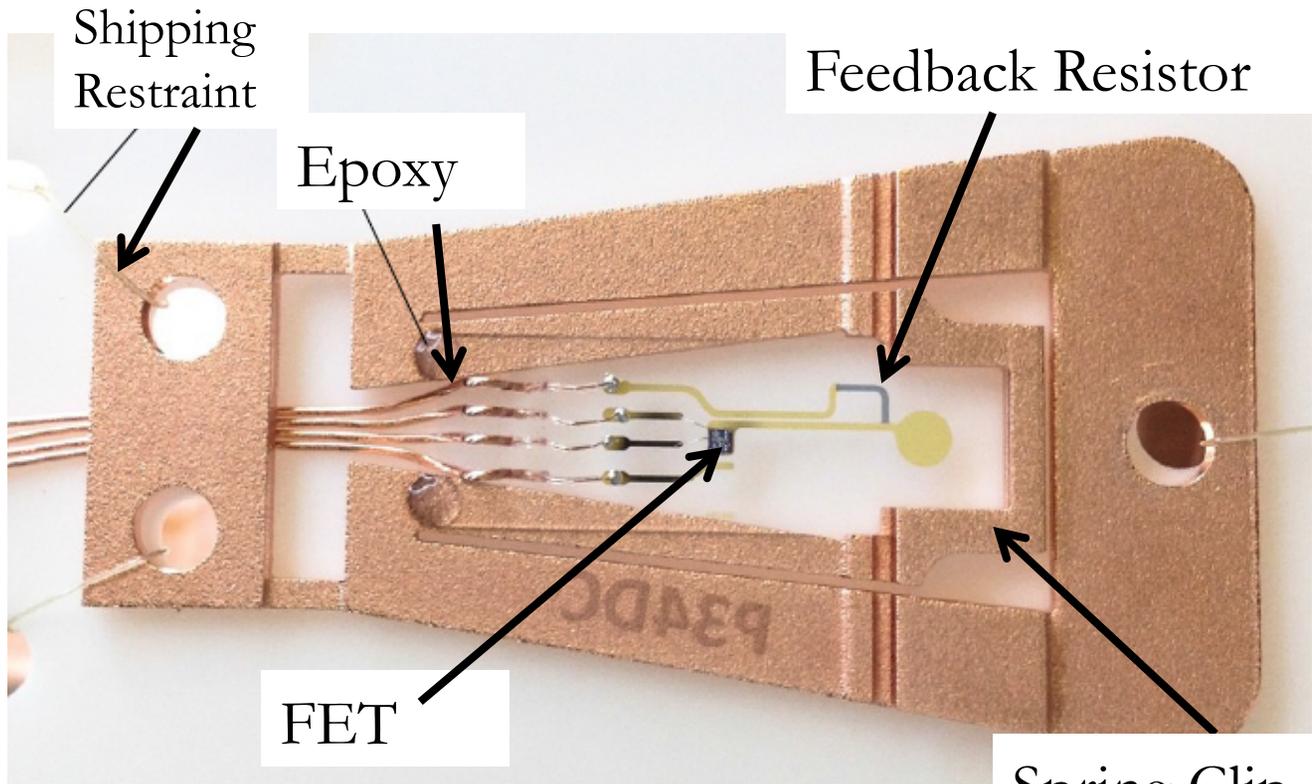
Assembled Detector Unit and String

Electroformed Copper

PTFE

PFA + fine Cu coaxial cable

Front-End Elec.

String Assembly

Electroformed Parts

All detector unit, string, and cryostat components
are made from underground electroformed copper.

Front-End Board

Shipping Restraint

Epoxy

Feedback Resistor

FET

Spring Clip

Clean Au+Ti traces on fused silica, amorphous Ge resistor, FET mounted with silver epoxy, EFCu + low-BG Sn contact pin

Pin

Spring clip

Front_end board

Brandon White
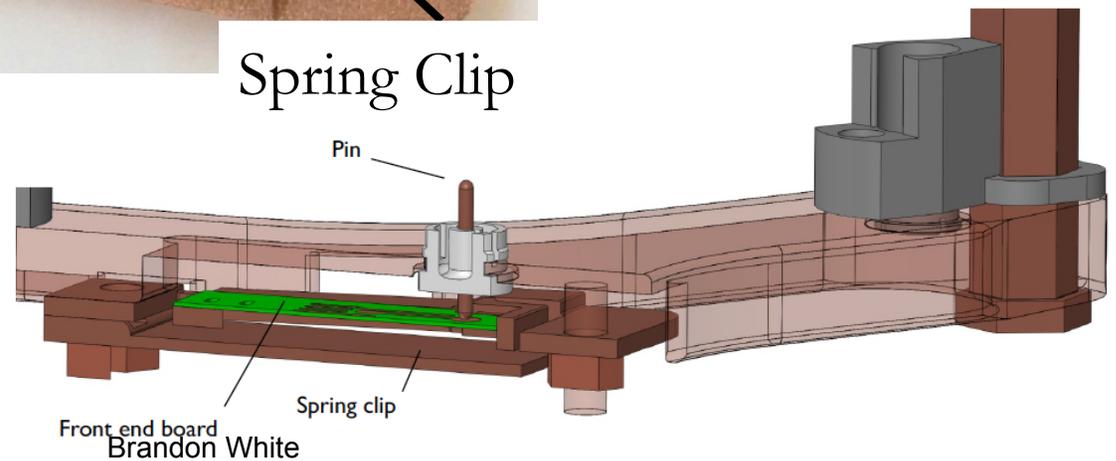
Signal Connectors

Connectors reside on top of cold plate.

In-house machined from vespel. Axon' pico co-ax cable.

Low background solder and flux.
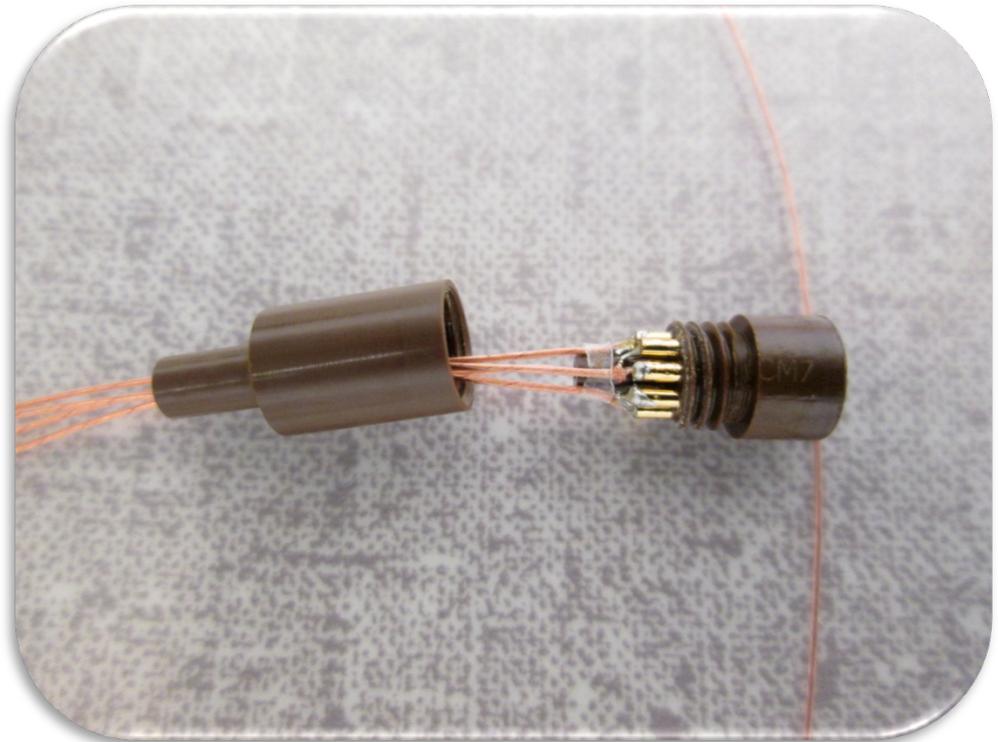
Detectors

P-type point contact (PPC) Ge detectors are used to maximize crystal size and allow for discrimination between multi-site and single-site interactions. This technique allows for the reduction of gamma backgrounds.
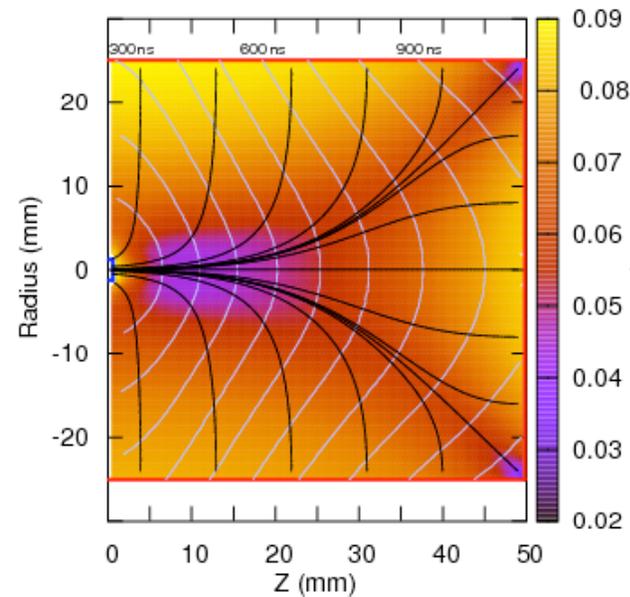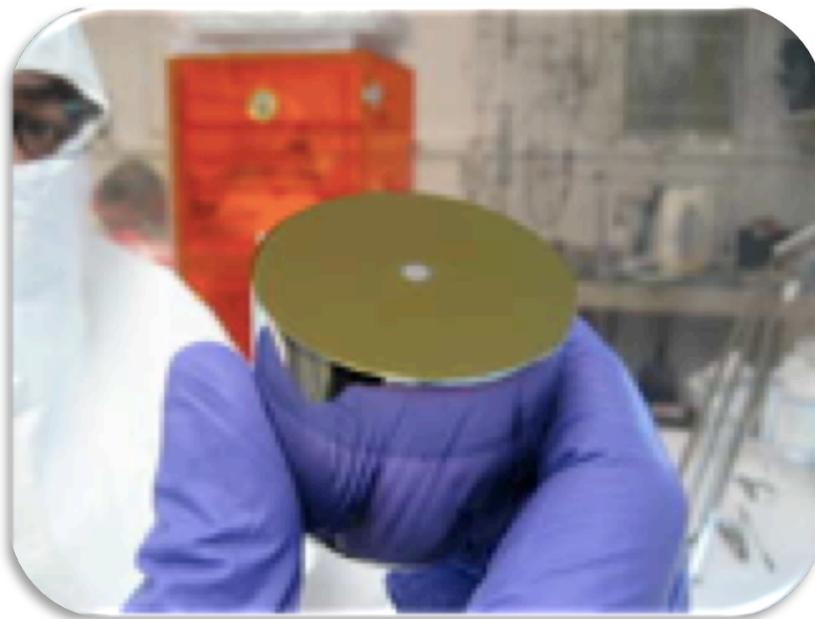

