EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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 ^{8}B at ISOLDE with the aim of determining the branching ratios 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 previously unobserved electron capture delayed proton emission branch expected to proceed via the 17.640-MeV state.

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Requested shifts: 15 shifts, split into 2 runs

1 Motivation

The combined interest in the decay of ^{8}B into ^{8}Be from nuclear physics[1] and astrophysics has led to it being studied several times during the last decades. 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 would give a 337 keV proton and a 48 keV recoiling ^{7}Li ion, see Fig. 1.

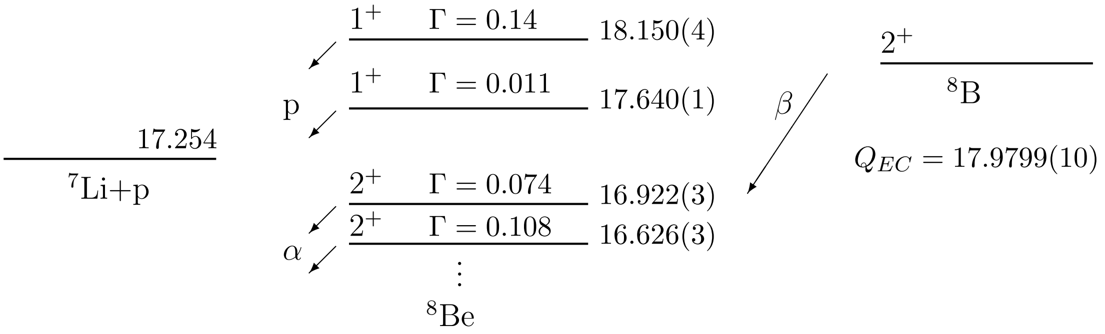

Figure 1: The excited state spectrum of ^{8}Be around 16 MeV. All energies are in MeV and are taken from AME2012 and TUNL.

A previous precision measurement of the decay of ^{8}B by our group [2] gave as a byproduct an upper limit on the beta-delayed proton branch of $2.6 \cdot 10^{-5}$ at 95% confidence level, as shown in Fig. 2 [3]. The decay rate can be estimated in a simple model that treats ^{8}B as a ^{7}Be+p system motivated by its small proton separation energy, one finds that the transition should have a strength very similar to the $B_{GT} = 1.83$ of the ^{7}Be ground state decay to ^{7}Li, see [3] for details. From this the decay into the 17.64-MeV state will have a theoretical branching ratio of $2.3 \cdot 10^{-8}$. The crude model estimate is supported by a three-cluster calculation [4] that for two different potentials yields B_{GT} values of 1.366 and 1.997.

The decay 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 [2]. 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 treatment of the 2^+ doublet. This famous [5] 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 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 [6] and references therein for details. A higher statistics beta-decay spectrum will give further experimental constraints and will allow to test that the two levels appear in the same way when seen in beta-decay and elastic scattering (this will not always be the case [7]).

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[1] Barker [1] refers to Louis Brown's unpublished book on Beryllium-8 subtitled: A History of Nuclear Physics.

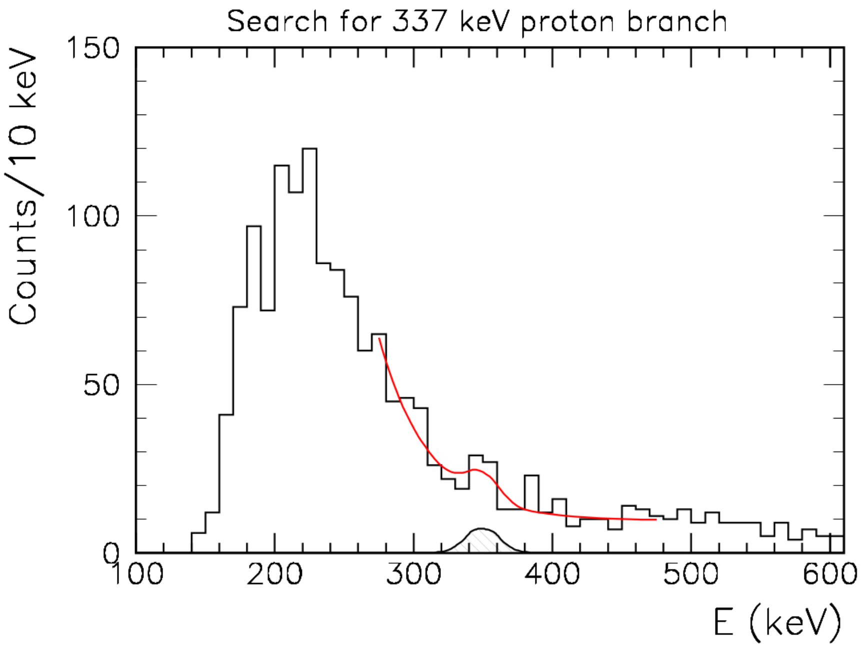

Figure 2: The experimental upper limit placed on the emission of 337-keV protons based upon data collected in anti-coincidence mode during the previous experiment at JYFL.

