EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Letter of Intent to the ISOLDE and Neutron Time-of-Flight Committee
An inelastic excitation study of multiple shape coexistence in ^{80}Zr

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Abstract

In line with the LoI I-102 [1], we propose to study a rare multiple shape co-existence phenomenon in the self-conjugate ^{80}*Zr nucleus, taking advantage of boost in beam energies at HIE-ISOLDE to perform multi-step inelastic excitations. The influence of proton-neutron interaction on the low-lying level structure in this nucleus will also be addressed. At present, no beam of the refractory* ^{80}*Zr element is available. Therefore, a development of* ^{80}*Zr beam is proposed, using a procedure that is similar to the development of Hf beams.*

Requested shifts: Will be requested during the submission of full proposals.
Beamline: [MINIBALL + CD-only or MINIBALL + T-REX]

1. Physics Motivation

The nuclei in the mass 80 region are very well known both theoretically and experimentally for exhibiting the shape coexistence phenomenon due to the presence of 40 shell gap and energy locations of the orbitals in the valance space [1-4]. Figure 1 (left) adopted from Ref. [3] shows the single particle levels relevant to this mass region. As can be seen the ($g_{9/2}$, $d_{5/2}$) orbitals compete with ($p_{1/2}$, $f_{5/2}$) orbitals in gaining proximity to the Fermi surface when the quadrupole deformation (β_2) is increased. As a consequence different energy minima with different deformations are expected, leading to shape coexistence.

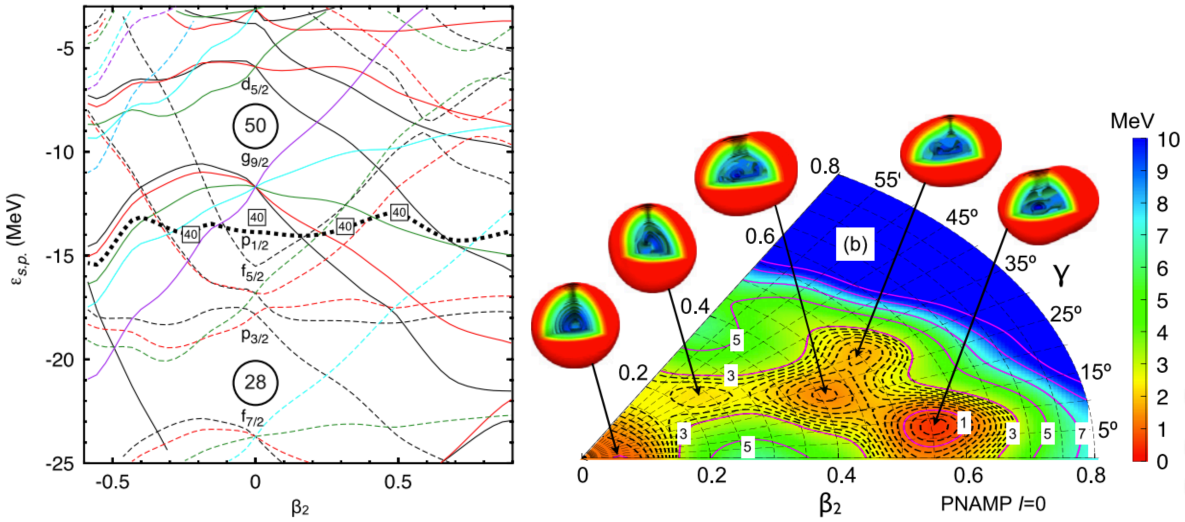

Figure 1 Taken from Ref. [3]. (left) Single particle energies for neutrons (protons follow a similar pattern with energies about 11 MeV higher) as a function of the quadrupole deformation β_2 calculated with the Gogny D1S interaction. The Fermi level is represented by a thick dotted line. (right) Potential energy surfaces calculated for ^{80}Zr using the Gogny D1S interaction together with spatial densities for each minimum. Contour lines are separated by 0.2 MeV (dashed) and 1 MeV (continuous).

The N=Z ^{80}Zr nucleus has been of a great interest both theoretically and experimentally [3-9]. In particular, the influence of the expected strong proton-neutron interaction, large deformation and shape coexistence on the structural features has been studied. Figure 1 (right) shows calculated potential energy surface for the case of ^{80}Zr [3]. It is evident that five energy minima below 2.25 MeV are predicted corresponding to different 0^+ states with different shape configurations, including spherical and triaxial shapes. This feature leads to a rare phenomenon of multiple shape coexistence. Figure 2 presents the data and predictions for the low-lying level structure in ^{80}Zr [3]. Currently, only a few levels are experimentally known. No data of B(E2) or of the excited 0^+ states are available to address the predicted multiple shape coexistence phenomenon. This situation warrants an experimental study in order to obtain transition matrix elements and the locations of the excited 0^+ as well as excited higher spin states in ^{80}Zr. Therefore, we propose inelastic excitation studies using ^{80}Zr beam of > 5 MeV/u and the MINIBALL setup. A target with high-Z will be chosen so as to obtain higher statistics with multi-step inelastic excitations. Both safe and unsafe Coulomb excitations, i.e, Coulomb as well as Coulomb-nuclear excitations [10], will be considered, taking full advantage of higher energy beams from HIE-ISOLDE compared to that of ISOLDE.

As ^{80}Zr is a self-conjugate nucleus strong proton-neutron correlations are expected due to large overlaps of the proton and neutron wave functions. Therefore, it also provides a good ground to study such correlations, which could shed further light on the origin of the delayed alignments and the role of isoscalar component of the proton-neutron interaction [5-9].

