Very forward particle measurement at RHIC

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on behalf of the RHICf Collaboration

RIKEN's Programs for Junior Scientists

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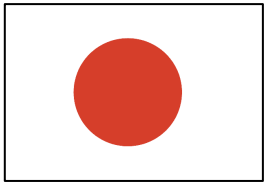
2nd International Workshop on Forward Physics
and Forward Calorimeter Upgrade in ALICE

RHIC forward (RHICf) experiment



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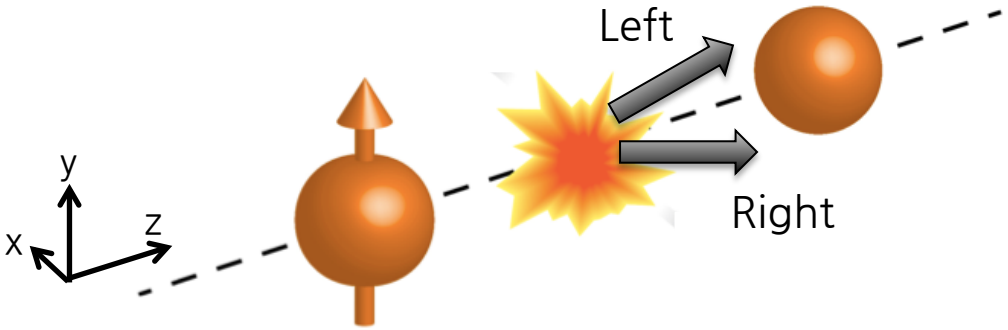
Korea Univ. (B. Hong), Sejong Univ. (Y. Kim, S. Oh, S. H. Lee)

INFN (O. Adriani, E. Berti, L. Bonechi, R. D'Alessandro, A. Tricomi)

- Cross section measurement to understand the origin of the ultra-high energy cosmic ray.
- Transverse single spin asymmetry measurement to study the spin-involved diffractive particle production mechanism.

Transverse single-spin asymmetry (A_N)

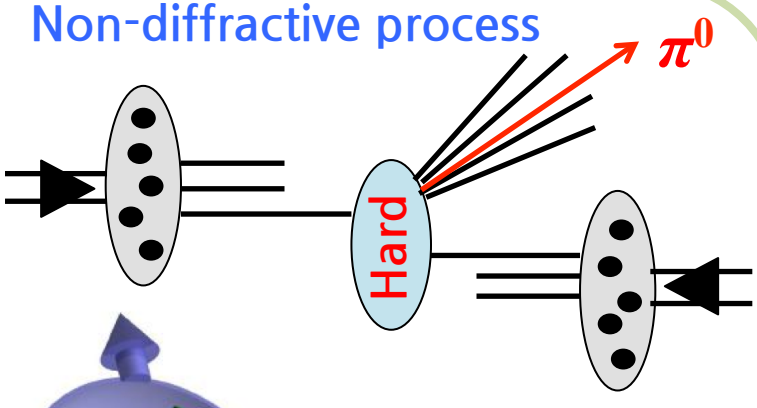


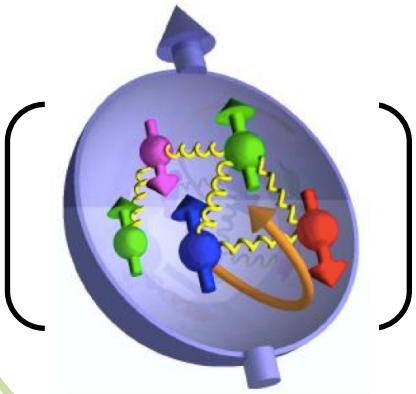
$$A_N = \frac{\sigma_L^{\uparrow} - \sigma_R^{\uparrow}}{\sigma_L^{\uparrow} + \sigma_R^{\uparrow}} = \frac{\sigma_L^{\uparrow} - \sigma_L^{\downarrow}}{\sigma_L^{\uparrow} + \sigma_L^{\downarrow}}$$

- In polarized p+p collision, A_N is defined by a left-right cross section asymmetry of a specific particle.
- In the p+p inelastic scattering, we can study two processes, the diffractive and non-diffractive processes.

