Opportunities for the Extraction Of TMD Fragmentation Functions

Electron Ion Collider User Group Meeting 2017

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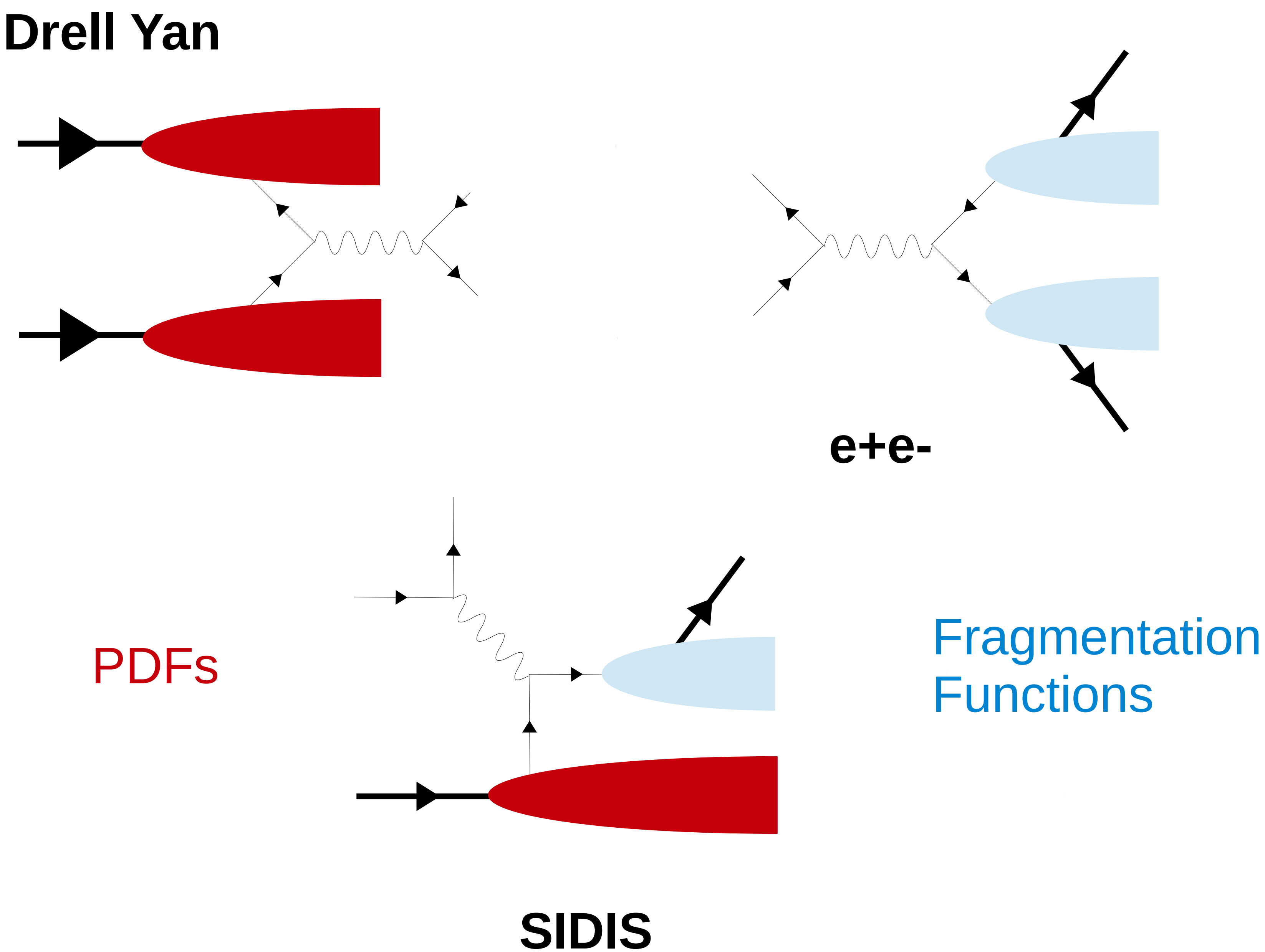
&
INFN


Drell Yan
e+e-
PDFs
Fragmentation
Functions
SIDIS

Global Fits?

A. Bacchetta, F. Delcarro, C. Pisano,
M. Radici , A. Signori
arXiv:1703.10157

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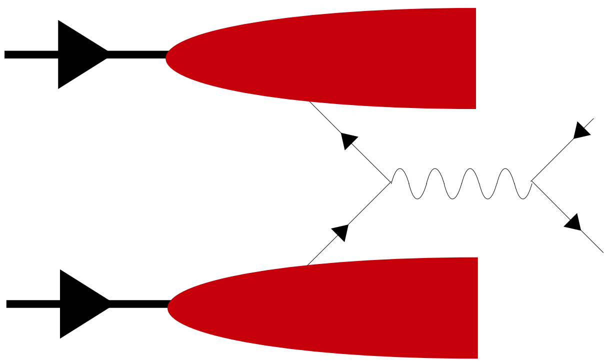

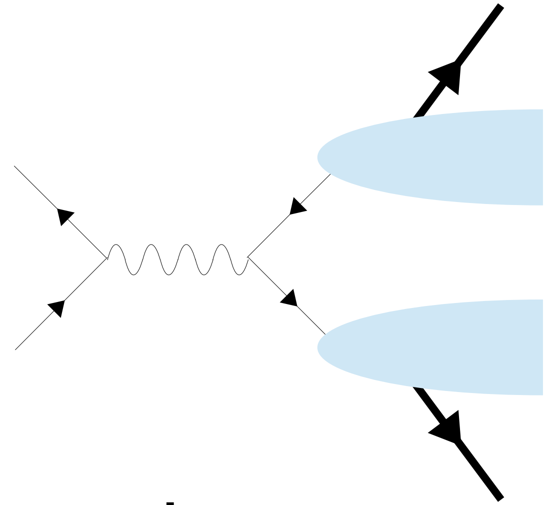

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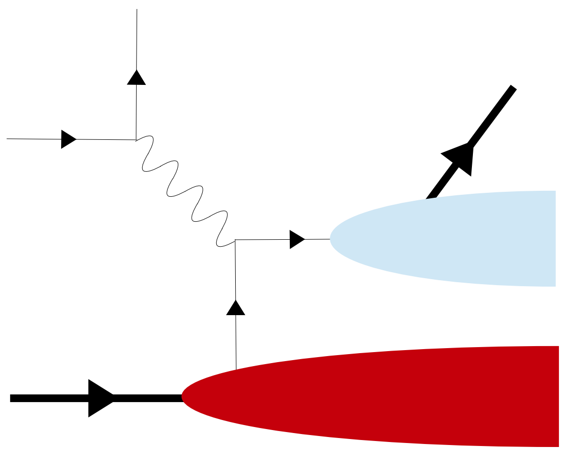

PDFs

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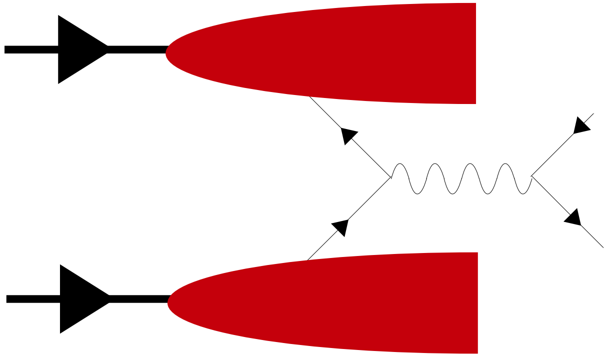
SIDIS

Drell Yan



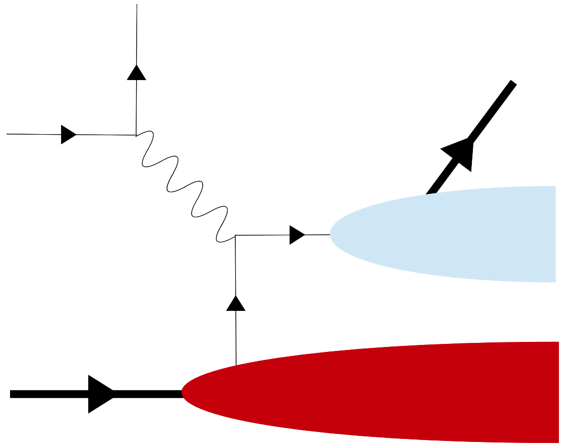
Under control, high precision phenomenology:

See for example:
arXiv:1706.01473
Ignazio Scimemi, Alexey Vladimirov

Must still address some issues.

