THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

Status and initial results from the MAJORANA DEMONSTRATOR Experiment

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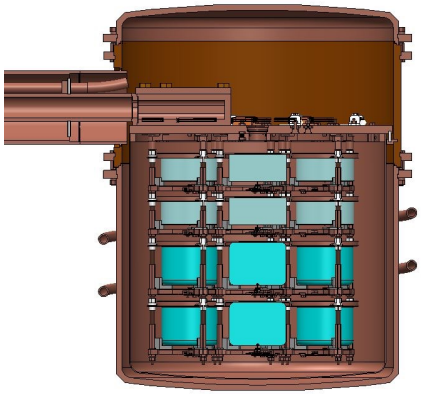
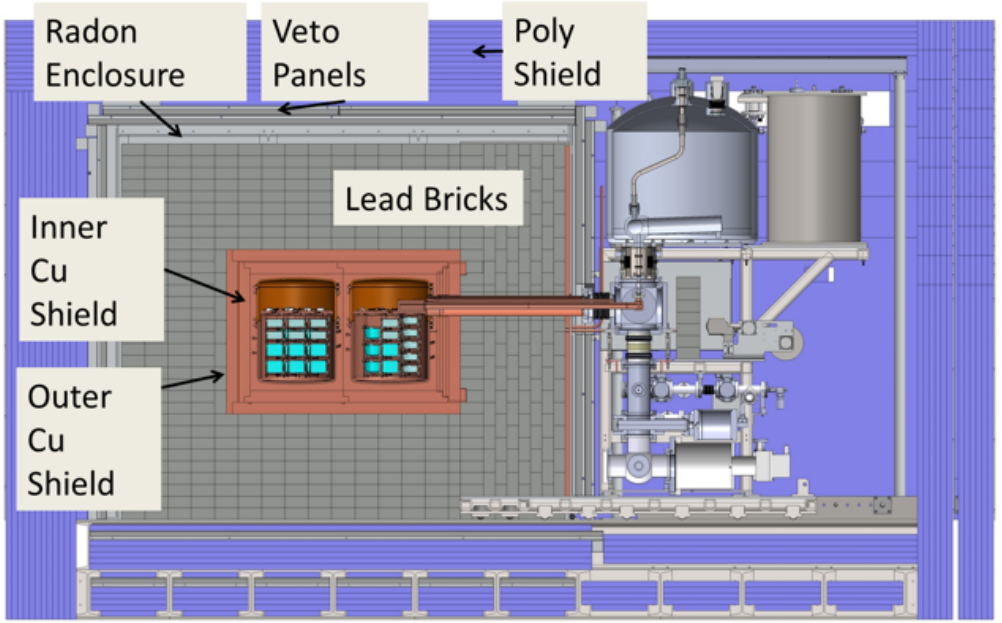
The MAJORANA DEMONSTRATOR

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-kg of Ge detectors
  - 29 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



Sensitivity, Background and Exposure

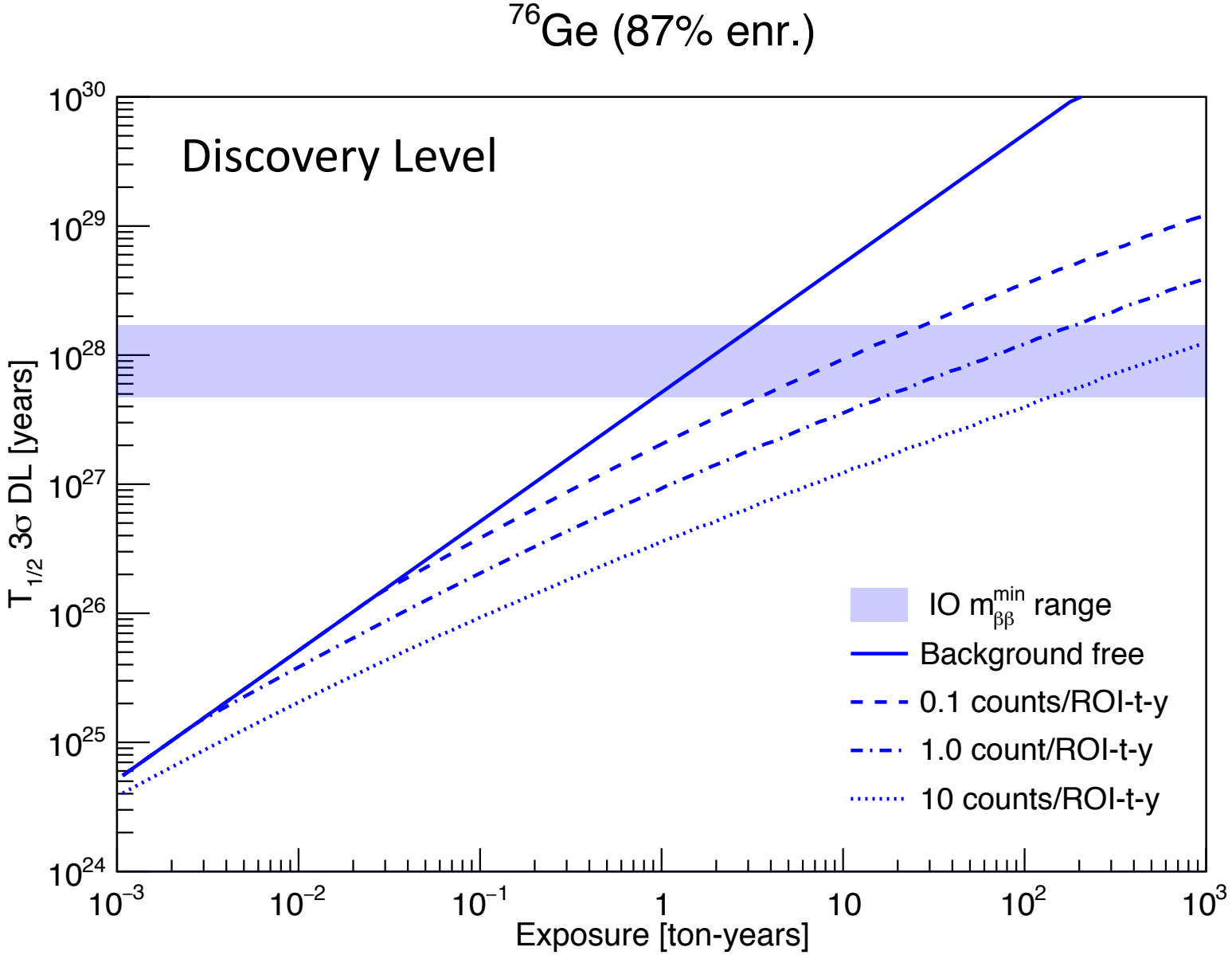
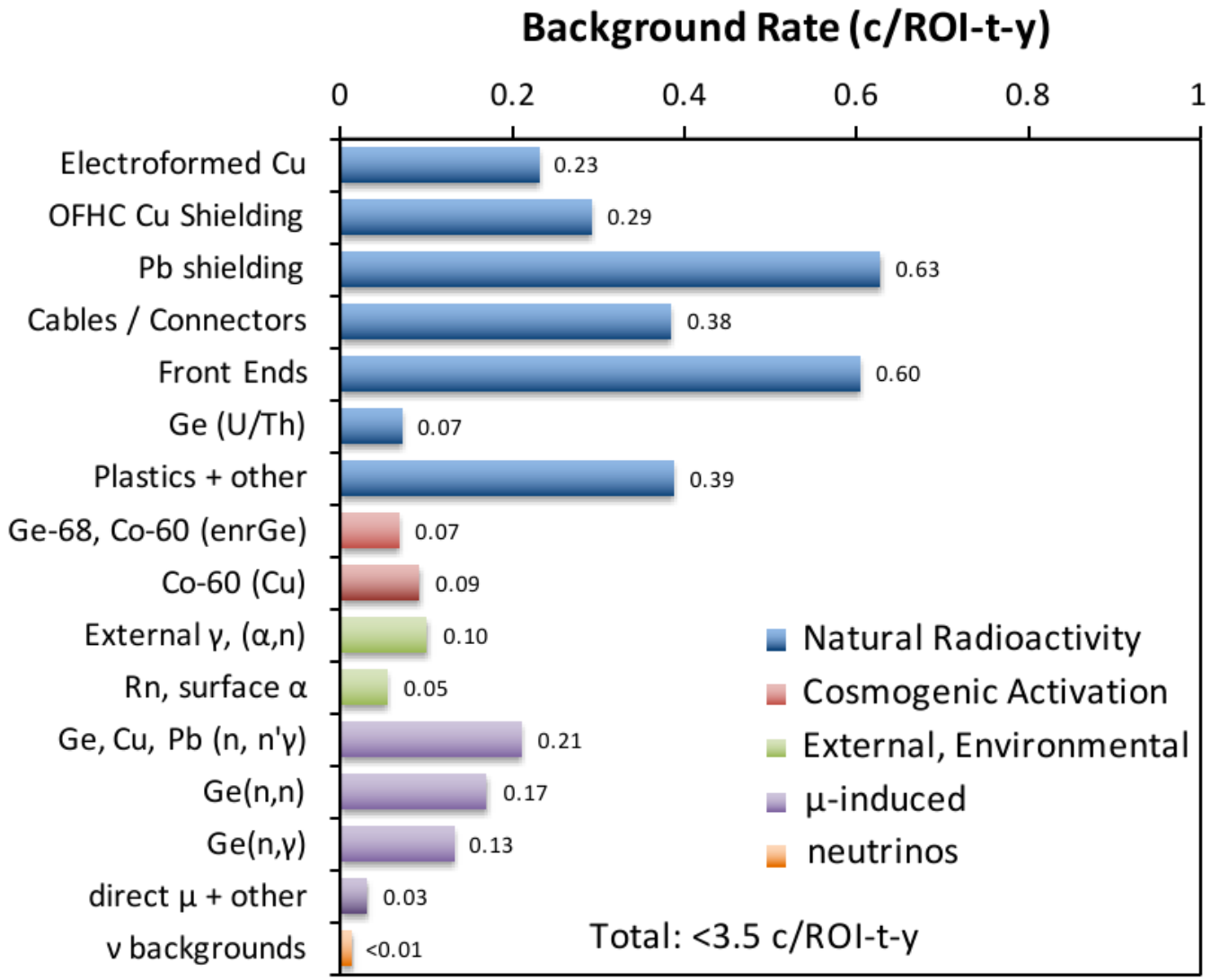


