LOW-MASS WIMP SEARCH USING THE MAJORANA DEMONSTRATOR

Gulden Othman
University of North Carolina-Chapel Hill

On behalf of the MAJORANA Collaboration

UCLA Dark Matter 2018
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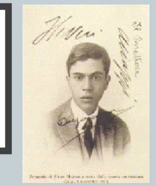
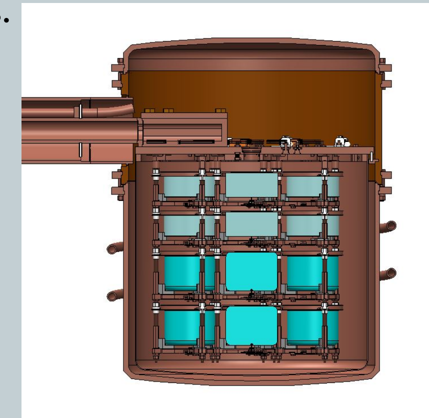
THE MAJORANA DEMONSTRATOR

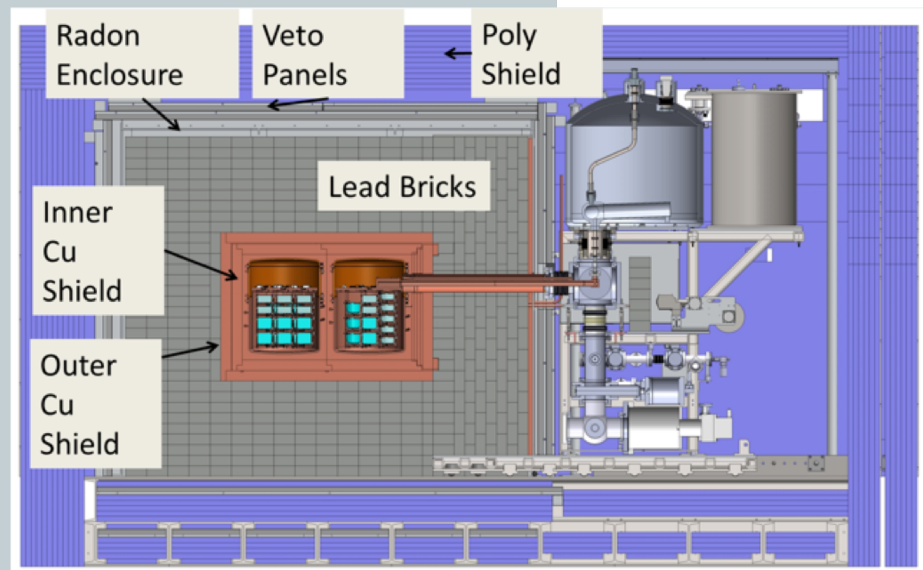


Operating underground at the 4850’ Sanford Underground Research Facility

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.



- ❖ Energy resolution of 2.5 keV FWHM @ 2039 keV is the best of any ββ-decay experiment
- ❖ Background Goal in the 0νββ peak after analysis cuts with the achieved resolution: 2.5 counts/(FWHM t yr)
  - Projected backgrounds based on assay results ≤ 2.2 counts/(FWHM t yr)
- ❖ 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



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

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

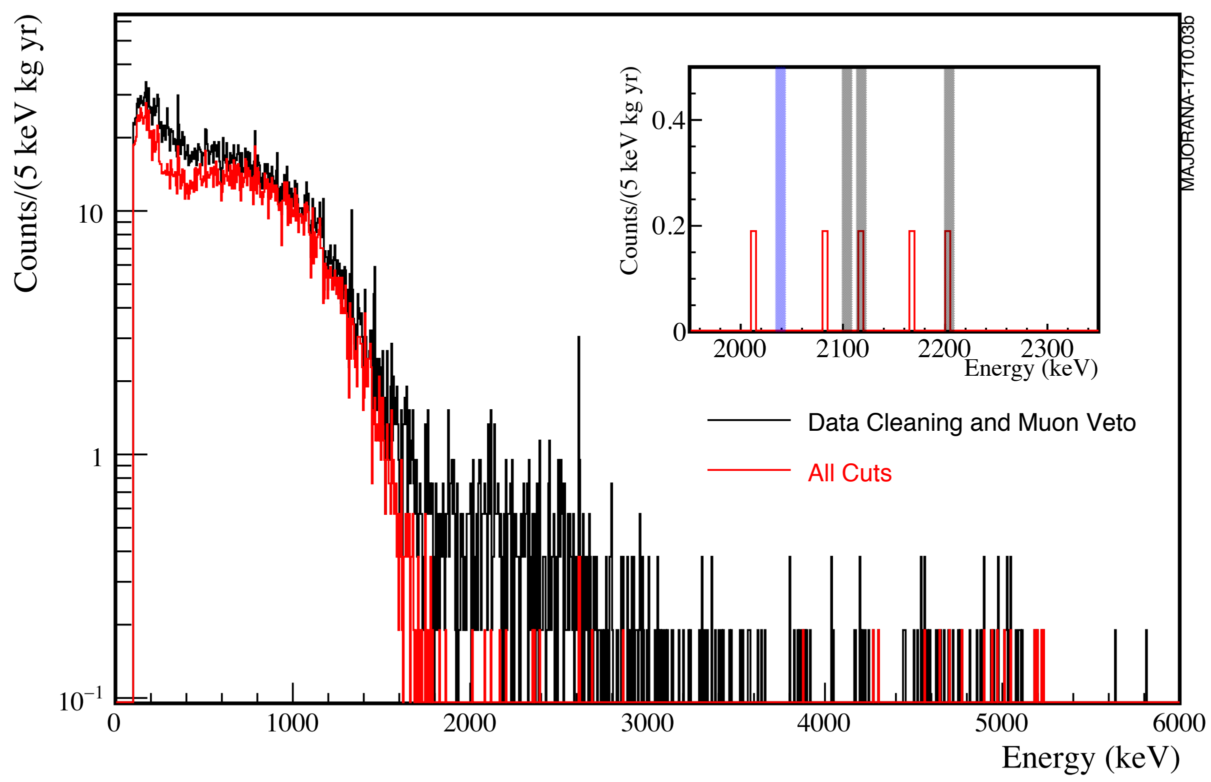
BACKGROUND SPECTRUM

Spectrum above 100 keV with lowest background configuration data-sets

First $0\nu\beta\beta$ result accepted to PRL; arXiv:1710.11608v1

Lower limit on the half-life: $T^{0\nu}_{1/2} > 1.9 \times 10^{25}$ **yr (90% CL)**

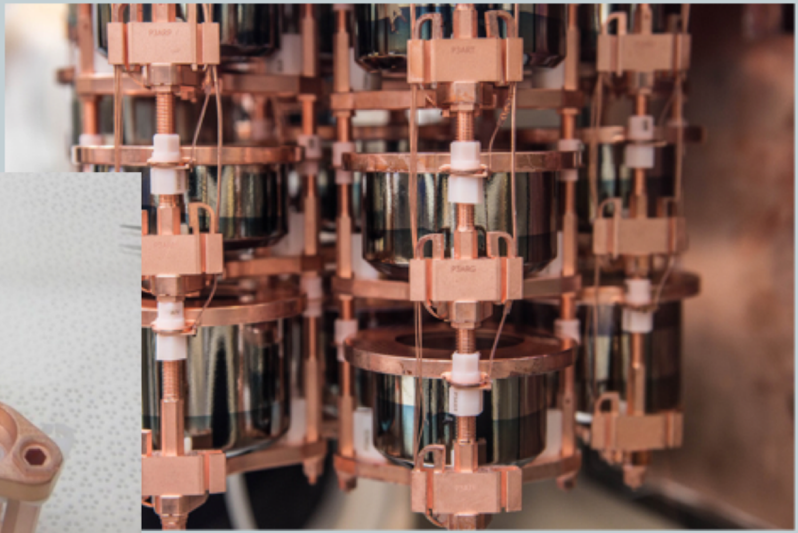
Median sensitivity for exclusion: $T^{0\nu}_{1/2} >$ 2.1×10^{25} **yr (90% CL)**



