Measurement of TSSA for forward π^0 in (non-)diffractive like events at RHICf and STAR

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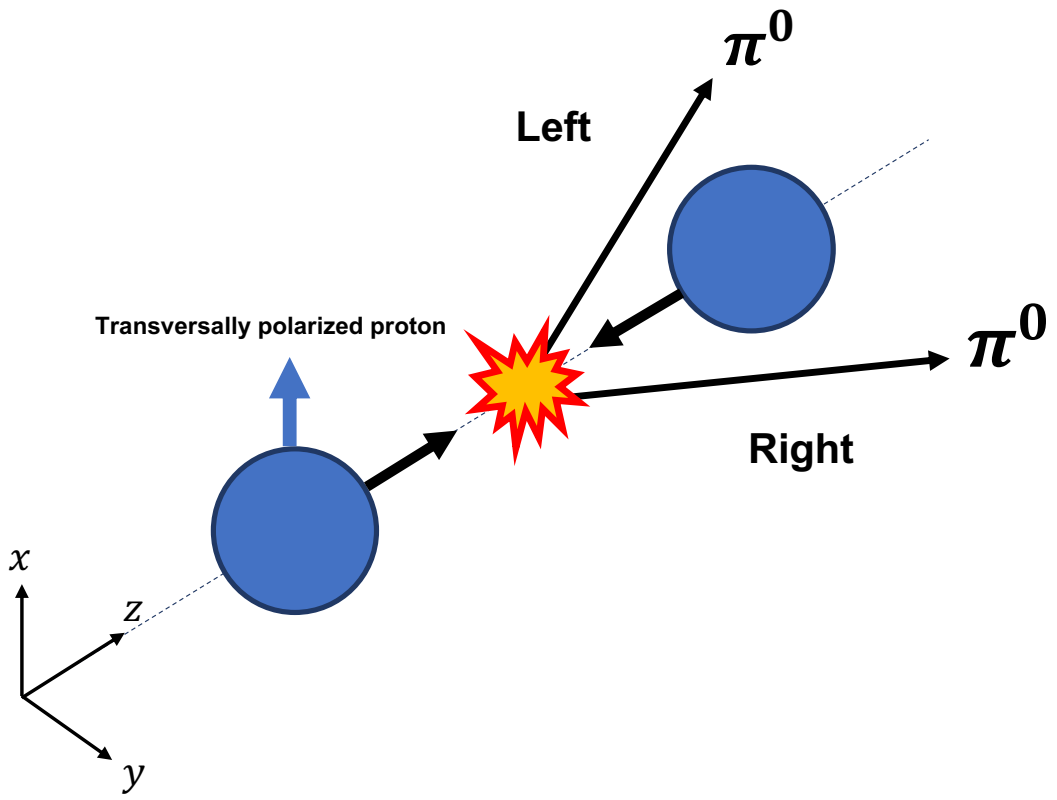
for the RHICf and STAR collaborations

Supported in part by

Transverse single spin asymmetry (A_N)

- **Definition**

$$A_N \equiv \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$



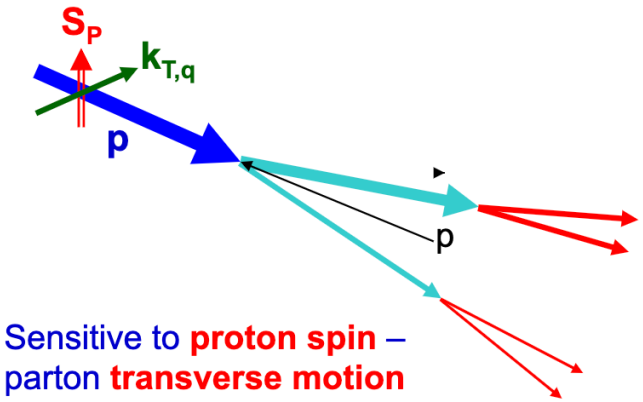
- The transverse single-spin asymmetry (A_N) represents a left-right asymmetry in particle production and reflects the underlying spin–transverse momentum correlations in a transversely polarized proton.

Transverse single spin asymmetry (A_N)

- **Theoretical framework**

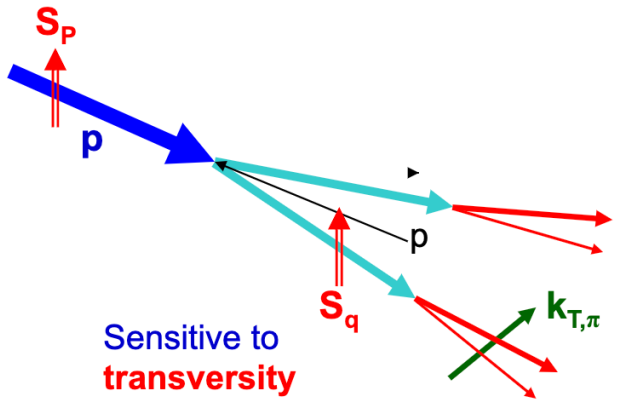
Sivers and Collins effects in pp collisions

