Transverse Single Spin Asymmetry of Electromagnetic Jets for Inclusive and Diffractive Processes at Forward Rapidity in $p^{\uparrow}+p$ Collisions at STAR

Xilin Liang, for the STAR Collaboration

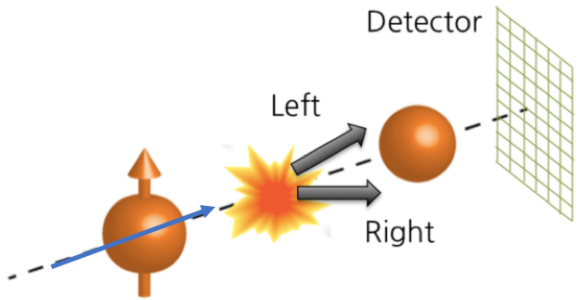
University of California, Riverside

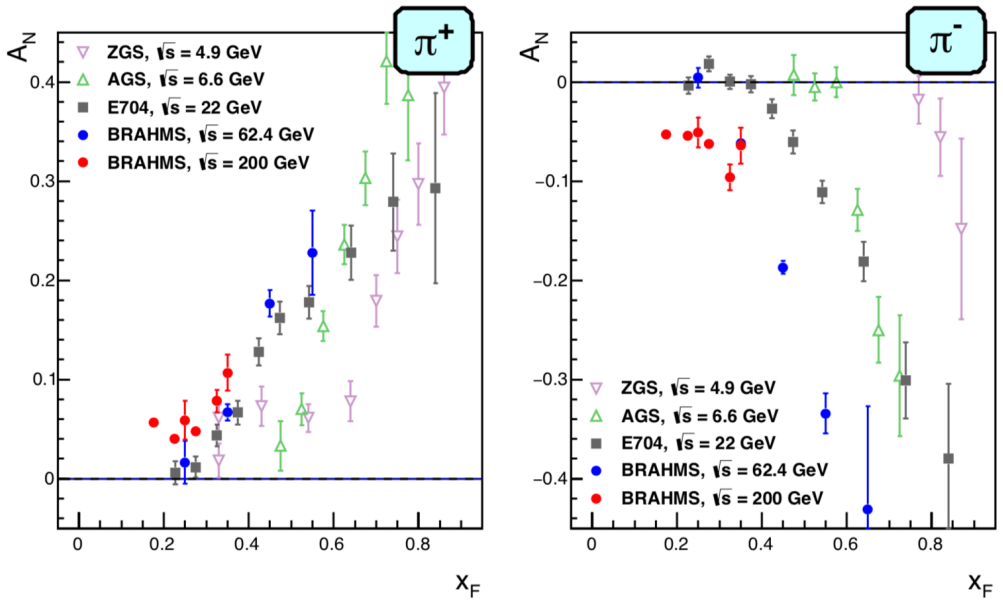
Diffraction and Low-x 2024
Palermo, Sicily, Italy
Sept. 10, 2024

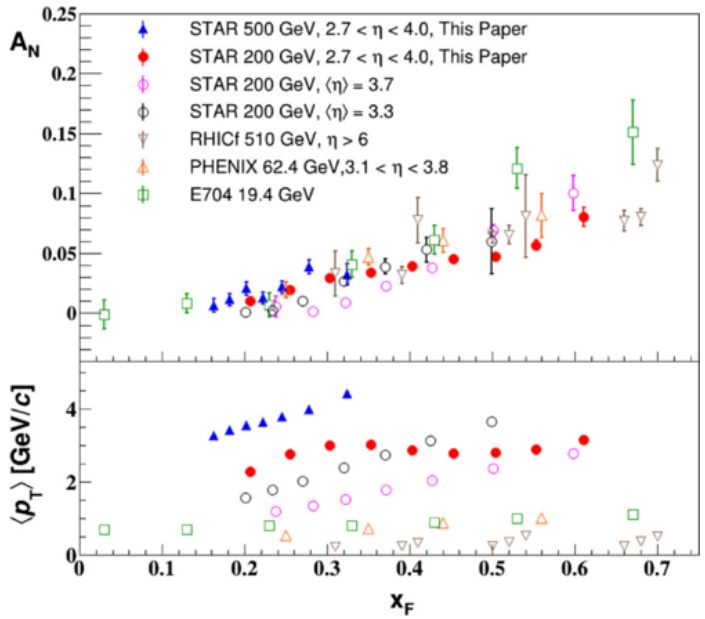
Supported in part by

Transverse Single-Spin Asymmetry (TSSA, A_N)

- A_N: $\frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$
- pQCD predicts A_N is small: $A_N \sim \frac{m_q \alpha_s}{p_T} \sim 0$
- Large A_N at forward region is observed in proton-proton collisions
- Possible theories: TMD framework (Sivers effect, Collins effect), Twist-3 framework





