



Nucleon Energy correlators

-a new way to study nucleon structure

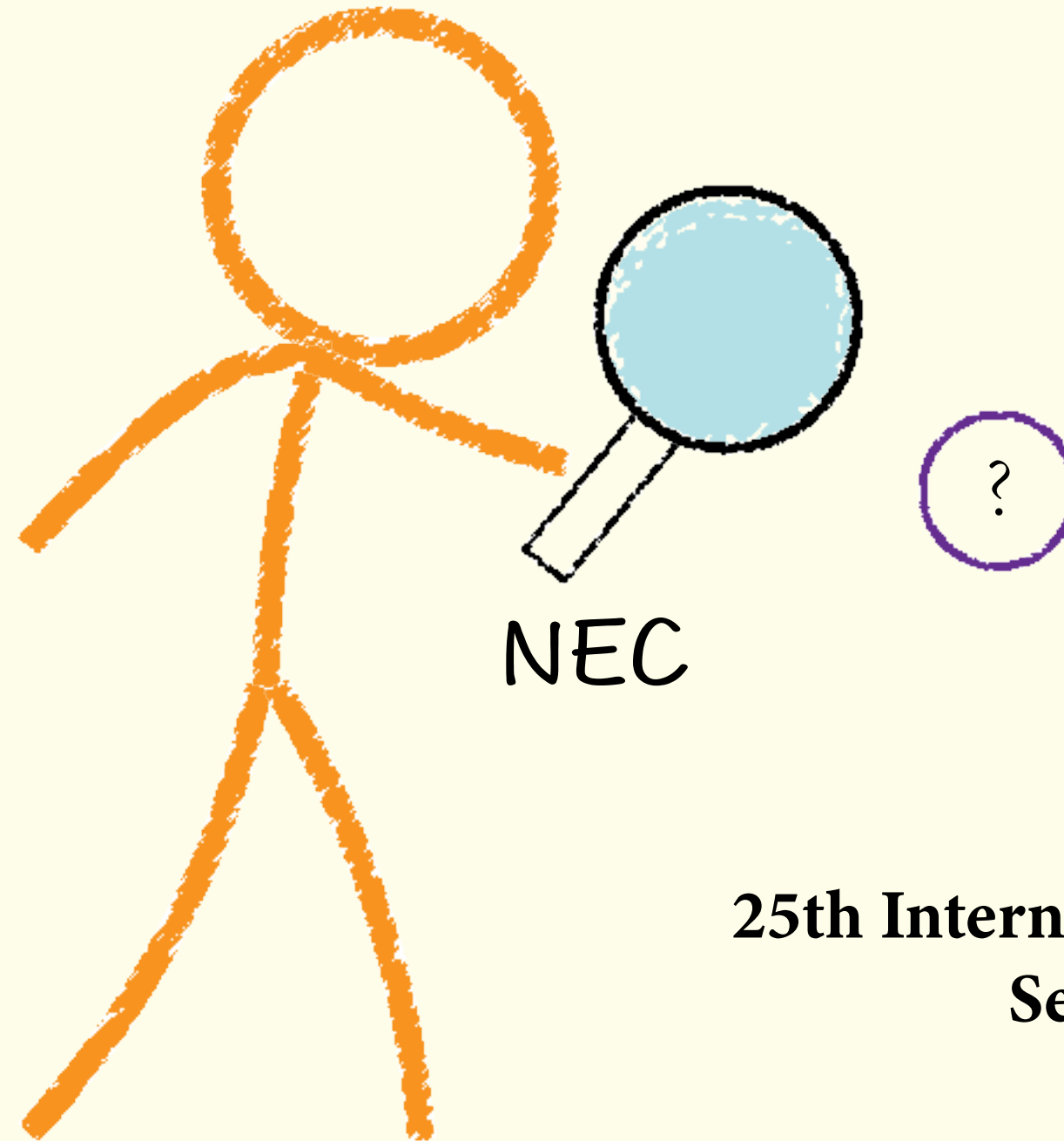


Liu, Zhu, PRL 130 (2023) 9, 9

HC, Liu, Zhu, PRD 107 (2023) 114008

Liu, Liu, Pan, Yuan, Zhu, PRL 130 (2023) 18, 18

Li, Liu, Yuan, Zhu arxiv:2308.1094



Haotian Cao

Beijing Normal University

25th International Spin Symposium
September 24-29

Outline

1. Conventional approach to nucleon structure
2. Concept and feature of Nucleon Energy Correlators
3. Numerical result
4. Application
5. Conclusion

Why are we interested in Nucleon Structure?

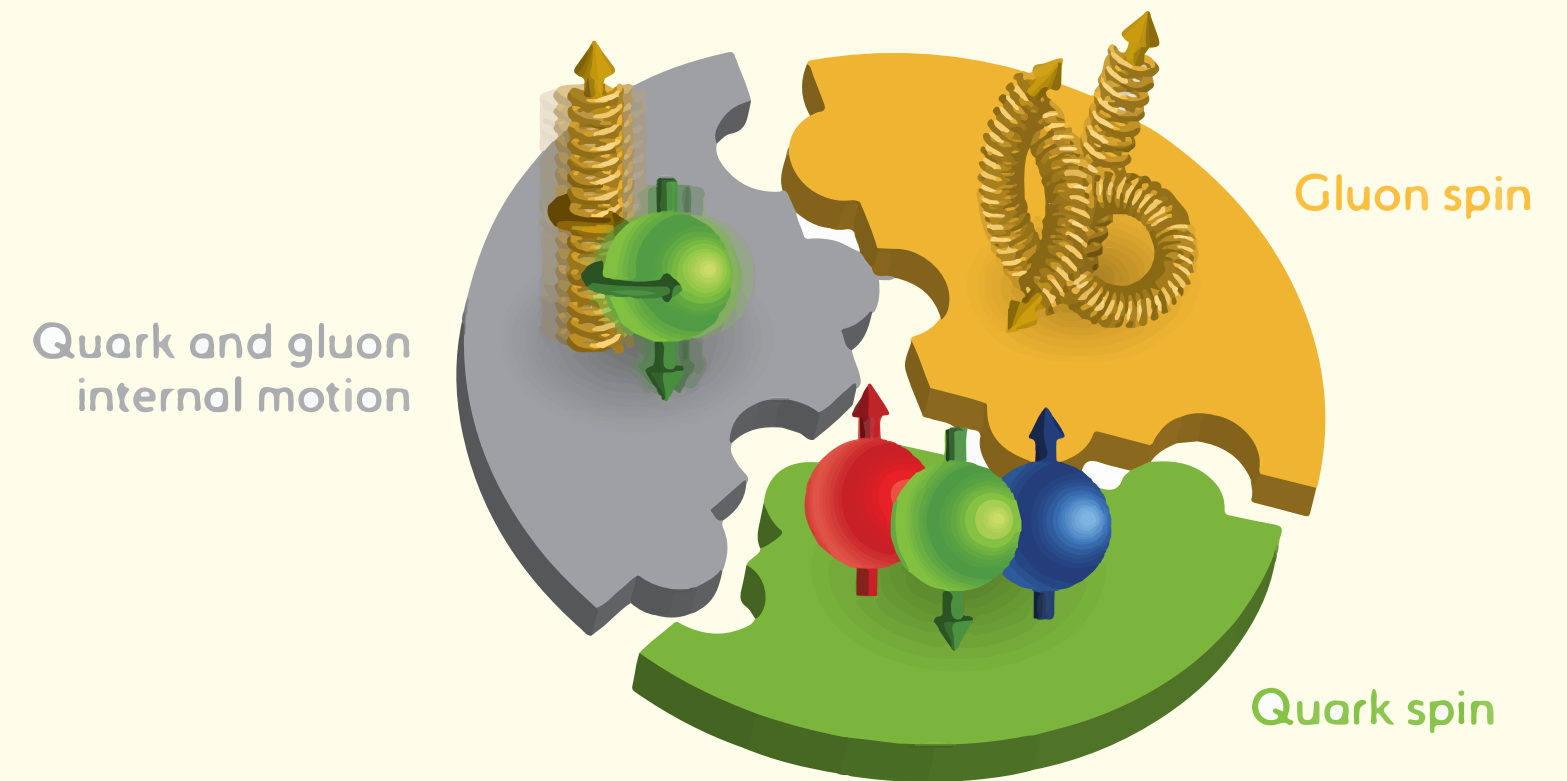
Still many question yet to answer

Spin components

Mass decomposition

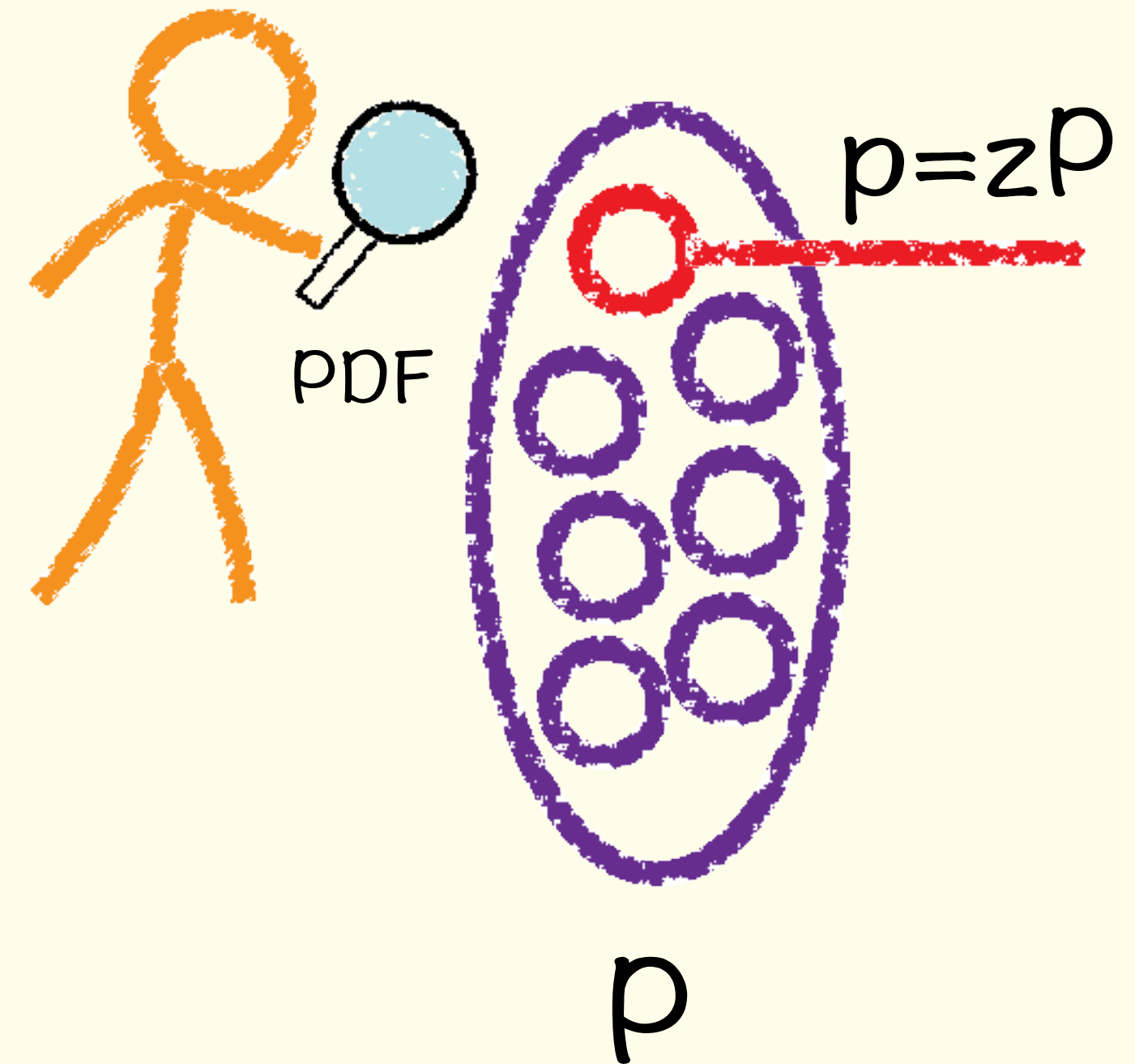
...

