Energy correlator measurements at the CMS

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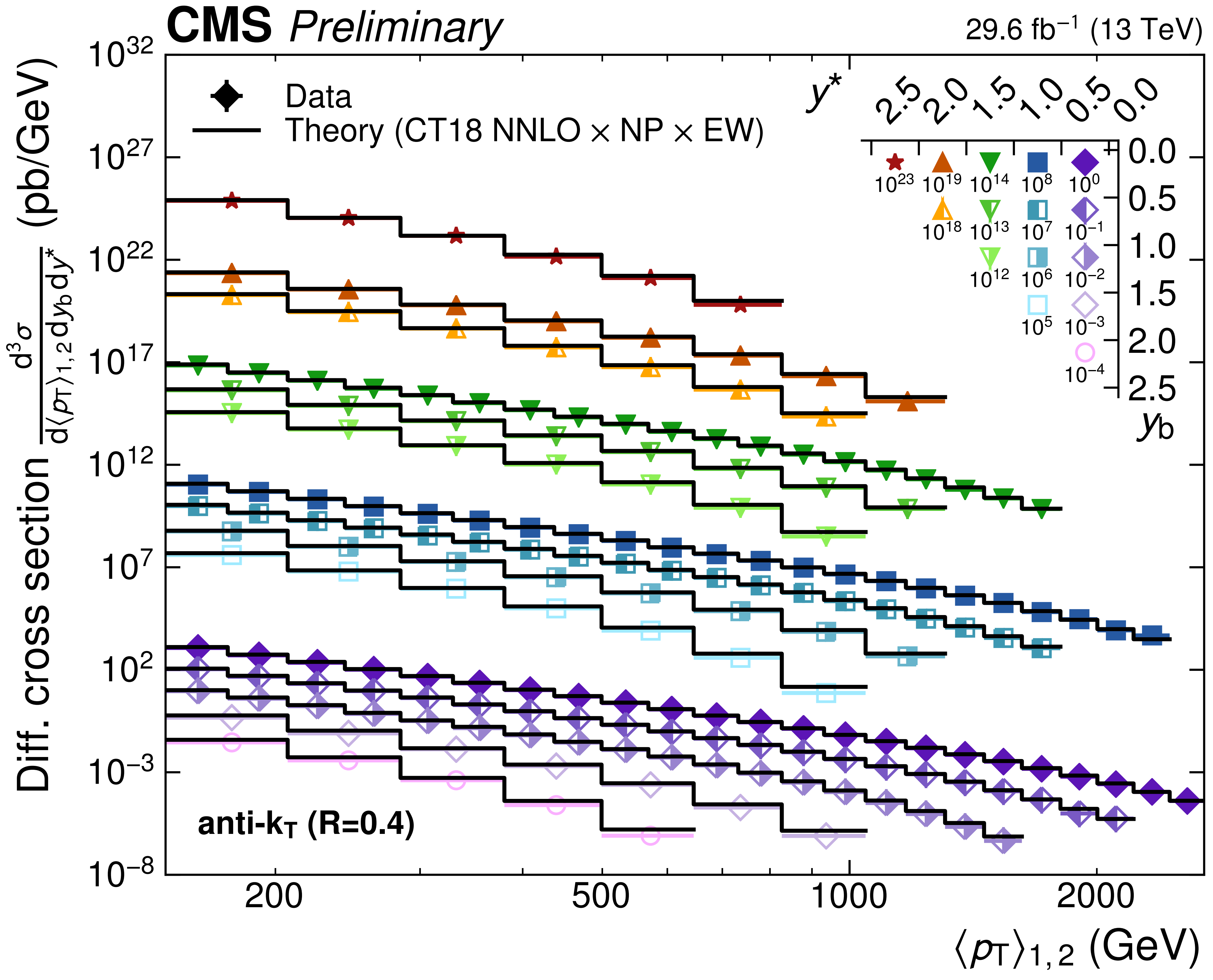
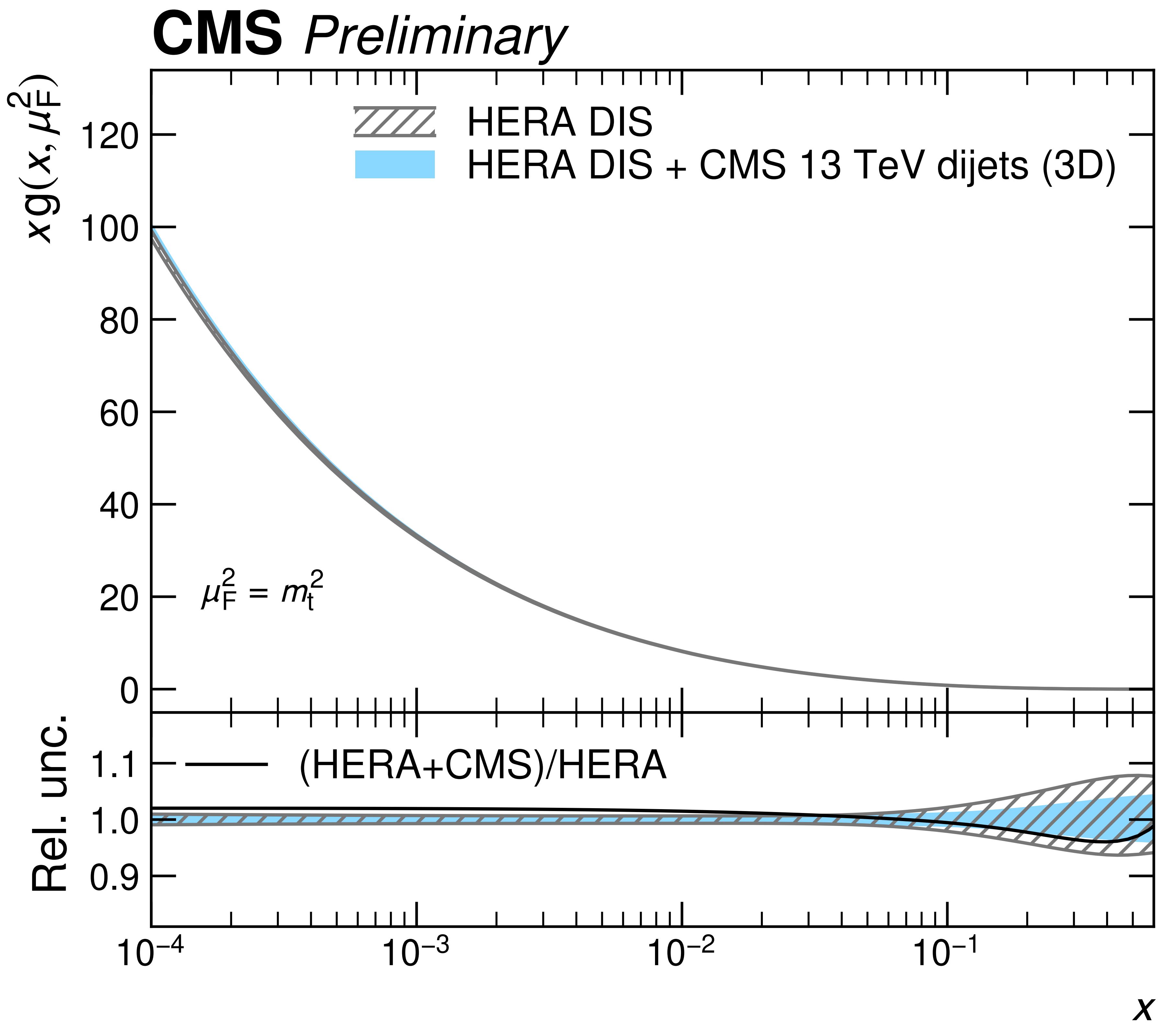
Jets: proxies to study QCD

Di-jet multi-differential cross section
Compared to NNLO predictions, 10^{-4} - 10^{23}

