Office of Nuclear Physics

The MAJORANA DEMONSTRATOR
search for neutrinoless double beta decay

C. M. O'Shaughnessy

Univ. of North Carolina & Triangle Universities Nuclear Laboratory

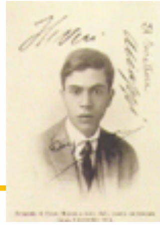
On behalf of the MAJORANA Collaboration

20th Particles and Nuclei International Conference 2014

25 – 29 August 2014

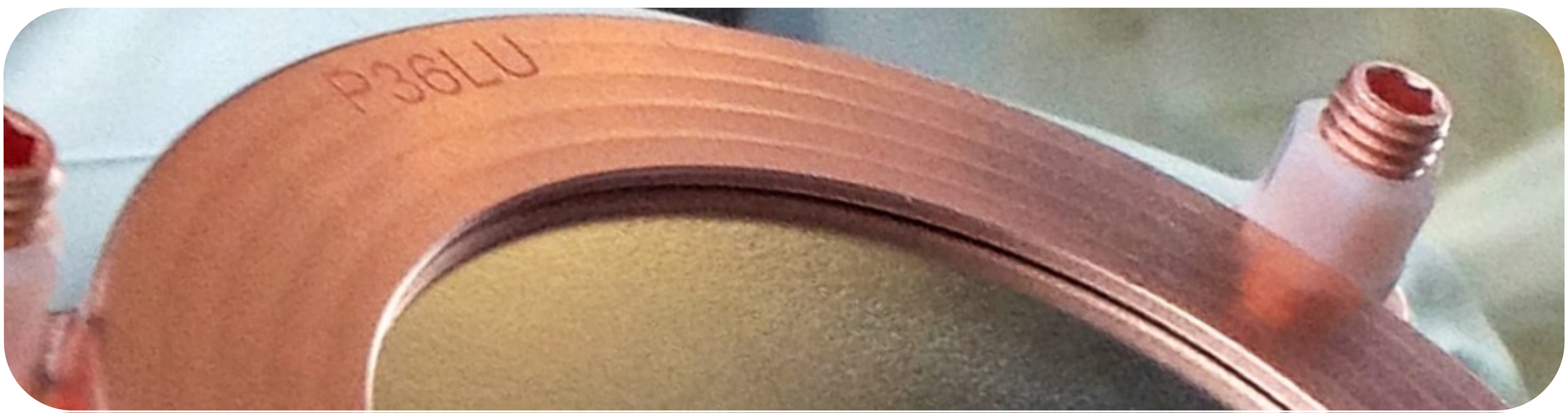
Hamburg, Germany

25 August 2014



Outline

- **MAJORANA DEMONSTRATOR Overview**
- **Backgrounds**
- **Status of the DEMONSTRATOR**



The MAJORANA Collaboration

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Ian Guinn, Greg Harper, Jonathan Leon, David Peterson, R. G. Hamish Robertson,
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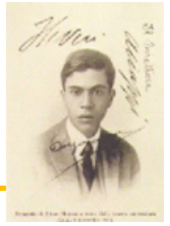
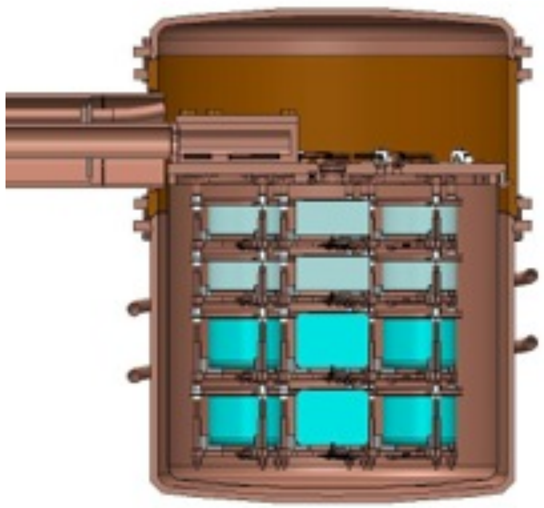
The MAJORANA DEMONSTRATOR

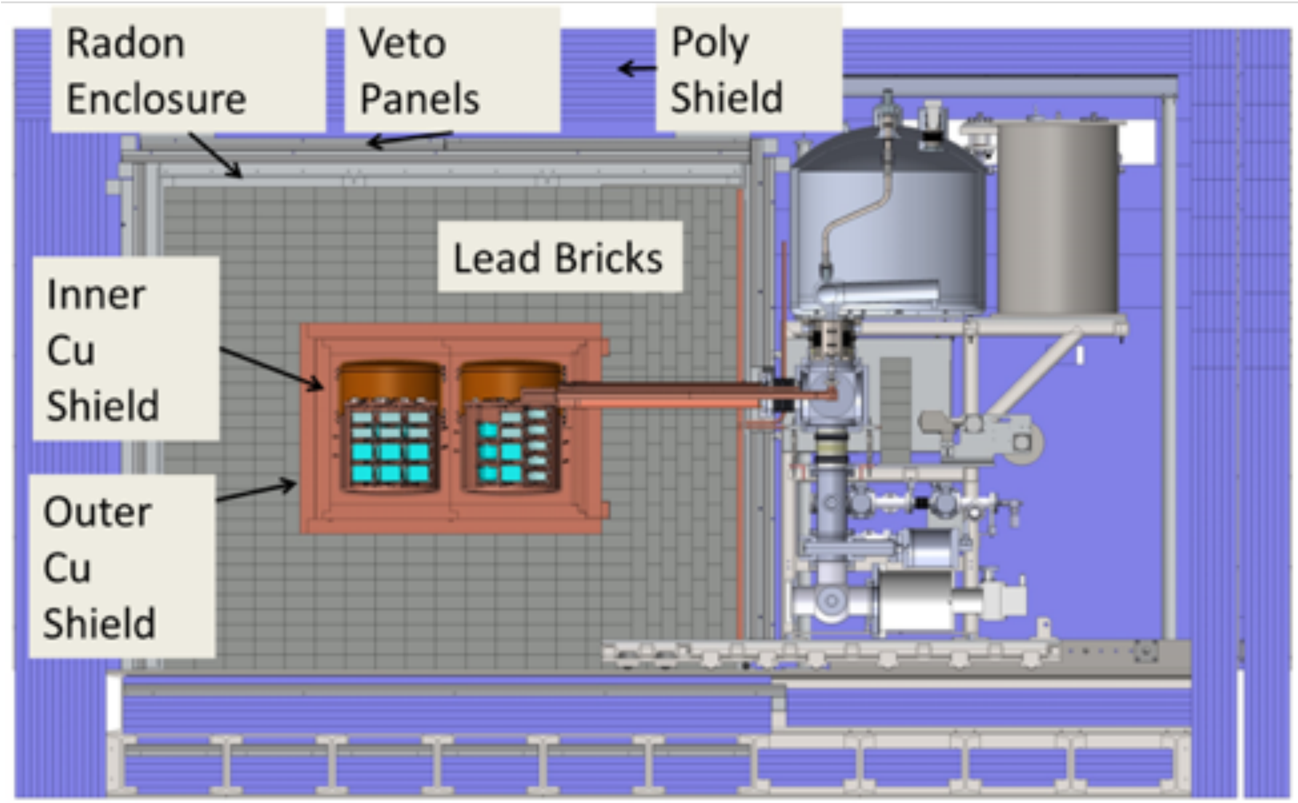


Funded by DOE Office of Nuclear Physics and NSF Particle Astrophysics,
with additional contributions from international collaborators.

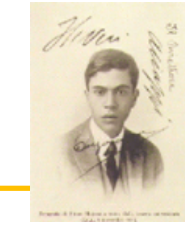
Goals:
- Demonstrate backgrounds low enough to justify building a tonne scale experiment.
- Establish feasibility to construct & field modular arrays of Ge detectors.
- Searches for additional physics beyond the standard model.



- **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 ≤ 4.1**
  scales to 1 count/ROI/t/y for a tonne 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.
- **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

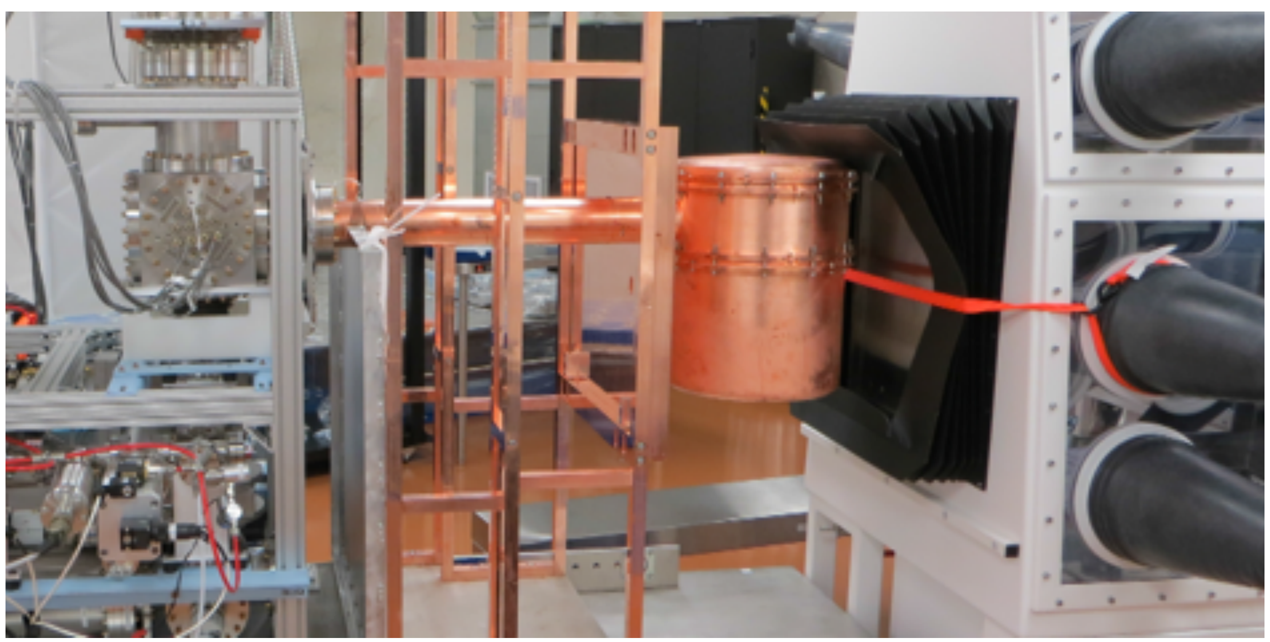


MJD Modular Approach

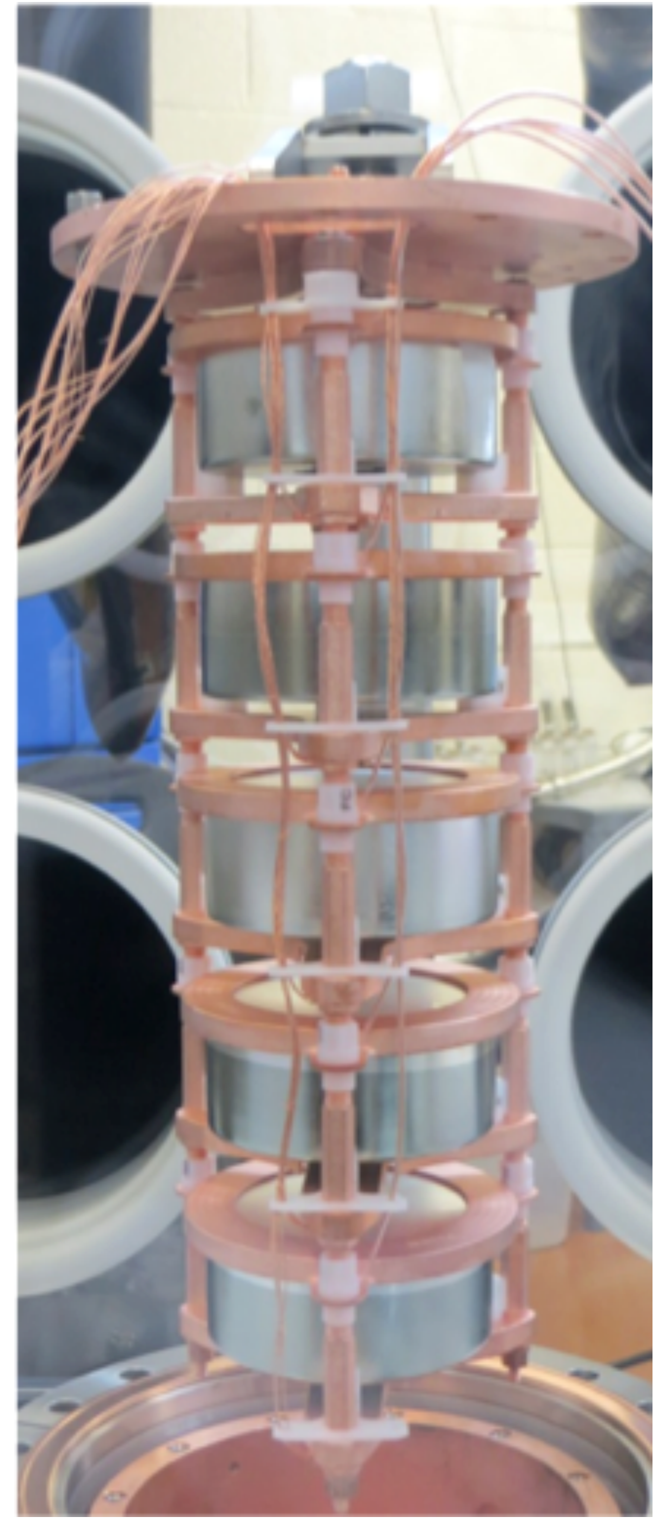


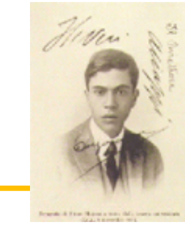
Detector, mount, and front end electronics

