Paper proposal: Transverse Single-Spin Asymmetry for Diffractive Electromagnetic Jets with $p^{\uparrow}+p$ Collisions at $\sqrt{s}=200$ GeV

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Paper Information

- Title: Transverse Single-Spin Asymmetry for Diffractive Electromagnetic Jets with $p^{\uparrow}+p$ Collisions at $\sqrt{s}=200$ GeV
- Target journal: PLB
- PAs: Kenneth Barish, Christopher Dilks, Carl Gagliardi, Latif Kabir, David Kapukchyan, **Xilin Liang*** , Mriganka Mondal

- Webpage: https://drupal.star.bnl.gov/STAR/blog/liangxl/Paper-Proposal-run-15-FMS-diffractive-EM-jet

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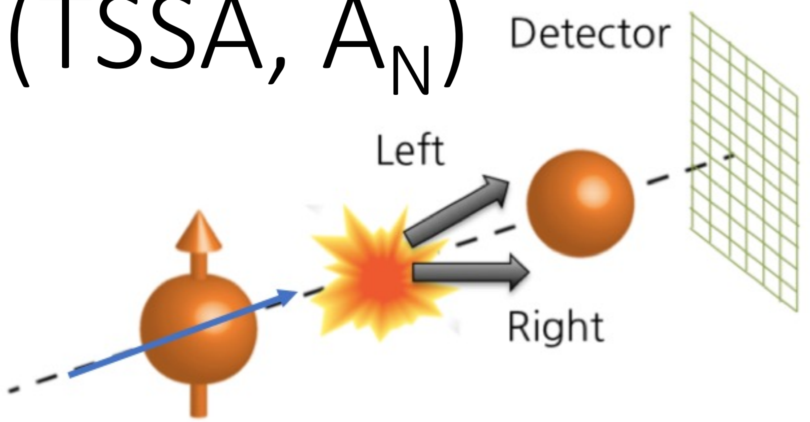
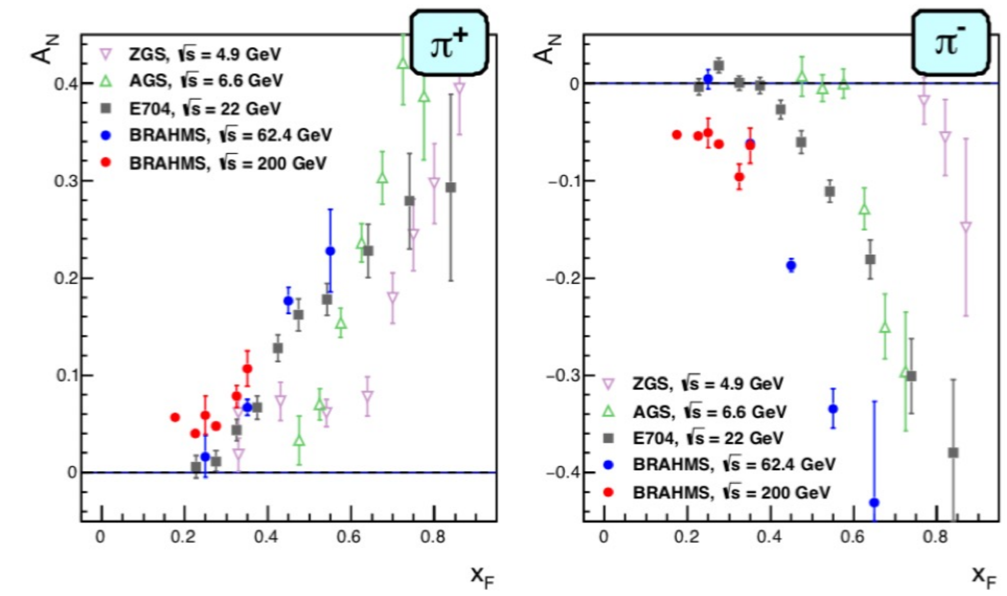
Data sets and triggers

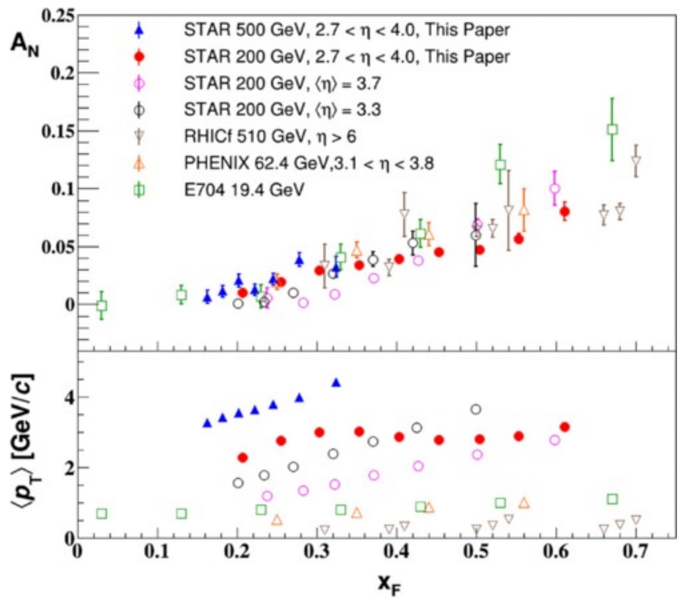
- Data sets: run15 pp transverse data , $\sqrt{s} = 200\ GeV$ (production_pp200trans_2015)
- Stream: st_fms
- Production type: MuDst ; Production tag: P15ik
- Trigger for FMS : FMS small board sum, FMS large board sum and FMS-JP.
    - Trigger list: FMS-JP0, FMS-JP1, FMS-JP2, FMS-sm-bs1, FMS-sm-bs2, FMS-sm-bs3, FMS-lg-bs1, FMS-lg-bs2, FMS-lg-bs3. (9 triggers)
- Requirement: Event must also contain at least 1 Roman Pot track.
- Trigger veto: FMS-LED
- STAR library: SL20a

Transverse Single-Spin Asymmetry (TSSA, A_N)



- $A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$
- pQCD predicts $A_N \sim \frac{m_q \alpha_s}{p_T} \sim 0.001$
- 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

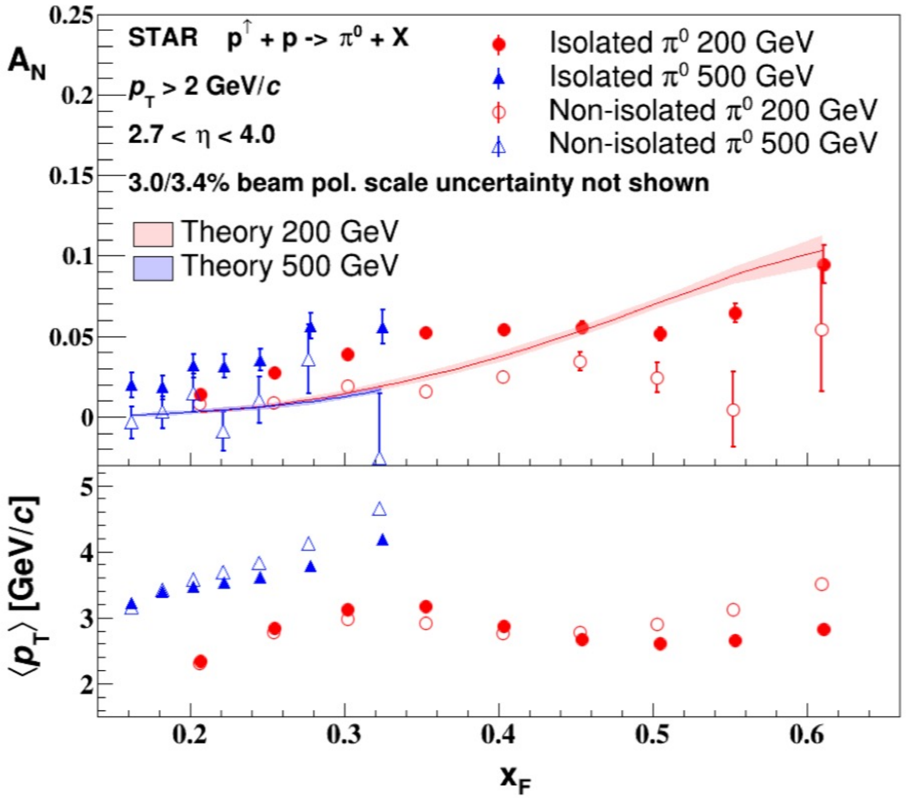




Indication of large TSSA from diffractive process

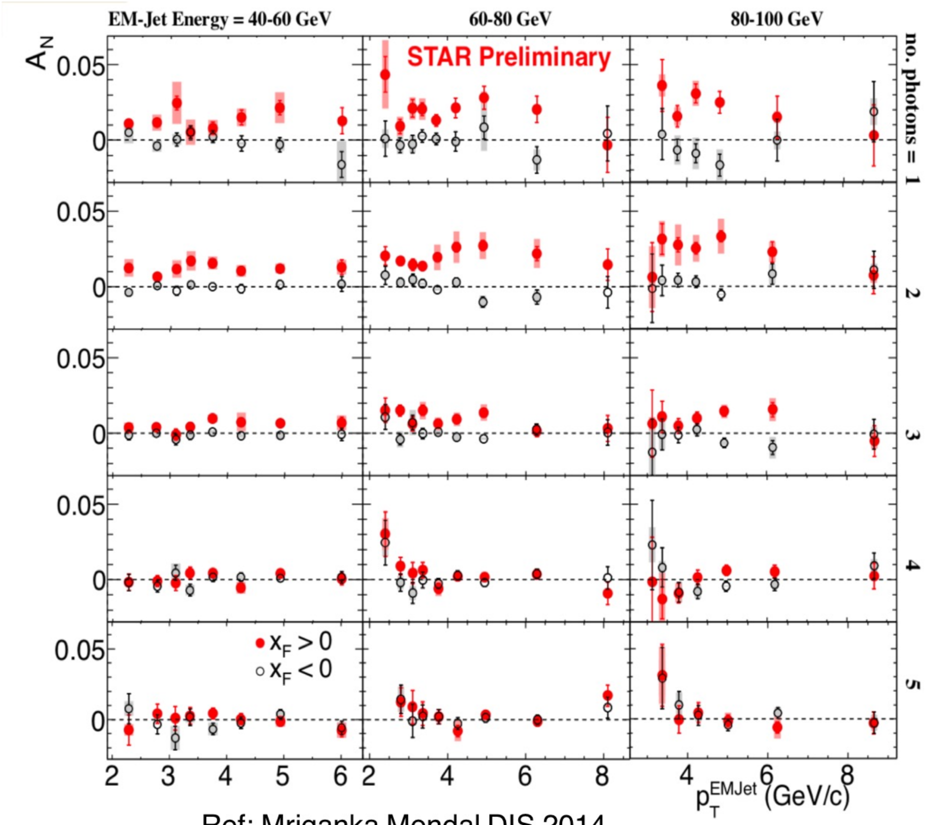
- Previous analyses of A_N for forward π^0 and electromagnetic jets in $p^{\uparrow}+p$ collisions at STAR indicated that there might be non-trivial contributions to the large A_N from diffractive processes.

