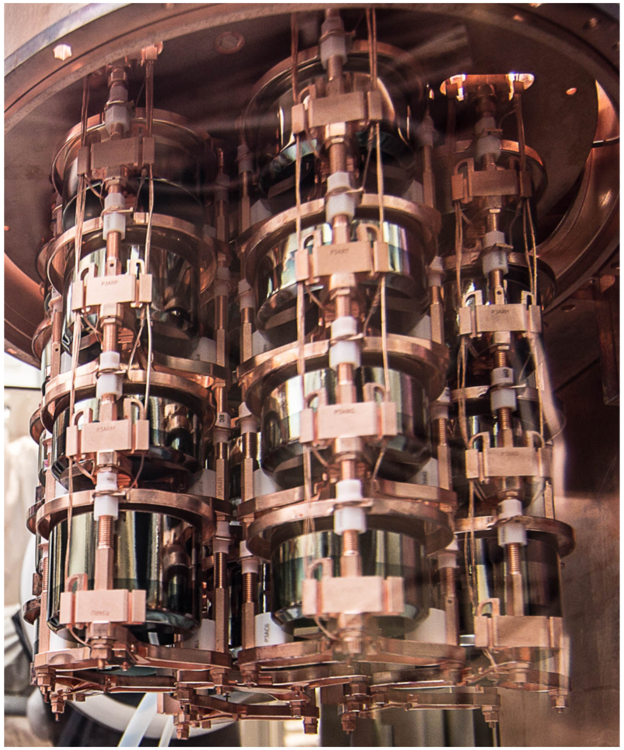
Background results from the MAJORANA DEMONSTRATOR



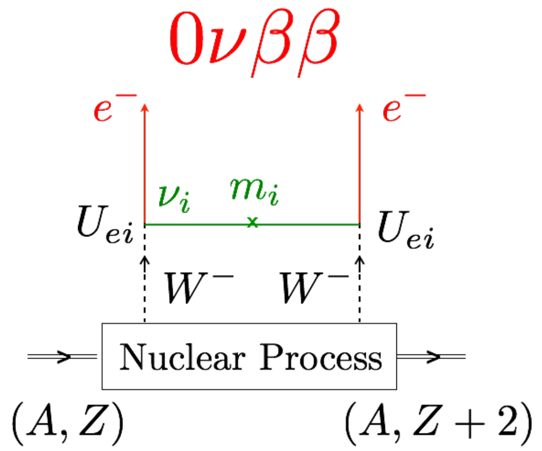
Jason Detwiler, UW / CENPA

CNNP2017, Catania, Italy

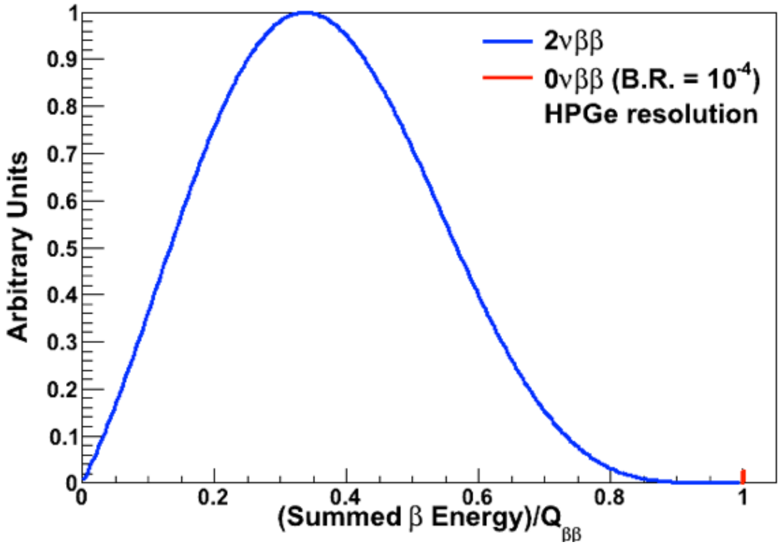
October 19, 2017

Neutrinoless Double-Beta Decay

- Neutrino mass requires BSM physics
  - Dirac mass: new particle N_R and/or extra-small Higgs coupling
  - Majorana mass: new unrenormalizable mass mechanism
- Motivation for Majorana neutrinos
  - L violation
  - “Minimally” non-renormalizable
  - Emerge “naturally” from GUTs (seesaw mechanism)
  - “Predicted” by leptogenesis
- Only feasible detection method: 0νββ decay



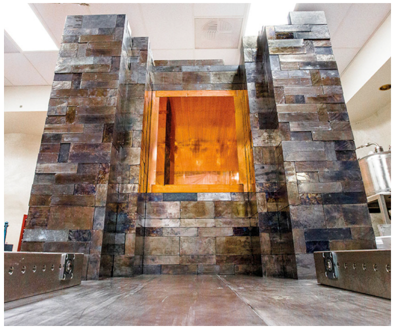
$$\Gamma^{0\nu}_{1/2} = G^{0\nu}|M^{0\nu}|^2 \left| \sum_{i=1}^{3} U_{ei}^2 m_i \right|^2$$



^{76}Ge Double-Beta Decay Searches

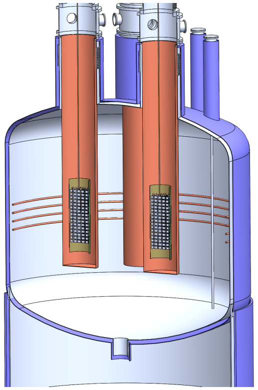
Advantages of Ge

- Intrinsic high-purity Ge detectors = source
- Excellent energy resolution: approaching 0.1% at 2039 keV
- Demonstrated ability to enrich from 7.44% to ≥87%
- Powerful background rejection: multiplicity, timing, pulse-shape discrimination



MAJORANA
Compact configuration: Vacuum cryostats in a passive graded shield with ultra-clean materials

GERDA
Direct immersion in active LAr shield



LEGEND
Combine best techniques of MAJORANA and GERDA

The MAJORANA Collaboration

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Matthew Busch

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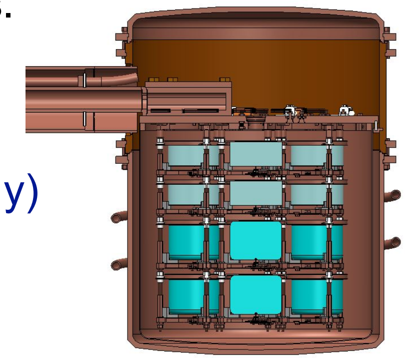
Yuri Efremenko, Andrew Lopez

University of Washington, Seattle, Washington
Sebastian Alvis, Micah Buuck, Clara Cuesta, Jason Detwiler, Julieta Gruszko, Ian Guinn, Walter Pettus, Nick Ruof

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.



Operating underground at 4850' Sanford Underground Research Facility

Background goal in the $0\nu\beta\beta$ peak after analysis cuts: 2.5 counts/(FWHM t y)
Projected backgrounds based on assay results: ≤ 2.2 counts(FWHM t y)

44.1-kg of Ge detectors

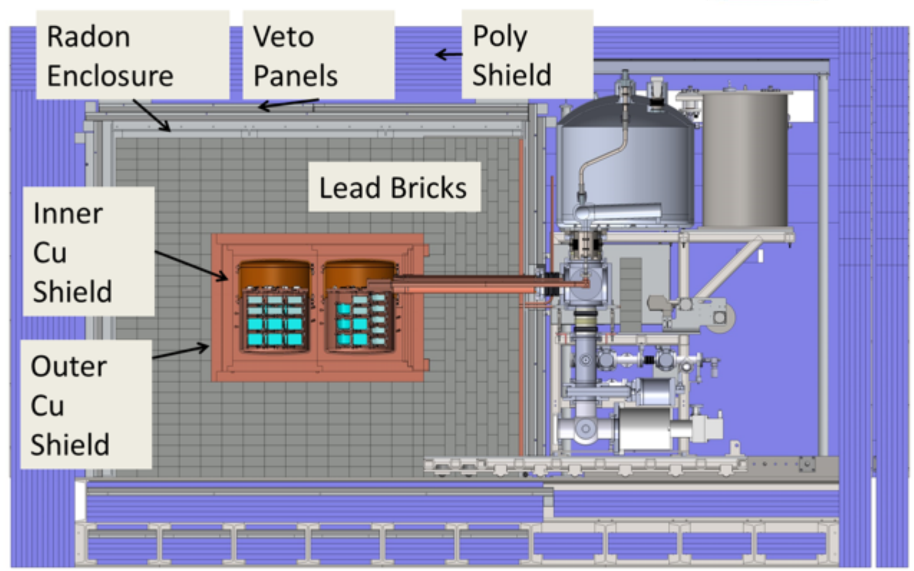
- 29.7 kg of 87% enriched ^{76}Ge crystals
- 14.4 kg of ^{nat}Ge
- Detector Technology: P-type, point-contact.

