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Date : 15-May-2009

Proposal for Nuclear Physics Experiment at RI Beam Factory

(RIBF NP-PAC-05, 2009)

Title of Experiment : Neutron density distributions of He & Li isotopes using (p,pn) neutron-knockout reactions

[X] NP experiment [ ] Detector R&D [ ] Construction

Spokesperson :

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Experimental Device:

[ ] GARIS [ ] CRIB [ ] RIPS [X] BigRIPS [ ] ZD [ ] SHARAQ

Beam Time Request Summary

Tuning with beam (including detector tuning)	1 Days
DATA RUNS	13 Days
Total	**14 Days**

Primary Beam

Particle ^{18}O Energy 350 (A MeV) Intensity ~200pnA

Sheet for an experiment with RI beam

[X] BigRIPS

RI Beams			Beam-On-Target Time for DATA RUN
isotope	Energy(MeV/A)	Intensity(/s)	days
p (^{18}O)	~250	~10^6	0.5 days
d (^{18}O)	~250	~10^6	0.5 days
$^{4,6,8}He$ (^{18}O)	~250	~$3x10^5$	2 days x 3 = 6 days
$^{6,9}Li$ (^{18}O)	~250	~$3x10^5$	2 days x 2 = 4 days
^{11}Li (^{18}O)	~250	~$2.4x10^5$	2 days

Estimated date ready to run the experiment **Feb-2010**

Dates which should be excluded, if any ______

Your proposal should be sent to User Support Office, (UserSupportOffice@ribf.riken.jp)

Summary of Experiments

We propose to study the neutron density distributions of the inner shell as well as the valence shell for He and Li isotopes using (p,pn) neutron knockout reactions at 250 MeV/A by measuring the momentum distributions.

List of Collaborators

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Neutron density distributions of He & Li isotopes using (p,pn) neutron-knockout reactions

[1] Goals and methods of the proposed experiment

Nucleon knockout (p,pN) reactions are one of the most direct experimental techniques to study single-particle properties of nuclei such as the separation energy, momentum distribution, angular momentum, and spectroscopic factors of bound nucleons in the nucleus. Using RI beams and a proton target in the inverse kinematics, properties of bound nucleons in the unstable nuclei can be studied. The bound nucleon in the projectile is knocked out via quasifree NN scattering with a proton target, and a hole state is produced as a residual nucleus. Measurements of the 4-momenta of two energetic nucleons in the final state provide information on the separation energy (S_N) and momentum ($\vec{q}$) of the knocked out nucleon. Since the hole state is produced in the beam rapidity, the decay modes of the hole states can be tagged with high efficiency by detecting the hole state itself or particles from the decay of the hole states in the forward direction. For the reaction to be quasifree, the beam energy needs to be relatively high, suited for the beam energies available at RIBF.

Unstable nuclei provide various conditions on the separation energy of bound nucleons. Proton-rich nuclei provide weakly-bound (<few MeV) valence protons and strongly-bound (>20 MeV) valence and inner-shell neutrons. Neutron-rich nuclei, on the other hand, provide weakly-bound valence neutrons and strongly-bound inner-shell protons. Weakly-bound valence protons and neutrons have been studied intensively because those nucleons are related to the exotic phenomenon of neutron skin or halo. On the other hand, properties of the strongly-bound inner-shell protons and neutrons, such as the density distribution and the spectroscopic factor, were poorly known.

We have proposed experiments on the charge radii of the inner-shell protons for He, Li, and C isotopes deduced from the momentum-distribution measurement using (p,2p) proton knockout reactions. Six days of running time has been approved in the RIBF PAC Feb-2007, as RIBF-017. For He and Li isotopes, charge radii extracted from the (p,2p) measurement can be partly compared with those from the laser spectroscopy.

Proton density distribution of each shell may be measured using (p,2p) reactions. Then the natural question that comes out is “what will happen to neutrons”? In this proposal, we propose (p,pn) neutron knockout reactions on He and Li isotopes to study the density distribution of inner-shell neutrons as well as valence neutrons. Combining (p,2p) and (p,pn) reactions, density distributions of protons and neutrons can be compared.

$^{3\text{-}8}$He(p,pn)$^{2\text{-}7}$H and $^{6\text{-}11}$Li(p,pn)$^{5\text{-}10}$He reactions are used to measure the momentum distributions of valence and inner-shell neutrons. The experimental setup is shown Fig. 1.

