Experimental studies of the ^{46}Mn β^{+}-decay channel and spectroscopy of ^{46}Cr at LISE-GANIL

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Abstract. In this work we present the preliminary results of analysing the ^{46}Mn β^{+} decay channel as a way to study the ^{45}V(p,γ)^{46}Cr reaction. ^{46}Mn was selected among other species in the cocktail beam delivered by the LISE fragment separator at GANIL (Caen, France) in order to study its beta decay and the excited states of its daughter nucleus ^{46}Cr. As part of the validation process we present the ^{46}Mn half-life, the proton and gamma emission peaks related to the ^{46}Mn decay and compare them with the results from previous works.

1 Introduction

Stars with initial mass greater than 8 solar masses ($M_{\odot}$) end their lives through a Core Collapse Supernova (CCSN) explosion. Besides, ^{44}Ti nucleosynthesis takes place in CCSN making this nucleus a good gamma astronomy tracer for SuperNova (SN) events due to the characteristic γ-rays emitted in its decay chain (67.9, 78.4, 1157 keV). Furthermore, the comparison between observations and models of the synthetized ^{44}Ti in CCSN gives important constrains to the models. In the latter, reaction networks are used for modelling nucleosynthesis occurring in the last stages of those stars with thermonuclear reaction rates as its inputs [1–3].

Unfortunately, a direct measurement of the cross section for many thermonuclear reactions is extremely difficult in current laboratories worldwide. Therefore, indirect methods can be used for this purpose, especially when the reaction rate is dominated by a narrow isolated resonance. In this context, beta-delayed proton emission is very useful with (p,γ) reactions involving low and medium mass proton-rich radioactive nuclei. That is a consequence of the fact that in those reactions narrow isolated resonances are likely to occur [2, 4].

It is believed that nucleosynthesis of ^{44}Ti in CCSN explosions is quite sensitive to the ^{45}V(p,γ)^{46}Cr reaction [5]. In addition, there is no information of this reaction as it has not been studied before. Therefore, by exploring this reaction it is possible to give new information for the ^{44}Ti production in CCSN models. In the present analysis we propose to use the

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^{46}Mn beta-delayed proton emission as a way to study the inverse reaction. For that purpose we analyze the data of the "Isospin mixing in pf-shell proton emitters" experiment (Code: E666, spokesperson: Bertram Blank, LP2I - Bordeaux France) performed with the LISE fragment separator at GANIL laboratory (Caen, France) focusing on the analysis of the ^{46}Mn isotope. In section 2 we discuss the analysis procedure and in section 3 we present our preliminary results, used for the validation of the procedure, for the half-life, and the proton and gamma energy spectra related to the β^{+} decay of the ^{46}Mn [6, 7].

2 Experimental setup and analysis

In the E666 experiment, a primary beam of ^{58}Ni^{26+} at 74.5 MeV/u collided with a 230.6 mg/cm^{2} thick ^{nat}Ni target. With the help of LISE, the isotopes to be implanted in the silicon detectors were selected. The detector array in the experiment (see figure 1) was composed by 4 HPGe clovers, each one divided into 4 HPGe crystals (labeled A, B, C, and D), surrounding 3 Si detectors: a ΔE detector of 316 μm thickness labeled as 2D6, a Double-Sided Silicon Strip Detector (DSSSD) of 297 μm where the fragments are implanted, and a SiLi detector of 5 mm used as veto for particles from the ion beam. In the beam line, upstream the detector array, was placed another Si detector labeled as 1D6 of 300 μm. Each of the sides of the DSSSD is divided in 16 strips, 3 mm width each, thus allowing for defining squared pixels 3 mm $\times$ 3 mm in size.

All the 32 signals of the DSSSD, along with the signals of the 1D6, 2D6, and SiLi detectors plus the 16 signals of all the HPGe crystals were preamplified, amplified and digitalized by Mesytec GmbH MPR64 preamplifiers, Mesytec GmbH STM amplifiers, and GANIL VXI electronics. The DAQ was triggered by the 1D6 and DSSSD detectors, saving all the data of the system alongside the information of the activated triggers.

