The MAJORANA Neutrinoless Double-Beta Decay Program

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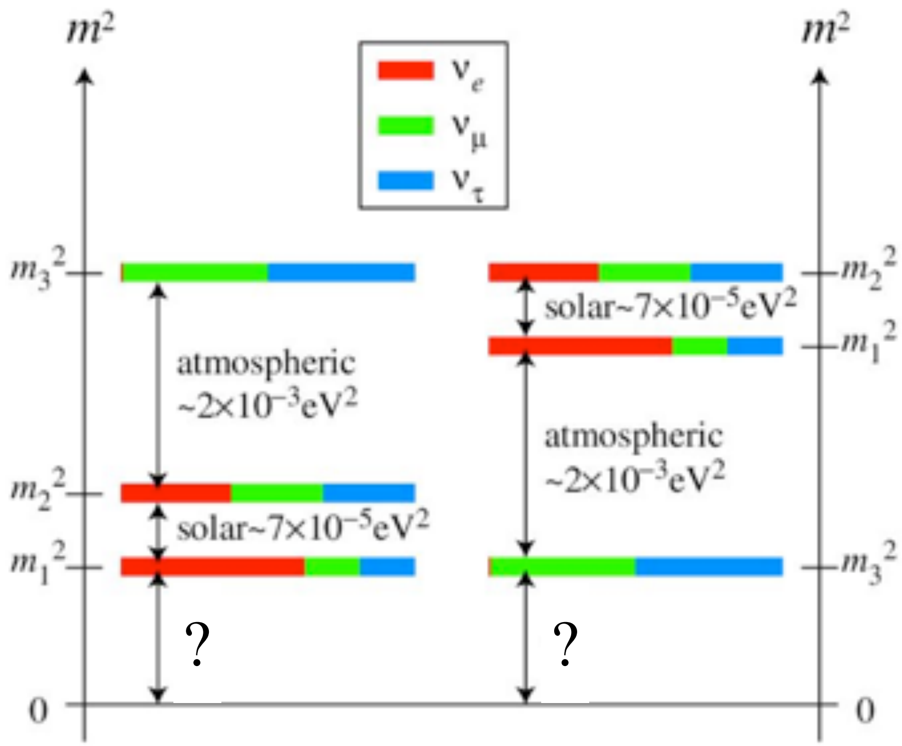
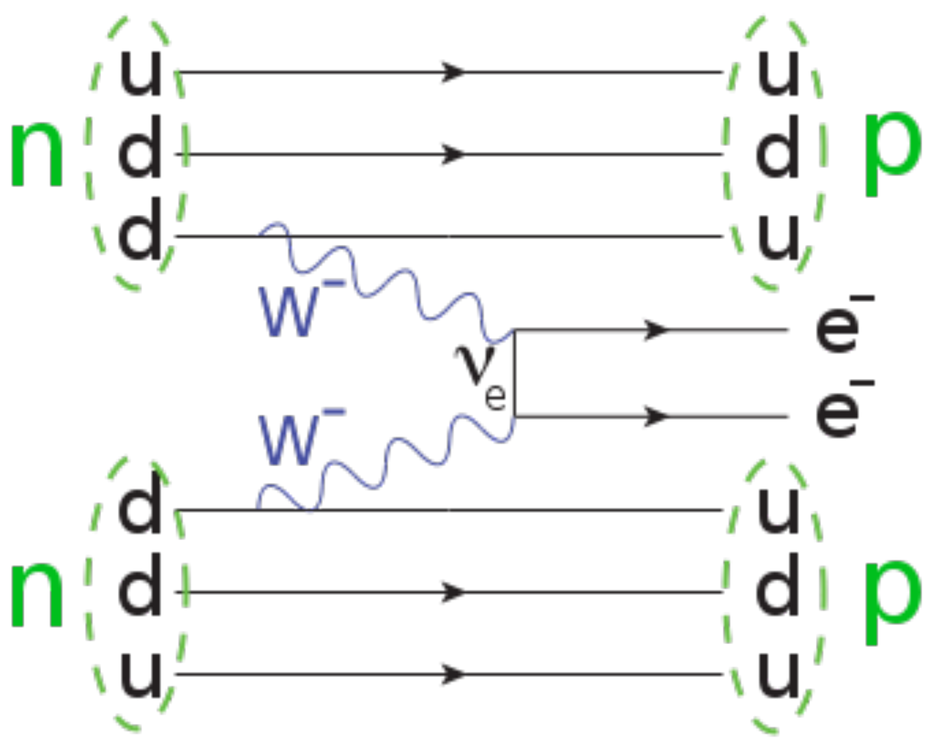
International Workshop on Double Beta Decay and Underground Science
Hawaii Island, USA
7 October 2014

The potential for 0νββ





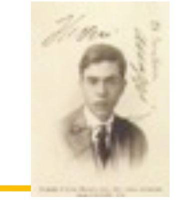
$$^{76}\mathrm{Ge} \Rightarrow ^{76}\mathrm{Se} + 2e^-$$

What we DON'T know about neutrinos

- How massive are they?
  - What is the absolute scale?
- Which one is the heaviest?
  - Which hierarchy is correct?
- Are they their own anti-particle?
- Is Lepton # violated
- Is there Leptonic CP-invariance violation

$$\Gamma_{0\nu} = G_{0\nu}|M_{0\nu}|^2 \langle m_{\beta\beta}\rangle^2$$

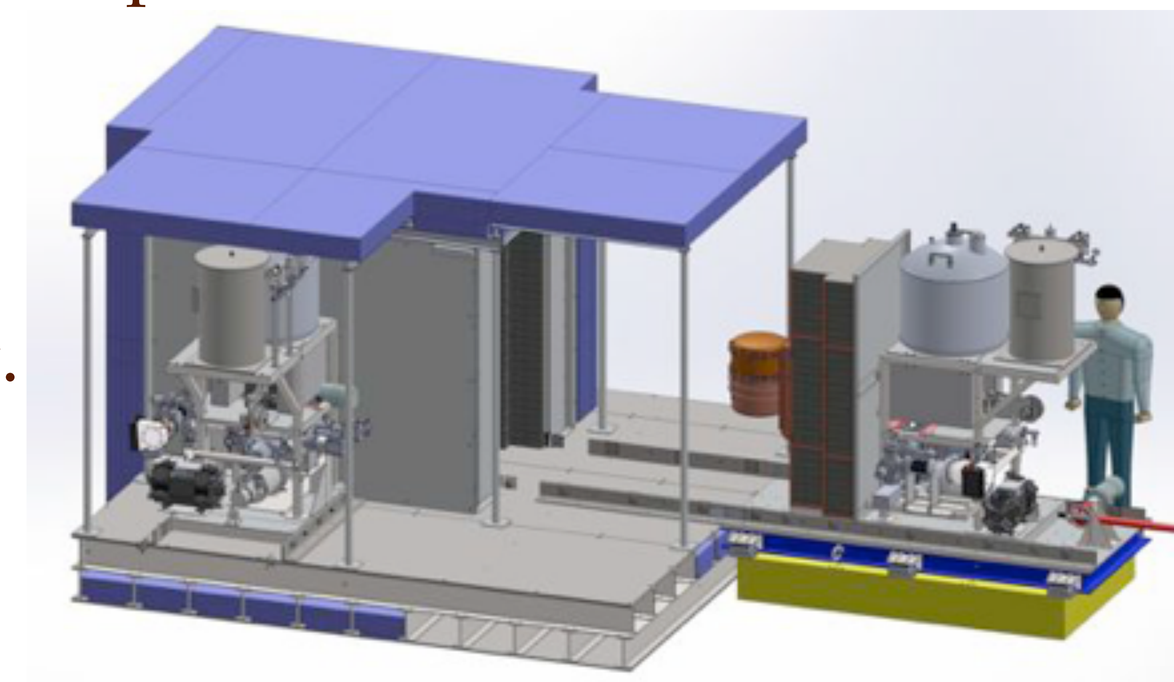
The MAJORANA DEMONSTRATOR



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

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 upper limit currently ≤ 4.1
- Scales to 1 count/ROI/t/y for a tonne-scale experiment

40 kg of Ge detectors
- 30 kg of 87% enriched ^{76}Ge crystals
- 10 kg of ^{nat}Ge
- Detector Technology: P-type, point-contact.

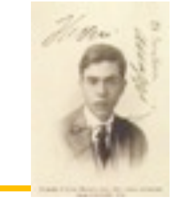


Two independent cryostats
- Ultra-clean, electroformed Cu
- 20 kg of detectors per cryostat
- Naturally scalable

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

Located underground at the 4850-foot level of the Sanford Underground Research Facility in Lead, SD

The MAJORANA DEMONSTRATOR



Goals

- Demonstrate background levels low enough to justify building a tonne-scale experiment
- Establish the feasibility of constructing & fielding modular arrays of Ge detectors
- Search for additional physics beyond the Standard Model, such as solar axions and dark matter

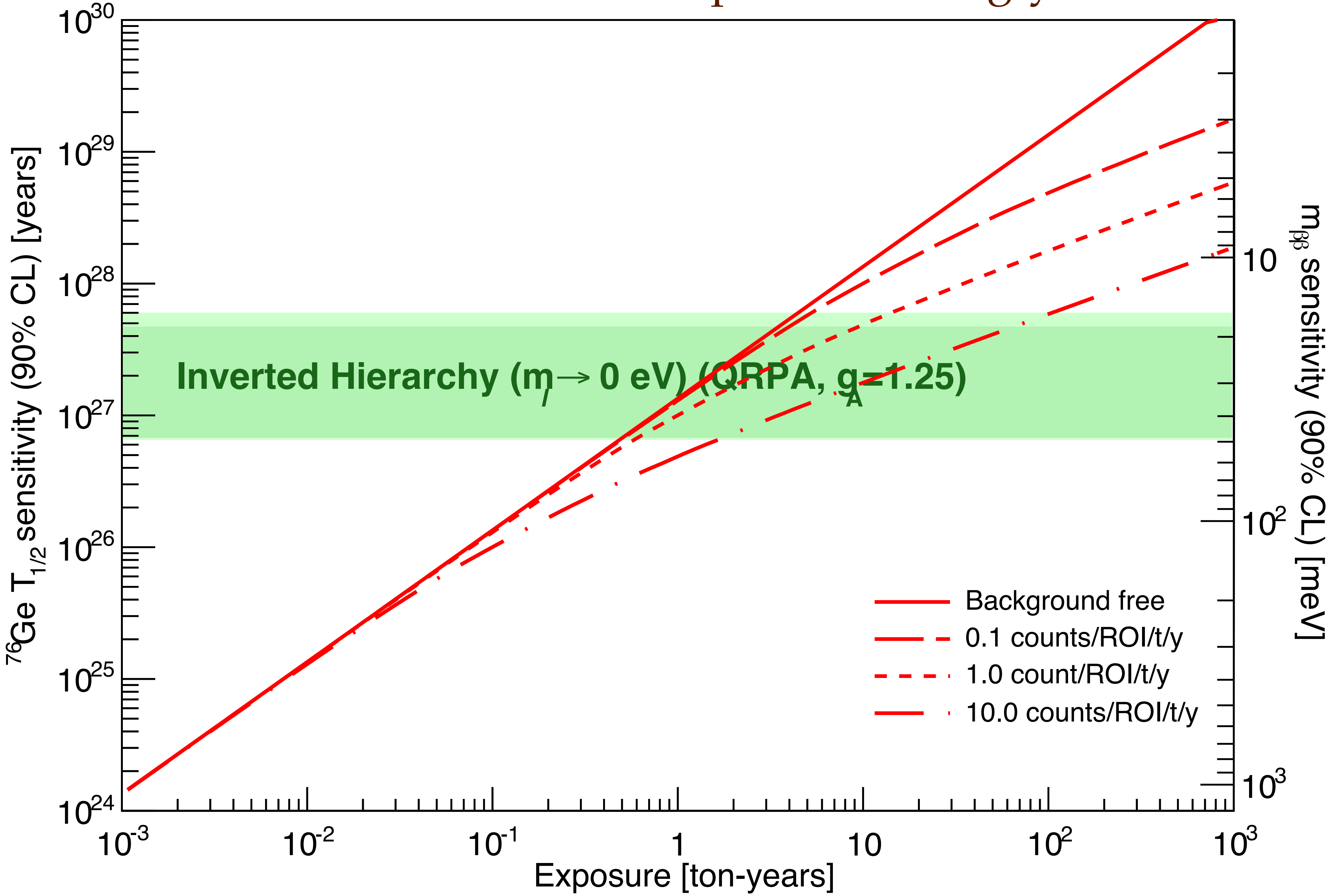
Status

- Operating *prototype module* with 3 strings of natural Ge
  - Same design as Modules 1 & 2, but fabricated using OFHC Cu (non-electroformed) components.
- Module 1 started commissioning in the Fall 2014 with one ^{enr}Ge string
  - 7 strings, 20 kg ^{enr}Ge
- Module 2 starting commissioning in the Fall 2015
  - 4 strings, 10 kg of ^{enr}Ge; 3 strings of ^{nat}Ge
- 30 enriched Ge detectors underground (25.2 kg detector mass), all natural Ge detectors on hand

MAJORANA ^{76}Ge Sensitivity

Motivation: achieve ultra-low backgrounds of < 1 count/ROI/t/y to probe the mass scale at the Inverted Hierarchy range

