A Dark Matter Search with MALBEK

Graham Giovanetti
on behalf of the MAJORANA Collaboration

The MAJORANA Collaboration

Black Hills State University, Spearfish, SD
Kara Keeter

Duke University, Durham, North Carolina , and TUNL
Matthew Busch, James Esterline, Gary Swift, Werner Tornow

Institute for Theoretical and Experimental Physics, Moscow, Russia
Alexander Barabash, Sergey Konovalov, Vladimir Yumatov

Joint Institute for Nuclear Research, Dubna, Russia
Viktor Brudanin, Slava Egorov, K. Gusey,
Oleg Kochetov, M. Shirchenko, V. Timkin, E. Yakushev

Lawrence Berkeley National Laboratory, Berkeley, California and the University of California - Berkeley
Nicolas Abgrall, Mark Amman, Paul Barton, Yuen-Dat Chan, Alex Hegai, Paul Luke, Ryan Martin, Susanne Mertens, Alan Poon, Kai Vetter, Harold Yaver

Los Alamos National Laboratory, Los Alamos, New Mexico
Melissa Boswell, Steven Elliott,, Johnny Goett, Keith Rielage, Larry Rodriguez, Michael Ronquest, Harry Salazar, Wenqin Xu

North Carolina State University, Raleigh, North Carolina and TUNL
Dustin Combs, Lance Leviner, David G. Phillips II, Albert Young

Oak Ridge National Laboratory, Oak Ridge, Tennessee
Fred Bertrand, Greg Capps, Alfredo Galindo-Uribarri,
Kim Jeskie, David Radford, Robert Varner, Brandon White,
Chang-Hong Yu

Osaka University, Osaka, Japan
Hiroyasu Ejiri, Ryuta Hazama, Masaharu Nomachi, Shima Tatsuji

Pacific Northwest National Laboratory, Richland, Washington
Estanislao Aguayo, Jim Fast, Eric Hoppe, Richard T. Kouzes, Brian LaFerriere, John Orrell, Nicole Overman, Doug Reid, Aleksandr Soin

Shanghai Jiaotong University, Shanghai, China
James Loach

South Dakota School of Mines and Technology, Rapid City, South Dakota
Adam Caldwell, Cabot-Ann Christofferson, Stanley Howard,
Anne-Marie Suriano, Jared Thompson

Tennessee Tech University, Cookeville, Tennessee
Mary Kidd

University of Alberta, Edmonton, Alberta
Aksel Hallin

University of North Carolina, Chapel Hill, North Carolina and TUNL
Florian Fraenkle, Graham K. Giovanetti, Matthew P. Green,
Reyco Henning, Mark Howe, Sean MacMullin, Benjamin Shanks,
Christopher O'Shaughnessy, Jacqueline Strain, Kris Vorren, John F. Wilkerson

University of South Carolina, Columbia, South Carolina
Frank Avignone, Vince Guiseppe, Leila Mizouni, Clint Wiseman

University of South Dakota, Vermillion, South Dakota
Nathan Snyder

University of Tennessee, Knoxville, Tennessee
Yuri Efremenko, Sergey Vasilyev

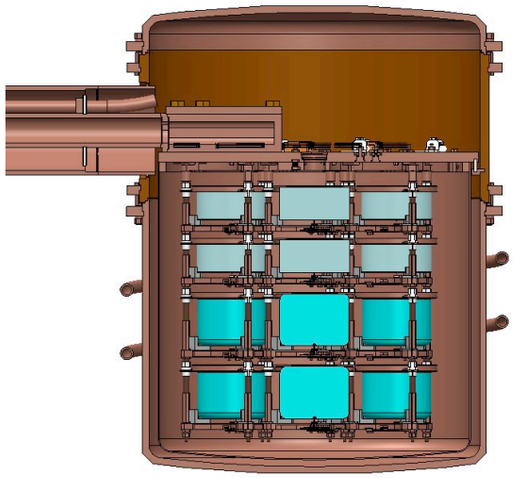
University of Washington, Seattle, Washington
Tom Burritt, Clara Cuesta, Jason Detwiler, Peter J. Doe, Julieta Gruszko, Greg Harper,
Jonathan Leon, David Peterson, R. G. Hamish Robertson, Alexis Schubert, Tim Van Wechel

The MAJORANA DEMONSTRATOR

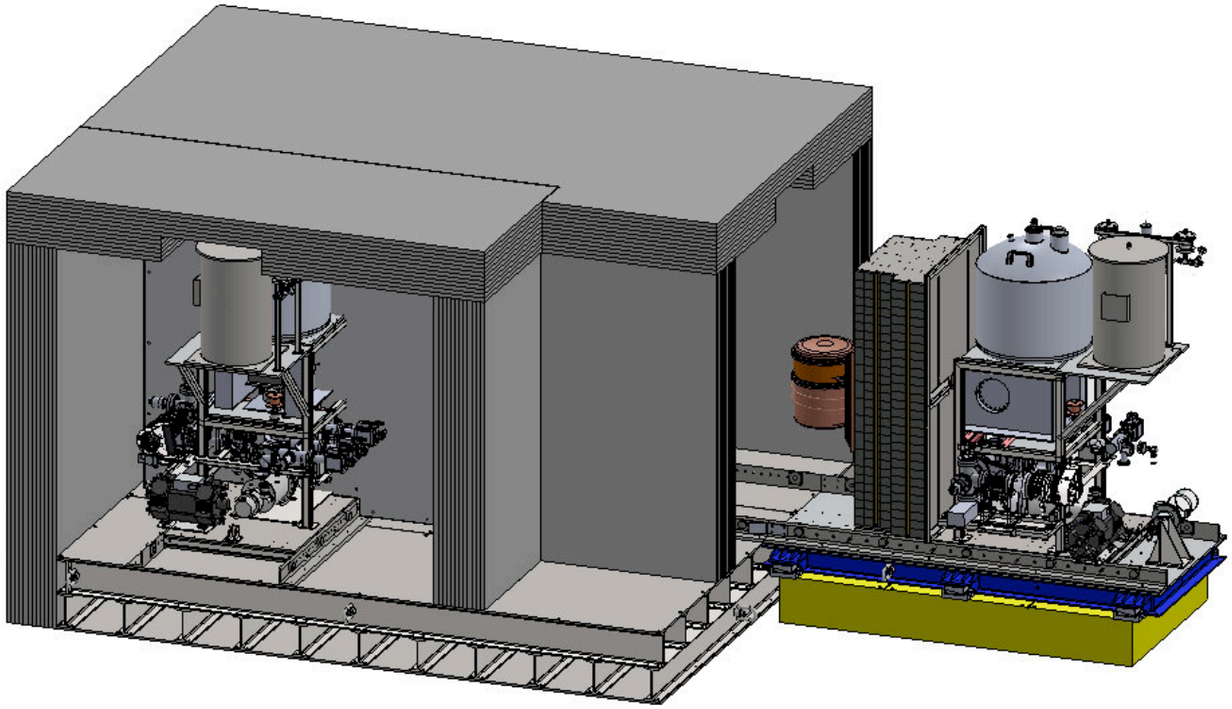
Funded by DOE Office of Nuclear Physics and NSF Particle Astrophysics,
with additional contributions from international collaborators.

Goals

- Demonstrate backgrounds low enough to justify building a tonne scale experiment
- Establish feasibility to construct & field modular arrays of Ge detectors.
- Test Klapdor-Kleingrothaus claim
- Search for additional physics beyond the standard model



- **Located underground at 4850' Sanford Underground Research Facility**
- **Background Goal in the 0νββ peak region of interest (4 keV at 2039 keV)**
  - **3 counts/ROI/t/y** (after analysis cuts)
  - *scales to 1 count/ROI/t/y for a tonne experiment*
- **40-kg of Ge detectors**
  - 30 kg of 86% enriched ^{76}Ge crystals
  - 10 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

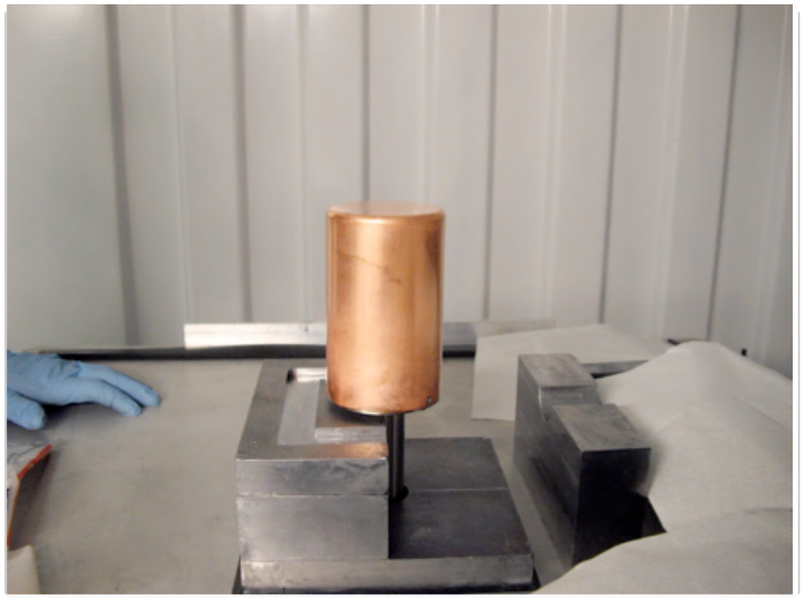


MALBEK

MAJORANA **L**ow-Background **BE**Ge Detector at **K**URF

Goals

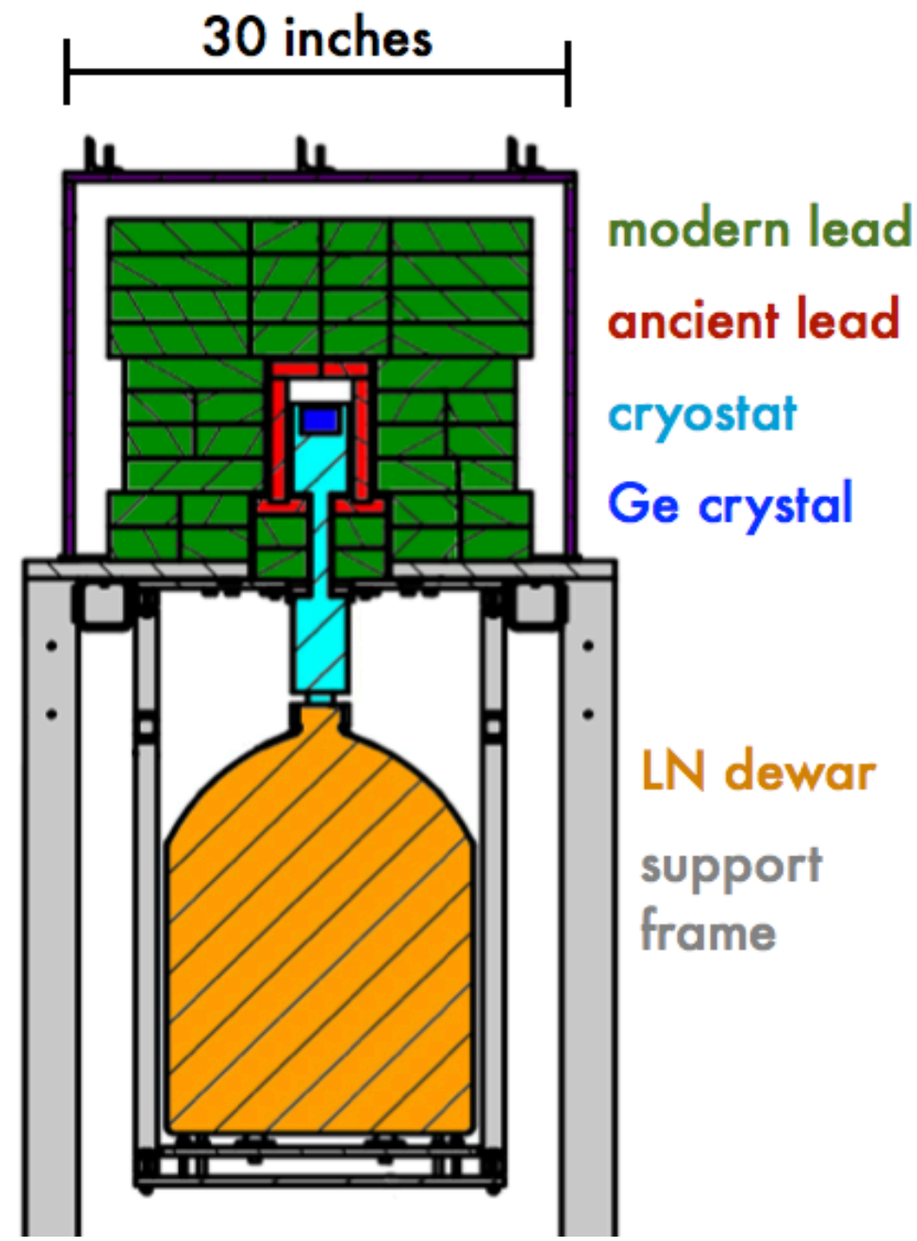
- Perform a search for light WIMP Dark Matter and test the sensitivity of MJD
- Study backgrounds over a wide energy range, including surface events
- Validate the MJD background model
- Detector geometry optimization study
- Test MJD-like DAQ



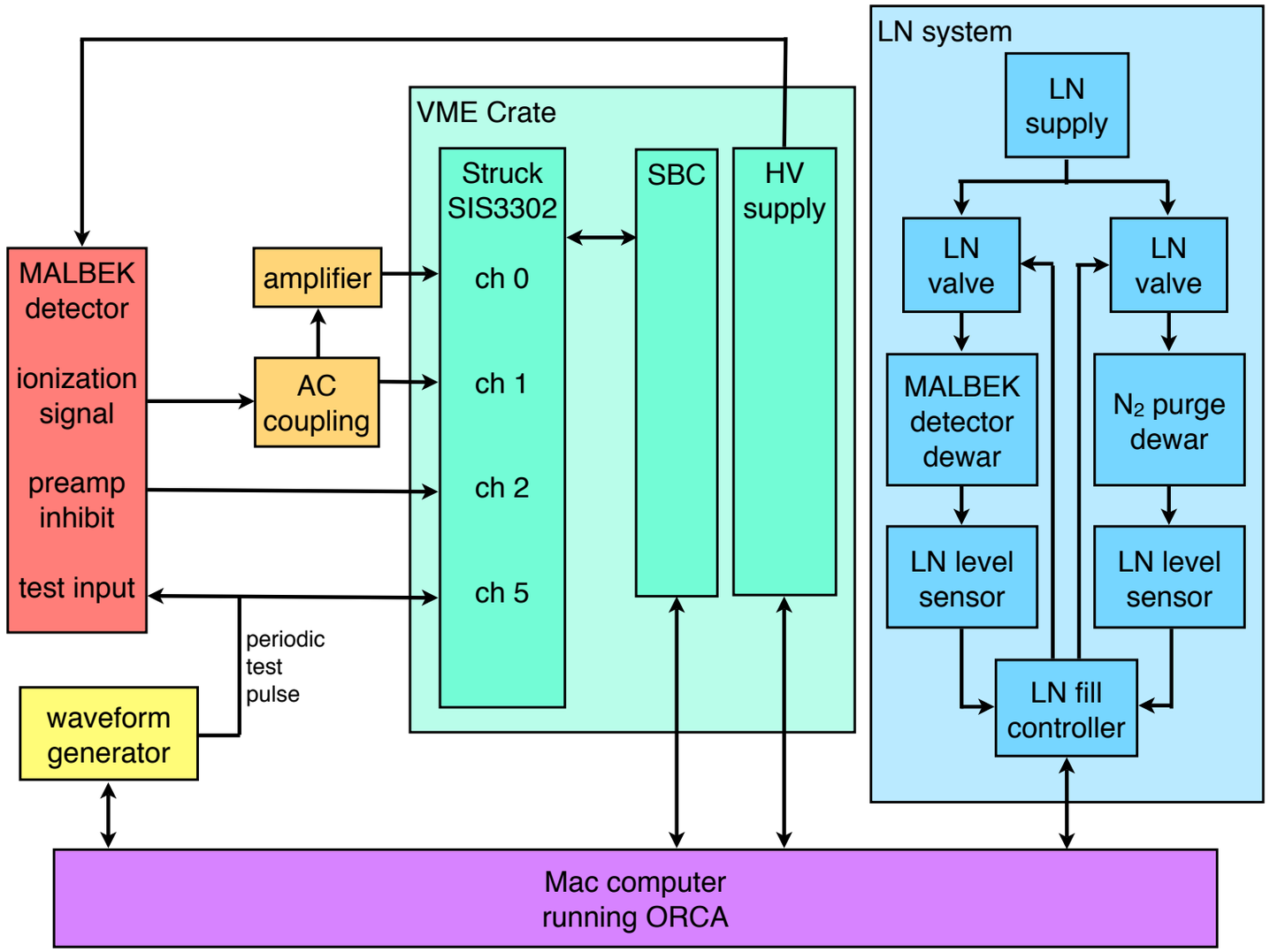
MALBEK

MAJORANA **L**ow-Background **BE**Ge Detector at **K**URF

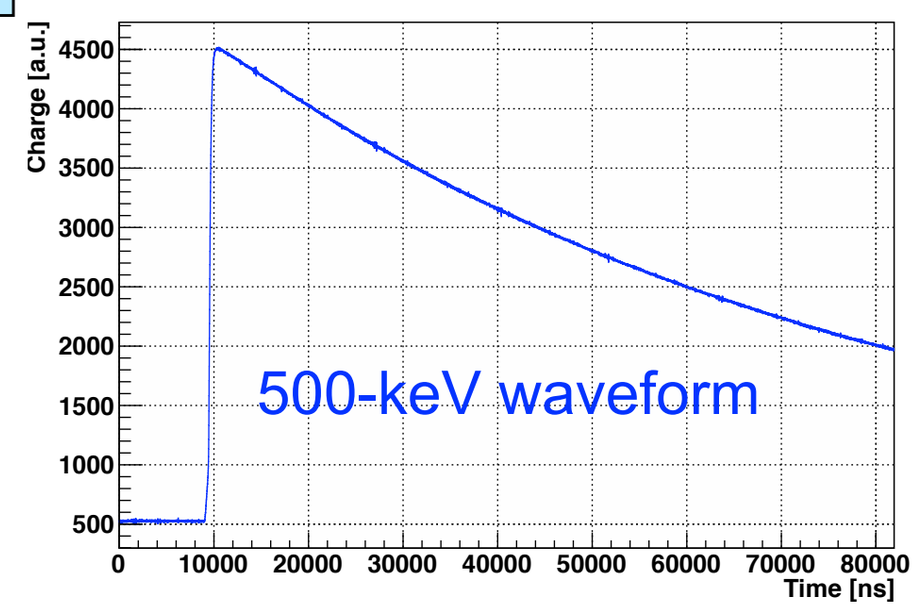
- 450 g Canberra modified Broad Energy Ge (BEGe) detector with ultra low-background components provided by J.I. Collar
- housed in shield at 1450 m.w.e. at the Kimballton Underground Research Facility (KURF) in Ripplemead, VA