Hole v_{drift} (mm/ns), isocrones (grey) and paths (black)

Materials and Assay

- Significant R&D and advances made in improvement of ICP-MS sensitivity for U and Th in copper near 0.1 mBq/kg level.
- Monitoring U and Th in copper baths electrolyte.
- All plastic materials selected after high sensitivity NAA analysis. Assay complete.
- Significant progress made in development of low background front-end electronics.
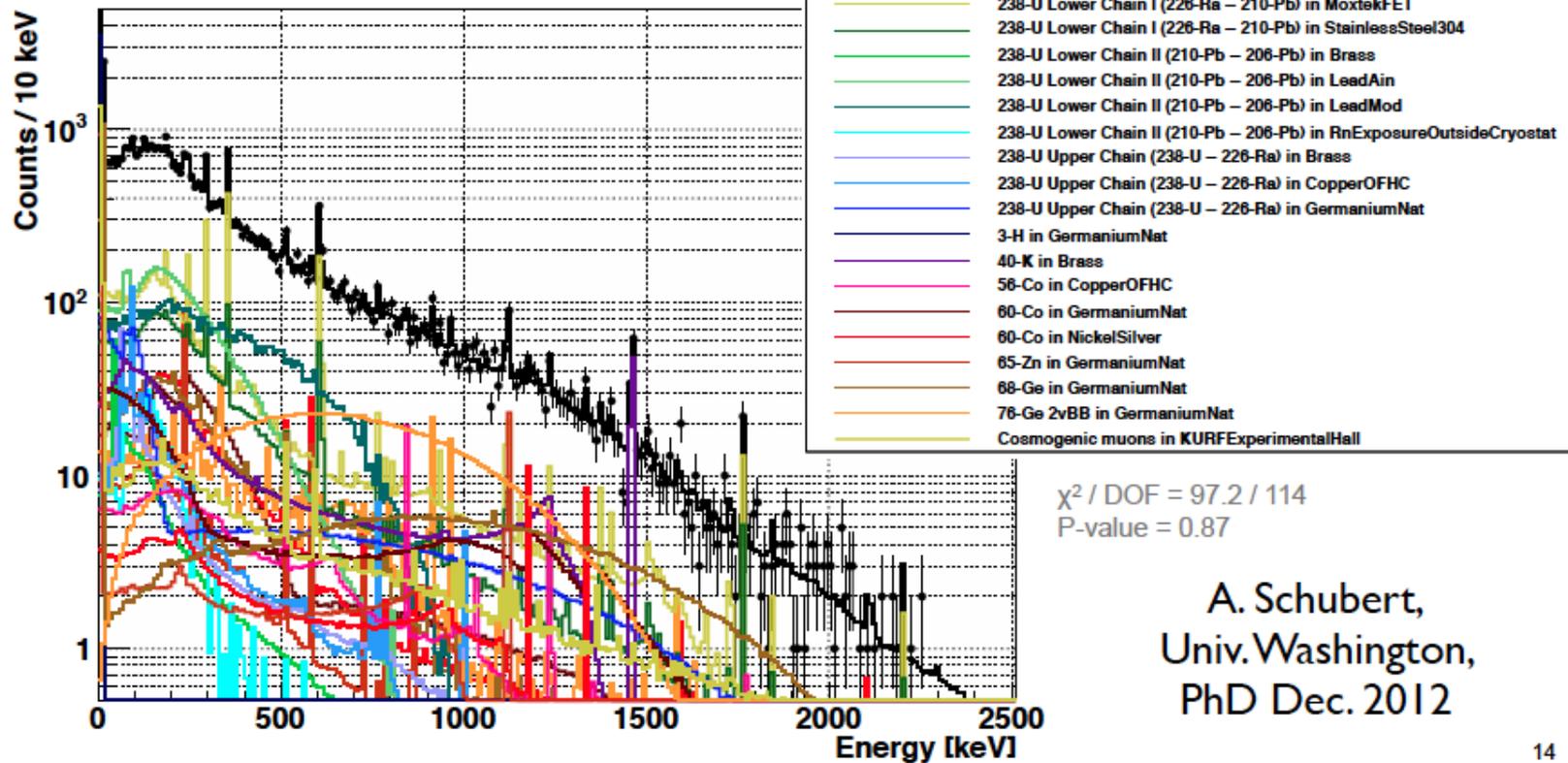

Plastics for NAA analysis

TIG rods in LB count system

Eformed Cu purity studies
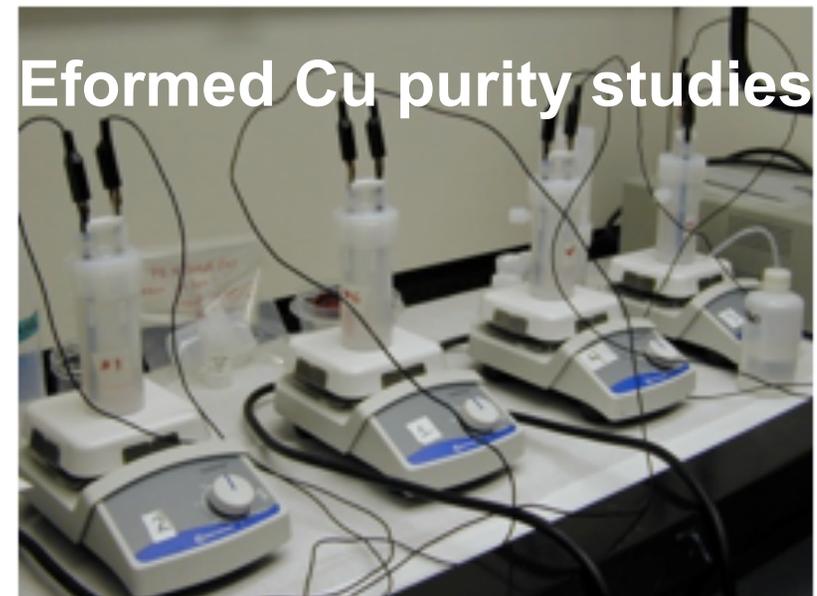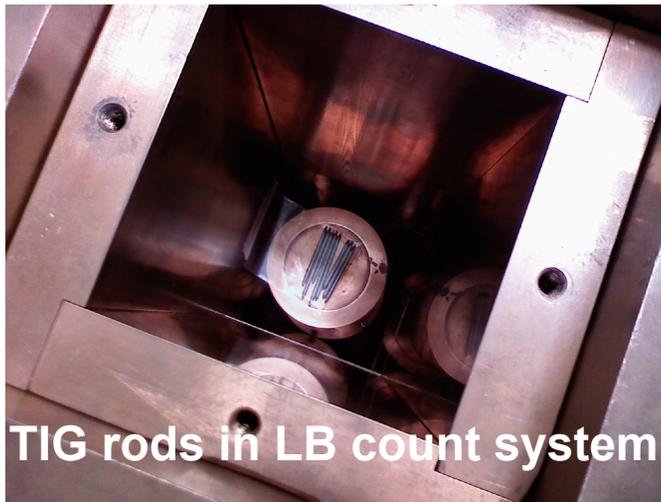
DEMONSTRATOR Background Model

GEANT4 simulations to determine efficiencies for contamination to deposit energy in our detectors

