Transverse single spin asymmetries of forward neutrons in $p+p$, $p+$Al and $p+$Au collisions at $\sqrt{s_{NN}} = 200$ GeV as a function of transverse and longitudinal momenta†

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In 2015 the PHENIX collaboration took data with transversely polarized proton beams in proton-proton, proton-Al and proton-Au collisions at center-of-mass energies of 200 GeV per nucleon. One of the mesurements that were performed with this dataset are very forward neutron single-spin asymmetries that were detected with the zero-degree calorimeter in the direction of the polarized proton beam. It is located ca 18m downstream of the beam collision point. As reported, nonzero single spin asymmetries for proton-proton collisions were already known,[1] but the fact that sign and magnitude of such asymmetries were different in proton-nucleus collisions[2] initially came as a surprise. Since then it has been realized, that apart from meson interchange,[3] in p-A collisions increasingly also ulatraperipheral collisions (UPC) can create such asymmetries.[4] In UPC, a nucleus emits virtual photons that can collide with the proton and create final states with forward neutrons, most notably via the production of a Delta resonance.

Previously, these results were extracted integrated over the transverse momentum p_T of the neutron and the longitudinal momentum fraction x_F relative to the proton beam momentum and its direction. Using Bayesian unfolding as implemented in ROOT the PHENIX experiment has now extracted also the explicit x_F and p_T dependence of these asymmetries for the first time. Additionally, the asymmetries were calculated in (anti) correlation with activity in other forward detectors (beam-beam counters, BBC) that are predominantly sensitive to hard collisions and thus allow to enhance or reduce the contribution of the mostly very soft UPC events.

It was found that the meson-based calculations describe the proton-proton data very well, showing roughly a linear transverse momentum dependence with very little x_F dependence. A comparison between inclusive and hard-collision enahanced (BBC tagged) asymmetries shows that some UPC contributions may be present. In p+Al collisions the inclusive asymmetries are comparable with zero over most of the phase-space while the hard-collision enhanced sample is comparable to the $p+p$ case. In contrast, the BBC-vetoed sample (softer processes such as UPC enhanced) shows already positive asymmetries as shown in Fig. 1. The asymmetries in this case are initially rising but do show an indication of a decrease at higher transverse momenta. Theoretical calculations[4] that include both effects qualitatively describe the behavior but do not reproduce the details very well. However, the UPC based calculations only take decays of resonances with one pion in addition to the neutron into account while unpolarized MCs show that other contributions are also present. This likely explains the very sharp kinematic dependence of the theory calculations as the phase-space for neutrons from Delta decays is very limited.

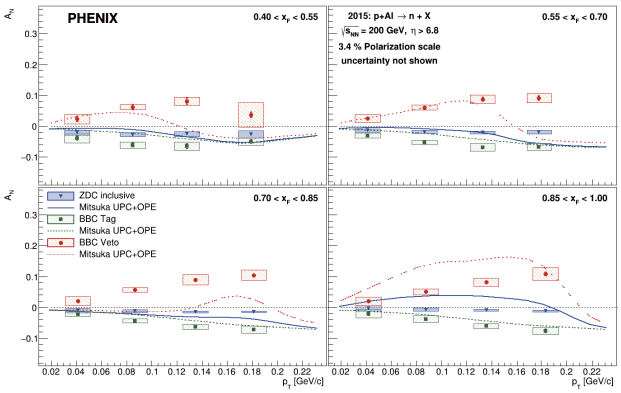

Fig. 1. Neutron single spin asymmetries for p+Al collisions either measured inclusively (blue), enhancing hard collisions (green, labelled BBC tagged) or enhancing UPC events (red, labeled BBC veto) as a function of transverse momentum p_T in bins of x_F.

In p+Au collisions the contributions from UPC are even larger as they increase quadratically with the charge of the nucleus. Here, even some UPC events seem to remain in the hard-collision enhanced data sample where the asymmetries are nearly vanishing while both inclusive and UPC enhanced asymmetries are positive. They reach up to 40% and show a similar behavior as in the UPC enhanced p+Al case.

These results will help further understand the mechanisms that create very forward neutron single spin asymmetries.

References
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