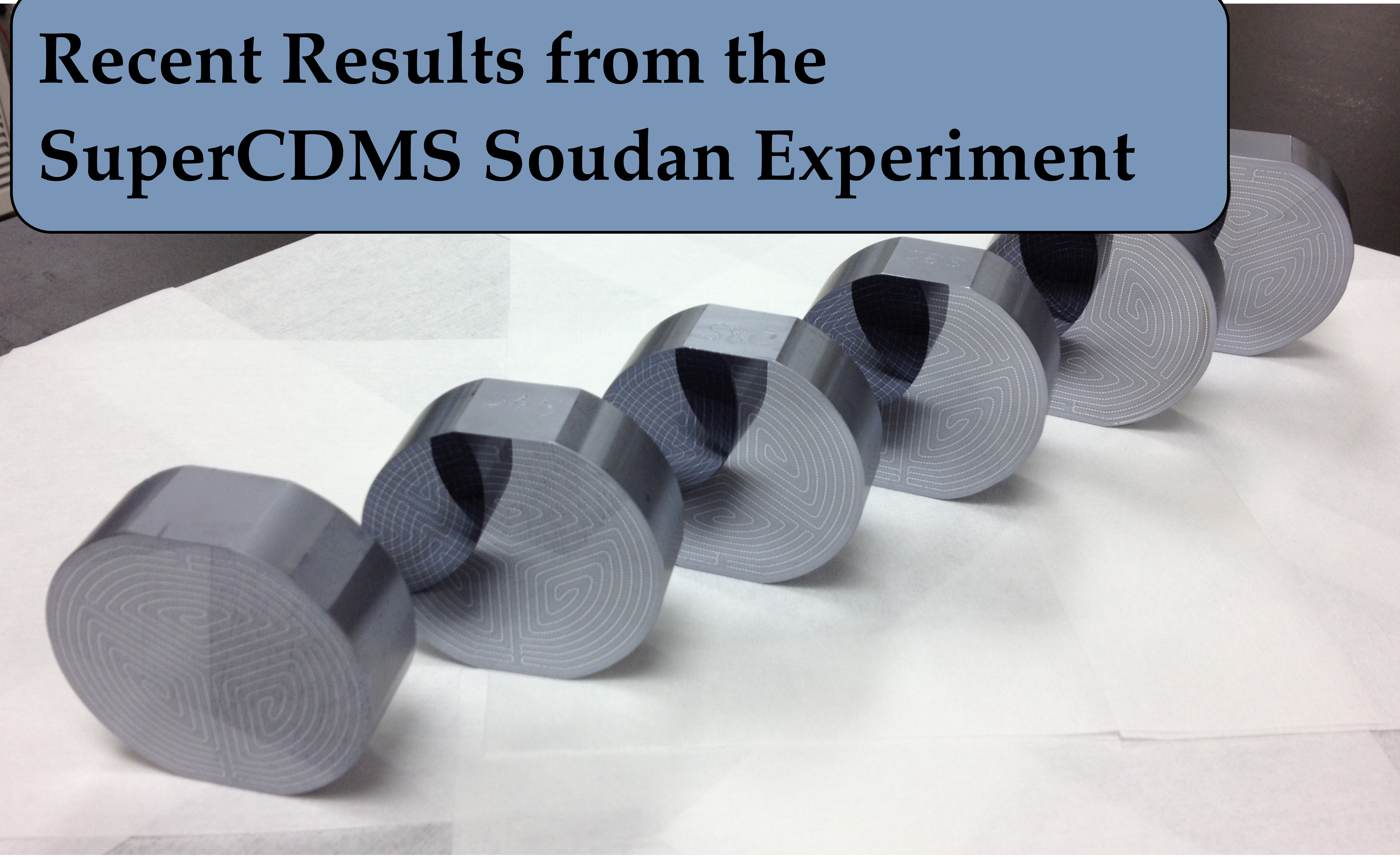
Recent Results from the SuperCDMS Soudan Experiment



SMU

Jodi Cooley
on behalf of the SuperCDMS Collaboration

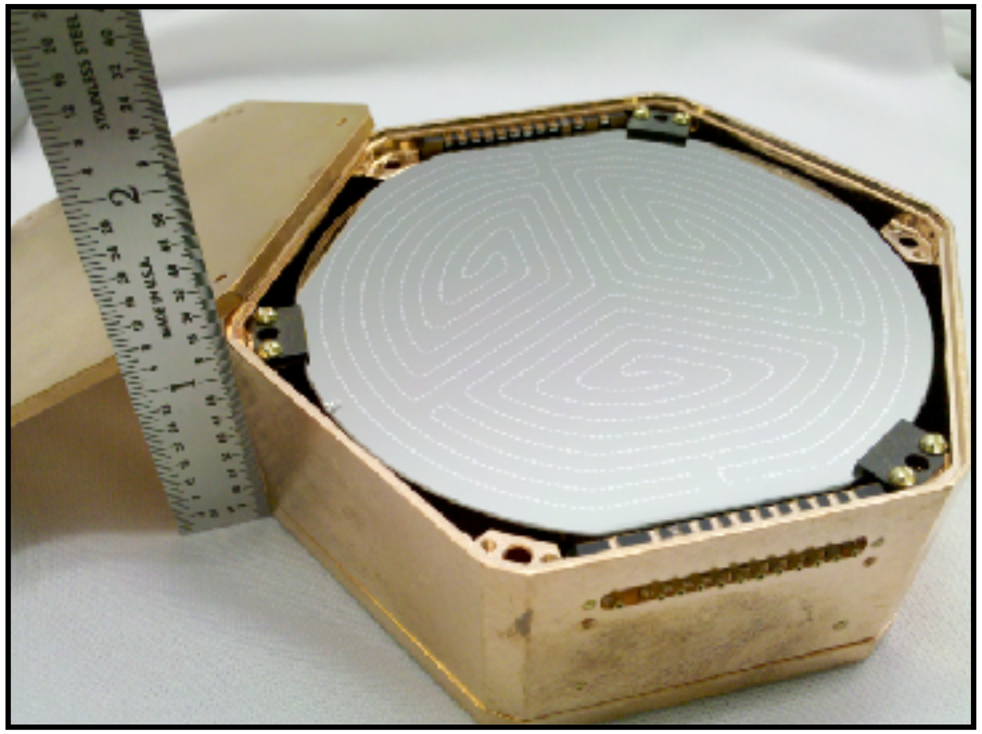
The SuperCDMS Collaboration

California Inst. of Tech.	CNRS-LPN*	Durham University	FNAL	NISER
NIST*	Northwestern	PNNL	Queen's University	Santa Clara University
SLAC	South Dakota SM&T	SMU	SNOLAB	Stanford University
Texas A&M University	TRIUMF	U. British Columbia	U. California, Berkeley	U. Colorado Denver
U. Evansville	U. Florida	U. Minnesota	U. South Dakota	U. Toronto

* Associate members

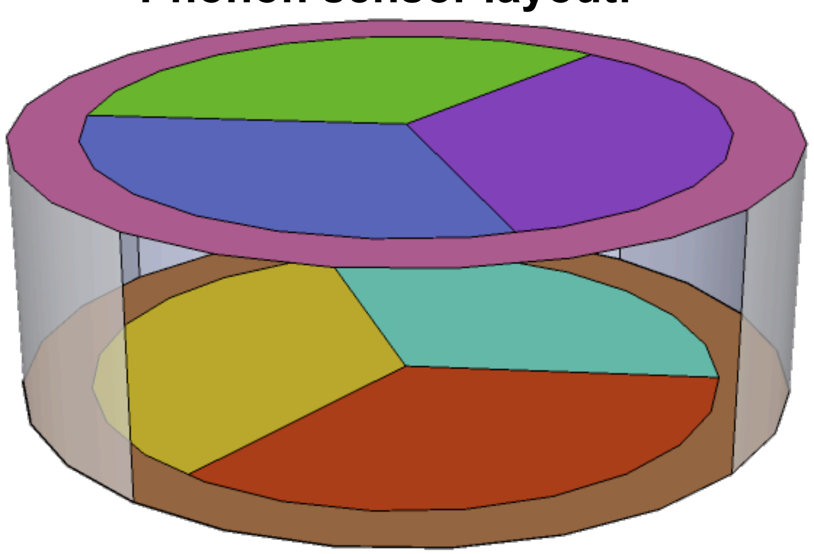
+The SMU SuperCDMS group is supported by the NSF under grant number 1151869.

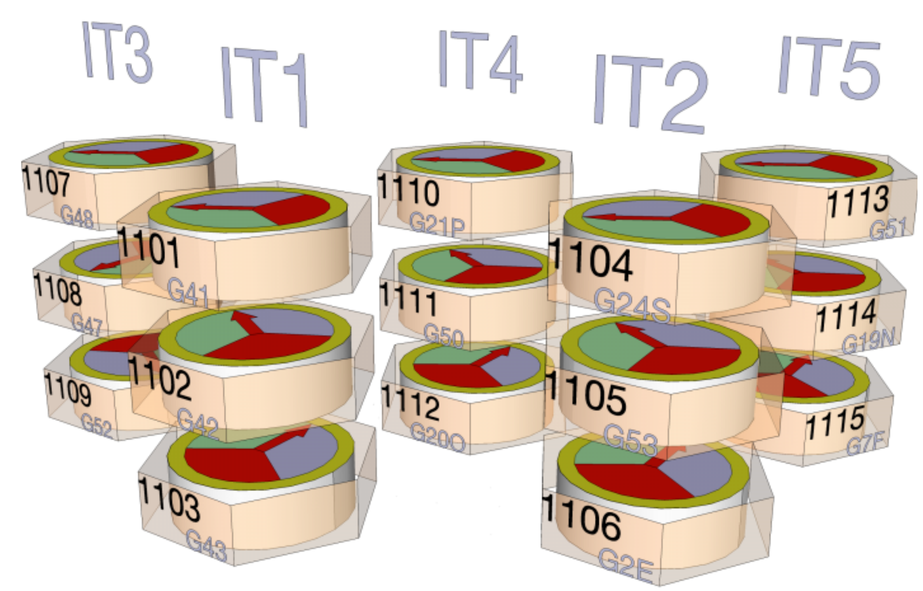
Overview: SuperCDMS Soudan



- Location: Soudan Underground Laboratory, Minnesota, USA @ ~2090 mwe
- Science operations from Mar. 2012 - late 2015.
- Experiment contains 15 iZIP detectors, stacked into 5 towers
  - **i**nterleaved **Z**-sensitive **I**onization and **P**honon detectors (**iZIP**)
- Each side instrumented with 2 charge (inner + outer) & 4 phonon (1 inner + 3 outer) sensors

Phonon sensor layout:





Active and Passive Shielding

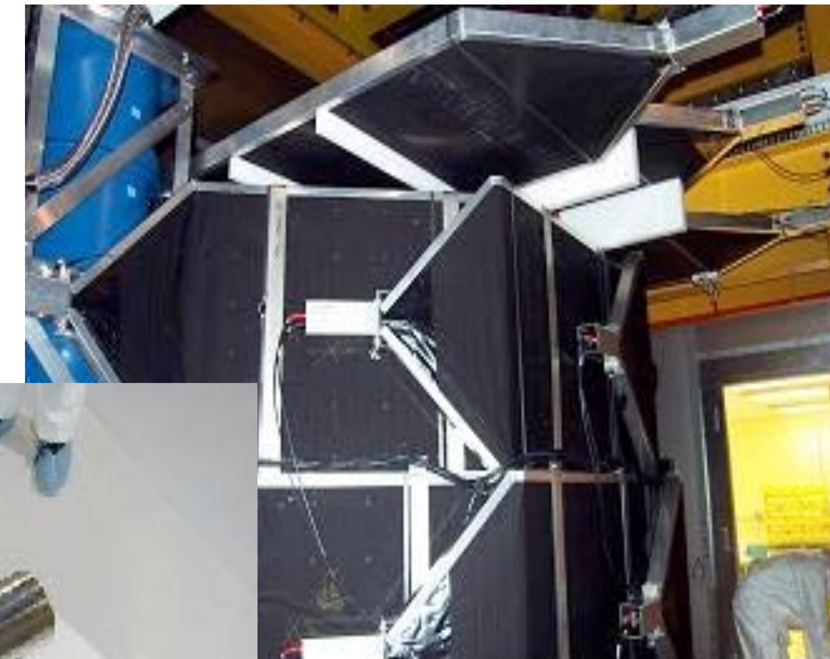
Active Muon Veto:
rejects events from cosmic rays

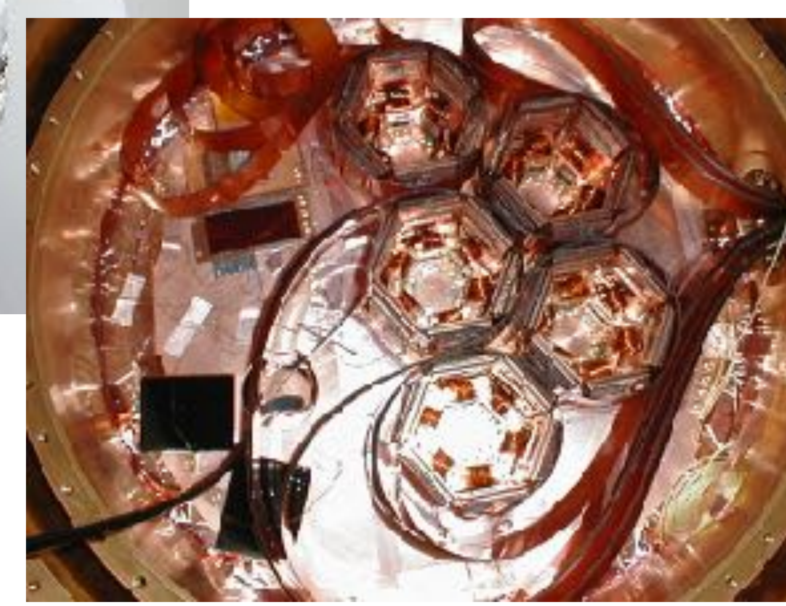
Polyethyene: moderate neutrons from fission decays and (α,n) interactions

Pb: shielding from gammas resulting from radioactivity

Low Radioactivity Pb: shields ^{210}Pb betas

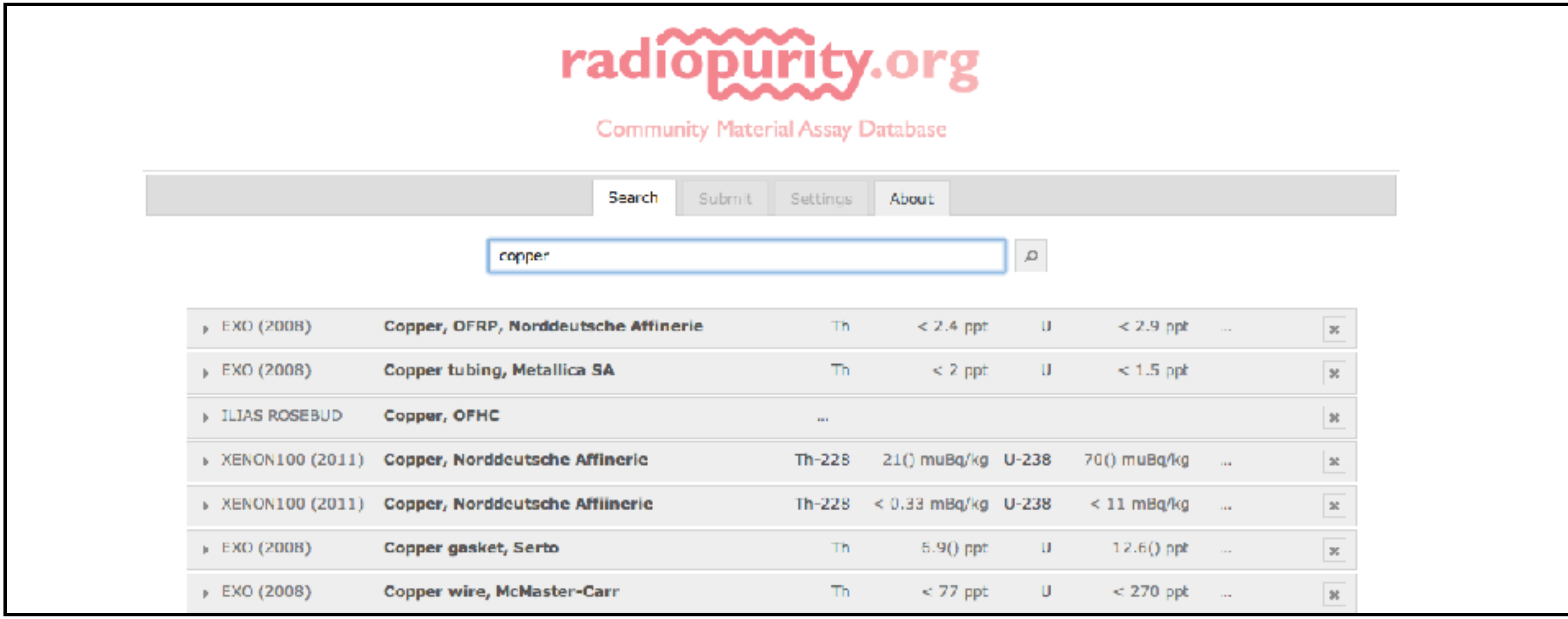
Cu: radio-pure inner copper can





Community Assays Database

Use Clean Materials

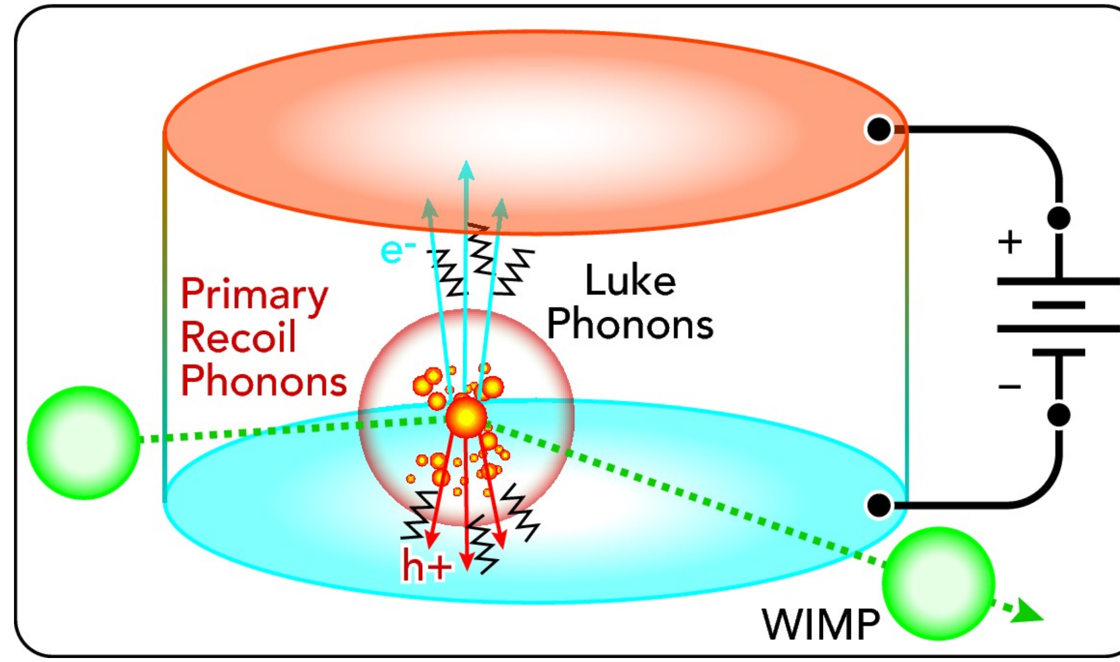


EXO (2008)	Copper, OFRP, Norddeutsche Affinerie	Th	< 2.4 ppt	U	< 2.9 ppt	...
EXO (2008)	Copper tubing, Metallica SA	Th	< 2 ppt	U	< 1.5 ppt	
ILIAS ROSEBUD	Copper, OFHC	...				
XENON100 (2011)	Copper, Norddeutsche Affinerie	Th-228	21() muBq/kg	U-238	70() muBq/kg	...
XENON100 (2011)	Copper, Norddeutsche Affinerie	Th-228	< 0.33 mBq/kg	U-238	< 11 mBq/kg	...
EXO (2008)	Copper gasket, Serto	Th	5.9() ppt	U	12.6() ppt	...
EXO (2008)	Copper wire, McMaster-Carr	Th	< 77 ppt	U	< 270 ppt	...

http://radiopurity.org

Supported by AARM, LBNL, MAJORANA, **SMU**, SJTU & others
Currently hosted by SNOLAB

Detection Principles



Standard iZIP Mode:

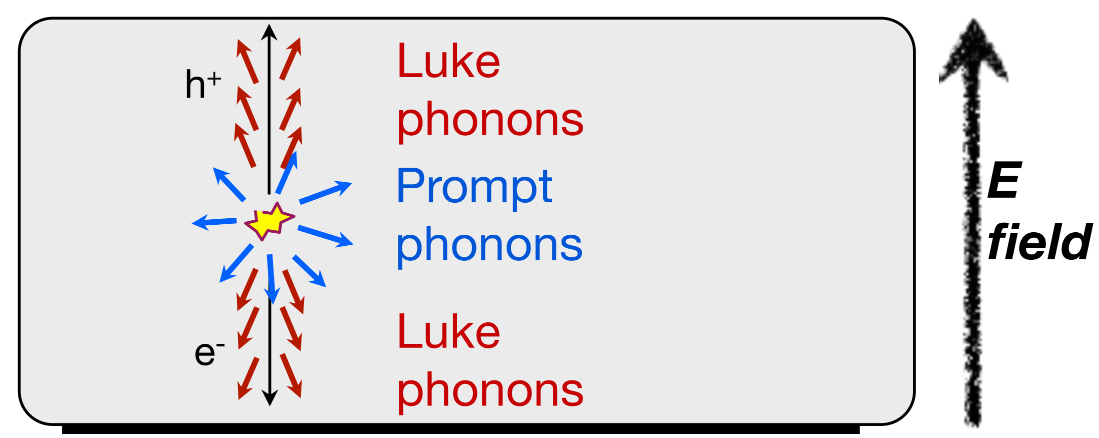
- Primary (prompt) phonon and ionization signals allow for discrimination between NR and ER events

CDMSlite HV Mode:

- Drifting electrons across a potential (V) generates a large number of phonons (Luke phonons).

