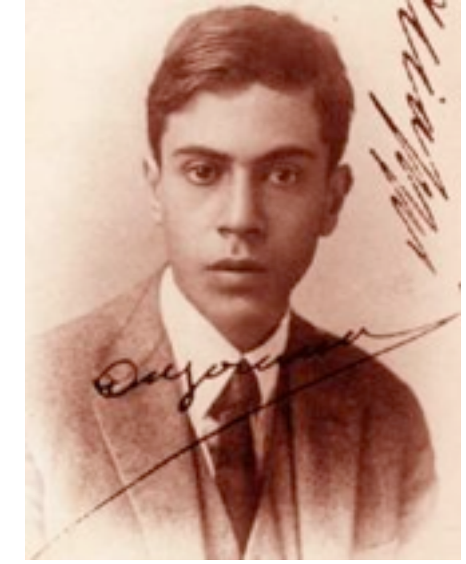


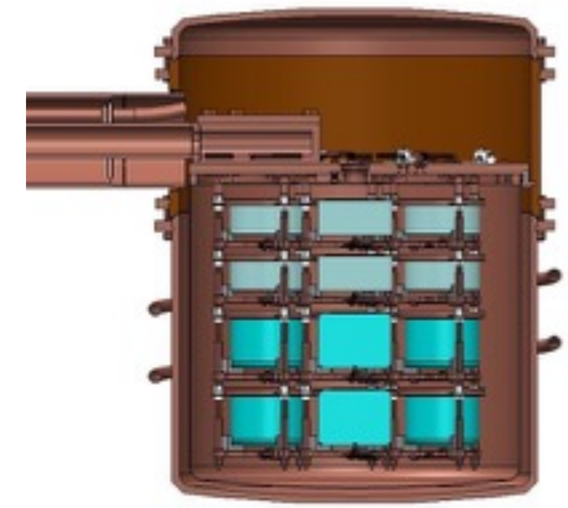
The Status and Initial Results of the MAJORANA DEMONSTRATOR Neutrinoless Double-Beta Decay Experiment

V.E. Guiseppe for the MAJORANA Collaboration
University of South Carolina

The MAJORANA DEMONSTRATOR

Funded by DOE Office of Nuclear Physics, NSF Particle Astrophysics, NSF Nuclear Physics 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 $0\nu\beta\beta$ 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

44.8-kg of Ge detectors

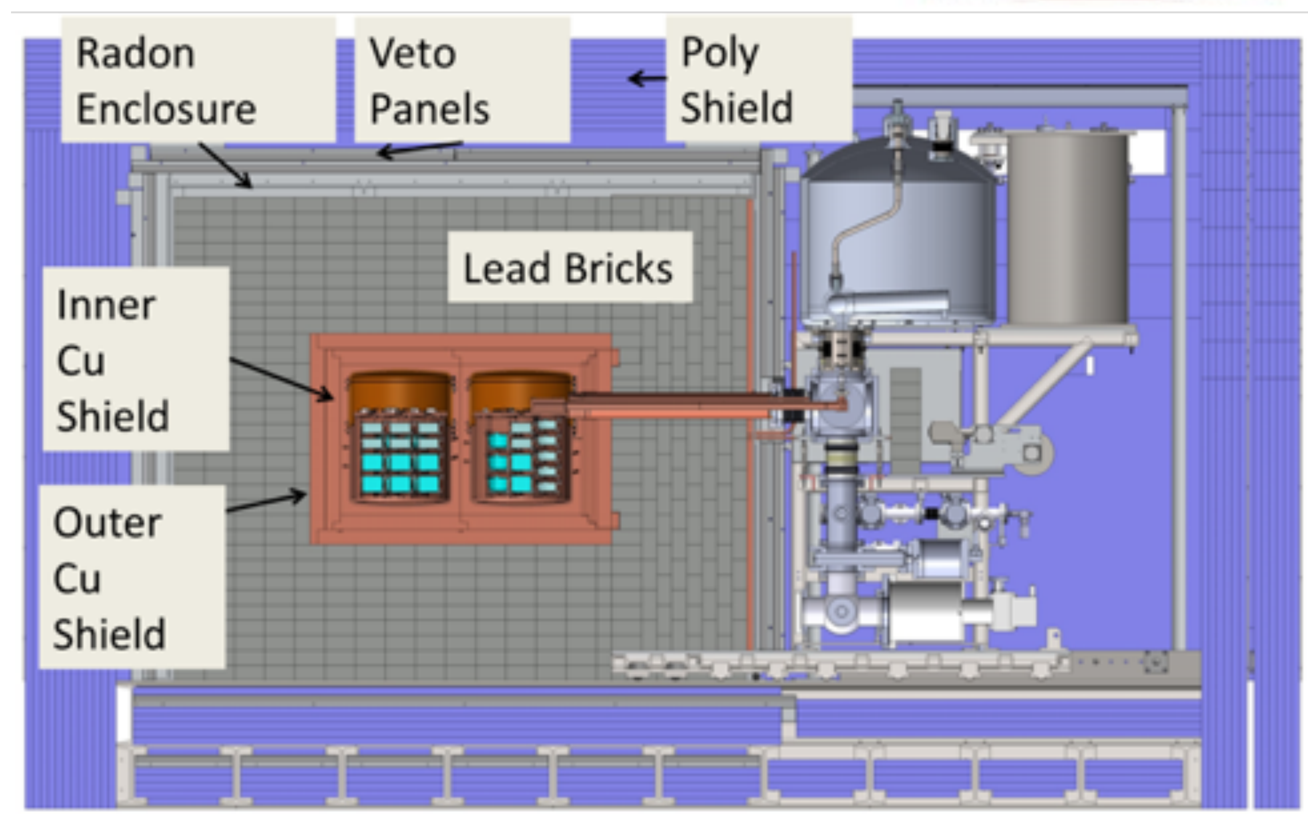
- 29.7 kg of 88% enriched ^{76}Ge crystals
- 15.1 kg of ^{nat}Ge
- Detector Technology: P-type, point-contact.

2 independent cryostats

- ultra-clean, electroformed Cu
- 22 kg of detectors per cryostat
- naturally scalable

