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

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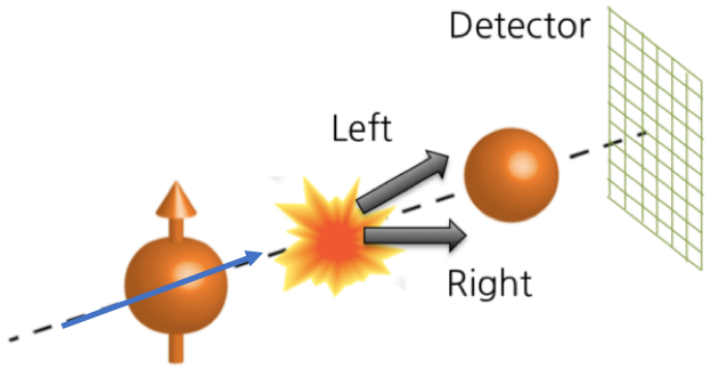
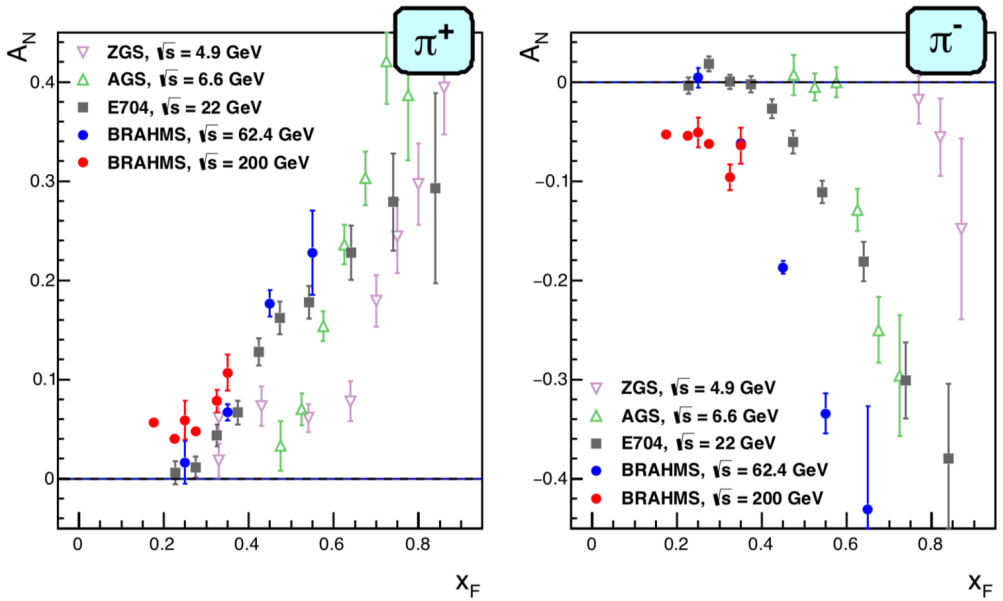
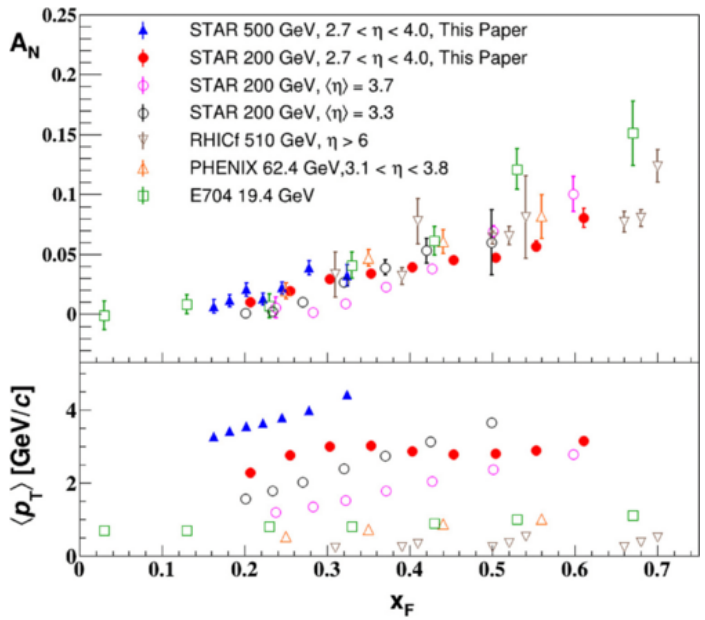
Transverse Single-Spin Asymmetry (TSSA, A_N)

- $A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$
- pQCD predicts A_N is small: $A_N \sim \frac{m_q \alpha_s}{p_T}$
- Large A_N at forward region is observed in proton-proton collisions







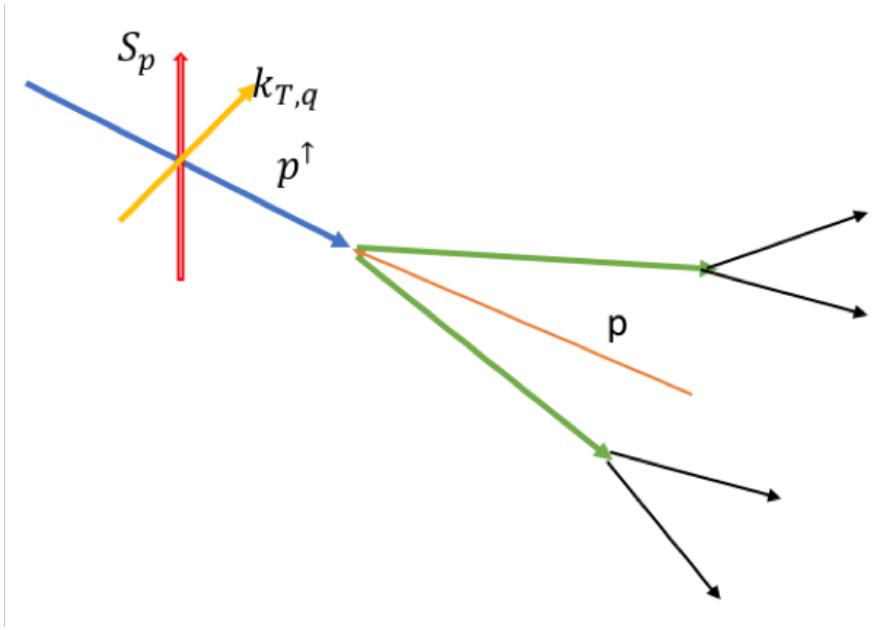
References:

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

Possible Mechanisms for TSSA

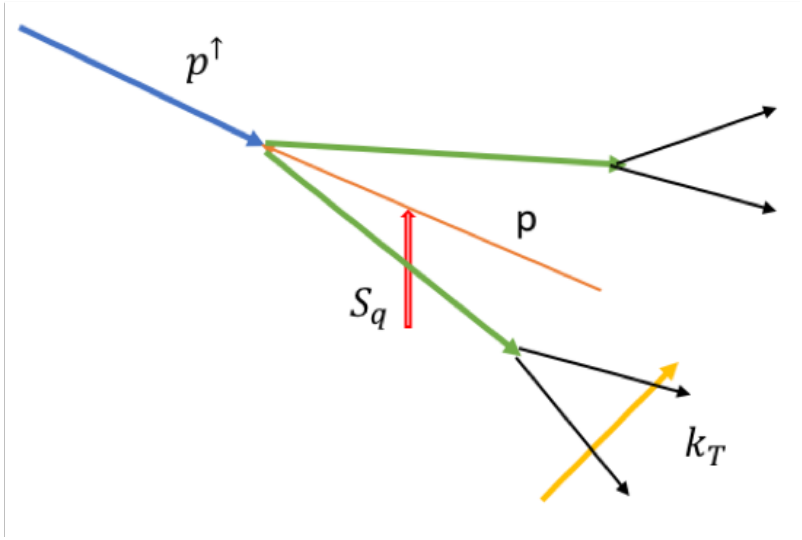
- **TMDs framework**:

