EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Pairing vibrations beyond $N = 82$

May 12, 2021

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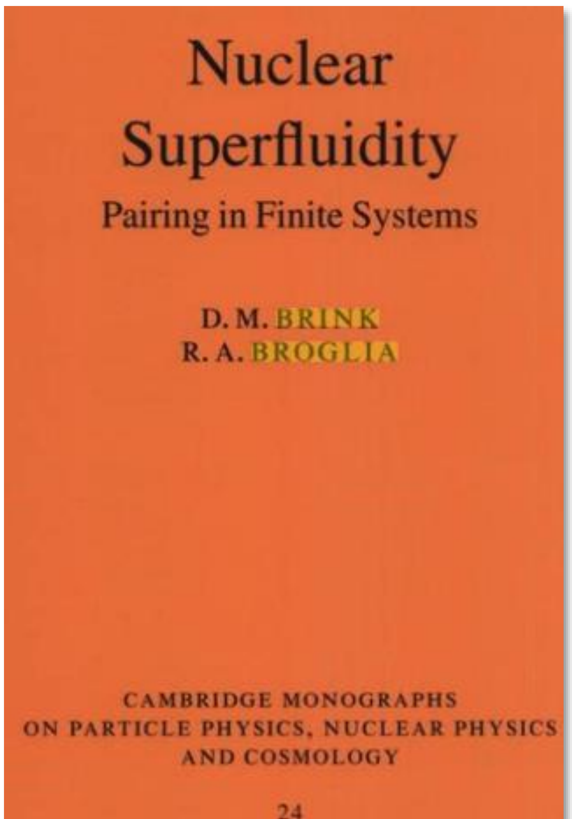
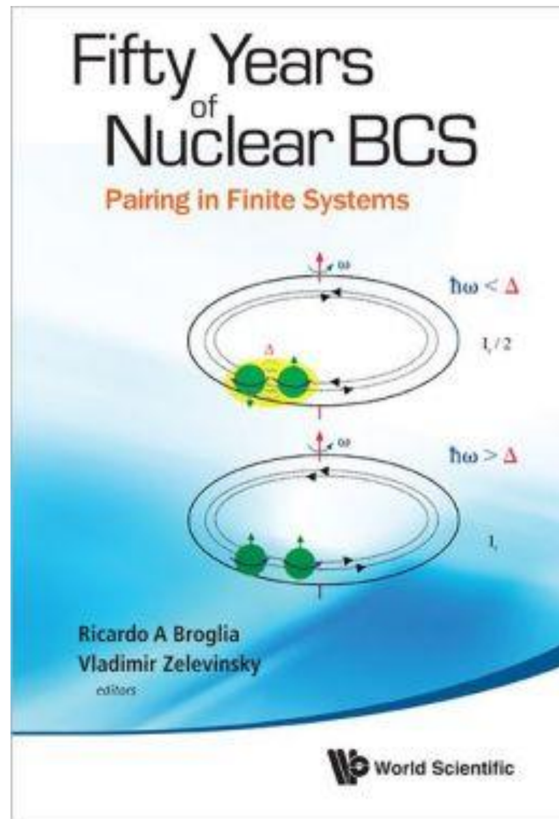
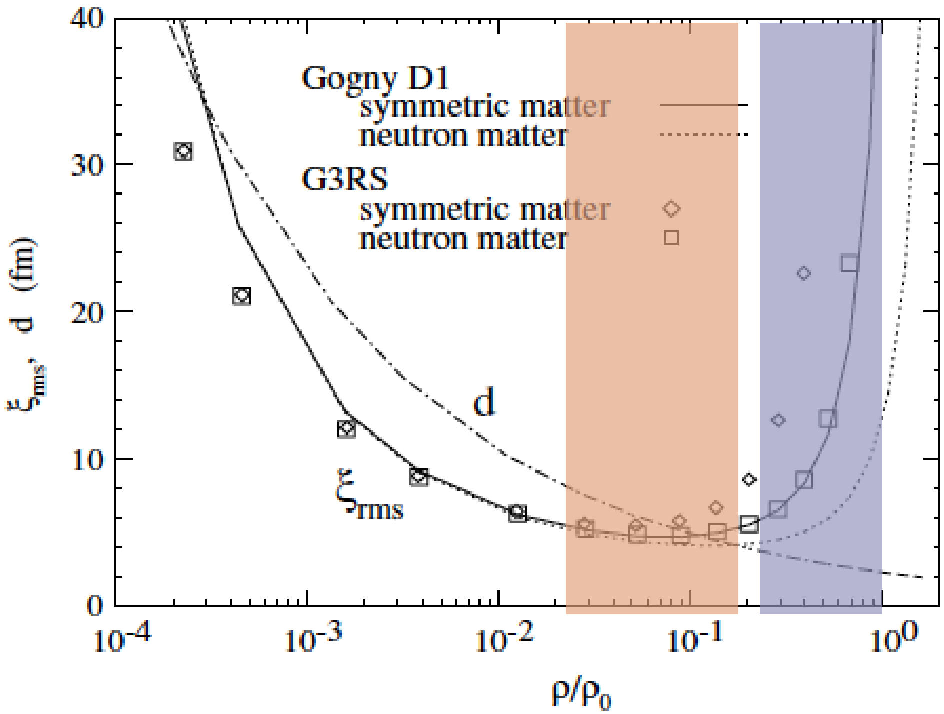
Pair correlations provided a key to understanding
- the excitation spectra of even-A nuclei,
- odd-even mass differences,
- rotational moments of inertia,
- … and a variety of other phenomena



