RARE LOW-ENERGY EVENT SEARCHES WITH THE MAJORANA DEMONSTRATOR

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On behalf of the MAJORANA Collaboration

TAUP 2017
Sudbury, Ontario
25 July, 2017

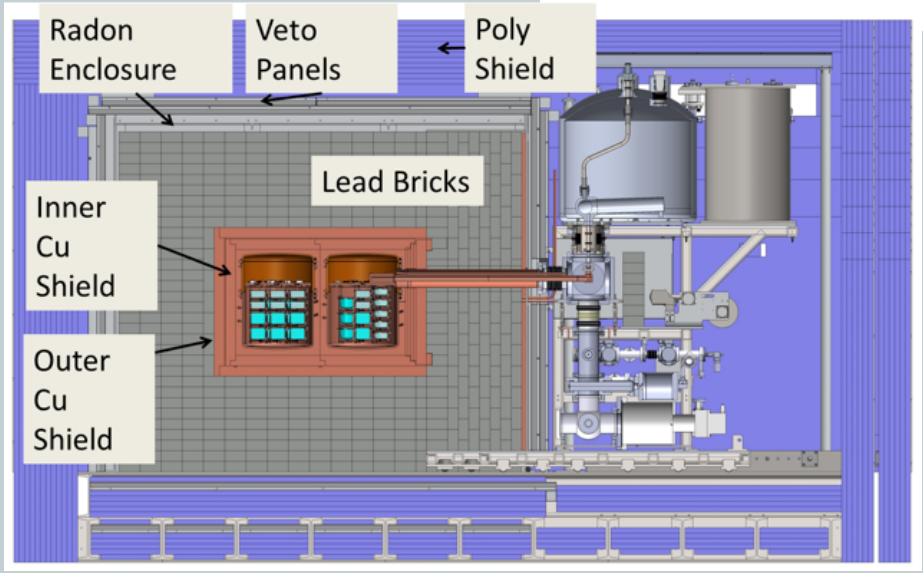
THE MAJORANA DEMONSTRATOR

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
- ❖Best energy resolution of any 0νββ experiment (2.4 keV FWHM at 2039 keV).
- ❖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 ≤ 3.5

- ❖44.1-kg of Ge detectors
  - 29.7 kg of 88% 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

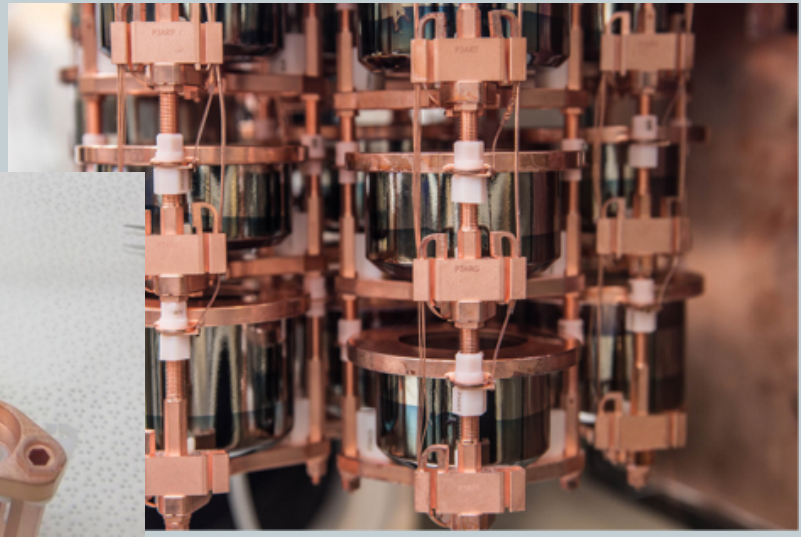


N. Abgrall et al. (Majorana Collaboration), Advances in High Energy Physics, 2014, 1 (2014).

THE MAJORANA LOW-ENERGY PROGRAM

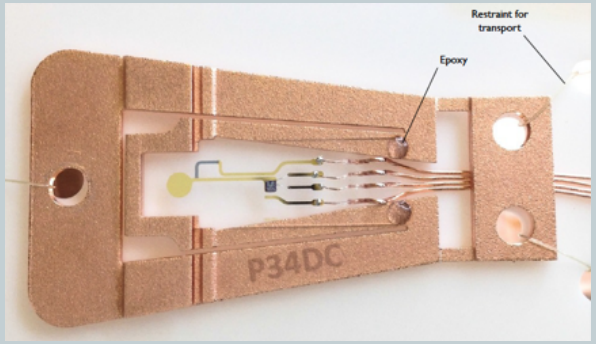
- **Low Energy program is interested in analysis of events in the energy region 1 keV - 100 keV**
- **MAJORANA PPC HPGe detector advantages:**
  - Sub-keV energy thresholds possible (< 500 eV)*
    *(Data for results shown has 5 keV threshold)
  - Excellent energy resolution (< 250 eV)
  - Ultra-low background components, including underground electroformed Cu
  - Reduced cosmogenic activation in our enriched detectors from exposure control

