Run15 EM-jet A_N for Semi-exclusive process

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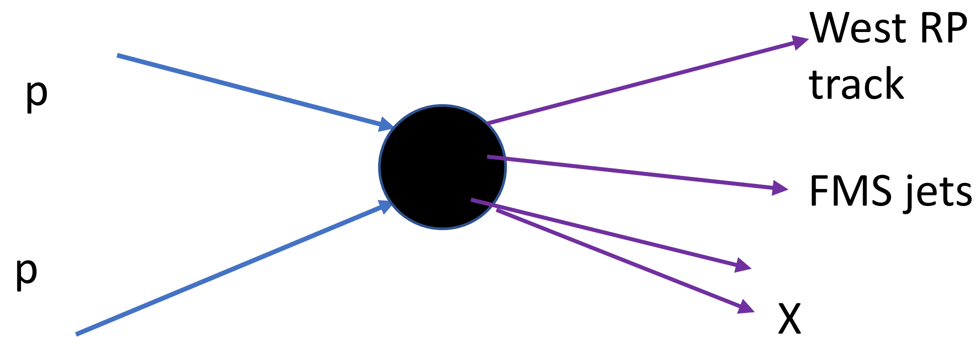
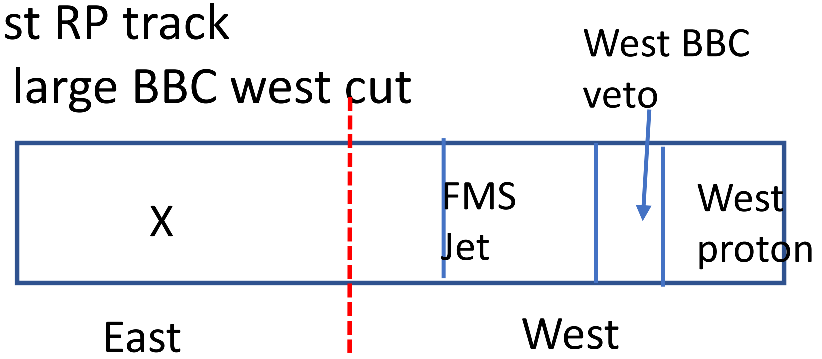
General Information for the data set

- 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.
- EM-jet reconstruction: Anti-k_T algorithm with R=0.7
  - EM-jet: the jet reconstructed using only photons (FMS point)
  - FMS point minimum energy: 1 GeV (to match with inclusive process)

Semi-exclusive process with 1 west RP track



semi-exclusive process
only 1 proton track on west side RP. No requirement on east RP track
Require: small and large BBC west cut



Semi-exclusive constrain the west side proton and FMS EM-jets
West BBC veto is for minimizing the accidental coincidence.

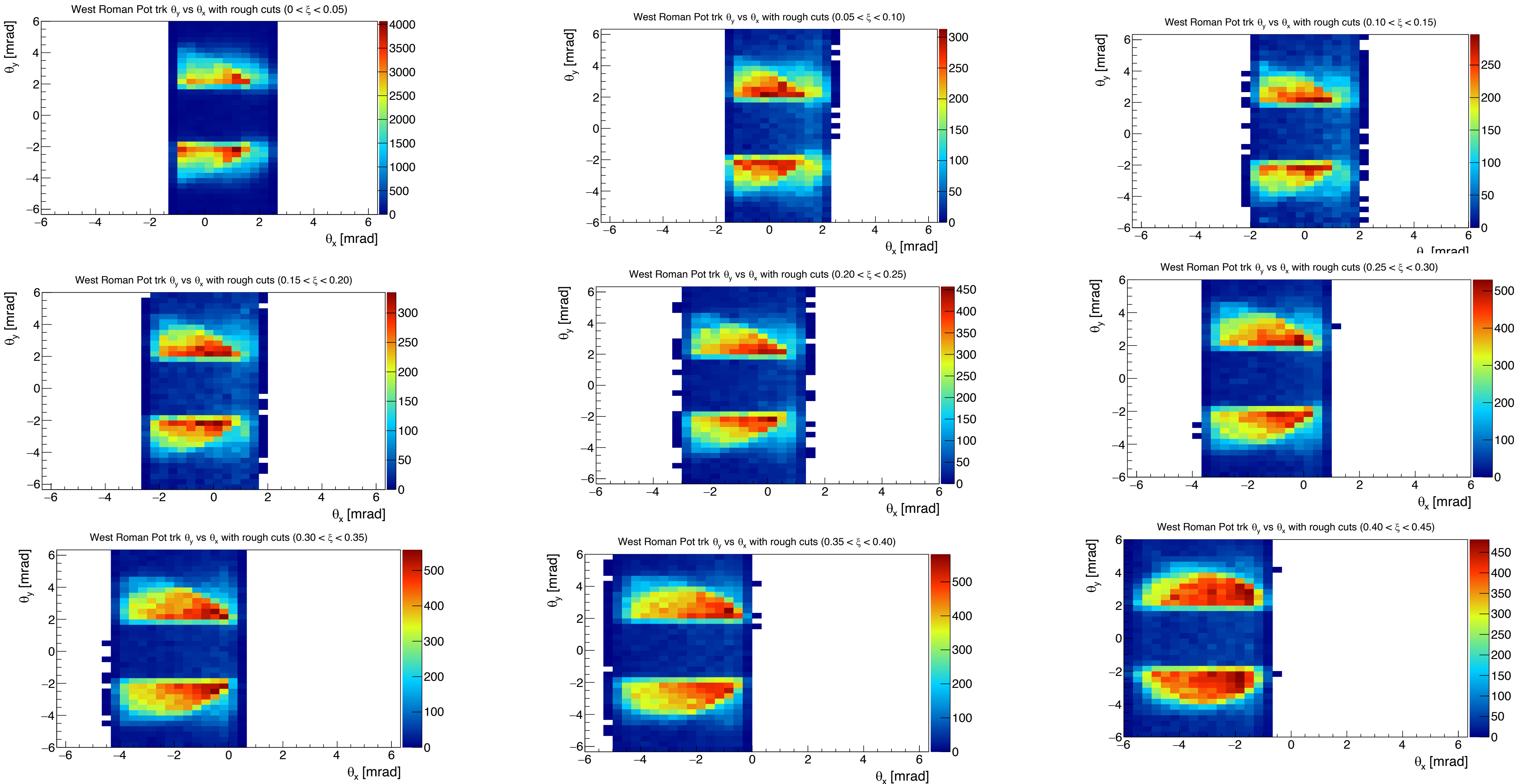
$$\xi = \frac{P_{beam} - P_{RP}}{P_{beam}}$$

Outline for studying the RP cuts and BBC cuts

- Here are the idea and steps for considering the cuts for RP and BBC:

1. Since we reach to the agreement that the low BBC threshold should be applied, we first apply a rough cut on small BBC west < 150 . Goal: explore a rough west RP P_X , P_Y cuts for different ξ range.
2. Apply the rough west RP P_X , P_Y cuts from step 1, study the small/large BBC west ADC distribution and consider further cuts for small/large BBC west cuts.
3. Apply the further cuts for west small/large BBC cuts, study the final west RP P_X , P_Y cuts, and θ_X , θ_Y cuts for different ξ range.