50k CPU hours
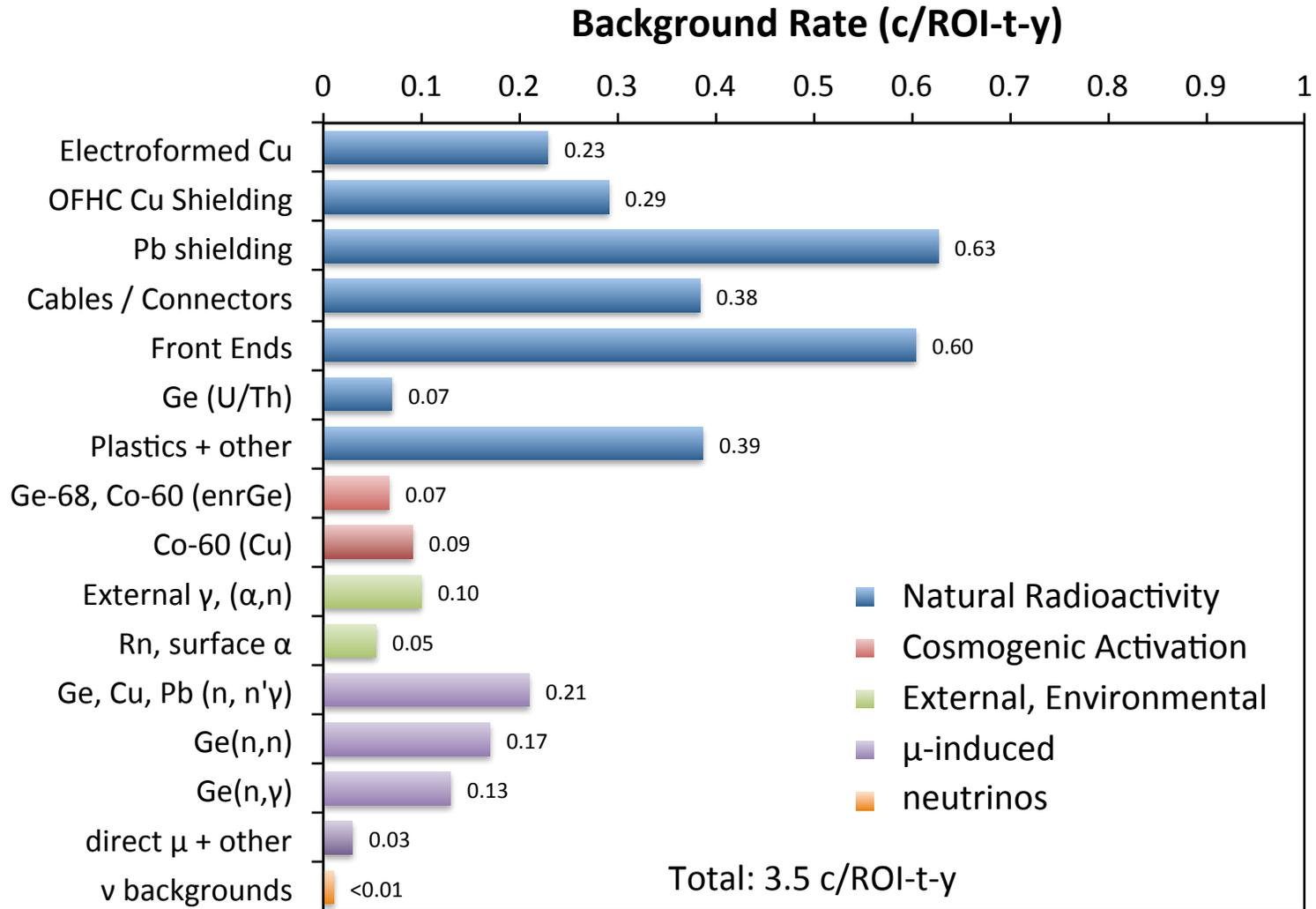
8k+ runs, 40+ contaminants, 56 components, 21 materials

─•─	ORCA/Struck data
───	Fit Result
───	232-Th Lower Chain (224-Ra – 208-Pb) in GermaniumNat
───	232-Th Lower Chain (224-Ra – 208-Pb) in StainlessSteel304
───	232-Th Lower Chain (224-Ra – 208-Pb) in Teflon
───	232-Th Upper Chain (232-Th – 224-Ra) in StainlessSteel304
───	232-Th Upper Chain (232-Th – 224-Ra) in Zeolite
───	238-U Lower Chain I (226-Ra – 210-Pb) in MoxtekFET
───	238-U Lower Chain I (226-Ra – 210-Pb) in StainlessSteel304
───	238-U Lower Chain II (210-Pb – 206-Pb) in Brass
───	238-U Lower Chain II (210-Pb – 206-Pb) in LeadAin
───	238-U Lower Chain II (210-Pb – 206-Pb) in LeadMod
───	238-U Lower Chain II (210-Pb – 206-Pb) in RnExposureOutsideCryostat
───	238-U Upper Chain (238-U – 226-Ra) in Brass
───	238-U Upper Chain (238-U – 226-Ra) in CopperOFHC
───	238-U Upper Chain (238-U – 226-Ra) in GermaniumNat
───	3-H in GermaniumNat
───	40-K in Brass
───	56-Co in CopperOFHC
───	60-Co in GermaniumNat
───	60-Co in NickelSilver
───	65-Zn in GermaniumNat
───	68-Ge in GermaniumNat
───	76-Ge 2νββ in GermaniumNat
───	Cosmogenic muons in KURFExperimentalHall

χ^2 / DOF = 97.2 / 114
P-value = 0.87

A. Schubert,
Univ. Washington,
PhD Dec. 2012

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DEMONSTRATOR Background Model

Background Rate (c/ROI-t-y)

Source	Value
Electroformed Cu	0.23
OFHC Cu Shielding	0.29
Pb shielding	0.63
Cables / Connectors	0.38
Front Ends	0.60
Ge (U/Th)	0.07
Plastics + other	0.39
Ge-68, Co-60 (enrGe)	0.07
Co-60 (Cu)	0.09
External γ, (α,n)	0.10
Rn, surface α	0.05
Ge, Cu, Pb (n, n'γ)	0.21
Ge(n,n)	0.17
Ge(n,γ)	0.13
direct μ + other	0.03
ν backgrounds	<0.01

Legend:
- Natural Radioactivity
- Cosmogenic Activation
- External, Environmental
- μ-induced
- neutrinos

Total: 3.5 c/ROI-t-y

Outline

- Neutrinoless $\beta\beta$ decay
- MAJORANA Demonstrator
- **Experiment Status**

Detectors

- **Germanium was enriched in Russia and shipped by sea to Oak Ridge.**

- **Germanium was stored underground when not in detector production.**

Iron Shipping Contain[er]
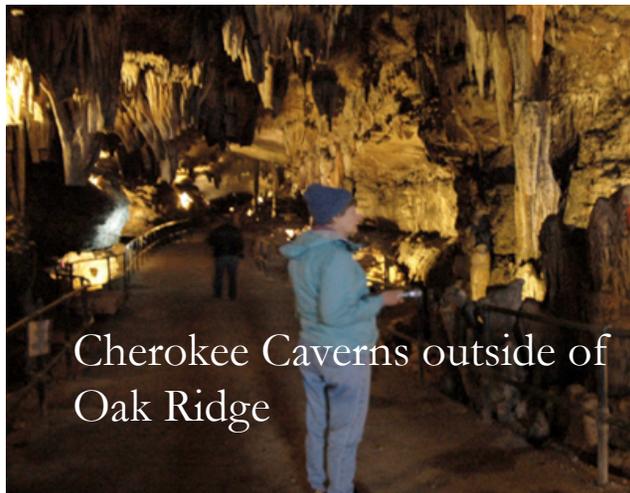
Cherokee Caverns outside of Oak Ridge

Graph — Number of Ge-68 Atoms per kg vs Date

Labels: Storage at ECP, Second half of material, Ship to US, Storage at Cherokee, ESI Processing, Storage at Cherokee, Detector Fabrication, Storage at Cherokee, Transport to SURF, Storage at SURF

Activation of first batch of Ge Specification: 178 atoms/kg when counting starts.

X-axis dates: 7/1/11, 1/1/12, 7/1/12, 1/1/13, 7/1/13, 1/1/14
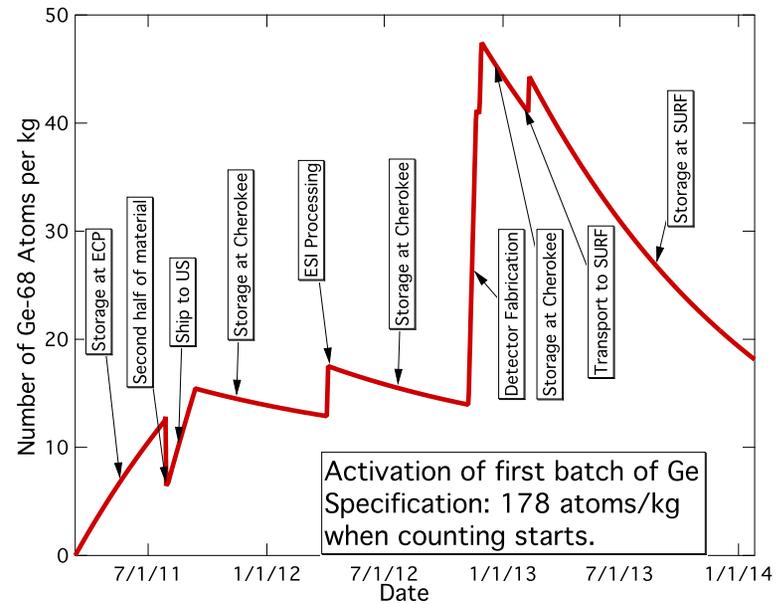
Detectors

- **ORTEC selected for enriched detectors from early 2013 through June 2015.**
- **35 Enriched detectors at SURF 29.7 kg, 87% ^{76}Ge**
- **20 kg of modified natural-Ge BEGe (Canberra) detectors in hand (33 detectors UG).**