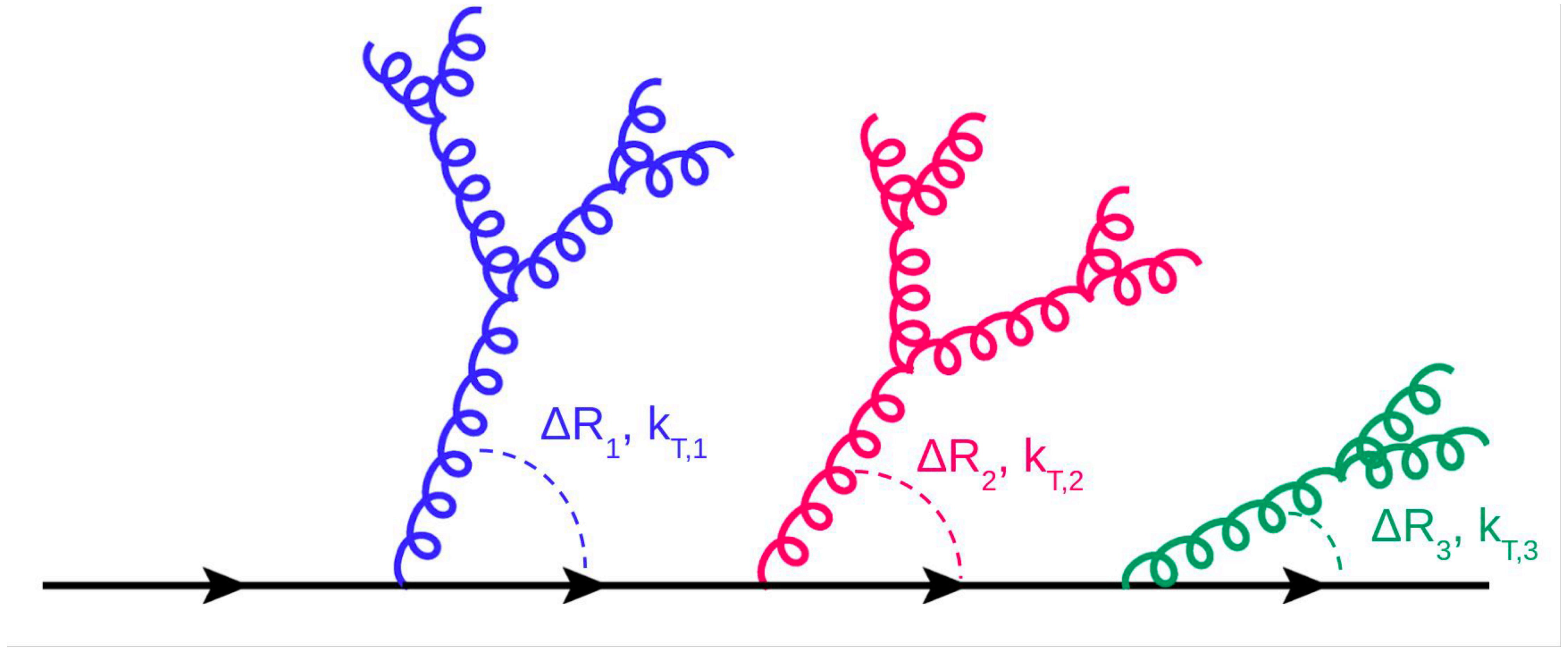


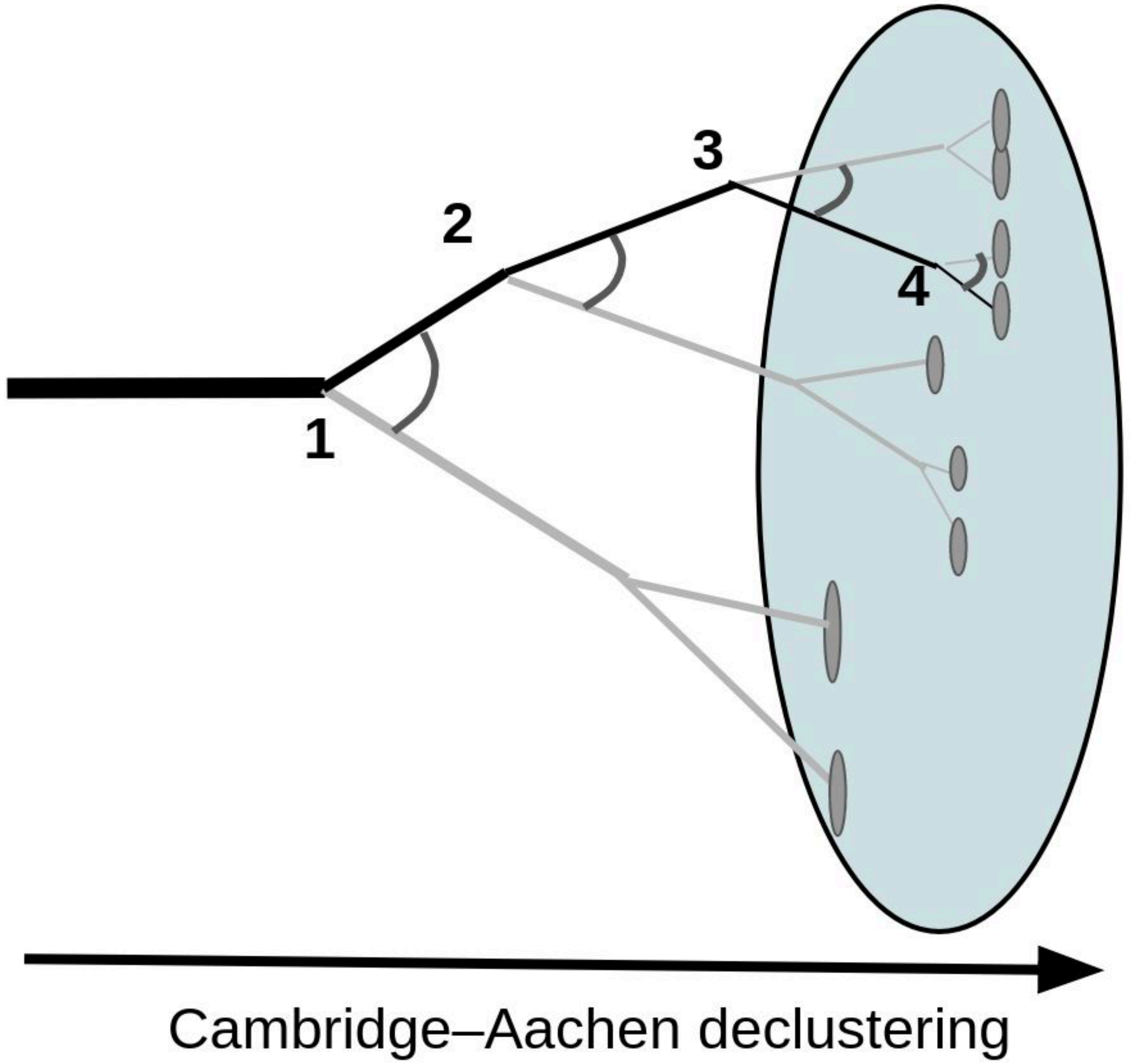
CMS-PAS-SMP-21-008

Constraints on gluon PDF



Jet formation and jet substructure

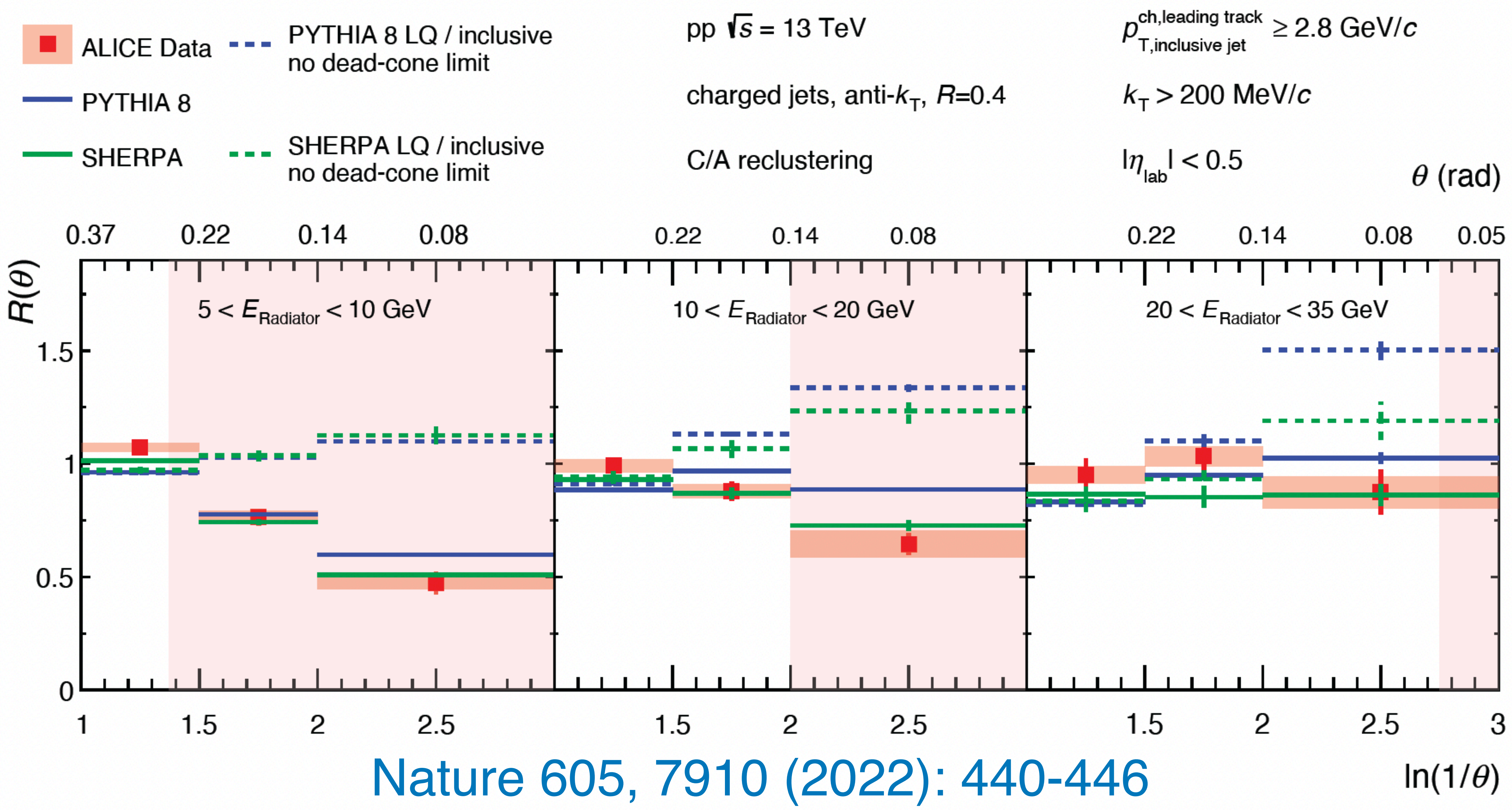




Angular-ordered

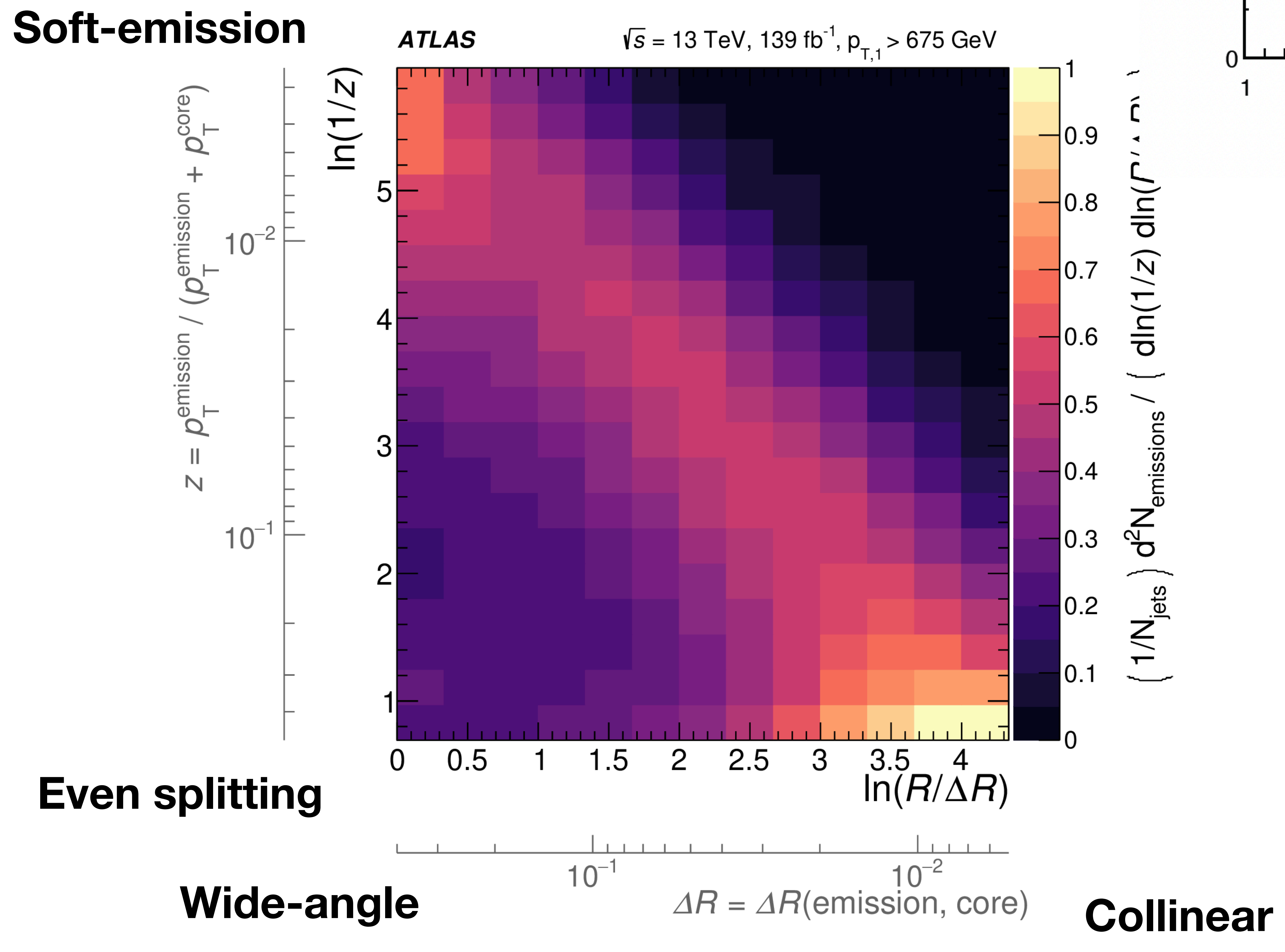
Jet substructure studies

Dead cone



