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Progress of the BRIF project and the β-decay of ^{53}Ni

W. P. Liu*, **for BRIF and nuclear astrophysics collaboration.**
China Institute of Atomic Energy, P. O. Box 275(1), Beijing 102413, China
E-mail: wpliu@ciae.ac.cn

For the nuclear physics facility development, CIAE is currently constructing the Beijing Rare Ion beam Facility (BRIF). The ISOL type facility BRIF under construction is composed of a 100 MeV 300 μA proton cyclotron, an ISOL with mass resolution of 20000, and a super-conducting LINAC of 2 MeV/q, and will be commissioned in 2014.
The β-delayed proton emission of ^{53}Ni was measured at the HIRFL-RIBLL facility in Lanzhou. p-γ coincidences were obtained for the first time for the βp decay of ^{53}Ni, which may imply the inconsistency of ^{53}Co isobaric analog state assignment.

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*Speaker.

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1. Introduction

Currently, there are two major nuclear physics centers in China. The Cooler-Storage Ring (CSR) is located at the Institute of Modern Physics (IMP), Lanzhou. CSR was commissioned in 2008, and it can deliver stable and unstable heavy-ion beams with an energy range between 10 and 1100 MeV/u. CIAE is equipped with Tandem accelerator. CIAE is currently constructing Beijing rare ion beam facility (BRIF). The rare ion beam facility can be classified into projectile fragmentation (PF) and isotope separation on line (ISOL) types. The BRIF under construction is an ISOL type facility, and will be commissioned in 2014. The ISOL facility is well suited for precise physics with high quality beams. The beam isospin (neutron to proton ratio) is limited to near beta stability line due to the reaction mechanism and long separation time of ion source. To achieve this, sophisticated target and ion source technology must be handled. Due to this challenge, less ISOL facilities were commissioned in recent years compared with PF facility. Some of the current operational ISOL facilities are, ISAC, REX-ISOLDE, and HRIBF etc[1, 2].

Decay properties of proton-rich nuclei are critical nuclear data for a better understanding of the astrophysical rapid proton-capture (rp-) process. In addition, the decay branching ratios of proton-rich nuclei help determing the evolution of shell structure of nuclei off stability. For example, it can constrain shell quenching factors through the comparison between the experimental and shell model B(GT) values [3]. It is also of interest to measure the isobaric analog states (IAS) via β-delayed proton emission because that the masses of parent nuclei can be precisely determined based on the isobaric multiplet mass equation (IMME) which has been tested for nuclei close to stability [4].

^{53}Ni decay has been measured [5] but has insufficient information on the full decay branching ratio and the IAS excitation energy in ^{53}Co. The lack of p-γ coincidence data in the previous work means that the excitation energy of the IAS assigned therein may be debatable. This in turn makes it premature to draw firm conclusions regarding the IMME in the fp shell region. Reexamining the excitation energy of the IAS in this region by p-γ coincidence measurement can verify the applicability of IMME.

We have measured the βp-decay in a fp shell nuclei with a focus on the p-γ coincidences of ^{53}Ni decay. Our new data are evaluated together with those from the previous works and used for discussing the excitation energy of ^{53}Co IAS .

2. BRIF status

BRIF aims at physics with unstable beams in the energy range of 100 keV to 10 MeV/u. The physics topic will be covered in the field of astrophysical rp process, reaction studies of N=Z nuclei, nuclear decay and the study of neutron rich nuclei. BRIF will be based on the existing 15 MV tandem accelerator. A compact cyclotron, with a proton beam energy of 100 MeV and intensity of 300 μA will be built upstream tandem. An ISOL with the mass resolution of 20000 will be constructed in between to convert intense proton beam into rare ion beams that suitable for tandem injection. After the tandem, a super-conducting LINAC sector will be installed to further boost the beam energy by 2 MeV/q. The species of unstable beam is includes proton-rich ones via fusion evaporation and charge exchange reactions. In addition, when a ^{238}U target is used, neutron-

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rich beams can be produced via proton–induced fission reaction. The ISOL mass resolution of 20000 is designed for the purpose of separating the isobars of these fission products. The project was approved in 2003, and its feasibility plan was approved in 2004. Due to the increased budget requirement, a revised feasibility plan was submitted in 2008, and was approved in 2009. The building construction and the component installation will be finished by the end of 2012. The whole project is planned to be ready for commissioning in 2014.

