Transverse Single-Spin Asymmetry for Inclusive and Diffractive Electromagnetic jet with $p^{\uparrow} + p$ Collisions at $\sqrt{s} = 200$ GeV

Xilin Liang, for the PAs

General Information

- Data set: run 15 pp transverse $\sqrt{s} = 200$ GeV ,fms stream
  - (production_pp200trans_2015)
- Production type: MuDst ; Production tag: P15ik
- Trigger for FMS : FMS small board sum, FMS large board sum and FMS-JP.
  - Trigger list: FMS-JP0, FMS-JP1, FMS-JP2, FMS-sm-bs1, FMS-sm-bs2, FMS-lg-bs1, FMS-lg-bs2, FMS-lg-bs3. (8 triggers)
- EM-jet reconstruction: Anti-k_T algorithm with R=0.7

Paper Information

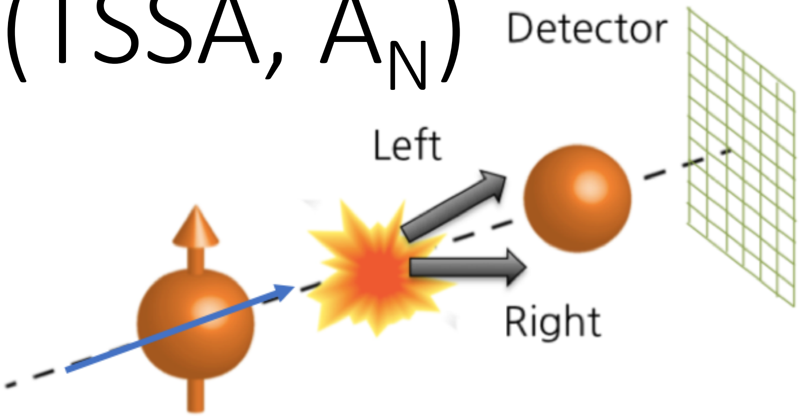
- Title: Transverse Single-Spin Asymmetry for inclusive and diffractive process with $p^{\uparrow} + p$ collision at $\sqrt{s} = 200$ GeV
- PAs: Kenneth Barish, Carl Gagliardi, Latif Kabir, **Xilin Liang***
- Target journal: TBD
- Webpage: https://drupal.star.bnl.gov/STAR/blog/liangxl/Paper-Transverse-single-spin-asymmetry-inclusive-and-diffractive-EM-jet-pup-p-collision

*Email: xilin.liang@email.ucr.edu

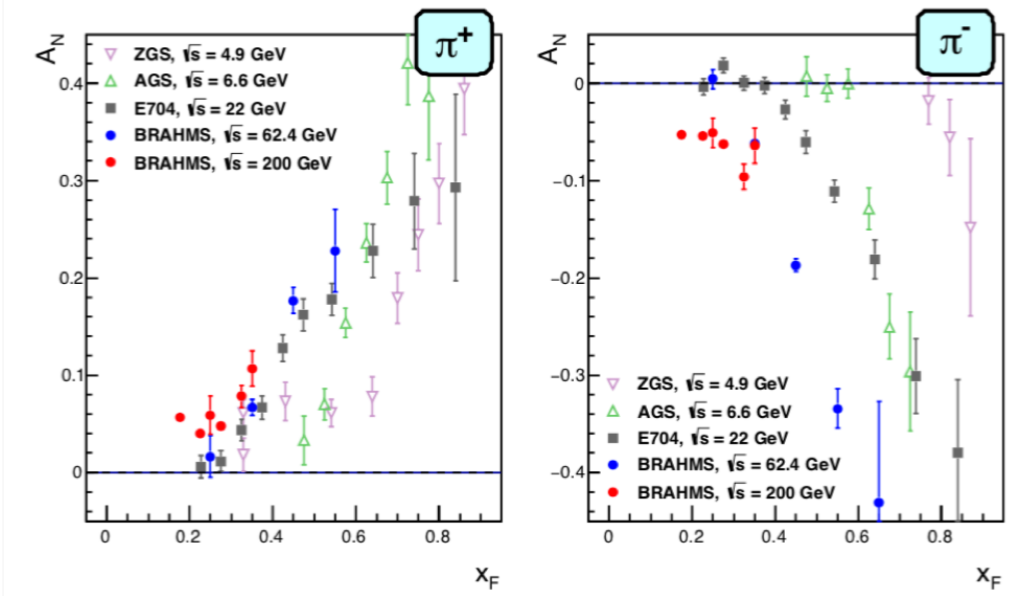
Abstract

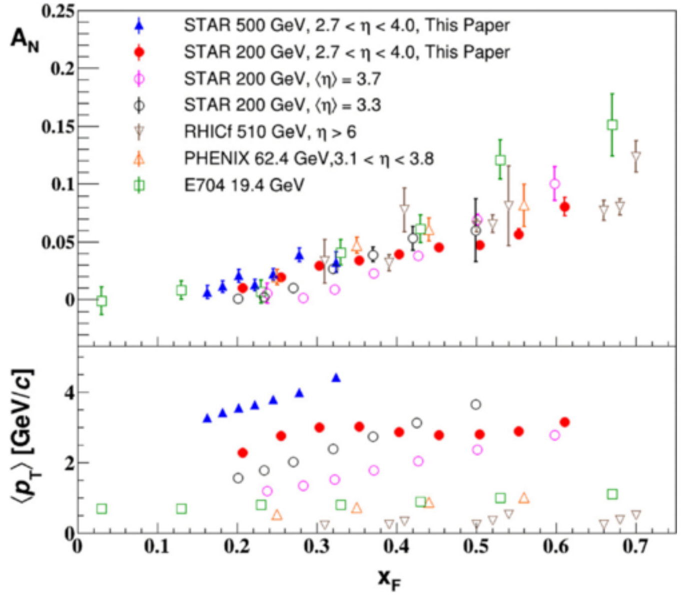
- The STAR Collaboration reports the measurements of transverse single-spin asymmetry, A_N, for inclusive and diffractive electromagnetic jets (EM-jets) at center-of-mass energy of 200 GeV in transversely polarized proton-proton collisions in the pseudorapidity region of 2.6 to 4.1. The photon-multiplicity dependent (jetness) A_N results of inclusive EM-jets are investigated. It shows the A_N of lower jetness inclusive EM-jets is significantly larger than that of higher jetness inclusive EM-jets. The A_N of inclusive EM-jets is observed to increase with increasing Feynman x (x_F) regardless of the jetness of the inclusive EM-jets. For the diffractive EM-jets, the non-zero A_N is observed with 3.8-sigma significance. However, the A_N value is negative, which is opposite to the results for inclusive EM-jets A_N. The diffractive process is not the possible explanation for sources of larger A_N for lower jetness inclusive EM-jets or isolated π^0.

