GANIL spiral2 — laboratoire commun CEA/DSM CNRS/IN2P3

PAC Date :	EXP # (Do not fill in):
09/06/16	E

PROPOSAL FOR AN EXPERIMENT

Title: Physics of Be and Li isotopes near the drip-line from (d,3He) reaction

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Abstract :

Following our discovery of an unprecedented reduction of the 11Li(d,3He)10He cross section, measured at RIKEN and interpreted by us an evidence of geometrical mismatch of valence nucleons' wave functions in 11Li and 10He, we propose to conduct a similar experiment 12Be(d,3He)11Li at GANIL. We expect that this reaction will display a measurable mismatch but at the same time it will be less affected by the final state interaction between 3He and the reaction product. The importance of experimental studying of the mismatch phenomenon follows from its possible interference with effects from fundamental NN and NNN interactions in the structure of light nuclei subject to modern ab-initio studies. In addition, we propose to study proton strength evolution in Be isotopes in the 10Be(d,3he) and 11Be(d,3He) experiments at GANIL with the aim to compare this evolution to the one observed by us in the RIKEN experiment with Li isotopes. We will measure other channels with the same set up, such as (d,d), (d,p), (d,alpha) and (d,6Li), which will enable us to get access to more physics in this region of the Segre chart. In particular we will obtain information about pre-asymptotic abnormalities in the valence neutron wave functions in 12Be, shell model and cluster structure of Beryllium isotopes, evolution of n-p pairing in even-even nuclei towards the edge of stability thus maximizing scientific output of the proposed experiment.

EXPERIMENTAL DEVICES REQUIRED

SPECTROMETERS

VAMOS (G1 Hall)	
LISE	
LISE 2000 (D4 Hall)	
LISE D4 (D4 Hall)	
LISE D6 (D6 Hall)	x
Wien Filter? [Yes/No]	no
SPEG (G3 Hall)	

REACTION CHAMBERS

ECLAN	

DETECTION SYSTEMS

AGATA		CATS	2
CAVIAR		Château Cristal	
DEMON		DIAMANT	
EXOGAM [(a)]		INDRA	
ACTAR TPC		MUST2 [(b)]	8
Neutron Wall		TIARA	
Other (specify)			

(a) Indicate the number of HPGe clovers
(b) Indicate the number of telescopes

BEAM LINES

G1	G21	G22	G3	G42	IBE
D1	D2	D4	D5	D6	LIRAT
				x	

NFS SET-UP

Irradiation Station	
Sample Transfer System	

EXPERIMENTAL SET UP

Reaction Targets: List any secondary reaction targets (materials and thicknesses) that will be installed in the experimental setup:
CD2 (0.5 1 and 2 mg/cm2), C (1mg/cm2)

Data Acquisition: Will you use the standard GANIL data-acquisition system? [Yes/No]: Yes
If No, please specify what system will be used:

Safety: List any hazardous materials or substances that will be used. Include, for example, radioactive targets and sources, high voltage, liquid nitrogen, and explosive gases even if they are standard for operating existing spectrometers or germanium detectors:

- High voltage for CATS (multiwire proportional counters), MUST2 (silicon detectors and CsI scintillators)
- Standard alpha source for the energy calibration of MUST2.

Additional Equipment: List any specialized equipment that needs to be installed or new equipment that has not yet been purchased or built. Provide the date in which this equipment is expected to be ready and indicate what help you may need from GANIL staff:

- No equipment required.

Were other experiments performed at GANIL in the past that used the same (or similar) experimental setup? [Yes/No]:
If Yes, please provide the experiment number(s): **e537, e552**
Specify any differences or improvements you would like to make to these previous setups: **we will not use 20um silicon detector**

Are there other experiments at GANIL (approved or proposed) that require the same experimental setup? [Yes/No]: Yes
If Yes, please provide the experiment number(s): **MUST2 @ Lise campaign experiments: 34Ar(p,p) reaction by F. Hammache and (d,t) reaction by D. Suzuki.**