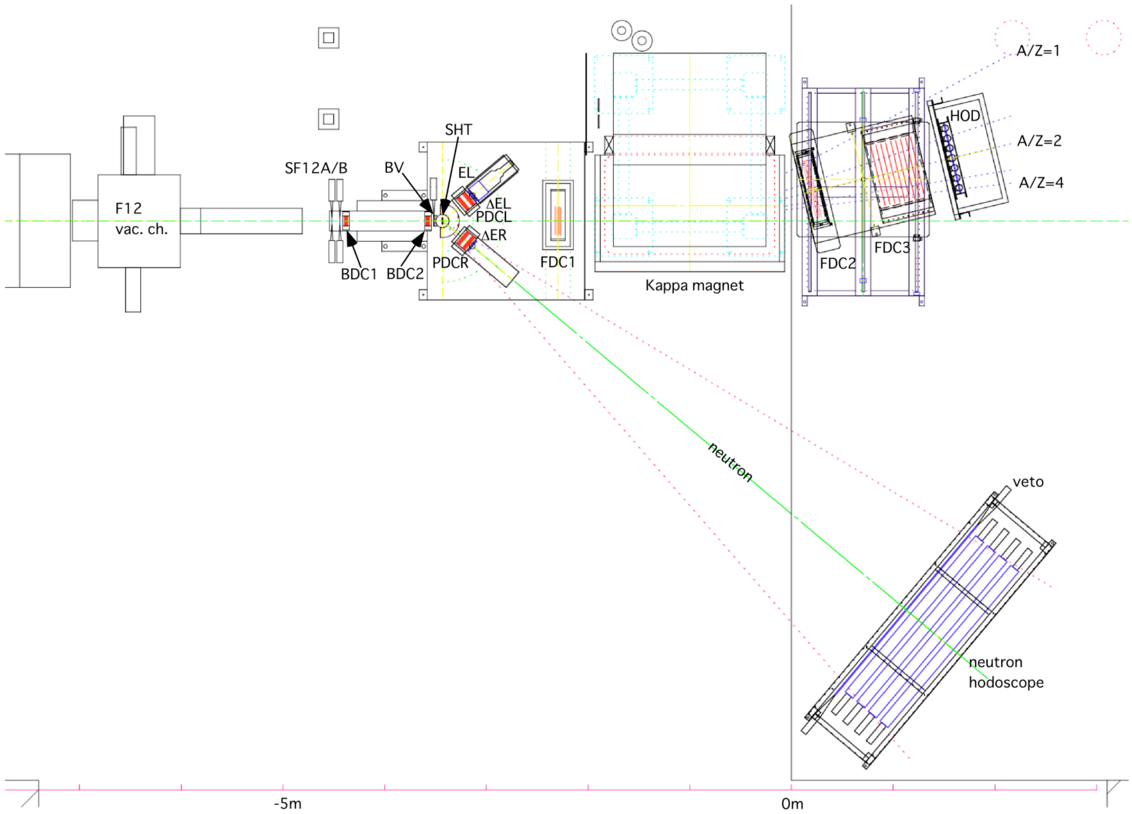

Fig. 1 : Experimental Setup at F12

Protons and neutrons are detected at laboratory angles around 40^{o} , corresponding to 90^{o} scattering in the p-n center of mass frame. The momentum distribution of the knocked out neutron is deduced from the 4-momenta of proton and neutron in the final state. It should be noticed that the momentum distribution of a single valence neutron could be deduced for ^{6,8}He and ^{11}Li with two weakly-bound valence neutrons. For inner-shell neutrons, the rms radius of the inner-shell neutron is deduced via the Fourier transform of the momentum distribution (which is presumably Ganssian). Then the density distribution of protons and neutrons in the inner-shell can be compared, combining (p,2p) and (p,pn) reactions.

[2] Experimental setup & Beam Time Estimate

The RI beam with energy of 250 MeV/A is momentum tagged by an MWPC (WCB) placed at the momentum dispersive focal plane F5. An MWPC is used instead of PPAC's in order to detect H, He and Li isotope beams. Momentum resolution is about 0.1% (rms) estimated from a momentum dispersion of 3.3 cm/% at F5. PPAC's at achromatic focal planes, F2, F3, F7, F8, are used during the beam tuning for p, d, He, and Li beams, but with lower efficiency. TOF and ΔE measurements are performed for particle identification by 5 plastic scintillators, SF3, SF7, SF8, SF12A, and SF12B, placed at achromatic focal planes.

