Cryogenic detectors for rare event experiments

V. K. S. Kashyap*, R. Karnam and B. Mohanty

National Institute of Science Education and Research

In collaboration with

Bhabha Atomic Research Centre, Mumbai, India and

Texas A & M University, Texas, USA

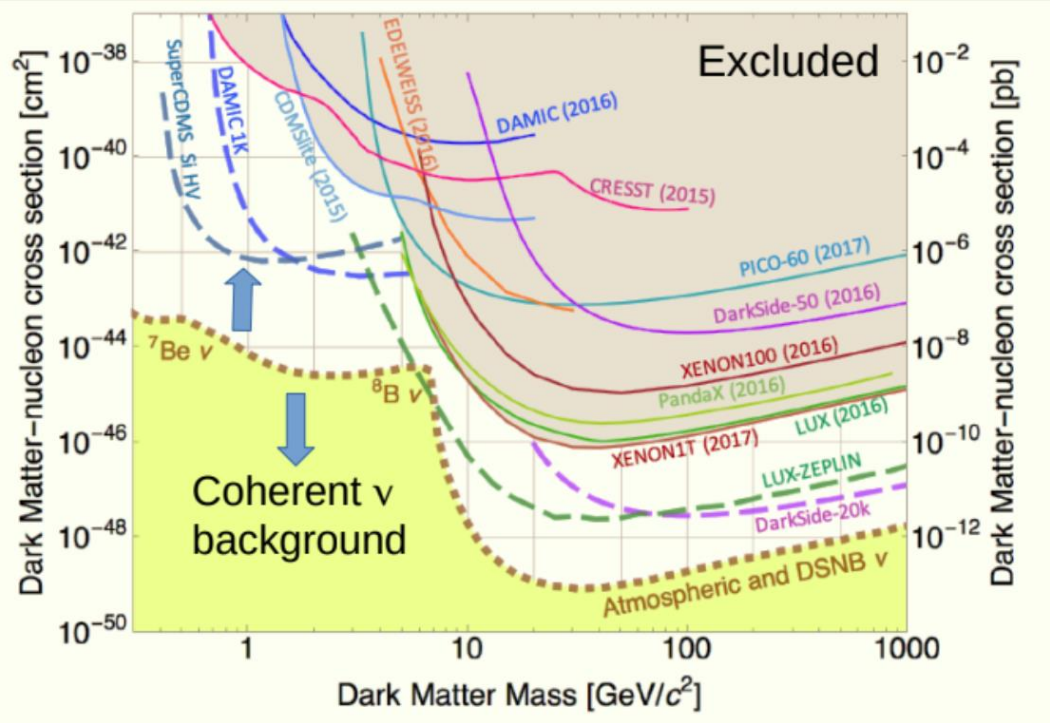
Underground labs are needed for:

- Dark matter physics
- FCP search
- Detector R & D and
- Experiments that need low background environment

OUTLINE

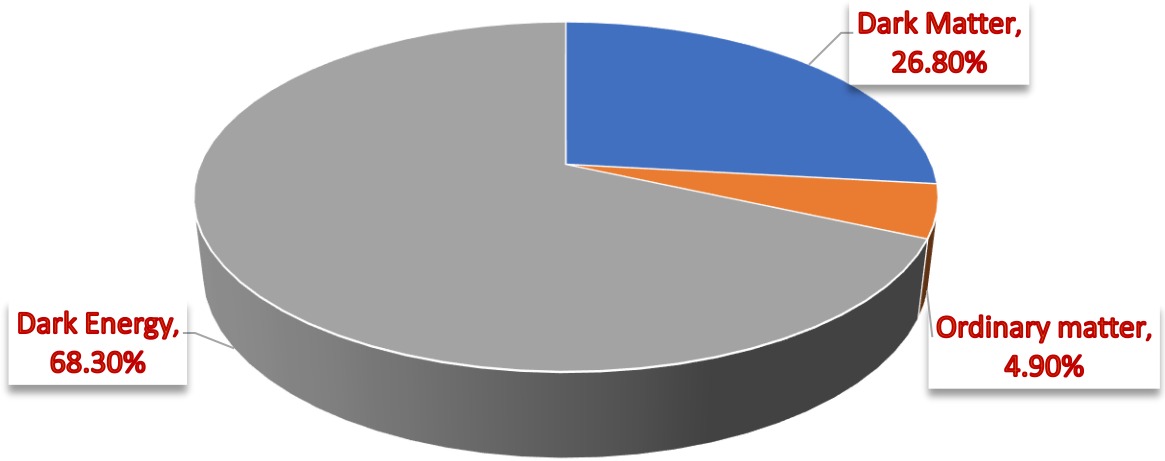
- Introduction
- Cryogenic Detectors
- Lightly ionizing / Fractionally charged particle search (SuperCDMS)
- Background estimates at Jaduguda
- ICNSE

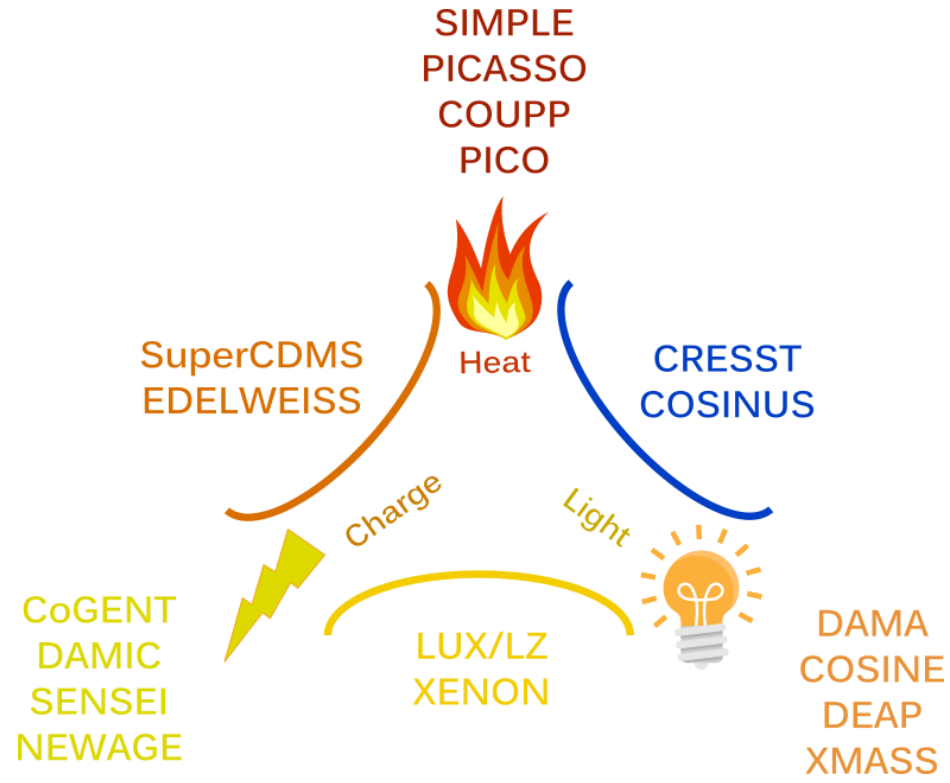
Detection of rare events



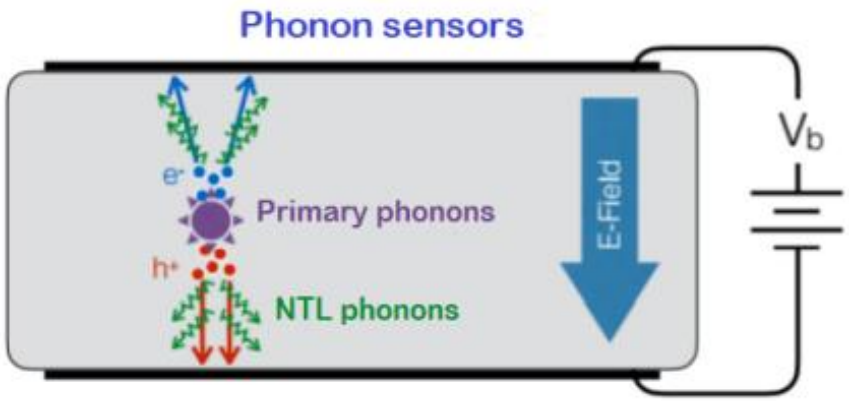
The requirements

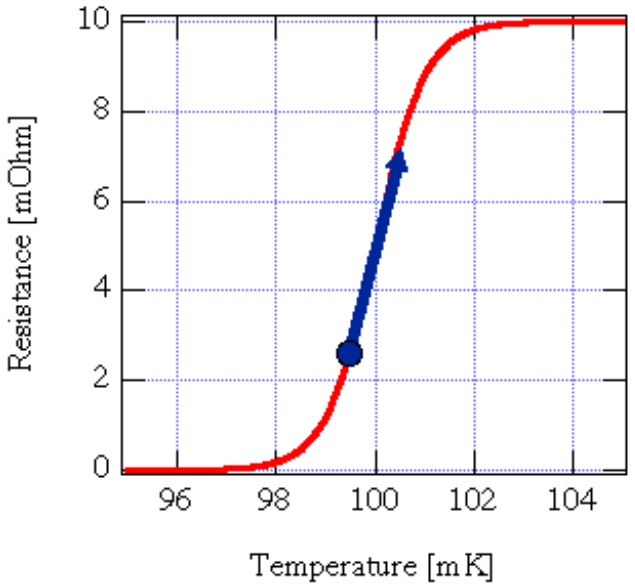
- Low background
- Low threshold
- High Signal to Noise Ratio





Detection of rare events (Bolometric)

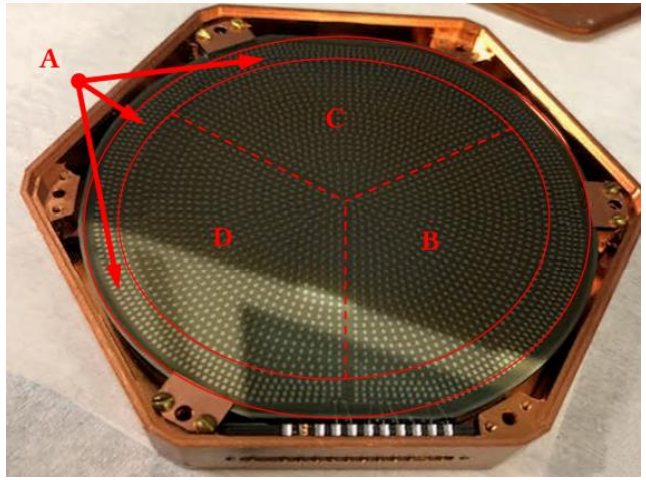


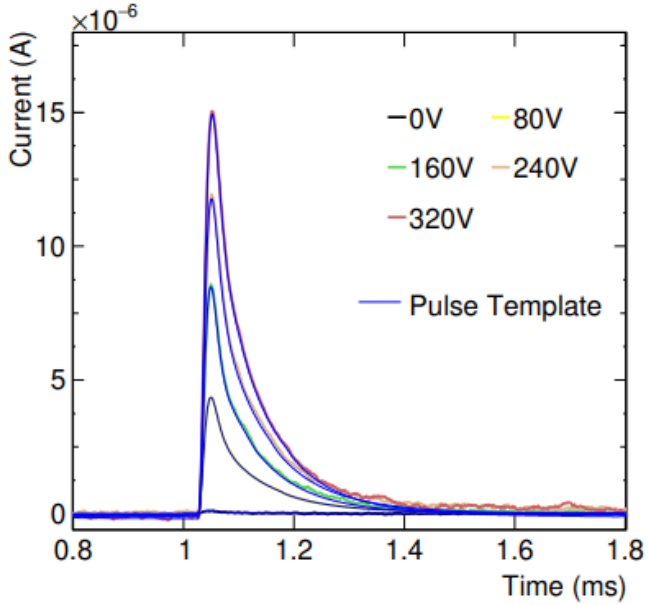


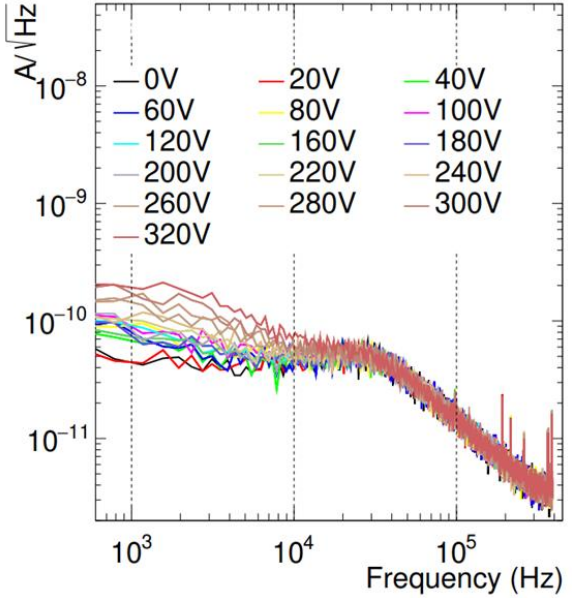
Source: MIT Experimental Cosmology and Astrophysics Laboratory

