Study for the neutrino coherent pion production experiment

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The short range correlation of nuclear force $g'_{\Delta\Delta}$ is important to study the phase transition of the nuclear matter. The extraction of the $g'_{\Delta\Delta}$ from the neutrino and proton coherent pion productions are discussed.

1. INTRODUCTION

The spin longitudinal response probed by a charge exchange reaction is one of the important topics in nuclear physics since it relates to the short range correlation of nuclear force. Based on the approach of Landau-Migdal theory, the short range component of the nuclear force can be parameterized as three zero range contact interactions (Landau-Migdal parameters), showing the couplings of nucleon-nucleon (g'_{NN}), nucleon-delta ($g'_{\Delta N}$), and delta-delta ($g'_{\Delta\Delta}$), while the long range part is the sum of the π- and ρ- meson exchanges [1]. The relativistic mean field theory shows that the critical density of the pion condensation phase is sensitive to the $g'_{\Delta\Delta}$ [2], but its experimental information is poor although the g'_{NN} and $g'_{\Delta N}$ are well known from various experiments [3]. We can investigate the property of the pion condensation in the high density nuclear matter through the $g'_{\Delta\Delta}$.

The Coherent Pion Production (CPP) process : ν (p)+A $\rightarrow$ μ^-(n)+ π^++A can be qualitatively interpreted as the emission of a virtual pion from the projectile neutrino (proton), followed by the elastic scattering of this off-shell pion with the target nucleus, till it becomes a real pion with the target nucleus left in the ground state. It is a good process to study the spin longitudinal response, since the longitudinal component is dominant in its cross section at forward angle and it is sensitive to the $g'_{\Delta\Delta}$ [4]. The neutrino beam is best to prove the interior of the nucleus, because it fully penetrates the nucleus and the response is fully predictable since the weak interaction is perfectly known. We can get the information on $g'_{\Delta\Delta}$ in the saturated nuclear density. On the other hand, proton induced CPP can access the $g'_{\Delta\Delta}$ at the low density in the nuclear surface, because of the highly peripheral feature of the nuclear reaction by the strong interaction. The measurements of the neutrino and proton induced CPP are both needed to determine the density dependence of Landau-Migdal parameters, which is important to extrapolate them to the high density region to predict the property of high density nuclear matter. We are performing the proton induced CPP experiment to determine the $g'_{\Delta\Delta}$ accurately for the first time.

2. PROTON INDUCED COHERENT PION

The proton induced CPP can access the kinematics region different from a real pion scattering, where the longitudinal response has its maximum strength near energy and momentum transfers with 210 MeV and 230 MeV/c respectively due to the attractive pion exchange leading to a collective pionic mode in the nucleus. The coherence of the propagating pion is built up with a $\mathbf{S}\cdot\mathbf{q}$ spin structure, where S is the N$\rightarrow\Delta$ spin transition operator, and proved by the decay of real pion through $\mathbf{S}^\dagger\cdot\mathbf{p}_\pi$ leaving the target in the ground state. The angular correlation is shown by a $(\mathbf{S}\cdot\mathbf{q})(\mathbf{S}^\dagger\cdot\mathbf{p}_\pi)$, namely $(\mathbf{q}\cdot\mathbf{p}_\pi)=qp_\pi\cos\Theta_\pi$. The cross section has a factor of $\cos^2\Theta_\pi$ and has a peak at Θ_{π}=0 degree [5]. Theoretical works suggest that the magnitude and the shape of the cross section at zero degree are sensitive to the $g'_{\Delta\Delta}$, which can be written by $\Delta E \sim g'_{\Delta\Delta}(hcf_{\pi N \Delta}/2\pi m_{\pi}{}^2)\rho_0$, where ρ_0 is the nuclear density [4].

The experiment is performed now at Research Center for Nuclear Physics (RCNP), Osaka University, Japan. We are measuring the CPP with the reaction $^{12}C(p,n\pi^{+})^{12}C$. The proton beam with 1 nA at 400MeV is supplied from the accelerator complex of injector AVF cyclotron and Ring cyclotron. The beam is transported to the neutron time of flight facility (NTOF) [6]. The scattered neutrons are detected by the neutron counter (NPOL2) consisting of liquid scintillators with charged particle veto detector, which is set at 70m downstream the target in the NTOF. The positive pions are momentum analyzed by the dipole magnet to sweep the primary beam into beam dump, and are detected by the tracking detector system installed inside the magnet as shown in the Figure 1.

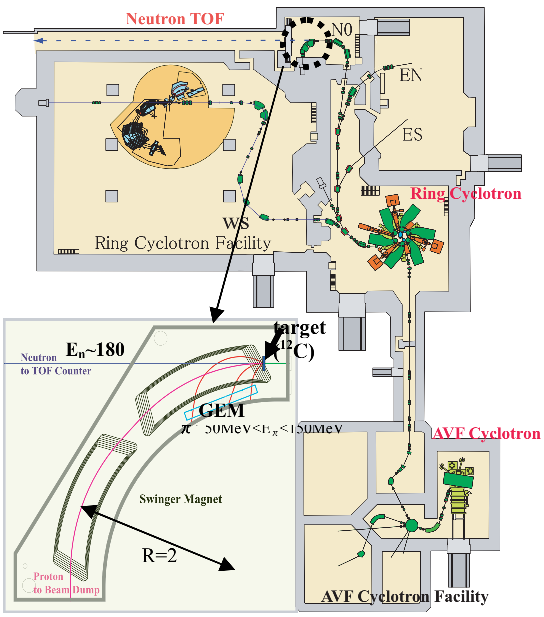

Figure 1. The overview of the experimental setup.

