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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

[title: Experimental investigation of decay properties of neutron deficient $^{116-118}$Ba isotopes and test of $^{112-115}$Ba beam counts]

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Abstract

We propose to study decay of neutron deficient isotopes $^{116-118}$Ba using Double sided Silicon Strip Detector (DSSSD). To study delayed-proton and alpha decay branching ratios of $^{116-118}$Ba are of special interest because of their vicinity to the proton drip line. The nuclear life-times and properties of the proton unstable states of Cs isotopes, populated through decay of $^{116-118}$Ba isotopes will be measured. In addition to that we propose beam development of $^{112-115}$Ba to study exotic decay properties of these neutron deficient nuclei and to search for super-allowed α-decay in future.

Requested Shifts : 22 shifts.

1. Introduction

Study of the exotic decay properties of nuclei near the proton drip line is at the frontier of nuclear physics today[1][2][3]. The nuclei in the mass region A~110-120 near the proton drip line exhibit a rich variety of structural information. Ba isotopes in this mass region are very close to the proton drip line. Several theoretical approaches predict exotic structure and exotic decay modes, in particular cluster decay, for these Ba isotopes[4][5]. Experimental verification of these predictions is lacking today. Moreover decay studies of these isotopes have been rarely undertaken, although their decay properties would provide very important structural information in particular concerning the coupling to continuum states occurring near the proton drip line. In this mass region several experimental observables clearly pointed out the failure of standard nuclear models which might be due to enhancement of the coupling to continuum states[6]. Beta delayed proton and beta-delayed alpha emission are expected to be observed in this mass region [7]. Cluster emission in this region might also be present which would yield additional structural information. Also in astrophysical environments the formation of clusters, respectively nuclei, plays a crucial role [8]. We would like to initiate a programme to study in details the properties of neutron deficient heavy nuclei. Since ISOLDE can produce beams of the light Barium isotopes, we propose here to make an accurate study of neutron deficient Ba isotopes. In a first step we would like to measure their delayed-alpha and delayed-p decay and branching ratios. In addition to that the life-times of the nuclear states, populated through electron capture or β^+-decay will be measured by proton-x-ray coincidence as described by Hardy et al[9]. As a further support of this region being prone to delayed-alpha emission it was reported that the only nucleus at intermediate and high mass that has a beta-delayed alpha branch of more than 1% is ^{110}I[10]. A review article [2] on decays of exotic nuclei recently written by M. Pfutzner and K.

Riisager has mentioned some of the challenges for such decay studies as well. S. W. Xu et al reported new β-delayed proton precursors in Nd, Pm, Sm, Gd, Dy near proton drip line[]. They measured β-delayed proton energy spectra and branching ratios which were compared with statistical model calculation.

We would, further, like to propose beam development of ^{112,113,114,115}Ba to determine the yield for future prospects. However, based on intensities of a similar beam like Cs, studied earlier[11], $^{118-116}$Ba should have sufficient yield to study the delayed proton and alpha branches from these isotopes. Delayed proton and alpha were measured for neutron deficient Cs isotopes at ISOLDE [12]. There have been attempts to perform these measurements [11] but due to experimental limitations they were never completed.

Present experimental Status from the available literature :

^{112}Ba : No Experimental study has been done yet.

^{113}Ba : Only one experimental study, has been reported by A. A. Hecht et al [13] using ^{58}Ni + ^{58}Ni and ^{58}Ni + ^{54}Fe reactions, but no details study of decay of the isotope have been done.

^{114}Ba : Cluster radio-activity and alpha decay of this isotope have been studied through a large number of experiments [14] [15] [16] [17]. Decay studies[11] has also been done but no idea about β-delayed α decay was obtained, β-delayed p decay was measured in an indirect method.