2 independent cryostats

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

Compact Shield

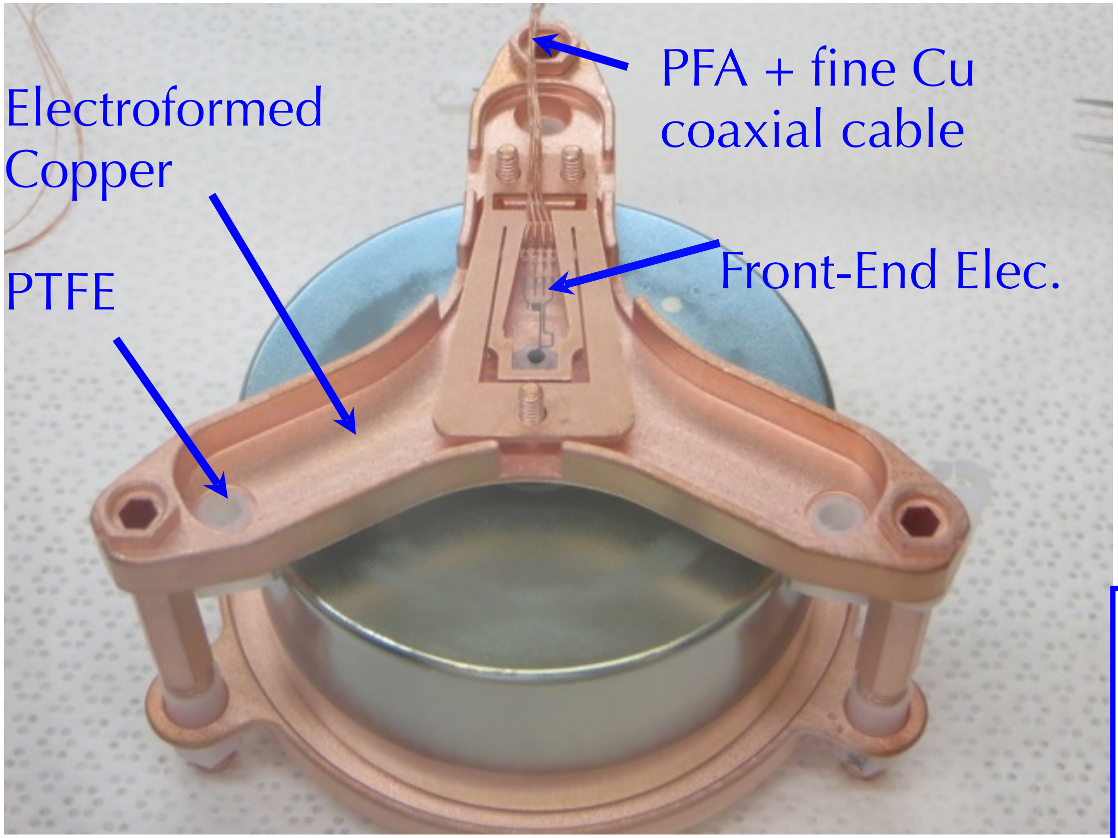
- low-background passive Cu and Pb shield with active muon veto

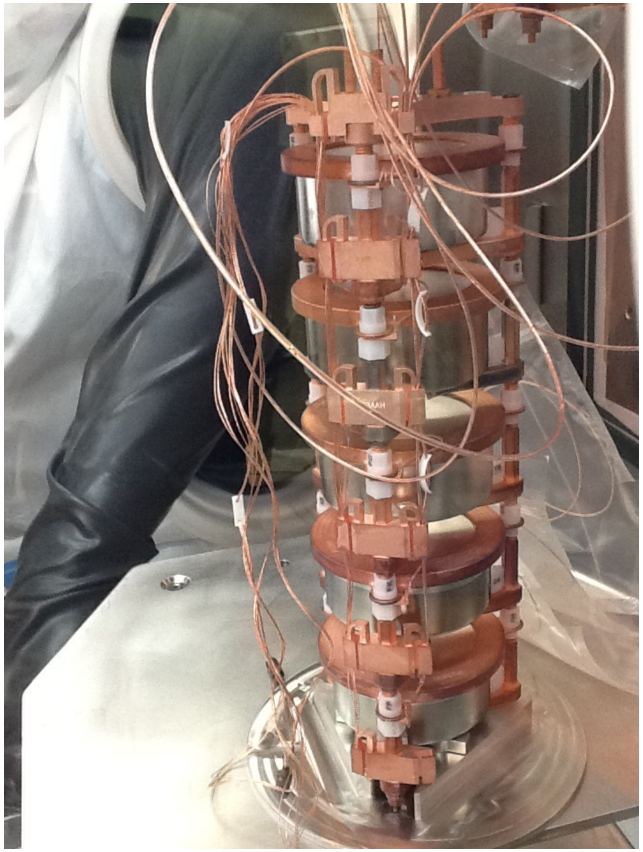


N. Abgrall *et al.*, Adv. High Ener. Phys. **2014**, 365432 (2014)

Assembled Detector Unit and String

AMETEK (ORTEC) fabricated enriched detectors.
35 Enriched detectors at SURF 29.7 kg, 88% ^{76}Ge.
20 kg of modified natural-Ge BEGe (Canberra) detectors in hand (33 detectors UG).