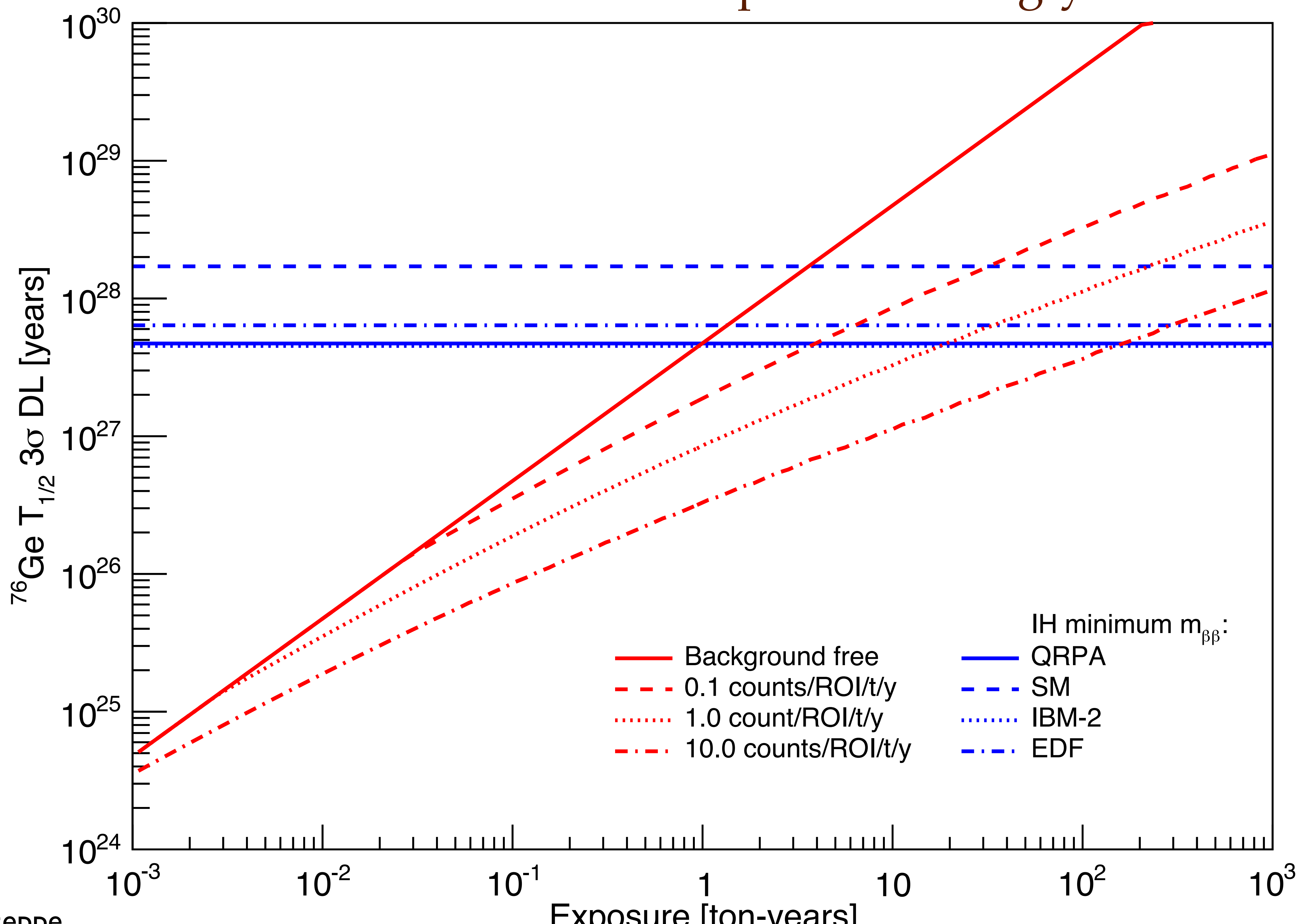
The DEMONSTRATOR exposure: 100 kg-y



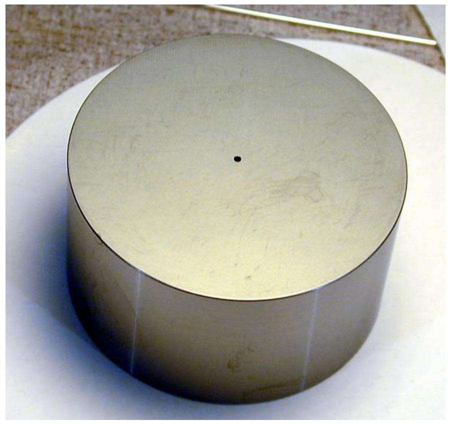
MAJORANA ^{76}Ge Discovery

Motivation: achieve ultra-low backgrounds of < 1 count/ROI/t/y to probe the mass scale at the Inverted Hierarchy range

The DEMONSTRATOR exposure: 100 kg-y

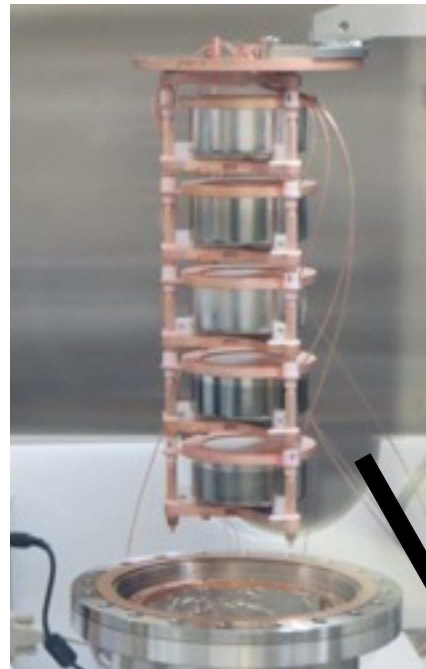


MAJORANA Approach



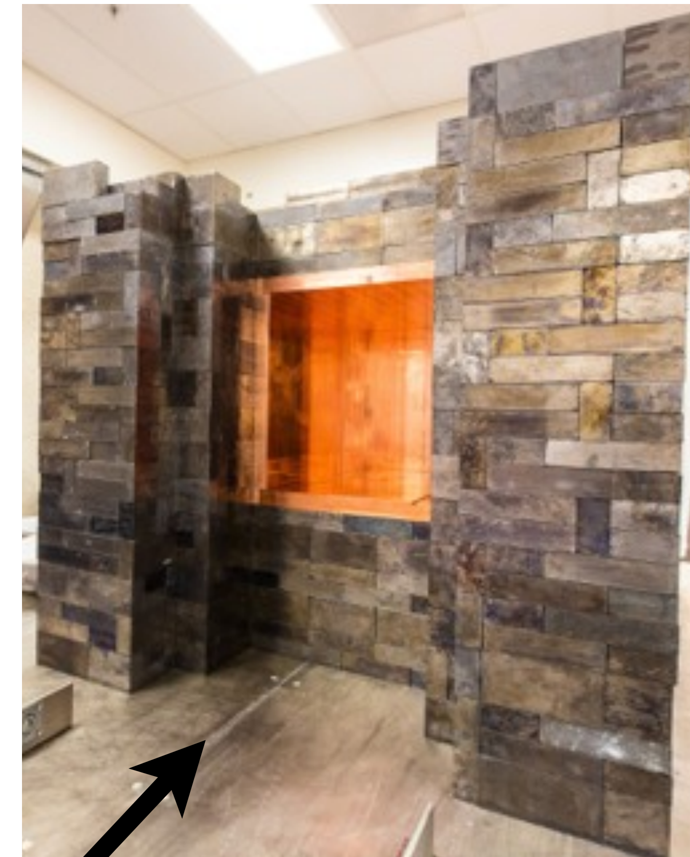
Ge crystal

Low mass mount



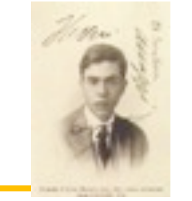
String

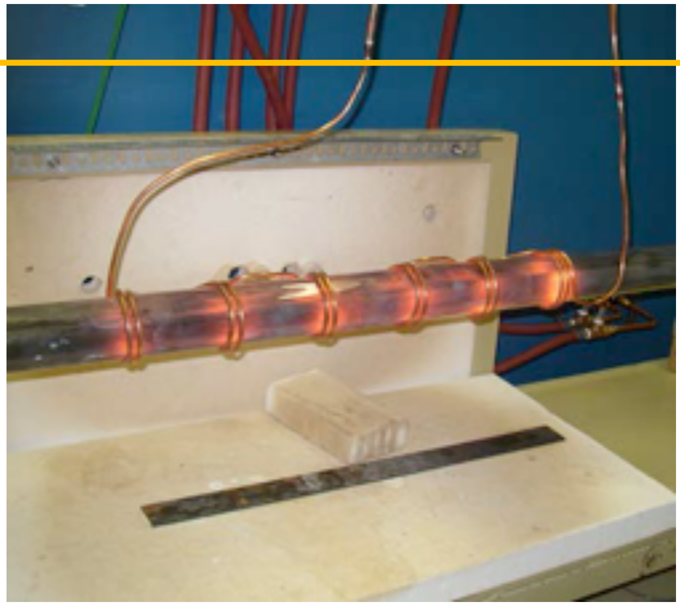
Array inside cryostat



Shield

Material Purity



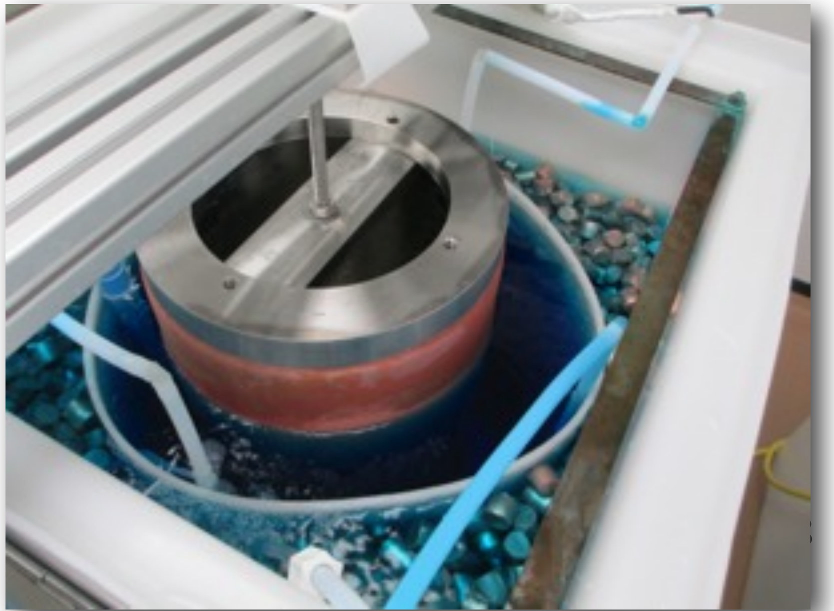


The detector

- Ge metal zone refined and pulled into a crystal that provides purification
- Limit above-ground exposure to prevent cosmic activation
- Deep underground operation

Detector mounts

- Ultra-pure plastic and electro-formed Cu
- Low mass design
- Custom cable connectors and front-end boards
- Carefully selected plastics (PTFE, PEEK, Vespel)
- Fine Cu coaxial cables



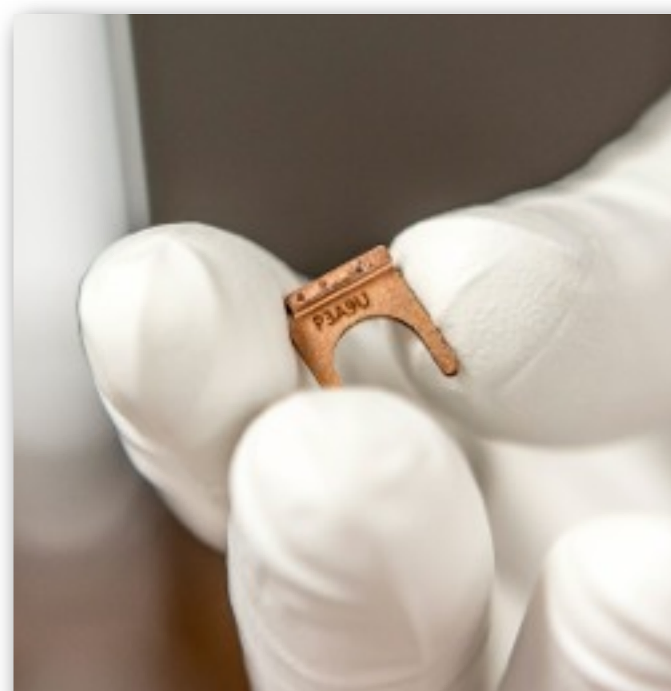
Cryostat and inner shielding

- Underground electro-formed Cu
  - 10 baths at 4850′ SURF
  - 6 baths at a shallow site at PNNL

Cu Production and Machining

All parts are uniquely tracked through machining, cleaning, and assembly by a custom-built database.

Underground Cu electro-forming laboratory produces all of the ultra-pure inner Cu machining in an underground clean room machine shop.

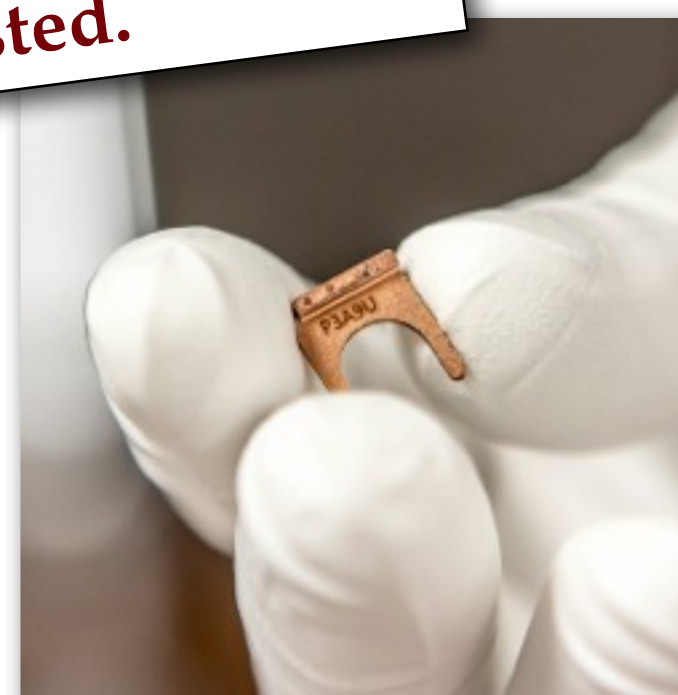


Cu Production and Machining

Electroforming of ultra clean Cu and of UG machining may become available in the future Groups should contact us if interested.

…quely tracked through machining, …embly by a custom-built database.

