Tree-level matching relations for next-to-leading power transverse momentum distributions with mass corrections

Alessio Carmelo Alvaro

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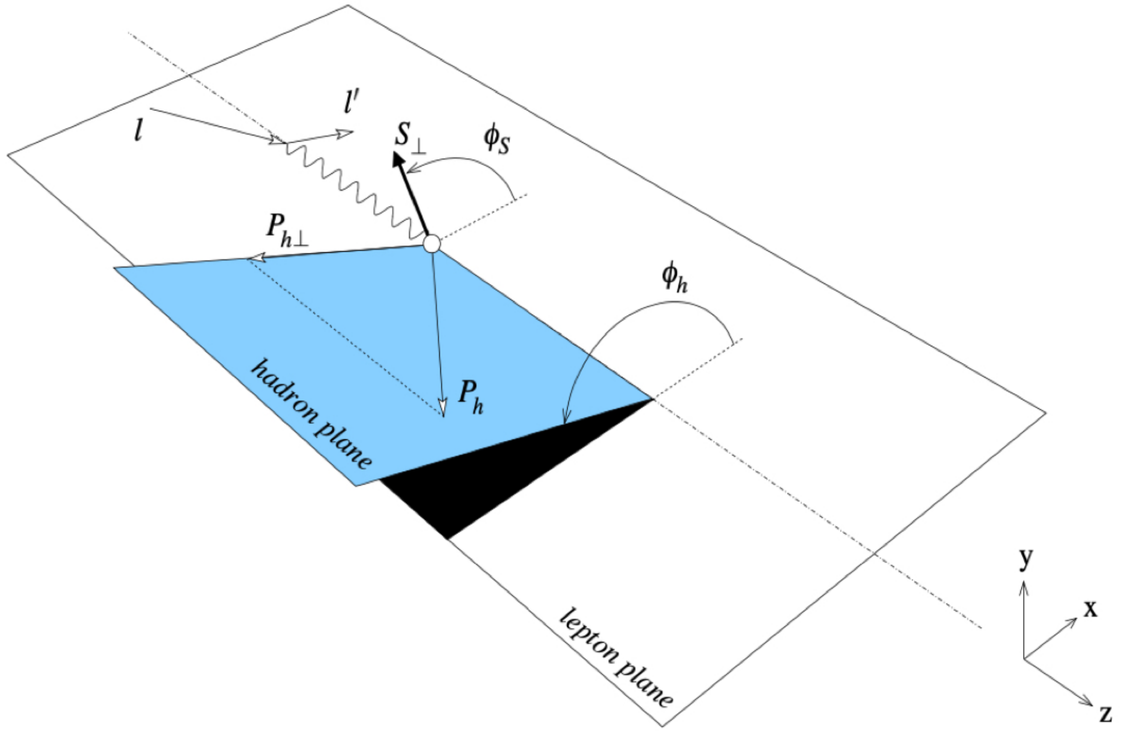
In collaboration with B. Pasquini and S. Rodini
Science at the Luminosity Frontier: Jefferson Lab at 22 GeV,
Laboratori Nazionali di Frascati, 9-13 December 2024

Alessio Carmelo Alvaro, University of Pavia and INFN Pavia, 10/12/2024

Why higher twists?