Rough west RP track θ_Y vs θ_X with different ξ ranges



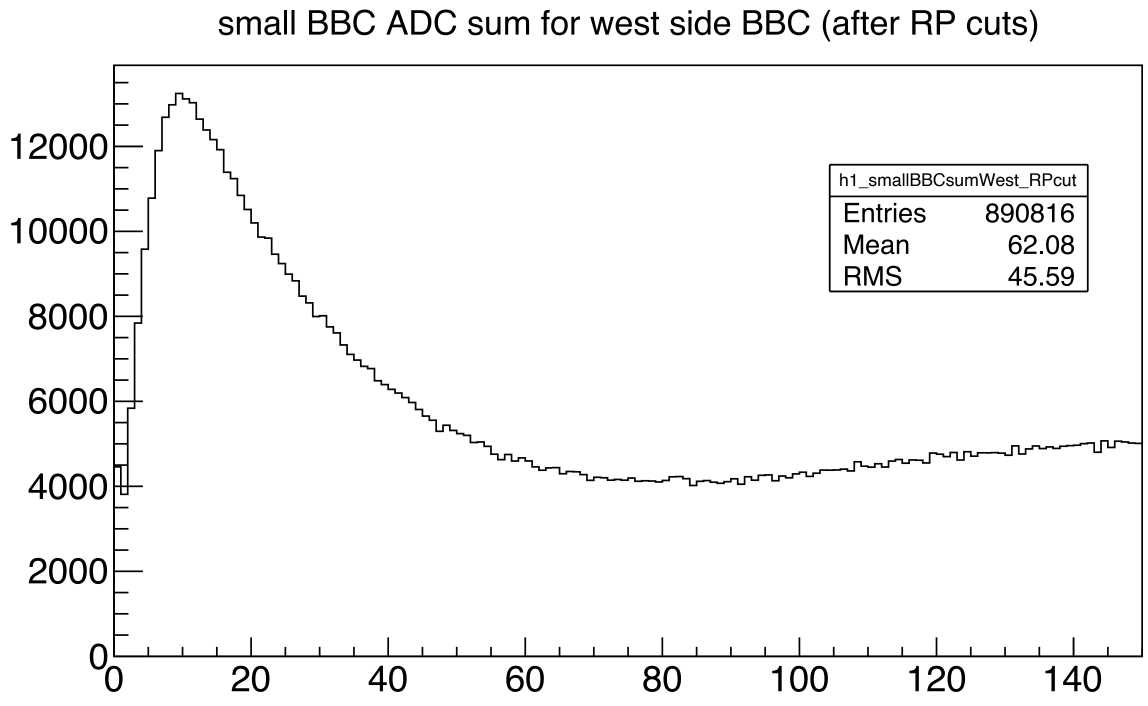
Rough west RP track θ_Y vs θ_X with different ξ ranges

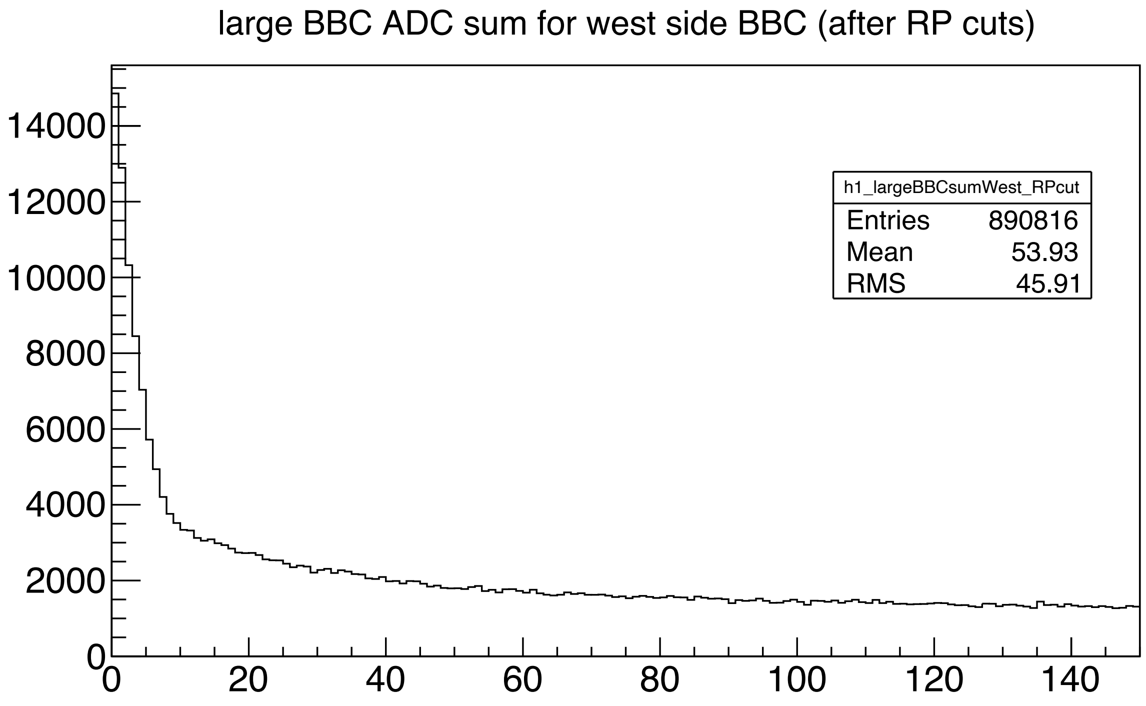
$(\xi = \frac{P_{beam} - P_{RP}}{P_{beam}})$

- Cuts applied at this stage: RP track hit at least 7 SSD planes , small BBC west < 150
- We can consider the rough west RP θ_Y cut: $1.5 < |\theta_Y| < 4\, mrad$
- The rough west RP θ_X cut can be applied with ξ dependent
  - $0.0 < \xi < 0.05$: $-1 < \theta_X < 1.75$ mrad
  - $0.05 < \xi < 0.10$: $-1.5 < \theta_X < 1.5$ mrad
  - $0.10 < \xi < 0.15$: $-1.75 < \theta_X < 1.25$ mrad
  - $0.15 < \xi < 0.20$: $-2.5 < \theta_X < 1.25$ mrad
  - $0.20 < \xi < 0.25$: $-3 < \theta_X < 1$ mrad
  - $0.25 < \xi < 0.30$: $-3.25 < \theta_X < 0.5$ mrad
  - $0.30 < \xi < 0.35$: $-3.75 < \theta_X < 0$ mrad
  - $0.35 < \xi < 0.40$: $-4.25 < \theta_X < -0.5$ mrad
  - $0.40 < \xi < 0.45$: $-5 < \theta_X < -1$ mrad