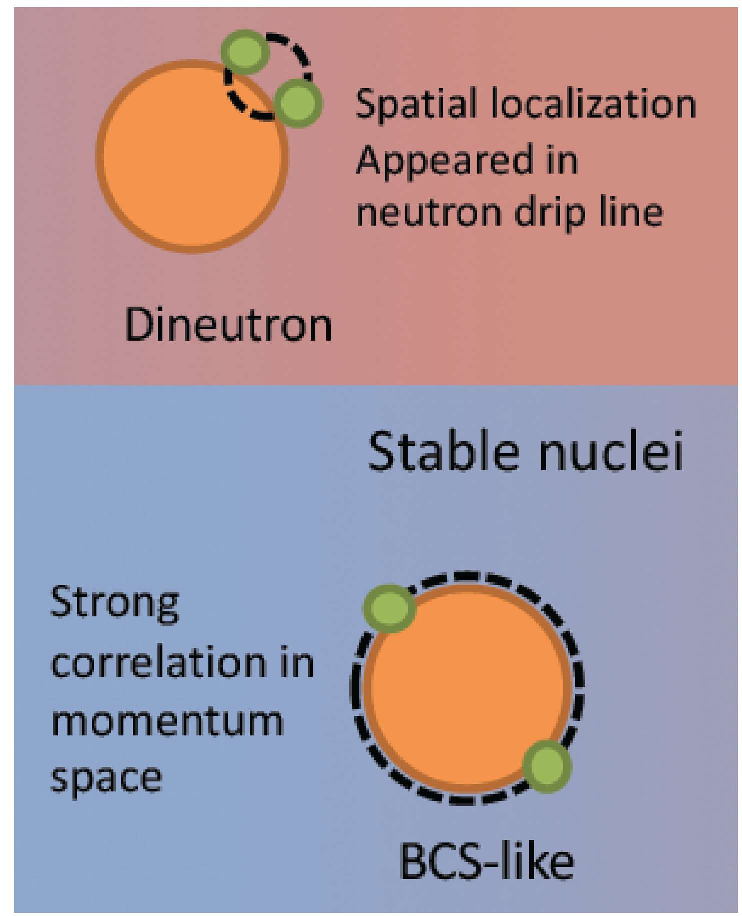


Motivation

The evolution of pairing correlations in exotic nuclei is a topic of great interest in nuclear structure, in particular pairing in neutron-rich isotopes and the role of weak binding.



Matsuo *et al*. PRC 73 (2006) 044309
Pillet *et al.* PRC 76 (2007) 024310



d **Separation**

ζ_{rms} **Correlation Length**

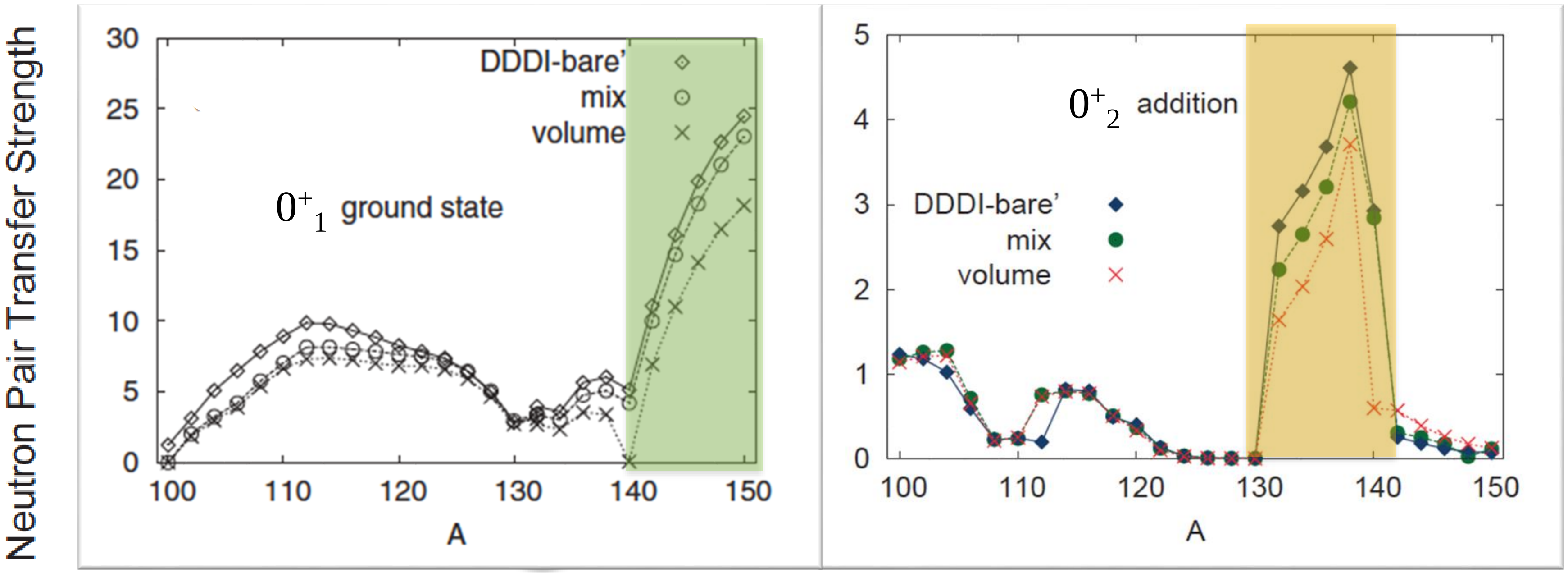
Key observable
→ (t,p) two-neutron transfer reactions

