14th International Conference on
Identification of Dark Matter

18-22 July 2022
Vienna, Austria

Reduction in radioactivity-induced backgrounds using a novel active veto detector for rare event search experiments

Mouli Chaudhuri

National Institute of Science Education and Research
HBNI, Jatni, India

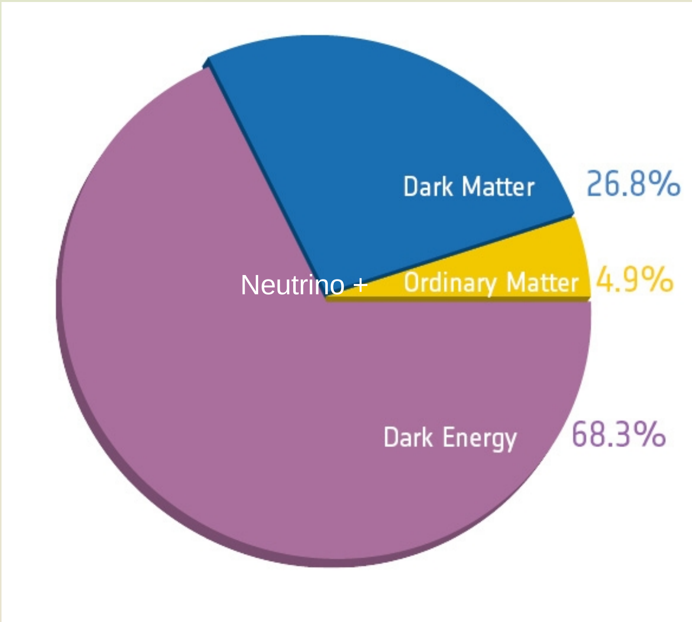
18.07.2022

In collaboration with Texas A&M University

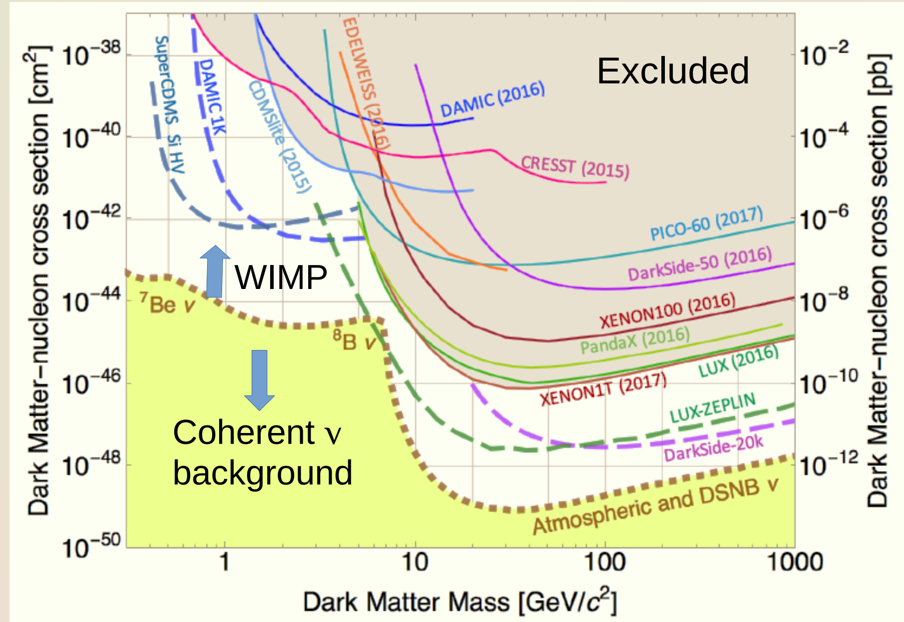
Outline

- Introduction
- Radioactivity induced backgrounds
- Active veto detector
- Results
  - Simulation
  - experimental data
- Summary and outlook

What are rare events?



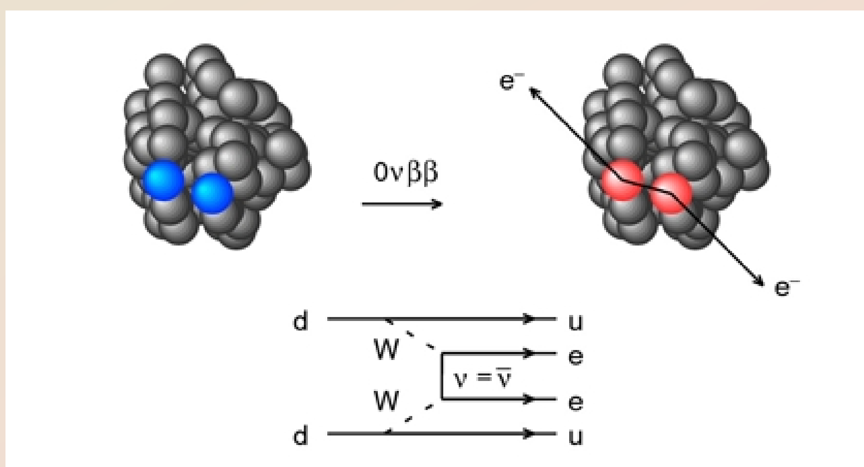
Plank 2018 result



SuperCDMS limit plotter

Direct detection of WIMP

Neutrinoless double beta decay



New Insight Into NeutrinolessDouble Beta Decay by Alex Brown

Search for rare signal needs:

- Fewer backgrounds
- Lower energy threshold

Radioactivity-induced backgrounds and its mitigation

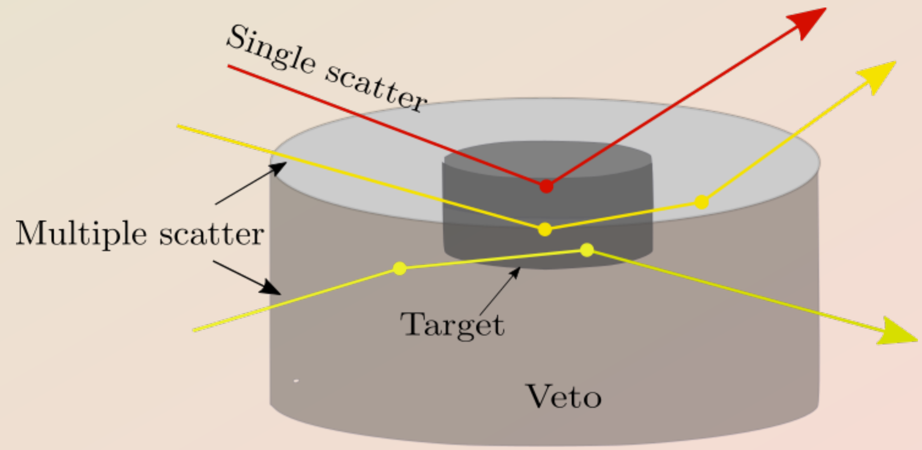
Background sources

Cosmogenic

- ❖ Muons and neutrons

Radiogenic

- ❖ ɣ-ray emitting isotopes like ^{40}K, ^{137}Cs, ^{60}Co, ^{238}U, ^{232}Th and their progeny