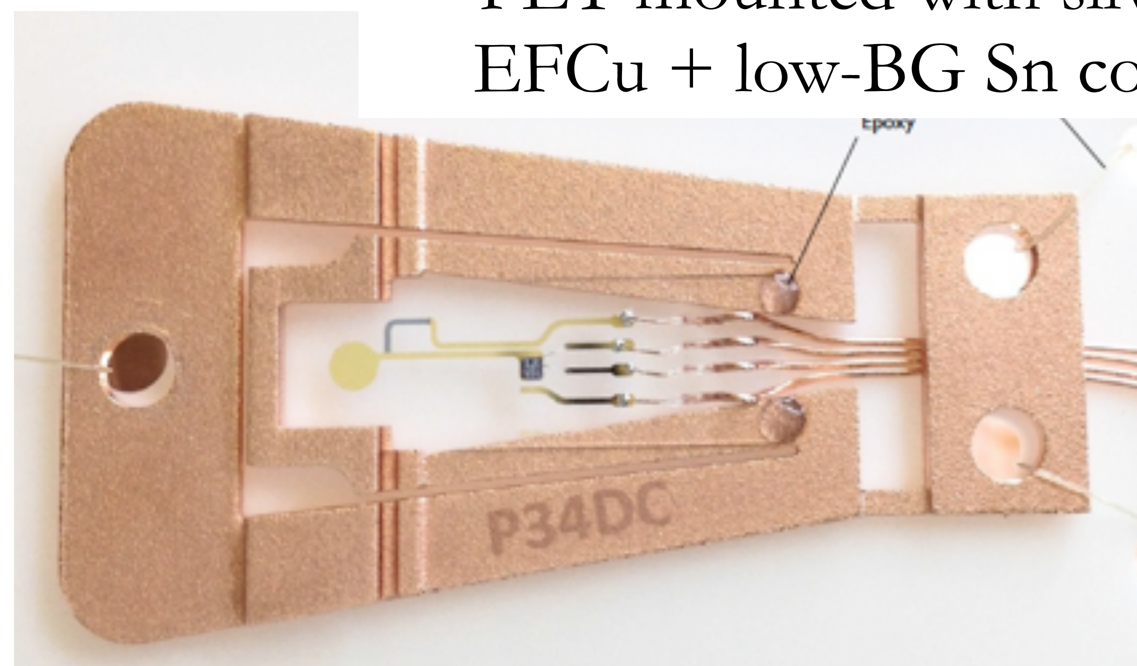
…achine shop.



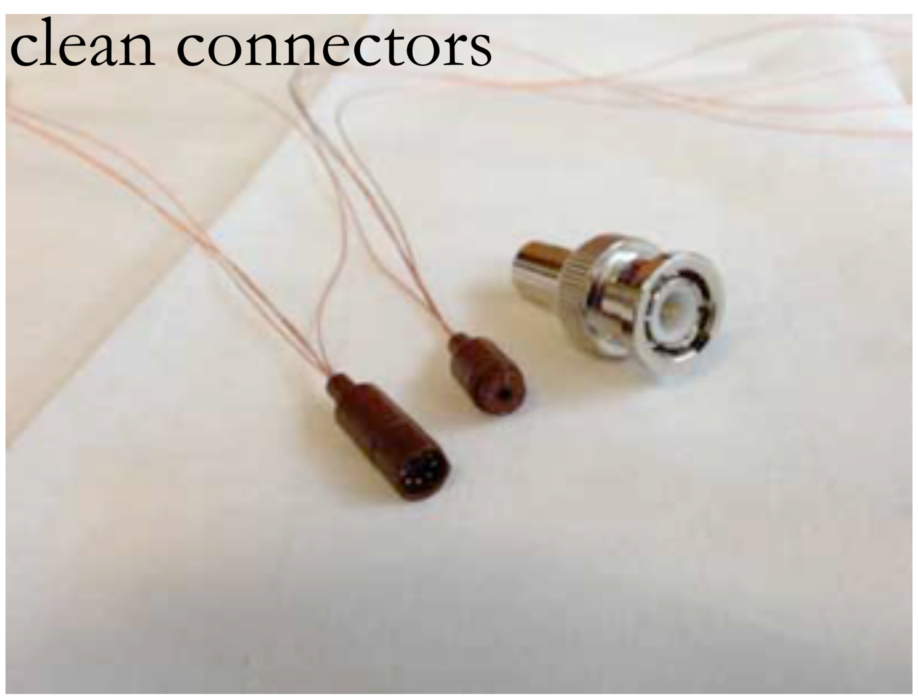
Carefully Selected Components

E-formed Cu mount

Custom low mass front-end boards
Clean Au+Ti traces on fused silica
Amorphous Ge resistor
FET mounted with silver epoxy
EFCu + low-BG Sn contact pin



Fine Cu coaxial cable and clean connectors



Other materials:

- Electroformed Cryostats
- Parylene coating / seals
- Vespel, PTFE, PEEK
- Shield:s low-BG EFCu & commercial Cu, Pb

Material Purity & Assay

Comprehensive program to assay all materials used in the DEMONSTRATOR

- Neutron activation analysis
- Gamma spectroscopy
- ICP-MS

By necessity have developed world's most sensitive ICP-MS based assay techniques for U and Th in Cu (Original MJD Goal : <0.3 μBq/kg for U and Th)

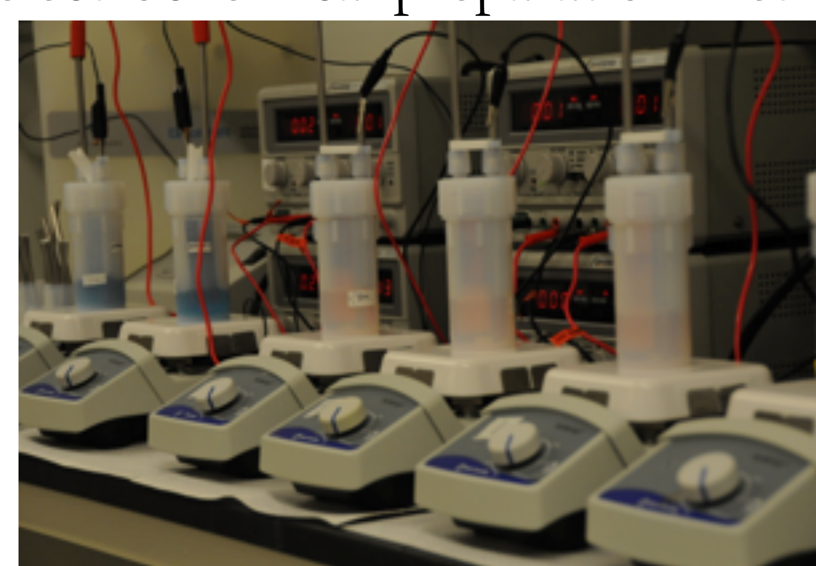
Current MDL (method detection limits) with iridium anode improvements

- U decay chain 0.1 μBq ^{238}U/kg
- Th decay chain 0.1 μBq ^{232}Th/kg

Sensitivities with ion exchange copper sample preparation

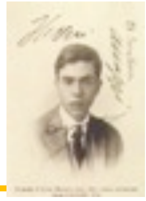
- U decay chain <0.10 μBq ^{238}U/kg
- Th decay chain <0.06 μBq ^{232}Th/kg

Processing of Cu samples using the electrochemical preparation method

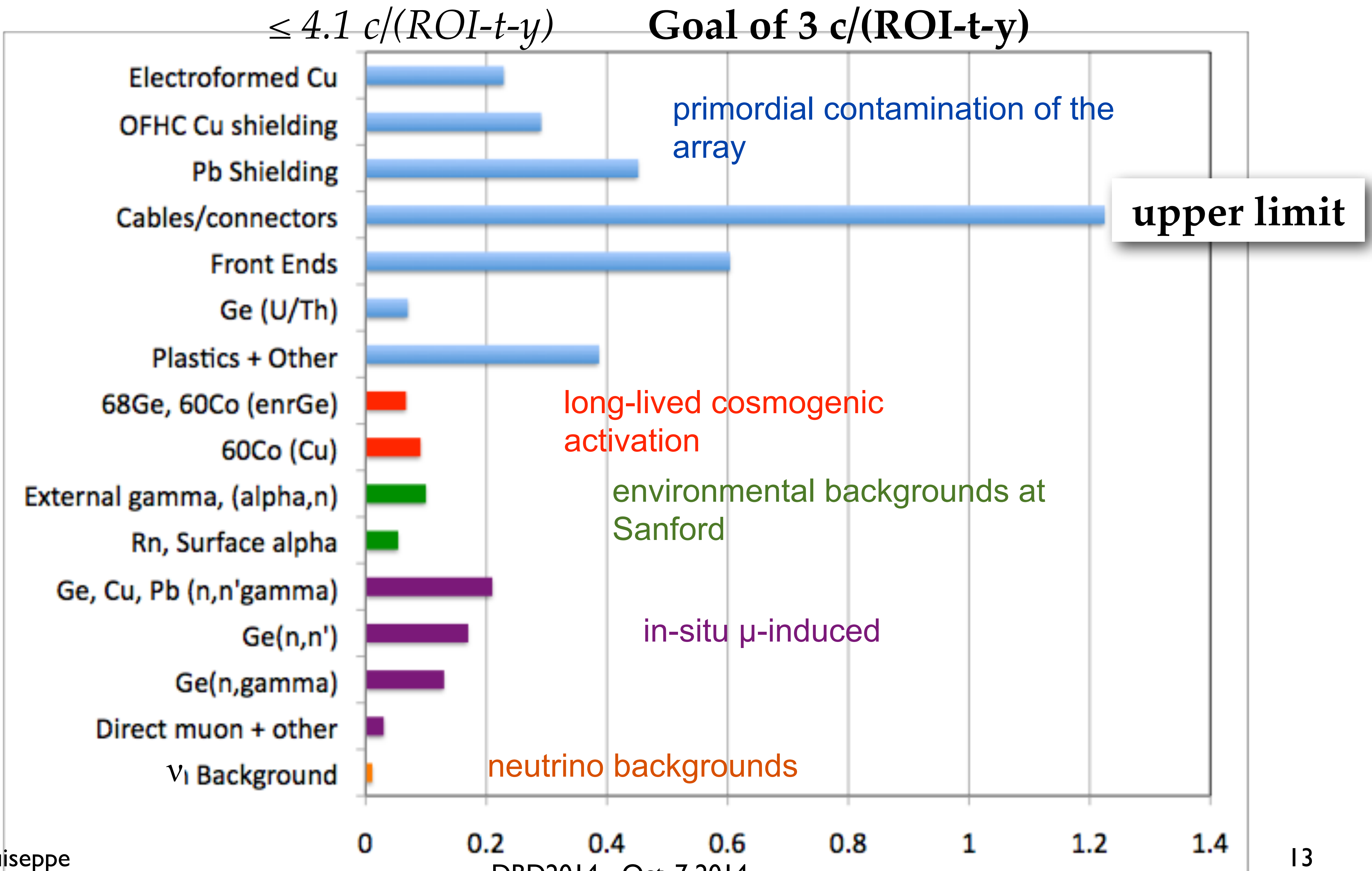


Plastic sample for NAA analysis

Demonstrator Backgrounds

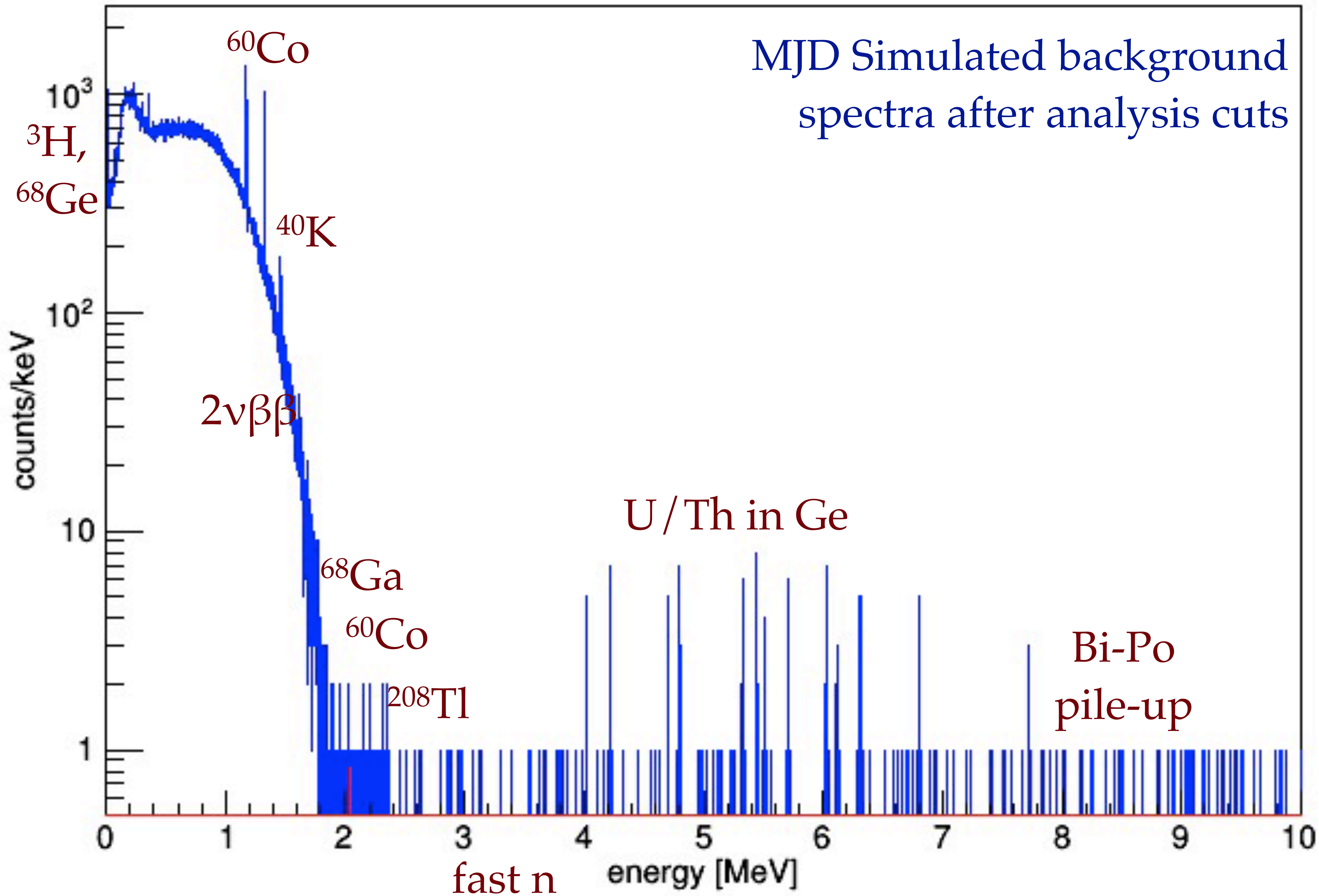


Background prediction based on achieved assays of materials



Backgrounds and Simulations

5 year MJD run: 30 kg 87% enriched ^{76}Ge; 92% fiducial; 90% livetime (108 kg-years) background of 4.1 cts / 4 keV / t-y