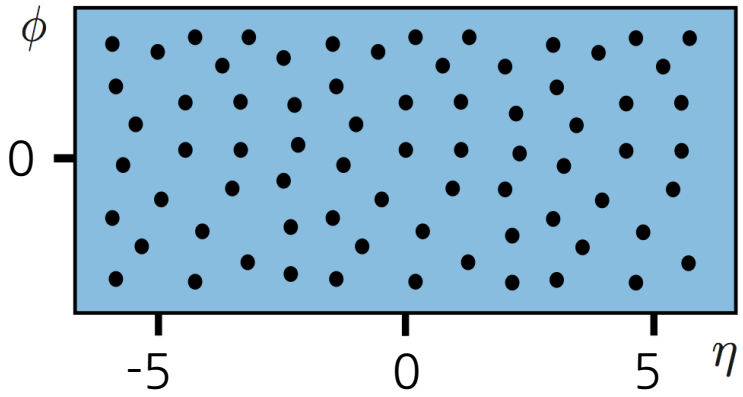
Non-diffractive Vs. Diffractive process

Non-diffractive process



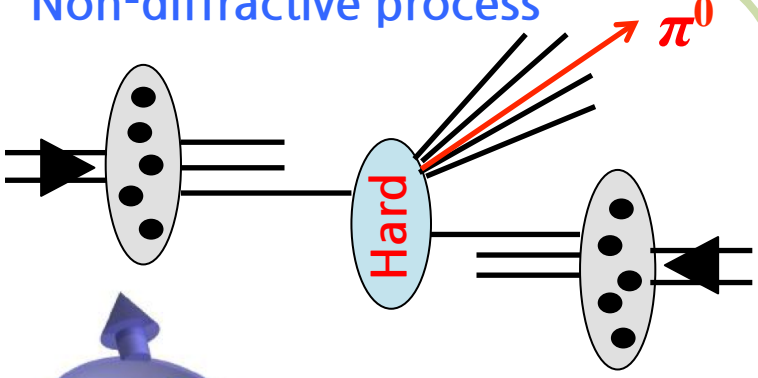


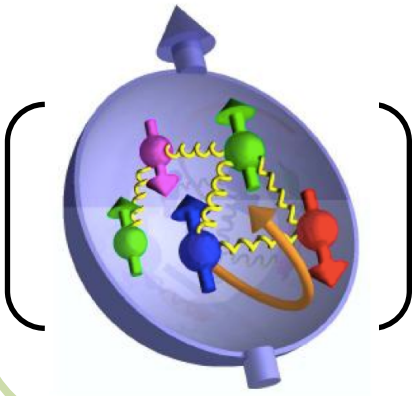
$p_T > 1$ GeV/c



Non-diffractive Vs. Diffractive process

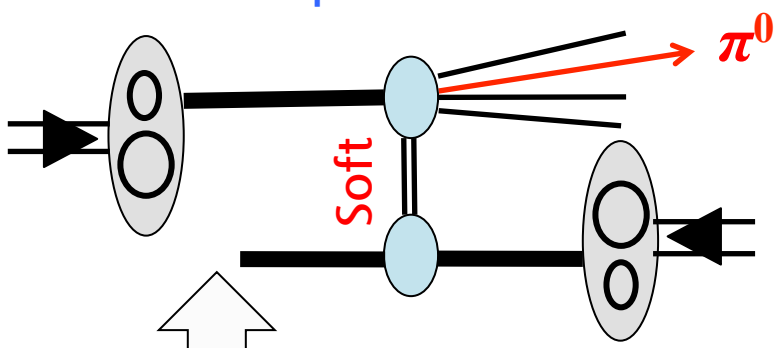
Non-diffractive process

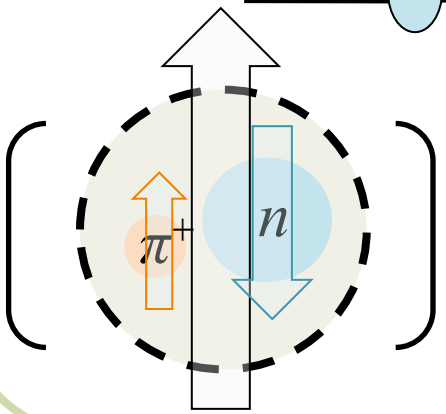




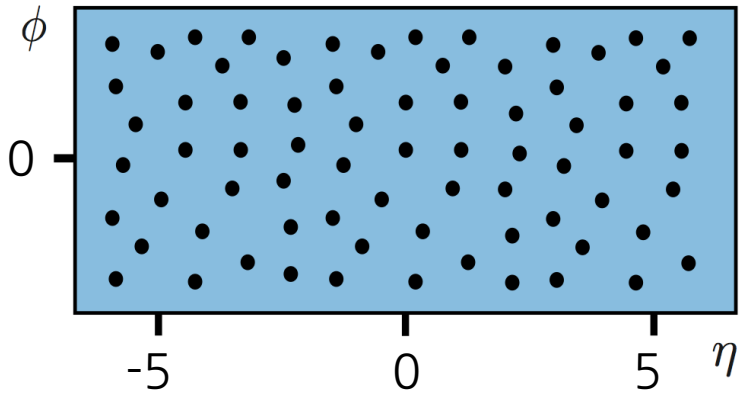
$p_T > 1$ GeV/c

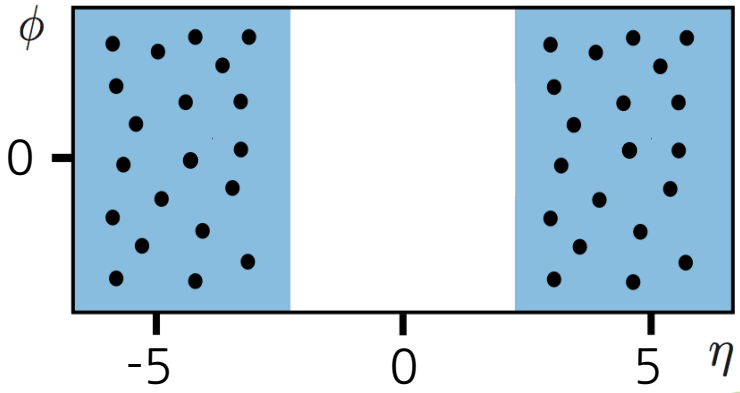
Diffractive process



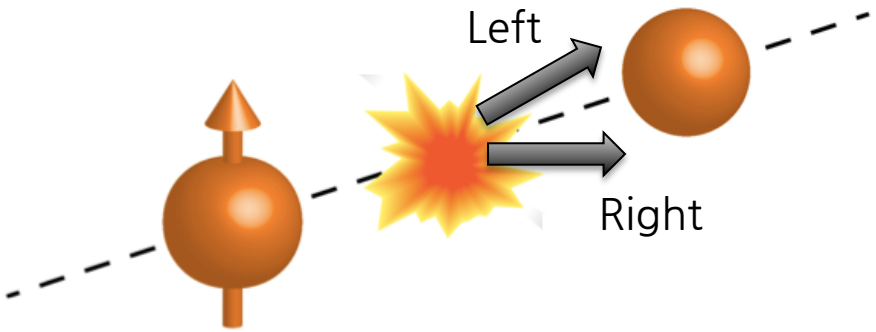


$p_T < 1$ GeV/c
$\eta > 6$





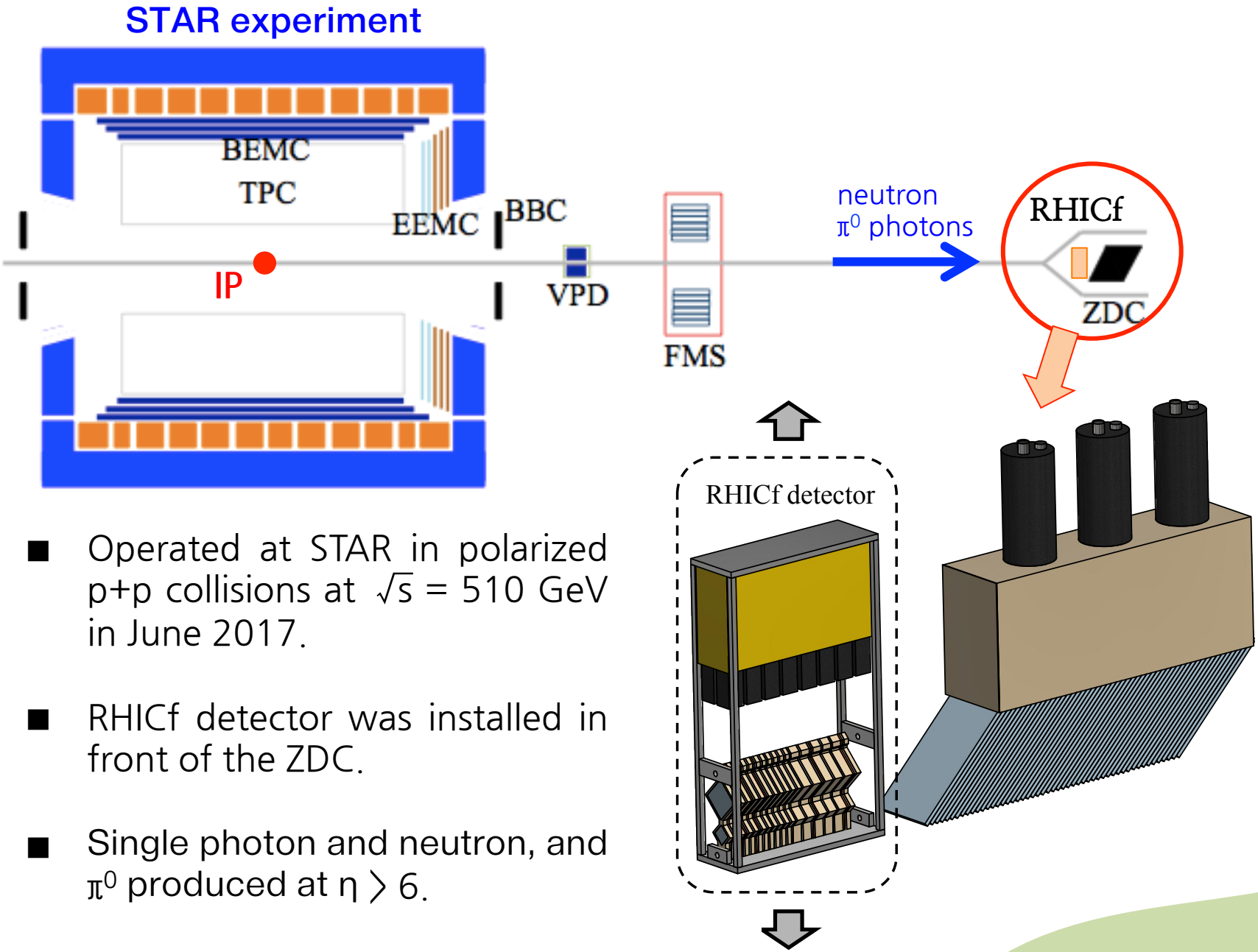
Transverse single-spin asymmetry (A_N)



