Investigation of Cosmic-Ray Muon Flux Variation with Overburden and Study of Nuclear Physics Inputs to Astrophysics

T. Ghosh[1,2,*]
Guide: M. K. Sharan[1,2]; Co-Guide: B. K. Agrawal[1,2]
[1] *Saha Institute of Nuclear Physics, Kolkata-700064, India* and
[2] *Homi Bhabha National Institute, Anushakti Nagar, Mumbai-400094, India*

In low count-rate experiments, cosmic muons represent the primary source of background interference for the detectors. Additionally, natural radioactivity, primarily consisting of gamma-rays and neutrons emitted from the surrounding rocks, contributes significantly to the background noise. These factors have a notable impact on the sensitivity of underground experiments. Therefore, the success of these experiments hinges on the effective deployment of compact, cost-efficient veto systems that can discern muons while mitigating gamma-ray and neutron background interference. Our study explores the challenges associated with background interference in low count-rate experiments. To address these challenges, measurements of muon flux were conducted at the UCIL underground laboratory in Jaduguda, India [1]. This investigation utilized a setup consisting of plastic scintillators, Silicon Photomultiplier (SiPM) detectors, and photomultiplier tubes (PMT) providing valuable insights into the efficiency and accuracy of the measurement setup, and has laid the foundation for future investigations and experiments in the field of low-background research.

To comprehensively understand nuclear astrophysical network calculations, especially in the context of processes like the r-process, it is crucial to consider astrophysical reaction rates at a fixed temperature which requires Maxwellian-averaged cross-sections across a wide range of energies for radiative neutron capture processes. Determining these cross-sections and reaction rates within a statistical framework primarily relies on three key components: (i) Neutron-Nucleus Optical Model Potential (OMP), (ii) Gamma-ray Strength Function (γSF), and (iii) Nuclear Level Density (NLD). While uncertainties in the Neutron-Nucleus Optical Model Potential (OMP) are relatively small, the Gamma-ray Strength Function (γSF) and Nuclear Level Density (NLD) have a more significant impact on shaping the calculated neutron capture rates. NLD provides insights into the total number of available states within a nucleus at specific excitation energies. Various methods, ranging from simple phenomenological models based on non-interacting degenerate Fermi gas principles to complex microscopic mean-field models, have been employed to calculate NLDs [2–6]. These models incorporate collective effects through rotational and vibrational enhancement factors. To ensure accuracy, these Nuclear Level Density (NLD) models are normalized against experimental data at low energies and neutron resonances.

Within the framework of the shell model, which inherently considers collective excitations through residual interactions, more realistic Nuclear Level Densities (NLDs) can be generated. Several approaches have been explored within this shell model framework for calculating NLDs. One such approach is the shell model Monte Carlo method [7], which employs auxiliary fields to compute the thermal trace for energy and subsequently employs inverse Laplace transforms to derive the NLDs. Another effective technique for constructing NLDs is based on the Spectral Distribution Method (SDM), applied to the many-body shell model Hamiltonian in the complete configuration space. This method avoids the need for diagonal-

*Electronic address: ghoshtanmoy536@gmail.com

izing large-dimensional matrices [8, 9]. The SDM has been extended to generate NLDs for many-body shell model Hamiltonians by calculating the first and second moments of the Hamiltonian for various configurations at fixed spin and parity. The resulting NLDs exhibit reasonable agreement with those obtained through the exact diagonalization of the shell model Hamiltonian in the complete configurational space [11].

In our study [9], We have obtained realistic NLDs using the Spectral Distribution Method applied to the many-body shell model Hamiltonian within the pf-model space for several pf-shell nuclei. To incorporate NLDs of opposite parities within the pf-model space, we employed a suitable parity equilibration scheme. The resulting NLDs and neutron resonance spacings in the s-wave channel show reasonable agreement with available experimental data. Employing these NLDs, we computed reaction cross-sections and astrophysical reaction rates for neutron capture processes involving $^{50}V(n,\gamma)^{51}V$, $^{54}Fe(n,\gamma)^{55}Fe$, and $^{58}Ni(n,\gamma)^{59}Ni$. Our calculated reaction cross-sections align well with experimental data, particularly for incident neutron energies relevant to astrophysical conditions [9]. In another study [10], we have computed D_0 values in the sd-pf model space for ^{24}Na, $^{25,26,27}Mg$ nuclei, and observed a noteworthy enhancement in agreement with experimental data when compared to earlier calculations [12] conducted solely within the sd model space. This improvement can be attributed to the existence of cross-shell excitations. We have also investigated the sensitivity of microscopic effects, including collective enhancement, pairing, and shell corrections, on total nuclear level densities in and around the β-stable nucleus Z_0 for a fixed mass number within the mass range $A = 40 - 180$, using data from two different widely-used microscopic mass models [13].

The density-dependent nature of nuclear symmetry energy plays a crucial role in determining various properties, from finite nuclei to neutron stars with a mass roughly 1.4 times that of our sun [14]. By analyzing observables such as neutron skin thickness, isovector giant dipole resonance energies, and different nuclear reaction cross-sections in asymmetric nuclei, we gain insights into the slope of symmetry energy (L_0) at saturation density. Recent measurements from the PREX-II and CREX campaigns, focusing on neutron skin thickness in ^{208}Pb and ^{48}Ca nuclei, have produced conflicting values for L_0, with little overlap in a 90% confidence interval [15]. In our recent study, we have explored the impact of symmetry energy on sub-barrier fusion cross-sections and astrophysical S-factors for asymmetric nuclei [16]. Our observation implies that accurate measurements of sub-barrier fusion cross-sections might offer an alternative approach for estimating neutron skin thickness or the slope parameter of the symmetry energy.

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References

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