18 Structure Functions in SIDIS



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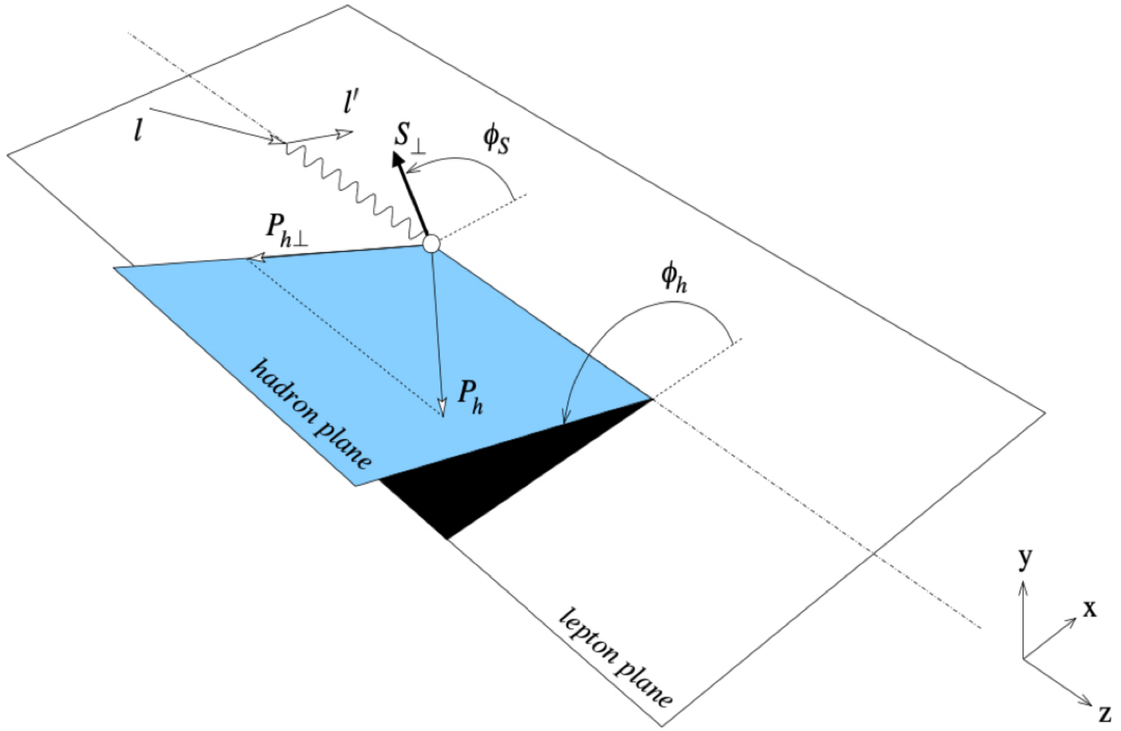
Why higher twists?

18 Structure Functions in SIDIS → Only 8 with LP TMDs



Leading Quark TMDPDFs

Nucleon Spin Quark Spin

Nucleon Polarization	Quark Polarization: Un-Polarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
U	f_1 = Unpolarized		$h_1^\perp$ = Boer-Mulders
L		g_1 = Helicity	$h_{1L}^\perp$ = Worm-gear
T	$f_{1T}^\perp$ = Sivers	$g_{1T}^\perp$ = Worm-gear	h_1 = Transversity; $h_{1T}^\perp$ = Pretzelosity

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Can we describe the other structure functions?

Why higher twists?

18 Structure Functions in SIDIS → Only 8 with LP TMDs

Can we describe the other structure functions?

Can we predict the magnitude of them?

Why higher twists?

18 Structure Functions in SIDIS → Only 8 with LP TMDs

Can we describe the other structure functions?

Can we predict the magnitude of them?

Do these structure functions provide new insights into proton structure?

Twist 3 in SIDIS

Kinematic NLP corrections $\propto \frac{2M}{Q} \mathring{f}(x,b) \otimes D(z,b)$