Sivers mechanism: initial-state k_T dependence in the parton distribution



Sensitive to **proton spin** – parton **transverse motion** correlations

Collins mechanism: final-state asymmetry in the forward jet fragmentation

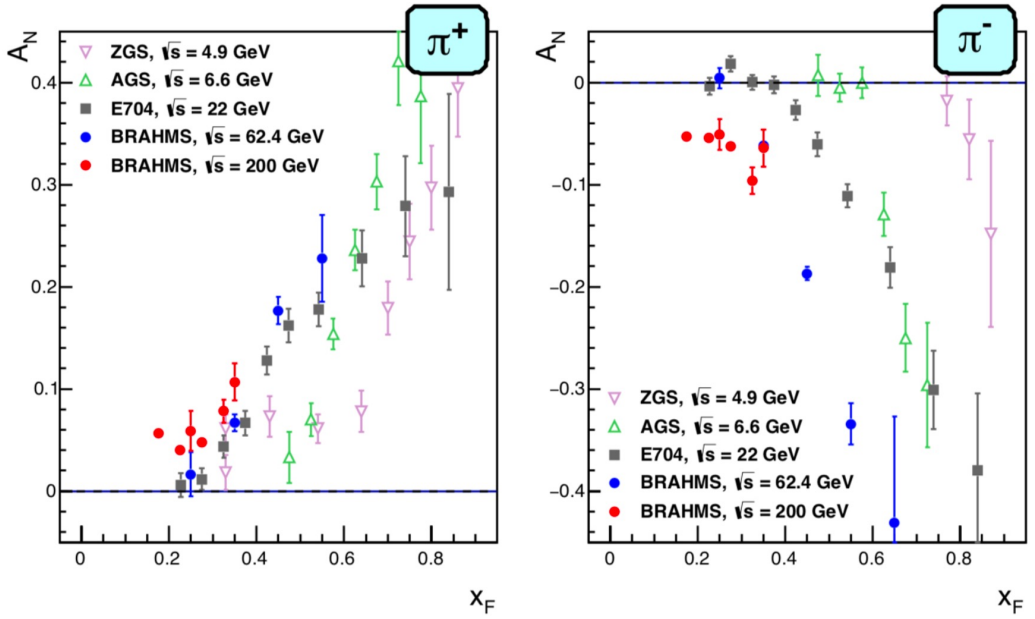


Sensitive to **transversity**

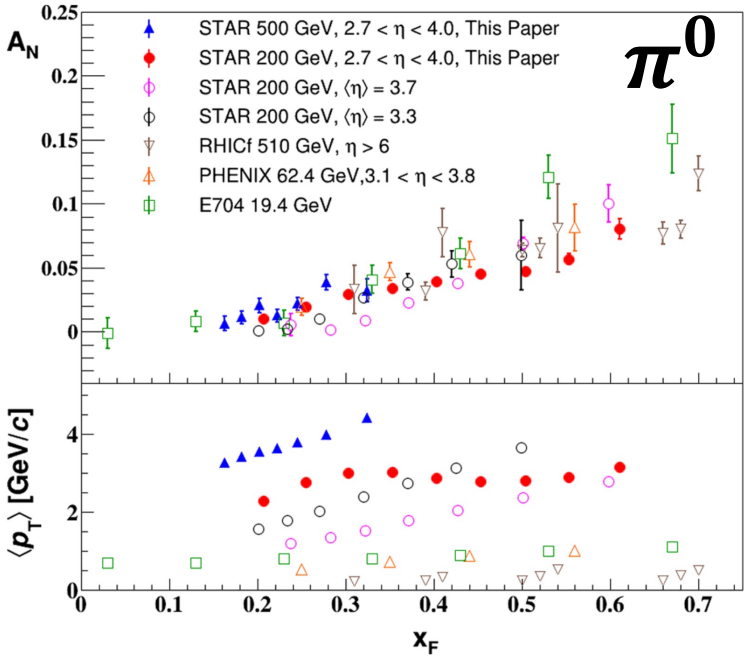
- These frameworks are related to the transverse spin structure of proton
- Sivers and Collins frameworks can predict the large A_N (pQCD prediction ~ 0)

Transverse single spin asymmetry (A_N)

- **Measurements**



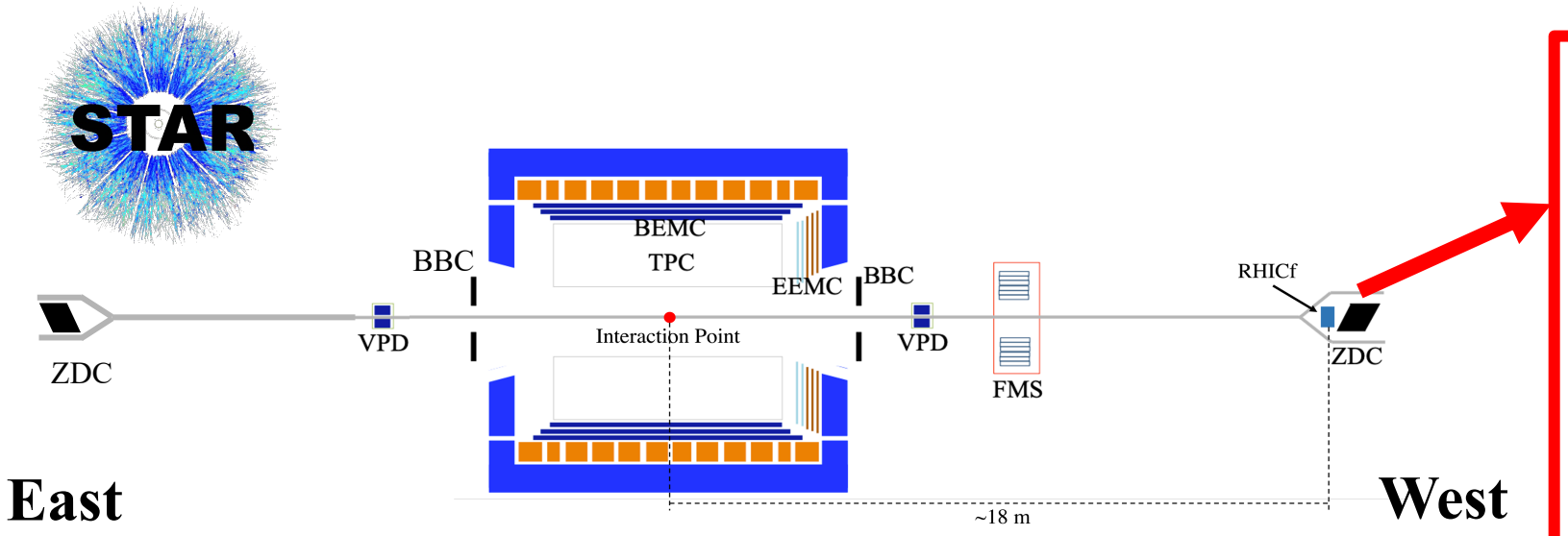
R. D. Klem et al., Phys. Rev. Lett. 36, 929 (1976)
D. L. Adams et al., Phys. Lett. B264, 462 - 466 (1991)
C. E. Allgowe et al., Phys. Rev. D 65, 092008 (2002)
I. Arsene et al., Phys. Rev. Lett. 101, 0420010 (2008)

