EM-jet A_N at Forward Rapidities in $p^{\uparrow}$+p Collisions at $\sqrt{s}$ = 200 GeV

Preliminary Request for Run 15 Results

Latif Kabir

August 11, 2021

Abstract

Title: Transverse Single-Spin Asymmetry for Electromagnetic Jets at Forward Rapidities in p$^{\uparrow}$+p Collisions at $\sqrt{s}$ = 200 GeV at STAR

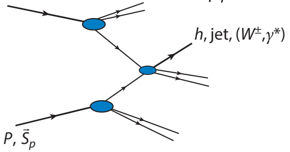
Abstract (SPIN21):
There have been various attempts, both experimentally and theoretically, to understand the origin of the unexpectedly large transverse single-spin asymmetries (A_N) for inclusive hadron production at forward rapidity in p$^{\uparrow}$+p collisions that persist from low to high center-of-mass energies. Two proposed potential sources are the twist-3 contributions in the collinear factorization and the transverse-momentum-dependent contributions from either the initial-state quark and gluon Sivers functions or the final-state Collins fragmentation function. Jet A_N is sensitive to the initial state effect and can provide access to Sivers functions. A_N for jets of different substructures can help better understand the underlying mechanism for the observed large A_N. Transversely polarized p$^{\uparrow}$+p collisions at RHIC are ideal to disentangle the initial and final state effects. The STAR Forward Meson Spectrometer (FMS) and Endcap Electromagnetic Calorimeter (EEMC), having pseudo-rapidity coverages of 2.6 - 4.2 and 1.1 - 2.0 respectively, can be used to detect photons, neutral pions, and eta mesons. We present preliminary results of A_N for electromagnetic jets in FMS and EEMC using p$^{\uparrow}$+p collisions at $\sqrt{s} =$ 200 GeV where we explore the dependences of A_N on photon multiplicity inside the jet, jet transverse momentum, and jet energy.

PAs: Latiful Kabir[1], Chong Kim, Ken Barish[2], Mriganka M Mondal
[1] Latiful.Kabir@ucr.edu
[2] Kenneth.Barish@ucr.edu (Supervisor)

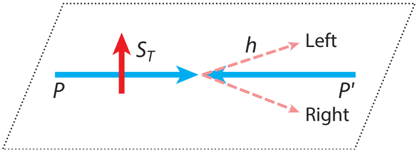
Transverse Single-Spin Asymmetry (A_N)

- Unexpected large transverse single-spin asymmetries (A_N) are observed in proton-proton collisions
- pQCD predicts $A_N \sim \frac{m_q}{p_T} \cdot \alpha_S \sim 0.001$

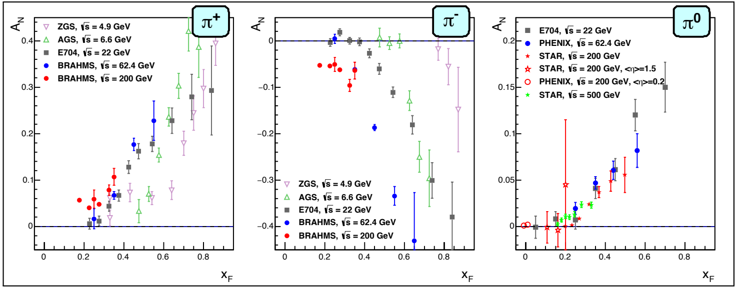
Kane, Pumplin and Repko
PRL 41 1689 (1978)



A_N in $p(S_T) + p \to h + X$



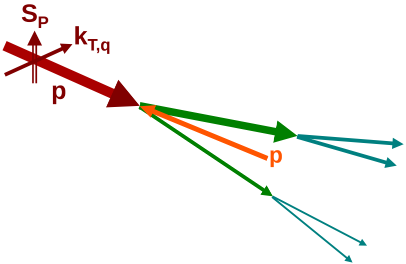
$$A_N = \frac{d\sigma_L - d\sigma_R}{d\sigma_L + d\sigma_R}$$



