Transverse Single Spin Asymmetries of Forward π^0 and Jet-like Events in $\sqrt{s} = 500$ GeV Polarized Proton Collisions at STAR

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Outline

TSSA in SIDIS & Polarized pp Collisions

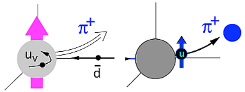
- The observation of non-trivial transverse spin asymmetries of particle productions in SIDIS and polarized pp collisions provides a good testbed for our knowledge of QCD at amplitude level.

  TMD factorization: hadrons in SIDIS, W/Z, di-jet in pp
  twist-3 collinear factorization: direct γ, inclusive jet/hadron in pp

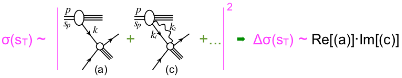
$$T_F^q(x,x) = -\int d^2\vec{p}_\perp \frac{\vec{p}_\perp^{\,2}}{M} f_{1T}^{\perp q}(x, \vec{p}_\perp^{\,2})|_{SIDIS}$$

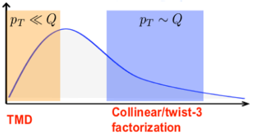
$$f_{1T}^{\perp q}(x, \vec{p}_\perp^{\,2})|_{SIDIS} = -f_{1T}^{\perp q}(x, \vec{p}_\perp^{\,2})|_{DY} = -f_{1T}^{\perp q}(x, \vec{p}_\perp^{\,2})|_{W^\pm/Z^0}$$

- The origin of transverse spin asymmetries provides insights into the spin structure of nucleon



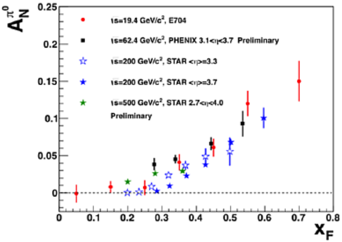
$$\sigma(p_h, s_\perp) \propto f_{a/A^\uparrow}(x, k_\perp) \otimes \hat{\sigma}_{parton} \otimes D_{h/c}(z, p_\perp)$$





Forward TSSA in Polarized pp Collisions

A_N of inclusive particle productions

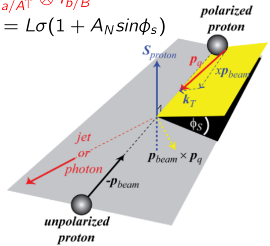


$N_{\phi_{\pi^0}} = L\sigma(1 + A_N sin\phi^s_{\pi^0})$
Possible event topology dependence

A_N forward jet-like events

$\Delta^N f_{a/A\uparrow} \otimes f_{b/B}$

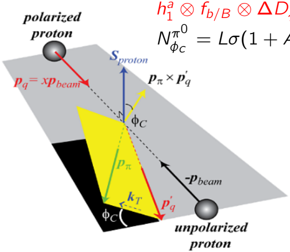
$N_{\phi_s} = L\sigma(1 + A_N sin\phi_s)$



$A_{UT}^{Collins}$ of π^0 within jets

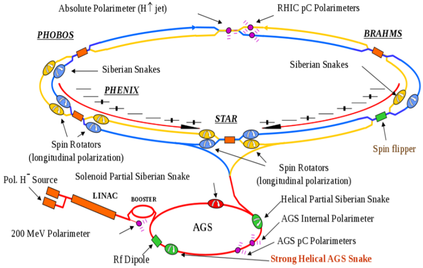
$h_1^a \otimes f_{b/B} \otimes \Delta D_{\pi/q\uparrow}$

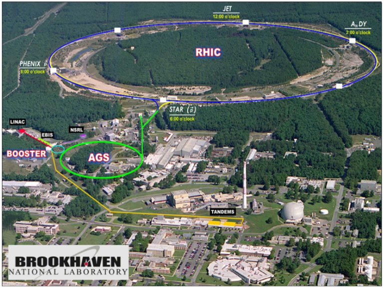
$N^{\pi^0}_{\phi_C} = L\sigma(1 + A_{UT} sin(\phi_s - \phi_h))$



