Collins asymmetries in $p^{\uparrow}p \rightarrow \text{jet}\, \pi\, X$

Cristian Pisano

International Workshop

TMDe2015

A Path towards TMD Extraction

Trieste (Italy)
September 2 - 4, 2015

With U. D'Alesio (U. & INFN Cagliari) and F. Murgia (INFN Cagliari)

Particle Physics Group
University of Antwerp

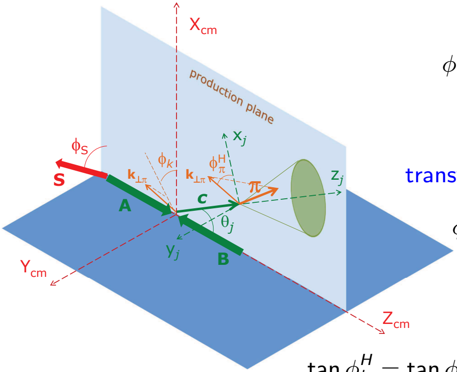
Fonds Wetenschappelijk Onderzoek
Vlaanderen
Opening new horizons

Kinematics

$$A(P_A; S) + B(P_B) \to \mathrm{jet}(P_\mathrm{j}) + h(P_h) \; + \; X$$

in the c.m.s. of the two spin $1/2$ hadrons A, B; the jet is in the XZ plane
A is polarized with transverse spin $S = (0, \cos\phi_S, \sin\phi_S, 0)$

D'Alesio, Murgia, CP, PRD 83 (2011) 034021;
PEPAN 45 (2014) 676



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

ϕ_k: azim. angle of π' s intrinsic transv. momentum w.r.t. the jet direction

ϕ_π^H: same angle, but measured in the H frame, where the jet (parton c) is along z_j

$$\tan\phi_h^H = \tan\phi_k \cos\theta_\mathrm{j}$$

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

The TMD generalized parton model (GPM)

- Spin and intrinsic parton motion effects in initials hadrons and fragm.
  Assumption: factorization holds for large p_T jet 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;
  Notation: Meissner, Metz, Goeke, PRD 76 (2007) 034002

- Factorization proven in a simpler framework: intrinsic parton motion only in fragmentation. Only Collins effect for quarks is at work
  F. Yuan, PRL 100 (2008) 032003;
  PRD 77 (2008) 074019

- 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 $p^{\uparrow}p \to \pi\, X$, 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 $p^{\uparrow}p \to \mathrm{jet}\, \pi\, X$ they (and otherTMDs) 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:
  - symm. pion distribution: fragmentation of an unp. parton (D_1)
  - $\cos\phi_\pi^H$ distribution for a transv. 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

- General structure of the single transverse polarized cross section

$$\begin{aligned} 2\mathrm{d}\sigma(\phi_S,\phi_\pi^H) \;\sim\; & \mathrm{d}\sigma_0 + \mathrm{d}\Delta\sigma_0 \sin\phi_S + \mathrm{d}\sigma_1 \cos\phi_\pi^H + \mathrm{d}\sigma_2 \cos 2\phi_\pi^H \\ & + \mathrm{d}\Delta\sigma_1^- \sin(\phi_S - \phi_\pi^H) + \mathrm{d}\Delta\sigma_1^+ \sin(\phi_S + \phi_\pi^H) \\ & + \mathrm{d}\Delta\sigma_2^- \sin(\phi_S - 2\phi_\pi^H) + \mathrm{d}\Delta\sigma_2^+ \sin(\phi_S + 2\phi_\pi^H) \end{aligned}$$

- Average values of the functions $W(\phi_S,\phi_\pi^H) = 1,\ \sin\phi_S,\ \cos\phi_\pi^H,\ \ldots$

$$\langle\, W(\phi_S,\phi_\pi^H)\,\rangle = \frac{\int \mathrm{d}\phi_S \mathrm{d}\phi_\pi^H W(\phi_S,\phi_\pi^H)\mathrm{d}\sigma(\phi_S,\phi_\pi^H)}{\int \mathrm{d}\phi_S \mathrm{d}\phi_\pi^H \mathrm{d}\sigma(\phi_S,\phi_\pi^H)}$$

single out $\mathrm{d}\sigma_0,\ \mathrm{d}\Delta\sigma_0,\ \mathrm{d}\sigma_1,\ \ldots$

- Unpolarized cross section:

$$\mathrm{d}\sigma(\phi_S,\phi_\pi^H)+\mathrm{d}\sigma(\phi_S+\pi,\phi_\pi^H) \equiv 2\mathrm{d}\sigma^{\mathrm{unp}}(\phi_\pi^H) \sim \mathrm{d}\sigma_0+\mathrm{d}\sigma_1\cos\phi_\pi^H+\mathrm{d}\sigma_2\cos 2\phi_\pi^H$$

- Numerator of the single spin asymmetry:

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

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

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

will single out the different contributions (analogy with SIDIS)

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

- Assumption for TMDs: $\mathcal{F}^{q,g}(x, \boldsymbol{k}_\perp^2) = f^{q,g}(x) g(\boldsymbol{k}_\perp^2)$, with $g(\boldsymbol{k}_\perp^2)$ being a flavor independent Gaussian-like function

- Parameterizations of the usual collinear LO pdfs (GRV98, GRSV2000) and FFs (Kre) evolved at the scale $\mu = P_{\mathrm{j}T}$

