EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Coherent contributions of protons and neutrons to octupole collectivity in the region above ^{100}Sn: ^{114}Xe (molten) Lanthanum target production test

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Abstract

Nuclei around N=Z=56, in the vicinity of the double-magic nucleus ^{100}Sn, are expected to show some of the largest octupole correlations in the whole Segrè chart. The experimentally deduced B(E3; $3^- \rightarrow 0^+$) value in ^{114}Xe of 77(27) W.u. from lifetime data is one of the largest measured so far, having almost twice the octupole strength measured in the ^{146}Gd region and interpreted as possibly due to coherent contribution of protons and neutrons to the octupole collectivity. This is a new mechanism, only possible for N=Z nuclei and presently unexplained by nuclear theories. With the intention to propose a direct determination of the octupole collectivity by means of proton or deuteron inelastic scattering detected by the ISS solenoidal spectrometer, we ask here a test of the ^{114}Xe extraction intensity using the newly developed molten Lanthanum target and the LaC nanotarget. Production and purity of isotopic beams in the ^{100}Sn region (^{101,102,103}Sn, ^{98,99,100,101}In) will also be tested.

The aim of this Letter of Intent is:
to test the ionization and extraction method of ^{114}Xe using a molten Lanthanum target coupled with the VADIS ion source. The performance of the LaC nanotarget will also be tested.

Testing the behavior of the molten Lanthanum target in this combination is essential for the future application of the ISOLDE beams in the ^{100}Sn region.

Requested shifts: [3] shifts
Beamline:

^{114}Xe extracted from a molten Lanthanum target coupled with the VADIS source.

1 Motivation

Reflection-asymmetric shapes of the atomic nucleus like octupole deformations, are relevant to nuclear stability, nuclear spectroscopy, nuclear decays and fission, and to the search for new physics beyond the standard model. Octupole correlations in nuclei are generated by the interaction between orbitals of opposite parity near the Fermi surface which differ by three units of angular momentum. In general this situation occurs when the Fermi level lies between an intruder-orbital and the normal parity subshell. For a general review we refer the reader to Ref. [1, 2]. This situation is expected to occur when the number of protons or neutrons is close to 32, 56, 88, 136 and 188 [1, 2, 3].

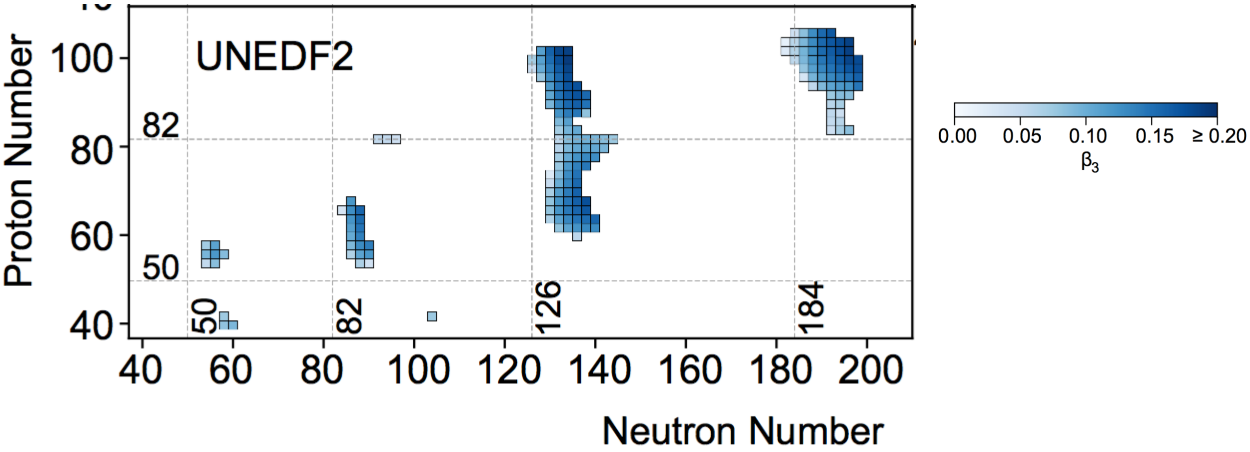

Figure 1: Total ground state octupole deformations β_3 of even-even nuclei in the (Z, N) plane predicted by Density Functional Theory calculations with the UNEDF2 interaction. Magic numbers are indicated by dashed lines [3].

