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

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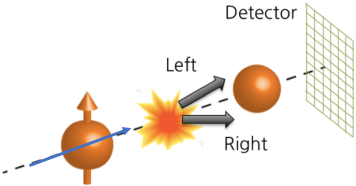
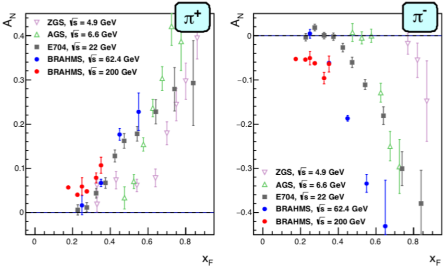
Transverse Single-Spin Asymmetry (TSSA, A_N)

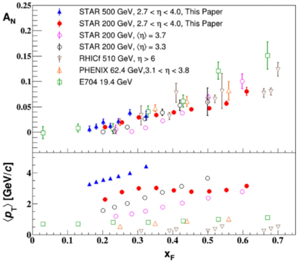
- Proton spin structure is still not fully understood.
- Studying proton spin structure via TSSA.
- pQCD predicts $A_N \sim \frac{m_q \alpha_s}{\sqrt{s}} \sim 0.001$
- Unexpectedly large A_N at forward region is observed in proton-proton collisions

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





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

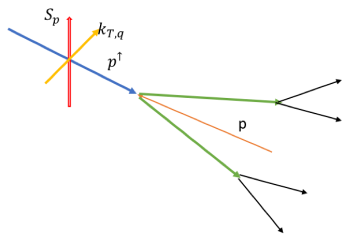


- (STAR) J. Adam *et al.*, Phys. Rev. D 103, 092009 (2021)

Possible Mechanisms for TSSA

- **TMDs framework**:

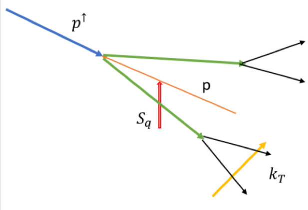
Sivers effect :correlation between initial parton k_T and proton spin



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

Signatures: A_N for jets or direct photons, $W^{+/-}$, Z , Drell-Yan

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



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

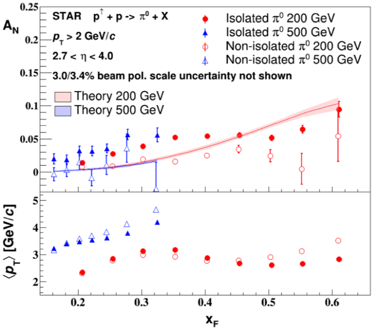
Signatures: Collins effect (Azimuthal asymmetry of hadrons in jets)

- **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

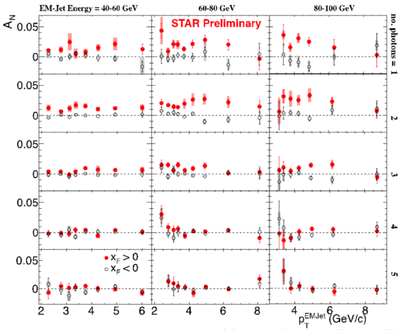
Previous analyses of A_N for forward π^0 and electromagnetic jets in $p^{\uparrow}$+p collisions at STAR indicated that there might be non-trivial contributions to the large A_N from diffractive processes.

- Inclusive π^0 A_N
  - Isolated π^0 have larger A_N



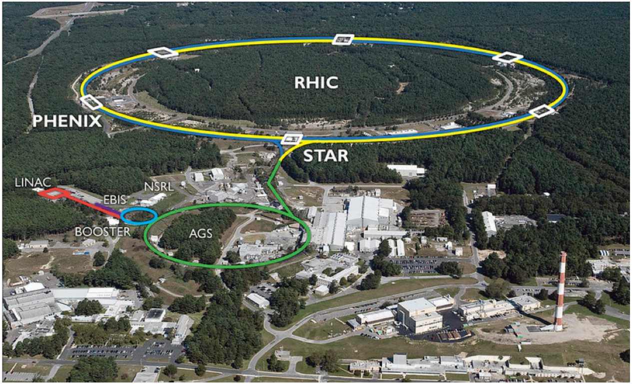
Ref: (STAR) J. Adam *et al.*, Phys. Rev. D 103, 092009 (2021)

