EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Letter of intent for the use of a tritium target to probe short-range interactions in neutron rich system at ISS

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Abstract

In this LoI we propose to study short-range interactions in neutron-rich systems by means of (^{3}H,^{4}He) transfer reactions at the ISS setup. The measurement aims to observing a possible depauperation of protons in the Fermi sea as a result of the scattering due to short range-correlations. A comparison between the differential cross sections from ^{68}Ni(^{3}H,^{4}He)^{67}Co and

the ones from ^{58}Ni (available in literature) will allow one to measure the predicted increase of such phenomenon as a function of isospin. With this LOI, we intend to propose an integration of a tritium target within the ISS setup.

Introduction

Pairing correlations are the basic elements of superconductivity and superfluidity in strongly interacting quantum many-body systems. These phenomena span very different size scales, from color-superconducting quark matter to neutron stars, and very different energies, from below meV in superconductors to MeV in nuclei and 100 MeV at the quark scale. Of particular interest are superfluid fermionic states in multicomponent systems with cross-species pairing.

Nuclei in this respect represent a very interesting case and indeed the existence of a coherent pn pairing state has been longly investigated with different experimental probes near the line of stability [Ced11, Ced20, Mar].

An open question is if pairing is modified in systems with neutron excess. A recent electron and proton scattering experiment [Due] has shown that nucleons form close proximity pairs, and that the fraction of high-momentum protons increases markedly with the neutron excess in the nucleus, whereas the fraction of high momentum neutrons decreases slightly. This effect is somewhat unexpected in the classical shell model, where protons and neutrons fill independent orbits, indicating the presence of a strong pn interaction. In neutron-rich systems, since the neutrons are occupying higher momentum orbitals a strong pn interaction will shift the protons toward more excited states across the Fermi energy surface making the proton distribution more diffuse. The net result should be a depletion of the bound proton shells.

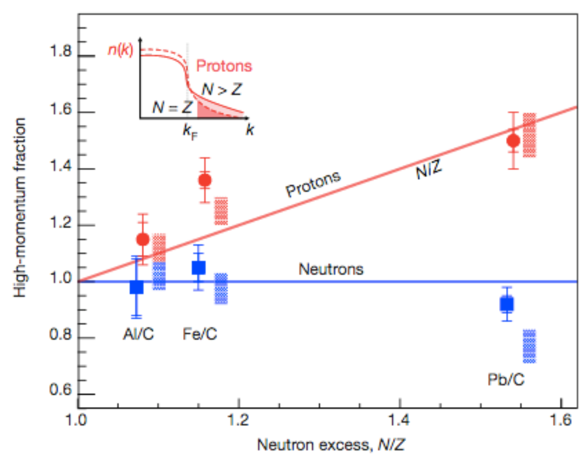

Fig. 1: Depletion of the proton Fermi sea due to high-momentum scattering as function of neutron number. Picture taken from [Due].

Physics Case

The Ni isotopic chain provides an ideal testing ground for the depletion of the proton shell below the Fermi sea surface. We have calculated the proton occupancies for the gs of ^{68}Ni (N=40, Z=28) comparing them with those of ^{56}Ni (N=Z isotope). Using a shell-model space of f7/2, p3/2, f5/2, p1/2 and g9/2 for both protons and neutrons we obtain spectroscopic factors of 7.754, 0.218, 0.021, 0.004, 0.004 for protons and 7.993, 3.933, 5.769, 0.099, 2.206 for neutrons in the case of ^{68}Ni and 7.310, 0.595, 0.076, 0.015, 0.004 for protons and 7.313, 0.587, 0.079, 0.016, 0.005 for neutrons in the case of ^{56}Ni. Results for protons are reported in the table below for a better comparison.

S.F.	πf7/2	πp3/2	πf5/2	πp1/2	πg9/2
^{56}Ni	7.31	0.60	0.08	0.02	0.004
^{68}Ni	7.75	0.22	0.02	0.004	0.004

Ona can deduce that interactions normally used to describe the Ni isotope structure do not predict any significant depletion of the proton shells below Z=28 going to more neutron-rich isotopes. On the contrary, going from N=28 to N=40 the proton occupancy below the closed core increases. This predicted behaviour would be opposite to the one expected if short-range correlations described in Ref. [Due] are present. This is not surprising, since the phenomenological two-body interactions employed ought not to contain such terms.

If the large particle scattering to high-energy states observed in [Due] is present, experimental results will show a behaviour opposite to the one predicted by shell-model interactions. Revision of the role of the pn interaction would be required.