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



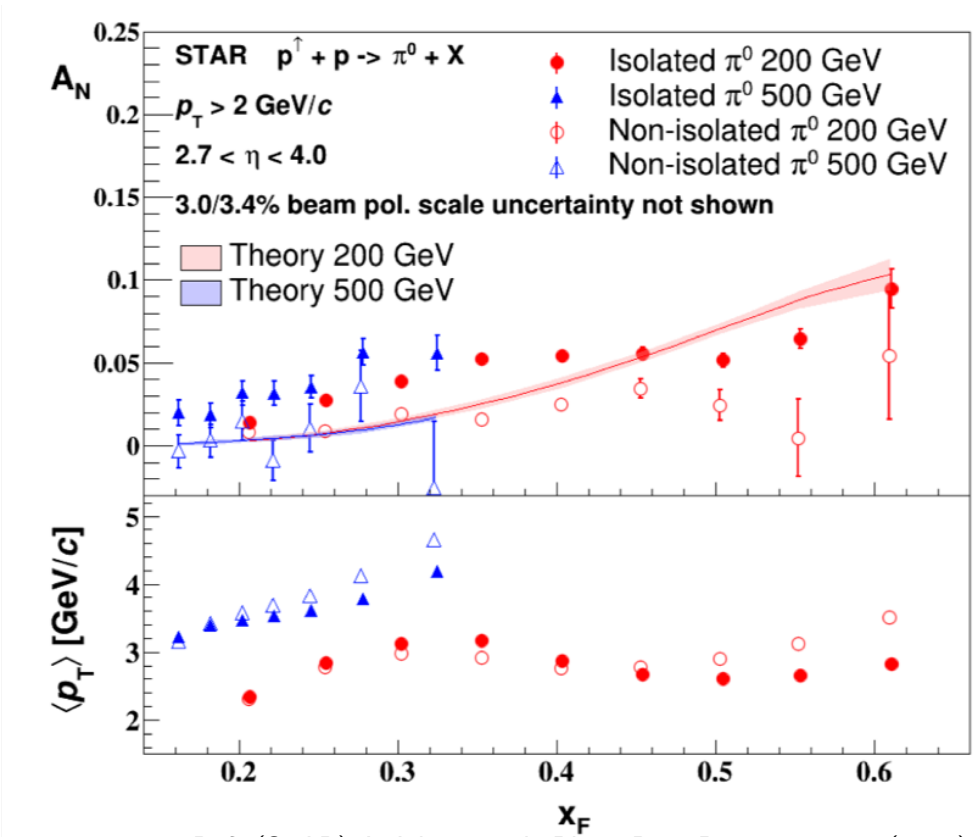
Ref: J. Collins, Nucl Phys B 396 (1993) 161

- **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

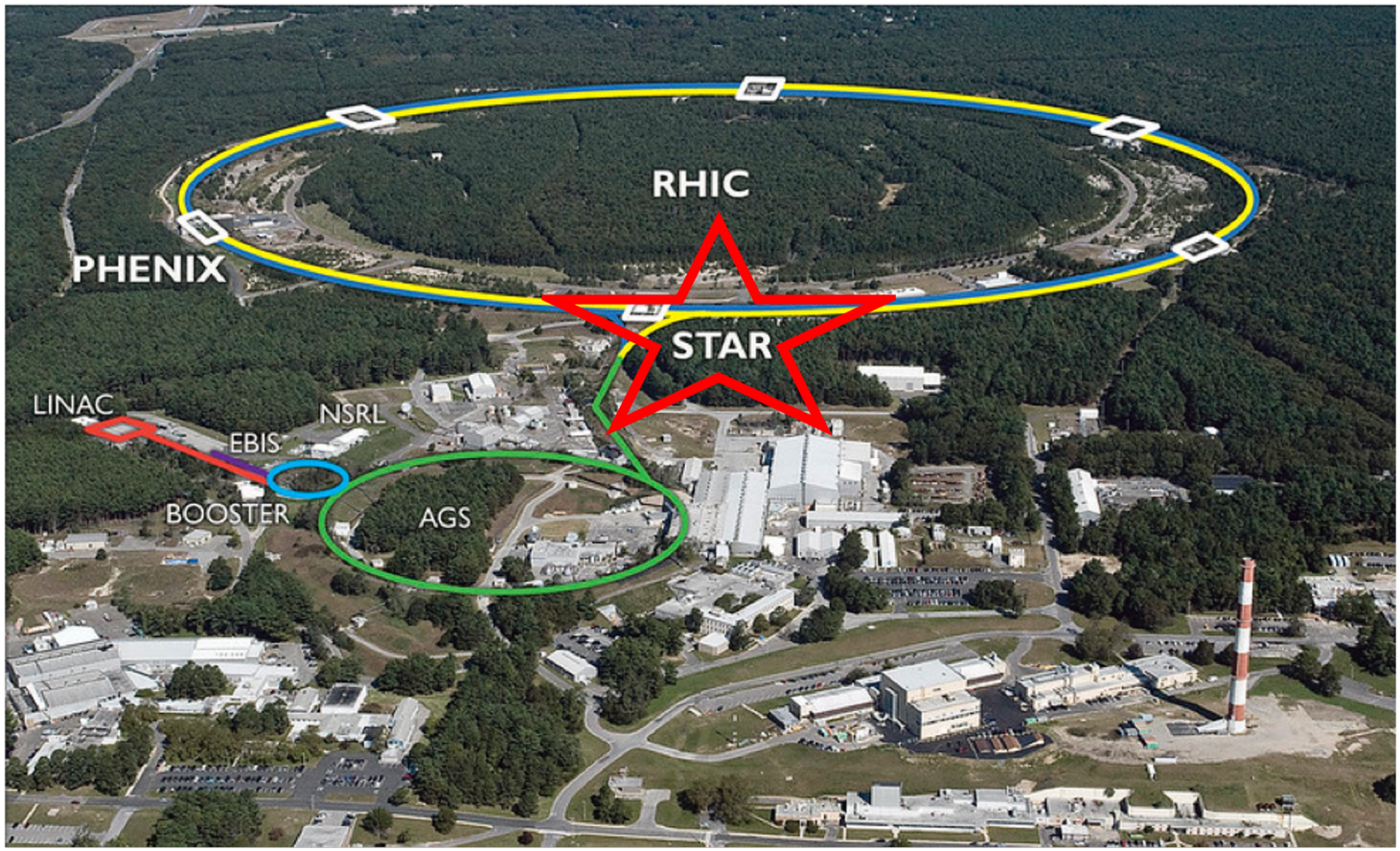
- STAR inclusive A_N for forward π^0 in $p^\uparrow + p$ collisions : Isolated π^0 has larger A_N than non-isolated π^0
  - Isolated π^0: No other nearby photons
- Indication: there might be non-trivial contributions to the large A_N from diffractive processes



