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

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on behalf of the RHICf collaboration

Programs for Junior Scientists

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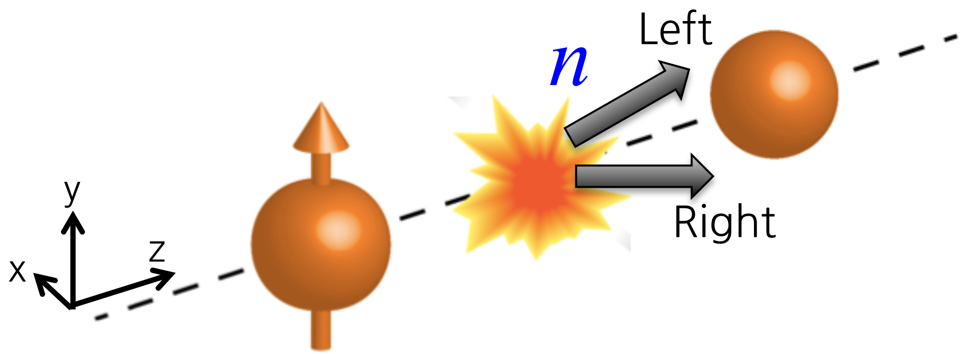
Transverse single spin asymmetry (A_N)

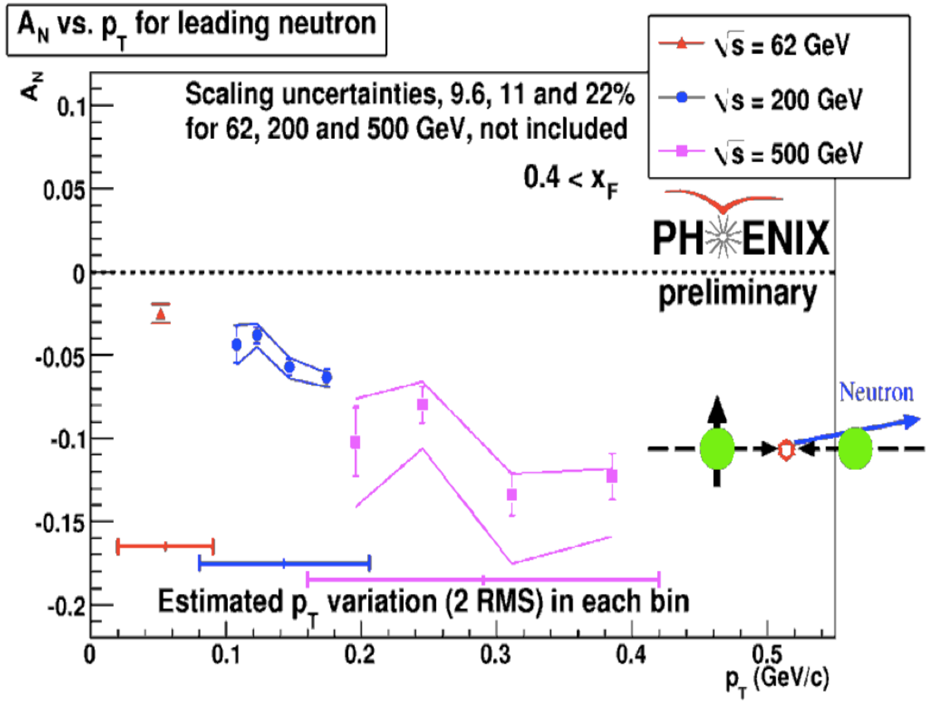


$$A_N = \frac{\sigma_L^\uparrow - \sigma_R^\uparrow}{\sigma_L^\uparrow + \sigma_R^\uparrow} = \frac{\sigma_L^\uparrow - \sigma_L^\downarrow}{\sigma_L^\uparrow + \sigma_L^\downarrow}$$

- 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.
- A_N of the very forward ($6 < \eta$) particle enables us to study the spin-involved diffractive production mechanism.

A_N for very forward neutron production

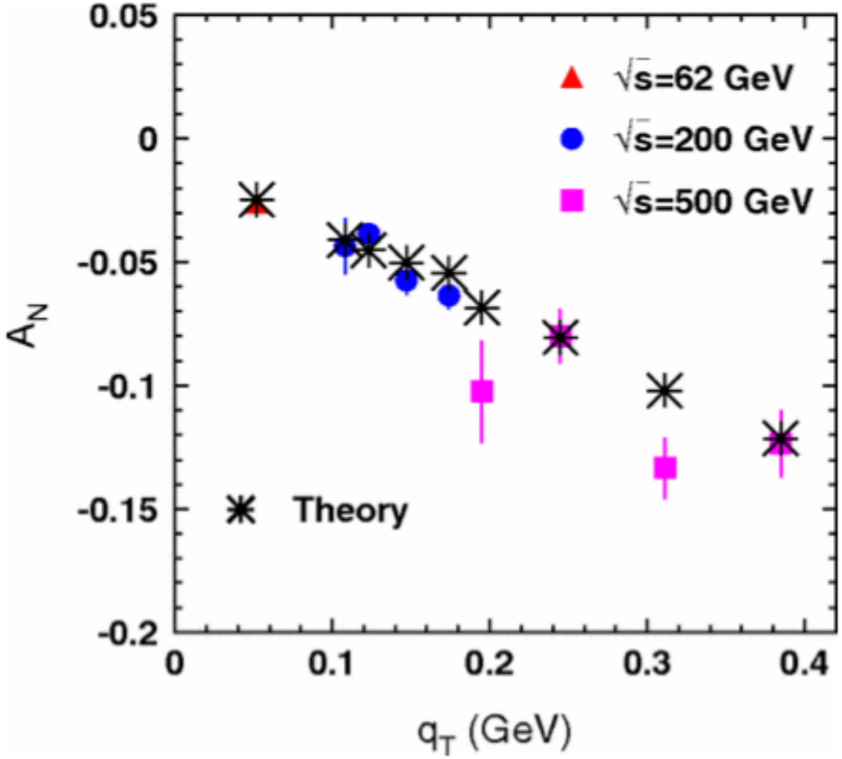
K. Tanida et al., J. Phys. Conf. Ser. 295 (2011) 012097



- 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, neutron A_N was measured by the PHENIX experiment with three different collision energies.
- However, the kinematic dependence was largely smeared by worse position resolution of the neutron detector.

