EM-Jet A_N at Forward Rapidities at STAR

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

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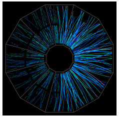

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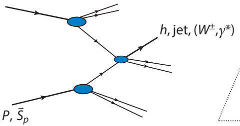
Outline

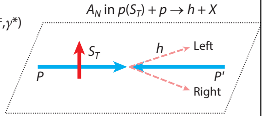
1. Transverse Single-Spin Asymmetry (A_N)
2. RHIC and The STAR Experiment
3. FMS and EEMC Detectors
4. Jet Reconstruction
5. A_N Extraction Status
6. Outlook

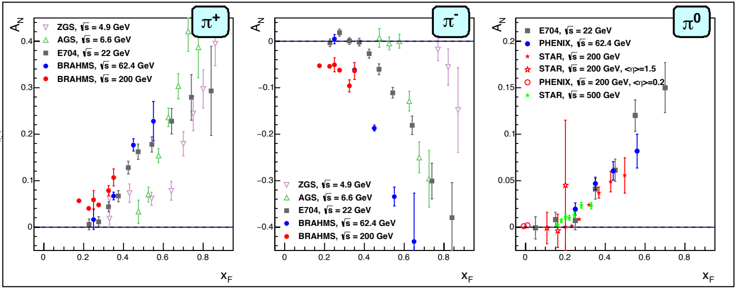
Transverse Single-Spin Asymmetry (A_N)

- 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)







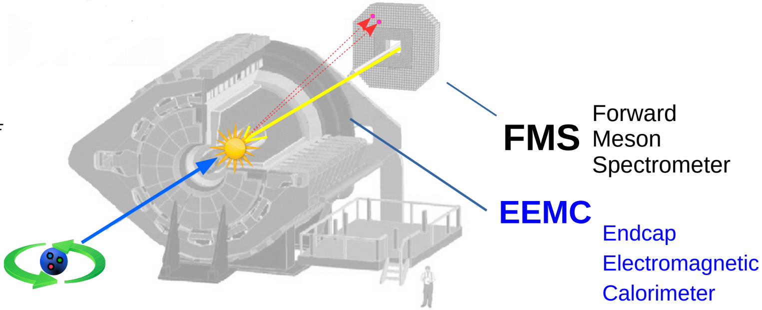
- Possible mechanisms:
  - Twist-3 mechanisms
  - TMD framework: Sivers and Collins effects
  - Diffractive contributions

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

EM-Jet A_N with FMS and EEMC

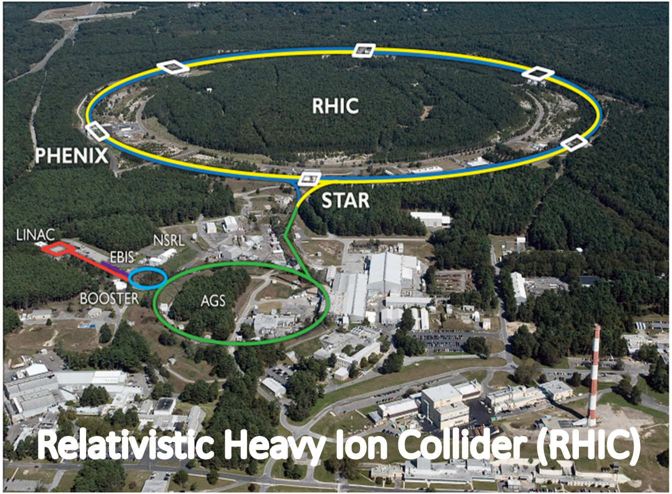
$$p^{\uparrow} + p \rightarrow \text{EM-jet} + X$$

- Explore potential sources of large A_N
- Measure subprocess contribution to the large A_N
- Characterize A_N in η, p_T, E and x_F
- EM-jet in FMS and EEMC
- Extract A_N as a function of EM-jet p_T, energy and photon multiplicity
- **Dataset:**
  - RHIC Run 15 data
  - $p^{\uparrow}p$ collisions at $\sqrt{s} = 200$ GeV
  - Transversely polarized protons
  - $\mathcal{L} = 52\ pb^{-1}$