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

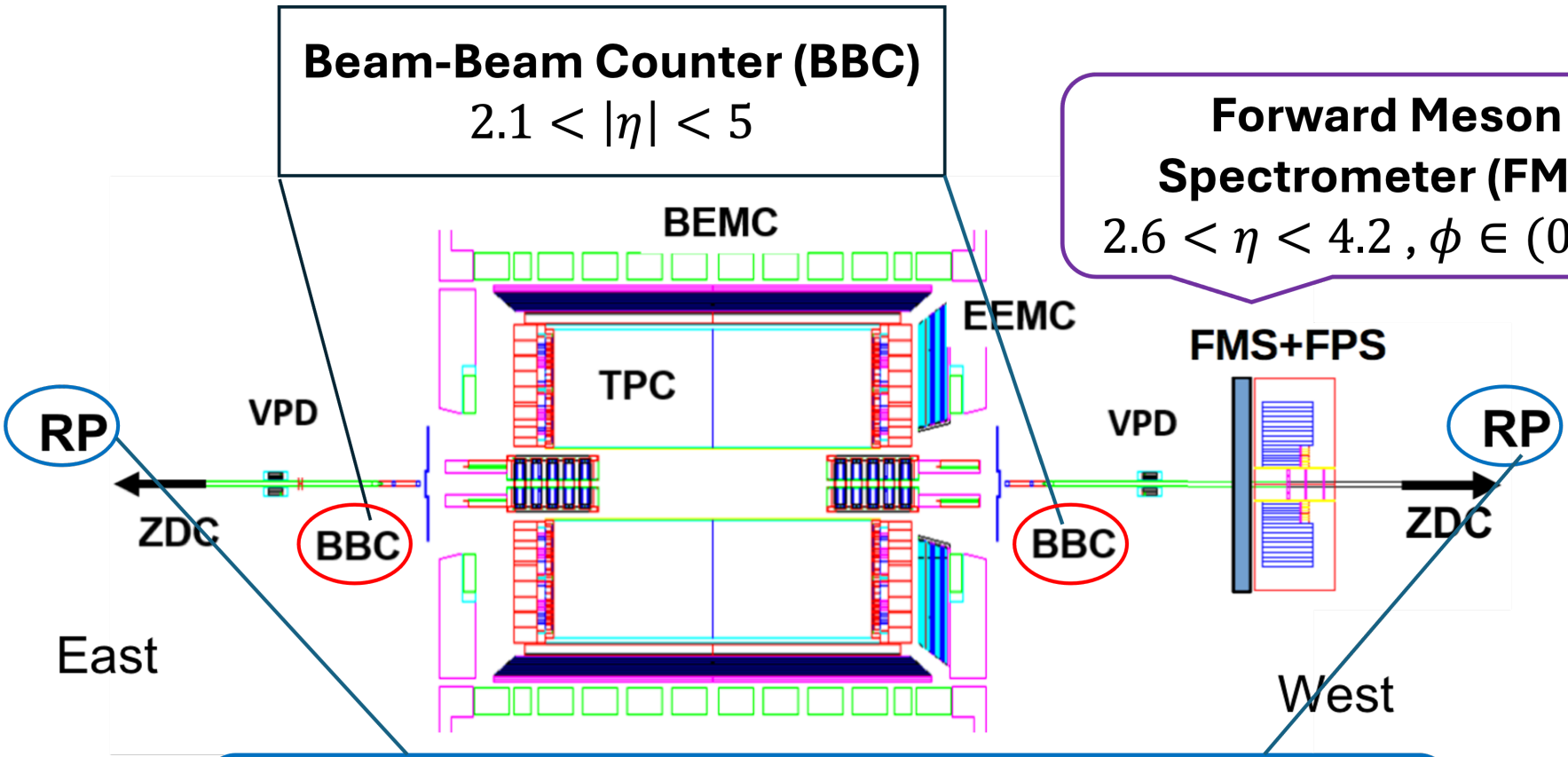
RHIC: Relativistic Heavy Ion Collider

- Located at Brookhaven National Laboratory (BNL) in US
- World's only polarized proton-proton collider with transverse and longitudinal polarization



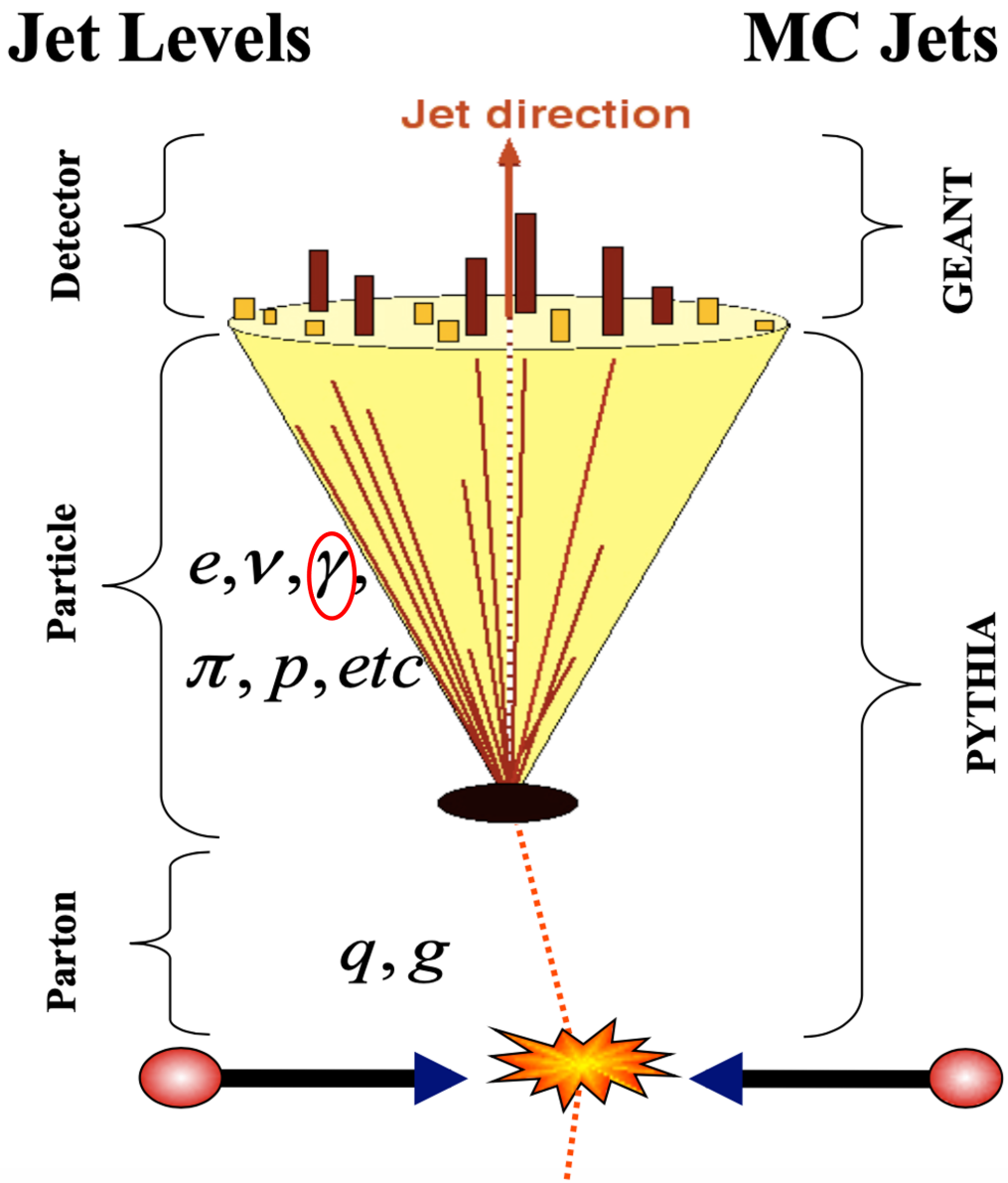
The STAR Experiment

- STAR sub-detectors used in measuring the A_N



Electromagnetic Jets at FMS (FMS EM-jets)

