SIDIS Phenomenology

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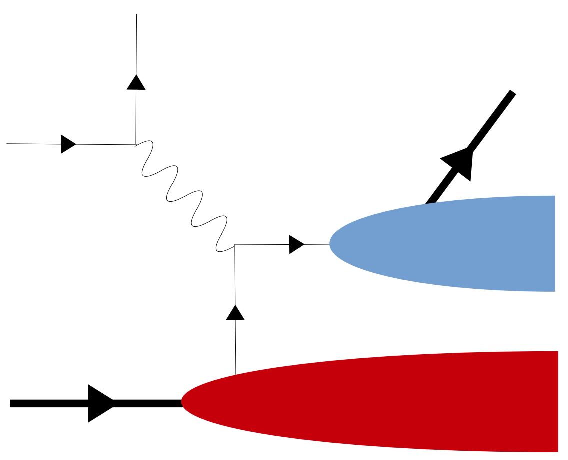
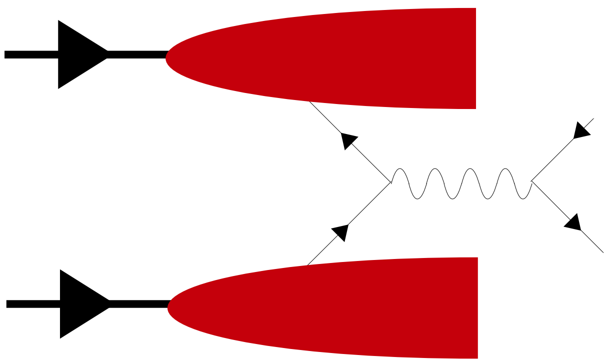
University of Turin

