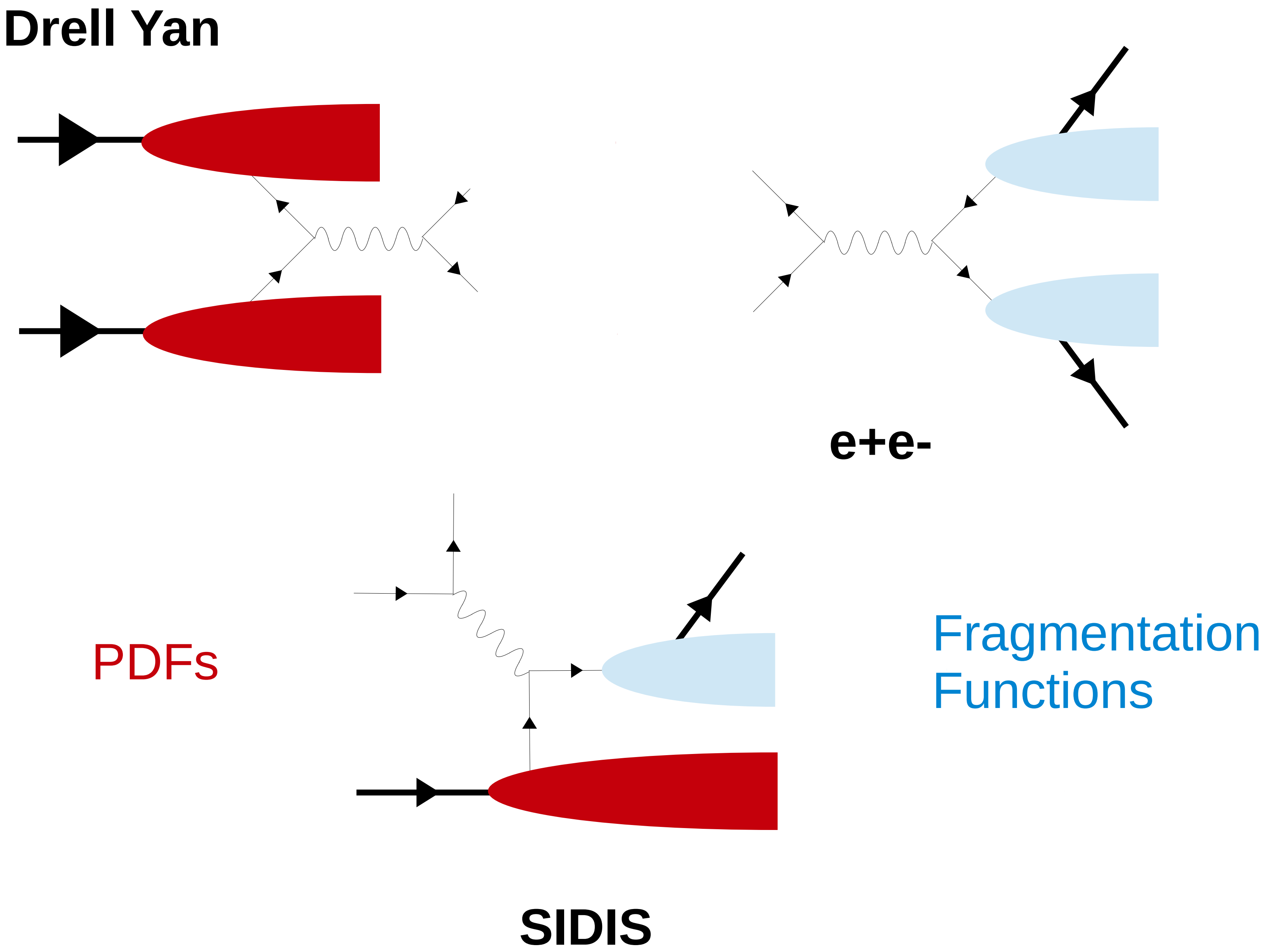
Decoupling TMD FF Effects from Data.

J. Osvaldo Gonzalez-Hernandez

University of Turin


Drell Yan
e+e-
PDFs
SIDIS
Fragmentation
Functions

Extraction from data?

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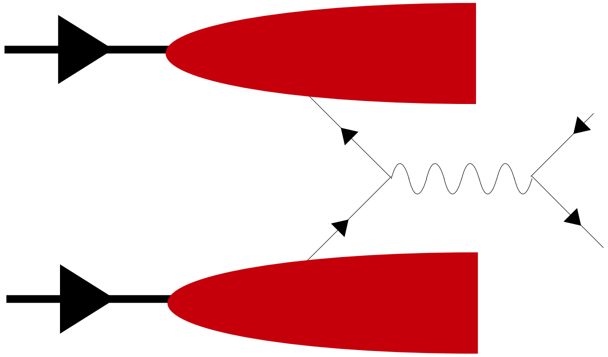
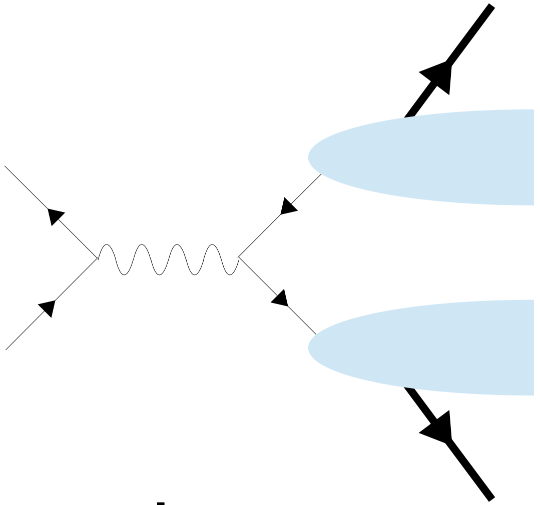
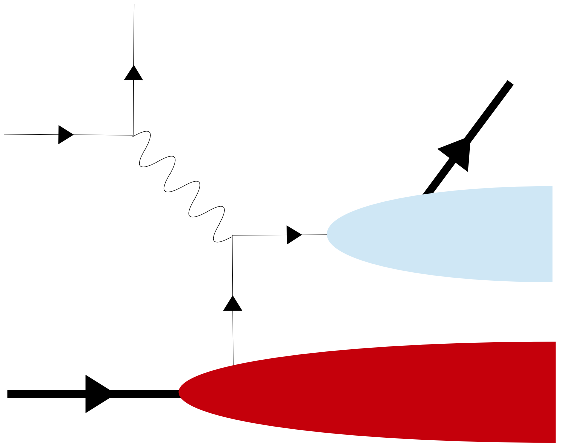




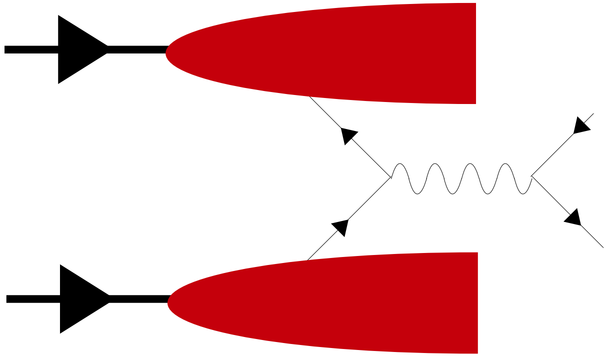
e+e-

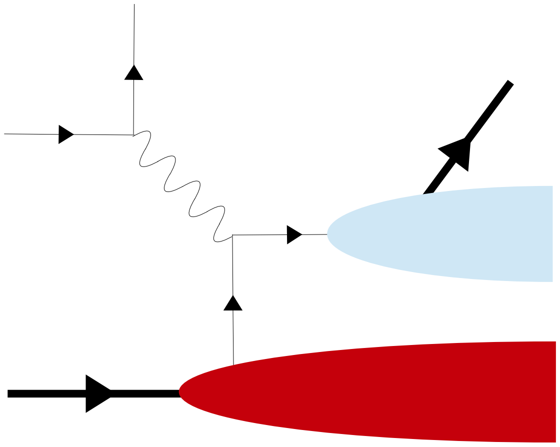


SIDIS

Fragmentation Functions

Drell Yan





SIDIS

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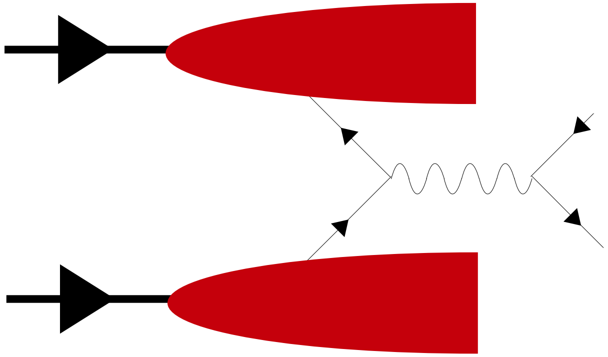


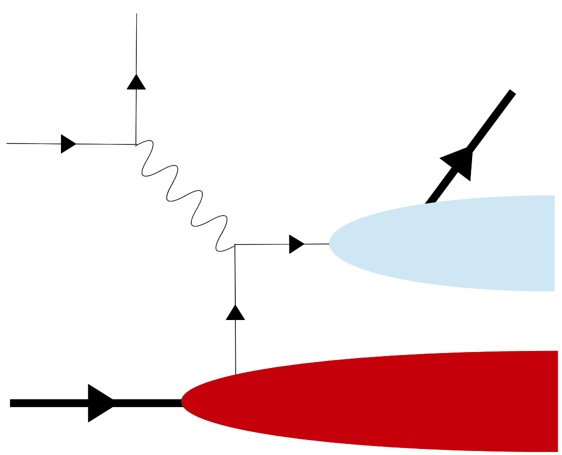
Under control, e.g. full implementation of CSS available

F. Landry, R. Brock, P. M. Nadolsky and C. P. Yuan,Phys. Rev. D67, 073016 (2003)

Must still address some issues.

