Paper Preview

Multi-dimensional study of transverse single-spin asymmetries for electromagnetic jets at forward rapidities in polarized pp collisions at $\sqrt{s}$ = 200 GeV

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(For the PAs)

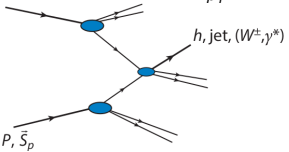
June 21, 2024

Paper Proposal

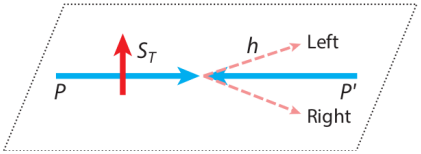
- Title: Multi-dimensional study of transverse single-spin asymmetries for electromagnetic jets at forward rapidities in polarized pp collisions at $\sqrt{s}$ = 200 GeV
- PAs: Ken Barish, Christopher Dilks, Carl Gagliardi, Latif Kabir, David Kapukchyan, Xilin Liang and Mriganka Mouli Mondal
- Target Journal: Physical Review D
- Drupal page for the paper: Link
- Abstract: The STAR Collaboration reports measurements of the transverse single-spin asymmetries, A_N, for electromagnetic jets (EM-jets) in pp collisions at $\sqrt{s}$ = 200 GeV as three-dimensional functions of the EM-jet Feynman-x (x_F), transverse momentum (p_T), and photon multiplicity. Results are presented for two different EM-jet pseudorapidity regions, $1.0 < \eta < 2.0$ and $2.8 < \eta < 3.8$. A_N is found to be strong functions of EM-jet x_F and photon multiplicity, and a weaker function of EM-jet p_T. These results can help to elucidate the dynamics underlying the large transverse single-spin asymmetries that have been observed for inclusive hadron production at forward rapidities.

Transverse Single-Spin Asymmetry (A_N)

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

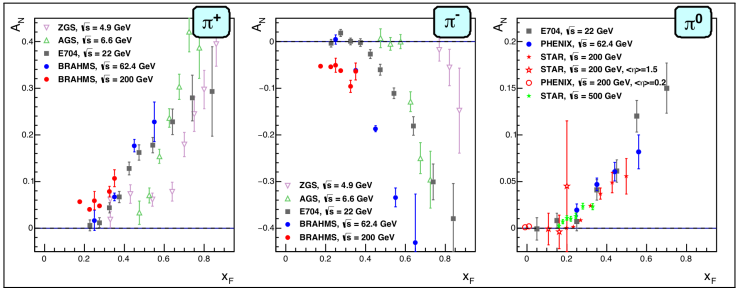


A_N in $p(S_T) + p \to h + X$



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

Kane, Pumplin and Repko
PRL 41 1689 (1978)

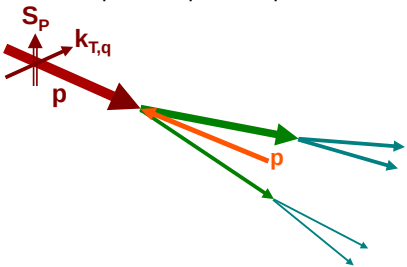


R. D. Klem *et al.*, PRL **36**, 929 (1976)
D.L. Adams *et al.*, PLB **264**, 462 - 466(1991)
I. Arsene *et al.*, PRL **101**, 042001 (2008)

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

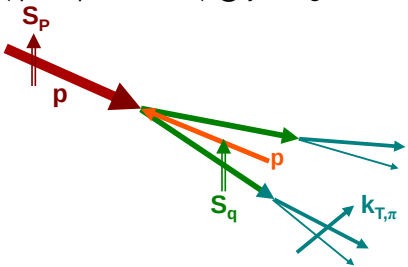
Sivers Mechanism:
Correlation between proton spin and parton k_T



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

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

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



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

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.