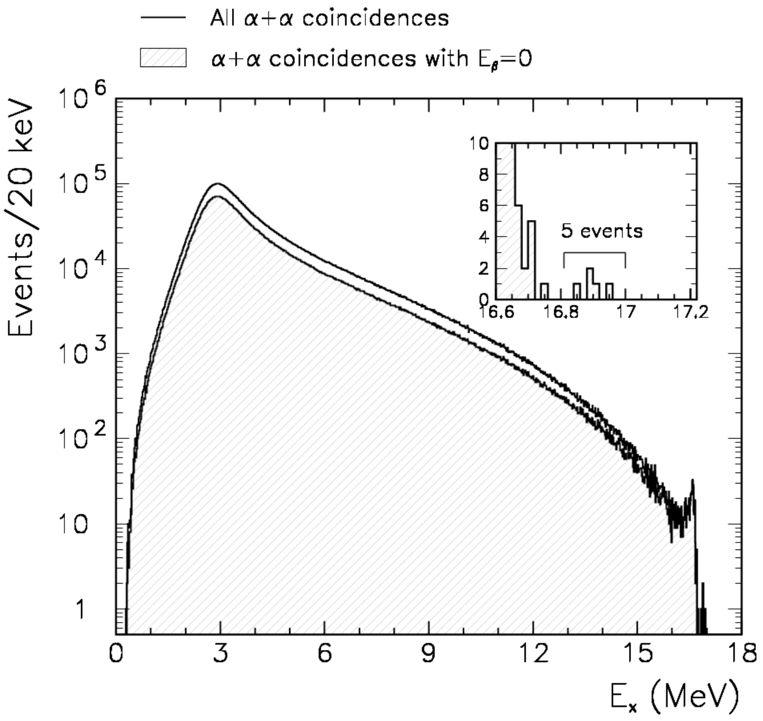

Figure 3: Excitation energy of ^{8}Be following ^{8}B decay as reconstructed from α coincidences. A total of 5 events were measured in the region corresponding to the population of the 16.922-MeV state.

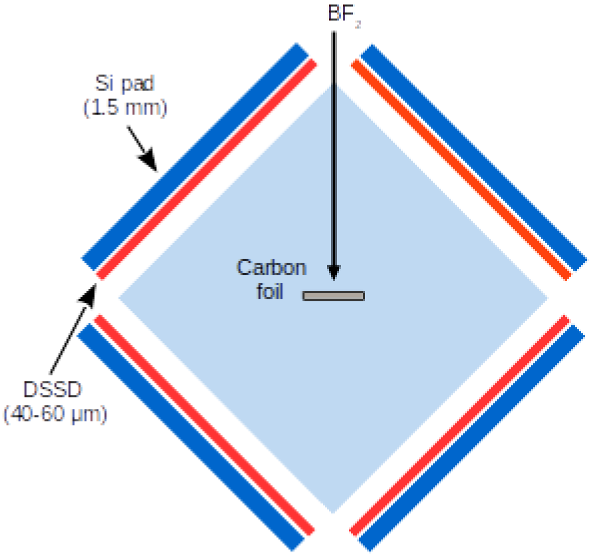

Figure 4: Schematic view of the proposed detector configuration. The sides of the box are formed of 60 (or 40) μm DSSD plus 1.5-mm pad telescopes. A thick pad detector is placed below the carbon foil.

The average yield of ^{8}B in the JYFL experiment was about 200/s. The recent target development at ISOLDE [8] 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 Setup

A schematic diagram of the proposed setup is shown in Figure 4. 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. 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

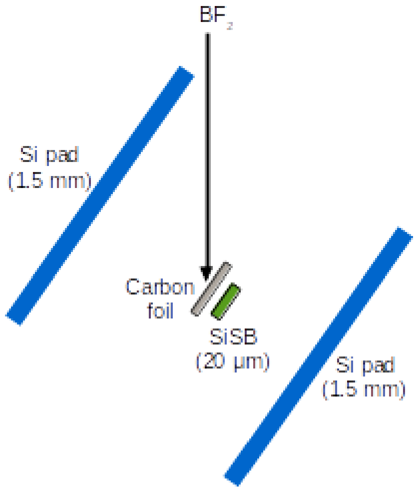

Figure 5: Schematic view of the proposed detector configuration for the second part of the experiment. A silicon surface barrier detector is placed in close proximity to the carbon foil with two thick pad detectors acting as anti-coincidence vetos.

detector (by limiting ourselves to the centre of each DSSD we ensure that the second α is emitted into 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 ~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 reduce this response substantially due to both the lower energy deposition and probability of interaction. The combination of these two improvements should permit a gain of at least two orders 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 Fig. 5. In this configuration, a single 20-μm thick silicon surface barrier (SiSB) detector is placed in close proximity to the implantation site to give a solid angle coverage of at least ~10%. It will be operated in anti-coincidence with the surrounding pad detectors 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 thus 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 separate runs of 6 and 9 shifts, respectively. The first 6 shifts will use a detector configuration as shown in Fig. 4, while the following 9 shifts will use the setup as shown in Fig. 5. We would also request that the two sets of shifts be separated by at least 1 month to permit optimisations of the setup for the second stage based on lessons learned during the first. We would request the use of either the IDS or LA1 for our setup, depending on the background conditions in these two areas.
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 these data we expect also 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 ∼25 should be incident on the 20-μm SiSB detector. This should enable us to be sensitive to this branching ratio at the 10^{-8} level.
Summary of requested shifts: 15 shifts total, split into 6 shifts and 9 shifts.

References

[1] F.C. Barker, Aust. J. Phys. **41** (1988) 743

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[4] L.V. Grigorenko et al., Nucl. Phys. A **665** (2000) 105

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[6] F.C. Barker, Aust. J. Phys. **42** (1989) 25

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

[8] 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]			
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]