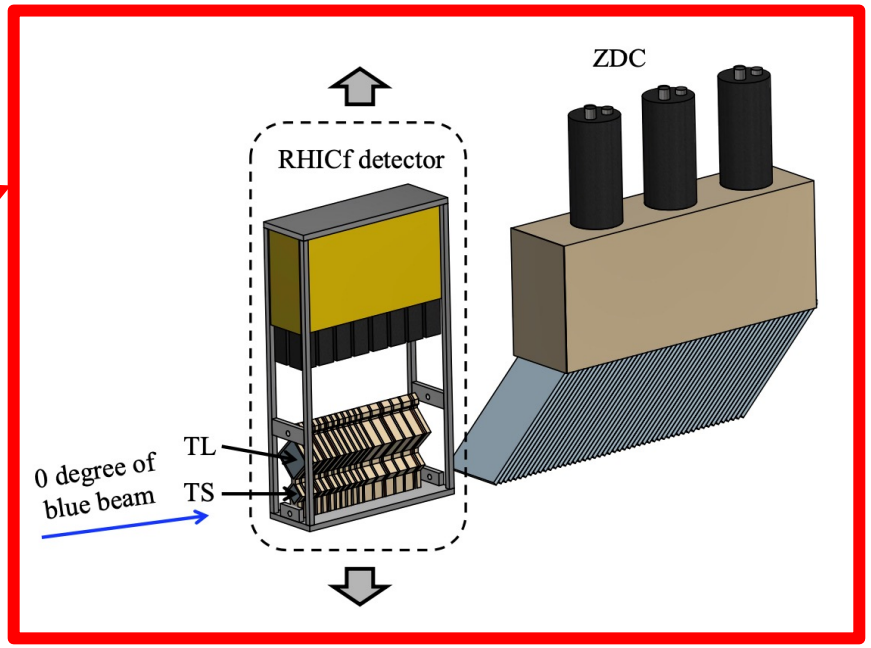


(STAR) J. Adam et al., PRD 103, 092009 (2021)

- Non-zero A_N for $\pi^{\pm}$ and π^0 in forward region

RHICf experiment



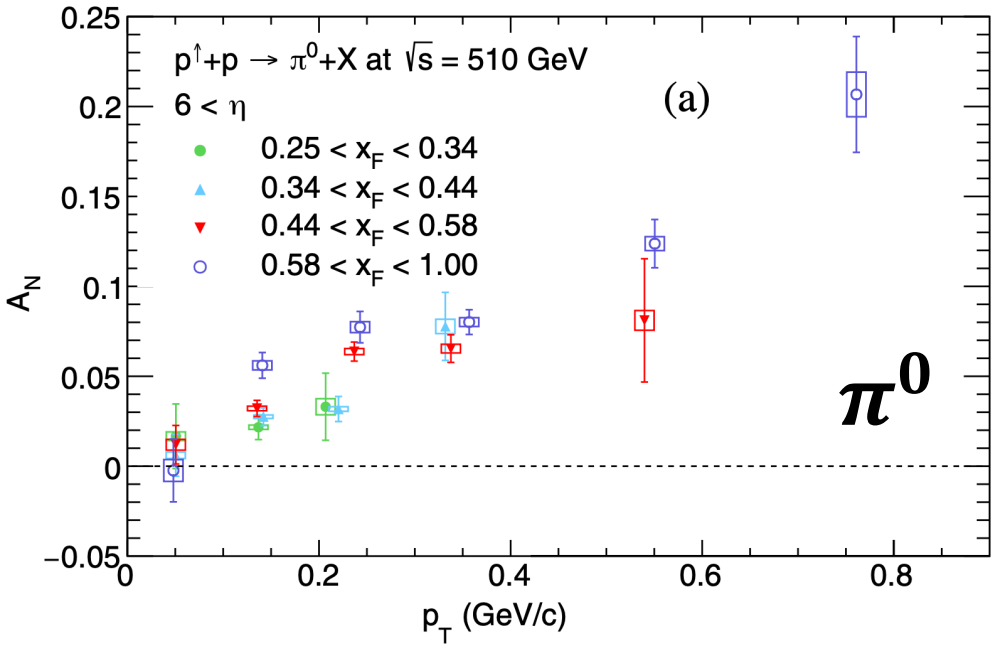


- RHICf detector installed in the far forward (η > 6) region of the STAR detector to collect transversally polarized $p + p$ collisions at $\sqrt{s} = 510$ GeV, operated in 2017

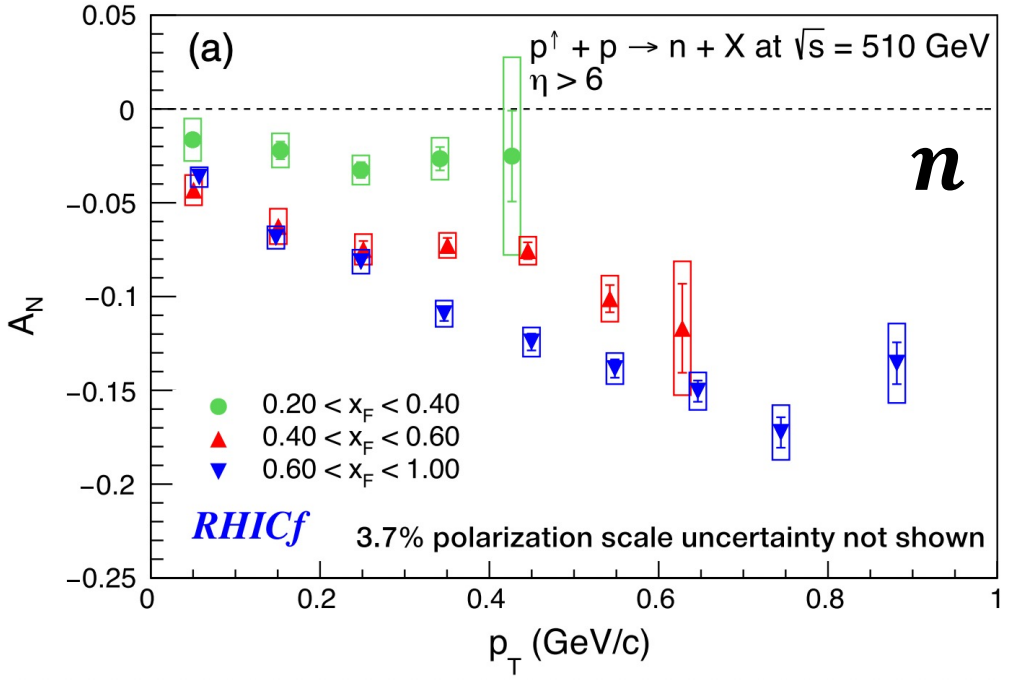
- RHICf detector consists of a large tower (TL, 40mm) and a small tower (TS, 20 mm), Each tower is composed of 4 position layers (1 mm) and 16 scintillating plate

RHICf results

RHICf, PRL 124, 252501 (2020)



