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Abstract. The neutron-deficient ^{115}Cs was produced at ISOLDE, CERN by spallation reaction using 1.4 GeV proton on LaC_2 target. The exotic decay modes were studied by using a charged particle array (DSSD and pad detectors) and a γ-detector array (four Clovers) at the ISOLDE decay station (IDS). In this report, results on observed β-delayed particle emission from ^{115}Cs, a nucleus close to proton drip line, is presented. By measuring the time distribution in the delayed proton spectrum, the half-life of the ground state of ^{115}Cs was extracted. The

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obtained half-life is in agreement with previous reported value. For the first time, the p-unbound states of ^{115}Xe, obtained by measuring beta-delayed protons from ^{115}Cs is reported.

1. Introduction

The study of properties of nuclei near and beyond the drip lines provides unique information on n-n interaction that is important in understanding the limits of existence of the quantum many body systems i.e. atomic nuclei [1]. The experimental data close to the drip line may validate the nuclear models and nucleon-nucleon interaction [2, 3, 4]. Many interesting properties are observed in these nuclei; the disappearance of the magic numbers [5, 6], appearance of PIGMY resonance [7, 8], exotic decay [9, 10, 11, 12], exotic cluster structure [13] etc. In this article, the study of exotic decay mode of neutron deficient nucleus, A$\sim$ 115 close to the proton drip-line is reported. Due to large difference in the binding energies of proton(s) and neutron(s) in the nuclei around drip-line, the Q-value for decay of the nucleus is large enough to populate the excited states of the daughter nucleus above the particle threshold. The study of these exotic decays may provide information on a rich variety of properties as spin, parity, energy and lifetime of the unbound states above particle threshold. Comparing the properties of those states, one access to the component of n-n interaction due to coupling to the continuum. Moreover, the effect of the proton-skin thickness on decays properties of neutron-deficient nuclei still needs further investigation. The mass region A$\sim$ 100-120 around the proton drip line is known as Island of cluster emitter, which yet need experimental verification. We have initiated an experimental investigation to study exotic decay for the nuclei Cs, Xe, Ba, near proton drip line. In this article, experimental observation of the decay of ^{115}Cs is presented. ^{115}Cs is located close to the proton drip line with a half-life of 1.4(8)sec according to latest evaluation [14]. Due to the large Q-value (Q_{EC}) for electron capture many different decay channels are open in the daughter nucleus. Thus after electron capture of ^{115}Cs, the daughter nucleus, ^{115}Xe can be populated in excited states above the proton threshold and it may further decay by proton or alpha emission. According to previous measurement [14] the delayed proton branch for this isotope is 0.07% . In case of ^{115}Xe, the one proton separation (S_p), two proton separation (S_{2p}), alpha separation energy (S_α) are (-3.15(15)) MeV, (-4.89(3)) MeV and 2.506(14) MeV [15], respectively. Fig. **??** represents schematic diagram of part of the exotic decay of ^{115}Cs.

2. Experiment

The radioactive Cs, Ba beam were produced by bombarding a tailored Lanthanum Carbide (LaC_2) target with 1.4 GeV protons, obtained from CERN PS booster, followed by spallation/fragmentation reaction in the target. The radioactive beams were produced, ionized, extracted by a hot rhenium surface ion source, and separated using the ISOL method. The extraction and ionization efficiencies of Cs isotopes exceed the ones for Ba isotopes significantly. Therefore, in-target fluorination was used in order to extract Ba as fluoride molecules on a mass with greatly reduced isobaric contaminations. Particular beam of mass (A) with energy of 60 keV was mass-separated and transferred to the experimental hall and implanted on a 20 μg/cm^2 carbon foil located in the middle of the detector setup. At IDS, a compact particle detection system consisting of four DSSDs (Double Sided Silicon Strip Detectors), stacked in telescope configuration with 4 PAD detectors. A fifth DSSD (1500 μm thick was placed below the setup for beta counting, see Fig.3. Four High-Purity Germanium(HPGe) clover detectors surround the chamber to provide better resolution and high γ-ray detection efficiency (see Fig.2). The detector setup is therefore able to detect both charged particles and γ-rays with high efficiency. The DSSDs are of different thickness. The thin DSSDs (65 and 67 μm) are insensitive to β radiation but they stop low energy protons, alphas etc. The thick DSSDs can fully stop high