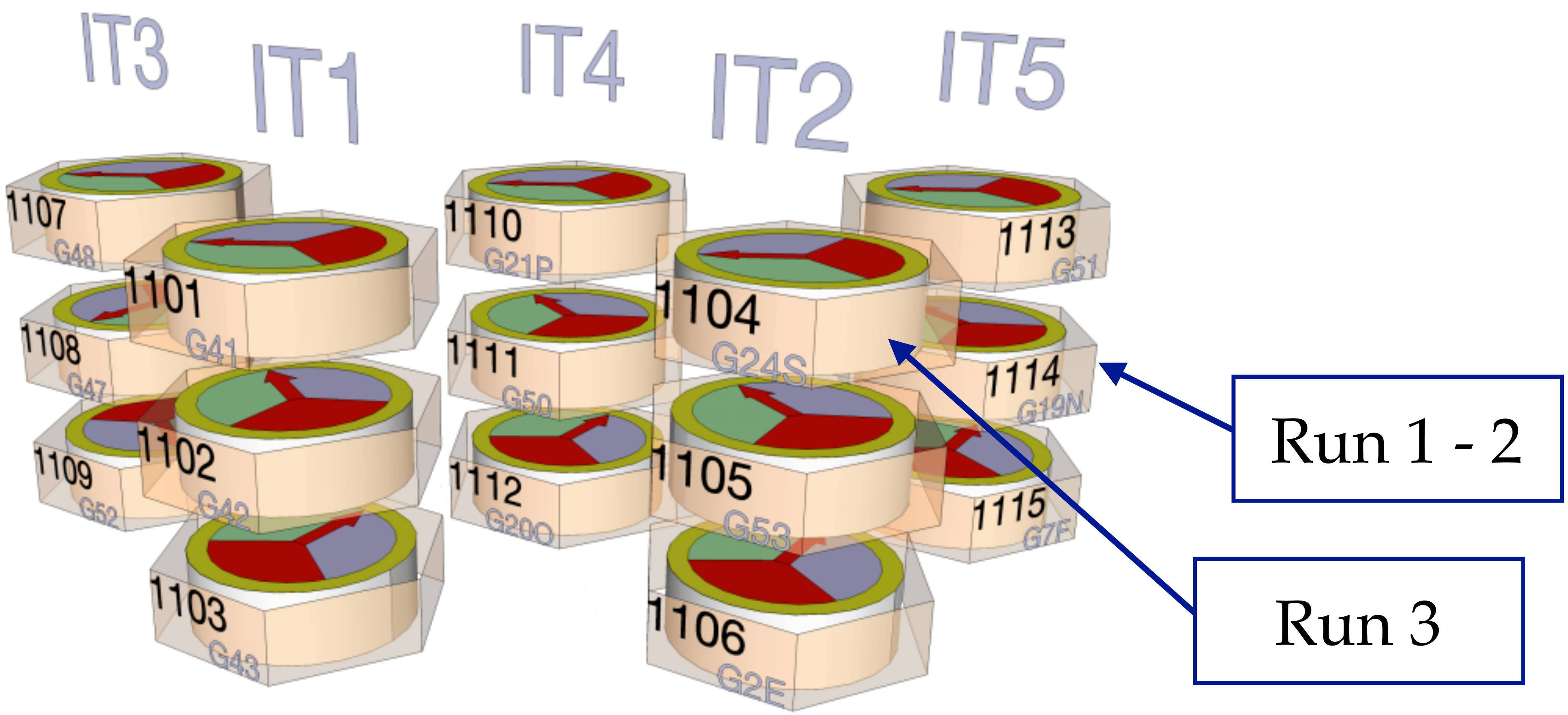
$$E_t = E_r + N_{eh} e V_b$$

total phonon energy *primary recoil energy* *Luke phonon energy*



- Enables very low thresholds!
- Trade-off: No NR/ER discrimination

CDMSlite Data



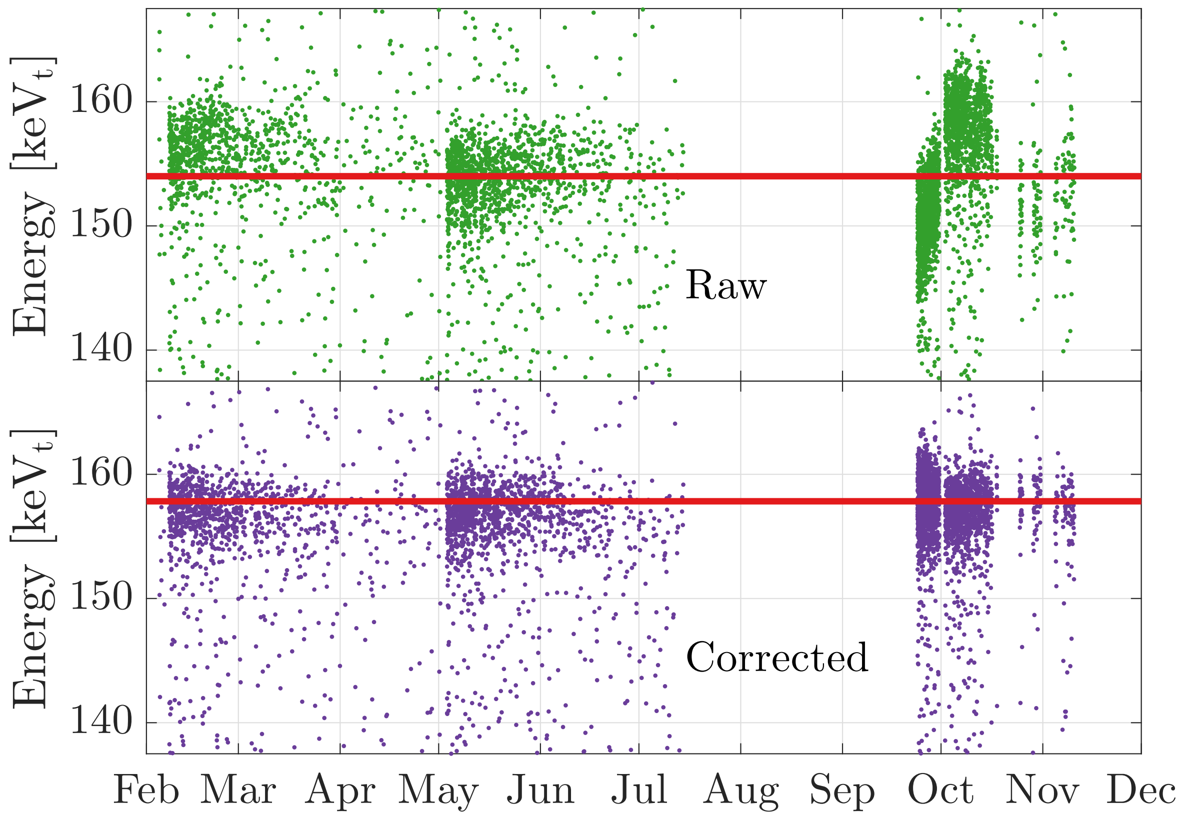
- Run 1: Aug. - Sept. 2012 *[PRL 112, 041302, 2014]*
- Run 2 (period 1): Feb. - July 2014
- Run 2 (period 2): Sept. - Nov. 2014

[PRL 116, 071301 ,2016]

- Run 3: Feb. - May 2015 (analysis ongoing)

