Andrea Simonelli

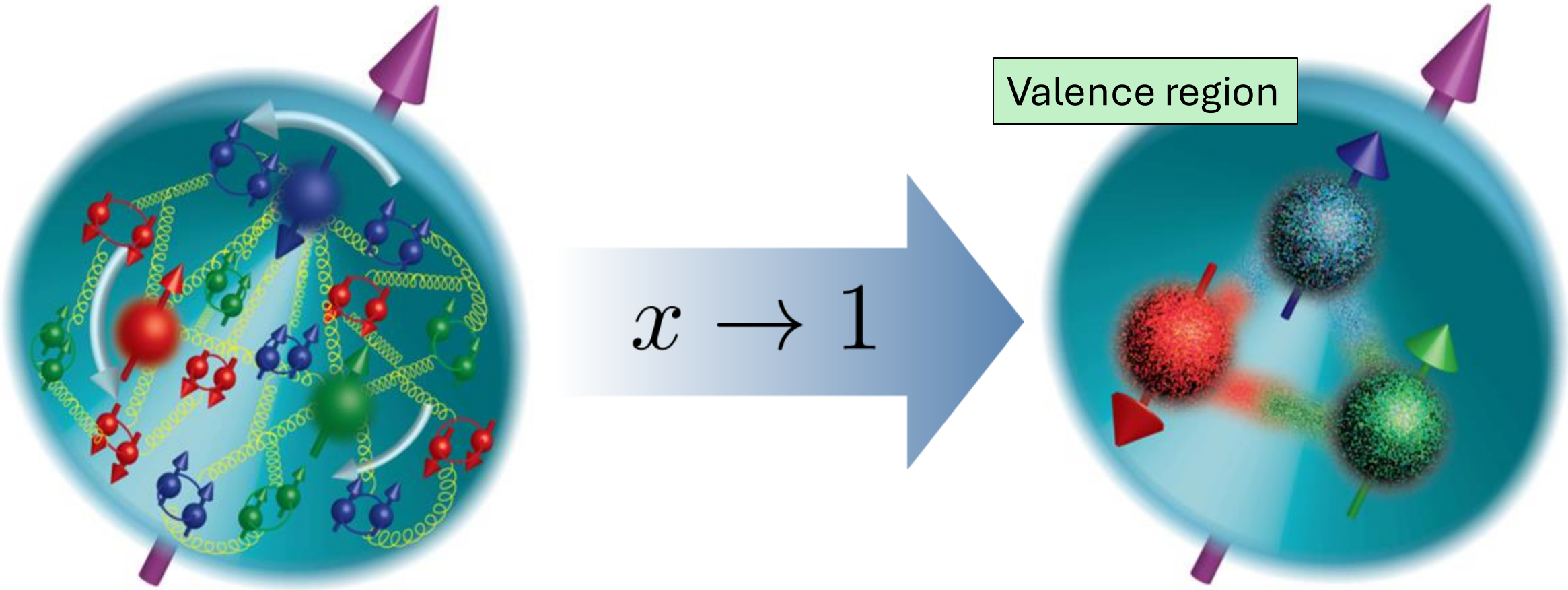
With A. Accardi, M. Cerutti, C. Costa, A. Signori

Unveiling the Collins-Soper kernel in inclusive DIS at threshold and implications at Jlab 22

INFN Istituto Nazionale di Fisica Nucleare Sezione di Roma

PDFs in the large-x region

Why relevant?

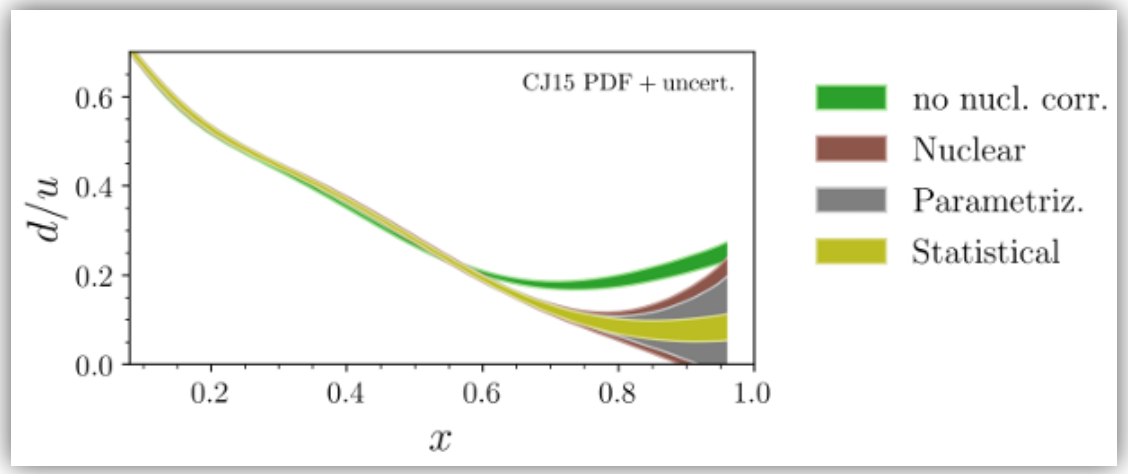


Images courtesy of A. Accardi et al, *Eur.Phys.J.A* 52 (2016) 9, 268

PDFs in the large-x region

Why relevant?

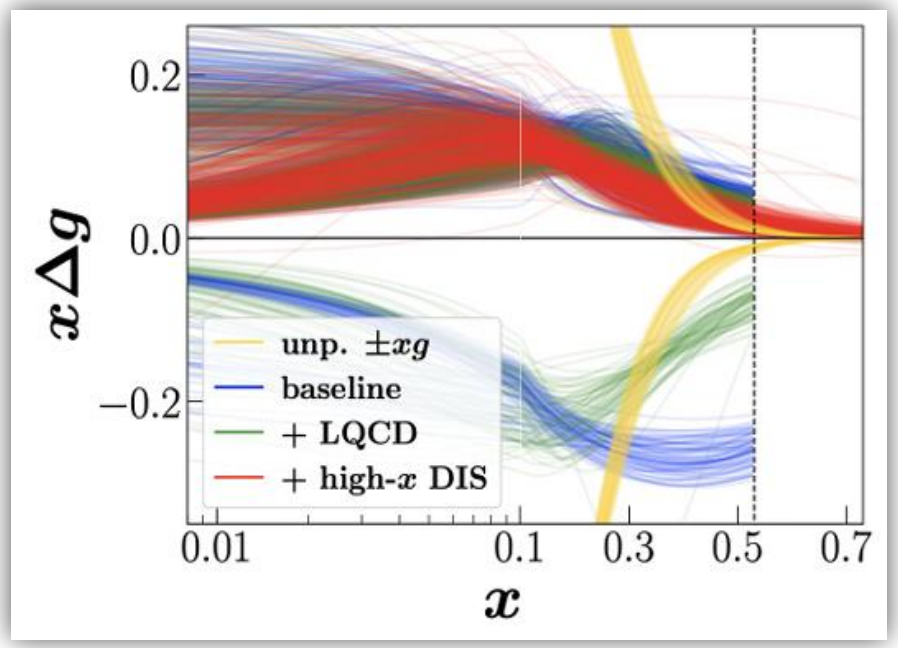
- d/u ratio for investigating confinement