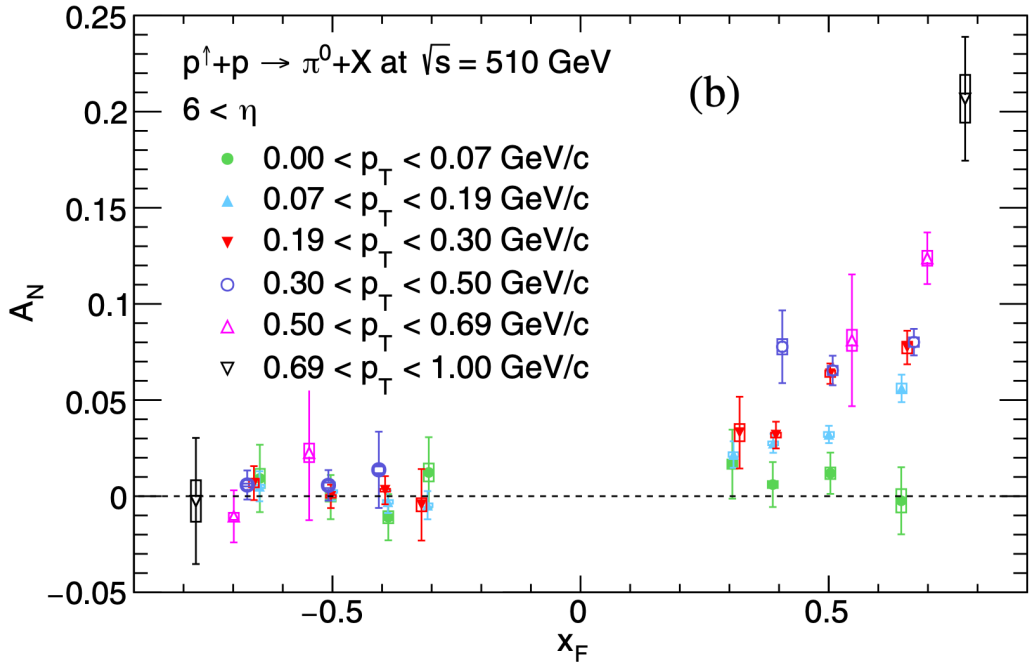
RHICf, PRD 109, 012003 (2024)



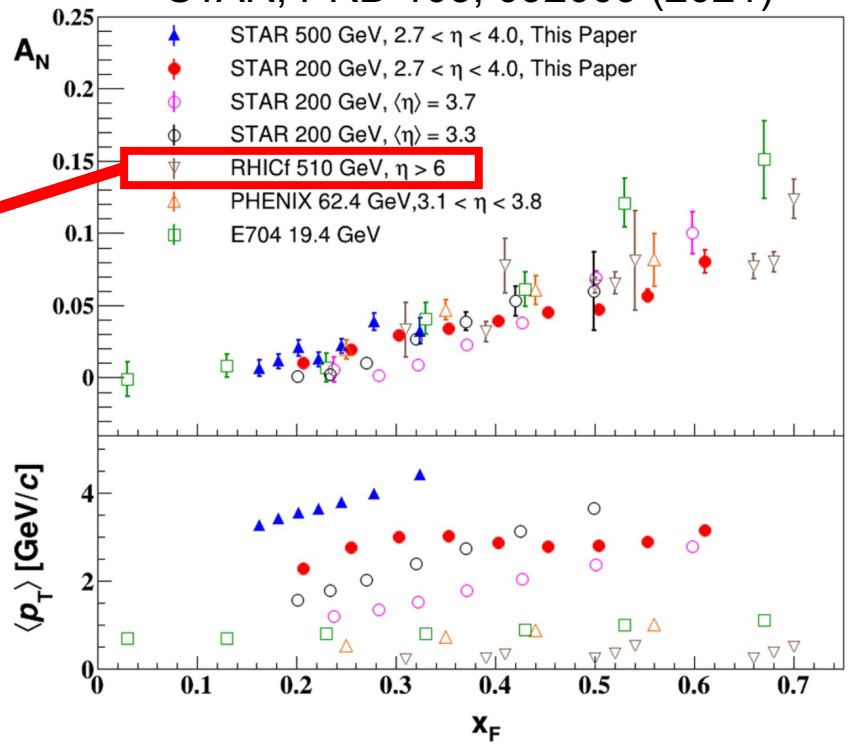
- RHICf Collaboration has successfully measured the A_N of π^0 and n in P_T < 1.0 GeV/c and $\eta > 6$
- RHICf has reported the non-zero A_N for π^0 and n ($\eta > 6$) in non-perturbative QCD regime

A_N for forward π^0 in different coverage

RHICf, PRL 124, 252501 (2020)



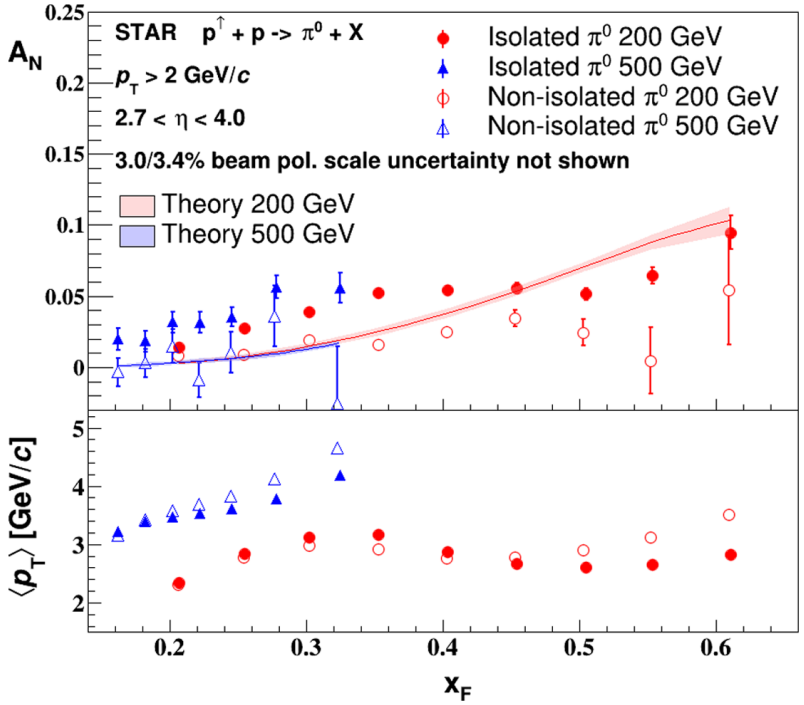
STAR, PRD 103, 092009 (2021)



- A_N for forward $(2.7 < \eta < 4)$ and RHICf ($\eta > 6$, $p_T < 0.2$ GeV/c) π^0 exhibit similar x_F scaling behavior
- Large A_N for RHICf π^0 may be contributed by other mechanisms, diffraction, or resonance particles