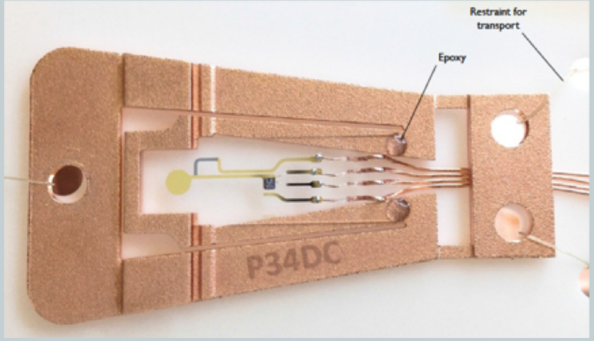
THE MAJORANA LOW-ENERGY PROGRAM

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


Modules 1 & 2 in Pb and Cu shielding


Detector Strings

Detector Module

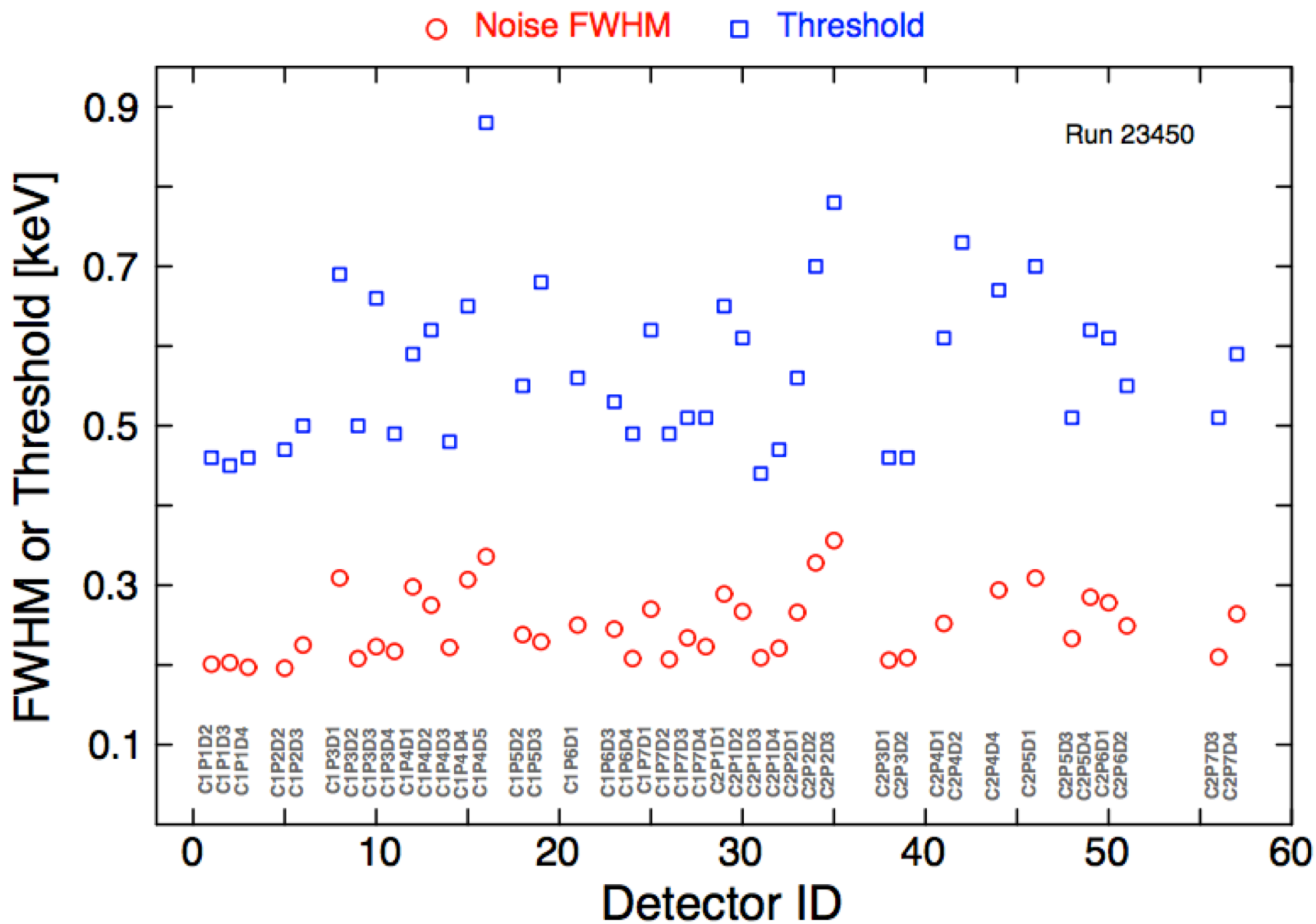



Low-Mass Front-End

SUB-keV THRESHOLDS AND EXCELLENT ENERGY RESOLUTION

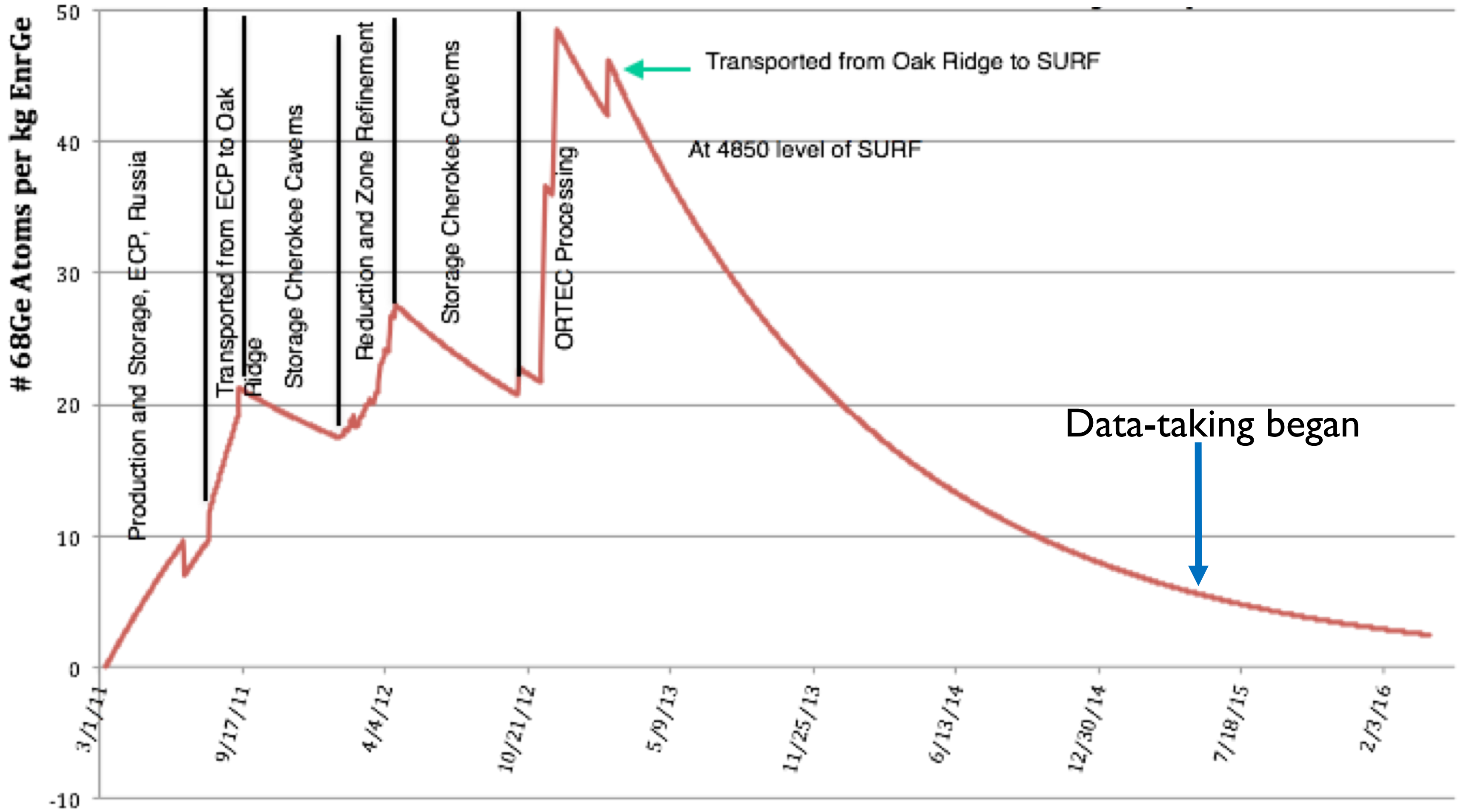
$FWHM_{Avg} \lesssim 250$ eV

$Threshold_{Avg} \lesssim 700$ eV



REDUCING ENRICHED Ge COSMOGENIC ACTIVATION

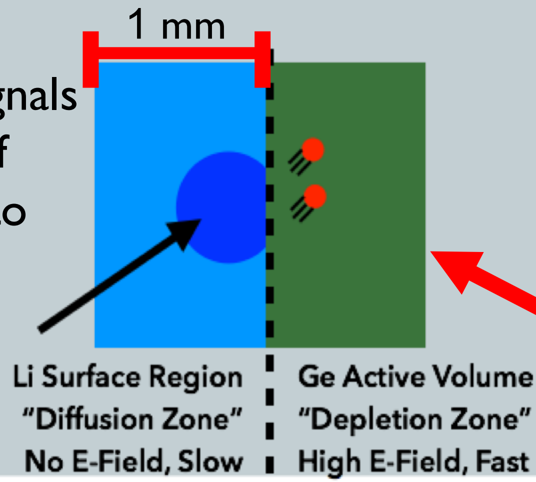
One detector example: ^{68}Ge activation

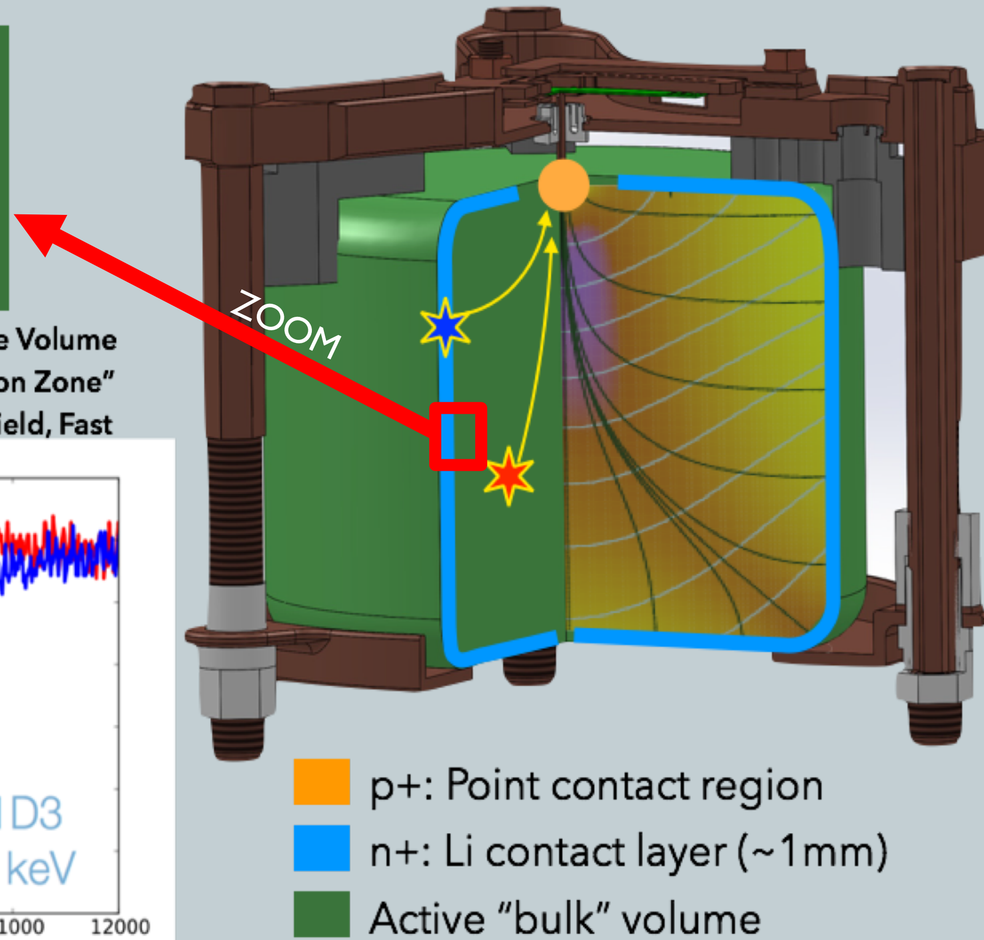


Sophisticated parts-tracking database: Nucl. Instr. and Methods A 779 (2015) 52—62