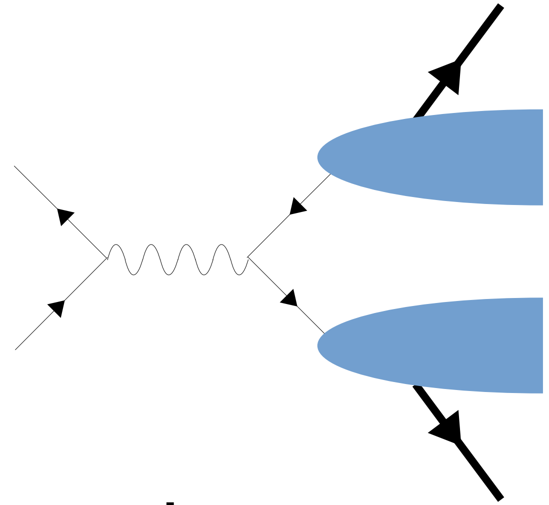


SIDIS

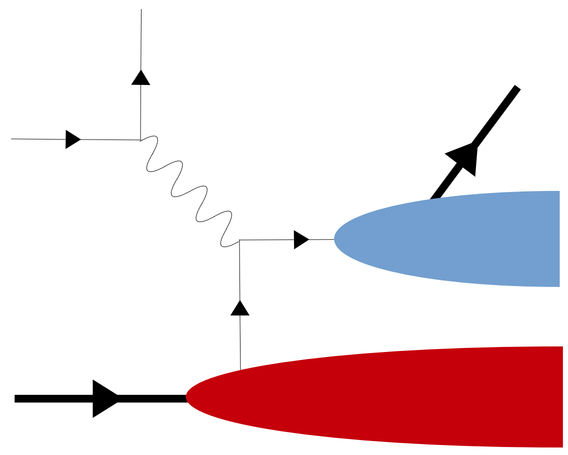
Phenomenology

Drell Yan





e+e-

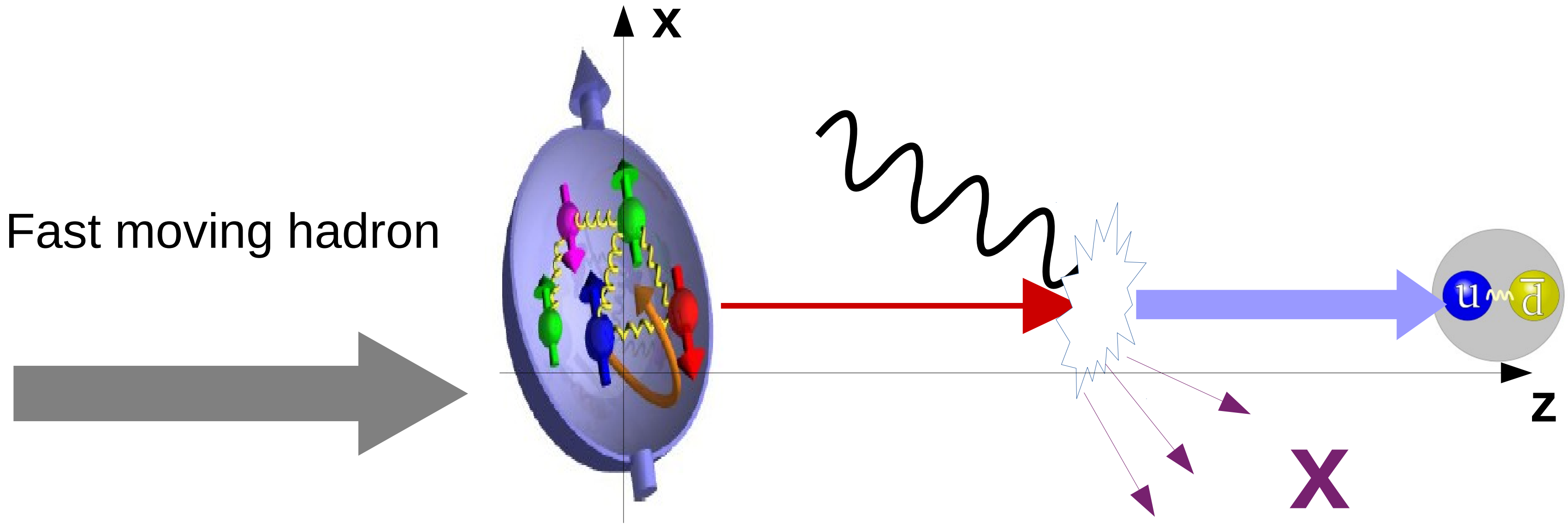


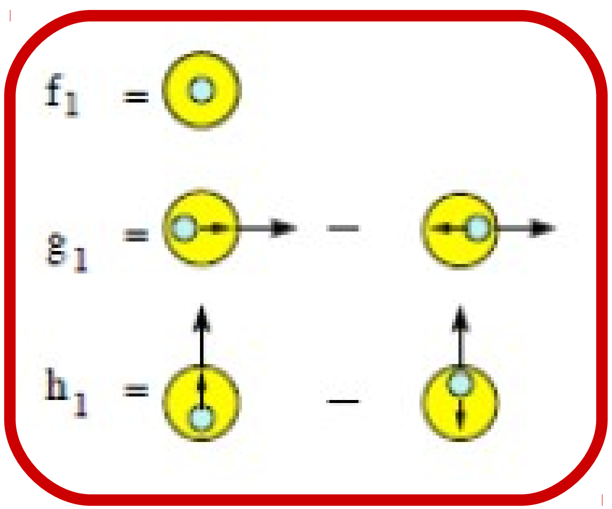
PDFs

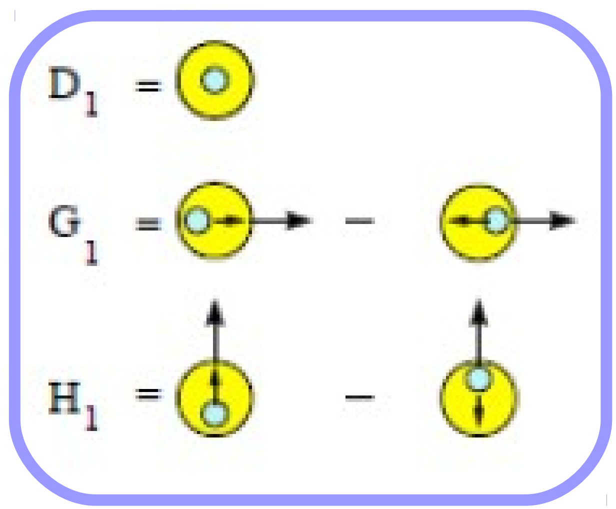
Fragmentation Functions

SIDIS

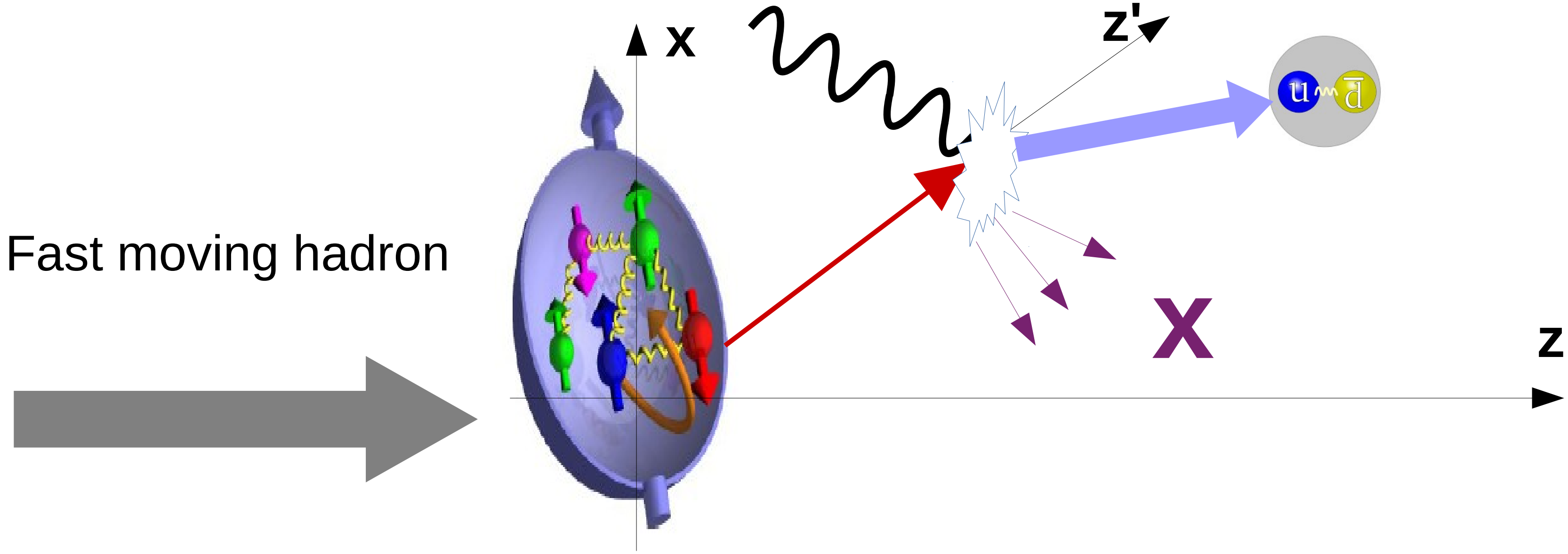
SIDIS: Collinear case

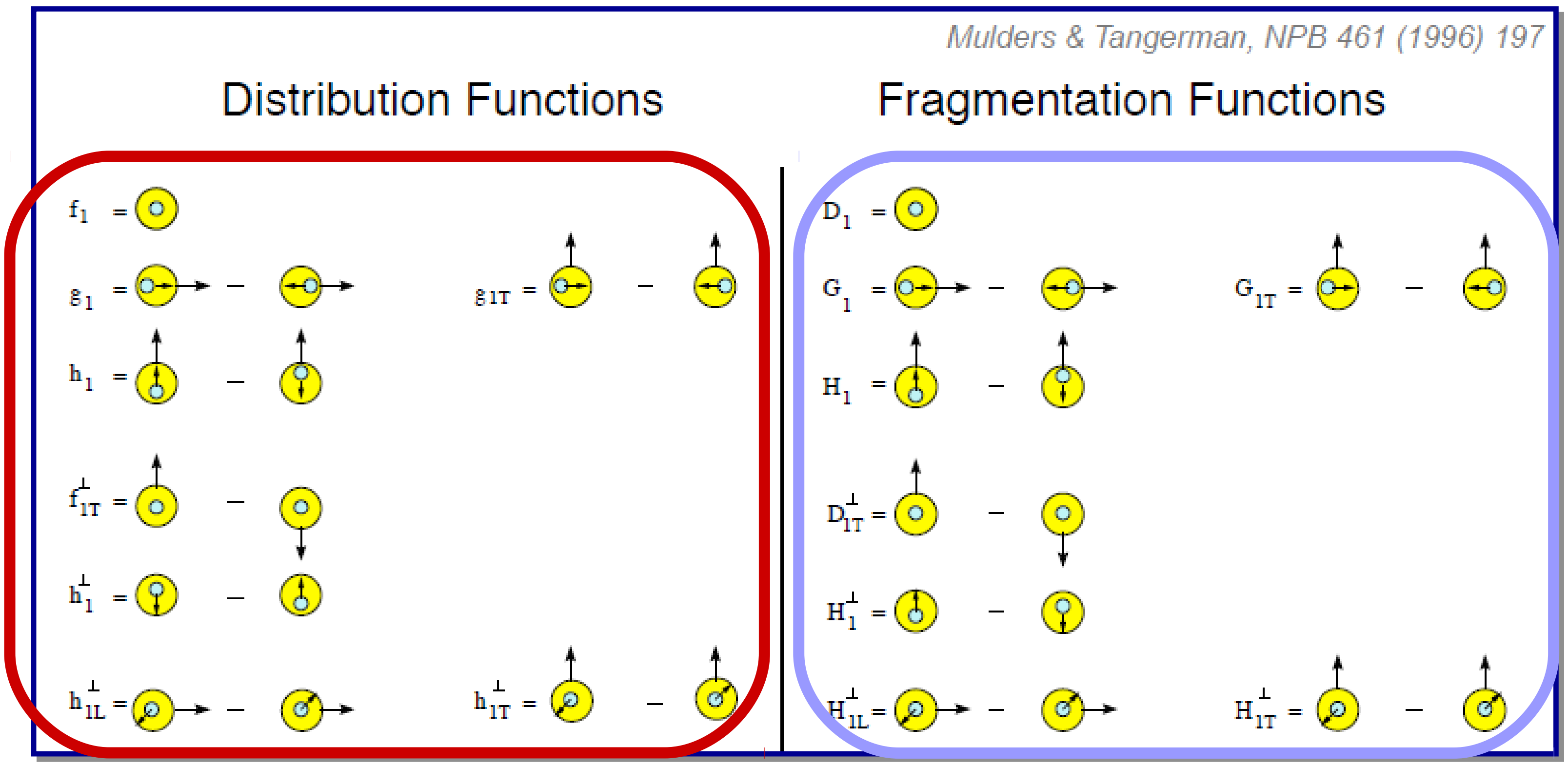






SIDIS: TMD case





Ultimately, we want to extract TMDs

Fourier Transform of:

$$\tilde{F}_j(x, b_T, Q, \zeta_F) = \left(\frac{\sqrt{\zeta_F}}{\mu_b}\right)^{\tilde{K}(b_*, \mu_b)} \sum_j \int_x^1 \frac{d\hat{x}}{\hat{x}} \tilde{C}_{ji}^{in}(x/\hat{x}, b_*, \mu_b, \mu_b^2) f_i(\hat{x}, \mu_b)$$
$$\times \exp\left\{\int_{\mu_b}^{Q} \frac{d\mu}{\mu}\left(\gamma_F(\mu; 1) - \ln\left(\frac{\sqrt{\zeta_F}}{\mu}\right)\gamma_K(\mu)\right)\right\}$$
$$\times \exp\left\{-g_P(x, b_T) - g_K(b_T) \ln\left(\frac{\sqrt{\zeta_F}}{\sqrt{\zeta_{F0}}}\right)\right\},$$

Unpolarized TMD PDF

$$\tilde{D}_j(z, b_T, Q, \zeta_D) = \left(\frac{\sqrt{\zeta_D}}{\mu_b}\right)^{\tilde{K}(b_*, \mu_b)} \sum_k \int_z^1 \frac{d\hat{z}}{\hat{z}^3} \tilde{C}_{kj}^{out}(z/\hat{z}, b_*, \mu_b, \mu_b^2) D_j(\hat{z}, \mu_b)$$
$$\times \exp\left\{\int_{\mu_b}^{Q} \frac{d\mu}{\mu}\left(\gamma_D(\mu; 1) - \ln\left(\frac{\sqrt{\zeta_D}}{\mu}\right)\gamma_K(\mu)\right)\right\}$$
$$\times \exp\left\{-g_H(z, b_T) - g_K(b_T) \ln\left(\frac{\sqrt{\zeta_D}}{\sqrt{\zeta_{D0}}}\right)\right\}.$$

Unpolarized TMD FF

Ultimately, we want to extract TMDs

Often times, simple models are considered (no-evolution)

$$f_{q/p}(x,k_\perp) = f_{q/p}(x)\,\frac{e^{-k_\perp^2/\langle k_\perp^2\rangle}}{\pi\langle k_\perp^2\rangle}$$

$$D_{h/q}(z,p_\perp) = D_{h/q}(z)\,\frac{e^{-p_\perp^2/\langle p_\perp^2\rangle}}{\pi\langle p_\perp^2\rangle}\,.$$

Useful to map the shape of TMDs and to quantify kinematical dependencies on data. (but careful, limited validity)