For further increasing beam energy and beam time, aiming for energies above the coulomb barrier for mass up to 100, we are also planning to install the retired super conducting LINAC from State University of New York and the retired K120 heavy ion cyclotron from PSI. The overall configuration of the Tandem lab and BRIF project, including the super conducting LINAC and the K120 cyclotron, is shown in Fig. 1.

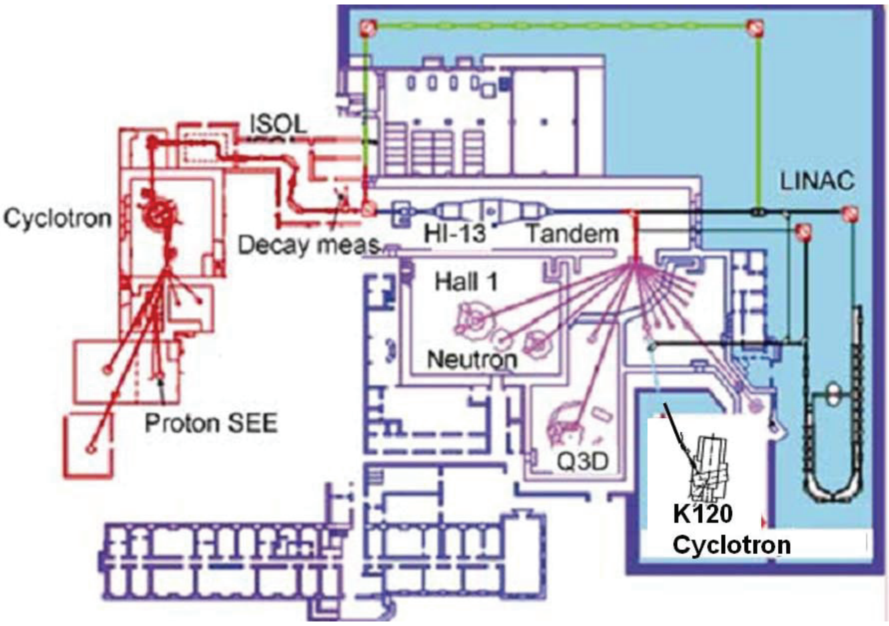

Figure 1: The overall configuration of the Tandem lab and BRIF project.

3. Study of ^{53}Ni decay

The experiment was performed at the Heavy Ion Research Facility in Lanzhou (HIRFL). The K450 separate sector cyclotron (SSC) provided a primary beam of ^{58}Ni with an intensity of 20 enA, and an energy of 68.6 MeV/u. The nuclides ^{50}Mn, ^{51}Fe, ^{52,53}Co, ^{53,54}Ni, and others were produced via ^{58}Ni projectile fragmentation using a natural nickel target with the thickness of 147 μm at the Radioactive Ion Beam Line in Lanzhou (RIBLL) [6]. The momentum acceptance of RIBLL was 0.49%. During the experiment, the typical intensity of the secondary ^{53}Ni beam was 3.8×10^{-3} pps, a factor of 10 lower than the calculation using the LISE++ [7] code. The lower than expected intensity could be due to an overestimation in LISE++ for multi-neutron stripping cross sections. Although the available secondary beam intensity was clearly low, it still allowed us to carry out

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the decay measurement, owing to the high efficiencies of our charged particle and γ-ray detection systems.

A double-sided silicon strip detector (DSSSD) of thickness 500 μm served as both implantation stopper and as $\beta/\beta p$ detector. A 132 μm thick aluminum degrader was placed upstream to ensure that the secondary beam can be stopped within the DSSSD. The DSSSD pixel position information was used in offline analysis to determine coincidences between implantation and $\beta/\beta p$-decay events. A veto detector with a thickness of 1500 μm was installed downstream to suppress the possible interference from the penetrating light particles. Before and after the experiment, the DSSSD and veto detectors were calibrated with ^{241}Am (α) and ^{207}Bi (β) sources. A logarithmic preamplifier was utilized to accommodate the large dynamic range of heavy ions, protons and β-rays.

Outside the DSSSD chamber, five segmented clover detectors were installed to measure the γ-rays associated with the decay of 53Ni. The absolute efficiency and energy resolution of this clover detector array for the 778.9 keV γ-ray of a ^{152}Eu source were measured to be (4.3 ± 0.3) % and 4 keV, respectively.