Ionization Energy Scale Calibration

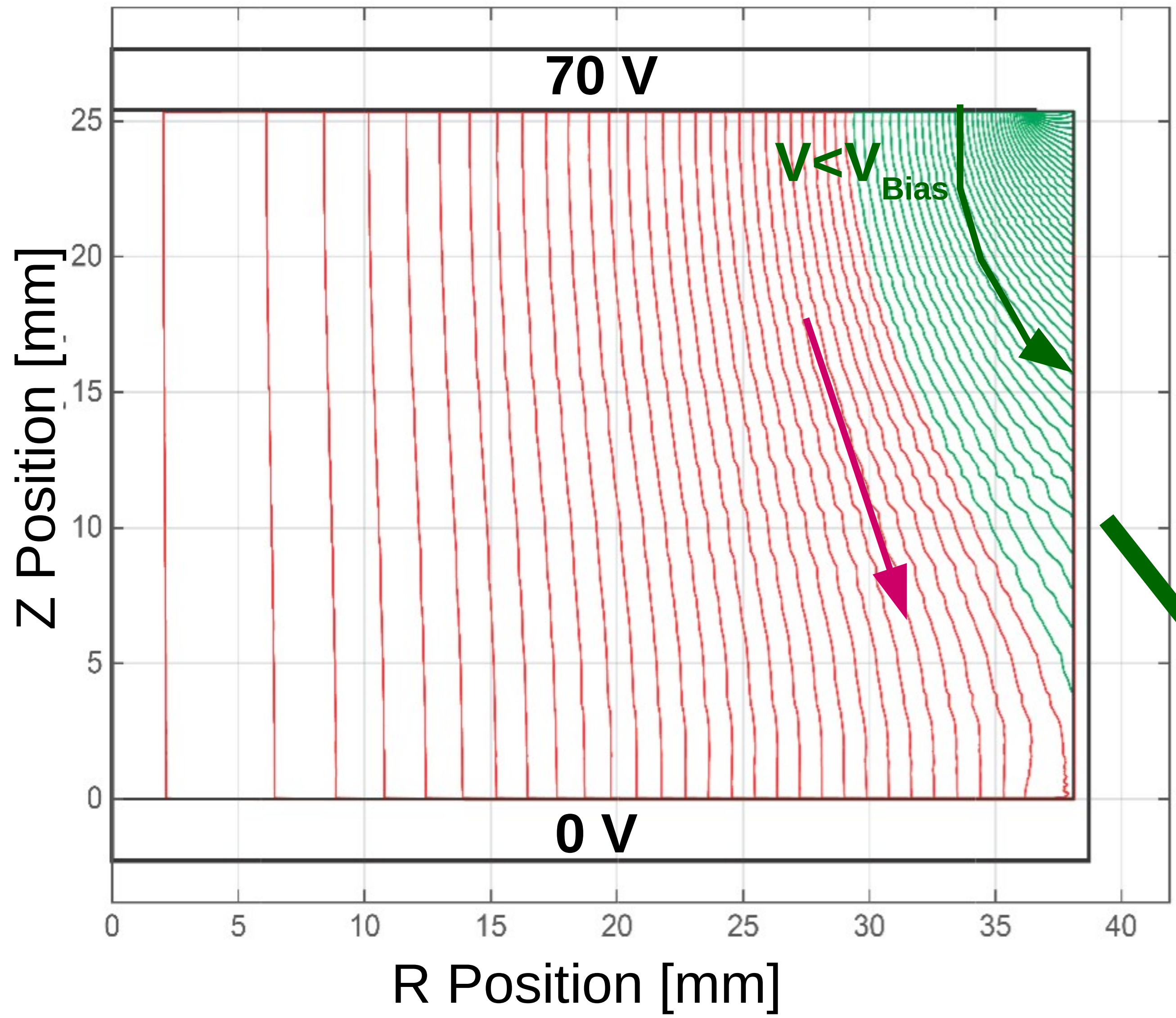
K-Shell Line



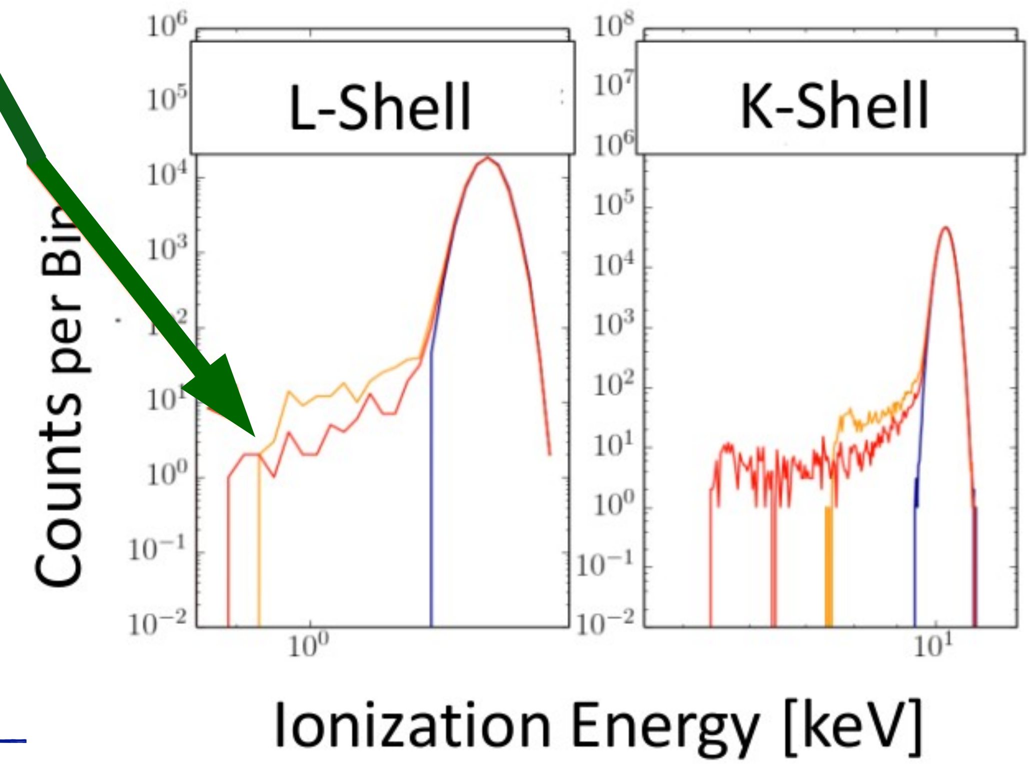
- Corrected for environmental and operational changes (i.e. base temperature, parasitic resistances, position dependence.)

- ^{232}Cf Source:
  - ^{70}Ge + n ⟶ ^{71}Ge
  - ^{71}Ge decays via electron capture
  - Well known energy released in K-, L-, and M-shell captures
    - K-shell (BR ≤ 88%): 10.37 keV
    - L-shell (BR ≤ 11%): 1.30 keV
    - M-shell (BR ≤ 2%): 0.16 keV
- High statistics K-shell capture used for calibration.

Run 2: Fiducial Volume

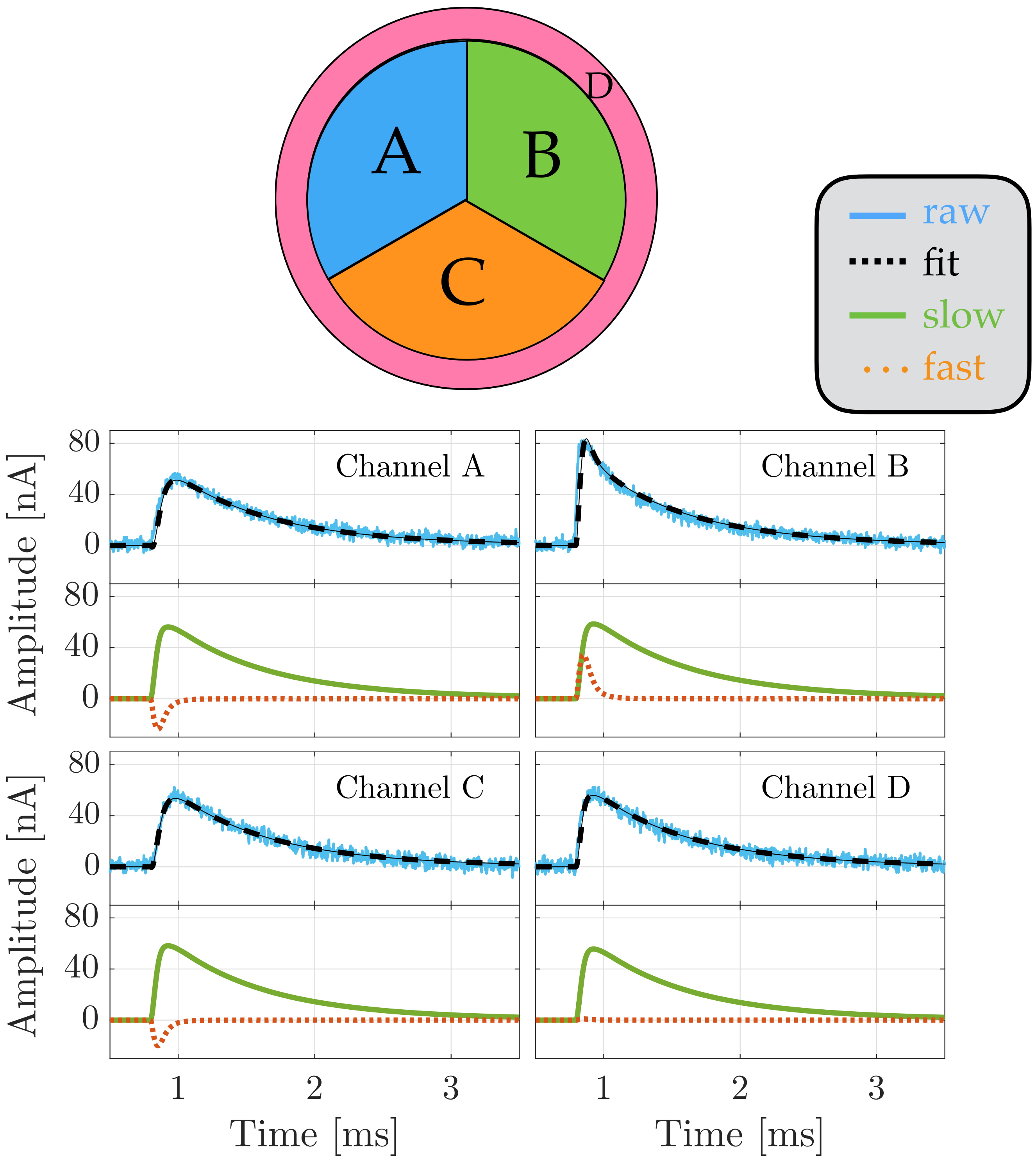


- Low energy background events (e.g. ^{210}Pb)
- Sidewalls are grounded and readout on one detector side
  - e/h pairs created near detector sides traverse a $V < V_{bias}$
    - Reduces Luke amplification
    - Adds low energy tail to spectrum