Theoretical model

B. Z. Kopeliovich et al., PRD 84 (2011) 114012



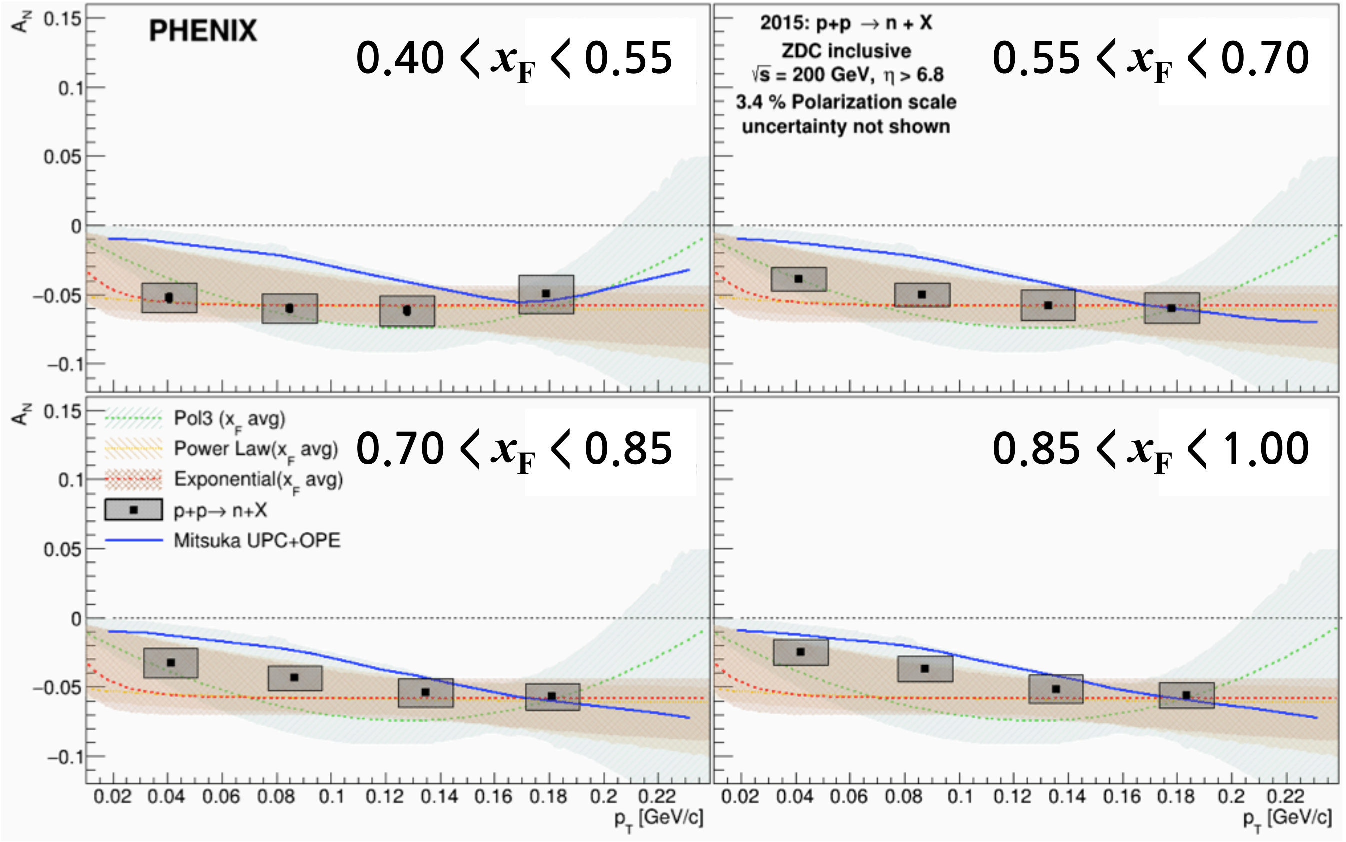
$$A_N = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$
$$= \frac{\sum_X |\langle cX|T|\uparrow\rangle|^2 - \sum_X |\langle cX|T|\downarrow\rangle|^2}{\sum_X |\langle cX|T|\uparrow\rangle|^2 + \sum_X |\langle cX|T|\downarrow\rangle|^2}$$
$$= \frac{-2\mathrm{Im}\sum_X \langle cX|T|-\rangle\langle +|T^{\dagger}|cX\rangle}{\sum_X |\langle cX|T|+\rangle|^2 + \sum_X |\langle cX|T|-\rangle|^2}$$

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

- Neutron A_N was explained by interference between the spin flip (π exchange) and spin non-flip (a_1 exchange) amplitudes.
- The π and a_1 exchange model predicts that the A_N increases in magnitude with increasing p_T.