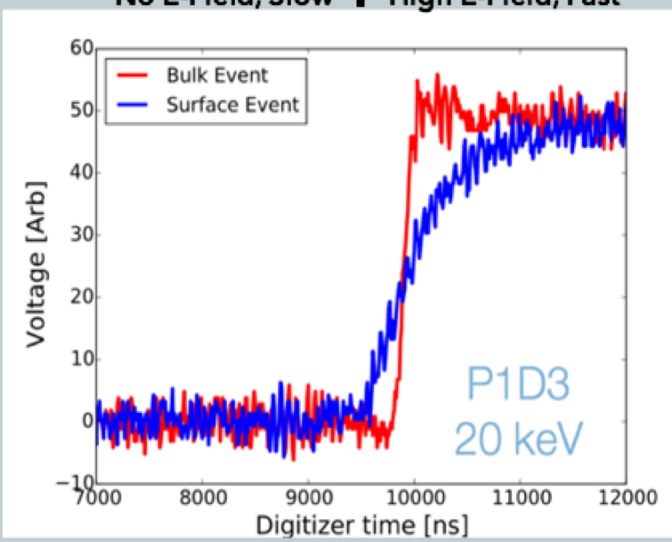
SIGNALS IN PPC HPGe DETECTORS

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





- Slow pulses are energy-degraded events



- Slow pulses are a significant background at energies below 30 keV [1,2]

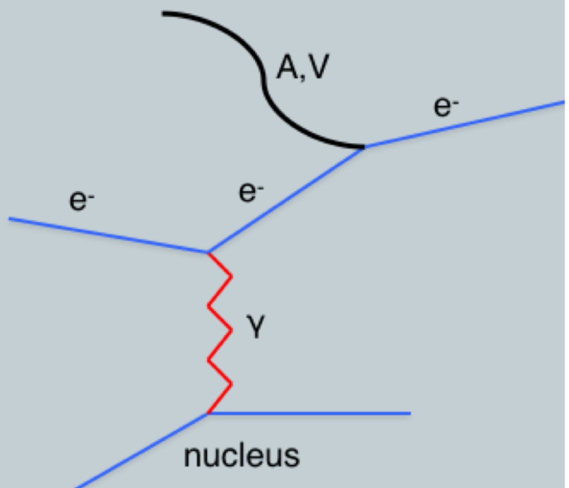
[1] G. Giovanetti et al., Phys. Proc., 61, 77 (2015), ISSN 1875-3892.

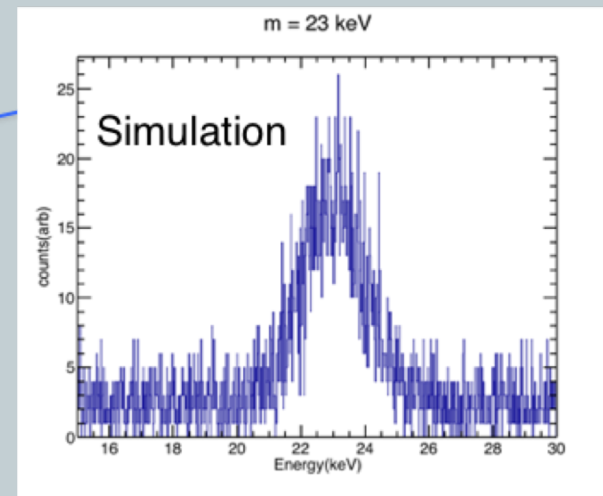
[2] C. E. Aalseth et al. (CoGeNT Collab.) Phys. Rev. D **88**, 012002, 2013.

PHYSICS REACH AT LOW ENERGIES

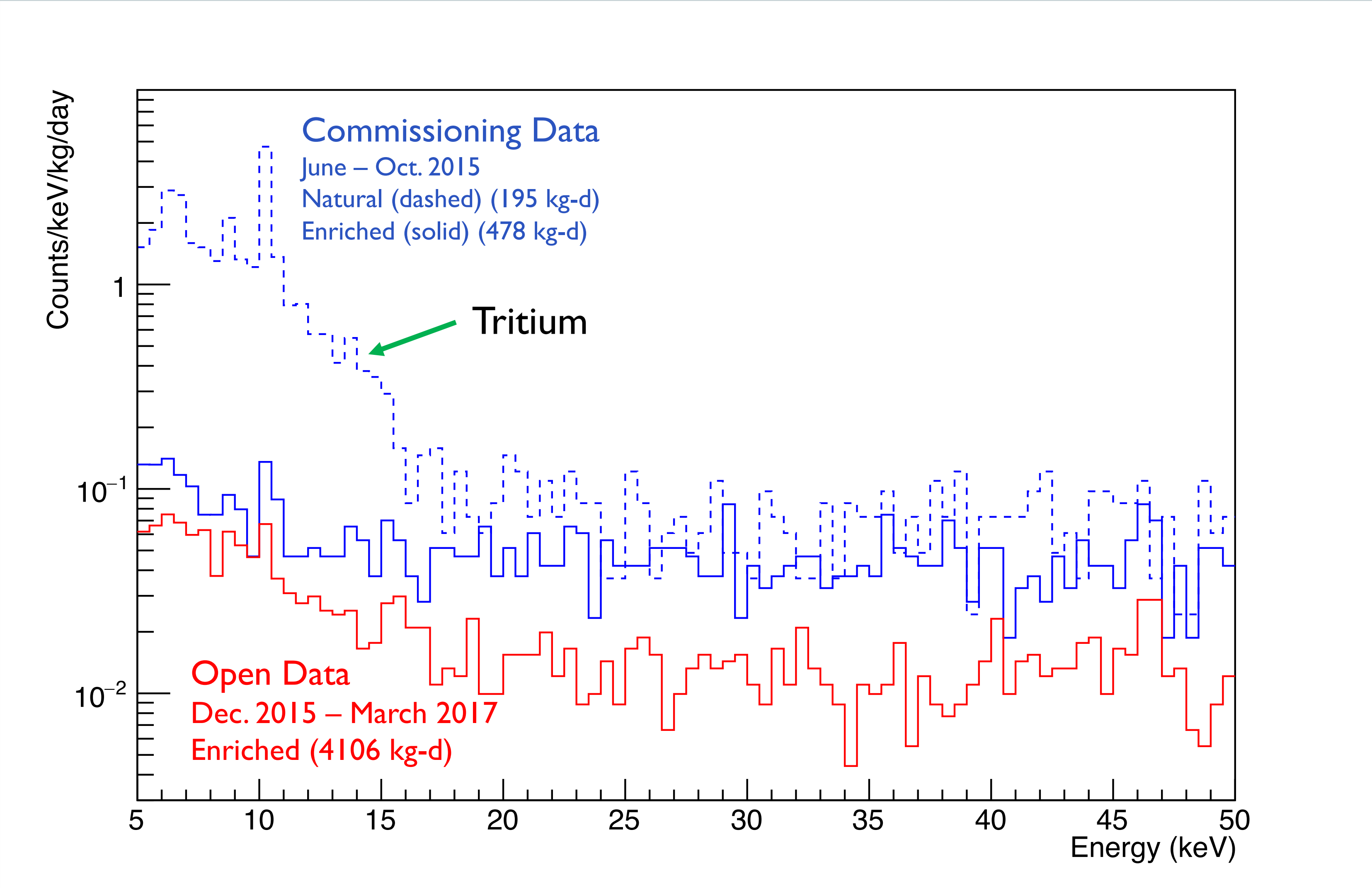
ONGOING SEARCHES		EXPECTED SIGNAL
❖ Bosonic Dark Matter	→	❖ Anomalous peak
❖ Pauli Exclusion Principle Violation	→	❖ Peak at 10.6 keV
❖ Electron decay: $e \rightarrow \nu \bar{\nu} \nu$	→	❖ Peak at 11.1 keV
❖ Solar Axions	→	❖ Characteristic spectrum below 15 keV, **peak at 14.4 keV from $^{57}\mathrm{Fe}$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