Transverse Single-Spin Asymmetry (TSSA, A_N)



- $A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$
- pQCD predicts $A_N \sim \frac{m_q \alpha_s}{\sqrt{s}} \sim 0.001$
- Unexpectedly large A_N at forward region is observed in proton-proton collisions.
- Possible mechanism for large TSSA:
  - TMDs framework: Sivers effect and Collins effect
  - Twist-3 mechanism

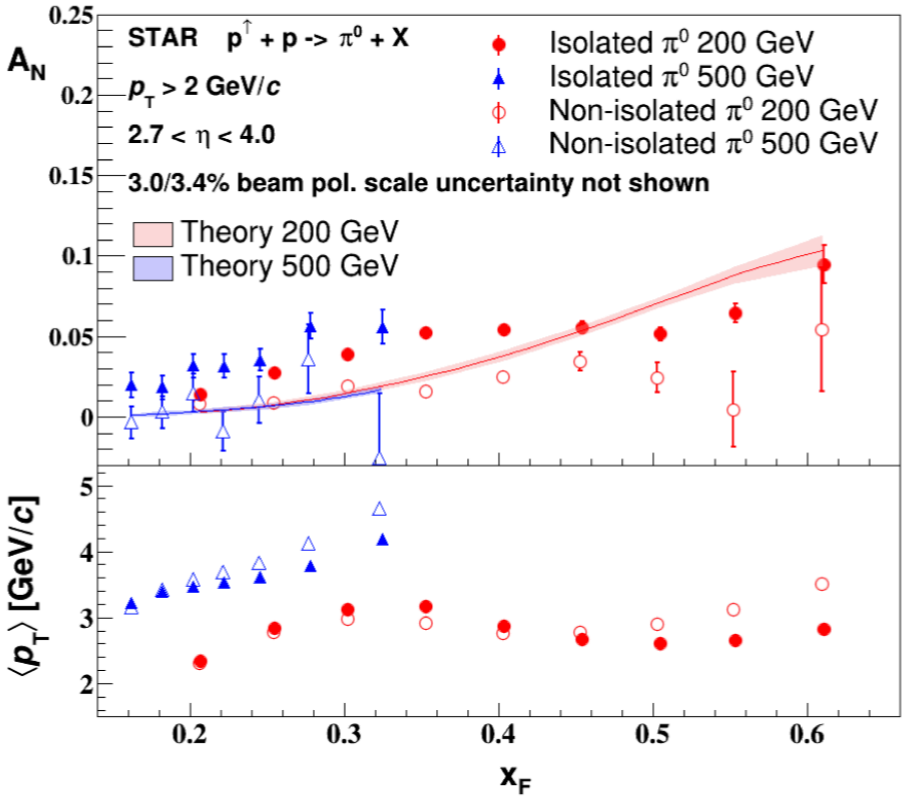




Indication of large TSSA from diffractive process

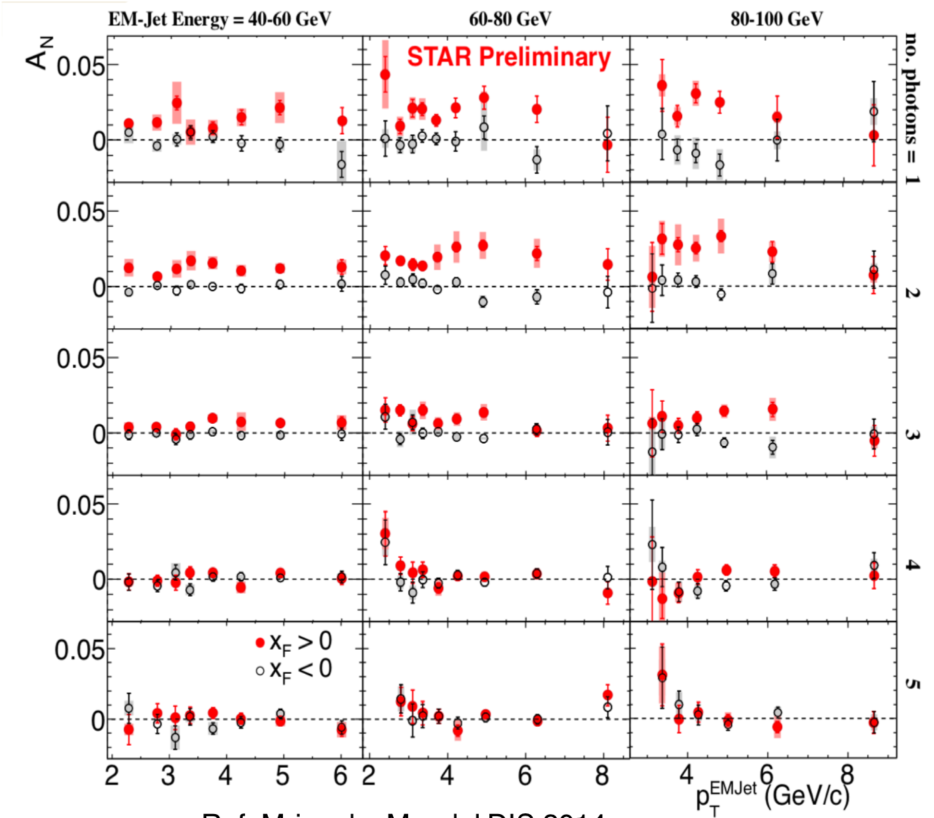
- Previous analyses of A_N for forward π^0 and electromagnetic jets in $p^{\uparrow} + p$ collisions at STAR indicated that there might be non-trivial contributions to the large A_N from diffractive processes.

Inclusive π^0 A_N: isolated π^0 have larger A_N



Ref: Phys. Rev. D **103**, 092009 (2021)

Inclusive EM-jet A_N: low photon multiplicity EM-jets have larger A_N



Ref: Mriganka Mondal DIS 2014

Event selection and corrections

- **FMS**
  - 8 Triggers (avoid ring of fire) , veto on FMS-LED
  - bit shift, bad / dead / hot channel masking (include fill by fill hot channel masking)
  - Jet reconstruction: StJetMaker2015 , Anti-kT, R<0.7 , FMS tower energy > 2 GeV, p_T > 1 GeV/c for diffractive EM-jet (p_T > 2 GeV/c for inclusive EM-jet), FMS point as input
  - Apply energy correction.
- **Only allow acceptable beam polarization (up/down).**
- **Vertex** (Determine vertex z priority according to TPC , VPD, BBC.)
  - Vertex $|z| < 80\ cm$
- **Roman Pot and Diffractive process (diffractive EM-jet only)**
  - Acceptable cases: (in next slide)
  1. Only 1 west RP track + no east RP track
  2. Only 1 east RP track + only 1 west RP track
  - RP track must be good track:
  a) Each track hits > 6 planes
  b) $-2 < \theta_X < 2$ mrad , $1.5 < |\theta_y| < 4.5$ mrad
  - Sum of west RP track energy and all EM Jet energy (see detail in table)
- **BBC ADC sum cuts (diffractive EM-jet only):**
  - West Large BBC ADC sum < 60 and West Small BBC ADC sum < 100