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



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

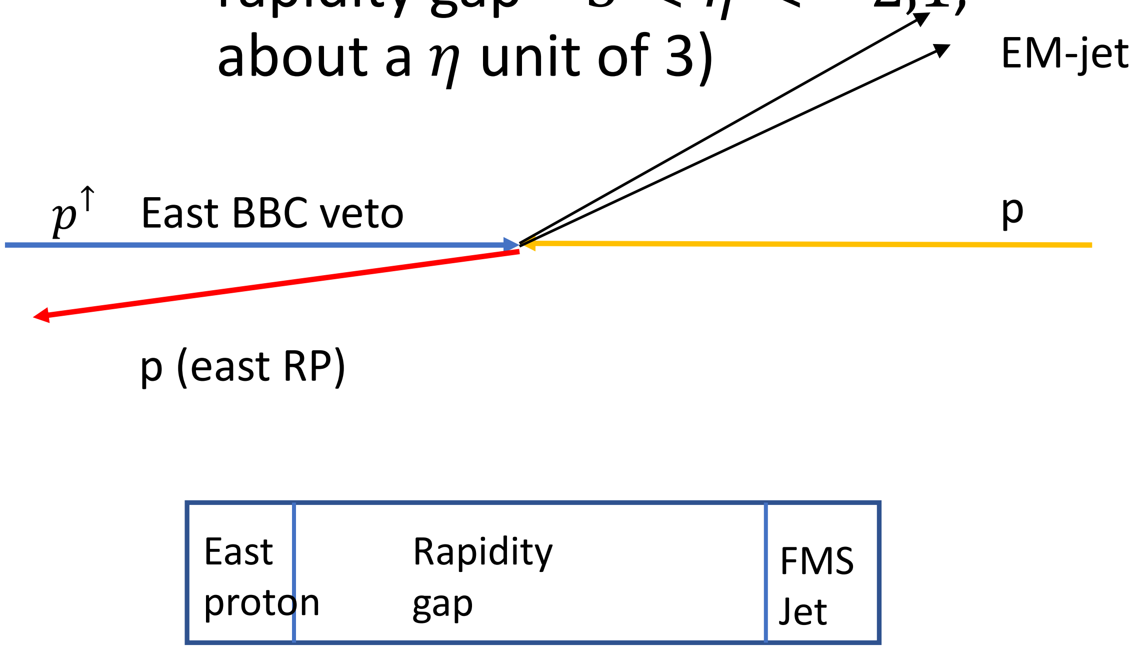
Inclusive EM-jet A_N: low photon multiplicity EM-jets have larger A_N



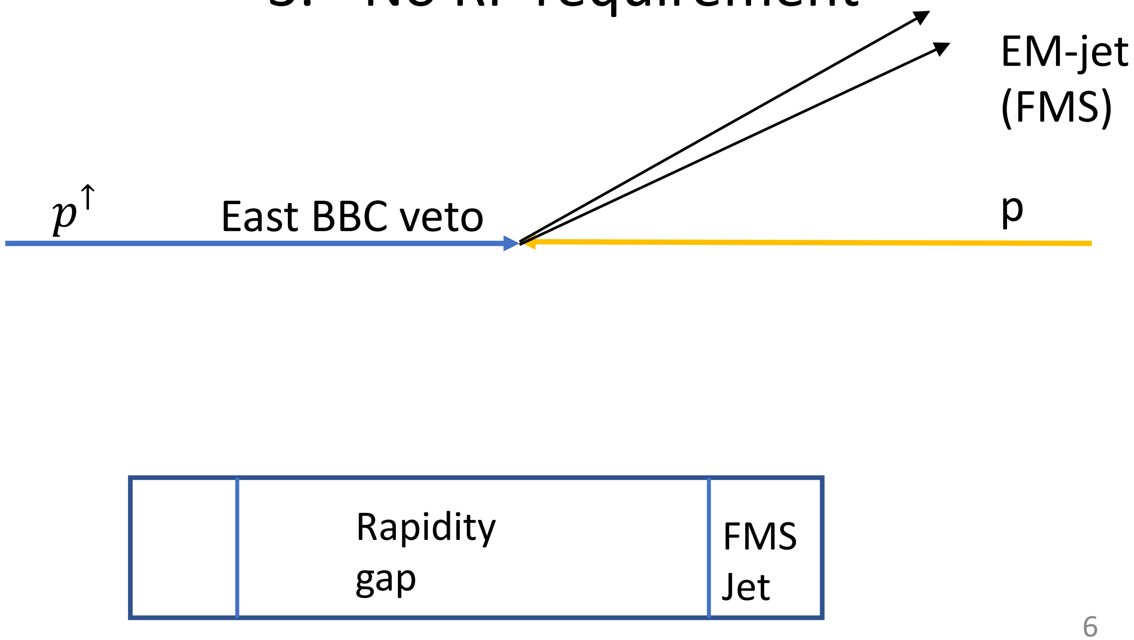
Ref: Mriganka Mondal DIS 2014

Single diffractive process and Rapidity gap events

- Single diffractive process (**SD**):
  1. Only 1 EM-jet at FMS
  2. Only 1 east RP track and it must be good RP track
  3. East BBC veto (determine rapidity gap $-5 < \eta < -2{,}1$, about a η unit of 3)



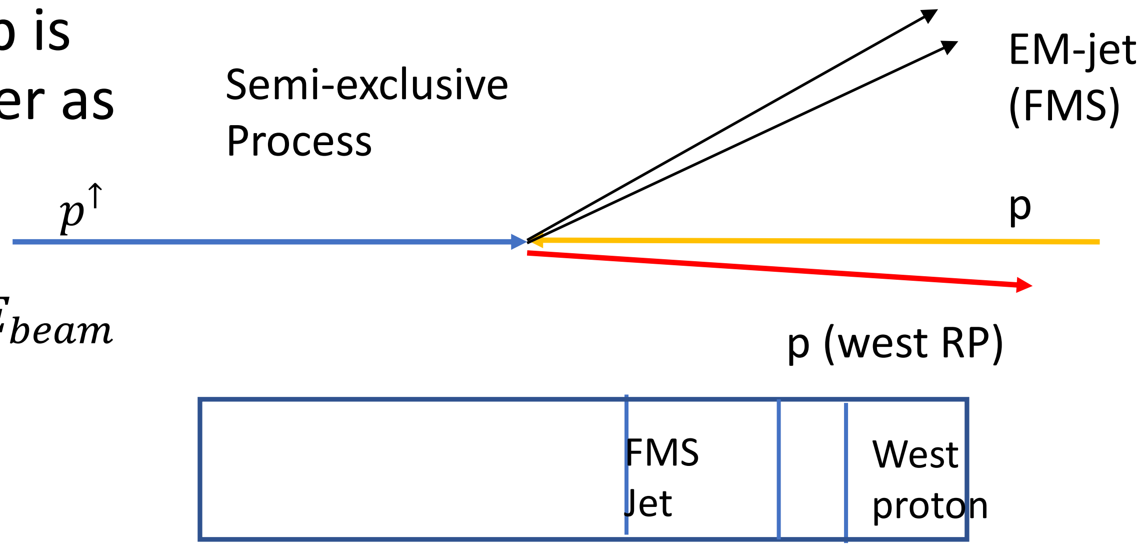
- Rapidity gap events (**RG**):
  1. Only 1 EM-jet at FMS
  2. East BBC veto (determine rapidity gap $-5 < \eta < -2{,}1$, about a η unit of 3)
  3. No RP requirement



Semi-exclusive process

- Semi-exclusive process (**SE**):
  1. Only 1 EM-jet at FMS
  2. Only 1 west RP track and it must be good RP track
  3. West BBC veto (rapidity gap is not large enough to consider as diffractive process)
  4. E sum requirement

     $E_{sum} = E_{EM-jet} + E_{west\ RP} \approx E_{beam}$



Systematic uncertainty for SD, RG, and SE events

- We use Bayesian method for systematic uncertainty study. (ref: arXiv:hep-ex/0207026)
- First of all, for the cuts we choose, varying each individual cut value for calculating the asymmetry. **The first three terms apply for all processes**
  - Small BBC ADC sum cuts
  - Large BBC ADC sum cuts
  - Ring of Fire (exclude small-bs-3 trigger)
  - E sum cut (**Only for SE events**)
  - Background (**Only for SD and SE events**)
- The final systematic will be counted bin by bin (x_F bins) : $\sigma_{summary} = \sqrt{\sum_i (\sigma_i)^2}$

Abstract

- The STAR Collaboration reports the transverse single-spin asymmetry, A_N , for the electromagnetic jets (EM-jets) at forward rapidity ($2.8 < \eta < 3.8$) in diffractive processes as the function of EM-jet Feynman-x (x_F) and photon multiplicity in transversely polarized pp collisions at $\sqrt{s}$ =200 GeV. The A_N in the processes with the situations that either the polarized proton stay intact (semi-exclusive process) or unpolarized proton stay intact (single diffractive process) are explored. A_N is found to be non-zero value for low photon multiplicity EM-jets in the single diffractive process but is consistent with A_N in the inclusive process within uncertainty. Furthermore, the cross section in single diffractive process compared to the inclusive process is small. The A_N in the semi-exclusive processes is non-zero with negative value. These results show the diffractive process can not provide evidence to have large contribution to the large A_N in the inclusive process.

