

Possible α_s extraction in the unexpected post-confinement regime of EEC

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The 1st Annual Conference on EIC Physics in China

Qingdao, 2026

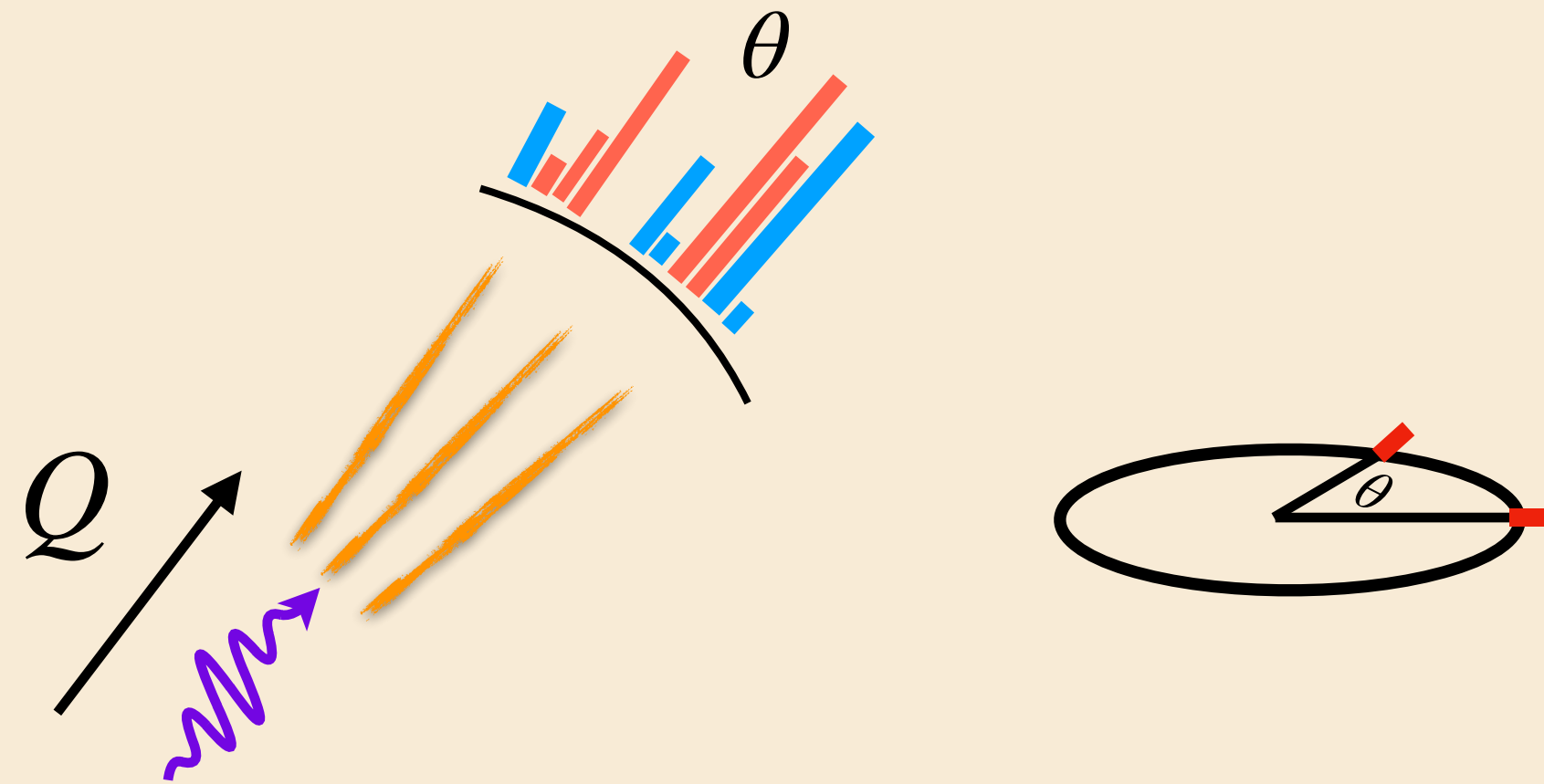
PRL 134 (2025), PRL 136 (2026)

Zhan Wang ,et al. In preparation

Outline

- Scaling behavior of the post-confinement EEC
 - light-ray OPE Analysis
- Phenomenology
 - Comparison with current data
 - α_s extraction
- Conclusion

Energy Energy Correlators

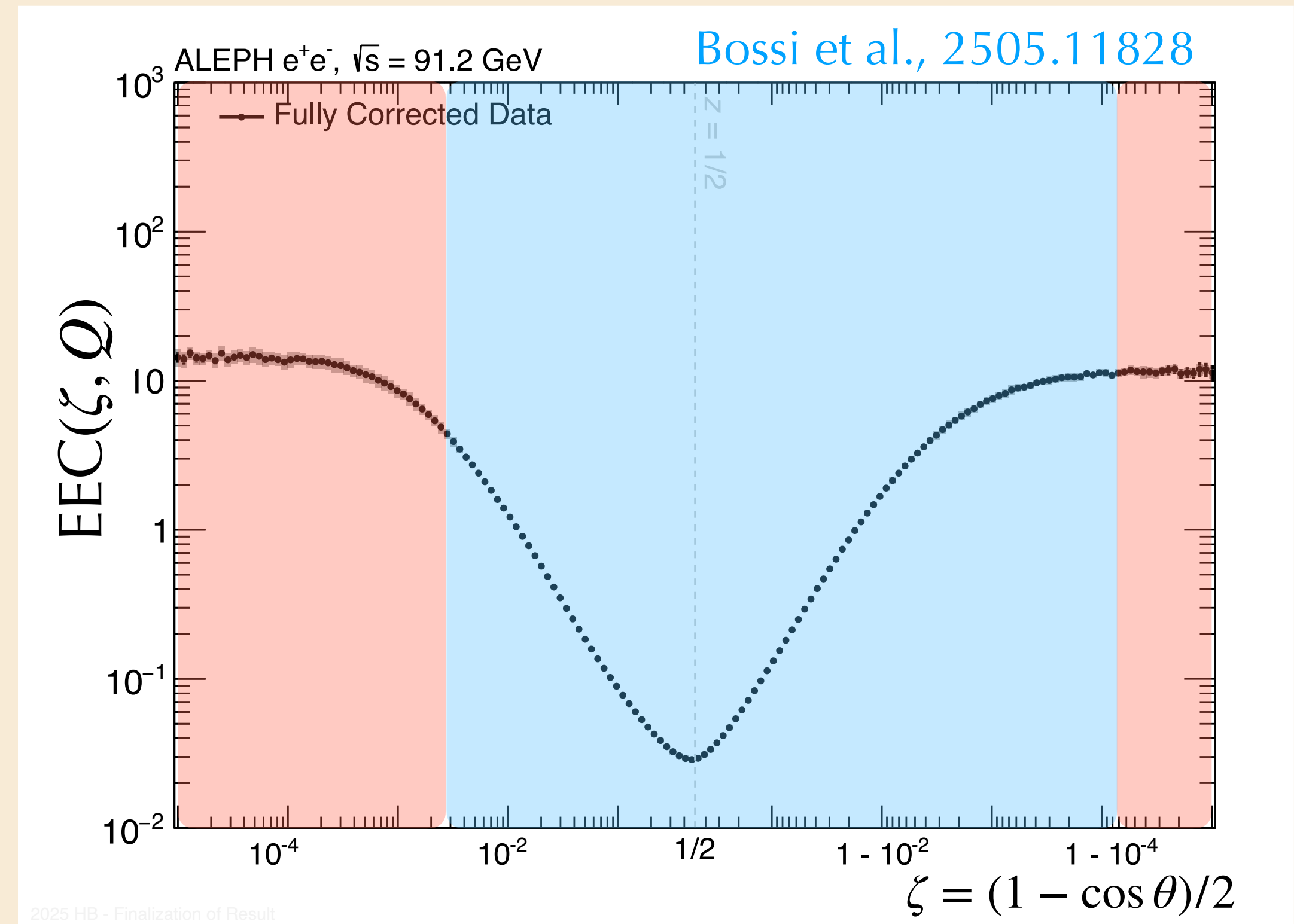


$$EEC = \frac{1}{\sigma} \int d\sigma \sum_{ij} \frac{E_i E_j}{Q^2} \delta(\theta - \theta_{ij})$$

$$= \frac{\langle \mathcal{E}(n_i) \mathcal{E}(n_j) \rangle}{Q^2} \quad \mathcal{E}(n) = \lim_{\vec{n} \cdot x \rightarrow \infty} (\vec{n} \cdot x)^{4-2} \int dn \cdot x T_{\mu\nu} \vec{n}^\mu \vec{n}^\nu$$

Sterman, 1975, Bashman, et al. 1978

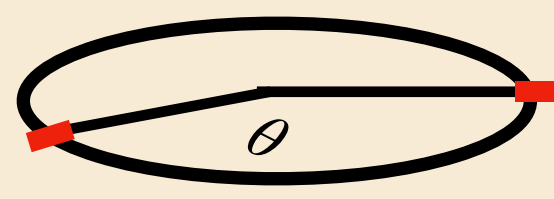
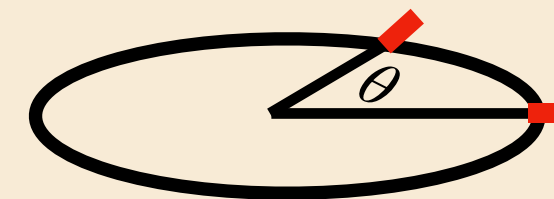
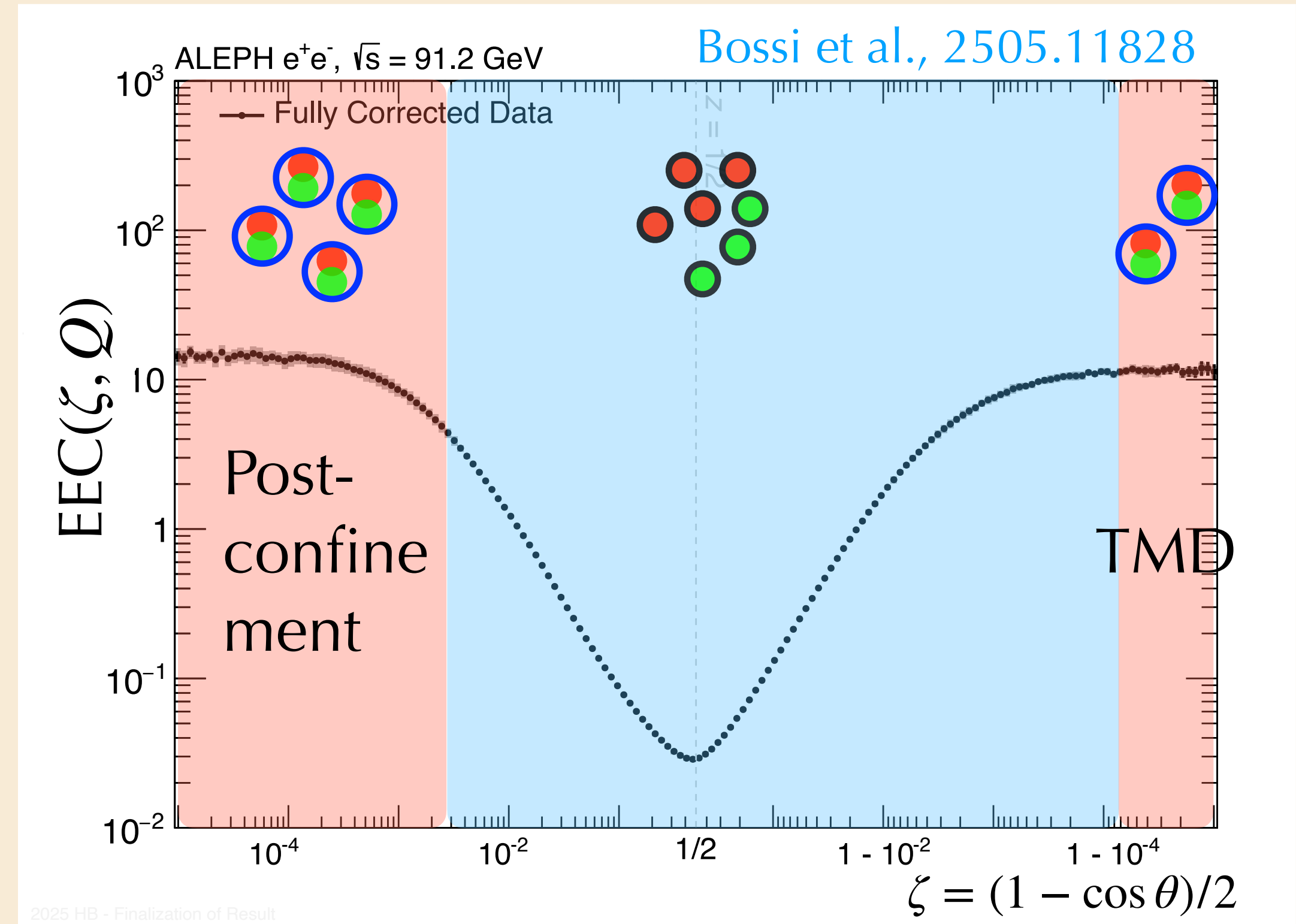
Moult, Zhu, 2506.09119 for reivew