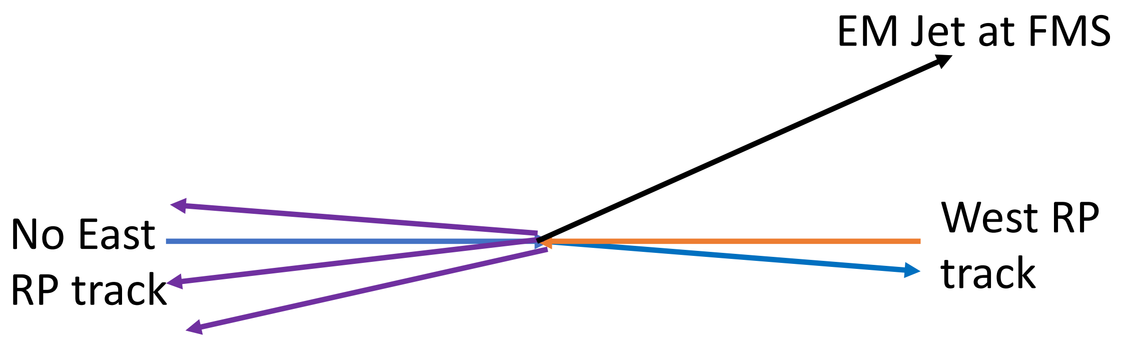
Corrections:
EM-jet energy correction and Underlying Event energy correction

x_F	E sum Cut
0.1 - 0.15	E_{sum} < 108 GeV
0.15 - 0.2	E_{sum} < 108 GeV
0.2 - 0.25	E_{sum} < 110 GeV
0.25 - 0.3	E_{sum} < 110 GeV
0.3 – 0.45	E_{sum} < 115 GeV

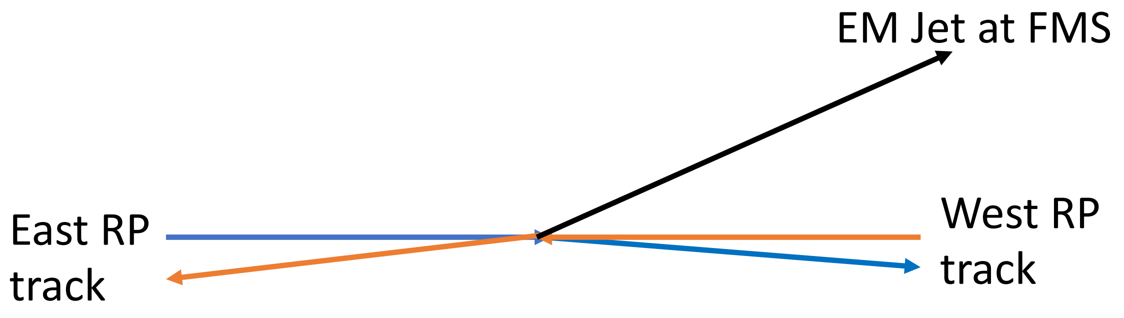
Diffractive process channels

2 diffractive channels are considered. They all contain only 1 west RP track.

Single diffractive event: Only 1 proton track on west side RP.
Require: sum of west side tracks energy (proton + EM Jet) less than beam energy



Double diffractive event: Only 1 proton track on east side RP and only 1 proton track on west side RP.
Require: sum of west side tracks energy (proton + EM Jet) less than beam energy



Technical details

- Event selection
- Corrections:
  - Energy correction: based on simulations, apply correction from detector level to particle level.
  - Underlying correction: use off-axis cone method.
- A_N extraction: cross ratio method.

Systematic uncertainty

- Inclusive EM-jet A_N:
  - Background uncertainty: pile-up, Abort gap, Ring of Fire, Underlying events.
  - Polarization uncertainty
  - p_T and energy uncertainty: calibration uncertainty, p_T correction, uncertainty due to radiation damage.
- Diffractive EM-jet A_N:
  - Background uncertainty: Ring of Fire, energy sum cuts, BBC cuts.
    - By changing the cuts.
  - Polarization uncertainty
  - Energy uncertainty: calibration uncertainty, energy correction, uncertainty due to radiation damage.

*Details in back up.

Results of systematic uncertainty Diffractive EM-jet analysis

x_F range	x_F uncertainty
0.1 - 0.15	8.78%
0.15 - 0.2	3.24%
0.2 - 0.25	3.79%
0.25 - 0.3	4.09%
0.3 – 0.45	4.74%

Polarization uncertainty: 3%

Summary for A_N systematic uncertainty: $\sqrt{\sum \sigma_i^2}$

Diffractive EM-jet A_N for blue beam

x_F range	Ring of Fire	E_sum	Small BBC	Large BBC	Summary
0.125	4%	30%	21%	26%	45%
0.175	22%	10%	7%	12%	28%
0.225	16%	4%	14%	7%	23%
0.275	22%	6%	1%	10%	25%
0.325	4%	0%	1%	5%	6%

Diffractive EM-jet A_N for yellow beam

x_F range	Ring of Fire	E_sum	Small BBC	Large BBC	Summary
0.125	15%	59%	4%	46%	77%
0.175	4%	7%	10%	16%	21%
0.225	2%	14%	11%	28%	34%
0.275	9%	53%	6%	76%	93%
0.325	17%	7%	5%	5%	20%

Fig. 1: A_N for inclusive EM-jet separated by EM-jet energy and jetness

- Fig. 1: Measurement of transverse single-spin asymmetry for three different jetness and three different EM-jet energy region, expressing as a function of EM-jet transverse momentum. The statistical uncertainties are shown in bar and the systematic uncertainties are shown in box. The lowest panel shows the average $|x_F|$.