Dimensional Measurement

UG Detector Assembly
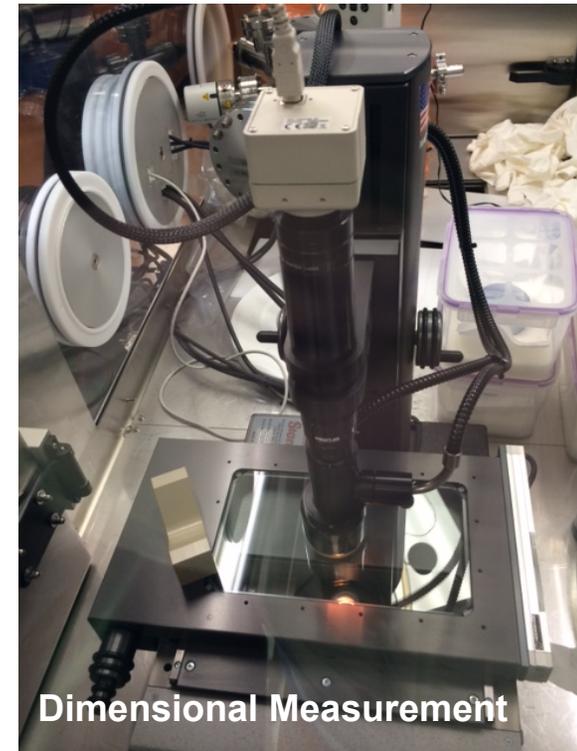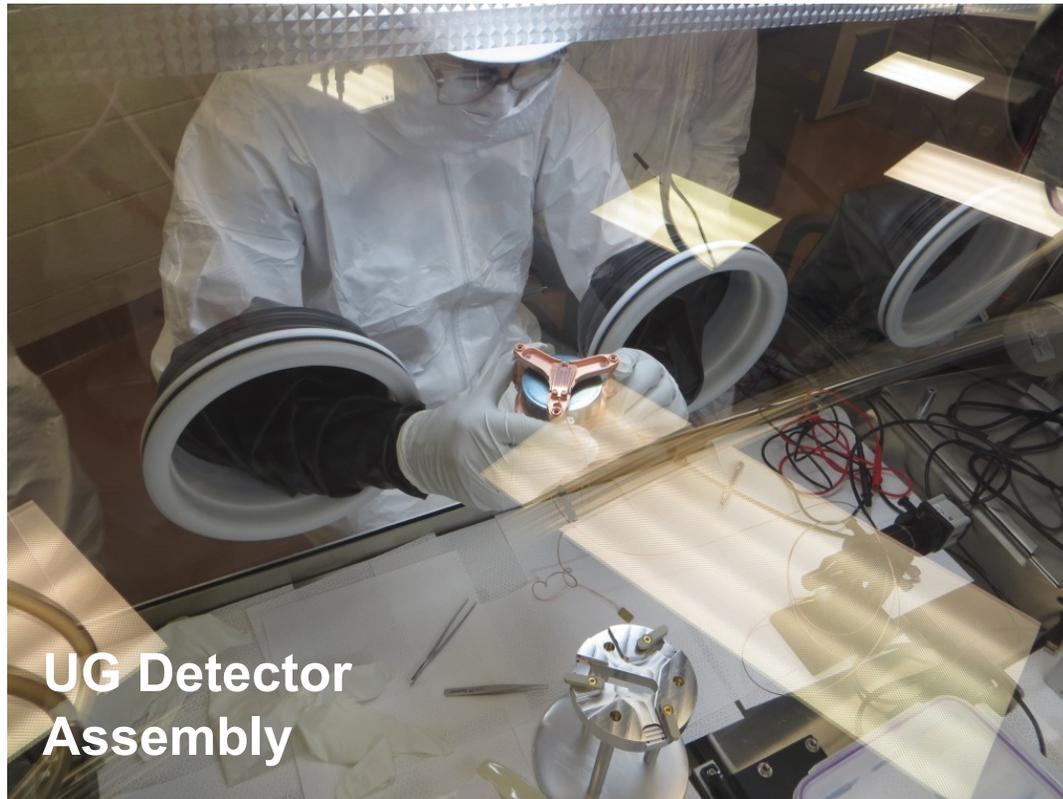
- **All detector related assembly performed in N_2 purged gloveboxes.**
- **All detectors' dimensions recorded by optical reader.**

Detector Resolution
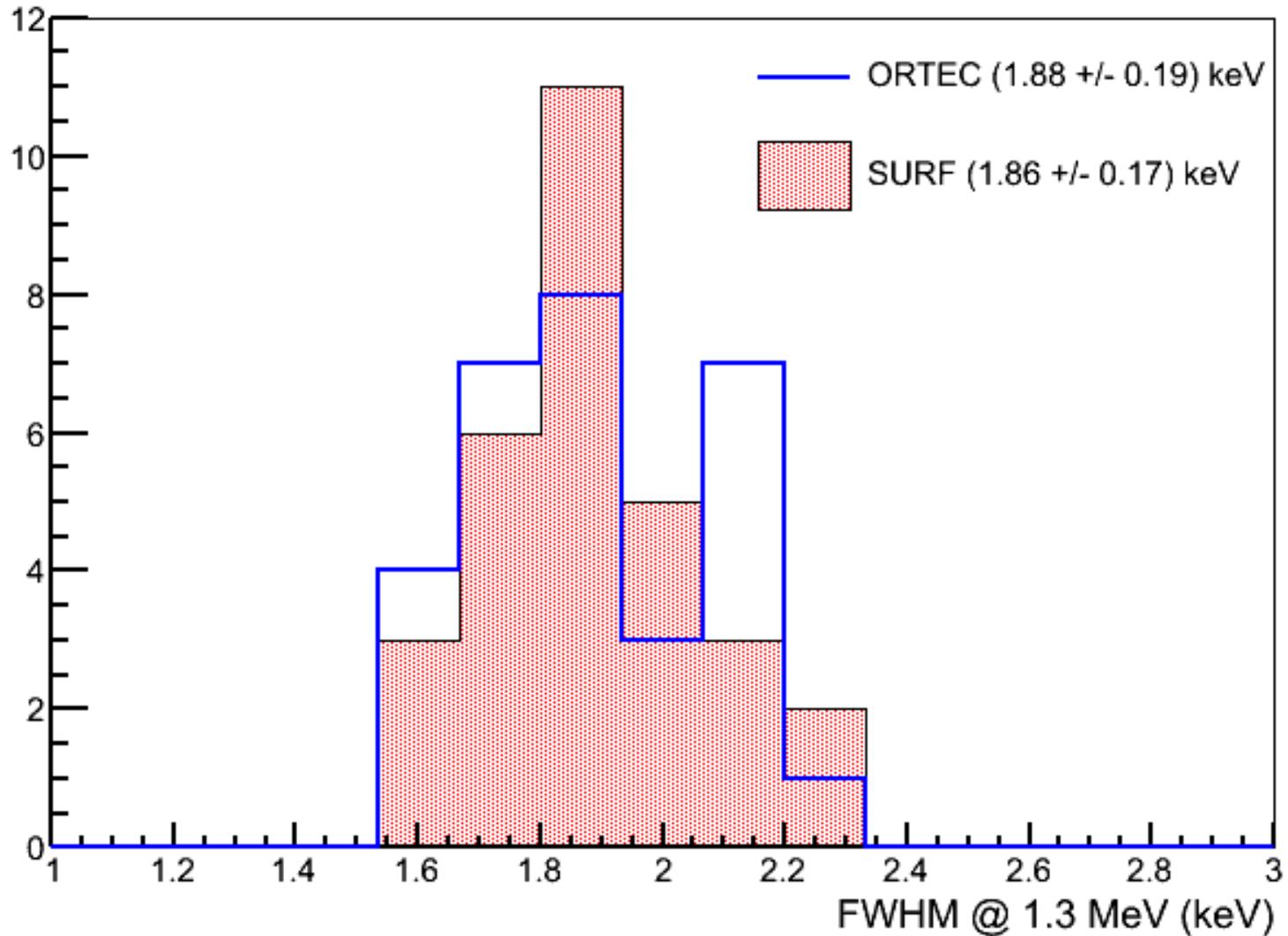
Detector Resolution

At 1332 keV, FWHM = 1.98 keV +/- 0.024 keV
At 2614 keV, FWHM = 2.72 keV +/- 0.15 keV
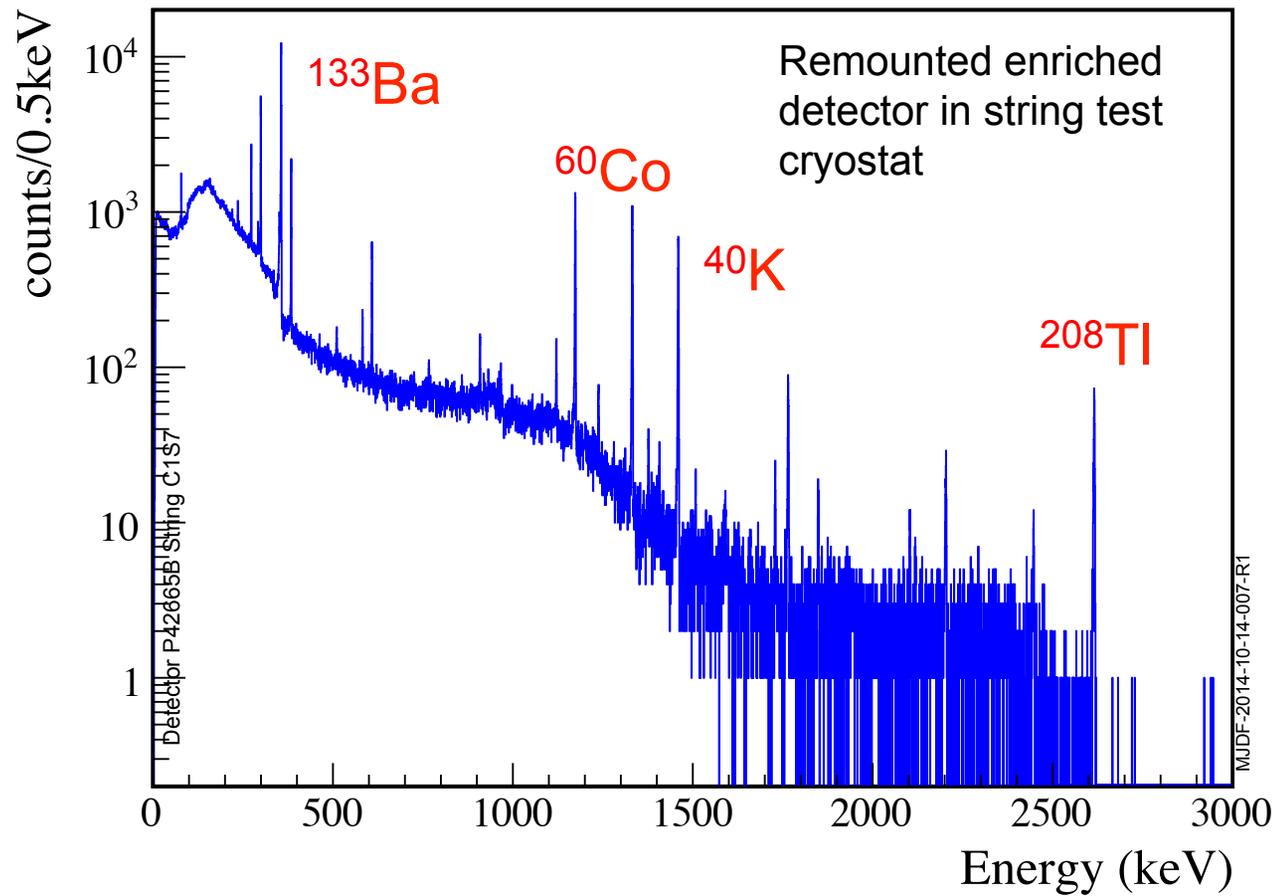
Pulse Shape Discrimination