West small and large BBC ADC sum after the rough west RP track θ_X and θ_Y cuts

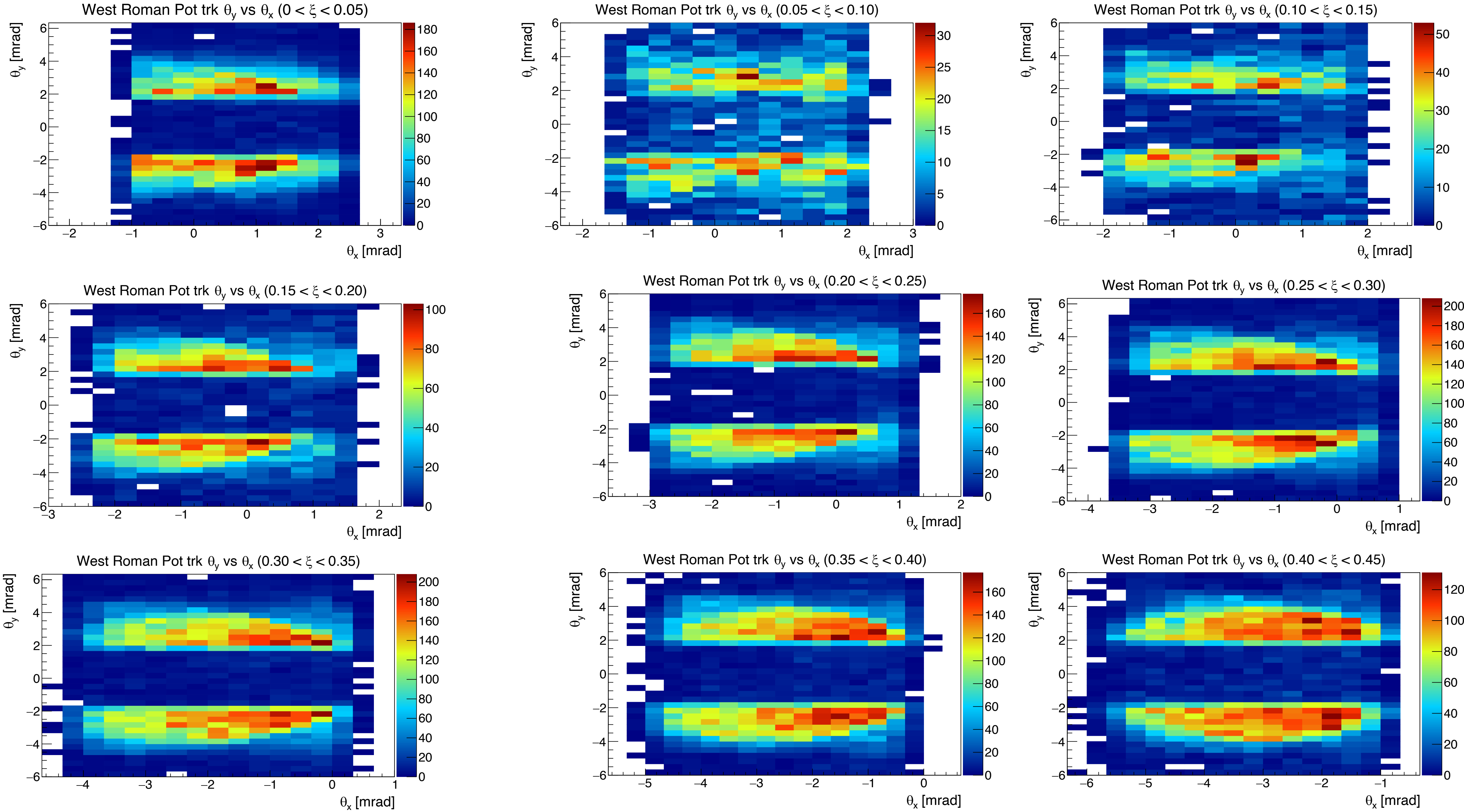
- Temporally apply the rough west RP track θ_X and θ_Y cuts to study the west small and large BBC ADC sum.
- We can consider small BBC west ADC sum < 80 and large BBC west < 60





Final cut on the west RP track θ_X and θ_Y

- We apply the BBC cuts: BBC west ADC sum < 80 and large BBC west < 60
- We can consider the west RP θ_Y cut: $1.5 < |\theta_Y| < 4\, mrad$
- The west RP θ_X cut can be applied with ξ dependent
  - $0.0 < \xi < 0.05$: $-1 < \theta_X < 1.75$ mrad
  - $0.05 < \xi < 0.1$: $-1.5 < \theta_X < 1.5$ mrad
  - $0.1 < \xi < 0.15$: $-1.75 < \theta_X < 1.25$ mrad
  - $0.15 < \xi < 0.2$: $-2 < \theta_X < 1$ mrad
  - $0.2 < \xi < 0.25$: $-2.75 < \theta_X < 0.5$ mrad
  - $0.25 < \xi < 0.3$: $-3.25 < \theta_X < 0.5$ mrad
  - $0.3 < \xi < 0.35$: $-3.75 < \theta_X < 0$ mrad
  - $0.35 < \xi < 0.4$: $-4.5 < \theta_X < -0.5$ mrad
  - $0.4 < \xi < 0.45$: $-5.5 < \theta_X < -1.25$ mrad