Fig: Courtesy J. Detwiler

Sensitivity, Background and Exposure

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

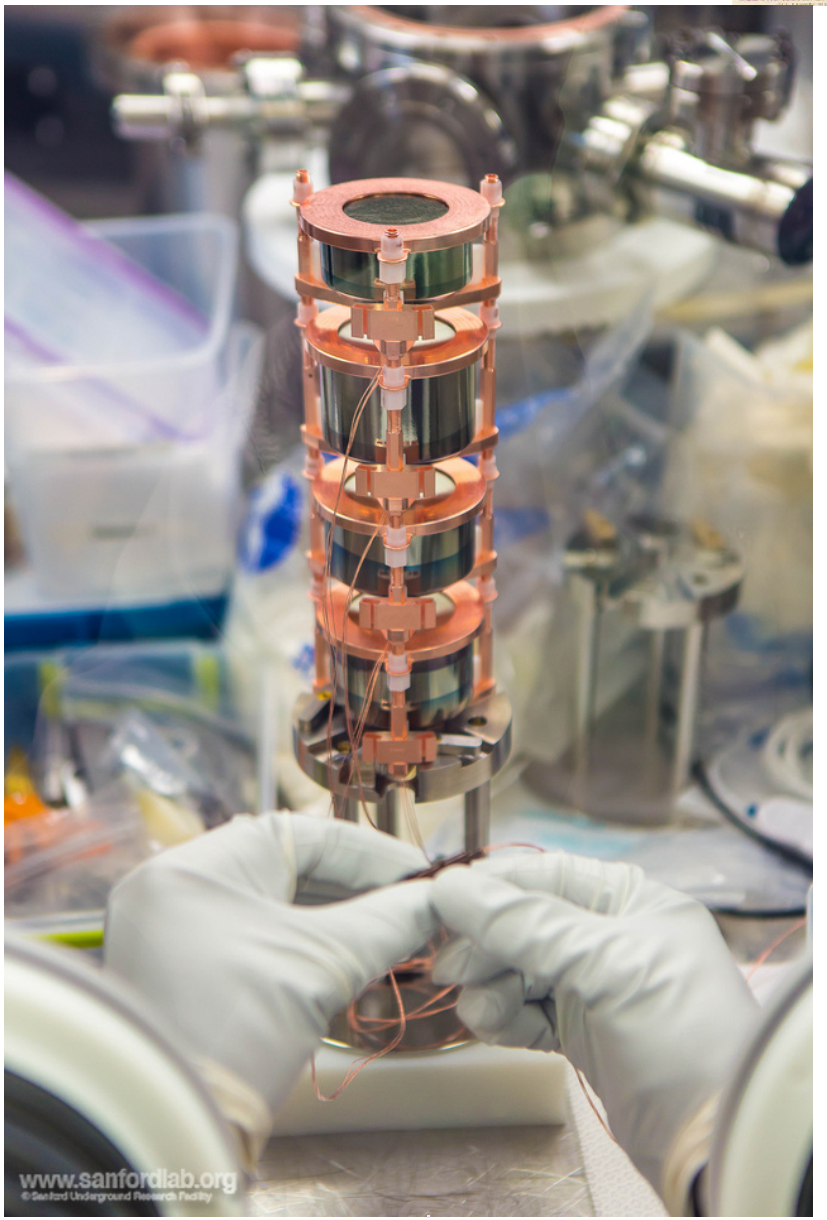
http://arxiv.org/abs/1601.03779



From electroformed Cu and enriched Ge

- electro-formed underground
- Th decay chain (ave) ≤ 0.1 µBq/kg
- U decay chain (ave) ≤ 0.1 µBq/kg
- ~1.1 tons used in MJD

Electroformed Cu and enriched Ge



- electro-formed underground
- Th decay chain (ave) ≤ 0.1 µBq/kg
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- ~1.1 tons used in MJD

Fig: Courtesy M. Kapust

Electroformed Cu and enriched Ge

Fig: Courtesy M. Kapust

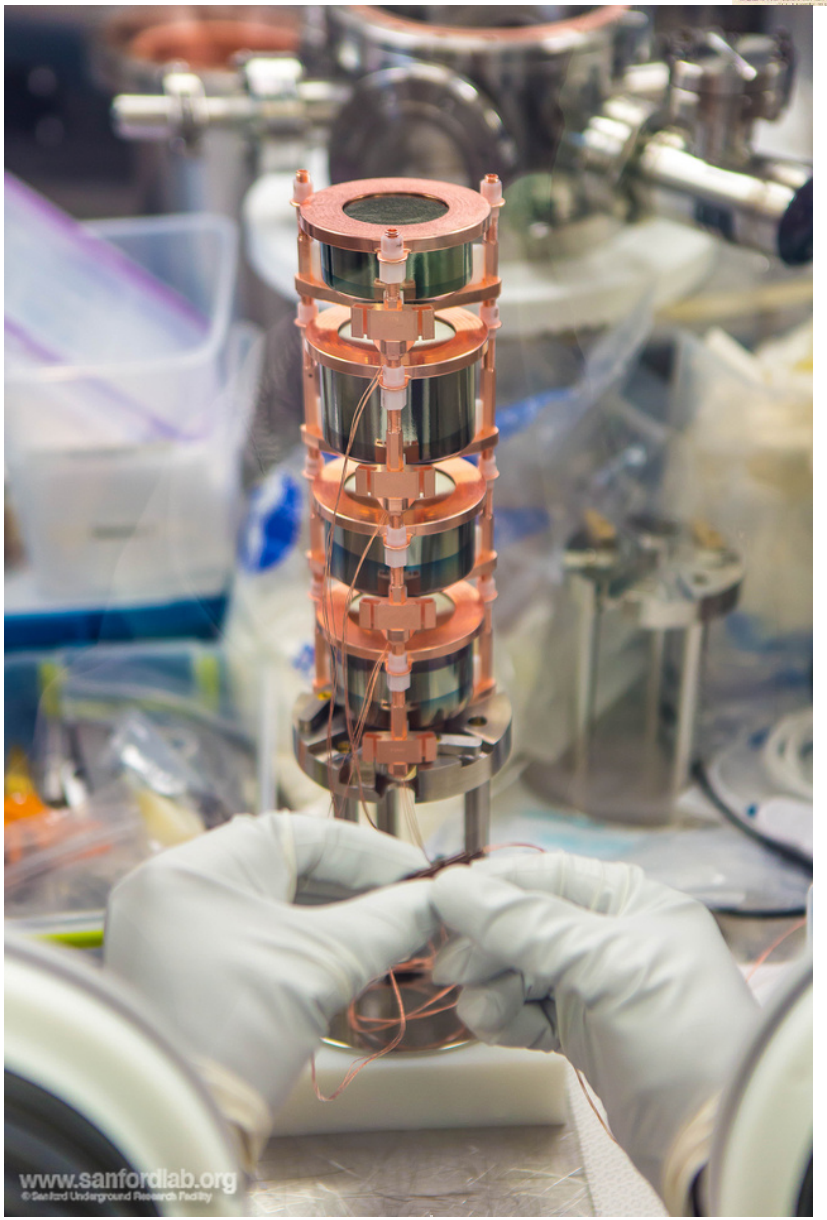
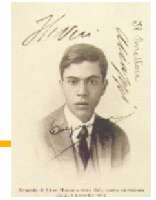


Fig: Courtesy M. Kapust

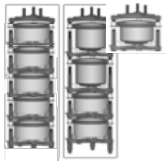
MAJORANA DEMONSTRATOR Implementation



Three Steps:

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

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

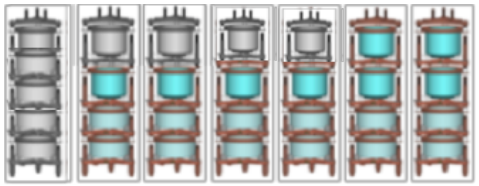


June 2014-June 2015

Module 1:

16.8 kg (20) ^{enr}Ge

5.7 kg (9) ^{nat}Ge

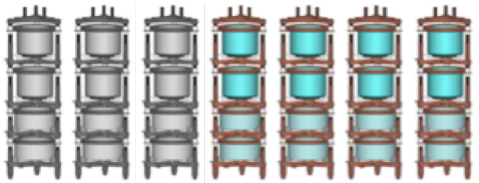


May–Oct. 2015, data-taking
Nov-Dec: Improvements
Jan. 2016 – present: data-taking

