LABORATÓRIO ABERTO DE FÍSICA NUCLEAR
PAC 2018

Proposal	N°
Title: **Particle-gamma coincidence measurements of reactions with weakly bound stable and radioactive beams**	
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Number of days for experiment:	48
Period planned for the experiment (is the setup ready for beam time?): January-December 2019	

Technical information

Ion source			Accelerator			Experimental Area	
Beam	Cathode	$I_{mínima}$	V_{min}	V_{max}	Bunched beam?	Beam line	Target
^{6}Li		10 nA (cup 7)	6	8		45A	^{120}Sn
^{7}Li,^{9}Be,^{16}O		10 nA (cup 7)	6	8		45A	^{154}Sm
^{7}Li (sec. ^{8}Li)		100 nA (cup 7)	6	8		45B	^{120}Sn
^{7}Li (sec. ^{8}Li)		100 nA (cup 7)	6	8		45B	^{154}Sm
^{28}Si		10 nA (cup 7)	6	8		45A	^{9}Be

Other relevant/needed information:

Research project: *Particle-gamma coincidence measurements of reactions with weakly bound stable and radioactive beams*

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Abstract

A multidetector system with funding from FAPESP is in final stage of assemblage and will allow for the in-beam particle-gamma coincidence measurements with stable or radioactive beams, provided by the Pelletron Accelerator of IFUSP in combination with the RIBRAS system. The array will have unique characteristics in the world, allowing cinematic coincidence measurements between the reaction fragments simultaneously with the measurement of gamma rays, and the detailed investigation of the reaction mechanisms, such as the projectile break up after direct particle transfers. The gamma transitions, besides allowing for the identification of the fragments and respective excited states, allow to investigate the angular momentum alignment in this type of reactions, an aspect experimentally unexplored up to now. We plan to study several reactions, of which we would like to start with ^{6,7,8}Li+^{120}Sn, ^{9}Be,^{16}O+^{154}Sm among other cases.

Physics motivation:

Reactions with weakly bound beams have presented interesting features such as break up after particle transfer, which can affect fusion suppression/enhancement. The measurement of the relative energy and angular correlations of the fragments allow, for example, for the classification of the reactions into “prompt” and “delayed” processes, depending on the lifetime of the projectile-like product of the transfer [1,3] (Fig. 1). The reaction mechanisms are complex and have been interpreted into a semi-classical framework [4,5], and calculations are performed with the PLATYPUS code. Further experimental investigation is important for a complete understanding of the processes, development and validation of the theoretical models.

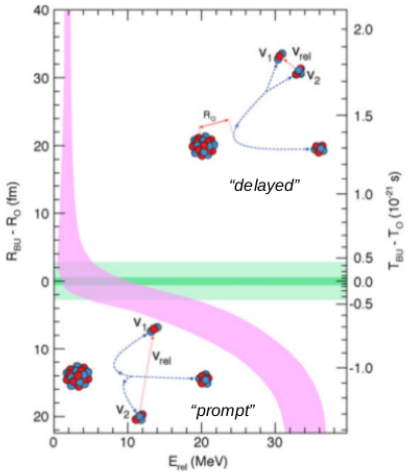

*Figure 1: **Prompt** and **delayed** break up and its relation to the projectile-target distance, time scale, and relative energy of the fragments. (figure adapted from ref. [1]).*

The Particle-ɣ coincidence technique:

The measurement of gamma transitions in coincidence with charged scattered particles allows, in many cases, for the identification of the reaction products and their excited states, and in addition, the gamma angular correlation can bring information regarding angular momentum alignment of the states [7]. This aspect has been little explored in the literature and can provide additional tests to the theoretical models which aim to describe the nuclear reactions. The localization of the particle transfer correlates with the transferred angular momentum, for example.

The experimental setup:

Fig. 2 presents the experimental setup which is presently under construction to be installed in the LINAC chamber, after the superbuncher, where we expect to have good timing quality pulsed beam in the future. The gamma array will consist of 36 LYSO(Ce) scintillator crystals of $12.4^2 \times 40$ mm³ dimensions coupled to SiPM (silicon photomultipliers). These devices are insensitive to magnetic fields and can also be used together with the RIBRAS superconducting solenoid system for production of radioactive beams. They can operate in vacuum. The crystals will be packed together in groups of 3 x 3 "pixels" of, in order to increase the photopeak efficiency, while preserving the information of the crystal in which the first interaction took place, therefore reducing the angular uncertainty of the emission of the original gamma ray. The energy resolution is rather poor, in the 5-30% range depending on gamma-ray energy, but is sufficient for typical cases of inelastic excitations and transfers [8]. For the particle detectors, plastic *phoswich* scintilator ΔE-E telescopes, with pixelated 12mm² SiPMs (4×4) for position sensitivity will be used. Initially, 4 of these detectors will be mounted, but a funding project has been submitted for the acquisition of additional ones. The array will allow for kinematic coincidence between the charged fragments as well as the gamma rays. A very good time resolution, around or even below 1 ns is expected for this system. These detectors are very radiation tolerant and can count at very high rates, in excess of 100 kHz, which is important for stable beams in such a close packed geometry. Several other combinations of the gamma array with other types of particle detectors are possible, such as surface barrier or Si strip detectors and will be used with radioactive beams, both in this and other proposals submitted to the PAC.