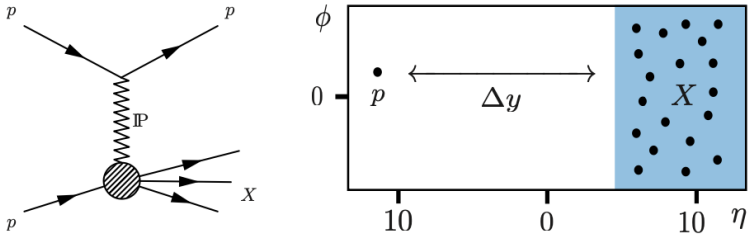
A_N of forward π^0 contributions

STAR, PRD 103, 092009 (2021)

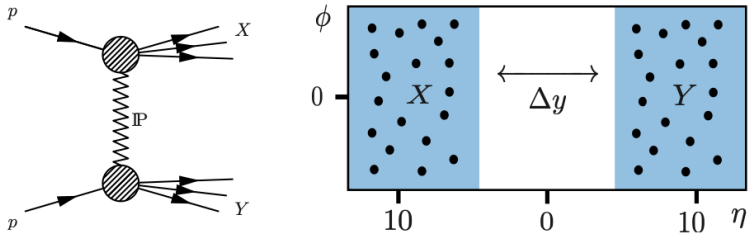


- STAR has reported the A_N of isolated and non-isolated π^0 in EM-jets
- The results suggest that diffractive processes may contribute to the large A_N of forward π^0
- We focus on investigating the contribution of diffractive processes to the A_N of RHICf π^0, through a combined RHICf+STAR analysis.

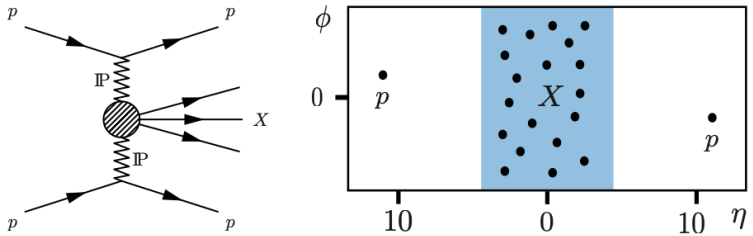
Diffraction in $p + p$ collisions



Single Diffraction (SD)



Double Diffraction (DD)



Central Diffraction (CD)

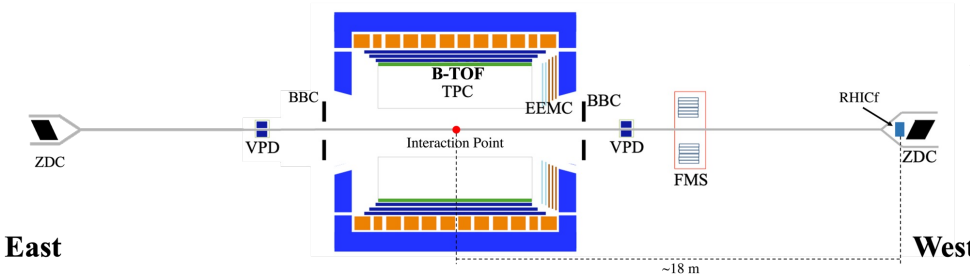
Diffractive process features:

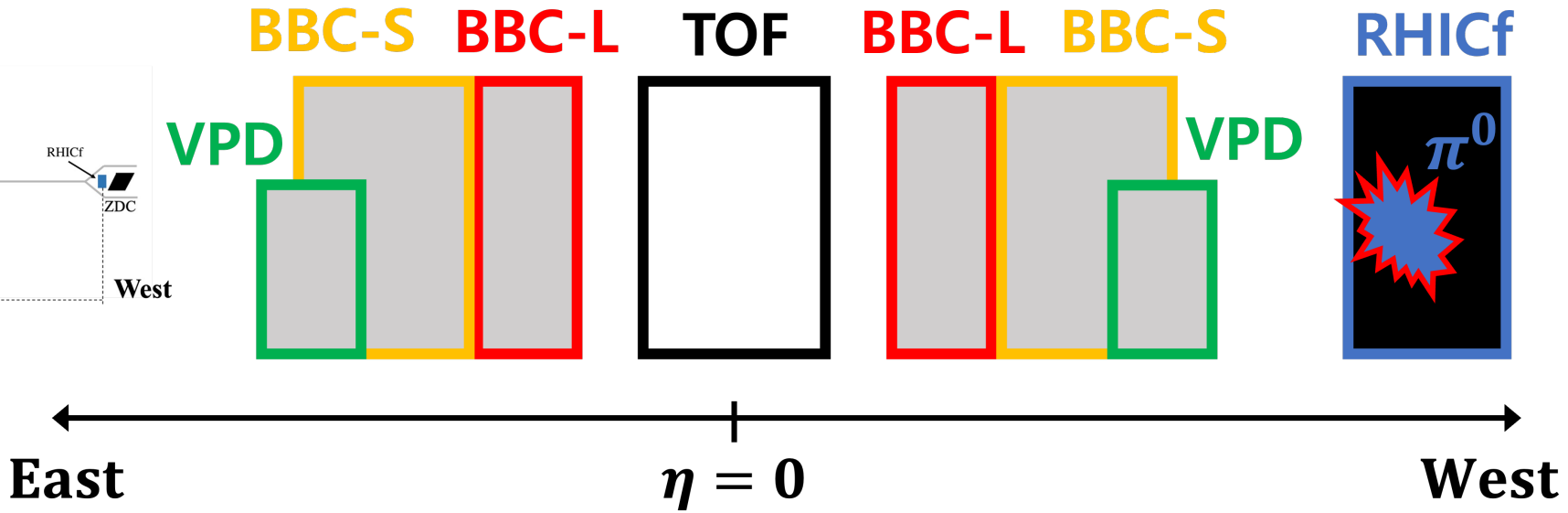
- Color Singlet Exchange (Pomeron exchange)
- Large Rapidity Gap
- Final state proton

- Color Singlet (such as photon or pomeron) exchange could contribute to the A_N

Event classification method

◆Condition definition



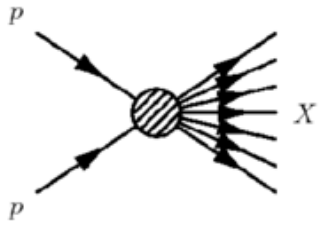


- Detector signal on-off cut is determined by min-bias trigger events
- Event classification method is based on the large rapidity gap in diffractive process