- Inclusive EM-jet A_N
  - Low photon multiplicity jets have larger A_N



RHIC: Relativistic Heavy Ion Collider

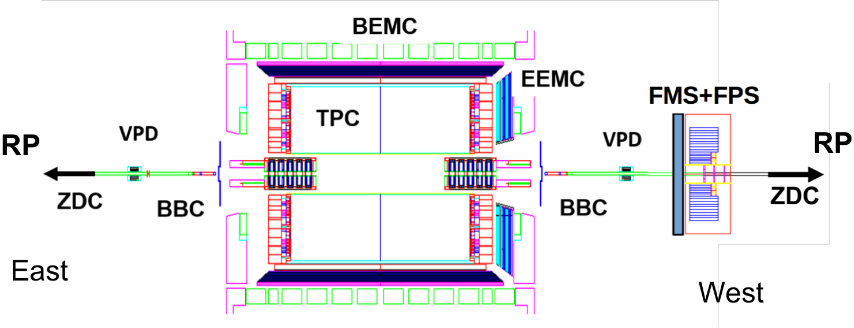
- Located at Brookhaven National Laboratory (BNL) on Long Island, NY
- World's only polarized proton-proton collider
- Transverse and longitudinal polarization
- Allows polarized p-p collisions for $\sqrt{s} = 200$ - 510 GeV



STAR Experiment at RHIC

STAR sub-detectors used in the A_N analyses

- Calorimetry system: BEMC, EEMC and **FMS**
  - Forward Meson Spectrometer (FMS): $2.6 < \eta < 4.2$, $\phi \in (0, 2\pi)$
- Roman Pot (RP) allows detection of scattered protons.
- ZDC, VPD and BBC are trigger detectors.

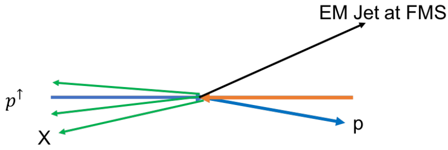


Diffractive EM-jet A_N at Forward Rapidity

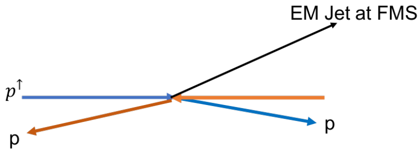
★ **Motivation:** Measure diffractive contributions to A_N in polarized p+p collisions.

★ **2 possible diffractive channels:**

① Only 1 proton track on FMS side and no proton track on the away side.



② Only 1 proton track on FMS side and only 1 proton track on away side.



★ **Requirements:** The scattered proton must be detected by Roman Pot.

★ **Limitation:** They are relatively rare processes, but have been observed at STAR.

Datasets and Event Selection

★ Data sets: Transversely polarized $p^{\uparrow}$+p at $\sqrt{s} = 200$ GeV collected in 2015.

★ FMS EM-jet reconstruction

- Only reconstructed FMS photon candidates as input for FastJet
- Anti-k_T algorithm with R = 0.7
- EM-jet $p_T > 1$ GeV/c
- EM-jet energy is corrected to particle level.

★ RP track selection

- RP track is required to be reconstructed and within geometric acceptance.
- Two acceptable scenarios for RP tracks based on the diffractive process channels:
  1. Only 1 west side RP track and 0 east side RP track
  2. Only 1 west side RP track and 1 east side RP track

★ BBC hit cuts to reduce accidental coincidences.

★ Energy sum cuts for diffractive process to reduce pile-up effect.

- Energy sum: E(west side RP track) + E(EM-jet)
- Apply different energy sum cut for each EM-jet energy region based on the energy sum spectrum.