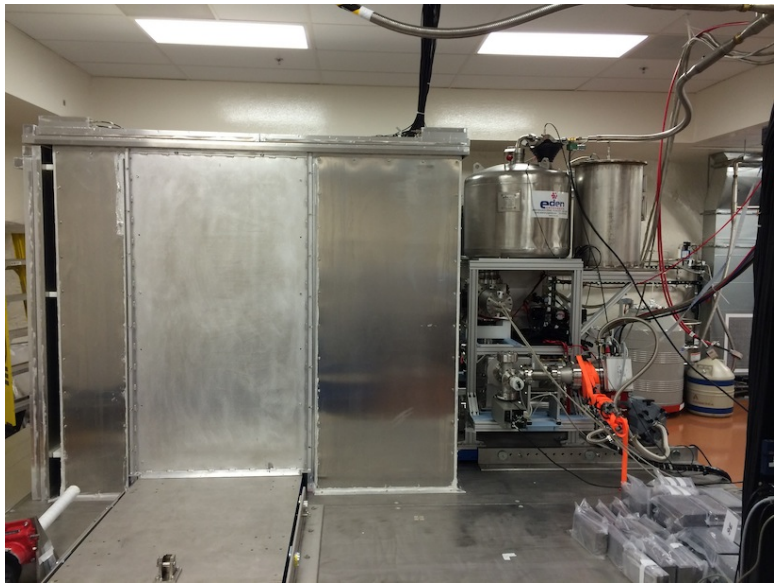
Module 2:

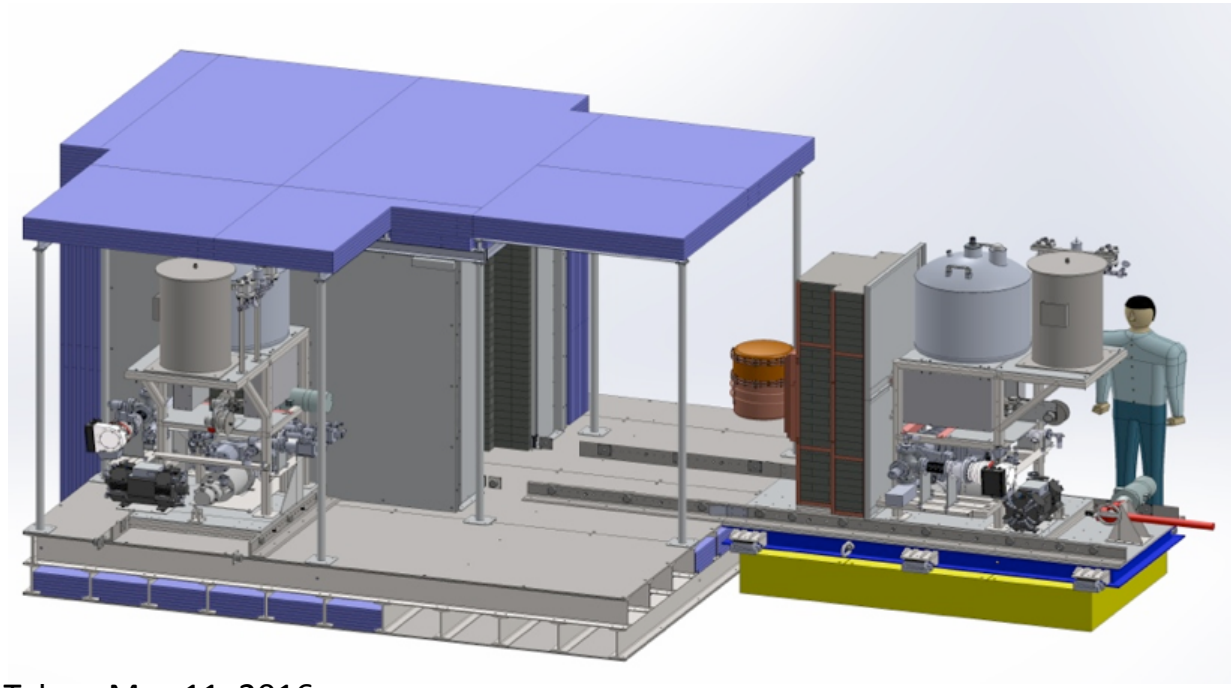
12.8 kg (14) ^{enr}Ge

9.4 kg (15) ^{nat}Ge



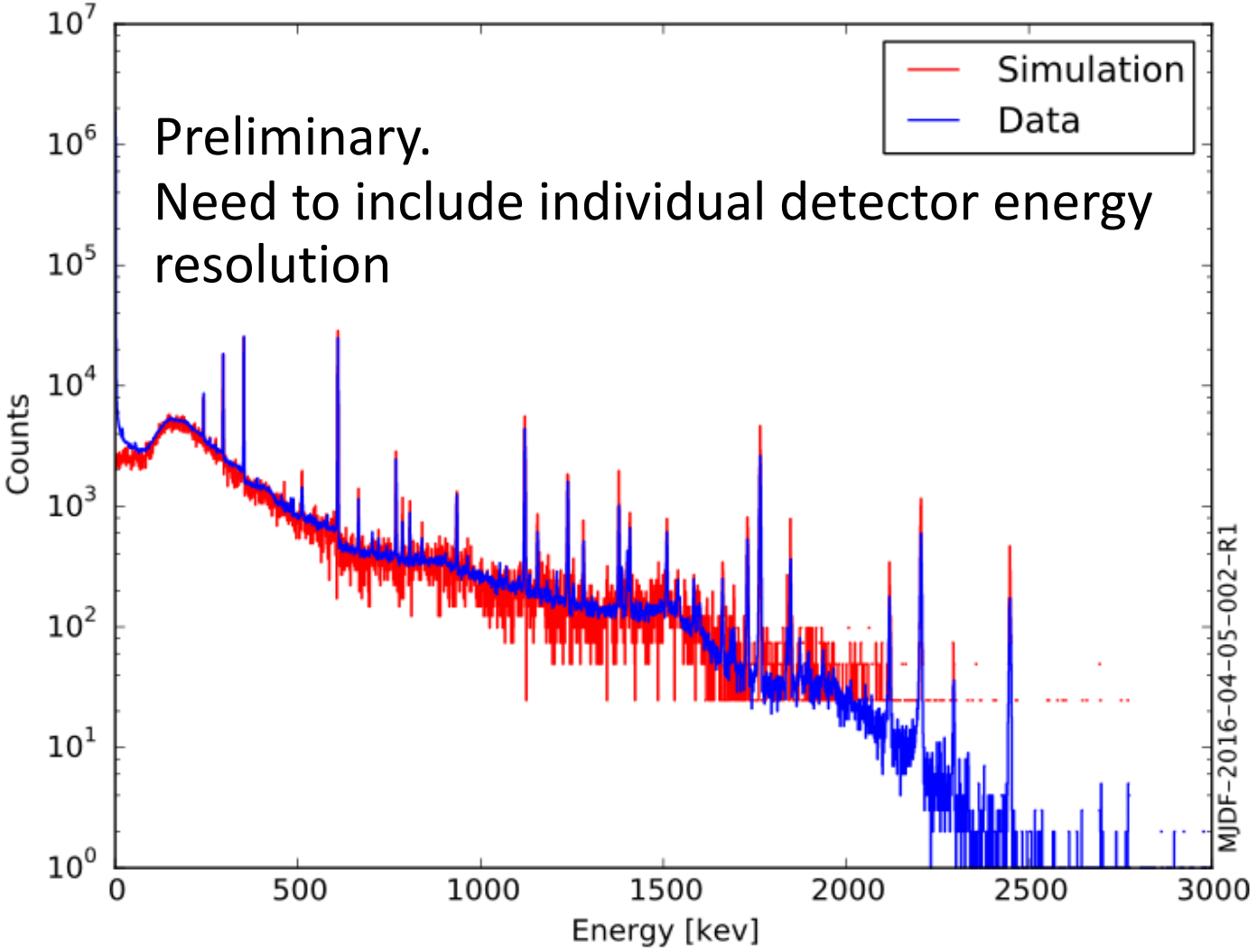
Mid 2016



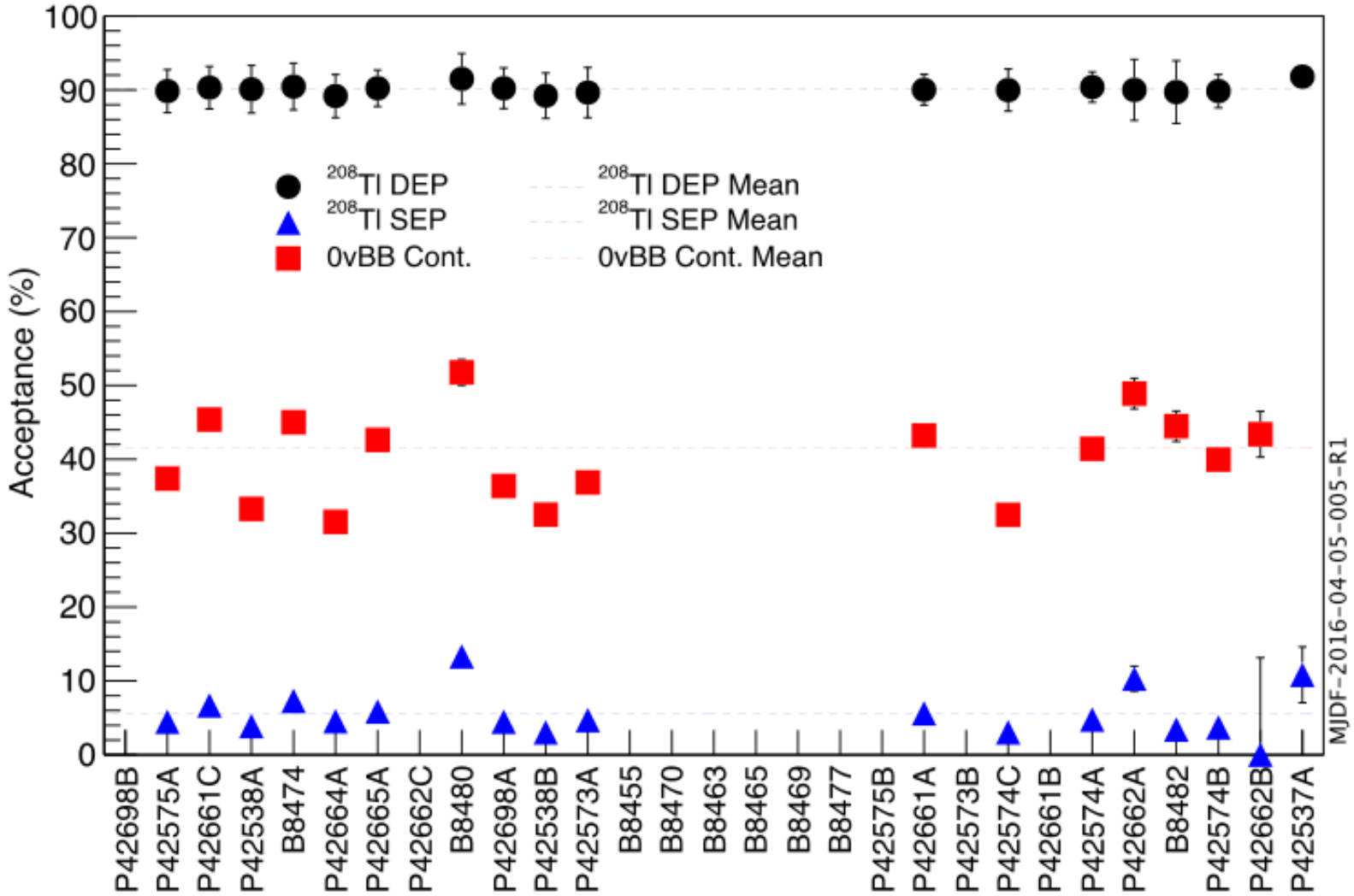


Module 1 – commissioning

Rn purge test Sept. 2015, during Module 1 commissioning.
Rn simulation compared to data. Fit around 609-keV peak.
Fit is 8.5 pCi/L, near room value of ~7 pCi/L, but no value for shield level.



Ge Detector PSD Performance in Module 1 (DS1)



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

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

Updates and status

<u>After commissioning run of Module 1 in Fall 2015, we....</u>

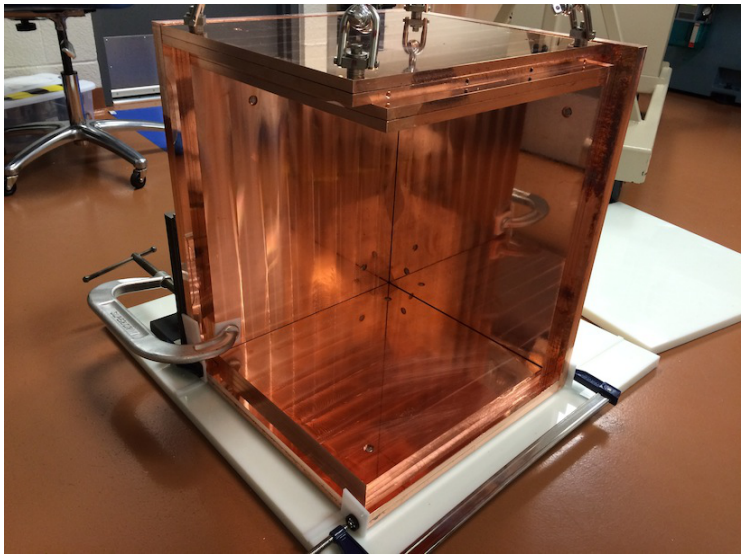
... installed the inner electroformed copper shield.

... added additional shielding in the crossarm.

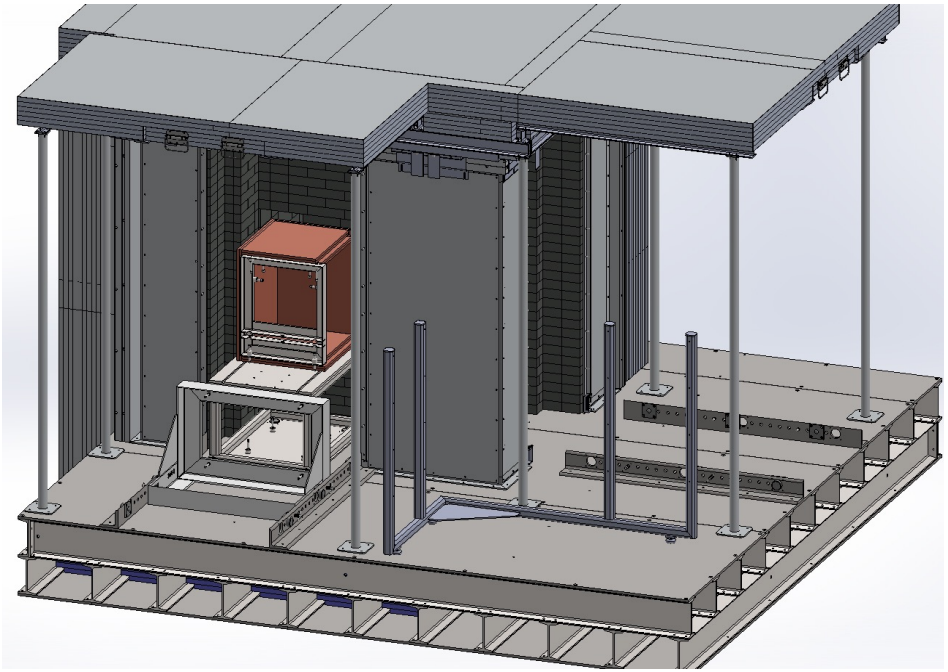
... replaced the cryostat seals with low radioactivity versions.

... repaired non-operating channels.

Inner Cu shield

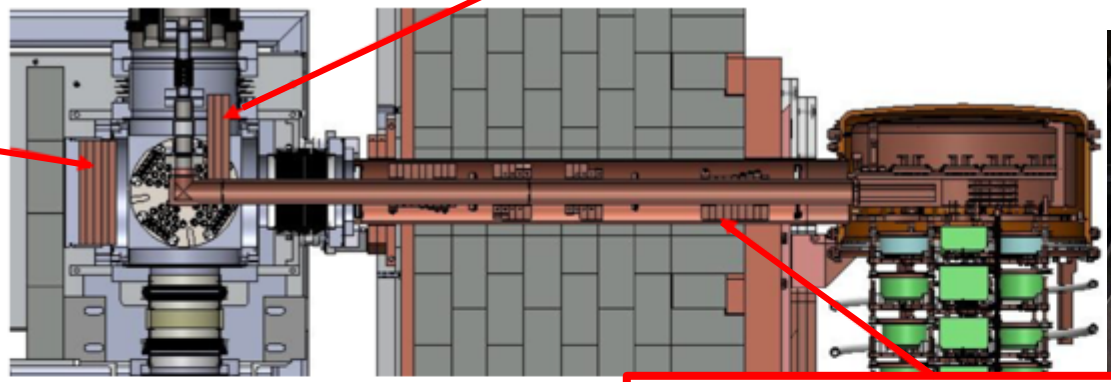


- Extensive time to electroform the Cu parts.
- String parts higher priority for machining.
- Hence installed after shield constructed.
- Installed in two parts in Nov. 2015.
- Expect x10 reduction in background from other shield materials.

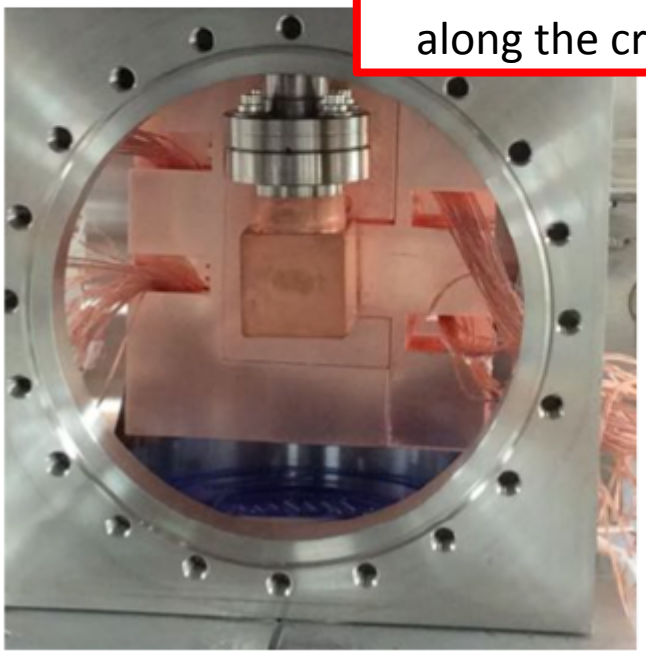


Extra crossarm shielding

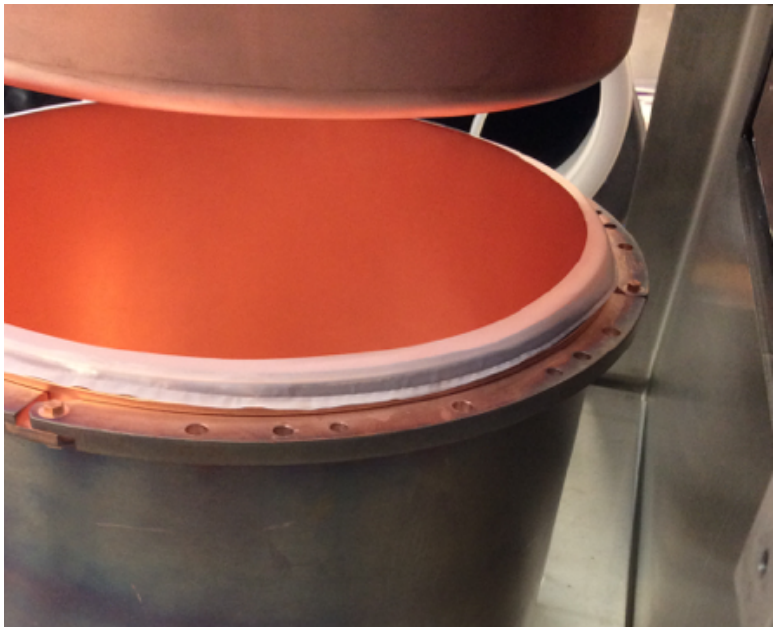
extra shield plates at the backside



extra shield plates
along the cross arm



Cryostat seals



Kalrez:

- reusable
- high mass
- activity 27.8 counts / ROI /t /year

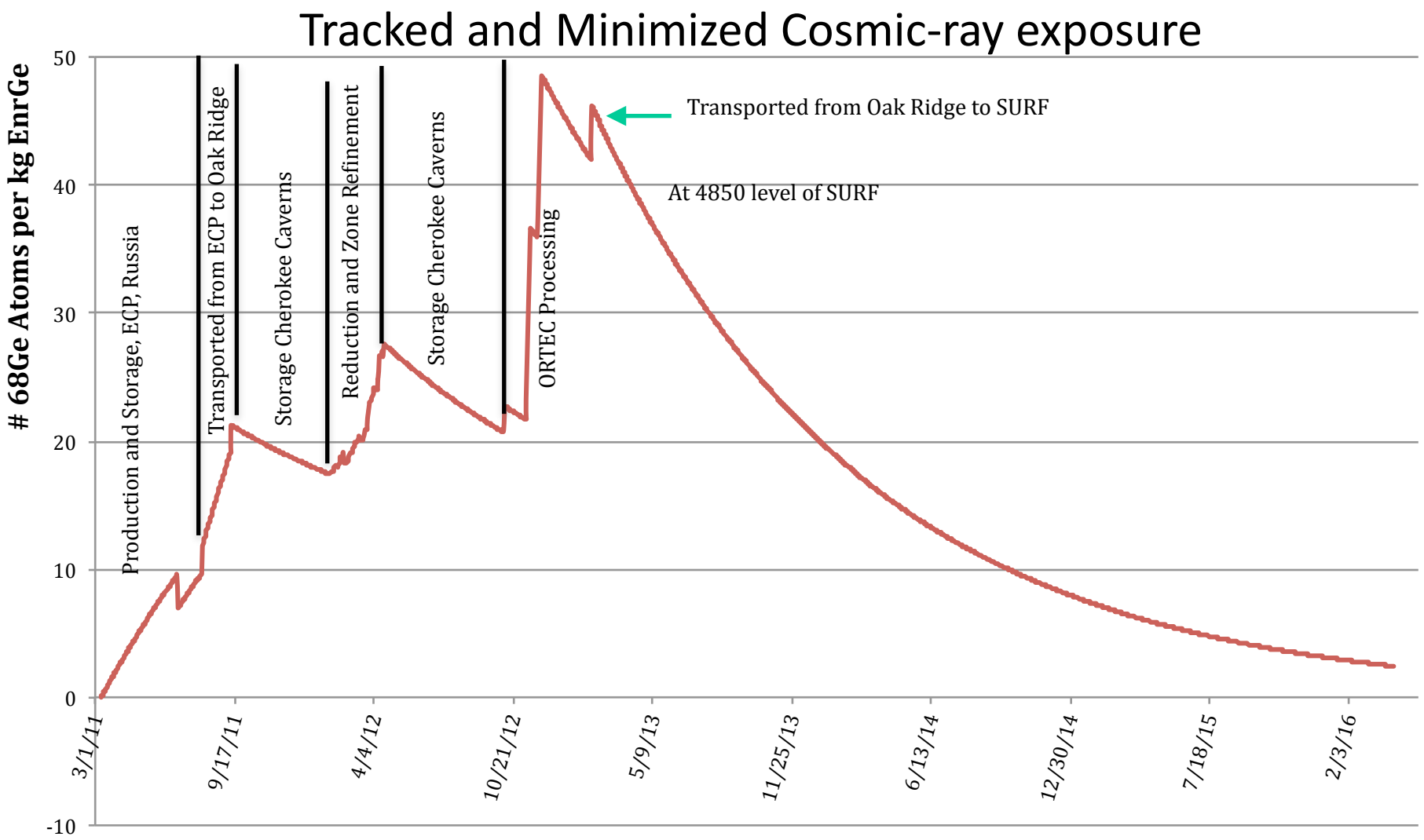
PTFE:

- single use
- low mass (only 0.002” thick)
- activity 0.013 counts / ROI /t /year

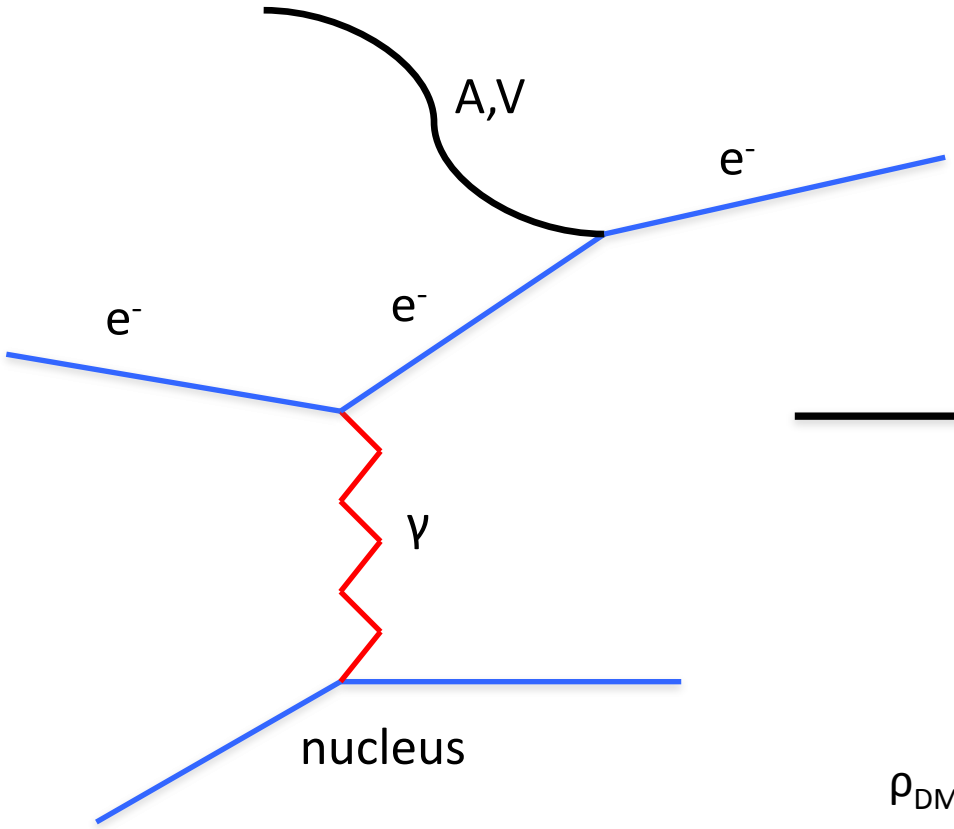
Low-energy physics with P-PC detectors

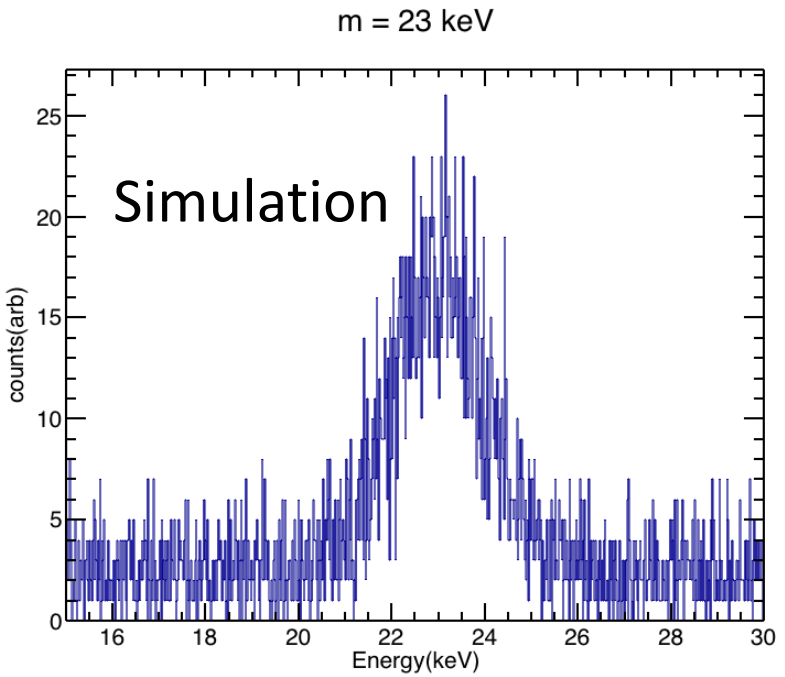
- Low-energy Thresholds (<500eV) of P-PC detectors and excellent energy resolution provides powerful tag of ^{68}Ge decays via K and L-Shell lines
- Also allows other science goals:
  - Light (<10 GeV/c2) WIMP searches
  - Bosonic Dark Matter
  - Solar Axions
  - Pauli-Exclusion Principle Violation
  - Electron Decay
  - Coherent nuclear-neutrino scattering
- **Isotopic enrichment and control of exposure to cosmic-rays reduces low-E backgrounds**

