Study of ^{14}B Using (d,p) Reaction in Inverse Kinematics

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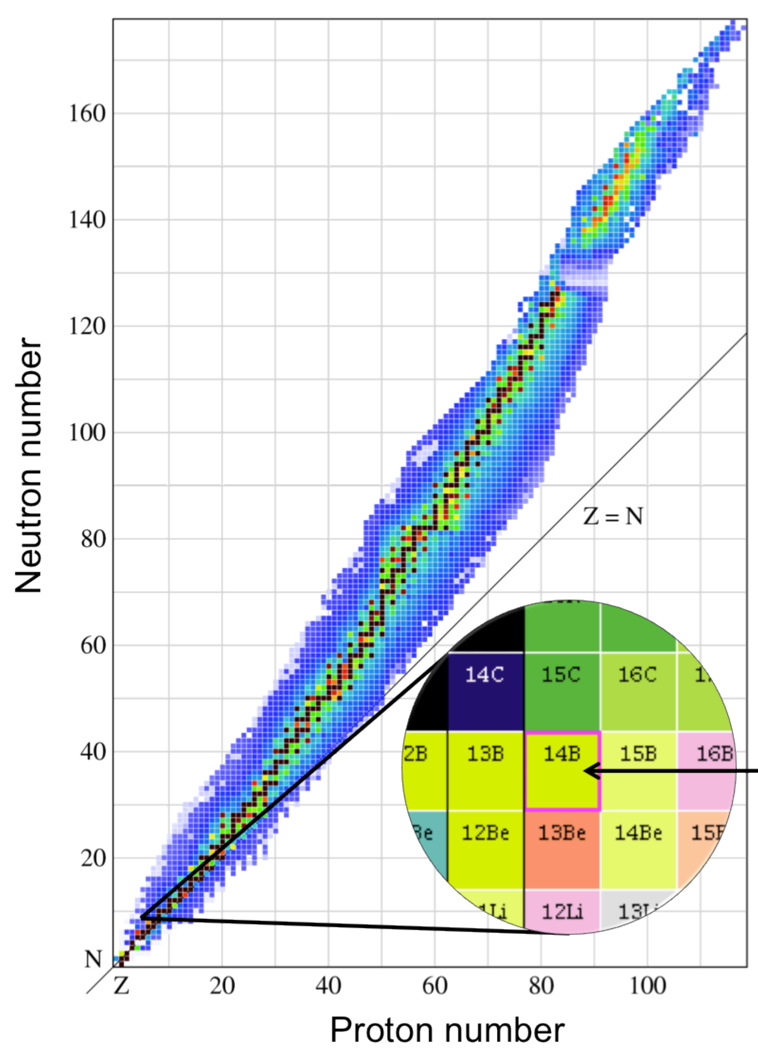
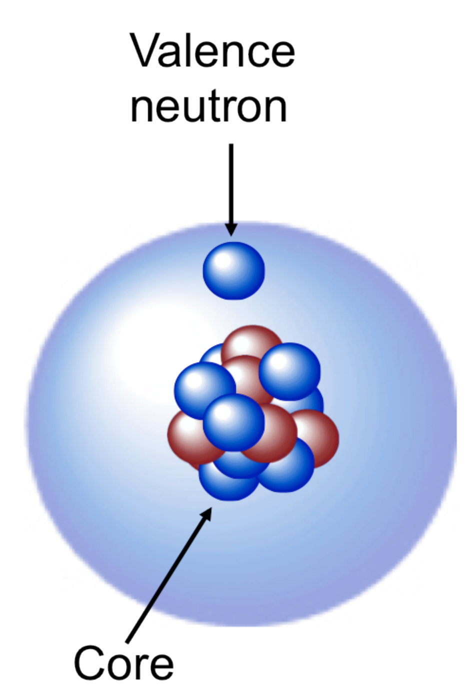
Abstract

We describe a study of the ^{14}B nucleus done using the ^{2}H(^{13}B,p)^{14}B reaction in inverse kinematics using HELIcal Orbit Spectrometer (HELIOS) at the Tandem Linac Accelerator System (ATLAS) at Argonne National laboratory (ANL). One neutron is transferred from a ^{2}H target to the ^{13}B beam to produce the ^{14}B nucleus. The excitation energies and the transferred angular momenta are determined for four observed states in ^{14}B, providing new information to guide models of nuclear structure.