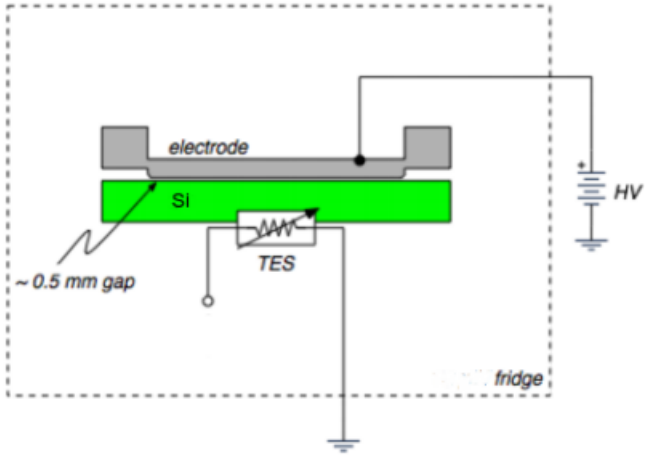
- A particle interacts with the detector elastically
- Produces nuclear/electron recoil depending on the type of particle and interaction creating phonons
- In the presence of electric field more phonons are generated by NTL effect
- Phonons are detected by TES sensors.
- Depending on the crystal type one can also obtain charge or photon signals

