Measurement of the transverse single spin asymmetry for very forward π^0 production in diffractive and non-diffractive processes

CENuM Workshop

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For the RHICf and STAR Collaborations

Outline

1. Introduction

2. RHICf and STAR experiments

3. Analysis

   3-1 Event classifying

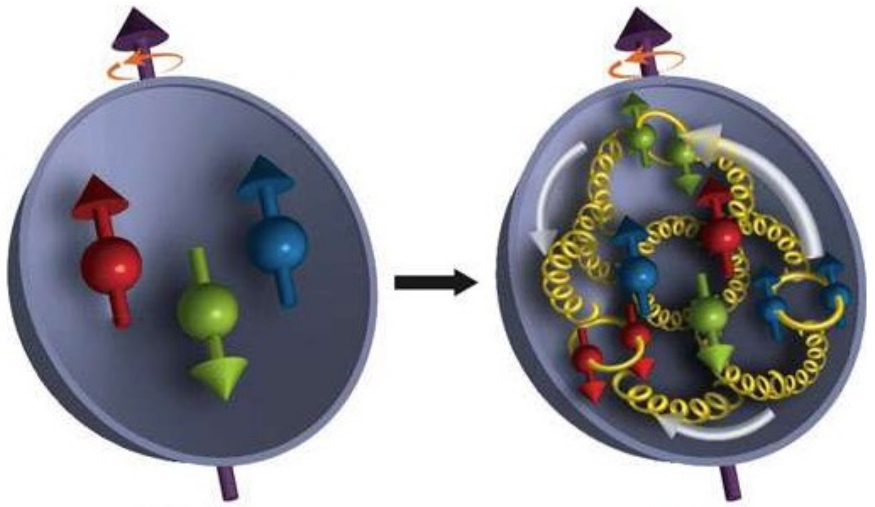
   3-2 Simulation

   3-3 Corrected A_N

4. Summary

Introduction

Proton spin mystery



$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta g + L_Q + L_G$$

q and g spin contribution

Orbital angular momentum of q and g

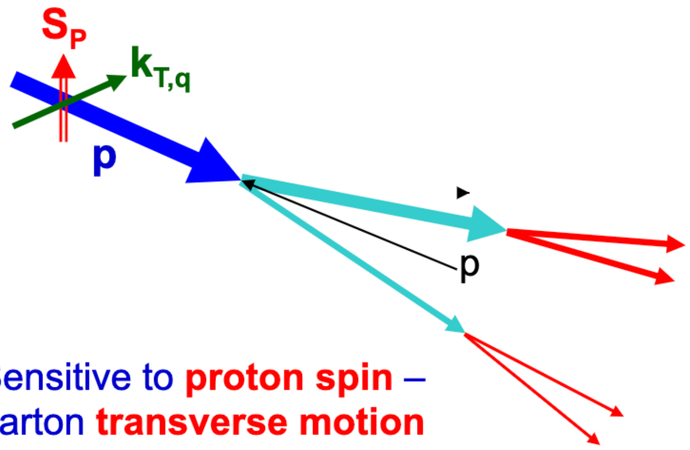
- Quarks only carried **30%** of the proton spin
- We don't understand the component of proton spin yet

Transverse single spin asymmetry (TSSA)

- **Theorical background**

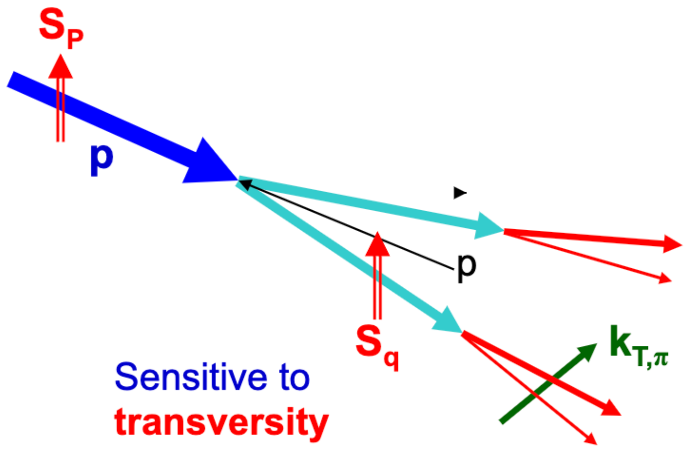
Sivers and Collins effects in pp collisions

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

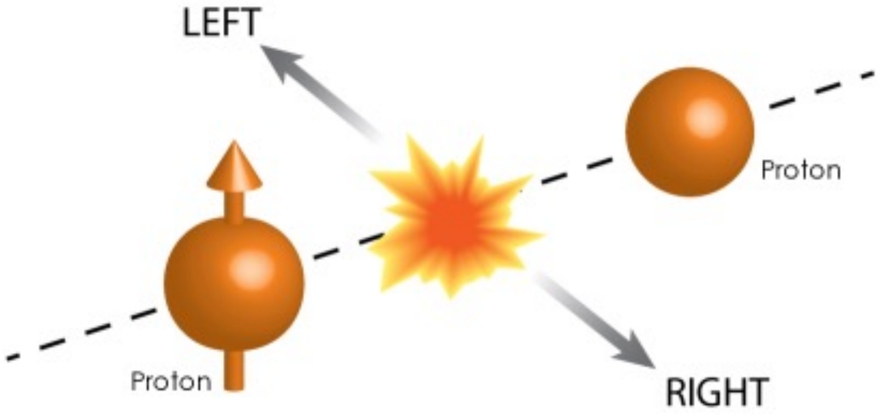


Sensitive to **transversity**

- These frameworks are related to spin structure and orbital angular momentum

Transverse single spin asymmetry (TSSA)