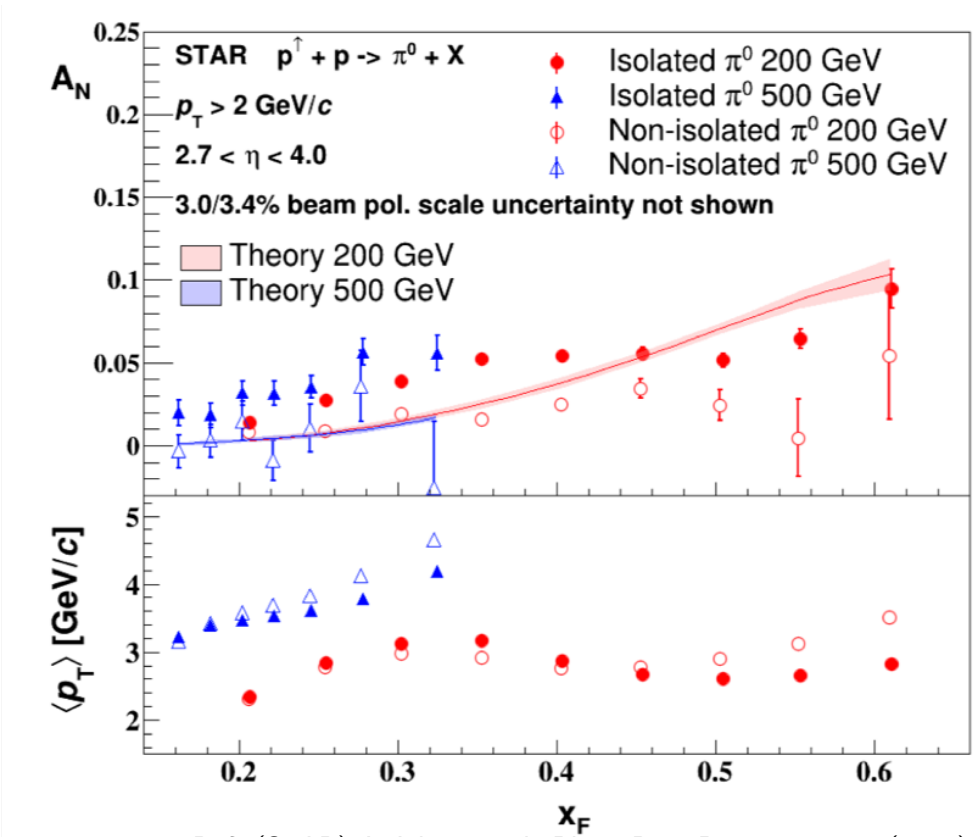


References:

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

Indication of Large TSSA from Diffractive Process

- STAR inclusive A_N for forward π^0 in $p^\uparrow + p$ collisions : Isolated π^0 has larger A_N than non-isolated π^0
  - Isolated π^0: No other nearby photons
- Might there be non-trivial contributions to the large A_N from diffractive processes?

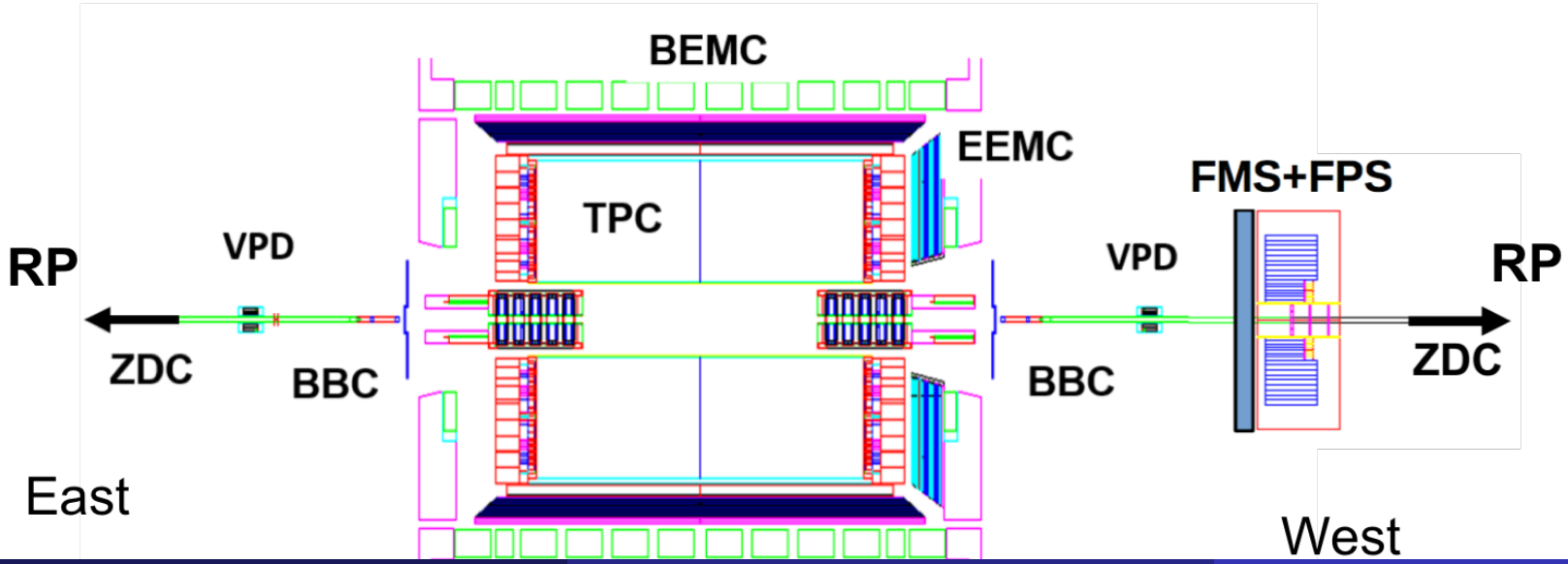


Ref: (STAR) J. Adam *et al.*, Phys. Rev. D 103, 092009 (2021)

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 at forward rapidity
  - Forward Meson Spectrometer (FMS): $2.6 < \eta < 4.2$, $\phi \in (0, 2\pi)$
  - Roman Pot (RP): detect scattered protons
  - Trigger detectors:
    - Beam-Beam Counter (BBC) , $2.1 < |\eta| < 5$, also used for determine the rapidity gap
    - Vertex Position Detector (VPD)
    - Zero Degree Calorimeter (ZDC)

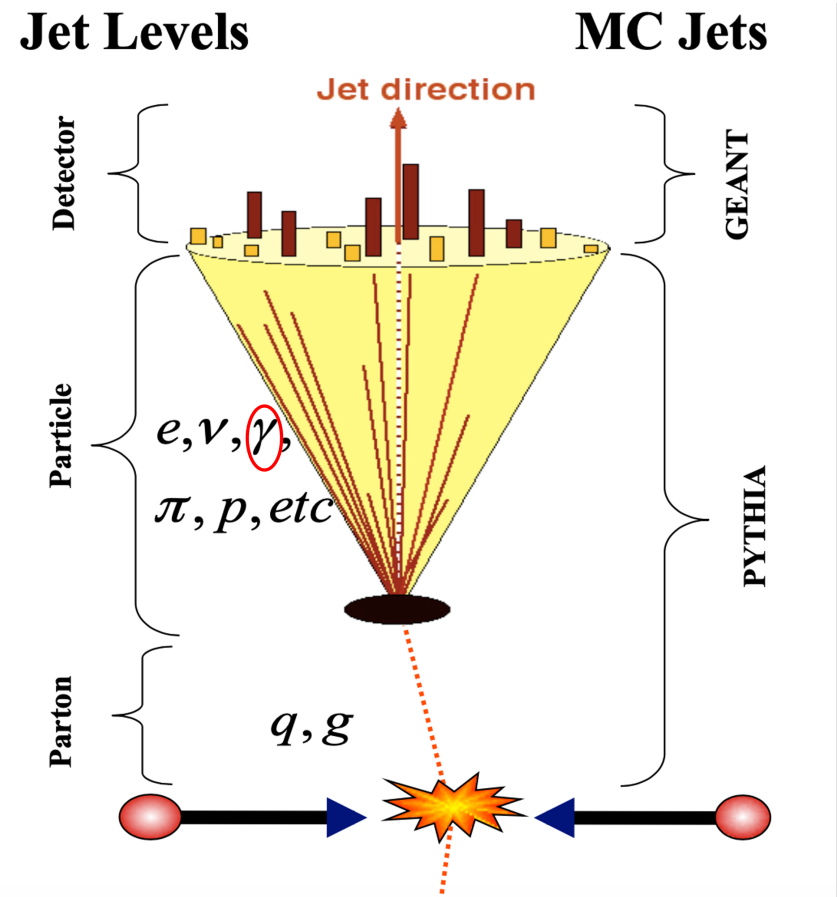


Datasets and Electromagnetic Jets (EM-jets)