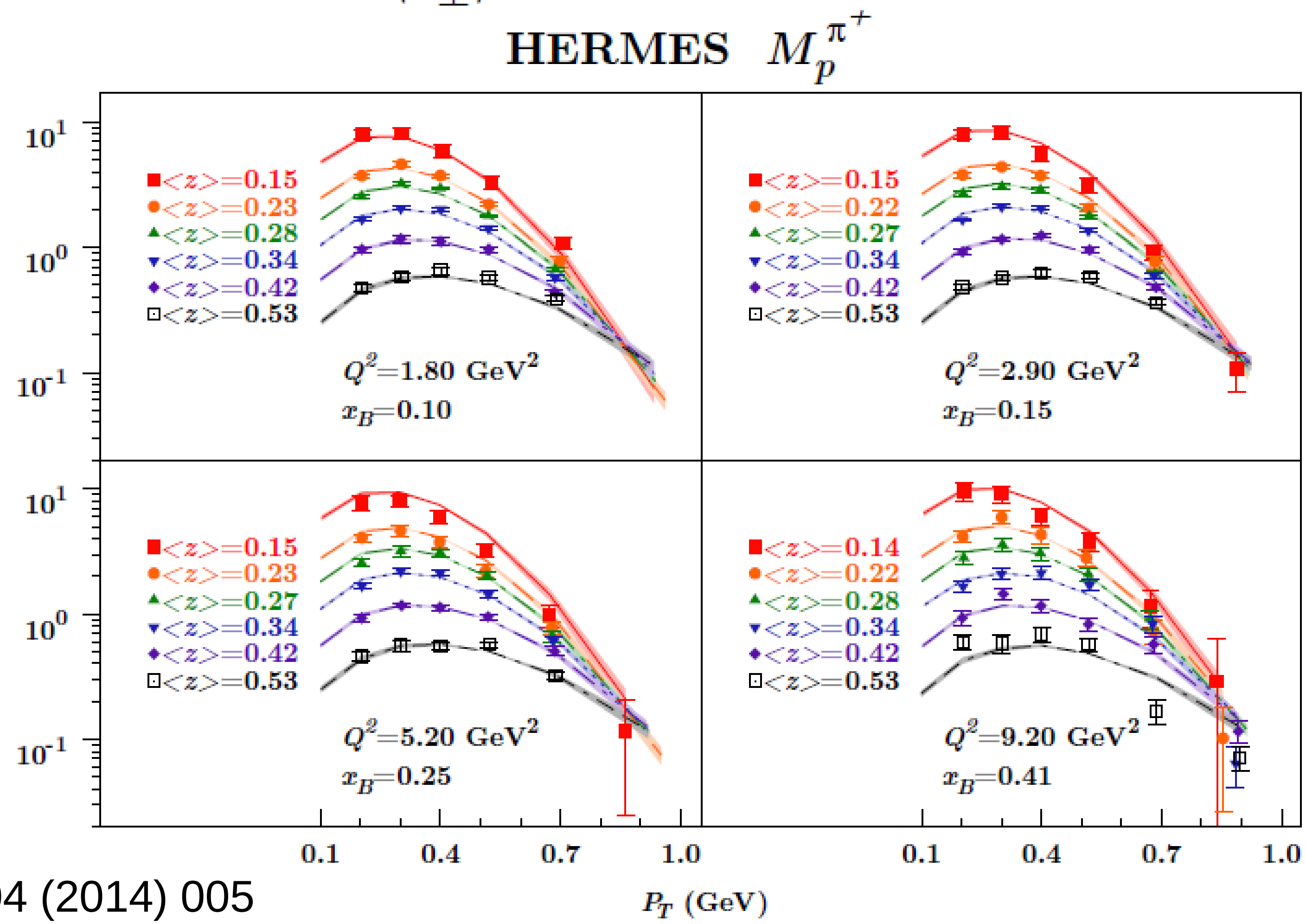
May be seen as a “snapshot” of the a TMD at some kinematics.

Example of simple model analysis

$$f_{q/p}(x,k_\perp) = f_{q/p}(x)\,\frac{e^{-k_\perp^2/\langle k_\perp^2\rangle}}{\pi\langle k_\perp^2\rangle}$$

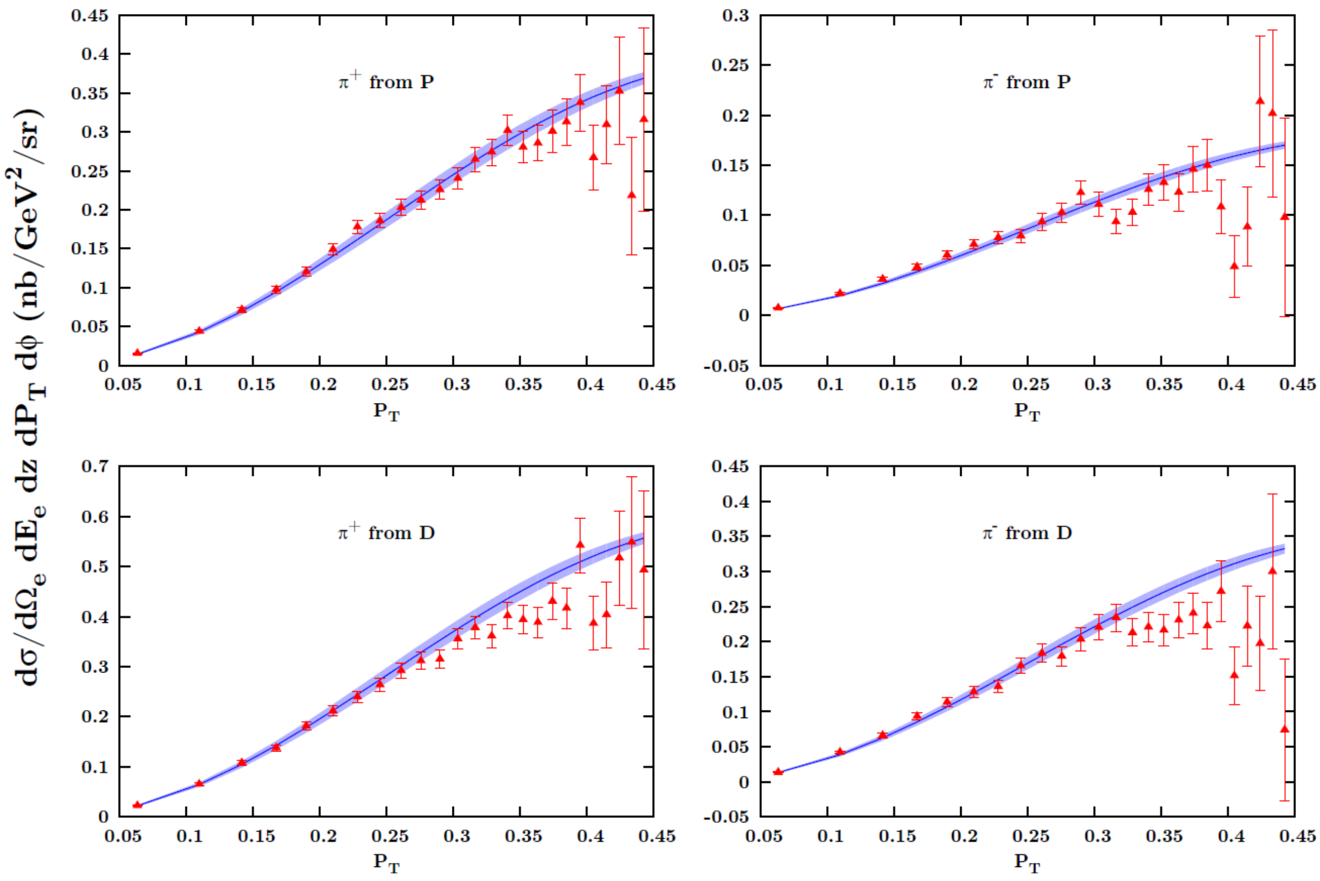
$$D_{h/q}(z,p_\perp) = D_{h/q}(z)\,\frac{e^{-p_\perp^2/\langle p_\perp^2\rangle}}{\pi\langle p_\perp^2\rangle}\,.$$

$$\langle P_T^2\rangle = \langle p_\perp^2\rangle + z_h^2\,\langle k_\perp^2\rangle\,.$$



JHEP 1404 (2014) 005

Anselmino, Boglione, Melis, JOGH, Prokudin

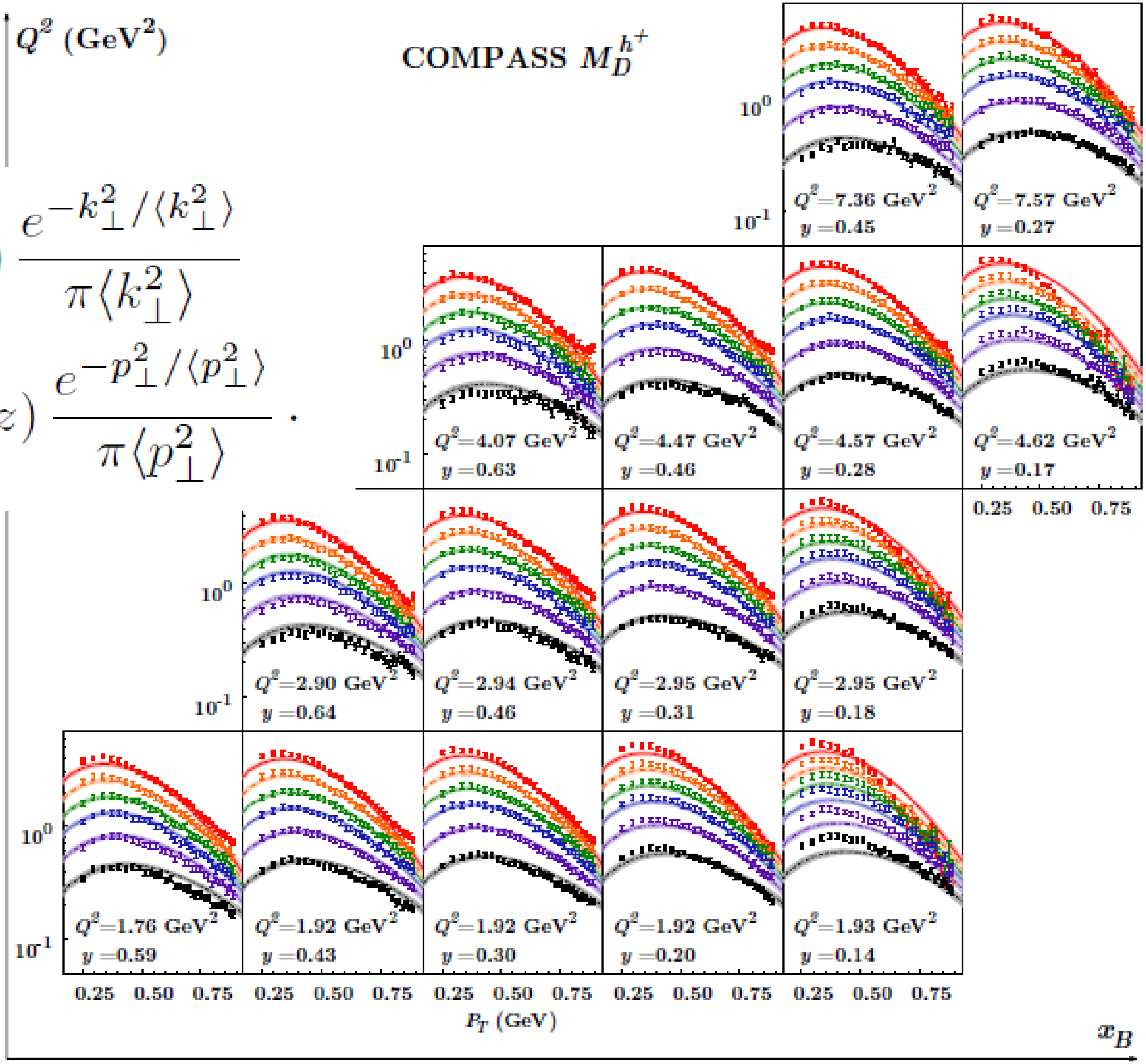


Constant widths: Comparison to Jlab data

Simple model

$$f_{q/p}(x, k_\perp) = f_{q/p}(x) \, \frac{e^{-k_\perp^2/\langle k_\perp^2 \rangle}}{\pi \langle k_\perp^2 \rangle}$$

$$D_{h/q}(z, p_\perp) = D_{h/q}(z) \, \frac{e^{-p_\perp^2/\langle p_\perp^2 \rangle}}{\pi \langle p_\perp^2 \rangle} \, .$$