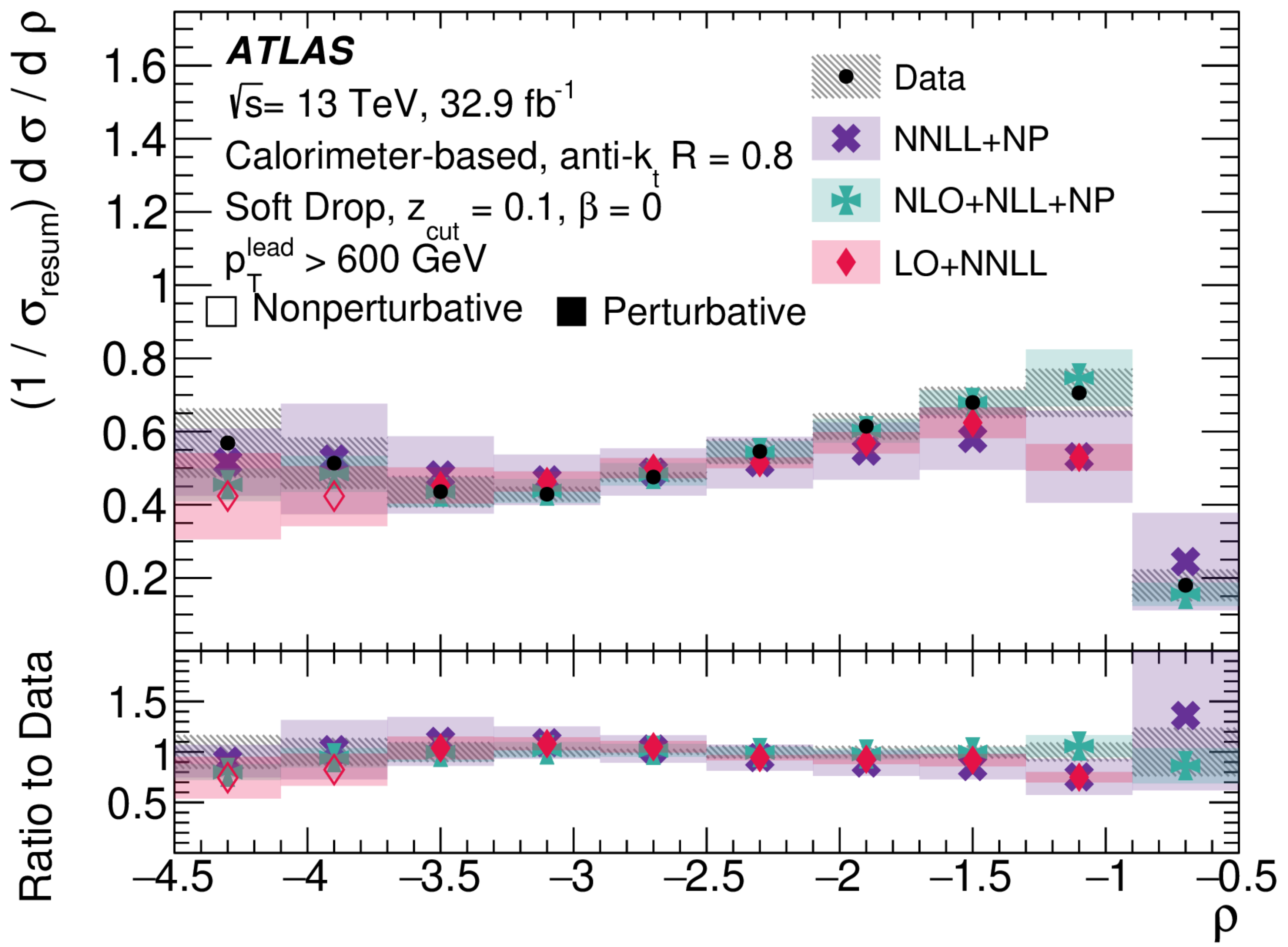
Nature 605, 7910 (2022): 440-446

Lund Plane

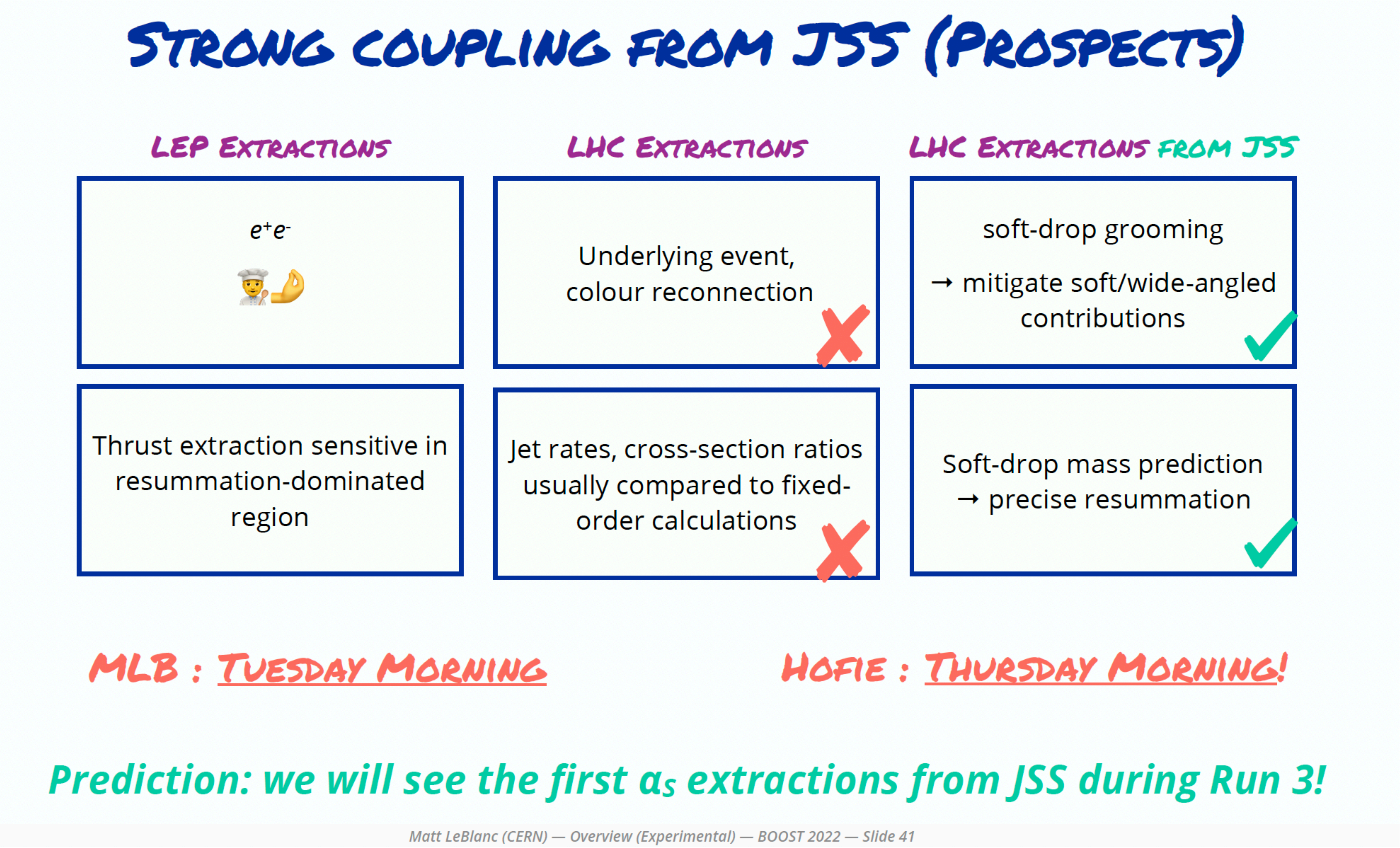


PRL 124 (2020) 222002

Soft drop jet mass

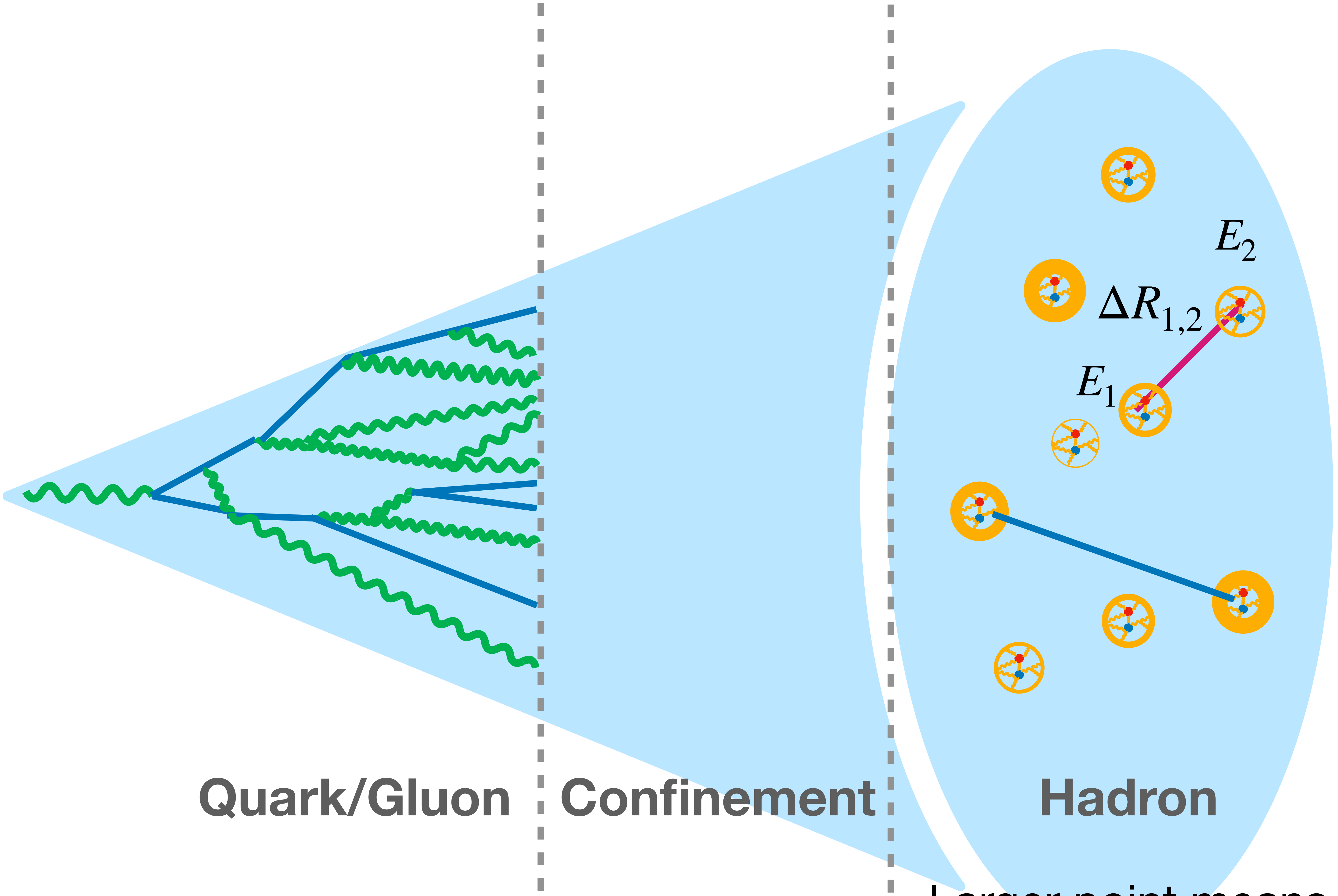


Jet substructure and alphaS

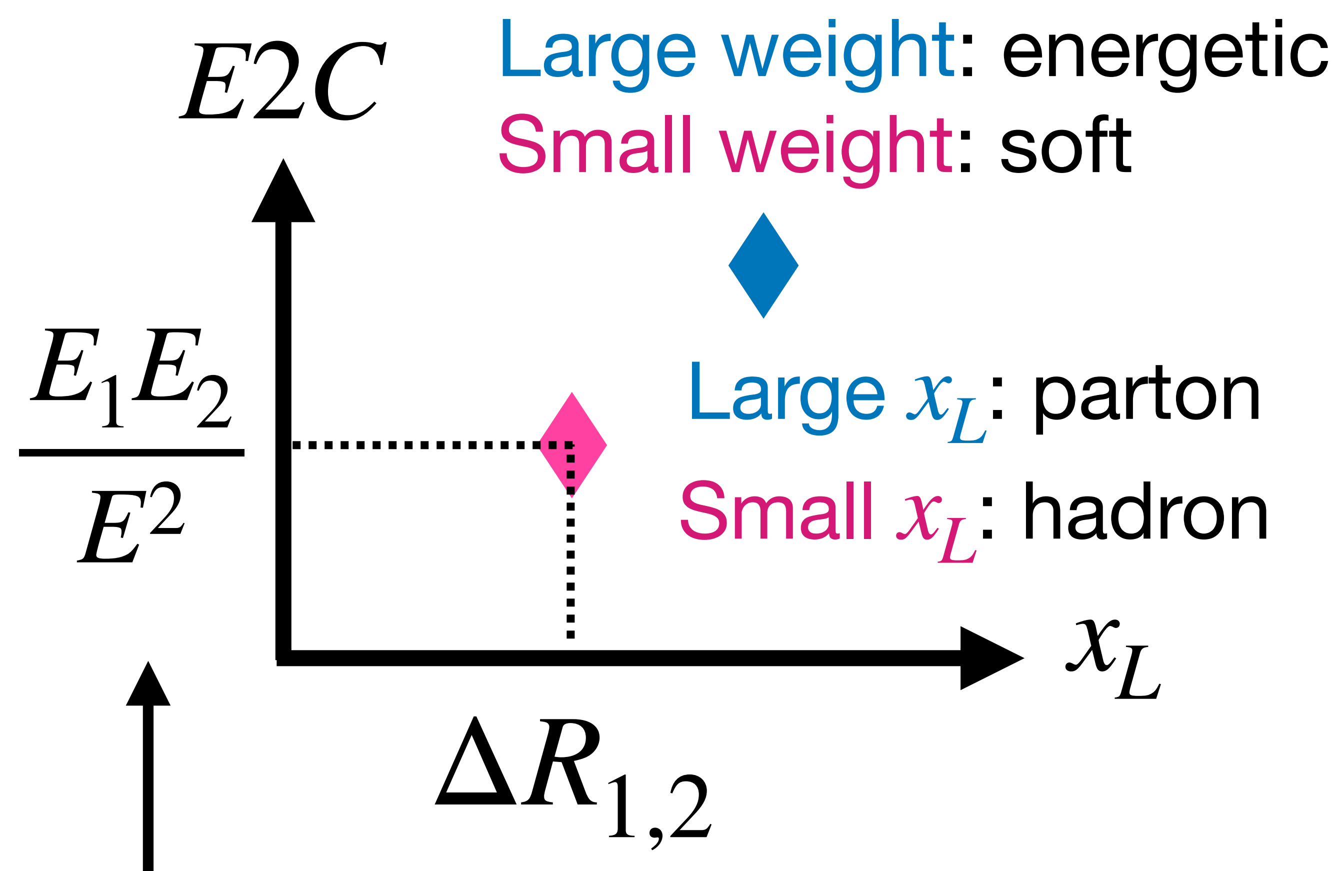


Leshouches2017, axXiv: 1803.07977, estimated precision on αS: 10%

