

Collins effect in pion-jet at RHIC

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In collaboration with

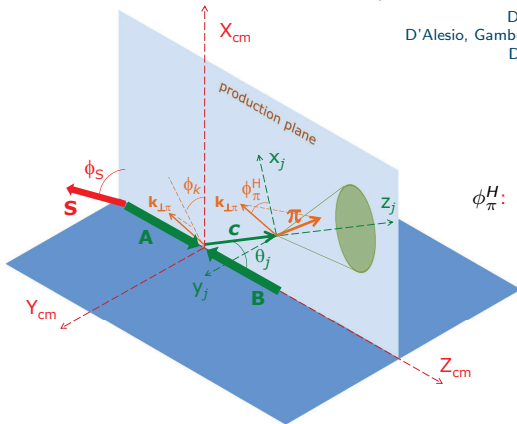
U. D'Alesio and F. Murgia

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$$A(P_A; S) + B(P_B) \rightarrow \text{jet}(P_j) + \pi(P_\pi) + X$$

A is polarized with transverse spin $S = (0, \cos \phi_S, \sin \phi_S, 0)$



D'Alesio, Murgia, CP, PRD 83 (2011) 034021
D'Alesio, Gamberg, Kang, Murgia, CP, PLB 704 (2011) 637
D'Alesio, Murgia, CP, PEPAN 45 (2014) 676;
PLB 773 (2017) 300

ϕ_π^H : azimuthal distribution of the pion
inside the jet, around the jet axis

$$\tan \phi_\pi^H = \tan \phi_k \cos \theta_j$$

c.m. and helicity H frames: related by a rotation around Y_{cm} by θ_j , polar angle of the jet

Theoretical framework and motivation

- ▶ Spin and intrinsic parton motion effects in initial hadrons and fragm.
Assumption: factorization holds for large p_T jet/hadron production

- ▶ SSA and azimuthal asymmetries are generated by TMD PDFs & FFs
Most relevant: f_{1T}^\perp (Sivers), h_1^\perp (Boer-Mulders), H_1^\perp (Collins)

Anselmino *et al.*, PRD 73 (2006) 014020;

Aschenauer, D'Alesio, Murgia, 1512.05379

Notation: Meissner, Metz, Goeke, PRD 76 (2007) 034002

- ▶ Collinear + TMD factorization: simpler framework, with intrinsic parton motion only in fragmentation. Only Collins effect for quarks is at work

F. Yuan, PRL 100 (2008) 032003;

Kang, Liu, Ringer, Xing, JHEP 1711 (2017) 068;

Kang, Prokudin, Ringer, Yuan, PLB 774 (2017) 635

- ▶ The present, more general, scheme requires a severe scrutiny by comparison with experimental results to clarify the validity of factorization and the relevance of possible universality-breaking terms

Why looking at pions inside a jet?

- ▶ SSAs in $p^\uparrow p \rightarrow \pi X$, due to Collins and Sivers effects, cannot be disentangled

Anselmino *et al.*, PRD 71 (2005) 014002;

Anselmino *et al.*, PRD 73 (2006) 014020

while in $p^\uparrow p \rightarrow \text{jet } \pi X$ they (and other TMDs) can be singled out

- ▶ Jets coming from quark or gluon fragmentation could be identified, since the pion azimuthal distribution is different in the two cases:
 - ▶ symmetric pion distribution: fragmentation of an unpolarized parton (D_1)
 - ▶ $\cos \phi_\pi^H$ distribution for a transversely polarized quark jet ($H_1^{\perp q}$)
 - ▶ $\cos 2\phi_\pi^H$ distribution for a linearly polarized gluon jet ($H_1^{\perp g}$)
- ▶ Complex measurement, but feasible and under consideration at RHIC

Fatemi [STAR], talk at QCD evolution (2015);

Drachenberg [STAR], PoS (DIS2015) 193;

STAR Collaboration, arXiv:1708.07080

- General structure of the single transverse polarized cross section

$$2d\sigma(\phi_S, \phi_\pi^H) \sim d\sigma_0 + d\Delta\sigma_0 \sin \phi_S + d\sigma_1 \cos \phi_\pi^H + d\sigma_2 \cos 2\phi_\pi^H \\ + d\Delta\sigma_1^- \sin(\phi_S - \phi_\pi^H) + d\Delta\sigma_1^+ \sin(\phi_S + \phi_\pi^H) \\ + d\Delta\sigma_2^- \sin(\phi_S - 2\phi_\pi^H) + d\Delta\sigma_2^+ \sin(\phi_S + 2\phi_\pi^H)$$