DAQ



- digitize waveforms of ionization signals
  - 82-μs long
  - 100 MHz
- pulser is used for determining cut acceptance



slide from A. Schubert

MALBEK data sets

start date	end date	live time	exposure	Pb shims	
11-03-08	11-08-16	108.81 d	44.00 kg-d	yes	multiple DAQ configurations
11-11-15	12-08-29	221.49 d	89.53 kg-d	no	used for DM search

Detector fiducial mass*: 404 ± 15 g

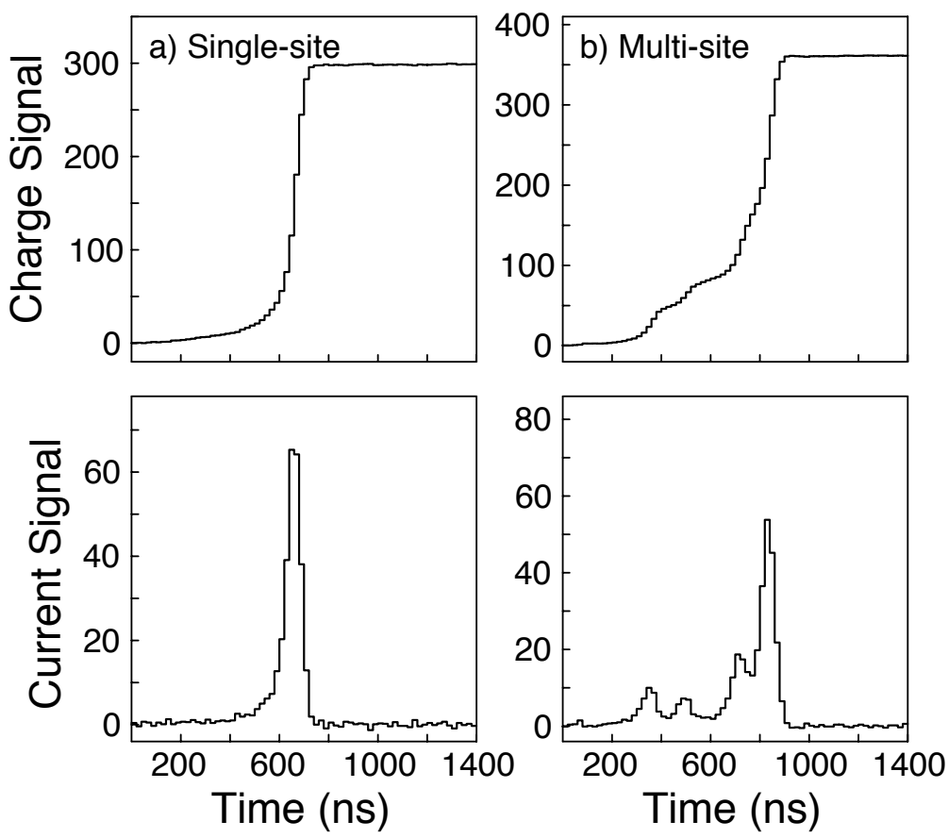
determined by comparing measured ^{133}Ba peak ratios to simulation

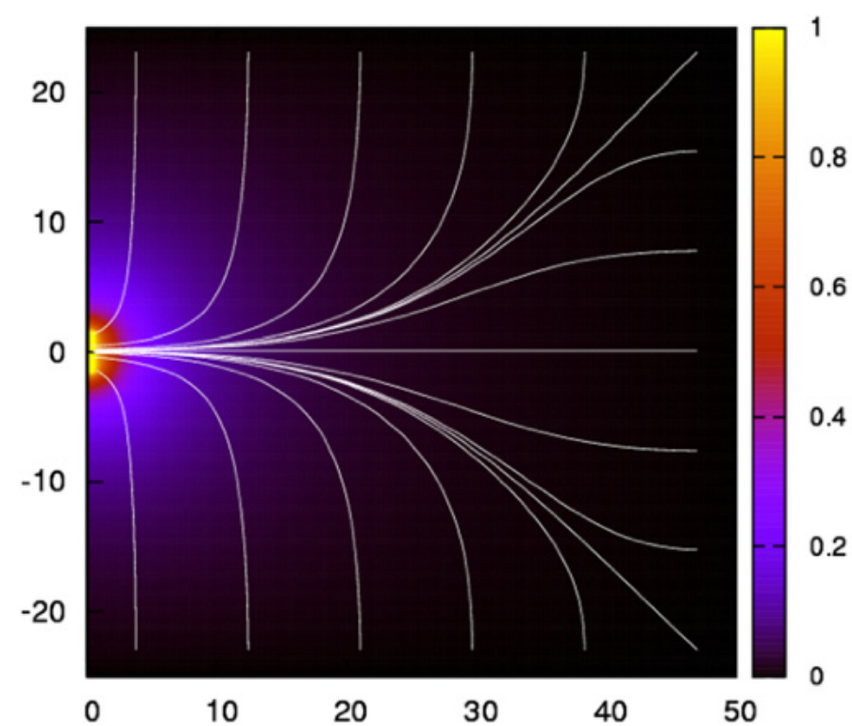
* A. G. Schubert, PhD Thesis, Univ. of Washington, 2012.

p-type point contact detectors

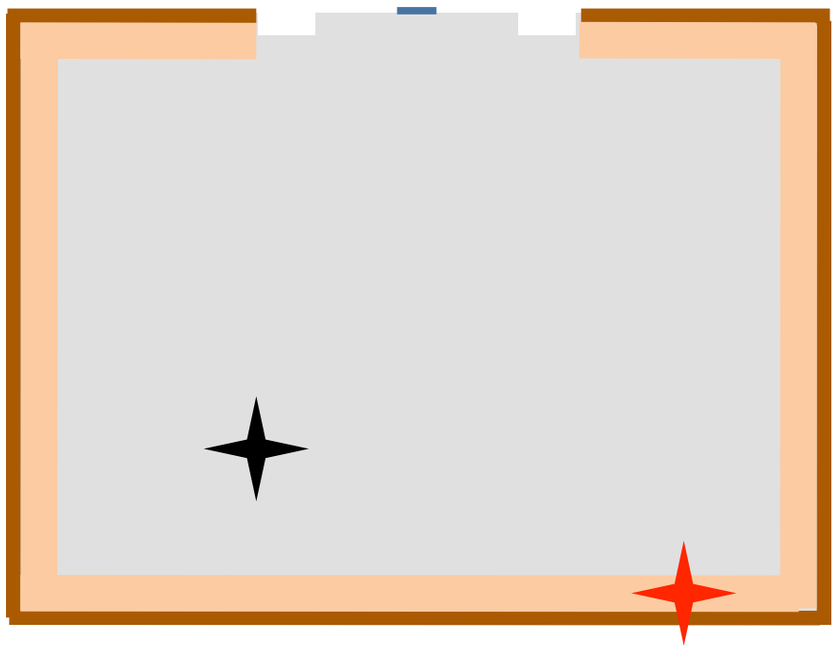
Luke et al., IEEE trans. Nucl. Sci. 36 , 926(1989); P. S. Barbeau, J. I. Collar, and O. Tench, J. Cosm. Astro. Phys. 0709 (2007)
R. J. Cooper et al., NIM A, 629 (2011)

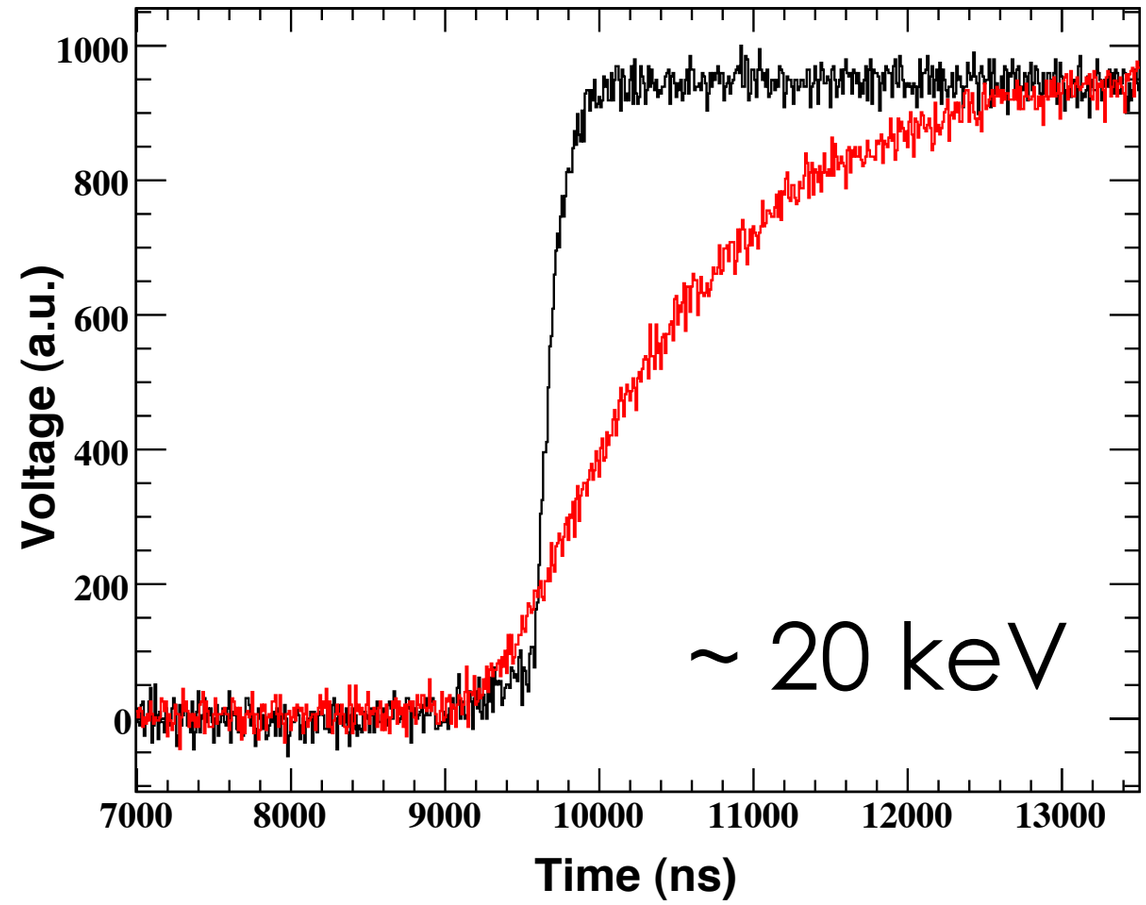
- allow multiple-site scattering event discrimination
- simple, relatively cheap, and easy to handle
- added benefits from sub-keV thresholds:
  - allow rejection of events from cosmogenically produced ^{68}Ge, a background to $0\nu\beta\beta$.
  - extends physics reach of the DEMONSTRATOR





slow surface events

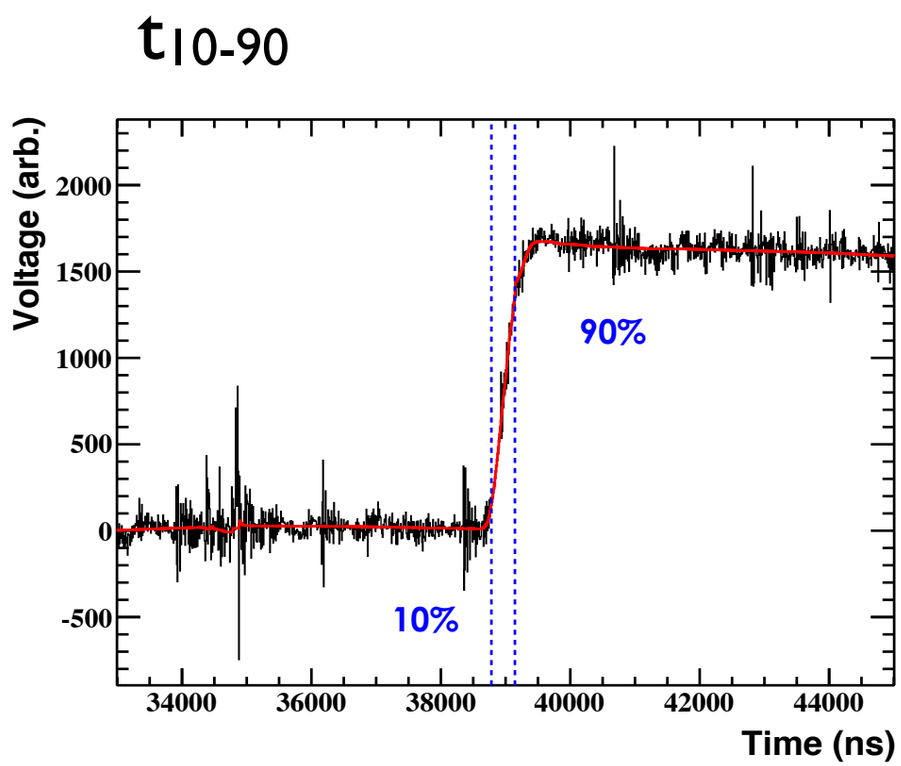


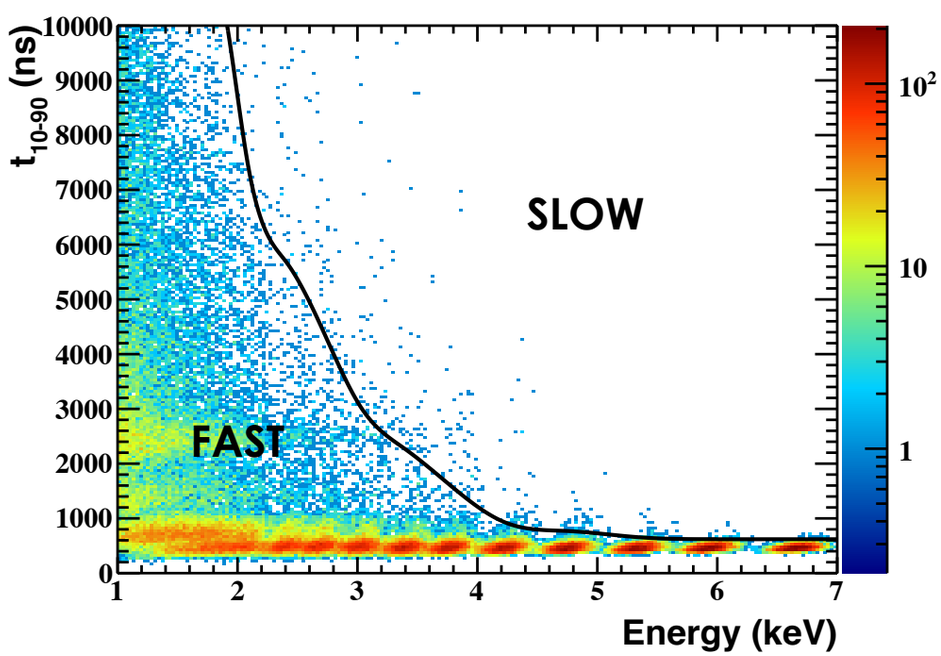


- active volume
- n+ dead layer
- transition region – partial charge collection

wavelet PSA to identify slow signals

from P. S. Finnerty, PhD Thesis, UNC - Chapel Hill.



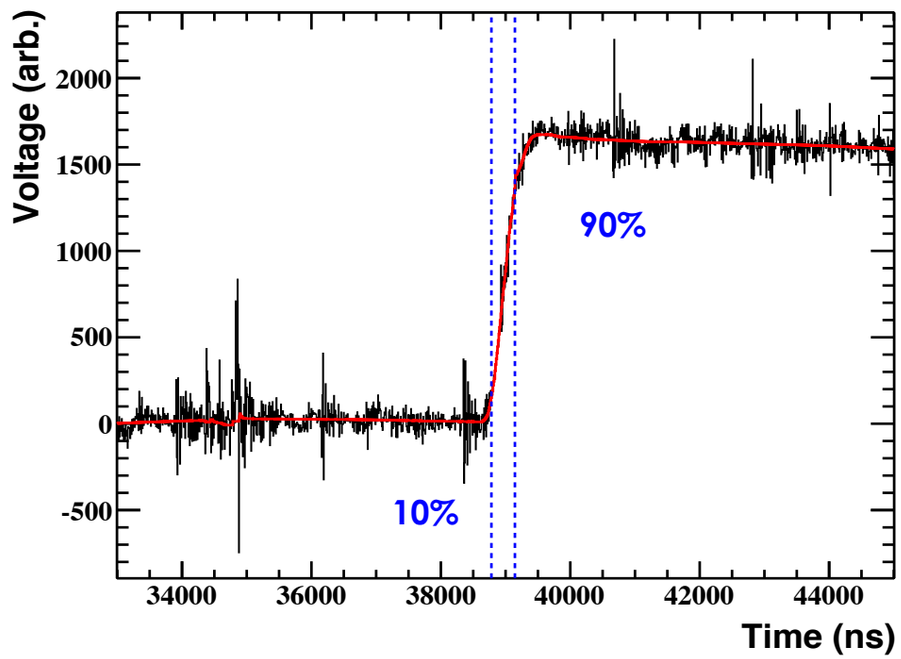


—— 99% acceptance curve estimated from fast pulser data

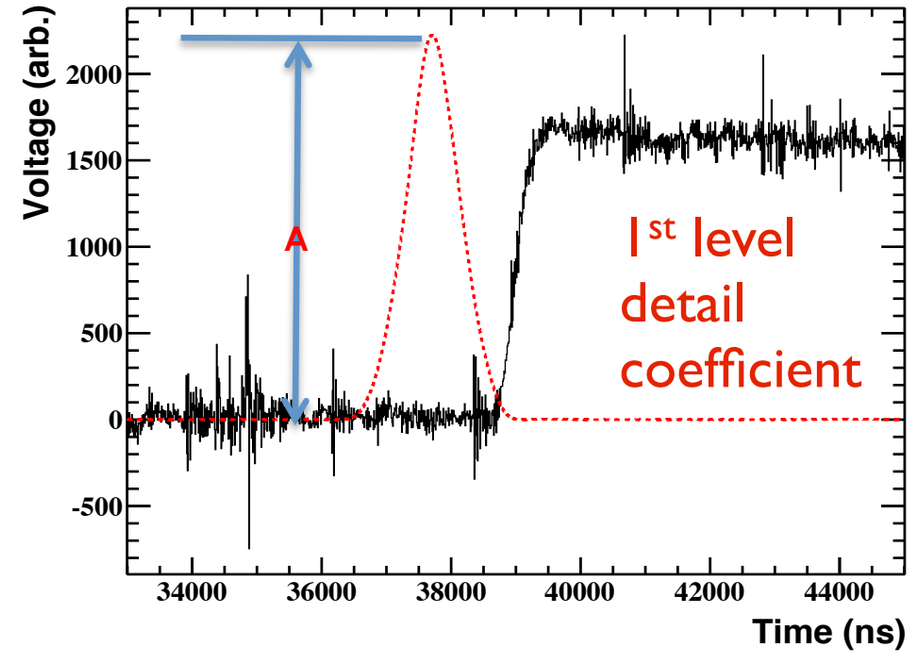
wavelet PSA to identify slow signals

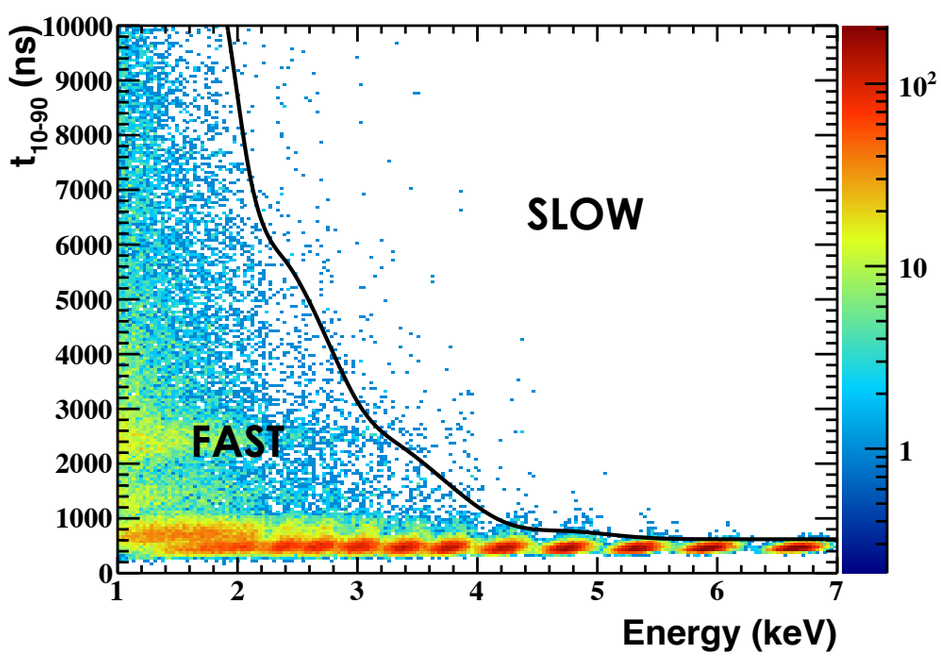
from P. S. Finnerty, PhD Thesis, UNC - Chapel Hill.