West Roman Pot trk θy vs θx (0 < ξ < 0.05)
West Roman Pot trk θy vs θx (0.05 < ξ < 0.10)
West Roman Pot trk θy vs θx (0.10 < ξ < 0.15)
West Roman Pot trk θy vs θx (0.15 < ξ < 0.20)
West Roman Pot trk θy vs θx (0.20 < ξ < 0.25)
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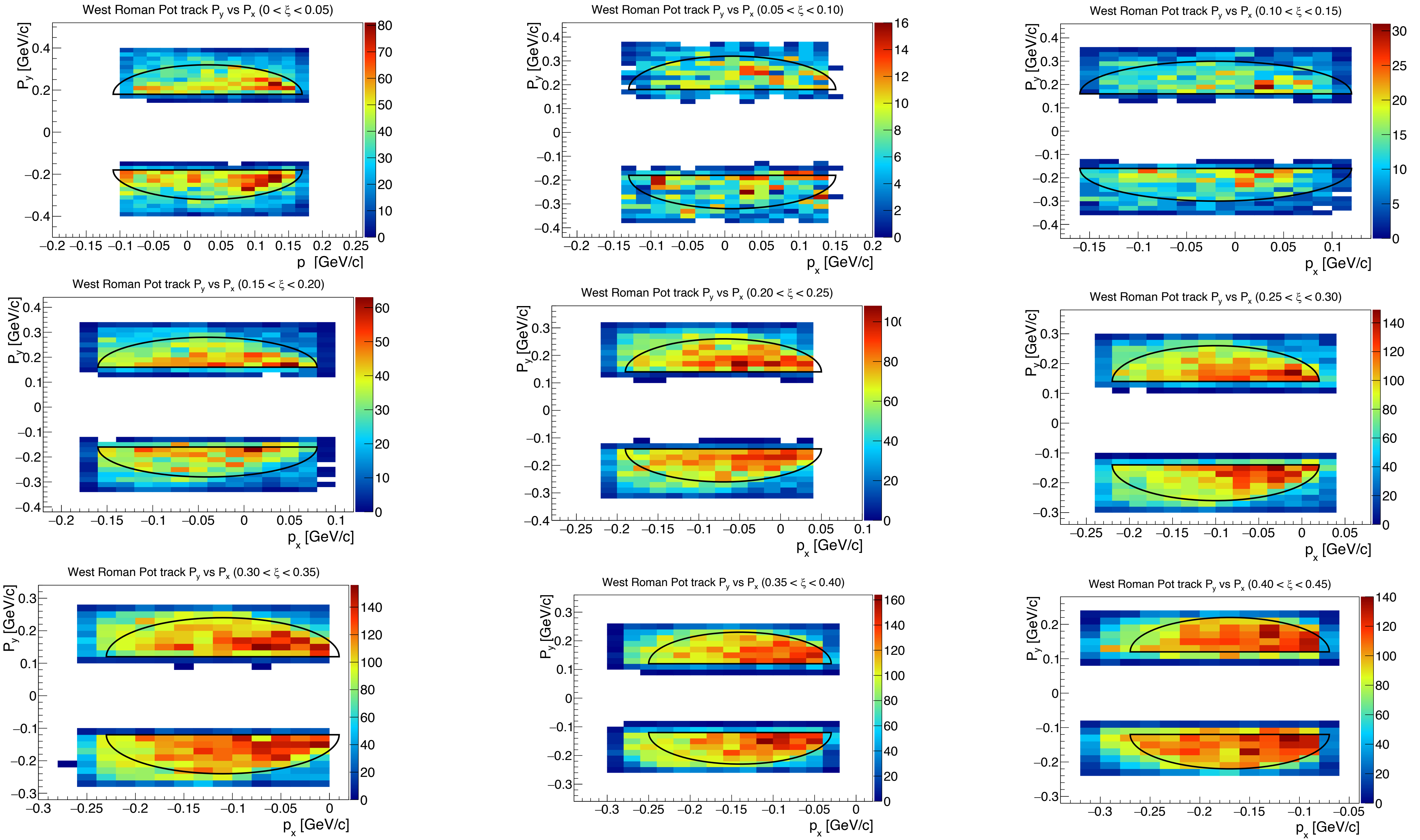
West Roman Pot trk θy vs θx (0.30 < ξ < 0.35)
West Roman Pot trk θy vs θx (0.35 < ξ < 0.40)
West Roman Pot trk θy vs θx (0.40 < ξ < 0.45)
θy [mrad]
θx [mrad]

Final **west** RP track P_X and P_Y cuts

- In addition to the west small/large BBC cuts and west RP track θ_X and θ_Y cuts, we apply the west RP track P_X and P_Y cuts:
- $0.0 < \xi < 0.05$: $(P_X - 0.03)^2 + (|P_Y| - 0.18)^2 < 0.14^2$ and $0.18 < |P_Y| < 0.32$
- $0.05 < \xi < 0.1$: $(P_X - 0.01)^2 + (|P_Y| - 0.18)^2 < 0.14^2$ and $0.18 < |P_Y| < 0.32$
- $0.1 < \xi < 0.15$: $(P_X + 0.02)^2 + (|P_Y| - 0.16)^2 < 0.14^2$ and $0.16 < |P_Y| < 0.3$
- $0.15 < \xi < 0.2$: $(P_X + 0.04)^2 + (|P_Y| - 0.16)^2 < 0.12^2$ and $0.16 < |P_Y| < 0.28$
- $0.2 < \xi < 0.25$: $(P_X + 0.07)^2 + (|P_Y| - 0.14)^2 < 0.12^2$ and $0.14 < |P_Y| < 0.26$
- $0.25 < \xi < 0.3$: $(P_X + 0.1)^2 + (|P_Y| - 0.14)^2 < 0.12^2$ and $0.14 < |P_Y| < 0.26$
- $0.3 < \xi < 0.35$: $(P_X + 0.11)^2 + (|P_Y| - 0.12)^2 < 0.12^2$ and $0.12 < |P_Y| < 0.24$
- $0.35 < \xi < 0.4$: $(P_X + 0.14)^2 + (|P_Y| - 0.12)^2 < 0.11^2$ and $0.12 < |P_Y| < 0.23$
- $0.4 < \xi < 0.45$: $(P_X + 0.17)^2 + (|P_Y| - 0.12)^2 < 0.1^2$ and $0.12 < |P_Y| < 0.22$


West Roman Pot track P_y vs P_x ($0 < \xi < 0.05$)
West Roman Pot track P_y vs P_x ($0.05 < \xi < 0.10$)
West Roman Pot track P_y vs P_x ($0.10 < \xi < 0.15$)
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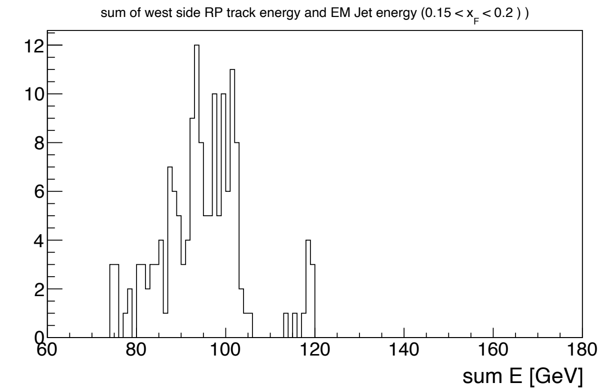
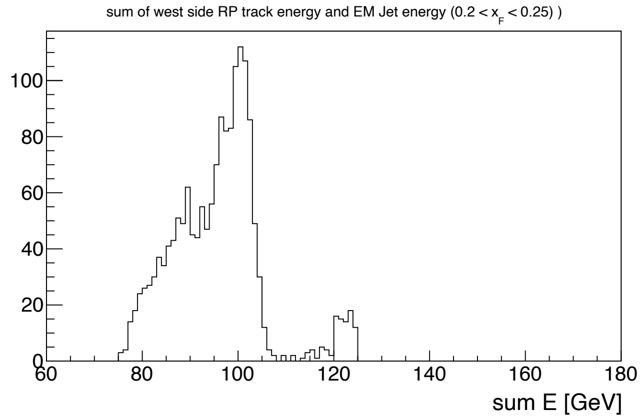
West Roman Pot track P_y vs P_x ($0.35 < \xi < 0.40$)
West Roman Pot track P_y vs P_x ($0.40 < \xi < 0.45$)
P_y [GeV/c]
p_x [GeV/c]

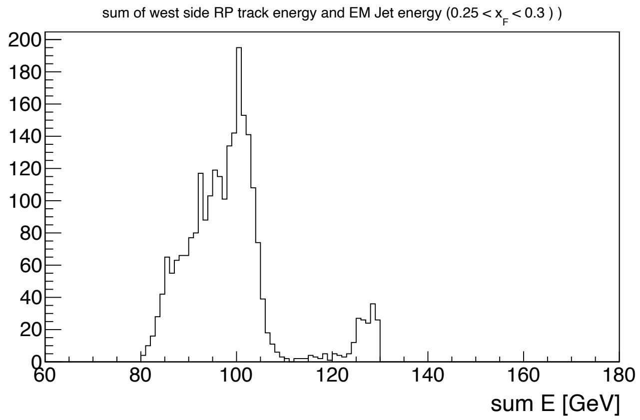
Energy sum plot for case with only 1 west RP track

- Sum energy: E(west RP track) + E(EM-jet)
- Applying cuts with west small/large BBC, RP track and FMS EM-jets.

