EPJ Web of Conferences **66**, 02090 (2014)
DOI: 10.1051/epjconf/20146602090

Beta decay to continuum states: the case of ^{11}Be

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Abstract. Beta decay in exotic nuclei can lead to multi-particle final states. This contribution discusses briefly what decay mechanisms may enter in such decays and presents, on behalf of the IS541 collaboration at ISOLDE/CERN, preliminary data from a search for the beta-delayed proton decay of the halo nucleus ^{11}Be.

1 Beta-particle decay mechanism

The Q-values for beta-decays increase as one moves towards the driplines and eventually become larger than the particle separation energies in the daughter nuclei. This allows population of final states containing, apart from the beta particle and the associated (anti)neutrino, one or more particles (protons, neutrons or heavier particles) in continuum states and a recoiling final nucleus. Such processes allow many different physics questions to be probed experimentally — see [1, 2] for recent reviews — and are normally referred to as beta-delayed particle emission. However, this name suggests a two-step process: the beta decay feeding resonance states in the daughter nucleus that subsequently decay by particle emission. The other possible decay mechanism, beta decays feeding the continuum states directly, deserves consideration as well.

Some indication for decays going directly into the continuum exist for halo nuclei, see [3–5] and references therein for details on the halo structure. The two-neutron halo nuclei ^{6}He and ^{11}Li appear both to have beta-delayed deuteron emission taking place directly into the continuum [1, 6]. For ^{11}Li this process has a branching ratio of the order of 10^{-4}, the low value mainly being due to the small energy window, whereas cancellation effects reduces the branching ratio for ^{6}He down to the 10^{-6} level. The simple-minded model of the decays is that one of the two halo neutrons beta-decay into a proton and combines with the other one to form a deuteron. A complicating factor in the theoretical description of these two decays is therefore the "two neutron to deuteron" overlap that is sensitive to the correlations between the two neutrons. This is an interesting physics problem, but if the focus is on investigating the decay mechanism a much cleaner case would be the beta-delayed proton decay of a single-neutron halo nucleus.

2 The ^{11}Be(βp) decay

The most favourable case is ^{11}Be(βp). Estimates of the branching ratio indicates that this will be a very rare process [7] due to the low energy available, see table 1; the branching ratio will in most

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Table 1. Energies [8] for ^{11}Be beta-delayed particle decays

x	p	n	α	t
$S_x(^{11}B)$ (keV)	11228.6 ± 0.4	11454.12 ± 0.16	8664.1 ± 0.4	11223.6 ± 0.4
$Q_{\beta x}$ (keV)	280.7 ± 0.3	55.2 ± 0.5	2845.1 ± 0.2	285.7 ± 0.2

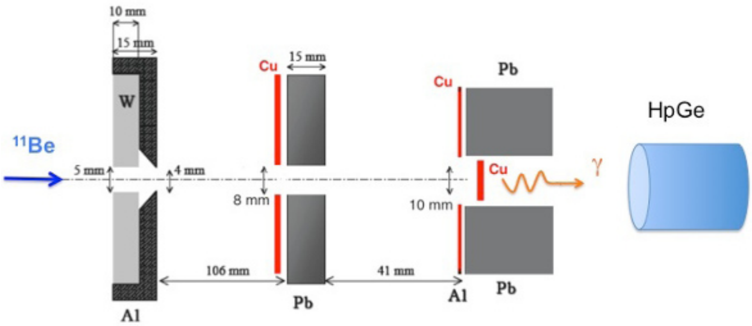

Figure 1. Sketch of the collection station at ISOLDE. The ^{11}Be beam is led through several collimators and collected in a Cu foil. Further shielding limits the count rate in the Ge detector that monitors the collection rate

estimates be a few times 10^{-8}. Looking for protons of kinetic energy a few hundred keV with this relative intensity is challenging, so the two attempts we have made have instead aimed at detecting the remaining nucleus, ^{10}Be, that exists only in very small quantities on earth. The two following sections present the results obtained so far.