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

- In polarized p+p collision, A_N is defined as a left-right cross section asymmetry of a specific particle.
- In the p+p inelastic scattering, we can study two processes, the diffractive and non-diffractive processes.
- A_N for very forward ($\eta > 6$) particle production allows us to study the spin-involved diffractive particle production mechanism.

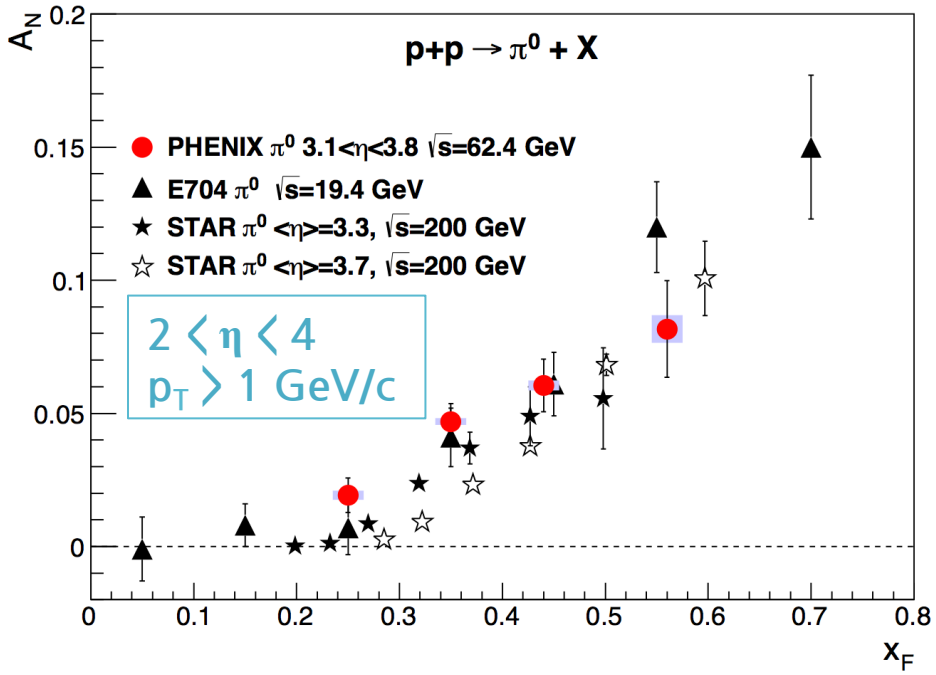
RHIC forward (RHICf) experiment

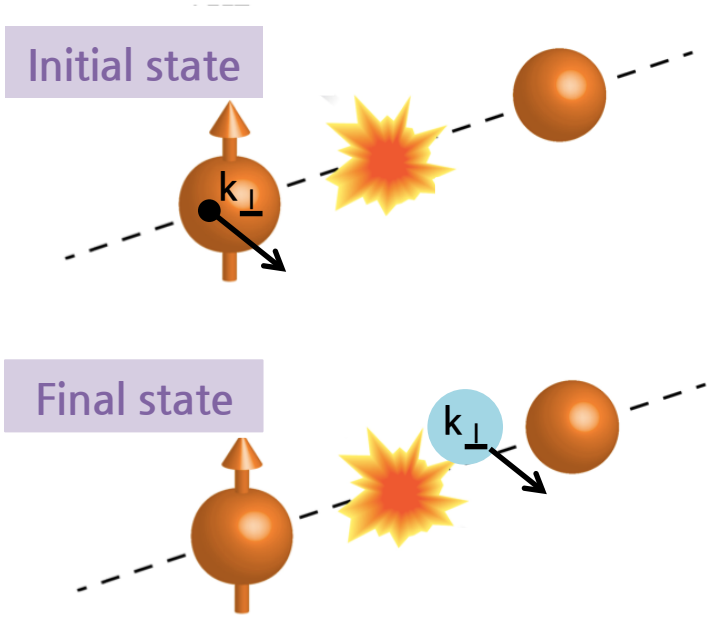


- Operated at STAR in polarized p+p collisions at $\sqrt{s}$ = 510 GeV in June 2017.
- RHICf detector was installed in front of the ZDC.
- Single photon and neutron, and π^0 produced at $\eta > 6$.

A_N for forward π^0 production

arXiv:1312.1995 (2013).