- Azimuthal moments, $W(\phi_S, \phi_\pi^H) = \sin \phi_S, \sin(\phi_S - \phi_\pi^H), \dots$

$$A_N^W = 2 \frac{\int d\phi_S d\phi_\pi^H W(\phi_S, \phi_\pi^H) [d\sigma(\phi_S) - d\sigma(\phi_S + \pi)]}{\int d\phi_S d\phi_\pi^H [d\sigma(\phi_S) + d\sigma(\phi_S + \pi)]}$$

will single out the different contributions (analogy with SIDIS)

Collins asymmetries

$$A_N^{\sin(\phi_S - \phi_\pi^H)} \sim h_1^q f_1 H_1^{\perp q}$$

D'Alesio, Murgia, CP, PLB 773 (2017) 300

- ▶ **Assumption for TMDs:** $\mathcal{F}^{q,g}(x, \mathbf{k}_\perp^2) = f^{q,g}(x)g(\mathbf{k}_\perp^2)$, with $g(\mathbf{k}_\perp^2)$ being a flavor independent Gaussian-like function
- ▶ **Parameterizations** of the usual collinear LO pdfs (GRV98, GRSV2000) and FFs (Kretzer, DSS) evolved at the scale $\mu = P_{jT}$
- ▶ $h_1^q, H_1^{\perp q}$ from SIDIS, e^+e^- data by Anselmino *et al*:

PRD 75 (2007) 054032 (SIDIS 1);

NP (Proc. Suppl.) 191 (2009) 98 (SIDIS 2);

PRD 87 (2013) 094019 (Fit 2013)

Anti- k_T jet reconstruction algorithm with parameter R Center of mass energy $\sqrt{s} = 200$ GeV

- ▶ Kinematic cuts on the jet:

$$R = 0.6$$

$$0 < \eta_j < 1$$

$$10 < P_{jT} < 31.6 \text{ GeV}$$

- ▶ Kinematic cuts on the pion:

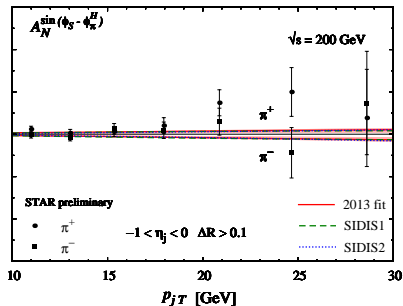
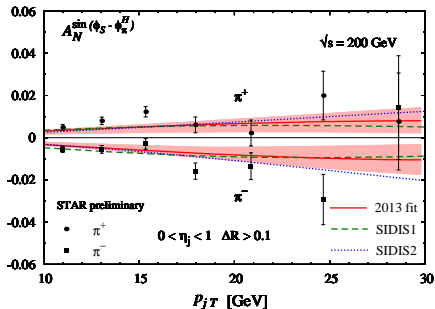
$$0.1 < z_{\text{exp}} \equiv \frac{E_\pi}{E_j} < 0.6$$

$$0.2 < P_{\pi T} < 30 \text{ GeV}$$

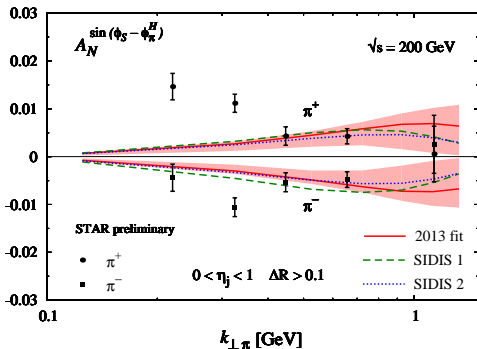
$$0.125 < k_{\perp\pi} < 4.5 \text{ GeV}$$

$$\Delta R = \sqrt{(\eta_j - \eta_\pi)^2 + (\phi_j - \phi_k)^2} > 0.1$$

We take $R \approx \Delta R$



Predictions differ as $p_{jT} > 20$ GeV ($\langle x_a \rangle \geq 0.3$): h_1^q not constrained by data



Some discrepancies between theory and data appear at small values of $k_{\perp\pi}$

- ▶ If data are confirmed, hint for a different $k_{\perp\pi}$ behaviour of FFs
- ▶ Agreement improves at $\sqrt{s} = 500$ GeV for $\langle z \rangle = 0.13, 0.37$

Kang, Prokudin, Ringer, Yuan, PLB 774 (2017) 635
 STAR Collaboration, arXiv:1708.07080

Center of mass energy $\sqrt{s} = 500 \text{ GeV}$

- ▶ Kinematic cuts on the jet:

$$R = 0.5$$

$$0 < \eta_j < 1$$

$$22.7 < P_{jT} < 55 \text{ GeV}$$

- ▶ Kinematic cuts on the pion:

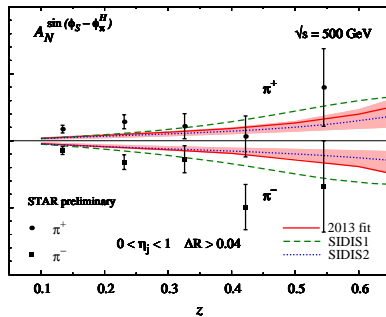
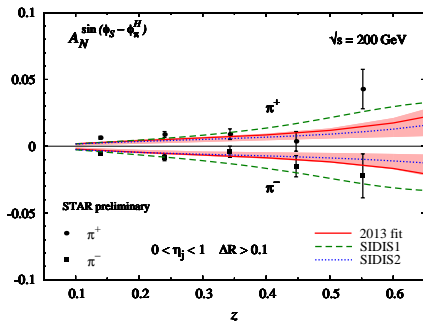
$$0.1 < z_{\text{exp}} \equiv \frac{E_\pi}{E_j} < 0.8$$

$$0.2 < P_{\pi T} < 30 \text{ GeV}$$

$$0.1 < k_{\perp\pi} < 2 \text{ GeV}$$

$$\Delta R = \sqrt{(\eta_j - \eta_\pi)^2 + (\phi_j - \phi_k)^2} > 0.04$$

The QCD evolution of $A_N^{\sin(\phi_S - \phi_\pi^H)}$ can be tested: almost no energy dependence



$\sqrt{s} = 200 \text{ GeV}$: $\langle x_a \rangle \sim \langle x_b \rangle \sim 0.2$, $\langle k_{\perp\pi} \rangle \sim 0.4 - 0.5 \text{ GeV}$, $\langle P_{jT} \rangle \sim 12 \text{ GeV}$

$\sqrt{s} = 500 \text{ GeV}$: $\langle x_a \rangle \sim \langle x_b \rangle \sim 0.2$, $\langle k_{\perp\pi} \rangle \sim 0.3 - 0.8 \text{ GeV}$, $\langle P_{jT} \rangle \sim 25 - 27 \text{ GeV}$

h_1^q probed in the valence region, where it is known

SIDIS 1 predictions larger because of the different unpolarized FF set

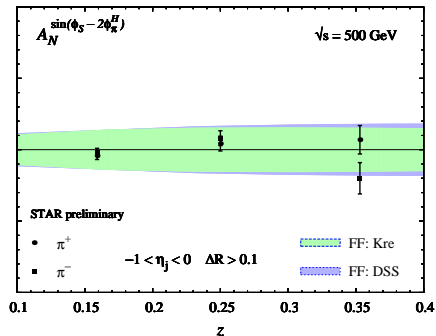
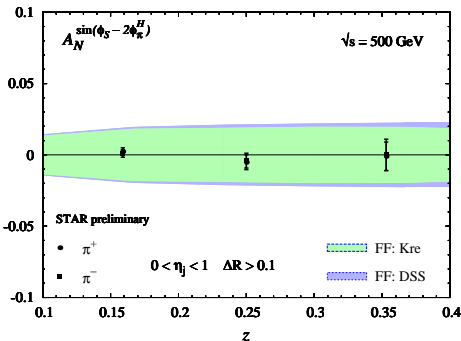
Collins-like asymmetries

Collins-like asymmetries $A_N^{\sin(\phi_S - 2\phi_\pi^H)}$

Comparison with STAR data

$$A_N^{\sin(\phi_S - 2\phi_\pi^H)} \sim h_1^g f_1 H_1^{\perp g}$$

$h_1^g, H_1^{\perp g}$ are unknown; their positivity bounds \rightarrow upper bounds on $A_N^{\sin(\phi_S - 2\phi_\pi^H)} \approx 2\%$



[STAR Preliminary] R. Fatemi, QCD Evolution 2015

$$\langle x_a \rangle \sim \langle x_b \rangle \sim 0.05; \quad \langle k_{\perp \pi} \rangle \sim 0.3 - 0.6 \text{ GeV}; \quad \langle P_{JT} \rangle \sim 7 - 8 \text{ GeV}$$

$H_1^{\perp g}$ can be determined separately from e^+e^- experiments

$h_1^g \neq h_1^{\perp g}$ (linearly polarized gluons inside an *unpolarized* proton)

- ▶ The process $p^\uparrow p \rightarrow \text{jet } \pi X$, under active investigation at RHIC, is studied within a TMD generalized factorization scheme
- ▶ In contrast to $p^\uparrow p \rightarrow \pi X$ and similarly to SIDIS, one can *discriminate among different effects* by taking moments of the asymmetries
- ▶ STAR data on Collins asymmetries are described by a **universal Collins function**, with discrepancies only in the description of their $k_{\perp\pi}$ -behavior
- ▶ Neither factorization-breaking nor TMD evolution effects emerge
- ▶ The size of the **Collins-like asymmetries**, involving linearly polarized gluons, is constrained for the first time by STAR data