Current Fragmentation at the kinematics of the EIC

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Old Dominion University

outline

Motivation

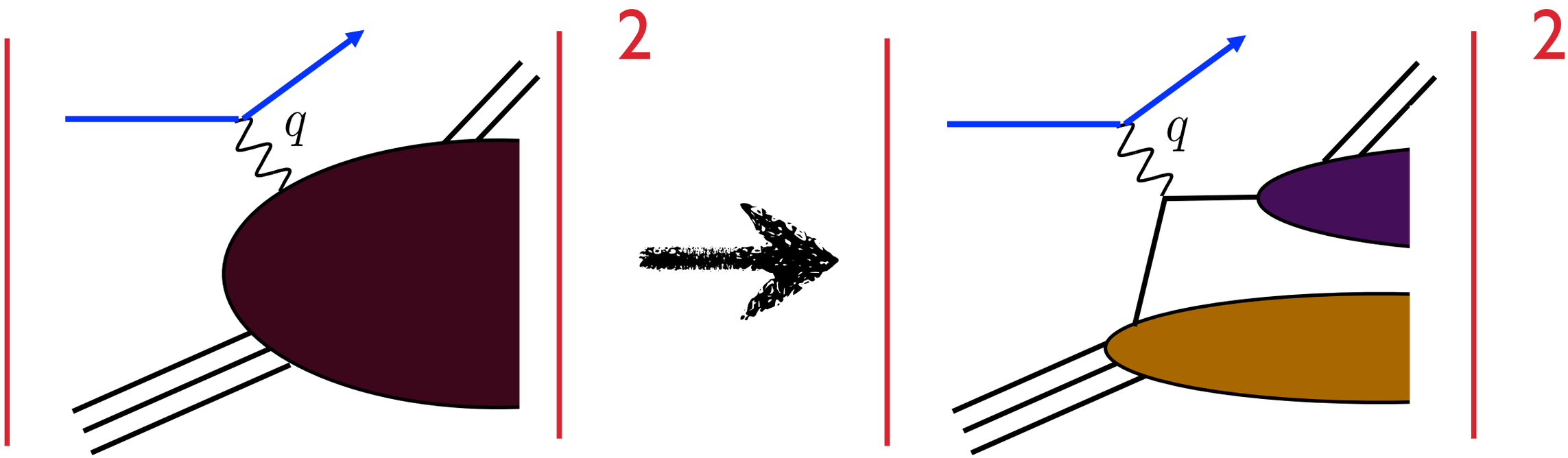
The Matching problem in SIDIS

SIDIS and the current
fragmentation region: physical picture

Defining the current fragmentation region

Final remarks

Motivation



Semi-inclusive deep inelastic scattering

TMDs are Non-perturbative functions, need to determine them from data. Many complications in phenomenological applications.

Motivation

Warning: not a comprehensive review of pheno.

Two stages (My view)

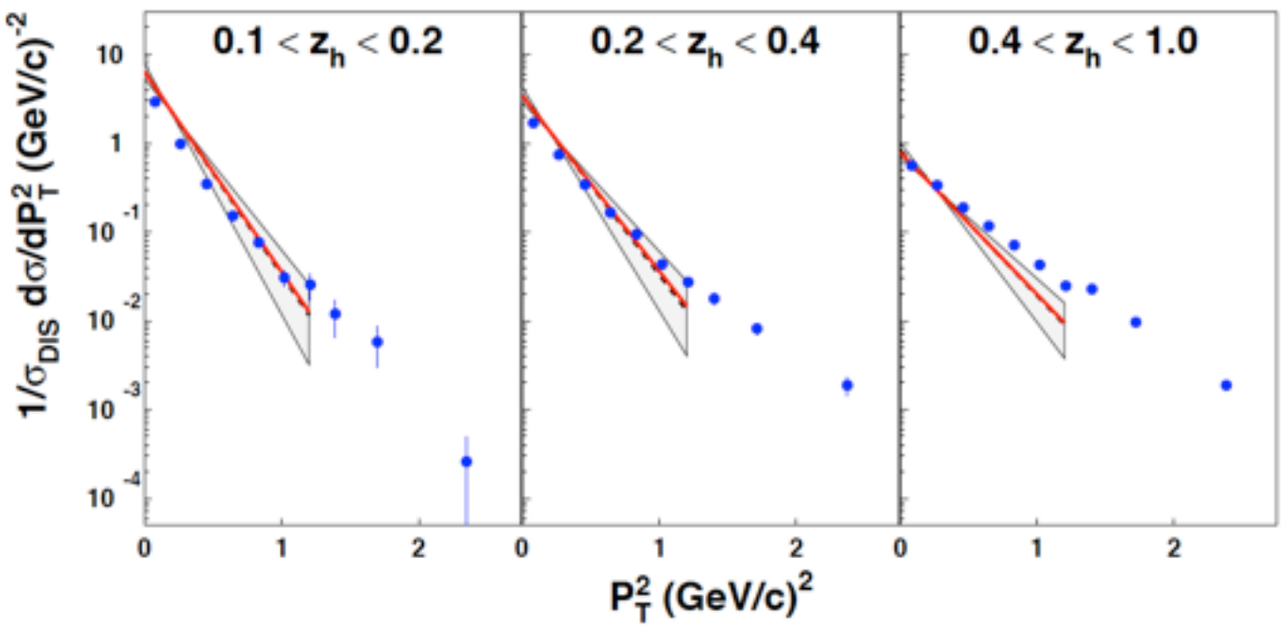
Simple models: gather as much intel as possible

easy to implement, generally leads to interpretations of limited validity

Full QCD picture: perturbative corrections, evolution equations ...

Ultimate goal, great predictive power. Many obstacles remain.

The Matching Problem in SIDIS

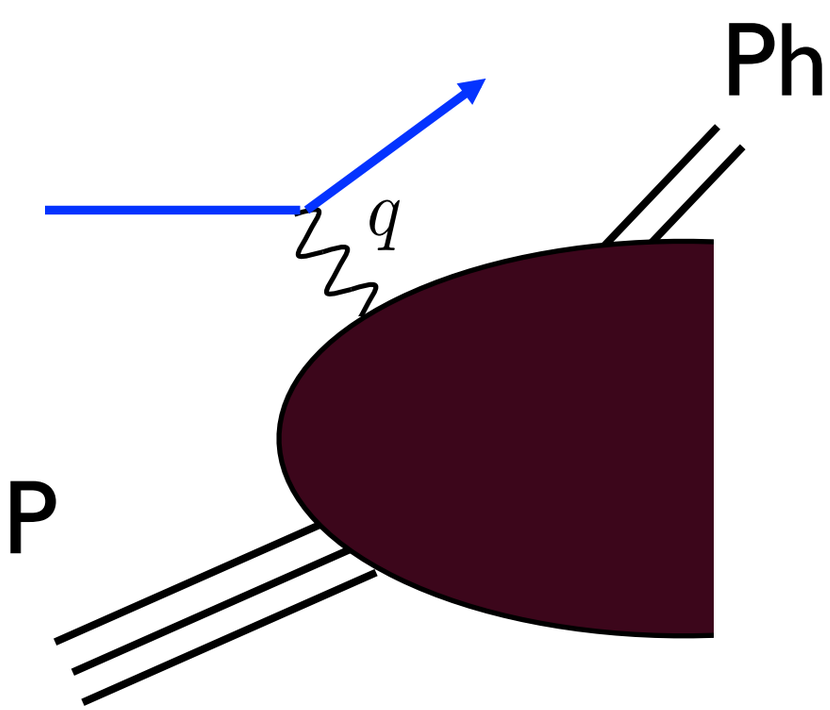


stage 1

Anselmino, Boglione, et.al. (2005)
DOI: 10.1103/PhysRevD.71.074006

z_h = Ph P / q P

P_T observed hadron

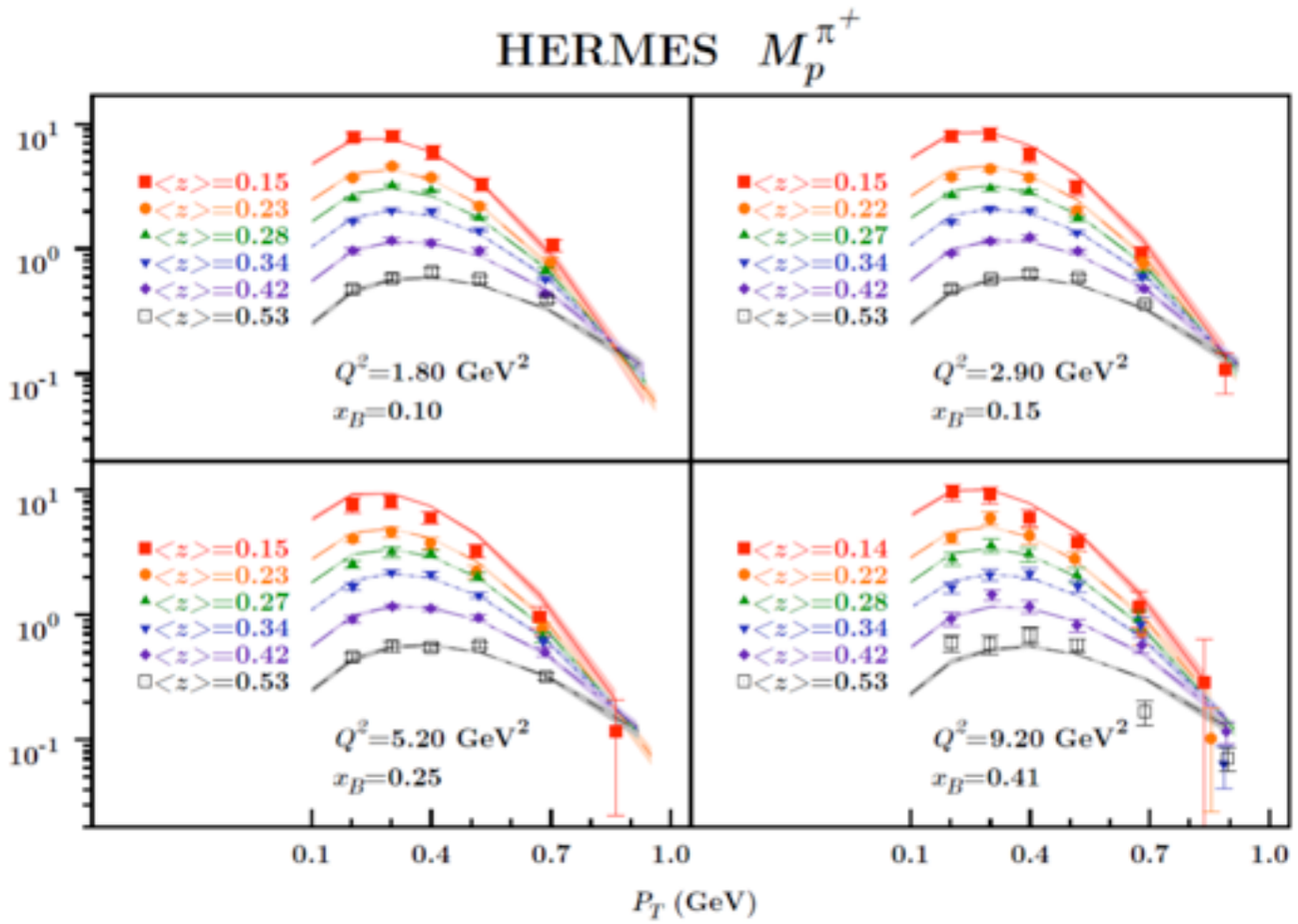


Gaussian model

Data integrated over other kinematical variables:

