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Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Electron capture of ^{8}B into highly excited states in ^{8}Be

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Abstract: We propose to study the decay of the proton halo nucleus ^{8}B at ISOLDE with the aim of determining the beta strength for decays into highly excited states of ^{8}Be. Of particular interest is the 16.922 MeV state, believed to be populated through electron capture, and the so far unobserved electron capture delayed proton emission branch expected to proceed via the 17.640 MeV state.

Requested shifts: 16 shifts

1 Motivation

The beta decay of the proton halo nucleus ^{8}B into ^{8}Be has been studied in detail several times during the last decades. Still, there is surprisingly little known experimentally about the beta strength distribution in the decay. The only transitions observed so far pass through 2^+ levels in ^{8}Be that break up into two alpha particles, but there is within the Q_{EC}-window a well established 1^+ level that decays mainly by proton emission. Decays through this level will give a 337 keV proton and a 48 keV recoiling ^{7}Li ion, see figure 1.

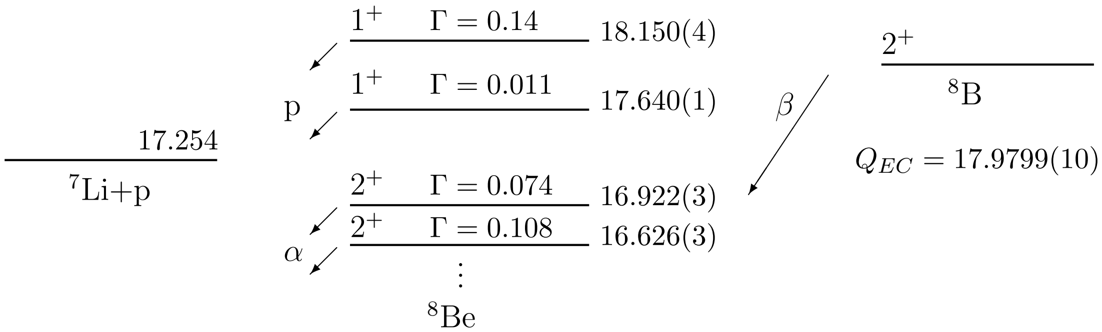

Figure 1: The excited state spectrum of ^{8}Be around 17 MeV. All energies are in MeV and are taken from AME2012 and TUNL.

This so far unobserved transition is highly interesting as a probe of the halo structure of ^{8}B. In a schematic model [1] that can be expected to describe the main strength of the decay, one could think of the decay as proceeding separately for the core and the halo proton with the non-decaying part as "spectator":

$$\mathcal{O} \mid c + h\rangle = \mathcal{O}(\mid c\rangle \mid h\rangle) = (\mathcal{O} \mid c\rangle) \mid h\rangle + \mid c\rangle(\mathcal{O} \mid h\rangle)$$

The decay through the 1^+ level is described by the first term and the strength can therefore be estimated from the known decay of the ^{7}Be core nucleus. This gives $B_{GT} = 1.83$ corresponding to a theoretical branching ratio of $2.3 \cdot 10^{-8}$, see [2] for details. The only experimental information at the moment is an upper limit on the beta-delayed proton branch of $2.6 \cdot 10^{-5}$ at 95% confidence level, as shown in fig. 2. (The limit was a byproduct from a precision measurement of the decay that focussed on the beta-delayed α branch [3].) Our simple estimate is supported by a three-cluster model calculation [4] that for two different potentials yields B_{GT} values of 1.366 and 1.997.
Support for the schematic model has been found in IS541 that successfully detected [5] beta-delayed proton decay from the neutron halo nucleus ^{11}Be. This decay is described by the last term in the equation.
The decay of ^{8}B into the 16.626 MeV state has been observed by several groups, but the (mainly EC) decay into the 16.922 MeV state was first seen in our JYFL experiment [3]. A total of five counts were observed compared to 180 events for the 16.626 MeV state, see fig. 3. *A confirmation of this decay with better statistics would be very valuable and would allow to test the current assumptions in the treatment of the 2^+ doublet:*
The famous [6] 16 MeV 2^+ doublet is strongly mixed in isospin so that the states have dominant configurations ^{7}Li+p and ^{7}Be+n, respectively. The beta decay through them