- **Definition**



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

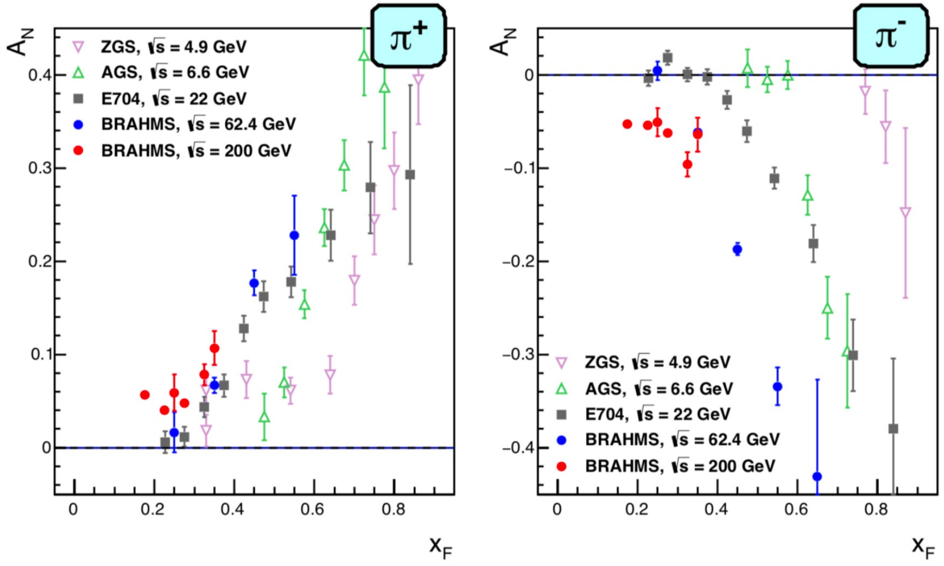
- A_{N} represents the asymmetric production of scattered final-state particles depending on the spin direction of the incoming particles.

- Sivers and Collins frameworks can predict the large A_{N} (pQCD prediction ~ 0)

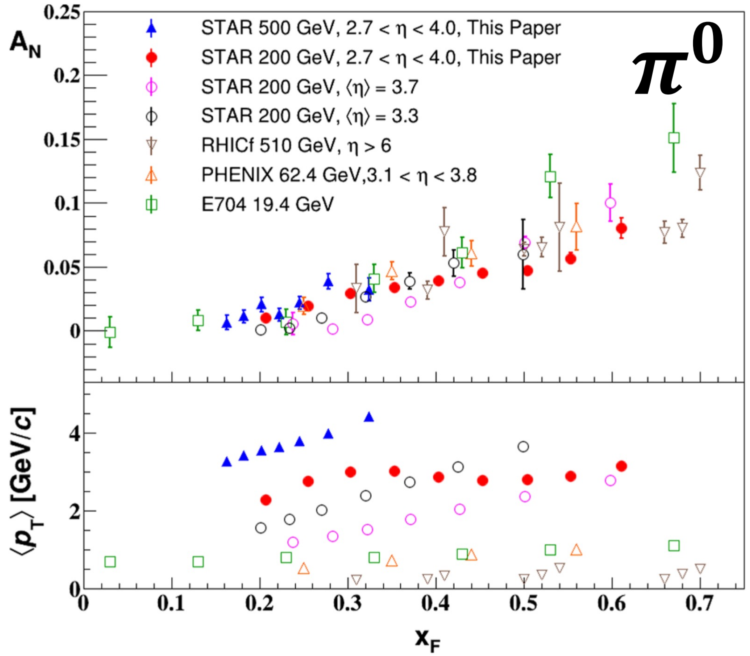
Transverse single spin asymmetry (TSSA)

- **Measurements**

E.C. Aschenauer et al., arXiv:1602.03922

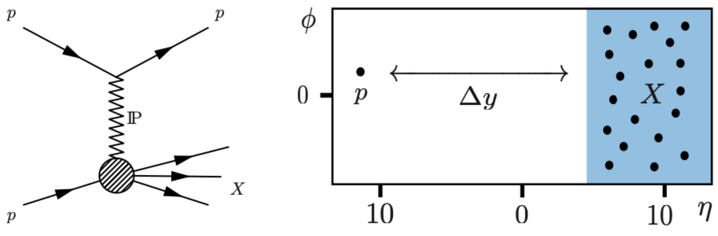


(STAR) J. Adam et al., PRD 103, 092009 (2021)