Delicate kinematics of available multidimensional data

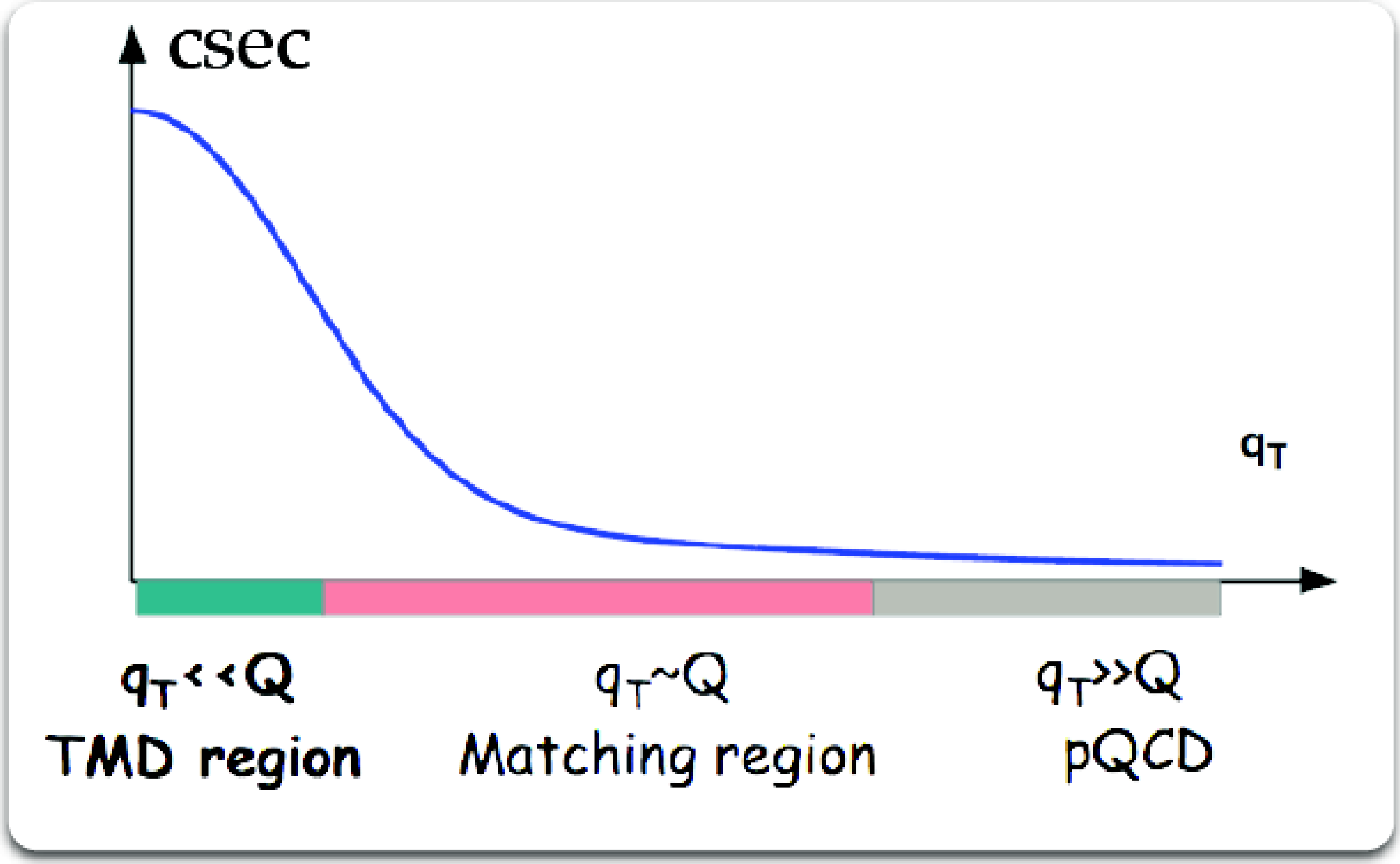
The matching between low and large transverse momentum



SIDIS

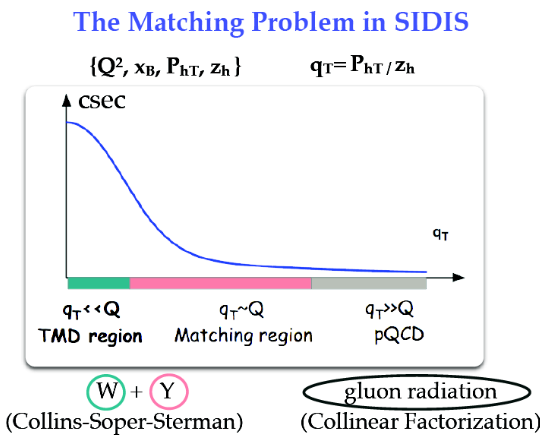
The Matching Problem in SIDIS

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



W + Y
(Collins-Soper-Sterman)

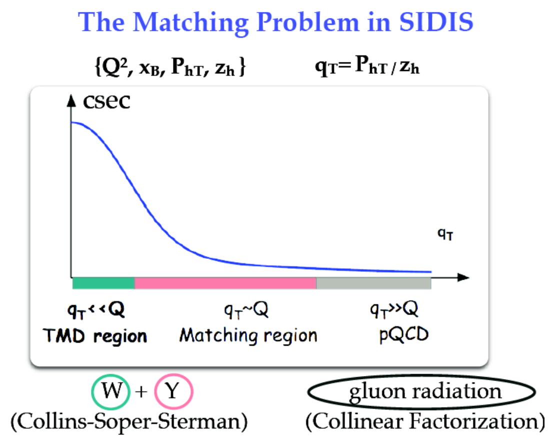
gluon radiation
(Collinear Factorization)



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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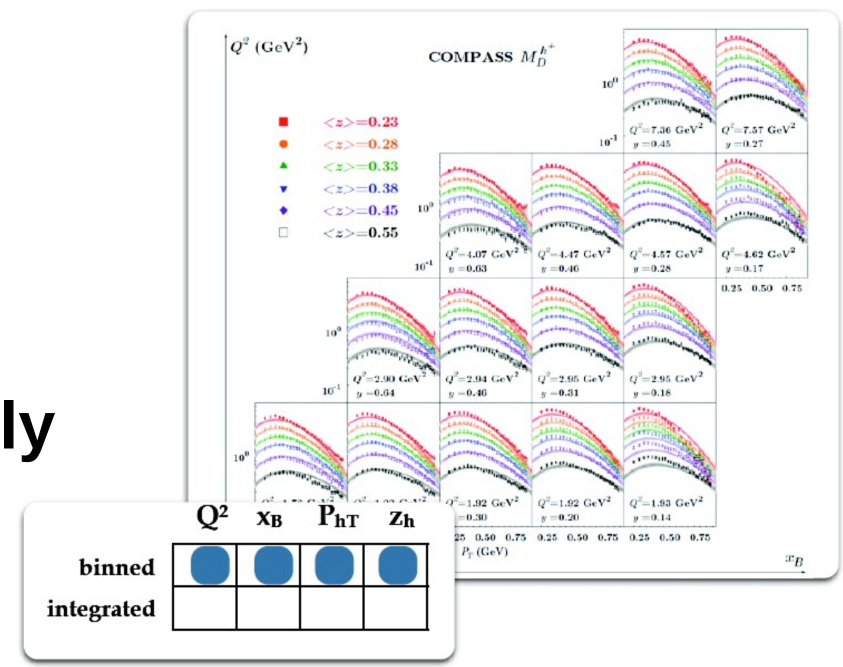
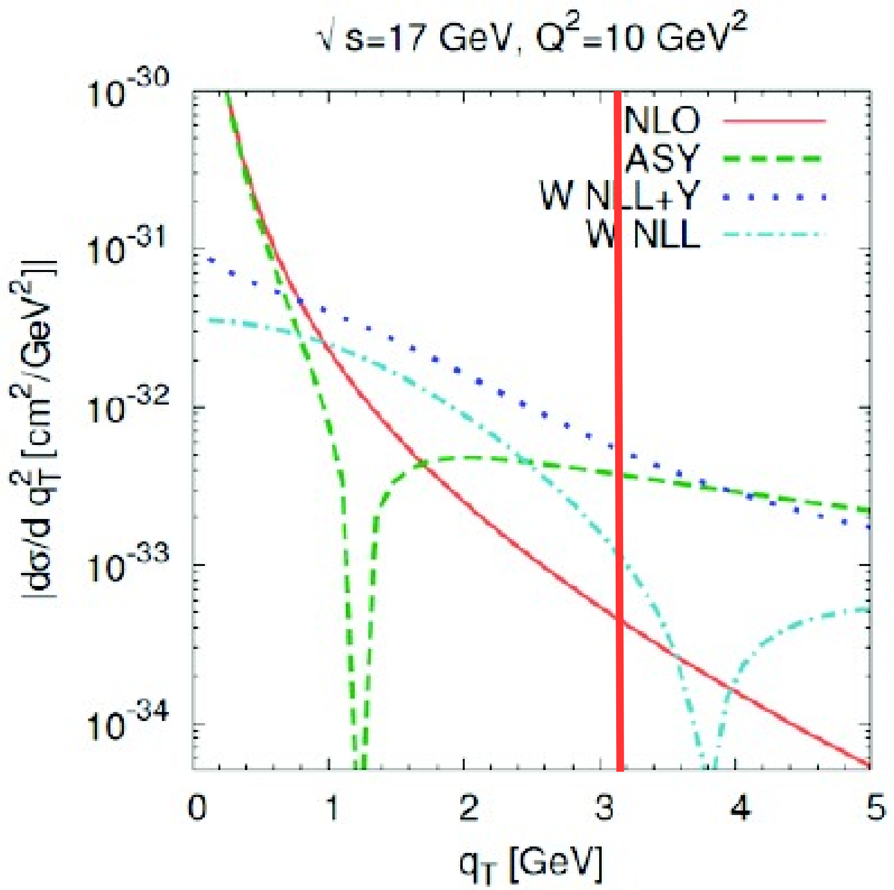
Multidimensional data are ideal.