GANIL FACILITY						
BEAM REQUEST						
	Ion(s)	**Energy (MeV/u)**	**Intensity on target (pps)**	**Purity (%)**	**Beam extension (ns)**	**Number of UT's (1 UT = 8 hours)**
			Indicate the minimum values required.			
Stable beam(s)	1. 2.					
Exotic Beams						
SPIRAL beam(s)	1. 2.					
LISE beam(s)*	1. 10Be 2. 11Be 3. 12Be	28 AMeV 30 AMeV 30 AMeV	1e5 pps 5e4 pps 1e4 pp	100 100 99		2 3 15
	Material*	**Thickness (µm)***	**Power (W)***			
LISE production* target(s)	1. Be 2.	2000	7.5 µAe	** For questions please contact the LISE scientific coordinator*		

SPIRAL2 FACILITY (NEW)						
LINAC BEAM						
	Ion(s)	**Energy (MeV/u)**	**Intensity on target (pps)**		**Pulsed beam**	**Number of UT's (1 UT = 8 hours)**
Beam						
NFS NEUTRON BEAM						

	Experimental area	Spectrum	Energy(MeV)	Flux ($n/cm^2/s$)	Pulsed beam	Number of UT's (1 UT = 8 hours)
Neutron beam	☐ Converter room ☐ TOF hall	☐ Continuous ☐ Quasi-mono-energetic				

IN-BEAM TESTS

In **exceptional cases** a dedicated in-beam test can be scheduled before your experiment or the number of requested UT's could be divided into two or more separate periods. Will your experiment require this? [Yes/No]:

If Yes, please specify the circumstances and explain how the UT's should be divided and the time required between test and experiment:

Important: The number of UT's must be included in the TOTAL BEAM-TIME REQUEST.

TOTAL BEAM-TIME REQUEST

Number of UT's required for beam tuning (including production of radioactive beams in LISE, contact your scientific coordinator):	3
Number of UT's required for planned settings/modifications of the experimental set-up:	2
Number of UT's requested for performing the experiment (data taking) and in-beam calibrations DURING the experiment:	20
Number of UT's required for performing in-beam tests BEFORE the experiment (if needed, see IN-BEAM TESTS above):	
Total number of UT's (sum of the 4 values above):	25

SCHEDULING

On what date will your experiment be ready to run? : January 2017

Time required (UT's) **before** the scheduled beam time for setting up the apparatus: 42 UT

Time required (UT's) **after** the scheduled beam time for calibration and take down: 21 UT

Do you require **auxiliary (parasitic beam)** to be delivered before the experiment for debugging purposes? [Yes/No]: No

If Yes, provide a range of possible isotopes, masses, and energies (MeV/u) that would be most suitable:

SCIENTIFIC PRODUCTION

Status of previous experiments performed by the spokesperson(s) in the last 3 years at GANIL (or related experiments elsewhere) : None

Publications, presentations, and theses completed in the last 3 years from past experiments at GANIL (or related experiments elsewhere):

ADDITIONAL INFORMATION

Please provide any additional information that may be relevant for the experiment:

1 PHYSICS CASE

We recently established that both *ab initio* and phenomenological models struggle to reproduce the transfer cross section from Li to He isotopes when approaching the drip-line, while those models provide accurate values near the valley of stability. We propose in this experiment to perform similar measurement for one proton transfer from Be to Li isotopes, allowing the production of reliable and consistent set of cross sections to help constraints those models and test newly develop interactions for this mass region. The Be isotopic chain exhibit strong clustering, while the Li isotopic chain exhibit a structure driven by core excitation, showcasing that for both, simple models are not sufficient. Those cross sections, combined with our previously obtained data from Riken, will provide a crucial set of transfer cross sections as well as elastic Nucleus-d scattering cross sections to help narrow down those effects in both structure and reactions models.

