EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Status report to the ISOLDE and Neutron Time-of-Flight Committee

Status report on HIE-ISOLDE experiment IS581 "Determination of the fission barrier height in fission of heavy radioactive beams induced by the (d,p)-transfer"

September 25 2019

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Abstract

Knowledge and thus measurement of fission barriers of unstable fissile nuclei away from the line of beta-stability is crucial information for understanding of the r-process nucleosynthesis in binary neutron star mergers, such as recently observed gravitational wave event GW170817. Thus IS581 can become one of the crucial experiments for nuclear astrophysics in the foreseeable future and we consider necessary to use all the beam-time which was approved by the INTC in 2014 (28 shifts). The ACTAR TPC chamber (both demonstrator and full version) are operational and will be ready for experiment by the time the HIE-ISOLDE facility will be started after LS2 shutdown of LHC facility.

Requested shifts: 28 shifts, (split into 2 runs over 2 years)
Beamline: 3rd beamline (for setups other than MINIBALL and ISS)

The experiment IS581 “Determination of the fission barrier height in fission of heavy radioactive beams induced by the (d,p)-transfer” was approved by the INTC in November 2013. It's main goal is direct measurement of fission barrier height of heavy fissile radioactive beams delivered by HIE-ISOLDE facility using an active target. The fission barrier heights of heavy fissile nuclei away from line of beta-stability are practically unkown. Aim of the IS581 proposal was to obtain such experimental information for the first time and this remains valid also now. In the meantime, the importance of such information for the solution of the problem of nucleosynthesis of heaviest elements further increased, specifically in the context of nucleosynthesis in the binary neutron star mergers (an event recently observed via gravitational wave signal). Importance to know fission rates (and thus fission barriers) for understanding of r-process nucleosynthesis in neutron star mergers (such as the recently observed gravitational wave event GW170817) was recently stated in the NuPECC long range plan from 2017. Thus we consider the IS581 as the experiment which provides an opportunity to obtain unique result of general interest using the recently commissioned HIE-ISOLDE facility, which is still the only facility in the world allowing to perform such measurement.

Since the approval, the programme of transfer-induced fission measurements using active target obtained a boost in the form of EOS grant, (an interregional programme of the Belgian communities, https://www.eosprogramme.be), awarded to the research group at the KU Leuven. Furthermore, since the spokesperson M. Veselsky moved recently to Institute of Experimental and Applied Physics of Czech Technical University in Prague, the experiment IS581 forms a backbone of the commitment of this institute, as a first research institution in Czech Republic, to collaboration with ISOLDE, recently formalized by signing of the agreement about institute membership between IEAP CTU and ISOLDE.

On practical level, since approval of the IS581 proposal, the construction and commissioning of the ACTAR TPC active target was under way. At the moment, both the ACTAR TPC Demonstrator and the final full-size ACTAR TPC chamber are fully operational. The performances meet, or even exceed, expectations of design. Several tests and physics experiments were already performed with Demonstrator at IPN Orsay, GANIL and LNL Legnaro and LNS Catania [Rog18]. The full-scale ACTAR TPC was used to successfully perform resonant scattering, inelastic scattering and implantation/decay experiments in the 2018-2019 period [Mau18,Mau19, Cer18, Rud16]. Further physics experiment will focus on studying rare decay modes of an excited resonance in 18Ne that plays an important role in the 14O(,p)17F reaction rate. This reaction is one of two possible breakout pathways from the HCNO cycle that occurs in explosive astrophysical environments such as novae and X-ray bursts.

From the point of view of IS581 experiment it is important that the experiment, aiming to measure directly several fission barriers in the region of lead with the stable beam 208Pb, was approved at the INFN LNS Catania. This is a crucial experiment for testing the performance of the active target with heavy beams. The beamtime is expected to take place in the early 2020. In this respect, the development of a dedicated mask is underway at GANIL. This mask is based on the concept of the electrostatic mask developed for the active target MAYA [Rod14]. It permits to extend the use of an active target to high intensity and/or heavy beams without degrading the quality of the charge projection. It consists in two metallic plates located above and below the beam, used to readily collect the ionisation products of the beam. The sides of the mask are equipped with a wire field degrader that efficiently screens the drift region from the high electric field generated by the beam ionisation. Such a mask was used with the active target MAYA and permitted to study the transfer-induced fission of ^{238}U, using a 1E6 pps ^{238}U beam at 5*A* Me V [Rod17].

The performance of ACTAR TPC Demonstrator can be judged from the Figure, originally published in [Rog18]. It clearly demonstrates that it is possible to achieve tracking in 3D for three separate tracks, what is an expected situation in IS581. In combination with ancillary detectors, the active target provides necessary sensitivity for successful execution of the experiment IS581. The measurement at LNS Catania will be performed with the ACTAR TPC Demonstrator, which can be fully surrounded with ancillary charged-particle detectors. For the measurement at ISOLDE, the full-size ACTAR TPC may be used instead, assuring a better energy and angular resolution, provided we can reach a similar efficiency for the detection of the escaping charged particles (the purchase of additional Si detectors is ongoing).