Bosonic Dark Matter Signature





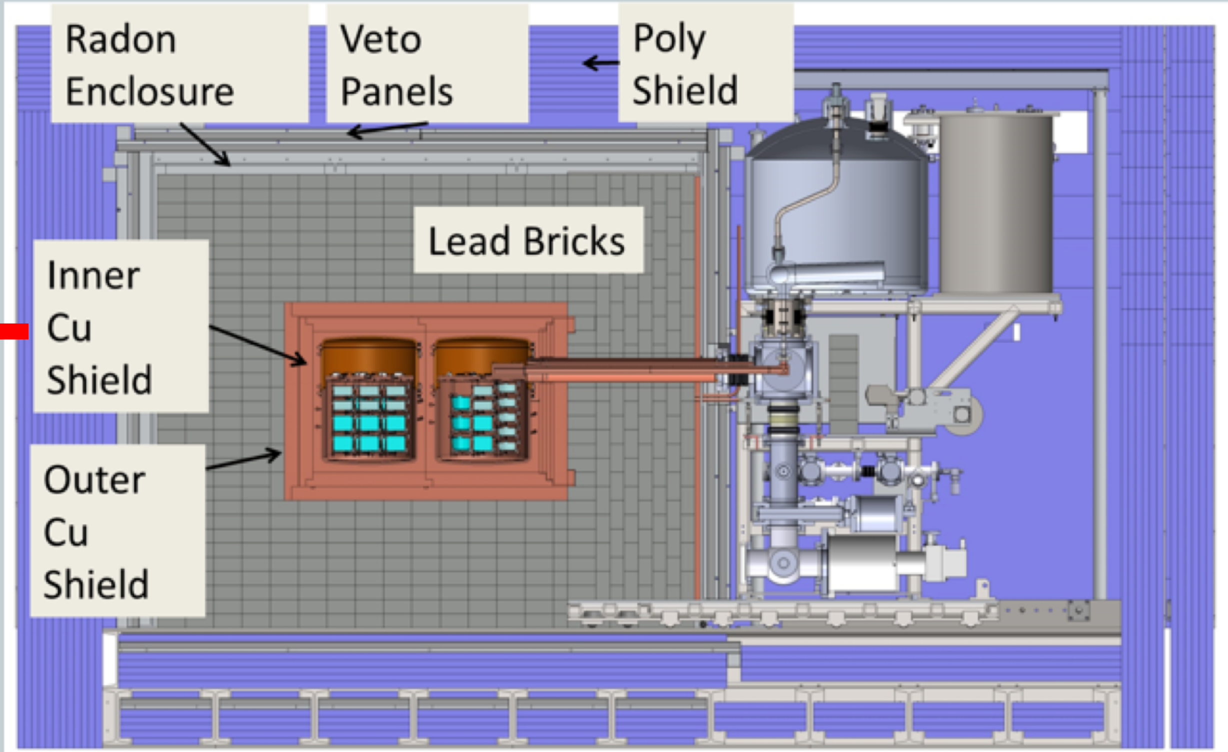
MAJORANA BACKGROUND SPECTRUM



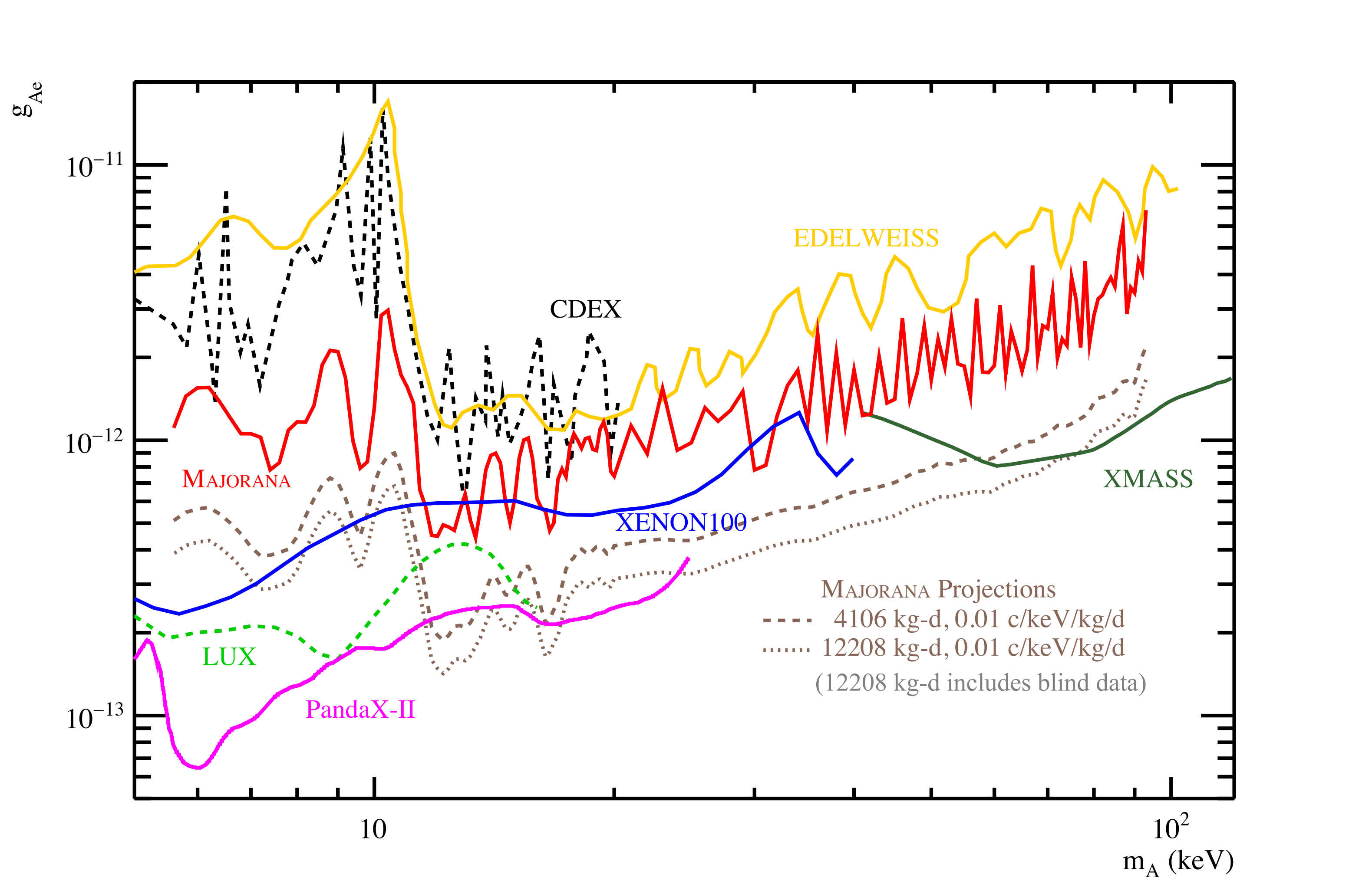
Previous result (blue curves):
PRL 118 (2017) 161801

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



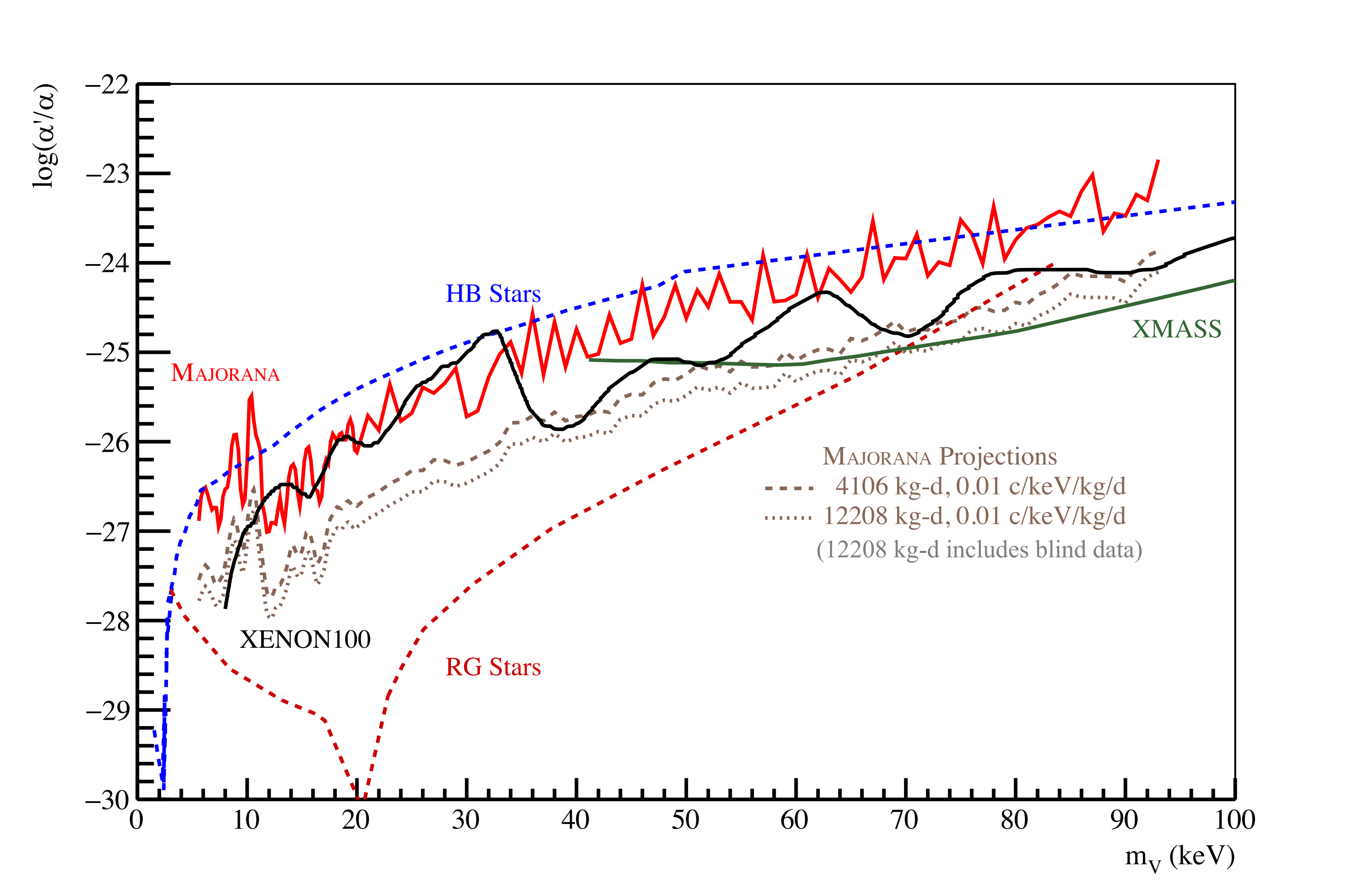
PSEUDOSCALAR DARK MATTER SENSITIVITY PROJECTION



Previous result (red curve): 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 SENSITIVITY PROJECTION