Mitigation

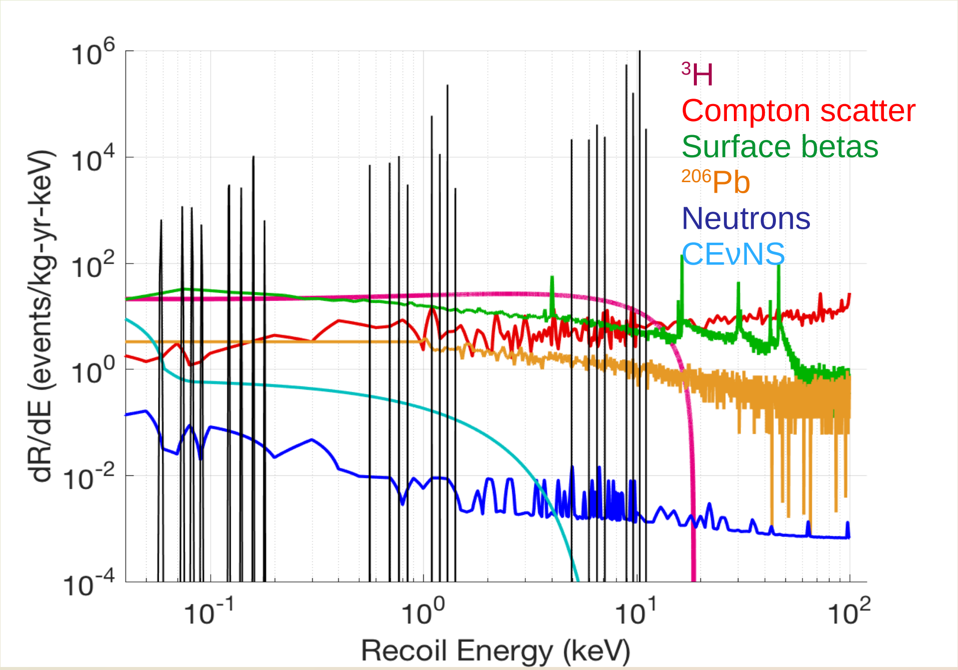
- **Passive shielding:** underground lab and hermetic shielding
- **Active shielding:** actively veto events.

Single scatter:

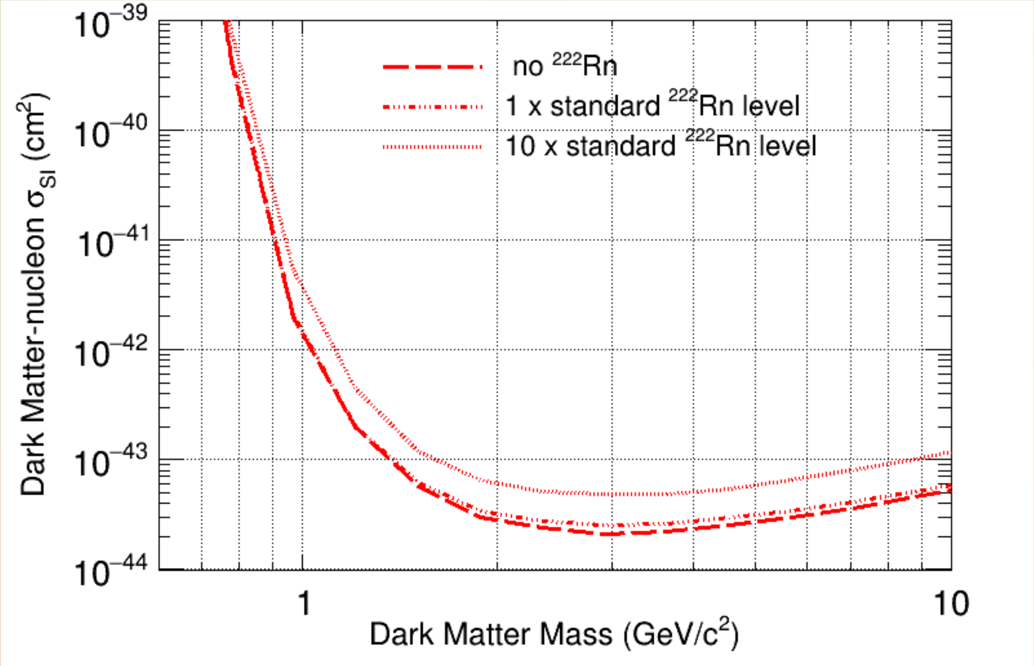
- ✔ $\text{Energy}_{\text{Target}} > \text{Noise}_{\text{Target}}$
- ✔ $\text{Energy}_{\text{Veto}} \leq \text{Noise}_{\text{Veto}}$
- ✔ $t_{\text{coincidence}} \sim$ few ms

- ✔ Most of the backgrounds are multiple scatter events.
- ✔ An annular active veto detector is fabricated and tested which act as a active shielding.

SuperCDMS SNOLAB background rate



Phys. Rev. D 95 (2017) 082002



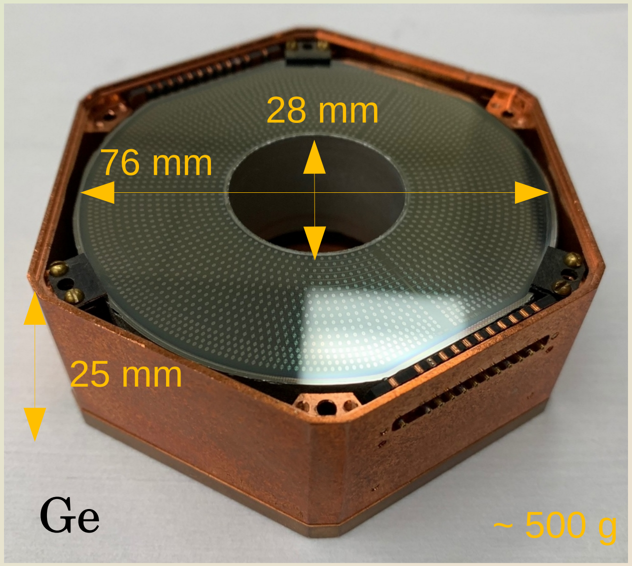
Nuclear Inst. and Methods in Physics Research, A (2022) 167150

- SuperCDMS SNOLAB will use HV detectors which are unable to discriminate between electron recoil and nuclear recoil.
- Projected sensitivity for SuperCDMS SNOLAB experiment with varing levels of ^{206}Pb background for Ge HV detector.

✔ Three backgrounds (Compton scatters, surface betas, ^{206}Pb) are expected to be reduced by the active veto detector.