Cryostat and vacuum system



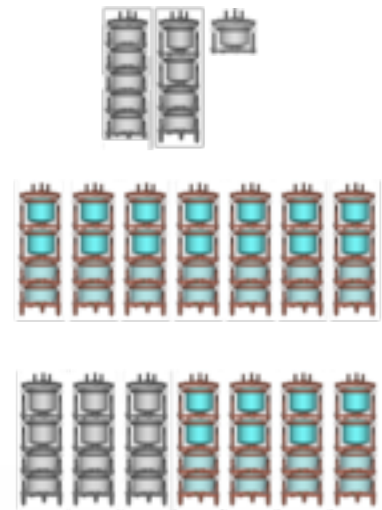
Detector string





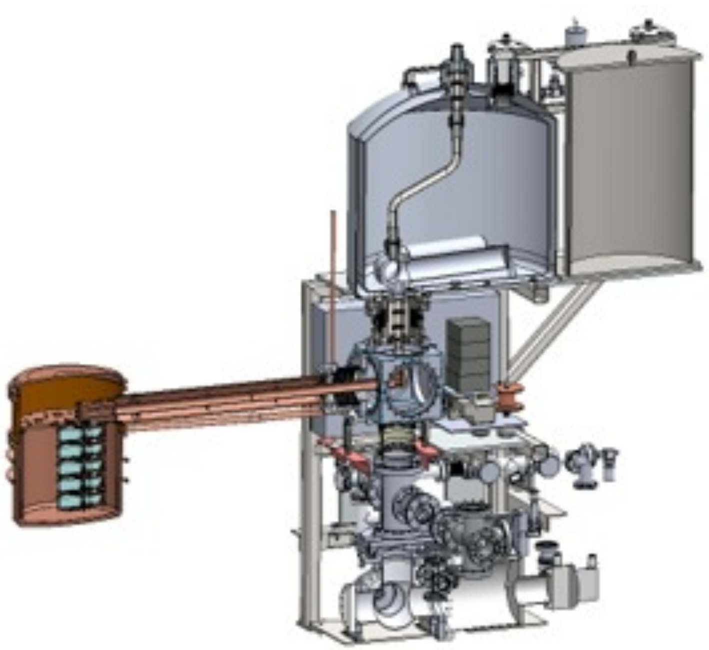
MJD Implementation

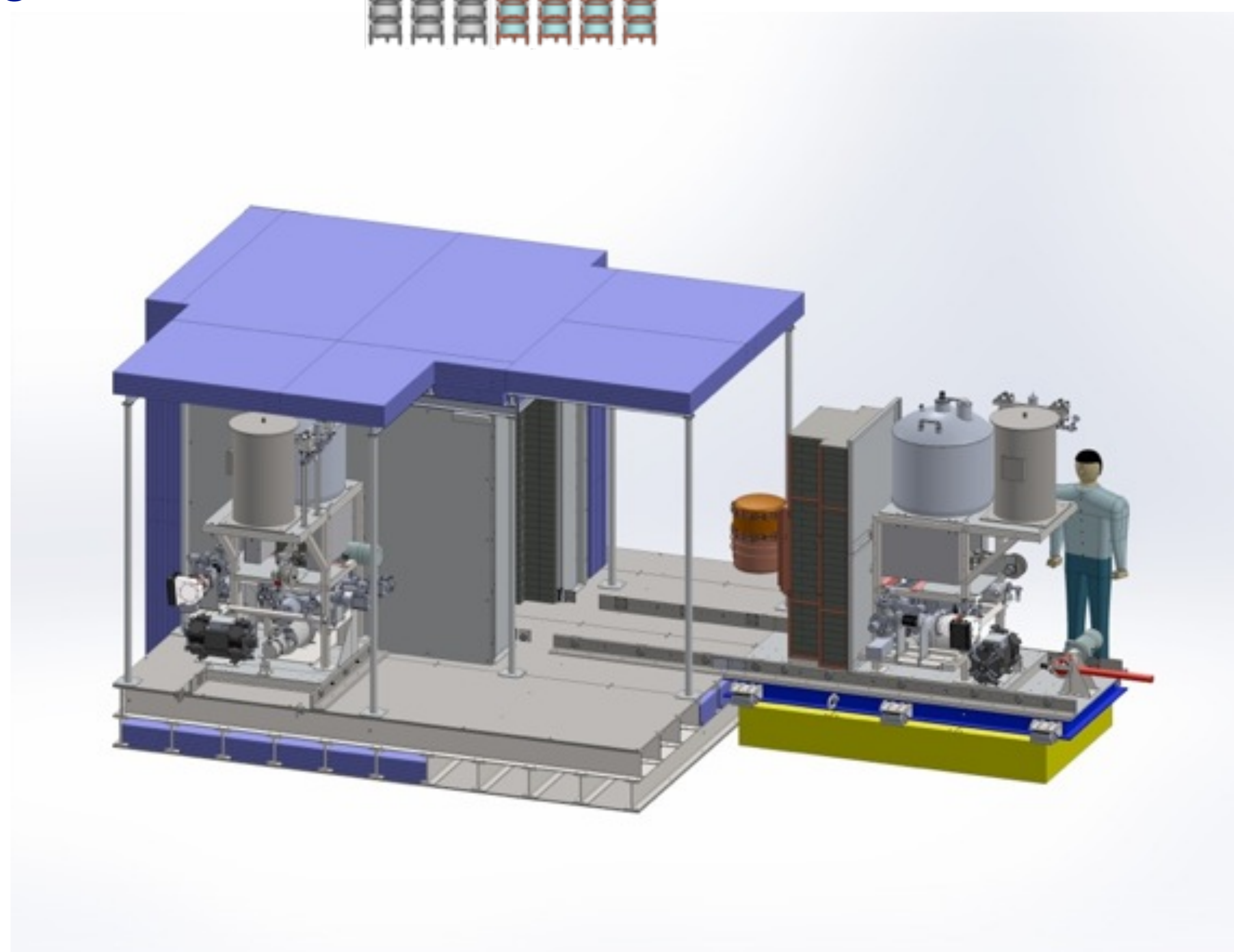
- Three Steps
  - ✓Prototype Module* (3 strings, ^{nat}Ge)
  - Module 1 (7 strings, 20 kg ^{enr}Ge)
  - Module 2 (4 strings, 10 kg ^{enr}Ge & 3 strings ^{nat}Ge)



Commissioning start dates
(Estimated)

- Nov. 2013
- (Fall 2014)
- (Fall 2015)



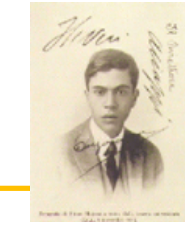


*Same design as Cryos 1 & 2, but fabricated using OFHC Cu (non-electroformed) components.

Outline

- Majorana Demonstrator Overview
- **Backgrounds**
- Status of the Demonstrator

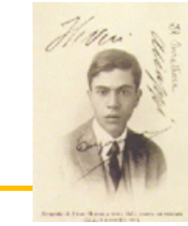
MJD Background Strategy



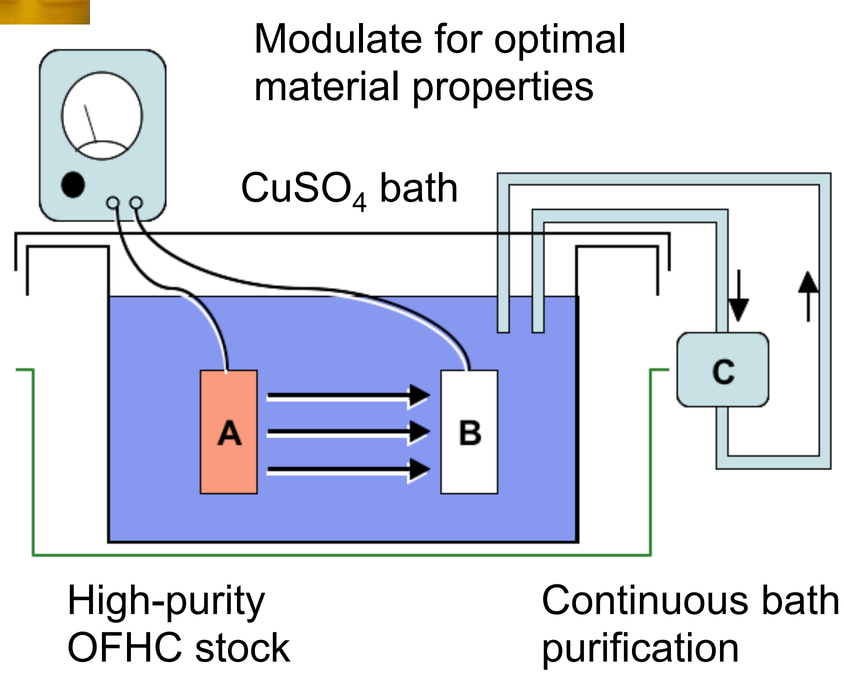
Backgrounds must be both reduced within/near the array & rejected in the analysis.

Reduction	Rejection
Low-inactive-mass design	Energy resolution
Ultra-pure materials	Array granularity
Clean handling	Pulse-shapes
Shielding and Depth	Time correlations

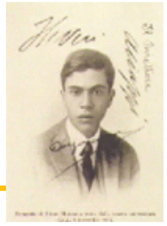
MJD Electroformed Cu



- Cu is the key material for MJD
  - detector mounts, cryostats, inner shield
- Electroplated on 316 SS mandrels in Class 1000 cleanroom
- Currently there are 10 baths in operation at SURF
- Average growth rate of 1mm/month or 0.033mm/day
- To date 25 of the 31 mandrels needed are complete
- This facility is now becoming available to others

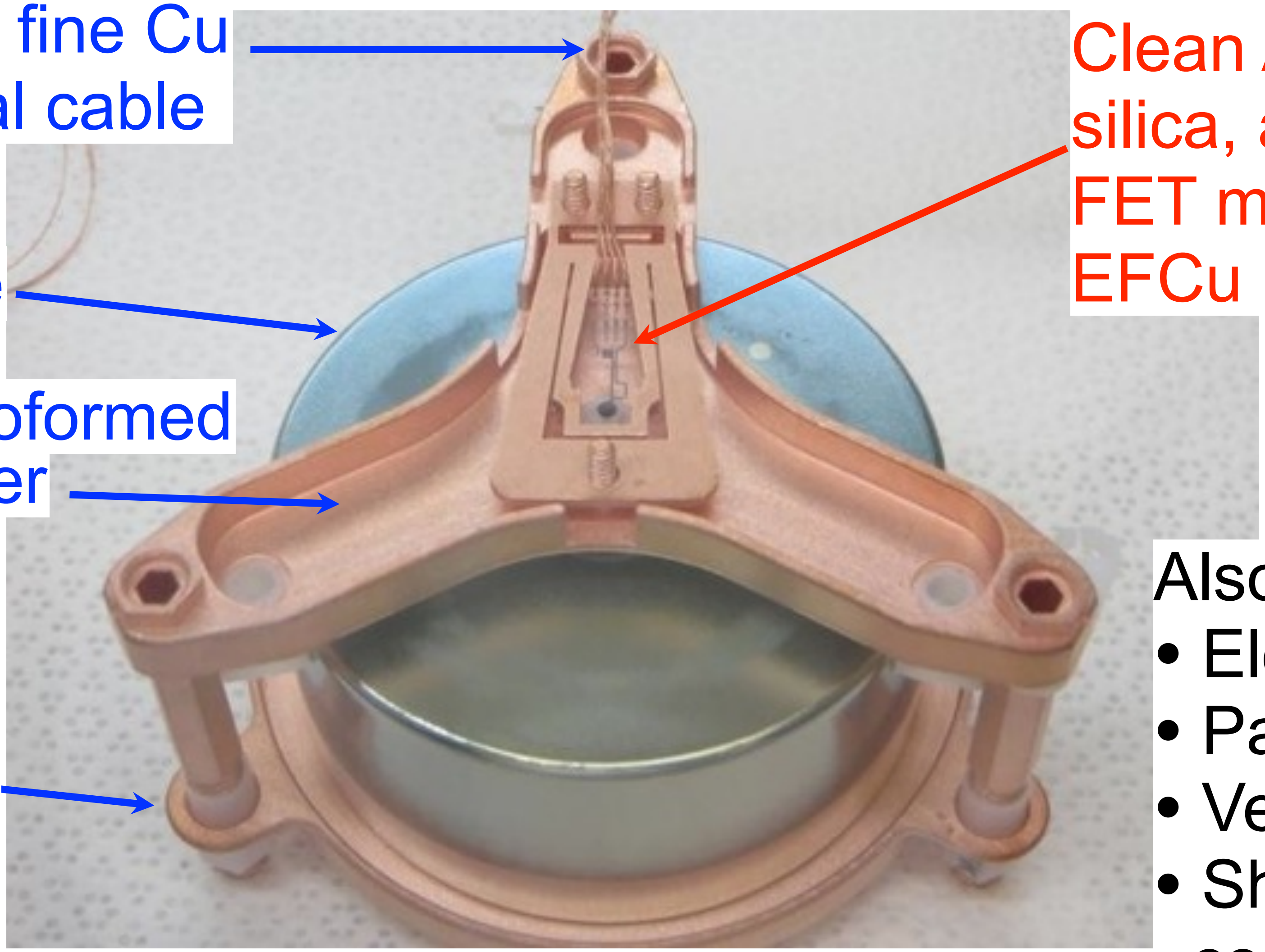


	Starting	**EF Cu**
Uranium	1.25 μBq/kg	0.17 μBq/kg
Thorium	1.10 μBq/kg	0.06 μBq/kg
Yield Strength	~50 MPa	70-100 MPa