Very low entries in x_F [0.15, 0.2] region, we decide to drop it.

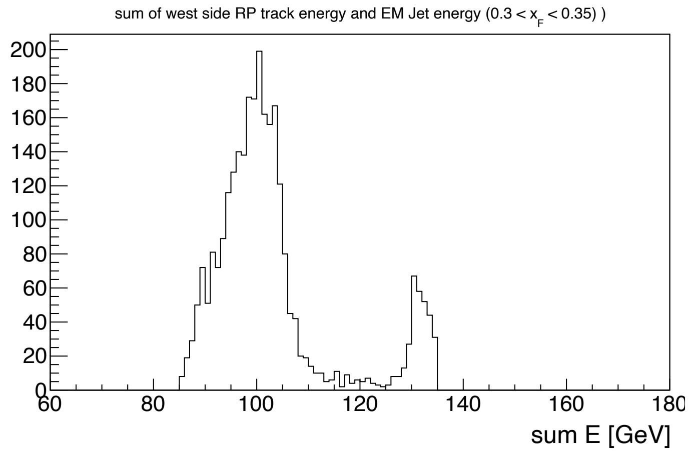


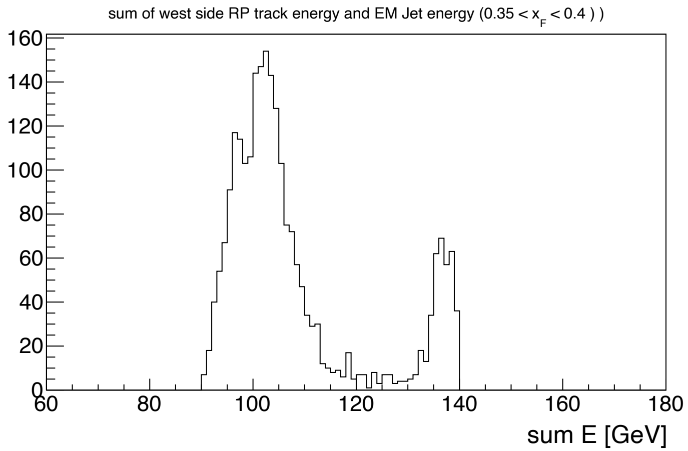


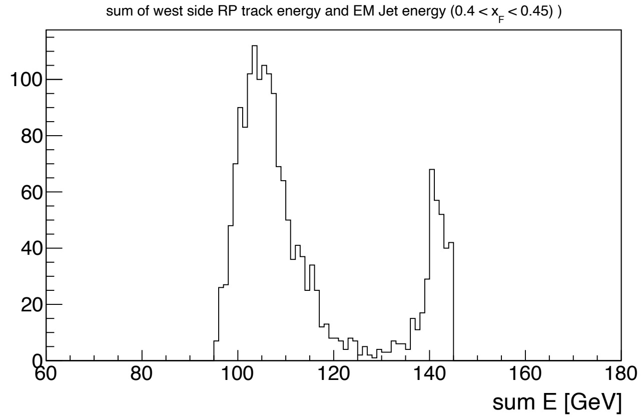


Therefore, we can consider the energy sum cuts below:

x_F	E sum Cut
~~0.15 - 0.2~~	~~E_{sum} < 105 GeV~~
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







Event selection and corrections

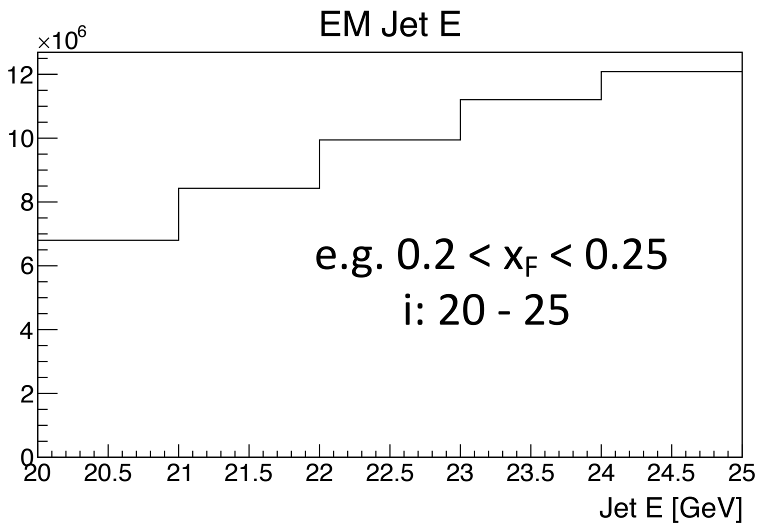
- **FMS**
  - 9 Triggers, veto on FMS-LED
  - bit shift, bad / dead / hot channel masking (include fill by fill hot channel masking)
  - Jet reconstruction: StJetMaker2015 , Anti-kT, R<0.7 , FMS point energy > 1 GeV, $p_T > 2$ GeV/c, trigger p_T threshold cut, FMS point as input.
  - Only 1 EM-jet per 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

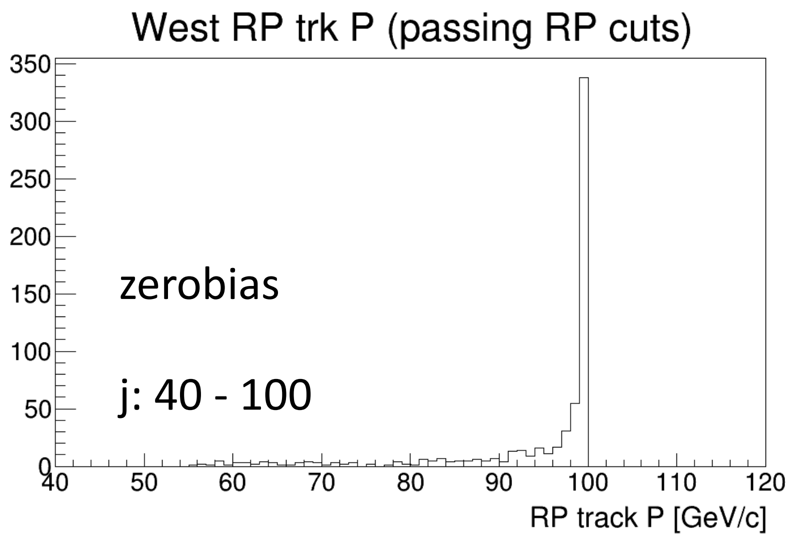
Corrections:
EM-jet energy correction and Underlying Event correction