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

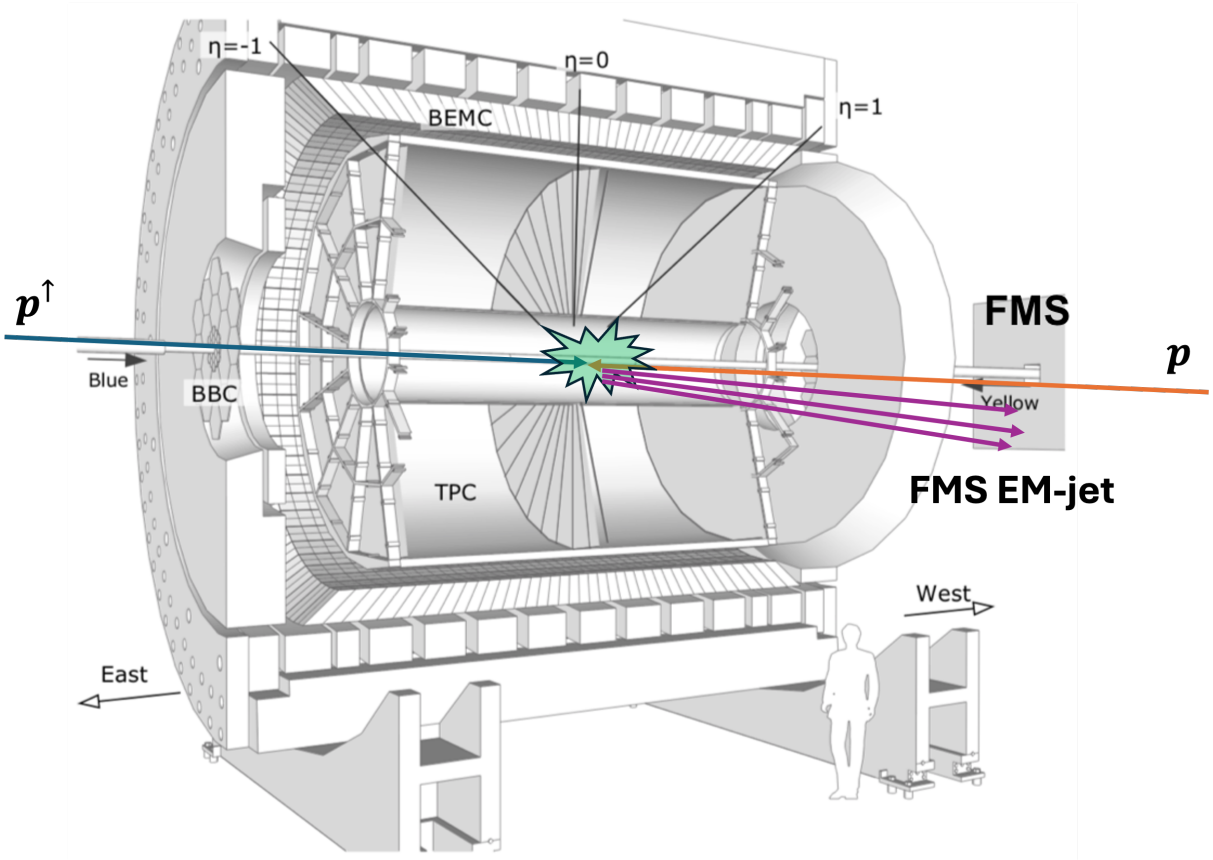


Inclusive EM-jet A_N at Forward Rapidity using FMS

Goals:

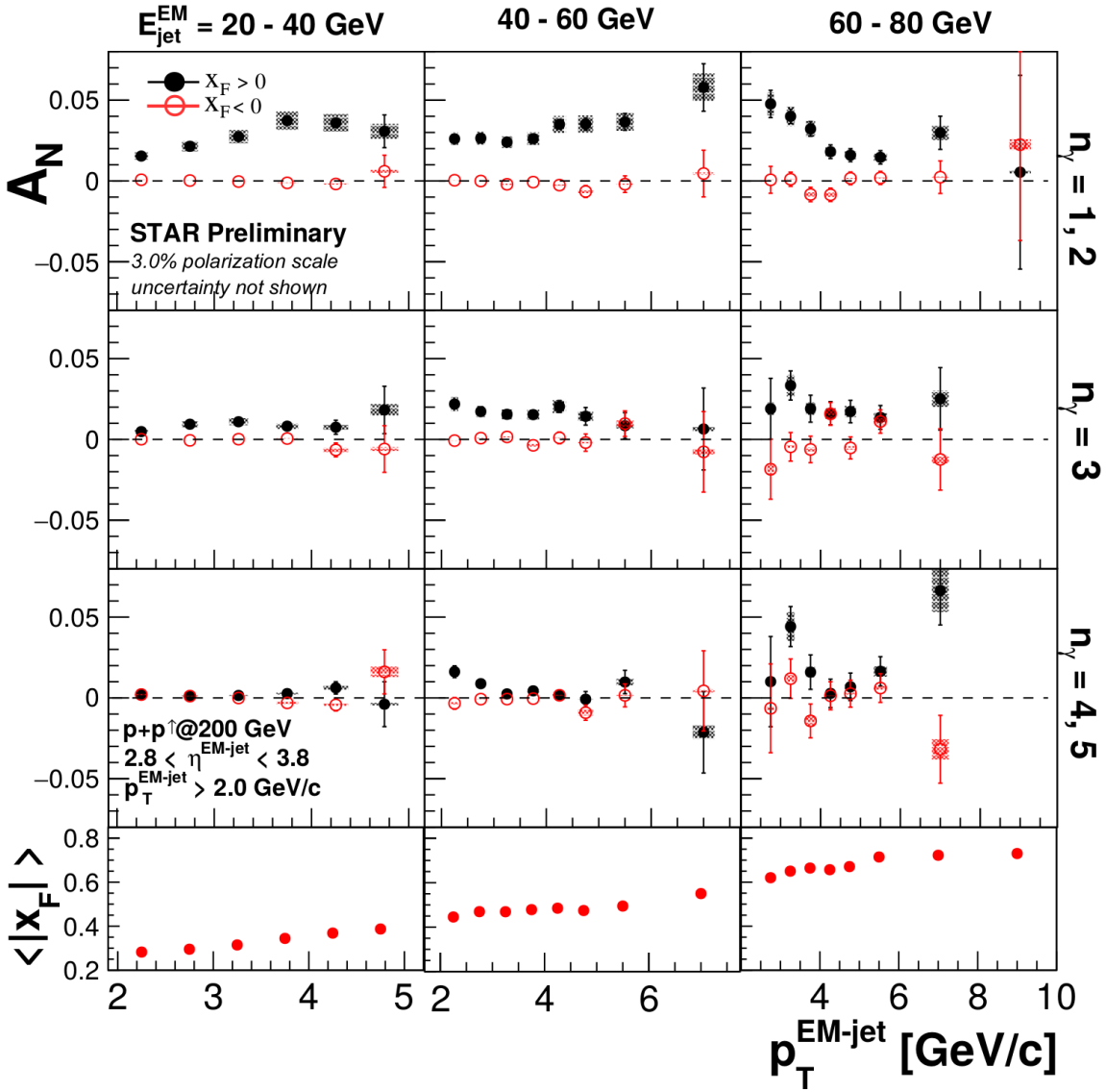
Characterize the EM-jet A_N as a function of EM-jet p_T, x_F and photon multiplicity to explore potential sources of large A_N

- Data set: Transversely polarized p + p collisions at $\sqrt{s} = 200$ GeV collected in 2015 at STAR
  - Integrated luminosity: 52 pb^{-1}
  - Average polarization: 57%
- This data set is used for all analyses in this talk