Major focus of EIC.



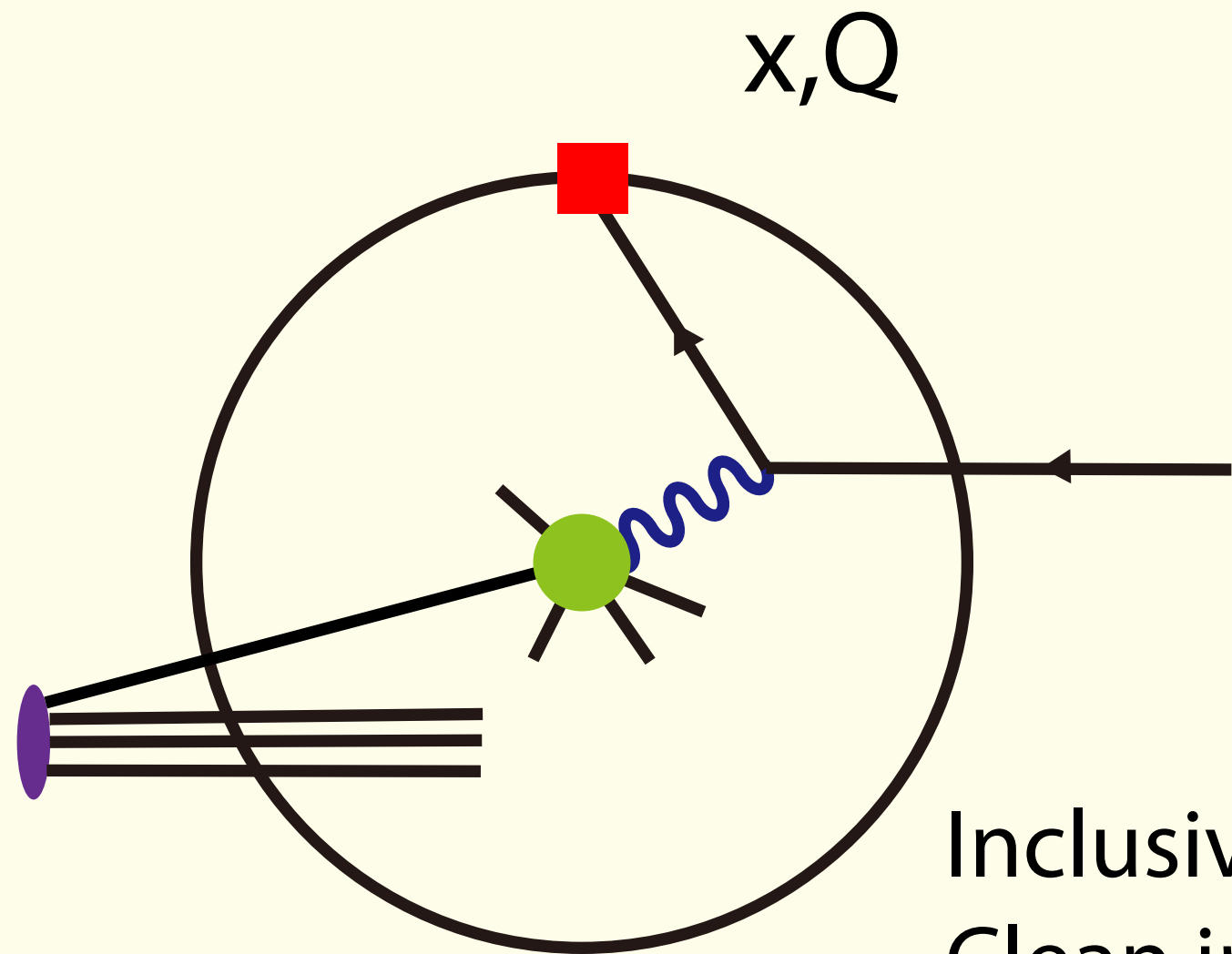
Conventional approach to nucleon structure

Parton distribution function(PDF)



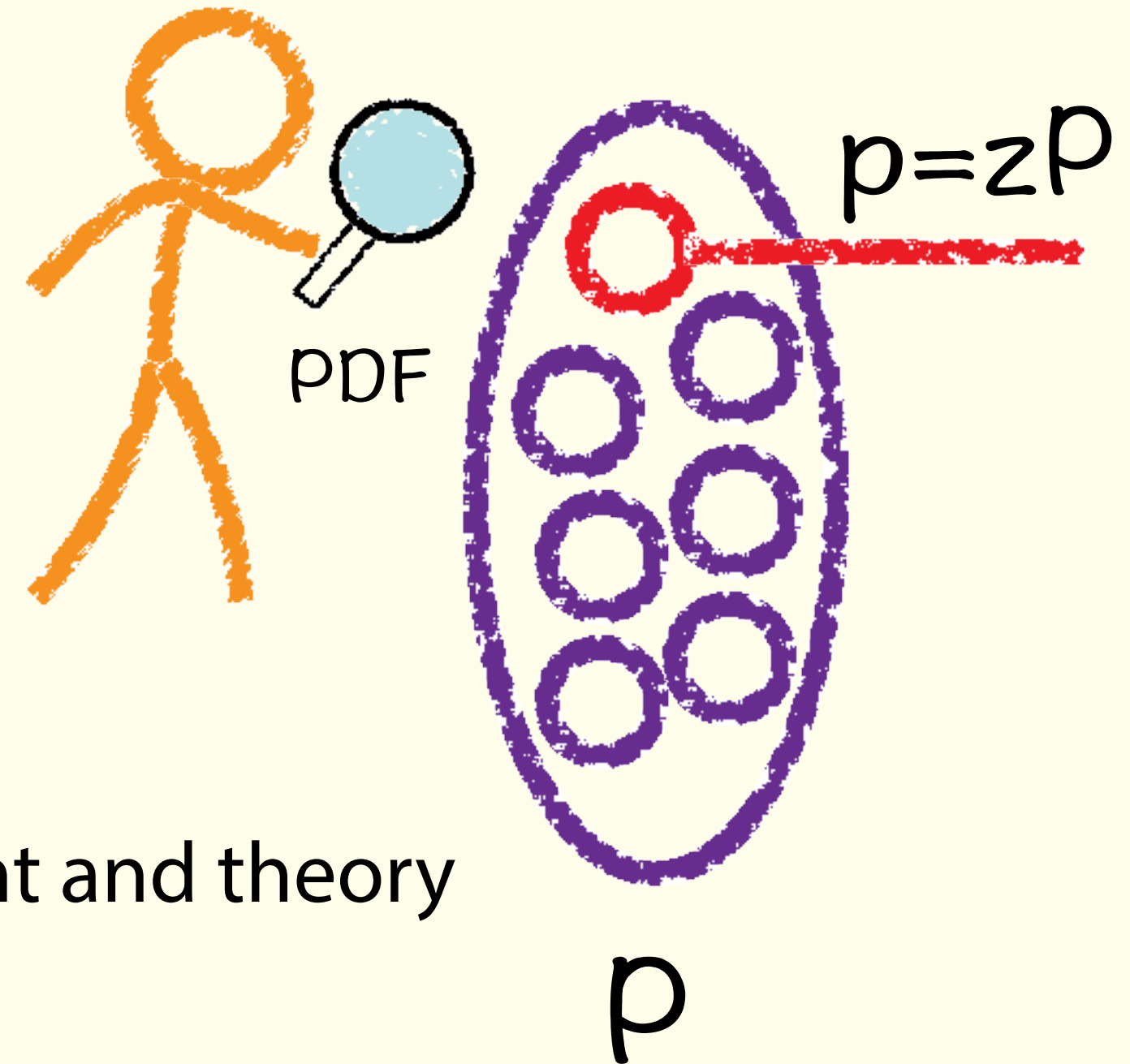
Conventional approach to nucleon structure

Parton distribution function(PDF)