Modules 1 & 2 in Pb and Cu shielding



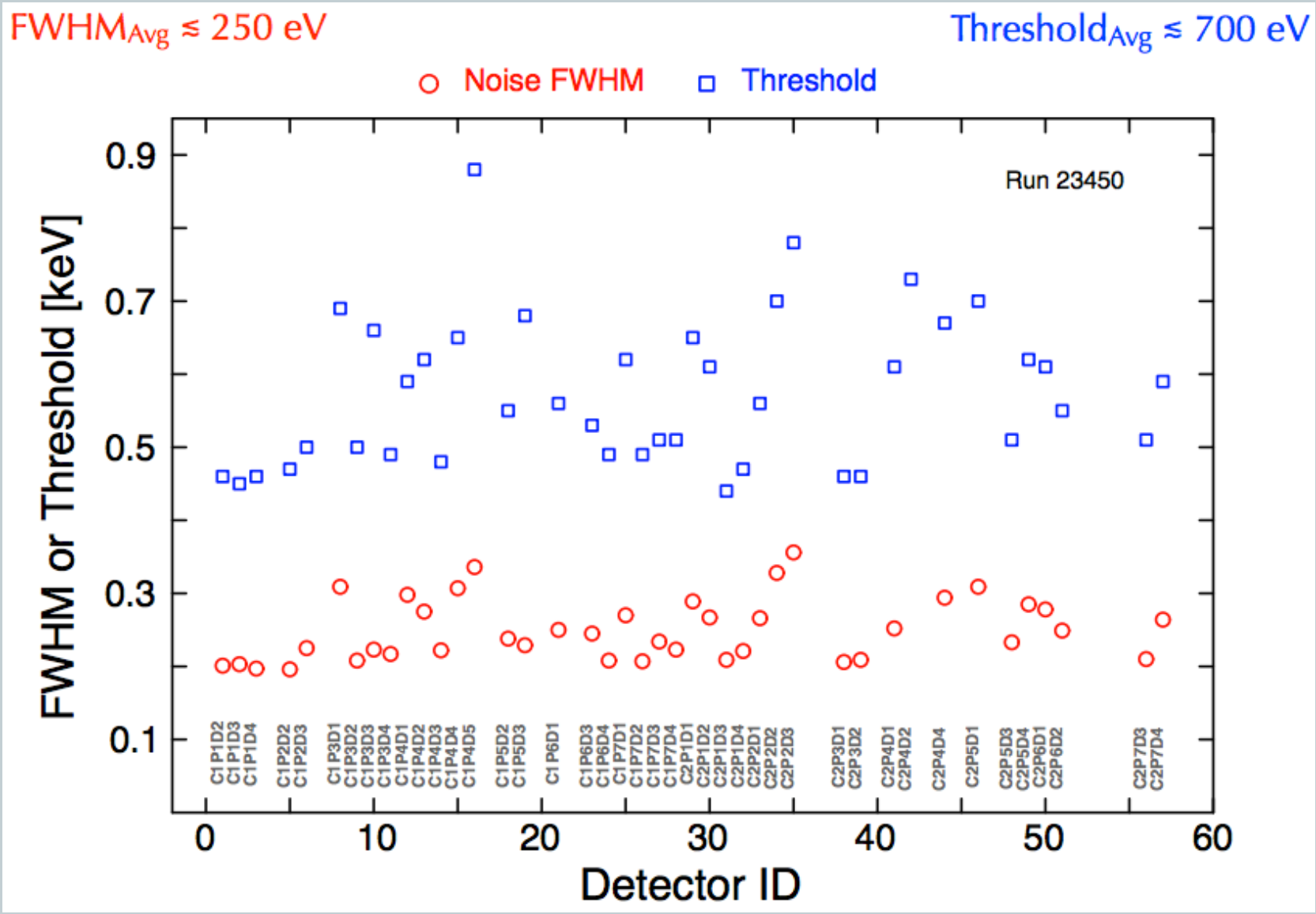
Detector Strings

Detector Module



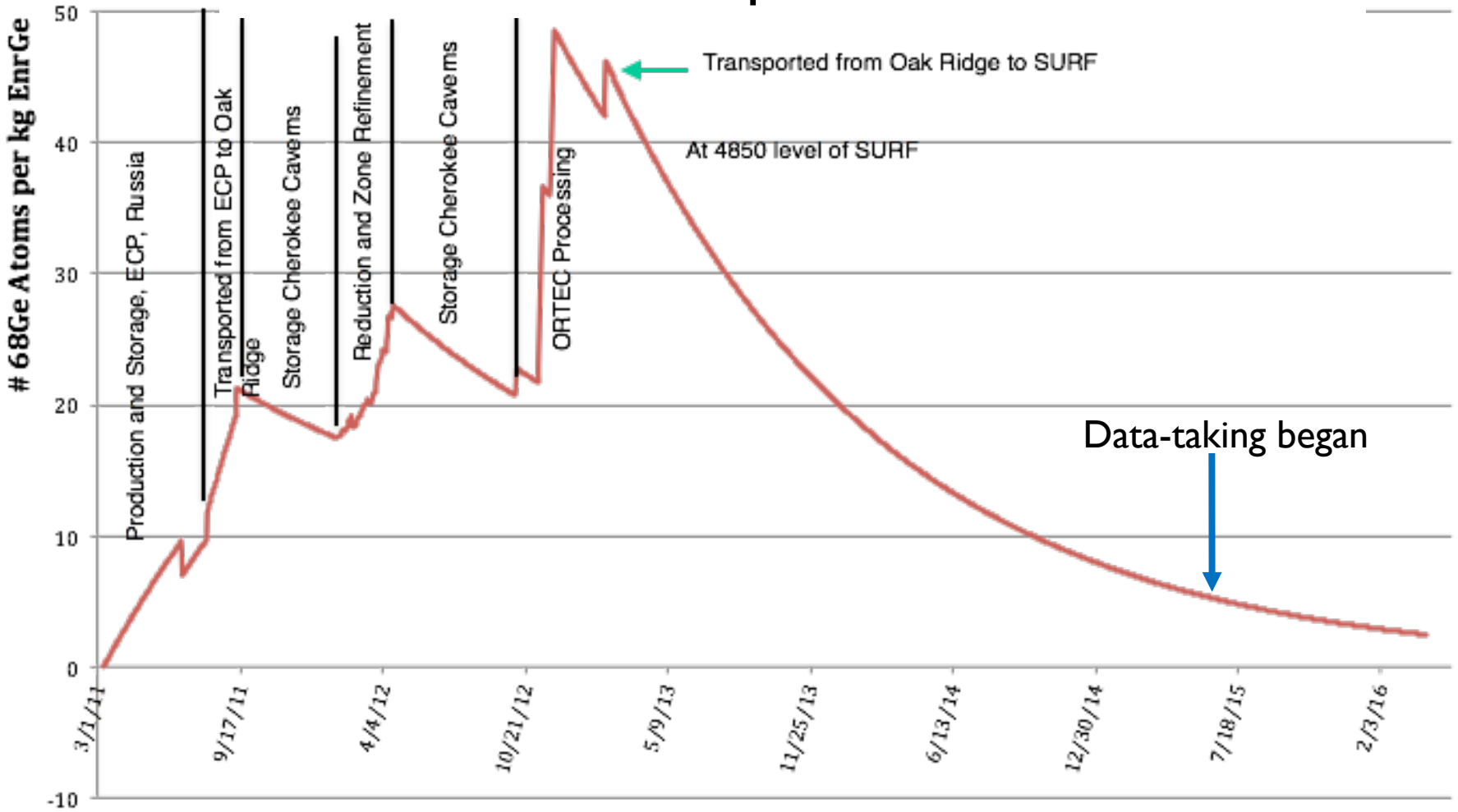
Low-Mass Front-End