Fig. 1: A_N for single diffractive events

Blue beam A_N is 2.7 σ to be non-zero for EM-jet with all photon multiplicity.

Constant fit: 0.024 ± 0.0089

$\chi^2/n.d.f$: 0.83

Blue beam A_N is 2.5 σ to be non-zero for EM-jet with 1 or 2 photon multiplicity.

Constant fit: 0.030 ± 0.012

$\chi^2/n.d.f$: 0.78

Blue beam A_N is 1.0 σ to be non-zero for EM-jet with 3 or more photon multiplicity.

Constant fit: 0.014 ± 0.013

$\chi^2/n.d.f$: 0.25

Yellow beam A_N is consistent with zero for all cases.

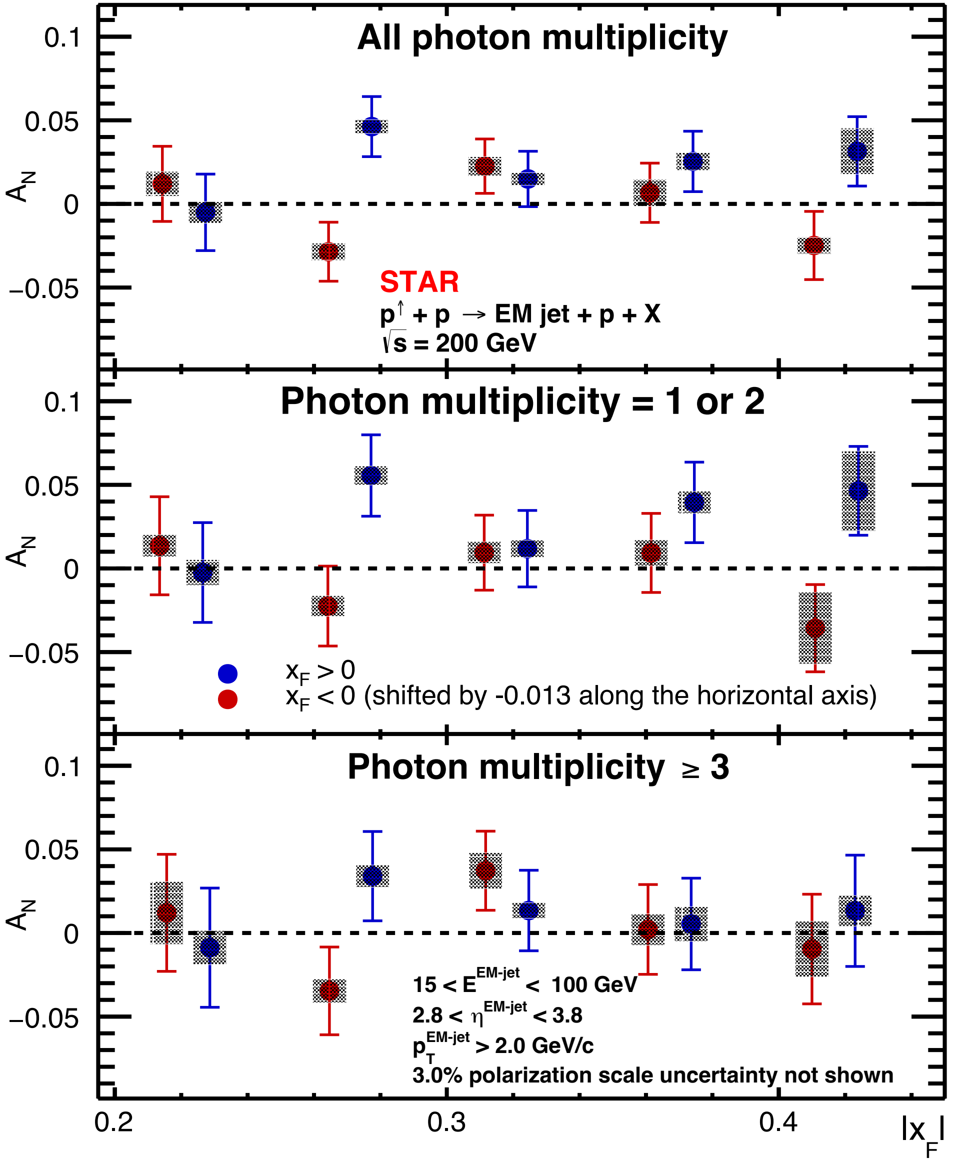


Figure 1: A_N for single diffractive events as a function of x_F for 3 different photon multiplicity cases: all photon multiplicity (top), 1 or 2 photon multiplicity (middle), and 3 or more photon multiplicity (bottom). The A_N for $x_F < 0$ (red points) shifts -0.013 along the x-axis.

Study the non single diffraction fraction in RG events

- We study the non single diffraction (NSD) fraction in RG events using the fraction of the SD events to the RG events from data and simulation.
  - SD simulation: Pythia 8: SoftQCD:singleDiffractive
- For the RG events in data, they contain the real SD (RSD) events and NSD events:
  - Frac(SD/RG in data)= $\frac{SD}{RSD+NSD}$ =11.08%
  - Frac(SD/RG in sim) $= \frac{SD}{RSD}$ =16.13%
  - Assuming $\frac{SD}{RSD}$ is same between data and simulation
- Therefore, NSD in RG events in data = $\frac{NSD}{RSD+NSD} = 31.3\%$
- **The SD fraction in RG events in data is 68.7% ± 0.56%± 8.18%**

Fig. 2: Cross section fraction

- We calculate the cross section fraction as a function of EM-jet x_F.
- The cross section fraction is: $\frac{\sigma(SD)}{\sigma(inc)}$ (single diffractive (SD) cross section to the inclusive process (inc) cross section for the run 15 FMS EM-jet A_N study

- The single diffractive process cross section is very small compared to the inclusive process cross section, which shows that it can not have significant contribution to the large A_N in inclusive process

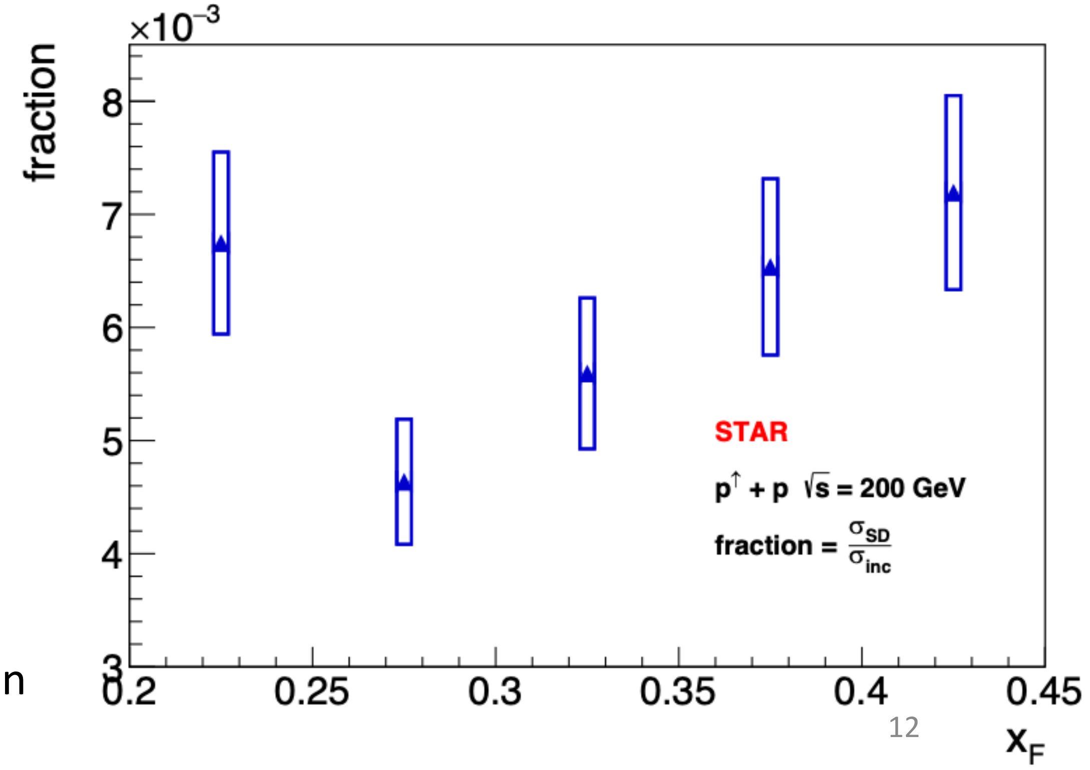


Figure 2: Cross section fraction of the single diffractive process (σ_{SD}) to the inclusive process (σ_{inc}) as a function of x_F.

Fig. 3: A_N for RG events

- About 68.7% of the RG events are single diffractive events.

