$p_\perp$ Dependent Parton Distributions and Final State Interactions

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- PDFs and PtPDFs
- Gauge Link and Final State Interactions
- Future Perspective

References:

Ji, FY, PLB543 (2002), hep-ph/0206057

Belitsky, Ji, FY, hep-ph/0208038

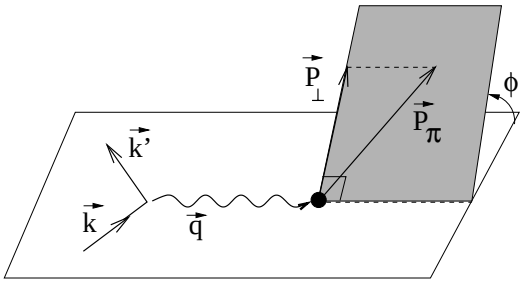
PDF and PtPDF

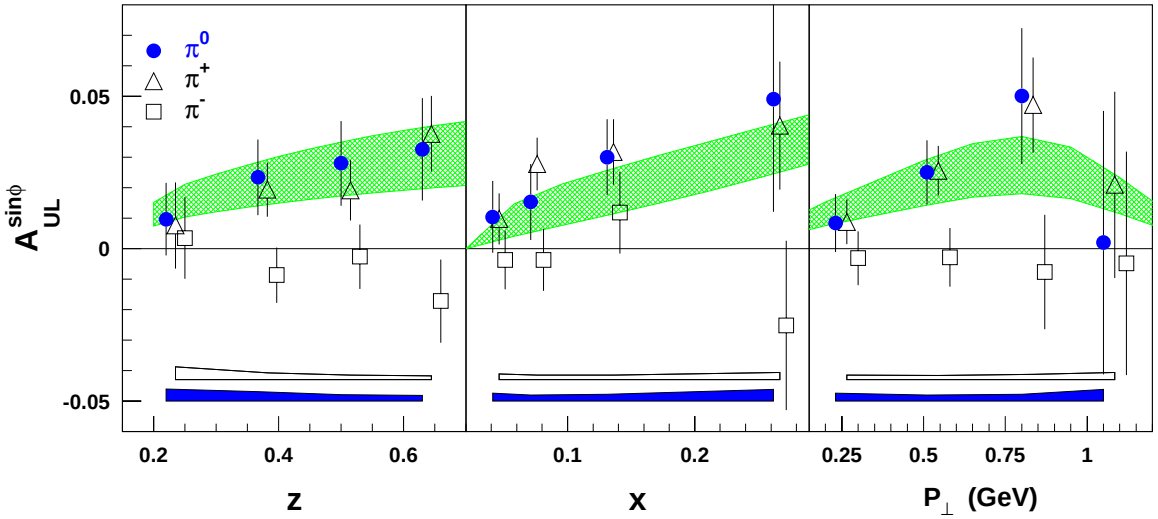
- Parton Distribution Functions have been studied and measured for more than 30 years. The theoretical aspects of these quantities are well understood.
- The new PDFs, PtPDFs—Transverse Momentum dependent Parton Distribution Functions have been widely discussed recently (Collins, Soper 1982; Mulders, Tangerman 1996; Boer, Mulders 1998,$\cdots$), but their theoretical foundation is not yet completely clear.
- In particular, T-odd PtPDFs have extremely interesting phenomenological applications, and are under study by many experiments (**HERMES, COMPASS, JLAB, RHIC**).

Azimuthal Asymmetry Observation at HERMES

SIDIS (Semi-inclusive Deep Inelastic Scatterings)

$e\vec{p} \to e'\pi X$ with target polarization parallel to lepton beam





HERMES, PRL84, 4047; PRD64, 097101

SIDIS

SSA (Single Spin Asymmetry) observed in these SIDIS processes can be interpreted as the consequences of $p_\perp$ dependent distribution functions:

- T-odd Fragmentation Functions $H_1^\perp$ (Collins Function)
- T-odd Parton Distributions $f^\perp(x, k_\perp)$ (Sivers Function)

where the transverse momenta of partons *play important role*.

Mulders, Tangerman, NPB461 (1996), 197

Boer, Mulders, PRD57 (1998), 5780

In general, these interesting T-odd PtPDFs involve nontrivial initial (final) state interactions.