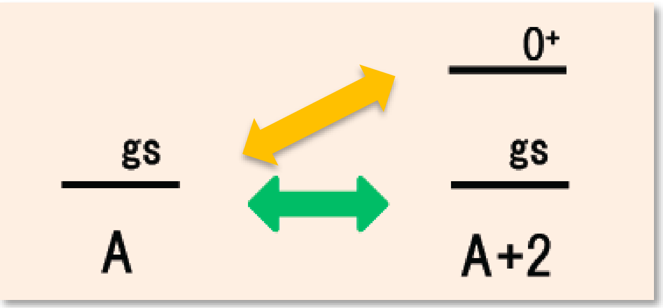
Motivation

PHYSICAL REVIEW C **84**, 044317 (2011)

Anomalous pairing vibration in neutron-rich Sn isotopes beyond the *N* = 82 magic number

Hirotaka Shimoyama and Masayuki Matsuo

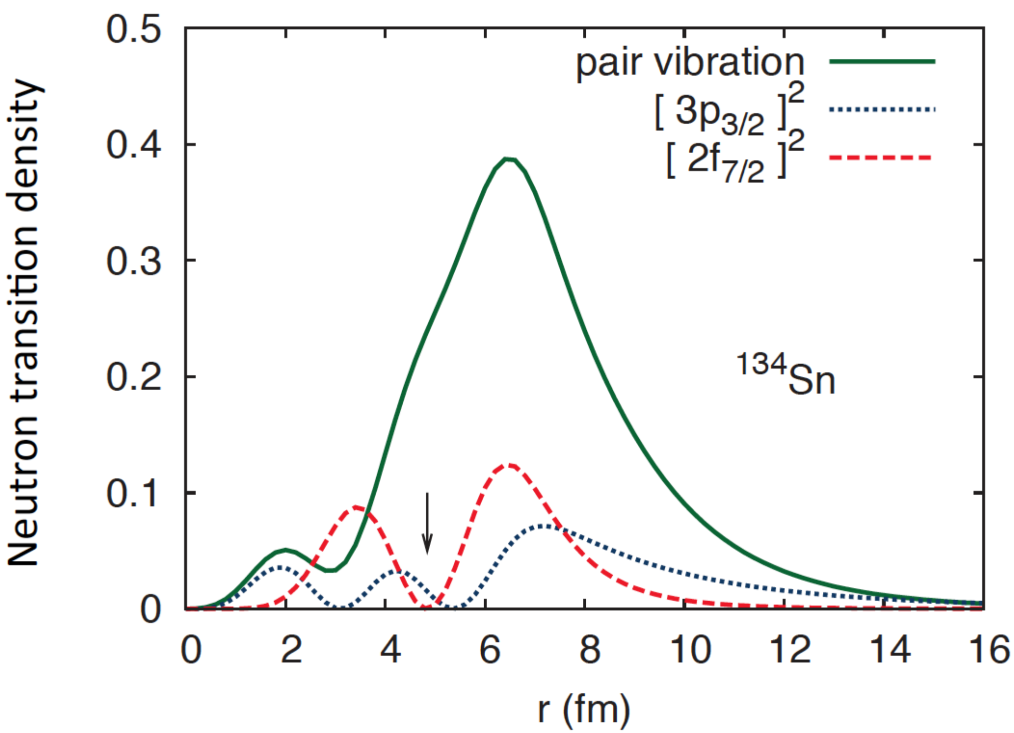




Motivation

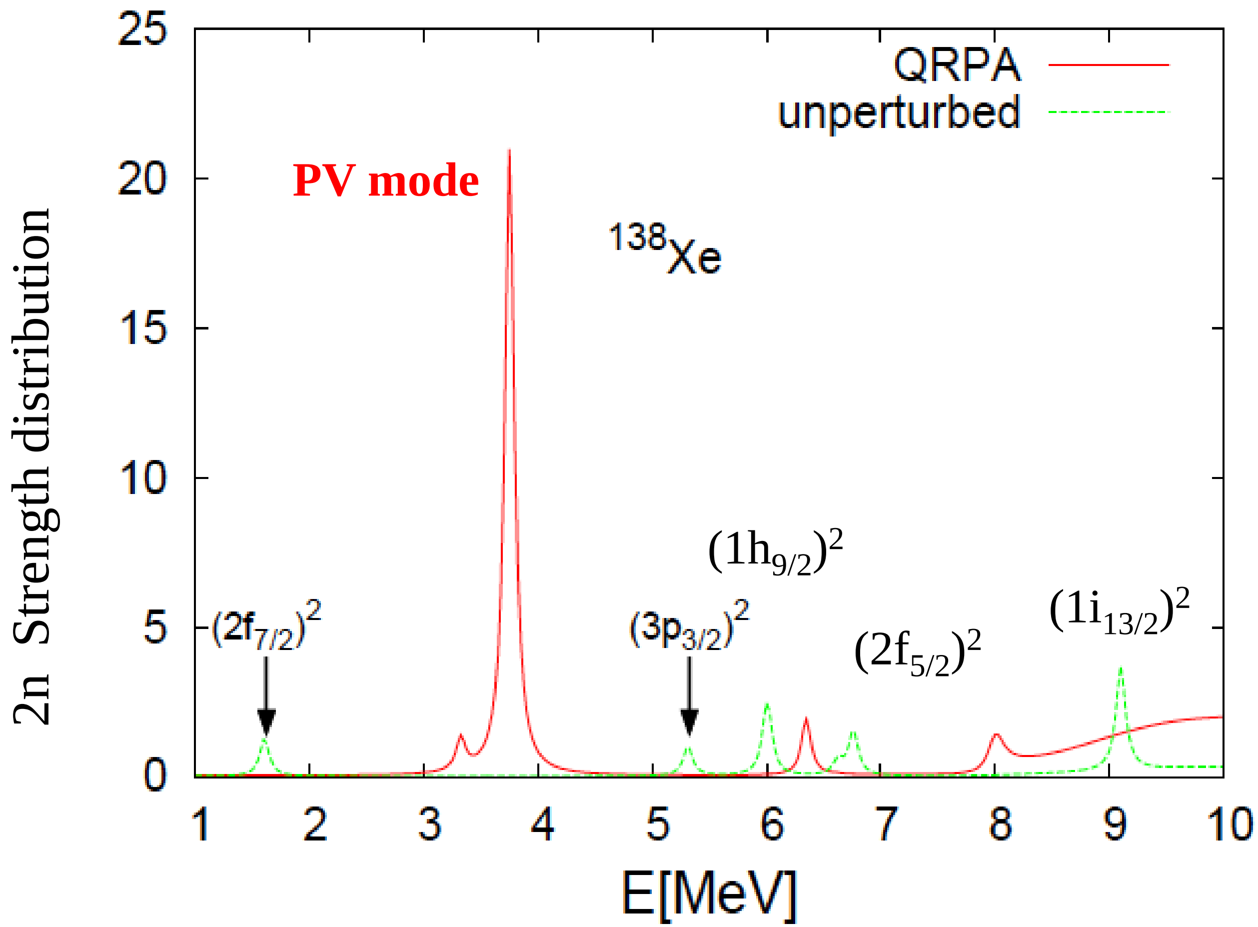
Currently it is not possible to study Sn nuclei with A > 140. However, the region 132 < A < 140 where strong transitions to an excited pairing vibrational 0^+_2 state are predicted is within reach of present accelerator facilities.

The first excited 0^+ state can be regarded as a pairing vibrational mode built on the weakly bound $p_{3/2}$ (and $p_{1/2}$ orbits), which show a rather long tail in the transition density extending beyond the nuclear surface, resulting in a large strength, comparable to that populating the ground state.



Motivation

Production of Sn beams challenging, but similar effects are expected in the PV mode in ^{138}Xe
[S. Tamaki. Master thesis, Niigata University, 2016]



