MEASUREMENTS AND SIMULATION OF BACKGROUND RADIATION FOR RARE EVENT SEARCH EXPERIMENTS AT AN UNDERGROUND LABORATORY

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Outline

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Motivation

- Rare event searches, like direct Dark Matter (DM) searches, neutrino-less double beta decay (NDBD), etc., look for extremely small signals ⟶ extremely low events rates.
- Accurate determination and mitigation of background radiation forms a very important aspects for setting up such experiments.
- Reduction of charged cosmic ray background is done by setting up these experiments in underground laboratories.
- The gamma ray and neutron background are artefacts of the radioactivity of the surrounding rock ⟶ irreducible and specific to the site.
- In an attempt to setup a rare event search experiment in India, an underground laboratory, named as Jaduguda Underground Science Laboratory (JUSL) has been set up at a vertical depth of 555 m (~ 1.6 kmwe) in the Jharkhand state of India.
- Here we present the experimental and simulation results of the gamma, cosmic muon and neutron background at this new underground site.

Gamma Background

- Gamma ray background in the underground laboratory generally arises from the radioactive decay of ^{238}U and ^{232}Th, along with the elements in their nuclear decay chain, and ^{40}K present in the surrounding rock.
- The measurement was done using a CsI(Tl) scintillator of 50 mm diameter and 1:1 (height:diameter) aspect ratio.
- The scintillator was manufactured by the Crystal Technology Section of Bhabha Atomic Research Centre (BARC), Mumbai and it was directly optically coupled to a Hamamatsu R1306 photomultiplier (PMT) with built-in ASIC board to provide bias voltage to the PMT and a multichannel analyzer (MCA).
- Calibration was done using various known gamma ray sources.
- Measurements were done both at the surface and at JUSL.

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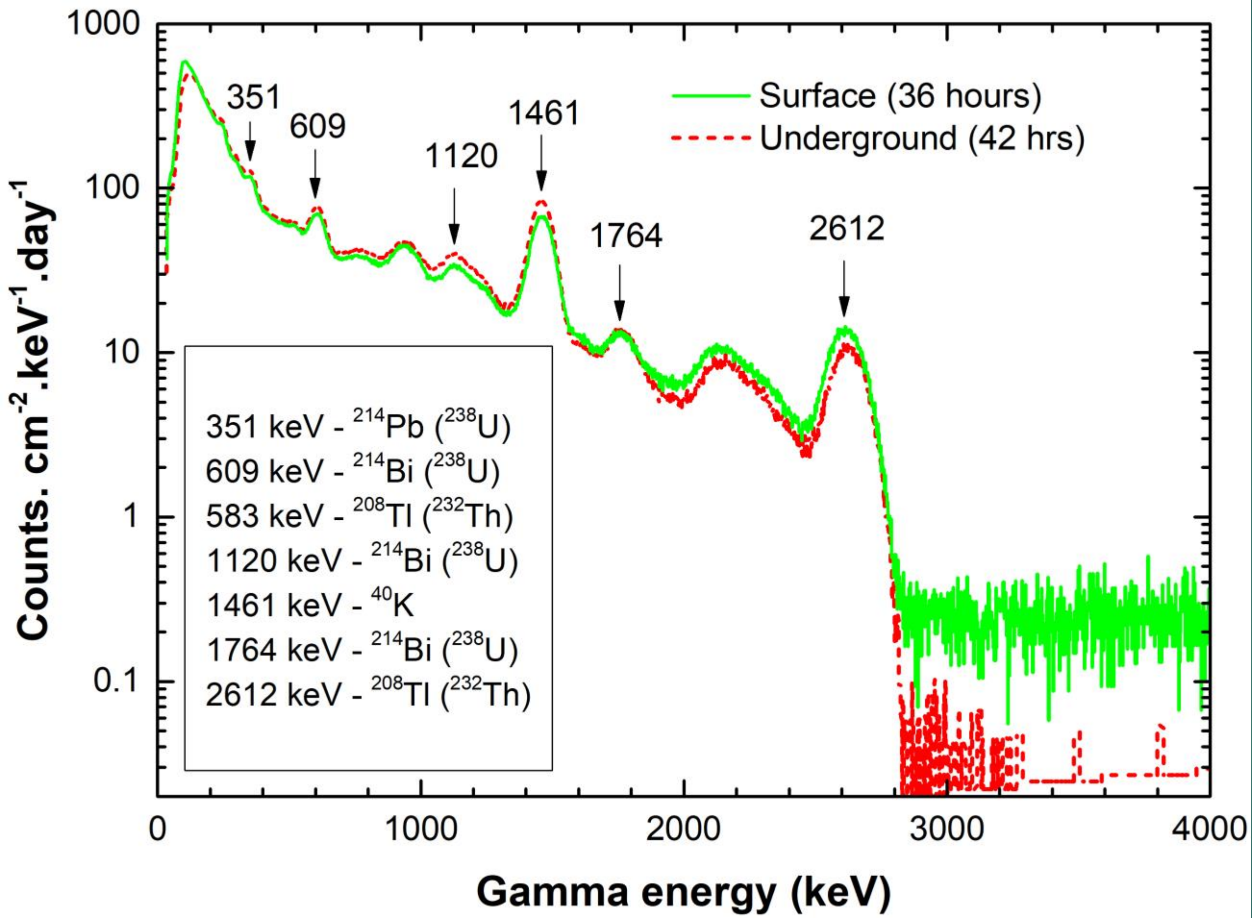

- The gamma ray spectrum as measured by the CsI(Tl) detector in both the surface and underground laboratories.
- Flux at both the surface and underground sites are comparable in the range $E_\gamma \leq 2.6$ MeV.
  - Suppression (~10) of gamma ray flux seen in the region $E_\gamma \geq 3$ MeV at JUSL.