SUB-keV THRESHOLDS AND EXCELLENT ENERGY RESOLUTION



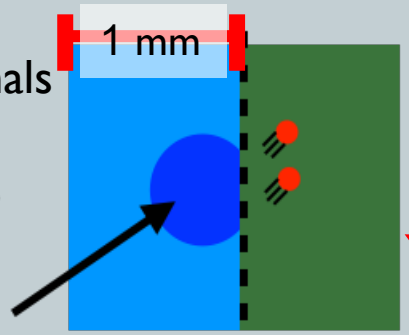
REDUCING ENRICHED Ge COSMOGENIC ACTIVATION

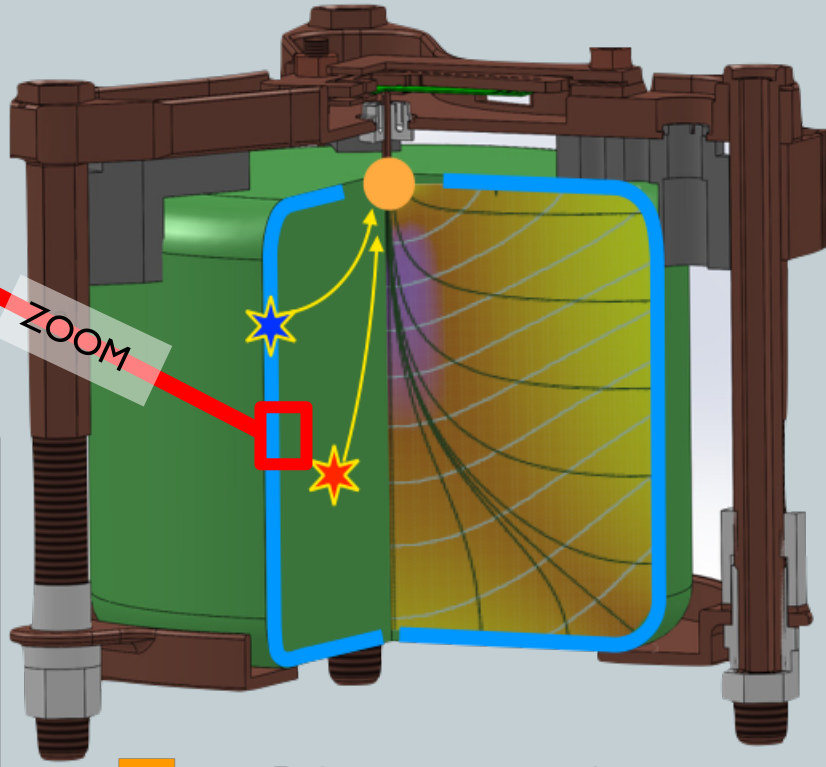
One detector example: ^{68}Ge contamination



