Measurement of transverse single spin asymmetry for π^0 production in (non-)diffractive like events at RHICf and STAR experiments

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for the RHICf and STAR collaborations

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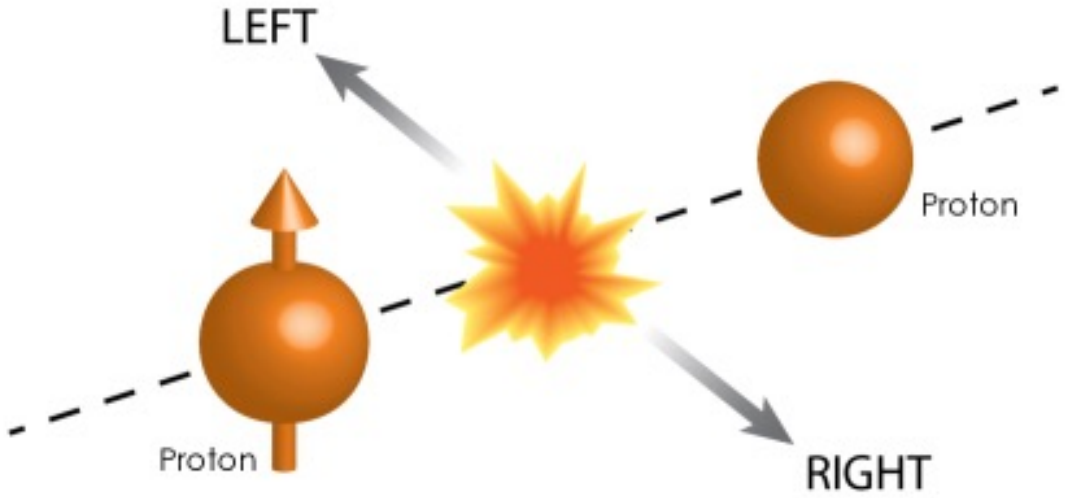
Transverse single spin asymmetry (A_N)

- **Definition**

$$A_N = \frac{\sqrt{N_R^{\uparrow} N_L^{\downarrow}} - \sqrt{N_L^{\uparrow} N_R^{\downarrow}}}{\sqrt{N_R^{\uparrow} N_L^{\downarrow}} + \sqrt{N_L^{\uparrow} N_R^{\downarrow}}}$$



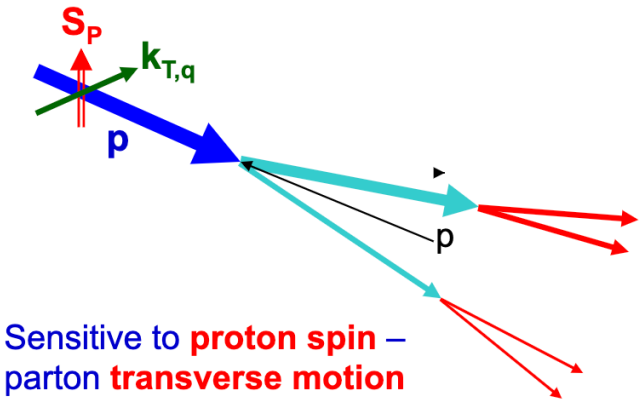
- The transverse single-spin asymmetry (A_N) represents a left-right asymmetry in particle production and reflects the underlying spin–momentum correlations in a transversely polarized proton.

Transverse single spin asymmetry (A_N)

- **Theoretical framework**

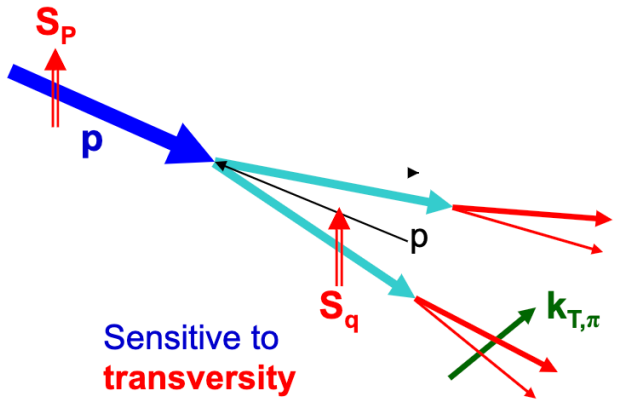
Sivers and Collins effects in pp collisions