Motovations

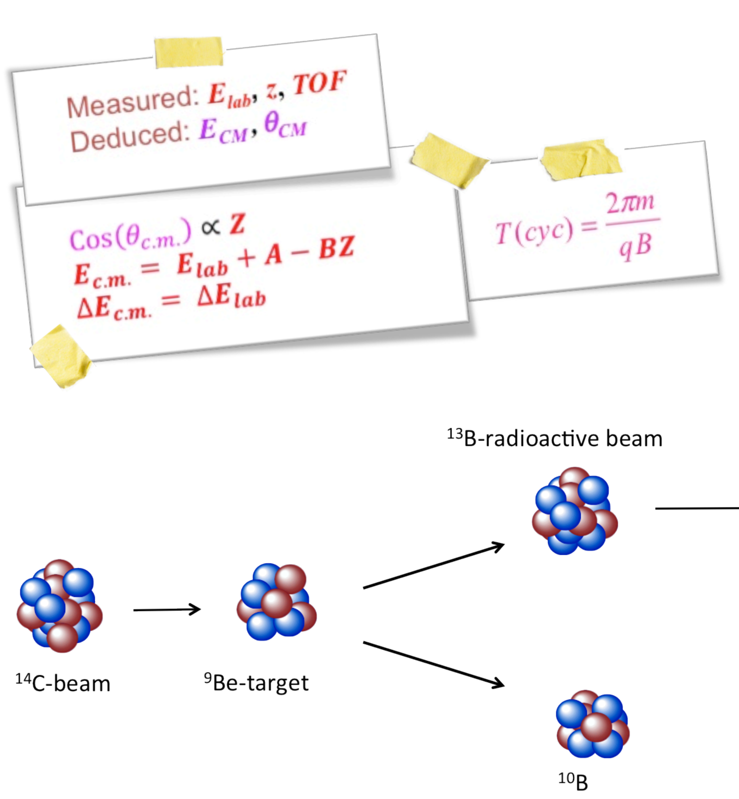


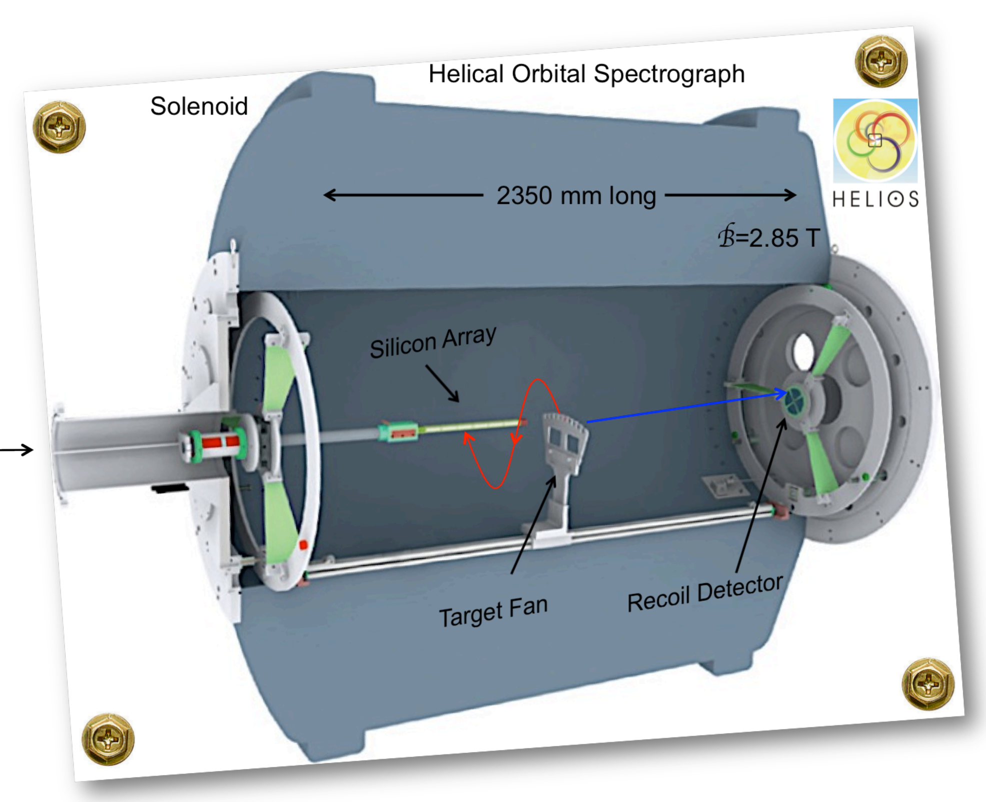


Introduction: Nuclei with neutron (N) to proton (Z) ratio (N/Z) ≈ 1 are typically stable nuclei, nuclei become unstable with extreme neutron-to-proton compositions, which are known as "$exotic\ nuclei$." Here, the nuclei start to show phenomena such as "$halos$", where the last, loosely-bound, neutron orbits far from the tightly bound object that is the core of the nucleus and the usual nuclear-radius relation, (R = 1.2×(atomic mass)$^{1/3}$), is not valid. ^{14}B is a halo nucleus with N:Z ratio = 9:5, and the valance neutron (the last neutron) is loosely bound with binding energy about 1 MeV.

Purpose of the research : The study of exotic nuclei is important for understanding how the chemical elements were created and synthesized in stars. Very little is know about the ^{14}B nucleus and most of what is known is tentative and a new study can help use understand not just the structure of ^{14}B but also other nuclei far from stability. For the first time a nucleon-transfer reaction is used to study ^{14}B which provides new data, previously unobtainable, about the structure of ^{14}B. These data will give new guidance for models of nuclear structure that can be used to describe not only ^{14}B, but also other nuclei that are far from stability.