- Jet w/o jet algorithms, a portal to hadrons
- Fundamental object in QFT

Energy Energy Correlators

- Different angles probe physics at different scales
 $\sim Q \min(\sqrt{\zeta}, \sqrt{1-\zeta})$
- Most regions are well-understood
- The post-confinement region, $\zeta \rightarrow 0 \lesssim \Lambda_{\text{QCD}}/Q$, remains challenging



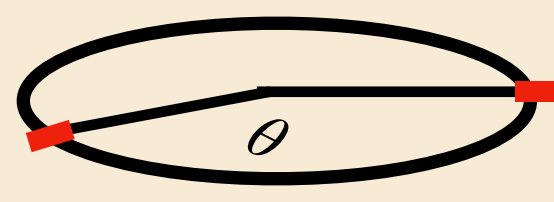
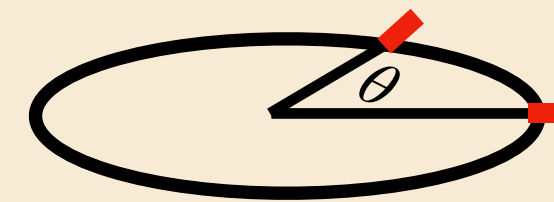
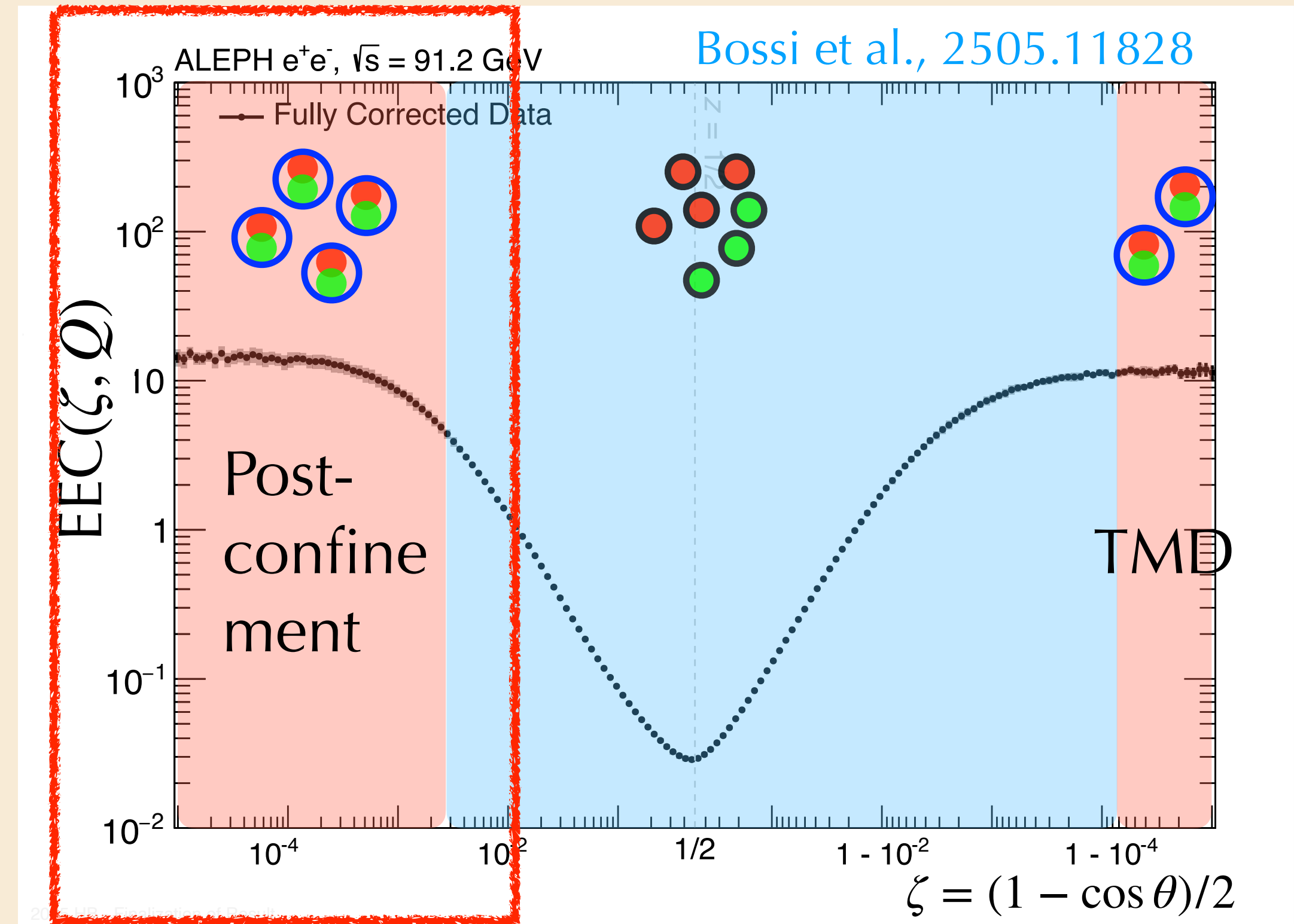
Energy Energy Correlators

- The post-confinement region, $\zeta \rightarrow 0 \lesssim \Lambda_{\text{QCD}}/Q$

AdS/CFT: [Hofman, Maldacena, 2008](#)

$$\text{EEC}(\zeta) \sim 1 + \frac{6\pi^2}{\lambda} \left(\frac{2}{3} - 4\zeta(1 - \zeta) \right) + \dots$$

- Height of the plateau $\propto Q^0$
- The shape is only a function of ζ or θ



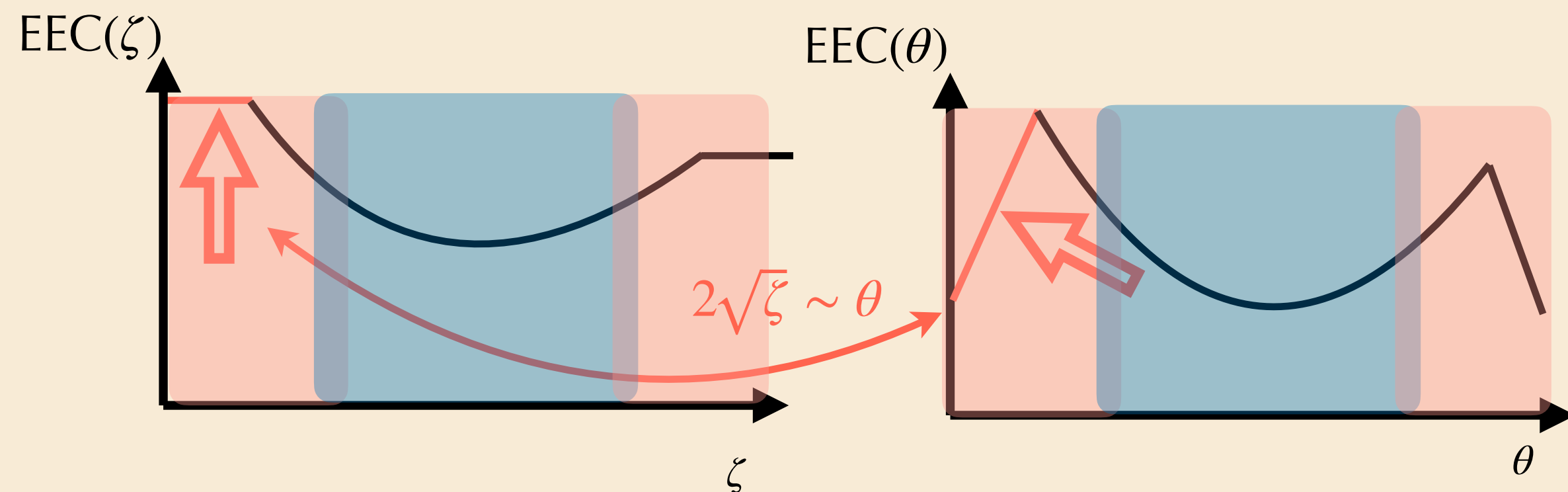
Energy Energy Correlators

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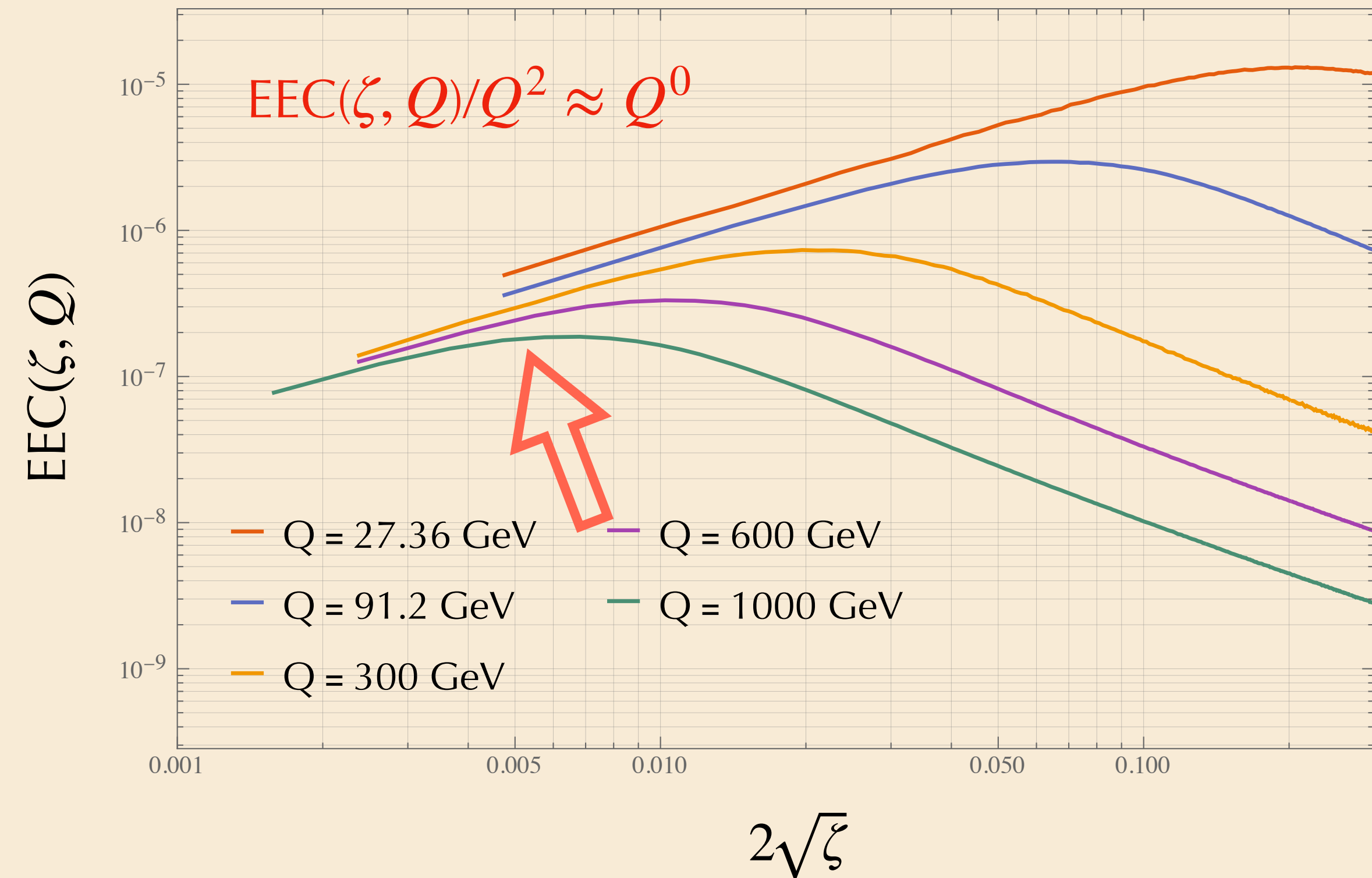
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- Height of the plateau $\propto Q^0$
- The shape is only a function of ζ or θ