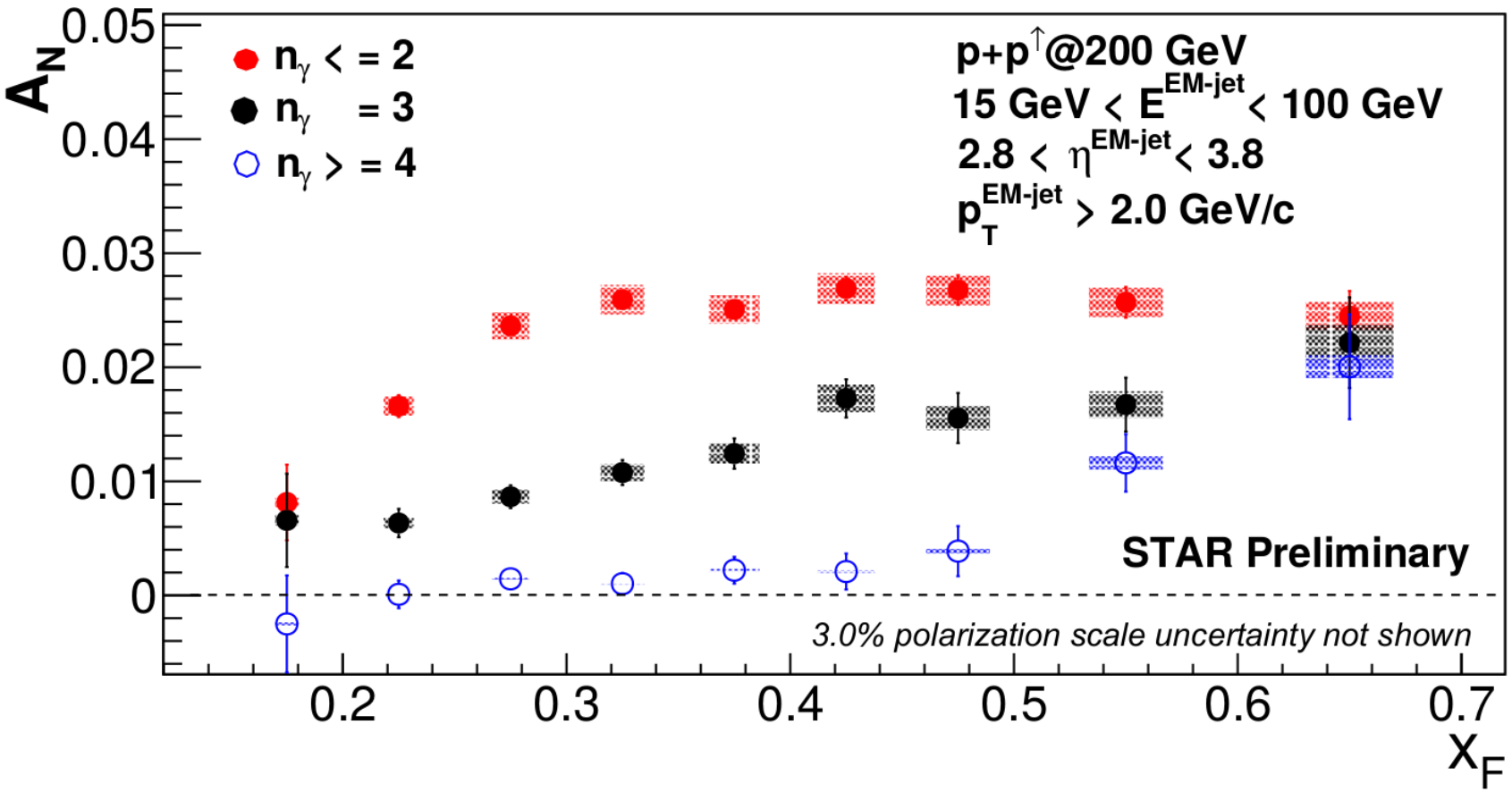
Multi-dimensional Inclusive EM-jet A_N at Forward Rapidity at 200 GeV

- 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 is smaller for EM-jets consisting of 3 or more photons
- A_N at $x_F < 0$ is consistent with 0



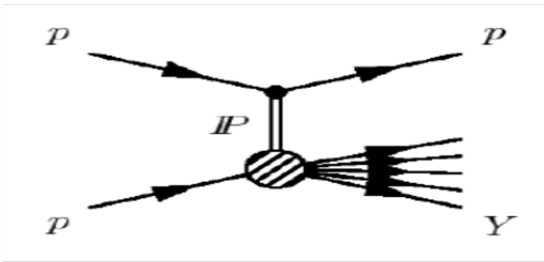
Inclusive EM-jet A_N at Forward Rapidity at 200 GeV

- A_N increases with x_F for all the cases of photon multiplicity
- EM-jets consisting of 1 or 2 photons have the strongest A_N
- Do they indicate the large A_N could come from diffractive processes?



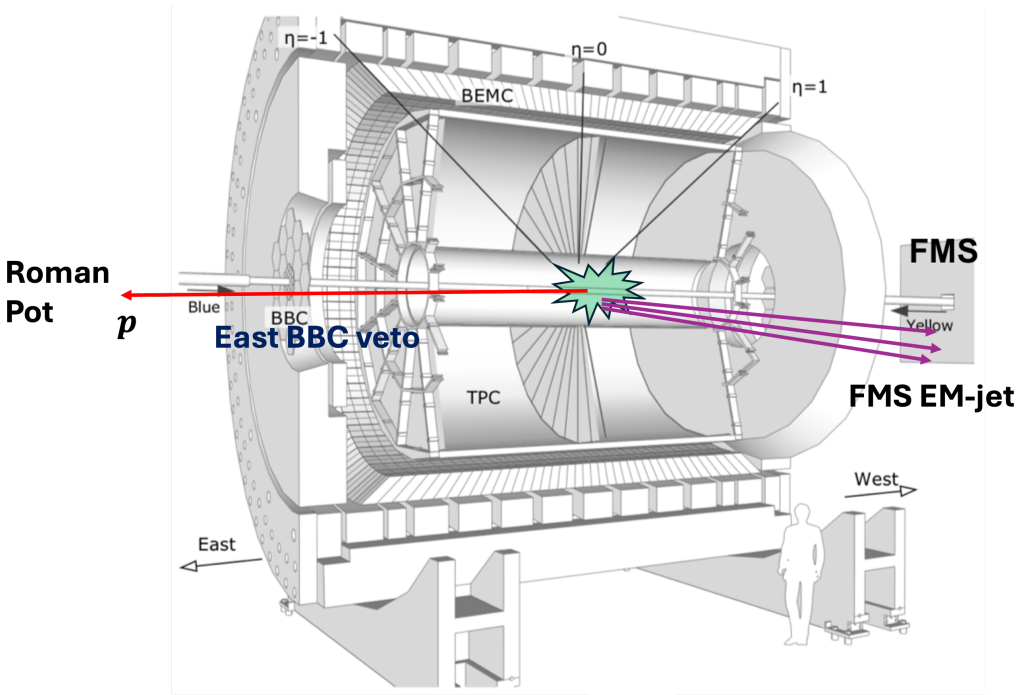
Single Diffractive EM-jet A_N at Forward Rapidity using FMS

