Transverse Single Spin Asymmetry for Inclusive and Diffractive Electromagnetic Jets at Forward Rapidity in $p^{\uparrow}+p$ Collisions at $\sqrt{s} = 200$ GeV and 510 GeV at STAR

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25th International Spin Symposium (SPIN 2023)
Duke University, Durham, NC
Sept. 25, 2023

Supported in part by

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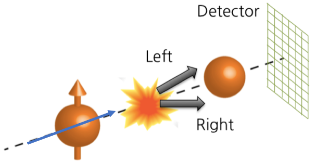
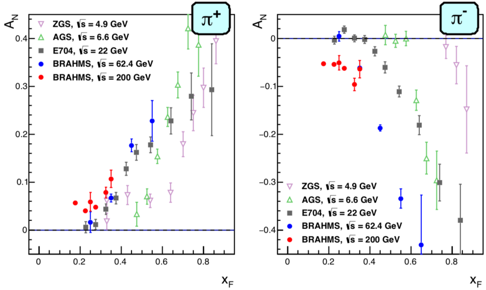
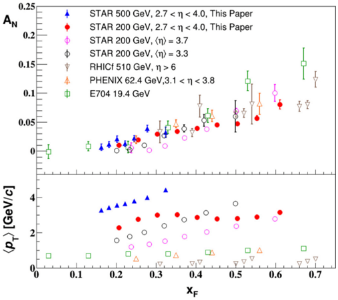
U.S. DEPARTMENT OF ENERGY

- $A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$
- pQCD predicts $A_N \sim \frac{m_q \alpha_s}{\sqrt{s}} \sim 0.001$
- Large A_N at forward region is observed in proton-proton collisions
  - eg. $p^{\uparrow} + p \rightarrow \pi + X$







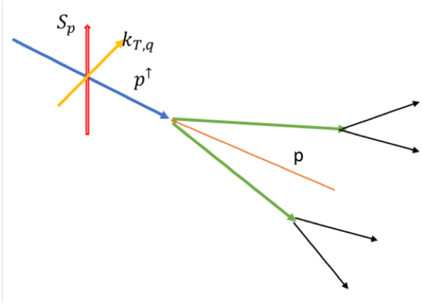
References:

- E.C. Aschenauer *et al.*, arXiv:1602.03922
- (STAR) J. Adam *et al.*, Phys. Rev. D 103, 092009 (2021)

Possible Mechanisms for TSSA

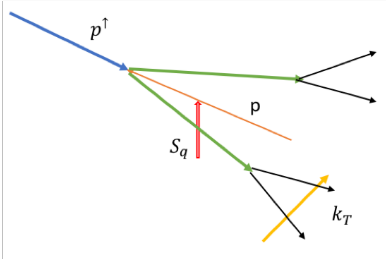
- **TMDs framework**:

Sivers effect : correlation between initial parton k_T and proton spin S_p



Ref: D. Sivers, Phys. Rev. D 41, 83 (1990)

Collins effect : correlation between fragmentation hadron k_T and its parent quark spin S_q



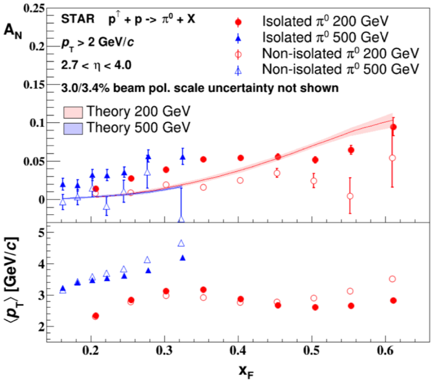
Ref: J. Collins, Nucl Phys B 396 (1993) 161

- **Twist-3**: Quark-gluon / gluon-gluon correlations and fragmentation functions

Ref: J.W. Qiu and G. Sterman, Phys. Rev. Lett. 67 2264 (1991)

Indication of Large TSSA from Diffractive Process

- Previous analysis of A_N for forward π^0 in $p^{\uparrow} + p$ collisions at STAR
  - Inclusive π^0 A_N: Isolated π^0 has larger A_N than non-isolated π^0
  - Isolated π^0: No other surrounding photons
- It indicates that there might be non-trivial contributions to the large A_N from diffractive processes

