RCNP EXPERIMENT E

PROPOSAL FOR EXPERIMENT AT RCNP

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TITLE:
Measurement of Proton-Induced Subthreshold Pion Pair Production

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RUNNING TIME:

Installation time without beam	3 days(for each beam time)
Development of device	1 days
Test running time for experiment	1 days
Data runs	4 days

BEAM LINE: Ring : WSS course

BEAM REQUIREMENTS:

Type of particle	unpolarized p
Beam energy	416 MeV
Beam intensity	$\leq$ 10 nA
Any other requirements	halo-free

BUDGET: Experimental expenses 950,000 yen

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Measurement of Proton-Induced Subthreshold Pion Pair Production

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SUMMARY OF THE PROPOSAL

We propose to measure the subthreshold two pion production reaction off nuclear target, the $A(p, \pi^+\pi^-)X$ reaction, with the 416 MeV proton beam at the WSS beam course of the RCNP Ring Cyclotron facility. The magnitude of the reaction cross section and the $\pi^+\pi^-$ invariant mass distribution will provide the information on the strength of the $\pi^+\pi^-$ amplitude in nuclei at the low invariant mass region. The information has a close relation with the modification of the spectral function of the σ meson or $f_0(600)$ resonance due to a partial restoration of the chiral symmetry in nuclei argued by the TRIUMF/CHAOS collaboration.

Though the subthreshold reaction cross section is expected to be tiny at the beam energy, the large acceptance Osho spectrometer system at the WSS beam course and a dedicated trigger system will make the measurement possible within a reasonable period of beamtime. In this proposal, the current status of the detector system, the trigger development and a pilot experiment is presented. An update plan of the DAQ and the trigger systems for the proposed experiment is described.

DETAILED DESCRIPTION OF PROPOSED RESEARCH

1 Introduction

All low energy phenomena in the system made of quarks and gluons, such as hadron reactions below the scaling region and ordinary nuclear reactions, are not free from the breaking of the chiral symmetry, so the understanding of the nature of the chiral symmetry breaking is one of the most important subject of the hadron physics. The hadron spectra, meson and baryon spectra, provide us an indirect information on the symmetry breaking. More direct information can be obtained by controlling the degrees of chiral symmetry breaking and see the change of the nature of hadrons. QCD based theories predict the chiral symmetry restoration when the energy density of the hadron system becomes high. Since the hadrons are isolated and finite in size, the methods of controlling the energy density are not trivial.

One promising method is the relativistic heavy-ion collision that increases the energy density of the hadron system extremely high for a short period of time (10–100 fm/c). Another promising method uses the nuclei as an environment with higher energy density than that of vacuum. Although the energy density is not high enough to establish the transition from the symmetry broken phase to the symmetry recovered phase, the environment is more stable and static compared with the relativistic heavy-ion collision case. In practical experiments, hadrons are created in nuclei and the properties of hadrons are compared with those in the vacuum. The change of the hadron properties is interpreted as a precursor of the chiral symmetry restoration.

2 Scientific Motivation

In recent years, experimental data related on the spectral functions of hadrons in nuclei drew special interests from the view point of the chiral symmetry breaking and its restoration. The CHAOS collaboration at TRIUMF measured the invariant mass distributions of $\pi^+\pi^-$ pairs in the vacuum and also in nuclei by the $(\pi^+, \pi^+\pi^-)$ reaction [1]. They observed a significant change for the distributions, and they argued that the change came from the modification of the spectral function of the σ meson ($f_0(600)$, $J^\pi=0^+$, I=0) in nuclei. The most significant change was the enhancement of the low invariant mass region ($\sim 2m_\pi$), and they argued a possibility of the partial restoration of the chiral symmetry in nuclei because theoretical works based on QCD predicted a decrease of hadron masses as a result of the chiral symmetry restoration.