4. Analysis of the ^{53}Co IAS

The energy spectrum of ^{53}Ni β-delayed protons measured in the present work is shown in Fig. 2. The main peaks are marked according to the results given by Dossat et al. [5]. In their work, the peak at 1929 keV was assigned to the decay of the IAS in ^{53}Co to the first excited state at 2^+ 849 keV in ^{52}Fe, hence the excitation energy of the ^{53}Co IAS was conjectured to be 4380 keV. However, according to the mass of ^{53}Ni measured at the HIRFL cooling storage ring recently [8] and the IMME, the excitation energy of ^{53}Co IAS was extracted to be 4302 keV which disagrees with that from Ref. [5].

It is worth noting that no p-γ coincidence events have been observed in the previous works [5, 9], and thus the assignment of ^{53}Co IAS lacked the sufficient experimental bases. To clarify the above discrepancy, we used our γ-spectra shown in Fig. 3. The spectrum obtained with the coincidence of β-rays and protons from ^{53}Ni decay is shown in Fig. 3a in which there are a clear peak at 511 keV and a visible peak at 849 keV. Fig. 3b adding a gate of proton peak at 1929 keV to Fig. 3a. One can see that no events appear at 849 keV. Fig. 3c adding a gate of proton peak at 2399 keV to Fig. 3a, three events appear at 849 keV. Fig. 3d shows the spectrum of γ-rays in coincidence with the random decay events, and nearly no events appear except around the 511 keV peak.

Our experimental results show four events at E_γ = 849 keV above background in coincidence with ^{53}Ni βp-decay (see Fig. 3a), and three of them were associated with the 2399 keV proton peak (see Fig. 3c). However, coincidences of 849 keV γ-rays with the 1929 keV protons were not observed (see Fig. 3b), which were expected if the previous decay mode of ^{53}Co IAS [5, 9] is correct. This discrepancy is perhaps due to our limited statistics of protons and limited efficiency of γ-detector, otherwise the ^{53}Co IAS excitation energy should be reduced from 4380 keV to 3531 keV which significantly deviates from the IMME prediction based on the new mass value of ^{53}Ni [8]. Indeed, an experiment with higher statistics is desired to clarify this inconsistency.

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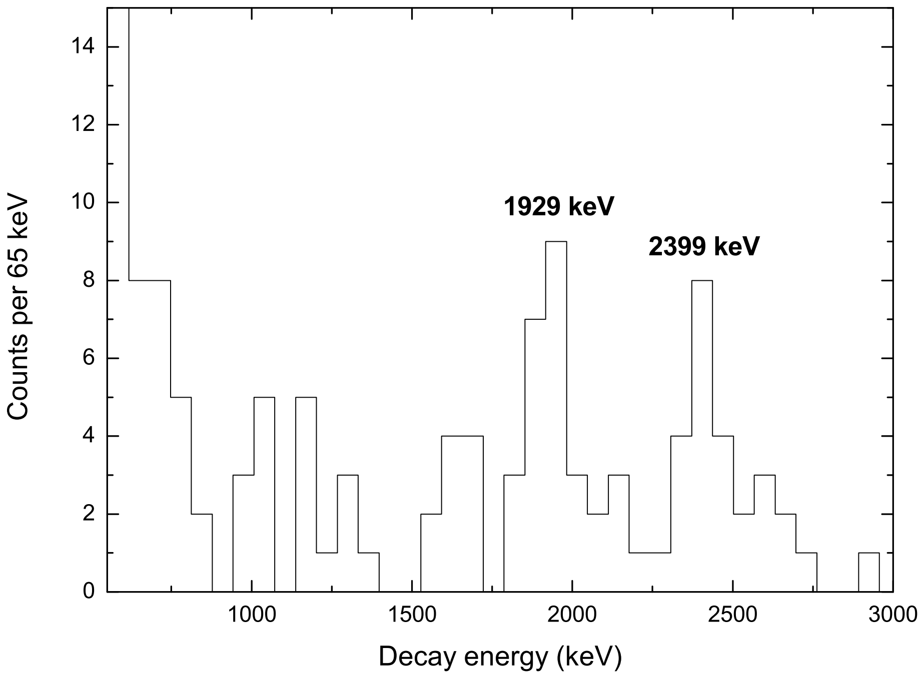

Figure 2: Energy spectrum of the ^{53}Ni β-delayed protons.