R. D. Klem *et al.*, PRL **36**, 929 (1976)
D.L. Adams *et al.*, PLB **264**, 462 - 466(1991)
I. Arsene *et al.*, PRL **101**, 042001 (2008)
D.L. Adams *et al.*, PLB **261**, 201(1991)
B. I. Abelev *et al.*, PRL **101**, 222001(2008)
A. Adare *et al.*, PRD **90**, 012006 (2014)
E.C. Aschenauer *et al.*, arXiv:1602.03922

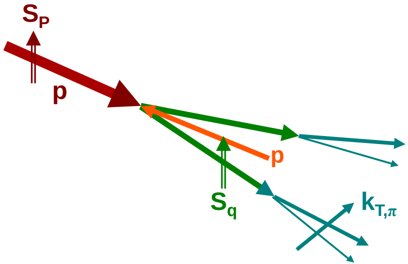
Possible Mechanisms

Sivers Mechanism:
Correlation between proton spin and parton k_T



D. Sivers, Phys Rev D **41** (1990) 83; **43** (1991) 261

Collins Mechanism:
Transversity (quark polarization) $\otimes$ jet fragmentation asymmetry



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

Signatures: A_N for jets or direct photons, $W^{+/-}$, Z^0, Drell-Yan

Signatures: Collins effect, Interference fragmentation function (IFF), pion A_N

Twist-3:
Quark-gluon / gluon-gluon correlations and fragmentation functions. A source for Sivers function.

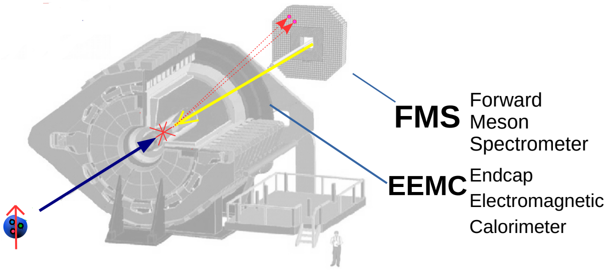
J.W. Qiu and G. Sterman, Phys Rev Lett **67** 2264 (1991)

EM-Jet A_N with FMS and EEMC at STAR

- **Motivation:**
  - Explore potential sources of large A_N
  - Isolate subprocess contribution (EM-jet A_N) to the large A_N
  - Characterize EM-jet A_N as a function of EM-jet p_T, energy and photon multiplicity
- **Advantages of EM-jet:**
  - Allows to investigate EM component of a full jet
  - Enables us to classify EM-jet in terms of its constituent photon multiplicity
- **Dataset:**
  - RHIC Run 15 data
  - $p^{\uparrow}p$ collisions at $\sqrt{s} = 200$ GeV
  - Transversely polarized protons with <P> = 57%
  - $\mathcal{L} = 52\ \mathrm{pb}^{-1}$

$$p^{\uparrow} + p \rightarrow \text{EM-jet} + X$$

EM-jet $\rightarrow$ Jet reconstructed out of photons only



Details of Dataset

- **Goal:** Extract A_N as a function of EM-jet p_T, energy and photon multiplicity for the reaction $p^{\uparrow} + p \rightarrow$ EM-jet + X using FMS and EEMC.
- **Dataset:**
  - Run 15(200 GeV pp trans)
  - Production tag: P15ik (FMS stream) and P16id (Physics stream)
  - Full Run List: Can be found in the files here (FMS) and here (EEMC)
  - Fill Numbers: Can be found in the files here (FMS) and here (EEMC)
  - Fill-by-fill FMS hot/bad channel list: Can be found in the file here
- **Data-stream:**
  -FMS-stream (For FMS EM-jet)
  - Physics-stream (For EEMC EM-jet)
- **Triggers:**
  - Small BS, Large BS and FMS-JP Triggers (For FMS EM-jet)
  - EHT0, JP and MB triggers (For EEMC EM-jet)
  - Veto on LED and abort gap
- **STAR library:** SL20a
- **Source code for this analysis:** github.com/latifkabir/BrightSTAR (Relevant directory is *emJetAnalysis*)