In relation with the CHAOS experiment, Crystal Ball collaboration at BNL measured the $(\pi^-, \pi^0\pi^0)$ reaction and reported a negative result [2]. The TAPS collaboration at MAMI measured the $(\gamma, \pi^0\pi^0)$ reaction and reported a positive result [3]. Another

study on the spectral function of the vector mesons in nuclei done at KEK by the (p, e^+e^-) reaction, and a similar change of the spectral function for the ρ meson was reported [4].
Although several fragments of interesting experimental results have been obtained, the direct relation between the results and the chiral symmetry restoration is not conclusive yet, and new types of data are necessary to understand the phenomena more clearly. In this proposal, we wish to measure the $\pi^+\pi^-$ invariant mass distribution in a proton-induced subthreshold two pion production reaction to investigate the chiral symmetry problem.

3 Basic Idea of Experiment

3.1 Proposed Measurement

We propose to measure the (p,$\pi^+\pi^-$) reaction off nuclear targets with the 416 MeV proton beam at the RCNP Ring Cyclotron. Though the energy threshold of the two pion production reaction is 600 MeV for a free nucleon target, the subthreshold production process opens at beam energies of 300 MeV, 285 MeV and 280 MeV for the C, Cu and Au targets. Thanks to Fermi motion of nucleons in the nuclei, the subthreshold production of the two pions is possible with the 416 MeV proton beam if the momentum of the Fermi motion is larger than 200 MeV/c.
A simple calculation based on the cross section data of the elementary reaction, $p+p \rightarrow \pi^+ + \pi^- + p + p$ [5], a realistic momentum distribution of Fermi motion of nucleon in nuclei and an effect of the nucleon binding in nuclei was made. The calculation told that the effective kinetic energy, Tp, of the beam proton contributes to the subthreshold production was about 760 MeV in average, and the cross section for the subthreshold process is about 1 nb per nucleon in nuclei (see Fig.1). Since the estimated cross section was considerably small and the ratio of the subthreshold reaction and the total hadron cross sections was tiny, $\sim 10^{-7}$, special care has to be paid for the design of the experiment. Fig.2 shows plots of the pion momentum distribution and the total energy of the $\pi^+\pi^-$ system. The information is useful to kinematically discriminate the signal events from backgrounds.

3.2 What can we learn from the measurement ?

The CHAOS data is indicating an enhancement of the yield of $\pi^+\pi^-$ pairs in the low invariant mass region only in nuclear targets. The enhancement ranged from the threshold, $2m_\pi$, to about 300 MeV/c^2. We can investigate the $\pi^+\pi^-$ invariant mass range from $2m_\pi$ to about 350 MeV/c^2 with the subthreshold reaction. Since the kinematical condition for the subthreshold reaction is quite tight, the yeild of the reaction is strongly related to the $\pi^+\pi^-$ strength in the low invariant mass region.

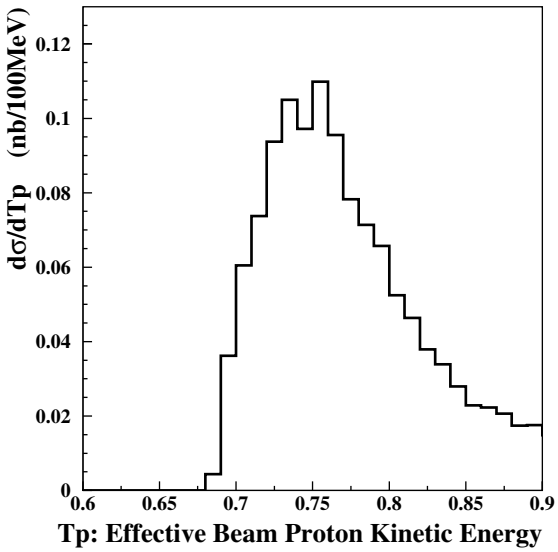

Figure 1: Distribution of the effective kinetic energy, Tp, of the beam proton contributes to the subthreshold two pion production process. The vertical axis shows the differential cross section per nucleon in 100 MeV Tp bin.