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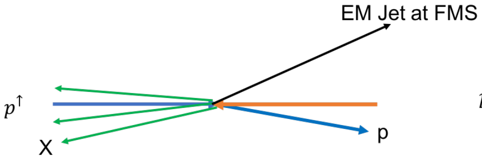

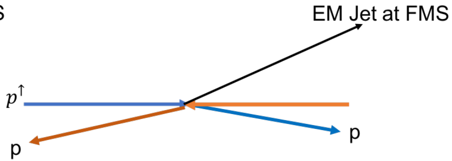

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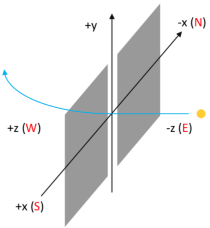
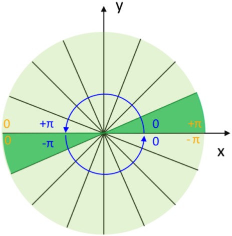
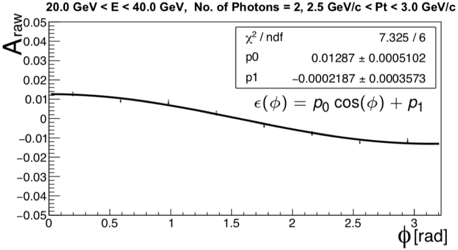
EM-jet A_N Extraction

- The cross-ratio method is used to calculate A_N.
- This method can take advantage of detector azimuthal symmetry and cancel effects on detector acceptance and beam luminosity.

$$\epsilon = PA_N cos(\phi) = \frac{\sqrt{N^{\uparrow}(\phi)N^{\downarrow}(\phi+\pi)} - \sqrt{N^{\downarrow}(\phi)N^{\uparrow}(\phi+\pi)}}{\sqrt{N^{\uparrow}(\phi)N^{\downarrow}(\phi+\pi)} + \sqrt{N^{\downarrow}(\phi)N^{\uparrow}(\phi+\pi)}}$$



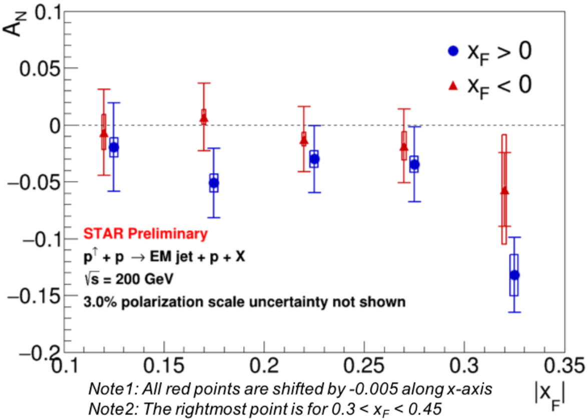




Diffractive EM-jet A_N at Forward Rapidity at 200 GeV

- A non-zero A_N for $x_F > 0$ is observed with 3.3-sigma significance for diffractive process at forward rapidity.
- Large A_N is observed in high x_F region.

- Sign of A_N is negative. Theoretical inputs are needed to understand the different sign.
- A_N at $x_F < 0$ is consistent with 0.
- Systematic uncertainties (boxes) mainly come from cuts for reducing background events.



Conclusion

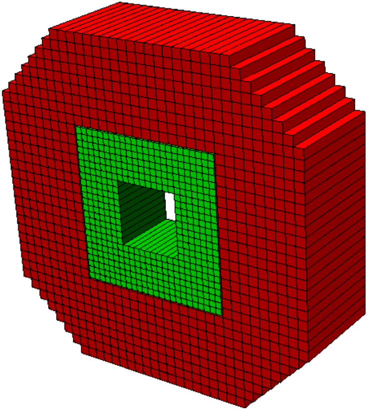
- ★ We study A_N for diffractive EM-jets using the FMS at STAR in $p^{\uparrow}$+p collisions at 200 GeV.
  - A non-zero diffractive EM-jet A_N for $x_F > 0$ is observed. Large A_N is observed in high x_F region.
  - Sign of A_N is negative, which needs further theoretical study to understand.
- ★ Diffractive EM-jet A_N using larger $p^{\uparrow}$+p datasets taken in 2017 is underway, which will increase the statistical precision.