Can CSS be successfully Implemented?



M. Anselmino, M. Boglione, J.O.G.H., S. Melis , A. Prokudin: Published in JHEP 1404 (2014) 005

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

Delicate kinematics

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

Source of Errors?

Unpolarized SIDIS cross section (current region)

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

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

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

Perturbation Theory **Factorization**

(Re)Calculation of large qT SIDIS cross section

Work in progress:

J.O.G.H., T. Rogers, N. Sato, A. Signori, B. Wang

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

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Perturbation Theory

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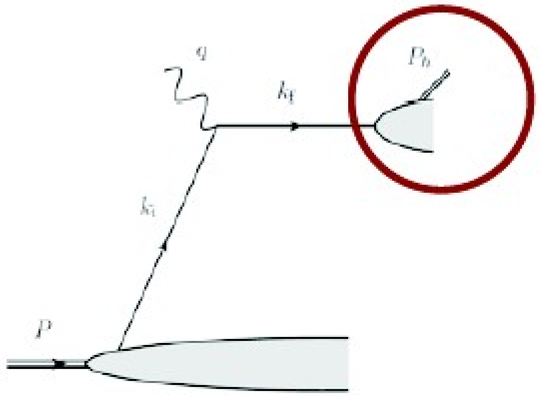
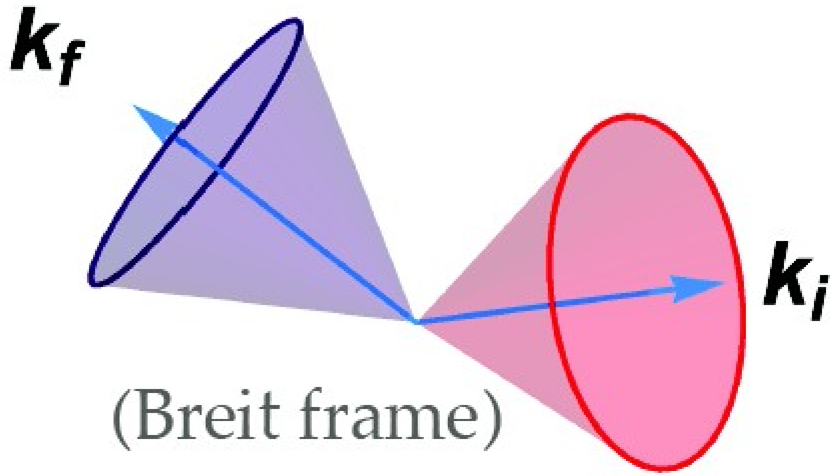
Factorization

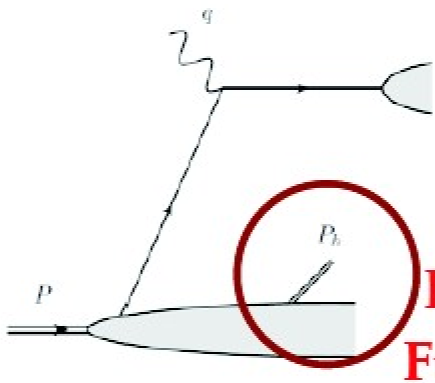
Which Region?



TMDs

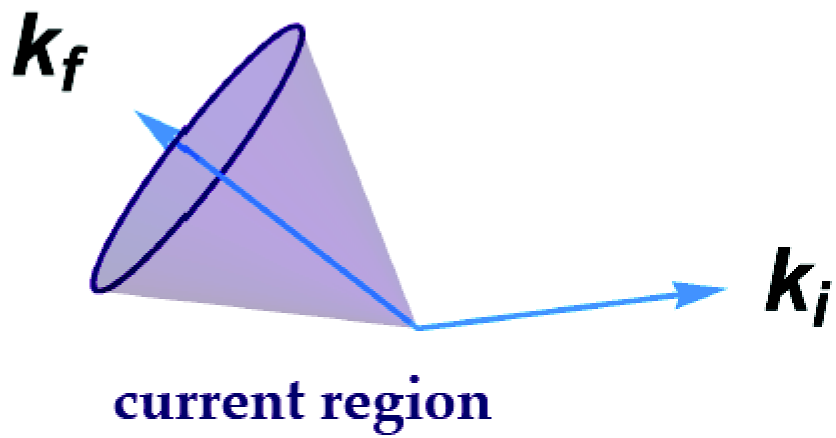


factorization theorems for different leading regions



Fracture Functions

Power counting and kinematics of the current region



small masses

$$P_h \cdot k_f = O\left(m^2\right)$$

$$P_h \cdot k_i = O\left(Q^2\right)$$

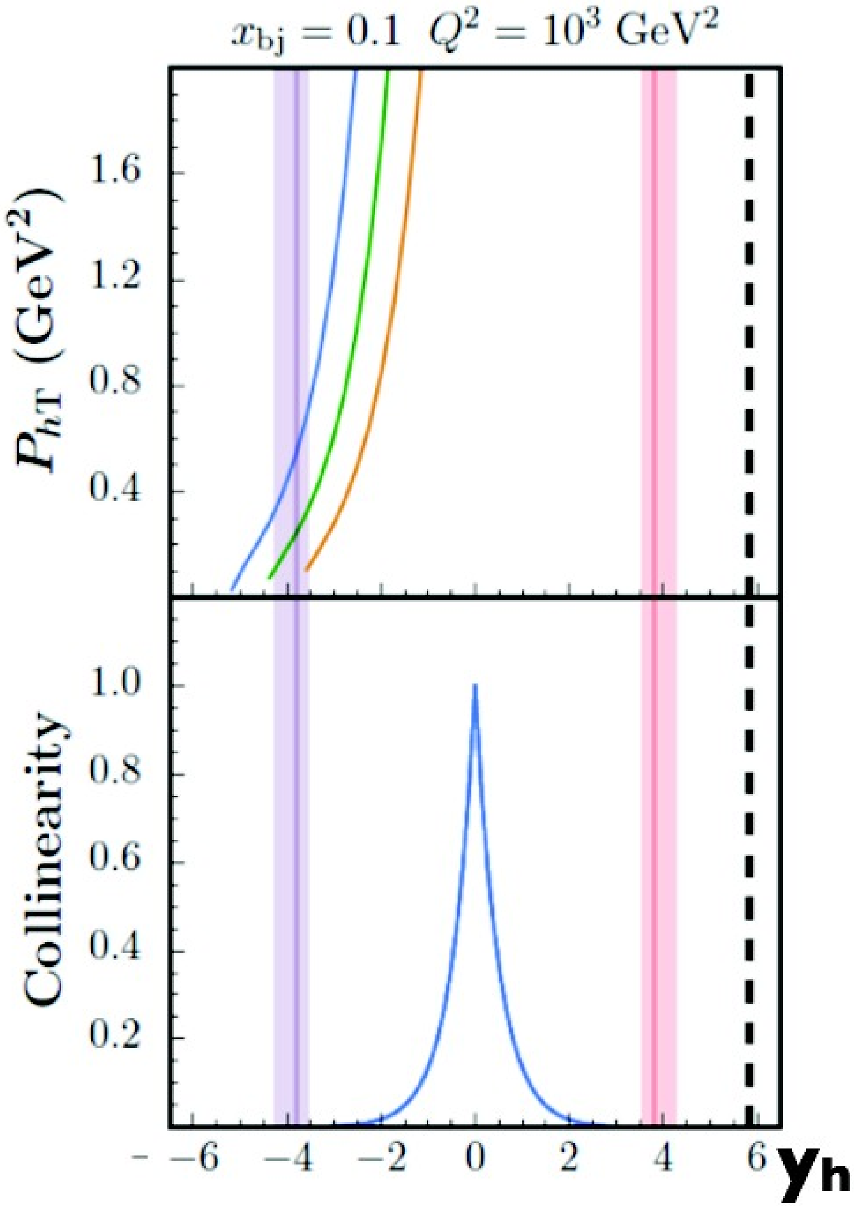
hard scale

require small values for

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

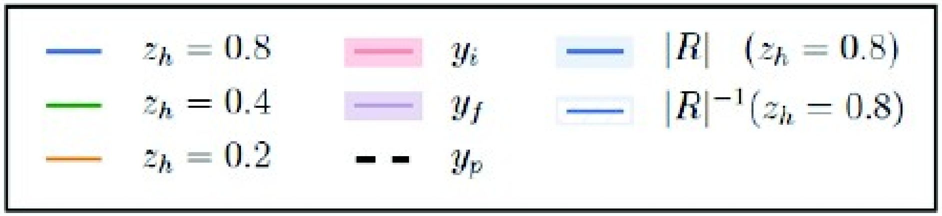
notice quark momenta have to be estimated