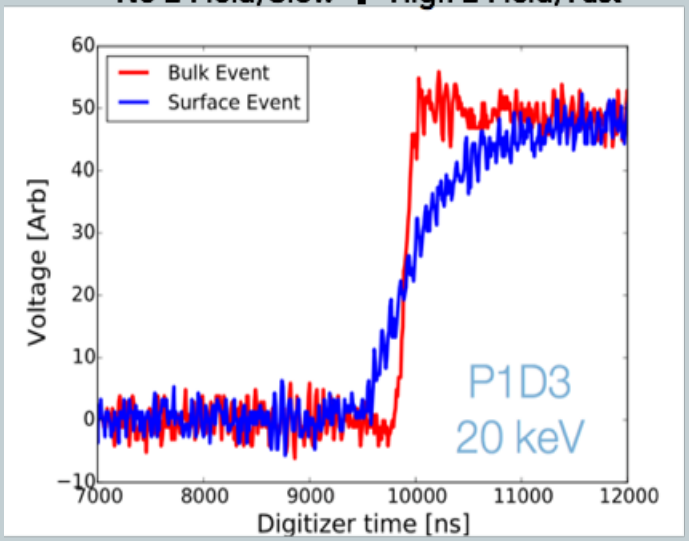
SIGNALS IN PPC HPGE DETECTORS

- "Surface" (Li layer) signals are from the *fraction* of charge that diffuses into the active region.





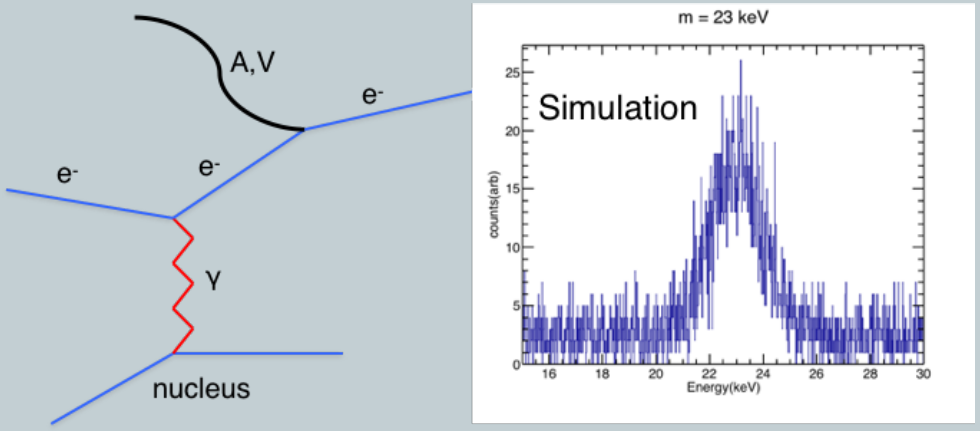
- Slow pulses are a significant background at energies below 30 keV [1]



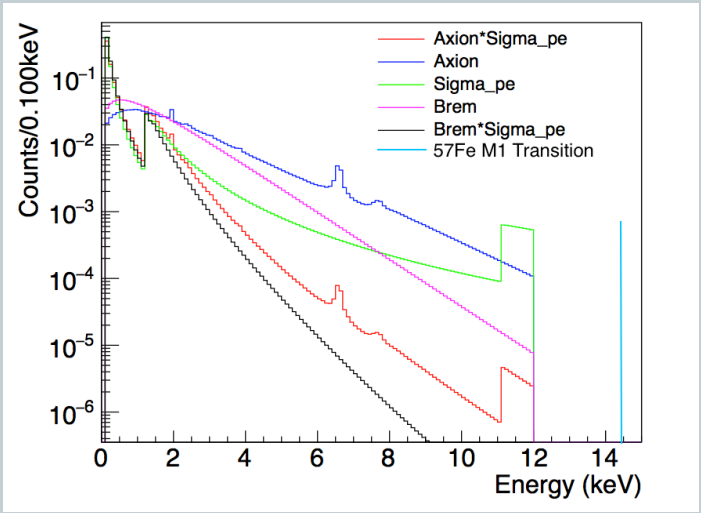
[1] G. Giovanetti et al., Phys. Proc., 61, 77 (2015), ISSN 1875-3892.

PHYSICS REACH AT LOW ENERGIES

ONGOING SEARCHES	EXPECTED SIGNAL
❖ Bosonic Dark Matter	❖ Anomalous peak
❖ Pauli Exclusion Principle Violation	❖ Peak at 10.6 keV
❖ Electron decay: $e \rightarrow \nu\bar{\nu}\nu$	❖ Peak at 11.1 keV
❖ Solar Axions	❖ Characteristic spectrum below 15 keV, **peak at 14.4 keV from ^{57}Fe M1 transition**
❖ Light ($< 10GeV/c^2$) WIMP searches	❖ Excess below 2-2.5 keV