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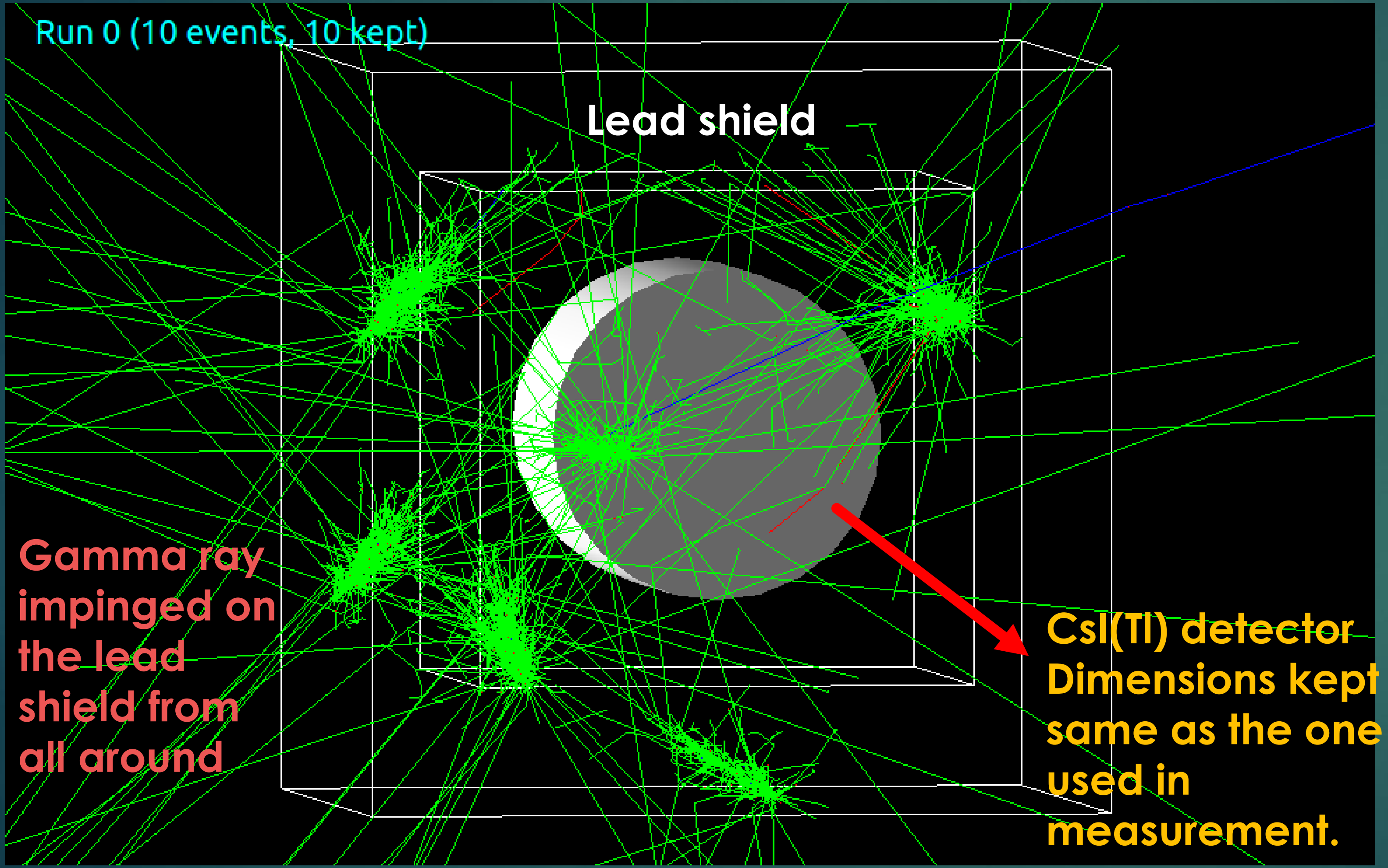

- In order to carry out DM direct detection experiment, the gamma ray background is reduced by passive shielding methods using high *Z* elements like Lead (Pb).
- We investigate the thickness of lead required to shield the gamma ray for different zones of the background spectrum using GEANT4 simulation.

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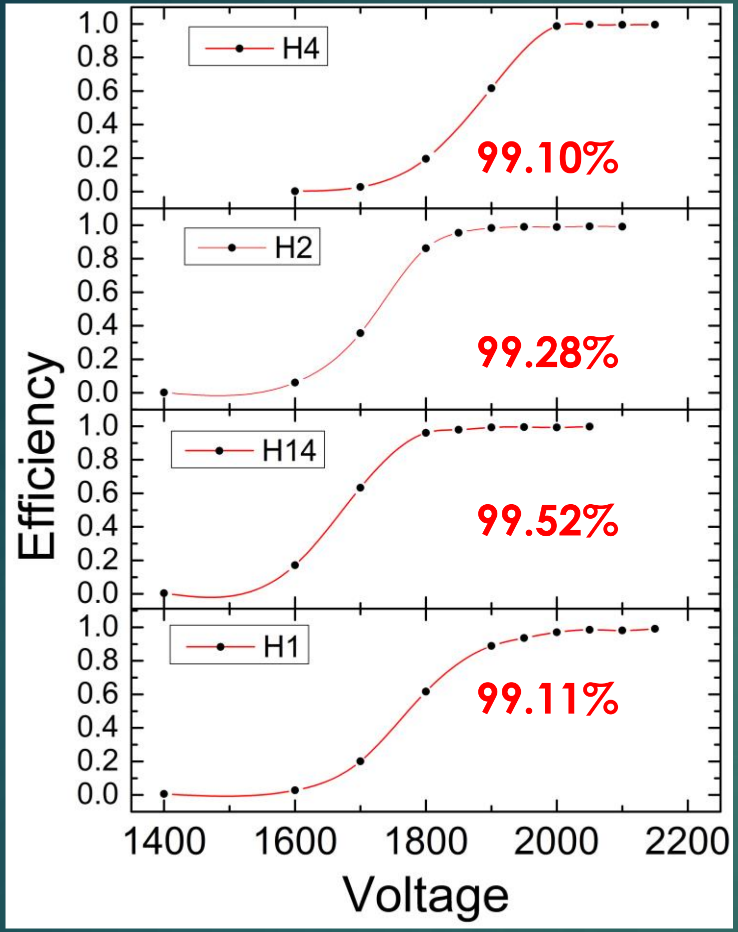
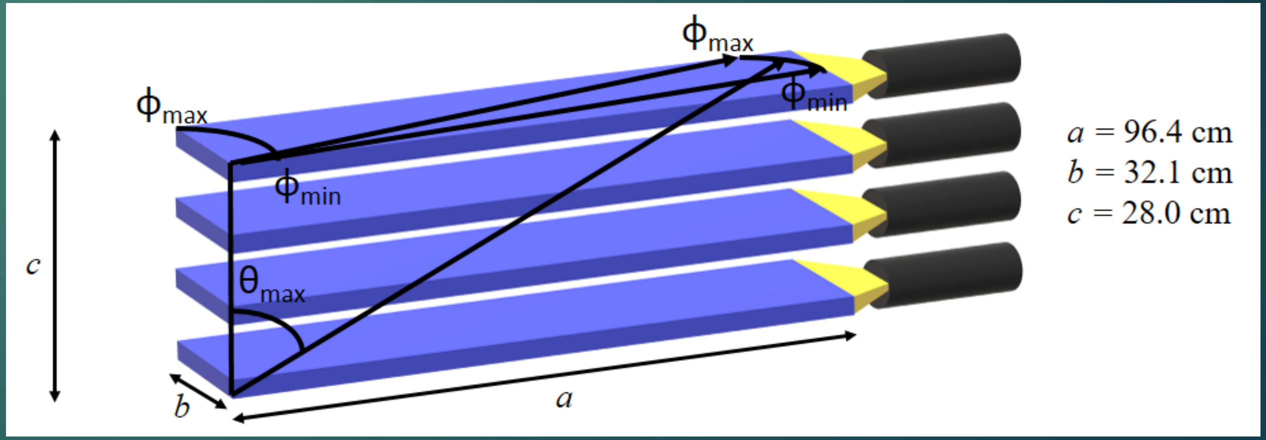
Zone	Range of E_γ (MeV)	Count rate at UG ($cm^{-2}.sec^{-1}$)	Suppression factor at UG (S)	Shielding factor at UG for the different Lead shield thickness (cm)			
				5	10	20	30
1	0 – 0.3	0.9028(32)	0.9202(46)	$\sim 10^{-6}$	$\sim 10^{-7}$	$< 10^{-7}$	$< 10^{-7}$
2	0.31 – 0.5	0.2146(15)	1.0762(96)	0.000614	1.921×10^{-6}	$\sim 10^{-7}$	$< 10^{-7}$
3	0.51 – 1.0	0.2796(18)	1.0753(99)	0.0201	0.00146	1.655×10^{-5}	1.428×10^{-7}
4	1.01 – 1.5	0.2177(16)	1.176(13)	0.0632	0.0101	0.000256	1.066×10^{-5}
5	1.51 – 2.0	0.06858(89)	0.984(18)	0.0970	0.0207	0.000888	5.493×10^{-5}
6	2.01 – 2.5	0.0333(6)	0.804(20)	0.122	0.0292	0.00157	9.753×10^{-5}
7	2.51 – 3.0	0.02095(49)	0.754(23)	0.143	0.0354	0.00251	0.000156
8	3.01 – 4.6	$1.06(35) \times 10^{-4}$	0.0226(76)	0.176	0.0435	0.00274	0.000194