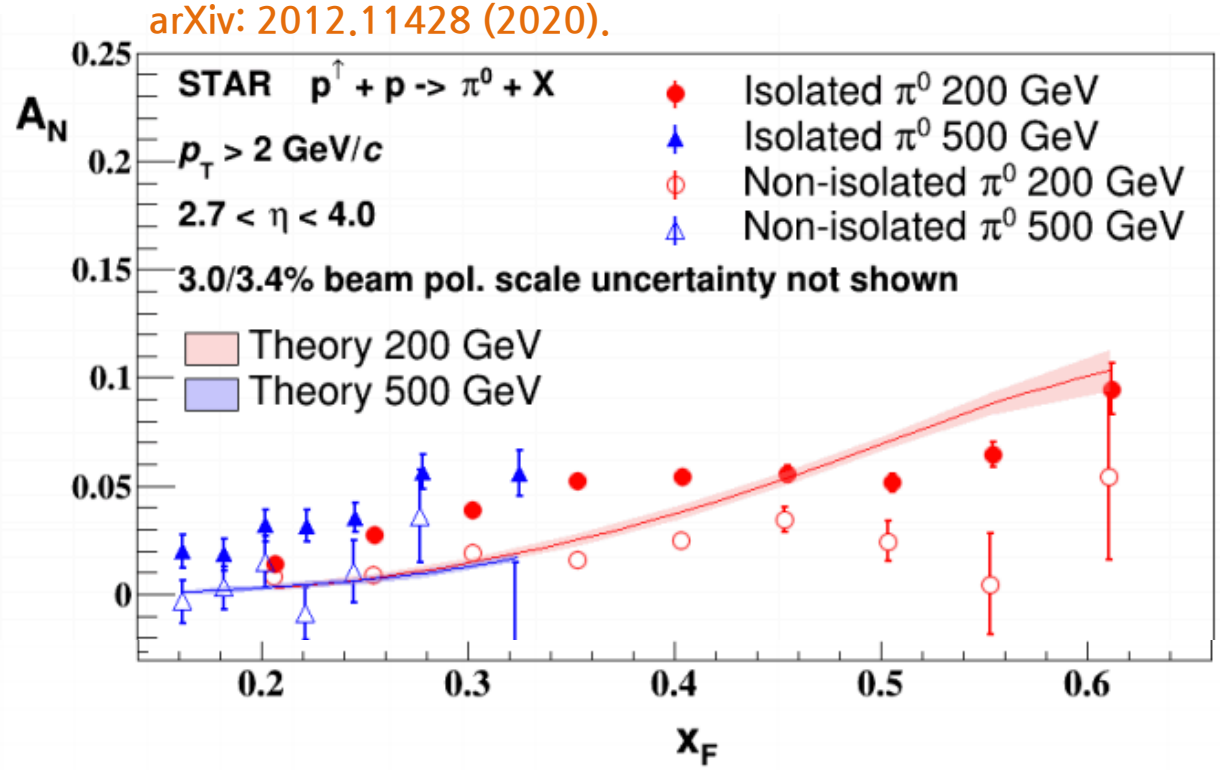




- Before the RHICf experiment, A_N for π^0 production has been measured only in the forward ($2 < \eta < 4$) region.
- Non-zero A_N has been explained by assuming an intrinsic transverse momentum of the initial state parton or final state hadron.

A_N for isolated π^0 production

arXiv: 2012.11428 (2020).

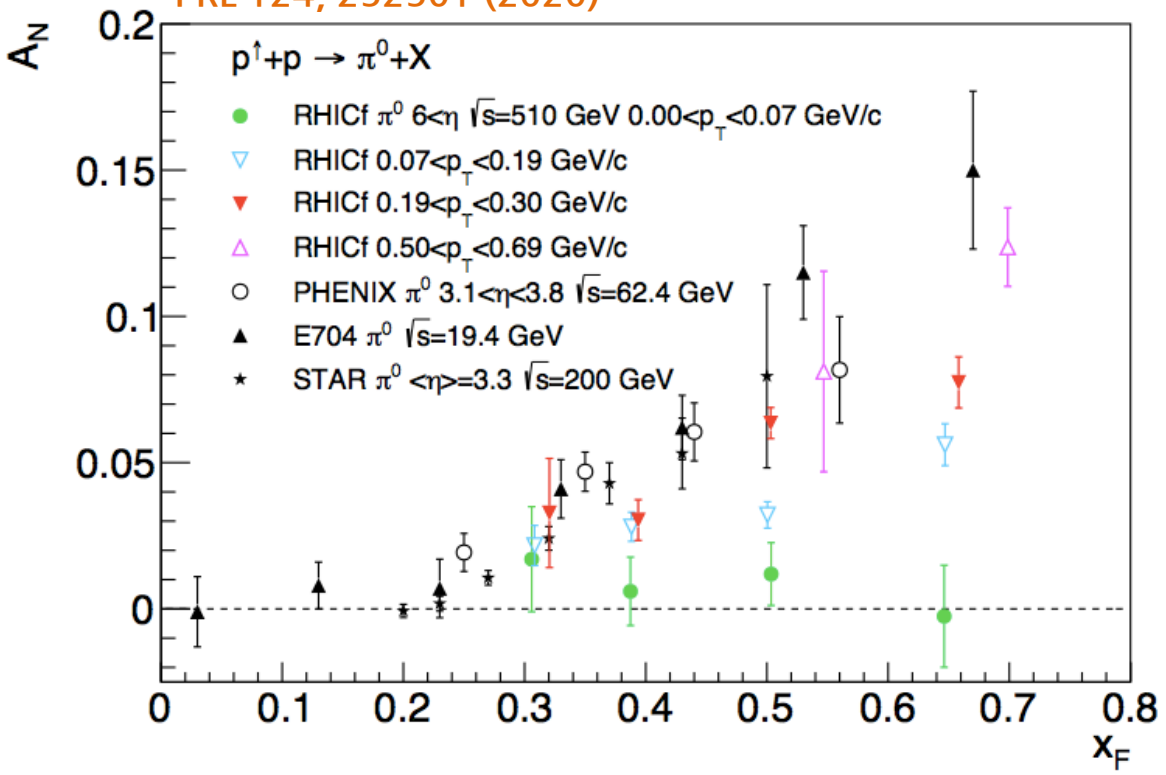


$2.6 < \eta < 4$
$p_T > 1$ GeV/c

- A_N of isolated π^0 is larger than that of non-isolated π^0.
- The isolated π^0 is connected to the diffractive process.
- Diffractive process may have a finite contribution to the π^0 A_N as well as the non-diffractive one.

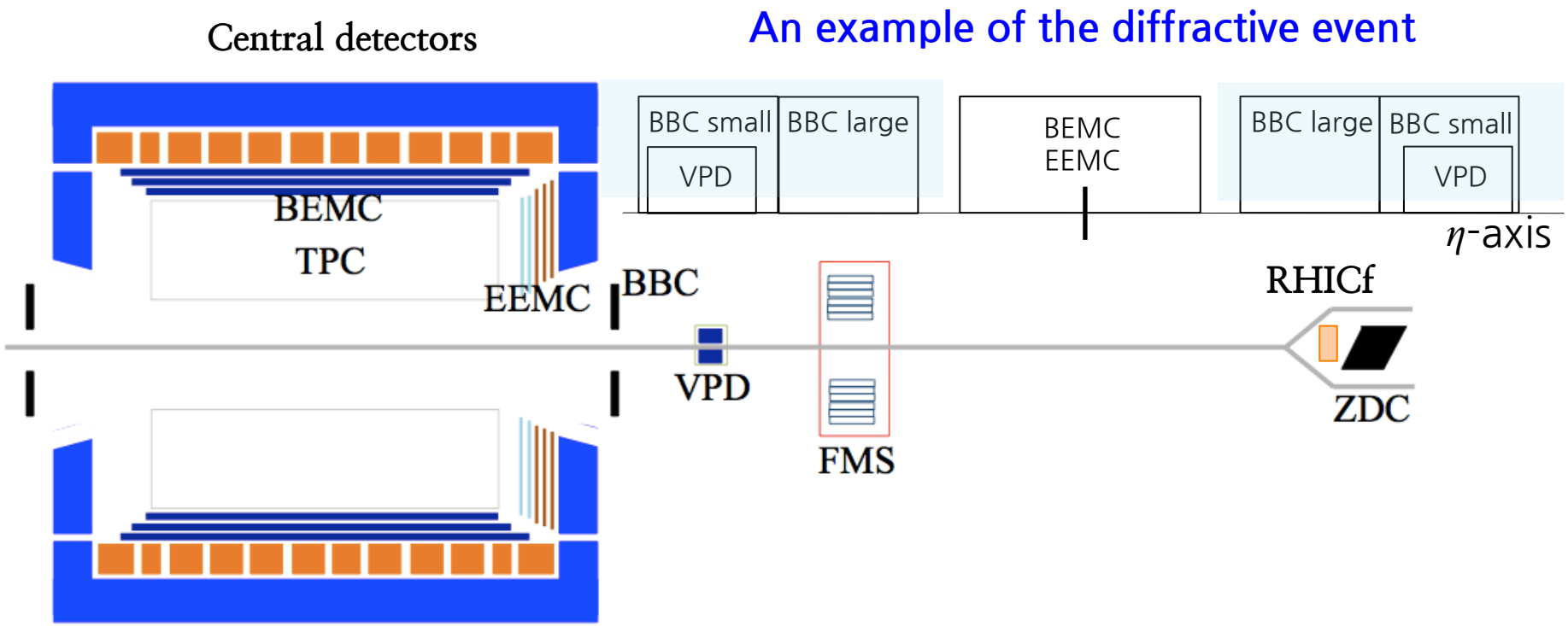
A_N for very forward π^0 production

PRL 124, 252501 (2020)



- A_N for very forward π^0 production seems to be comparable with that of forward π^0 even at low $p_T < 1$ GeV/c.
- They may share a common underlying production mechanism or have their own ones.