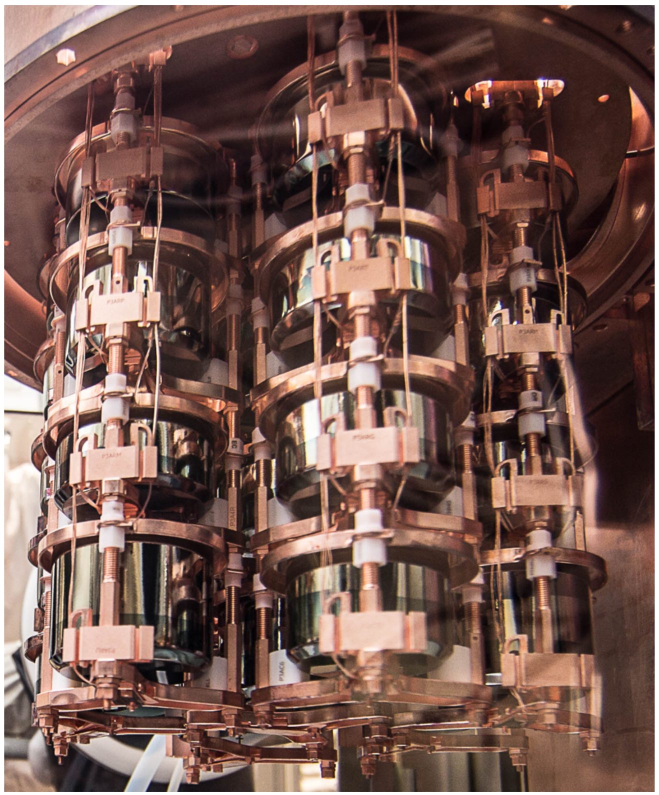




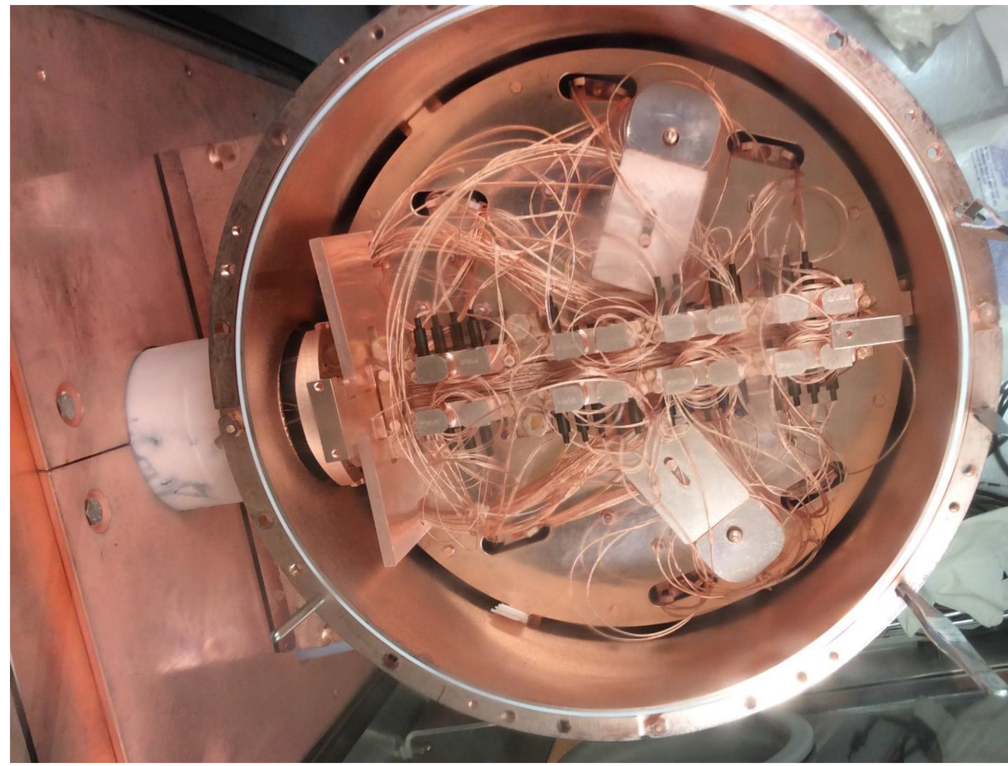
All detector assembly performed in N_2 purged gloveboxes.
All detectors' dimensions recorded by optical reader.