1.1 The (d,^{3}He) reaction channel

The nuclei in the light part of the Segre chart present a unique laboratory to test our knowledge of the fundamental nucleon-nucleon (NN) interactions. Understanding this interaction and its influence on properties of light nuclei through ab initio calculations is a major effort of today's nuclear theory. The ab initio studies confirm important role of NN correlations which manifest in quenching of the spectroscopic strength of individual nucleon states. Experimentally, this quenching has been known for stable nuclei for a long time from the (e,ep) experiments and over the last decade this quenching has attracted a lot of attention in connection with asymmetry in spectroscopic quenching in loosely- and strongly-bound nuclei [1 and ref. therein]. The observation of this asymmetry seems to be controversial as different types of reactions used to remove nucleons provided contradictory results [1] . In connection with this, our recent observation of unprecedented reduction of spectroscopic strength, about a factor on ten, in the ^{11}Li(d,^{3}He)^{10}He reaction, measured in RIKEN, looks astonishing [2]. We explained this reduction by mismatch of the valence neutron radial wave functions in the parent ^{11}Li and the daughter ^{10}He nuclei. The mismatch, Geometrical Mismatch Factor (GMF) [3,4], effect could interfere with important effects from NN interactions in ab initio calculations and thus should be understood both experimentally and theoretically. Moreover the GMF strongly affect the reaction cross sections and a better understanding of the phenomena would allow better planning of experiment near the drip-line, whenever studying halo or unbound nuclei.

There is a possibility that an unprecedented reduction of the ^{11}Li(d,^{3}He)^{10}He cross sections, at least partly, results from the poor understanding of final state interaction between ^{3}He and unbound Borromean nucleus ^{10}He, for which no theory exists. Therefore, to have a better idea about the mismatch phenomenon, we need to find another case, accessible to ab initio studies, where the mismatch can be expected but the final state interaction is better known. The obvious case is the ^{12}Be(d,^{3}He)^{11}Li reaction. Here the energy of the last two neutrons in ^{12}Be is 3.6 MeV, while after removal of one proton the daughter ^{11}Li has two valence neutrons with the energy of 370 keV. We estimate that a possible GMF is about 0.5 for 1s neutrons and 0.8 for 0p neutrons. Thus depending on the ratio of probabilities of 1s^2 and 0p^2 in ^{12}Be and ^{11}Li we can observed up to 50% reduction of the (d,^{3}He) cross section in the ^{12}Be(d,^{3}He)^{11}Li experiment that we propose to carry out in GANIL. In this experiment, the residual nucleus ^{11}Li is bound and its interaction with ^{3}He can be reliably calculated using a theoretical model thus reducing uncertainties of reaction theory used to analyse this experimental data. Apart from the strong quenching, our ^{11}Li(d,^{3}He)^{10}He experiment at RIKEN has revealed for the first time the importance of the core excitations both in ^{11}Li and ^{10}He [2]. We will look for a similar phenomenon in the ^{12}Be(d,^{3}He)^{11}Li experiment by detecting different decay modes of unbound ^{11}Li states. This will give us new information about continuum part of the spectra of Lithium isotopes. Our experimental findings will help to further constrain both phenomenological and ab initio theories to describe continuum effects in light nuclei.

In our previous RIKEN experiment [2], a ^{9}Li beam has been used for calibration purposes. The measured reaction ^{9}Li(d,^{3}He)^{8}He has also revealed reduction of the cross sections pointing at a particular evolution of spectroscopic strength consistent with observation from many knockout experiments. This reduction cannot be understood using a reaction theory that employs the ^{9}Li proton spectroscopic factor from ab initio Variational Monte Carlo (VMC)[4] calculations [2]. However, it can been explained by reaction theory that uses the Source Term Approach (STA) [6-9]. The latter suggests a slightly different view of the physical meaning of spectroscopic factors implying that apart from occupancies of nuclear shells they also measure the strength of the effective interaction of the removed nucleon with the nucleons of the daughter nucleus. We propose to continue these observations by studying evolution of the proton strength in the Be isotopic chain, measuring the ^{11}Be(d,^{3}He)^{10}Li and ^{10}Be(d,^{3}He)^{9}Li reactions together with ^{12}Be(d,^{3}He)^{11}Li. These reactions will be analysed using the STA, which is currently being further developed at Surrey to include excitation of nucleons to the sd-shell. Additionally ab initio VMC overlap are available for ^{10}Be(d,^{3}He)^{9}Li reaction, and can be confronted to the experimental cross section in a similar fashion to ref [2]. We expect that application of the STA to reactions with lighter Be isotopes is justified because the mismatch effect in this mass region should be reduced. On the other hand, we keep in mind that Be isotopes are well-known to be influenced by clustering [10,13]. Comparing evolutions of proton spectroscopic strengths in Lithium and Beryllium isotopic chains we will be able to answer the question about specific role of clustering in the quenching phenomena.