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

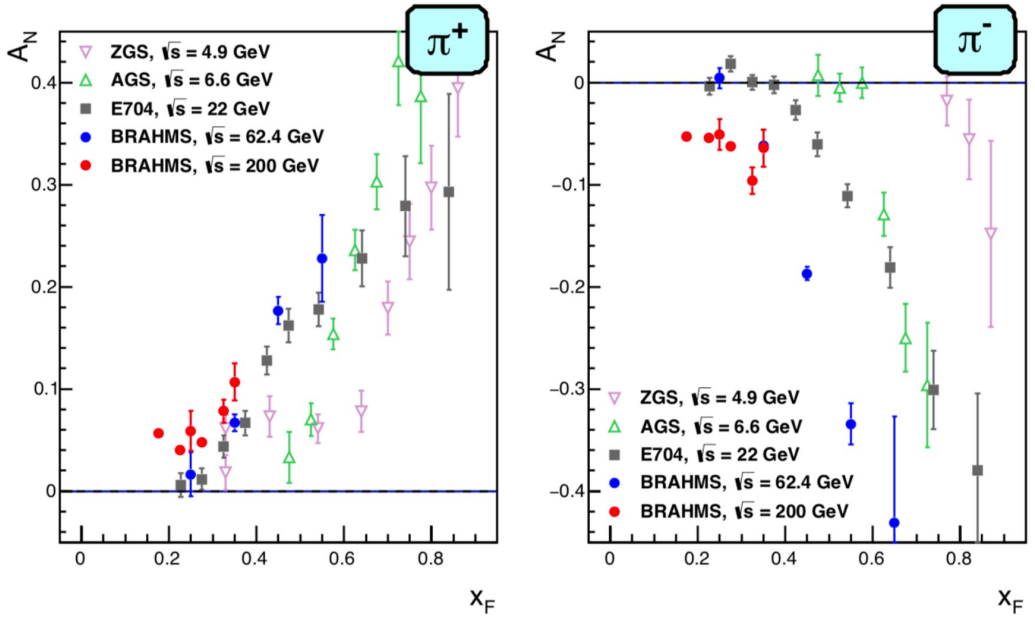


Sensitive to **transversity**

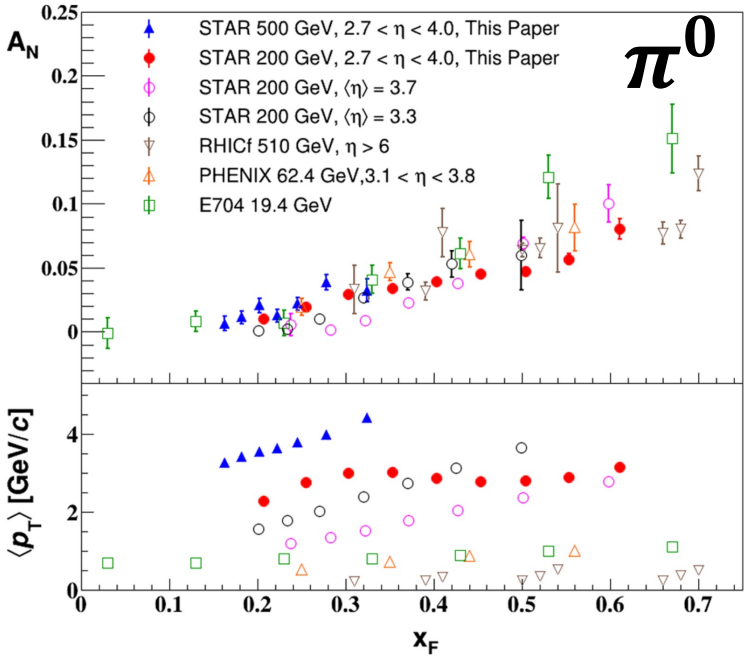
- These frameworks are related to spin structure and orbital angular momentum
- Sivers and Collins frameworks can predict the large A_N (pQCD prediction ~ 0)

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)

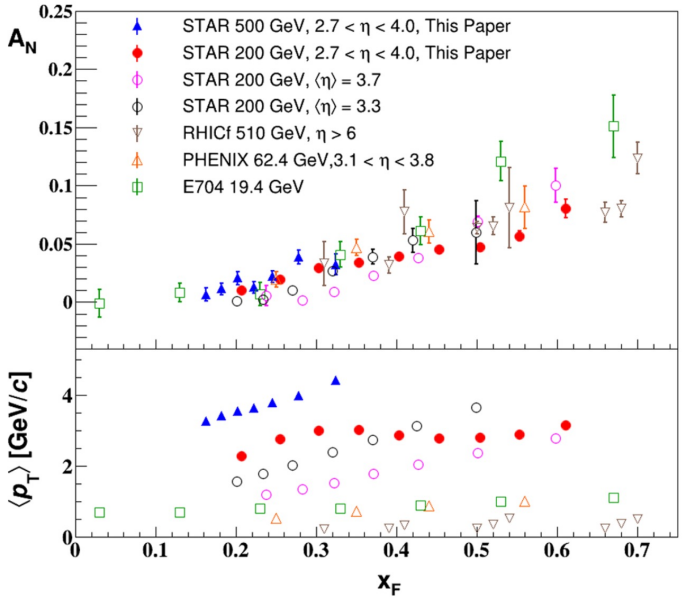


(STAR) J. Adam et al., PRD 103, 092009 (2021)

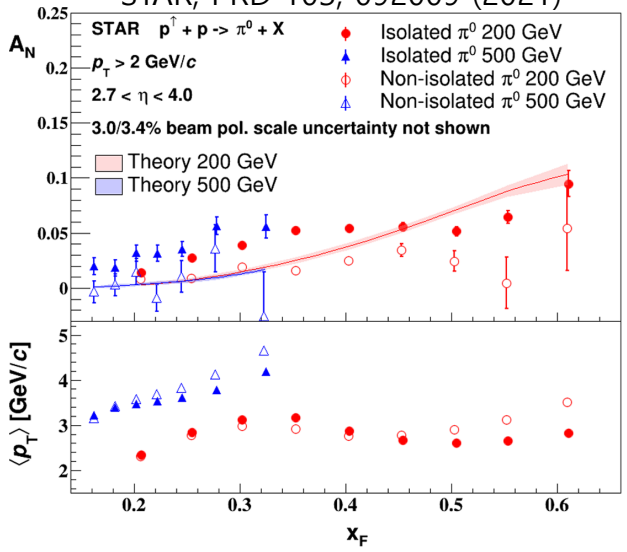
- Non-zero A_N for $\pi^{\pm}$ and π^0 in forward region

Motivation

STAR, PRD 103, 092009 (2021)

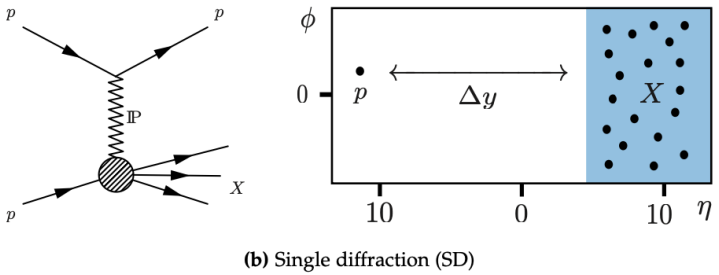


STAR, PRD 103, 092009 (2021)