Figure 1, extracted from [3], shows the octupole deformation parameter β_3 of even-even nuclei in the (Z, N) plane calculated using Density Functional Theory. The region above ^{100}Sn shows an island of octupole deformation for nuclei along the N=Z line. Nuclei in the region around N = Z = 56, are rather unique since octupole correlations are predicted to happen both for protons and neutrons. In particular it has been suggested that octupole correlations should appear at low and medium spins in the light Te, I and Xe nuclei [4]. Microscopically the Fermi surface for both protons and neutrons lies between the $d_{5/2}$ and the $h_{11/2}$ orbitals, where the octupole correlation emerges from the coupling of these two orbitals from both valence neutrons and protons outside the ^{100}Sn core [1,2,5]. Therefore, an enhancement of the octupole collectivity is expected to appear. In this region, only for a few cases the octupole band is known and only for ^{114}Xe the reduced transition probability B(E3) has been determined, resulting in one of the largest octupole strengths that has ever been experimentally measured [6]. In such a case the high collectivity of the 3^- state is strongly corroborated by the lifetime measurements. The deduced B(E3) transition matrix elements for the $3^- \rightarrow 0^+$ and $5^- \rightarrow 2^+$ transitions, respectively correspond to 77(27) and 68(17) W.u.. They are twice as large as the B(E3) of the $3^- \rightarrow 0^+$ transition (37 W.u.) in ^{146}Gd, involving the same proton excitations. Such strong B(E3) matrix elements cannot be explained within the standard mean field approach. It has been suggested that since protons and neutrons fill the same shell, a coherent enhancement of the collectivity can appear, possibly due to dynamical coupling of the proton–neutron type $(\pi(\nu)d_{5/2}- \nu(\pi)h_{11/2})$, a phenomenon which, if present, is only specific of this region of the nuclear chart.

The strongest octupole is supposed to happen for ^{112}Ba (N = Z = 56), that in fact, is out of reach in any facility at the moment. However, since octupole correlations are expected to be strongly enhanced when approaching the N = Z line, the identification of octupole structures for neutron deficient systems close to the N=Z=56 region that benchmark our best nuclear models is of utmost importance.

Theoretical calculations for the Xe isotopes have been performed using the symmetry-conserving configuration-mixing method (SCCM) based on the Gogny D1S interaction [7]. The method includes particle number, parity and angular momentum projections of HFB states and axial quadrupole and octupole shape mixing within the generator coordinate method framework. In the calculated HFB Potential Energy Surface – figure 2 – two minima are observed, the first for a quadrupole deformation of β_2=0.30 and octupole deformation β_3 ranging in the interval -0.2,+0.2 and the second for an oblate minimum with β_2=-0.20 and β_3=0.

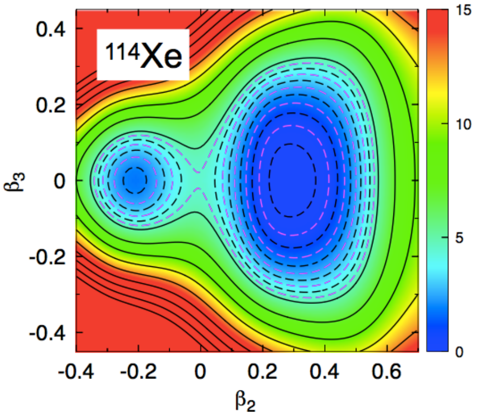

Figure 2: HBF potential energy surface in the (β_2, β_3) plane

The calculated ground state band is characterized by quadrupole deformation close to zero at low spin but β_3 deviates from zero already at spin 10. The excited negative parity band shows two symmetrical well-developed minima in β_3 which appear stable at increasing angular momentum – figure 3 -.