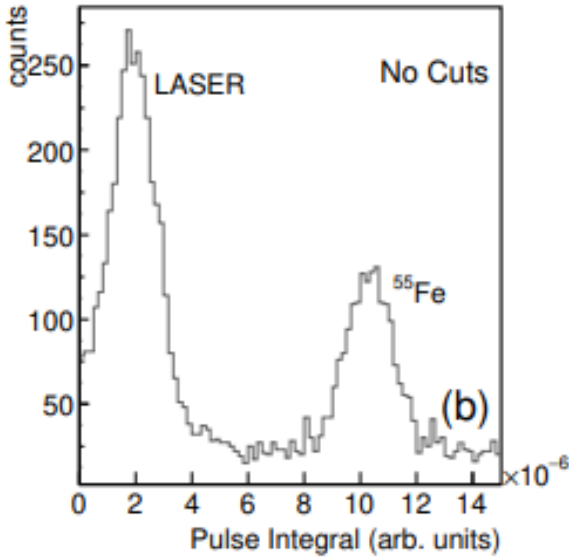
Silicon High Voltage detector

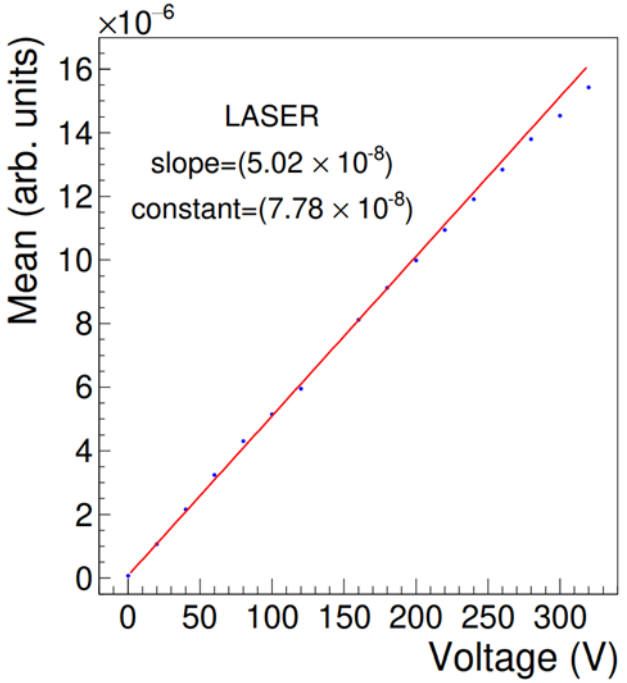


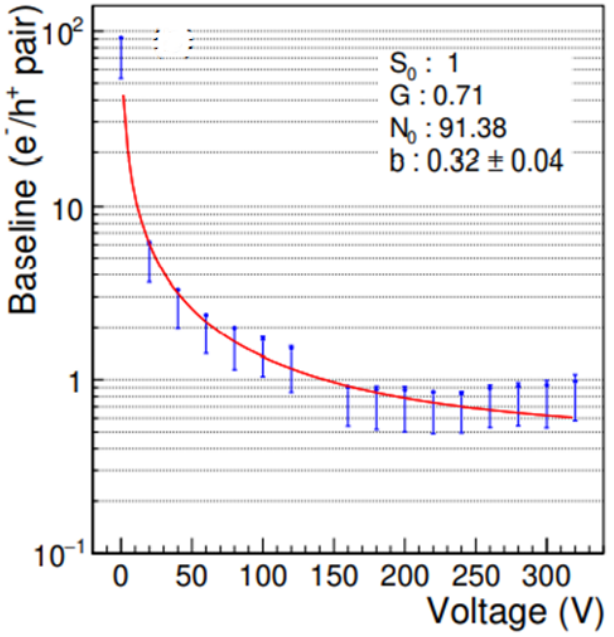




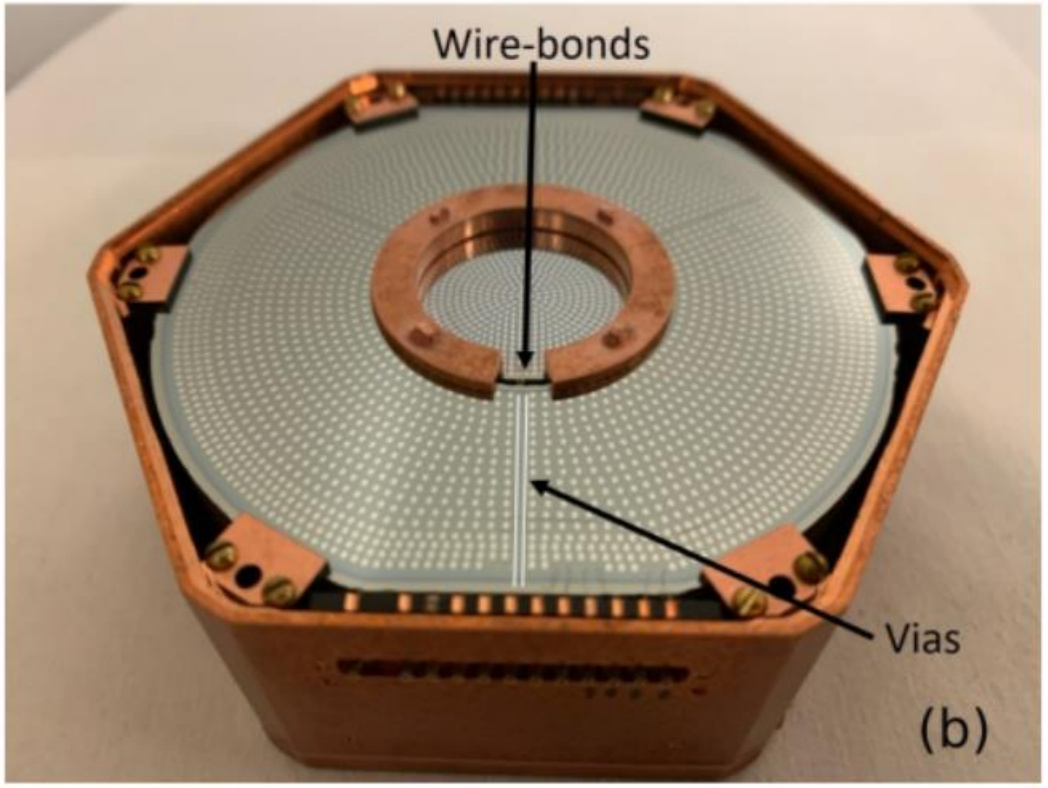


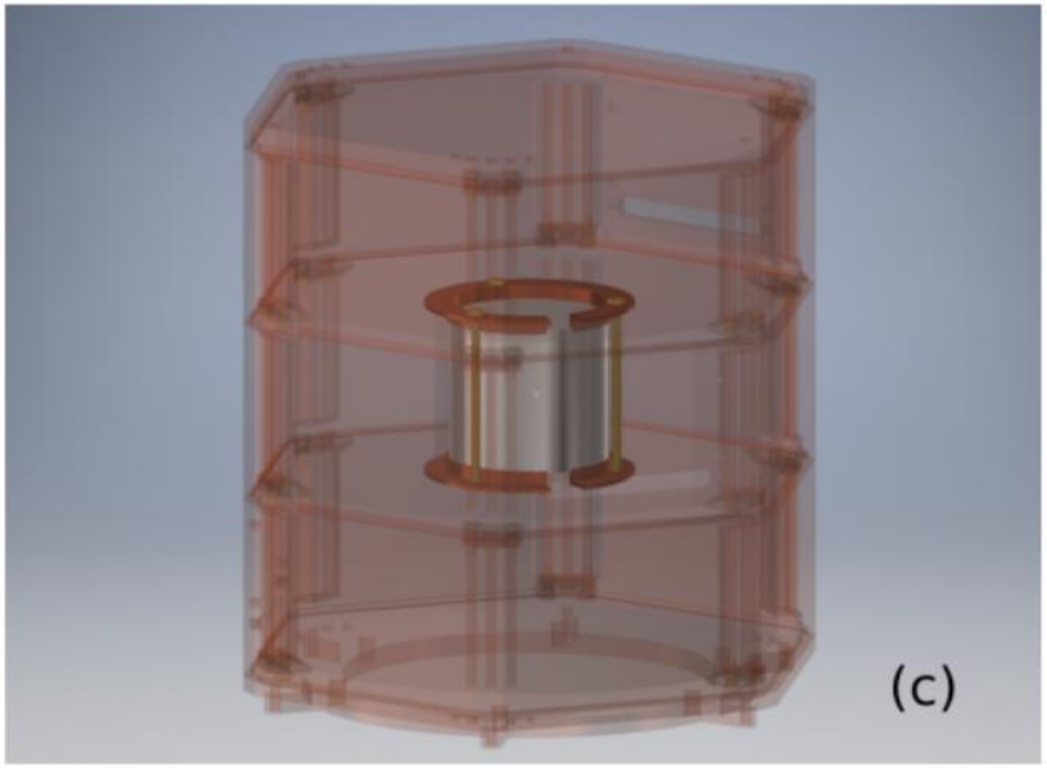






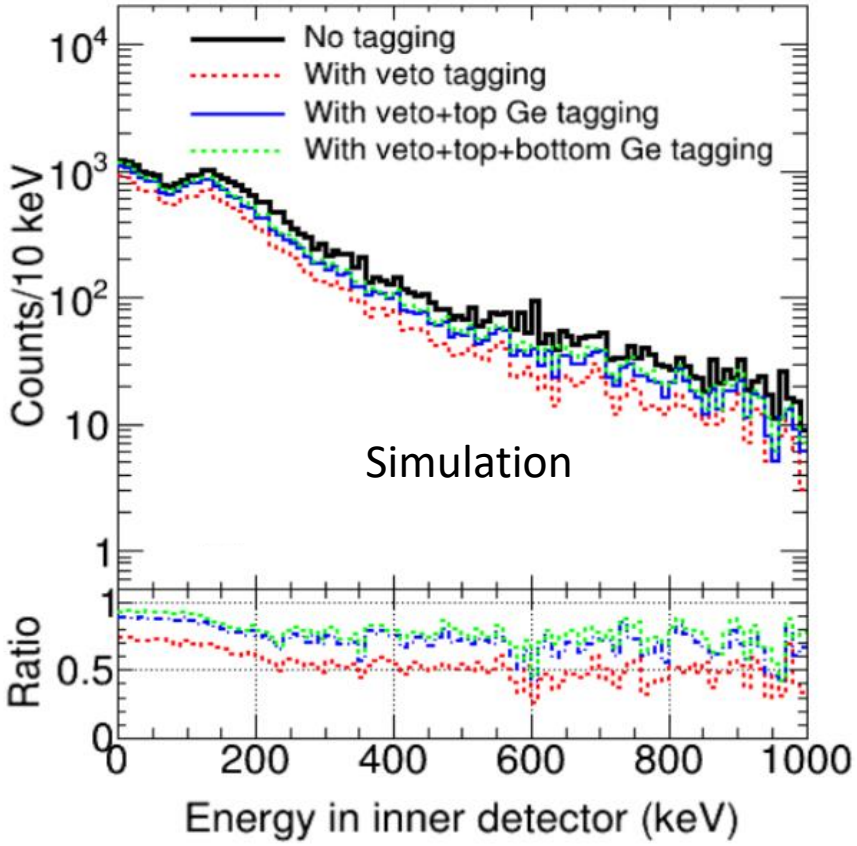
Active veto detector

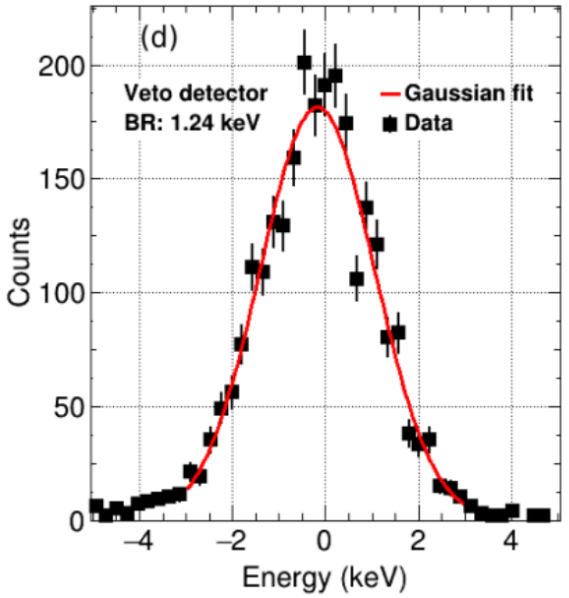


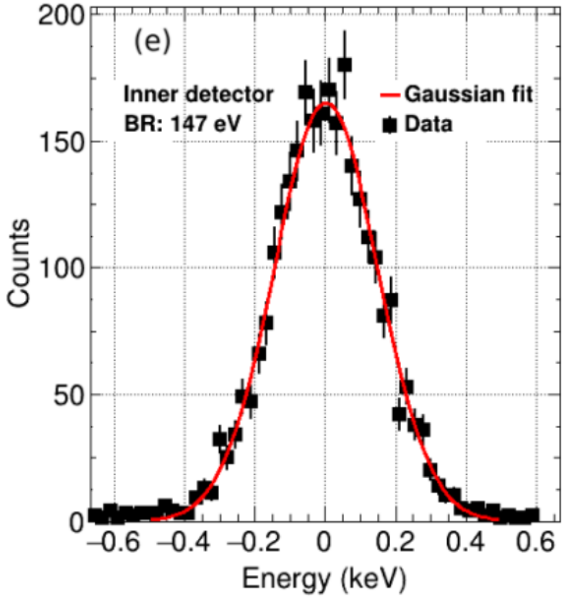


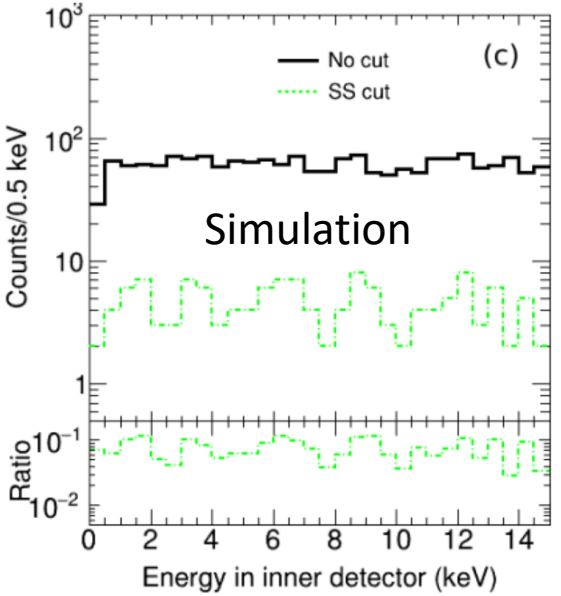
7.5 cm outer diameter, 2.8 cm inner diameter and 2.5 cm thick Ge donut having a 2.5 cm diameter and 0.1 cm thick Ge coin inside.

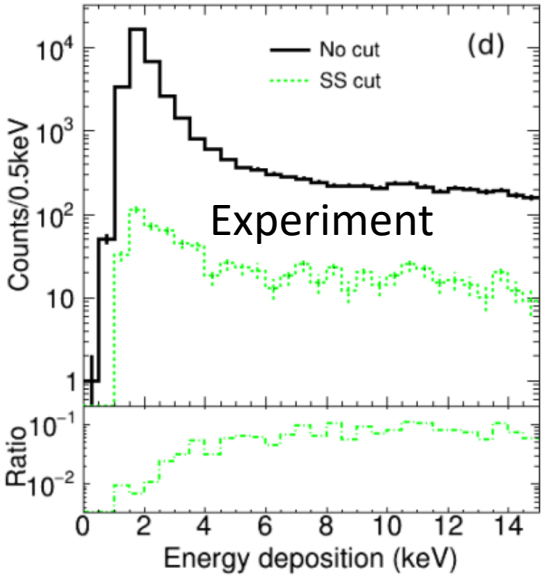
Active veto detector contd.





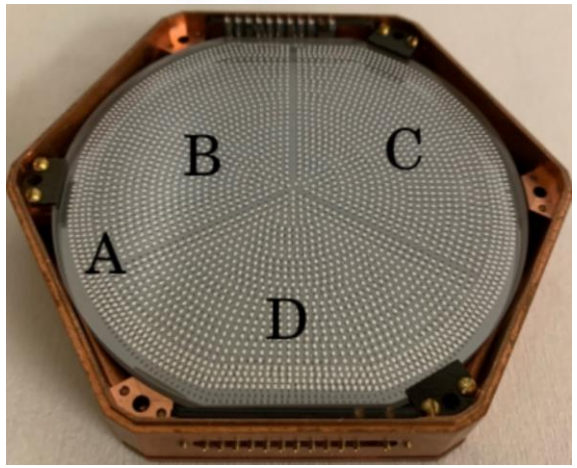




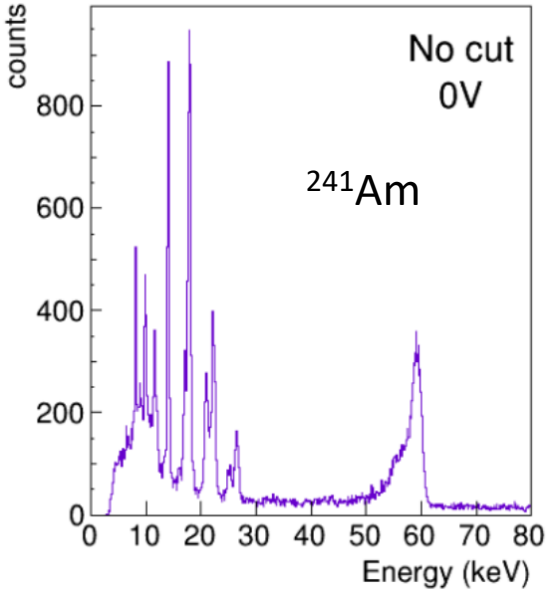


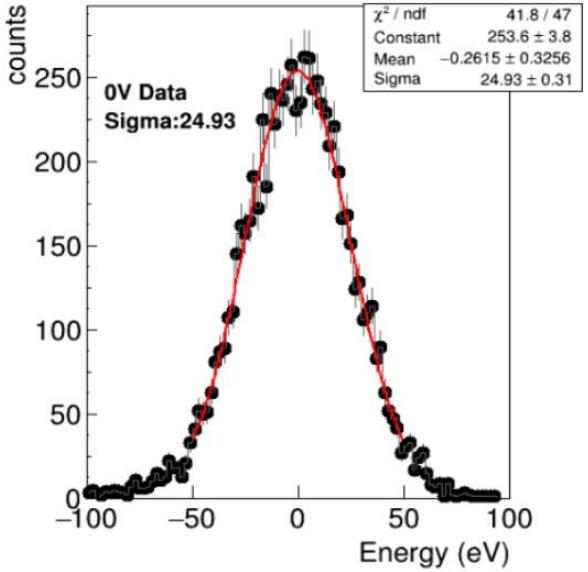
M. Chaudhuri et al, **NIMA**, 1039 (2022) 167150.

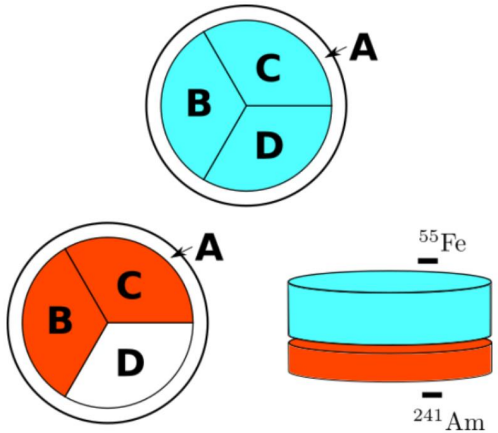
Sapphire detector

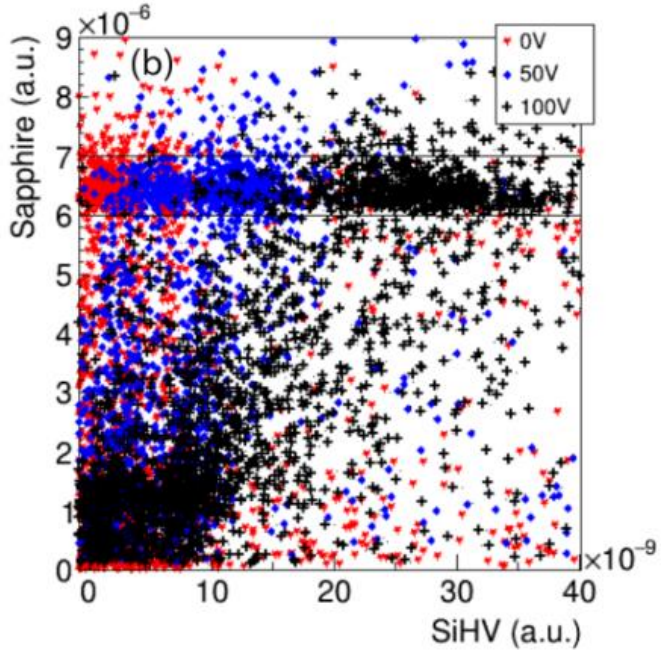


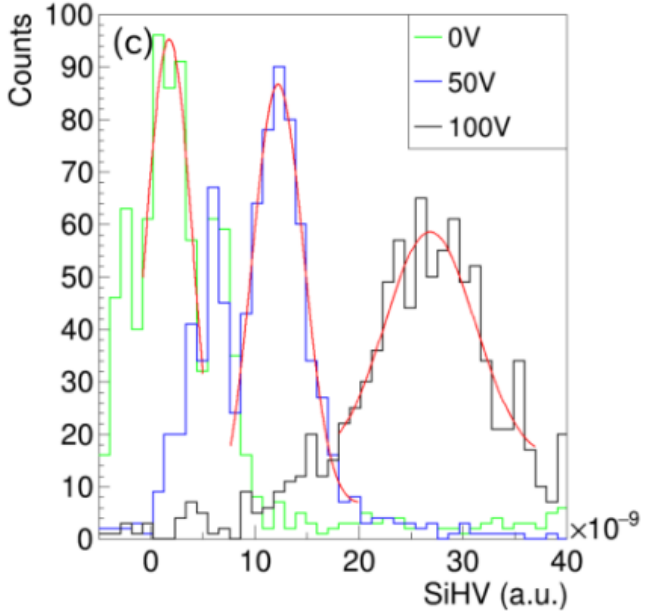
- Detector mass ~ 72 g.
- Made up of Al_2O_3
- Dimension: 7.62 mm x 4 mm
- Phonon sensors: A, B, C and D.
- Voltage applied ~ 0 V

