EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Search for beta-delayed protons from ^{11}Be

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Abstract:
Beta-delayed proton emission from ^{11}Be will be a very rare process, but is believed to proceed as decays directly into continuum states which implies it will be a sensitive probe of the halo structure of the one-neutron halo nucleus ^{11}Be. We propose to improve existing (unpublished) limits on this decay mode by two orders of magnitude. Our earlier collection at ISOLDE indicates that the required intensity and purity of the source can be obtained. The branching ratio will be measured by counting the number of produced ^{10}Be atoms via accelerator mass spectrometry.

Requested shifts: 15 shifts

1 Introduction

An attempt to measure the ^{11}Be βp decay was made a decade ago [1] (experiment IS374). At first sight it may seem counterintuitive to search for a βp decay in a nucleus close to the neutron dripline, but this decay mode is energetically allowed exactly because the neutron separation energy is so low in ^{11}Be [2]. The physics motivation for looking for this decay is that it is most likely to take place as a decay of the halo neutron of ^{11}Be directly into a continuum proton [1, 3, 4]. The branching ratio of the decay will be very small, but the decay mode may give a new and independent probe for the single neutron halo structure. It should be noted that due to the unusually long total halflife of ^{11}Be the branching ratio is expected to be several orders of magnitude larger here than in other one-neutron halo nuclei, so this is the optimal case for searching for this specific halo decay mode. The original estimates of the branching ratio [1, 3] were of the order a few times 10^{-8} ranging up to above 10^{-6} depending on the assumptions made in the models used for the calculation. The theoretical arguments for seeing the decay have recently been strengthened by a more sophisticated calculation [4] in a two-body potential model that gives a broad energy spectrum peaking at 0.1–0.2 MeV and a branching ratio of $3.0 \cdot 10^{-8}$.

The IS374 experiment gave valuable experience in production of a source of the required high purity. A source with $5 \cdot 10^{11}$ atoms was collected, and a subsequent accelerator mass spectrometry (AMS) measurement gave a limit of 10^6 atoms of ^{10}Be in the source, giving a limit on the branching ratio of the order $2 \cdot 10^{-6}$. These results are now being written up for publication [3]. The ISOLDE yields of ^{11}Be have increased during the last decade from $7 \cdot 10^6$ ions/μC to about $2 \cdot 10^7$ ions/μC mainly due to increases in the laser ionization efficiency (information given at the 2008 ISOLDE workshop). For reference, the average ^{11}Be intensity at the IS374 collection in 2001 was $3.6 \cdot 10^6$ ions/s, this intensity is lower than the old yield value since the beam purity is crucial and narrow slits were used (see the next section) but the beam intensity also decreased somewhat during the collection. Today one can therefore safely count on obtaining an average intensity of 10^7 ions/s and on being able to collect a source of a few times 10^{12} atoms.

2 Proposed experiment

The βp decay mode can be identified through detection either of the proton or of the resulting ^{10}Be ion. We shall, as in IS374, focus our efforts now on the detection of the longlived ^{10}Be since the detection of protons of a few hundred keV and this relative intensity is far from trivial and since beta-delayed triton emission in the same energy range cannot be excluded [1]. A repetition of the experiment today would give a sample with between 10^4 and 10^5 ^{10}Be atoms (using the branching ratio from [4]). Luckily, improvements in AMS techniques have taken place that make measurements of a sample of this magnitude feasible.

The detection efficiency of ^{10}Be (ions counted in the final detector per atom in sample) at VERA, the AMS facility at the University of Vienna, is approximately $5 \cdot 10^{-5}$ with the traditional detection method [5]. This low efficiency is mainly caused by the low yield

of negative BeO^- ions in the cesium sputter source generally used in AMS, which is on the order of 10^{-3}. While little can be done in this respect, with recent improvements ([6] as well as partly unpublished newer work) the VERA group was able to reduce the other losses, which are mainly caused by transmission through the AMS, from a factor 20 to a factor 2. This results in an improved overall efficiency of $5 \cdot 10^{-4}$, ten times higher than before. The methodical improvement was the use of a stack of silicon nitride foils to separate the stable isobar ^{10}B instead of the gas absorber used previously. This not only reduced the detector background, but also works at lower particle energy, allowing the use of charge state 2+ with a stripping yield of 60% instead of 3+ with a yield of only 5% after the tandem accelerator.