x_B, $Q^2 = -q^2$

The Matching Problem in SIDIS



Multidimensional data

z_h = Ph P / q P

P_T observed hadron

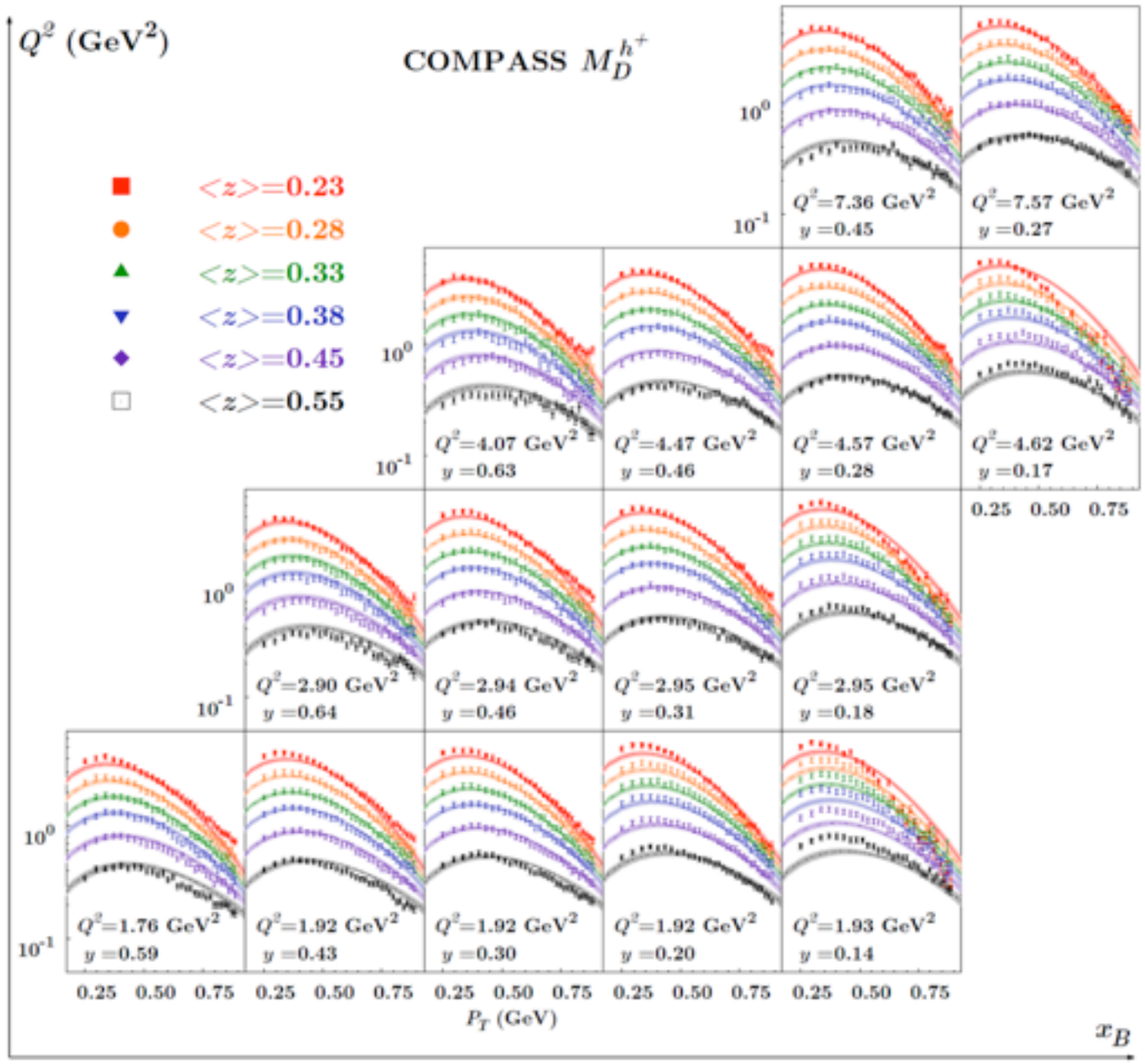
x_B, Q^2

Gaussian model

Describes well low-z_h and low P_T

stage 1

The Matching Problem in SIDIS



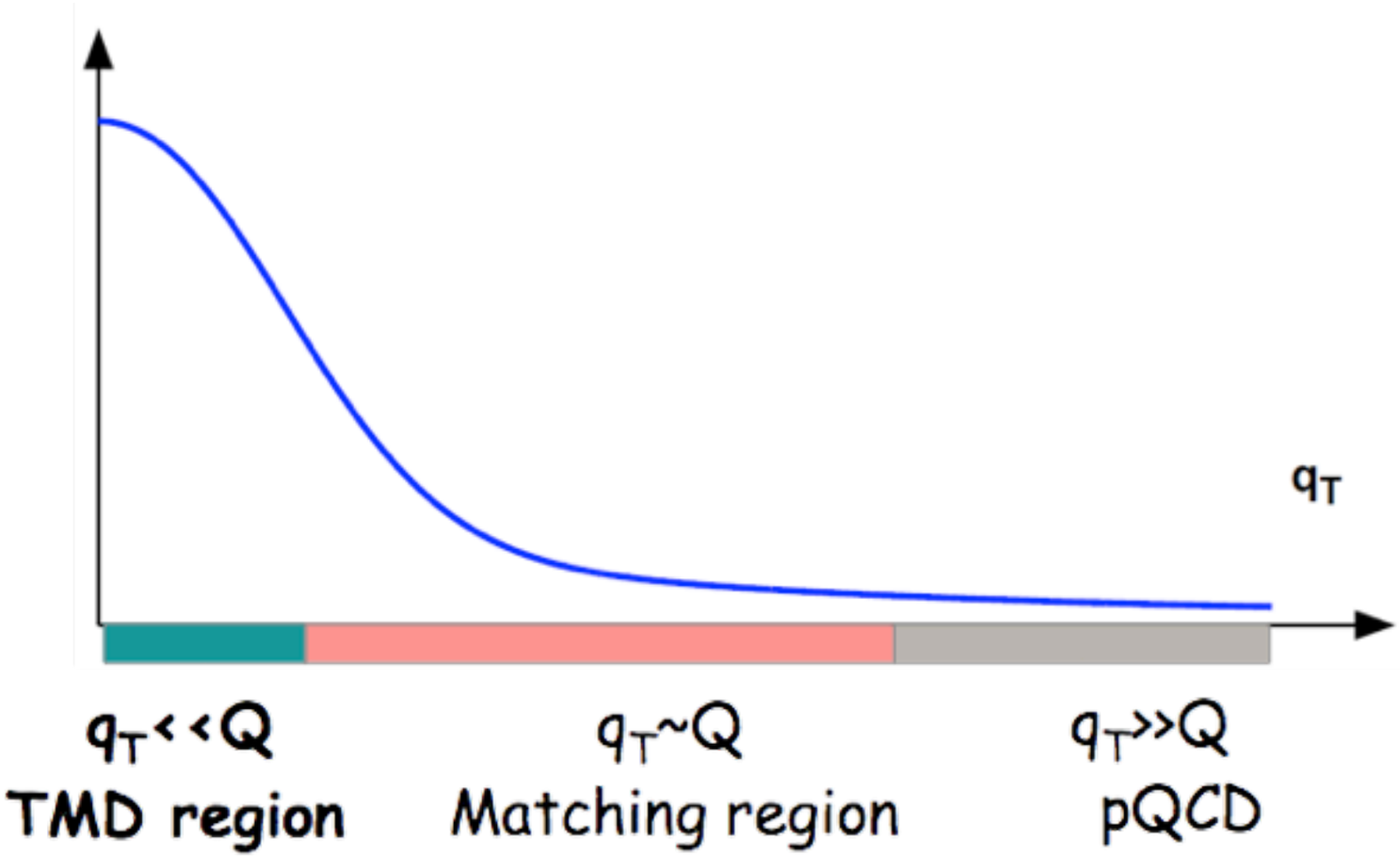
stage 1

Gaussian model

Describes well a subset of low-z_h and low P_T

Observe mild Q^2 dependence in data. Need to think about TMD evolution, stage 2

The Matching Problem in SIDIS

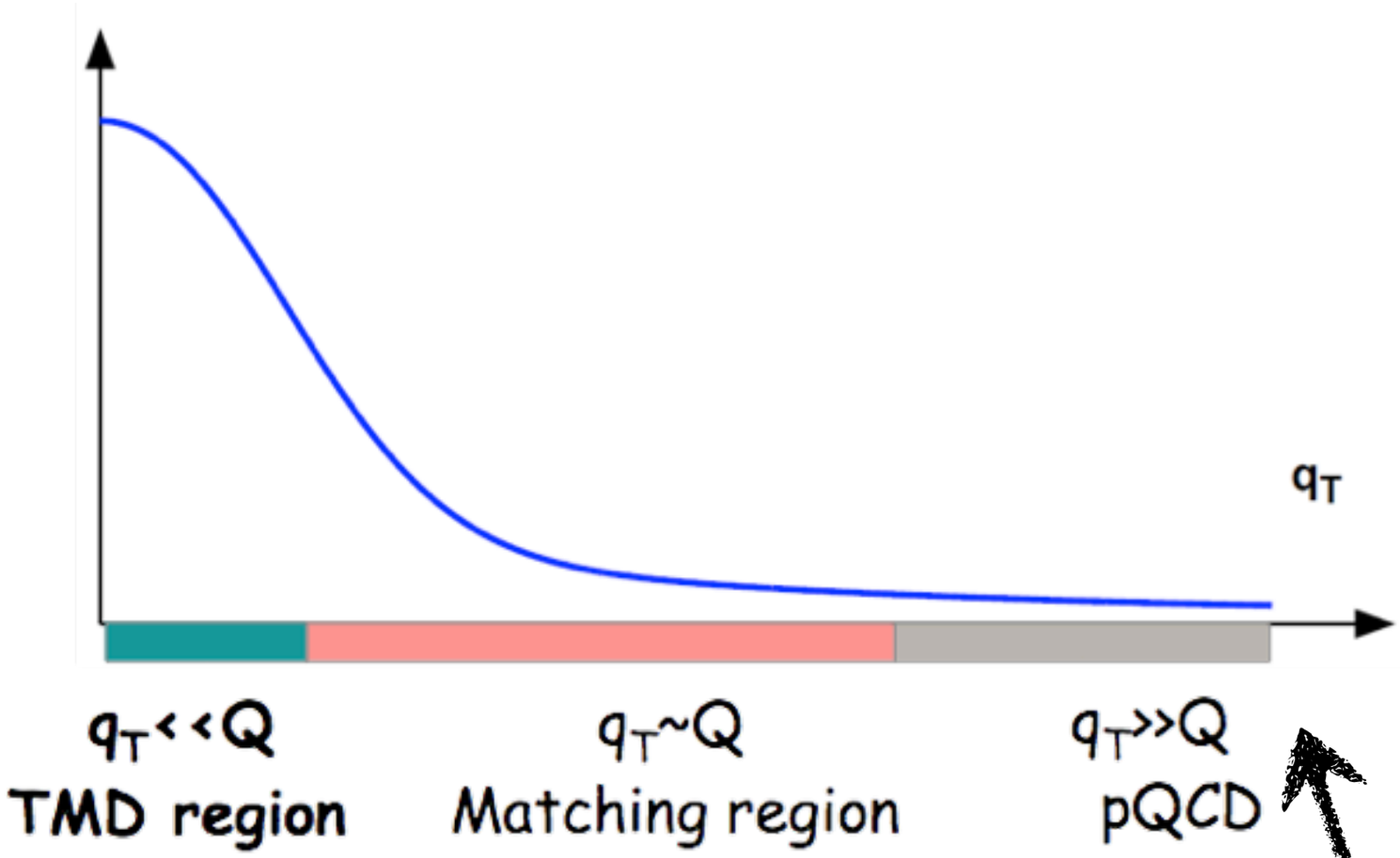


$\mathbf{q_T = P_{T/z_h}}$

W + Y construction
Collins-Soper-Sterman

W describes the TMD region
Y pQCD corrections at
larger $\mathbf{q_T = P_{T/z_h}}$

The Matching Problem in SIDIS



$q_T = P_T / z_h$

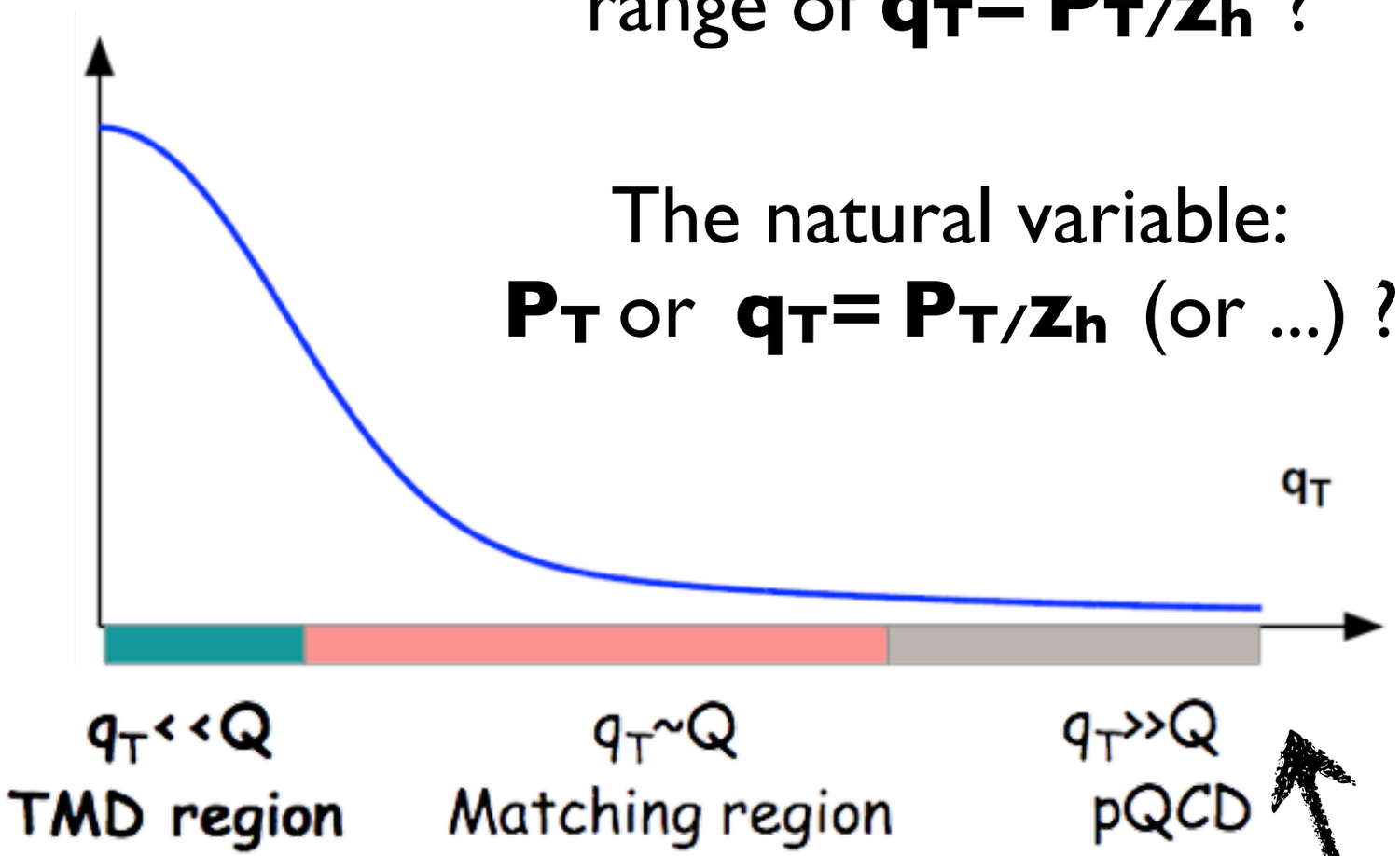
W + Y construction
Collins-Soper-Sterman

Coming from
gluon radiation, Collinear
Factorization

The Matching Problem in SIDIS

Can we describe the entire range of $\mathbf{q_T = P_T/z_h}$?

The natural variable:
$\mathbf{P_T}$ or $\mathbf{q_T = P_T/z_h}$ (or ...) ?