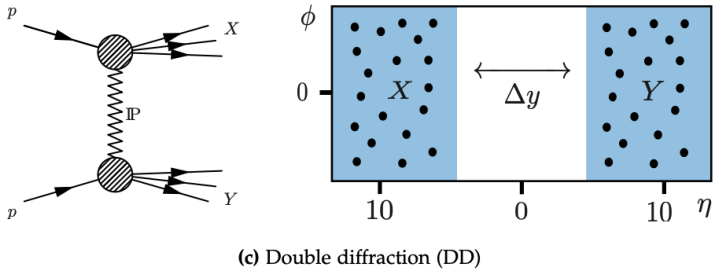


- A_N for forward π^0 $(2.7 < \eta < 4)$ and for RHICf π^0 $(\eta > 6)$ exhibit similar x_F scaling behavior
- RHICf particles are expected to be dominated by the diffractive processes, but contribution from non-diffractive processes is also possible
- Diffractive processes could contribute the large A_N in RHICf coverage
- We want to find out the origin of A_N of π^0 with RHICf+STAR studies

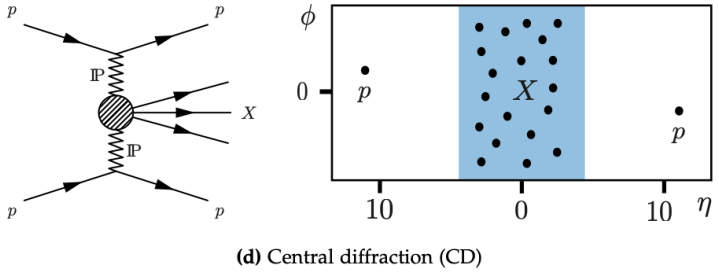
Diffraction in $p + p$ collisions



(b) Single diffraction (SD)



(c) Double diffraction (DD)



(d) Central diffraction (CD)

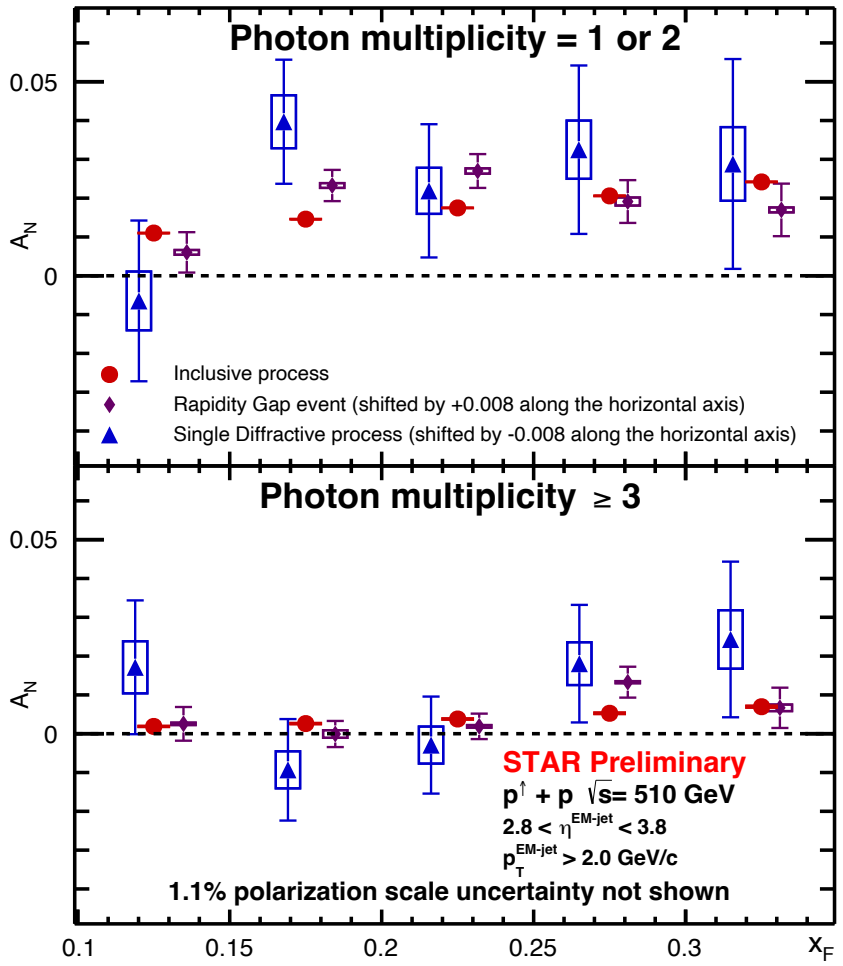
Diffractive process:

- 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}

A_N with diffraction

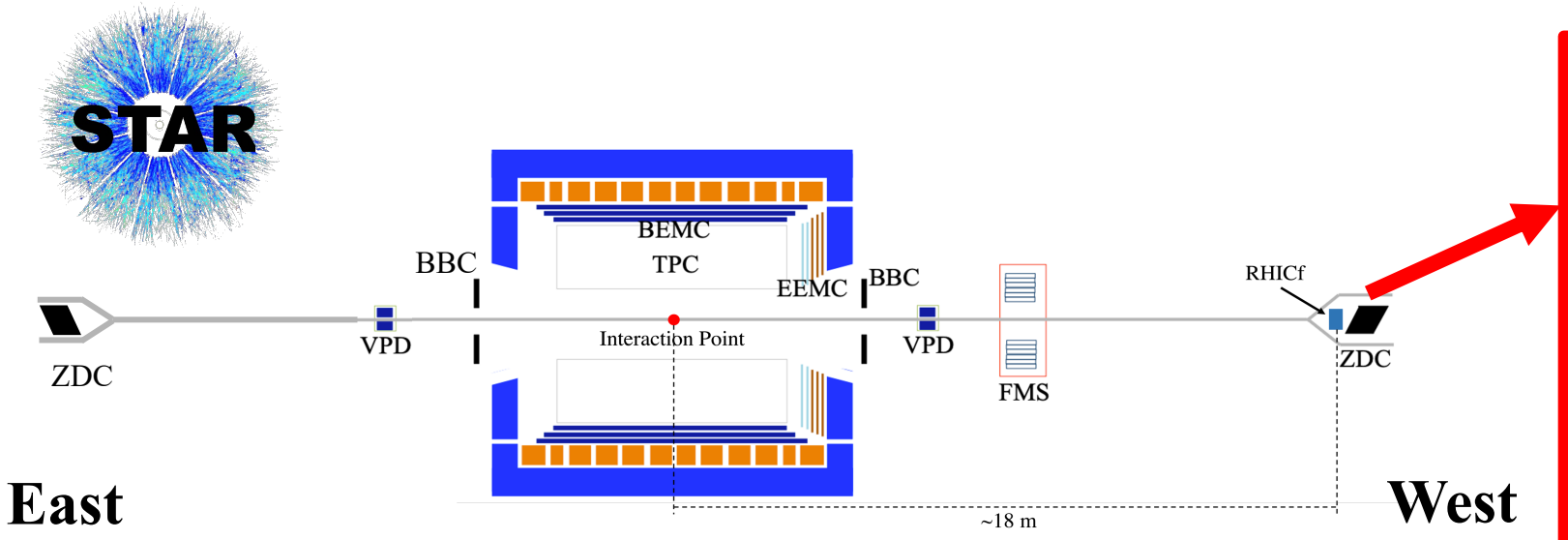
(STAR) Xilin Liang, DIS2025

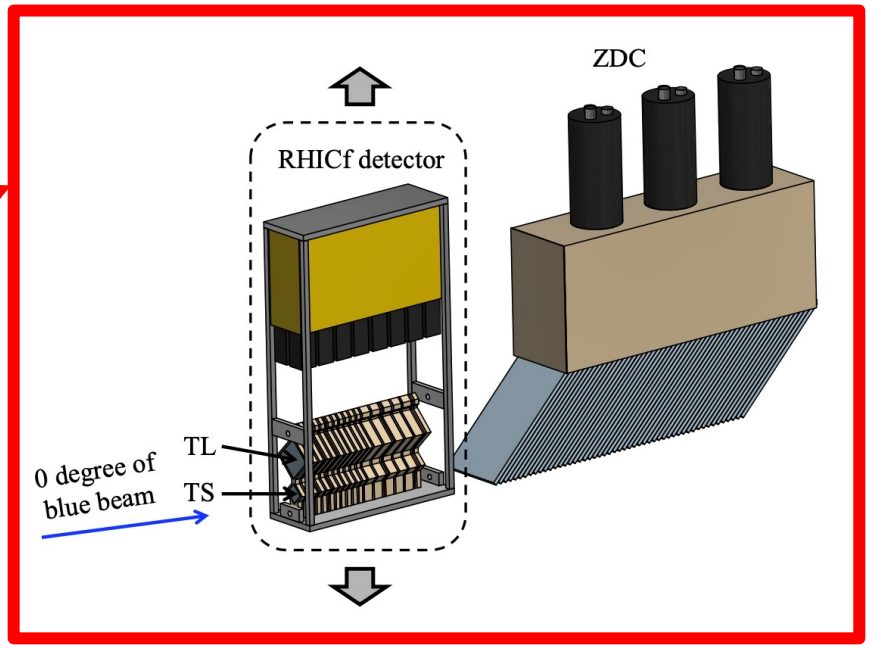


For EM-Jet

- It shows the A_N with diffractive process within $p_{\mathrm{T}} > 2.0$ GeV/c , $2.8 < \eta < 3.8$
- A_N for diffractive process is consistent with inclusive process

RHICf experiment



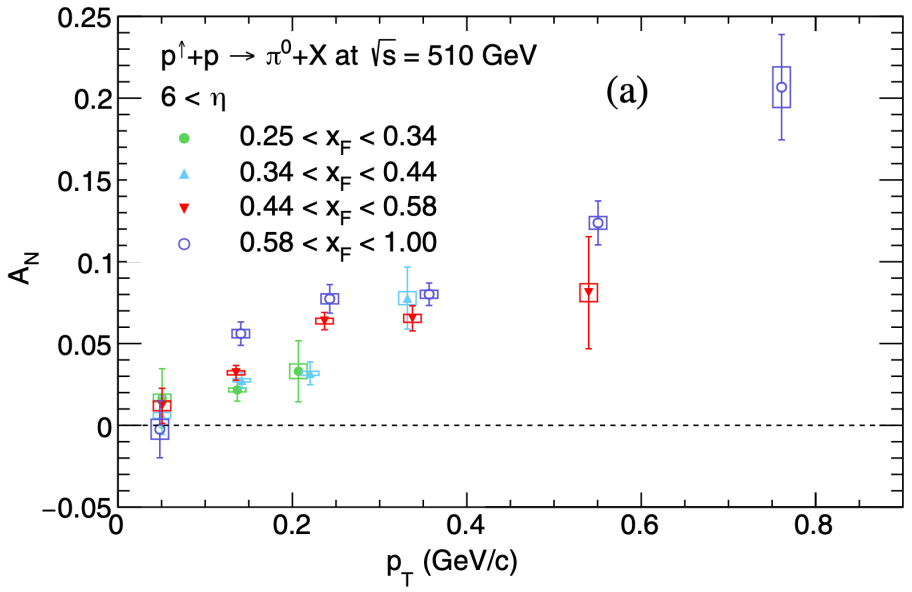


- RHICf detector installed in the far forward (η > 6) region of the STAR detector to collect transversally polarized $p + p$ collisions at $\sqrt{s} = 510$ GeV