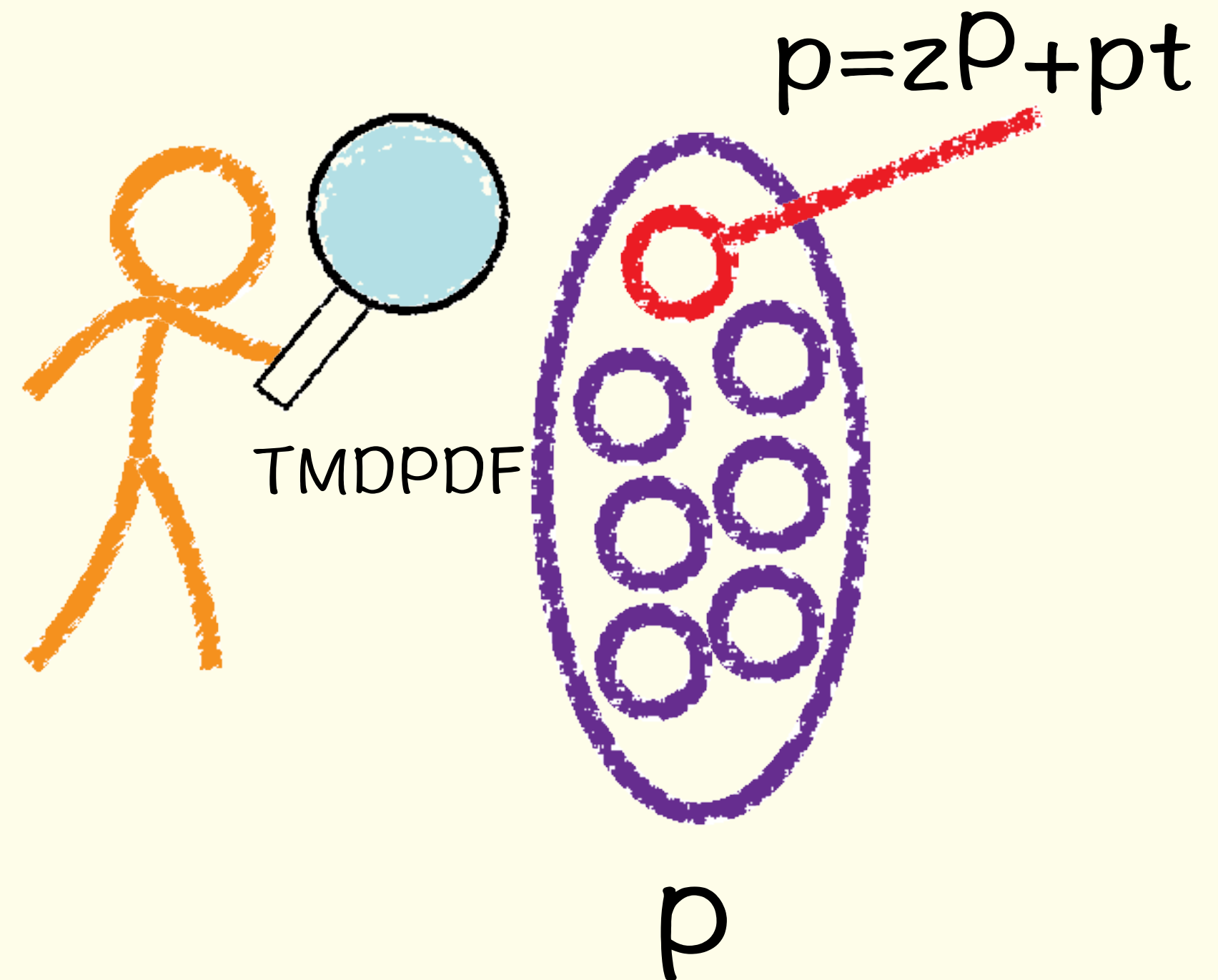
x, Q

Inclusive
Clean in both experiment and theory
Lose information



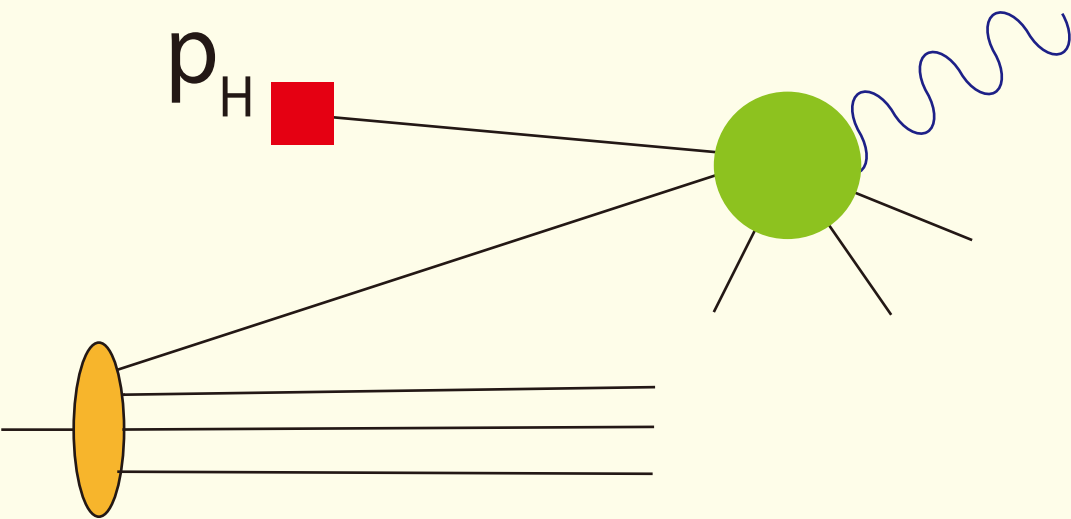
Conventional approach to nucleon structure

Transverse momentum dependent (TMD) PDF



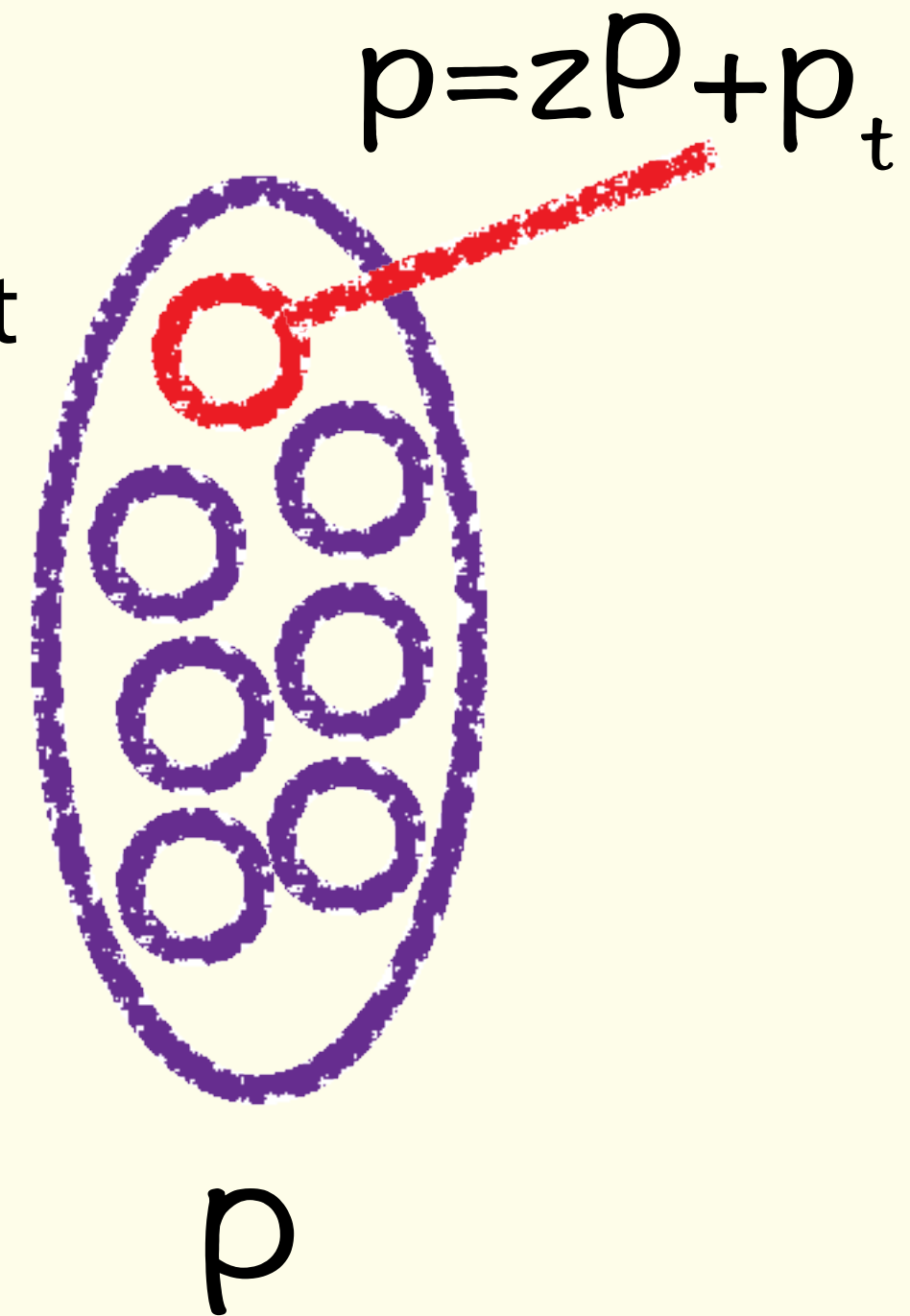
Conventional approach to nucleon structure

Transverse momentum dependent (TMD) PDF



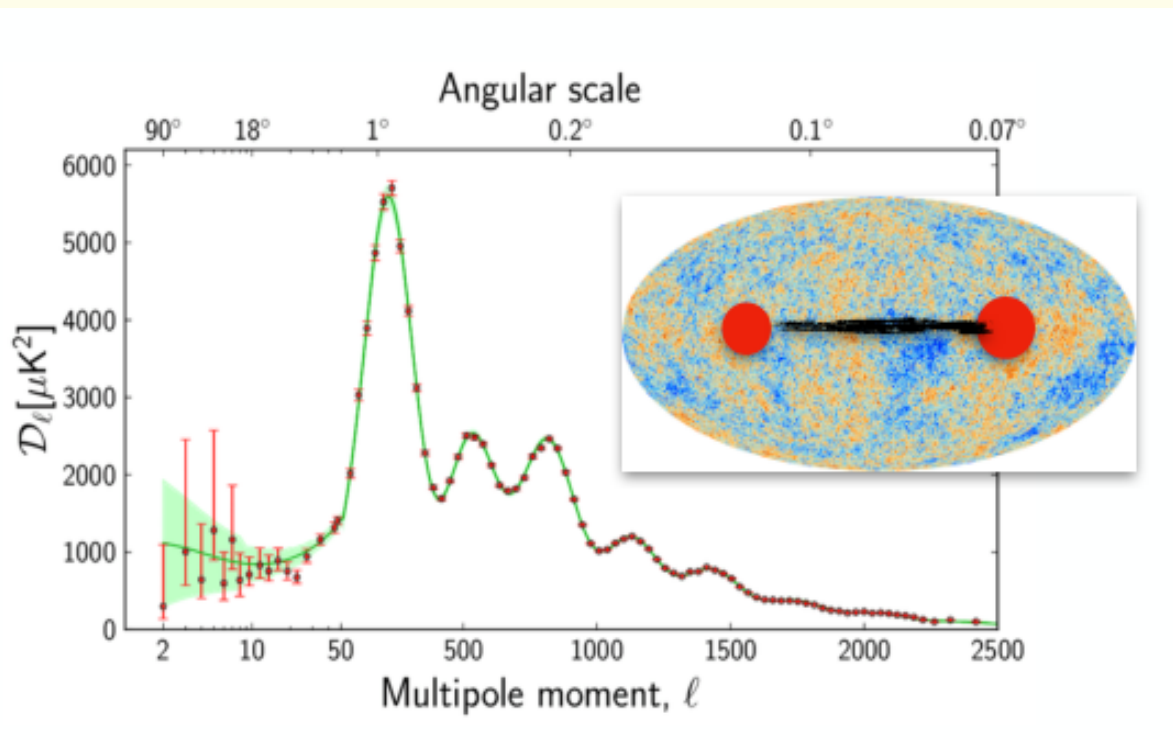
Semi-Inclusive DIS

1. Usually needs 2 non-pert object
2. exponentially suppressed in non-pert region when Q is large
3. Loses information

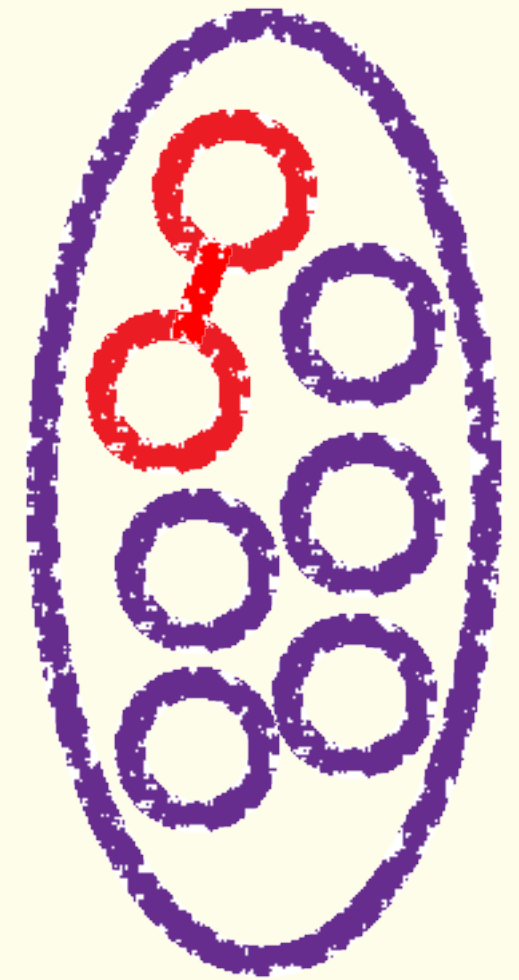


Conventional approach to nucleon structure

Transverse momentum dependent (TMD) PDF



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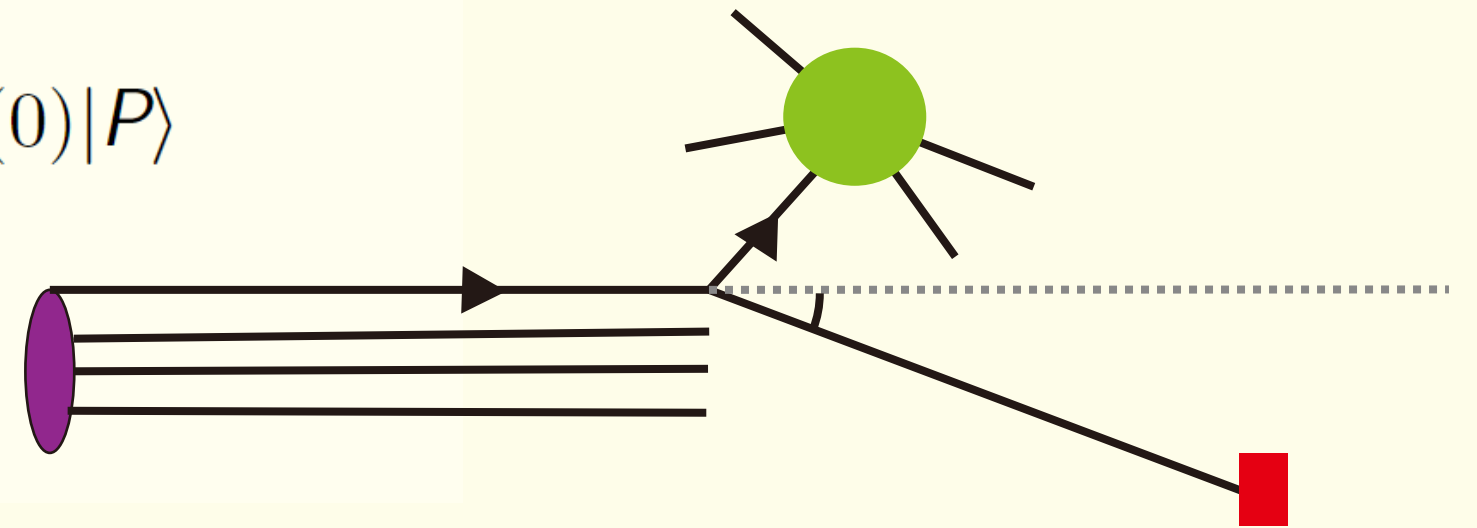


