Letter of Intent for J-PARC 50 GeV Synchrotron

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

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We will study pion double charge exchange $(\pi^{\pm}, \pi^{\mp})$ 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}n), whose candidates have been observed in the ^{4}He(^{8}He, ^{8}Be) reaction at RIBF. First of all, an analog transition, the ^{18}O$(\pi^+, \pi^-)^{18}$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}He$(\pi^-, \pi^+)^4$n reaction, with much smaller cross section.

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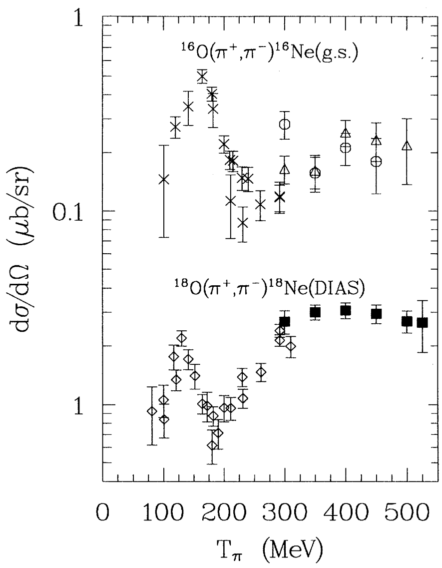

FIG. 1. Excitation functions at $\theta = 5^\circ$ for a non-analog transition of $^{16}O(\pi^+, \pi^-)^{16}Ne$ (g.s.) and an analog-transition of $^{18}O(\pi^+, \pi^-)^{18}Ne$ (DIAS). Taken from Ref. [7].

I. INTRODUCTION

Recent observation of a possible tetraneutron resonance in the $^4He(^8He, ^8Be)$ 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 tetraneutron state (0.83 ± 0.65(stat) $\pm$ 1.25(syst) 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 tetraneutron 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. $^{18}O(\pi^+, \pi^-)^{18}Ne$ (DIAS[1]), will have a local maximum according to a theoretical calculation [4]. It should be noted that the $^4He(\pi^-, \pi^+)^4n$ 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. Tetraneutrons 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 tetraneutron 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 enables an almost background-free measurement, in a similar way to the $(\pi^\pm, K^+)$ 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 $^{18}O \to {}^{18}Ne$ (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 $^4He(\pi^-, \pi^+)$ reaction in search of tetraneutron 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].

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[1] Double Isobaric Analog State.

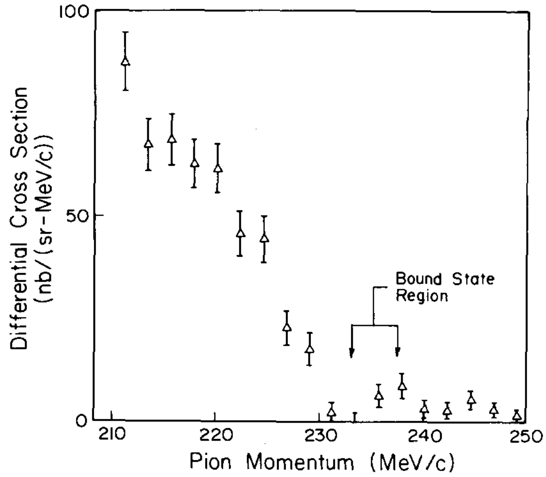

FIG. 2. π^+ momentum distribution for the ^{4}He(π^-, π^+) reaction with the incident energy of 165 MeV. Taken from Ref. [8].