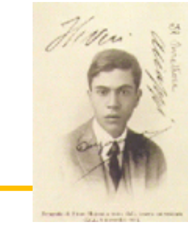
MJD Ultra-Pure Materials

We are working with a novel palette of ultra-pure materials, while also minimizing the total amounts



Also:

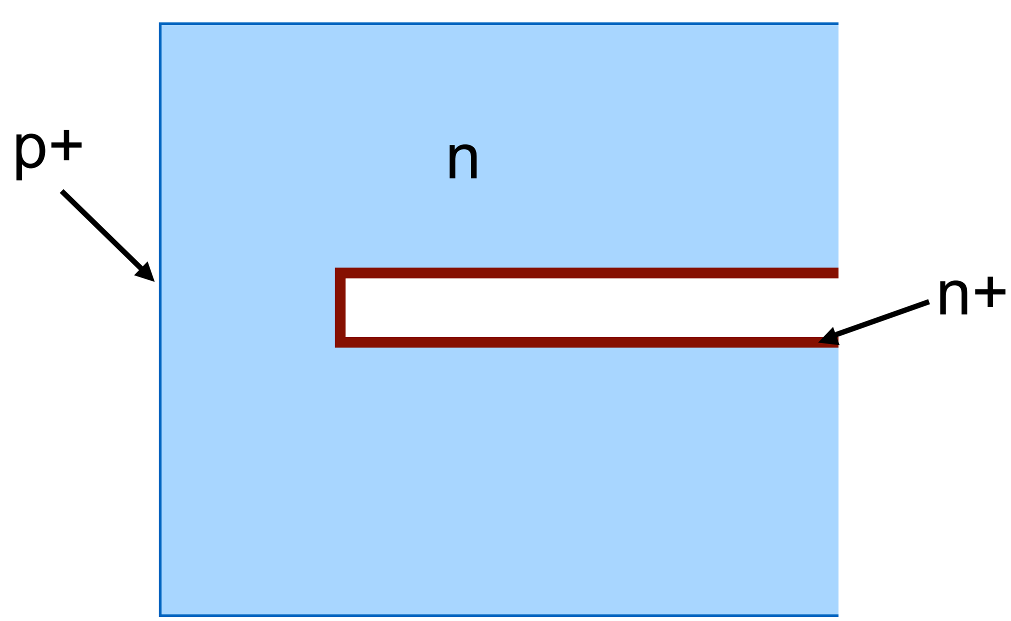
- Electroformed Cryostats
- Parylene coating / seals
- Vespel, PEEK supports
- Shields: Low-BG commercial Cu and Pb



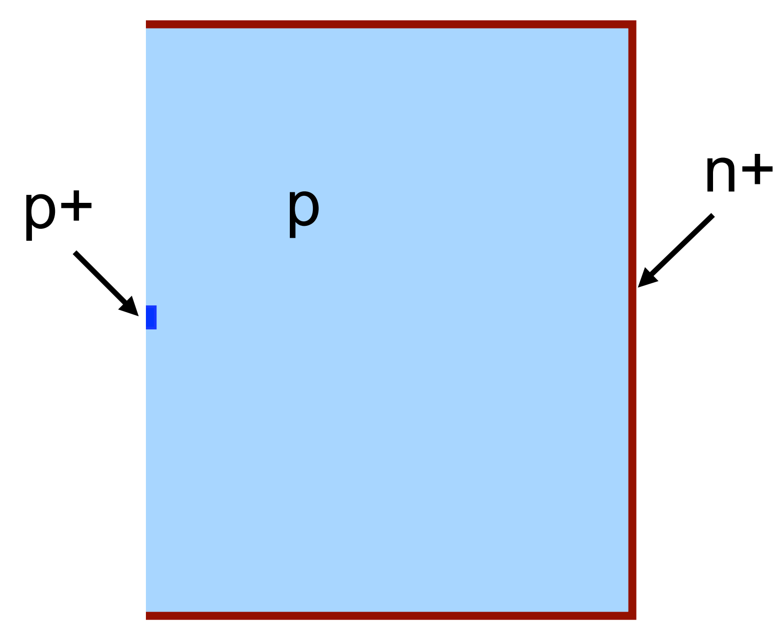
Point Contact Detectors (PPC)

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).

- Ultra-low background requires PSA rejection of multi-site gamma events
- Initially considered coaxial n-type detectors with modest segmentation
- Chose P-type Point-Contact (PPC) detectors
  - No deep hole; small point-like central contact
  - mm thick n+ outer contact
  - Localized weighting potential gives excellent multi-site rejection
  - Low capacitance (~ 1 pF) gives superb resolution at low energies

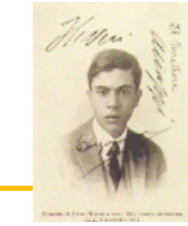


N-type Coaxial



P-type Point Contact

Point Contact Detectors (PPC)



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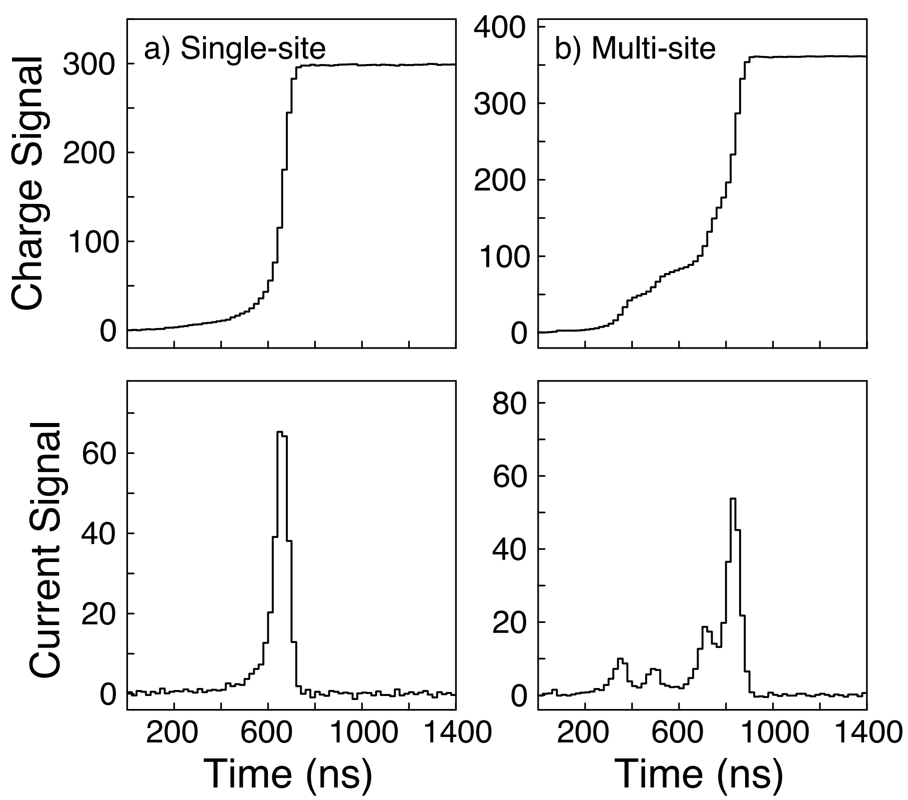
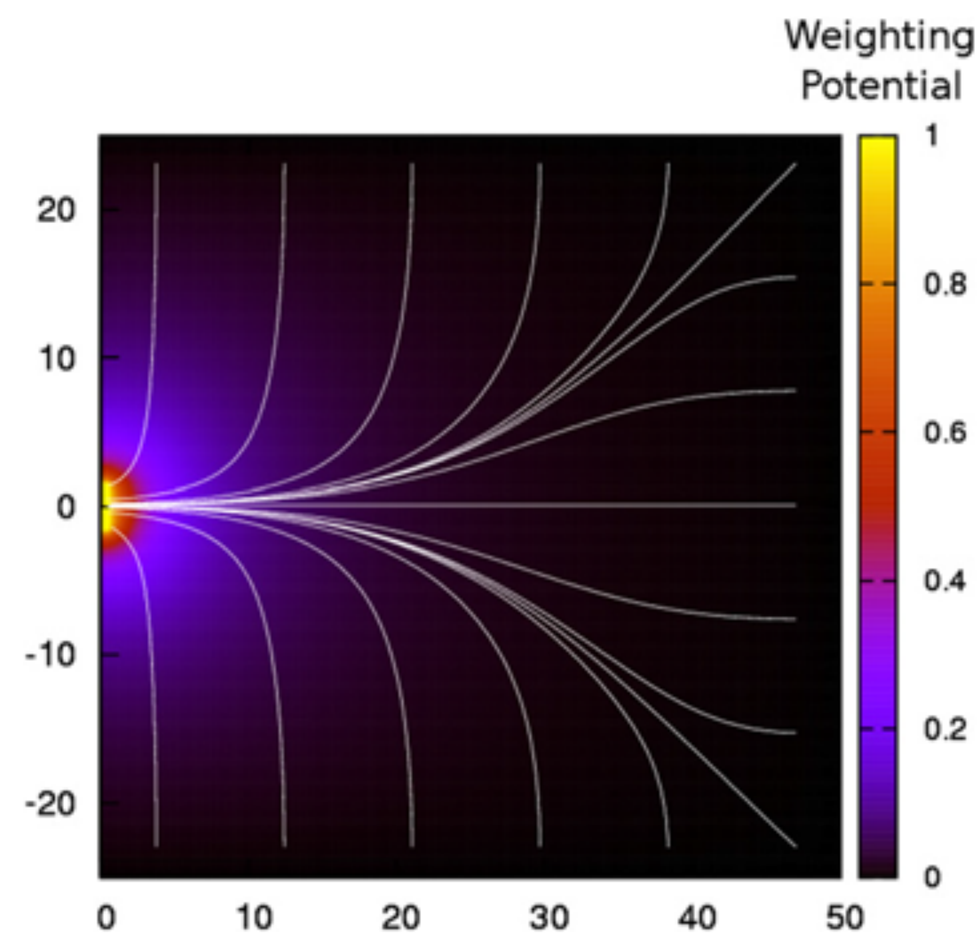
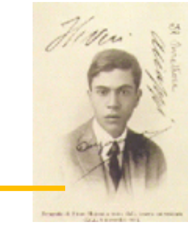