Compact Shield

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



MAJORANA DEMONSTRATOR Implementation

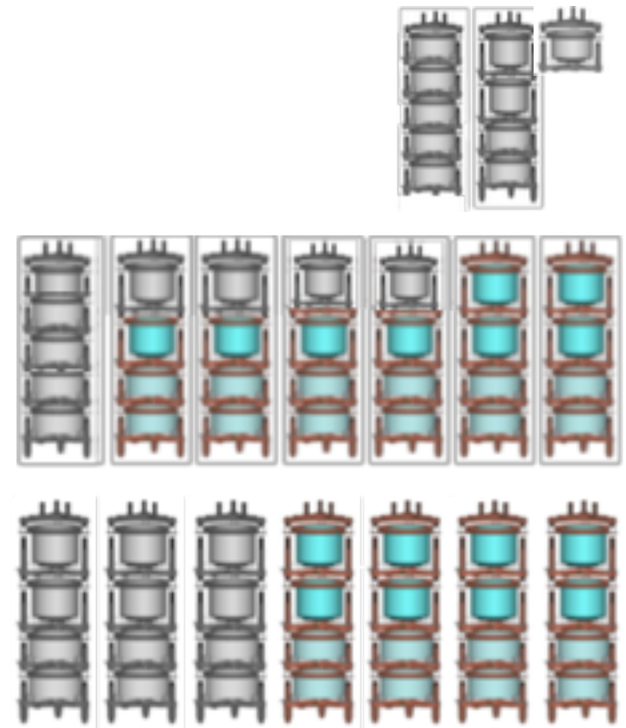
Three Steps

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

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

Module 2: 12.8 kg (15) ^{enr}Ge
9.4 kg (14) ^{nat}Ge

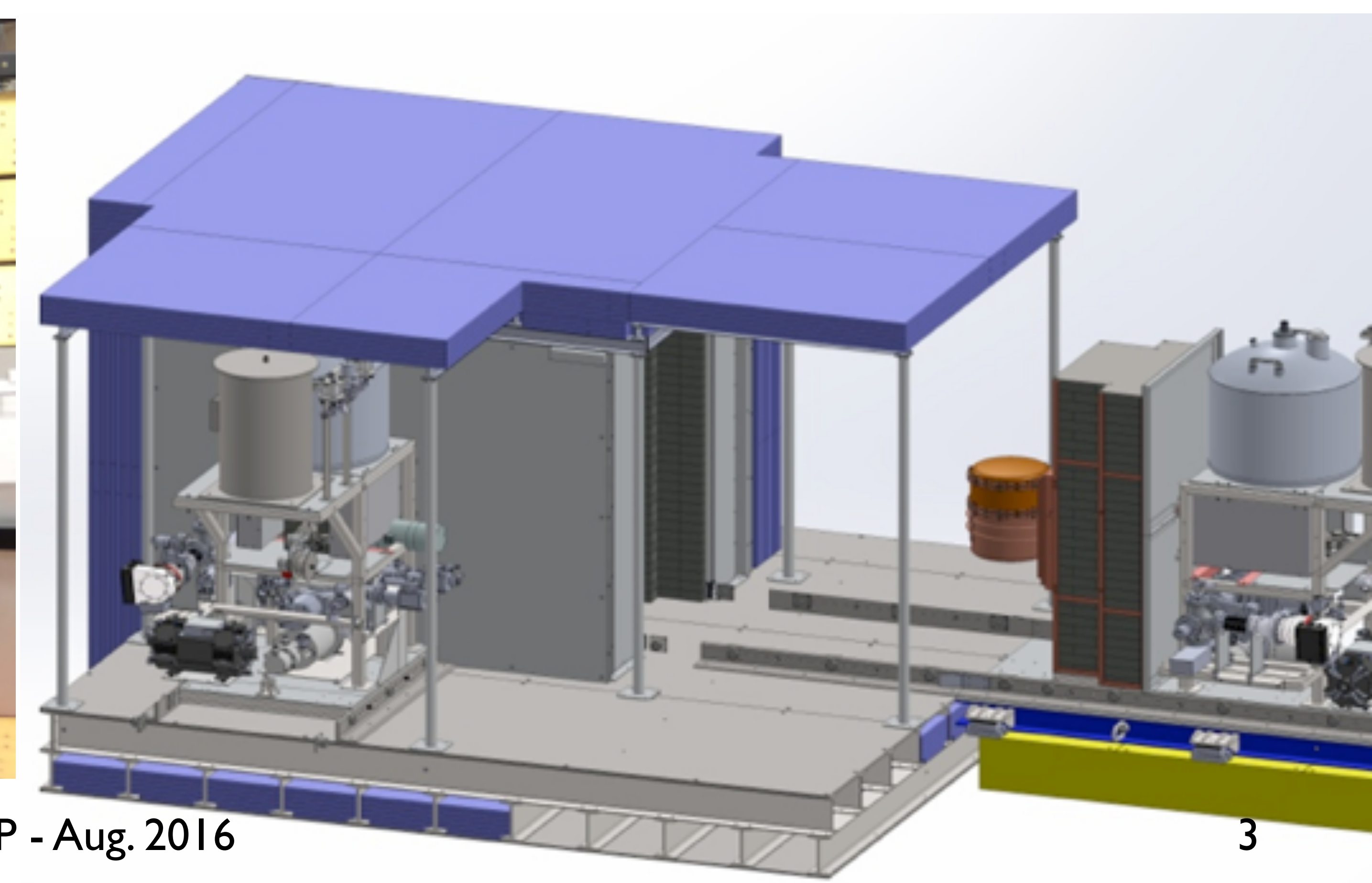
In shield Operation



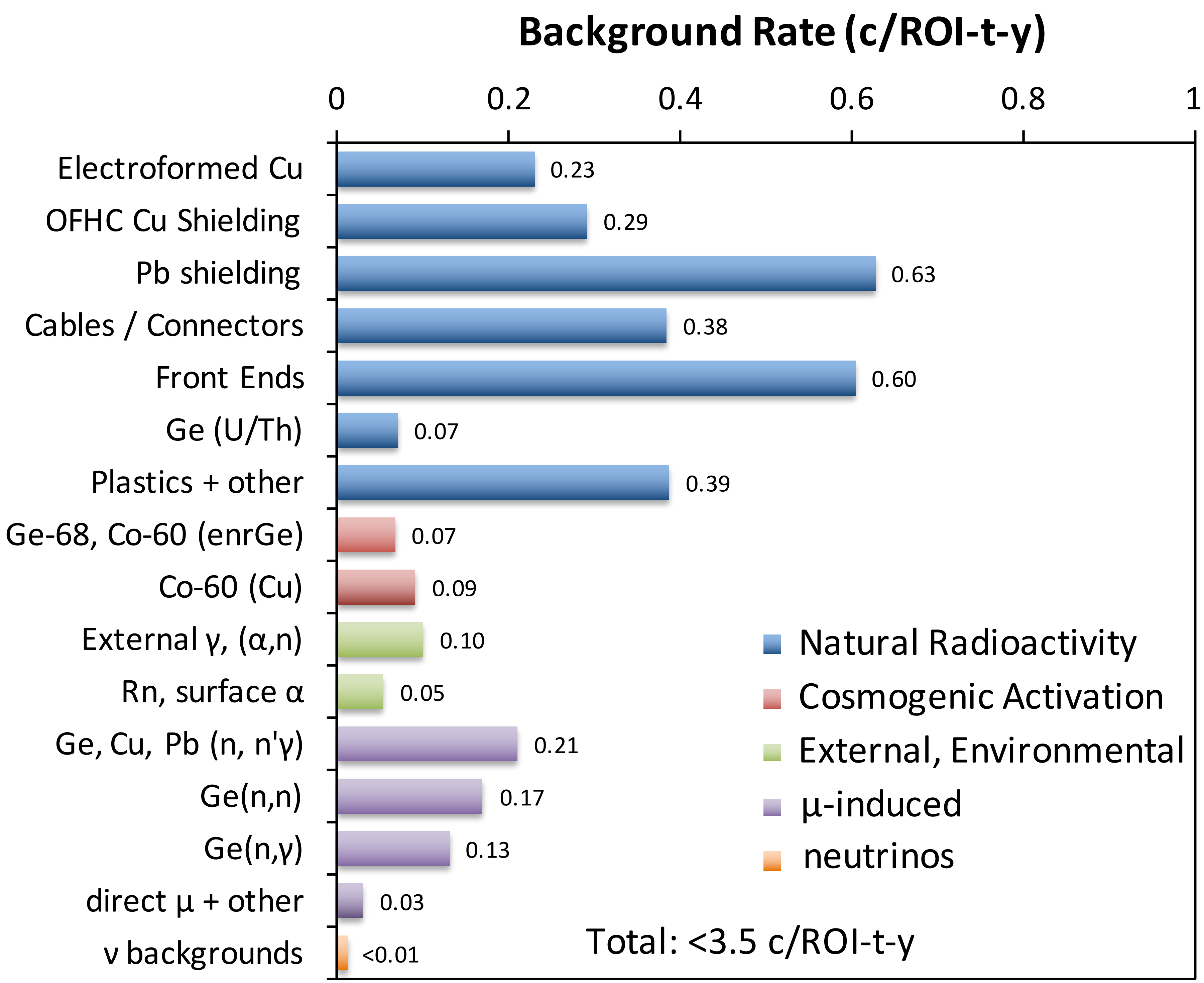
June 2014-June 2015

May–Oct. 2015,
Final Installation,
Dec 2015 - present

August 2016

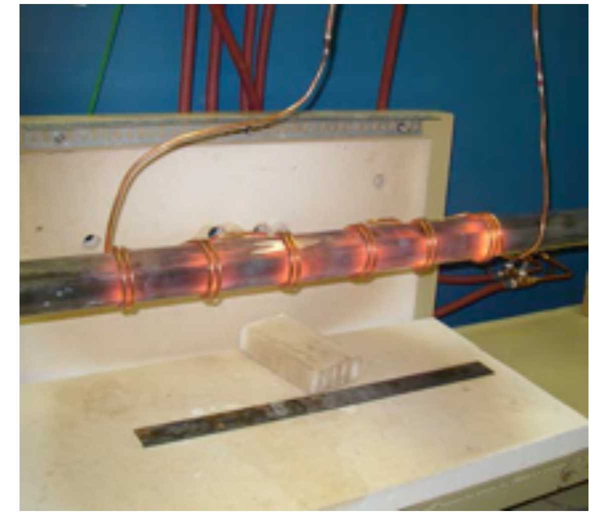


DEMONSTRATOR Background Model



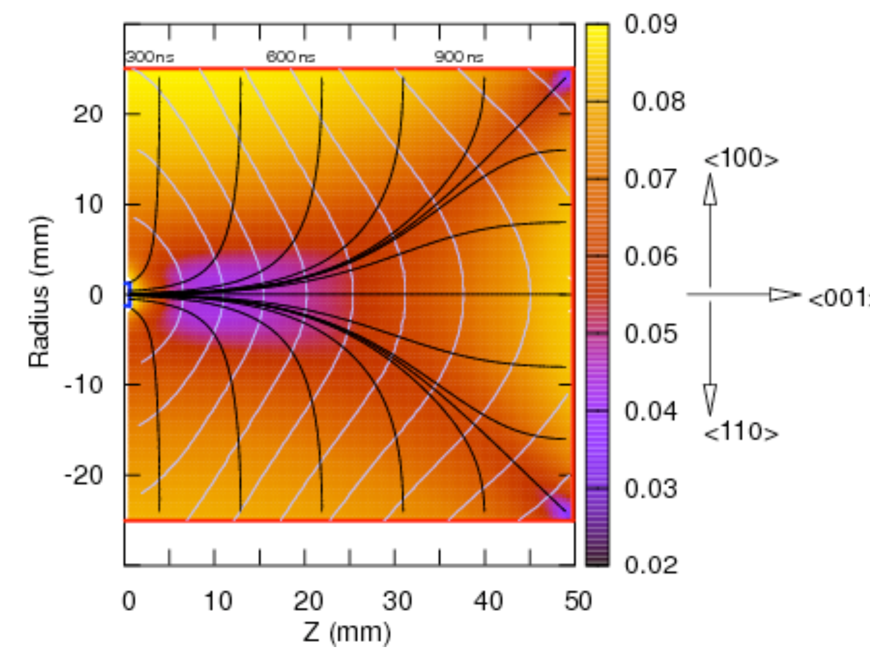
Background based on assay of materials:
NIMA **828** (2016) 22–36 arXiv:1601.03779 [physics.ins-det]

Majorana Approach to Backgrounds



The detector: P-type point contact

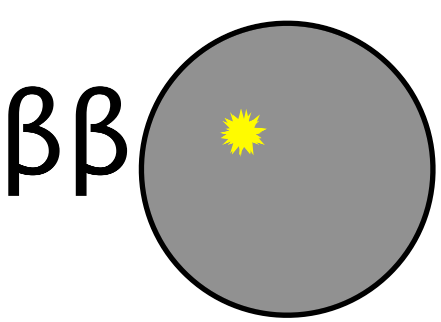
- ^{enr}Ge metal zone refined and pulled into a crystal that provides purification
- Limit above-ground exposure to prevent cosmic activation
- Slow drift velocity and localized weighting potential: separation of multi-site events



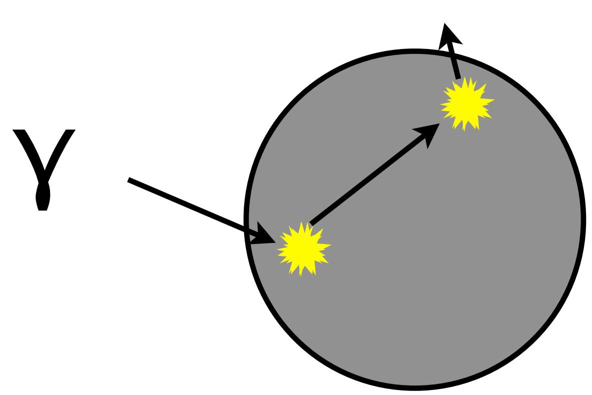
Rejection of backgrounds

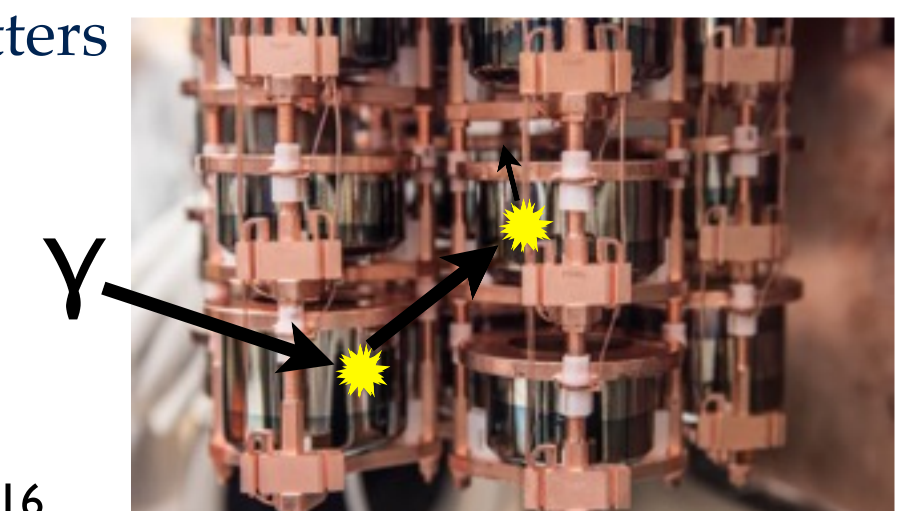
- Granularity: multiple detectors hit
- Pulse shape discrimination: multiple hits in a detector
- Alpha events near surface: based on response

Single-site event

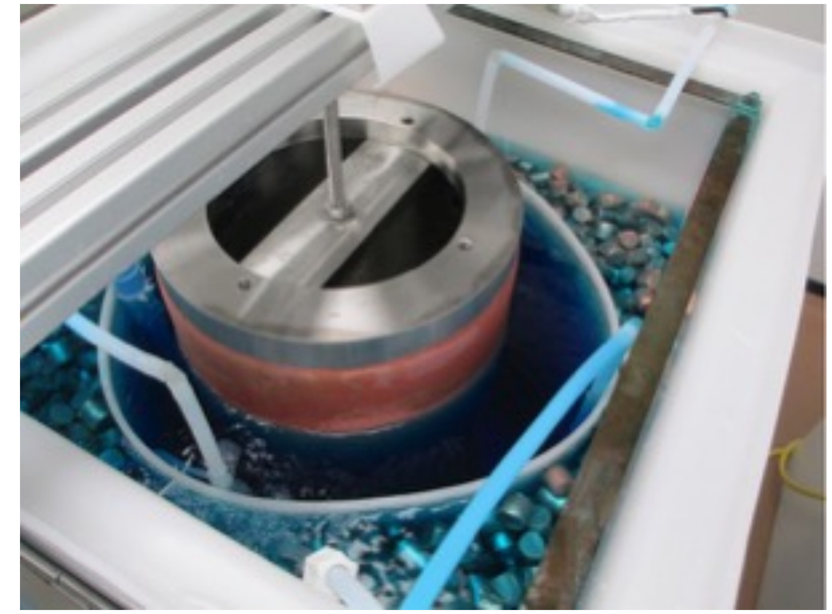


Multiple scatters





Majorana Approach to Backgrounds



Ultra-pure materials

- Low mass design
- Custom cable connectors and front-end boards
- Carefully selected plastics & fine Cu coax cables
- **Underground Electro-formed Cu**

  10 baths at SURF, 6 baths at PNNL

  2654 kg of electroformed copper produced.