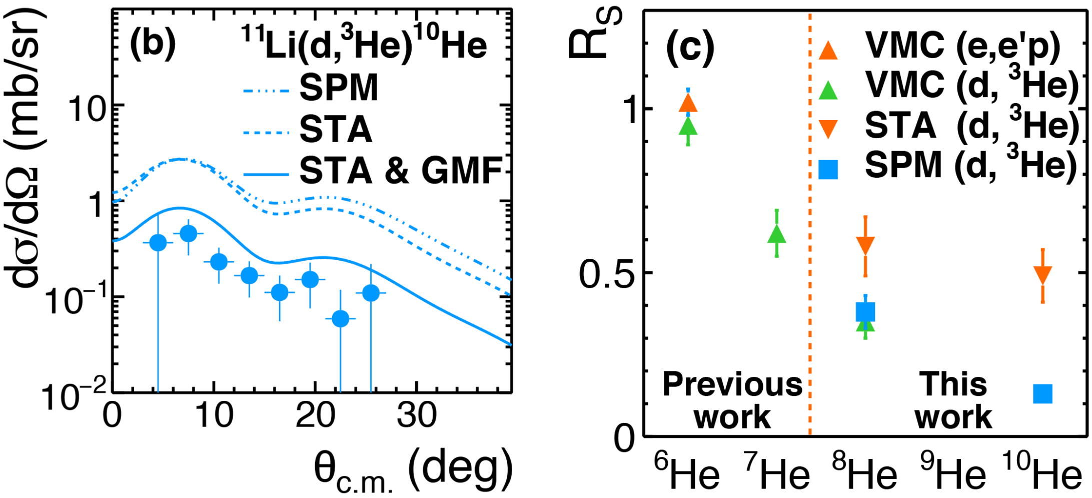

Figure 1: (left) Differential transfer cross section for the ^{11}Li(d,^{3}He)^{10}He reaction compared to predicted cross section using phenomenological models. (rigth) Reduction factor for (d,^{3}He) differential cross section for population of neutron rich He isotopes. While getting closer to drip line the reduction factor drop significantly, showing off the failure of both ab initio (VMC) and phenomenological (STA) models.

1.2 The (d,t) reaction channel

We will be able to detect tritons in the proposed experiment with Beryllium beams and deuteron target. The most interesting case here is the ^{12}Be(d,t)^{11}Be reaction. It has been shown in and confirmed in three-body calculations in [14] that the overlap between ^{12}Be and ^{11}Be should have pre-asymptotic abnormality. This abnormality has been shown to influence spectroscopic information obtained from the knockout experiment with ^{12}Be beam [14] but the GMF could also play a role [15]. The expected abnormality should be seen even better in the proposed ^{12}Be(d,t)^{11}Be experiment, which is more sensitive to the pre-asymptotic part of the overlap between ^{12}Be and ^{11}Be than the surface-peaked knockout reactions is. A confirmation of existence of this abnormality in our experiment would open a new trend in nuclear physics research challenging available microscopic theories. On the other hand, measuring relative population of ^{11}Be(1/2+) and ^{11}Be(1/2-) states we will be able to pin down the relative content of 1s^2 and 0p^2 in ^{12}Be, which will help to further constrain the mismatch factor expected to be seen in the ^{12}Be(d,^{3}He)^{11}Li experiment [16].

The ^{11}Be(d,t)^{10}Be experiment would complement the world first ever transfer reaction experiment with radioactive beam pioneered in GANIL [17], where the core excitations in ^{11}Be were studied. We will focus particularly on (strong) population of weakly-bound states in ^{10}Be just below the nucleon decay previously seen in ^{11}Be(p,d)^{10}Be reaction [17], which may hold a clue to the origin of the parity inversion in ^{11}Be.

1.3 Other reaction channels

1.3.1 *Elastic scattering : (d,d)*

In order to test available structure model accurately a good description of the elastic scattering is required. By placing additional detection around 90° in the laboratory frame, we will be able to provide three new elastic scattering cross section. These will be use to validate current optical model available, or, combined with previous data from Riken, to develop a new one adapted to these energy and mass region.