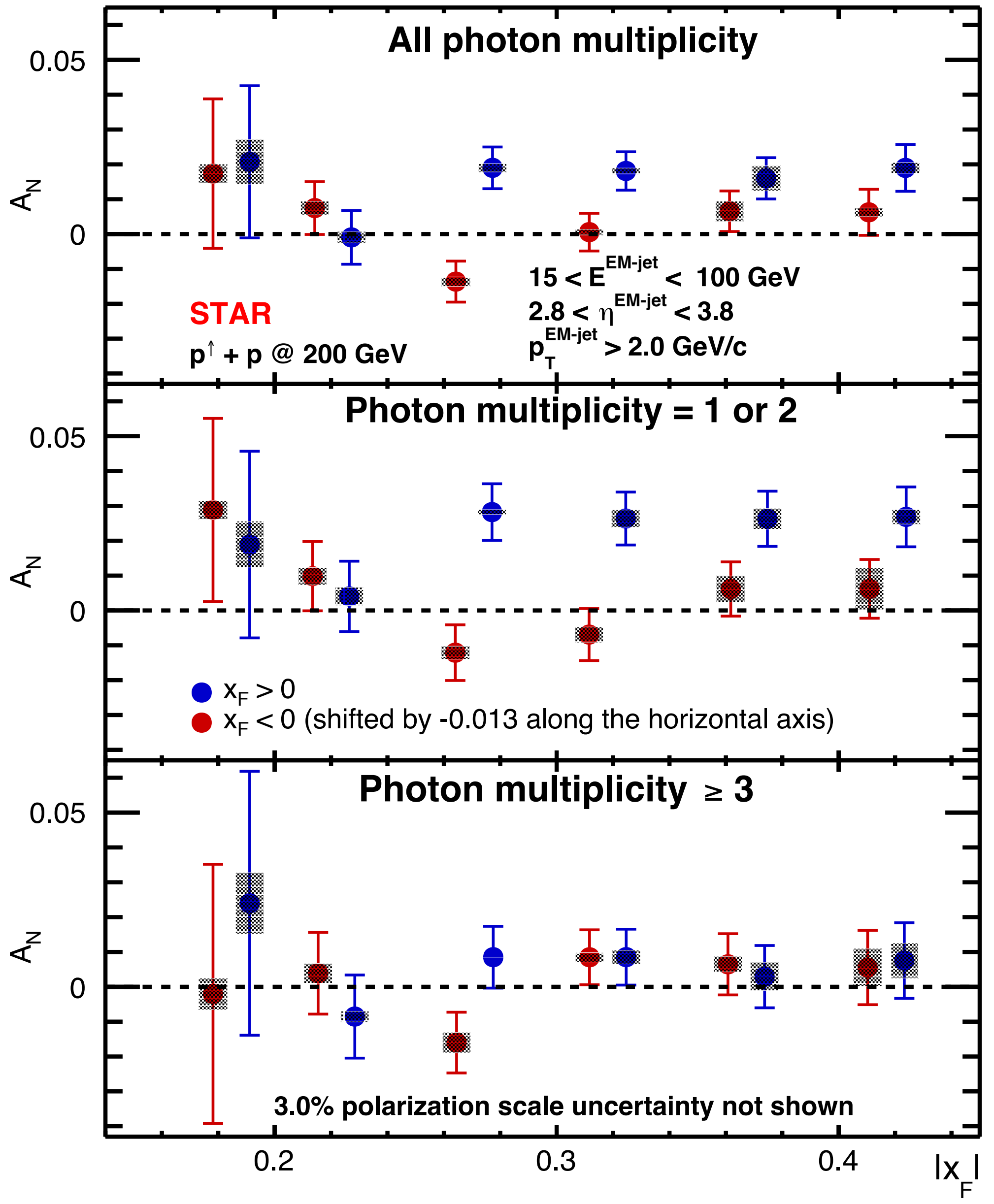


Figure 3: A_N for rapidity gap events as a function of x_F for 3 different photon multiplicity cases: all photon multiplicity (top), 1 or 2 photon multiplicity (middle), and 3 or more photon multiplicity (bottom). The A_N for $x_F < 0$ (red points) shifts -0.013 along the x-axis.

Fig. 4 : Comparison plot of A_N for inclusive, single diffractive, and rapidity gap events

- The A_N for inclusive, single diffractive, and rapidity gap events are consistent within uncertainty
- The events with polarized proton breakup and unpolarized proton intact are showing with the similar A_N as for inclusive process

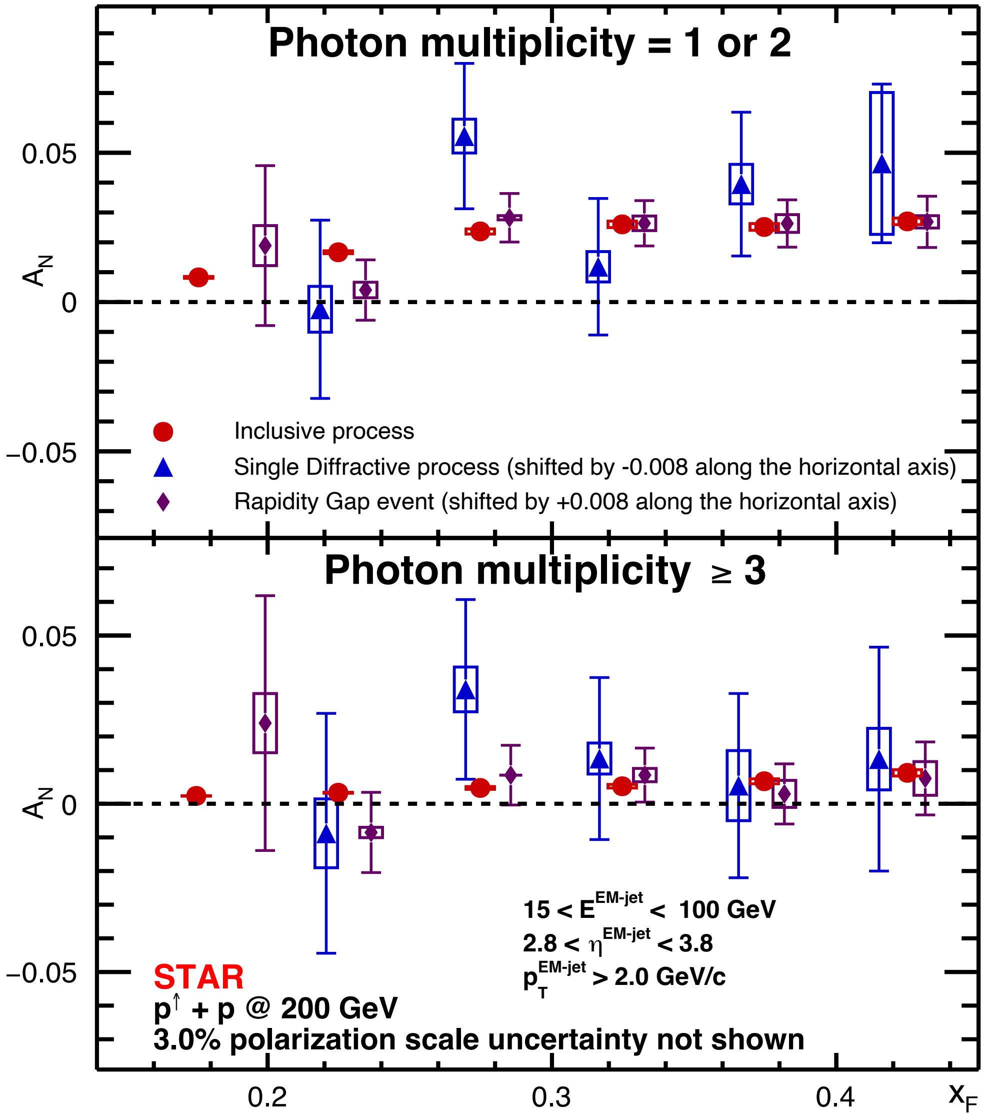


Figure 4: A_N as a function of x_F for 3 processes for the case of photon multiplicity 1 or 2 (top panel) and photon multiplicity 3 or more (bottom panel) : inclusive process (red), single diffractive process (blue), and the rapidity gap events (magenta)

Fig. 5: A_N for semi-exclusive process

- Only 1 or 2 photon multiplicity
- Blue beam A_N is 3.1 σ to be non-zero.
    - Constant fit: -0.10 ± 0.032
    - $\chi^2/n.d.f$: 1.17
- Yellow beam A_N is 1.4 σ to be non-zero.
    - Constant fit: -0.042 ± 0.031
    - $\chi^2/n.d.f$: 1.36

- The EM-jet A_N is negative for events with polarized proton intact and unpolarized proton breakup

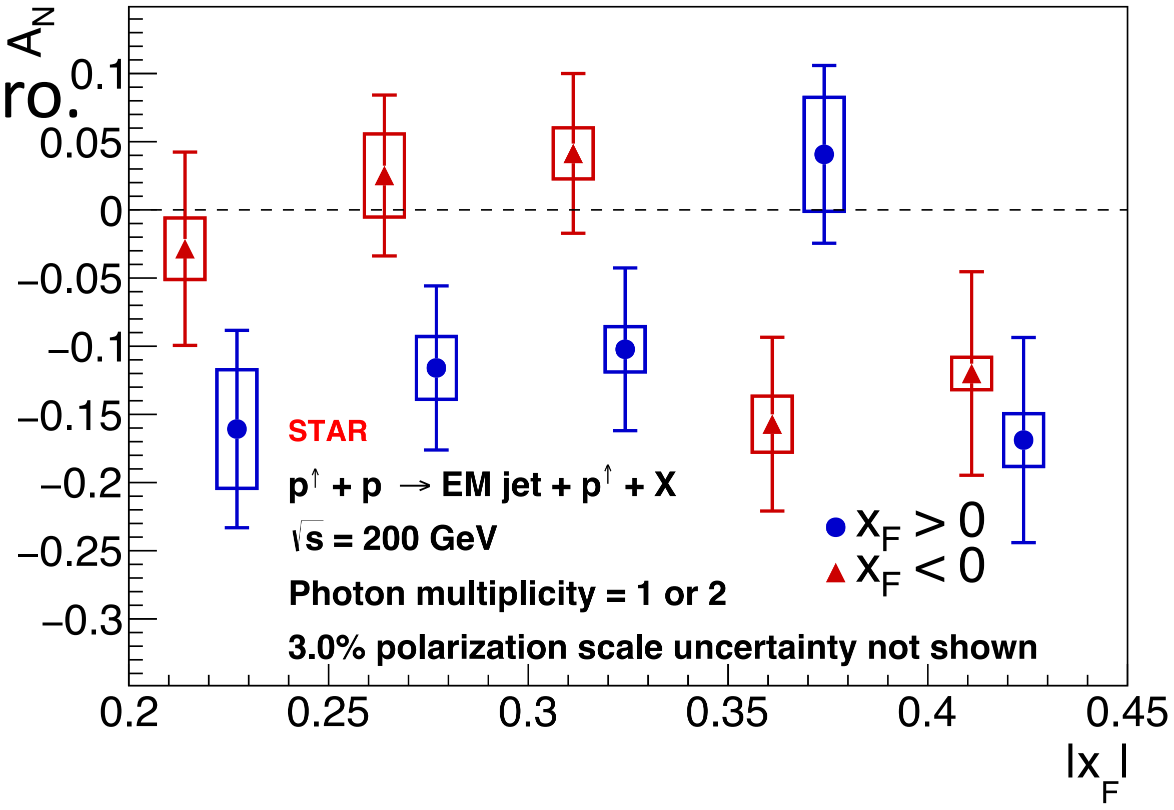


Figure 5: A_N as a function of x_F for the semi-exclusive process with 1 or 2 photon multiplicity EM-jets. The blue points are for $x_F > 0$, while the red points are for $x_F < 0$.