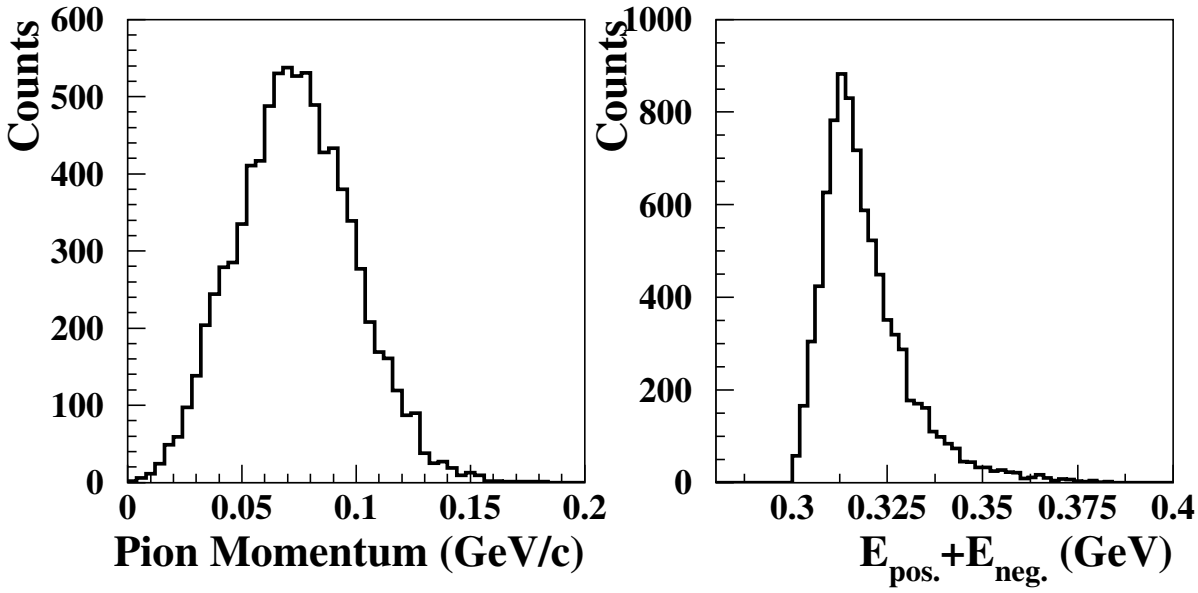

Figure 2: Distributions of the pion mementa (left) and the sum of total energies of the π^+ and π^- mesons (right).

The higher invariant mass component is forbidden due to the kinematical limit, so the feeding from secondary processes may be small. In this sense, the cross section measuremnt of the subthreshold two pion production will answer to the question if the enhancement in the $\pi^+\pi^-$ strength exist or not in the low invariant mass region.
Although the invariant mass window we can access by the subthreshold reaction is limited, we still can see the distribution of the $\pi^+\pi^-$ invariant mass and it may help us the understanding of the nature of the two pion correlation in nuclei.
It was known that the $\pi\pi$ invariant mass distributions of the elementary $(\pi, \pi\pi)$ reactions were quite different from the distribution propotional to the phase space (the CHAOS and the Crystall Ball experiments), and it indicated that the reaction mechanism was not simple and/or the final state interaction was not negligible. For the $(p, \pi^+\pi^-)$ reaction, the distribution of the $\pi^+\pi^-$ invariant mass was not far from the phase space distribution [5], and it may be an advantage of the reaction. The photon induced reaction, the $(\gamma, \pi^0\pi^0)$ reaction, may have the same advantage (the TAPS experiment).

