

Energy correlator measurements at the CMS

肖朦，浙江大学

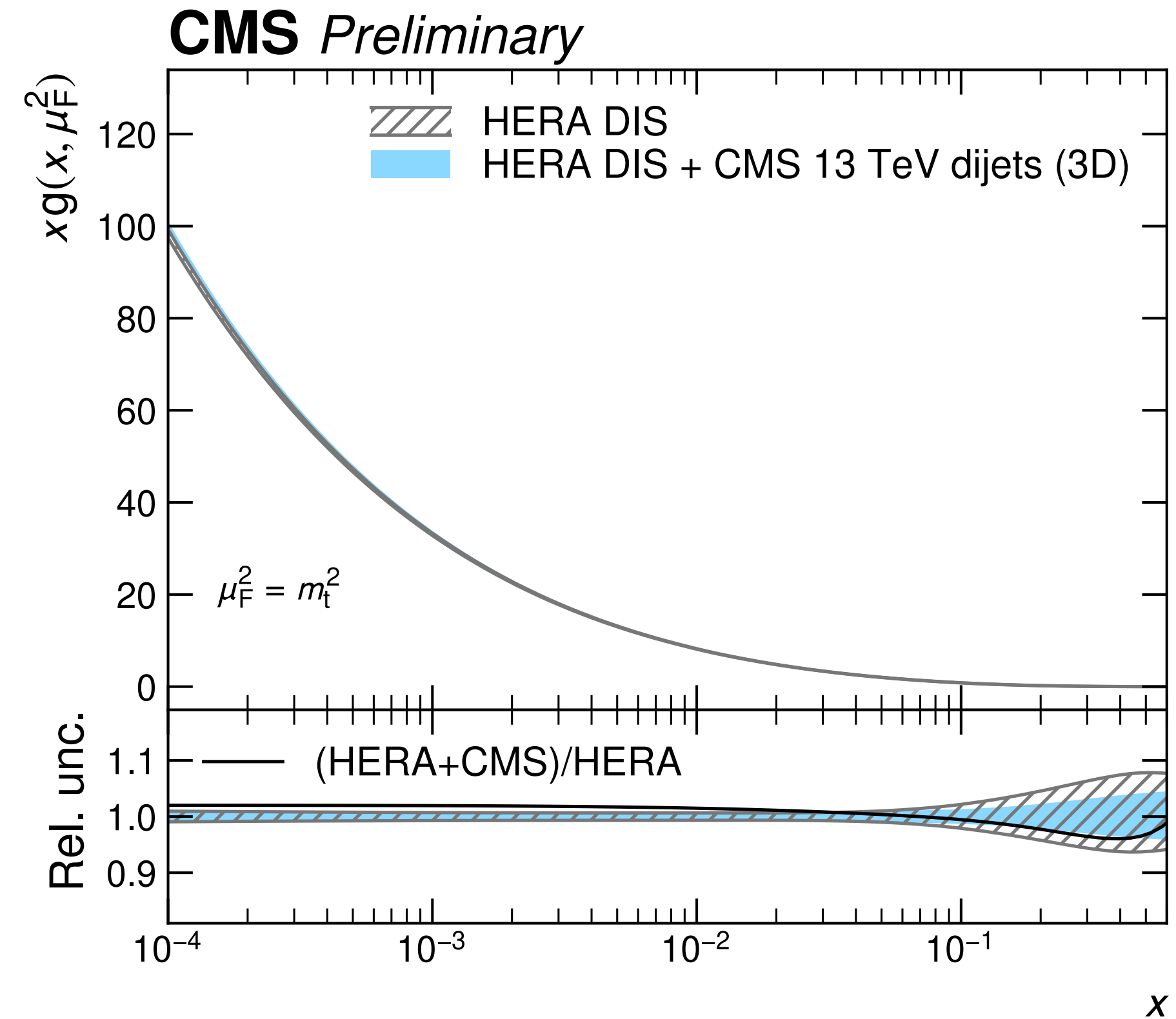
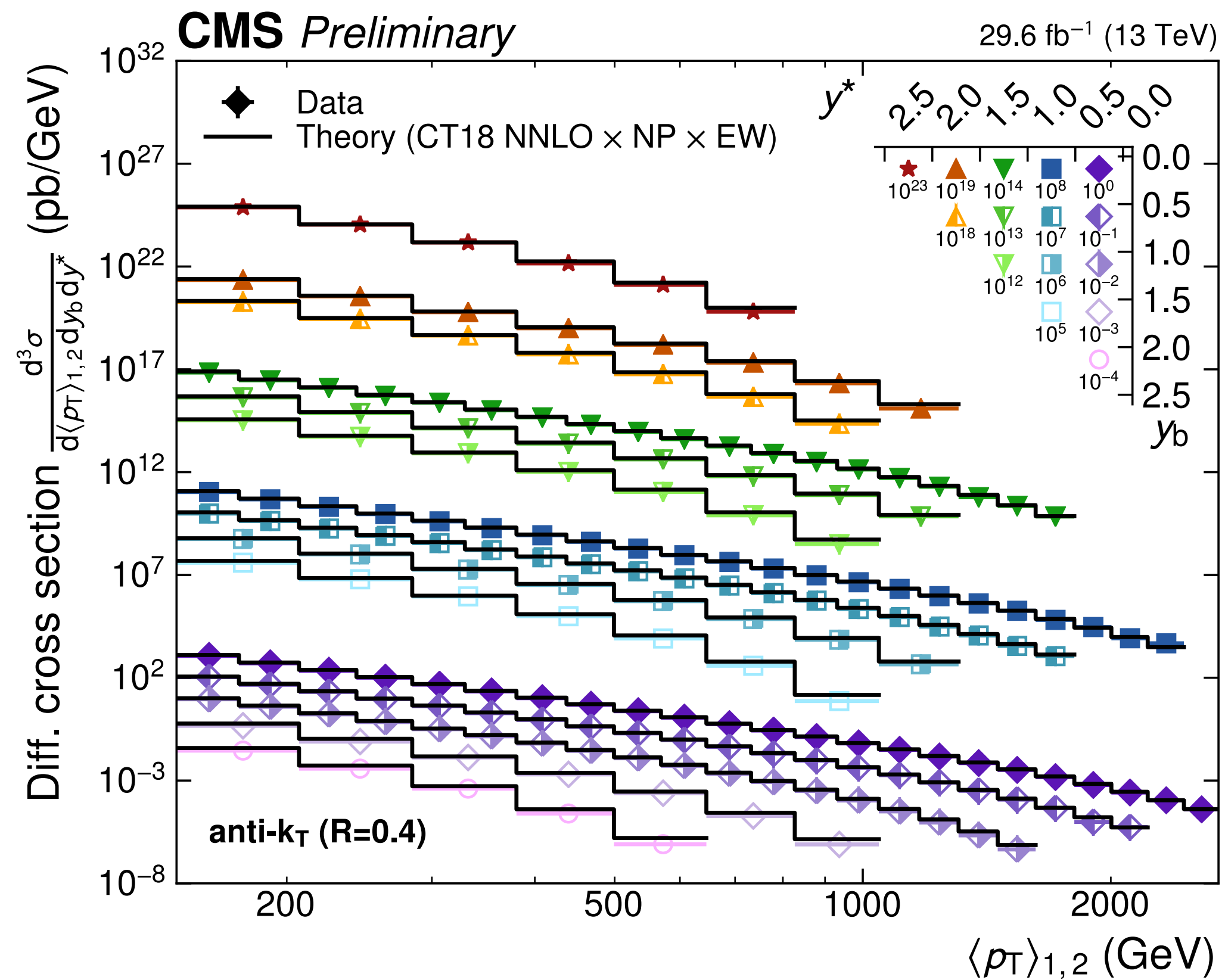
CEPC味物理-新物理和相关探测技术研讨会，上海，2023年8月16日