Back up

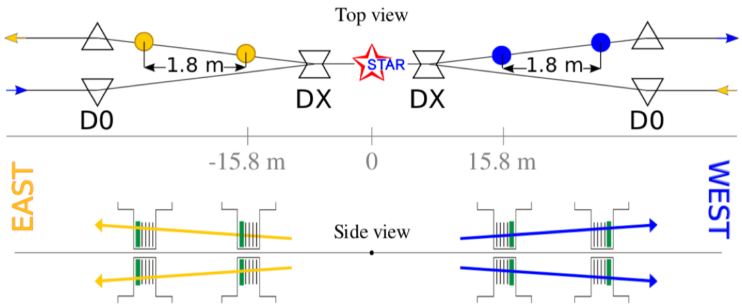
Forward Meson Spectrometer (FMS)

- 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 ∼18 radiation length.



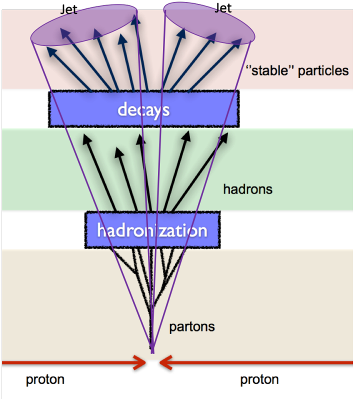
Roman Pot (RP)



- 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).

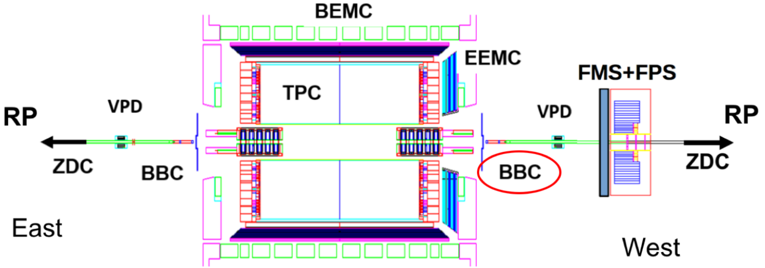
Particle jets

- Unlike stable particles like protons, quarks and gluons can not be extracted and detected directly because of color confinement.
- When a quark or a gluon flies off on its own, it will undergo hadronization and create new particles and they will roughly travel in the same direction.
- So Jet is the narrow cone of the particles produced by the hadronization of the quark or gluon.
- In experiment, jets are measured in the detectors and studied in order to determine the properties of the parton and the original proton to study the QCD structure of proton.
- Electromagnetic jet (EM jet) is the jet that only contains photons.



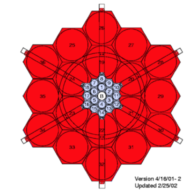
BBC hit cuts

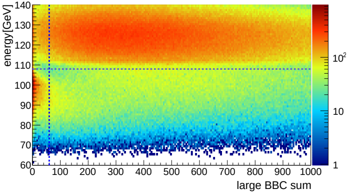
- Beam Beam Counter (BBC) can be used to triggering, monitoring luminosity and local polarimetry.
- BBC are located on both forward and backward side.
  - BBC: $2.1 < |\eta| < 5$.
- Benefits for cuts on BBC hits:
  - Reduce accidental coincidence events with a second interaction in the same bunch crossing.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

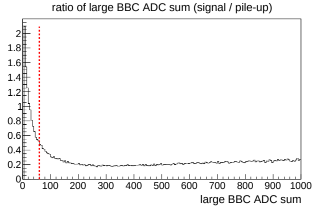


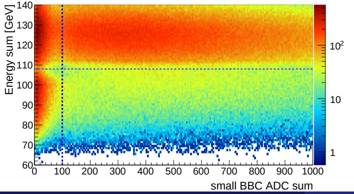
Details on BBC cuts for diffractive EM-jet A_N analysis

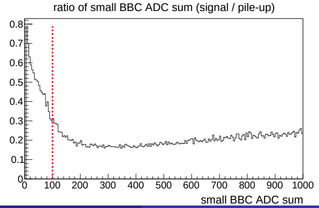
- Based on the sum energy ($E_{EM-jet} + E_{RPtrack}$) vs BBC ADC sum.
- Horizontal line ($E = 108$ GeV) splits signal and background region.
- Optimize the fraction of signal and background.











Energy sum cut

- Calculate energy sum: E(west side RP track) + E(FMS EM-jet) for each event.
- Apply energy sum cut based on the separation of diffractive process peak and pile-up peak. (Left plot as example)
- Pile-up peak mainly come from the events with RP track energy around 100 GeV (pile-up events).