Progress on test of the generalized Brink-Axel hypothesis in ^{63}Ni.

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Abstract. The validity of the generalized Brink-Axel hypothesis was tested for the first time on ^{63}Ni. This hypothesis is assumed in various experimental methods and nuclear reactions models. It's experimental test across the nuclear chart is crucial. The result show the γ-ray strength function of ^{63}Ni does not depend on the initial excitation energy; supporting the validity of the generalized Brink-Axel hypothesis. However, it still remains important to test the dependence of the γ-ray strength function of ^{63}Ni on its final excitation energy as well. This will be done in future to draw the final conclusion about the generalized Brink-Axel hypothesis on ^{63}Ni.

1 Introduction

As the excitation energy increases to the quasi-continuum region, the level spacing, D, significantly decreases and the width , Γ, of the quantum states becomes wider. The γ-ray strength function ($f(E_\gamma)$) and nuclear level density ($\rho(E_x)$) are fundamental quantities that best describe the statistical γ-decay of nuclei excited up to the quasi-continuum region. The nuclear level density is defined as the number of nuclear states per unit excitation energy, and it can be estimated with a variety of theoretical models including the constant temperature model [1, 2]:

$$\rho(E_x) = \frac{1}{T} e^{(Ex - E_0)/T} \tag{1}$$

where T is the nuclear temperature, and E_0 is a energy shift constant. The γ-ray strength function is defined as the probability for the nucleus to absorb or emit a γ-ray. It is related to the nuclear level density, average radiative width of the states and γ-ray energy through [3]:

$$f_{J^\pi}(E_\gamma) = \frac{\Gamma_{J^\pi}(E_i, E_\gamma)\rho_{j^\pi}(E_i)}{E_\gamma^{2\lambda+1}} \tag{2}$$

where $\Gamma_{J^\pi}(E_x,E_\gamma)$ is the average radiative width, ρ_{J^π} is the nuclear level density, E_γ is the γ-ray energy, λ is the multipolarity of the γ-ray, and E_i is the initial excitation energy. The γ-ray strength function between the initial excitation and final excitation energy states is often assumed, based on the generalized Brink-Axel (gBA) hypothesis [4–6], to be independent of the properties of the states; it only depends on the γ-ray energy. This hypothesis is a fundamental assumption in various experimental methods, such as the Oslo Method which has gained global recognition and used in many studies in the literature [7–10]. It is also used as the fundamental assumption in large network nucleosynthesis calculations [11]. Therefore, experimental test of the generalized Brink-Axel hypothesis is important for the reliability of experimental γ-ray strength function data measured using the Oslo Method and elemental abundances calculated under the assumption that the gBA is true. However, the gBA has not been tested within ^{63}Ni mass region. In fact, some theoretical and experimental studies have been found to support the Brink-Axel hypothesis [12–22], while others show results disputing it [23–25]. This work presents the first test of the generalized Brink-Axel hypothesis in ^{63}Ni. In particular, we tested the variation of the γ-ray strength function on the initial excitation energies.

2 Methods

The nucleus ^{63}Ni was populated through the ^{64}Ni(p,d)$\,^{63}$Ni* reaction. The ^{64}Ni target, with a thickness of 4.56 mg/cm^2, was bombarded with a 27.4 MeV proton beam. The beam was delivered by the Separated Sector Cyclotron (SSC) at iThemba LABS, which is the only one if its kind in the Southern hemisphere, and has been utilized in numerous studies [26–30]. Particle–γ coincidences were measured using the AFRODITE array [31, 32]. The AFRODITE array was equipped with eight high-purity germanium detectors and two large-volume LaBr$_3$(Ce) detectors for the detection of γ-rays. Charged particles were detected using a silicon detectors with a ΔE–E configuration, placed downstream of the target. The front detector (ΔE) had a thickness of 309 μm, and the back detector (E) had a thickness of 1041 μm. An aluminium foil of 10 μm thickness was placed in front of the silicon detector for δ-electron shielding.

