

Letter of Intent for J-PARC 50 GeV Synchrotron

Investigation of Pion Double Charge Exchange Reaction with S-2S Spectrometer

H. Fujioka,* S. Kanatsuki, T. Nagae, and T. Nanamura
Department of Physics, Kyoto University

T. Fukuda and T. Harada
Osaka Electro-Communication University

E. Hiyama, K. Itahashi, and T. Nishi
RIKEN Nishina Center
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We will study pion double charge exchange (π^\pm, π^\mp) reactions with approximately 850 MeV (980 MeV/ c) π beams at J-PARC. The ultimate goal is to search for a tetraneutron resonance state (${}^4\text{n}$), whose candidates have been observed in the ${}^4\text{He}({}^8\text{He}, {}^8\text{Be})$ reaction at RIBF. First of all, an analog transition, the ${}^{18}\text{O}(\pi^+, \pi^-){}^{18}\text{Ne}$ (g.s.) reaction, will be investigated at the existing K1.8 beamline with the S-2S spectrometer. It will be an important step toward a non-analog transition, the ${}^4\text{He}(\pi^-, \pi^+){}^4\text{n}$ reaction, with much smaller cross section.

* fujioka@scphys.kyoto-u.ac.jp

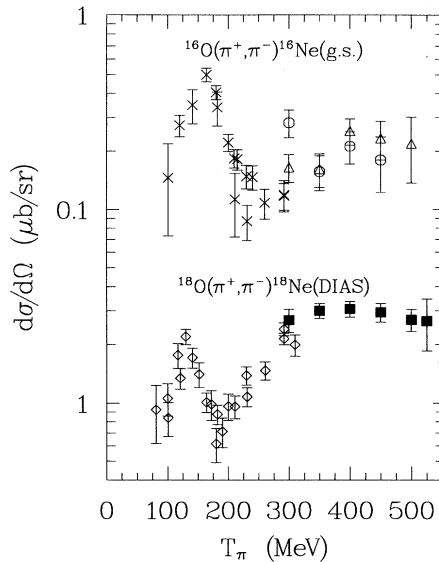


FIG. 1. Excitation functions at $\theta = 5^\circ$ for a non-analog transition of $^{16}\text{O}(\pi^+, \pi^-)^{16}\text{Ne}(\text{g.s.})$ and an analog-transition of $^{18}\text{O}(\pi^+, \pi^-)^{18}\text{Ne}(\text{DIAS})$. Taken from Ref. [7].

I. INTRODUCTION

Recent observation of a possible tetra-neutron resonance in the $^4\text{He}(^8\text{He}, ^8\text{Be})$ reaction at RIBF [1] raises a challenging question concerning the strength of three-nucleon or four-nucleon force. In order to account for the energy of the tetra-neutron state ($0.83 \pm 0.65(\text{stat}) \pm 1.25(\text{syst})\text{MeV}$) relative to the $4n$ threshold, it has been pointed out that remarkably strong $I = 3/2$ three-nucleon force, which has a sizable impact on the mass-radius relation of neutron stars through the nuclear Equation of State, may be needed [2]. Therefore, it is of pressing importance to confirm (or discard) the existence of such an exotic four-neutron system, by means of a measurement independent from the existing result.

For this purpose, a different reaction, i.e. a pion double charge exchange (pion DCX) reaction, for populating a tetra-neutron state is proposed in another Letter of Intent [3]. As the formation cross section will be of the order of nb/sr at most, the HIHR (High-Intensity High-Resolution) beamline at an extended Hadron Experimental Facility (in a planning stage) will be the most suitable place to investigate such an exotic system. The beam energy will be 850 MeV, at which a DCX cross section for an *analog transition* which does not change the isospin (I) between the initial and final nuclides ($|\Delta I| = 0$), e.g. $^{18}\text{O}(\pi^+, \pi^-)^{18}\text{Ne}(\text{DIAS}^1)$, will have a local maximum according to a theoretical calculation [4]. It should be noted that the $^4\text{He}(\pi^-, \pi^+)^4n$ reaction is a *non-analog transition* with $|\Delta I| = 2$, and it is not clear that such a behavior holds for a non-analog transition, neither theoretically nor experimentally.