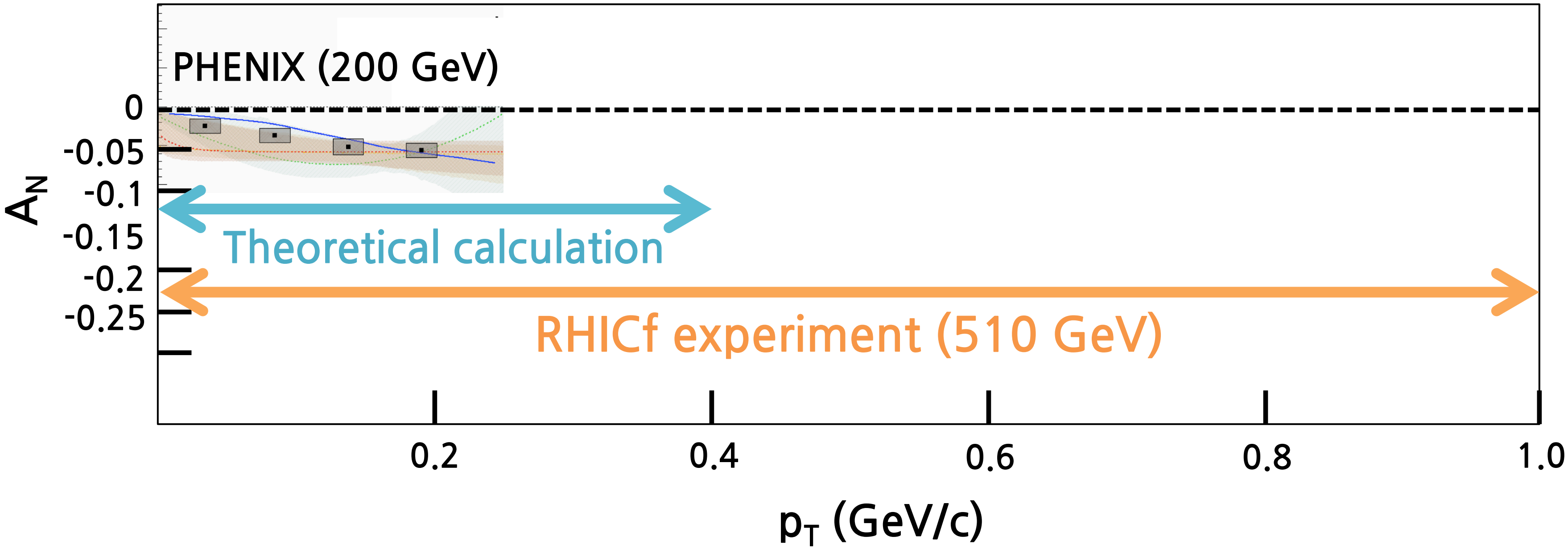
Unfolded neutron A_N at PHENIX

PHENIX, PRD 105 (2022) 032004



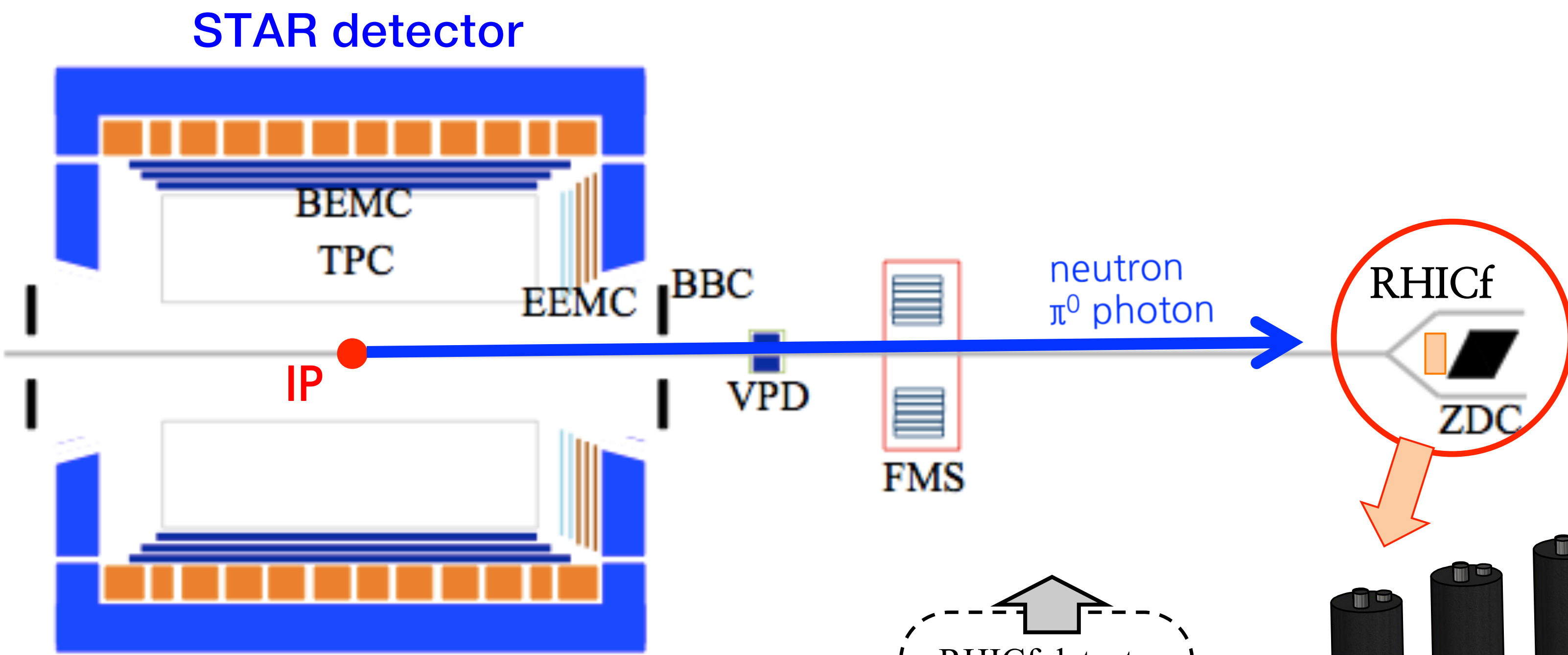
- Recently, p_T dependence of the PHENIX neutron A_N at $\sqrt{s}$ = 200 GeV was obtained by unfolding the data.
- The unfolded data showed a tendency that the A_N increased in magnitude with p_T as the model predicted.

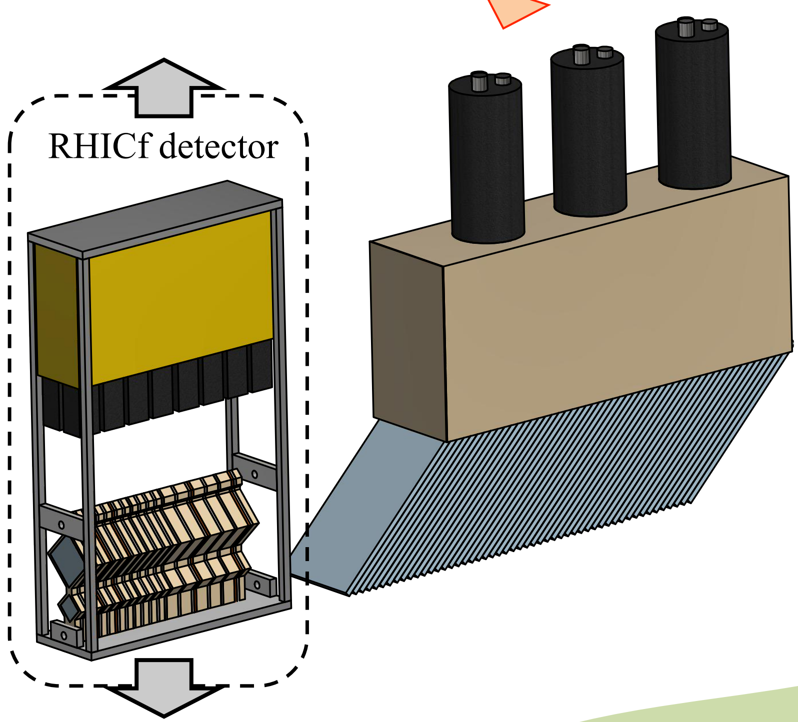
Neutron A_N measurement at RHICf



- RHICf experiment measured the neutron A_N in a wide p_T range compared to the previous experiments.
- RHICf data can not only be compared with the PHENIX one but also study the validity of the π and a_1 exchange model in a wide p_T range.