Li, Accardi et al, *PRD 109 (2024)*

- Theoretical constraints (positivity bounds)

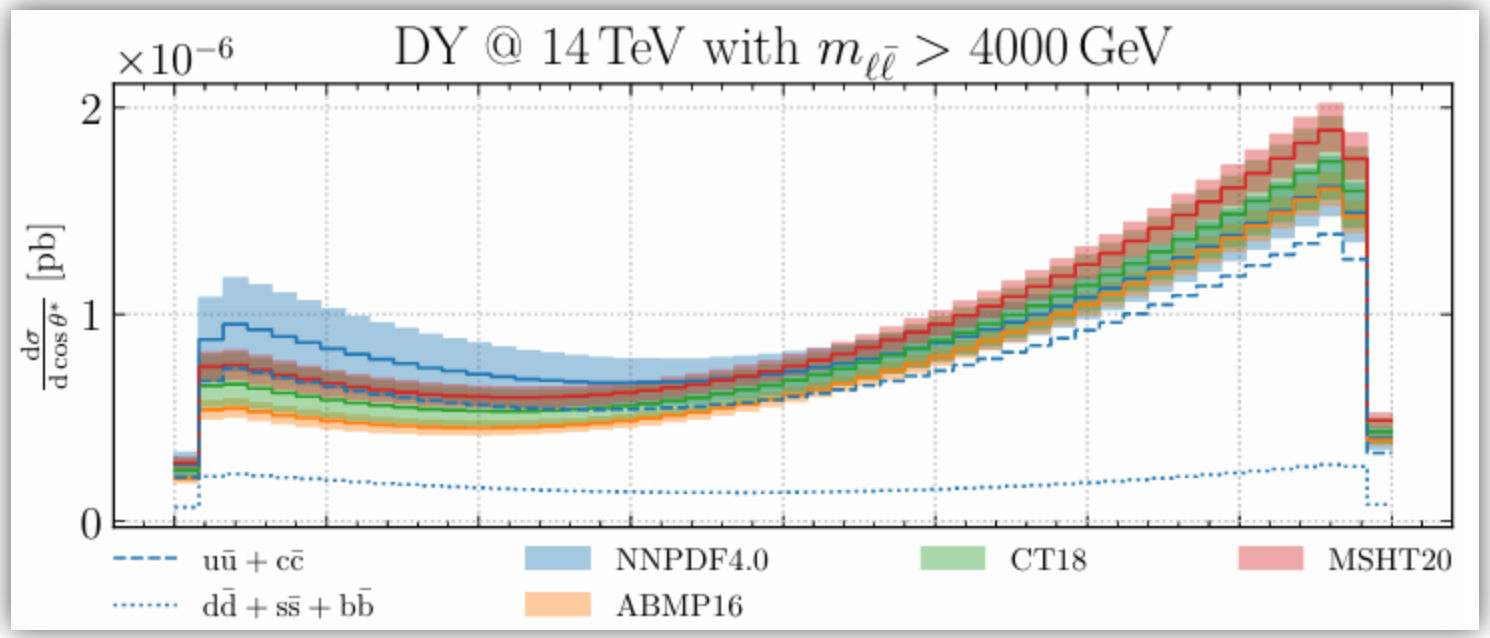
N. Sato @ PDFLattice 2024



PDFs in the large-x region

Why relevant?

- Beyond Standard Model searches
- Forward facilities (LHC)



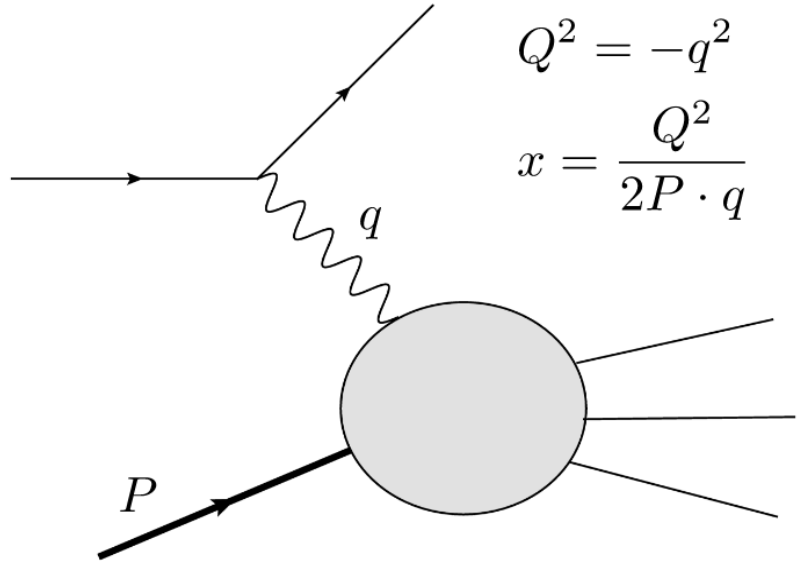
R. Ball et al, *Eur.Phys.J.C* 82 (2022) 12, 1160

PDFs in the large-x region

How to access them?

DIS at threshold

(simplest case)



- High precision data from Jefferson Lab

Strong interaction physics at the luminosity frontier with 22 GeV electrons at Jefferson Lab