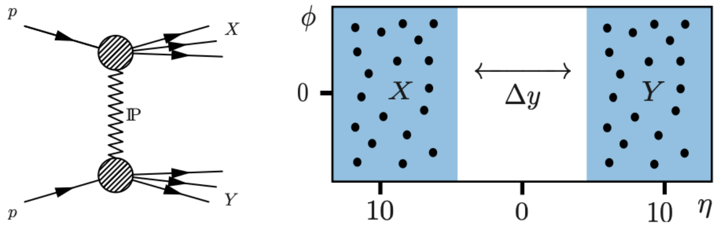


- A_{N} for charged pion and neutral pion in forward region behavior non-zero

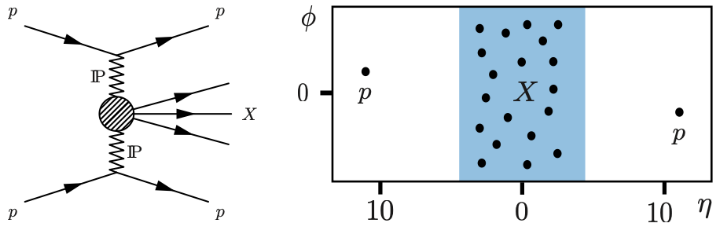
Diffraction in p-p collision



(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 the TSSA

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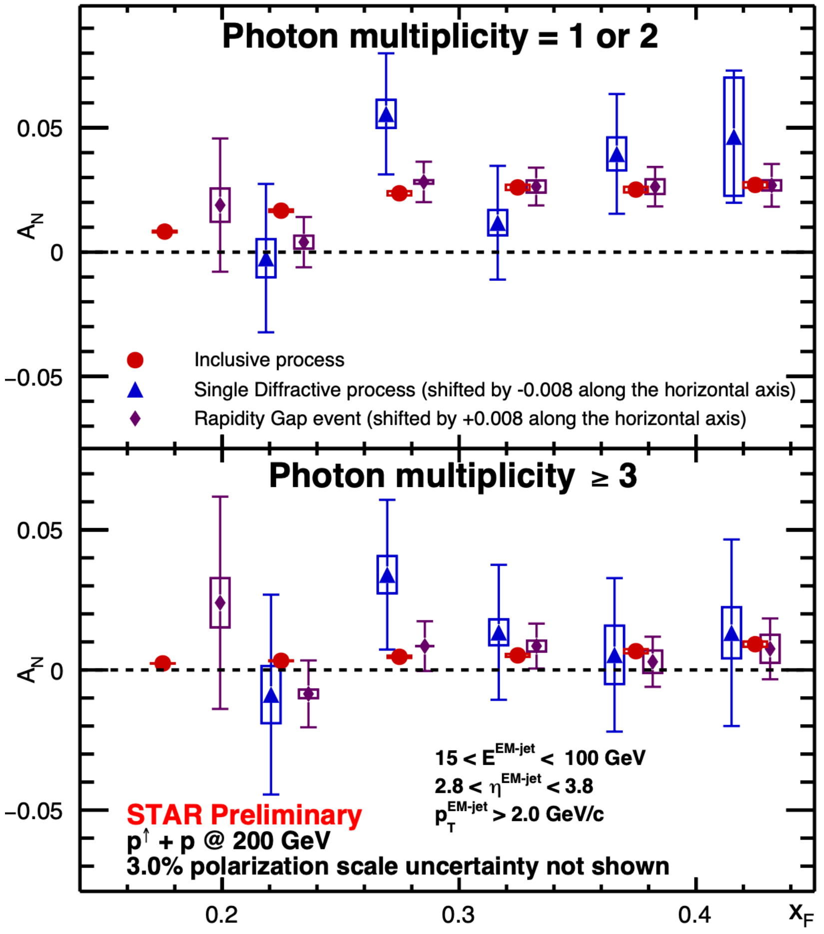
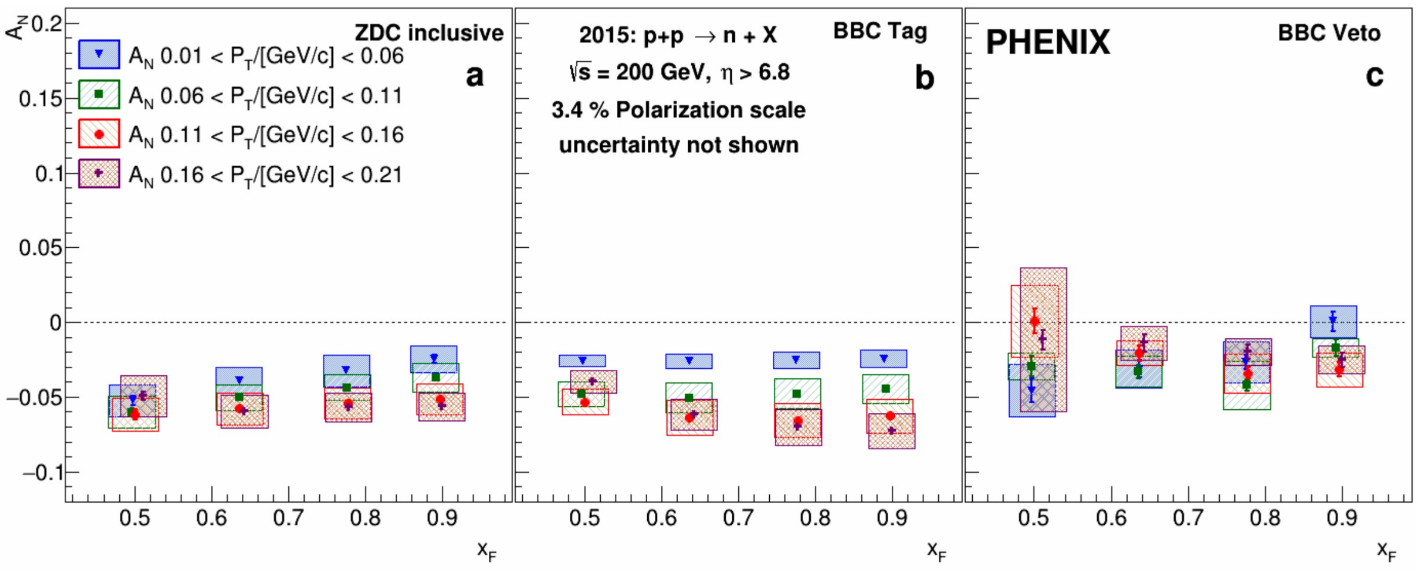
TSSA with Diffraction