RHIC forward (RHICf) experiment

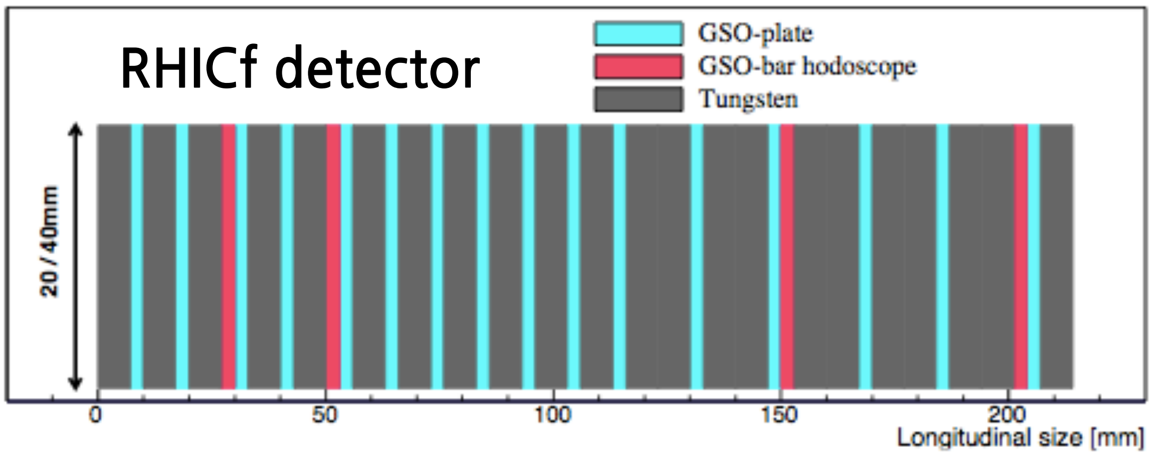




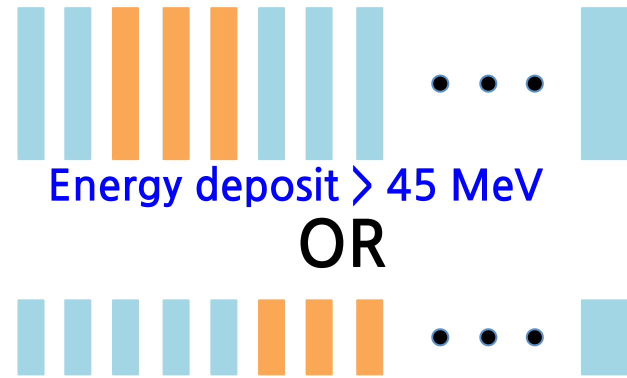
- Operated at STAR in polarized p+p collisions at $\sqrt{s}$ = 510 GeV in June 2017.
- RHICf detector was installed in front of the ZDC.
- Large p_T coverage ($0 < p_T < 1$ GeV/c) by moving the detector up and down.

Neutron measurement

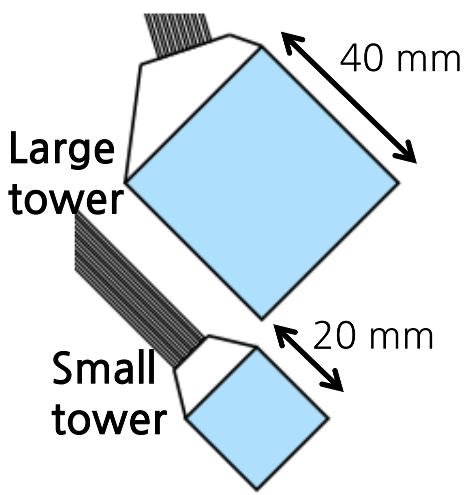
Side view



Shower trigger



Front view

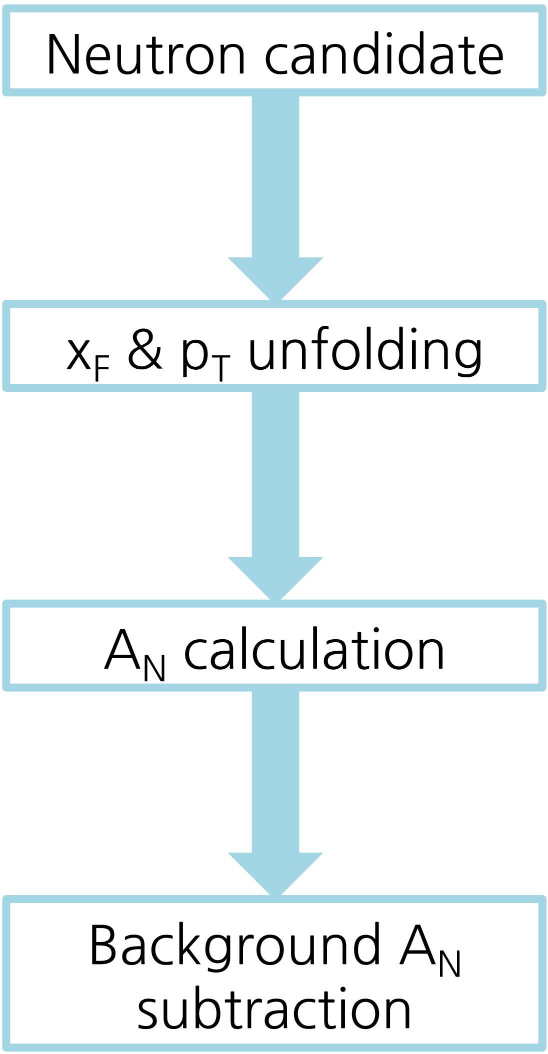


- 17 tungsten absorbers (44 X_0, 1.6 λ_{int}), 16 GSO plates, and 4 layers of GSO bar hodoscope (1 mm interval).
- Shower trigger: Energy deposits of any three successive layers are larger than 45 MeV.