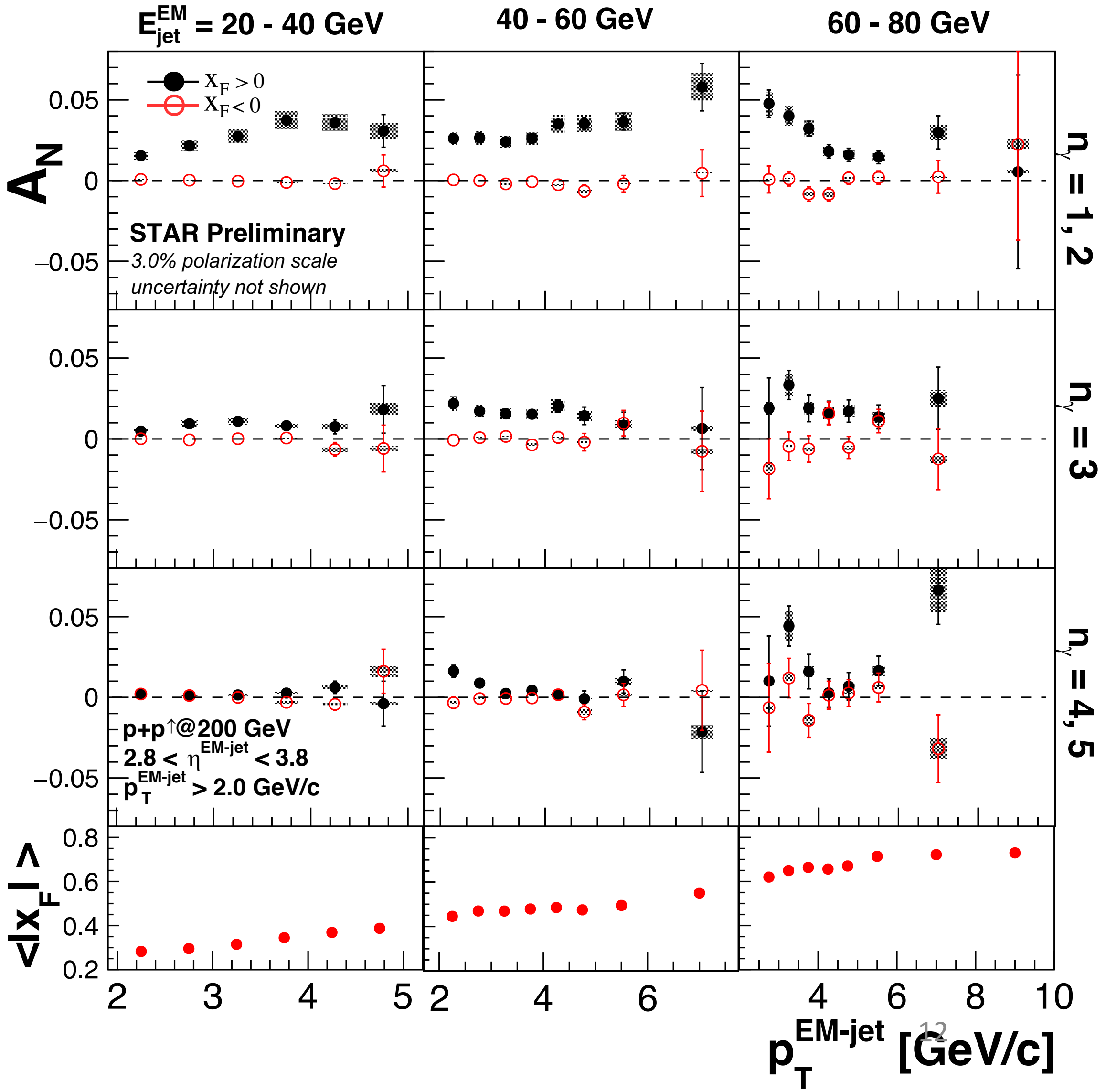


Fig. 2: A_N for inclusive EM-jet vs x_F

- Fig. 2: Measurement of transverse single-spin asymmetry for three different jetness as a function of x_F. The statistical uncertainties are shown in bar and the systematic uncertainties are shown in box.

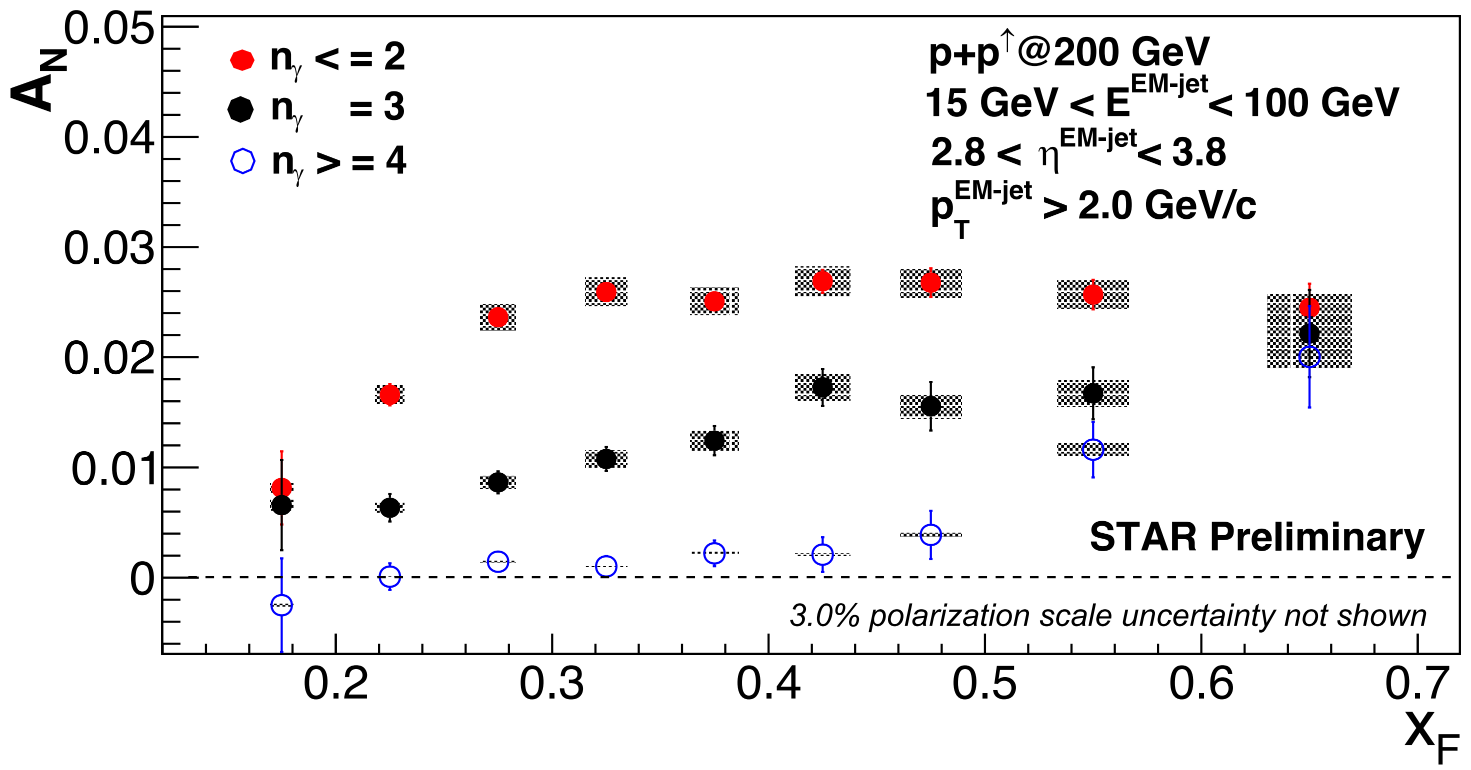
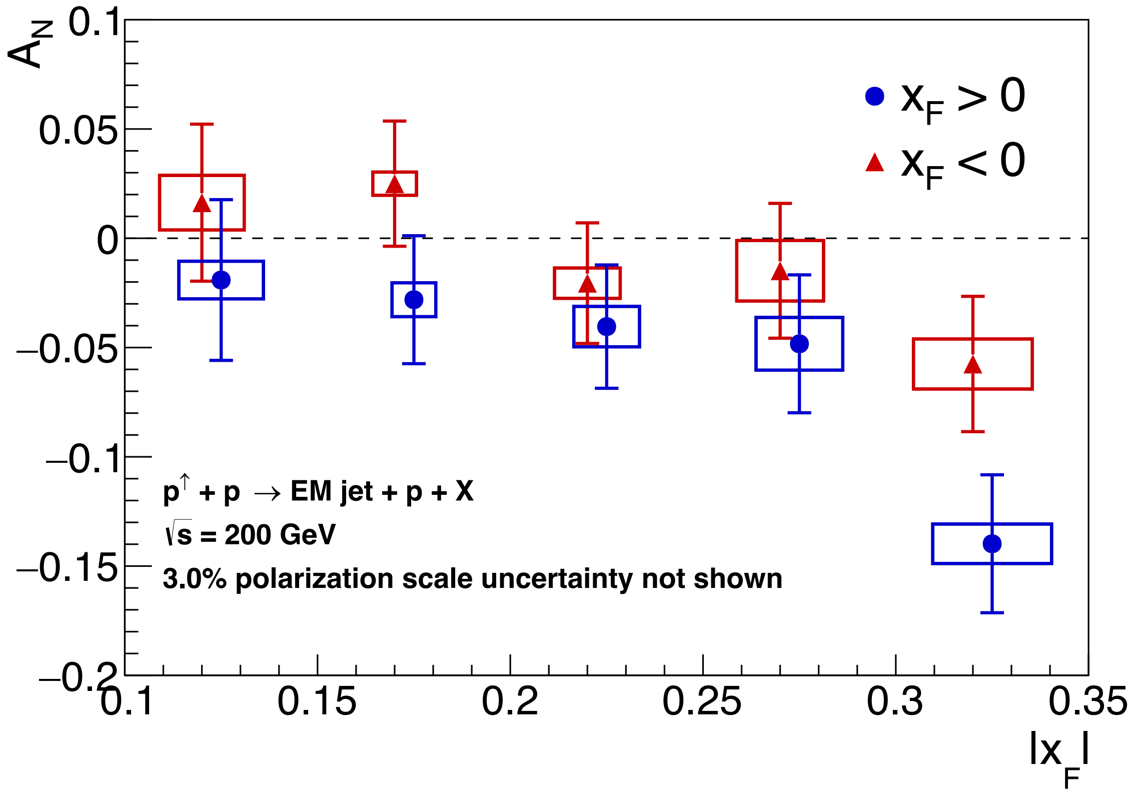