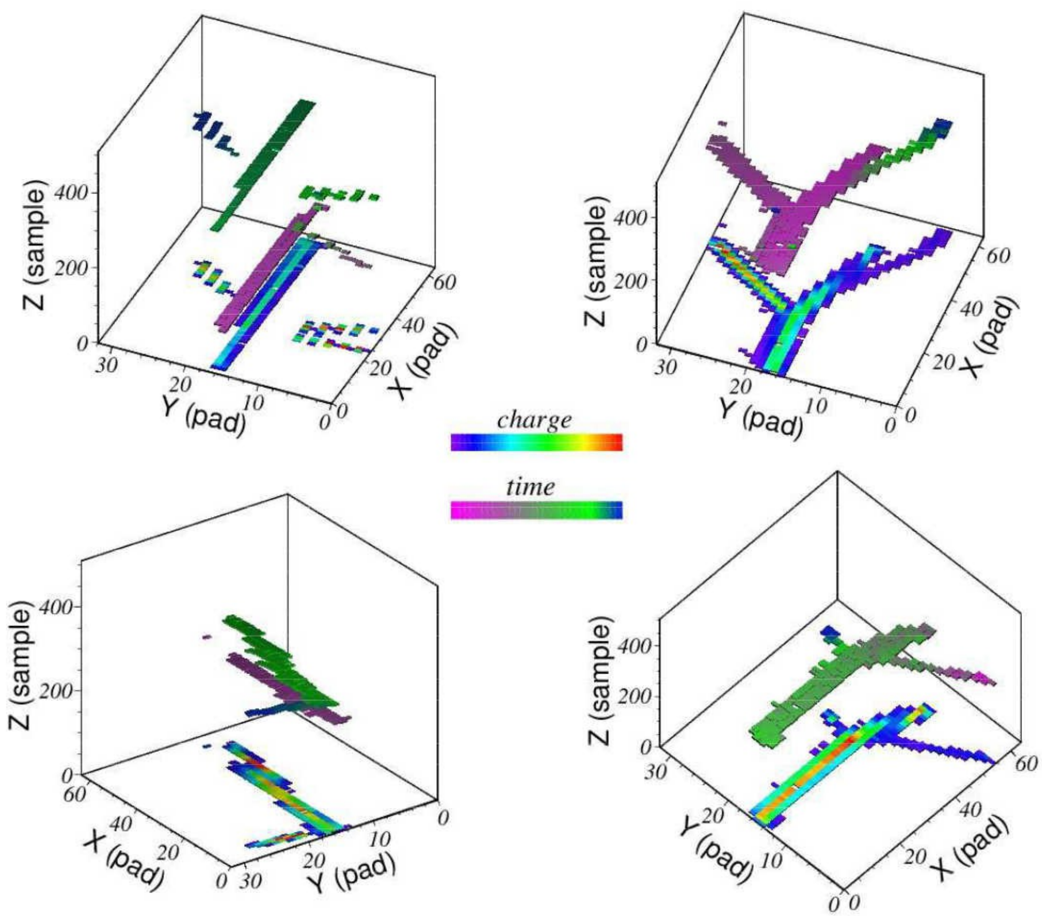

Figure 11: (Color Online) 3D events recorded by the ACTAR TPC demonstrator during the ^{58}Ni and the ^{24}Mg beam tests. The charge projection is plotted using a violet-to-red color palette, while the third dimension (time) is indicated on the voxels using a pink-to-blue color palette. The left two plots show pileup events while the right two plots show multi-particle final state tracking capabilities.

In summary, the experiment IS581 will be ready to be performed by the time the HIE-ISOLDE facility will be started after LS2 shutdown of LHC facility. HIE-ISOLDE is still the only facility in the world where such experiment can be performed. As documented by the NuPECC long range plan from 2017, the knowledge and thus measurement of fission barriers of unstable fissile nuclei away from the line of beta-stability is crucial information for understanding of r-process nucleosynthesis in binary neutron star mergers, such as recently observed gravitational wave event GW170817. Thus IS581 can become one of the crucial experiments for nuclear astrophysics in the foreseeable future. We consider necessary to use all the beam-time which was approved by the INTC in 2014 (28 shifts).

Summary of requested shifts:

In 2014, 28 shifts were allocated by INTC for IS581. As explained above, we consider necessary to use all the beam-time which was approved by the INTC in 2014 (28 shifts).