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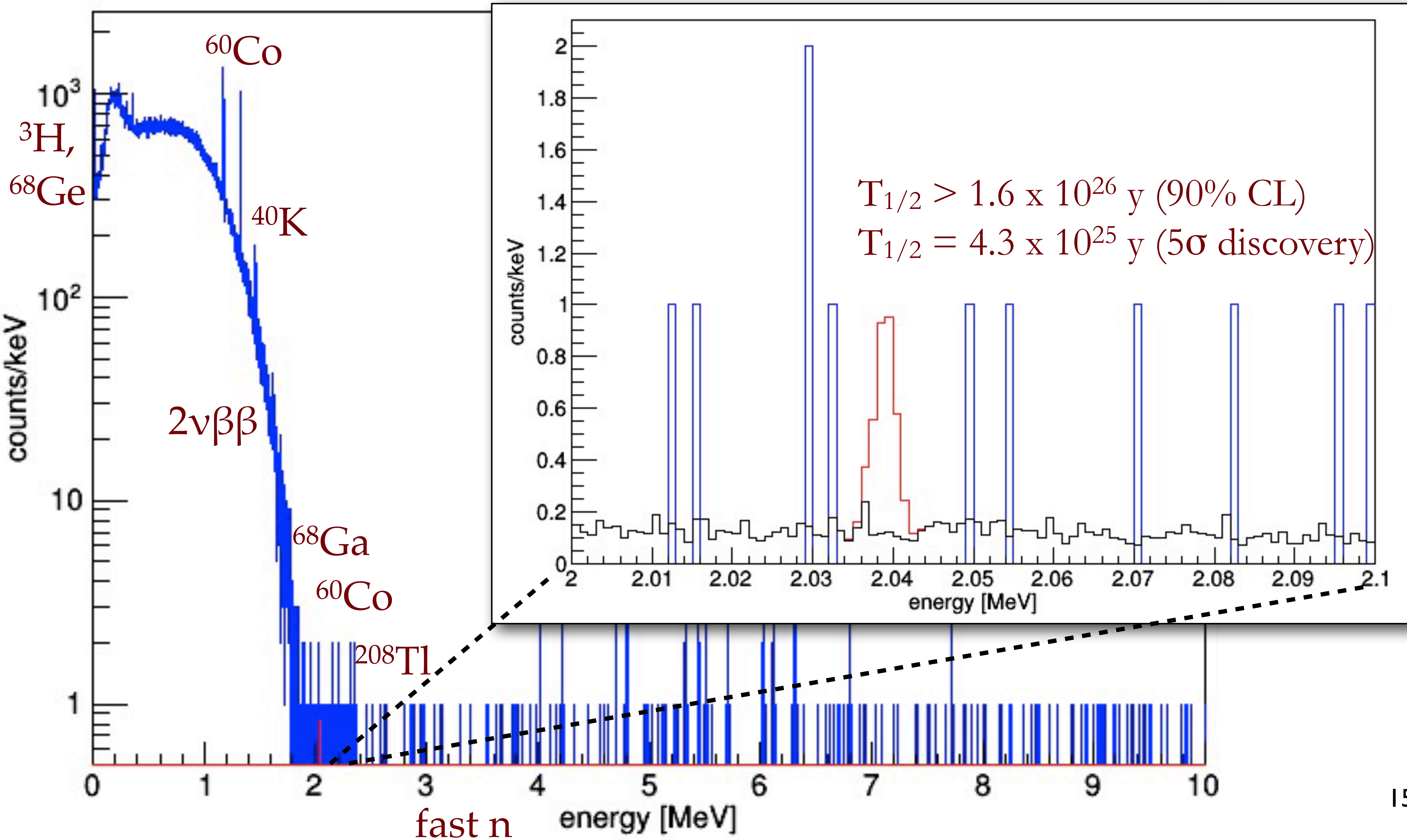
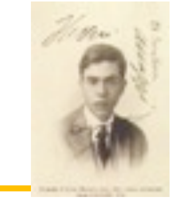


P-type Point Contact Detectors

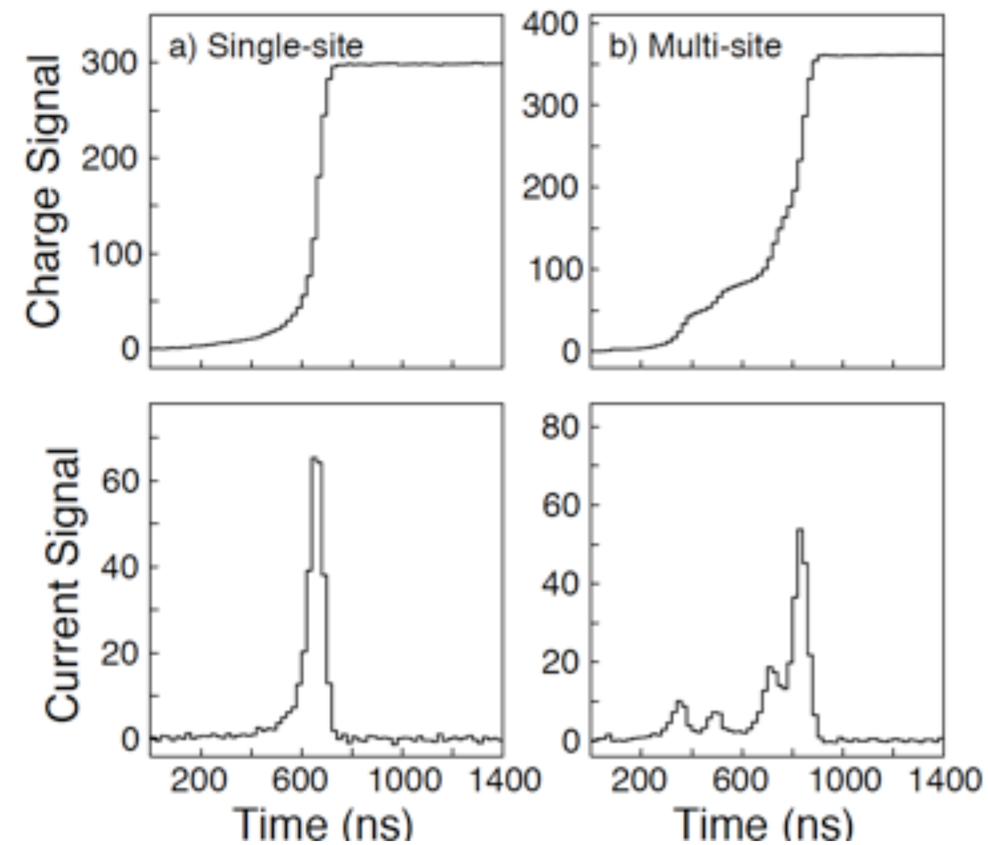


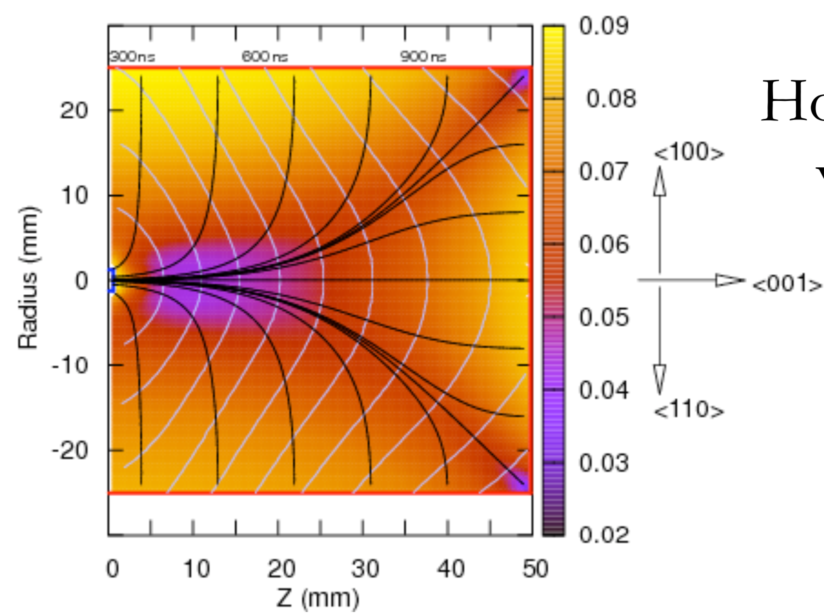
Ultra-low background rate requires a pulse shape analysis (PSA) rejection of multi-site gamma events

P-type Point-Contact (PPC) detectors

- No deep hole; small point-like central contact
- Length is shorter than standard coaxial detector
- Simple, cost-effective, low background
- Localized weighting potential gives excellent multi-site rejection
- Low capacitance (~ 1 pF) gives superb resolution at low energies

Rising edge "stretched" in time
⇒improved PSA

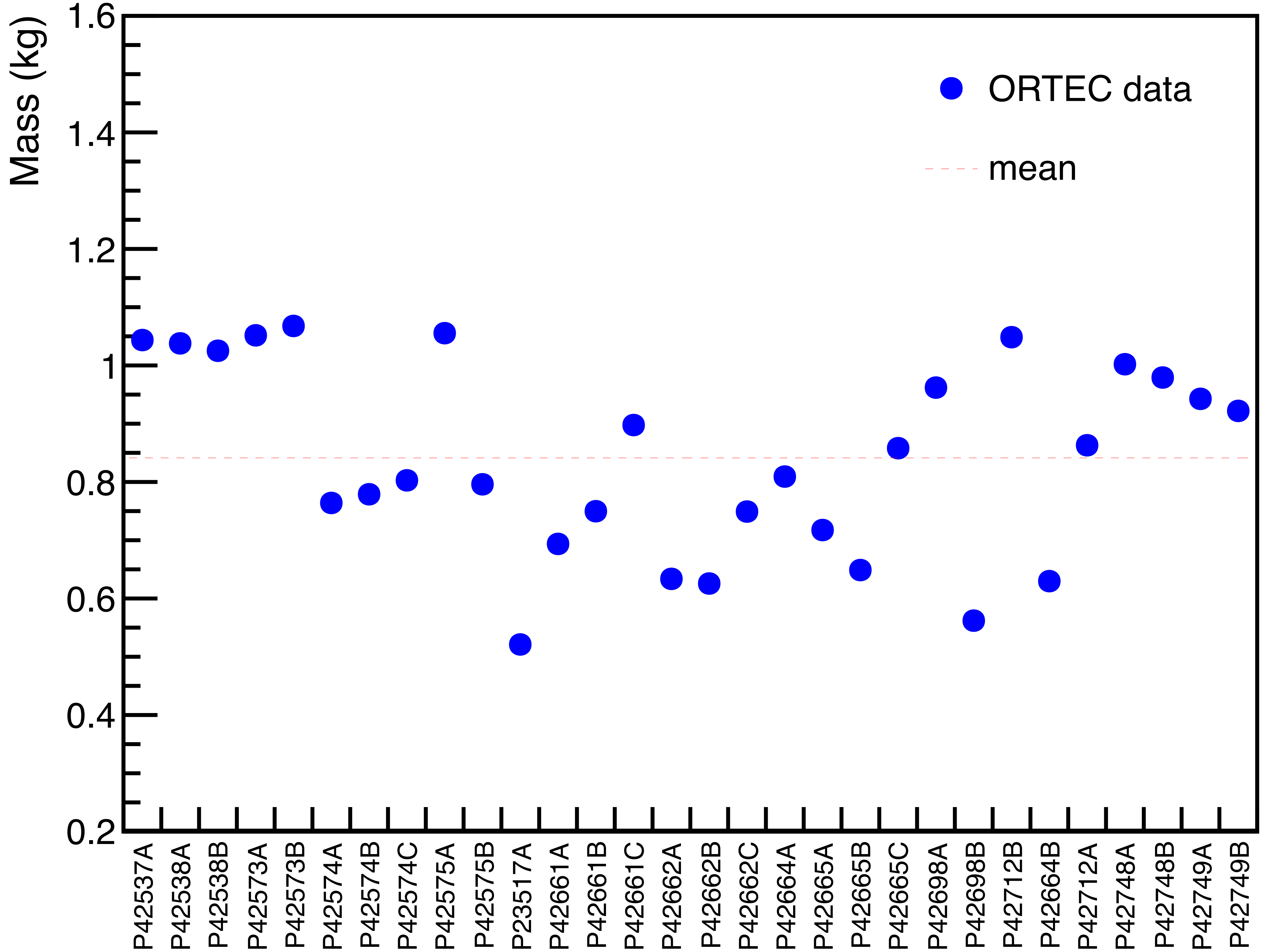




Hole v_{drift} [mm/ns] with paths and isochrones

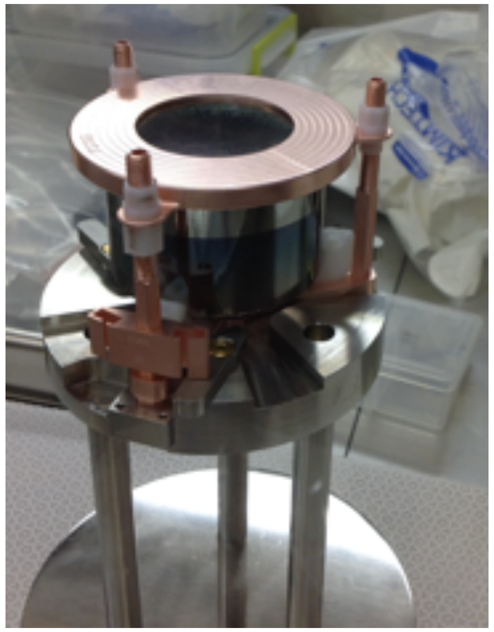
^{enr}Ge Detector Mass

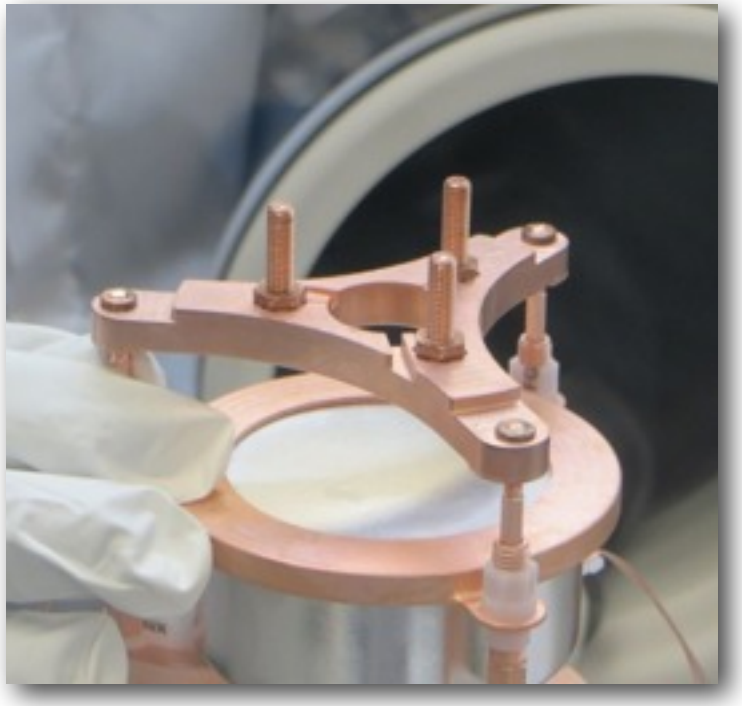
Mean mass of 840 g (Presently: 25.2 kg of detectors UG)