Fig. 3: A_N for diffractive EM-jet

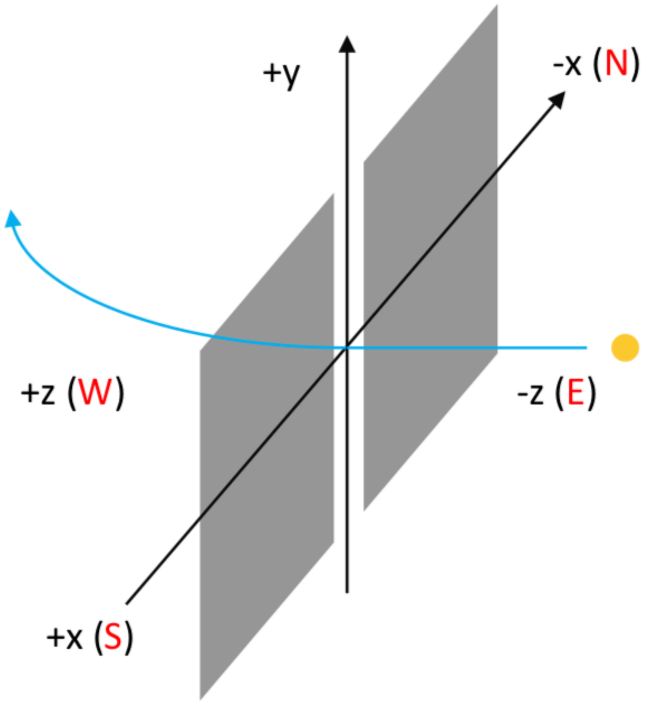
- Fig. 3: Measurement of transverse single-spin asymmetry for diffractive EM-jet as a function of x_F. The statistical uncertainties are shown in bar and the systematic uncertainties are shown in box. The rightmost blue (red) points are for $0.3 < x_F < 0.45$ $(-0.45 < x_F < -0.3)$. All the red points shift -0.005 in x-axis.

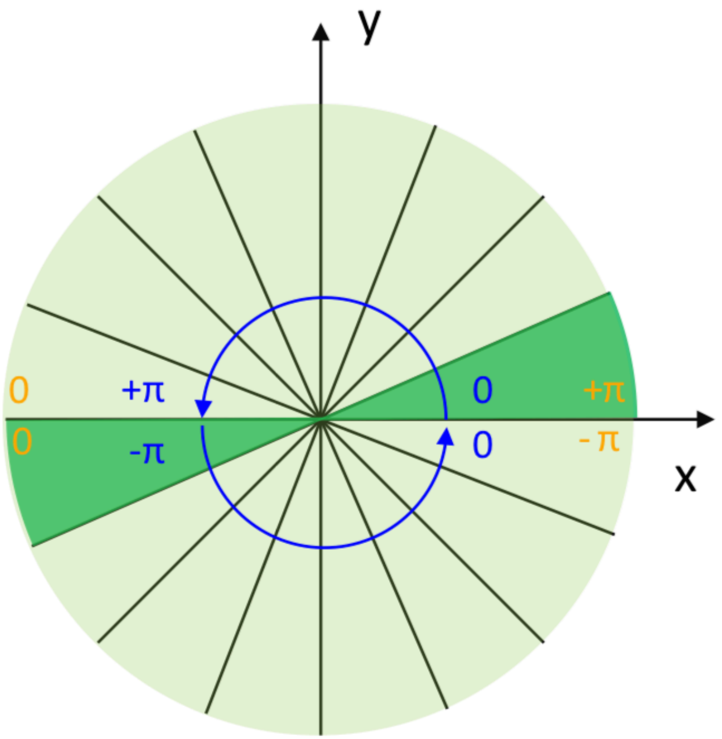


Back up

Transverse single spin asymmetry (A_N) calculation

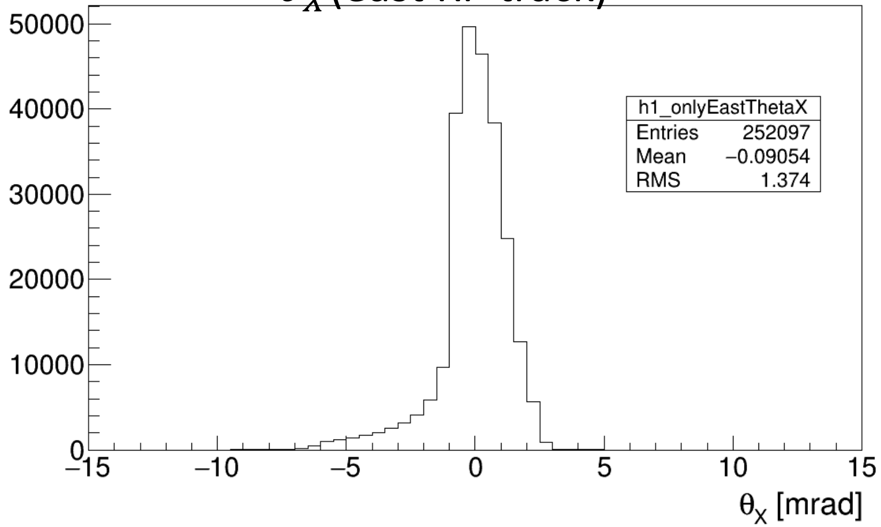
- We use **cross ratio** method to calculate the diffractive EM Jet A_N at FMS.
  - Raw A_N: $\varepsilon = \frac{\sqrt{N^{\uparrow}(\phi)N^{\downarrow}(\phi+\pi)} - \sqrt{N^{\downarrow}(\phi)N^{\uparrow}(\phi+\pi)}}{\sqrt{N^{\uparrow}(\phi)N^{\downarrow}(\phi+\pi)} + \sqrt{N^{\downarrow}(\phi)N^{\uparrow}(\phi+\pi)}} \approx pol * A_N * \cos(\phi)$
  - Plot A_N as a function of x_F, or p_T ($x_F = \frac{E_{EM\ jet}}{E_{Beam}}$)
  - Divide full ϕ range [-π , +π] into 16 bins.