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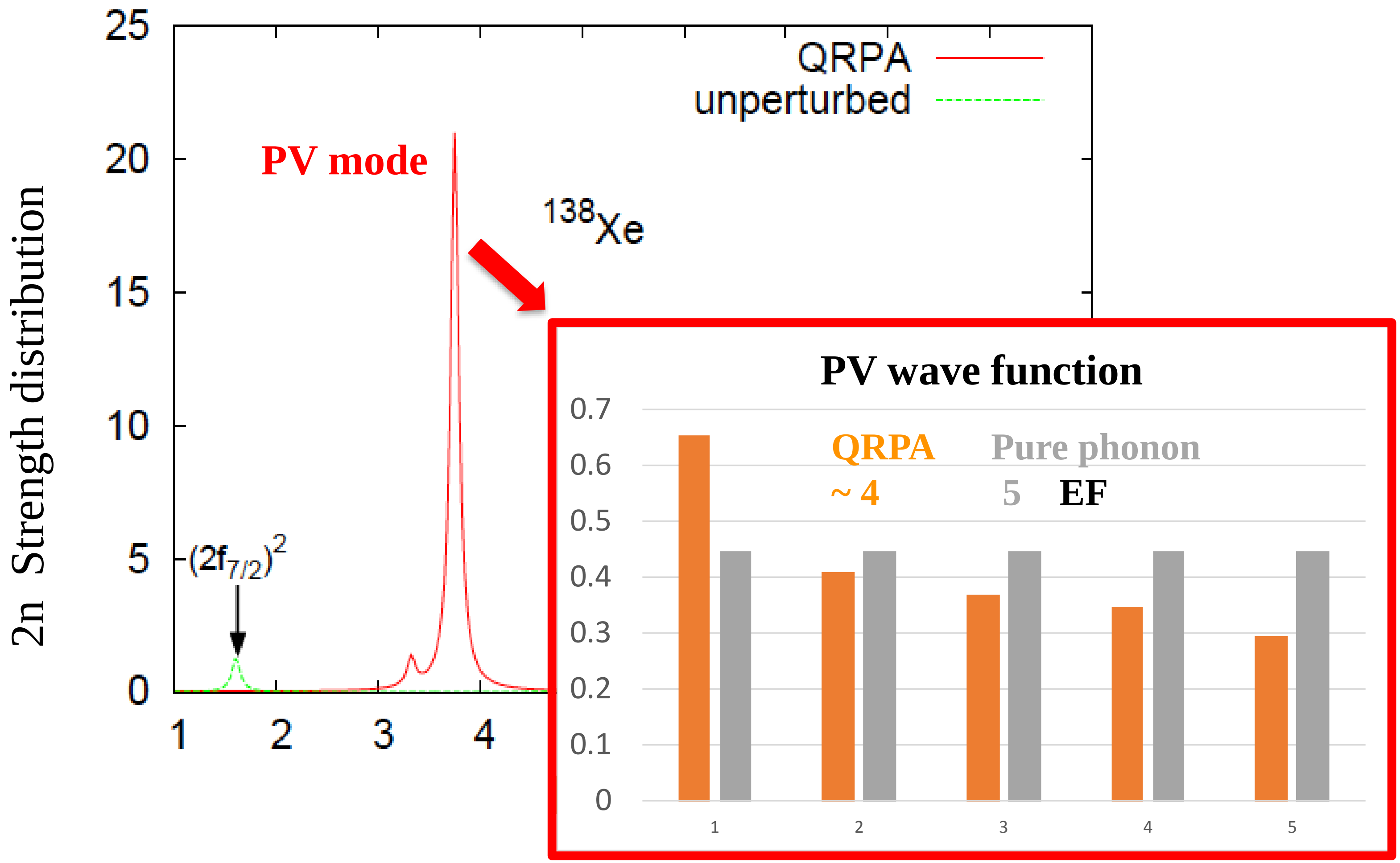
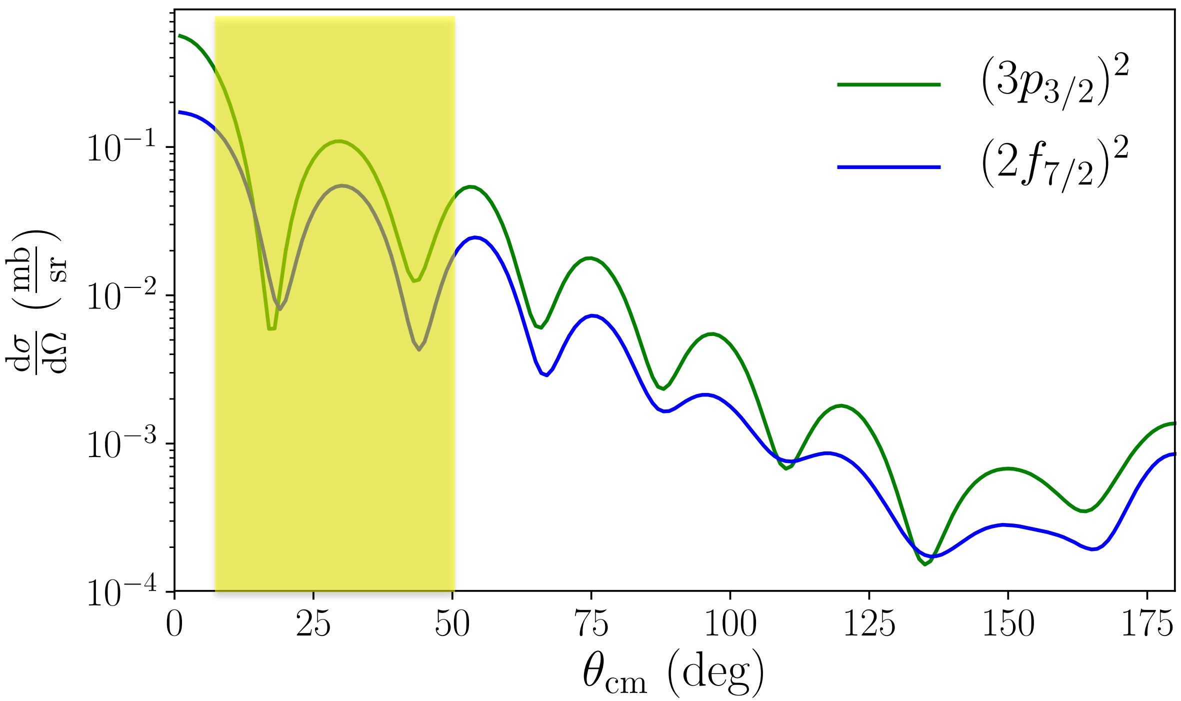