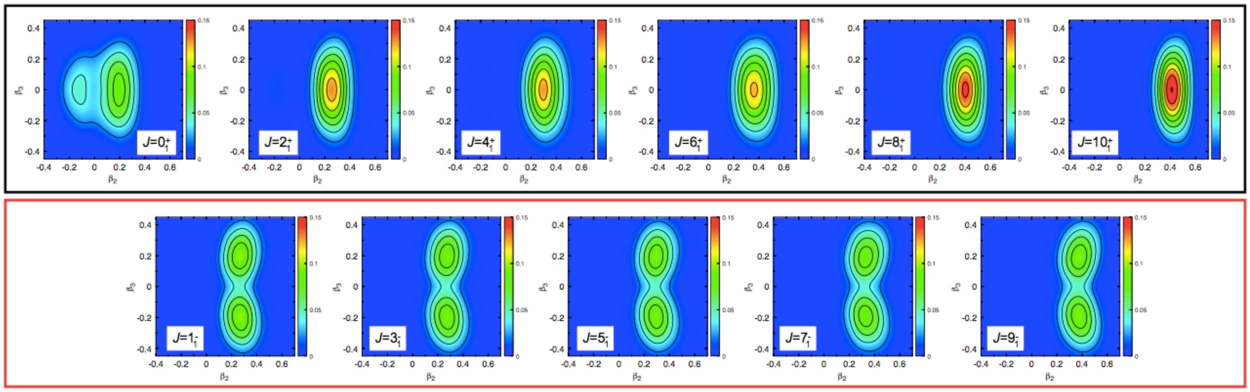

Figure 3: Collective wave functions for the ground state (up) and negative-parity bands (down) for ^{114}Xe.

The calculated B(E3) value is 20 W.u., a value that is much below the measured one.

With the intention to measure the octupole collectivity of the neutron deficient nuclei around ^{112}Ba using proton and deuteron inelastic scattering we propose here a test of the extraction intensities for nuclei above ^{100}Sn. In case of a successful test (extraction intensity of the order of 10^5 pps or larger for ^{114}Xe, about a factor 5 more than present one) those reactions, in the contest of a future request to INTC, will be proposed in reverse kinematics using the ISS solenoidal spectrometer. Figure 4 shows, as an example, the proton inelastic spectrum on a radioactive ^{148}Gd target [8]. The p,p' data for the 2^+ and 3^- states show that in the ^{148}Gd nucleus the octupole collectivity is larger than the quadrupole collectivity, a result in line with the data from many spherical nuclei. From that measurement a value for B(E3) = 42(9) W.u. was deduced.

