Neutron and Proton Hole States in N=Z=28 Closed Shell

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(For the HiRA collaborations)
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The exact shell structure of the unstable nucleus ^{56}Ni (N=Z=28) has attracted a lot of interest recently. According to independent particle model ^{56}Ni is the first unstable doubly magic nucleus. However, recent analysis of neutron spectroscopic factors suggests [1] significant shell breaking of N=28 in the core. ^{56}Ni is also a "waiting point" nucleus in the astrophysical rapid proton (rp) capture process. Experimental investigation to extract the precise nature of single particle states of the nucleus ^{56}Ni is crucial to calibrate theoretical understanding of the shell models of the nucleus and predict the properties of the many currently unmeasured exotic nuclei which are involved in the astrophysical rp-process.

To test if ^{56}Ni is really a good core, the most direct way is to measure the single particle nature of the neutrons and protons in the f7/2 orbits. Transfer reaction is a powerful probe to extract the single-particle structure in a nucleus. The degree of single-particle nature is governed by the nucleon-nucleon (N-N) correlations which modify the nuclear wave functions from the independent particle mean-field model. These correlations manifest themselves indirectly through the reduction in the occupancy of a single-particle state which is quantified by spectroscopic factor (SF). The experimental SF value for transfer reaction is defined as the measured transfer cross section divided by the cross section calculated with a reaction model. The measurements of the neutron and proton SF for ^{56}Ni will verify if it is really a doubly-magic nucleus.

^{56}Ni(p,d)^{55}Ni and ^{56}Ni(d,^{3}He)^{55}Co transfer reactions were carried out to extract neutron and proton SF respectively for ^{56}Ni nucleus at 80 MeV/u, in inverse kinematics. The secondary beam of ^{56}Ni was produced from the fragmentation of a primary beam of ^{58}Ni at 140 MeV/u, on a Be production target, at the entrance to the A1900 separator at the National Superconducting Cyclotron Laboratory at Michigan State University.

In an earlier experiment [2], ^{56}Ni(p,d)^{55}Ni reaction in inverse kinematics at 37 MeV/u was studied and the spectroscopic factors obtained show agreement with shell model calculations The new experiment will probe the energy dependence of SF obtained in transfer reactions.

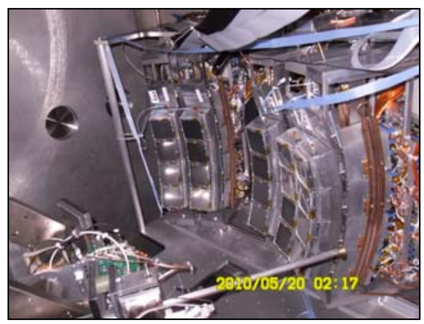

Figure 1: HiRA set up with 20 telescopes inside the S800 scattering chamber

Deuterons and ^{3}He were detected in the High-Resolution Array (HiRA) in coincidence with the recoil residues detected in the S800 spectrograph focal plane. An array of 20 HiRA telescopes (shown in Figure 1) was placed at 50 cm from the target where they subtended polar angles of $6° \leq \theta_{lab} \leq 45°$ covering nearly the full solid angle in the center-of-mass frame because of kinematic focusing. Each telescope contained 65μm thick ΔE and 1500 μm thick E silicon strip detectors, backed by 3.9 cm thick CsI(Tl) crystals. The strips in these telescopes effectively subdivided each telescope into 1024 2*mm* x 2*mm* pixels. Two multichannel-plate (MCP) detectors, placed at 10 cm and 50 cm upstream from the reaction target, were used to track the beam particles. This was required to ensure good position determination at the target position since the secondary ^{56}Ni beam had a very large beam spot.

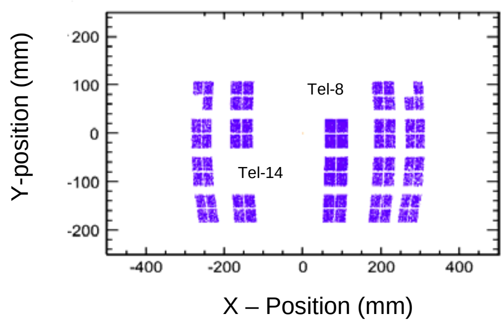

Figure 2: Beams eye view of the HiRA configuration for the ^{56}Ni(p,d)^{55}Ni measurements in the Cartesian co-ordinate system.

Figure 2 shows the HiRA configuration for the ^{56}Ni(p,d)^{55}Ni measurements. Beam position is at the (0,0) position in the plot. Two E detectors (labeled Tel-8 & Tel-14) and two CsI crystals (at telescope position 0 and 16) did not work during the experiment. In the preliminary analysis of the data, we have not considered the data in the middle strips (strip 15 and 16) of E detectors as they cover the gaps between four CsI crystals. We also discarded the data of the edge strips (strip 0 & 31) of the E detectors as we found these nosier than other strips. The geometric efficiency of the HiRA array set up is shown in Figure 3.

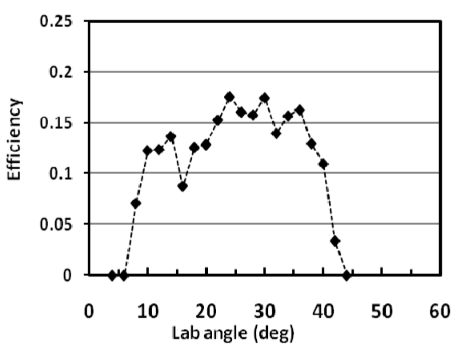

Figure 3: Geometrical efficiency of HiRA for the present experimental set up

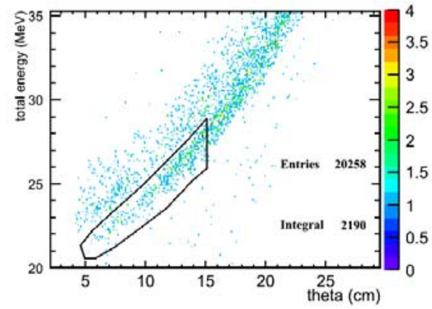

Figure 4: Deuteron kinematics for ^{56}Ni(p,d)^{55}Ni reaction.

Figure 4 shows the deuteron kinematics for ^{56}Ni(p,d)^{55}Ni reaction in centre of mass frame. Even without incorporating the use of the MCPs, ground state can be clearly separated from the excited state in the forward angles (cm angle < 15 deg). The gated events were used for angular distribution shown in Figure 5. Analysis of the experiment is still in progress

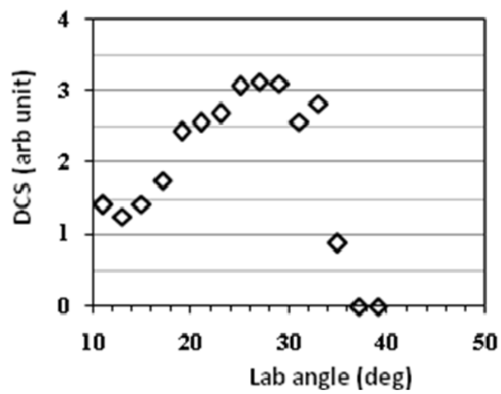

Figure 5: Ground state angular distribution of deuterons for ^{56}Ni(p,d)^{55}Ni reaction.

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References

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[2] A. Sanetullaev, PhD thesis, MSU (2011)