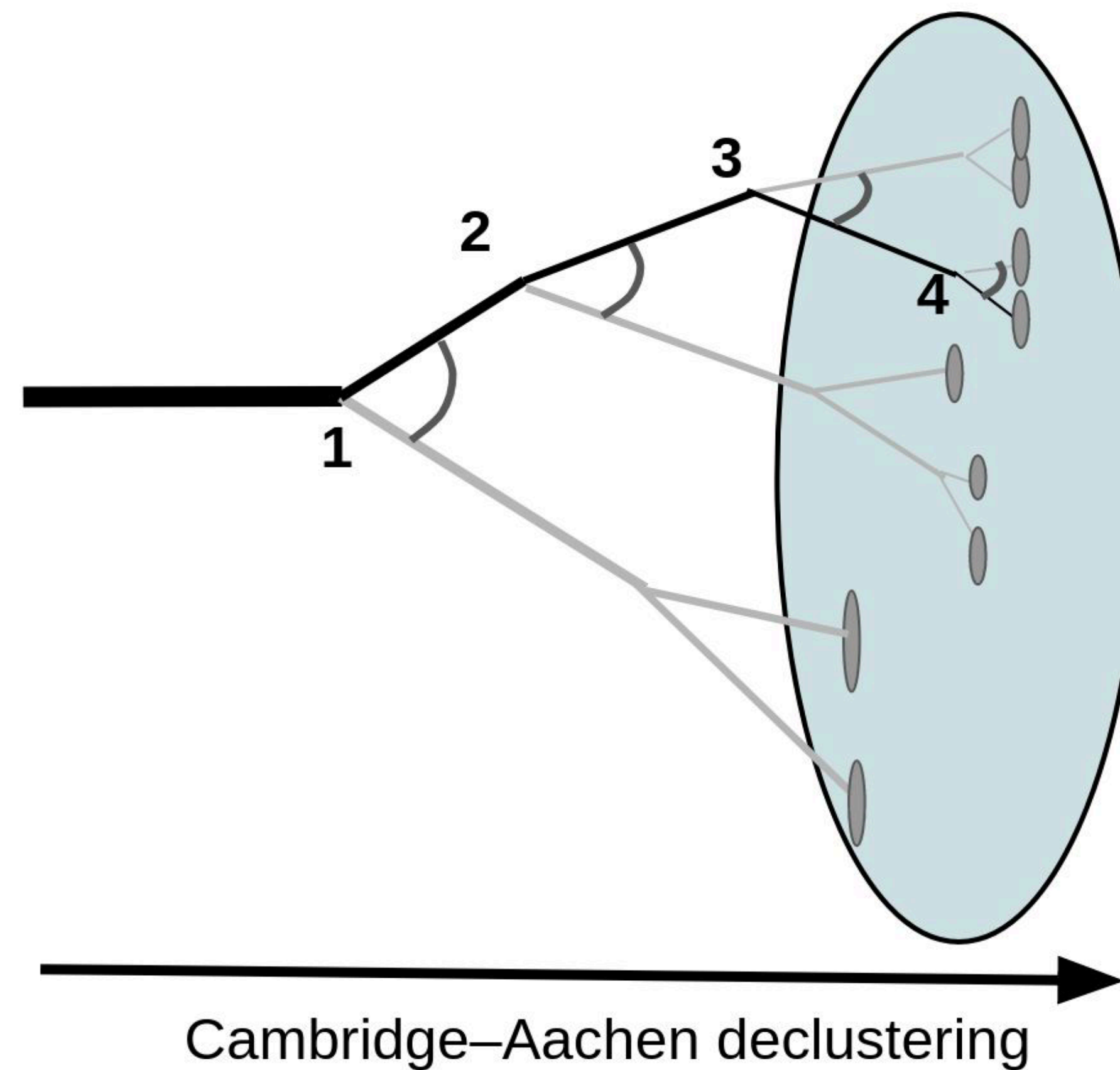
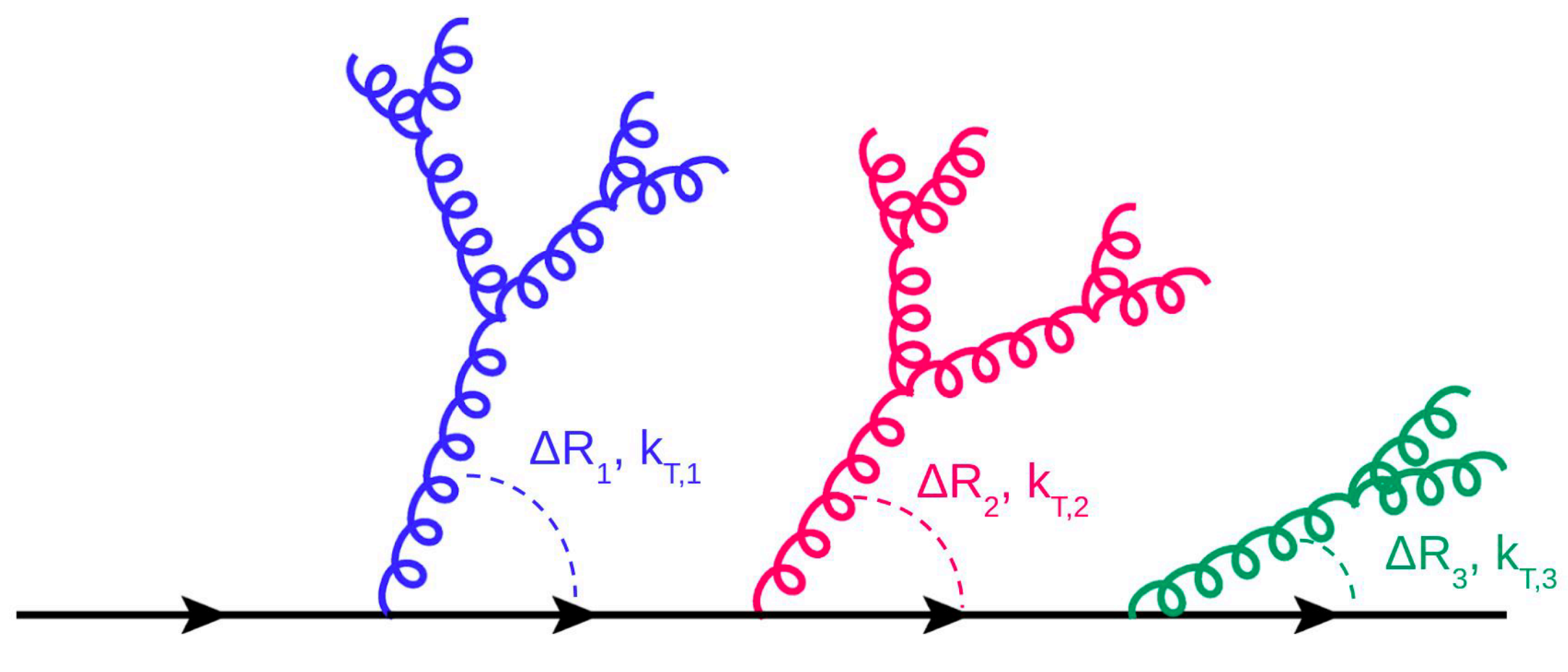
Jets: proxies to study QCD