$\mathbf{q_T = P_T/z_h}$

W + Y construction
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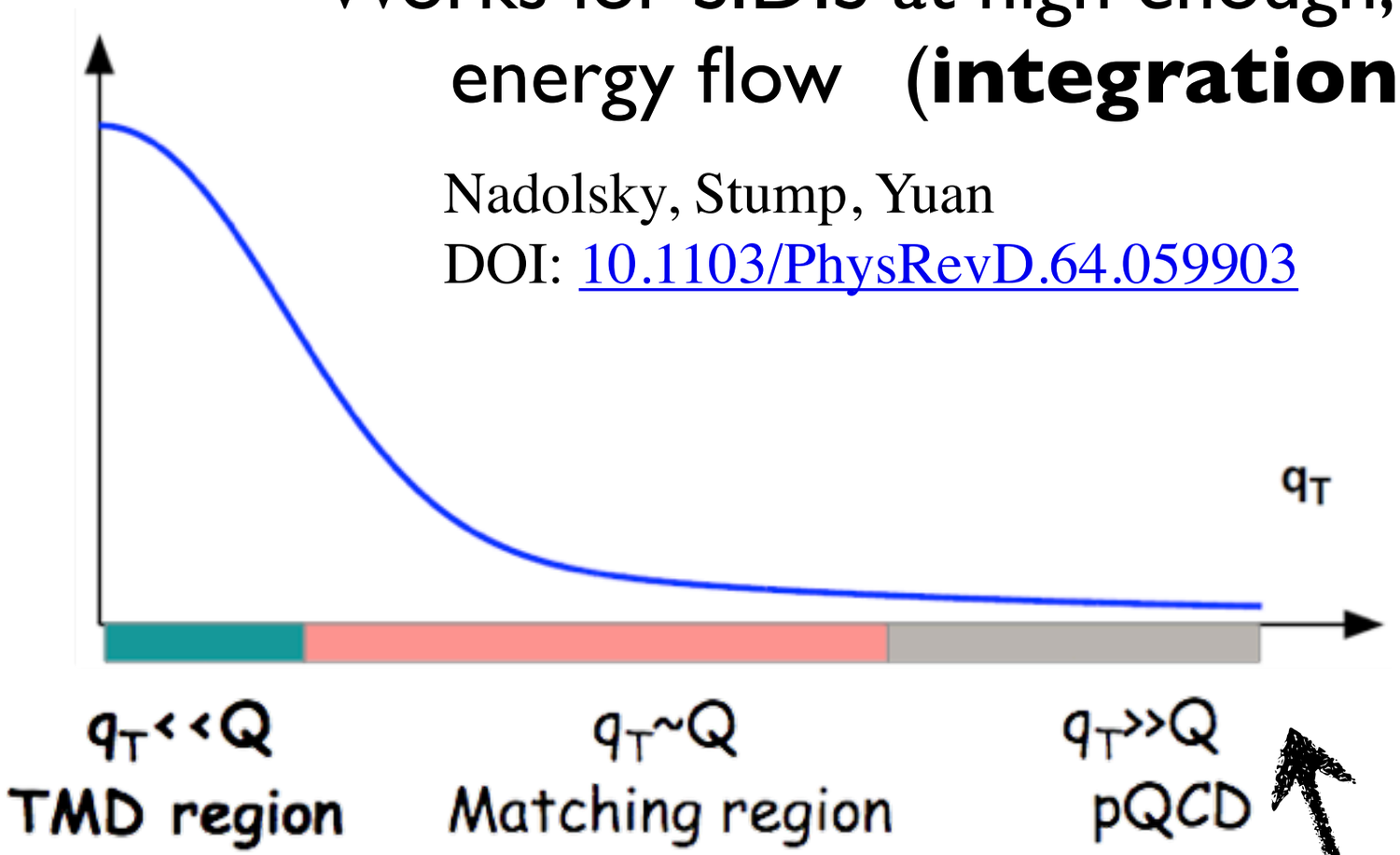
Coming from
gluon radiation, Collinear
Factorization

The Matching Problem in SIDIS

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



$q_T = P_T / z_h$

W + Y construction
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Coming from
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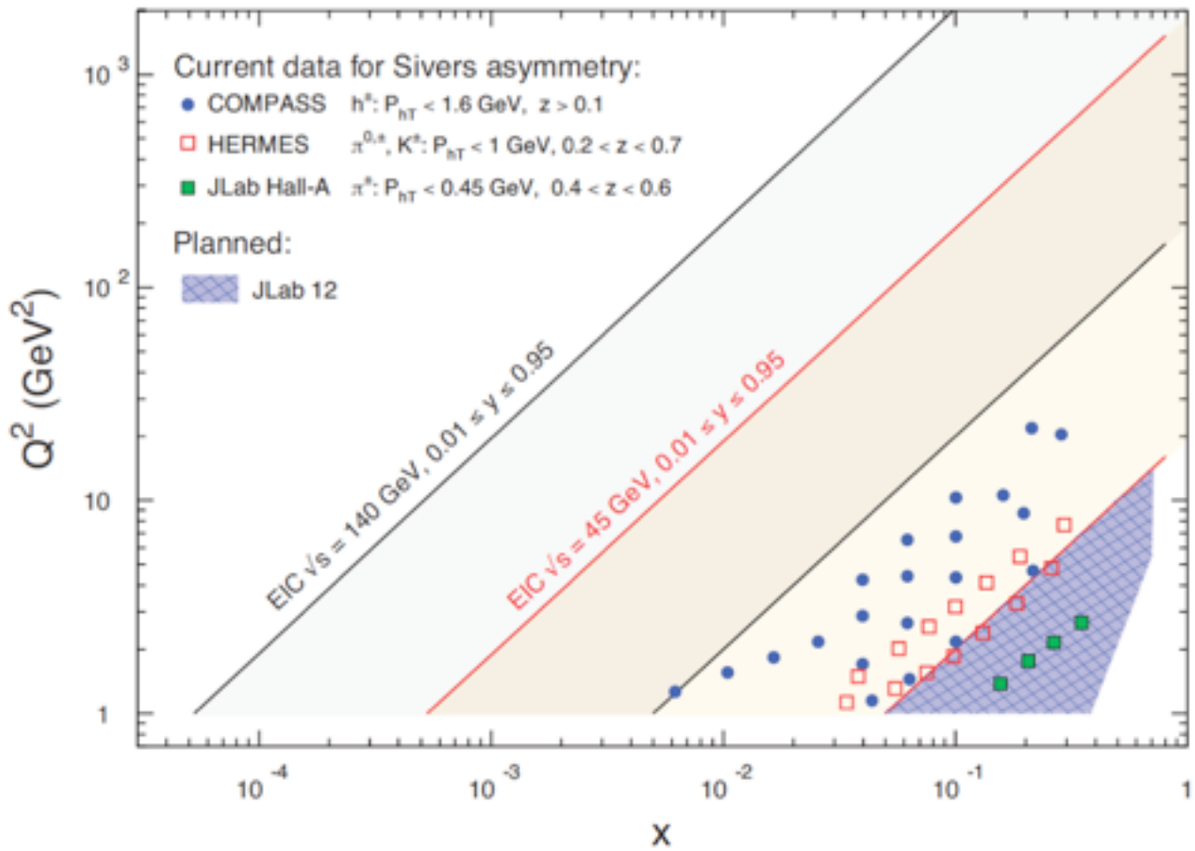
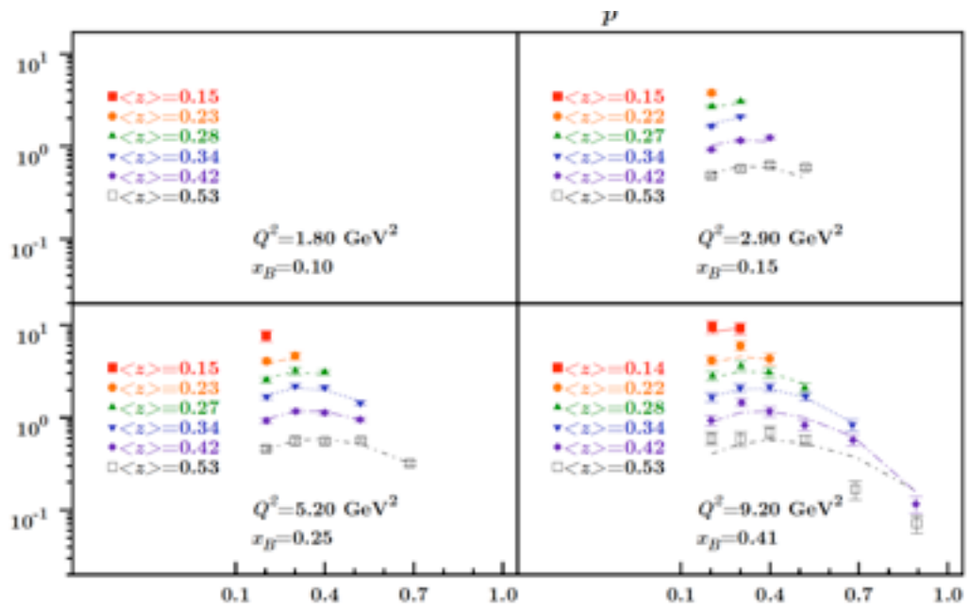


Multi-dimensional SIDIS data at the kinematics of EIC will play an essential role in the determination of TMDs

The Matching Problem in SIDIS

$Q^2 < 10\ \mathrm{GeV}^2$

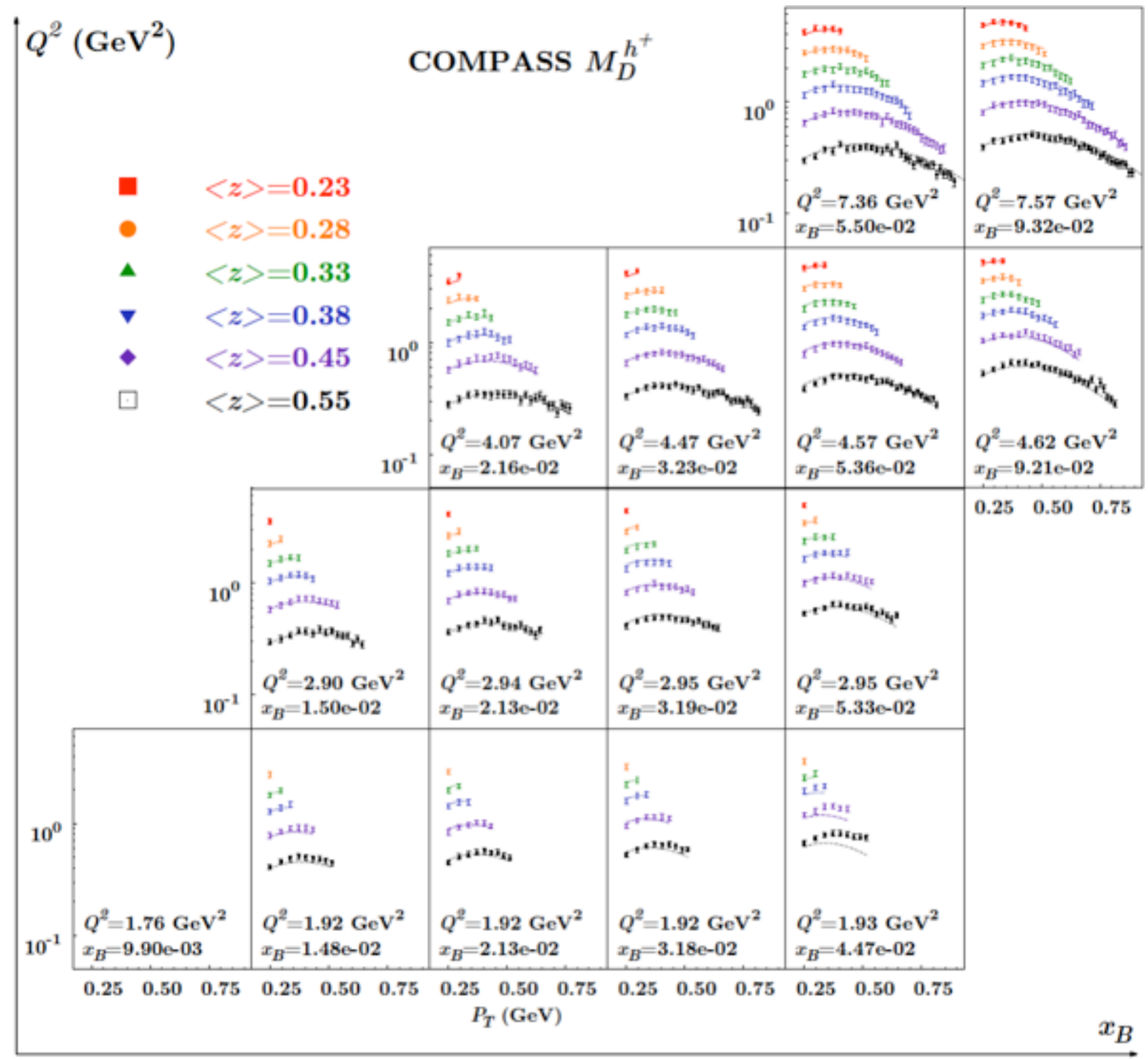


$\chi^2_{\mathrm{tot}} = 1.17$

Note:

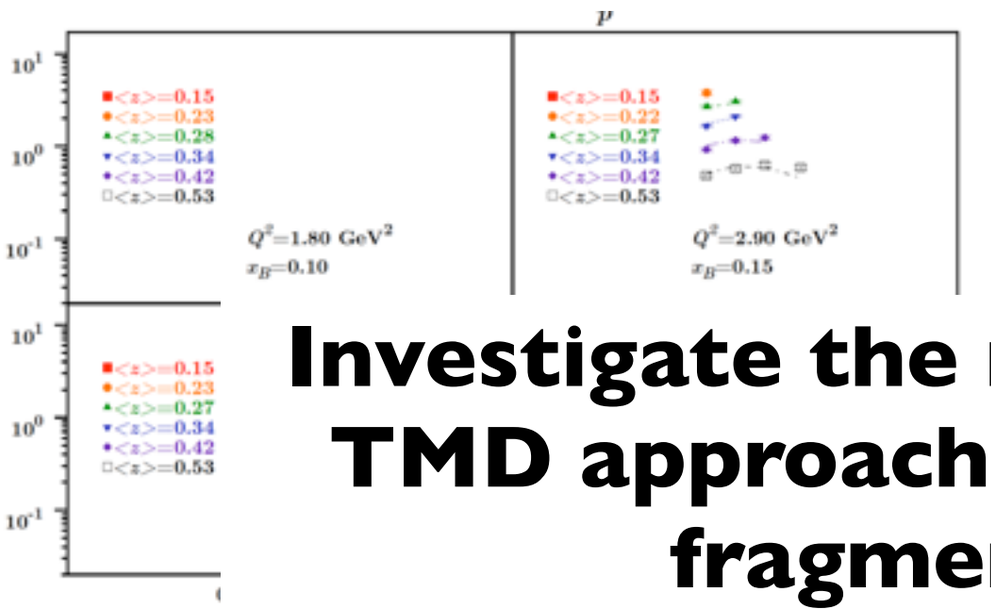
i) cuts in $\mathbf{q_T = P_T/z_h}$

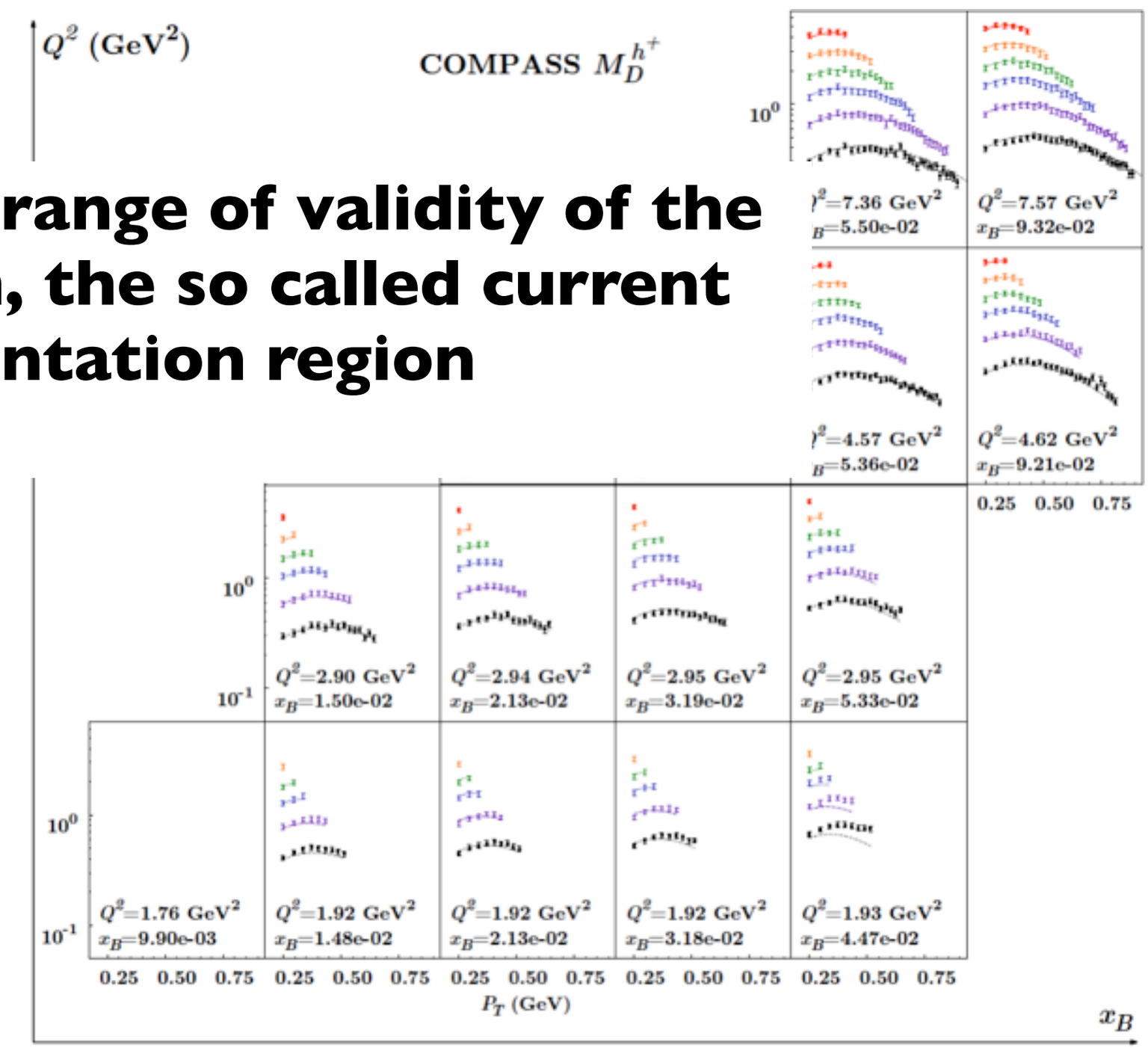
ii) no Y term



The Matching Problem in SIDIS

$Q^2 < 10\ \mathrm{GeV}^2$





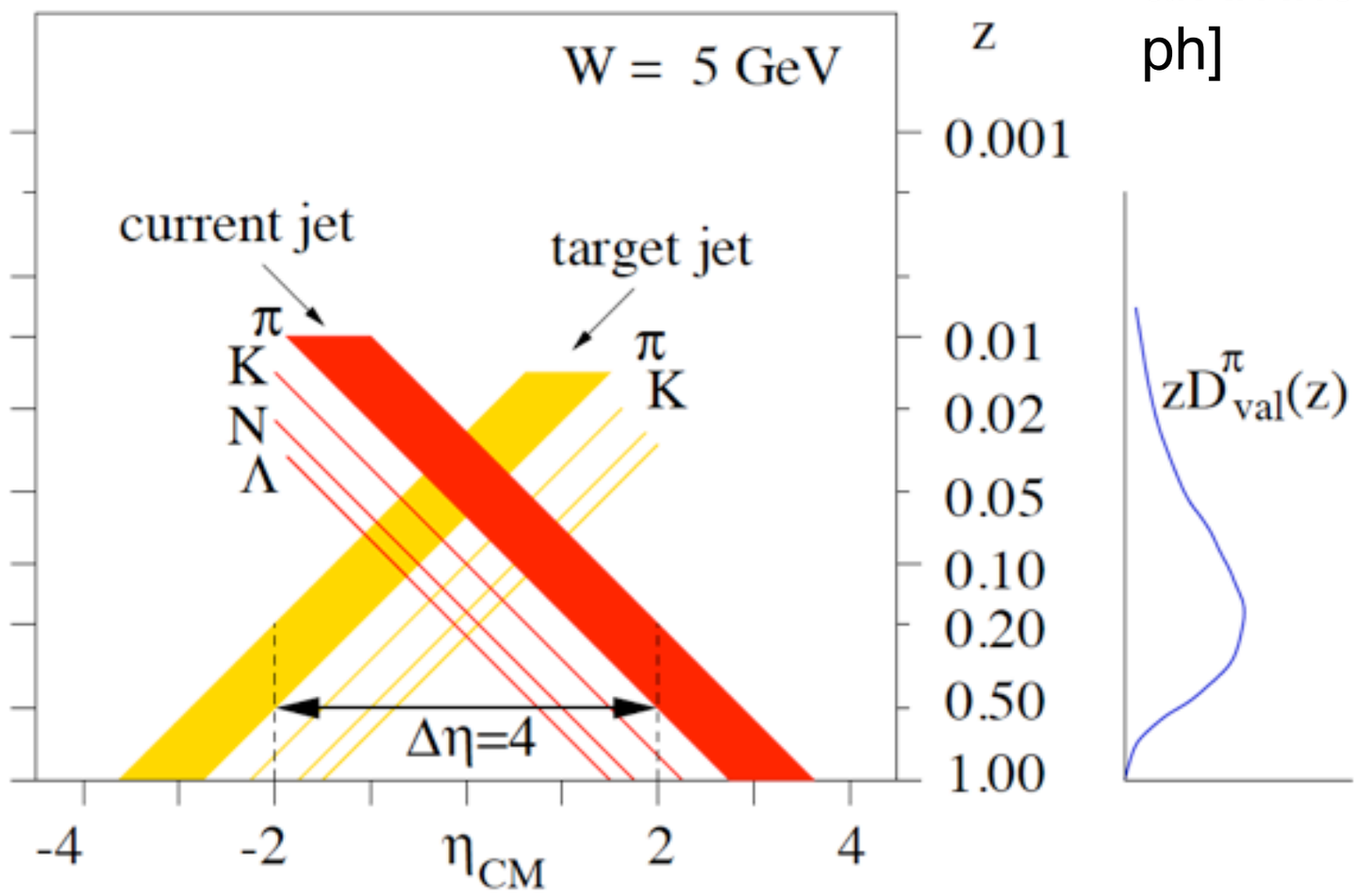
Investigate the range of validity of the TMD approach, the so called current fragmentation region

Trouble describing data in the CSS formalism (including Y term and large $\mathbf{q_T = P_T/z_h}$)

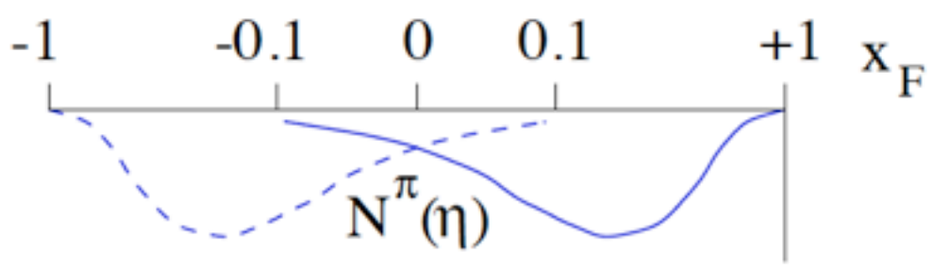
SIDIS and the current fragmentation region

It should be noted ...

P. J. Mulders, AIP Conf. Proc. 588, 75 (2001), [,75(2000)], arXiv:hep-ph/0010199 [hep-ph]



Phase space should be large enough to distinguish current/target regions

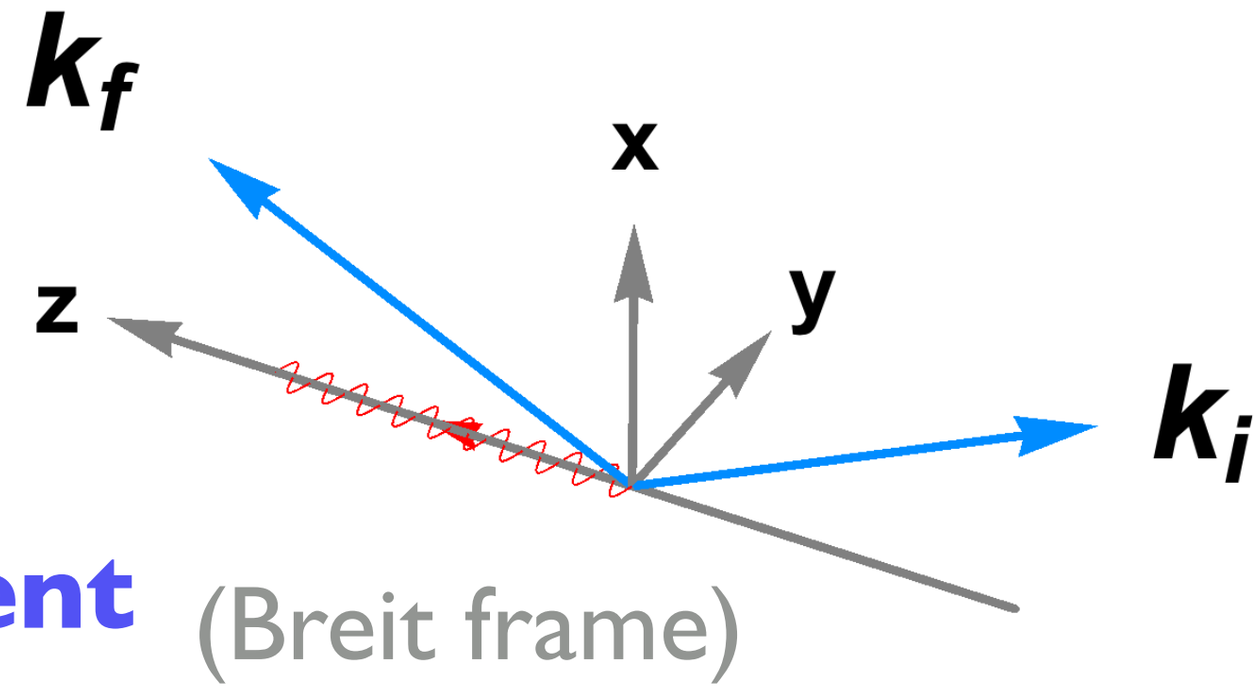


("Berger criterion")

E. L. Berger, (1987).

SIDIS and the current fragmentation region

We need a quantitative way to identify the current region.



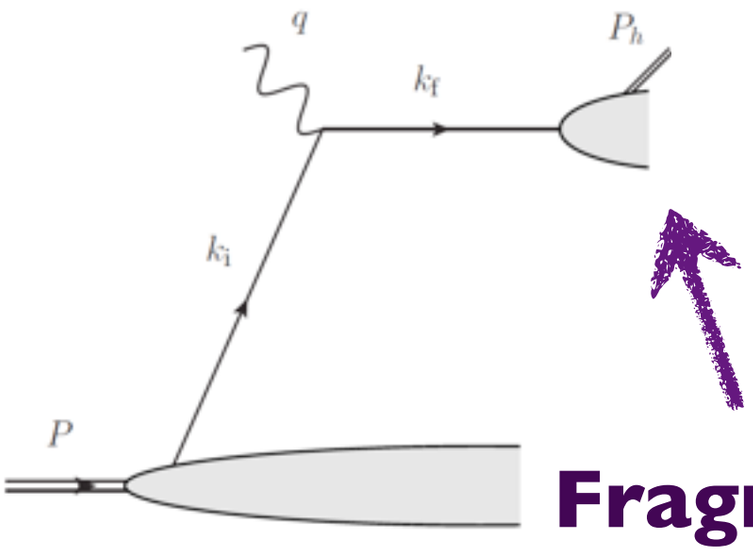
(Breit frame)

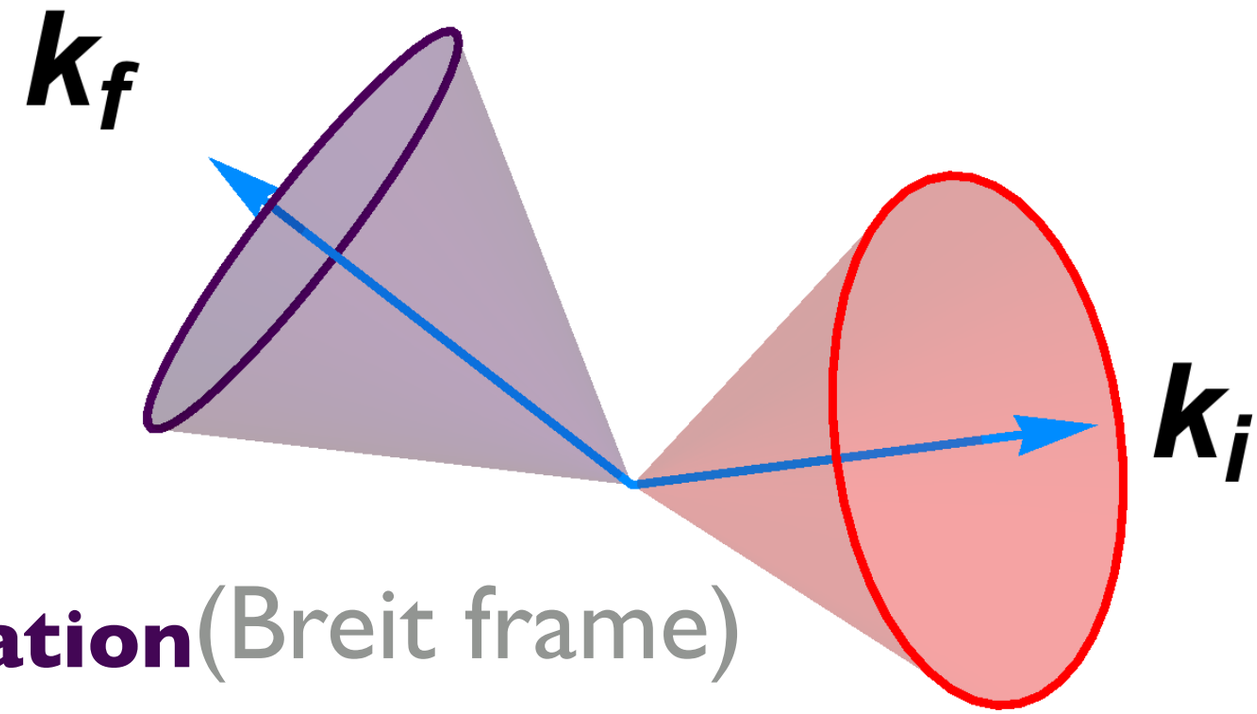
SIDIS and the current fragmentation region: physical picture

Notice this is work in progress!!!

