Estimation of ^{32}Si and ^{32}P background rate in CDMS II experiment

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Outline

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  - CDMS II experiment
- Motivation
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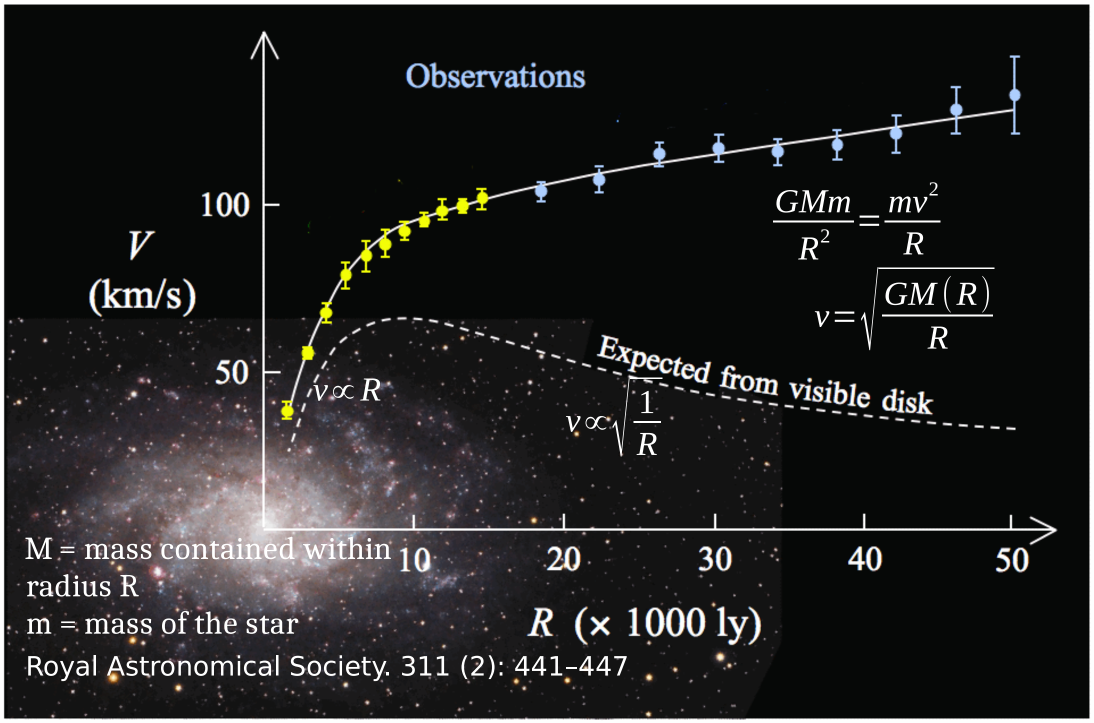
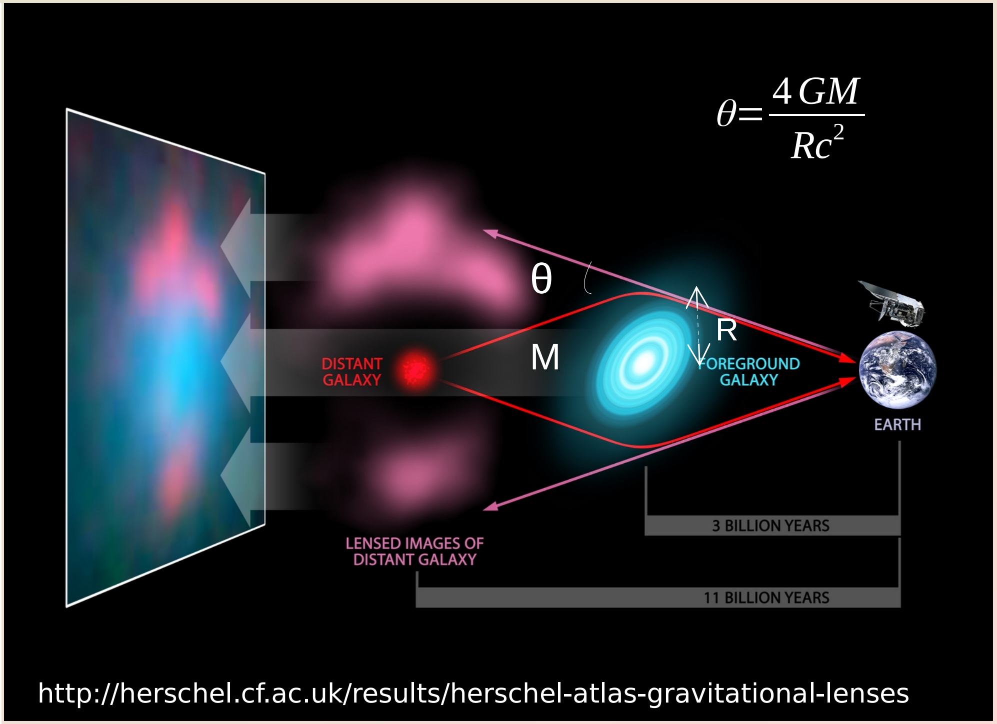
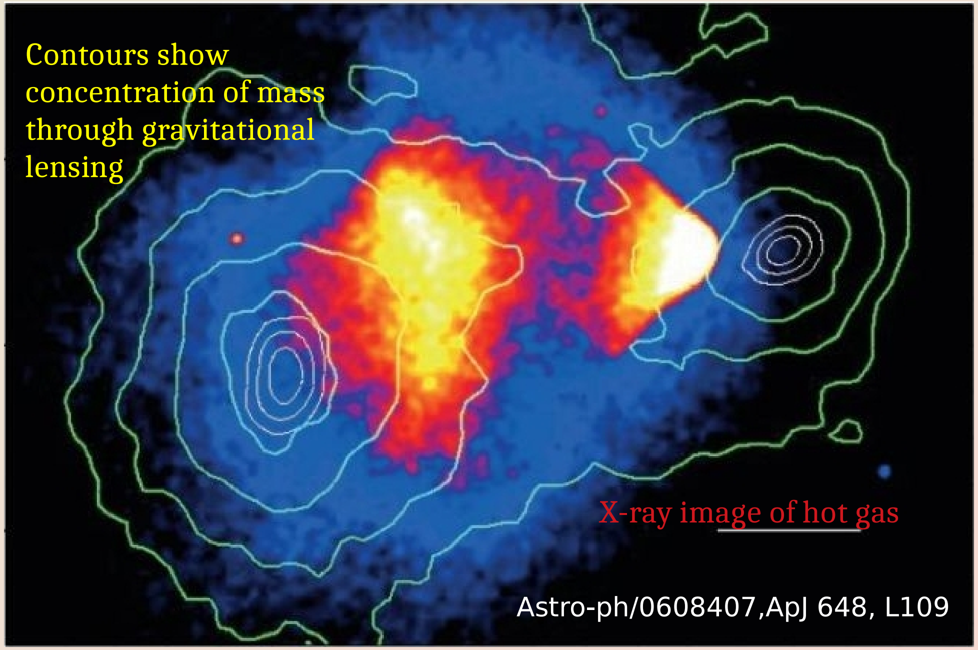
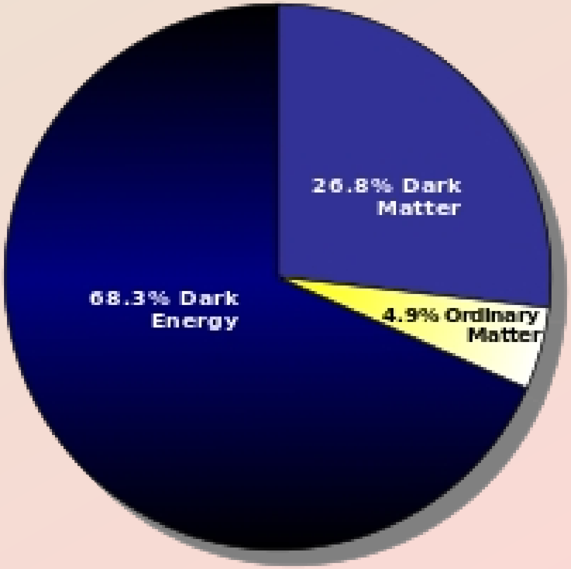
- Charge energy spectrum
  - Linearity of energy scale
  - Resolution
- Summary and outlook