Review | Published: 04 September 2024

Volume 60, article number 173, (2024) Cite this article

PDFs in the large-x region

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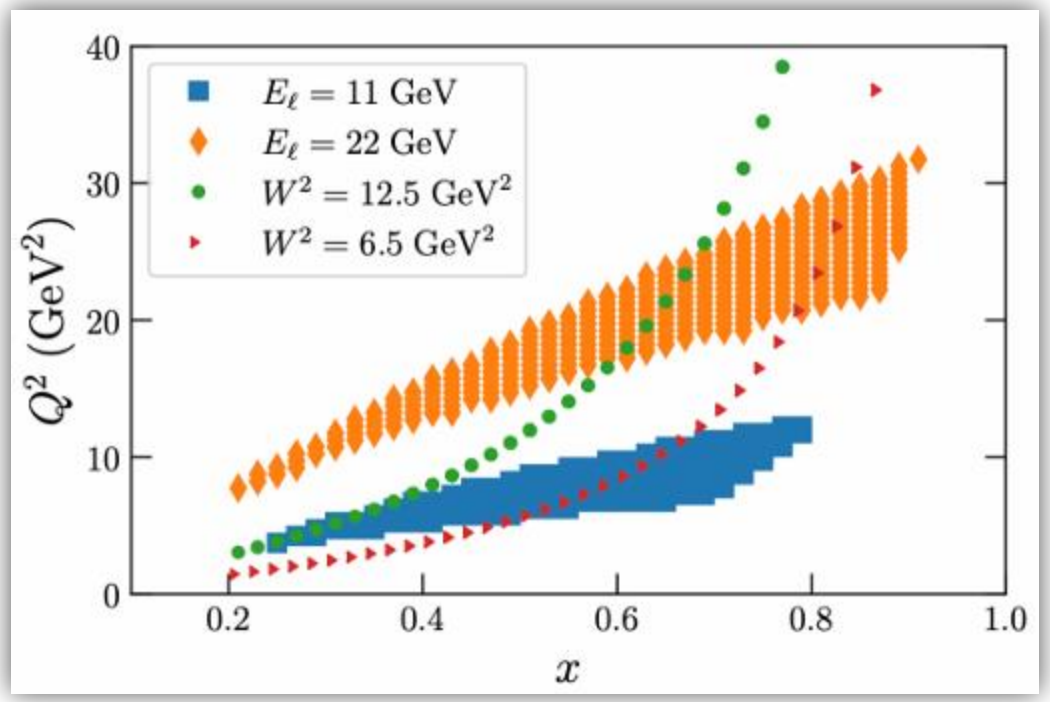
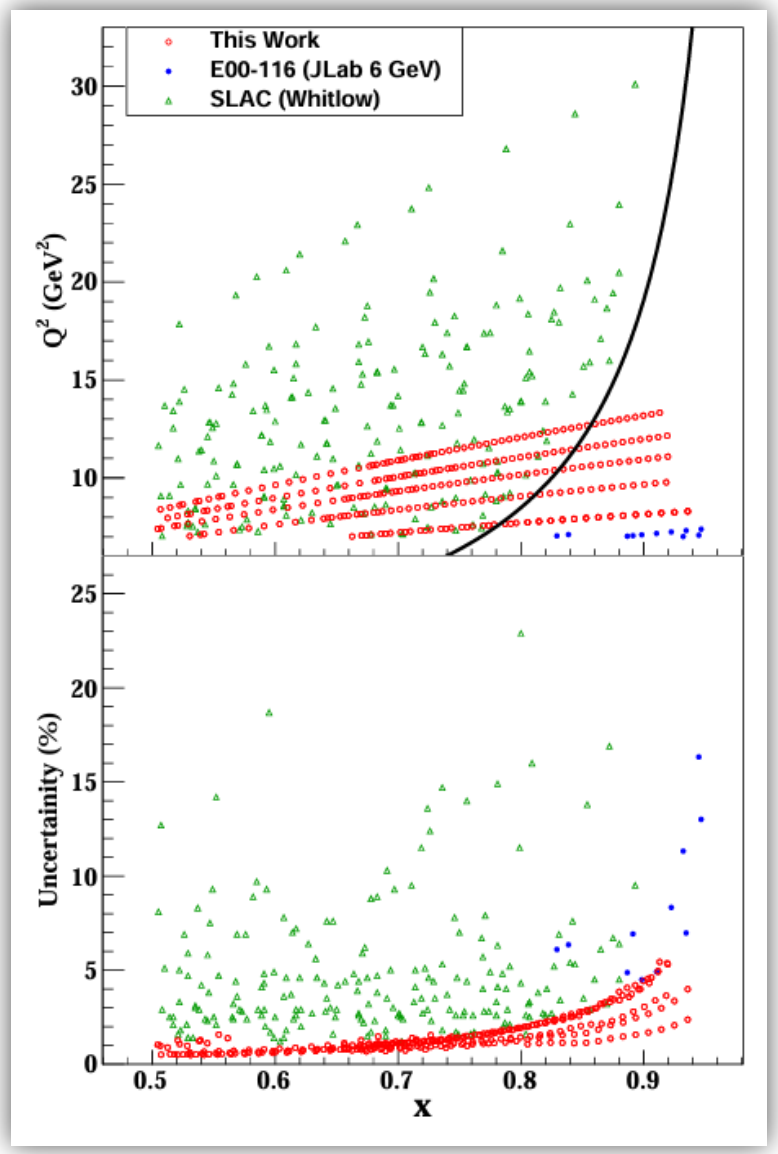


$x \lesssim 0.9$!

Hall C (11 GeV), 2409.15236



PDFs in the large-x region

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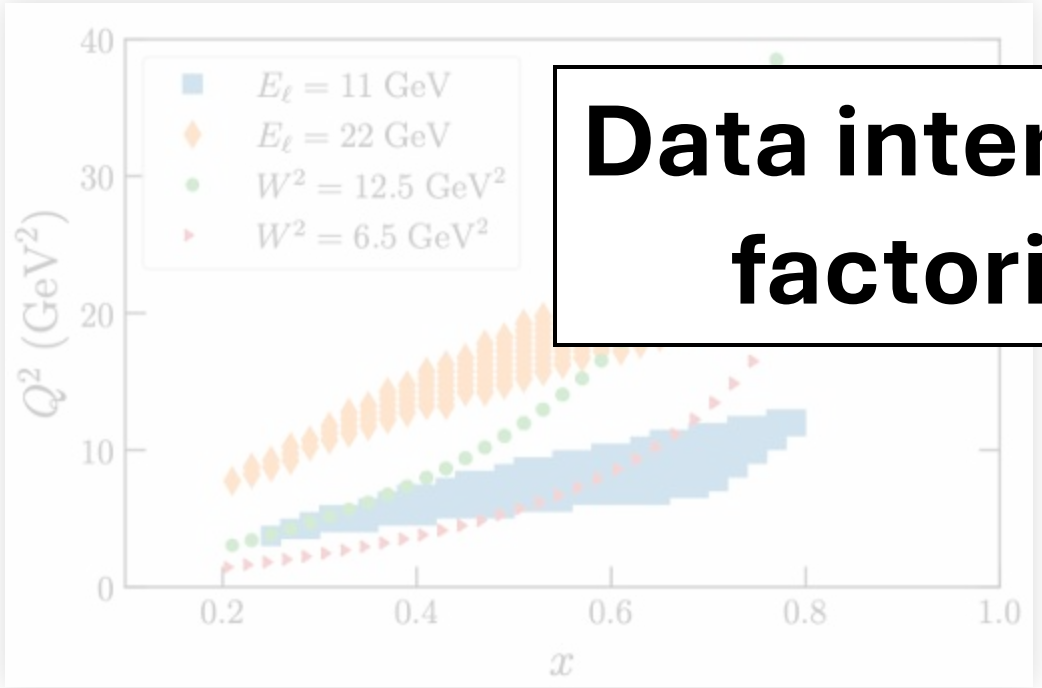
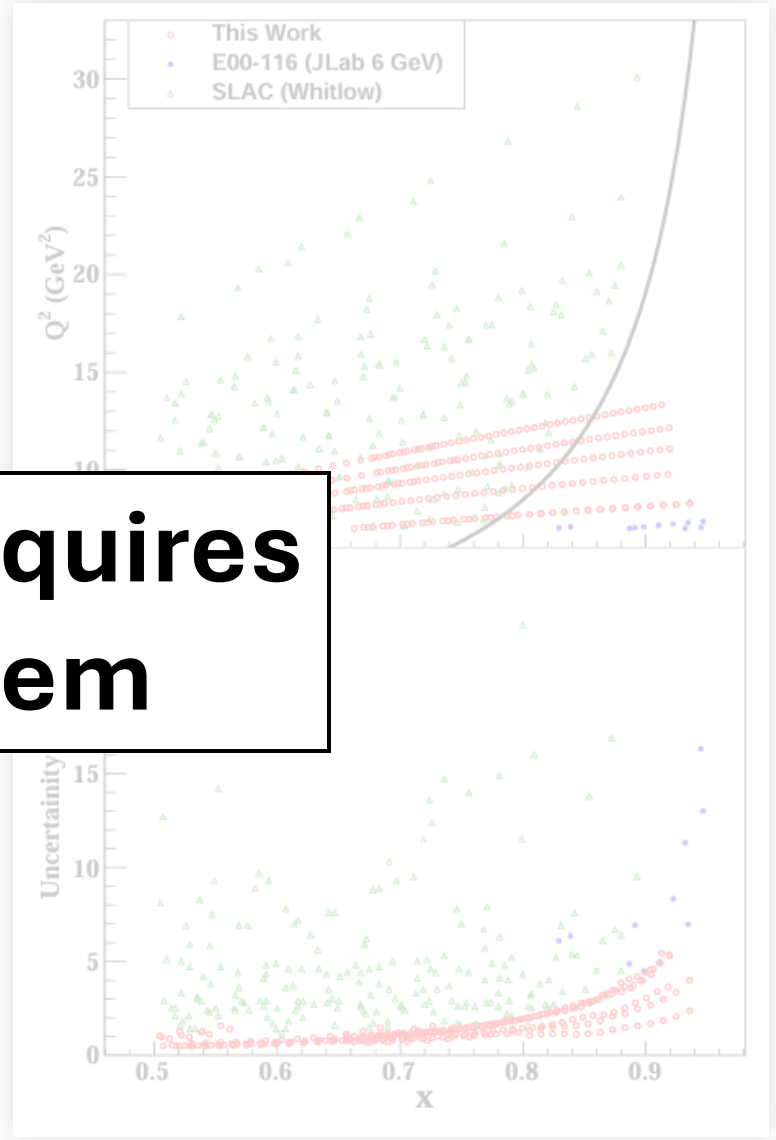