The detector system for the (p,pn) measurement is placed at F12 area as shown in Fig. 1, and the target region is expanded in Fig. 2. For the (p,pn) setup, NaI(Tl) detector on the right side is removed from the (p,2p) setup. Summary of the position detectors are shown in Table.1.

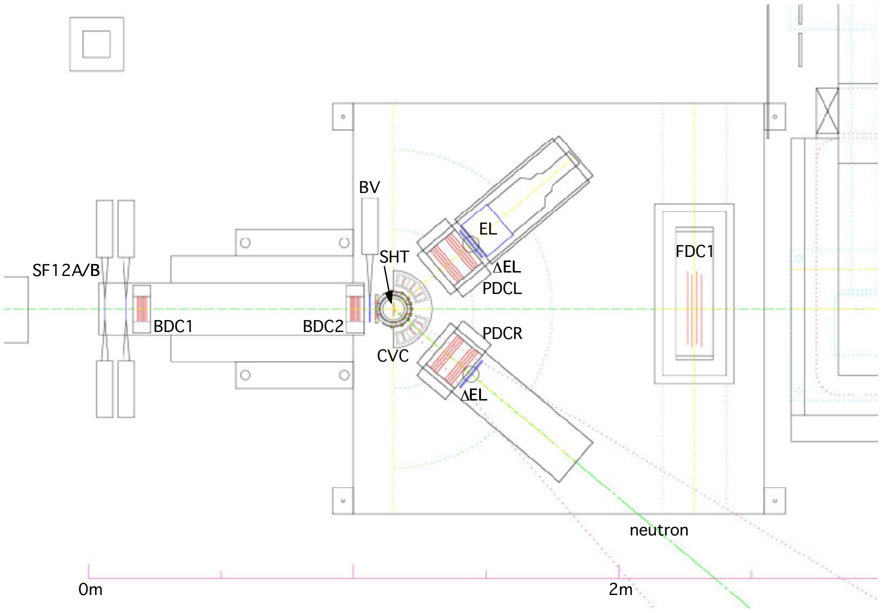

Fig. 2 : Experimental setup in the target region

The beam vector on the target is measured by two sets of high-rate drift chambers (BDC1 and BDC2). The two sets are separated by about 1m with a He bag in between in order to have an angular resolution much less than 1 mrad. A beam veto scintillator (BV) with a (20-)25mmϕ hole is placed between BDC1 and the target chamber for rejecting the beam halo hitting the copper block around the target.

The solid hydrogen target (SHT), with a thickness of 5mm, a diameter of 35mm and covered by two 9 μm-thick aramid windows, is used. It provides high S/N ratios of over 100 and is essential for the observation of the deep hole states. Entrance and exit windows for the beam and the exit window for the protons of the SHT vacuum chamber are made of

50 μm-thick Kapton .

Detector	Half cell [mm]	Cell type	Plane configuration	Effective area [mm]	#Readout channels
WCB	2	MWPC	xx	240 x 150	64 x 2
BDC1	2.5	Walenta	xx'yy'xx'yy'	80 x 80	16 x 8
BDC2	2.5	Walenta	xx'yy'xx'yy'	80 x 80	16 x 8
FDC1	10.5	hexagonal	xx'xx'	242 x 160	12 x 4
FDC2	10.5	hexagonal	xx'xx'	558 x 400	28 x 4
FDC3	20	box, field shaping	xyx'y'xyx'y'x	600 x 400	16 x 9
CVC	~25	jet	xxxxxx	half cylindrical	6 x 6
PDCL	10	Walenta	xx'yy'xx'yy'	140 x 140	8 x 8
PDCR	10	Walenta	xx'yy'xx'yy'	140 x 140	8 x 8
				Total #readout	1024

Table 1. : Summary of position detectors

Protons emitted from the (p,pn) reaction are measured by a proton telescope on the left side, consisting of a half-cylindrical vertex chamber (CVC), a proton drift chamber (PDCL), a 5 mm-thick ΔE scintillator (ΔEL), and a 6"-diameter x 5"-thick NaI(Tl) scintillator (EL). Telescope will be set at an optimum angle for the separation energy of interest: e.g. 43^o for S_N~ 0MeV, 40^o for S_N~ 18MeV, 39^o for S_N~ 33MeV. Angular acceptance is $\pm 10^o$ in both horizontal and vertical directions. Protons up to 210 MeV can be measured by 5"-thick NaI(Tl) detector with about 1% energy resolution. Angular resolution of 1.5-2.0 mrad (rms) can be obtained by a combination of the CVC and PDC detectors.