Delicate kinematics of available multidimensional data

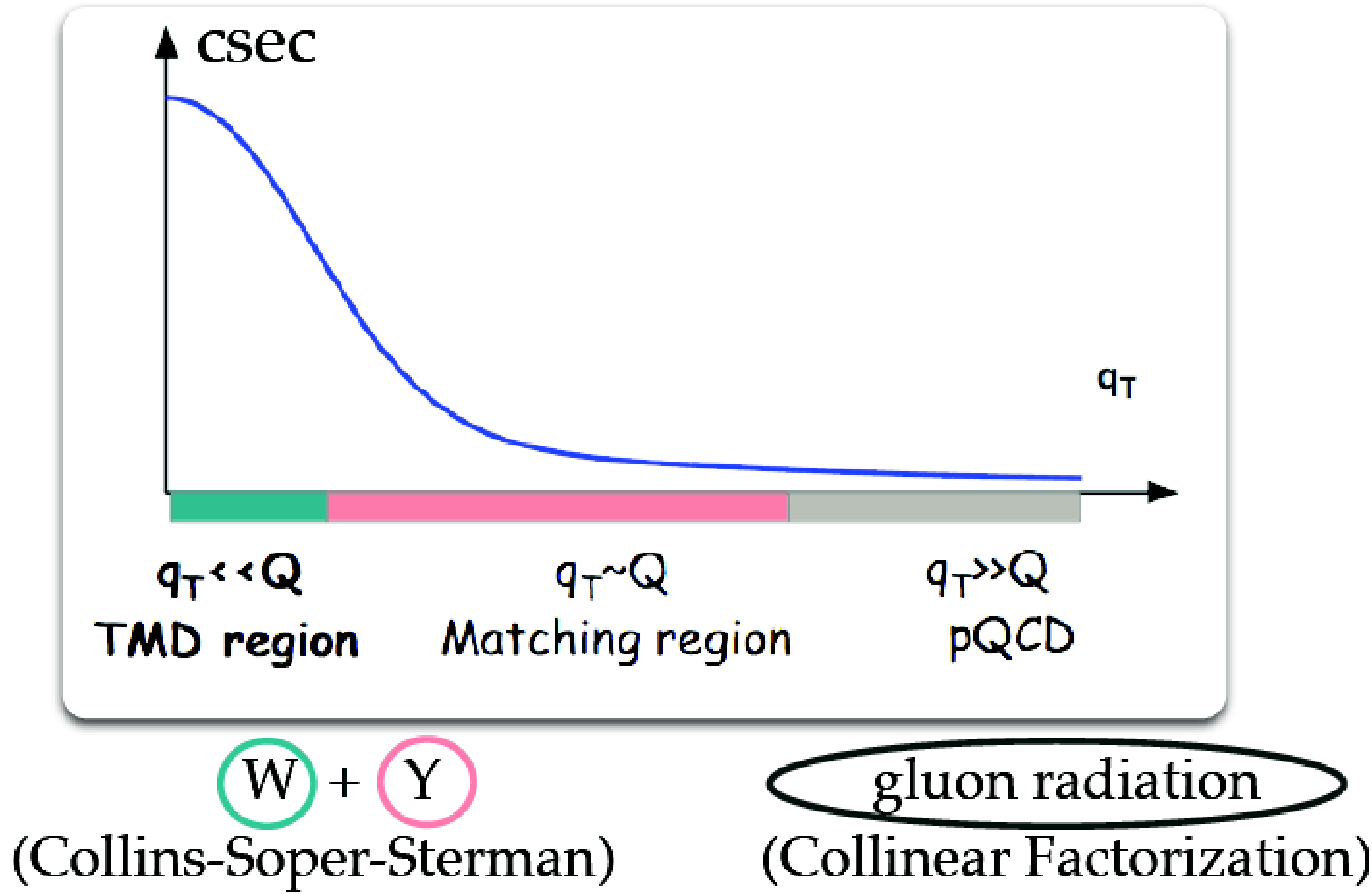
The matching between low and large transverse momentum

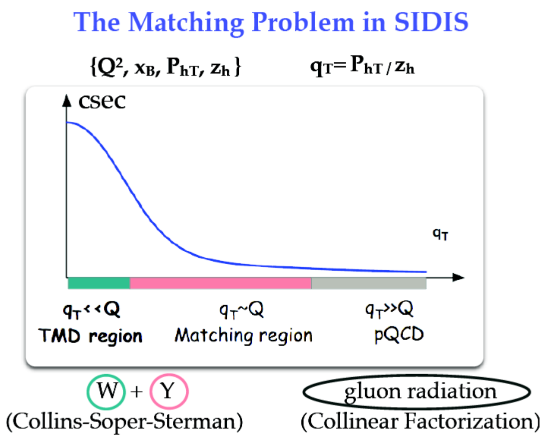


SIDIS

The Matching Problem in SIDIS

$\{Q^2, x_B, P_{hT}, z_h\}$ $\quad q_T = P_{hT} / z_h$

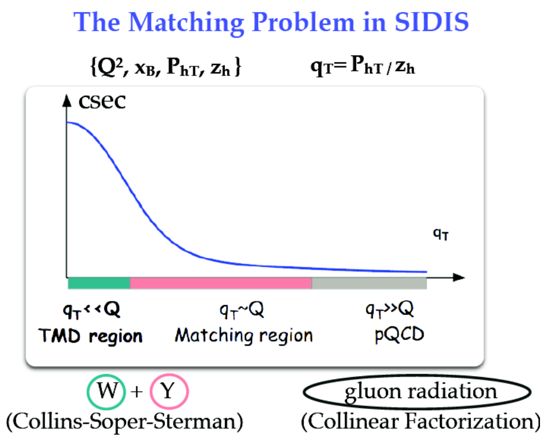




Works for SIDIS at high enough, Q^2 > 10 GeV^2, energy flow **(integration over z_h)**

Nadolsky, Stump, Yuan
DOI: 10.1103/PhysRevD.64.059903

However, information about z-dependence gets washed out. Also, integration over z mixes TMD and collinear factorization effects.



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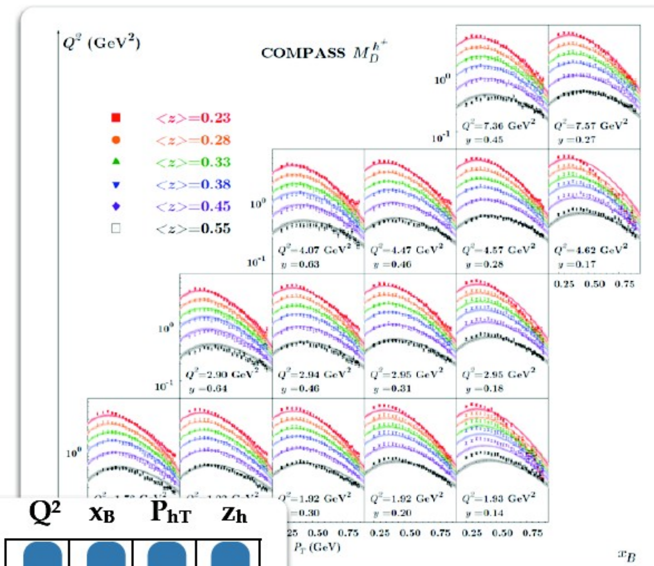
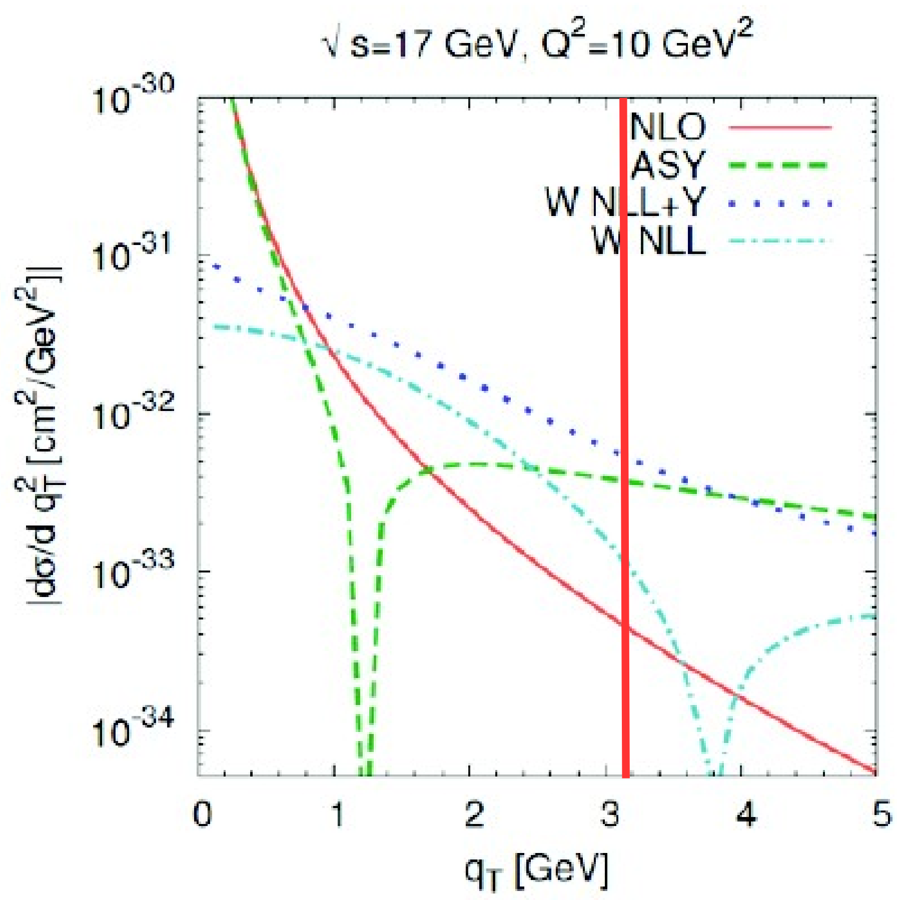
Multidimensional data are ideal.

