Diffractive EM Jet A_N at FMS with run 15 data updates and preliminary request

Xilin Liang

UC Riverside

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Outline

- Reviews for analysis motivation, data sets, event selection and analysis procedure.
- Reproduce Chris's proton – EM jet (pion) asymmetry.
- Current status and results for systematic uncertainty.
- Preliminary request for physics plot (A_N) – target for DIS 2022

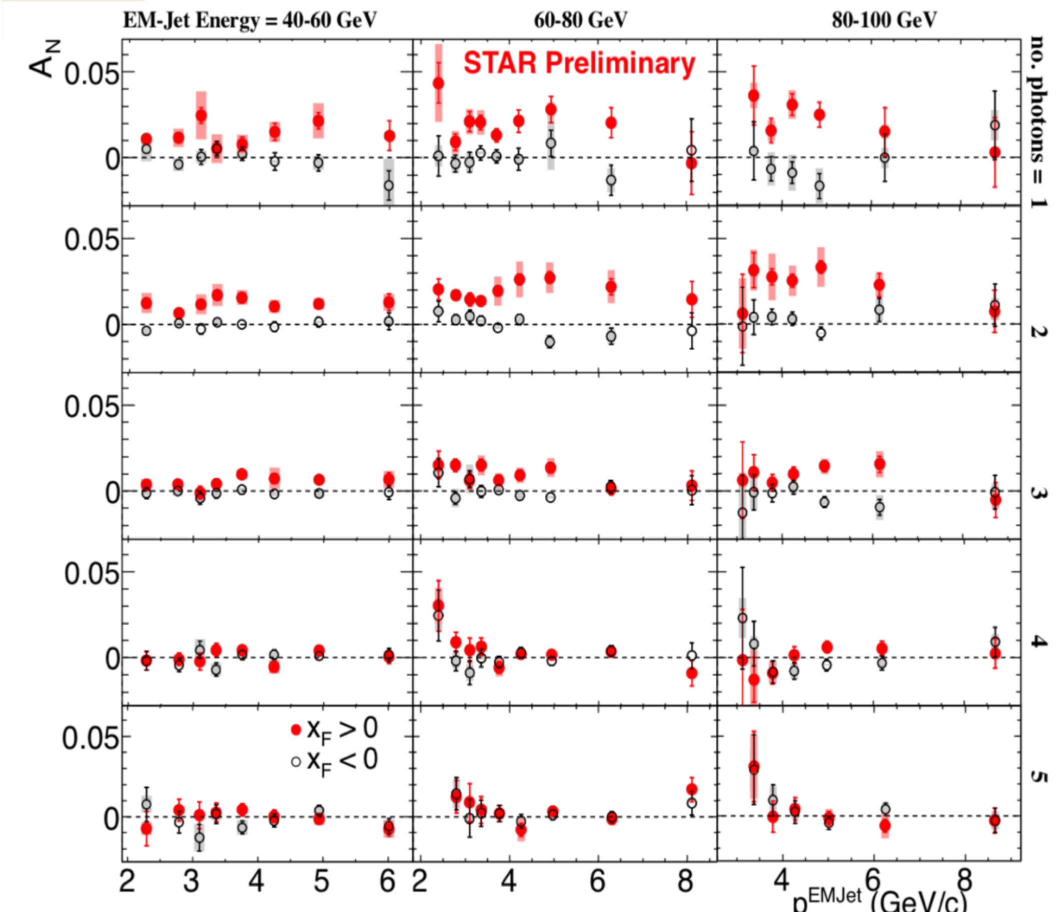
Contact information

- PA: **Xilin Liang**[1], Latif Kabir[1], Kenneth Barish[1]
- PA email address: xilin.liang@email.ucr.edu
- Supervisor: Kenneth Barish[1]
- Supervisor email address: kenneth.barish@ucr.edu

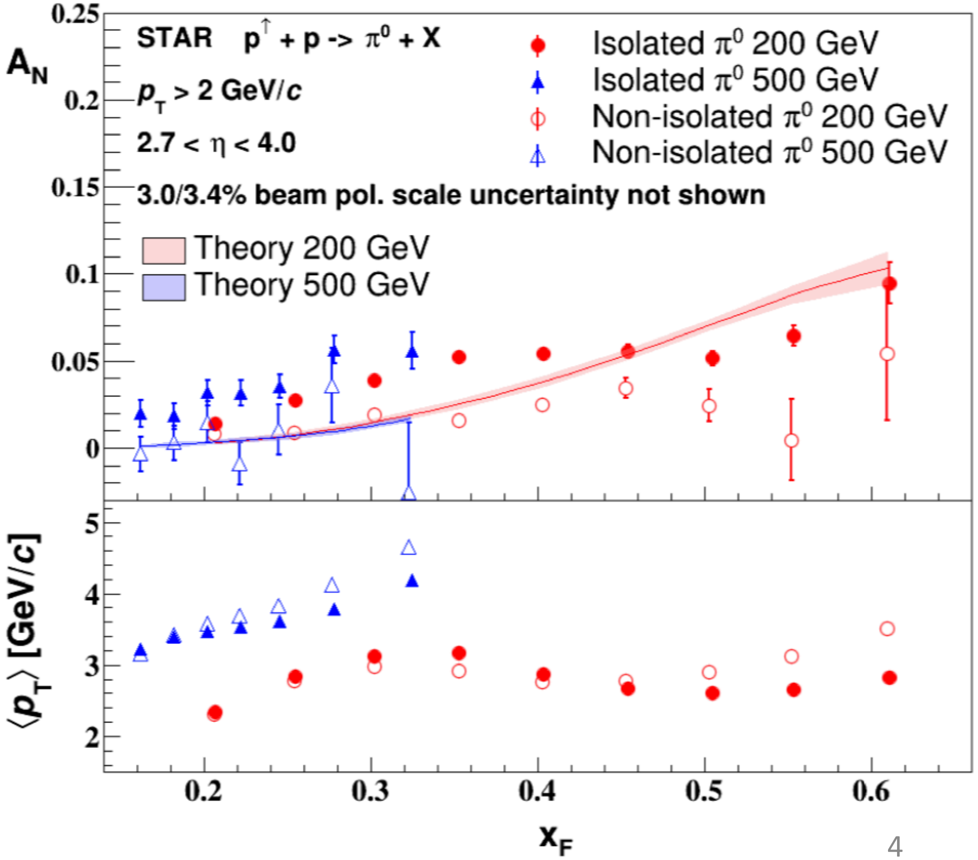
[1] Institution: UC Riverside

Physics motivation

- Diffractive process may play a role to explain large A_N.
  - A_N decreases with Increasing number of photons in EM jets.
  - Isolated π^0 events have larger A_N.



Ref: Mriganka Mondal DIS 2014



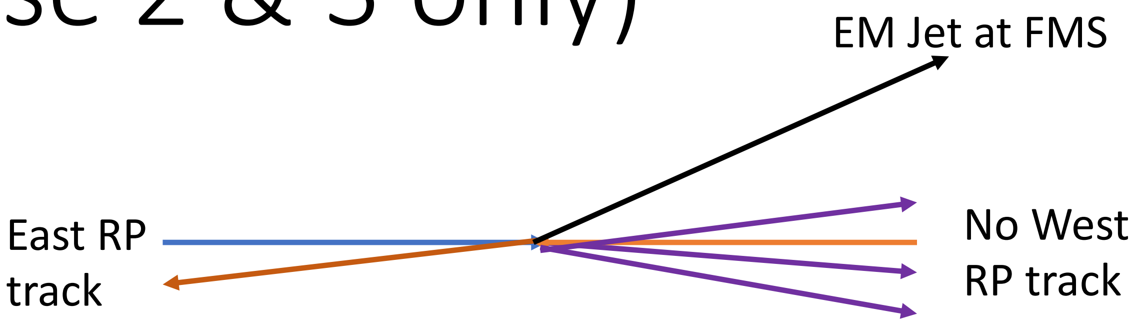
Ref: Phys. Rev. D **103**, 092009 (2021)

Data sets and triggers

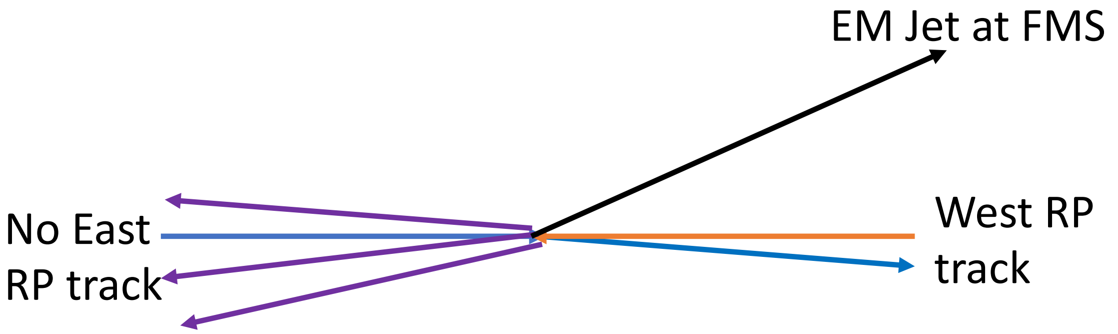
- Data sets: run15 pp transverse data , $\sqrt{s} = 200\ GeV$ (production_pp200trans_2015)
- Stream: st_fms
- Production type: MuDst ; Production tag: P15ik
- Trigger for FMS : FMS small board sum, FMS large board sum and FMS-JP.
    - Trigger list: FMS-JP0, FMS-JP1, FMS-JP2, FMS-sm-bs1, FMS-sm-bs2, FMS-lg-bs1, FMS-lg-bs2, FMS-lg-bs3. (8 triggers)
- Requirement: Event must also contain at least 1 Roman Pot track.
- Trigger veto: FMS-LED
- STAR library: SL20a

Diffractive process (case 2 & 3 only)

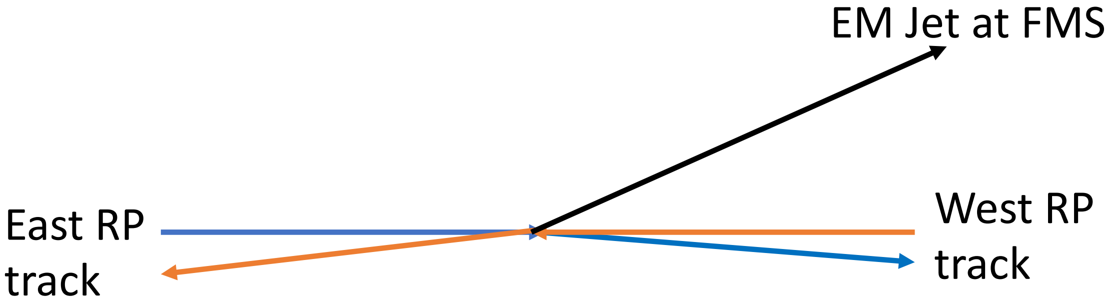
Case 1:
Single diffractive event: we can detect only 1 proton track on east side RP.
Require: only 1 east side RP track



Case 2:
Single diffractive event: we can detect only 1 proton track on west side RP.
Require: sum of west side tracks energy (proton + EM Jet) less than beam energy



Case 3:
Double diffractive event: we can detect 1 proton track on east side RP and 1 proton track on west side RP.
Require: sum of west side tracks energy (proton + EM Jet) less than beam energy



Procedure for data analysis

MuDst files

Trigger selection, FMS bad/hot channel masking, jet reconstruction, event contains at least 1 RP track information

Nano Dst files (keep the physics measurements used for this analysis)

Event selection with vertex cut, RP cuts , FMS EM jet and BBC cut

Physics measurements and uncertainty study

Cross ratio method for A_N calculation

Systematic uncertainty: energy correction, Ring of fire background, beam polarization

Event selection

- **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) , FMS tower energy > 2 GeV
  - Jet reconstruction: StJetMaker2015 , Anti-kT, R<0.7 , p_T > 1 GeV/c, FMS point as input
  - Apply energy correction.
- **Only acceptable spin pattern.**
- **Vertex** (Determine vertex z priority according to TPC , VPD, BBC.)
  - Vertex $|z| < 80\ cm$
- **Roman Pot and Diffractive process**
  - Acceptable cases:

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:

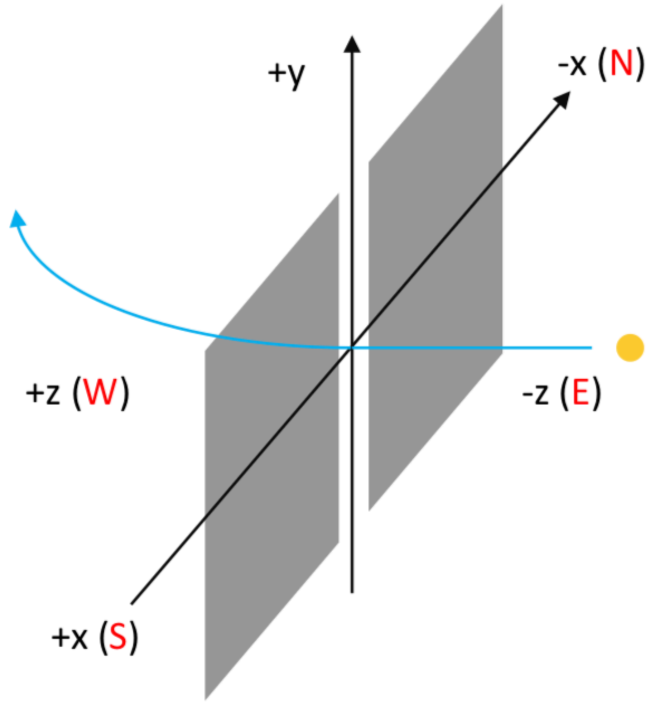
a) Each track hits > 6 planes

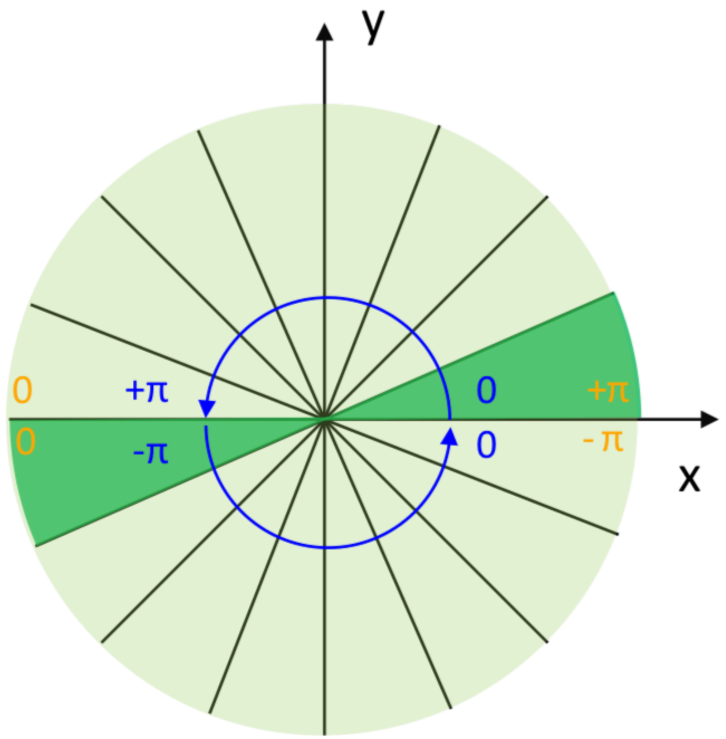
b) $-2 < \theta_X < 2$ mrad , $1.5 < |\theta_y| < 4.5$ mrad

  - Sum of west RP track energy and all EM Jet energy < 108 GeV
- **BBC ADC sum cuts:**
  - West Large BBC ADC sum < 60
  - West Small BBC ADC sum < 100

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. ($x_F = \frac{E_{EM\ jet}}{E_{Beam}}$) , 4 bins in range $x_F \in [0.1, 0.3]$
  - Divide full ϕ range [-π , +π] into 16 bins.



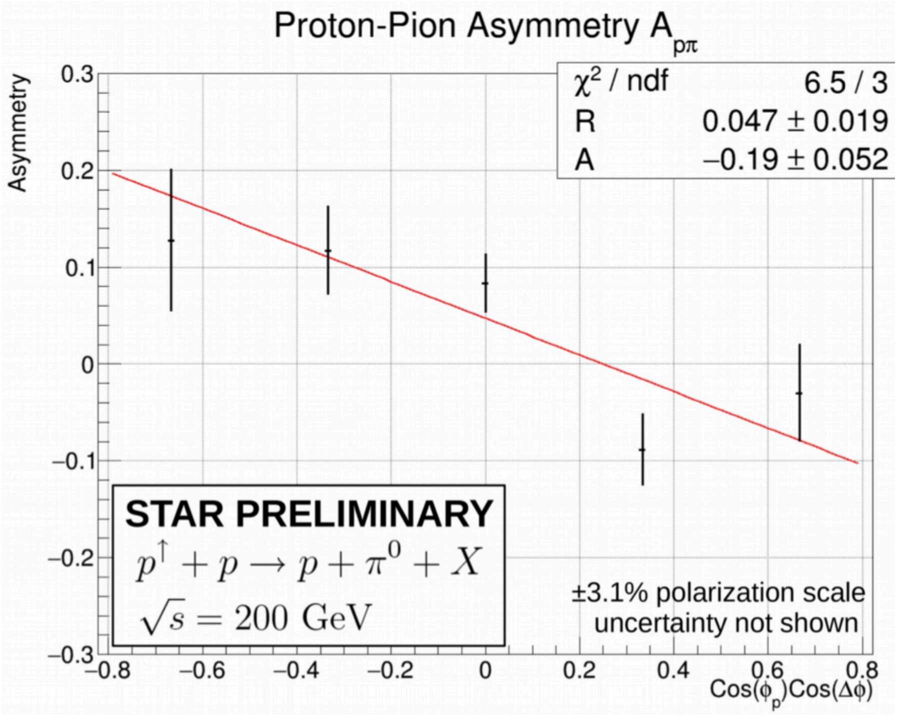


Cross check with Chris's analysis

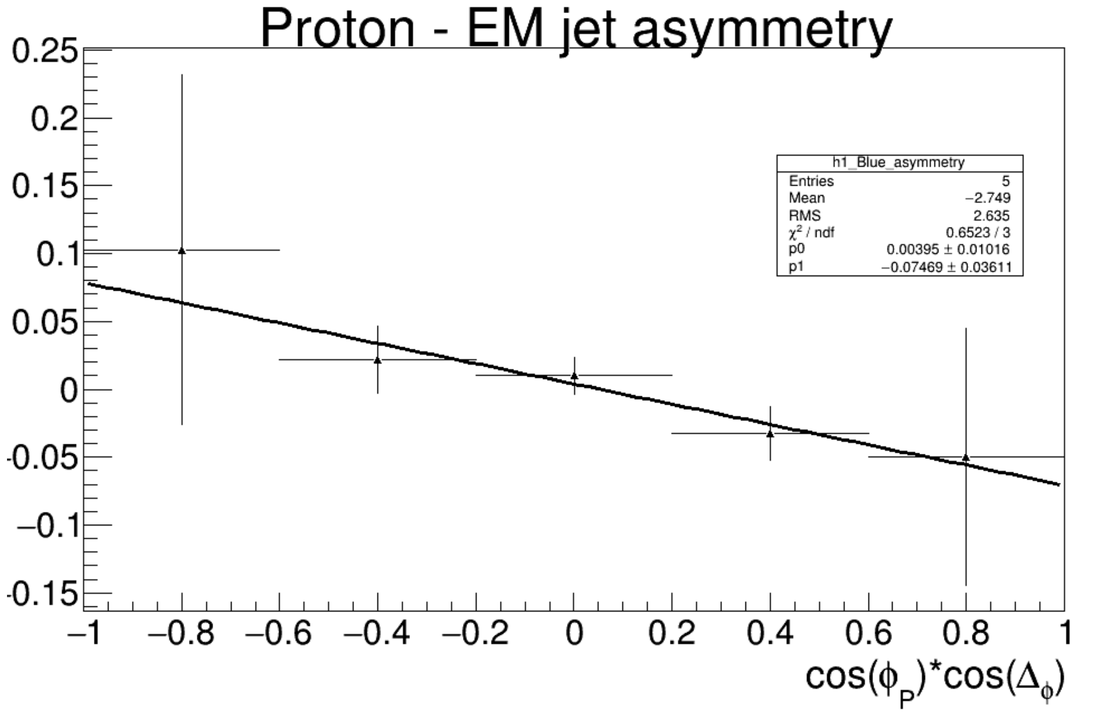
All photon multiplicity EM jets

- Asymmetry related to A_N: $\cos(\phi_p)\cos(\phi_{EM-jet} - \phi_p)$
  - $\sigma \propto \cos(\phi_p)\cos(\phi_{EM-jet} - \phi_p)$
- Fit function: $\frac{N^{\uparrow} - N^{\downarrow}}{P(N^{\uparrow} + N^{\downarrow})} = R + A\cos(\phi_P)\cos(\Delta\phi)$, where $\Delta\phi = \phi_{EM-jet} - \phi_P$

Chris's result (-19%±5.2%)



My result (-7.5%±3.6%)

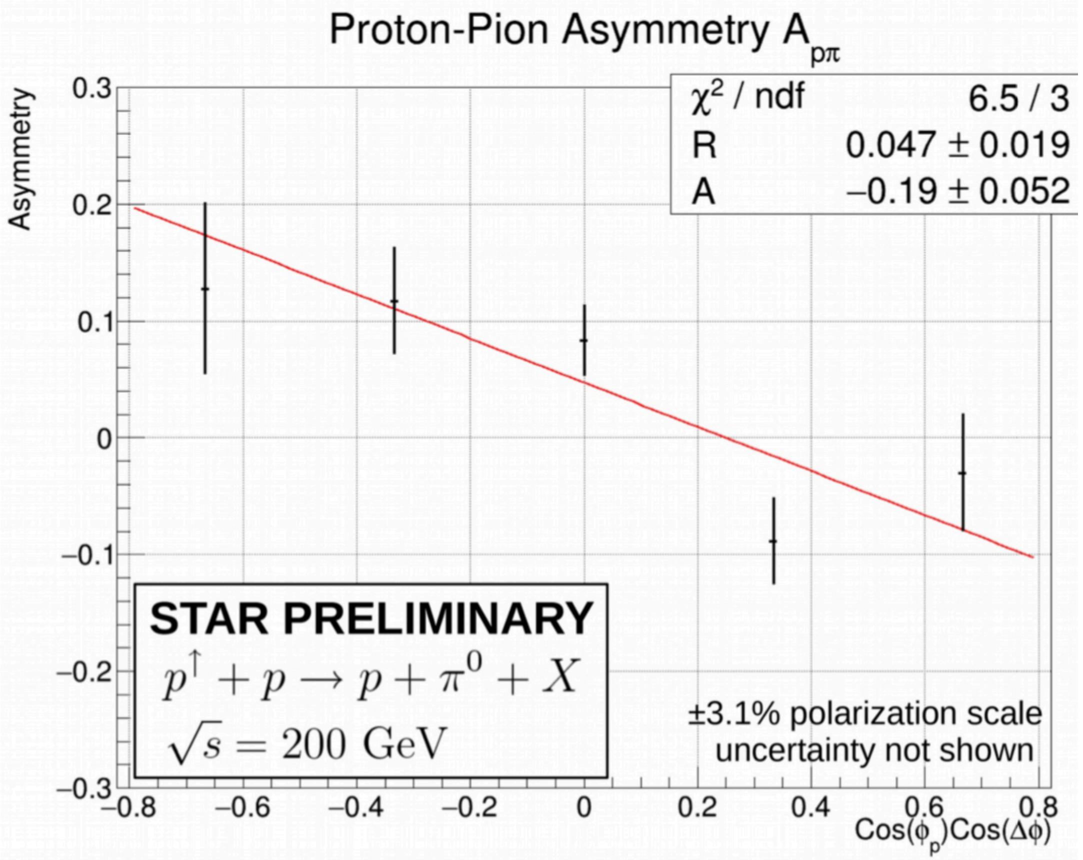


Proton – EM jet asymmetry

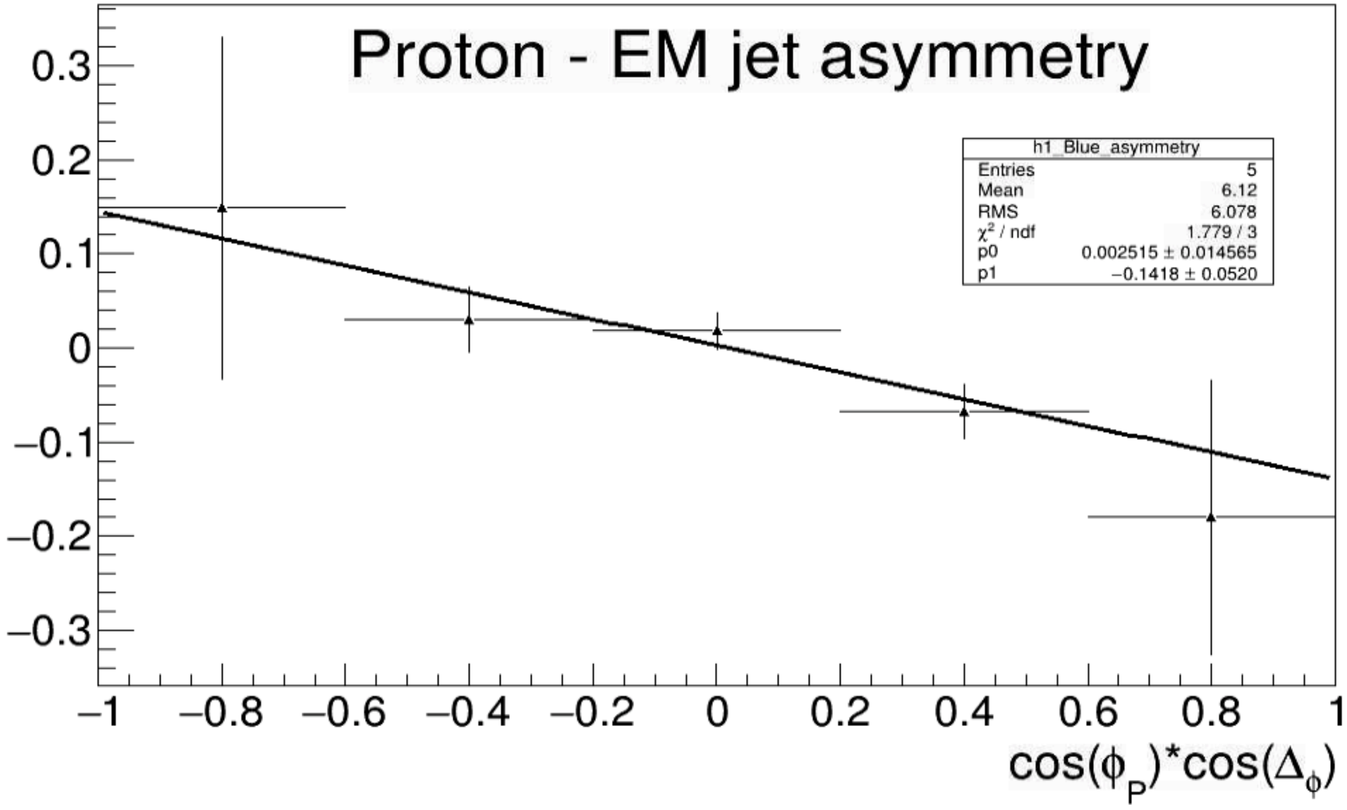
Fit function: $\frac{N^{\uparrow}-N^{\downarrow}}{P(N^{\uparrow}+N^{\downarrow})} = R + Acos(\phi_P)cos(\Delta\phi)$

- **Only 2 photon multiplicity** EM jets, where they are comparable to π^0.
- Both results for asymmetry are close.

Chris's result (-19%±5.2%)

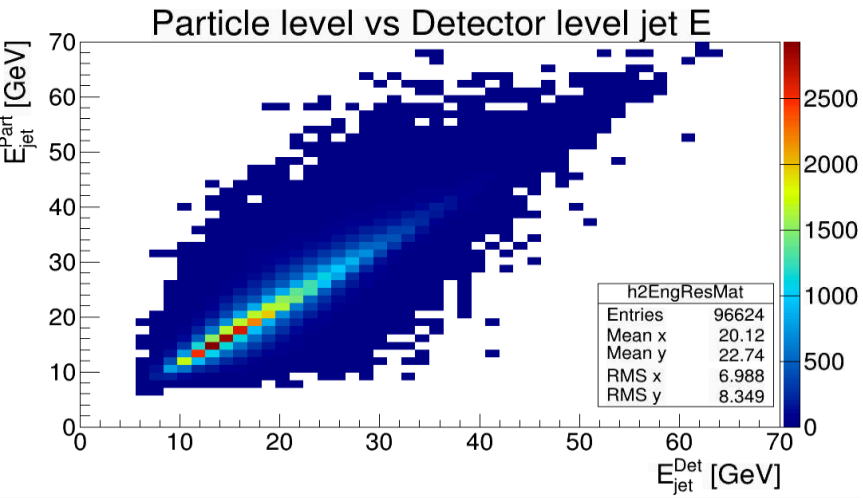


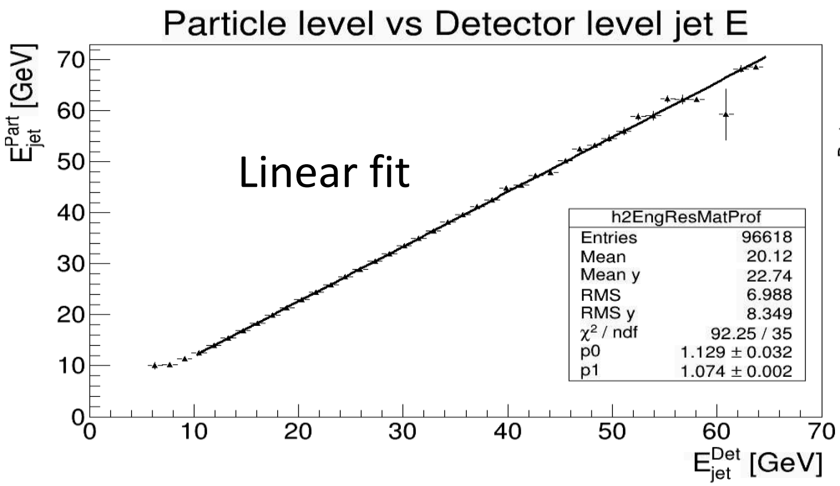
My result (-14.2%±5.2%)

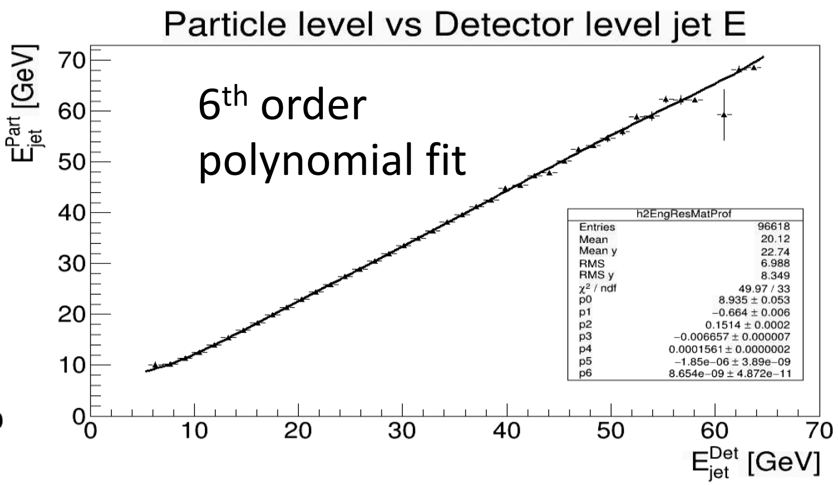


Apply energy correlation from simulation

- Detector level to particle level EM jet energy correlation from simulation.
  - Use 6th order polynomial to fit range [5,65] GeV, but apply [5, 10] GeV into correction.
  - Use linear fit for range [10, 65] GeV, but apply [10, 65] GeV into correction

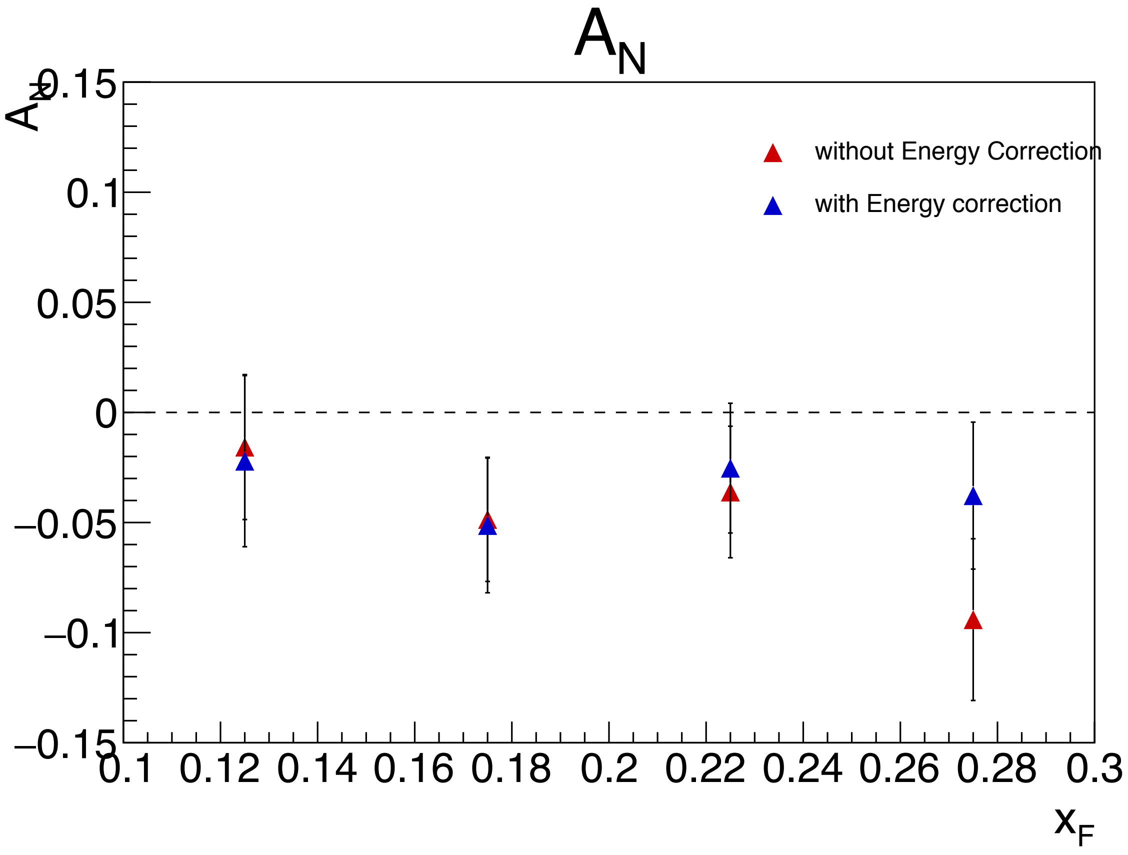






A_N with / without energy correction

- When we apply the energy correction, we can see some differences in A_N with / without the energy correction.
- Compare with / without the energy correction.



EM jet energy uncertainty

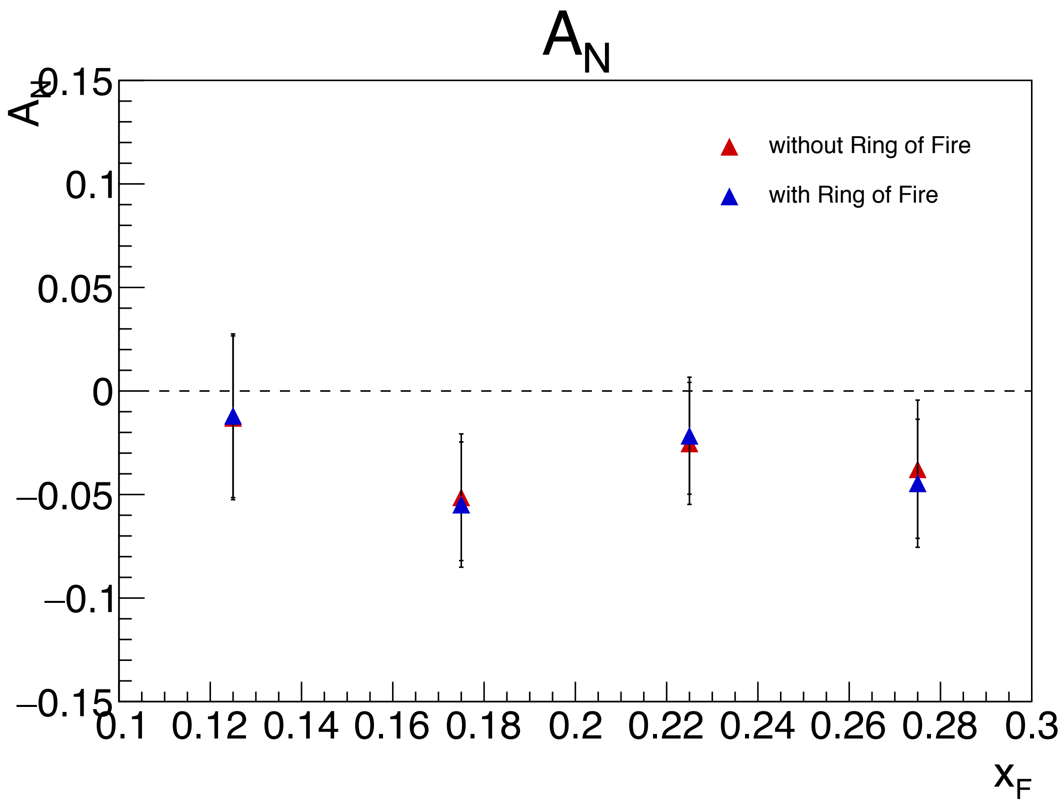
- $\sigma_E = C \oplus R \oplus E$
  - C: Calibration uncertainty (2.5%)[1]
  - R: Radiation damage and non-linear response uncertainty (0.5%)[1]
  - E: Energy resolution and correction uncertainty (separate by different x_F bins)

Energy correction x_F range	Energy correction uncertainty A_N result Difference
0.1- 0.15	21.53%
0.15 - 0.2	5.34%
0.2- 0.25	42.84%
0.25 - 0.3	149.10%

[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

Systematic uncertainty (Ring of fire)

- Ring of fire
  - Trigger: fms-sm-bs3
- Compare by with and without such trigger.



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]
- $\sigma_{set}(fill\ to\ fill) = \sqrt{1 - \frac{M}{N}\frac{\sum_{fill} L_{fill}\sigma(P_{fill})}{\sum_{fill} L_{fill}}} = 1.77\%$
    - $\sigma(P_{fill}) = \sigma(P_0) \oplus \sigma(\frac{dP}{dt})(\frac{\sum_{run} t_{run} L_{run}}{L_{fill}} - t_0) \oplus \frac{\sigma(fill\ to\ fill)}{P} P_{fill}$ [2]

