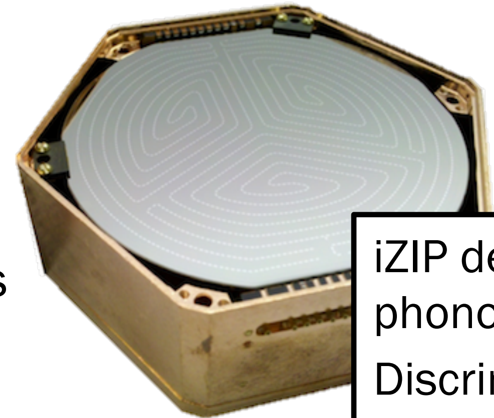
Measurement of Cosmogenic Production Rates in Germanium with CDMSlite

Eleanor Fascione

CAP June 11th 2018

SuperCDMS



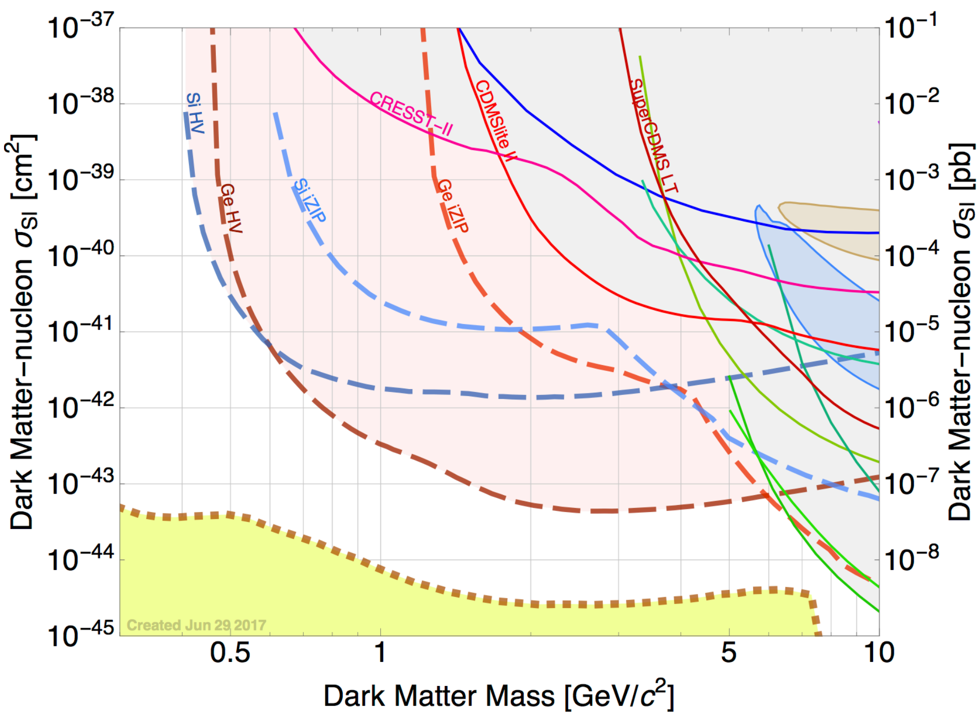
Cryogenic semiconductor detectors search for dark matter

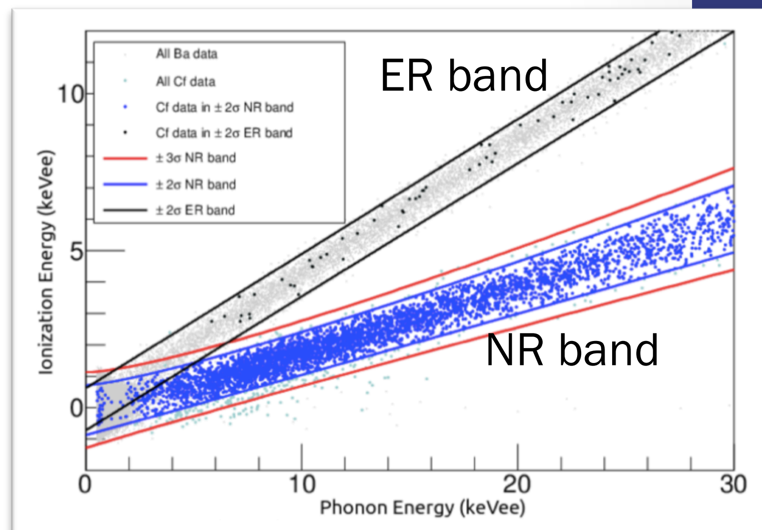
iZIP detector: measure phonons + ionization

Discriminate electron vs. nuclear recoils

Past (2012-2015)

- 15 Ge detectors (~9 kg)
- At Soudan, MN (~700m below ground)





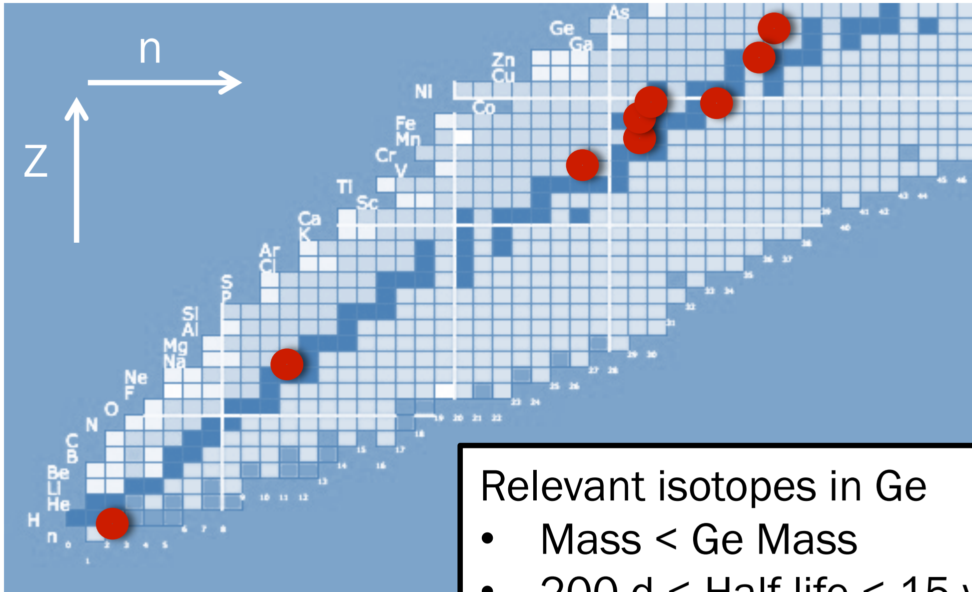
Future

- SuperCDMS SNOLAB
  Is under construction
- Commissioning in 2020

Outline

- Cosmogenic production of isotopes in detector materials
- HV mode and CDMSlite Run 2
- Analysis approach and signal efficiency
  - Published efficiency
- Extension of efficiency to higher energies
- Likelihood fit to Run 2 spectrum
  - Backgrounds contributing to spectrum
  - Consideration of other backgrounds
- Extracting cosmogenic production rates in germanium