Can CSS be successfully Implemented?



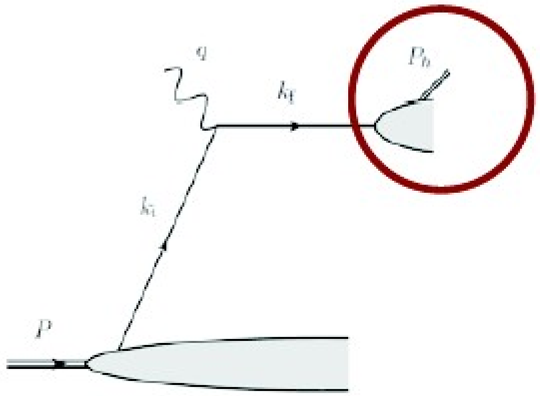
	Q^2	x_B	P_{hT}	z_h
binned	●	●	●	●
integrated				

Large qT corrections are hard to implement.

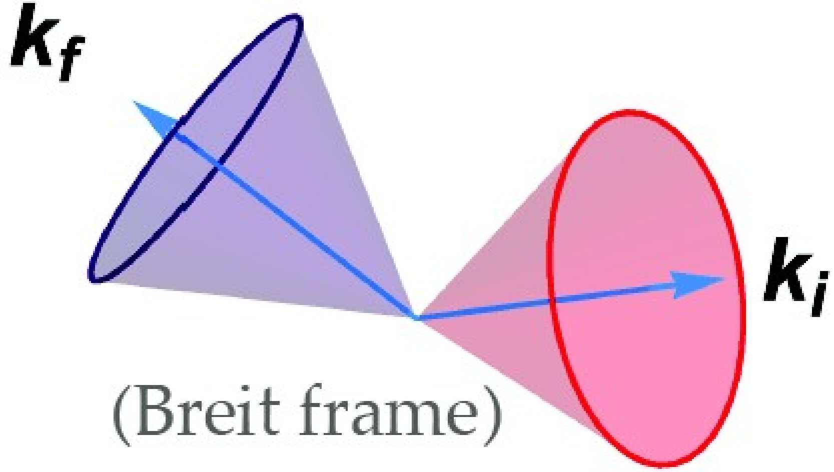


- Large Y-term at small q_T
- Small cross section at large q_T
- No smooth matching