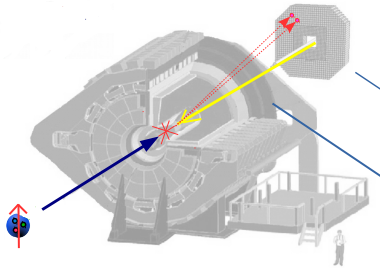
J.W. Qiu and G. Sterman, Phys Rev Lett **67** 2264 (1991)

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, x_F and 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 pb^{-1}
- **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)

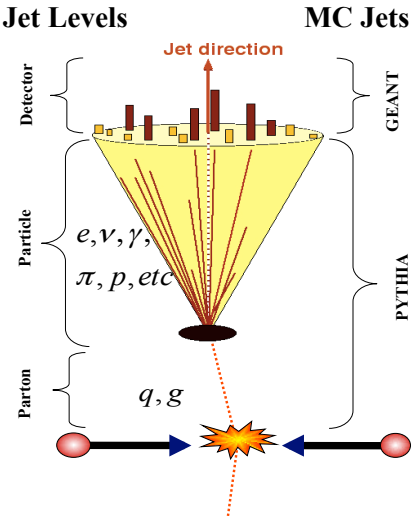
$$p^{\uparrow} + p \rightarrow \text{EM-jet} + X$$