- Inclusive and diffractive EM-jet A_N studies using STAR 2015 and 2017 data

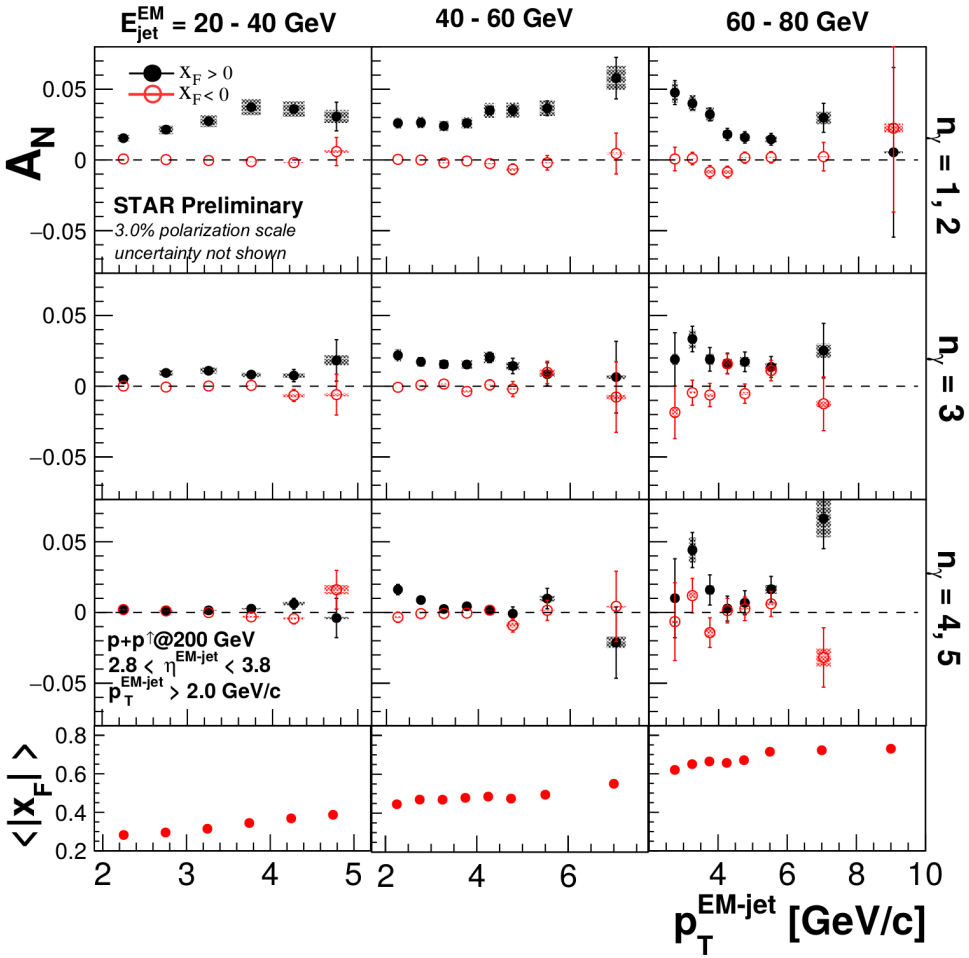
Year	$\sqrt{s}$ [GeV]	$\mathcal{L}$ $[pb^{-1}]$	Polarization orientation	Polarization P [%]
2015	200	52	Transverse	57
2017	510	350	Transverse	55

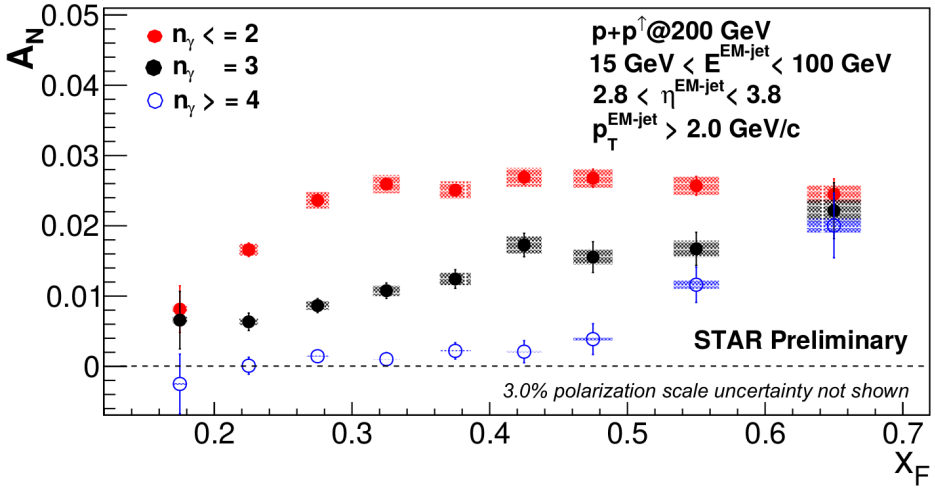
- Electromagnetic jets (EM-jets) are the jets that are reconstructed using only photons
  - EM-jet reconstruction: Anti-k_T, R = 0.7
  - EM-jet correction for p_T: corrected for Underlying Event using off-axis cone method
  - EM-jet correction for energy: corrected to the particle level based on the MC simulation



Multi-dimensional Studies for Inclusive EM-jet A_N at 200 GeV

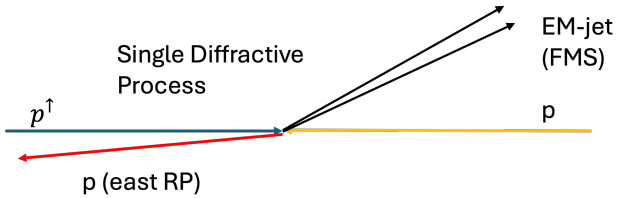
The Electromagnetic jets (EM-jets) are the jets reconstructed using only photons