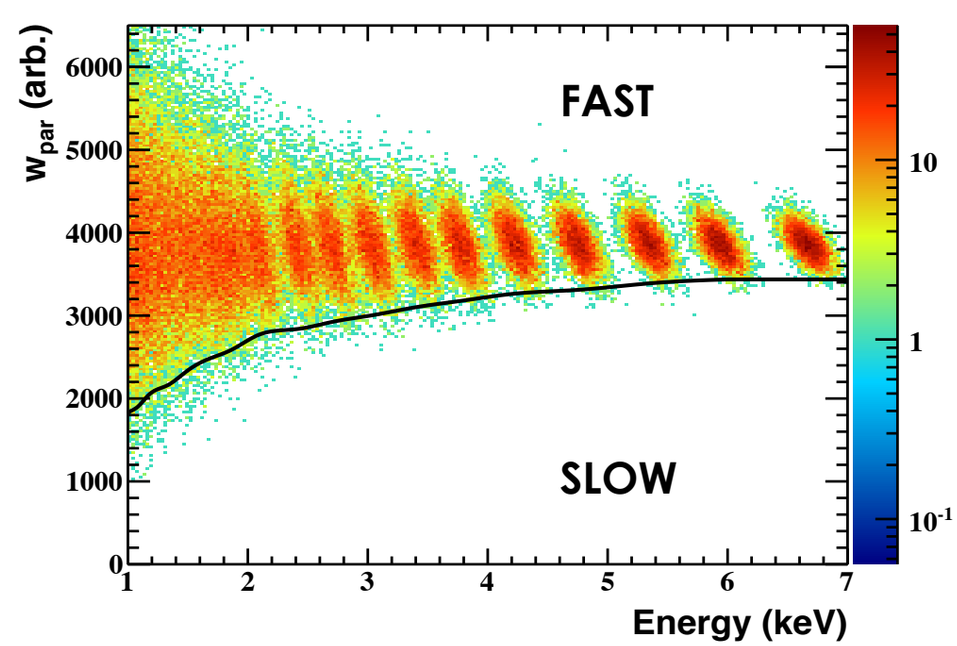
$t_{10\text{-}90}$



$w_{par}=A/E^2$

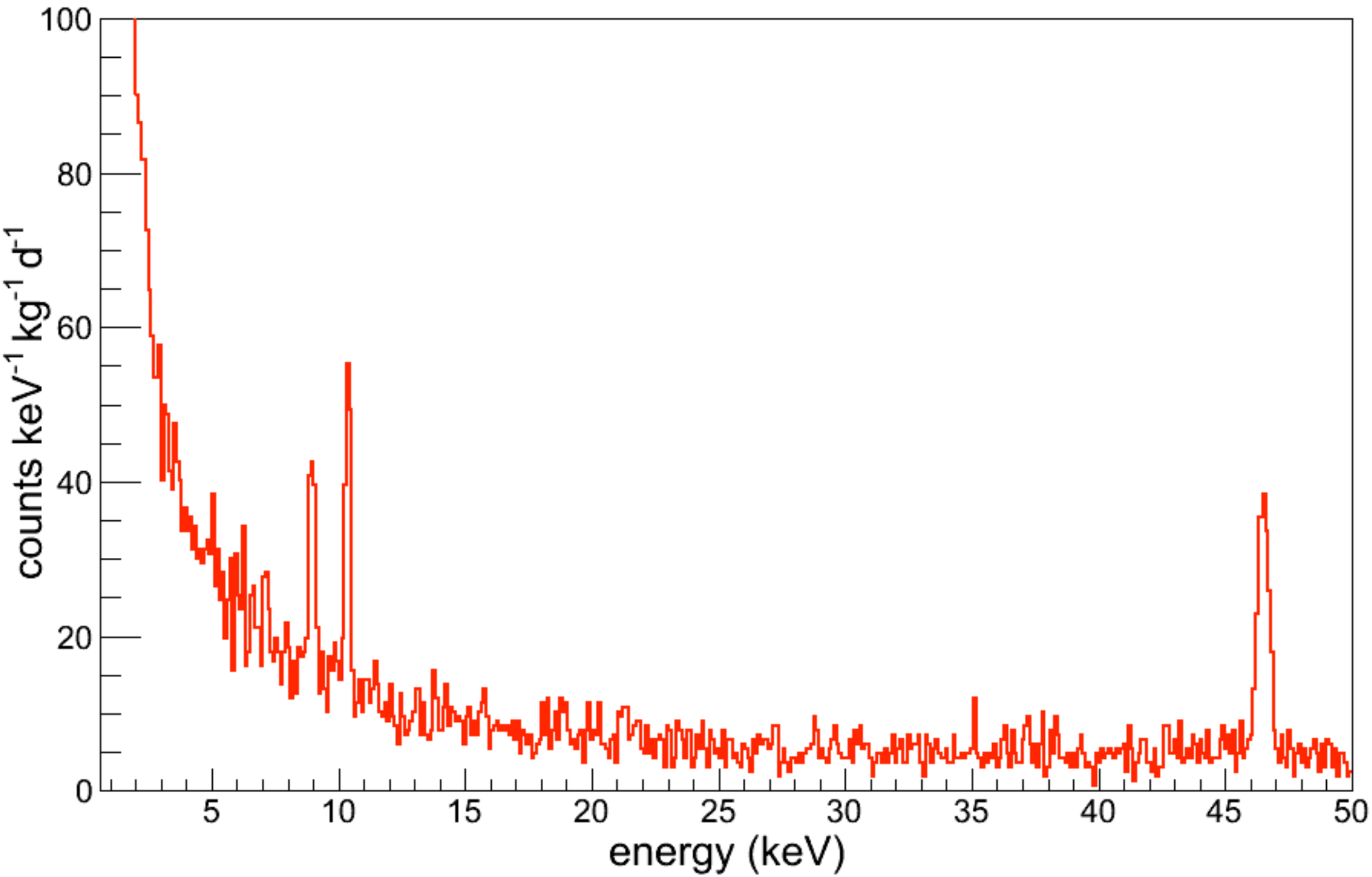




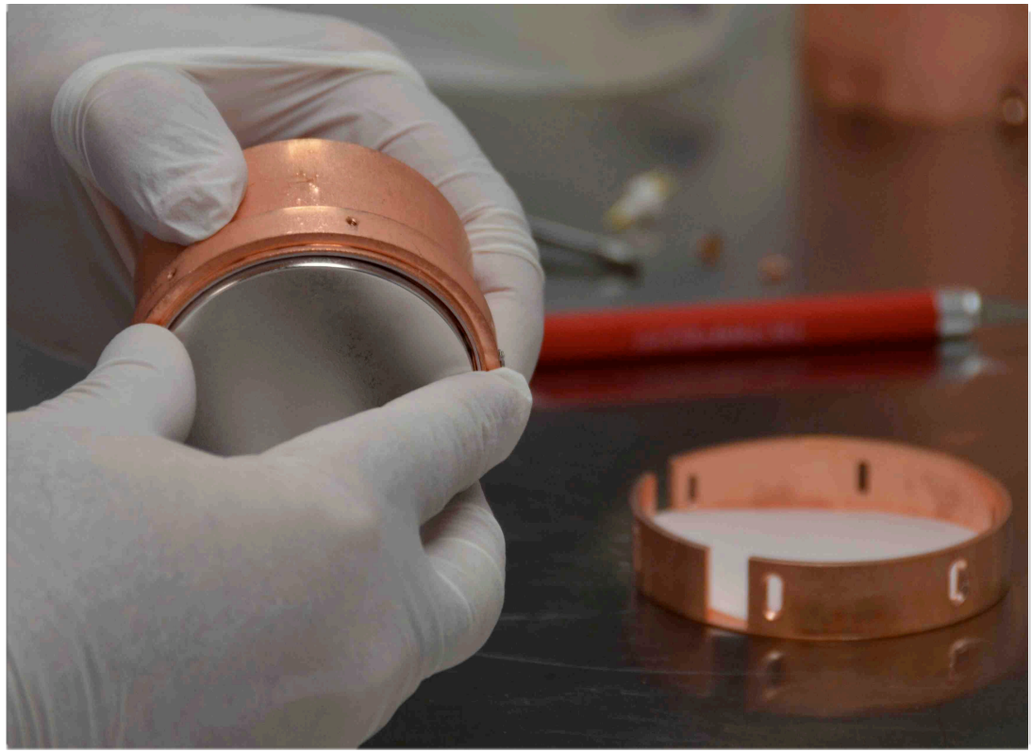


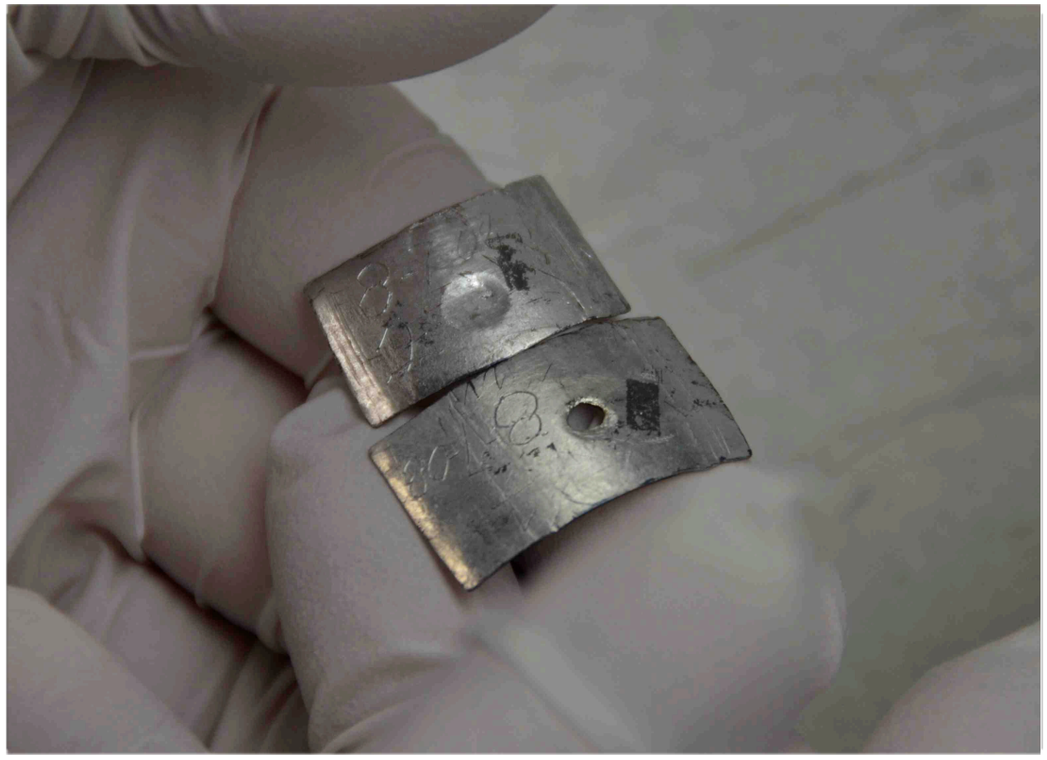
—— 99% acceptance curve estimated from fast pulser data