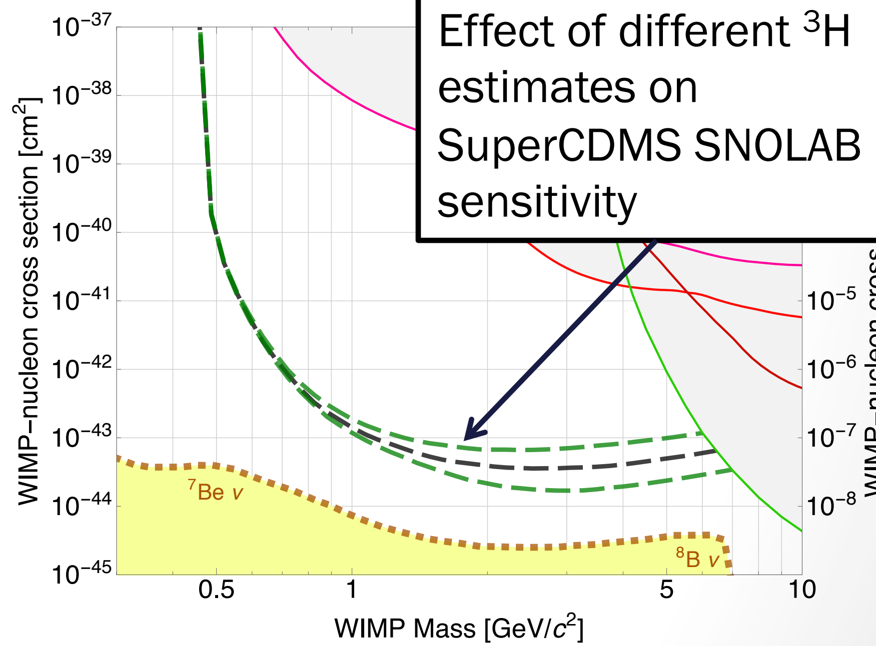
Cosmogenic Production



Relevant isotopes in Ge
- Mass < Ge Mass
- 200 d < Half life < 15 yr

- Earth's surface: detector is exposed to cosmic rays
- Interactions can produce radioisotopes

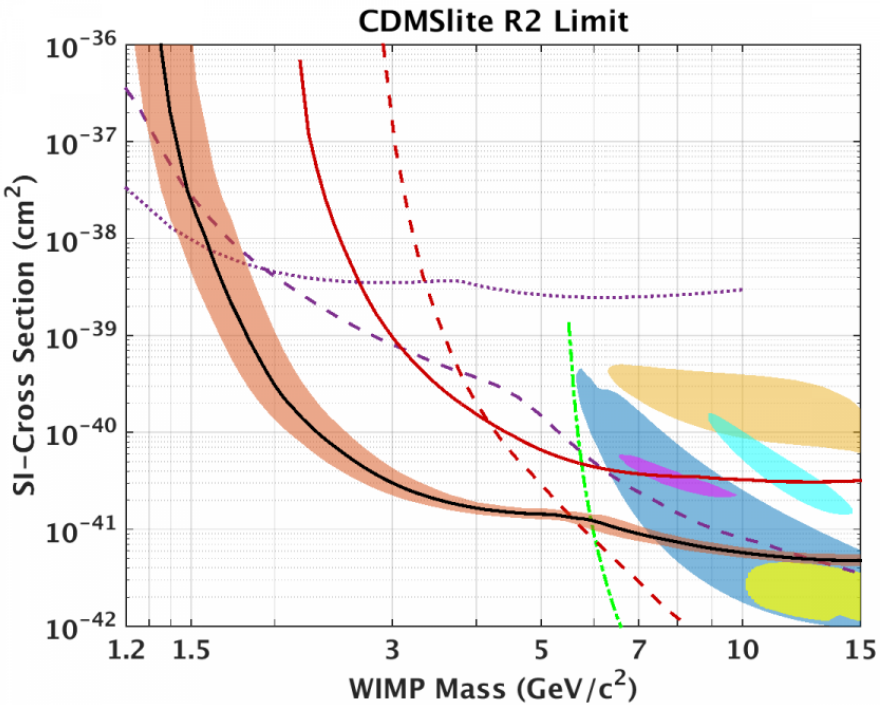
- Cosmogenic isotopes create background in sensitive experiments
- Expected limiting background in SuperCDMS SNOLAB: ^3H
- Production rates in Ge not well understood
- <u>Only one other measured rate (EDELWEISS, 2017)</u>



Effect of different ^3H estimates on SuperCDMS SNOLAB sensitivity

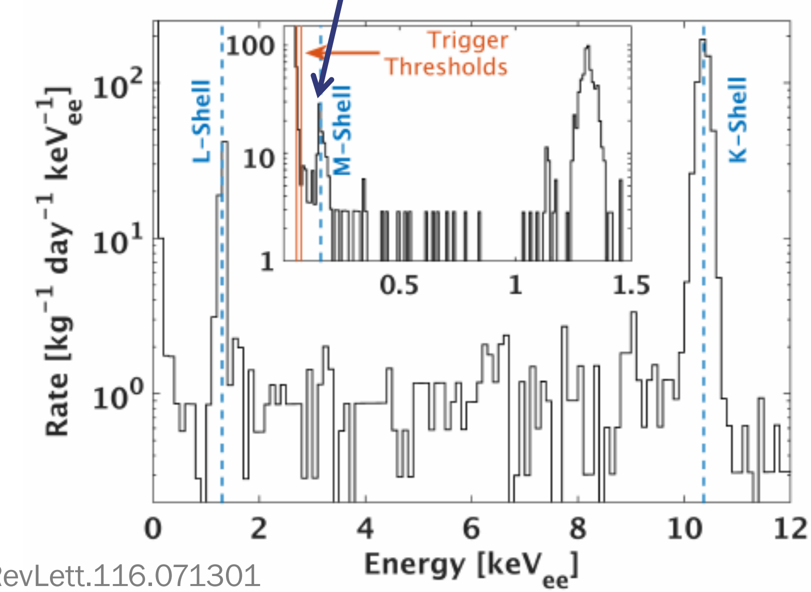
Projected sensitivity of the SuperCDMS SNOLAB experiment
10.1103/PhysRevD.95.082002

HV mode: CDMSlite Run 2



- High bias (~70 V): drifting charges generate large phonon signal (NTL effect)
- Reach much lower thresholds: ~56 eV in Run 2
- No ER vs. NR discrimination