Data interpretation requires factorization theorem

$x \lesssim 0.9$!

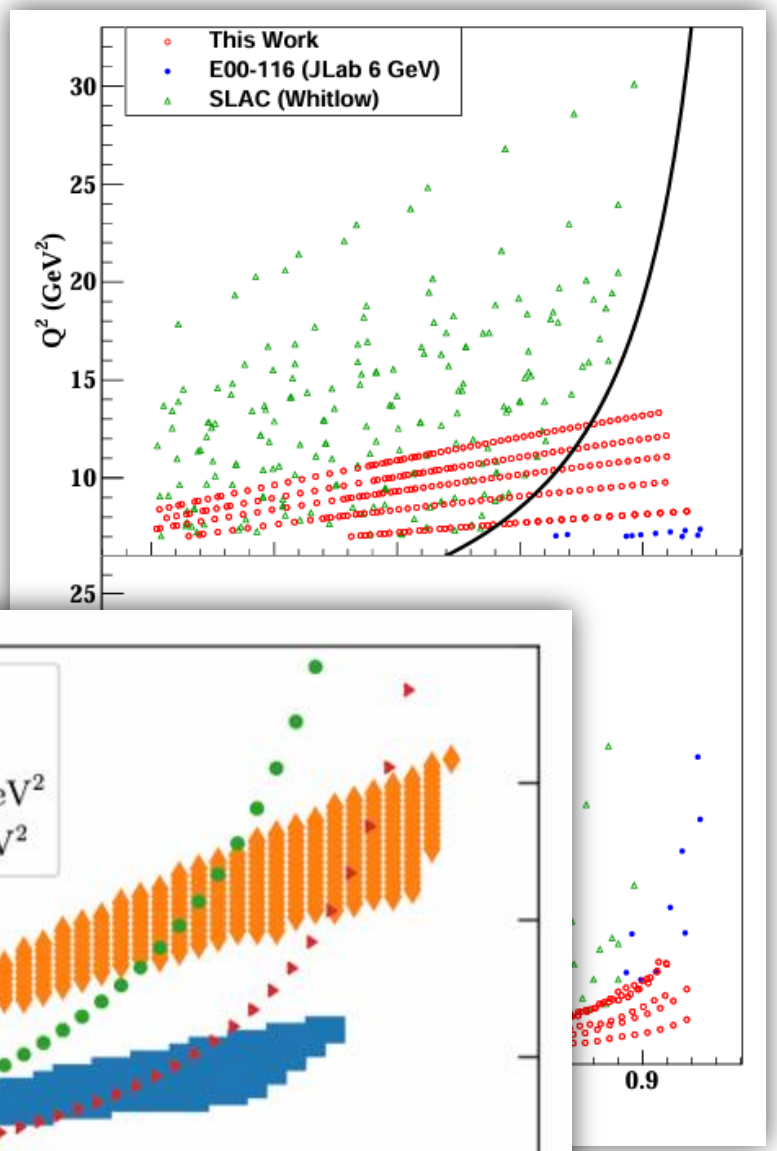


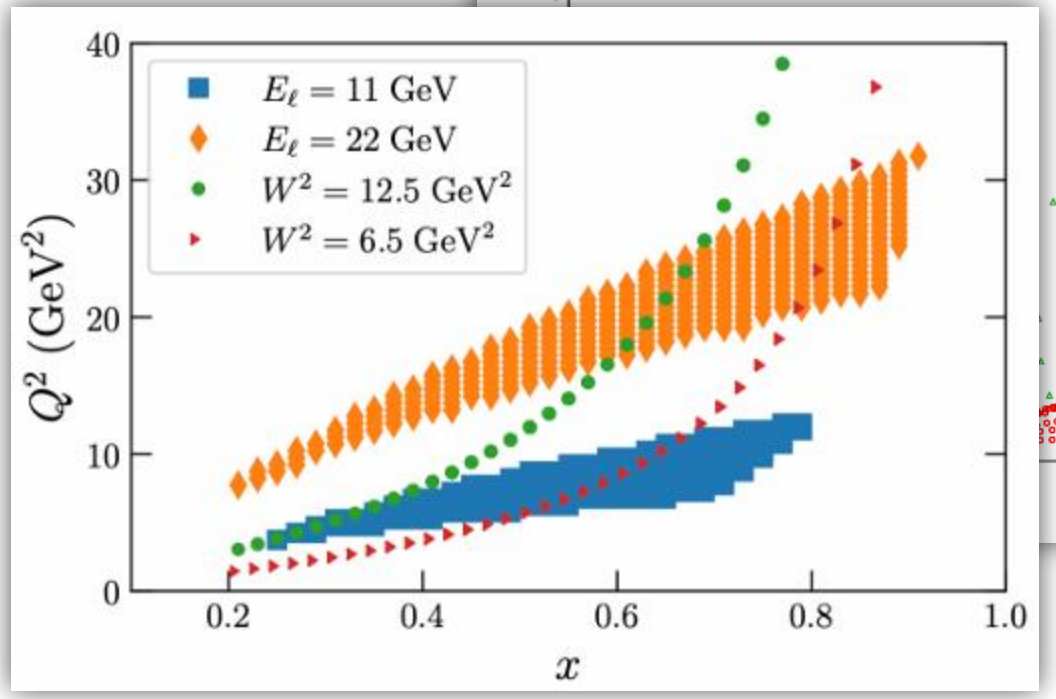
- High precision data from Jefferson Lab

Can't we just use the usual DIS collinear factorized cross section?