- Single diffractive process:
  $p + p \rightarrow p +$ EM-jet $+$ X



East RP track

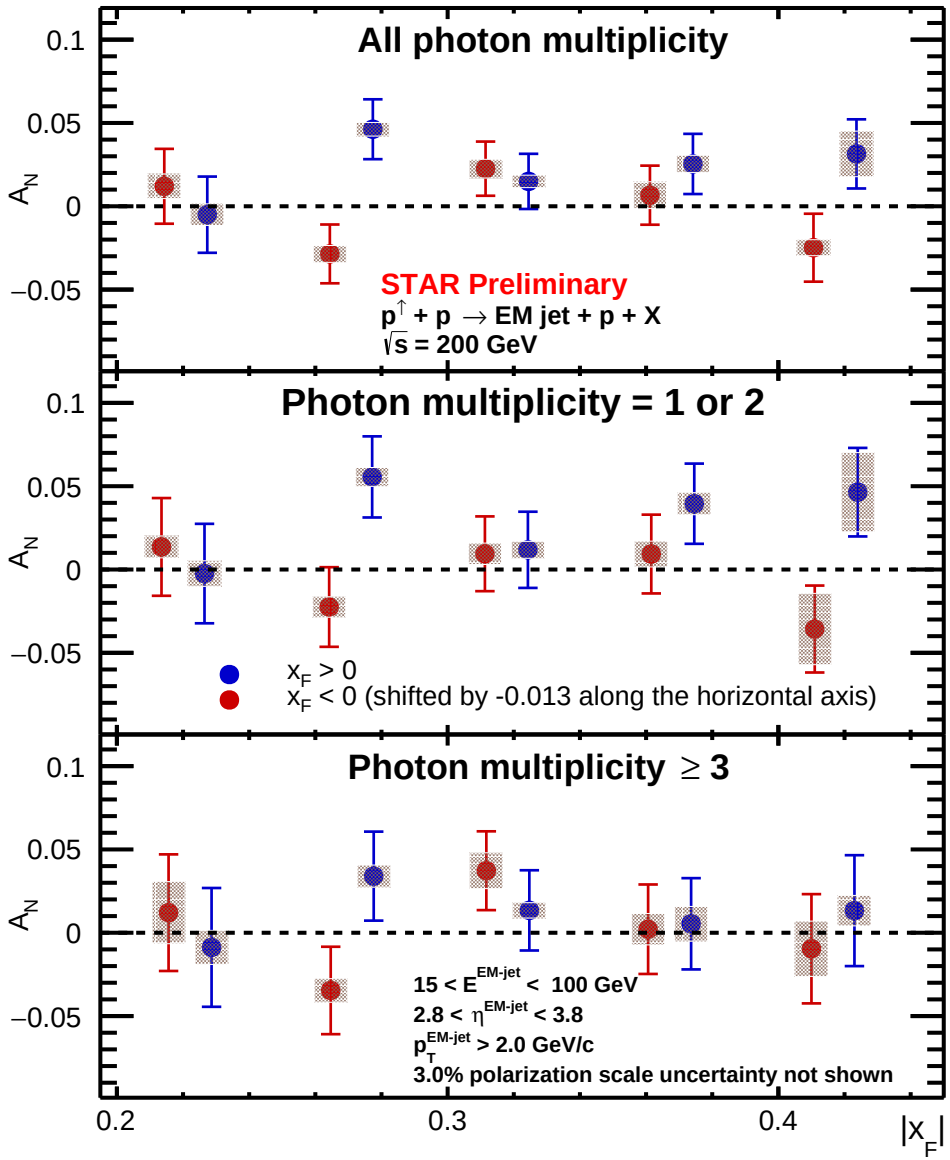
FMS EM-jets



- Event selection:
  1. One EM-jet at FMS: Same FMS EM-jet reconstruction and correction
  2. One proton track detected by east side Roman Pot
     - proton momentum loss $(\xi) < 0.15$
  3. Veto on east side BBC ($-5 < \eta < -2.1$, Rapidity Gap!)

Photon Multiplicity Dependent Single Diffractive EM-jet A_N

- The EM-jet A_N for $x_F > 0$ (> 2 σ significance of non-zero) is observed for the case of all photon multiplicity and 1 or 2 photon multiplicity
- The EM-jet with 1 or 2 photon multiplicity has stronger A_N
- The EM-jet with 3 or more photon multiplicity has A_N consistent with 0
- A_N at $x_F < 0$ is also consistent with 0



Rapidity Gap Event A_N at Forward Rapidity using FMS

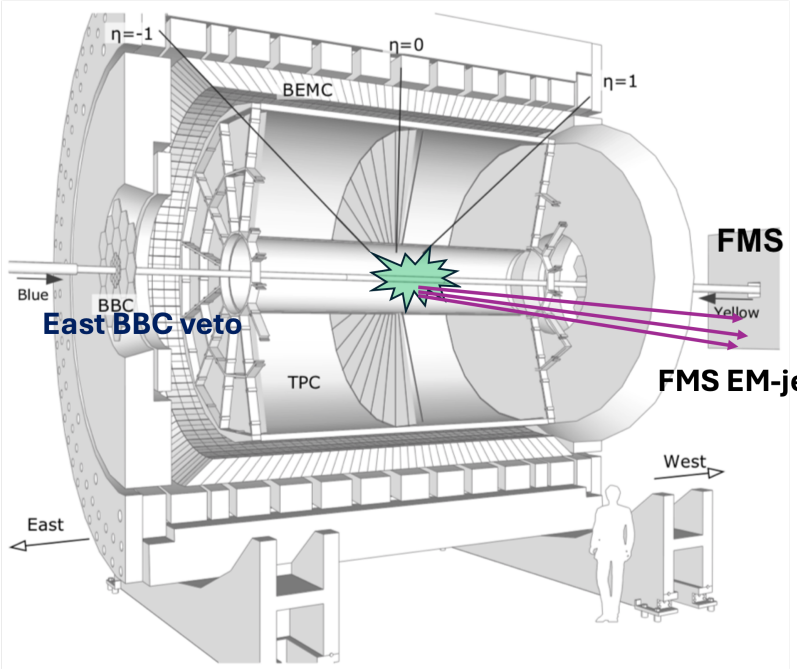
Rapidity gap (RG) events

The Rapidity gap events require:

- EM-jet at FMS
- East side BBC veto (Rapidity gap)

Both are the same requirements as single diffractive process

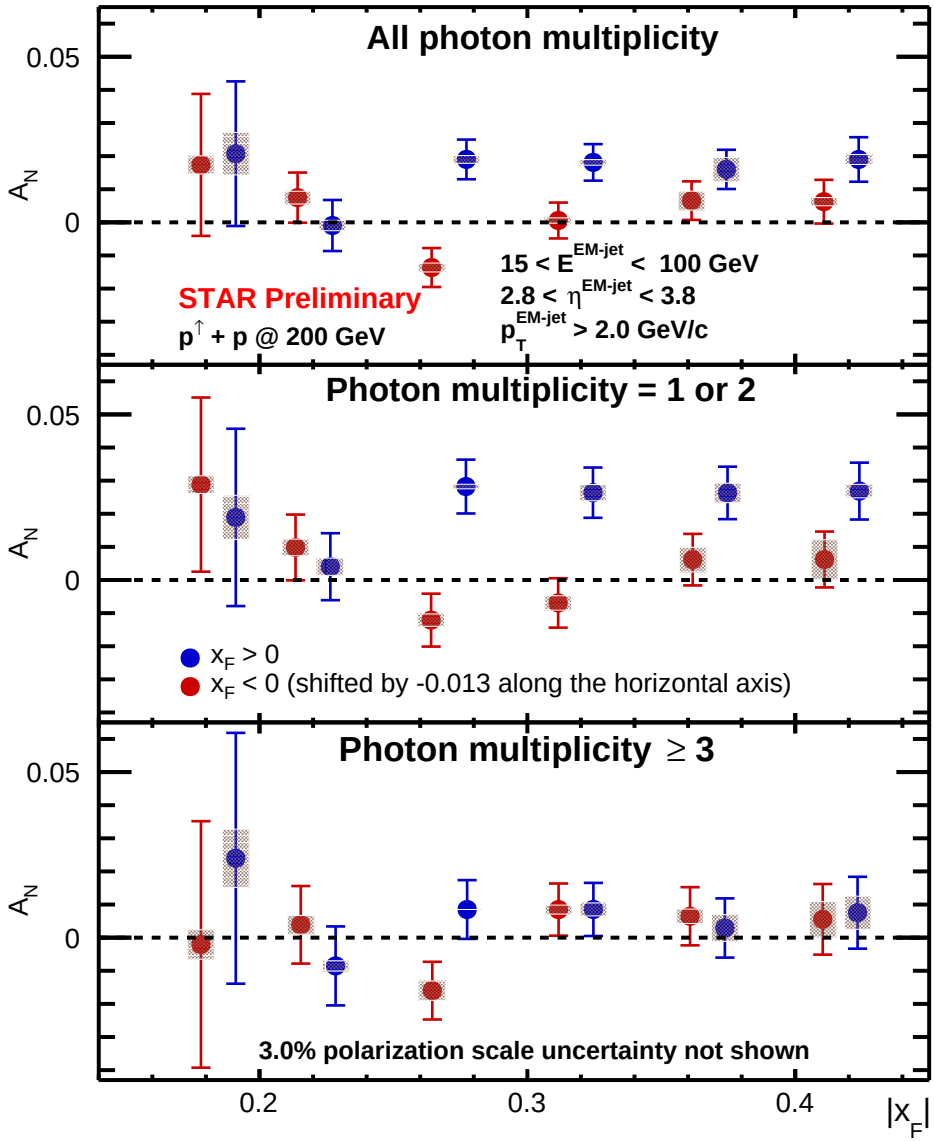
No RP requirement for RG events



- Motivation:
  - The single diffractive events with the proton tagged by east RP are small fraction of real single diffractive events due to limited RP acceptance
  - At least 50% RG events are single diffractive events (precise fraction is under investigation)

