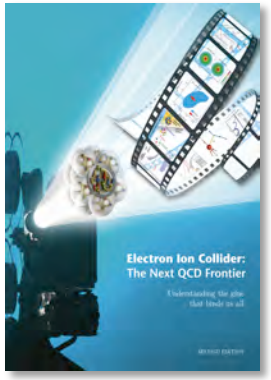
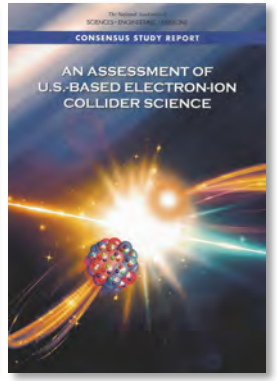
Center for Frontiers in Nuclear Science

Discussion Topics:

An experimentalist asking questions about theory





1. What should be done in the development of the phenomenological data analyses to be prepared for the extraction of QCD-interpretable quantities from the future data with the US EIC?

2. How can we gain insight into hadron mass generation and the mass and pressure distributions within nucleons and nuclei from future EIC studies of the nucleon glue component?

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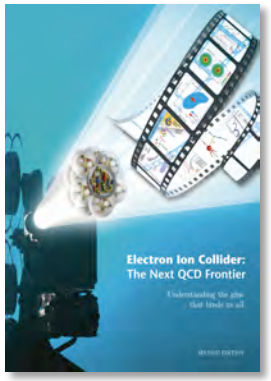

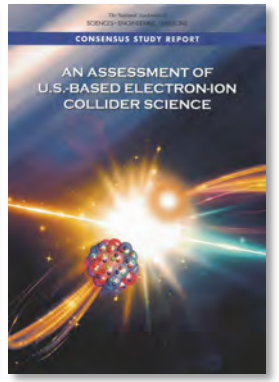

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   - *Nucleon Spin➔ Longitudinal Spin + TMDs + GPDs ➔ lab12 & EIC*
   - *Understanding low-x dynamics in hadrons ➔ Is theory ready? Problems?*

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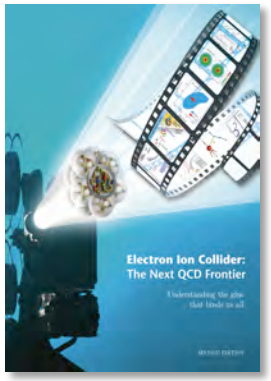

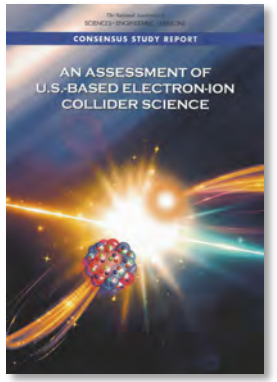

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2. How can we gain insight into hadron mass generation and the mass and pressure distributions within nucleons and nuclei from future EIC studies of the nucleon glue component?
   - *Can the saturation regime manifest itself in any particular behavior of the mass and pressure distributions at small x_B?*

Nucleon Structure: parton distributions & dynamics

Library and Plotting tools for collinear parton distributions

LHAPDF
lhapdf.hepforge.org

xFitter
www.xfitter.org

APFEL++
github.com/vbertone/apfelxx
apfel.mi.infn.it

Dedicated Softwares to study GPDs

PARTONS
partons.cea.fr

PARtonic
Tomography
Of
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Software

GeParD
not yet public

Dedicated software to study and fit TMDs

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public soon

Efforts to combine different inputs to understand TMDs and GPDs in an unified framework

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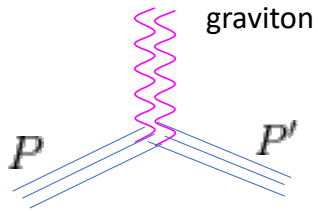
Nucleon Gravitational Form Factors

$$\langle P'|T^{\mu\nu}_{q,g}|P\rangle = \bar{u}(P')\left[A_{q,g}\gamma^{(\mu}\bar{P}^{\nu)} + B_{q,g}\frac{\bar{P}^{(\mu}i\sigma^{\nu)\alpha}\Delta_\alpha}{2M} + D_{q,g}\frac{\Delta^\mu\Delta^\nu - g^{\mu\nu}\Delta^2}{4M} + \bar{C}_{q,g}M\eta^{\mu\nu}\right]u(P)$$