Indeed, a seminal work from 1966 measured the spectroscopic factors for the ^{58}Ni(^{3}H,^{4}He)^{57}Co, ^{60}Ni(^{3}H,^{4}He)^{59}Co, ^{62}Ni(^{3}H,^{4}He)^{61}Co and ^{64}Ni(t,^{4}He)^{63}Co [Bla]. They did not find a monotone decreasing of the proton f7/2 shell when going from N=30 to N=36. Our plan is to measure at N=40 and compare it with the ^{58}Ni case (or ^{56}Ni(^{3}H,^{4}He)^{55}Co if the experiment becomes feasible with increased ^{56}Ni beam intensities). In ^{68}Ni less single-particle strength fragmentation is expected and the N/Z ratio of 1.4 approaches a proton Fermi sea depletion of 30% according to Fig. 1. Such a depletion of the f7/2 shell should be observable experimentally, making the ^{68}Ni(^{3}H,^{4}He)^{67}Co an ideal testing in nuclear structure of the effect observed by electron scattering by the CLAS collaboration.

Experimental details

Proton stripping reactions for nuclei near shell closures (Z=28 or 50) are suited to probe depletion of bound proton orbitals. The proton-stripping ^{68}Ni(t,^{4}He)^{67}Co reactions using the ISS solenoid will represent a pivotal measurement. For a ^{68}Ni beam ($5*10^4$ pps at Isolde) at 7.6 MeV/u, cross sections of the order of 10-20 mb/sr at the maximum are expected for the most intense single-particle states in ^{67}Co.

The characteristics of the titanium-implanted ^{3}H target made available by the Sodern company (France) are the following:

· Titanium sheet: supplied by user (three sheets for one target)

- Welded (by SODERN) between two frames of stainless steel (thickness: 0.2mm)

- High purity titanium: > 99.95%

- Thickness: 1μm +/- 5% (~450μg/cm^2)

- Sheet size: adapted to the frames; the precise weight of each sheet will be given by user.

· Tritium loading ratio: T/Ti ≥ 0.75 (if achievable with respect to the size of the titanium sheet and to the maximum allowed activity)

· Tritium content activity: 1Ci max: the tritium loading operation will be done in order to get less than 37GBq.

This implies an effective ^{3}H target thickness of $4*10^{18}$ at/cm^{2}. This would give about 350 reactions/day for the most important single-particle states in ^{68}Ni. In five days of beam time the measurement is feasible (15 shifts).

We have performed a simulation with NPTool with the following conditions:

$^{68}Ni(^{3}H,^{4}He)^{67}Co$

- 9 MeV/u
- B = 1.5 T
- Target 0.5 mg/cm^{2} Ti^{3}H
- Detectors forward

The main known, low-lying, excited states of ^{67}Co were considered. They are distinguishable, except the 1/2^{-} 481 keV state. As discussed above, the f7/2 strength is the main aim of the experiment.

