Measurements of very low energy protons from β-delayed p-decays

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In the last two years, we have taken a strong interest in investigating beta-delayed proton decays of proton-rich nuclei, primarily motivated by unanswered questions in nuclear astrophysics. In particular we are looking at reactions important in H-burning in novae [1]. Through a series of experiments, we have developed a new experimental technique that has produced favorable results. The general set-up includes a thin Si strip detector (proton detector) in front of a thicker Si detector (beta detector), although in the more recent experiments for ^{23}Al and ^{31}Cl a thin Si detector was also placed in front of the proton detector to act as a second beta detector. The two (or three) detectors are then mounted onto an Al frame and cooled with water running through a pipe on the back of the frame in order to help reduce the noise. This telescope is placed at 45° with respect to the beam axis so that Ge detectors (one or two, depending on the experiment) may be placed close to the chamber and at 90° with respect to the beam axis in order to detect the gamma rays. The resonances of interest require that we measure low energy protons. To do this we chose to implant the exotic nuclei in the center of the proton detector. We produce and separate these nuclei with MARS, in-flight, in inverse kinematics. For implantation we slow them from 30-40 MeV/u by using a rotatable Al degrader, which is controlled such that the source nuclei of interest are stopped in the center of the proton detector. The beam from the cyclotron was then pulsed on and off, with cycles depending on their lifetime. We have applied this technique for ^{23}Al [2] and ^{31}Cl [3]. Here we want to report on efforts made to lower the minimum proton energy that we can measure.

In both cases studied, the proton branchings are very small, at the percent level. Each decaying event produces a small signal in the proton detector due to the energy loss of the positron. This is a continuum spectrum, with shape and maxima given by the size and thickness of the detector. In the rarer case when a proton is emitted after beta decay, the proton is fully stopped in a few microns of Si and all energy of the proton (hundreds of keV or more) adds to the energy loss of the positron. This results in proton peaks with a tail on their high-energy side. This tail depends on how thick and large the detector is, and affects the resolution, of course. More importantly, the thickness and size of the detector determine the shape of the beta-only background continuum at low energy (about 200 keV to 500 keV), limiting the minimum proton energies which can be measured. In this region, the continuous beta contribution becomes a dominant feature. When it is combined with the noise that arises from the beam line and electronics, the peaks can not be clearly identified. A goal of our recent beta-delayed proton decay experiments was to minimize this beta contribution as much as possible. One way to do this is to change the dimensions of the proton detector. Two different proton detectors have been used up to this point in time, the W1 and the BB2, both created by Micron Semiconductor Ltd.

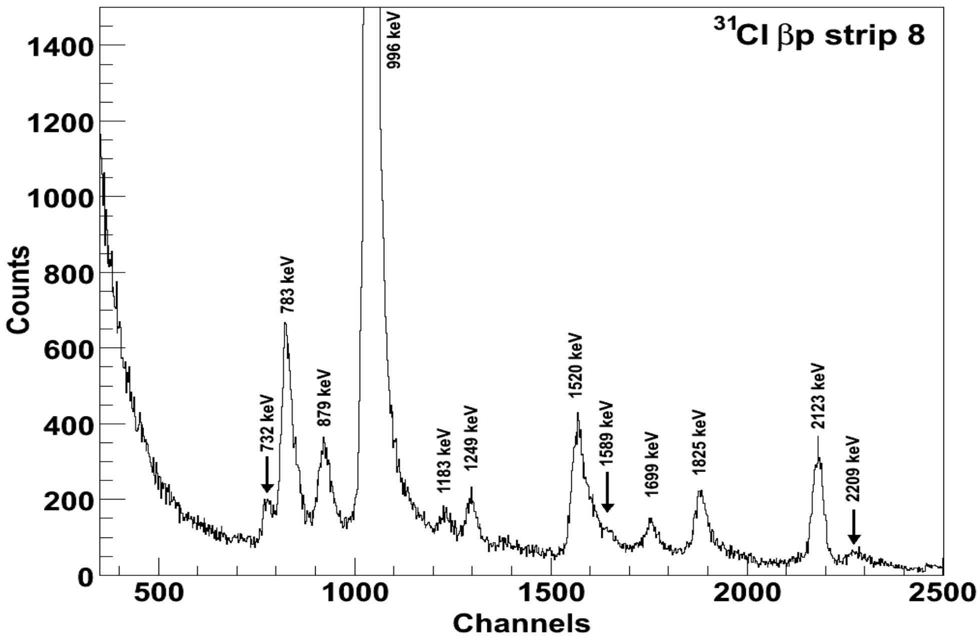

FIG. 1. A proton spectrum from the ^{31}Cl experiment done in 2007 with the W1-65 proton detector.