Conclusion

- The non-zero A_N for single diffractive process and the semi-exclusive process are observed for the EM-jets with 1 or 2 photon multiplicity
- The A_N values for the single diffractive process with the unpolarized proton intact are consistent with A_N for inclusive process within uncertainty, showing that the single diffractive process can not provide evidence to have great contribution to the large A_N in the inclusive process
- The cross section fraction for single diffractive process to the inclusive process in the forward region is very small, so single diffractive process can not have major contribution to to the large A_N in the inclusive process
- The A_N value for semi-exclusive process with polarized proton intact is negative, which also can not have great contribution to the large A_N in the inclusive process

Back up

Event selection and corrections for SD process

- **FMS**
  - 9 Triggers, veto on FMS-LED
  - Only 1 EM-jet per event is allowed
  - bit shift, bad / dead / hot channel masking (include fill by fill hot channel masking)
  - Jet reconstruction: StJetMaker2015 , Anti-kT, R<0.7 , FMS point energy > 1 GeV, $p_T > 2$ GeV/c, trigger p_T threshold cut, FMS point as input.
- **Only allow acceptable beam polarization (up/down).**
- **Vertex** (Determine vertex z priority according to TPC , VPD, BBC.)
  - Vertex $|z| < 80\ cm$
- **Roman Pot and Single Diffractive process:**
- Acceptable cases:
  1. Only 1 east RP track , no requirement on west RP
  - RP track must be good track:
  a) Each track hits > 6 planes
  b) East RP ξ dependent θ_X , θ_Y , P_X and P_Y cuts
  c) East RP $0 < \xi < 0.15$
- East Large BBC ADC sum < 80 and East Small BBC ADC sum < 90

Corrections:
EM-jet energy correction and Underlying Event correction

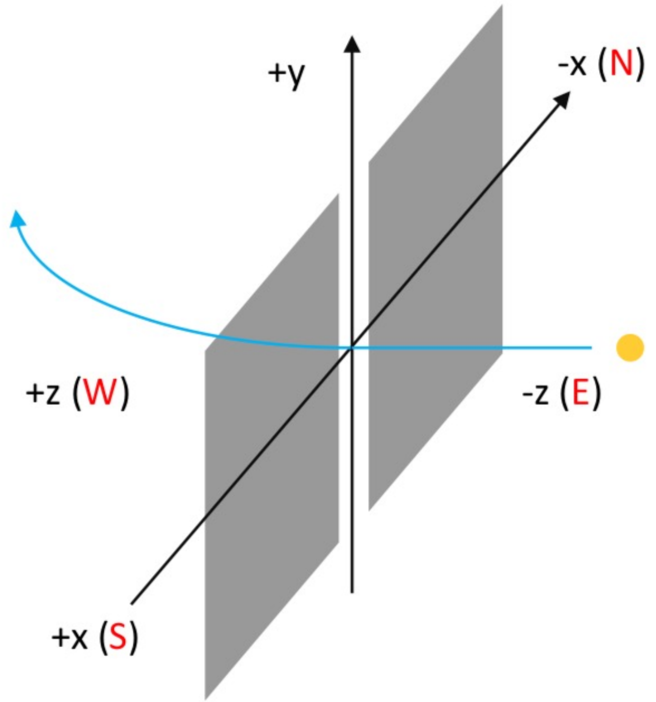
Event selection and corrections for RG process

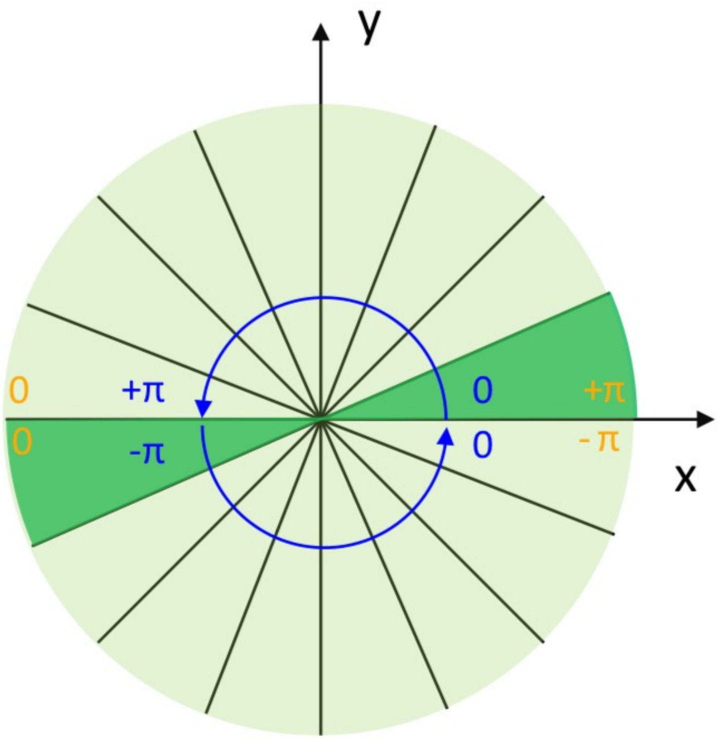
- **FMS**
  - 9 Triggers, veto on FMS-LED
  - Only 1 EM-jet per event is allowed
  - bit shift, bad / dead / hot channel masking (include fill by fill hot channel masking)
  - Jet reconstruction: StJetMaker2015 , Anti-kT, R<0.7 , FMS point energy > 1 GeV, $p_T > 2$ GeV/c, trigger p_T threshold cut, FMS point as input.
- **Only allow acceptable beam polarization (up/down).**
- **Vertex** (Determine vertex z priority according to TPC , VPD, BBC.)
  - Vertex $|z| < 80\ cm$
- **No Roman Pot requirement**
- East Large BBC ADC sum < 80 and East Small BBC ADC sum < 90

Corrections:
EM-jet energy correction and
Underlying Event correction

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 [$-\pi$, $+\pi$] into 16 bins.





Systematic uncertainty for SD and RG events

- We use Bayesian method for systematic uncertainty study. (ref: arXiv:hep-ex/0207026)
- First of all, for the cuts we choose, varying each individual cut value for calculating the asymmetry. **The first three terms apply for both processes**
  - Small BBC east ADC sum cuts: choose < 70, < 80, <100, <110 for systematic uncertainty
  - Large BBC east ADC sum cuts: choose < 60, < 70, <90, <100 for systematic uncertainty
  - Ring of Fire (get rid of small-bs-3 trigger)
  - Background (Only for SD events)
- Then, find out the maximum ($A_N(1) \pm \delta(1)$, with statistical uncertainty) , and the minimum ($A_N(2) \pm \delta(2)$, with statistical uncertainty) for the varying cuts as systematic uncertainty.
- If the $\frac{|A_N(1)-A_N(2)|}{\sqrt{|(\delta(1))^2-(\delta(2))^2|}} > 1$ (Barlow check), use the **standard deviation** of all the A_N from varying all the cuts for this systematic term (σ_i), otherwise, the systematic (σ_i), for this term will be assigned 0
- The final systematic will be counted bin by bin (x_F bins) : $\sigma_{summay} = \sqrt{\sum_i (\sigma_i)^2}$

Systematic uncertainty results for SD process

The background is estimated from zerobias events (back up)

All Photon multiplicity

Blue beam x_F	Small BBC east	Large BBC east	Ring of Fire	Background	Summary
0.2 - 0.25	0.0026	0.0041	0	0.0044	0.0064
0.25 - 0.3	0	0	0.0022	0.0034	0.0041
0.3 – 0.35	0	0.0020	0	0.0032	0.0037
0.35 – 0.4	0.0017	0.0034	0	0.0035	0.0052
0.4 – 0.45	0.0022	0.0052	0.012	0.0041	0.014

Yellow beam x_F	Small BBC east	Large BBC east	Ring of Fire	Background	Summary
0.2 - 0.25	0.0027	0.0054	0	0.0043	0.0074
0.25 - 0.3	0.0028	0.0025	0	0.0034	0.0051
0.3 – 0.35	0	0.0046	0	0.0031	0.0056
0.35 – 0.4	0.0018	0.0048	0.0051	0.0035	0.0080
0.4 – 0.45	0.0013	0.0022	0	0.0040	0.0048

1 or 2 Photon multiplicity

Blue beam x_F	Small BBC east	Large BBC east	Ring of Fire	Background	Summary
0.2 - 0.25	0.0040	0.0033	0	0.0057	0.0077
0.25 - 0.3	0.0024	0	0.0022	0.0046	0.0056
0.3 – 0.35	0.0018	0.0018	0	0.0044	0.0051
0.35 – 0.4	0.0032	0.0034	0	0.0047	0.0066
0.4 – 0.45	0.0055	0.0072	0.022	0.0052	0.024

Yellow beam x_F	Small BBC east	Large BBC east	Ring of Fire	Background	Summary
0.2 - 0.25	0.0035	0	0	0.0056	0.0065
0.25 - 0.3	0.0021	0.0035	0	0.0045	0.0061
0.3 – 0.35	0.0025	0.0041	0	0.0043	0.0064
0.35 – 0.4	0	0.0062	0	0.0046	0.0077
0.4 – 0.45	0.0016	0.0036	0.020	0.0052	0.021

3 or more Photon multiplicity

Blue beam x_F	Small BBC east	Large BBC east	Ring of Fire	Background	Summary
0.2 - 0.25	0	0.0076	0	0.0068	0.010
0.25 - 0.3	0.0022	0.0028	0.0023	0.0051	0.0066
0.3 – 0.35	0	0	0	0.0046	0.0046
0.35 – 0.4	0	0.0047	0.0076	0.0055	0.010
0.4 – 0.45	0.0035	0.0053	0	0.0066	0.0091

Yellow beam x_F	Small BBC east	Large BBC east	Ring of Fire	Background	Summary
0.2 - 0.25	0.0098	0.014	0	0.0067	0.019
0.25 - 0.3	0.0037	0.0033	0	0.0046	0.0071
0.3 – 0.35	0.0030	0.0081	0.0046	0.0045	0.011
0.35 – 0.4	0.0037	0.0047	0.0051	0.0052	0.011
0.4 – 0.45	0	0	0.015	0.0065	0.017