Analysis Details and List of Cuts

	Status / Value
1. Trigger:	
1.1. FMS Data	FMS BS and JP
1.2. EEMC Data	EHT0, JP and MB
2. Jet Reconstruction:	
2.1. FMS hot channel masking before reconstruction	Yes
2.2. Exclude highly bit-shifted channel	Yes
2.3. Fill-by-fill hot/bad channel masking	Yes
2.4(a). FMS Calibration	UCR (Chong)
2.4(b). FMS points as input for Anti-k_T	Yes
2.4(c). FMS Point: Try 1 photon fit (default is yes)	Yes
2.4(d). FMS point: Scale shower shape to 0.8 for large and 0.6 for small cells (default)	Yes
2.4(e). FMS point: Merge Small to large (default)	Yes
2.4(f). FMS point: Choose cluster categorization algorithm (default)	Yes
2.5. R for Anti-k_T	0.7
2.6. Photon energy cut	E_γ > 1.0 GeV
2.7. Jet p_T	Jet p_T > 2.0 GeV/c
2.8. Vertex z priority according to TPC, VPD, BBC	Yes
2.9. BBC slewing correction	Yes
2.10. Jet Finder Class	`StJetMaker2015`

Analysis Details and List of Cuts

	Status / Value
3. Event Selection Cuts:	
3.1(a). Veto on LED	Yes
3.1(b). Veto on abort gap	Yes
3.2(a). Eta (η) range covered (FMS)	2.8 - 3.8
3.2(b). Eta (η) range covered (EEMC)	1.0 - 2.0
3.3. Vertex z cut	-80 cm < V_z < 80 cm
3.4. Trigger dependept p_T cut	Yes
3.5. Exclude bad spin status	Yes
3.6. Ring of fire cut: BBC and TOF	No
3.7. Ring of fire cut: Exclude Sm-bs3 trigger	Yes
3.8. Exclude fills with wrong spin pattern	Yes
3.9. Exclude events with x_F > 1 or E_{jet} > 100 GeV	Yes

	Status / Value
4. Corrections:	
4.1. Photon energy correction	No
4.2. Jet energy correction	Yes
4.3. Jet Pt correction	Yes
4.4. Underlying event correction	Yes
4.5. Time dependent correction	No
5. A_N Extraction:	
5.1. Extraction method	Cross-Ratio Formula
5.2. Phi binning	16

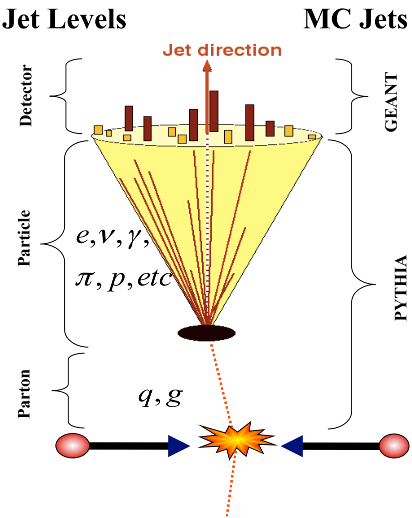
Trigger Dependent p_T Cut

Trigger	Id	E_T (GeV)	15% Higher
FMS-sm-bs1	480801	1.1	
FMS-sm-bs1	480821 / 480841	1.0	
FMS-sm-bs2	480802 / 480822	1.6	
FMS-sm-bs3	480803	2.2	
FMS-sm-bs3	480823 / 480843	1.9	
FMS-lg-bs1	480804	1.1	
FMS-lg-bs1	480824 / 480844	1.0	
FMS-lg-bs2	480805 / 480825	1.6	
FMS-lg-bs3	480806 / 480826	2.4	
FMS-JP0		1.6	
FMS-JP1		2.4	
FMS-JP2		3.2	

