Current Fragmentation at the kinematics of the EIC

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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

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

Easy to implement, generally leads to interpretations of limited validity

Ultimate goal, great predictive power. Many obstacles remain.
The Matching Problem in SIDIS

stage I

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

\[ z_h = \frac{P_h \cdot P}{q \cdot P} \]

\( P_T \) observed hadron

Gaussian model

Data integrated over other kinematical variables:

\[ x_B, Q^2 = -q^2 \]
The Matching Problem in SIDIS

**Gaussian model**

Describes well low-$z_h$ and low $P_T$

**Multidimensional data**

\[ z_h = \frac{P_h P}{q P} \]

$P_T$ observed hadron $x_B, Q^2$

**stage 1**
The Matching Problem in SIDIS

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

$q_T = \frac{P_T}{z_h}$

$q_T \ll Q$
TMD region

$q_T \approx Q$
Matching region

$q_T \gg Q$
pQCD

$W$ + $Y$
Collins-Soper-Sterman

$W$ describes the TMD region

$Y$ pQCD corrections at larger $q_T = \frac{P_T}{z_h}$
The Matching Problem in SIDIS

\[ q_T = \frac{P_T}{z_h} \]

- \( q_T \ll Q \) (TMD region)
- \( q_T \sim Q \) (Matching region)
- \( q_T \gg Q \) (pQCD)

**W + Y** construction (Collins-Soper-Sterman)

Coming from gluon radiation, Collinear Factorization

Wednesday, November 16, 16
The Matching Problem in SIDIS

Can we describe the entire range of $q_T = P_T / z_h$?

The natural variable: $P_T$ or $q_T = P_T / z_h$ (or ...)?

Coming from gluon radiation, Collinear Factorization

Collins-Soper-Sterman
The Matching Problem in SIDIS

Works for SIDIS at high enough, $Q^2 > 10 \text{ GeV}^2$, energy flow (integration over $z_h$)

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

$q_T = P_T/z_h$

Coming from gluon radiation, Collinear Factorization

Collins-Soper-Sterman

$W + Y$ construction
Multi-dimensional SIDIS data at the kinematics of EIC will play an essential role in the determination of TMDs.
The Matching Problem in SIDIS

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

\[ \chi^2_{\text{tot}} = 1.17 \]

Note:

i) cuts in $q_T = P_T/z_h$

ii) no Y term
The Matching Problem in SIDIS

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

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 $q_T = P_T/z_h$)
It should be noted...

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

("Berger criterion")


SIDIS and the current fragmentation region

We need a quantitative way to identify the current region.
SIDIS and the current fragmentation region: physical picture

In collaboration with:
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Leonard Gamberg (Penn State Berks)
Ted Rogers (ODU/JLab)
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Notice this is work in progress!!!
Fragmentation Functions

Fracture Functions

factorization theorems
these regions are often assumed to be well separated in the observed hadron rapidity
However, this neglects the soft fragmentation region

(No factorization theorem for this region)
One may take this into account, at least when defining **kinematic limits** for current/target region.
Observed

$y_k f$

current region
(fragmentation functions)
Impose rapidity cuts

Alternatively, require small values for

\[ R \equiv \frac{P_h \cdot k_f}{P_h \cdot k_i} \]

notice quark momenta have to be estimated
Power counting and kinematics of the current region

small masses

\[ P_h \cdot k_f = O(m^2) \]
\[ P_h \cdot k_i = O(Q^2) \]

Alternatively, require small values for

\[ R \equiv \frac{P_h \cdot k_f}{P_h \cdot k_i} \]

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 \( R \equiv \frac{P_h \cdot k_f}{P_h \cdot k_i} \) to be small, simple test for current region

Kinematical constraints involve both \( P_{hT} \) and \( \sim_h \)
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.