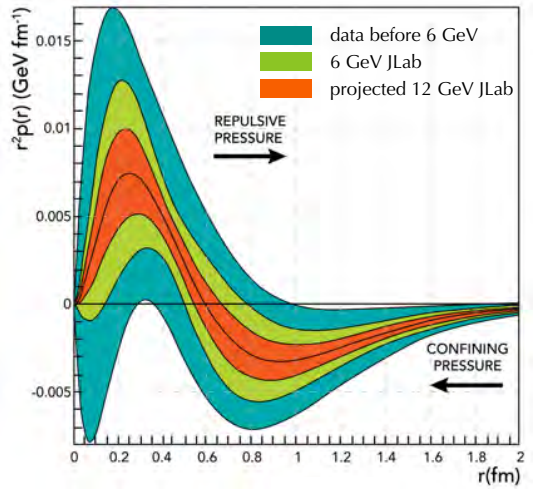


All the form factors are interesting and measurable!

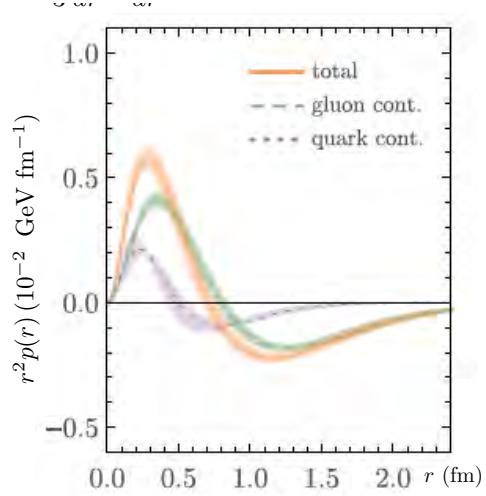
A, B Ji sum rule $J_{q,g} = \frac{1}{2}\int dx(H_{q,g}(x) + E_{q,g}(x)) = \frac{1}{2}(A_{q,g} + B_{q,g})$

D Pressure — Radial pressure distribution inside nucleon

$\bar{C}$ Mass, pressure



Girod, Elouadrhiri,Burkert, Nature 557 (2018) 7705



Shanahan, Detmold, PRL122 (2019) 072003

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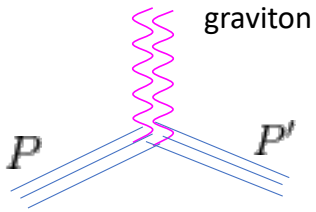

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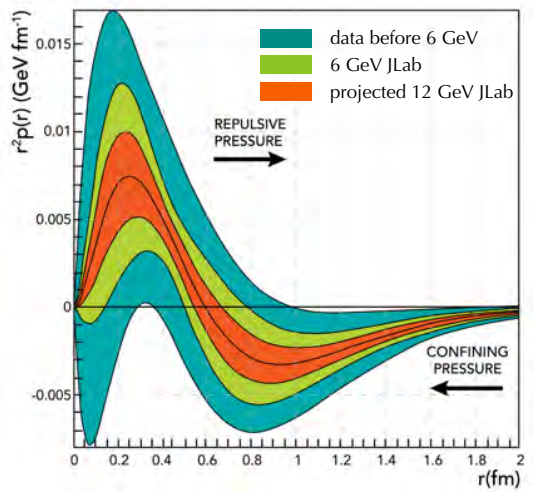

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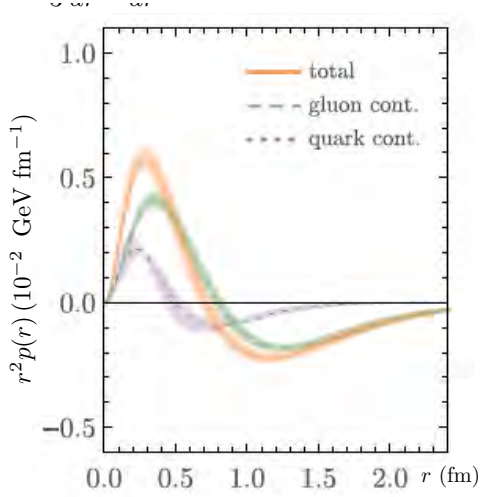

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Are there interesting "pressure" signals from low-x/saturation?