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



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

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



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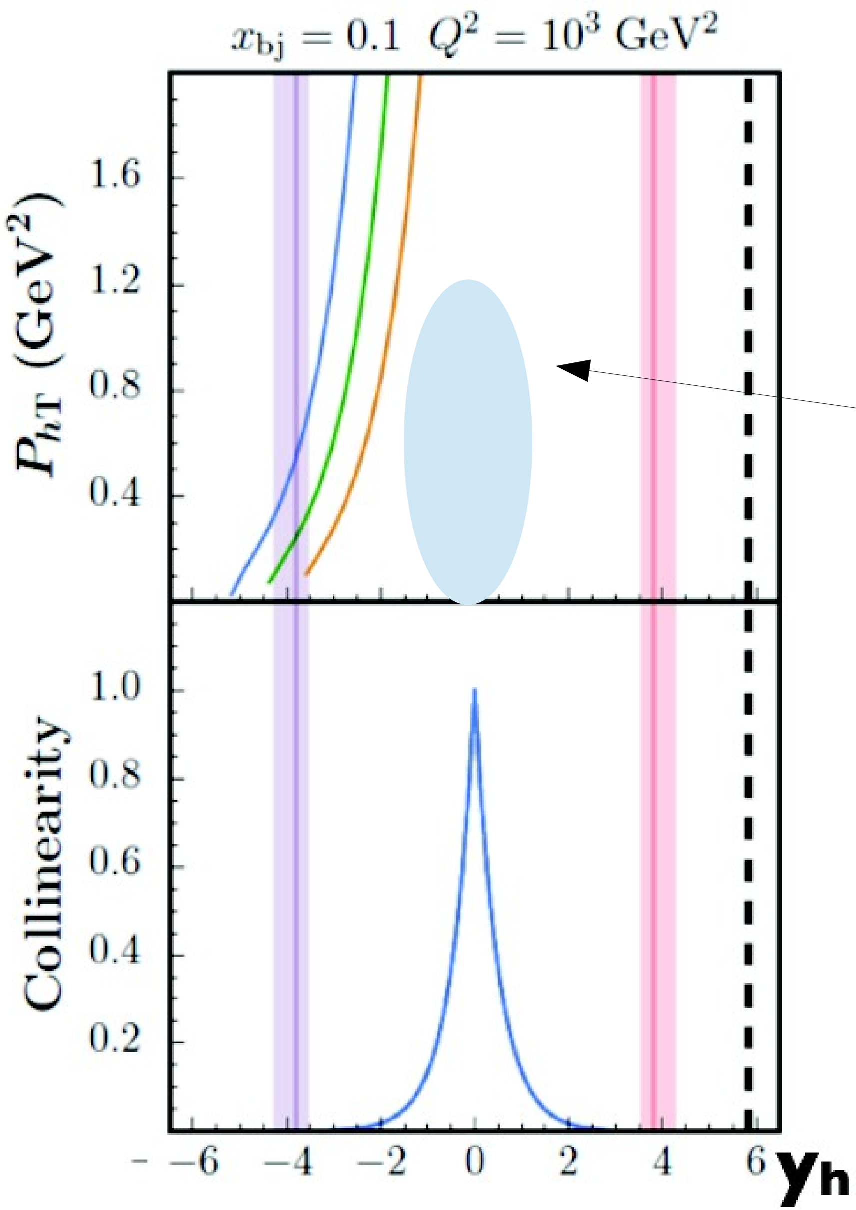
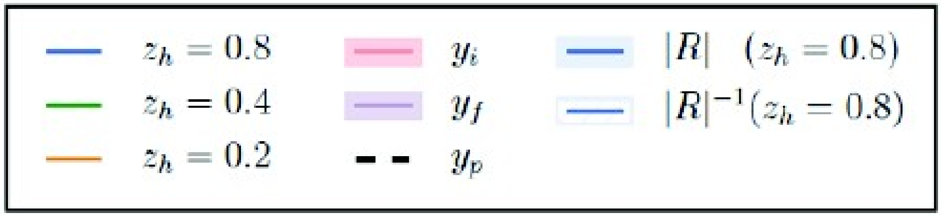


EIC projected energies.

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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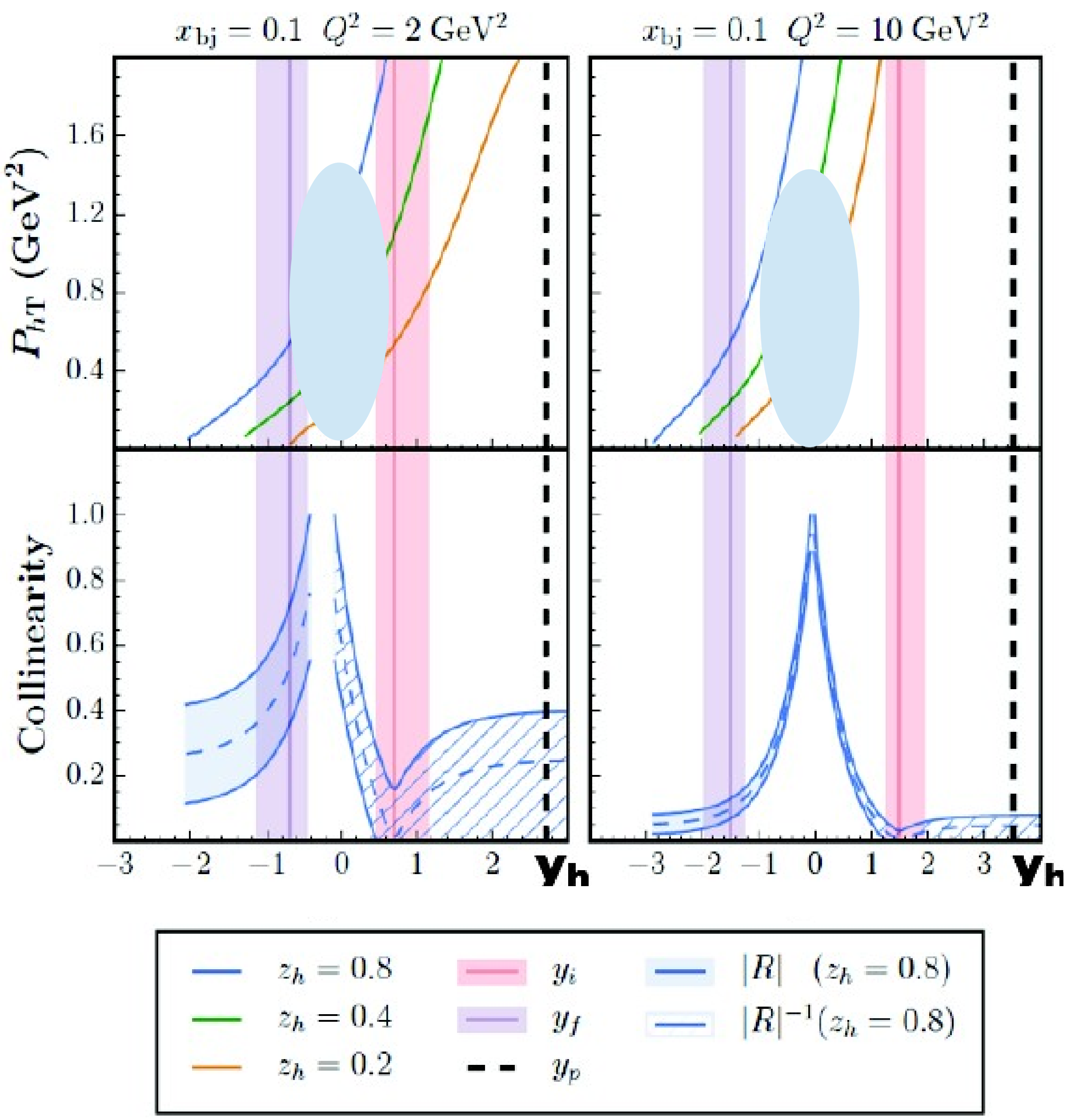
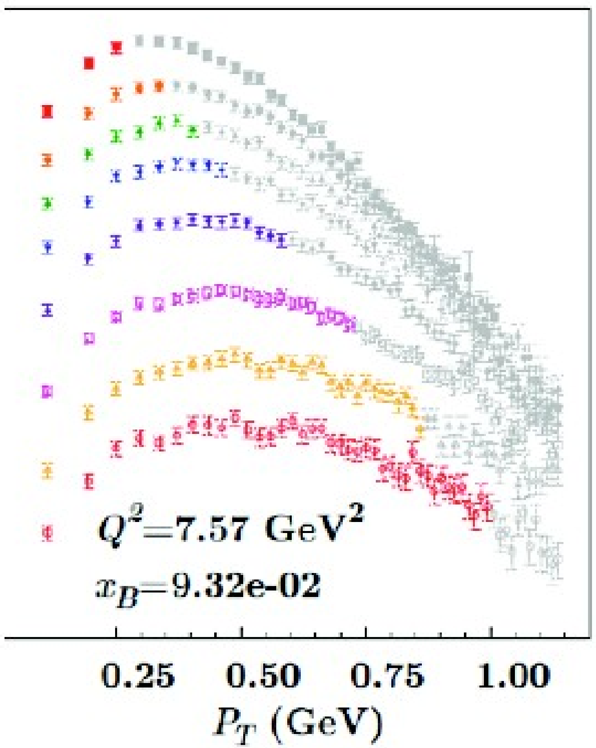