Energy correlators: EnC



Larger point means higher energy



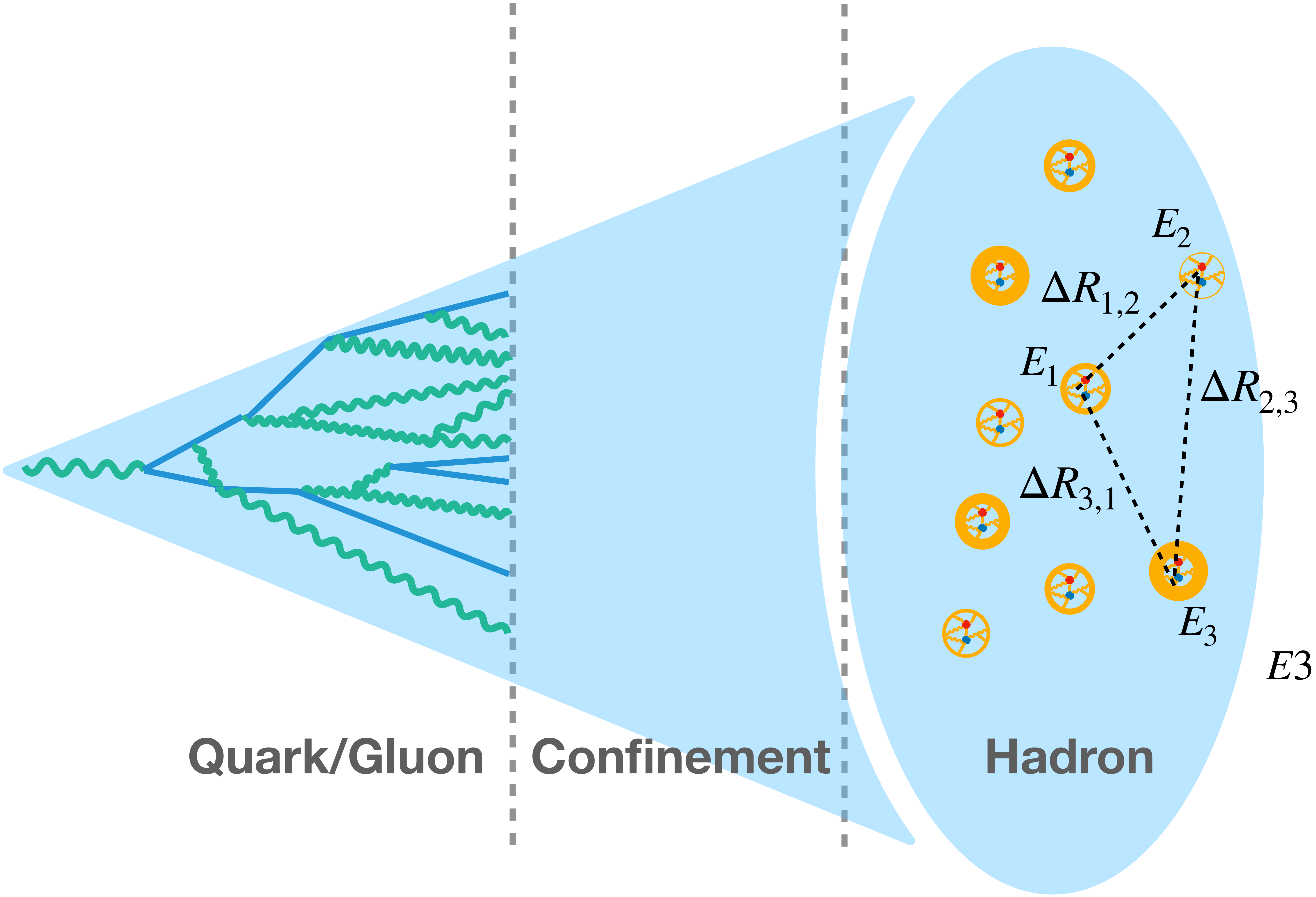
$$E2C = \frac{d\sigma^{[2]}}{dx_L} = \sum_{i,j}^{n} \int d\sigma \frac{E_i E_j}{E^2} \delta(x_L - \Delta R_{i,j})$$

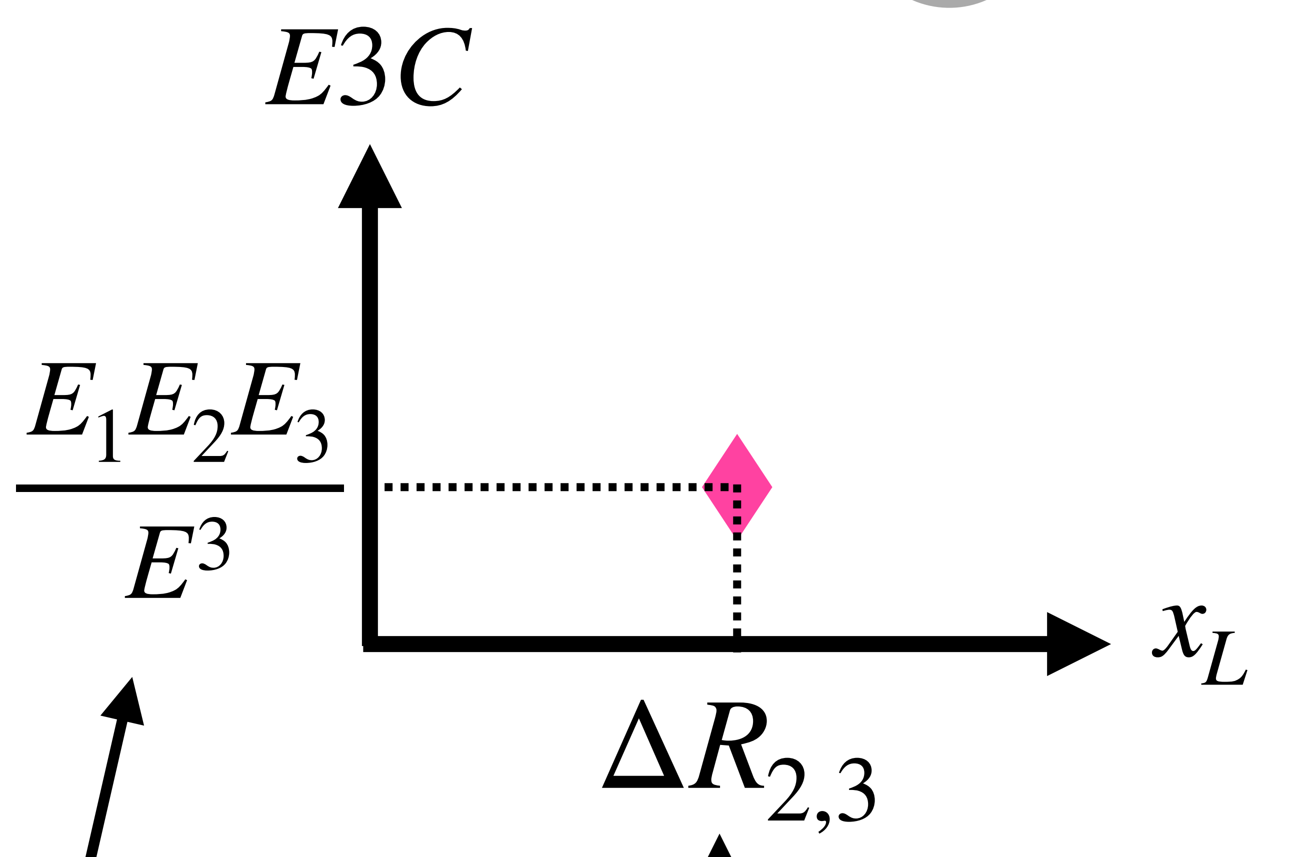
Chen, Moult, Zhang, and Zhu, *arXiv:2004.11381*