Pion DCX reactions were extensively investigated at LAMPF, TRIUMF, and PSI (former SIN) [5, 6]. To our knowledge, however, the energy dependence of the DCX cross section was experimentally investigated only below 550 MeV, for both analog and non-analog transitions [7] (Fig. 1), and only theoretical calculations, e.g. Ref. [4], exist for an analog transition with incident energies above 550 MeV. Tetra-neutrons were also searched for in the pion DCX reaction on ^4He with 165 MeV π^- beam [8]. However, as shown in Fig. 2, several events in the bound region, where only a bound tetra-neutron state should contribute, were observed because of imperfect rejection of π^+ decay in the spectrometer. From an experimental point of view, the use of a higher-energy π beam will enable an almost background-free measurement, in a similar way to the (π^\pm, K^+) reaction for Λ -hypernuclear spectroscopy.

We consider a two-step strategy for the investigation with unexplored **pion DCX reaction much above Δ -resonance region** 1) at the existing K1.8 beamline and 2) at the HIHR beamline [3]. First, an analog transition of $^{18}\text{O} \rightarrow ^{18}\text{Ne}(\text{DIAS})$ will be measured with the S-2S spectrometer at the K1.8 beamline, which is the scope of this Letter of Intent. Analog transitions is expected to have an order of magnitude larger cross section than non-analog transitions, inferred from Ref. [7]. In addition, a feasibility study for the $^4\text{He}(\pi^-, \pi^+)$ reaction in search of tetra-neutron will be carried out with the same experimental setup. It will provide important inputs for expanding the investigation with a much higher beam intensity at the HIHR beamline [3].

¹ Double Isobaric Analog State.

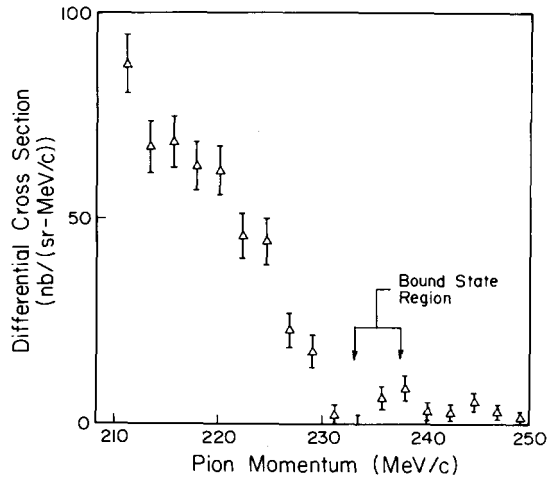


FIG. 2. π^+ momentum distribution for the ${}^4\text{He}(\pi^-, \pi^+)$ reaction with the incident energy of 165 MeV. Taken from Ref. [8].

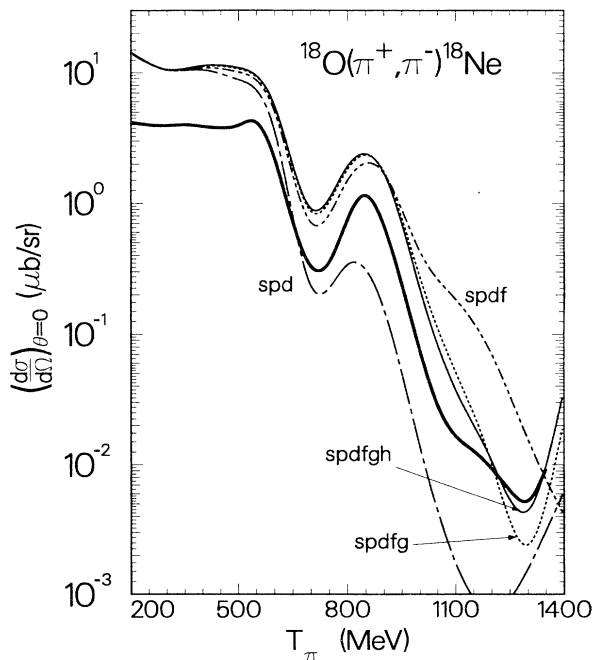


FIG. 3. Theoretical calculation of differential cross section of an analog ${}^{18}\text{O}(\pi^+, \pi^-){}^{18}\text{Ne}$ (DIAS) transition as a function of the pion kinetic energy. The bold line is the result with the partial wave up to $l = 5$ and isovector polarization included. Taken from Ref. [4].