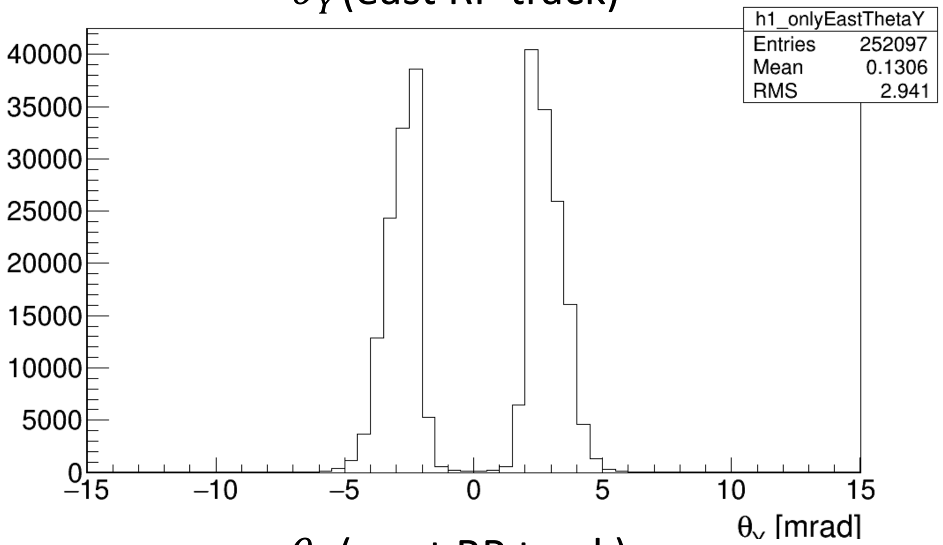


Event selection (RP track)

θ_X(east RP track)



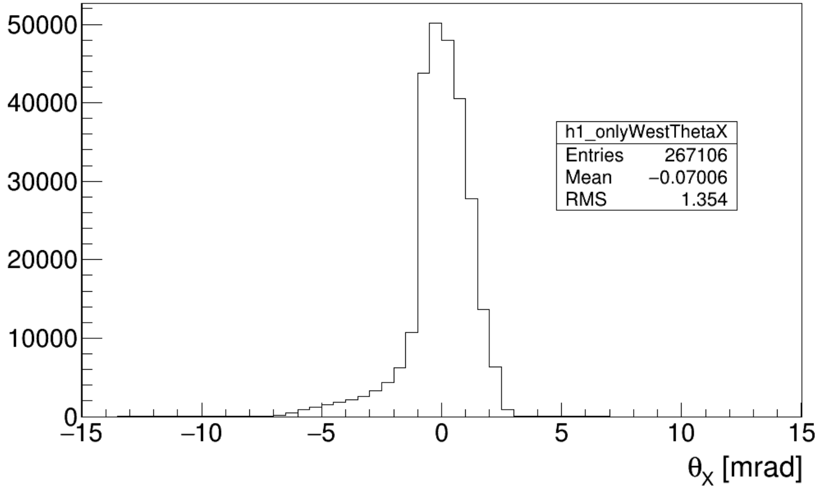
θ_Y(east RP track)



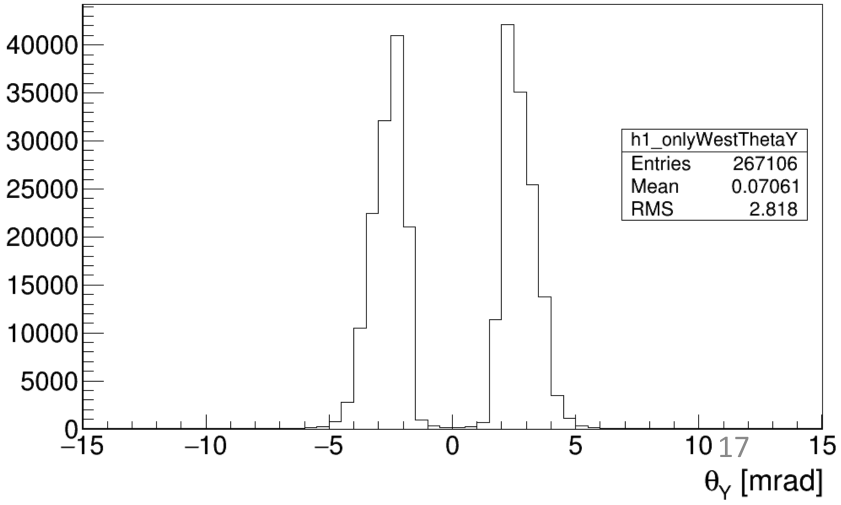
$-2 < \theta_X < 2$ mrad

$1.5 < |\theta_y| < 4.5$ mrad

θ_X(west RP track)



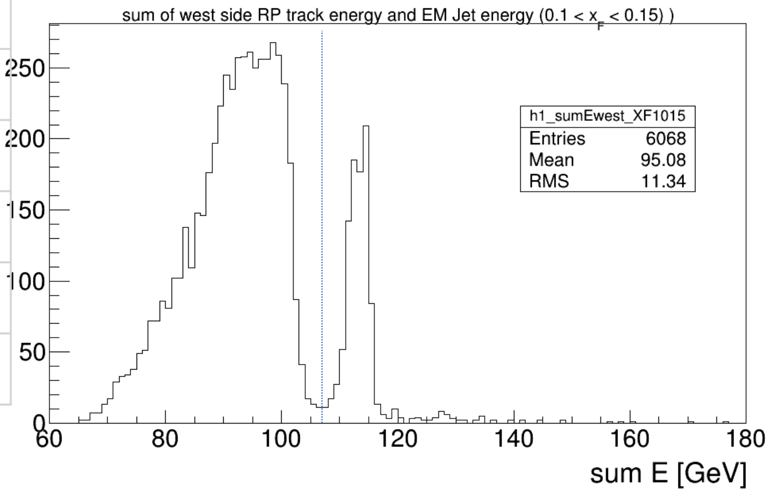
θ_Y(west RP track)