Natural BEGe detector in Prototype Cryostat

B8466
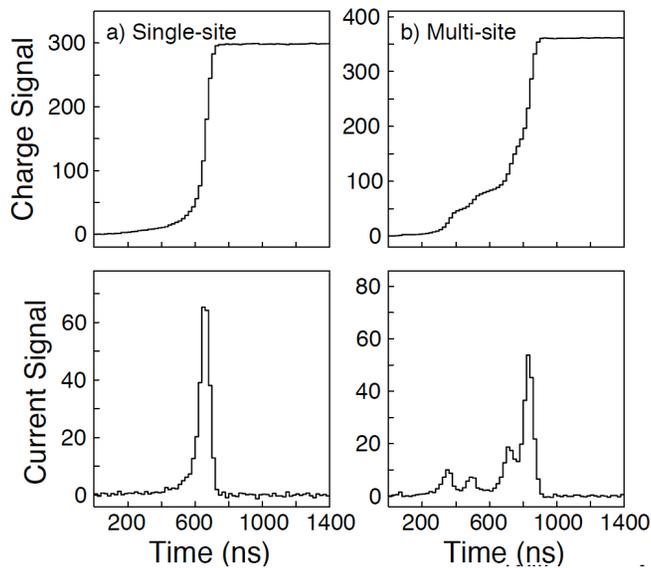
Rising Edge for singe and multi-site events
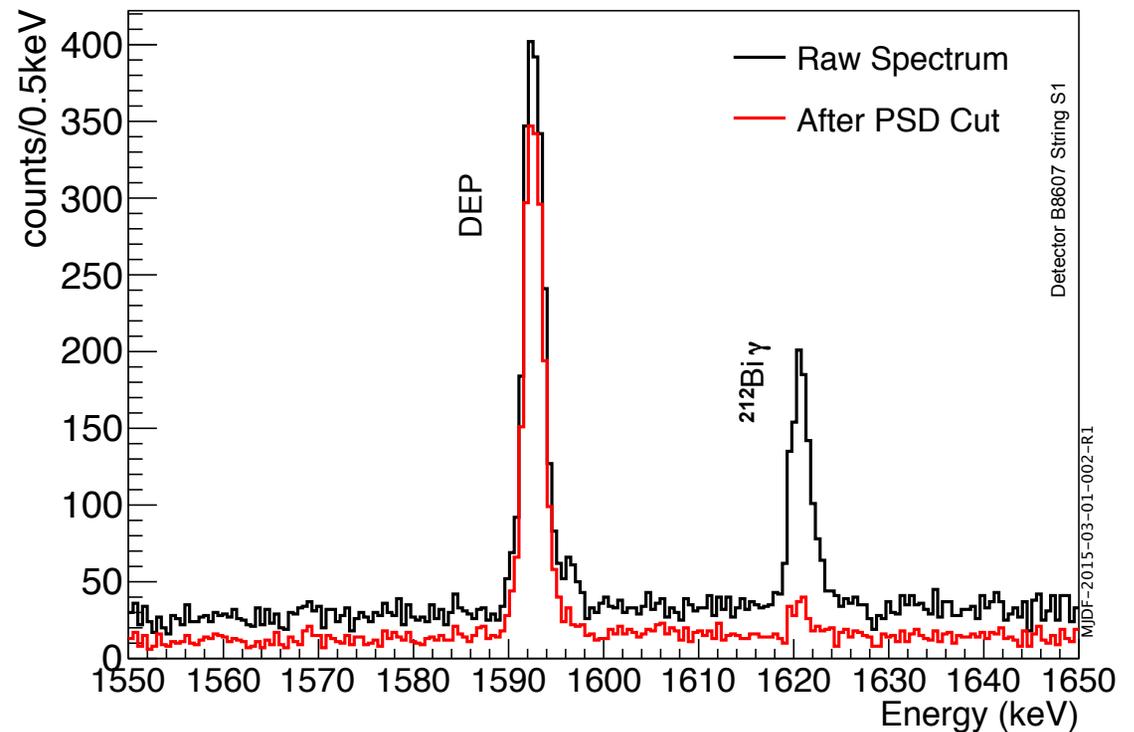
Brandon White

Electroforming

Temporary Clean Room at Ross Shops

Installation of mandrel in bath

Underground Electroformed copper growing since 2011.
Electroforming completed May 2015

MJD Status

Underground Clean Machine Shop operating since early 2012

Bake/Quench

Copper ready to cut

Flattened Plate

Clean Lab Occupancy Since Summer 2012

The Shield

- Pb shield constructed
- Outer Cu shield layer installed
- Rn exclusion box installed
- Poly layers being installed
- Hovair in-use underground
- Most veto panels operational
- Calibration system demonstrated

MAJORANA DEMONSTRATOR Implementation

Three Steps

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

Same design as Modules 1 and 2, but fabricated using OFHC Cu Components
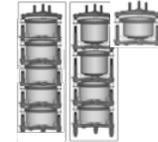
June 2014

Module 1: 16.8 kg (20) ^{enr}Ge
5.7 kg (9) ^{nat}Ge
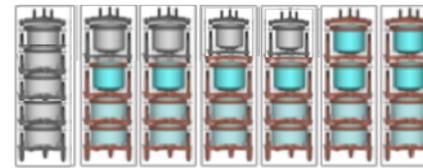
May 2015

Module 2: 12.6 kg (14) ^{enr}Ge
9.4 kg (15) ^{nat}Ge
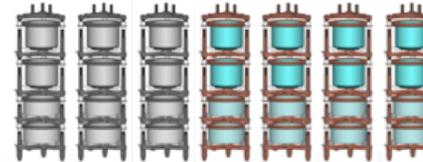
End 2015
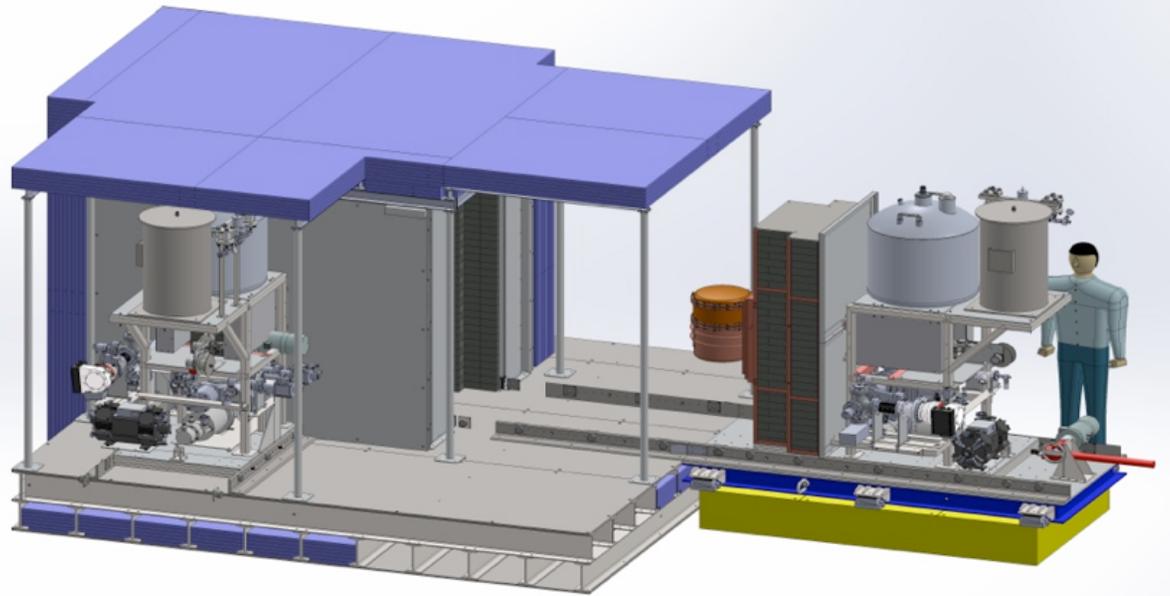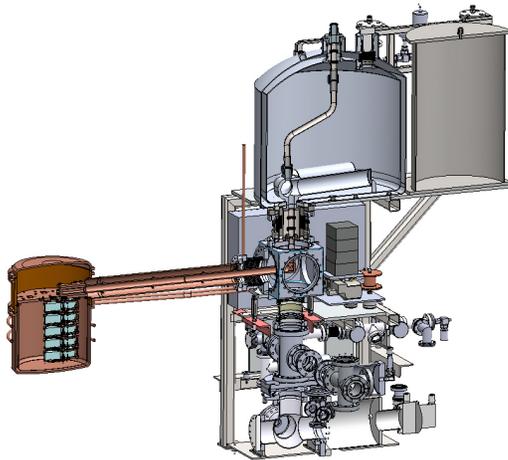
Modules

- Prototype cryostat operating, over 140 d live.
- Prototype was populated with two full strings and one single detector string of natural Ge detectors.
- Commercial copper components were used.