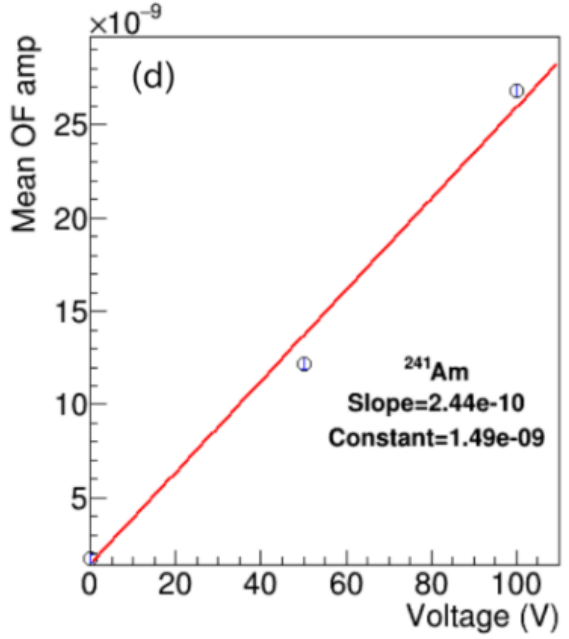










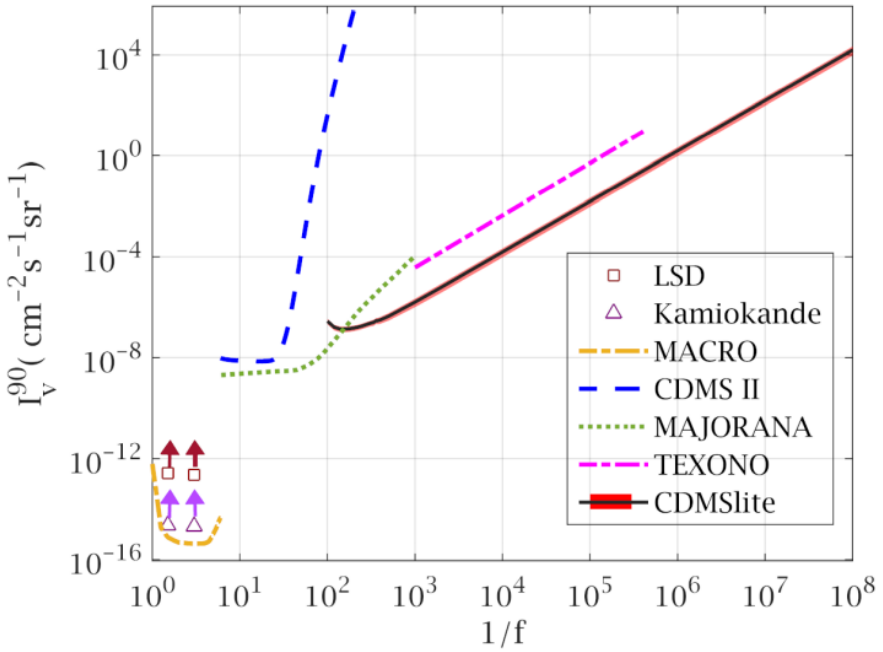


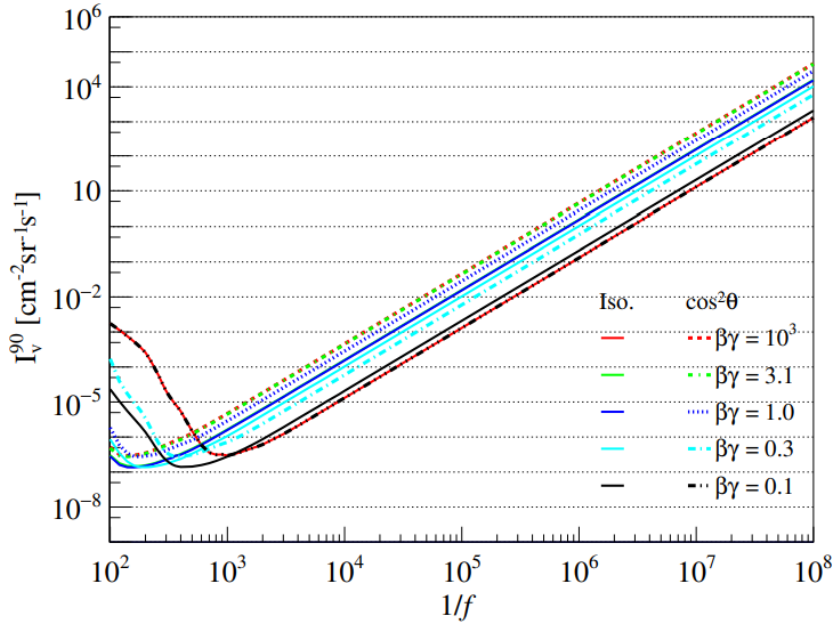
Fractionally charged particle/ Lightly ionizing particle search (SuperCDMS)

Search for FCPs or LIPs

- Free charged particles have charges that are integer multiples of charge of electrons
- No strong theoretical motivation for quantization of particle charges. Many theoretical models suggest possibility for existence of fractional charges
- Several experiments have looked for fractionally charged particles (FCPs), exploring wide range of masses and charges
- Since these particles (q<1) tend to loose lesser energy in matter they are sometimes also called lightly ionizing particles (LIPs).

- First limit on vertical intensity of cosmogenically produced LIPs with an electric charge smaller than e/(3×10^5)
- Strongest limits for charge ≤e/160, with a minimum vertical intensity of 1.36×10^{-7} cm^{-2} s^{-1} sr^{-1}



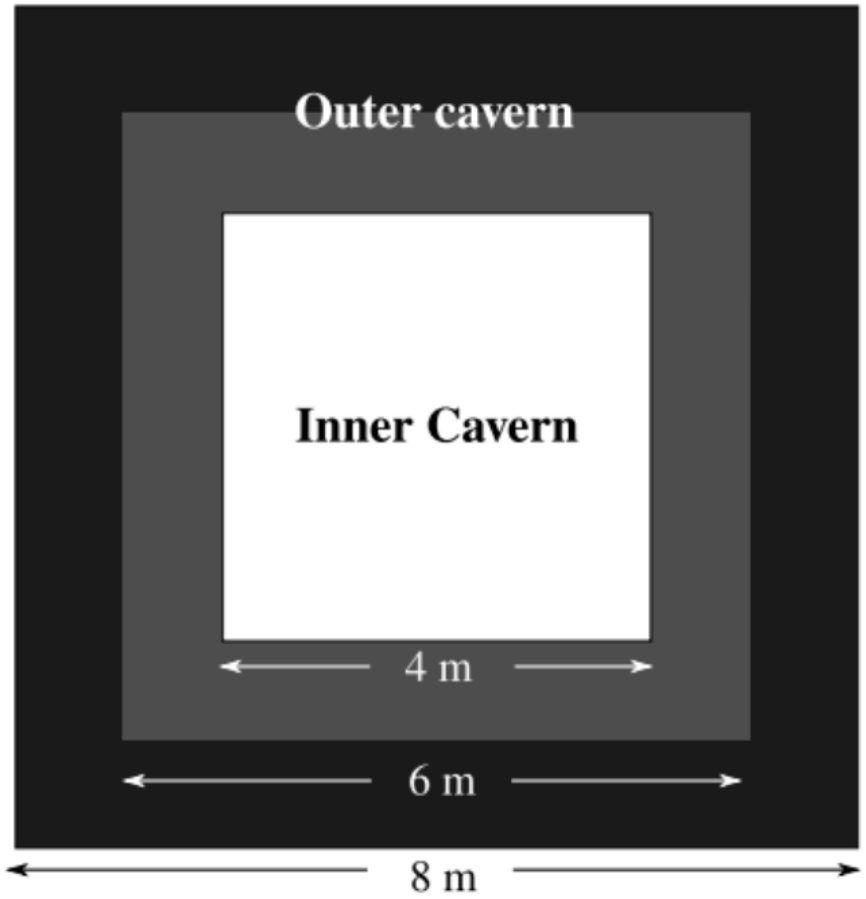


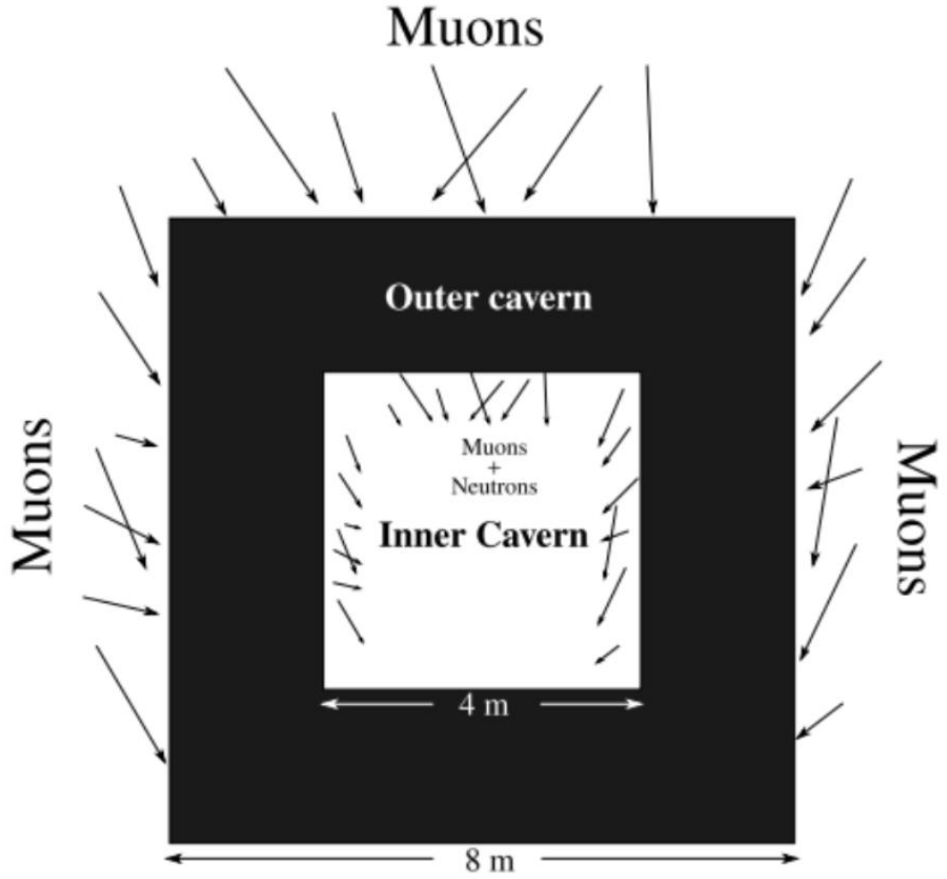
I. Alkhatib *et al.* (SuperCDMS Collaboration) Phys. Rev. Lett. **127**, 081802

Estimation of muon, radiogenic and cosmogenic neutron flux at JADUGUDA

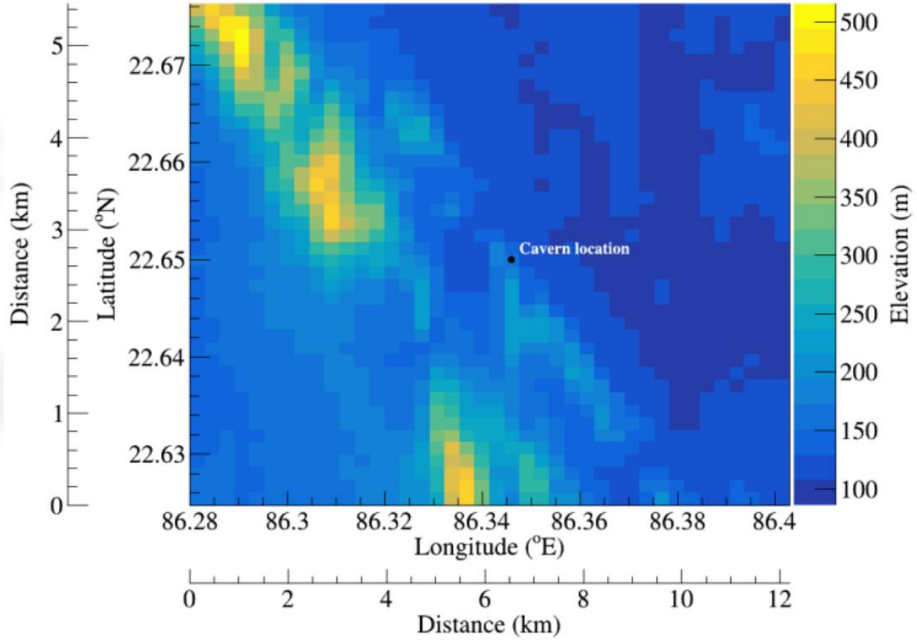
- In collaboration with SINP, Kolkata, estimation of muon and neutron background at the Jaduguda site has been done using GEANT4.
- With knowledge of rock composition, density and depth of the site, the code/framework can be used to estimate cosmogenic and radiogenic background at any site in India.

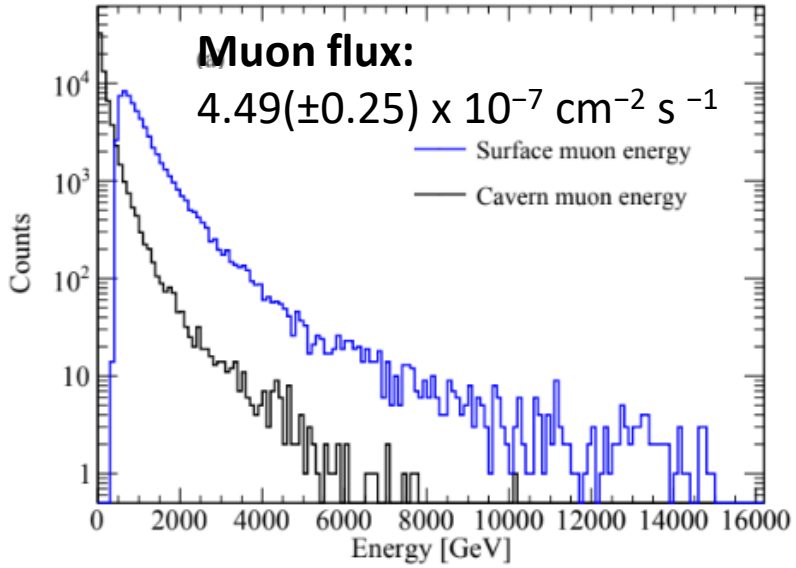
Estimation of muon, radiogenic and cosmogenic neutron flux at JADUGUDA