Real World:

[XL, Vogelsang, Yuan, Zhu, PRL 134 \(2025\)](#)



- Height of the plateau $\propto Q^2 + \text{corrections}$
- The shape also depends on Q
- $\text{EEC} \sim Q^2/\Lambda_{\text{QCD}}^2$

Scaling behavior by light-ray OPE

Chang, Chen, **XL**, Simmons-Duffin, Yuan, Zhu, PRL 136 (2026) 8, 081903

Approach using dihadron picture see: Lee, Stewart, PRL 2026

Kang, et al., PRL 2026

Guo, et al., PRL 2026

Scaling behavior by ~~light-ray OPE~~

primary school math

Chang, Chen, XL, Simmons-Duffin, Yuan, Zhu, PRL 136 (2026) 8, 081903

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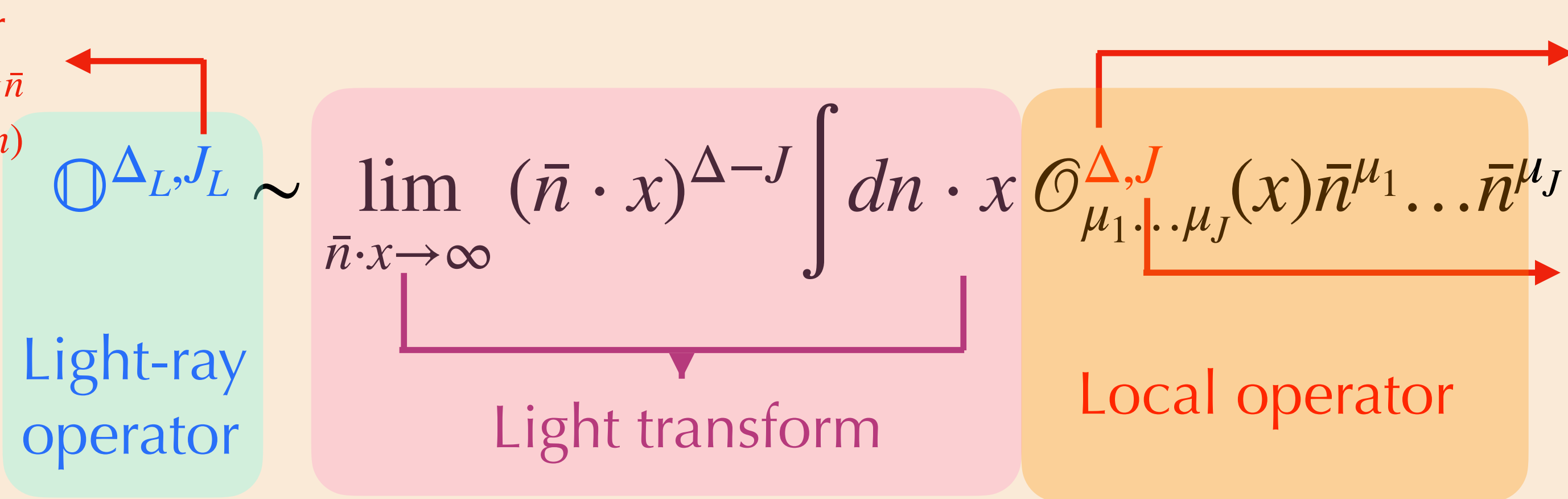
Kang, et al., PRL 2026

Guo, et al., PRL 2026

Scaling behavior by light-ray OPE

Scaling under
 $n \rightarrow \rho n, \bar{n} \rightarrow \rho^{-1} \bar{n}$
 $\mathbb{O}(\rho n) = \rho^{J_L} \mathbb{O}(n)$

1905.01311



Dimension,
 classic scaling

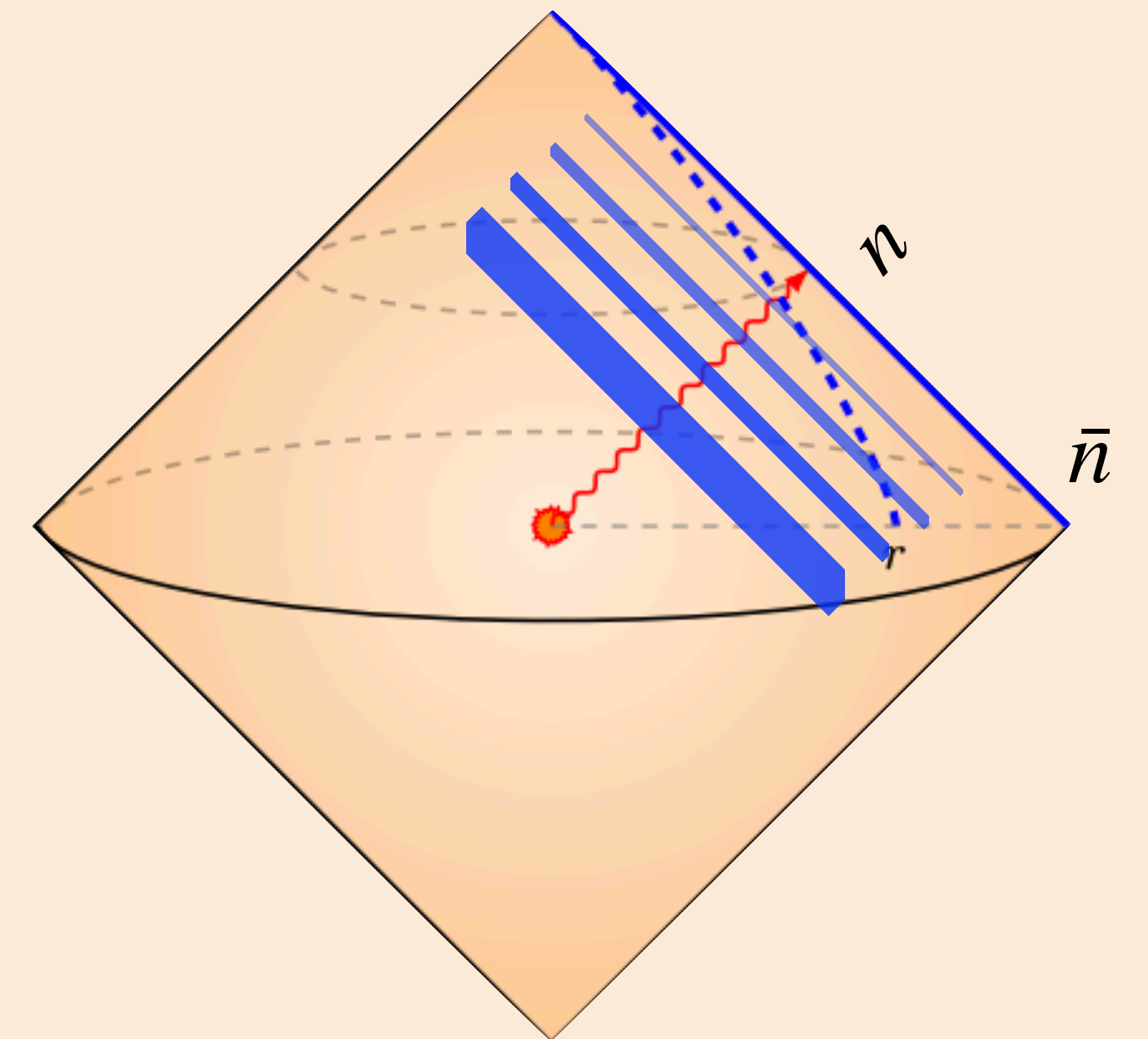
Spin

e.g. $T_{\mu\nu}$

$\bar{\psi} \gamma_{\mu_1} iD_{\mu_2} \dots iD_{\mu_J} \psi$

$$-\Delta_L = \Delta - 1 - \Delta + J = J - 1 \quad J_L = -\Delta + J + 1 - J = -\Delta + 1$$

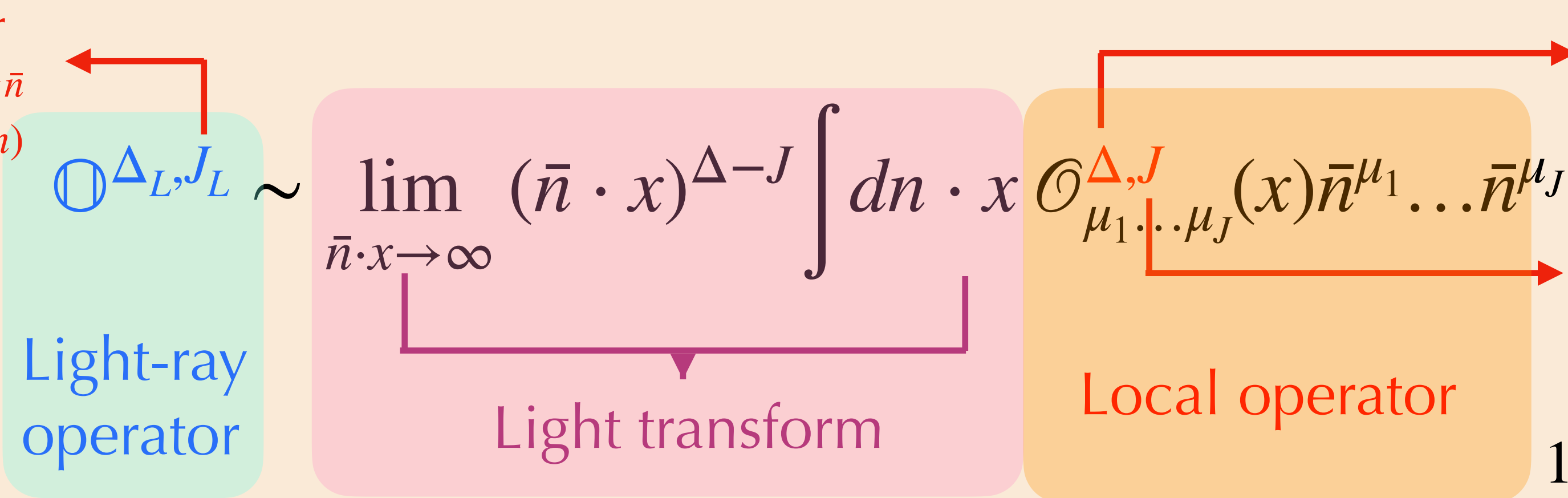
$$\Delta_L - J_L = \Delta - J = \tau \quad \text{Conserves twist}$$



Scaling behavior by light-ray OPE

Scaling under
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 $\mathbb{O}(\rho n) = \rho^{J_L} \mathbb{O}(n)$