Module Assembly

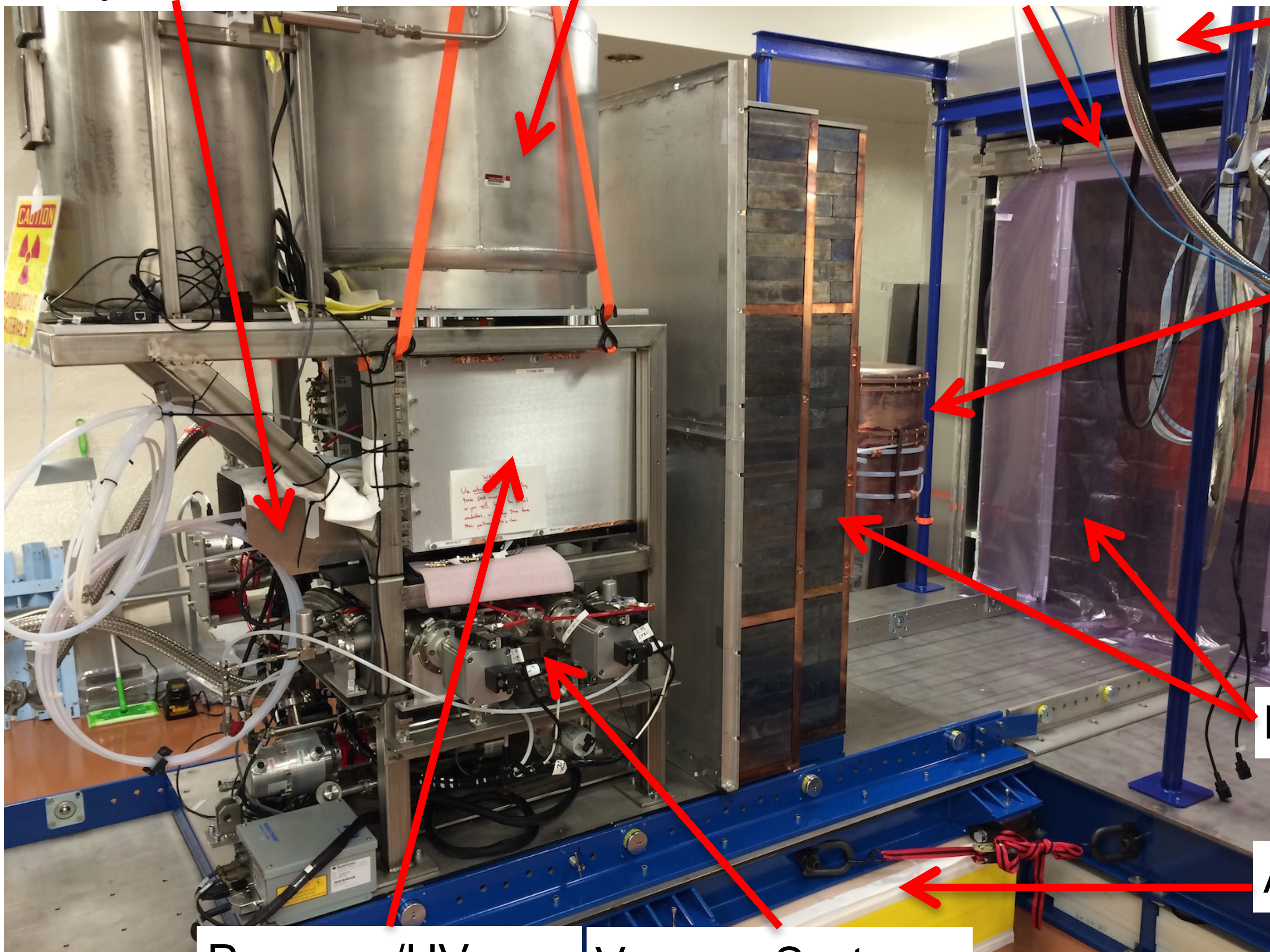
Module 1 array in glovebox



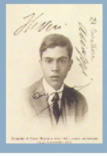
Cable management…

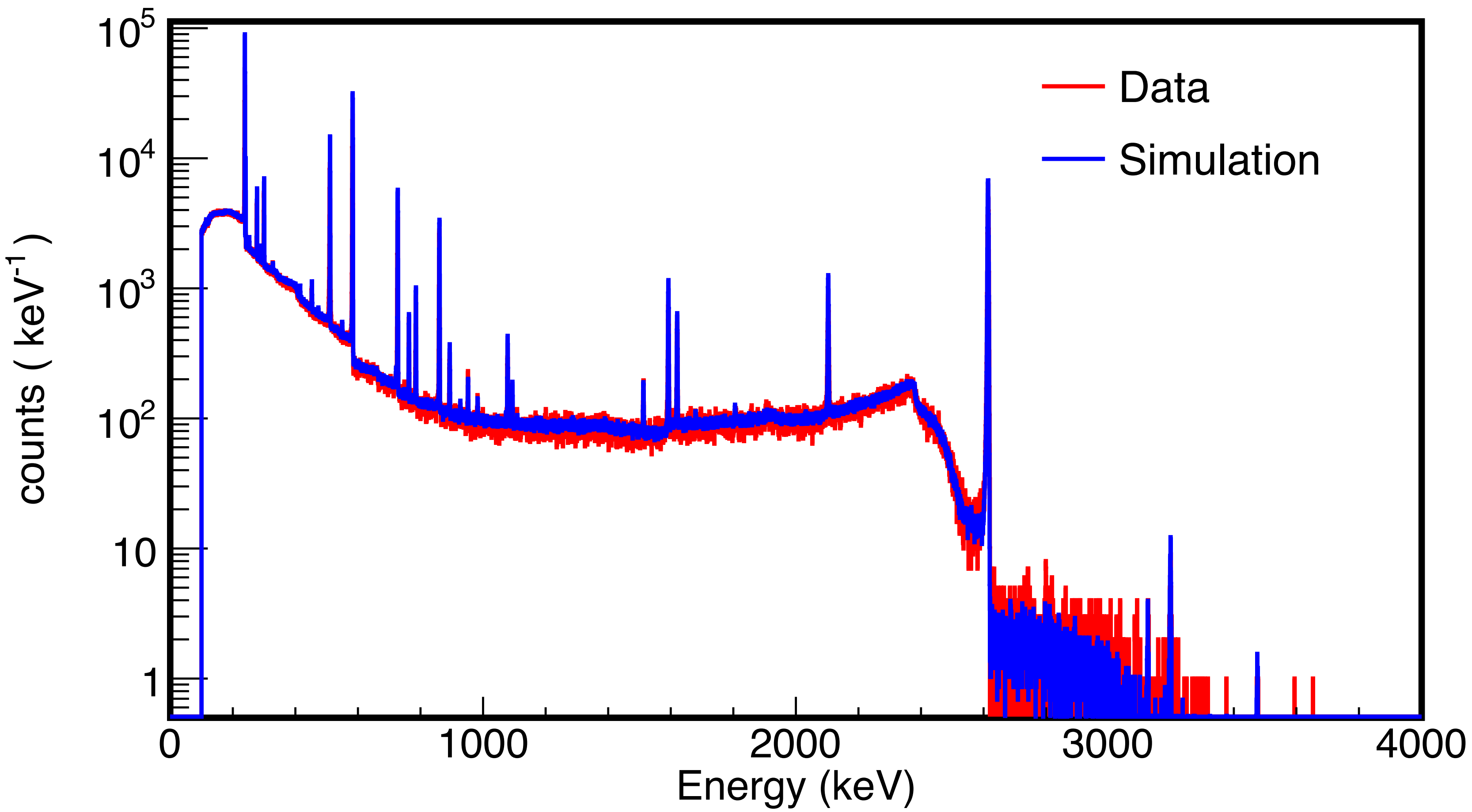


Module and Shield Details



^{228}Th Calibration & Simulation

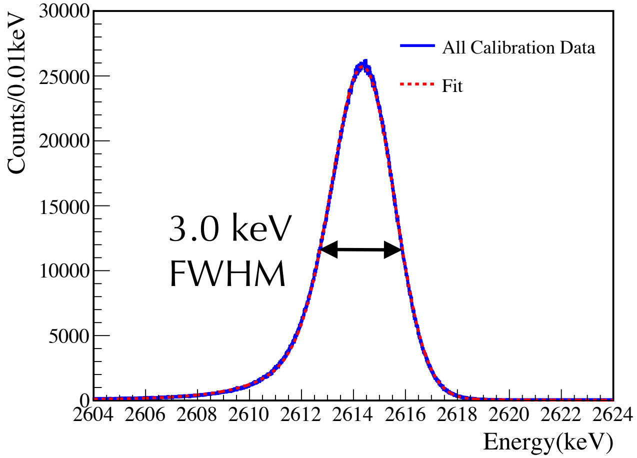




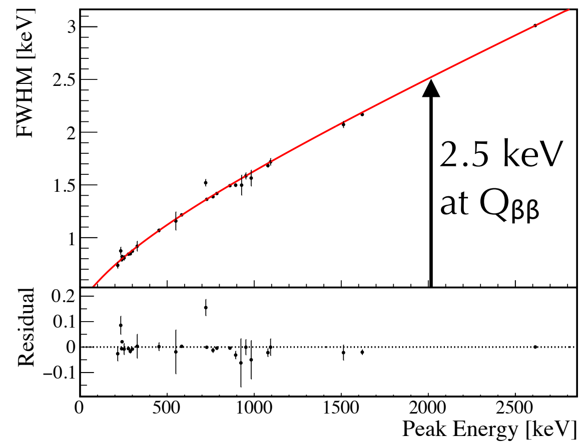
NIMA **872**, 16 (2017)

Energy Performance

^{208}Tl 2615 keV Peak

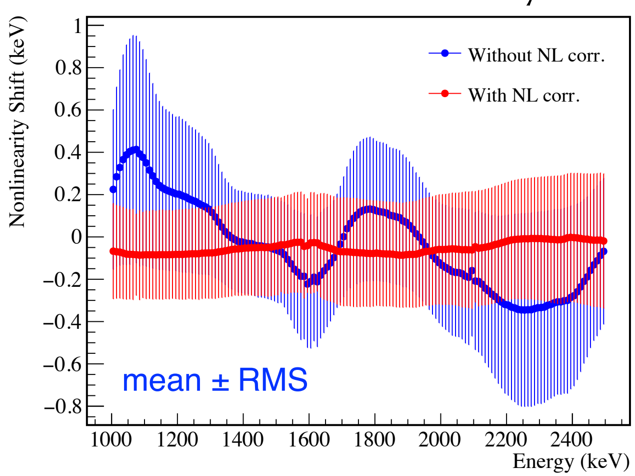


FWHM(E)

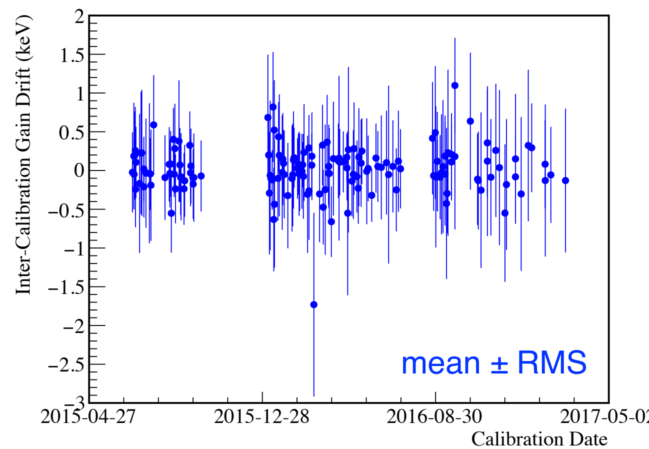


Best ever for 0νββ searches!