3.3 Existing Setup and Status

We are planning to make the experiment at the WSS beam line by using the Osho magnetic spectrometer system. The Osho spectrometer system covers the polar angles from 15° to 105°, covers full azimuthal angles. The geometrical coverage of the solid angle is about 2.4π. The transverse momentum limit of particle detection is as low as 30 MeV/c, and overall acceptance of the spectrometer system for the two pion production process is estimated to be about 60 % by a Monte Carlo simulation calculation. This large acceptance of the spectrometer is a great advantage in the measurement of the tiny reaction cross section.
The schematic views of the Osho spectrometer system are shown in Fig.3. The target is placed at the center of the spectrometer system in the vacuum chamber. Experimental triggers are created with the Inner and the Outer hodoscopes. The particle tracking is made with a Cylindrical Drift Chamber (CDC) and momenta of particles are estimated together with a solenoidal magnetic field in the Osho magnet (B=0.3T). Particle identification is made with the momentum information and the time-of-flight calculated from the timing information of the Outer hodoscope and the beam RF signal.
Most of products in the proton-induced reactions are protons from the elastic and inelastic scattering. Since the DAQ speed is finite, an efficient data collection is not possible without intelligent selections of particles in the trigger level. We developed a trigger quite sensitive to negatively charged particles. Modules of the Outer hodoscope are arranged to have a finite tilting angle looking from the target position. As shown in Fig.3, negatively charged particles, e.g., π^- mesons, pass through more than 3 modules of the Outer hodoscope. On the other hand, positively charged particles, e.g., protons, pass through only two modules. By counting number of hit modules in the

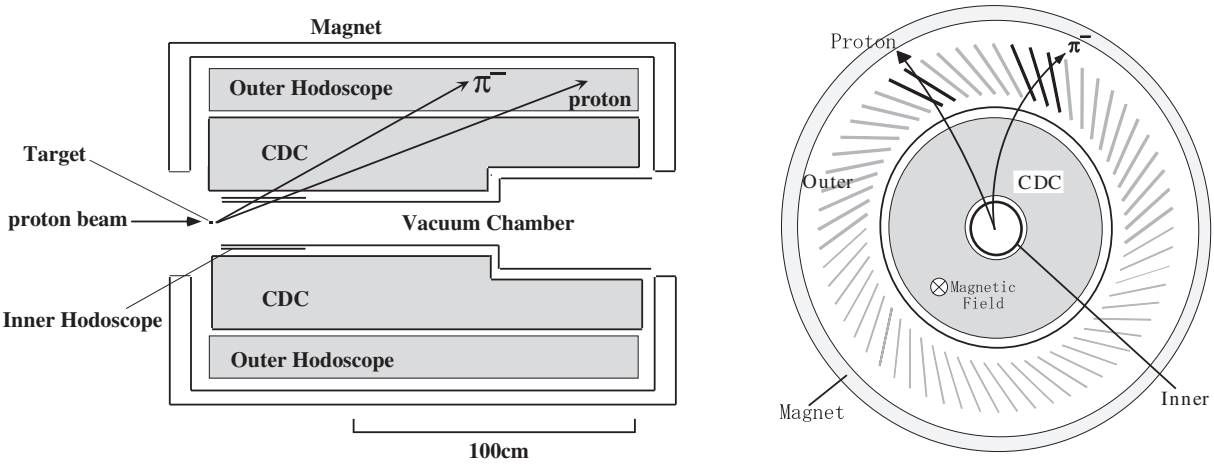

Figure 3: Schematic views of the Osho spectrometer system looking from side (left) and from the beam (right).

trigger level, we can select negatively charged particles efficiently. The efficiency of the trigger depends on the transverse momentum of the particle. Almost 100 % efficiency is obtained for particles with transverse momenta from 30 MeV/c to 80 MeV/c, and the efficiency is still larger than 50 % at 100 MeV/c.