Evidences for Dark matter







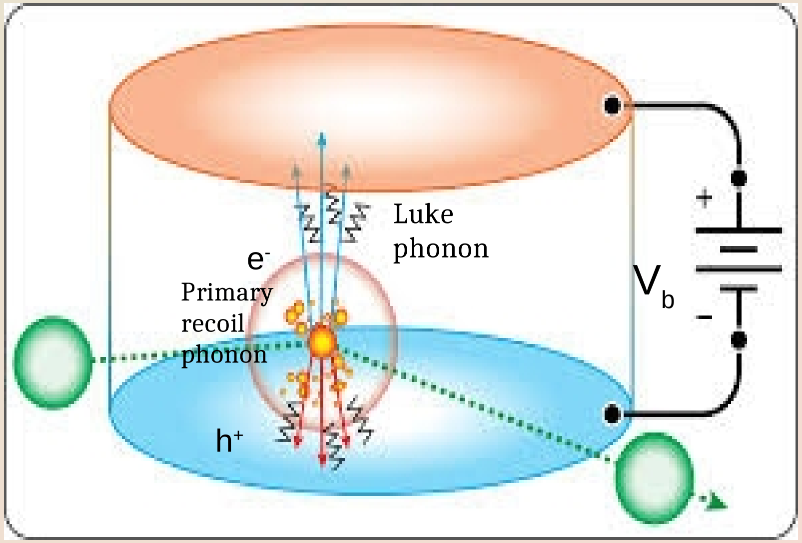


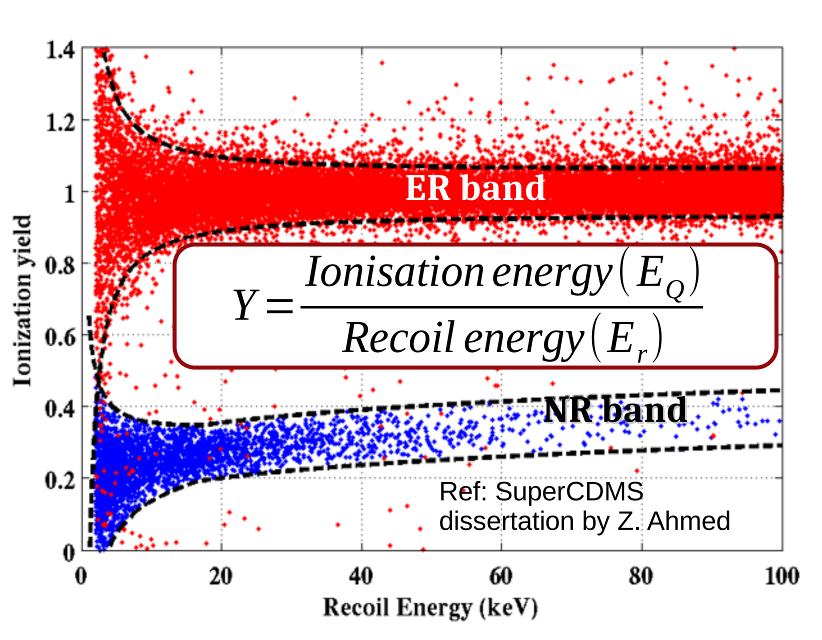
Plank 2018 Results

➔ Observations in astronomy hint towards major mass discrepancy of the universe which is known as 'Dark matter'.

Cryogenic Dark Matter Search II

- Cryogenic Dark Matter Search (CDMS) is a direct dark matter search experiment located in Soudan, MN, USA (2003 - 09).
- Types of interactions:
  - Nuclear recoil (NR) :
    - dark matter, neutrinos interacts with the nucleus.
  - Electron recoil (ER) :
    - β, γ interacts with the atomic electrons.
- A voltage bias across the detector makes the e^- and h^+ to drift towards their respective electrodes
- Ability to discriminate between NRs and ERs aids in background rejection
- At high voltages (HV) detector loses the ability to discriminate between ER and NR.





Backgrounds in underground labs

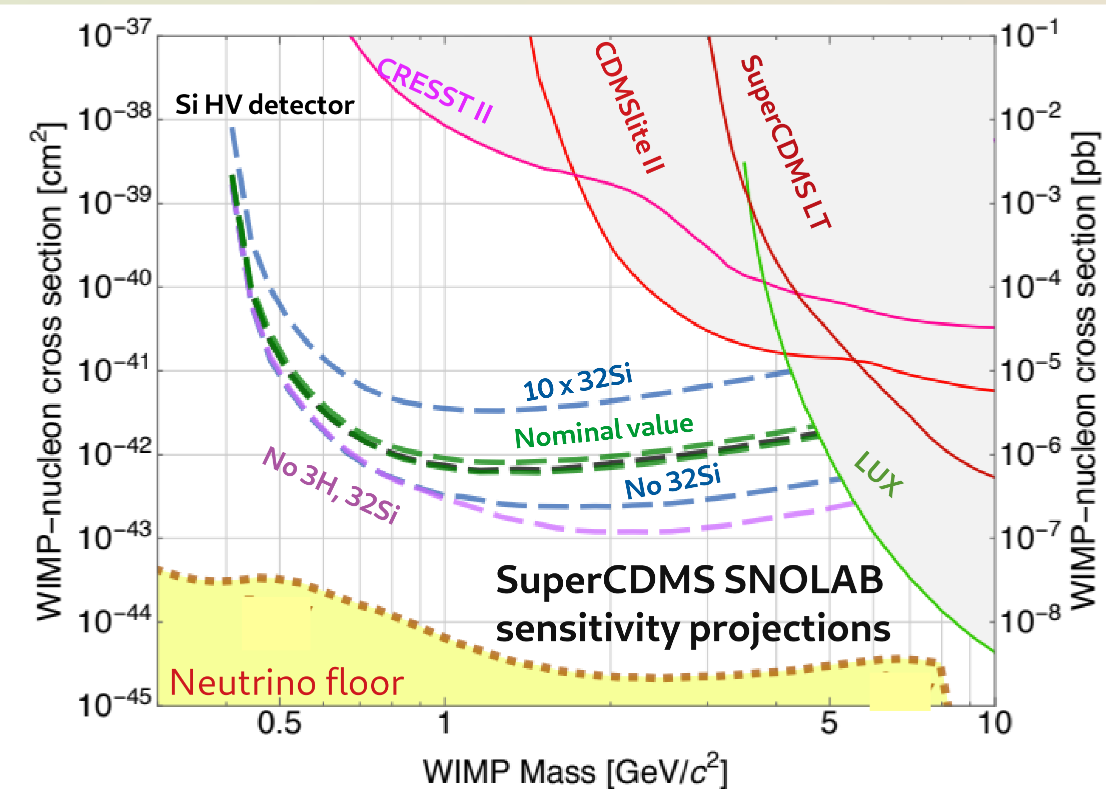
- All direct DM experiments are rare event searches. Hence, a thorough understanding of the backgrounds in data is necessary.