1.3.2 *One neutron addition: (d,p)*

While the beam energy is not well suited for (d,p) reaction measurement, those data come at no extra cost by simply adding two detectors at backward angles.

The identification of protons in the proposed experiments will gives us opportunity to access additional physics near the drip line. The ^{11}Be(d,p)^{12}Be(g.s.) will probe the same possible pre-asymptotic abnormalities to be studied in the ^{12}Be(d,t)^{11}Be experiment. Simultaneous observation of such abnormalities both in (d,t) and (d,p) reaction would give this phenomenon scientific credibility. Also, the population of excited ^{12}Be states will clarify their (yet unknown experimentally) shell model content and perhaps will make possible observation of rotational bands predicted recently in ab initio no-core calculations.

In addition we will be able to make spin and parity identification of neutron states in unbound isotope ^{13}Be through ^{12}Be(d,p)^{13}Be where the N=8 magicity has been predicted to be broken [10]. The current information about his nucleus is contradictory. However, correct information about its spin-parities and spectroscopic factors is very important to understand evolution of the shell structure of Beryllium isotopes, especially near N=8,9 where inversion between the s and d orbitals occurs, and to clarify the role of intruder negative parity states. It is important to notice that the only ^{12}Be(d,p)^{13}Be experiment performed in [18] has low statistics that does not allow for spin-parity assignment to be made.

1.3.3 *Cluster and pair transfer: (d,^{6}Li) and (d,α)*

Our detection system will also detect alphas and ^{6}Li from Be(d,α) and Be(d,^{6}Li) reactions. This is a bonus to study additional physics with the same set of beams and the target. The (d,α) reaction will probe the n-p paring in even-even isotopes and its evolution towards the neutron drip line while the (d,^{6}Li) experiment will allow us to explicitly access the cluster structure of Beryllium isotopes. In the case of ^{11}Be(d,^{6}Li)^{7}He reaction we will get a new tool to access the illusive spectrum of ^{7}He where current observations are controversial. With these reaction channels we will maximise the scientific output of out experiment.

2 EXPERIMENTAL SETUP

2.1 Beam production

^{10,11,12}Be beams will be produce by the LISE fragment separator from ^{18}O(8^+) stable beam at 50 AMeV on a 2 mm thick Be target with an intensity of 7.5µAe (maximum allowed in D3). The radioactive beam will be obtained at energies ranging from 28 AMeV to 30 AMeV and separated using a 2 mm thick Be wedge. The position and energy of the incident radioactive beam will be measured event by event using two CATS detectors upstream of the secondary target. The beams will impinged a solid deuterated polypropylene CD_2 target of 1 mg/cm^2. The expected resolution in excitation energy is 600 keV. In case of a lower than expected intensity, the experiment could be carried out with a thicker target, up to 2 mg/cm^2, at the expense of resolution.

Beam	D31	D32	Energy	Size	Yield	Contaminant
^{10}Be	2.19 Tm	1.92 Tm	28 AMeV	±15 mm	3e5 pps	pure
^{11}Be	2.44 Tm	2.18 Tm	30 AMeV	±15 mm	1e5 pps	pure
^{12}Be	2.67 Tm	2.42 Tm	30 AMeV	±15 mm	2e4 pps	pure

Table 1: Predicted yield on the secondary target from LISE++ for each requested radioactive beams assuming 7.5µAe primary beam delivered on target. Those prediction has been validated by the LISE team.

2.2 Charged particles detection

The nuclei of interest will be studied using the missing mass method, detecting ^{3}He, ^{3}H and proton produced in transfer reaction. Those light particle will be detected using an array of four MUST2 telescopes located at forward angle, at 18cm from the secondary target. Each telescope is composed a 300µm thick DSSD detector with 128 strips on each size, covering a surface of 10×10 mm^2. The DSSD is followed by an array of 4 × 4 CsI(Tl) crystals readout by photodiodes. Two additional telescopes will be place upstream of the target in order to study the (d,p) reaction channel, equipped with a 16 folds Si(Li) detector as a second stage and no CsI(Tl) stage. This second layer is well suited for (d,p) studies by allowing to stop high energy proton from the reaction while providing good energy resolution.