ADC Non-Linearity

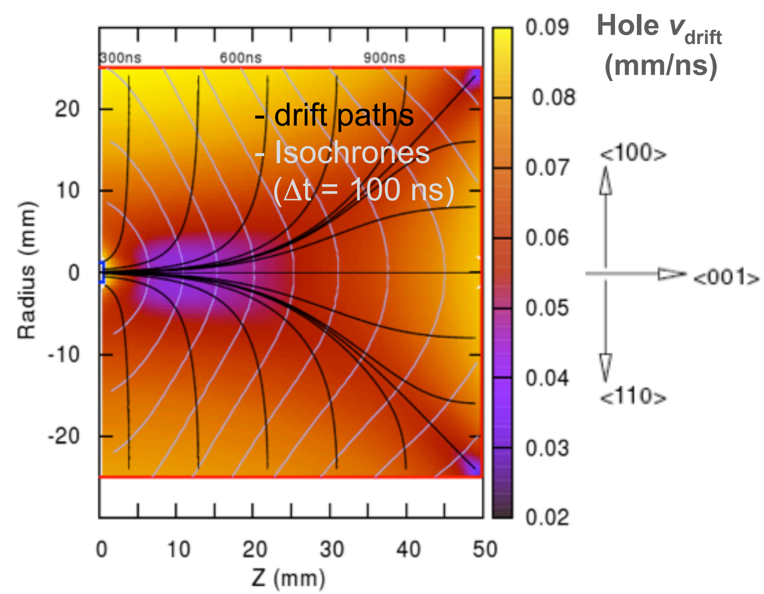


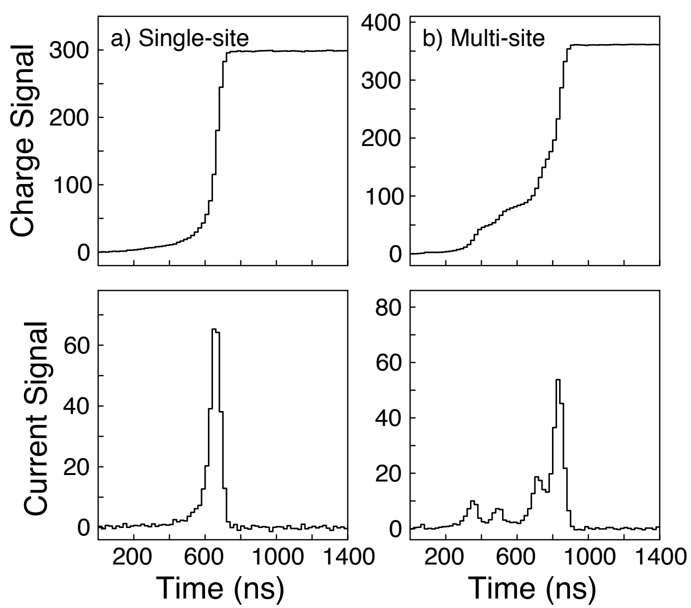
Time Variation

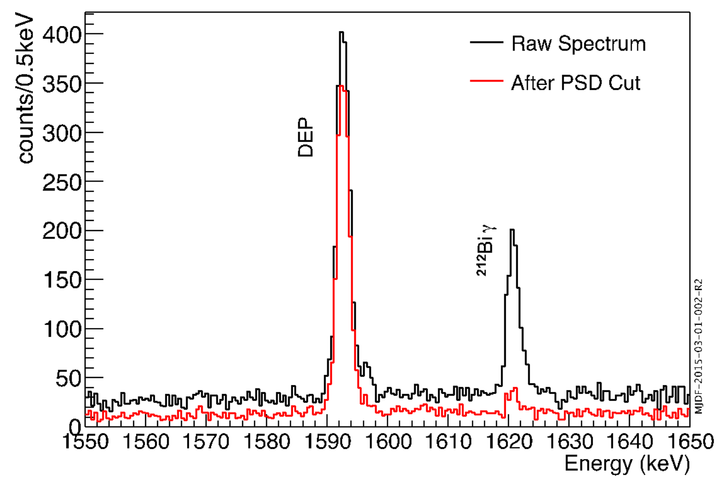


Multi-Site Rejection

- Slow drift + sharply peaked weighting potential near point contact gives step-like response for each interaction site
- Max current (A) varies almost linearly with E for single-site events
- Reject events with anomalously low "AvsE"

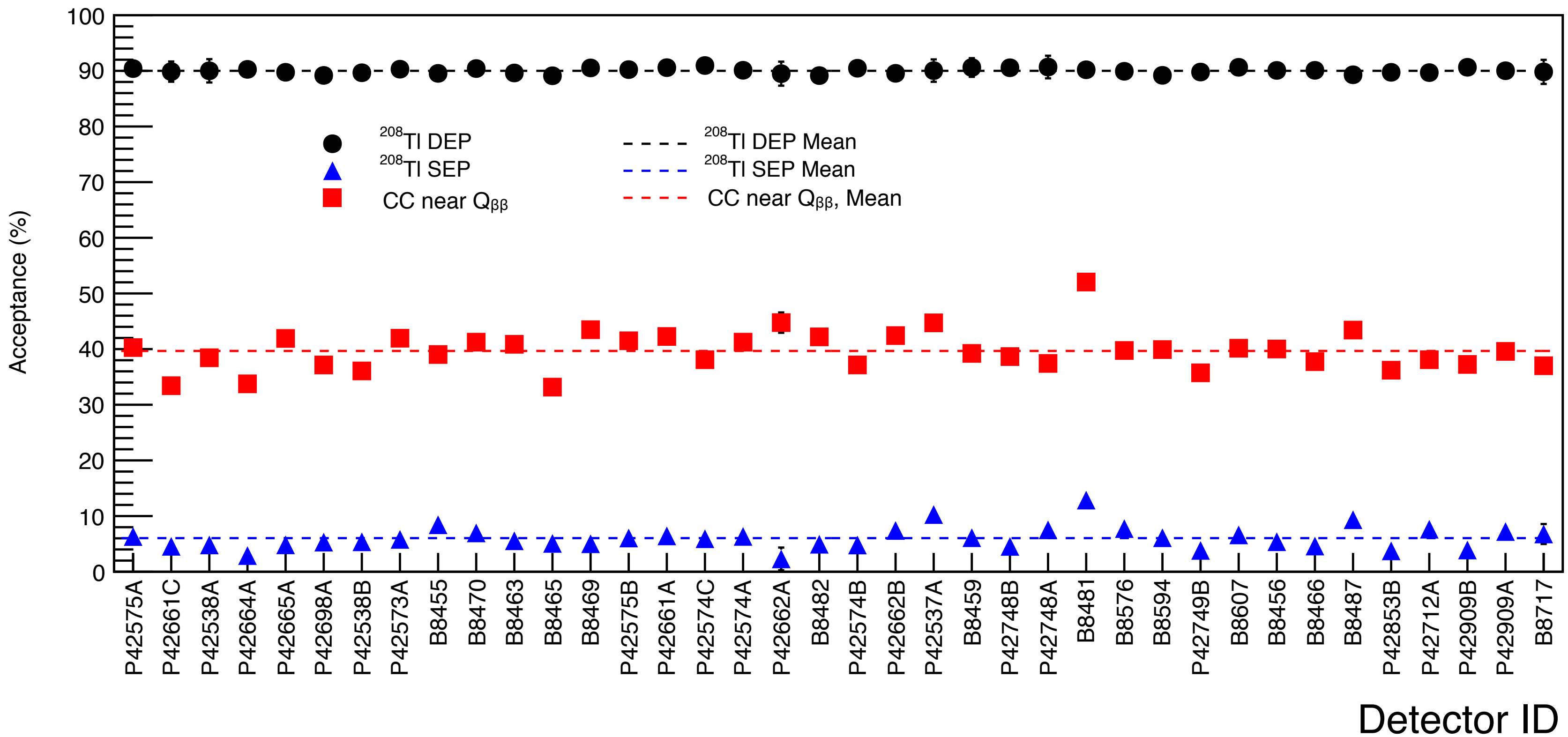






Multi-Site Rejection

- Tune cuts to retain 90% single-site events (0νββ and DEP are single-site)
- Compton continuum near $Q_{\beta\beta}$ reduced by factor >2
- Other gamma lines reduced by a factor of 10-20

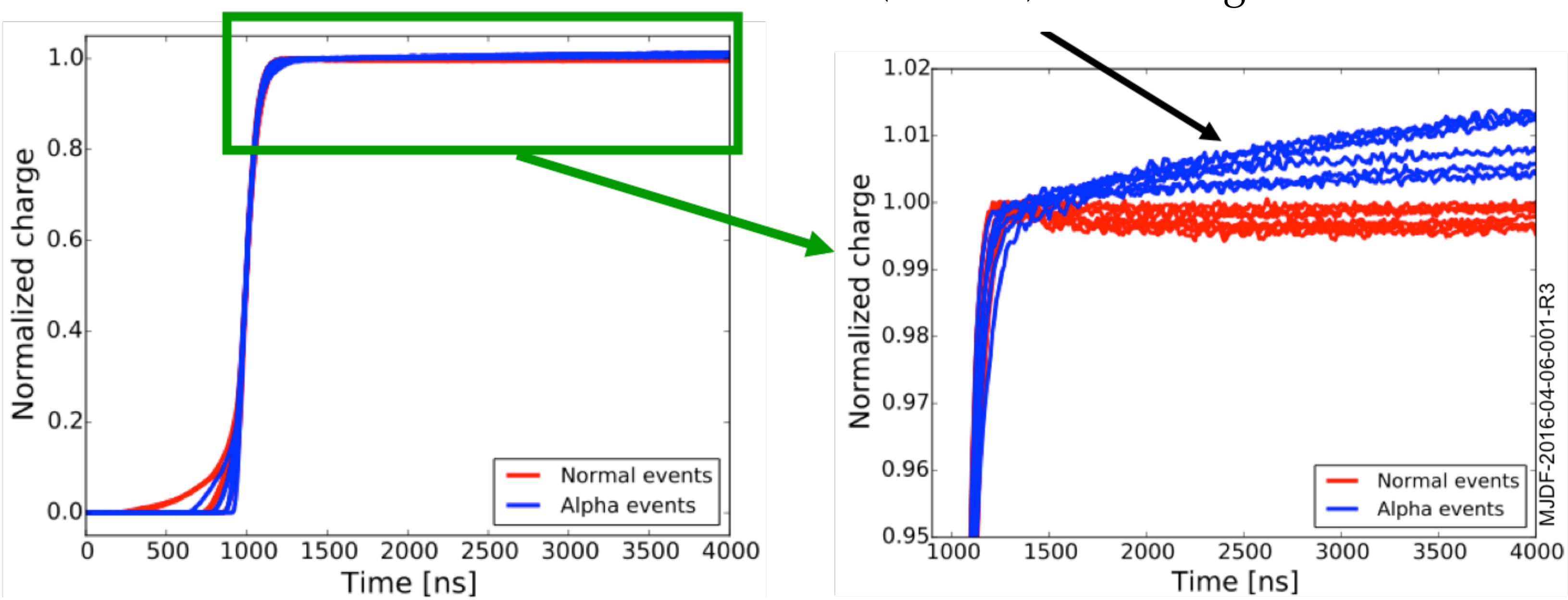


Alpha Rejection: Delayed Charge Recovery

- Alpha background with degraded energies observed, likely from ^{210}Pb-supported ^{210}Po on teflon bushings
- Charge trapped at passivated surface, slowly released into bulk
- Produces a distinctive waveform allowing a high-efficiency cut (99%)