Visible M-shell at 0.16 keV from ^{71}Ge decay



- 70 kg day data set
- Published world-leading limits for 1.6 – 5.5 GeV/c^2 WIMPs
- Use spectrum to measure cosmogenic production rates of ^{3}H, ^{55}Fe, ^{65}Zn, and ^{68}Ge

10.1103/PhysRevLett.116.071301

Analysis Approach

- Consider different background components
- Spectral shape of each component is determined to fit spectrum
- Measured spectral shape depends on signal efficiency, must know over entire fit range

Background Components

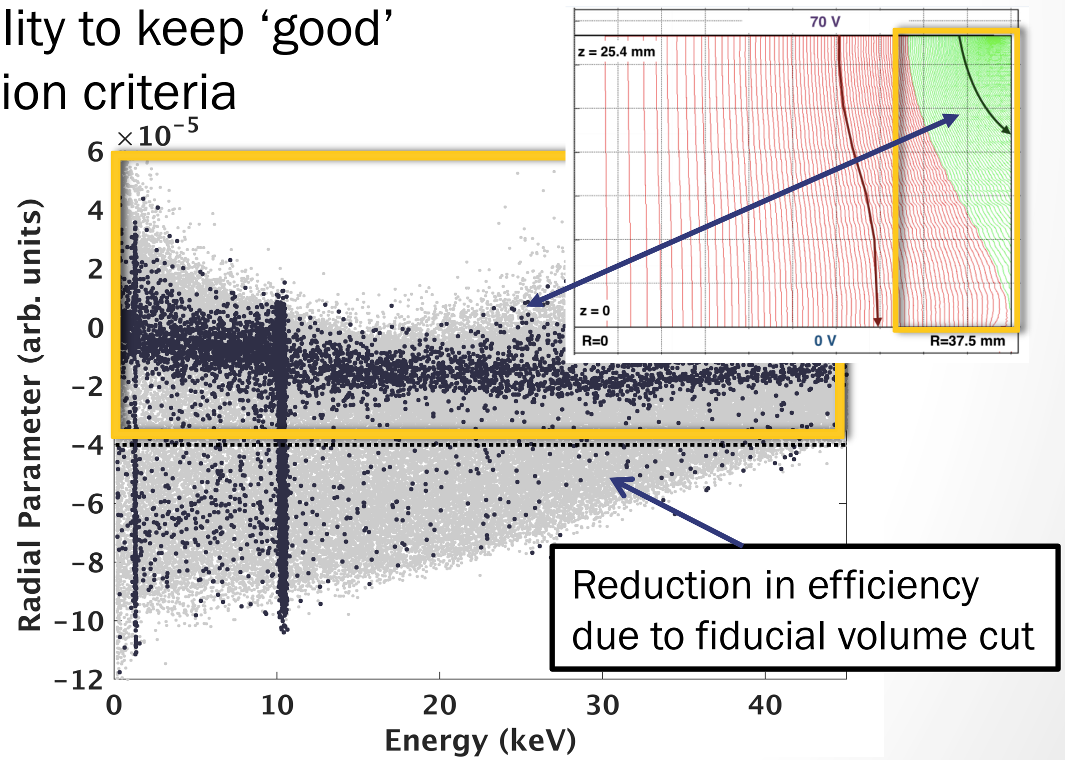
- ^3H: β^- spectrum
- Compton: flat with steps at Ge K-, L-, M-shell binding energies
- Electron capture (EC): peaks

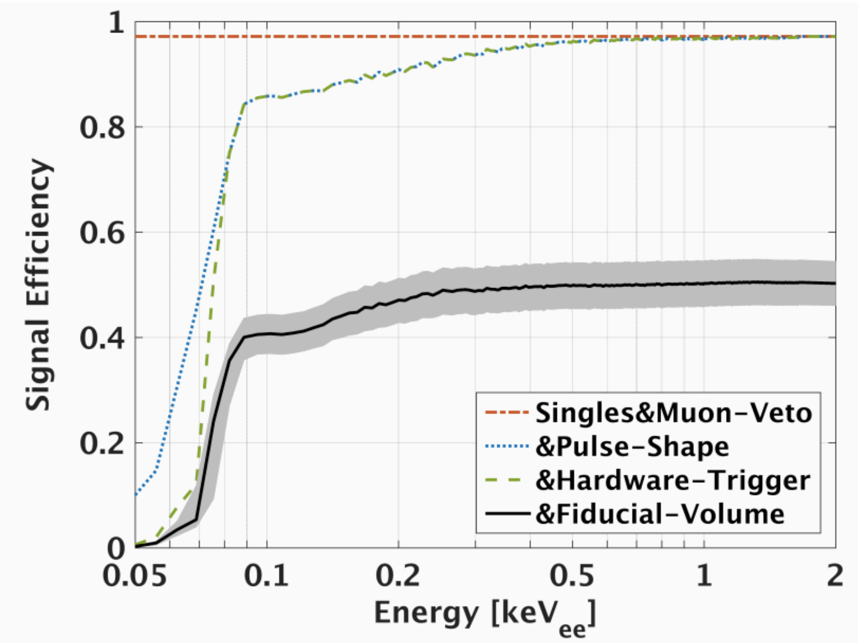
Signal Efficiency

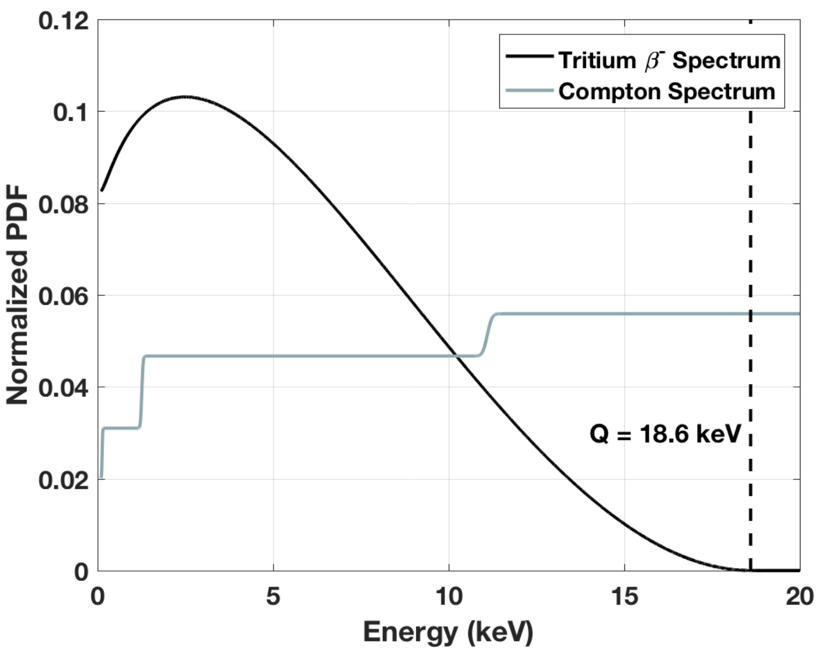
Energy dependent probability to keep 'good' event after applying selection criteria