Nucleon Energy Correlators

Follow the idea of Energy Correlators[\[Dixon, Mout, Zhu...\]](#), Nucleon Energy Correlators was proposed[\[Liu,Zhu\(2023\)\]](#). It can be regarded as the target EC, which is an inclusive version of the fracture function / target fragmentation function, without tagging an explicit hadron.

$$f_{q,\text{EEC}}(z, \theta) = \int \frac{dy^-}{4\pi} e^{-izP^+ \frac{y^-}{2}} \langle P | \bar{\chi}_n(y^-) \frac{\gamma^+}{2} \hat{\mathcal{E}}(\theta) \chi_n(0) | P \rangle$$

$$\hat{\mathcal{E}}(\theta) |X\rangle = \sum_{i \in X} \frac{E_i}{E_P} \Theta(\theta - \theta_i) |X\rangle$$



We do not constrain on the parton transverse momentum. The transverse dynamics are encoded in the energy density operator

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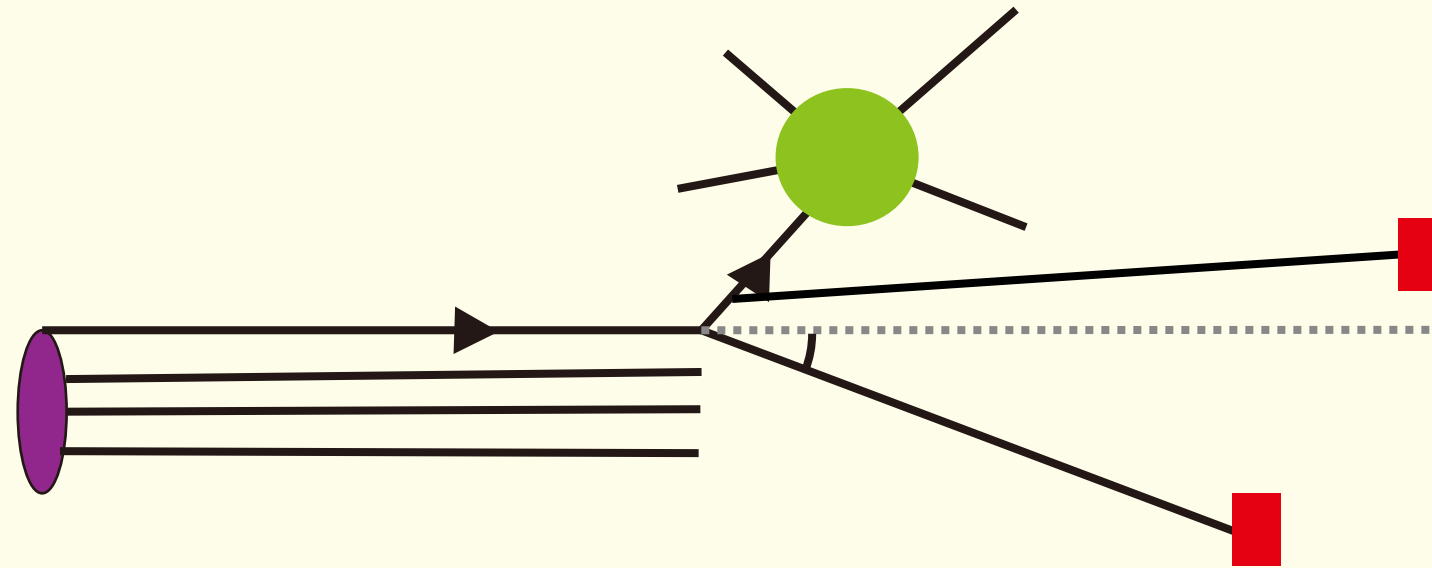
$$f_q(z) = \int \frac{dy^-}{4\pi} e^{-izP^+ \frac{y^-}{2}} \langle P | \bar{\chi}_n(y^-) \frac{\gamma^+}{2} \chi_n(0) | P \rangle$$

Compare it with pdf

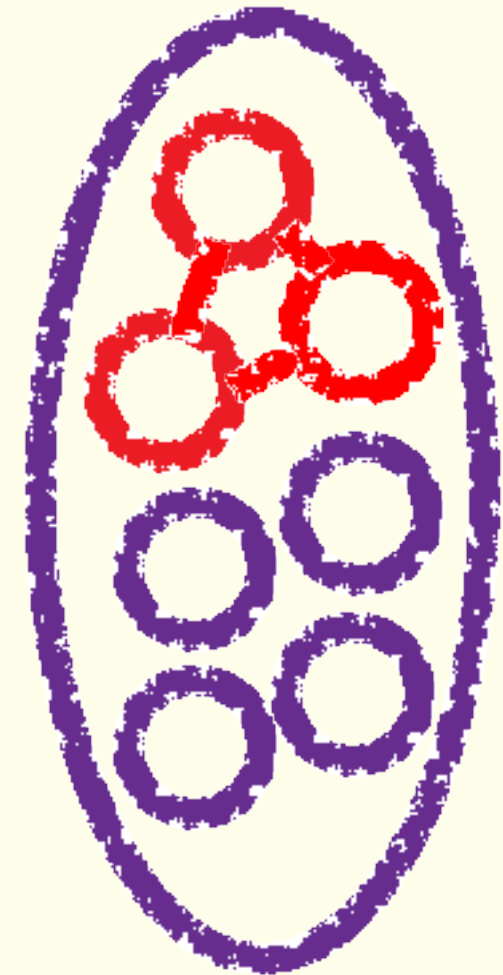
the only difference is the energy density operator.

Higher-Point correlator

Multi-point correlation is straightforwardly generalized with

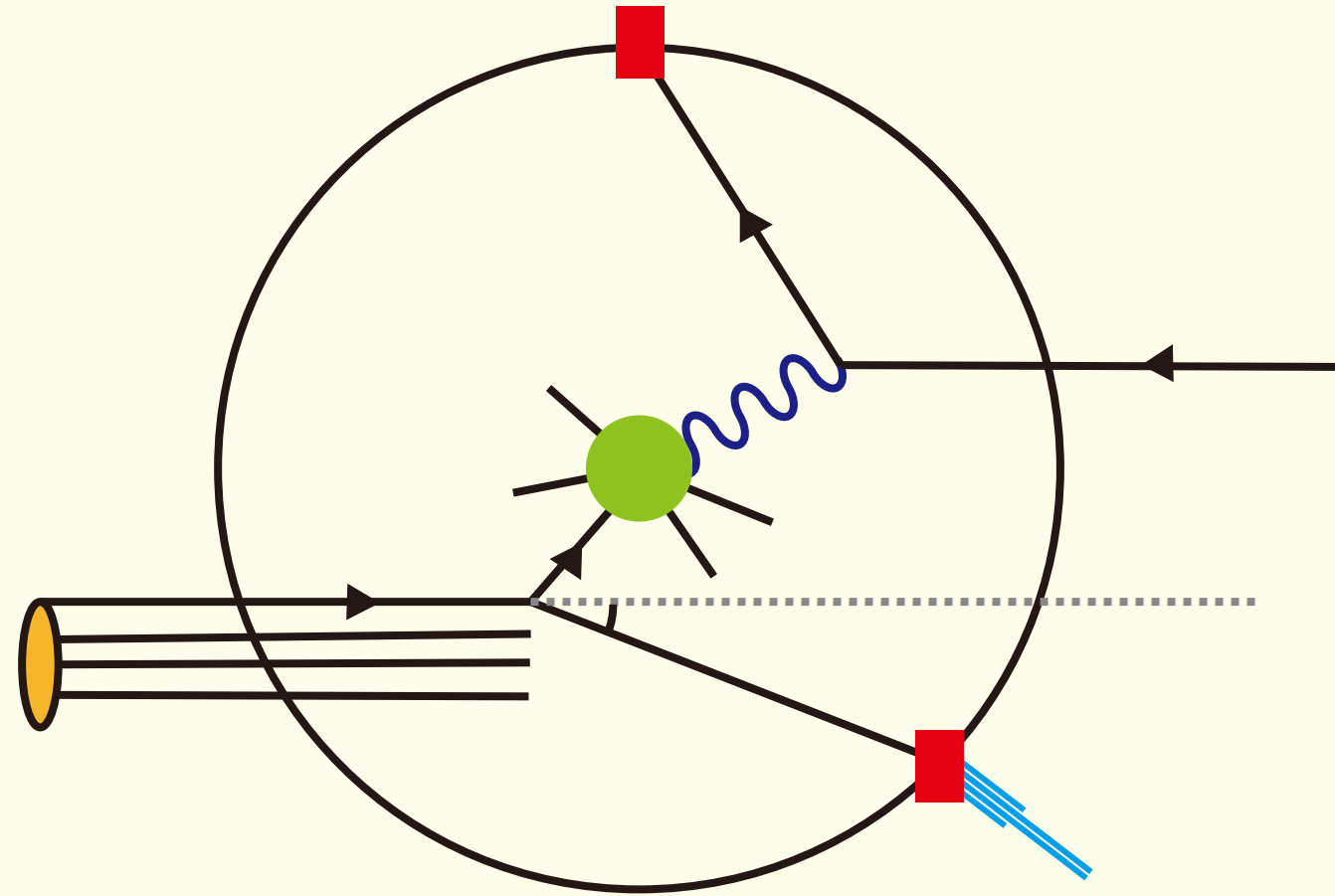


Nucleon internal dynamics will be imprinted in the detailed structure of these correlation functions.