The ^{23}Al and ^{31}Cl experiments that were preformed in 2007 both used a W1-65 as proton detector. This Si detector has 16 strips on the front and 16 strips on the back, it is 65 μm thick and the width of the strips is about 3.1 mm. A reasonable 40 keV (fwhm) resolution was obtained for the proton peaks and the spectra are virtually background free down to about 400 keV (Fig. 1). Below these energies, a beta continuum is clearly visible and becomes a problem for the identification of low energy proton peaks. In order to minimize the background we put a multiplicity M_x=M_y=1 condition on x- and y- strips, and that the energies measured on each side are equal. In more recent ^{23}Al and ^{31}Cl experiments we have used a BB2-45 Si strip detector for protons. The BB2 detector has 24 strips on the front and 24 on the back. It is

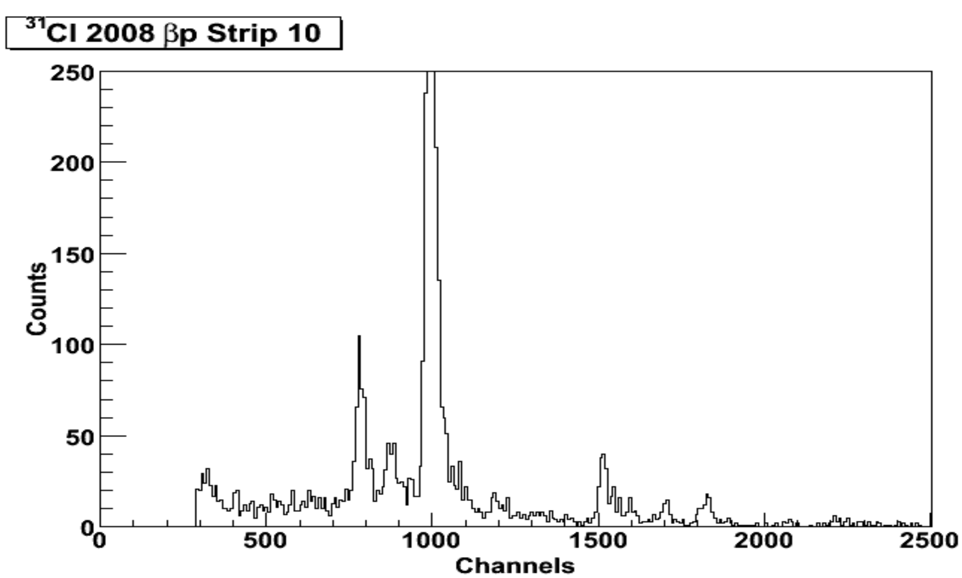

FIG. 2. A spectrum from the ^{31}Cl experiment done in 2008 with the BB2-45 proton detector. Only part of statistics is shown, but resolution is visibly better and the minimum energy threshold goes below 300 keV.

45 μm thick and its strips are about 1mm in width. Comparing the results of these experiments we found that decreasing the width of the strips and making the proton detector thinner noticeably reduced the beta continuum in the low-energy range and allowed the peaks to become more visible. Same multiplicity and energy conditions were used. At this point, the beta continuum became lower than the electronic noise in our setup, and the noise was the limiting factor (Fig. 2). The spectra are clean down to 280 keV or lower.

[1] A. Coc, *Proceedings of the 10th International Symposium on Origin of Matter and Evolution of Galaxies (OMEGA07)*; http://nucl.sci.hokudai.ac.jp/~omeg07/.

[2] L. Trache *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2006-2007), p. I-29; http://cyclotron.tamu.edu/2007%20Progress%20Report/index.html

[3] L. Trache et al., *Progress in Research*, Cyclotron Institute, Texas A&M University (2006-2007), p. I-9; http://cyclotron.tamu.edu/2008%20Progress%20Report/index.html