ISS Experiment

^{138}Xe(t,p)^{140}Xe at 7 AMeV focus on L=0 transfers to PV → forward CM angles



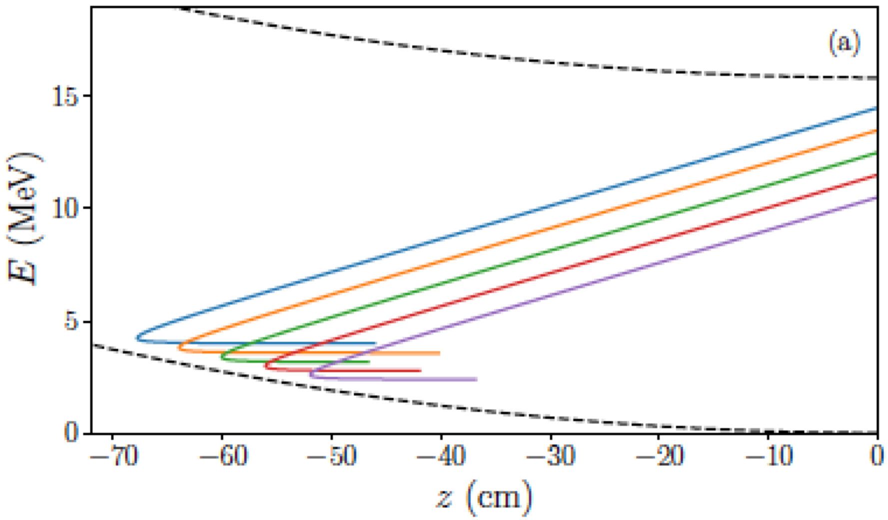
A typical DWBA calculation for j^2 TNA's (FRESCO)

ISS Experiment: Kinematics considerations

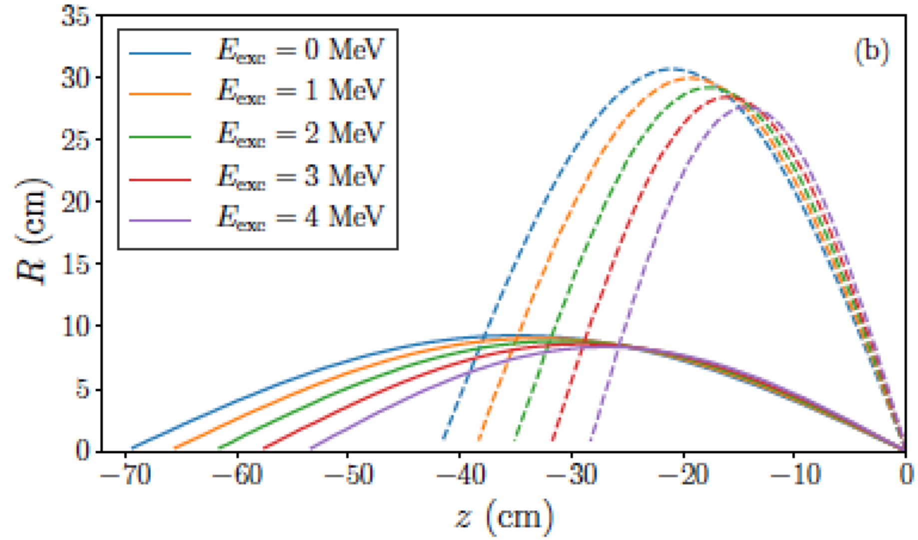
Reaction kinematics for a ^{138}Xe beam at 7 AMeV impinging on the tritium-loaded titanium target. **ISS operating at 2.5 T.**

The reaction kinematics for different excitation energies in ^{140}Xe are indicated by different colors.

Energy of recoiling protons as a function of the position on the ISS silicon array.



Proton orbits for CM scattering angles 10^0(solid lines) and 35^0(dashed lines).



ISS Experiment: Estimated Rates

Measured ISOLDE yields from S. Rothe. priv. comm., 2021.

Beam	Yield $/\mu C$	Target material	Ion Source
^{134}Xe	stable	none	EBIS
^{136}Xe	stable	none	EBIS
^{138}Xe	$1.6 \cdot 10^8$	UC_x	cold plasma
^{140}Xe	$0.8 \cdot 10^8$	UC_x	cold plasma

Assuming 2 μA proton beam and 2% overall extraction/post-acceleration efficiency, we consider a conservative beam intensity on target of $5\ 10^6$ pps for ^{138}Xe, and $3\ 10^6$ pps for ^{140}Xe.

