Transverse momentum dependence of forward neutron single spin asymmetries in polarized $p^{\uparrow}+p$ collisions at $\sqrt{s}=200$ GeV†

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The PHENIX Collaboration has, for the first time, explicitly measured the transverse momentum (p_T)-dependent single spin asymmetries (A_N) for inclusive neutrons produced in the forward region of the PHENIX detector with $\eta > 6.8$ using 2015 data. During this time, a proton with transverse polarization collided with another proton at $\sqrt{s} = 200$ GeV. Owing to the limited acceptance and resolution of the detector, the measured quantities were considerably smeared. We, therefore, corrected for the smearing in the measured p_T and azimuth (ϕ) using unfolding.[1)]

As the physics of forward neutron production is not clearly understood, we performed detailed simulations using different event generators as input to a full GEANT3 simulation.[2)] The generators DPMJET3.1, PYTHIA6.1, and PYTHIA8.2 were used because diffractive processes are very differently handled. Another generator was an empirical distribution of forward neutrons in p_T, mimicking a one-pion exchange (OPE) model in which a pion balancing the momentum between the incoming proton and outgoing neutron collided with the other proton beam using PYTHIA 8. Ultra-peripheral collisions (UPCs) also play a role in forward neutron production.[3)] The distribution of photons was, therefore, simulated using the STARLIGHT[4)] generator, and the photons collided with the proton beam using PYTHIA 8. As all Monte Carlo (MC) generators were intrinsically spin independent, we simulated spin effects by re-weighting events as a function of the generated p_T ($p_{T,g}$) and azimuth (ϕ_g) with the spin states (↑) and (↓) randomly assigned. Furthermore, as the shape of p_T-dependent A_N is not precisely known, we used three weight forms to provide as much flexibility as possible. The weight (w) based on a polynomial of third order (Pol3), power law, and exponential forms is given by Eqs. (1), (2), and (3), respectively, with Pol3 being the most general one:

$$w=\left(a\cdot p_{T,g}+b\cdot p_{T,g}^2+c\cdot p_{T,g}^3\right)\sin(\phi_g+\lambda\cdot\pi), \quad (1)$$

where λ (±1) is the spin state and a, b, and c are free parameters. Accordingly, the power-law weight is,

$$w=\left(a\cdot p_{T,g}^b\right)\sin(\phi_g+\lambda\cdot\pi), \quad (2)$$

and the last parameterization is an exponential form, which eventually decays asymptotically as

$$w=a\left(1-e^{b\cdot p_{T,g}}\right)\sin(\phi_g+\lambda\cdot\pi). \quad (3)$$

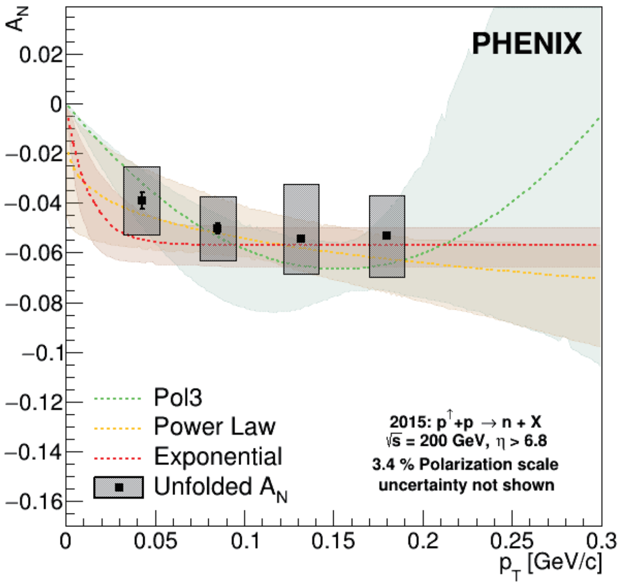

Fig. 1. Overall p_T-dependent A_N values shown as black solid square points averaged over all parameterizations, MC, and unfolding. Shaded boxes display total uncertainties from the unfolding, choice of MC, and functional form. Light-green, brown, and yellow shaded regions show χ^2 below 10 units for Pol3, power-law, and exponential forms, respectively, while the corresponding broken lines show the best matching parameterizations.

The performance of parameters, functional form, and MC generator in reproducing A_N values was evaluated by the minimum χ^2 between the measured MC and data asymmetries. The 2D spin-dependent neutron yields in p_T and ϕ were then unfolded using the TSVDUnfold class based on a singular value decomposition (SVD)[1)] of the smearing response matrix. Overall A_N values were finally calculated from the unfolded yields using the left-right A_N formula[5)] after fitting a sine modulation having magnitude and phase as free parameters. In Fig. 1, overall A_N values rapidly increase at low p_T ($\lesssim 0.1$ GeV/c) and slowly level off at high p_T. With this result, the first reliable tests of mechanisms producing these asymmetries can be performed.

References
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