It's a twist-2 term, dominated by large-x partons, but the C_q which is a twist-4 gravitational form factor & related to the trace anomaly.

➔ Is a connection to small-x?

➔ Model dependence addressed via Q^2 lever arm @EIC?

Comment? DISUCUSSION?

Low-x and mass

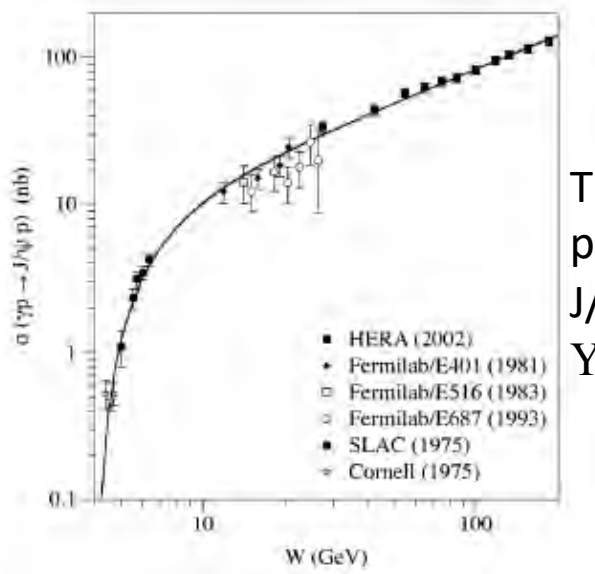
Proton mass decomposition

quark mass trace anomaly

$$M = \underbrace{M_q + M_g}_{\text{quark/gluon kinetic energy}} + M_m + M_a$$

X. Ji, PRD 52 (1995) 271

Kharzeev et al. (1998), Brodsky et al. (2000)



Threshold production of J/Ψ @ SoLID
Υ @ EIC

Kinetic energy terms are twist two and hence dominated by high-x partons. Small x partons by definition have low momentum and hence don't contribute. However trace anomaly-- Twist-4 entity characterized as "non-perturbative gluon condensate". **Does this non-perturbative gluon condensate have any connection the low-x physics at the EIC (including the Color Glass Condensate)?**

Anyone care to comment?

What happens in other (C. Roberts & C. Lorce') decompositions of mass?

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quark mass M_m, trace anomaly M_a

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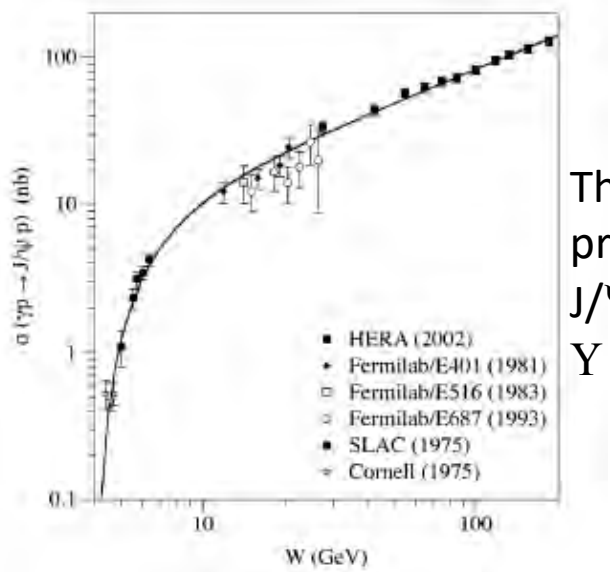

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Jianwei's comment:

In the proton's rest frame, there is no large momentum scale involved, the matrix elements of the high twist local operators do not have to be smaller than the matrix elements of lower twist local operators, since all of them are related by the same mass scale. That is, we expect these terms are in a similar size.