Past experience with Xe beams at HIE-ISOLDE, IS548, has shown that, due to the nobel gas nature, the only contaminants are decay products originating from the decay during the breeding of the beam.

We will limit the current of stable Xe on the tritium target to 10^7 pps .

ISS Experiment: Estimated Rates

Count rates estimates for the Xe(t,p) reactions proposed assuming a cross section of 0.55 mb for the pairing vibrational mode (PV).

This is a conservative estimate obtained from the pure $(3p_{3/2})^2$ single-particle configuration
Total counts include the overall efficiency of ISS, in the CM (LAB) angular range
$10\text{-}50^0$ ($160\text{-}100^0$).

Tritium loaded titanium foil (Ti thickness 0.5 mg/cm^2, atomic ratio t/Ti ~ 1 ~ 40$\mu g/cm^2$)

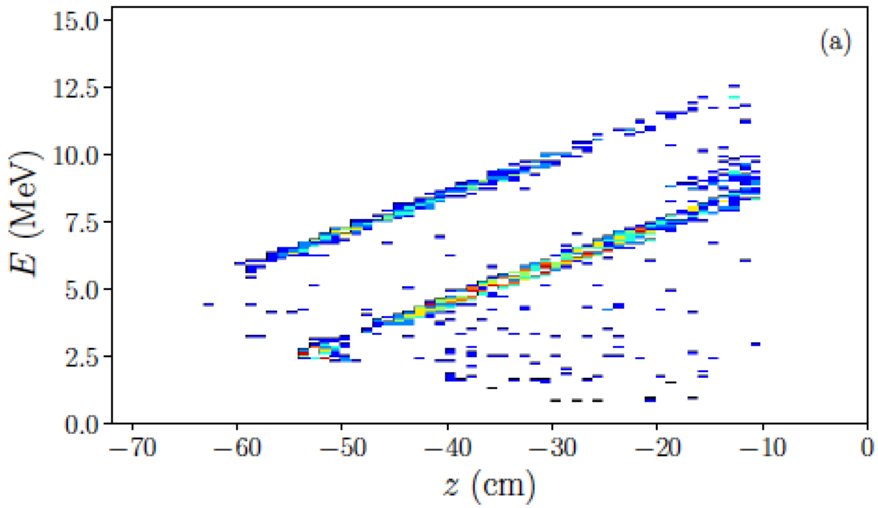
Beam	Intensity (pps)	reactions per h for 0.55 mb	Shifts 8 hour	Total reactions	Detected events
^{134}Xe	$1 \cdot 10^7$	119	3	2850	620
^{136}Xe	$1 \cdot 10^7$	119	3	2850	620
^{138}Xe	$5 \cdot 10^6$	59	6	2850	640
^{140}Xe	$3 \cdot 10^6$	36	6	1720	380

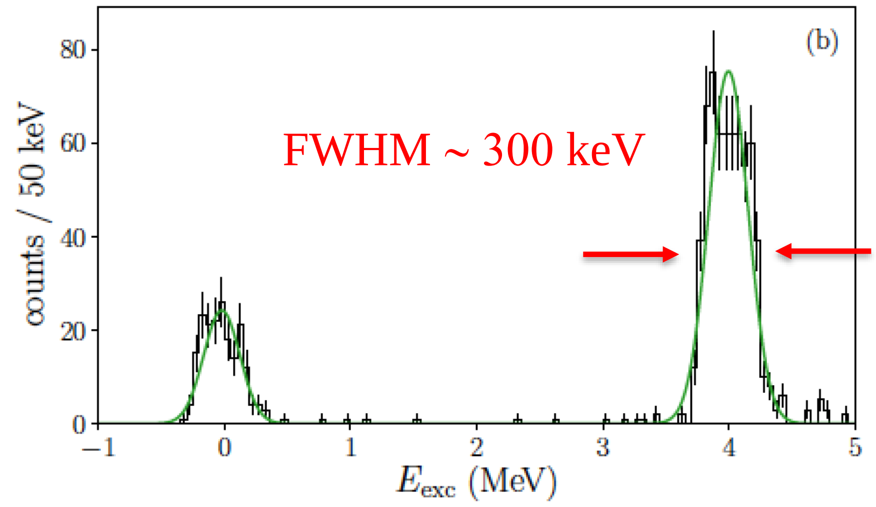
ISS Experiment: Realistic simulations

Simulation for the $^{138}Xe(t, p)$ reaction for the population of two states at 0 and 4 MeV excitation energy in ^{140}Xe

Proton kinetic energy vs. the distance from the target. The detectors will be placed covering the solid angle from -10 cm

Excitation energy of ^{140}Xe reconstructed from the measured proton energies and positions.