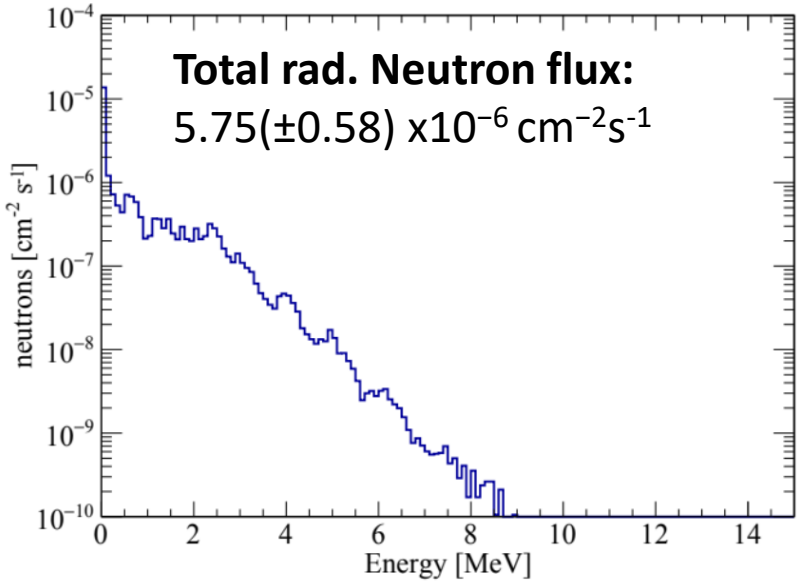


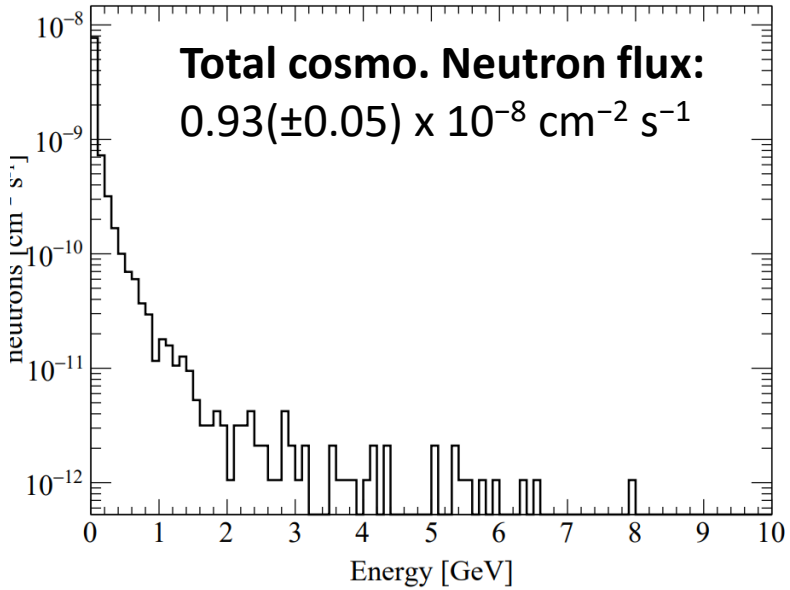


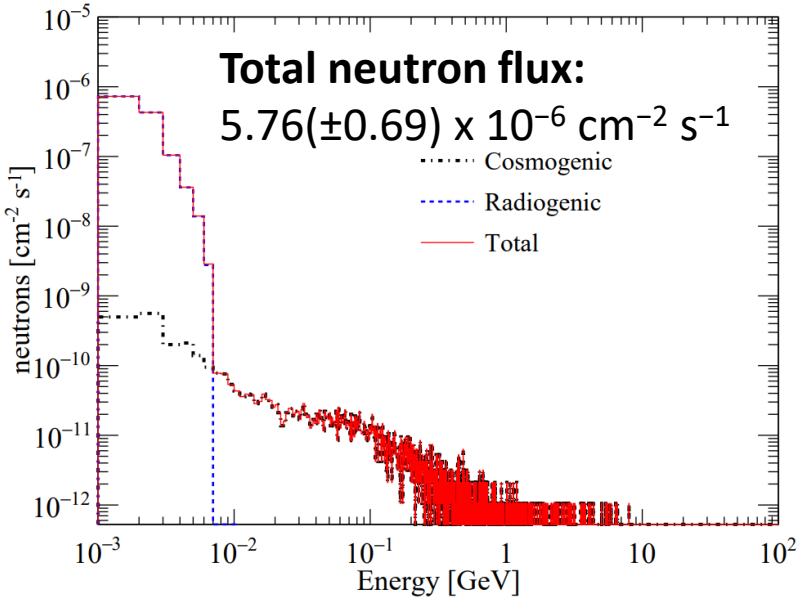
Cosmogenic muon and neutron flux





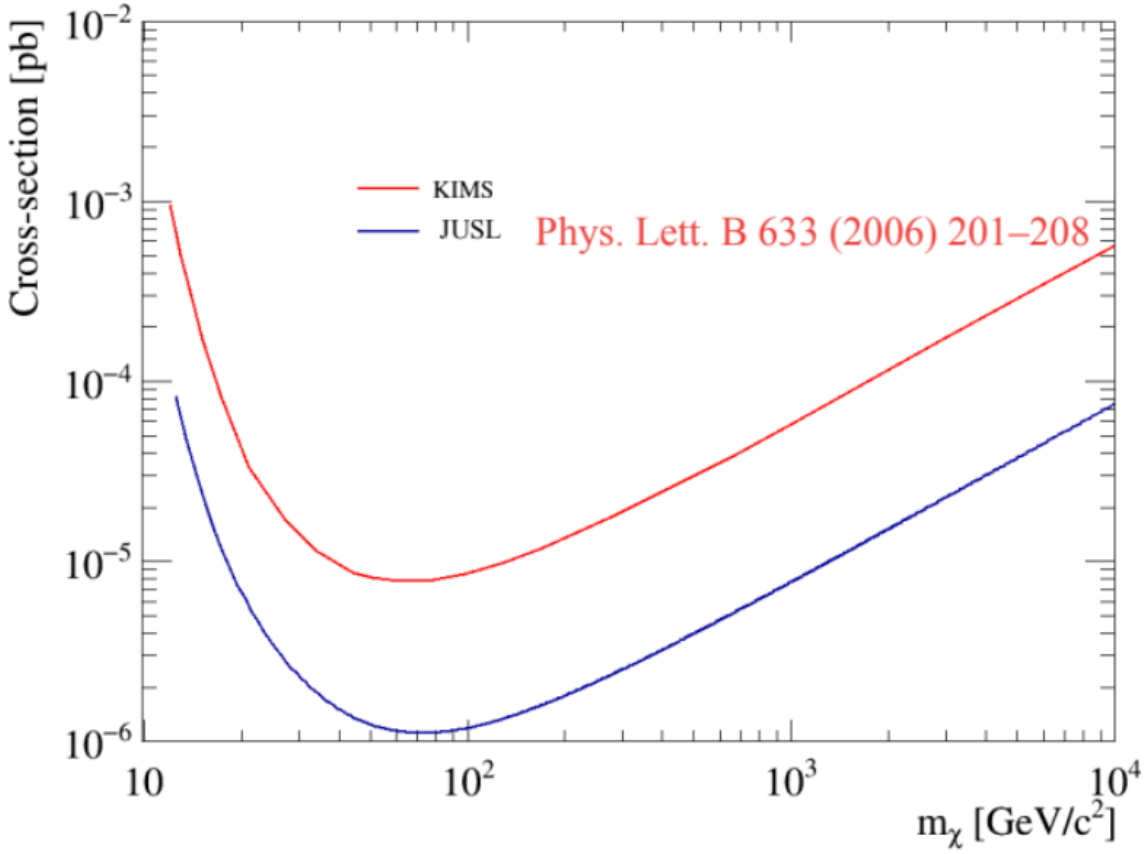


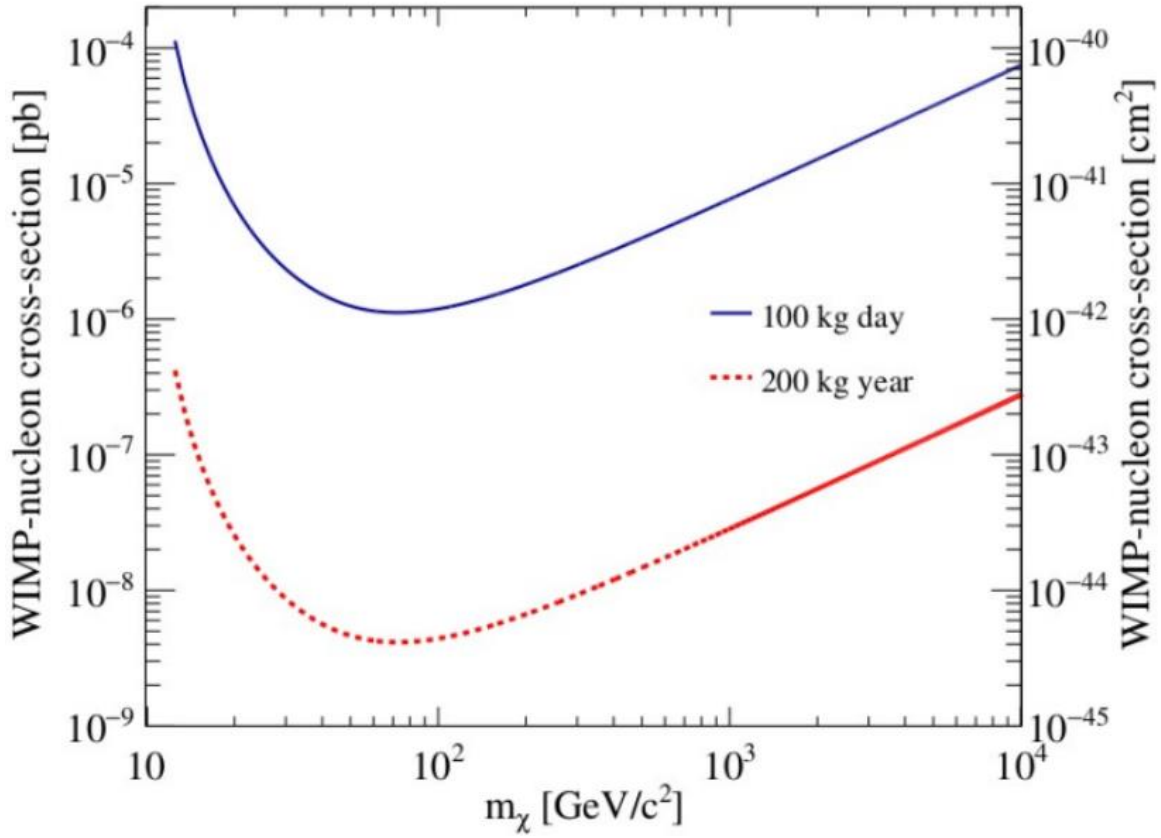




S. Banik et al 2021 **JINST** 16 P06022

Projected sensitivity at JADUGUDA





Considering neutron only background

S. Banik et al 2021 **JINST** 16 P06022

BARC

- Head-NPD
- Head-TPD
- V. Jha
- S. Sen
- D. K. Mishra
- M. Tyagi
- P. K. Netrakanti
- S. G. Singh
- S. P. Behera
- G. D. Patra
- R. Sehgal
- S. Joy
- S. Neema
- S. Rastogi
- S. Rajan