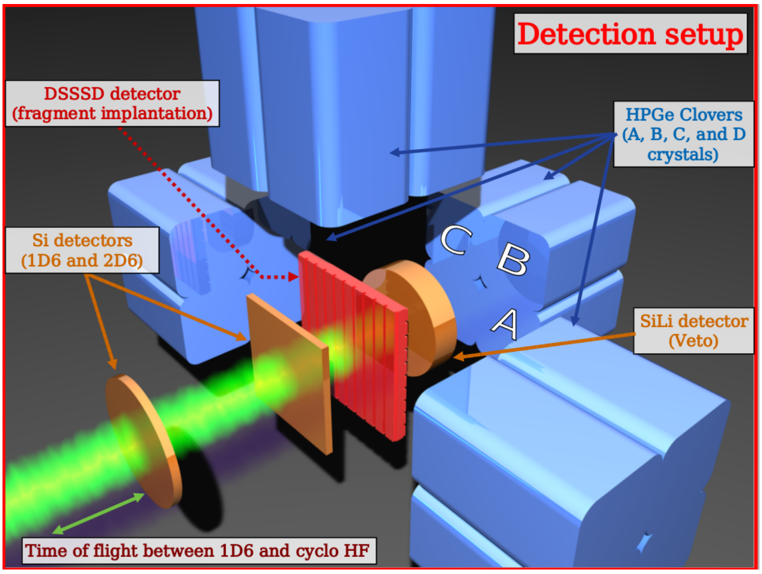

Figure 1. Detector array diagram. The HPGe clovers are depicted in blue, the Si and SiLi detectors in orange and the DSSSD in red. Image modified from [8].

2.1 Experimental analysis

We worked with a software developed at LP2I - Bordeaux complemented with a specific code, written using the CERN Root libraries, in order to complete the analysis. Firstly, we performed the calibrations of the DSSSD's X-Y strips and the clovers' HPGe crystals. A 3α source was used for the DSSSD and $^{56+60}$Co and ^{133}Ba+^{137}Cs sources were used for the clovers.

Secondly, the ion of interest was selected, ^{46}Mn, by means of an energy loss - time-of-flight 2D histogram (see figure 2). There we could easily identify, with the help of LISE simulations and previous works, the different ions implanted in the DSSSD. A graphical cut was used to make the selection of ^{46}Mn.

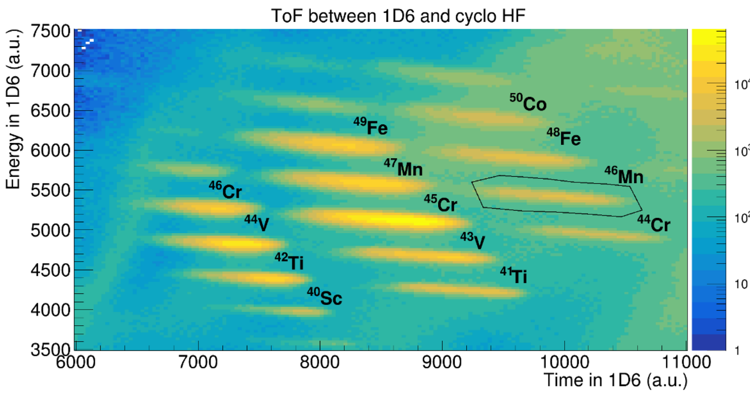

Figure 2. Energy loss in 1D6 detector vs time-of-flight 2D histogram used for the fragments identification of the nucleons implanted in the DSSSD detector.

Finally, time correlations between implantation and decay events were made. The correlations were established by opening a 1 s time window before and after a ^{46}Mn implantation event, and associating to it any decay event characterizing each correlation with a time difference ($\Delta t \equiv t_{\text{implantation}} - t_{\text{decay}}$). The negative Δt correlations were used to remove the background from the signal of the true correlation events. This allowed us to obtain the energy spectra for emitted protons and γ photons linked with the ^{46}Mn β^+-decay.

3 Discussion and results

By plotting the ^{46}Mn decay events with energy $E > 1500$ keV vs its Δt we obtained the decay curve, to which we calculated the half-life by fitting a 3 degrees of freedom exponential curve. We obtained $T_{1/2} = 37.5(4)$ ms with a $\chi^2/N = 1.01$, that is in agreement with $T_{1/2} = 36.2(4)$ ms obtained by [7] and $T_{1/2} = 34^{+4.5}_{-3.5}$ ms from [6]. It is important to note that we are only reporting the statistical error and it is pending to obtain the systematic one.