A Cu-foil (containing no ^{9}Be) could be used for collection. The sample will be produced by solving the foil in acid and precipitating BeOH. A known amount of ^{9}Be can be added as carrier in the solved state so that the amount of material going into the ion source is under control and the measured isotope ratio can be trusted. (The main constraints for the foil are that the material should not precipitate together with the BeOH and should have a low boron content.)

The collection of the ^{11}Be is planned to proceed as in IS374 [3]. The source activity will be monitored throughout the collection by recording the γ-rays from the ^{11}Be decay, in particular the 2124 keV line. The two main contaminants that could endanger the experiment are ^{11}Li, whose main decay branch is βn that also produces a ^{10}Be ion, and directly produced ^{10}Be from the target (the peak yield will be a factor about 10^3 higher). The ^{11}Li ion is displaced in mass with respect to ^{11}Be by $M/\Delta M = 500$ and use of the HRS will therefore reduce the contamination considerably, in the 2001 collection we obtained a suppression factor of about 10^3 through use of narrow slits. The primary yield of ^{11}Li is lower than that of ^{11}Be by a factor at least 2000, and the remaining orders of magnitude suppression is achieved by blocking collection in the first 150 ms after proton impact on target, by which time most of the ^{11}Li will have decayed.

Concerning the possible ^{10}Be background earlier measurements of the HRS response tails made using the strong ^{8}Li activity indicates that the tail of the mass 10 peak will not be a problem. We shall nevertheless check this by measuring the decrease of the ^{11}Be activity as well as of ^{8}Li (that is easily monitored) as we go off mass. Since many unusual molecular species have been observed in small amounts from various targets we should also worry about the possibility of collecting ^{10}Be as a beryllium hydride ion (BeH^+). The mass difference to ^{11}Be, $M/\Delta M = 36600$, is here too small to allow direct separation. Dedicated runs to look for BeH components in the other cases — ^{11}Be observed on mass number 12 (via particle detection), ^{7}Be observed on mass number 8 (via gamma detection) or ^{9}Be observed on mass number 10 (e.g. via AMS) — will all require long beamtime. We therefore have to check directly for ^{10}Be on mass 11, this will be done by collecting a separate sample without laser ionization. The BeH ion will, if it appears at all, not be produced via laser ionization and its yield should therefore be the same when lasers are turned off in contrast to ^{11}Be. We stress that we do not expect a strong BeH component since the ionization energy of the BeH molecule is 8.22 eV [7] and its dissociation energy 3.26 eV.

We expect to measure some tens of atoms in the AMS experiment and the statistical uncertainty will therefore be noticable. To limit the systematic uncertainty we propose a

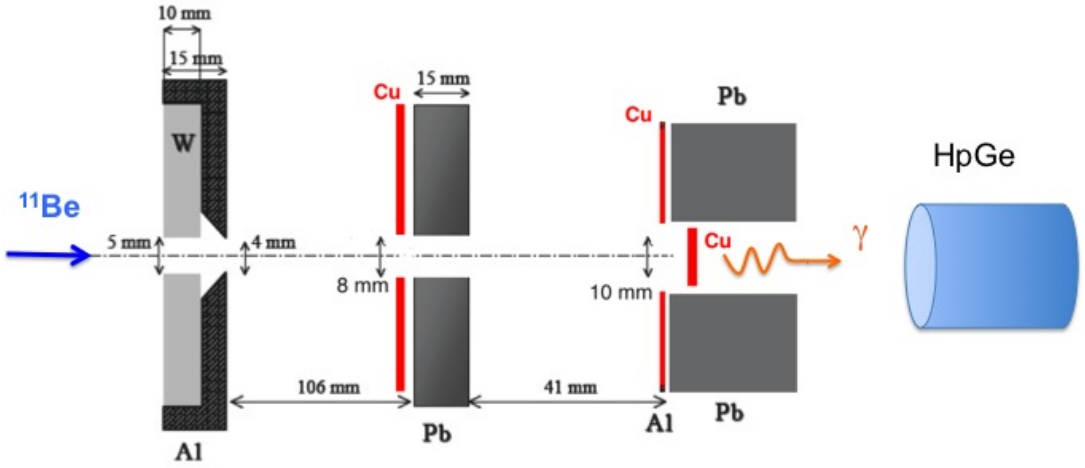

Figure 1: The set-up for collection (based on the 2001 IS374 run) with several collimation stages. The Ge detector will be placed more than 30 cm downstream.

