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Letter of Intent to the ISOLDE and Neutron Time-of-Flight Committee

High-energy Fission around Z=82,78 Measured with an Optical Chamber

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Abstract: We propose to use a long-lived beam of ^{148}Gd accelerated at 5 MeV/u to study fusion-induced, high-energy fission of Z=82,78 systems in inverse kinematics. The shell structure of these systems might display different roles at the barrier and at the scission point. The measurement of the angular and mass distributions of the fragments will inform about the survival of shell effects in these conditions of high excitation energy. This experiment will also serve as test of a new detector, currently under development, based on optical-chamber technology. The experiment will test both solid- and active-target configurations.

Requested shifts: 12 shifts, (3 of beam + 3 of change of setting + 6 of beam)
Installation: 2nd beamline

1 Introduction

Since its discovery, fission was understood as a long and complex process modeled by macro- and microscopic properties. From the experimental point of view, the set of observables collected before and after the process help to understand what happened in between, and allow us to construct models describing the process. For quite some time, these observables were mostly gathered in fixed-target experiments and permitted to access the fragment mass and kinetic energy distributions, neutron and gamma evaporation multiplicities, among others. These observables built the general picture we have nowadays about fission and feed the different theoretical models [1, 2].

1.1 Inverse kinematics

The available set of observables was increased in the last decade with the use of inverse kinematics in fission studies [3, 4, 5]. The velocity boost that inverse kinematics gives to the fragments allows them to escape from thicker targets and eases the measurements of their energy loss, and thus it facilitates their identification. These experimental traits offer the possibility to new observables, such as the fragment proton and neutron numbers distributions, their excitation energy [6], and the scission configuration [7].

However, to produce this wealth of information through inverse kinematics, the use of a magnetic spectrometer is almost mandatory. This need forces these experiments to be performed at specific facilities and thus it restricts the available beams/systems. At the University of Santiago de Compostela we are currently developing a new general-purpose detector that includes the possibility of studying fission in inverse kinematics, being at the same time portable enough to be installed at any facility. The detector is based on the concept of optical TPC [8, 9, 10], and it shall be used either with solid targets or using the filling gas as an active target. The advantage with respect to existing active targets consists in the detection of the primary light emission from ionisation instead of the collection of electrons. This direct detection would avoid the complications arising from the electron drift within an electric field, particularly when used with very high-ionising particles, such as those involved in fission reactions.

1.2 Structure at high-energy fission

Recent studies on high-energy fission are bringing back the discussion on the role of shell structure in fission. Mass distributions showed features expected at lower energy that might be explained by the effect of shells at the barrier [11] or at the scission point [6, 12]. Among the former, systems close to Z=82 are particularly attractive and accessible; the interest of fission around these species was recently boosted by the measurement of asymmetric fragment distributions in both low- and high-energy fission of ^{180}Hg [13, 11]. The nature of this fission mode was interpreted in terms of the dynamics around the barrier rather than being due to the influence of fission channels in the potential landscape [14]. Remarkably, the effect seems to survive even at high excitation energy. In the case of lead isotopes, the Z=82 closed shell might have a reinforced influence of structure at the level

of the fission barrier, which could also survive high excitation energy.
Fission around Z=78 is also interesting due to the possibility of producing fragment pairs around magic numbers Z=50 and Z=28. In this case, the effect of closed shells should be more important at the scission stage than at the barrier. It would be very informative to see whether these shells maintain a relevance at high excitation energy.

A simple way to study high-energy fission around these regions is to measure fusion-induced fission of systems produced with a beam of ^{148}Gd impinging on ^{40}Ar and ^{28}Si targets. With these two beam-target combinations, we can test the influence of structure on the fission process at the barrier and at the scission stage, and whether they keep up with high excitation energy. The use of inverse kinematics will make relevant observables accessible, and will provide new fragment data to this region, seldom explored through high-energy fission [15, 16].
In addition, it is important to note that these input channels will have an important component of quasi-fission reactions that might reach around 50% of the fission events [17, 18]. The output of these reactions is known to depend on the magicity of the nuclei involved rather than on that of the compound nucleus [18]. With the proposed channels, we will be able to obtain a first evaluation of the competition between the structure of the compound system and that of the initial nuclei.