- Need to remove events with reduced NTL gain
- Radial parameter: imperfect proxy for real radius
- Poor performance of Radial parameter above ~20 keV

E-field in z vs. radius plane



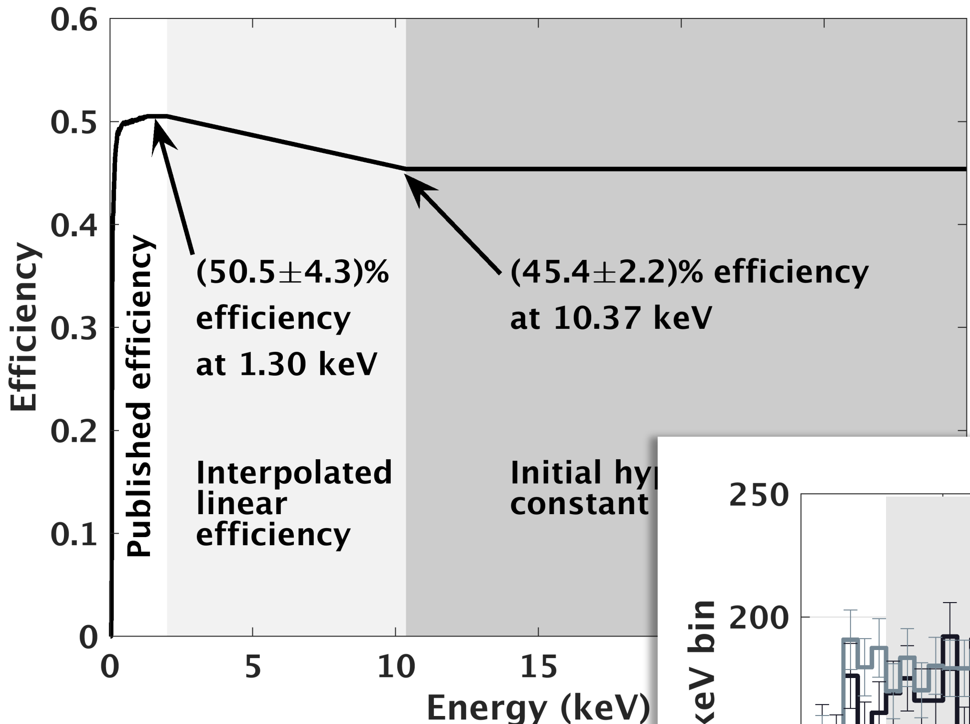




Extending the Efficiency

- Originally calculated up to 2 keV: range for DM analysis
- Separation of ^{3}H and Compton requires fit at higher energy where ^{3}H contribution is small
- Fit up to 20 keV is a good compromise: above ^{3}H endpoint (18.6 keV) and below region where efficiency drops drastically