II. ${}^{18}\text{O}(\pi^+, \pi^-)$ REACTION

Figure 3 shows the energy dependence of the differential cross section for the analog transition of interest, i.e. the ${}^{18}\text{O}(\pi^+, \pi^-){}^{18}\text{Ne}$ (DIAS) reaction, calculated by Oset and Strottman [4]. We will investigate the differential cross section in the vicinity of $T_\pi = 850$ MeV, where it is supposed to be considerably large reflecting the πN amplitude.

The missing-mass spectra for low incident energies are available, as shown in Figs. 4 and 5. A prominent peak of the ground state (DIAS) is seen in each spectrum, while the first excited 2^+ state at 1.88 MeV is visible only in Fig. 4 because of a worse missing-mass resolution in the latter experiment.

As a target, we will use ${}^{18}\text{O}$ -enriched water, which is commercially available as the precursor for ${}^{18}\text{F}$ -FDG (Fludeoxyglucose) to be used in FDG-PET (positron emission tomography). Assuming 10^7 π^+ 's per spill impinge on a 2 g/cm^2 water target, the yield of the ground state will be approximately 4×10^2 counts per day. Therefore, energy scan around 850 MeV will be possible in one week. It will help to determine an optimum beam energy for the

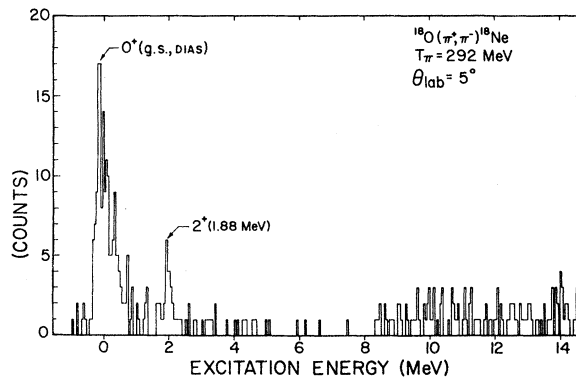


FIG. 4. Missing-mass spectrum of $^{18}\text{O}(\pi^+, \pi^-)$ reaction at $T_\pi = 292$ MeV and $\theta_{\pi^-} = 5^\circ$. Taken from Ref. [9].

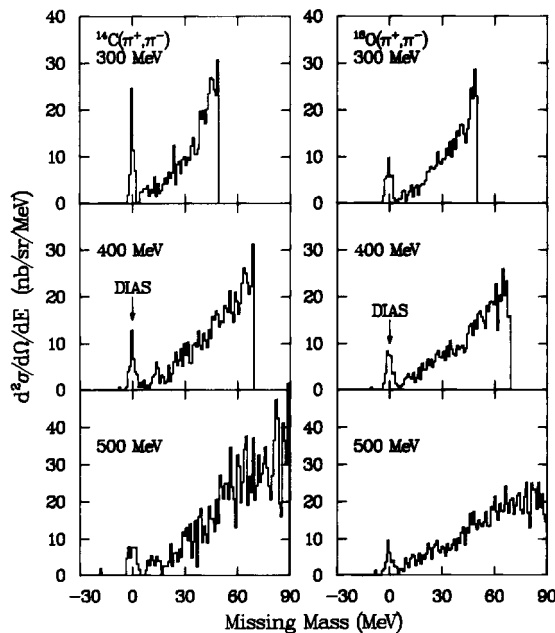


FIG. 5. Missing-mass spectrum of $^{14}\text{C}(\pi^+, \pi^-)$ (left) $^{18}\text{O}(\pi^+, \pi^-)$ (right) reaction at $T_\pi = 300$ – 500 MeV and $\theta_{\pi^-} = 5^\circ$. Taken from Ref. [10].

$^4\text{He}(\pi^-, \pi^+)$ reaction with the aid of theoretical calculations.

III. $^4\text{He}(\pi^-, \pi^+)$ REACTION

Almost nothing is known for the pion DCX reaction on ^4He above the Δ resonance, except for old measurements with liquid-helium bubble chambers [11]. As the total cross section for the DCX reaction will be almost energy-independent, the double differential cross section into continuum, where four neutrons fall apart, near the $4n$ threshold (see Fig. 2) could be suppressed for a higher incident beam energy, because of increasing five-body phase space. Although a quantitative evaluation of the yield for a given beamtime is impractical at this moment, a measurement for a few days will provide information on the background level in searching for a possible peak structure of tetra-neutron slightly

above the $4n$ threshold.

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