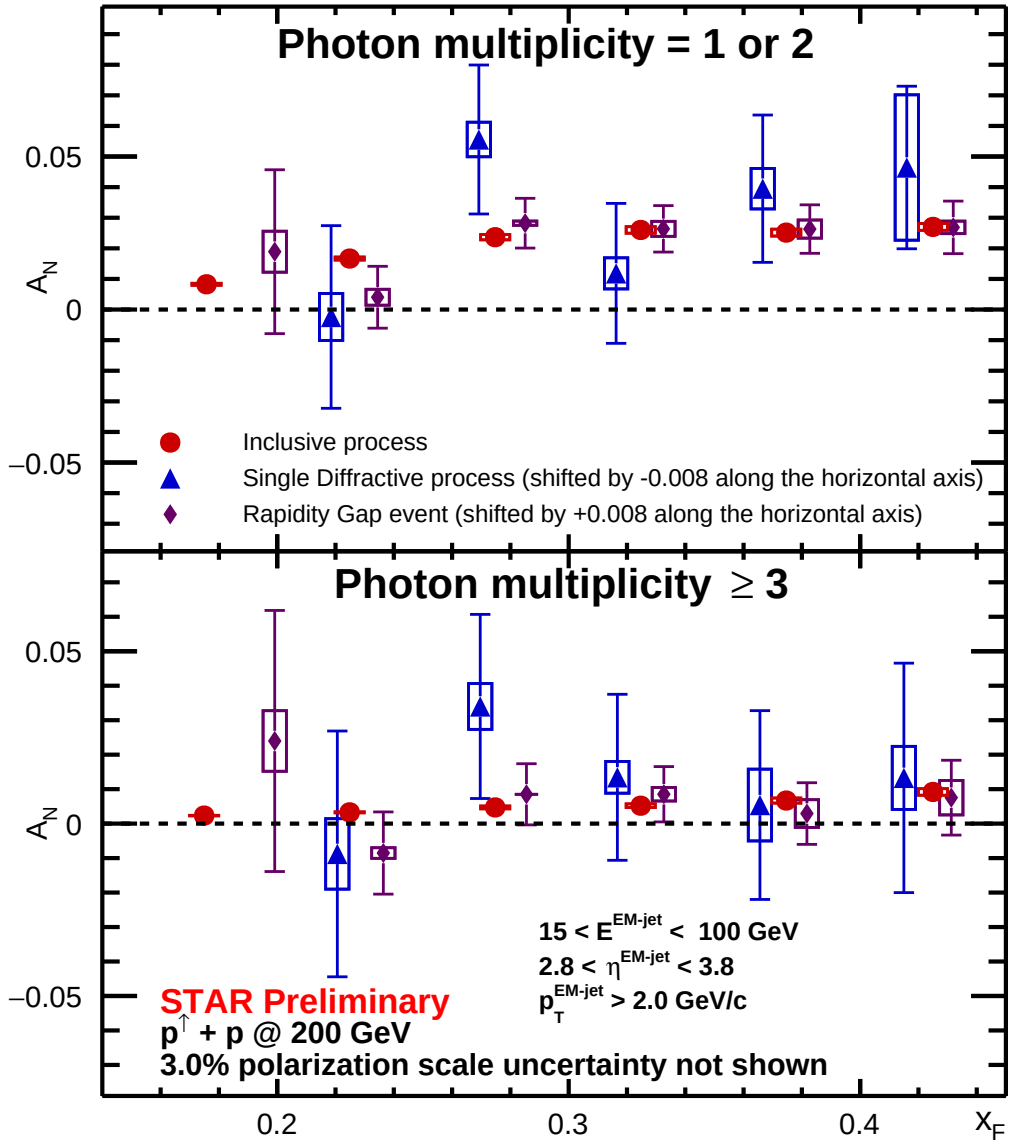
Photon Multiplicity Dependent EM-jet A_N for Rapidity Gap Events

- 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 strongest



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, the 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



Conclusion

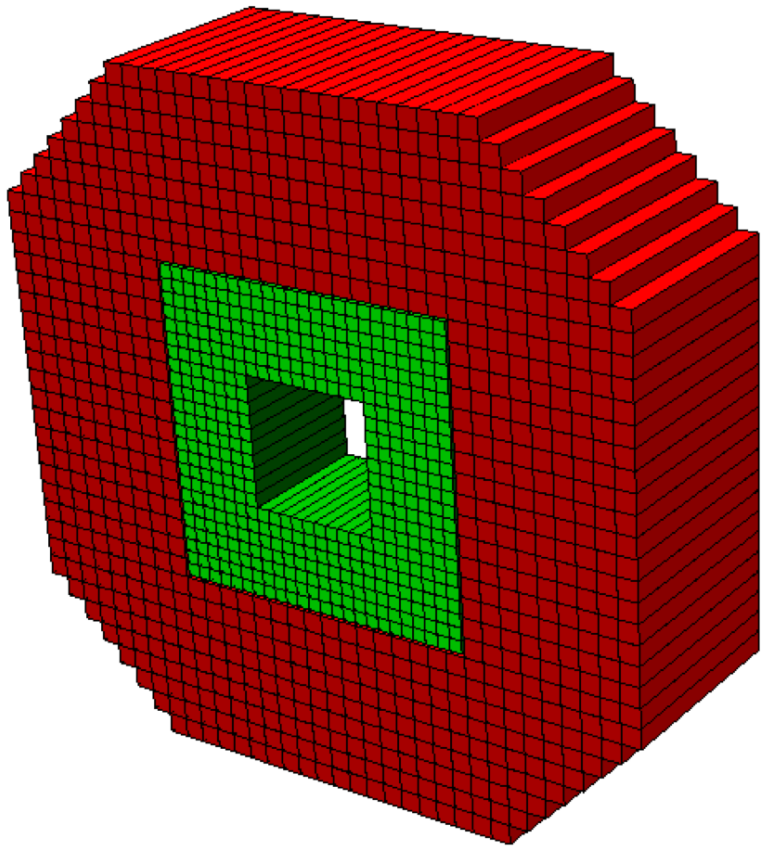
- ★ Multi-dimensional studies of A_N for inclusive EM-jets
  - The EM-jet A_N increases with decreasing photon multiplicity and increasing x_F, but with weak dependent on p_T
- ★ A_N for single diffractive EM-jets
  - A_N for the EM-jet with the case of EM-jet with all photon multiplicity, as well as 1 or 2 photon multiplicity are $> 2\ \sigma$ significance to be non-zero
  - A_N for EM-jet with 3 or more photon multiplicity is consistent with zero
- ★ A_N for EM-jets from rapidity gap events
  - The A_N is similar to the inclusive EM-jet A_N
- ★ The single diffractive process can not provide evidence to have significant contribution to large A_N in inclusive process