Experimental Technics

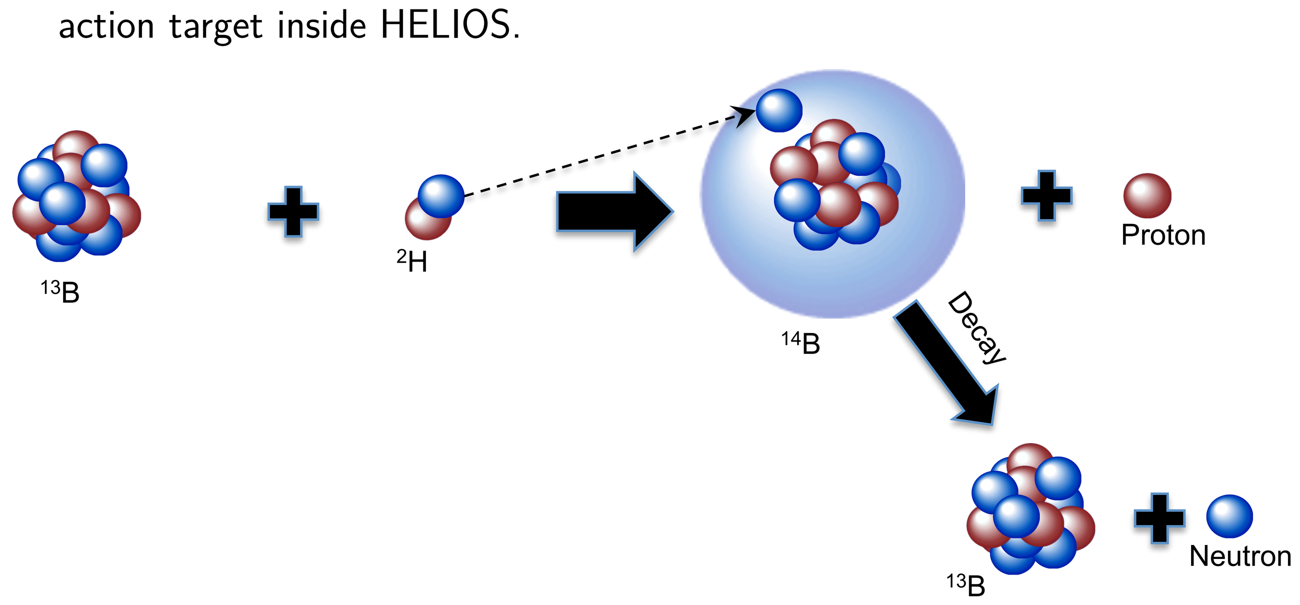




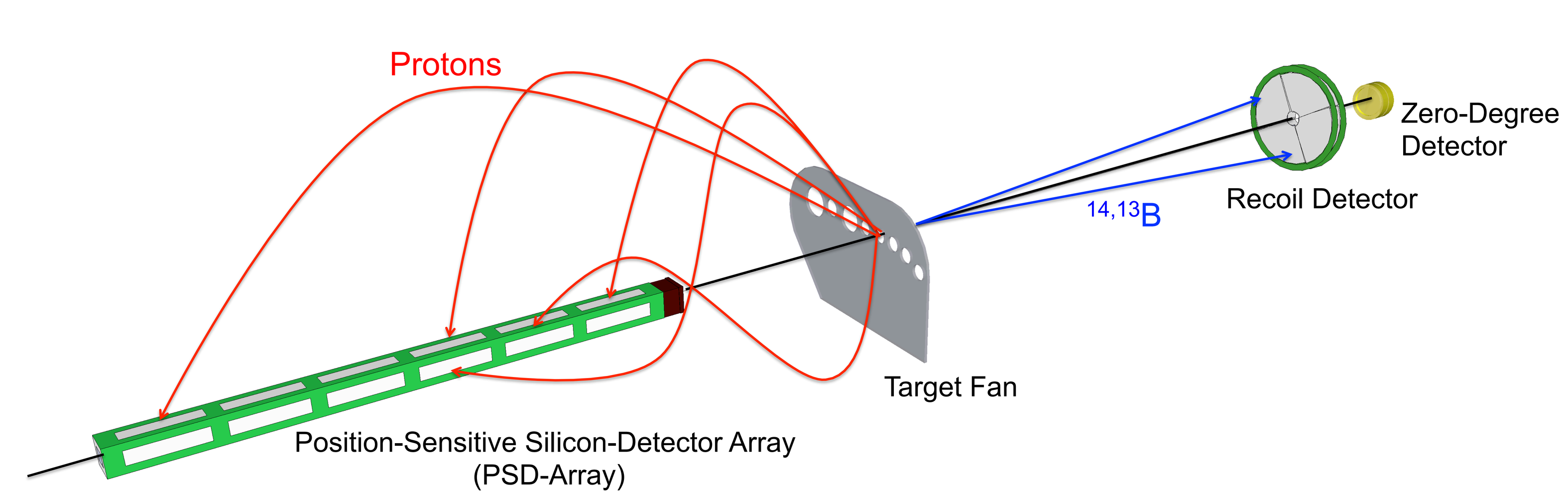
The radioactive "secondary" ^{13}B-beam was produced at the ATLAS facility. The ^{14}C-beam collided with a solid ^{9}Be target to make ^{13}B. The secondary-beam ions are focused by a superconducting magnetic solenoid, and then transported to the reaction target inside HELIOS.