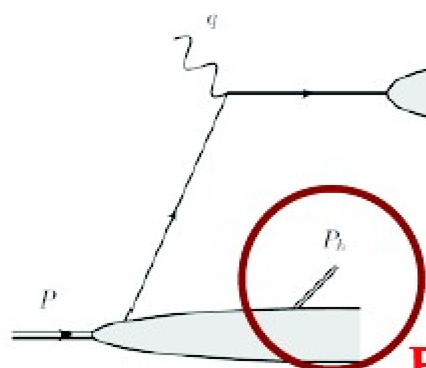
Delicate kinematics



TMDs

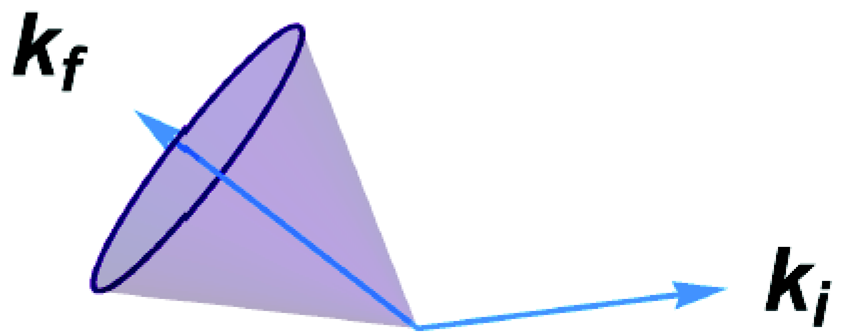


factorization theorems for different leading regions



Fracture Functions

Power counting and kinematics of the current region



current region

small masses

$$P_h \cdot k_{\mathrm{f}} = O\left(m^2\right)$$

$$P_h \cdot k_{\mathrm{i}} = O\left(Q^2\right)$$

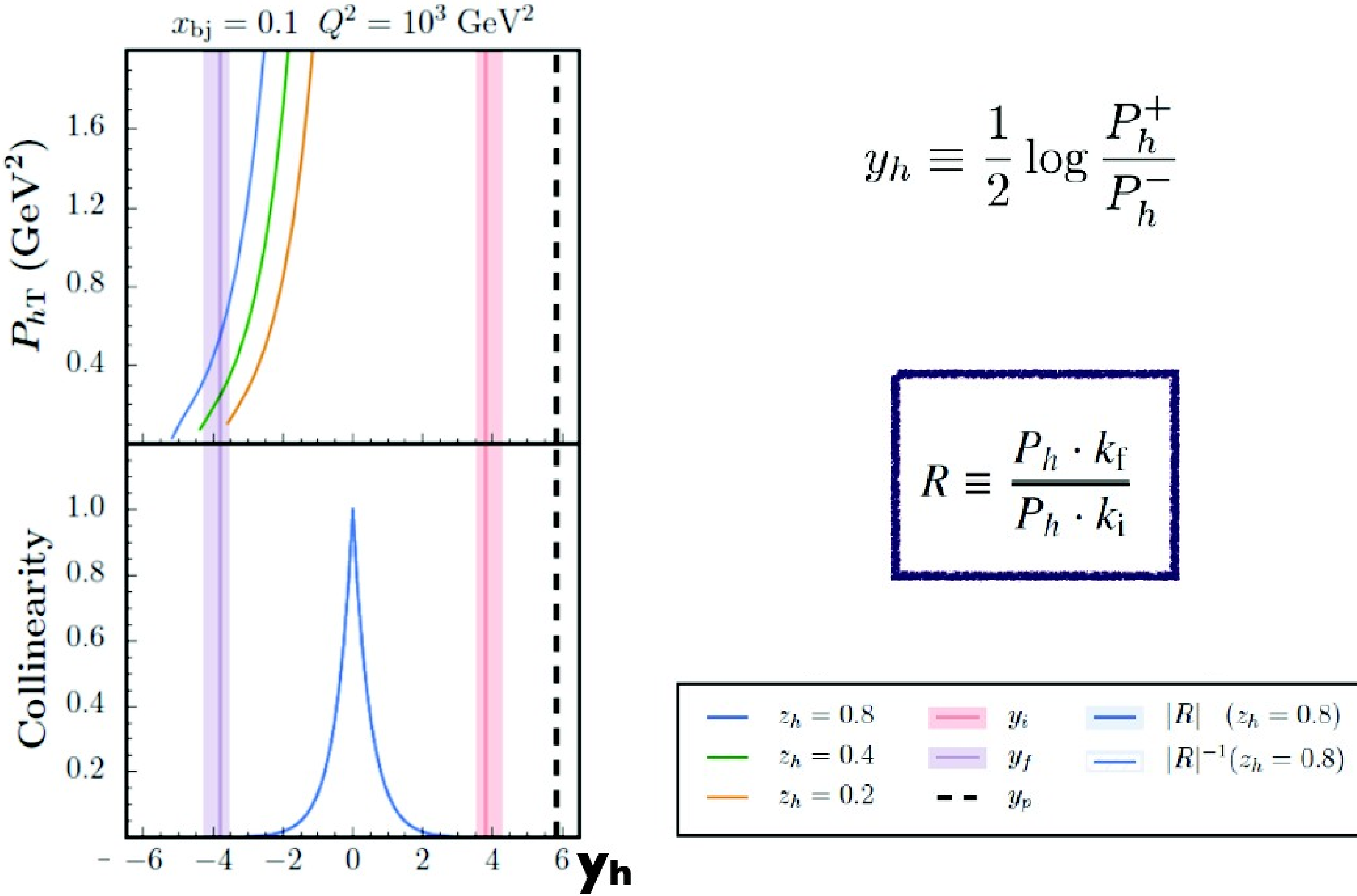
hard scale

require small values for

$$R \equiv \frac{P_h \cdot k_{\mathrm{f}}}{P_h \cdot k_{\mathrm{i}}}$$

notice quark momenta have to be estimated

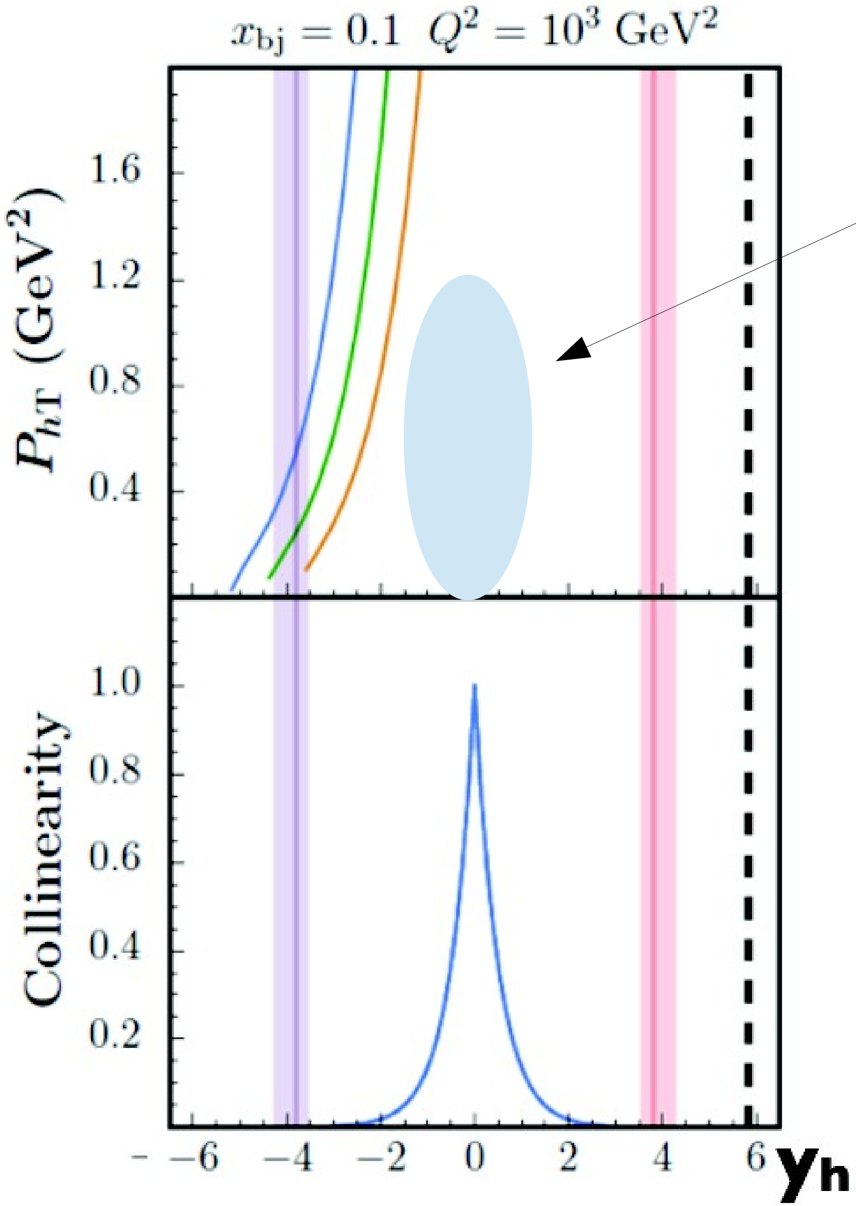
M. Boglione, J. Collins, L. Gamberg, JOGH, T. C. Rogers, and N. Sato, Phys. Lett. B766, 245 (2017), 1611.10329.



$$y_h \equiv \frac{1}{2} \log \frac{P_h^+}{P_h^-}$$

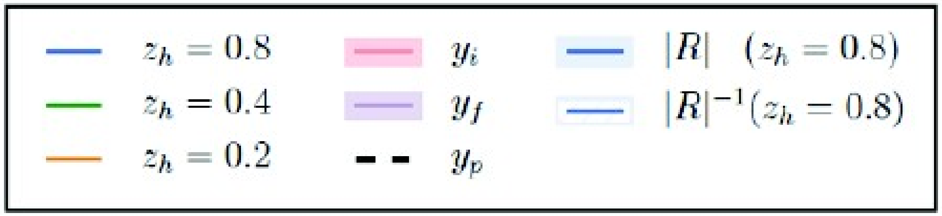
$$R \equiv \frac{P_h \cdot k_f}{P_h \cdot k_i}$$

M. Boglione, J. Collins, L. Gamberg, JOGH, T. C. Rogers, and N. Sato,Phys. Lett.B766, 245 (2017),1611.10329.



Avoid region of central rapidity, soft non-TMD effects

$$R \equiv \frac{P_h \cdot k_f}{P_h \cdot k_i}$$



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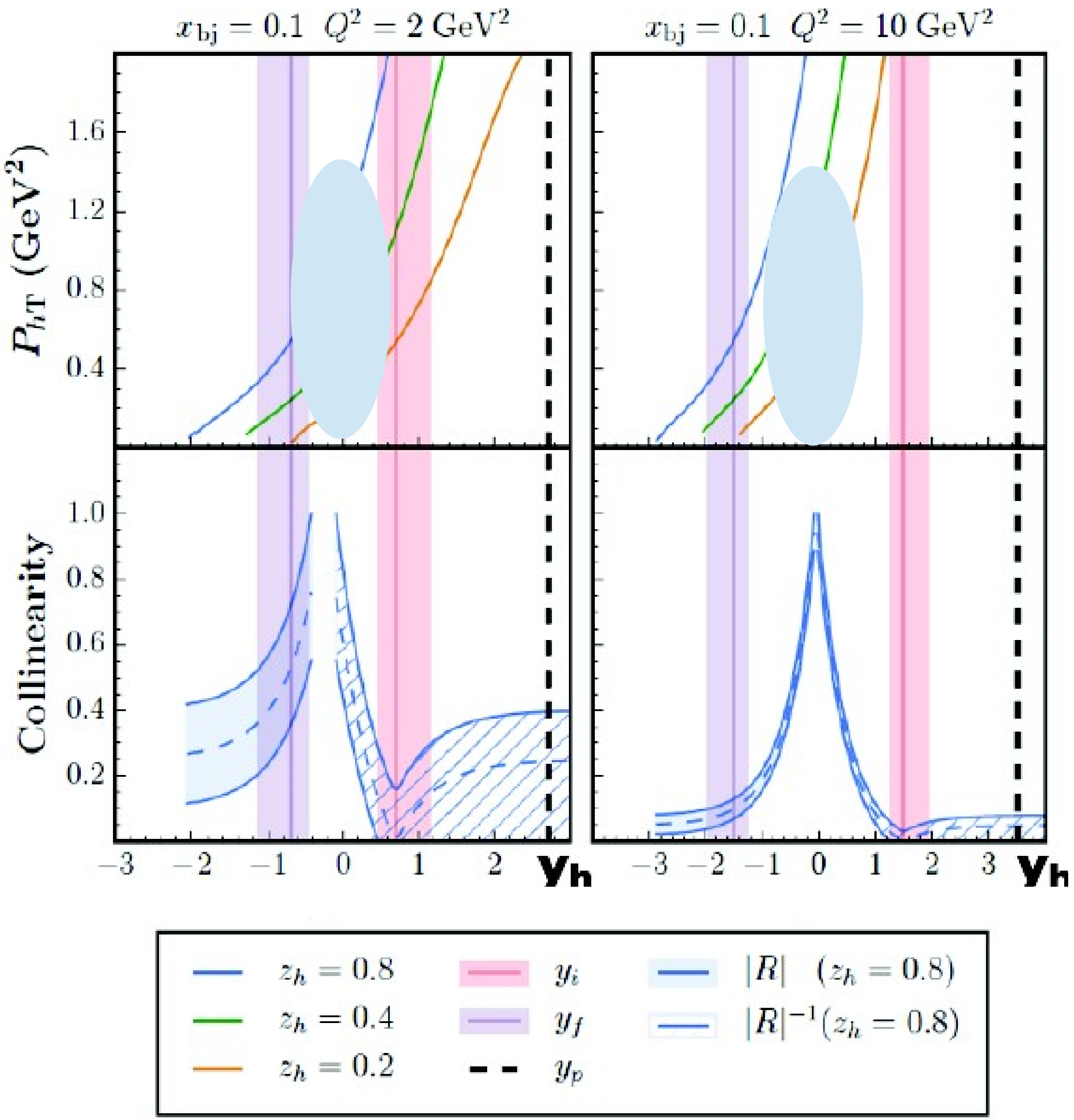
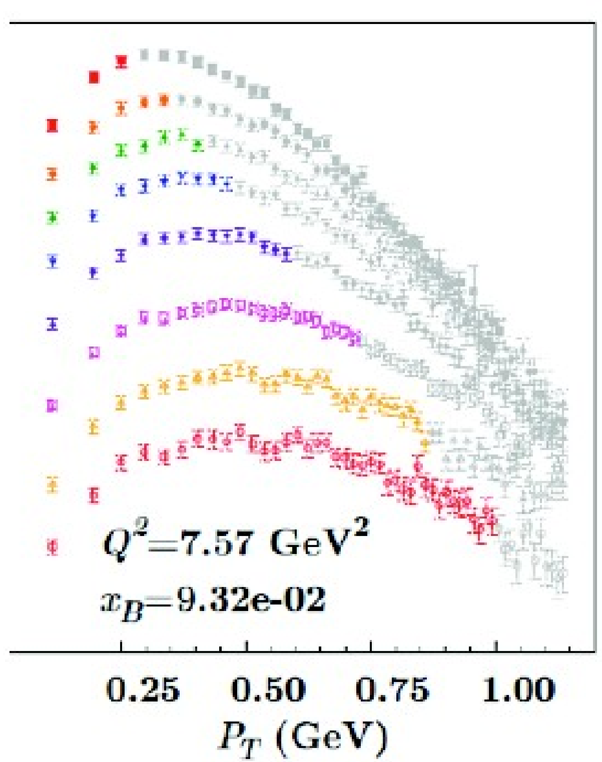


Available data is likely to receive contributions from non-TMD physics.

$$R \equiv \frac{P_h \cdot k_f}{P_h \cdot k_i}$$

M. Boglione, J. Collins, L. Gamberg, JOGH, T. C. Rogers, and N. Sato, Phys. Lett. B766, 245 (2017), 1611.10329.



precise implementation of the R criterion on data is work in progress

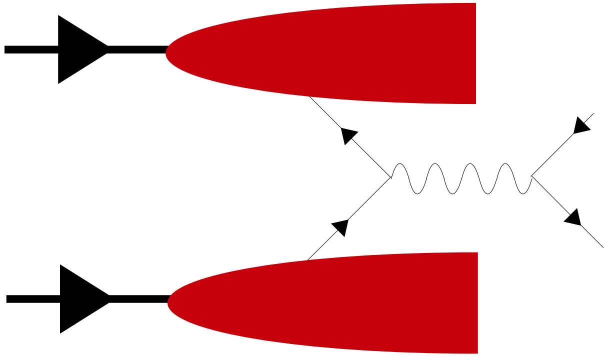
a better set of variables?