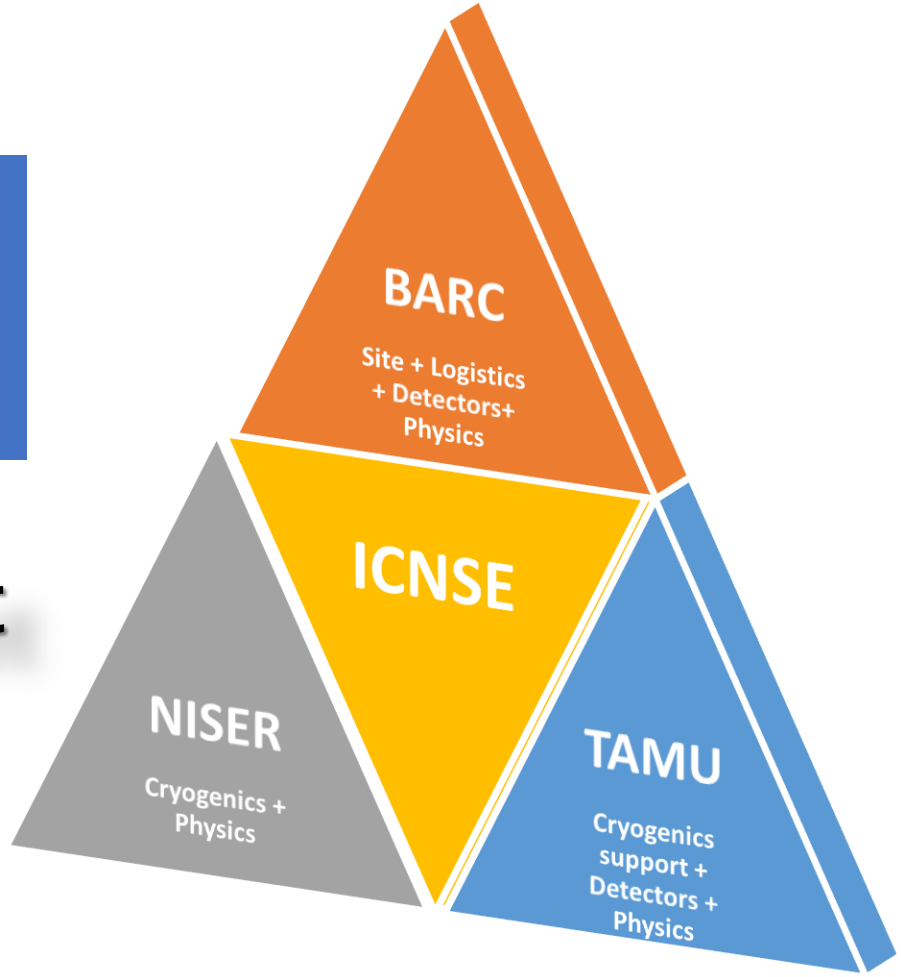
NISER

- B. Mohanty
- V. K. S. Kashyap
- R. Karnam

TAMU

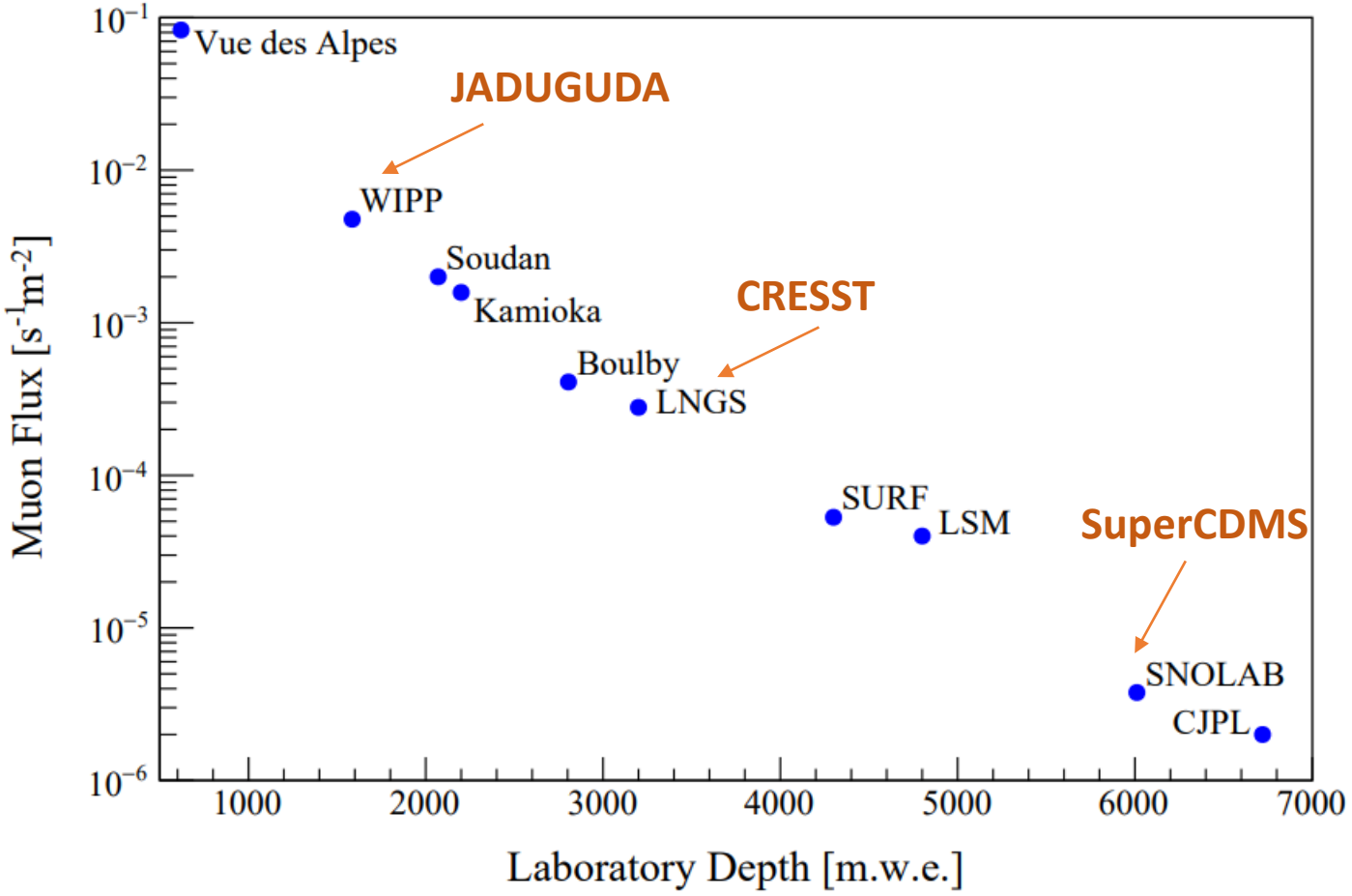
- R. Mahapatra
- B. Dutta
- N. Mirabolfathi

India based Coherent Neutrino Scattering Experiment (ICNSE) at Apsara-U



- Cryogenic sapphire detector based experiment for measuring CEvNS from Apsara-U at BARC
- MoU is in the process of being established

Need for a deeper and larger site



- Jaduguda depth almost same as WIPP
- Lower the depth better would be the cosmogenic background reduction and more competitive would be the experiment

Typical lab area in existing experiments

1. **SNOLAB:** Approx. 42 ft x 12 ft
   a. In addition, Supply and service area of similar size
2. **CRESST:** Approx. 30 ft x 30 ft

Summary and outlook

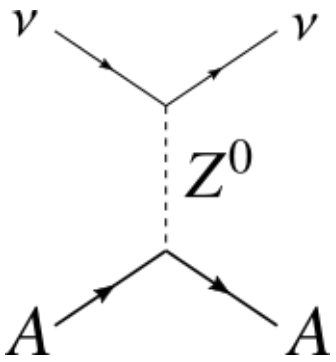
- An underground facility is crucial for rare event experiments like dark matter and fractionally charges particles / lightly ionizing particle search.
- Detectors with very low threshold, very low noise and low mass are required to search for low mass dark matter. Cryogenic detectors are very well suited for these searches.
- Three detectors were presented: SiHV, Active veto and sapphire. All of them are good candidates for low mass dark matter search.
- Muon and neutron background estimates have been done for Jaduguda using simulation. The simulation framework can be used to estimate expected background rates at other potential underground sites in India.

Thank you

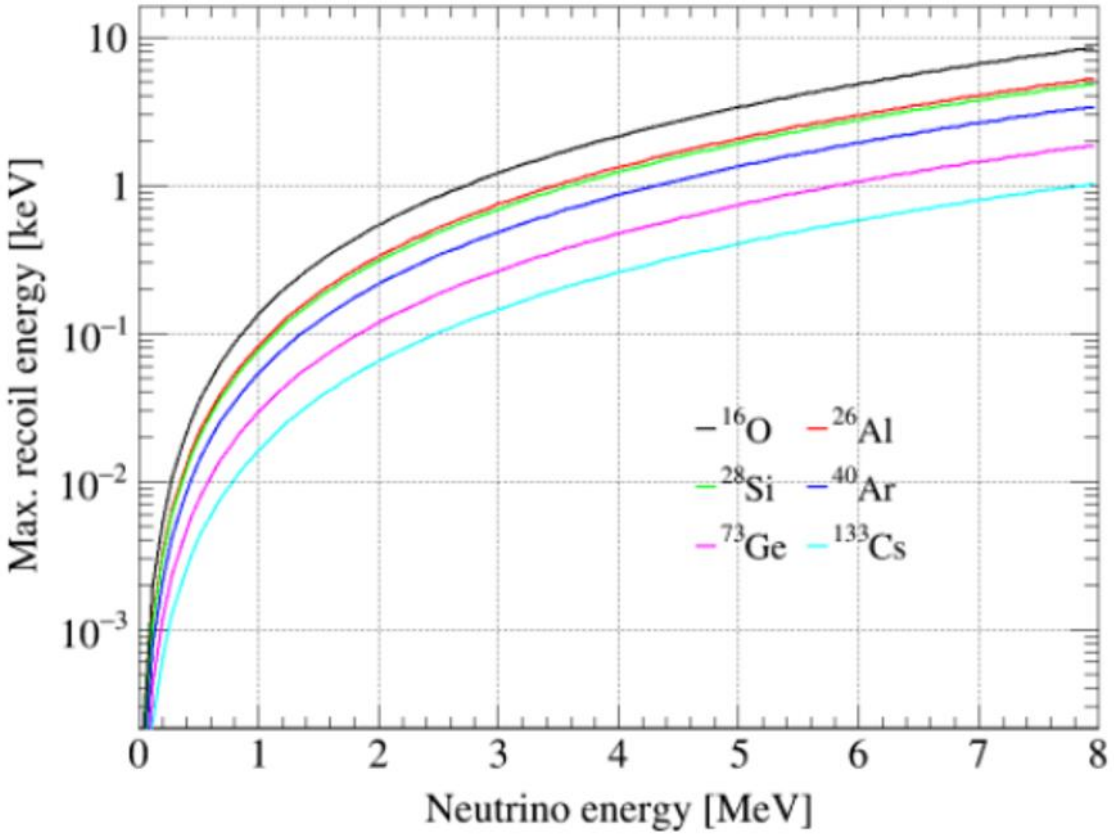
Backup

Coherent Elastic Neutrino Nucleus Scattering (CEνNS)

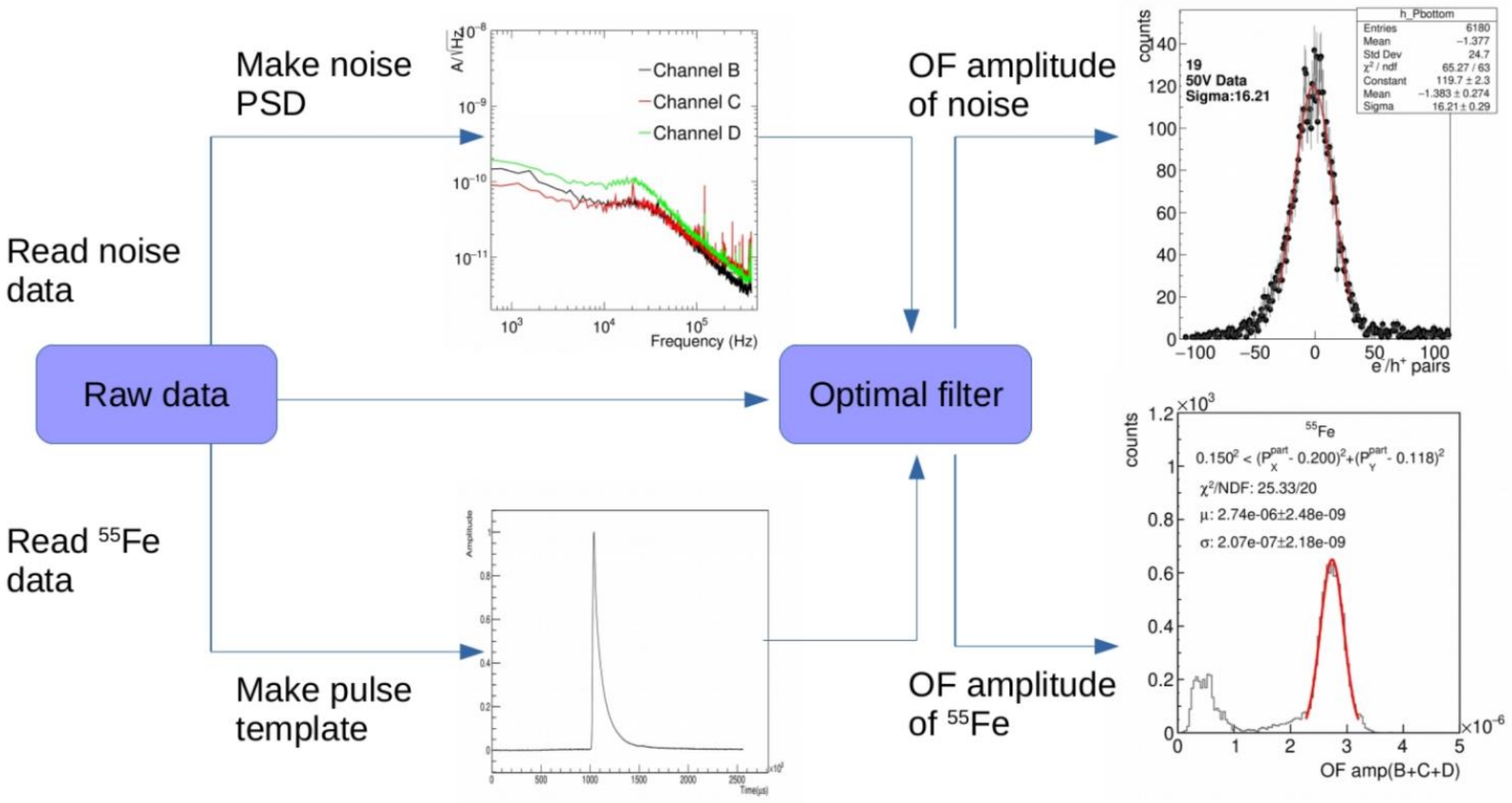
- Neutrino elastically scatters of a nucleus through the Z boson interaction
- Produces nuclear recoil
- The cross-section for the process is pretty well understood in standard model theory
- All flavors of neutrino will have the same cross section since the interaction is through neutral current



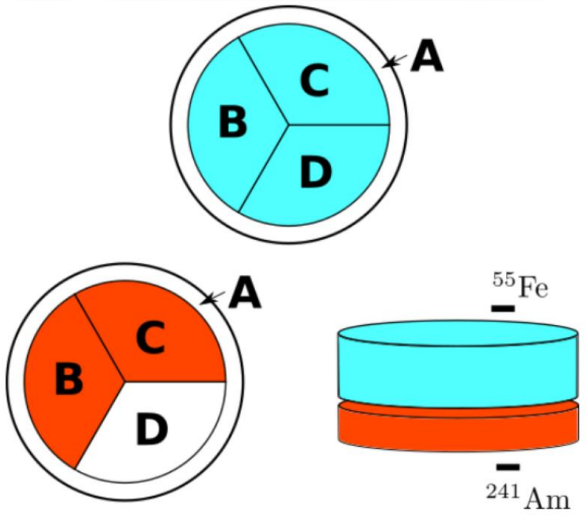
$$\sigma \propto N^2$$
$$\sigma \propto E, M$$