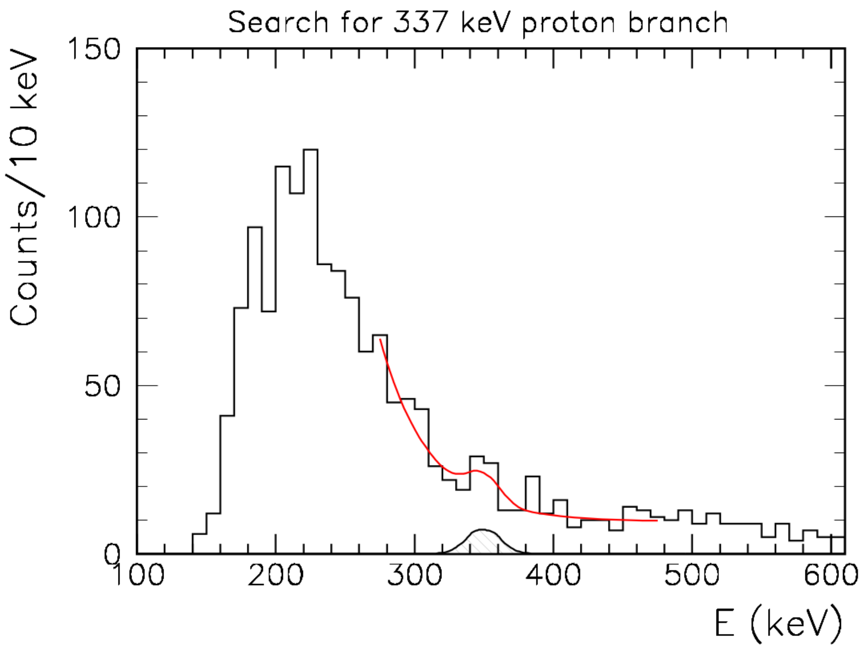

Figure 2: The experimental upper limit placed on the emission of 337-keV protons based upon data collected in anti-coincidence mode during our previous experiment at JYFL [2].

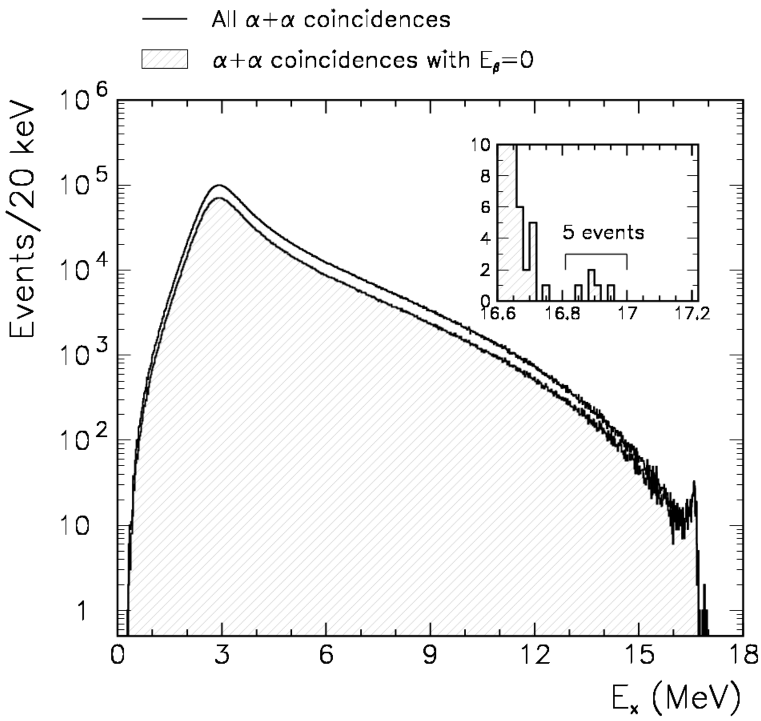

Figure 3: Excitation energy of ^{8}Be following ^{8}B decay as reconstructed from α coincidences [3]. A total of 5 events were measured in the region corresponding to the population of the 16.922-MeV state.