Particle–γ coincidences were selected by placing a time gate on the particle–γ time-difference spectrum between the detection of a γ-ray and a particle. The LaBr$_3$(Ce) data were used in this analysis due to their high γ-ray detection efficiency. The corresponding (p,d) reaction channel for ^{63}Ni was selected using a graphical cut on the particle identification (PID) matrix. The deuteron energy deposited in the silicon detector was converted into the excitation energy of ^{63}Ni using two-body reaction kinematics, and a 2D matrix (excitation energy vs γ-ray energy) was constructed. Using the LaBr$_3$(Ce) response function simulated for the AFRODITE array with GEANT4 [33], the γ spectra of ^{63}Ni were unfolded with the unfolding method developed by Ref. [34]. The unfolded γ spectra were used to obtain the first-generation matrix shown in figure 1 containing primary γ-rays obtained with the first generation method discussed in Ref. [35]

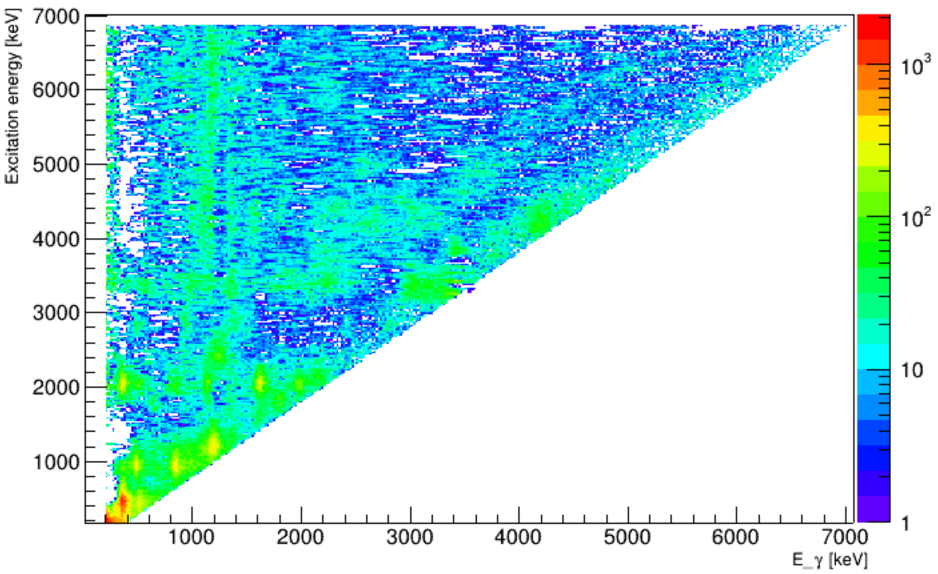

Figure 1: First generation matrix containing primary γ-rays for ^{63}Ni.

The gBA hypothesis in ^{63}Ni was tested using the method of Ref. [12]. The first-generation matrix in figure 1 contains primary-γ spectra, $g(E_i, E_\gamma)$, at each initial excitation energies (E_i). The $g(E_i, E_\gamma)$ are normalized to

$P(E_\gamma, Ei)$ through:

$$P(E_\gamma, E_i) = \frac{g(Ei, E_\gamma)}{\Sigma g(E_i, E_\gamma)} \tag{3}$$

$P(E_\gamma, E_i)$ is the probability matrix of the nucleus to emit a γ-ray energy (E_γ) from E_i. From the nuclear level density (ρ), extracted from the Oslo method [31], the transmission coefficient (T) as function of excitation energy can be derived as follows:

$$T(E_i, E_\gamma) = N(E_i)\frac{P(E_\gamma, E_i)}{\rho(E_f)} \tag{4}$$

where $N(E_i)$ is the normalization factor to correct for scaling given by [12]:

$$N(E_i) = \frac{\int_0^{E_i} P(E_\gamma, E_i)\, dE_\gamma}{\int_0^{E_i} T(E_\gamma)\,\rho(E_f)\, dE_\gamma} \tag{5}$$

and E_f is the final excitation energy given by:

$$E_f = E_i - E_\gamma \tag{6}$$

The functional form of the γ-ray strength function ($f(E_\gamma)$), at different initial energies is obtained by converting equation 4 to the following equation:

$$f(E_\gamma) = \frac{T(E_\gamma)}{2\pi E_\gamma^3} \tag{7}$$

3 Results and discussion

Figure 2 shows γ-ray strength function for ^{63}Ni (black data) at different initial excitation energies, compared with the γ-ray strength function (blue line) of ^{63}Ni extracted from the entire 3200 keV to 6700 keV excitation energy region using the standard Oslo Method [31]. The results show that the γ-ray strength function remain the same in both magnitude and shape at all different initial excitation energies, within the experimental error bars. Therefore, the data from ^{63}Ni supports the Brink-Axel hypothesis in the quasi-continuum region. These observations are consistent with previous studies that tested the validity of the gBA [12, 36, 37]. The gBA is fundamental in the Oslo method analysis [7–10], therefore, these results support the reliability of the Oslo method analysis.

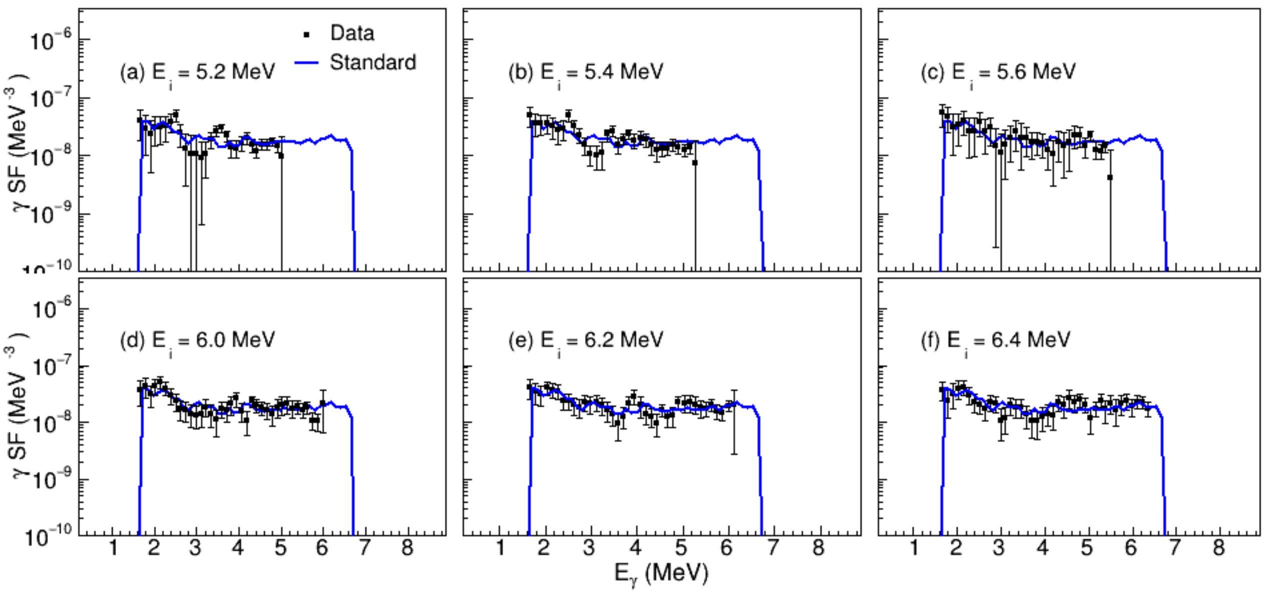

Figure 2: γ-ray strength functions for ^{63}Ni compared and extracted from six different excitation energies.

4 Conclusion

The γ-ray strength function for ^{63}Ni was extracted at six different initial excitation energies. The results show no significant variations except with minor statistical fluctuations. These fluctuations, due to fewer statistics in the extracted region, do not prove against the validity of the generalized Brink-Axel hypothesis. Therefore, the initial excitation energy data in ^{63}Ni, support and validate the generalized Brink-Axel hypothesis. In future, we shall conclude the analysis by testing the variation of the γ-ray strength function of ^{63}Ni on the final excitation energies.

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