EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Status Report to the ISOLDE and Neutron Time-of-Flight Committee
(Following HIE-ISOLDE Letter of Intent I-CERN-INTC-2010-032, INTC-I-100 and the endorsed proposals CERN-INTC-2011-002, INTC-P-290 and CERN-INTC-2012-051 / INTC-P-352)

Status Report on IS556

Spectroscopy of low-lying single-particle states in ^{81}Zn populated in the ^{80}Zn(d,p) reaction

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Abstract

Despite important progress in the study of the ^{78}Ni region, including the measurement of the first excited 2^+ state in ^{78}Ni, the energies of single-particle orbits near Z=28 and N=50 are still largely unknown. We have proposed to study neutron single-particle states in ^{81}Zn populated via the ^{80}Zn(d,p)^{81}Zn reaction in inverse kinematics, using a laser-ionized, 5.5 MeV/u HIE-Isolde ^{80}Zn beam impinging on a deuterated-polyethylene target. In this report, we would like to reinstate the importance of this measurement, which can only be carried out at Isolde. This experiment will constitute the first spectroscopic study of low-lying neutron states in ^{81}Zn. Their observation will elucidate the energy and ordering of neutron single-particle orbits above the N=50 gap, and the properties of neutron-rich nuclei in the ^{78}Ni region. The experiment was approved by INTC but has not yet been scheduled.

Requested shifts: 36 shifts, (split into 1 run over 1 year)
Beamline: MINIBALL + T-REX

Introduction

Experiment IS556 (proposals INTC-P-290 and INTC-P-352) was approved by the INTC but has not yet been performed. The physics case is linked to the study of neutron single-particle energies above the N=50 shell gap above doubly magic ^{78}Ni, and we believe that it is still valid and timely. Recent experiments on the one hand confirmed the magicity of ^{78}Ni [Taniuchi], but also highlighted the complexity of the region, where low-lying deformed configurations seem to coexist with spherical states [Taniuchi, Yang, Gottardo, Nowacki]. Due to the difficulty of producing ^{78}Ni, however, the energies of the neutron orbits above N=50 are still unknown, and different theoretical models show significant discrepancies. We proposed to determine the effective single-particle energies of neutron orbits above the N=50 gap by carrying out the single-neutron transfer reaction ^{80}Zn(d,p)^{81}Zn, i.e. two protons above ^{78}Ni, since the ^{78}Ni(d,p)^{79}Ni reaction is still unfeasible at any facility.

Isolde is the only laboratory in the world where such measurement can be carried out, and we would like to retain the approved shifts. The reason why this experiment has not yet been performed was the expected increase in intensity of the ^{80}Zn beam which could be achieved by using a new type of neutron converter, and the recent test of the new converter suggests that it is indeed the case. This report will briefly review the physics case and comment on the status of the beam development.

Physics Case and recent related measurements

In recent years, a vast amount of experimental evidence revealed that the shell structure of nucleon orbits can undergo large modifications away from the line of β stability, sometimes leading to the erosion of familiar magic numbers. The monopole central force and the monopole component of the tensor interaction have been proposed as the main agents inducing this evolution of nuclear structure [Otsuka2005, Otsuka2010]. Furthermore, the lowering of intruder configurations due to shell evolution was linked to the phenomenon of shape coexistence [Tsunoda].

Neutron-rich doubly magic nuclei and nuclei in their vicinity can be used to benchmark different models as well as provide key inputs for theoretical predictions, and in particular for shell model calculations. Reliable theoretical calculations for nuclei far from stability are also paramount to the study of stellar nucleosynthesis, and particularly the rapid neutron capture process [Mumpower, Surman]. In this context, the study of the properties of doubly magic ^{78}Ni, at the crossing of the Z=28 and N=50 shell gaps, and its neighbors, constitutes one of the main aims of both existing and planned large scale facilities worldwide.