The mass decomposition is "useful" only if individual terms can be measured independently. Since none of the matrix elements of quark and gluon operators are direct physical observable, the relation is more valuable if all terms can be measured with similar controllable approximation.

Small-x: factorization, much needs to be pursued

- **A thought experiment**: an electron vs. a quark come to rest from a state of motion…. After they are @ rest, no radiation around an electron (abelian QED), but ample radiation (& keeps growing) around the quark (non-Abelian QCD)
  - F. Wilczek in his 2004 Nobel Lecture, *Origin of Mass*: "a color thundercloud"

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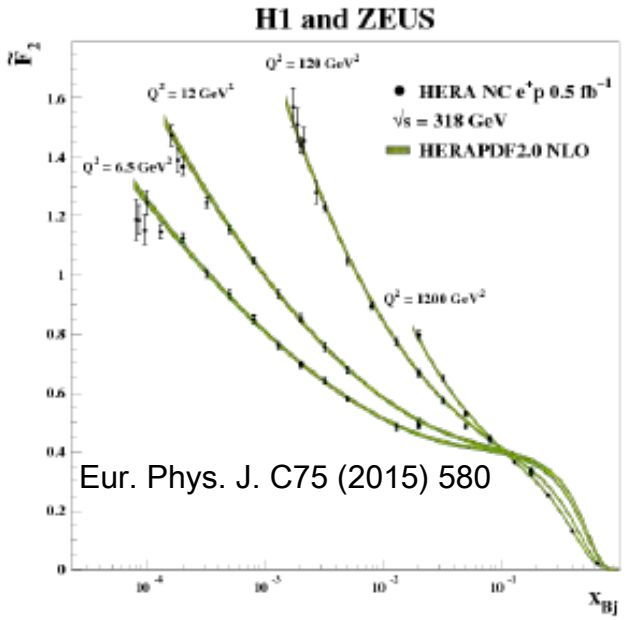

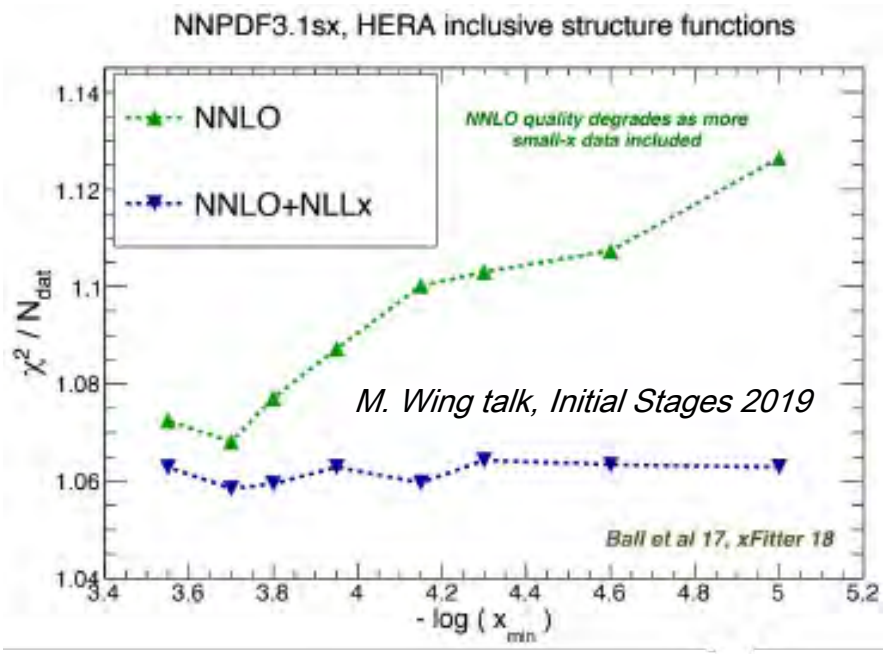

Only saturation can fix the low-x power law growth in a non-Abelian theory

Exp. Confirmation of gluon saturation is fundamental test of UV completeness in the SM and more generally in QFT

