# Technique to study β-delayed p-decay of proton-rich nuclei

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In the last two years we had at TAMU cyclotron experiments to produce, separate and study the β-decay of $^{23}$Al. The interest was initially spurned by a nuclear astrophysics problem: the need to unambiguously determine the spin and parity of $^{23}$Al ground state, and remove an ambiguity of factors 30-50 in the $^{22}$Mg(p,γ)$^{23}$Al cross section at astrophysically relevant energies. Parts of the results were already published [1], proving that this reaction is not a leading competitor to explain the non-observation of the 1.275 MeV gamma-ray from the decay of long-lived $^{22}$Na from space telescopes. It was for the first time that pure samples of $^{23}$Al could be separated and their decay studied. Before, β-decay of $^{23}$Al could only be studied using the small p-decay branches following the β-decay to levels in $^{23}$Mg above the proton threshold at $S_p$=7580 keV. These states constitute resonances in the proton capture reaction $^{22}$Na(p,γ)$^{23}$Mg, crucially important for the depletion of $^{22}$Na in ONe novae [2, 3]. Two different experiments [4, 5] concur in their results at proton energies above $E_p$=500 keV, but differ at lower energies, in particular in the region $E_p$=200 keV where the important resonances lay, and in particular in the decay of the Isobar Analog State. Also the protons to gamma branching ratios were only poorly determined in this nucleus. All of the above led us to seek the study of β-delayed proton decay of this nucleus using our well separated, high energy $^{23}$Al beam.

To measure protons at such low energies, the windows of the detectors are always a problem. We decided to avoid it by implanting the source in the detector. This can be done given the large kinetic energy of our sources produced in inverse kinematics. A setup consisting of a thin Si strip detector (p-detector) and a thick Si detector (β-detector) was designed and realized (Figure 1). The two detectors were mounted on an Al frame which was cooled to minimize the noise. This telescope is at 45° to the beam axis to allow for good gamma-ray detection with the HpGe detector situated at 90° outside the small chamber. A variable energy degrader consisting of an Al foil (0.8 mm thick in our case) on a computer controlled rotating feed-through was used to stop the source nuclei in the middle of the thin p-detector. We pulse the beam from the cyclotron, implanting the source nuclei (for 1 sec. in the case of $^{23}$Al), then switch the beam off and, after a very short delay (10 msec), measure for β-p and β-γ coincidences simultaneously (1 sec. again). Si detectors are sensitive to positrons, and the total signal in the implantation detector is the sum of the proton and beta contributions. The latter is a continuum, which shifts the proton peak and produces an asymmetry on the high energy side of it. It also produces a large background at lower energies. To minimize these effects, the p-detector must be as thin as possible, and the size of the pixel must be small.

The setup was used in a very recent experiment. The $^{23}$Al beam was obtained as described before [1]: using a 48 MeV/nucleon $^{24}$Mg beam from the K500 cyclotron and MARS to separate $^{23}$Al (at 40 MeV/nucleon). The measurements used the telescope in two different modes:

a) – the implantation control mode, in which the two detectors worked as a $\Delta$E-E HI telescope. It was used to determine the correct angle of the energy degrader for which the desired source was implanted in the first detector and to make sure the implantation is restricted to a central region of the detector. The signals in each detector were up to 300 MeV.

b) – the decay mode, in which the gain was adjusted to accommodate the detection of low energy protons and betas (up to 2.5 MeV in the p-detector and 5-6 MeV in the $\beta$-detector).