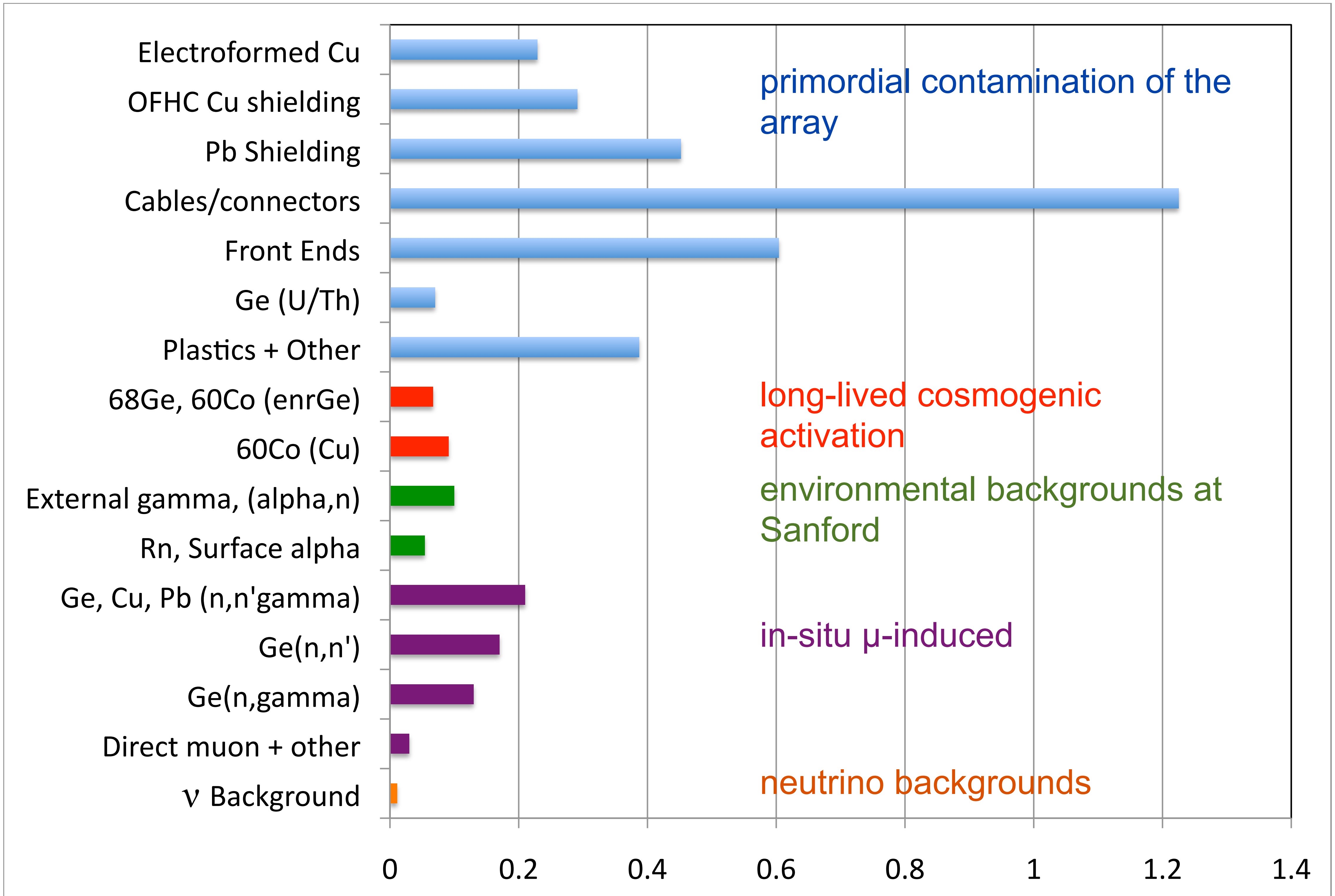


DEMONSTRATOR Background Budget



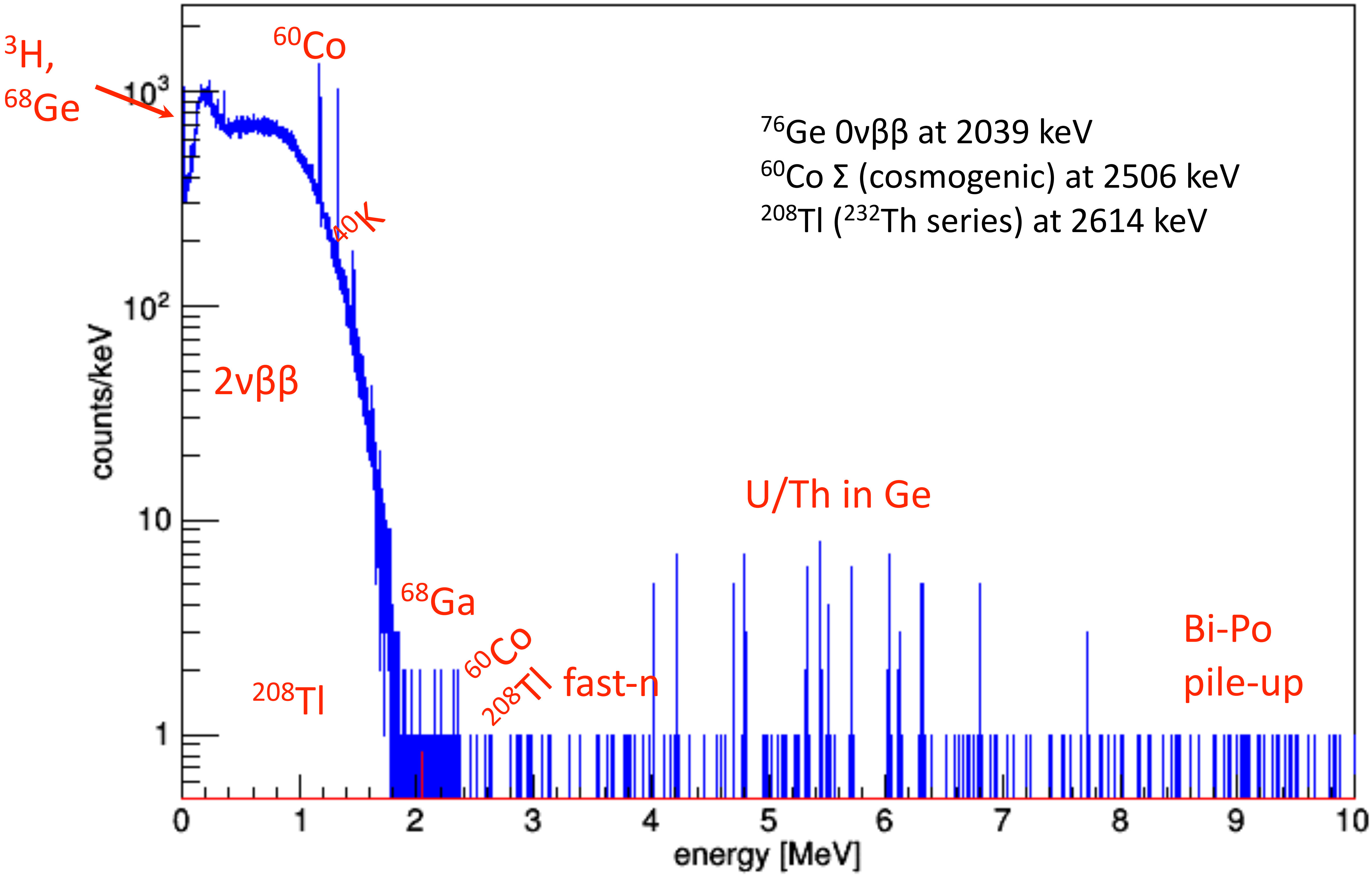
Based on achieved assays of materials
When UL, use UL as the contribution

Current Value: ≤ 4.1 cts / 4 keV / t-y
MJD Goal: 3.0 cts / 4 keV / t-y



MAJORANA DEMONSTRATOR Simulation

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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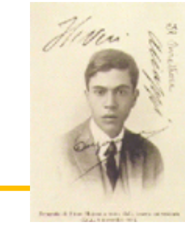

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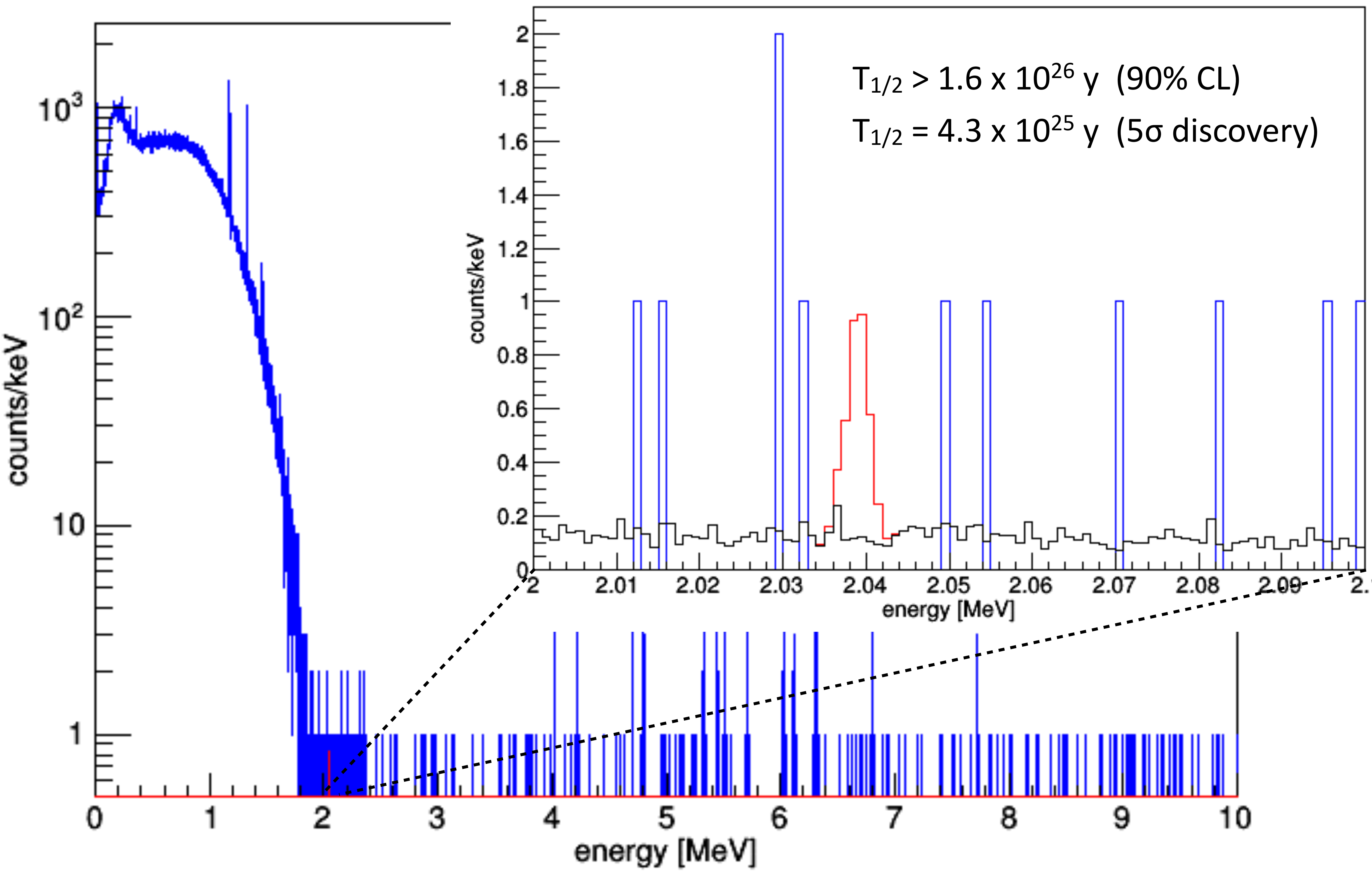
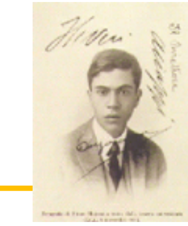
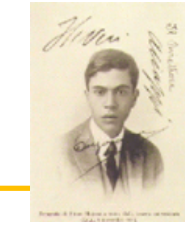


Outline



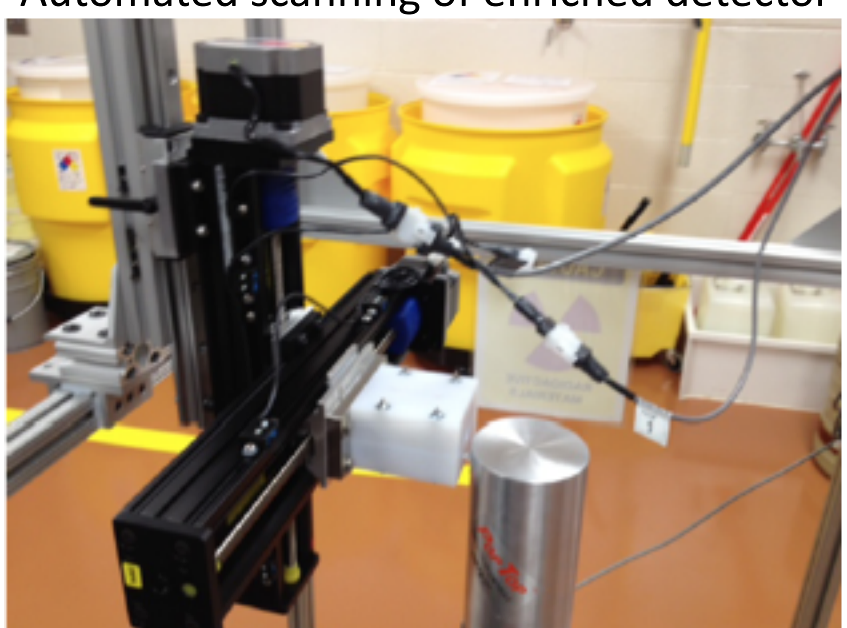
- Majorana Demonstrator Overview
- Backgrounds
- **Status of the Demonstrator**

MJD Enriched Detectors

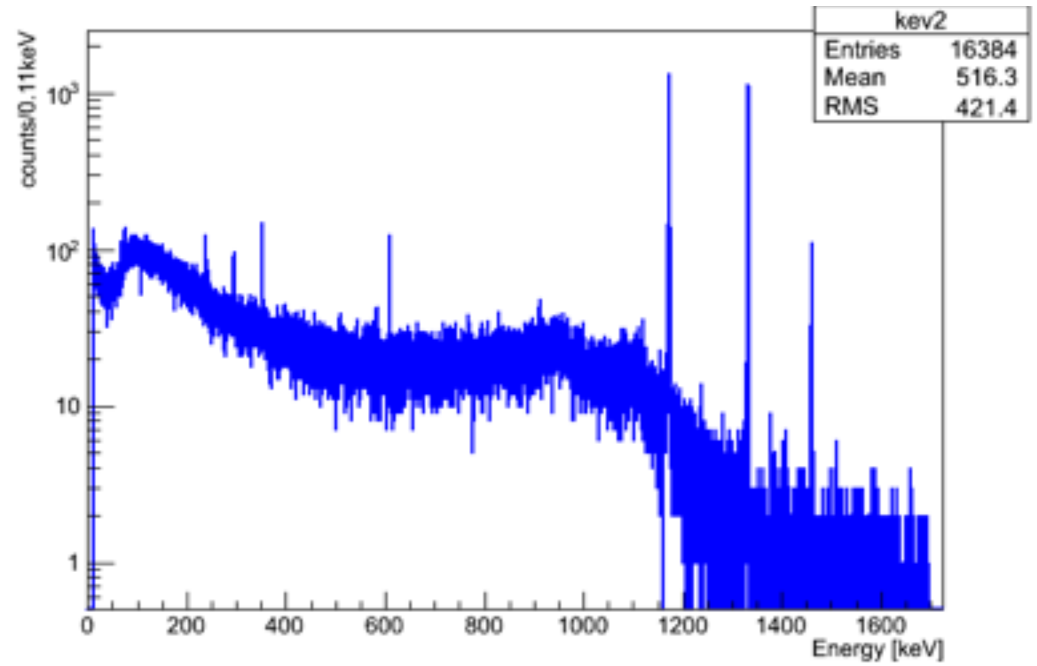


- 30 enriched PPC detectors produced by ORTEC are UG at SURF
  - total mass 25.2 kg
- ^{60}Co flood measurements to determine detector resolution & detection efficiency
- ^{133}Ba and ^{214}Am flood measurements low energy resolutions and dead layer estimation
- ^{133}Ba collimated source scans detector response uniformity
- ^{232}Th flood measurement to study PSA performance