Lee, Meçaj, and Moult, *arXiv:2205.03414*

Chen, Gao, Li, Xu, Zhang, and Zhu, *arXiv:2307.07510*

Energy correlators: EnC





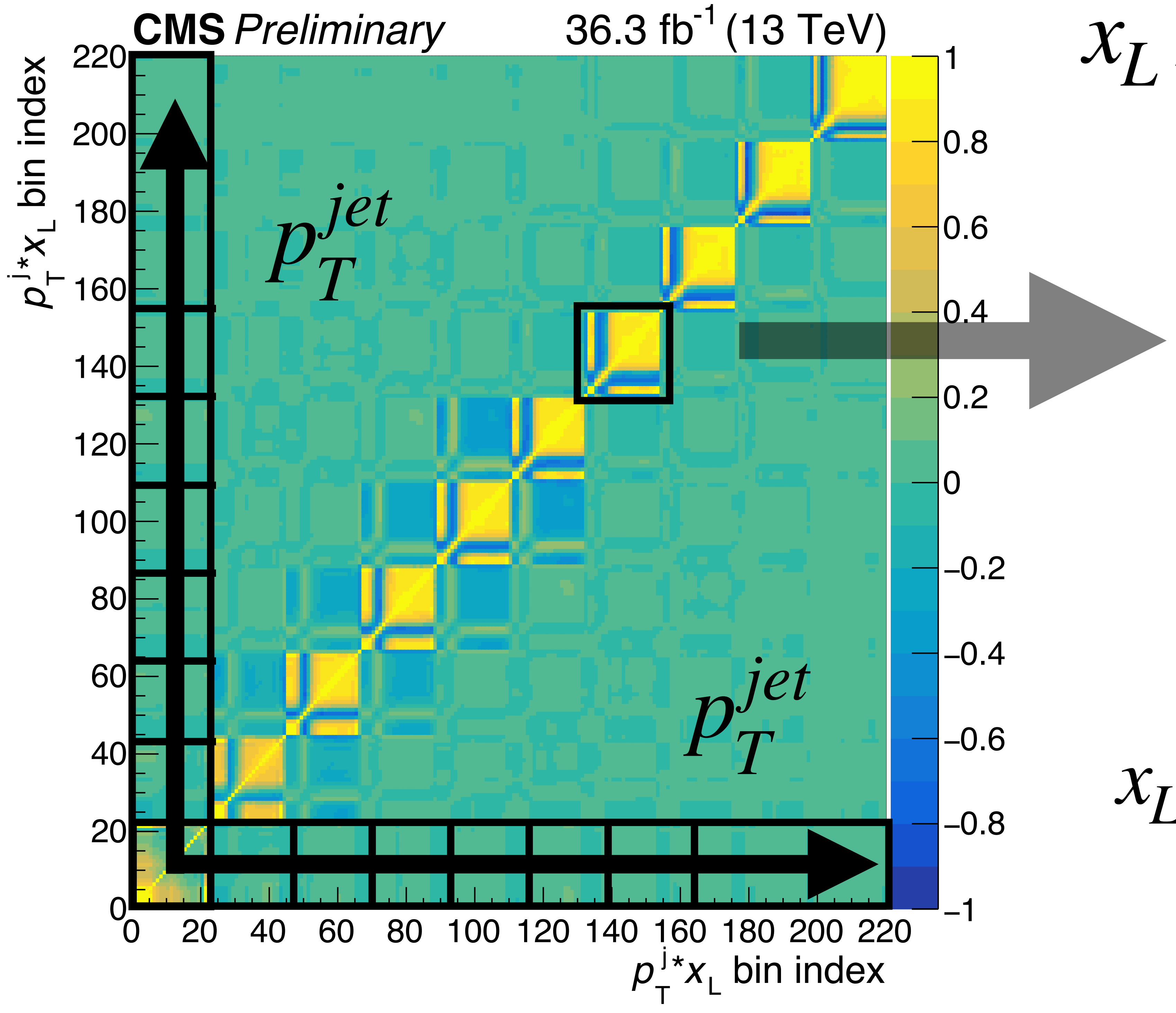
$$E3C = \frac{d\sigma^{[3]}}{dx_L} = \sum_{i,j,k}^{n} \int d\sigma \frac{E_iE_jE_k}{E^3} \delta(x_L - \max(\Delta R_{i,j}, \Delta R_{i,k}, \Delta R_{j,k}))$$