^{68}Ge Production in Detector P42537A



Example: Light (1-100 keV-scale) Bosonic DM



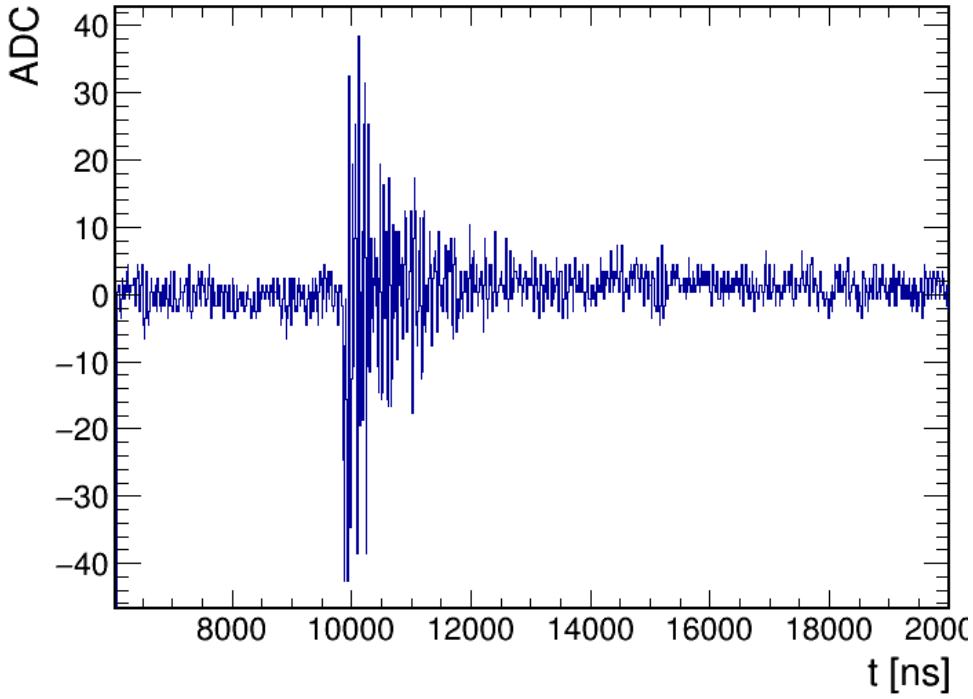


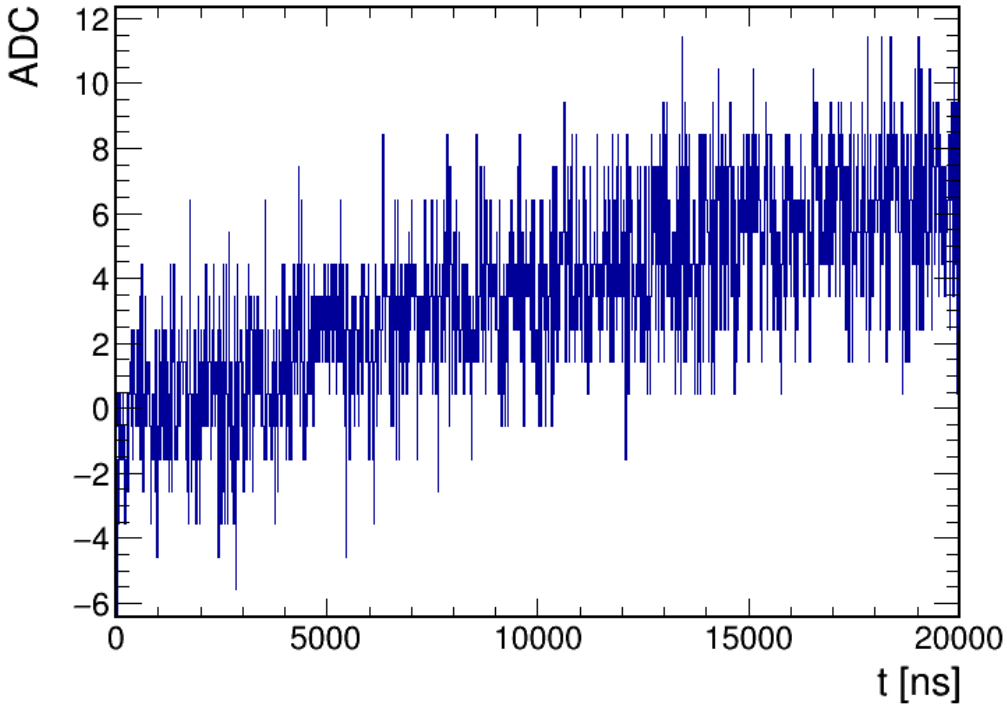
ρ_{DM} = 0.3 GeV/cm^3 $\beta = v/c \sim 0.001$

- Low threshold PPC Ge detectors well suited for keV-scale DM search
- Pseudoscalar (ALPs) or Vector DM could deposit rest mass-energy in detector

See: M. Pospelov, A. Ritz, and M. Voloshin, Phys. Rev. D, 78, 115012 (2008).

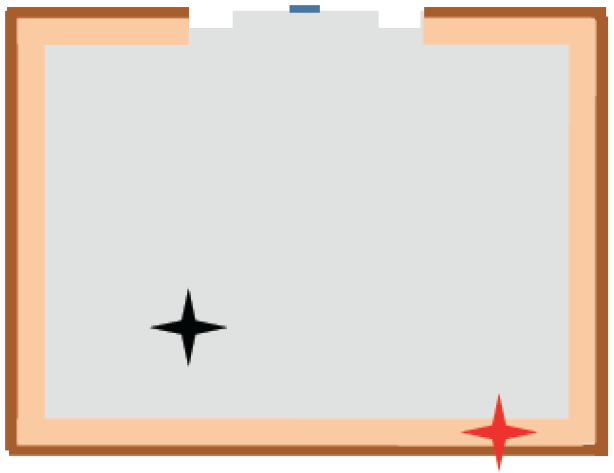
Electronic Noise Removal at low-E





- Left: Transient noise (removed by considering only single detector events)
- Right: Internal pulser recovery events (very low E, <3 keV)
- Pulse shape analysis provides additional suppression

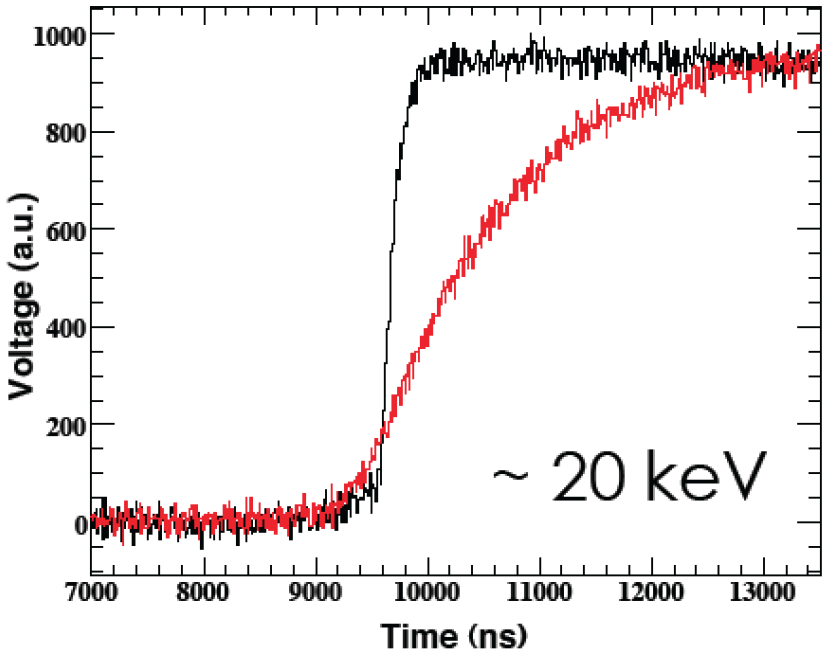
Slow Surface Events Near Detector Surface



active volume

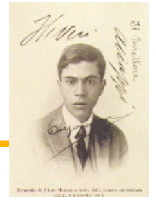
n+ dead layer

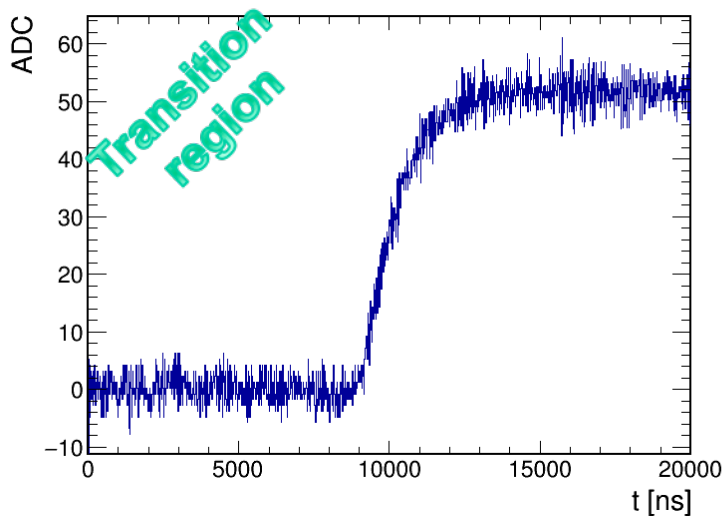
transition region – partial charge collection