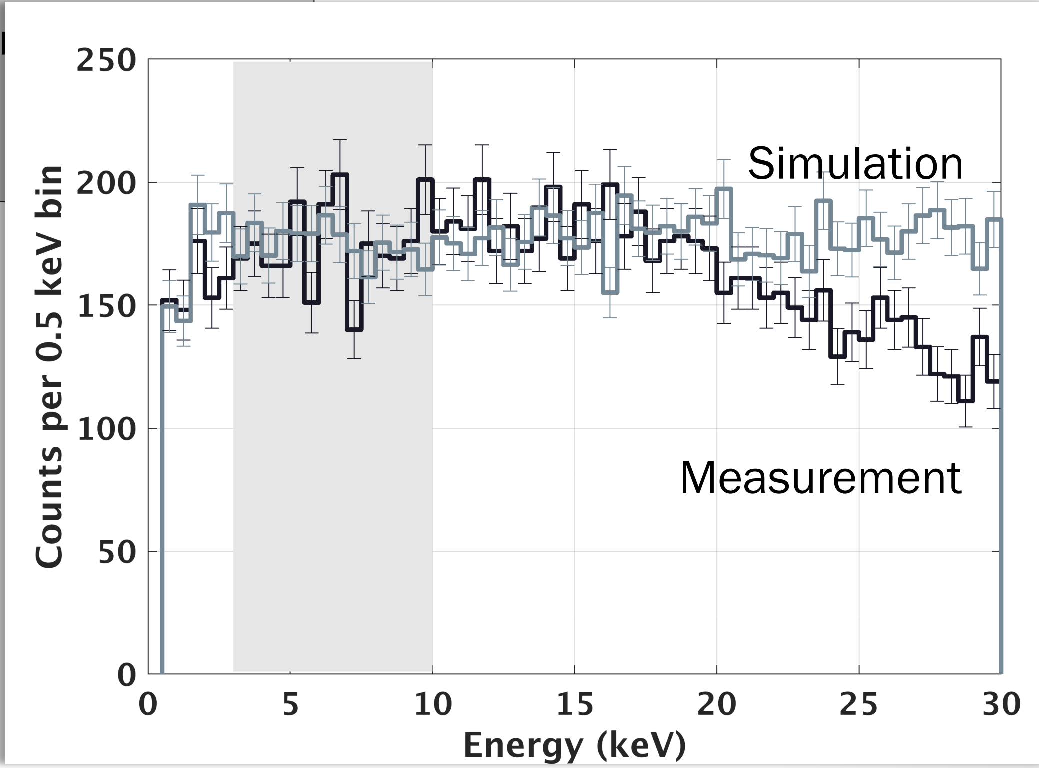
Extending the efficiency



Initial hypothesis efficiency

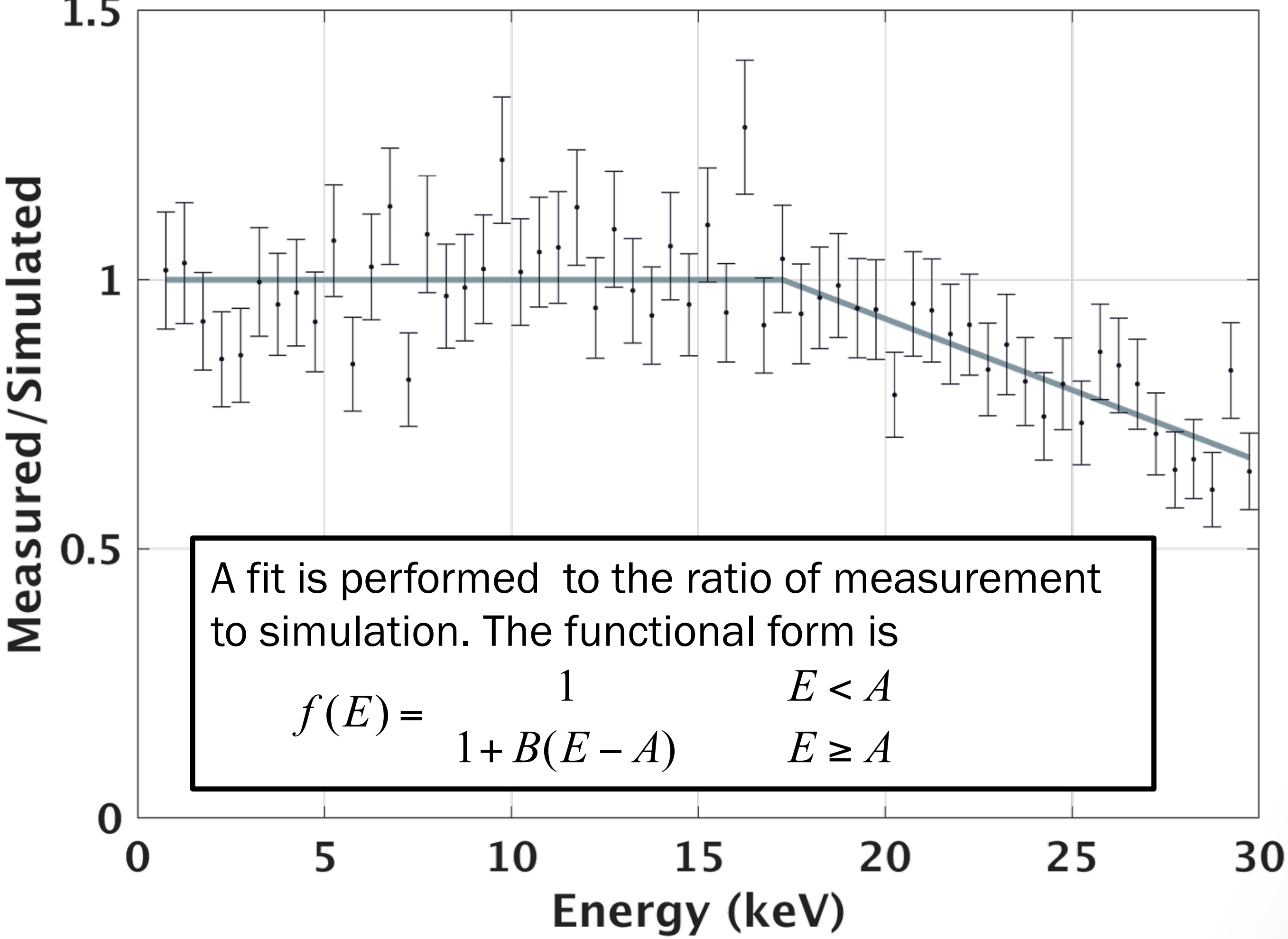
- Published efficiency below 2 keV
- Linearly interpolated to efficiency measured at 10 keV
- Constant above 10 keV

Applied to simulated ^{133}Ba calibration spectrum, compared with measured spectrum



Clear deviation is seen above 20 keV

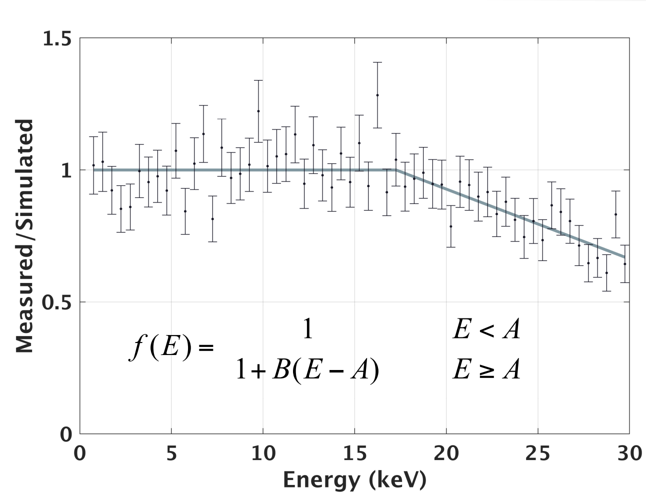
Adapting the efficiency

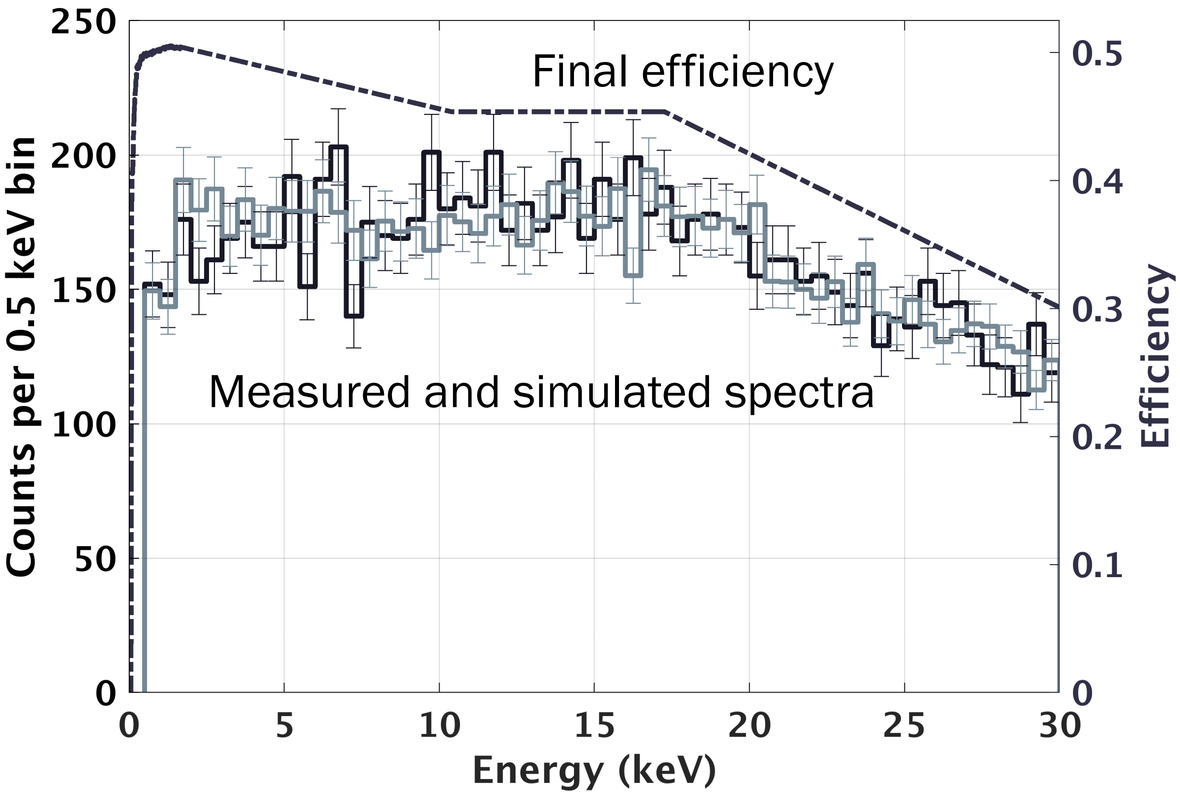


A fit is performed to the ratio of measurement to simulation. The functional form is