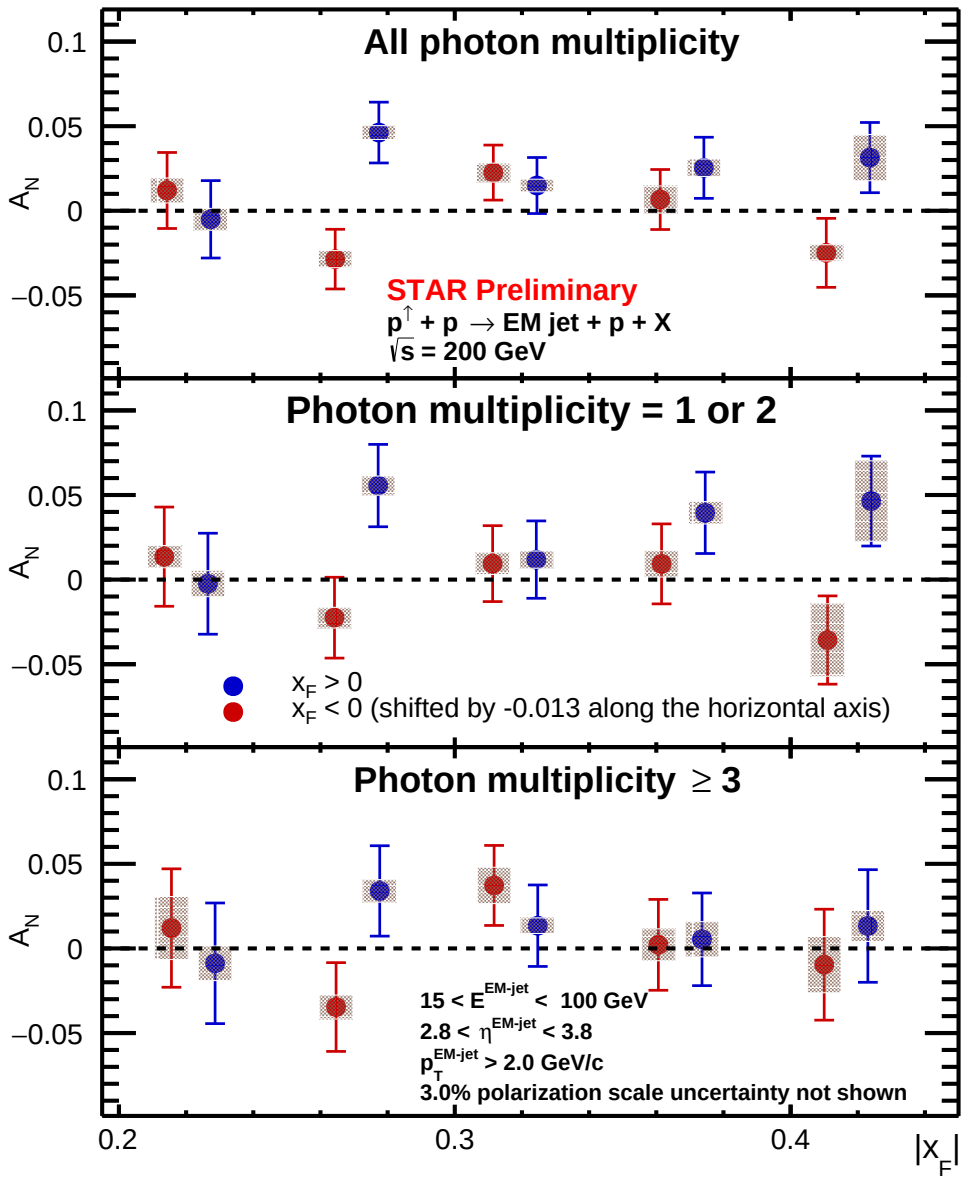


- The EM-jet A_N decreases with increasing photon multiplicity for $x_F > 0$
  - A_N is larger for the EM-jets consisting of 1 or 2 photons
- A_N increases with x_F for all the cases of photon multiplicity
- Does it indicate that large A_N come from diffractive processes?

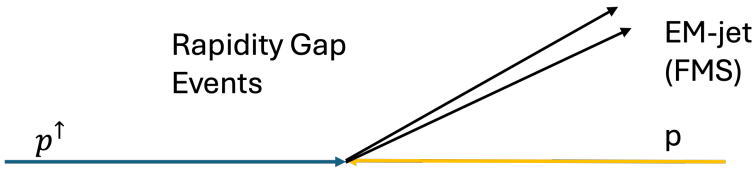
Single Diffractive EM-jet A_N at 200 GeV