^{115}Ba : Preliminary half-life values have been determined by Guglielmetti et al[18]. No information about β-delayed α decay have been obtained from decay studies done by Z. Janas [11]

^{116}Ba, ^{117}Ba , ^{118}Ba: Decay studies have been done by Z. Janas [11][19], again with no prior information about delayed-α decay. study of excited states through ^{58}Ni(^{64}Zn, 2n2p) reaction [20], has been done for ^{118}Ba.

These are the all experimental studies done for these neutron deficient Ba isotopes and clear information about decay properties of these nuclei are really scarce.

The information so far known for these isotopes is given in the table below (nndc.bnl.gov) :

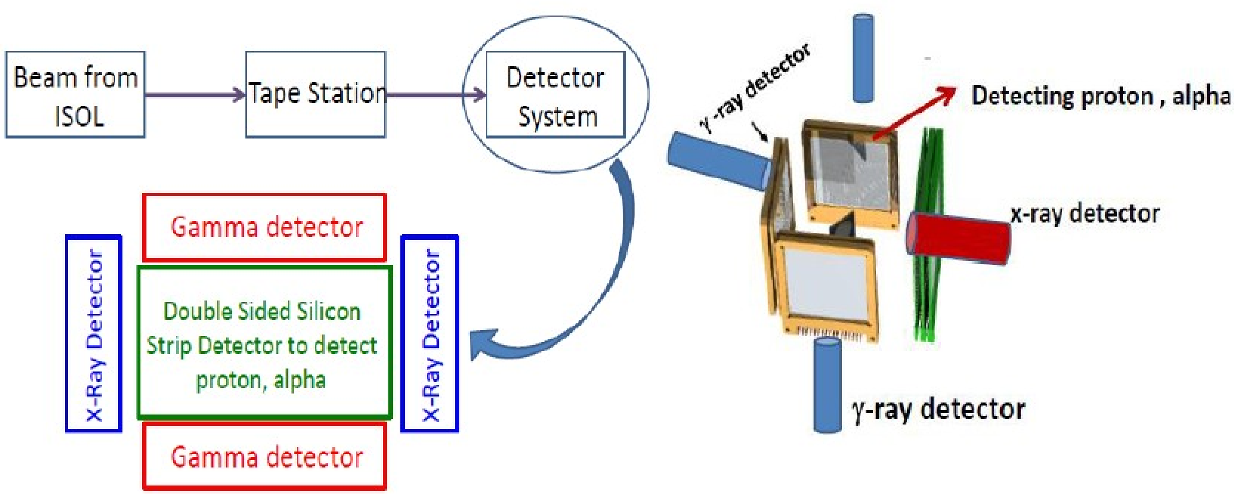
Isotope	Half-life (Sec)	Qα (MeV)	$Q_{\beta+}$ (MeV)	Decay mode
^{118}Ba	5.5	2.3	5.02	ε : 100.00 % εp
^{117}Ba	1.75	2.3	8	ε : 100.00 % εα > 0.00 % εp > 0.00 %
^{116}Ba	1.3	3	6.4	ε : 100.00 % εp : 3.00 %
^{115}Ba	0.45	2.9	9.7	ε : 100.00 % εp > 15.00 %
^{114}Ba	0.43	3.5	7.7	ε : 99.10 % εp : 20.00 % α : 0.90 % 12C < 0.0034 %
^{113}Ba	Not Known	3.7	11	Not Known
^{112}Ba	Not Known	Not Known	Not Known	Not Known

Physics Motivation:

The light Ba isotopes in this mass region have been populated using fusion-evaporation reaction in all the previous experiments. Decay study of these isotopes using the ISOLDE facilities will itself be very interesting. Due to lack of experimental data, clear idea about the decay properties as well as any structural information of these isotopes are rare. Particularly β-dacay of even-even nuclei will populate states of odd-odd nuclei, hence the experimental informations can provide very useful information regarding pair correlation close to the proton drip line. β-delayed proton decay from $^{116-118}$Ba have already been identified [11]. By means of the information of the delayed-protons, i.e. its energy spectra and coincidence measurements, one can obtain structural information of the parent nuclei and those could be compared to the theoretical models. The electron capture or positive β-decay could produce proton unstable (proton separation energies of ^{116}Cs and ^{117}Cs are 700 KeV and 740 KeV respectively) states of the daughter nuclei ($^{116-118}$Cs) and we can measure the life-times of those nuclear states though proton-x-ray coincidence [9] . In this region it would also be interesting to look for α-decay transition which might be possible according to several predictions. It is of our particular interest to search the following α-decay chain ^{112}Ba – ^{108}Xe – ^{104}Te - $^{!00}$Sn in future. In addition to that exotic cluster decay is another interesting part for our experimental investigation. In this respect accurate beam count information is essential for future experimental studies.

Experimental Procedure :

We propose to measure the exotic decay mode of $^{118-116}$Ba . Since the life time of these isotopes are rather long (5.5s to 0.45 s), we propose to use a tape transport system together with a detection system consisting of four 60-μm-thick, double-sided silicon strip detectors (DSSSD), each backed by a 1.5-mm-thick, un segmented silicon detector. The detectors are to be placed at 5 cm distance from the collection point in a rectangular configuration, whereby a solid-angle coverage of 30% can be achieved with an angular resolution of 3^0. The detector thicknesses are chosen such that the most energetic α particles (~8.5MeV) are completely stopped in the DSSSD. The delayed proton will be detected by the thick PAD Si detectors placed behind the DSSSDs. These detectors will be calibrated using standard alpha source and online produced known activity. Further, either a number of HpGe or LaBr3 detectors will be placed to detect gamma-rays. Earlier several decay studies were performed with Ge detectors in collaboration MINIBALL collaboration .



Set-up for experiment

Details of beam requirements :

We request beam time in two phase. In first phase, beam purity and events checking 4 shifts and in 2nd phase 18 shifts decay.

^{118}Ba : In the literature details of delayed proton and alpha decay is not available. Only indication of delayed proton is there. Considering similar situation like ^{118}Cs, we get

proton decay ~ $4x10^{-4}$/sec
alpha decay ~ $2x10^{-5}$/sec
Considering beam of ~10^5 p/sec, 6 shifts give ~ $3.5x10^5$ alpha events

Considering 30% detector solid-angle coverage, no. of events in all detectors ~ 10^5

^{117}Ba : Similarly for ^{117}Ba,

proton decay ~ 13%
alpha decay ~ $2x10^{-4}$/sec
Considering beam of ~10^4 p/sec, 6 shifts give ~ $3.5x10^5$ alpha events

Considering 30% detector solid-angle coverage, no. of events in all detectors ~ 10^5

^{116}Ba :

proton decay ~ 3%
alpha decay ~ $2x10^{-4}$/sec
Considering beam of ~10^4 p/sec, 6 shifts give ~ $3.5x10^5$ alpha events

Considering 30% detector solid-angle coverage, no. of events in all detectors ~ 10^5

The beam-time requirement is summarized in the following table :

Beam	Expected Intensity(particles/sec)	Target material	No of shifts required	Purpose
^{112}Ba		La	1	Beam development
^{113}Ba	10^2	La	1	Beam development

^{114}Ba	10^2	La	1	Beam development
^{115}Ba	10^2	La	1	Beam development
^{116}Ba	10^4	La	6	Delayed p and α decay study
^{117}Ba	10^4	La	6	Delayed p and α decay study
^{118}Ba	10^5	La	6	Delayed p and α decay study