Example pole-zero-corrected waveforms

Alphas have a positive slope (“DCR”) in this region



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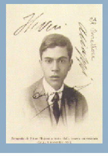

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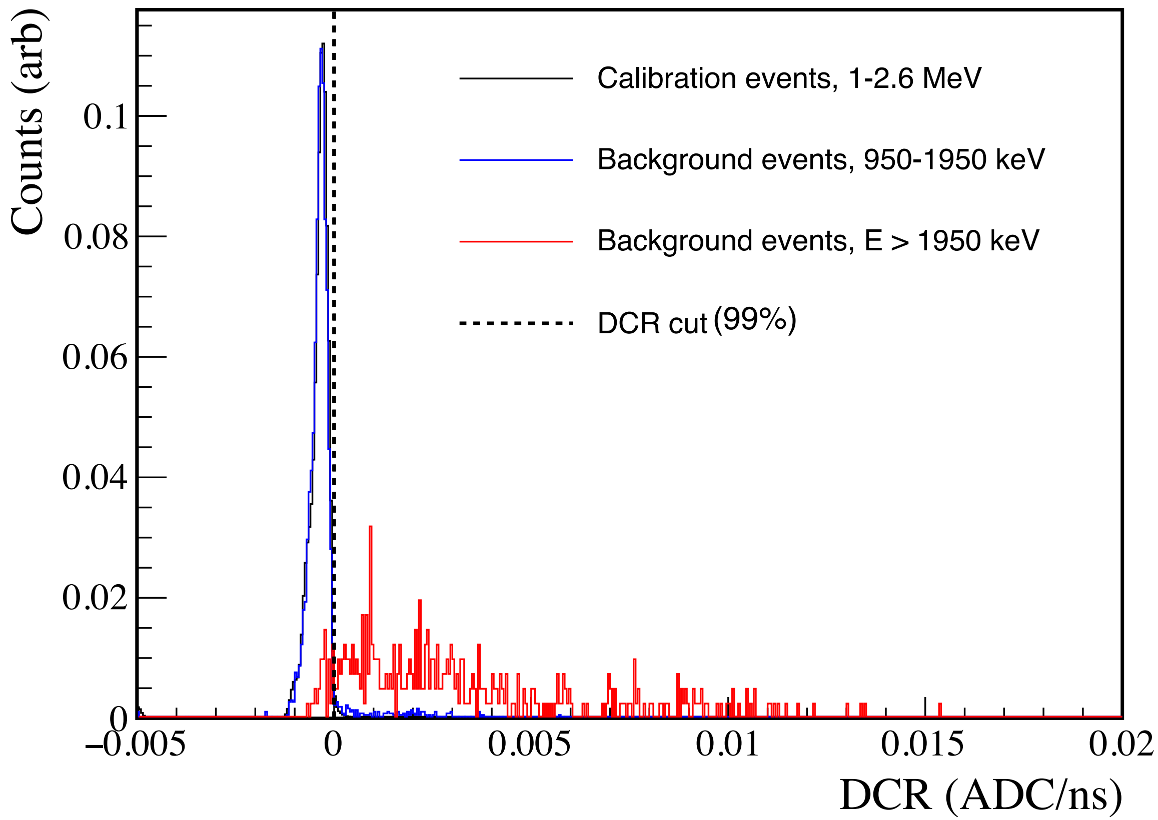
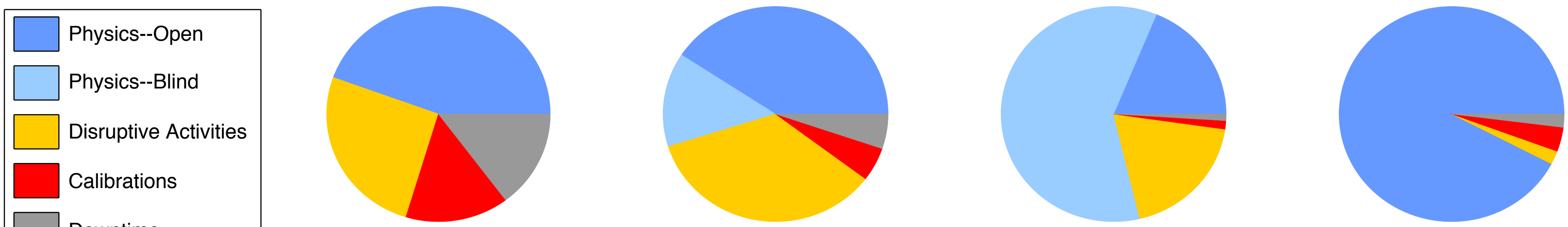