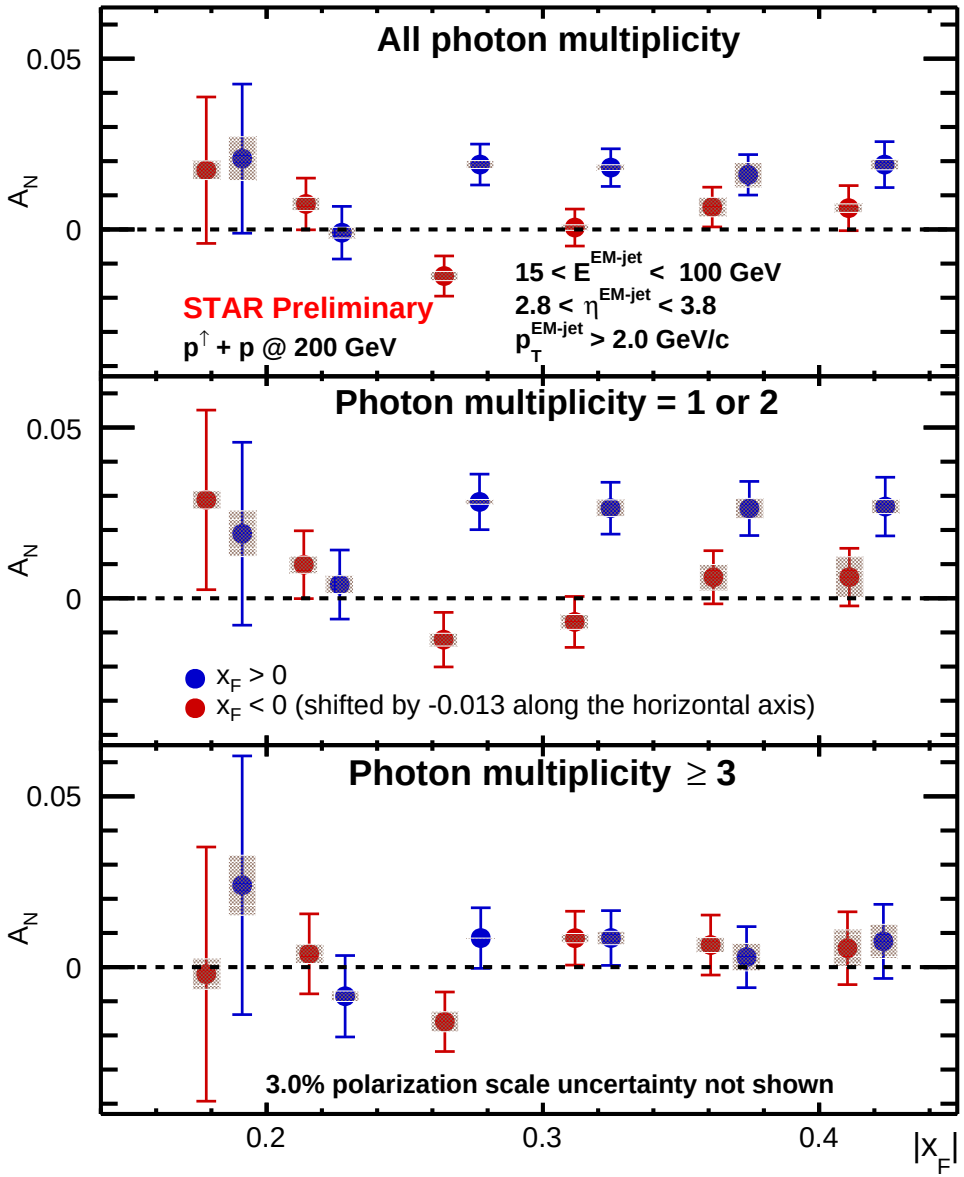
- Single diffractive process: Unpolarized proton intact, with the rapidity gap on the east side ($-5 < \eta < -2.1$)
- The EM-jet A_N for $x_F > 0$ is observed for the case of all photon multiplicity and 1 or 2 photon multiplicity with $> 2\ \sigma$ significance of non-zero
- The EM-jet with 1 or 2 photon multiplicity has larger A_N than with 3 or more photon multiplicity



Rapidity Gap Event EM-jet A_N at 200 GeV

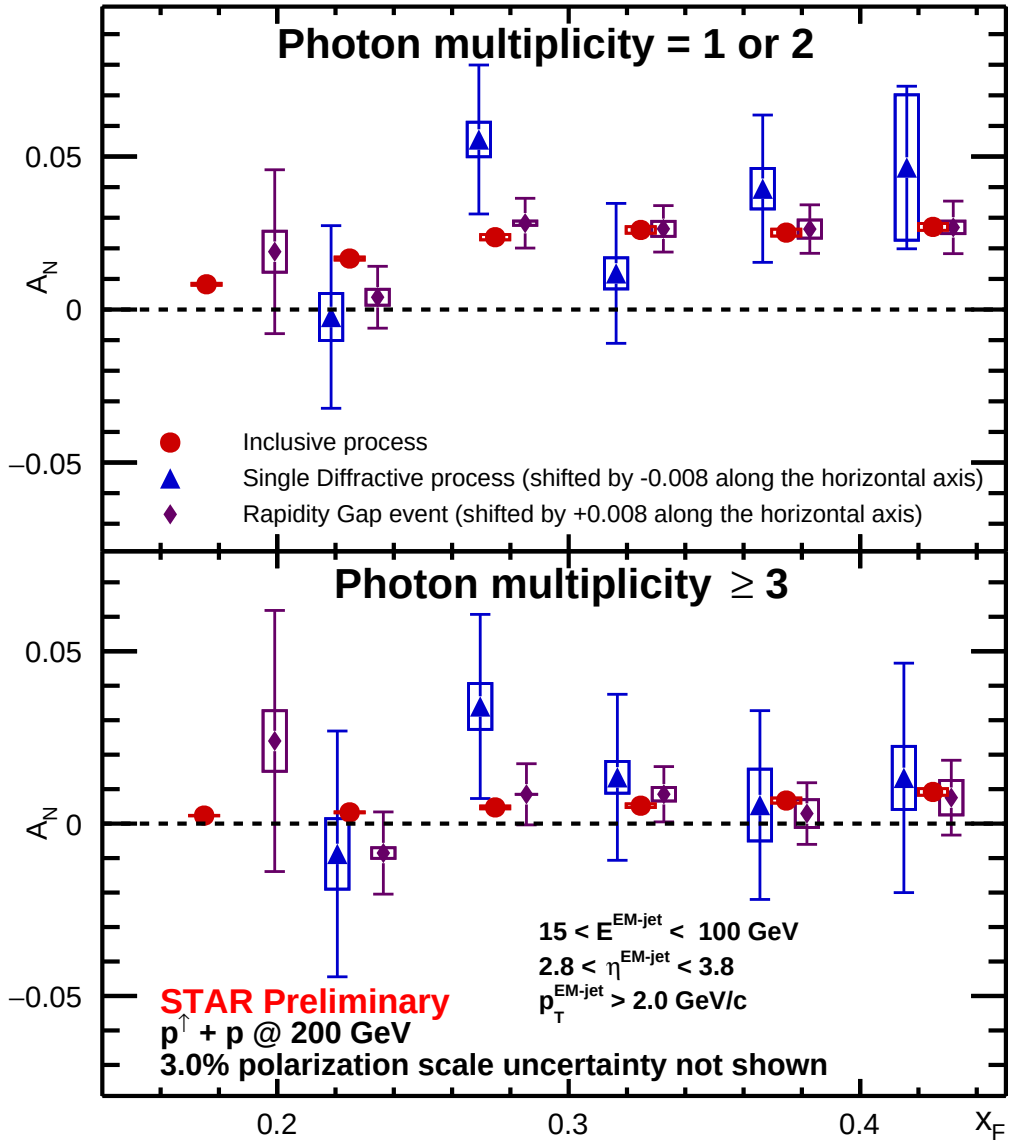


- Rapidity gap events: rapidity gap on the east side $(-5 < \eta < -2.1)$; no requirement on protons
- About 70% of the rapidity gap events are single diffractive process events
- The size of EM-jet A_N for rapidity gap events is similar to that for inclusive process
- The A_N for the EM-jet with 1 or 2 photon multiplicity is the largest