- 30 cm Lead shield successfully shields gamma background of energies even in the range $E_\gamma \geq 3$ MeV.
- Suppression factor ~ 10^4 for $E_\gamma \geq 3$ MeV.

Muon Background:- Experimental Measurements



- Cosmic muons can penetrate large depths of Earth and give rise to considerable background at experimental sites.
- Interaction of muons with the surrounding rock can produce neutrons (cosmogenic) in the energy range of a few MeV to 100s of GeV ⟶ mimic DM like signals in the detector.



- Total effective efficiency is **(97.04±1.17)%**

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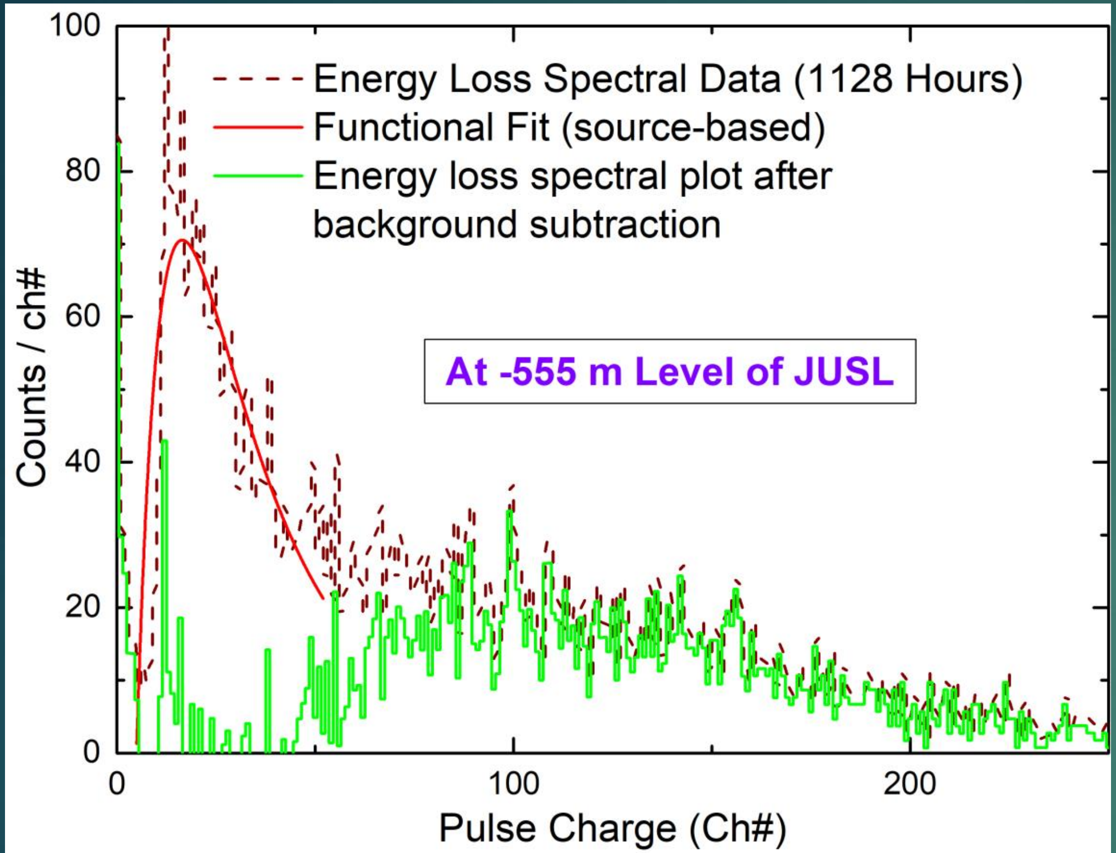
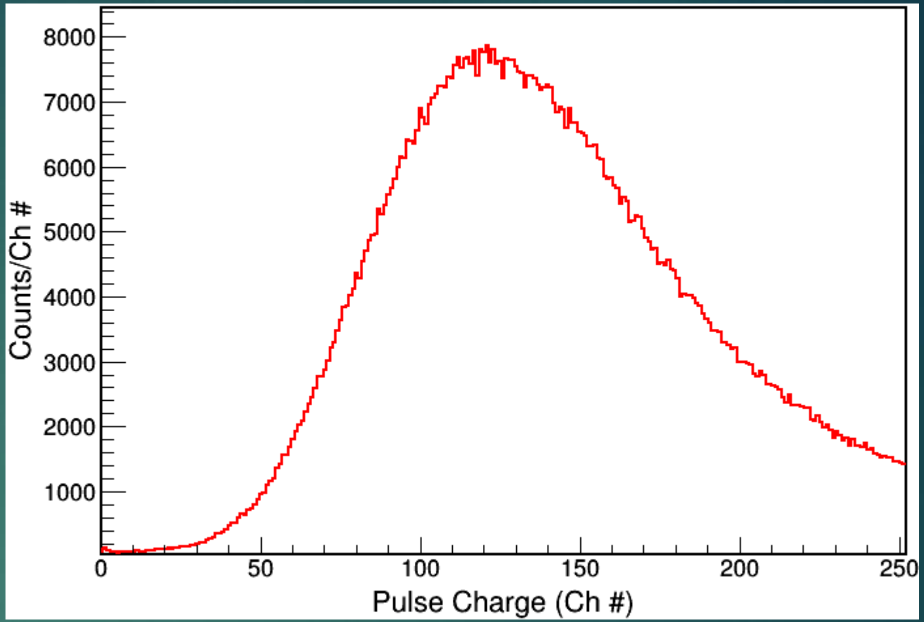
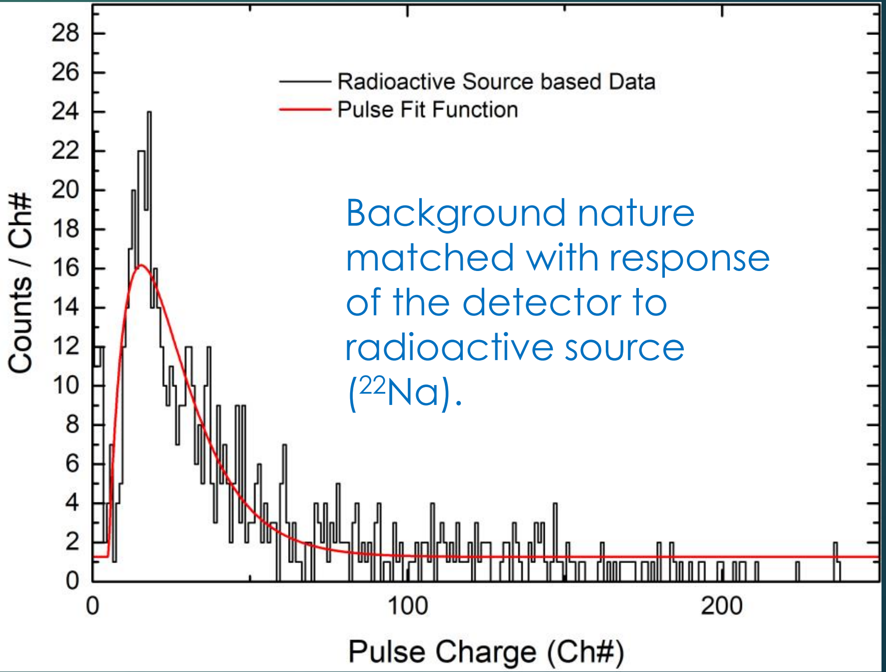




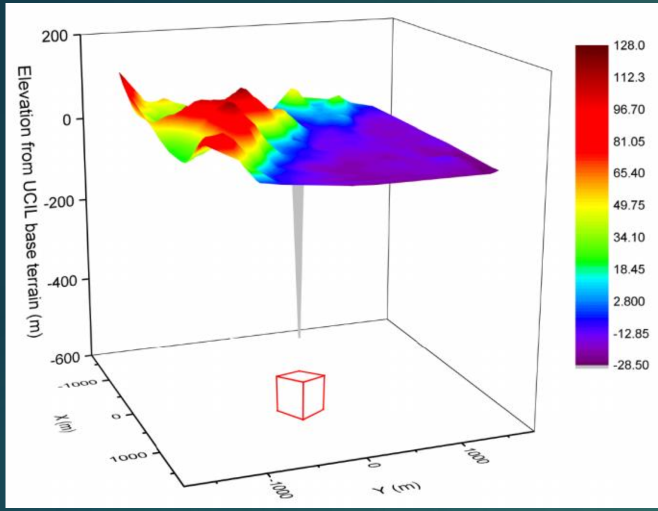
Muon Energy deposition (ΔE) spectrum at the surface