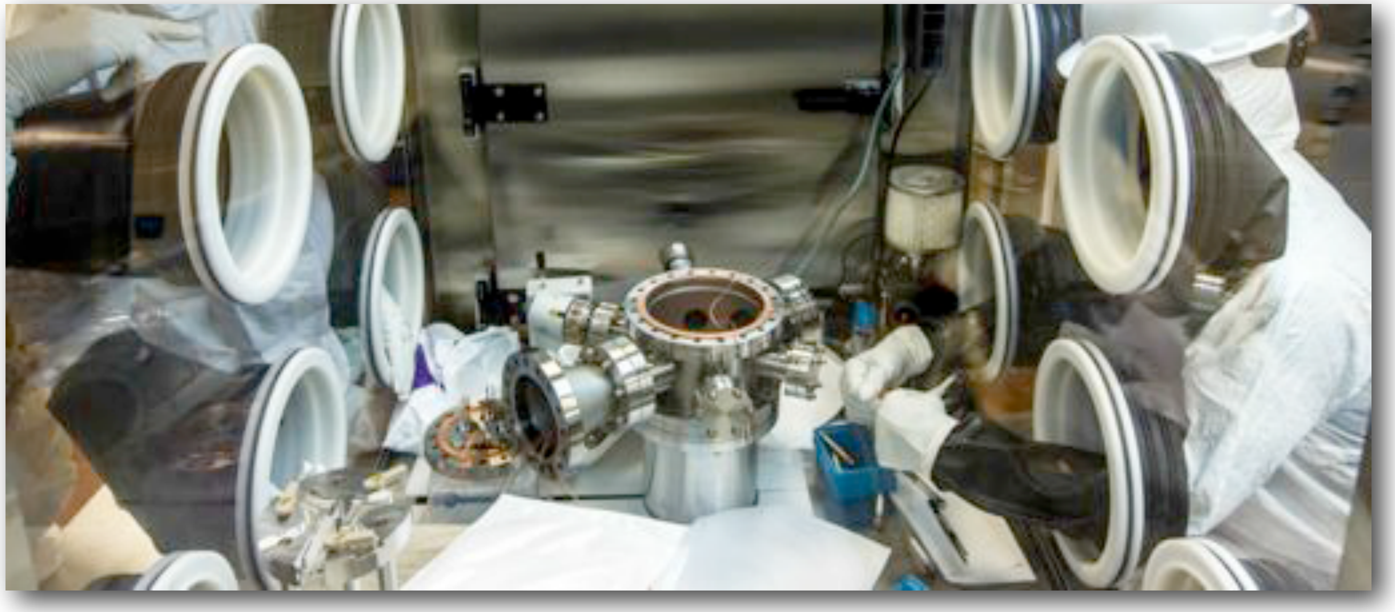


Detector Units and Strings

Detector units and strings built inside a glovebox with a radon-reduced, dry N2 environment

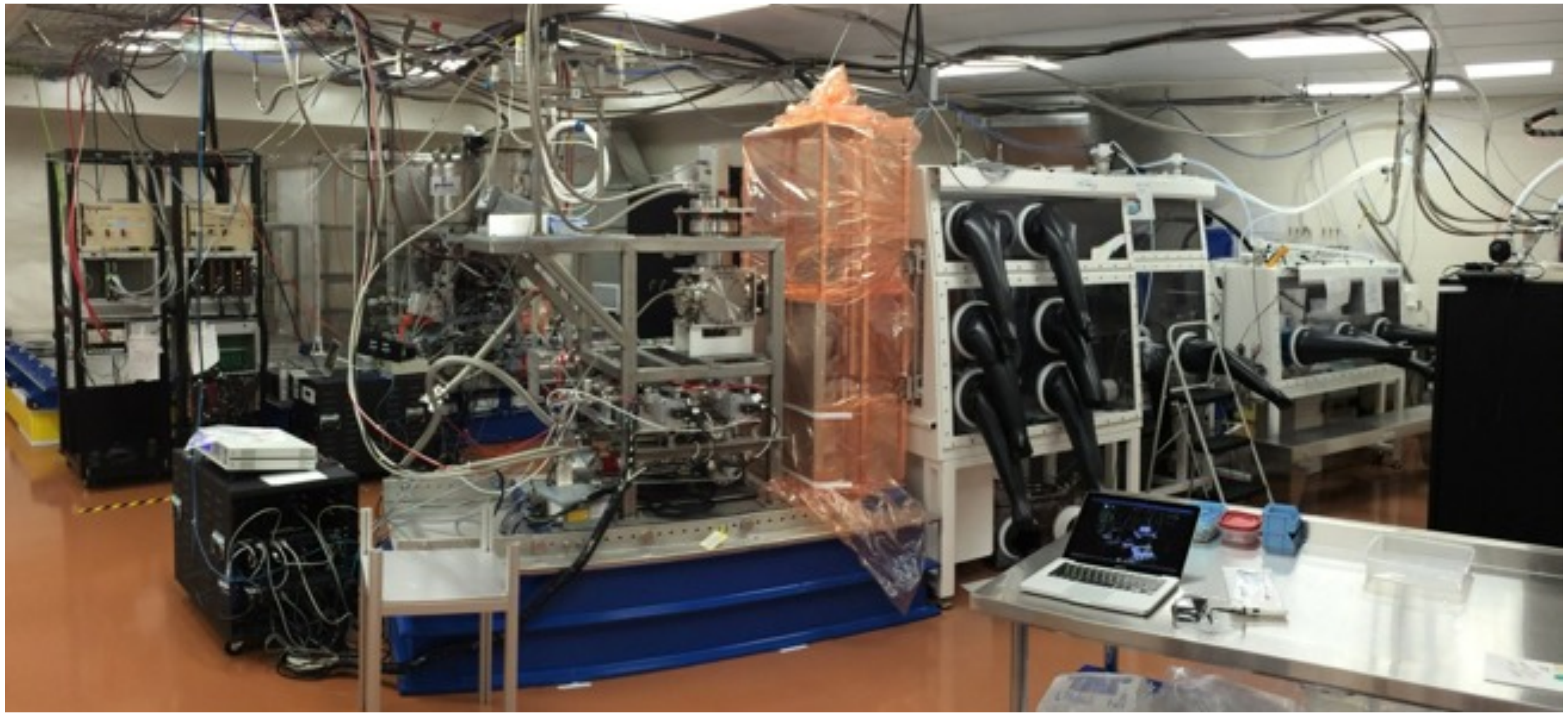


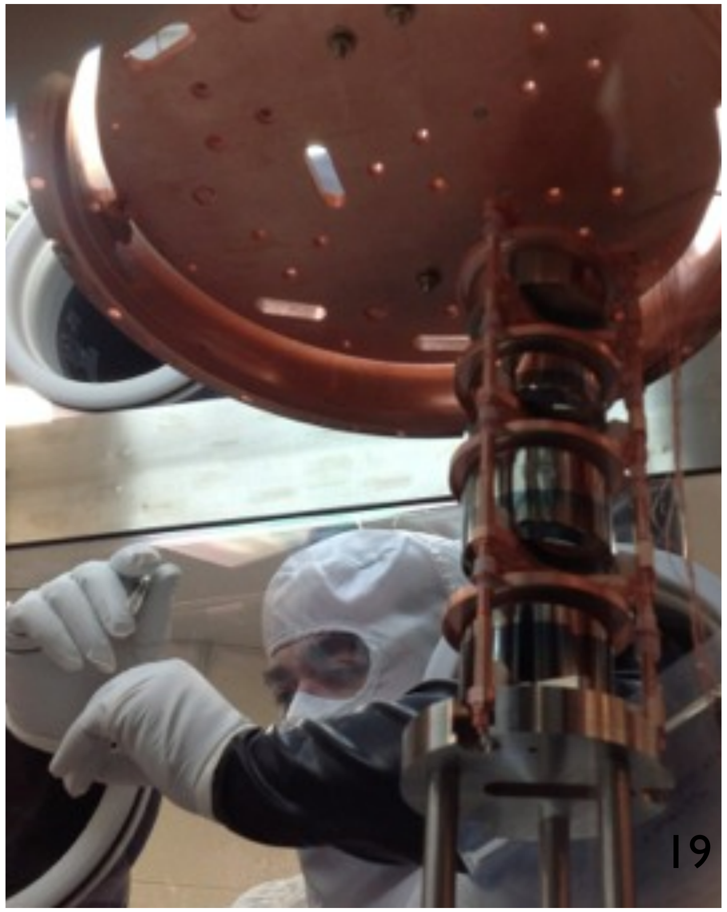




PC string with 2 BEGe and 2 ORTEC PPC detectors

Glovebox Assembly





Detector Module

Cryostat mated to the glovebox for string installation

First string of ^{enr}Ge in Cryostat 1

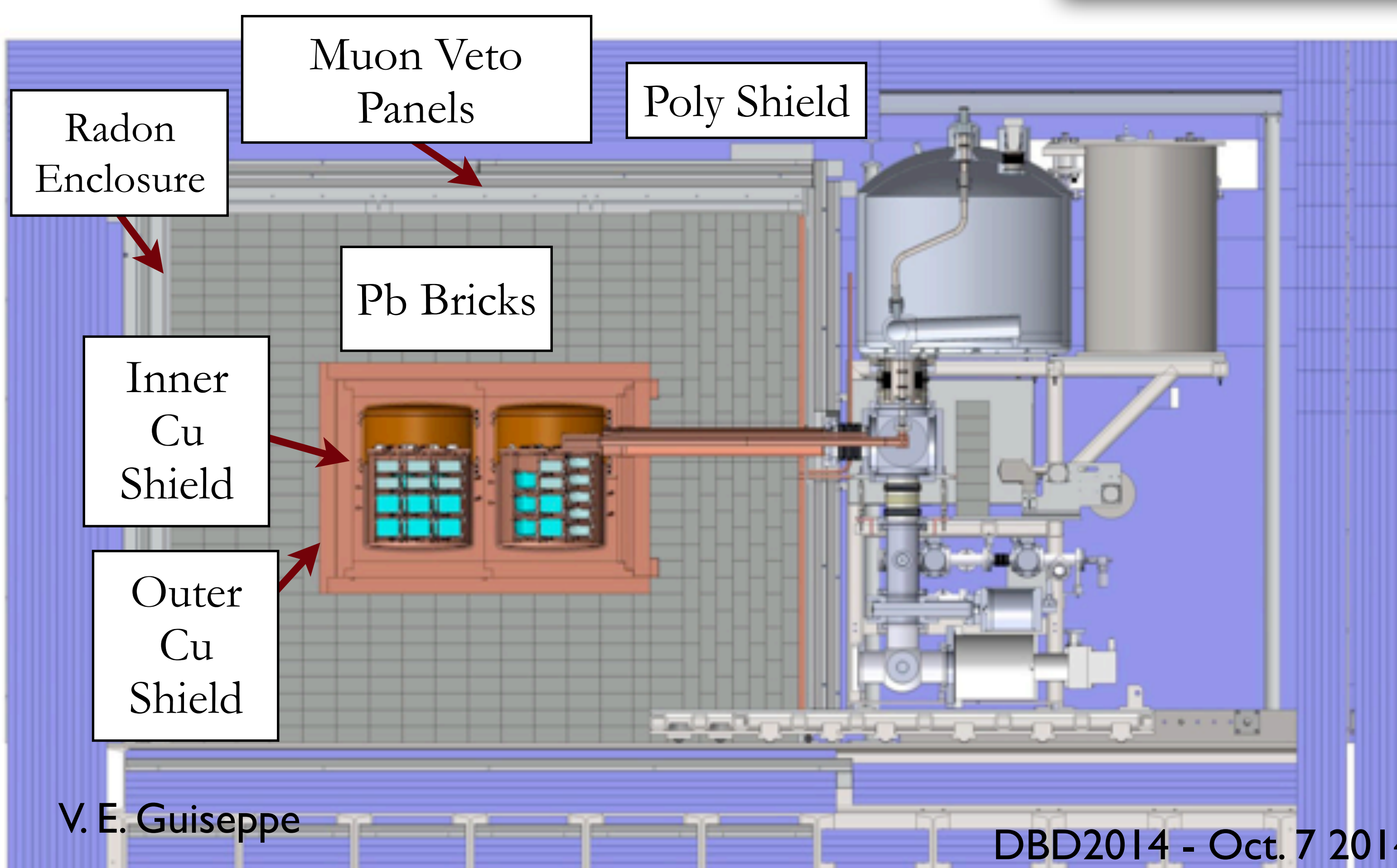
Detector Module

- A self contained vacuum and cryogenic vessel
- Contains a portion of the shielding
- Can be transported for assembly and deployment