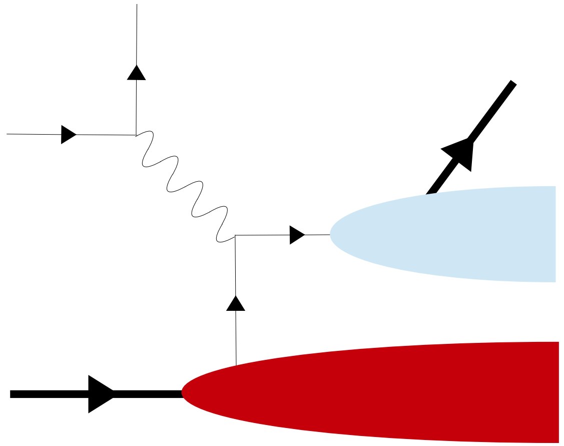
$\{Q^2, x_B, P_{hT}, z_h\}$

$q_T = P_{hT} / z_h \quad y_h$

***ONLY AN EXAMPLE**

Drell Yan

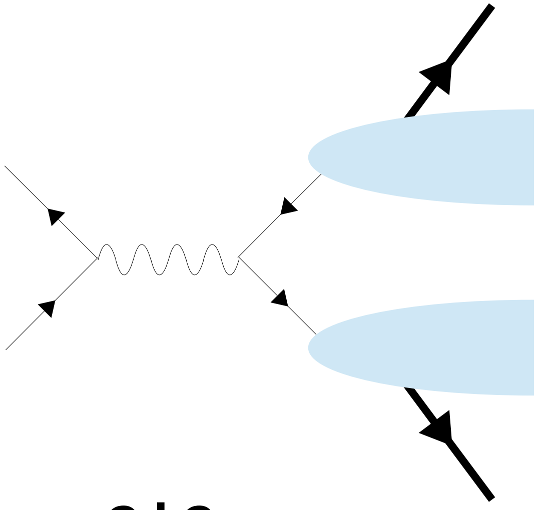




SIDIS

Recently, BELLE, BaBar, BES III Collins asymmetries.

No modern unpolarized measurements are available.



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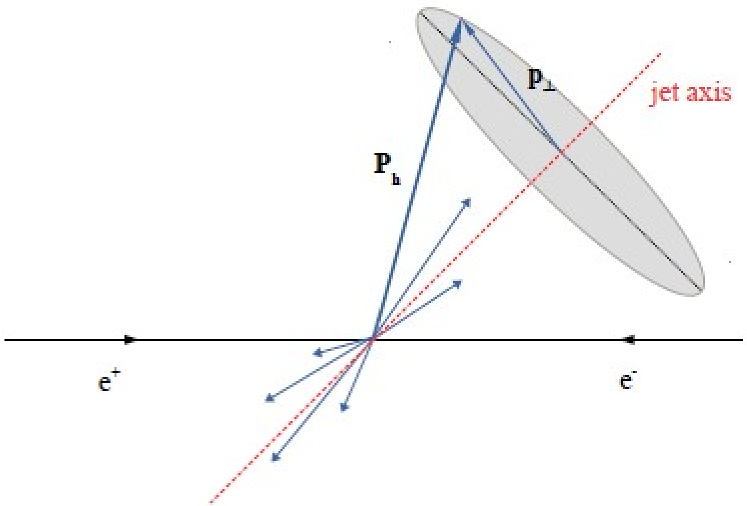
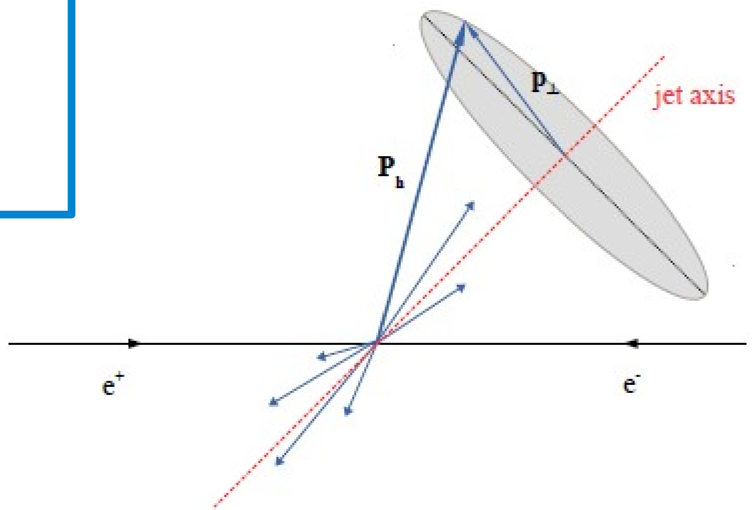
No modern unpolarized measurements are available.

TASSO, MARK II available for
e+e- → X h

- **pT** distributions
- different energies
- integrated over **z**



Boglione, JOGH, R. Taghavi
arXiv:1704.08882v1



TASSO, MARK II available for
e+e- → X h

- **pT** distributions
- different energies
- integrated over **z**

New analysis:
how much information about the **unpolarized TMD FF** can we get from these data sets?

Use this...

$$D_{h/q}(z, p_\perp) = d_{h/q}(z)\, h_d(p_\perp)$$

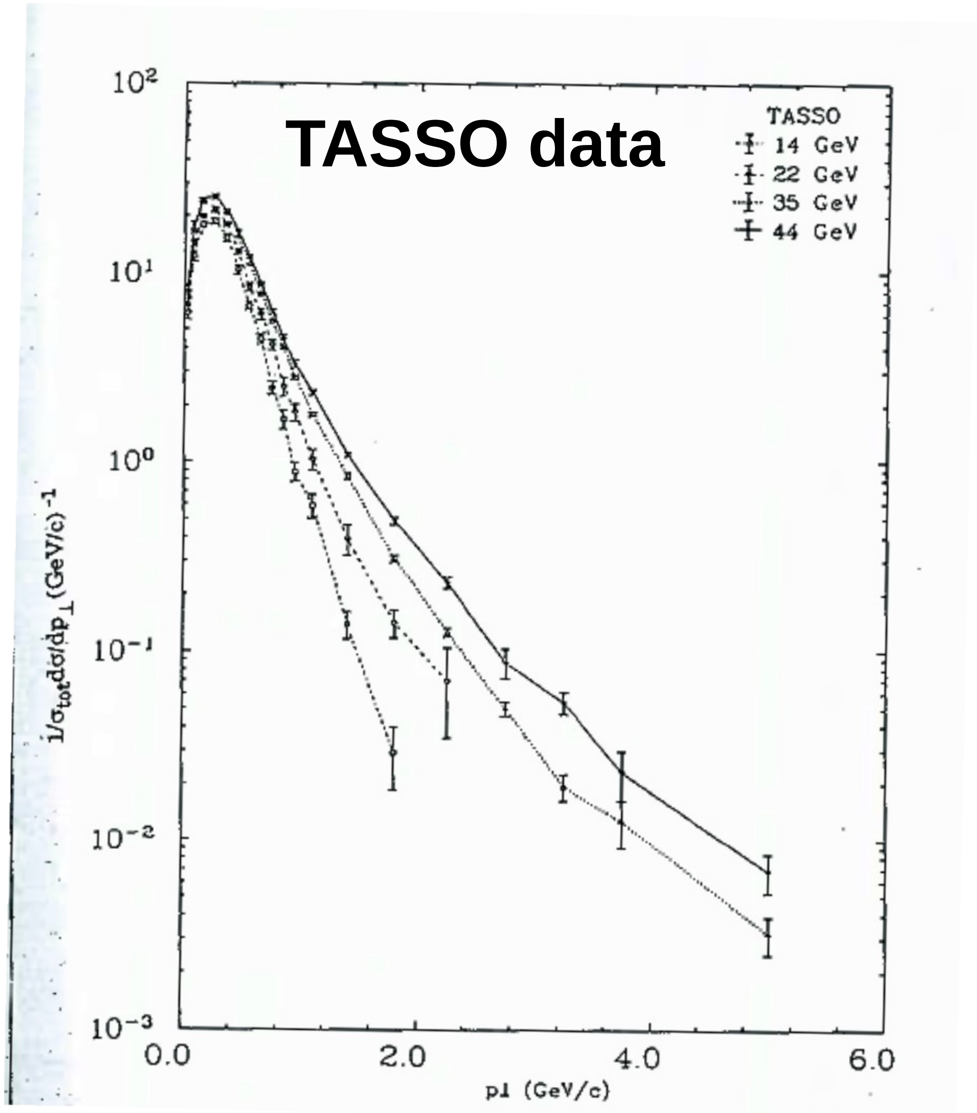
To get information about this

QCD picture

$$\tilde{D}_{h/q}(z, \boldsymbol{b}_\perp; Q) = \sum_j \left[\left(\tilde{C}_{j/q} \otimes \frac{d_{h/j}}{z^2} \right) e^{\Gamma_D(Q)} \right] \exp\left\{ g_{j/P}(x, b_\perp) + g_K(b_\perp) \log\left(\frac{Q}{Q_0} \right) \right\}$$