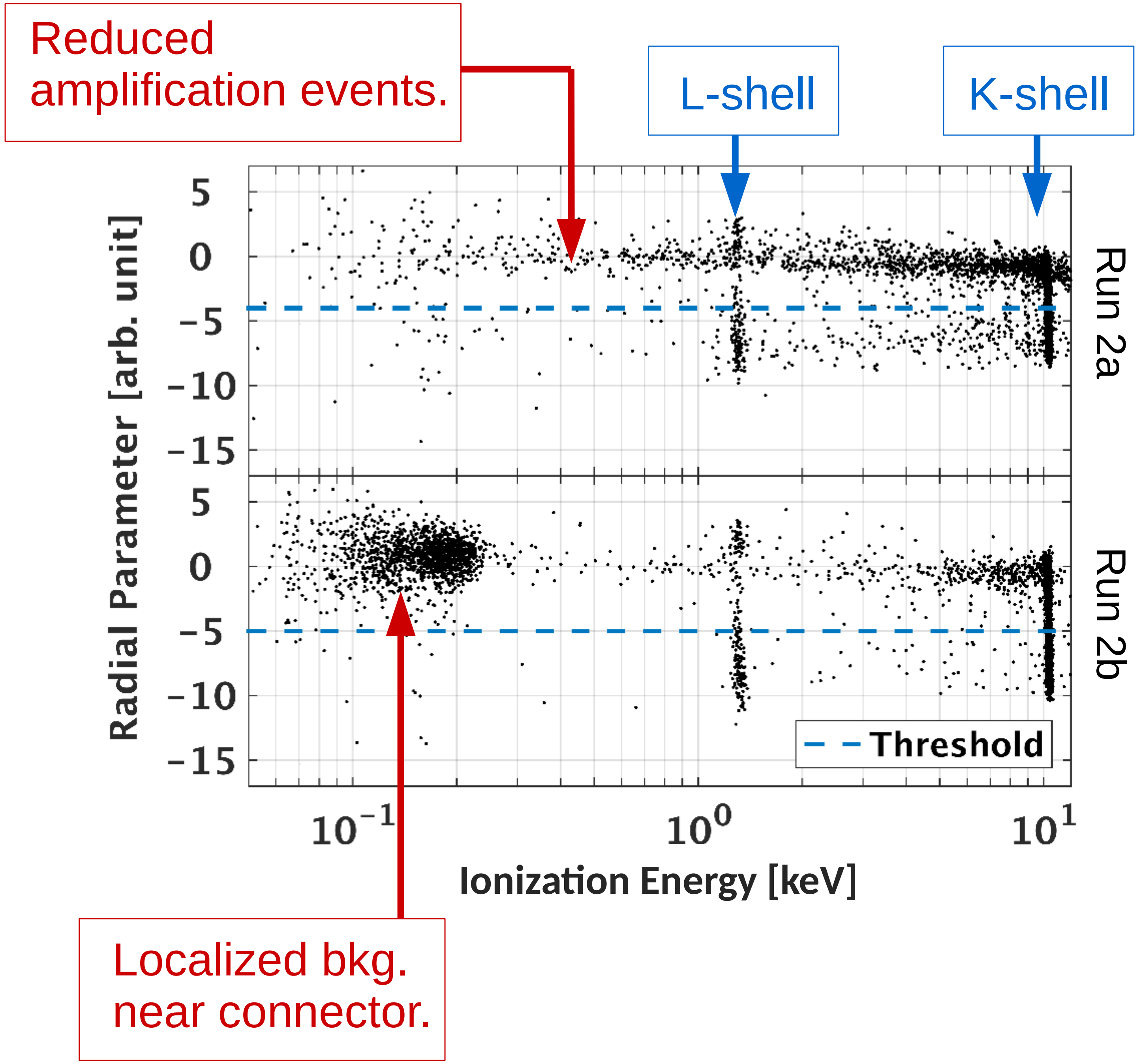


Radial Parameter

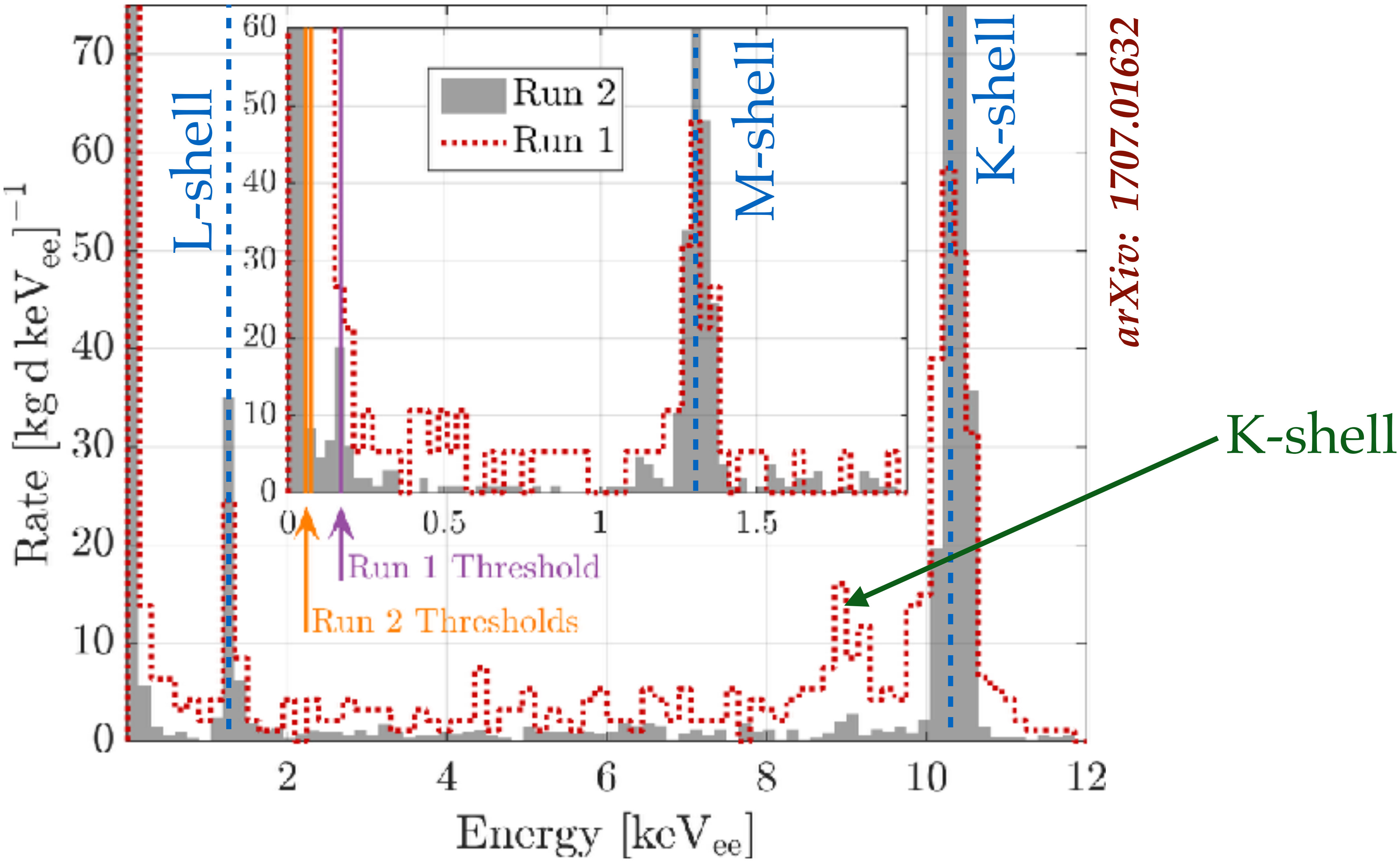
- Each pulse is fit with a "slow" and "fast" template.
- Use pulse features (amplitude, energy and delay) to derive empirical radial parameter.
- Empirical radial parameter is used to define a fiducial volume.



Fiducial Radial Cut

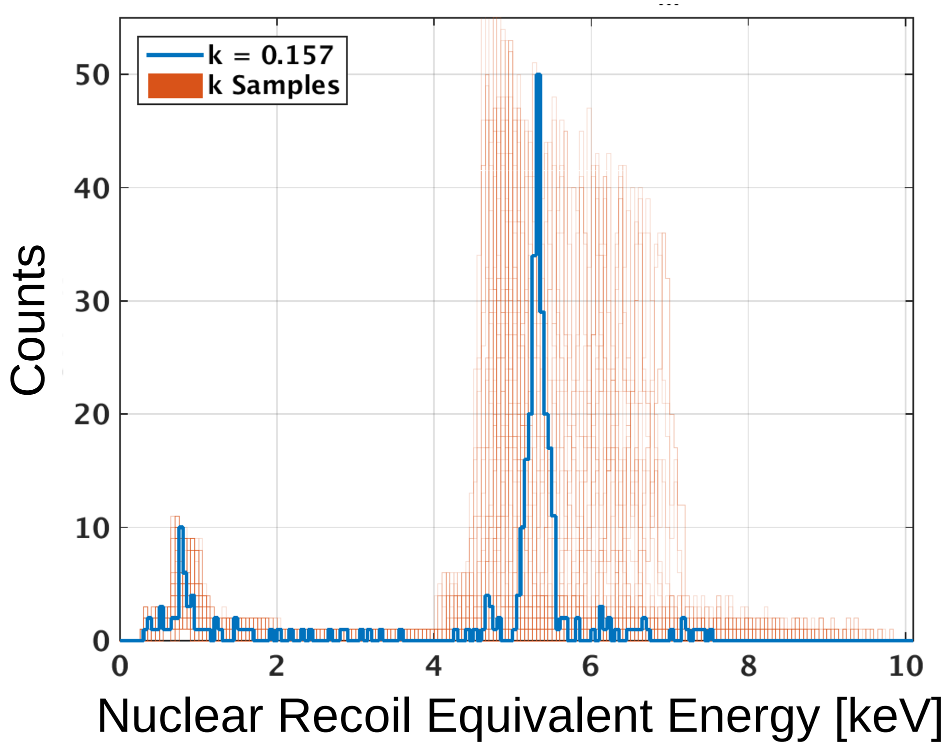


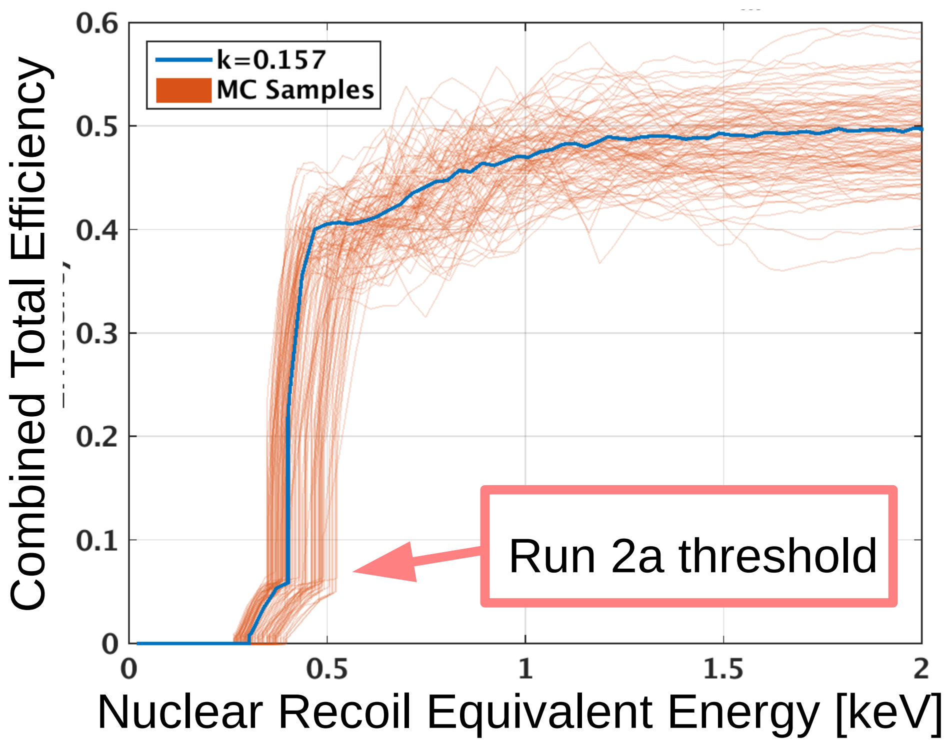
Removes >90% of reduced amplification events.



- ^{71}Ge activation peaks are visible in both Runs 1 & 2.
- ^{65}Zn K-shell electron capture peak visible in Run 1.
- Run 1 threshold 170 eV$_{ee}$
- Run 2 (period 1) threshold 75, (period 2) 56 eV$_{ee}$

Run 2 Limit Setting





- Used Optimal Interval* with no background subtraction.
- Converted to nuclear recoil (NR) equivalent energy using Lindhard model:

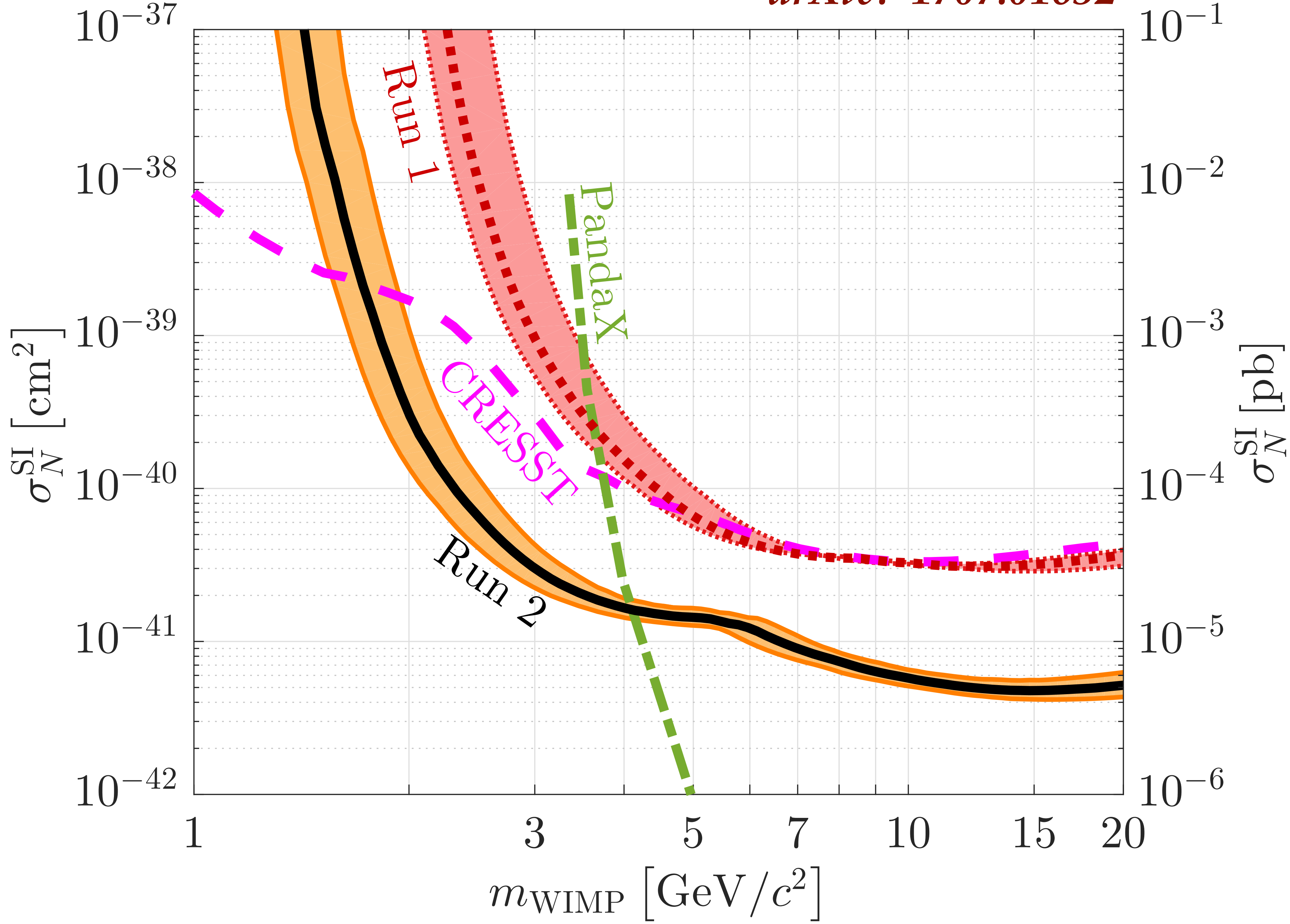
$$Y\left(E_{nr}\right) = k\left(Z,A\right) \cdot \frac{g\left(E_{nr},Z,A\right)}{1+k\left(Z,A\right) \cdot g\left(E_{nr},Z,A\right)}$$

- Created 1000 samples with input parameters drawn from uncertainty distributions.
- k(Ge) = 0.157, scanned over [0.1, 0.2]. Final result given by median. Uncertainty given by distribution.