Passive Shielding and Muon Veto

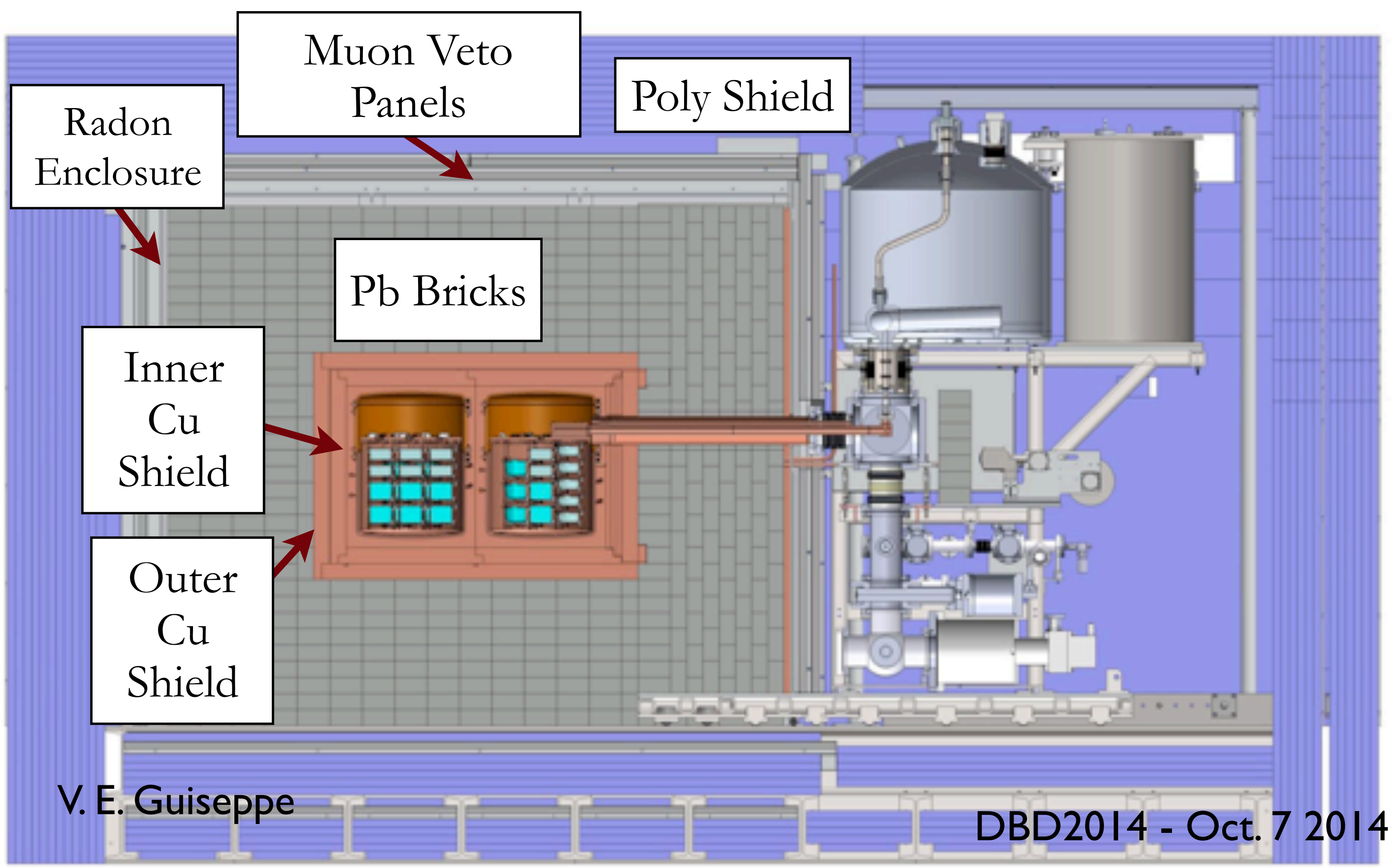
Pb and outer Cu shield installed

Detector deployment



Passive Shielding and Muon Veto

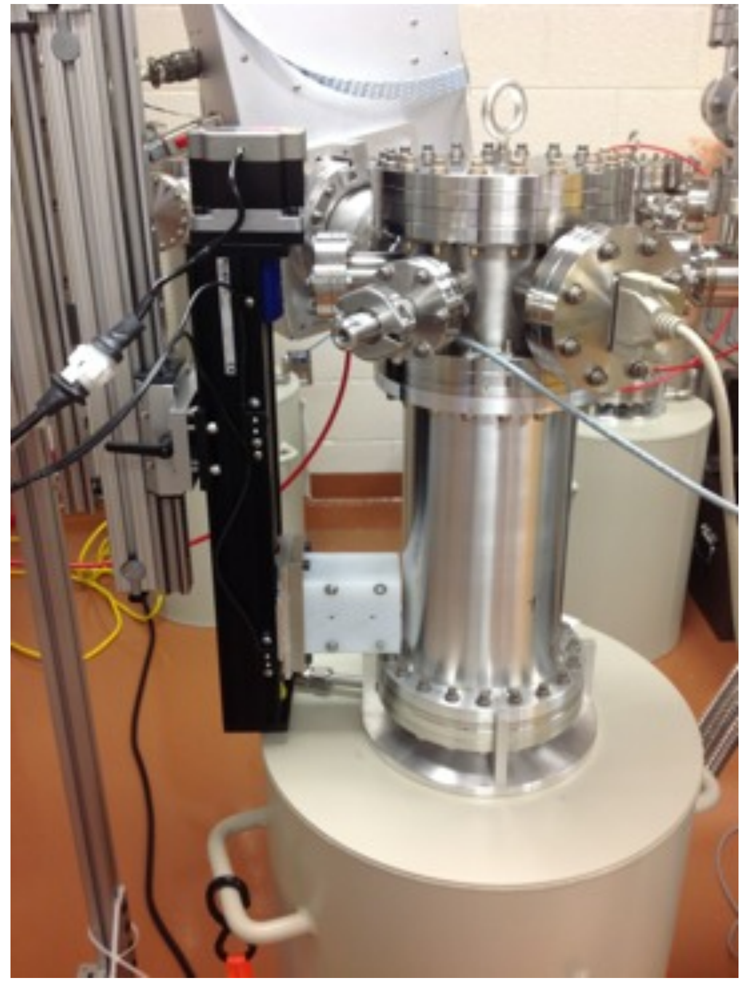
Prototype Cryostat Deployed

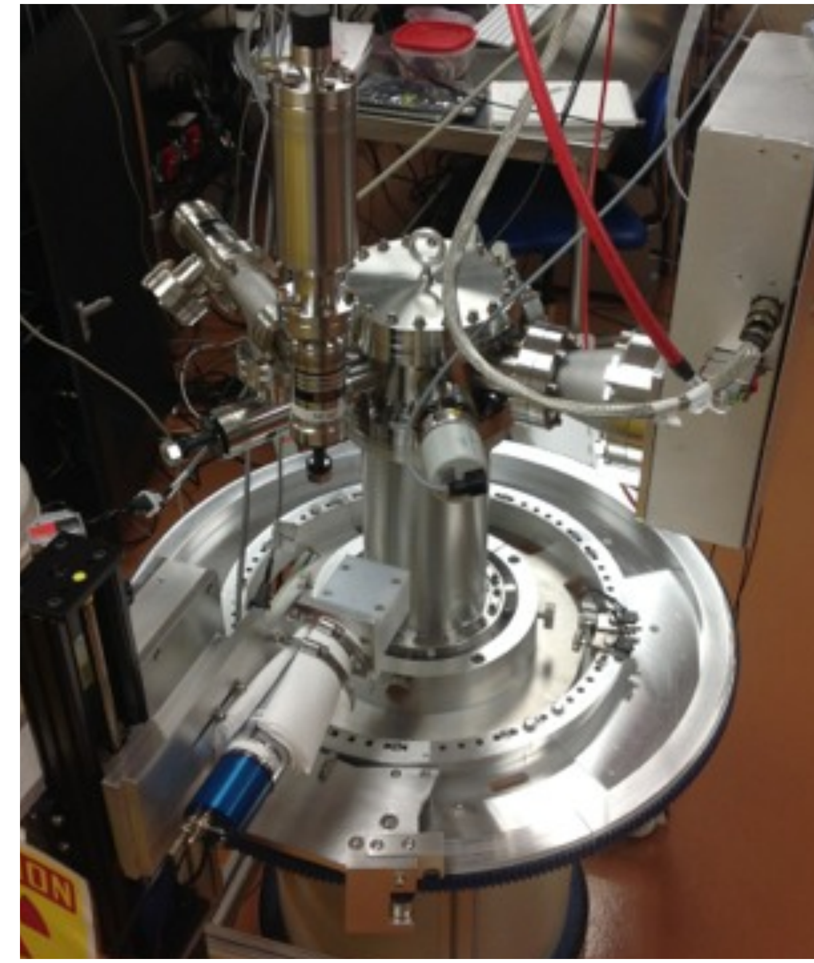


24 of 32 muon panels deployed

Characterization Hardware

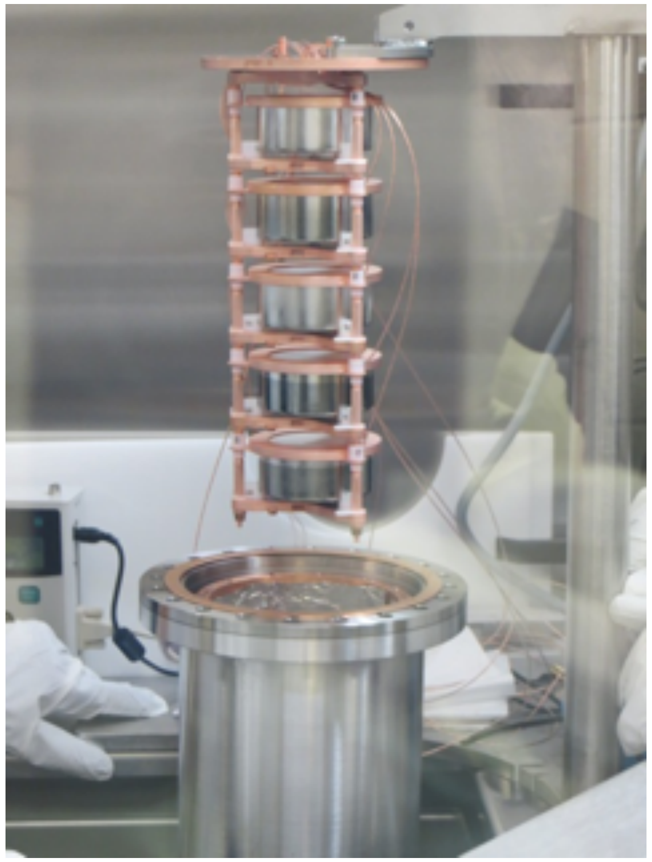
Vendor Cryostat





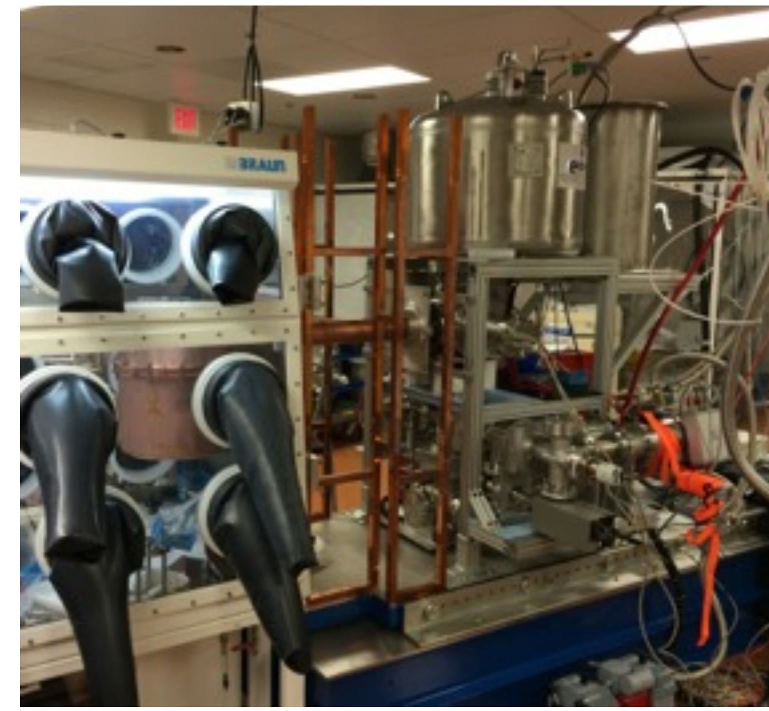
String Test Cryostat
X, Y, Z, Theta Scanning Capability

Detector Status



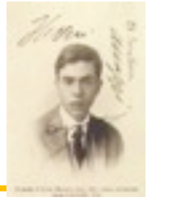
String Test Cryostat:
Testing and
Characterization of strings

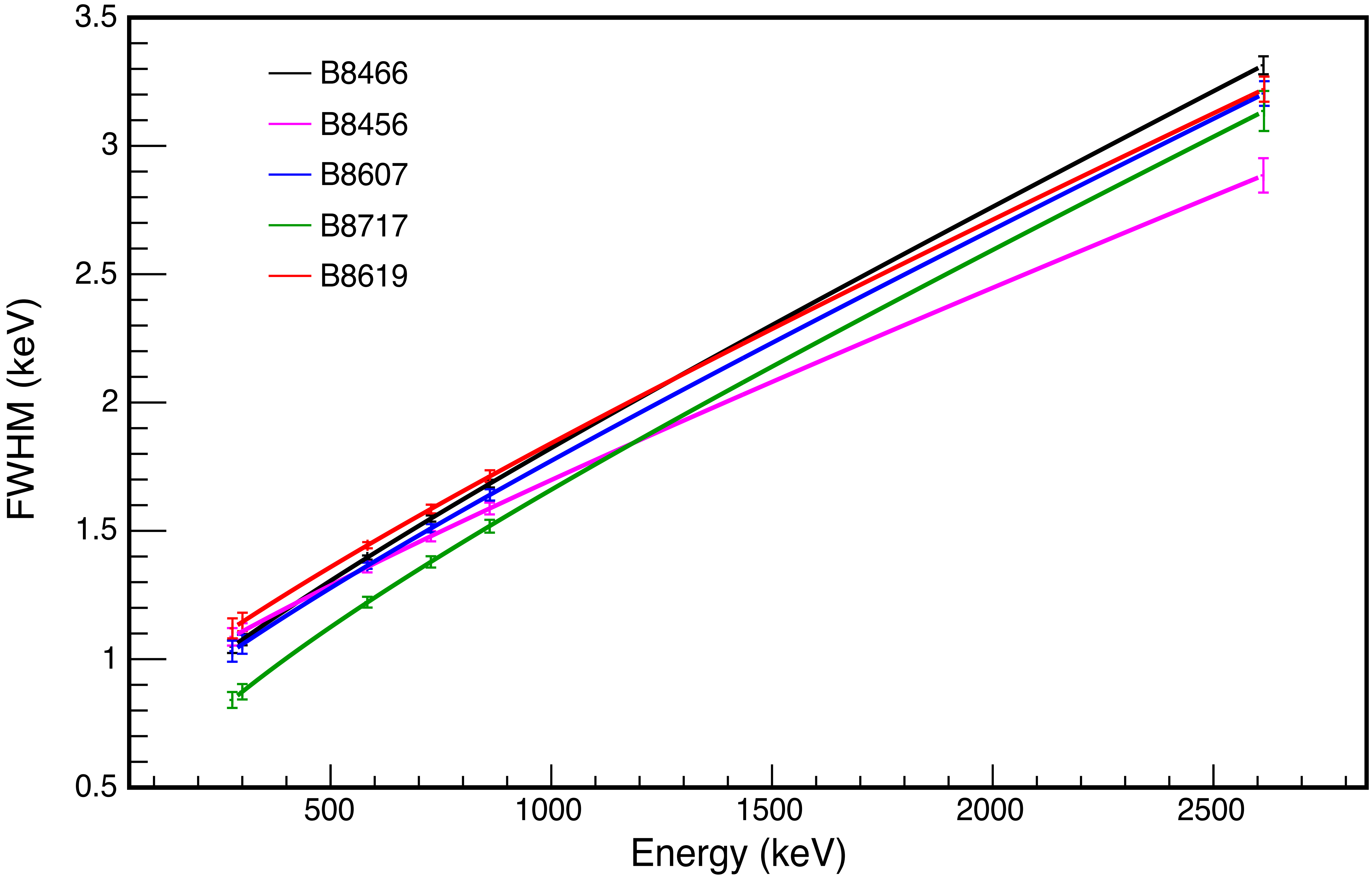
Prototype Cryostat:
3 strings of natural Ge
Deployed in shield