Close to 0

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

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

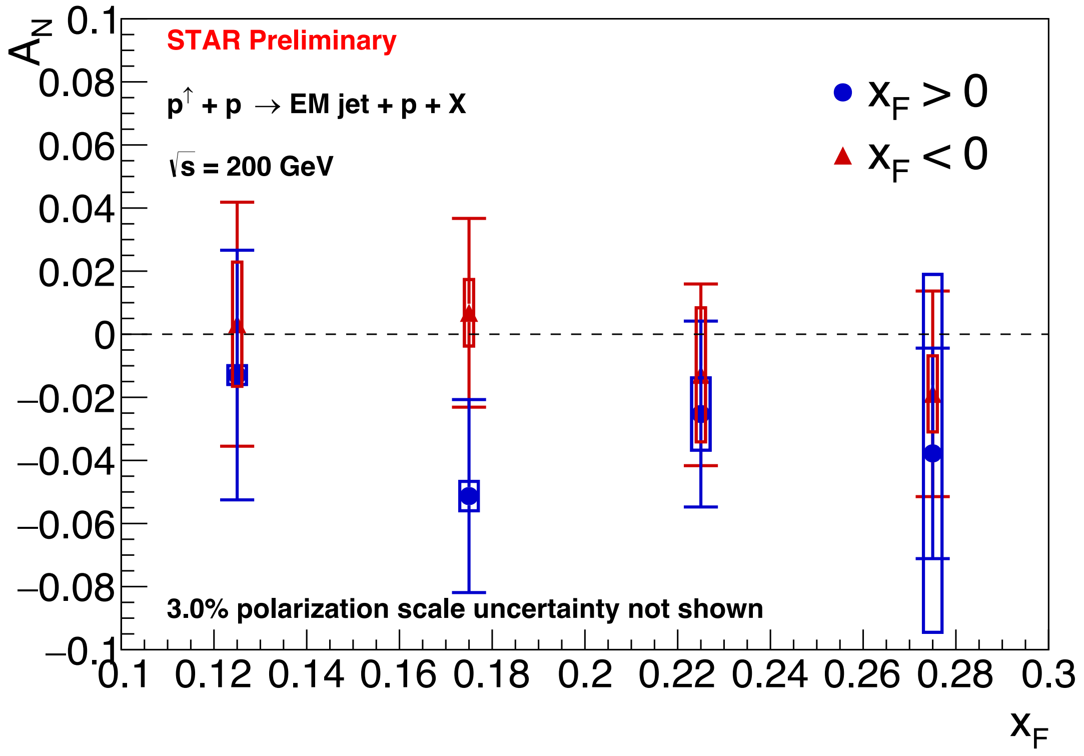
Summary for systematic uncertainty

- From the table, we can see that the EM jet energy correction have relatively large uncertainty. This may possibly due to very low statistics for some x_F range bins.
- The underlying events correction is not considered.
- Polarization uncertainty seems reasonable.

Types of uncertainty x_F ranges	Ring of fire	FMS EM jets energy uncertainty	Summary
x_F:[0.1, 0.15]	7.63%	21.68%	22.98%
x_F:[0.15, 0.2]	6.90%	5.91%	9.09%
x_F:[0.2, 0.25]	14.65%	42.91%	45.34%
x_F:[0.25, 0.3]	17.94%	149.12%	150.20%

Preliminary request plot

- Diffractive EM jet A_N
- Statistics error and systematic error uncertainty are included for polarized and unpolarized beam A_N.
- Polarized beam A_N is relatively large, but with negative value. Unpolarized beam A_N is close to 0.



Back up

Abstract (for DIS 2022)

- There have been numerous attempts, both theoretical and experimental, to understand the origin of the unexpectedly large transverse single spin asymmetry (A_N) for the inclusive hadron production at forward rapidities observed in $p^{\uparrow}$ + p collisions at various center-of-mass energies. The twist-3 contributions in the collinear factorization framework and the transverse-momentum-dependent contributions from the initial-state quark and gluon Sivers functions and/or final-state Collins fragmentation functions are potential explanations to this puzzle. 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.
- The STAR Forward Meson Spectrometer (FMS) can detect photons, neutral pions, and eta mesons in the forward direction, with pseudo-rapidity coverages of 2.6 < eta < 4.2. In this talk, we will present the latest preliminary results and analysis updates on A_{N} for diffractive electromagnetic jets in the FMS using $p^{\uparrow}$ + p data at $\sqrt{s}$ =200 GeV collected at STAR.

Blue/Yellow beam spin obtain

- We obtain blue and yellow spin from 4-spin bits: https://drupal.star.bnl.gov/STAR/blog/oleg/spin-patterns-and-polarization-direction
- Only accept the 4 cases below:

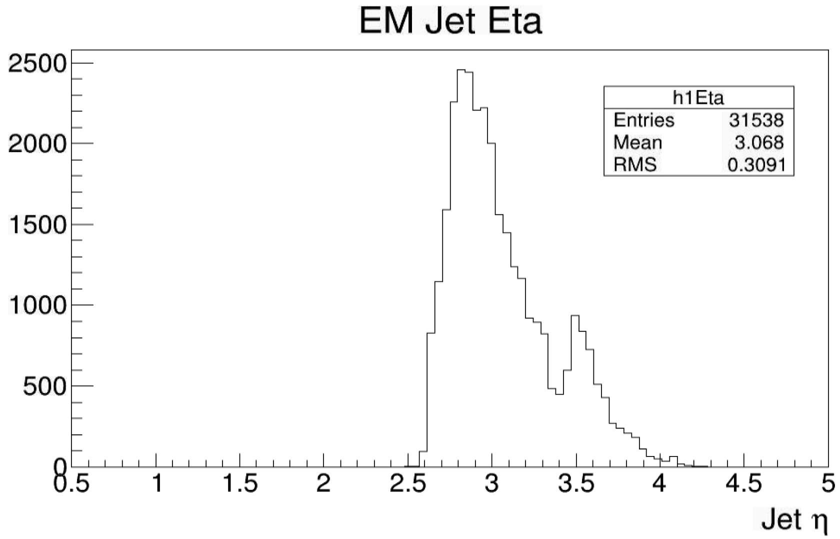
4-spin bits		Blue spin	Yellow spin
5	0101	U	U
6	0110	U	D
9	1001	D	U
10	1010	D	D

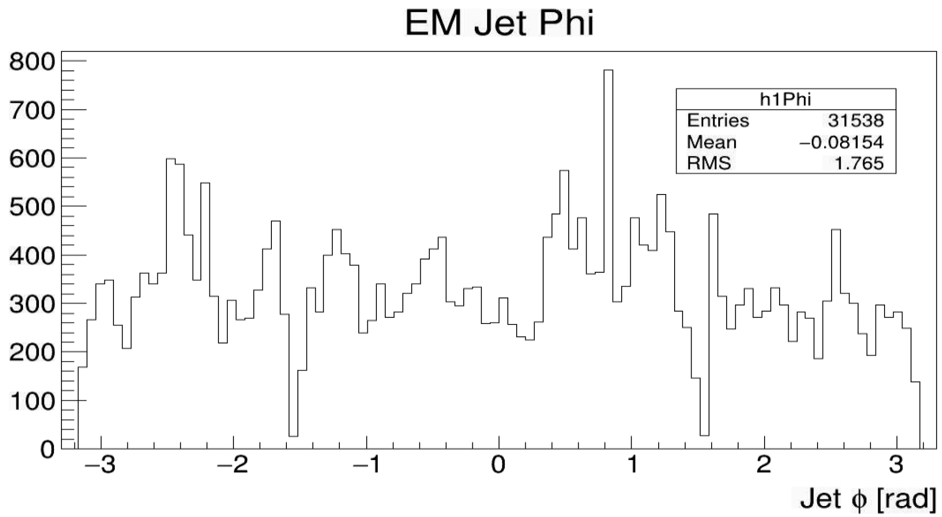
Calibration for FMS

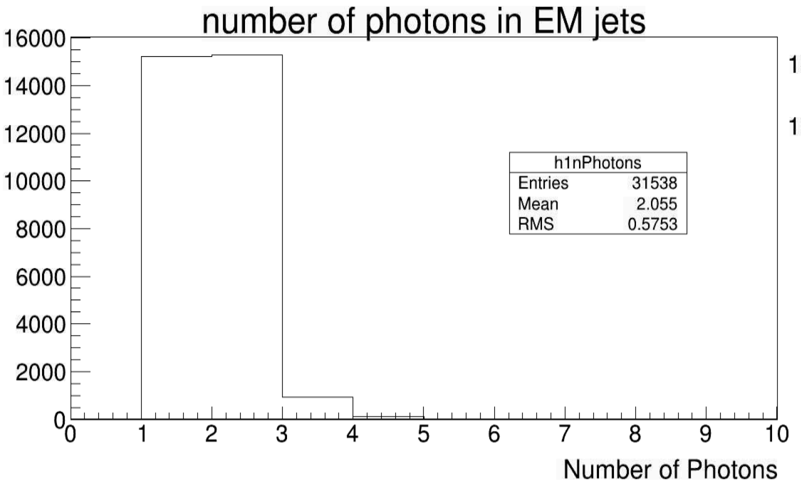
- FMS calibration mostly based on Chong's calibration for run 15 FMS.
  - Hot/bad channel masking before reconstruction.
  - Exclude highly bit-shifted channel
- Additional hot/cold channel masking fill by fill. (see FMS QA in 3/31/21)