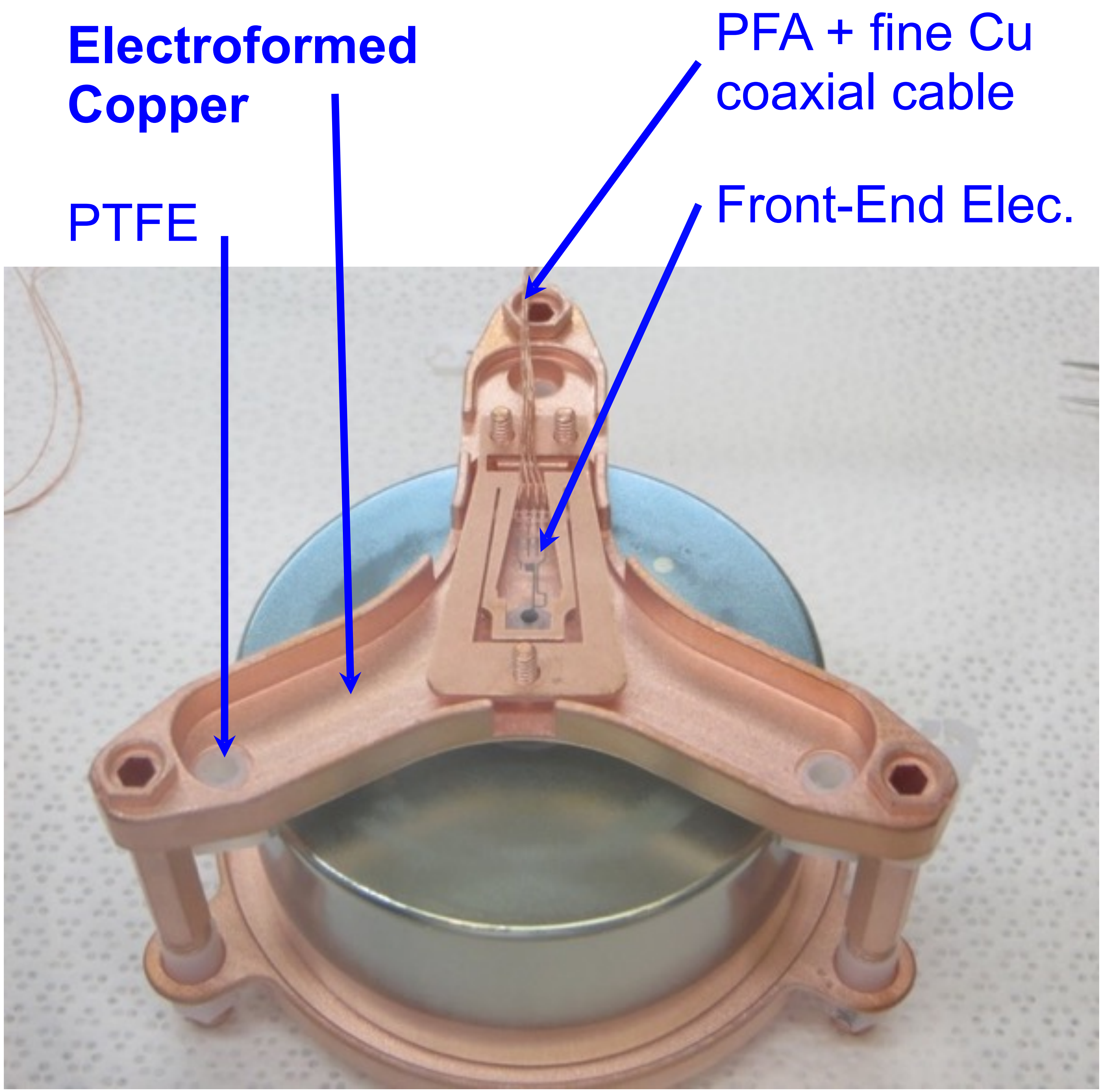
  Th decay chain (ave) $\leq 0.1\ \mu Bq/kg$

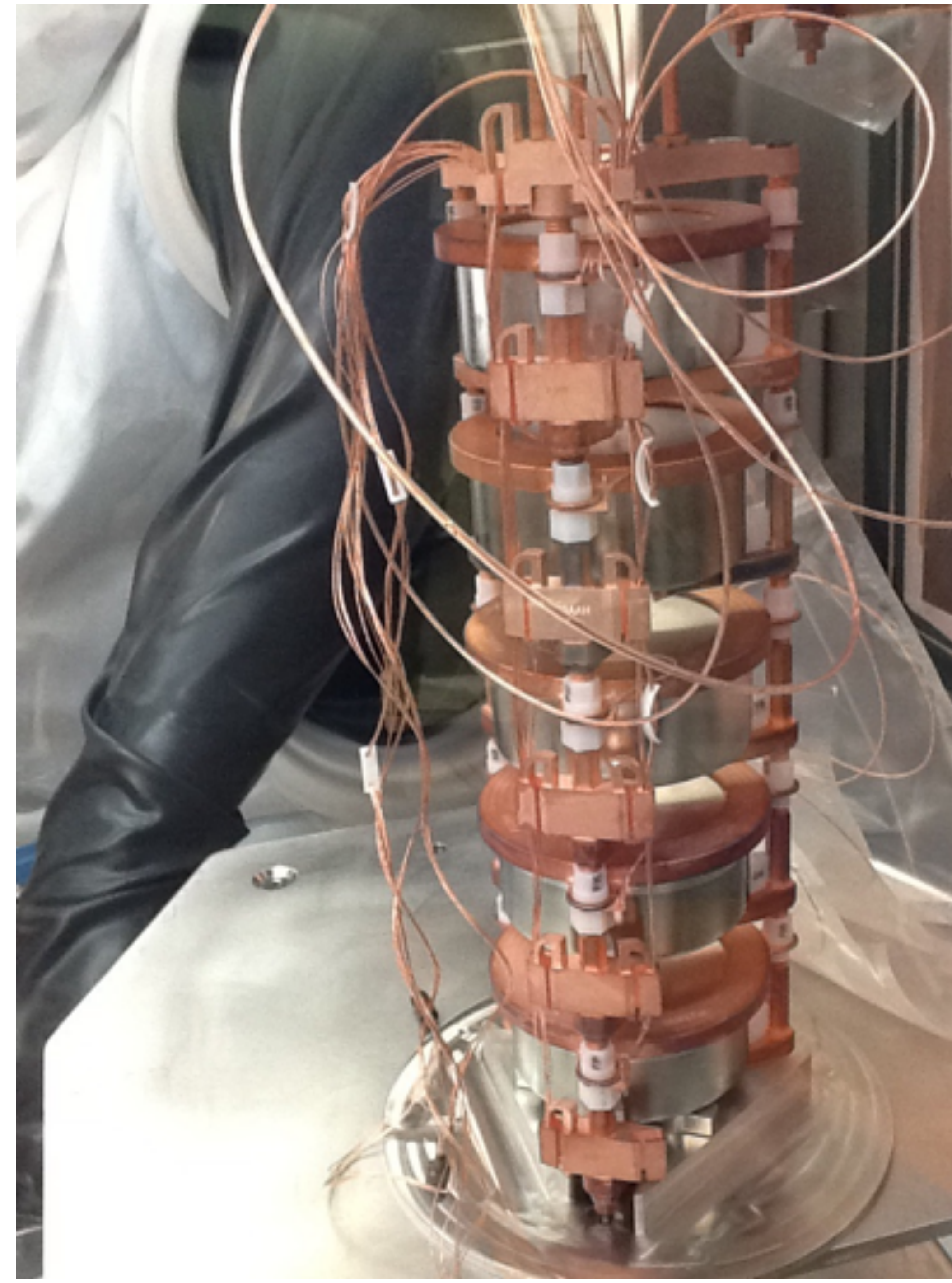
  U decay chain (ave) $\leq 0.1\ \mu Bq/kg$

Machining and Cleaning

- Cu machining in an underground clean room
- Cleaning of Cu parts by acid etching and passivation
- Nitric leaching of plastic parts