Available data is likely to receive contributions from non-TMD physics.

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

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

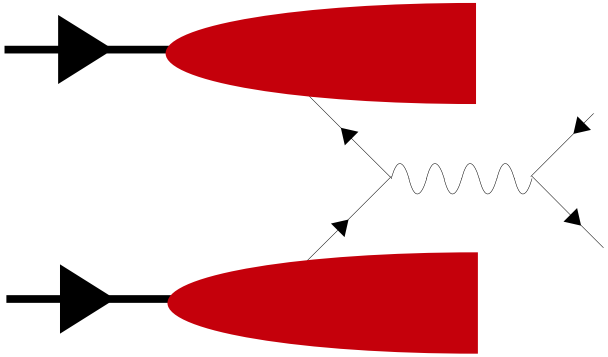
a better set of variables?

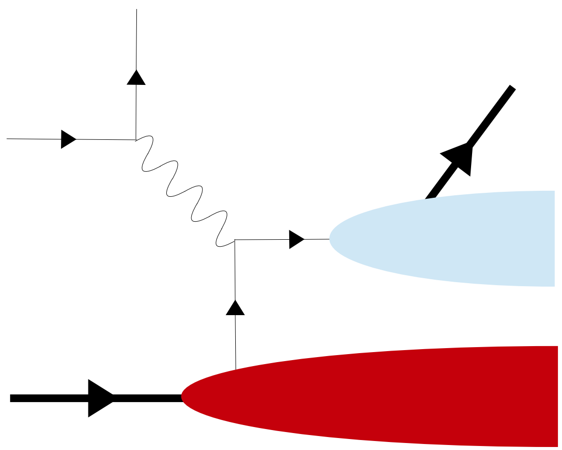
$\{Q^2, x_B, P_{hT}, z_h\}$

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

*ONLY AN EXAMPLE

Drell Yan



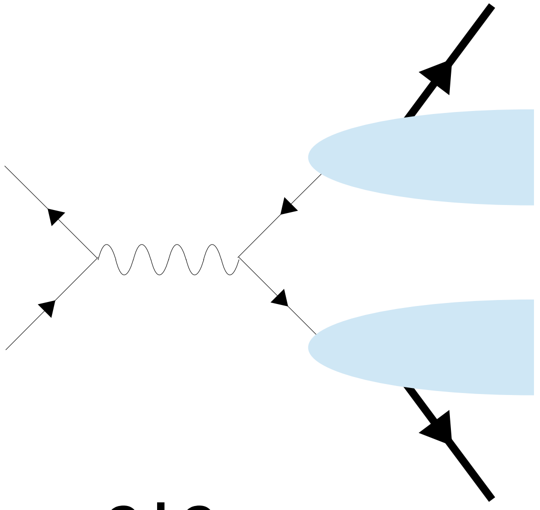


?

SIDIS

Recently, BELLE, BaBar, BES III Collins asymmetries.

No modern unpolarized measurements are available.



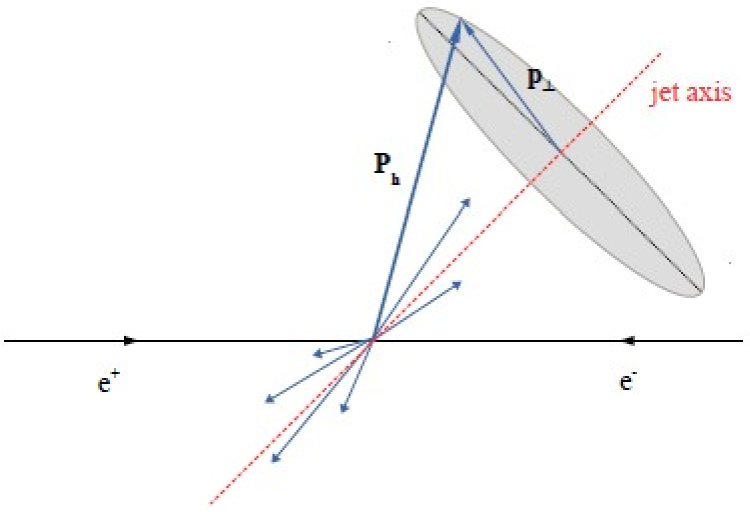
e+e-

Recently, BELLE, BaBar, BES III Collins asymmetries.

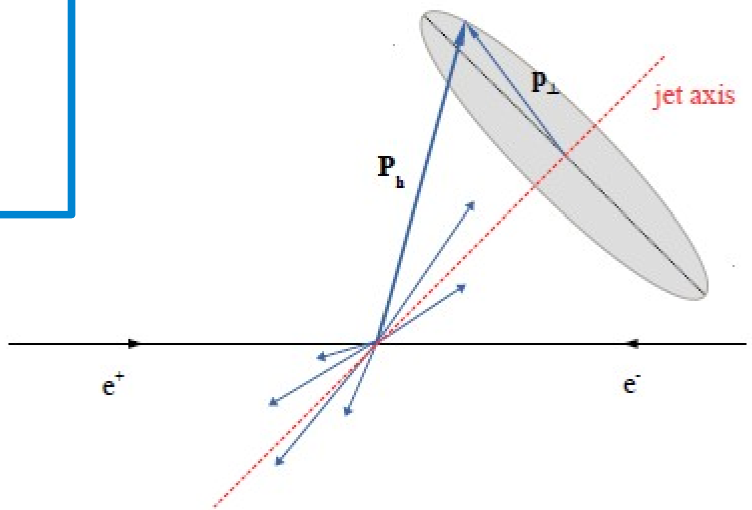
No modern unpolarized measurements are available.

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

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



Boglione, JOGH, R. Taghavi
Phys.Lett. B772 (2017) 78
arXiv:1704.08882



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

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

Big Limitation

New analysis:

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

Use this...