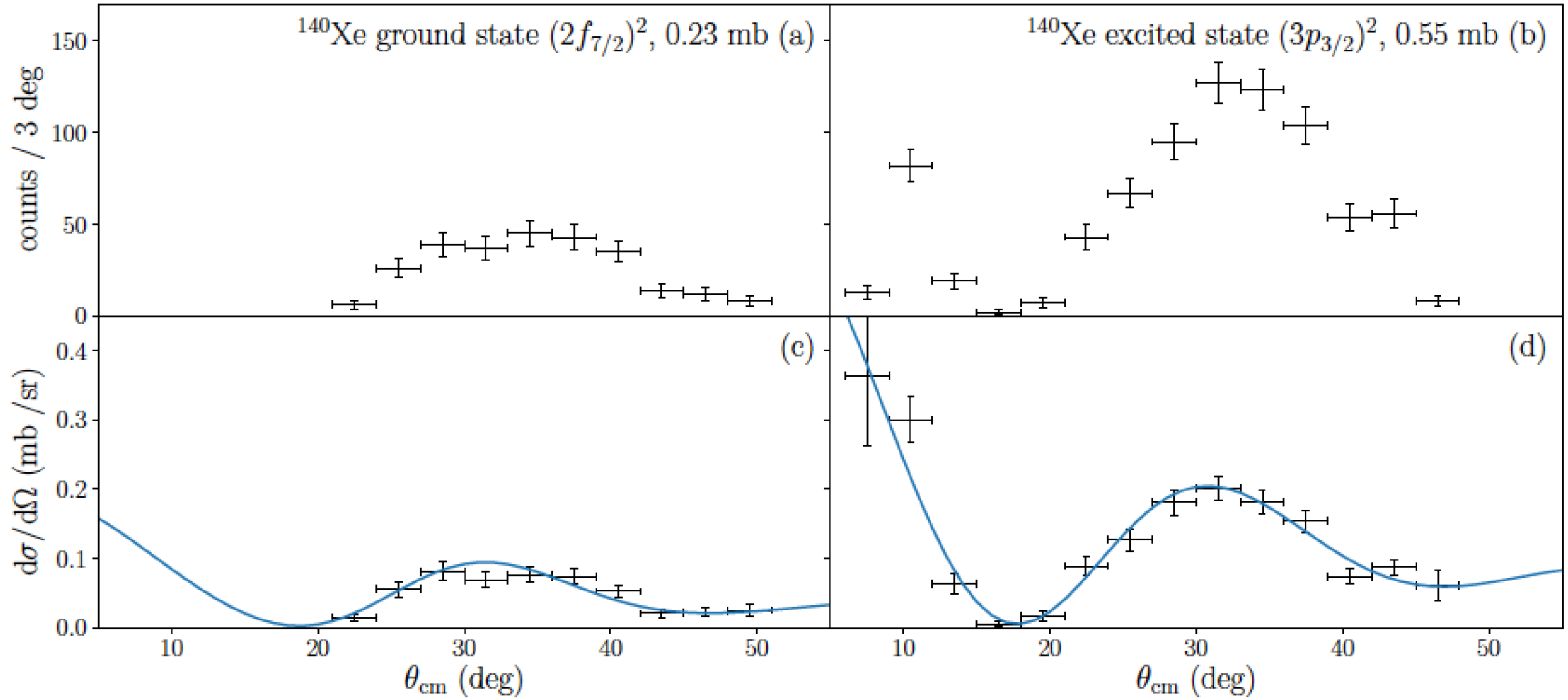




ISS Experiment: Realistic simulations

Analysis of simulated data for the $^{138}Xe(t,p)$ reaction to two states with $(2f_{7/2})^2$ and $(3p_{3/2})^2$ configurations.

The level of statistics is sufficient to identify the characteristic shape of the differential cross section of 0^+ states.



Summary

We propose to study pairing correlations in neutron-rich Xe isotopes, by systematically comparing the 2n transfer cross sections as a function of the projectile mass using beams of $^{134,136,138,140}Xe$. Theoretical predictions suggest an enhancement of the two-neutron transfer strength going to excited 0^+ states beyond N=82, both in Sn's and Xe's isotopes.

The experiment will be performed at HIE ISOLDE, using 7 MeV/A Xe beams impinging on a radioactive tritium target. ISS, operating at 2.5 T, will identify the outgoing protons with a resolving power much improved over that of conventional setups.

Angular distributions in the angular range of 10-50^0 CM and integrated cross-sections will be measured for L assignment and to assess the anticipated enhancement of the cross-section with respect to a single-particle transition.

In total we request 21 shifts, 7 days, of beam time: six days of beam on target measurement (6 shifts stable, 12 shifts radioactive Xe beams) and 3 shifts for tuning, setup and debugging. This time is also required for switching the beams and tuning to the ISS target.

While the stable beam part of the experiment could run any time without PSB protons, it would be advantageous, if the experiment were scheduled as one run to avoid systematic differences between the different beams. Furthermore, the operation of the tritium target requires substantial preparation of the setup at ISS.

Thank you !