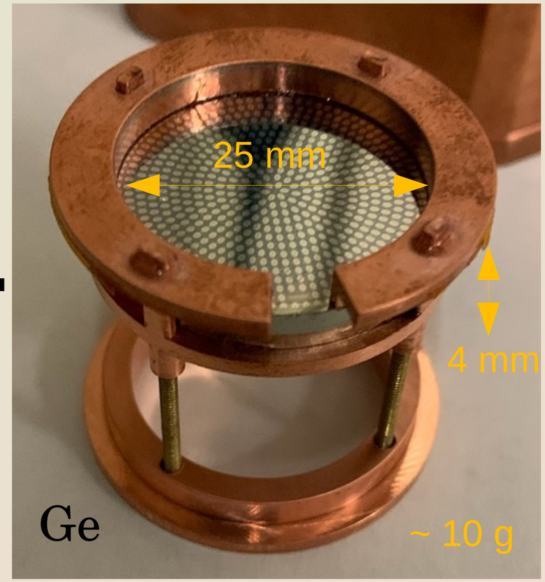
Active veto hosting an inner target detector

Annular veto detector



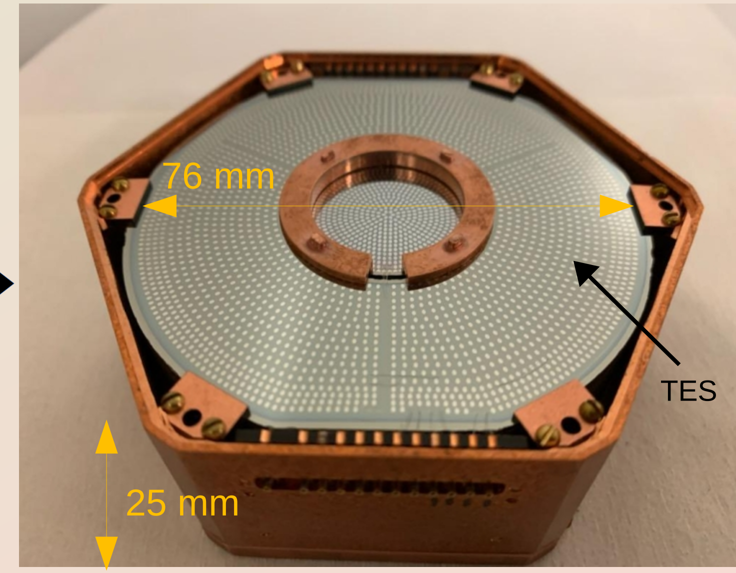
- Core is drilled for hosting the target

Inner target



- Mounted in a copper nest for suspending inside the veto

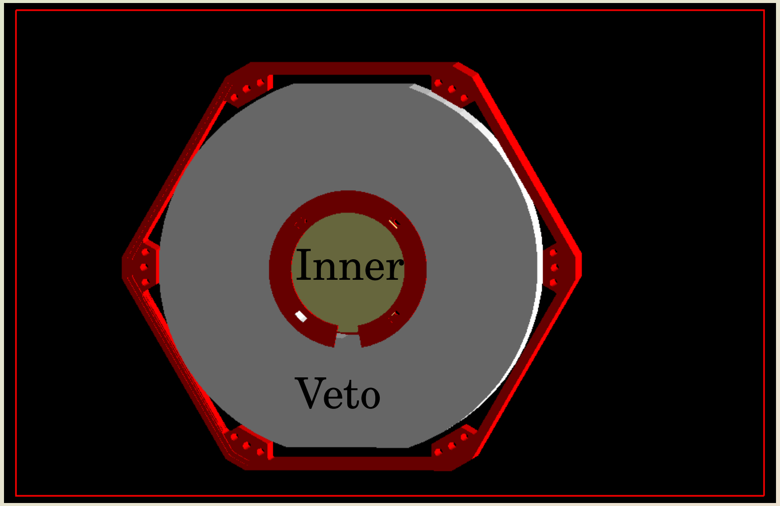
Veto with target

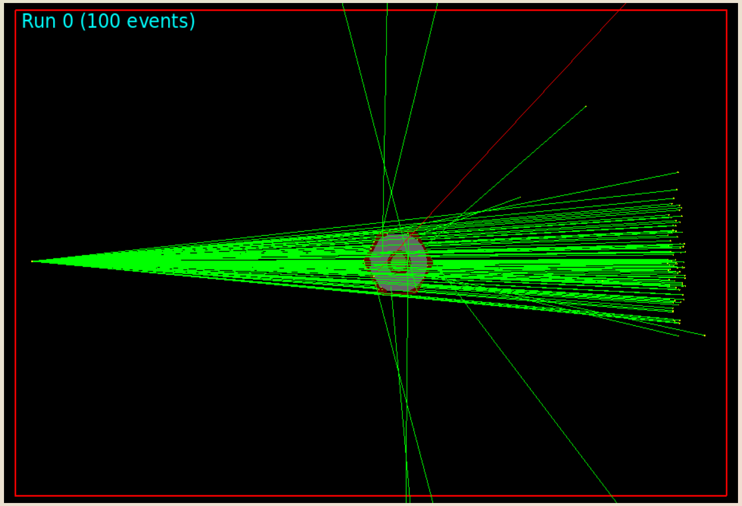


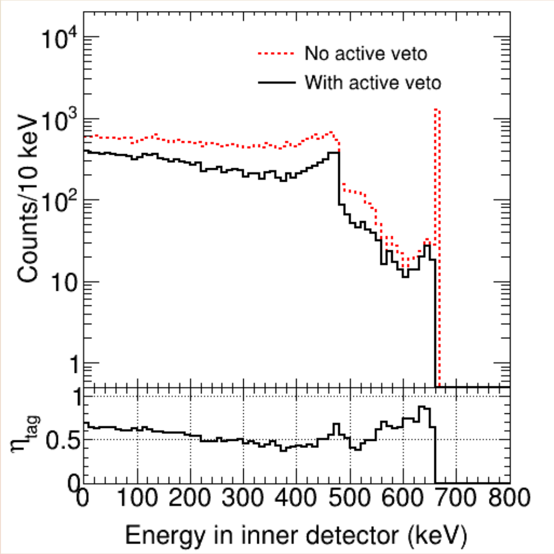
- Combining the two detector as one module

✔ Transition-Edge-Sensors (TES) patterned lithographically on the surface.
✔ The active veto tags an event as background that deposits energy both in active veto and inner target.