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

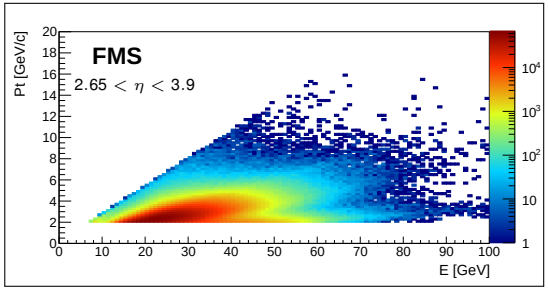


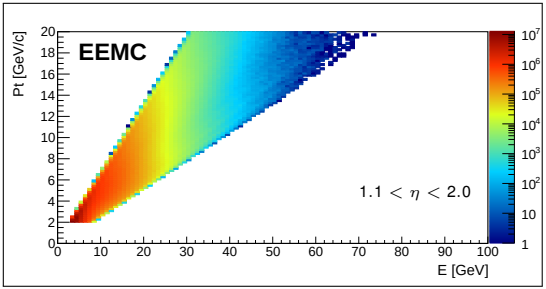
Jet Reconstruction

- 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 $x_F < 0$

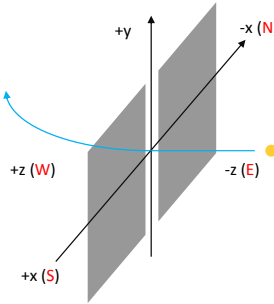
EM-Jet A_N Extraction

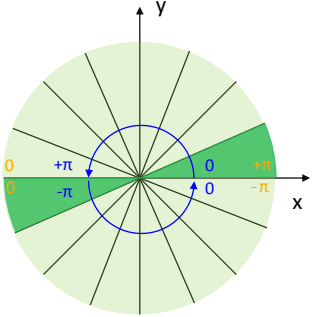
- Cross-ratio formula to calculate A_N

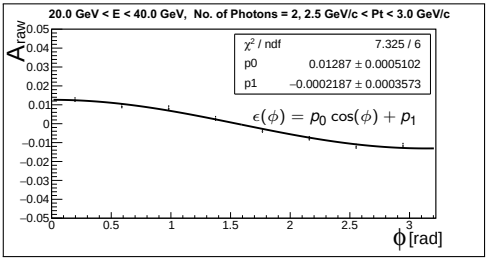
$$\epsilon = P A_N \cos(\phi)$$

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

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







EM-Jet A_N Extraction

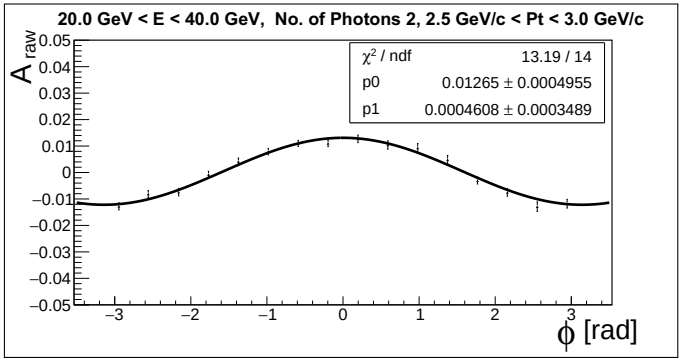
$$N^{\uparrow} = I_0^{\uparrow}\epsilon(1 + PA_N \cos\phi)$$
$$N^{\downarrow} = I_0^{\downarrow}\epsilon(1 - PA_N \cos\phi)$$

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

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

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

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



- 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

Leading systematic uncertainty contributions

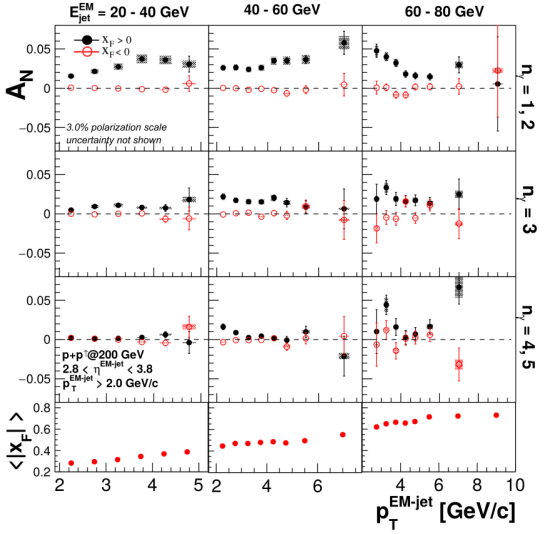
- Event Misidentification (Up to 20%)
- Calibration uncertainty (3%)
- All others (< 1%)

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

Paper Plots

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
- $2.8 < \eta^{EM-jet} < 3.8$
- Statistical and systematic error bars
- 3.0% polarization scale uncertainty not shown
  - EM-jet A_N decreases with increasing photon multiplicity (jettiness)
  - A_N is the strongest for EM-jets consisting of 1 or 2 photons
  - A_N is significantly smaller for EM-jets with 4 or 5 photons
  - A_N at $x_F < 0$ is consistent with 0



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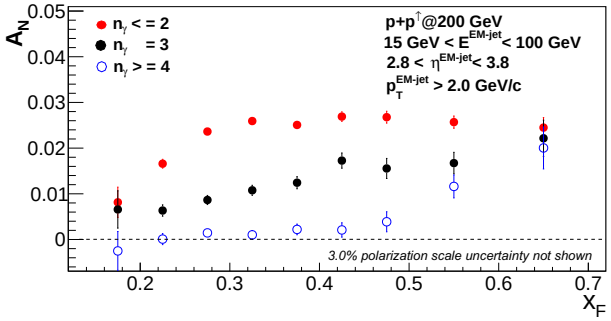
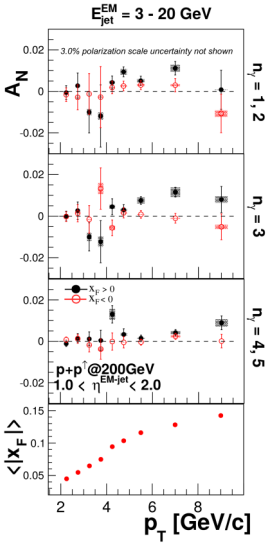


- EM-jet A_N is the strongest for EM-jets consisting of 1 or 2 photons
- EM-jets with 3 photons has a non-zero A_N but lower than that of 1-photon or 2-photon EM-jets
- EM-jets with higher photon multiplicities have significantly smaller asymmetries
- A_N increases with increasing x_F

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
- $1.0 < \eta^{EM-jet} < 2.0$
- Statistical and systematic error bars
- 3.0% polarization scale uncertainty not shown