– Matt Sievert @ IS2019

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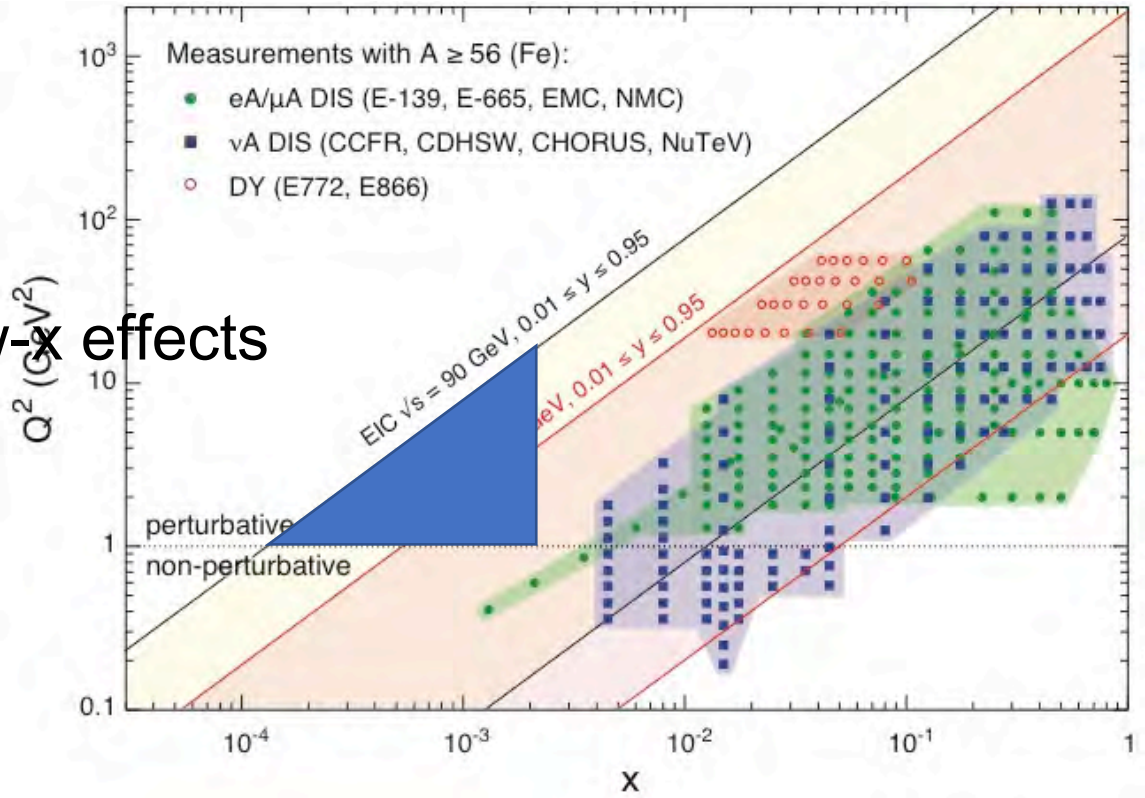
Low-x measurements

Experimentally: limited x-Q^2 space

➔Need >1 measurements to confirm novel low-x effects

➔Global Analyses: NLO and power suppressed corrections

➔ LO Ok, but NLO not fully understood yet!



