Probing the Neutron and Proton Hole States in ^{56}Ni

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(For the HiRA collaborations)
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^{56}Ni is a nucleus outside the valley of stability. According to Independent Particle Model (IPM) it is a doubly magic nucleus with N=Z=28. It is a "waiting point" nucleus in the rapid proton (rp) capture process and hence an important nucleus in the astrophysical network calculation. The degree of fragmentation of single particle states (quantified by spectroscopic factor) near a double shell closure provides important information for shell-model calculation. Therefore, understanding the shell structure of ^{56}Ni nucleus is of considerable interest both for the nuclear structure and nuclear astrophysics [1].

Single-nucleon transfer reaction is a powerful tool to study single particle states and extract quantitative spectroscopic information. With transfer reactions, one can obtain information about the angular momentum of the orbital from the angular distributions, the excitation energy of the states and the occupancies or spectroscopic factors of the various single particle orbits. Spectroscopic factor (SF) quantifies the nature and occupancy of the single particle orbits in a nucleus. 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.

Analysis of the ground state neutron SF of nickel isotopes suggests that ^{56}Ni is not a good closed core for Ni isotopes [2]. Direct measurements of the neutron and proton SF for ^{56}Ni will verify if it is a double magic nucleus. We studied ^{56}Ni(p,d)^{55}Ni reaction in inverse kinematics at 37 MeV/u and 80 MeV/u to extract neutron spectroscopic factor (n-SF) of ^{56}Ni and probe the energy dependence of SF obtained in transfer reactions. The ^{56}Ni(d,^{3}He)^{55}Co reaction experiment was carried out at 80 MeV/u to extract proton spectroscopic factor (p-SF) of ^{56}Ni. The study of the two reactions at the same experimental condition will allow us to compare the n-SF and p-SF and test the isospin symmetry of the valence neutrons and protons in the $f_{7/2}$ shell of ^{56}Ni.

The measurement was carried out in inverse kinematics using a secondary beam of ^{56}Ni, 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. Beam purity was about 52%. Polyethylene targets (CH_2)n of 100 micron and (CD_2)n of 10 micron thickness were used in the experiment. The thinner CD_2 target is necessary due to the energy and angular straggling of the outgoing ^{3}He particles.

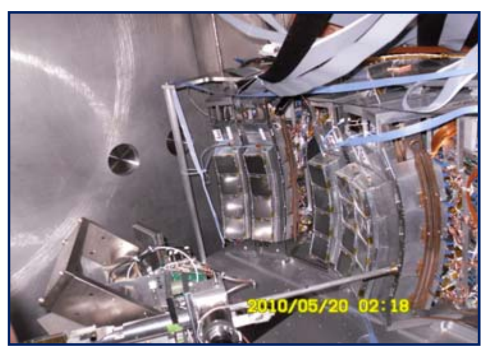

Figure 1: HiRA set up with 20 telescopes inside the S800 scattering chamber.

Light particles (deuteron and ^{3}He) were detected in the High-Resolution Array (HiRA) in coincidence with the recoil residues detected in the S800 focal plane. The HiRA, consisting of

20 telescopes, [shown in Fig1] was placed at 50 cm from the target where they subtended polar angles of 6° $\leq \theta_{lab} \leq 45°$. Due to the kinematics and forward focusing of the reaction products, this covers nearly the total solid angle in the center of mass frame. Fig. 2 shows the geometrical efficiency for the experimental setup.

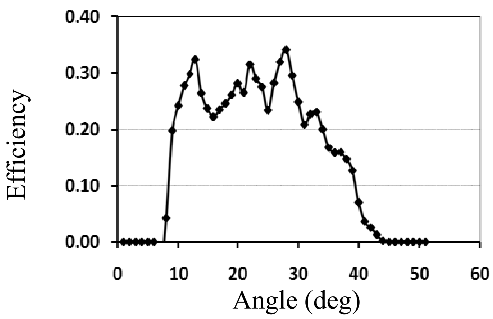

Figure 2: Geometrical efficiency of HiRA for the present experimental set up

Each HiRA telescope with an active area of 6.25 cm x 6.25 cm, contained 65 µm thick ΔE with 32 strips and 1500 µm thick E double sided (32 x 32) silicon strip detectors, backed by four 4 cm long CsI(Tl) crystals. The strips in these telescopes effectively subdivided each telescope into 1024 pixels of 2 mm x 2 mm area. Since the ^{56}Ni beam had a very large beam spot, to ensure good position determination at the target, the experiment employed two MCP detectors to track the beam particles. MCP0 was placed 50 cm upstream of the reaction target while MCP1 was 10 cm upstream from the target.

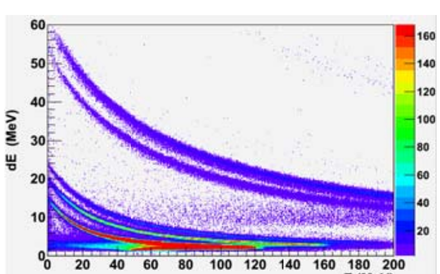

Figure 3: Particle identification in HiRA

Deuterons were identified in HiRA with standard energy loss techniques using the energy deposited in the ΔE and E silicon strip and CsI detectors. Figure 3 shows the particle identification in HiRA, y axis is the energy deposited in 1.5 mm thick silicon detector while x axis is the residual energy in CsI . Reaction residues were identified in the S800 spectrometer using the energy loss in the ion chamber and the time-of-flight (TOF) between the MCP1 and plastic scintillator placed at the focal plane of S800. Figure 4 shows the particle identification of the heavy residue fragments in S800.

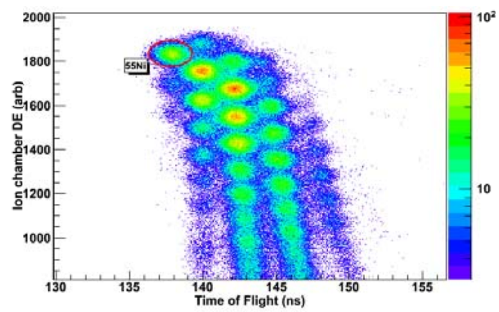

Figure 4 : Residue identification in S800

The analysis of the experiment is still in progress. In summary, to study the exact shell structure of the unstable doubly magic nucleus ^{56}Ni (N=Z=28), we measured the angular distribution of deuteron and ^{3}He produced in inverse kinematic reactions of ^{56}Ni (p,d)^{55}Ni and ^{56}Ni(d,^{3}He)^{55}Co. The focus of the present experiment is to look for the single particle nature of the proton and neutron hole states in the doubly magic nucleus ^{56}Ni.

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References

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