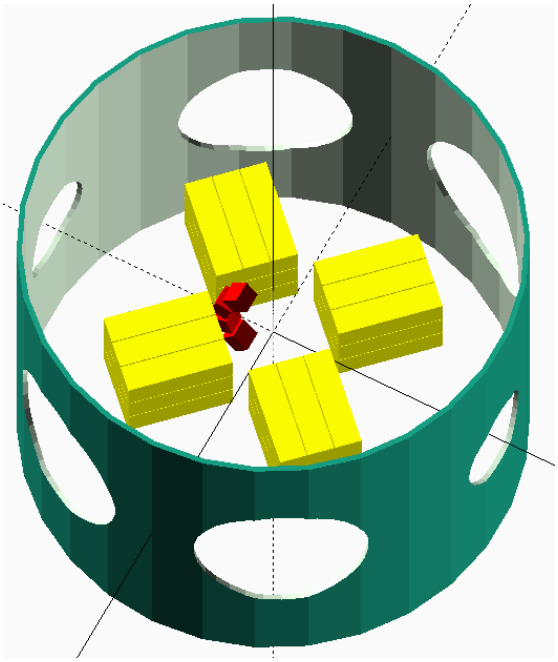

Figure 6: Scheme of the -ray (yellow) and particle (red) detector setup inside the LINAC chamber. The target should be inserted at the center.

The proposed experiments

Several weakly bound stable beams are available, such as ^{6,7}Li, ^{9}Be, ^{10,11}B, and can be used in combination with spherical or deformed targets, such as ^{120}Sn, and ^{154}Sm, respectively. Radioactive beams, such as ^{6}He and ^{8}Li can also be used. We plan to do several of these reactions, over the next years, beginning with ^{6}Li+^{120}Sn, similar to the one we studied in [8], and of which we have some familiarity, and which is the theme of the PhD thesis of V. Kurman. A typical experiment with radioactive beams takes about two weeks of continuous measurements, for a few angular distribution data points. For the stable beams we plan to measure several particle angular distribution data points and a few beam energies around the barrier. Since we intend to measure also the gamma angular correlation, a good statistical sampling is needed, and we estimate that for each reaction, at least 6 days of nearly continuous beam time will be necessary. We request 36 days for the measurement of ^{6,8}Li+^{120}Sn and ^{7,8}Li, ^{9}Be+^{154}Sm reactions. In addition we request 12 days for the measurement of the inverse reaction of ^{28}Si+^{9}Be, and for the strongly bound beam reaction of ^{16}O+^{154}Sm, which has considerable interest due to the deformation of the target and will be a contrasting case in comparison to the weakly bound ones.

Expected statistics

The project involves several different beam/target combinations and setup modifications and adaptations for each one. A large variation of data rates are expected. Just for reference, we give a typical example of statistics. With a particle detector pixel solid angle of 15 msr, a gamma detector pixel solid angle of 170 msr and 50% photopeak efficiency, 1pnA (stable) beam on a 2×10^{18} atoms/cm² target, a 1 mb/sr cross section yields about 200 counts per day. With the multidetector array and expected future upgrades, several data points can be measured simultaneously allowing for the measurement of a few variations in angular range and beam energies during a typical 6-day experiment.

References

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[8] V A B Zagatto *et al.*, 2016 J. Phys. G: Nucl. Part. Phys. 43 055103.

Previous Information on Project

Proposal approved	No. E-130
Period of beam time (date)	7
Results or problems: E-130: New multidetector system for particle-gamma coincidence measurements. Only seven days were requested (and approved) for the performance of tests with the new system. There was a large delay due to difficulties with the production of the electronic circuit board of the detectors, among other things, before the equipment was ready for tests. Finally the tests were made together with another project E-106b with the 8Li radioactive beam on the RIBRAS system (April, 23-28, 2018). The test was successful and confirmed several important issues, like the operation of the detectors in vacuum and in presence of strong magnetic fields, time and energy resolutions as expected, and the practical elimination of the LYSO(Ce) intrinsic radiation background due to the decay of the 176Lu isotope in the particle-gamma coincidence measurements.	
Proposal approved	N
Period of beam time (date)	

Results or problems: