Measurement and analysis of the A_N for forward neutron production at RHICf

LHCf Collaboration Meeting

Oct 16

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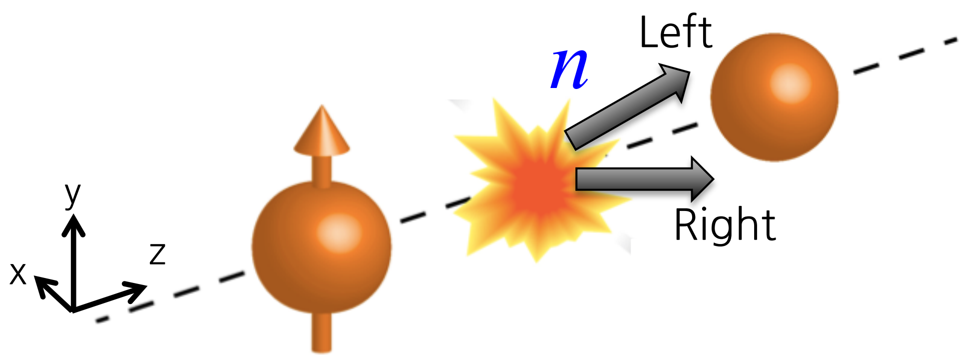
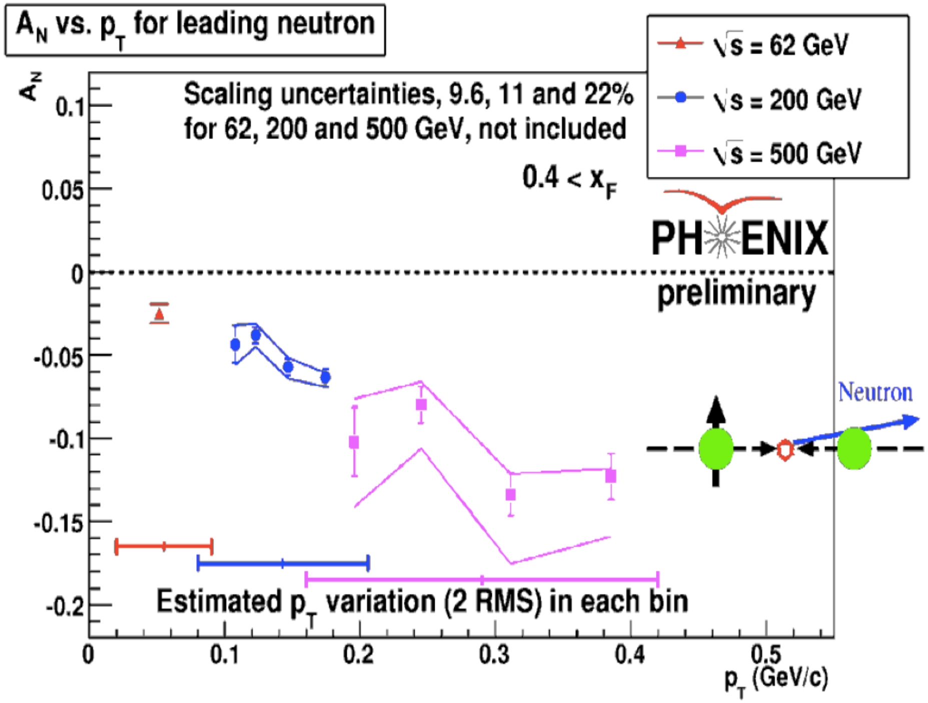
Transverse single-spin asymmetry (A_N)



- In the polarized p+p collision, the A_N is defined by a left-right cross section asymmetry of a specific particle or event.
- The RHICf experiment measured the A_N of the forward neutron produced in $\eta > 6$ and $p_T < 1$ GeV/c.
- A_N of the forward particle is especially important to study the particle production mechanism in the regime where the pQCD is not applicable.

A_N for forward neutron production

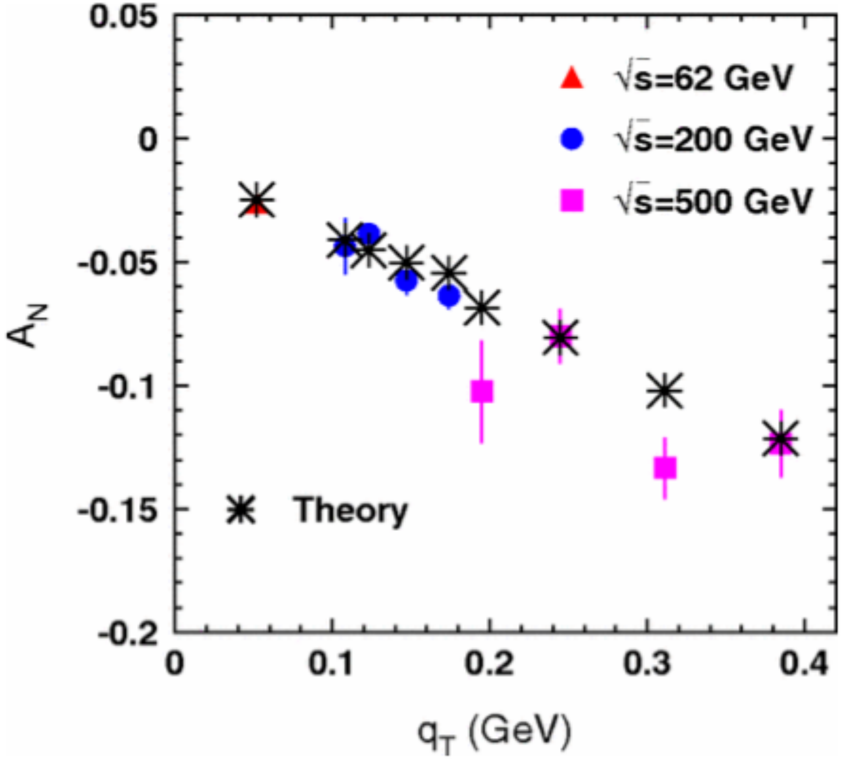
K. Tanida et al., J. Phys. Conf. Ser. 295 (2011) 012097



- Non-zero A_N for forward neutron production was first observed by the IP12 experiment at RHIC. Y. Fukao et al., PLB 650 (2007) 325
- Afterwards, the PHENIX measured the neutron A_N as a function of p_T with three different collision energies.
- The measurement results showed a possible p_T dependence of the neutron A_N.