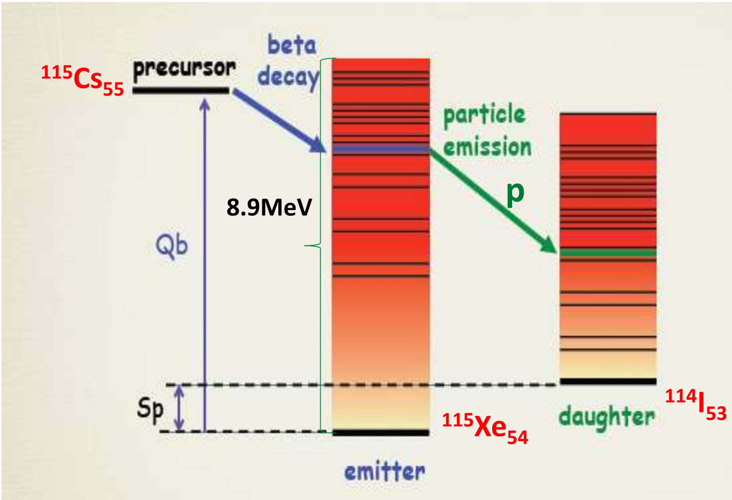

Figure 1. Schematic diagram of the part of exotic decay mode.

energy protons, while a fifth thick horizontal DSSD is mainly used for detection of β radiation. The PADs have been used for β detection.

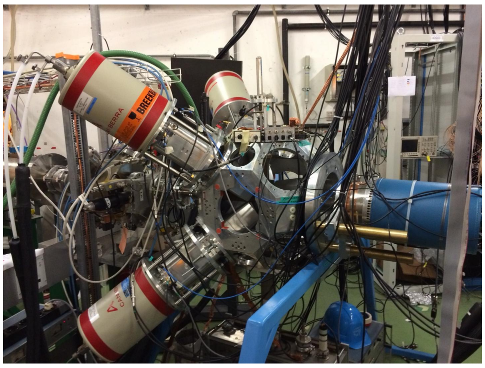

Figure 2. Photograph of the experimental setup at IDS, ISOLDE, CERN during experiment IS545.

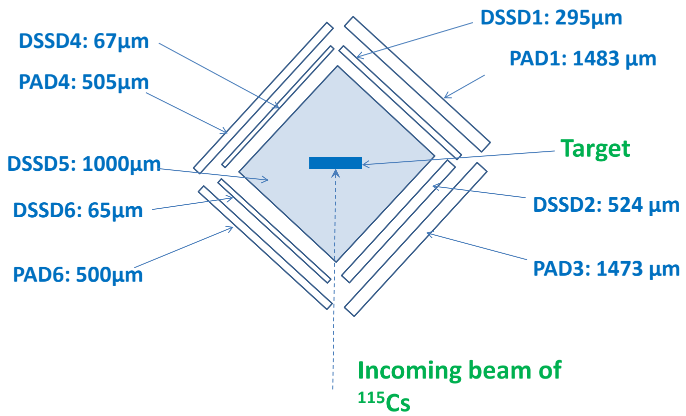

Figure 3. Arrangements of Double sided silicon detector (DSSD) and PAD detector setup used during IS545 experiment at IDS, ISODE, CERN.