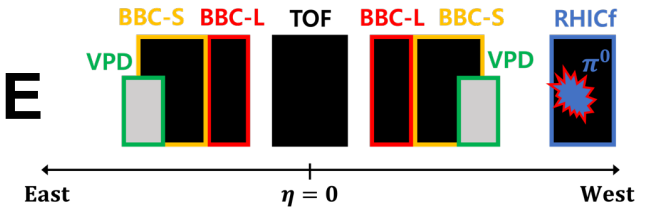
Legend:

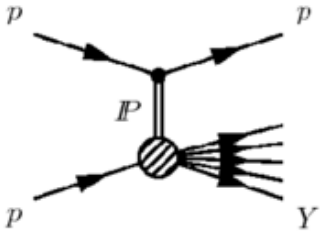
- **Always signal**
- **signal or not**
- **No signal**

(Non-)Diffractive-Likely-Event (DLE)

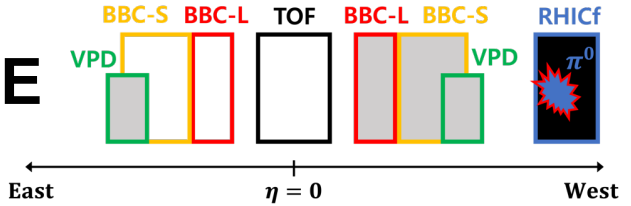


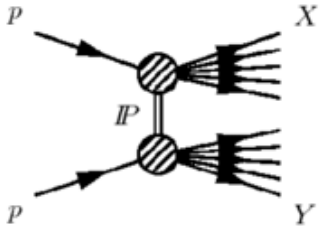
Non Diff. ⟷ **NDLE**



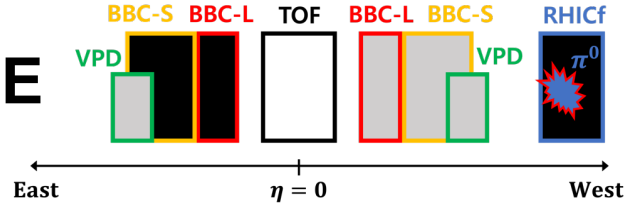


Single Diff. ⟷ **SDLE**





Double Diff. ⟷ **DDLE**



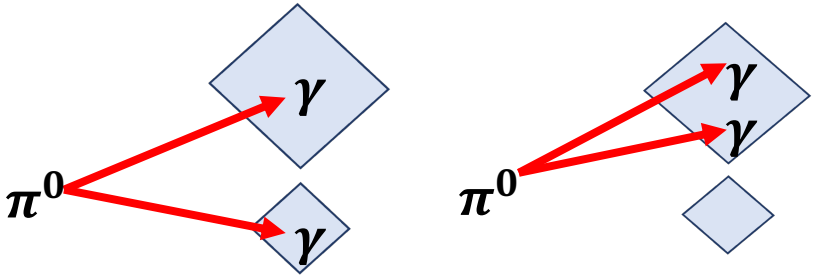
Legend:

- **Always signal**
- **signal or not**
- **No signal**

- We classified the three different processes with detector correlations

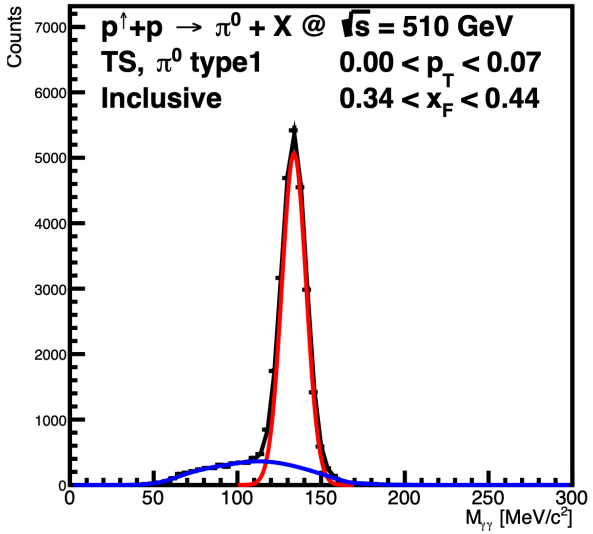
RHICf π^0 measurement

◆ **Definition of RHICf π^0 type**

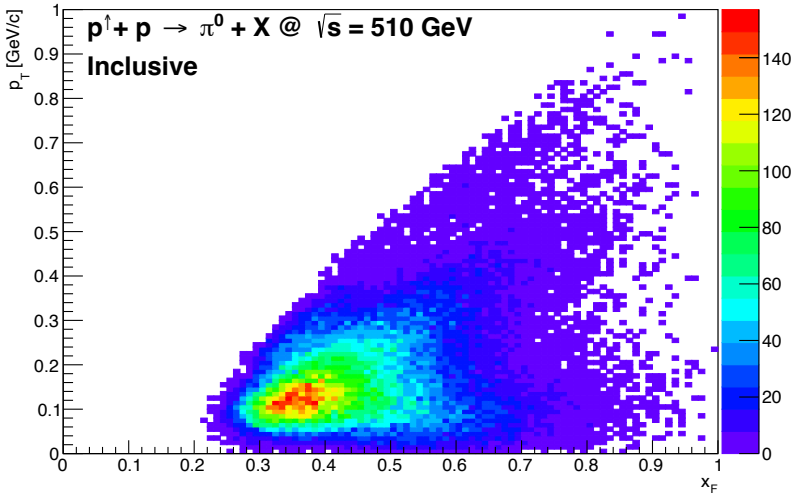


Type-1 π^0 Type-2 π^0

Two γ invariant mass



p_T and x_F correlations for π^0



- π^0 candidates are selected based on the two-gamma invariant mass
- Background estimation has been conducted by using Gaussian Process Regression method
- Energy resolution σ_E ~3.5% and transverse momentum resolution σ_{p_T} ~4.5% for π^0 are observed