Cryostat 1:
1 strings of ^{enr}Ge
Commissioning
(unshielded)

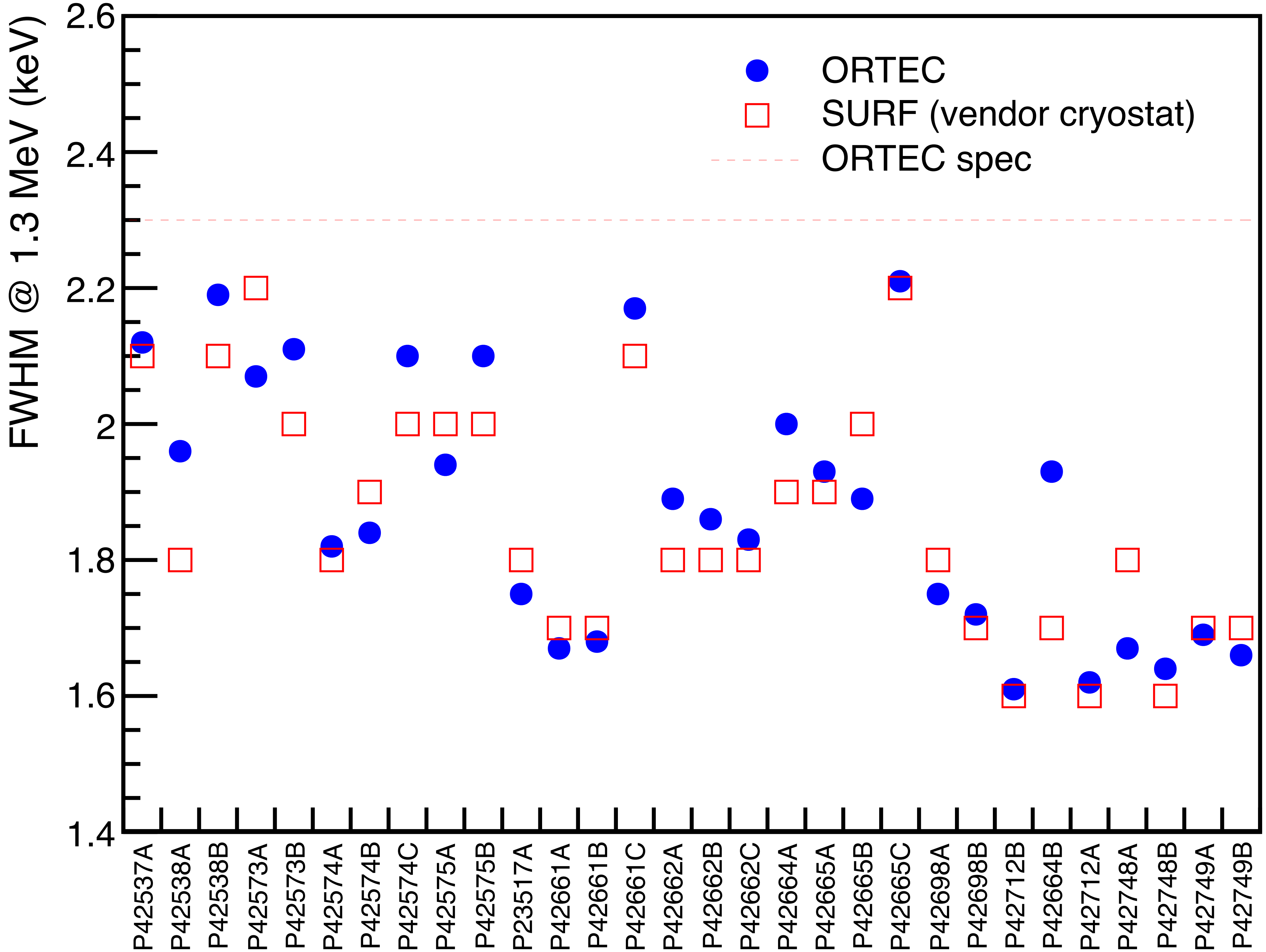
Resolution of BEGe Detectors within Prototype Cryostat



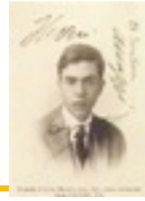


^{enr}Ge Detector Energy Resolution

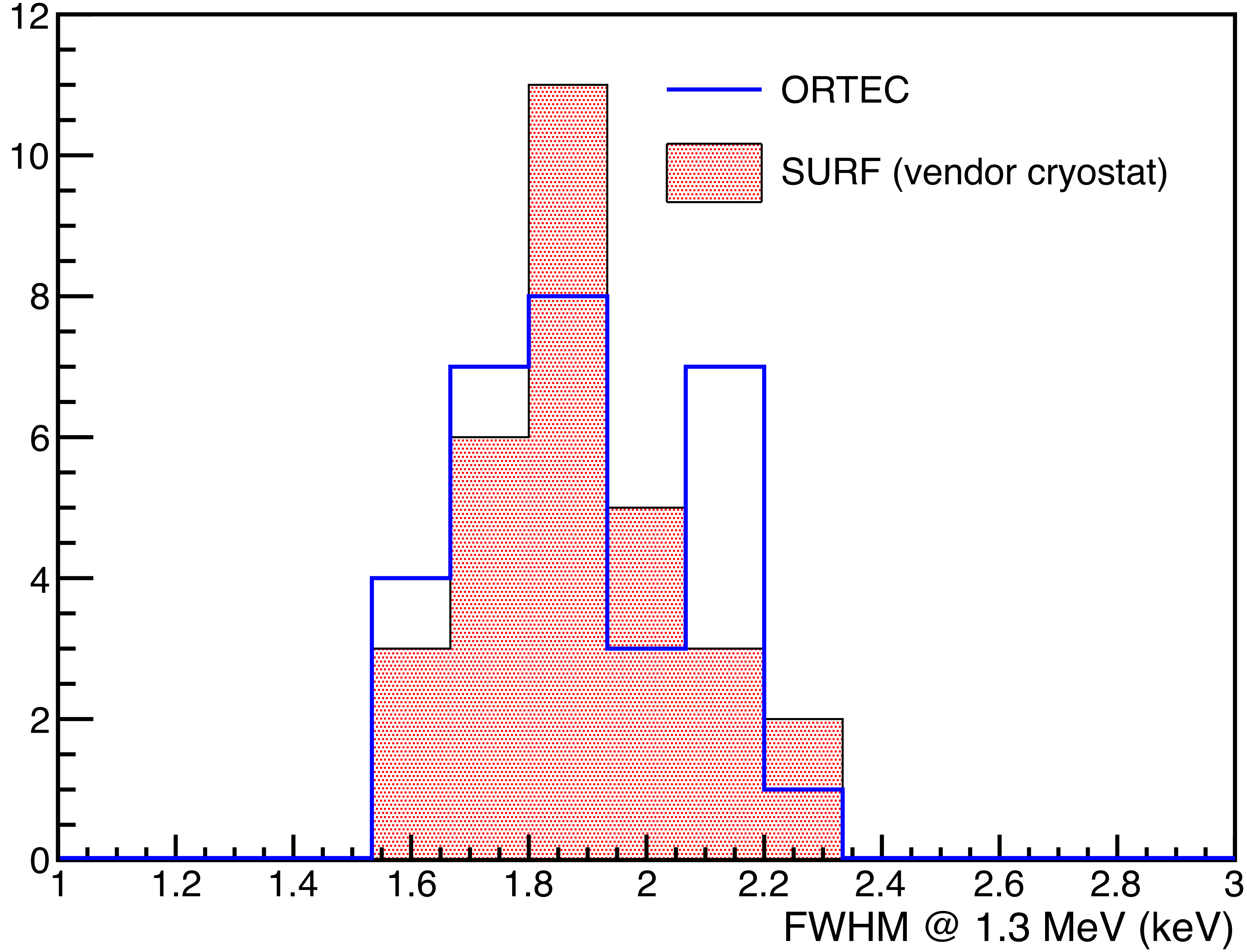
Comparison of measurements done at ORTEC and SURF within the vendor cryostat. All are better than specification.



^{enr}Ge Detector Energy Resolution



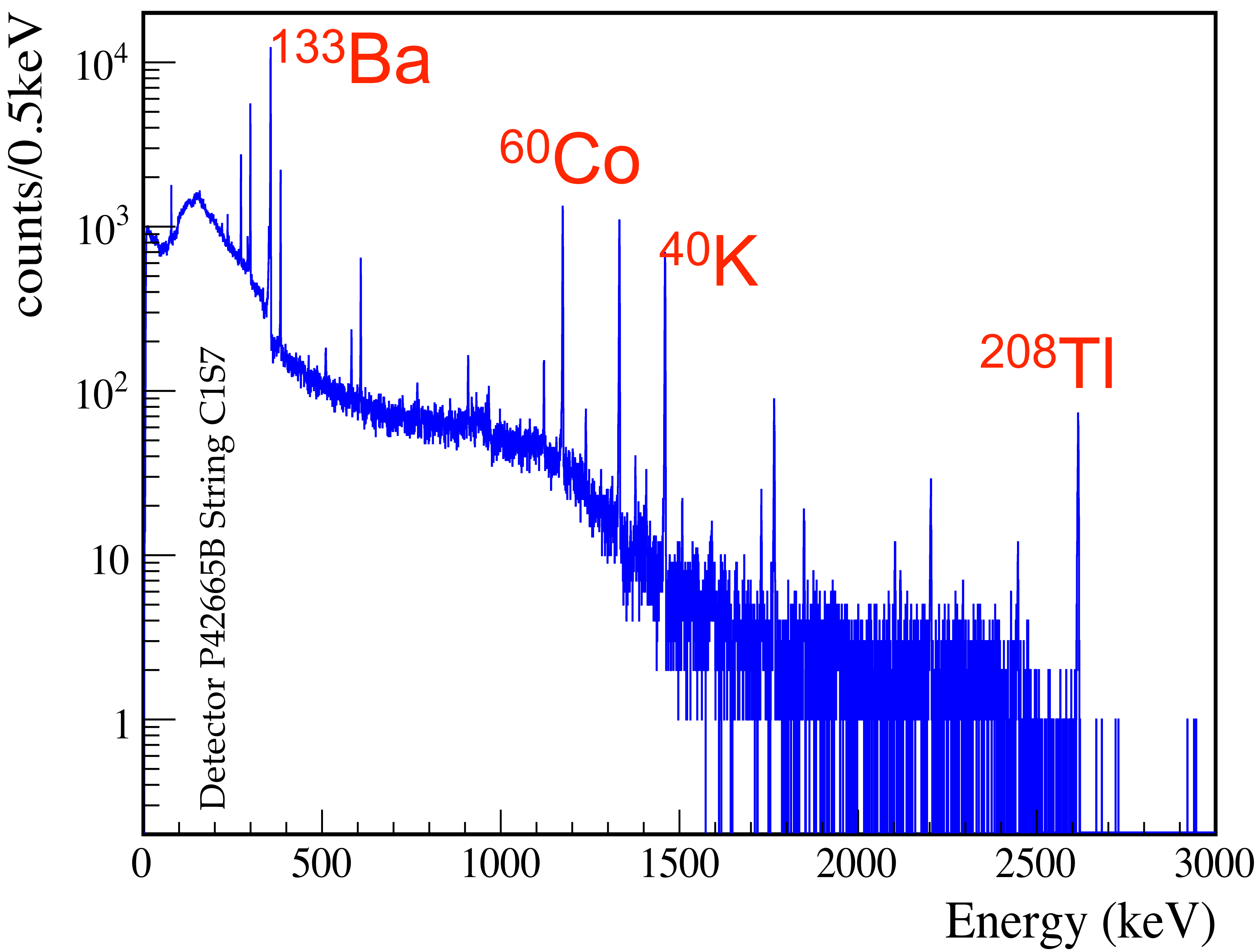
Resolution measurements in vendor cryostat