GEANT4 simulation with annular active veto



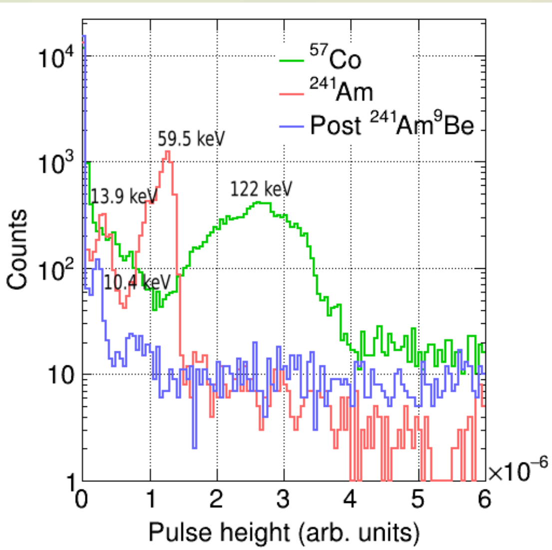


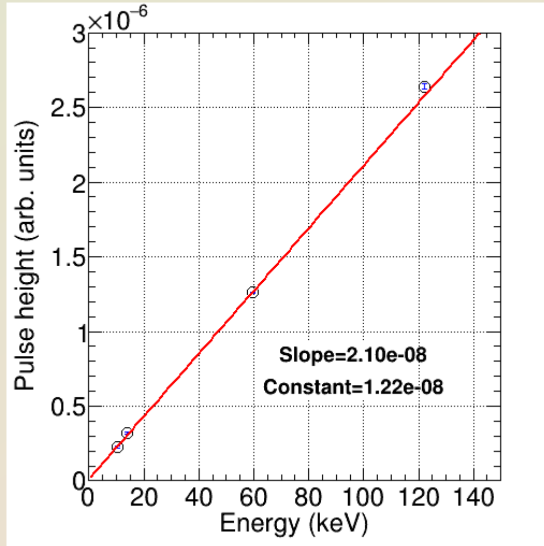


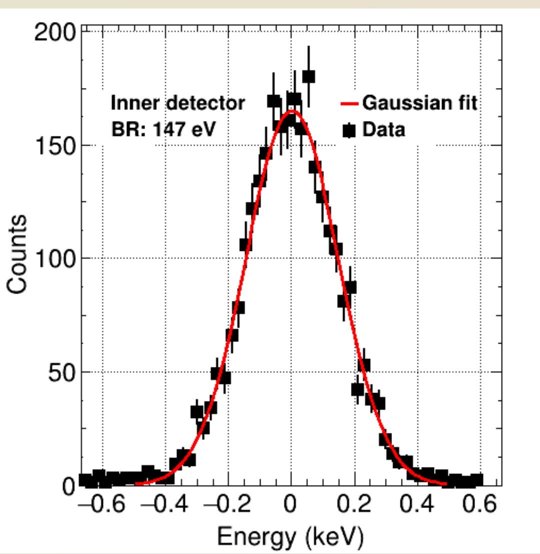
- Detector modeled in GEANT4
- 662 keV gammas from a ^{137}Cs point source is simulated at a distance 50 cm.
- Tagging efficiency (η_{tag}) for compton scatters is 50 – 80%.

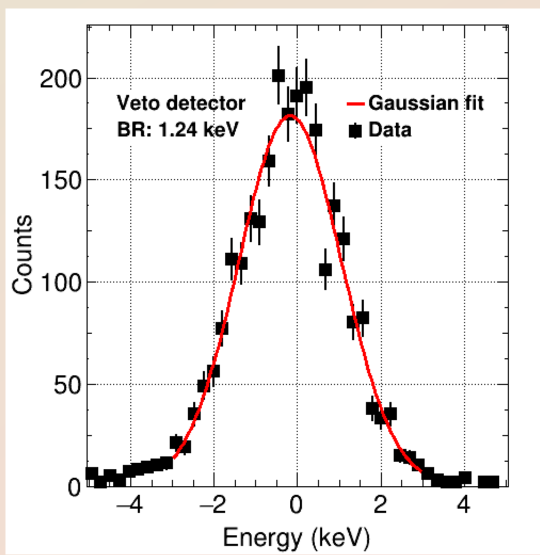
✔ Tagging efficiency, $\eta_{\text{tag}} = \dfrac{\text{No. of events detected by both inner and veto}}{\text{Total no. of events detected by inner detector}}$

Detector calibration and baseline resolution





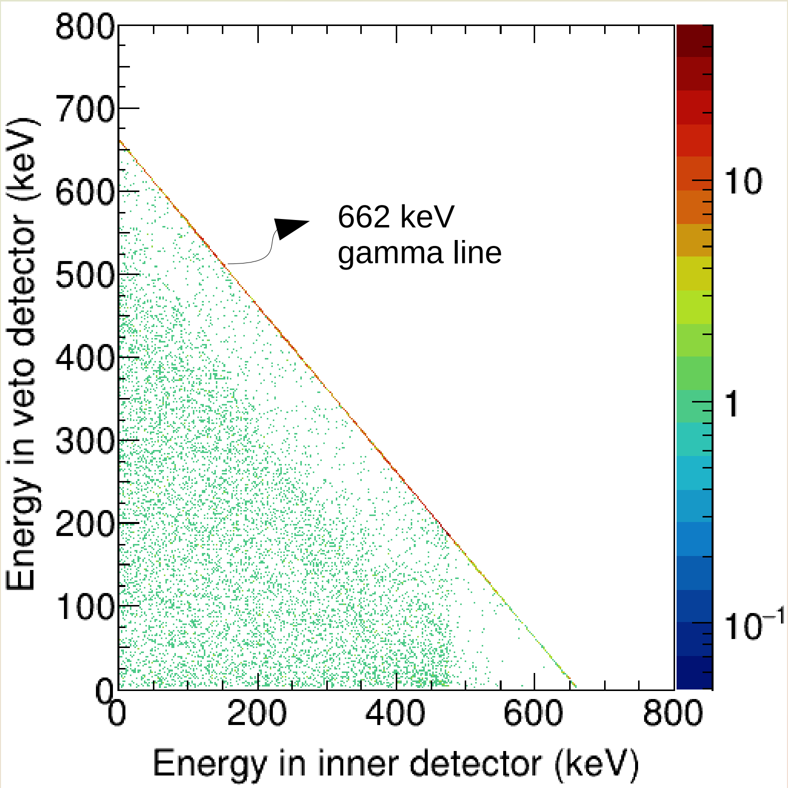




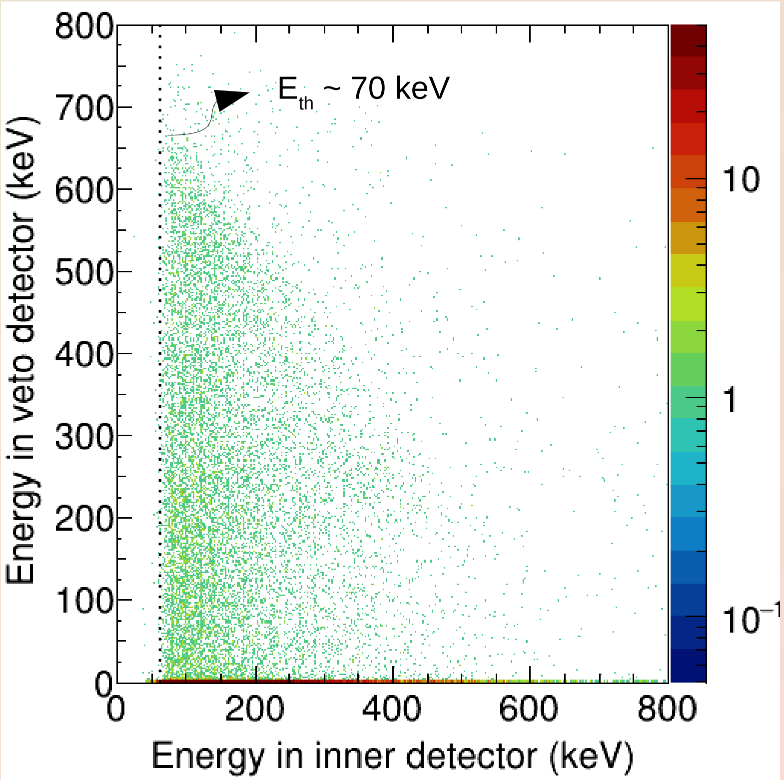
- ✔ The data is taken at Mitchell Institute Neutrino Experiment at Reactor (MINER).
- ✔ Experiment is looking for CEvNS using reactor neutrinos.
- ➔ Calibration sources used:
  - ^{57}Co (122 keV)
  - ^{241}Am (13.9 keV, 59.5 keV)
  - Ge activation peak (10.4 keV)
- ➔ Verified linearity of the energy scale up to 122 keV.
- ➔ Baseline resolution:
  - ➔ Veto: 1.24 keV.
  - ➔ Inner detector: 147 eV.