(STAR) Xilin Liang, DIS2024



For EM Jet

PHENIX Collaboration, Phys. Rev. D **105**, 032004 (2022)

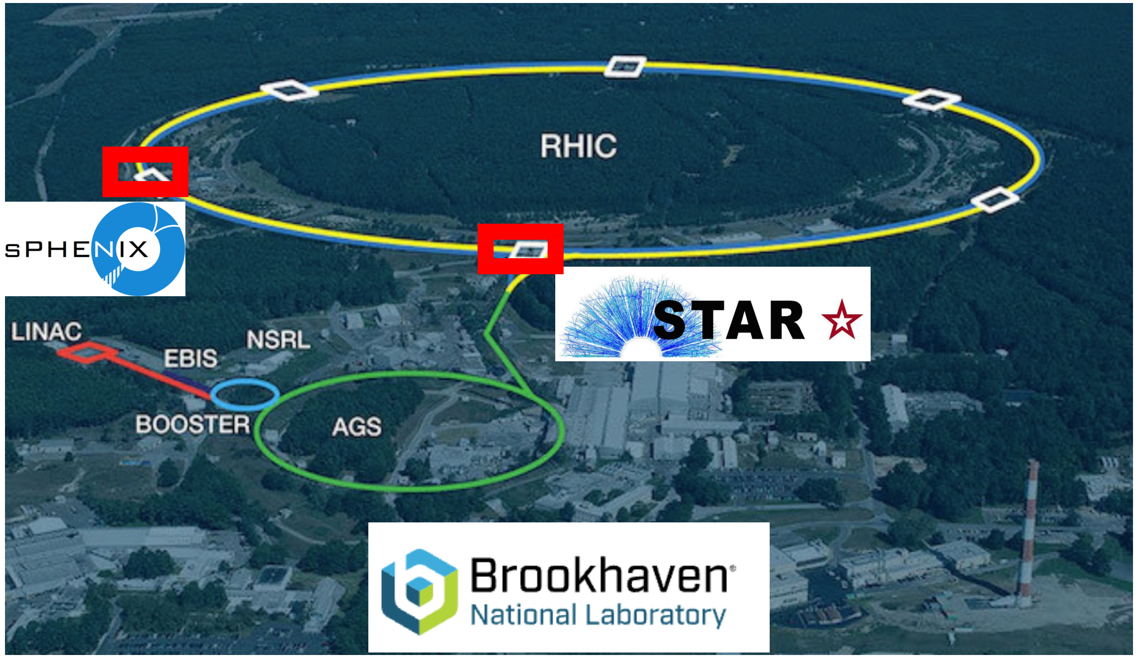


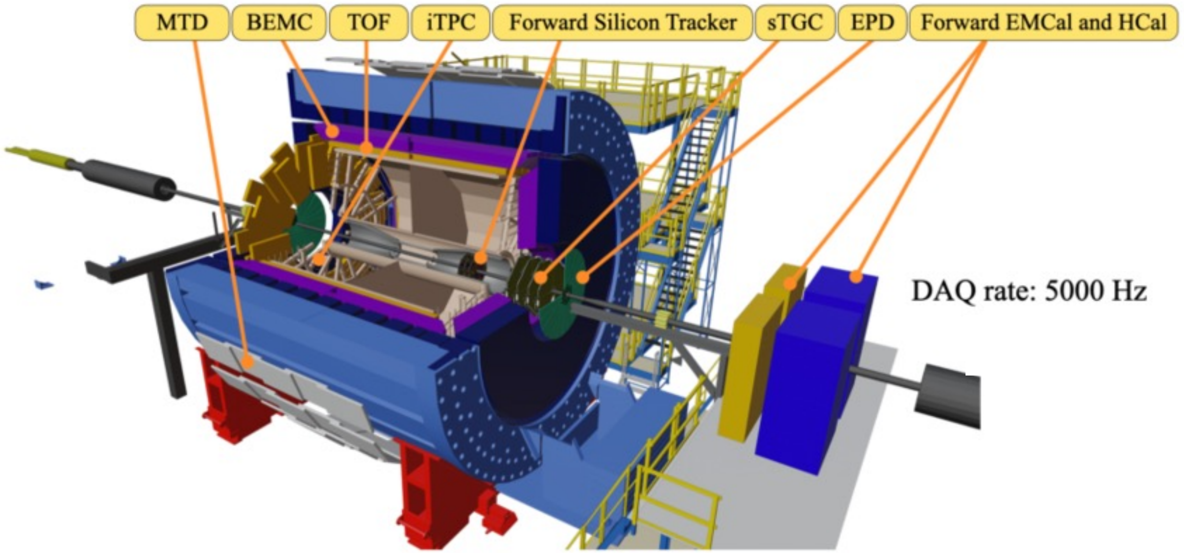
For Neutron

- These show the A_N with diffractive process

RHICf and STAR experiments

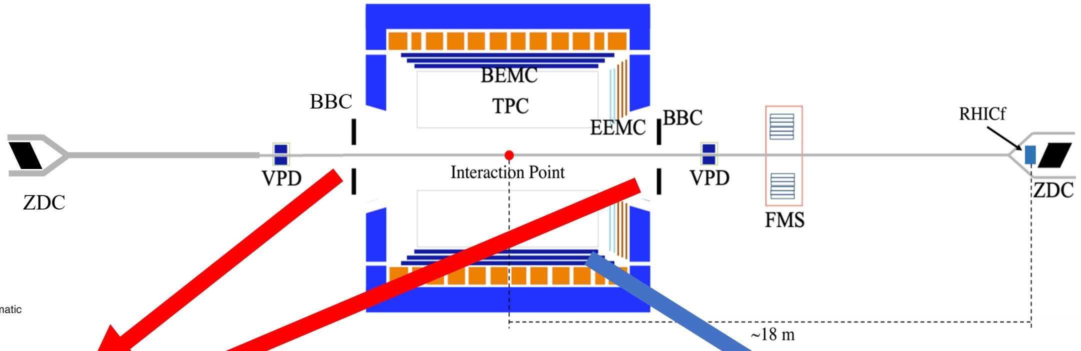
STAR experiment

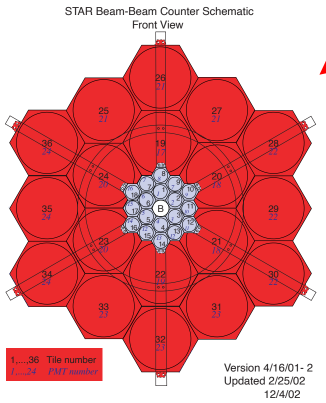




- RHIC collider can produce the (transversally or Longitudinally) polarized proton beam