→ Unfolding

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

Analysis procedure



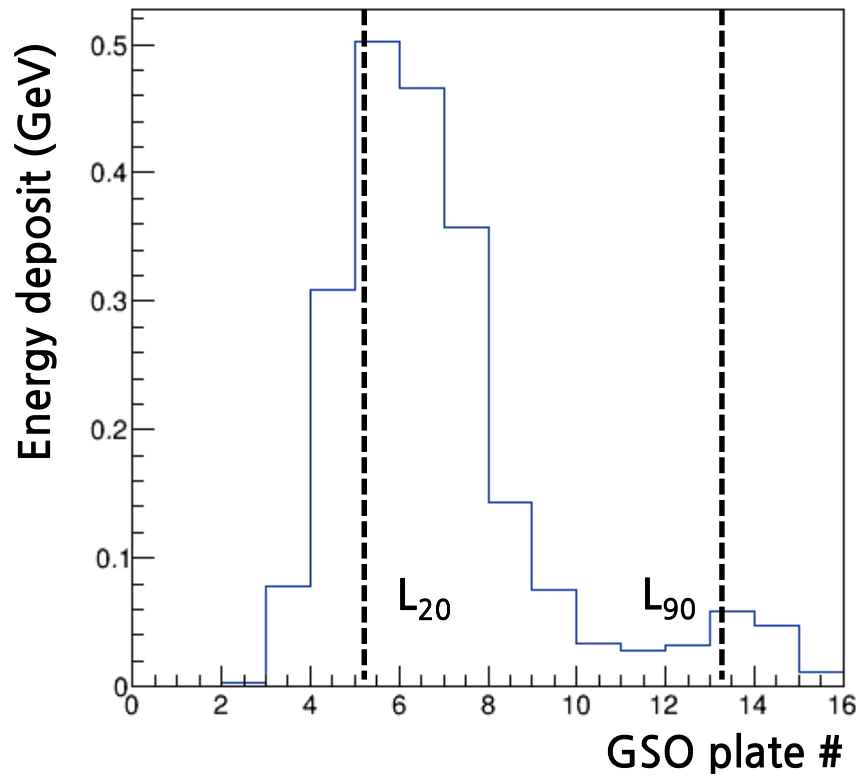
Neutron photon separation

Neutron candidate

x_F & p_T unfolding

A_N calculation

Background A_N subtraction



- L_{20} and L_{90} is defined by the longitudinal depth of the detector where the accumulated energy deposit reaches 20% and 90% of the total amount.