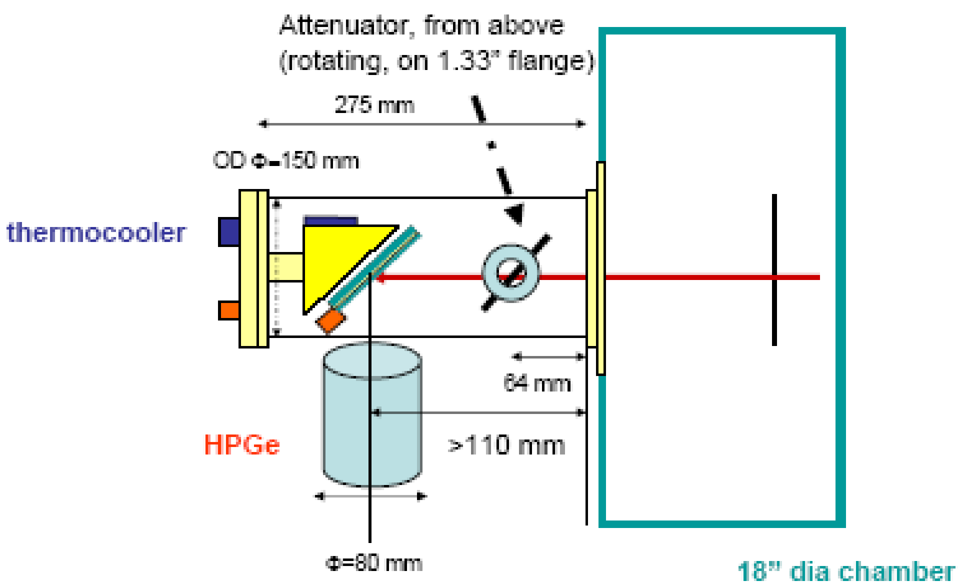


**Figure 1.** The experimental setup used to measure $\beta$-delayed p-decay from implanted sources.

After checking various configurations, in the end we opted for a W1(DS)-70 detector and the RAL108 preamp with CAEN N568B shapers. W1 are 50x50 mm$^2$ double sided Si 16x16 strip detectors produced by Micron Semiconductor Ltd. The high gain, low noise RAL108 preamplifiers were developed at the University of Edinburgh. The thinner detector was good for resolution, but implied a more careful implantation control. Mesytec electronics promised similar resolution.

We have measured in the setup above, the following:

- implantation control in the "HI telescope mode" for $^{24}$Al (and later for $^{23}$Al, $^{22}$Mg, $^{20}$Na, and $^{21}$Mg)
- gamma-ray detector calibration with $^{24}$Al implanted at the p-det position (either in p-det, or in an Al thin foil)
- $^{23}$Al $\beta$-delayed p-decay with $^{23}$Al implanted in the p-detector. $\beta$-proton and $\beta$-$\gamma$ coincident spectra were measured here to identify the proton peaks and get the proton branchings.

- β-background with $^{22}$Mg implanted in the p-detector.
- β-detector calibration with $^{20}$Na implanted in β-detector.
- p-detector calibration with:
  - $^{20}$Na (known βα emitter) implanted in p-detector
  - $^{21}$Mg (known βp emitter) implanted in p-detector
- off-line Ge detector efficiency calibration with sources ($^{152}$Eu, $^{60}$Co, $^{137}$Cs).

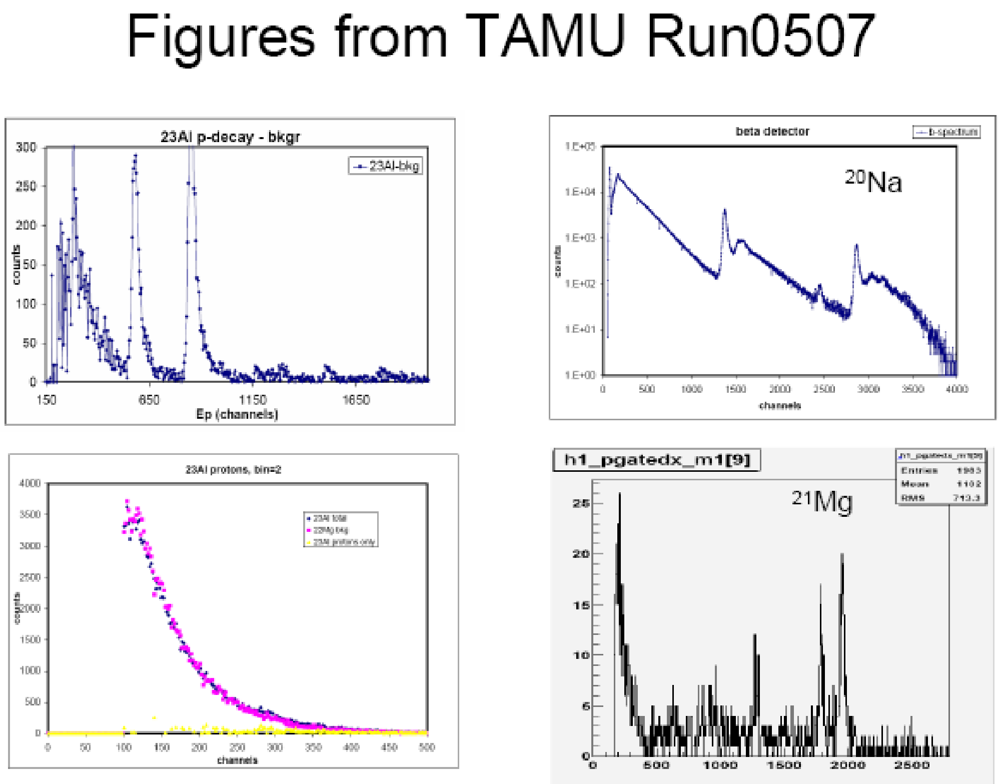


**Figure 2**. Spectra from the study of β-delayed p-decay of $^{23}$Al. Preliminary data only! Top left: a proton spectrum with β background subtracted. The proton peaks at 550 and 824 keV are very well separated. Bottom left: comparison of lower energy part of the spectra in p-detector from the decay of $^{23}$Al (β and p-decay) and of $^{22}$Mg (β only). Right: calibration spectra. Top: of the thick β-detector using implanted $^{20}$Na (β and α), bottom: of the thin p-detector using implanted $^{21}$Mg.

We intend to continue our studies to nuclei with similar properties and similar importance in explosive H-burning in stars: $^{27}$P and $^{31}$Cl.

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