Feasibility test for coherent pion production experiment

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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. The relativistic mean field theory shows that the critical density of the pion condensation phase is sensitive to the $g'_{\Delta\Delta}$, but its experimental information is poor although the g'_{NN} and $g'_{\Delta N}$ are well known from various experiments. We investigate the property of the pion condensation phase through the $g'_{\Delta\Delta}$ using the Coherent Pion Production (CPP) process. The CPP : $p+A \rightarrow n+\pi^{+}+A$ can be qualitatively interpreted as the emission of a virtual pion from the projectile, 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 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 $\Theta_{\pi}=0$ degree. 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 $\Delta E\sim\Delta g'_{\Delta\Delta}(hcf_{\pi N\Delta}/2\pi m_{\pi}^{2})\rho_{0}$, where ρ_{0} is the nuclear density. 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 $g'_{\Delta\Delta}$.

The experiment is performed in the neutron time of flight facility (NTOF) at RCNP to check the feasibility of the measurement technique for 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 scattered neutrons are detected by the neutron counter consisting of liquid and plastic scintillators, which is set at 70m downstream the target in the NTOF. The positive pions are momentum analyzed by the swinger magnet, and detected by the tracking detector system installed inside the magnet. We need to separate the ground state of the residual ^{12}C from the excited states to get the accurate signature of the CPP. The required resolution of the tracking system is set to 1 MeV, and the Monte-Carlo study shows that the position resolution should be less than 100 μm to achieve the required energy resolution. The tracking detector based on a Gas Electron Multiplier (GEM) technology was constructed in the end of 2005. It has a high position resolution and a stable performance under the severe radiation environment closed to the reaction point. The Figure 1 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 coherently produced pions are expected to be dominant in the coincidence pions with the scattered neutron. The CPP events are selected by the TOF and energy cuts of charged particles, and their plot is shown in the magnified plot inside the Figure 1. The enhancement can be observed in the region of the CPP. The red line shows the theoretical predication of the CPP[1], assuming the appropriate detector efficiencies. The statistics is too small to discuss physics further, and the data accumulation run including new GEM detector is planed in the next experiment.

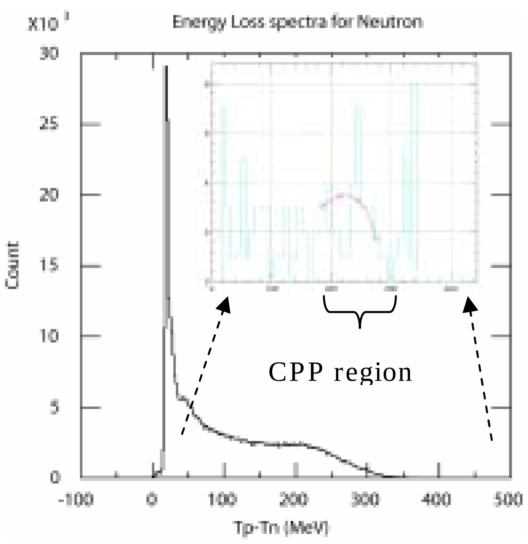

Fig.1. This plot shows the neutron energy loss spectrum. The coherent pions are distributed in the energy region from 200 to 300 MeV. The measure background source is from edge scatterings of beam halo. It is difficult to separate them in the data analysis, since their energy and flight time are located in the same region as coherent pions. This background should be reduced by the halo-free beam tuning.

References

[1] P.Fernandez de Cordoba *et al.*, Nucl. Phys. A592, 472 (1995)