2.1 The IS374 experiment

Both experiments have made use of the ISOLDE facility at CERN and its high-resolution separator that is crucial in order to limit the amount of contaminants in the samples. The IS374 experiment made sample collections in 2001 and the amount of remaining ^{10}Be in the samples were determined in an accelerator mass spectromery (AMS) experiment in Uppsala in 2008, details of the experimental procedures can be found in a recent paper [7].

No conclusive evidence for the decay were found. The amount of ^{10}Be in the sample was compatible with zero within the uncertainty and converted into a branching ratio of $(2.5 \pm 2.5) \cdot 10^{-6}$, significantly above the published theoretical expectations, the most detailed of which [9] gave $3.0 \cdot 10^{-8}$.

2.2 The IS541 experiment

The IS541 experiment [10] made sample collections in December 2012, a schematic diagram is given in figure 1. The evaluation is still ongoing, so only preliminary results can be presented at this stage.

The normalization was obtained from a Ge-detector that recorded the γ spectrum from the decay of ^{11}Be during collection, see figure 2. The main line seen is at 2124 keV, correcting its intensity for detection efficiency and absorption gives a deduced amount of collected ^{11}Be in the first sample slightly above 10^{12}. Two other samples were taken: at the mass position of ^{11}Li (0.02 mass units heavier than ^{11}Be) and, for one second only, at the ^{10}Be mass position.

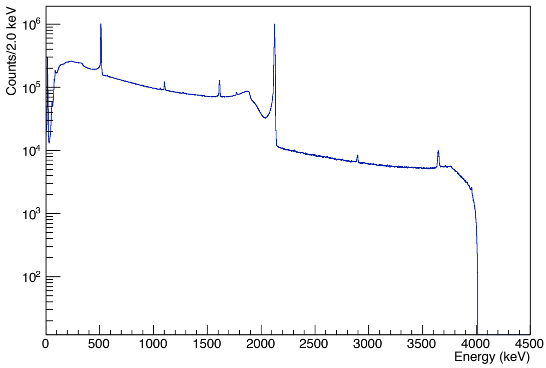

Figure 2. The main lines in the γ spectrum recorded during the collection are the 2124 keV line from the decay of ^{11}Be and the 511 keV line from positron annihilation

The AMS was this time performed at the Vera facility in Vienna. Details of the procedure will be reported later, they resulted in a significant improvement of the sensitivity to the number of ^{10}Be atoms, measured relative to a known number of added ^{9}Be atoms. The deduced amount of atoms in the ^{10}Be sample agreed with the estimation from the implantation current. The number for the ^{11}Li sample was below 10^5 and consistent with the lack of observed γ-rays from the decay of ^{11}Li. The number for the ^{11}Be sample was just above 10^7.

Contaminations in our sample could arise due to the tail of the main ^{10}Be peak or due to the tail of ^{11}Li, whose decay also produces ^{10}Be. Both possibilities are ruled out by the low recorded number of atoms for the ^{11}Li sample. The ISOLDE mass separator profile was followed down to the 10^{-5} level that occured at a mass difference of 0.05 mass units. In principle the molecule ^{10}Be^{1}H would appear on the ^{11}Be position, but this molecule is unlikely to be formed in the target and to survive through the laser ion source. The result gives therefore a strong indication for the ^{11}Be(βp) decay with a branching ratio in the range (5–10) $\cdot 10^{-6}$.

3 Discussion and outlook

The experimentally found branching ratio is surprisingly large, but actually consistent with the outcome of the first experiment. As a first step, the intensity can be converted into a beta-strength via the standard relation $ft = K/(g_V^2 B_F + g_A^2 B_{GT})$. A Gamow-Teller beta-strength B_{GT} below 3 (the free neutron value, the Fermi-strength is expected to concentrate in the isobaric analogue state) is consistent with decays that take place with a centre-of-mass energy for the outgoing proton below 200 keV, above 200 keV the f-factor is too small. The definition of beta-strength is actually depending on what theoretical framework is used to extract it; however, this will not contribute significantly to the uncertainty here so the above simple relation can be used safely.