How to probe NEEC

We first claim NEEC can be probed with

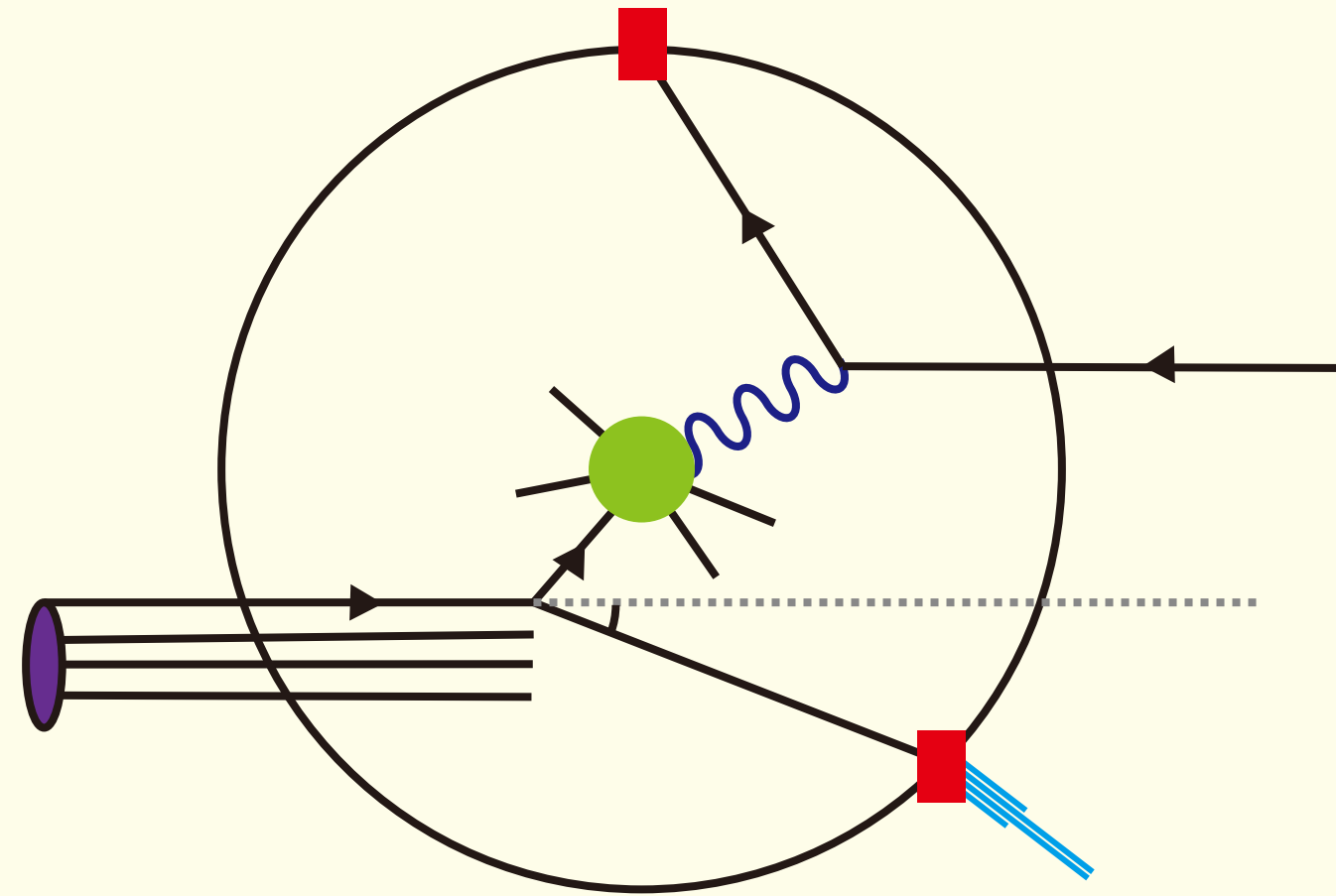


We first claim NEEC can be probed with

$$\Sigma(Q^2, x_B, \theta) = \sum_i \int d\sigma(x_B, Q^2, p_i) \frac{E_i}{E_P} \Theta(\theta - \theta_i)$$

How to probe NEEC

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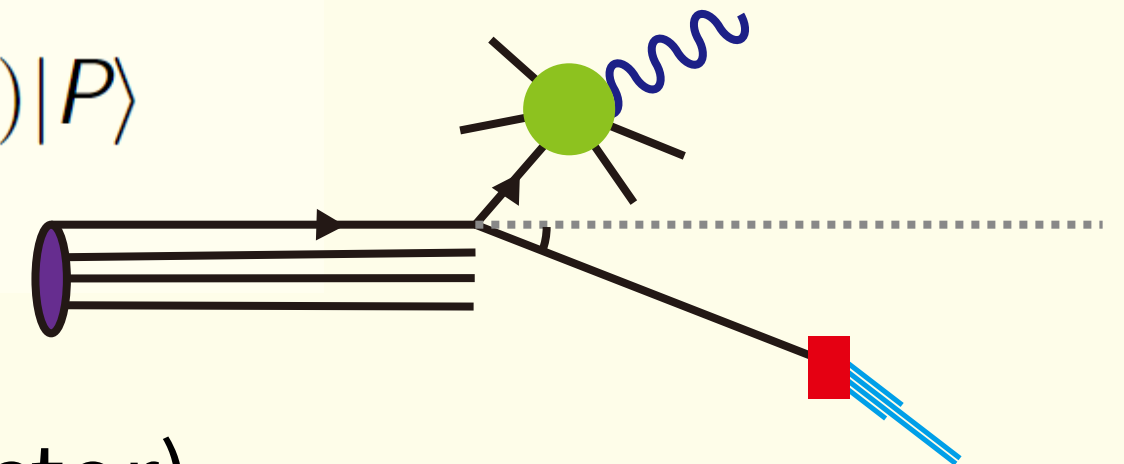
Inclusive
No jet, No hadron

We first claim NEEC can be probed with

$$\Sigma(Q^2, x_B, \theta) = \sum_i \int d\sigma(x_B, Q^2, p_i) \frac{E_i}{E_P} \Theta(\theta - \theta_i)$$

Factorization

$$\begin{aligned}\Sigma(Q^2, x_B, \theta) &= \sum_i \int d\sigma(x_B, Q^2, p_i) \frac{E_i}{E_P} \Theta(\theta - \theta_i) \\ &= \frac{\alpha^2}{Q^4} L_{\mu\nu}(Q^2, x_B) \int d^4x e^{iq \cdot x} \langle P | j^{\mu\dagger}(x) \hat{\mathcal{E}}(\theta) j^\nu(0) | P \rangle\end{aligned}$$



When we remove the Energy density operator (detector) in collinear region, The weighted cross section will recover to the cross section of inclusive DIS.

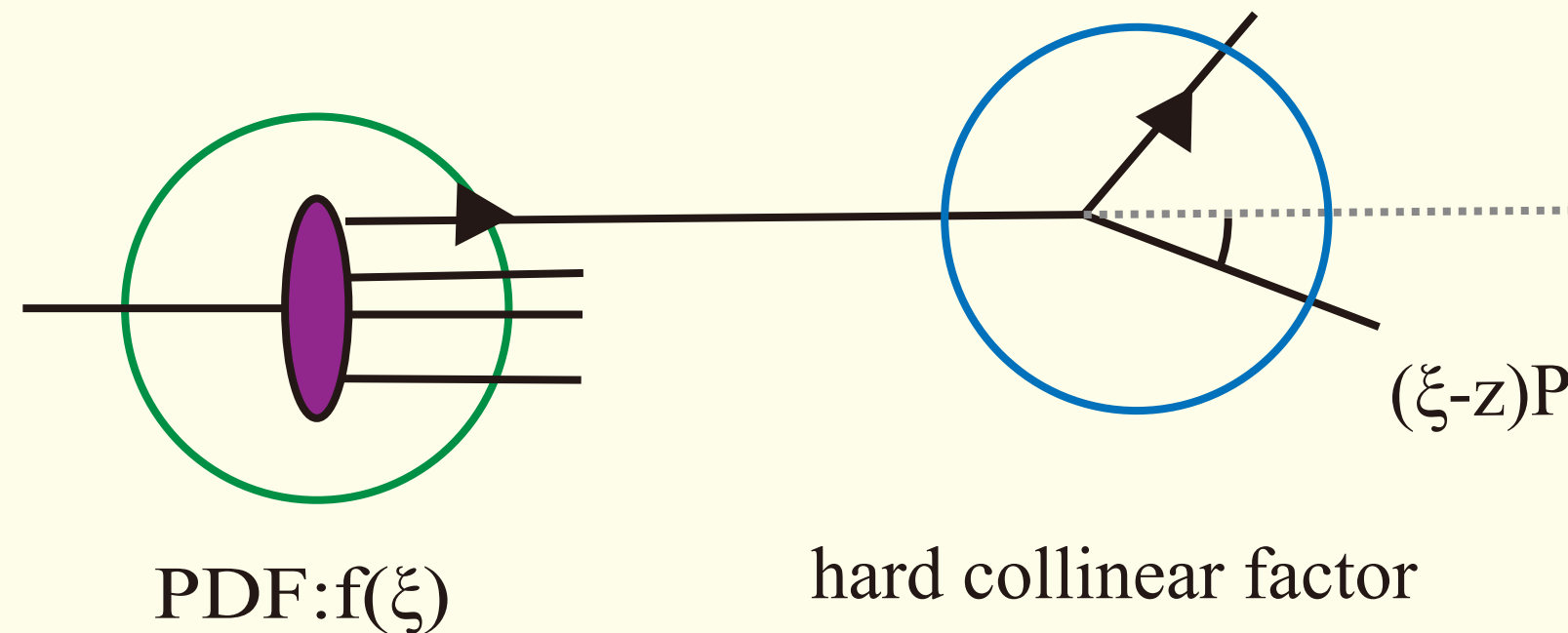
$$\Sigma(Q^2, x_B, \theta) = \int_{x_B}^1 \frac{dz}{z} \hat{\sigma}_i \left(\frac{x_B}{z} \right) f_{i,\text{EEC}}(z, P^+ \theta)$$

Unlike TMD region, There will be gluon contribution.

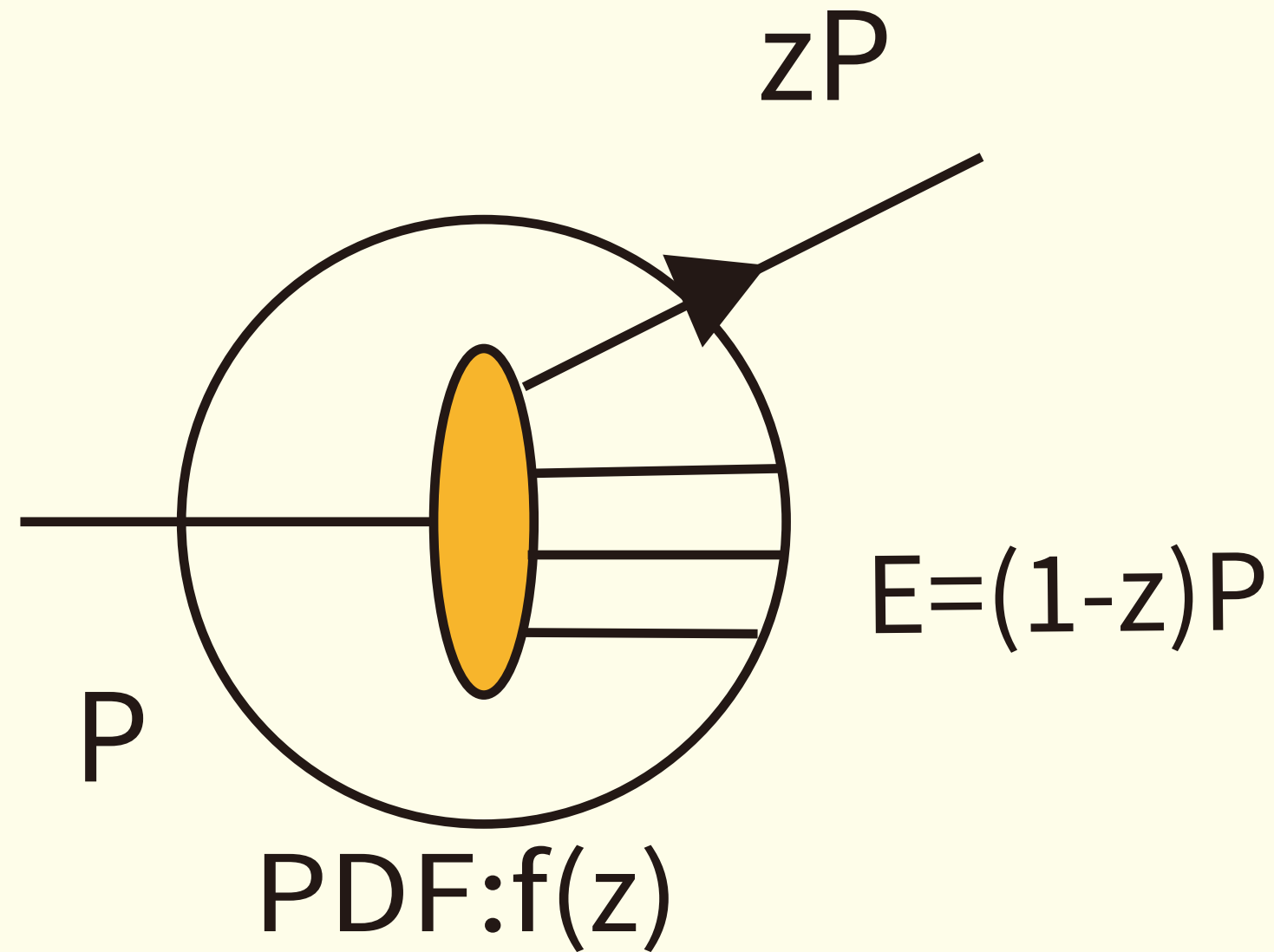
From the consistency relation, NEEC will satisfy the DGLAP equation as PDF

