Azimuthal transverse single-spin asymmetries of inclusive jets and identified hadrons within jets from polarized p+p collisions at $\sqrt{s}$ = 200 GeV

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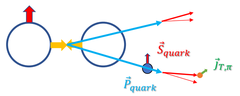
Abstract

The Collins effect involves the combination of the quark transversity in the proton with the spin-dependent Collins fragmentation function, leading to azimuthal modulations of identified charged hadron yields about the jet axis. The STAR Collaboration reports a new measurement of Collins asymmetry for charged hadrons inside jets in polarized pp collisions at $\sqrt{s}$ = 200 GeV, based on data taken during 2015. These results probe transversity for quark momentum fractions $0.1 \le x \le 0.4$ at Q^2 scales that are one to two orders of magnitude larger than similar measurements in semi-inclusive deep-inelastic scatterings (SIDIS). They also provide a direct probe to the Collins fragmentation function and enable testing its evolution, universality and factorization breaking in the transverse momentum dependent formalism (TMD).

Collins Effect

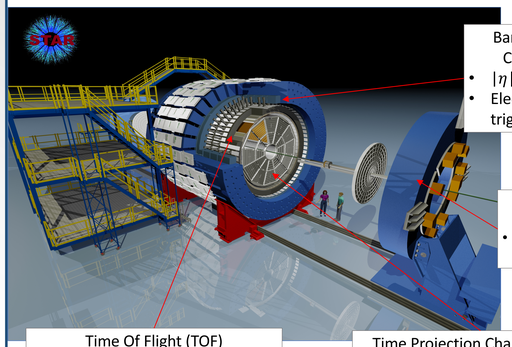
Correlation between the polarization of a scattered quark and the momentum of a hadron fragment transverse to the scattered quark direction;

- Collins effect combines the quark transversity in the proton with the spin-dependent Collins fragmentation function, leading to azimuthal modulations of identified charged hadron yields about the jet axis;
  - Integral of transversity gives the nucleon tensor charge; $\langle \vec{S}_{quark} \cdot (\vec{P}_{quark} \times \vec{j}_{T,\pi}) \rangle \neq 0$
  - Difference of helicity and transversity has direct x-dependent connection to quark orbital angular momentum;



  - Collins fragmentation function in pp probes fundamental questions regarding factorization, universality, and evolution of TMDs.

The Solenoidal Tracker At RHIC (STAR)



Barrel Electromagnetic Calorimeter (BEMC)
- $|\eta| < 1.0$, $0 < \varphi < 2\pi$;
- Electromagnetic energy; triggering

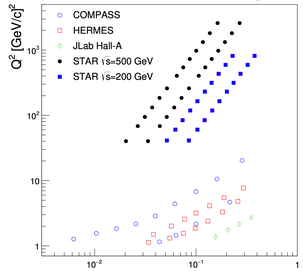
Endcap Electromagnetic Calorimeter (EEMC)
- Extend EM coverage to $1.09 < \eta < 2.0$

Time Of Flight (TOF)
- $|\eta| < 1.0$, $0 < \varphi < 2\pi$;
- Measures arrival times of the charged particles;

Time Projection Chamber (TPC)
- $|\eta| < 1.0$, $0 < \varphi < 2\pi$;
- Charged particle momentum, dE/dx

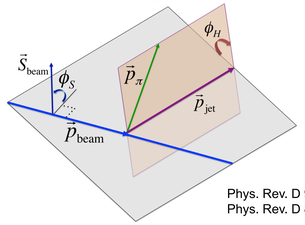
Collins Effect in p+p

Kinematic Coverage



- STAR covers a similar range in momentum fractions (x) to that of SIDIS results with much higher Q^2

Transverse Single-Spin Asymmetry



Phys. Rev. D 97, 032004 (2018)
Phys. Rev. D 83, 034021 (2011)

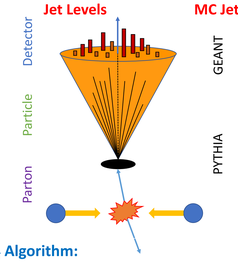
- For pions within jets, the spin dependent cross section is:

$$d\sigma^{\uparrow}(\phi_S,\phi_H) - d\sigma^{\downarrow}(\phi_S,\phi_H) \sim d\Delta\sigma_0 \sin(\phi_S) + d\Delta\sigma_1^{-} \sin(\phi_S - \phi_H) + d\Delta\sigma_1^{+} \sin(\phi_S + \phi_H) + d\Delta\sigma_2^{-} \sin(\phi_S - 2\phi_H) + d\Delta\sigma_2^{+} \sin(\phi_S + 2\phi_H)$$