Systematic uncertainty results for RG process

All Photon multiplicity

Blue beam x_F	Small BBC east	Large BBC east	Ring of Fire	Summary
0.1 - 0.2	0	0.0064	0	0.0064
0.2 - 0.25	0.0016	0	0	0.0016
0.25 - 0.3	0.00051	0.00096	0.00042	0.0011
0.3 – 0.35	0.00084	0	0	0.00084
0.35 – 0.4	0.0014	0	0.0033	0.0036
0.4 – 0.45	0.0010	0.0011	0	0.0015

Yellow beam x_F	Small BBC east	Large BBC east	Ring of Fire	Summary
0.1 - 0.2	0.0027	0	0	0.0027
0.2 - 0.25	0.00052	0.0019	0	0.0019
0.25 - 0.3	0.00064	0.0012	0	0.0013
0.3 – 0.35	0.00066	0.00047	0	0.00081
0.35 – 0.4	0.00092	0.0013	0.0023	0.0029
0.4 – 0.45	0	0.0012	0	0.0012

1 or 2 Photon multiplicity

Blue beam x_F	Small BBC east	Large BBC east	Ring of Fire	Summary
0.1 - 0.2	0.0028	0.0061	0	0.0067
0.2 - 0.25	0.0018	0.0019	0	0.0026
0.25 - 0.3	0	0	0.00070	0.00070
0.3 – 0.35	0.00094	0	0.0023	0.0025
0.35 – 0.4	0.0024	0.0017	0	0.0030
0.4 – 0.45	0.00074	0.0019	0	0.0020

Yellow beam x_F	Small BBC east	Large BBC east	Ring of Fire	Summary
0.1 - 0.2	0.0027	0	0	0.0027
0.2 - 0.25	0.00081	0.0024	0	0.0018
0.25 - 0.3	0.0015	0.0011	0	0.0019
0.3 – 0.35	0.00086	0.0011	0.0017	0.0022
0.35 – 0.4	0	0.0015	0.0034	0.0037
0.4 – 0.45	0.00069	0	0.0059	0.0060

3 or more Photon multiplicity

Blue beam x_F	Small BBC east	Large BBC east	Ring of Fire	Summary
0.1 - 0.2	0	0.0088	0	0.0088
0.2 - 0.25	0.0015	0	0	0.0015
0.25 - 0.3	0	0	0	0
0.3 – 0.35	0.00082	0	0.0018	0.0020
0.35 – 0.4	0	0	0.0040	0.0040
0.4 – 0.45	0.0028	0.0021	0.0036	0.0050

Yellow beam x_F	Small BBC east	Large BBC east	Ring of Fire	Summary
0.1 - 0.2	0.0045	0	0	0.0045
0.2 - 0.25	0	0.0028	0	0.0028
0.25 - 0.3	0.0014	0.0026	0	0.0029
0.3 – 0.35	0.0014	0	0	0.0014
0.35 – 0.4	0.0017	0.0014	0	0.0022
0.4 – 0.45	0.0017	0.0021	0.0046	0.0053

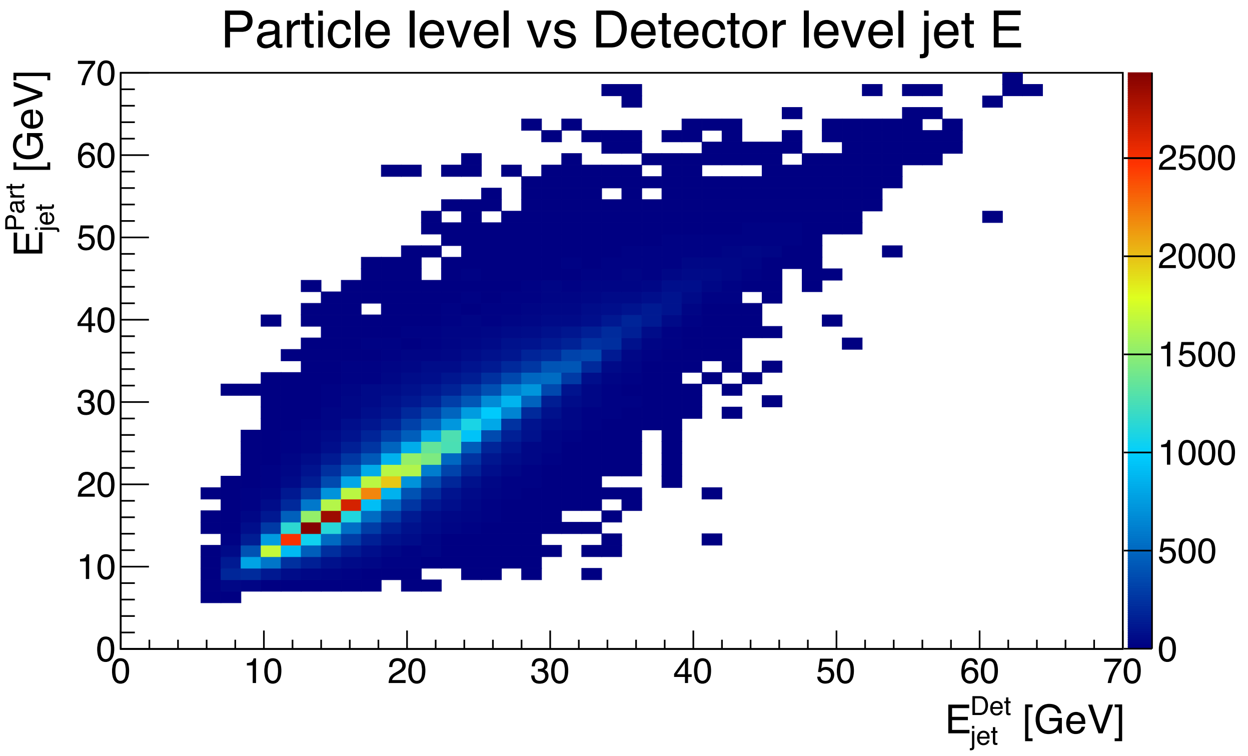
Apply the trigger threshold p_T cut

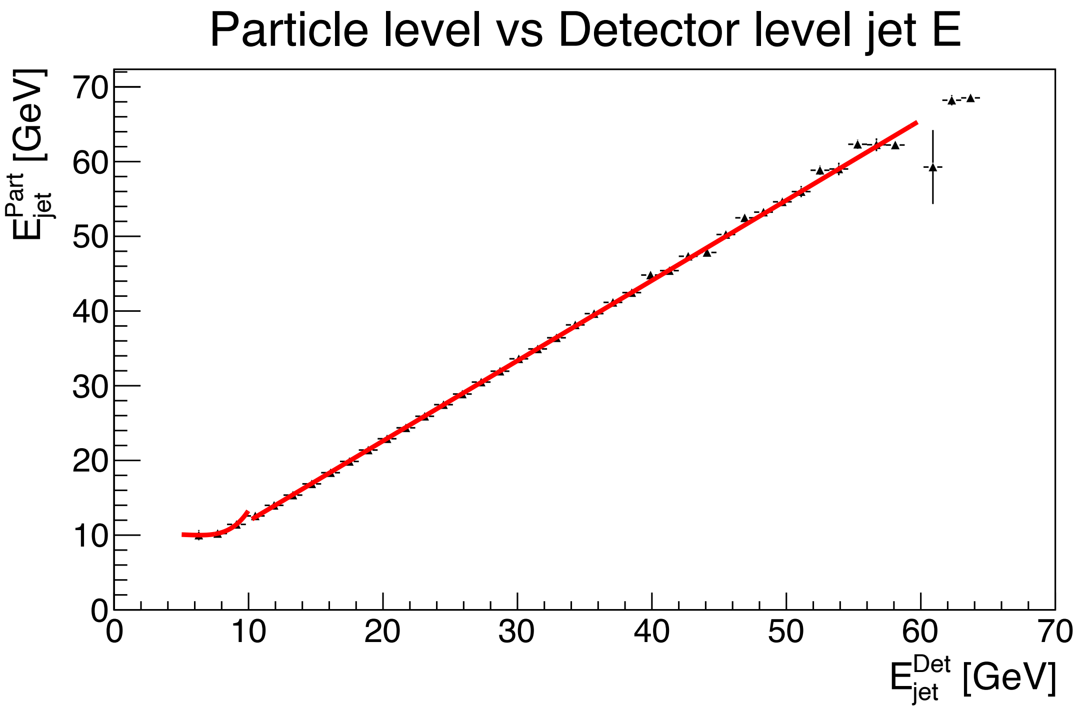
- The EM-jet p_T based on the trigger threshold are listed as follows, with 15% increase. Consistent with inclusive EM-jet A_N analysis

Trigger name	Trigger ID	15% increase p_T cut [GeV]
FMS-JP0	480810 / 480830	1.84
FMS-JP1	480809 / 480829	2.76
FMS-JP2	480808 / 480828	3.68
FMS-sm-bs1	480801	1.26
FMS-sm-bs1	480821 / 480841	1.15
FMS-sm-bs2	480802 / 480822	1.84
FMS-sm-bs3	480803	2.53
FMS-sm-bs3	480823 / 480843	2.18
FMS-lg-bs1	480804	1.26
FMS-lg-bs1	480824 / 480844	1.15
FMS-lg-bs2	480405 / 480425	1.84
FMS-lg-bs3	480406 / 480426	2.76

Energy correction

- Detector level to particle level correction.
  - 6-th order polynomial for [5, 10] GeV
  - Linear function for [10, 60] GeV





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

Background study: FMS EM-jet and BBCE veto (RG)

- The process with FMS EM-jets and BBCE veto are one potential source of the background
  - The east BBC covers a unit of 3 for pseudorapidity gap. We call it Rapidity Gap event set (RG)
  - They are a subset of inclusive process
- The study of RG events also serves as additional enrichment for the inclusive process and help to separate the diffractive and non-diffractive process with the rapidity gap requirement.
- Also, we use this set of events to estimate the background fraction: about 1.8 -1.9%

The random coincidence of the single diffractive events in the RG events is 0.2% (zerobias events)

$$frac_{bkg} = \frac{n_{AC}}{n_{mea}} = \frac{n_{AC}}{n_{RG}} \times \frac{n_{RG}}{n_{mea}}$$