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

Constraints on gluon PDF



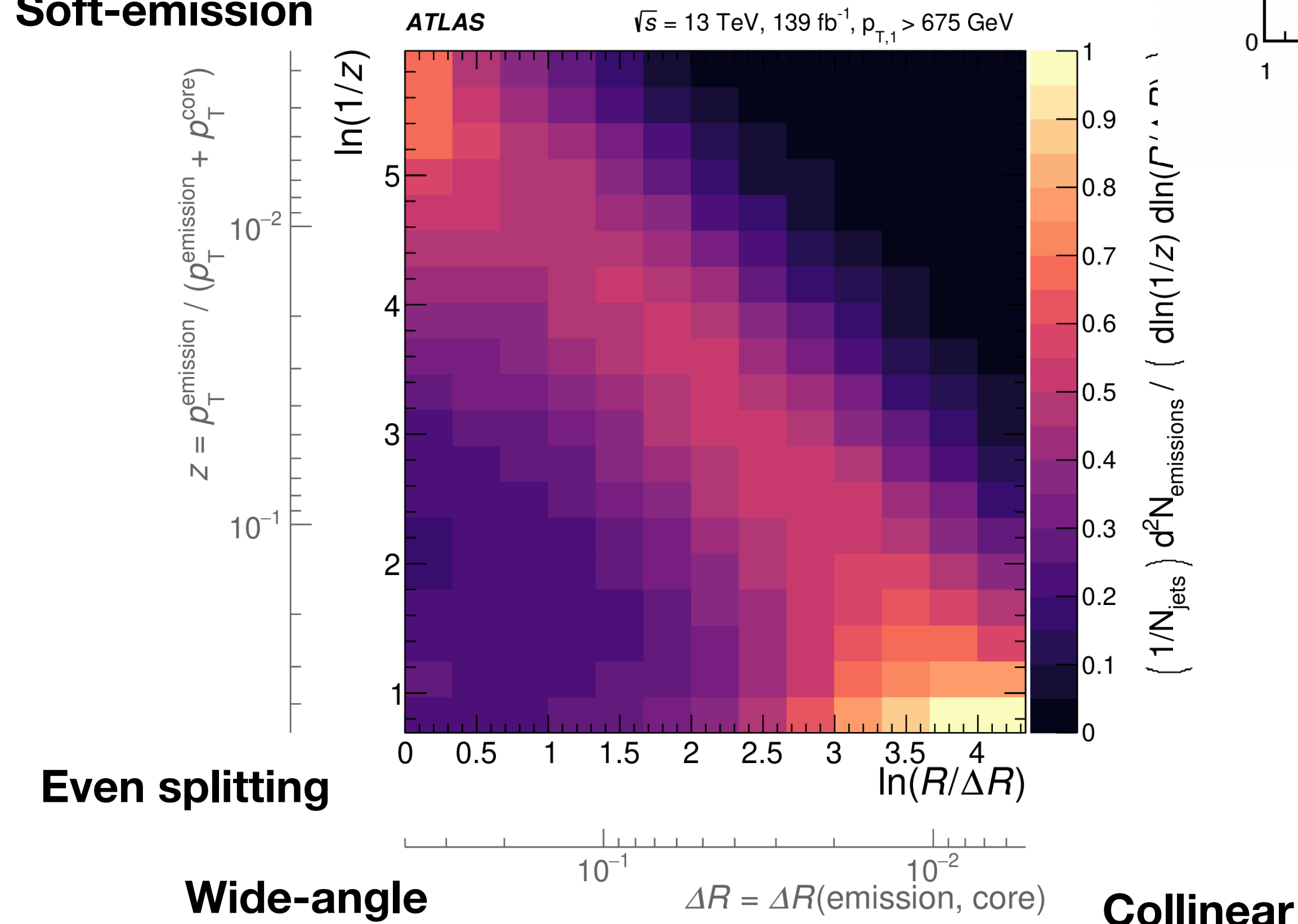
Jet formation and jet substructure



Angular-ordered

Jet substructure studies

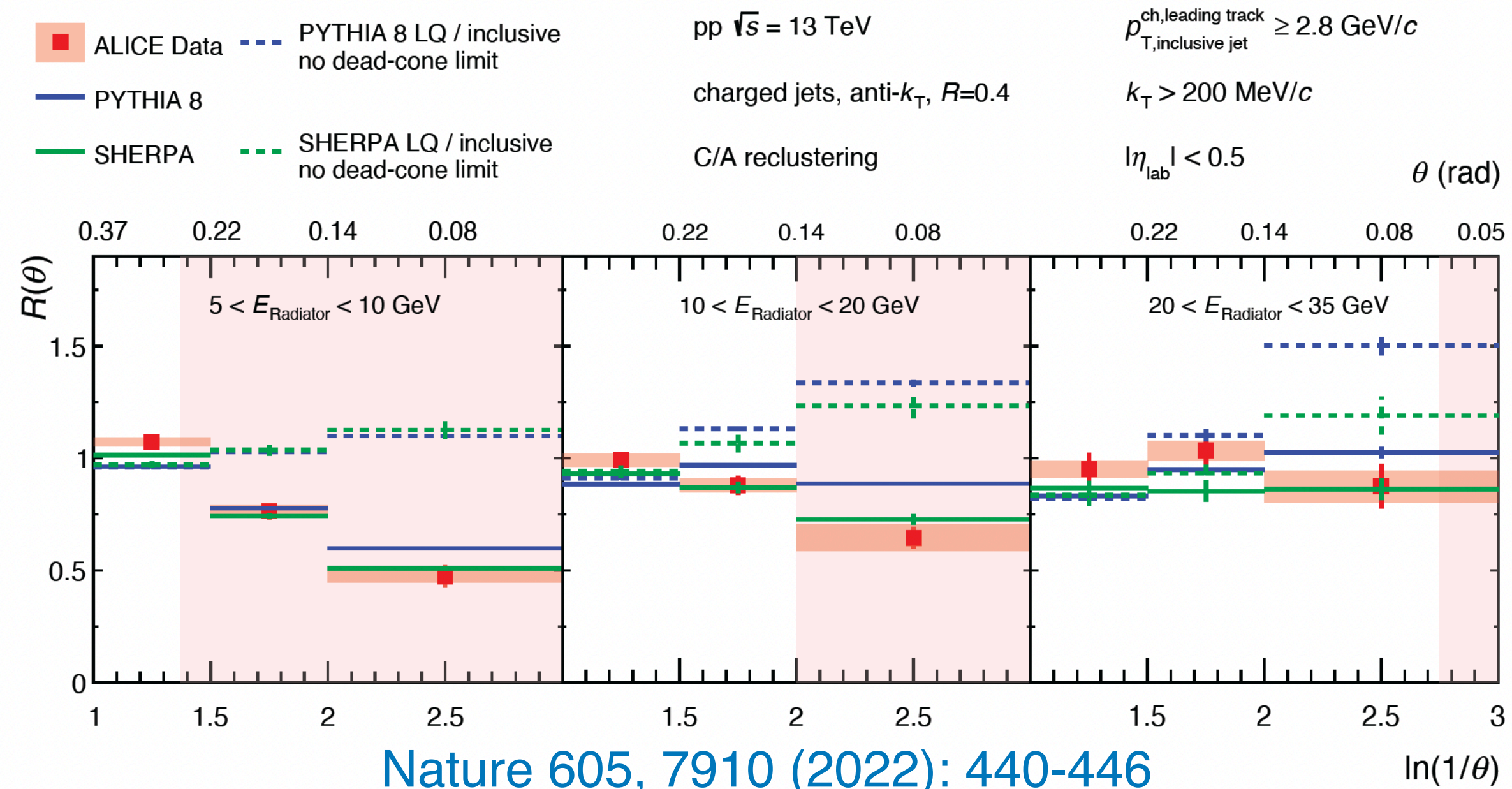
Soft-emission



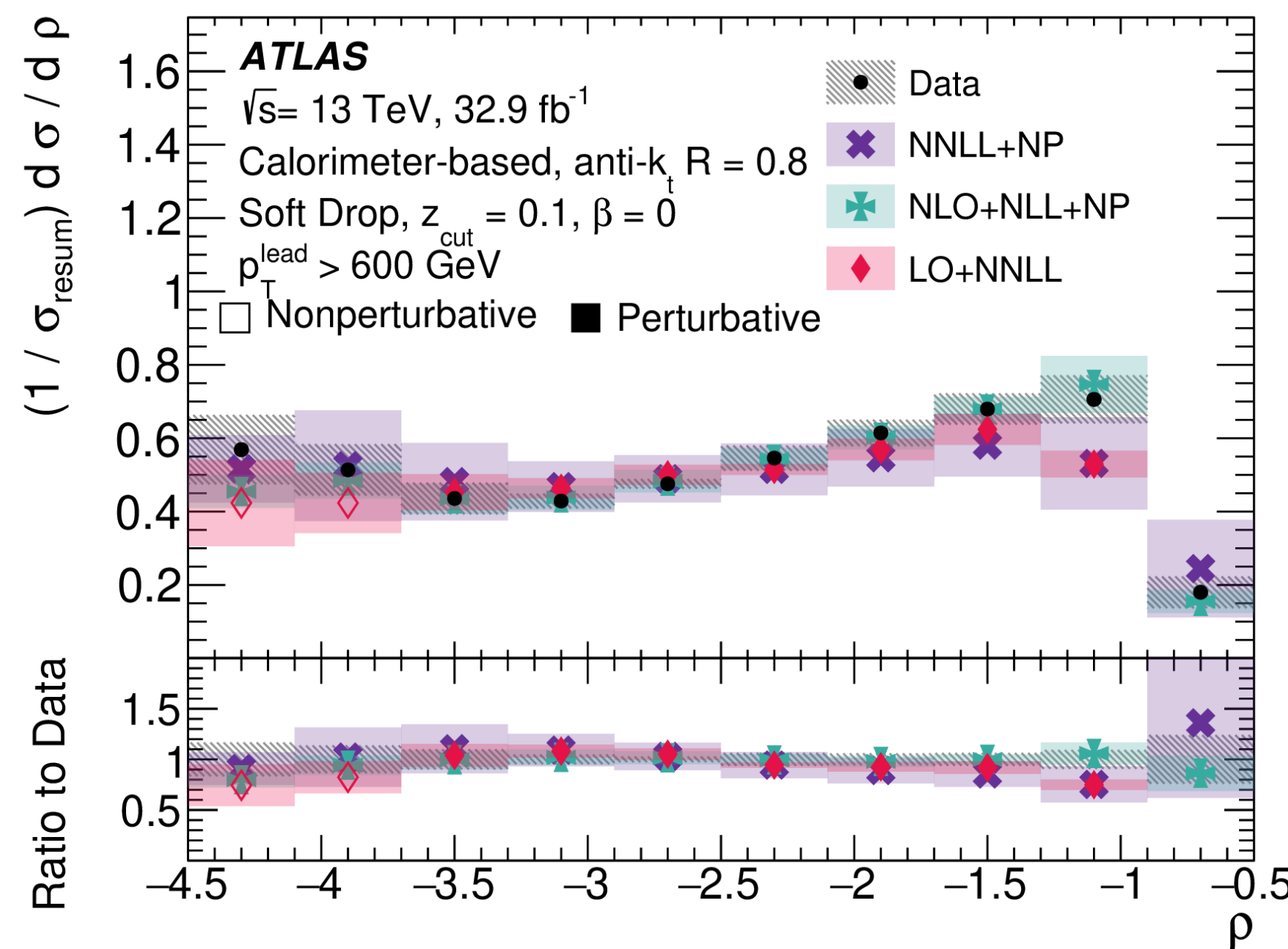
PRL 124 (2020) 222002

Dead cone

Lund Plane



Soft drop jet mass




STRONG COUPLING FROM JSS (PROSPECTS)