Background	Type	Source	Mitigation
Neutrinos, cosmic rays	Cosmogenic	Solar and atmospheric neutrinos for CEvNS, Muons and neutrons from cosmic rays	None for neutrinos but annual modulation signals vary for DM and neutrinos, underground depth for cosmic rays
Detector-internal contamination(β-decays)	Cosmogenic	^{3}H, ^{32}Si	None – Measure and model the background
Material activation and contamination(α, β and γ decays)	Radiogenic	^{40}K, ^{60}Co, ^{238}U, ^{232}Th, Cu, ^{222}Rn	Detector shielding, and model background

- Si HV detectors are essential for probing sub GeV dark matter as CDMS takes its next run at SNOLAB called SuperCDMS SNOLAB.
- Understanding the ^{32}Si background is very crucial for a significant improvement in SuperCDMS sensitivity.

Motivation for ^{32}Si background study

PhysRevD.95.082002 (2017)



- Nominal value (green dashed line) is the DAMIC measurement of 80^{+110}_{-65} counts kg^{-1} d^{-1}

  (JINST 10 (2015) P08014)

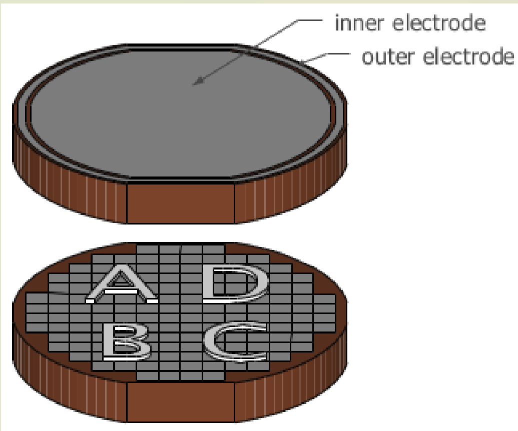
- ^{32}Si isotope is an inherent impurity in Si detectors. It emits beta particles which creates ER backgrounds.

β^- decay of ^{32}Si :

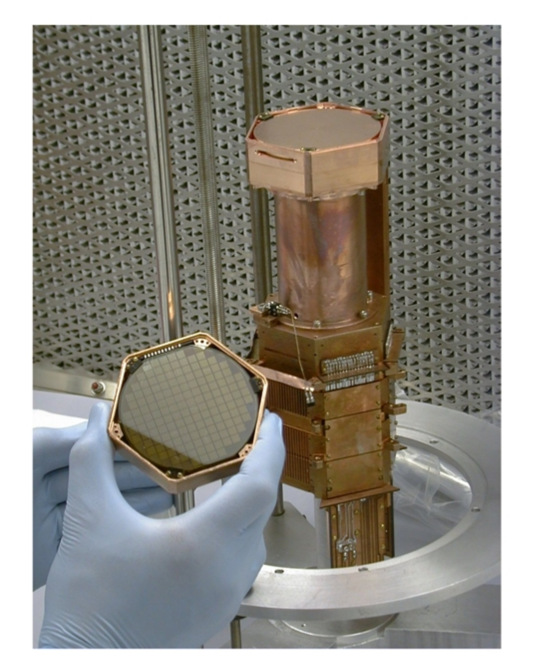
$$^{32}\mathrm{Si} \xrightarrow{\beta^-} {}^{32}\mathrm{P} \xrightarrow{\beta^-} {}^{32}\mathrm{S}\ \text{(Stable)}$$