3.1 Proton and γ energy spectra

We also obtained the energy spectrum of protons emitted after the ^{46}Mn β^+-decay (see figure 3), and the emission spectrum for γ-rays (see figure 4). In both spectra it is possible to observe proton and γ peaks seen and listed by [7]; we are using for the peaks the same numeration as in his work. Nevertheless, it is interesting to note that in our results appear γ peak structures candidates at energies around 1, 1.08, and 1.17 MeV that are yet to be determined.

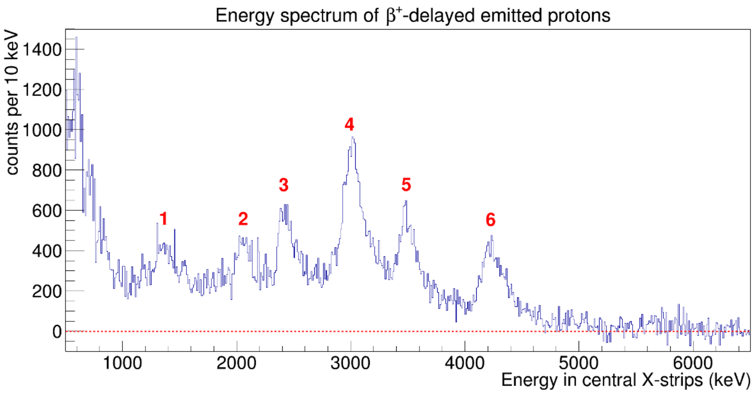

Figure 3. Sum-of-the-energy spectrum of the charged particles emitted after the ^{46}Mn β^{+} decay for the central implantation pixels of the DSSSD. The red numbers list the proton peaks as they appear in the figure 22(b) of [7] Only the peaks 2, 4, 5, and 6 have an energy level assigned to them, while the peak 2 is associated with the decay of ^{45}Cr. The peaks 4-6 are assigned to the decay of the IAS to ^{45}V 4th, and 5th excited states, and to the ground state respectively.

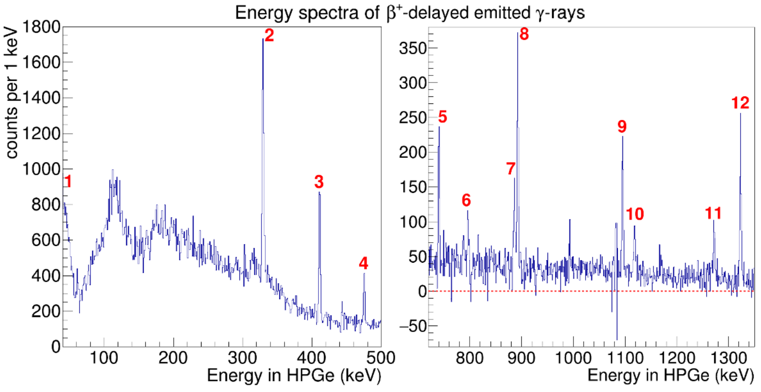

Figure 4. Sum-of-the-energy spectrum of the γ-rays emitted after the ^{46}Mn β^{+} decay for all the HPGe crystals. The red numbers list the γ-rays peaks as they appear in the figure 23 of [7] The peaks 5, 6, and 10 have no energy levels assigned to them yet, while the peaks 8, and 9 are associated with ^{46}Cr ones. The other peaks are assigned to ^{45}V energy level transitions.

4 Conclusions

In this work we have obtained the ^{46}Mn β^{+}-decay time curve and calculated the half-life. The half-life is compatible with previous results from the literature. In addition, energy spectra for protons and γ-rays related to the decay were also obtained. Those spectra are also compatible with [6, 7] results, with greater resolution than either two publications. The above results obtained are part of the analysis validation for the ^{45}V(p,γ)^{46}Cr inverse reaction study. Weather we find at the end of the analysis any resonances contributing to the ^{45}V(p,γ)^{46}Cr reaction, according to [5] estimations, it would translate in a meaningful reduction of the ^{44}Ti production in CCSN.

The future steps for the analysis include the estimation of beta and γ-ray detection efficiencies of the silicon detectors and clovers respectively; and to find the branching ratios of the inverse reaction of ^{45}V(p,γ)^{46}Cr. Besides, not all the peaks enumerated in figures 3 and 4 have a physical process assigned to them yet in the literature. The identification of such processes is still in progress.

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