HELIcal Orbit Spectrometer (HELIOS) is a large spectrometer designed to detect the products of nuclear reactions done in inverse kinematics, and is constructed using a large-bore superconducting solenoid with a uniform magnetic field.

- The beam enters the solenoid through a hollow position-sensitive silicon-detector array (PSD-Array) placed inside the solenoid along the magnetic axis.
- The beam intercepts a ^{2}H target placed inside the solenoid in a position along the magnetic axis.
- The emitted ^{1}H (protons, red lines) are transported in a helical orbit back to the solenoid axis where the energy $(\mathbf{E})$, the axial position $(\mathbf{z})$, and the time of flight $(\mathbf{t})$ are measured in the PSD-Array. We can calculate $\mathbf{E_x}$ and θ from $\mathbf{E}$ and $\mathbf{z}$.
- The beam-like particles (^{13,14}B, blue lines) emitted in the forward direction were detected in the recoil detector to insure we are looking at the right reaction .
- The beam intensity and purity were monitored using a silicon surface-barrier detector (called Zero-Degree) telescope placed on the solenoid axis.

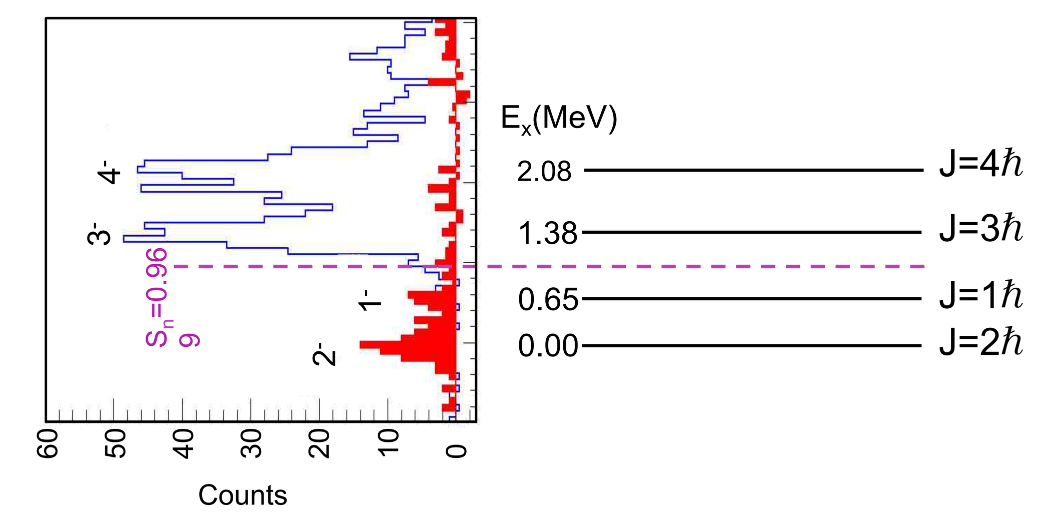


"Inverse Kinematics" means a heavy beam and a light target. Above ∼ 1 MeV ^{14}B decays to ^{13}B by emitting one neutron.



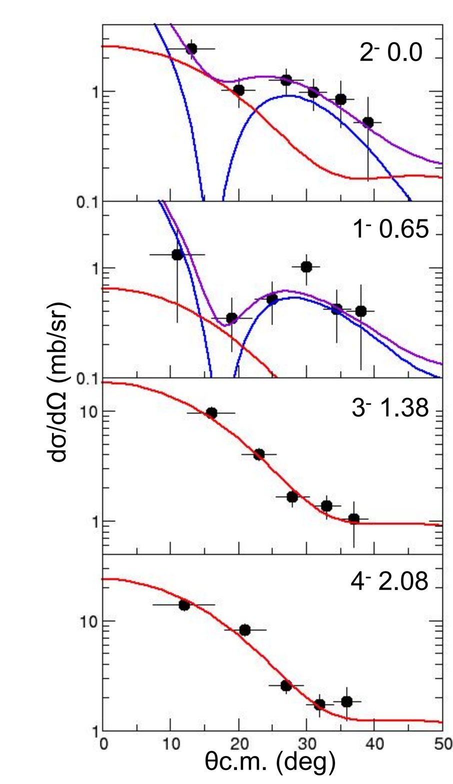
A schematic of the experimental setup inside the HELIOS solenoid.