Theoretical model

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



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

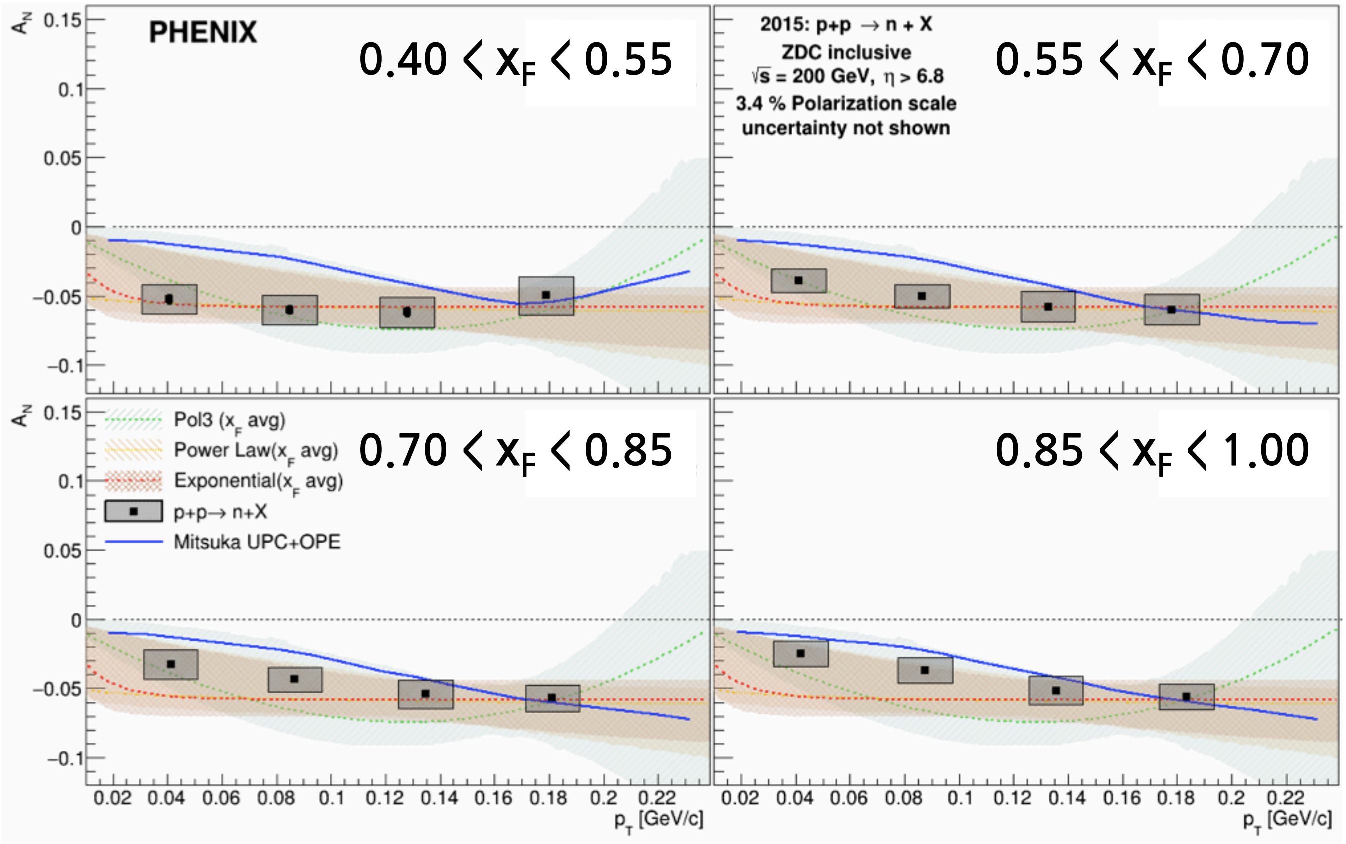
π exchange: spin flip

a_1 exchange: spin non-flip

- Neutron A_N was explained by an interference between the spin flip and spin non-flip exchange leading to non-zero phase shift.
- The π and a_1 exchange model showed that the neutron A_N increased in magnitude with increasing p_T with little $\sqrt{s}$ dependence.

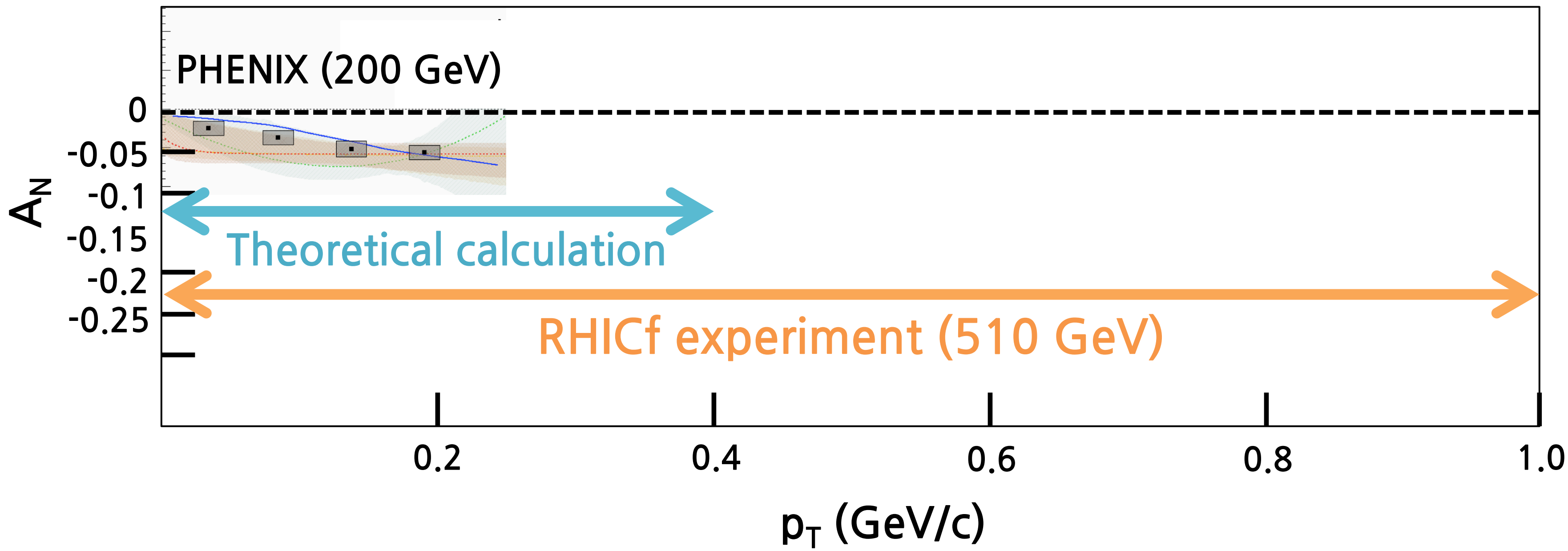
Unfolded neutron A_N at PHENIX

PHENIX, PRD 105 (2022) 032004



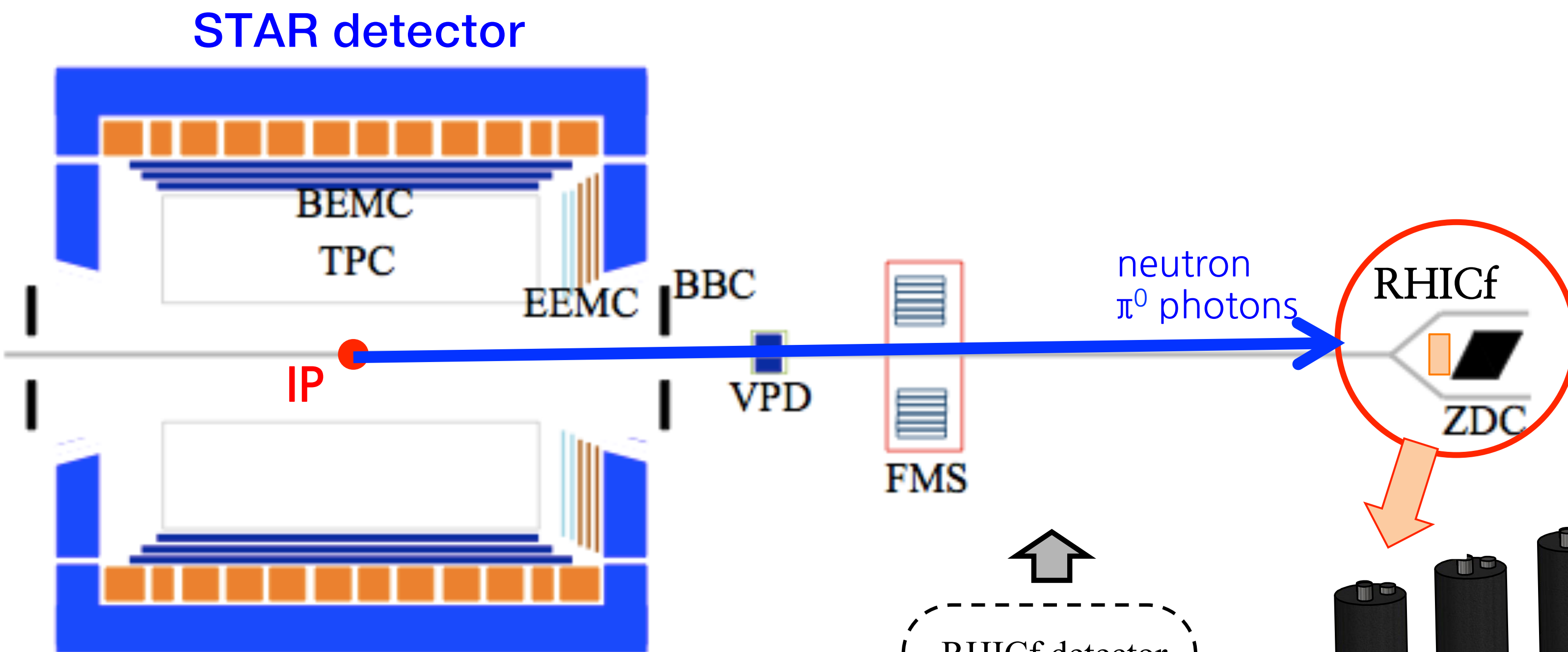
- Recently, p_T dependence of the PHENIX neutron A_N at $\sqrt{s}$ = 200 GeV was obtained by unfolding the data.
- The unfolded data showed the same tendency with the model calculations.

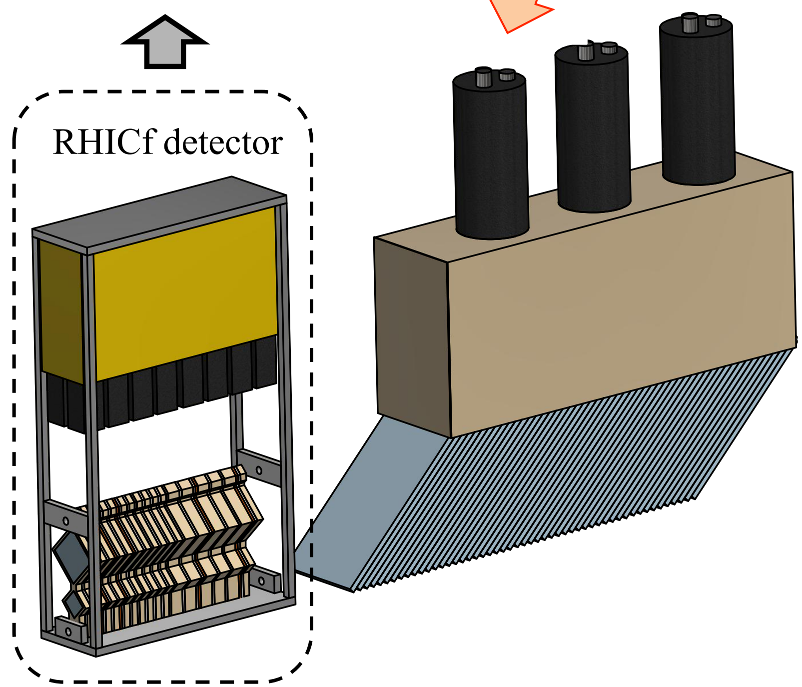
Neutron A_N measurement at RHICf



- RHICf experiment has extended the previous measurements up to 1 GeV/c to study the kinematic dependence of the neutron A_N in more detail.
- We used a detector with one order of better position resolution (1 cm → 1 mm).
- We can also study the $\sqrt{s}$ dependence of the neutron A_N by comparing the RHICf data with that of PHENIX.

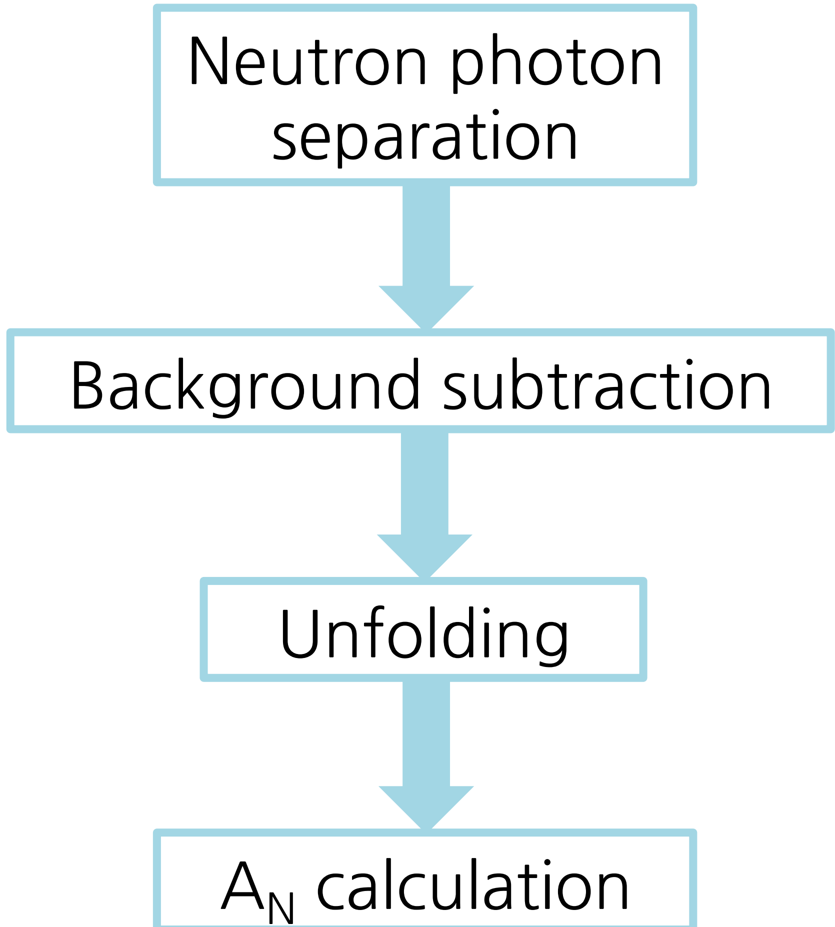
RHICf experiment



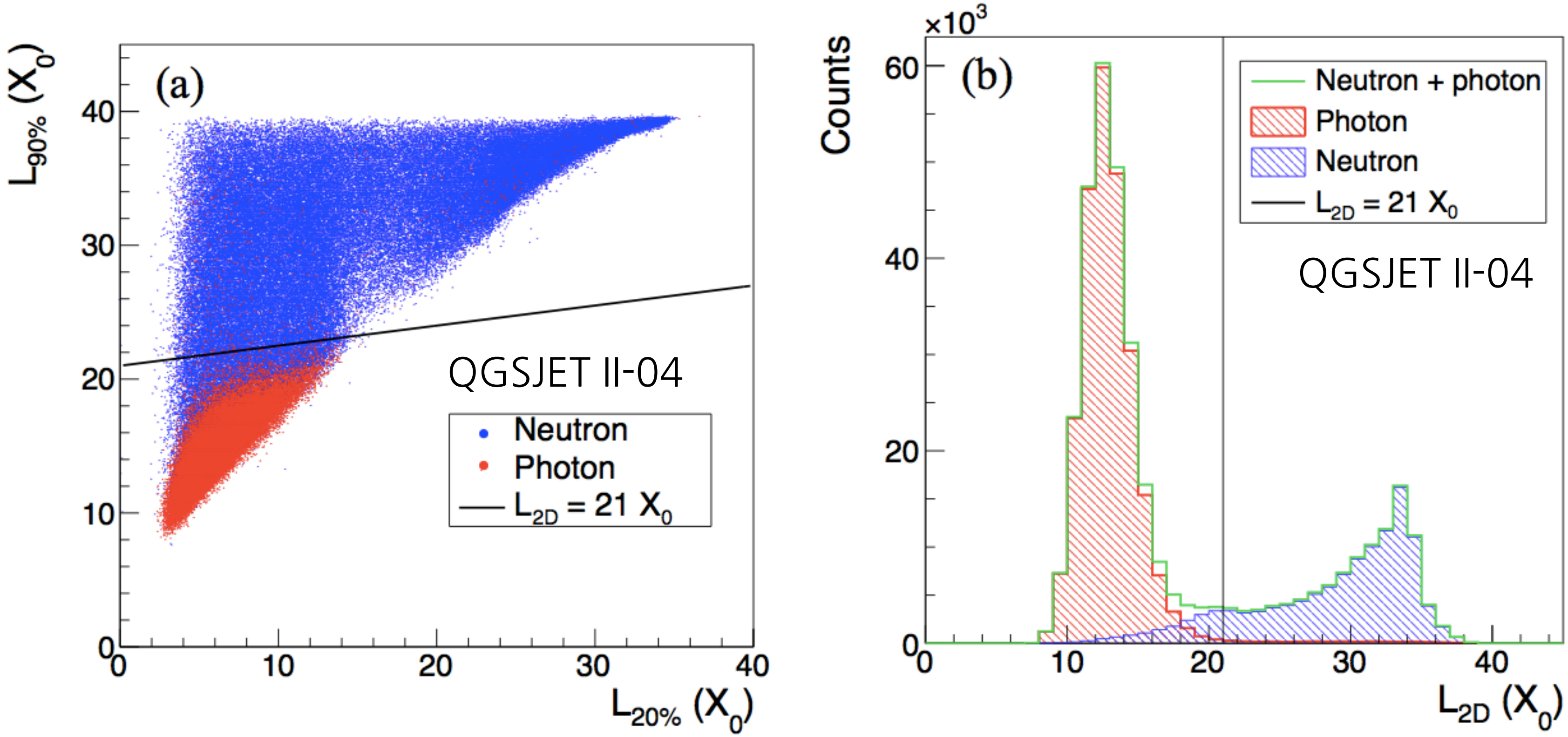


- Operated at STAR in polarized p+p collisions at $\sqrt{s}$ = 510 GeV in June 2017.
- Arm1 detector was installed in front of the ZDC.
- Large p_T coverage ($0 < p_T < 1$ GeV/c) by moving the detector vertically.

Analysis flow



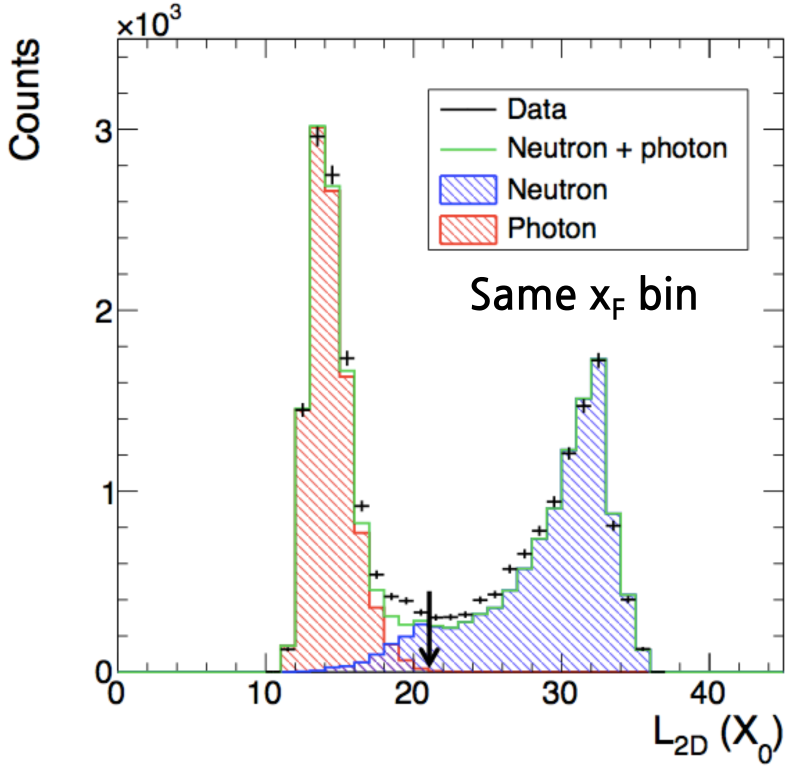
Neutron photon separation

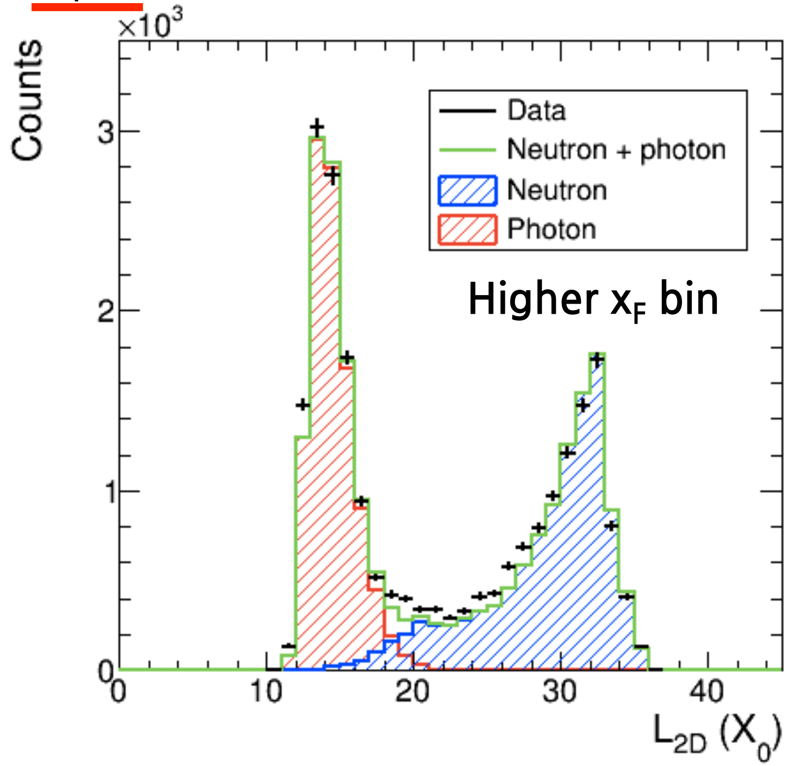


- An event was considered as a neutron if $L_{90\%} > aL_{20\%} + b\ X_0$.
- Among "a" and "b" values that made the neutron purity higher than 99%, they were optimized so that (purity) x (efficiency) had a maximum value.
- The optimized "a" and "b" are 0.15 and 21, respectively, thereby the L_{2D} was defined as $L_{90\%}$ - $0.15L_{20\%}$.

Photon background subtraction

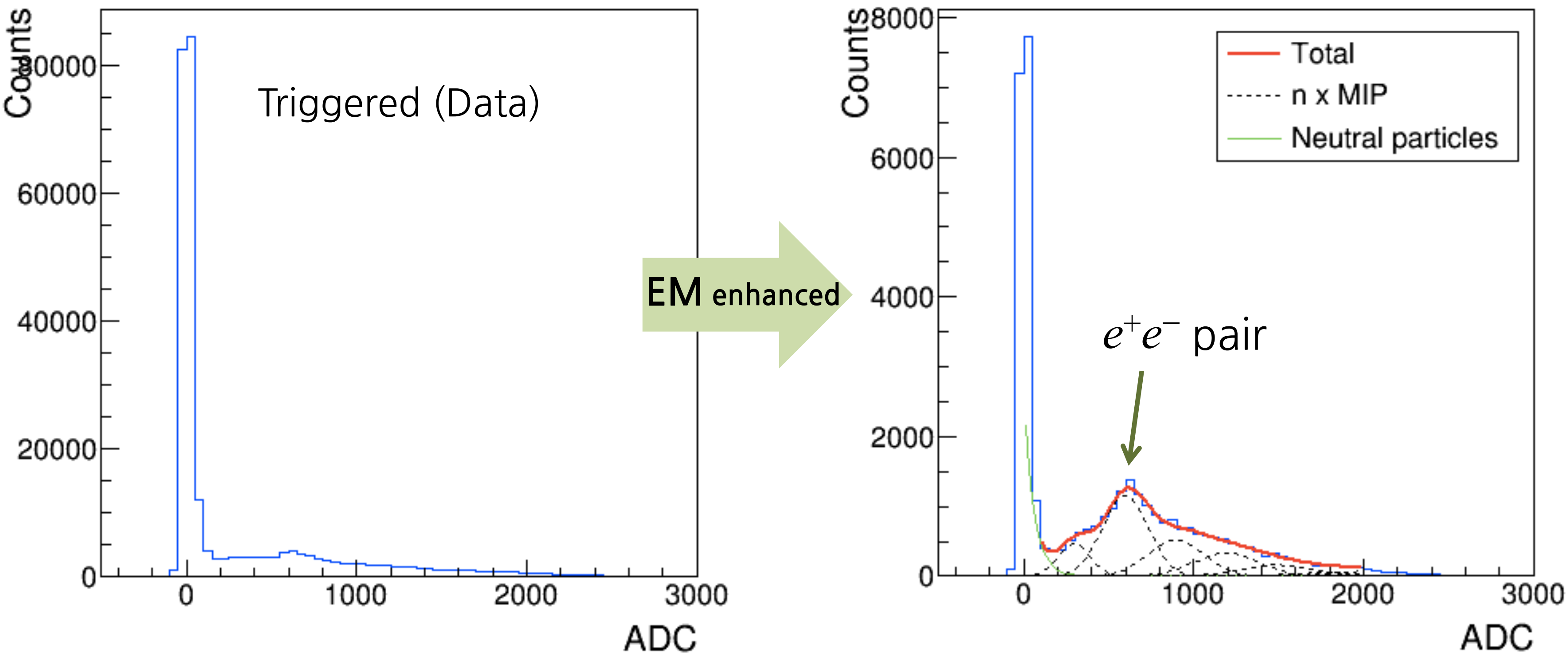
$N_{trig} = N_{neu} + N_{pho} + N_{cha}$





- To estimate and subtract the photon contamination, a template fit was performed to the L_{2D} distribution.
- To study effect of the discrepancy between the MC and data, the template fit was performed again using the template of the higher x_F bin.
- A_N difference after unfolding between the two methods was negligible, which was less than 0.0007. → No systematic uncertainty was assigned.

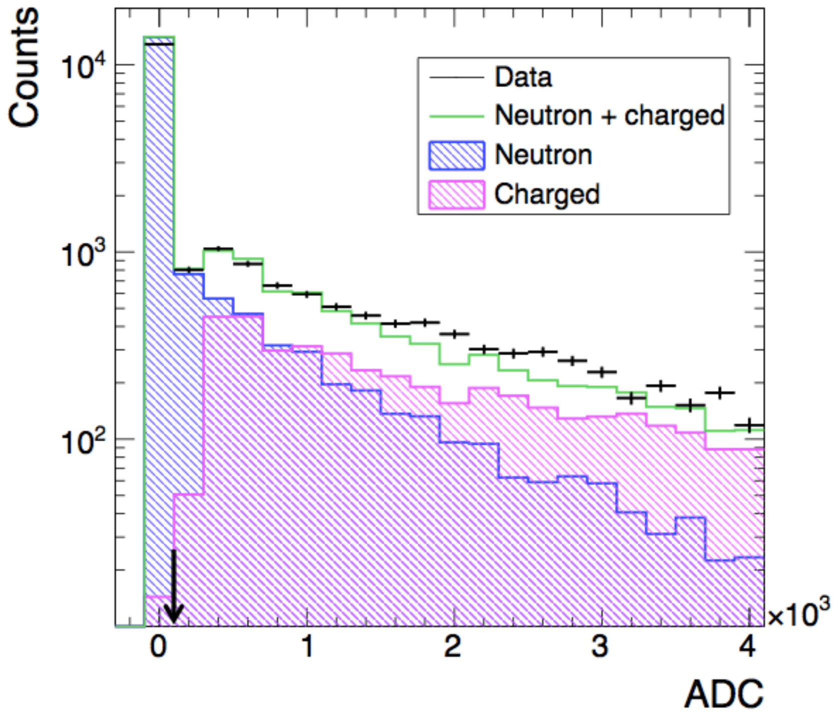
Reproduction of the front counter response



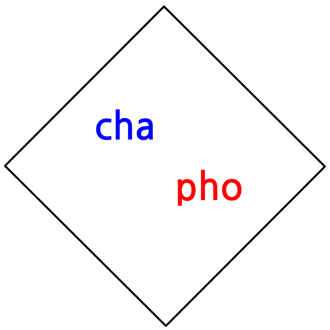
- To fit the front counter ADC distribution, EM events were enhanced.
- The ADC distribution was fitted by assigning free parameters to MIP mean, MIP sigma, and number of events of n x MIP distributions.

Charged background subtraction

$N_{trig} = N_{neu} + N_{pho} + N_{cha}$



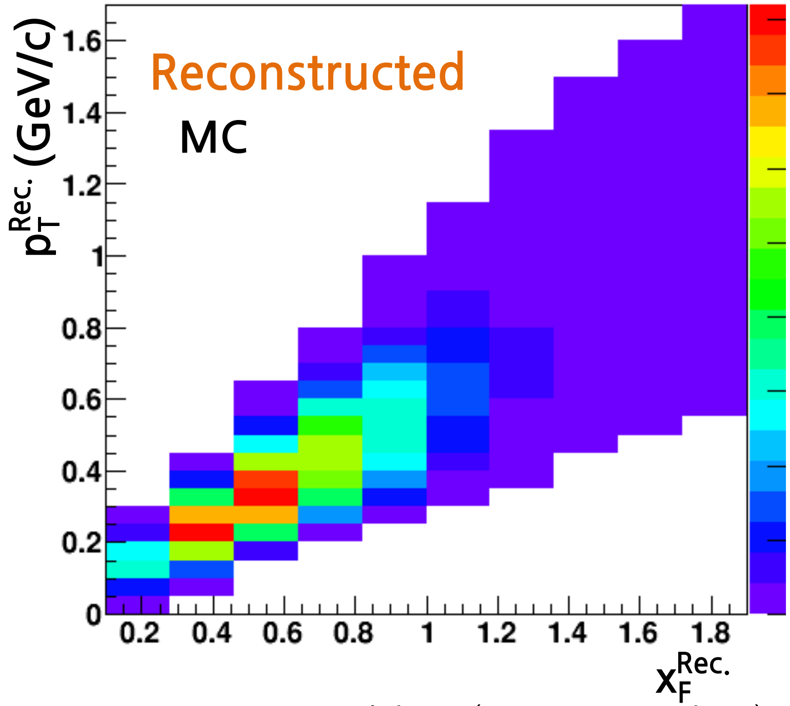
If every charged hadron event includes at least one photon on the detector,

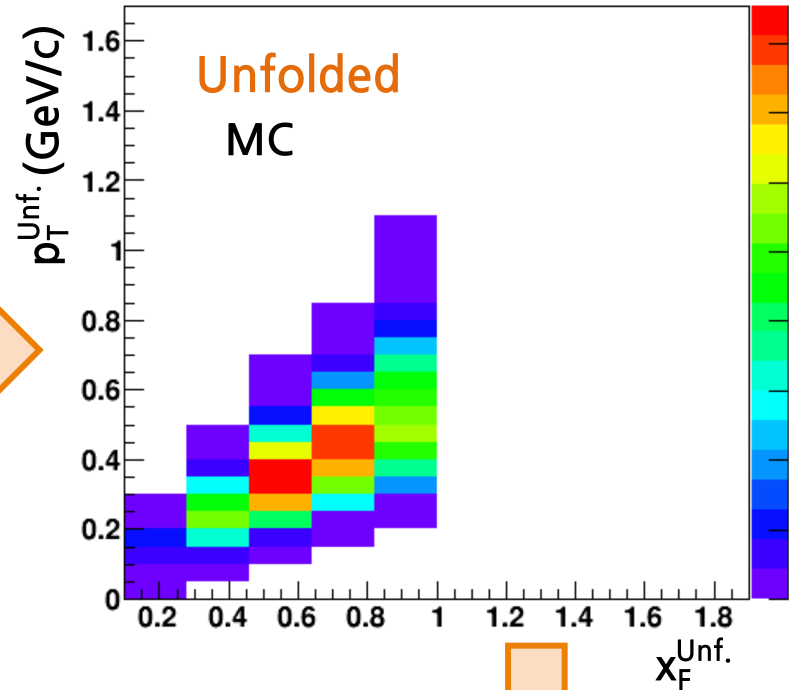


only the photon contamination needs to be subtracted because $N_{cha} < N_{pho}$.

- To estimate and subtract the charged contamination, another template fit was performed to the front counter ADC distribution.
- According to QGSJET II-04, less than 5% of the charged hadron event has photon. → Photon and charged contaminations were subtracted separately.
- There is almost no difference in the resulting A_N (< 0.0004) even if only one contamination was subtracted. → No systematic uncertainty was assigned.

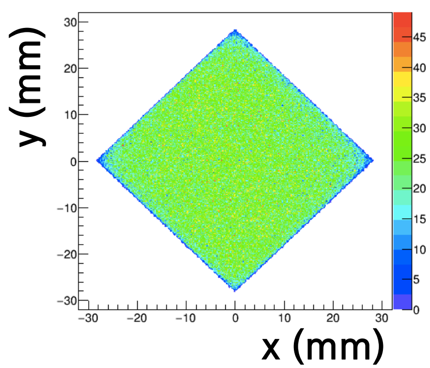
Unfolding

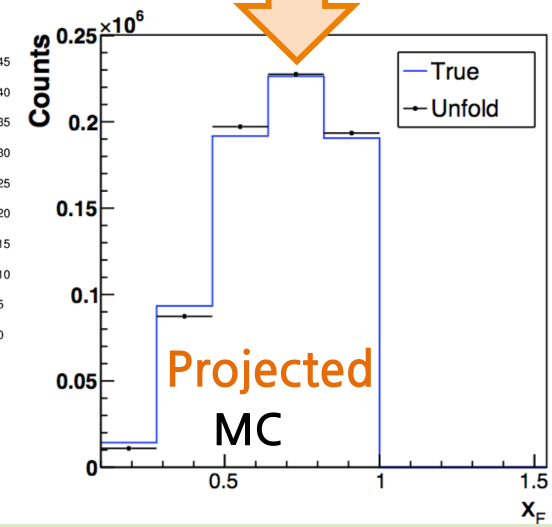




- Kinematic variables (x_F, p_T, and Φ) of neutrons were unfolded by Bayesian unfolding.

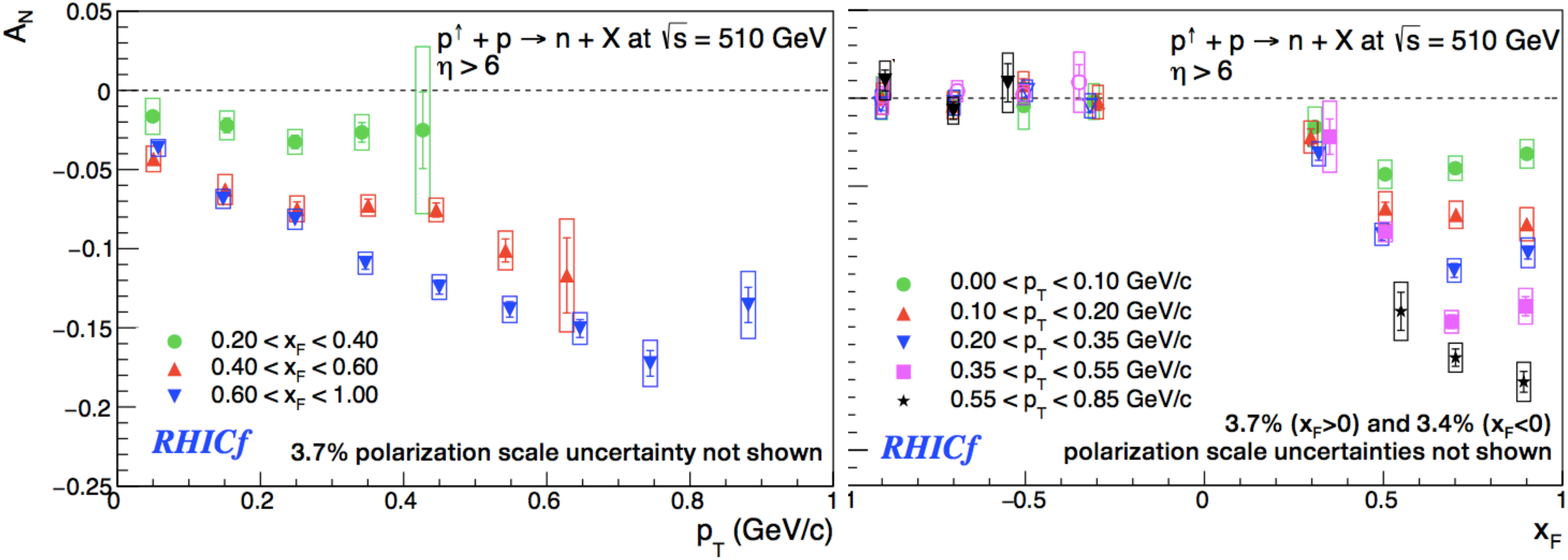
- For input distribution, neutrons were uniformly generated to the detector.





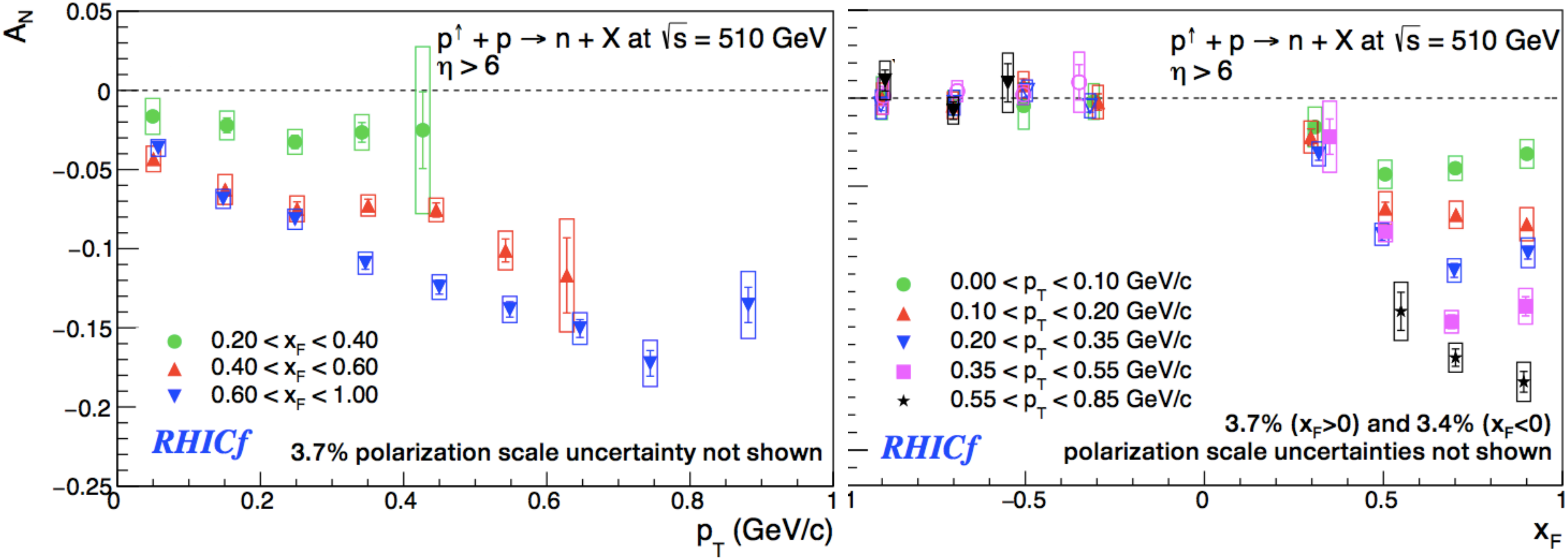
- Spin up and down kinematic spectra were unfolded separately. The iteration was proceeded until $\Delta\chi^2 < 1$.