Fig.4 shows distributions of transverse momenta multiplied by the charge of particles for three different triggered conditions. For the left plot, no selection of particles was made in the trigger level. Most of particles detected with the simple trigger were protons as expected. In the center plot, a set of hits in three neighboring Outer hodoscope modules was required in the trigger level, and an enhancement of π^- events was observed. In the right plot, a requirement on the pulse height of the Outer hodoscope modules was added in the trigger level to reduce the proton hits further. With the intelligent trigger, we could reduce the trigger rate by roughly 2.5 orders of magnitude with keeping the trigger efficiency high for the negatively charged particles. Since the cross section of the proton-induced hadron reaction per target nucleon is a few 10 mb order and the π^- production reaction cross section is about 50 μb in the elementary processes, we could measure the single-π^- production reaction quite efficiently. The intelligent trigger was also usuful to measure the $\pi^+\pi^-$ production reaction and we already achieved a sensitivity down to a few 0.01 nb in the cross section per target nucleon with one day measurement.

Fig.5 shows a preliminary result of the $(p, \pi^+\pi^-)$ reaction measurement with a Cu target in a pilot measurement for about 8 hours. The DAQ speed limited the accepted trigger rate ($\sim$500 s^{-1}) in the measurement. The plot shows a momentum$\times$charge vs β (=v/c) distribuion for detected positively charged particles with a requirement at least one negatively charged particle, assumed to be π^-, in the spectrometer. A loose cut on the total energy of the positively and negatively charged particle pair, $E_{pos.} + E_{neg.} < 400 MeV$, was also applied to reduce backgrounds because background

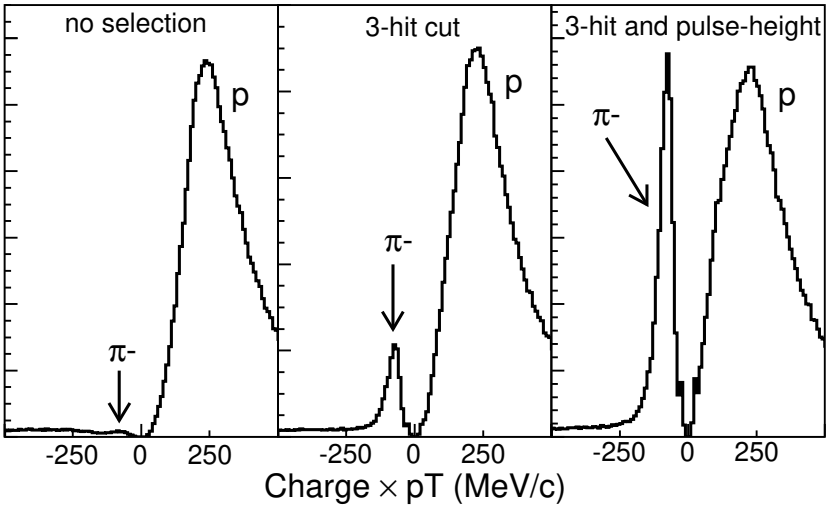

Figure 4: Distributions of transverse momenta multiplied by the charge of particles. From left to right, trigger conditions are without 3-hit selection, with 3-hit selection and with 3-hit and pulse-height selections.