has so far been modelled by assuming that Fermi strength only goes to the $T = 1$ component and Gamow-Teller strength only to the $T = 0$ and with the level mixing being constrained by alpha scattering data, see [7] and references therein for details. With this assumption one deduces a model-dependent value of $B_{GT} = 2.06$. A higher statistics beta-decay spectrum will give further experimental constraints and allows to test that the feeding of the two 16 MeV levels are consistent with what the level mixing model predicts. It has recently been shown [8] that resonances may appear in a different way when seen in beta-decay and in elastic scattering, in particular when fed in beta-decay from a halo state.

We note that the total Gamow-Teller beta strength (neglecting quenching) in the decay is 6. The transitions we are considering here will therefore have about two thirds of the maximum strength. This of course implies that *we are not looking just at small components of the wavefunction of ^{8}B, but are sensitive to major parts of it.*

The average yield of ^{8}B in the JYFL experiment was about 200/s. The recent target development at ISOLDE [9] has succeeded in producing a substantially higher yield of $2.8 \cdot 10^4$ ions/μC as a BF_2 molecule. This now allows to tackle the above two challenges in the ^{8}B decay.

2 Set-up

A schematic diagram of the first proposed setup is shown in figure 4, left panel. The BF_2 beam is implanted in a 20μg/cm^2 carbon foil located in the centre of a silicon detector array. On all four sides of the implantation site are double-sided strip detectors (DSSDs) backed by 1.5 mm thick pad detectors. An additional pad detector is placed directly underneath the setup, leaving only the top surface uncovered.

Two of the opposing DSSD detectors will have thickness 60μm, which is sufficient to stop α particles emitted in the decay of the 16.922 MeV state in ^{8}Be. By selecting coincident events between these detectors, and requiring that the particles have opposite momenta, a clean selection is possible, as demonstrated in figure 3.

Detection of protons resulting from the decay of the 17.640-MeV state is more difficult due to the lack of a coincident particle to gate on; the decay proceeds via electron capture so no other charged particle emission is expected. Instead we must rely on anti-coincidence cuts to remove unwanted events from the region of interest. By considering only the central region of the DSSDs, the contribution from α particles is removed by detection of the partner α in the opposite detector (by limiting ourselves to the centre of each DSSD we ensure that the second α is emitted in the solid angle occupied by the opposite DSSD).

With respect to the results from the previous experiment at JYFL (see again Fig. 2), there are *two improvements* required to be sensitive to proton emission at the branching ratio expected. The *first* is an increase in statistics, which is provided by the factor of $\sim$100 greater yield now available at ISOLDE. The *second* is the suppression of the background component in the region of interest.

This background component is likely to represent the detector response to cosmic muons, in addition to positrons emitted in the decay of ^{8}B. The use of two 40-μm DSSDs should permit this response to be substantially reduced due to both the lower energy deposition