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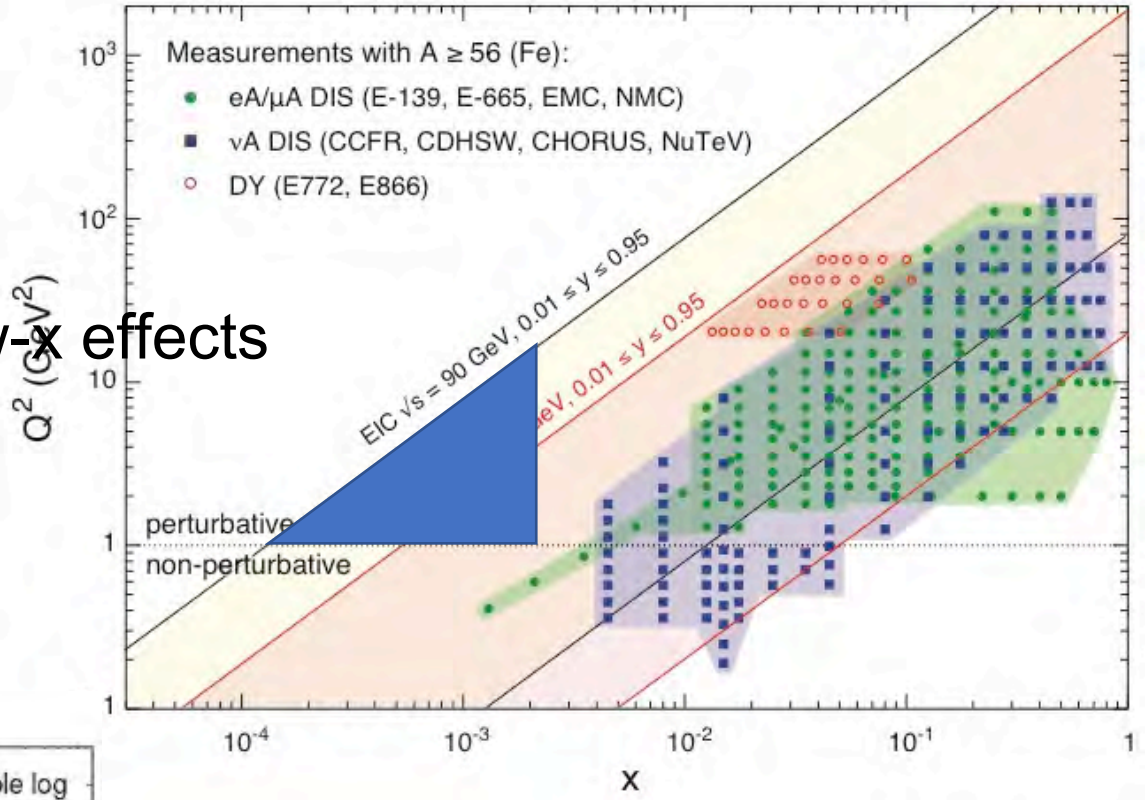
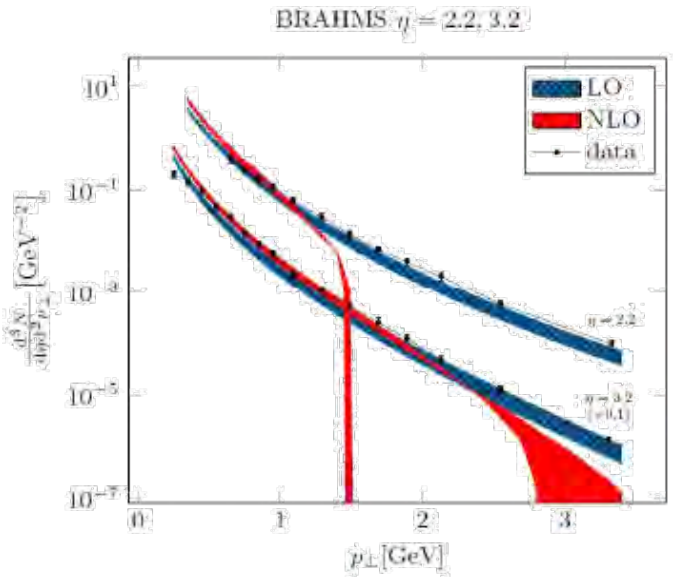
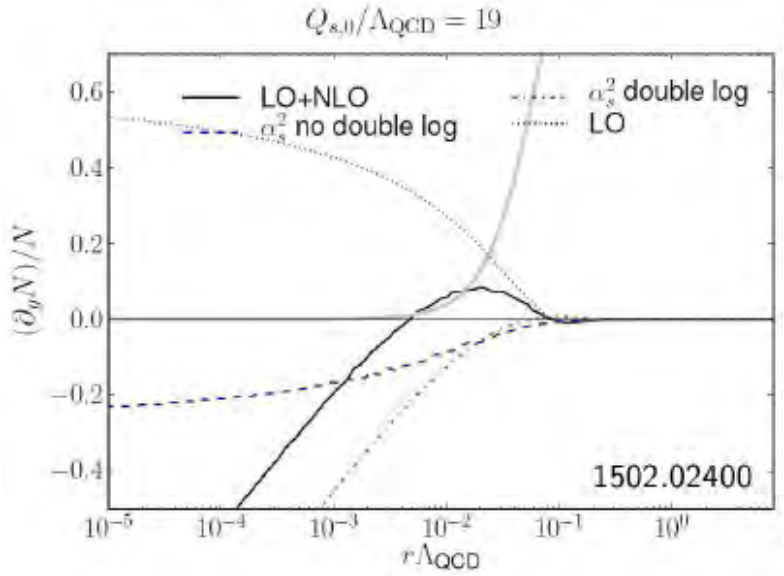