The distance of each of the DSSDs from the target is $\sim$ 4.0 cm. Each of the DSSD is made of 5cm$\times$5cm silicon wafer. There are 16 strips in each of the front layer and back side layer of the DSSD. The width of each strip is 3.0 mm, where the front strips are vertical and back strips are horizontal. The Solid angle coverage of of the silicon strip detectors is nearly 43%. For the calibration of silicon detectors long-lived calibrated standard alpha sources were used: ^{148}Gd$_{64}$(T$_{1/2}$=71.1 years), ^{241}Am$_{95}$(T$_{1/2}$=432.6 years),^{239}Pu$_{94}$(T$_{1/2}$=24110 years),^{249}Cf$_{98}$(T$_{1/2}$=351 years). For the calibration of HPGe a standard calibrated gamma source ^{152}Eu was used.

3. Data Analysis

After calibration and validating the events the data analysis has been performed using the CERN-ROOT platform. For the first time detailed study of exotic decay mode of delayed proton(s), alpha, γ-rays and exotic clusters of ^{115}Cs, beyond proton drip line is reported and the delayed bound and resonance states of daughter nuclei have been identified. Fig.4 [left] shows the thin DSSD energy spectrum which contains the energy loss of β-particles, proton and alphas. By performing coincidence and anti-coincidence with consecutive PAD detector spectrum, these spectra can be separated into each component. Fig. 4 [right] shows two dimensional particle energy-loss spectrum obtained in coincidence with the thin DSSD and consecutive pad detector. Clearly, proton and beta related parts have been separated (see Fig.4[right]). The proton spectrum is shown in the fig. 4 [right] by a banana-plot. Where as the alpha spectrum can be obtained from the energy loss spectrum in the thin DSSD in anti-coincidence mode with consecutive PAD detector.

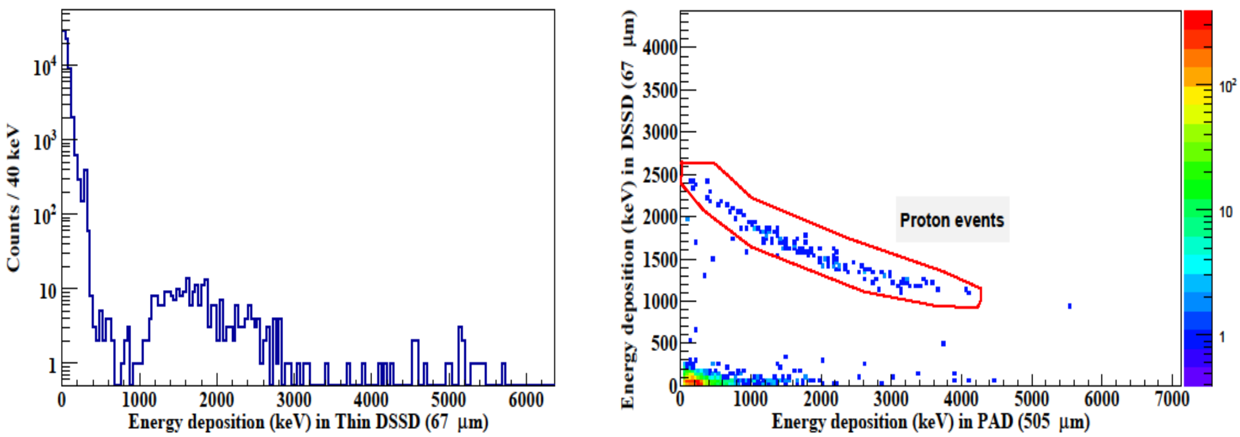

Figure 4. [left] The energy loss spectrum obtained from thin DSSD detector of this experiment. [right] Two dimensional coincidence spectrum for dE-E telescope where dE was obtained from above thin DSSD and E was obtained from consecutive PAD detector. For more details see text.

4. Results and discussion

4.1. Determination of Half-life

The half-life of ^{115}Cs has been obtained from the time distributed protons spectrum. Fig.5 shows time distributed proton obtained from the proton banana-plot condition as shown in Fig 4. To obtain the decay half-life of ^{115}Cs, the time distributed proton spectrum was fitted with the function N=N$_0$e$^{-\lambda t}$ as shown in Fig. 5. The obtained half-life of ^{115}Cs is 1.03(10) sec. The previous reported value is 1.4(8) sec [14].