Excitation Energy



Nuclei, like atoms, have discrete energy levels whose positions and orbits are governed by quantum mechanics.

Angular Distribution



ground state mix of ℓ=0 and ℓ= 2

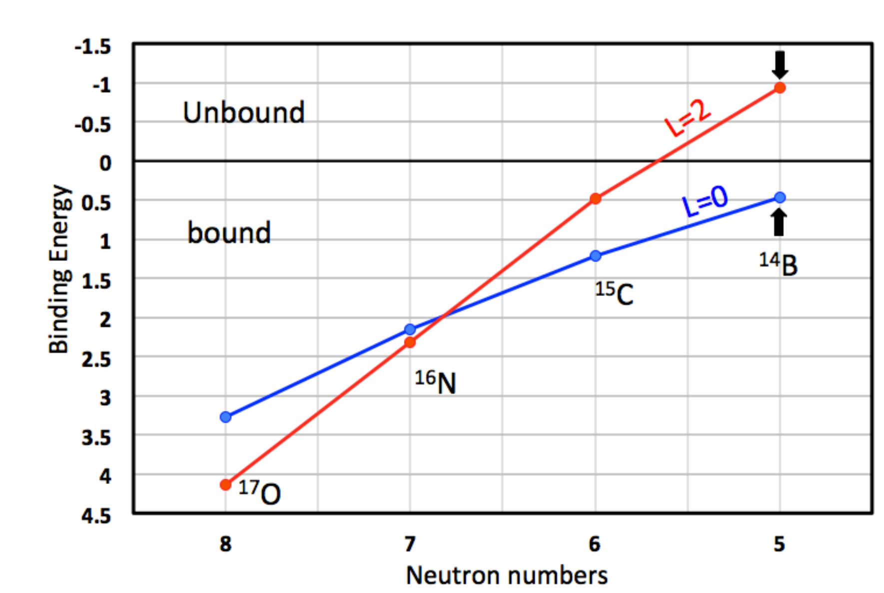
first excited state mix of ℓ=0 and ℓ= 2

second excited state ℓ= 2

third excited state ℓ= 2

Different angular-distribution shapes refer to different angular momentum transitions. The blue curves represent the orbital angular quantum number ℓ=0, while the red curves represent ℓ=2. The black dots represent experimental data while the violet curves are the sums of the blue and red curves fitted to the data.

Valance Neutron Binding Energy



The neutron binding energy at the $s_{1/2}$ and $d_{5/2}$ orbits of ^{14}B, ^{15}C, ^{16}N, and ^{17}O nuclei. Where the neutron in ^{14}B became unbound at $d_{5/2}$ orbit and the $s_{1/2}$–$d_{5/2}$ orbits are inverted.

The Conclusions

- 4 negative parity states have been observed; namely $(2,1,3,4)^{-}$ at energies: 0.00, 0.65, 1.38, and 2.08 MeV respectively.
- The ground and first excited states have a mix of ℓ=0 and ℓ=2 , dominated by the ℓ=0 with a loosely bound valance neutron: one neutron halo nucleus.
- The ℓ=0 and ℓ=2 orbits are inverted with highest splitting at the region of N=9.

References

[1] A.H. Wuosmaa et al, Nuclear Instruments and Methods in Physics Research A 580 (2007)

[2] J.C. Lighthall et al, Nuclear Instruments and Methods in Physics Research A622 (2010)

This work was supported by the U. S. Department of Energy, Office of Nuclear Physics, under Contracts DE-FG02-04ER41320 and DE-AC02-06CH11357.