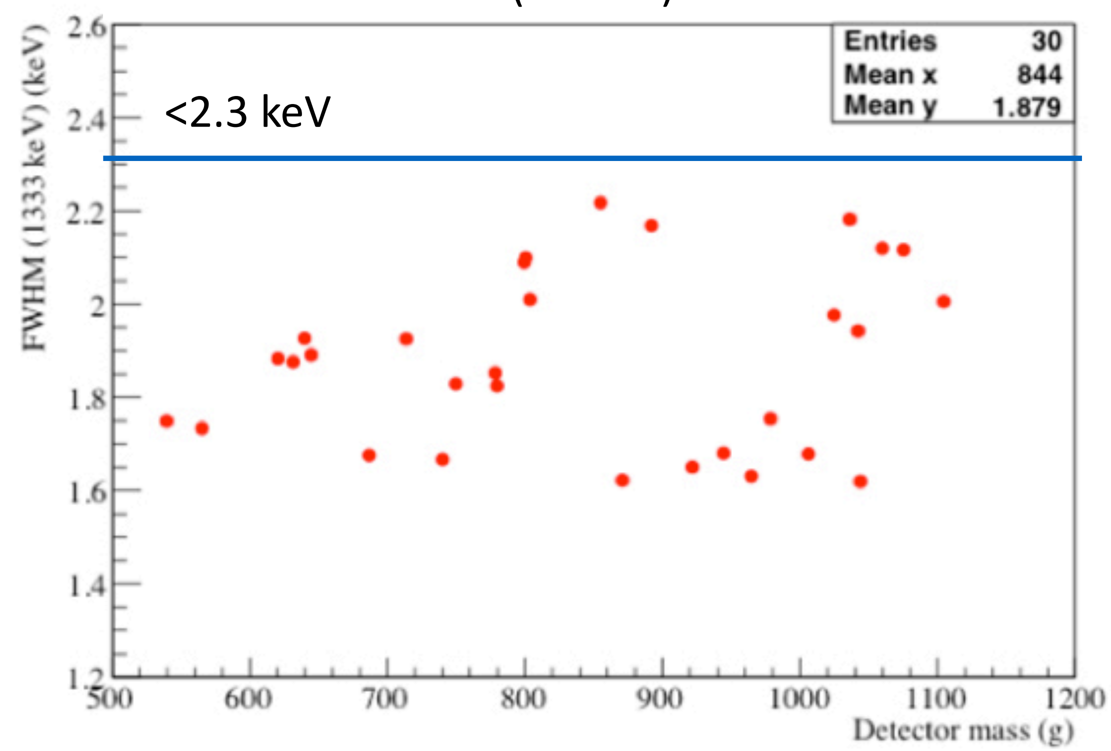
Automated scanning of enriched detector



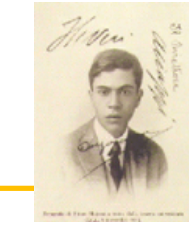
Enriched ORTEC PPC UG (60Co Calibration)



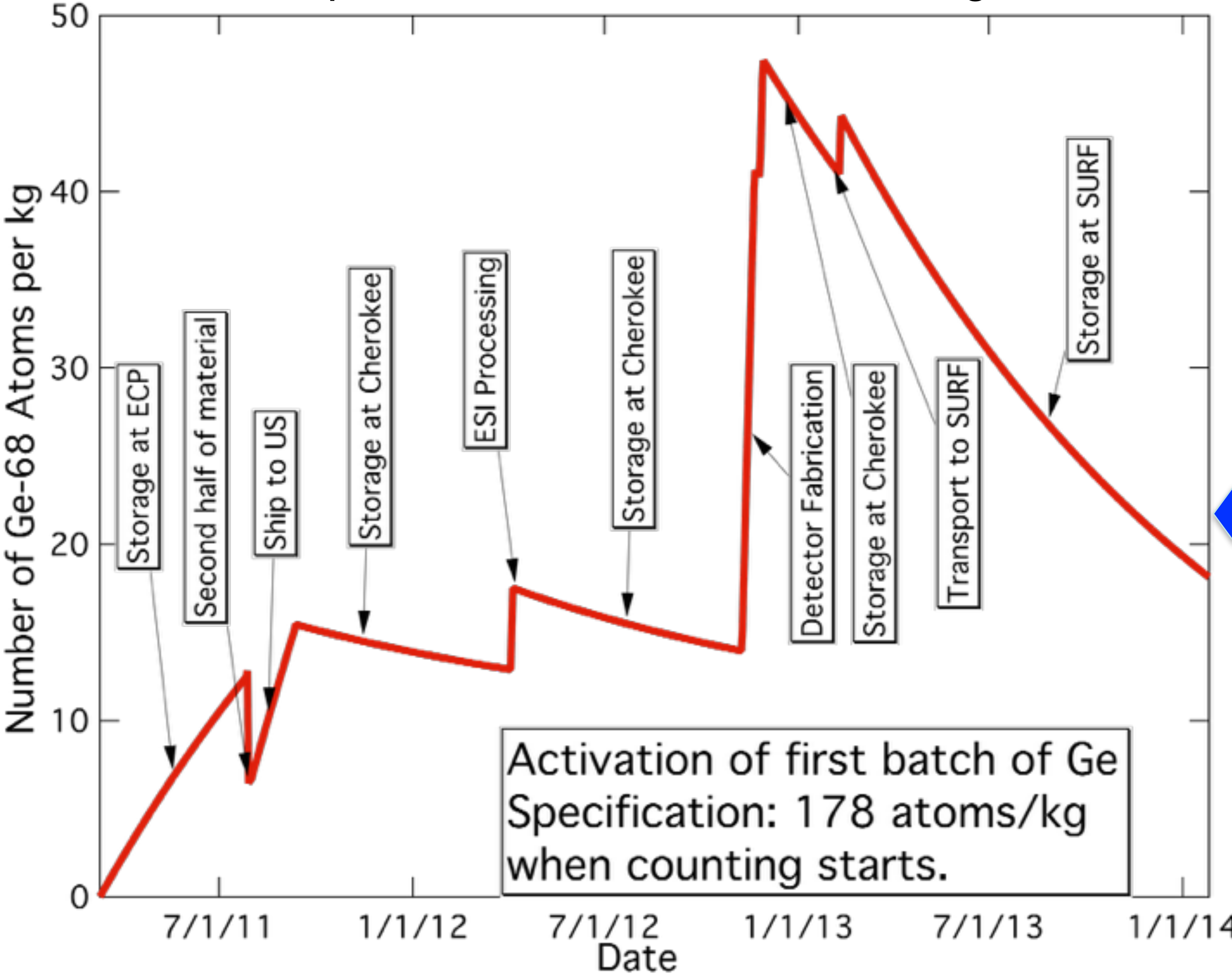
Detector Resolution (FWHM) vs Detector Mass



EnrGe Typical Effective Surface Exposure

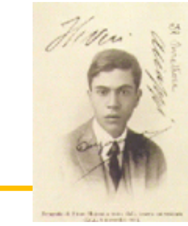


Storage and shipping with overburden
and fast process times minimize cosmogenics



UG storage at ECP x22 reduction
Shipping container x10 reduction
UG at Cherokee x100 reduction

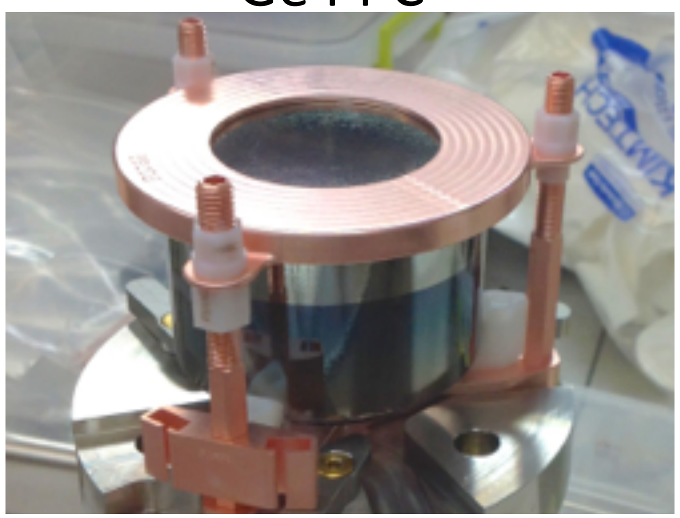
10 days equivalent sea level exposure

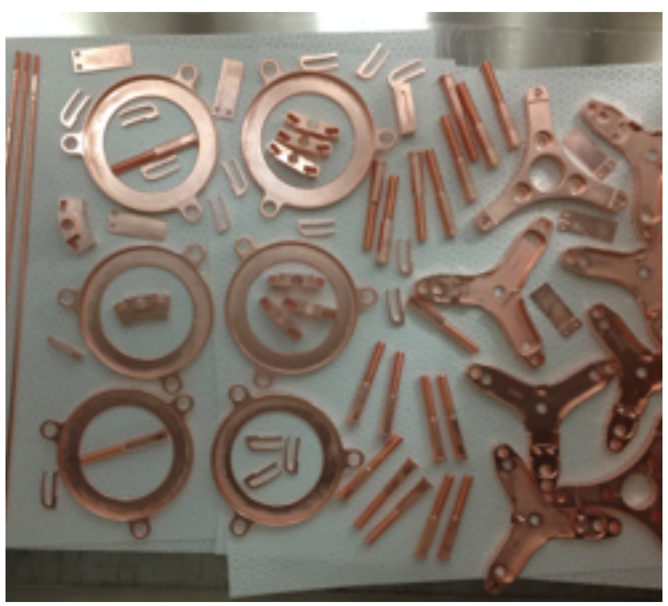


MJD Strings

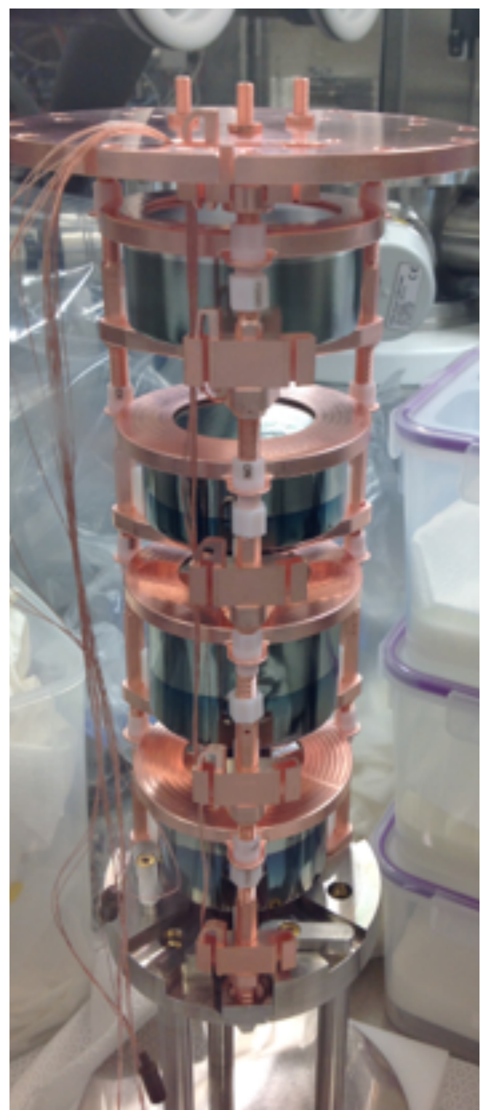
- Four strings of natural Ge detectors have been built in the UG glove boxes.
- Strings have been tested in string test cryostats and in the prototype cryostat
- Two of seven enriched strings for module 1 have been built