- A_N is significantly smaller for EM-jets in the intermediate rapidity, probing much lower x_F range, compared to forward rapidity
- The trend of EM-jet A_N decreasing with increasing photon multiplicity (jettiness) seems to hold
- A_N is zero at low p_T and positive at higher p_T for $x_F > 0$
- A_N at $x_F < 0$ is consistent with 0

Status and Plans

- **Status of the analysis:**
  - Inclusive EM-jet A_N: The analysis is completed. Paper proposal now.
  - Diffractive EM-jet A_N: Single diffractive process is at the preliminary level, and will be finalized soon; semi-exclusive process will be finalized in April
  - Paper draft and analysis note are in progress
  - PAs are regularly meeting for the last several months
- **Plan for the paper:**
  - We plan to have two papers for the inclusive and diffractive EM-jet A_N
  - 1. 1st paper: PRD paper will focus on inclusive EM-jet A_N, and it will plan to release earlier than the other one
  - 2. 2nd paper (TBD): will focus on diffractive EM-jet A_N. The FMS and EM-jet part will cite the first paper.
  - We will do the paper proposal separately for the two papers.

Previous Presentations on This Analysis

- PWG Meeting on June 3, 2020: FMS Hot Channels and Data QA
- PWG Meeting on October 14, 2020: FMS Jet Simulation
- PWG meeting on October 21, 2020: Trigger Dependent Cut
- PWG meeting on November 18, 2020: Fit Quality, Ring of Fire
- PWG meeting on February 17, 2021: EEMC Jet
- PWG meeting on February 24, 2021: EEMC Jet
- PWG meeting on June 2nd, 2021: Corrections and Systematics
- PWG meeting on August 11, 2021: Early Results
- Comparing with Zhanwen's results
- DNP 2020 Presentation
- GPH 2021 Workshop Presentation
- SPIN 2021 Workshop Presentation
- SPIN 2021 Workshop Proceeding
- DIS 2022 Workshop Proceeding

Backup Slides

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

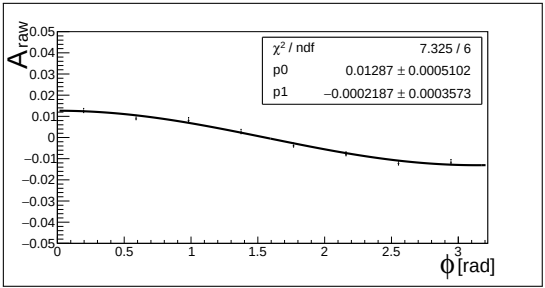
	Status / Value
4. Corrections:	
4.1. Photon energy correction	No
4.2. Jet energy correction	Yes
4.3. Jet Pt correction	Yes
4.4. Underlying event correction	Yes
4.5. Time dependent correction	No
5. A_N Extraction:	
5.1. Extraction method	Cross-Ratio Formula
5.2. Phi binning	16

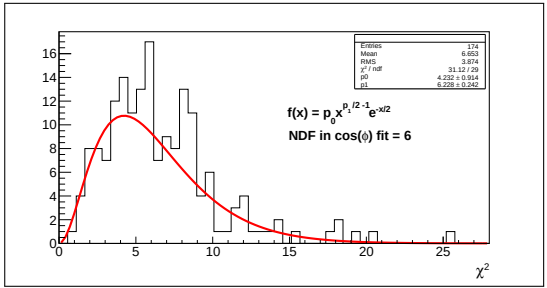
Trigger Dependent p_T Cut

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.

Fit Quality


A_{raw}
χ^2 / ndf 7.325 / 6
p0 0.01287 ± 0.0005102
p1 −0.0002187 ± 0.0003573
ϕ [rad]


Entries 174
Mean 6.863
RMS 3.874
χ^2 / ndf 31.12 / 29
p0 4.232 ± 0.914
p1 6.228 ± 0.242
$f(x) = p_0 x^{p_1/2-1} e^{-x/2}$
NDF in cos(ϕ) fit = 6
χ^2

Details of Dataset

- **Goal:** Extract A_N as a function of EM-jet p_T, x_F 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*)