LEP EXTRACTIONS




Thrust extraction sensitive in resummation-dominated region


LHC EXTRACTIONS

Underlying event, colour reconnection 

Jet rates, cross-section ratios usually compared to fixed-order calculations 

LHC EXTRACTIONS FROM JSS

soft-drop grooming
→ mitigate soft/wide-angled contributions 

Soft-drop mass prediction
→ precise resummation 

MLB : TUESDAY MORNING

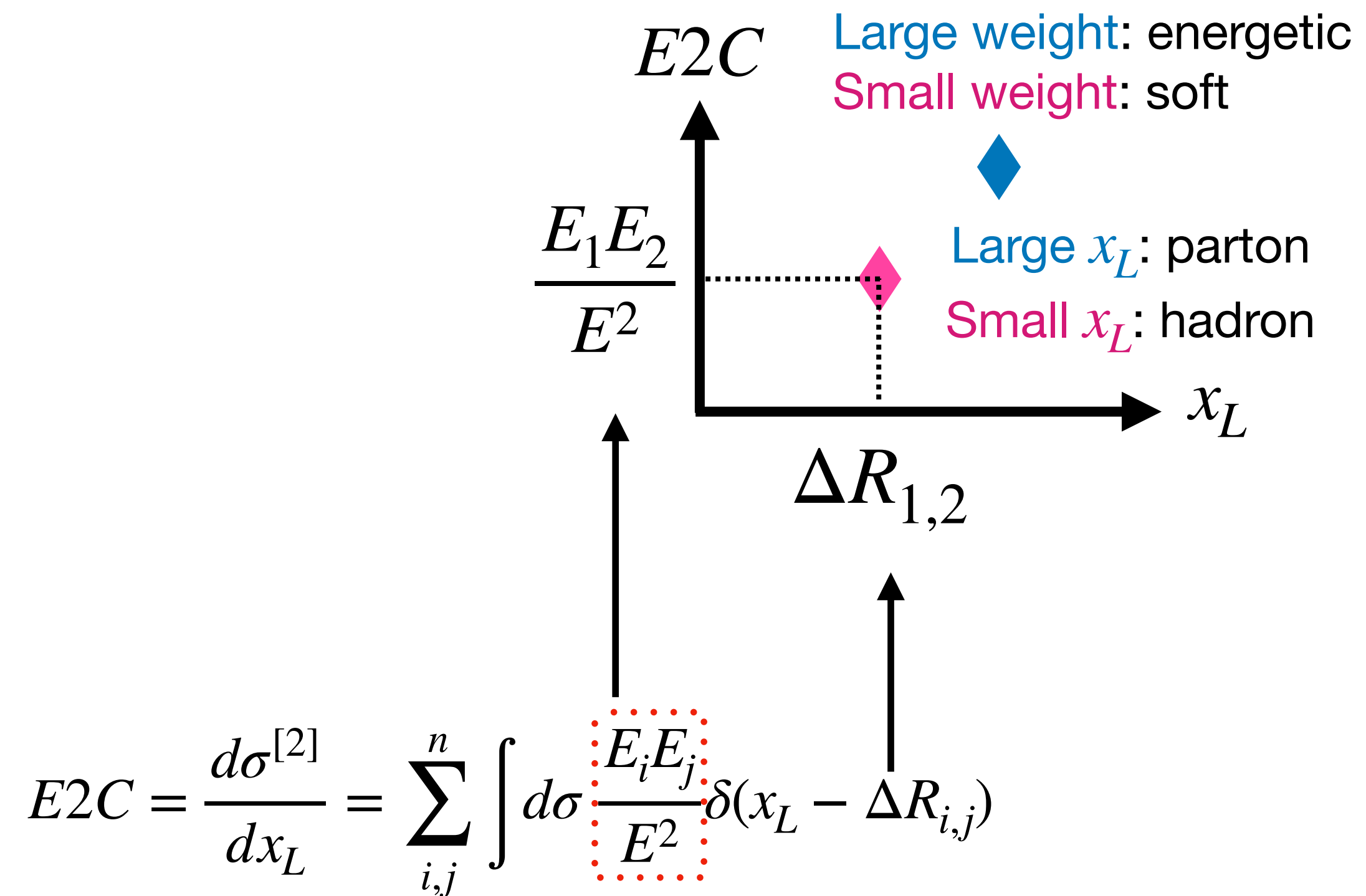
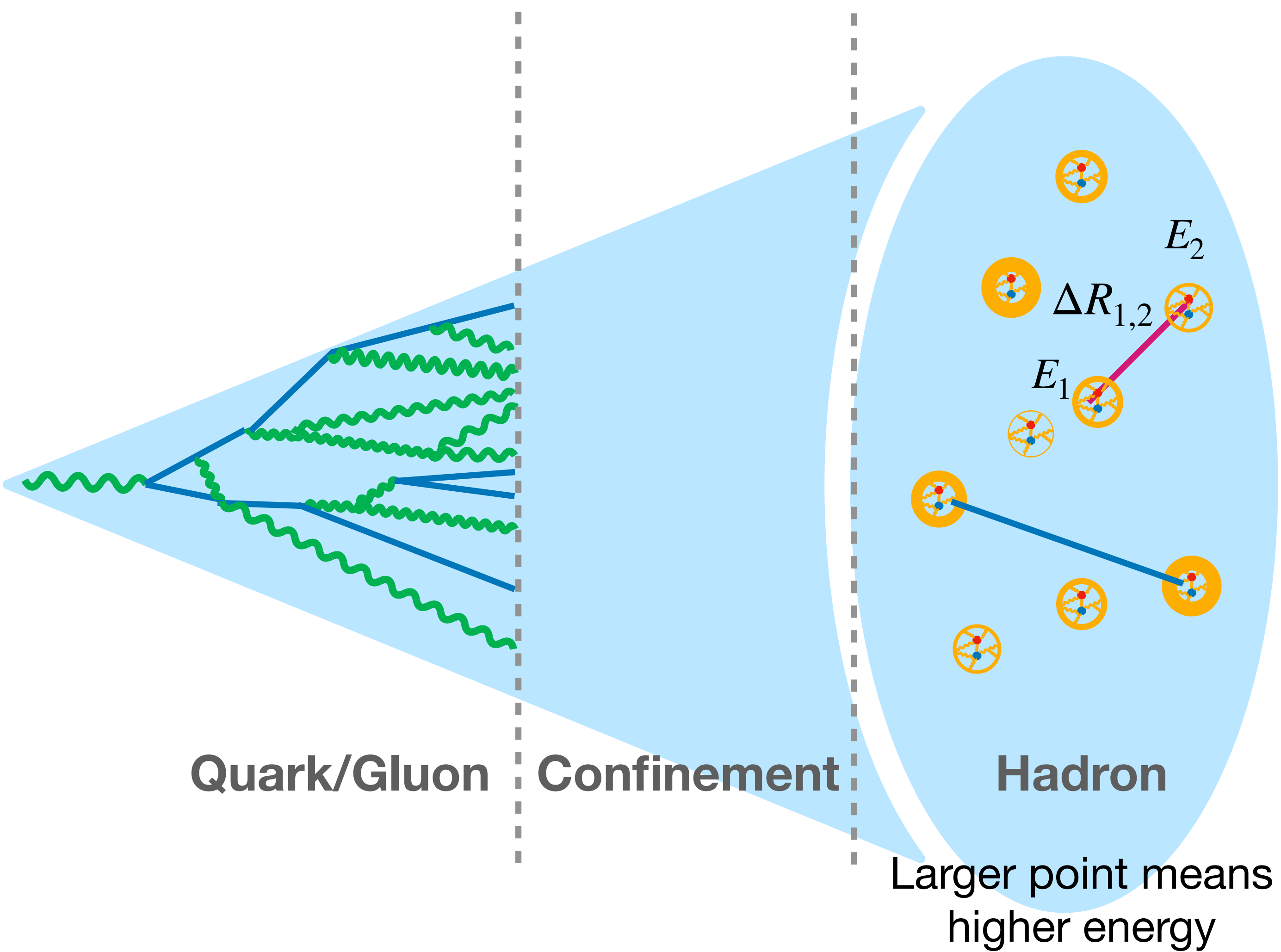
HOFIE : THURSDAY MORNING!

Prediction: we will see the first α_s extractions from JSS during Run 3!