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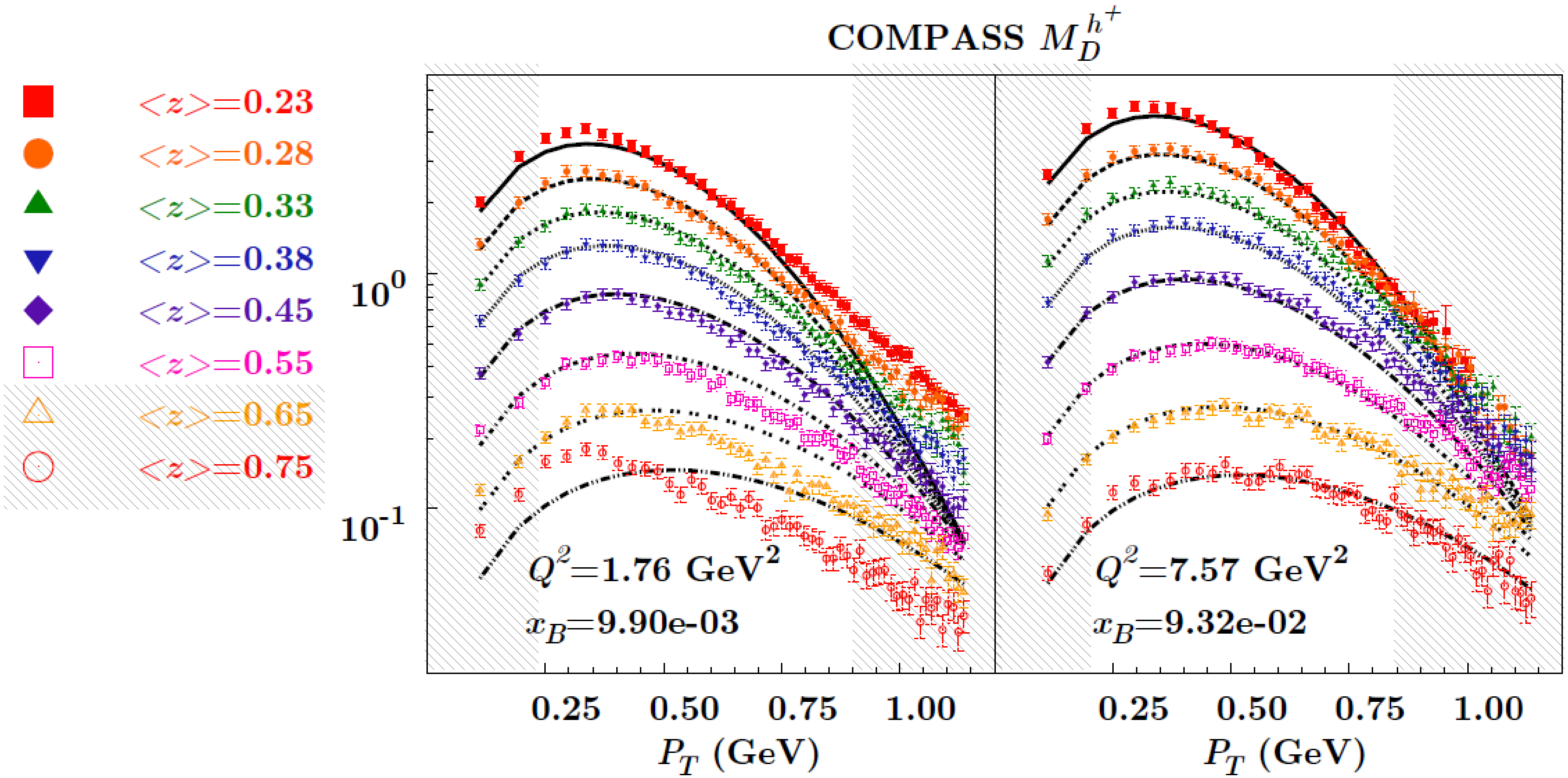
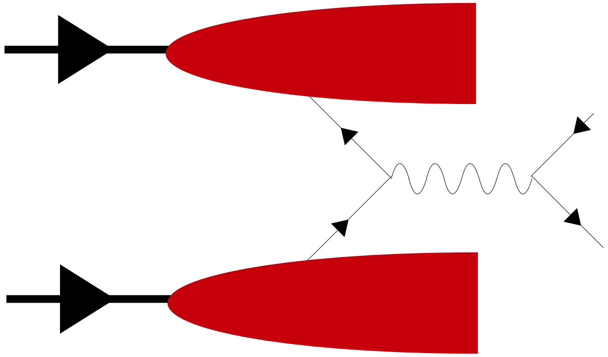


Need to go beyond simple model picture

What about the full (actual) definitions of the TMDs?

Some very interesting implementations in the market.

Drell Yan

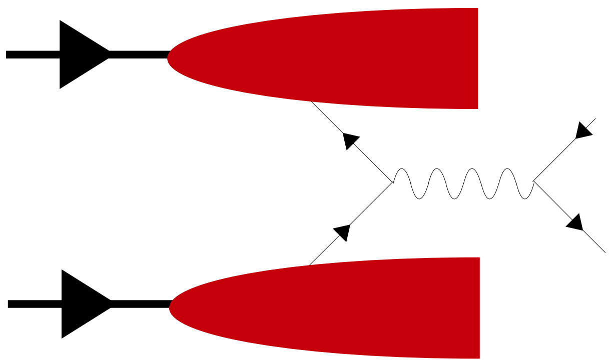


Under control, high precision phenomenology:

See a recent example:
Eur.Phys.J. C78 (2018) no.2, 89
Ignazio Scimemi, Alexey Vladimirov

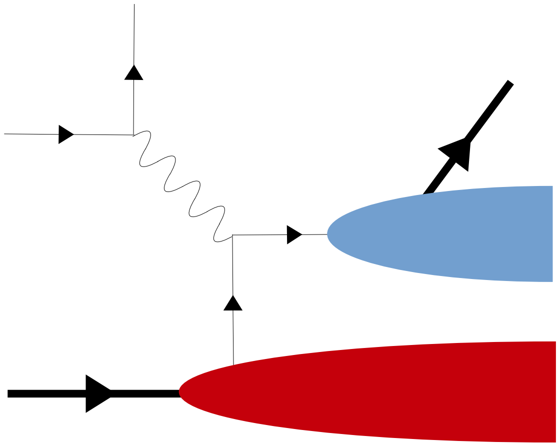
Global Fits? First attempts

Drell Yan



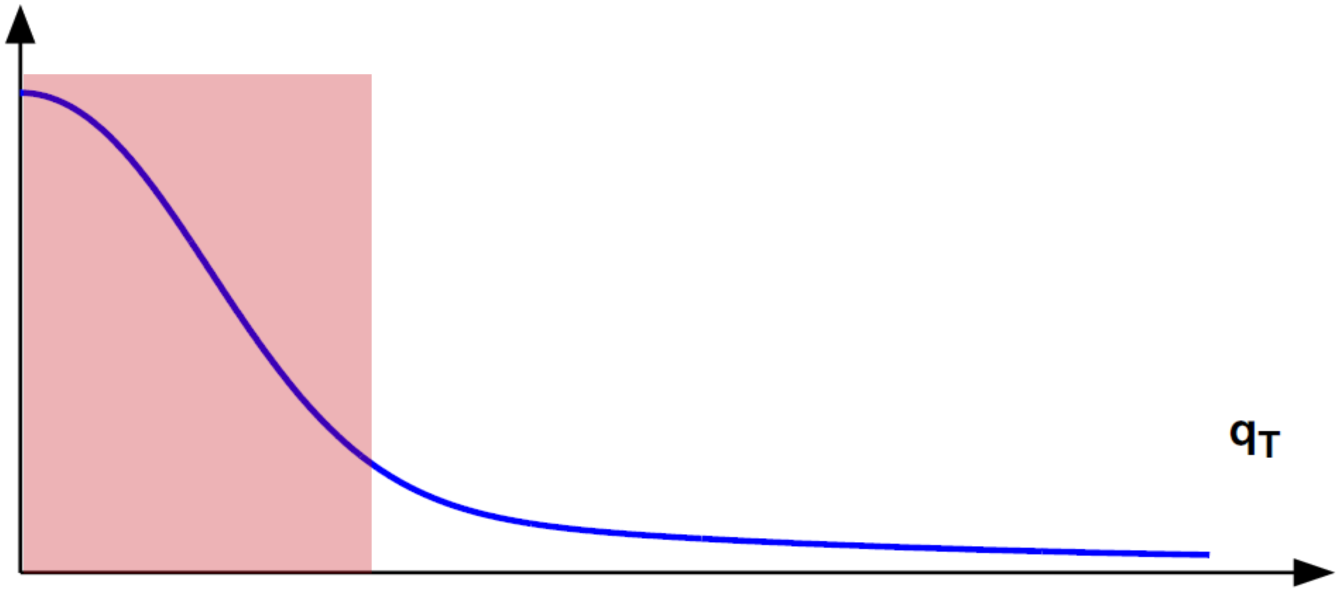
A. Bacchetta, F. Delcarro, C. Pisano, M. Radici , A. Signori
JHEP 1706 (2017) 081