*S. Yellin, Phys. Rev. D 66, 032005 (2002)

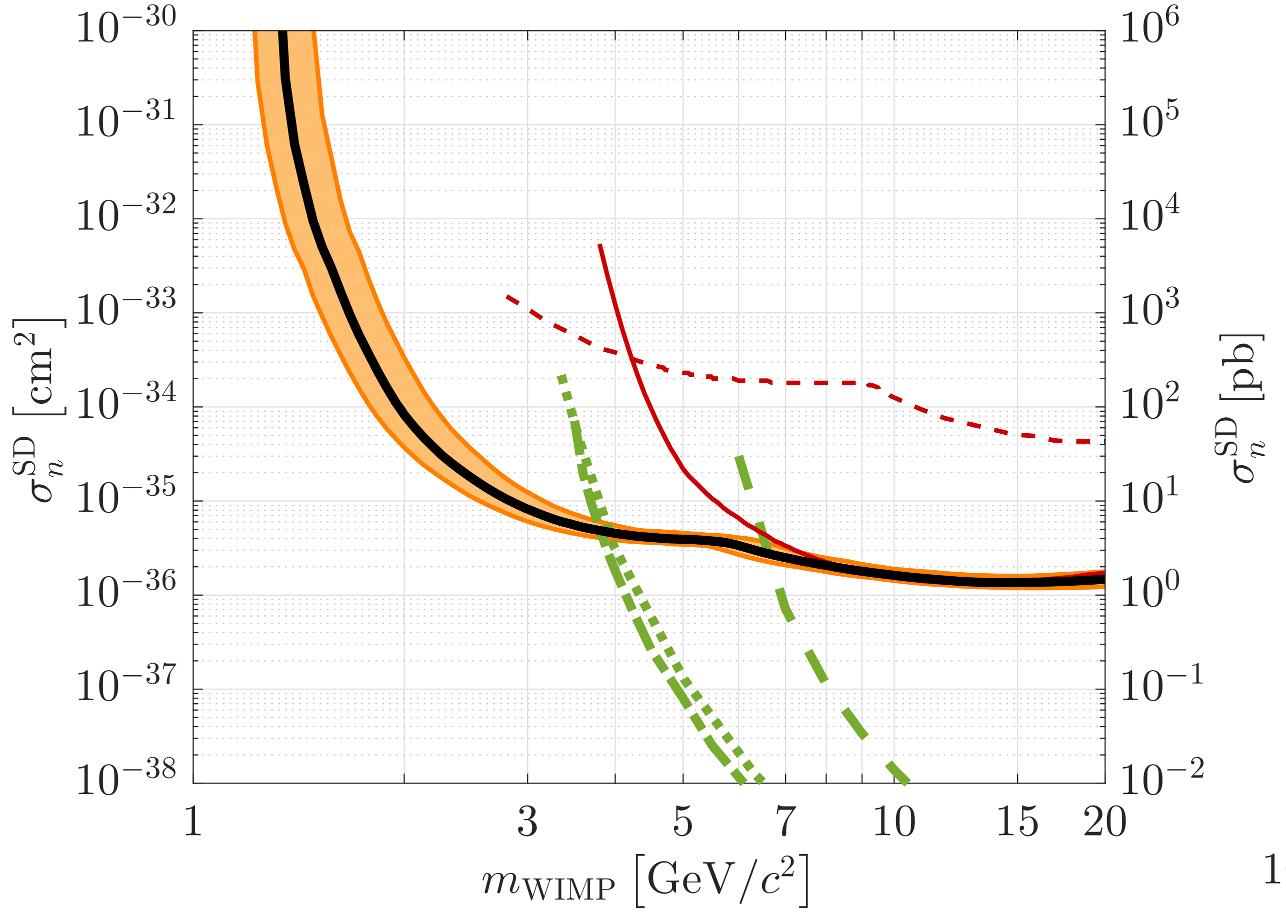
CDMSlite Results

arXiv: 1707.01632



Run 2: Spin Dependent Results

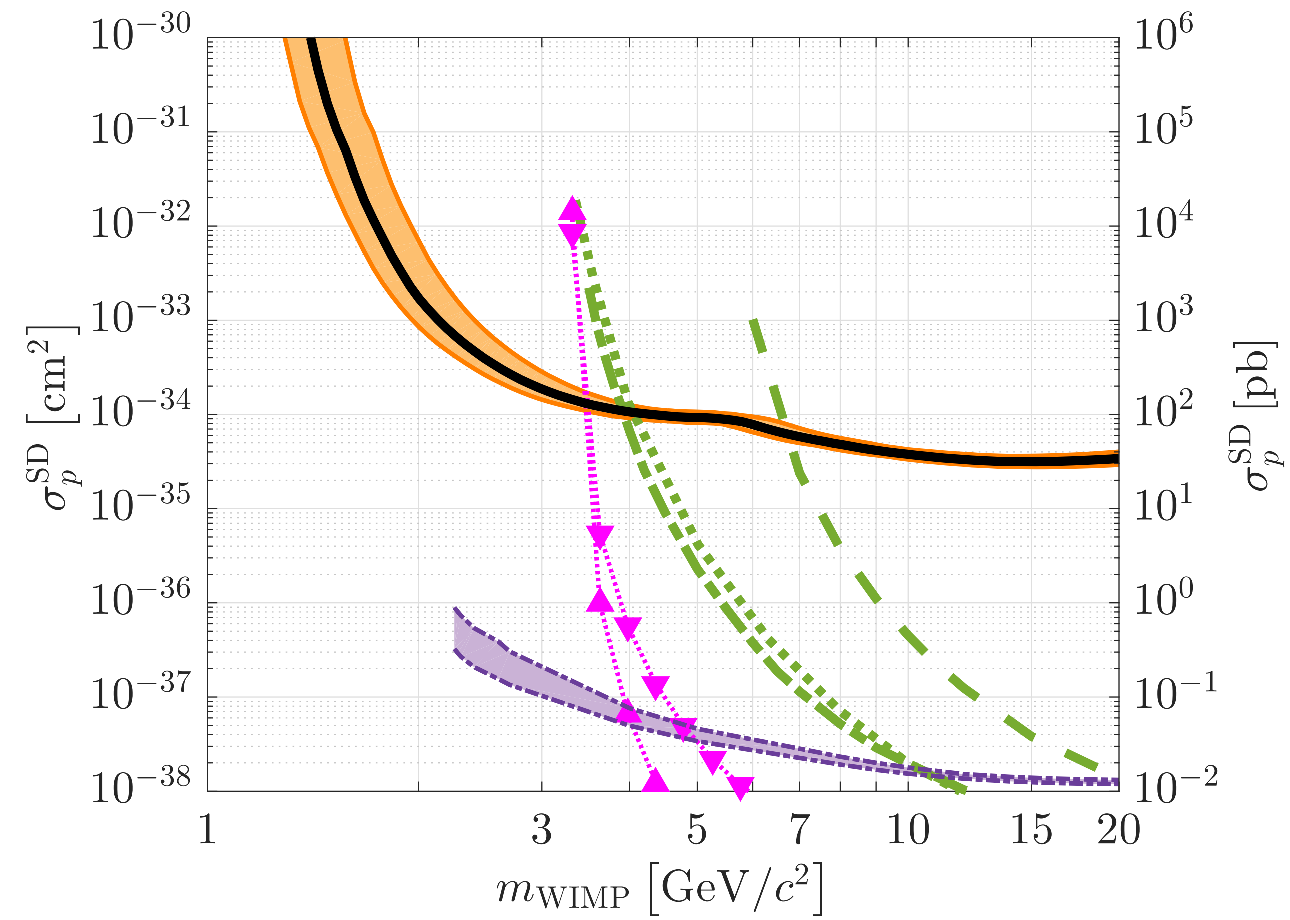
arXiv: 1707.01632



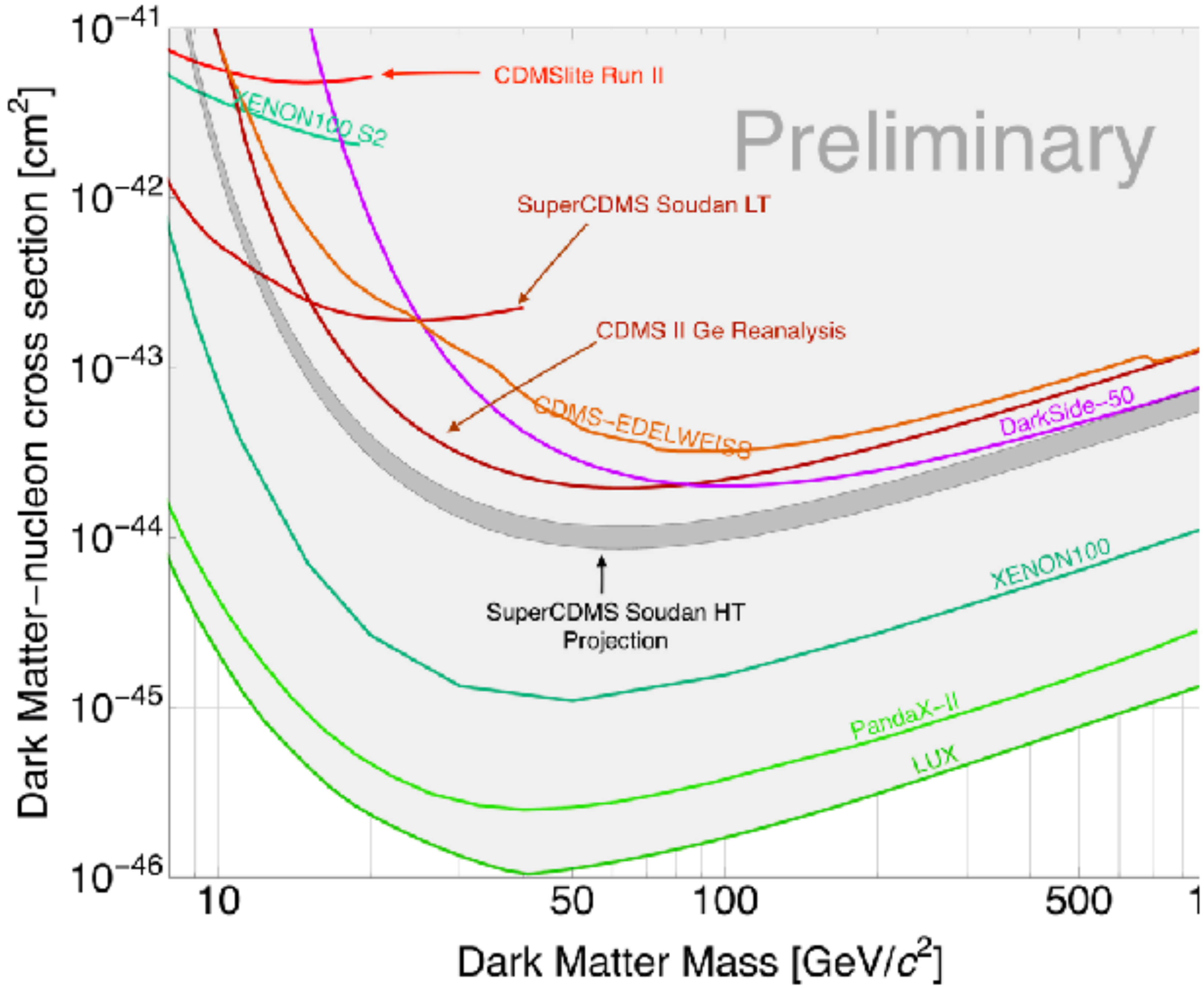
For WIMP masses < 4 GeV / c² *(<2 GeV/c²)* SuperCDMS has leading results for spin dependent WIMP-n *(WIMP-p)* interactions.