	Endpoint energy (keV)	Half life
^{32}Si	227	153 years
^{32}P	1710	14 days

CDMS-II Tower Design

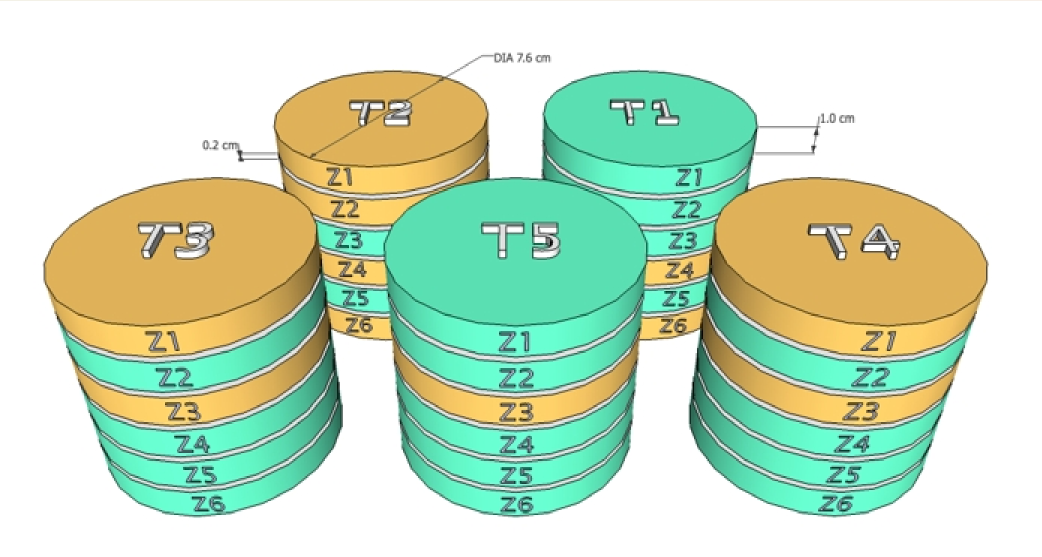


ZIP detector schematic



Tower with 6 ZIP detectors

Tower configuration



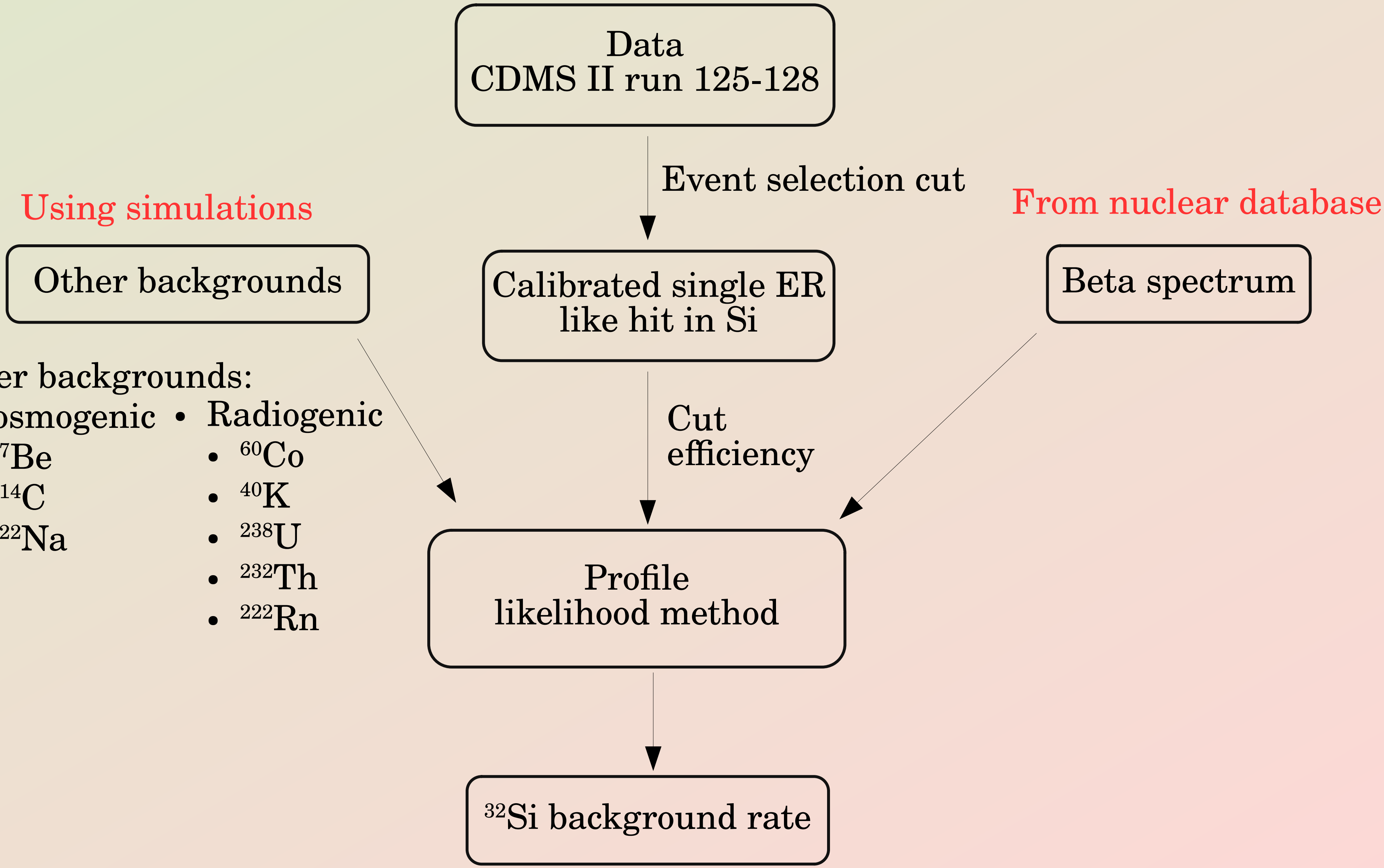
- CDMS II used total 30 ZIP detectors in a 5 tower configuration.
- 19 Ge detectors and 11 Si detectors.

- Each detector has
  - Four phonon channels A, B, C and D.
  - Two charge channels, outer and inner.
- Dimension:
  - 76 mm in diameter
  - 10 mm in thickness

	Ge	Si
Mass	~ 250 g	~ 100 g
Bias voltage	3 V	4 V

✔ Observable for the analysis: Total charge energy (qsum)

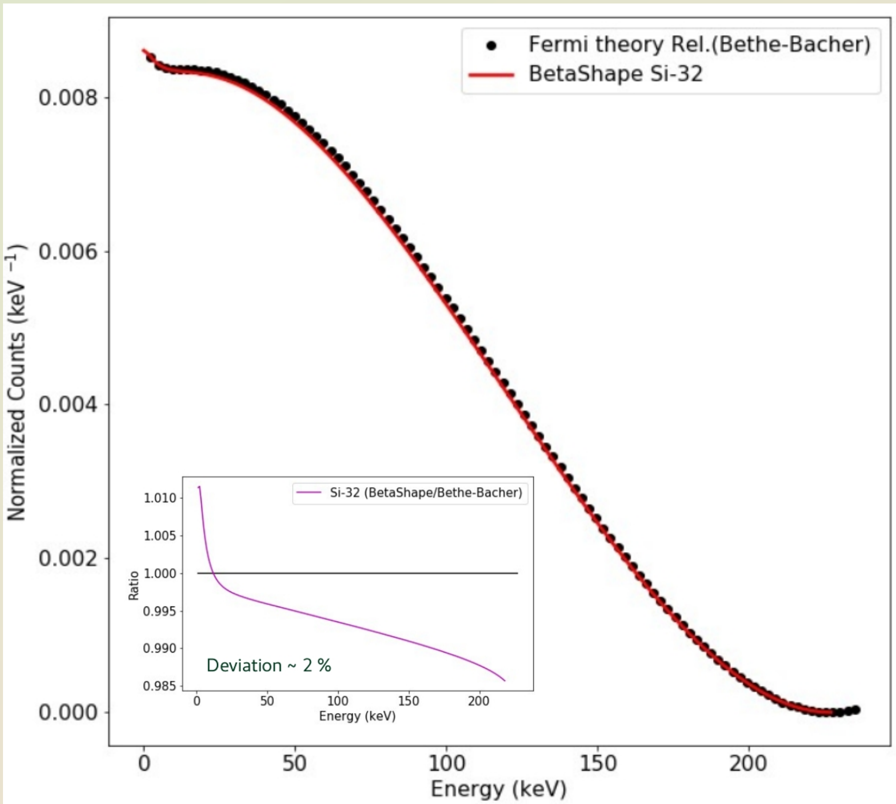
^{32}Si analysis flowchart

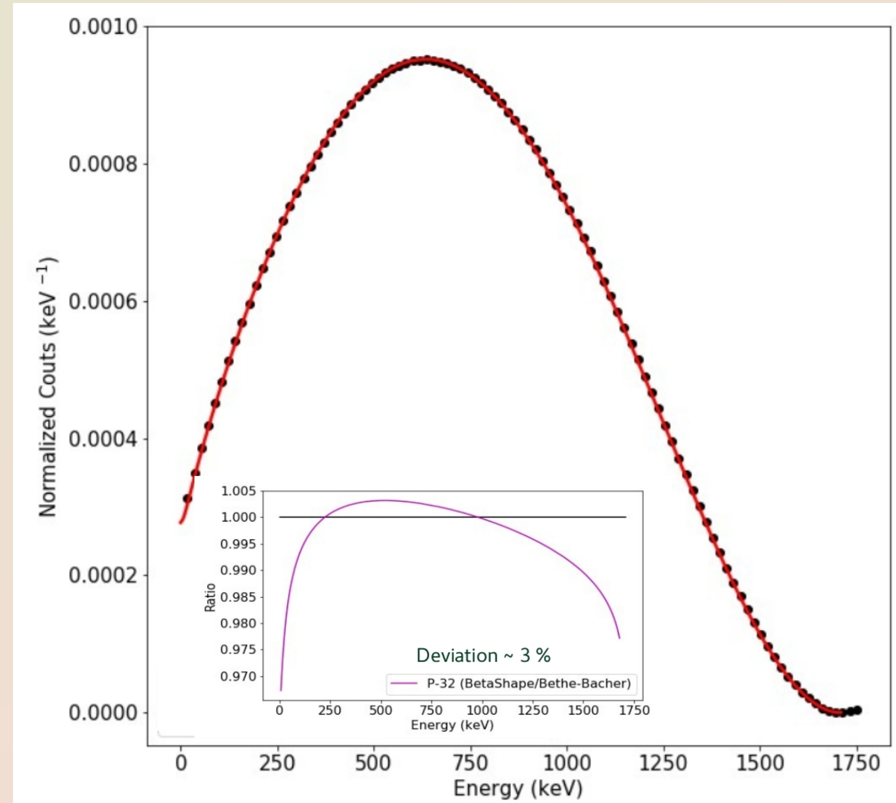


Other backgrounds:

- Cosmogenic
  - ^{7}Be
  - ^{14}C
  - ^{22}Na
- Radiogenic
  - ^{60}Co
  - ^{40}K
  - ^{238}U
  - ^{232}Th
  - ^{222}Rn

Signal modeling: ^{32}Si and ^{32}P decay spectrum





- Fermi theory of beta decay:

$$N(T_e)=C\sqrt{T_e^2+2T_e m_e}(Q-T_e)^2(T_e+m_e)F(Z,T_e)$$

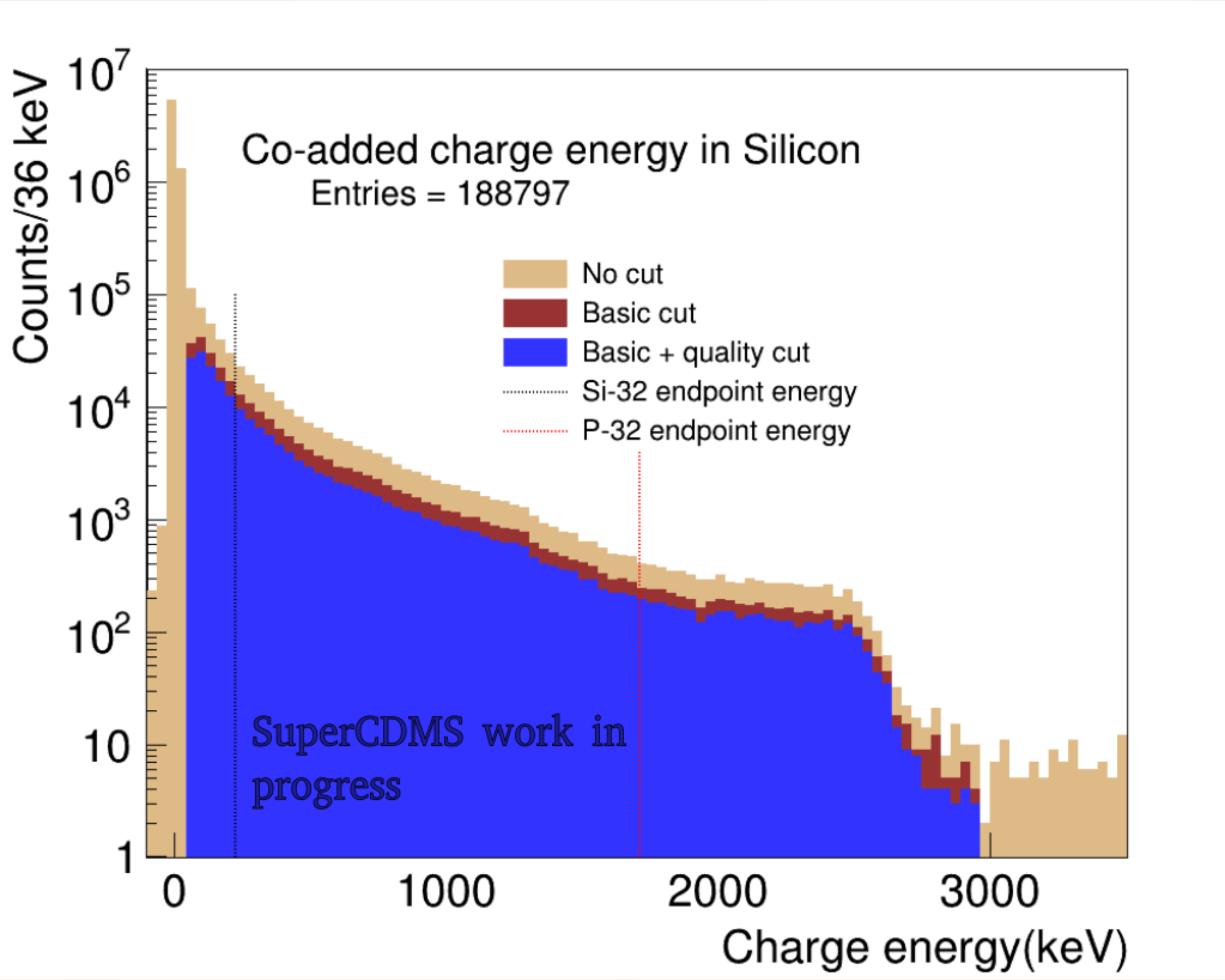
- Relatavistic Fermi function (Bethe-Bacher):

$$F_R(Z,T_e)=F_{NR}(Z,T_e)[T_e^2(1+4\gamma^2)-1]^s$$

✔ We use the beta-decay spectrum obtained from BetaShape as a ^{32}Si and ^{32}P signal model in this analysis

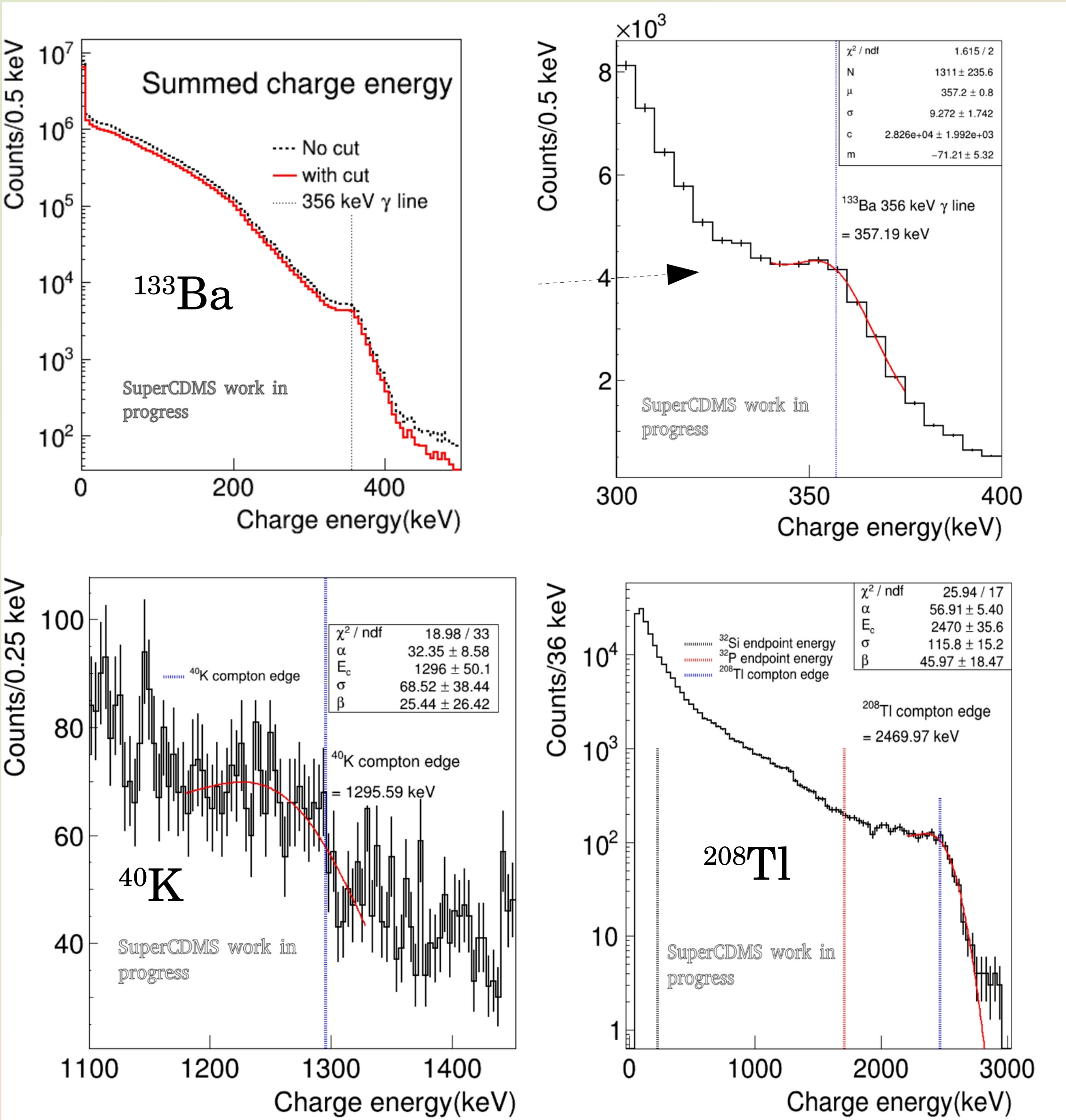
J. Phys. G: Nucl. Phys. 11 (1985) 359-364.