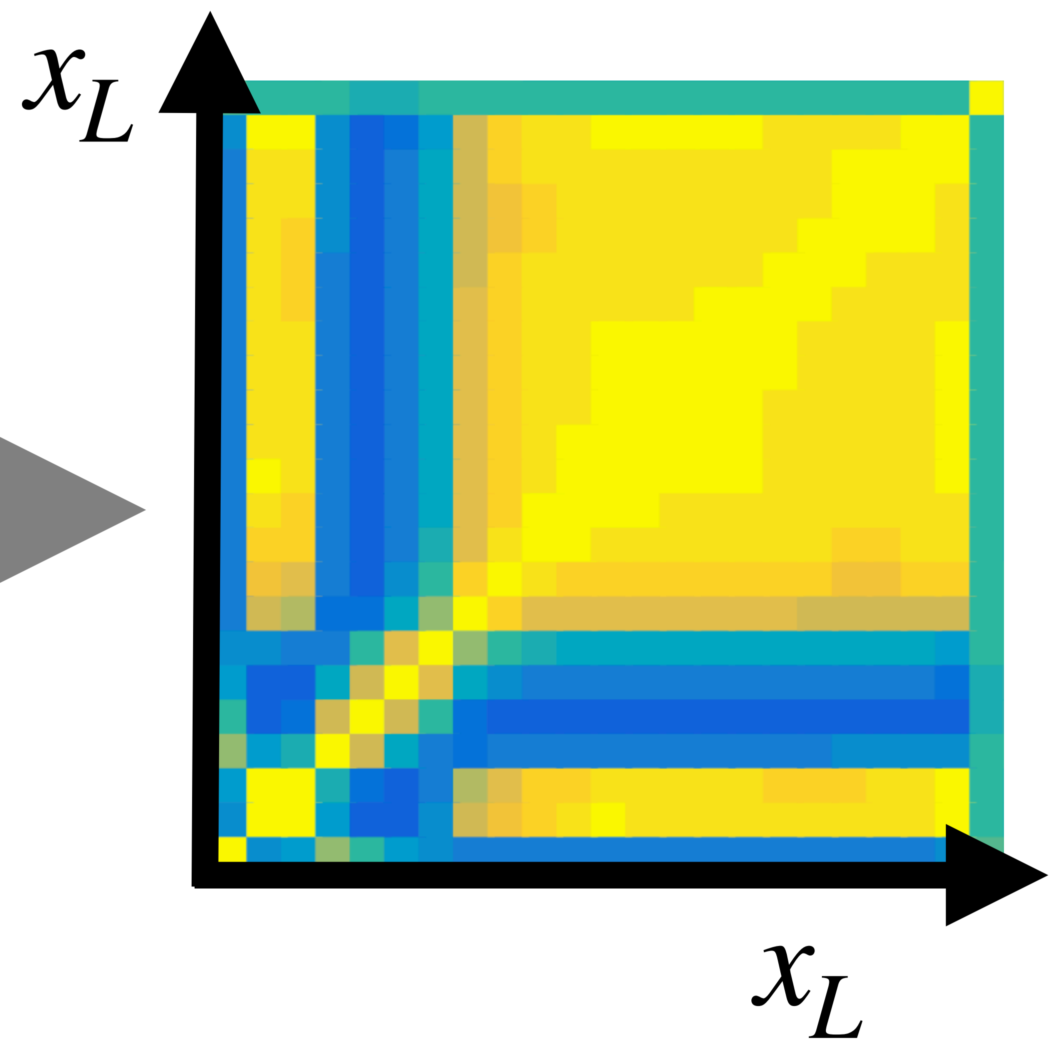
Insensitive to soft radiation

EnC: statistical correlations

Multi entry distribution for every jet, statistical correlation important

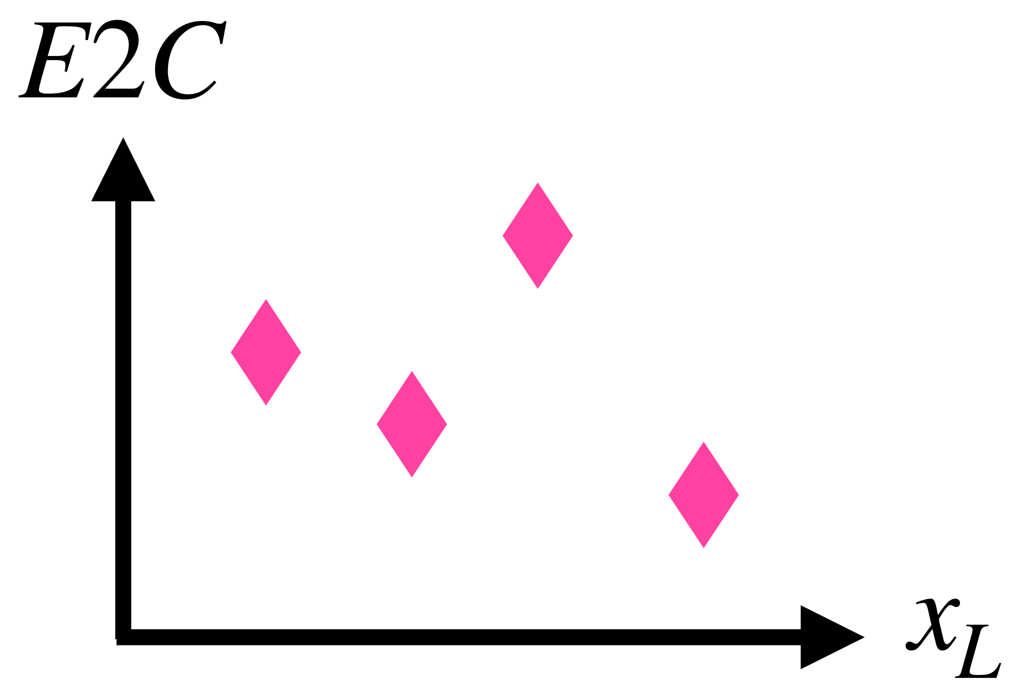
E2C correlation matrix





x_L bins in a p_T^{jet} region

Correlation: 80%

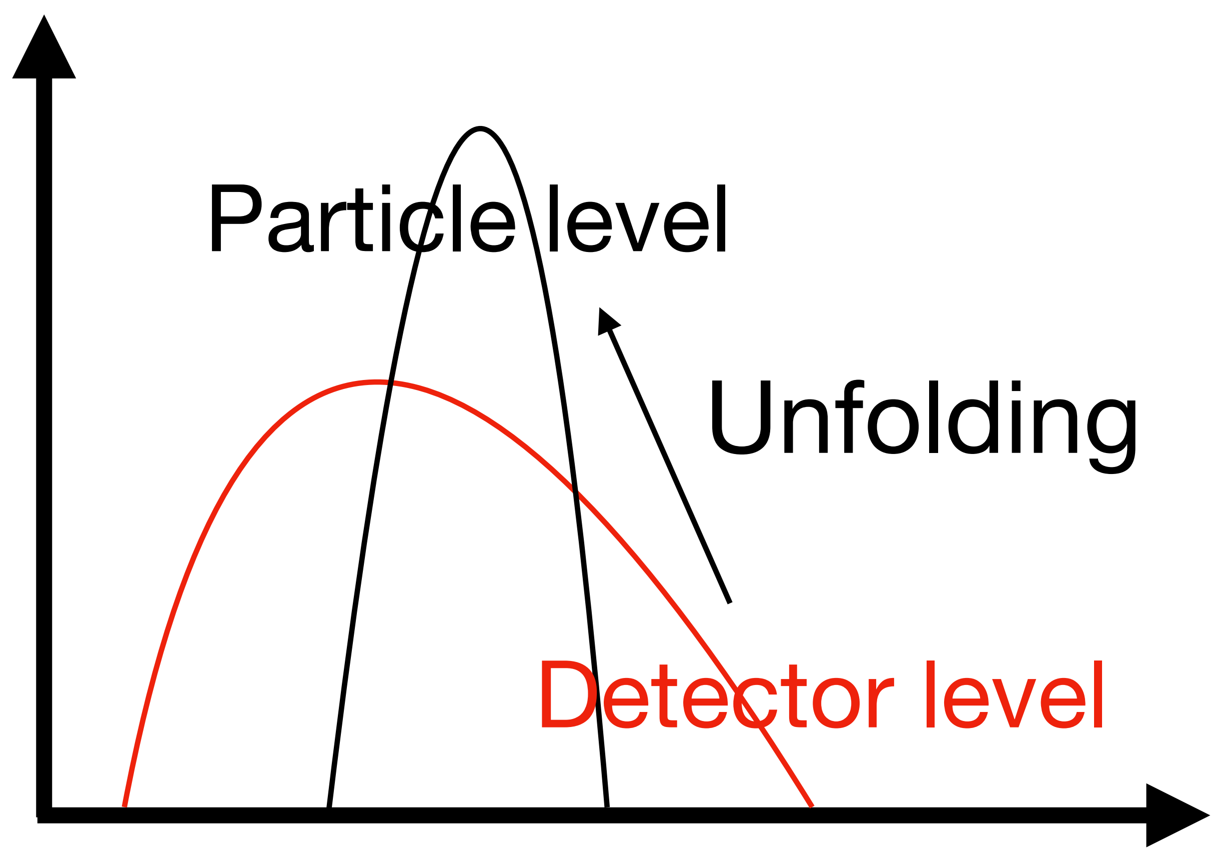


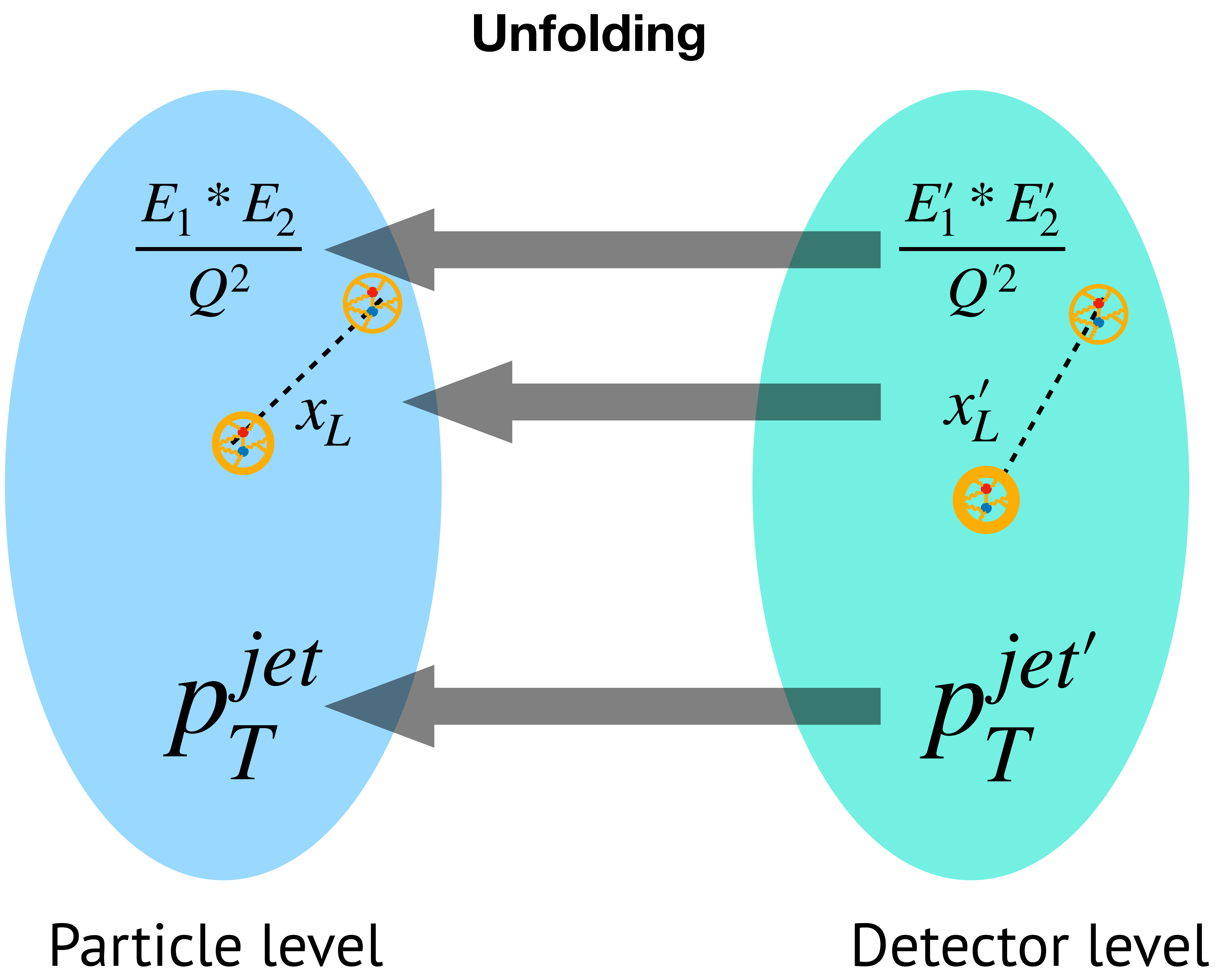
EnC: Constituent unfolding

Unfolding: detector level -> particle level

Unfold jet constituents instead of distribution:

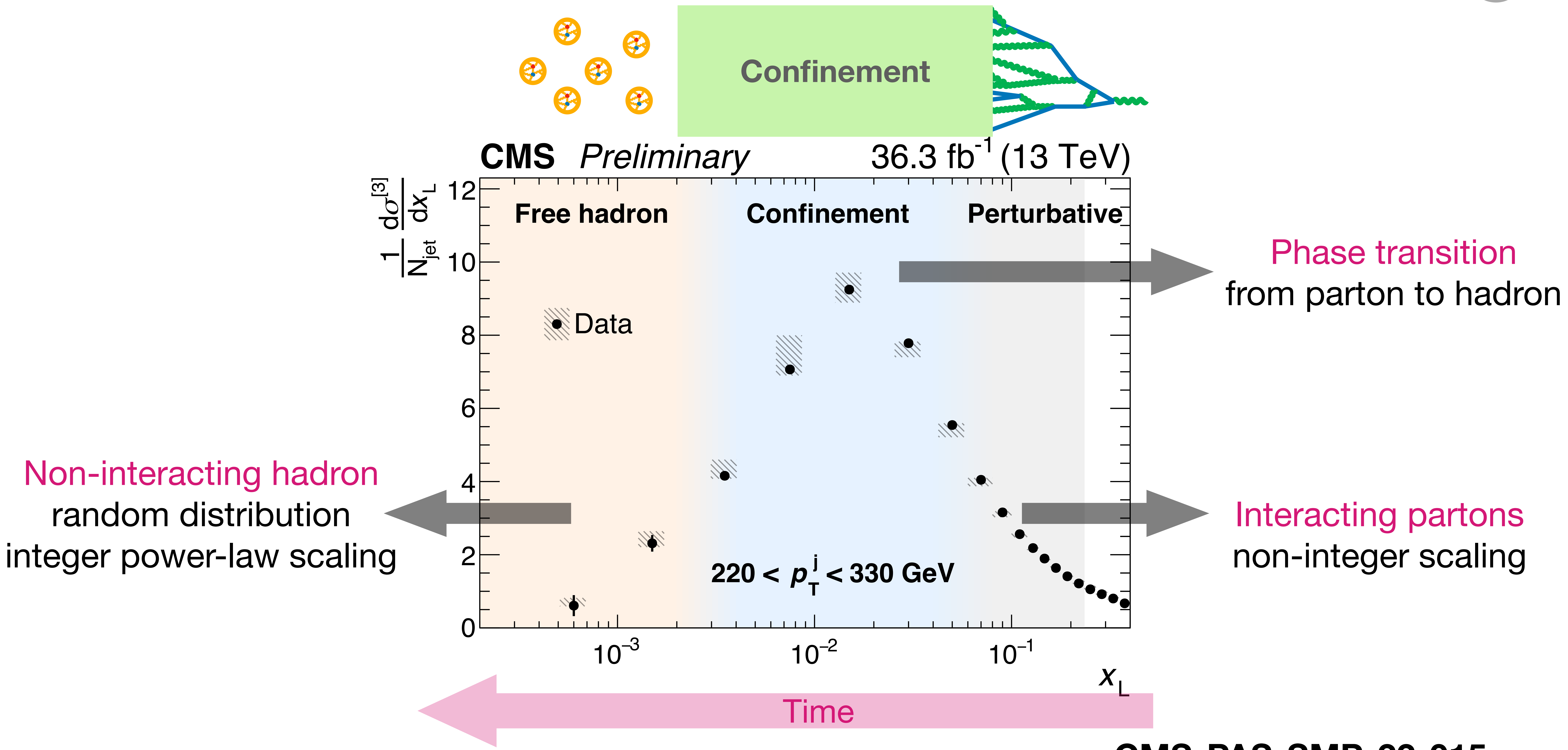
- p_T^{jet}, x_L and energy weight, 3D unfolding
- $10 * 22 * 20 = 4400$ bins