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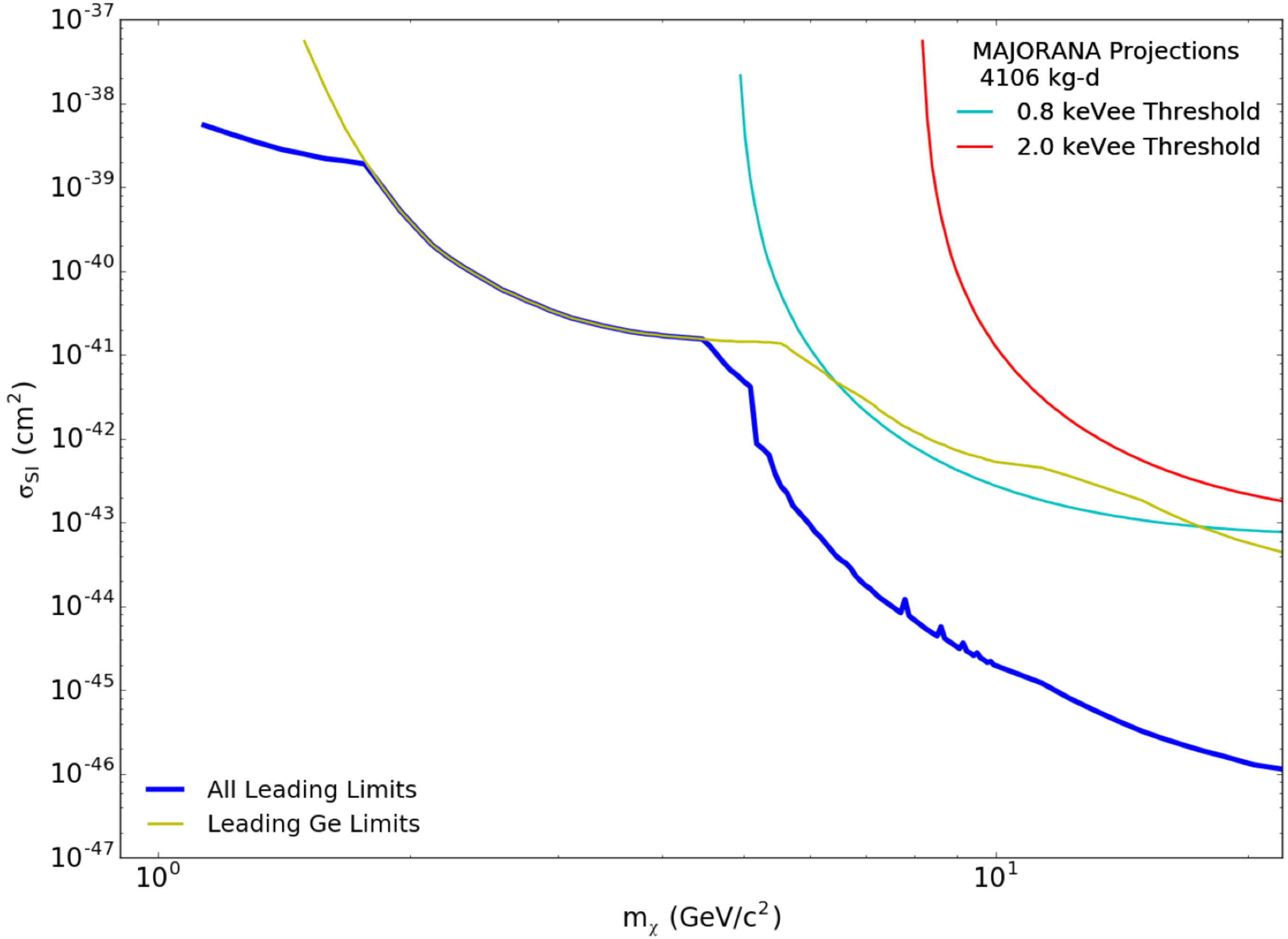
WIMP SENSITIVITY PROJECTION



ELECTRONIC RECOIL SIGNATURES OF WIMP-NUCLEAR SCATTERING

Because we do not discriminate between nuclear and electronic recoils, we are able to take advantage of electronic signatures due to nuclear recoils

- Migdal Effect
  - Takes into account that the electrons take time to catch up with the nucleus after a nuclear recoil
  - May result in additional ionizations and excitations compared to just the pure nuclear recoil
- Bremsstrahlung emission
  - Possibility of bremsstrahlung gamma emission do to the deceleration of the nucleus in the detector medium after a nuclear recoil
  - Expect this to be sub-dominant compared to the Migdal effect
- Sensitivity studies for these effects are underway

Migdal Effect in direct dark matter detection: arXiv:1707.07258v1

Bremsstrahlung emission: Phys.Rev.Lett. 118 (2017) no.3, 031803

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
- ❖Ongoing work to reduce analysis thresholds and explore effects such as Migdal and bremsstrahlung emission in order to extend sensitivity to lower-mass WIMPs

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.

The MAJORANA Collaboration

Black Hills State University, Spearfish, SD
Kara Keeter

Duke University, Durham, North Carolina, and TUNL
Matthew Busch

Joint Institute for Nuclear Research, Dubna, Russia
Viktor Brudanin, M. Shirchenko, Sergey Vasilyev, E. Yakushev, I. Zhitnikov

Lawrence Berkeley National Laboratory, Berkeley, California and the University of California - Berkeley
Nicolas Abgrall, Yuen-Dat Chan, Lukas Hehn, Jordan Myslik, Alan Poon, Kai Vetter

Los Alamos National Laboratory, Los Alamos, New Mexico
Pinghan Chu, Steven Elliott, Ralph Massarczyk, Keith Rielage, Larry Rodriguez, Harry Salazar, Brandon White, Brian Zhu

National Research Center '*Kurchatov Institute' Institute of Theoretical and Experimental Physics, Moscow, Russia*
Alexander Barabash, Sergey Konovalov, Vladimir Yumatov

North Carolina State University, and TUNL
Matthew P. Green

Oak Ridge National Laboratory
Fred Bertrand, Charlie Havener, Monty Middlebrook, David Radford, Benjamin Shanks, Robert Varner, Chang-Hong Yu

Osaka University, Osaka, Japan
Hiroyasu Ejiri

Pacific Northwest National Laboratory, Richland, Washington
Isaac Arnquist, Eric Hoppe, Richard T. Kouzes

Princeton University, Princeton, New Jersey
Graham K. Giovanetti

Queen's University, Kingston, Canada
Ryan Martin

South Dakota School of Mines and Technology, Rapid City, South Dakota
Brady Bos, Colter Dunagan, Cabot-Ann Christofferson, Jared Thompson

Tennessee Tech University, Cookeville, Tennessee
Mary Kidd

Technische Universität München, and Max Planck Institute, Munich, Germany
Tobias Bode, Susanne Mertens

University of North Carolina, Chapel Hill, North Carolina, and TUNL
Thomas Caldwell, Thomas Gilliss, Chris Haufe, Reyco Henning, Mark Howe, Samuel J. Meijer, Gulden Othman, Jamin Rager, Anna Reine, Kris Vorren, John F. Wilkerson

University of South Carolina, Columbia, South Carolina
Frank Avignone, Vincente Guiseppe, David Tedeschi, Clint Wiseman

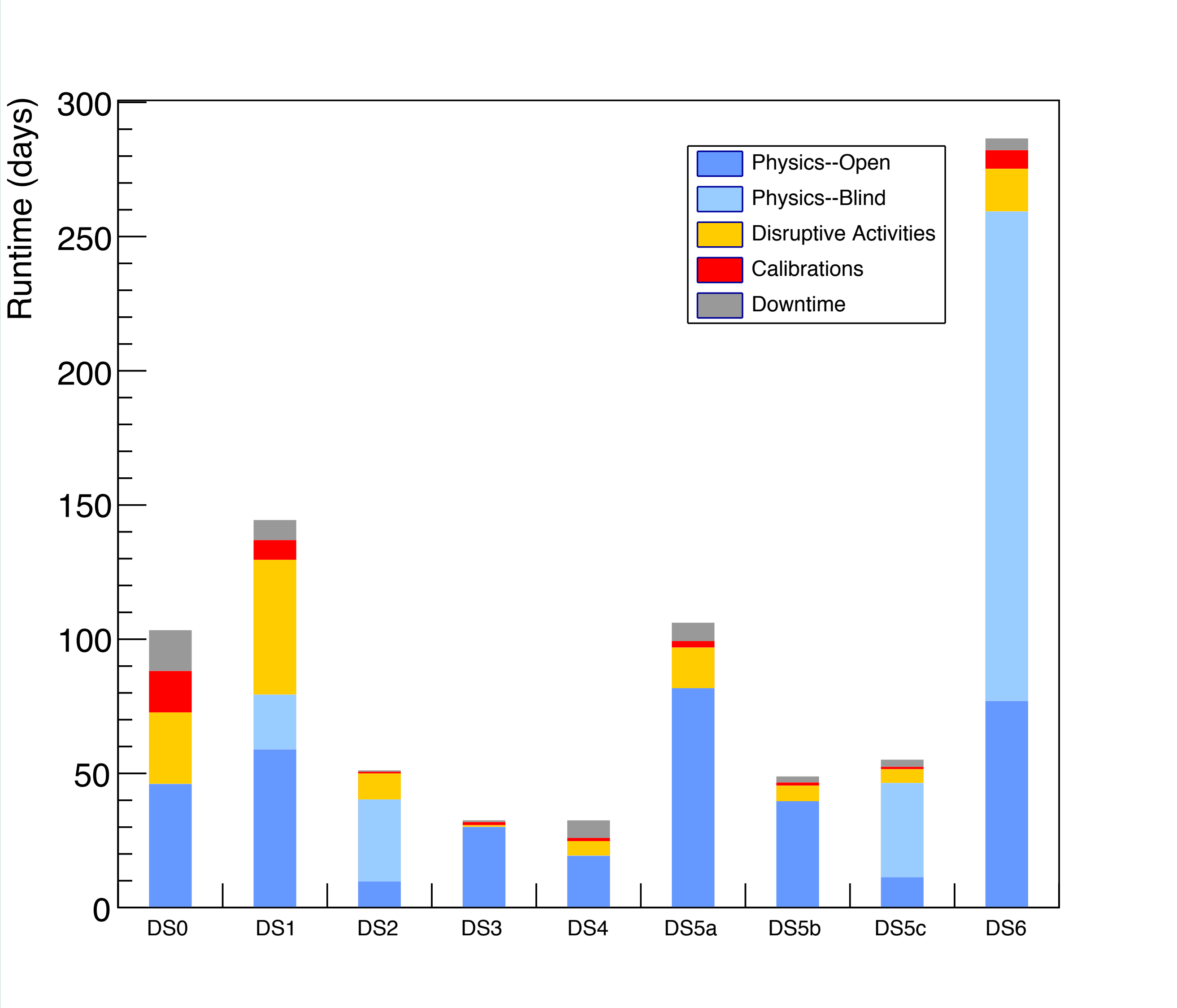
University of South Dakota, Vermillion, South Dakota
Clay J. Barton, Wenqin Xu