2 Methodology

2.1 Reaction channels

The aim of this letter is then to propose the measurement of fission of Z=82,78 systems in inverse kinematics produced with a long-lived beam of ^{148}Gd. The fission reactions will be induced by fusion between the ^{148}Gd beam at 5 MeV/u and both a solid target of ^{28}Si and a gas target of ^{40}Ar. The energy of the beam is chosen as $\sim$10% above the Coulomb barrier in order to allow fusion channels with enough cross section (σ_{F}) and excitation energy (E^*) while restraining other channels. The expected reactions are listed in Table 1. Other reaction channels, such as inelastic- and transfer-induced fission are expected to be well below 10% of the total events.

Table 1: Expected reactions and total beam counting. The fusion cross sections σ_{F} are estimated with the Bass model [19].

Beam @ Energy	Target (atoms/cm^2)	Compound system (E^* MeV)	σ_{F} (mb, [19])	Beam counting for 1e4 fission events
^{148}Gd @ 5 AMeV	^{40}Ar (2.5e20)	^{188}Pb (64)	620	6.4e7
^{148}Gd @ 5 AMeV	^{28}Si (2e18)	^{176}Pt (49)	335	1.5e10

2.2 Experimental setup

The experimental setup will be based on a new optical chamber that is being developed at the University of Santiago de Compostela. The detector is planned to be completed and ready by the end of 2018, nicely timed with the second long shutdown at CERN. This device is basically a gas chamber, filled with a gas mixture of Ar+CF_4. Charged nuclei entering the chamber ionise the gas, producing electrons and emitting light. Tipically, the electrons are then driven towards an amplification plane, where they further ionise the gas and produce light. The light emitted from this plane is recorded in commercial CMOS cameras, while the drift time is measured with a set of photomultipliers. A three-dimensional reconstruction of the particles trajectories is obtained from the pixelated image on the camera and the drift time [8, 9, 10].

The measurement of high-Z particles with high energy loss is particularly complicated in drift chambers, since the high electron yield can modify the drift field, and thus the reconstruction. A solution might be the direct detection of the light emitted in during the primary ionisation produced by fission fragments with energies of hundreds of MeV [20]. The image recorded in two or more cameras would allow a three-dimensional reconstruction, free of distorsions due to an inhomogeneus electric field. In our case, the optical chamber is being built to allow both direct and amplified detection.

In the case of the present experiment, the chamber will be filled with 1 bar of Ar+CF_4. This pressure is enough to stop the fission fragments in its 20x20x20 cm^2.

The chamber will be used in two different configurations: fixed target and active target. The fixed-target setup will include a ^{28}Si target of 100 μg/cm^2, while the active-target setup will use the ^{40}Ar contained in the gas, with an equivalent thickness of 17 mg/cm^2.

The direct observables obtained from the optical chamber will be the emission angles and ranges of the products, and their energy loss in the chamber. The pitch cell of the CMOS camera (of some hundreds of μm) allows the resolution in position and angle to be dominated by the straggling of the particles within the gas. The energy resolution was measured at 3 keV for 5.9 keV β emission in similar detectors [21]. The final performance for high-ionising particles will be determined during the development of the chamber.

From these direct observables, secondary quantities will be deduced. The energy-loss profile along the track of the particle will be compared with GEANT4 and SRIM simulations to evaluate a possible particle identification.[1] This tentative identification will be checked against the measurement of the total energy of the particles.