Matt LeBlanc (CERN) — Overview (Experimental) — BOOST 2022 — Slide 41

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

Energy correlators: EnC

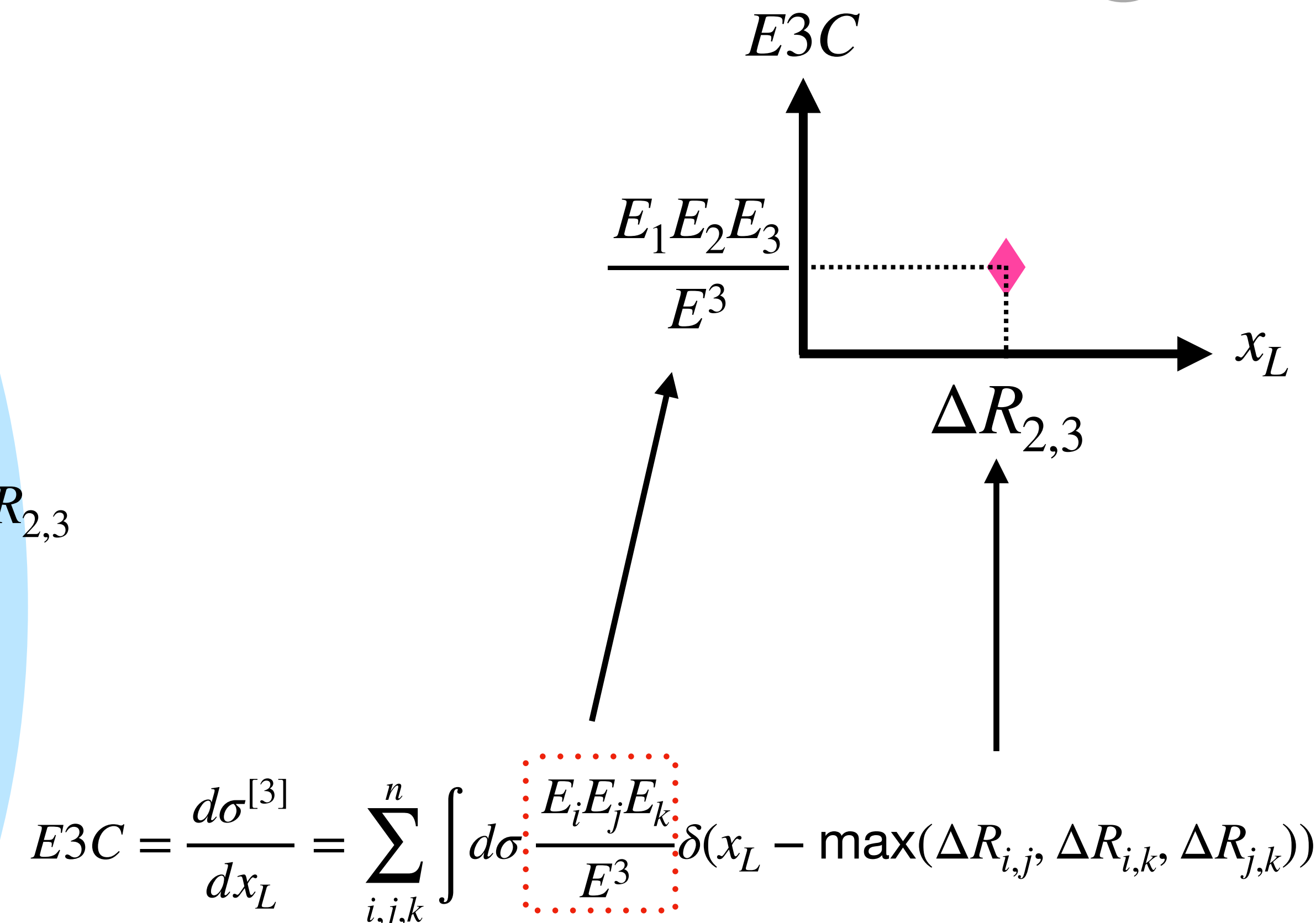
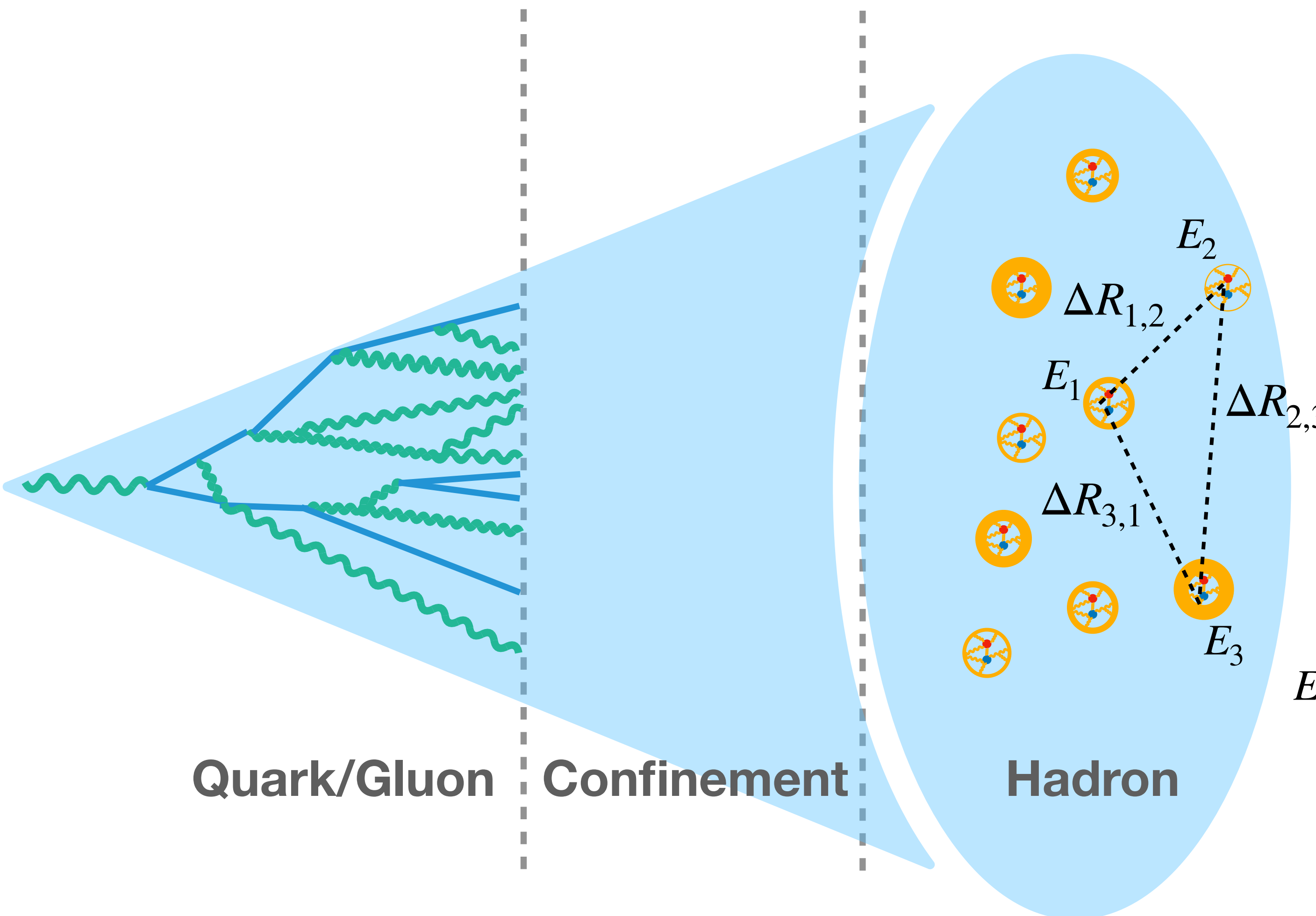


Chen, Moulton, Zhang, and Zhu, [arXiv:2004.11381](https://arxiv.org/abs/2004.11381)

Lee, Meçaj, and Moulton, [arXiv:2205.03414](https://arxiv.org/abs/2205.03414)

Chen, Gao, Li, Xu, Zhang, and Zhu, [arXiv:2307.07510](https://arxiv.org/abs/2307.07510)

Energy correlators: EnC



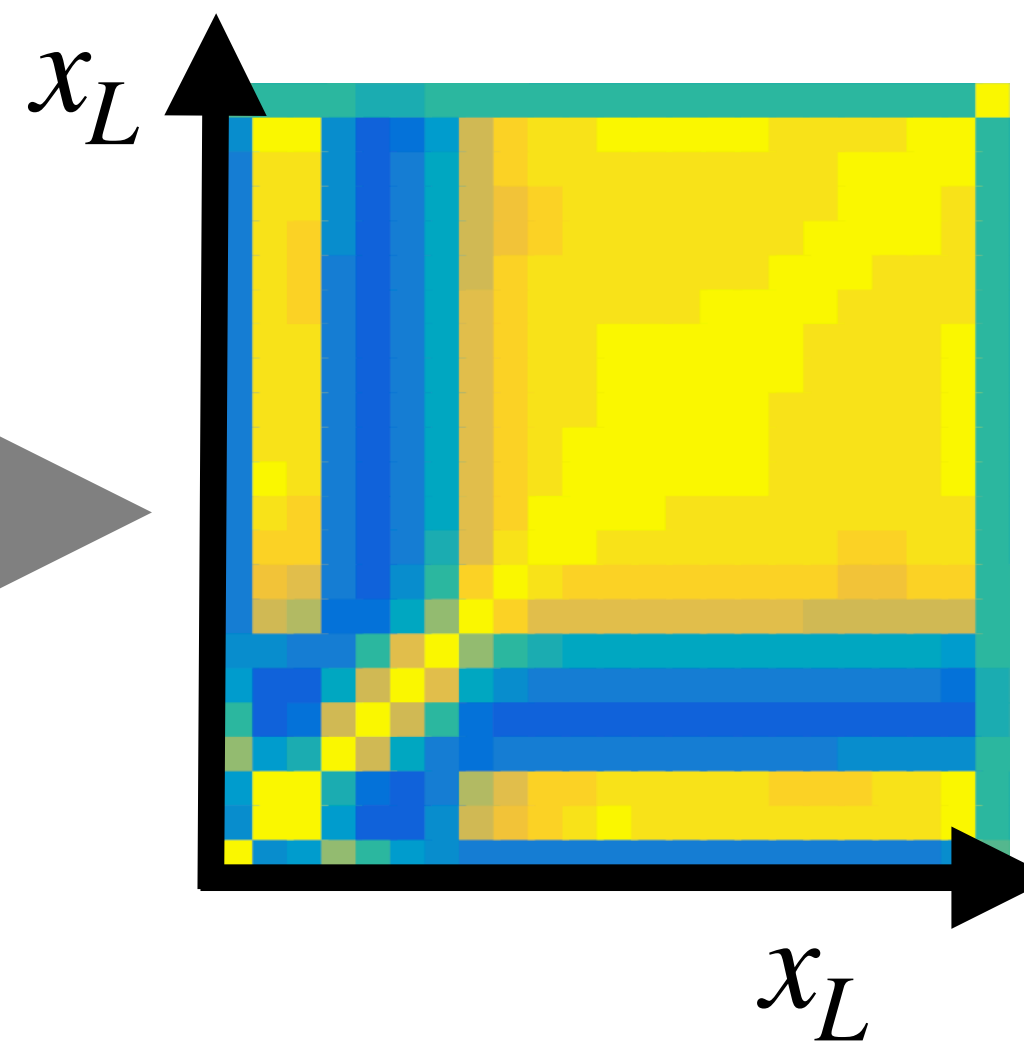
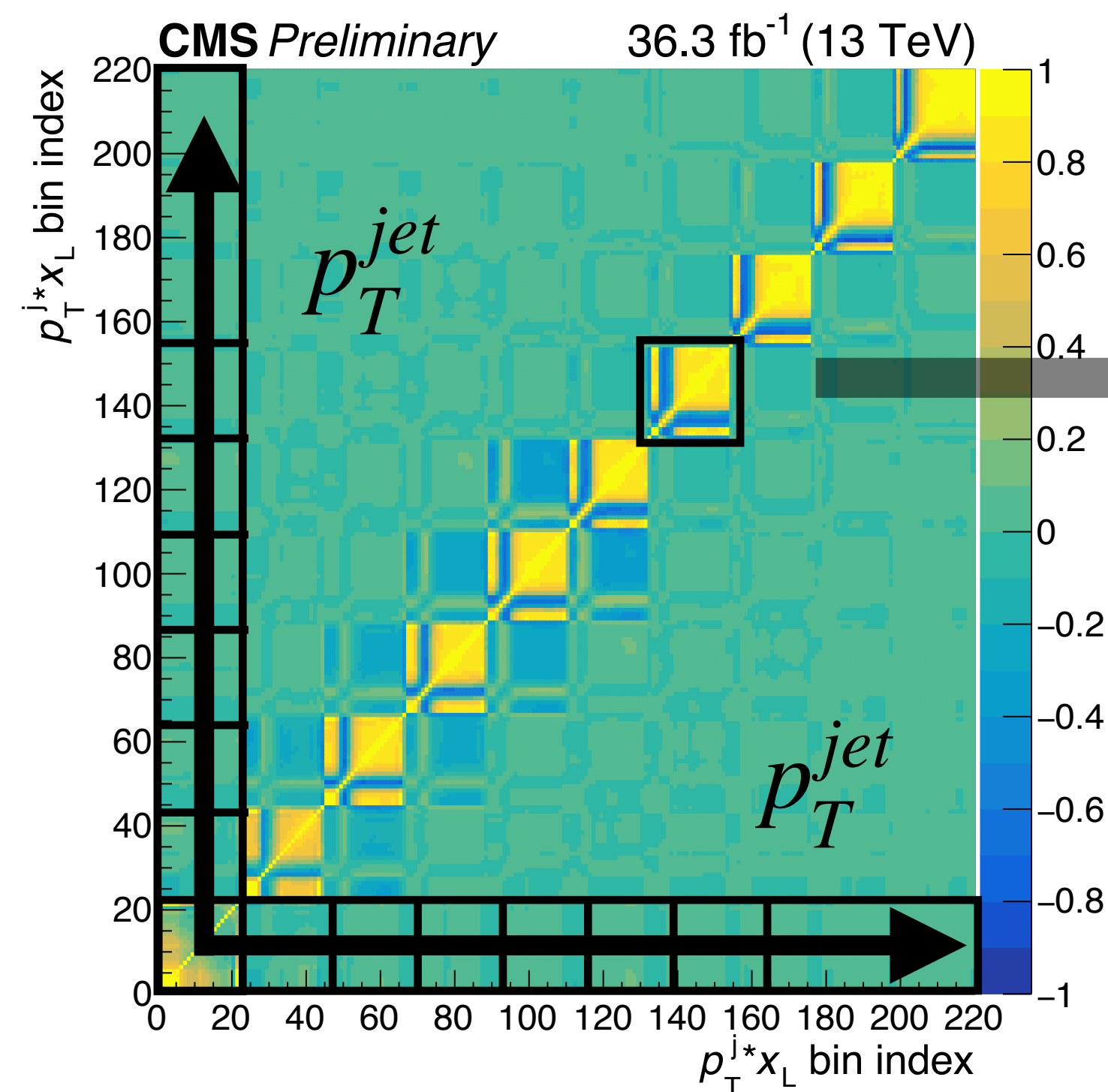
$$E3C = \frac{d\sigma^{[3]}}{dx_L} = \sum_{i,j,k} \int d\sigma \frac{E_i E_j E_k}{E^3} \delta(x_L - \max(\Delta R_{i,j}, \Delta R_{i,k}, \Delta R_{j,k}))$$