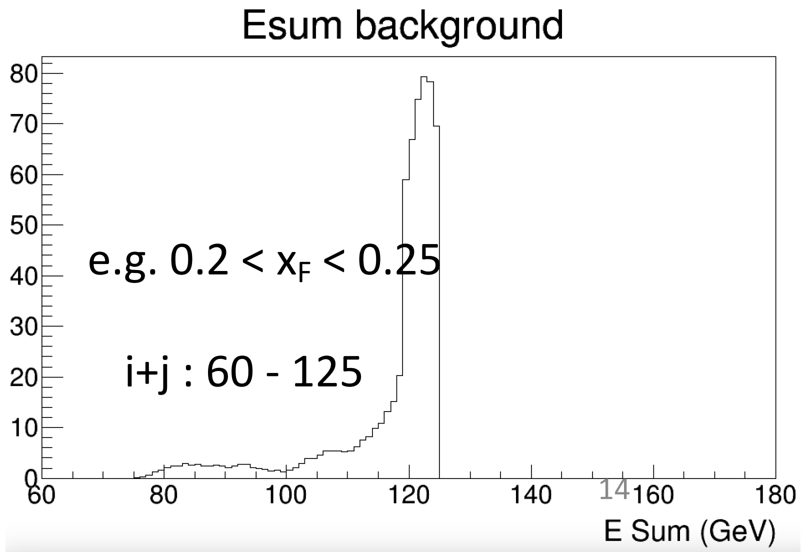
x_F	E sum Cut
0.2 - 0.25	E_{sum} < 110 GeV
0.25 - 0.3	E_{sum} < 110 GeV
0.3 – 0.35	E_{sum} < 115 GeV
0.35 – 0.4	E_{sum} < 115 GeV
0.4 – 0.45	E_{sum} < 120 GeV

Background study for E sum

- 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: $\boldsymbol{Esum(i+j) = \sum_{i,j} P(i) * n(j)}$, 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).

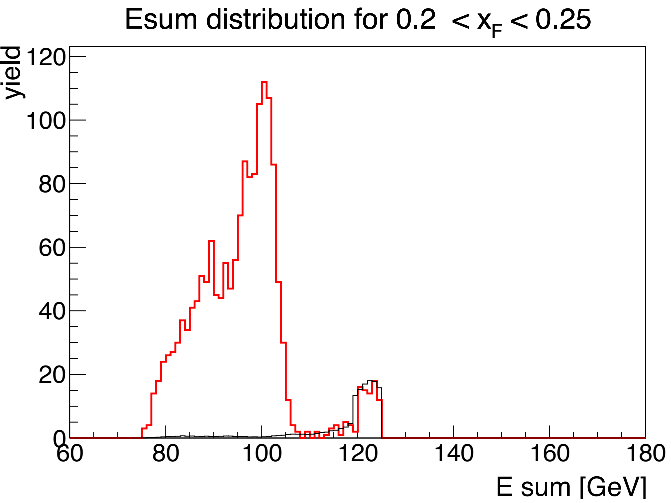


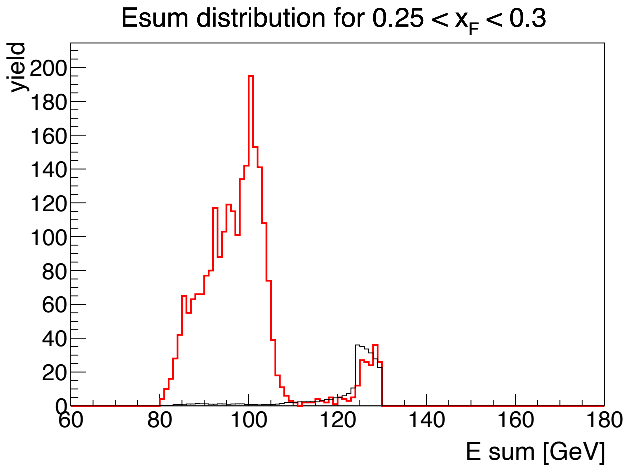




Mix event energy sum study results

- 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**)