Neutrons emitted from the (p,pn) reaction are measured by a neutron hodoscope on the right side, with about 6m of flight path. The angular coverage is $\pm 9.5^o$ horizontally and $\pm 4.8^o$ vertically. Neutron detector consists of 64 plastic scintillators, 6.5cm high x 2m long x 10cm deep, arranged in 4 layers. Each layer consists of 16 stacked detectors, covering 2m horizontally and 1m vertically. The total thickness is 40 cm, providing about 40% detection efficiency. Four veto scintillators, 29cm high x 2m long x 1cm thick, are placed in front of the neutron hodoscope for charged-particle veto. In order to reduce the running time, proton and neutron detectors will be set at around $\pm 40^o$ to detect both weakly- and strongly-bound neutrons.

From the 4-momenta of the incident beam, proton, and neutron, the separation energy and momentum of the knocked out neutron are obtained. Separation energy resolution will be about 1.6 MeV (rms), resulting from the accuracies of beam momentum tagging (~0.1%), angular measurements for protons (~1.5 mrad) and neutrons (~3.1 mrad), multiple

Coulomb scattering in the target, and the energy measurement for protons (~1%) and neutrons(~1%).

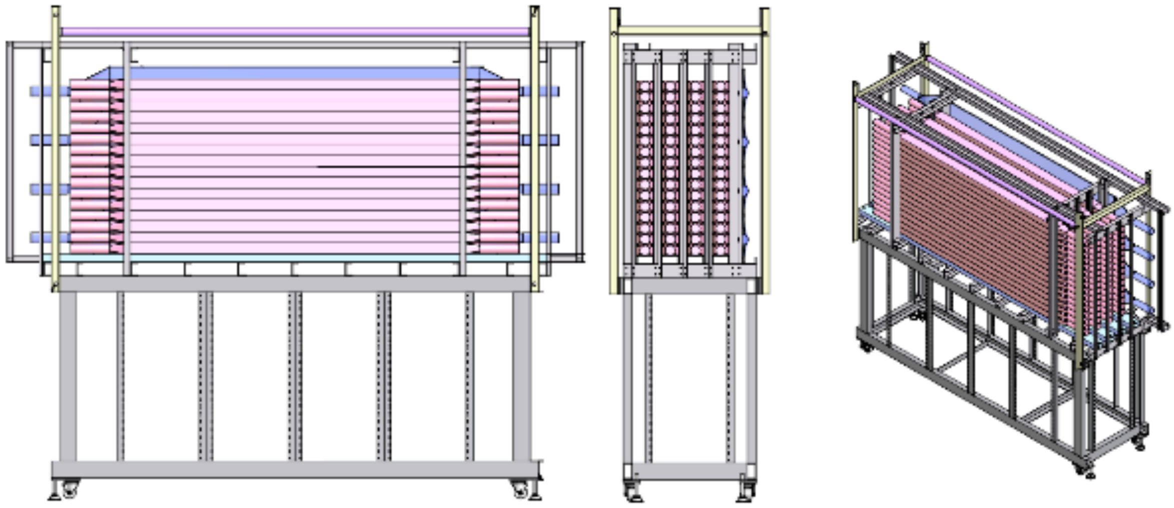

Fig. 3 : Neutron hodoscope for the (p,pn) measurement

The energy calibration of two NaI(Tl) detectors is made by measuring p(p,2p) reactions using a 250 MeV secondary proton beams on SHT. The beam momentum is tagged by the WCB placed at F5. By setting the NaI(Tl) detectors at (34^o,53^o), (43^o,43^o), and (53^o,34^o), the detectors are calibrated between 50 MeV and 210 MeV.

Time zero of the neutron TOF is obtained by measuring prompt g-rays from carbon target. The overall calibration of the energy and the neutron detection efficiency will be made by measuring d(p,pn)p reactions using 250 MeV secondary deuteron beams on STT, triggered by a scattered proton in the NaI(Tl) detector and a spectator proton in the forward magnetic spectrometer.