Factorization

When $\theta \ll 1$ but it is large enough that $\Lambda_{\text{QCD}} \ll \theta Q$, We can further split the collinear mode into the **hard collinear mode (C_1)**, $pt \sim \Lambda_{\text{QCD}}/Q$ and **SCET₂ mode (C_2)** $pt \sim \theta Q$ mode NEEC can be further matched to pdf



Factorization

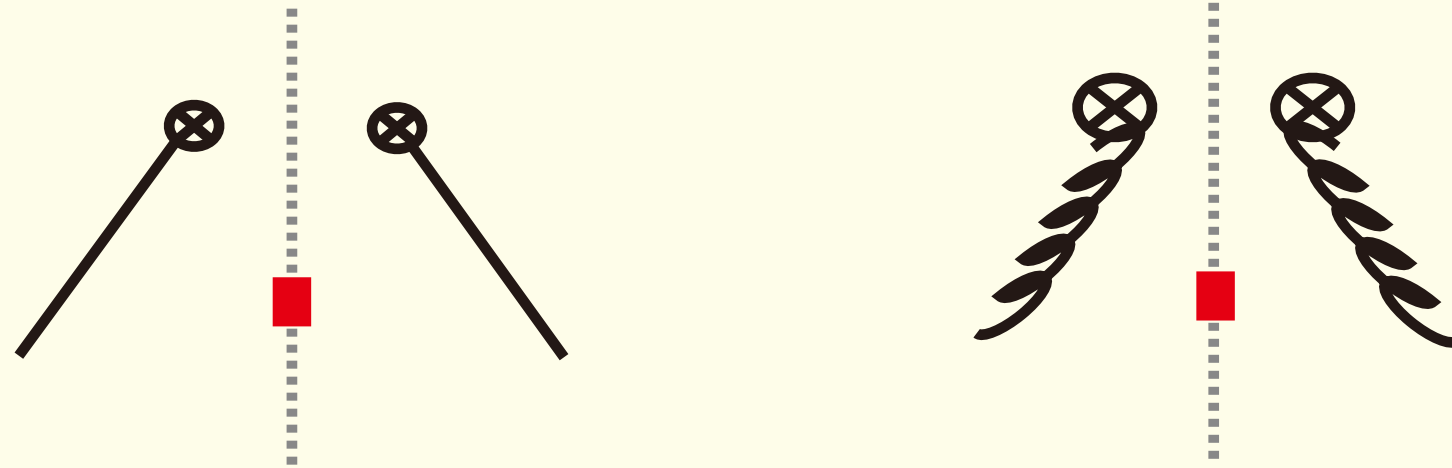


Since the angle in SCET_2 region will always be smaller than θ , it will contribute as

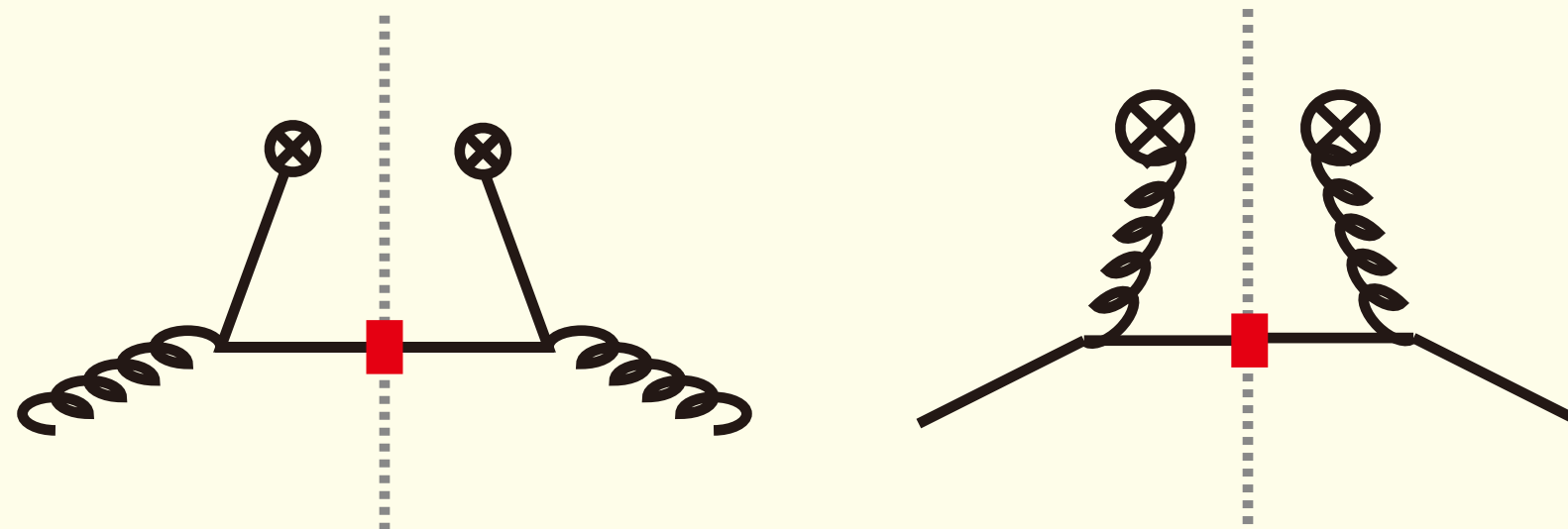
$$f_{i,\text{EEC}}^{(0)}(z, \theta) = f_i(z) - z f_i(z)$$

Factorization

The LO contribution of **hard collinear region** will be zero, which can be noticed by the feynman graphs



The NLO contribution are calculated with graphs like these.



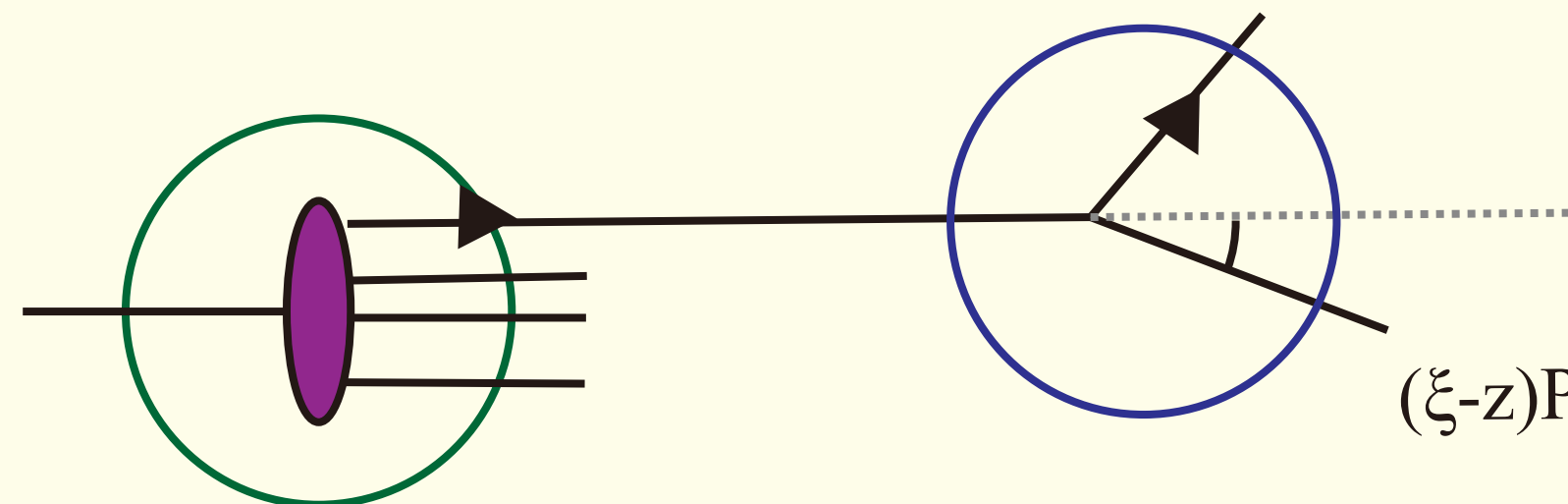
Factorization

We can understand why this object is called NEEC, which is obvious from the fix order calculation.

$$\frac{df_{\text{EEC}}^{(1)}(z, \theta)}{d\theta} \propto \left[\left(1 - \frac{z}{\xi}\right) \frac{1}{\theta} P\left(\frac{z}{\xi}\right) \right] \xi f(\xi)$$