- $p + p$ collision @ $\sqrt{s} = 510\ \mathrm{GeV}$
- Proton polarization efficiency up to 70%

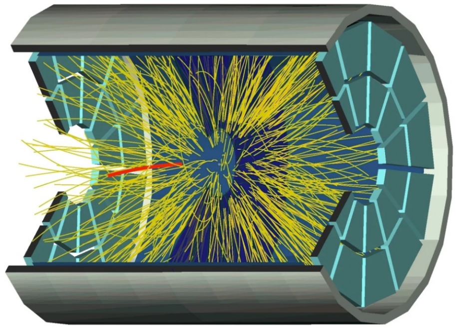
STAR detectors





STAR BBC (Beam-Beam Counter)

- BBC-Large (2.2 < $|\eta|$ < 3.4)
- BBC-Small (3.4 < $|\eta|$ < 5.0)

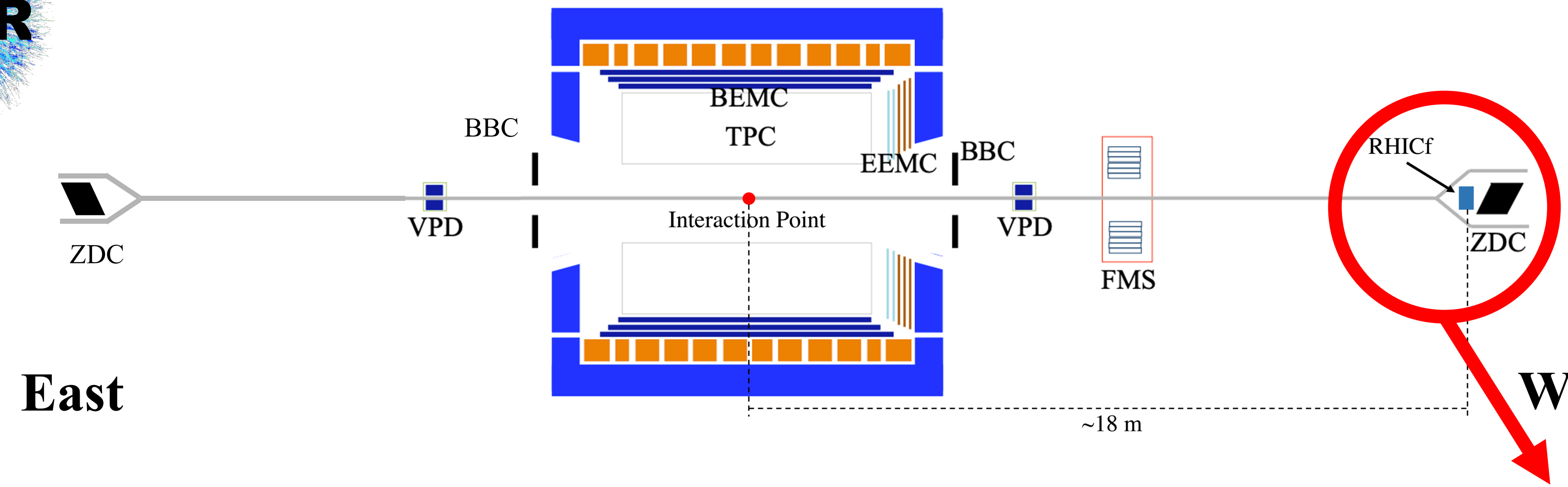


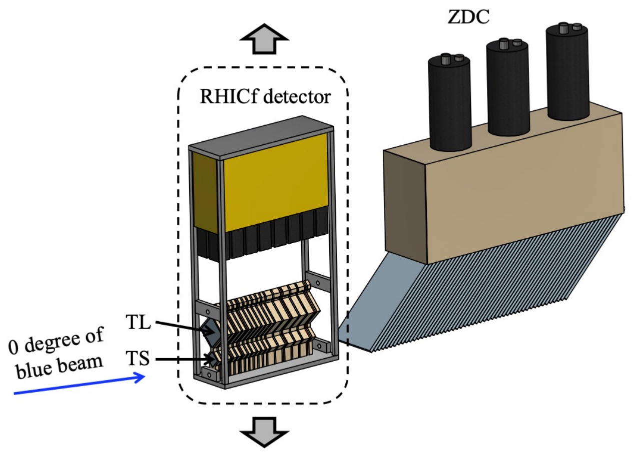
STAR B-TOF (Barrel Time-Of-Flight)