Since the most recent [9] theoretical prediction for a direct decay mechanism lies more than two orders of magnitude below the experimental value we shall look here mainly for an explanation of the decay intensity in terms of a sequential model. The latest compilation [11] lists three levels in the appropriate excitation energy range in ^{11}B with excitation energy (keV), spin-parity and width (keV): 11272 ± 14, $9/2^+$, 110 ± 20; 11450 ± 17, unknown, 93 ± 17; 11600 ± 20, $5/2^+$, 180 ± 20. Due to the Coulomb barrier the penetrabilities are low even for s-wave protons, see figure 3, and the $9/2^+$ and $5/2^+$ levels are therefore not expected to contribute to the decay since they would correspond to g- and d-waves. The 11.45 MeV level may contribute if its spin-parity is $1/2^+$, but it is known to mainly decay via α-particle emission. Decays through this level would therefore only contribute

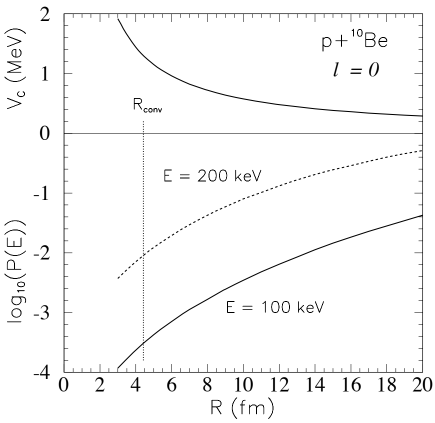

Figure 3. The upper part of the figure shows the Coulomb potential in the p+^{10}Be system. The lower part shows the penetrability for s-wave protons of centre-of-mass energy 100 keV and 200 keV. The line marks the channel radius calculated as 1.4 fm $\cdot(1 + 10^{1/3})$

to the proton channel with probability Γ_p/Γ_{tot} and one has to go to the limit of current error bars in order to make this level fit. Let us consider whether a new level in ^{11}B could describe the decay. The requirements of a large B_{GT} and a penetrability that does not quench the decay too much may be fulfilled simultaneously if the proton wave-function of the level extends into the p+^{10}Be channel. This is a situation that has been considered theoretically earlier by Barker [12], but it would clearly be valuable to have a more thorough investigation of resonant structures in the p+^{10}Be continuum.

If our final analysis and future experiments confirm the present indications for a βp branching ratio much above the predicted value there will clearly be a need for clarification of our theoretical understanding of the process.

Acknowledgements

The results presented here are due to the efforts of my colleagues in the IS541 collaboration. We would like to thank the ISOLDE group for the successful operation of the HRS separator at very high resolution. My final thanks goes to Aksel Jensen for many illuminating discussion of the conceptual issues in the decay mechanism.

References

[1] M. Pfützner, M. Karny, L.V. Grigorenko and K. Riisager, Rev. Mod. Phys. **84**, 567 (2012)
[2] B. Blank B and M.J.G. Borge, Prog. Part. Nucl. Phys. **60**, 403 (2008)
[3] K. Riisager, Physica Scripta T**152**, 014001 (2013); arXiv:1208.6415
[4] A.S. Jensen, K. Riisager, D.V. Fedorov and E. Garrido, Rev. Mod. Phys. **76**, 215 (2004)
[5] I. Tanihata, H. Savajols and R. Kanungo, Prog. Part. Nucl. Phys. **68**, 215 (2013)
[6] T. Nilsson, G. Nyman and K. Riisager, Hyperfine Int. **129**, 67 (2000)
[7] M.J.G. Borge et al., J. Phys. G **40**, 035109 (2013); arXiv:1211.2133
[8] M. Wang et al., Chinese Phys. C **36**, 1603 (2012)
[9] D. Baye and E.M. Tursonov, Phys. Lett. B **696**, 464 (2011)
[10] A. Becerril et al., CERN-INTC-2012-017 / INTC-P-331 (2012)
[11] J.H. Kelley et al., Nucl. Phys. A **880**, 88 (2012)
[12] F.C. Barker, Phys. Lett. B **322**, 17 (1994)