NO!

The kinematics is different!





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Same question

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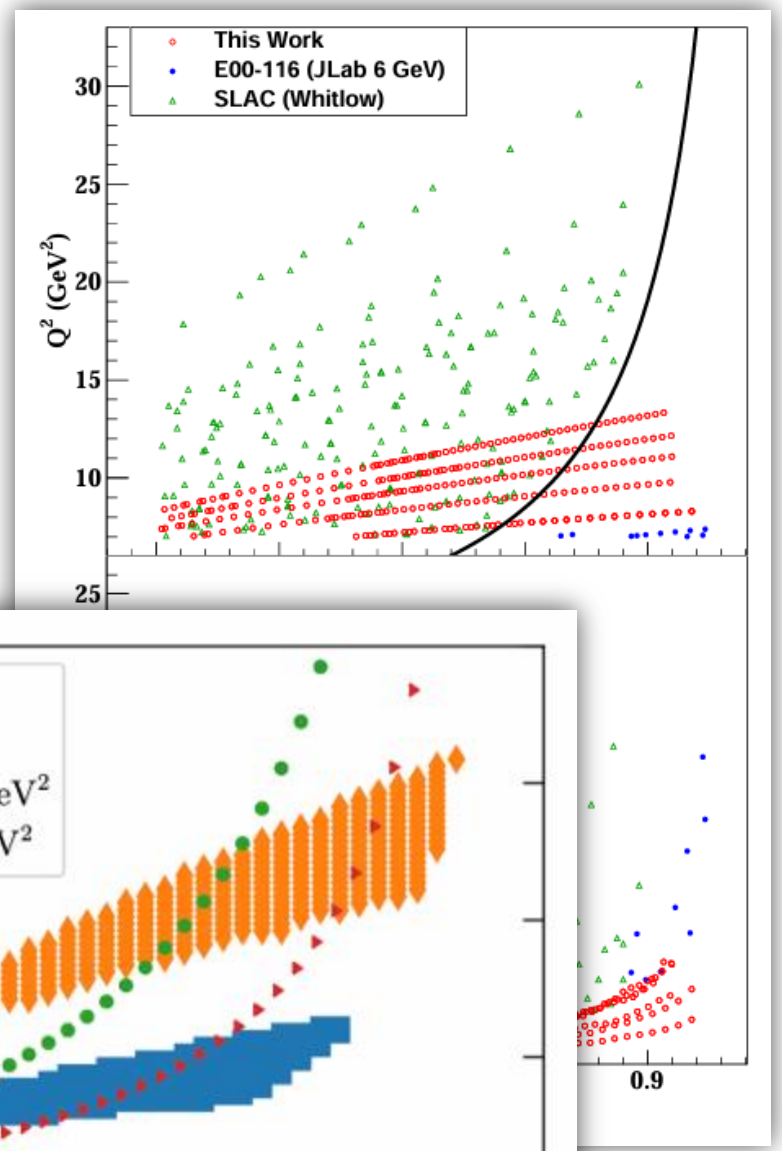
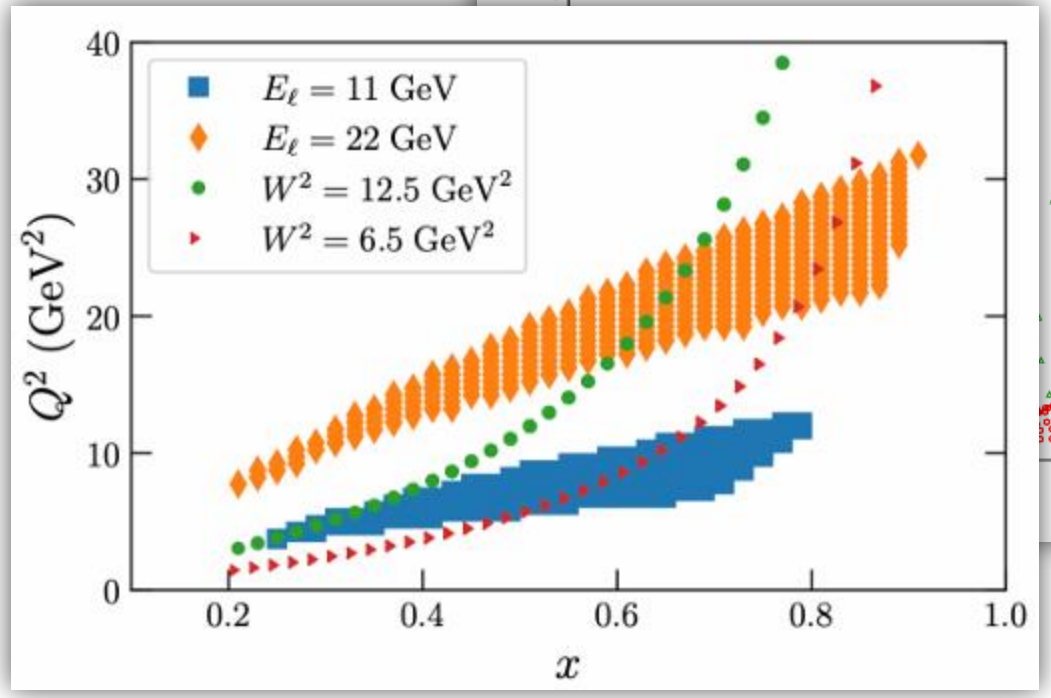
The kinematics is different!



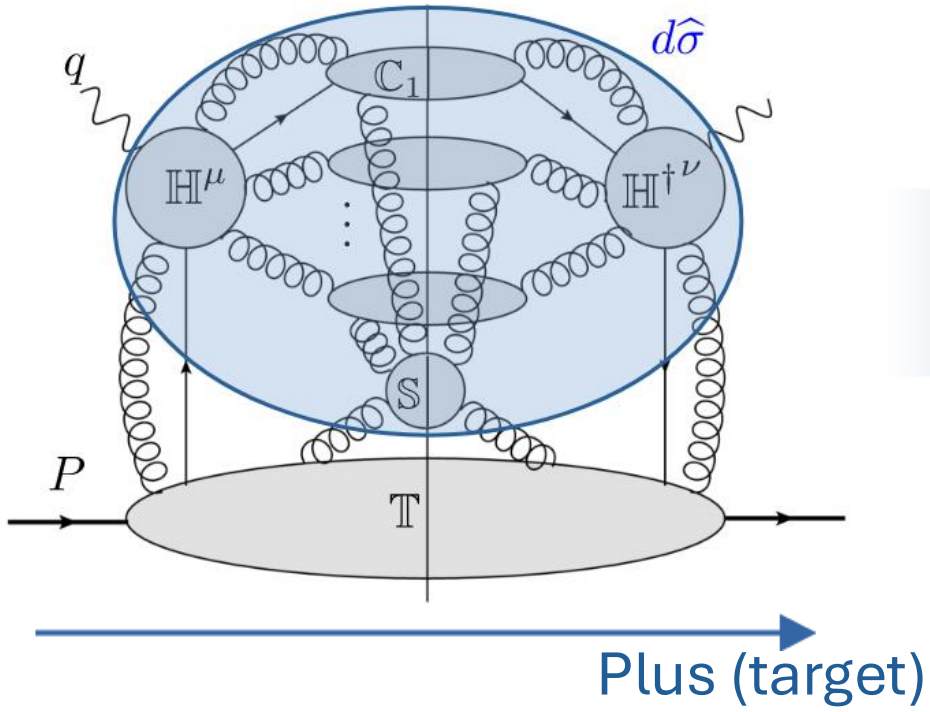


Can't we just use the collinear factorization (SIDIS) for describing low q_T data?