$p_\perp$ dependent PDF in Covariant Gauge

Collins & Soper, NPB194 (1982), 445

The transverse-momentum parton distribution is defined

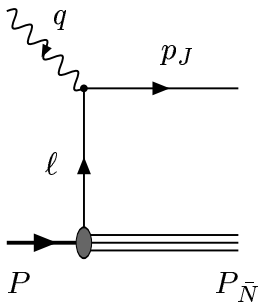
$$\begin{aligned} f(x,k_\perp) &= \frac{1}{2}\int \frac{d\xi^- d^2\xi_\perp}{(2\pi)^3} e^{-i(\xi^- k^+ - \vec{\xi}_\perp\cdot\vec{k}_\perp)} \\ &\quad \times \langle P|\overline{\psi}(\xi^-,\xi_\perp) L^\dagger_{\xi_\perp}(\infty,\xi^-)\gamma^+ L_0(\infty,0)\psi(0)|P\rangle \end{aligned}$$

The path-ordered light-cone gauge link L

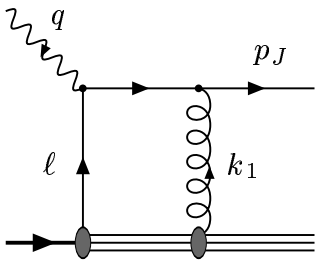
$$L_{\xi_\perp}(\infty,\xi^-) = P\exp\left(-ig\int_{\xi^-}^{\infty} A^+(\zeta^-,\xi_\perp)d\zeta^-\right) \ .$$

arises from the final state interactions (Brodsky, Hoyer, Marchal, Peigne, Sannino, hep-ph/0104291), and will lead to T-odd PtPDFs (Brodsky, Hwang, Schmidt, PLB530(2002), 99; Collins, PLB536(2002), 431).

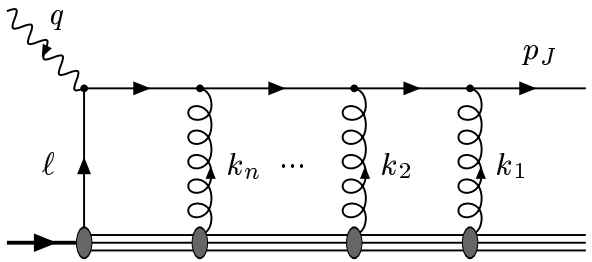
The gauge link represents factorizable final state interactions which can be calculated in eikonal approximation



(a)



(b)



(c)

Belitsky, Ji, FY, hep-ph/0208038

$p_\perp$ dependent PDFs in Light-cone Gauge

Ji & FY, PLB543 (2002), 66, hep-ph/0206057

In Light-cone gauge, the light-cone gauge link vanishes.

The final state interactions generates a gauge link at $\xi^- = \infty$, which has been missed in the literature before.

$$L_0(\infty, 0) \to \Delta L = P \exp\left(-ig \int_0^\infty d\zeta_\perp \cdot A_\perp(\zeta^- = \infty, \zeta_\perp)\right)$$

The new gauge link makes the PtPDFs completely gauge invariant, including fixing the prescription for light-cone singularity.

Fixing light-cone singularity

Light-cone gauge propagator,

$$D_{\mu\nu}(q^2) = \frac{-i}{q^2 + i\epsilon}(g_{\mu\nu} - \frac{q_\mu n_\nu + q_\nu n_\mu}{q \cdot n})$$

has singularity at $q \cdot n = 0$. To regularize these light-cone singularities, the following prescriptions are usually used

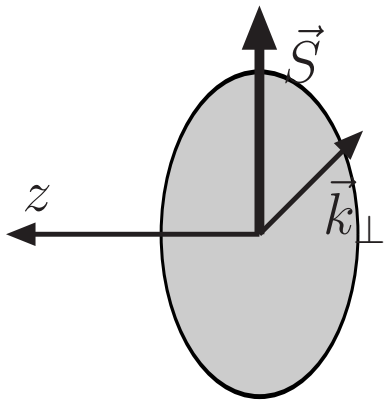
$$\frac{1}{[k^+]} = \begin{cases} \text{Adv}: & \frac{1}{k^+ - i\epsilon} \\ \text{Ret}: & \frac{1}{k^+ + i\epsilon} \\ \text{PV}: & \frac{1}{2}\left\{\frac{1}{k^+ + i\epsilon} + \frac{1}{k^+ - i\epsilon}\right\} \end{cases}$$

The extra gauge link guarantee the calculation of PtPDFs in light-cone gauge completely independent of these prescriptions.

Belitsky, Ji, FY, hep-ph/0208038

A Bag Model calculation of PtPDFs

- Bag model quark state contains both S and P wave components, which are necessary to generate an interference. However, there is no phase difference.
- The final state interactions (gauge link) is crucial to generates ϕ dependent parton distribution function. (S and P waves have different final state interaction phases.)



- Results and comparison with experiments will be published soon (Ji & FY, to be published).

Two comments about PtPDFS

- Non-universality of the PtPDFs,

$$\text{DIS} \quad \text{PtPDFs} \neq \text{DY} \quad \text{PtPDFs}$$

  because of gauge link ($\infty \to -\infty$)

- Universality of PDFs,

$$\text{DIS} \quad \text{PDFs} = \text{DY} \quad \text{PDFs}$$

  because of unitairity.