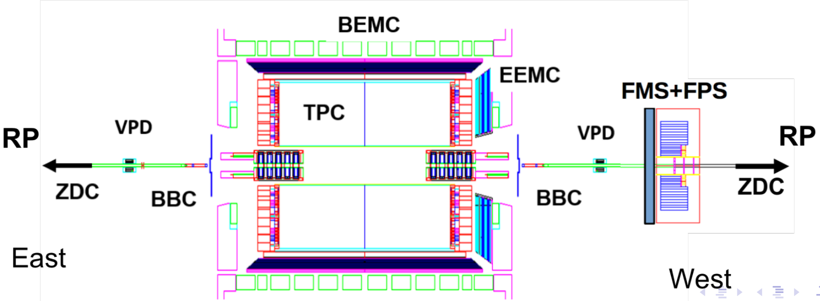


Ref: (STAR) J. Adam *et al.*, Phys. Rev. D 103, 092009 (2021)

The STAR Experiment

The STAR Experiment is at a collision point at Relativistic Heavy Ion Collider (RHIC) located at Brookhaven National Laboratory (BNL).

- STAR sub-detectors used in measuring the A_N
  - Forward Meson Spectrometer (FMS): $2.6 < \eta < 4.2$, $\phi \in (0, 2\pi)$
  - Roman Pot (RP): detect scattered protons
  - Triggering, determining vertex:
    - Beam-Beam Counter (BBC)
    - Vertex Position Detector (VPD)
    - Zero Degree Calorimeter (ZDC)



Datasets and Electromagnetic Jets (EM-jets)

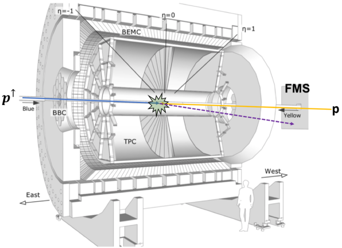
Year	$\sqrt{s}$ [GeV]	$\mathcal{L}$ [pb^{-1}]	Polarization orientation	Polarization P [%]
2015	200	52	Transverse	57
2017	510	350	Transverse	55

- Inclusive and diffractive EM-jet A_N studies using STAR 2015 and 2017 data
  - These are the currently available datasets at forward region with high luminosity and good beam polarization
  - The analysis results for STAR 2015 data and statistical projections for STAR 2017 data will be presented
- Electromagnetic jets (EM-jets) are jets that consist of only photons
  - FMS can detect photons, neutral pions, and eta mesons in the forward direction
  - Unable to detect charged hadrons at the forward region for these 2 datasets

Inclusive EM-jet A_N at Forward Rapidity using FMS

★ Motivation:

- Explore potential sources of large A_N
- Characterize EM-jet A_N as a function of EM-jet p_T, energy and photon multiplicity



★ EM-jet reconstruction for inclusive processes:

- Only reconstructed FMS photon candidates as input for jet reconstruction: Anti-k_T algorithm with R = 0.7
- Minimum EM-jet p_T requirement based on trigger threshold or fixed threshold depending on the dataset

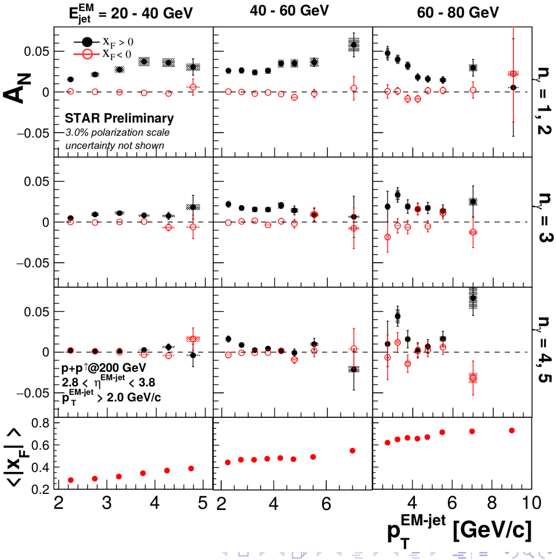
★ Corrections for EM-jets based on simulation:

- PYTHIA 6.4 Perugia 2012 with GEANT based STAR detector simulation

- EM-jet p_T is corrected for Underlying Event using off-axis cone method
- EM-jet energy is corrected to the particle level based on the simulation

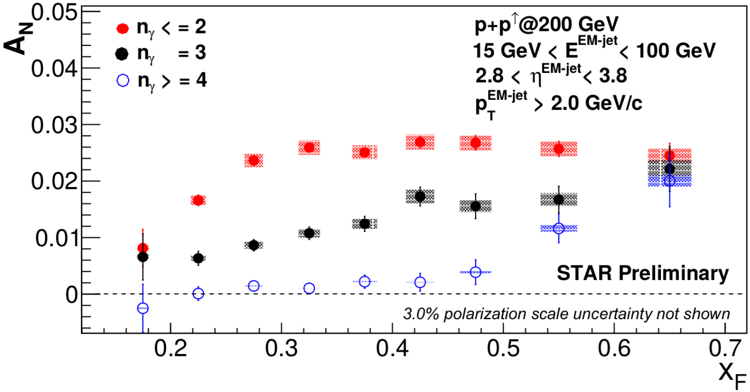
Detailed Investigations of Inclusive EM-jet A_N at Forward Rapidity at 200 GeV

- The EM-jet A_N decreases with increasing photon multiplicity
  - A_N is larger for the EM-jets consisting of 1 or 2 photons
  - A_N is smaller for EM-jets consisting of 4 or 5 photons
- A_N at $x_F < 0$ is consistent with 0
- The systematic uncertainties (boxes) mainly come from possible misidentification of the event categories



Inclusive EM-jet A_N at Forward Rapidity at 200 GeV

- A_N increases with x_F
- EM-jets consisting of 1 or 2 photons have the strongest A_N
  - Indications that large A_N could come from diffractive processes



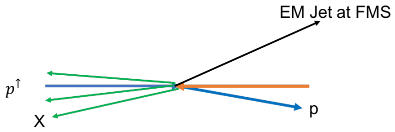
Diffractive EM-jet A_N at Forward Rapidity using FMS

★ Motivation: Measure diffractive contributions to A_N in $p^{\uparrow} + p$ collisions

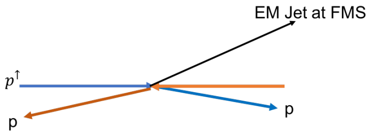
★ Determine the diffractive channels:

- 2 possible diffractive channels. Both Require to tag scattered proton(s) in Roman Pot

① Only 1 proton track on FMS side (west side) and no proton track on the away side (east side)



② Only 1 proton track on FMS side (west side) and only 1 proton track on away side (east side).



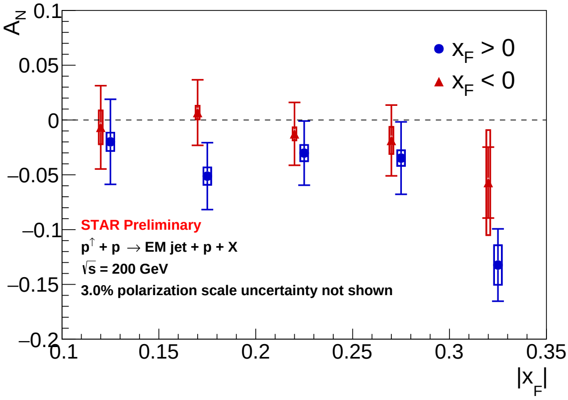
★ Event selection:

- The EM-jet reconstructions and corrections are the same as inclusive processes
- RP track is required to be well reconstructed and within geometric acceptance
- BBC hit cuts to reduce accidental coincidences and ensure the presence of rapidity gap for diffractive processes
- Energy sum cuts to reduce pile-up effect
  - Energy sum: E(west side RP track) + E(EM-jet)