In addition a fifth telescope will be placed around zero degree to detect the heavy residues of the reaction, allowing for full kinematic study, taking advantage on the granularity and particle identification capabilities of MUST2. A detector will be placed around 90° to study elastic scattering, effectively allowing for absolute normalisation and providing additional constraint to the optical potential used to describe the reactions of interest.

3 YIELD ESTIMATE

During our previous MUST2 campaign at Riken we successfully managed to measure the abnormally low cross section for population ^{10}He from ^{11}Li. This cross section was only of 0.3 mb but the powerful experimental setup allowed us to extract a differential cross section and compare it theoretical predictions with 10 days of beam time. In the proposed experiment, the beam energy is lower, around 30 AMeV compared to the 50 AMeV of the previous experiment. This and the Q-Value of the reaction lead to significantly enhanced cross-section and therefore reasonable count rates with similar beam intensities. The cross sections have been estimated using the DWUCK4 and potential identical to the one used in the ^{8}He case of reference [6]. We assumed a reduction factor 0.5.

Beam	Reaction	Populated	Cross section	N_R	N_D	UT
^{10}Be	(d,^{3}He)	^{9}Li	5 mb	4000	800	2 UT
	(d,t)	^{9}Be	20 mb	15k	2500	
^{11}Be	(d,^{3}He)	^{10}Li	7.5 mb	3500	750	3 UT
	(d,t)	^{10}Be	8 mb	4000	800	
^{12}Be	(d,^{3}He)	^{11}Li	7.5 mb	6250	1250	15 UT
	(d,t)	^{11}Be	15 mb	12k	2500	

Table 2: Number of reaction N_R and number of detected light particle N_D at the end of the experiment, based on the expected cross section assuming a reduction factor of 0.5 and a 1 mg/cm^2 CD_2 target.

4 REQUEST FOR BEAM TIME

We request a total of **25 UT** of beam time with the following breakdown:

- **3 UT** for the initial secondary beam production and data acquisition tuning.
- **2 UT** for switching beam during the experiment.
- **2 UT** for measurement using the ^{10}Be beam
- **3 UT** for measurement using the ^{11}Be beam
- **15 UT** for measurement using the ^{12}Be beam

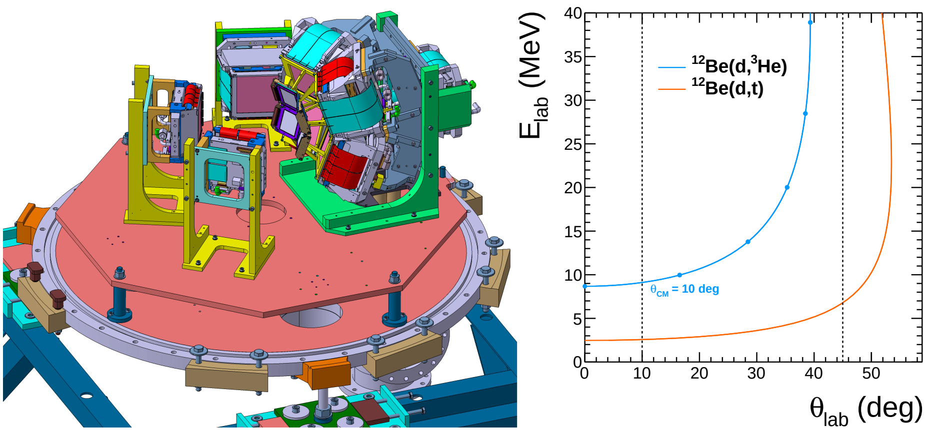

Figure 2: (left) The MUST2 array as used during our previous MUST2 campaign at RIKEN. The proposed experiment will use the same geometry and the same mechanical support, with the exception that we will not use thin 20μm detectors, instead relaying on the detection around zero-degree. (right) The kinematic of the reaction of interest (d,^{3}He) (blue). The black dotted line show the angle span by the forward detector of 10-45°. Point are place every 10° in the center of mass on the (d,^{3}He).

5 REFERENCES

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