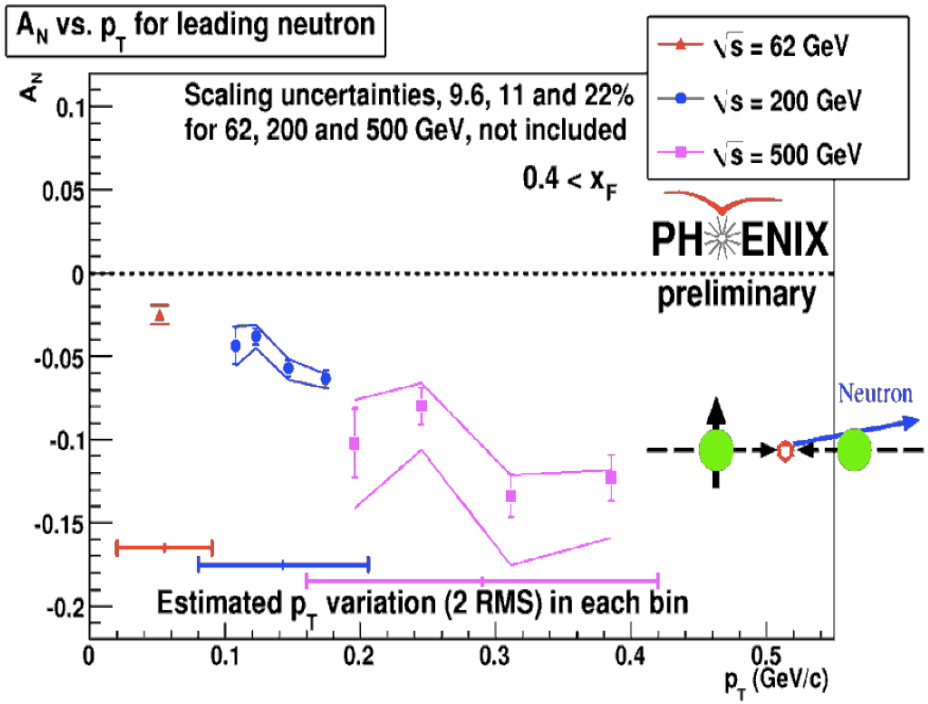
RHICf-STAR combined analysis



- Using STAR ToF, BBC, and VPD, we can study the detector correlation or event type dependence for the very forward π^0 A_N.
- For example, there should be no signal in the detectors that cover a specific η region if the RHICf π^0 comes the diffractive process.

Neutron A_N measurements

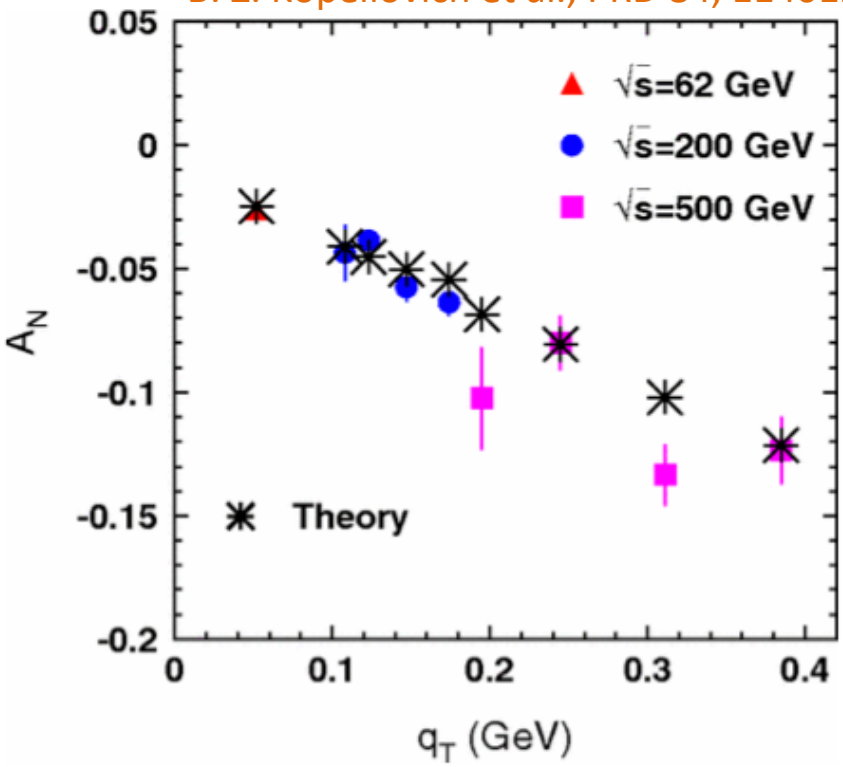
J. Phys. Conf. Ser. 295, 012097.



- Non-zero A_N for neutron production was first observed at the IP12 experiment at RHIC.
- Afterwards the neutron A_N has been measured by the PHENIX experiment with three different collision energies.
- However, the data points were largely smeared by worse position resolution of the neutron detector.

Theoretical prediction

B. Z. Kopeliovich et al., PRD 84, 114012.



$$A_N = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$

$$= \frac{\sum_X |\langle cX|T|\uparrow\rangle|^2 - \sum_X |\langle cX|T|\downarrow\rangle|^2}{\sum_X |\langle cX|T|\uparrow\rangle|^2 + \sum_X |\langle cX|T|\downarrow\rangle|^2}$$

$$= \frac{-2\mathrm{Im}\sum_X \langle cX|T|-\rangle\langle +|T^{\dagger}|cX\rangle}{\sum_X |\langle cX|T|+\rangle|^2 + \sum_X |\langle cX|T|-\rangle|^2}$$