Results



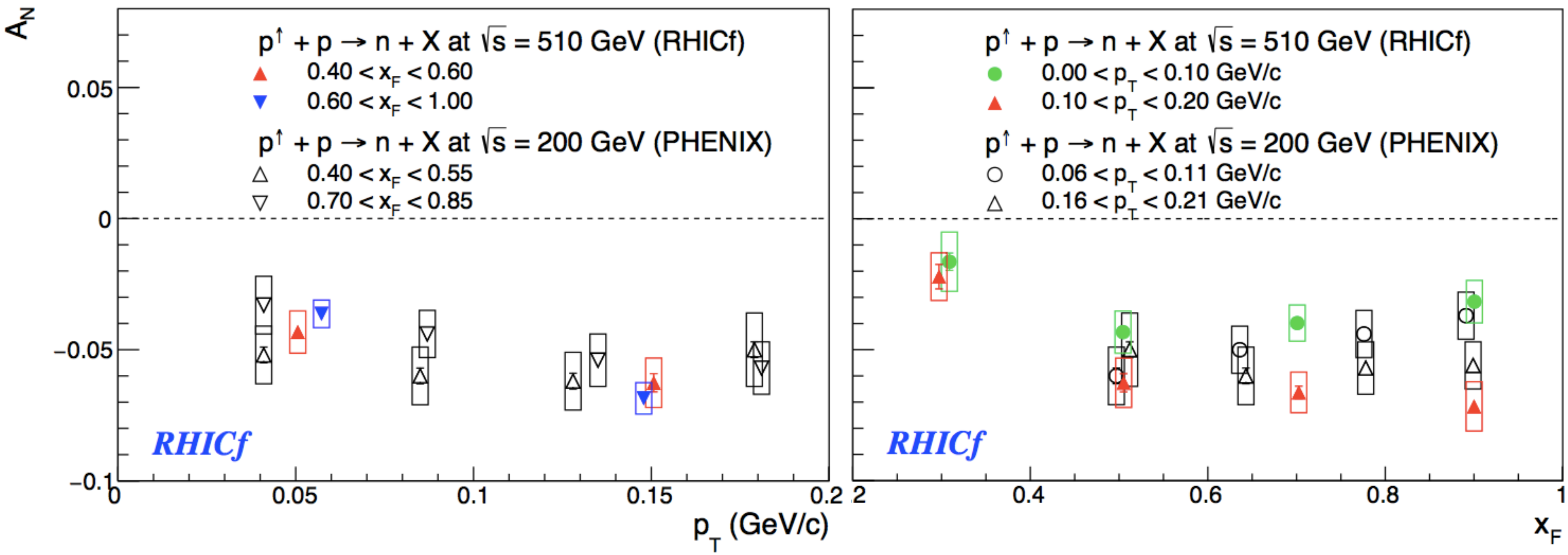
- Systematic uncertainties of unfolding and beam center calculation processes were included in the final data points.
- In the low x_F range, the neutron A_N reaches a plateau at low p_T.
- In the high x_F range, the A_N doesn't seem to reach the plateau yet, but we can confirm that the A_N explicitly increases in magnitude with p_T.

Results



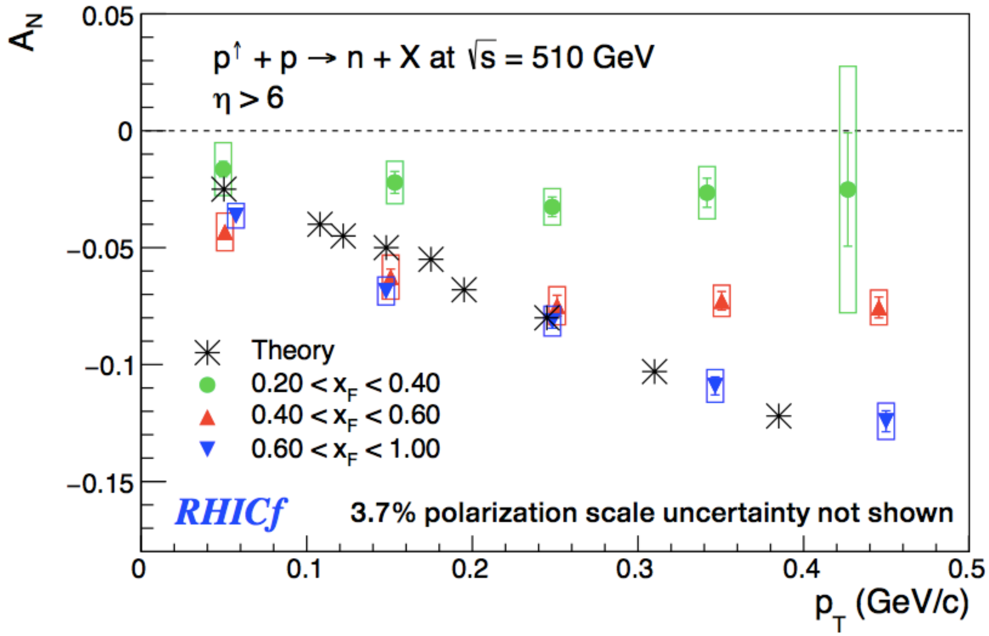
- Systematic uncertainties of unfolding and beam center calculation processes were included in the final data points.
- In the low p_T range, the A_N reaches a plateau at low x_F with little x_F dependence.
- In the high p_T range, the A_N reaches a higher plateau at higher x_F with a clear x_F dependence.

Comparison with the PHENIX data



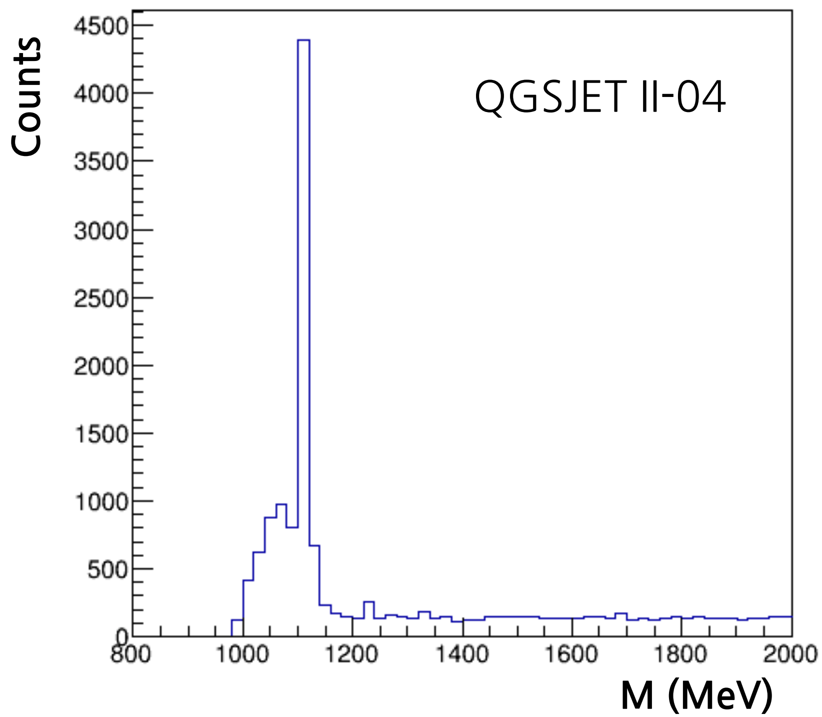
- The RHICf results are consistent with of those of PHENIX in general.
- In the range of $x_F > 0.4$ and $p_T < 0.2$ GeV/c, the consistency suggests that there is no $\sqrt{s}$ dependence in the neutron A_N.