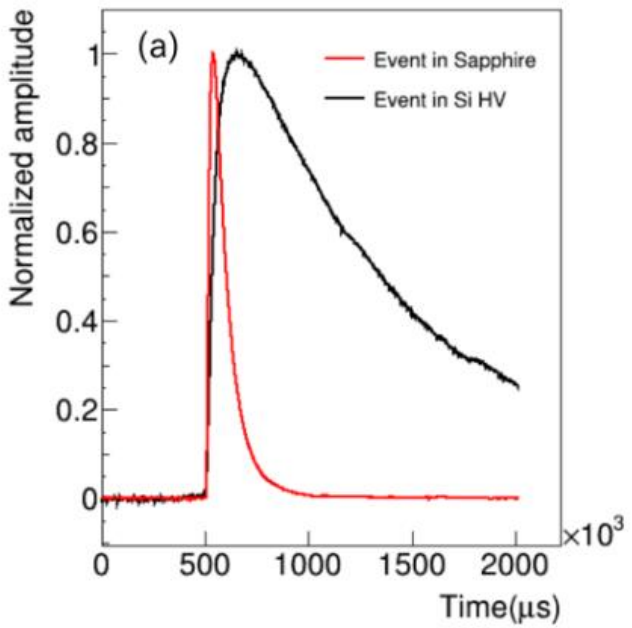


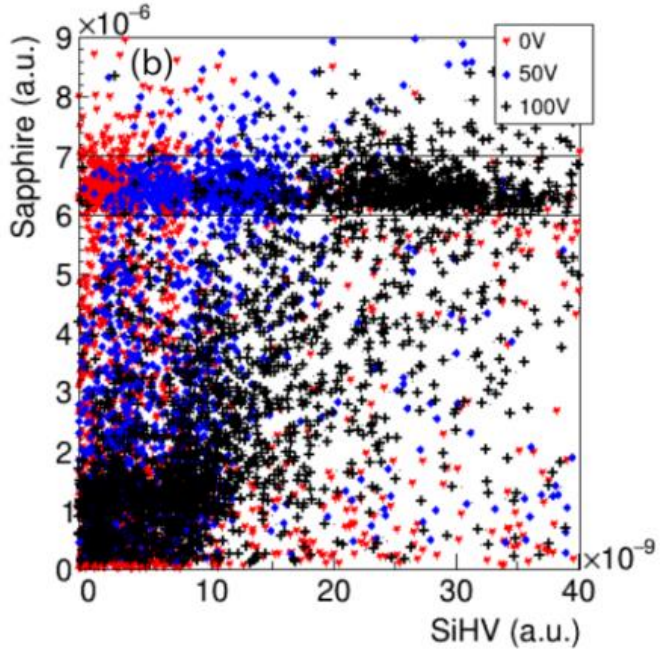
Silicon High Voltage detector contd.

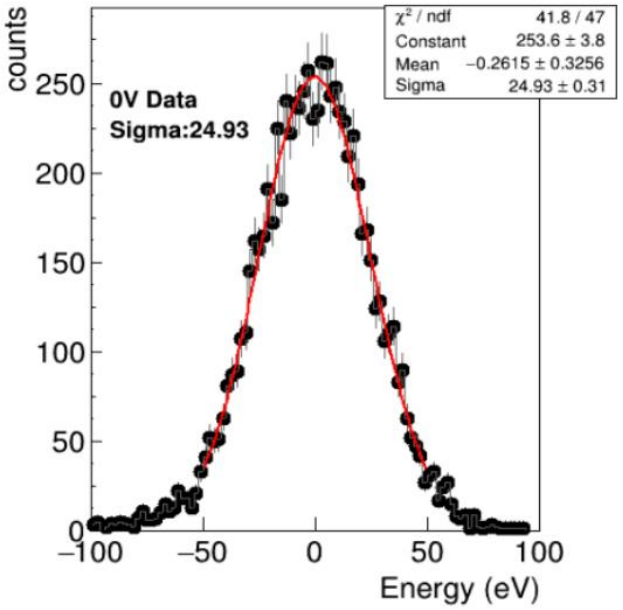


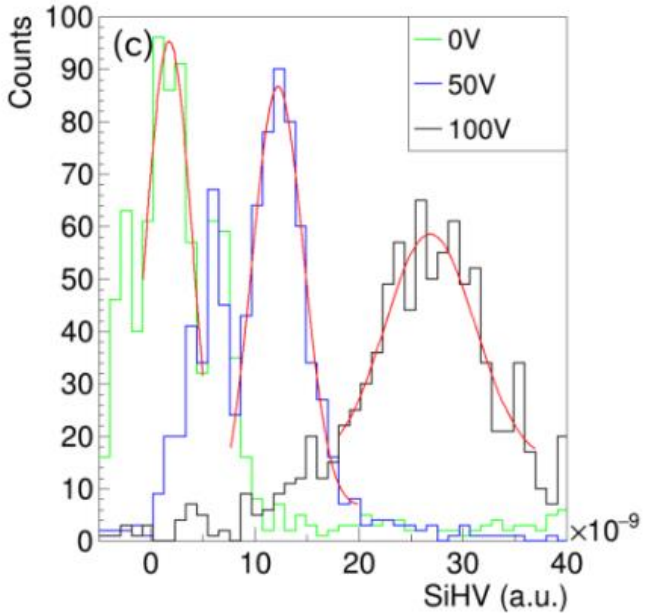
Sapphire detector contd.

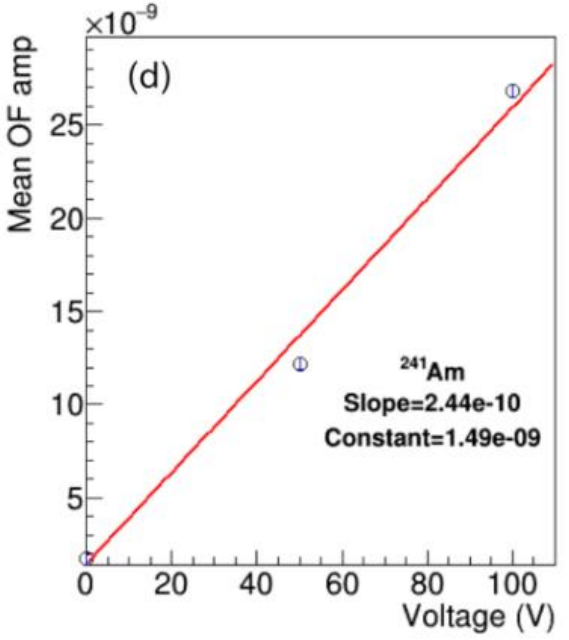




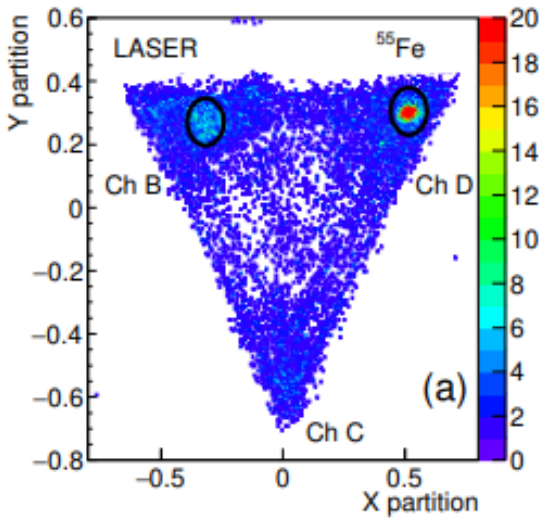


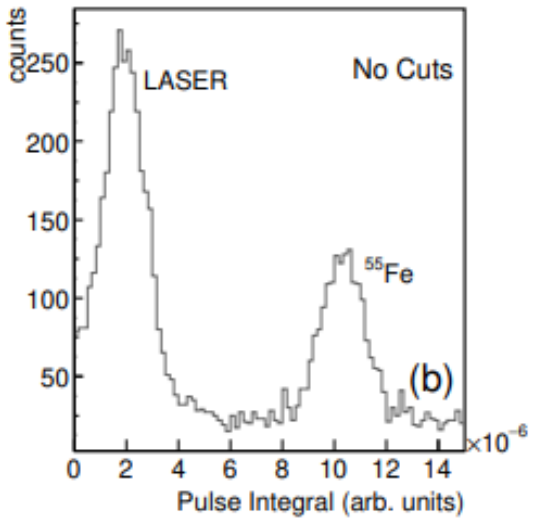


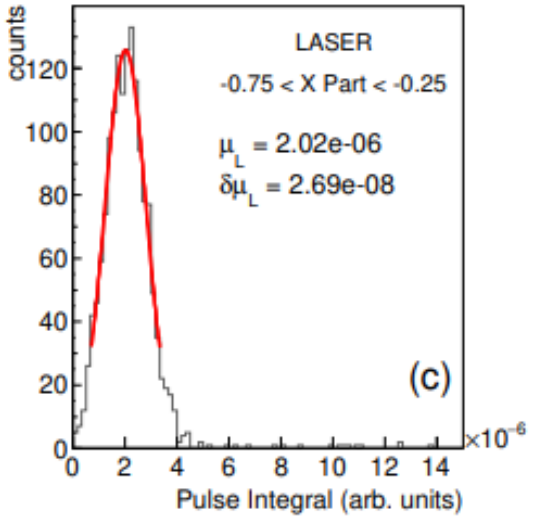


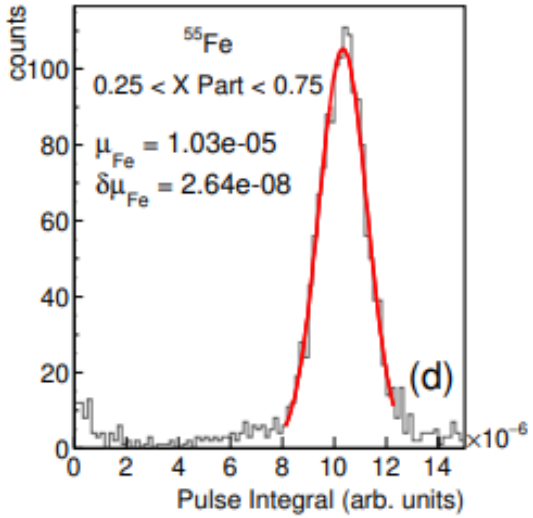


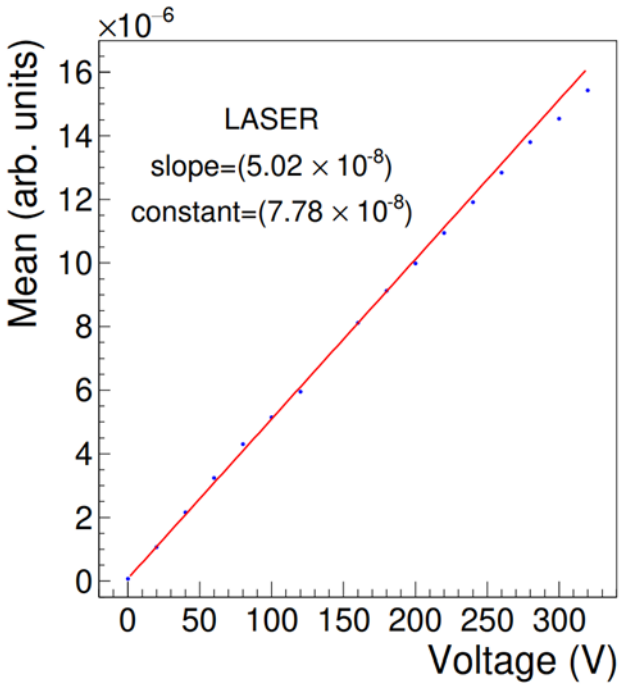
Silicon High Voltage detector contd.