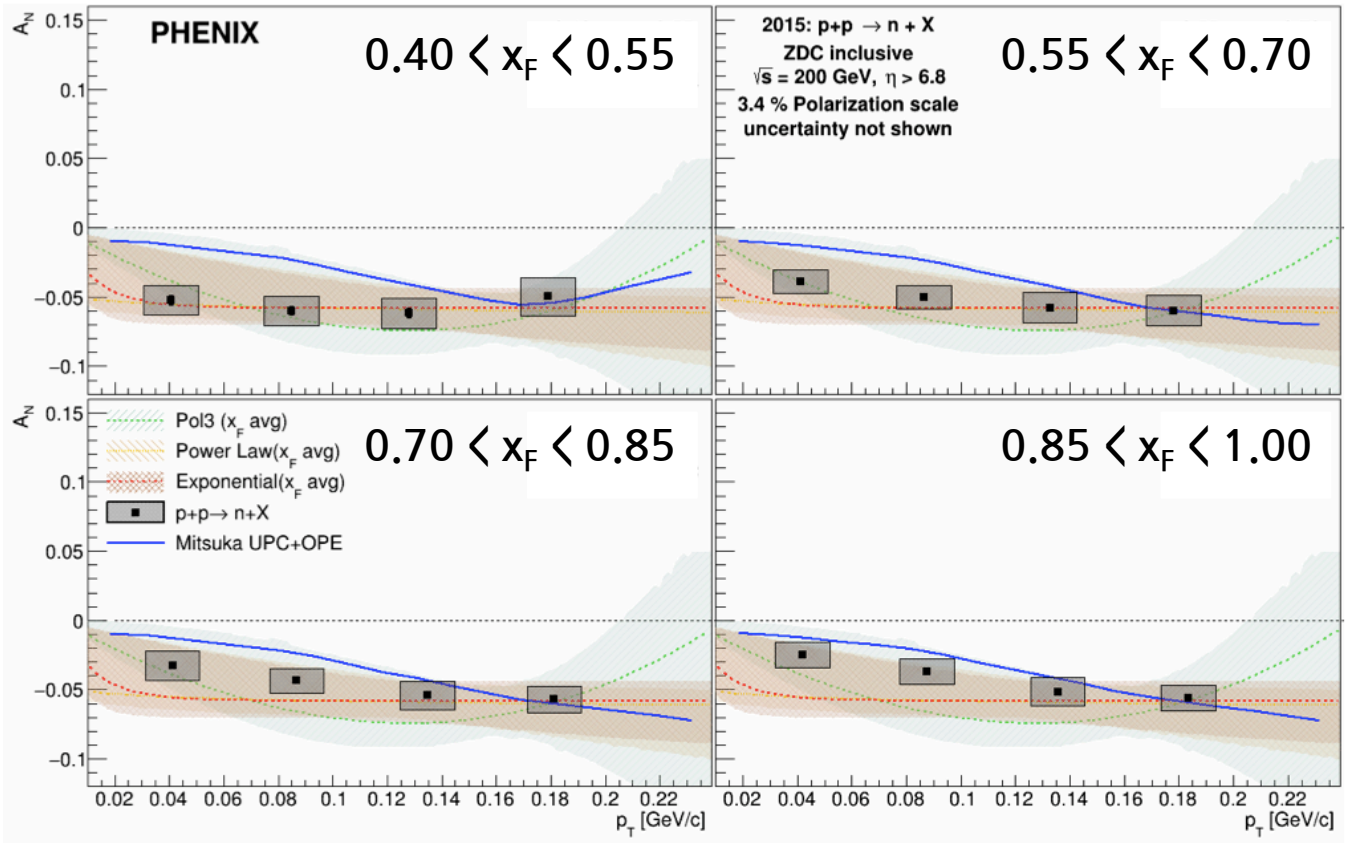
π exchange: spin flip

a_1 exchange: spin non-flip

- Neuron A_N has been explained by an 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 p_T without the collision energy dependence.

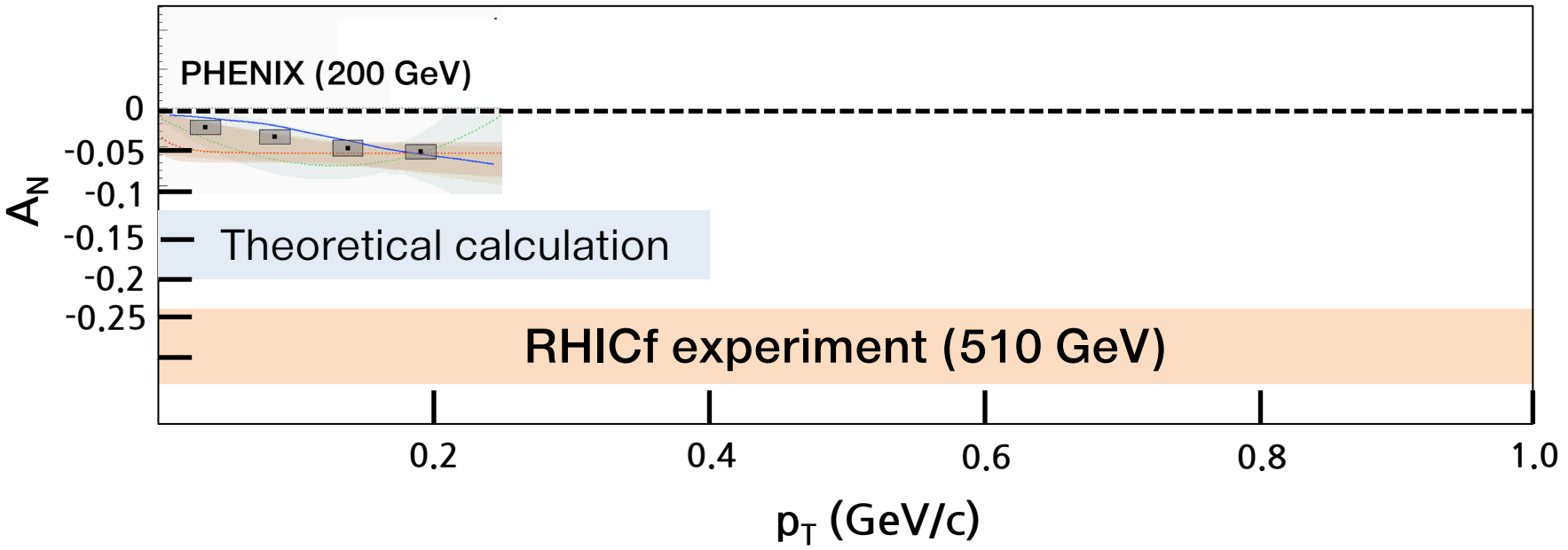
Unfolded neutron A_N

PRD 105, 032004 (2022).