Assuming factorization

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

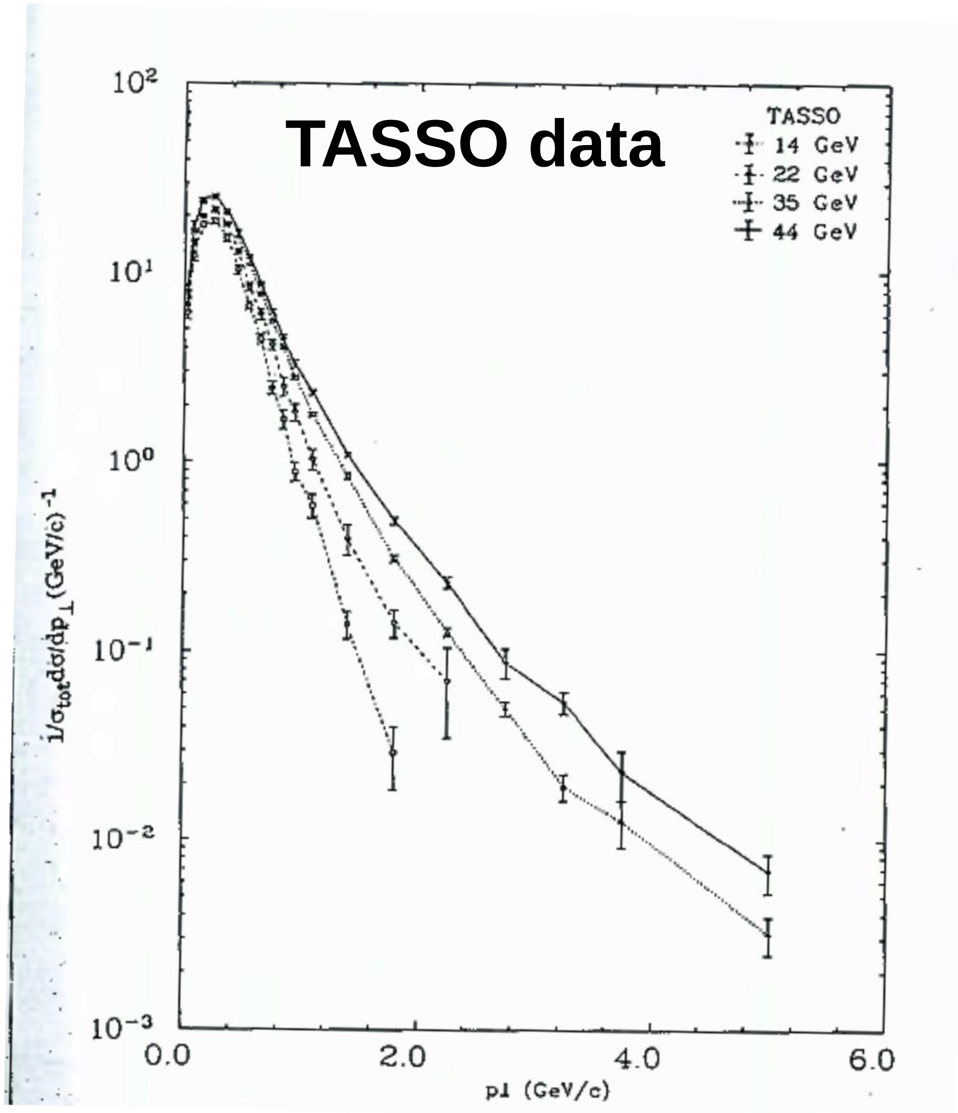
To get information about this

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 $\mathbf{g}_K$



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

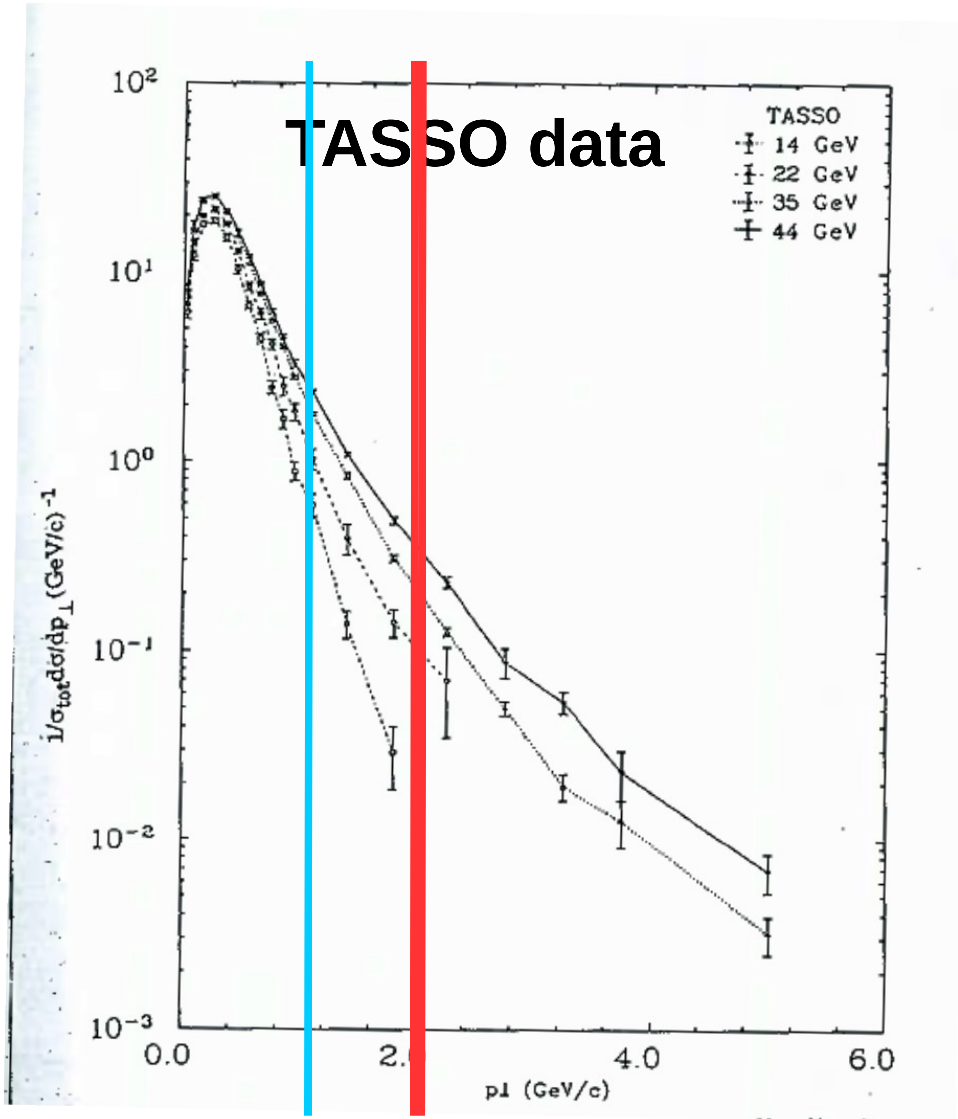
Identify region where TMD Effects dominate:

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

$$p_\perp \sim zQ$$

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

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



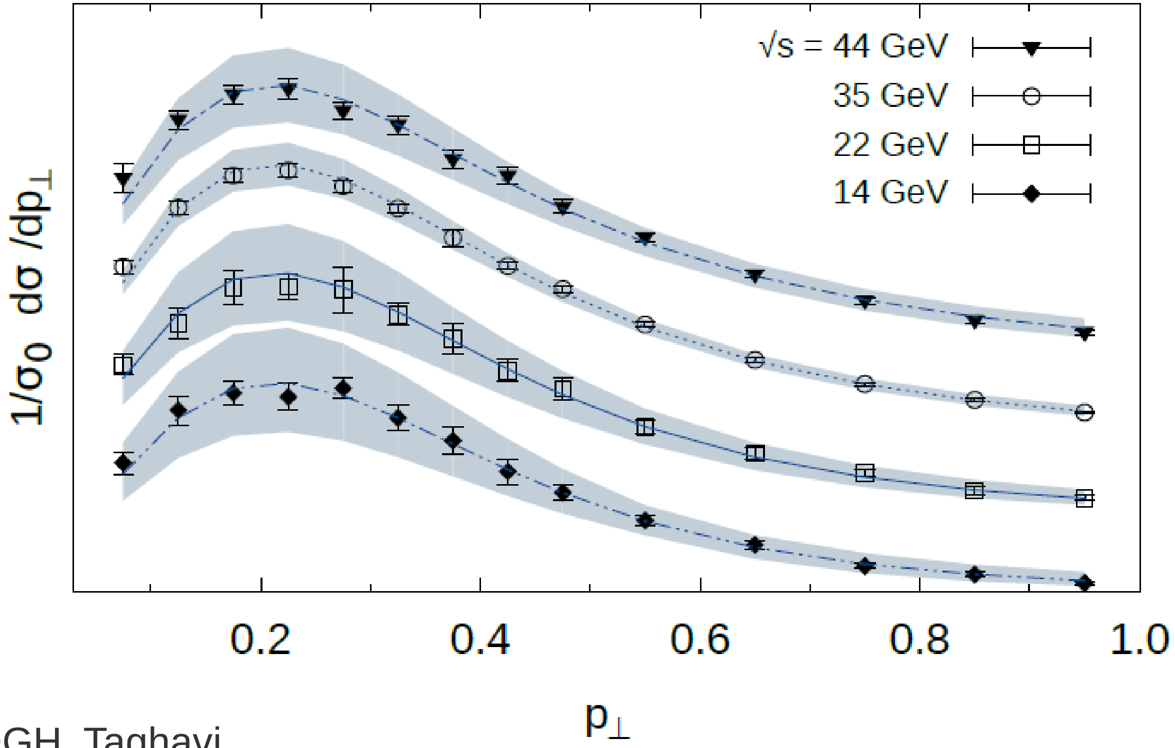
We looked at a restricted range: $p_\perp < 1\ \mathrm{GeV}$