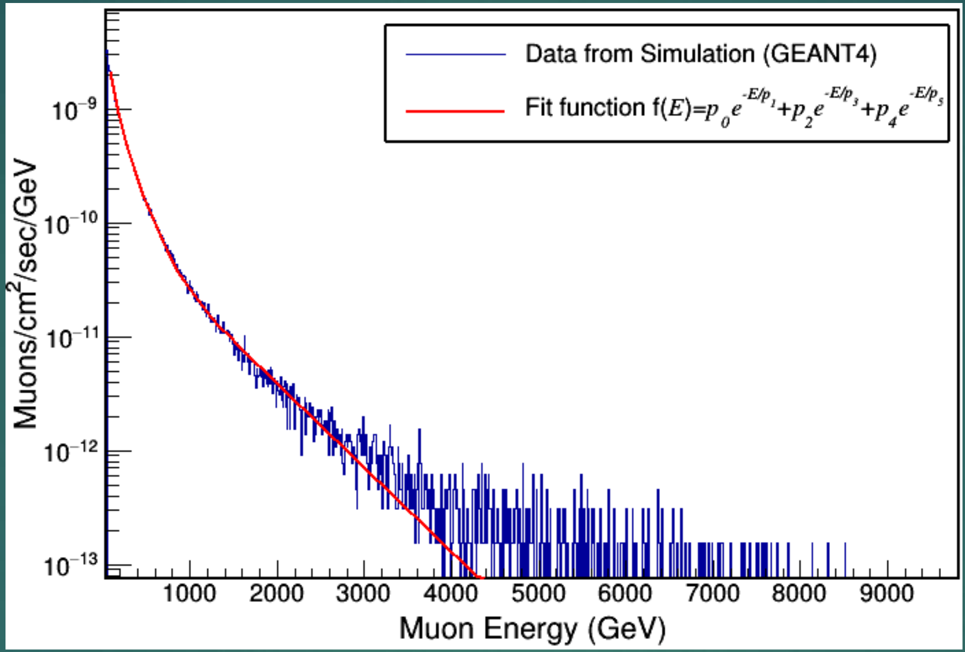


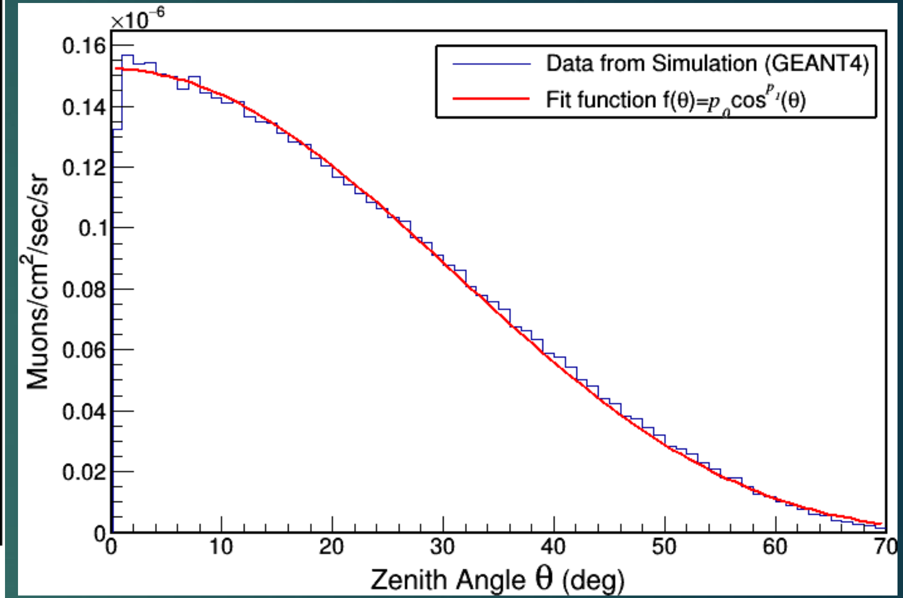
Background nature matched with response of the detector to radioactive source (^{22}Na).

- Energy spectrum of muons at the underground site.
- Total spectrum has a background riding over the landau distribution.
- Muon flux after background subtraction is $(2.257 \pm 0.261 \pm 0.042) \times 10^{-7}$ cm^{-2} sec^{-1}.

Muon Background:- Simulation







- Energy spectrum and zenith angle distribution of muons at the underground site.
- $E_\mu^{\text{avg}} = 186.45 \pm 0.51$ GeV. Exponent of Zenith angle variation $n = 3.756 \pm 0.047 \pm 0.009$.
- Vertical muon intensity $I_0 = (1.558 \pm 0.099 \pm 0.002) \times 10^{-7}$ cm^{-2} sec^{-1} sr^{-1}.

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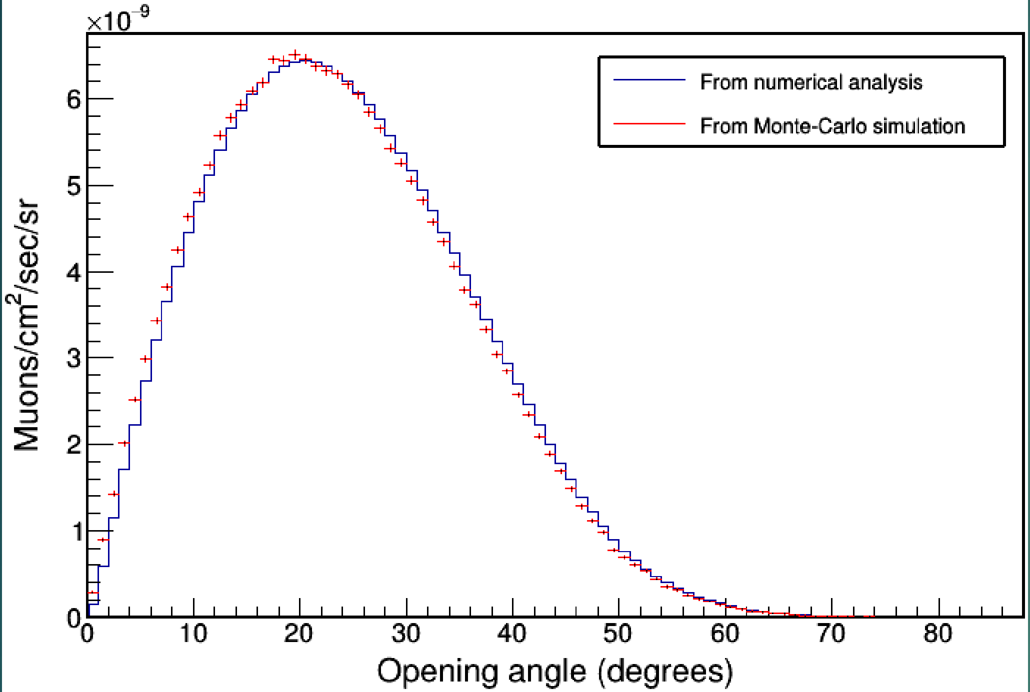

$$\Phi_{\mu}^{\mathrm{detector}} = \frac{4I_0}{a \times b} \times \int_0^{\theta_{\max}} \int_{\phi_{\min}}^{\phi_{\max}} (a - c\tan\theta\cos\phi)(b - c\tan\theta\sin\phi)\cos^{n+1}\theta\sin\theta\, d\theta\, d\phi$$

Resultant muon flux obtained from simulation :-
$(2.051 \pm 0.142 \pm 0.009) \times 10^{-7}$ **cm^{-2} sec^{-1}**.

- The detector (muon telescope) is not symmetrical and does not have full solid angle coverage ⟶ Aperture like effect.
- Estimate of muon flux observed by the telescope done by numerical and Monte-Carlo (MC) simulation.
- MC simulation done by generating muons on the top surface of the detector stack and recording the number of successful 4-fold coincidences for each zenith angle bin.

