Study of nuclear reactions with exotic beams using γ-particle coincidences.

Experiment previously approved as E-106b in the 2016 PAC

Requested beam time: 15 days.

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Summary:

The project consists in measurements of nuclear reactions induced by exotic beams produced in RIBRAS in coincidence of particles with the gammas from the decay of the residual nucleus. The double solenoid RIBRAS [1] system will be used to produce the secondary beams of ^{8}Li, ^{6}He, ^{8}B and others. The main idea is to investigate a few nuclear reactions mechanism measuring reactions channels other than the elastic scattering, such as: Fusion, Transfer, Coulomb Excitation (COULEX) of 8Li, and Breakup. In many of these reactions, the system decays by emitting particles as well as gammas from the excited residual nuclei; in this initial approach, it will be given priority to fusion reactions due to its relatively high cross-sections.

Introduction:

The possibility of producing secondary beams of unstable nuclei opened a huge field of research in Nuclear Physics. Since 2004 the Radioactive Ion Beams in Brazil (RIBRAS) system is in operation producing secondary beams of light exotic nuclei such as ^{8}Li, ^{6}He, ^{7}Be, ^{8}B and others. Since then, a systematic study of elastic scattering of these beams on targets of different masses has been performed [1].

Up to now, RIBRAS facility is mainly used on elastic scattering and transfer measurements, but the facility can be improved to include gamma rays detection. Initially, it had been planned to use HpGe detectors; however, as HpGe detectors are quite sensitive to the neutron damage, it was decided to use LYSO(Ce) (*Cerium-doped Lutetium Yttrium Orthosilicate* – hereafter: LY*SO*) crystals. LYSO detectors have the advantages of: high light output and density (high photo-peak detection efficiency); fast decay time; and low cost. These detectors are also compact and can be used with a high neutron background. However, LYSO’s main disadvantage is its energy resolution (about 10%); but, some nuclear reactions, such as low energy density compound nucleus resulting from fusion reactions of relatively high cross-sections, could be devised to target only a few γ rays. In this scenery, it is supposed that LYSO's resolution would not significantly depreciate the experiment outcome.

Additionally, p-gamma coincidences experiment can be applied to more elaborated phenomena. For example, in the ^{6}He+^{120}Sn scattering described in the Faria's PhD thesis [4], elastic scattering angular distributions was measured at four energies above the Coulomb barrier using the central RIBRAS chamber, between the two solenoids. In this experiment, it was found a large yield of alpha particles in the E-ΔE spectra, with energy spectra somewhat lower than the ^{6}He projectile energy. This energy distribution was analyzed by DWBA [3] and it was found that, probably, a two-neutron transfer reaction from projectile to highly excited states of the ^{122}Sn was taking place.

More recently [5], a new ^{6}He+^{120}Sn experiment was done in the RIBRAS secondary scattering chamber using the double solenoid system, where a quite untainted beam could be achieved. Indeed, all the previous results have been confirmed [7]; but, additional measurements of coincident gamma rays would shed more light in such matters. For this reason, It has been considered new measurements of the $^{120}Sn(^{6}He, \alpha\text{-}\gamma)X$ reaction, in order to detecting alpha particles in coincidence with the gammas emitted by the decay of the residual nucleus ^{121}Sn.

Finally, it is desirable to extend the RIBRAS research program for the measurements of gamma-ray spectra in coincidence with the charged particles to measure the fusion cross sections for specific reaction channels (transfer /break-up and complete fusion). With this purpose an extension of the RIBRAS beam line has been mounted and a new scattering chamber for the γ-particle coincidence measurements is being designed.

Method:

In the scheme below, it is shown the RIBRAS system and its extension - new γ-particle coincidence chamber - beyond the secondary scattering chamber. The system will consist of four E-ΔE silicon telescopes placed 7 cm distant from the target to detect the alpha particles.