Modules

Module 1 currently in commissioning phase.

Module 2 construction and commissioning by the end of 2015

Sensitivity, Background and Exposure
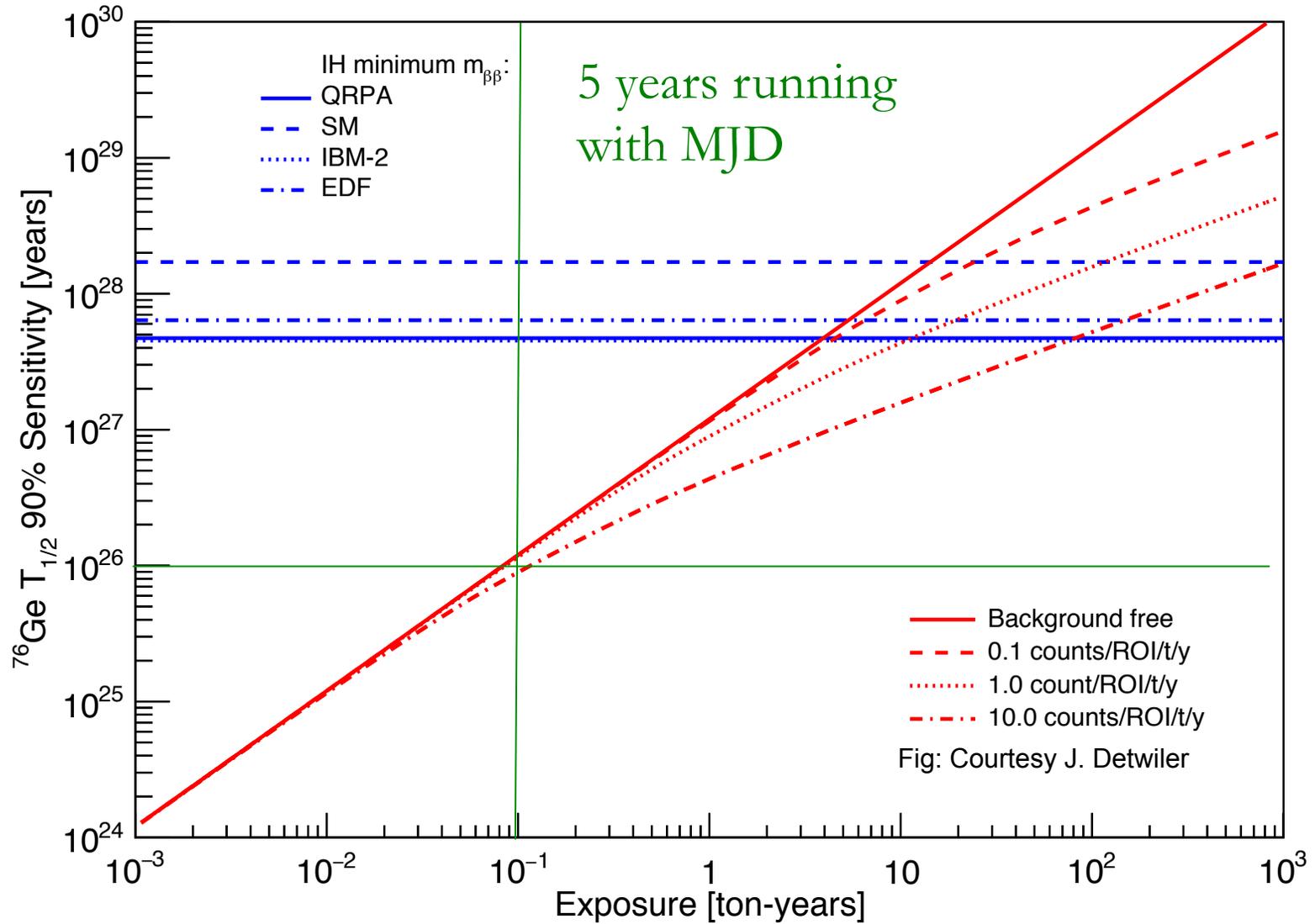
Fig: Courtesy J. Detwiler

Acknowledgements

Thank you to the organizers of
the conference

Simulation: MJD 0-10 MeV

MJD, 5-year exposure

Background Level
A sample of that level
90% CL UL
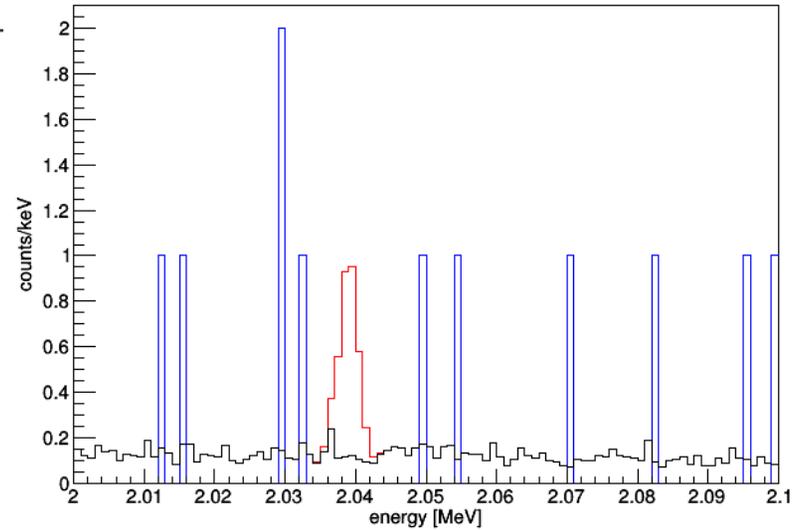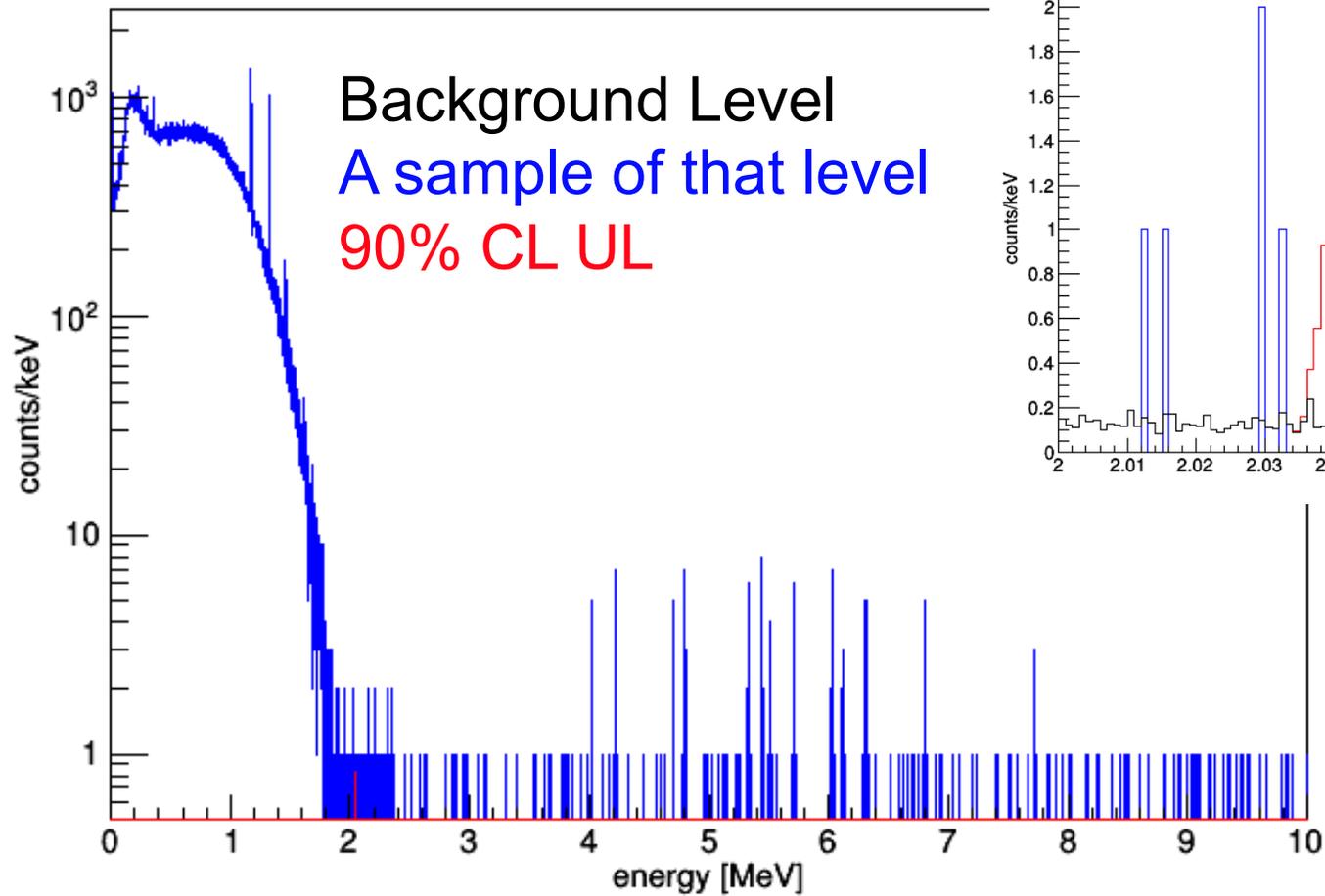
Backup

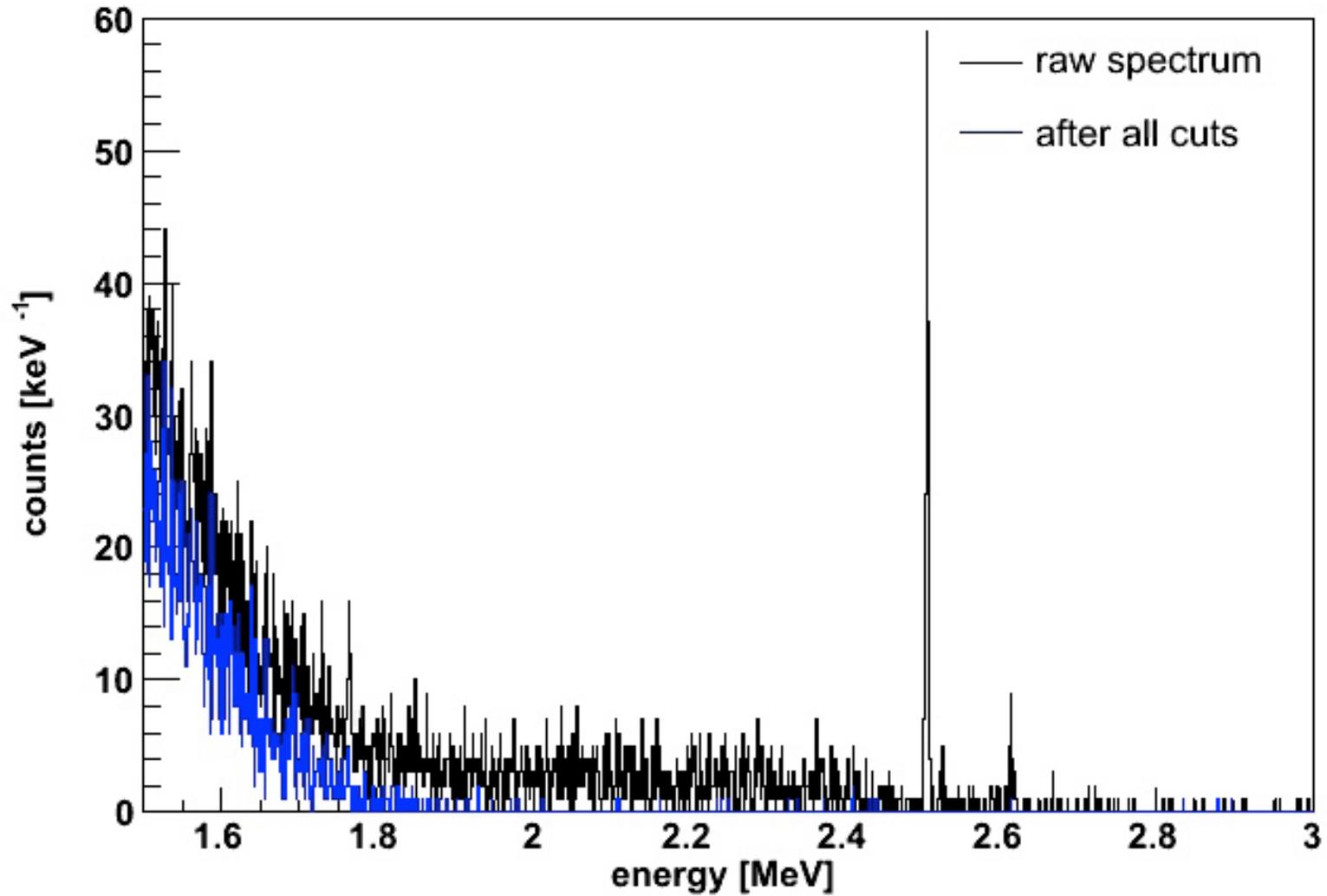Scaling from MJD projects

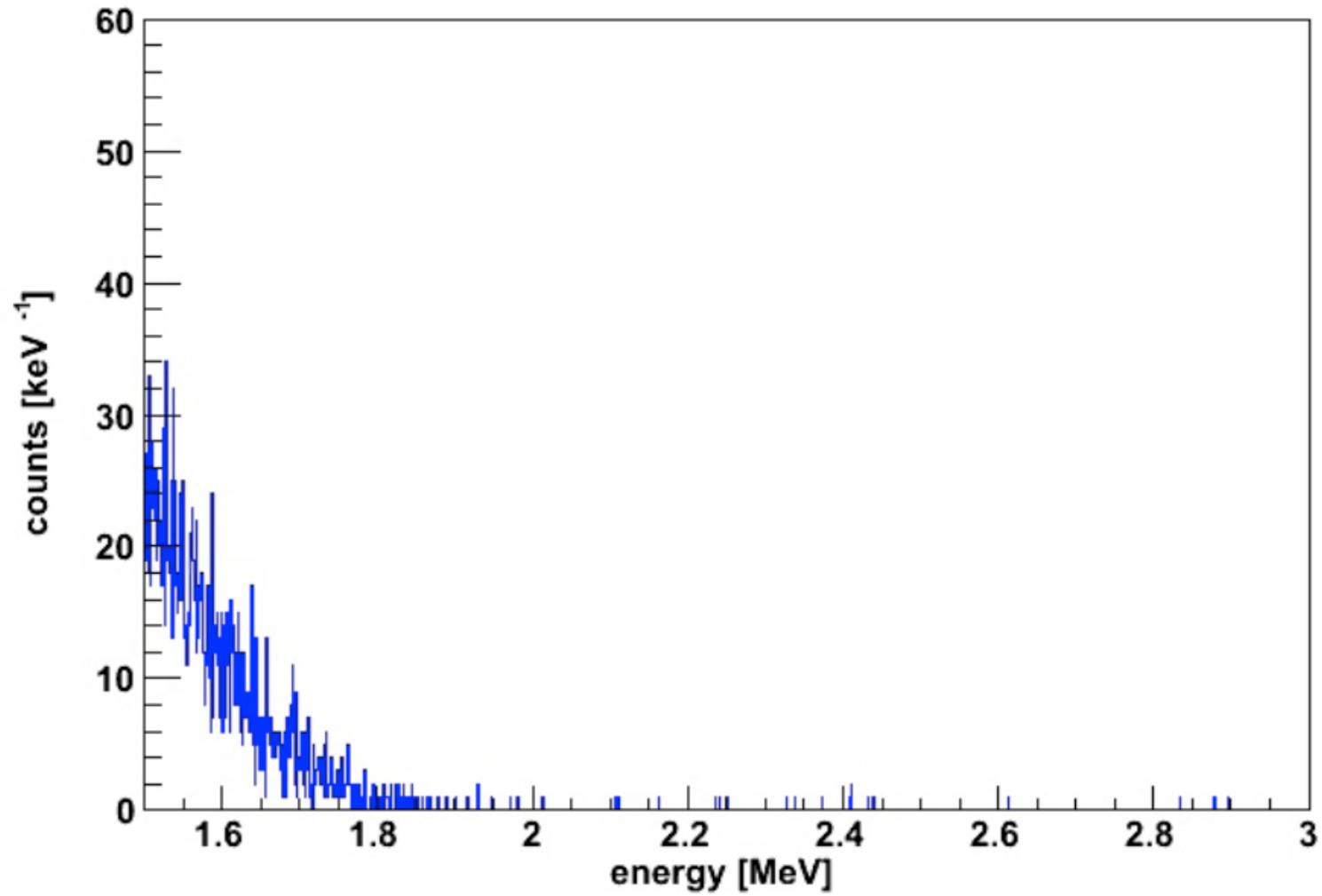Tonne-sclae 76Ge 0νββ background goals [cnts/ROI-t-y]