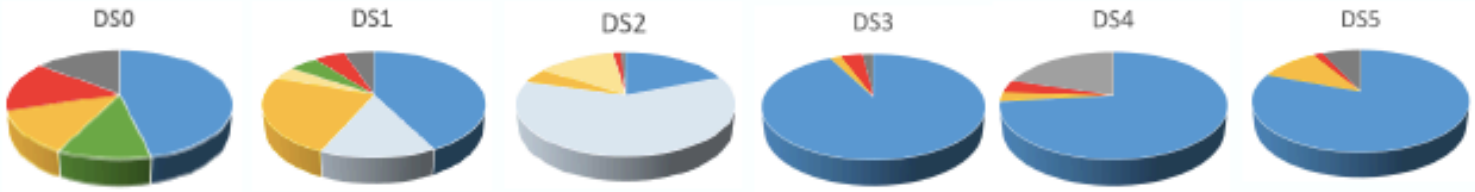
Dark Matter Signature



Solar Axion Spectrum in Ge

J. Redondo, arXiv:1310.0823 [hep-ph]

INITIAL DEMONSTRATOR DATA-SETS



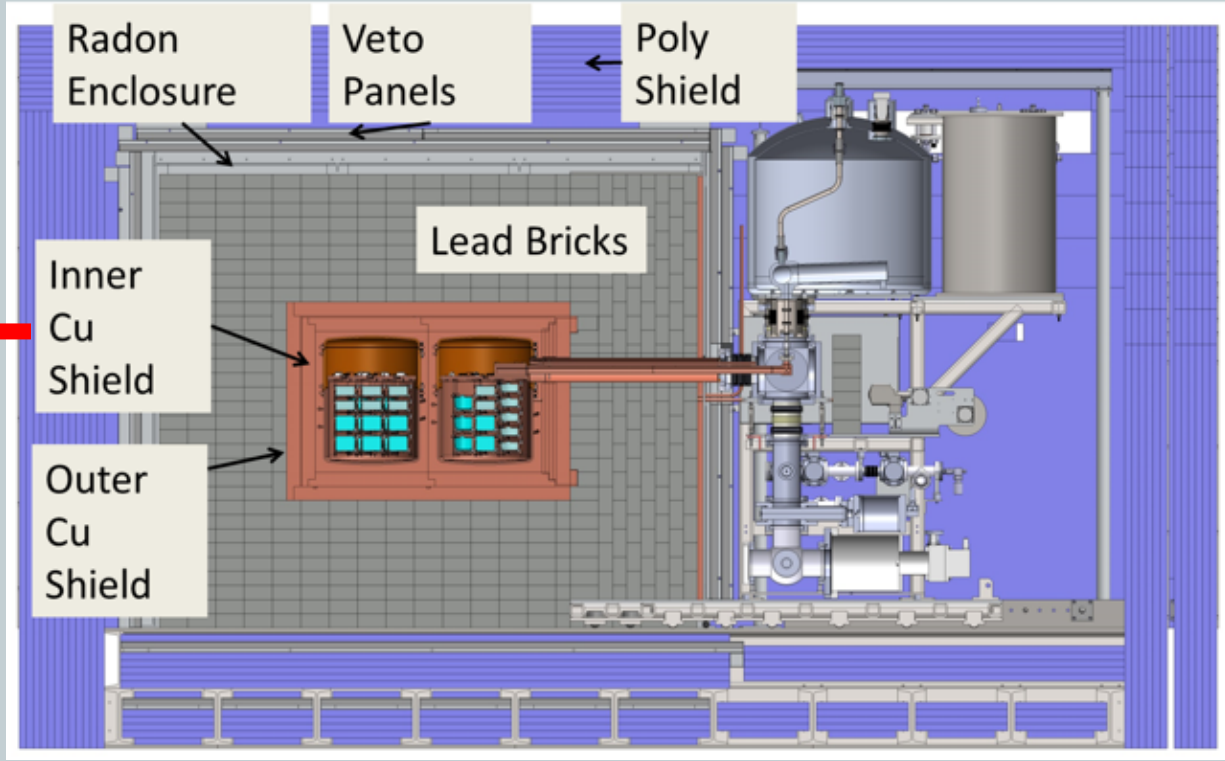
M1 Commissioning, no inner shield	*M1 inner shield*	*M1 Multi-sampling*	*Modules 1 and 2 Together in-shield*		*Module 1 & 2 Integrated DAQ*

	DS0 (days) Module 1 June 26, – Oct. 7, 2015	DS1 (days) Module 1 Dec. 31, 2015 – May 24, 2016	DS2 (days) Module 1 May 24 – July 14, 2016	DS3 (days) Module 1 Aug. 25, – Sept. 27, 2016	DS4 (days) Module 2 Aug. 25, – Sept. 27, 2016	DS5 (days) Module 1 & 2 Oct. 13, 2016 – May 11, 2017*
Total	103.15	144.50	50.97	32.37	32.36	147.68
Total acquired	87.93	136.98	50.47	31.73	25.80	137.42
Physics *	47.70	61.34 + 20.41*	9.82 + 30.56*	29.91	23.69	119.38
High radon	11.76	7.32	-	-	-	-
Disruptive Activities *	13.10	34.43+ 5.92*	2.41 + 7.03*	0.63	0.93	15.68
Calibration	15.44	7.32	0.65	1.18	1.17	2.36
Down time	15.21	7.51	0.50	0.64	6.56	10.25

