LABORATÓRIO ABERTO DE FÍSICA NUCLEAR

PAC 2023

Proposal	N°
Title: Particle-gamma coincidence measurements of weakly bound stable beam nuclear reactions with the new “Nossa Caixa” spectrometer	
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Number of days for experiment:	21
Period planned for the experiment (is the setup ready for beam time?): From August 2023 (no)	

Technical information

Ion source			Accelerator			Experimental Area	
Beam	Cathode	$I_{mín}$	V_{min}	V_{max}	Bunched beam?	Beam line	Target
$^{7}Li(3+)$		50 nA	6	7	no	30B	^{120}Sn
$^{10}B(4+)$		50 nA	7	8	no	30B	p (polyethilene)

Other relevant/needed information:

Particle-gamma coincidence measurements of weakly bound stable beam nuclear reactions with the new “Nossa Caixa” spectrometer

Weakly bound stable and radioactive beam reactions present many features that constitute interesting theoretical and experimental challenges. The objective of the present proposal is to perform 3 different system reactions with weakly bound stable beams that are known to present some peculiar features, and to evaluate the performance of the new spectrometer under varied situations. All three reactions have already been performed at LAFN, two of them with the precursor of the “Nossa Caixa” (NC) array, with only two gamma detectors and one plastic *phoswhich* detector (the phase 1 version of the array: NC1), and the other with Si charged particle detectors only. Starting with this last one:

1) **The ^{10}B+^{120}Sn reaction:** An interesting feature was observed in this system [1,2] (as well as in a few other systems, *e.g.*, with ^{6}Li beam) which is the presence of the single charge exchange channel (SCE) ^{120}Sn(^{10}B,^{10}Be)^{120}Sb. This is interesting because it connects to a challenge of the NUMEN collaboration (LNS/Catania), of which we actively participate, which is the detailed description of a network of direct nuclear reactions which are linked to alternative pathways [3] to the mesonic double charge exchange mechanism of the Majorana type (MDCE) [4]. This process is analogous to the neutrinoless double beta decay (DBD). Below 5 MeV/A, the mesonic DSCE (Double Single Charge Exchange, which is analogous to the 2 neutrino DBD) [4,5] cross section drops dramatically. Nevertheless, it is still important to understand the SCE nucleon transfer mechanism between heavy ions, as it is the less known part of the network that could contaminate the process of main physical interest (MDCE) at higher energies, and this can be done below 10 MeV/A, where they are dominant [5]. In the present proposal, the gamma rays can help to confirm the charge exchange mechanism by identifying the characteristic gamma rays of ^{120}Sb. This reaction has other exit channels which are interesting also for the evaluation of the performance of the gamma spectrometer, such as the 1*n* transfer (^{10}B,^{11}B). Figure 1 shows the energy spectrum of a Silicon detector, where the gs and a set of excited states from this channel are marked in blue. The gamma array should be able to resolve the energy transitions from those states, allowing for the individual measurement of their cross sections. This could be done by selecting the gamma rays detected in coincidence with this energy region of the charged particle spectra. The reaction would be studied at 35 and 40 MeV beam energies in the MSc project of C.E.C. Vasconcellos.

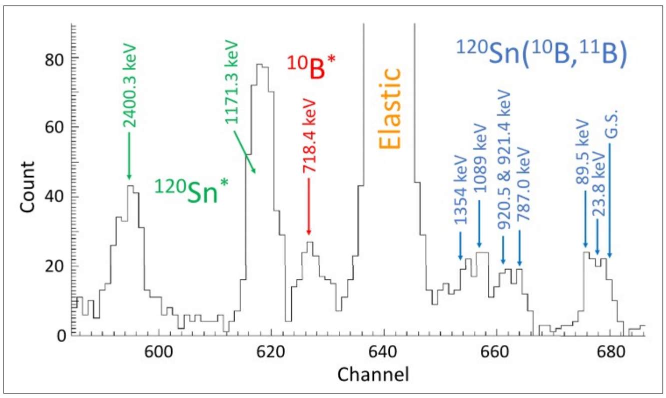

Figure 1: Energy spectrum of a Si detector at 125º from the ^{10}B+^{120}Sn reaction at 37.5 MeV [2].

2) **The ^{7}Li+^{120}Sn reaction:** This reaction was measured with NC1 at two different particle detector angles (90° and 135°), at 20, 24 and 28 MeV, with a 1.66 mg/cm² target. This is the measurement of the PhD work of V. Kurman which is, unfortunately, in standby for several months due to health issues. One of the interesting features of this reaction is that the pickup of a proton by the beam leads to ^{8}Be with the subsequent break up into two α particles. The two α particles were identified as being detected together in the same detector, in coincidence with a γ ray from an excited state of ^{119}In. A more detailed investigation of this type of mechanism should be performed with a larger array of particle detectors which is presently under development. The challenge of the theoretical description of this kind of process is under attempt by A.S. Serra with use of the Platypus semiclassical code developed by A. Diaz-Torres [6-8]. With the new NC array it should be possible to investigate also the 2n stripping channel leading to ^{5}Li with subsequent break up into d+α, of which just a few counts were observed in the already performed measurement. These two types of channels are representative of delayed and prompt break up, respectively, [6,9,10] which could affect differently the complete and incomplete fusion processes.