final energy density

initial energy density

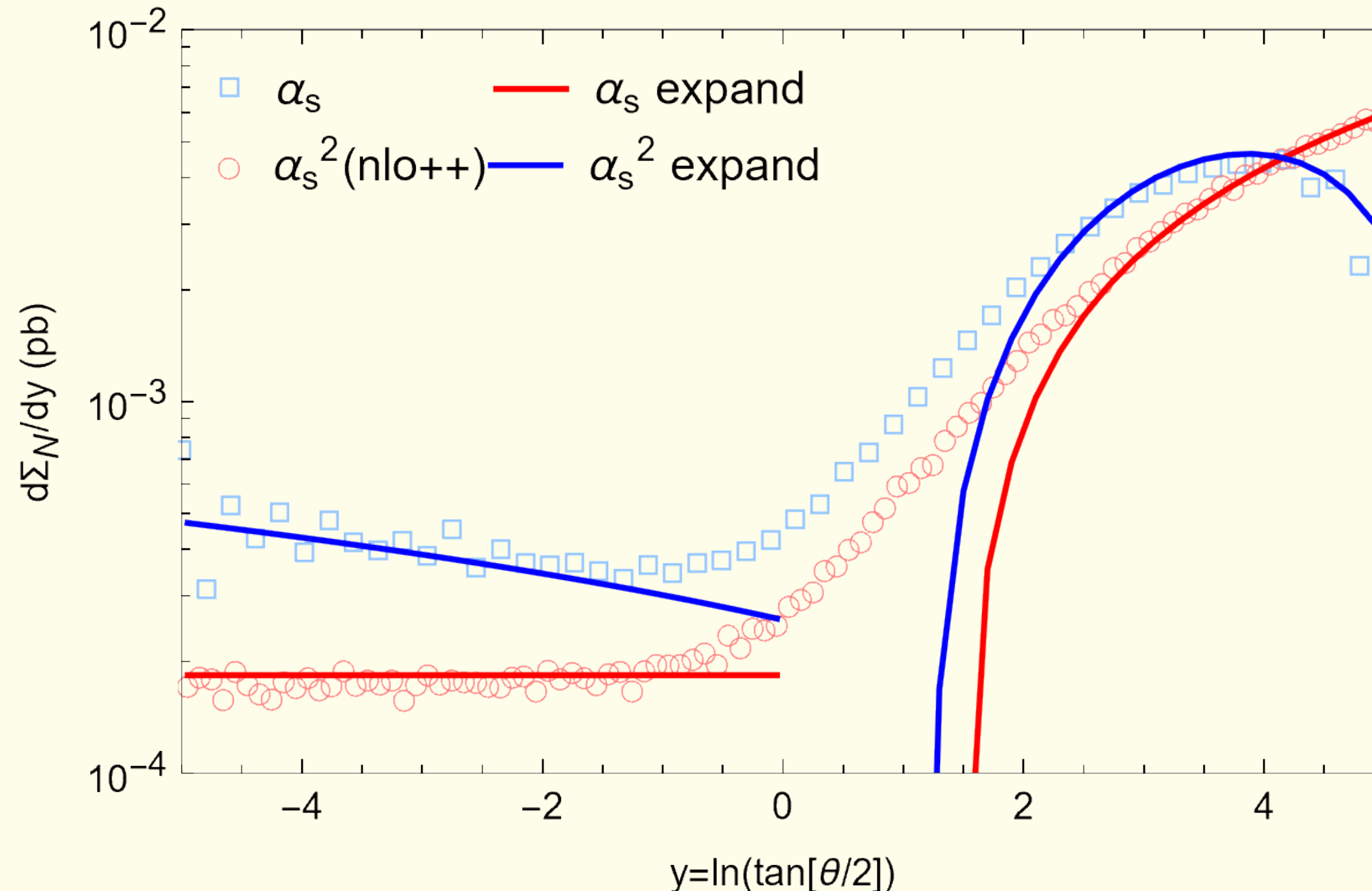


PDF: $f(\xi)$

hard collinear factor

Consistency check

Compare the complete fixed order result with NLL resummed result expanded to $O(\alpha_s)$ and $O(\alpha_s^2)$



N=4

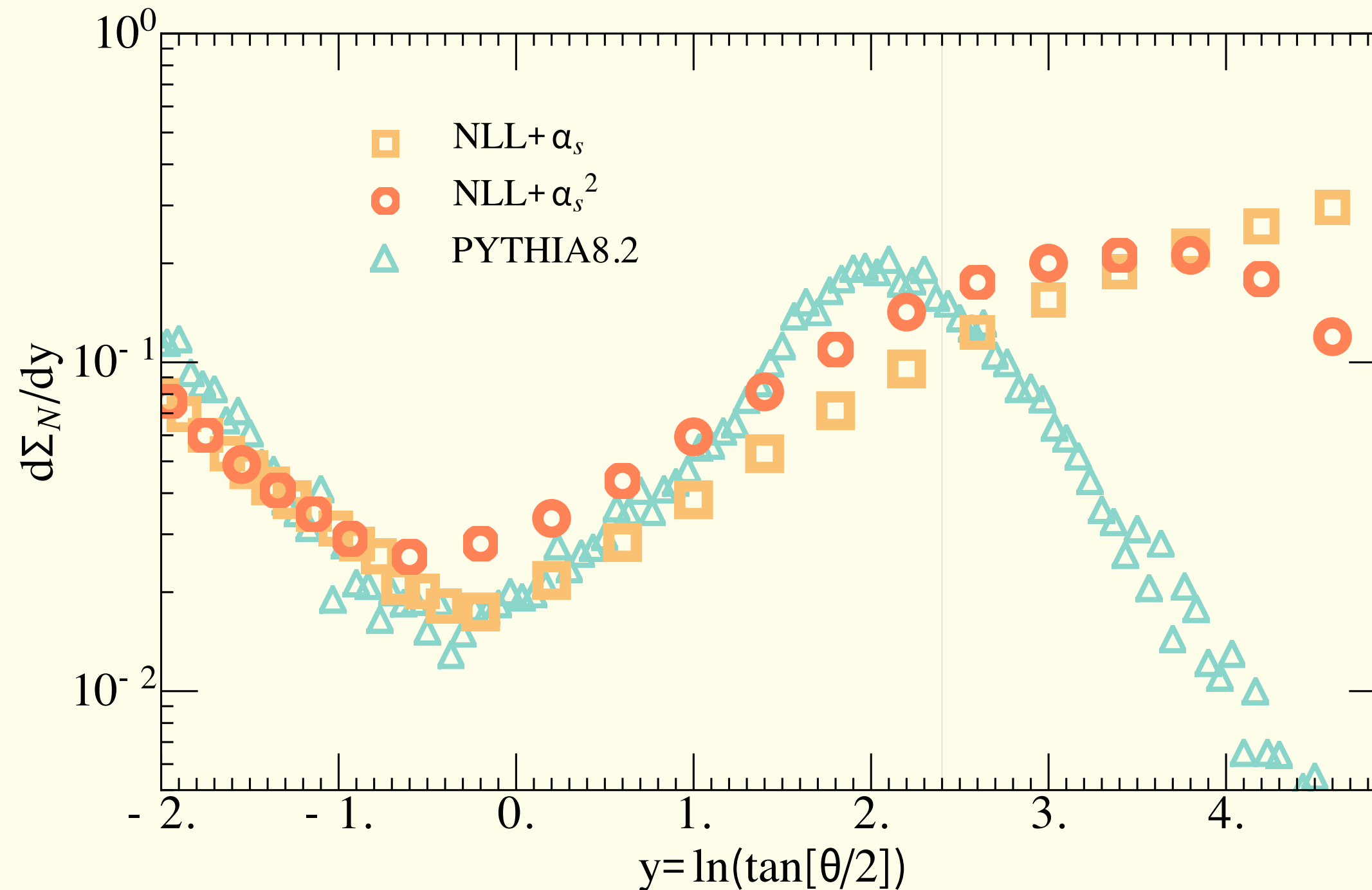
$E_p=275\text{GeV}$

$E_l=18\text{GeV}$

$Q=20\text{GeV}$

Numerical result for NLL

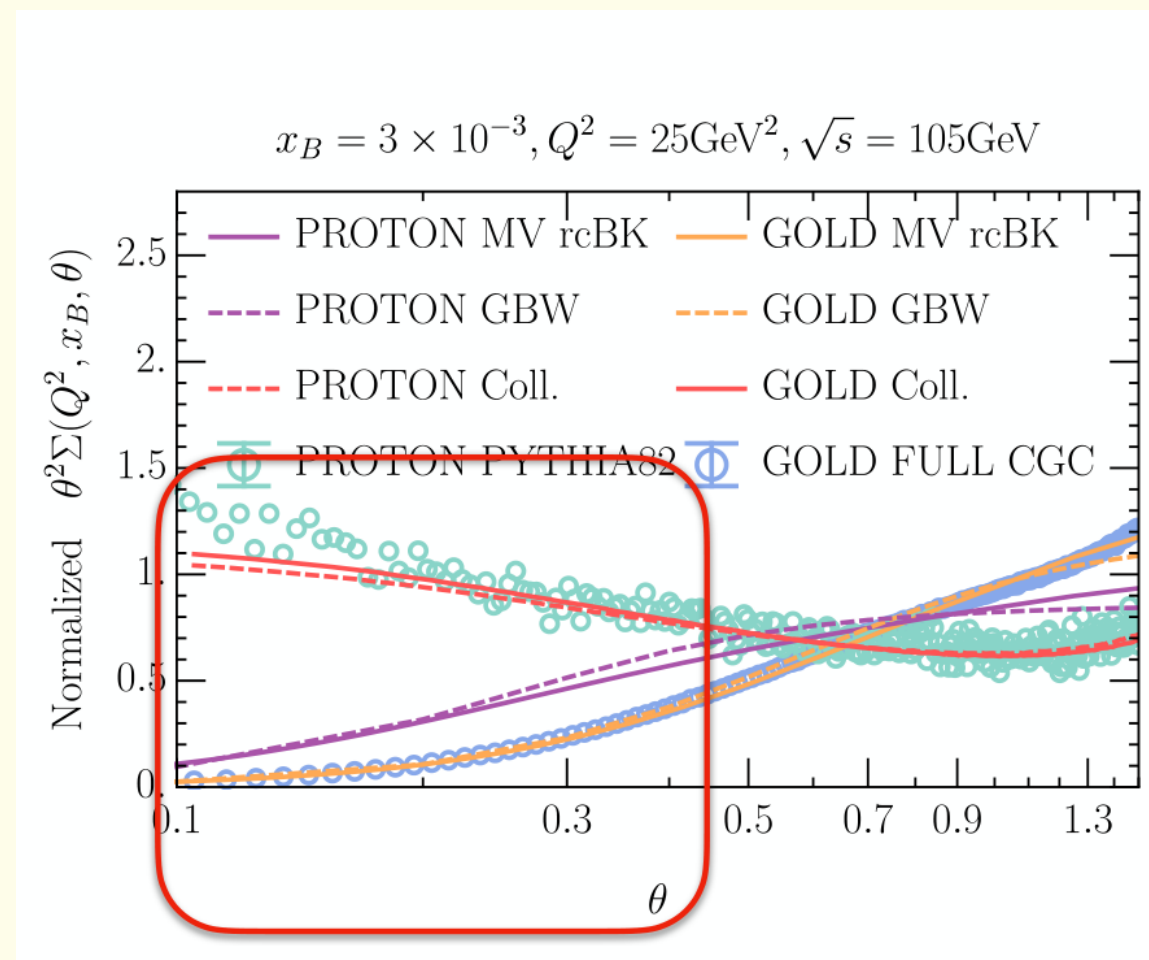
Comparison of the $\text{NLL} + \alpha_s$, $\text{NLL} + \alpha_s^2$ and the Pythia simulation at partonic level. Work in progress. We are still working on TMD region.



N=3
Ep=275GeV
El=18GeV
Q=10GeV

Application to the gluon saturation

NEEC as evident portal to the onset of gluon saturation. We can define a turning point around which the slope of the distribution starts to switch its monotonicity.



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A Different Angle on the Color Glass Condensate

June 12, 2023 • Physics 16, s89

Predictions indicate that a new type of measurement at the future electron-ion collider could spot an elusive high-density regime of gluons called the color glass condensate.

SYNOPSIS

PDF Version

Nucleon Energy Correlators for the Color Glass Condensate
Hao-Yu Liu, Xiaohui Liu, Ji-Chen Pan, Feng Yuan, and Hua Xing Zhu
Phys. Rev. Lett. 130, 181901 (2023)
Published May 2, 2023

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A zigzag arrangement that appears spontaneously in a collection of magnetic particles and some other colloids is explained by the fluid flow around each particle.