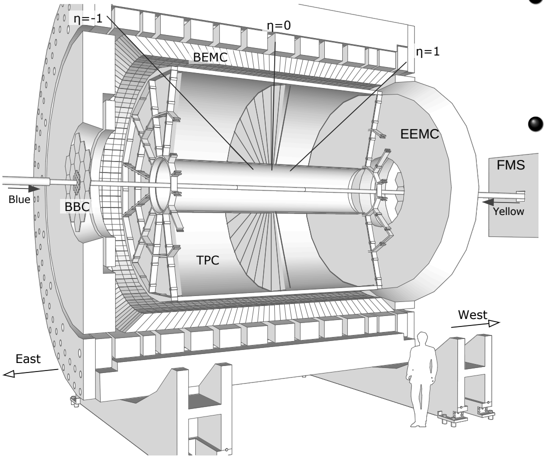


Relativistic Heavy Ion Collider (RHIC)

- Only polarized proton-proton collider
- Transverse and longitudinal polarization
- Spin direction varies bucket-to-bucket (9.4 MHz)
- Fill-to-fill variations in spin pattern
- Polarized protons up to $\sqrt{s} = 510$ GeV
- Allows to probe hard scattering processes with control of systematic effects



The STAR Experiment at RHIC

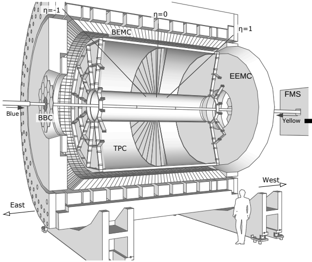


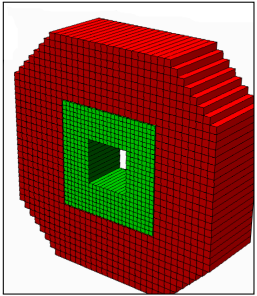
- **Calorimetry System:**
  - Barrel Electromagnetic Calorimeter (**BEMC**): $-1 < \eta < 1$
  - Endcap Electromagnetic Calorimeter (**EEMC**): $1.1 < \eta < 2$
  - Forward Meson Spectrometer (**FMS**): $2.65 < \eta < 3.9$
- Full azimuthal coverage

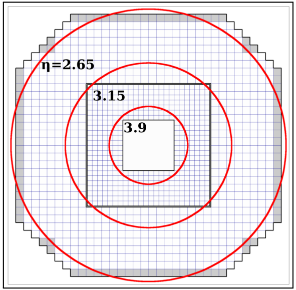
Year	$\sqrt{s}$ (GeV)	Recorded Luminosity (pb^{-1})	Polarization Orientation	B/Y $\langle P \rangle$
2009	200	25	Longitudinal	55
2009	500	10	Longitudinal	39
2011	500	12	Longitudinal	48
2011	500	25	Transverse	48
2012	200	22	Transverse	61/56
2012	510	82	Longitudinal	50/53
2013	510	300	Longitudinal	51/52
2015	200	52	Transverse	53/57
2015	200	52	Longitudinal	53/57
2017	510	320	Transverse	55

- Polarized pp dataset since 2009

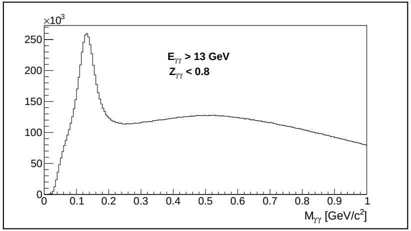
Forward Meson Spectrometer (FMS)