Brandon White
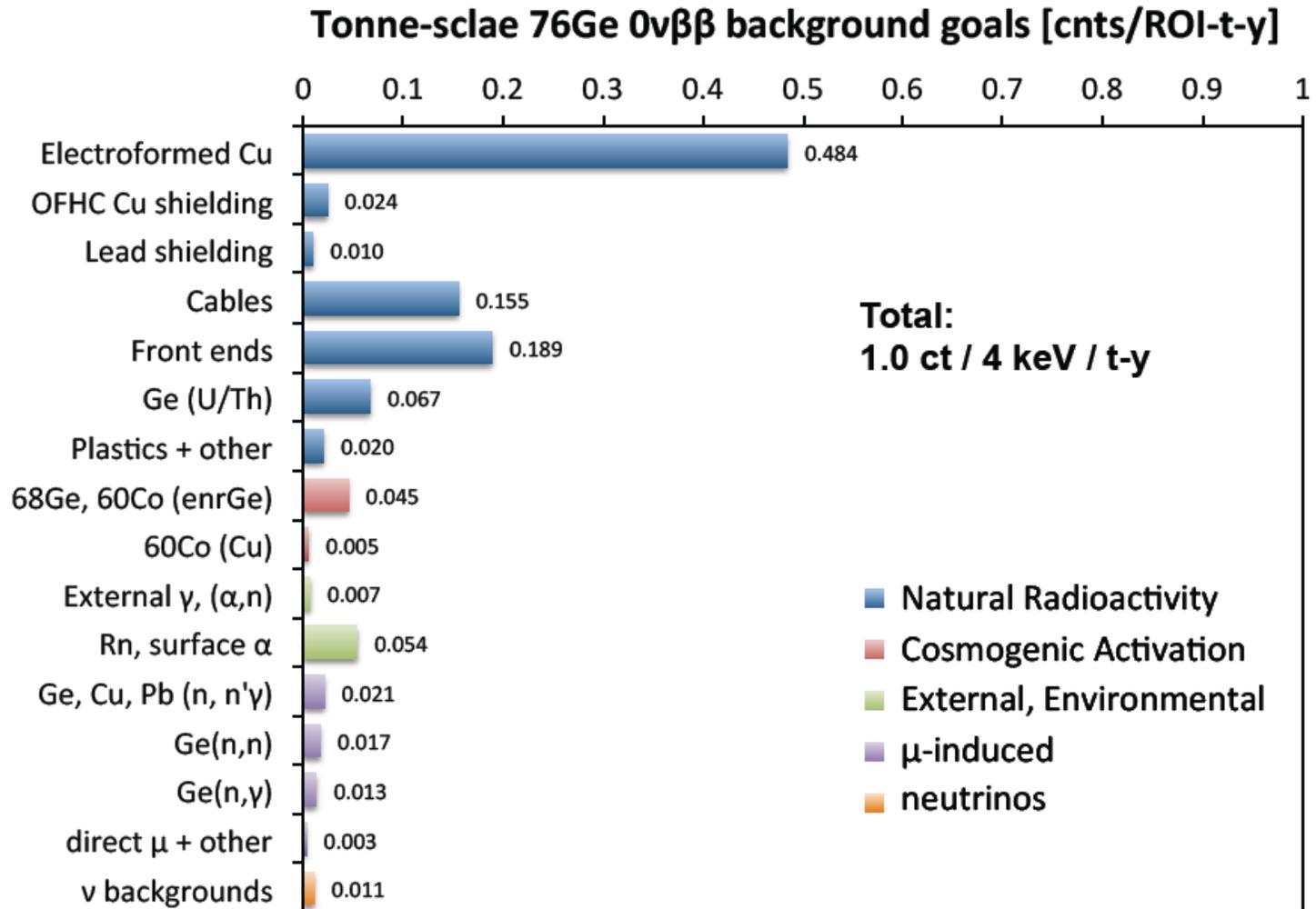
Backup

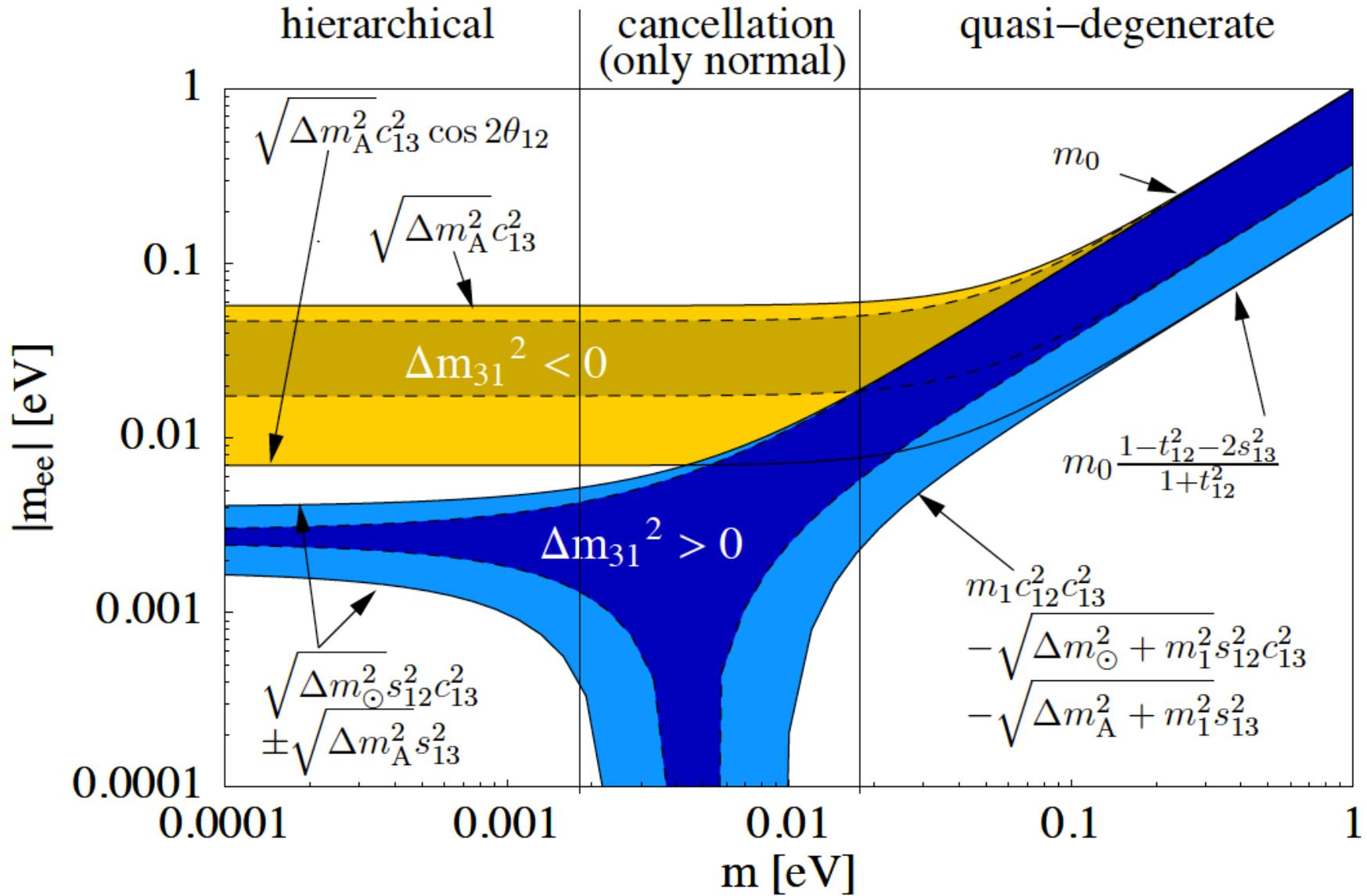Simulated spectra, 60 kg yrs, detector resolution applied

Backup

Simulated spectra, 60 kg yrs, detector resolution + all cuts applied
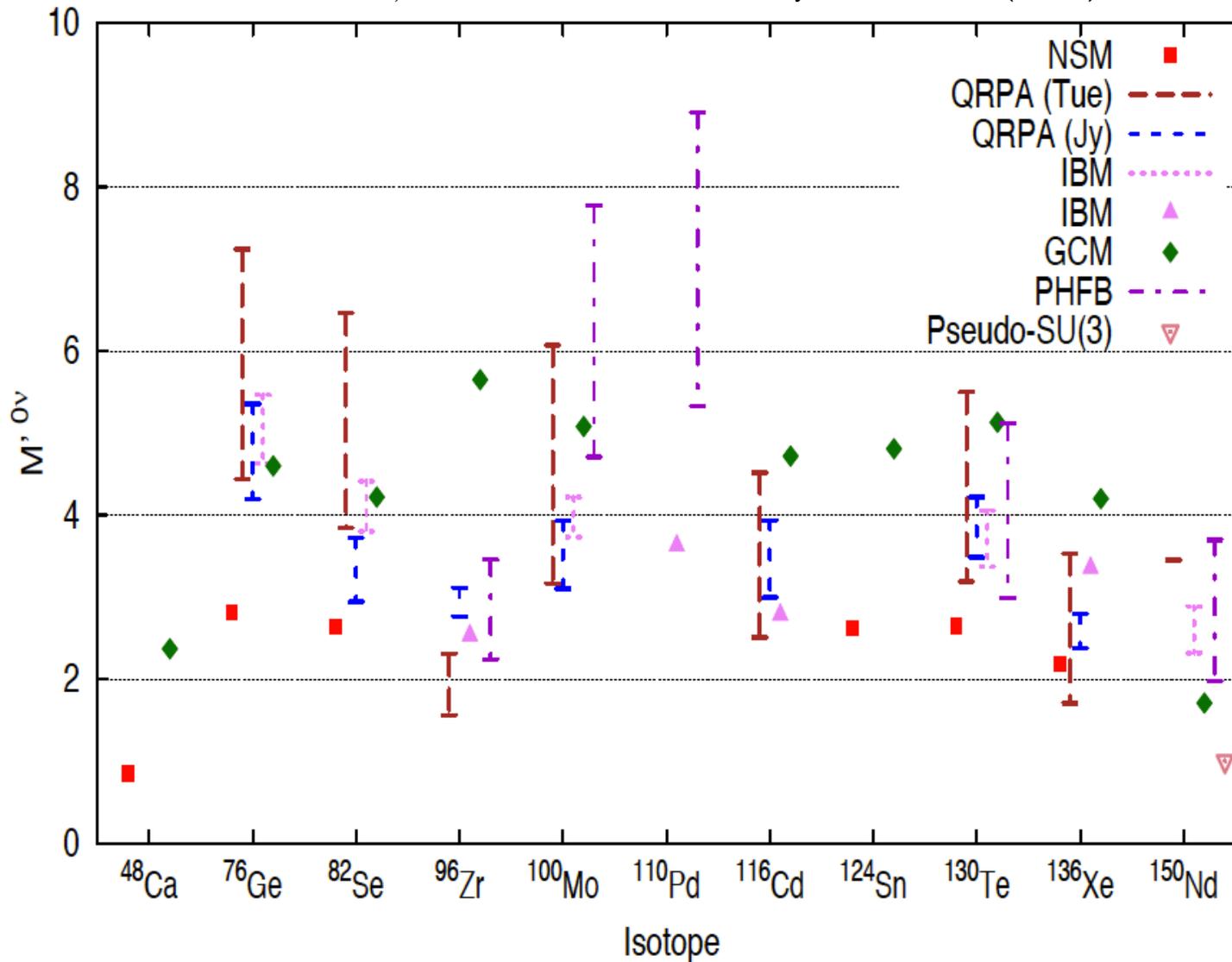
Brandon White

Backup

Backup

A.Dueck, W. Rodejohann and K. Zuber, Phys. Rev. D83 (2011)

Backup

H.V. Klapdor‑Kleingrothaus And I. V. Krivosheina, Mod. Phys.
LeN. A 21, 1547 (2006)