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Brookhaven National Laboratory

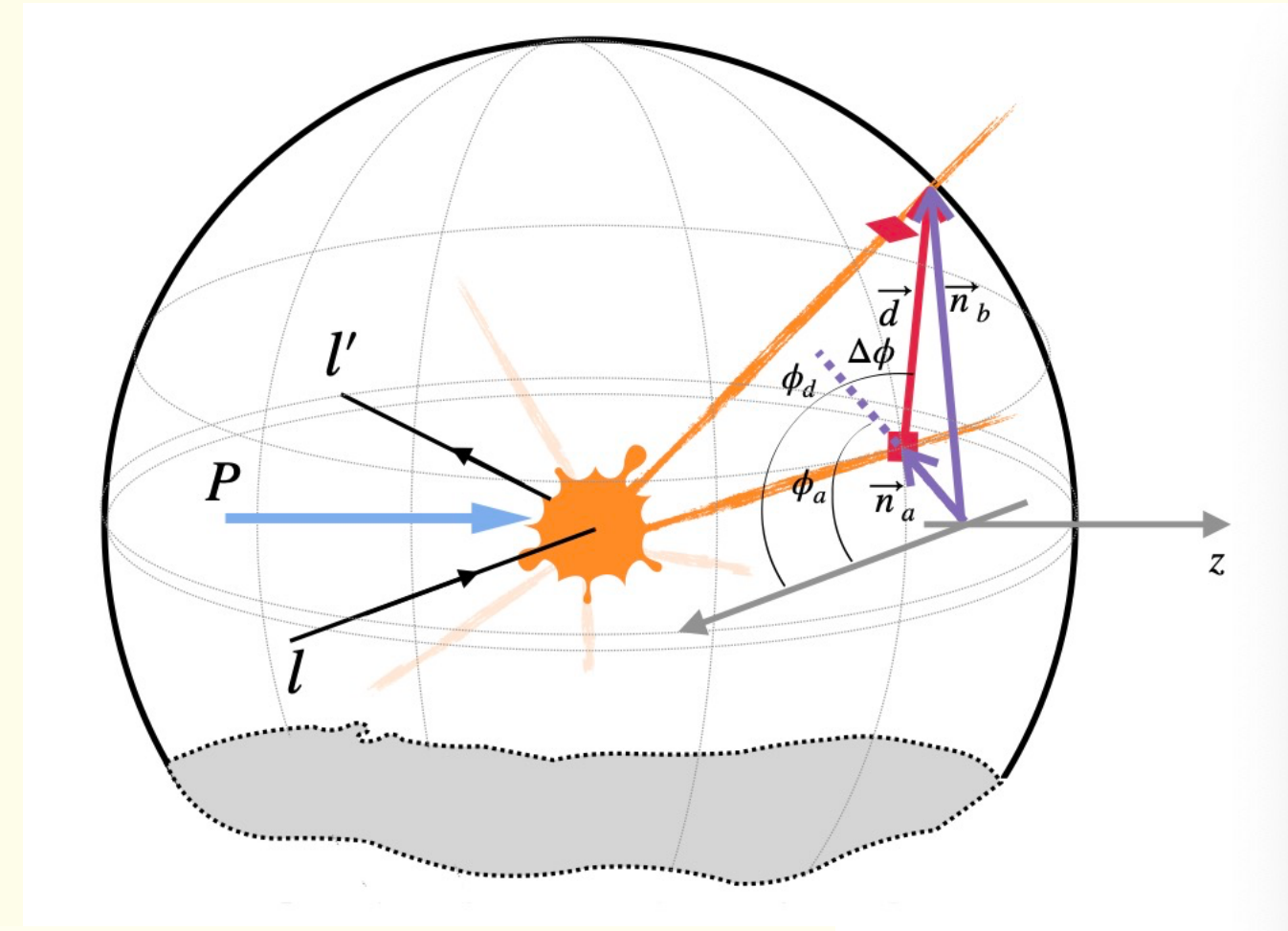
Highlighted by Physics synopsis

Application to parton polarization

It can be proved for NE3C, When $\theta_b \gg \theta_a$ and $1 \gg \theta_a$

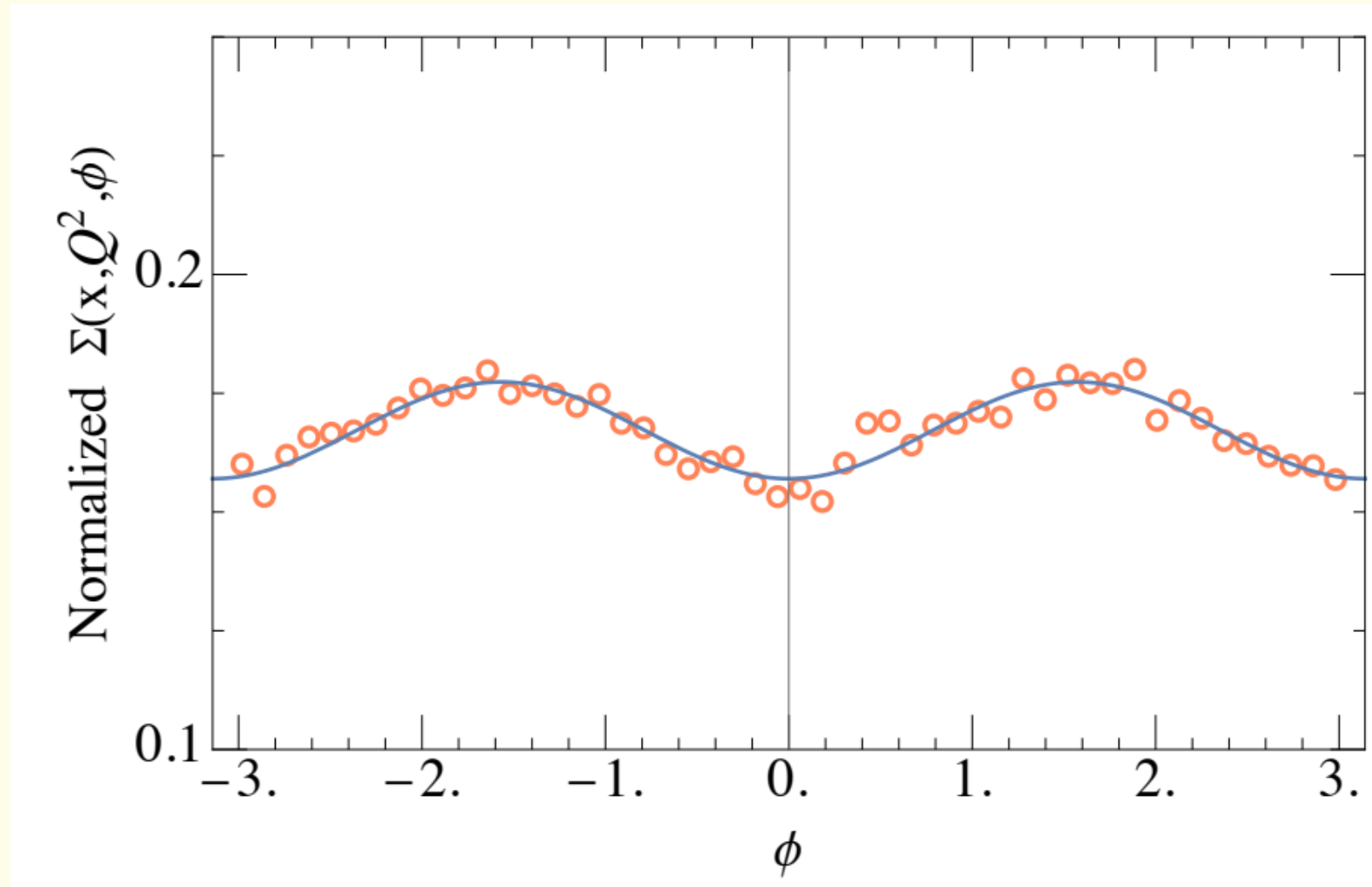
No soft/radiation contamination, $\cos(2\phi)$ to all orders guaranteed by the lorentz structure.

$d_{g,EEC}$: helicity dependent gluon EEC



$$\Sigma(Q^2, x_B, \phi, \theta_{a,b}) \propto \int \frac{dz}{z} \left[\sum_{i=q,g} H_i(y, z, \theta_b) \frac{x_B}{z} f_{i,EEC} \left(\frac{x_B}{z}, \theta_a \right) + \frac{1}{2} \Delta H_g(z, y, \theta_b) \frac{x_B}{z} d_g(\theta_a) \cos(2\phi) \right]$$

Application to parton polarization



NLO

$E_l = 18 \text{ GeV}$

$E_p = 275 \text{ GeV}$

$x_B = 0.03$

$Q = 10 \text{ GeV}$

$0.3 > \theta_a > 0.1$

$0.02 > \theta_b > 0.005$

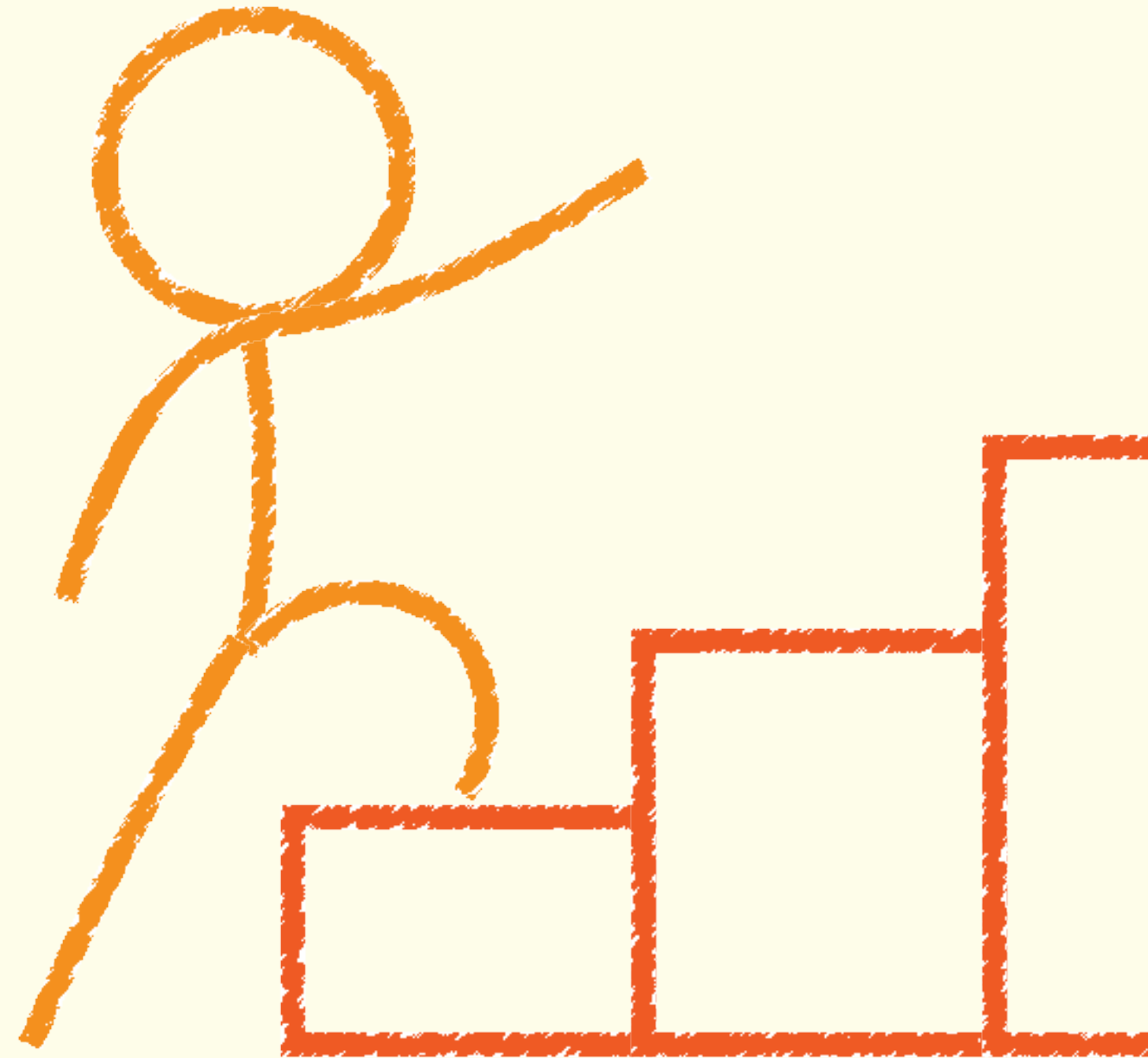
With explicit $\cos(2\phi)$ modulation, We can estimate the “amount” of linearly polarized gluons.

Conclusion

NEEC is a brand new description of the nucleon structures and QCD dynamics.

The factorization theorem is ready.

There can be many things to do with NEEC.



Thank You