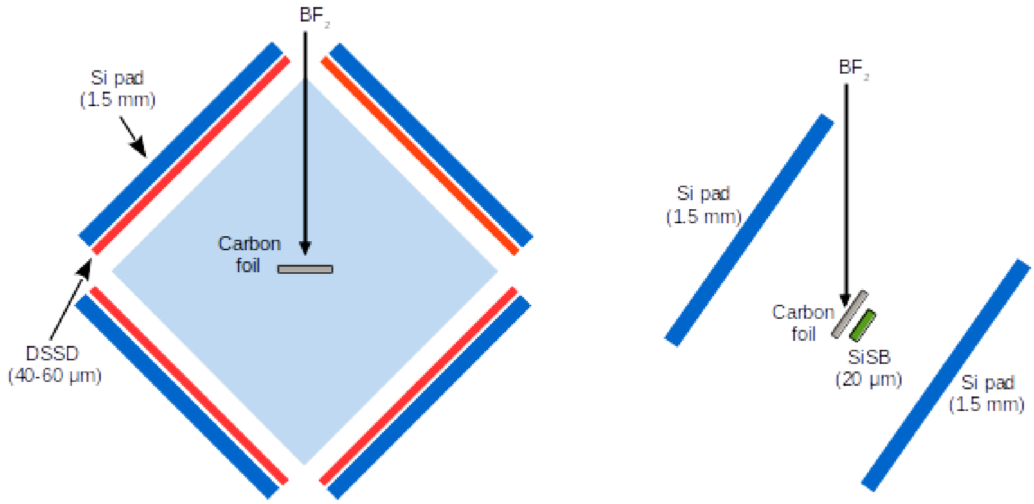

Figure 4: Left: Schematic view of the proposed detector configuration. The sides of the box are formed of 60 (or 40) μm DSSD plus 1.5-mm pad telescopes. A thick pad detector is placed below the carbon foil. Right: the proposed detector configuration for the second part of the experiment. A silicon surface barrier detector is placed in close proximity to the carbon foil with two thick pad detectors acting as anti-coincidence vetos.

and probability of interaction. The combination of these two improvements should permit a gain of at least one order of magnitude in sensitivity to proton emission relative to the previous experiment at JYFL.
To increase the sensitivity of the setup to the point required for detection of the proton branch at the expected 10^{-8} level we propose to perform a second measurement using a modified setup, shown in the right panel of fig. 4. In this configuration a single 20 μm thick silicon surface barrier (SiSB) detector is placed in close proximity to the implantation site in order to give a solid angle coverage of at least $\sim$10%. It will be operated in anti-coincidence with the two pad detectors shown in order to remove α and β contributions as far as is possible.
An additional gain in sensitivity in this configuration is expected to be obtained from the lack of segmentation, and so interstrip regions, in the detectors used. In principle these could lead to α particles being missed (a problem for the veto detectors) or registered with only a fraction of their energies, resulting in a low-energy tail. The decrease in detector thickness will also significantly lower the detector beta response further boosting the signal to background ratio.

3 Beam request

We request 15 shifts of ^{8}B beam, delivered as BF_2, split into two parts of 6 and 9 shifts, respectively. The first 6 shifts will use a detector configuration as shown in the left panel

of fig. 4, while the following 9 shifts will use the setup in the right panel. We request one extra shift for the change over between the two configurations, but could also (if this eases the scheduling) take the two parts at different occasions. We request the use of the IDS position (but do not need the IDS γ set-up) since we know the background conditions here and expect the background to be lower than at the alternative LA1 position.
The background at IDS were measured this May in the IS605 set-up that is very similar to the one we intend to use. From a background run we have a cosmic ray count rate in the 325–375 keV region of 2.5/h in a 60 μm DSSSD detector, and about a fourth of that in 40 μm. The cosmic ray background in a 40 μm DSSSD is thus about as intense as our signal, and for the 20 μm SiSB detector it will be much less. From the same run the probability of a beta particle giving a signal in the 325–375 keV interval in the central part of a 40 μm DSSSD was found to be $1.1 \cdot 10^{-6}$, i.e. an improvement with respect to the JYFL experiment of more than an order of magnitude. The beta response in the 20 μm SiSB detector should therefore be reduced down to the same level as the expected proton signal.
Given a yield of $2.8 \cdot 10^4/\mu$C, and assuming a proton current of 1.5 μA, we expect a total of $7.3 \cdot 10^9$ implantations over 6 shifts, representing a factor of 130 increase over the previous study at JYFL and a similar increase in the statistics with which decays to the states at 16.6 and 16.9 MeV can be observed. With this data it should also be possible to improve the limit on the branching ratio to the 17.64 MeV state by some two orders of magnitude. Over the following 9 shifts we expect a further $1.09 \cdot 10^{10}$ implantations. Taking the expected proton branching ratio to the 17.64 MeV state of $2.3 \cdot 10^{-8}$, this corresponds to 250 protons being emitted over 4π, of which $\sim$25 should be incident on the SiSB detector. This should permit us to be sensitive to this branching ration at the 10^{-8} level.
Summary of requested shifts: 16 shifts total, split into 6 shifts and 9 shifts for the two configurations with 1 shift for the change over.