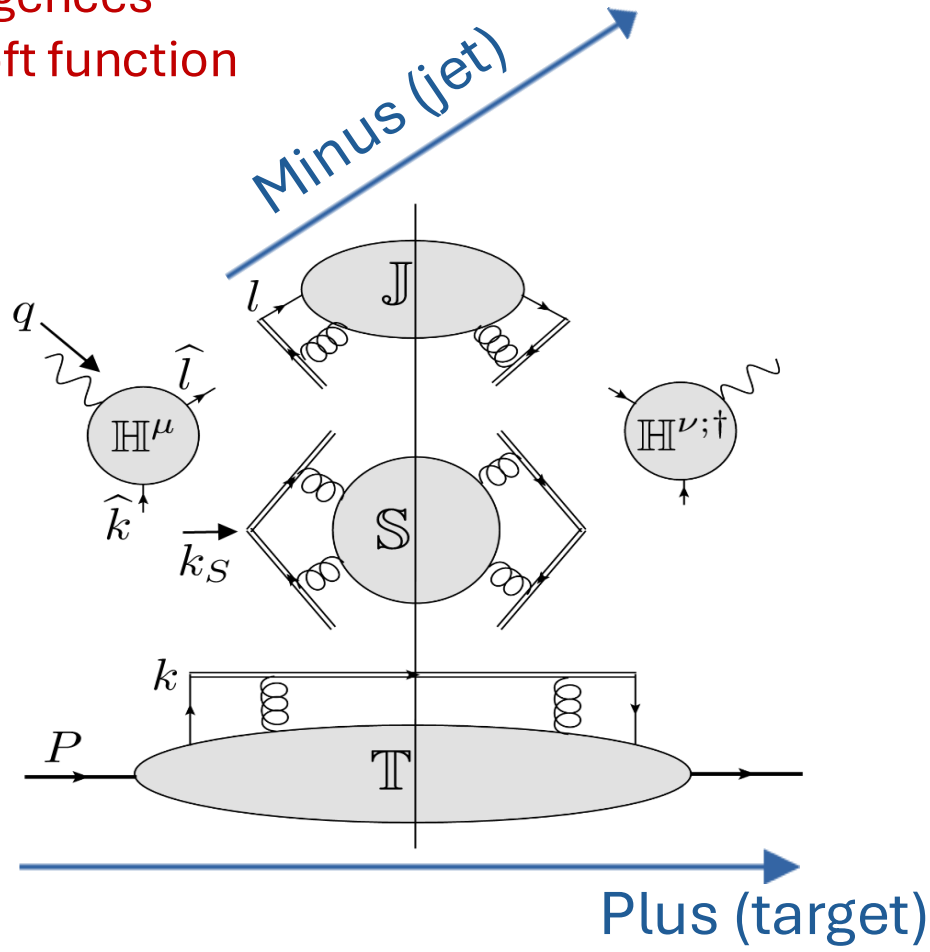
Analogies with TMD case

Same problems of TMD case:

- Rapidity divergences
- Correlating soft function



$x \to 1$



- One single (approximately) light-cone direction
- One hard scale Q^2

- Two (approximately) light-cone directions
- One hard scale Q^2 + One IR scale W

Analogies with TMD case

Same problems of TMD case:

- Rapidity divergences
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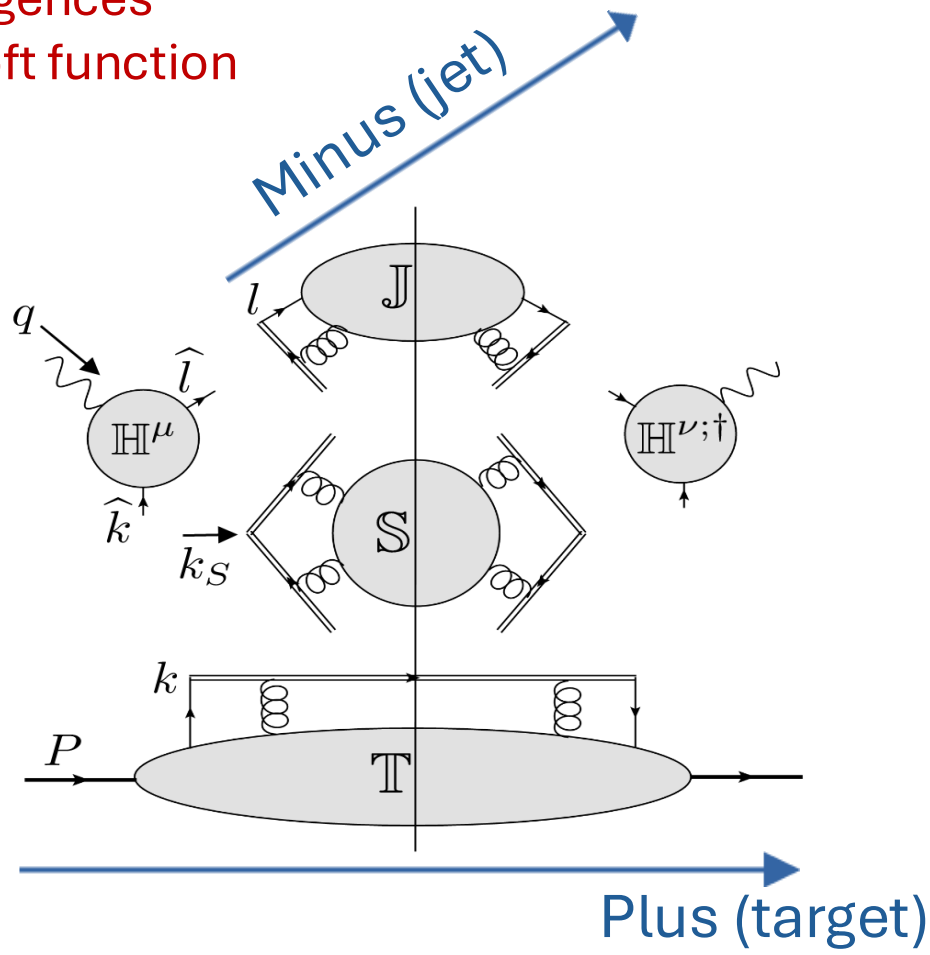


The validity of factorization *was* not clear

[rapidity anomalous dimensions] reveal sensitivity to IR scales, which may signal a breakdown of rapidity factorization in $\mathrm{SCET}_{\mathrm{II}}$.