In addition, the energetics of the fission reaction permits an approximate mass identification from the energy of the fragments [22]. With a conservative estimation of less than 10% resolution in energy loss, the masses can be deduced with a resolution of around 5%, which is less than 5 mass units for the heaviest fragments. The measurement of the angles

[1] This is of particular interest to the new generation of active targets detectors that employ the range and/or energy-loss profile to identify the reaction products. It is known that current simulation packages have issues when reproducing the energy-loss profile of high-Z particles, and when dealing with fast charge-state changes.

will also allow to deduce the angular distribution of the fragments in the reference frame of the fissioning system with a resolution below 4^o, considering the energy and emission angle measurements. From these observables, we can build the mass-angle distribution of the fragments, whose characteristics are a consequence of the competition between fusion-fission and quasi-fission, and thus it permits to assess the fraction of each channel [23].

3 Counting rate

The main objectives of this proposal can be achieved with an average of $\sim$1000 counts for the masses at the tails of the distributions; this results in some 1e4 fission counts per fissioning system. Following the approximate cross sections calculated with the Bass model and the thickness of the targets, the total beam counting needed for the ^{40}Ar target is 6.4e7 beam counts, while for the ^{28}Si is 1.5e10 beam counts (see Table 1).
While the trigger and acquisition rate of the optical chamber detector are still under development, we expect rates somehow higher than 50 Hz for the final setup. This rate imposes a limit below 1e5 pps for the incoming beam, when considering the more probable ^{40}Ar fission channel. With such beam intensity of 1e5 pps, the desired fission counts would be achieved in two days for the ^{28}Si target, while the ^{40}Ar target would fulfill its goal in less than a day.

Summary of requested shifts: 9 shifts (3 days) of beam taking + 3 shifts (1 day) for change of target.

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Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: (*name the fixed-ISOLDE installations, as well as flexible elements of the experiment*)

<table>
<tr><td>Part of the</td><td>Availability</td><td>Design and manufacturing</td></tr>
<tr><td rowspan="2">Optical TPC Chamber</td><td>☐ Existing</td><td>☐ To be used without any modification
☐ To be modified</td></tr>
<tr><td>☒ New</td><td>☐ Standard equipment supplied by a manufacturer
☒ CERN/collaboration responsible for the design and/or manufacturing</td></tr>
</table>

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	[Part 1 of experiment/ equipment]	[Part 2 of experiment/ equipment]	[Part 3 of experiment/ equipment]
Thermodynamic and fluidic			
Pressure	1 bar, 10 l		
Vacuum			
Temperature	293 K		
Heat transfer			
Thermal properties of materials			
Cryogenic fluid			
Electrical and electromagnetic			
Electricity	up to 10 kV drift field, up to 500 V amplification plane		
Static electricity			
Magnetic field			
Batteries	☐		
Capacitors	☐		
Ionizing radiation			
Target material [material]	$Ar+CF_4$(90,10) (gas), ^{28}Si (solid)		
Beam particle type (e, p, ions, etc)	^{148}Gd ions		
Beam intensity	up to 1e5 pps		
Beam energy	740 MeV		

Cooling liquids			
Gases	Ar+CF_4(90,10)		
Calibration sources:	☒		
• Open source	☒		
• Sealed source	☒ [ISO standard]		
• Isotope α and Cf sources			
• Activity			
Use of activated material:			
• Description	☐		
• Dose rate on contact and in 10 cm distance			
• Isotope			
• Activity			
Non-ionizing radiation			
Laser			
UV light			
Microwaves (300MHz-30 GHz)			
Radiofrequency (1-300 MHz)			
Chemical			
Toxic			
Harmful			
CMR (carcinogens, mutagens and substances toxic to reproduction)			
Corrosive			
Irritant			
Flammable			
Oxidizing			
Explosiveness			
Asphyxiant			
Dangerous for the environment			
Mechanical			
Physical impact or mechanical energy (moving parts)			
Mechanical properties (Sharp, rough, slippery)			
Vibration			

Vehicles and Means of Transport			
Noise			
Frequency			
Intensity			
Physical			
Confined spaces			
High workplaces			
Access to high workplaces			
Obstructions in passageways			
Manual handling			
Poor ergonomics			

Hazard identification:

Average electrical power requirements (excluding fixed ISOLDE-installation mentioned above): ... kW