$$f(E) = \begin{cases} 1 & E < A \\ 1 + B(E - A) & E \geq A \end{cases}$$

Adapting the efficiency

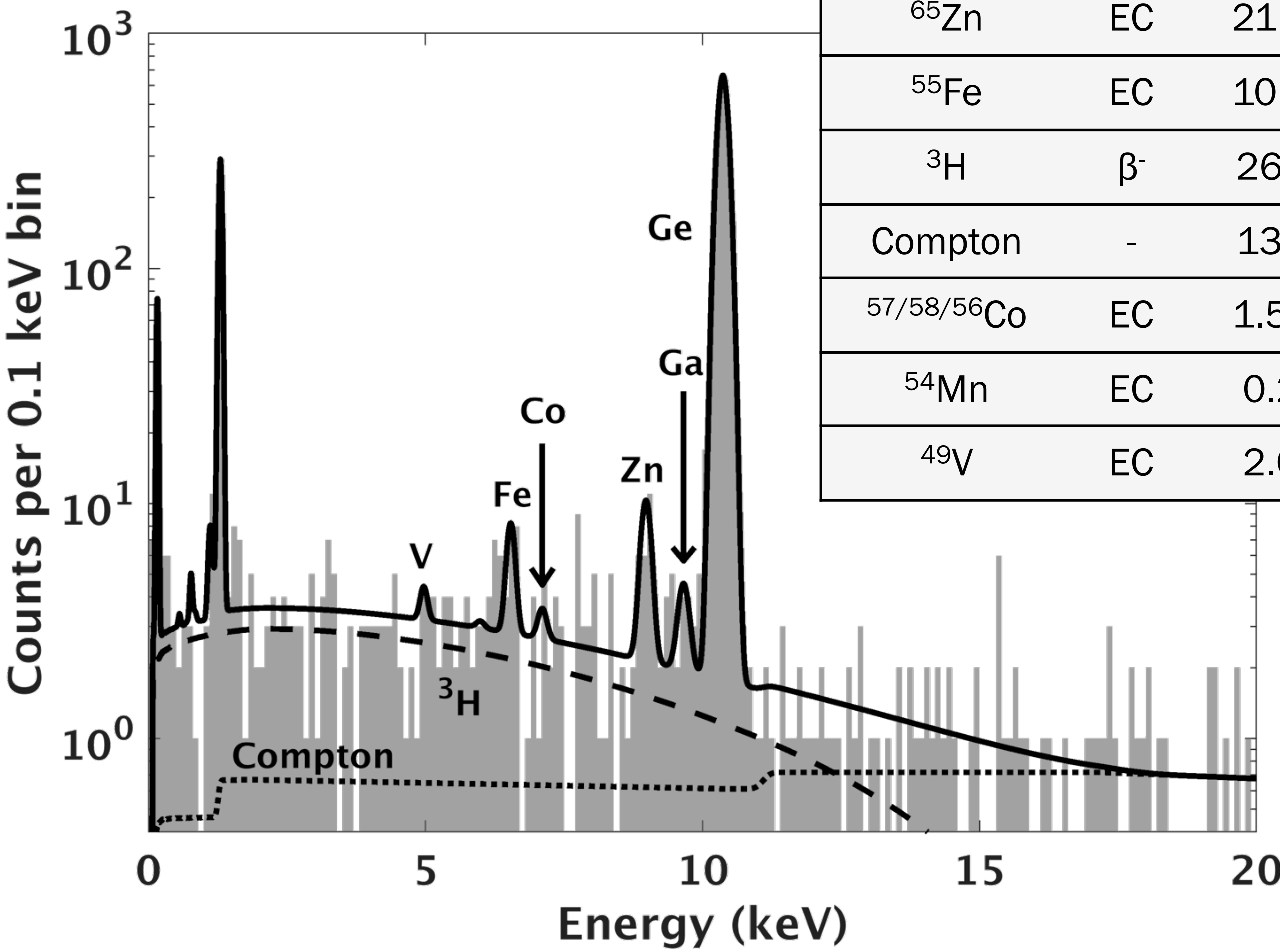




(Fit) x (initial efficiency) applied to simulated spectrum:

Good agreement between measurement and simulation is observed

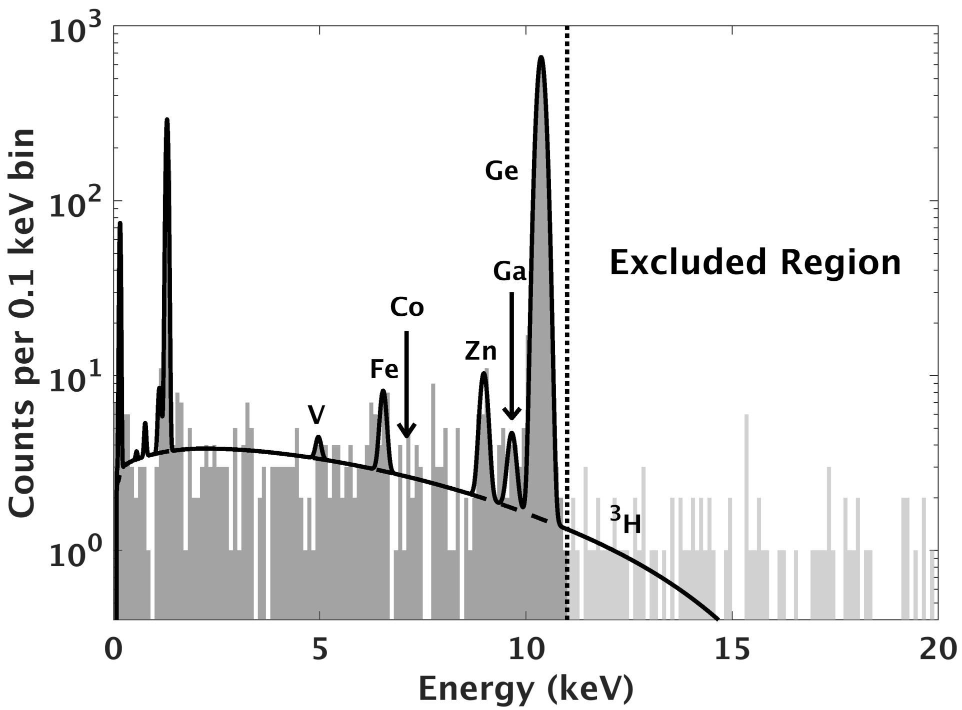
Likelihood Fit Results



Background	Type	Fit Result	1σ Confidence Interval
$^{71/68}$Ge	EC	1932	[1912, 1950]
^{68}Ga	EC	7.2	[4.0 12.7]
^{65}Zn	EC	21.5	[16.7, 28.4]
^{55}Fe	EC	10.4	[7.7, 17.7]
^{3}H	β^-	265	[245, 294]
Compton	-	130	[114, 154]
$^{57/58/56}$Co	EC	1.57	[-0.3, 6.7]
^{54}Mn	EC	0.2	[-1.7 4.9]
^{49}V	EC	2.0	[-0.1 6.5]

Other Backgrounds

- Instrumental noise removed by quality cuts
- β^+ and β^- backgrounds (other than ^3H) shown to be negligible
- Surface background from ^{210}Pb is subdominant
- Accounting for unknown backgrounds:
  - worst case for projected sensitivity of SuperCDMS SNOLAB: all continuous BG between peaks is ^3H
  - a conservative fit is performed, setting Compton contribution to zero



Conservative fit below 11 keV, where Compton and ^3H β^- spectra are most similar

Results in 30% higher ^3H component

Production Rate Results

Production rates determined using isotope decay rates (determined from likelihood fit) and detector history

Isotope	Production Rate (atoms/kg/day)	Comment/Assumptions	EDELWEISS (atoms/kg/day)
^{3}H	74 ± 9 (96 ± 10)	Best fit result Neglecting Compton component	82 ± 12
^{55}Fe	1.5 ± 0.7	-	4.6 ± 0.7
^{65}Zn	17 ± 5	-	106 ± 13
^{68}Ge	29 ± 18	-	>71

^{3}H rate is **consistent** with EDELWEISS

Other rates are significantly **lower** than those from EDELWEISS

Conclusion

- Extended efficiency up to 30 keV
- Likelihood fit determines backgrounds event rates in CDMSlite Run 2 spectrum
- Extracted production rates using detector history and event rates
- ^{3}H rate is compatible with that from EDELWEISS, other isotope rates are significantly lower
- Need better understanding of dependence of cosmic ray flux on location, overburden, etc. and more measurements to interpret data

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. Montréal
U. Minnesota
U. South Dakota
U. Toronto

* Associate members

BACKUP SLIDES

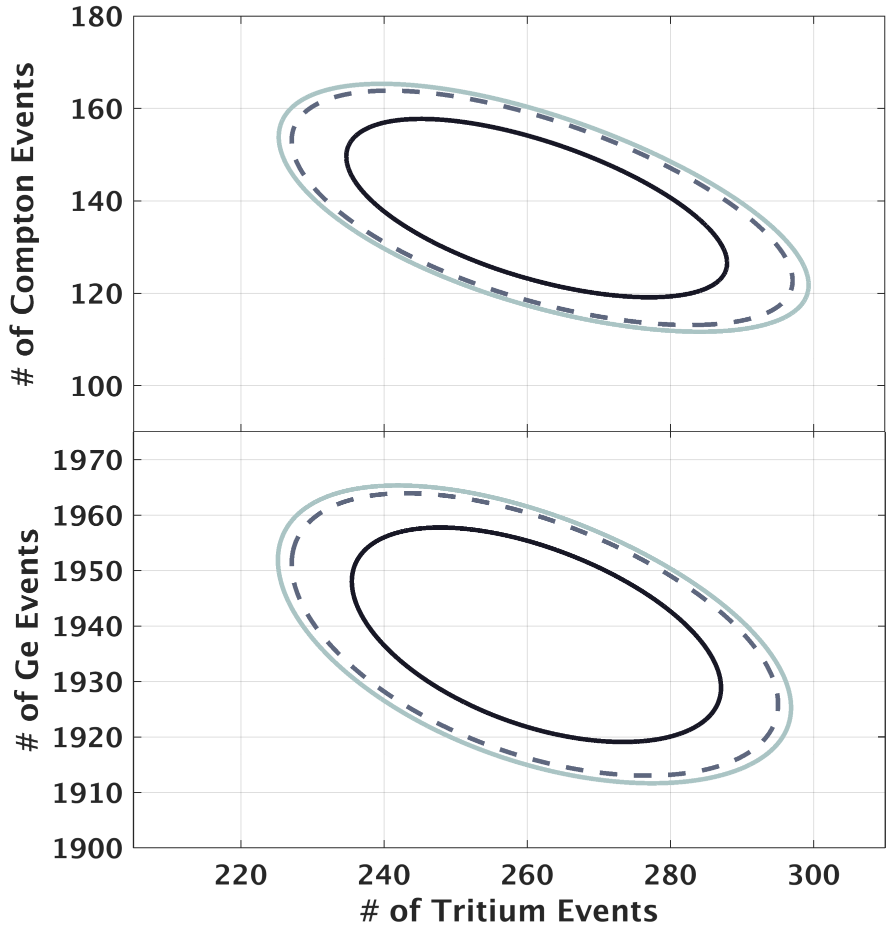
Uncertainties and Correlation

1d Uncertainties

- Hold one background fixed, allow others to float, maximize likelihood
- Repeat over large range of values of the fixed background
- Results in likelihood distribution, can extract confidence intervals