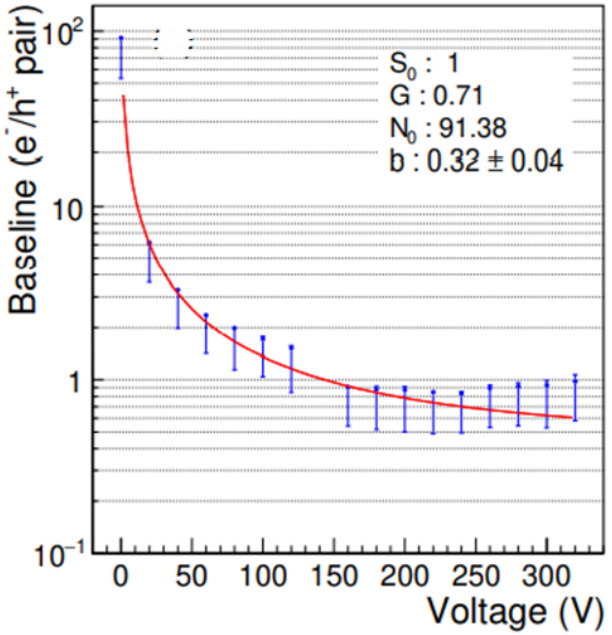






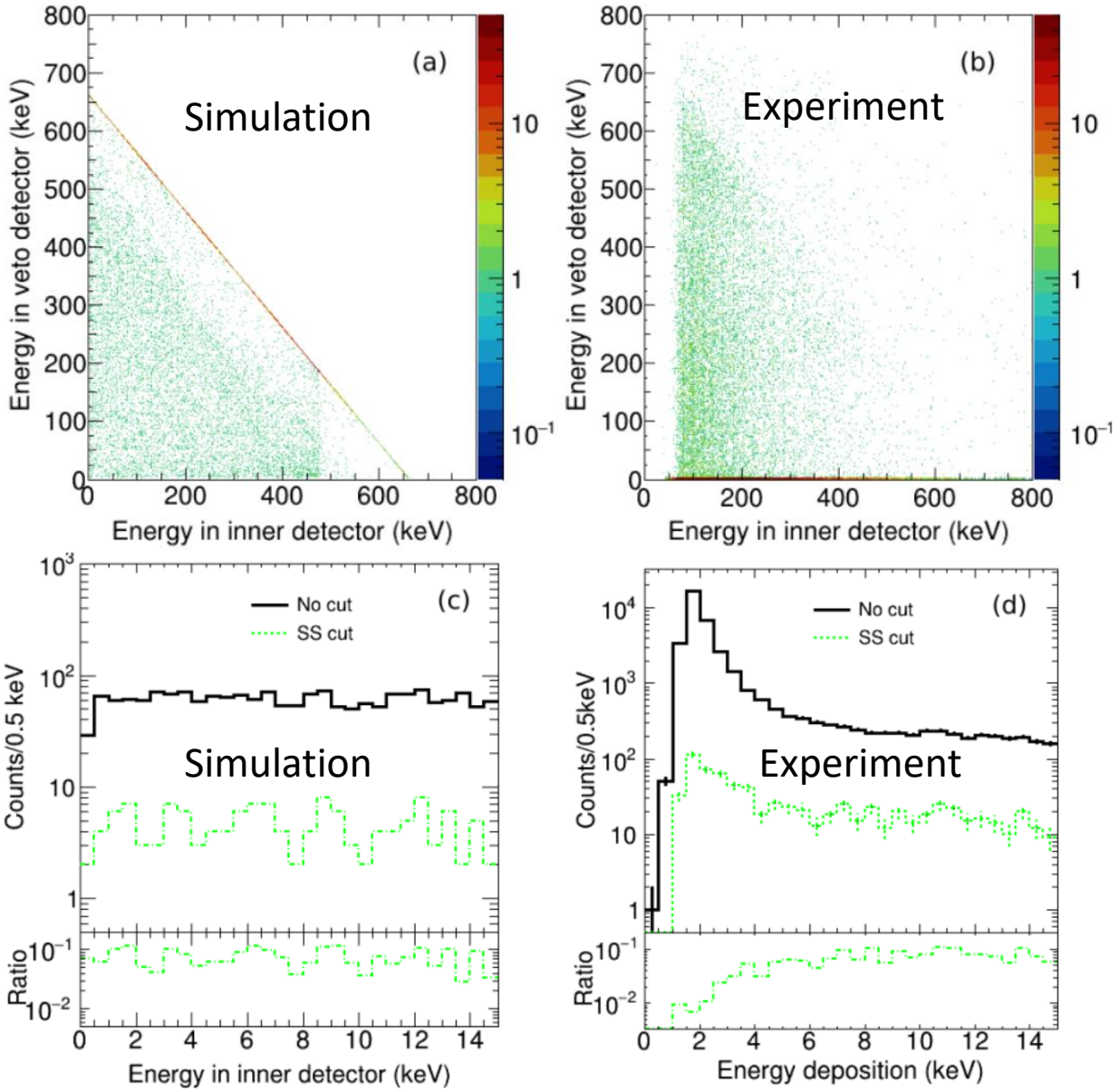


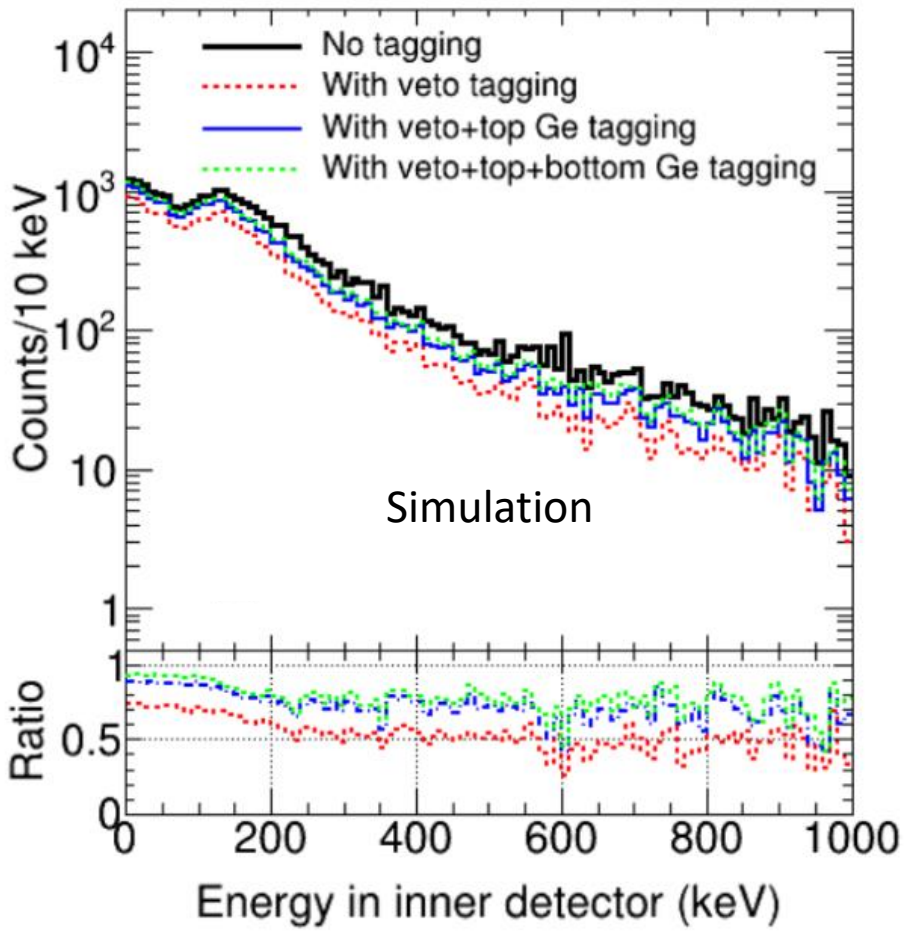




V. Iyer et al, **NIMA,** 1010 (2021) 165489.

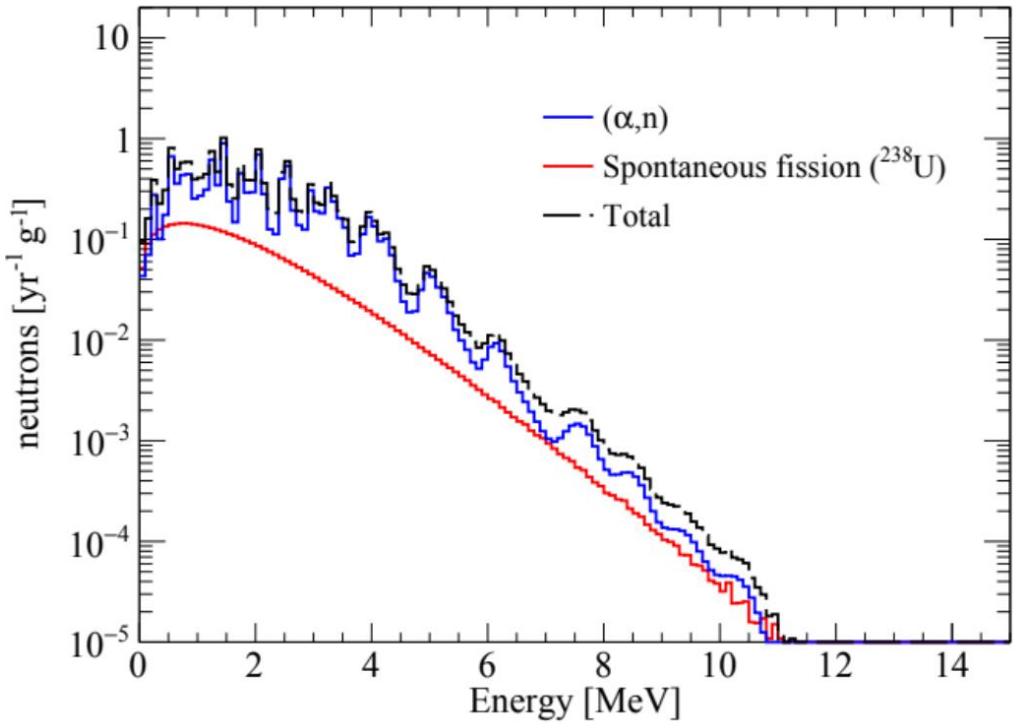
Active veto detector contd.





M. Chaudhuri et al, **NIMA**, 1039 (2022) 167150.

Radiogenic neutron flux



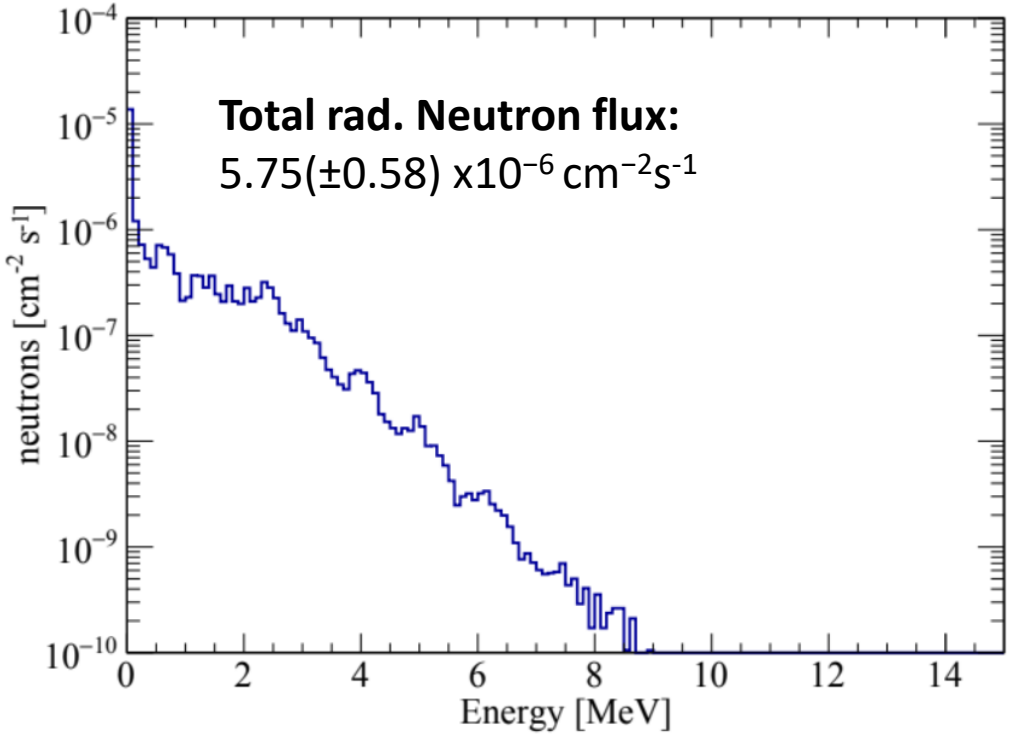
$$W(a,b,E') = a\sqrt{\frac{4a}{\pi b}}\exp\left(-\frac{b}{4a} - aE'\right)\sinh(\sqrt{bE'}),$$

where $a = 1.54245$ MeV^{-1} and $b = 6.81057$ MeV^{-1} are constants (for ^{238}U)

Element	Conc (%)	Element	Conc (%)
U	0.0008	Na	1.2
Th	0.0016	K	2.2
^{40}K	0.00034	Ti	0.34
Si	31.0	P	0.079
O	47.8	Mn	0.023
Al	9.6	Mo	0.002
Fe	3.8	H	0.028
Ca	1.3	S	0.3
Mg	0.83	Others	< 1.5

J. M. Verbeke, C. Hagmann and D. Wright, Tech. Rep. UCRL-AR-228518, LLNL, 2014.
D.-M. Mei, C. Zhang and A. Hime, **NIMA** (2009) 651 – 660.
S. Banik et al 2021 **JINST** 16 P06022

Radiogenic neutron flux



Element	Conc (%)	Element	Conc (%)
U	0.0008	Na	1.2
Th	0.0016	K	2.2
^{40}K	0.00034	Ti	0.34
Si	31.0	P	0.079
O	47.8	Mn	0.023
Al	9.6	Mo	0.002
Fe	3.8	H	0.028
Ca	1.3	S	0.3
Mg	0.83	Others	< 1.5

J. M. Verbeke, C. Hagmann and D. Wright, Tech. Rep. UCRL-AR-228518, LLNL, 2014.
D.-M. Mei, C. Zhang and A. Hime, **NIMA** (2009) 651 – 660.
S. Banik et al 2021 **JINST** 16 P06022