Neutron Background:- Experimental Determination

- Neutrons are generated from the (α, n) reactions from decay of ^{238}U, ^{232}Th and their decay remnants and their spontaneous fission in the surrounding rock.
- The experimental measurement was done using a pressurized ^{4}He detector manufactured by Arktis Radiation Detectors, Switzerland ⟶ 600 mm long cylinder with an inner diameter of 65 mm with ^{4}He kept at 150-180 bar.[1]
- Fast neutrons give rise to nuclear recoils and these recoils deposit energy into the medium giving rise to scintillation in VUV region (λ~80 nm).[2]
- Lithium coating along the inner walls of the detector imparts thermal neutron sensitivity.
- Low number of electrons in ^{4}He decreases sensitivity to gamma rays.[3]
- *n*-γ and thermal-fast neutron discrimination done by pulse shape discrimination (PSD) based on a time over threshold (ToT) analysis. Electronics board and discrimination algorithm already incorporated into the system.

[1] R. Chandra, et. al., Jour. Instrum. 7 (2012) C03035.
[2] R. Kelley, et. al., AIP Advances 5 (2015) 037144.
[3] R. Kelley, et. al., Nucl. Instrum. Meth. A 830 (2016) 44-52.

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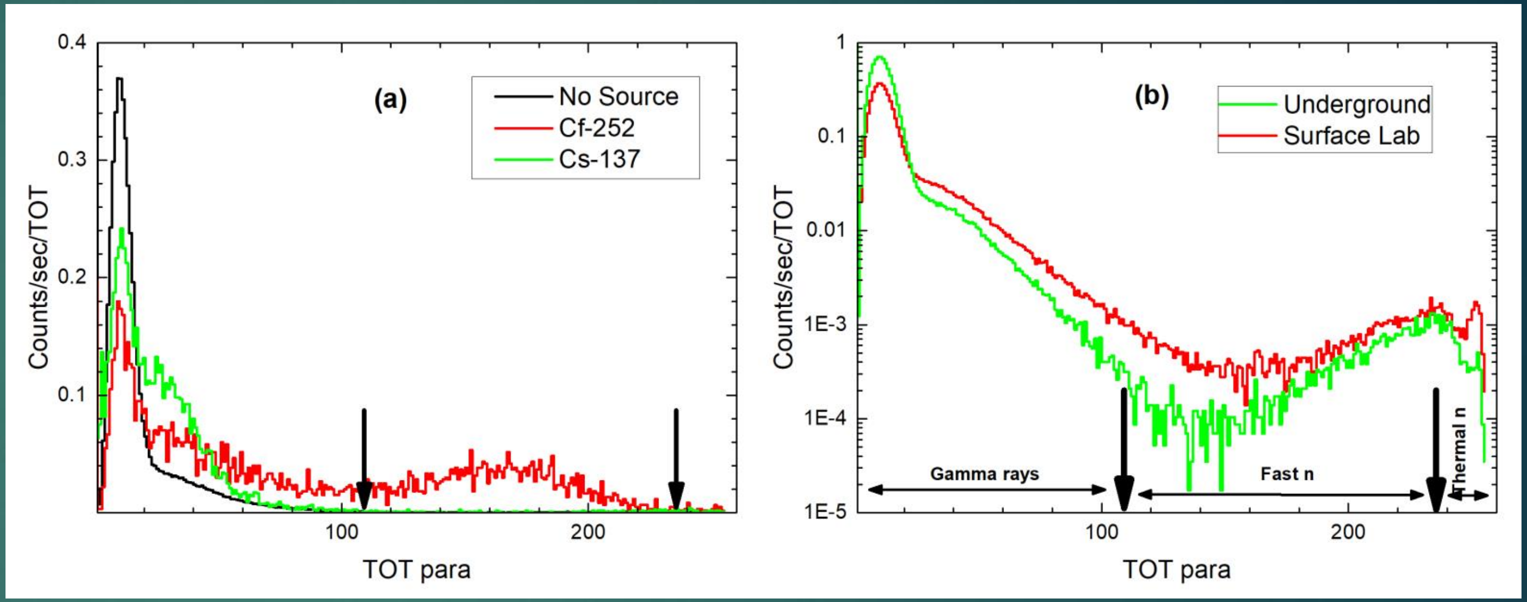
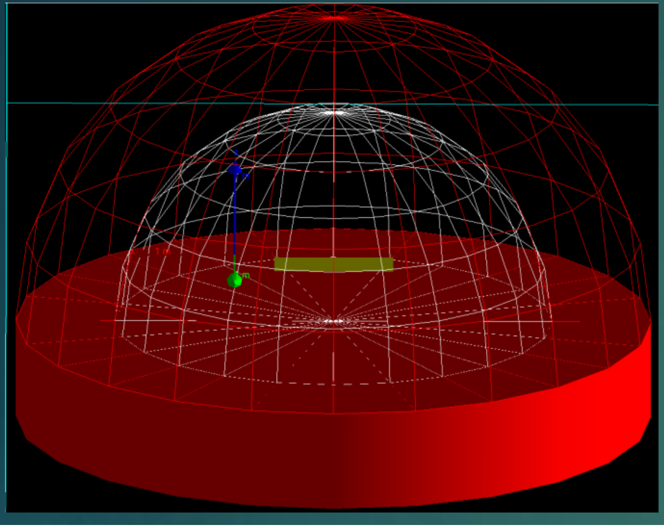
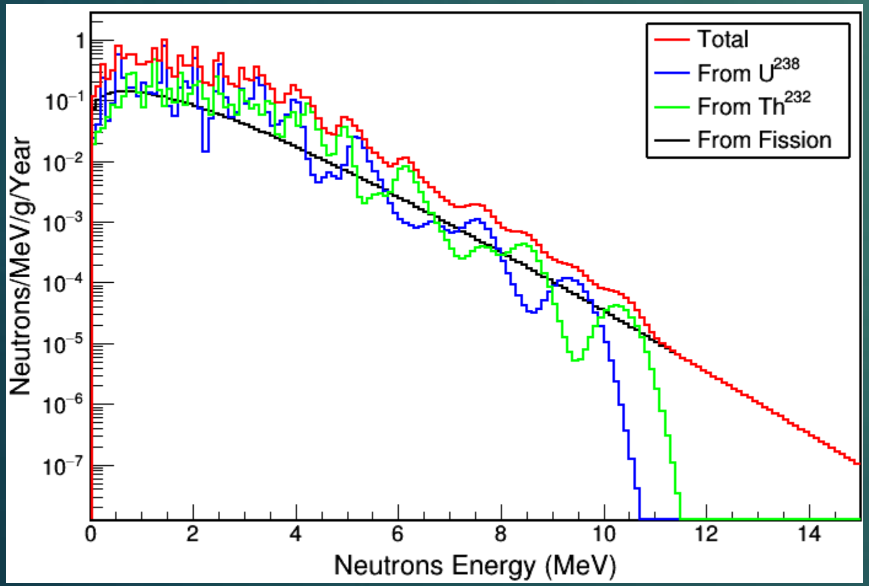