References

[1] T. Nilsson et al., Hyperfine Int. **129** (2000) 67

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[8] K. Riisager et al., Nucl. Phys. A **940** (2015) 119

[9] C. Seiffert, contribution to the ISOLDE workshop 2015

Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: (*name the fixed-ISOLDE installations, as well as flexible elements of the experiment*)

Part of the	Availability	Design and manufacturing
(if relevant, name fixed ISOLDE installation: COLLAPS, CRIS, ISOLTRAP, MINIBALL + only CD, MINIBALL + T-REX, NICOLE, SSP-GLM chamber, SSP-GHM chamber, or WITCH)	☒ Existing	☒ To be used without any modification
[Part 1 of experiment/ equipment]	☐ Existing	☐ To be used without any modification ☐ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[Part 2 of experiment/ equipment]	☐ Existing	☐ To be used without any modification ☐ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[insert lines if needed]		

HAZARDS GENERATED BY THE EXPERIMENT (if using fixed installation:) Hazards named in the document relevant for the fixed [COLLAPS, CRIS, ISOLTRAP, MINIBALL + only CD, MINIBALL + T-REX, NICOLE, SSP-GLM chamber, SSP-GHM chamber, or WITCH] installation.

Additional hazards:

Hazards	[Part 1 of experiment/ equipment]	[Part 2 of experiment/ equipment]	[Part 3 of experiment/ equipment]
Thermodynamic and fluidic			
Pressure	[pressure][Bar], [volume][l]		
Vacuum			
Temperature	[temperature] [K]		
Heat transfer			
Thermal properties of materials			
Cryogenic fluid	[fluid], [pressure][Bar], [volume][l]		

Electrical and electromagnetic			
Electricity	Si detectors up to 400 V, 5 μA		
Static electricity			
Magnetic field	[magnetic field] [T]		
Batteries	☐		
Capacitors	☐		
Ionizing radiation			
Target material [material]	C		
Beam particle type (e, p, ions, etc)	^{8}B		
Beam intensity	$4.2 \cdot 10^4$ /s		
Beam energy	30–40 keV		
Cooling liquids	[liquid]		
Gases	[gas]		
Calibration sources:	ISOLDE triple-α source		
• Open source	☐		
• Sealed source	☐ [ISO standard]		
• Isotope			
• Activity			
Use of activated material:			
• Description	☐		
• Dose rate on contact and in 10 cm distance	[dose][mSV]		
• Isotope			
• Activity			
Non-ionizing radiation			
Laser			
UV light			
Microwaves (300MHz-30 GHz)			
Radiofrequency (1-300 MHz)			
Chemical			
Toxic	[chemical agent], [quantity]		
Harmful	[chem. agent], [quant.]		
CMR (carcinogens, mutagens and substances toxic to reproduction)	[chem. agent], [quant.]		
Corrosive	[chem. agent], [quant.]		
Irritant	[chem. agent], [quant.]		
Flammable	[chem. agent], [quant.]		

Oxidizing	[chem. agent], [quant.]		
Explosiveness	[chem. agent], [quant.]		
Asphyxiant	[chem. agent], [quant.]		
Dangerous for the environment	[chem. agent], [quant.]		
Mechanical			
Physical impact or mechanical energy (moving parts)	[location]		
Mechanical properties (Sharp, rough, slippery)	[location]		
Vibration	[location]		
Vehicles and Means of Transport	[location]		
Noise			
Frequency	[frequency],[Hz]		
Intensity			
Physical			
Confined spaces	[location]		
High workplaces	[location]		
Access to high workplaces	[location]		
Obstructions in passageways	[location]		
Manual handling	[location]		
Poor ergonomics	[location]		

Hazard identification:

Average electrical power requirements (excluding fixed ISOLDE-installation mentioned above): [make a rough estimate of the total power consumption of the additional equipment used in the experiment]