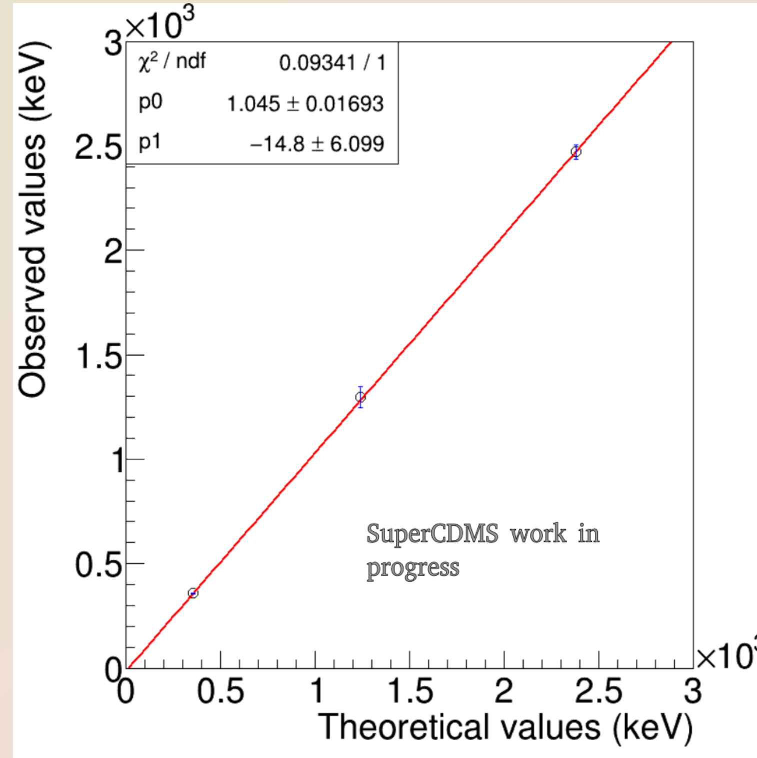
Charge energy spectrum for CDMS II Si detector



- Charge energy spectrum of single ERs in Si detector is obtained after applying event selection cuts:
  - Basic cuts (removes bad events originating from hardware/DAQ related issue)
  - Quality cuts (optimize data quality through additional analysis)

Linearity check of charge energy scale

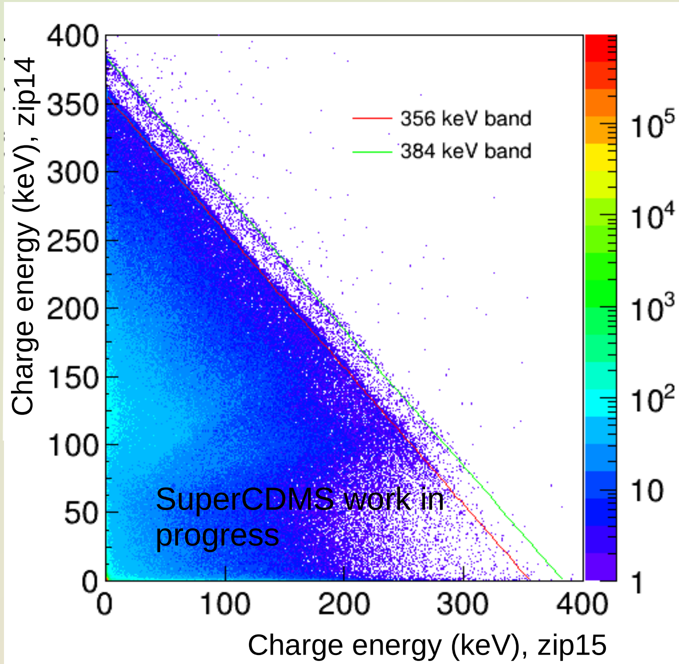


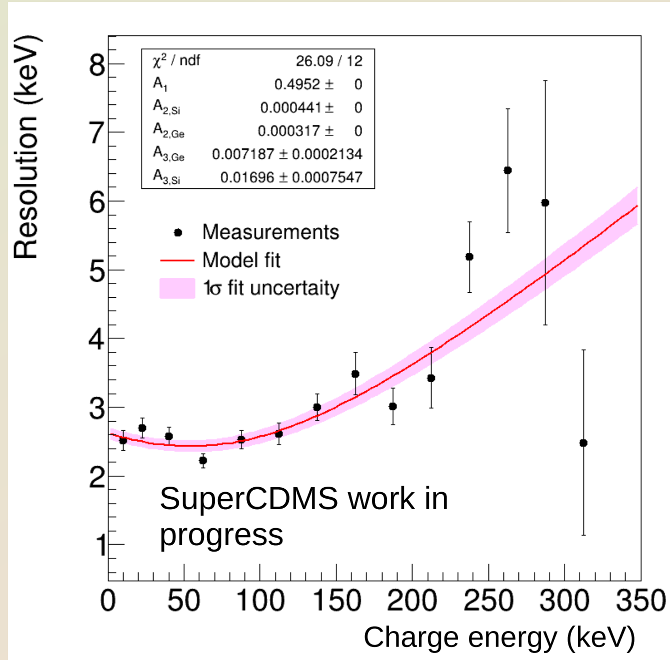


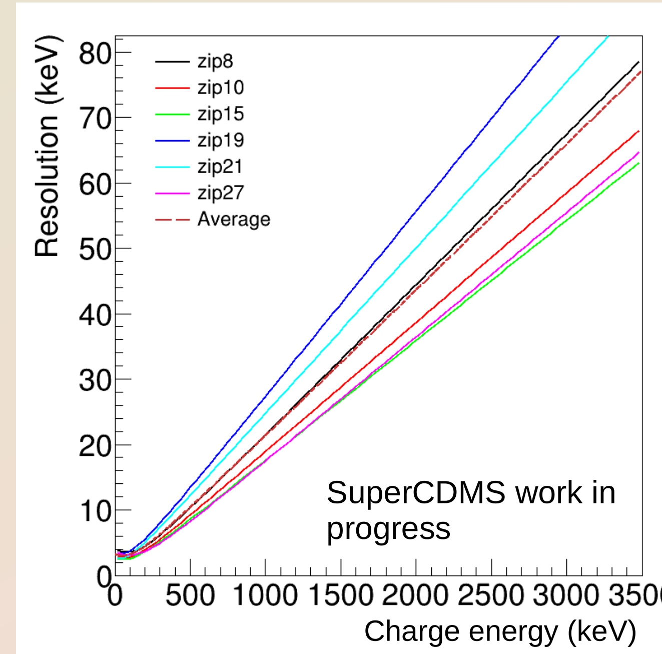
Calibration points		
^{133}Ba gamma peak (keV)	^{40}K compton edge (keV)	^{208}Tl compton edge (keV)
356	1240	2381
357.2 ± 0.8	1295.6 ± 50.1	2470.0 ± 35.9

- Linearity of the charge energy scale has been observed.