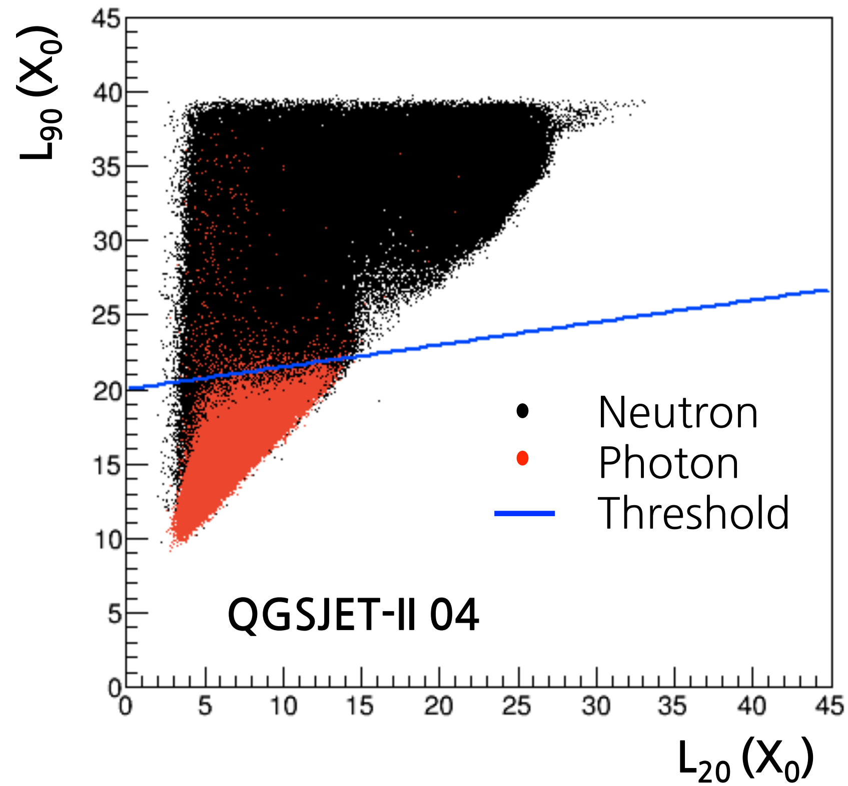
Neutron photon separation

Neutron candidate

x_F & p_T unfolding

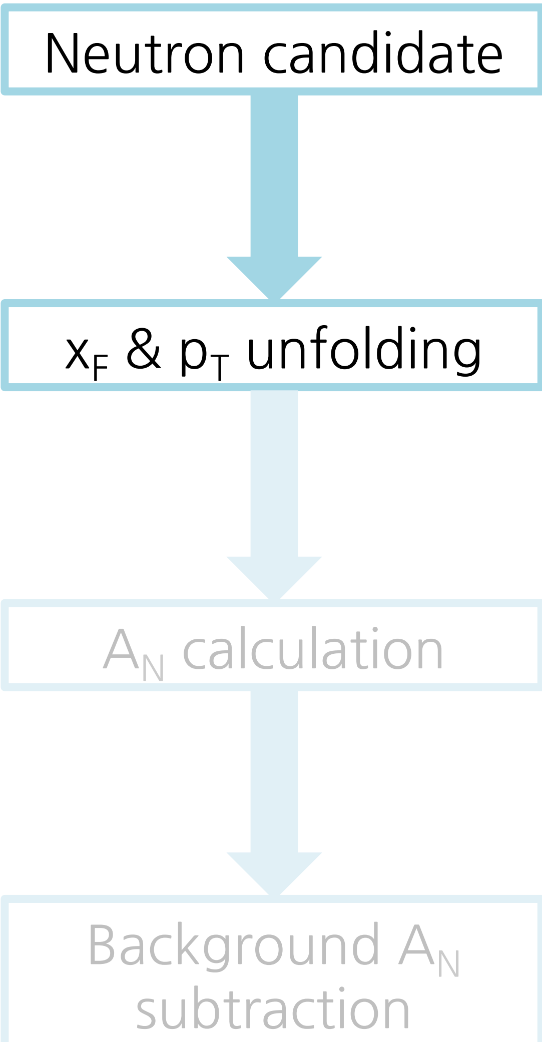
A_N calculation

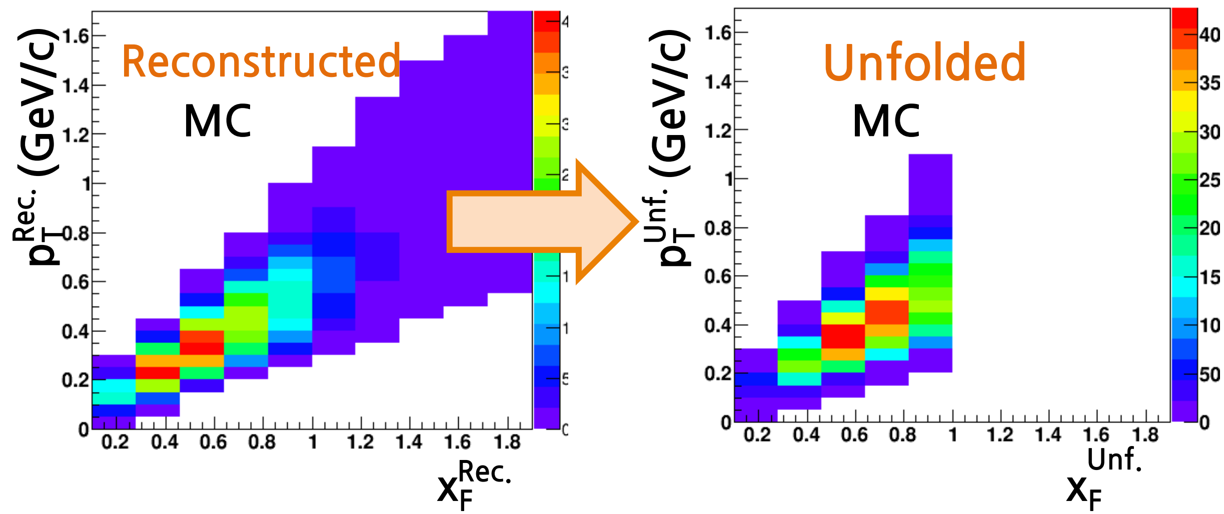
Background A_N subtraction



- The blue line threshold was optimized taking into account the neutron purity and efficiency.