Data Sets and Duty Cycles

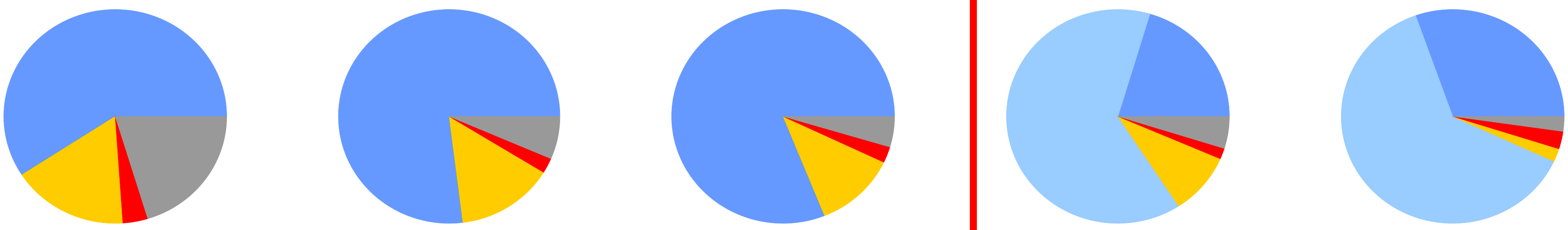


DS0
M1 Commissioning
No Inner Shield
June 26—Oct. 7, 2015

DS1
M1 Inner Shield
Dec. 31, 2015—May 24, 2016

DS2
M1 Multisampling
May 24—July 14, 2016

DS3
Module 1
M1 & M2 Together in-shield
Aug. 25—Sept. 27, 2016



DS4
Module 2
M1 & M2 Together in-shield
Aug. 25—Sept. 27, 2016

DS5a
Module 1&2
Integrated DAQ (high noise)
Oct. 13, 2016—Jan. 27, 2017

DS5b
M1& M2 Optimized Grounding,
10 kg-yr Analysis Cutoff
Jan. 27—Mar. 17, 2017

DS5c
Module 1&2
Blindness Implemented
Mar. 17—May 11, 2017

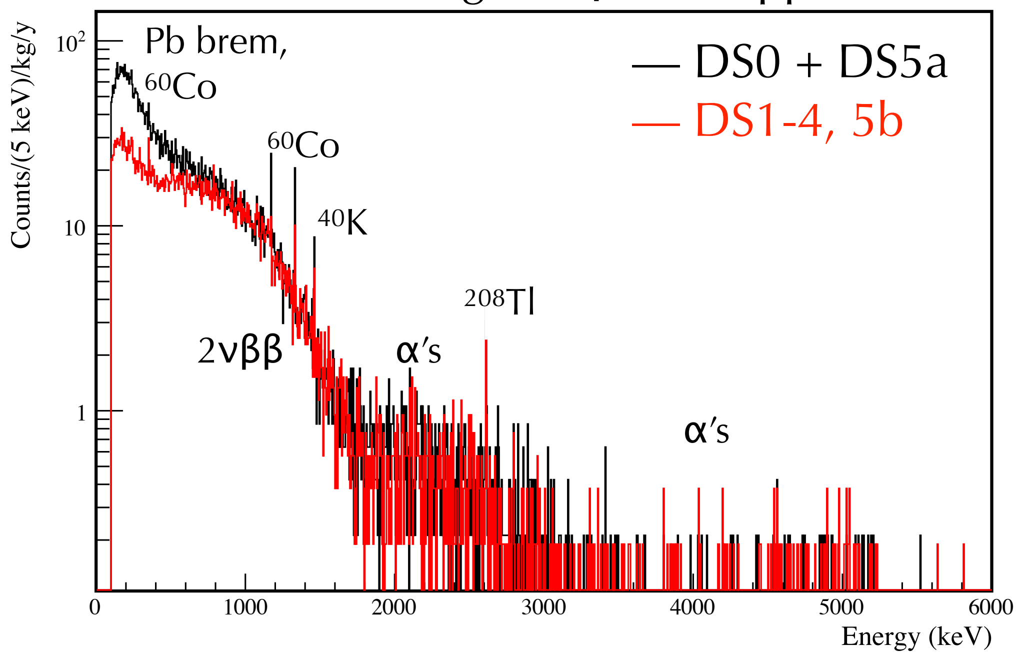
DS6 (ongoing)
M1 & M2 with Multisampling
May 11, 2017—present

These results

Data Sets and Backgrounds

- DS0: no inner copper shield
- DS5a: high electronic noise after DAQ integration until shield completed and proper grounding paths established — degraded PSA
- DS1-4, 5b used to estimate achieved background level
- All DS's effectively BG-free for $0\nu\beta\beta$ search: will use all for limit-setting

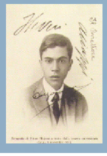
Data cleaning and μ veto applied



Exposure for First Results

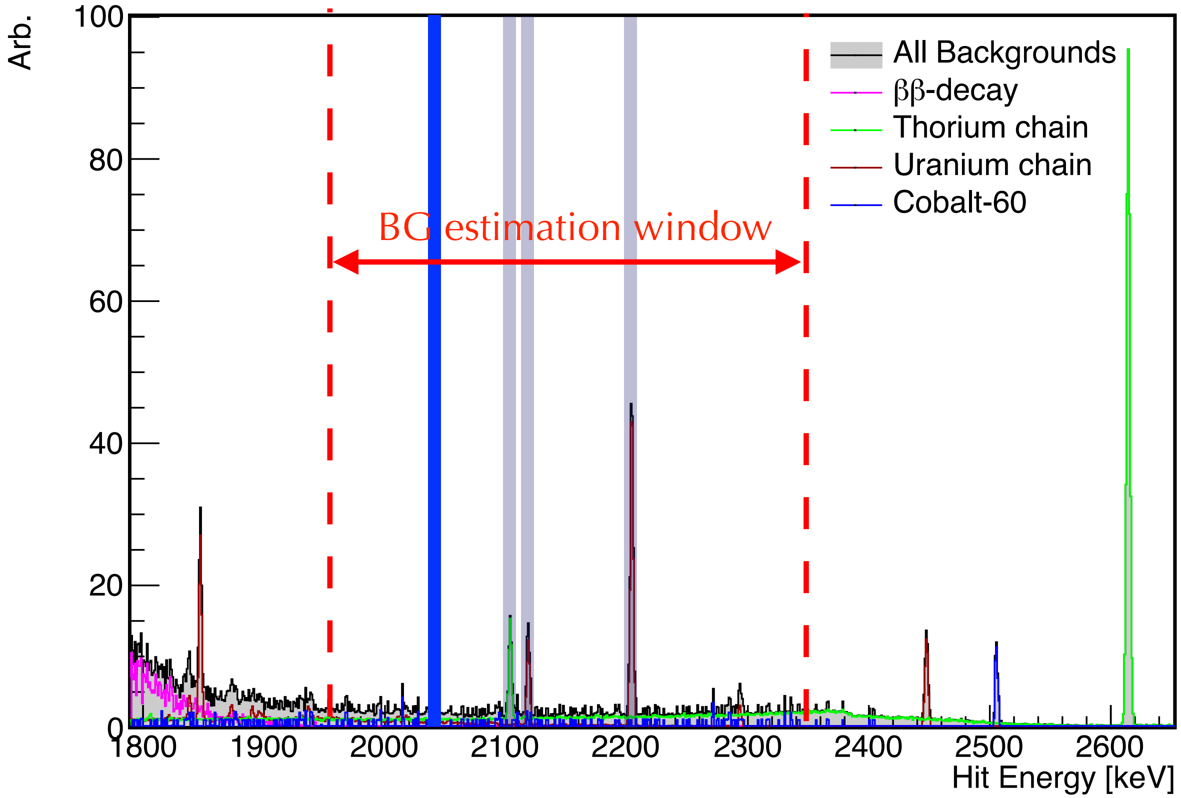
Data Set	Start Date	Hardware Distinction	Active Enriched Mass (kg)	Open Exposure (kg-y)
DS0	June 26, 2015	No Inner Cu Shield	10.69±0.16	1.26±0.02
DS1	Dec. 31, 2015	Inner Shield added	11.90±0.17	1.83±0.03
DS2	May 24, 2016	Multisampling	11.31±0.16	0.29±0.01
DS3	Aug. 25, 2016	M1 and M2 installed	12.63±0.19	1.01±0.01
DS4	Aug. 25, 2016	M1 and M2 installed	5.47±0.08	0.28±0.00
DS5a	Oct. 13, 2016	M1, M2 integrated DAQ	18.44±0.26	3.45±0.05
DS5b	Jan. 27, 2017	Construction Complete	18.44±0.26	1.85±0.03
Total				9.97±0.22
Total	(DS1-4,5b)			5.26±0.17

360 keV Background Window

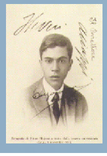


- Simulated background PDFs, relative scaling based on assay results
- Flat between 1950 keV and 2350 keV
- Remove ±5 keV around $Q_{\beta\beta}$ and prominent γ lines
- Use counts in this window to estimate background level at $Q_{\beta\beta}$

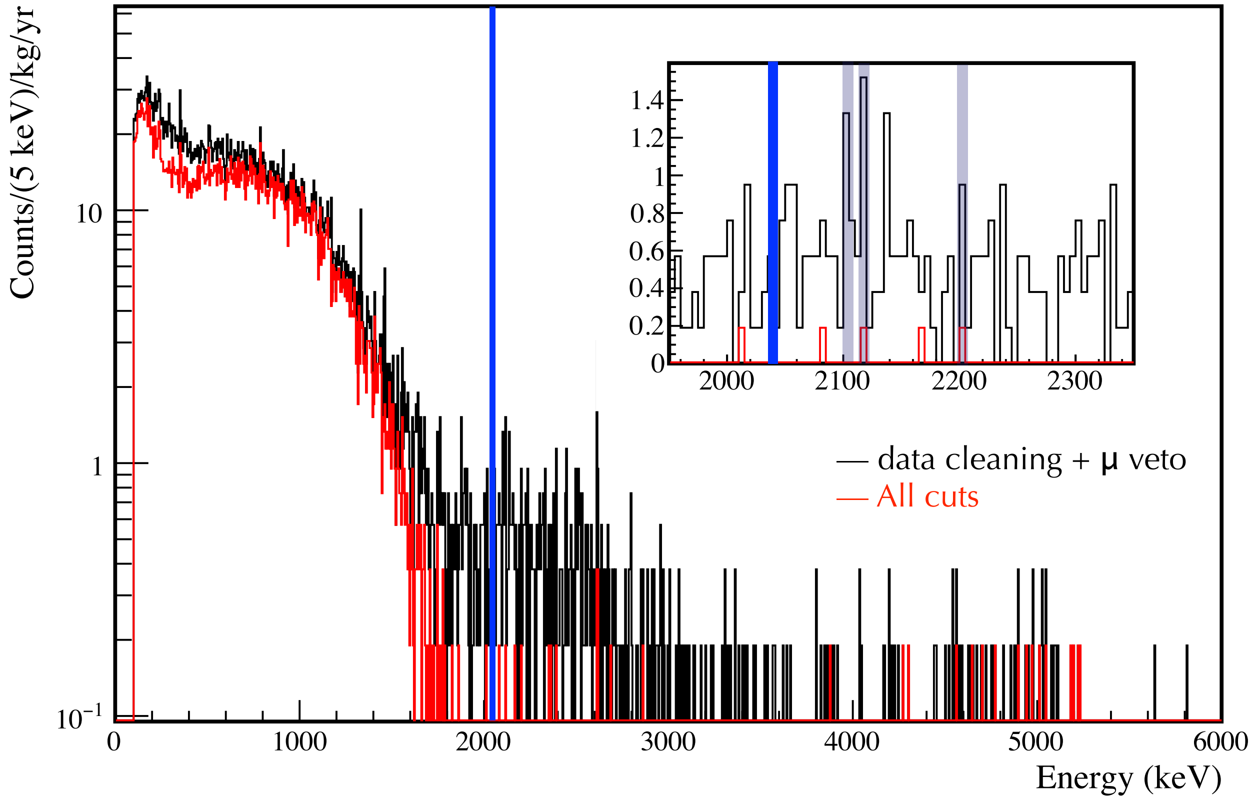
Simulated Background near $Q_{\beta\beta}$ (no cuts)