Charge energy resolution







$$\sigma(E)=\sqrt{\sigma_{BR}^2+\sigma_F^2+\sigma_{PD}^2}$$

$$\sigma(E)=\sqrt{A_{1,Si}^2+A_{1,Ger}^2+A_{2,Si}^2\,E+(356-E)\,A_{2,Ger}^2+A_{3,Si}^2\,E^2+(356-E)^2\,A_{3,Ger}^2}$$

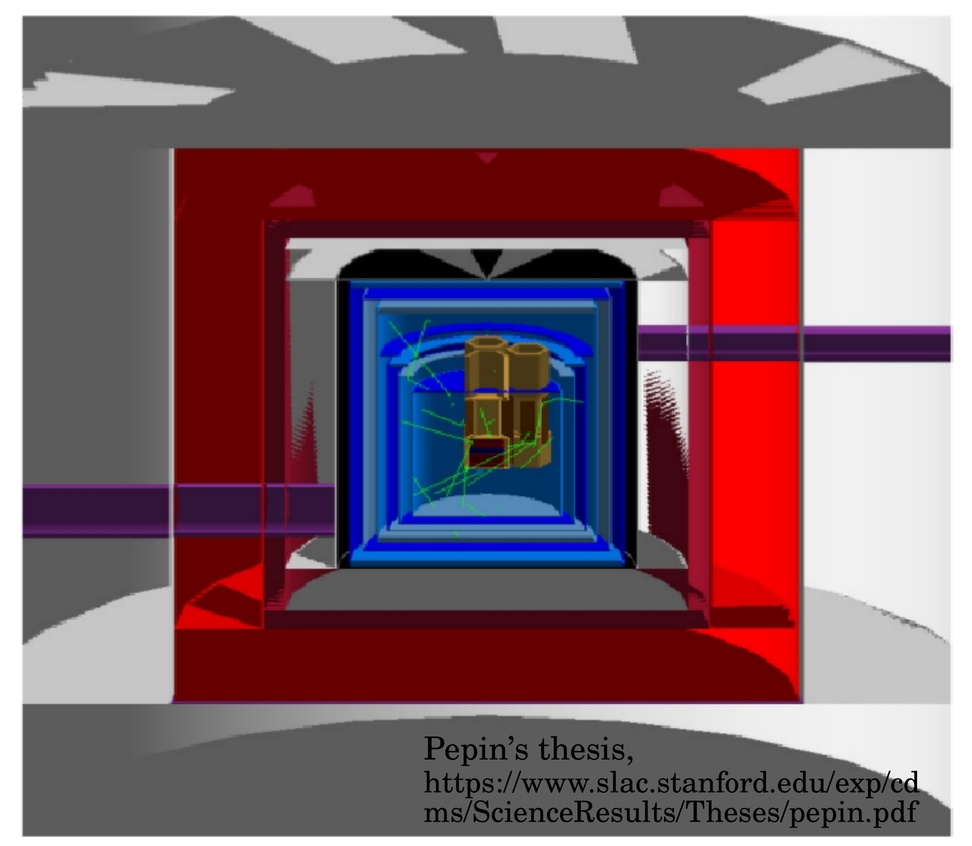
- We look for 356 keV events in the nearest neighboring Ge detectors to check the resolution of the Si detectors at high energies (~3000 keV).
- The above model is used to fit the combined resolution of Ge and Si.

Simulation to modeling other backgrounds

- Other backgrounds need to be simulated using CDMS II geometry.

Backgrounds	
Cosmogenic	^{7}Be, ^{14}C, ^{22}Na
Radiogenic	^{60}Co , ^{40}K, ^{238}U, ^{232}Th, ^{222}Rn

- We will be using GEANT4 simulation to model our backgrounds.
- We will use likelihood analysis to estimate ^{32}Si and ^{32}P background rate.



Geometry used in Global Gamma Monte Carlo

Summary and future work

- **Summary:**
  - We have shown total charge energy spectrum from all the Si detector after optimizing all the cuts.
  - Linearity check of the charge energy scale has been done.
  - To model the other backgrounds detector resolution has been estimated.
  - We have investigated and compiled a list of all possible backgrounds for our analysis.

- **Future work:**
  - GEANT4 based simulation is ongoing to model other backgrounds for this analysis and to calculte cut efficiency.
  - Understand and implement likelihood analysis to estimate ^{32}Si decay rate.