- 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)

Anti-k_T jet reconstruction algorithm with parameter R

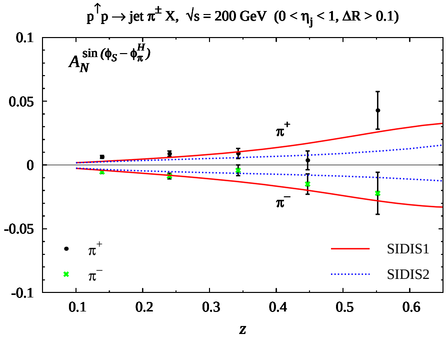
Center of mass energy $\sqrt{s} = 200$ GeV

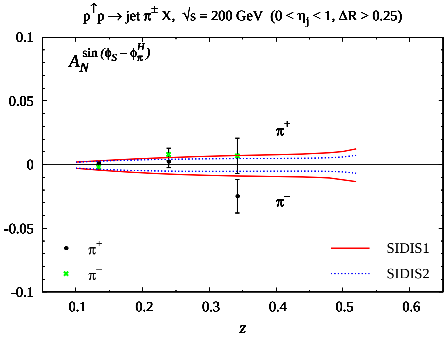
- Kinematic cuts on the jet:
  $$R = 0.6$$
  $$0 < \eta_{\mathrm{j}} < 1$$
  $$10 < P_{\mathrm{j}T} < 31.6 \text{ GeV}$$
- Kinematic cuts on the pion:
  $$0.1 < z_{\mathrm{exp}} \equiv \frac{E_\pi}{E_{\mathrm{j}}} < 0.6$$
  $$0.2 < P_{\pi T} < 30 \text{ GeV}$$
  $$0.125 < k_{\perp\pi} < 4.5 \text{ GeV}$$

$$\Delta R = \sqrt{(\eta_j - \eta_\pi)^2 + (\phi_j - \phi_k)^2} > 0.1 \ (0.25)$$

We take $R \approx \Delta R$

Comparison with preliminary STAR results
$\sqrt{s} = 200$ GeV





All other (partonic) variables are integrated over, with

$$\langle x_a \rangle \sim \langle x_b \rangle \sim 0.2\,, \quad \langle k_{\perp\pi} \rangle \sim 0.5 - 0.4 \text{ GeV}\,, \quad \langle P_{jT} \rangle \sim 11.8 - 11.9 \text{ GeV}$$

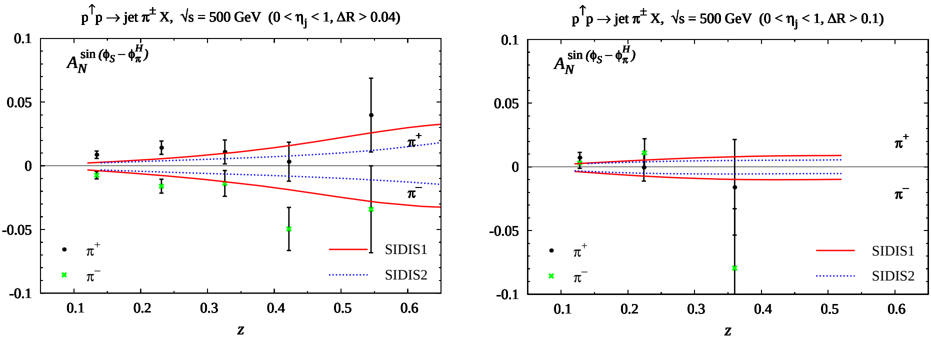
Center of mass energy $\sqrt{s} = 500$ GeV

- Kinematic cuts on the jet:
  $R = 0.5$
  $0 < \eta_{\mathrm{j}} < 1$
  $22.7 < P_{\mathrm{j}T} < 55$ GeV

- Kinematic cuts on the pion:
  $0.1 < z_{\mathrm{exp}} \equiv \frac{E_\pi}{E_{\mathrm{j}}} < 0.8$
  $0.2 < P_{\pi T} < 30$ GeV
  $0.1 < k_{\perp\pi} < 2$ GeV

$$\Delta R = \sqrt{(\eta_j - \eta_\pi)^2 + (\phi_j - \phi_k)^2} > 0.04\ (0.1)$$

The QCD evolution of $A_N^{\sin(\phi_S - \phi_\pi^H)}$ can be tested



Similarly to $\sqrt{s} = 200$ GeV:

$$\langle x_a \rangle \sim \langle x_b \rangle \sim 0.2\,, \quad \langle k_{\perp\pi} \rangle \sim 0.3 - 0.8\ \mathrm{GeV}\,,$$

while the hard scale takes larger values, $\langle P_{jT} \rangle \sim\ 27 - 25$ GeV

- Study of the process $p^{\uparrow}p \to \mathrm{jet}\,\pi\,X$, under active investigation at RHIC, within a TMD generalized factorization scheme
- In contrast to $p^{\uparrow}p \to \pi\,X$ and similarly to SIDIS, one can discriminate among different effects by taking moments of the asymmetries
- Measurements of Collins asymmetries: indication on the size and sign of transversity in a new kinematic region
- Comparison with similar studies in DY, SIDIS, $e^{+}e^{-}$: validation of universality of the Collins function
- From the phenomenological point of view, the measurement of such asymmetries is a crucial test for the TMD factorization approach