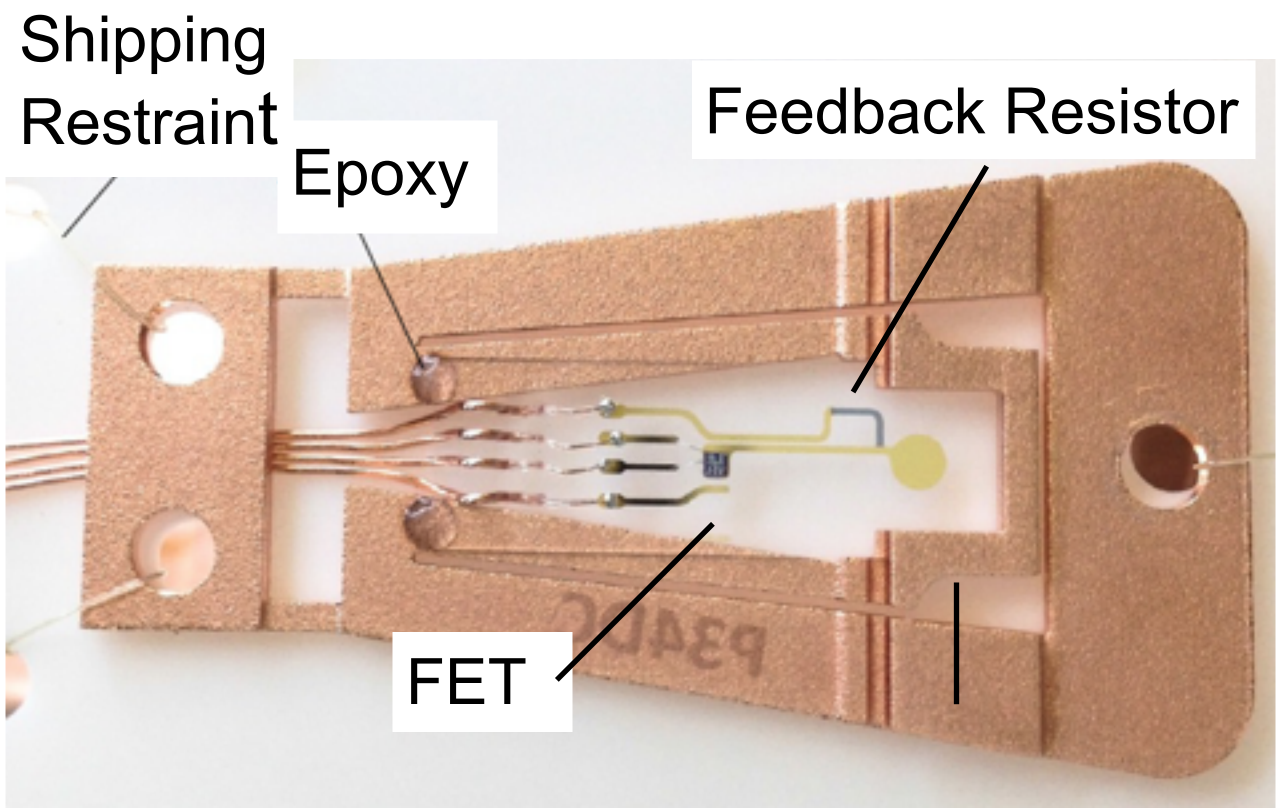
Assembled Detector Unit and String





String Assembly

Detector Readout Components



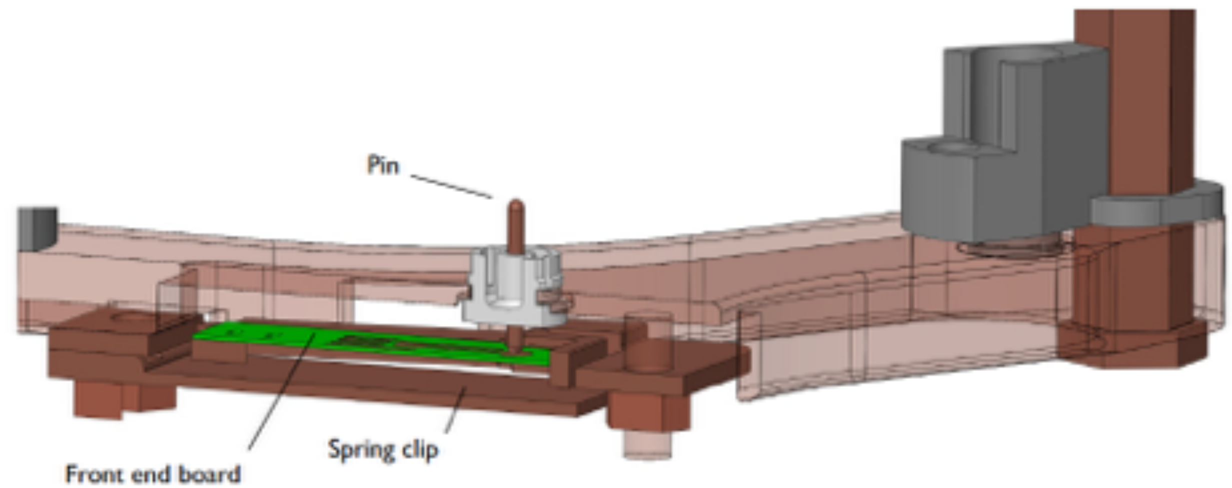
Custom low mass front-end boards

Clean Au+Ti traces on fused silica

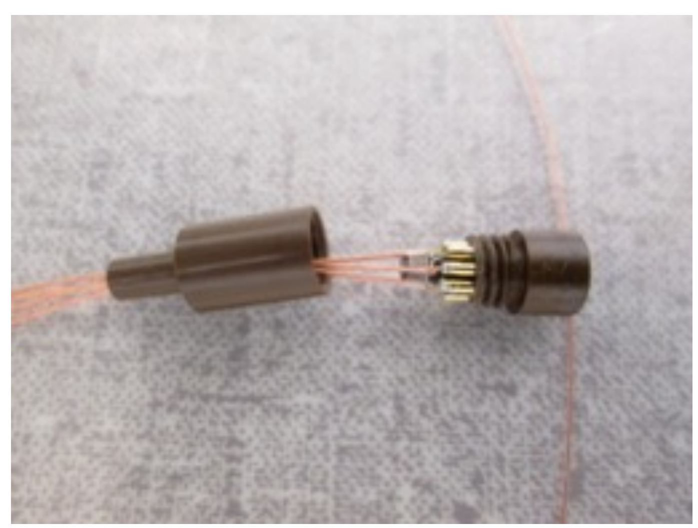
Amorphous Ge resistor

FET mounted with silver epoxy

EFCu + low-BG Sn contact pin



Fine Cu coaxial cable and clean connectors



Connectors reside on top of cold plate.

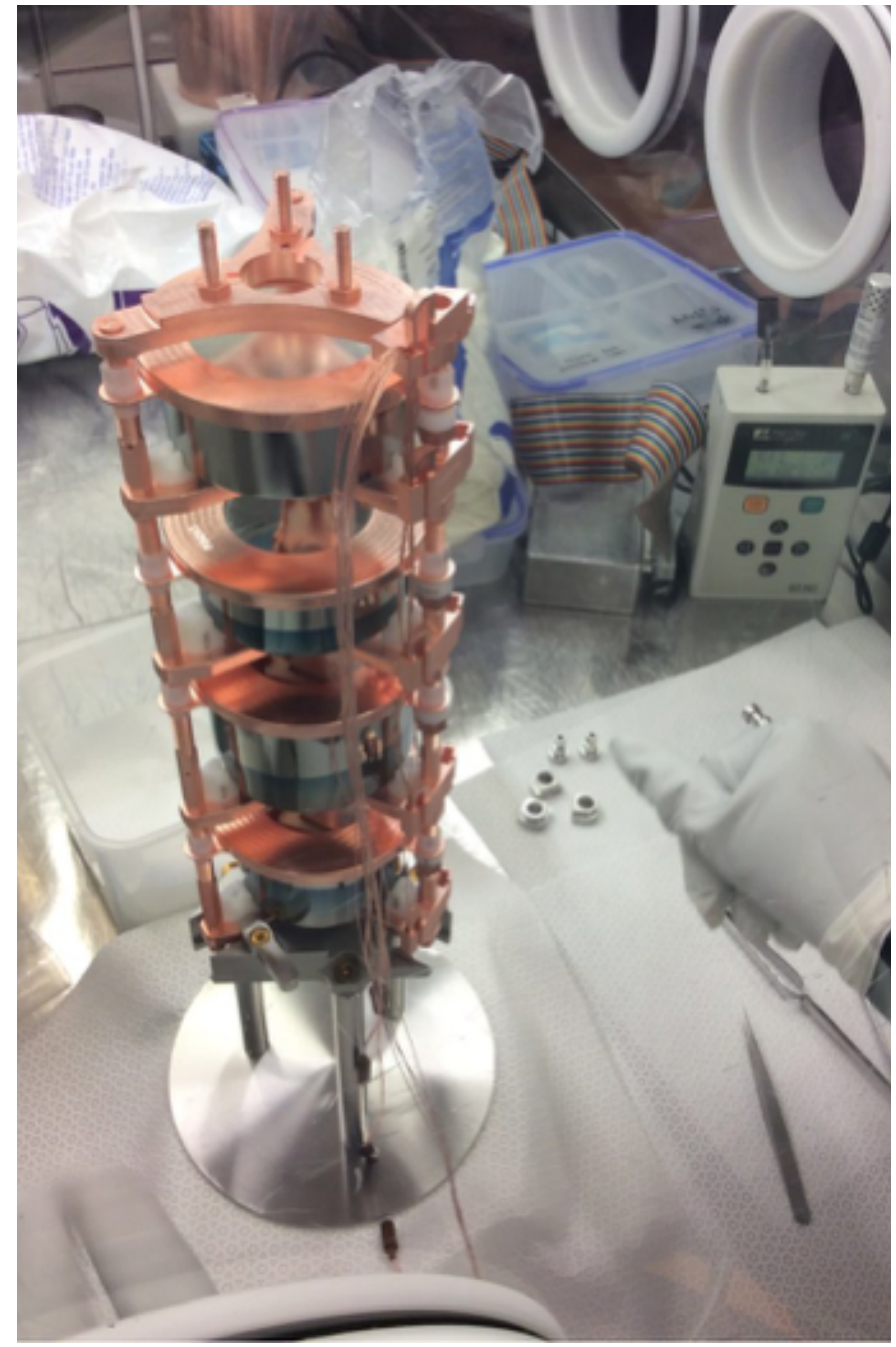
In-house machined from Vespel.

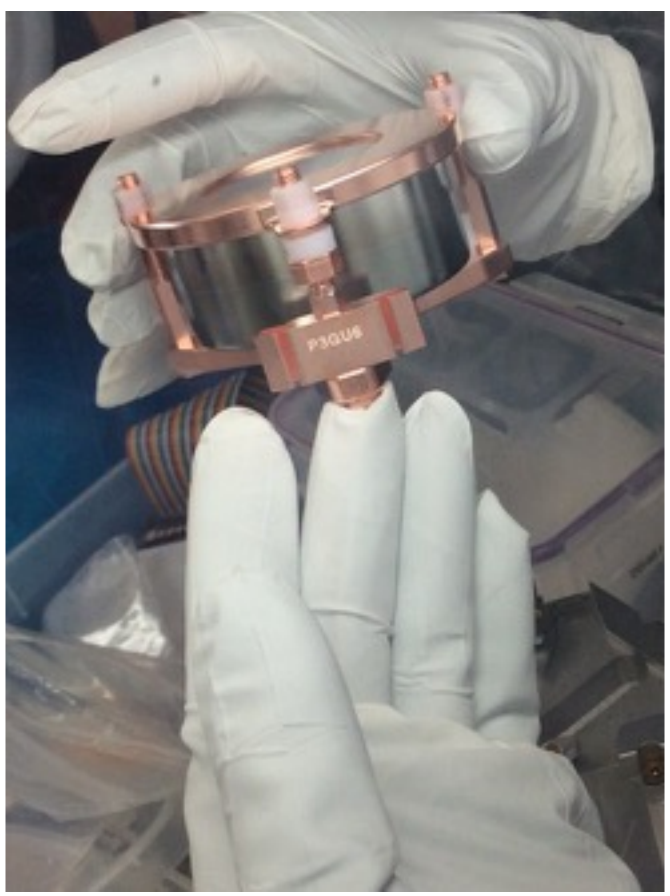
Axon' pico co-ax cable.

Low background solder and flux.