Stasto, B.-W. Xiao, D. Zaslavsky, Phys. Rev. Lett. 112 (2014) 012302



T. Lappi, H. Mantysaari, Phys. Rev. D91 (2015) 074016

Resummation cures these unphysical results but no unique definition of the NLO accuracy yet and may create scheme dependent answers

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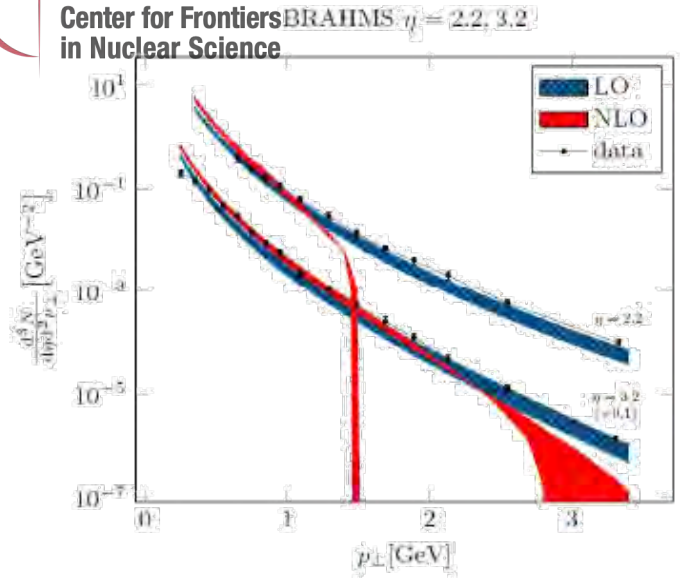

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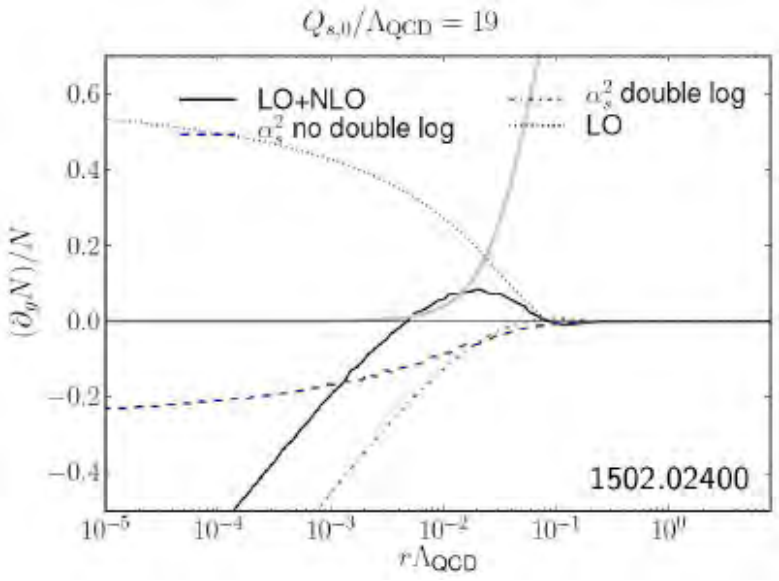

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Jianwei's comment:

Either factorization formalism is not valid, or the calculations and organization of scales are not done correctly

None of the low x factorization formalisms proposed have been proven to all orders in perturbative theory. Hence such a discovery of strange behavior is **very valuable and could be a first step towards identifying a true all order formalism.**

Comments or/and discussion?

Thank you: comments, discussion, criticism welcome