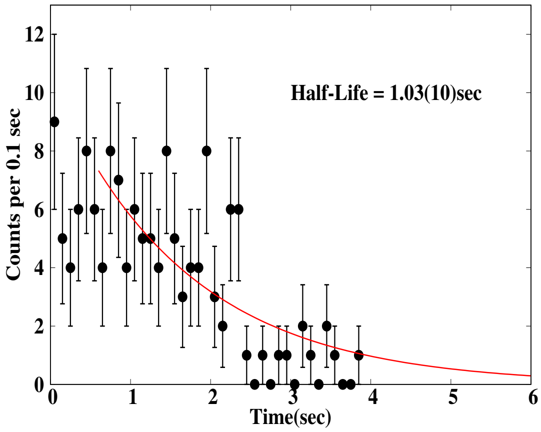

Figure 5. The time distribution of delayed proton events obtained from ^{115}Cs of present experiment. The time distributed spectrum has been fitted with the function $N=N_0e^{-\lambda t}$.

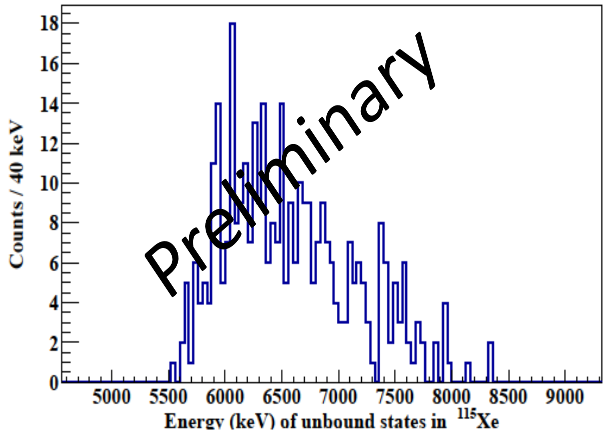

Figure 6. The energy spectrum of unbound resonance states of nucleus ^{115}Xe, populated after decay of ^{115}Cs.

4.2. Unbound resonance states

After electron capture or positron decay of ^{115}Cs, the daughter nucleus ^{115}Xe, was populated with energy upto 8.0 MeV and the unbound states above one proton threshold (S_p = 3.15 MeV for ^{115}Xe) can be reconstructed from delayed proton energy measurement. From the preliminary data analysis, it has been observed that the delayed proton branch for this isotope is much larger than previous reported value[14]. Fig.6 shows reconstructed excited states (preliminary) of ^{115}Xe, populated after decay of ^{115}Cs. It is evident from Fig.6 that the populated states are sharp resonance closely spaced states in the energy-range energy 5.5 MeV to 8.0 MeV. More investigations are ongoing to study the properties of those p-unbound states which may allow to constrain the component of coupling to the continuum in the n-n interaction of nuclei around proton drip line. Thus for the first time p-unbound states (preliminary) of ^{115}Xe obtained by measuring delayed proton from ^{115}Cs is reported.

5. Summary

The neutron deficient Cs isotope close to the proton drip line was studied at ISOLDE using IDS facility. Details of the exotic decay mode i.e. decaying delayed proton, alpha, γ-rays and exotic clusters from the neutron deficient nuclei near proton drip line was measured using a compact dE-E telescope and a clover array. The half life ($t_{1/2}$) of ^{115}Cs was obtained from the data analysis of time distributed delayed proton events that is in agreement with previous reported value within error. We report for the first time on the p-unbound excited states of ^{115}Xe obtained by studying the delayed protons from ^{115}Cs. Further data analysis are going on to understand the background from different sources. Further investigation to identify multi-particles or cluster decaying unbound states in this mass region will be performed.

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