^{Enr}Ge PPC

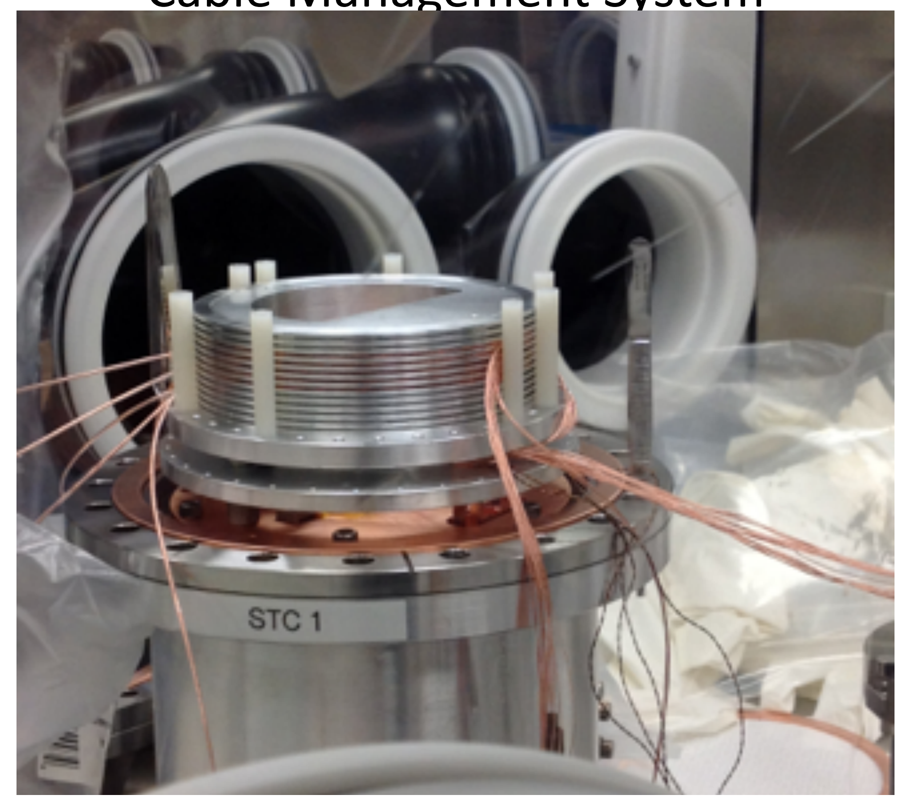




String with
3 ^{Enr}Ge PPCs and
1 ^{Nat}Ge BEGe

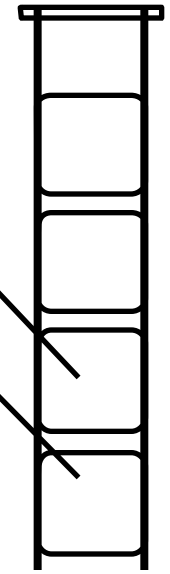


Cable Management System

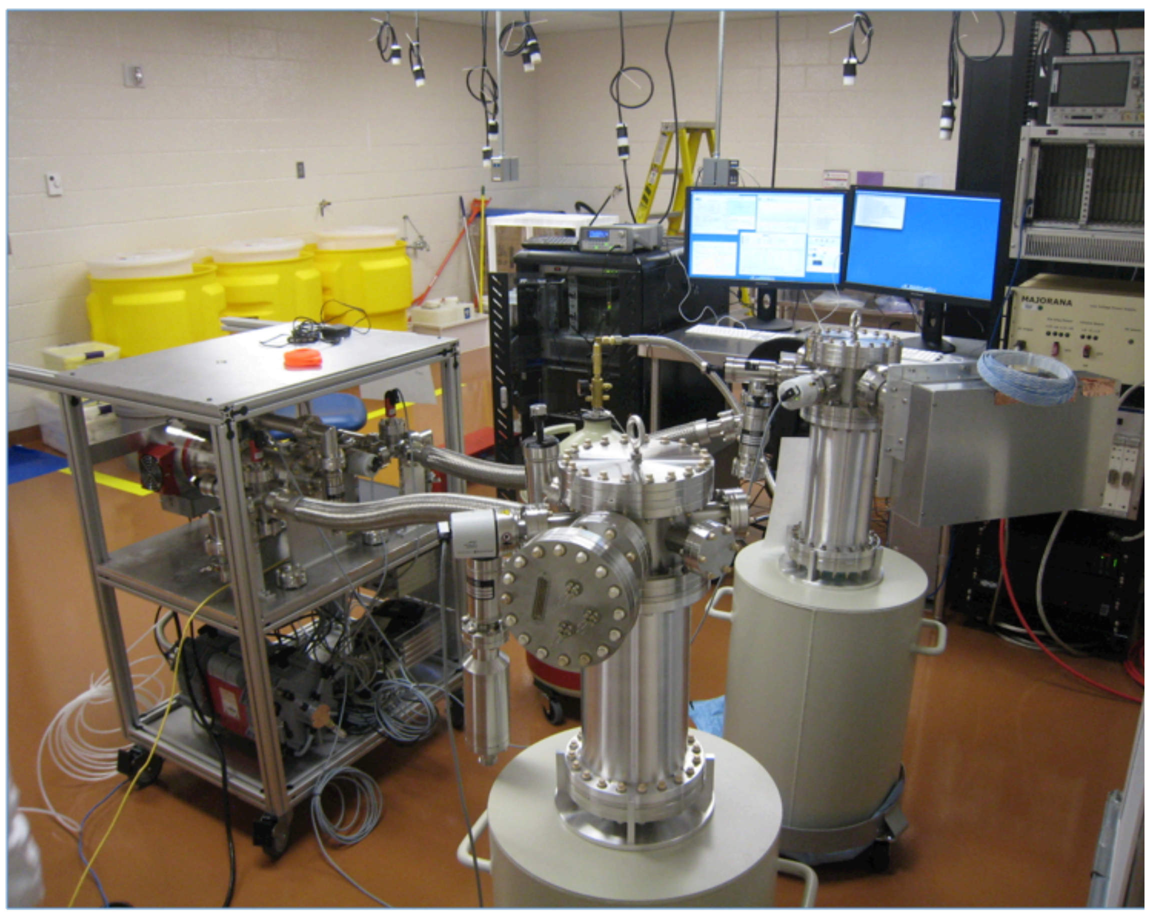


Loading string into string test cryostat in Glove Box

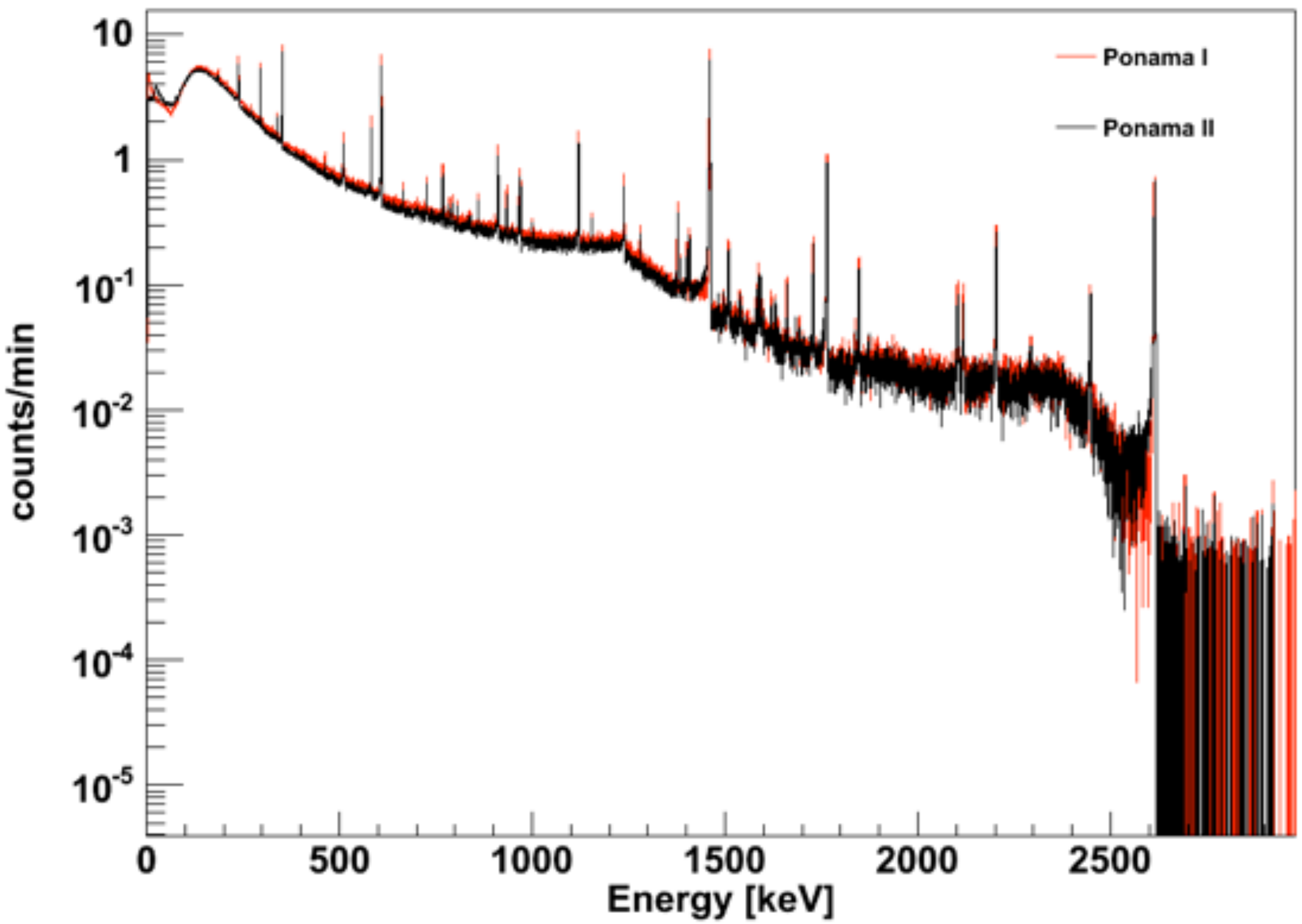
MJD String Characterization



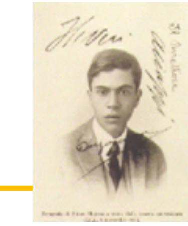
String Test Cryostats and Pumping Station



Background Run (~17 hours)

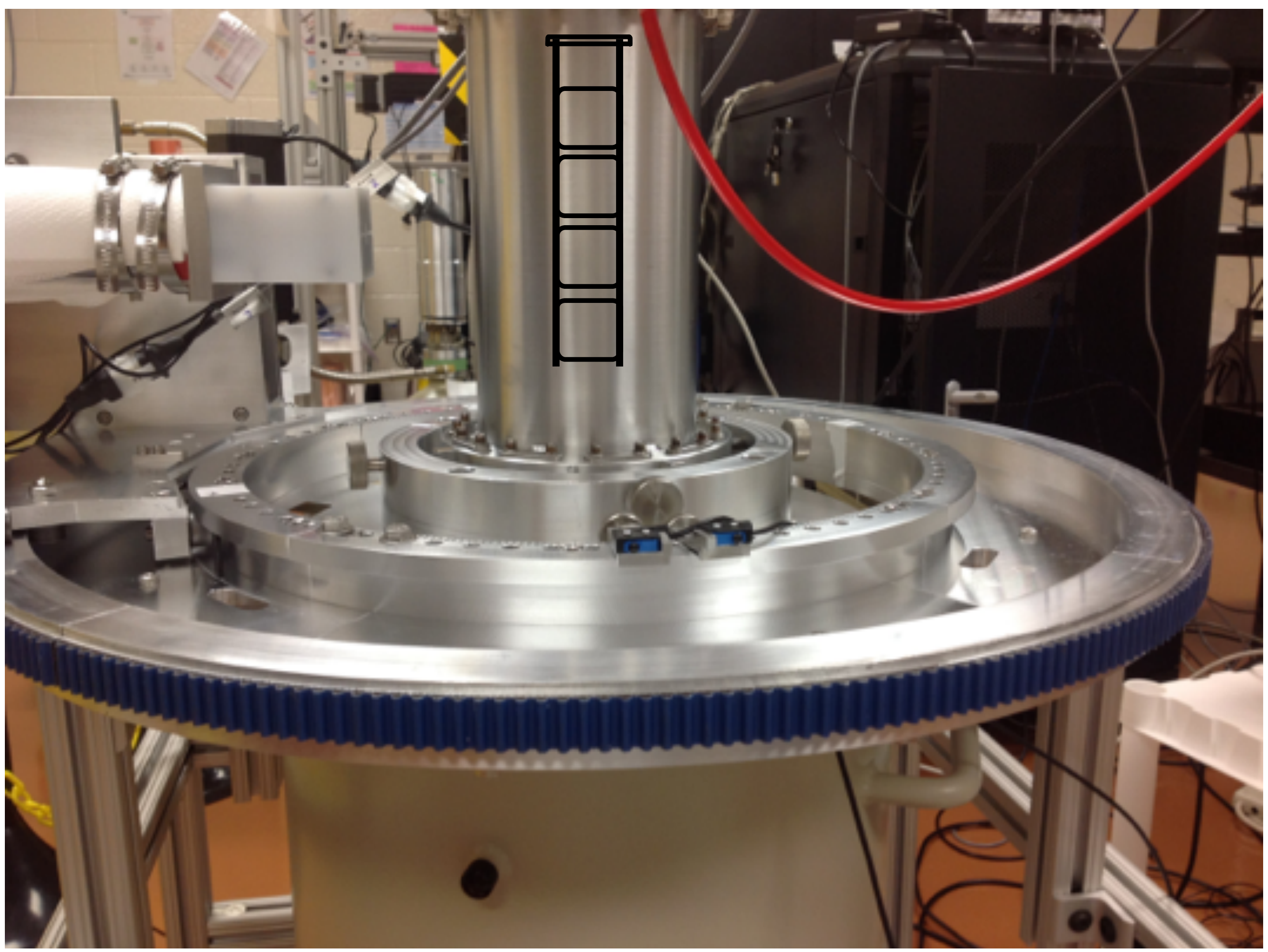


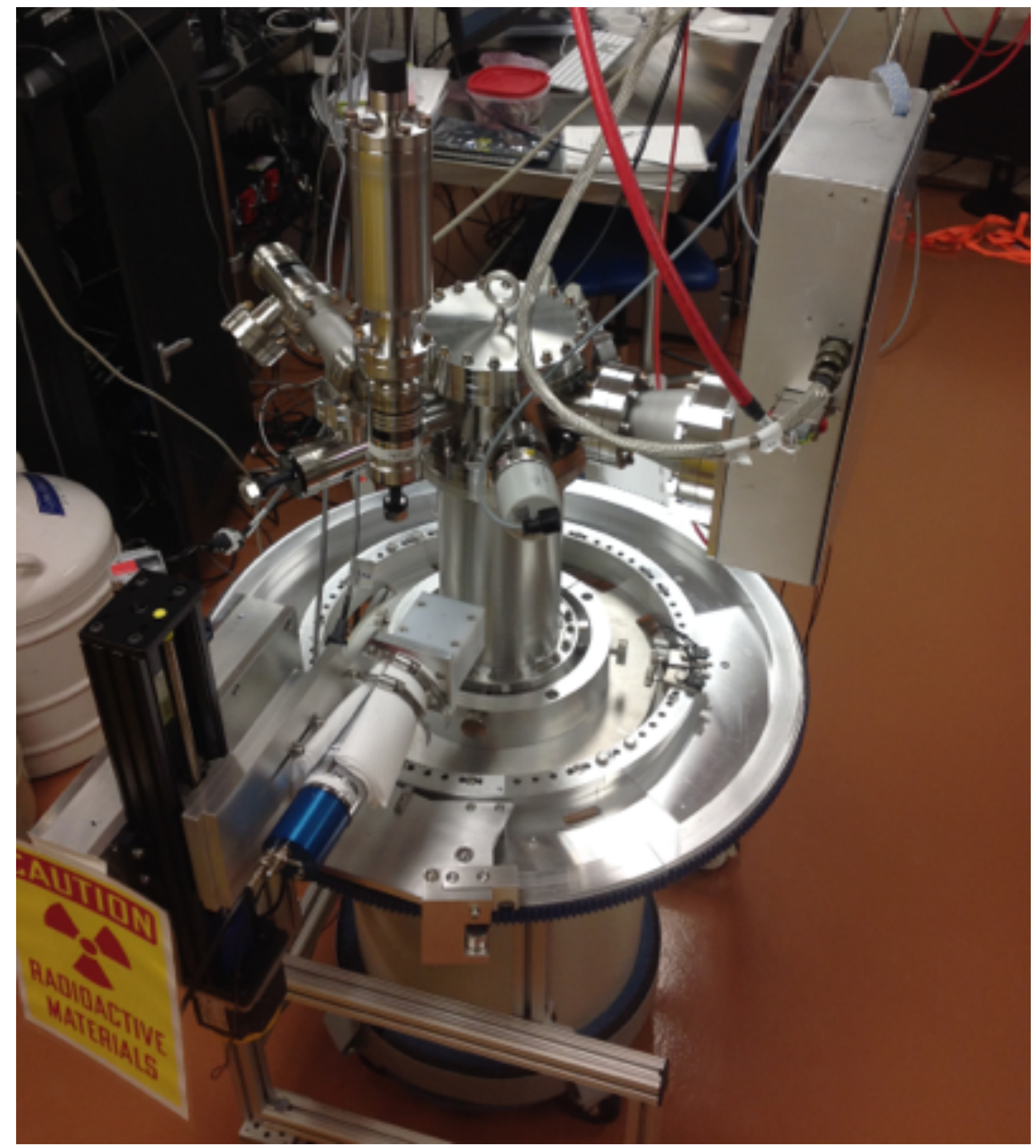
MJD String Characterization



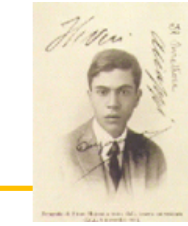
- String Performance and Characterization
- Study drift times using ^{133}Ba — utilizing 356 keV and 81 keV coincidences
- PSA efficiency as a function of position