In collaboration with:

Mariaelena Boglione	(Torino)
John Collins	(Penn State)
Leonard Gamberg	(Penn State Berks)
Ted Rogers	(ODU/JLab)
Nobuo Sato	(JLab)

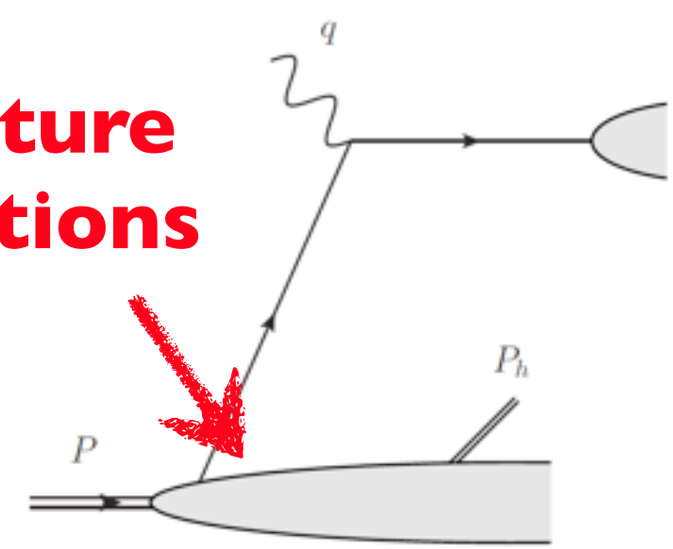




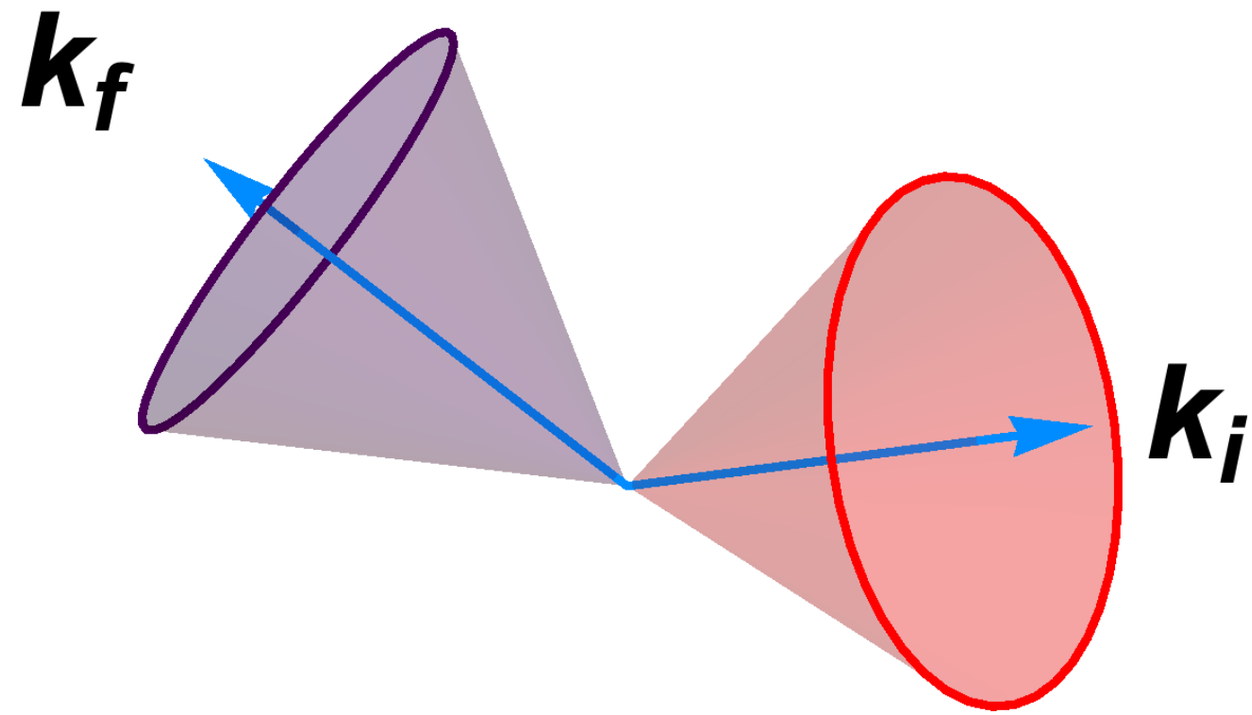
Fragmentation Functions (Breit frame)

factorization theorems

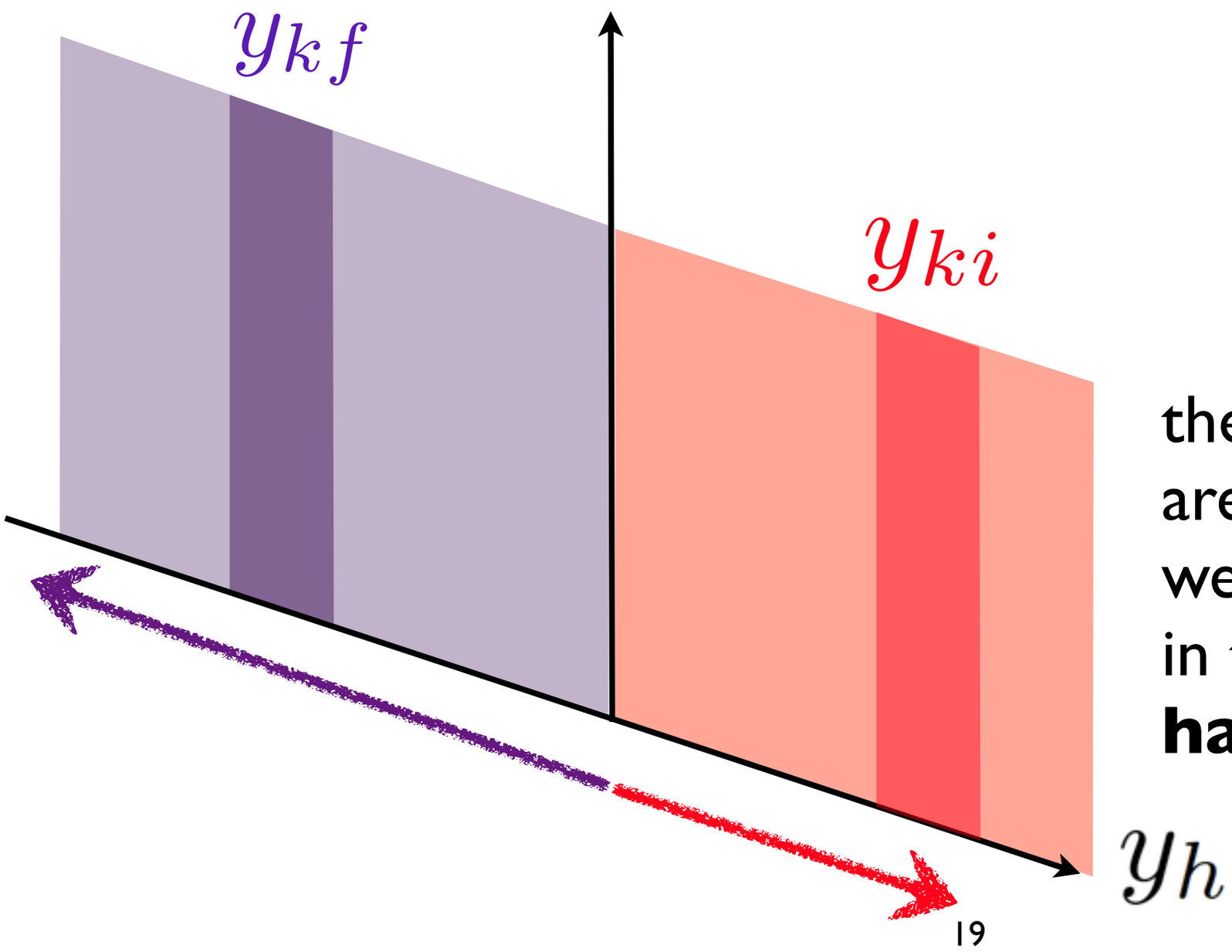
Fracture Functions



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

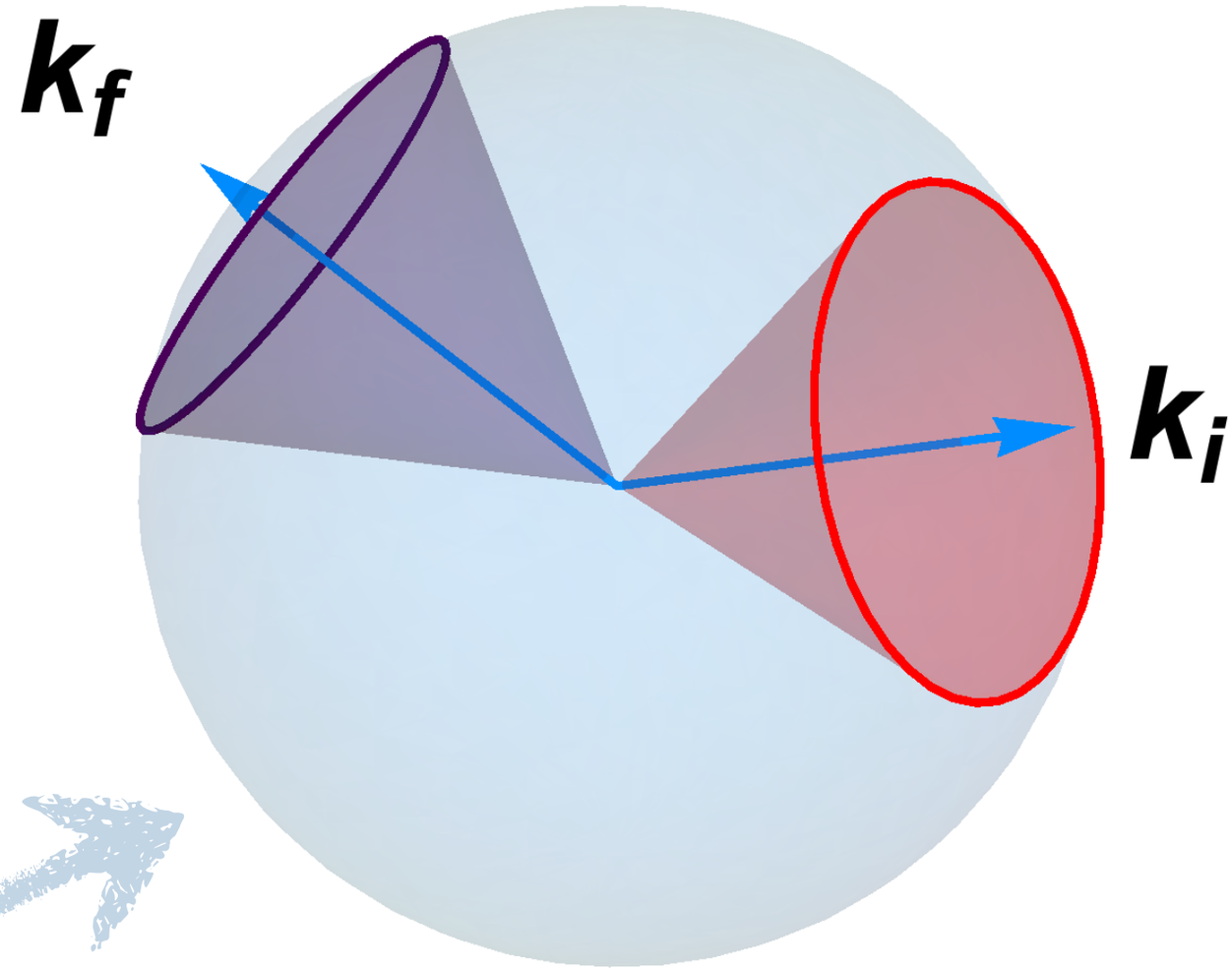


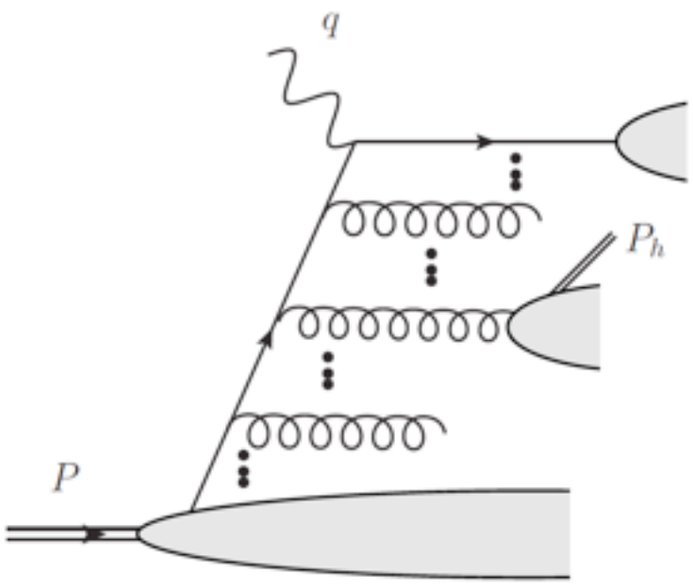
Observable



these regions
are often assumed to be
well separated
in the **observed**
hadron rapidity