$$\propto \frac{2M}{Q} f(x_1, x_2, x_3, b) \otimes D(z,b)$$

Genuine NLP corrections

$$\propto \frac{2M}{Q} f(x,b) \otimes D(z_1, z_2, z_3, b)$$

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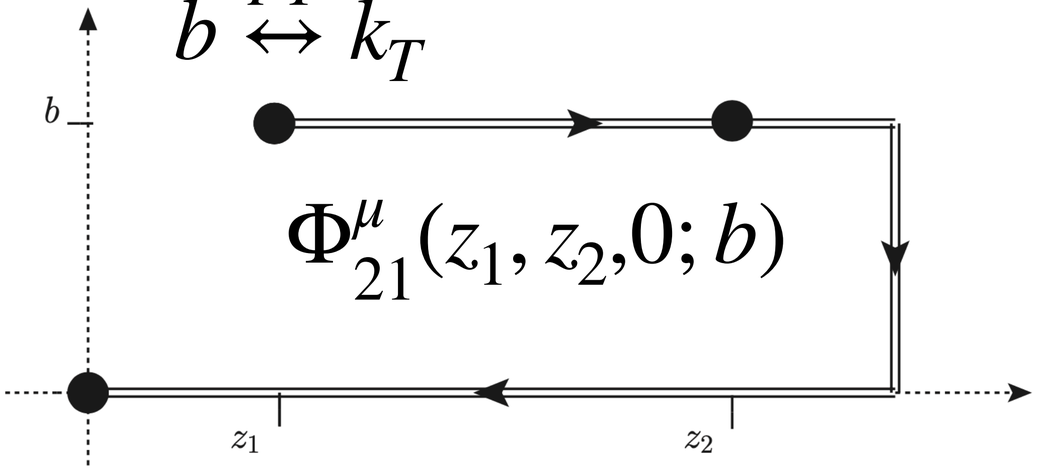
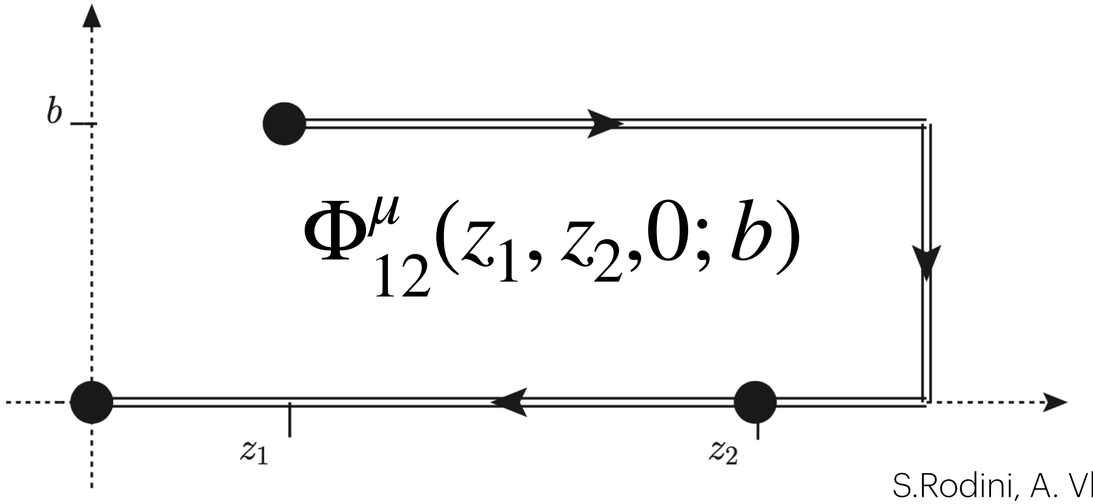
Twist 3 TMDPDFs

$$b \overset{FT}{\leftrightarrow} k_T$$





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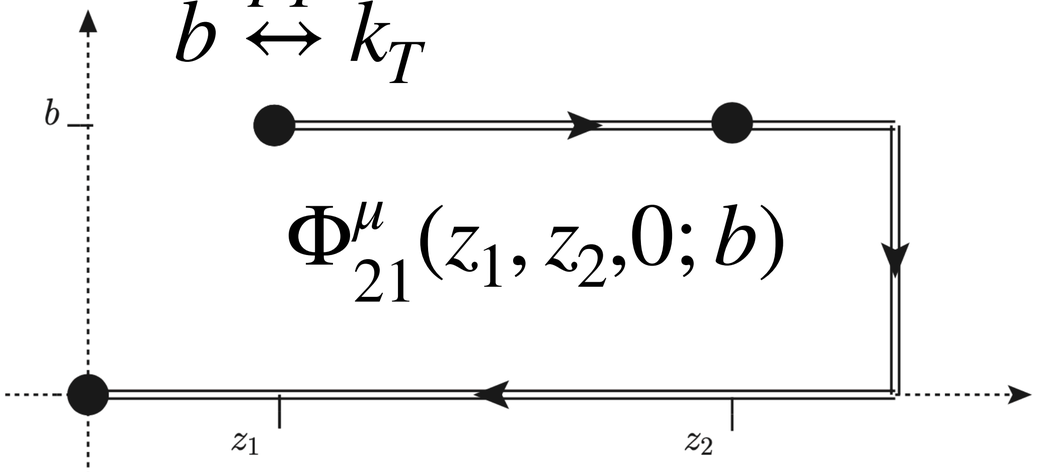