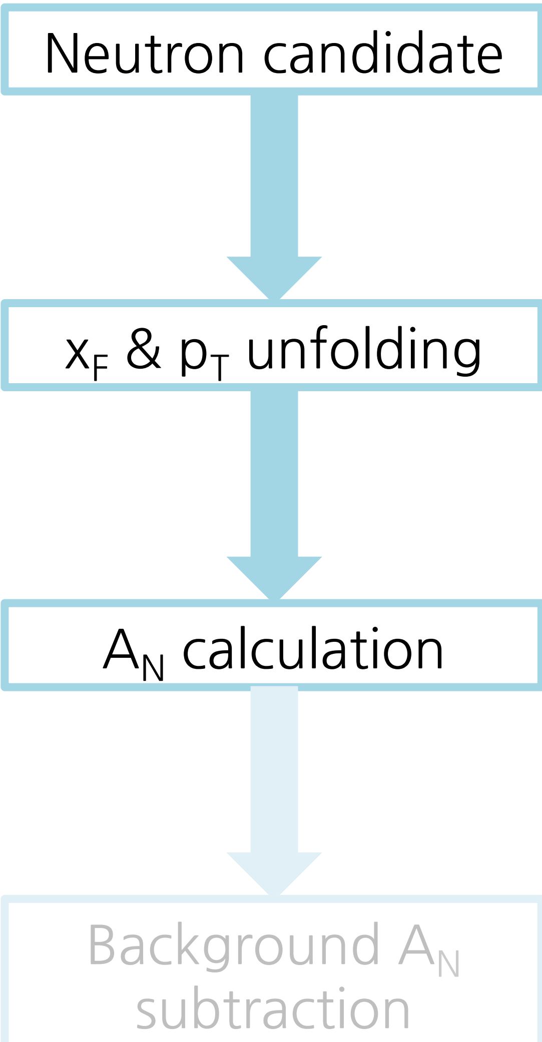
Neutron photon separation

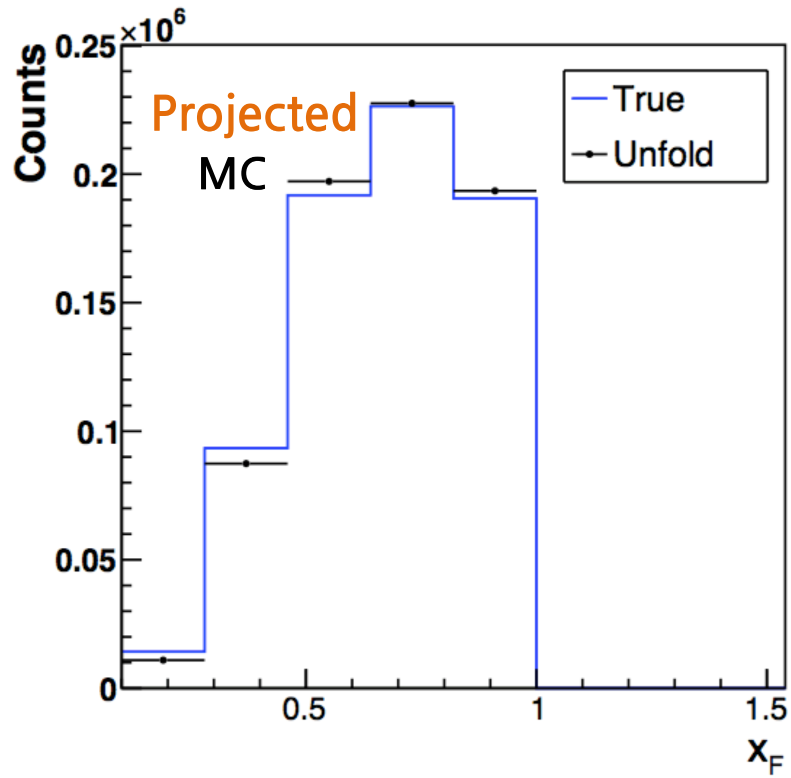




- Bayesian unfolding was used to unfold the x_F and p_T distribution.
- To build the response matrix, neutrons with randomized energy were uniformly generated to the detector.

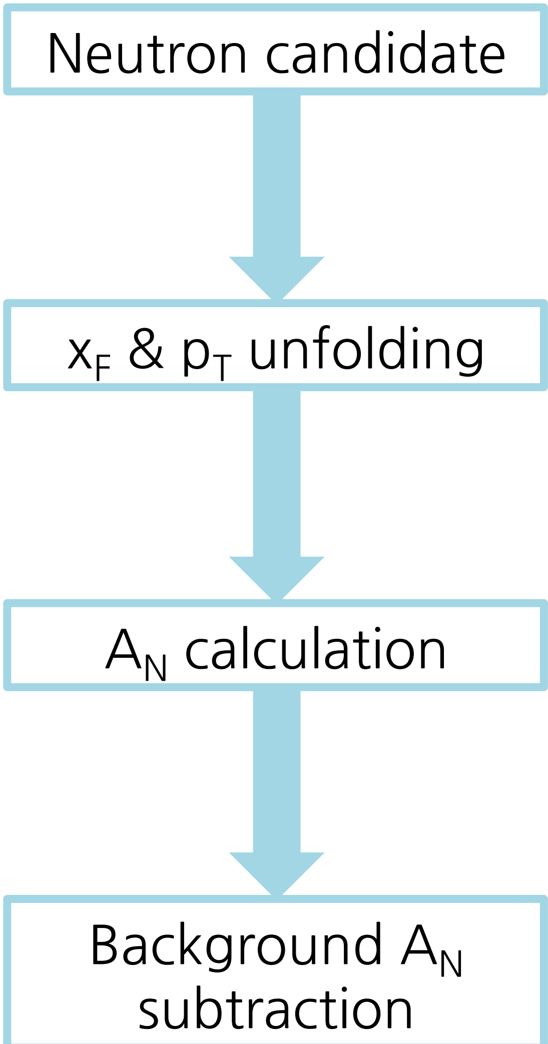
Neutron photon separation

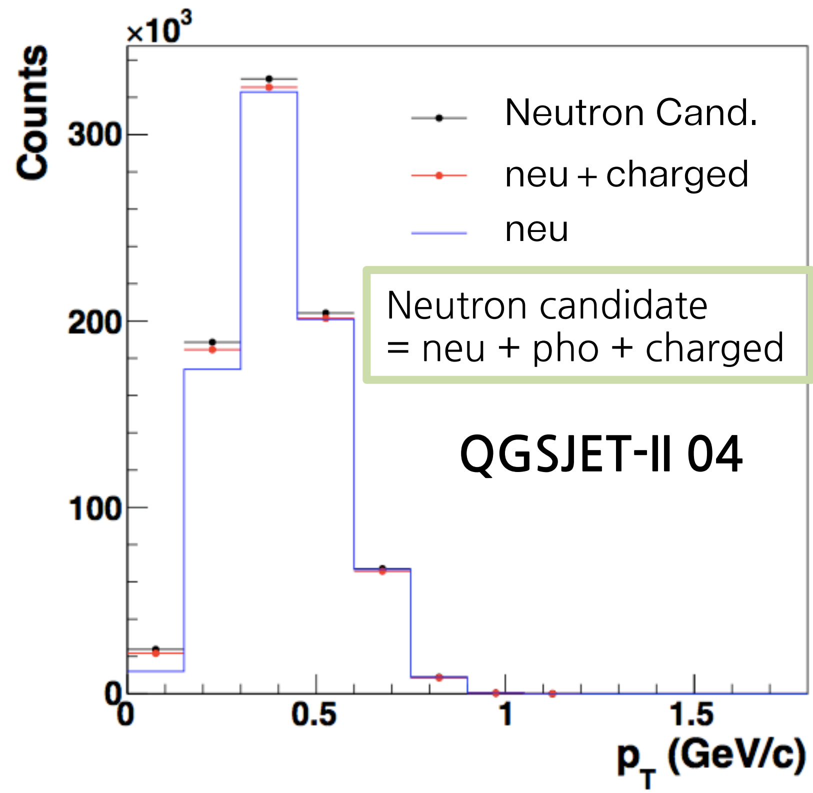




- We can calculate the A_N because the unfolded x_F and p_T distribution is provided for both spin up and down events.