Multiple Source Calibration within a String Test Cryostat

At 1332 keV, FWHM = 1.98 keV +/- 0.024 keV

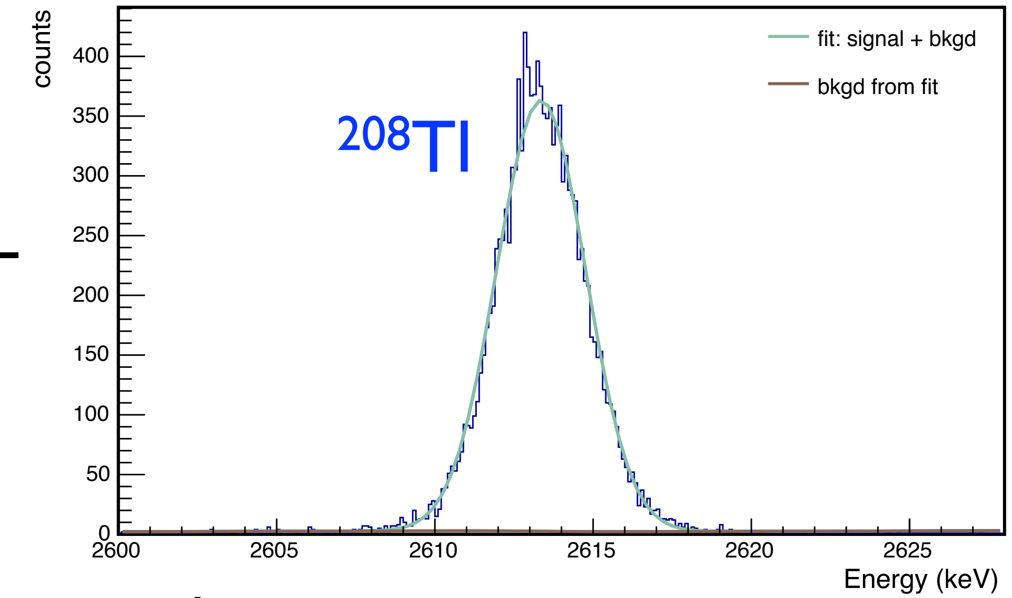
At 2614 keV, FWHM = 2.72 keV +/- 0.15 keV

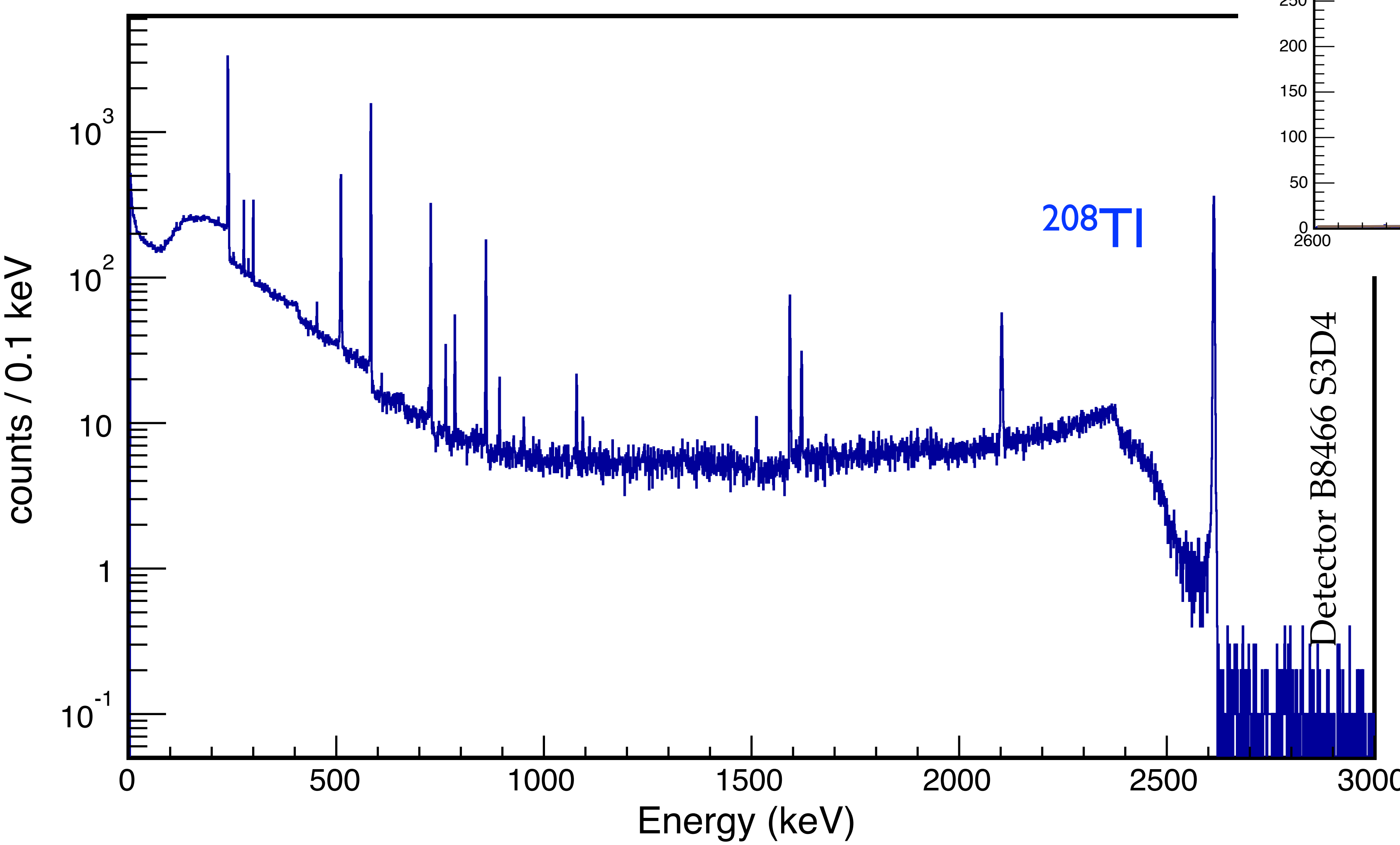


Remounted enriched detector in string test cryostat

^{228}Th Calibration Spectrum in Prototype Cryostat

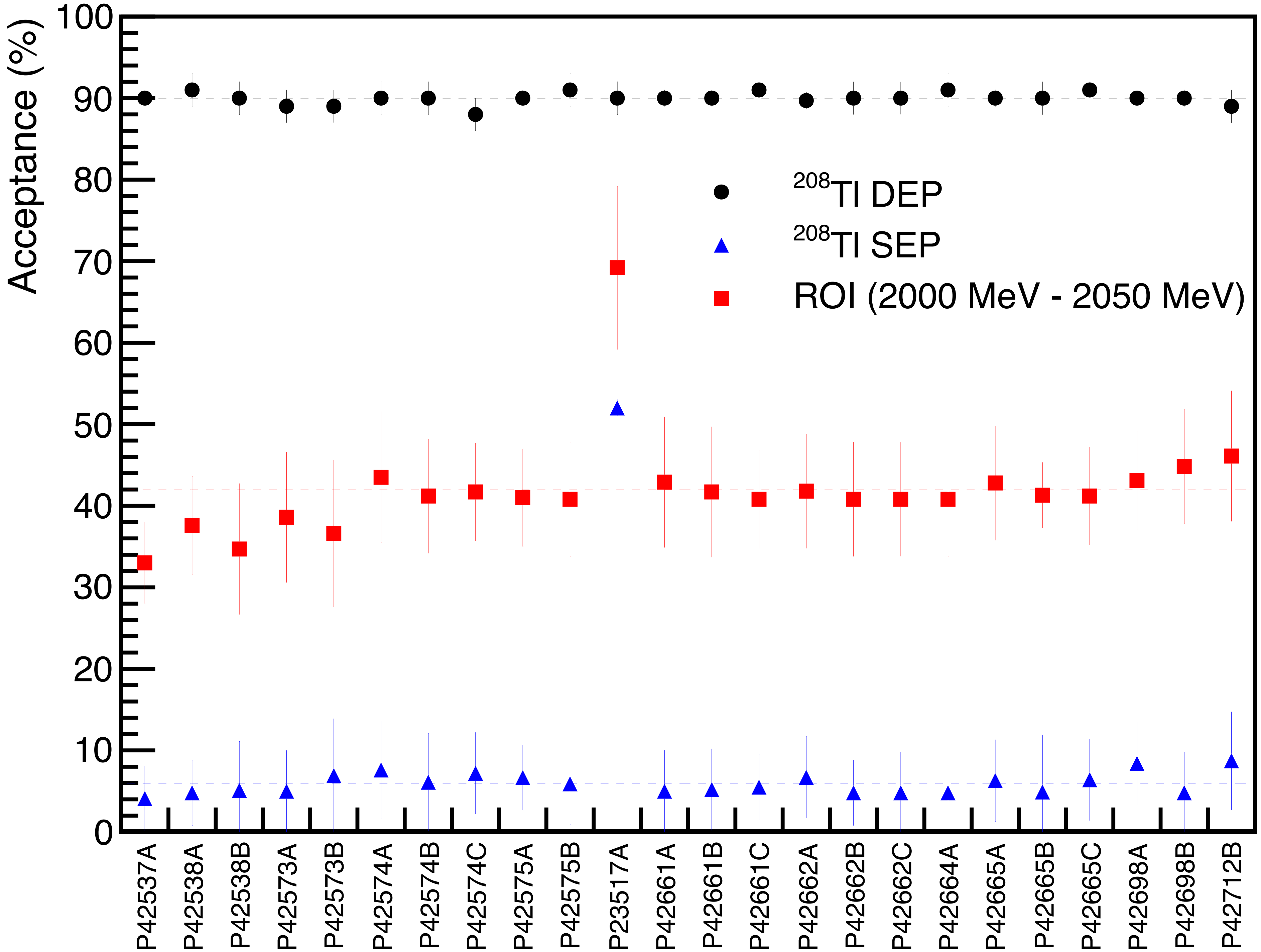
One detector spectrum within a string mounted in the prototype cryostat and inside shield. FWHM 3.2 keV at 2.6 MeV





^{enr}Ge Detector PSD Performance in Vendor Cryostats

One detector has degraded PSD

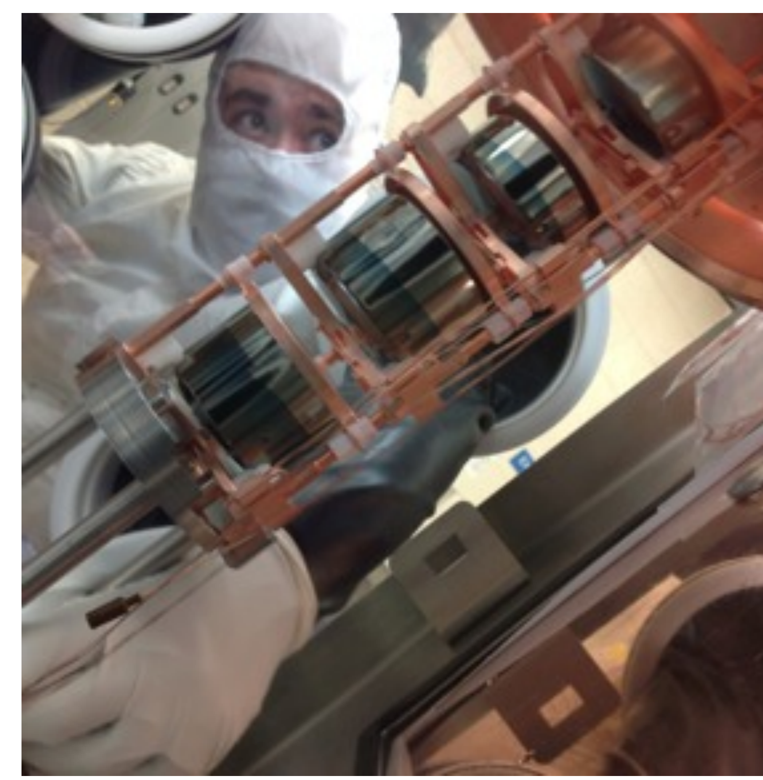


^{208}Tl DEP (single site events) fixed to 90%

^{208}Tl SEP (multi-site events) reduced to 10%

MAJORANA DEMONSTRATOR Summary

- Current background budget is < 4.1 cts/4 keV/t-y
  - close to the original MJD goal of 3.
- Prototype Cryostat: 3 strings of natural Ge
  - Deployed in partial shield
    - radon exclusion not fully functional
    - muon and neutron shield incomplete
  - Analyzing backgrounds
- Module 1: Installed 1 string of ^{enr}Ge
  - Initial commissioning
  - 25 kg of characterized enriched detectors on hand
  - 4 of 7 enriched strings assembled
  - Start engineering run in early 2015
- Phased start of operations of Module 1 in 2015 as we complete fabrication and assembly of Module 2.



Future Program

- MAJORANA and GERDA are working towards the establishment of a single international ^{76}Ge $0\nu\beta\beta$ collaboration
  - Envision a phased, stepwise implementation;
    - e.g. 250 → 500 → 1000 kg
  - Moving forward predicated on demonstration of projected backgrounds by MJD and/or GERDA
  - Anticipate down-select of best technologies, based on results of the two experiments

- During 2015 both GERDA Phase II and MJD Module 1 should be collecting data
- A Large-Scale ^{76}Ge double beta decay experiment would have a lot in common with the present generation experiments.
  - A large and experienced collaboration is expected to form from the present-generation experimental groups.

The MAJORANA Collaboration

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The MAJORANA Collaboration

Black Hills State University
Duke University
ITEP
Joint Institute for Nuclear Research
Berkeley Lab
Los Alamos National Laboratory
Oak Ridge National Laboratory
University of Alberta
Osaka University
North Carolina State University
Pacific Northwest National Laboratory
Sanford Underground Research Facility
TUNL
The University of North Carolina at Chapel Hill
University of South Carolina
Tennessee Tech University
Shanghai Jiao Tong University
M
University of South Dakota
The University of Tennessee
W

MAJORANA Posters at DNP

Session GB: Conference Experience for Undergraduates Poster Session (1:30-3:00PM)

- GB.00007: A. Bowes, Investigations of p-type point contact detectors for the MAJORANA Experiment
- GB.00008: S. Elia, Front-End Electronics Characterization, Production, and QA for the Majorana Demonstrator
- GB.00009: W. Thompson et al, The trigger card system for the MAJORANA DEMONSTRATOR
- GB.00010: C. Wilson, Ge Detector Data Classification with Neural Networks
- GB.00012: C. Dugger, Automation of the Characterization of High Purity Germanium Detectors

MAJORANA Talks at DNP

Session CM: Mini-Symposium on Double Beta Decay and Dark Matter I
7:00 PM–9:45 PM, Wednesday, October 8, 2014

- CM.00008: S Mertens, Overview and Status of the MAJORANA DEMONSTRATOR
- CM.00009: C. O'Shaughnessy, MAJORANA DEMONSTRATOR: Prototype Module Commissioning

Session DM: Mini-Symposium on Double Beta Decay and Dark Matter II
9:00 AM–12:00 PM, Thursday, October 9, 2014

- DM.00010: N. Abgrall, Design and performance of the MAJORANA low-noise low-background front-end electronics
- DM.00011: B. Jasinski, Assembly and design of the germanium detectors for the Majorana DEMONSTRATOR