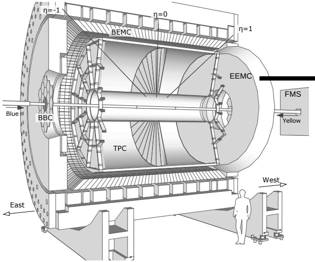


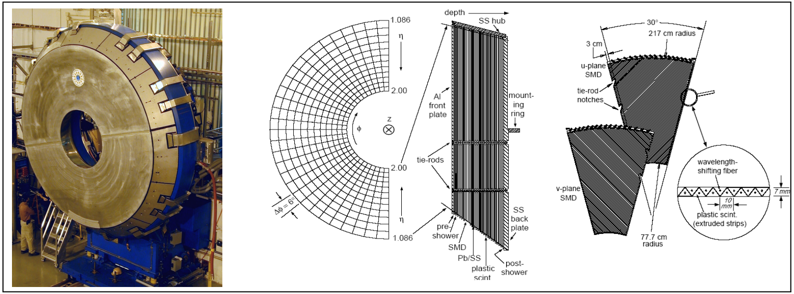


- FMS is a lead-glass electromagnetic calorimeter
- Array of $\sim$1200 Pb-glass cells coupled to PMTs
- Forward pseudorapidity coverage: $2.65 < \eta < 3.9$
- $\gamma, e^-, e^+ \rightarrow$ EM shower
- Observables: $\pi^0 \rightarrow \gamma\gamma$

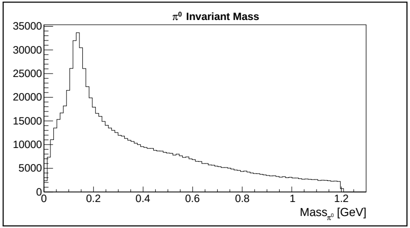


Endcap Electromagnetic Calorimeter (EEMC)





- Coverage: $1.1 < \eta < 2.0$, $0 < \phi < 2\pi$
- 12 sectors (matched to TPC sectors) $\times$ 5 subsectors x 12 η-bins = 720 towers.
- 1 tower = 24 layers, Layer 1 = pre-shower 1, Layer 2 = pre-shower 2, Layer 24 = post-shower
- SMD u and v planes at $5X_0$
- 288 SMD strips/plane/sector

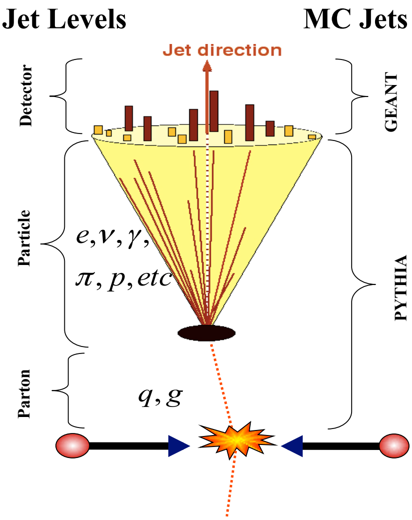


Jet Reconstruction

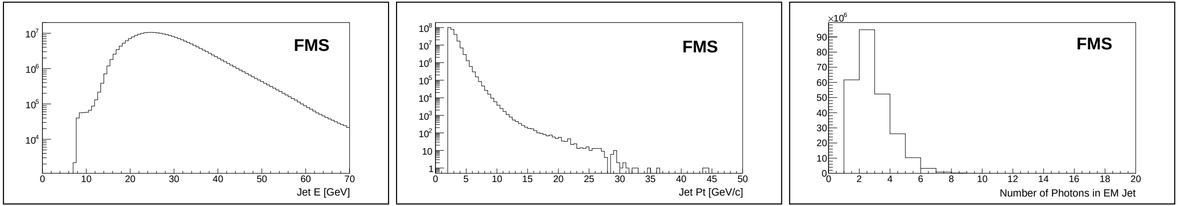
- Vertex z priority: TPC, VPD, BBC
- Reconstructed FMS photons as input for anti-k_T
- Anti-k_T with R = 0.7
- $E_\gamma > 2.0$ GeV (For FMS EM-Jet)
- Jet p_T > 2.0 GeV/c
- -80 cm $< V_z <$ 80 cm
- Trigger dependent jet-p_T cut