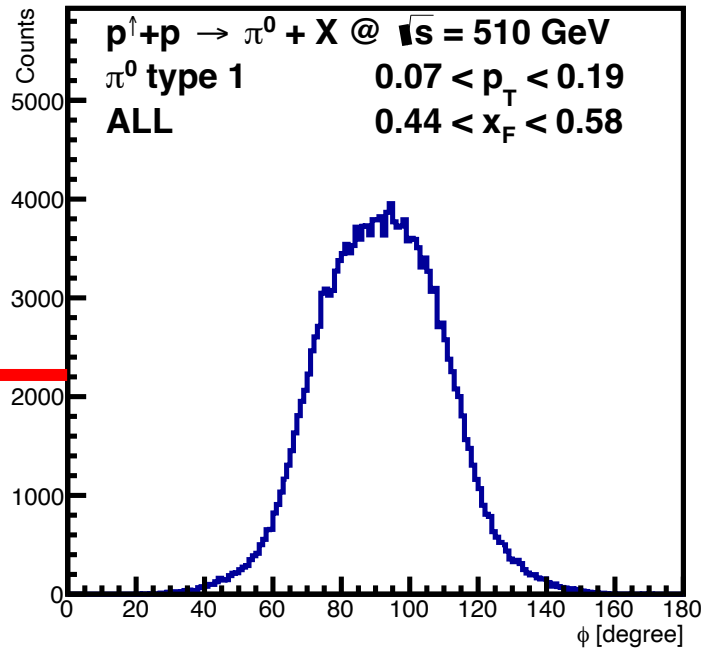
RHICf, PRL 124, 252501 (2020)

A_N of RHICf π^0 calculation

$$A_N = \frac{1}{P\, D_\phi}\left(\frac{N_R^\uparrow - R\, N_R^\downarrow}{N_R^\uparrow + R\, N_R^\downarrow}\right)$$

$D_\phi = \frac{1}{N}\sum \sin\phi$

Azimuthal angle distribution



$\boldsymbol{P}$ = Beam polarization

$\boldsymbol{D_\phi}$ = Dilution factor

$\boldsymbol{R}$ = Relative luminosity

$\boldsymbol{N_R^{\uparrow,\downarrow}}$ = number of spin up and down for π^0 event

- A_N was calculated using the luminosity-based formula
- A dilution factor was applied to correct for the ϕ modulation of π^0 due to the finite detector acceptance

Background A_N of RHICf π^0 subtraction

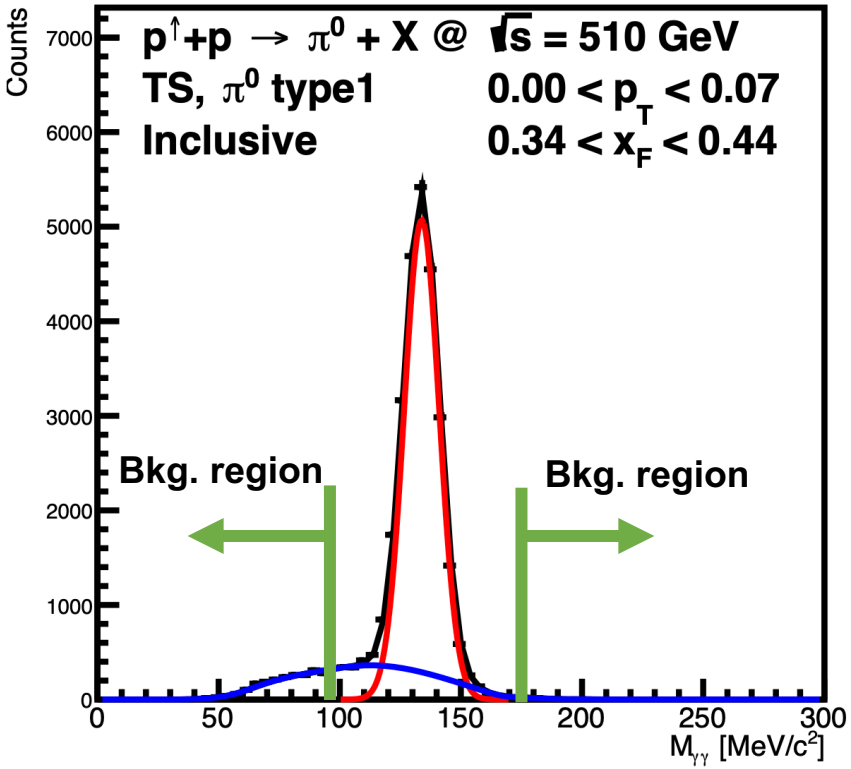
$$A_N^S = \left(1 + \frac{N_B}{N_S}\right) A_N^{S+B} - \left(\frac{N_B}{N_S}\right) A_N^B$$

A_N^{S+B} = Signal + background A_N withtin 3σ

A_N^B = Background A_N in 5σ away from mass peak

A_N^S = Subtracted A_N

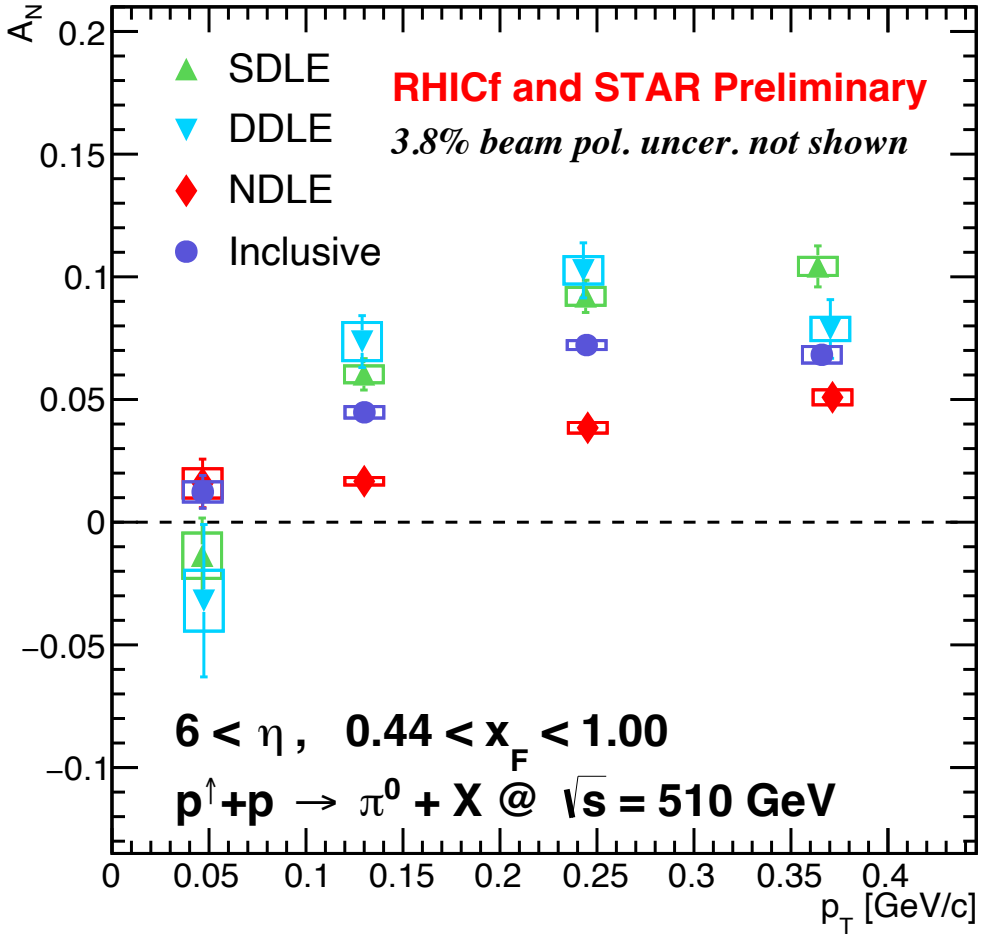
$N_{B(S)}$ = Integrated counts of background (signal) within 3σ

