A_N of forward neutron production in $\sqrt{s}$=200 GeV polarized proton-nucleus collisions in the PHENIX expermient

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The first attempt to collide a polarized proton and a nucleus was executed at RHIC in Run15. This provides a unique opportunity to study the totally unexplored reaction mechanism of $p^{\uparrow}+A$ at high energy. We report the first asymmetry measurement of forward ($6.8 < \eta < 8.8$) neutron results from $p + Al$, and $p + Au$. The observed asymmetries showed unexpectedly large values and strong A-dependence.

The single transverse spin asymmetry, A_N, is written as

$$A_N = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}} \tag{1}$$

where $\uparrow$ and $\downarrow$ represent the spin directions of incident protons. In terms of scattering amplitudes, the condition for nonzero A_N is

$$A_N \propto Im\{\phi^{*}_{\rm filp}\phi_{\rm nonfilp}{\rm sin}\delta\} \neq 0 \tag{2}$$

where $\phi^{*}_{\rm filp}(\phi_{\rm nonfilp})$ is the spin flip (nonfilp) amplitude, and δ is a relative phase between the two amplitudes.

In 2011, a one pion exchange (OPE) model that well describes the cross section and A_N of forward neutron production from the PHENIX data[1)] for $\sqrt{s}$=200 GeV $p{+}p$ collision was published[2)]. The model describes the spin flip amplitude by pion exchange and the non-spin flip amplitude mainly by the a1-Reggeon exchange. As a consequence, the model satisfactory reproduced the experimental A_N data.

Fig. 1 shows a preliminary plot of the Run15 forward neutron A_N results.The red points are A_N of ZDC (zero degree calorimeter, a neutron detector) inclusive measurements. They show unexpectedly strong mass number (A) dependence; $A_N^{p^{\uparrow}+Au}$ is 3 times larger than $A_N^{p^{\uparrow}+p}$, and they have opposite sign.

The observed A dependence immediately eliminates naive expectations such as isospin symmetric effects, which do not change the sign of A_N with increasing number of protons and neutrons.

Although electromagnetic interaction was not even considered in $p{+}p$, it may not be ignorable in $p{+}A$ because of the smallness of the $-t$ range ($< 0.5{\rm GeV/c^2}$) of the measurements. Without full description, equation 2 is thus modified as

$$\begin{aligned} A_N \propto\ & \phi^{\rm EM*}_{\rm filp}\phi^{\rm EM}_{\rm nonfilp}{\rm sin}\delta_1 + \phi^{\rm EM*}_{\rm filp}\phi^{\rm had}_{\rm nonfilp}{\rm sin}\delta_2 \\ & + \phi^{\rm had*}_{\rm filp}\phi^{\rm EM}_{\rm nonfilp}{\rm sin}\delta_3 + \phi^{\rm had*}_{\rm filp}\phi^{\rm had}_{\rm nonfilp}{\rm sin}\delta_4 \end{aligned} \tag{3}$$

where "EM" stands for electromagnetic interactions,

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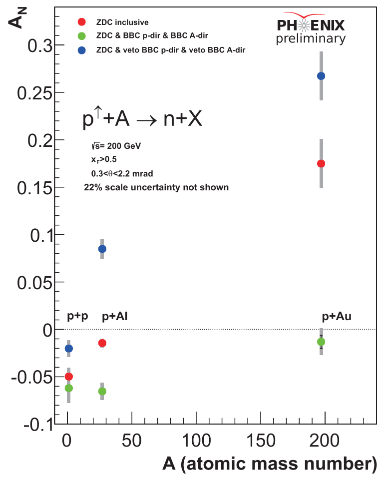

Fig. 1. Forward neutron A_N ploted as a function of atomic mass number with BBC correlations in $\sqrt{s} = 200$ GeV $p + p$, $p + Al$, and $p + Au$ collisions.

"had" stands for strong interaction, and from δ_1 to δ_4 are relative phases. The majority of the elecromagnetic process should be given by $\gamma^{*}p \to \Delta^{+} \to n + \pi^{+}$ where γ^{*} is supplied from the EM field of the nucleus. The second and third terms are known as Coulomb nuclear interference (CNI), which is observed to cause $\lesssim 5\%$ asymmetry in the elastic scattering in $p{+}p$, and $p + C$ processes[3)]. According to an MC simulation, Δ^{+} decay products are predicted to be more forward boosted as compared to hadronic interactions[4)]. In order to suppress competing effects, a correlation study was carried out using beam beam counters (BBCs, $3.1 < \eta < 3.9$). Since the most of neutron and pion pairs decayed from Δ^{+} via the EM process events pass through the BBC hole, requiring/vetoing activities in BBC can suppress/enhance contributions from the EM terms in equation 3. The green points in Fig. 1 denote A_N with BBC activities, and the blue points denote A_N without BBC activity. We can see a clear correlation between the A_N and BBC activities.

There can be other processes that are not discussed here. Theoretical development is underway to explain this interesting discovery.

References

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