initial data showed a significant ^{210}Pb peak



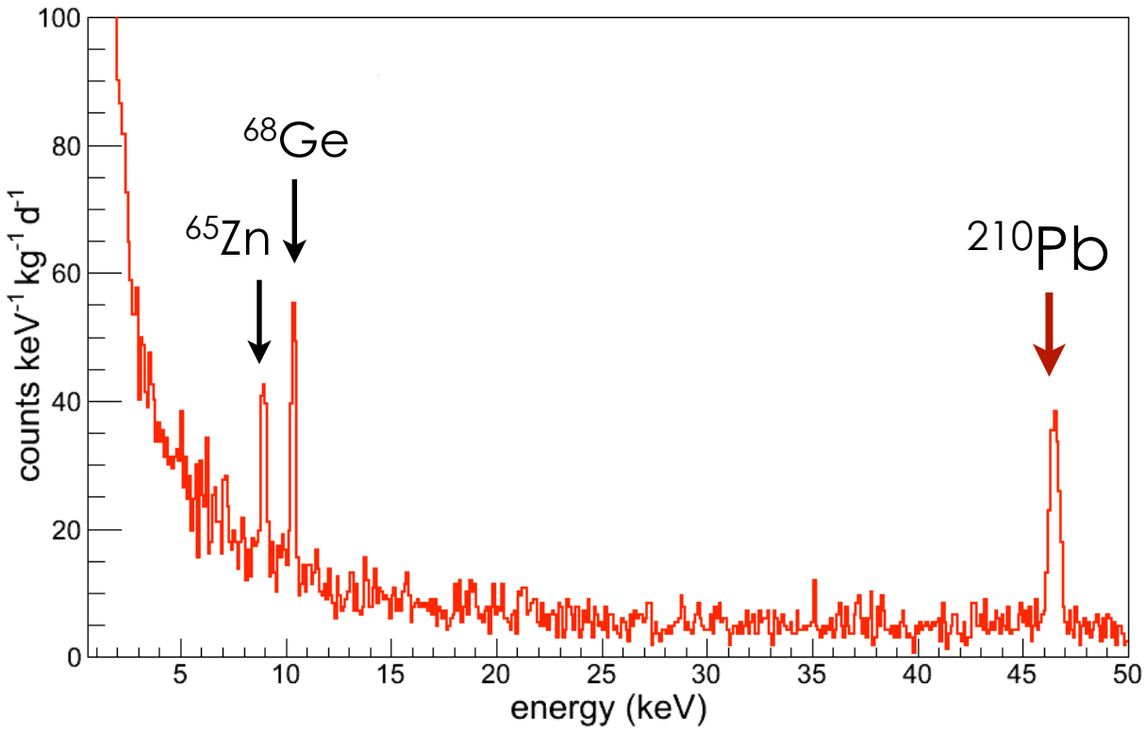
an inadvertent slow pulse source

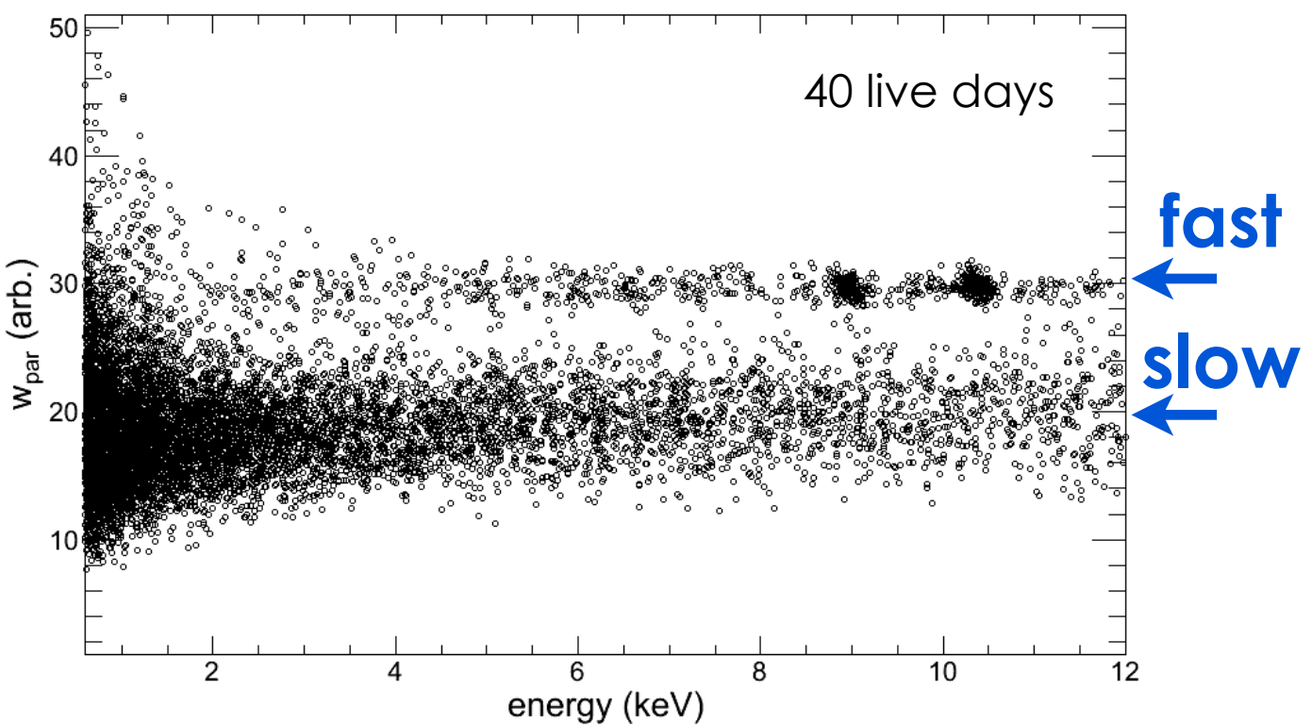




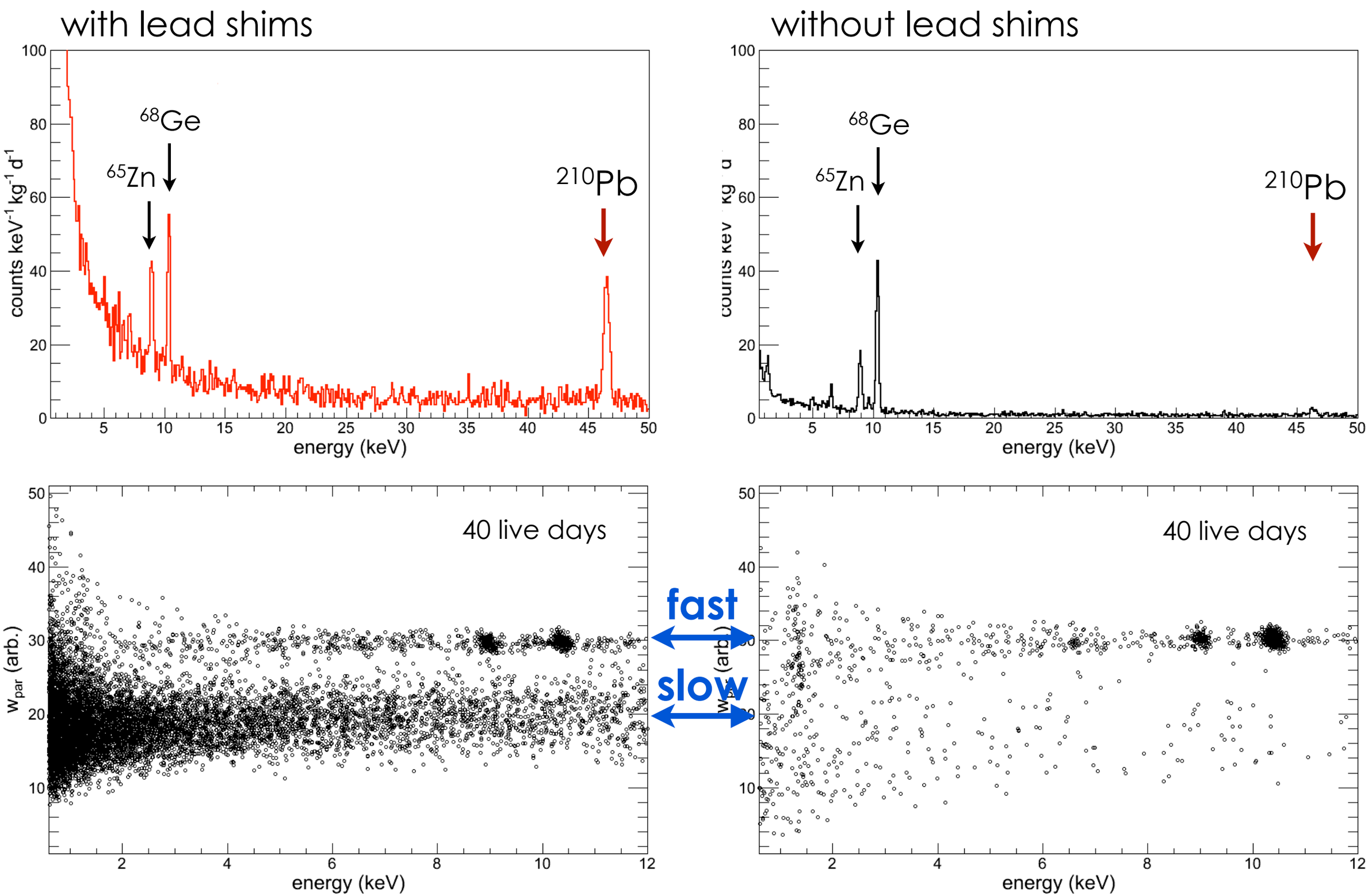
an inadvertent slow pulse source

with lead shims

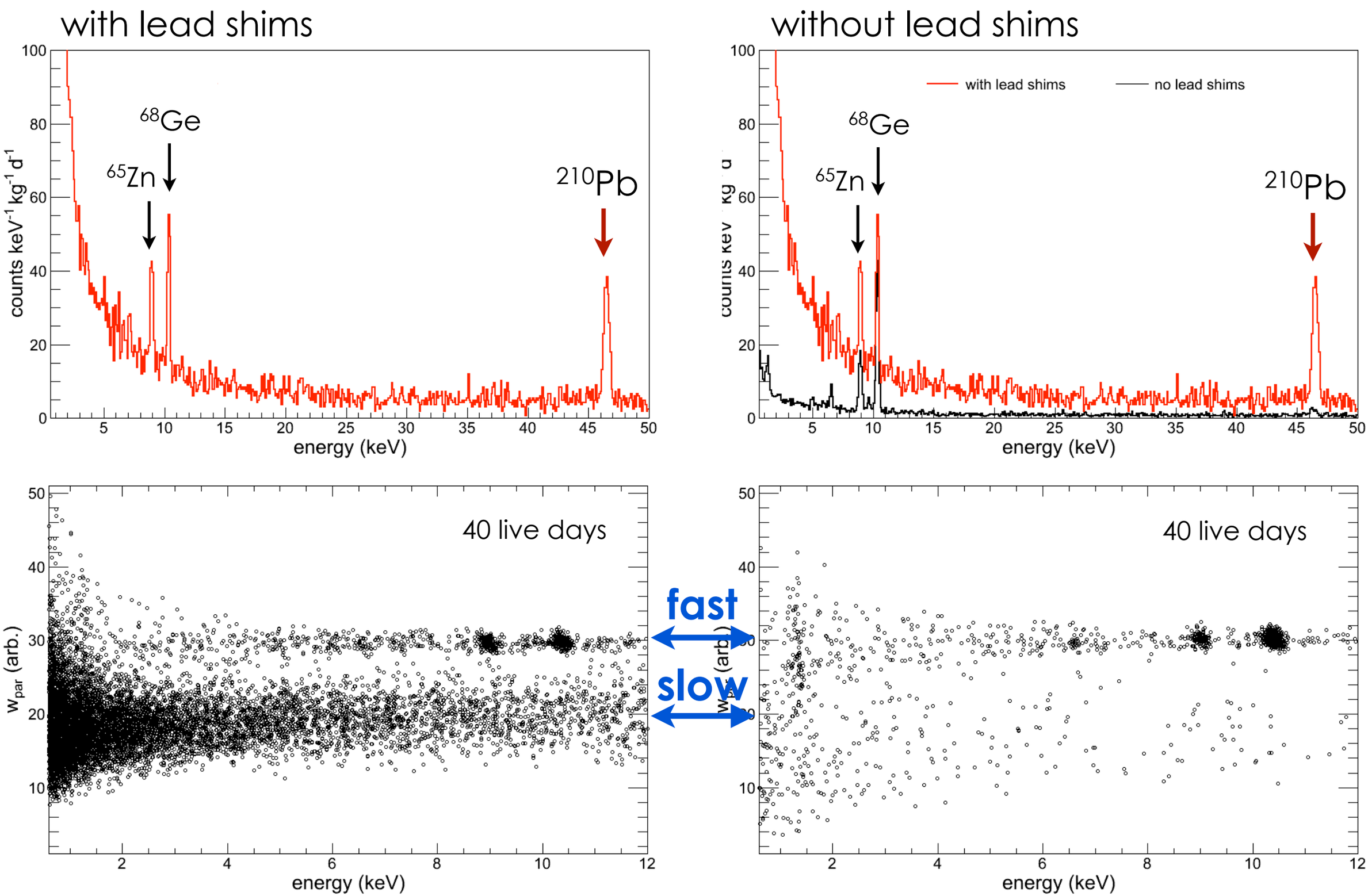




an inadvertent slow pulse source



an inadvertent slow pulse source

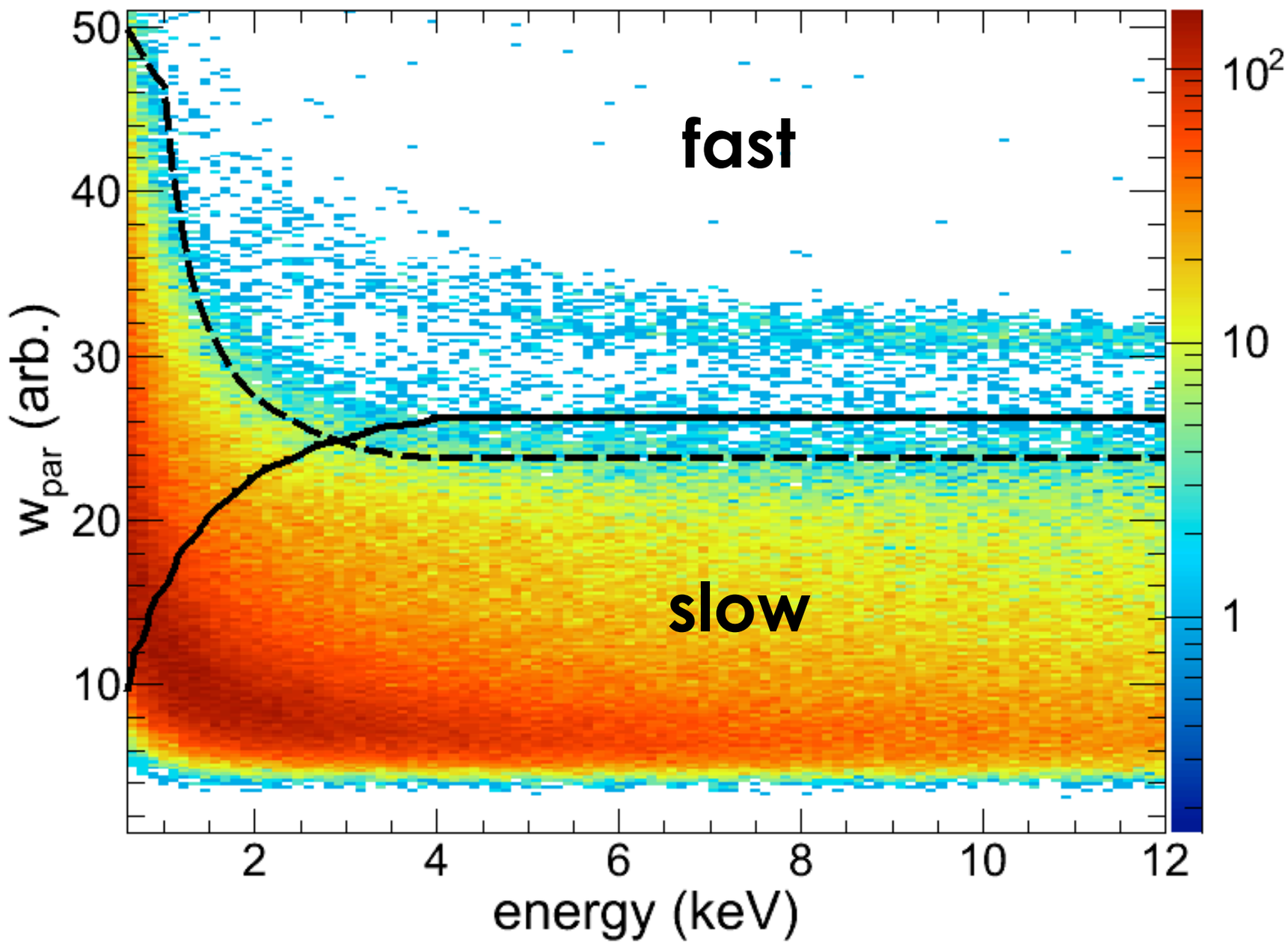


^{241}Am flood measurement

99% acceptance curve estimated from fast pulser

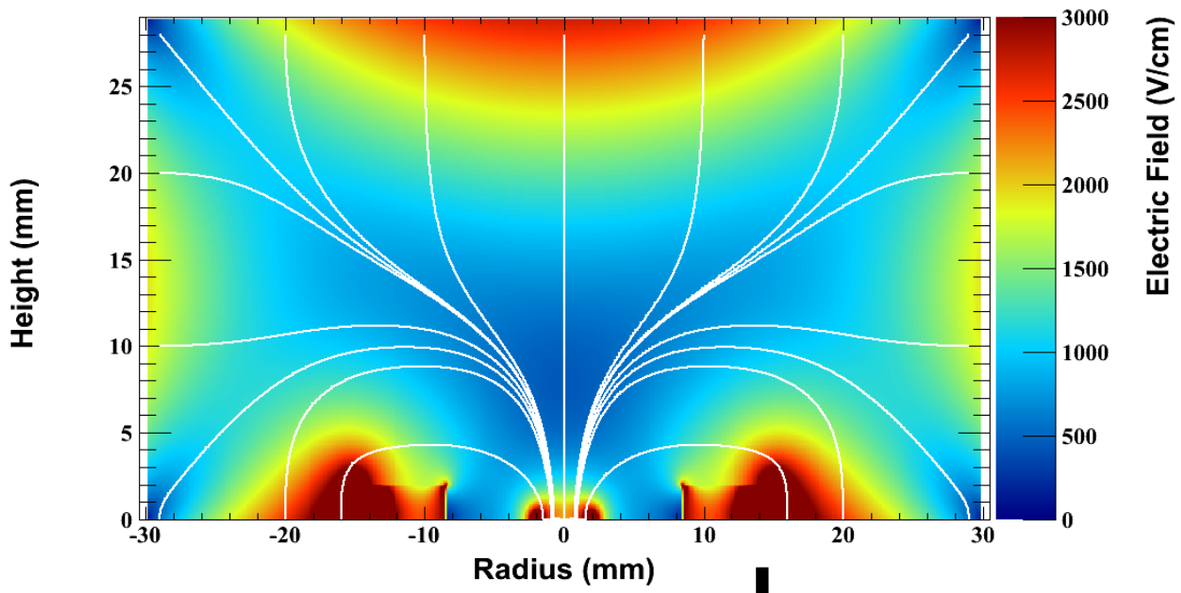
99% rejection curve for ^{241}Am data

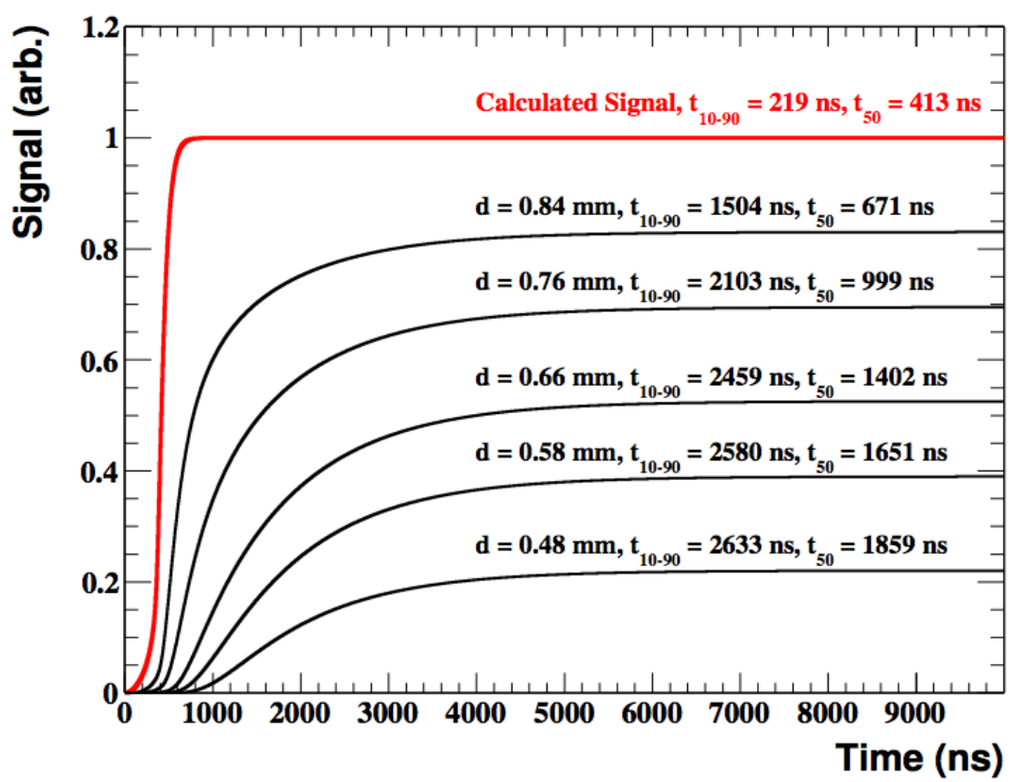
There is clear leakage of slow signals from the 60 keV line into the fast signal region