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



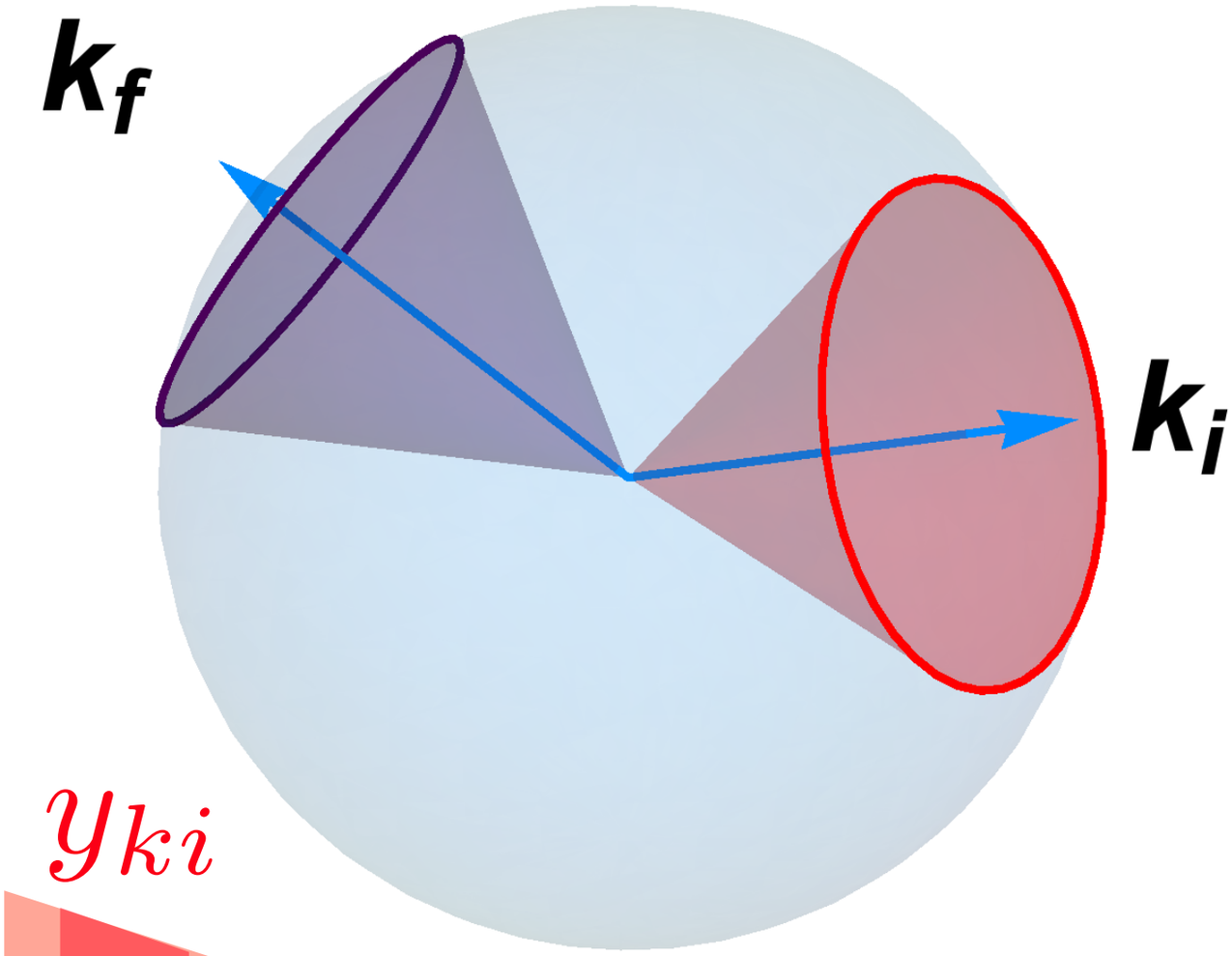


soft

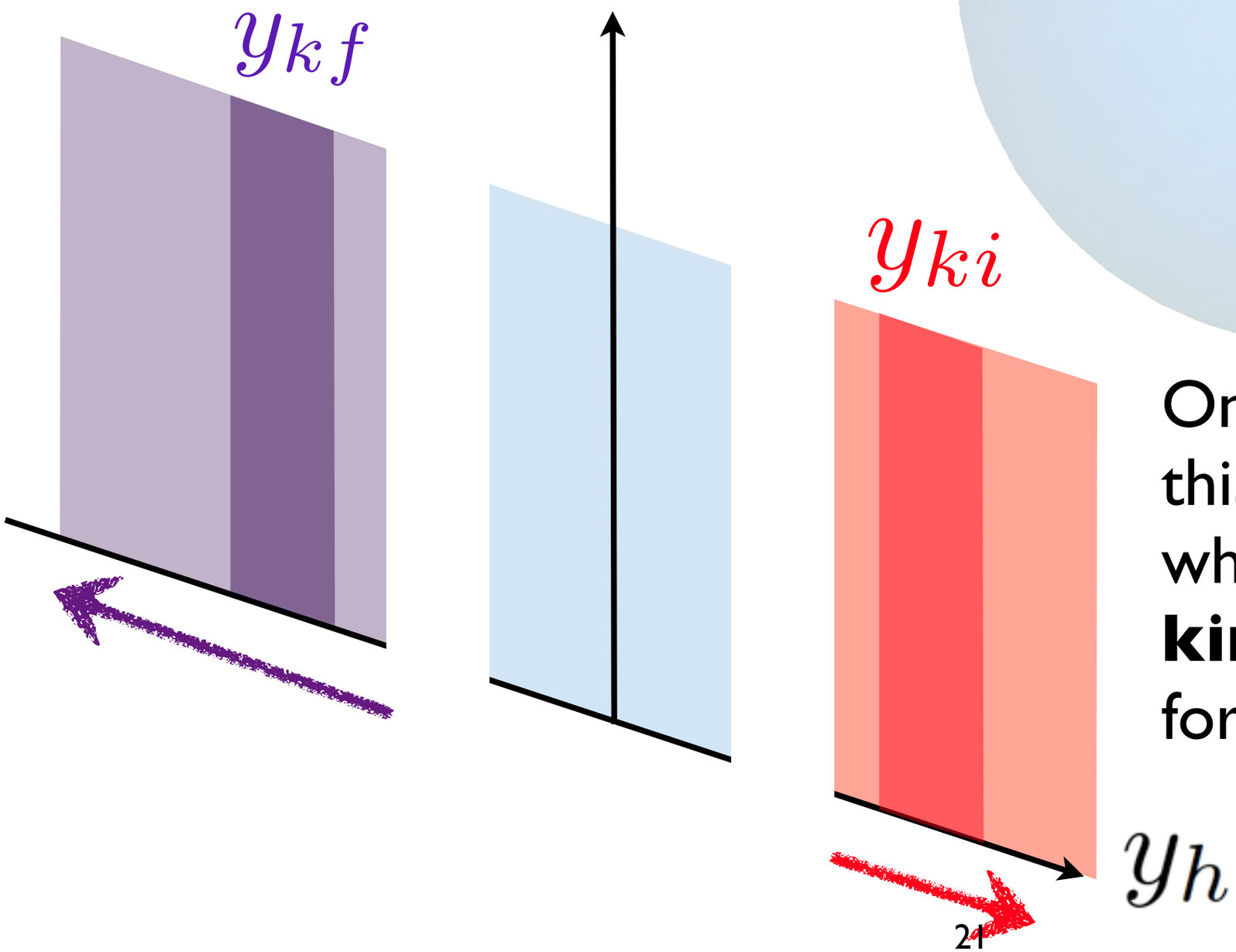
However, this neglects the soft fragmentation region

(No factorization theorem for this region)

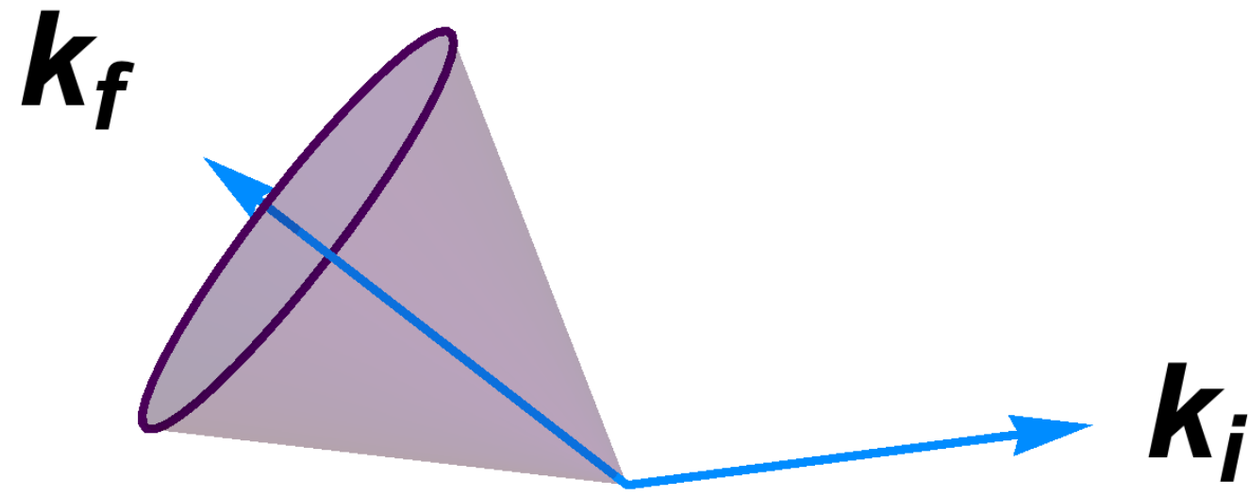
$$y_h \equiv \frac{1}{2} \log \frac{P_h^+}{P_h^-}$$

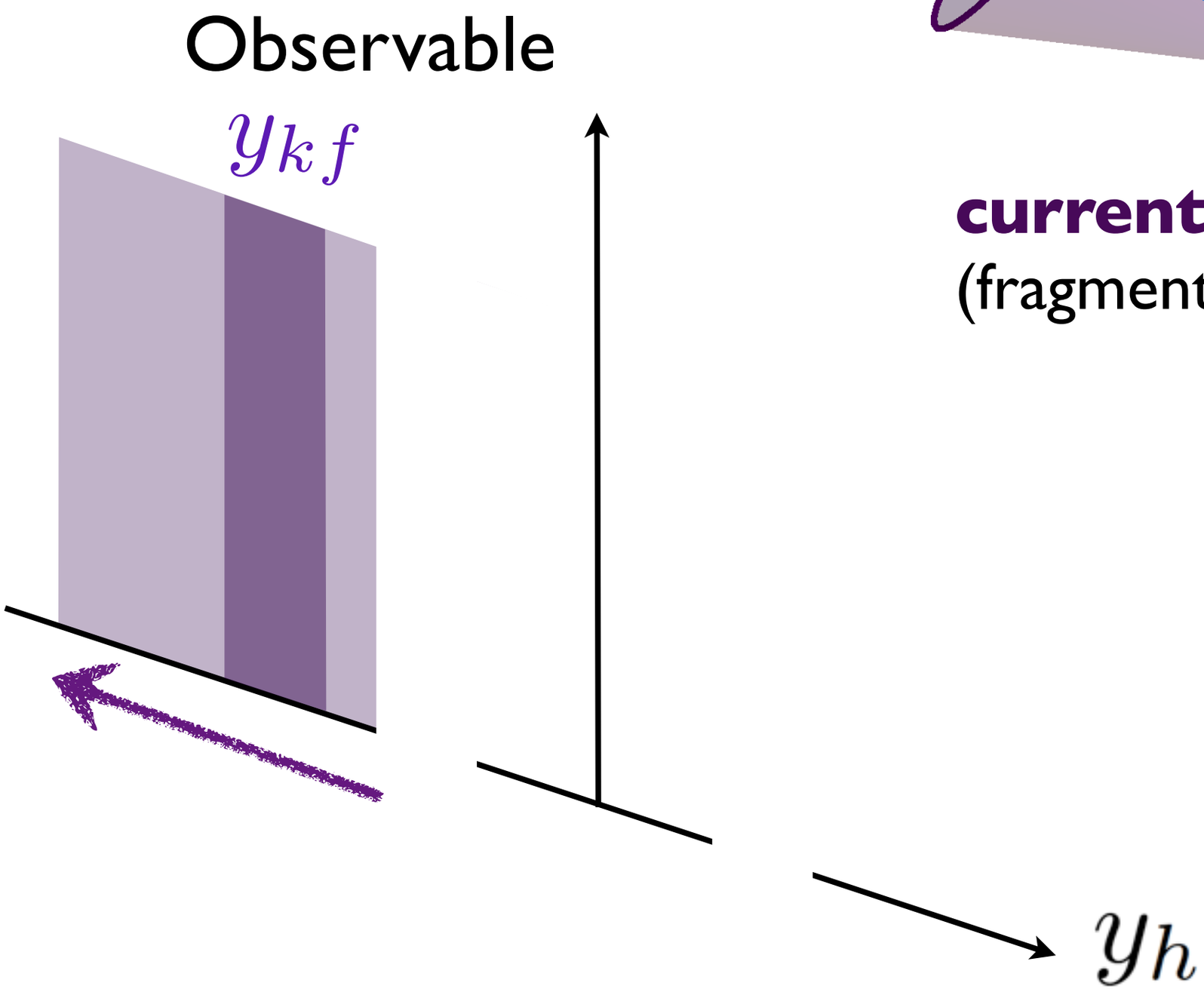


Observable



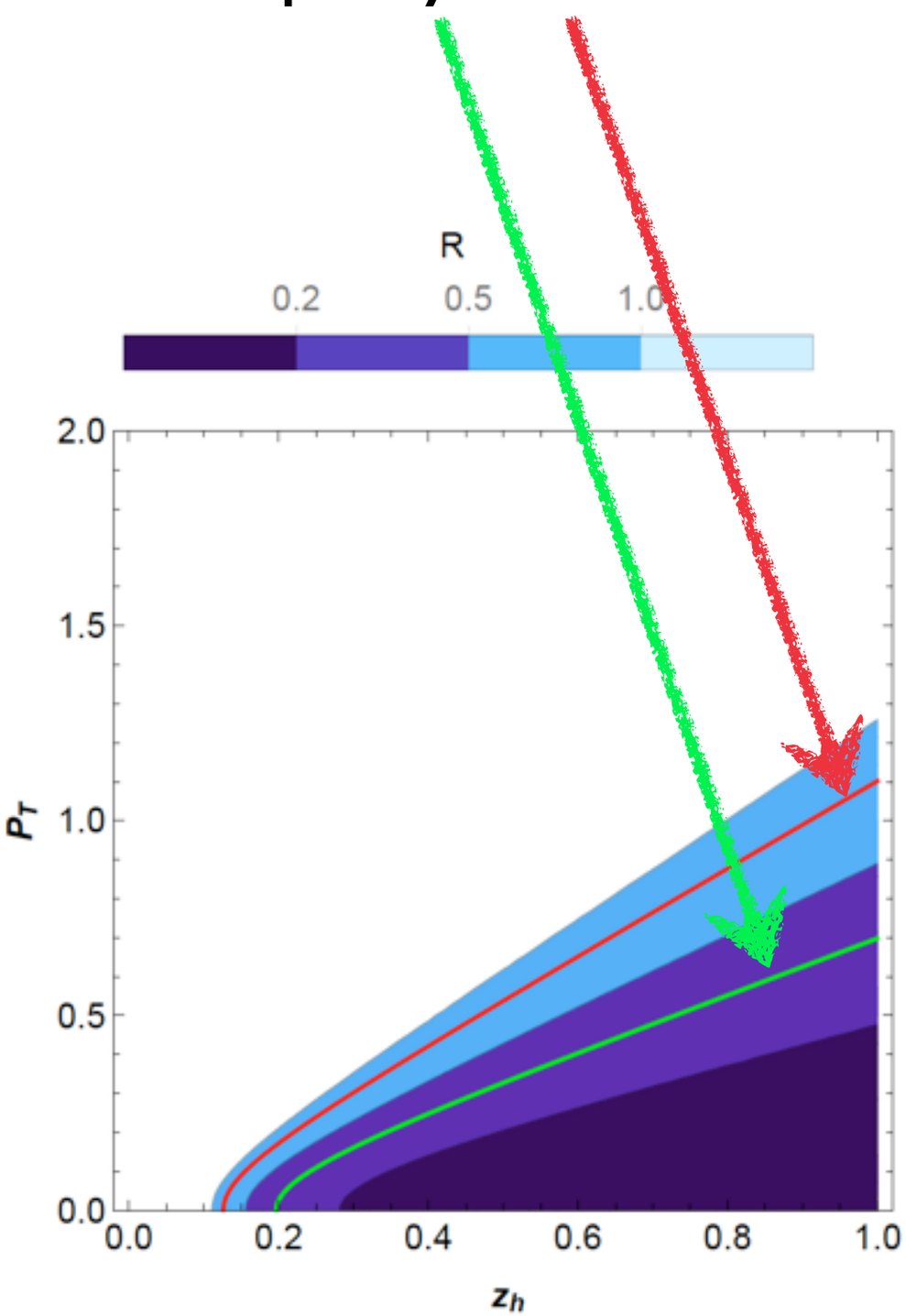
One may take this into account, at least when defining **kinematic limits** for current/target region