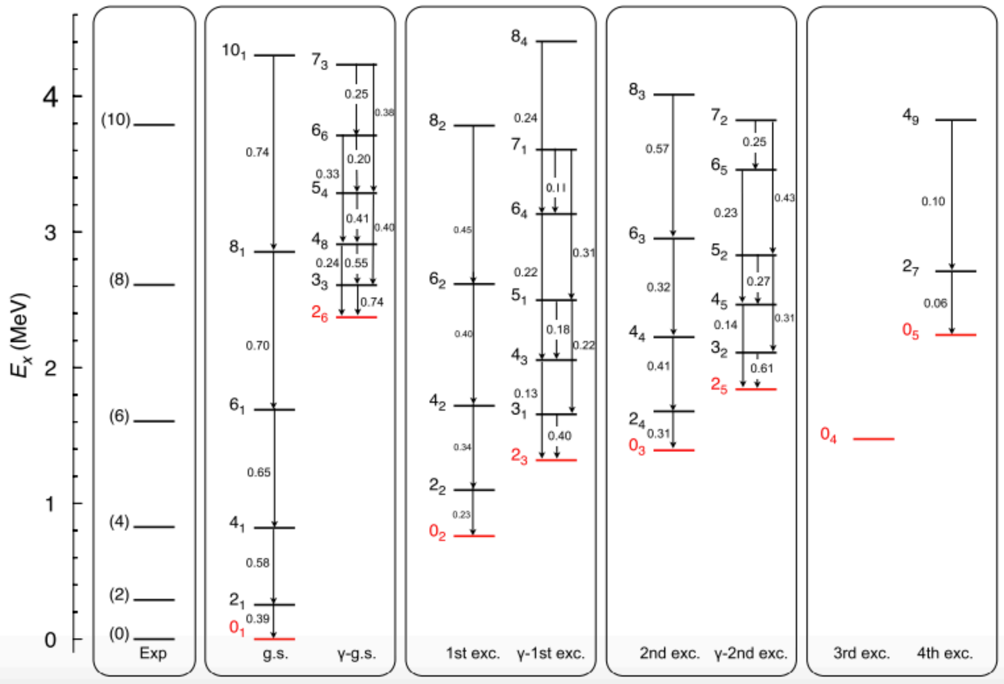

Figure 2 Taken from Ref. [3]. The experimental and predicted low-lying structure of ^{80}Zr [5, 6]. The predicted B(E2) values are given in e^{2}b^2.

Interest also stems from the relevance of shape coexistence to the rapid-proton capture (rp) process. In particular, some of the shape isomeric states in ^{80}Zr may well be very low in excitation energy that can be statistically populated in these astrophysical scenarios [11]. Experimental information of the excitation energies of these states and the β decay characteristics are required in order to definitively conclude their role on the path of the rp-process and nuclear abundances.

The proposed inelastic scattering experiments will be followed by the lifetime measurements of excited states in ^{80}Zr [12] using a two- [13] or three-foil plunger [14].

2. Experimental Setup

We will use the standard CD only Coulomb excitation Miniball or the C-REX setup for inelastic excitation study. A three-foil plunger developed by the Manchester group can be employed for lifetime measurements as it is expected to be more efficient compared to a two-foil plunger as a significant reduction in beam time is expected and it is possible in some cases to measure lifetimes of two states, simultaneously [12]. However, if it is strategically preferable to use two-foil plunger of Cologne that is currently installed at Miniball or the one developed by Manchester [13] for proton-emitting nuclei [16-19], it could be also employed.

3. Beam Requirements

The ^{80}Zr beam has never been produced at ISOLDE or HIE-ISOLDE, therefore, we propose to develop the beam employing a procedure similar to that of the production of Hf beams [15]. In particular, a chemical evaporation in a molecular form and mass separation in a molecular band will be utilized in order to produce the beams of the refractory Zr elements.

4. Safety Aspects

No particular hazards.

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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)*

Part of the Choose an item.	**Availability**	**Design and manufacturing**
[if relevant, name fixed ISOLDE installation: MINIBALL + only CD, MINIBALL + T-REX]	☒ Existing	☒ To be used without any modification
[Part 1 of experiment/ equipment]	☐ 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
[Part 2 experiment/ equipment]	☐ 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			
	[Part 1 of the experiment/equipment]	*[Part 2 of the experiment/equipment]*	*[Part 3 of the experiment/equipment]*
Thermodynamic and fluidic			
Pressure	[pressure][Bar], [volume][l]		
Vacuum			
Temperature	[temperature] [K]		
Heat transfer			
Thermal properties of materials			
Cryogenic fluid	[fluid], [pressure][Bar], [volume][l]		
Electrical and electromagnetic			
Electricity	[voltage] [V], [current][A]		
Static electricity			
Magnetic field	[magnetic field] [T]		
Batteries	☐		
Capacitors	☐		
Ionizing radiation			
Target material	[material]		
Beam particle type (e, p, ions, etc)			
Beam intensity			
Beam energy			
Cooling liquids	[liquid]		
Gases	[gas]		
Calibration sources:	☐		
• Open source	☐		

• Sealed source	☐ [ISO standard]		
• Isotope			
• Activity			
Use of activated material:			
• Description	☐		
• Dose rate on contact and in 10 cm distance	[dose][mSV]		
• Isotope			
• 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	[chemical agent], [quantity]		
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]		

0.1 Hazard identification

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)*
… kW