1905.01311



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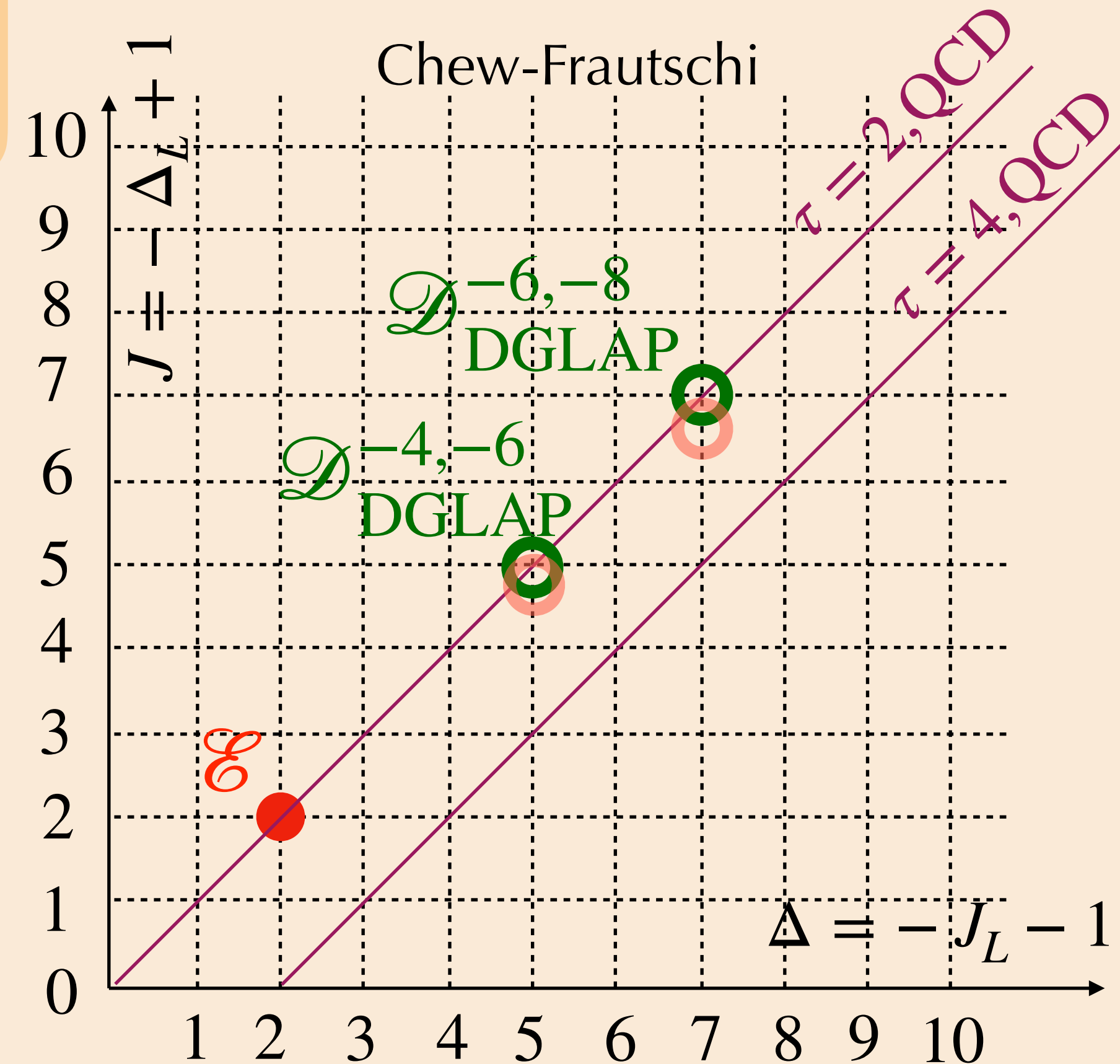
$$\mathcal{E} : \quad -\Delta_L = 2 - 1 = 1, \quad J_L = -4 + 1 = -3$$

$$\sqrt{\zeta} : \quad -\Delta_L = 0, \quad J_L = 1 \quad (p_{\perp} \sim \bar{n} \cdot P \sqrt{\zeta} \text{ unchanged under boost})$$

$\mathcal{D}_{\text{DGLAP}}$, Light-ray transformation of the local twist-2 operators:

$$\tau = 2 = \Delta - J = \Delta_L - J_L$$

$$\frac{d\mathcal{D}_{\text{DGLAP}}}{d \ln \mu^2} = \hat{\gamma}(J) \mathcal{D}_{\text{DGLAP}}$$

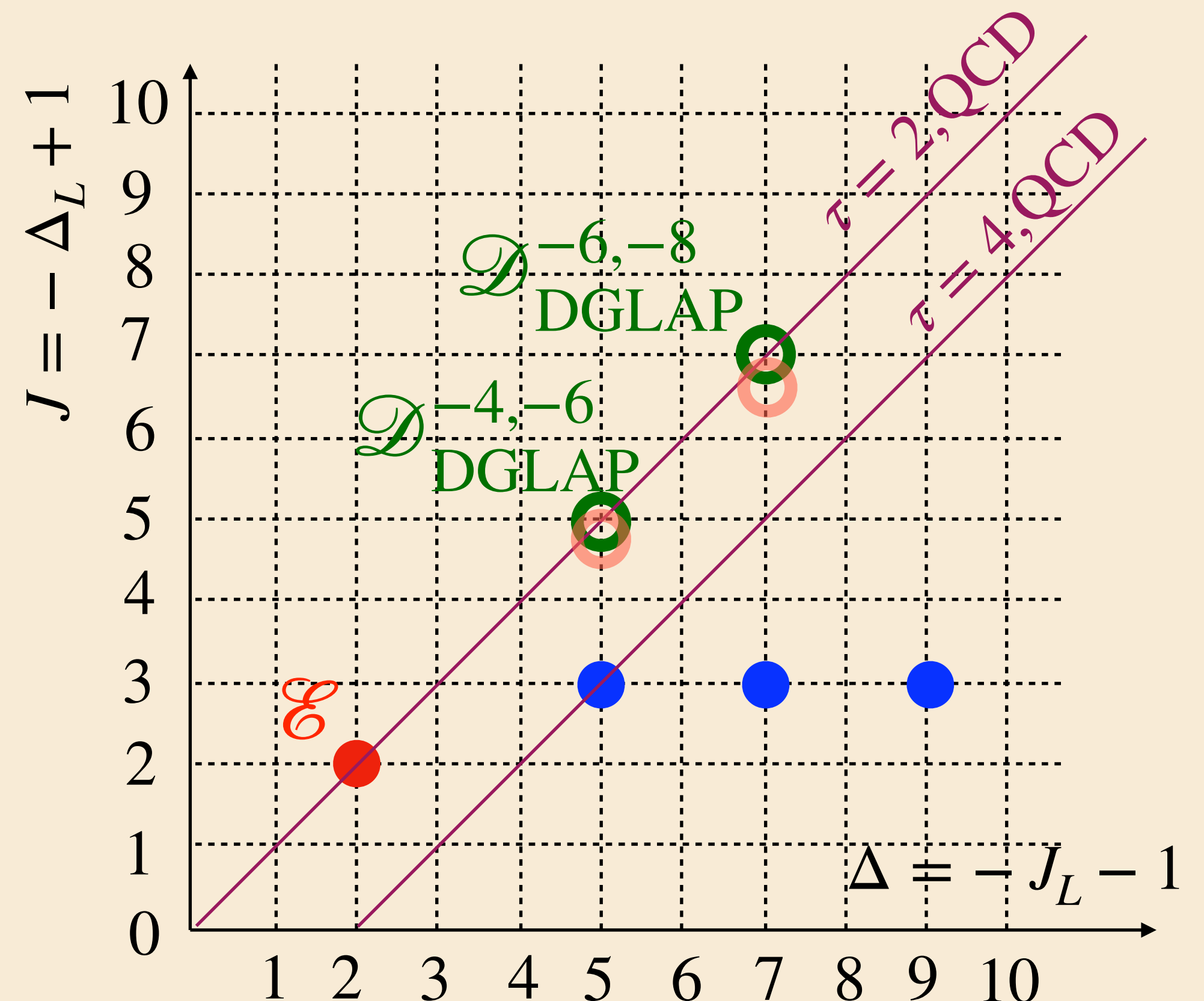


Two Step Matching: 1. onto hadronic operators

$$\begin{aligned}
 -\Delta_{L,\mathcal{E}\mathcal{E}} = 2 \\
 J_{L,\mathcal{E}\mathcal{E}} = -6
 \end{aligned}
 \quad
 \mathcal{E}(n_1)\mathcal{E}(n_2) = \sum_{J_L} A_{J_L} \sqrt{\zeta}^{-6-J_L} \mathbb{O}_H^{-2,J_L}(n_2)
 \quad
 = A_0 \zeta^0 \mathbb{O}_H^{-2,-6} + \dots$$

$-\Delta_L = 2$
 $-J_L = 6$

- Light-ray OPE in the small ζ limit with a hadron EFT ((boost)-Chiral?), in the free hadron regime, assume zero hadron mass
- Equate the Lorentz dimension and Lorentz spin on both sides of the expansion. Keep the dimension unchanged, All $\mathbb{O}_H^{\Delta_L, J_L}$ have the same $\Delta_L = -2$
- Both A_{J_L} and \mathbb{O}_H can be calculated within the hadron EFT



Two Step Matching: 2. onto QCD partonic operators

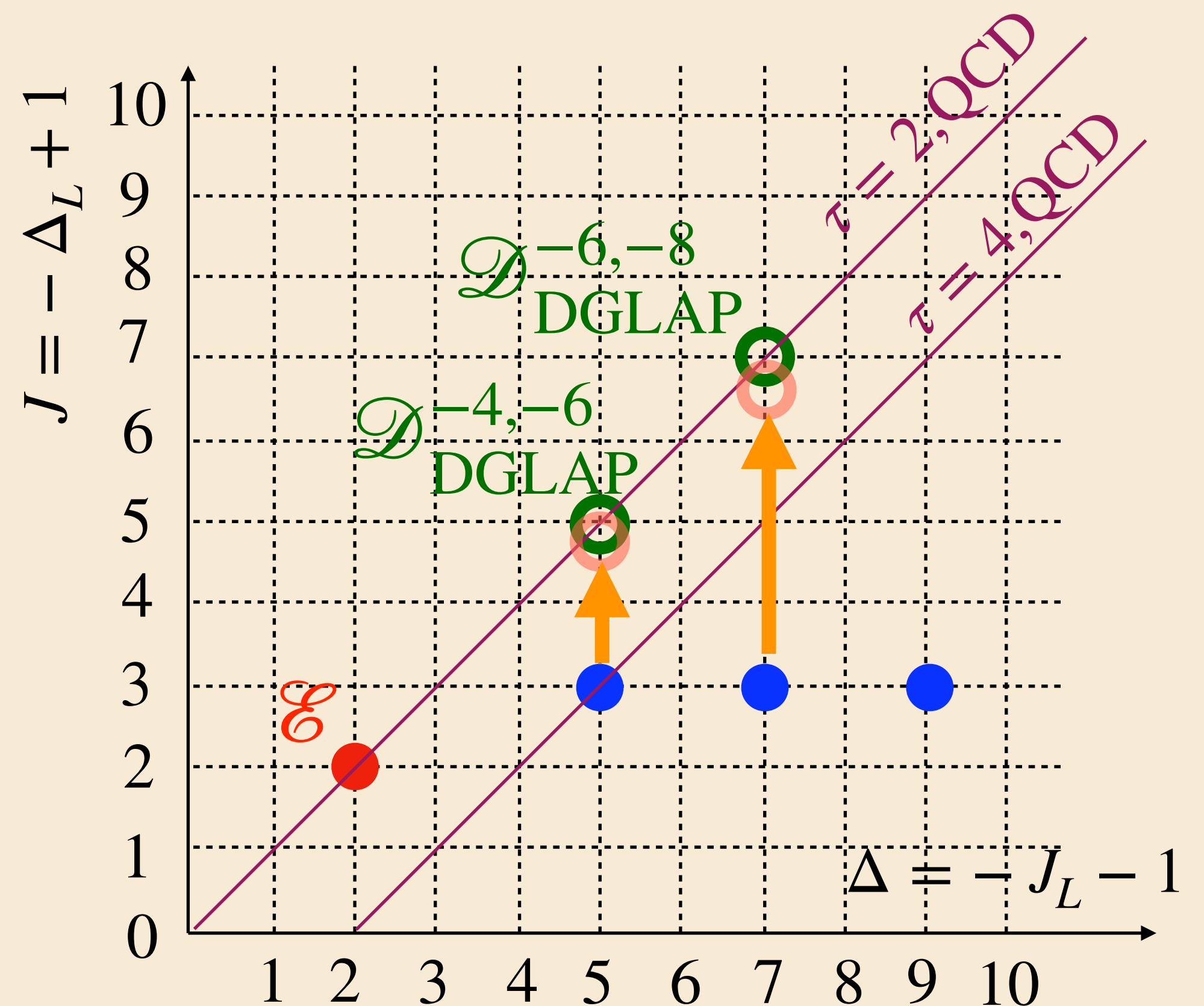
$$\begin{aligned}
 -\Delta_{L,\mathcal{E}\mathcal{E}} = 2 \\
 J_{L,\mathcal{E}\mathcal{E}} = -6
 \end{aligned}
 \quad
 \mathcal{E}(n_1)\mathcal{E}(n_2) = \sum_{J_L} A_{J_L} \sqrt{\zeta}^{-6-J_L} \mathbb{O}_H^{-2,J_L}(n_2) = A_0 \zeta^0 \mathbb{O}_H^{-2,-6} + \dots$$