In recent years, the first experimental γ-ray spectroscopy of ^{78}Ni [Taniuchi] and its nearest neighbor ^{79}Cu (Z=29) [Olivier] were successfully carried out at RIBF, RIKEN, using one- and two-proton knock-out reactions. The ^{78}Ni experiment confirmed the magicity of ^{78}Ni but also revealed the presence of a second excited 2^+ state that conforms with the notion of a coexisting low-lying deformed configuration. The ^{79}Cu experiment provides some indication on the energy of the $f_{5/2}$ and $p_{3/2}$ proton orbits above the Z=28 gap, but no spectroscopic factors were measured. At the same facility, the first γ-ray spectroscopy of ^{81,82,83,84}Zn was also carried out [Shand]; due to the proton knock-out reaction mechanism, however, these experiments informed only on the role of proton orbits on low-lying excitations of these nuclei. In ^{81}Zn, produced from the ^{82}Ga(p,2p) reaction, two γ-ray transitions were observed with energies 938(13) and 1235(17) keV, and tentatively assigned to two different excited states with a $(\pi f_{5/2})^2(2^+) + \nu d_{5/2}$ configuration. In our experiment, we intend to advance significantly the knowledge of neutron states in ^{81}Zn since ISOLDE offers the unique possibility of populating excited states in ^{81}Zn using the low-energy single-nucleon transfer reaction ^{80}Zn(d,p)^{81}Zn in inverse kinematics.

Some years ago, our collaboration successfully carried out at Isolde the first γ-ray spectroscopy of ^{79}Zn [Orlandi]. This experiment identified the lowest lying excited $5/2^+$ at 983(3) and the intruder $1/2^+$ state at 1100(150) keV. The latter was revealed to be a long-lived isomer, observed in a following experiment using laser spectroscopy ($t_{1\backslash 2} \geq 200$ms). The large quadrupole deformation (β_2=0.22) of the isomer, compared to the smaller deformation of the ground state (β_2=0.14), was interpreted to be a manifestation of shape-coexistence [Yang]. To study ^{81}Zn, we intend to employ the same experimental setup (T-REX + Miniball) which led to the successful spectroscopy of ^{79}Zn.

Using single-neutron transfer, we expect to directly populate primarily the $d_{5/2}$, $s_{1/2}$ and $d_{3/2}$ neutron orbits above the N=50 shell, as well as states where these configurations are coupled to excitations of the ^{80}Zn core, possibly leading also to the observation and placement in the level scheme of those transitions recently observed in RIKEN. As the ^{79}Zn experiment showed, negative parity states could also be indirectly populated. By coupling γ-ray and particle spectroscopy, we aim to measure not only γ-ray transitions but, by determining the amount of orbital angular momentum transfer, to discriminate between the population of *s* and *d* states, and measure relative spectroscopic factors.

The new neutron converter and ^{80}Zn beam

Our proposal was endorsed by the INTC committee, but the scheduling was delayed until a newly designed neutron-converter was tested. The simulations for the new converter in fact predicted a 5-fold increase of the ^{80}Zn released from the ISOL target. A new neutron converter geometry was developed and tested in November 2018. The offline development part has been published [Ramos20], while the analysis of the online results is currently ongoing. From the measurement of the Rb and Cs yields the converter behaved as expected, leading to approximately 5 times larger yields [Ramos]. The measurement of Zn, In and Ga yields, however, were affected by premature ageing of the target (the target container started to fail). The ageing issues are being addressed and another test is required with proton beam. If the issues are solved, the predicted yield increase of ^{80}Zn seems achievable.

If the new converter indeed provides the expected 5-fold increase, the expected yield for ^{80}Zn will be ~1.5 10^5 at/μCi at the target, i.e. similar to that available in the ^{78}Zn(d,p) experiment. The beam purity is not expected to improve using the new converter, with a significant amount of ^{80}Ga (50-70%) in the beam, more or less the same as with the old converter. The contribution of the ^{80}Ga can be removed alternating laser on/laser off ionization. Since our beam request was made assuming the 5-fold increase in yield from the new converter, we ask to retain all the approved shifts. Finally, even if the new converter geometry were not to provide the expected increase in yields, we still would like to run using a thick target and focusing mainly on γ-ray spectroscopy, using the identified protons as a gate, as already discussed in our proposal.

Summary of requested shifts:

In summary, we request to retain all approved 36 shifts.

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Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: T-REX+Miniball (fixed installation)

Part of the Choose an item.	Availability	Design and manufacturing
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

Hazards named in the document relevant for the fixed 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