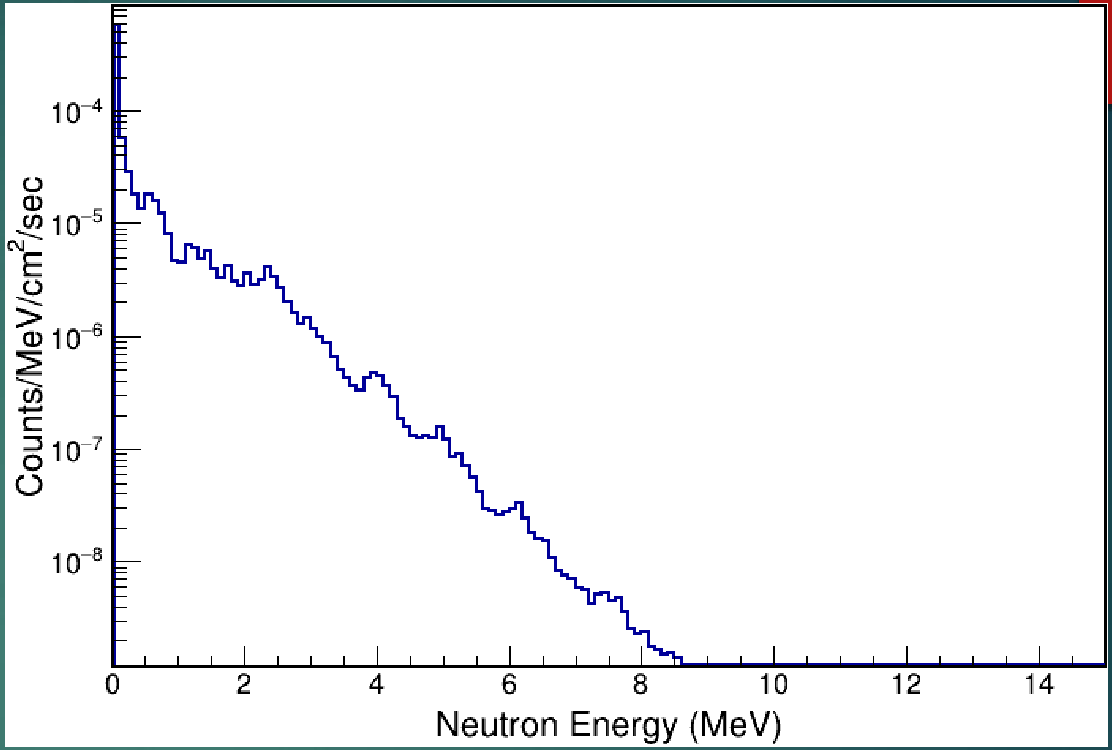
- Flux of neutrons in the energy range $E_n \leq 10$ MeV was found to be $\mathbf{(1.63 \pm 0.03) \times 10^{-4}}$ **cm^{-2} sec^{-1}**.

Neutron Background:- Radiogenic

Neutron Simulation







- The underground laboratory is a room that of dimensions (4.5 × 4.5 ×

Neutron Background:- Cosmogenic

Neutron Simulation

- These neutrons are produced due to the interaction of muons with the surrounding rock ⟶ dependence on penetration depth of muons.
- Typically in the energy range of a few MeV to few 100s of GeV. Therefore they can mimic the DM signal.
- Muons following the energy and zenith angle distribution obtained from simulation are generated on outer surface of the hemispherical rock shell of varying thicknesses.
- Neutrons produced will be scattered in all directions and some will reach the detector geometry kept in the middle ⟶ Backscattering also accounted for.