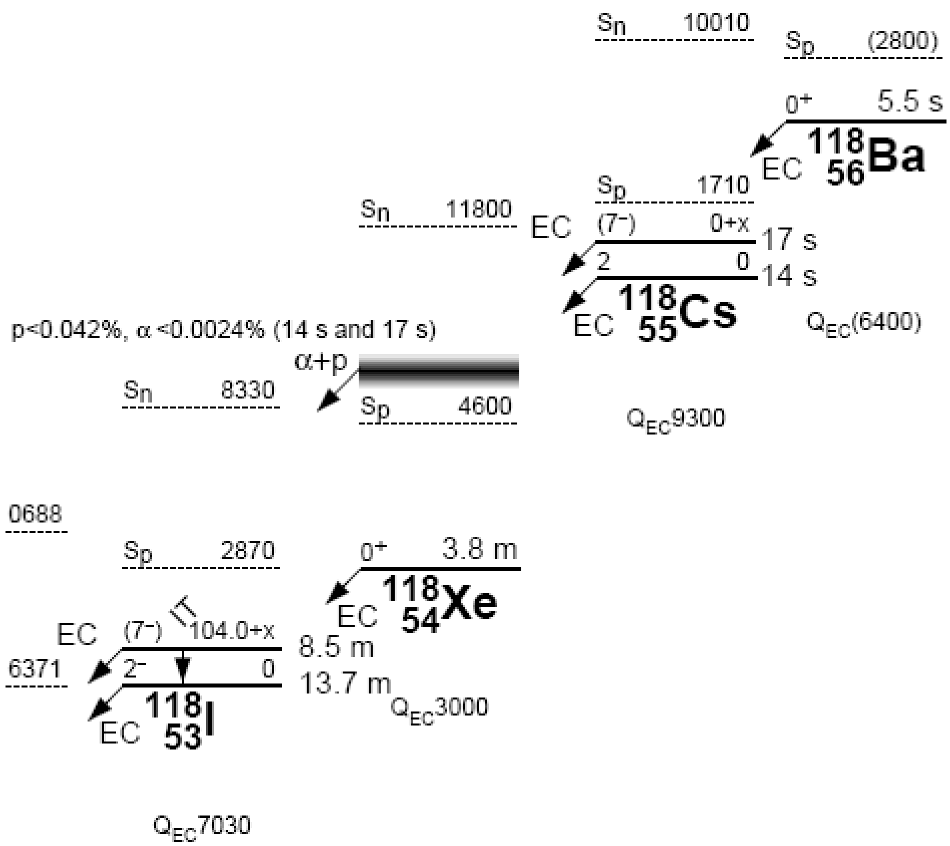


Fig.1a. Partial decay scheme of A~118

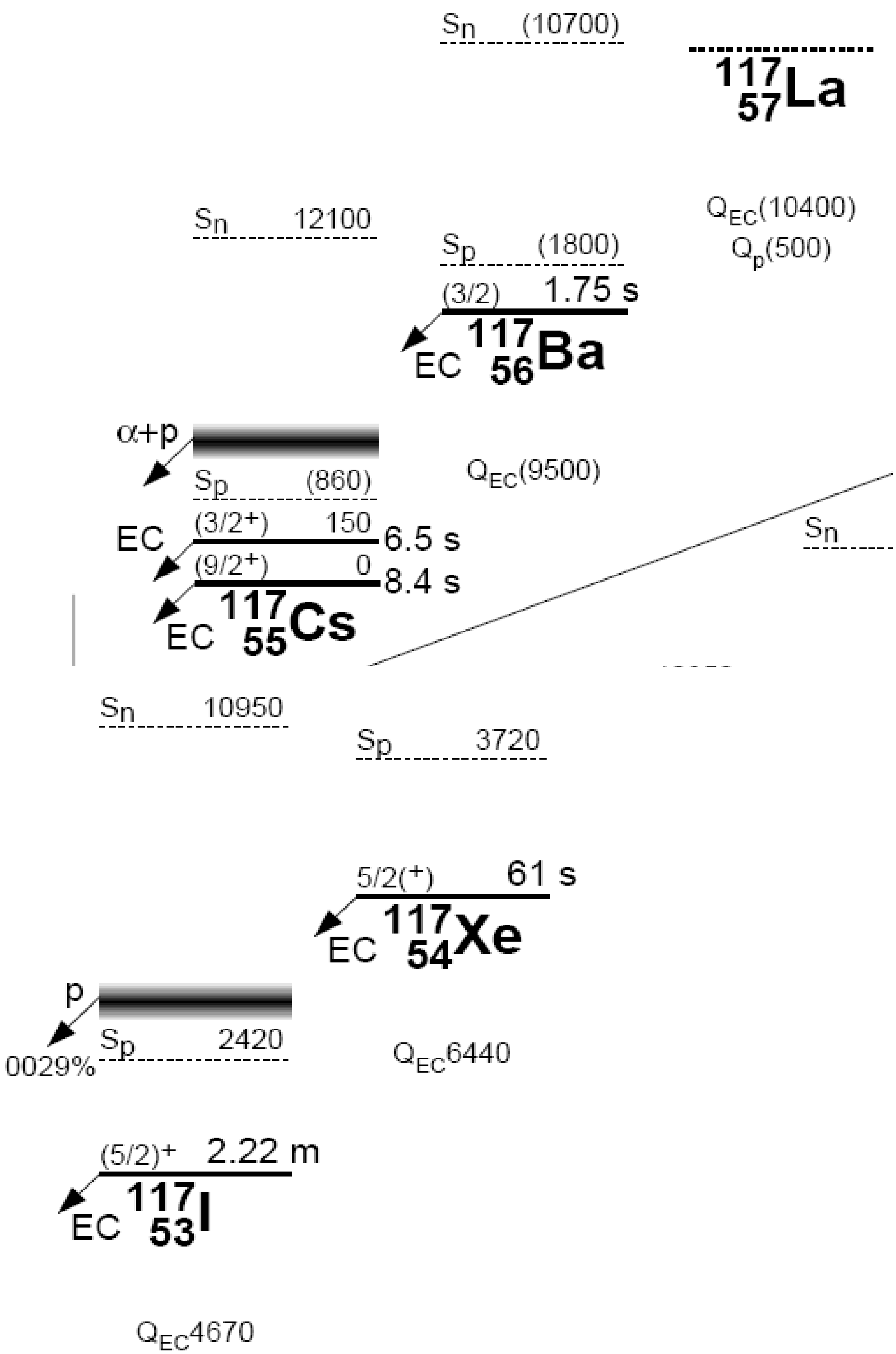


Fig.1b. Partial decay scheme of A~117

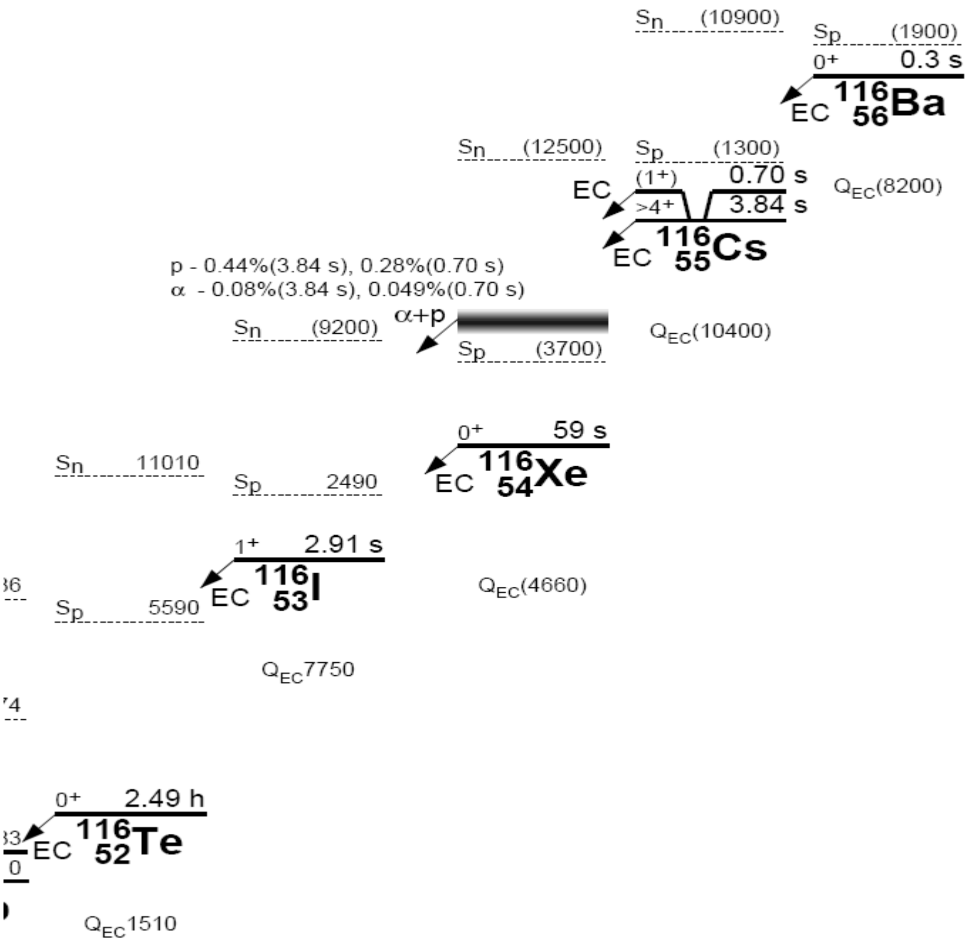


Fig.1c. Partial decay scheme of A~116

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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 Choose an item.	Availability	Design and manufacturing
Delayed proton and delayed alpha measurements	☐ Existing	☐ To be used without any modification ☐ To be modified
	☒ New	☐ Standard equipment supplied by a manufacturer ☒ collaboration responsible for the design and/or manufacturing

HAZARDS GENERATED BY THE EXPERIMENTS

(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 the experiment/equipment]	*[Part 2 of the experiment/equipment]*	*[Part 3 of the experiment/equipment]*