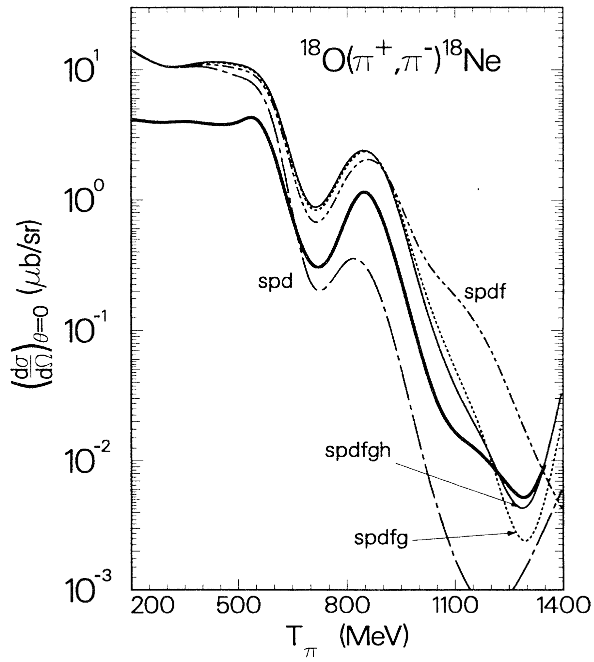

FIG. 3. Theoretical calculation of differential cross section of an analog ^{18}O(π^+, π^-)^{18}Ne (DIAS) transition as a function of the pion kinetic energy. The bold line is the result with the partial wave up to $l = 5$ and isovector polarization included. Taken from Ref. [4].

II. ^{18}O(π^+, π^-) REACTION

Figure 3 shows the energy dependence of the differential cross section for the analog transition of interest, i.e. the ^{18}O(π^+, π^-)^{18}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}O-enriched water, which is commercially available as the precursor for ^{18}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

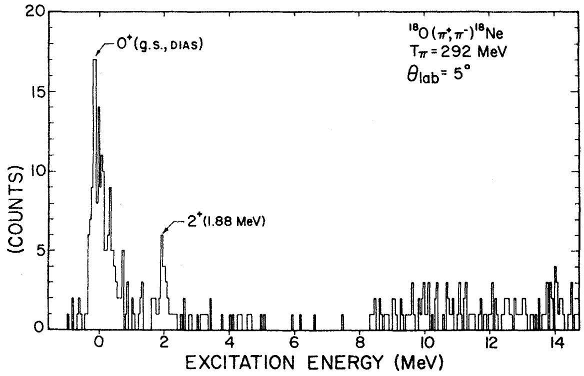

FIG. 4. Missing-mass spectrum of $^{18}O(\pi^+, \pi^-)$ reaction at $T_\pi = 292\,\mathrm{MeV}$ and $\theta_{\pi^-} = 5°$. Taken from Ref. [9].

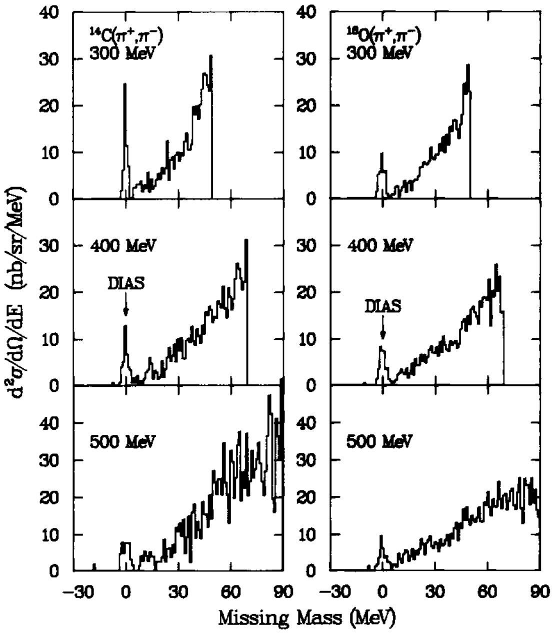

FIG. 5. Missing-mass spectrum of $^{14}C(\pi^+, \pi^-)$ (left) $^{18}O(\pi^+, \pi^-)$ (right) reaction at $T_\pi = 300$–$500\,\mathrm{MeV}$ and $\theta_{\pi^-} = 5°$. Taken from Ref. [10].

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

III. $^4He(\pi^-, \pi^+)$ 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 tetraneutron slightly above the $4n$ threshold.

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