Things to investigate:

- appropriate functional form for $\mathbf{g}_{j/P}$
- scale evolution regulated by $\mathbf{g}_K$



$$\tilde{D}_{h/q}(z, \boldsymbol{b}_\perp; Q) = \sum_j \left[\left(\tilde{C}_{j/q} \otimes \frac{d_{h/j}}{z^2} \right) e^{\Gamma_D(Q)} \right] \boxed{\exp\left\{ g_{j/P}(x, b_\perp) + g_K(b_\perp) \log\left(\frac{Q}{Q_0} \right) \right\}}$$

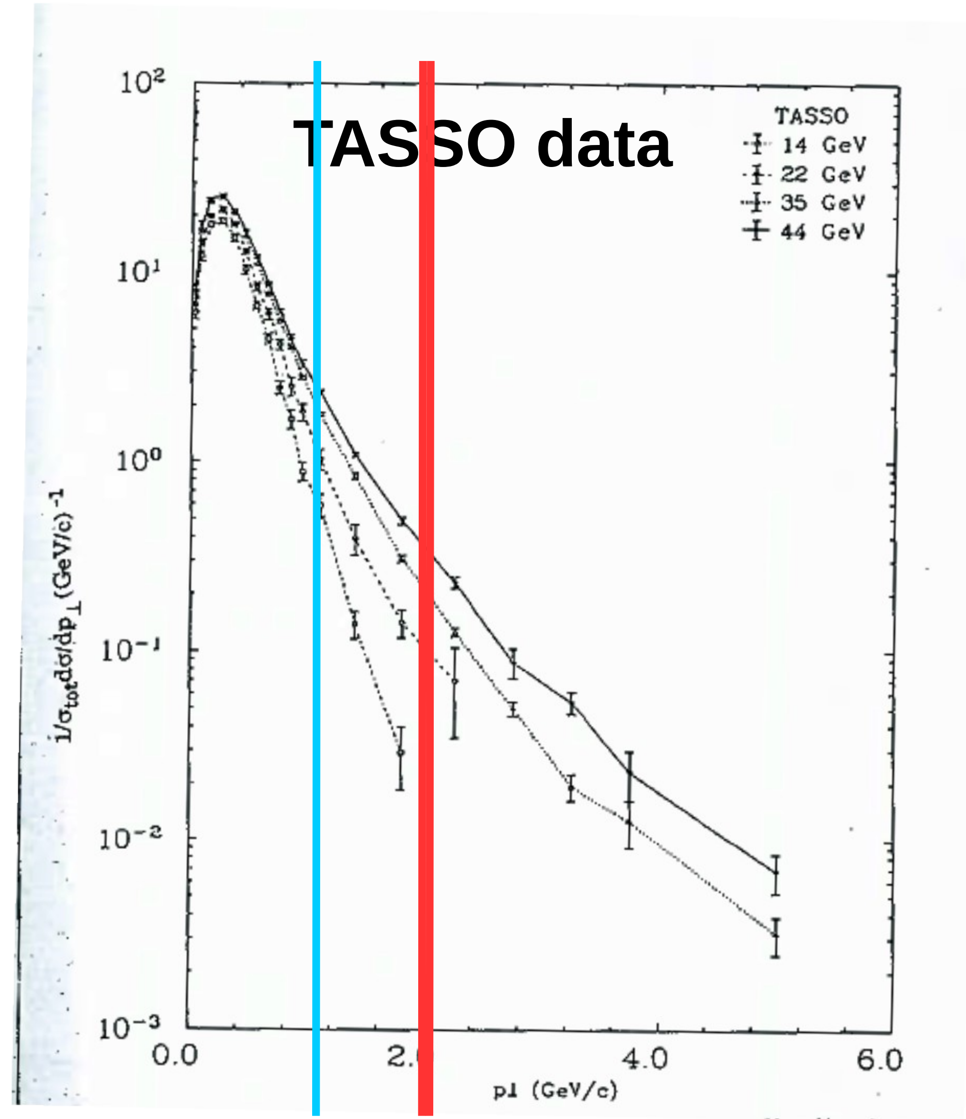
Identify region where TMD Effects dominate:

For fully differential cross sections, matching region is Expected to be at

$$p_\perp \sim zQ$$

Use experimental **<z>** to make an estimate

$$p_\perp \sim 2\,\mathrm{GeV}$$



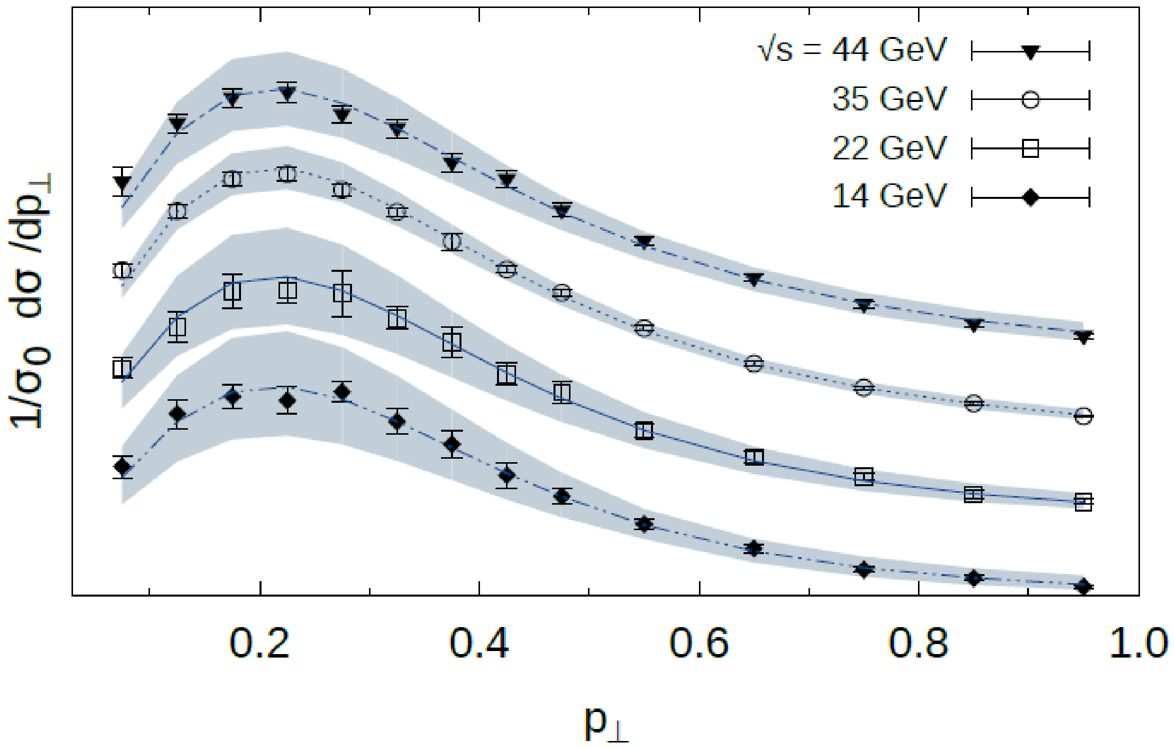
We looked at a restricted range: $p_\perp < 1\ \mathrm{GeV}$

Power law to model transverse momentum dependence

$$D_{h/q}(z, p_\perp) = d_{h/q}(z)\, h_d(p_\perp)$$

$$h(p_\perp) = 2(\alpha - 1) M^{2(\alpha-1)} \frac{1}{\left(p_\perp^2 + M^2\right)^\alpha}$$