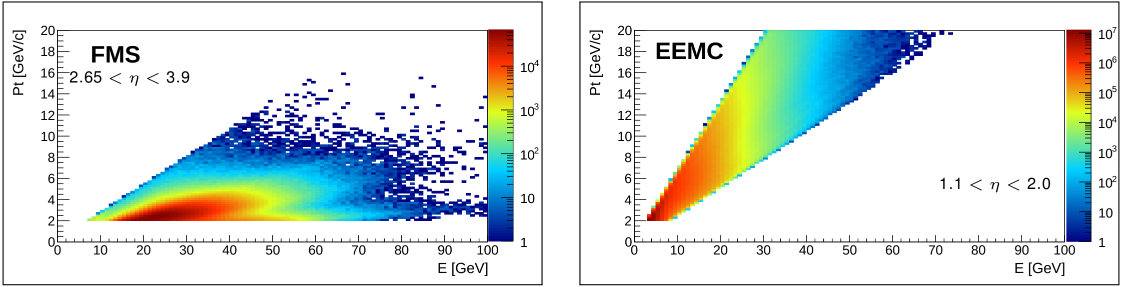
- For EEMC,
  -Trigger thresholds for EH0, JP1, JP2 are taken 4.25, 5.41, 7.28 GeV respectively.

Jet Reconstruction

- FMS hot channel masking before reconstruction.
- Fill-by-fill FMS hot/bad channel list
- Exclude highly bit-shifted FMS channels
- Vertex z priority: TPC, VPD, BBC
- Updated *StJetMaker* for FMS. Tuned for EM-jet analysis.
- FMS points as input for Anti-k_T
- EEMC towers as input for EEMC EM-jet
- Anti-k_T with R = 0.7
- $E_\gamma > 1.0$ GeV (For FMS EM-Jet)
- E_T (tower) > 0.2 GeV (For EEMC EM-jet)
- Jet p_T > 2.0 GeV/c
- -80 cm $< V_z <$ 80 cm



EM-Jet A_N Extraction



Binning:

- Energy bins: 0 - 20 GeV, 20 - 40 GeV, 40 - 60 GeV and 60 - 80 GeV
- p_T bins: 0 - 5 GeV/c with 0.5 GeV/c increment, 5.0 - 6.0, 6.0 - 8.0 GeV/c
- 16 equal ϕ bins in the range $-\pi$ to π
- Up to 5 photon multiplicity bins
- Done separately for $x_F > 0$ and $x_F < 0$

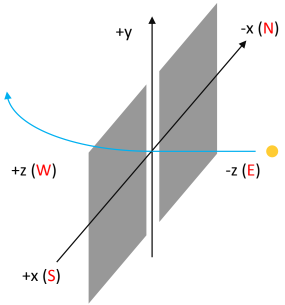
EM-Jet A_N Extraction

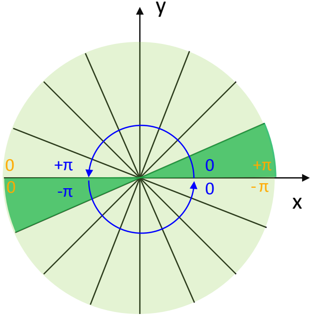
- Cross-ratio formula to calculate A_N

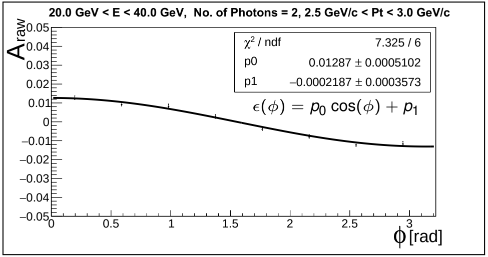
$$\epsilon = PA_N \cos(\phi)$$

$$\epsilon \approx \frac{\sqrt{N_{\phi}^{\uparrow} N_{\phi+\pi}^{\downarrow}} - \sqrt{N_{\phi+\pi}^{\uparrow} N_{\phi}^{\downarrow}}}{\sqrt{N_{\phi}^{\uparrow} N_{\phi+\pi}^{\downarrow}} + \sqrt{N_{\phi+\pi}^{\uparrow} N_{\phi}^{\downarrow}}}$$