further cross-check of the efficiency of the AMS part of the measurement by collecting a sample of ^{10}Be obtained as decay product of ^{11}Li. This collection should take place at the end, since the beta-delayed neutron decay leads to recoiling ^{10}Be ions where only about 50% will stay in the collection foil so that the collection chamber may be contaminated. We only aim for a control sample of about 10^6 atoms which can be obtained in a few hours even with a reduced ^{11}Li yield. The absolute number of atoms is not critical, but we must know that number well and determine it through monitoring the activity of the 320 keV gamma line during collection.

3 Set-up and beam request

The set-up for the collection is simple, see figure 1. The collimators ensure that the spot on the Cu foil containing the activity is well defined. A standard Ge detector will be placed downstream to monitor the activity, it will be efficiency calibrated before the collection and will cover only a small solid angle to reduce its deadtime. We will furthermore measure the integrated current on the collection foil.
The collection can be done at LA1 or LA2. The 10 MBq source of ^{11}Be (in equilibrium during collection) would give a dose rate of about 0.4 mSv/h in 10 cm distance without shielding. Due to the halflife of 13.8 s the ^{11}Be activity will decrease after collection within a few minutes and the final sample will in practice have no observable ^{10}Be activity.
The plan of the experiment is as follows:

- Optimization of the HRS for high resolution and purity, 2 shifts. Due to the low mass values we need to operate at 60 kV.
- Collection of one source of ^{11}Be of high intensity (a few times 10^{12} atoms), this will be doable in two days corresponding to 6 shifts. A second control sample to check

for BeH contamination will be collected for 3 shifts. The final ^{10}Be content of the two samples will be measured via AMS.

- Careful tracking of the beam profile of the HRS with our setting by following the ^{8}Li (2 shifts) and ^{11}Be (1 shift) beam profiles as a function of mass, in total 3 shifts. This will allow the direct contamination of ^{10}Be in the sample to be estimated.

- A collection of ^{11}Li in order to have a control sample with known content of ^{10}Be, 1 shift.

This gives a total of 15 shifts.

Summary of requested shifts: 15 shifts in total on a UC_x target with RILIS. The division of the shifts is as follows: 2 shifts set-up of HRS, 10 shifts ^{11}Be, 2 shifts ^{8}Li, 1 shift ^{11}Li.

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Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: Chamber for collection at LA1 or LA2.

Part of the	Availability	Design and manufacturing
Collection set-up	☒ 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

HAZARDS GENERATED BY THE EXPERIMENT

Additional hazards:

Hazards	Collection set-up	[Part 2 of experiment/ equipment]	[Part 3 of experiment/ equipment]
Thermodynamic and fluidic			
Pressure	[pressure][Bar], [volume][l]		
Vacuum	Standard ISOLDE vacuum		
Temperature	[temperature] [K]		
Heat transfer			
Thermal properties of materials			
Cryogenic fluid	LN_2 cooling of HPGe detector		
Electrical and electromagnetic			
Electricity	3 kV (HPGe detector)		
Static electricity			
Magnetic field	[magnetic field] [T]		
Batteries	☐		
Capacitors	☐		
Ionizing radiation			
Target material [material]			
Beam particle type (e, p, ions, etc)	^{11}Be		
Beam intensity	10^7 ions/s		
Beam energy	60 keV		
Cooling liquids	LN_2		
Gases	[gas]		
Calibration sources:	☒		
• Open source	☐		

• Sealed source	☒ [ISO standard]		
• Isotope	^{60}Co, ^{137}Cs, ^{228}Th		
• Activity	all sources $<$ 500 kBq		
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): less than 1 kW