$(|\eta| < 1)$

- BBC and B-TOF are used in this study

RHICf experiment



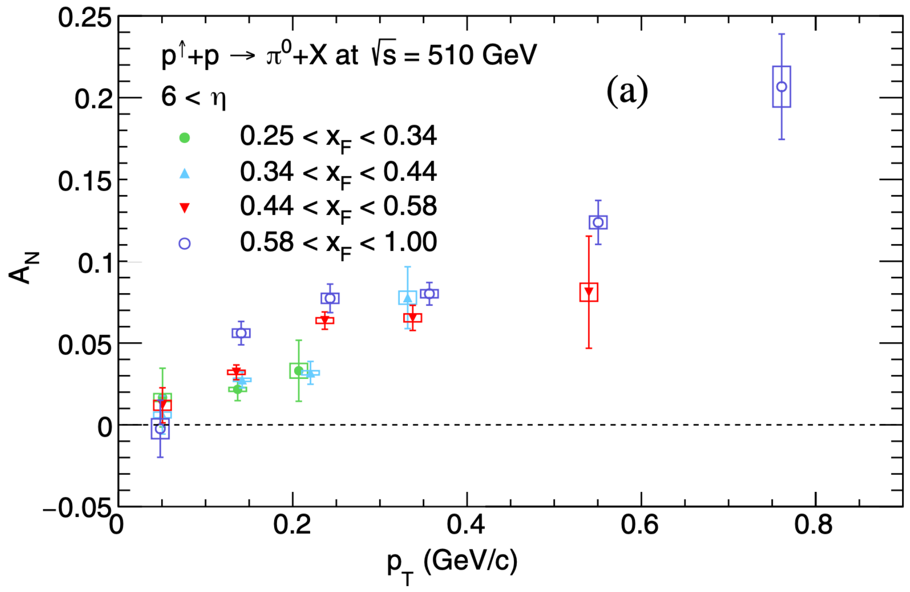


- In 2017, RHICf experiment had been installed in STAR experiment
- RHICf detector was developed as Arm1 detector for LHCf

RHICf experiment

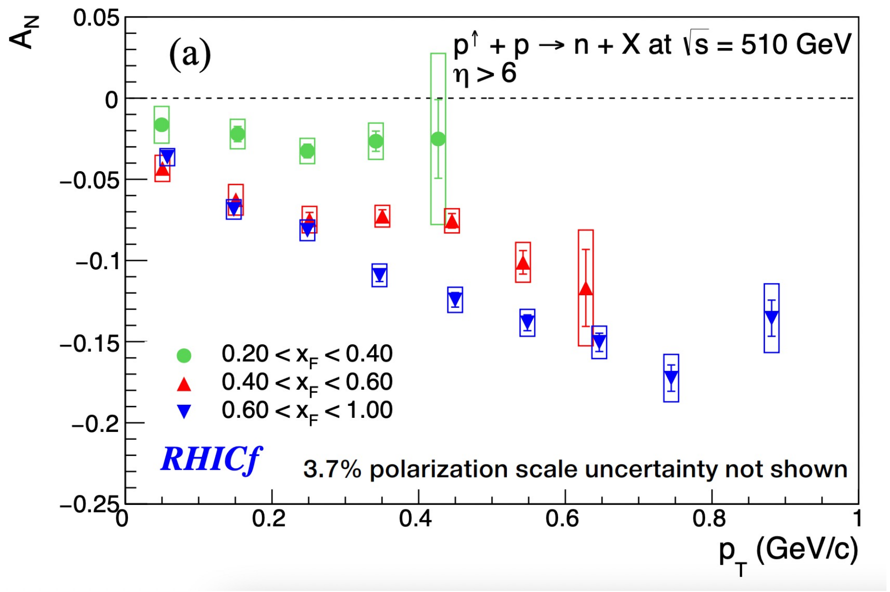
RHICf π^0

M.H.Kim et al, PRL 124, 252501 (2020)



RHICf Neutron

M.H.Kim et al, PRD **109**, 012003 (2024)



- RHICf had run for polarized $p^{\uparrow} + p$ collisions at $\sqrt{s} = 510$ GeV (Luminosity ~ 10^{31} cm^{-2} s^{-1})
- Able to measure particles in 0.0 < P_T < 1.0 GeV/c and $6 < \eta < 11$

Motivation

- RHICf π^0 and Neutron is expected to be dominated by the diffractive processes
  ($6 < \eta < 11$)

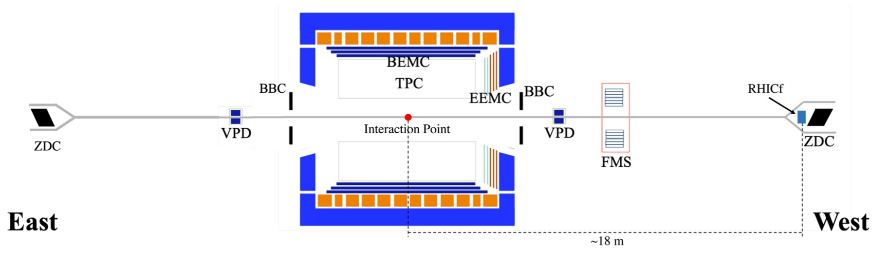
- It is possible that RHICf particles originated from diffractive and non-diffractive.