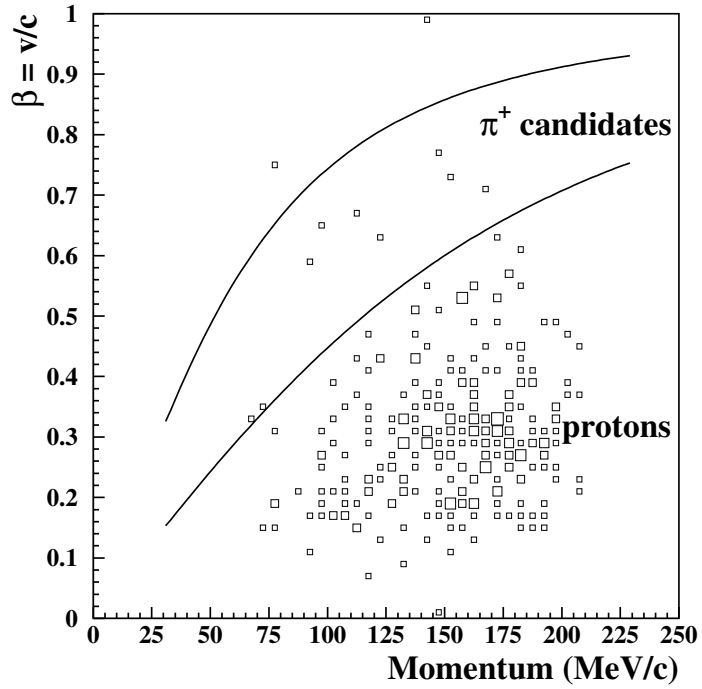

Figure 5: Candidates of the $Cu(p,\pi^+\pi^-)X$ events. The plot shows a momentum vs β distribuion for positively charged particles. At least one negatively charged particle in the spectrometer is requited in the off-line analysis for the plot. A loose cut on the total energy of the positively and negatively charged particle pair was also applied to reduce backgrounds.

protons had higher momentum than the signal π^+'s. Although most of π^- particles were emitted together with protons, π^+-like particles were also emitted togeter with π^- for several events. The signal region of the $\pi^+\pi^-$ events is indicated in the plot. In the data sample, one event corresponds to roughly 0.1 nb in the cross section per target nucleon estimated from yield of the single-π^- reaction and the known reaction cross section ($\sim$50 μb).

4 New Trigger Design and Prospects

Since the current data correction efficiency is limited by the DAQ speed and the trigger rate, we are planning to improve the efficiency as follows:

- Improve the DAQ speed by a factor of 2. This can be achieved by an introduction of a double buffer to the DAQ system. There is no technical problem.

- Constract the 1st level triger which identify two clusters of hits in the Outer hodoscope modules. At least one negative particle hit (the 3-hit and pulse-height cut) can be requested at the same time. The effect to the trigger rate is expected to be a factor of 2. The 1st level trigger can be obtained by a modification of a FPGA software for the trigger system based on the Universal Logic Module (ULM). There is no technical problem.

- Include the CDC hit wire information into the trigger to require at least two tracks. This is the 2nd level trigger. Basic studies of the trigger have been finished in off-line simulations with the existing experimental data. The effect to the trigger rate is estimated to be more than a factor of 3. Addition of the ULM modules, development of the FPGA software and a modification of the DAQ sequence are necessary.

By the improvement of DAQ and the trigger system, we expect an increase of the yield of the subthreshold reaction in a unit of time by one order of magnitude.
The development of the trigger with the CDC hits requires one day beamtime to confirm the effiency of the trigger. If the reduction of the trigger will be achieved, we wish to increase the proton beam intensity. The nominal beam intensity used in the previous experiment was less than 0.5 nA (beam energy was 392 MeV), and the increase of the beam intensity is possible (increase of the target thickness is also possible). The increase of the beam intensity results in the increase of the single rate of the detectors in the spectrometer system, and we wish to have one day beamtime to optimize the detector operation to the higher countrate.
So far, the measurement of the subthreshold reaction was done as a byproduct of data from other experiments. The longest data taking usuful for the analysis was only 8 hours, so we wish to have at least 4 days of beamtime dedicated for the measurement

Table 1: Summary of the beamtime request.

Subject	Request (days)
measurement for final data	4
new trigger development	1
detector tuning in high rate	1
total	6

to increase the yield by one order of magnitude. The request of the beamtime is summarized in Table 1. We are planning to use a Cu target for the mesurement (C and Au targets are also available if necessary).

5 Budget Request

We need following items for the proposed experiment.

trigger logic module (ULM) : 2 $\times$ 300,000 yen = 600,000 yen
cable for trigger assembling : 2 $\times$ 100,000 yen = 200,000 yen
LEMO cable and connector : 150,000 yen

The total budget request is 950,000 yen.

References

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