E3C measurement

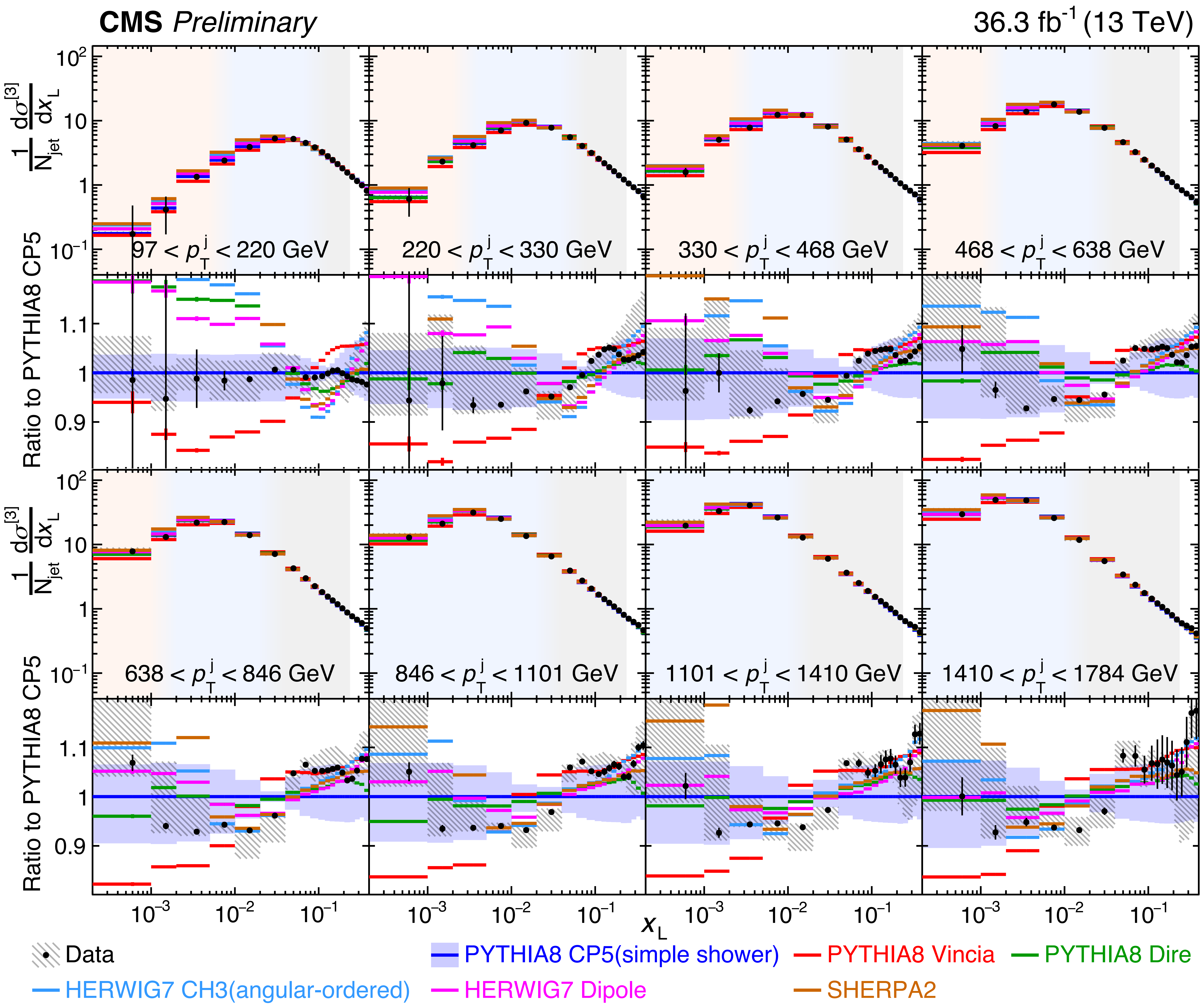
Using all neutral & charged hadrons > 1GeV in a jet