- 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

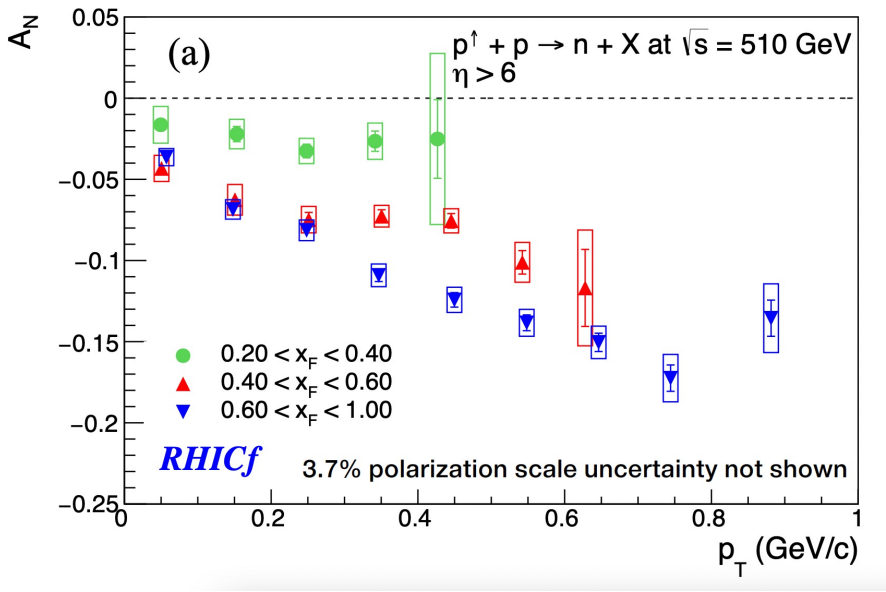
RHICf experiment

RHICf, PRL 124, 252501 (2020)



RHICf π^0

RHICf, PRD 109, 012003 (2024)

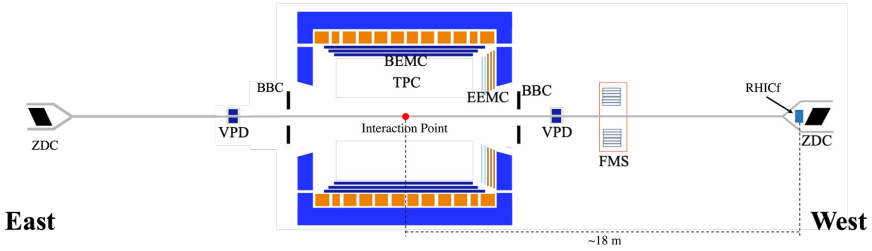


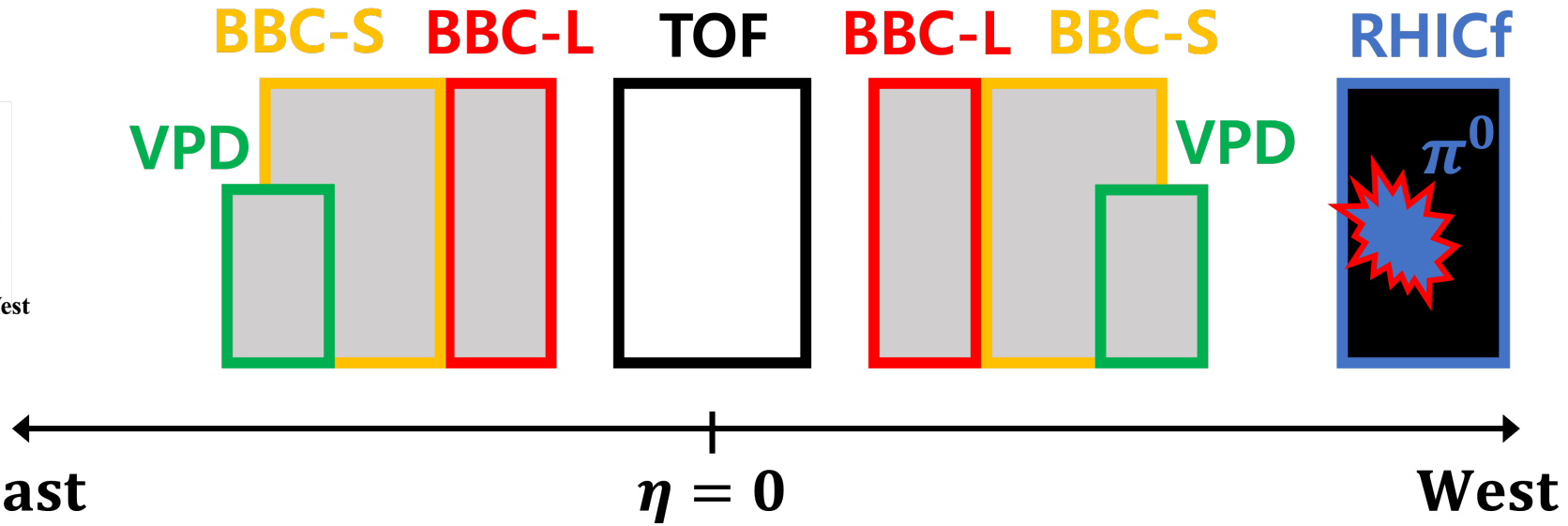
RHICf neutron

- RHICf Collaboration has successfully measured the A_N of π^0 and n in P_T < 1.0 GeV/c and $\eta > 6$

Event classification method

◆Condition definition



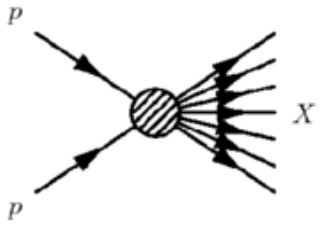


- Detector signal on-off cut is determined by min-bias trigger events
- Event classification method are based on the large rapidity gap in diffractive process

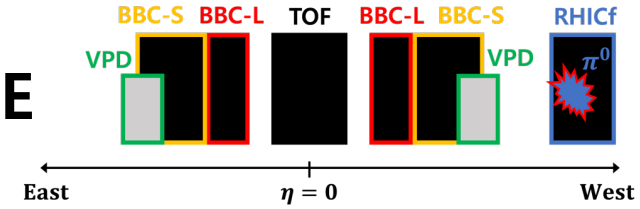
Legend:

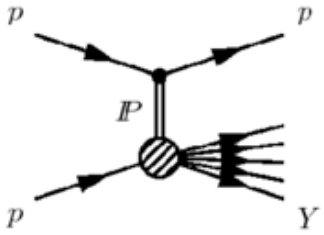
- Always signal
- signal or not
- No signal

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

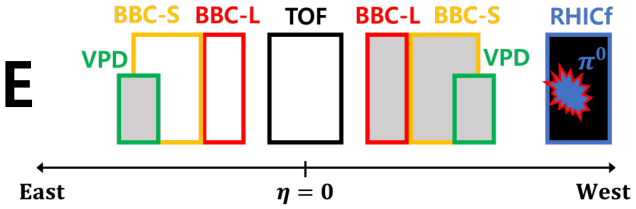


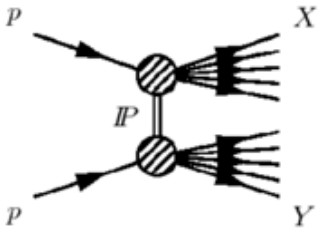
Non Diff. ⟷ NDLE



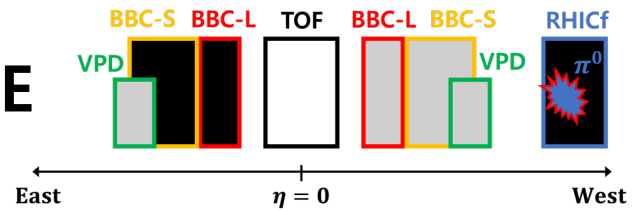


Single Diff. ⟷ SDLE





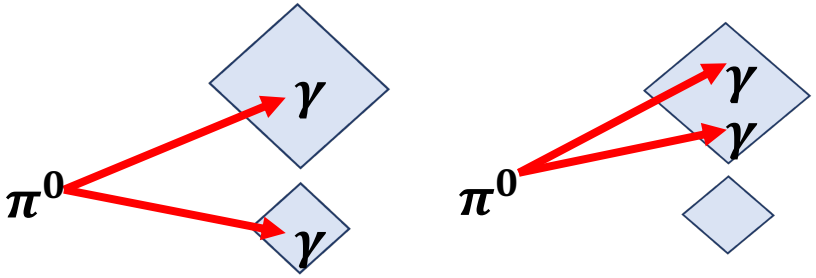
Double Diff. ⟷ DDLE



- We classified the three different processes with detector correlations

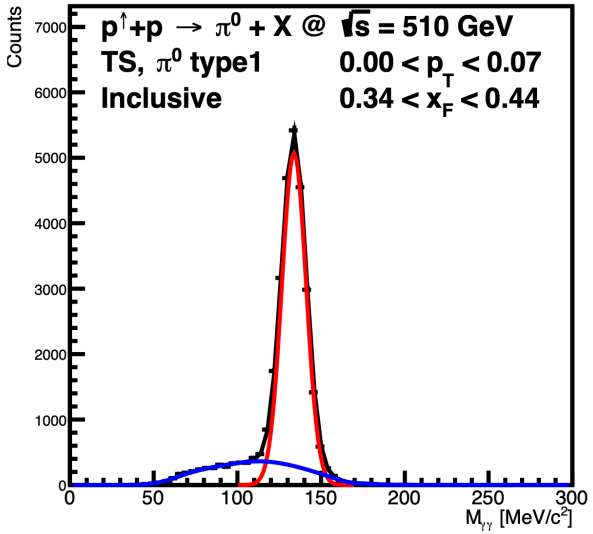
π^0 measurement

◆ **Definition of RHICf π^0 type**

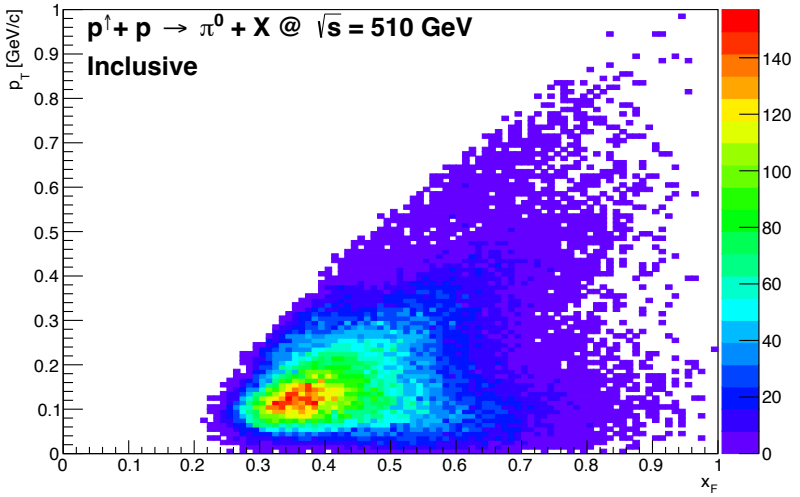


Type-1 π^0 Type-2 π^0

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 and its fitting has been conducted 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 calculation

