Transverse single spin asymmetry for very forward neutron production in polarized p+p collisions at $\sqrt{s} = 510$ GeV

Minho Kim (RIKEN) on behalf of the RHICf collaboration



28 March DIS2023

Contents

- $A_{\rm N}$ for very forward neutron production
 - Previous measurements
 - Theoretical prediction
 - Motivation
- RHICf experiment
 - Preliminary result
- Updates
 - Analysis updates
 - Theoretical approach

Transverse single spin asymmetry (A_N)



- In the polarized p+p collision, the A_N is defined by a left-right cross section asymmetry of a specific particle.
- Due to the rotational invariance, the left-right asymmetry can also be expressed by the spin up-down asymmetry.
- If we measure the A_N of the very forward (6 $\langle \eta \rangle$) particle, we can study the spin-involved diffractive production mechanism.

A_N for very forward neutron production



- Non-zero A_N for very forward neutron production was first observed by the IP12 experiment at RHIC. Y. Fukao et al., PLB 650 (2007) 325
- Afterward, PHENIX measured the neutron A_N again as a function of p_T with three different collision energies.
- However, the kinematic dependence was largely smeared by worse position resolution of the neutron detector.

Theoretical model



$$\begin{split} \mathcal{A}_{\mathrm{N}} &= \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}} \\ &= \frac{\sum_{X} |\langle cX|T| \uparrow \rangle|^{2} - \sum_{X} |\langle cX|T| \downarrow \rangle|^{2}}{\sum_{X} |\langle cX|T| \uparrow \rangle|^{2} + \sum_{X} |\langle cX|T| \downarrow \rangle|^{2}} \\ &= \frac{|-2\mathrm{Im}\sum_{X} \langle cX|T| - \rangle \langle + |T^{\dagger}|cX\rangle}{\sum_{X} |\langle cX|T| + \rangle|^{2} + \sum_{X} |\langle cX|T| - \rangle|^{2}} \end{split}$$

 π exchange: spin flip a_1 exchange: spin non-flip

- Neutron A_N was explained by an interference between the spin flip and spin non-flip amplitudes leading to non-zero phase shift.
- The π and a_1 exchange model predicts that the A_N increases in magnitude with increasing p_T .

Unfolded neutron $A_{\rm N}$ at PHENIX

PHENIX, PRD 105 (2022) 032004



- Recently, $p_{\rm T}$ dependence of the PHENIX neutron $A_{\rm N}$ at \sqrt{s} = 200 GeV was obtained by unfolding the data.
- The unfolded data showed a tendency that the $A_{\rm N}$ increased in magnitude with $p_{\rm T}$ as the model predicted.

Neutron A_N measurement at RHICf



- RHICf experiment measured the neutron $A_{\rm N}$ in a wide $p_{\rm T}$ range from 0 to 1 GeV/*c* to test the validity of the π and a_1 exchange model in the higher $p_{\rm T}$ region.
- RHICf data can also be compared with the PHENIX to study if there is any collision energy dependence.
- RHICf detector has one order better position resolution (~ 1 mm) than the previous neutron detector (~ 1 cm).

RHIC forward (RHICf) experiment

STAR detector



Neutron $A_{\rm N}$ as a function of $p_{\rm T}$



RHICf data is consistent with the PHENIX one.

- In $x_{\rm F}$ > 0.46, the $A_{\rm N}$ increases in magnitude with $p_{\rm T}$ as the model predicted.
- There seems to be a gap between different $x_{\rm F}$ ranges.

Neutron $A_{\rm N}$ as a function of $x_{\rm F}$



- In $p_T < 0.25$ GeV/c, the A_N s are flat showing no x_F dependence which is consistent with the PHENIX data.
- In $p_{\rm T}$ > 0.25 GeV/*c*, a clear $x_{\rm F}$ dependence is seen.

Neutron $A_{\rm N}$ as a function of $x_{\rm F}$



- In $p_T < 0.25$ GeV/c, the A_N s are flat showing no x_F dependence which is consistent with the PHENIX data.
- In $p_{\rm T}$ > 0.25 GeV/c, a clear $x_{\rm F}$ dependence is seen.
- Front counter analysis was not included in the preliminary result.
 → Not sufficient to evaluate the effect of the charged particles.

Minho Kim (RIKEN)

Front counter analysis



We reproduced the front counter response by fitting the ADC distribution.

Front counter analysis



- We reproduced the front counter response by fitting the ADC distribution.
- MC reproduces the data well showing a peak in the MIP position.
- Events where the front counter has the signal were removed to suppress the charged hadron background.

Theoretical approach to the higher $p_{\rm T}$ region



We studied the spin effect by initial/final-state elastic interactions.

Since the relative phase shift due to the absorptive correction starts to deviate from $p_{\rm T} = 0.3$ GeV/c, $A_{\rm N}$ can increase in the higher $p_{\rm T}$ region.

Theoretical approach to the higher $p_{\rm T}$ region



- The absorptive correction in the single pion exchange doesn't reproduce the RHICf data well.
- However, it shows a possible origin of the $x_{\rm F}$ dependence.

Summary

- The RHICf experiment measured the very forward neutron $A_{\rm N}$ in a wide $p_{\rm T}$ coverage (0 < $p_{\rm T}$ < 1 GeV/c).
- In $x_{\rm F}$ > 0.46, the neutron $A_{\rm N}$ increases in magnitude with $p_{\rm T}$ as the model predicted.
 - A clear $x_{\rm F}$ dependence was observed in $p_{\rm T}$ > 0.25 GeV/c.



Final result will be published soon with more precise background estimation.

Backup

Neutron measurement

Side view



Shower trigger





- 17 tungsten absorbers (44 X₀, 1.6 λ_{int}), 16 GSO plates, and 4 layers of GSO bar hodoscope (1 mm interval).
- Shower trigger: Energy deposits of any three successive layers are larger than 45 MeV.

→ Unfolding

• $\sigma(E) \sim 30\%$ and $\sigma(x) \sim 1$ mm for 200 GeV neutron.

Minho Kim (RIKEN)

Analysis procedure













Minho Kim (RIKEN)