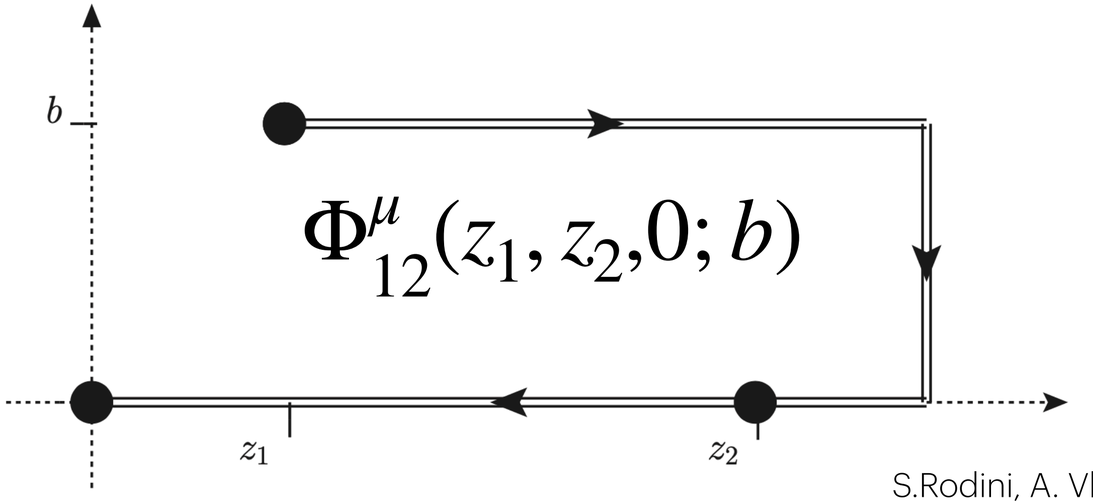

Quark-gluon correlations

32 Twist 3 TMDs

Physical distributions:

$$\Phi^{\mu}_{\oplus} = \frac{1}{2}\left(\Phi^{\mu}_{21} + \Phi^{\mu}_{12}\right)$$

$$\Phi^{\mu}_{\ominus} = \frac{i}{2}\left(\Phi^{\mu}_{21} - \Phi^{\mu}_{12}\right)$$

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Matching Relations

In the small b regime:

$$f_i(x_1, x_2, x_3, b) = \sum_j C_{ij}(x_1, x_2, x_3, b) \otimes f_j(x_1, x_2, x_3) + O(b^2)$$

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Constraint on TMDs functional form

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Predictions for TMD observables in the small b region

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Constraint on TMDs functional form

Predictions for TMD observables in the small b region

$$f_j(x_1, x_2, x_3) \in \{T, \Delta T, E, H\}$$

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The technique

1. Compactification of the correlator $\mp\infty \rightarrow L$

V.Moos, A. Vladimirov, 2008.01744

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The technique

1. Compactification of the correlator $\mp\infty \to L$

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The technique

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4. Forward matrix element, limit $L \to \mp\infty$ and Fourier transform to the space of partons fractions of momentum

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Results

$$h_{\oplus}(x_1, x_2, x_3, b) = E(x_1, x_2, x_3)$$

$$+\sum_{n=1}^{\infty} \frac{1}{n!(n-1)!} \left(\frac{x_3^2 M^2 b^2}{4} \right)^n C \left[u \left(\frac{\bar{u}}{u} \right)^{n-1} E(y_1, y_2, y_3) \right]$$

Leading Term

Mass Series

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Results

$$h_{\ominus T}^{D\perp}(x_1, x_2, x_3, b) = -x_3 \int_0^1 du H\left(\frac{x_1}{u}, \frac{x_2}{u}, \frac{x_3}{u}\right) + O(x_3^2 M^2 b^2)$$

Wandzura-Wilczek like relation

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7 twist 3 TMDPDFs match onto twist 3 PDF

$$\{f_{\oplus T}, g_{\ominus T}, h_{\oplus}, h_{\ominus L}\}, \{f_{\oplus L}^{\perp}, g_{\ominus L}^{\perp}, h_{\ominus T}^{D\perp}\}$$

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Application to SIDIS

$$F_{LU}^{\sin\phi} \propto h_{\oplus} \otimes H_1^{\perp}$$

No kinematic corrections

Magnitude of Genuine NLP corrections

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Application to SIDIS

$$F_{UU}^{\cos\phi} \propto \left(h_{\oplus} \otimes H_1^{\perp}\right) \delta(x_2) + kin$$

$$h_{\oplus}(-x,0,x,b) \approx \pi^{-1} h_1^{\perp}(x,b) \Rightarrow F_{UU,QS-like}^{\cos\phi} \gtrsim \frac{2M}{Q} F_{UU,T}^{\cos 2\phi}$$

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Application to SIDIS

- $F_{UT}^{\sin 2\phi-\phi_S} \propto h_{\ominus T}^{D\perp} \otimes H_1^{\perp} + kin$

- $F_{UL}^{\sin\phi}, F_{LL}^{\cos\phi}, F_{UT}^{\sin\phi_S}, F_{LT}^{\cos\phi_S}$: interplay between different TMDPDFs

- $F_{LT}^{\cos 2\phi-\phi_S} \sim NLO$

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Summary

Why higher twists: new insights in proton structure and phenomenology

Twist 3 TMDs: quark-gluon correlations

Technique: OPE + twist decomposition

Results: leading term + mass corrections' series

Application to SIDIS: simplification in NLP structure functions

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