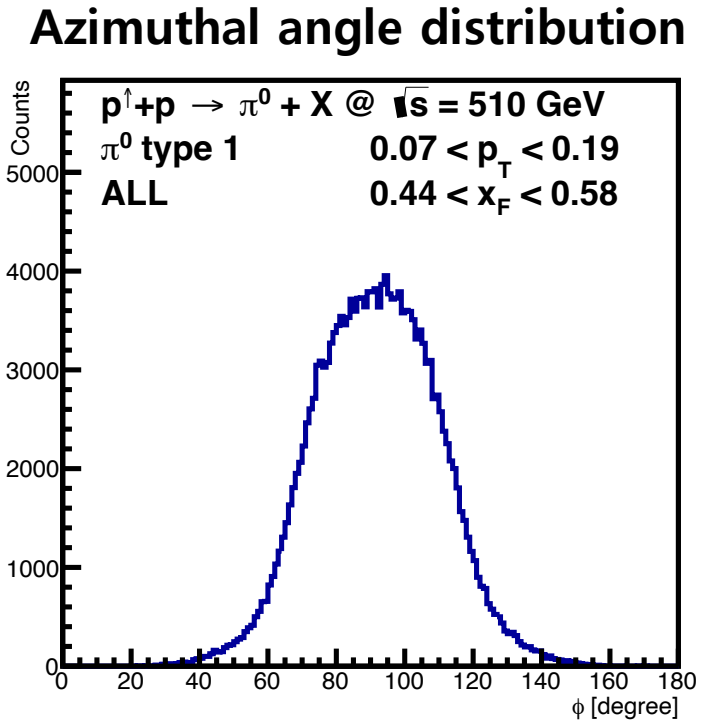
$$A_N = \frac{1}{P\ D_\phi}\left(\frac{N_R^\uparrow - R\ N_R^\downarrow}{N_R^\uparrow + R\ N_R^\downarrow}\right)$$

$\boldsymbol{P}$ = 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 subtraction

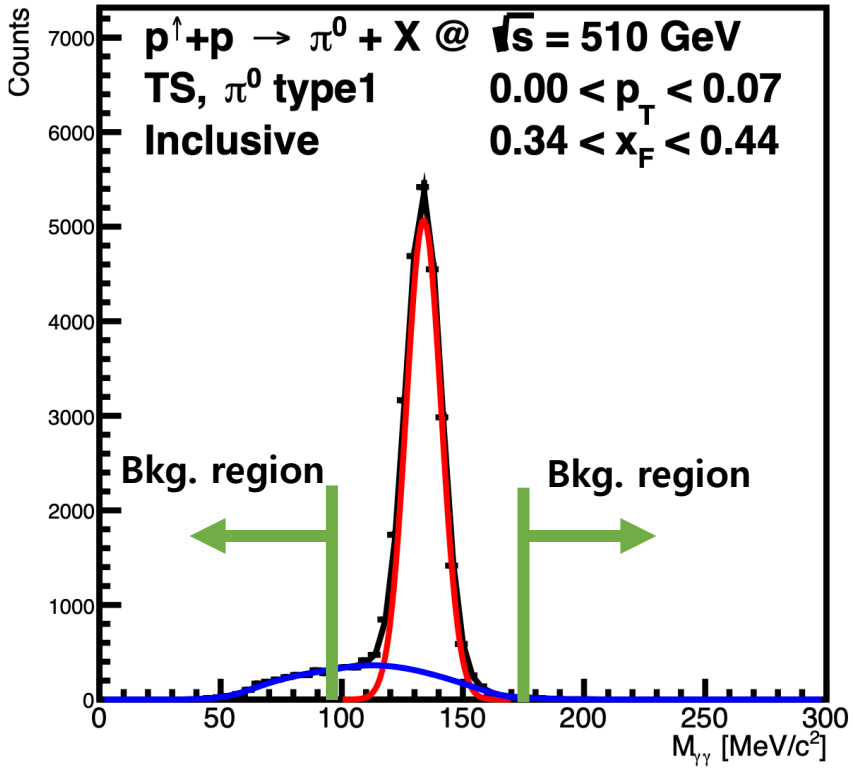
$$A_N^S = \left(1 + \frac{N_B}{N_S}\right) A_N^{S+B} - \left(\frac{N_B}{N_S}\right) A_N^B$$

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

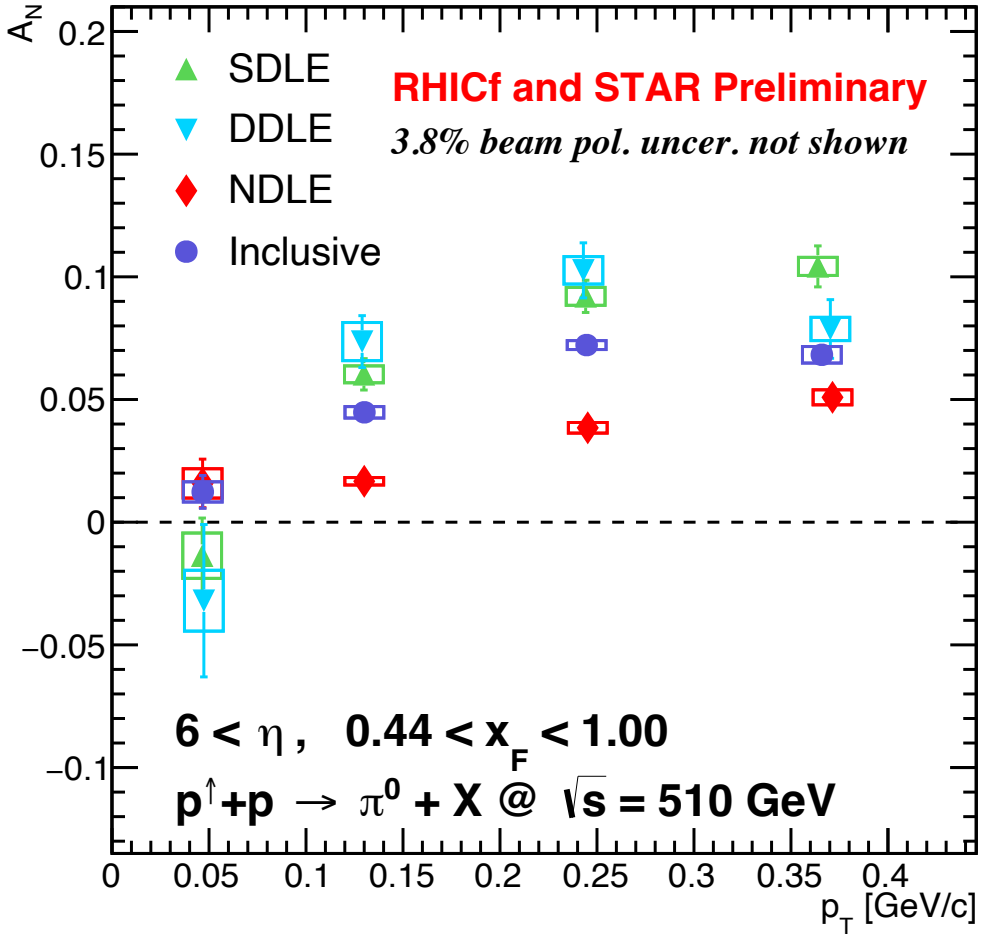
$N_{B(S)}$ = Integrated counts of background (signal) within 3σ