CDMSlite Run2
PANDAX-II
LUX
XENON100
CDEX-0
CDEX-1
PICASSO
PICO-60
PICO-2L

arXiv: 1707.01632



High Threshold Analysis Sensitivity



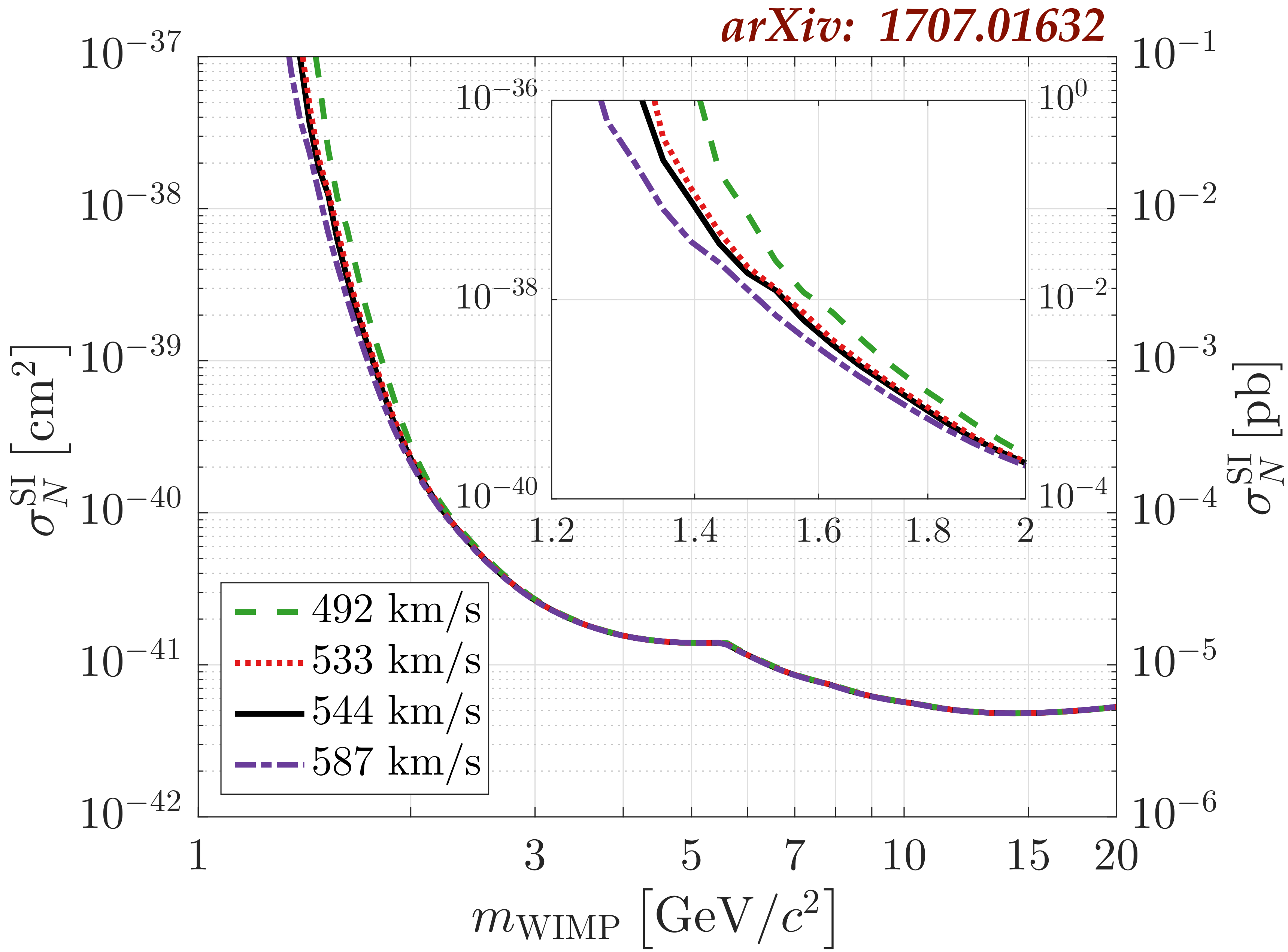
New Results to be announced soon!

Conclusions

- CDMSlite Run 2 has produced world leading limits in the search for low mass WIMPs. It excludes parameter space for WIMPs with masses between 1.6 and 5.5 GeV/c^2 for spin independent interactions and new parameter space below 4 GeV/c^2 (2 GeV/c^2) for spin-dependent WIMP-neutron (proton) interactions .
- The interpretation of the excess events seen by CoGeNT as a WIMP signal is disfavored. CDMS II (Si) disfavored assuming standard WIMP interactions and a standard halo model.
- The standard high threshold analysis of SuperCDMS is ongoing and aims for a background of less than 1 event. Results will be reported soon.
- Further analyses of SuperCDMS Soudan data are ongoing including CDMSlite Run 3 and a search for Lightly Ionizing Particles.