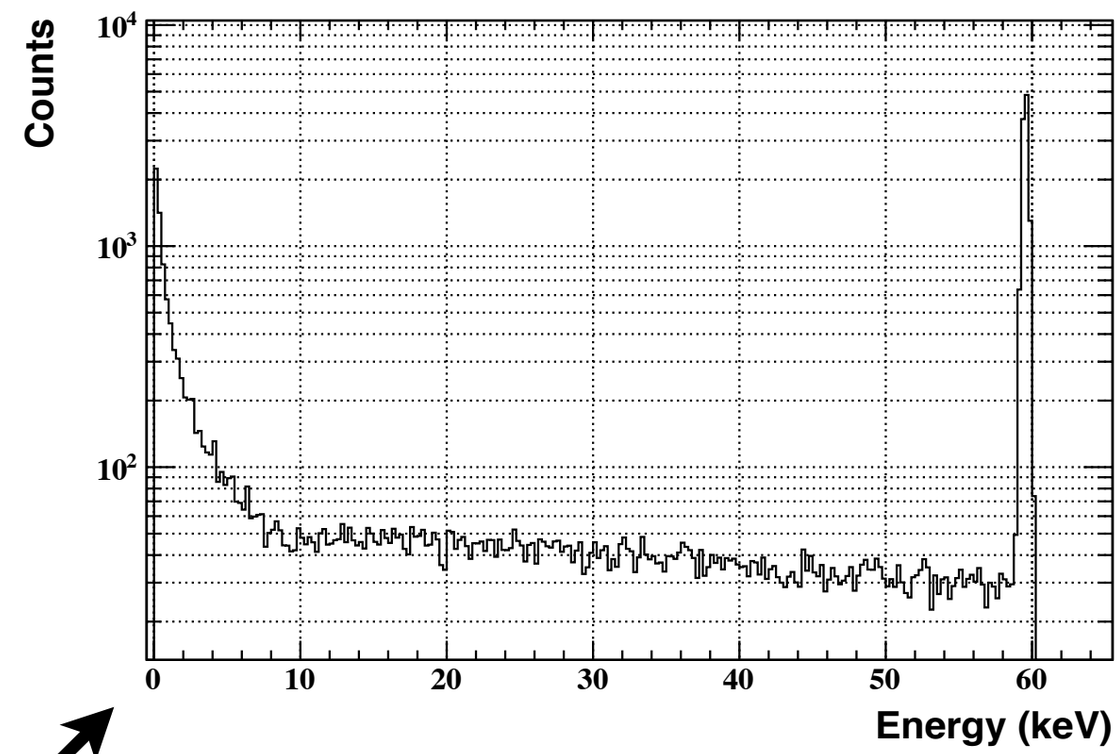


a qualitative slow pulse diffusion model

D.C. Radford and P. Finnerty



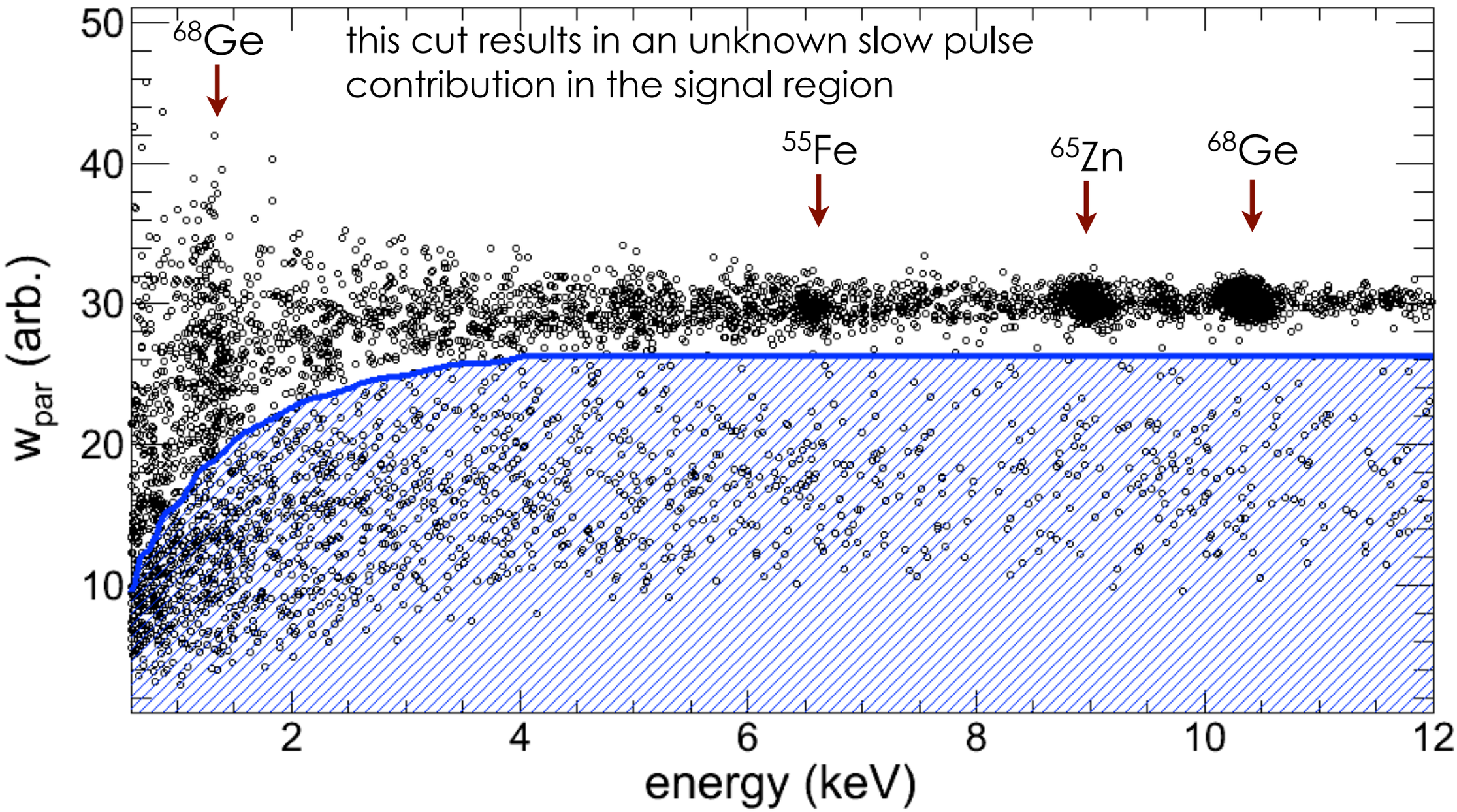




Big first step towards understanding physical mechanism responsible for slow-signals in PPC detectors.

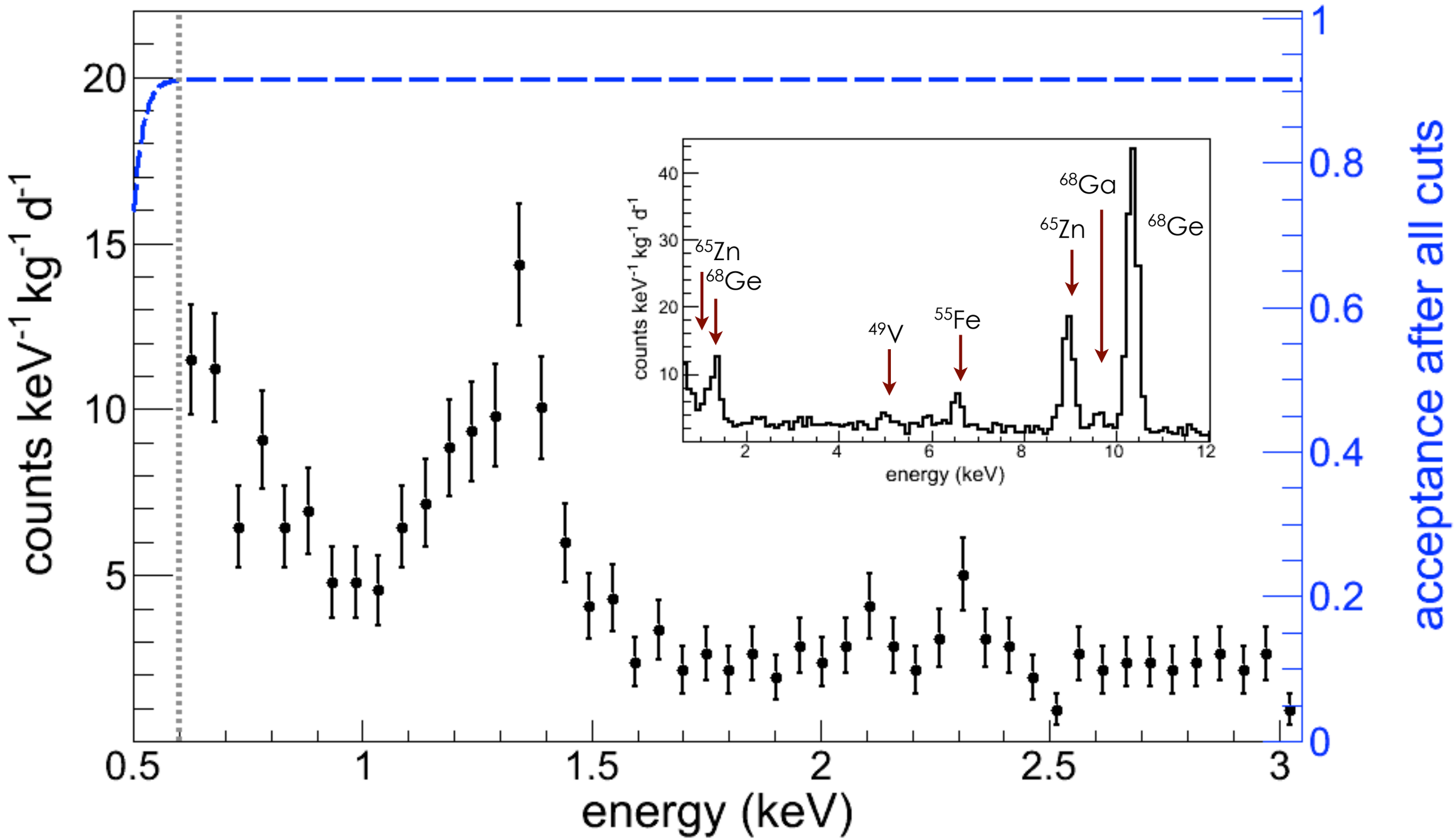
P. S. Finnerty, PhD Thesis, UNC - Chapel Hill.

w_{par} vs energy for 221 days of data



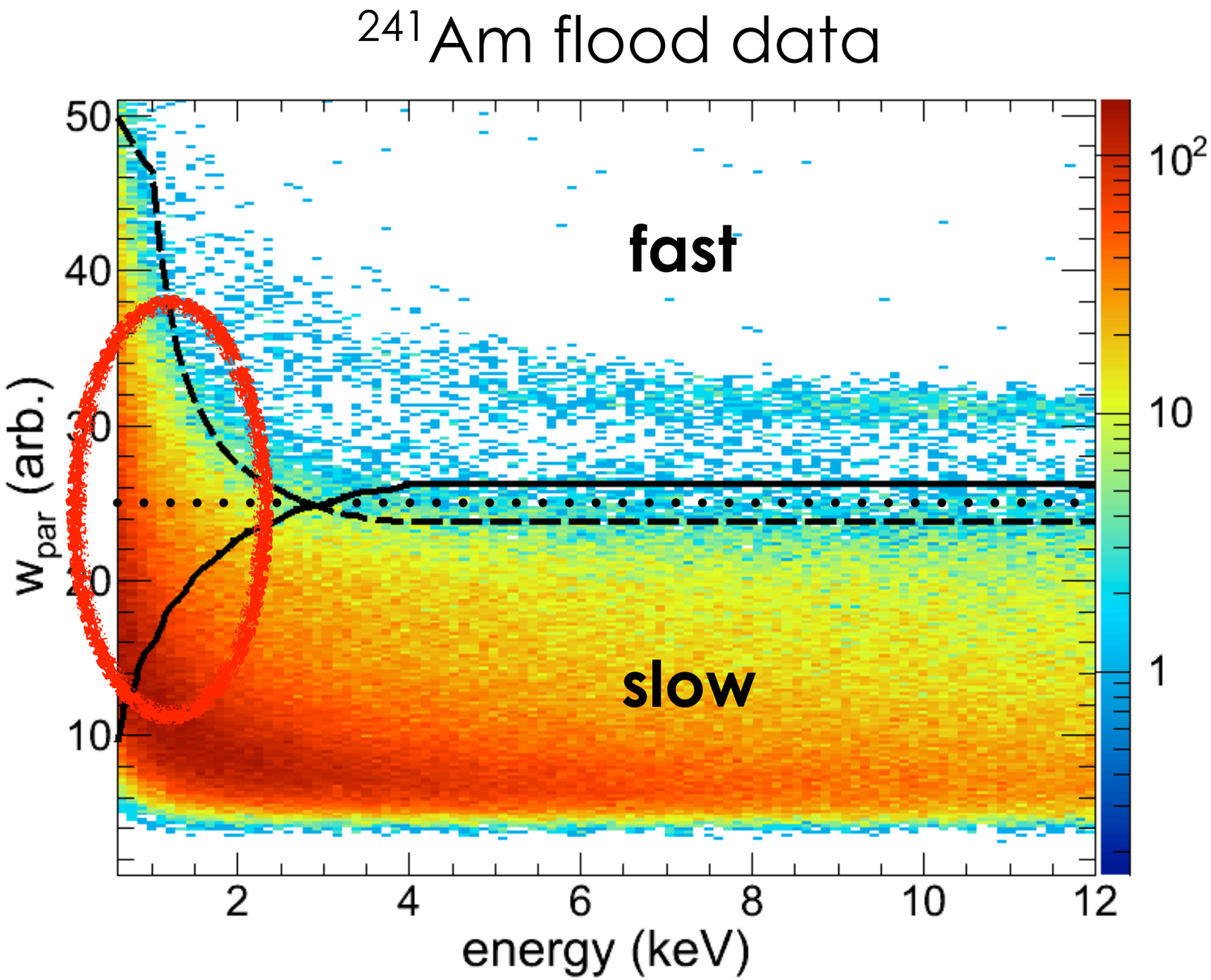
99% fast event acceptance curve determined from pulser data

221 day spectrum after 99% acceptance cut determined from fast pulser data

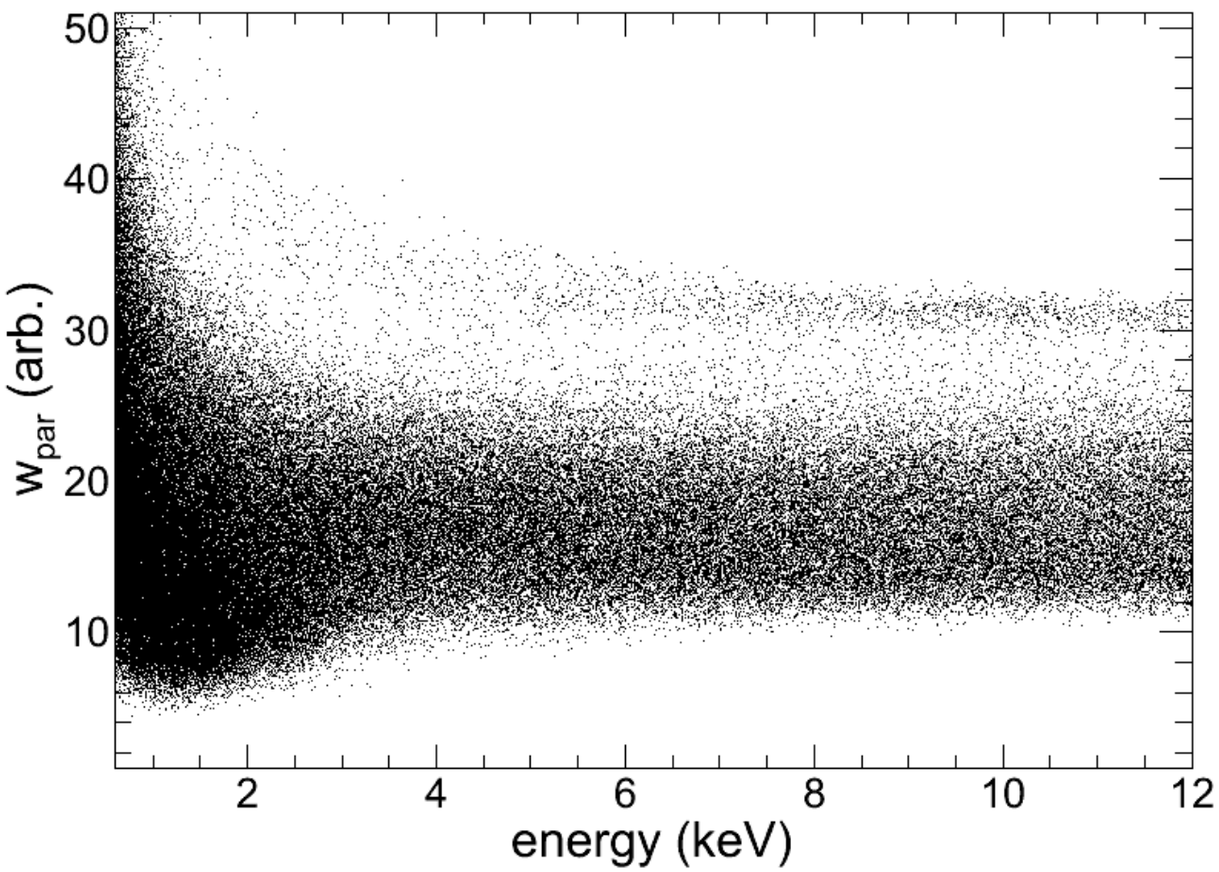


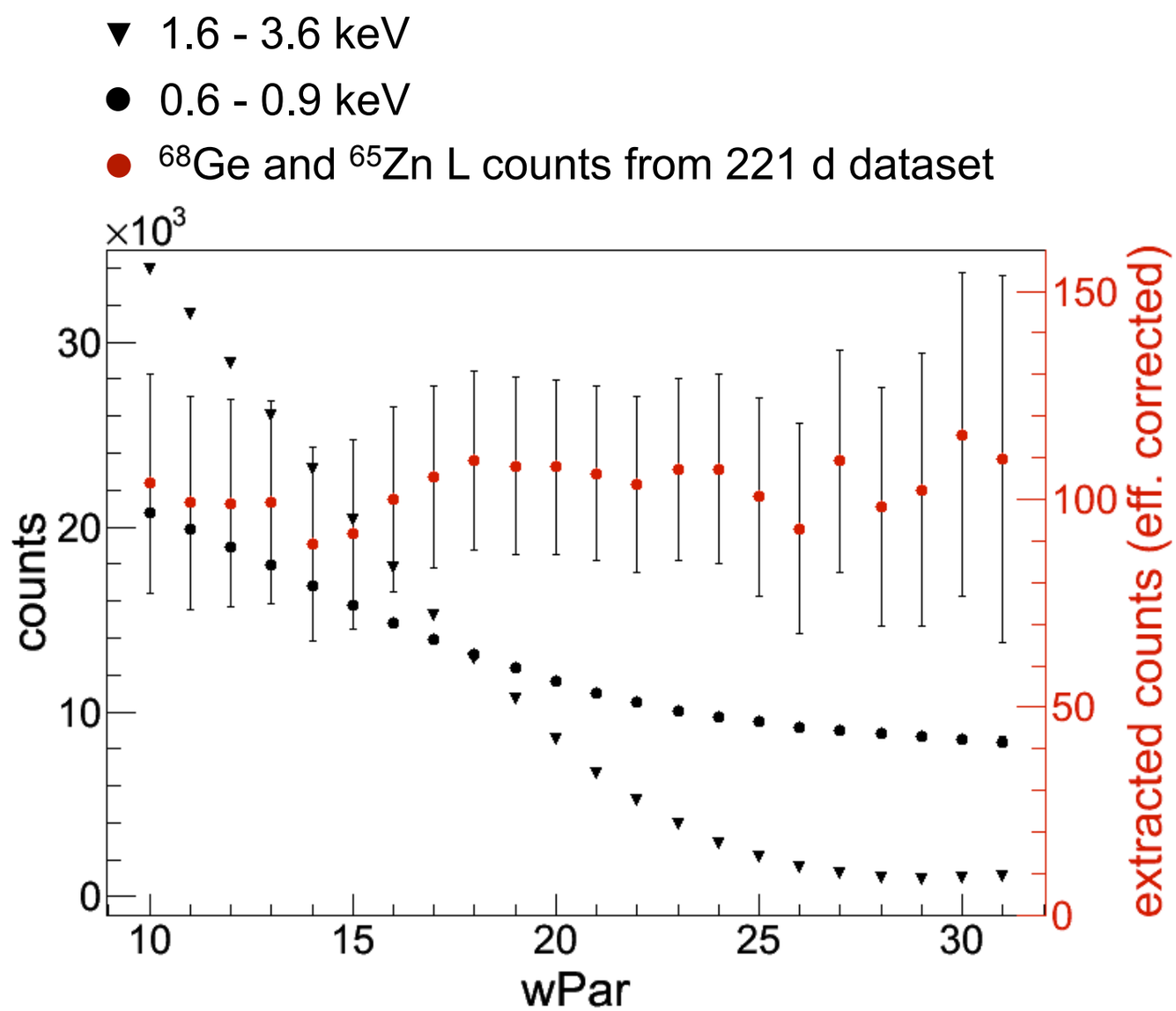
an alternative: constant w_{par} cut

remove slow events that leak into the signal region at the expense of reduced signal efficiency