FIT TO TASSO



Power law parameters follow a logarithmic trend

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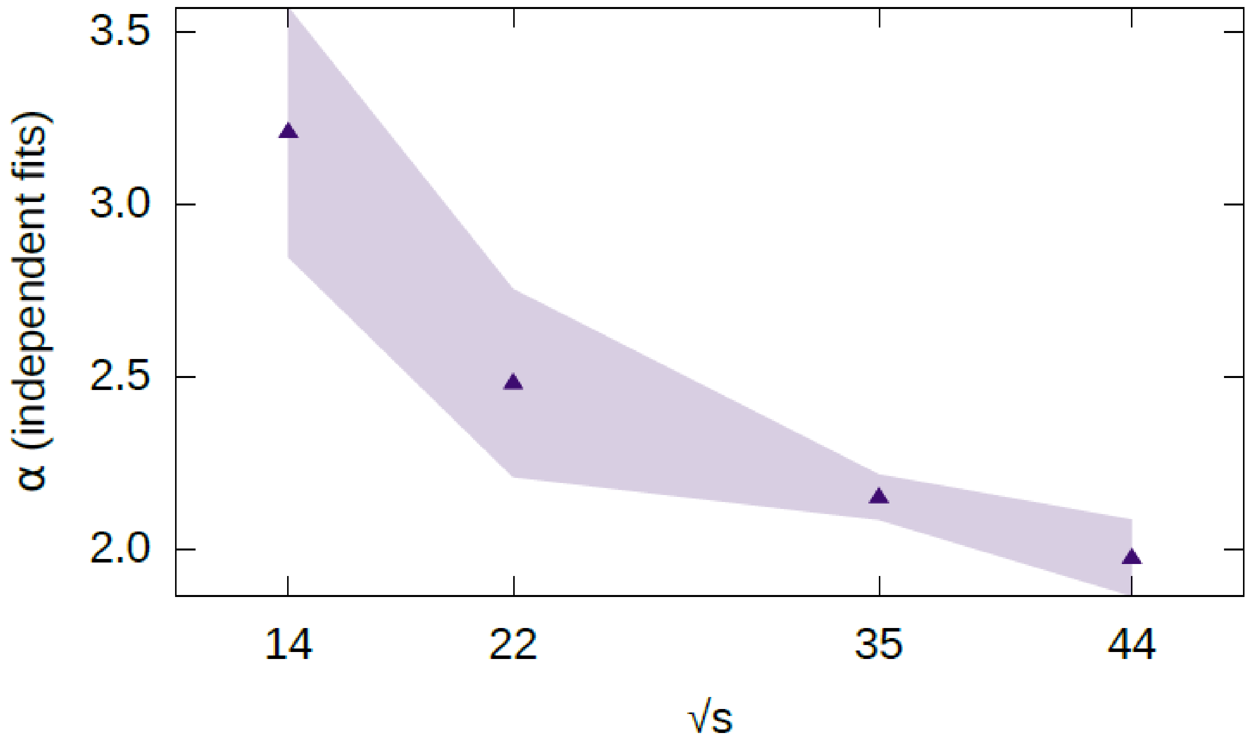
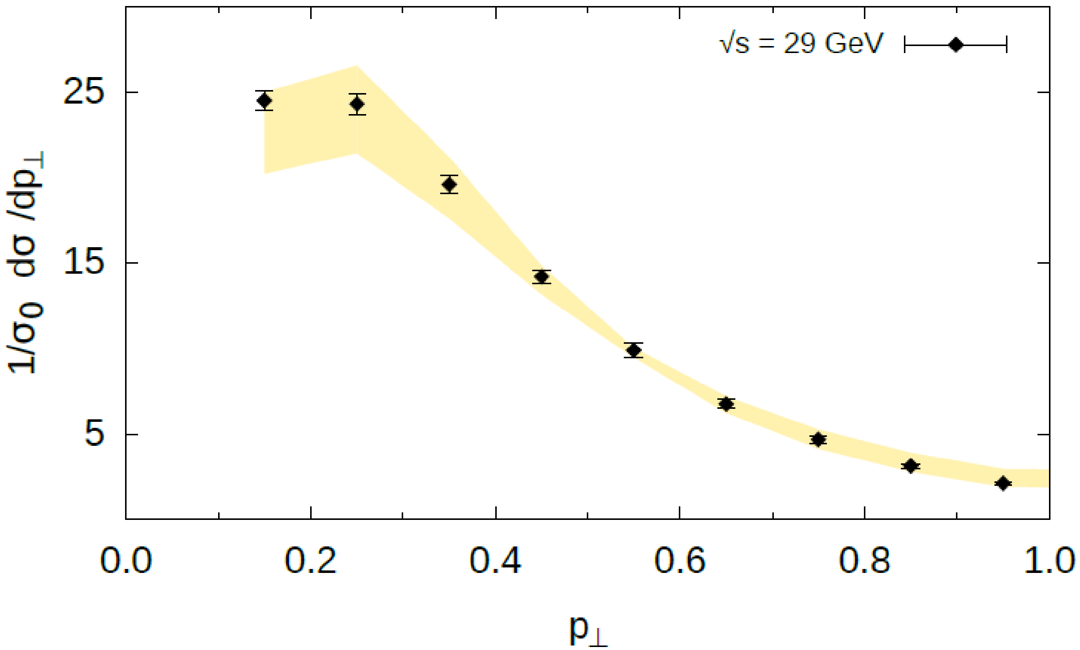


Power law parameters follow a logarithmic trend
Consistent with MARK II data.

$$h(p_\perp) = 2(\alpha - 1)\mathrm{M}^{2\,(\alpha-1)} \frac{1}{\left(p_\perp^2 + \mathrm{M}^2\right)^{\alpha}}$$

COMPARISON TO MARK II



TMD

$$\mathcal{F}^{-1}\left\{\frac{d\sigma^h}{dz\,d^2\boldsymbol{p}_\perp}\right\} \propto \exp\left\{\left(\lambda_\Gamma(b_*) + g_K(b_\perp)\right)\log\left(\frac{Q}{Q_0}\right)\right\}\Bigg|_{b_\perp \to z\,b_\perp}$$

$$\lambda_\Gamma(b_*) \equiv \frac{32}{27}\log\left(\log\frac{2e^{-\gamma_E}}{\Lambda_{QCD}\,b_*}\right)$$

MODEL

$$h(p_\perp) = 2(\alpha-1)\mathrm{M}^{2\,(\alpha-1)}\frac{1}{\left(p_\perp^2+\mathrm{M}^2\right)^{\alpha}}$$

$$\mathcal{F}^{-1}\left\{\frac{1}{\left(p_\perp^2+\mathrm{M}^2\right)^{\alpha}}\right\} \xrightarrow{\text{large}\, b_\perp} \frac{1}{2^\alpha\,\pi\,\Gamma(\alpha)}\left(\frac{b_\perp}{\mathrm{M}}\right)^{\alpha-1}\sqrt{\frac{\pi}{2}}\,\frac{e^{-b_\perp \mathrm{M}}}{\sqrt{b_\perp \mathrm{M}}}\left[1+\mathcal{O}\left(\frac{1}{b_\perp \mathrm{M}}\right)\right]$$

TMD

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$$\lambda_\Gamma(b_*) \equiv \frac{32}{27}\log\left(\log\frac{2e^{-\gamma_E}}{\Lambda_{QCD}\, b_*}\right)$$

Logarithmic behavior of alpha may be interpreted as a consequence of the **Log** in the definition of the **TMD FF**.

$$\alpha = \alpha_0 + \tilde{\alpha}\log\left(\frac{Q}{Q_0}\right)$$

$$g_K(b_\perp) \xrightarrow{\text{large } b_\perp} \tilde{\alpha}\log(\nu\, b_\perp)$$

TMD

There are caveats on this interpretation, while consistent with theoretical expectations, its not the only possibility.
(loss of information through z-integration)

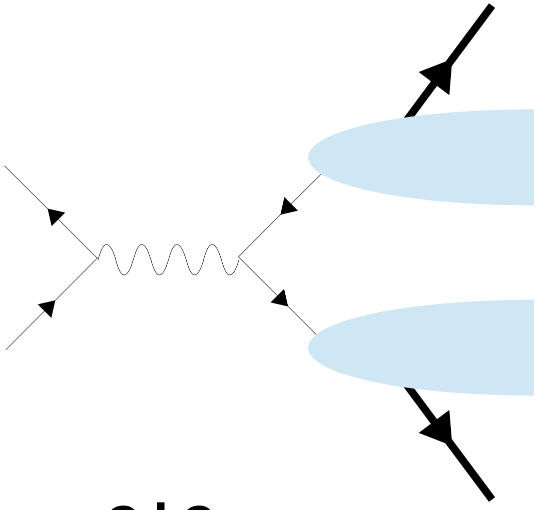
Logarithmic behavior of alpha may be interpreted as a consequence of the **Log** in the definition of the **TMD FF**.

$$\alpha = \alpha_0 + \tilde{\alpha} \log\left(\frac{Q}{Q_0}\right)$$

$$g_K(b_\perp) \xrightarrow{\text{large } b_\perp} \tilde{\alpha} \log(\nu\, b_\perp)$$

The lack of information about **z** hinders a full TMD extraction of the FF.

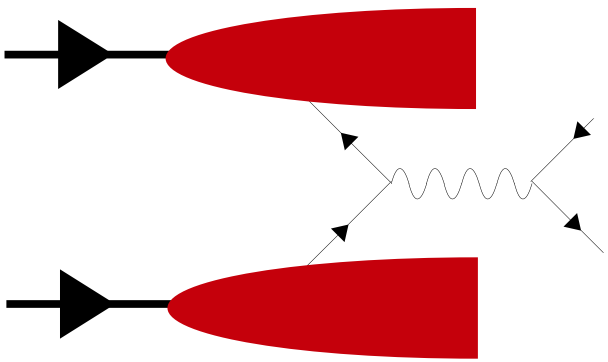
Future upcoming data by BELLE on unpolarized one-hadron production may allow for a combined analysis with TASSO and MARK II data.

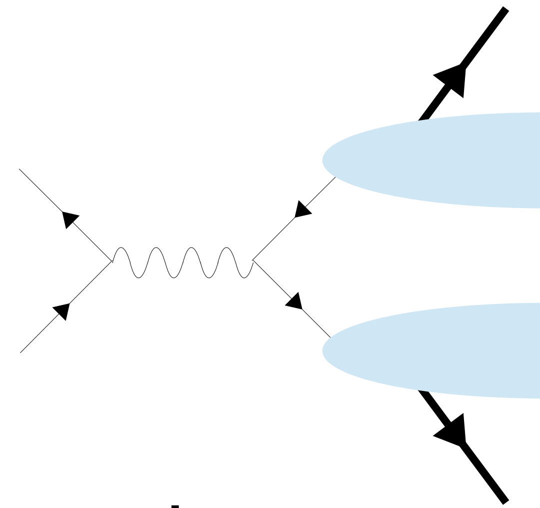


e+e-

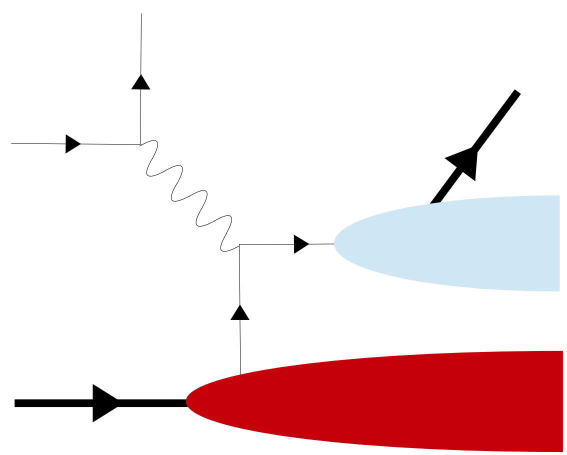
Extraction from data?