University of Tennessee, Knoxville, Tennessee
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

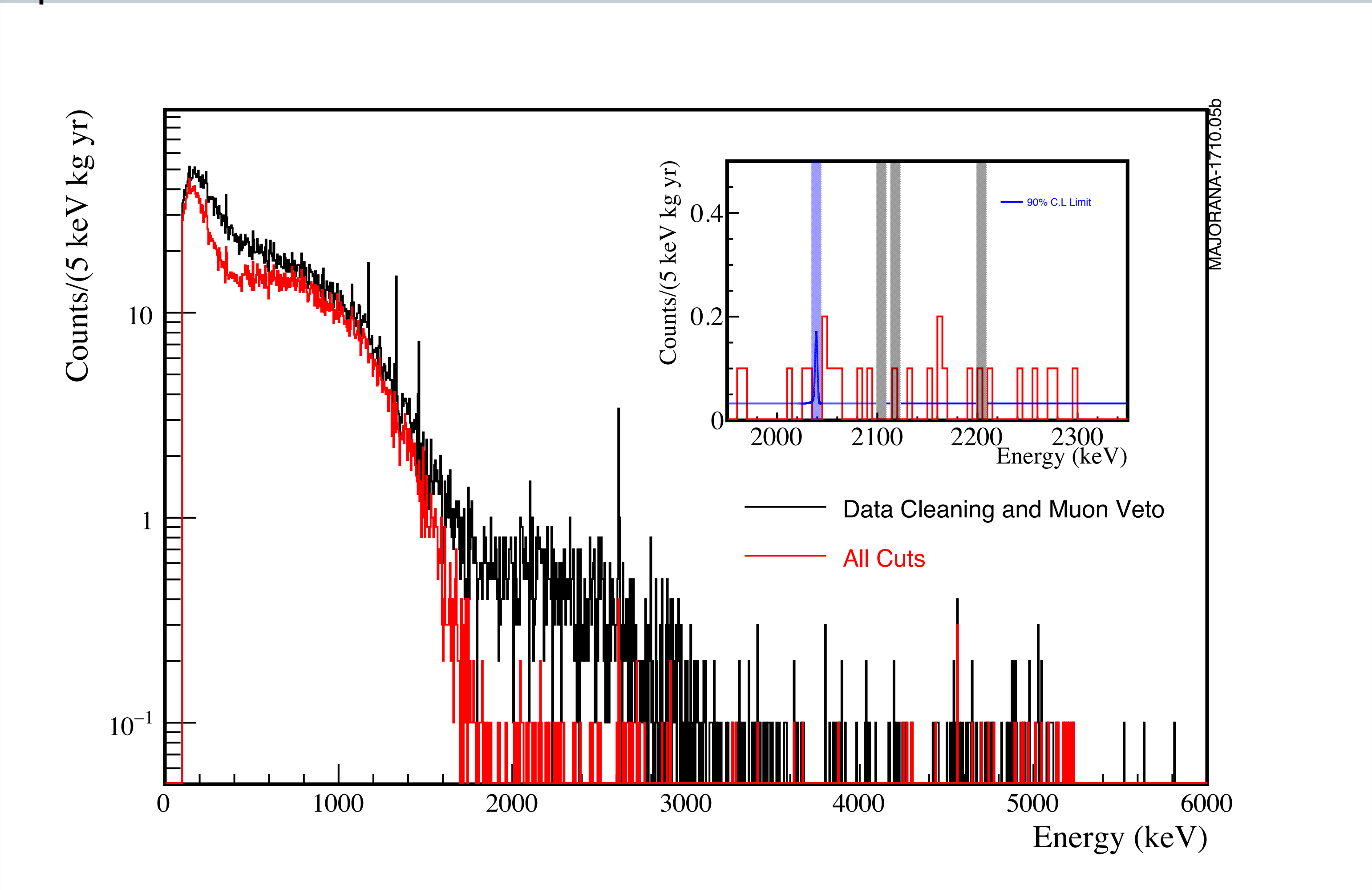
BACKUP SLIDES

DATA-SETS AND DUTY CYCLES



BACKGROUND SPECTRUM

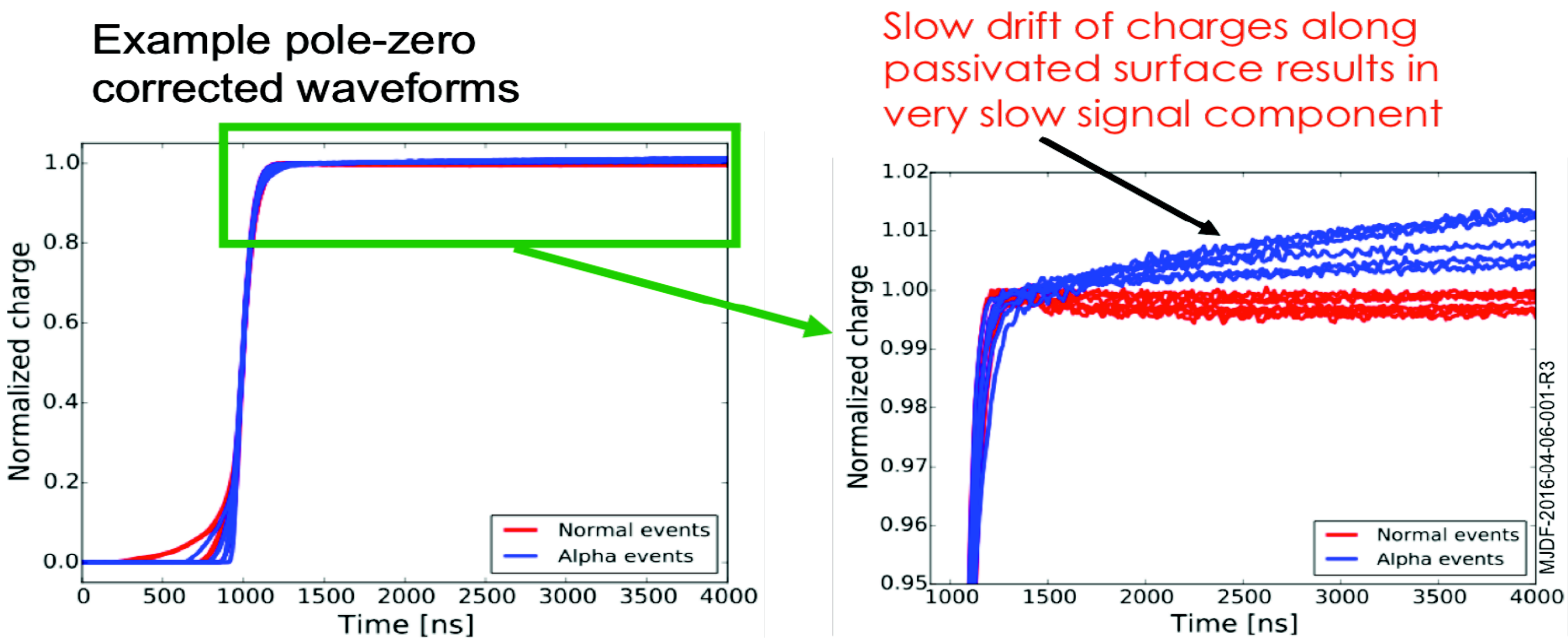
Spectrum above 100 keV with all data-sets