Outline

The Relativistic Heavy Ion Collider

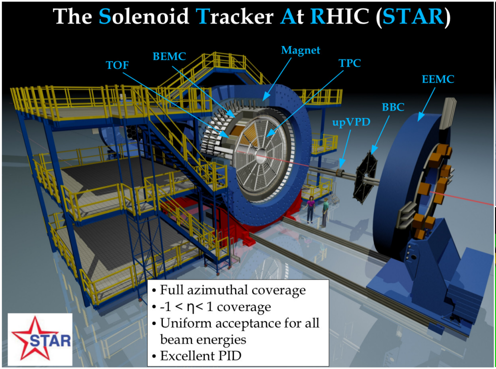


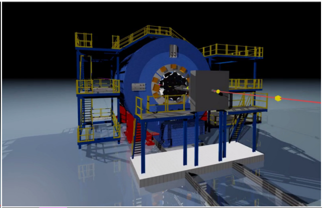


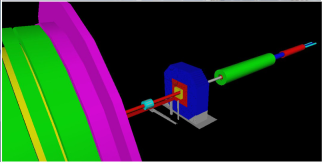
- Alternating spin orientations bunch-by-bunch
- Different spin patterns fill-to-fill
- Helical magnets in AGS & RHIC to preserve polarization
- Spin rotators in each IP to choose transverse/longitudinal pol.

Outline

STAR Detector





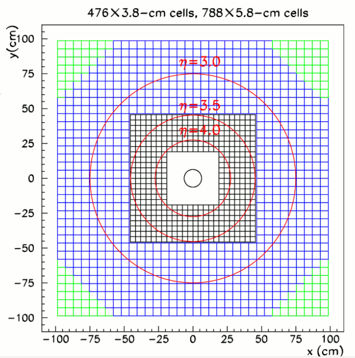


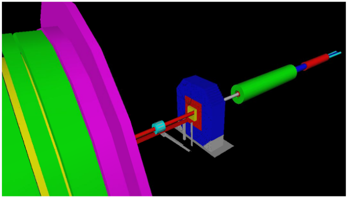
Detector capabilities

- Central ($-1 < \eta < 1$): $\pi^{\pm}$/K/p ID by TPC dE/dX and TOF, $e^{\pm}/\gamma$ by EMCAL
- Mid-Forward ($1 < \eta < 2$): π^0, η, direct γ from Endcap-EMCAL
- Forward ($2.5 < \eta < 4.0$): π^0, η, EM-jets by Forward Meson Spectrometer

STAR Forward Meson Spectrometer

- Pb Glass calorimeter provides EM coverage in $2.5 < \eta < 4.0$
- small cells: $3.81x3.81cm^2$
  large cells: $5.81x5.81cm^2$
- detect π^0, η and jet-like events





Outline

1. Transverse Single Spin Asymmetries in SIDIS & Polarized pp Collisions

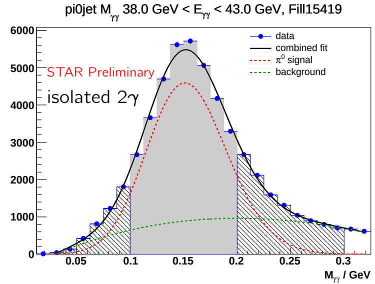
2. Forward Transverse Single Spin Asymmetry Measurements at RHIC/STAR
   - Colliding Polarized Protons at RHIC
   - STAR Detector
   - Transverse Single Spin Asymmetries of π^0 and jet-like events

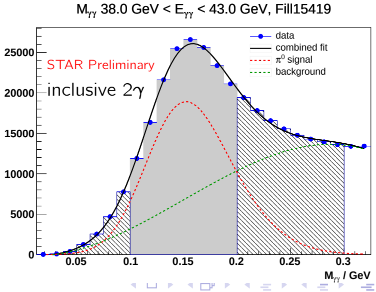
A_N of inclusive and isolated π^0

- 2011 dataset with $\sqrt{s} = 500\,GeV$, $\mathcal{L} = 22pb^{-1}$ and beam polarization 52.3%
- Isolation defined by *anti-k_T* jet algorithm with R = 0.7
- A_N of inclusive π^0 is calculated by statistically subtracting off bkg. asymmetries from all possible photon pairs regardless of isolation

$$A_N^{tot} = f_{sig} A_N^{\pi^0} + (1 - f_{sig}) A_N^{bkg}$$

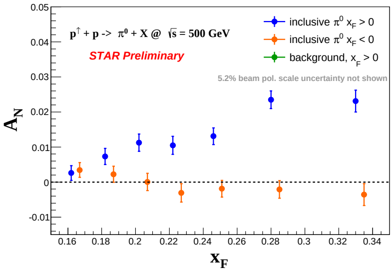
- Signal/bkg. shapes are derived from simulation but allowed to vary during the fit