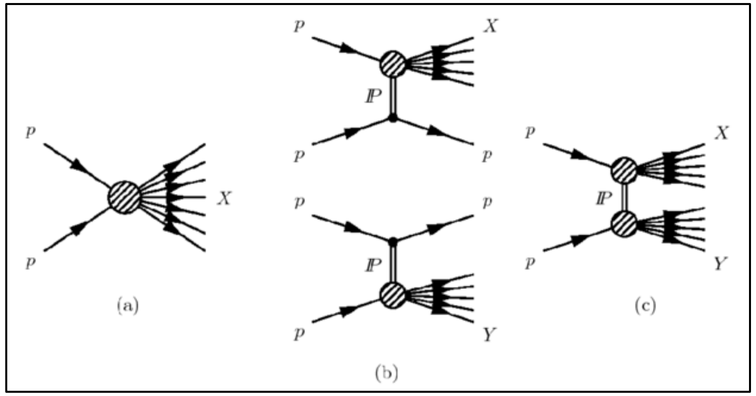
- We want to find out the originating of TSSA of π^0 and Neutron with RHICf+STAR study

Analysis

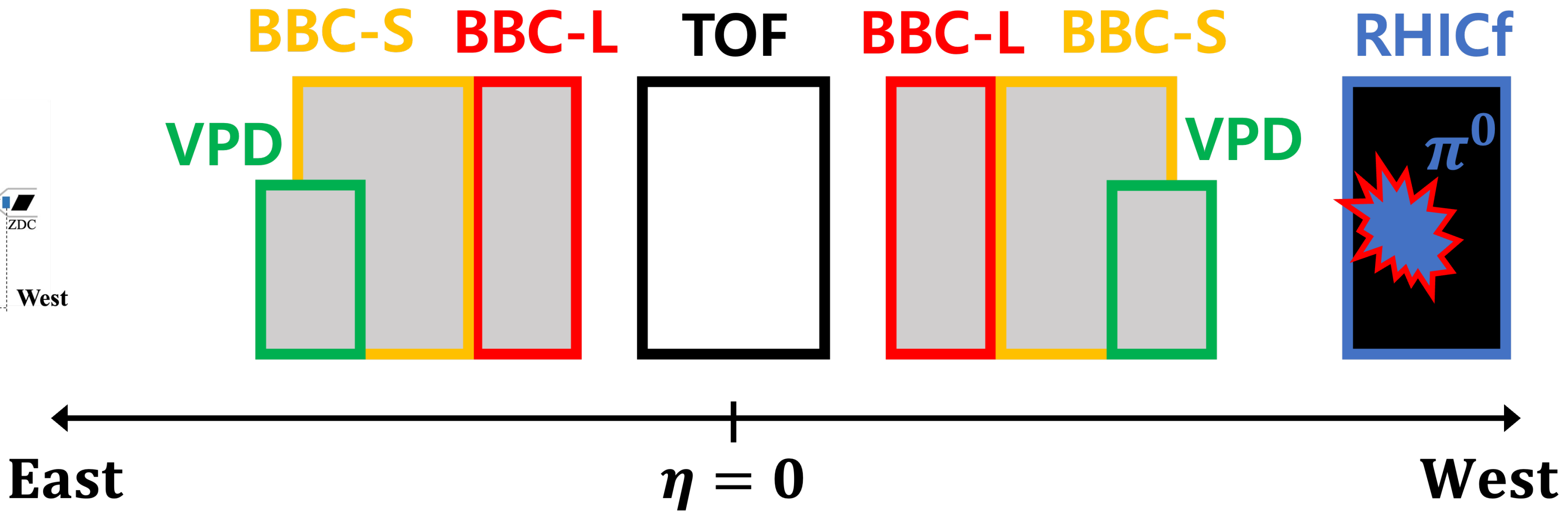
Event classification

◆Condition definition

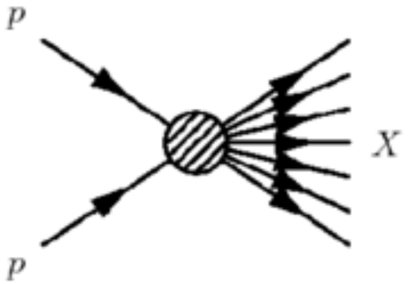




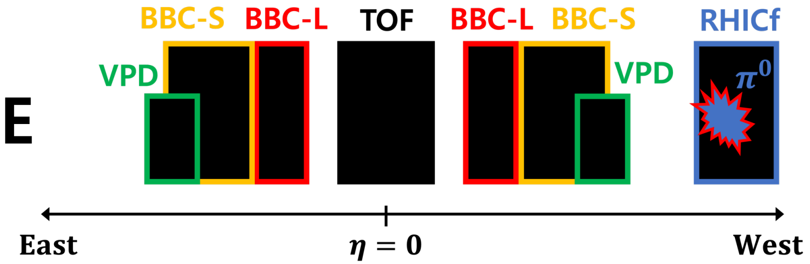
Diffractive processes

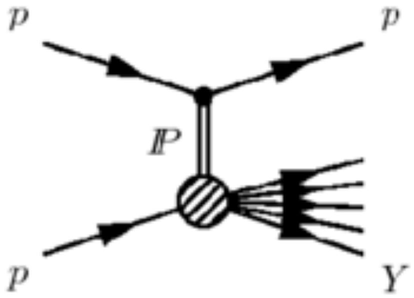


(Non-)Diffractive-Likely-Event (DLE)