Detector Units and Strings

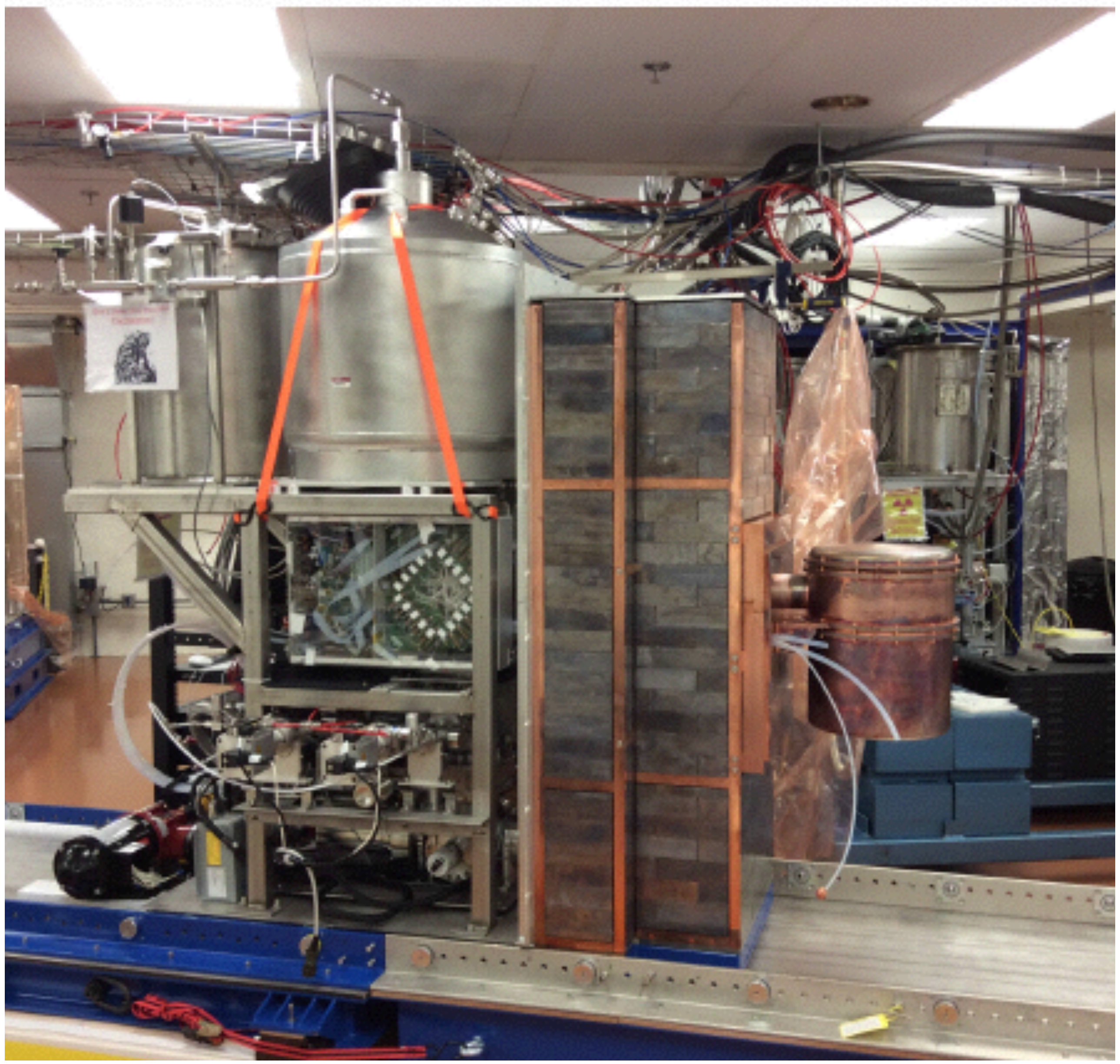
Detector units and strings built inside a glovebox with a radon-reduced, dry N_2 environment





Detector Module

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

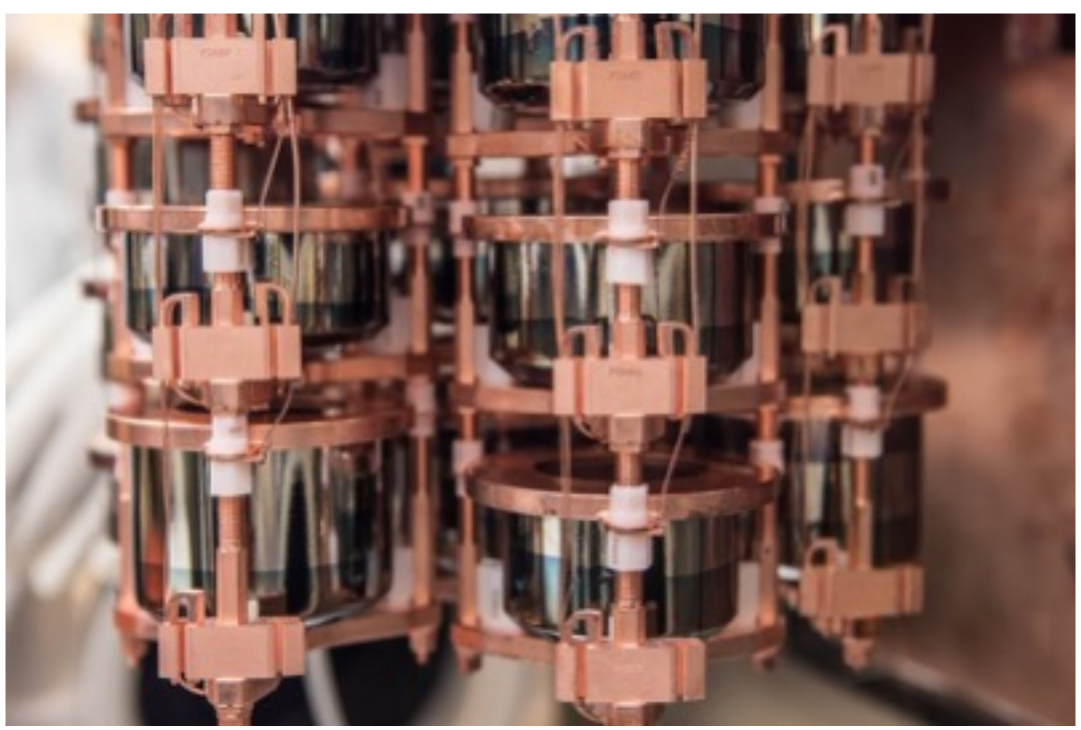


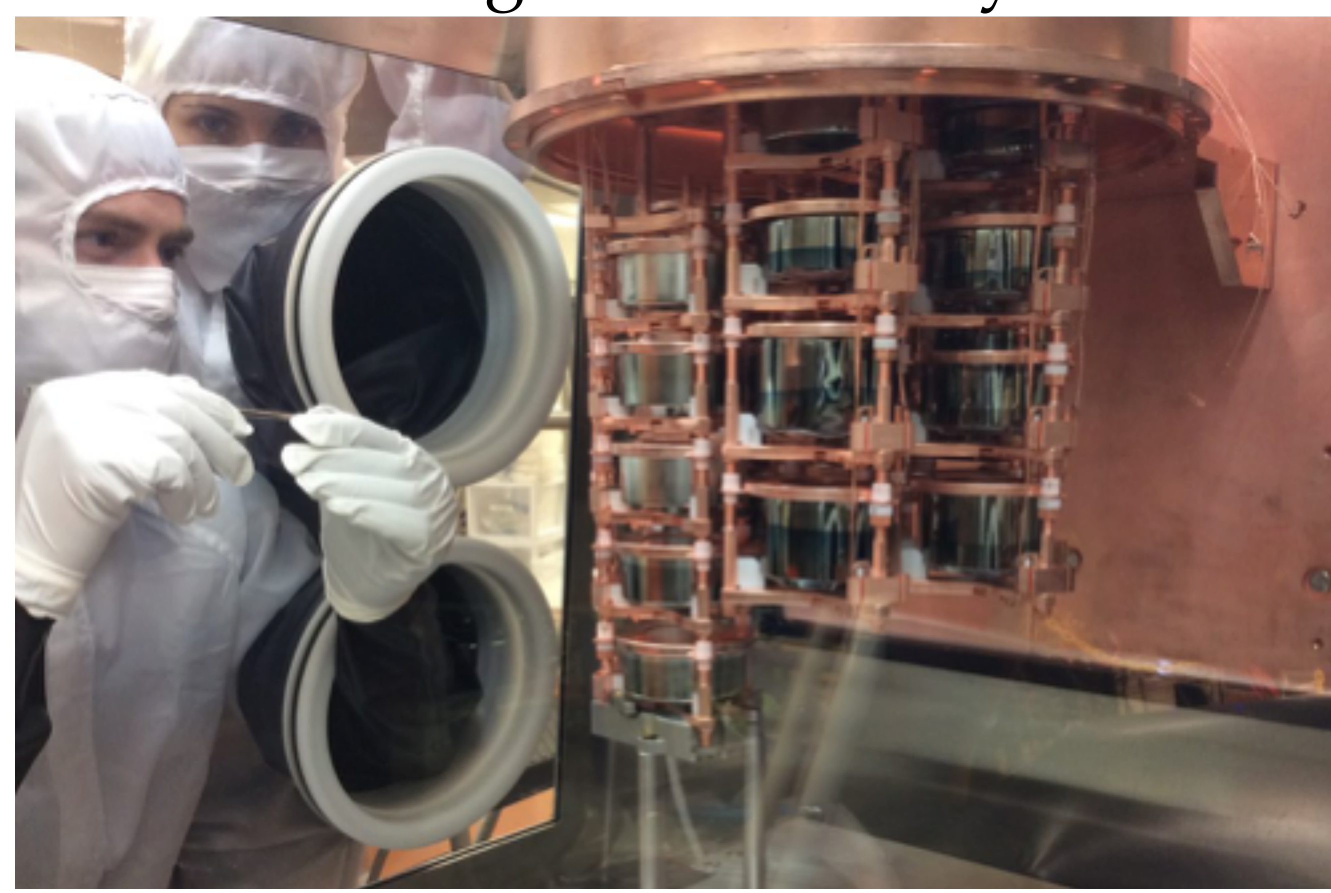
Cryostat mated to the glovebox for string installation