Azimuthal Scanning Table





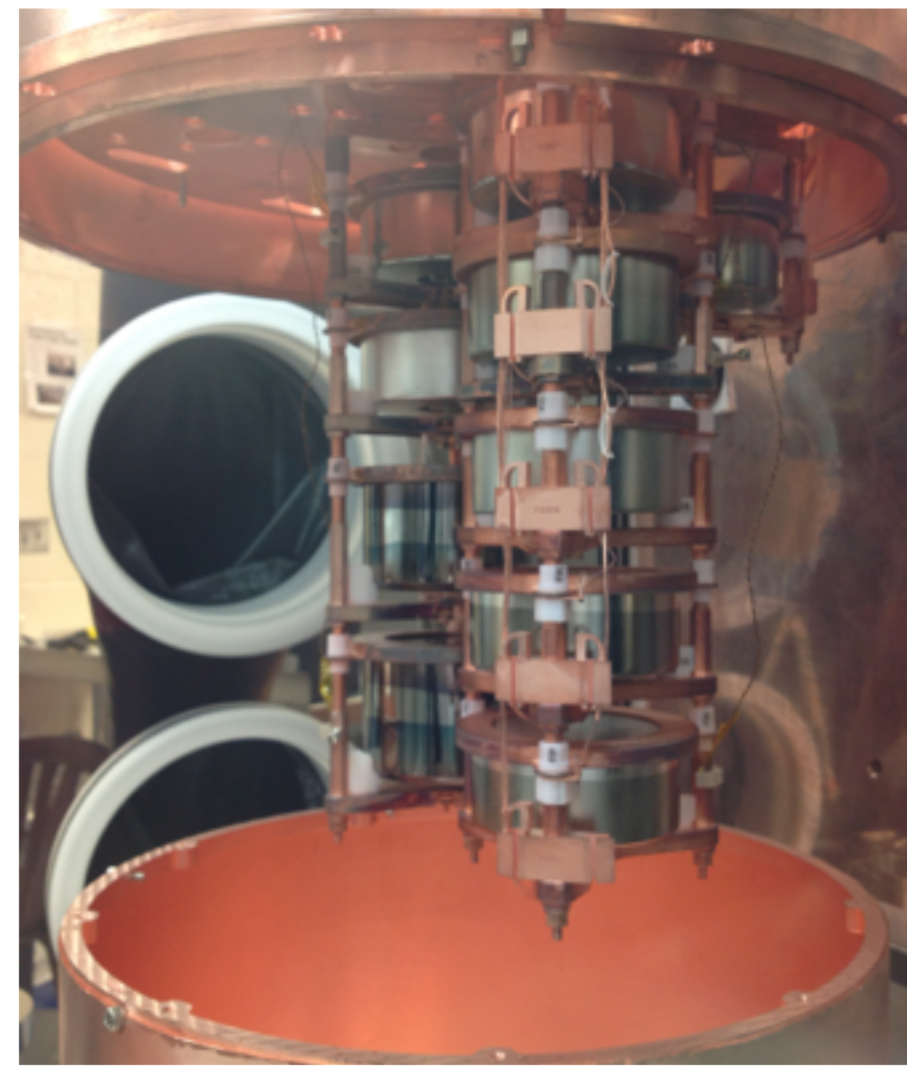
Prototype Module

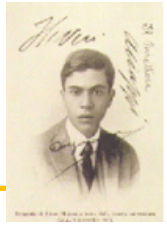


- Aim to debug and validate : cryostat design, vacuum system, monolith, coupling to glove box, string insertion, string cooling & readout, operation. (cryostat not electoformed)
- Define, test and refine all clean procedures.
- Serving the planned purpose in preparations for Module 1
  - operations, cleanliness, glovebox work, IR shielding, cabling, readout, noise
- Have been operating three strings in the prototype cryostat

Prototype Cryostat inserted into the glove box

Prototype Cryostat with three installed strings



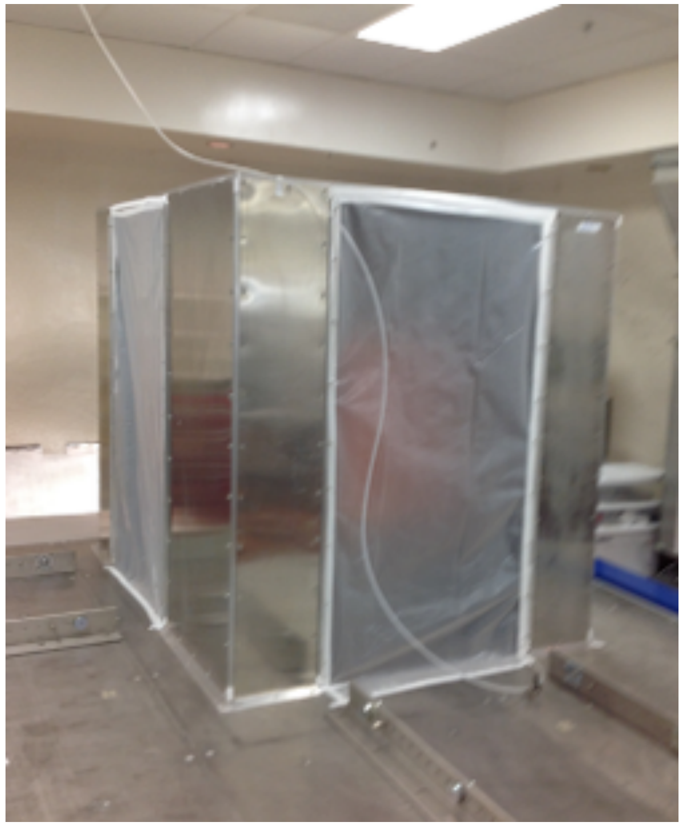


MJD Shield

- Shield assembly underway with the lead shield completed.
- Movable (air pad) monoliths operational.
- Radon exclusion box has been fabricated and installed.
- Polyethylene neutron shield designed, being cut on the surface.
- Veto panels fabricated, tested, on-site, and 75% installed. Commissioning data being taken.
- Calibration system partially installed on prototype cryostat

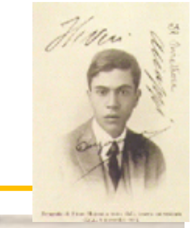
Shield with inner copper components and “slot” for monolith

Shield with Radon exclusion box installed



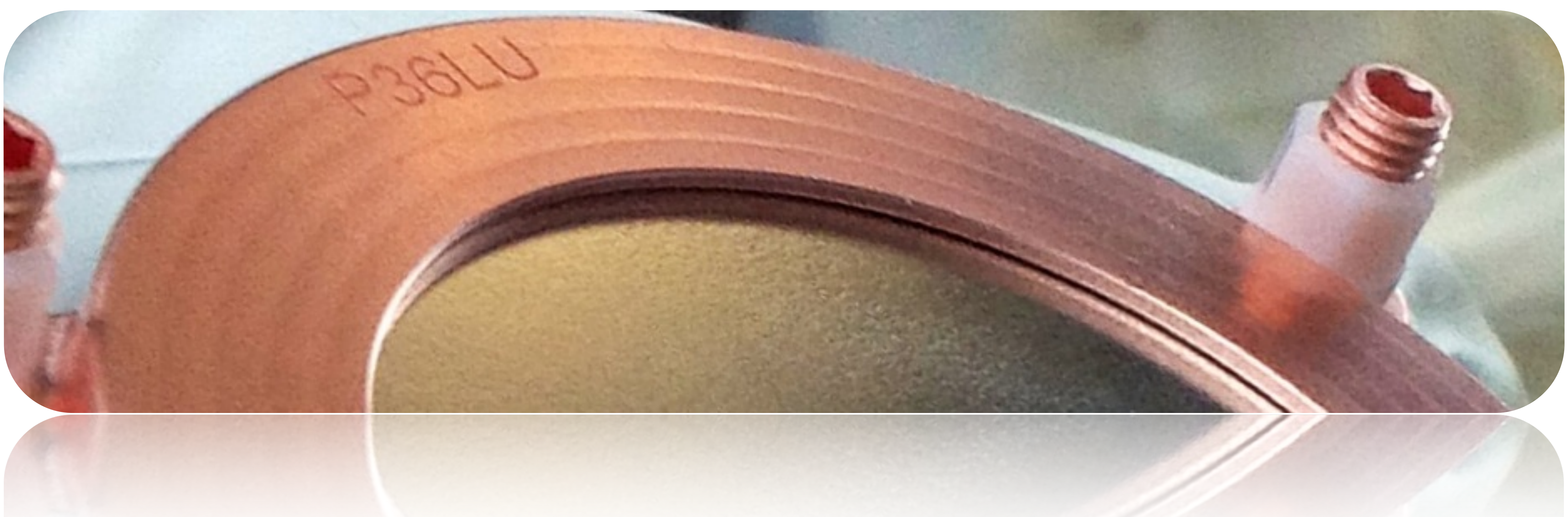
Shield with veto monolith blank and prototype cryostat

MAJORANA DEMONSTRATOR Summary



- Growth of all electroformed copper needed for the DEMONSTRATOR is nearly complete.
- Current background budget is limited by assay measurement to < 4.1 counts/4 keV/t-y, close to the original MJD goal of 3.
- Module 1 EF Cu & 25 kg of enriched detectors in hand.
- Module 1 vacuum system is complete and cryostat assembly nearing completion.
- Shield progressing on schedule.
- Aim to start commissioning Module 1 in September 2014 and taking engineering run in early 2015.
- Phased start of operations of Module 1 in 2015 as we complete fabrication and assembly of Module 2.

Supporting Slides



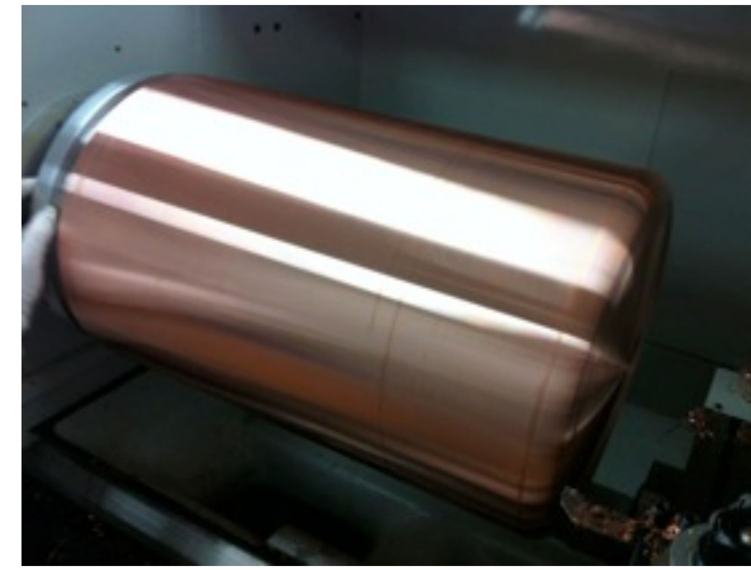
MJD Electroformed Cu

- MJD operates 10 baths at the Temporary Clean Room (TCR) facility at the 4850' level and 6 baths at a shallow UG site at PNNL. All copper is machined at the MJD Davis campus.