Tagging of Compton scatters in simulation and experimental data

Simulation

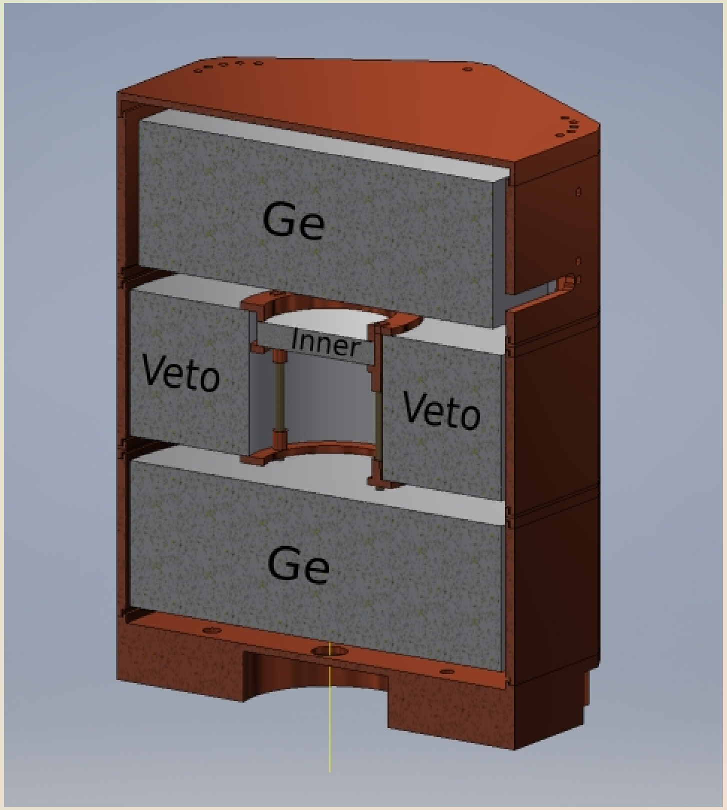


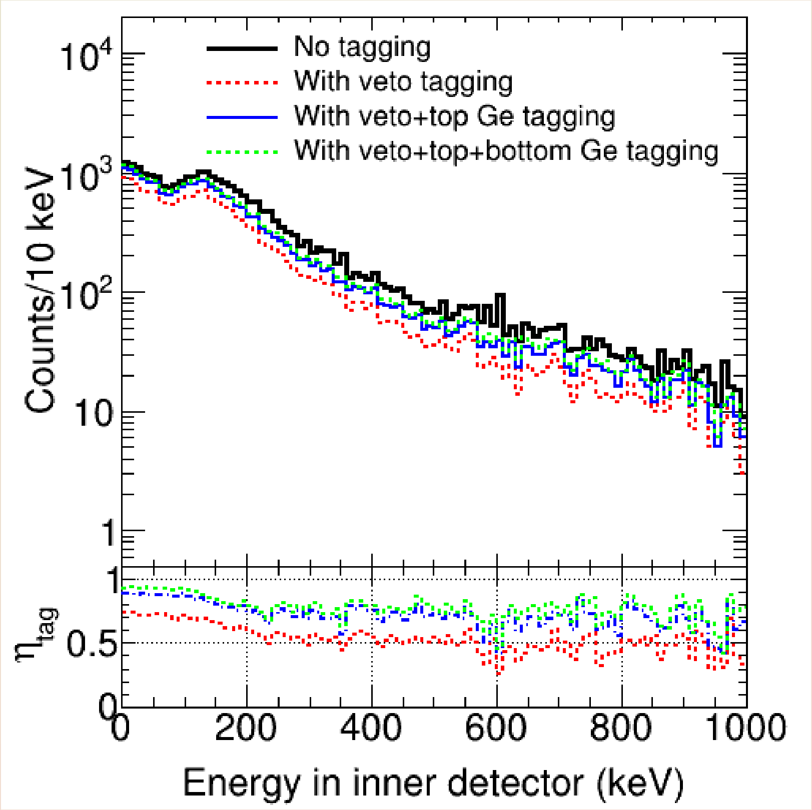
Experimental data



✔ Energy correlation observed in experimental data is qualitatively consistent with simulation.