Thermodynamic and fluidic			
Pressure	-		
Vacuum	Standard ISOLDE vacuum		
Temperature	-		
Heat transfer	-		
Thermal properties of materials	-		
Cryogenic fluid	LN2 cooling of HPGe detectors		
Electrical and electromagnetic			
Electricity	3 kV (HPGe detectors)		
Static electricity	-		
Magnetic field	-		
Batteries	☐ -		
Capacitors	☐ -		
Ionizing radiation			
Target material	-		
Beam particle type (e, p, ions, etc)	$^{112-118}Ba$		
Beam intensity	10^5		
Beam energy	-		
Cooling liquids	LN_2		
Gases	-		
Calibration sources:	☐		
• Open source	☐		
• Sealed source	☐ [ISO standard]		
• Isotope	152 Eu, 60Co and 133Ba, 241 Am		

• Activity	all the sources <40 kBq		
Use of activated material:			
• Description	☐		
• Dose rate on contact and in 10 cm distance	-		
• Isotope			
• Activity			
Non-ionizing radiation			
Laser			
UV light			
Microwaves (300MHz-30 GHz)			
Radiofrequency (1-300MHz)			
Chemical			
Toxic	Pb shielding of HPGe detectors		
Harmful	-		
CMR (carcinogens, mutagens and substances toxic to reproduction)	-		
Corrosive			
Irritant	-		
Flammable	-		
Oxidizing	-		
Explosiveness	-		
Asphyxiant	-		
Dangerous for the environment	-		
Mechanical			
Physical impact or mechanical energy (moving parts)	-		
Mechanical properties (Sharp, rough, slippery)	-		
Vibration	-		
Vehicles and Means of Transport	-		
Noise			
Frequency	-		
Intensity			
Physical			
Confined spaces	-		
High workplaces	-		
Access to high workplaces	-		
Obstructions in passageways	-		
Manual handling	-		
Poor ergonomics	-		

3.1 Hazard identification: negligible