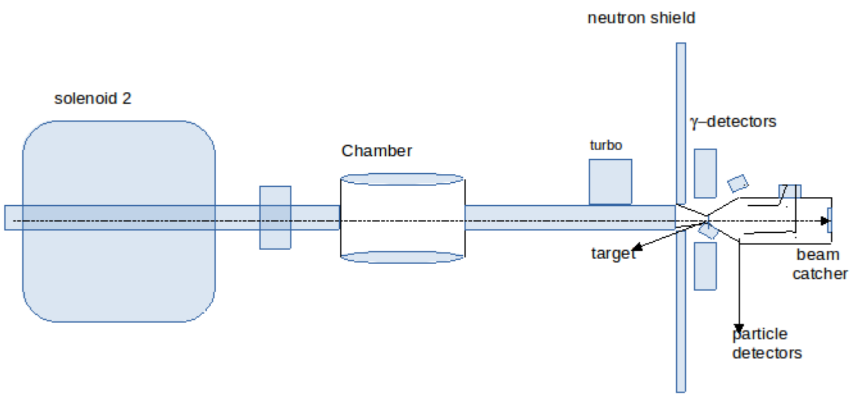

Figure 1 - RIBRAS extended set up for p- γ coincidence measurement using HPGe detectors.

There are two possibilities for the gamma measurements: target surrounded by two HpGe detectors (**setup 1**); or surrounded by LYSO detectors (**setup 2**).

Setup 1- The target will be surrounded by two HpGe detectors to detect the gamma rays in coincidence with the charged particles. When the secondary beam (^{6}He) is produced in-flight by using the transfer reaction $^{9}Be(^{7}Li,^{6}He)^{10}B$, a large neutrons flux will be produced from this reaction. To protect the HpGe detectors from the neutron damage, we plan to build a neutron shield (wall, see the picture) of thickness around 50 – 60 cm using borated de-ionized water. Additionally, we also plan to use paraffin bars to moderate the neutrons and shield the detectors. To stop the neutrons coming in the zero degrees (beam pipe), we plan to place blockers at strategic positions made of high-density materials.

Setup 2- Further, due to the vulnerability of HpGe detectors to high fast neutron background, it had been considered to replace them by LYSO detectors and, for this reason, it was bought a couple of detectors for preliminary tests. In April 2018, it was performed a preliminary experiment using LYSO detectors for the gamma measurements. A ^{8}Li beam impinged in a ^{120}Sn target and the scattered ^{8}Li was detected in four E-ΔE telescopes placed at forward angles (see figure below) in coincidence with the gammas detected in four LYSO detectors placed around the target.

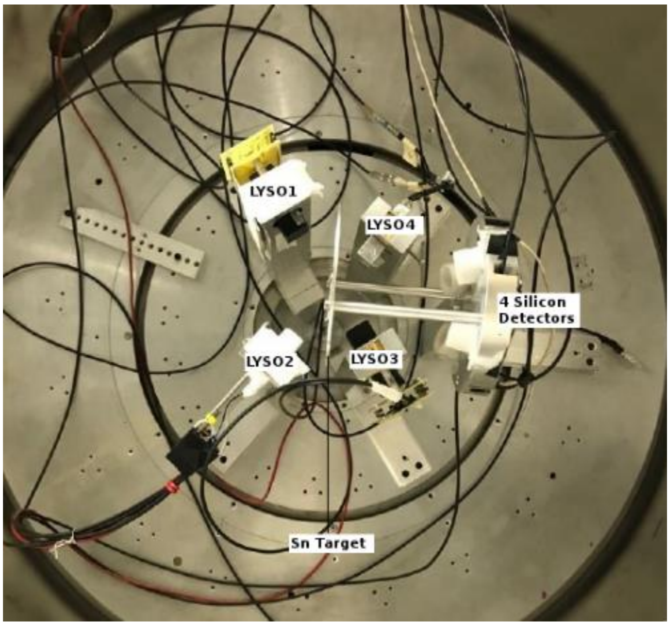

Figure 2 - Set up for p- γ coincidence measurement using LYSO detectors at the secondary chamber.

The results were promising; in the next figure, one can see a clear p- γ coincidence peak. Indeed, it was observed some coincident gammas with light particles such as: alphas, protons, deuterons and tritons, indicating that these events could have come from fusion.