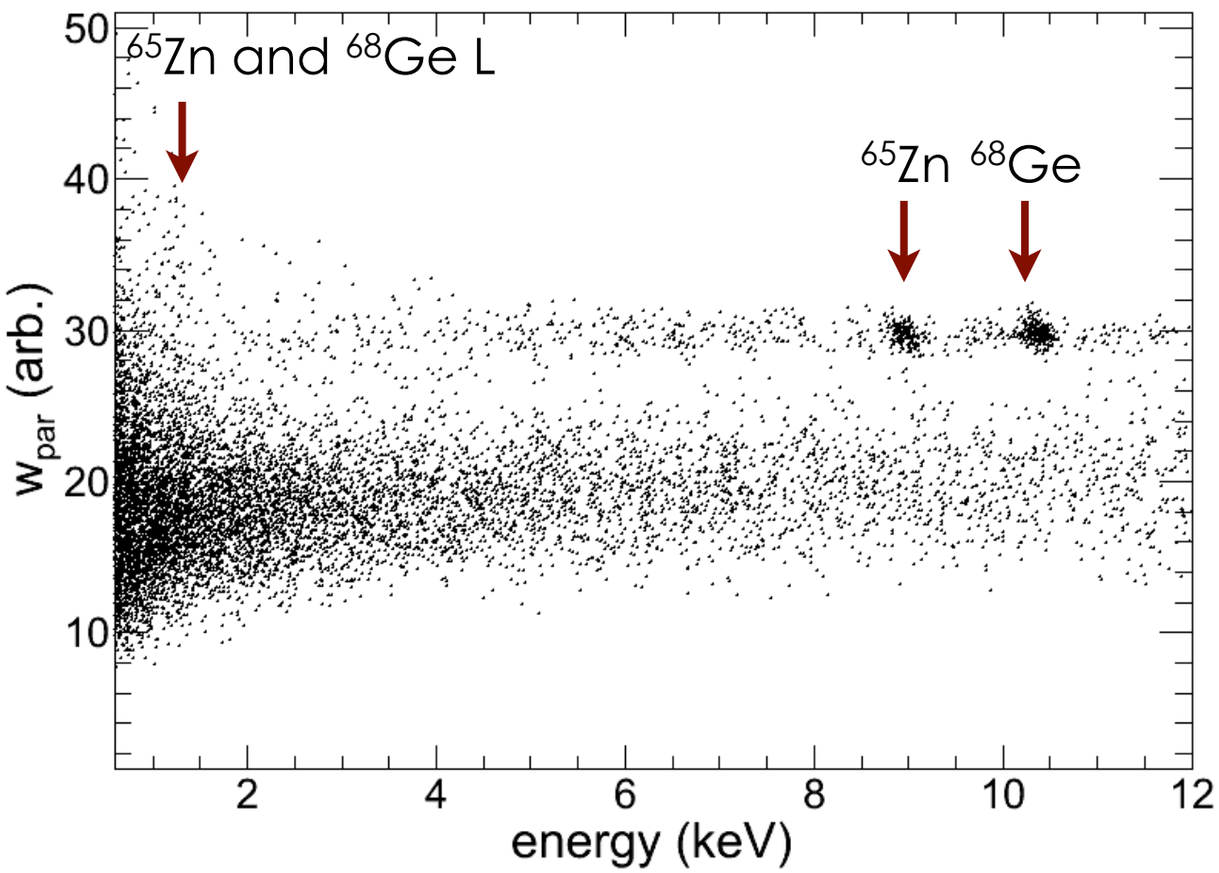
counts vs w_{par} for ^{241}Am data

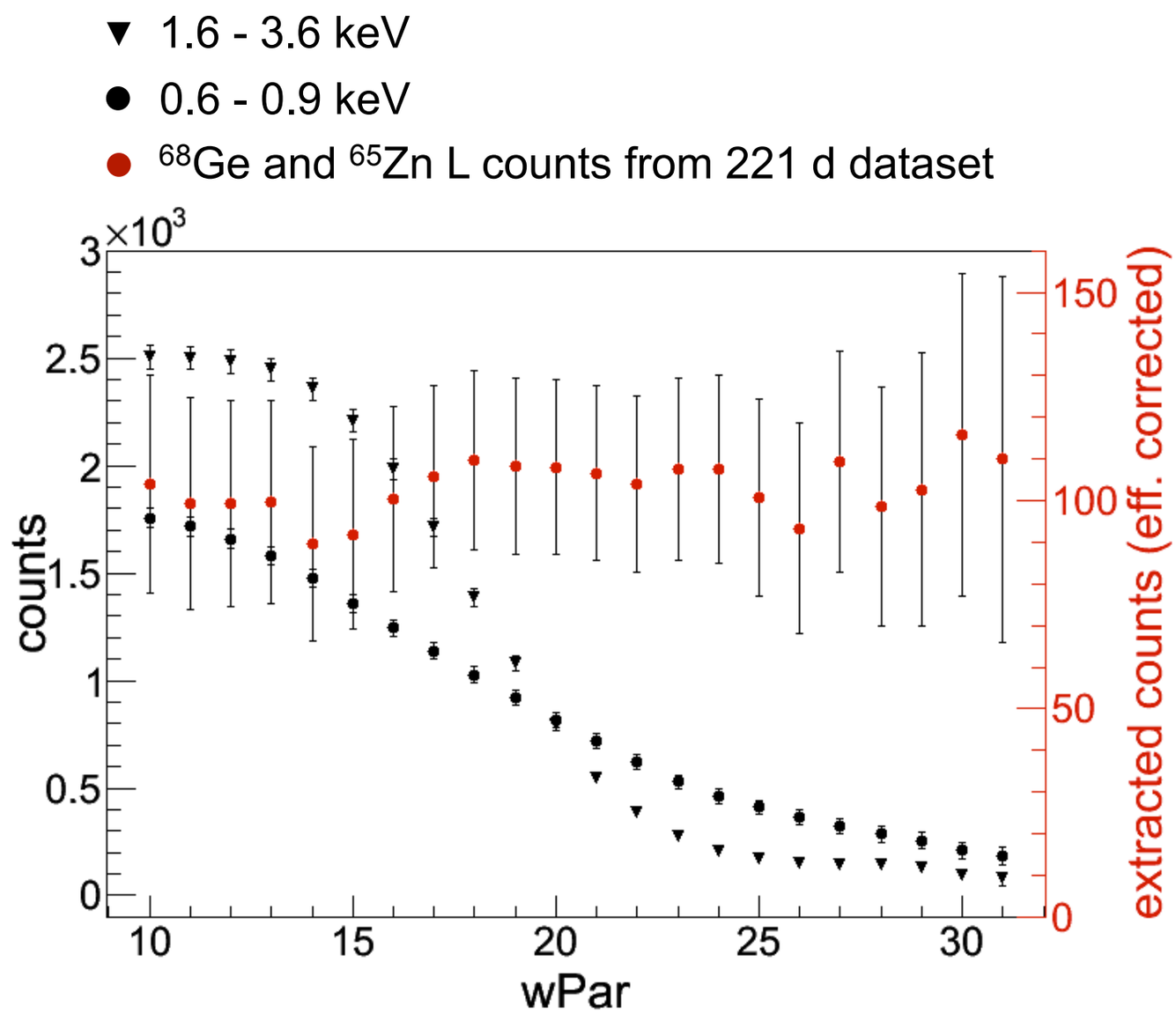




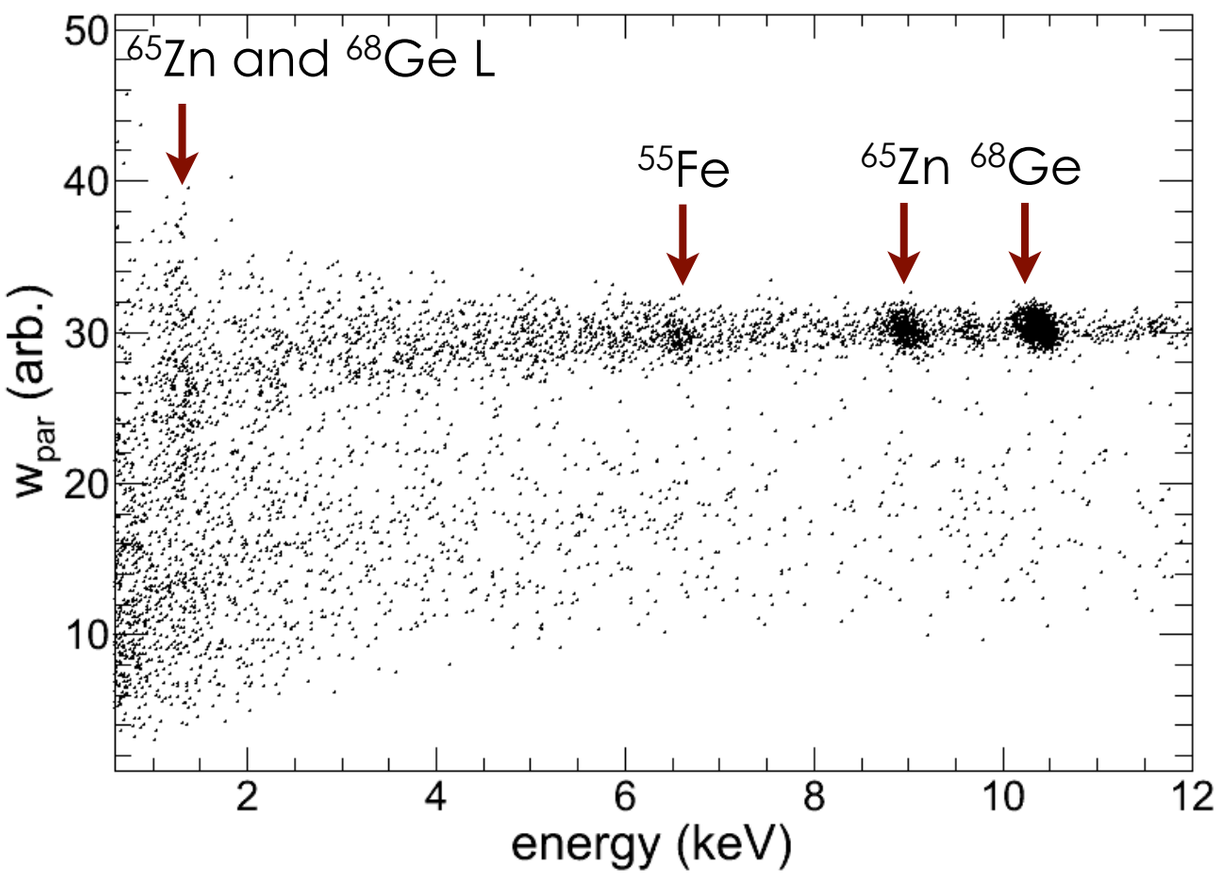
counts vs w_{par} for Pb data

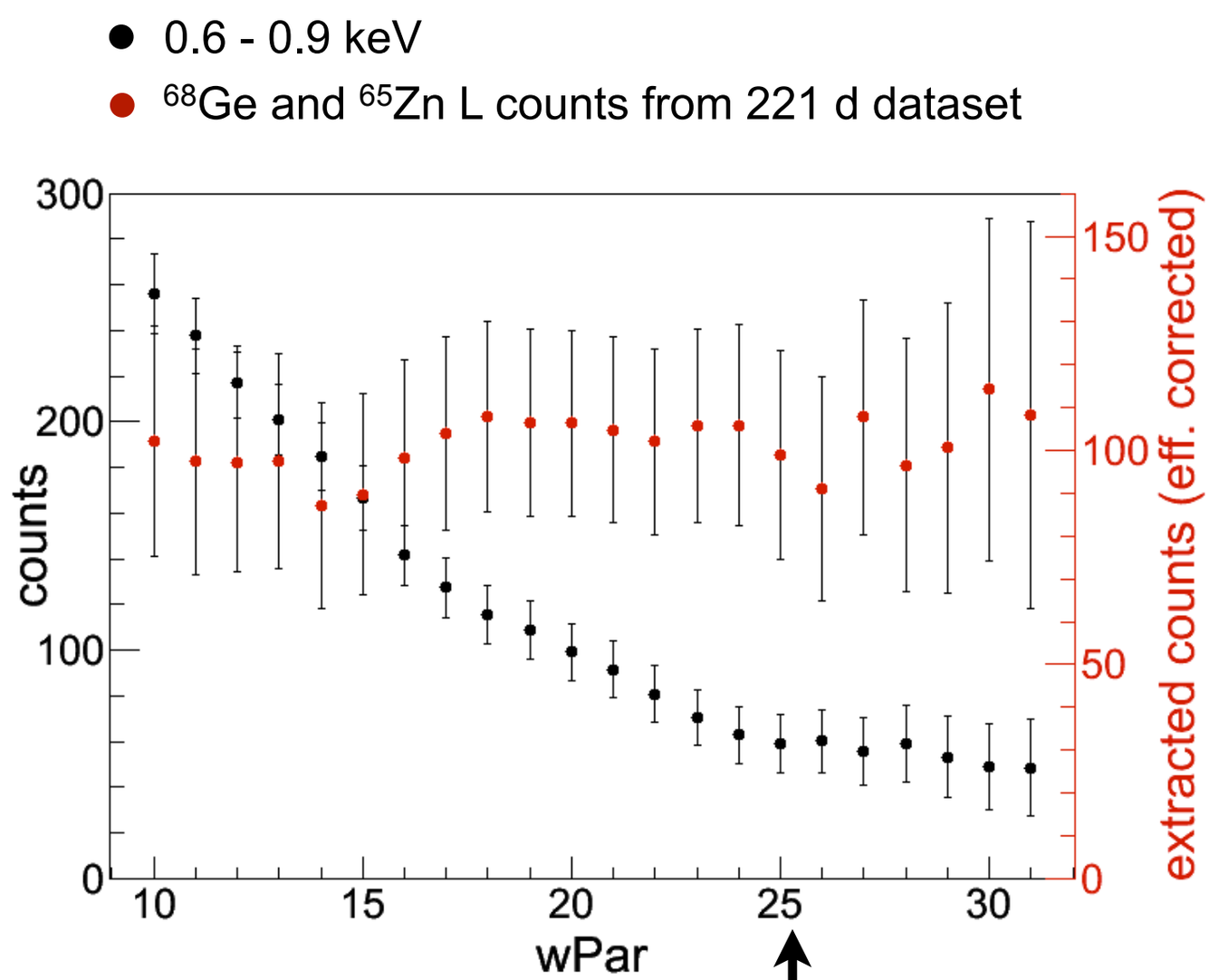
40 live days





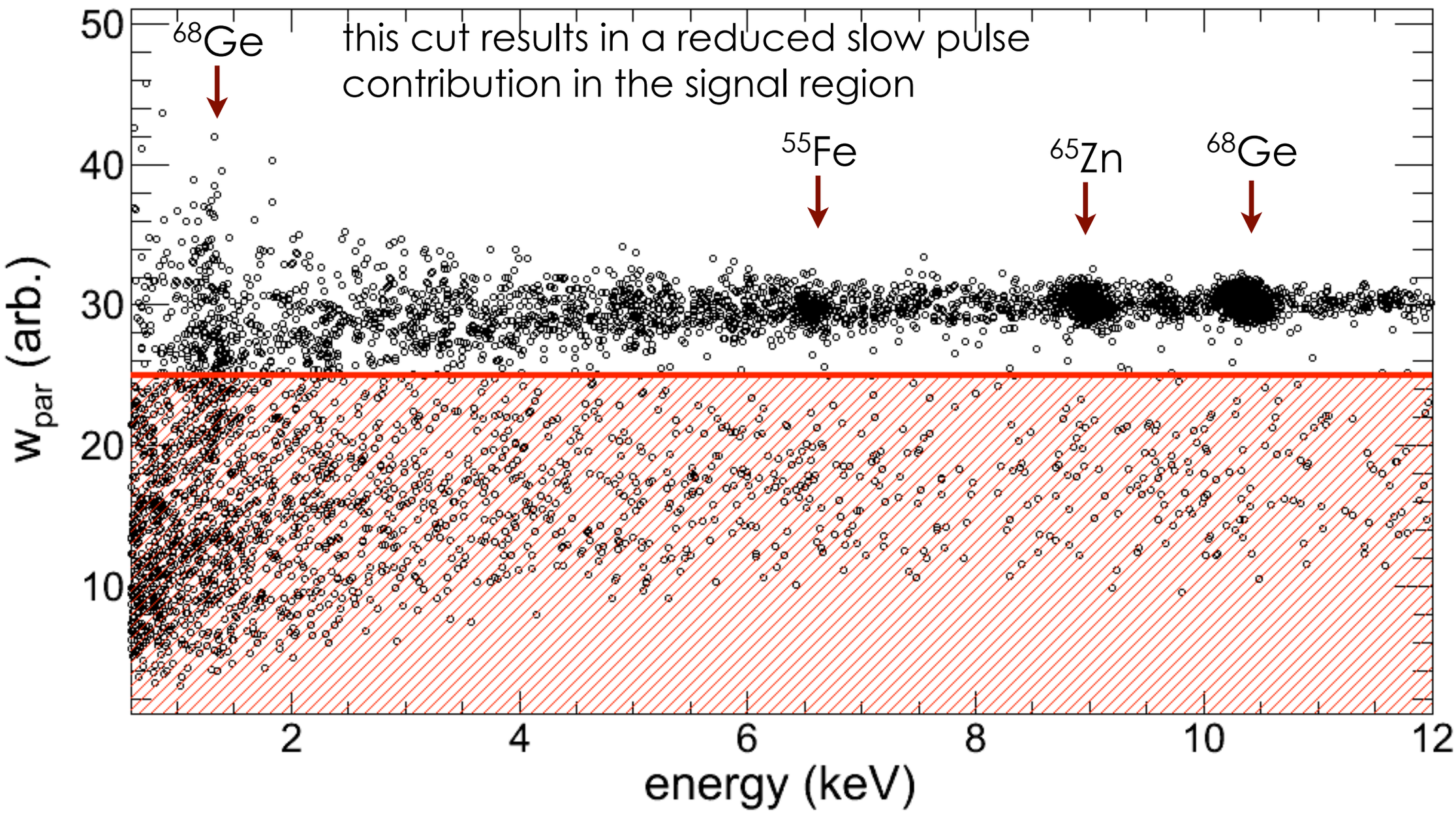
counts vs w_{par} for 221 day dataset





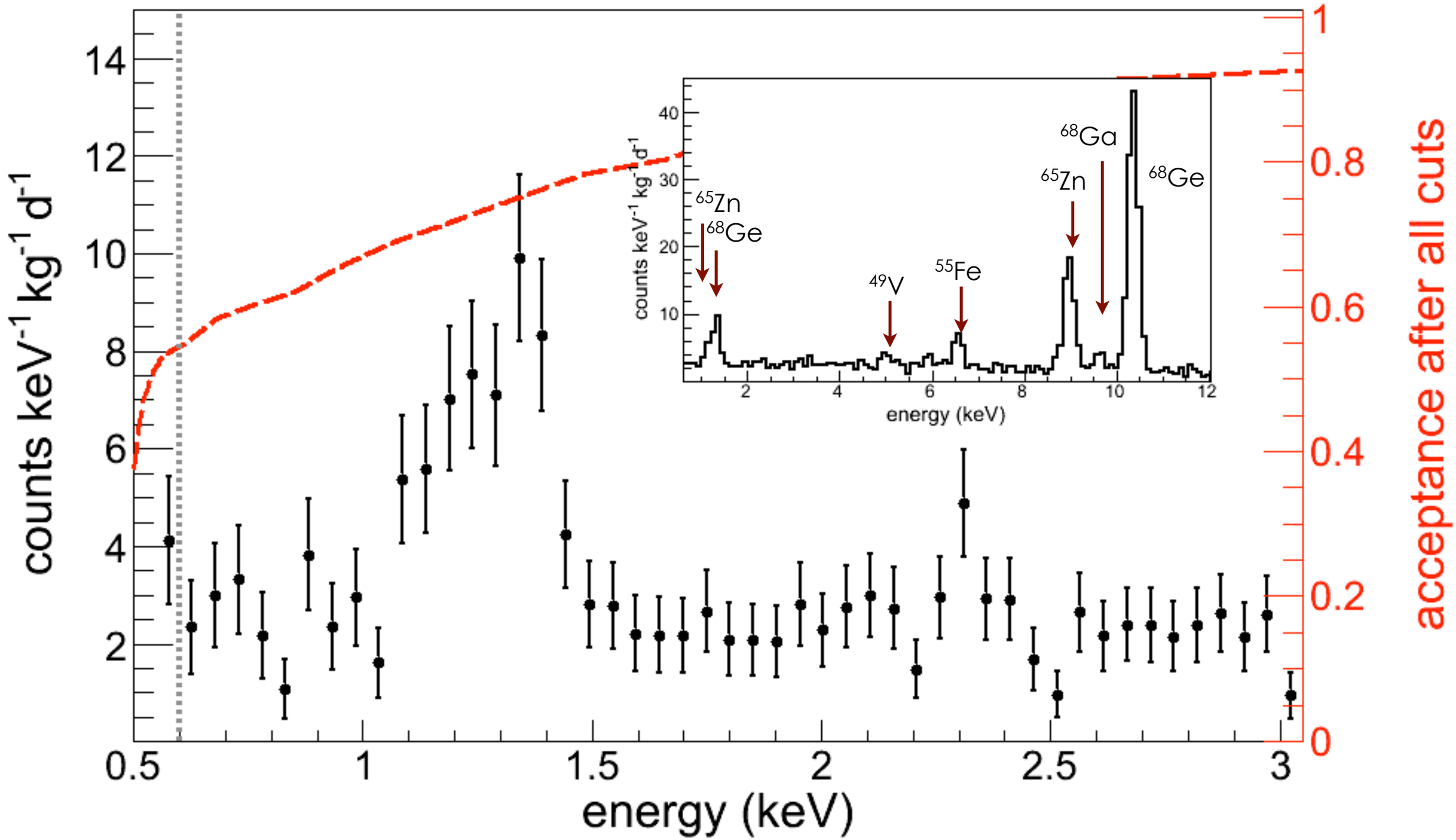
cut placed here to optimize the efficiency/√(background)

w_{par} vs energy for 221 days of data



slow event cut that is constant in w_{par}

221 day spectrum after constant w_{par} = 25 cut and efficiency correction



90% exclusions from 221 day dataset

fit components:

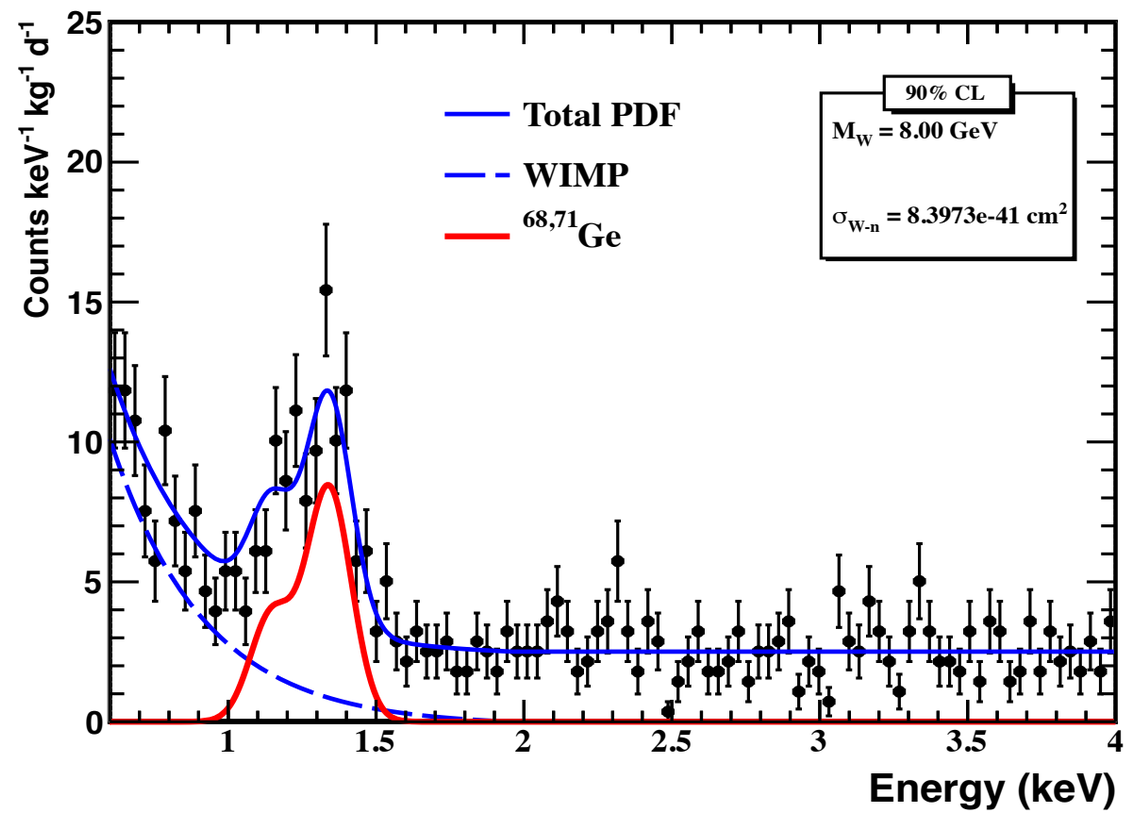
- flat background
- ^{65}Zn L-capture line
- ^{68,71}Ge L-capture line
- *exponential background**
- WIMP signal

*the exponential is only included in fits of the spectrum generated with the 99% cut

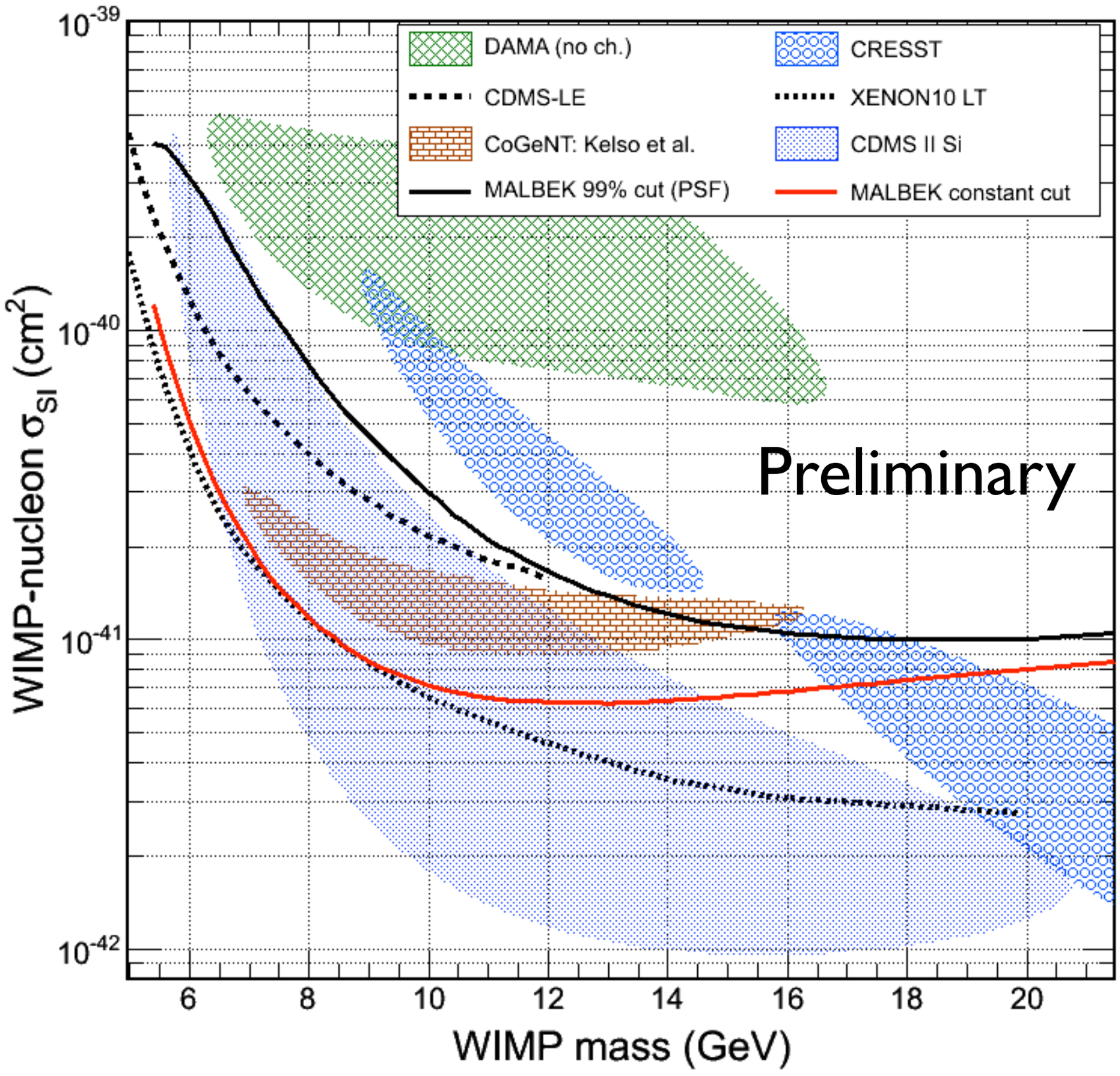
90% confidence limits extracted using profile-likelihood method suggested by Rolke et al.

W.A. Rolke et al., NIM A, 551, (2005).

8.0 GeV WIMP best fit for 99% cut spectrum

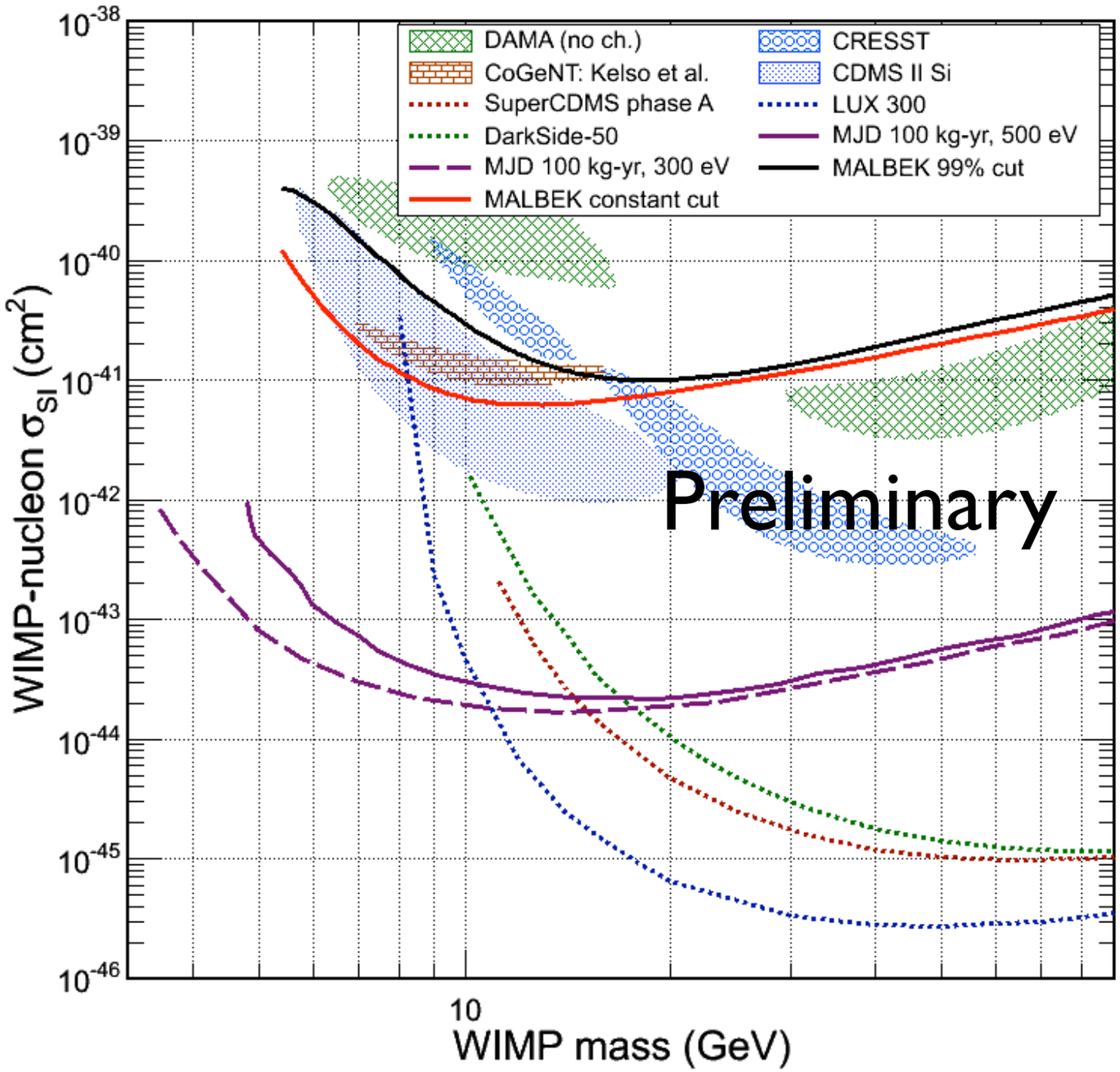


90% exclusions from 221 day dataset



MAJORANA DEMONSTRATOR outlook

- MJD may have sensitivity to WIMP nuclear recoils if
  - we reach our target background goals
  - and achieve a low energy threshold
- projected sensitivity assumes 0.001 counts/keV/kg/day continuum and 15 days of ^{3}H activation time*



*simulation performed by M.G. Marino, PhD Diss., Univ. of Washington (2010)

summary

- slow events can be a significant background in PPC detectors at low energies
- MALBEK sees no evidence of a WIMP signal
- our work towards understanding systematic effects in PPC detectors, particularly near the detector threshold, is ongoing

searching for modulation in the data with 99% cut

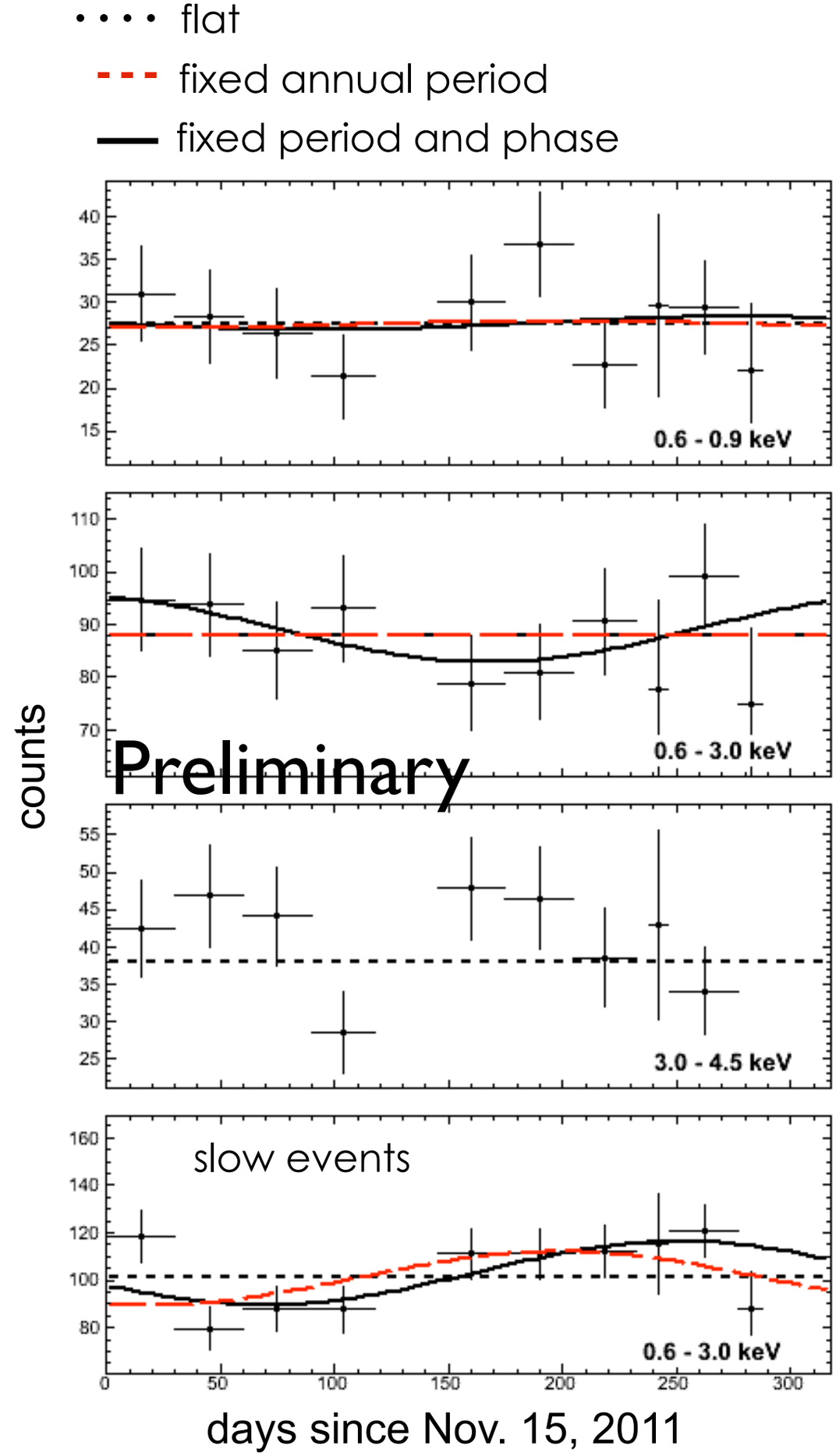
	best fit modulating %	p-value
flat	-	0.72
fixed period	2.8%	0.52
& fixed phase	1.5%	0.63

flat	-	0.80
fixed period	7%	0.79
& fixed phase	0.0%	0.71

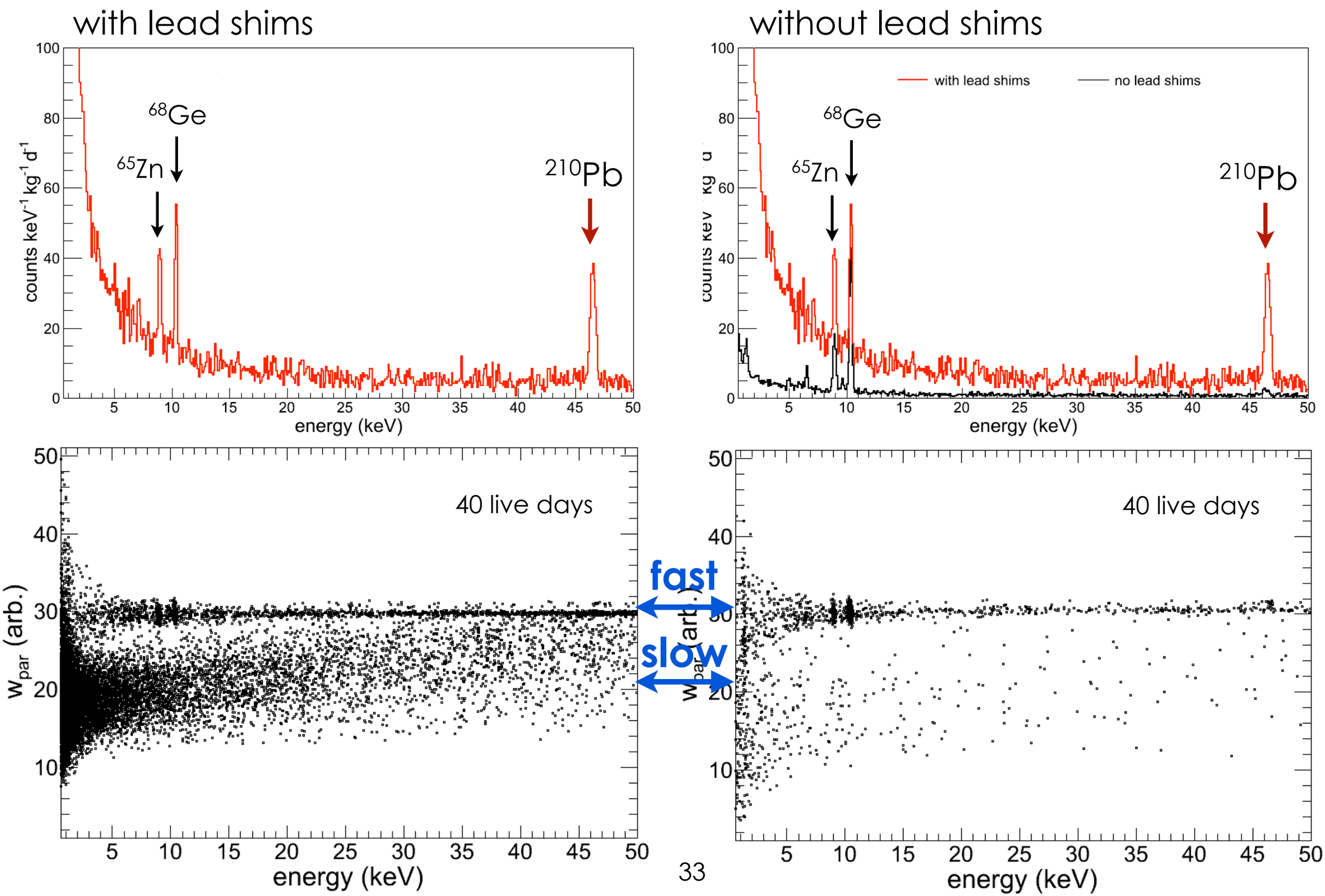
flat	-	0.02

flat	-	0.02
fixed period	13.0%	0.18
& fixed phase	11.3%	0.09

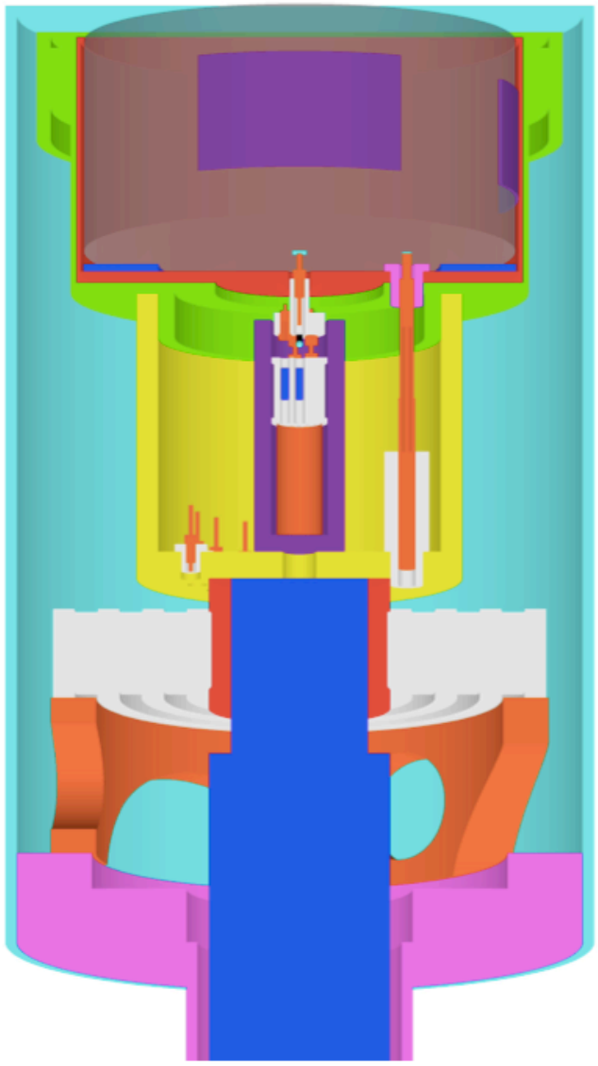
no significant evidence of modulation but not incompatible with CoGeNT

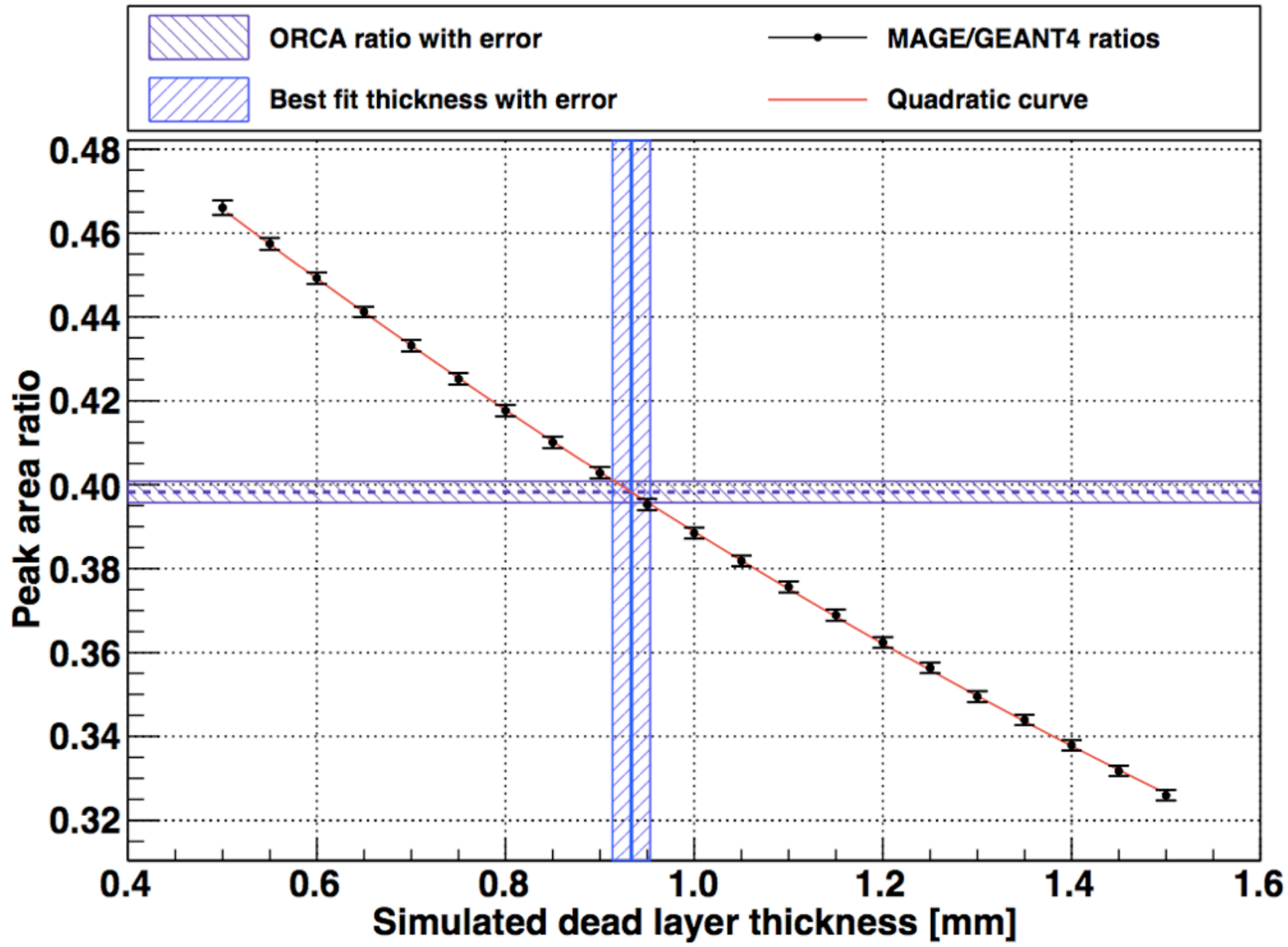


an inadvertent slow pulse source



^{133}Ba dead layer measurement



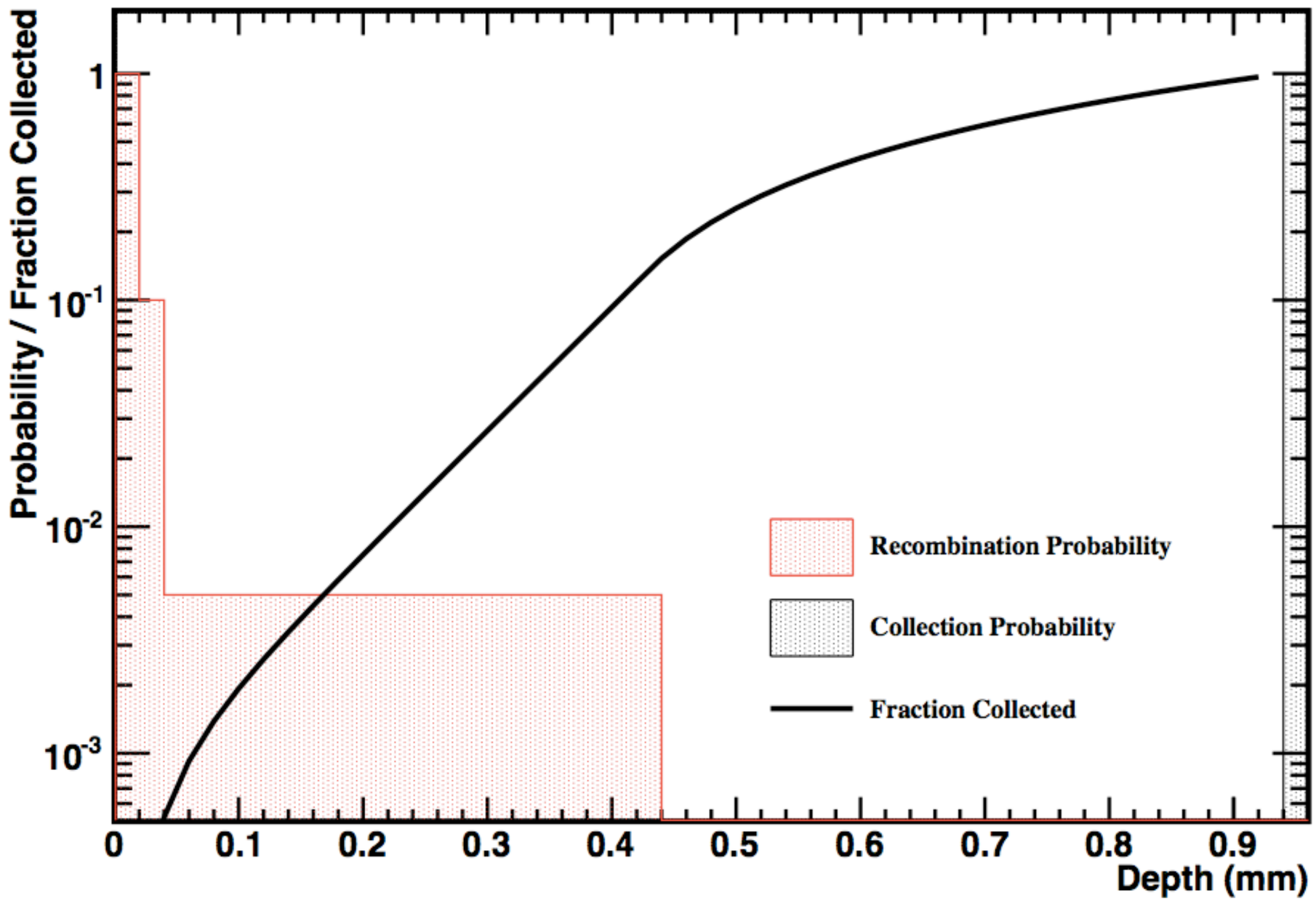


0.933 ± 0.018 stat. ± 0.092 sys. mm

* A. G. Schubert, PhD Thesis, Univ. of Washington, 2012.

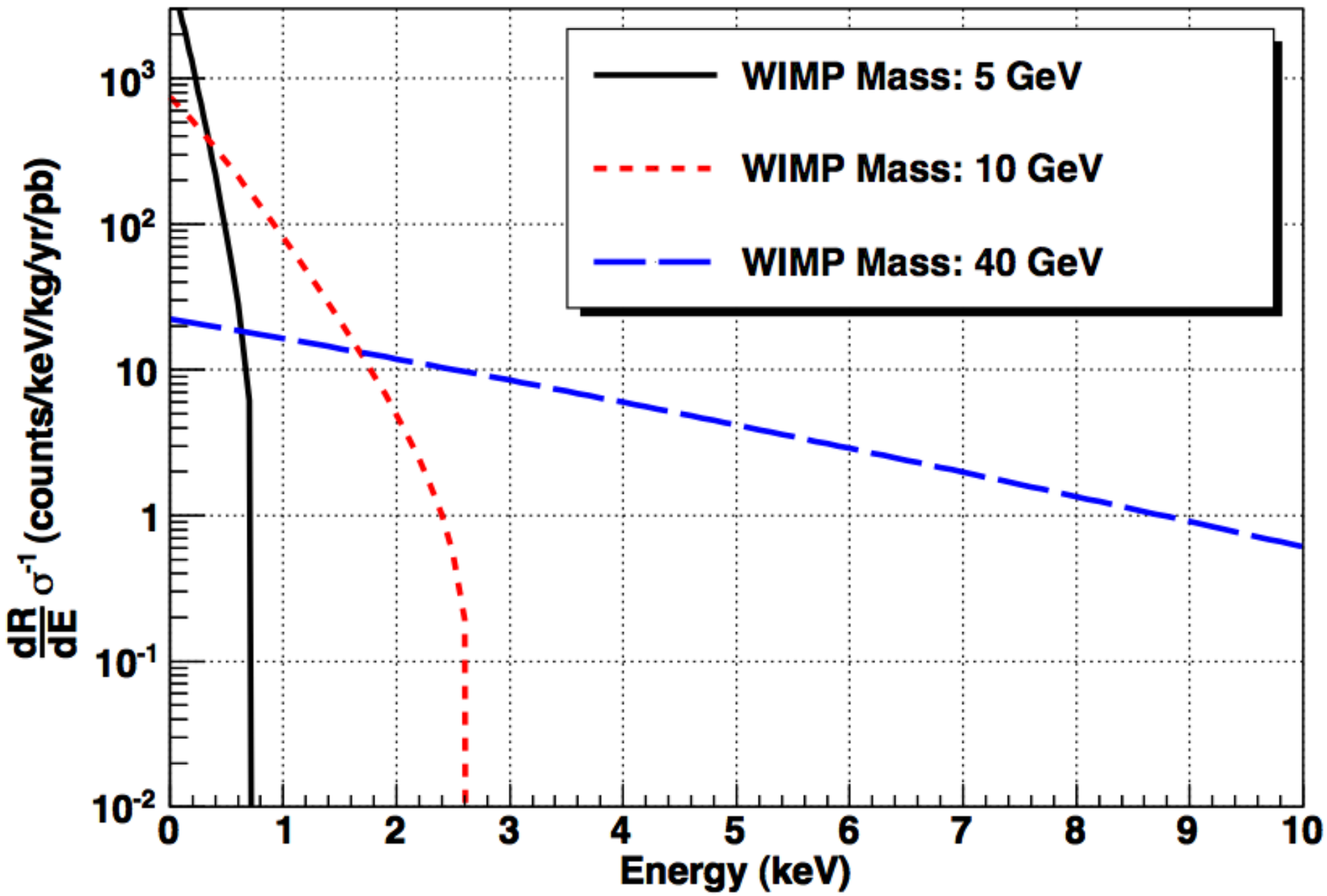
a qualitative slow pulse diffusion model

D.C. Radford and P. Finnerty



P. S. Finnerty, PhD Thesis, UNC - Chapel Hill.

detector response to WIMP recoil



M.G. Marino, PhD Diss., Univ. of Washington (2010)

systematic errors

source	estimate
fiducial mass error	3.83%
non-Poisson noise contribution	<0.57% of counts
threshold drift	~6.8 eV
fast event acceptance	<0.3%
slow event rejection error	unknown

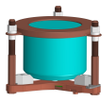
P. S. Finnerty, PhD Thesis, UNC - Chapel Hill.

table of systematics

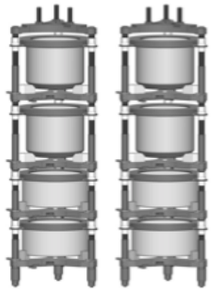
Source	Estimate	Comments
Fiducial mass error	3.83%	See Section 6.1.2 [122], negligible/ignored.
Non-Poisson process contribution	$\leq$ 0.57% of counts	Less than or equal to the error in the count rate in $0.6-1.0$ keV after LN_2 cut, negligible/ignored.
Threshold drift	~6.8 eV	Estimated from shifts in pulser mean (Section 5.4.1), negligible/ignored.
SSC acceptance efficiency error	$\lesssim$ 0.3%	Based on statistics from pulser efficiency runs, negligible/ignored.
SSC rejection efficiency error	Unknown	Attempts were made to quantify this, see Section 6.5.

MJD construction schedule

Construction of the DEMONSTRATOR is proceeding in three stages.

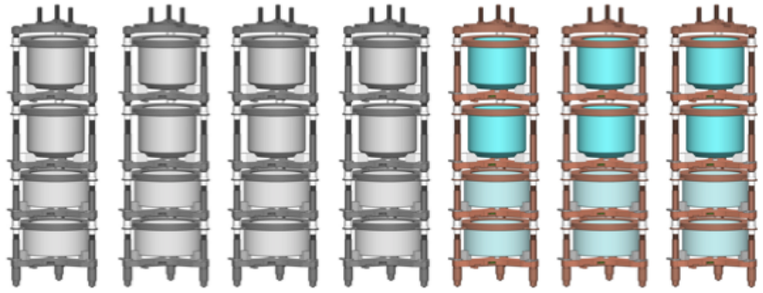


Prototype Cryostat*



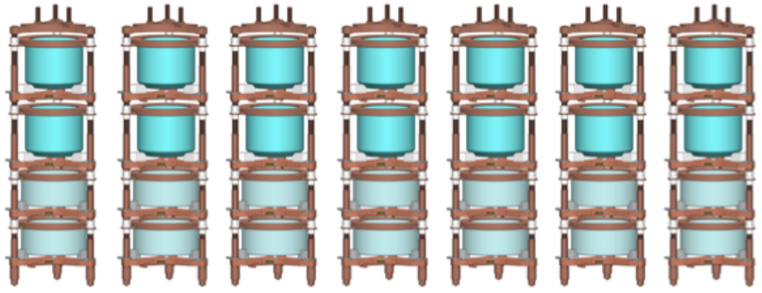
summer 2013

Cryostat 1



early 2014

Cryostat 2



late 2014

**The Prototype Cryostat components are built from OFHC copper.*