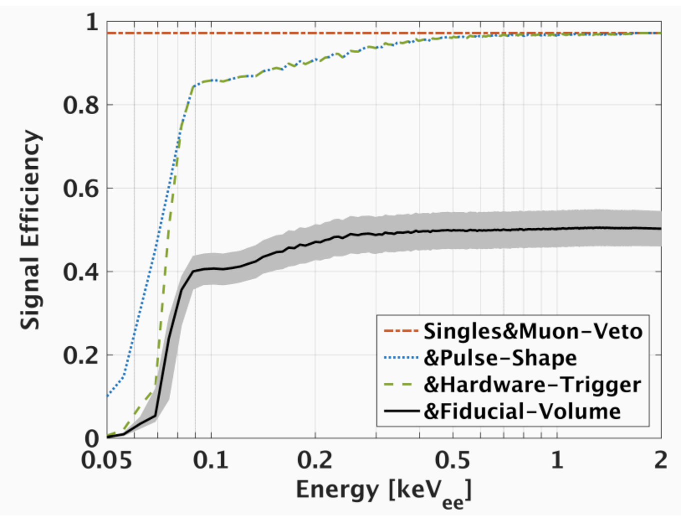
Correlation

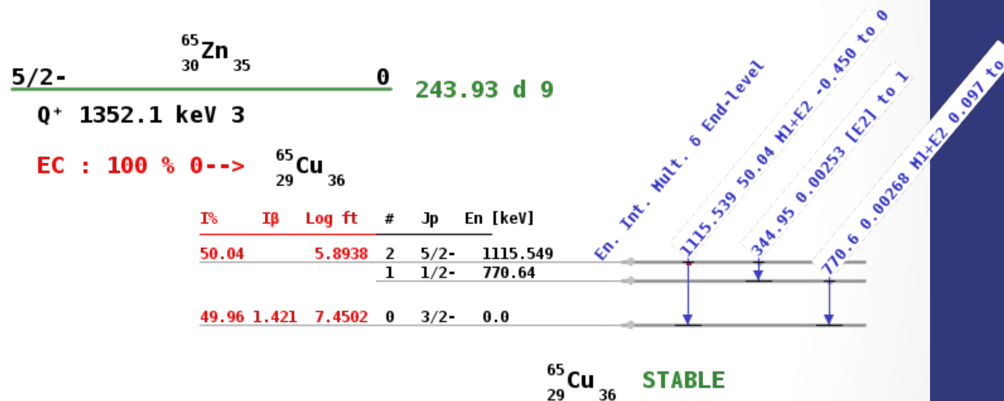
- Similar method, fixing two backgrounds over a grid
- Accept-reject method samples distribution



Total Number of Decays

- Likelihood fit estimates number of events in spectrum
- Need the total number of decays of each isotope, correct for:
  - Detection efficiency
  - Decay type branching ratios



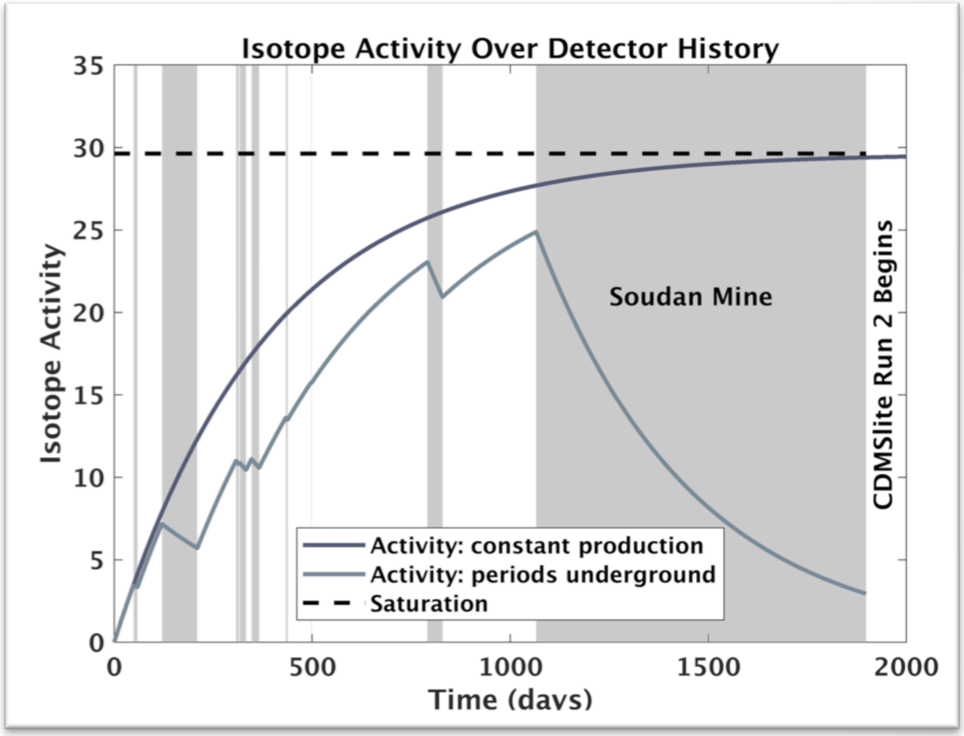


  - Fraction of EC events in the singles EC peak (ground state decays)
    - ^{65}Zn and ^{68}Ga can decay via EC to an excited state
    - If coincident gamma escapes, event ends up in singles EC peak

Extracting Production Rates

Detector location history post crystal pulling

- Kept above ground at Stanford or SLAC, or in underground tunnel
- Later at Soudan mine



^{68}Ge activity during detector fabrication, testing, & storage

- Production rates determined using isotope decay rates (determined from likelihood fit) and detector history

Fraction of EC Events in Single Scatter Peak

^{65}Zn

Electron Capture

Ground State

Excited State, the Coincident Gamma:

Interacts in another detector

Escapes all detectors

CD

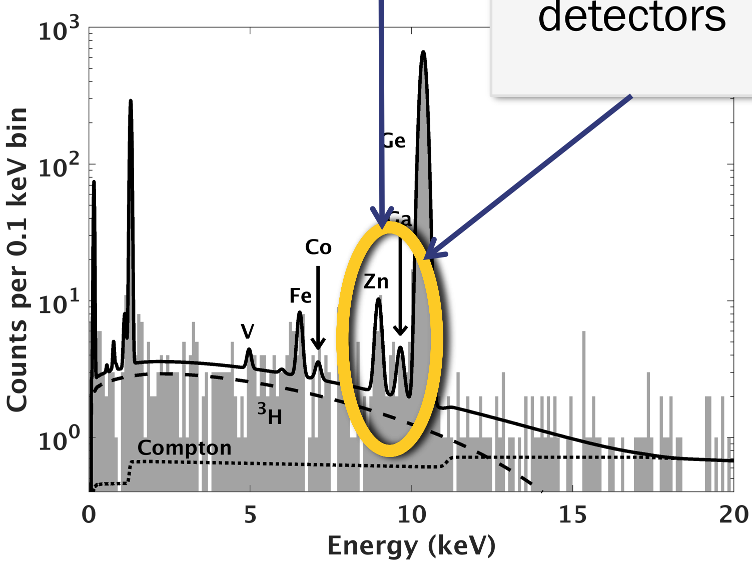
e

py

cut

pton

Singles EC peak



Counts per 0.1 keV bin

EC events to ground state or to an excited state where the gamma ray escapes all detectors end up in the singles peak.

The fraction of these events out of all EC decays is the “singles efficiency”, and is determined using a Monte Carlo simulation