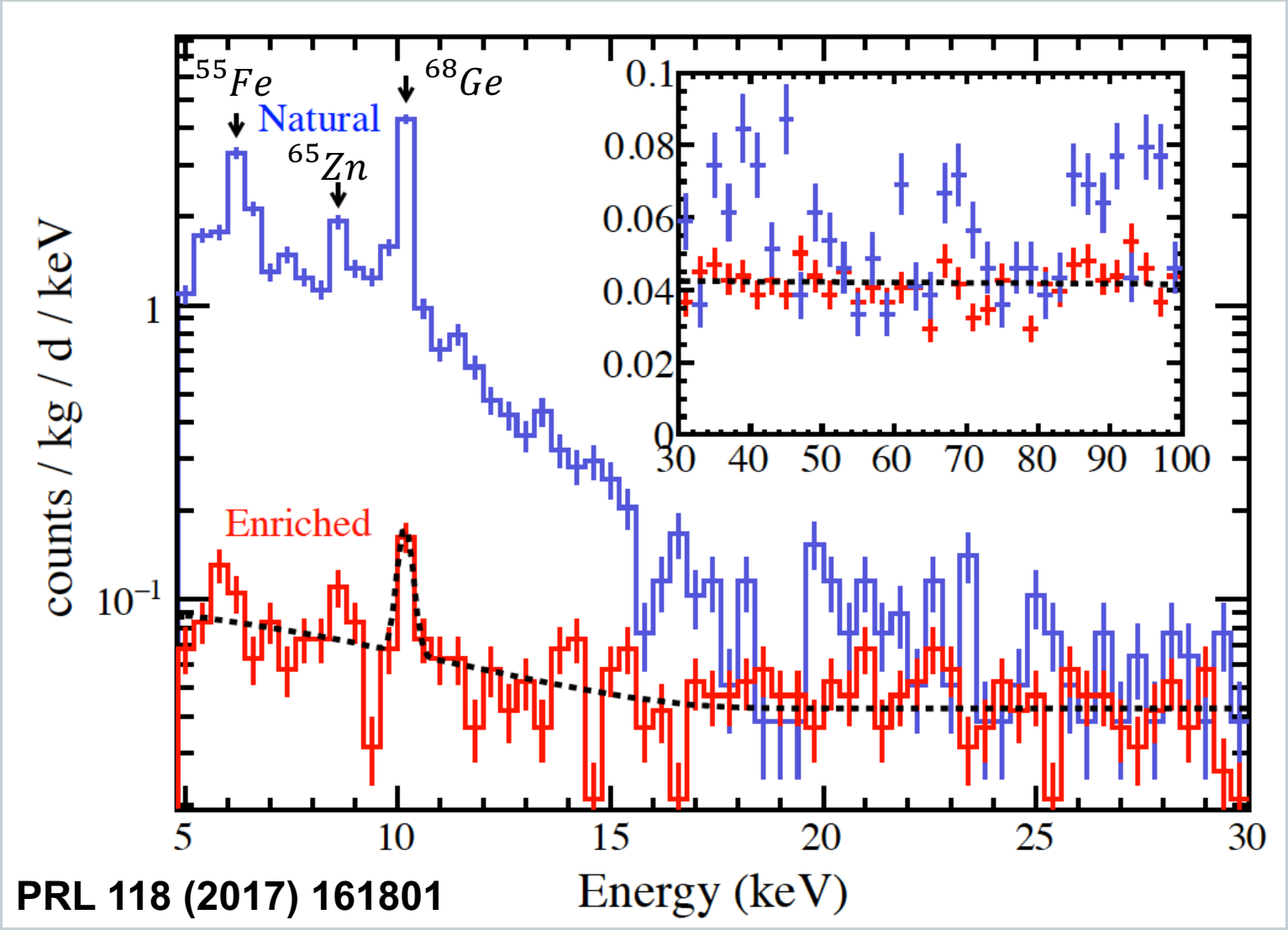
*Values thru 03/10/17

SHIELD NOT COMPLETE DURING COMMISSIONING DATA-SETS

- Inner 5 cm of underground electroformed Cu shield was not present
- Additional shielding in the Cu cross-arm not present