Insensitive to soft radiation

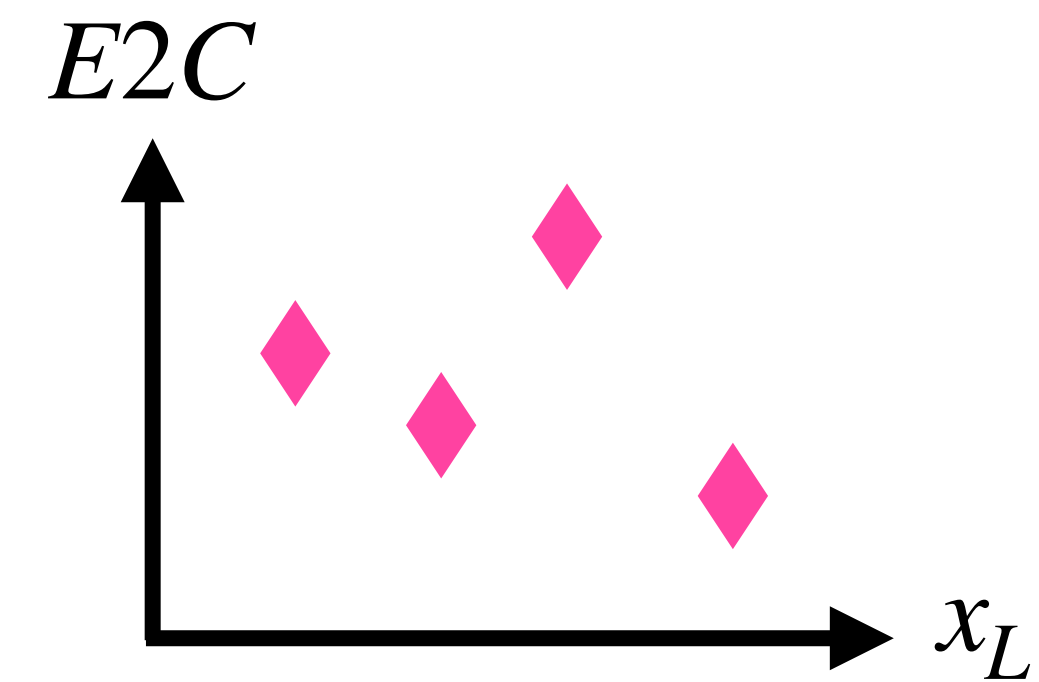
EnC: statistical correlations

Multi entry distribution for every jet, statistical correlation important

E2C correlation matrix



x_L bins in a p_T^{jet} region
Correlation: 80%

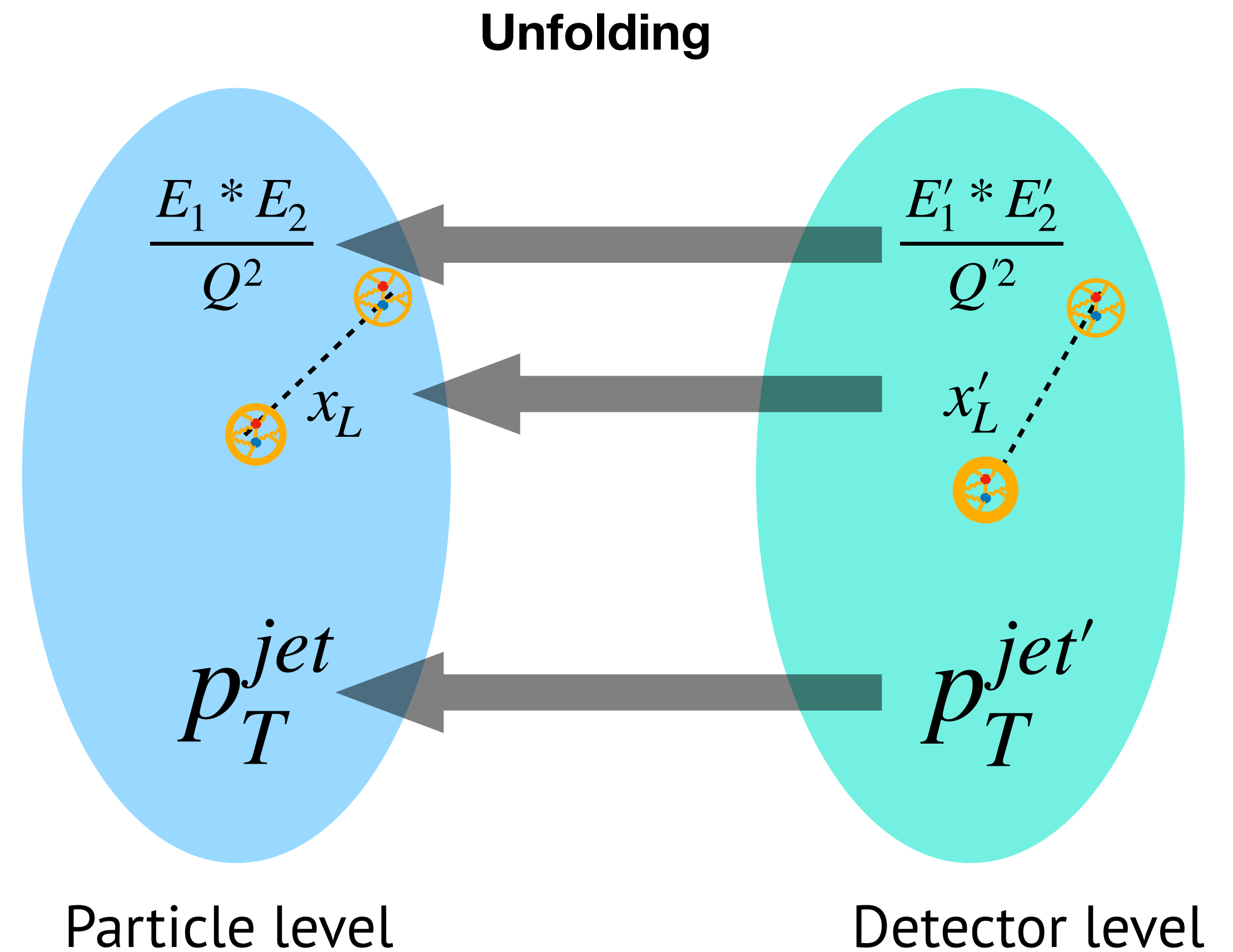
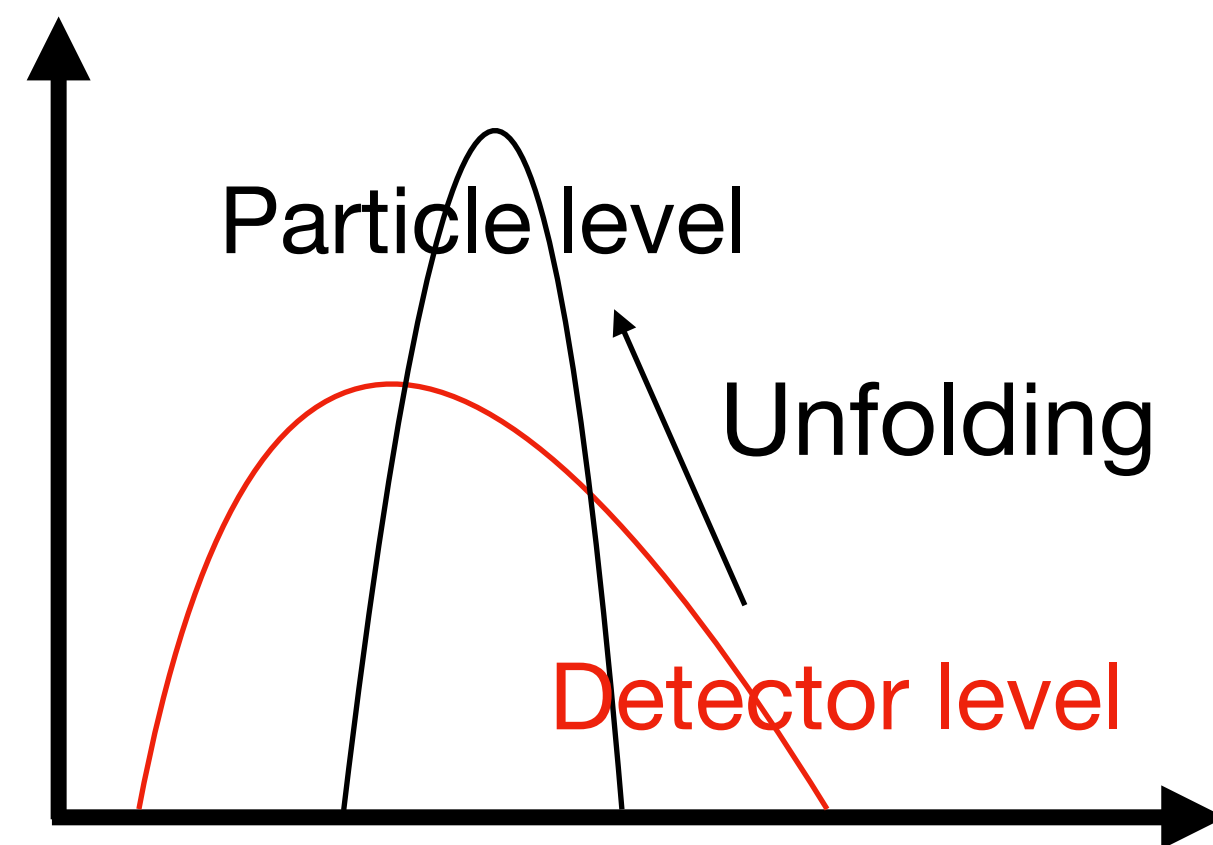