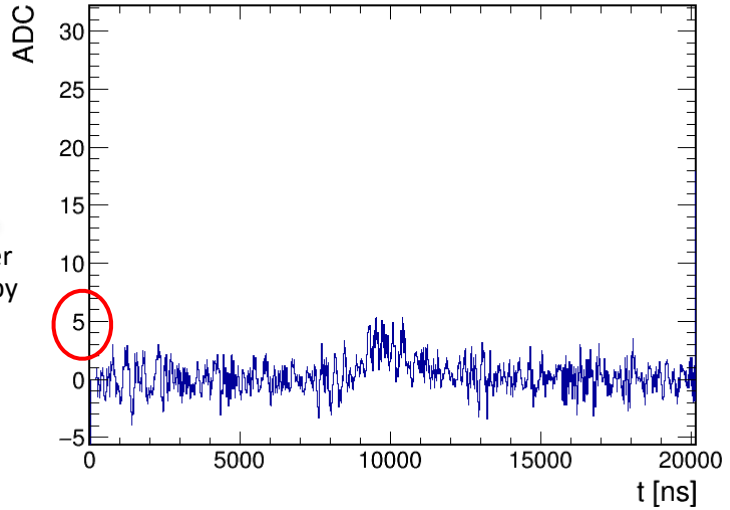
Also energy-degraded

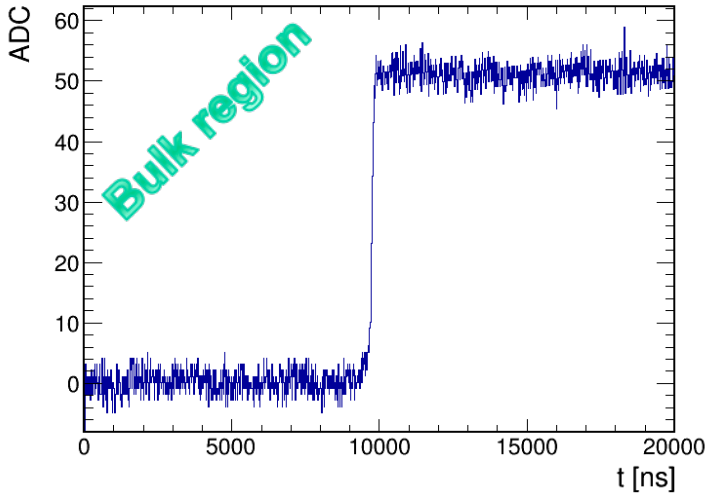
Transition Region Event Tagging

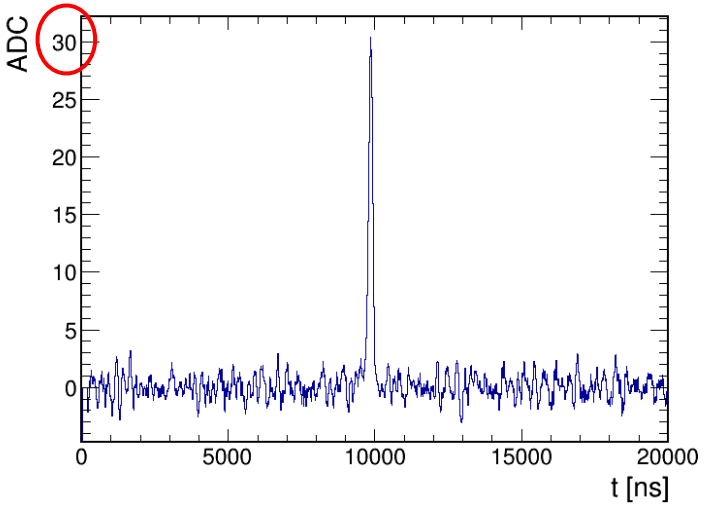




1) Apply triangle filter
2) Scale Filtered WF by event Energy

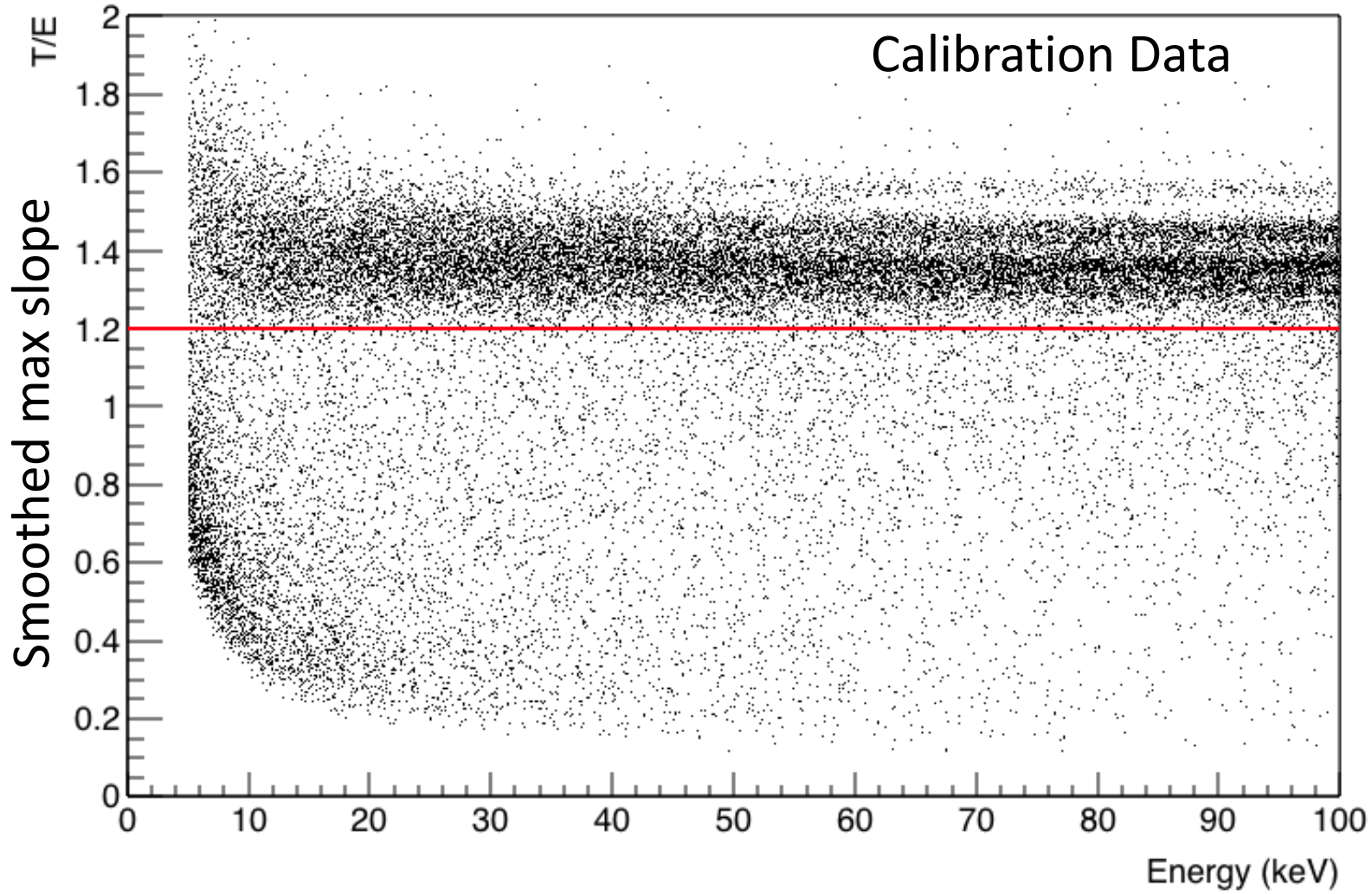






- Energy degraded events originating in transition region between dead layer and bulk region are a major background in low energy Ge experiments
- G. Giovanetti et al., A Physics Procedia, **61**, 2015, 77, C. E. Aalseth et al., Phys. Rev. D **88,** 012002, 2013