$-\Delta_L = 2$
 $-J_L = 6$

○ Match onto quark/gluon operators

$$\mathbb{O}_H^{-2,-6} = \frac{B_{-4}}{\Lambda_{\text{QCD}}^2} \mathcal{D}_{\text{DGLAP}}^{-4,-6}(\mu^2) + \text{higher twist}$$

J_L keeps fixed while Δ_L could change due to Λ_{QCD}



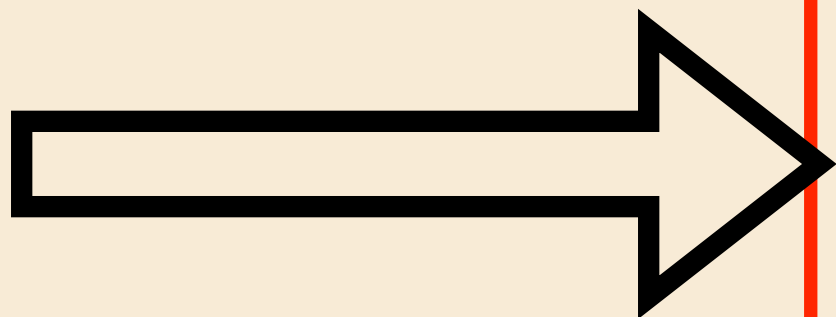
Scaling behavior by light-ray OPE

$$H(Q) \equiv \langle \mathcal{E}(n_1) \mathcal{E}(n_2) \rangle / Q^4 = A_0 B_{-4} \frac{1}{\Lambda_{\text{QCD}}^2} \langle \mathcal{D}_{\text{DGLAP}}^{-4,-6}(\mu^2) \rangle / Q^4 + \dots$$

- $A_0 B_{-4}$ Non-pert. (diFF)
- $\langle \mathcal{D}_{\text{DGLAP}} \rangle$ calculable in pQCD, the 5-th moment of single parton production cross section

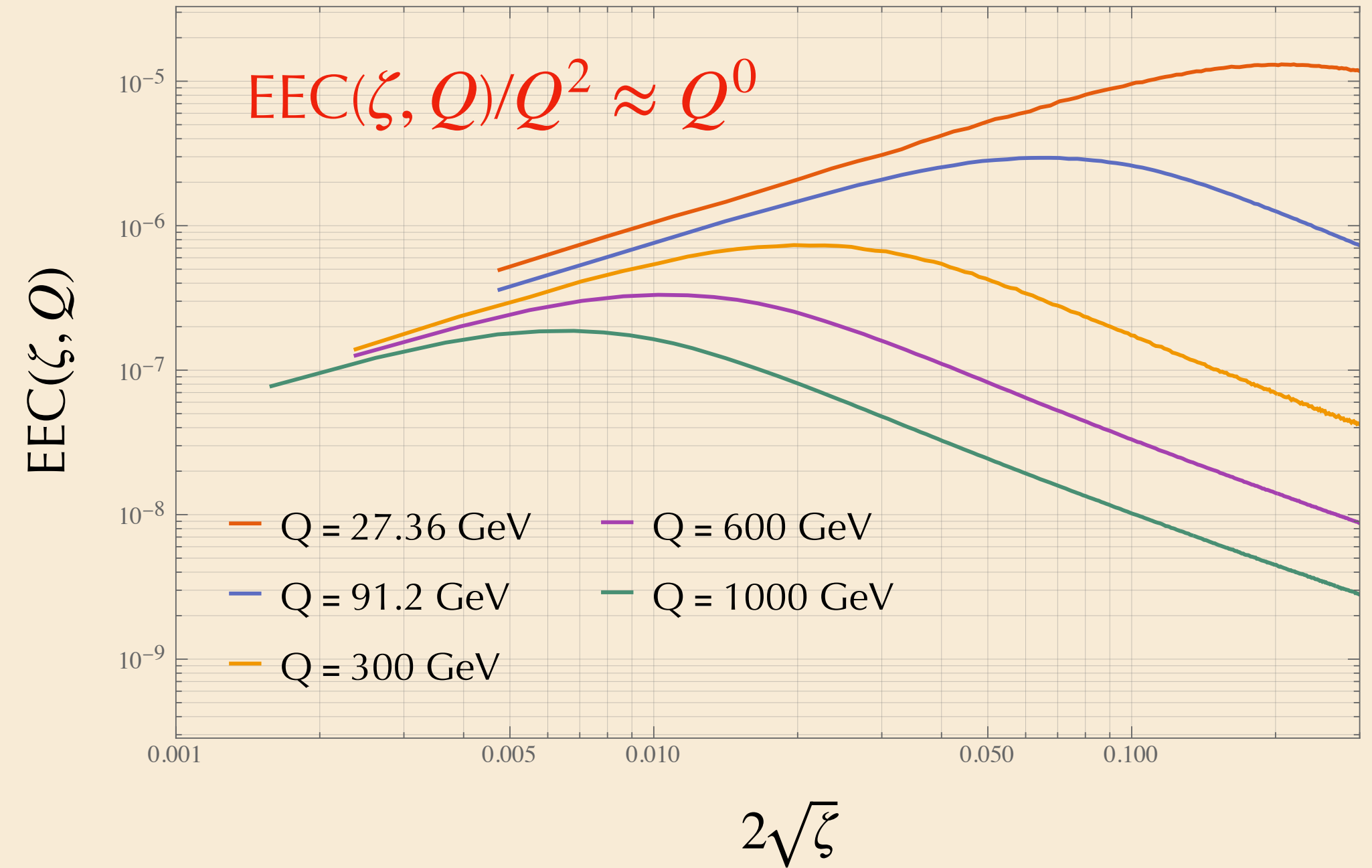
- Classic $(Q^2)^0$ scaling naturally recovers the plateau behavior, can also predict finite ζ terms ($-J_L > 6$)
- Quantum scaling for the post confinement plateau :

μ cancellation
between $A_0 B_{-4}$
and $\langle \mathcal{D}_{\text{DGLAP}} \rangle$



$$\frac{d\mathcal{D}_{\text{DGLAP}}}{d \ln \mu^2} = \hat{\gamma}(J=5) \mathcal{D}_{\text{DGLAP}}$$

$$\frac{H(Q_2)}{H(Q_1)} \sim \left[\frac{\alpha_s(Q_2)}{\alpha_s(Q_1)} \right]^{\gamma(J=5)/\beta_0}$$