Detector Module

Loading of ^{enr}Ge in Cryostat 2

Loading of ^{enr}Ge in Cryostat 1

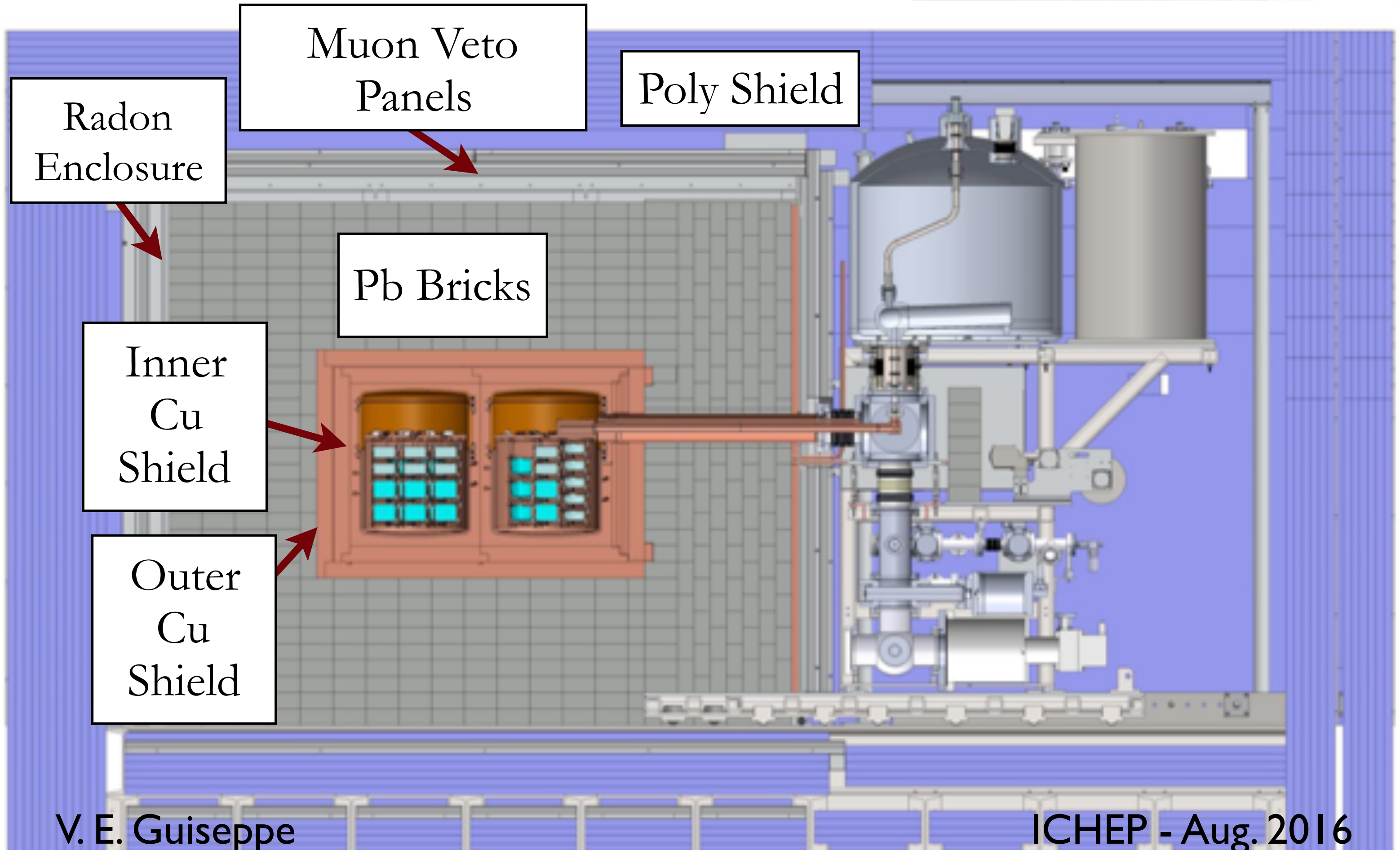




Passive Shielding and Muon Veto

Pb and outer Cu shield

Module deployment



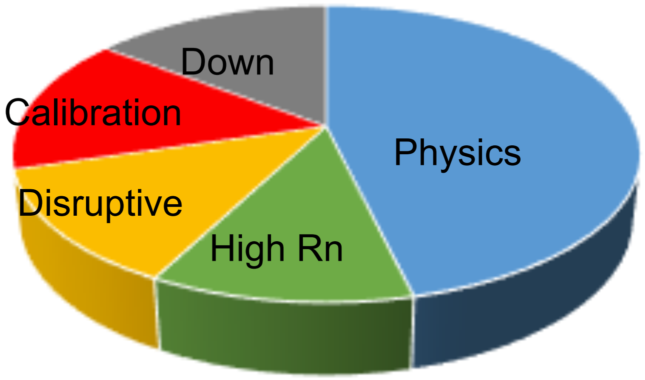
Muon panels

Module 1 Data Set Duty Cycles

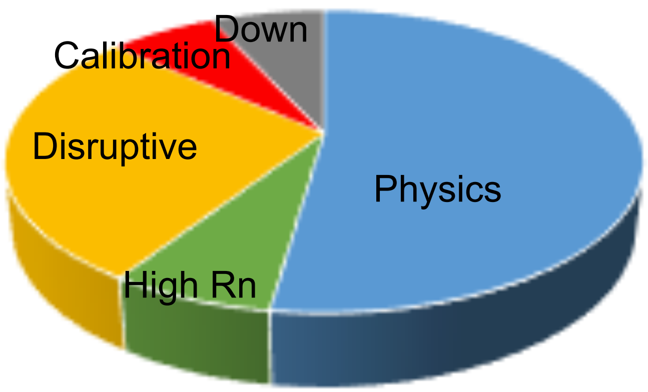
Break for Module 1 planned improvements

		DS0 (days) No inner shield June 26, – Oct. 7, 2015	DS1 (days) with inner shield Dec. 31, 2015 – Apr. 14, 2016*
Total		103.15	104.68
Total acquired		87.93	97.49
Physics	(blue)	47.70	54.73
High radon	(green)	11.76	7.32
Disruptive Commissioning tests	(yellow)	13.10	28.61
Calibration	(red)	15.44	6.86
Down time	(grey)	15.21	7.19

DS0



DS1



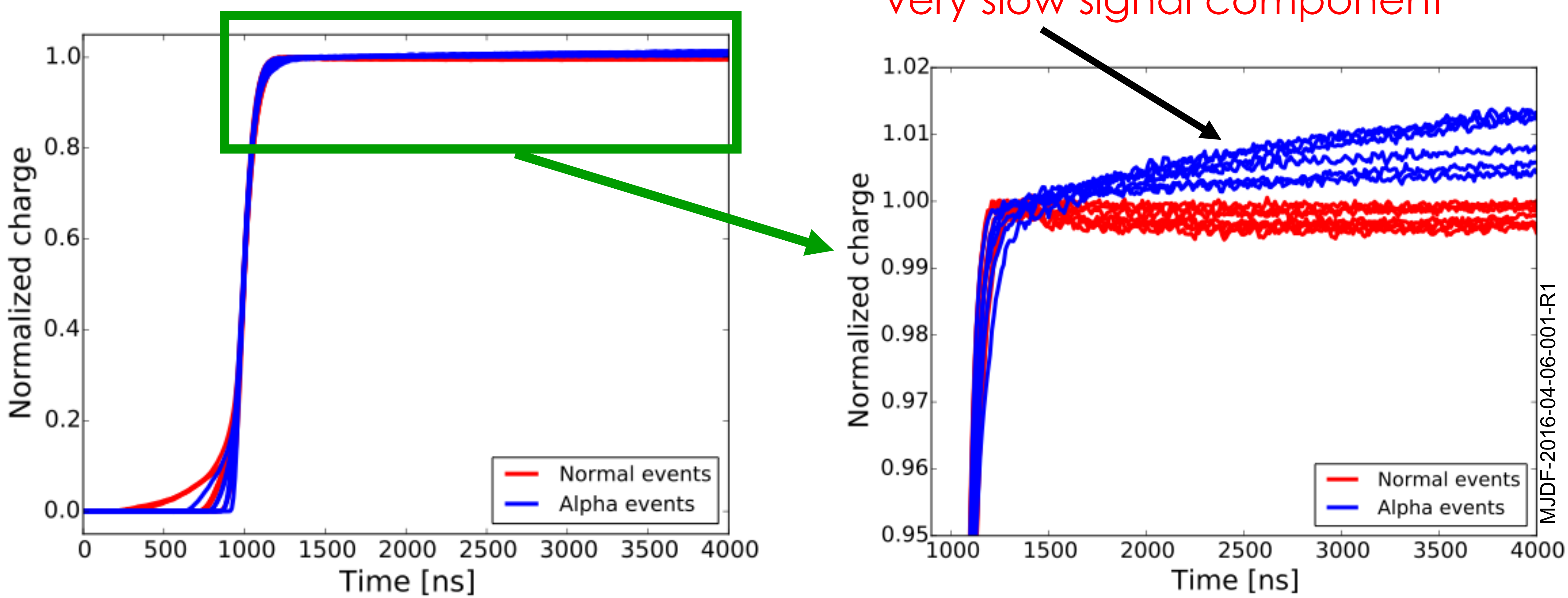
*Data taking ongoing

Delayed Charge Recovery and Alphas

- Alpha background response observed in Module 1 commissioning (DS0)
  - Identified as arising from alpha particles impinging on passivated surface
- Results in prompt collection of some energy, plus very slow collection of remainder
- Enables a powerful PSA rejection of alpha events
- "Delayed Charge Recovery" parameter related to slope of tail

Example pole-zero corrected waveforms

Slow drift of charges along passivated surface results in very slow signal component



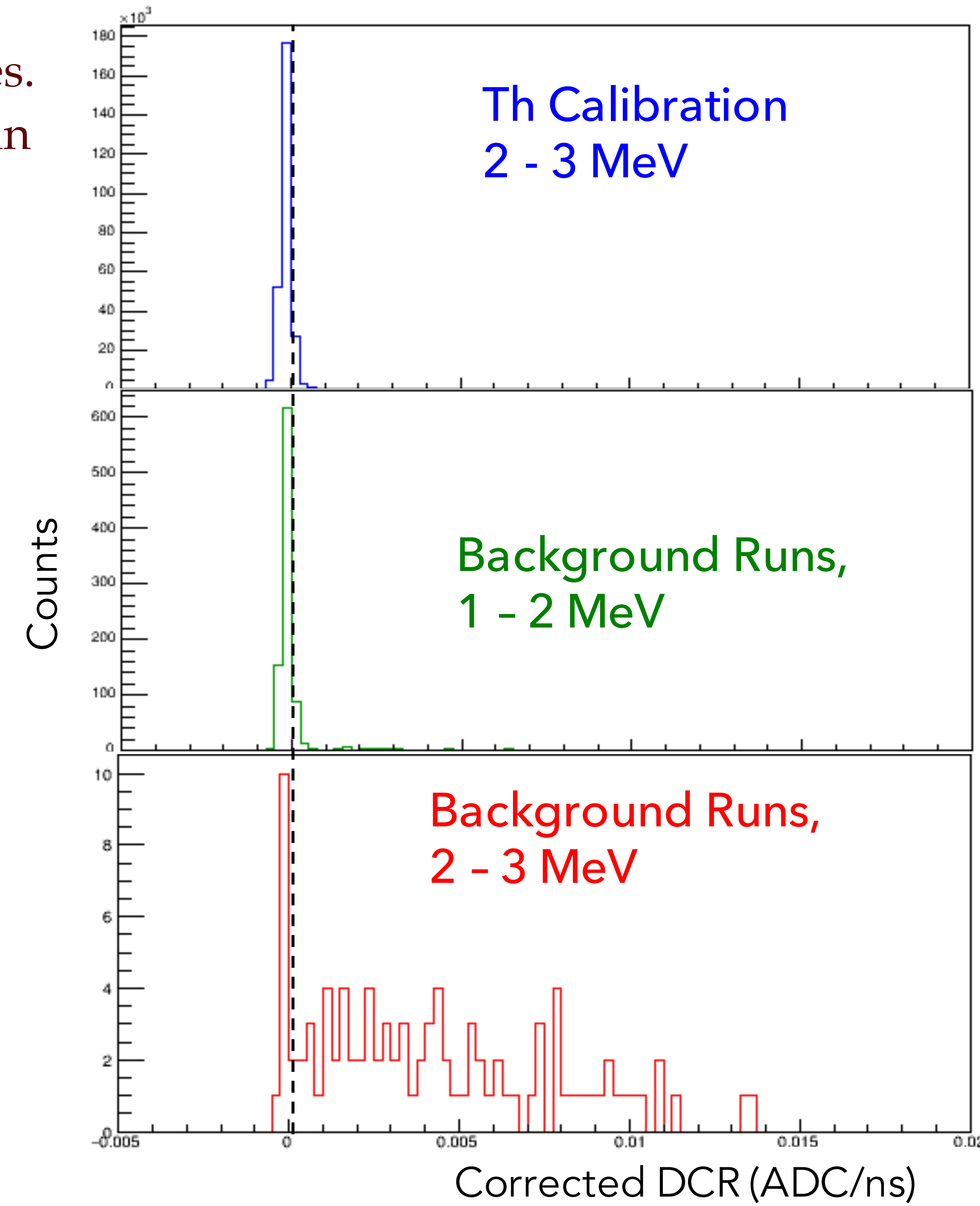
DS1 DCR Cut and Bulk-Event Response

Removes most events above 2 MeV in the background spectrum, which are α candidates. Cut is 90% efficient for retaining events within detector bulk. Only ~5% of α's survive cut.