First $0\nu\beta\beta$ result accepted to PRL;
arXiv:1710.11608v1

Alpha Backgrounds

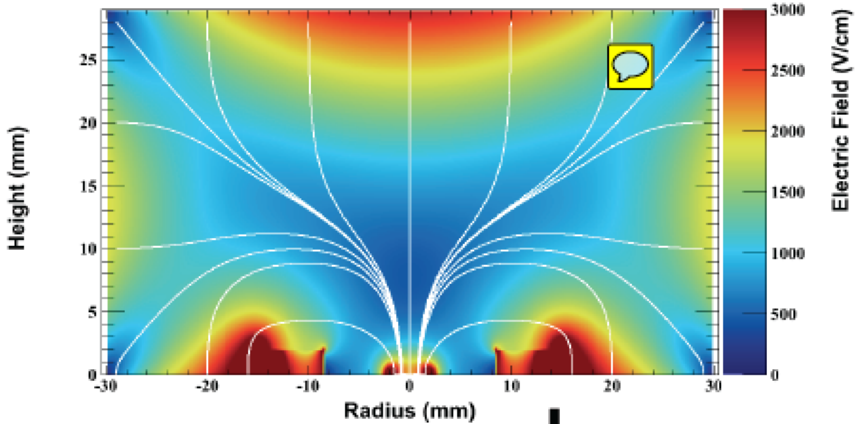
- Energy degraded alpha background observed in early data sets
- Charge from these events drifts along the surface rather than through the bulk
- Results in a distinctive delayed charge recovery (DCR) signal which is used to efficiently cut alpha events based on the slope past the rising edge
- Measurements taken and being analyzed from a DEMONSTRATOR detector in the TUBE alpha scanner at Technical University of Munich to better understand the source and response of surface alphas

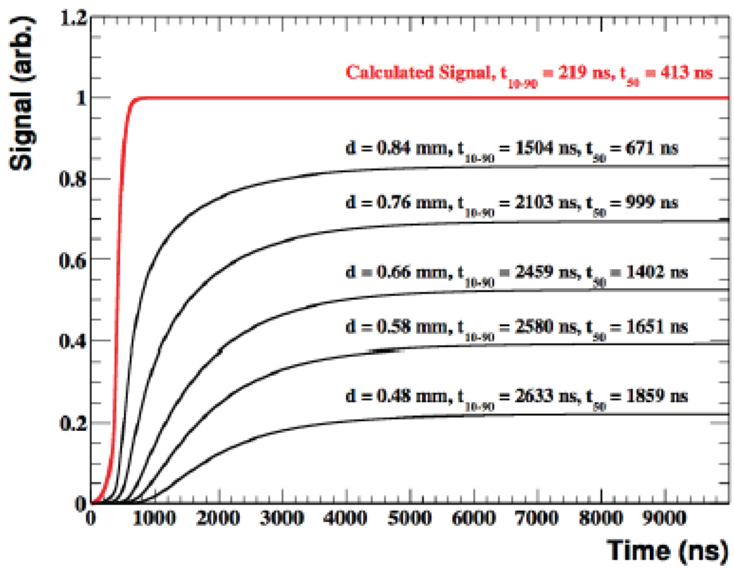


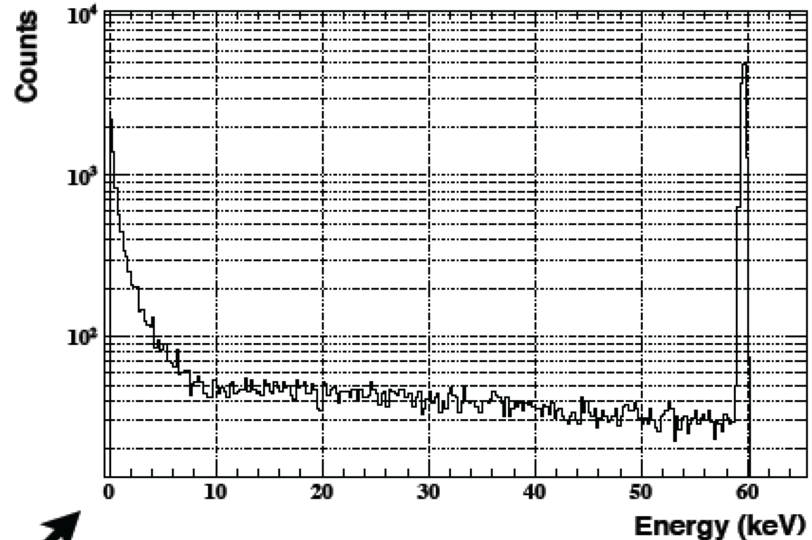
T. Caldwell   TAUP, July 2017   13

a qualitative slow pulse diffusion model

D.C. Radford and P. Finnerty

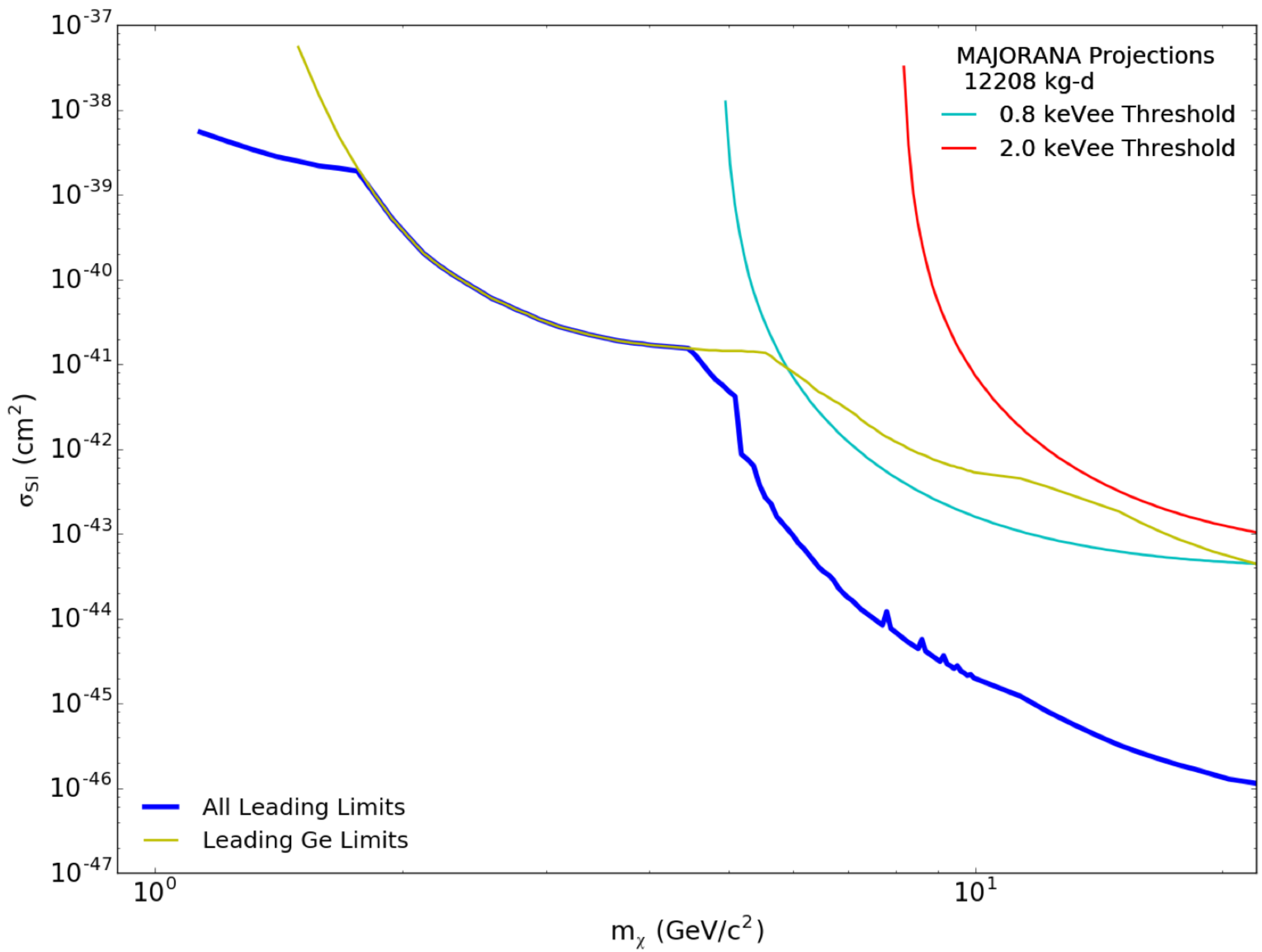






Big first step towards understanding physical mechanism responsible for slow-signals in PPC detectors.

PROJECTED WIMP SENSITIVITY INCLUDING BLIND EXPOSURE



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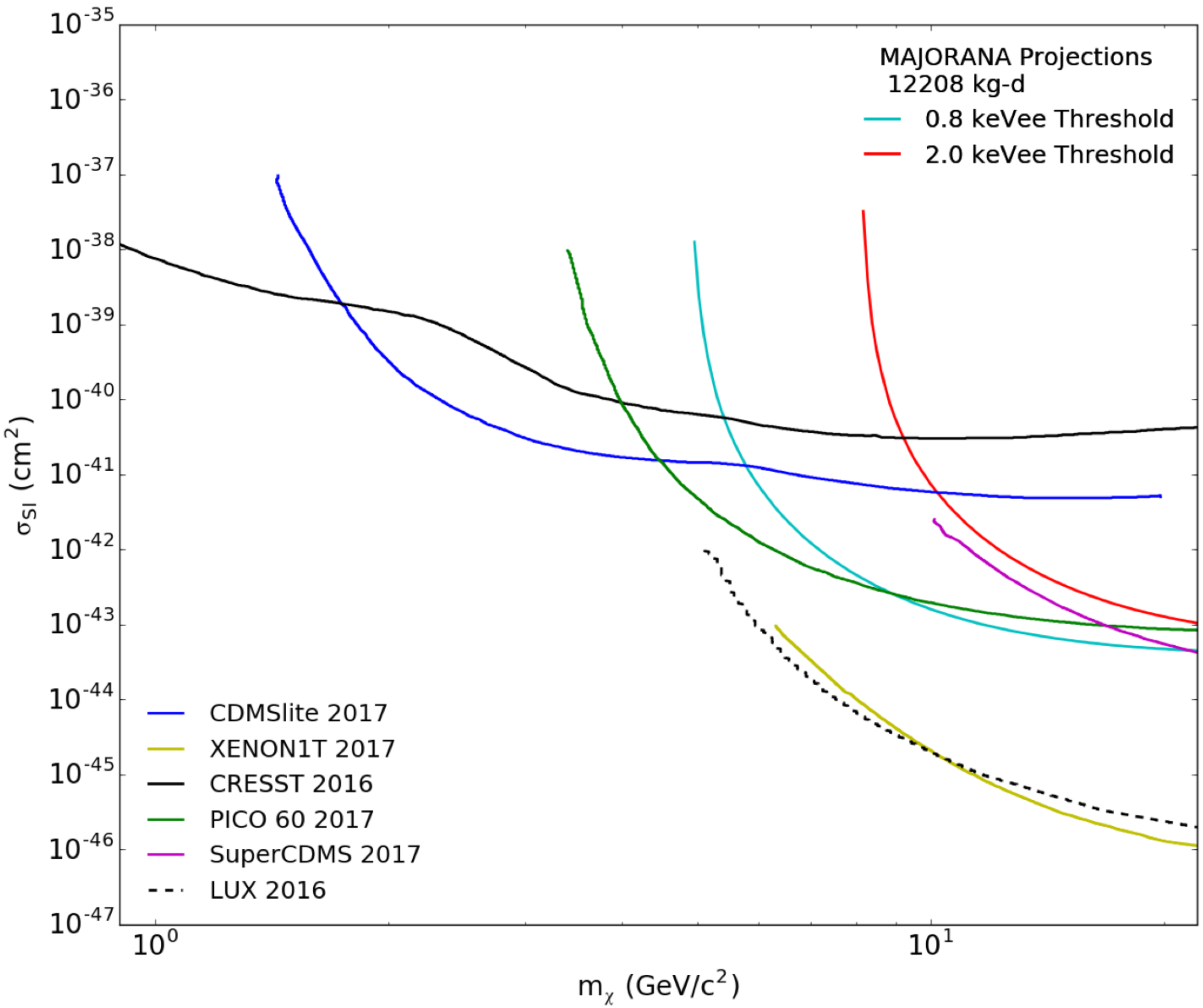