The height difference governed by α_s
Possible for α_s extraction

Phenomenology

Zhan Wang ,et al. In preparation

Phenomenology

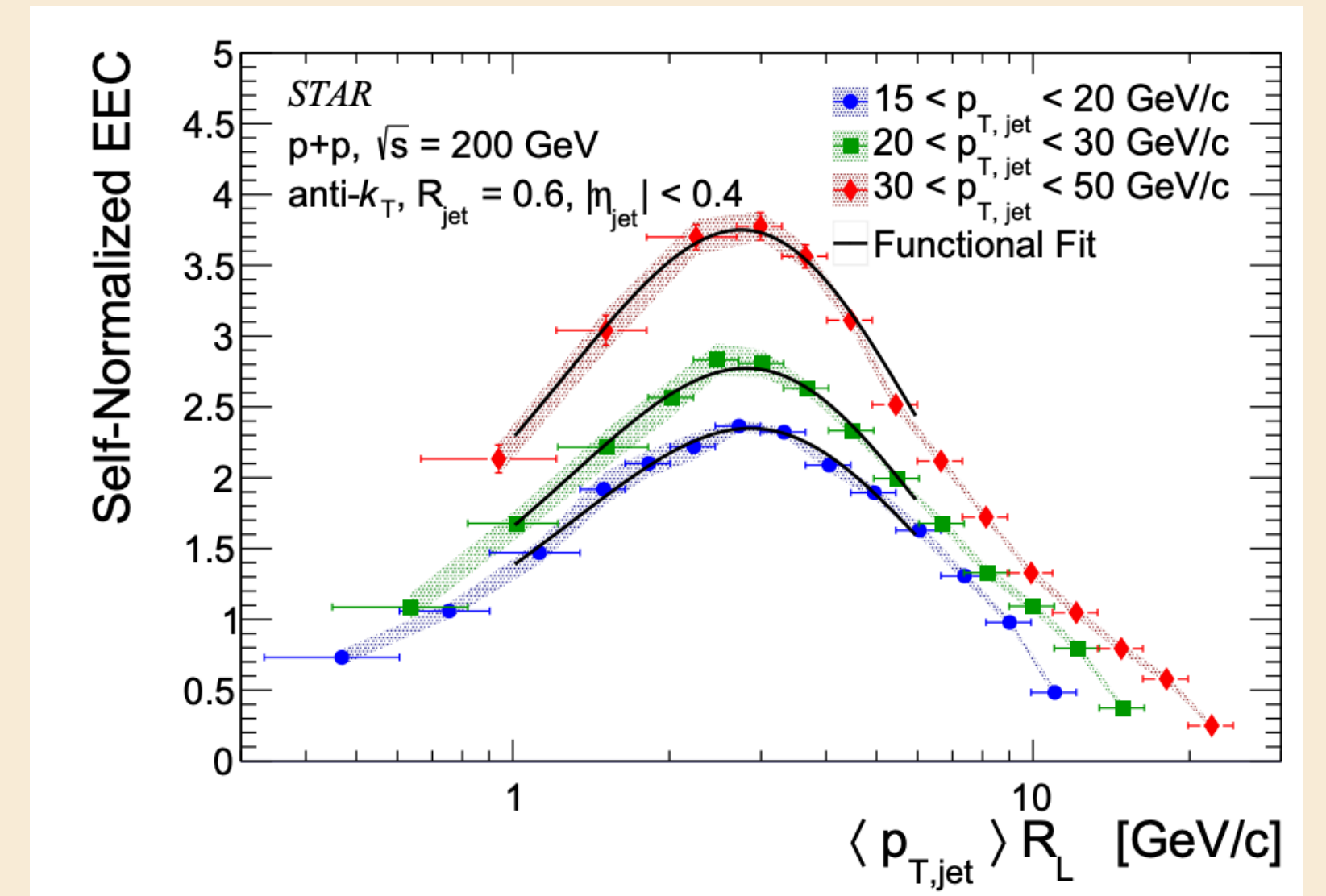
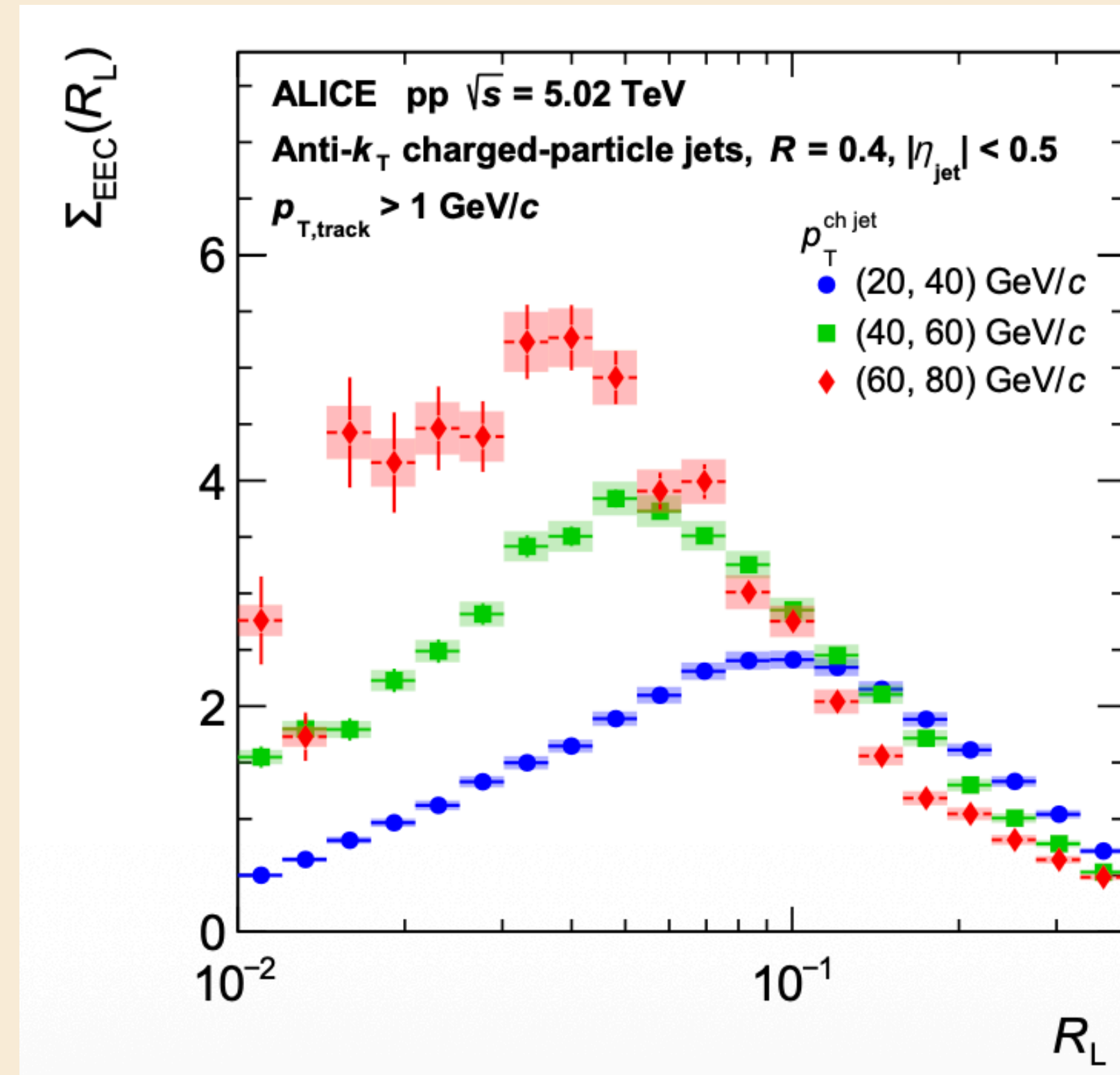
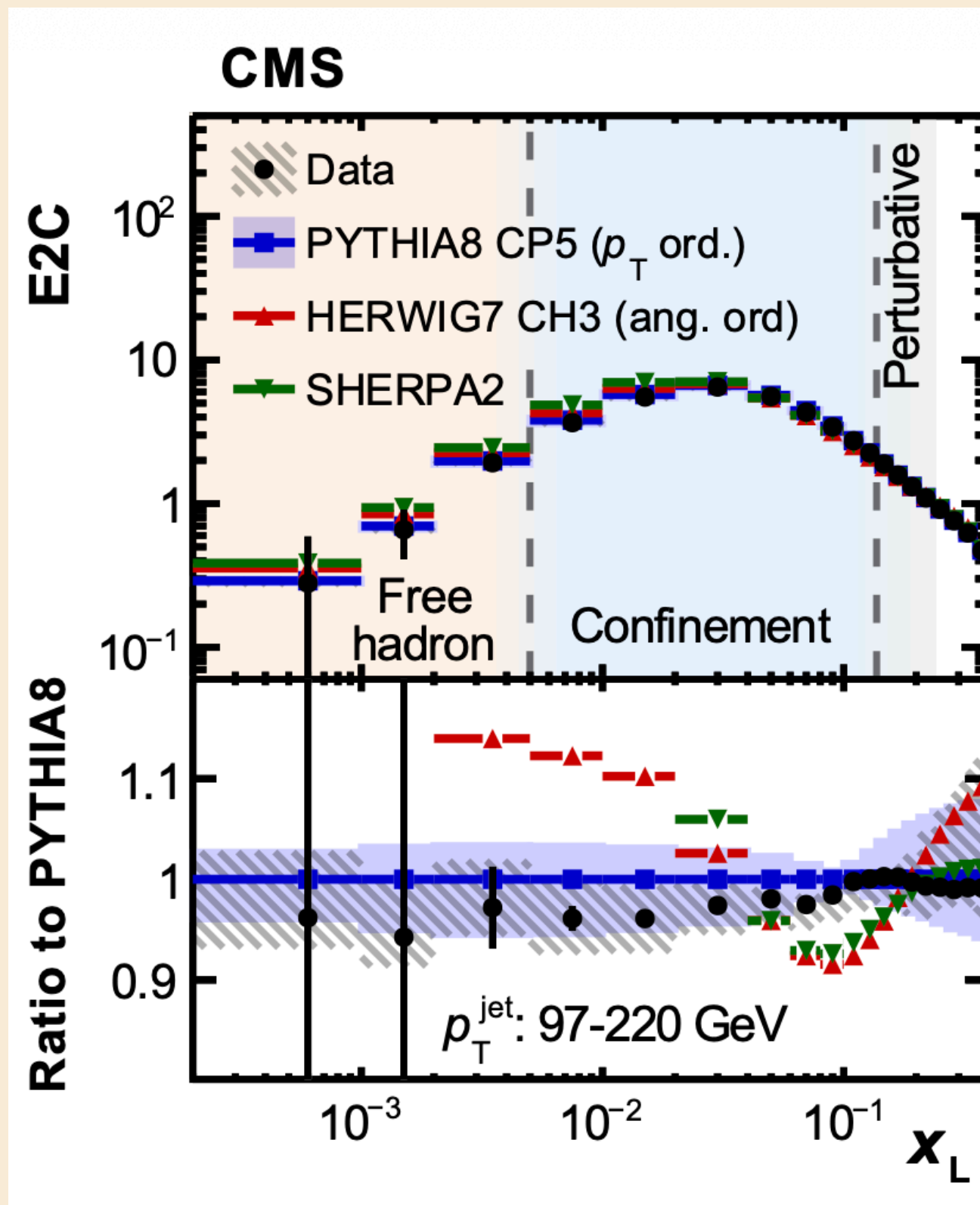
Precision budget:

- N3LO + NNLL for e^+e^- , N3LO adapted from hadron leptonic production [He, Xing, Yang, Zhu PRL 2025](#)
- NLO + NNLL for pp , NLO by hacking FMNLO [C. Liu, X. Shen, B. Zhou, and J. Gao, JHEP 2023](#)
- NNLO + NNLL for pp in principle achievable [Czakon, et al., 2025; NNLOJET group, 2025](#)
- N3LO + NNLL for ep in principle achievable [Dong, Fang, Gao, Li, Shao, Zhu, Zhu, 2603.29673](#)
- N3LL needs 4-loop splitting function, now known for space-like non-singlet
[Gehrmann, Manteuffel, Sotnikov, Yang, 2604.09534](#)

Phenomenology

Experiment status:

- CMS, ALICE, STAR

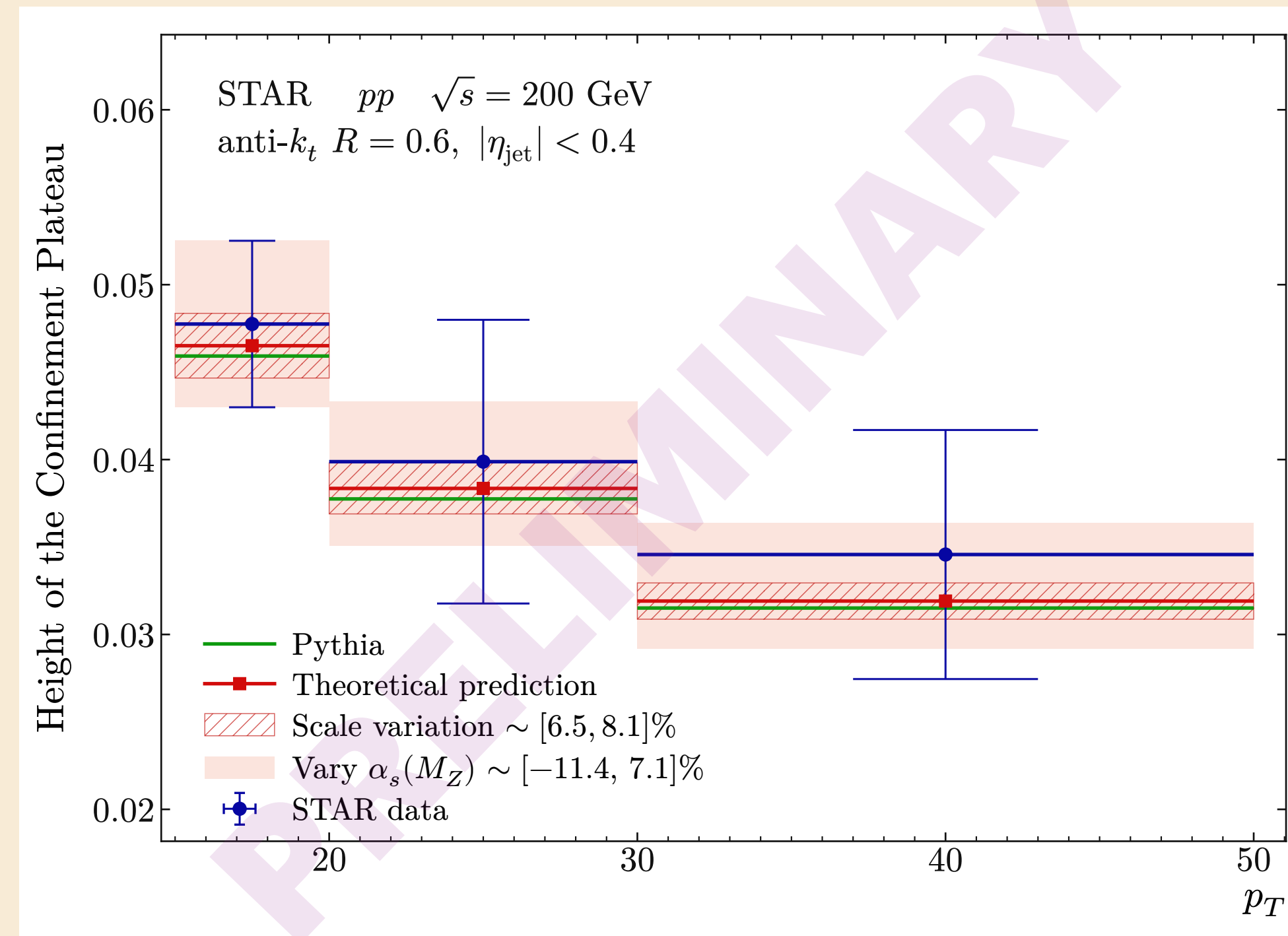
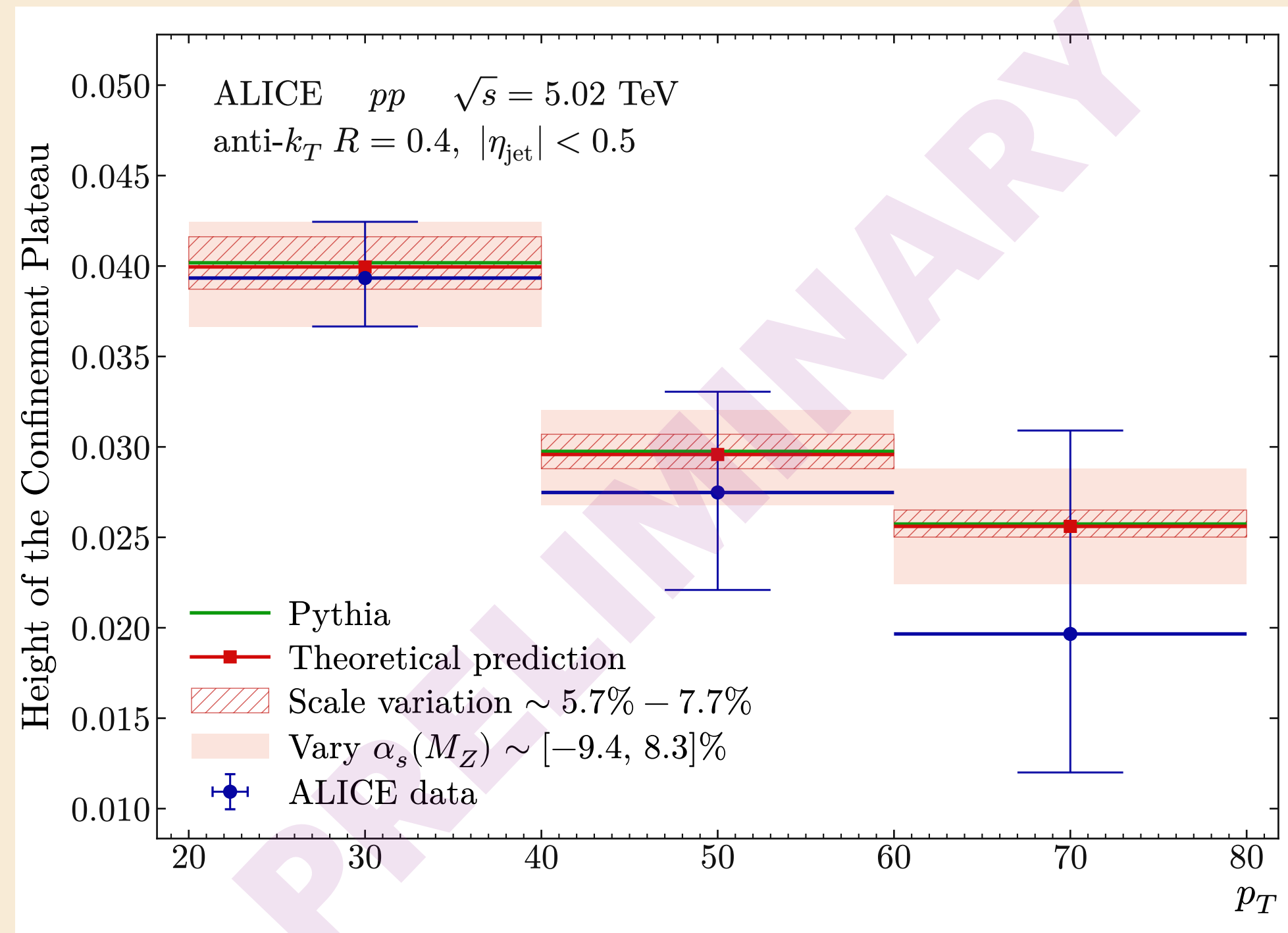