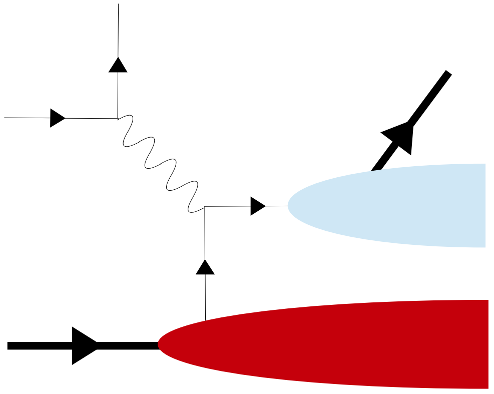
PDFs



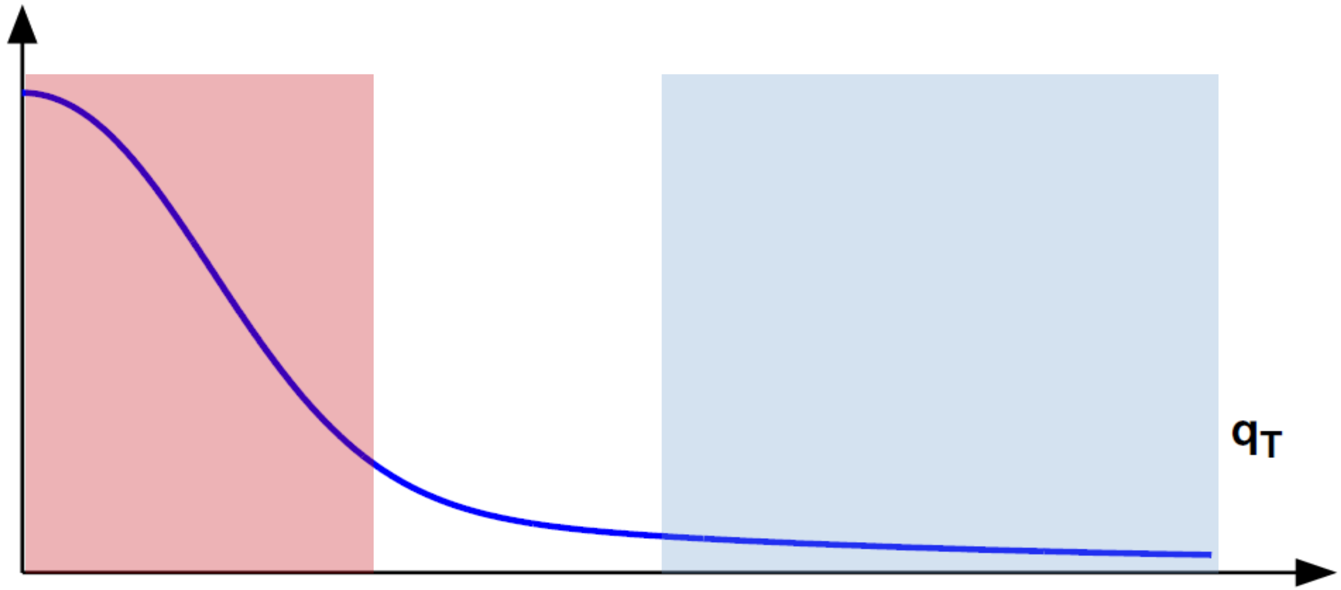
Fragmentation Functions

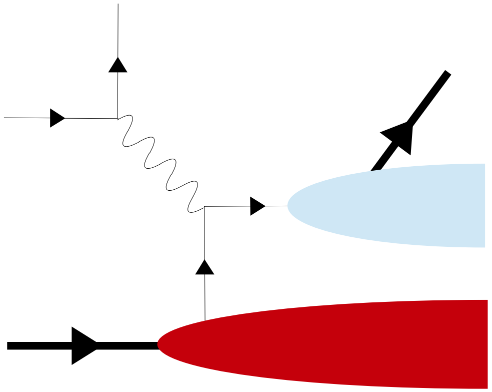
SIDIS



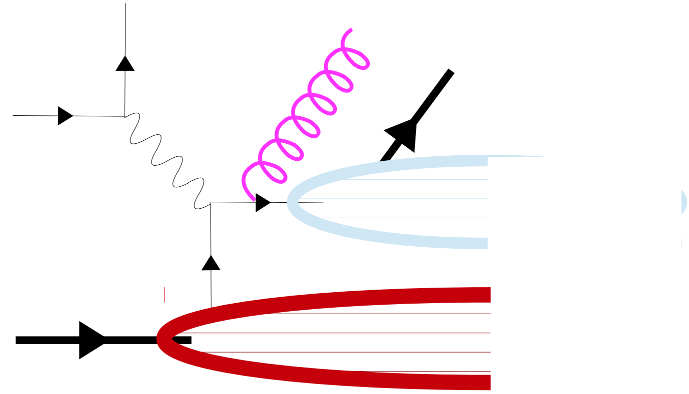


Non-perturbative
Transverse Momentum

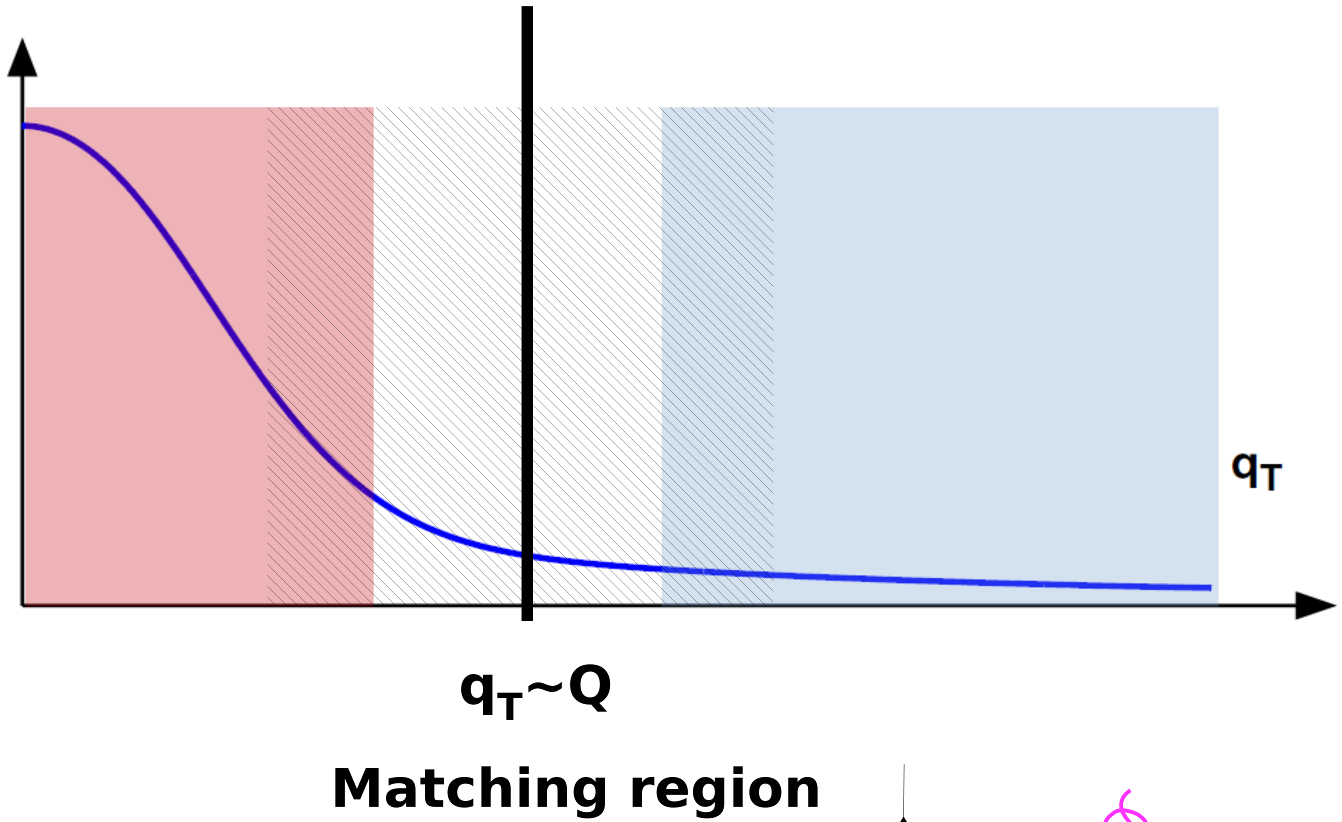


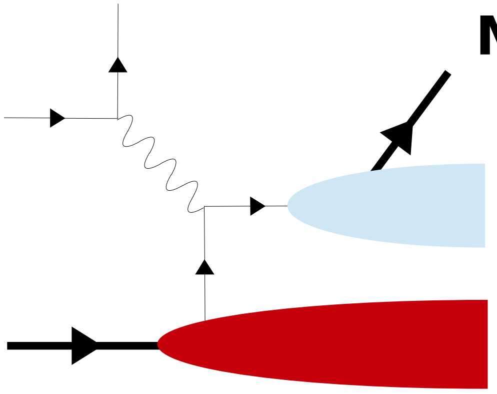


Non-perturbative
Transverse Momentum

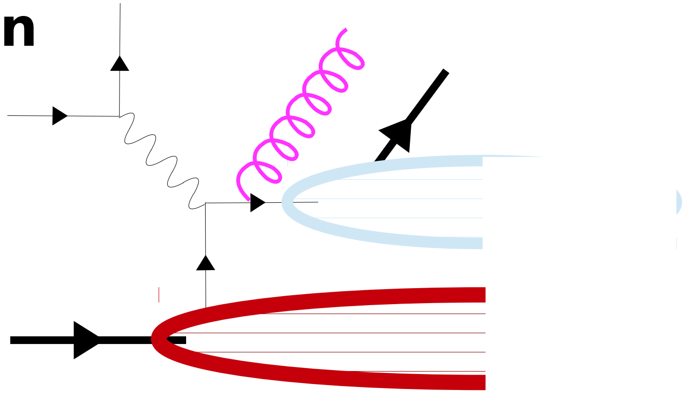


Hard gluon radiation