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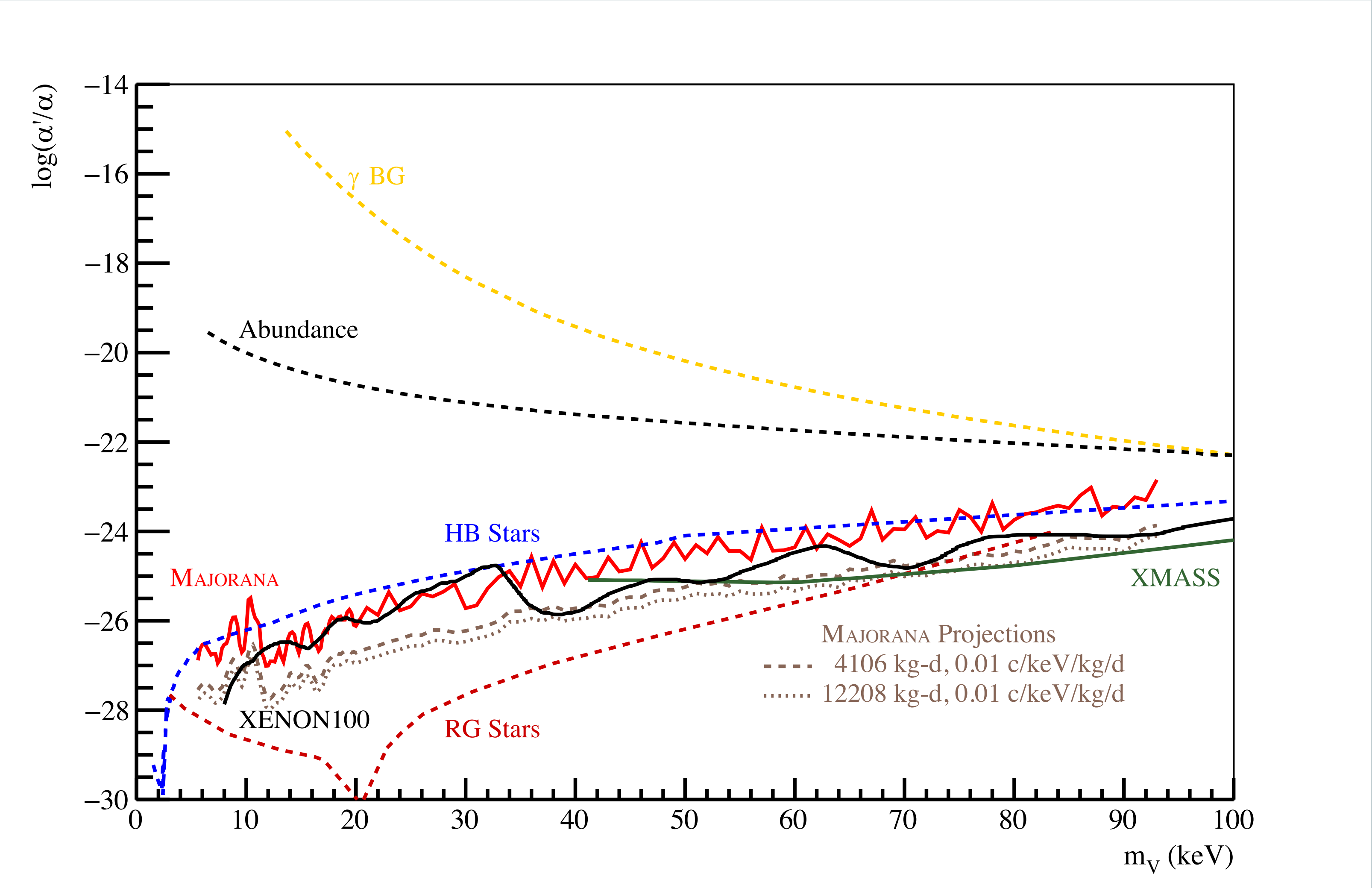

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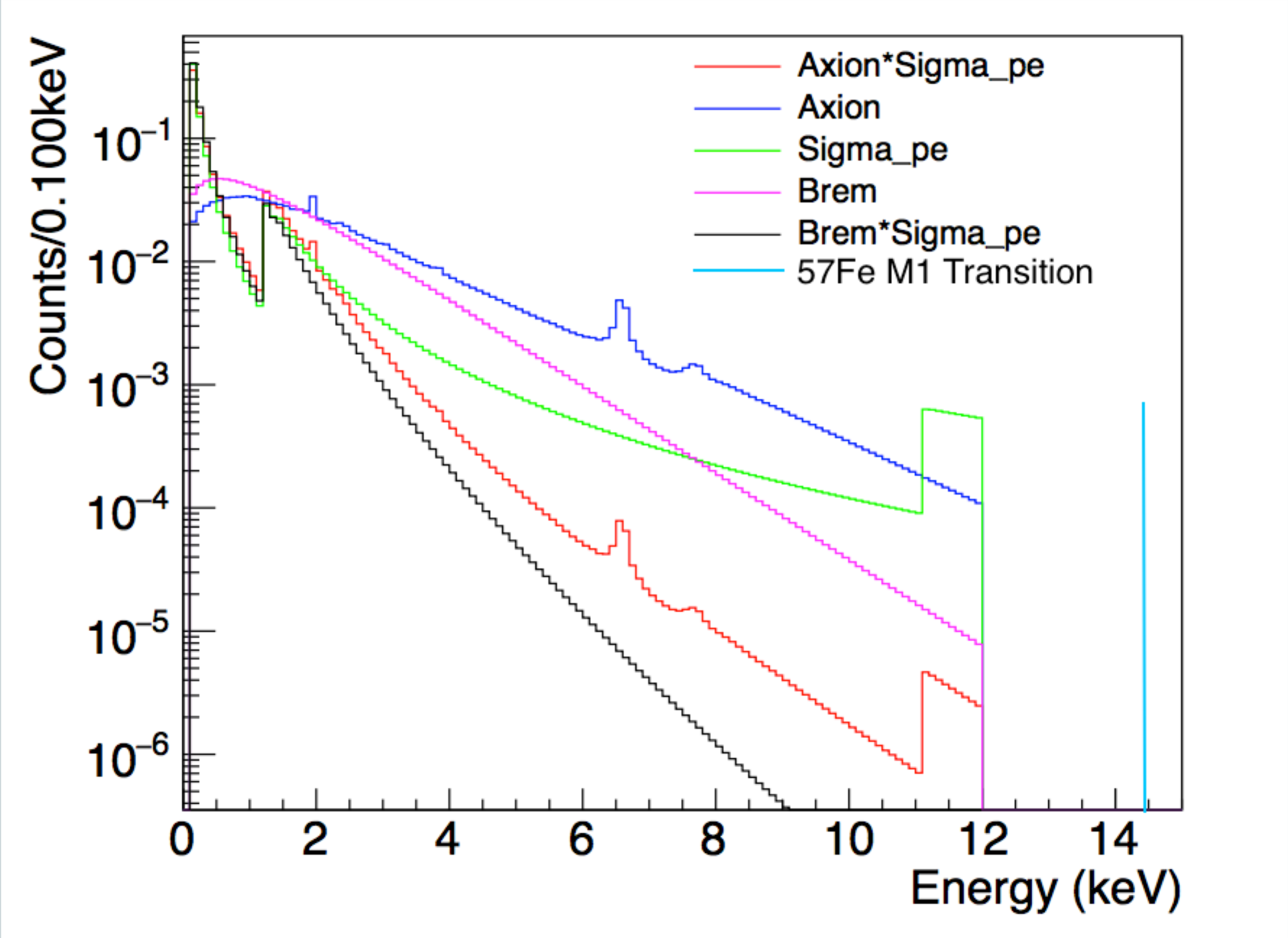
SOLAR AXION SPECTRUM IN Ge



Idea from J. Redondo, [arXiv:1310.0823](https://arxiv.org/abs/1310.0823) [hep-ph]

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❖ Electron Decay:

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