Comparison with the theoretical calculation



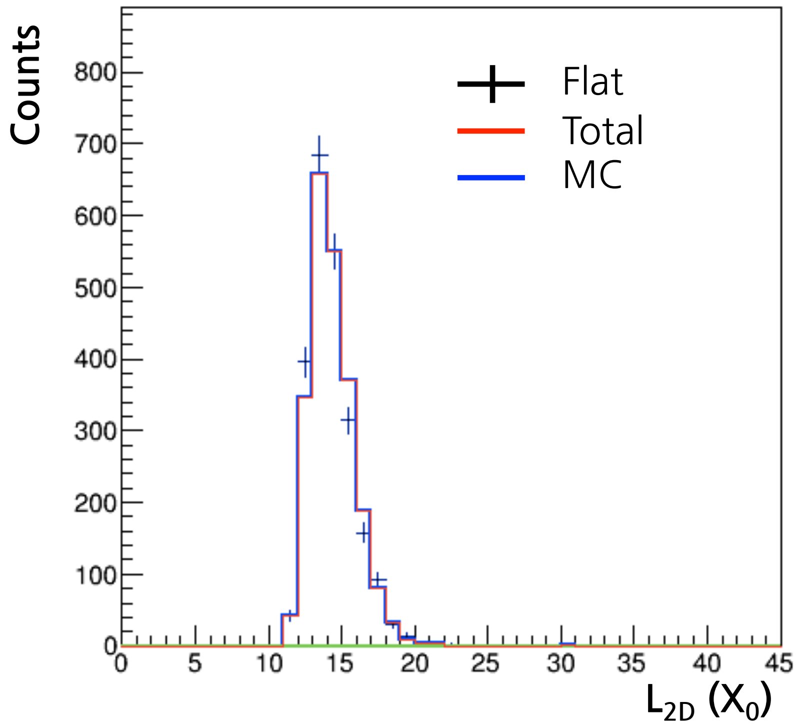
- In the high x_F range, the A_Ns are mostly consistent with the model calculation.
- However, the model doesn't reproduce the A_Ns in the low x_F ranges because of the x_F dependence.
- More comprehensive theoretical considerations, e.g., the absorptive correction and other Reggeon exchanges like ρ and a_2, are necessary to explain the present results.

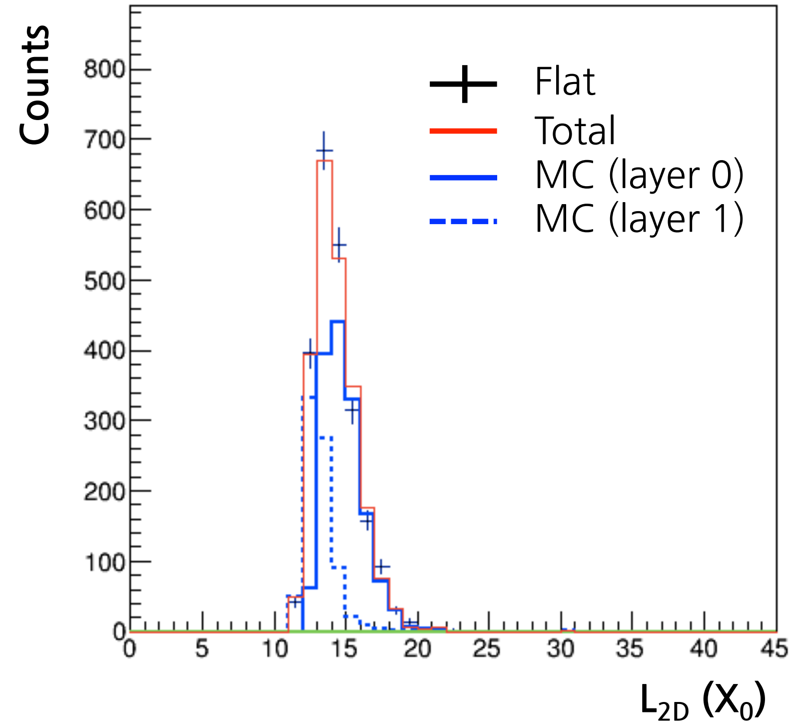
Next target: Λ reconstruction



- A neutron at ZDC acceptance and two photons at RHICf detector showed a clear Λ peak → We expect that we can reconstruct Λ with ZDC or RHICf only.
- Feasibility of the Λ reconstruction (the lowest photon energy, opening angle, and so on) is now under way.

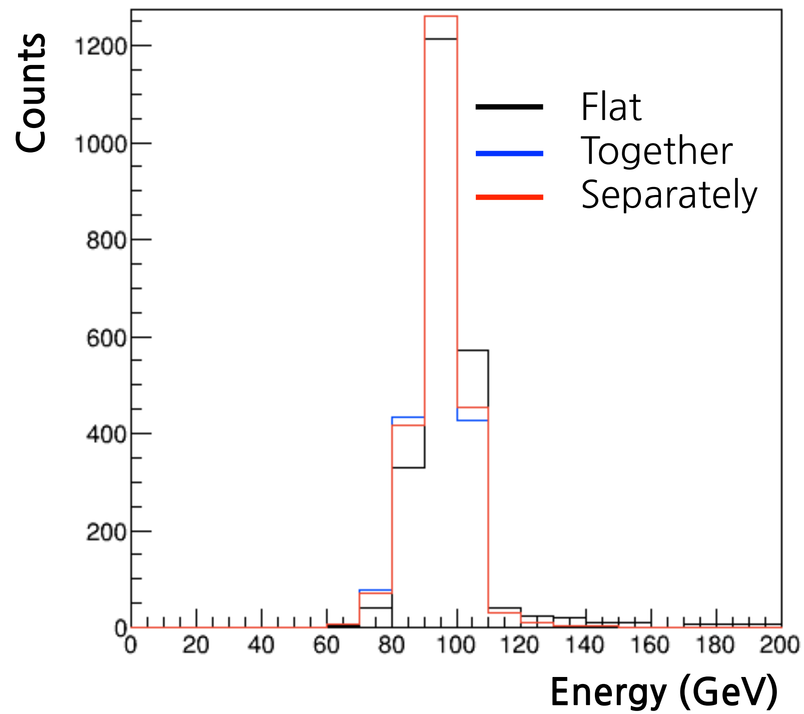
Improvement of the L_{2D} template fit





- To study a possible improvement of the template fit, a flat photon distribution was generated assuming it was real data as a test.
- Since energy distributions of MC and data are not completely the same, the L_{2D} distributions are also not.
- If we scale the lower and higher energy parts separately, we can better reproduce the true L2D distribution

Improvement of the L_{2D} template fit



- When the lower and higher energy distributions are scaled separately, it also better reproduces the original energy distribution.
- The whole energy spectrum will also be compared.