- All measure EEC and the data cover the post-confinement region
- Not directly the height of the EEC/Q^2 , less sensitive to quantum scaling currently
- Linear fit

Phenomenology

CMS, ALICE, STAR

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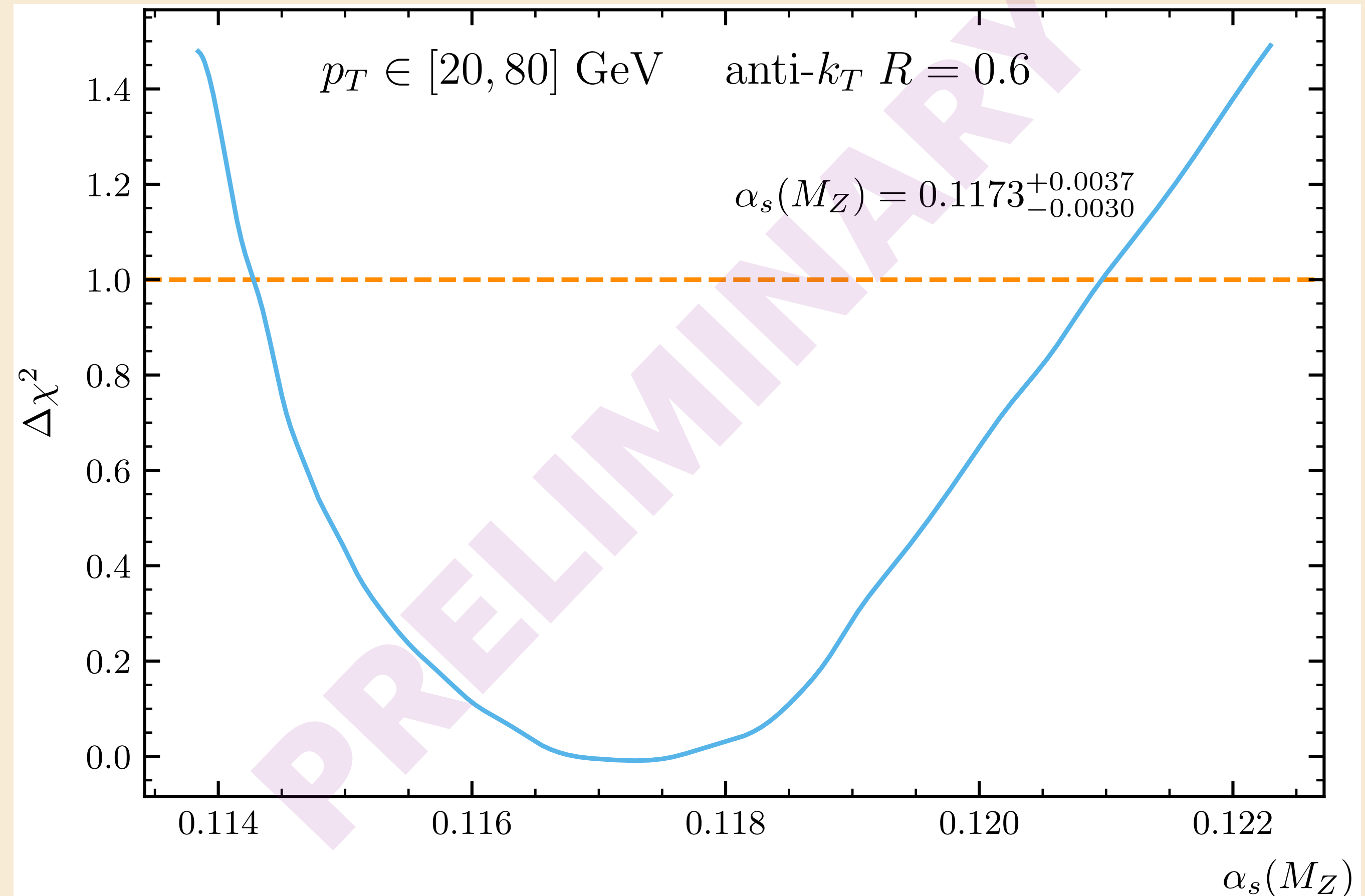


o Overall good agreement with NLO + NNLL @ LHC

Phenomenology

CMS, ALICE, STAR

- α_s extraction study using Pythia pseudo-data
 - Vary α_s while fitting the NP parameters (height)
 - $\sim \pm 5\%$ precision in α_s extraction, better than other jet-substructure approaches

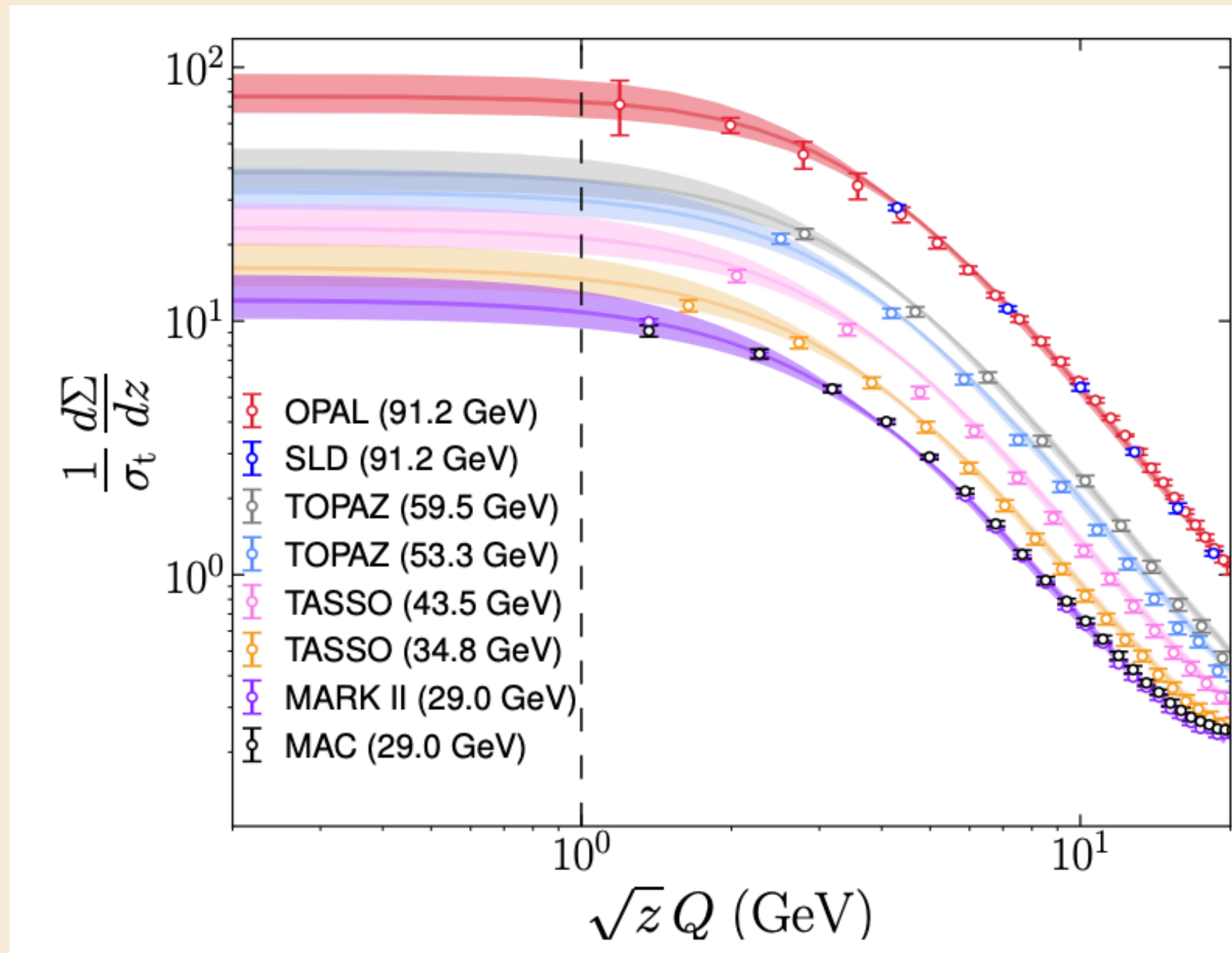


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Phenomenology

Experiment status:

○ e^+e^-

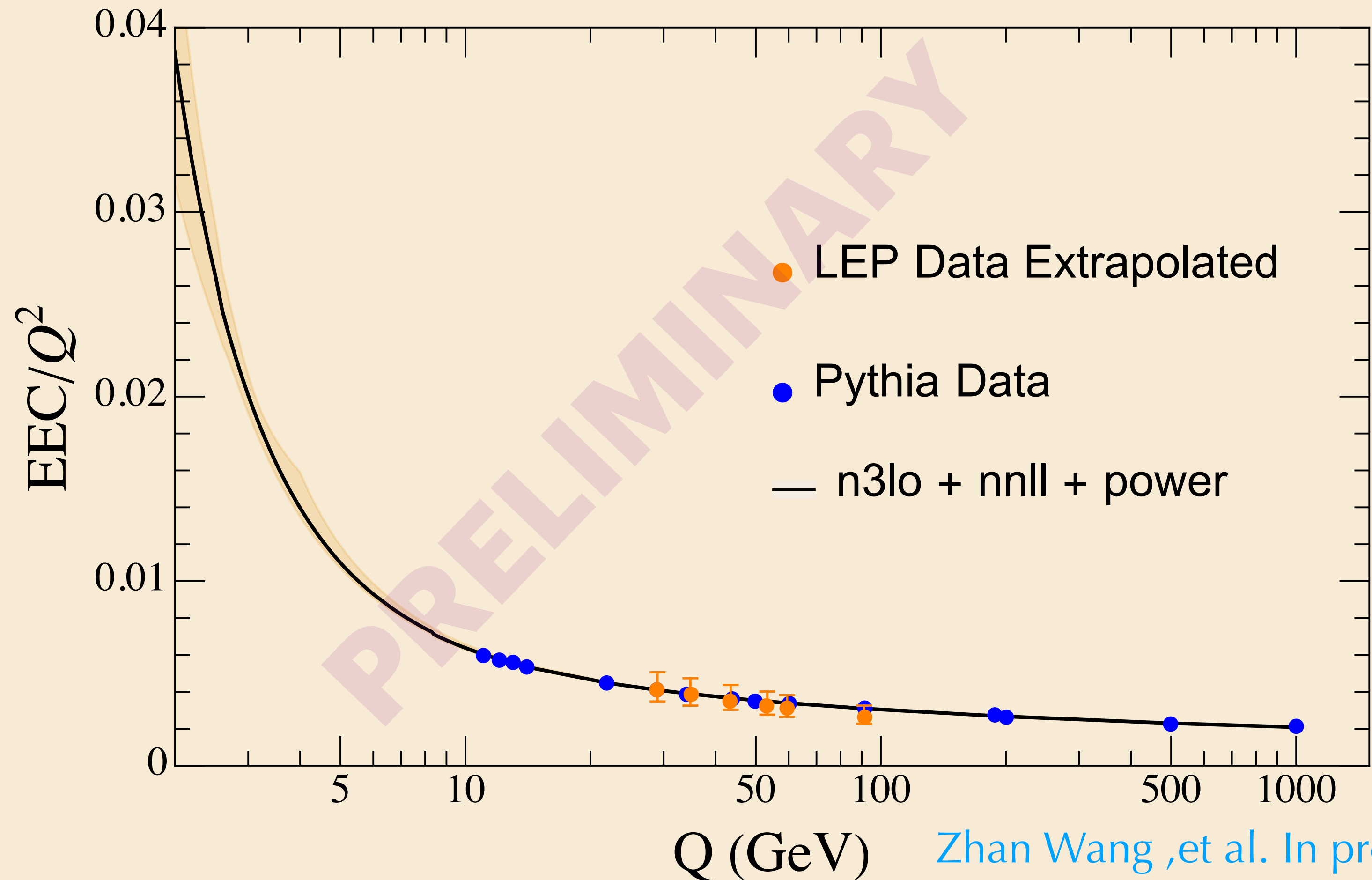


- Mainly old data, do not cover the post-confinement region
- Extrapolation

[Herrmann et al., 2507.17704](#)

Phenomenology

e^+e^-

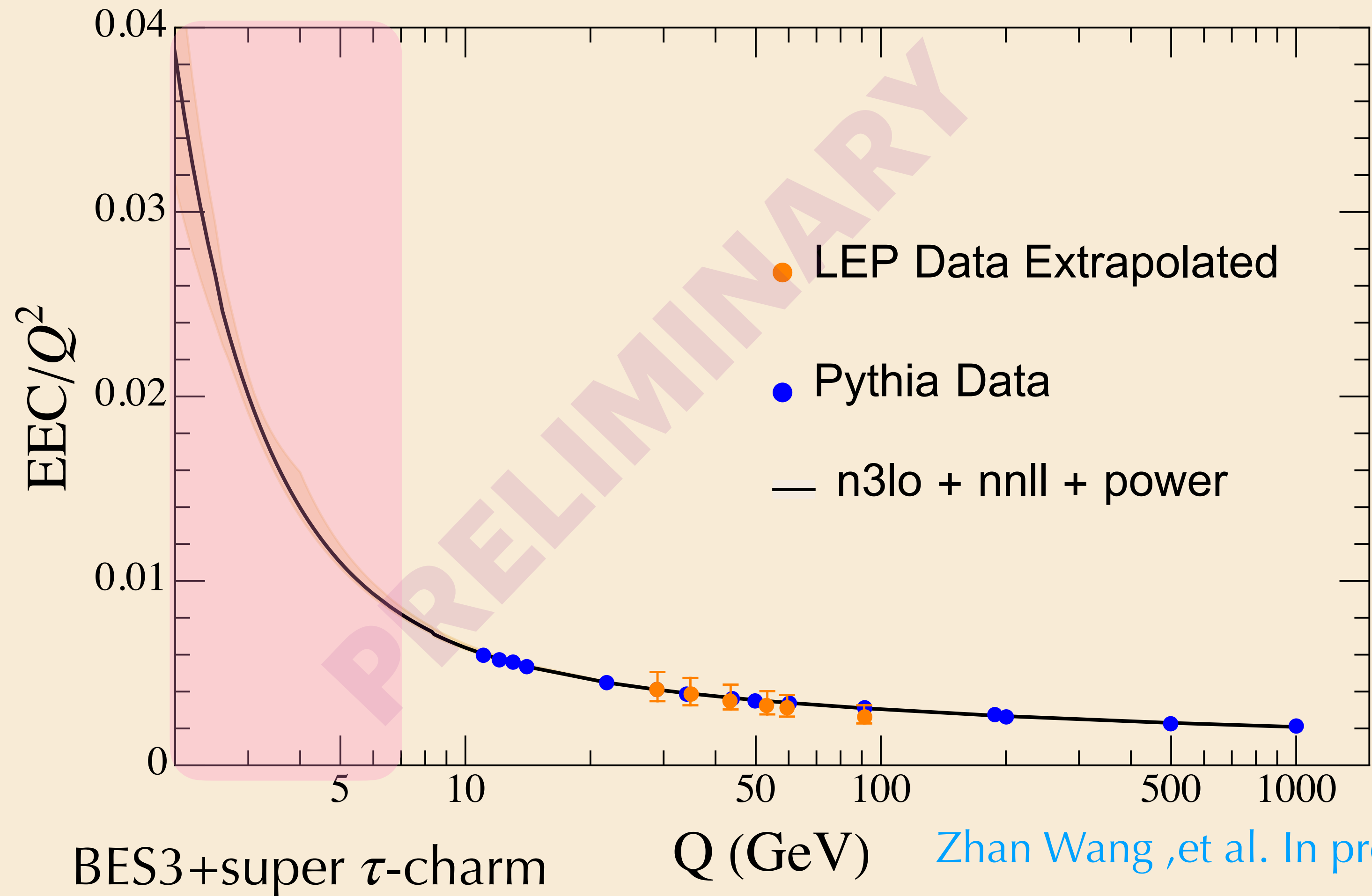


○ Overall good agreement with N3LO + NNLL @ LEP kinematics

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Phenomenology

e^+e^-

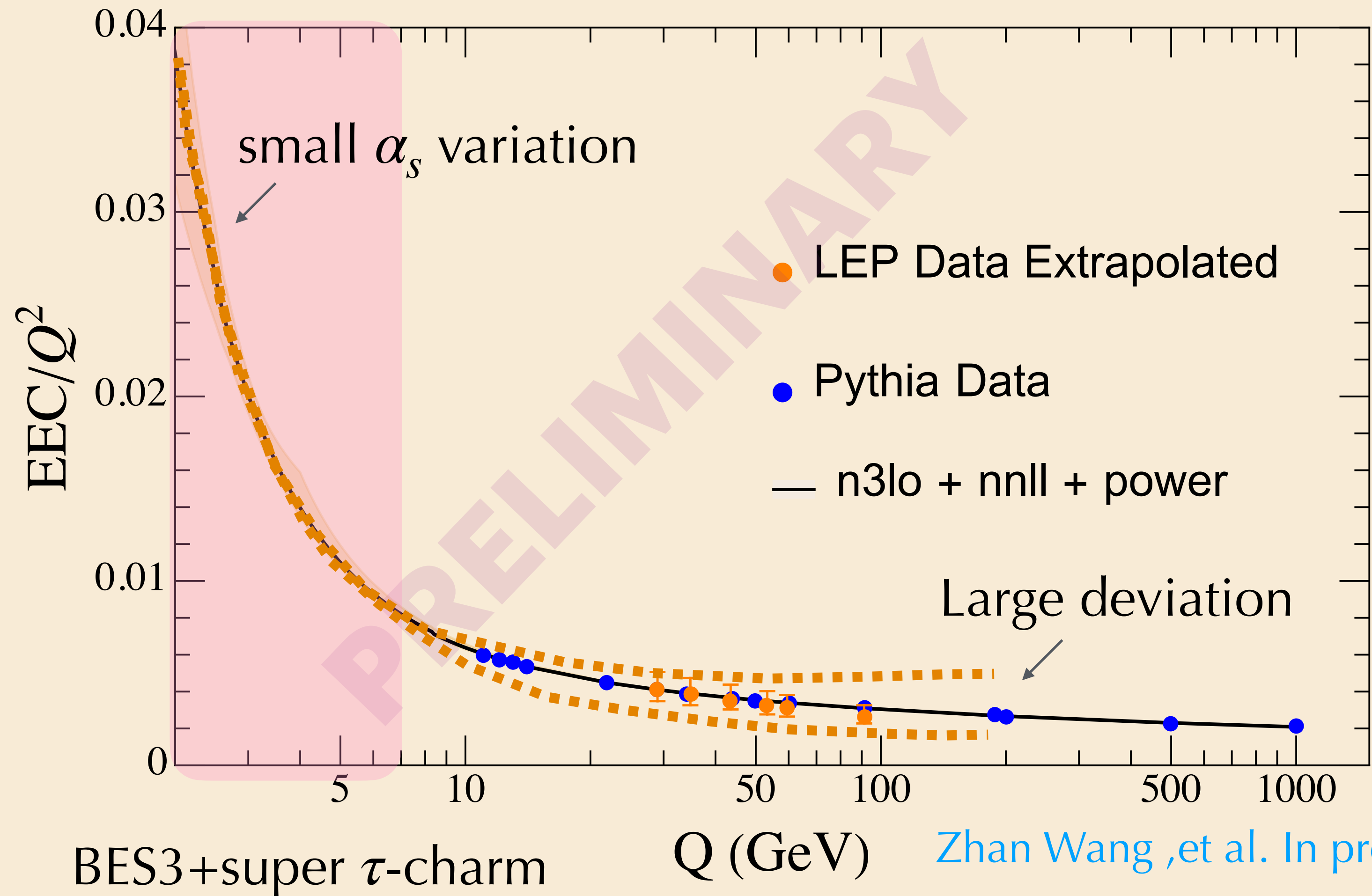


- Overall good agreement with N3LO + NNLL @ LEP kinematics
- Important future check (NP power corrections) within the BES3+super τ -charm region

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Phenomenology

e^+e^-



- Possible precision α_s extraction with BES3/super τ -charm + LEP



Conclusion

- Quantum scaling behavior of the post-confinement EEC governed by DGLAP $J = 5$
- Realizing N3LO+NNLL for e^+e^- and NLO+NNLL for pp , finding good agreement with current data and Pythia
- Similar Idea applicable to EIC, (EEC or NEEC)
- Further pushing the theory precision and possible α_s extraction in the future

Thanks