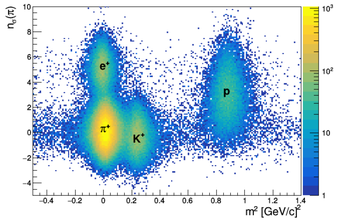
$$A_{UT}^{\sin(\varphi_S - \varphi_H)} = \frac{\sigma^{\uparrow}(\phi) - \sigma^{\downarrow}(\phi)}{\sigma^{\uparrow}(\phi) + \sigma^{\downarrow}(\phi)} \propto \frac{\sum_{a,b,c} \boldsymbol{h_1^a(x_1,\mu)}\ f_b(x_2,\mu)\ \sigma_{ab\to c}^{\text{Collins}}\ \boldsymbol{H_{1,h/c}^{\perp}(z_h, j_T; Q)}}{\sum_{a,b,c} f_a(x_1,\mu)\ f_b(x_2,\mu)\ \sigma_{ab\to c}^{\text{unpol}}\ D_{h/c}(z_h, j_T; Q)}$$

Kang et al, JHEP 11, 068 (2017) and PLB 774, 635 (2017)

- Collins effect in pp involves a mixture of collinear transversity and TMD Collins factorization function
  - Initial jet production involves the collinear transversity $\boldsymbol{h_1^a}$
  - Polarized quark then fragments according to the TMD Collins fragmentation function $\boldsymbol{H_{1,h/c}^{\perp}}$
- Cleaner kinematic separation of transversity and TMD physics than SIDIS, which convolutes the TMD transversity distribution with the Collins FF;

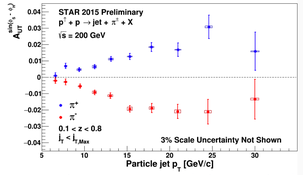


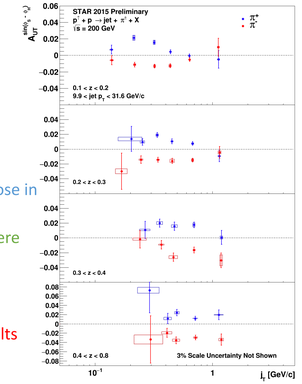
Anti-k_T Algorithm:
- Radius = 0.6
- Resilient to underlying event and pile-up effects
- Used in both data and simulation



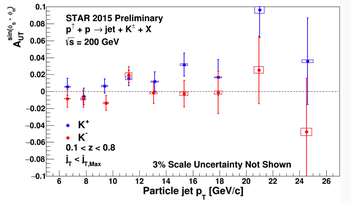
- 52 pb^{-1} transversely polarized p+p data at $\sqrt{s}$ = 200 GeV, twice as 2012;
- 57% averaged beam polarization;
- Particle identification from TPC and TOF;

Results





- Asymmetries are comparable in magnitude to those in SIDIS, favoring weak evolution effects;
- 200 GeV pp provides sensitivity up to $x \sim 0.4$, where SIDIS statistics are very limited;
- Several new analysis techniques developed to minimize systematic uncertainties;
- 2015 asymmetries agree with previous 2012 results and have uncertainties smaller by approximately 1/√2;
- Asymmetry vs. jet p_T measures the collinear transversity; vs. z, $j_T$maps the Collins fragmentation function;



- K^+, which can be produced through favored fragmentation of a valence u quark, has asymmetries that are about 1.5-sigma larger than π^+;
- K^-, which is produced by unfavored fragmentation, has asymmetries that are consistent with zero at the current precision.
- Both observations are similar to SIDIS.

Summary

- We present the most precise measurement of Collins asymmetry for charged hadrons inside jets at 200 GeV pp collisions to date;
- These results are consistent with the previous STAR results and have smaller statistical and systematic uncertainties;
- Similar x coverage as SIDIS and overlap with the $x - Q^2$ coverage of Electron Ion Collider, providing critical tests for factorization, universality and evolutions in TMD frameworks.

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The STAR Collaboration
https://drupal.star.bnl.gov/STAR/presentations