[Fleming, Labun (2012)]

...but now it is! (coming very soon)

Unveiling the Collins-Soper kernel in inclusive DIS at threshold

Andrea Simonelli,[1,2,*] Alberto Accardi,[3,1,†] Matteo Cerutti,[4,1,‡] Caroline S. R. Costa,[1,5,§] and Andrea Signori[6,7,¶]

- Two (approximately) light-cone directions
- One hard scale Q^2 + One IR scale W

Factorization for DIS at threshold

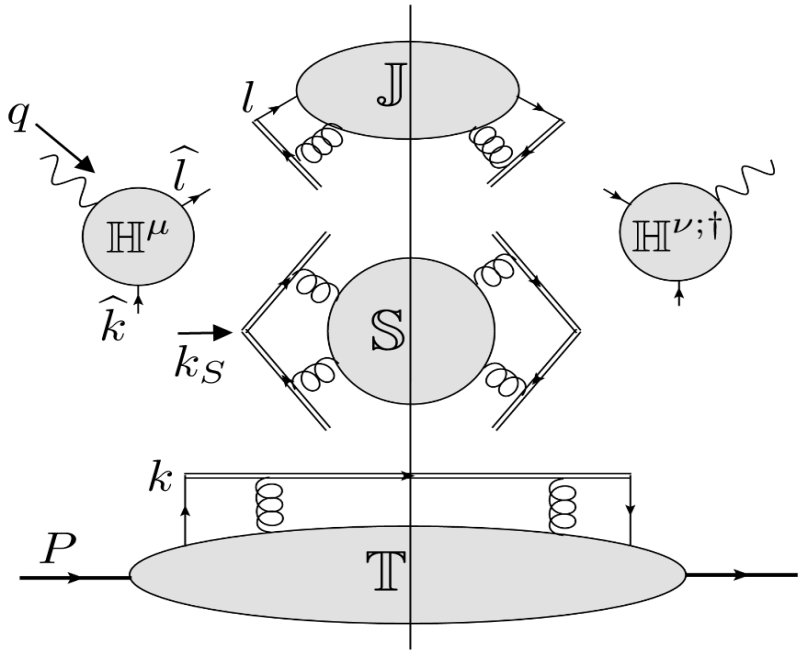
$$W^{\mu\nu} = N_C\, \mathbf{u}^{\mu\nu}\, H(\mu, Q) \sum_j \int \frac{dN}{2\pi i} x^{-N}$$

$$\times\, \widehat{\phi}^{\,\text{sqrt.}}_{1,j/h}(N, \mu, y_n)\, \widehat{\mathcal{T}}^{\,\text{sqrt.}}_j(N, \mu, y_n)$$

Square root of soft factors included (subtractions, rapidity divergences)

Off light-cone target function

Off light-cone Jet function



$$\frac{\partial}{\partial y_n} \log \widehat{\mathcal{T}}^{\,\text{sqrt}}(N, \mu, y_n) = +K(a_S(\mu), L_N + y_n)$$

$$\frac{\partial}{\partial y_n} \log \widehat{\phi}^{\,\text{sqrt}}(N, \mu, y_n) = -K(a_S(\mu), L_N + y_n)$$

The Collins-Soper kernel appears

New venues to access it (lattice)

Factorization for DIS at threshold

$$W^{\mu\nu} = N_C\, \mathbf{u}^{\mu\nu}\, H(\mu, Q) \sum_j \int \frac{dN}{2\pi i} x^{-N}$$

$$\times\, \widehat{\phi}^{\,\mathrm{sqrt.}}_{1,j/h}(N, \mu, y_n)\, \widehat{\mathcal{J}}^{\,\mathrm{sqrt.}}_j(N, \mu, y_n)$$

Off light-cone
target function

Off light-cone
Jet function

$$\frac{\partial}{\partial y_n} \log \widehat{\mathcal{J}}^{\,\mathrm{sqrt}}(N, \mu, y_n) = +K(a_S(\mu), L_N + y_n)$$

$$\frac{\partial}{\partial y_n} \log \widehat{\phi}^{\,\mathrm{sqrt}}(N, \mu, y_n) = -K(a_S(\mu), L_N + y_n)$$

How to get back to usual light-cone operators (threshold PDF)?

The Collins-Soper kernel appears
New venues to access it (lattice)

Factorization for DIS at threshold

$$W^{\mu\nu} = N_C\, \mathbf{u}^{\mu\nu}\, H(\mu, Q) \sum_j \int \frac{dN}{2\pi i} x^{-N}$$

$$\times\, \widehat{\phi}^{\,\mathrm{sqrt.}}_{1,j/h}(N, \mu, y_n)\, \widehat{\mathcal{J}}^{\,\mathrm{sqrt.}}_j(N, \mu, y_n)$$

Off light-cone
target function

Off light-cone
Jet function

How to get back to usual light-cone operators (threshold PDF)?

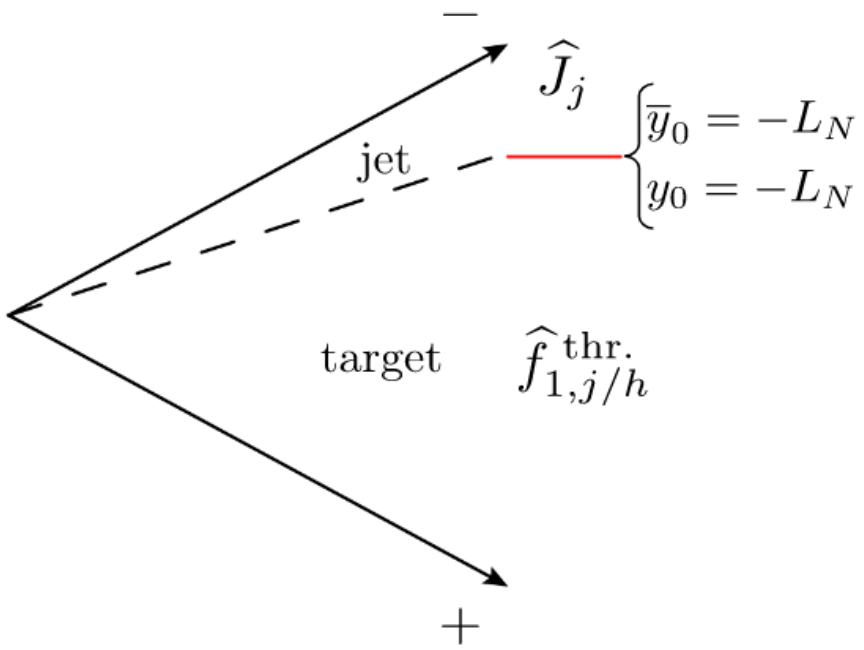
$$y_n = -L_N$$

$$\frac{\partial}{\partial y_n} \log \widehat{\mathcal{J}}^{\,\mathrm{sqrt}}(N, \mu, y_n) = +K(a_S(\mu), L_N + y_n)$$

$$\frac{\partial}{\partial y_n} \log \widehat{\phi}^{\,\mathrm{sqrt}}(N, \mu, y_n) = -K(a_S(\mu), L_N + y_n)$$