5. Summary and discussion

In summary, nuclear physics basic research is carried out based on Tandem accelerator in CIAE. BRIF under construction will become a competitive ISOL facility when commissioned in 2014.

^{53}Ni proton-γ coincidence was observed for the first time, but the previous assigned ^{53}Co IAS were not observed. We would like to perform a new experiment with higher statistics to clarify this situation.

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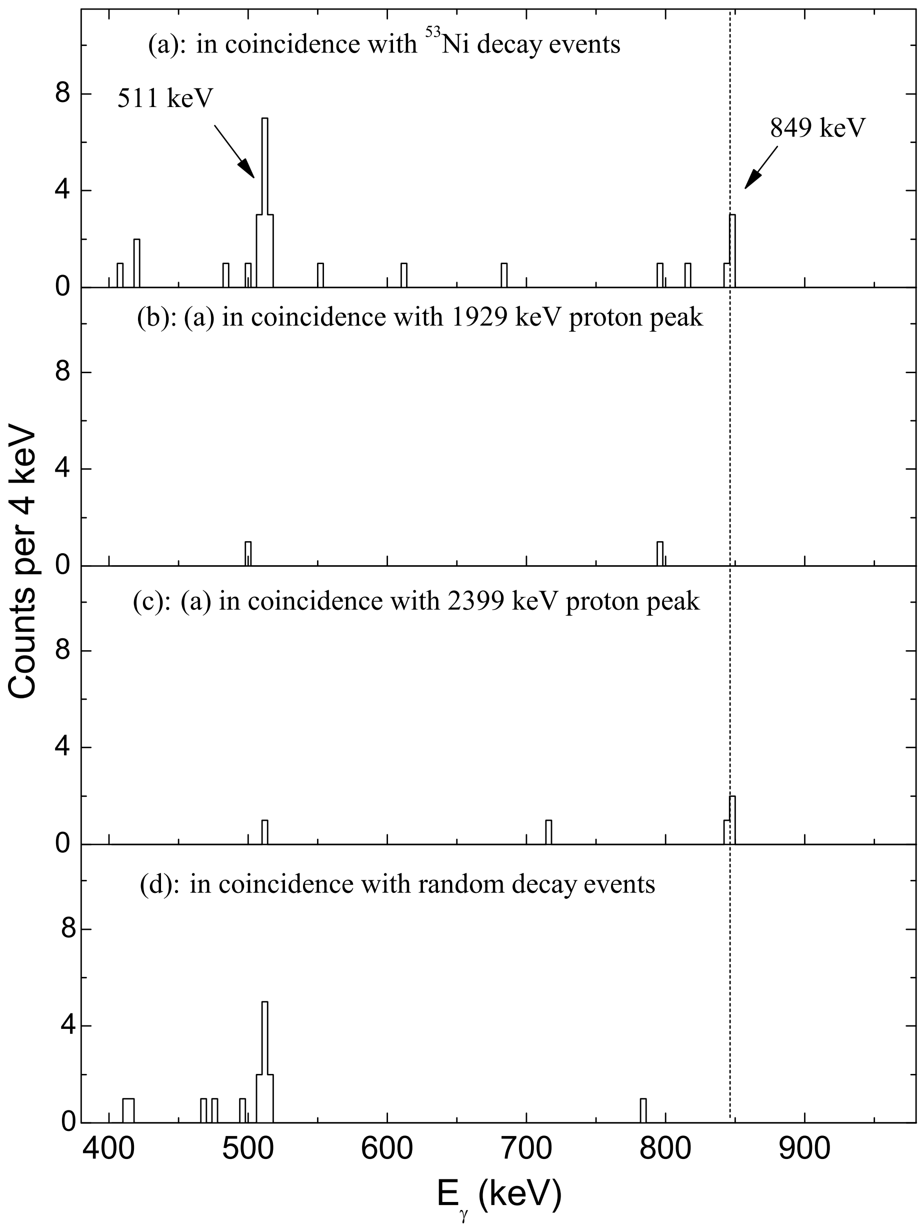

Figure 3: γ-ray spectra measured in this work (a): in coincidence with β-rays and proton gated by ^{53}Ni; (b): (a) further coincidence with 1929 keV proton peak ; (c): (a) further coincidence with 2399 keV proton peak and (d): in coincidence with random decay events.

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