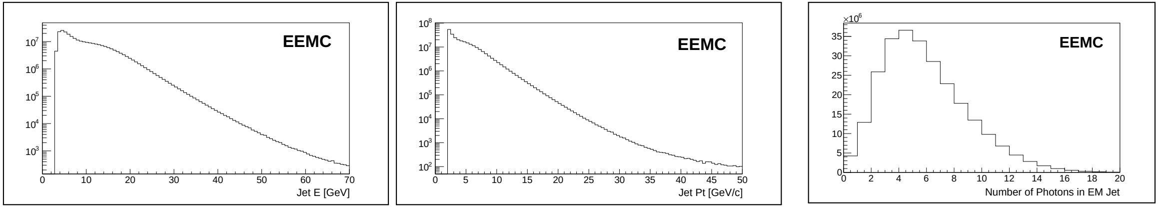
Monte Carlo

- PYTHIA event generator
- Tune: Perugia 2012 with CTEQ6 structure functions
- GEANT based STAR detector simulation

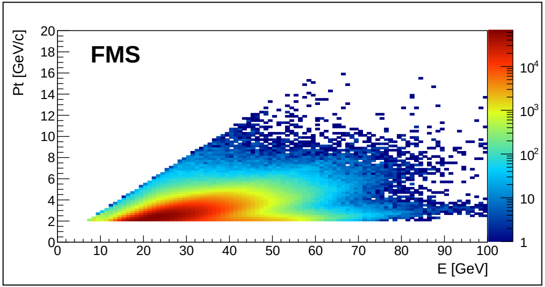


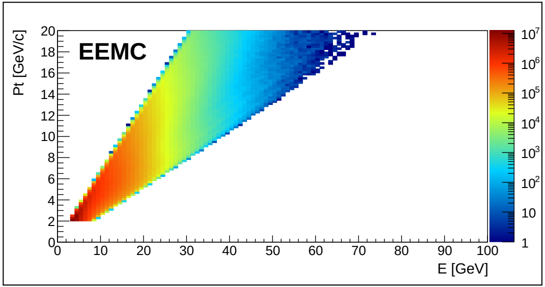
EM-Jets in FMS and EEMC





EM-Jet A_N Extraction





Binning:

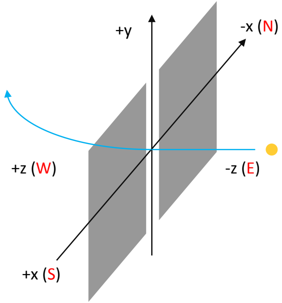
- Energy bins: 0 - 20 GeV, 20 - 40 GeV, 40 - 60 GeV and 60 - 80 GeV
- p_T bins: 0 - 5 GeV/c with 0.5 GeV/c increment, 5.0 - 6.0, 6.0 - 8.0 GeV/c
- 16 equal ϕ bins in the range $-\pi$ to π
- Up to 5 photon multiplicity bins
- Separately for $x_F > 0$ and $x_F < 0$

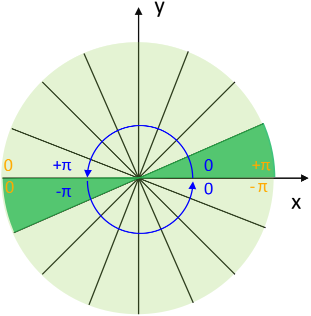
EM-Jet A_N Extraction

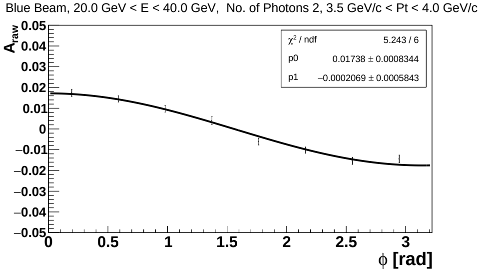
- Cross-ratio formula to calculate A_N

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

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







Current Status and Outlook

- We are studying A_N in the subprocess: $p^{\uparrow} + p \rightarrow$ EM-jet + X
- Understanding the dependences of A_N on photon multiplicity inside EM-jet, jet p_T and jet E can help further characterize large A_N in the forward rapidities
- Current efforts include: improving the EM-jet simulation and better understanding of the sources of systematic uncertainties
- Expect physics results soon!

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