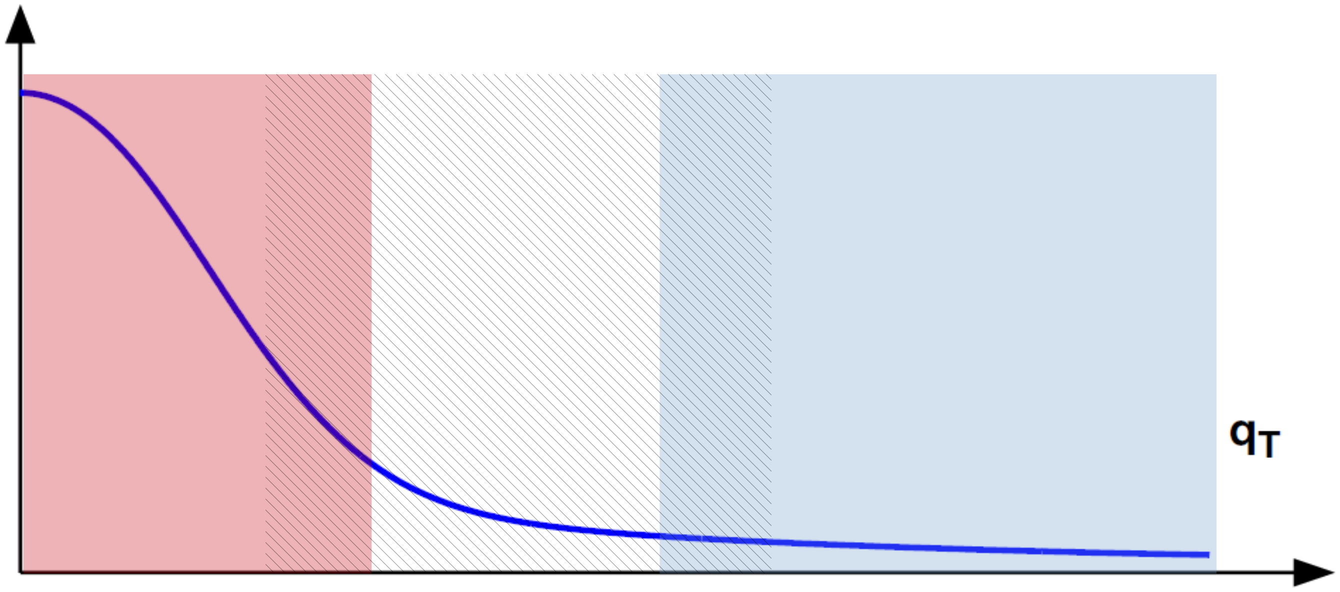




Non-perturbative
Transverse Momentum



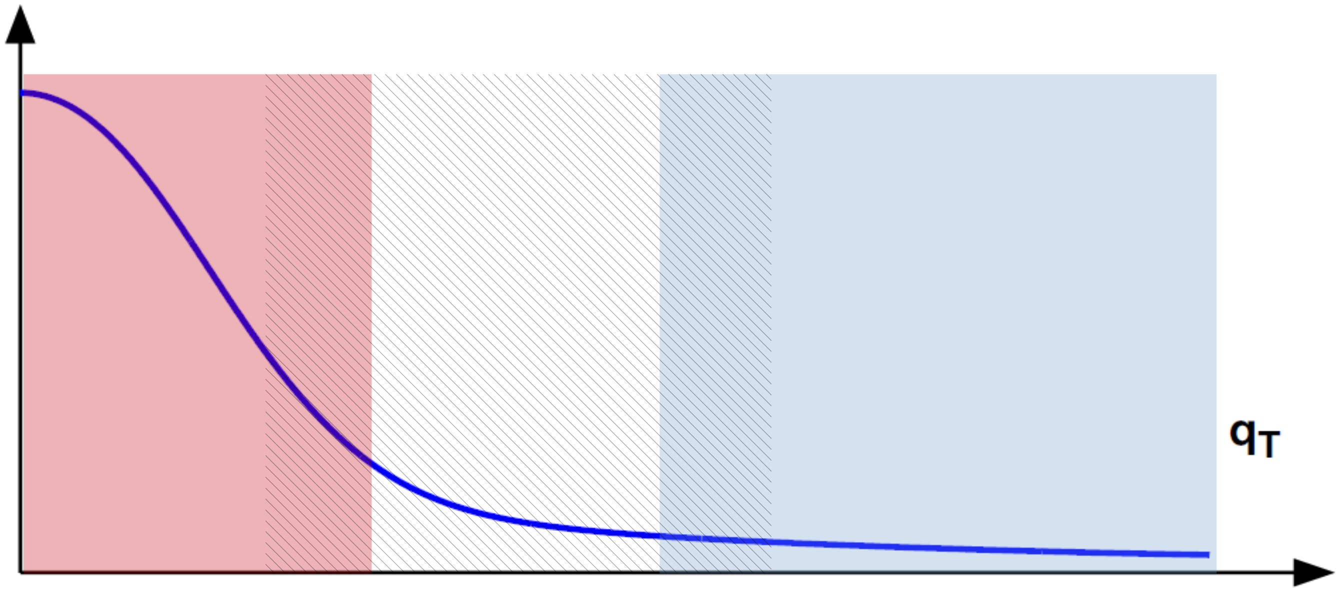
Hard gluon radiation



Collins-Soper-Sterman (CSS) formalism provides a matching scheme (other schemes available).

Successful implementations In Drell-Yan.

Several challenges in SIDIS.



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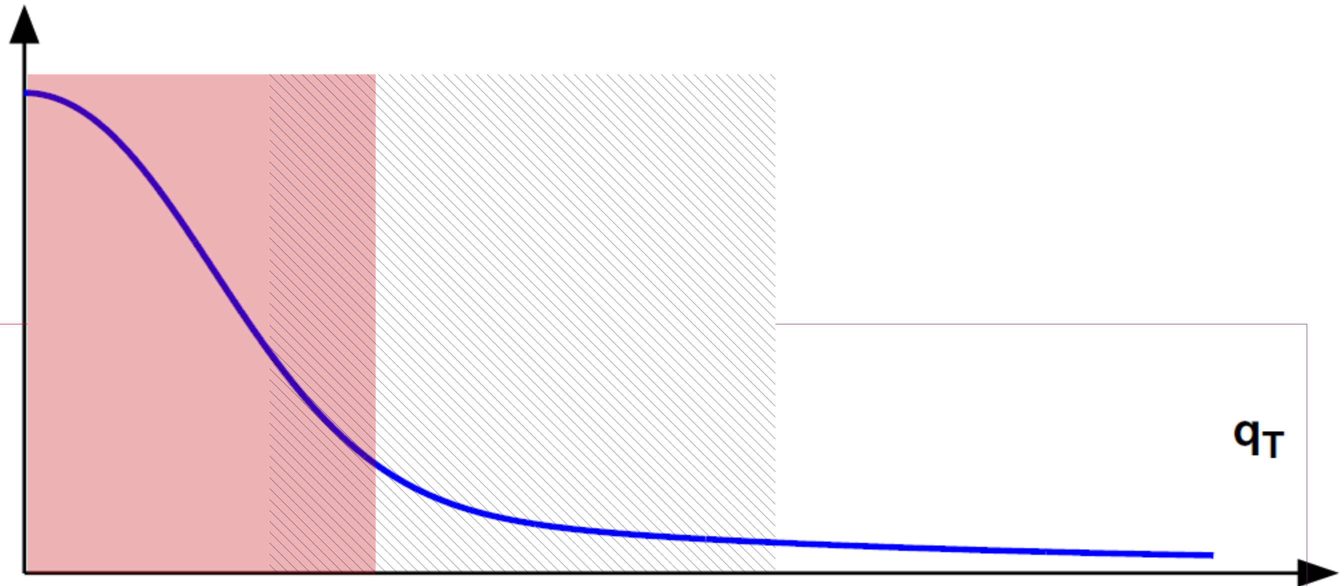
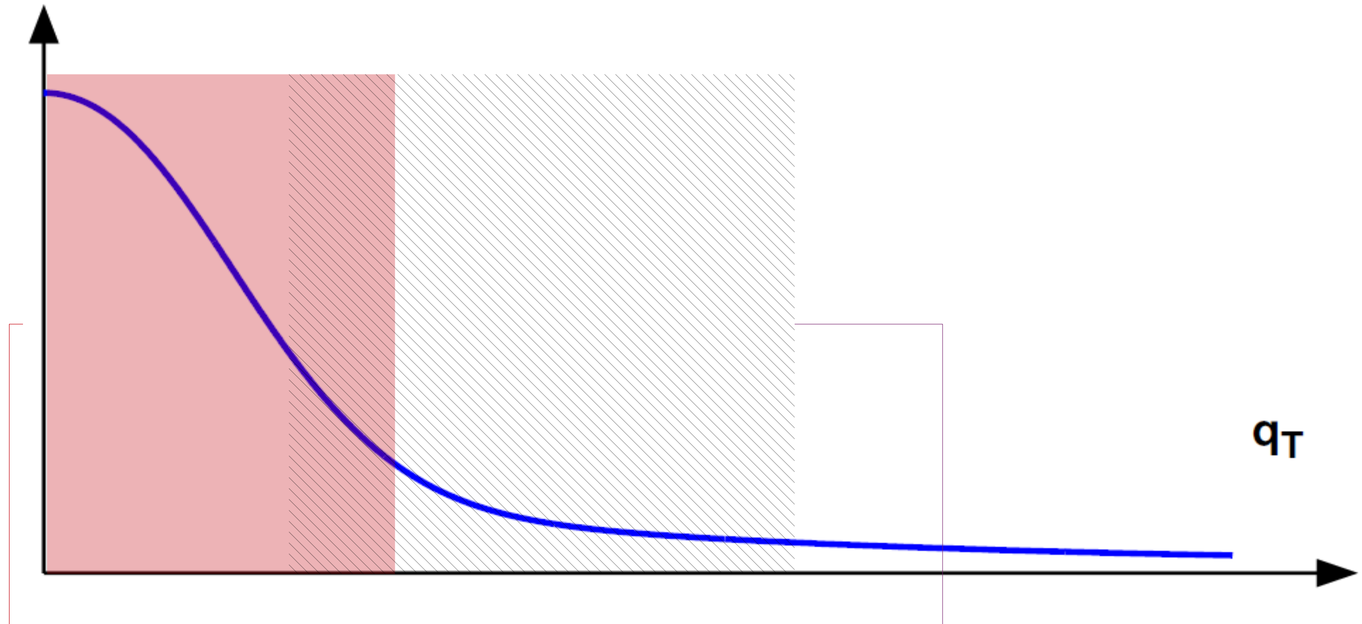