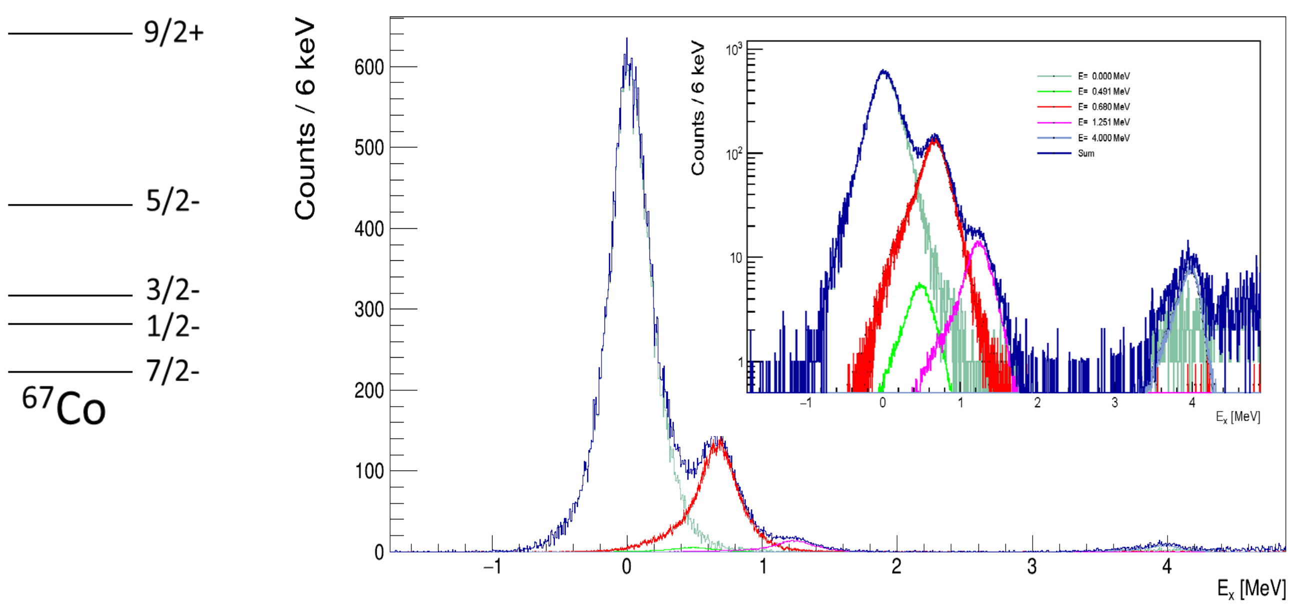

Fig. 2 Level scheme of ^{67}Co and Monte Carlo simulation for the excitation energy spectrum derived from the ^{4}He ejectiles from the $^{68}Ni(t,^{4}He)^{67}Co$ reaction.

From a LISE kinematic calculation, ^{4}He fragments at forward angle will be in the 100 - 6 MeV energy range.

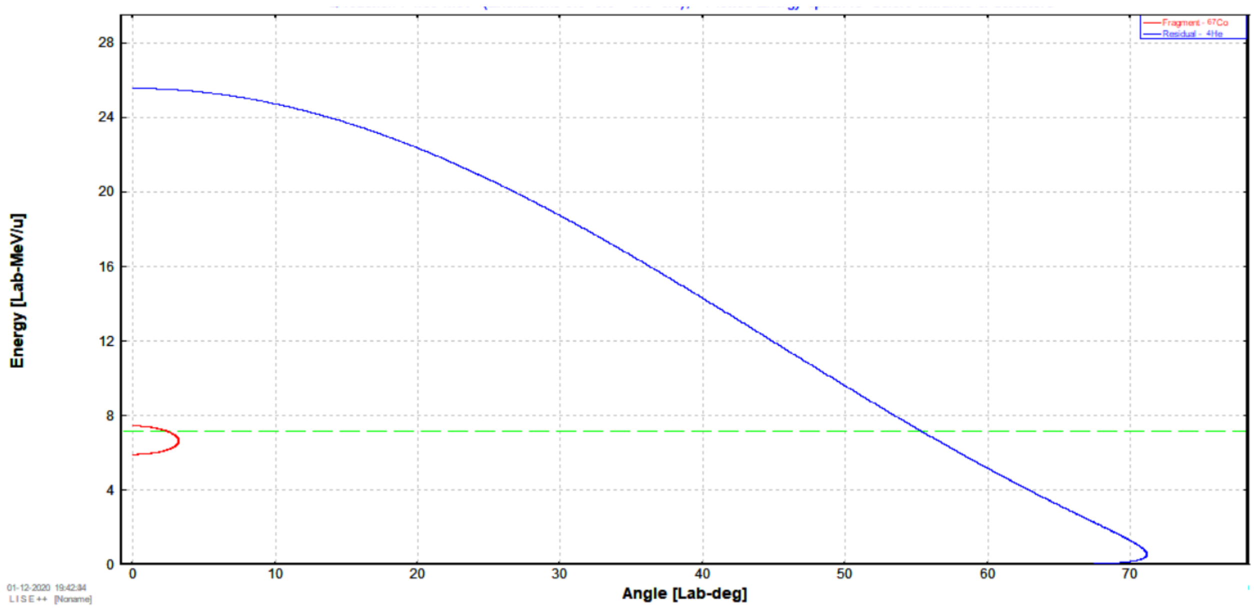

Fig. 3 Kinematic lines of the ^{4}He ejectiles (blue line) and ^{67}Co residues (red line). From the LISE++ code.

Requested shifts: [0] shifts: we present a LoI requiring the procurement of ^{3}H target.
Beamline: ISS

References:

[Bla] A. G. Blair and D. D. Armstrong, Phys. Rev. 151 (1966).

[Ced11] B. Cederwall et al., Nature 469, 68–71(2011).

[Ced20] B. Cederwall et al., Phys. Rev. Lett. 124, 062501 (2020).

[Due] Duer, M., Hen, O. et al., Nature 560, 617–621 (2018).

[Mar] N. Marginean et al., Phys. Rev. C 63, 031303(R) (2001).

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]tritium implanted on Ti foil: <37 GBq		

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]		

3.1 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