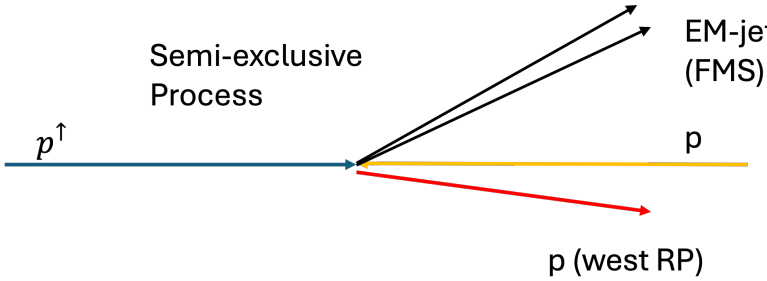


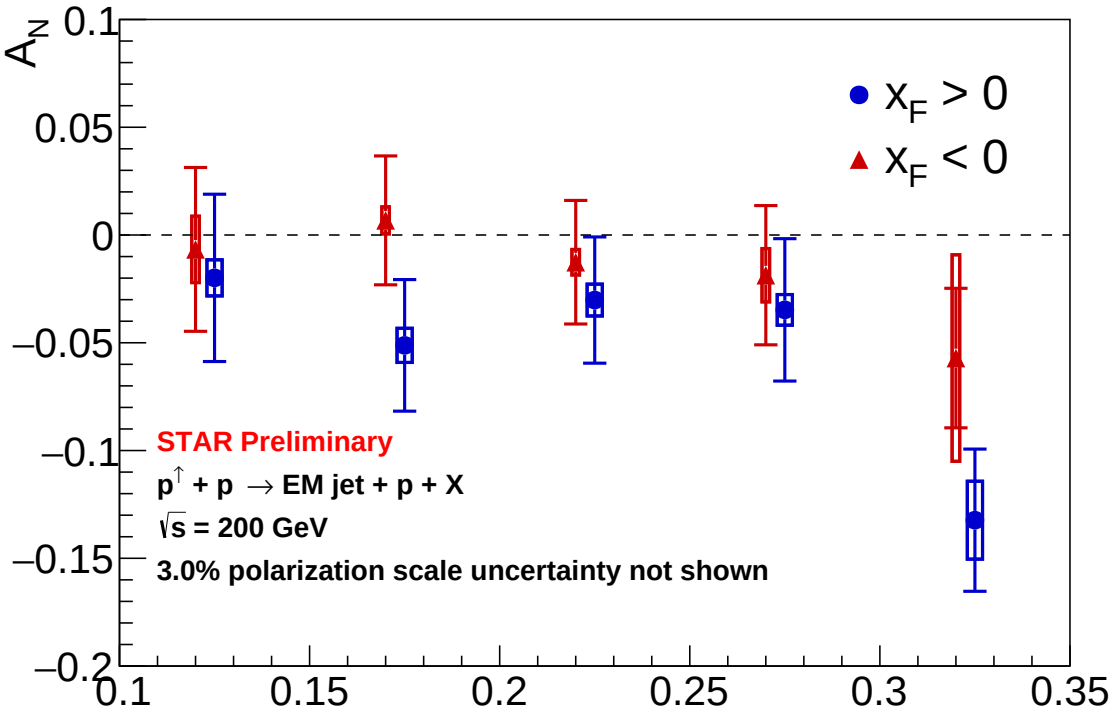
Will Single Diffractive Process Contribute to Large A_N in Inclusive Process?

- A_N for the three processes are the same within uncertainty
- Fraction of diffractive cross session in the total inclusive cross section at the forward region is about 20%
  - If the diffractive process have great contribution to large A_N in inclusive process, a huge A_N for diffractive process should be observed
- The single diffractive process can not provide evidence to have significant contribution to large A_N in inclusive process



Semi-exclusive Process EM-jet A_N at 200 GeV





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

- Semi-exclusive process: Polarized proton intact; constrain the energy of EM-jet at FMS and west side proton to equal to beam energy within resolution
- A non-zero A_N for $x_F > 0$ is observed with 3.3 σ significance for semi-exclusive process
- Sign of A_N is negative. Theoretical inputs are needed to understand the different sign

Inclusive and single diffractive EM-jet A_N projection

- Expect to have much higher statistical measurements with $p^{\uparrow} + p$ at 510 GeV dataset in 2017 compared to $p^{\uparrow} + p$ at 200 GeV dataset in 2015
- Allow to explore A_N for single diffractive process at lower x_F region