Power law to model transverse momentum dependence

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

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

FIT TO TASSO

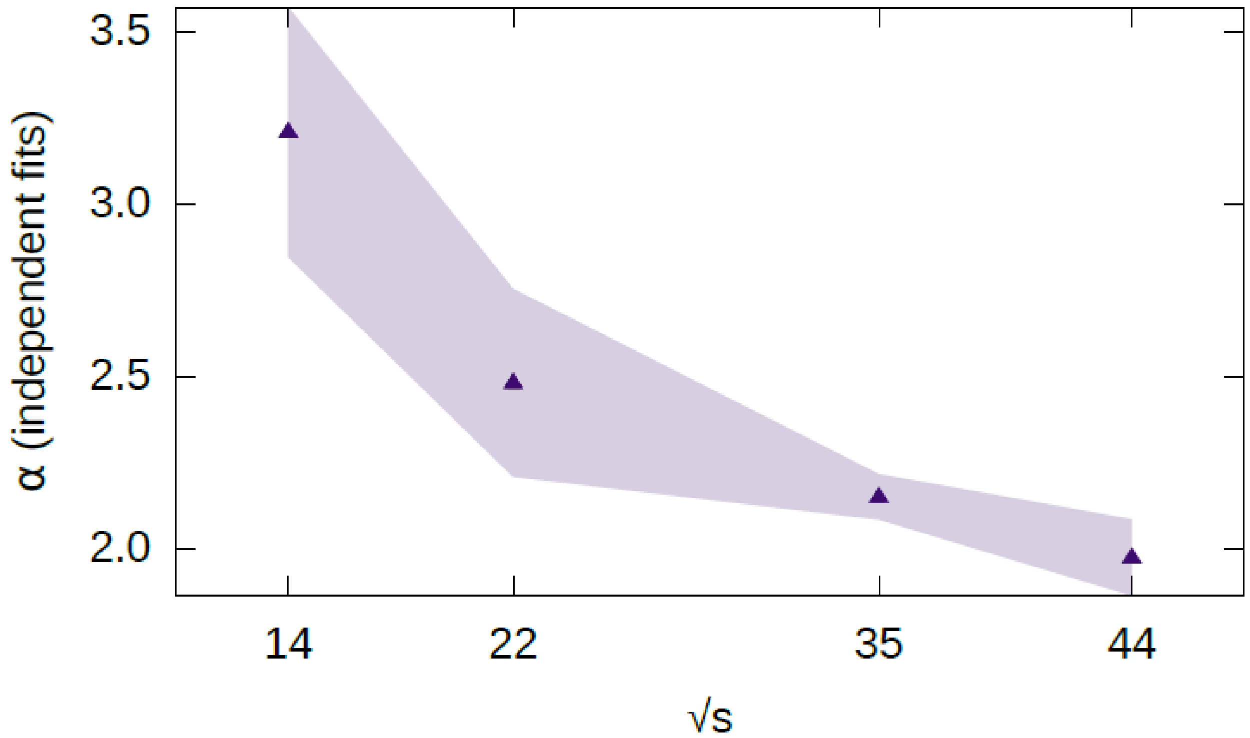


Boglione, JOGH, Taghavi

Phys.Lett. B772 (2017) 78-86

Power law parameters follow a logarithmic trend

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



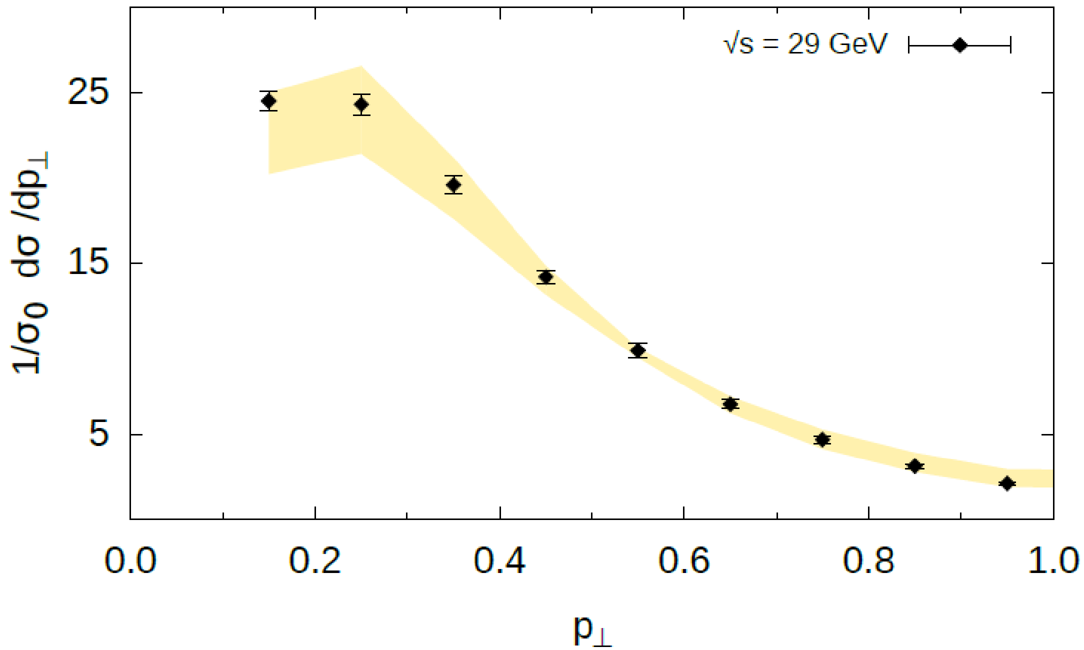
Boglione, JOGH, Taghavi

Phys.Lett. B772 (2017) 78-86

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



Boglione, JOGH, Taghavi

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TMD

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

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

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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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, it's 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**.

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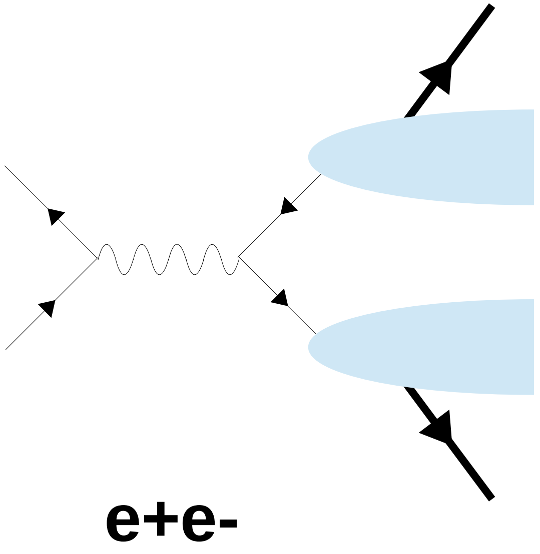
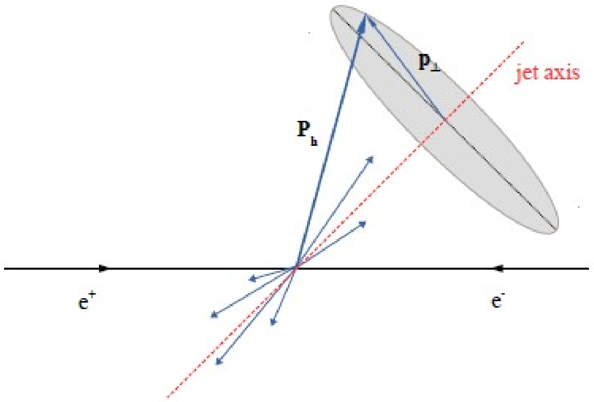
The lack of information about **z** hinders a full TMD extraction of the FF.

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





Phenomenological Test for factorization

Extraction from data?

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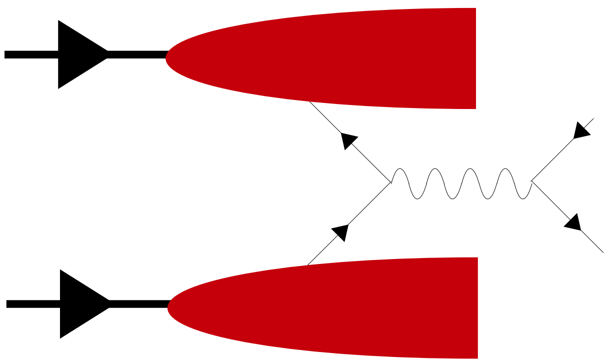
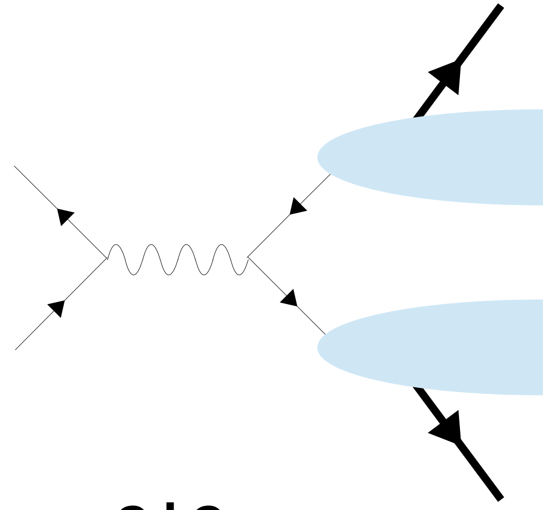
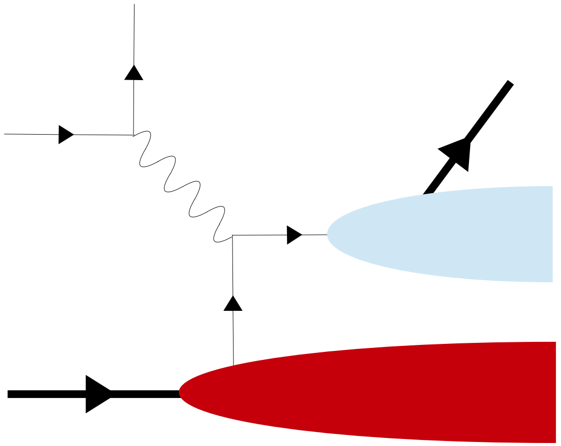