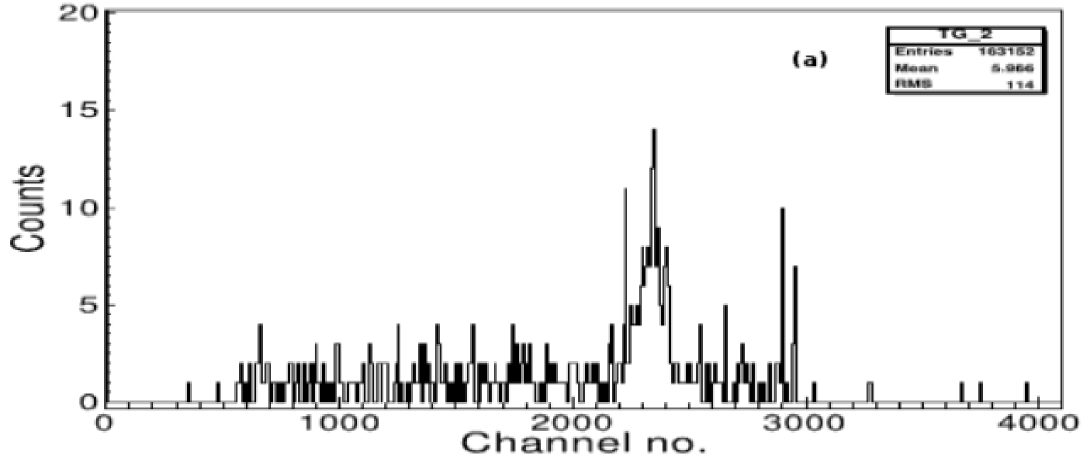

Figure 3 – Preliminary results from April 2018. It can be seen a quite clear coincidence peak.

γ-p counting rate estimation:

The data from this last p- γ coincidence measurement is still been analyzed; but, the peak of coincidence indicated that, at least, hundreds of real coincident events were collected.

Finally, for the $^{120}Sn(^{6}He,\alpha\text{-}\gamma)X$ nuclear reaction, if one considers: setup 1; $I(^{6}He)=10^{5}$ pps (from the last experiment); HpGe detectors placed at a distance of 10 cms; E-ΔE detectors placed at 7 cm from the target; and a 400 mb α-production cross section (measured), we can predict 50 γ-particles coincidences/day.

References:

[1]A. Lépine-Szily, R. Lichtenthäler, V. Guimarães., *Eur. Phys. J A. (2014) 50:128*

[2]P.N. de Faria, R. Lichtenthaler et al. *Physical Review C* ***81****, 044605 (2010).*

[3] P.N. de Faria, R. Lichtenthaler et al. *Physical Review C* ***82****, 034602 (2010).*

[4] P.N. De Faria, Tese de doutoramento, IFUSP (2008).

[5]Appannababu Selaboina, private communication, see paper attached.

*[6]*R. Lichtenthäler et al, Few-Body Syst. (2016) 57:157–163

[7] S. Appannababu, R. Lichtenthäler et al, Phys,. Rev. C (2018)

LABORATÓRIO ABERTO DE FÍSICA NUCLEAR
PAC 2016

Technical information:

Proposal	N° E-106b
Title: Study of nuclear reactions with exotic beams using p- γ coincidences	
Responsable: Rubens Lichtenthäler.	E-mail: rubens@if.usp.br
Participants: André Serra, Appannabau Selaboina, Alinka Lépine-Szily, Nemitala Added, V. Guimarães, José Roberto Brandão de Oliveira, Kelly Cristina Cezaretto Pires, Marlete Assunção, Juan Carlos Zamora, Valdir Bruneti Scarduelli, Osvaldo Camargo Botelho dos Santos, Uiran Umbelino, Cristiane Santos Oliveira; V. Kurman and the RIBRAS collaboration.	
Spokesperson: André Serra	e-mail: andreserra@ymail.com
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Number of days for experiment: **20**	
Period planned for the experiment: MAY, 2019. Is the setup ready for beam time? The set up will be appropriately built in due time.	

Ion source			Accelerator			Experimental Area	
Beam	Cathode	$I_{mínima}$	V_{min}	V_{max}	Bunched beam?	Beam line	Target
$^{7}L^{+3}$	----	300nA	3MVe	7MeV	No	RIBRAS	3,8mg/cm^2 [^{120}Sn]

Other relevant/needed information: In April 2018 a preliminary and similar experiment was conducted. As a result, it was obtained a figure of approximately a thousand real p-γ coincidences probably from fusion events.

Previous Information on Project

Proposal approved	Nº E-106b
Period of beam time (date)	April, 2018
Results or problems:	

In April 2018 a preliminary and similar experiment was conducted. As a result, it was obtained a figure of approximately a thousand real p-γ coincidences probably from fusion events. This new proposal is an extension of the previous one.