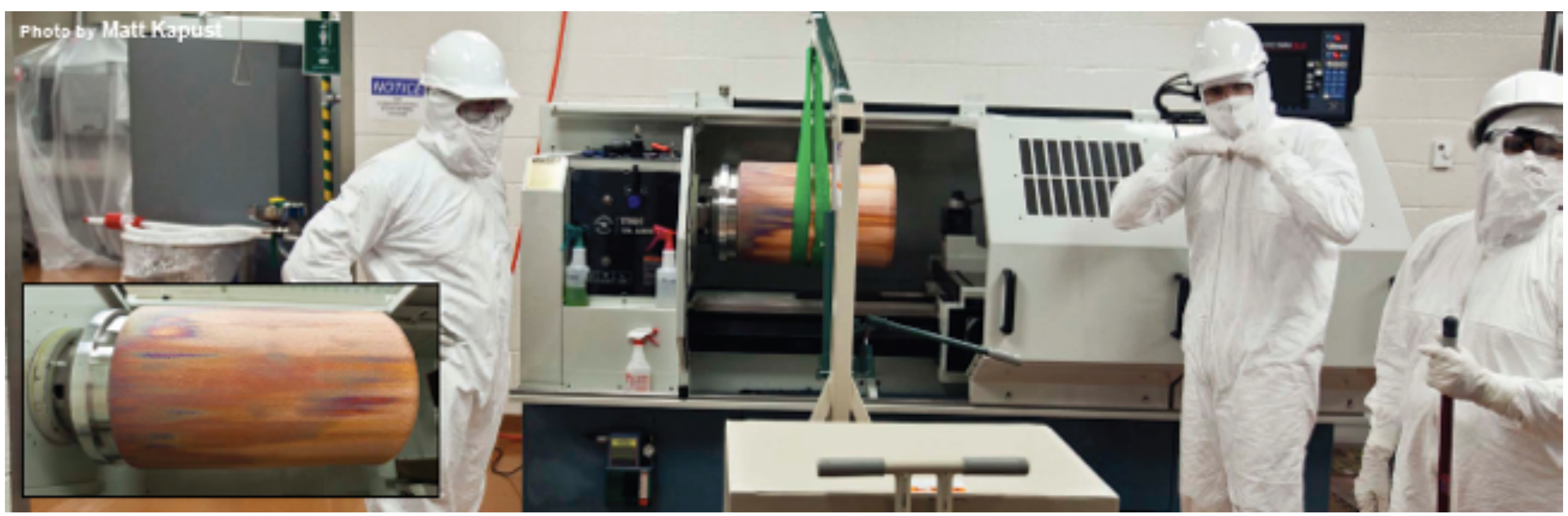
Electroforming Baths in TCR

Inspection of EF copper on mandrels

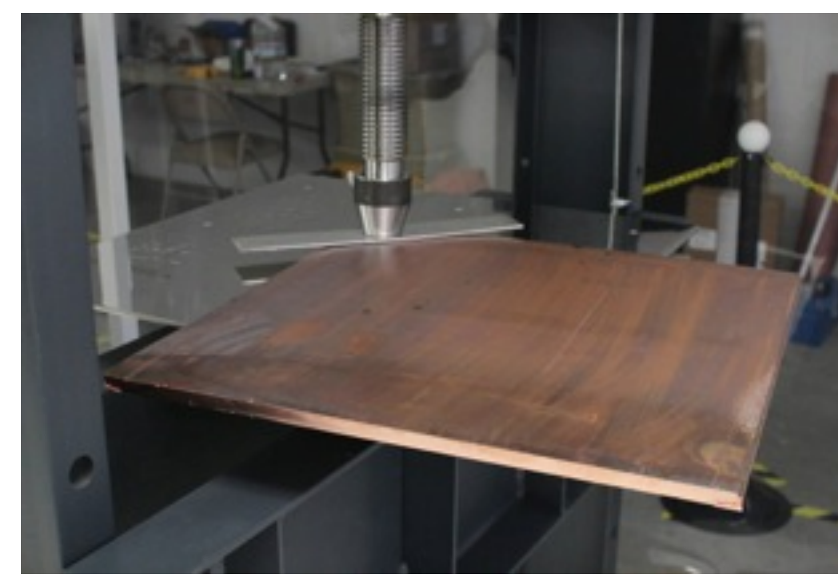
EF copper after turning on lathe



Preparing to machine electroformed copper mandrel in the clean machine shop, MJD Davis Campus, 4850'

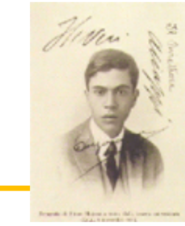


Flattened plate



- Th decay chain 0.06 ± 0.02 μBq/kg (0.15 counts in ROI)
- U decay chain 0.17 ± 0.03 μBq/kg (0.08 counts in ROI)

MJD Materials Assay Results



Material	Part of Demonstrator	Decay Chain	Achieved Assay [mBq/kg]	Achieved Assay [c/ROI/t/y]	Reference
EFCu	Inner Cu Shield, Cryostat, Coldplate, Thermal Shield, Detector Mounts	Th	0.06	0.15	[1]
		U	0.17	0.08	
OFHC	Outer Copper Shield (O.Cut)	Th	1.1	0.26	[2]
		U	1.25	0.03	
Pb	Lead Shield	Th	<4.1	<0.20	[3]
		U	<24.9	<0.26	
PTFE	Detector Supports	Th	0.1 ± 0.01	0.01	[4,5]
		U	<5	<0.01	
Vespel	Cold Plate Supp., Connectors	Th	<12	<0.01	[4,5]
		U	<1050	<0.4	
Parylene	Cu coating, Cryostat seals	Th	2150	0.27	[6]
		U	3110	0.09	
Silica / Au, Epoxy	Front-End Electronics	Th	6530	0.32	[7]
		U	10570	0.28	
Cu Wire + PFA	Signal /HV Cable	Th	2.2	0.01	[8]
		U	145	0.08	
Stainless Steel	Service Body	Th	13000	<0.04	[9]
		U	<5000	<0.03	
Solder Flux	Connectors	Th	365	0.12	Old SNO Report
		U	1157	0.07	

[1] "Determination of Method Detection Limits for Trace 232-Thorium and 238-Uranium in Copper using Ion Exchange and ICPMS-January 2014", [M-TECHDOCPhys-2014-72].

[2] Commercial Copper Assay Report[M-TECHDOCDET-2012-149]

[3] Results of Lead Assay by GDMS; final [M-TECHDOCDET-2012-146]

[4] Final report on assay of plastic for MAJORANA DEMONSTRATOR [M-TECHDOCDET-2011-137].

[5] Report on NAA performed at HFIR (ORNL) for samples of TE-6742 for the MAJORANA DEMONSTRATOR [M-TECHDOCDET-2011-128].

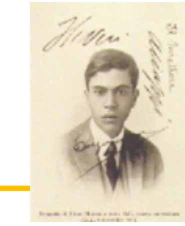
[6] Cable Assay [M-TECHDOCDET-2011-124].

[7] ICP-MS of Low Mass Front-End Board; final [M-TECHDOCDET-2013-157]

[8] ICP-MS Assay of MJD Copper Cables for Uranium & Thorium - December 2013; [M-TECHDOCMJTEST-2014-027].

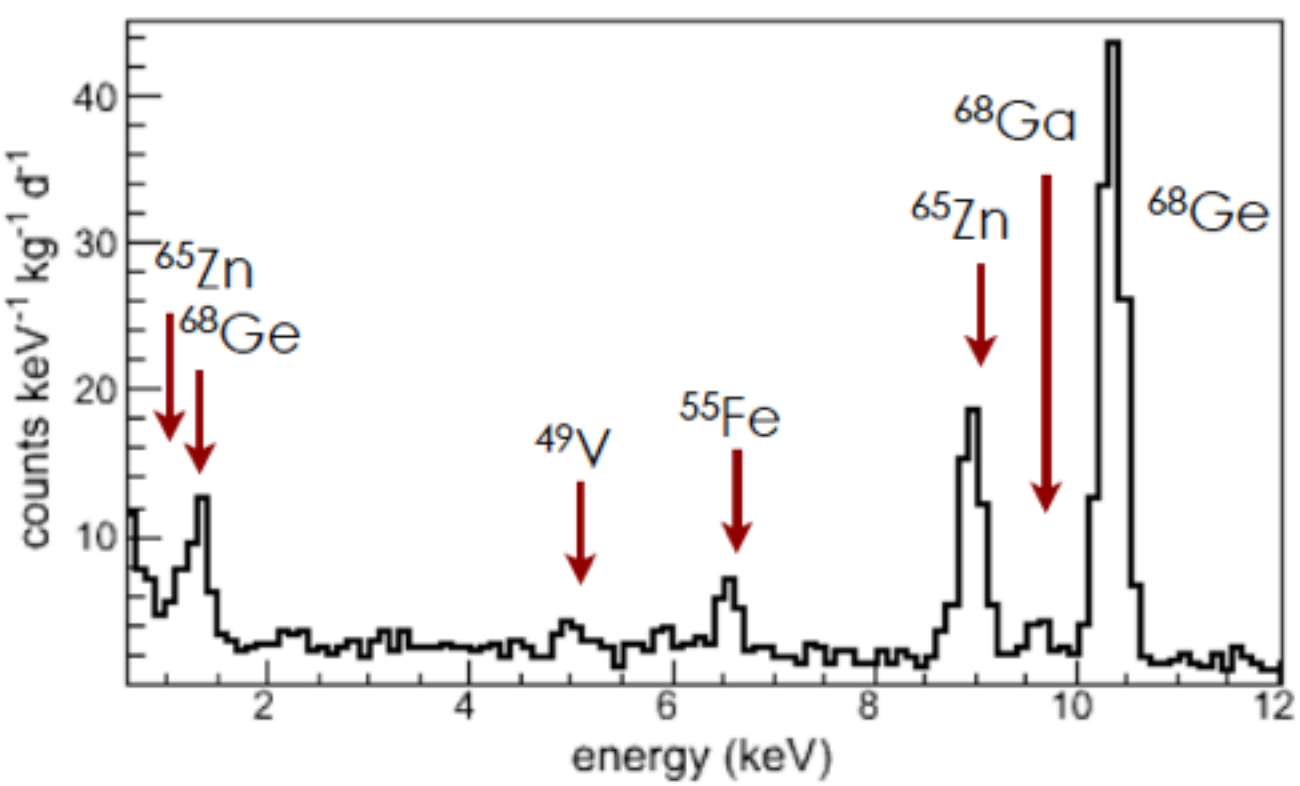
[9] Service Body Assay Results; final [M-TECHDOCDET-2012-143]

Backgrounds from Ge Crystals

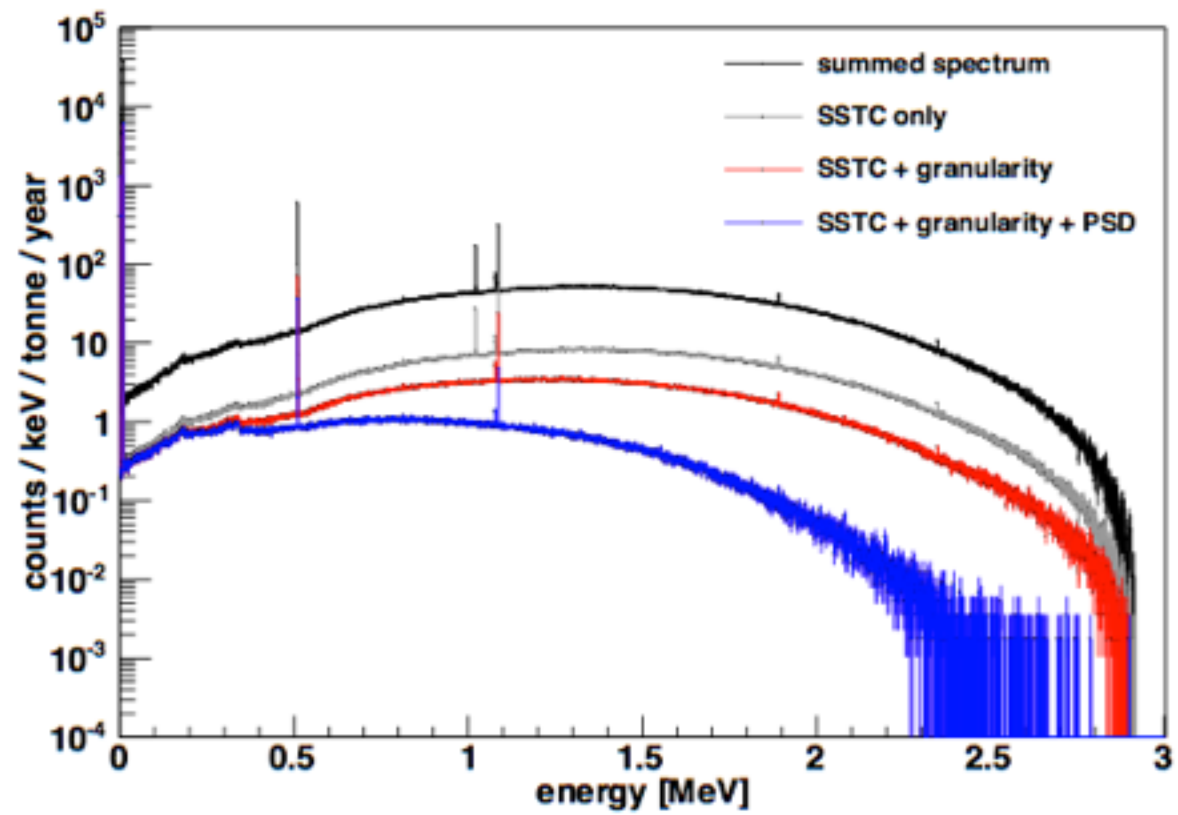


^{68}Ge(EC, $T_{½}$ = 270 d) → ^{68}Ga(90% 1.9 MeV β^+, $T_{½}$ = 68 min):

Data from MJD R&D detector - MALBEK



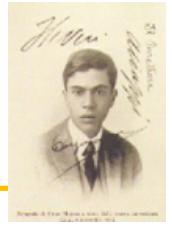
Simulations for the DEMONSTRATOR



– **S**ignal **S**election in **T**ime **S**election tag ^{68}Ge decay via K-shell (~10 keV, 86.4%), L-shell (~1 keV, 11.5%) de-excitations

– If one observes ^{68}Ge decay in a detector veto for several half-lives

MJD Cosmogenic Activation



Cosmogenic activation backgrounds can be mitigated with minimized exposure and cuts

- Our background calculations for Ge assume <100 days sea-level equivalent exposure (slee) after enrichment, <50 days slee after crystal pulling.
- For ^{60}Co in Cu, assumed:
- 1 month slee for EFCu
- 6 months slee for OFHC
- Saturation for cables
- We are doing much better than this for EFCu due to co-located UG production, machining and final use.

^{68}Ge-^{68}Ga in ^{enr}Ge detectors