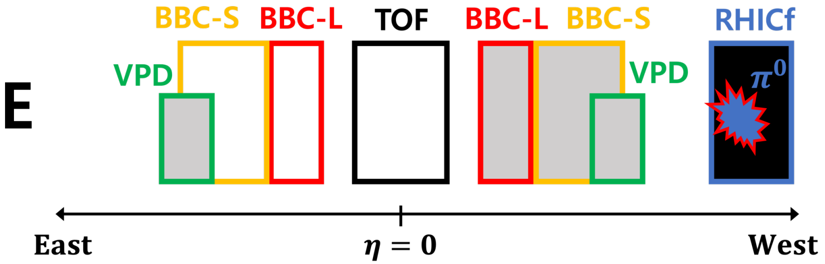


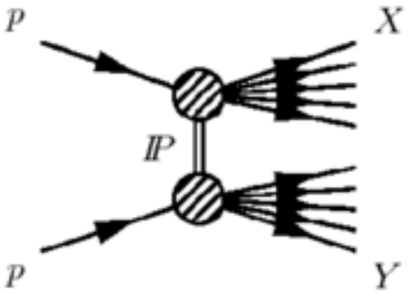
Non Diff. ⟷ **NDLE**



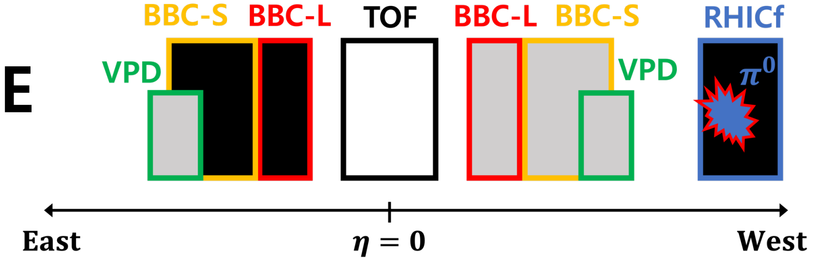


Single Diff. ⟷ **SDLE**





Double Diff. ⟷ **DDLE**

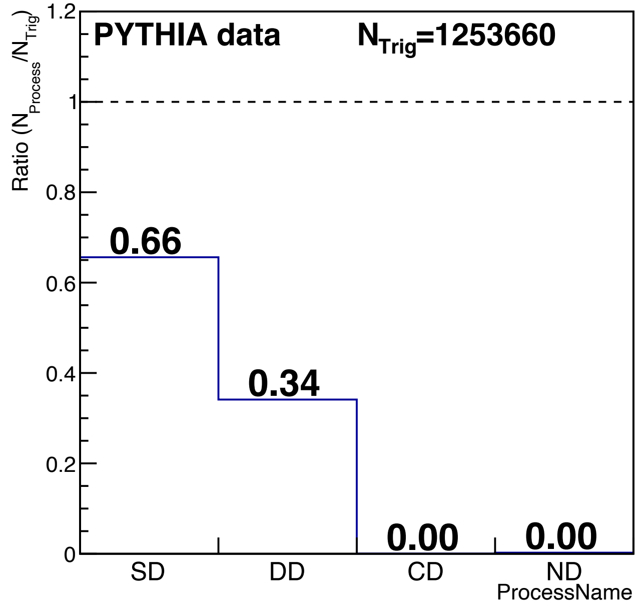


RHICf+STAR simulation

- **Event generators:**

1. **PYTHIA8 Detroit tune, SoftQCD**
2. HERWIG7 Soft tune
3. EPOS-LHC
4. QGSJETII-04

Example R_C



- **Definition of contamination ratio, R_C**

$$R_C = \frac{N_{process}}{N_{Trig}}$$

$N_{process}$ = number of each **truth** process events in selected events

N_{Trig} = number of selected events according to conditions

- This data set also designed for checking the ratio of processes in each condition events

Contamination Ratio, R_C

- **For π^0**

- Each condition has a truth process ratio of more than 80%
- Other processes are slightly contribute in each DLE

Contamination Ratio, R_C

- **For Neutron**

A_N correction

- **Correction method**

$$R^{C}_{i,j} \cdot A^{corr}_{N,j} = A^{measured}_{N,i}$$

$$\begin{pmatrix} R^{C}_{SDLE,SD} & R^{C}_{SDLE,DD} & R^{C}_{SDLE,ND} \\ R^{C}_{DDLE,SD} & R^{C}_{DDLE,DD} & R^{C}_{DDLE,ND} \\ R^{C}_{NDLE,SD} & R^{C}_{NDLE,DD} & R^{C}_{NDLE,ND} \end{pmatrix} \begin{pmatrix} A^{corr}_{N,SD} \\ A^{corr}_{N,DD} \\ A^{corr}_{N,ND} \end{pmatrix} = \begin{pmatrix} A^{measured}_{N,SDLE} \\ A^{measured}_{N,DDLE} \\ A^{measured}_{N,NDLE} \end{pmatrix}$$

$R^{C}_{i,j}$ = DLE contamination ratio matrix

$A^{corr}_{N,i}$ = corrected DLE A_N matrix

$A^{measured}_{N,i}$ = measured DLE A_N matrix

Corrected A_{N} for π^0

- Systematic uncertainty for MC statistics not shown (scale ~ 10^{-5})

Corrected A_N for Neutron

- Systematic uncertainty for MC statistics not shown (scale ~ 10^{-5})

Summary

- Diffractive processes might be contributed to TSSA
- RHICf experiment measured the A_{N} for π^0 and Neutron ($\eta > 6$)
- (Non-)Diffractive Event classification conducted with RHICf+STAR correlation study
- A_{N} for RHICf π^0 and Neutron significantly depend on diffractive processes
- More detailed measurements with several models will be studied
- Preliminary result will be received and present on INPC2025

Thank you