Back up

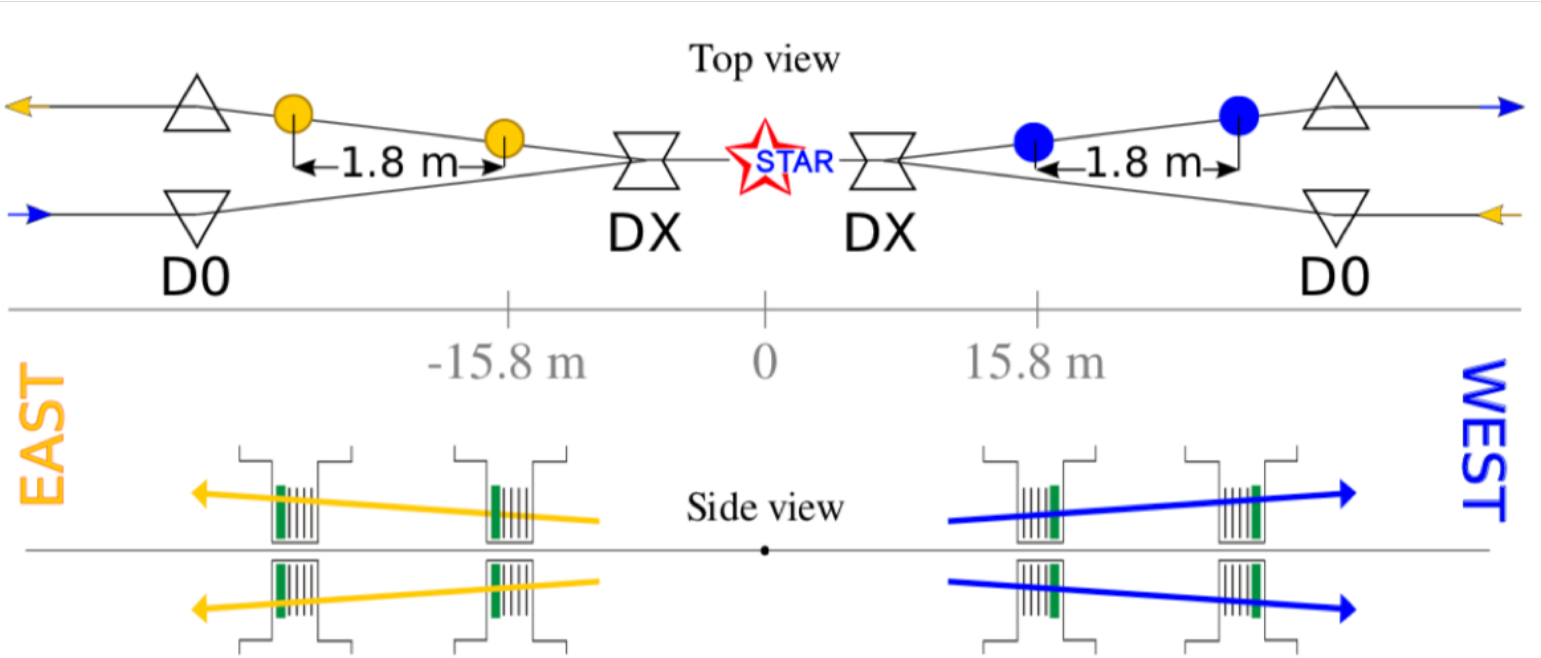
Forward Meson Spectrometer (FMS)

- 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 $\sim$18 radiation length



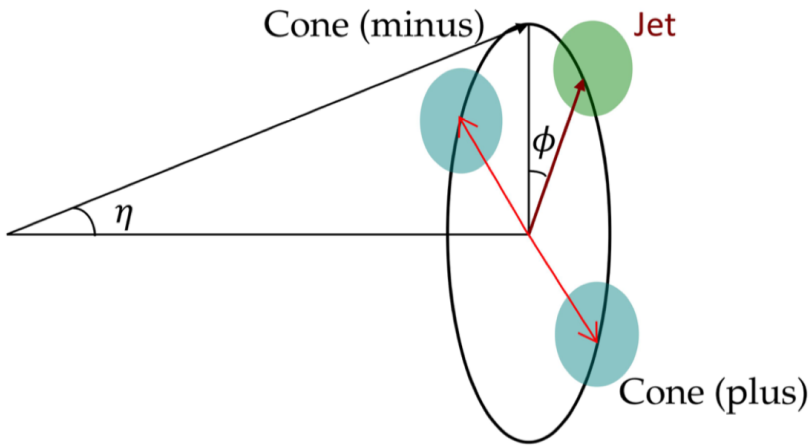
Roman Pot (RP)



- 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 MC simulation



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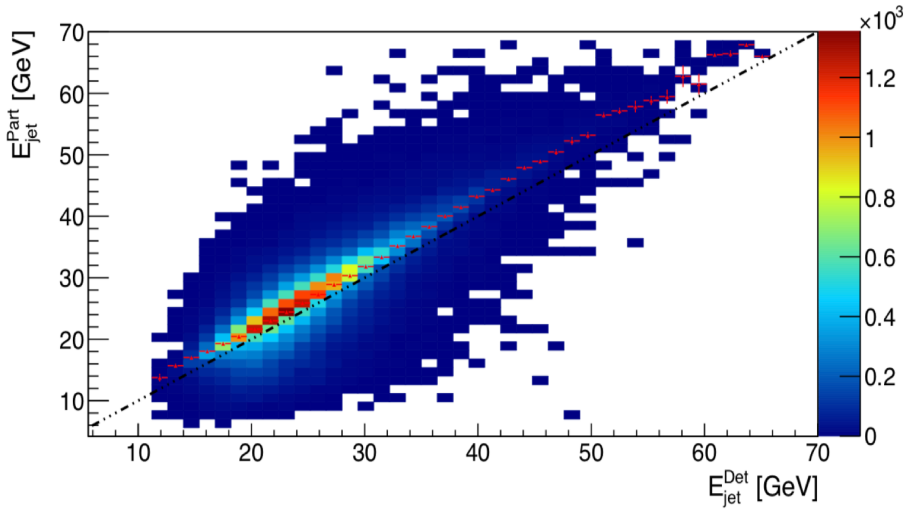

Figure: Detector EM-jet energy to particle level correction

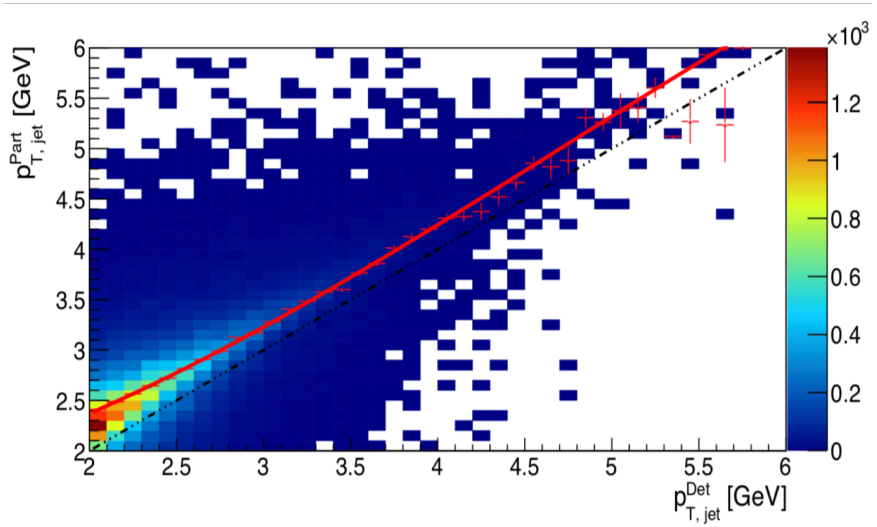

Figure: UE correction