Unpolarized SIDIS cross section (current region)

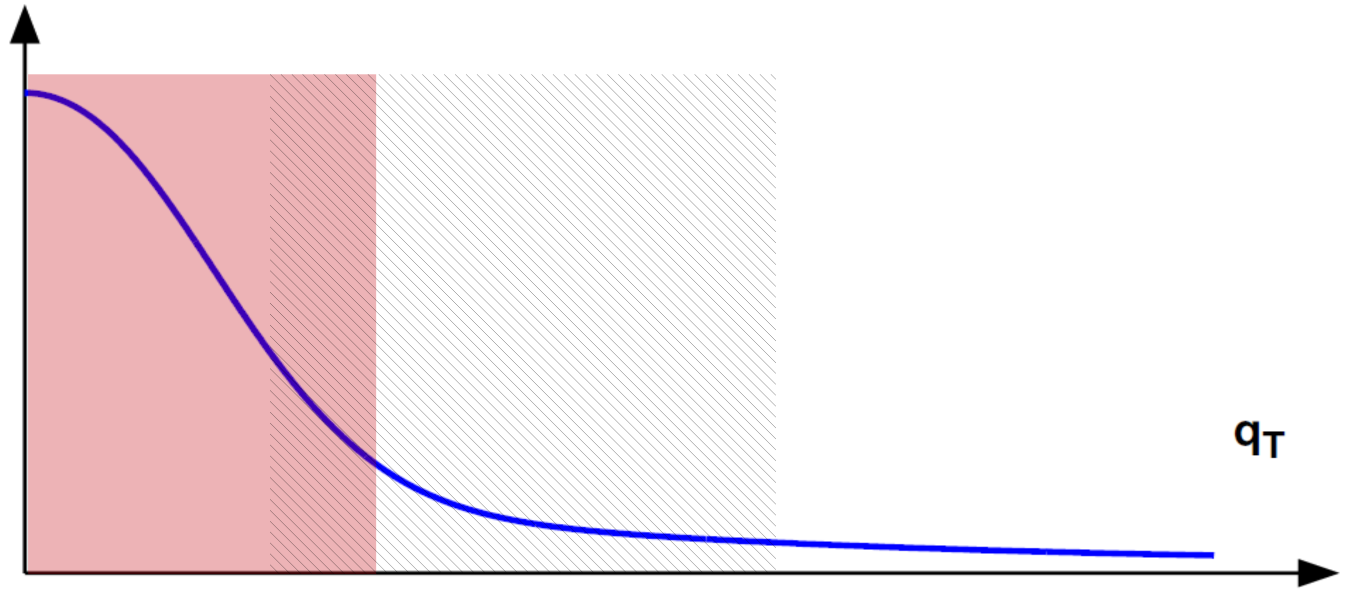
$$\frac{d\sigma^{\ell+p\to\ell' h X}}{dx_B\, dQ^2\, dz_h\, dP_T^2} = \frac{2\,\pi^2\alpha^2}{(x_B\, s)^2}\,\frac{\left[1+(1-y)^2\right]}{y^2}\, F_{UU}$$

$$F_{UU} = \sum_q \mathcal{H}_q \text{ F.T.}\left\{\tilde{D}_{h/q}(z, z\,\boldsymbol{b}_\perp; Q)\ \tilde{f}_{q/P}(x, \boldsymbol{b}_\perp; Q)\right\} + \text{large } q_T \text{ corrections}$$

$$+ \text{ power suppressed terms}$$



$$W + Y$$

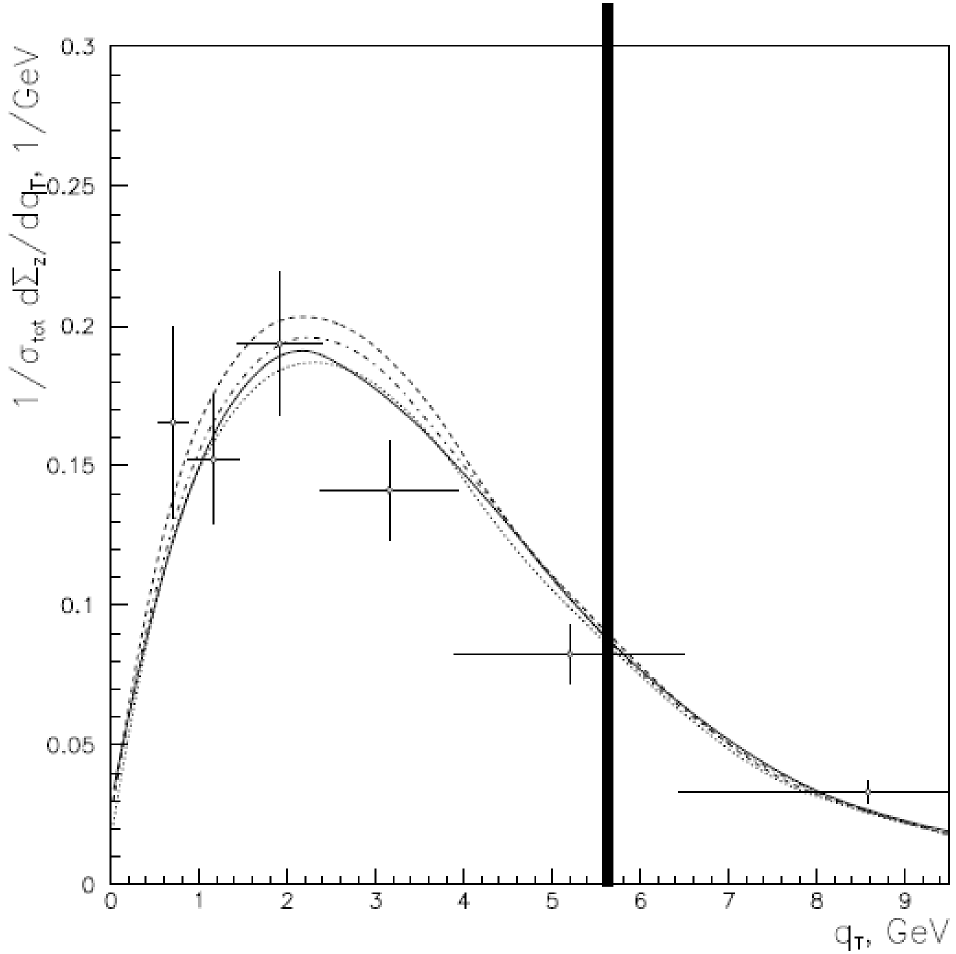


No sharp transitions between regions.