Exploiting the inclusivity of DIS

Factorization for DIS at threshold



How to get back to usual light-cone operators (threshold PDF)?

$$y_n = -L_N$$

$$\widehat{\mathcal{J}}_i^{\mathrm{sqrt}}(N,\mu,-L_N) = C(a_S(\mu),L_N)\,\widehat{J}_j(N;\mu)$$

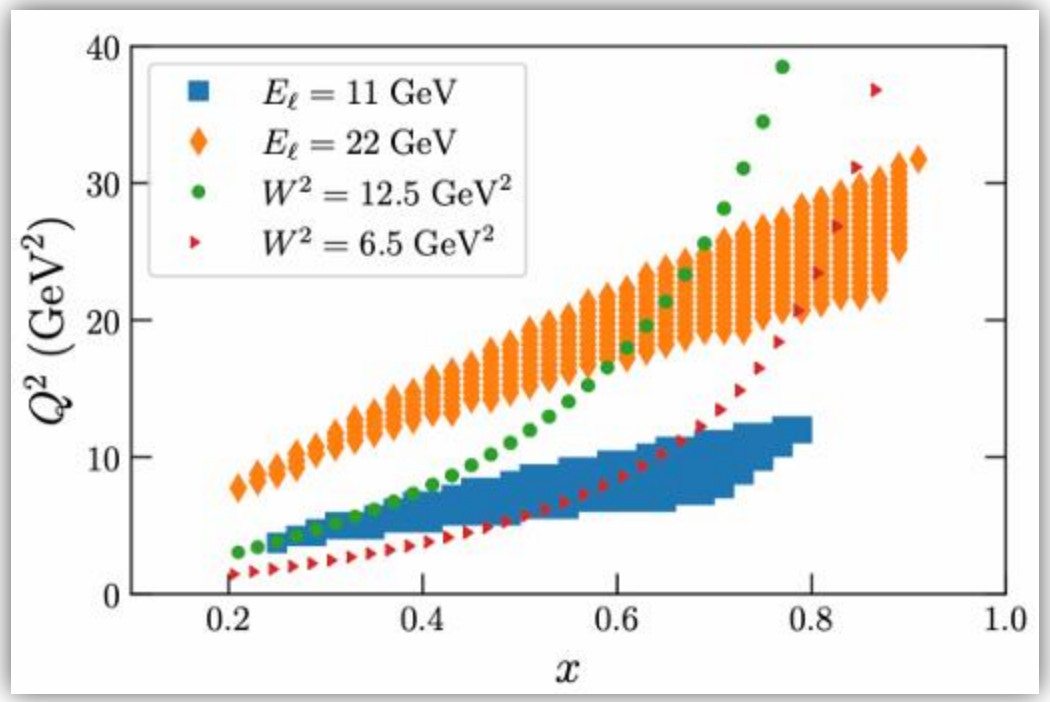
$$\widehat{\phi}_j^{\mathrm{sqrt}}(N,\mu,-L_N) = \frac{\widehat{f}_j(N,\mu)}{C(a_S(\mu),L_N)}$$

Matching to light-cone operators

Factorization for DIS at threshold

$$W^{\mu\nu} = N_C \, \mathbf{u}^{\mu\nu} \, H(\mu, Q) \sum_j \int \frac{dN}{2\pi i} x^{-N} \, \widehat{f}_j(N, \mu) \, \widehat{J}_j(N, \mu)$$

Naïve intuition on factorization confirmed



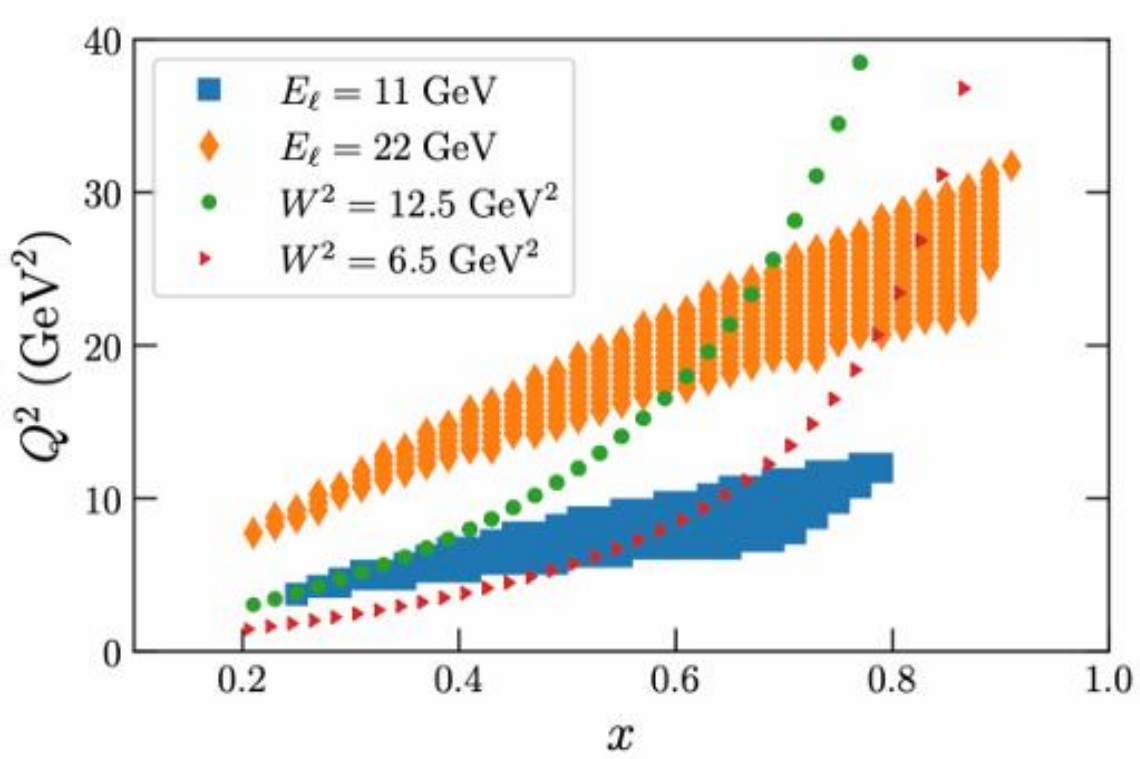
Threshold PDF

Jet Function

Now (and only now) we are ready for phenomenology

Conclusions

- All the problems/issues with the factorization of DIS at threshold are now solved.
- The analogies with the TMD case are made transparent and used as tools to get the final result.
- The Collins-Soper kernel appears!
- The theory ground for threshold DIS is now solid and ready for phenomenology to be built on it.



Determination of large-x behavior of PDFs