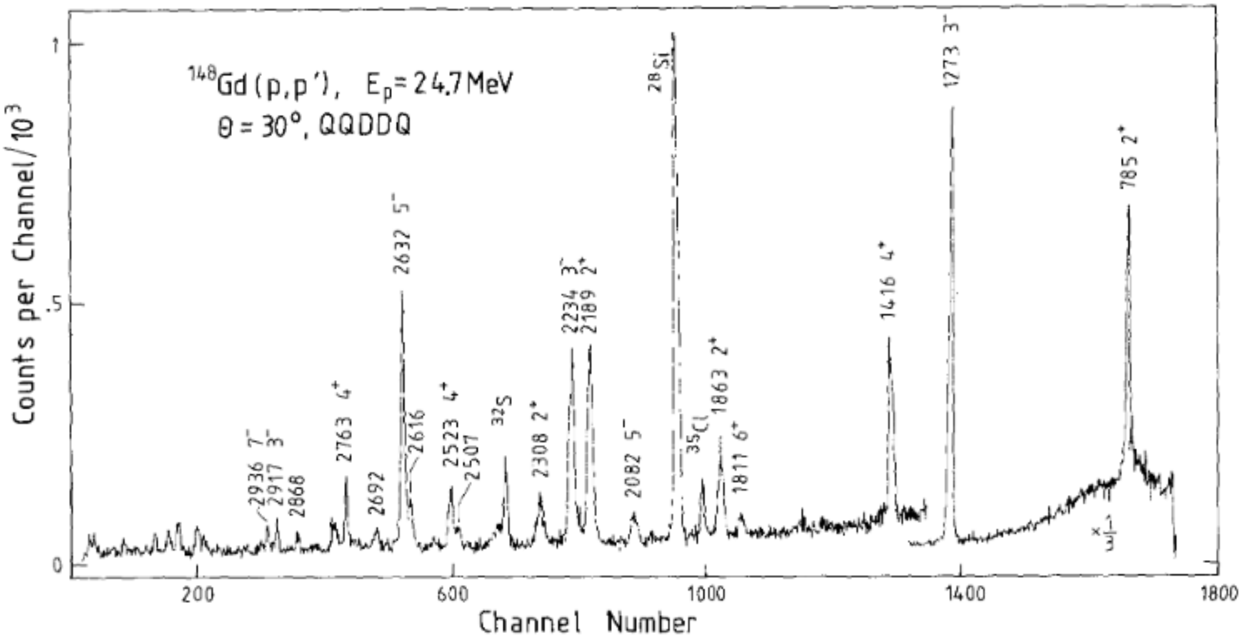

Figure 4: Spectrum from proton inelastic scattering on a ^{148}Gd radioactive target [8]. Excitation energies are given in keV; spin-parity values deduced in the present experiment are also specified. One notices that the 3^- excitation is dominating the spectrum, showing that the octupole collectivity is larger than the quadrupole collectivity. A value for B(E3) = 42(9) W.u. was deduced.

^{114}Xe is presently extracted at ISOLDE from CeO_x target with an intensity of about 2.4 10^4 pps. The calculated achievable intensities and purities using a molten Lanthanum target coupled with the VADIS (Versatile Arc Discharge Ion Source) [9] depend by the use of ABRABLA or FLUKA. For the intensity one expects at least one order of magnitude larger respect to the present one. The development of a molten Lanthanum target coupled with a "cold line" (to condense La and other non volatile elements) has already been tested for static targets, however the full combination with the VADIS ion source suitable for Xe (to reach a ionization efficiency larger the 30%) needs still to be tested [10]. Xe, being a volatile element and a noble gas, is a perfectly suited element for an extraction test using the VADIS ion source and the lifetime of τ=10s for the 114 isotope is not introducing limitations related to the extraction time. The ISOLDE target group is also developing a high power target prototype (LIEBE) able to receive higher proton beam intensity (factor 2 or factor 4 if the upgrade in the EPIC project is approved) and a faster release of Xe which could be very important for the more exotic Xe isotopes and in general for the ^{100}Sn region [10].

In conclusion:

The aim of this Letter of Intent is to determine the ^{114}Xe extraction intensity using the molten Lanthanum Target recently developed by the ISOLDE target group coupled with the VADIS ion source as well as the LaC nanotarget. The final aim will be the direct measurement of the octupole collectivity in ^{114}Xe and in other nuclei in the region of the N=Z=56 ^{112}Ba. Production and purity of isotopic beams in the mass region (^{101,102,103}Sn, ^{98,99,100,101}In) will also be tested. This is an essential step to benchmark nuclear models in the ^{100}Sn region.

Summary of requested shifts:

Xe A=114 3 shifts (Molten Lanthanum Target and LaC nanotarget).

References:

[1] P.A. Butler and W. Nazarewicz, Rev. Mod. Phys. 68 (1996) 349.

[2] P. A. Butler J. Phys. G: Nucl. Part. Phys. 43 (2016) 073002.

[3] Y. Cao et al. arXiv:2002.01319v2 (2020).

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[8] G. de Angelis et al., Z. Phys. A 336 (1990) 375.

[9] Y. Martinex Panenzuela et al., Nucl. Instrum. Methods Phys. Res. B 431 (2018) 59.

[10] F. Boix Pamies et al., Nucl. Instrum. Methods Phys. Res. B 463 (2020) 128.

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
	☒ 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