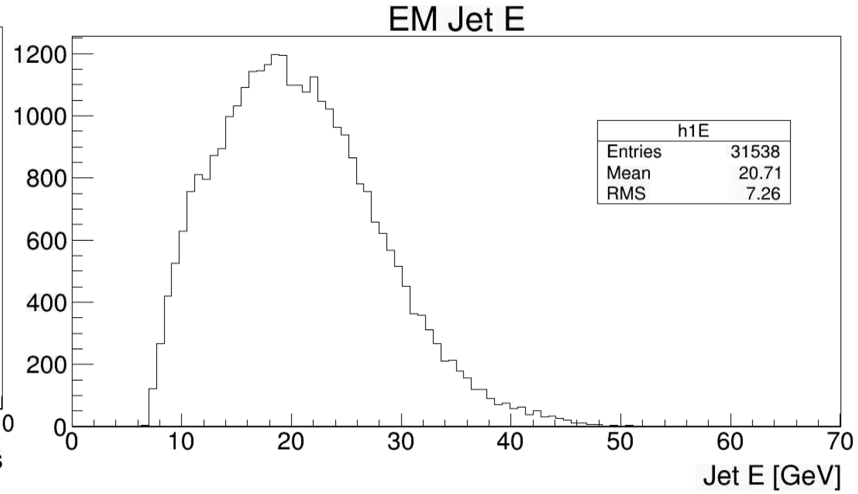
QA for EM Jet in FMS (case 2 & 3)

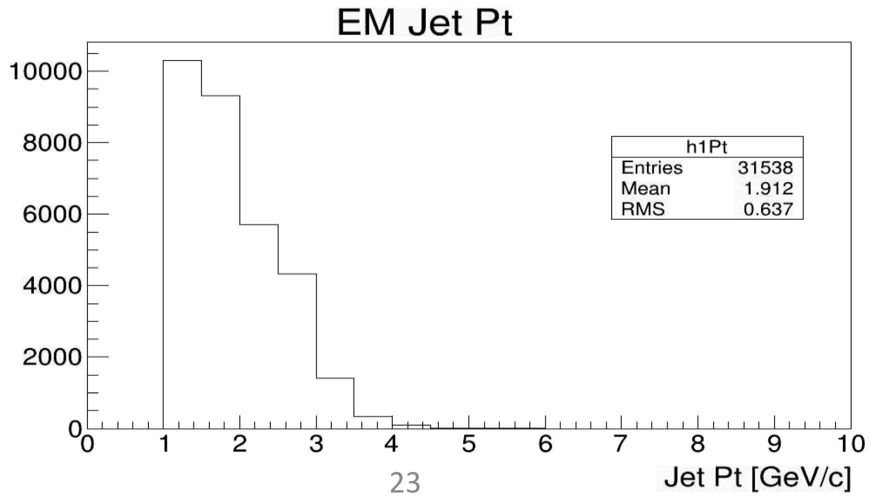
- EM jets are all the events with all cuts for case 2 and case 3.







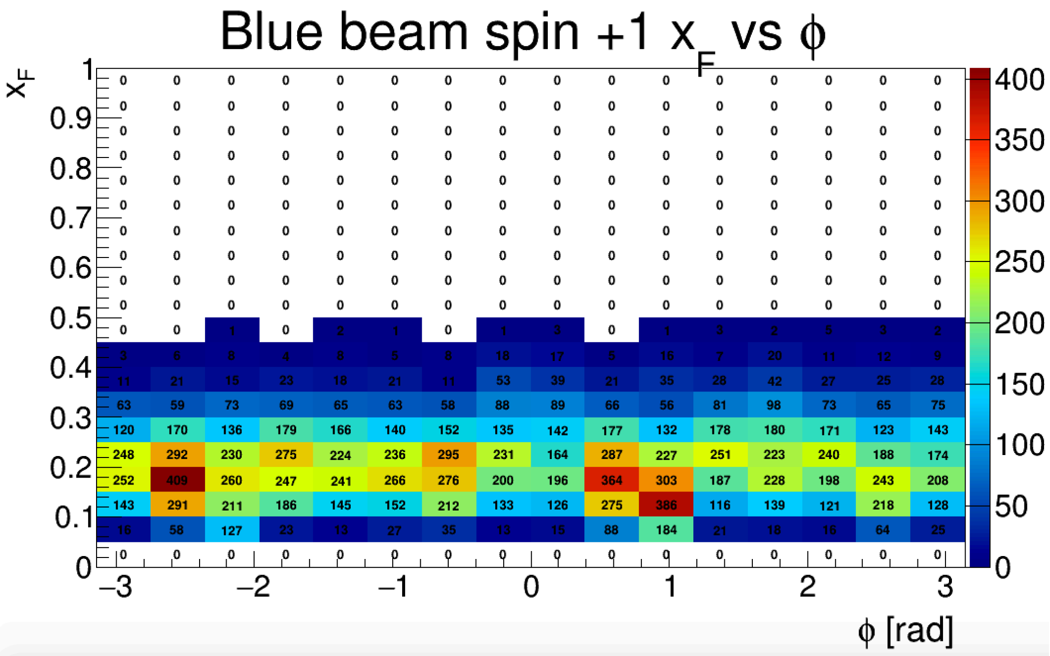




Transverse single spin asymmetry (A_N) calculation

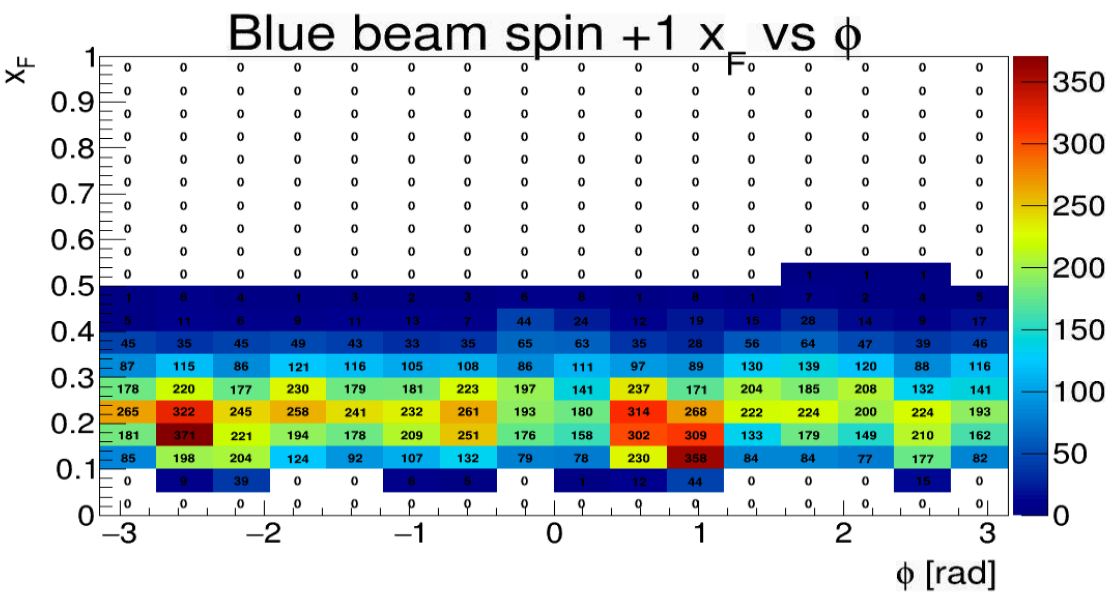
- We use cross ratio method to calculate the diffractive EM Jet A_N at FMS.
  - Raw A_N: $\varepsilon = \dfrac{\sqrt{N^{\uparrow}(\phi)N^{\downarrow}(\phi+\pi)} - \sqrt{N^{\downarrow}(\phi)N^{\uparrow}(\phi+\pi)}}{\sqrt{N^{\uparrow}(\phi)N^{\downarrow}(\phi+\pi)} + \sqrt{N^{\downarrow}(\phi)N^{\uparrow}(\phi+\pi)}} \approx pol * A_N * \cos(\phi)$
  - Plot A_N as a function of X_F. ($x_F = \dfrac{E_{EM\ jet}}{E_{Beam}}$) , 4 bins in range $x_F \in [0.1, 0.3]$
  - Divide full ϕ range [$-\pi$, $+\pi$] into 16 bins.