Counting yields of each kinematic bins for RG events and measured FMS events

Event selection and corrections for SE process

- **FMS**
  - 9 Triggers, 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 point energy > 1 GeV, $p_T > 2$ GeV/c, trigger p_T threshold cut, FMS point as input.
  - Only 1 EM-jet per event allowed
- **Only allow acceptable beam polarization (up/down).**
- **Vertex** (Determine vertex z priority according to TPC , VPD, BBC.)
  - Vertex $|z| < 80\ cm$
- **Roman Pot and Semi-exclusive process:**
- Only 1 west RP track (no restriction on east RP track)
- RP track must be good track:
  a) Each track hits > 6 planes
  b) West RP ξ dependent θ_X , θ_Y , P_X and P_Y cuts
  c) 0 < ξ < 0.45
  - Sum of west RP track energy and all EM Jet energy (see detail in table)
- West Large BBC ADC sum < 60 and West Small BBC ADC sum < 80

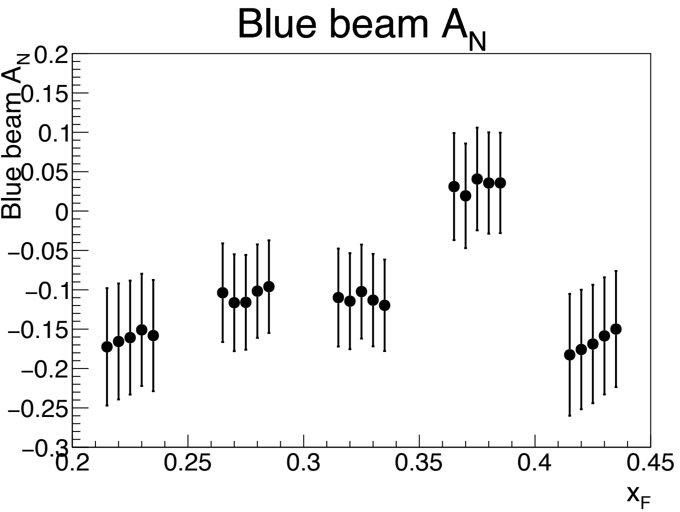
Corrections:
EM-jet energy correction and Underlying Event correction

x_F	E sum Cut
0.2 - 0.25	E_{sum} < 110 GeV
0.25 - 0.3	E_{sum} < 110 GeV
0.3 – 0.35	E_{sum} < 115 GeV
0.35 – 0.4	E_{sum} < 115 GeV
0.4 – 0.45	E_{sum} < 120 GeV

Systematic uncertainty

- We use Bayesian method for systematic uncertainty study. (ref: arXiv:hep-ex/0207026)
- First of all, for the cuts we choose, varying each individual cut value for calculating the asymmetry.
  - Small BBC west ADC sum cuts: choose < 60, < 70, <90, <100 for systematic uncertainty
  - Large BBC west ADC sum cuts: choose < 40, < 50, <70, <80 for systematic uncertainty
  - E sum cut, varying each cut by ±10 , and ±5 GeV, accordingly
  - Ring of Fire (get rid of small-bs-3 trigger)

x_F	E sum Cut
0.2 - 0.25	E_{sum} < 110 GeV
0.25 - 0.3	E_{sum} < 110 GeV
0.3 – 0.35	E_{sum} < 115 GeV
0.35 – 0.4	E_{sum} < 115 GeV
0.4 – 0.45	E_{sum} < 120 GeV



Example: Small BBC west cuts

Each x_F set, from left to right: varying the cuts from original: -20, -10, 0, +10, +20

Calculating the systematic uncertainty (1 or 2 photon multiplicity)

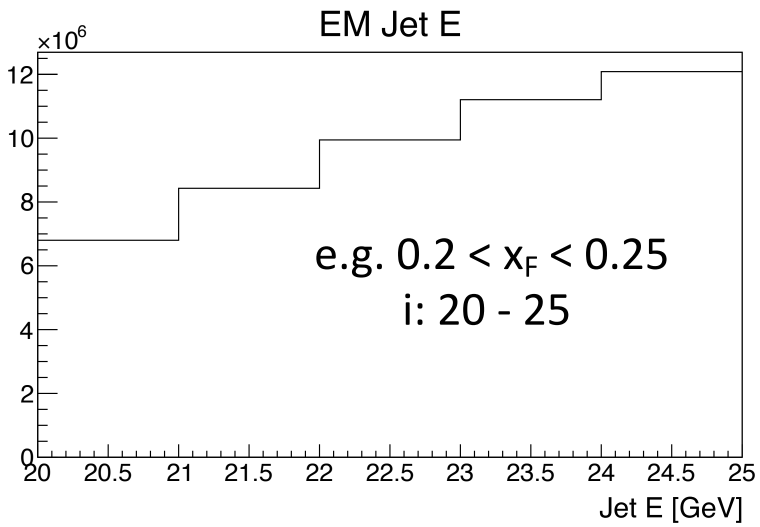
- Then, find out the maximum ($A_N(1) \pm \delta(1)$, with statistical uncertainty) , and the minimum ($A_N(2) \pm \delta(2)$, with statistical uncertainty) for the varying cuts as systematic uncertainty.
- If the $\frac{|A_N(1)-A_N(2)|}{\sqrt{|(\delta(1))^2-(\delta(2))^2|}} > 1$, use the **standard deviation** of all the A_N from varying all the cuts for this systematic term (σ_i), otherwise, the systematic (σ_i), for this term will be assigned 0
- The final systematic will be counted bin by bin (x_F bins) : $\sigma_{sys} = \sqrt{\sum_i (\sigma_i)^2}$
- The background refers to the potential background in E sum, estimated using the mix event background (see back up slides)

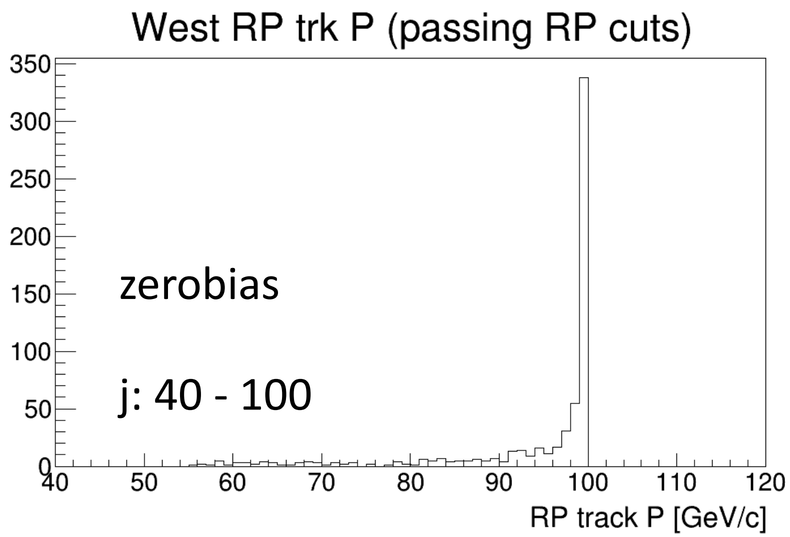
Blue beam x_F	Small BBC west	Large BBC west	Ring of Fire	Energy sum	Background	Summary
0.2 - 0.25	0	0.033	0	0.028	0.0033	0.043
0.25 - 0.3	0.0081	0.021	0	0	0.0031	0.023
0.3 – 0.35	0.0058	0	0.010	0.011	0.0027	0.017
0.35 – 0.4	0.0072	0.011	0	0.040	0.0011	0.041
0.4 – 0.45	0.012	0.015	0	0	0.0045	0.019

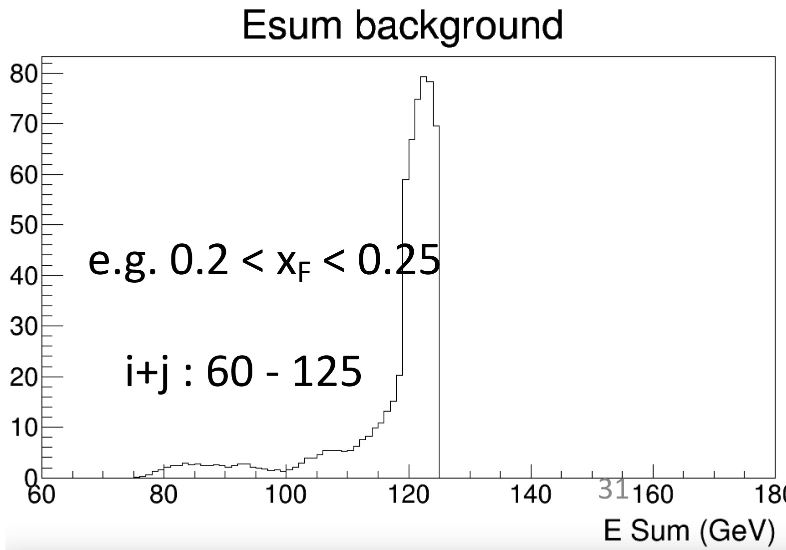
Yellow beam x_F	Small BBC west	Large BBC west	Ring of Fire	Energy sum	Background	Summary
0.2 - 0.25	0.018	0.014	0	0	0.00059	0.023
0.25 - 0.3	0.012	0	0.0045	0.027	0.00068	0.030
0.3 – 0.35	0	0.015	0	0.0012	0.0011	0.019
0.35 – 0.4	0	0.010	0.017	0	0.0042	0.020
0.4 – 0.45	0	0	0	0.011	0.0032	0.012

Background study for E sum in SE process

- We use zerobias stream events to study the background shape for E sum spectrum for different EM-jet x_F ranges.
  - E sum (**background**)= E(EM-jet from **inclusive process**) + E(west RP from **zerobias**)
- Calculation: $\boldsymbol{Esum(i+j)} = \sum_{i,j} \boldsymbol{P(i)} * \boldsymbol{n(j)}$, i are all possible energies (in 1 GeV bin) for specific x_F range ; j are all possible energies (in 1 GeV bin) for west RP track energy (momentum) in zerobias data.
  - P(i) is the fraction for EM-jet yields in [i,i+1] (GeV) within the specific x_F range .
  - n(j) is the yields in west RP energy (momentum) in [j,j+1] (GeV).