- **Advantages:** Cancels systematics, such as luminosity and detector effects







EM-Jet A_N Extraction

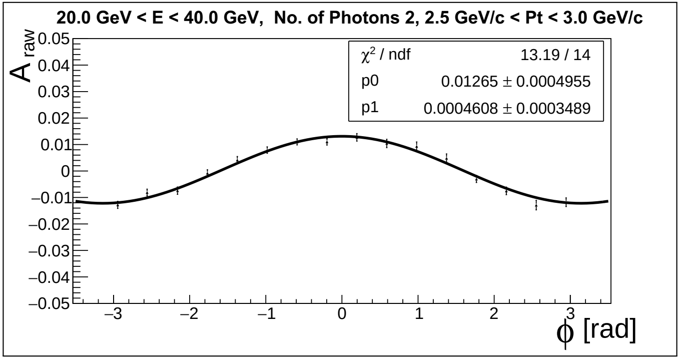
$$N^{\uparrow} = I_0^{\uparrow}\epsilon(1 + PA_N \cos\phi)$$
$$N^{\downarrow} = I_0^{\downarrow}\epsilon(1 - PA_N \cos\phi)$$

$$A(\phi) = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

$$A(\phi) \approx PA_N \cos\phi + \frac{I_0^{\uparrow} - I_0^{\downarrow}}{I_0^{\uparrow} + I_0^{\downarrow}}$$

$$A(\phi) = PA_N\cos(\phi) + p_1$$

$$A(\phi) + A(\phi + \pi) \approx 2\frac{I_0^{\uparrow} - I_0^{\downarrow}}{I_0^{\uparrow} + I_0^{\downarrow}}$$



- Allows extraction of both physics asymmetry and beam asymmetry
- Used to cross check the other extraction method

EM-jet A_N Corrections and Systematic Uncertainties

A_N Corrections and Uncertainties:

- Event Misidentification:
  - Misidentification of 1, 2 etc photons as other types (2, 1, etc)
- Background Uncertainty
  - Pile-up, Abort gap, Ring of fire
  - Underlying events
- Polarization Error

Energy or p_T Corrections and Uncertainties:

- Calibration uncertainty
- Energy or p_T correction
- Uncertainty due to radiation damage

Remaining work on systematic uncertainties to be used for final results

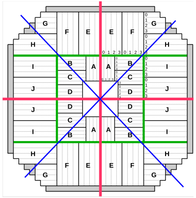
- Current systematics for A_N is likely over estimated as it is based on a simulation that is not perfect. Final results aim to address this.

- For Details of the corrections and systematic uncertainties, see the pwg presentation here