EnC: Constituent unfolding

Unfolding: detector level \rightarrow particle level

Unfold jet constituents instead of distribution:

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

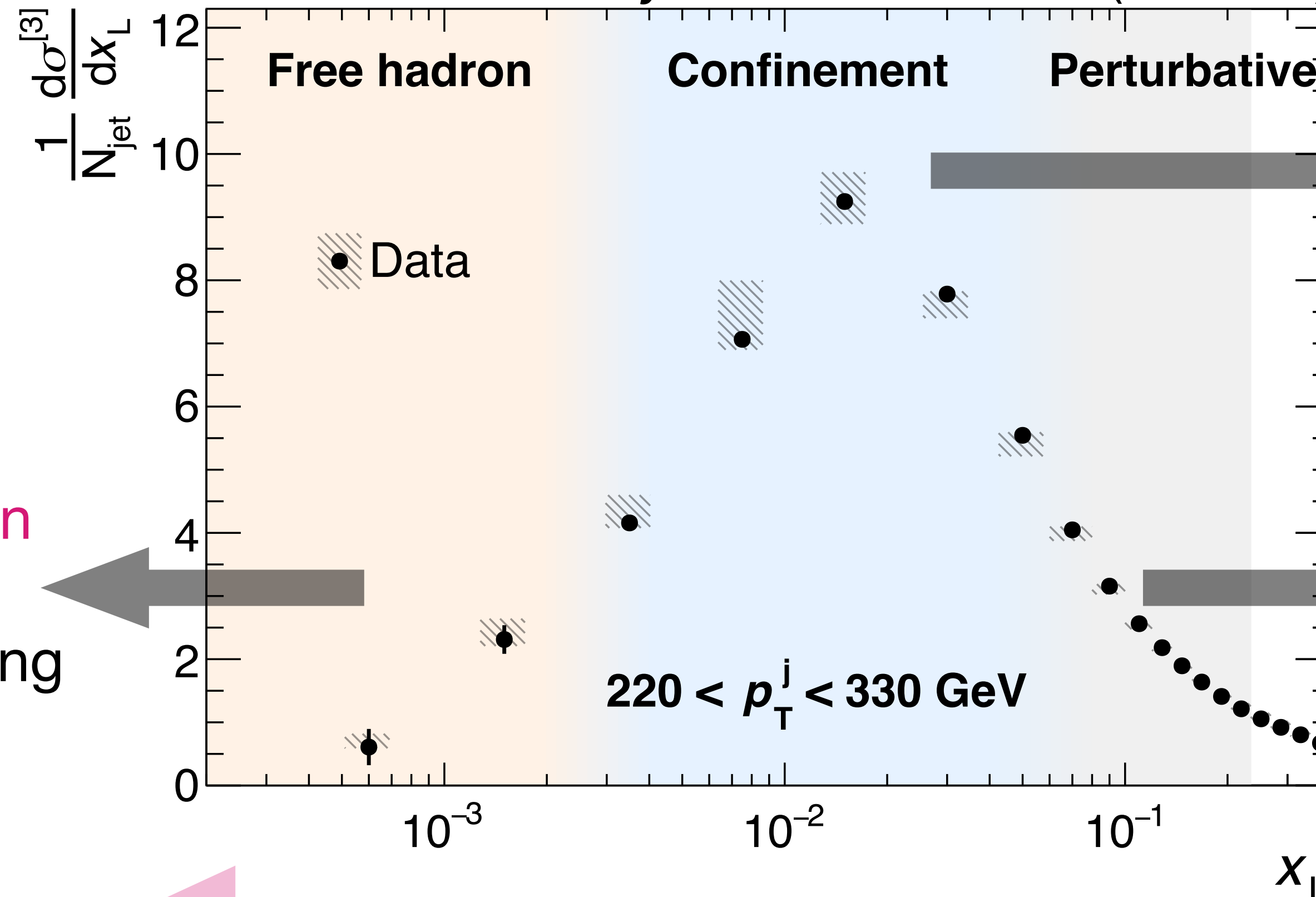


E3C measurement

Using all neutral & charged hadrons $> 1\text{ GeV}$ in a jet



CMS Preliminary 36.3 fb^{-1} (13 TeV)