Large qT-corrections cannot be ignored in TMD phenomenology.

$$\boxed{W} + \boxed{Y}$$

$$\langle x \rangle = 0.0049, \ \langle Q^2 \rangle = 32.6 \ \mathrm{GeV}^2$$



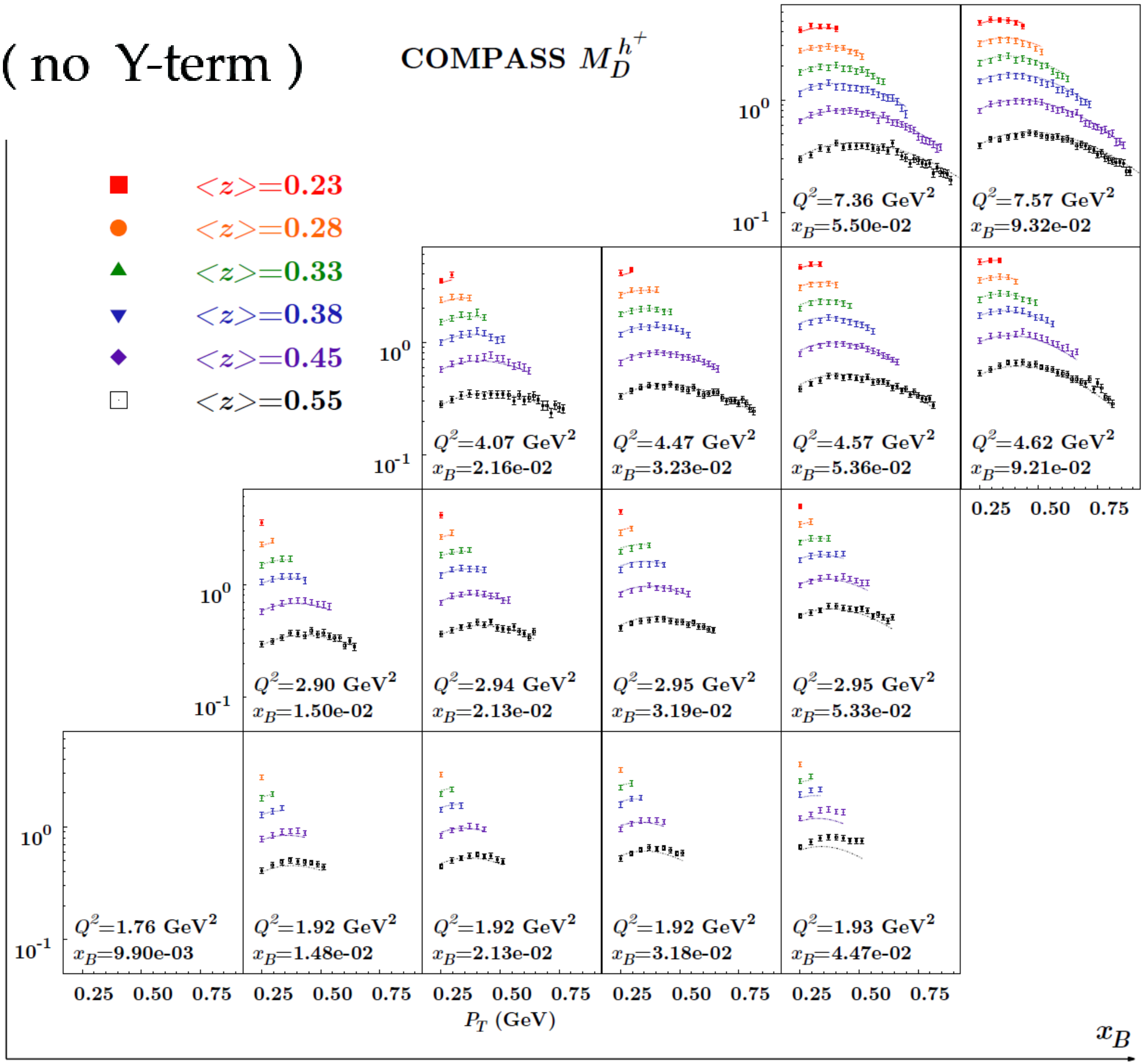
HERA data

Nadolsky, Stump, Yuan

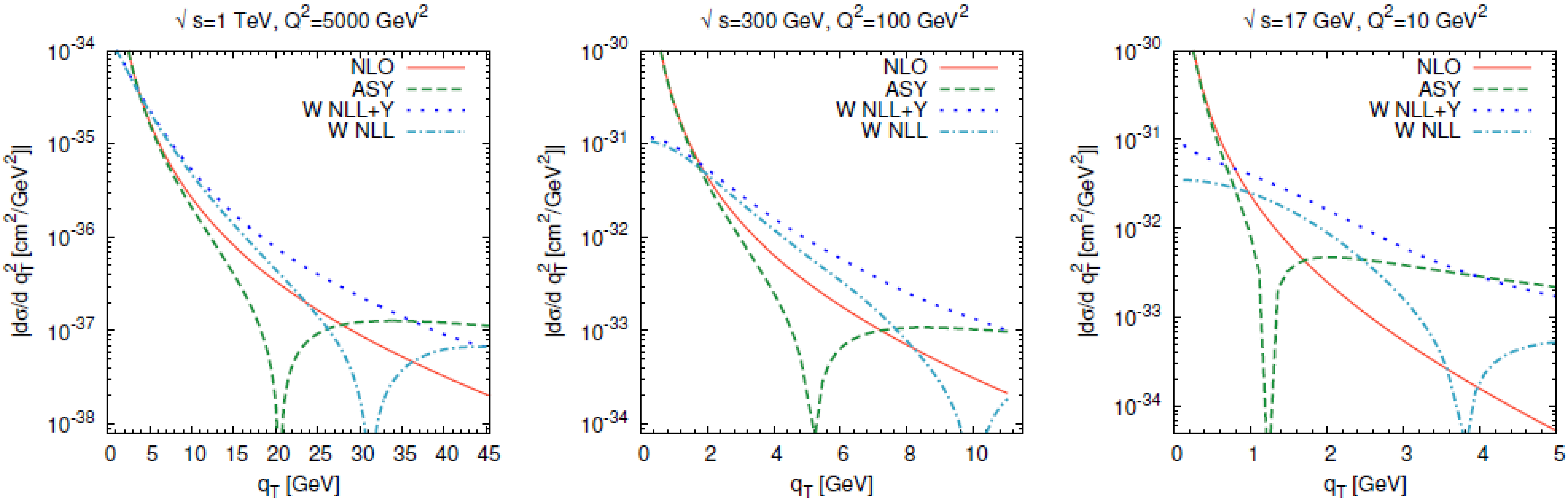
Phys.Rev.D61:014003,2000

$$\langle E_T \rangle_{\Phi_B} = \frac{1}{\sigma_{tot}} \sum_B \int_{\Phi_B} d\Phi_B \ E_T \frac{d\sigma(e + A \to e + B + X)}{d\Phi_B}$$

W (no Y-term)



COMPASS $M_D^{h^+}$
$<z>=0.23$
$<z>=0.28$
$<z>=0.33$
$<z>=0.38$
$<z>=0.45$
$<z>=0.55$
Q^2=7.36 GeV^2 x_B=5.50e-02
Q^2=7.57 GeV^2 x_B=9.32e-02
Q^2=4.07 GeV^2 x_B=2.16e-02
Q^2=4.47 GeV^2 x_B=3.23e-02
Q^2=4.57 GeV^2 x_B=5.36e-02
Q^2=4.62 GeV^2 x_B=9.21e-02
Q^2=2.90 GeV^2 x_B=1.50e-02
Q^2=2.94 GeV^2 x_B=2.13e-02
Q^2=2.95 GeV^2 x_B=3.19e-02
Q^2=2.95 GeV^2 x_B=5.33e-02
Q^2=1.76 GeV^2 x_B=9.90e-03
Q^2=1.92 GeV^2 x_B=1.48e-02
Q^2=1.92 GeV^2 x_B=2.13e-02
Q^2=1.92 GeV^2 x_B=3.18e-02
Q^2=1.93 GeV^2 x_B=4.47e-02
10^0
10^{-1}
0.25 0.50 0.75
P_T (GeV)
x_B



Matching is crucial, cannot afford to miss any constraint.

Final remarks...

Any other TMD extraction relies on Unpolarized functions

$e^+e^- \to \pi\,\pi\,X$ (Belle and BaBar)

Unpolarized TMDFF — Collins TMDFF

$$\frac{d\sigma^{e^+e^-\to h_1 h_2 X}}{dz_1\,dz_2\,d^2\boldsymbol{P}_{1T}\,d\cos\theta_2} = \frac{3\pi\alpha^2}{2s}\left\{D_{h_1\,h_2} + N_{h_1\,h_2}\cos 2\phi_1\right\}$$

$$P_0^{U,L,C} = \frac{N^{U,L,C}}{D^{U,L,C}}$$

Ratio

$$D^U = D_{\pi^+\pi^-} + D_{\pi^-\pi^+} \qquad N^U = N_{\pi^+\pi^-} + N_{\pi^-\pi^+}$$
$$D^L = D_{\pi^+\pi^+} + D_{\pi^-\pi^-} \qquad N^L = N_{\pi^+\pi^+} + N_{\pi^-\pi^-}$$
$$D^C = D^U + D^L \qquad N^C = N^U + N^L\,,$$

$$\frac{A_0^U}{A_0^{L(C)}} \equiv 1 + \cos(2\phi_1)\,A_0^{UL(C)}$$

Double Ratio

SIDIS (HERMES and COMPASS)

$$\frac{d\sigma^{\ell(S_\ell)+p(S)\to\ell' hX}}{dx_B\,dQ^2\,dz_h\,d^2\boldsymbol{P}_T\,d\phi_S} =$$
$$\frac{2\alpha^2}{Q^4}\left\{\frac{1+(1-y)^2}{2}F_{UU} + \;\cdots\right.$$
$$\left. + S_T(1-y)(\sin(\phi_h+\phi_S)F_{UT}^{\sin(\phi_h+\phi_S)}\right\}.$$

$$A_{UT}^{\sin(\phi_h+\phi_S)} \sim \frac{F_{UT}^{\sin(\phi_h+\phi_S)}}{F_{UU}}$$

Ratio

Unpolarized TMDFF &TMDPDF

TMD Transversity & Collins function

Thank you.