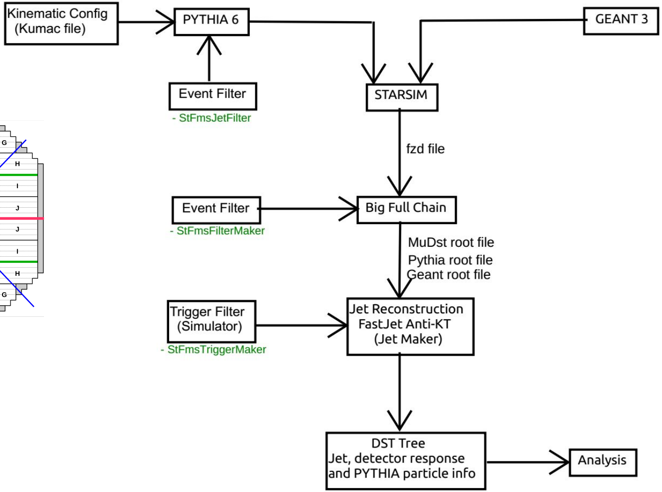
FMS EM-Jet Simulation: Configuration

- **Library version:** SL20a
- **Geometry:** y2015
- **Chain option:** "ry2015a agml usexgeom MakeEvent McEvent vfmce Idst BAna l0 l3 Tree logger fmsSim fmspoint evout -dstout IdTruth bigbig fzin geantout clearmem sdt20150417.193427"
- **Beam Energy:** 200 GeV
- **PYTHIA Tune:** Tune Perugia6 (Tune param 370): Perugia with CTEQ6 structure functions.
- **FMS Gain and Gain Correction:** Same as data.
- **Event Filter:** PYTHIA and BFC level filtering (*StFmsFilterMaker*).
- **Trigger Simulation:** FMS Trigger Simulator (*StFmsTriggerMaker*).
- **Bad/Hot channels:** Same as data.

FMS EM-Jet Simulation: Workflow



E_Q^{thr} = Energy sum (per quadrant)



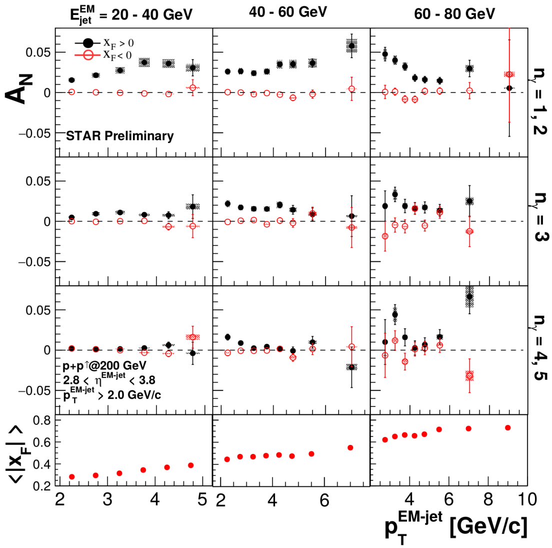
(SL20a)

- For Details about the outcome of simulation studies, see the pwg meeting presentation here

Preliminary Request for Run 15 Results

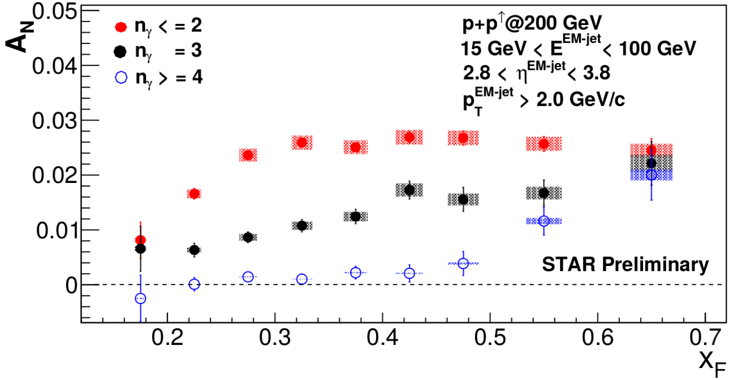
Run 15 FMS EM-jet A_N Results

- Small BS, Large BS and FMS-JP Triggers
- Anti-k$_T$ with R = 0.7
- $E_\gamma > 1.0$ GeV
- Jet p_T > 2.0 GeV/c
- 2.8 < η^{EM-jet} < 3.8
- Statistical and systematic error bars
- 3.46% polarization scale uncertainty not shown



Run 15 FMS EM-jet A_N Results

- Small BS, Large BS and FMS-JP Triggers
- Anti-k$_T$ with R = 0.7
- $E_\gamma > 1.0$ GeV
- Jet p_T > 2.0 GeV/c
- 2.8 < η^{EM-jet} < 3.8
- Statistical and systematic error bars
- 3.46% polarization scale uncertainty not shown



Run 15 EEMC EM-jet A_N Results

- EHT0, JP and MB triggers
- Anti-k$_T$ with R = 0.7
- Photon multiplicity based on EEMC tower counts
- Tower $E_T > 0.2$ GeV
- Jet p_T > 2.0 GeV/c
- 1.0 < η^{EM-jet} < 2.0
- Statistical and systematic error bars
- 3.46% polarization scale uncertainty not shown