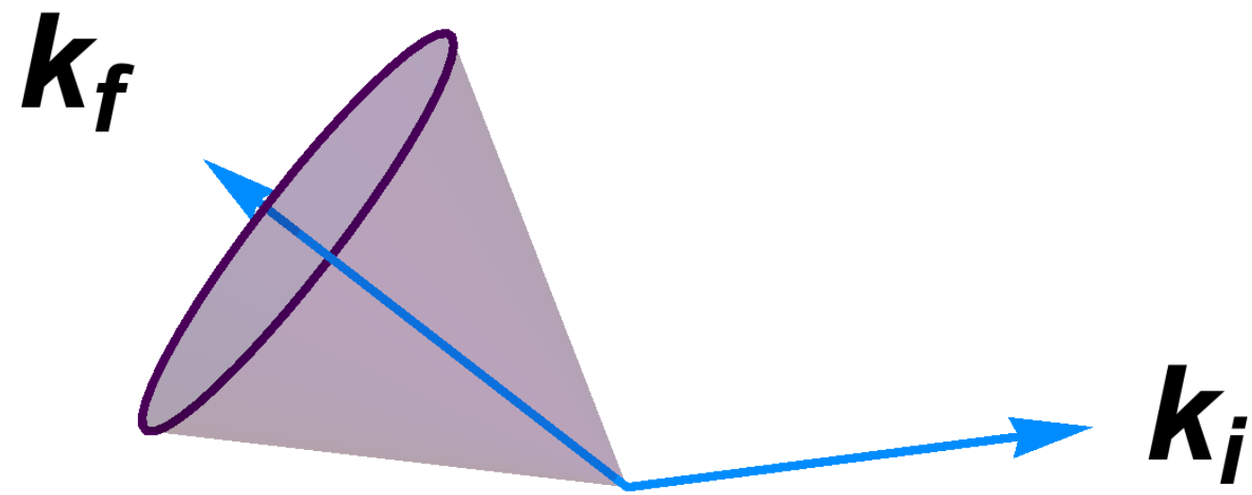




current region
(fragmentation functions)

Impose
rapidity cuts





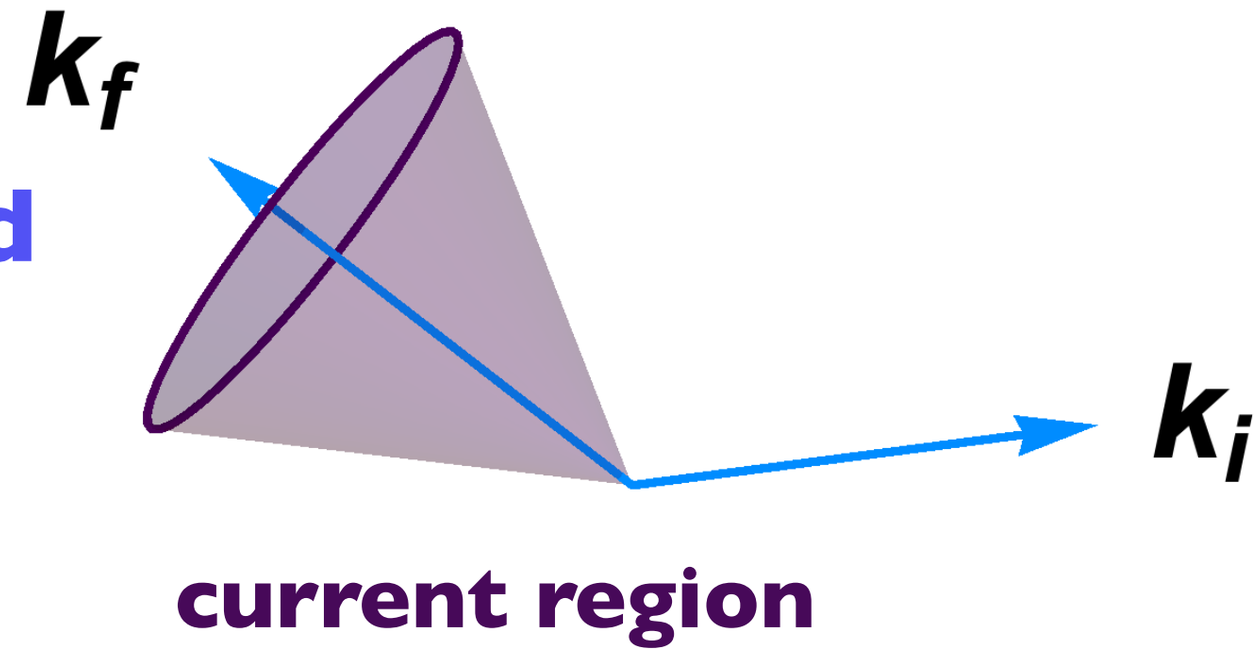
current region

Alternatively,
require small values
for

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

notice quark momenta
have to be estimated

Power counting and kinematics of the current region



small masses

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

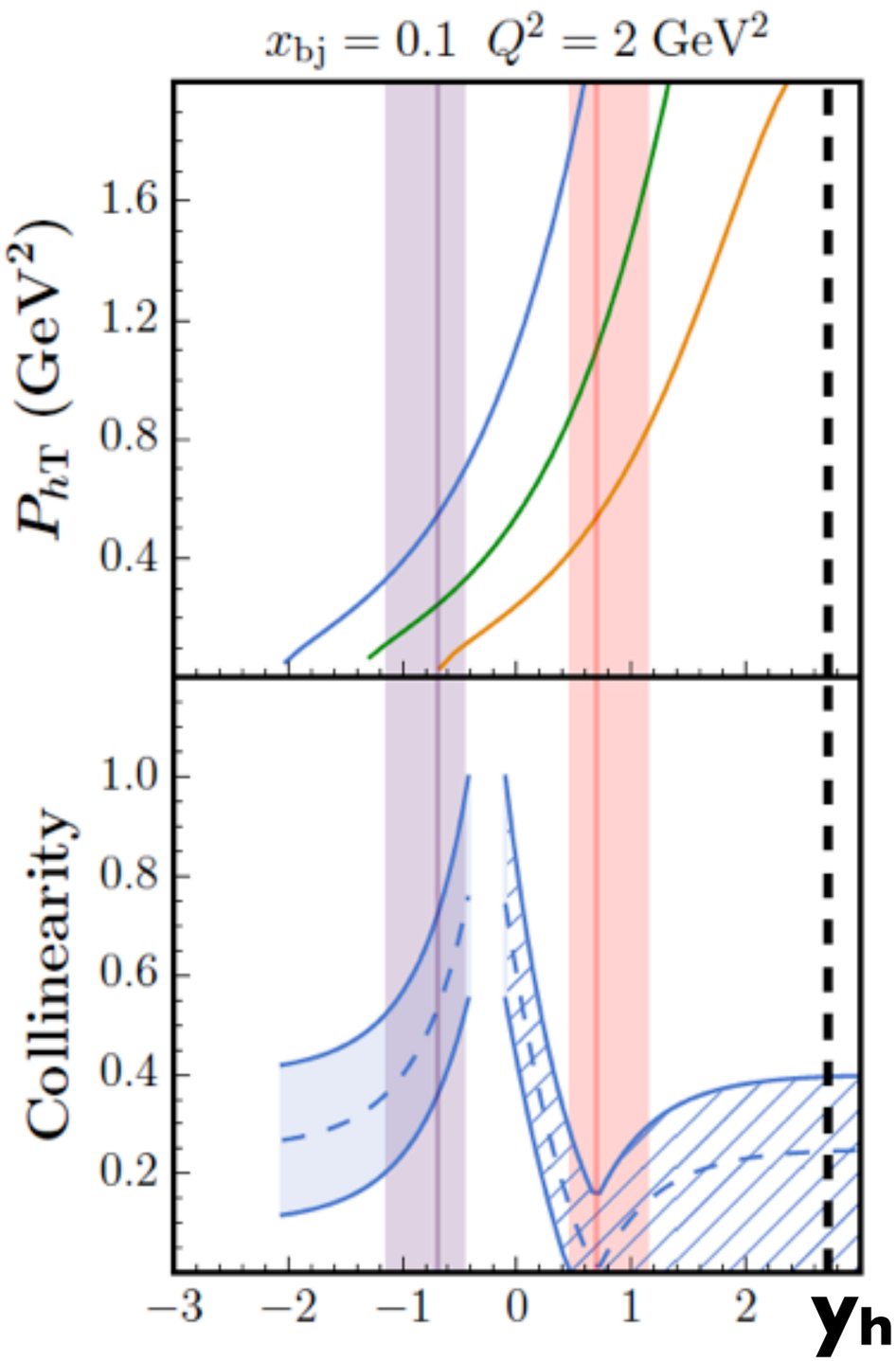
$$P_h \cdot k_{\rm i} = O\left(Q^2\right)$$

hard scale

Alternatively, require small values for

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

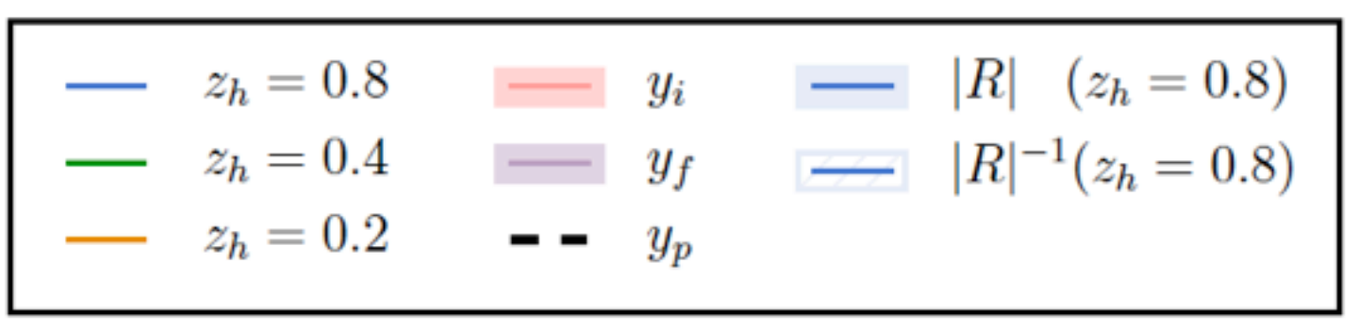
notice quark momenta have to be estimated