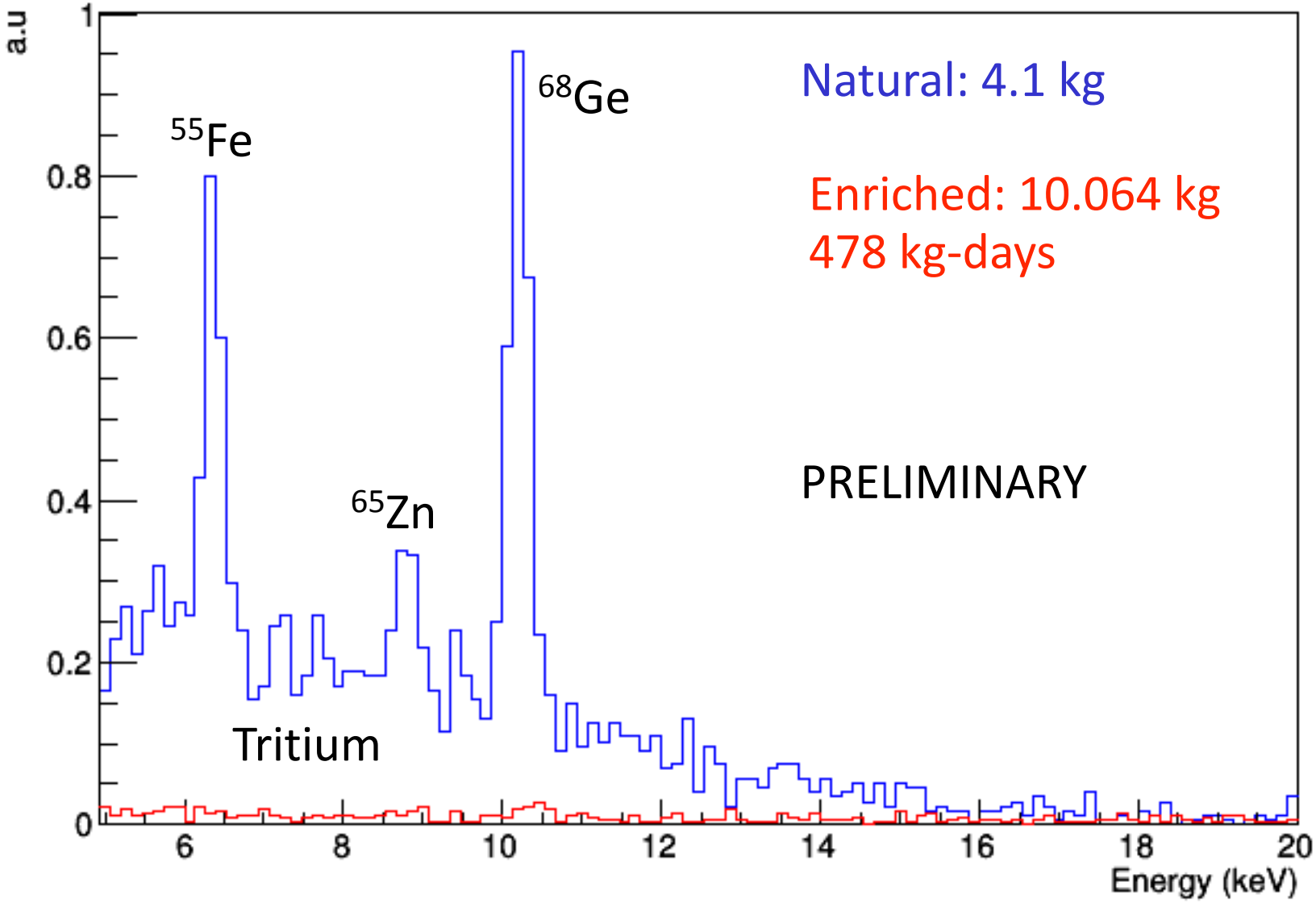
Transition Region Event Cut



- Accept events above red line (T/E = 1.2)
- Determined acceptance via attenuated external pulser calibration
  - 96% acc at 5 keV
  - >99% acc for E > 10 keV

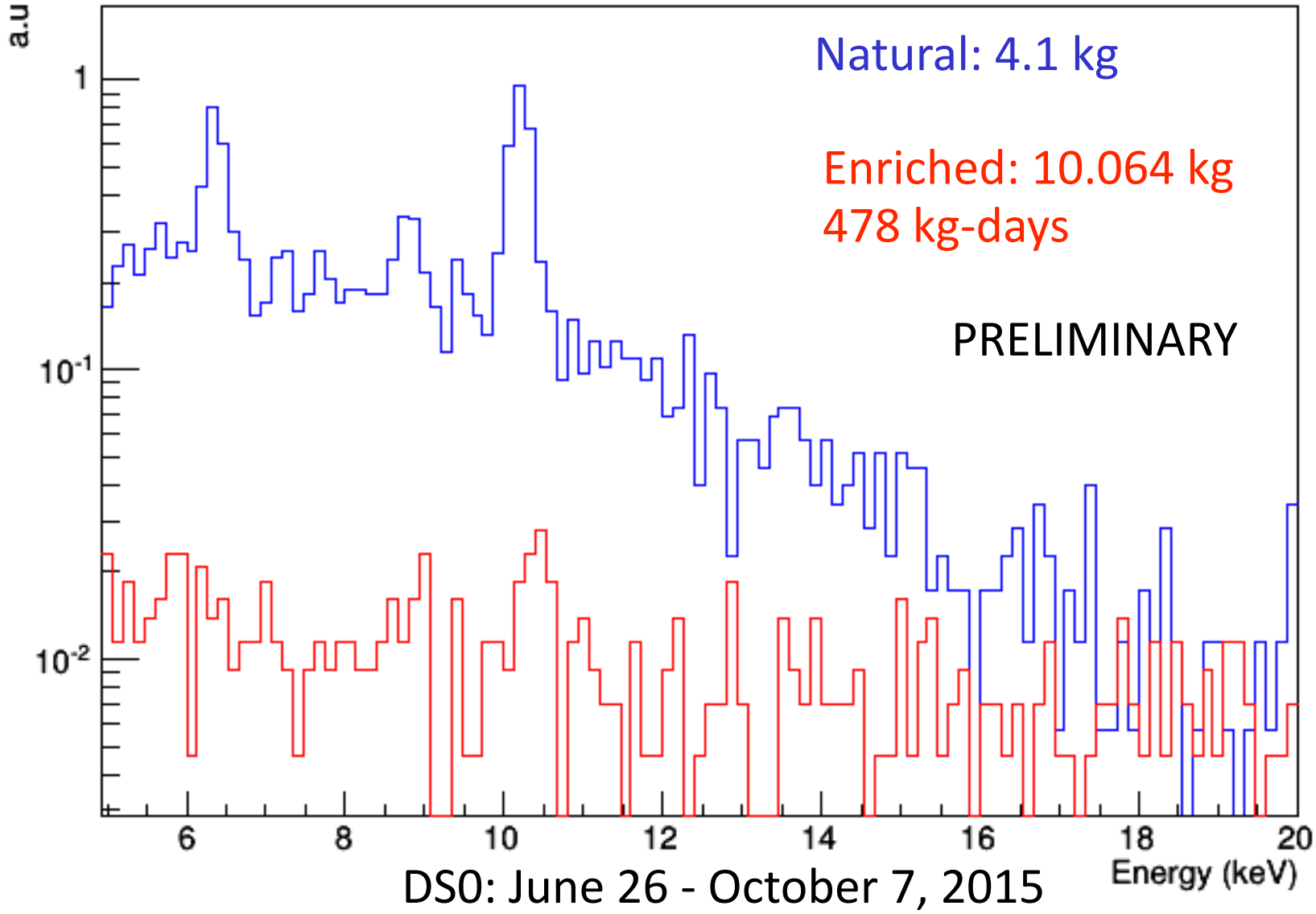
Low-Energy Spectrum Commissioning Data

DS0: June 26 - October 7, 2015



Low-energy spectrum (log scale)

Significant reduction in low-E background in enriched detectors!



DS0: June 26 - October 7, 2015

Upcoming Results

Limits to be presented in upcoming papers

- Pseudoscalar dark matter coupling, g_{Ae}
- Vector dark matter coupling, α'/α
- 14.4 keV solar axion, g_{AN}^{eff} x g_{Ae}
- 11.1 keV electron decay
- 10.6 keV Pauli Exclusion violating decay

Production rate of Tritium and other isotopes.

Reduction in background and increased exposure will result in more stringent limits soon

Systematic Considerations

Energy calibration

- ^{228}Th source + zero-point noise measurement

Resolution

- Fit resolution curve from sources, zero-point noise measurement

Cut acceptances

- Measured from external pulser data

Quantification of systematics nearly complete

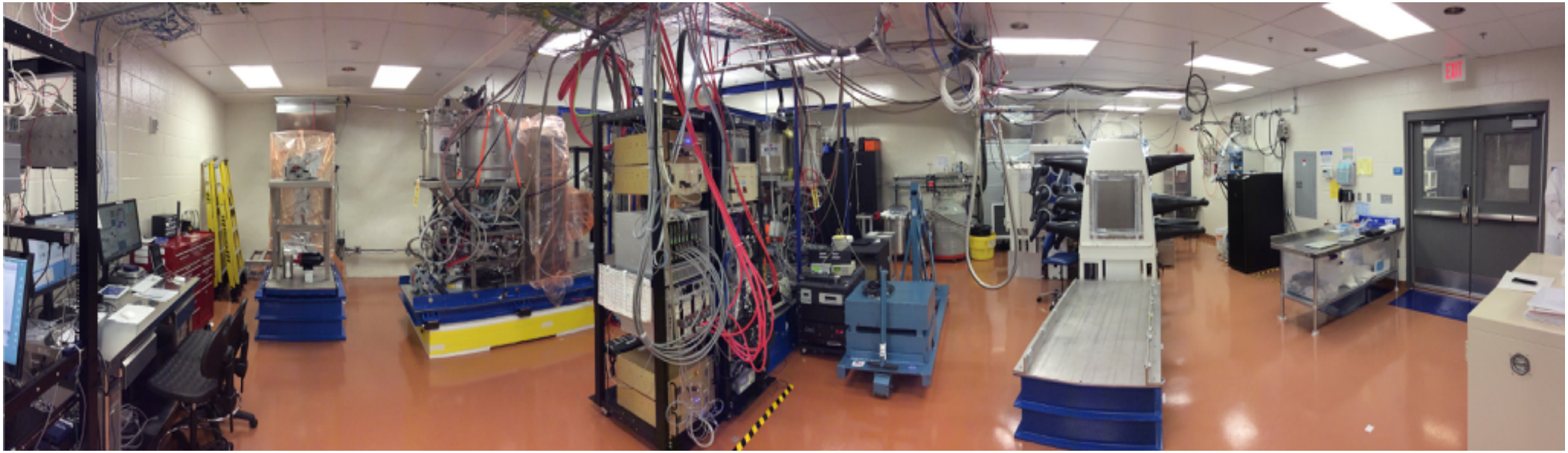
MAJORANA DEMONSTRATOR Progress

Goal: - Demonstrate backgrounds needed for a tonne scale 0νββ experiment.
- 5 year run (108 kg-years): $T_{1/2} > 1.6\ 10^{26}$ years (90 % CL)
$T_{1/2} = 4.3\ 10^{25}$ years (5σ discovery)

Configuration: - 44-kg of Ge detectors, in two independent cryostats
- 29 kg of 87% enriched ^{76}Ge crystals; 15 kg of ^{nat}Ge, P-type point-contact detectors

Module One: - installed in-shield and taking low background data since January 2016.
- end-to-end analysis underway from July - Oct. 2015 dataset to shake down data cleaning and analysis tools (relatively insensitive because of partial shielding) .
- expect to have first background information from 2016 run in the summer.

Module Two: - construction and assembly proceeding on schedule, in-shield commissioning started ~ May 2016



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