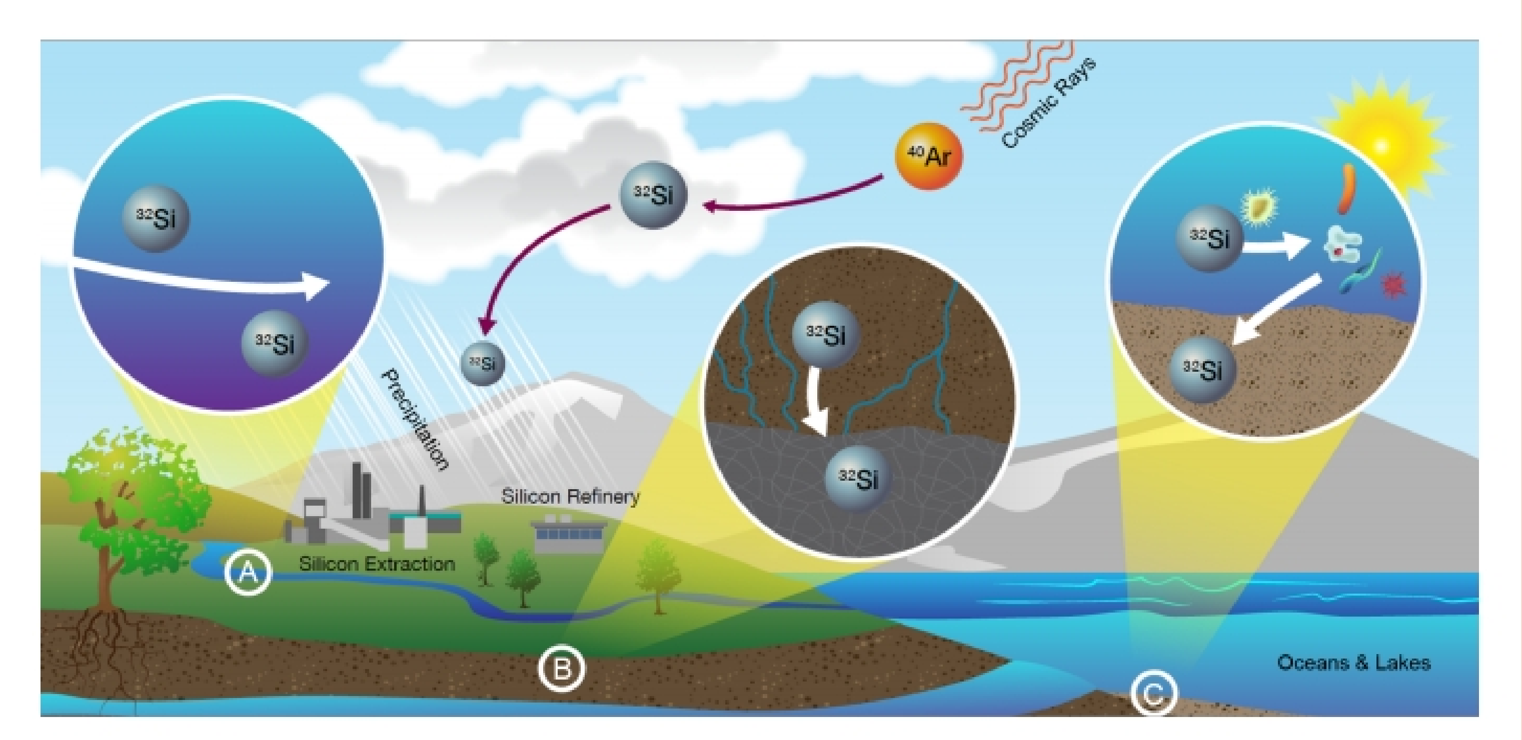
Thank You

The SuperCDMS Collaboration

@SuperCDMS

Back up

Source of ^{32}Si



Transportation of cosmogenically produced ^{32}Si : (A) stream and pond, (B) surface sands, (C) ocean and lakes.

Ref : Astroparticle Physics 99 (2018) 9-20. arXiv:1708.00110

List of cuts for this analysis

Basic cuts

- Remove events during data taking with hardware/DAQ related issues.

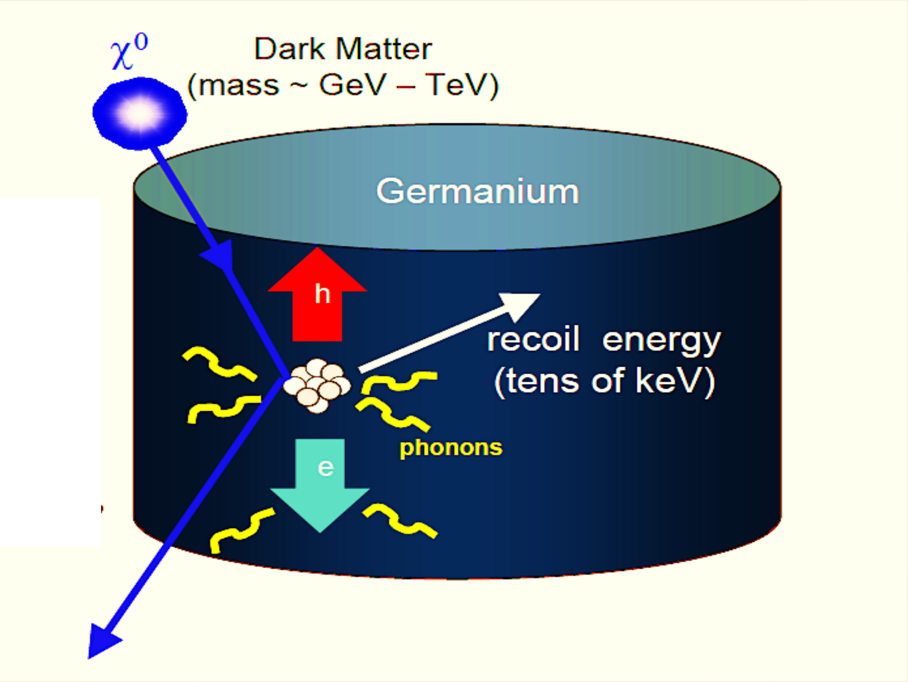
1. **Not random**
2. **Voltage bias**
3. **Bias flashtime**
4. **Analysis threshold**
5. **Bad detector**
6. **Charge pre-pulse standard deviation**
7. **Saturated charge pulse**

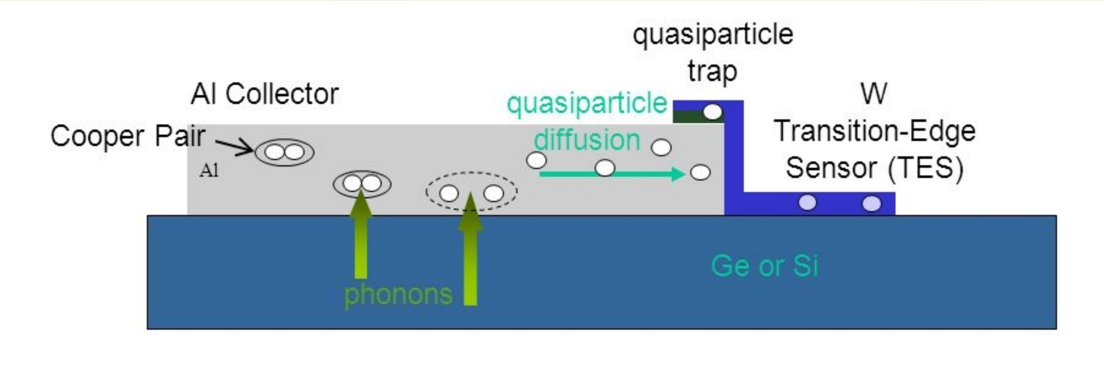
Data quality cuts

- Applied in addition to the basic cuts.

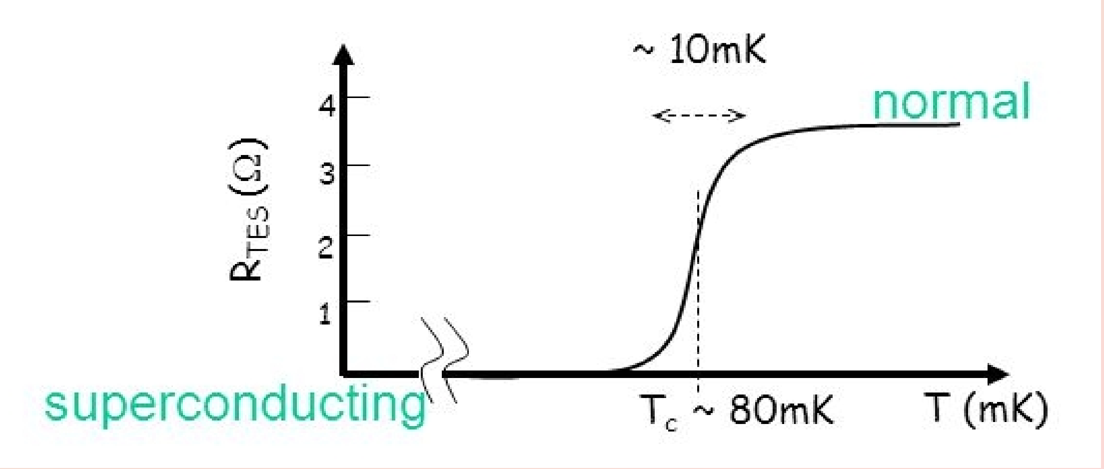
1. **Glitch cut:** removes electronic glitches.
2. **Charge χ^2 cut:** pulse shape cut applied on charge signal.
3. **Fiducial volume cut:** selects bulk events.
4. **Alpha cut:** removes alpha events.
5. **ER band cut:** selects electron recoil events.

Detection principle





- Superconducting layer on the surface operating near T_c



- The detectors are operated at cryogenic temperature (~ 50 mK).
- A particle interacting with the detector creates phonons and electron-hole pairs.
- Superconducting tungsten Transition Edge Sensors (TES)

- Read out of phonon energy as an electronic signal due to change in TES resistance