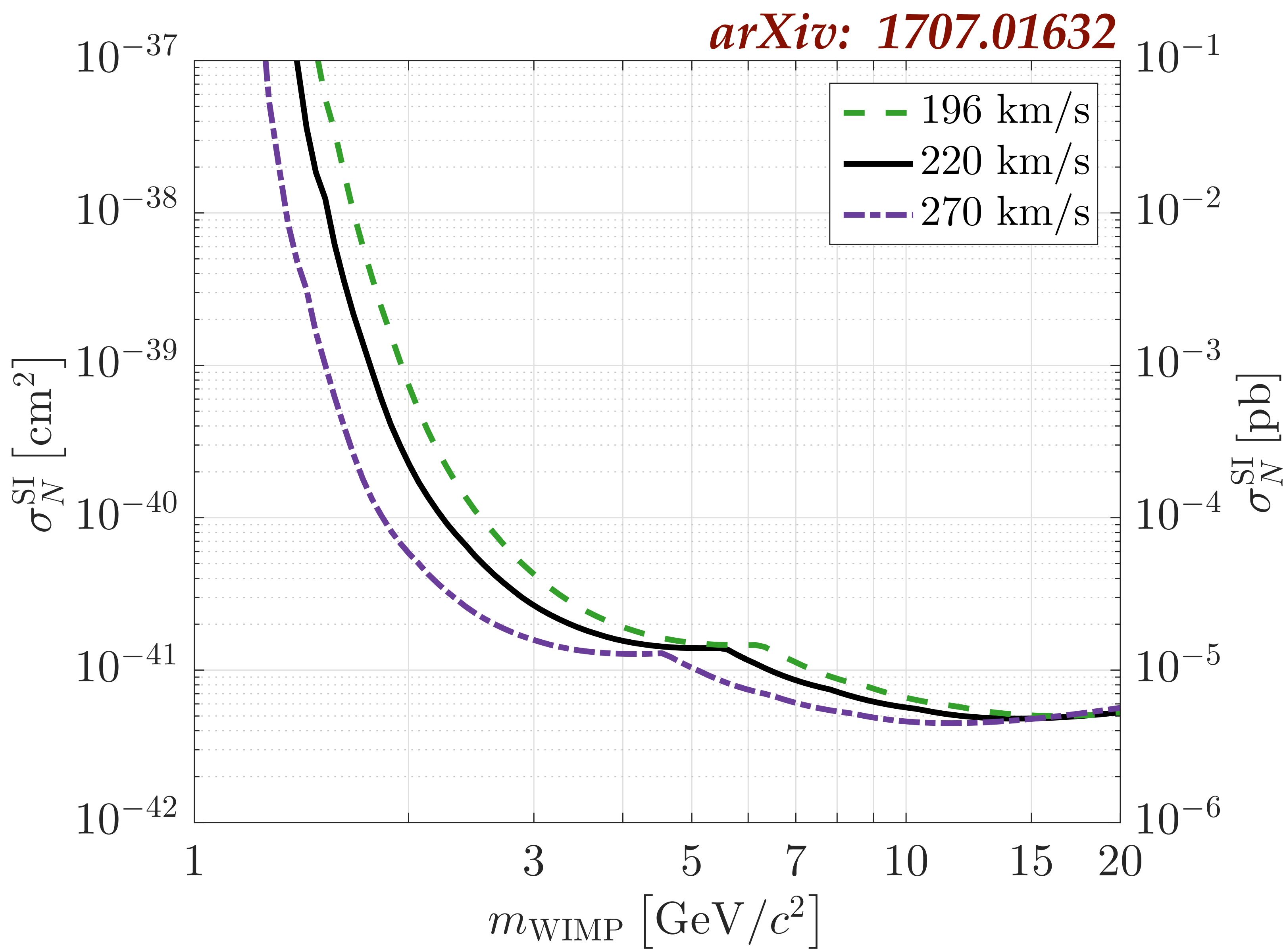
Backup Slides

Astrophysical Uncertainties



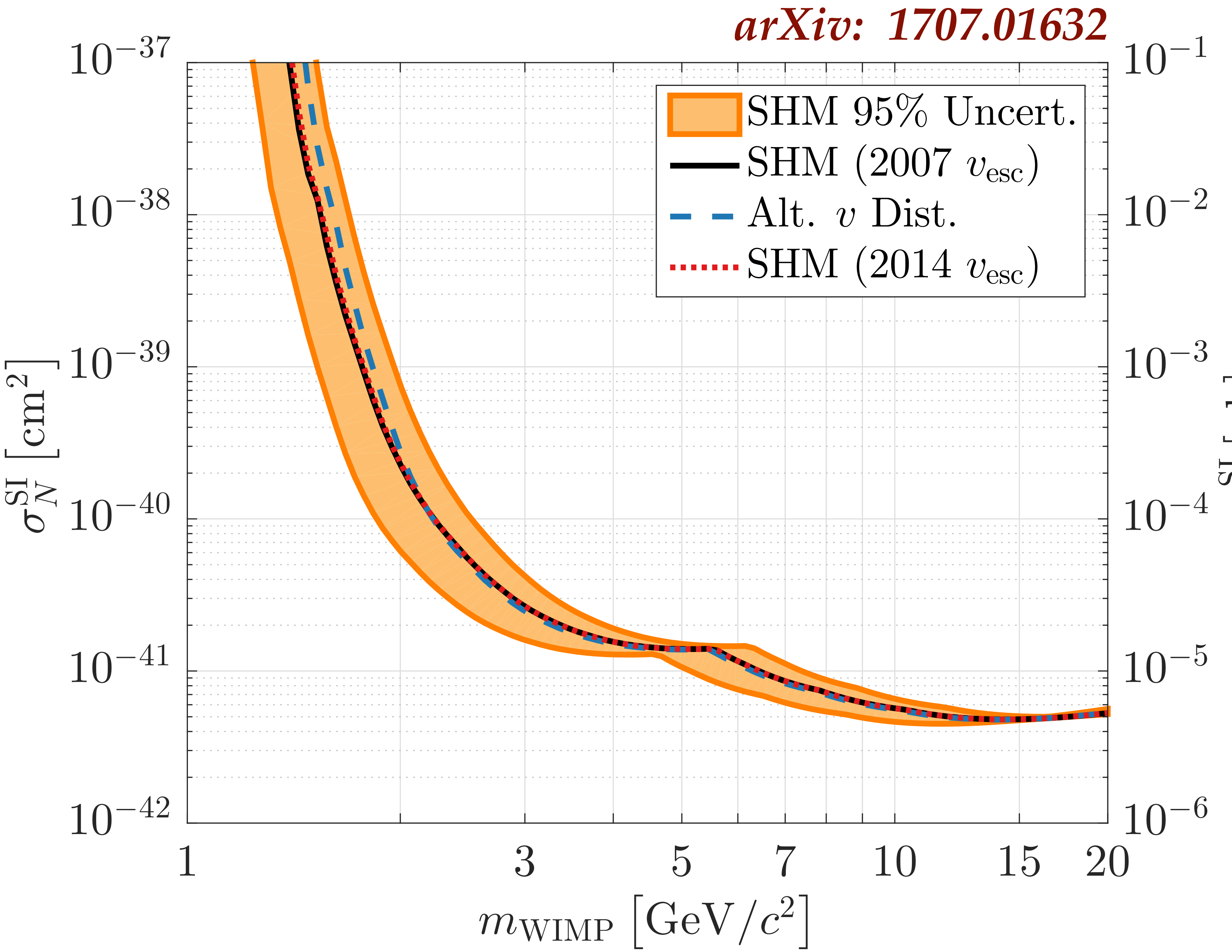
Limit dependence on galactic escape velocity assuming Maxwellian halo model.

Astrophysical Uncertainties



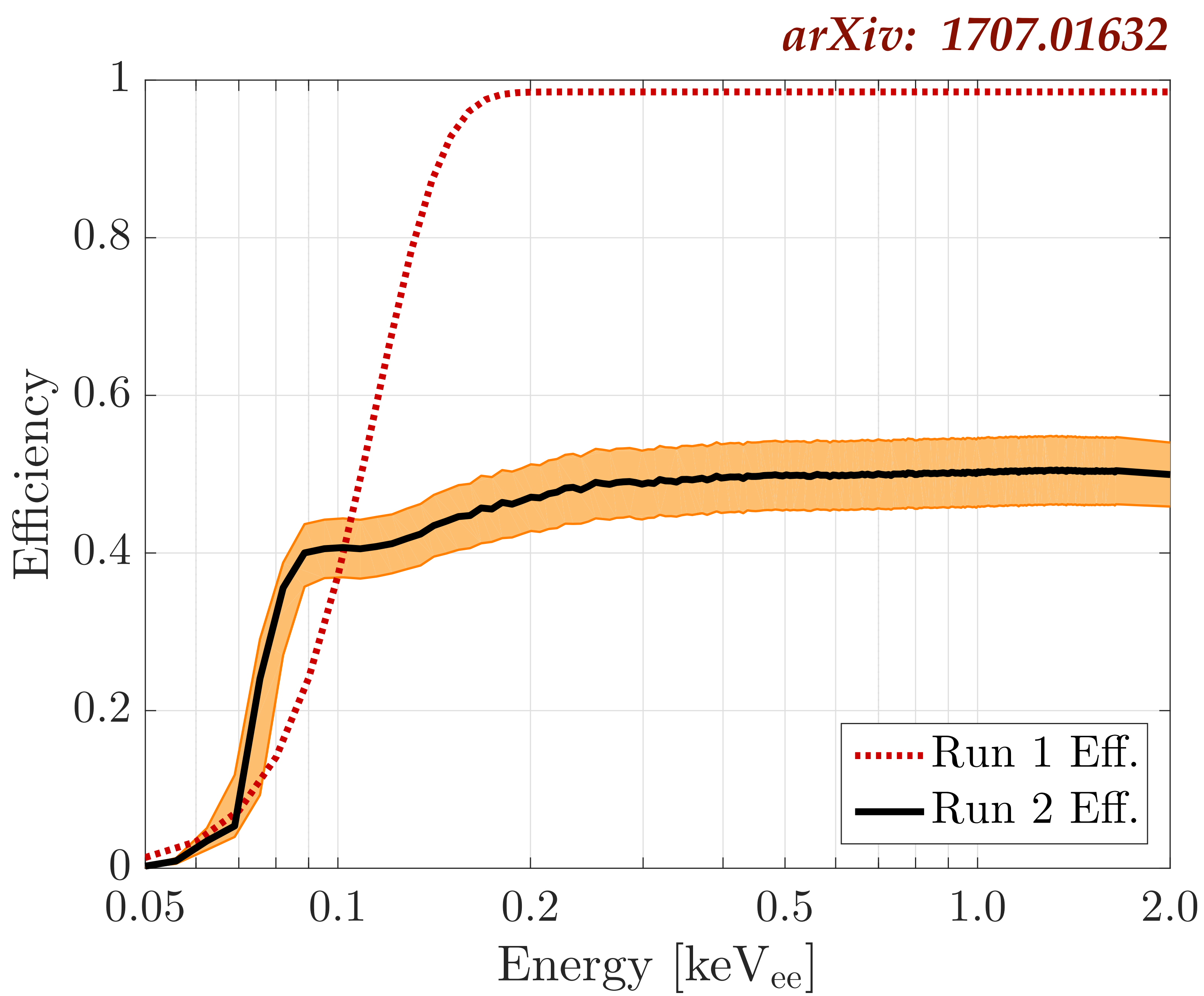
Limit dependence on WIMP velocity assuming Maxwellian halo model.

Astrophysical Uncertainties



95% Uncertainty band on limit due to uncertainties in the WIMP velocity and the galactic escape velocity.

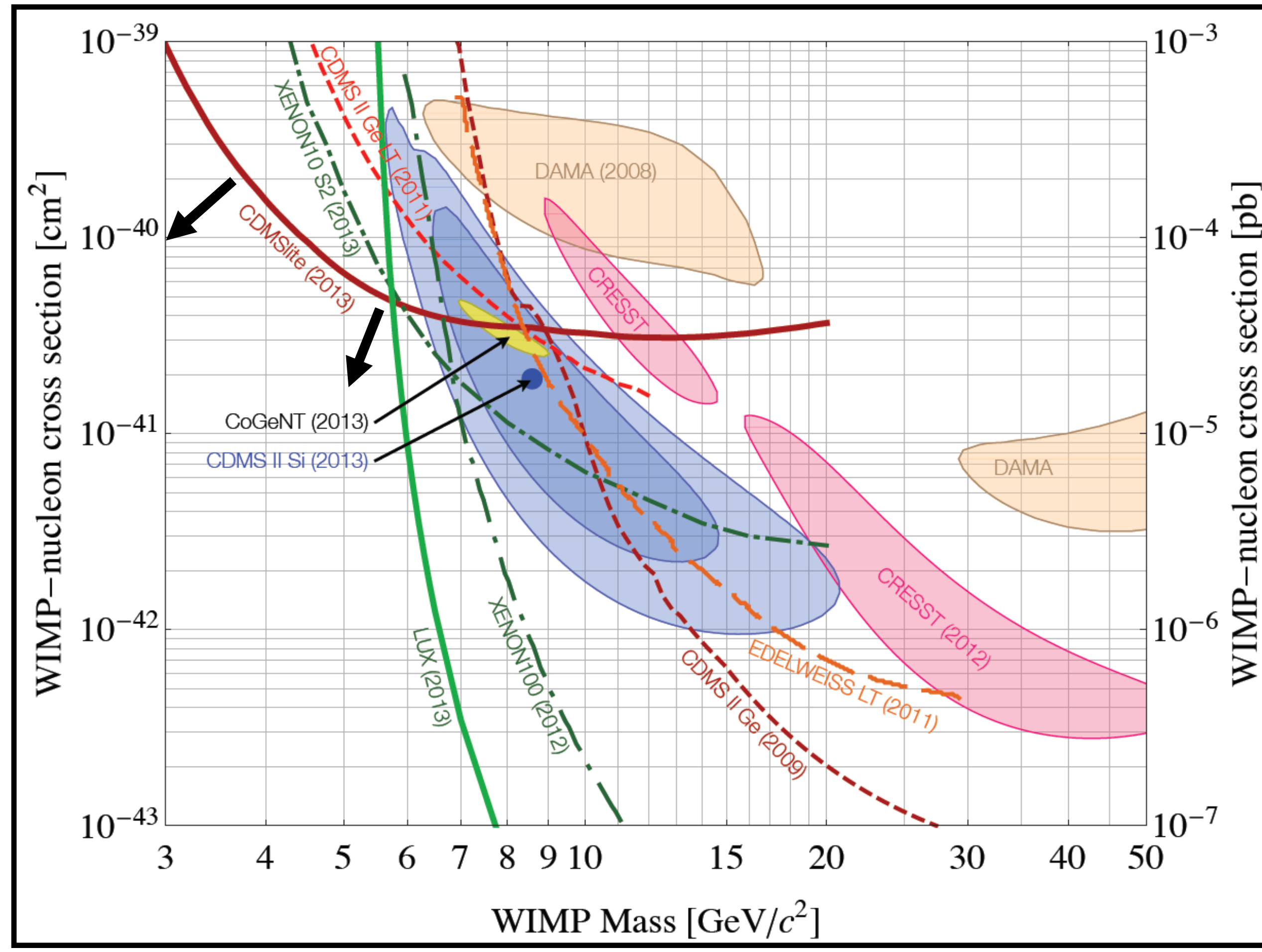
Efficiencies



Fiducial volume cut is primarily responsible for reduction in efficiency between Run 1 and Run 2.

CDMSlite: Run 2 Data

- Same iZIP was used, IT5Z2 – 0.6 kg
- 70 kg-days of data taken between Feb - Nov 2014.
  - Two data periods 59.32 kg-days and 10.78 kg-days



- Improvements over Run 1
  - Mitigate transient detector leakage current
  - Improved electronics board reduced variation in bias potential
  - Vibration sensors installed to monitor cryocooler low frequency noise.

- Analysis improvements lead to better energy calibration, low frequency noise rejection and improved fiducial volume.

Reached energy threshold for electron recoils of 56 eV!

CDMSlite: Run 1 Data

PRL 112, 041302, 2014

- Proof of Principle
- Data were taken during three periods in 2012
  - 6.25 kg-days exposure
- One iZIP was used, (IT5Z2 – 0.6 kg)
  - Selected for its low trigger threshold and low leakage current
  - 170 eV ionization threshold