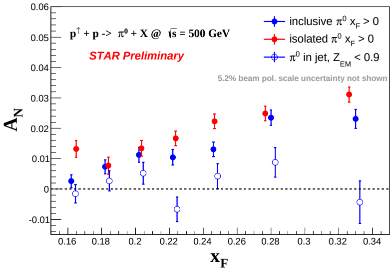




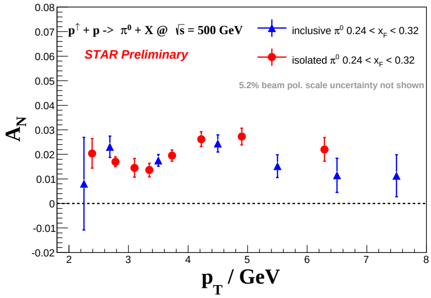
A_N of inclusive and isolated π^0 -event topology dependence

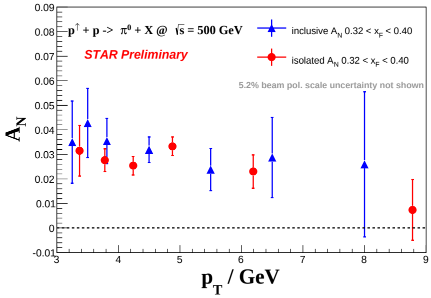
- Calculated A_N for jet-isolated π^0, background subtracted A_N for inclusive π^0 and π^0 in EM-jet
- Isolation defined by *anti-k_T* jet algorithm with R = 0.7
- Longitudinal momentum fraction Z of π^0 is calculated w.r.t the EM-jet as Z_{EM}
- Asymmetries of less exclusively produced π^0 (Z_{EM} < 0.9) is smaller than isolated π^0





A_N of inclusive and isolated π^0 -p_T dependence

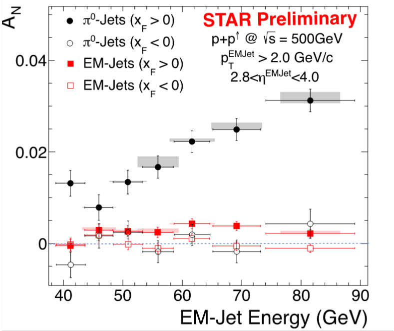




- Uncertainties for inclusive π^0 is larger due to background subtraction process
- Possible hints of falling A_N at high p_T

A_N for forward jet-like events

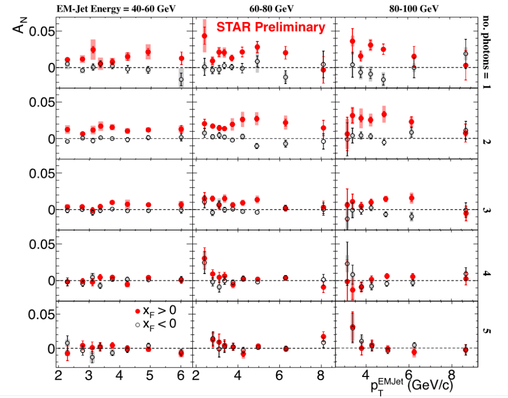
- Apply Anti-k_T jet algorithm on FMS photons, R = 0.7
- Isolated π^0 has larger asymmetries than EM-jet which contains more than two photons



Mriganka M. Mondal (DIS 2014)

A_N for forward jet-like events

- Apply Anti-k_T jet algorithm on FMS photons, R = 0.7
- Isolated π^0 has larger asymmetries than jet-like events
- Study dependence of A_N on number of photons and away-side jet activities