Without energy correction



Example EM jet yield for case 2 & 3

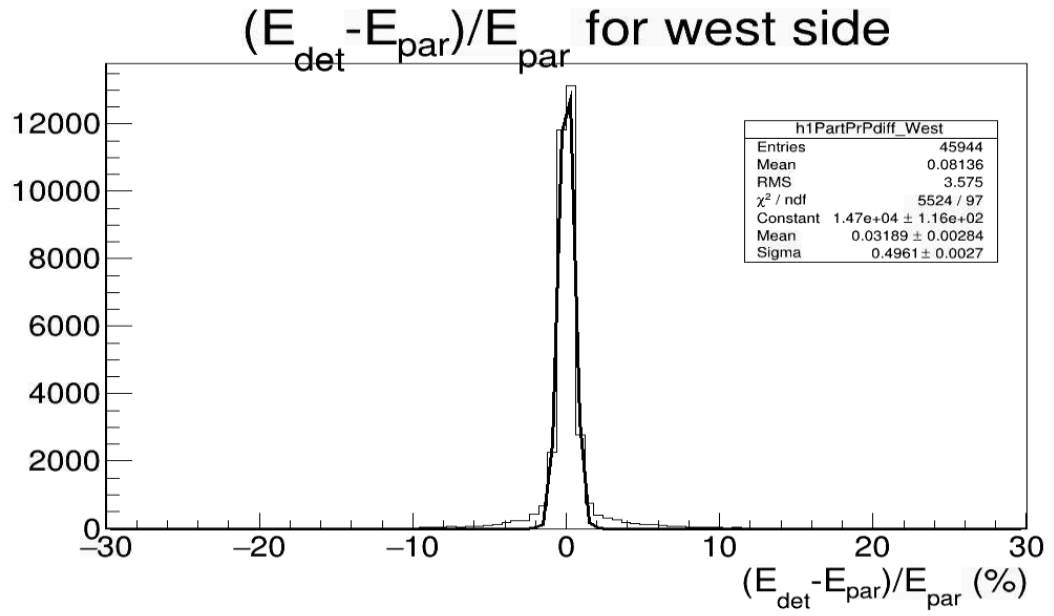
With energy correction



Systematic uncertainty

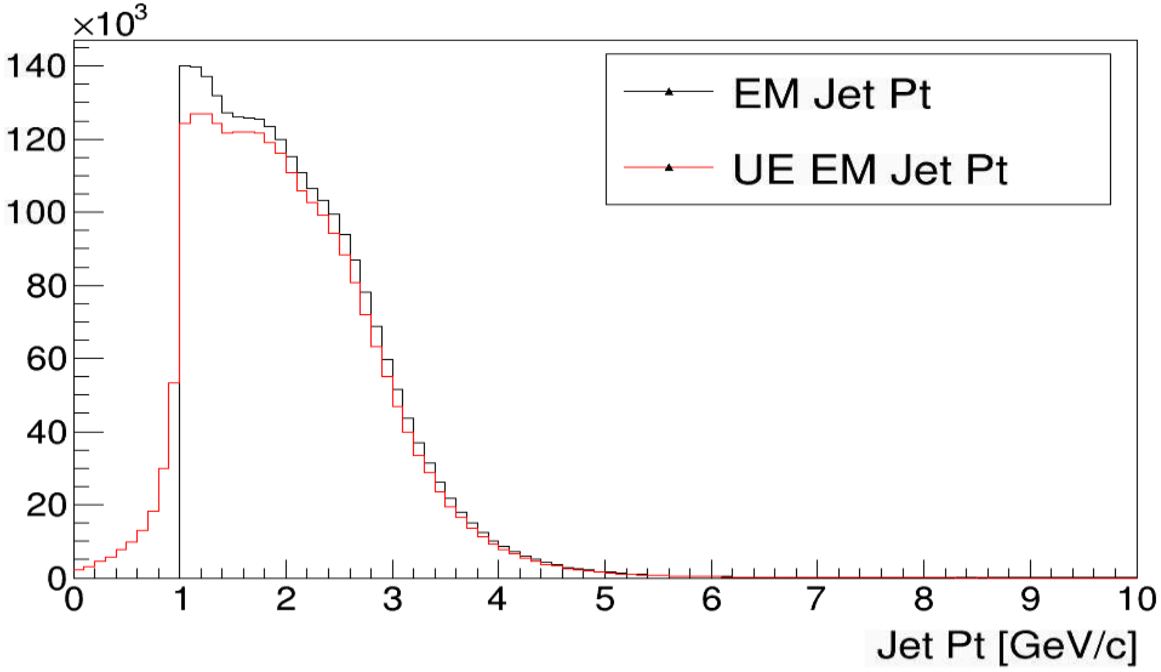
$$\frac{E_{detector} - E_{particle}}{E_{particle}} \times 100\%$$

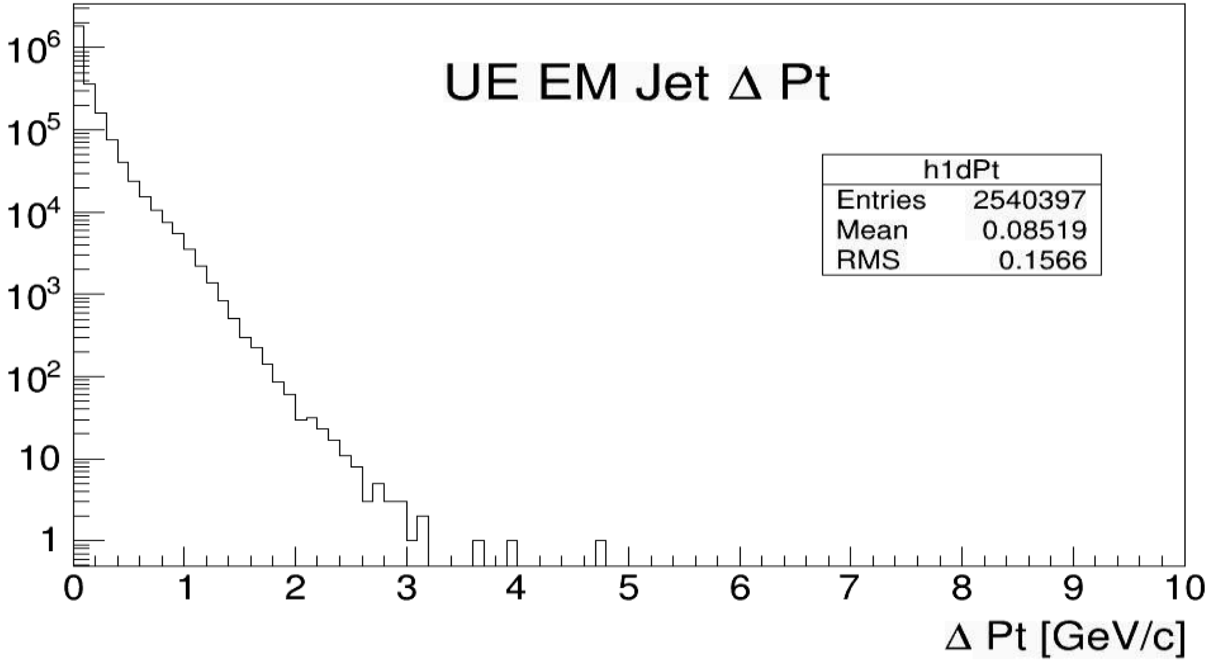
- Roman Pot track uncertainty.
- Use 8M hard QCD event (Pythia 8 + Geant 4) simulation with RP simulation. Calculate the difference between the energy of **det**ector level track energy and **par**ticle level track for only 1 west side RP track case.
- Use Gaussian fit.
  - Sigma = 0.496%



Fill 18795 with/without UE correction

- Use off-axis cone method for Underlying Event (UE) correction.
- UE EM jet P_t = EM jet P_t - ΔP_t , where ΔP_t = Underlying Event Density * Area





Systematic uncertainty table and calculation

Energy correction x_F range	With energy correction	Without energy correction
0.1- 0.15	-0.012942	-0.0157277
0.15 - 0.2	-0.05131	-0.0485722
0.2- 0.25	-0.025299	-0.0361381
0.25 - 0.3	-0.037774	-0.094093

Ring of Fire x_F range	Without Ring of fire A_N result	With ring of fire A_N result
0.1- 0.15	-0.012942	-0.0119546
0.15 - 0.2	-0.05131	-0.054852
0.2- 0.25	-0.025299	-0.0215923
0.25 - 0.3	-0.037774	-0.0445506