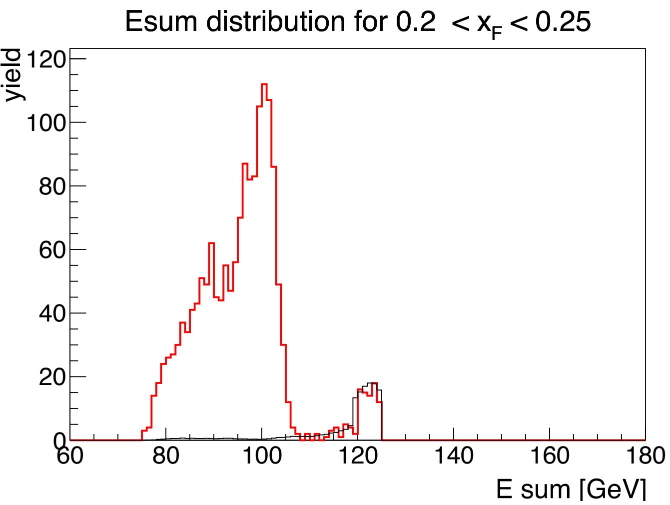


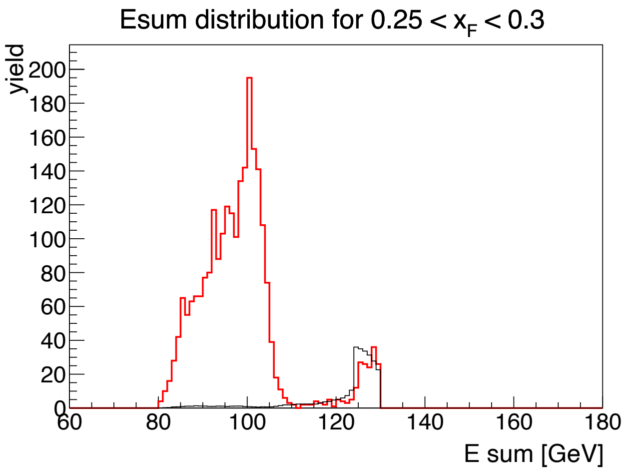




Mix event energy sum study results

- We use zerobias stream events to study the background shape for E sum spectrum for different EM-jet x_F ranges.
  - E sum (**background**)= E(EM-jet from **inclusive process**) + E(west RP from **zerobias**)

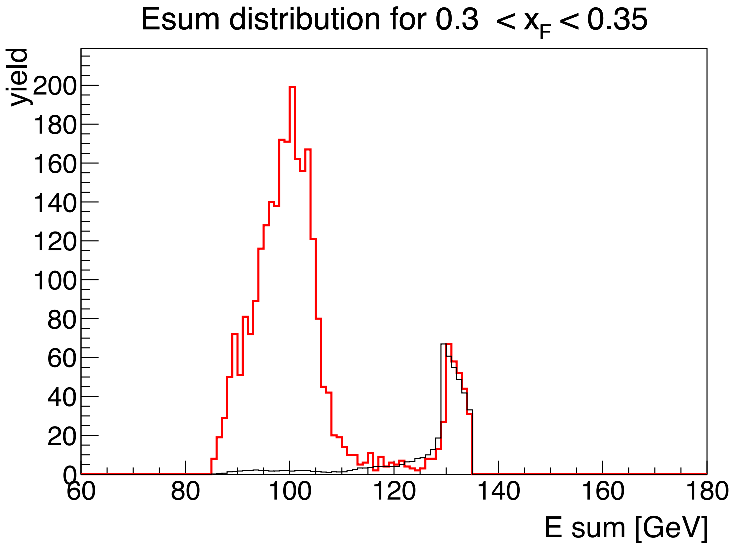


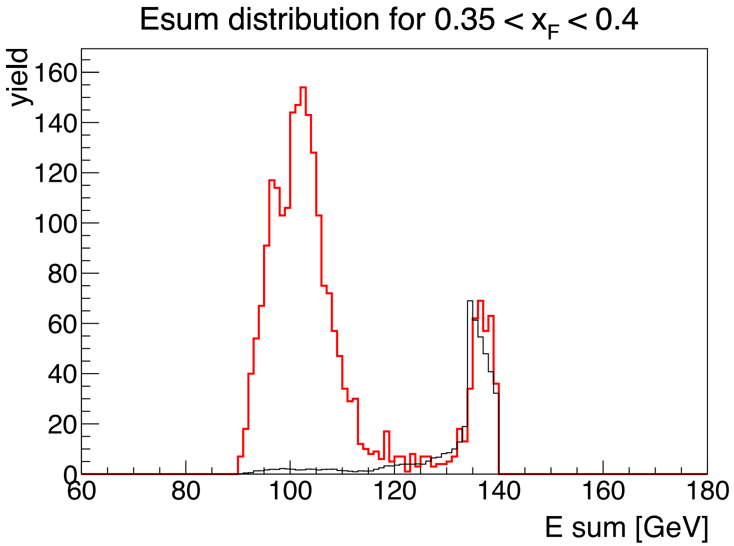


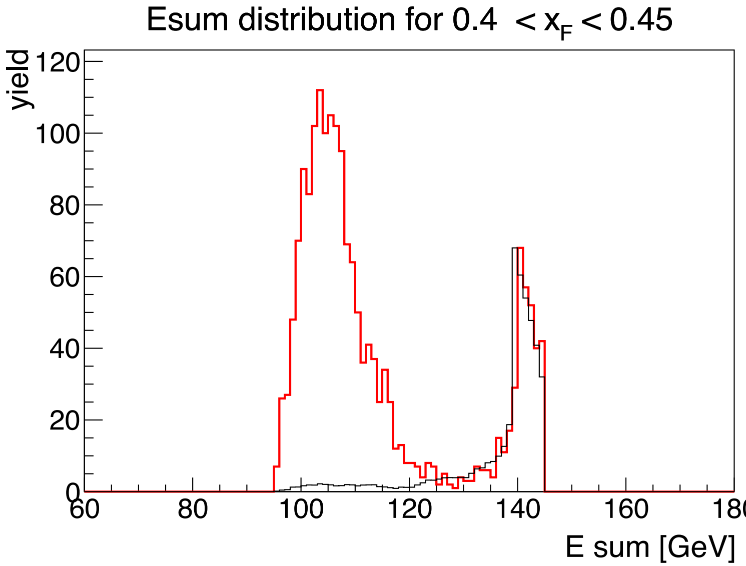
<u>All photon multiplicity</u>

Black curve (Background) is mixed events from zerobias events (scaled to data).

Red curve is the FMS stream data







Mix event background study results

- The background from mix event will be counted as systematic uncertainty results.
  - $frac = \frac{Integral\ of\ yields\ in\ signal\ region\ for\ mix\ event\ background}{Intrgral\ of\ yields\ in\ signal\ region\ for\ FMS\ data}$

x_F	Signal region	Frac of background (%)
0.2 - 0.25	E_{sum} < 110 GeV	1.3
0.25 - 0.3	E_{sum} < 110 GeV	1.3
0.3 – 0.35	E_{sum} < 115 GeV	2.1
0.35 – 0.4	E_{sum} < 115 GeV	2.0
0.4 – 0.45	E_{sum} < 120 GeV	2.7

Estimating the cross section fraction

- The cross section fraction : $\frac{\sigma(SD)}{\sigma(inc)}$
- $\sigma(SD) = \frac{N_{SD} * purity}{\mathcal{L} * \varepsilon_{RP} * \varepsilon_{BBC} * \varepsilon_{FMS} * \varepsilon_{trigger}}$
- $\sigma(inc) = \frac{N_{inc}}{\mathcal{L} * \varepsilon_{FMS} * \varepsilon_{trigger}}$
- Since both analysis are using the same dataset, same triggers and same FMS detector, so we assume $\mathcal{L}, \varepsilon_{FMS}, \varepsilon_{trigger}$ are same in calculating for both single diffractive and inclusive cross section
- So, $\frac{\sigma(SD)}{\sigma(inc)} = \frac{N_{SD} * purity}{N_{inc} * \varepsilon_{RP} * \varepsilon_{BBC}}$

Systematic uncertainty for the efficiency

- ε_{RP}: From the STAR central exclusive paper (JHEP07(2020)178 , GPC #290):*Measurement of the central exclusive production of charged particle pairs in proton-proton collisions at sqrt(s)=200 GeV with the STAR detector at RHIC* , the relative uncertainty of the RP efficiency is up to 6.5%

$\delta_{\text{syst}}/\sigma_{\text{fid}}$ [%]

	TOF	TPC	RP	Other	Lumi.	Total
$\pi^+\pi^-$	$^{3.0}_{-2.8}$	$^{3.5}_{-3.3}$	$^{5.8}_{-5.1}$	$^{3.2}_{-3.1}$	$^{6.4}_{-5.7}$	$^{10.3}_{-9.3}$
K^+K^-	$^{9.3}_{-9.4}$	$^{5.2}_{-7.5}$	$^{4.9}_{-6.4}$	$^{4.7}_{-6.1}$	$^{6.4}_{-5.7}$	$^{14.2}_{-16.0}$
$p\bar{p}$	$^{5.8}_{-5.0}$	$^{4.1}_{-3.4}$	$^{6.5}_{-5.5}$	$^{10.2}_{-9.9}$	$^{6.4}_{-5.7}$	$^{15.4}_{-14.0}$

- ε_{BBC}: According to the STAR proposed paper (GPC #307): *Measurement of charged-particle production in single diffractive proton-proton collisions at $\sqrt{s}=200$ GeV with the STAR detector at RHIC* , the relative uncertainty of efficiency of the (small) BBC is up to 10% ($\delta\varepsilon_{BBC}/\varepsilon_{BBC}$).
  - The deviations between PYTHIA 8 and HERWIG models are of the order of 4% at 0.02 < ξ < 0.05, 2% at 0.05 < ξ < 0.1 and about 10% at 0.1 < ξ < 0.2. The differences between PYTHIA 8 and EPOS-LHC predictions are at the level of 3%, except nch ≤ 3 for which the difference varies up to 6%. The maximum difference between PYTHIA 8 and HERWIG/EPOS-LHC hadronization models is used as the relative systematic uncertainty.