Simulation: vetoing with 4π coverage

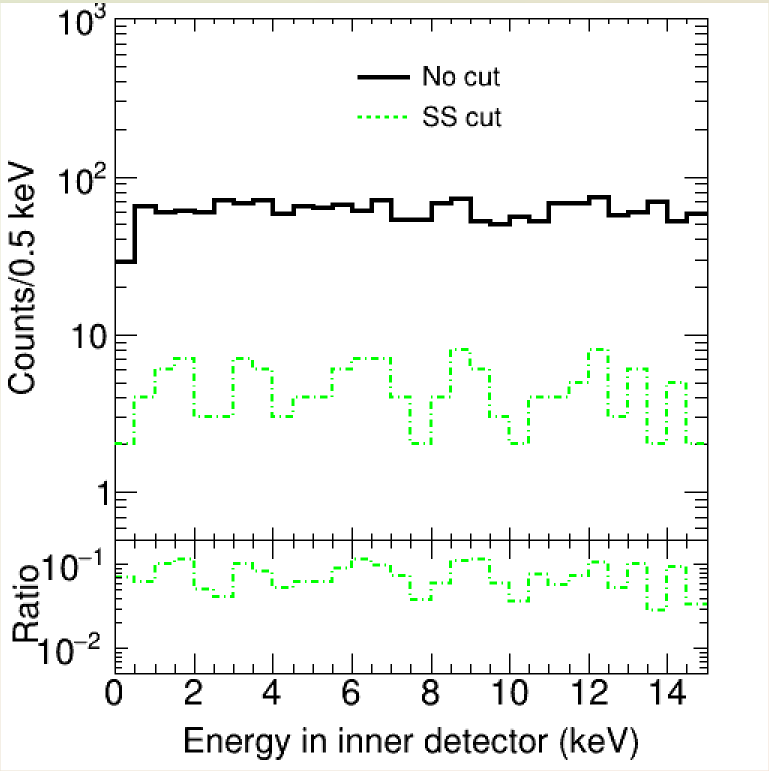




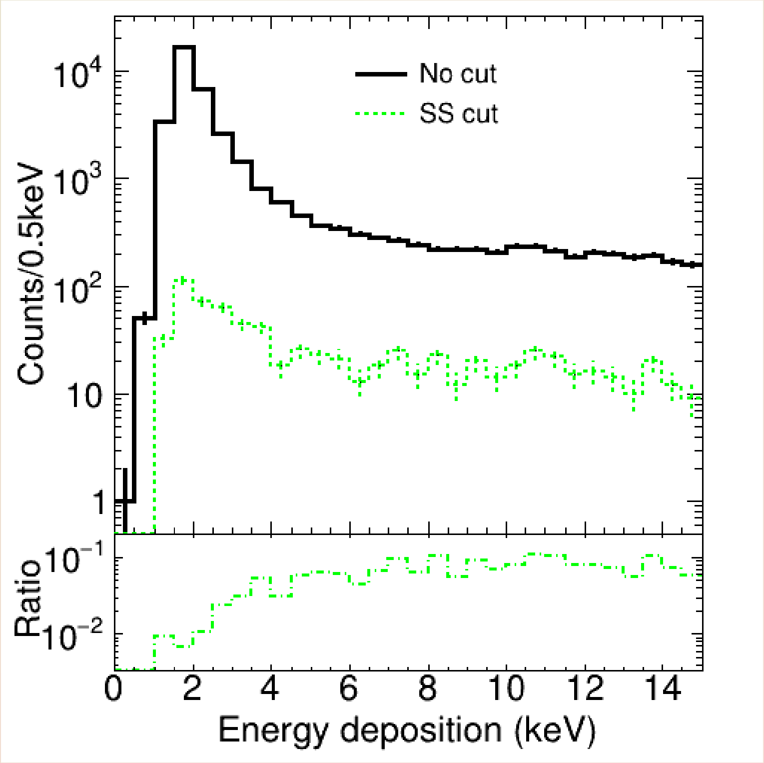
- ✔ Expected SuperCDMS SNOLAB like backgrounds (^{40}K, U, Th) sources are simulated.
- ✔ At low energies (< 100 keV) with only the annular active veto (red curve), η_{tag} > 70%.
- ✔ η_{tag} increases to > 90% with the 4π veto coverage (green curve).

Reduction in backgrounds: simulation vs data

Simulation



Experimental data



- ✔ Energy deposited by single scatter (SS) events are estimated by the target.
- ✔ With the 4π veto coverage, an order of magnitude reduction in the backgrounds is observed both in the simulation as well as in the data taken at the MINER site.
- ✔ The annular active veto removes low-energy electron recoil background events (< 5 keV) very efficiently.

Summary

- The detector shows an excellent reduction of gamma backgrounds and also capable of rejecting surface betas, ^{206}Pb, Compton scatters for SuperCDMS like experiment.
- The detector is tested in the lab and placed in the MINER experimental site for background measurement.
- An order of magnitude reduction in the backgrounds is observed both in the simulation as well as in the data taken at the MINER site.
- With the 4π veto coverage, tagging efficiency increases > 90%.

Outlook

- Fabrication of a veto detector with a silicon inner detector is being planned.
- The detectors will be operated at high voltages to explore lower recoil energy regions.

Publication: This work has been recently published in Nuclear Inst. and Methods in Physics Research A, 1039 (2022) 167150.

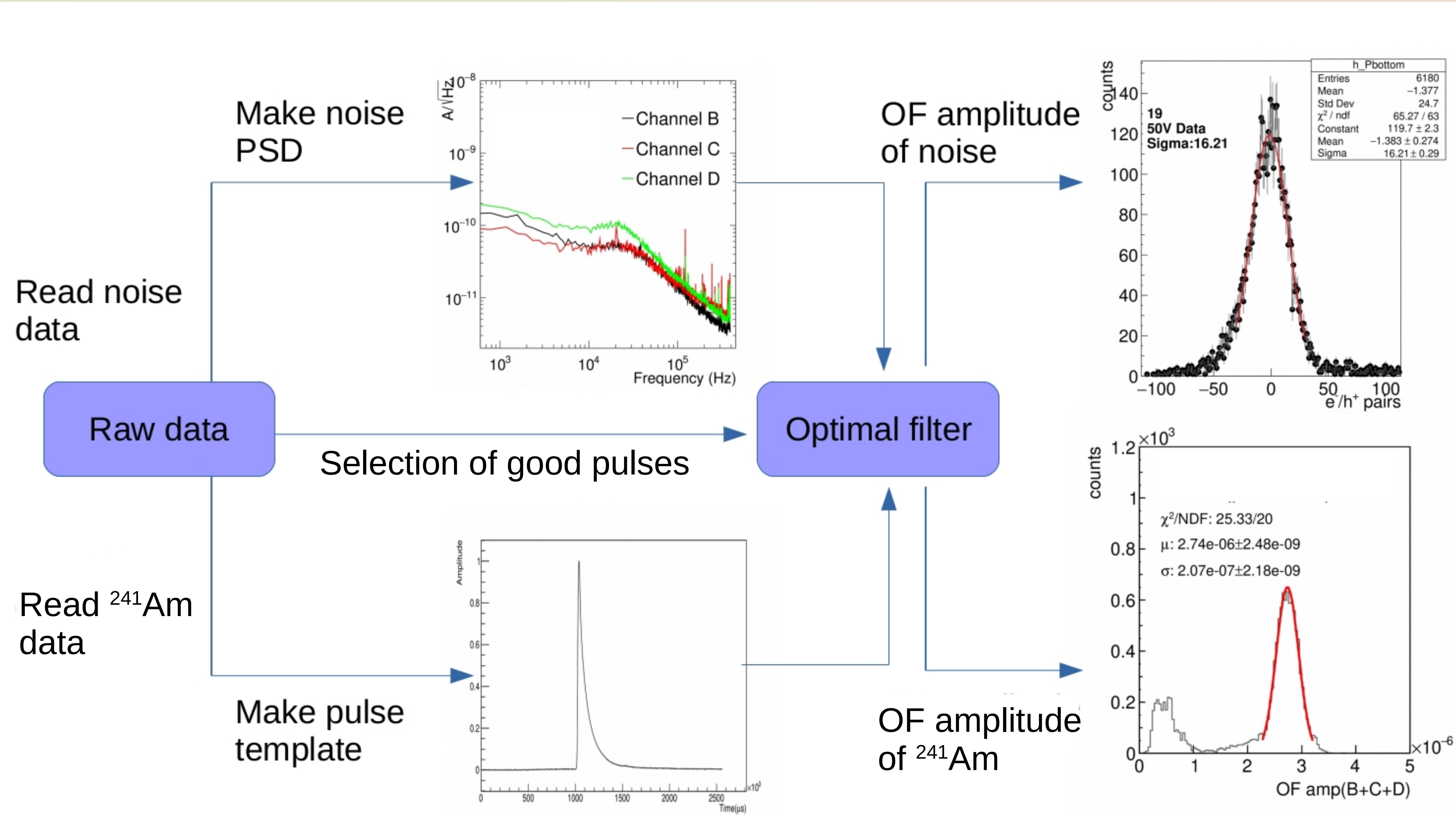
Acknowlegdement

- I want to acknowlegde my collaborators A. Jastram, G. Agnolet, S. Banik, H. Chen , V. Iyer, V. K. S. Kashyap, A. Kubik, M. Lee, R. Mahapatra, S. Maludze, N. Mirabolfathi, N. Mishra, B. Mohanty, H. Neog and M. Platt.
- This work was supported by the Department of Energy, USA. We also acknowledge the seed funding provided by the Mitchell Institute for the early conceptual and prototype development.
- We would like to acknowledge the support of DAE-India through the project Research in Basic Sciences - Dark Matter and SERB-DST-India through the J. C. Bose Fellowship.