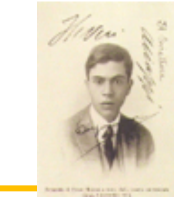
During calibration runs, γ events survive cut.

During Background runs, $\beta\beta(2\nu)$ events survive cut.

Candidate α events from background runs are removed.

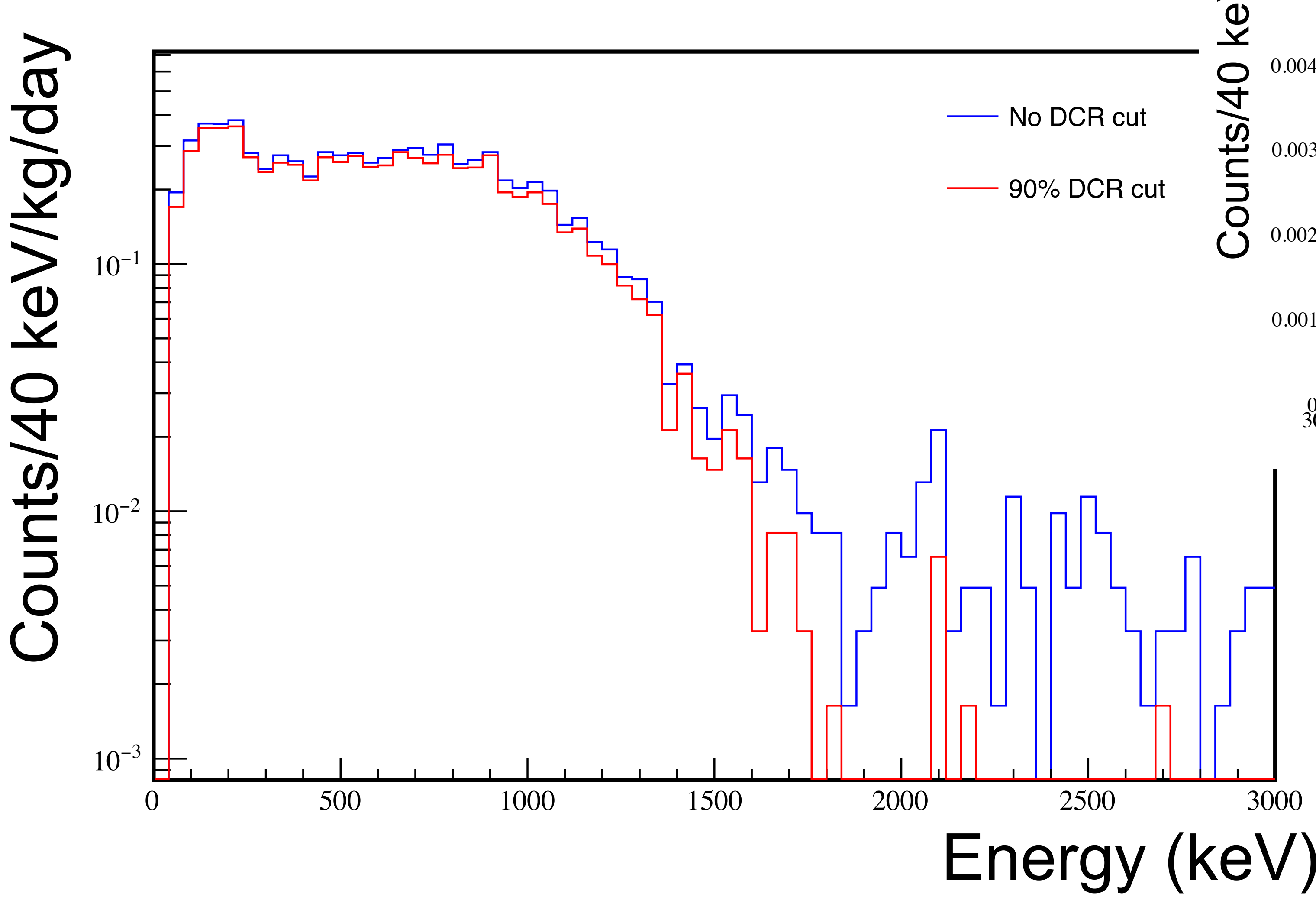


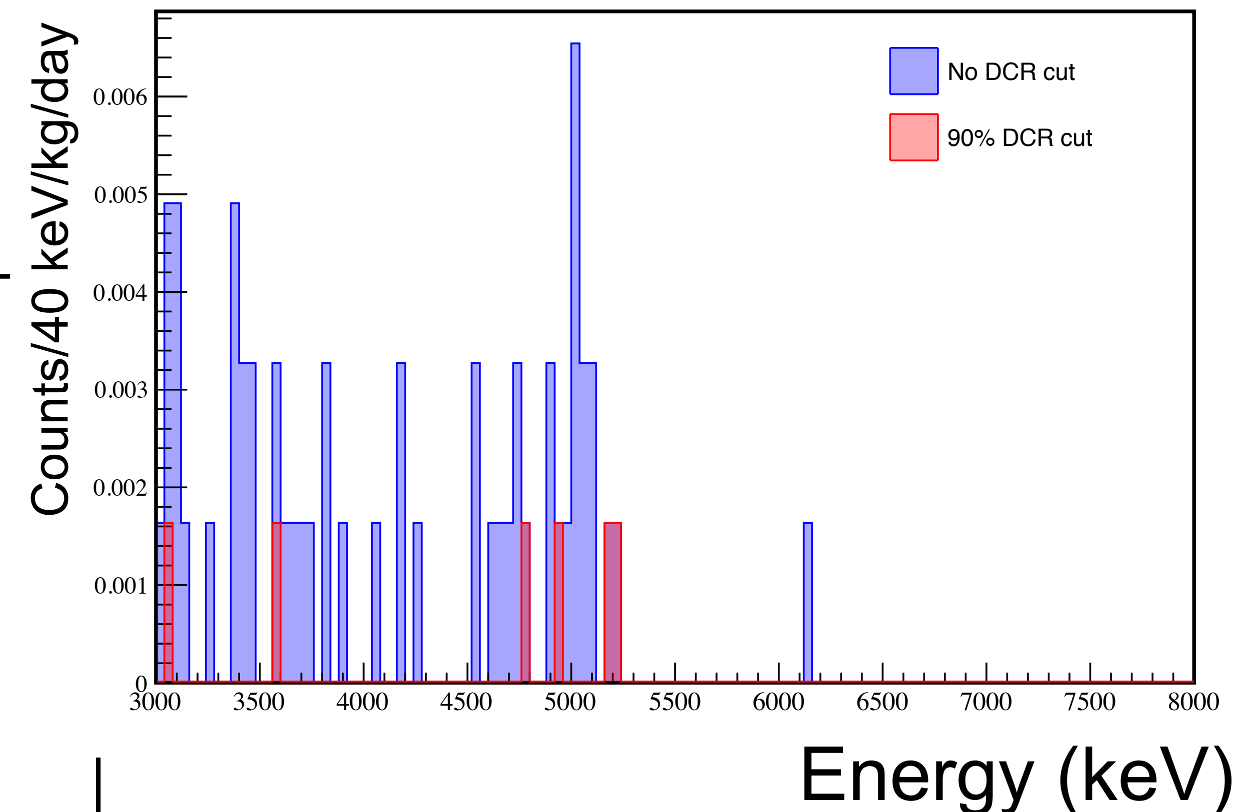
DS1 Spectrum with DCR Cut



We perform some data cleaning cuts, granularity and PSD cuts to remove multiple site energy deposits, and the DCR cut to remove surface alphas.

- DCR cut events stop at about 5.3 MeV. Circumstantial evidence that its Po.



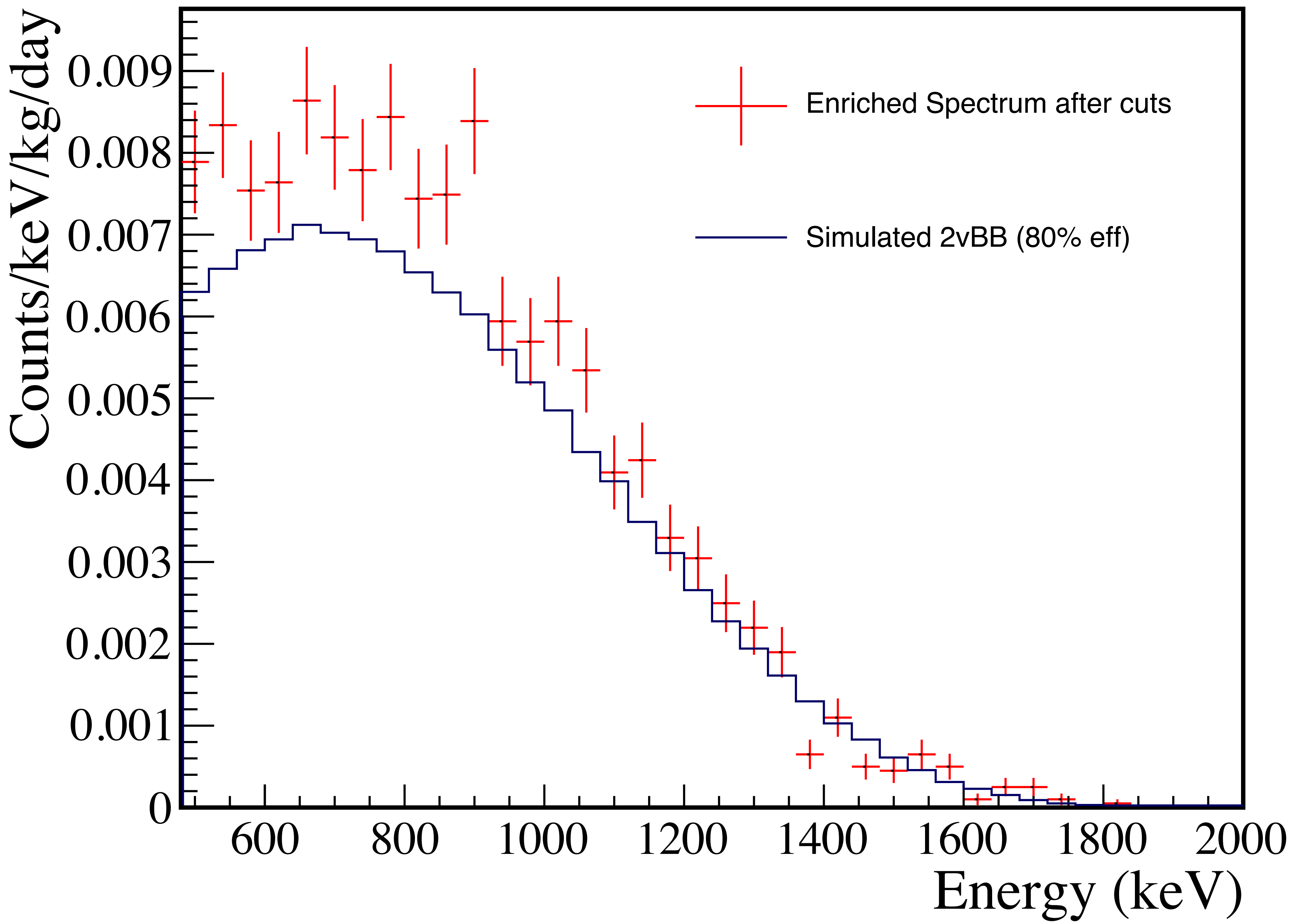


DS1: 500-2000 keV, ββ(2ν)

Data Set 1 spectrum after all cuts.