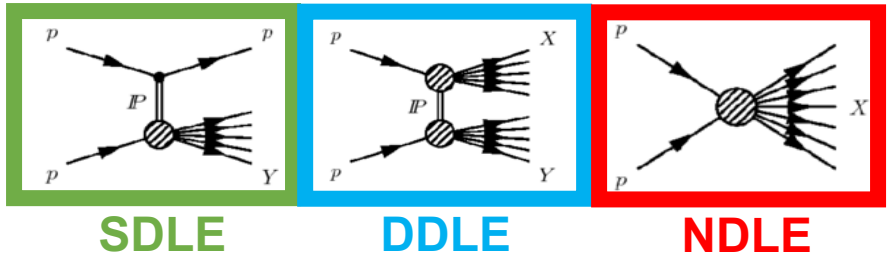


- Background subtraction was performed using A_N^B and the background-to-signal ratio (B/S ratio) within the 3σ of the mass peak

- A_N^B was estimated from background events located more than 5σ away from the mass peak.

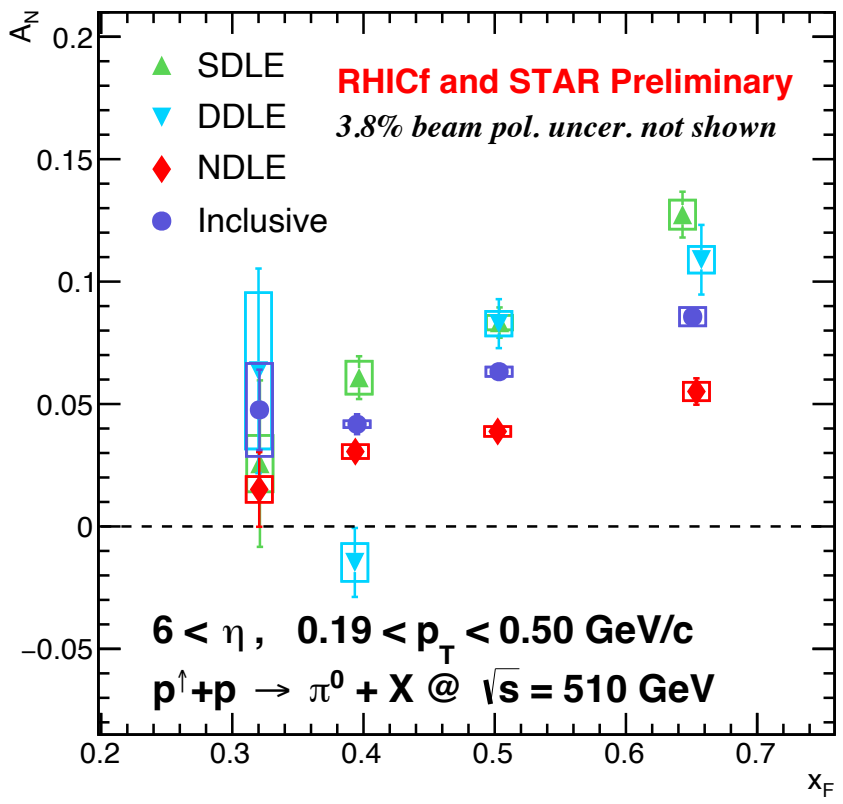
Results

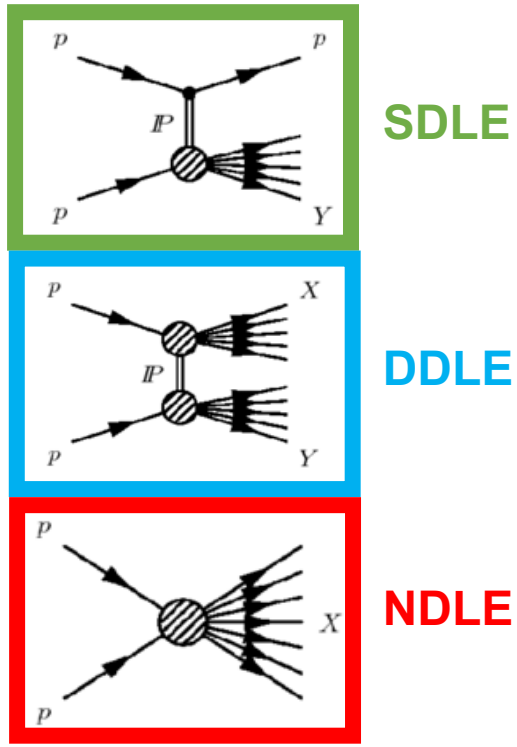




- We observed the non-zero A_N of RHICf π^0 under the SDLE, DDLE and NDLE conditions
- The SDLE and DDLE show similar behavior and exhibit a more enhanced A_N compared to the inclusive result
- NDLE condition shows a suppressed A_N relative to the inclusive result

Results





- It shows different A_N values for S/DDLE and NDLE compared with inclusive result as a function of x_F

- Diffractive process may contribute the large A_N in $\eta > 6$ region

Summary

- A_{N} is measured for (non-)diffractive like events in $p^{\uparrow} + p$ collision at $\sqrt{s} = 510$ GeV at RHICf and STAR experiments

- Non-zero A_{N} values of RHICf $\boldsymbol{\pi^0}$ are observed across all classified event types

- A_{N} values for SDLE and DDLE show an enhancement relative to the inclusive events
  In contrast, A_{N} for NDLE is suppressed compared to the inclusive event

- These results suggest that diffractive processes may contribute to the large A_{N} observed in the very forward region.

Thank you for your attention!