A_N for forward jet-like events

- Apply Anti-k_T jet algorithm on FMS photons, R = 0.7
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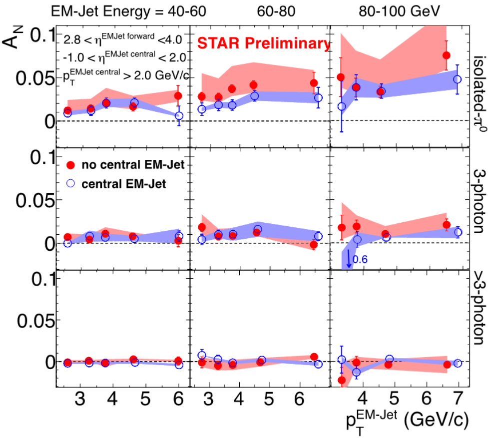
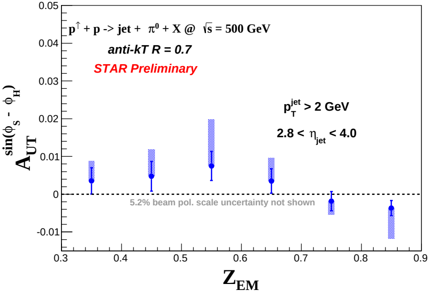
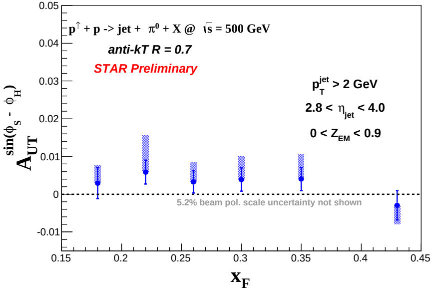
with and without a central EM-jet $p_T^{EMjet} > 2.0$ GeV



Collins asymmetries for π^0 in EM-jets



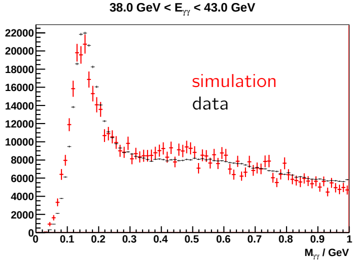


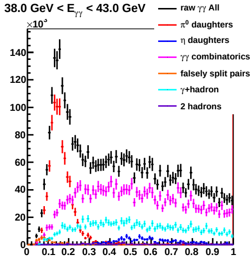
- background asymmetries are subtracted statistically
- Z of π^0 is calculated w.r.t the EM-jet
- one-sided systematic uncertainty accounts for the reduction of amplitude due to Collins angle resolutions and the use of only EM components of the jet
- hints of possible non-zero Collins asymmetries of π^0

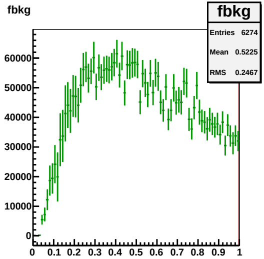
Summary

- STAR has measured transverse single spin asymmetries for forward inclusive π^0, which can be readily compared with theory predictions
- Observed event topology dependence of π^0 single spin asymmetries: isolated π^0 has significantly higher asymmetries than less exclusively produced π^0 ($Z_{EM} < 0.9$)
  Z dependence of A_N is too dramatic to be explained by simple 2-2 hard scattering. Possible contributions from diffractive production?
- Both Sivers & Collins-type asymmetries are small and not enough to explain the size of inclusive π^0 A_N
  twist3 FF? Describe SIDIS and pp at the same time?