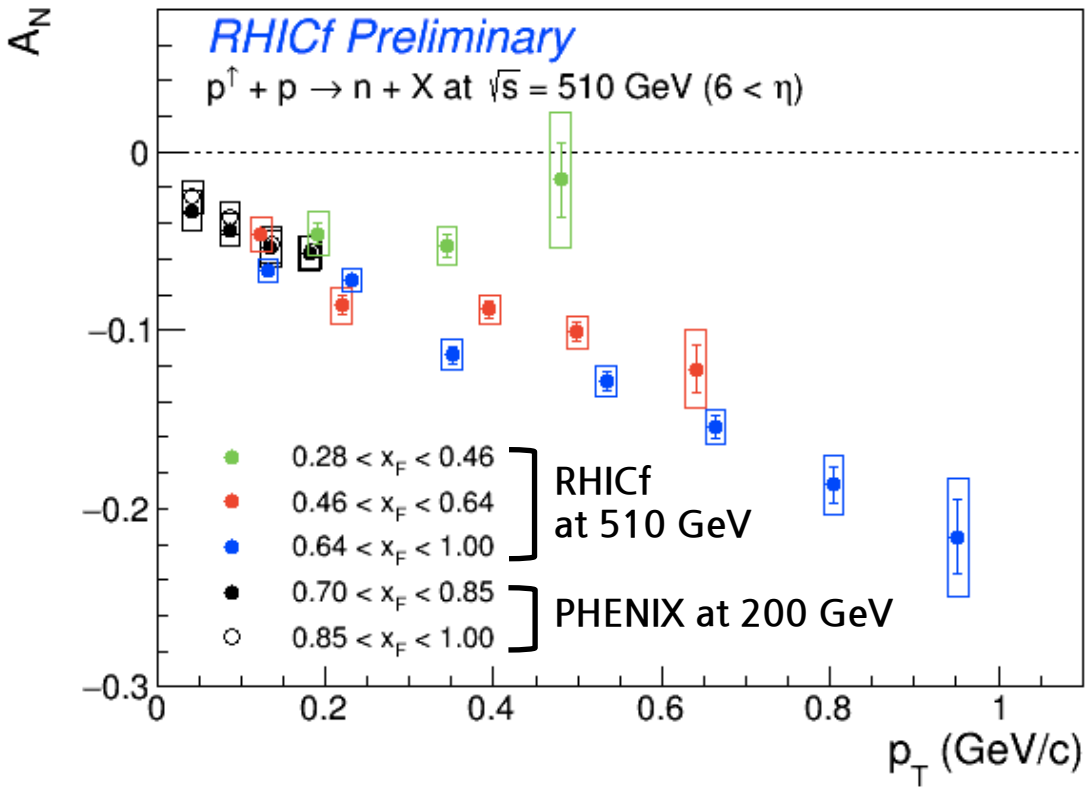
- Recently, PHENIX unfolded the neutron A_N at 200 GeV to precisely compare the data with the theoretical calculation.
- The unfolded A_N at PHENIX showed the same tendency with the model prediction.

Neutron A_N measurement at RHICf



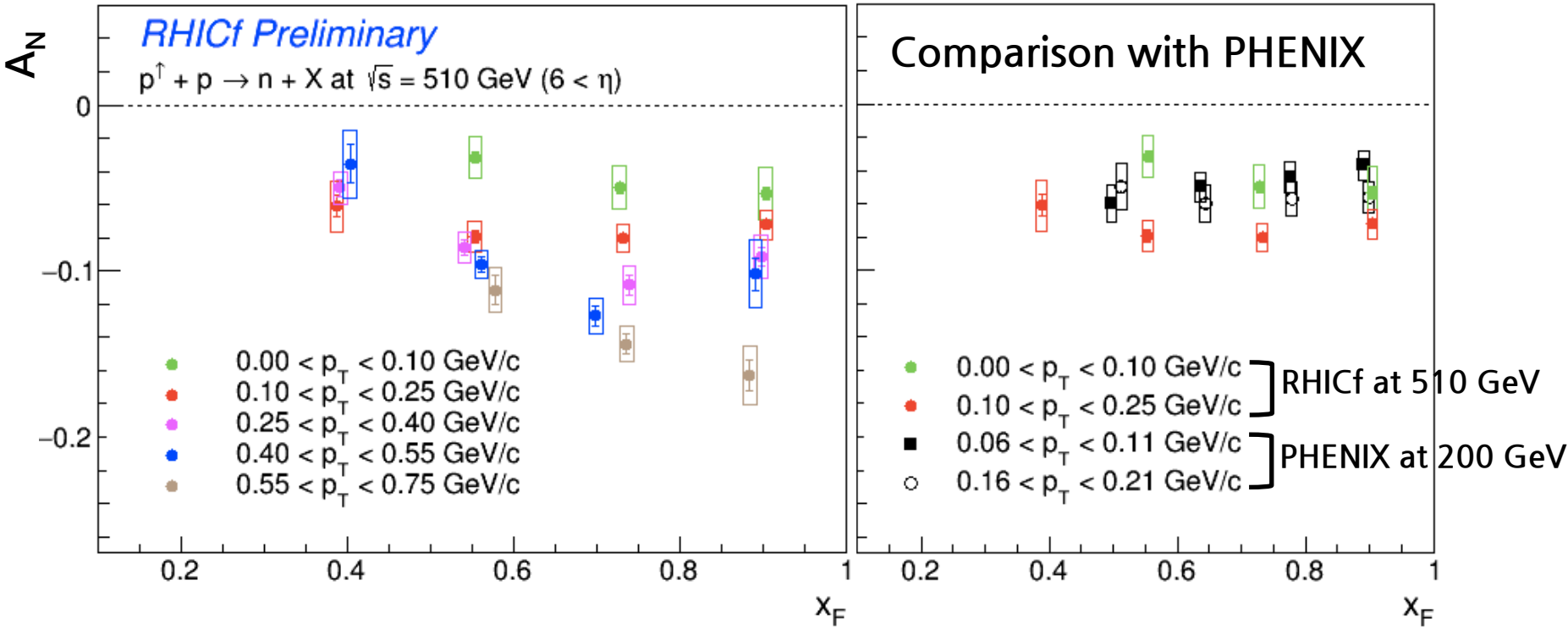
- RHICf experiment measured the neutron A_N up to the highest p_T region ever measured to test the π and a_1 exchange model in a wide p_T coverage.
- Comparison between RHICf and PHENIX data also can be done to make sure if there is collision energy dependence.

Neutron A_N as a function of p_T



- In the higher x_F region, the A_N increases in magnitude with p_T.
- In the low p_T region, RHICf and PHENIX data are consistent with each other.
- In the higher p_T region, there seems a x_F dependence.