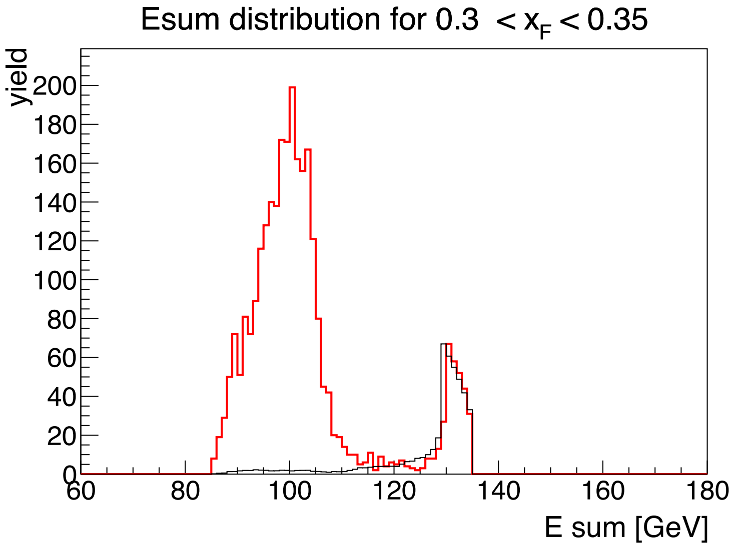


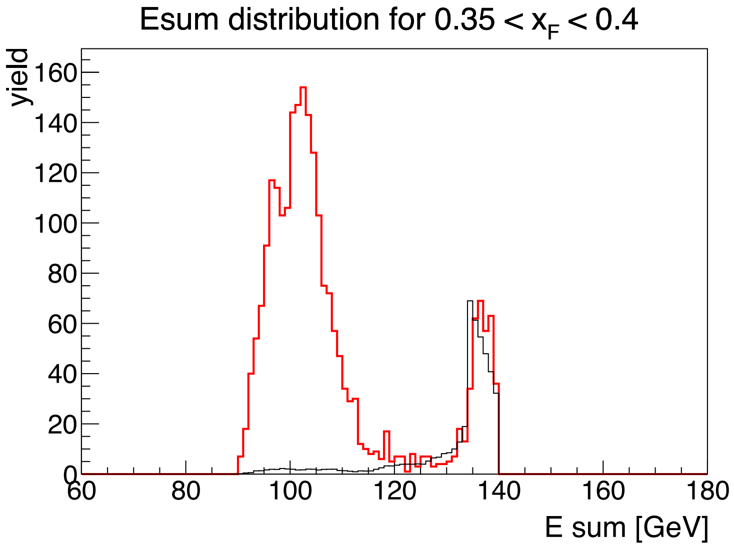


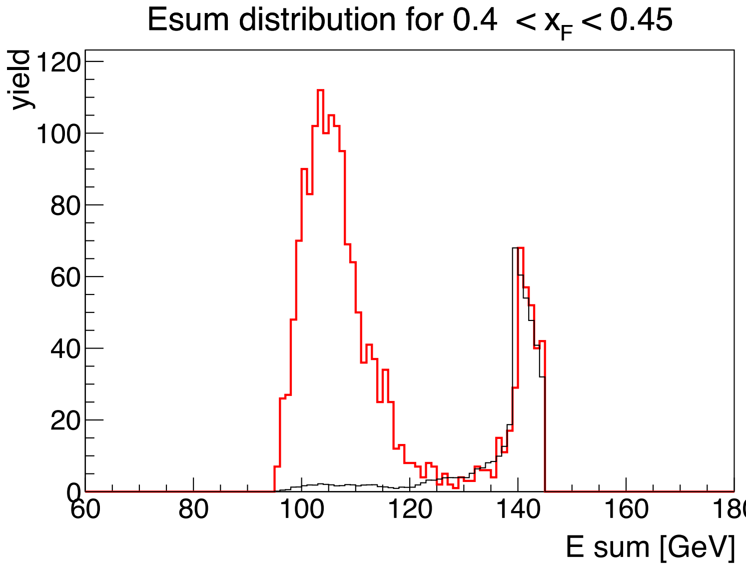
<u>All photon multiplicity</u>

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

Red curve is the FMS stream data







Mix event background study results

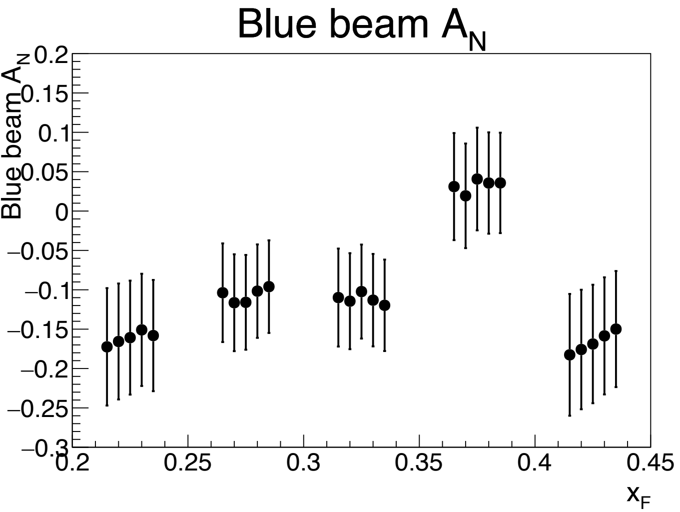
- The background from mix event will be counted as systematic uncertainty results.
  - $frac = \frac{Integral\ of\ yields\ in\ signal\ region\ for\ mix\ event\ background}{Intrgral\ of\ yields\ in\ signal\ region\ for\ FMS\ data}$

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

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



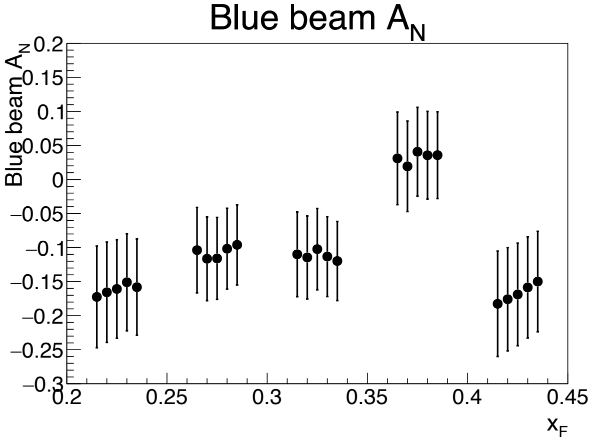
Example: Small BBC west cuts

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

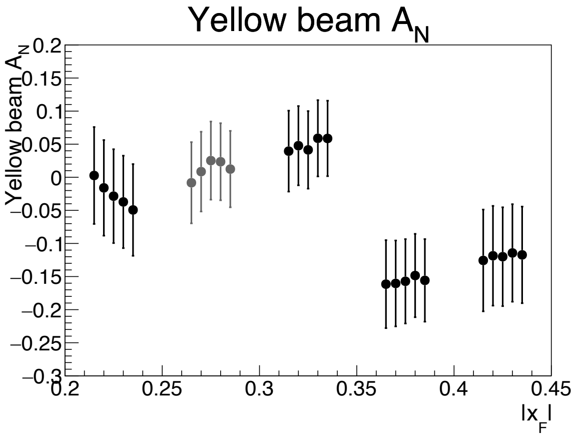
A_N results for varying the cuts (systematic)

1 or 2 photon multiplicity EM-jet

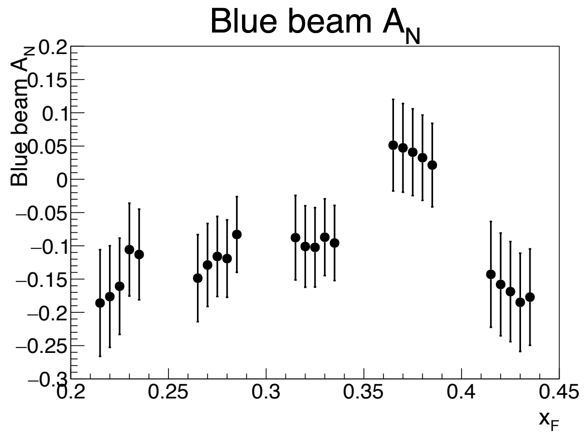
Small BBC west cuts



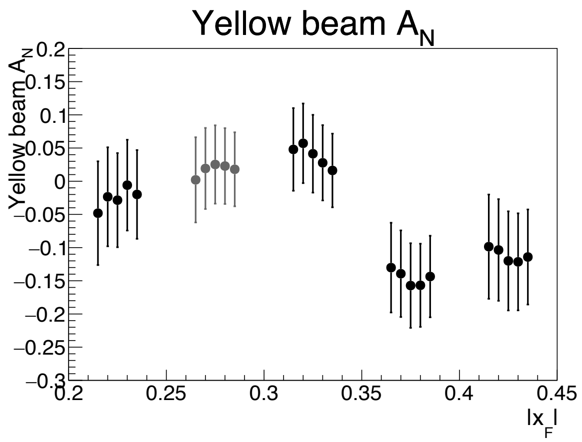
Each x_F set, from left to right: varying the cuts from original: -20, -10, 0, +10, +20