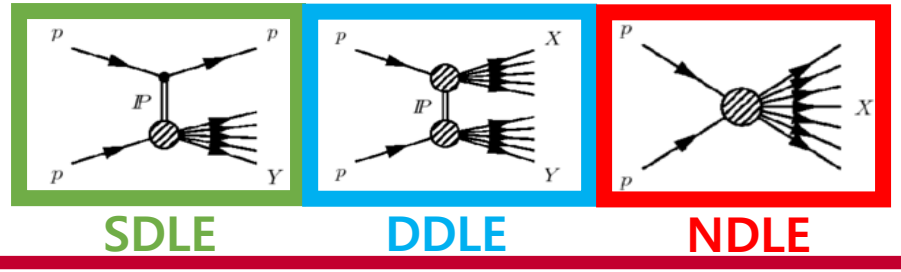


- Background subtraction was performed using A_N^B and the background-to-signal ratio (B/S ratio) within the 3σ of the mass peak

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

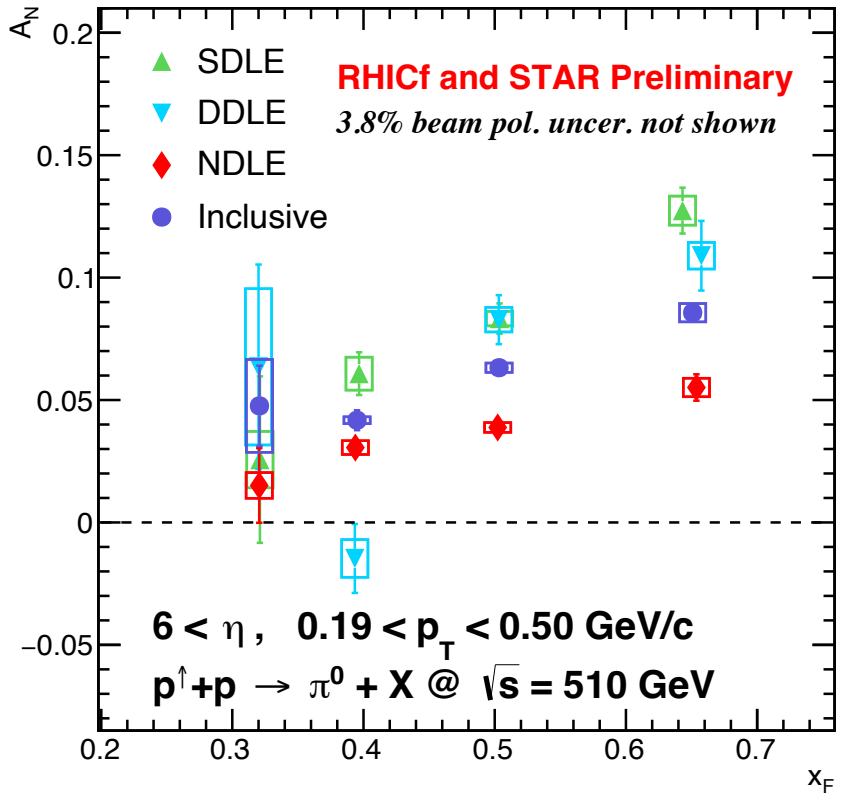
Results

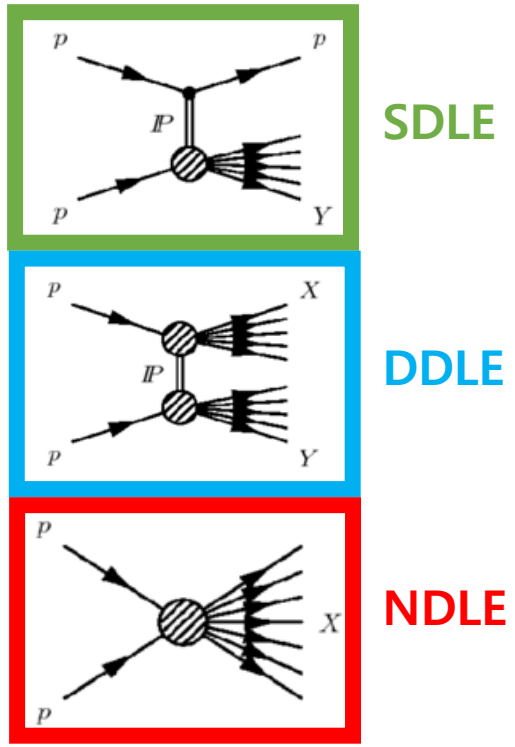




- We observed the non-zero A_N under the SDLE, DDLE and NDLE conditions
- The SDLE and DDLE show similar behavior and exhibit a more enhanced A_N compared to the inclusive
- NDLE condition shows a suppressed A_N relative to the inclusive result

Results





- A_{N} under (N-)DLE conditions exhibit different x_{F} scaling behavior
- Diffractive process may contribute the large A_{N} in $\eta > 6$ region

Summary

- A_{N} was measure for (non-)diffractive like events in $p^{\uparrow} + p$ collision at $\sqrt{s} = 510$ GeV at RHICf and STAR experiments
- Non-zero A_{N} were observed across all classified event types
- A_{N} for SDLE and DDLE show an enhancement relative to the inclusive event
  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.