Map of Semi-Inclusive Deeply Inelastic Scattering

T. Rogers

CLAS Collaboration Meeting – March, 29 2017

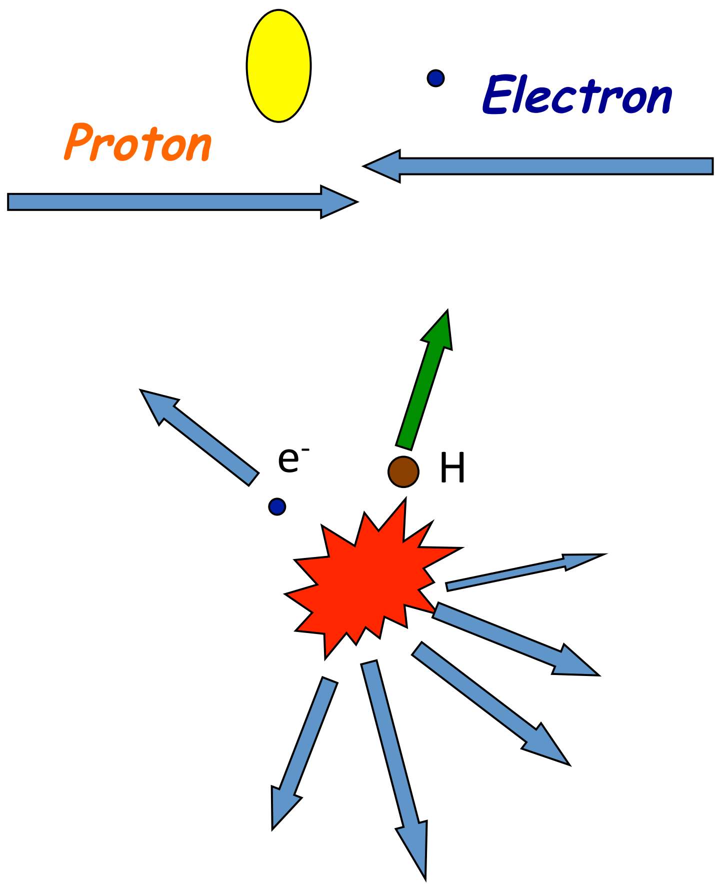
Outline

- Kinematical Categories.

- What can be learned?

What is it?

$$\text{Proton} + \text{lepton} \longrightarrow \text{hadron} + \text{lepton} + X$$



Must have:

- Hard scale (Q >> m)
- One observed hadron (H)
- Unobserved particles

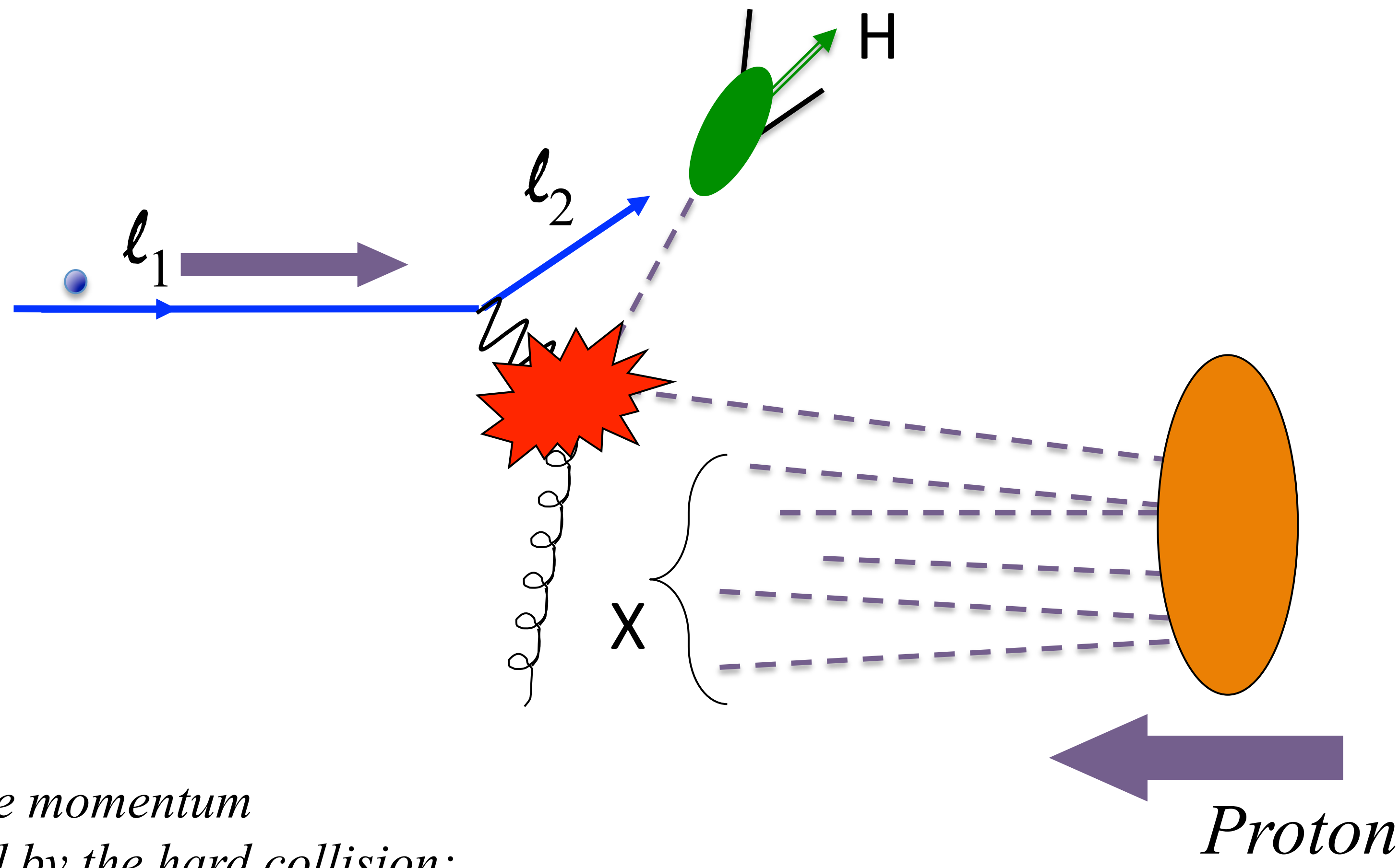
Optional:

- Differential in $\mathbf{P}_{H,T}$
- Integrated over $\mathbf{P}_{H,T}$

Where does the hadron come from?

A. Hadron has large transverse momentum.
   - Natural interpretation: Hadron is produced as part of hard collision.

Large Transverse Momentum: Contribution A.



Transverse momentum Generated by the hard collision; Does not "come from" PDF or fragmentation function.

Where does the hadron come from?

A. Hadron has large transverse momentum.
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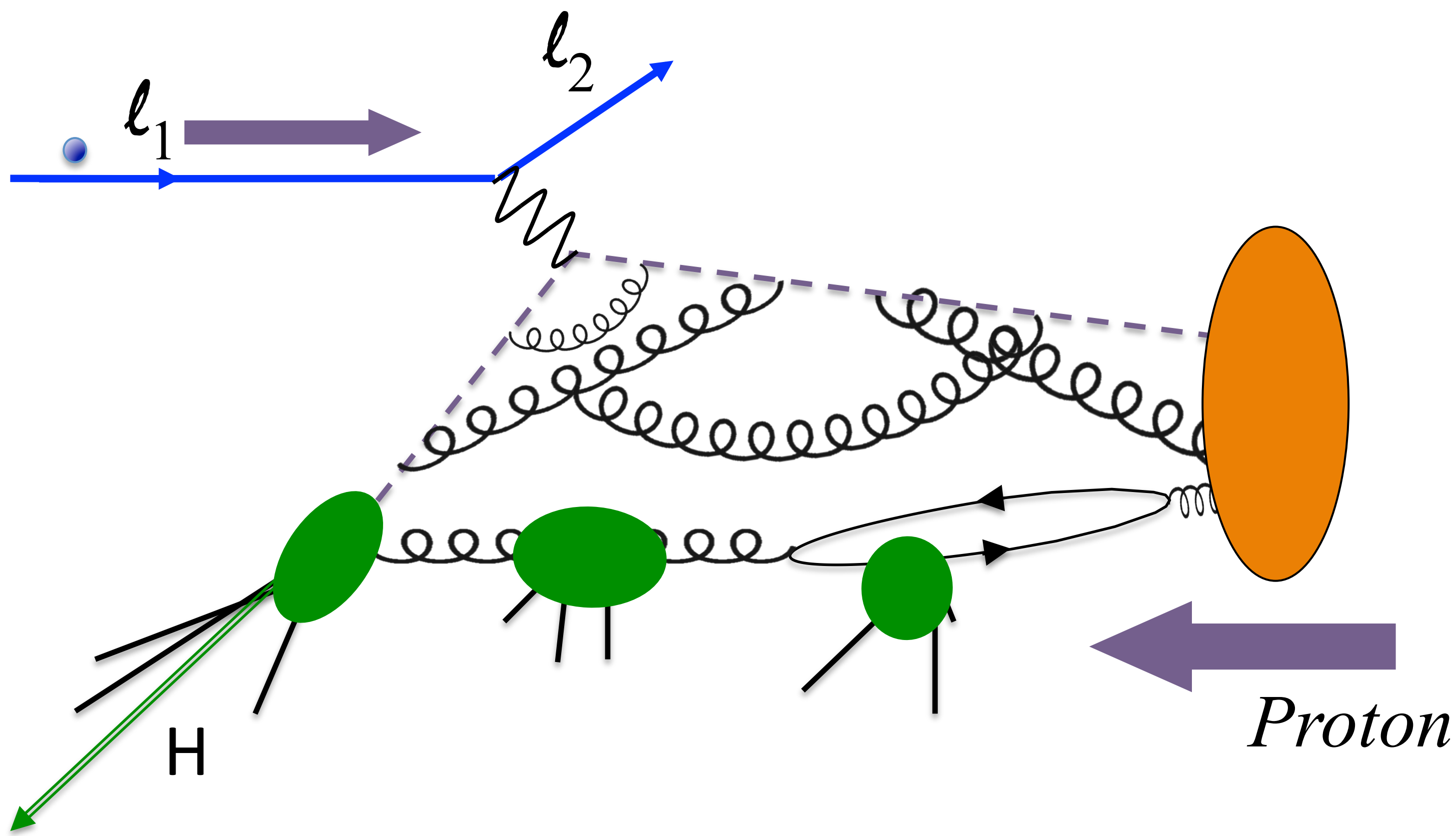
B. Hadron has small transverse momentum but rapidity opposite to proton.
   - Natural interpretation: Hadron is a decay product of struck quark with transverse momentum generated in hadronization process.

Small Transverse Momentum: Contribution B.



Fragmentation Function: dependence on Q^2, z

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B. Hadron has small transverse momentum but rapidity opposite to proton.
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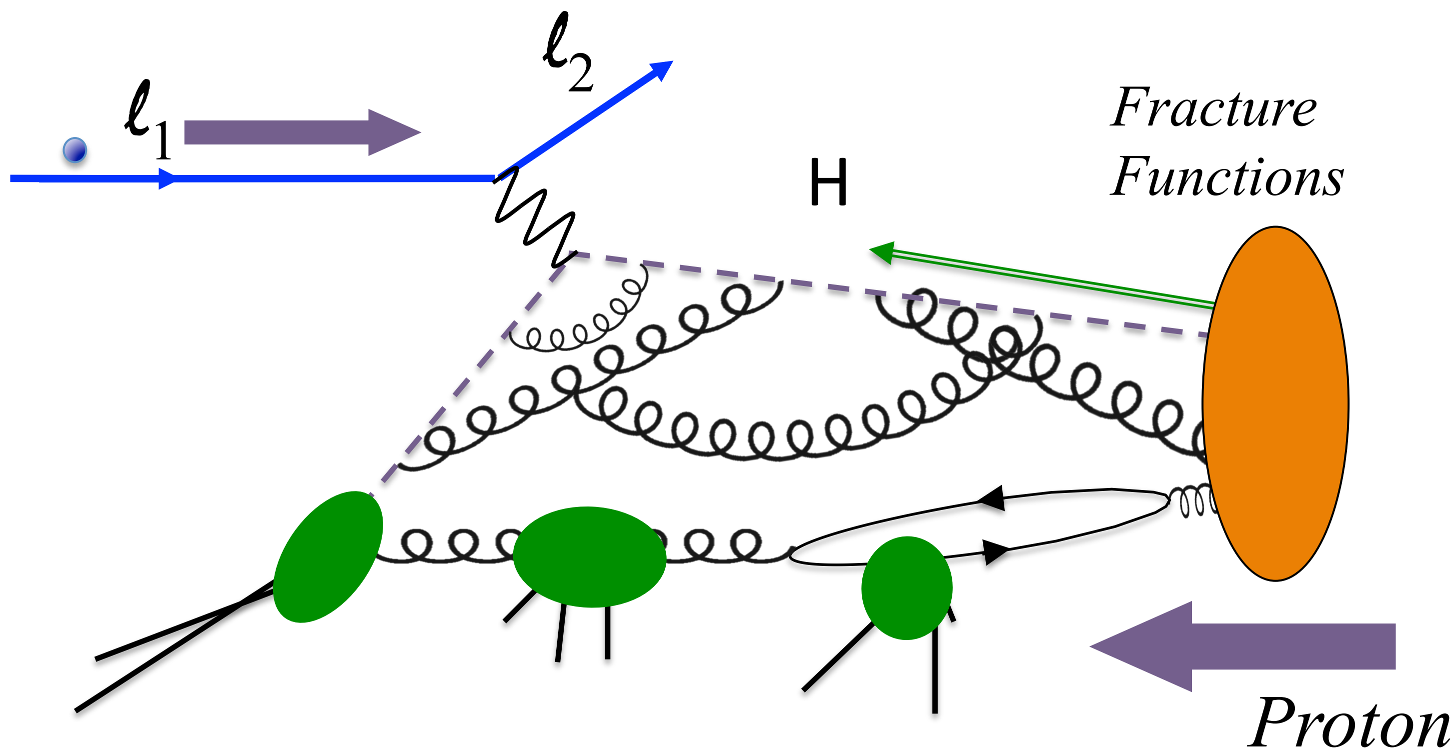
C. Hadron has small transverse momentum and rapidity in nearly same direction as the proton.
   - Natural interpretation: Hadron is a leftover remnant of proton.

Small Transverse Momentum: Contribution C.



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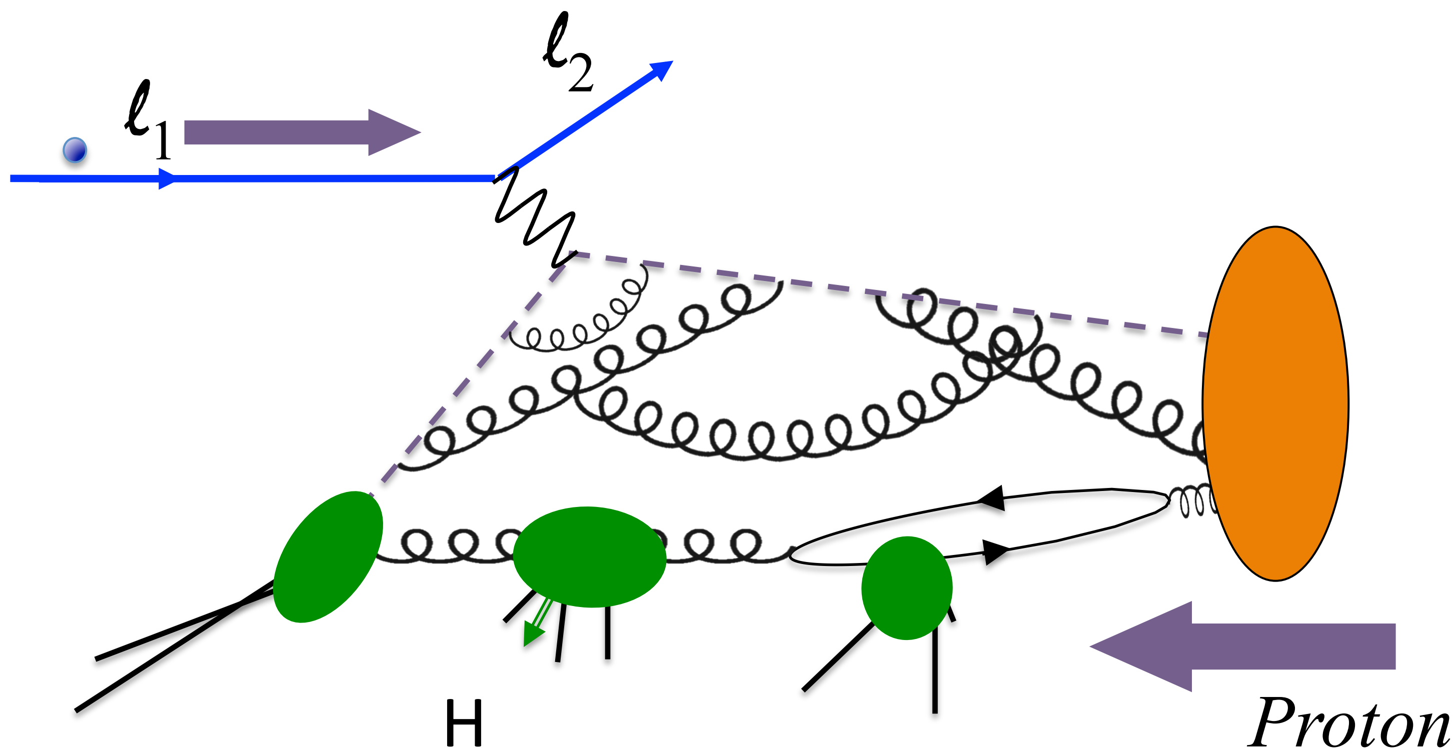
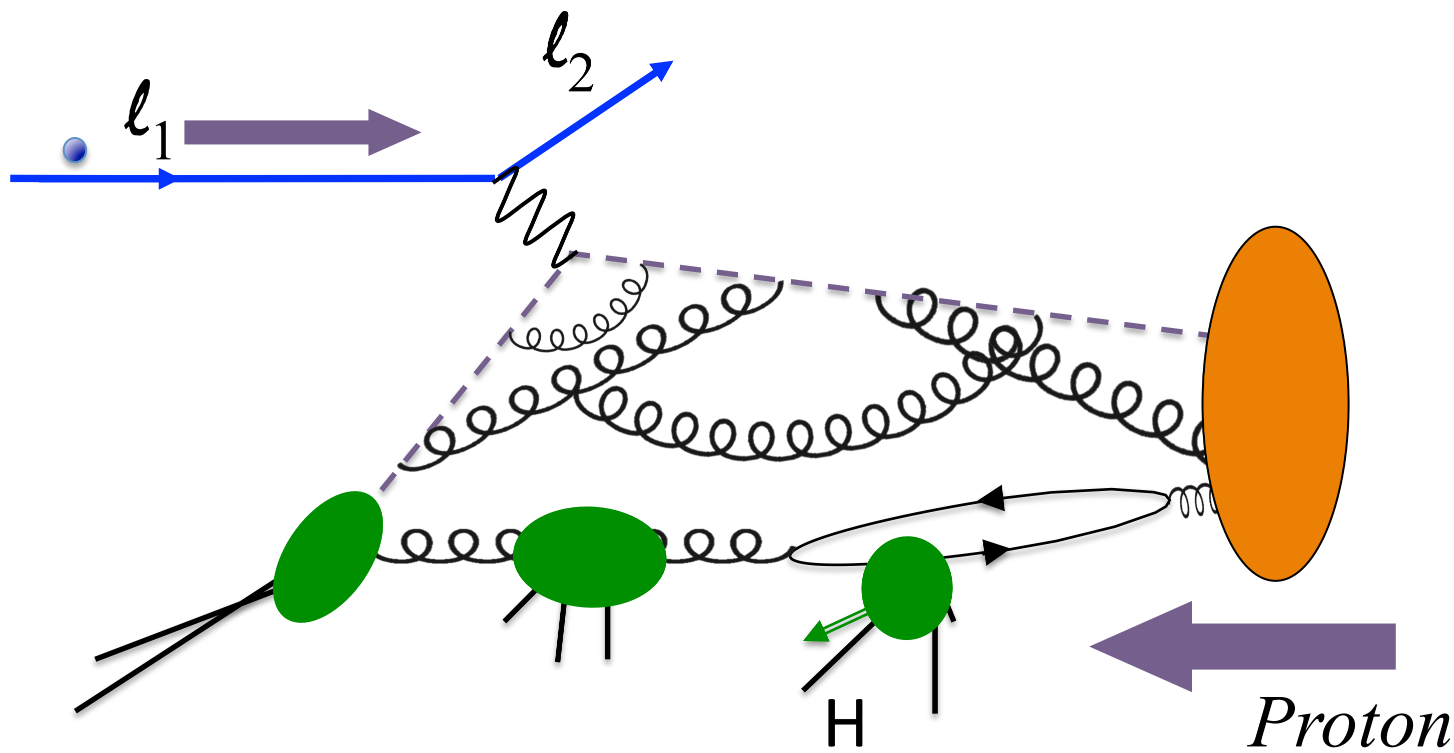
D. Hadron has small transverse momentum and rapidity.
   - Natural interpretation: Hadron is a non-perturbatively produce of the collision that is associated with neither the struck quark nor the initial proton.

Small Transverse Momentum: Contribution D.



Small Transverse Momentum: Contribution D.



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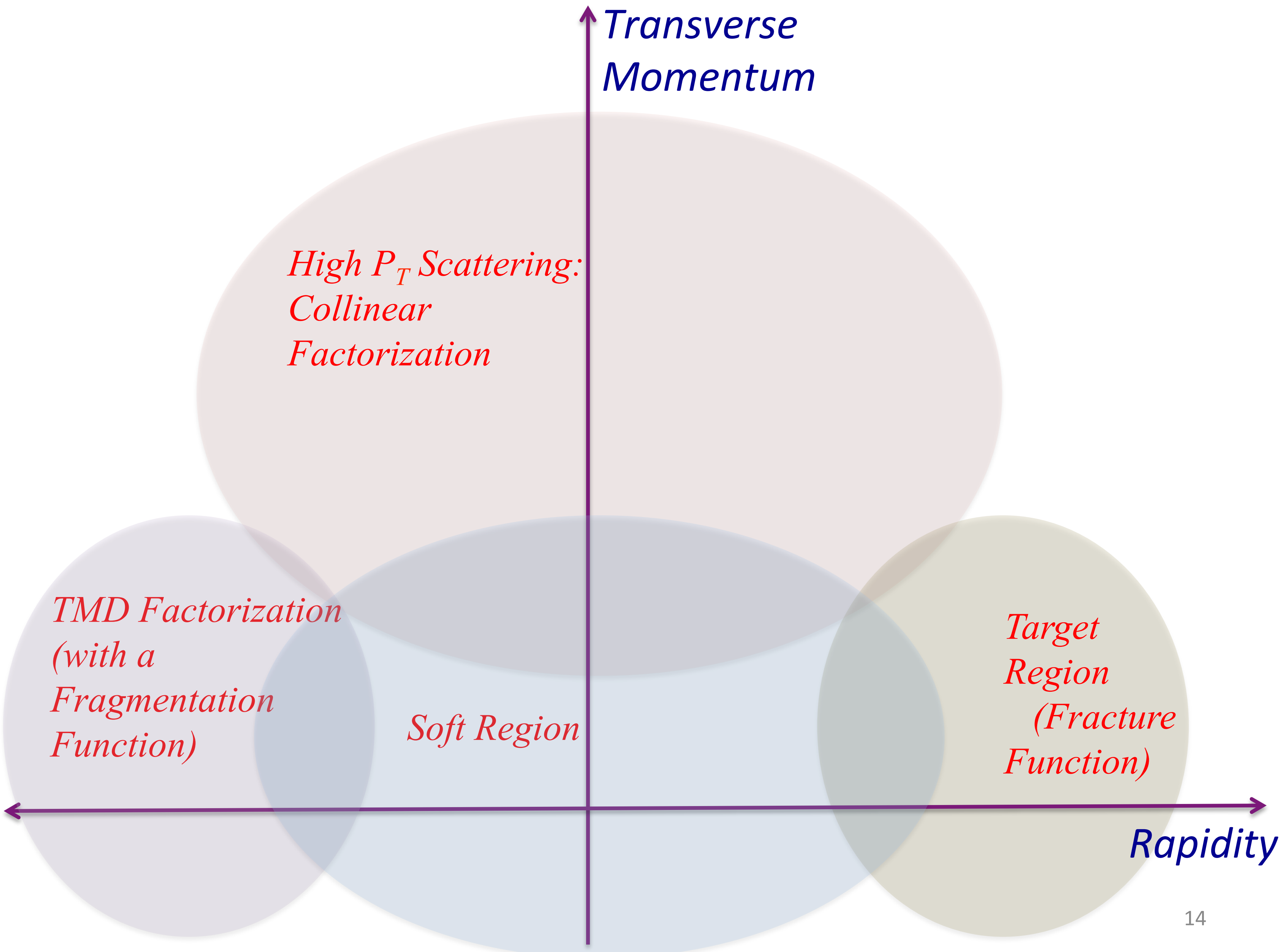
E. Hadron is at the border of one of the above.


Transverse Momentum
High P_T Scattering: Collinear Factorization
TMD Factorization (with a Fragmentation Function)
Soft Region
Target Region (Fracture Function)
Rapidity

Series Expansions

$$\mathrm{d}\sigma = \frac{1}{\Phi}\sum\int |\langle P_H, P_a, P_b \cdots | P, l_e\rangle|^2$$

- Interpretation needed.

- Theorists like specific correlation functions:
  - E.g., parton distributions, fragmentation functions, etc…

$$\int \frac{dw^-}{(2\pi)} e^{-i\xi P^+ w^-} \langle P| \bar{\psi}_0(0, w^-, \mathbf{0}_t) \frac{\gamma^+}{2} \psi_0(0, 0, \mathbf{0}_t) |P\rangle$$

Series Expansions

Series Expansions

$$\mathrm{d}\sigma = \frac{1}{\Phi}\sum\int |\langle P_H, P_a, P_b \cdots | P, l_e\rangle|^2$$

$$A_0\left(\frac{\Lambda^2}{Q^2}\right)^0 + A_1\left(\frac{\Lambda^2}{Q^2}\right)^1 + A_2\left(\frac{\Lambda^2}{Q^2}\right)^2 + \cdots O\left(\left(\frac{\Lambda^2}{Q^2}\right)^N\right)$$

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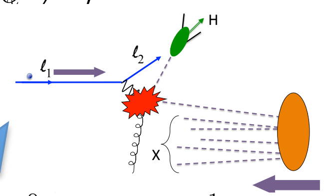
Small $P_{H,T}$?

Or



$$D_0\left(\frac{P_T^2}{Q^2}\right)^0 + D_1\left(\frac{P_T^2}{Q^2}\right)^1 + D_2\left(\frac{P_T^2}{Q^2}\right)^2 + \cdots O\left(\left(\frac{P_T^2}{Q^2}\right)^N\right)$$

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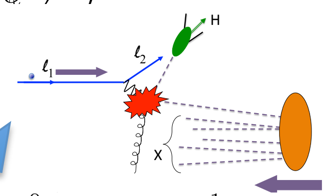
Small $P_{H,T}$ *?*

Or



A.

$$D_0\left(\frac{P_T^2}{Q^2}\right)^0 + D_1\left(\frac{P_T^2}{Q^2}\right)^1 + D_2\left(\frac{P_T^2}{Q^2}\right)^2 + \cdots O\left(\left(\frac{P_T^2}{Q^2}\right)^N\right)$$

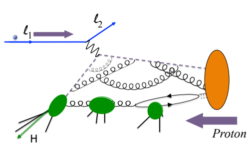
$$E_0\left(\frac{\Lambda^2}{P_T^2}\right)^0 + E_1\left(\frac{\Lambda^2}{P_T^2}\right)^1 + E_2\left(\frac{\Lambda^2}{P_T^2}\right)^2 + \cdots O\left(\left(\frac{\Lambda^2}{P_T^2}\right)^N\right)$$

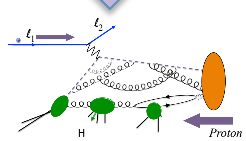
B.

D.

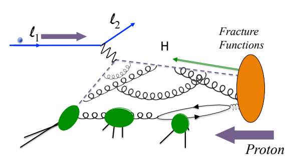
C.

$$F_0 + F_1\left(e^{y_H}\right)^1 + \cdots O(e^{y_H N})$$





$$G_0 + G_1\left(e^{-y_H}\right)^1 + \cdots O(e^{-y_H N})$$



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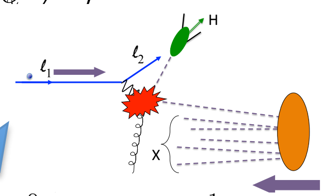
Or



$$D_0\left(\frac{P_T^2}{Q^2}\right)^0 + D_1\left(\frac{P_T^2}{Q^2}\right)^1 + D_2\left(\frac{P_T^2}{Q^2}\right)^2 + \cdots O\left(\left(\frac{P_T^2}{Q^2}\right)^N\right)$$

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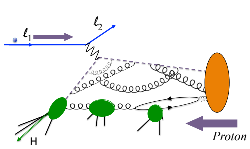

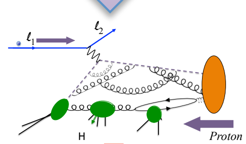

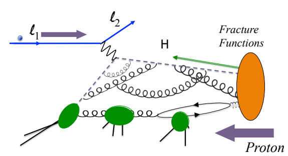

$$B_0\,\alpha_s(Q)^0 + B_1\,\alpha_s(Q)^1 + B_2\,\alpha_s(Q)^2 + \cdots O(\alpha_s(Q)^N)$$

$$C_0\,\alpha_s(P_T)^0 + C_1\,\alpha_s(P_T)^1 + C_2\,\alpha_s(P_T)^2 + \cdots O(\alpha_s(P_T)^N)$$

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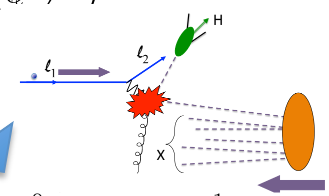

$$D_0\left(\frac{P_T^2}{Q^2}\right)^0 + D_1\left(\frac{P_T^2}{Q^2}\right)^1 + D_2\left(\frac{P_T^2}{Q^2}\right)^2 + \cdots O\left(\left(\frac{P_T^2}{Q^2}\right)^N\right)$$

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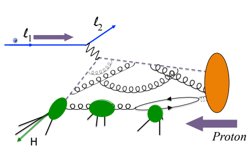

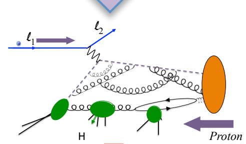

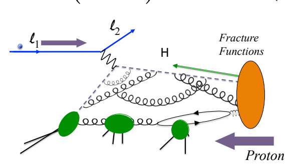

$$B_0\,\alpha_s(Q)^0 + B_1\,\alpha_s(Q)^1 + B_2\,\alpha_s(Q)^2 + \cdots O(\alpha_s(Q)^N)$$

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LDRD personnel

JLab

Pythia

Other

LDRD:
LABORATORY DIRECTED
RESEARCH & DEVELOPMENT

Study of hadronization

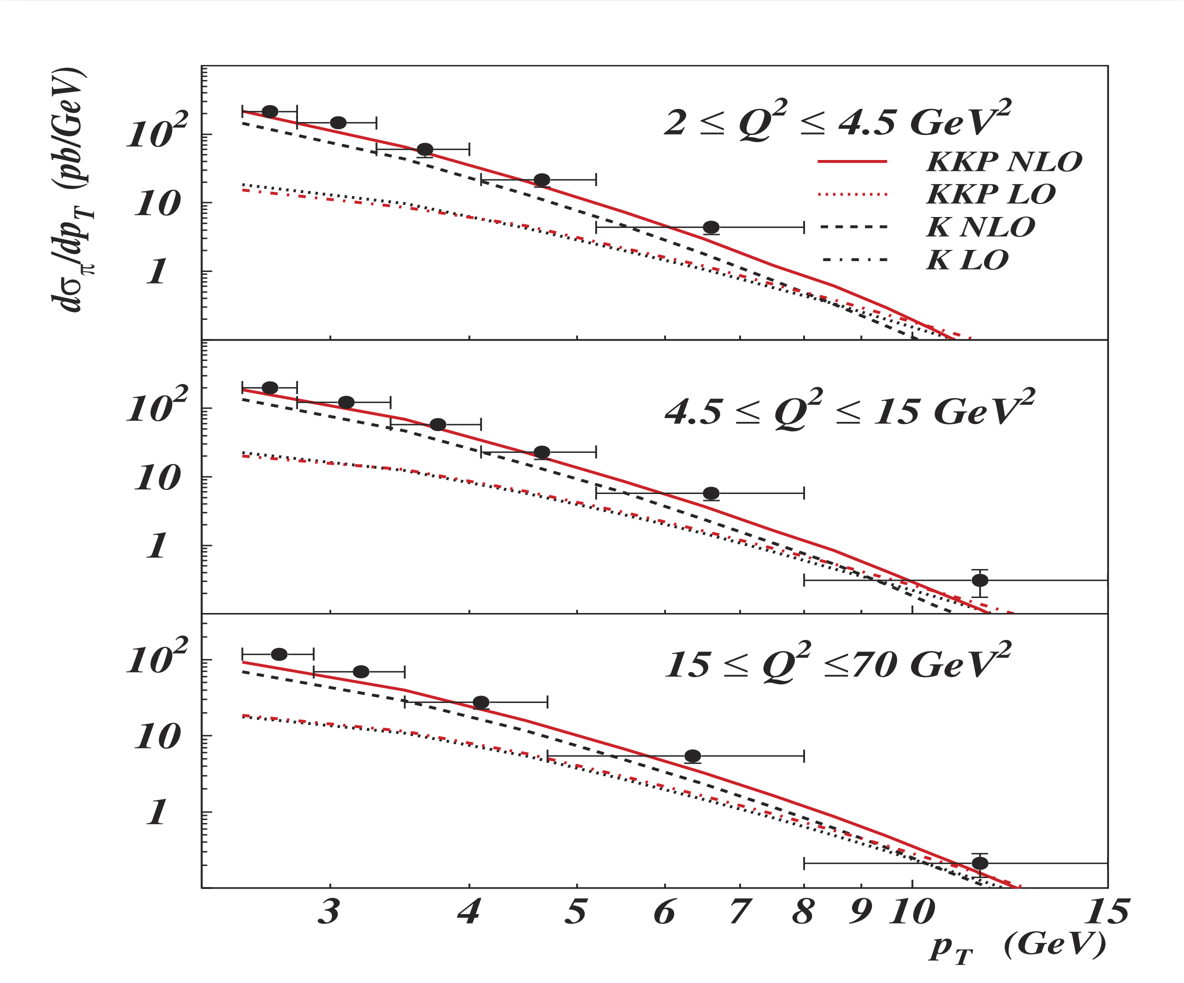
Correlation functions of TMD factorization ↔ Pythia Monte Carlo Event Generator

Experimentalists

Theorists

Need to address

- Large transverse momentum.

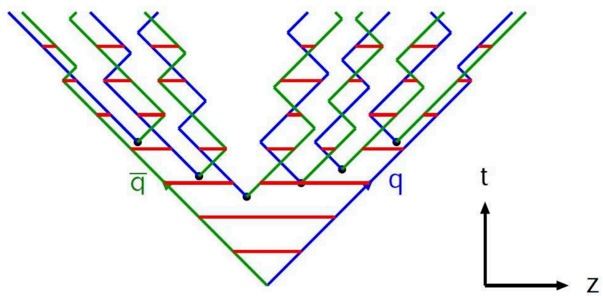


Daleo, de Florian, Sassot (2005)
Phys.Rev. D71 (2005) 034013

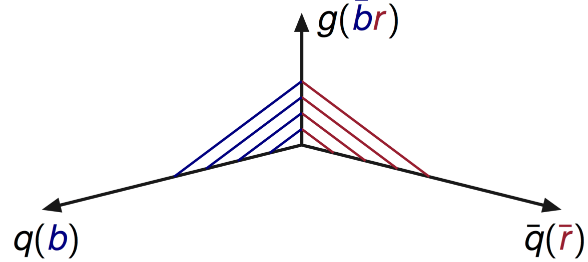
Data: H1 (2004)
Eur.Phys.J.C36:441-452,2004

- Explicit theory of hadronization.

String breakup



String drawing



- Universal behavior for soft (small rapidity) hadrons?

- Matching to large transverse momentum.

Questions

- Does SIDIS at small transverse momentum exhibit increasingly TMD-factorization-like behavior as Q increases?

- Need improved understanding of non-perturbative behavior / hadronization.

Need to address

- Approximations can be very good in multiple regions at the same time.

- Variables to catalogue regions?
  - E.g., z vs. rapidity?

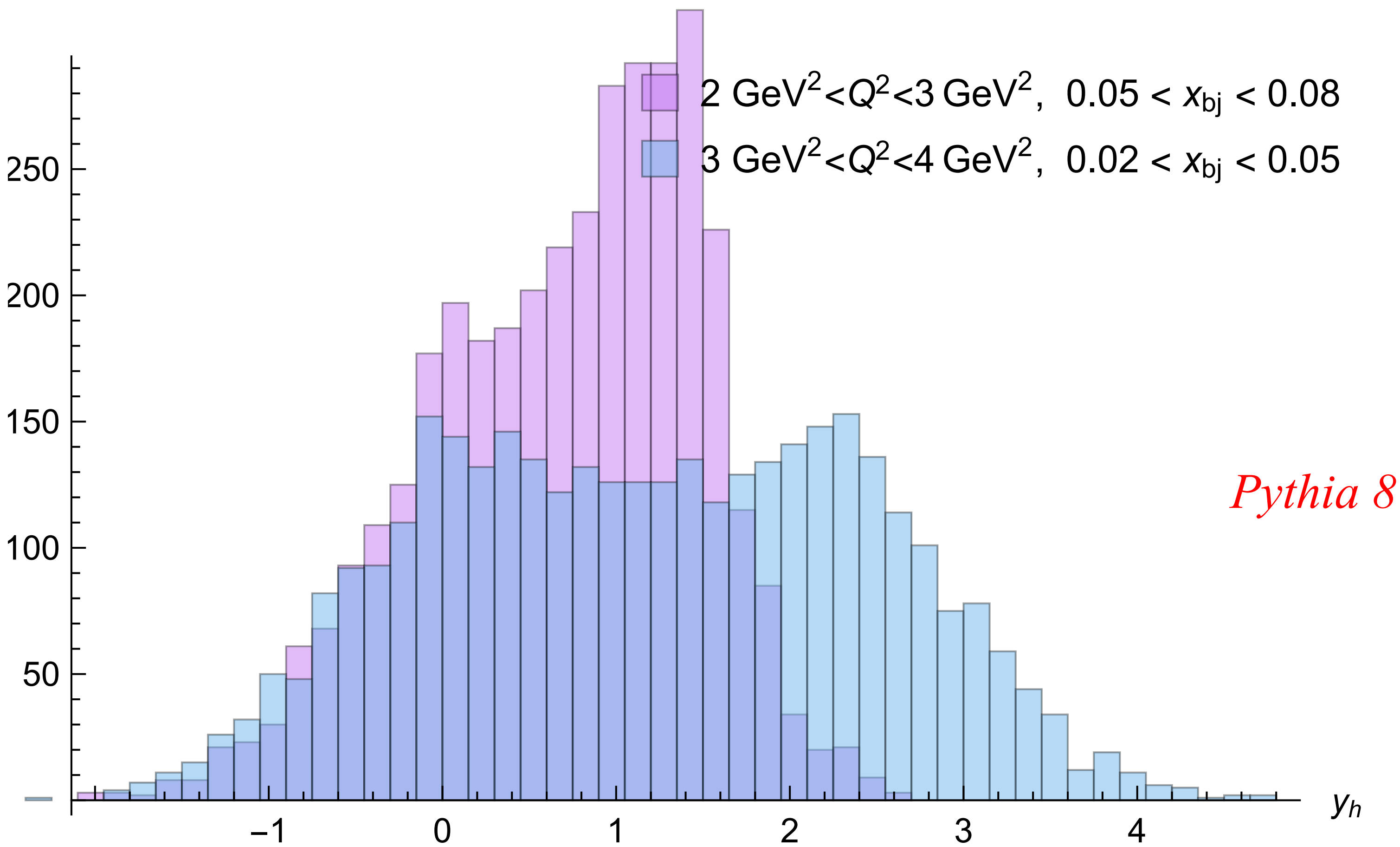
- What is Λ in Λ/Q? $\frac{M_p^2}{Q^2}, \quad \frac{k^2}{Q^2}, \quad \frac{m_q^2}{Q^2}$