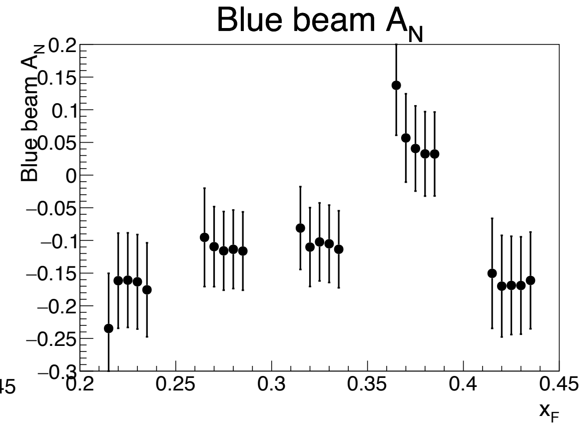
Large BBC west cuts



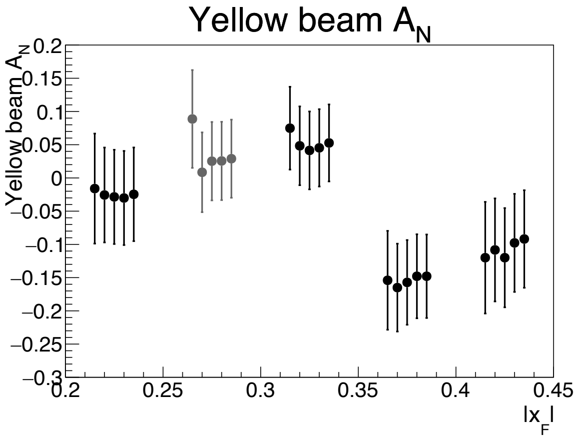
Each x_F set, from left to right: varying the cuts from original: -20, -10, 0, +10, +20



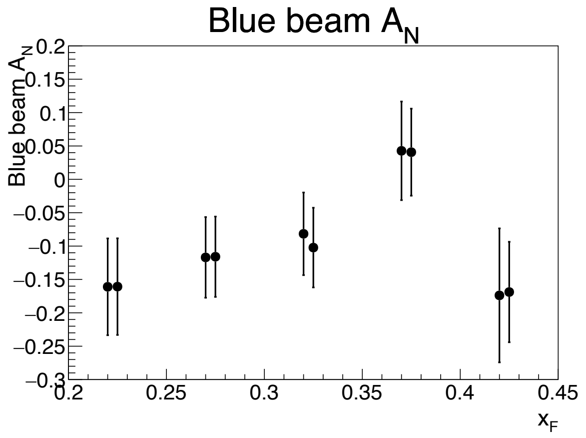
Energy sum cuts



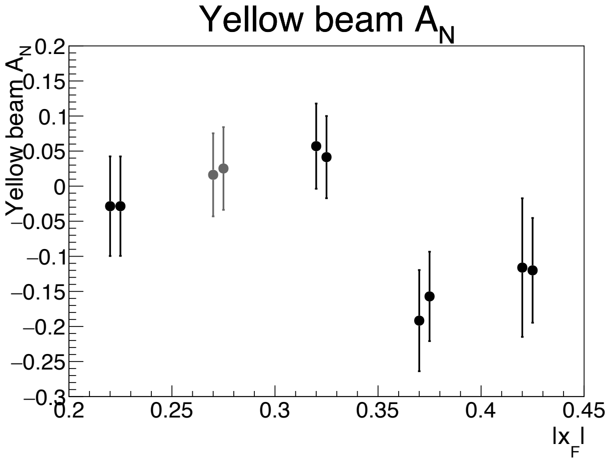
Each x_F set, from left to right: varying the cuts from original: -10, -5, 0, +5, +10 (GeV)



Ring of Fire cuts



Each x_F set, from left to right: Apply Ring of Fire cut, do not apply Ring of Fire cut



Calculating the systematic uncertainty (1 or 2 photon multiplicity)

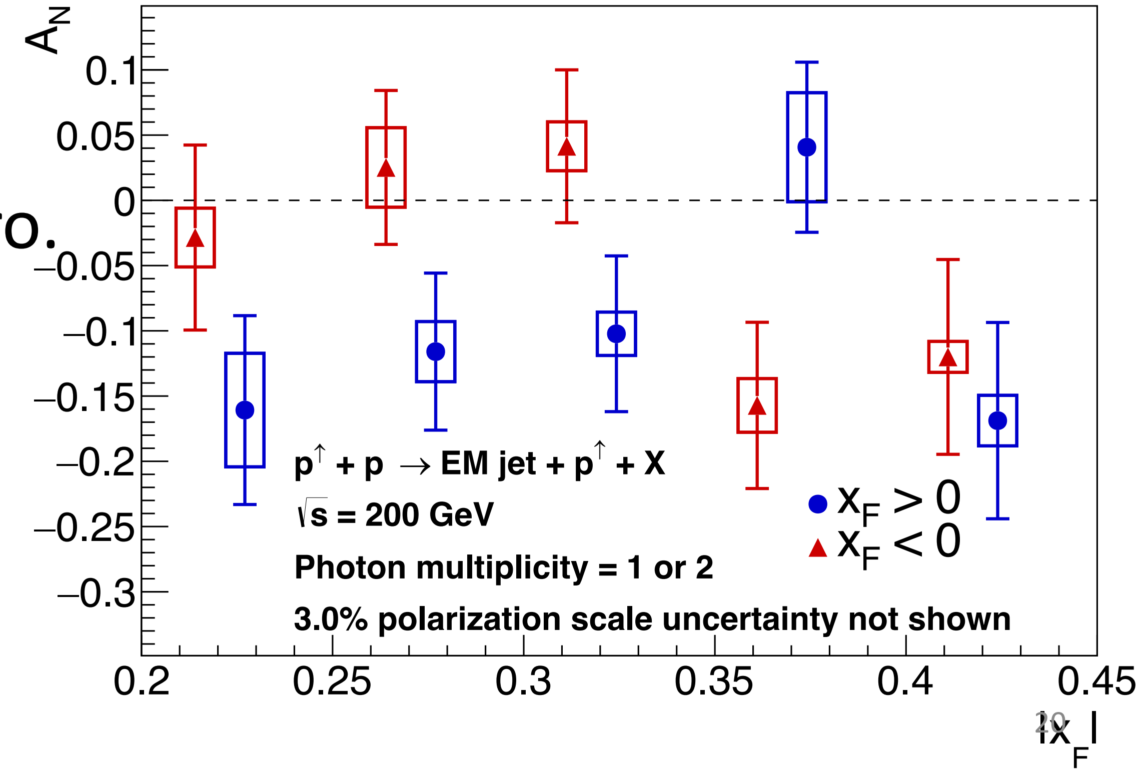
- Then, find out the maximum ($A_N(1) \pm \delta(1)$, with statistical uncertainty) , and the minimum ($A_N(2) \pm \delta(2)$, with statistical uncertainty) for the varying cuts as systematic uncertainty.
- If the $\frac{|A_N(1)-A_N(2)|}{\sqrt{|(\delta(1))^2-(\delta(2))^2|}} > 1$, use the **standard 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) : $\sigma_{sys} = \sqrt{\sum_i (\sigma_i)^2}$

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

A_N results for 1 or 2 photon multiplicity

- Only 5 x_F bins are considered: [0.2,0.25], [0.25,0.3], [0.3,0.35] , [0.35,0.4], [0.4,0.45]
- 1 or 2 photon multiplicity
- Constant fit is applied to calculate the significance of non-zero
- 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



Conclusion

- The non-zero blue beam A_N with 3.1 σ significant is observed for the semi-exclusive process.
- Most of the blue beam A_N are with negative values. We need more theories to explain such behavior.
- The semi-exclusive process also can not provide evidences to contribute to large A_N in inclusive process.
- The analyses for run 15 diffractive EM-jet A_N measurement are closing to complete. We will have paper proposal soon.