We need to separate the ground state of the residual ^{12}C from the excited states located at higher than the first excited state of 4.4 MeV to get the accurate signature of the CPP. The required resolution of the tracking detector system is set to 1 MeV, taking into account the resolution of incidence beam with ~200 keV, neutron counter with ~500 keV. The Monte-Carlo study shows that the position resolution should be less than 100 μm to achieve the required pion energy resolution. The tracking detector based on a Gas Electron Multiplier (GEM) technology [7] is now constructed. It has a high position resolution and a stable performance under the severe radiation environment closed to the reaction point thanks to the multi-layered GEM structure. The construction will be completed in the end of 2005.

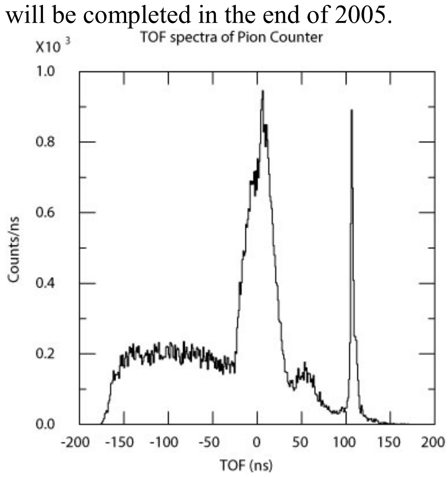

Figure 2. The TOF spectrum of charged particles.

The Figure 2 shows the TOF spectrum of charged particles with plastic scintillators installed in the tracking detector system. The coherent pions are buried in the background in the central peak. The high energy protons from edge scatterings of beam halo are a dominant component in the background. It is difficult to separate them in the data analysis, since their energy and flight time are located in the same region as coherent pions. This background should be reduced by the halo-free beam tuning. Other backgrounds of charged particles from proton inelastic scattering, quasi-free scattering, delta and nucleon spreading processes can be neglected, because the low energy protons with same momentum as coherent pions are stopped in the first layer of the plastic scintillators. The Figure 3 shows the neutron energy loss spectrum. The CPP events are distributed in the region 200~300 MeV. The target is exited by the incoherent pion production process which results in the continuum or excited protons together with pions from the quasi-free delta production and its decay, where its cross section is small in this incidence energy. So the coherent pions are expected to be dominant among pion events in coincidence with the scattered neutron. The data analysis is in progress now.

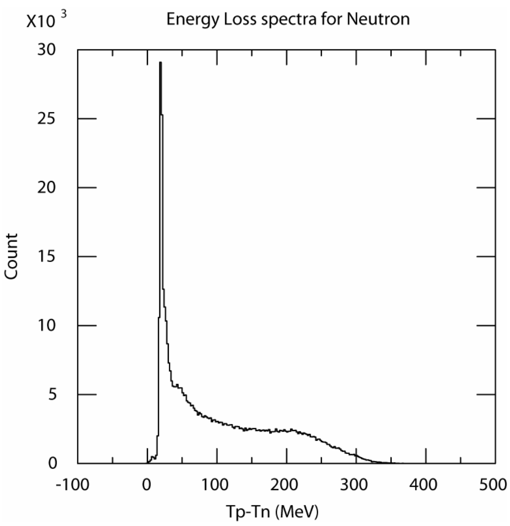

Figure 3. The neutron energy loss spectrum.

3. NEUTRINO INDUCED CPP

The neutrino can be viewed as virtually decomposing into a virtual pion and lepton, Adler's theorem shows that the weak interaction matrix element for a forward neutrino reaction is proportional to the corresponding T matrix element for the virtual pion induced reaction [8]. The virtual pion beam causes a non-vanishing wave in the nuclear medium, penetrate a nuclear interior and this wave produces pionic process in the nuclear volume. The neutrino induced CPP, therefore, can be used to determine the $g'_{\Delta\Delta}$ in the saturated nuclear density.

Recently K2K collaboration published the data on the neutrino induced CPP [9] showing that the cross section is significantly small compared with the theoretical calculation. Its result is interesting and more statistics of the data in a GeV region is needed to extract the short range component $g'_{\Delta\Delta}$ in the saturated nuclear density. J-PARC is suitable facility for this purpose, since the beam energy spread is narrow and the intensity peak of 0.8 GeV can be expected if we locate the detector with off-axis of 2.5 degree. The detector consisting of fiber and liquid scintillators is good choice, because we can accumulate the CPP data from ^{12}C and also the data of quasi-elastic scattering to study the strange quark contents in the nucleon [10] can be measured in parallel.

4. SUMMARY

The coherent pion production induced by proton and neutrino is good probe to investigate the density dependence of the short range component of nuclear force $g'_{\Delta\Delta}$. The neutrino will be able to prove the $g'_{\Delta\Delta}$ in the saturated density, while the proton induced CPP experiment, which is going on at RCNP now, can study it in the nuclear surface.

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