- Large/small transverse momentum separation?

Need to address

- If modifications are needed, are they from higher orders, higher powers, logarithmic resummation… ?
- Does cross section follow general expectations?
  - E.g., rapidity plateau at large Q, universal behavior for soft hadrons
- Guide from experiments: Where are modifications most needed?
  - Low Q vs. large Q
  - Low P_T vs. Large P_T
  - Low rapidity vs. large rapidity

Plateau Shape



Measure closeness to current region

- Lorentz invariant test:

$$R(y_{\rm h}, z_{\rm h}, x_{\rm bj}, Q) \equiv \frac{P_h \cdot k_{\rm f}}{P_h \cdot k_{\rm i}} \,,$$

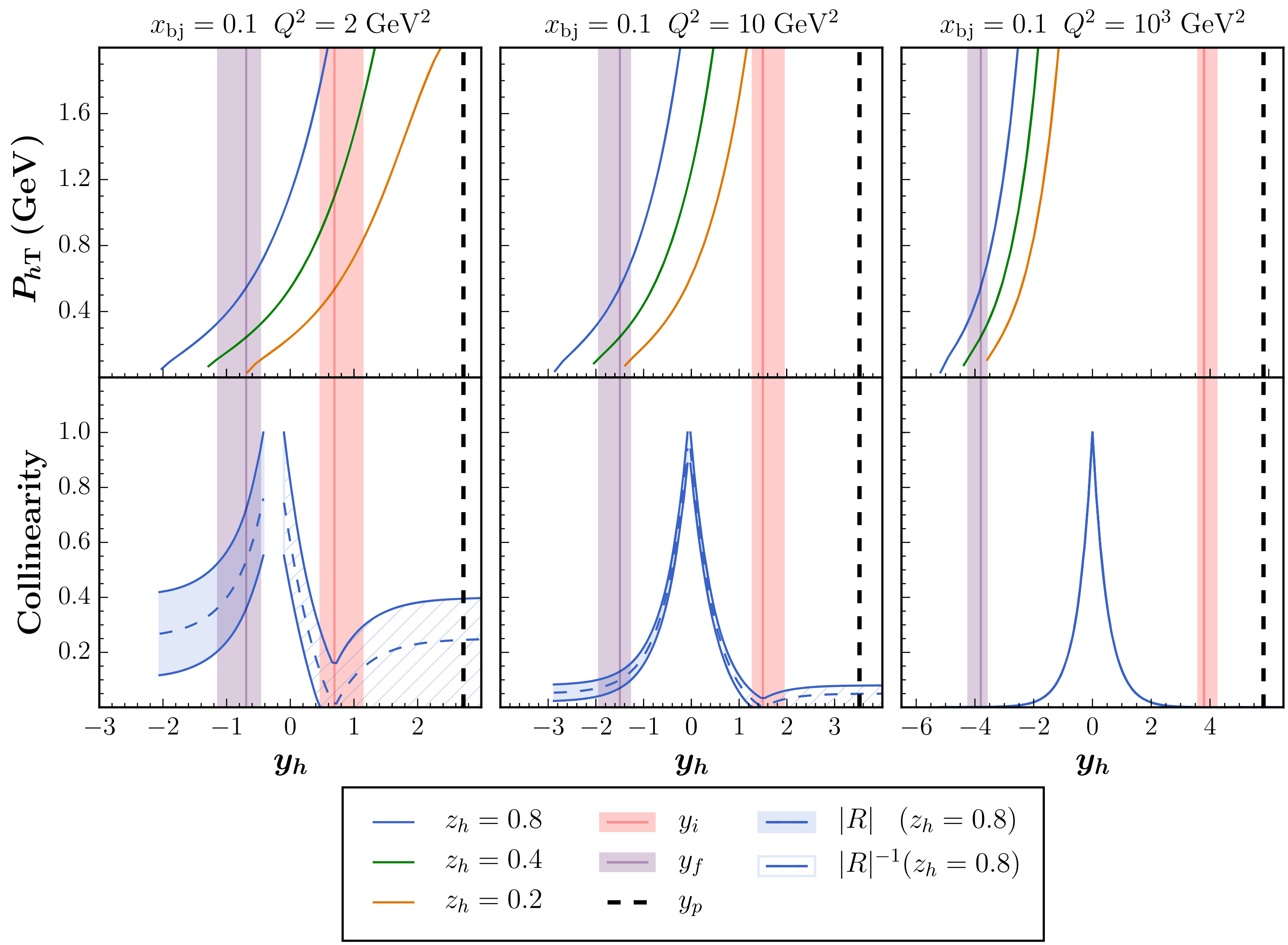
- Approximately $\exp(y_h)$

Phys.Lett. B766 (2017) 245-253

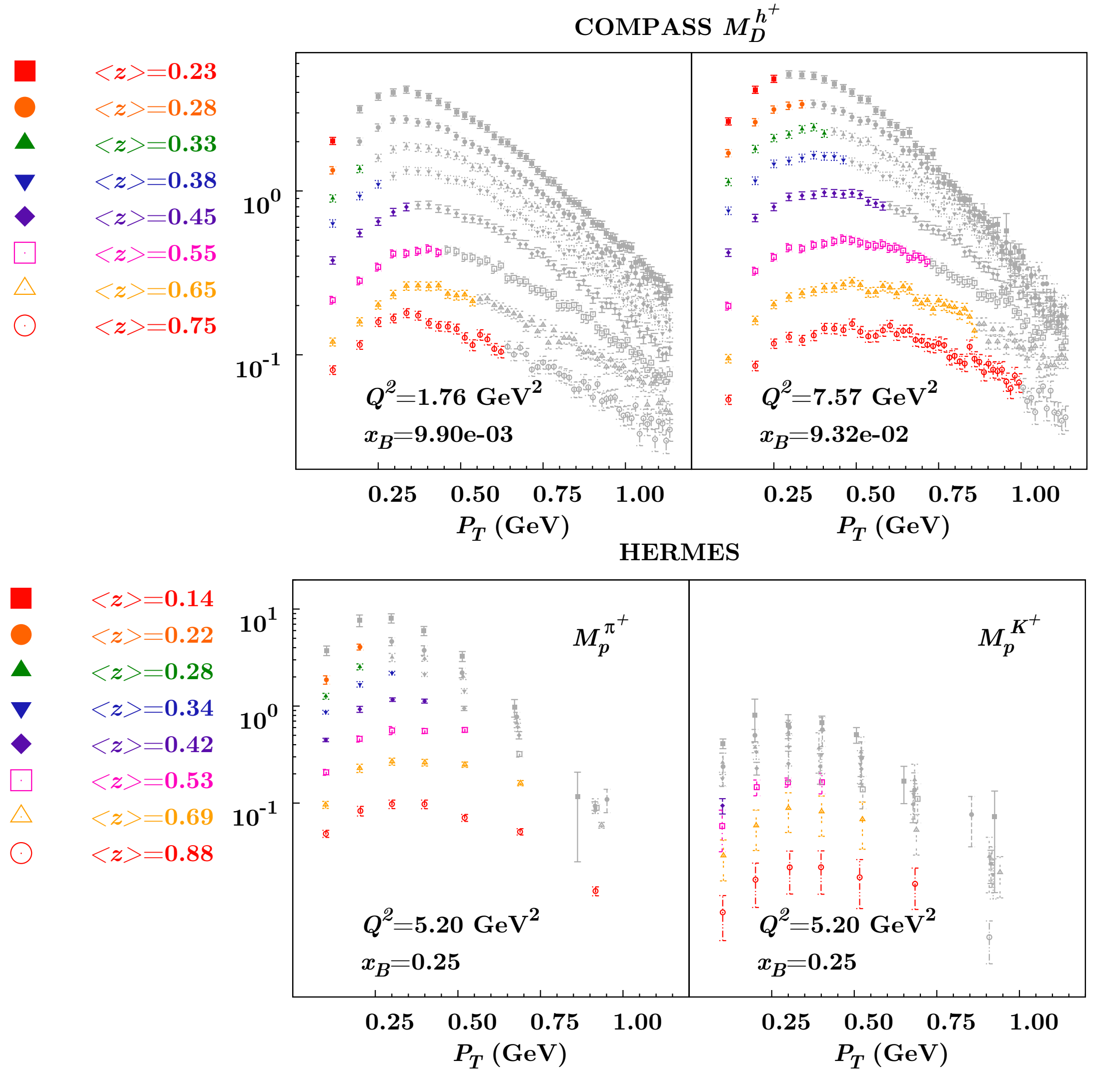
arXiv:1611.10329

M. Boglione , J. Collins, L. Gamberg , J. O. Gonzalez-Hernandez , T. C. Rogers , N. Sato

Rapidity Regions



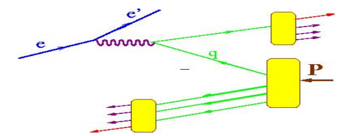
Effect of restricting data



- Colored points: R < .25

Future:

Slide from Harut Avakian



Non-perturbative distributions in hard scattering

TMDs

	U	L	T
U	f_1	✖	$h_1^\perp$
L	✖	g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$h_1, h_{1T}^\perp$

GPDs

N/q	U	L	T
U	H	✖	$\bar{E}_T$
L	✖	$\widetilde{H}$	$\widetilde{E}_T$