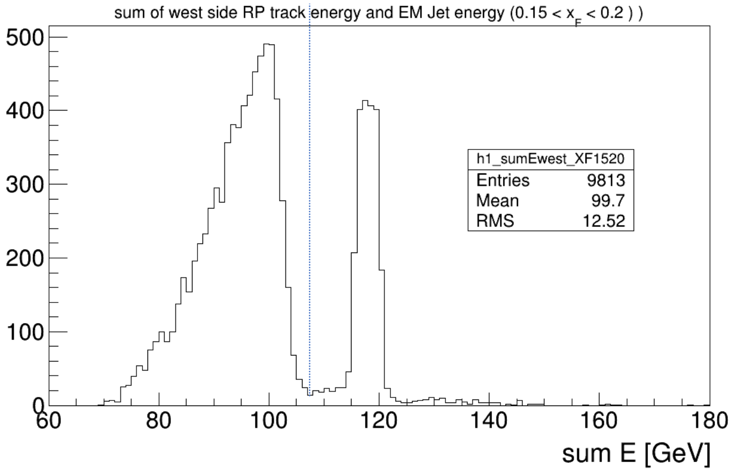


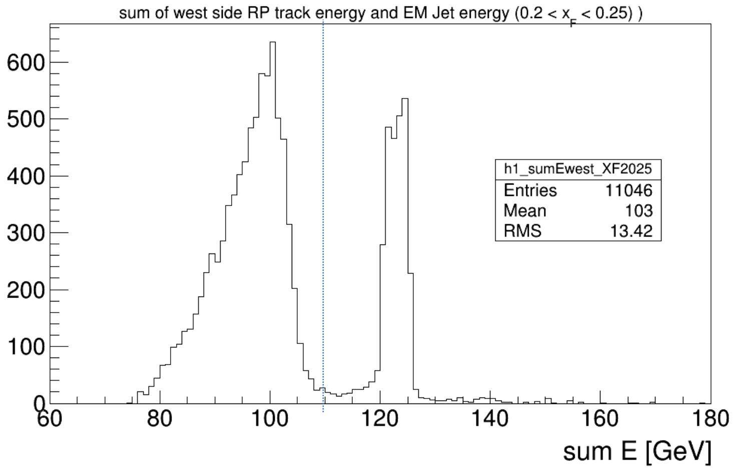
Event selection (sum energy)

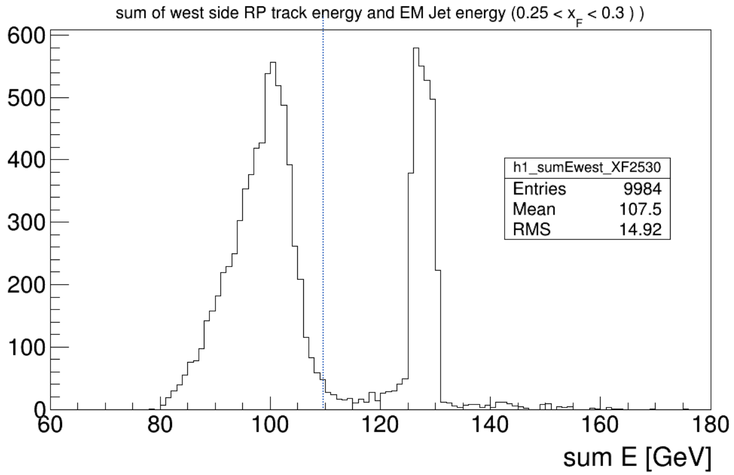
Sum energy = $E_{EM-jet} + E_{west\ RP\ track}$

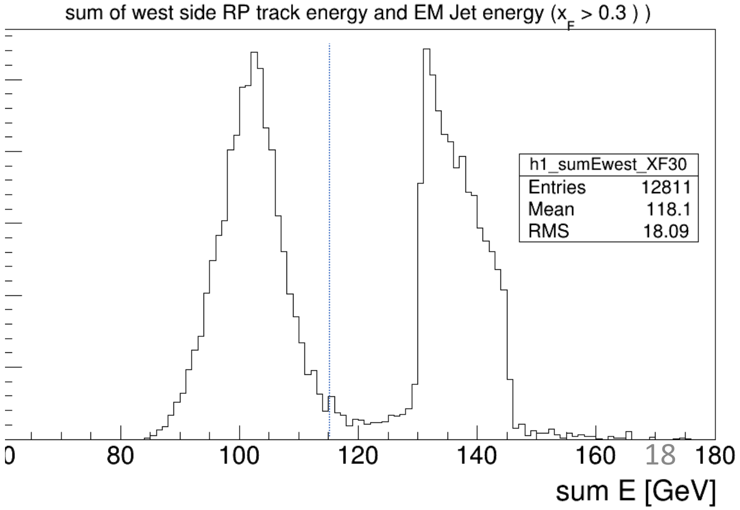
x_F	Sum energy Cut
0.1 - 0.15	E_{sum} < 108 GeV
0.15 - 0.2	E_{sum} < 108 GeV
0.2 - 0.25	E_{sum} < 110 GeV
0.25 - 0.3	E_{sum} < 110 GeV
0.3 – 0.45	E_{sum} < 115 GeV