e+e-



SIDIS

Fragmentation Functions

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

Final Remarks

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

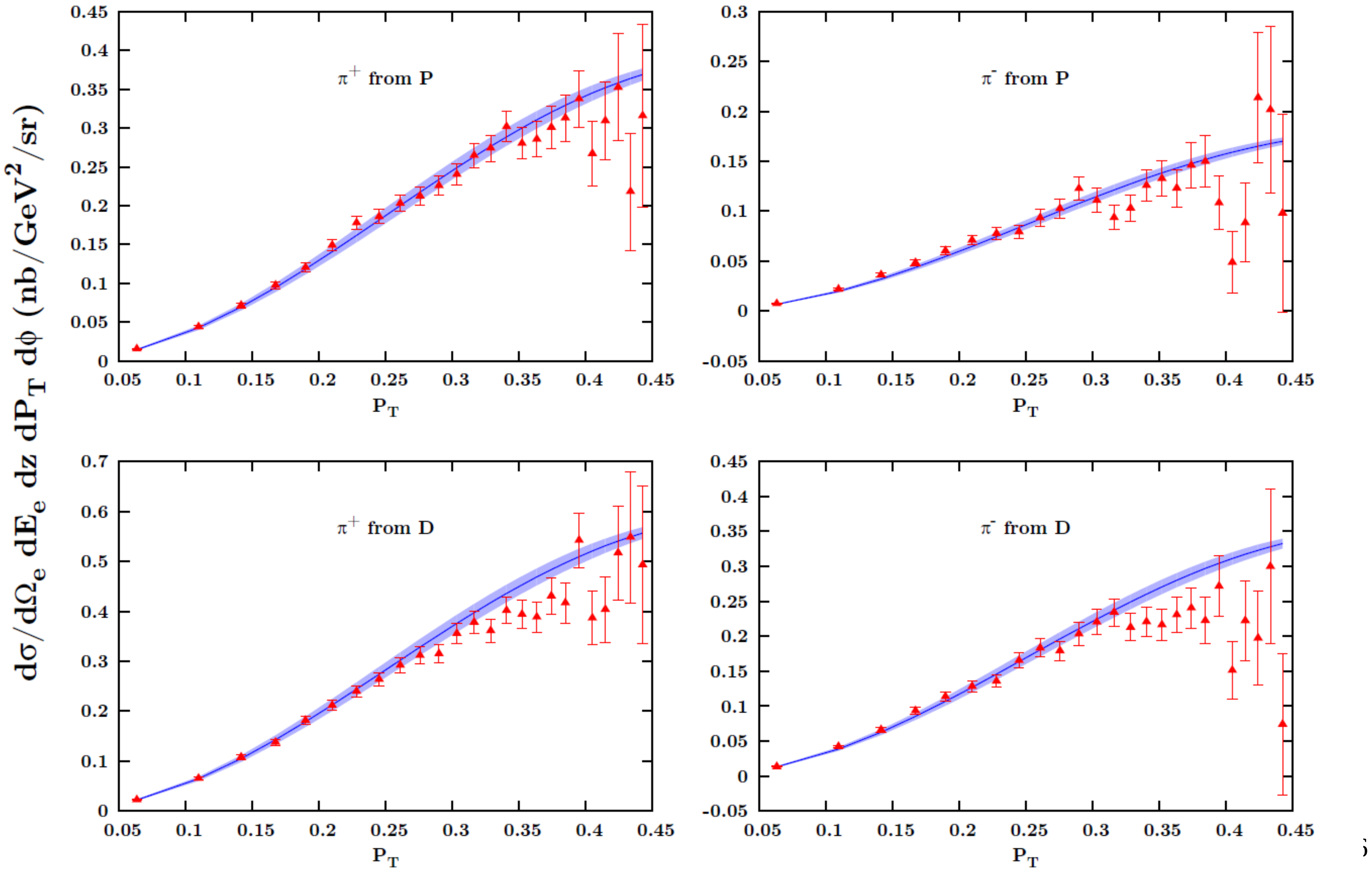
Recent SIDIS multidimensional data is so far the most suitable way to access information about the unpolarized TMD FF. Must solve some *theoretical issues*.

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.

TMD Factorization for e+e- one hadron production?

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

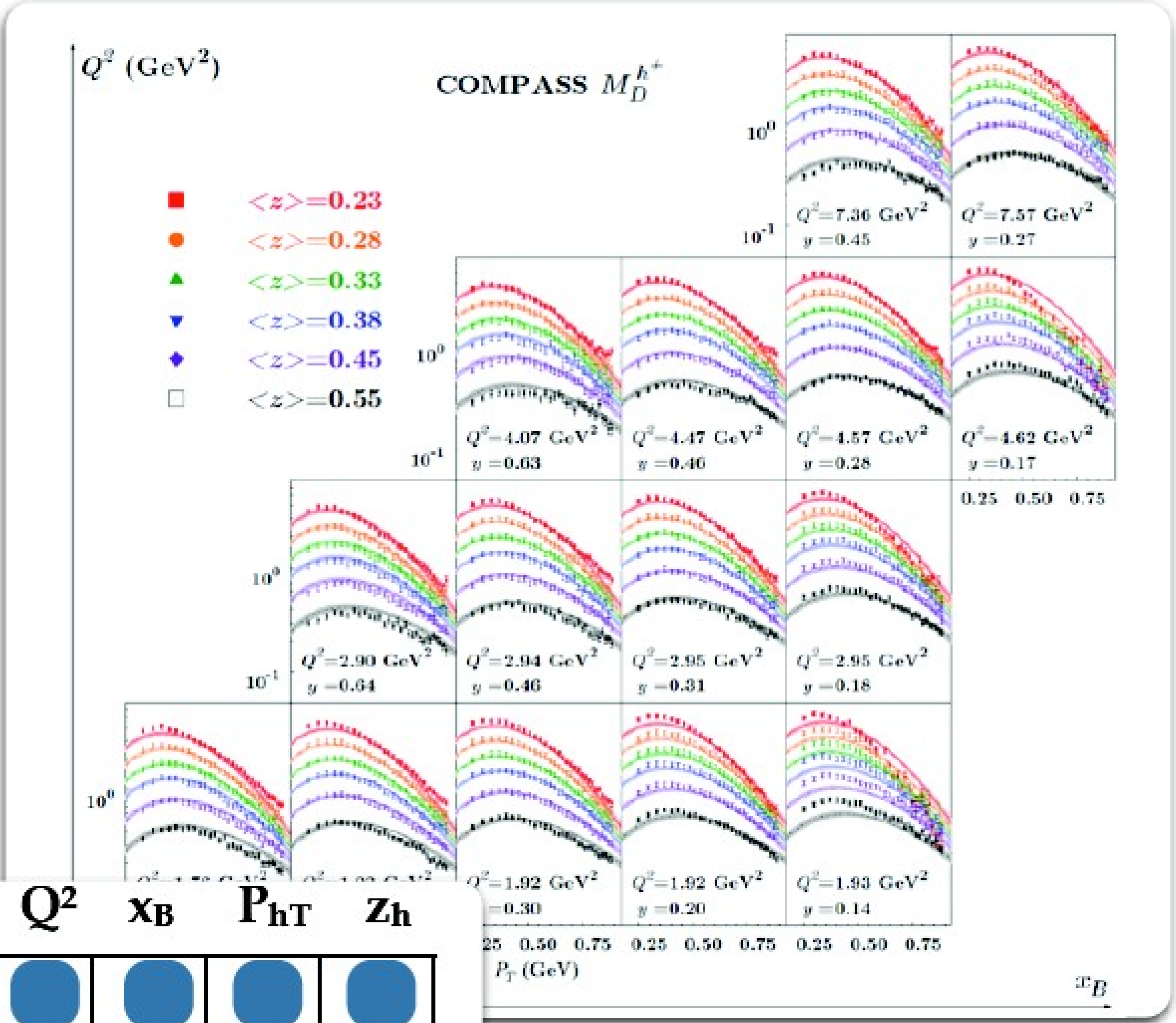
Unpolarized TMDFF &TMDPDF

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				