PREVIOUS BACKGROUND SPECTRUM

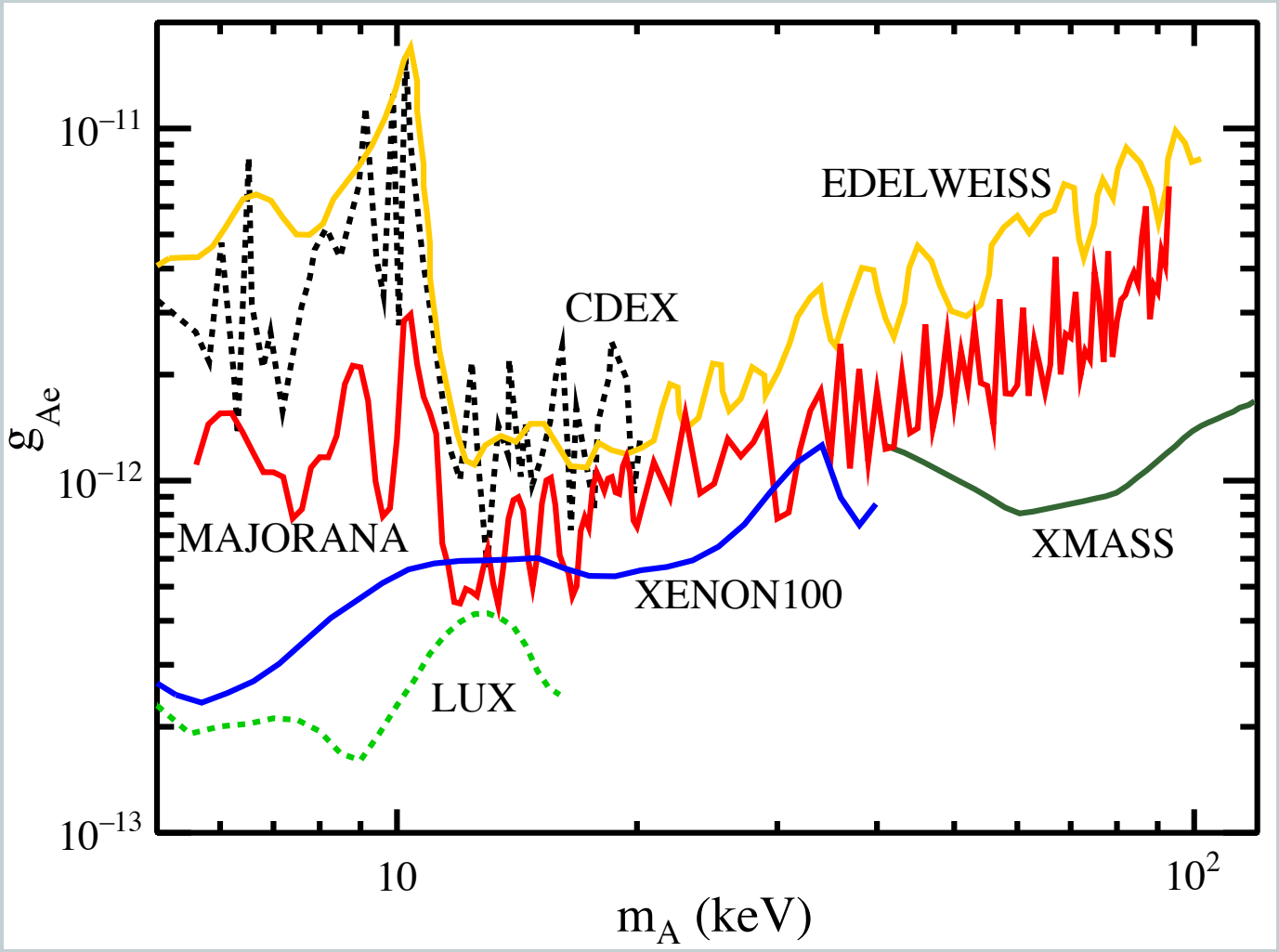


PRL 118 (2017) 161801

PSEUDOSCALAR DARK MATTER LIMIT

For a 11.8 keV mass particle, we set a limit

$g_{Ae} < 4.5 \times 10^{-13}$



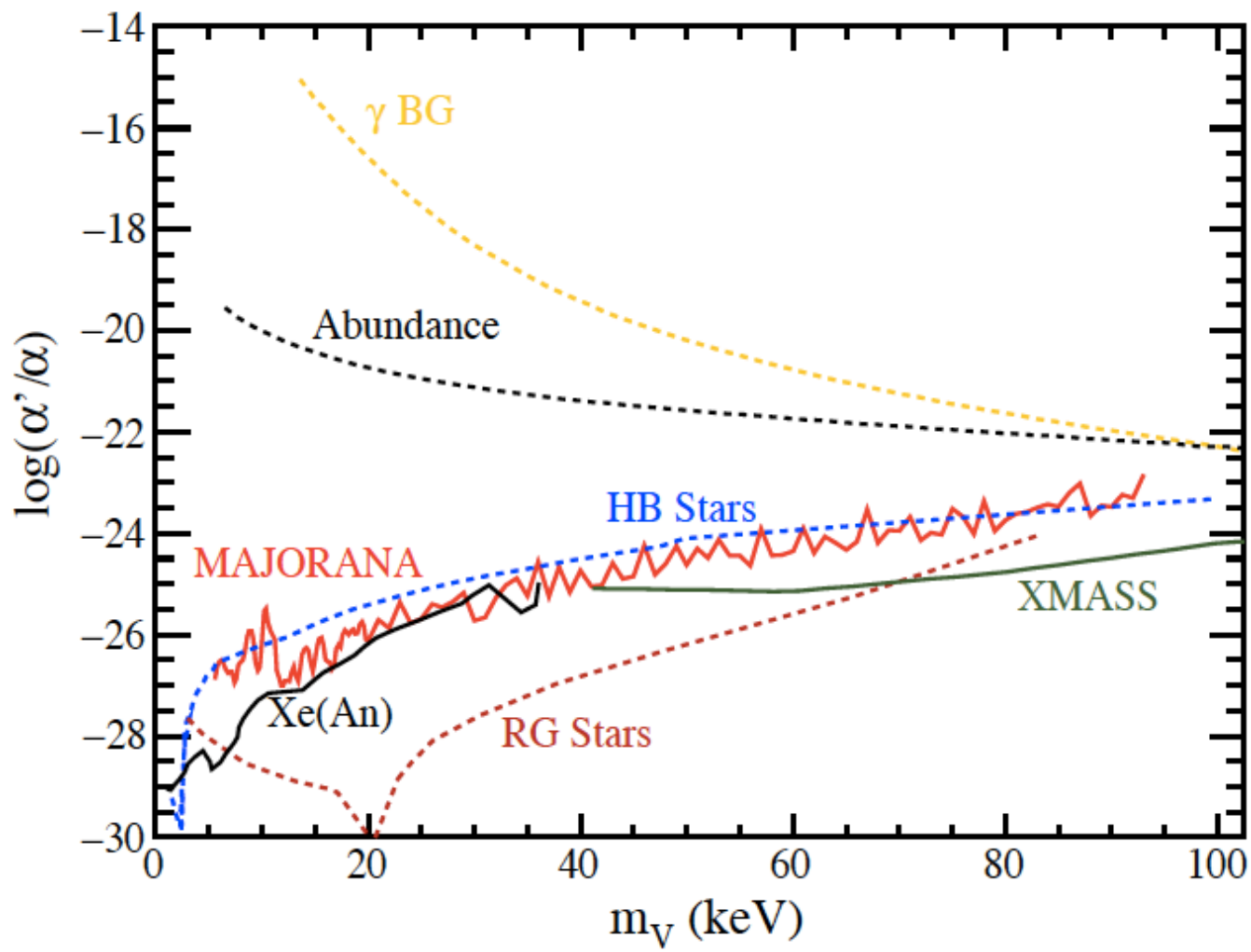
PRL 118 (2017) 161801

E. Armengaud et al. (EDELWEISS), JCAP, 2013, 067 (2013), K. Abe et al. (XMASS), Phys. Rev. Lett., 113, 121301 387 (2014). , E. Aprile et al. (XENON100), Phys. Rev. D, 90, 062009 389 (2014).

VECTOR DARK MATTER LIMIT

For a 11.8 keV mass particle, we set a limit

$(\alpha'/\alpha) < 9.7\times10^{-28}$



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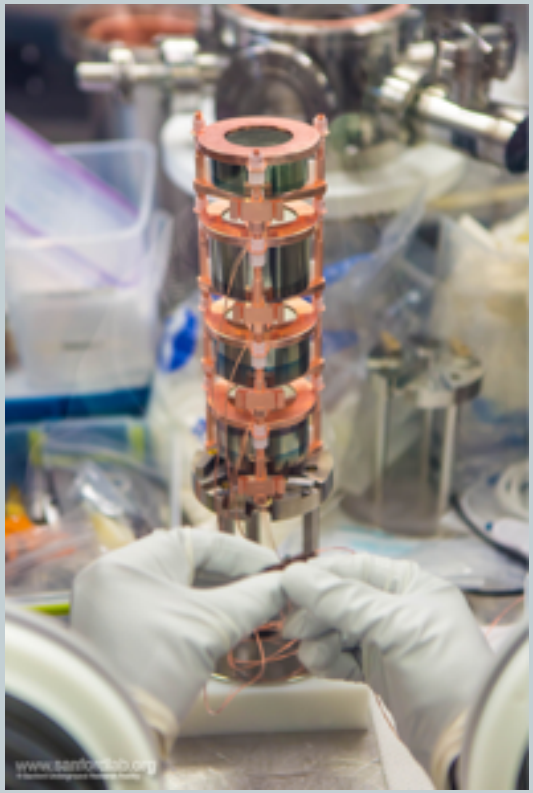
OTHER LIMITS

- **Solar axion coupling** (14.4 keV ^{57}Fe M1)
  - Low-mass limit. 90% UL.
  - $g_{AN}^{Eff} \times g_{Ae} < 3.8 \times 10^{-17}$)

- **Electron decay**
  - Unbinned likelihood analysis for peak at 11.1 keV
    $e \rightarrow \nu \bar{\nu} \nu$
  - $\tau_e > 1.2 \times 10^{24}\ yr$ (90% CL UL)



- **Non-Paulian transition** in Ge:

$$a_i a_j^\dagger - q\, a_j^\dagger a_i = \delta_{ij}$$
$$q = -1 + \beta^2$$

  - Unbinned likelihood analysis for peak at 10.6 keV
  - $^1/_2\ \beta^2 < 8.5 \times 10^{-48}$ (90% CL UL)

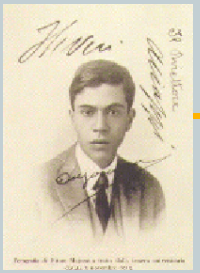
PRL 118 (2017) 161801

SUMMARY AND OUTLOOK

- Excellent energy resolution, Pulse Shape Analysis abilities, and low backgrounds allow the DEMONSTRATOR to achieve competitive limits for several rare-event searches
- Shielding is now complete, exposure is accumulating, analysis techniques are becoming more powerful, and analysis thresholds are decreasing
- We expect ~3x lower backgrounds and ~75x more exposure

ACKNOWLEDGEMENTS

❖ This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, the Particle Astrophysics and Nuclear Physics Programs of the National Science Foundation, and the Sanford Underground Research Facility.



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