Drell Yan





e+e-



Fragmentation Functions

**Let's keep working,
but let us
be careful with
interpretations**

SIDIS

Final Remarks

Currently, we are attempting to do phenomenology within **full QCD picture**.

Need to describe regions of **low and large transverse momenta** simultaneously.

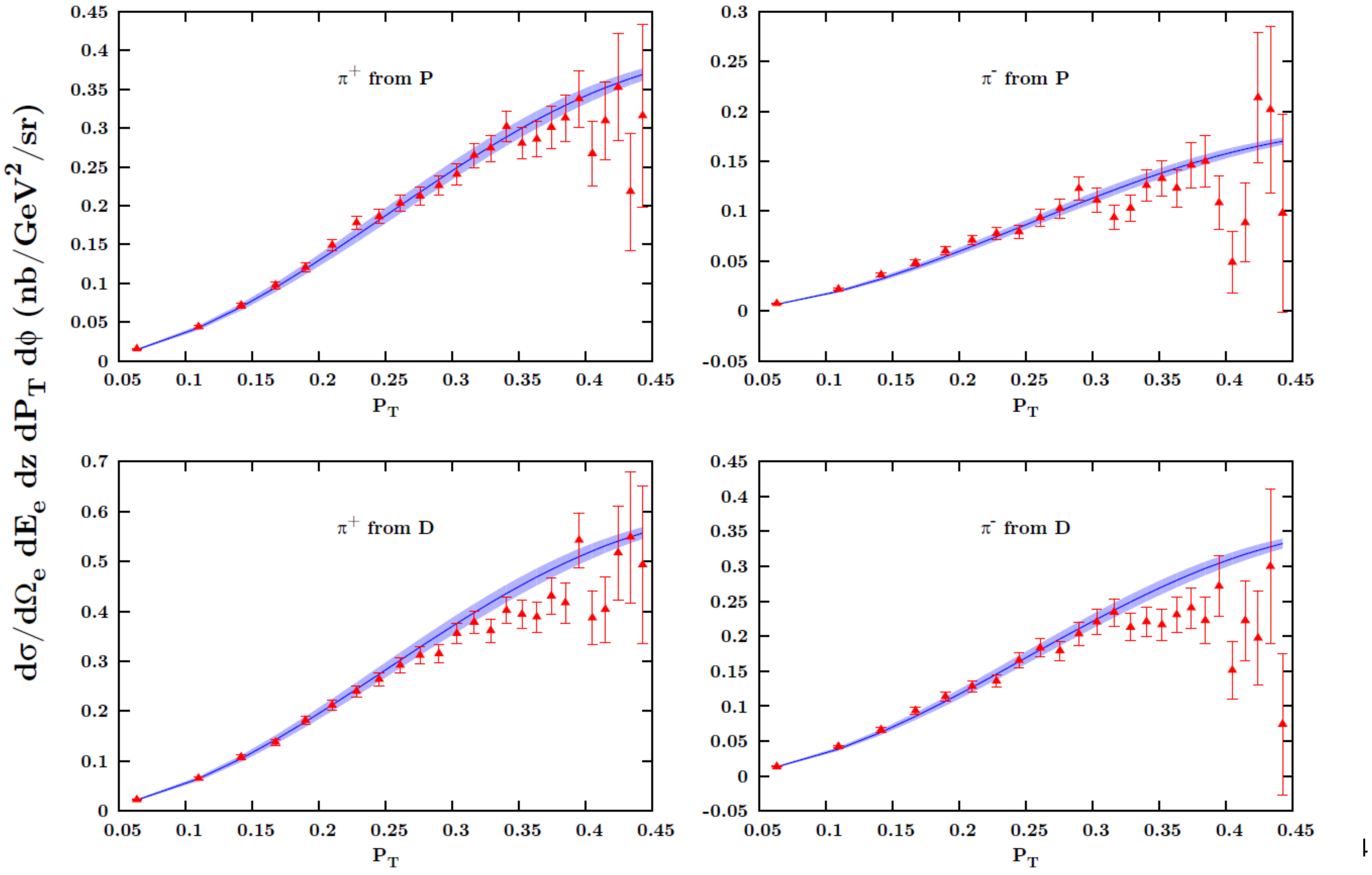
More work to be done, it's important to take a step back and think of the **theoretical issues** (solving the "matching problem" at delicate kinematics).

In SIDIS, while we have great data sets, some work need to be done to understand theoretical errors of factorization. This is needed for a correct interpretation of phenomenological analyses.

On the side of e+e- one hadron production, in the near future unpolarized cross sections by BELLE may allow for an analysis of the older sets, TASSO MARKII within a full TMD picture.

Thank you.

Jlab SIDIS data (2012) (Parameters from HERMES extraction).



Ingredients for extraction of Collins function.

$e^+e^- \to \pi\,\pi\,X$

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

$$\frac{d\sigma^{\ell(S_\ell)+p(S)\to\ell' hX}}{dx_B dQ^2 dz_h d^2\boldsymbol{P}_T d\phi_S} =$$

$$\frac{2\alpha^2}{Q^4}\left\{\frac{1+(1-y)^2}{2}F_{UU} + \quad \cdots\right.$$

$$\left. + S_T(1-y)(\sin(\phi_h+\phi_S)F_{UT}^{\sin(\phi_h+\phi_S)}\right\}.$$

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

Ratio

Unpolarized TMDFF &TMDPDF

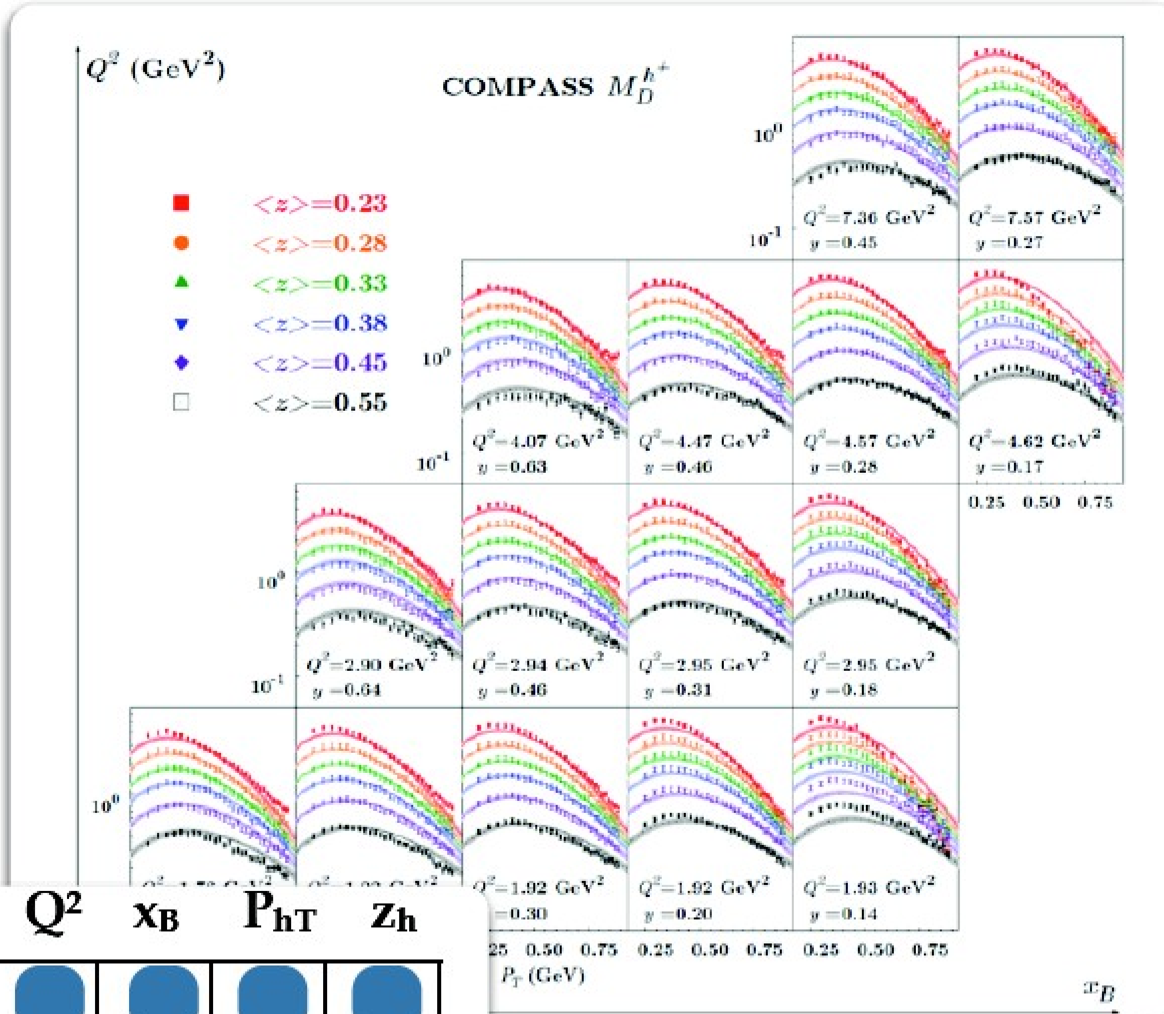
TMD Transversity & Collins function

Unpolarized SIDIS cross section (current region)

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

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

$$+ \text{ large } q_T \text{ corrections} + \text{power suppressed terms}$$



	Q^2	x_B	P_{hT}	z_h
binned	●	●	●	●
integrated				