References:

[Rog18] T. Roger et al., Nucl. Instr. And Meth. A895, 126 (2018): Demonstrator Detection System for the Active Target and Time Projection Chamber (ACTAR TPC) project

[Mau18] Benoit Mauss. Réactions élastiques et inélastiques résonantes pour la caractérisation expérimentale de la cible active ACTAR TPC, PhD thesis, Normandie Université, Caen, 2018, https://tel.archives-ouvertes.fr/tel-01987365v2

[Mau19] B. Mauss et al., Nucl. Instr. And Meth. A940, 498 (2019): Commissioning of the ACtive TARget and Time Projection Chamber (ACTAR TPC)

[Cer18] S. Cerruti, R. Raabe et al., Proposal to the GANIL PAC: Study of giant resonances in exotic Ni isotopes at LISE

[Rud16] D. Rudolph, B. Blank et al., Proposal to the GANIL PAC: Proton-decay Branches from the 10^+ Isomer in ^{54}Ni

[Rod14] C. Rodriguez-Tajes et al., Nucl. Instr. And Meth. A768, 179 (2014): A mask for high-intensity heavy-ion beams in the MAYA active target

[Rod17] C. Rodriguez-Tajes et al., Nucl. Phys. A 958, 246 (2017): First inverse-kinematics fission measurements in a gaseous active target

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
No existing setup will be used, existing 3rd beamline is required	☐ Existing	☐ To be used without any modification
ACTAR TPC	☐	☐
	☐ New	CERN/collaboration responsible for the design and/or manufacturing
none	☐ Existing	☐ To be used without any modification ☐ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[insert lines if needed]		

HAZARDS GENERATED BY THE EXPERIMENT

(if using fixed installation) Hazards named in the document relevant for the fixed [MINIBALL + only CD, MINIBALL + T-REX] installation.

Additional hazards:

Hazards			
	ACTAR TPC	*[Part 2 of the experiment/equipment]*	*[Part 3 of the experiment/equipment]*
Thermodynamic and fluidic			
Pressure	0.5[Bar], 20[l]		
Vacuum	not relevant		
Temperature	ambient		
Heat transfer	not relevant		
Thermal properties of materials	stable		
Cryogenic fluid	none		
Electrical and electromagnetic			
Electricity	15 kW		
Static electricity	none		
Magnetic field	no magnetic field		
Batteries	☐none		
Capacitors	☐none		
Ionizing radiation			
Target material	Deuterium gas		
Beam particle type (e, p, ions, etc)	193Tl, 199Bi, 201At and 209Fr		
Beam intensity	10^6 at maximum		
Beam energy	5 AMeV		
Cooling liquids	none		
Gases	Deuterium gas		
Calibration sources:	☐		
• Open source	☐		
• Sealed source			

• Isotope	^{241}Am		
• Activity	< 40 kBq		
Use of activated material:			
• Description	Beam dump		
• Dose rate on contact and in 10 cm distance	> 5 mSv/h on contact, <40 microSv/h at 10cm distance. Standard shielding will be sufficient.		
• Isotope	193Tl, 199Bi, 201At and 209Fr (primary)		
• Activity	Max. 1 MBq of primary activity		
Non-ionizing radiation			
Laser			
UV light			
Microwaves (300MHz-30 GHz)			
Radiofrequency (1-300MHz)			
Chemical			
Toxic	[chemical agent], [quantity]		
Harmful	[chemical agent], [quantity]		
CMR (carcinogens, mutagens and substances toxic to reproduction)	[chemical agent], [quantity]		
Corrosive	[chemical agent], [quantity]		
Irritant	[chemical agent], [quantity]		
Flammable	Deuterium gas, 20l		
Oxidizing	[chemical agent], [quantity]		
Explosiveness	[chemical agent], [quantity]		
Asphyxiant	[chemical agent], [quantity]		
Dangerous for the environment	[chemical agent], [quantity]		
Mechanical			
Physical impact or mechanical energy (moving parts)	[location]		
Mechanical properties (Sharp, rough, slippery)	[location]		
Vibration	[location]		
Vehicles and Means of Transport	[location]		
Noise			
Frequency	[frequency],[Hz]		
Intensity			
Physical			
Confined spaces	[location]		
High workplaces	[location]		
Access to high workplaces	[location]		
Obstructions in passageways	[location]		
Manual handling	[location]		
Poor ergonomics	[location]		

3.1 Hazard identification

The major safety concern is the activity of the beams ^{193}Tl, ^{199}Bi, ^{201}At and ^{209}Fr collected in the beam dump (up to 1MBq for beam rate 10^6/s) and subsequent build-up of longlived activity from the decay chains of the radioisotopes ^{193}Tl and ^{209}Fr. Activity caused by the beams can be handled by shielding of the beam dump, which will be separate from the ACTAR TPC chamber. The use of deuterium gas poses potential safety risk, due to its flammability when mixed with air, however the active target ACTAR TPC is designed so that it can handle this issue. Several tests with H2 gas were already performed and safety procedures implemented. Further potential safety risks are posed by use of high voltage, which is however a standard issue in experimental nuclear physics.

3.2 Average electrical power requirements (excluding fixed ISOLDE-installation mentioned above): *(make a rough estimate of the total power consumption of the additional equipment used in the experiment)*

< 20 kW