Back up

Data analysis flowchart

Calibrated noise distribution



Optimal Filter (OF) method flowchart

- **OF method:** A fitting method to determine the amplitude of a noisy signal.
- OF fit maximizes S/N ratio by transforming the signal from a time domain to frequency domain where the fitting is performed by distinguishing noisy part of the signal from the underlying true signal.

Input

Signal: $S(t)$
Pulse template: $A(t)$
Noise template: $\xi(t)$
Sampling frequecy

$S(t) = aA(t - t_0) + n(t)$
Where,
a = scaling factor
n = gaussian noise
t_0 = time delay

F.T.
$S(t) \rightarrow S'(\omega)$
$A(t) \rightarrow A'(\omega)$
$\xi(t) \rightarrow \xi'(\omega)$ (noise PSD)

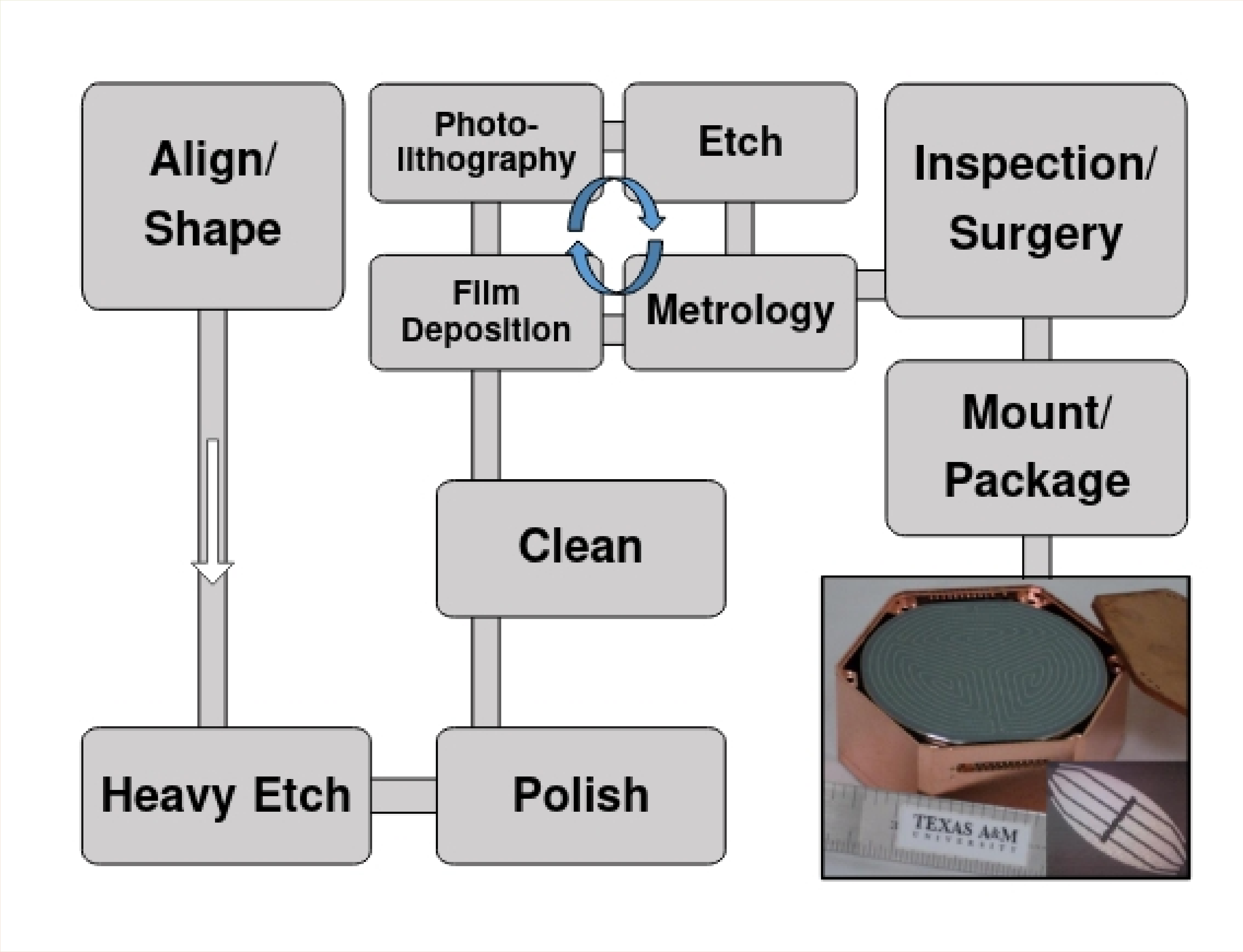
Find 'a' when χ^2 is minimum

$$\chi^2 = \int_{-\infty}^{\infty} \frac{|S'(\omega) - aA'(\omega)|^2 \, d\omega}{\xi'(\omega)}$$

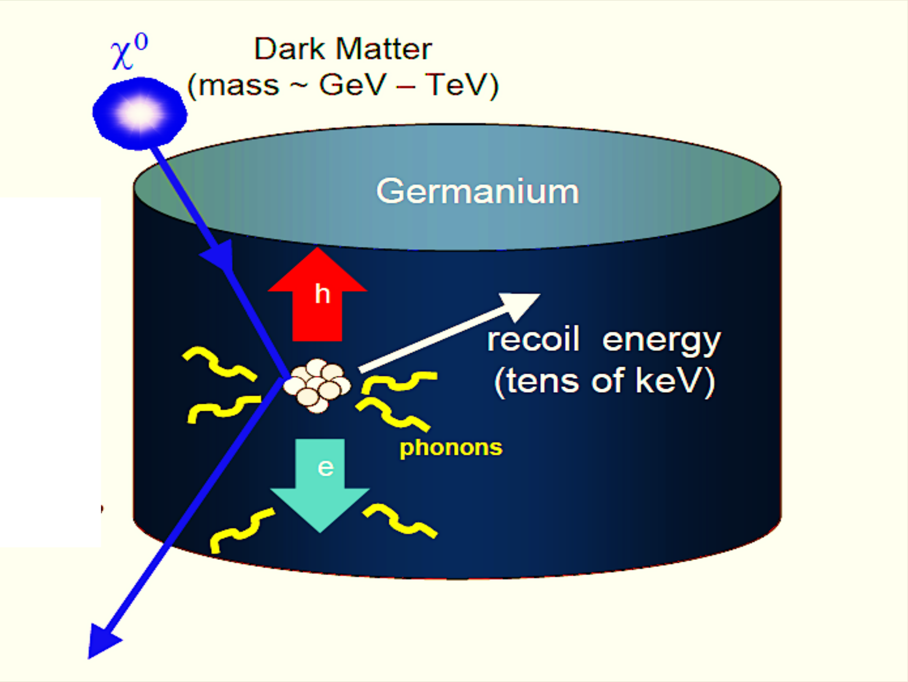
Output

OF amplitude: a
OF χ^2
t_0

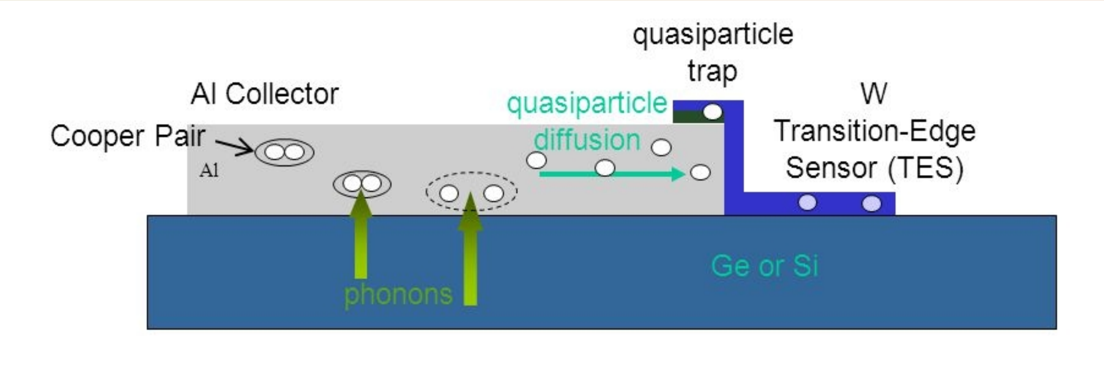
Flow chart of detector fabrication



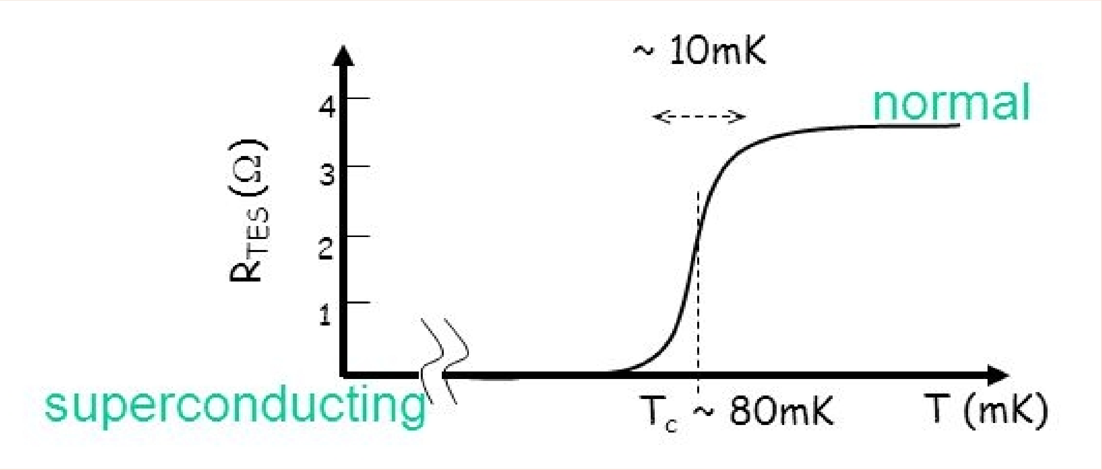
Detection principle



- 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)

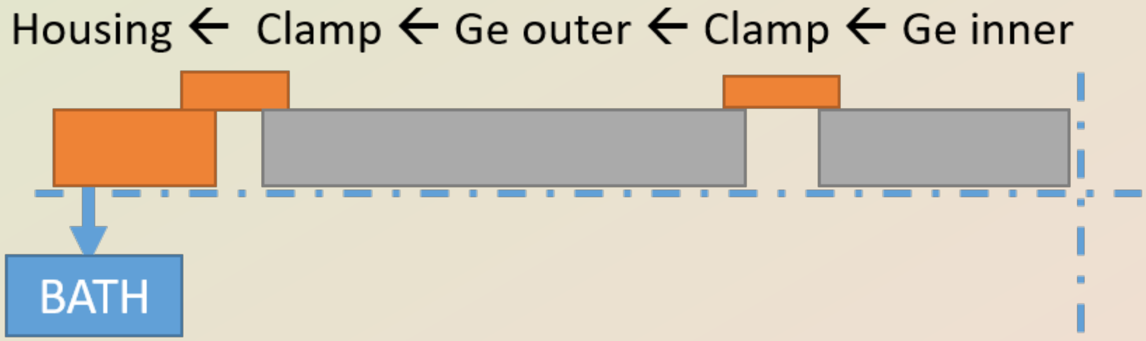


- Superconducting layer on the surface operating near T_c

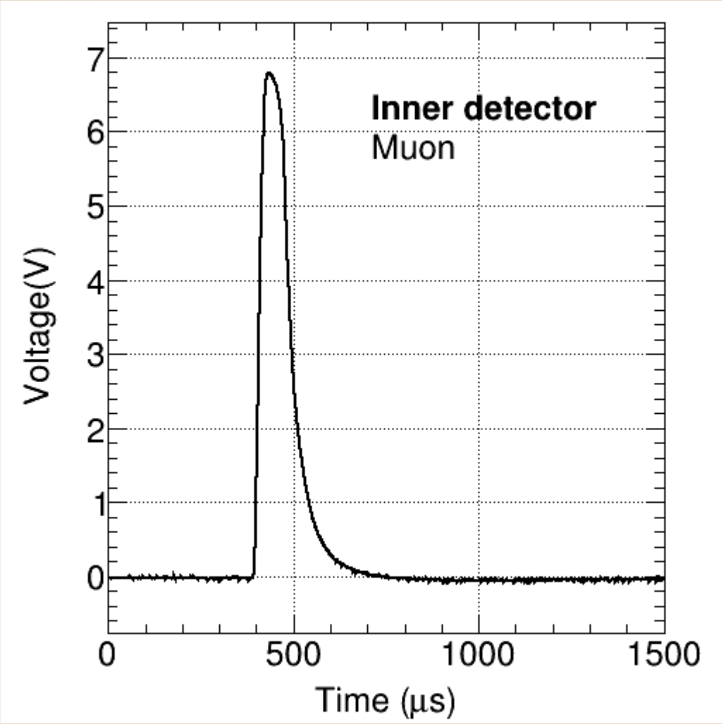


- Read out of phonon energy as an electronic signal due to change in TES resistance

Thermal performance of inner detector



Thermal conduction path from inner to refrigerator (bath) for cooling both the veto and inner in operational temperature



Thermal performance of the inner detector has been studied using 3 MeV muons.

- Risetime: 20 μs
- Falltime: 90 μs