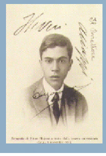
Low-Background Data: DS1-4,5b



- Active Exposure: 5.29 kg y (^{enr}Ge)
- Background after cuts: 3 counts in 360 keV window
- Background rate: $4.0^{+3.0}_{-2.5}$ c/(FWHM t y), $1.6^{+1.2}_{-1.0}$ c/(keV t y)

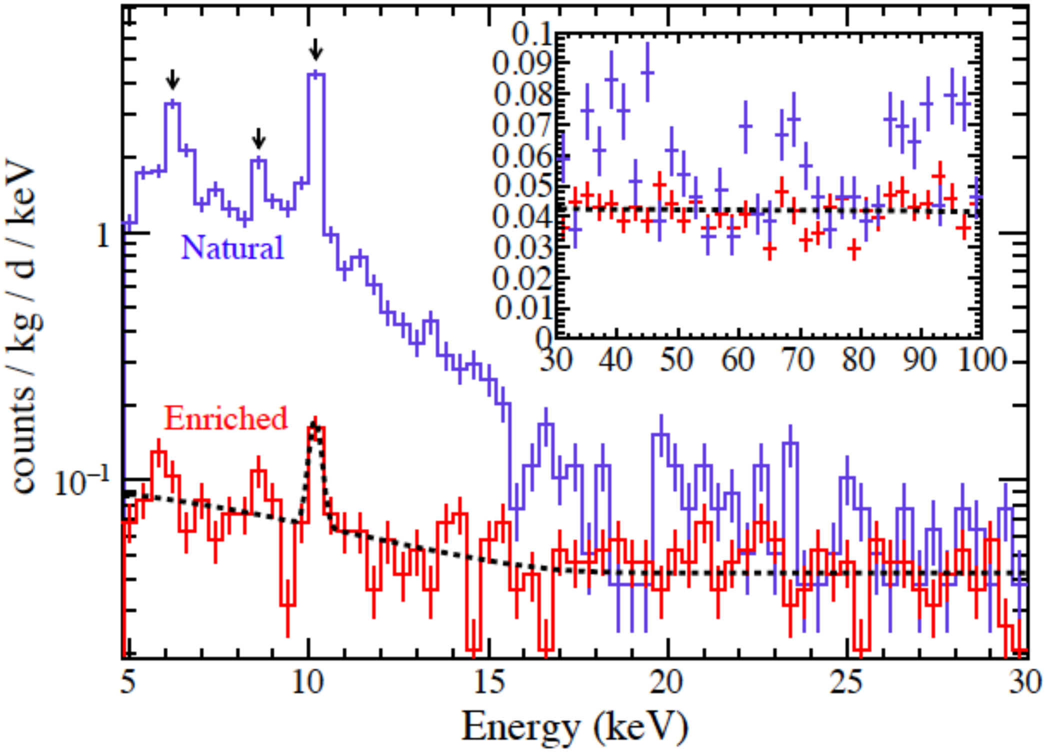


Low-energy spectrum (DS0 only)



- Controlled surface exposure of enriched material: significant reduction of cosmogenics in the low-energy region. Factor of a few better in DS1+.
- Tritium is obvious and dominates in natural detectors below 20 keV.
- Efficiency below 5 keV is under study.

Natural 4.1 kg Enriched 10.06 kg: 478 kg d

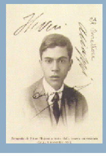


Low-Energy Searches for Physics Beyond SM

- Pseudoscalar dark matter
- Vector dark matter
- 14.4-keV solar axion
- $e^- \rightarrow 3\nu$
- Pauli Exclusion Principle violation

Phys. Rev. Lett. **118**, 161801 (2017).

Low-energy spectrum (DS0 only)



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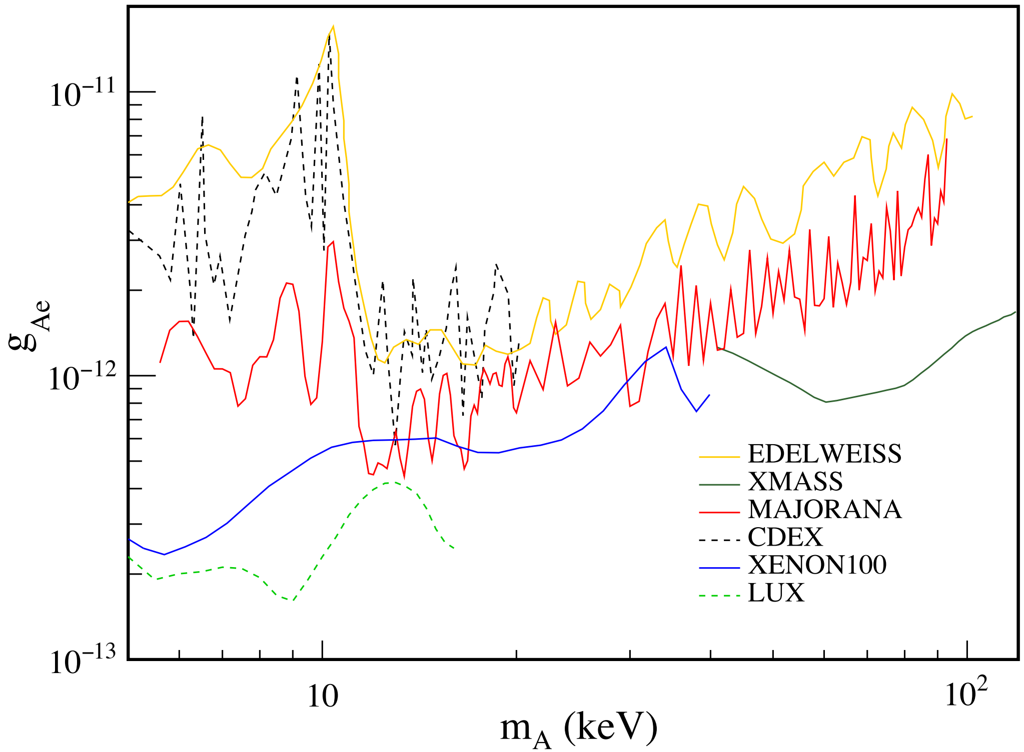

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- Vector dark matter
- 14.4-keV solar axion
- $e^- \rightarrow 3\nu$
- Pauli Exclusion Principle violation

Phys. Rev. Lett. **118**, 161801 (2017).

Summary and Outlook

- MAJORANA DEMONSTRATOR construction complete, now stably taking data. Have achieved record energy resolution at $Q_{\beta\beta}$ and excellent PSA performance.
- First $0\nu\beta\beta$ results to appear on arXiv soon based on 10 kg-yr exposure. Achieved background level is consistent with our original goal and with GERDA's record low BG.
- Low background + low threshold allows for broad physics program, many analyses in preparation — stay tuned!