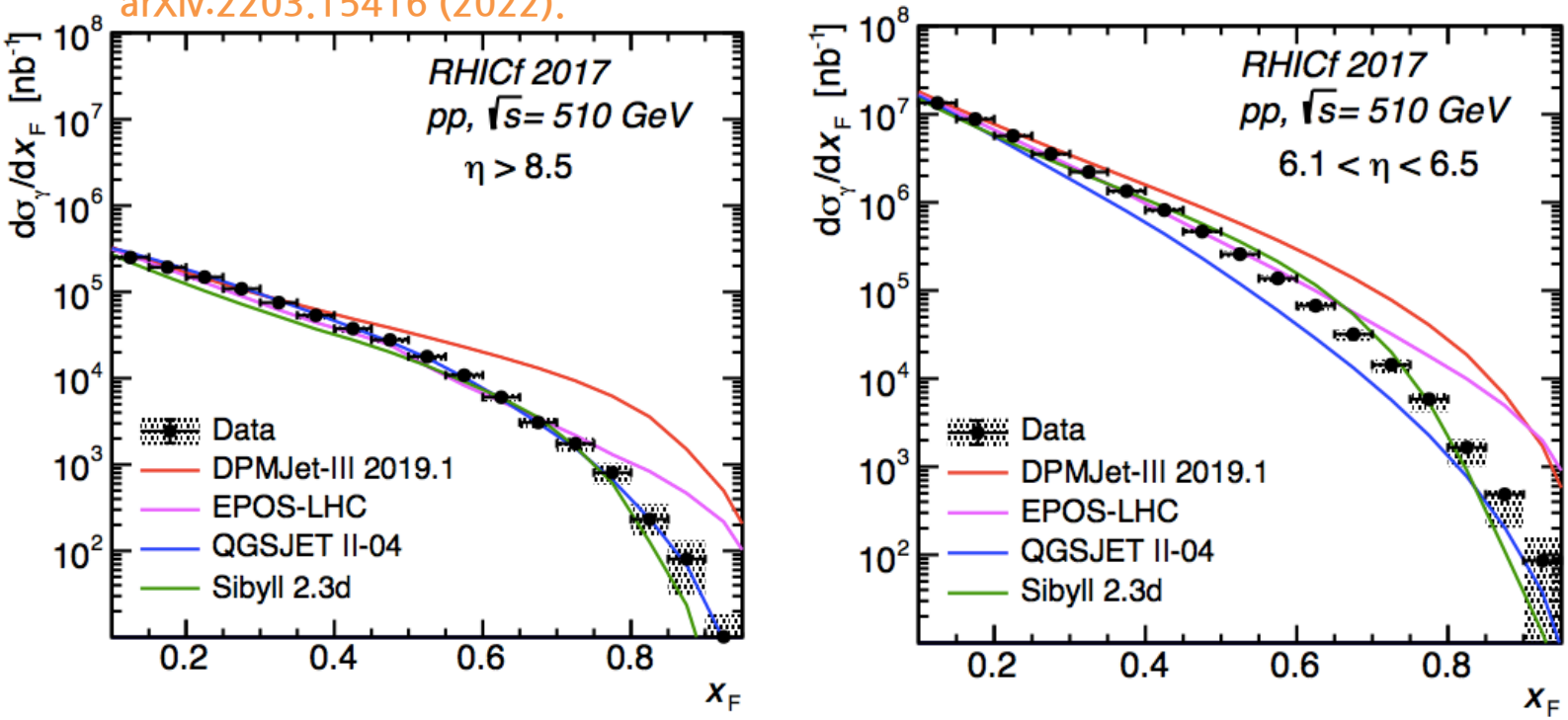
Neutron A_N as a function of x_F



- In the lower p_T region, the A_Ns are flat showing no x_F dependence.
- In the higher p_T region, a clear x_F dependence is observed.
- The analysis will be complete soon with more precise background estimation.

Photon cross section result

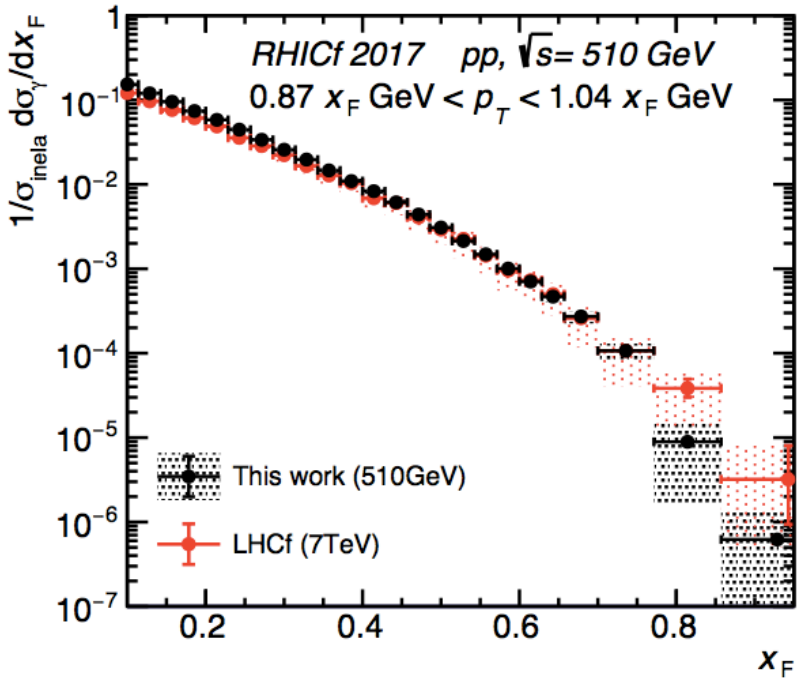
arXiv:2203.15416 (2022).

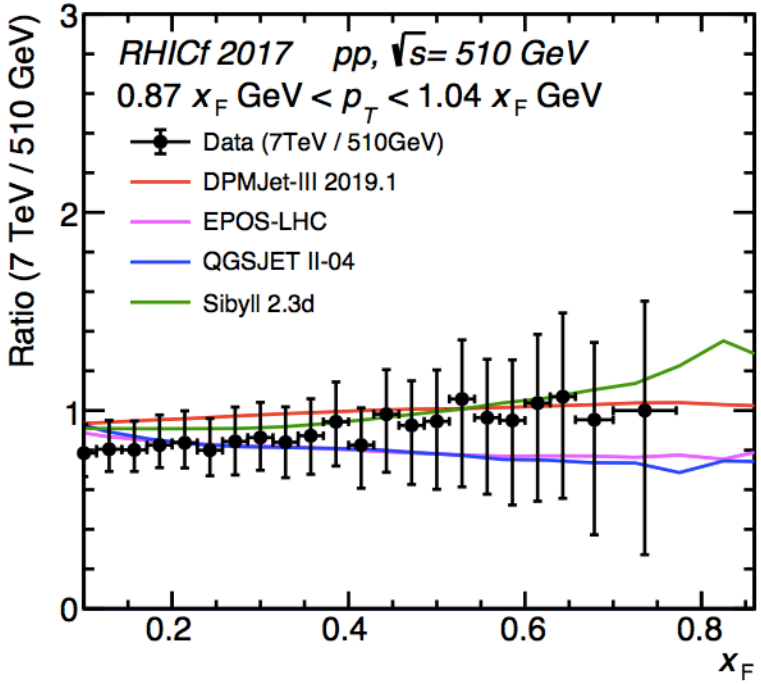


- DPMJet-III 2019.1 and EPOS-LHC well reproduce the data in the lower x_F region, but predict larger flux in the higher x_F.
- QGSJET-II 04 and Sibyll 2.3d show good agreement with data in the higher η, but show softer and harder slope in the lower η.

Photon cross section result

arXiv:2203.15416 (2022).





- RHICf result is consistent with the LHCf result within the uncertainty.
- However, if the x_F scaling raw works or there is still a weak x_F dependence is not clear due to the uncertainty. → Will be more clear in the future publications.

Summary

- In June 2017, the RHICf experiment measured the cross sections and A_Ns for very forward particle production.
- Non-zero A_N was observed even in the very forward π^0 production.
  - Will be studied in more detail by the RHICf-STAR combined analysis.
- A x_F dependence was observed in the neutron A_N.
  - Analysis will be complete with more precise background estimation.
- Photon cross section at RHICf energy is consistent with that of LHCf.
  - Cross sections of other particles will also be compared.