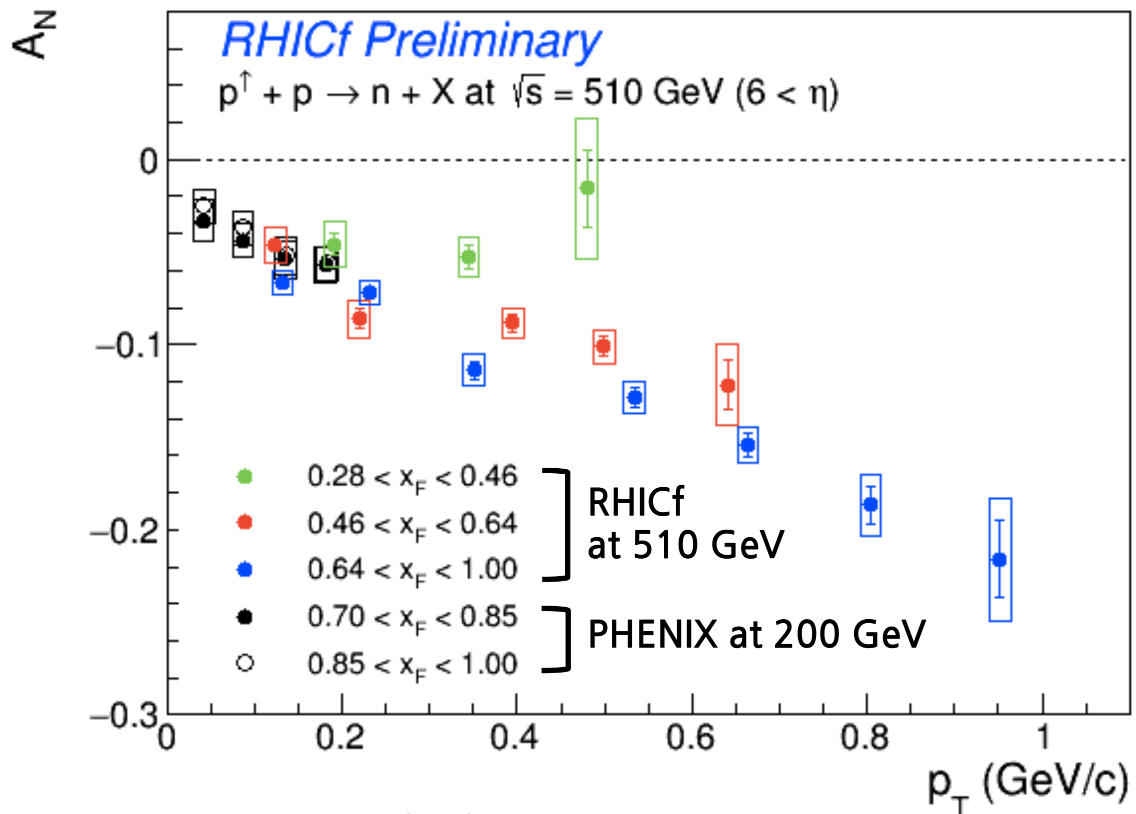
Neutron photon separation





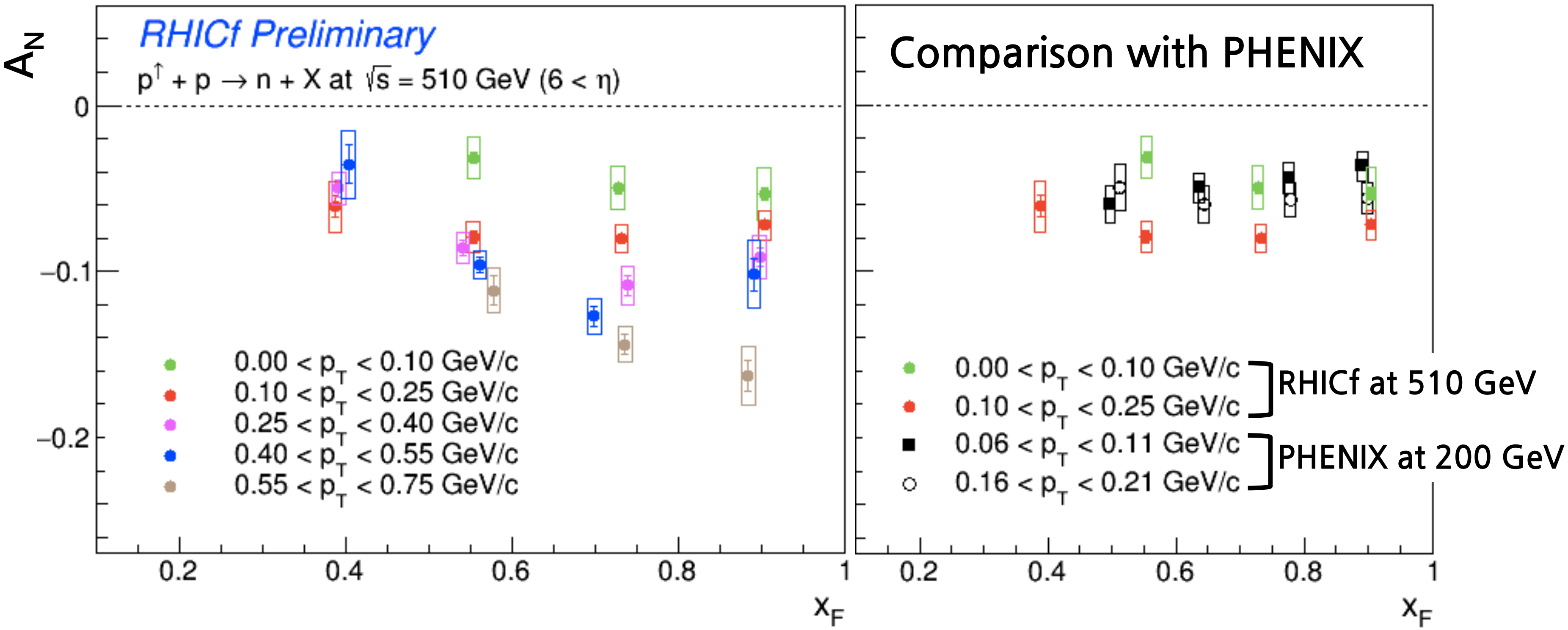
- In this analysis, neutron event also includes the neutral hadron (Λ~5%, K<1%, ...).
- To estimate the background fractions, three QGSJET-II 04 samples were unfolded.

Neutron A_N as a function of p_T



- RHICf data is consistent with the PHENIX one.
- In $x_F > 0.46$, the A_N increases in magnitude with p_T.
- There seems a gap between different x_F ranges.

Neutron A_N as a function of x_F



- In $p_T < 0.25$ GeV/c, the A_Ns are flat showing no x_F dependence which is consistent with the PHENIX data.
- In $p_T > 0.25$ GeV/c, a clear x_F dependence is seen.
- This result will be finalized with more precise background estimation especially on the charged hadron event.

Summary

- RHICf experiment measured the very forward neutron A_N in a wide p_T coverage ($0 < p_T < 1$ GeV/c).
- In $x_F > 0.46$, the neutron A_N increases in magnitude with p_T as the model predicted.
- A clear x_F dependence was observed in $p_T > 0.25$ GeV/c.
- Final result will be released soon with more precise background estimation.

Backup