3) **The ^{7}Li+^{154}Sm reaction:** this system was also measured with NC1 at 26 MeV, with a 90 μg/cm² target. The analysis was done by a student from UNAL (F. Ramírez), Colombia, and the inelastic cross sections of the first 3 gs band states of the highly deformed ^{154}Sm target were measured by particle gamma coincidence, as well as that of the first excited state of the ^{7}Li beam. The results were compared with theoretical calculations with the FRESCO Coupled Channels code performed by V.A.B. Zagatto, and show good agreement for the 2^{+} band state, and for the beam excitation, but significantly under-predict that of the other two. The work is still in progress but should be soon submitted for publication. This is a result for only one particle detector angle in a very short time measurement. Additional measurements are highly desirable. With the full NC array, additional particle detectors, thicker target and long time measurement (*e.g.*, 1 week) it should be possible to obtain a complete angular distribution for a comprehensive investigation, eventually including additional energies. Besides the inelastic data, it is important to do a separate measurement with good resolution Si detectors to include the elastic channel information, even if not separable from the first excited state at 82 keV (this is not part of the present request).

The new NC array is depicted in Fig. 2. It consists of 12 gamma detectors, at 55 mm from the target, each one with 3×3 LYSO(Ce) [11] scintillator crystals (12.4 mm²×40 mm “pixels”), coupled to Silicon photomultipliers (SiPM, Sensl, J-series, 2×2 pixels). The detectors are arranged in two diagonal crossed rings in order to allow the placement of charged particle detectors near the horizontal plane. The array can go inside a scattering chamber, in vacuum. The full system (without cables) can fit inside a 125 mm sphere radius. The compact geometry results in a high solid angle coverage and, with the high effective Z and density of the crystal composition, in a total photopeak absolute efficiency of 10% at 1.3 MeV. The relatively fast scintillation decay time (40ns) of LYSO(Ce) results in measured timing resolutions around 10 ns (FWHM) or better. The system was designed to operate in a high *n* radiation and magnetic field environment, such as that present at the RIBRAS system for radioactive beam production (45B line). It fits inside both scattering chambers, the one between the solenoids, and that after the second one. For the present experiments with stable beams it will be mounted in the 45A chamber at the entrance of the LINAC hall, after the superbuncher. Additional *phoswich* detectorswill be built [12] to increase the charged particle detection efficiency.

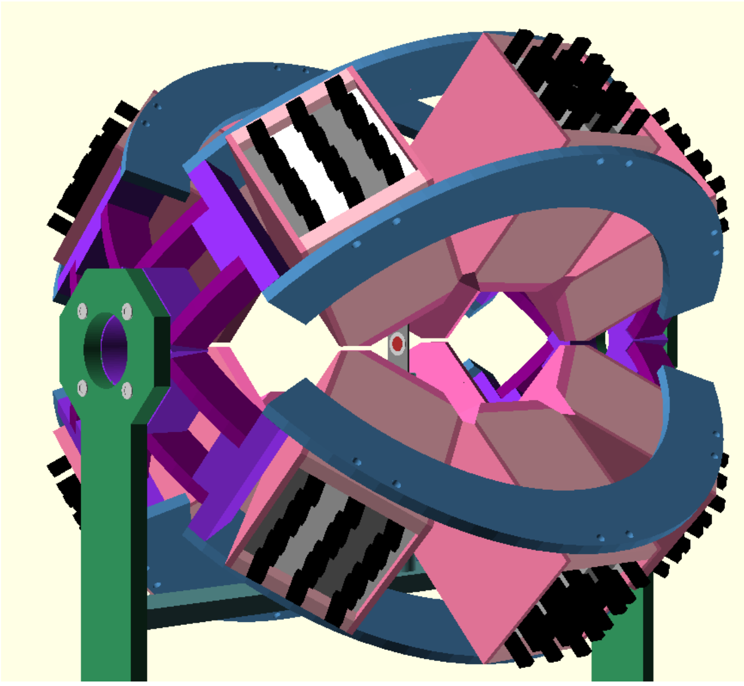

Figure 2: The "Nossa Caixa" spectrometer. The 12 pixelated scintillators are directed toward the target, at the center. The beam enters from the circular opening at the left, but other orientations of the spectrometer are possible, depending on the particle detector array required for each experiment.

Recently, the new CAEN digitizer data acquisition system has been successfully tested by measuring particle gamma coincidences from the ^{241}Am alpha source. In this test the half-life of the second excited state of ^{237}Np was measured with high accuracy. The results were accepted for publication in Nuclear Physics A (O.C.B. Santos *et al.*).

Besides their intrinsic interest, the proposed experiments will allow for a characterization of the array performance under practical situations, such as higher or lower level density of the residue and selectivity of the charged particle array. The understanding of the type of response that can be obtained with the array will be very important for future similar experiments but with radioactive beams from the RIBRAS system.

References

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