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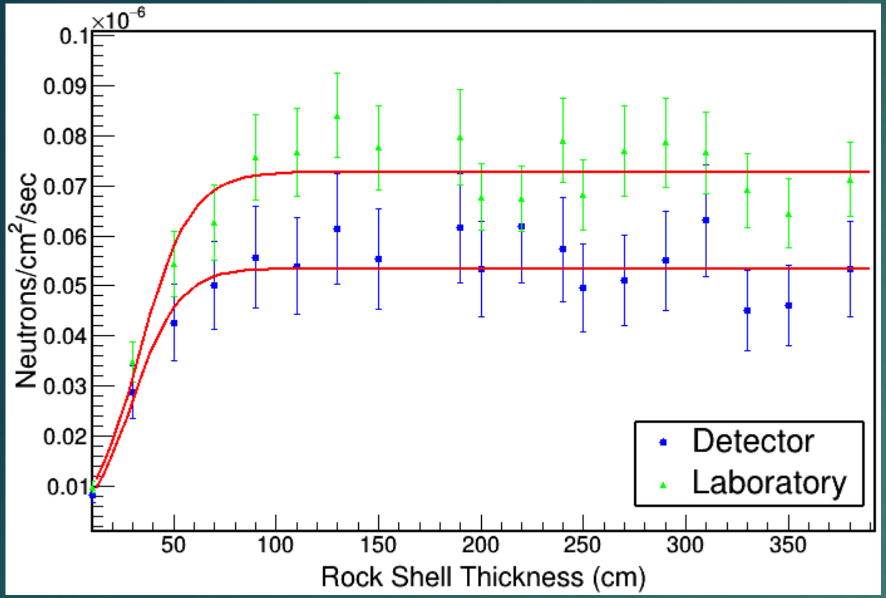
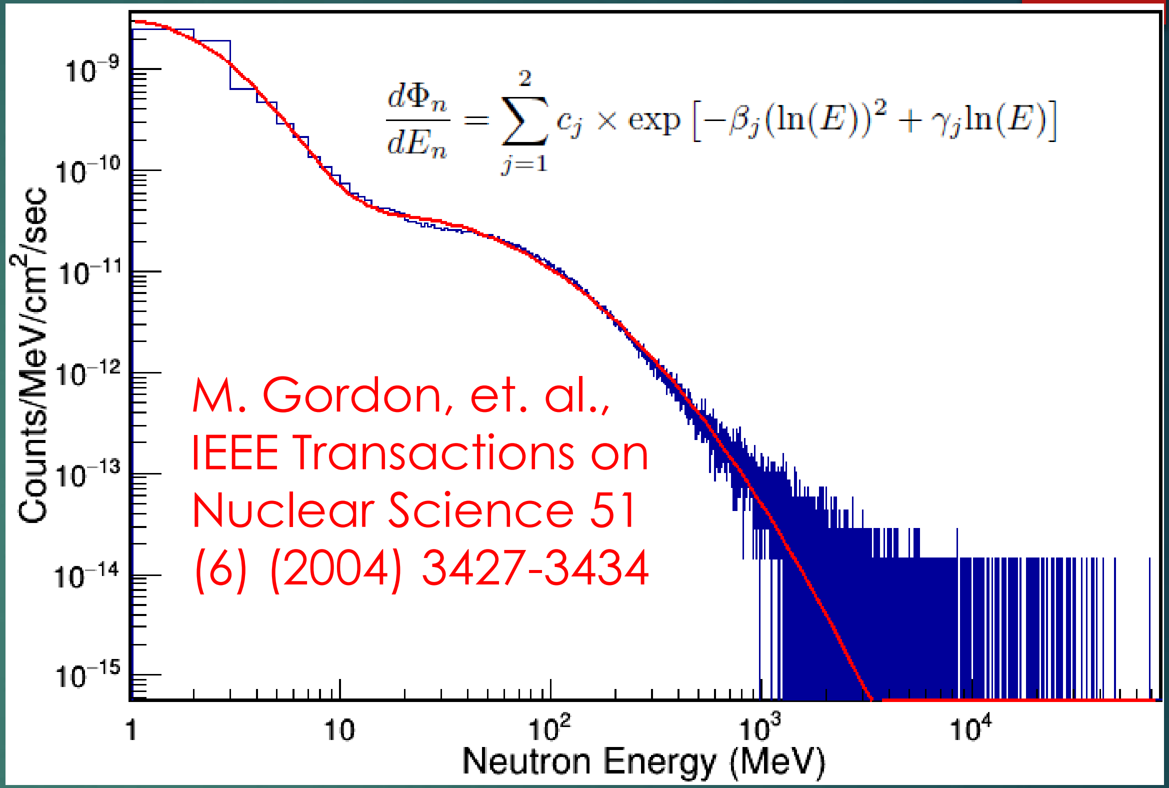
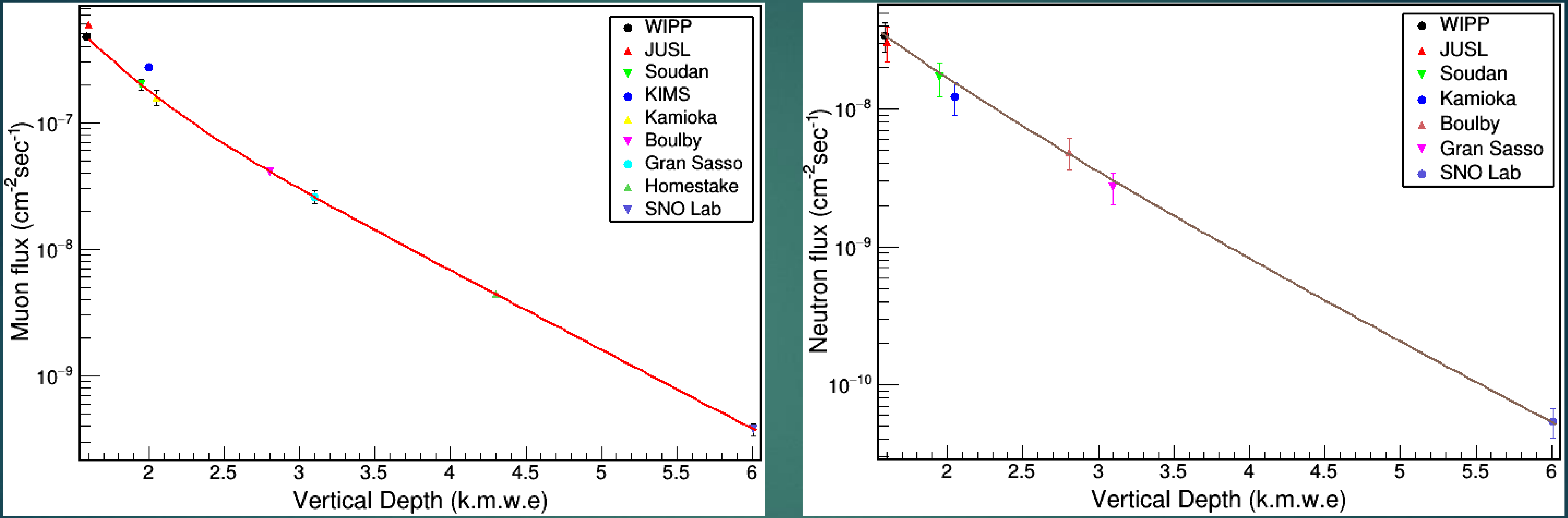


j	c_j	β_j	γ_j
1	$(2.964 \pm 0.038) \times 10^{-9}$	(0.785 ± 0.021)	(-0.047 ± 0.036)
2	$(9.418 \pm 2.099) \times 10^{-13}$	(0.413 ± 0.011)	(2.425 ± 0.099)



- 2 m of rock shell thickness found to be the optimum choice again. Floor thickness 100 cm not found to cause any difference in the cosmogenic neutron flux.
- Flux of cosmogenic neutrons at the detector was found to be $(\mathbf{5.661} \pm \mathbf{0.103}) \times \mathbf{10^{-8}}$ **cm^{-2} sec^{-1}**.

Comparison with other labs



- Global Fit functions :- D. Mei, A. Hime, Phys. Rev. D 73 (2006) 053004.
- Simulation results from both the cosmic ray muon flux and cosmogenic neutron fluxes match well with data from other underground sites.

Conclusion

- Various background measurements were carried out at the new underground laboratory set up for rare events search in India.
- Gamma ray background was measured, future plans of passive shielding was investigated and optimized using GEANT4 simulation.
- Cosmic muon flux was measured using a 4-fold plastic scintillator stack. Experimental results were verified using GEANT4 simulation and good agreement was obtained between them.
- Neutron background measurements were done using a pressurized ^{4}He detector.
- Simulation of radiogenic and cosmogenic neutrons were carried out using GEANT4 package. In both cases, backscattered neutrons were found to have significant contribution to the flux inside the laboratory volume.
- Cosmic muon and cosmogenic neutron fluxes, obtained from experiment and simulation, were compared those of other underground laboratories located at different depths and were found to be in agreement with the global fits.

Thank You