T	E	$\widetilde{E}$	$H_T, \widetilde{H}_T$

Wigner Distributions

	U	L	T
U	F_{11}	G_{11}	H_{11}, H_{12}
L	F_{14}	G_{14}	H_{17}, H_{18}
T	F_{12}, F_{13}	$\bar{G}_{12}, \bar{G}_{13}$	$\bar{H}_{13}, H_{14}$ $\bar{H}_{15}, \bar{H}_{16}$

Fracture Functions

	U	L	T
U	M	$M_L^{\perp,h}$	$M_T^h, M_T^\perp$
L	$\Delta M^{\perp,h}$	ΔM_L	$\Delta M_T^h, \Delta M_T^\perp$
T	$\Delta_T M_T^h, \Delta_T M_T^\perp$	$\Delta_T M_L^h$ $\Delta_T M_L^\perp$	$\Delta_T M_T, \Delta_T M_T^{hh}$ $\Delta_T M_T^{\perp\perp}, \Delta_T M_T^{\perp h}$

N/q	U	L	T
U	$f^\perp$	$g^\perp$	h, e
L	$f_L^\perp$	$g_L^\perp$	h_L, e_L
T	$f_T, f_T^\perp$	$g_T, g_T^\perp$	$h_T, e_T, h_T^\perp, e_T^\perp$

Quark polarization

	U	L	T
U	$\mathcal{E}_{2T}$	$\mathcal{E}'_{2T}$	$\mathcal{H}_2, \mathcal{H}'_2$
L	$\tilde{\mathcal{E}}_{2T}$	$\tilde{\mathcal{E}}'_{2T}$	$\tilde{\mathcal{H}}_2, \tilde{\mathcal{H}}'_2$
T	$\mathcal{H}_{2T}, \tilde{\mathcal{H}}_{2T}$	$\mathcal{H}'_{2T}, \tilde{\mathcal{H}}'_{2T}$	$\mathcal{E}_2, \tilde{\mathcal{E}}_2, \mathcal{E}'_2, \tilde{\mathcal{E}}'_2$

ξ -odd

unpol. quarks in long. pol. nucleon related to OAM!

Wish list

- (In additional to polarization observables) Multidimensional differential cross sections.
- Distributions in rapidity.
- No additional cuts (z, etc)