CMS-PAS-SMP-22-015

https://cds.cern.ch/record/2866560

E3C in all pT regions

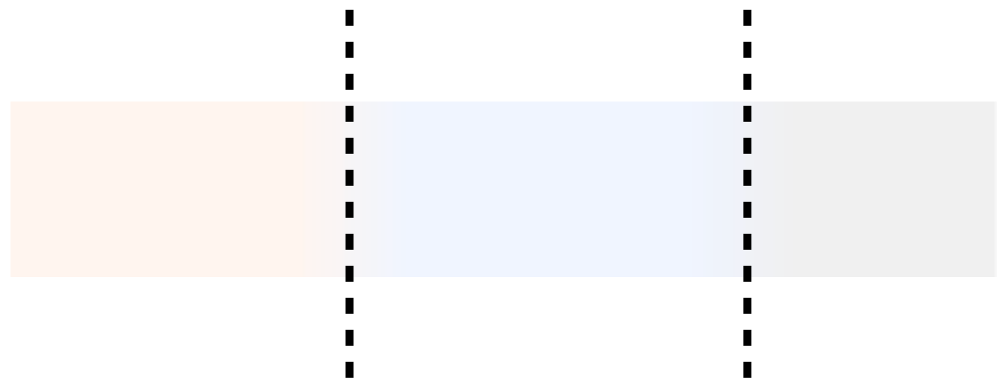


Boundary shift with jet pT

$Q \propto x_L{}^* p_T^{jet}$

$p_T^{jet} \uparrow,\ x_L \downarrow$

Boundary

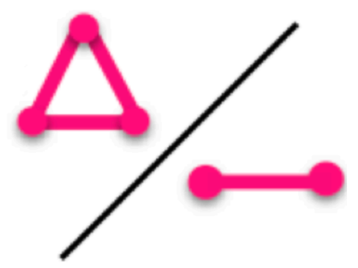


$x_L \approx \frac{0.8}{p_T^{jet}}$ $x_L \approx \frac{20}{p_T^{jet}}$

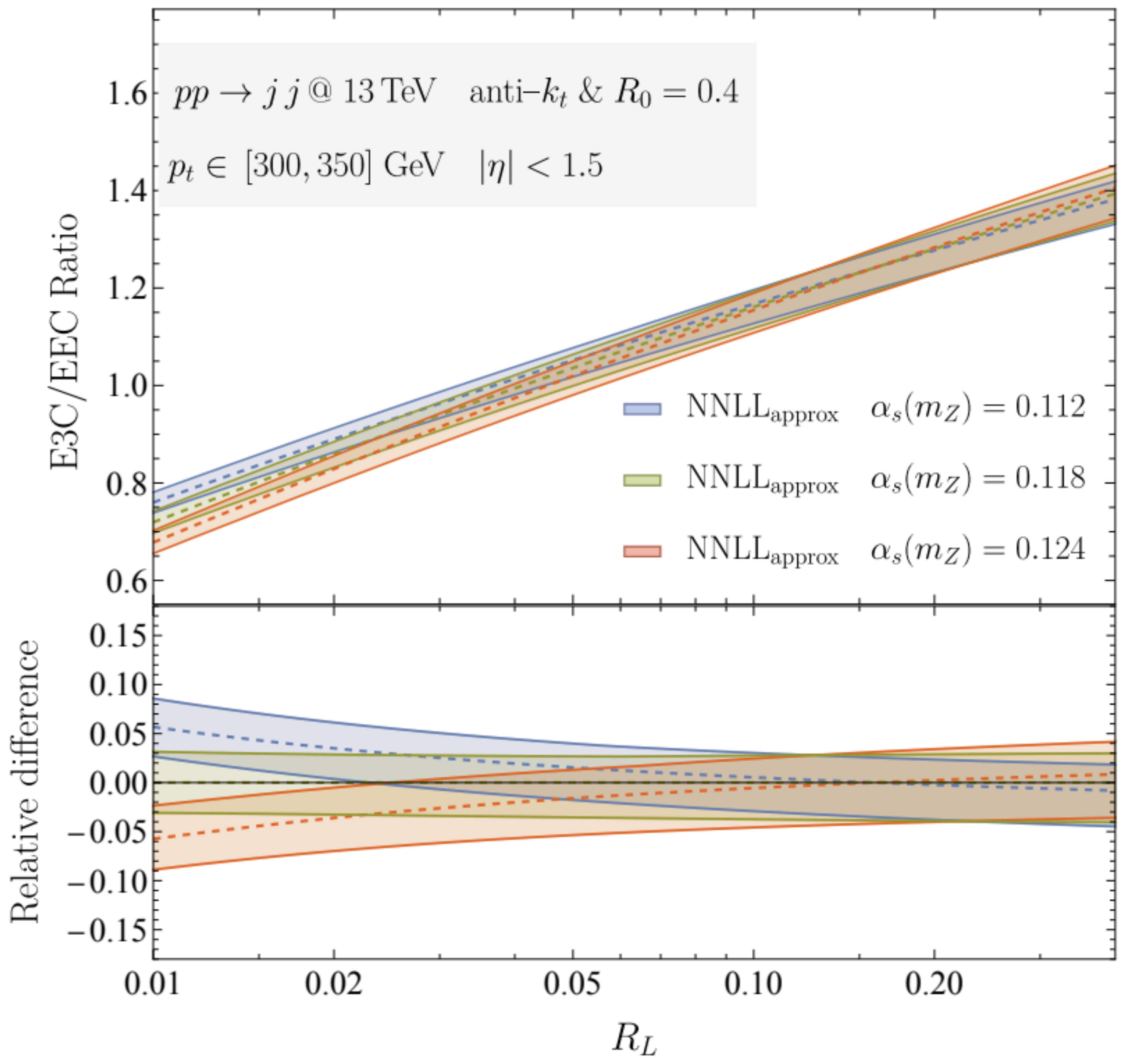
E3C/E2C: a new way to extract α_S

Chen, Gao, Li, Xu, Zhang, Zhu,
arXiv:2307.07510

At LL, E3C/E2C is a linear function of α_s

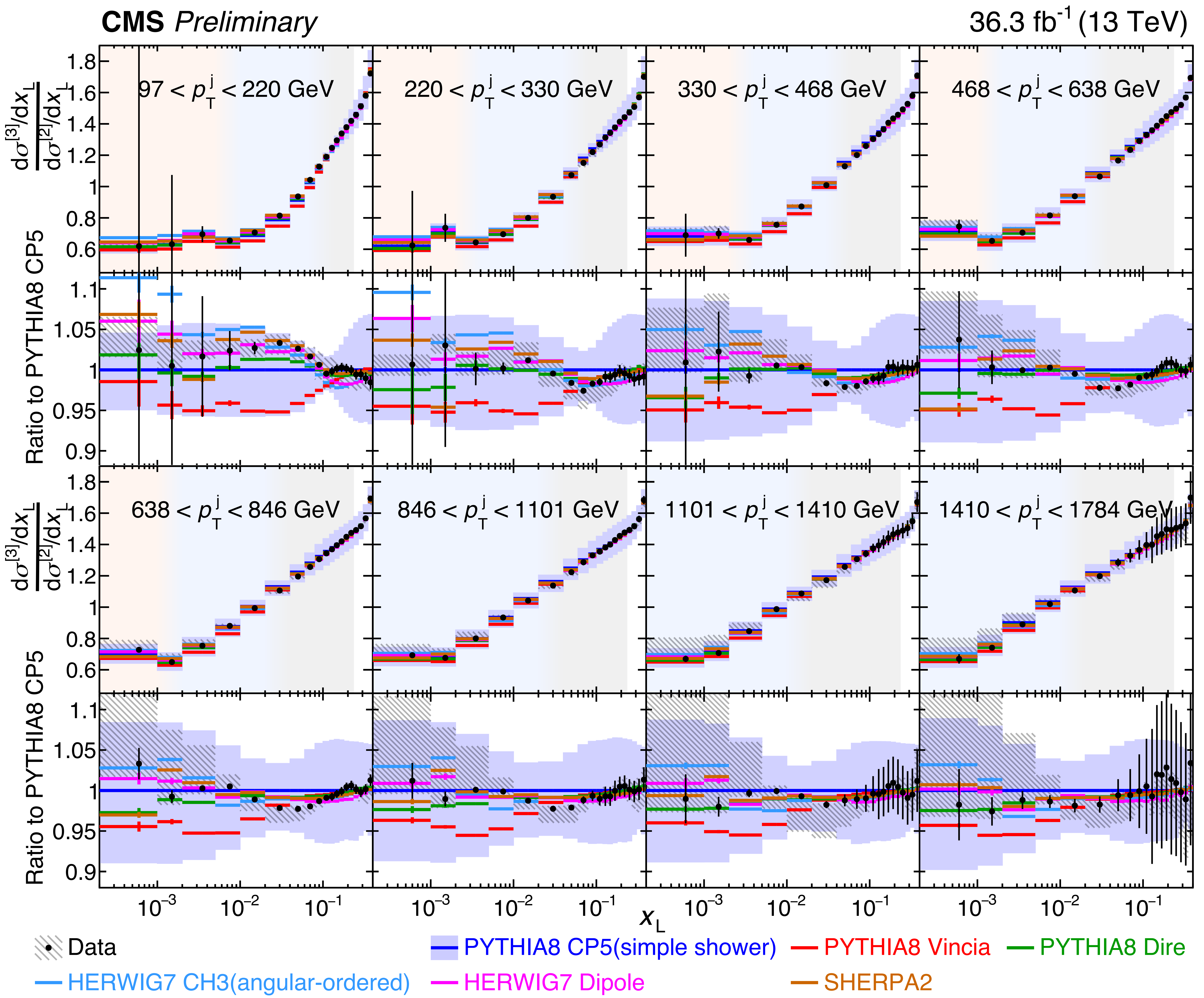


$$\propto \alpha_S(Q) \ln x_L + O(\alpha_s^2)$$



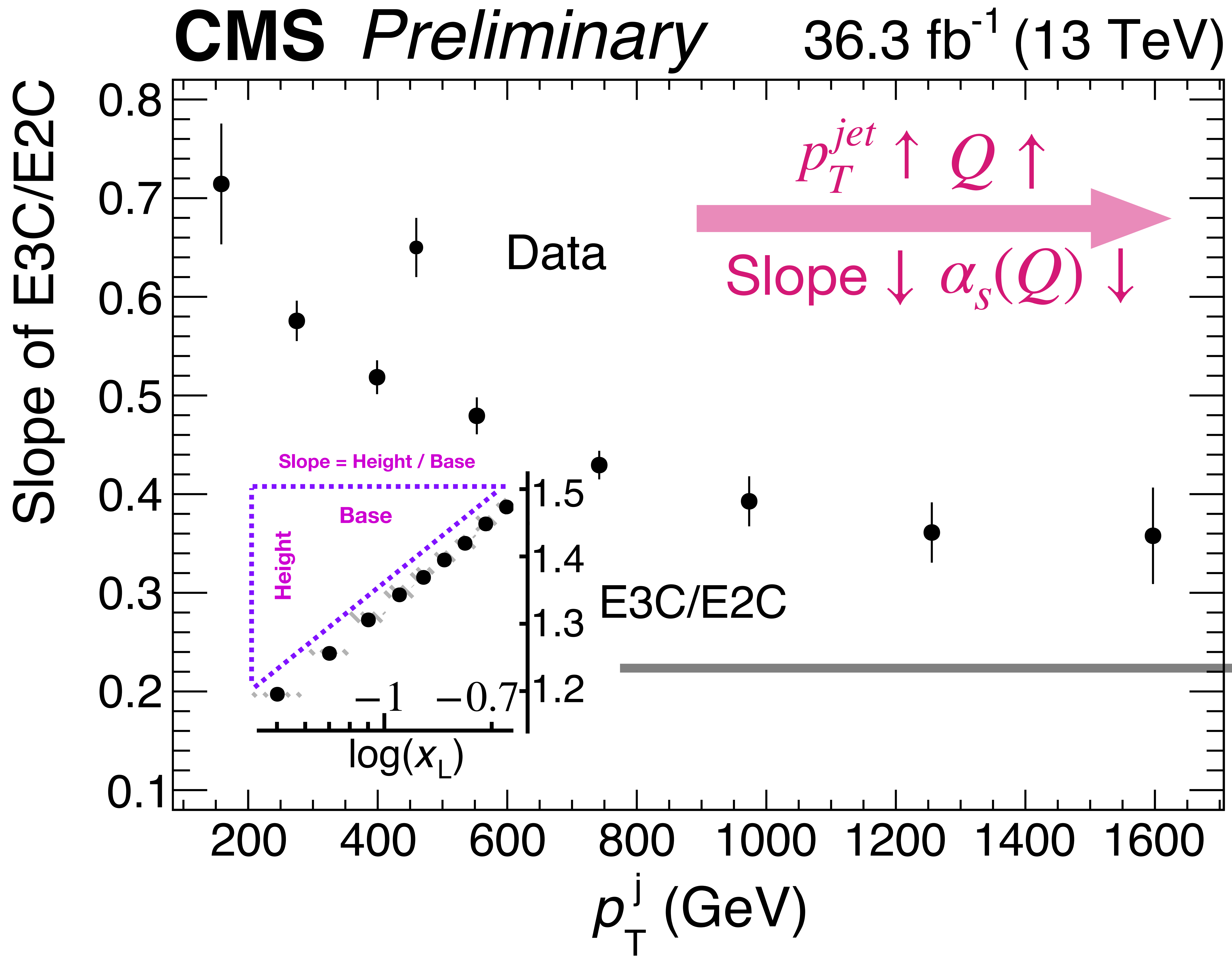
$\alpha_S(M_Z) \uparrow$ Slope $\uparrow$

E3C/E2C



$p_T^{jet} \uparrow$, Slope $\downarrow$

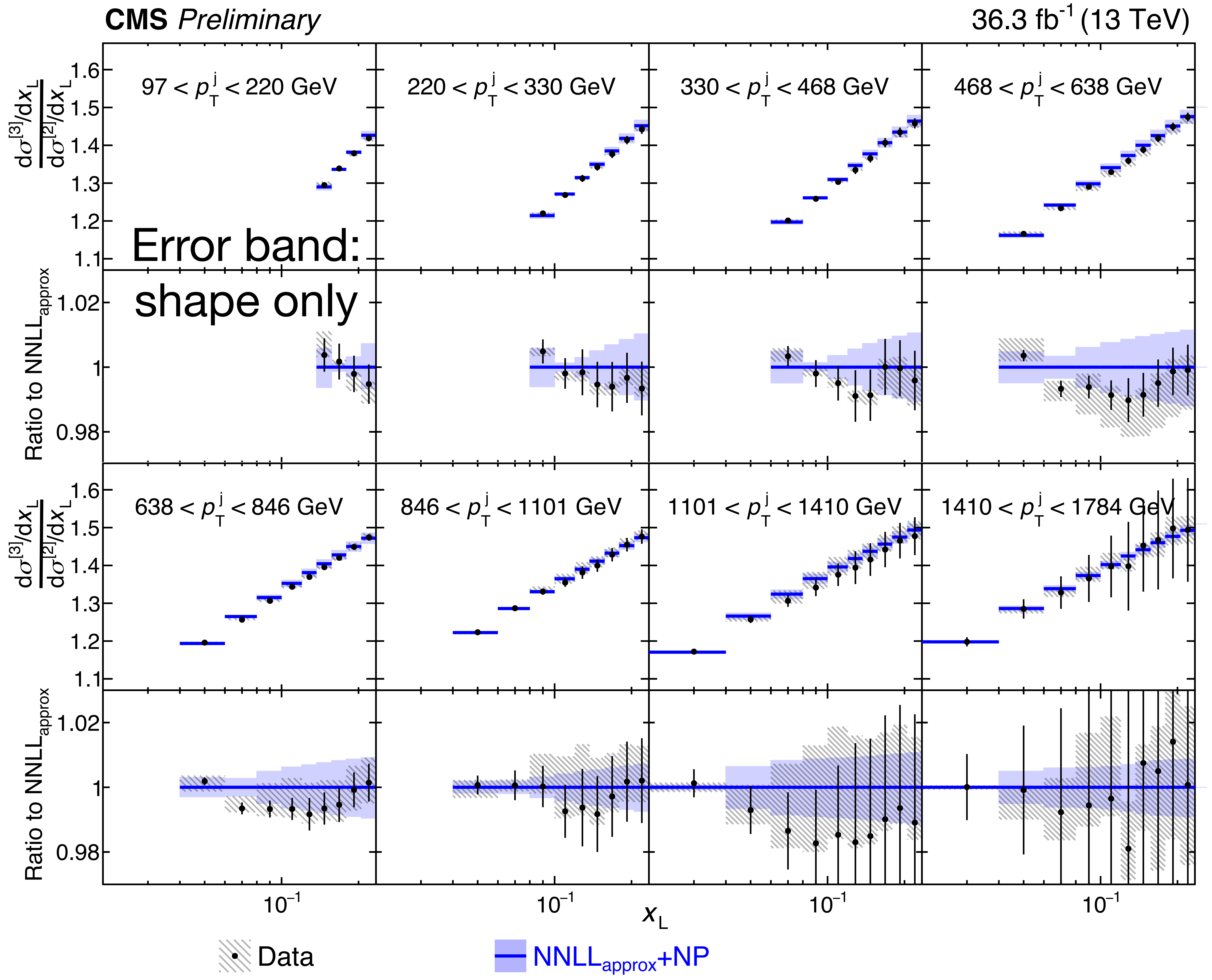
Direct observation of asymptotic freedom



$\propto \alpha_S(Q) \ln x_L + O(\alpha_s^2)$

Data point: slope fitted in a p_T^{jet} region

Unfolded E3C/E2C vs NNLL-approx



$$\alpha_s(m_Z) = 0.1229^{+0.0040}_{-0.0050}$$

$$= 0.1229^{+0.0014(stat.)+0.0030(theo.)+0.0023(exp.)}_{-0.0012(stat.)-0.0033(theo.)-0.0036(exp.)}$$

major source

Covariance matrix

QCD scale of $NNLL_{approx}$

Neutral hadron energy scale

Uncertainty ~ 4%,

Most precise from jet substructure to date

Summary

- Jet substructure has become a powerful tool to understand QCD with high precision
- Energy correlators provide new ways to understand the jet formation
    - Color confinement
    - Asymptotic freedom
- 4% precision of α_S, the most precise using jet substructure to date