Recent progress in understanding hadronization in semi-inclusive observables

Nobuo Sato
University of Connecticut
Synergies of pp and pA Collisions with an Electron-Ion Collider
BNL, 2017

Jefferson Lab TMD LDRD

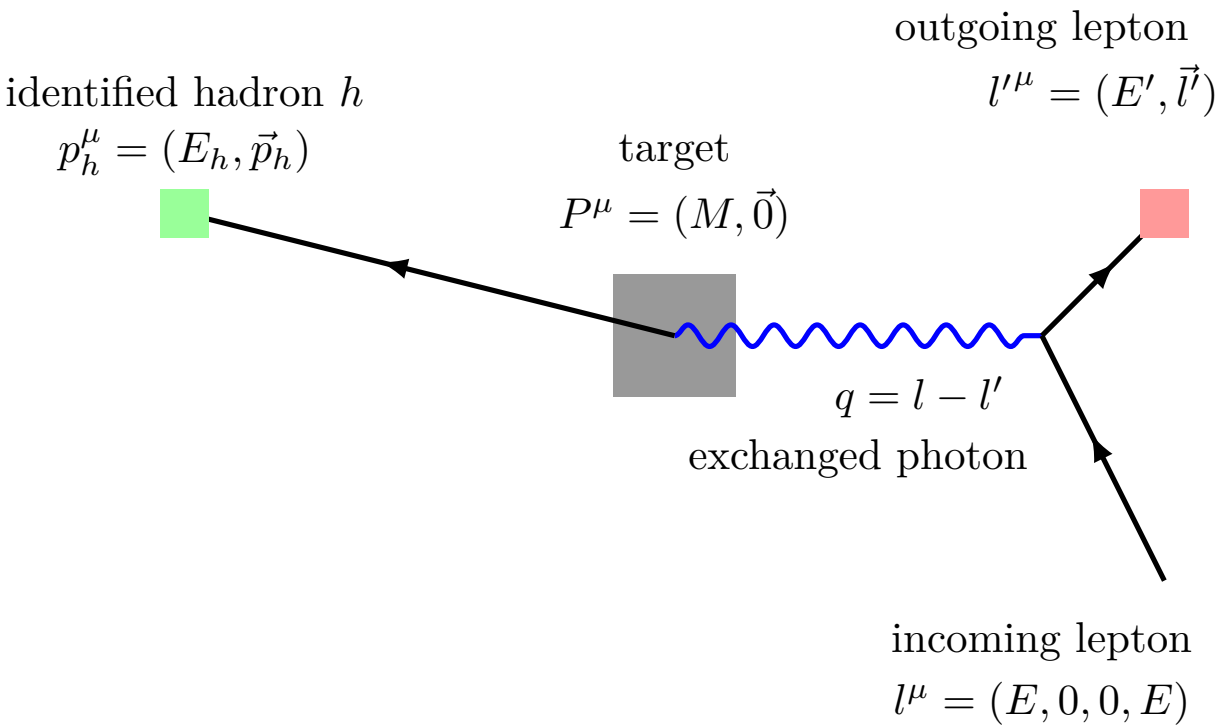
Outline

- Basic overview of SIDIS
- Recent progress
- JLab TMD LDRD

Basic overview SIDIS

Semi inclusive deep inelastic scattering (SIDIS)

Breit frame



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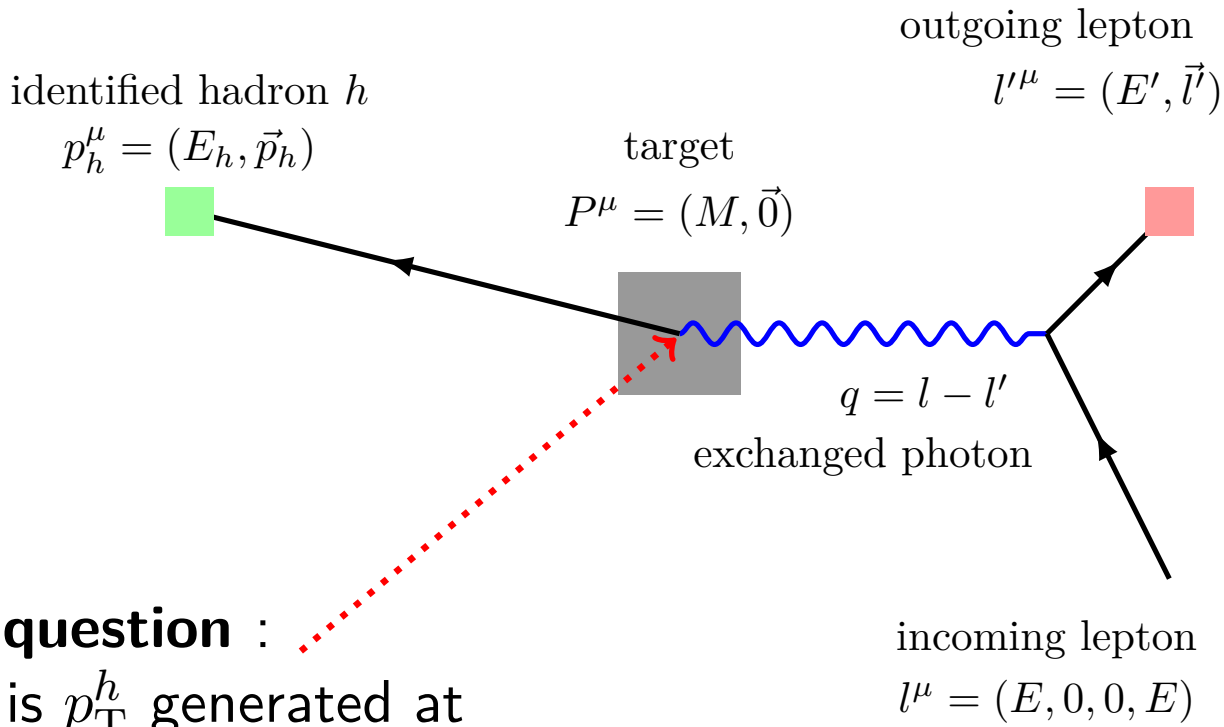

- **Key question** :
  How is p_{T}^h generated at short distances?

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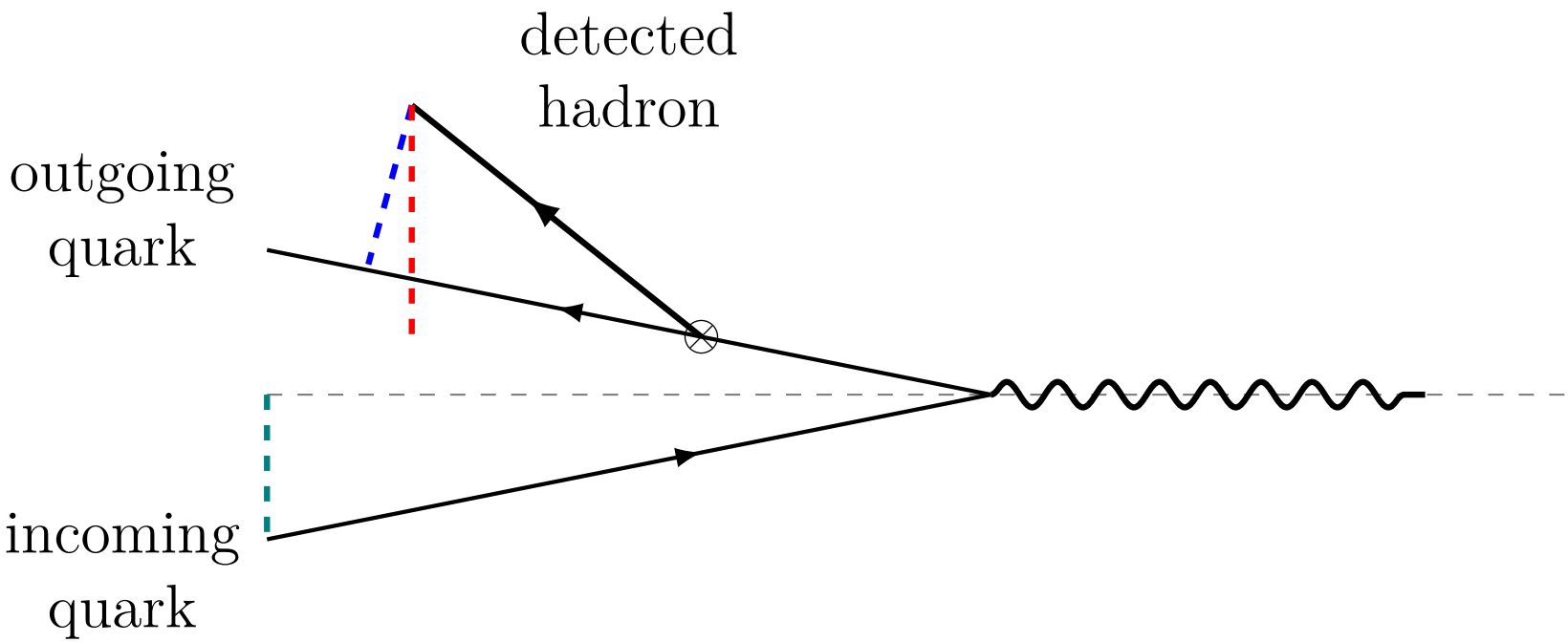
Current fragmentation at small p_{T}^{h}:



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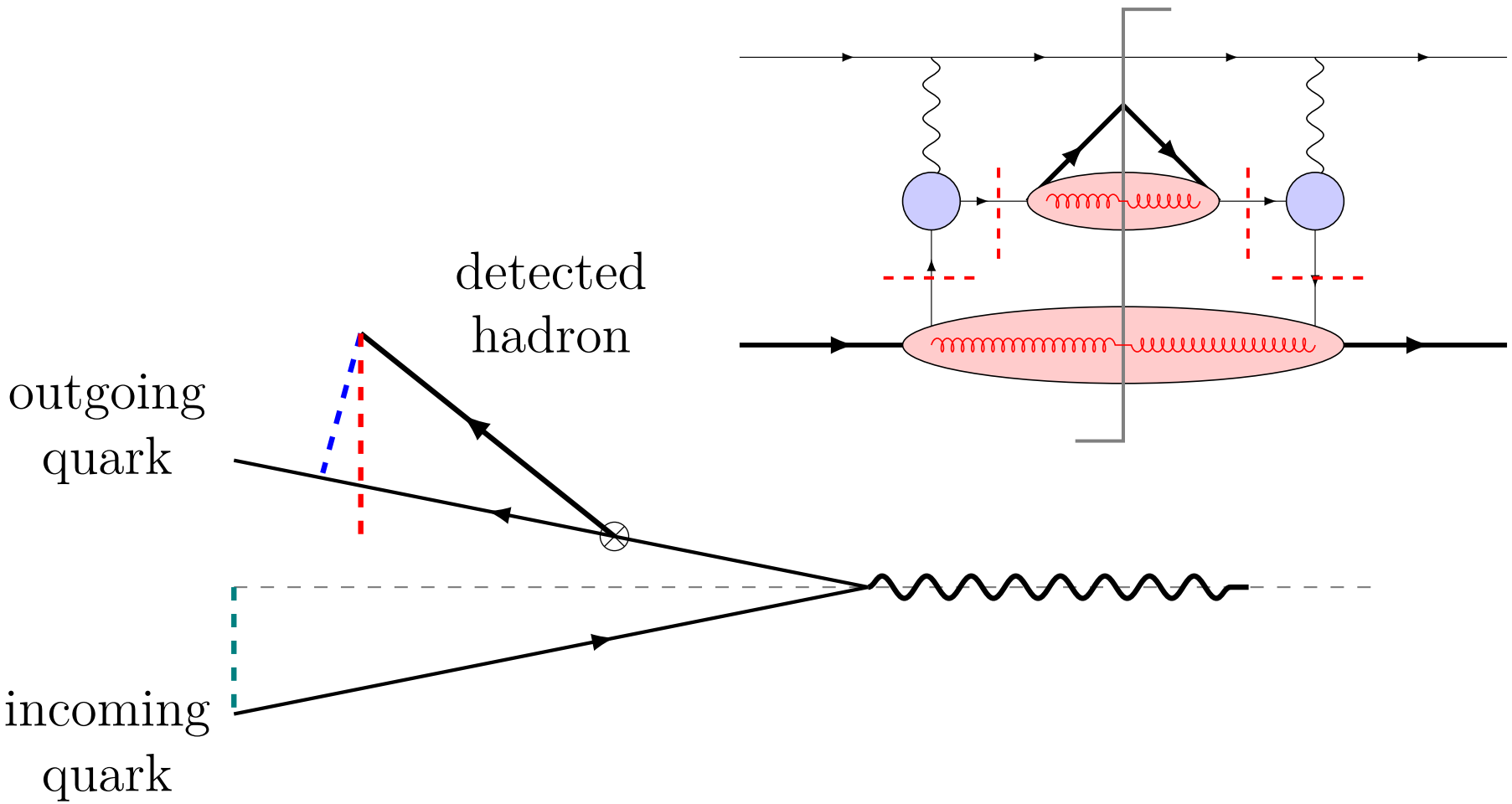

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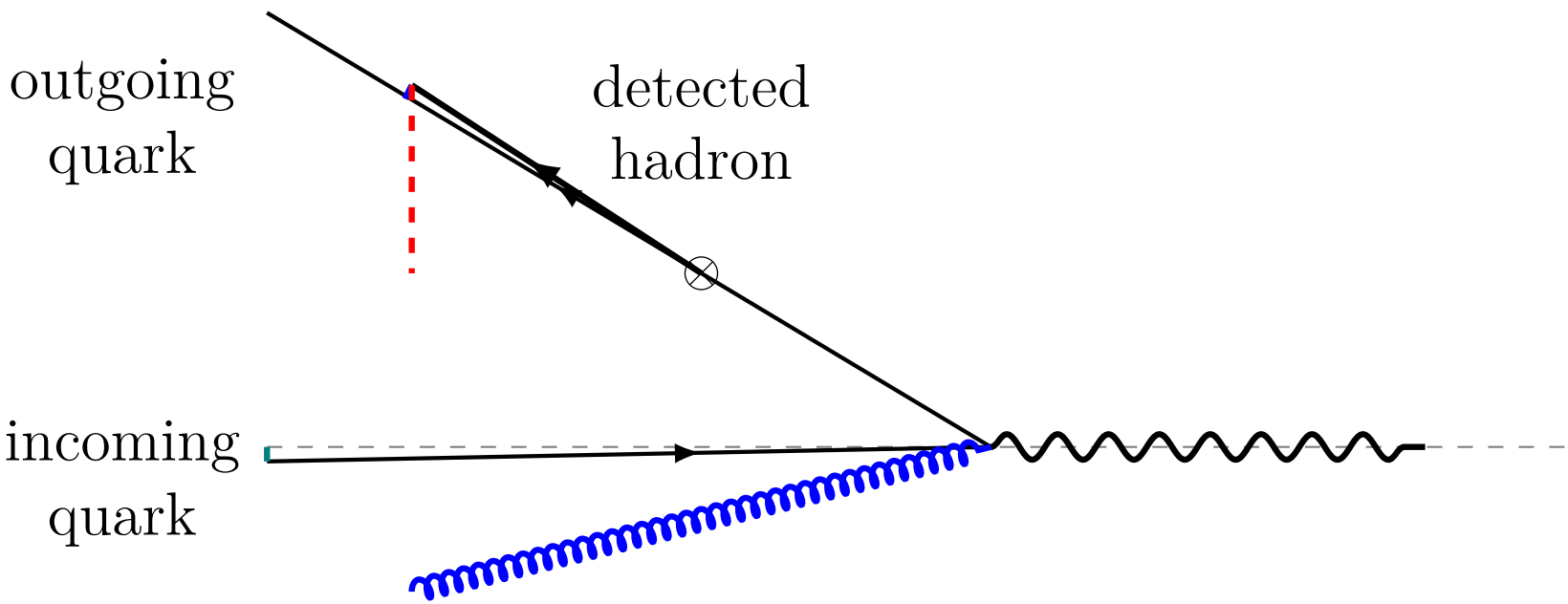

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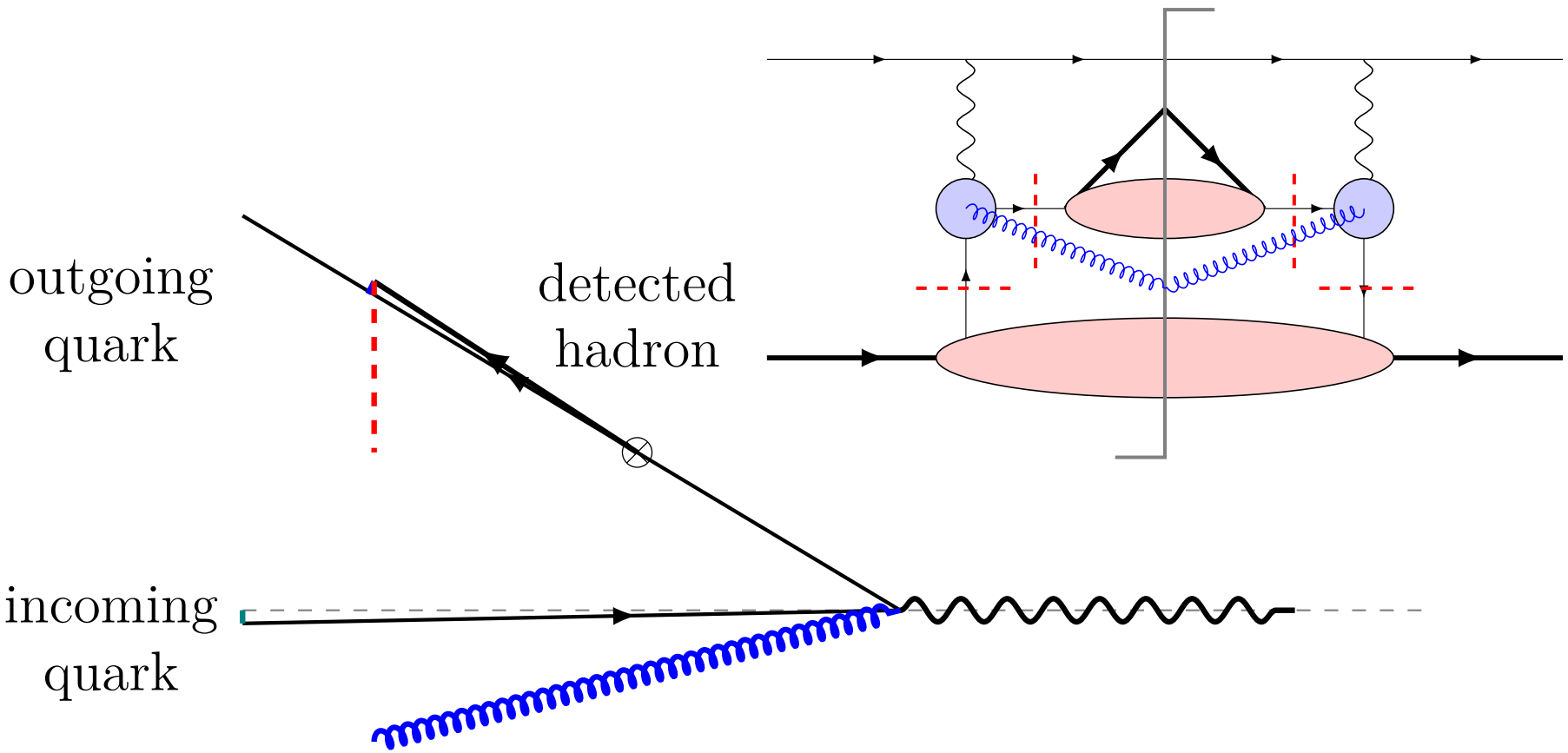
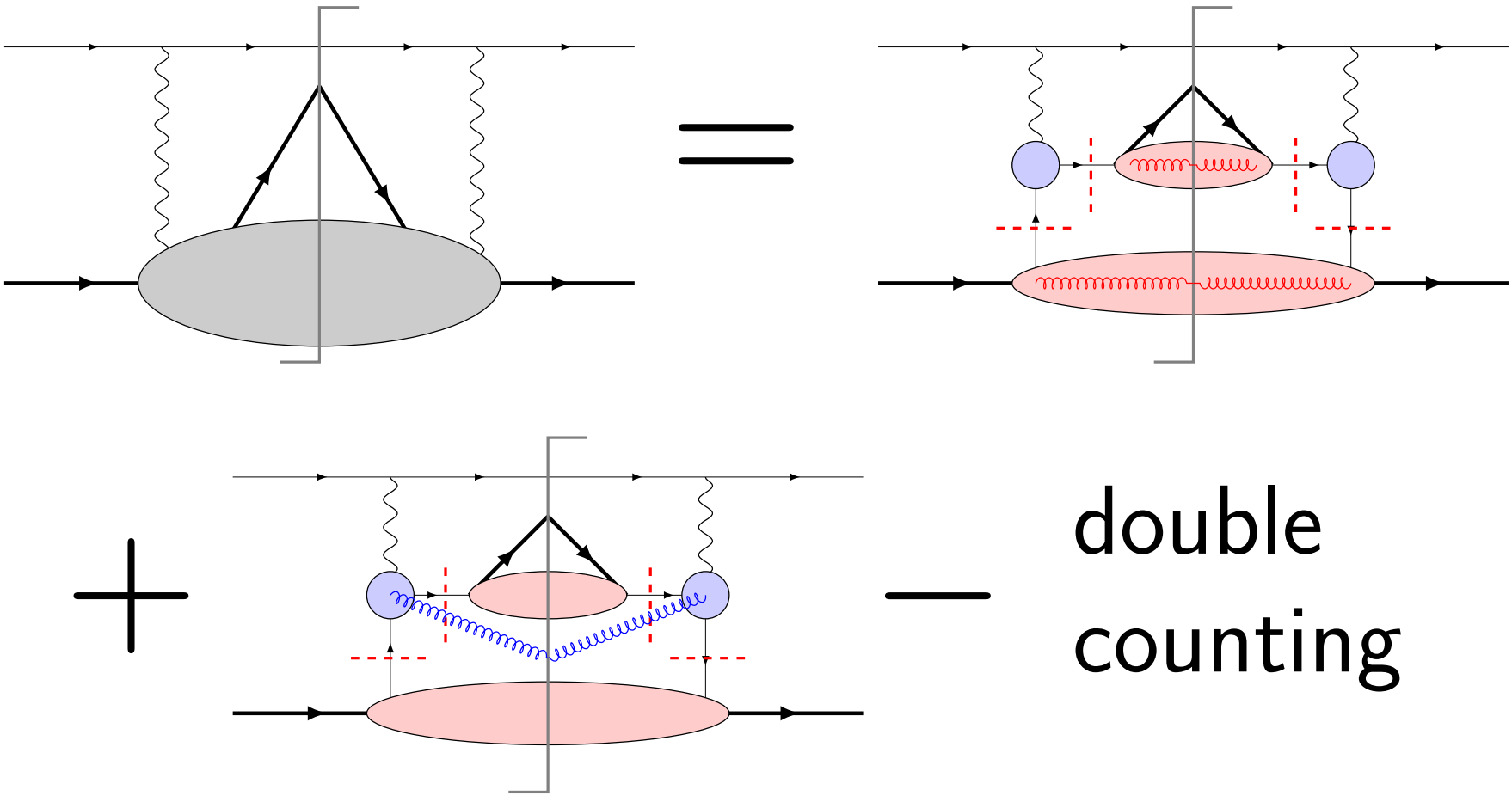


Combining large and small p_{T}^h approximation



Combining large and small p_{T}^h approximation

- Notation

$$\Gamma \equiv \frac{d\sigma}{dx dQ^2 dz dq_T}$$

- The W+Y construction

$$\begin{aligned}\Gamma &= \Gamma \\ &= \mathbf{T}_{\mathrm{TMD}}\Gamma + [\Gamma - \mathbf{T}_{\mathrm{TMD}}\Gamma] \\ &= \underbrace{\mathbf{T}_{\mathrm{TMD}}\Gamma}_{\mathbf{W}} + \underbrace{\mathbf{T}_{\mathrm{coll}}\,[\Gamma - \mathbf{T}_{\mathrm{TMD}}\Gamma]}_{\mathbf{Y}} + \mathcal{O}(m^2/Q^2)\Gamma\end{aligned}$$

- More notation

$$\mathbf{T}_{\mathrm{coll}}\Gamma \equiv \mathrm{FO}$$
$$\mathbf{T}_{\mathrm{coll}}\mathbf{T}_{\mathrm{TMD}}\Gamma \equiv \mathrm{ASY}$$

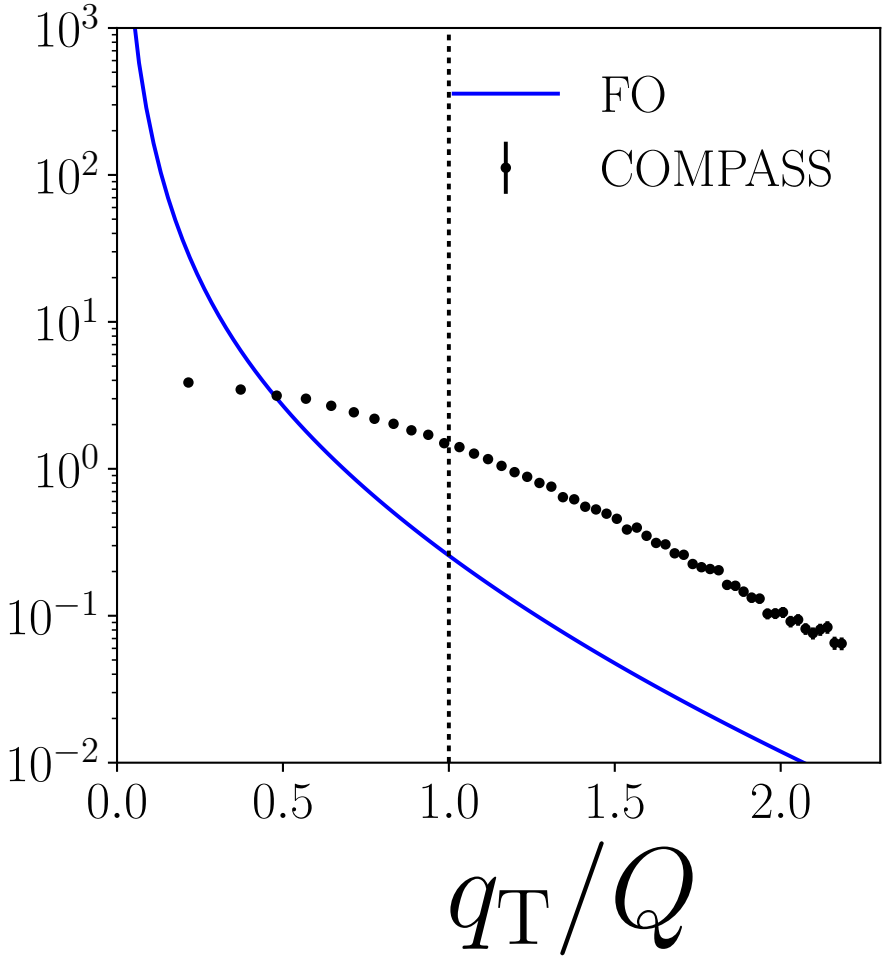
Recent progress

Some recent progress: Collins, et al. (PRD.94.0340)

- FO is a bad approximation for small q_T but its a valid approximation if is integrated over all q_T
- ASY gives a divergent integral over q_T as $q_T \to \infty$
- The integral of W over all q_T is zero
- In the original CSS, W+Y cannot be used to construct a q_T integrated cross section.
- To solve this, an extended version of the original CSS W+Y was proposed

Still some issues...

$$\frac{\frac{d\sigma}{dxdzdQ^2dp_{\mathrm{T}}^2}}{\frac{d\sigma}{dxdQ^2}}$$



- Kinematics

  $Q^2 = 1.92\ \mathrm{GeV}^2$

  $x = 0.0318$

  $z = 0.375$

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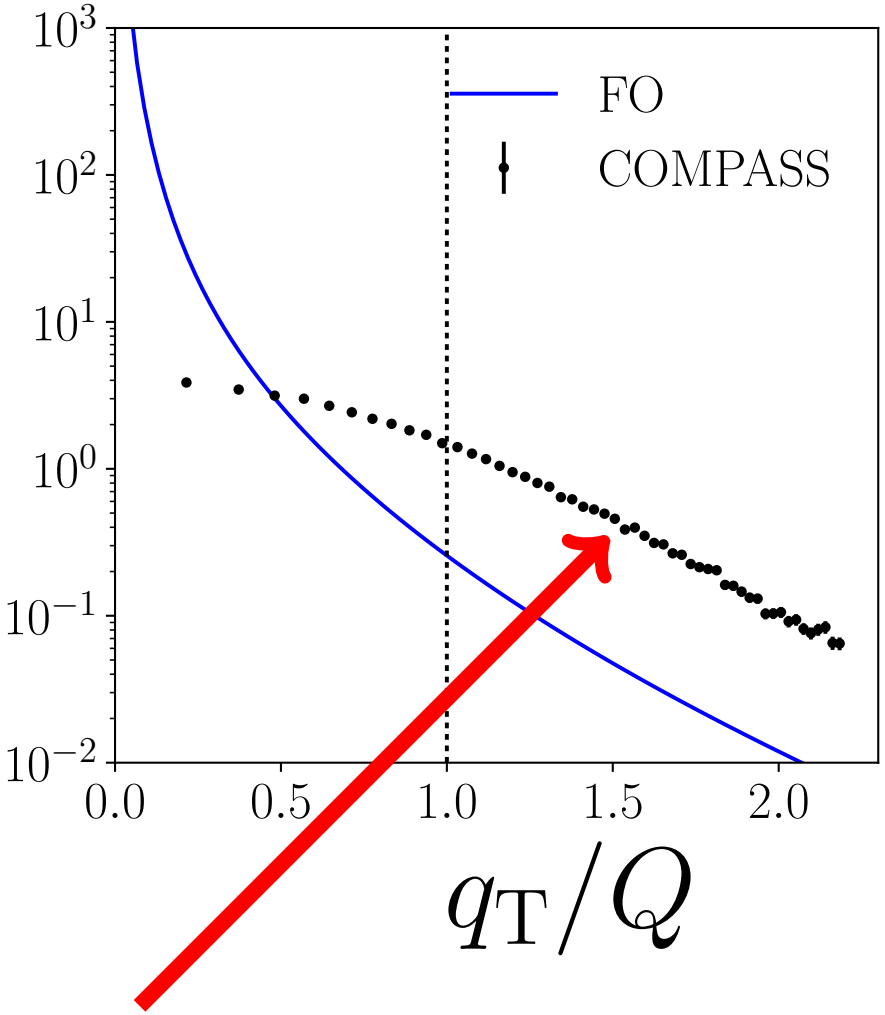

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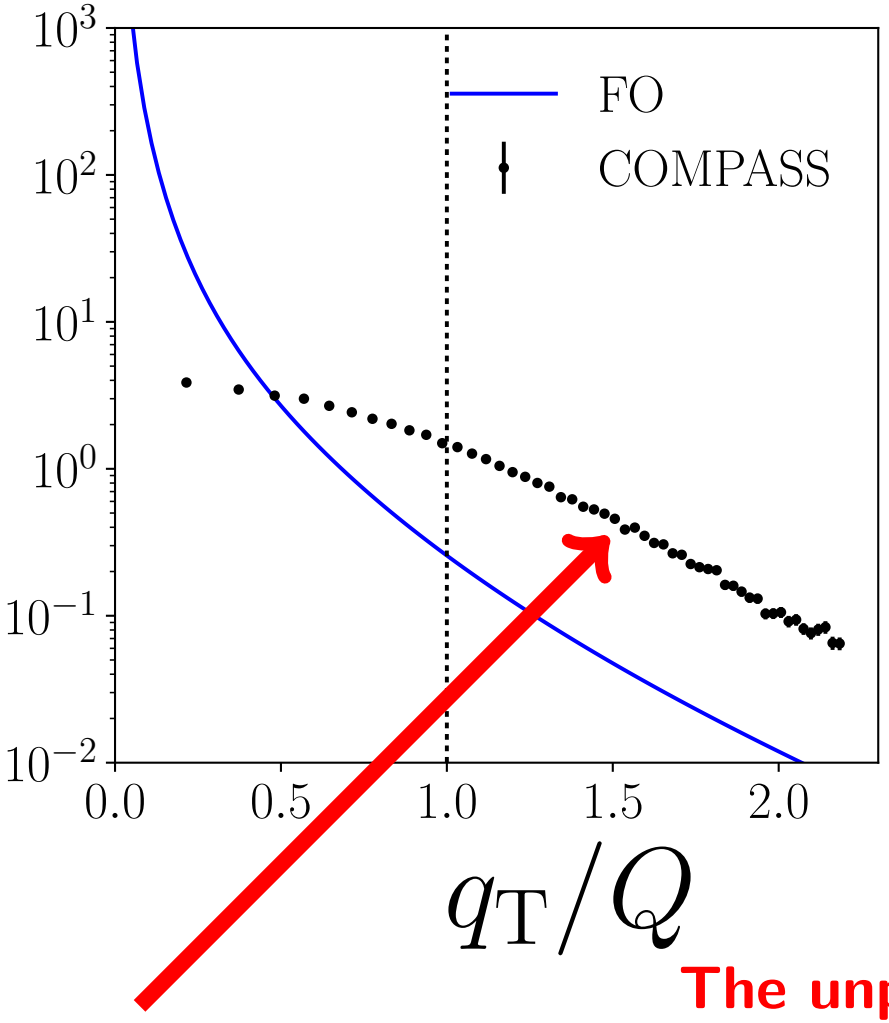

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The unpolarized SIDIS cross sections needs to be ready to interpret upcoming TMD data from JLab 12

SIDIS kinematics analysis Boglione et al. (PLB766,245)

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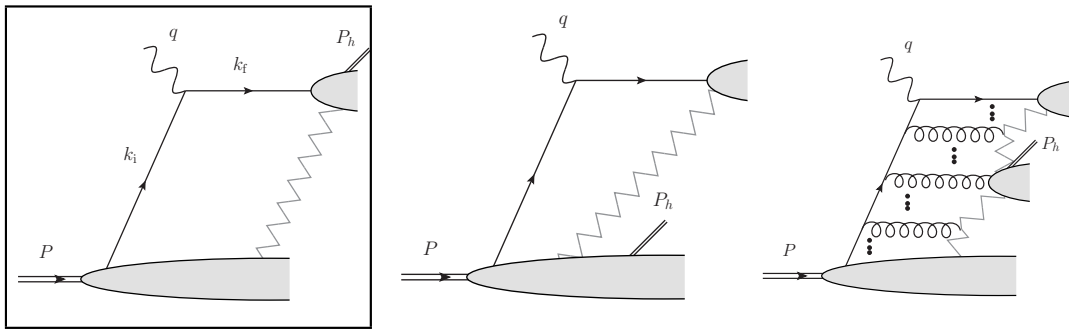

$$p_h \cdot k_f = \mathcal{O}(m^2)$$
$$p_h \cdot k_i = \mathcal{O}(Q^2)$$

- Define a *collinearity* parameter

$$R = \frac{(p_h \cdot k_f)}{(p_h \cdot k_i)} = \mathcal{O}(m^2/Q^2)$$

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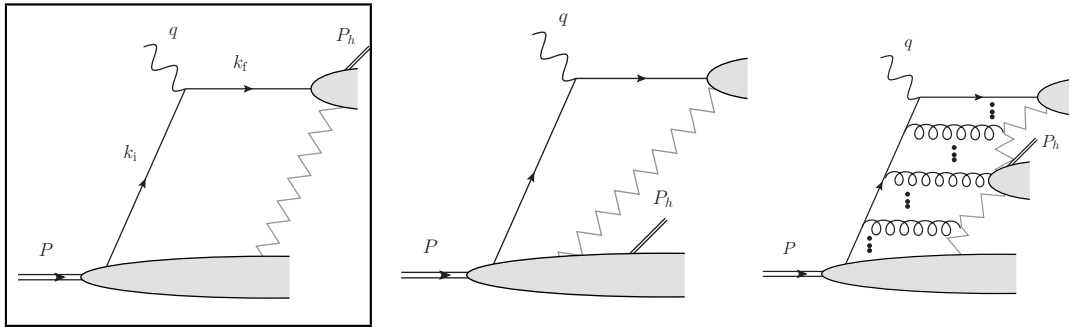

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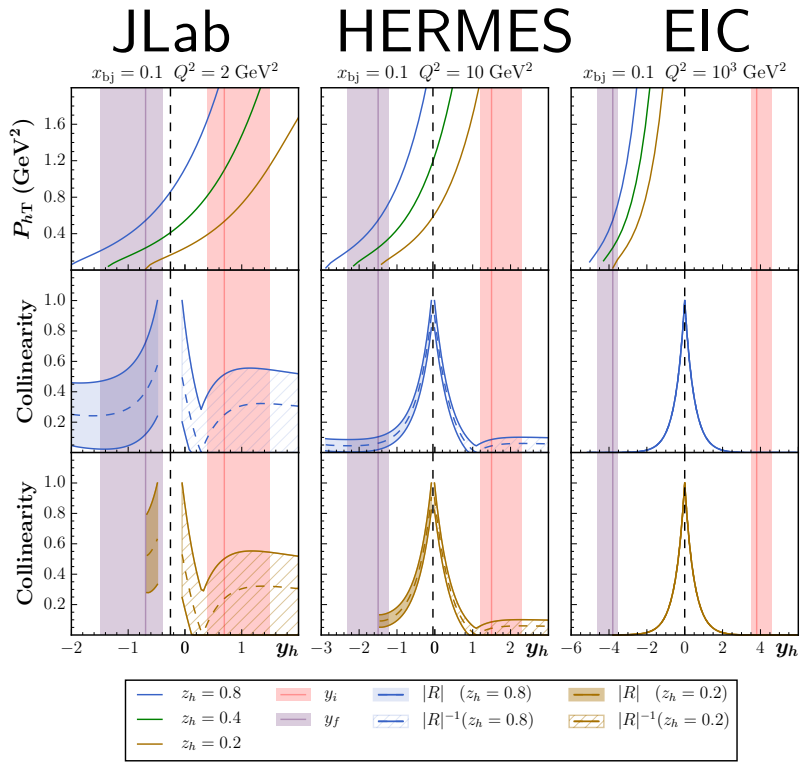

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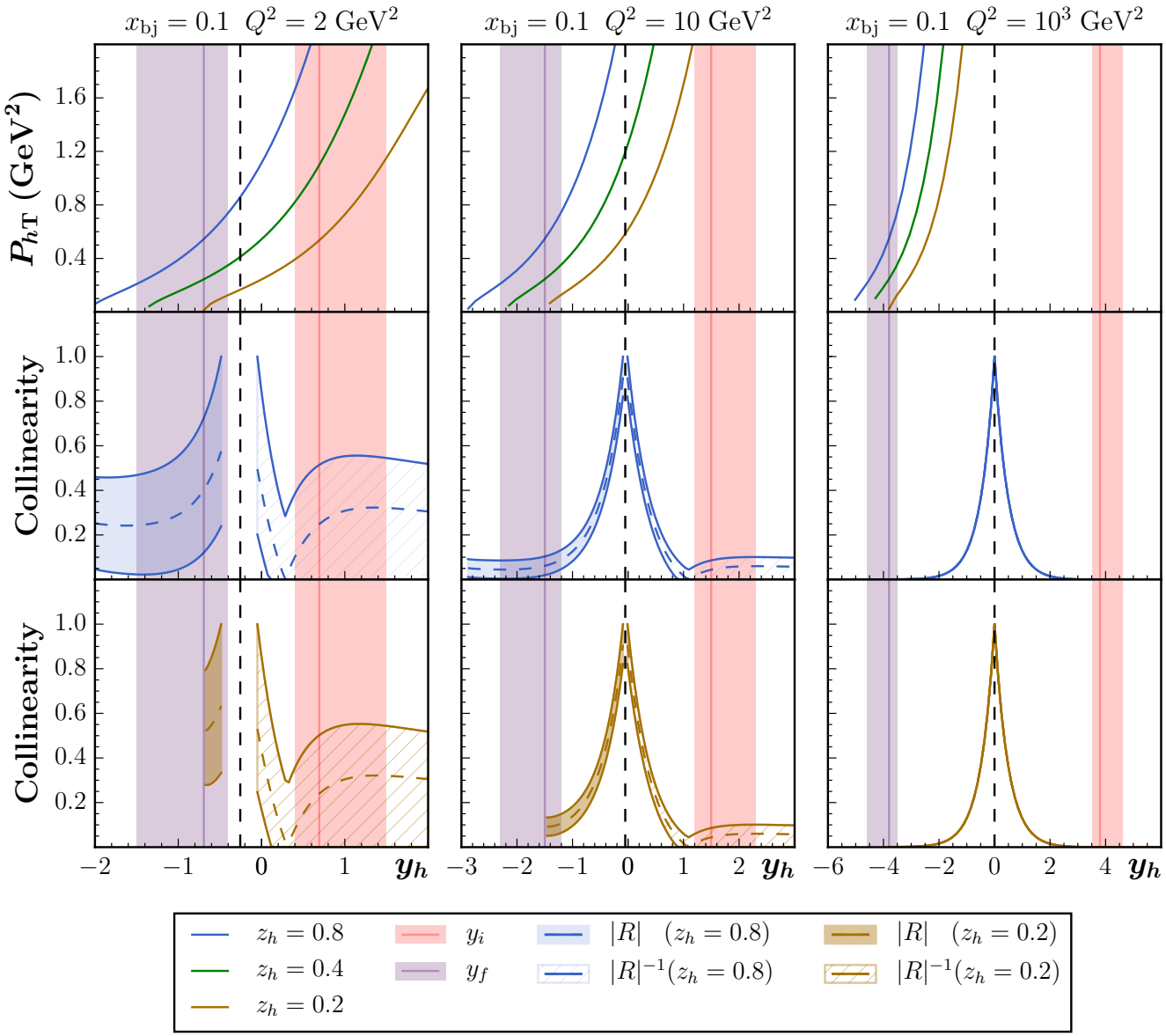
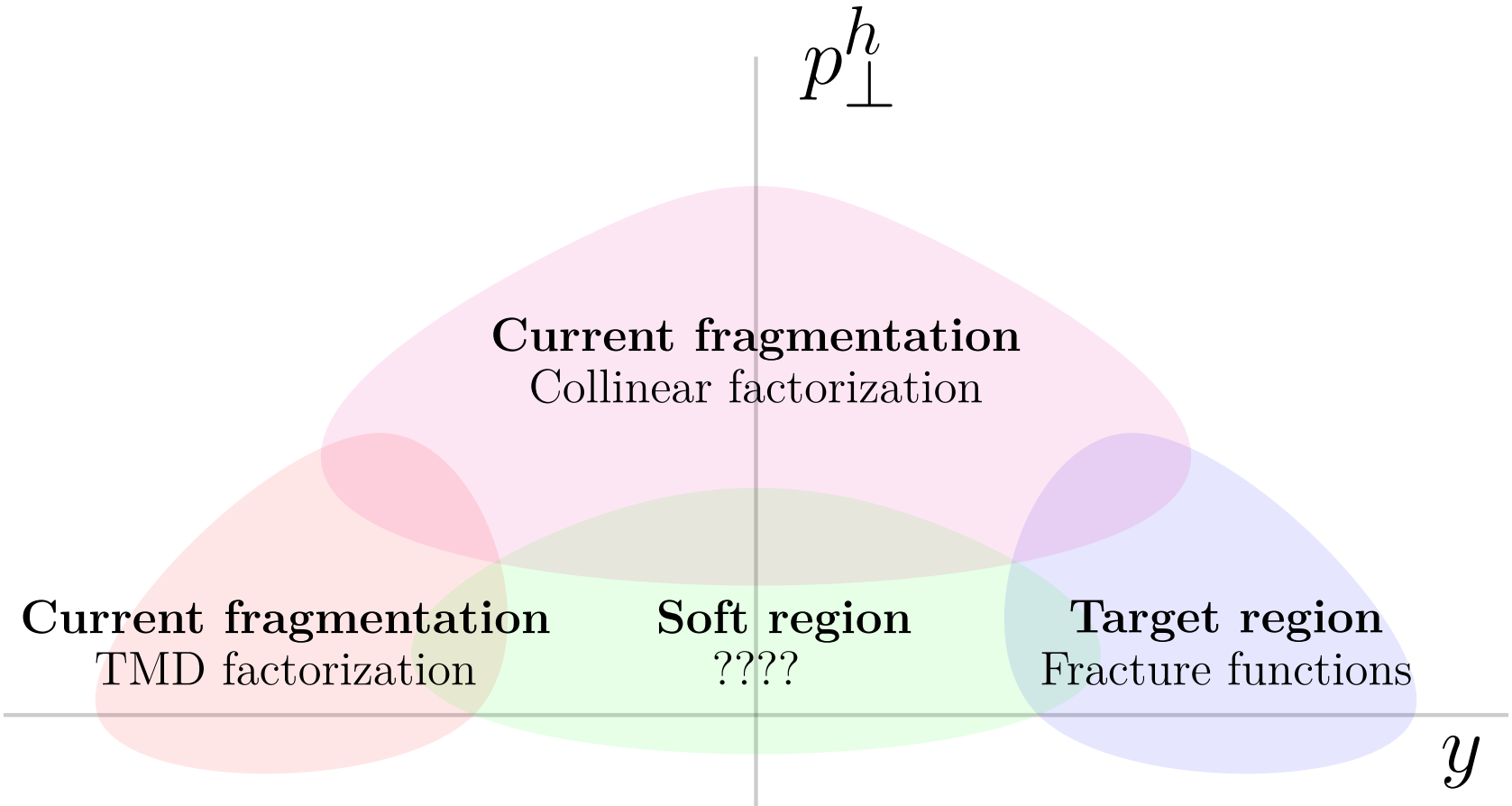


Regions in SIDIS



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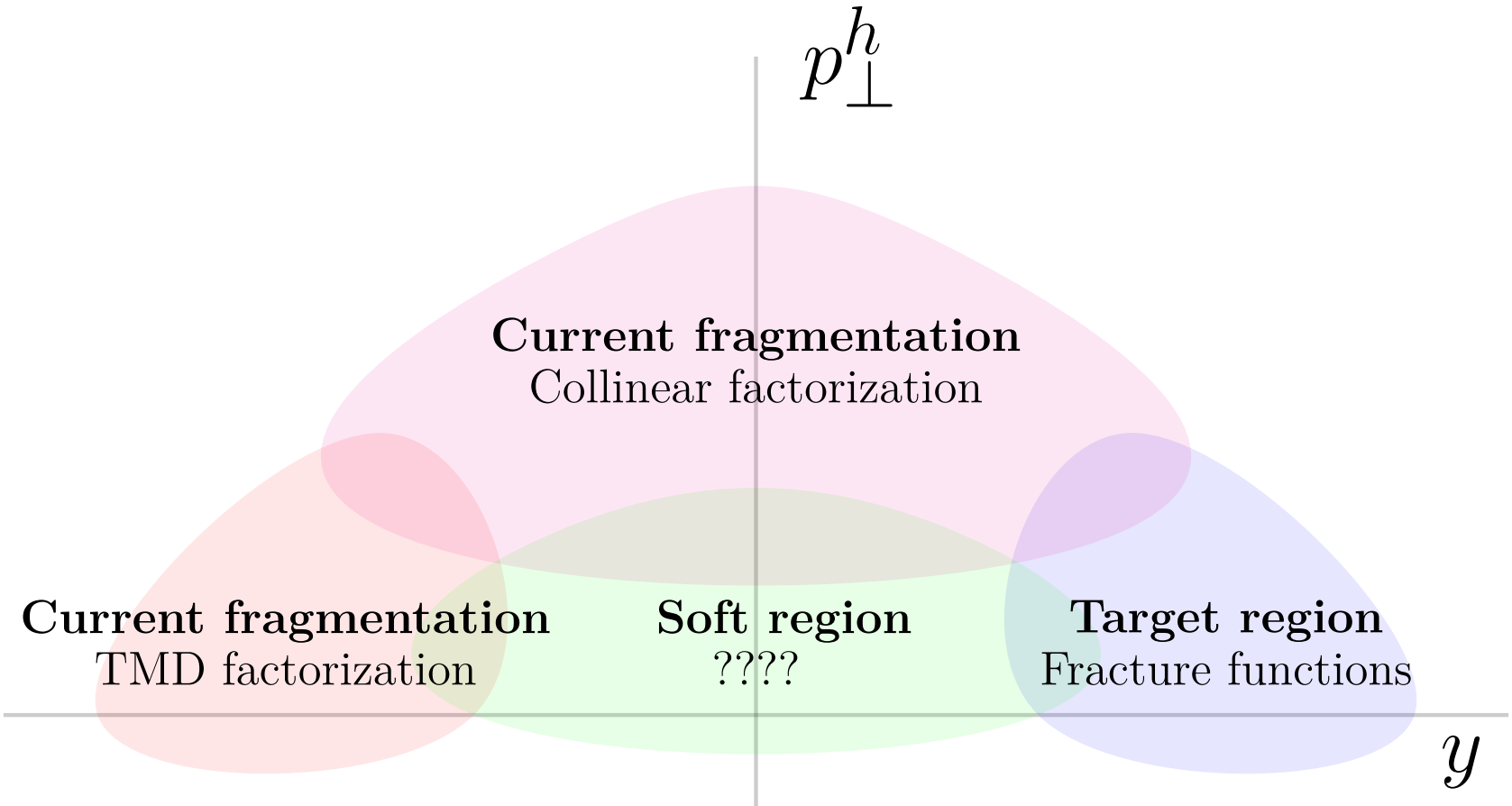
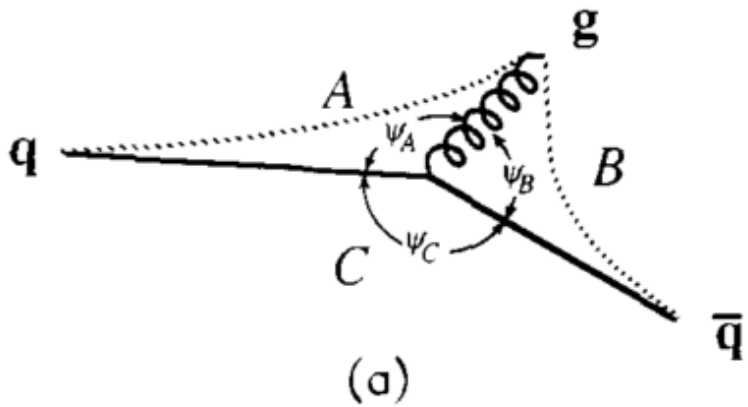


- Hadrons can also be produced in the mid rapidity region → see discussion by J. Collins arXiv:1610.09994
- String type effects are potentially important

String effects: PLB261 (1991) (OPAL Collaboration)



- 3 Jets events: $Q\bar{Q}$ and gluon jets. Jets are projected into a plane
- ψ: angle of a given particle relative to the quark jet with the highest energy
- ψ_A: angle between highest energetic jet and gluon jet
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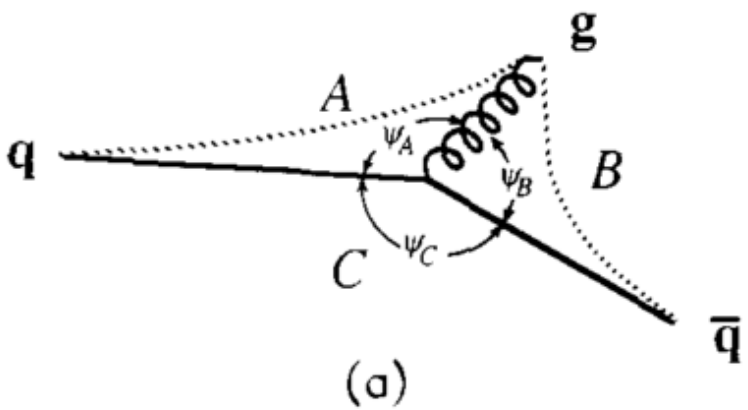

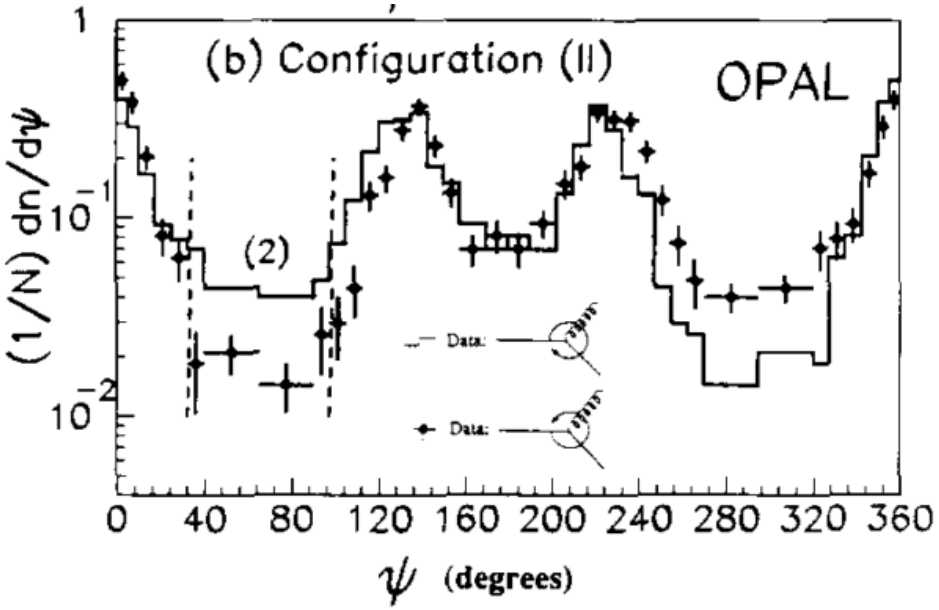

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- **Particle flow asymmetry is observed $\rightarrow$ evidence of string effects**

JLab TMD LDRD

Jefferson Lab TMD LDRD

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  - Language dictionary between in NP and HEP
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- **What do we need?**
  - Put a bunch of physicists in a room
  - Use Pythia8+DIRE as a starting point
  - Use QCD factorization theorems as a guidance

LDRD personnel

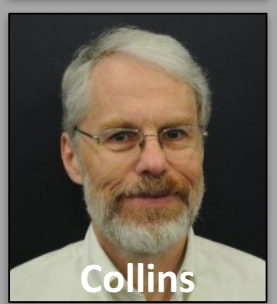
JLab

Pythia

Other

Experimentalists

+ Jake Ethier
+ Eric Moffat
+ Andrea Signori



Theorists

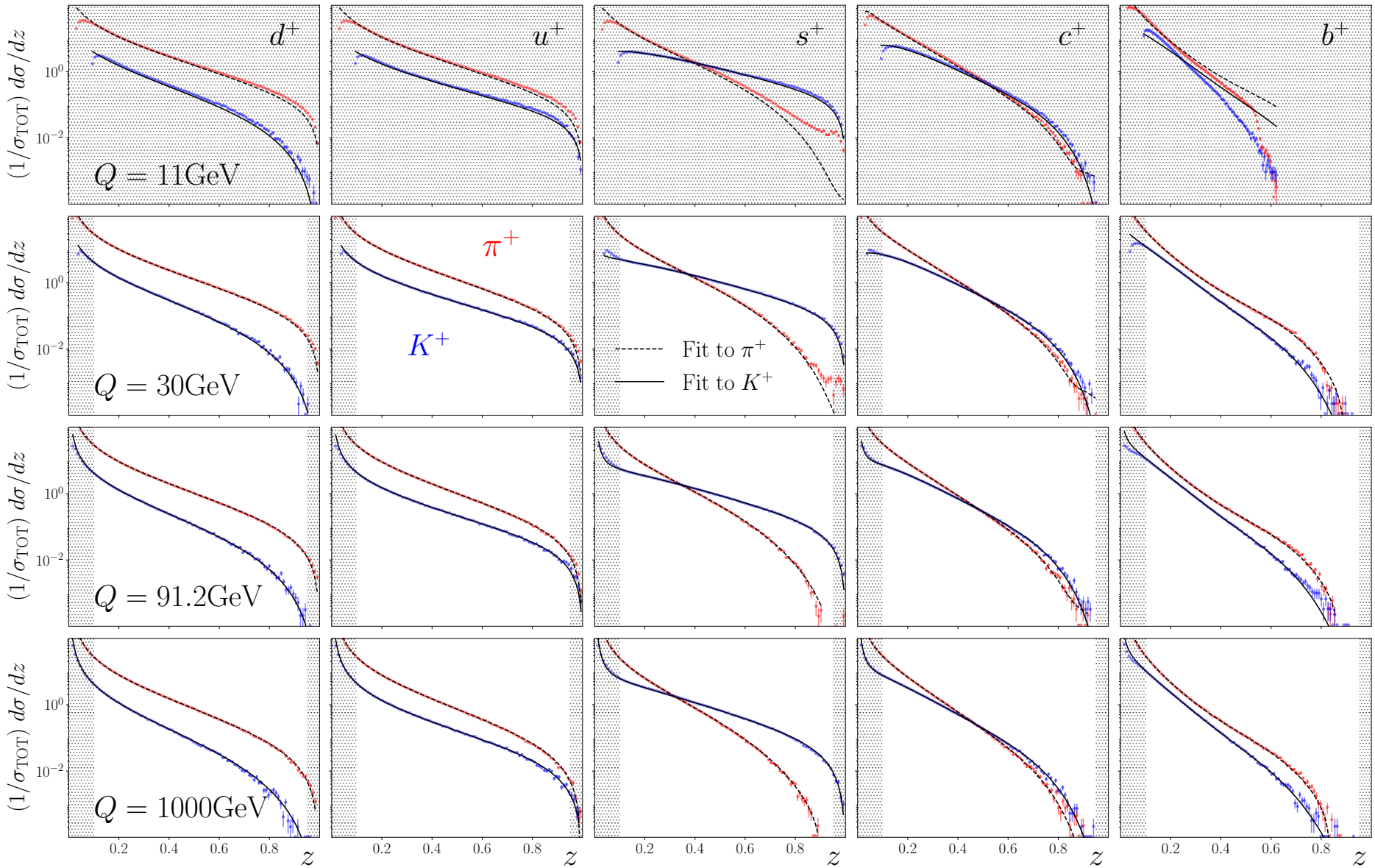
Technical details

- Simulate e^+e^- at $Q = 30, 91.2, 1000$ GeV flavor by flavor
- Fit π and K FFs using pQCD @ NLO

$$\frac{1}{\sigma_{\mathrm{TOT}}}\frac{d\sigma_q^{h^\pm}}{dz}(z,Q^2) = \frac{2}{\sigma_{\mathrm{TOT}}}\left[C_q \otimes D_{q^+}(z,Q^2) + C_g \otimes D_g(z,Q^2)\right]$$

- ZMVS with input $Q_0 = 11\mathrm{GeV}$
- Parametrization: $D_{q^+}(z) = Nz^\alpha(1-z)^\beta(1 + c_1 z + c_2 z^2 + ...)$

Pythia8 vs. collinear factorization (preliminary)



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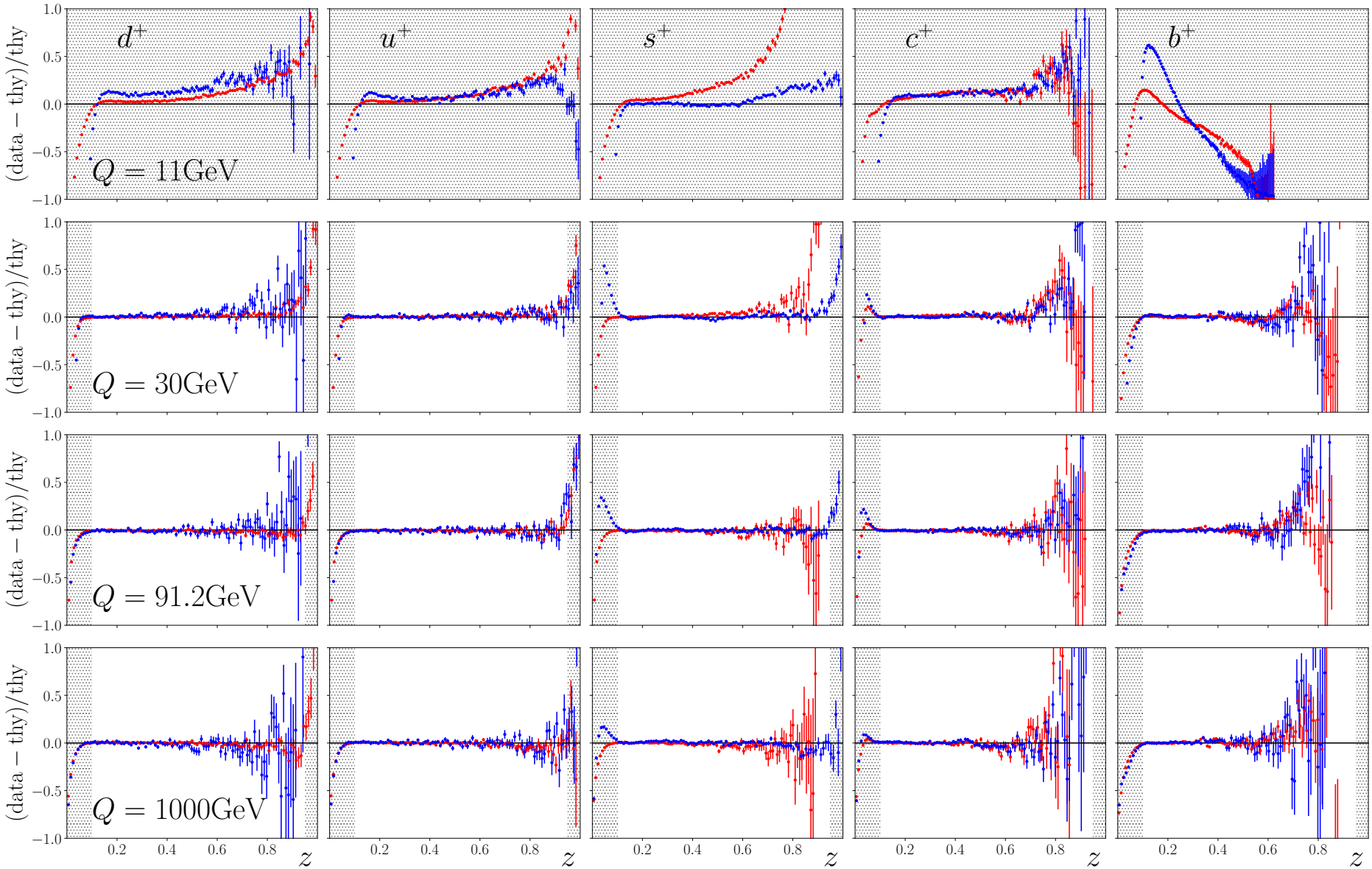

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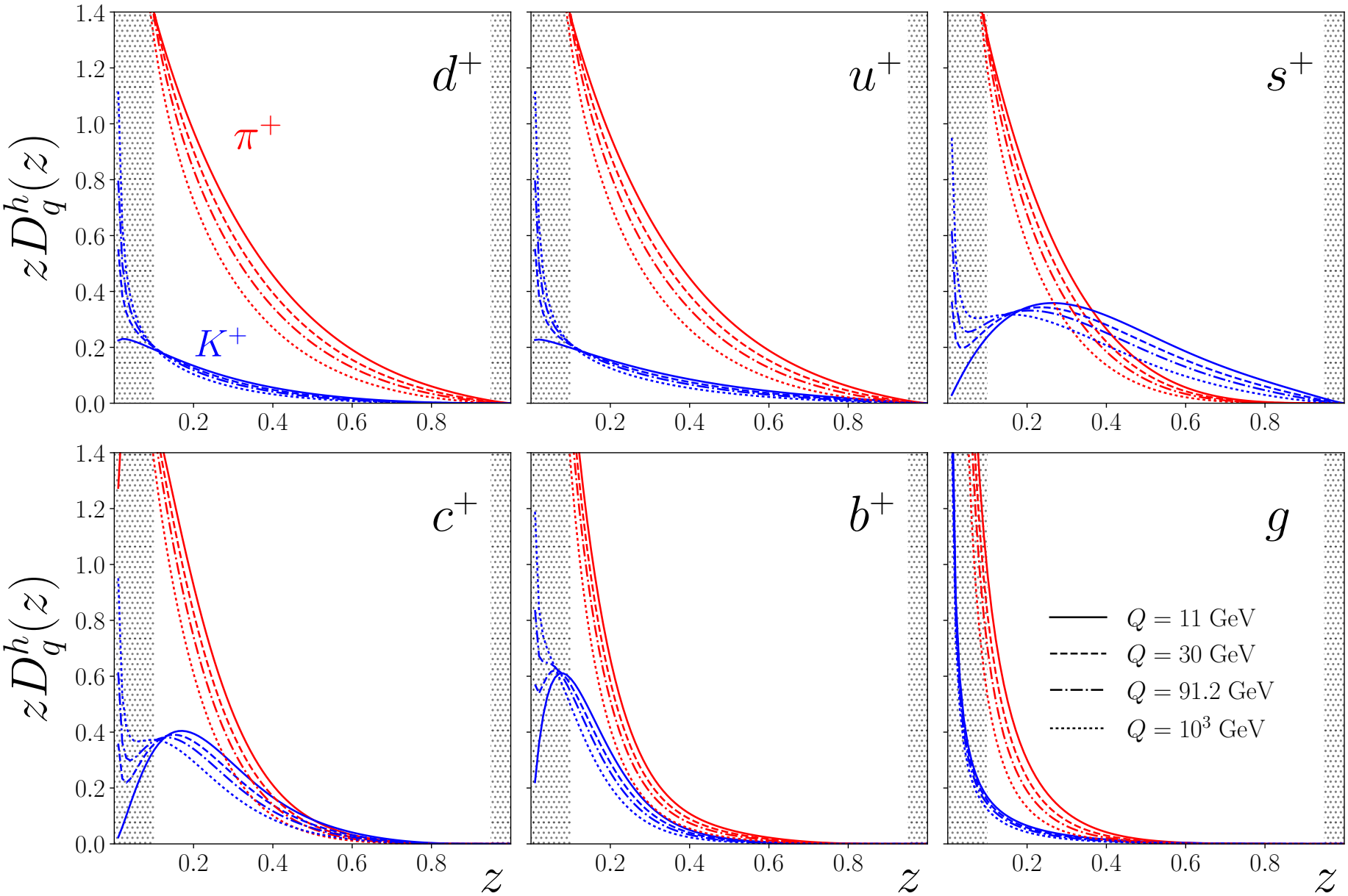

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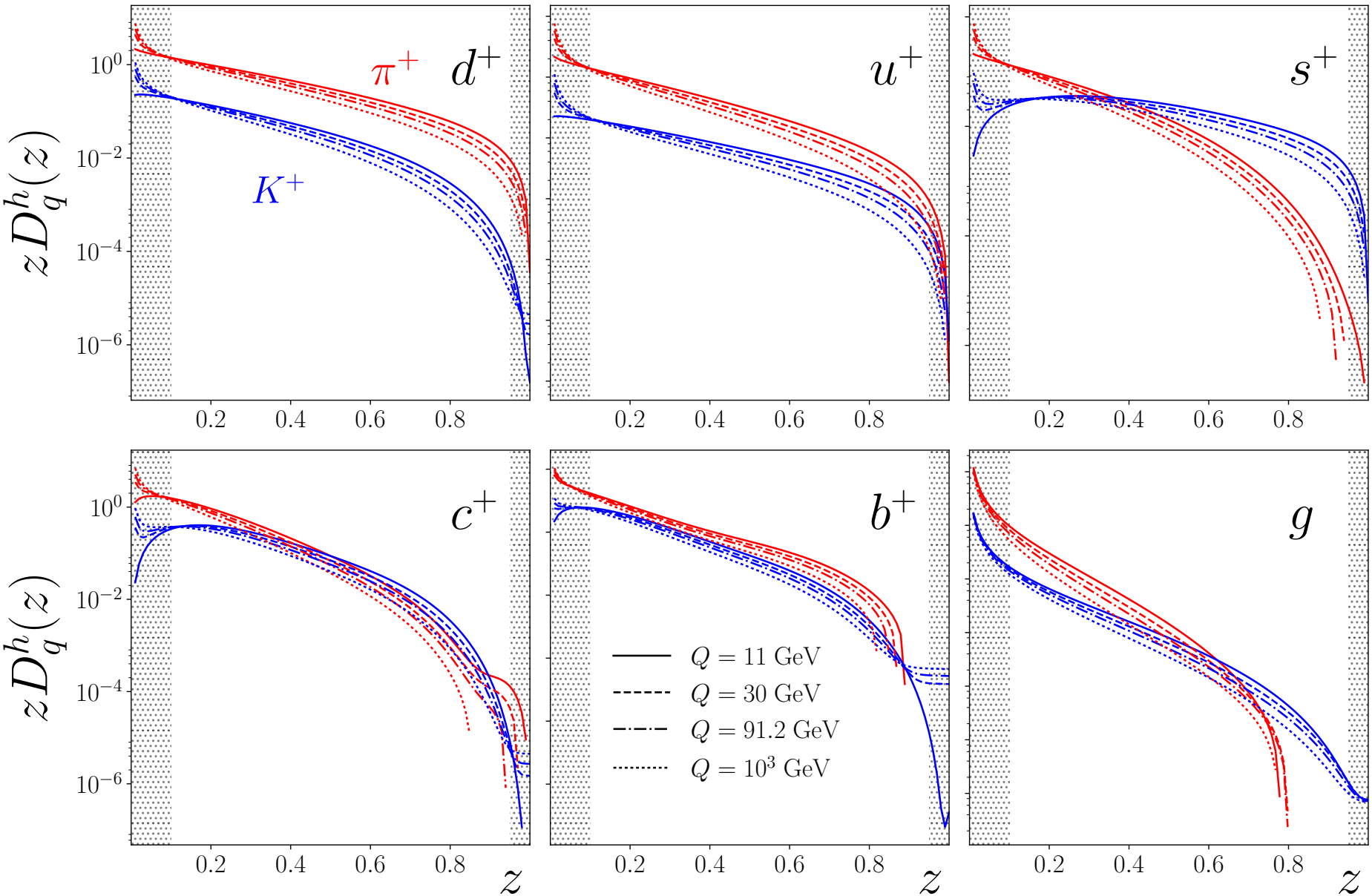
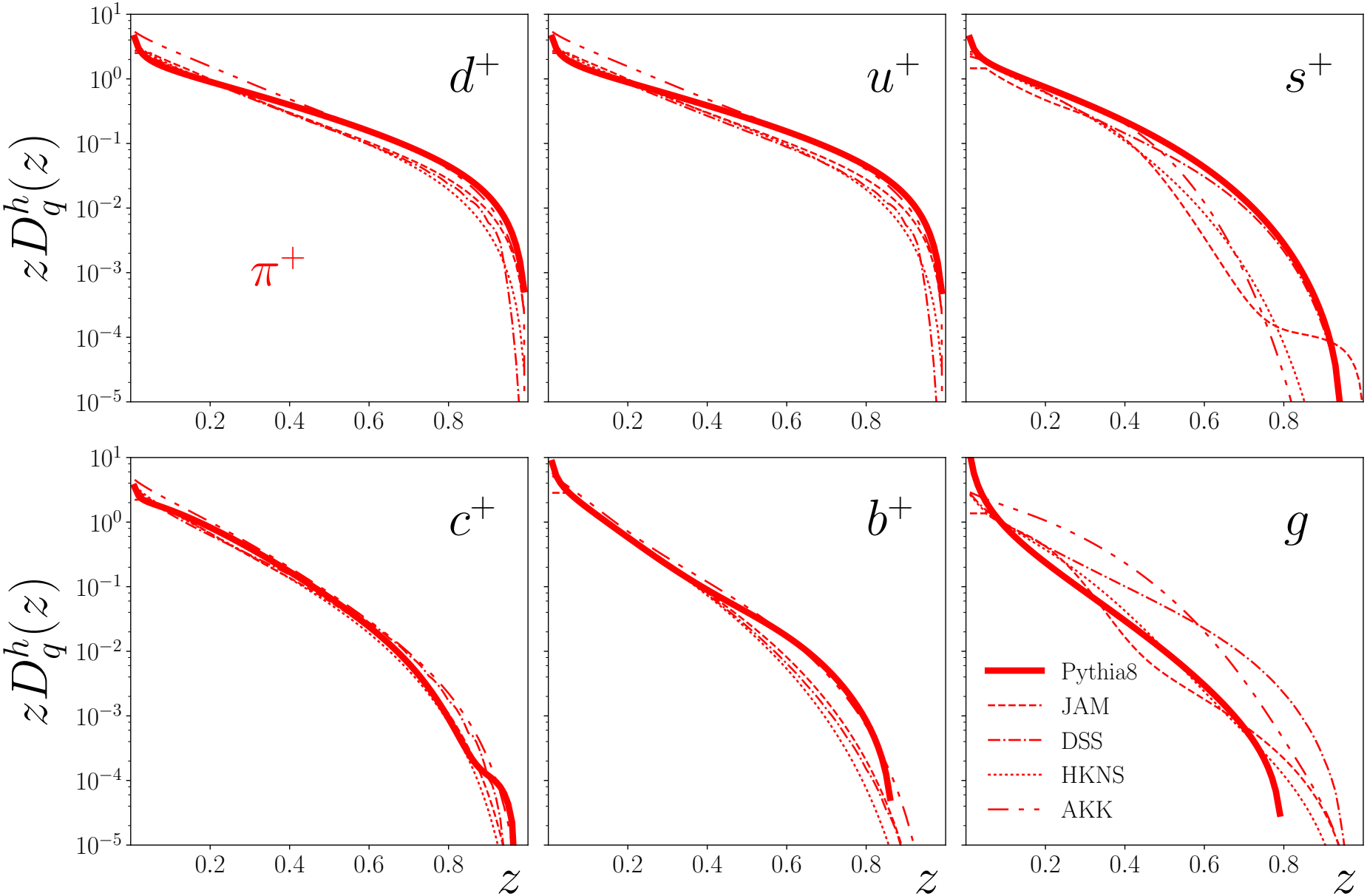
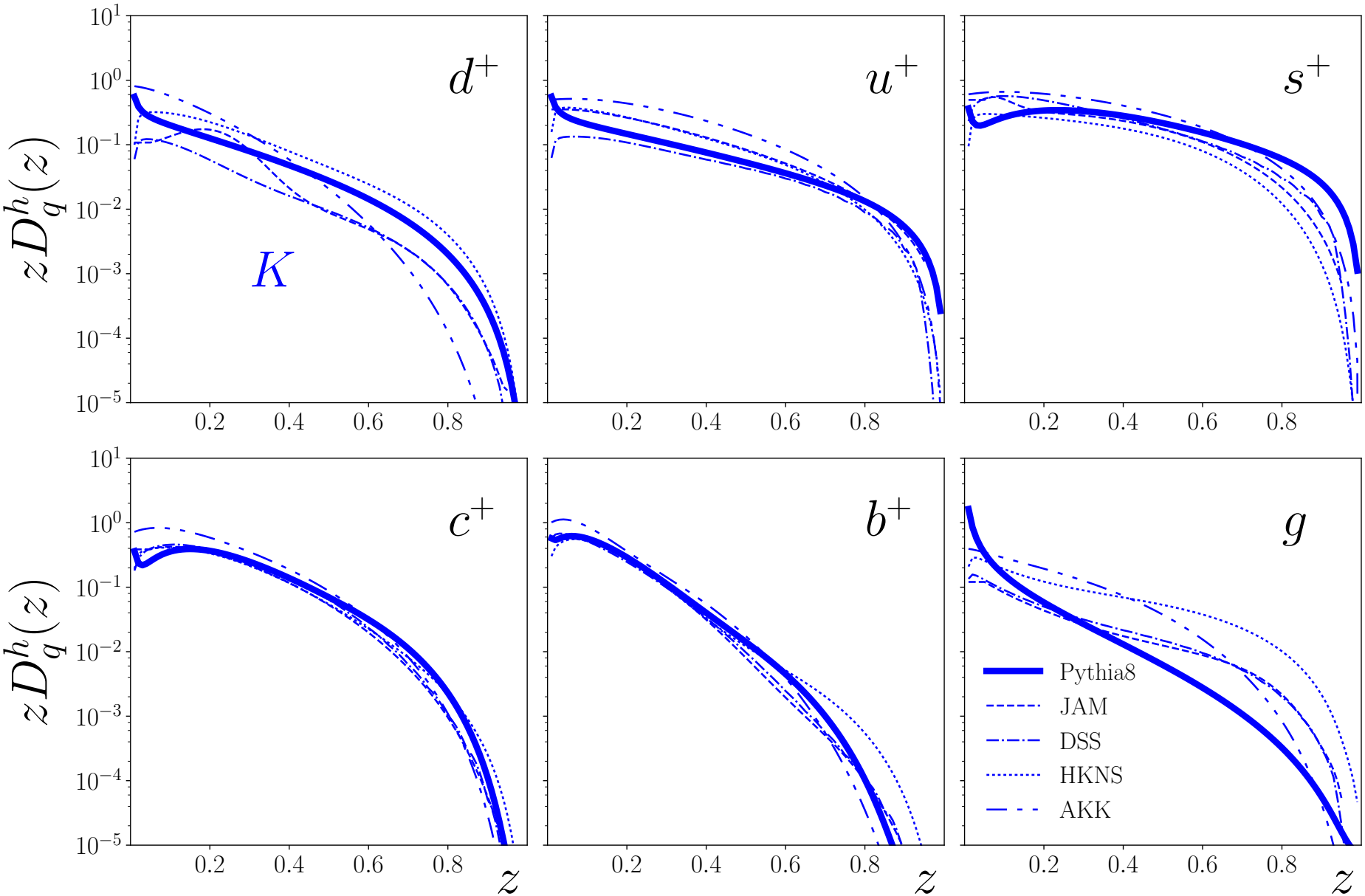


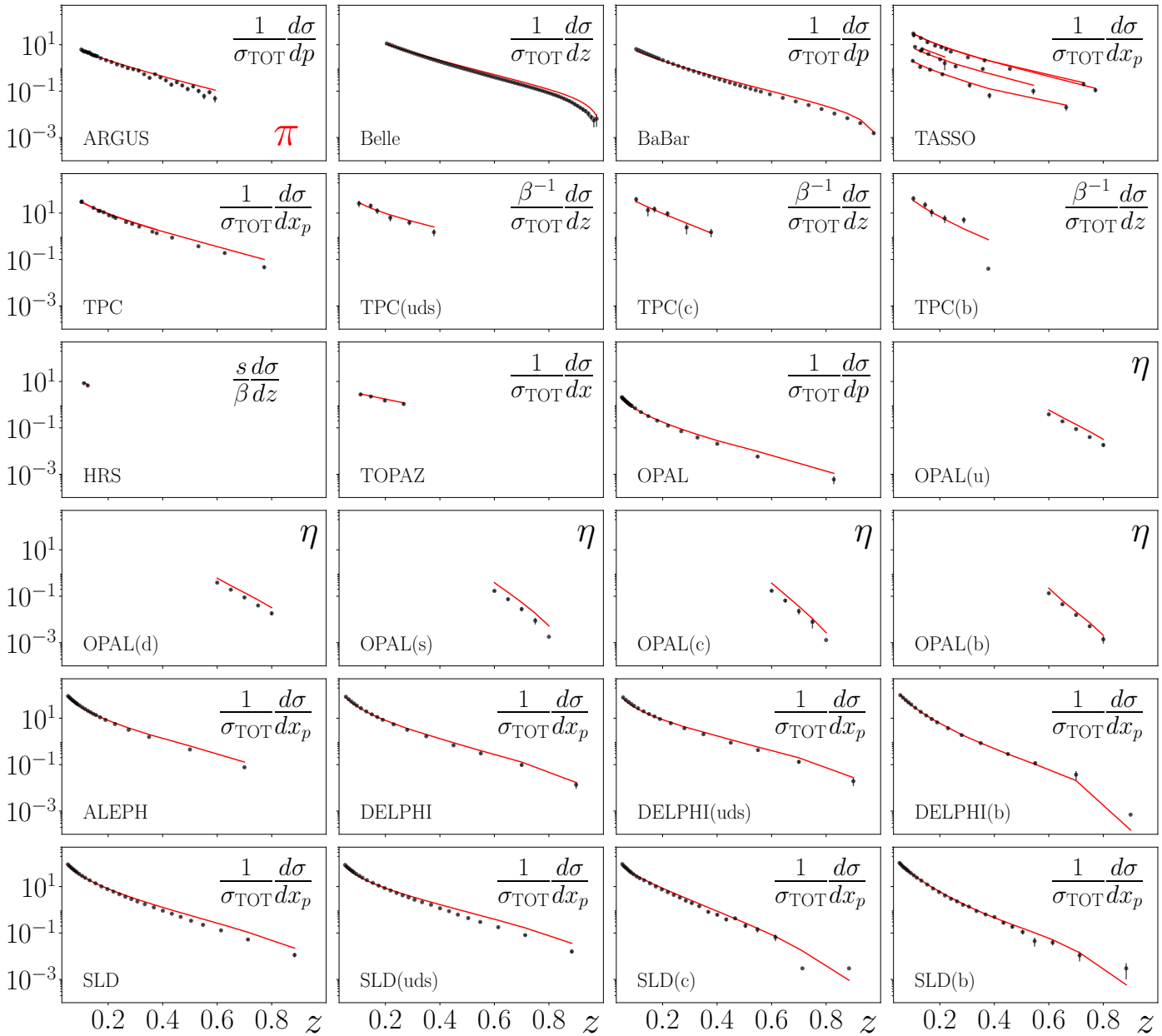
Pythia8+DIRE π FFs and other global analyses



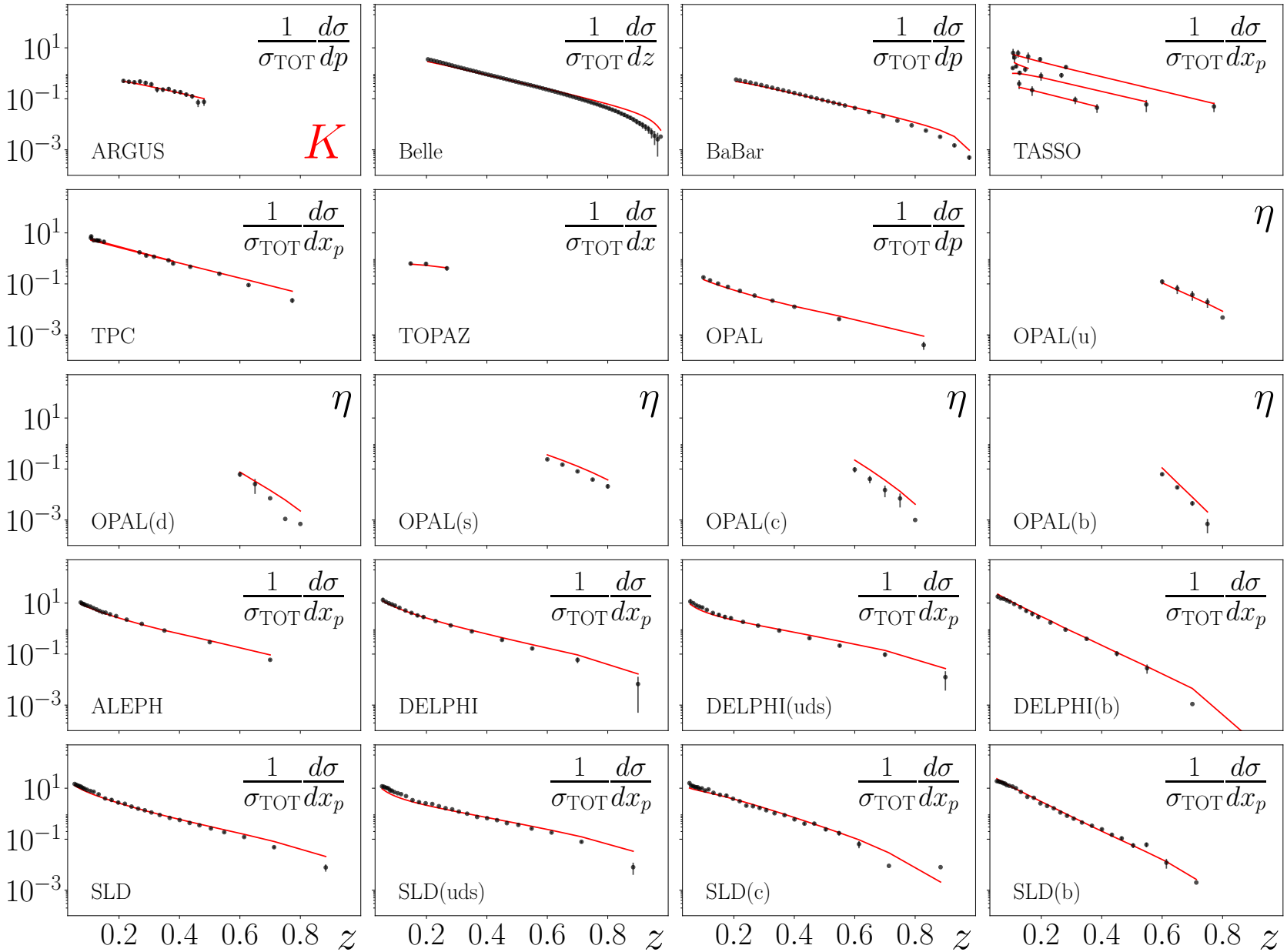
Pythia8+DIRE K FFs and other global analyses



Pythia8+DIRE vs global $e^+e^- \to \pi + X$



Pythia8+DIRE vs global $e^+e^- \to K + X$



Summary and outlook

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  - Improvements on the CSS formalism to extend the range of validity to all q_T
  - α_S^2 corrections are on the way
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- **Factorization and MCEG**
  - JLab founded LDRD to study interplay between factorization methods and MCEG
  - New studies of FFs from pythia
  - Does collinear factorization work in the combined SIDIS+e^+e^- ?
  - Can we see the role of string effects?