Backup -Extract signal & background shapes from simulation

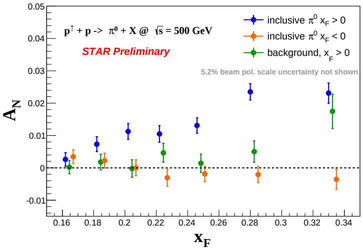


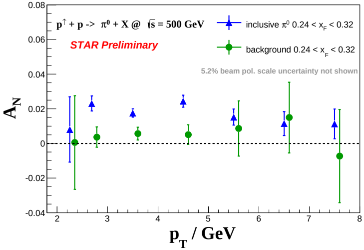


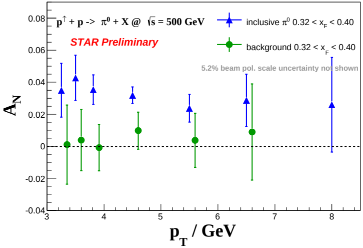


Backup -Inclusive π^0 A_N and background asymmetries

$$A_N^{tot} = f_{sig} A_N^{\pi^0} + (1 - f_{sig}) A_N^{bkg}$$

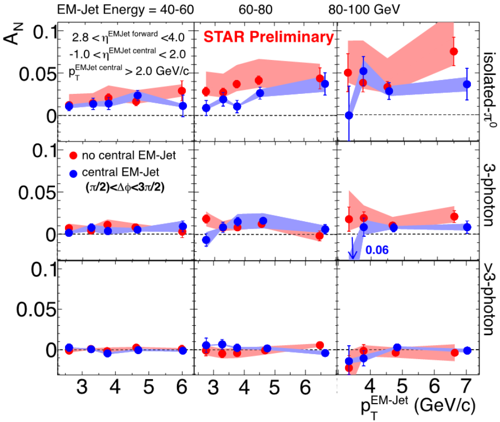






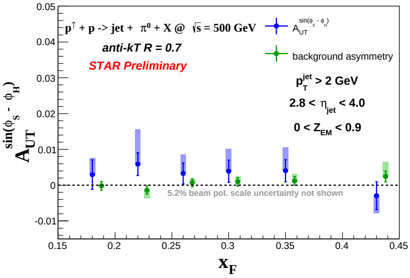
Backup - A_N for forward jet-like events

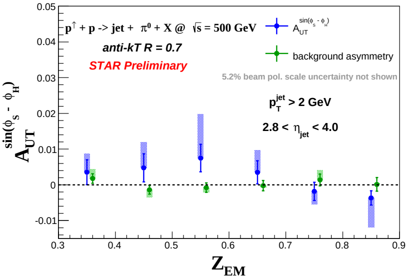
- Apply Anti-k_T jet algorithm on FMS photons, R = 0.7
- Isolated π^0 has larger asymmetries than jet-like events
- Study dependence of A_N on number of photons and away-side jet activities



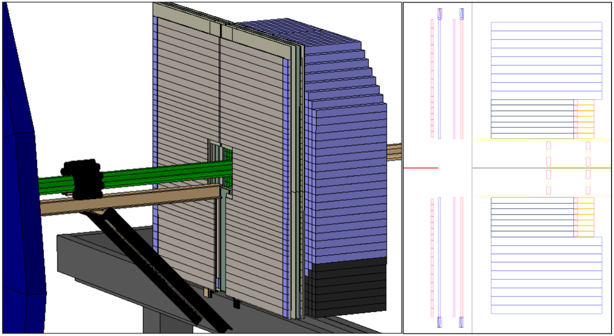
with and without a correlated central EM-jet on the away-side $p_T^{EMjet} > 2.0$ GeV

Backup -Inclusive π^0 A_{UT} and background asymmetries



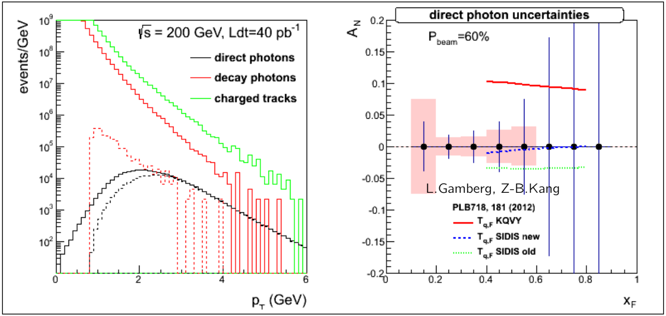


Backup -Direct γ with FMS + Preshower detector for Run15



- FMS lead glass was exposed to sunlight to recover from radiation damage
- first two layers of preshower provides γ/charged-track separation and (x,y)
- 3rd layer of preshower separates electrons and γ from charged hadrons

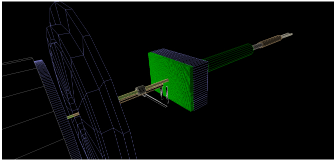
Backup -Direct γ A_N for Run15



- $p^{\uparrow} + p$ @ $\sqrt{s} = 200$ GeV, $\mathcal{L} = 40pb^{-1}$, $pol. = 60\%$
- track matching between FMS and layer1 & 2 of preshower
- $E_{cluster} > 15$ GeV, $p_T > 2.0$ GeV

Backup -Forward Tracking & Calorimeter System for 2020

- ECAL: W powder + scintillating filters
  σ_E / E = $0.11/\sqrt{E} + 0.007$
- HCAL: Lead plates + scintillating tiles
  σ_E / E = $0.58/\sqrt{E} + 0.007$
- Prototypes tested extensively at Fermilab



- Silicon micro-strip technology based on experience from STAR IST
- GEM technology from FGT design
- Still in early stage of development