Diffractive EM-jet A_N at Forward Rapidity at 200 GeV

- A non-zero A_N for $x_F > 0$ is observed with 3.3 σ significance for diffractive process at forward rapidity at 200 GeV
- A_N at $x_F < 0$ is consistent with 0

- Large A_N is observed in high x_F region
- Sign of A_N is negative, which is different from that for inclusive process. Theoretical inputs are needed to understand such different sign
- The diffractive EM-jet A_N does not show evidence to have contribution to large A_N in inclusive process



Note 1: All red points are shifted -0.005 along x-axis
Note 2: The rightmost point is for $0.3 < |x_F| < 0.45$

Inclusive and diffractive EM-jet A_N projection

- Expect to have much more precise measurements with $p^\uparrow + p$ 510 GeV dataset in 2017 compared to $p^\uparrow + p$ 200 GeV dataset in 2015
- Allow to explore A_N more precisely at higher kinematic regions

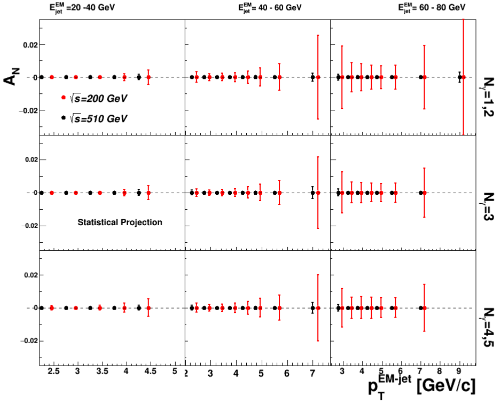


Figure: Statistical projection plot for inclusive EM-jet A_N

Note: All red points are shifted 0.2 GeV/c along x-axis

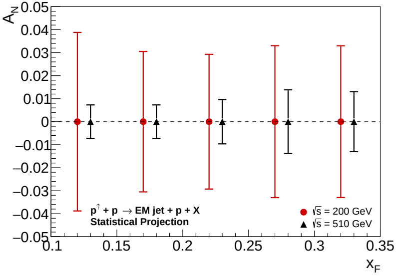


Figure: Statistical projection plot for diffractive EM-jet A_N

Note 1: All black points shifted 0.005 along x axis

Note 2: All red points shifted -0.005 along x axis

Conclusion and Outlook

★ A_N for inclusive EM-jets with different jet substructures in $p^{\uparrow} + p$ collisions at 200 GeV at STAR

- The EM-jet A_N increases with decreasing photon multiplicity and increasing x_F

★ A_N for diffractive EM-jets in $p^{\uparrow} + p$ collisions at 200 GeV at STAR

- A non-zero diffractive EM-jet A_N with negative sign for $x_F > 0$ is observed
- Sign of A_N is negative, which needs further theoretical study to understand
- The diffractive EM-jet A_N can not provide evidence to have contribution for large A_N in inclusive process at 200 GeV

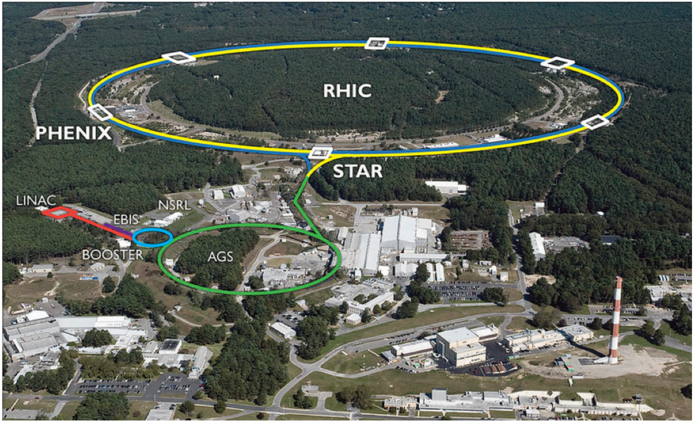
★ Analyses for inclusive and diffractive EM-jet A_N in $p^{\uparrow} + p$ collisions at 510 GeV at STAR are in progress