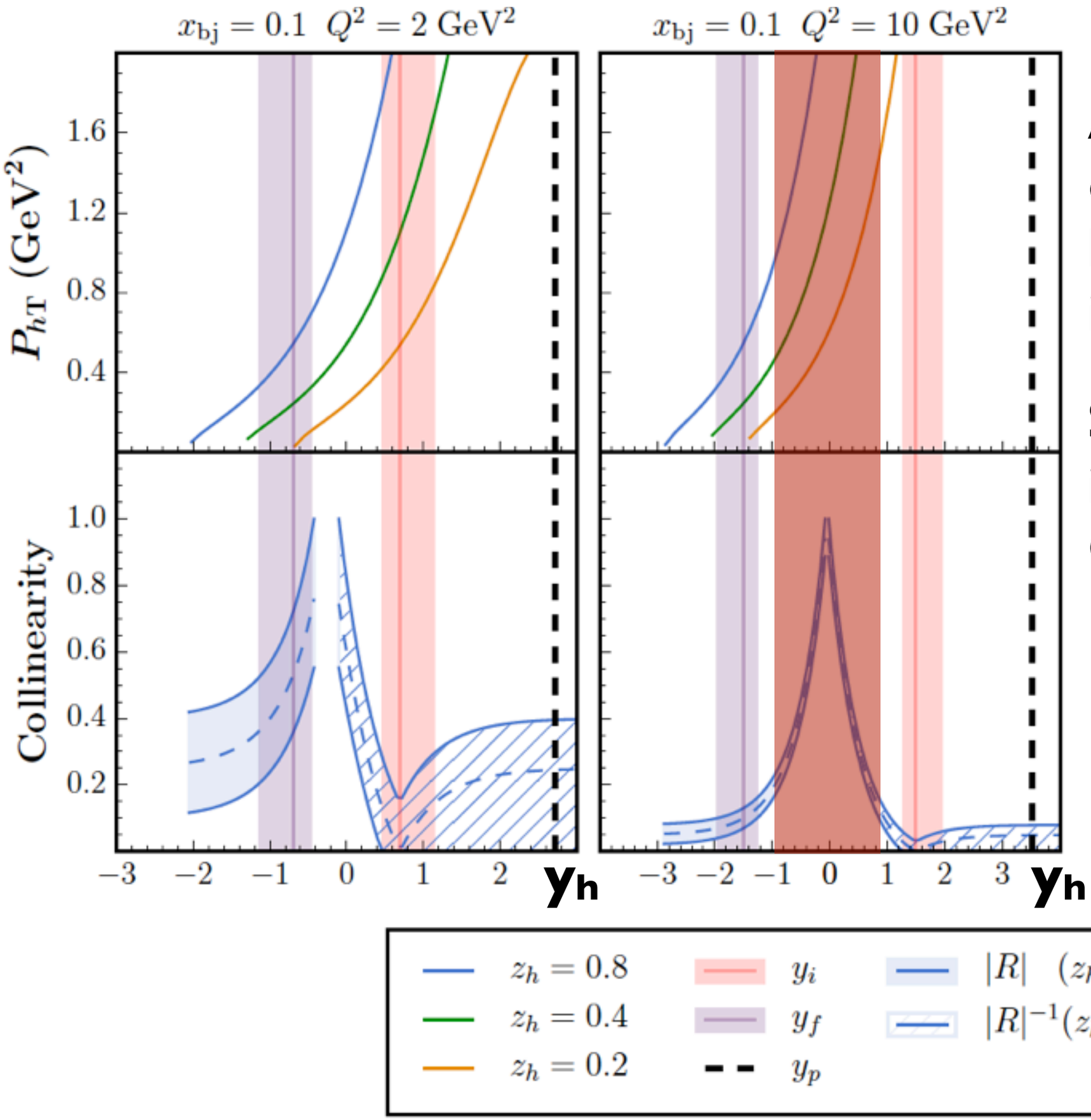


Incoming and outgoing quark rapidities very close, likely overlap

Estimates for quark momenta make it hard to impose a cut

Estimates for quark momenta introduce larger errors



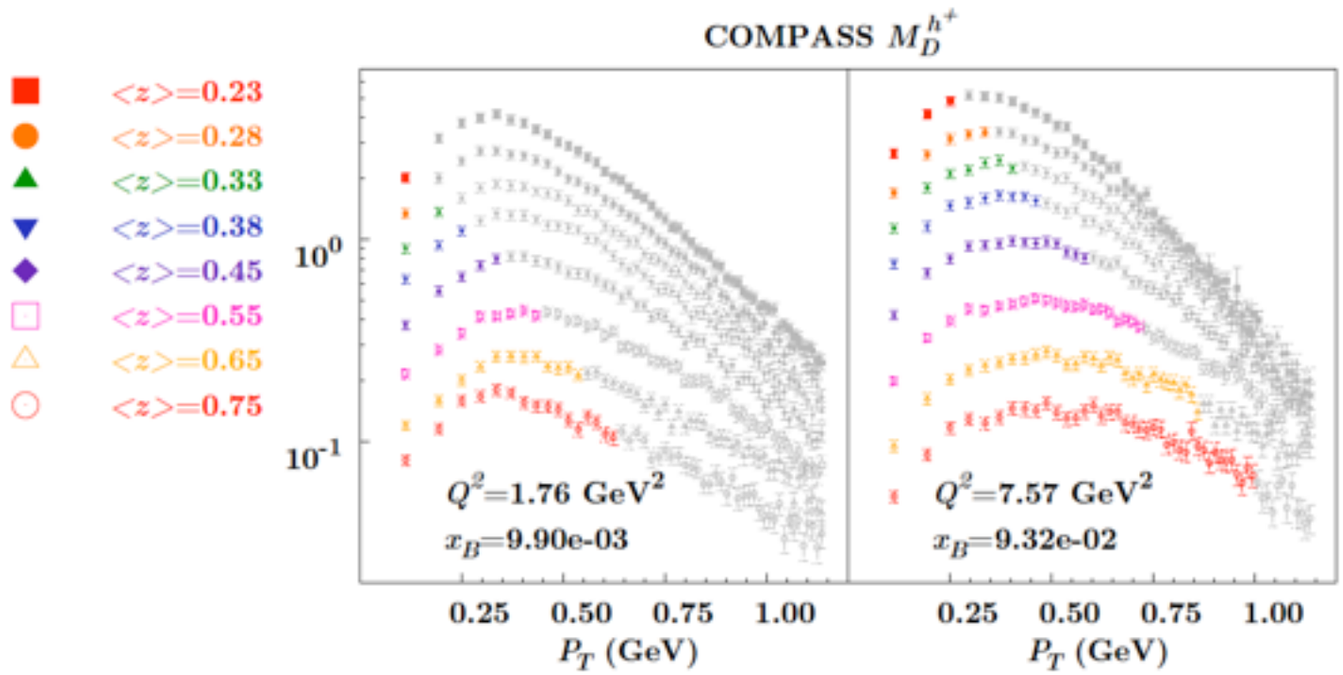


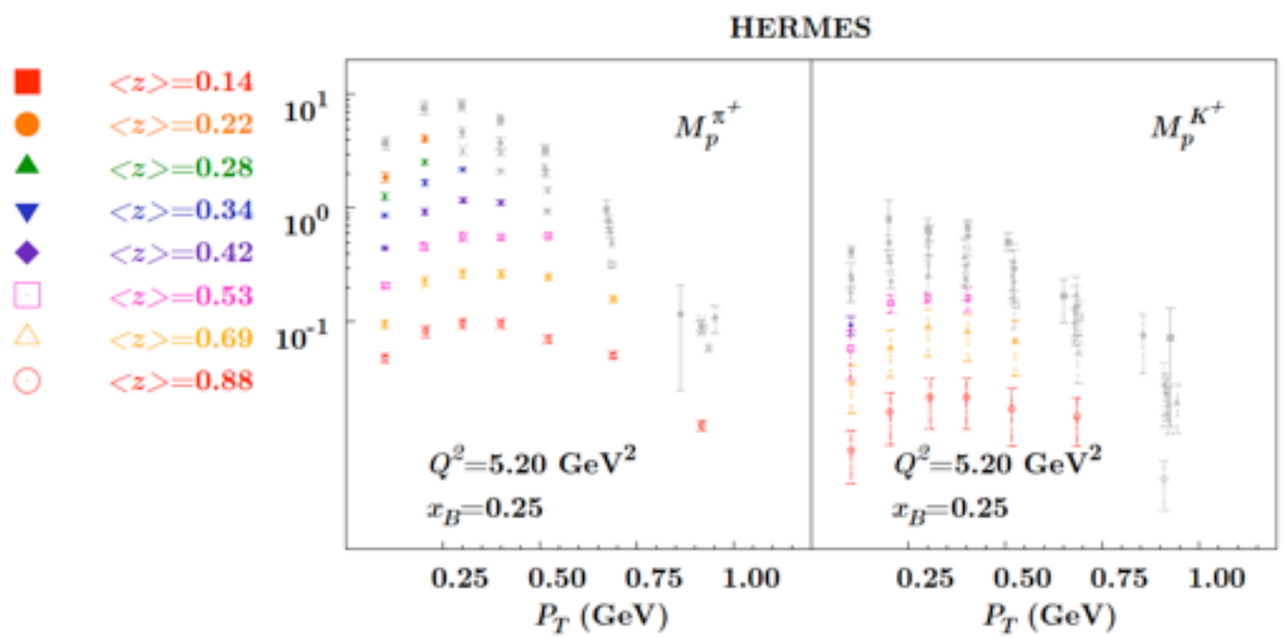
At available multi-dimensional data kinematics, picture improves.

Still, have trouble implementing full CSS.

Y-term relevant

$q_T = P_T/z_h$

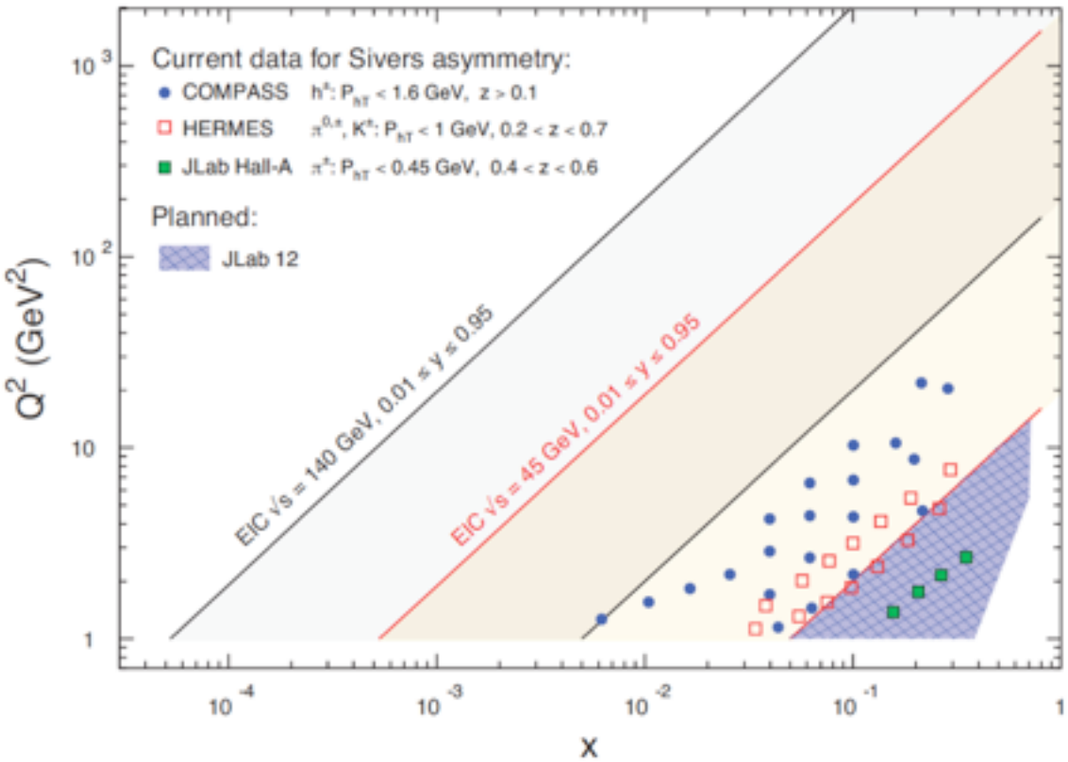




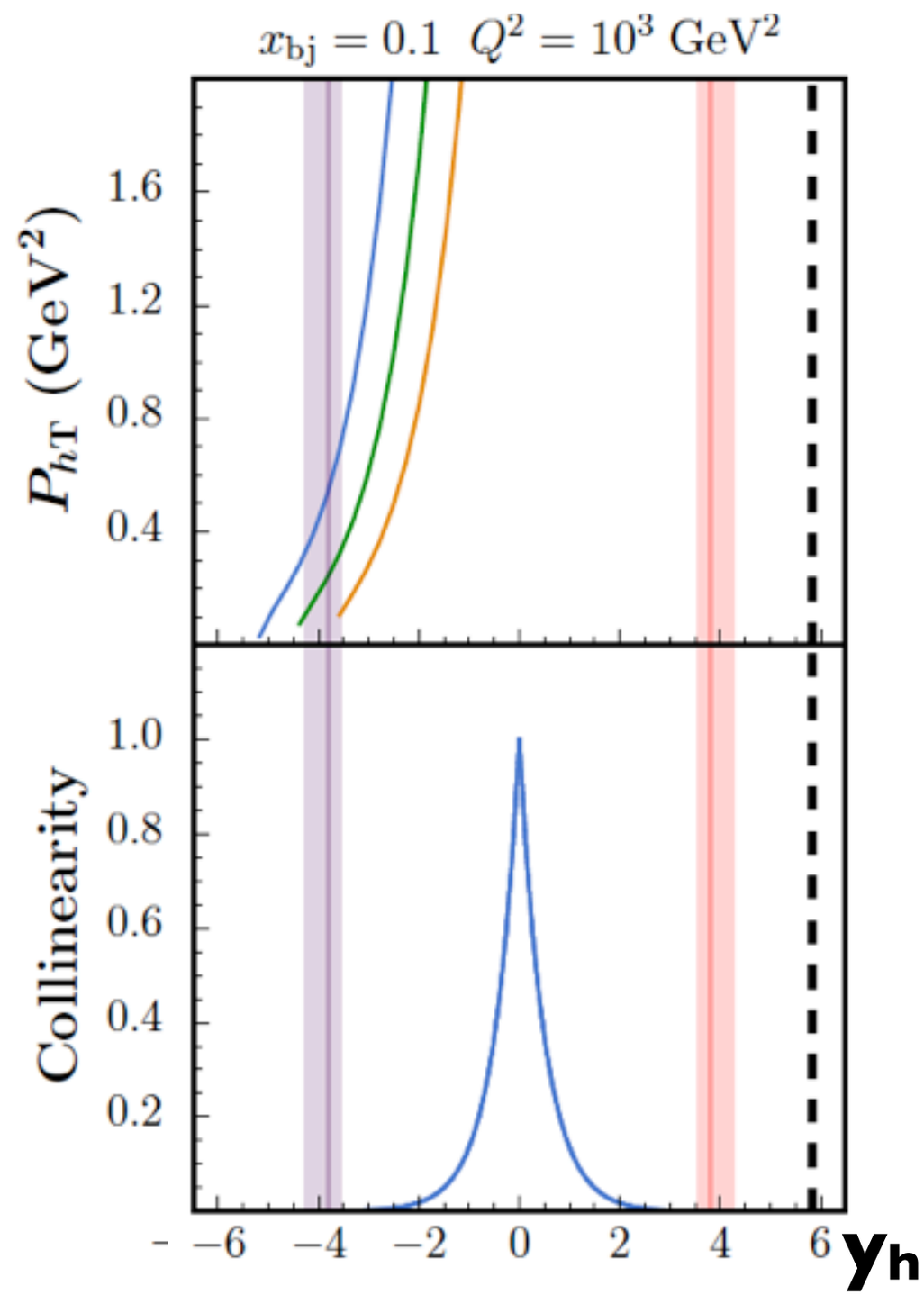
Example* of implementation of rapidity cut

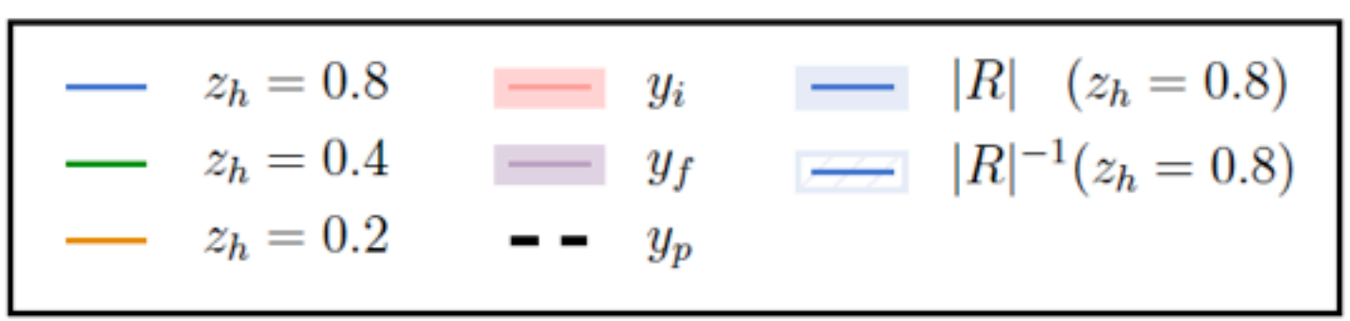
Grey points likely to receive large contributions from non-current region

***ONLY AN EXAMPLE**



Multi-dimensional data at the kinematics of EIC are expected to be well into the current region, TMD region





Final remarks

Important to always keep track of the range of applicability of the formalism of fragmentation functions (self-consistency)

Requiring $R \equiv \dfrac{P_h \cdot k_{\rm f}}{P_h \cdot k_{\rm i}}$ to be small, simple test for current region

Kinematical constraints involve both P_{hT} and z_h

Final remarks

Within the available formalisms, fragmentation and fracture functions may overlap at low Q^2 (how low?). May even need unifying formalism of extensions of CSS to include some of the soft effects.

SIDIS multi-dimensional data from the EIC , safely in the current fragmentation region, necessary for TMD-determination.

This will allow to push the kinematical boundary of TMDs to lower Q^2

Thanks.