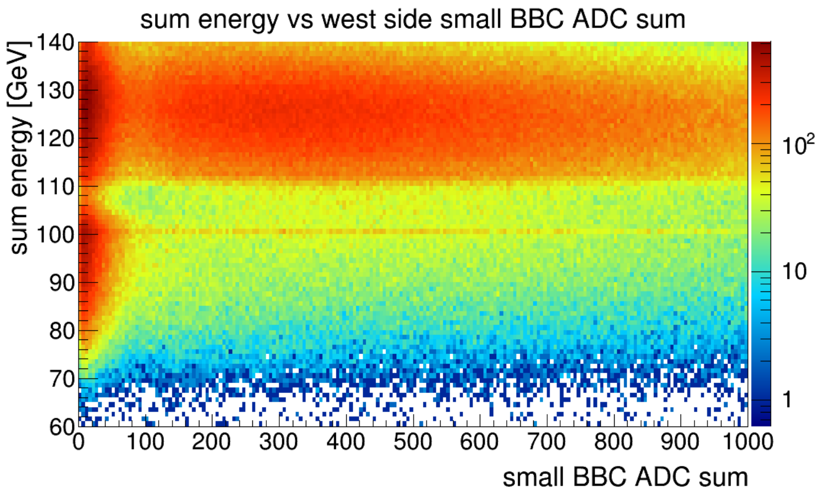


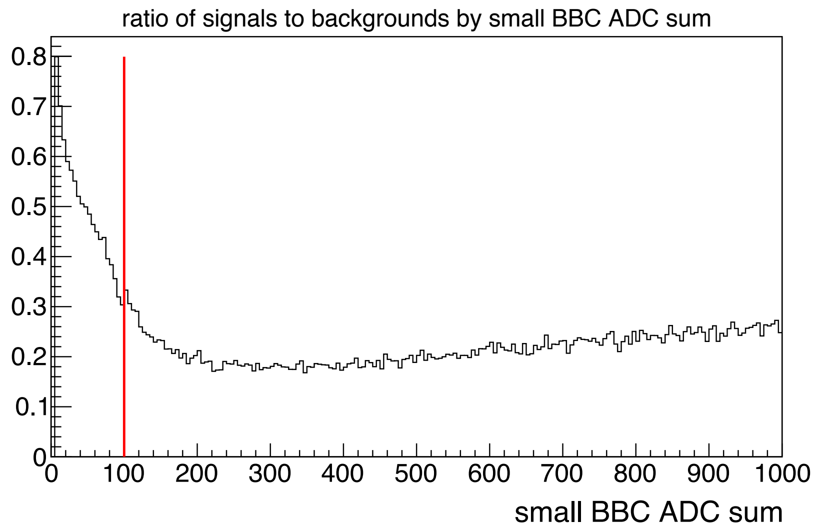




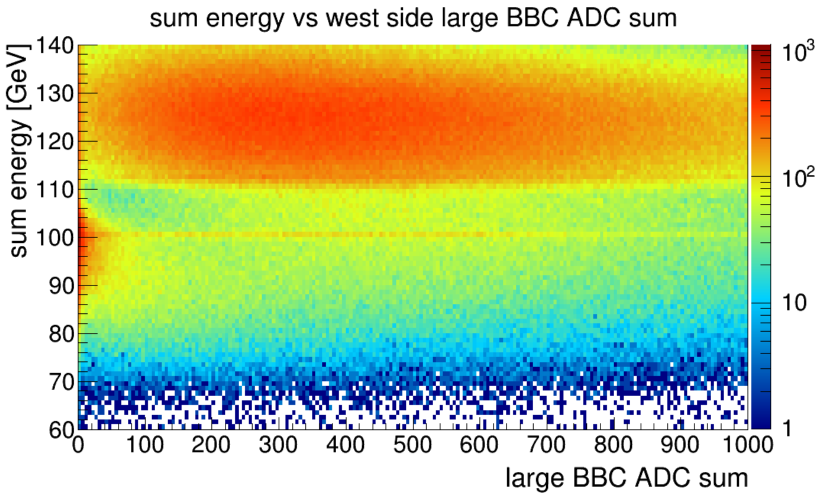
Event selection (BBC cut)

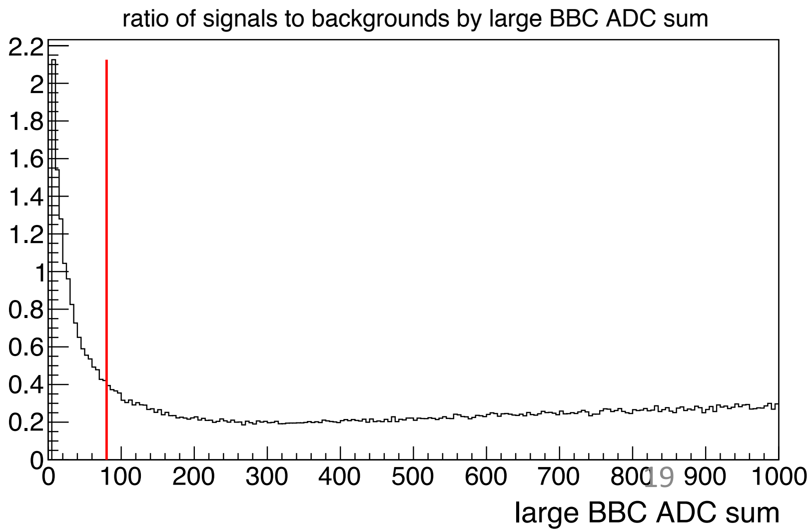
West Small BBC ADC sum < 100





West Large BBC ADC sum < 60





Background uncertainty for diffractive process

- Systematic uncertainties for residual background effect mainly come from the cut for selecting signal from background.
  - Energy sum cut: change the energy sum cut to check the uncertainty.
  - Small BBC ADC sum cut: change 100 to 105
  - Large BBC ADC sum cut: change 60 to 65
- Ring of fire
  - Trigger: fms-sm-bs3

x_F	E sum Cut original	E sum cut for systematic
0.1 - 0.15	E_{sum} < 108 GeV	E_{sum} < 112 GeV
0.15 - 0.2	E_{sum} < 108 GeV	E_{sum} < 112 GeV
0.2 - 0.25	E_{sum} < 110 GeV	E_{sum} < 114 GeV
0.25 - 0.3	E_{sum} < 110 GeV	E_{sum} < 114 GeV
0.3 – 0.45	E_{sum} < 115 GeV	E_{sum} < 120 GeV

Calculate each systematic uncertainty by result difference fraction when changing the cuts:

$$uncertainty = \frac{|A_{N,change\ cut} - A_{N,origin}|}{|A_{N,origin}|}$$

Polarization uncertainty

- $\sigma(P_{set}) = P_{set} \cdot \frac{\sigma(scale)}{P} \oplus \sigma_{set}(fill\ to\ fill) \oplus P_{set} \cdot \frac{\sigma(profile)}{P}$
- $\frac{\sigma(scale)}{P} = 3\%$ [1]
- $\frac{\sigma(profile)}{P} = \frac{2.2\%}{\sqrt{M}} = 0.3\ \%$ [1]
- $\sigma^2{}_{set}(fill\ to\ fill) = (1 - \frac{M}{N}) \frac{\sum_{fill} L_{fill}{}^2 \sigma^2(P_{fill})}{(\sum_{fill} L_{fill})^2}$
  - $\sigma_{set}(fill\ to\ fill)$ = 0.3%
  - $\sigma(P_{fill}) = \sigma(P_0) \oplus \sigma(\frac{dP}{dt})(\frac{\sum_{run} t_{run} L_{run}}{L_{fill}} - t_0) \oplus \frac{\sigma(fill\ to\ fill)}{P} P_{fill}$ [2]

Close to 0

- so $\sigma(P_{set}) = 3.0\%$

[1] W. B. Schmidke, RHIC polarization for Runs 9-17

[2] Z. Chang Example calculation of fill-to-fill polarization uncertainties

EM-jet energy uncertainty for diffractive process

- $\sigma_E = C \oplus R \oplus E$
  - C: Calibration uncertainty (2.50%)[1]
  - R: Radiation damage and non-linear response uncertainty (0.50%)[1]
  - E: Energy resolution and correction uncertainty (separate by different x_F bins)
    - Change the energy correction function to calculate the resolution.

x_F range	Energy resolution	x_F uncertainty
0.1 - 0.15	8.40%	8.78%
0.15 - 0.2	2.00%	3.24%
0.2 - 0.25	2.80%	3.79%
0.25 - 0.3	3.20%	4.09%
0.3 – 0.45	4.00%	4.74%

[1] Z. Zhu , Measurement of Transverse Single Spin Asymmetry for pi0 at Forward Direction in 200 and 500 GeV Polarized Proton-Proton Collisions at RHIC-STAR