The forward magnetic spectrometer is used to detect the hole state itself or particles from the decay of the hole state in order to measure the decay modes of the hole state. The system consists of a C-type magnet (Kappa), three sets of drift chambers (FDC1, FDC2, FDC3), and a scintillator hodoscope (HOD). The magnet provides a field integral of BL= 1.4 Tm at 1100A : projectiles of A/Z=3 at 250 MeV/A (R=2.2 GeV/c) are bent (only) by 9^o. The hodoscope consists of 7 slats of 1cm-thick plastic scintillators with transistorized bases for high rates, covering 70cm horizontally and 45 cm vertically. He bags are inserted between SHT target and FDC1, Kappa magnet gap, and between FDC2 and FDC3. The momentum resolution is about 1%. The high voltages of the FDC's have to be adjusted to projectile fragments with smaller charges. The severest case is for the He isotope beams, where the FDC's have to be sensitive to fragments with Z=1. Due to the higher high voltage/gain and the limited segmentation of FDC's, the beam intensity is limited to below 200-300 KHz. Charge and mass of the fragments are identified by combining momentum, energy loss, and TOF measurements. For a TOF resolution of 0.1 nsec over a flight path of 6 m, mass separation for He and Li isotopes is sufficient.

All the drift chambers, except the WCB, are operated using a He+60%CH_4 (*L*r= 1000m) gas mixture after bubbling through isopropyl alcohol.

Signals from the position detectors are processed by ASD's mounted on the detector, followed by multi-hit TDC's in a local VME crate which is connected to DAQ PC in BF3 via optical fiber.

Anode signals from 136 PMT's in the neutron hodoscope are sent to 16ch CAMAC discriminators. Or signal from the discriminator is used as a trigger signal for neutrons. ECL signals from the discriminators are sent to TFC/FERA circuits via 300+200nsec logic delays in the local CAMAC crate. FERA's are readout via the driver module connected to the dual port memory in the CAMAC crates in BF3. Anode signals are also sent to the charge integrating circuits. Voltage signals from the circuits are further processed by shaping amplifiers, and then sent to VME peak-sensitive ADC's in the local VME Crate, providing effective 1μsec analog delays.

The (p,pn) reaction trigger is formed by (SF12A*SF12B*SF12_window) x (ΔEL) x (NEUT).

The thicknesses of the production target thickness and the degrader at F1/4 are optimized to have maximum beam intensity at around 250 MeV/A starting from 350 MeV/A ^{18}O primary beams. Proton and deuteron beams with about 1MHz intensity is used for the energy calibration of the NaI(Tl) & neutron detectors. Although a beam intensity of He and Li isotopes are higher than 1MHz in most cases, we need to limit the actual beam intensities to below 200-300 KHz for the drift chambers in the forward magnetic spectrometer.

Assuming a beam intensity of 300KHz on a 5mm-thich SHT target, about 10 hours for one isotope are necessary for the (p,2p) measurement. Compared with the (p,2p) measurement, the angular acceptance is about 50% and the detection efficiency is about 40% for the (p,pn) measurement: yielding about 50 hours/isotope. For He isotope, ^{4}He data serves as a reference data for the He core, ^{6,8}He data are interesting for 2 and 4 valence neutron cases. For Li isotopes, ^{6}Li data serves as reference data. ^{9,11}Li data are interesting for 2 valence neutron case and its core. It will take about 12 hours for proton and deuteron beams, respectively, for the calibration. Adding about 24 hours for beam and detector tuning, we request 14 days for the ^{4,6,8}He, ^{6,9,11}Li(p,pn) measurements.

[3] Readiness

Construction of the forward magnetic spectrometer, including all tracking detectors and a trigger hodoscope, proposed in the previous proposal (RIBF-017) was finished. The system was tested using 250MeV/A ^{14}N primary beams on 11-May-2009.

Beam tagging MWPC (WCB) at F5 was built and tested offline. Installation into the F5 vacuum chamber needs to be finished.

For a cylindrical vertex detector (CVC), a prototype detector with jet-type cell structure was built and tested. In order to solve the L/R ambiguity in the jet-type cell, difference between two potential wire signals on both sides of the anode were used. Position resolution of about 150μm rms was obtained. The CVC is under construction.

For a neutron hodoscope, assembly of 64 neutron detectors and 4 veto detectors were finished. Detector stand is under construction, and the neutron hodoscope will be ready before Aug-2009. Eight charge integrating modules for the analog delay needs to be constructed. A prototype circuit is working.

All other detectors including the SHT target will be transported from HIMAC and Tohoku University to RIKEN before the run.

The experiment will be ready to run before Feb-2010.