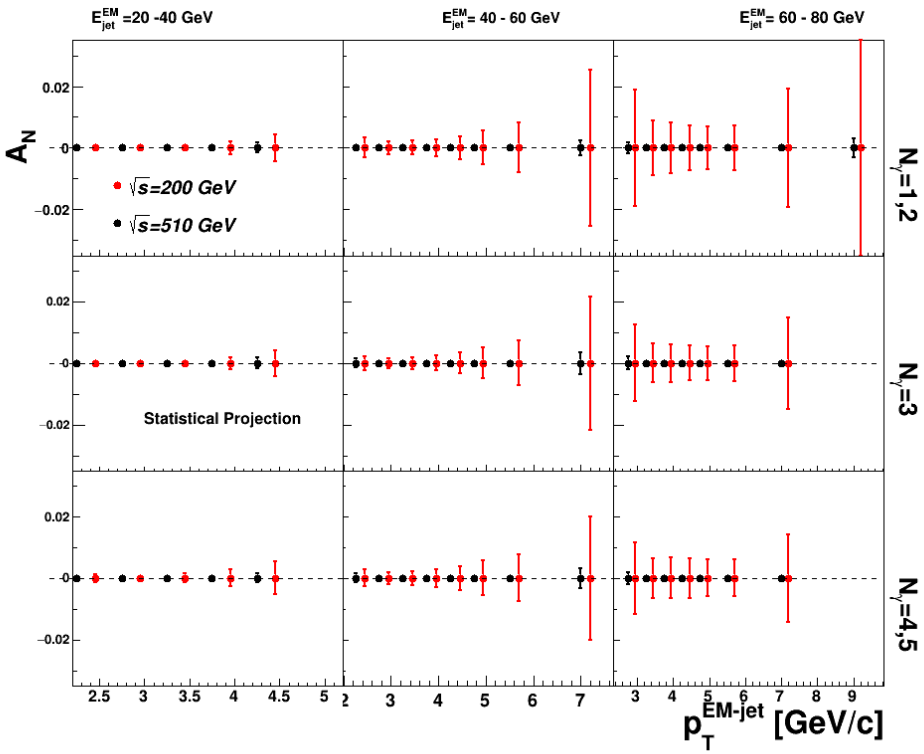


Figure: Statistical projection plot for inclusive EM-jet A_N

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

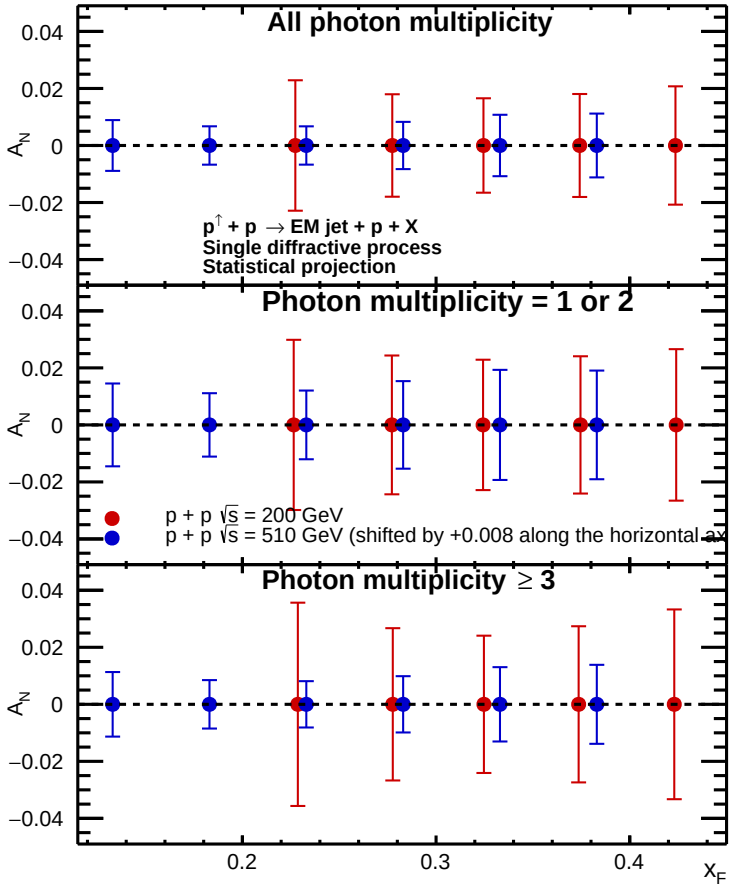


Figure: Statistical projection plot for single diffractive EM-jet A_N

Conclusion and Outlook

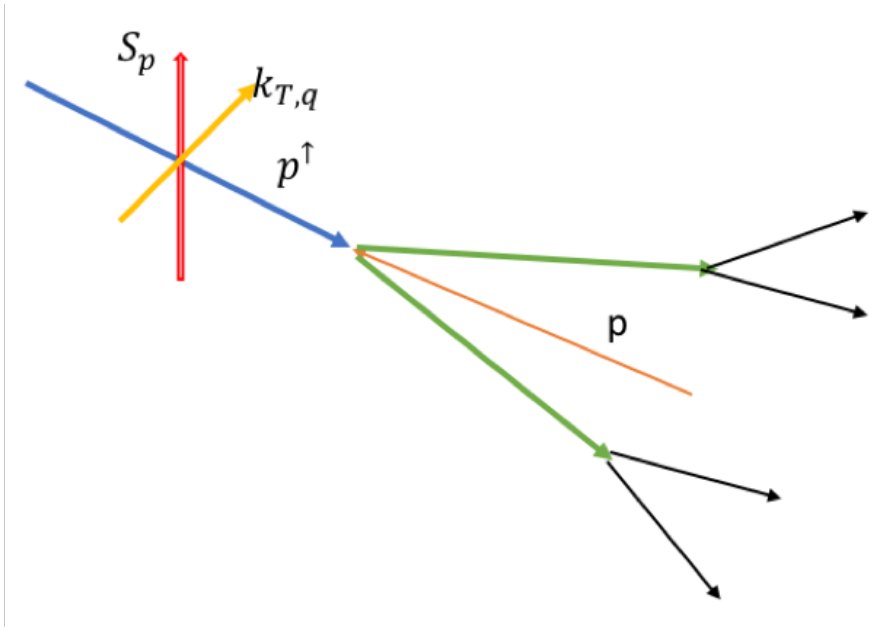
- ★ A_N for inclusive EM-jets with different jet substructures in $p^{\uparrow} + p$ collisions at 200 GeV at STAR
  - The EM-jet A_N increases with decreasing photon multiplicity and increasing x_F
- ★ EM-jet A_N for the single diffractive processes and rapidity gap events in $p^{\uparrow} + p$ collisions at 200 GeV at STAR
  - The A_N for the processes with polarized proton break-up and unpolarized proton intact is consistent with the inclusive EM-jet A_N within uncertainty
- ★ EM-jet A_N for the semi-exclusive processes in $p^{\uparrow} + p$ collisions at 200 GeV at STAR
  - The A_N for the processes with polarized proton intact and unpolarized proton break-up is non-zero but with negative sign
- ★ 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

Possible Mechanisms for TSSA

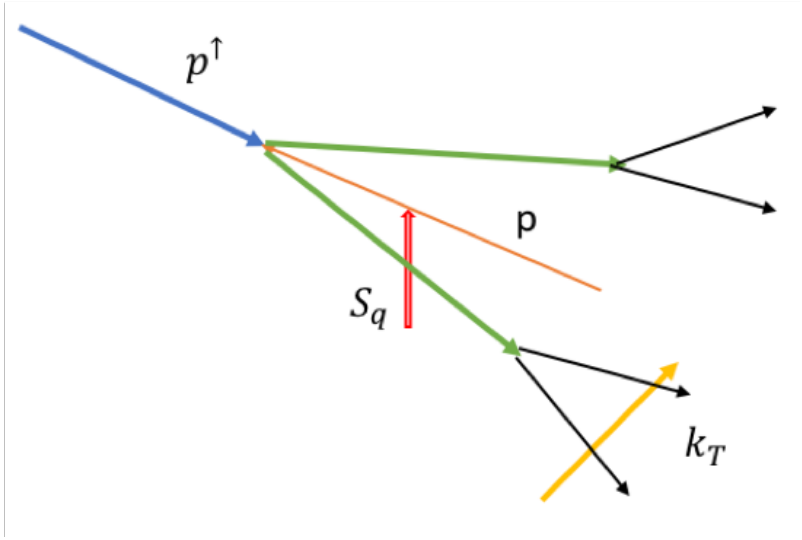
- **TMDs framework**:

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



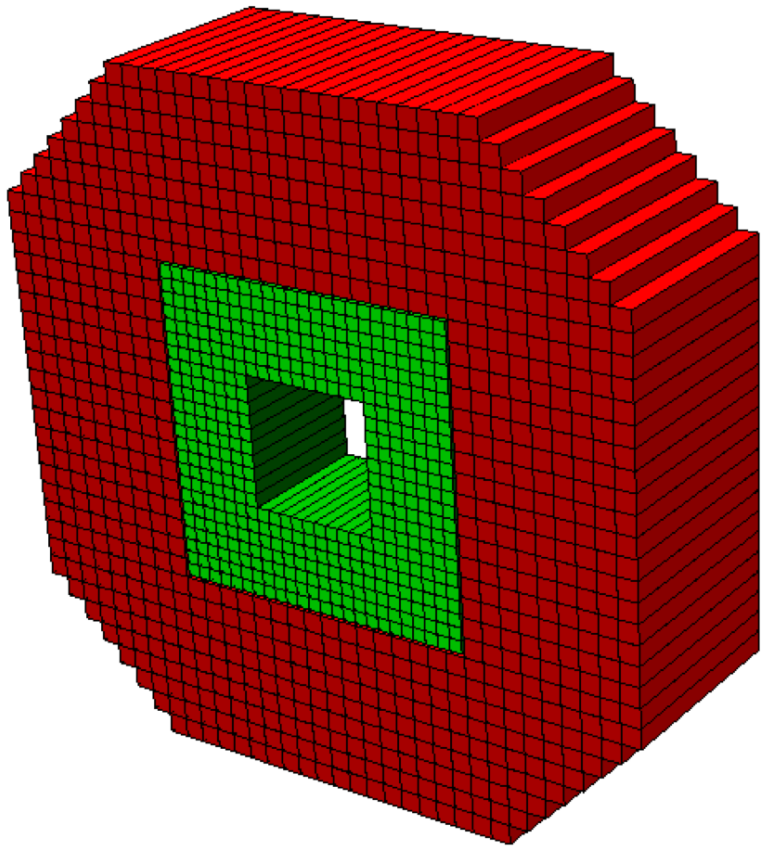
Ref: J. Collins, Nucl Phys B 396 (1993) 161

- **Twist-3**: Quark-gluon / gluon-gluon correlations and fragmentation functions.
  Ref: J.W. Qiu and G. Sterman, Phys. Rev. Lett. 67 2264 (1991)

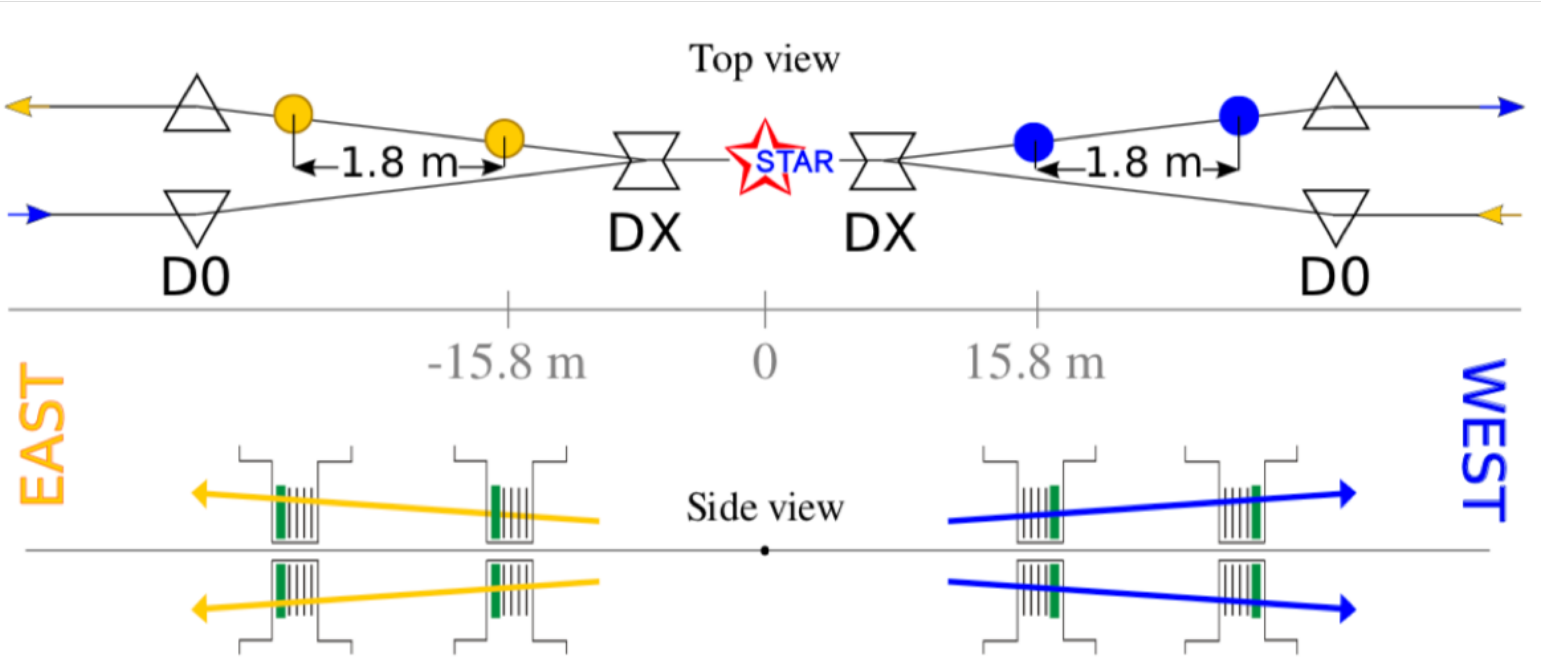
Forward Meson Spectrometer (FMS)

- 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)

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
  - Determine the rapidity gap for single diffractive process and rapidity gap process