Above ~1200 keV the spectrum is dominated by ββ(2ν).

Simulated rate using previously measured half-life (Eur. Phys. J. C 75 (2015) 416).



The Region of Interest in DS1

The enriched detectors in Data Set 1 are used to estimate the background.

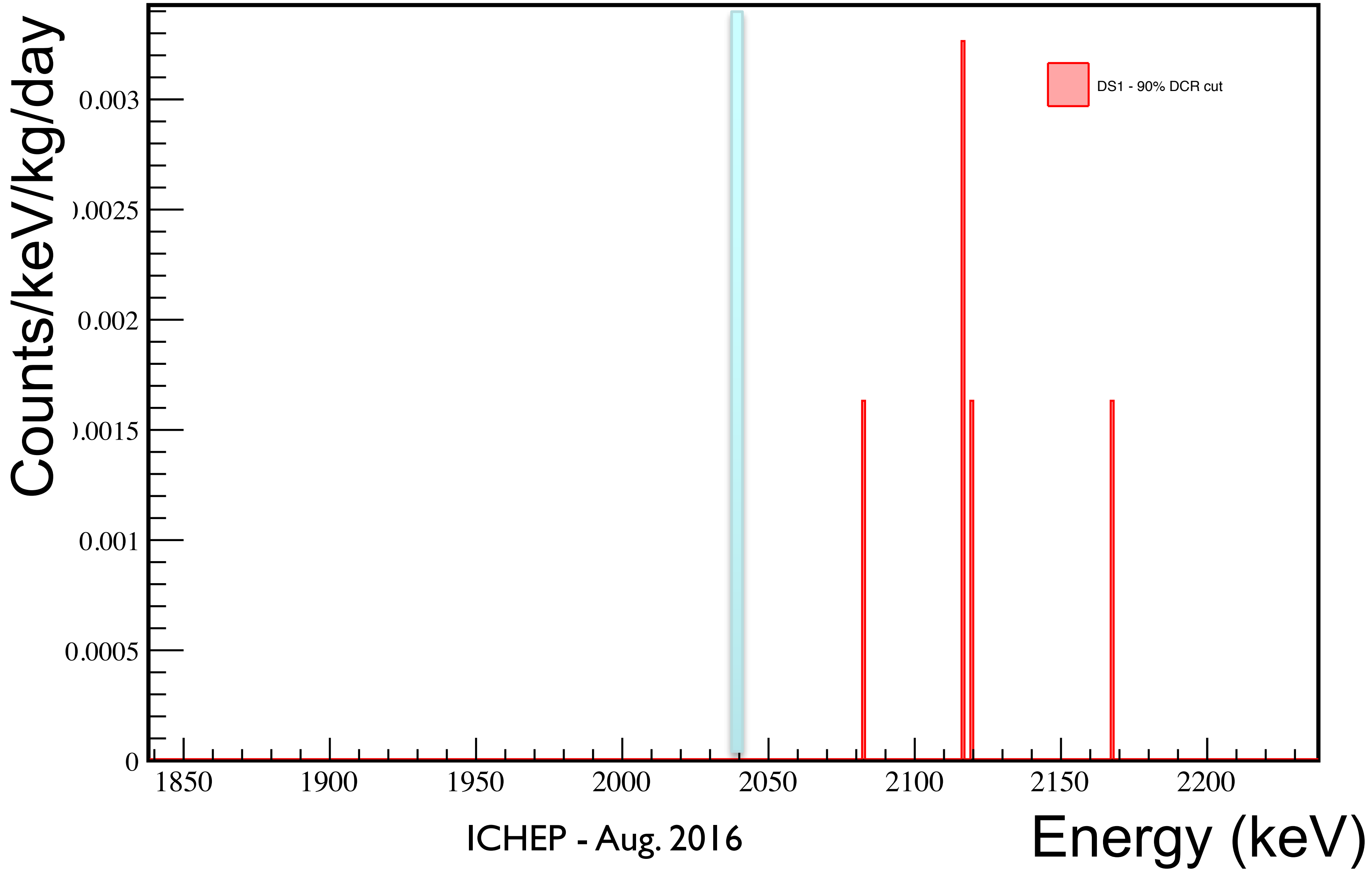
The lowest-background configuration. $Q_{\beta\beta} = 2039$ keV.

Most events near ROI are removed by the DCR cut. Only 5 survive in 400 keV window.

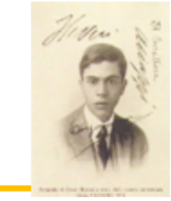
Background rate is 23^{+13}_{-10} counts/(ROI t y) for a 3.1 keV ROI, (68% CL).

Background index is $7.5^{+4.5}_{-3.4} \times 10^{-3}$ counts/(keV kg y).

All analysis cuts are still being optimized.



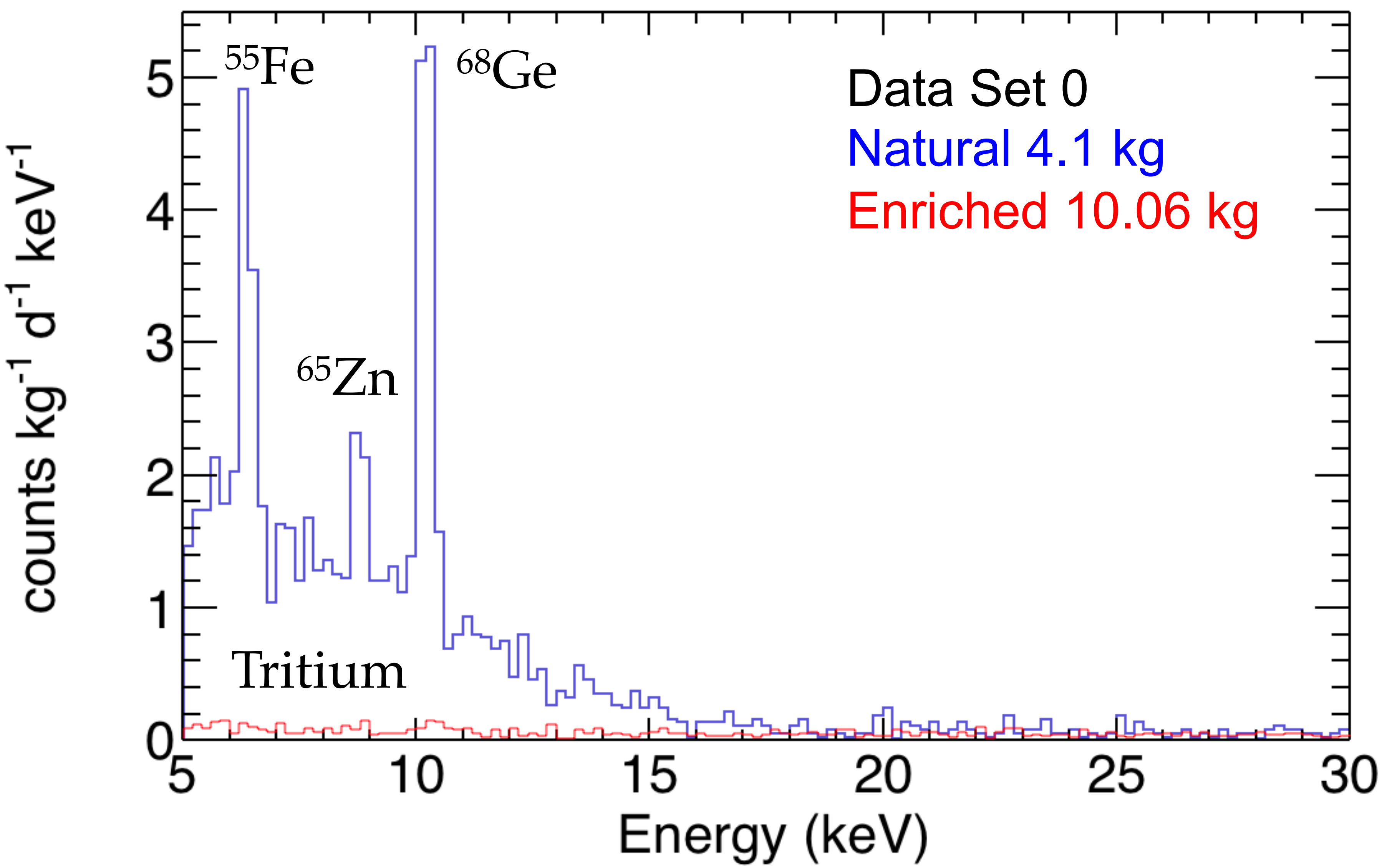
Low Energy Spectrum in DS0



Controlled surface exposure of enriched material to minimize cosmogenics
Significant reduction of cosmogenics in the low-energy region.

- Factor of a few better in DS1.
- Enriched Detectors: ~0.04 cts/(kg-keV-d) near 20 keV

Efficiency below 5 keV is under study.



Permits Low-Energy physics

Pseudoscalar dark matter
Vector dark matter
14.4-keV solar axion
e- 3ν
Pauli Exclusion Principle

MAJORANA DEMONSTRATOR Summary

- Produced 35 (29.66 kg) of 88% enriched ^{76}Ge p-type point contact detectors.
- Attained highest yield to date (74.5%) of enriched ^{76}Ge detectors from initial material.
- Module 1 in operation with improved shielding since January 2016, blind data collection mode since April 2016.
- Module 2 undergoing commissioning. In-shield background measurements in August. Final additions (neutron shielding) to main shield will be installed once Module 2 is in shield.
- Independent work continues to improve cables and connectivity in terms of an optimized next generation ton scale ^{76}Ge $0\nu\beta\beta$ experiment.
- Collected 3.03 kg yr of exposure from DS0 & DS1 before going blind. $T_{1/2} > 3.7\text{x}10^{24}$ y
- Measured background level in DS1 at ROI is 23^{+13}_{-10} counts/(ROI t y). The ROI is 3.1 keV.
- The low energy spectrum in DS0 is producing physics results.
- Predict $T_{1/2} = 1.2 \text{ x } 10^{26}$ y (90% Sensitivity) and $T_{1/2} = 1.2 \text{ x } 10^{26}$ y (3σ Discovery)

  MJD 100 kg-year at 3.5 counts/ROI-t-y

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