- High luminosity dataset from 2017 will significantly improve the measurements

Back up

RHIC: Relativistic Heavy Ion Collider

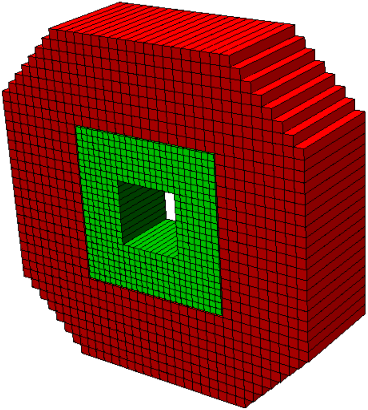
- Located at Brookhaven National Laboratory (BNL) on Long Island, NY
- World's only polarized proton-proton collider with transverse and longitudinal polarization
- STAR experiment is at one of the collision points at RHIC (6 o'click)



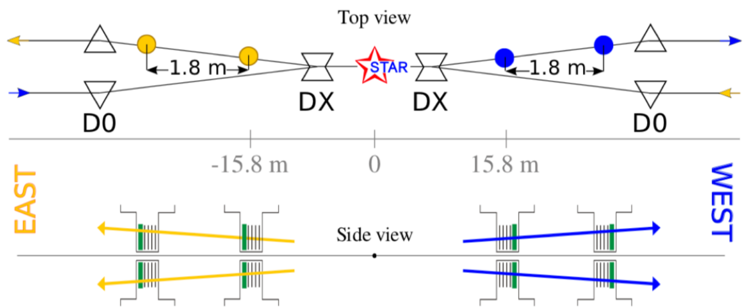
Forward Meson Spectrometer (FMS)

- FMS can detect photons, neutral pions, and eta mesons in the forward direction
- $2.6 < \eta < 4.2$

- FMS consists of 1264 Lead-Glass cells with photomultiplier tubes (PMT) readout connected, separated into two regions
- Inner region (green) have smaller size cells than the outer region (red), which can provide better photon separation ability
- All cells have $\sim$18 radiation length



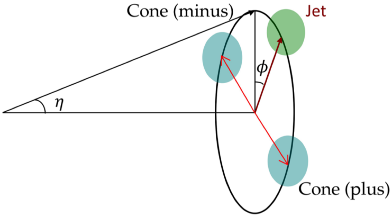
Roman Pot (RP)



- Roman Pots (RP) are vessels which house the Silicon Strip Detector planes (SSDs). They are put close to the beam pipe
- RPs are able to detect and track slightly scattered protons close to beamline
- 2 sets of RP (inner and outer) on each side
- Each RP set contains a package above and below the beamline
- 4 SSDs per package (2 x-type and 2 y-type)

Underlying Events Correction and Energy Correction

- The EM-jet p_T values are corrected for contamination from Underlying Events (UE) with off-axis cone method
- The EM-jet energy is corrected to the particle level from simulation



Phys Rev D **91** 112012 (2015), ALICE Collaboration

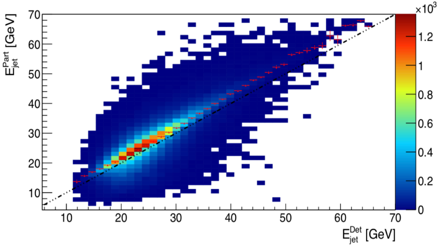


Figure: Detector EM-jet energy to particle level correction

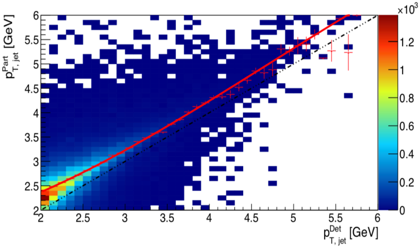


Figure: UE correction

BBC hit cuts

- Beam Beam Counter (BBC) can be used to triggering, monitoring luminosity and local polarimetry
- BBC are located on both forward and backward side
  - BBC: $2.1 < |\eta| < 5$, partially overlap with FMS in some η coverage
- Benefits for cuts on BBC hits:
  - Reduce accidental coincidence events with a second interaction in the same bunch crossing
  - Get rid of high luminosity events which may cause pile-up effect