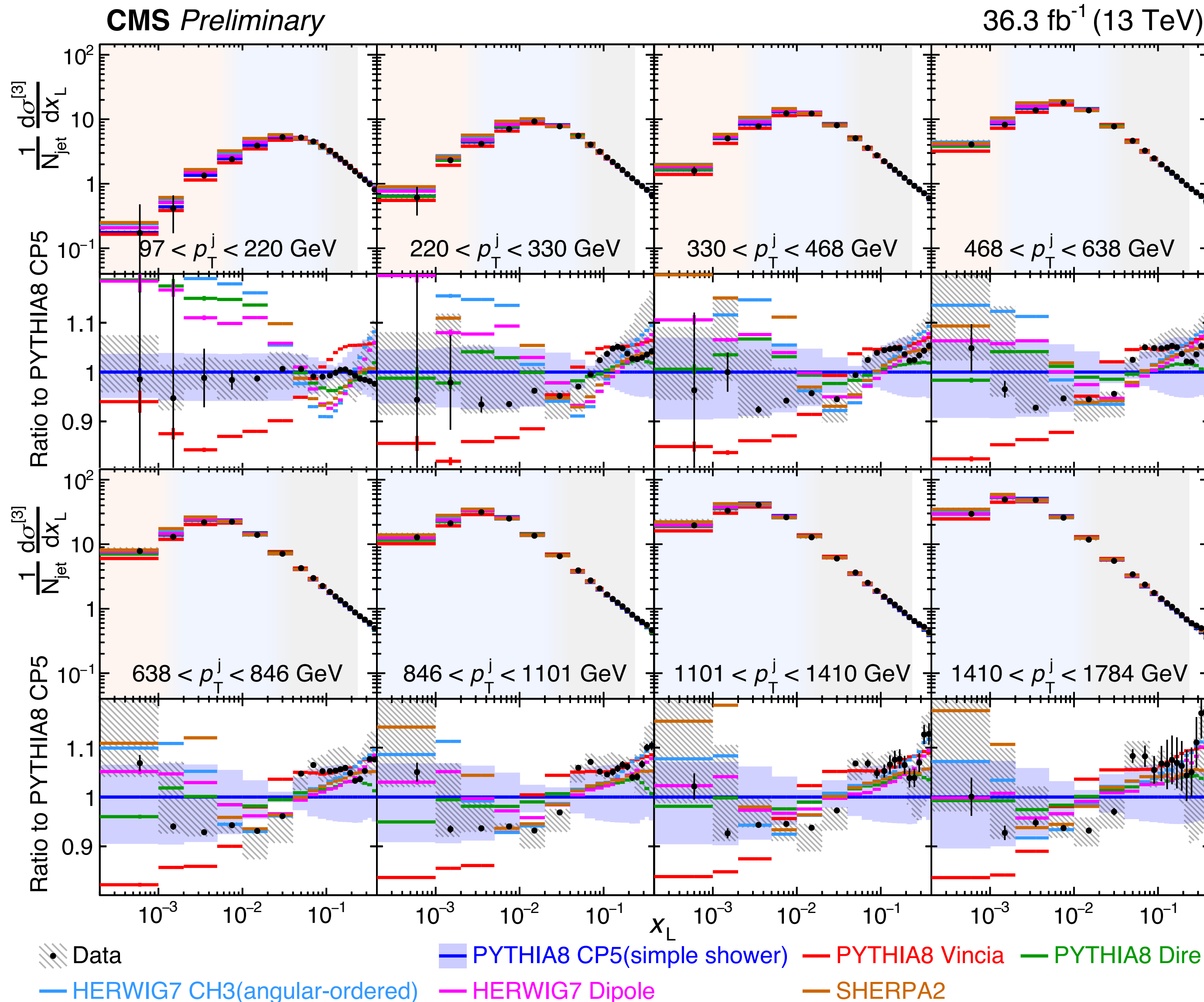


Phase transition from parton to hadron

Non-interacting hadron random distribution integer power-law scaling

Interacting partons non-integer scaling

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

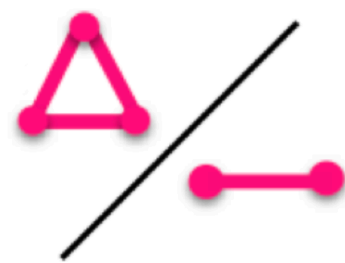
$$x_L \approx \frac{0.8}{p_T^{jet}}$$

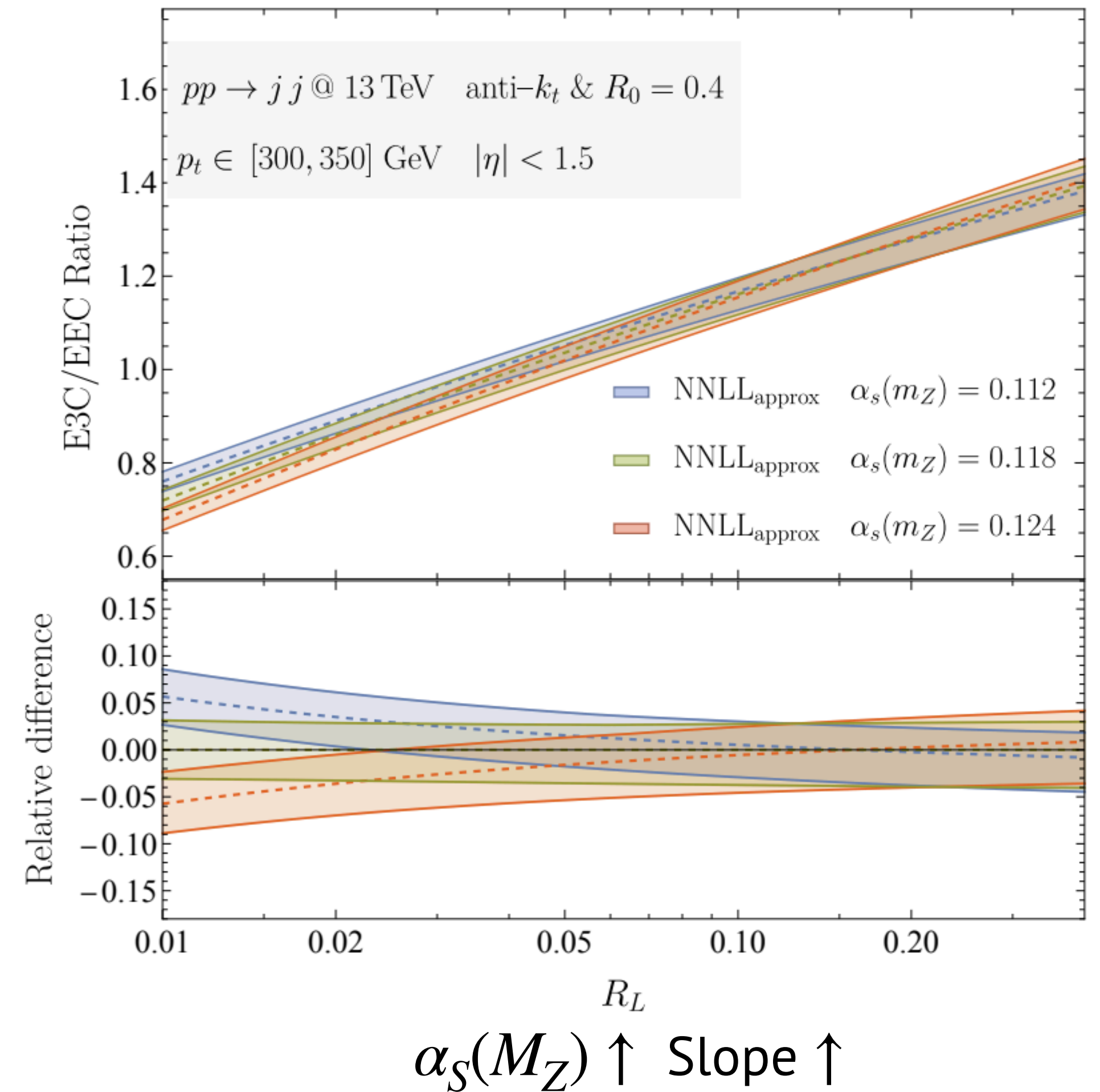
$$x_L \approx \frac{20}{p_T^{jet}}$$

E3C/E2C: a new way to extract α_s

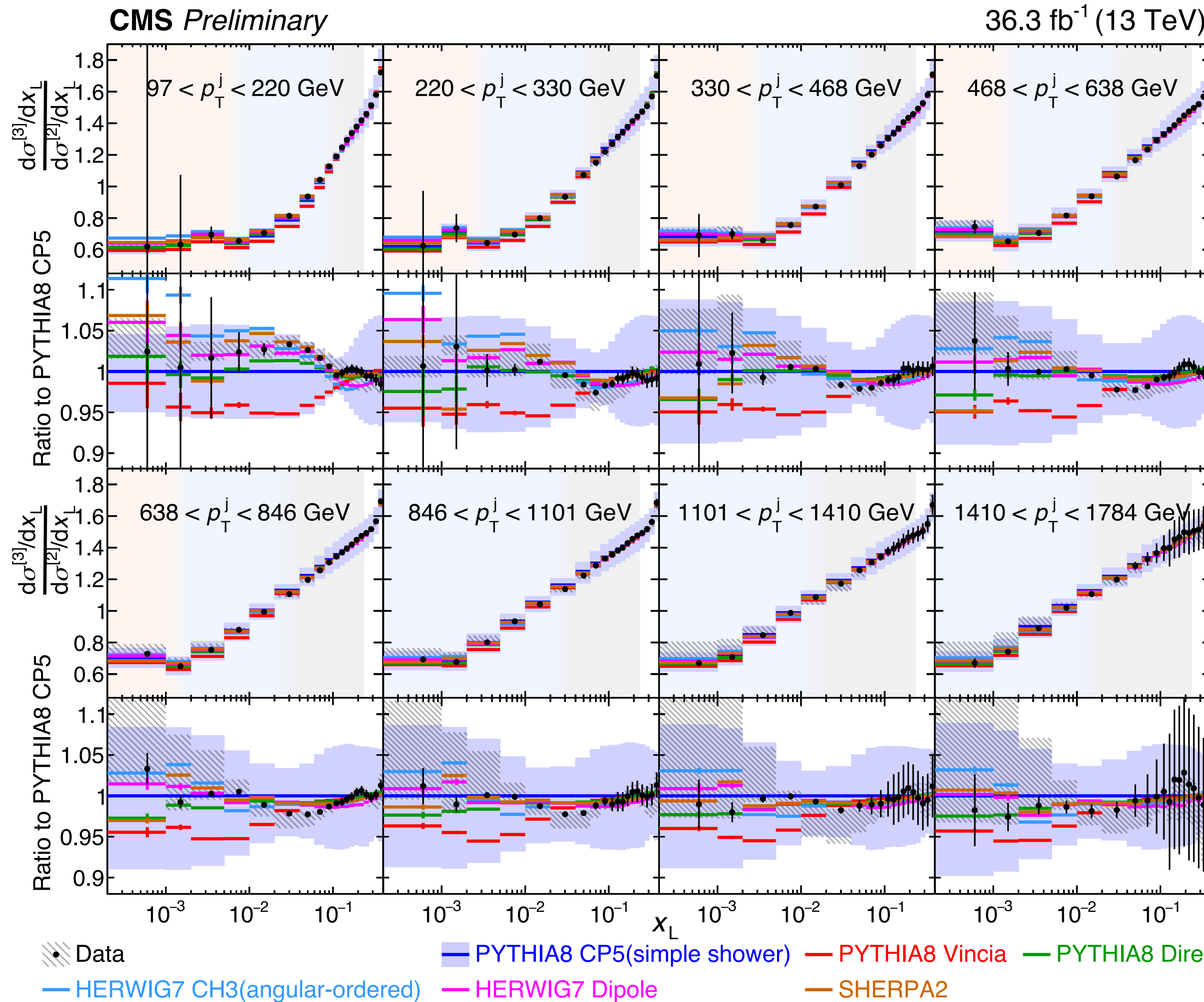
Chen, Gao, Li, Xu, Zhang, Zhu,
[arXiv:2307.07510](https://arxiv.org/abs/2307.07510)

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


$$\propto \alpha_s(Q) \ln x_L + \mathcal{O}(\alpha_s^2)$$



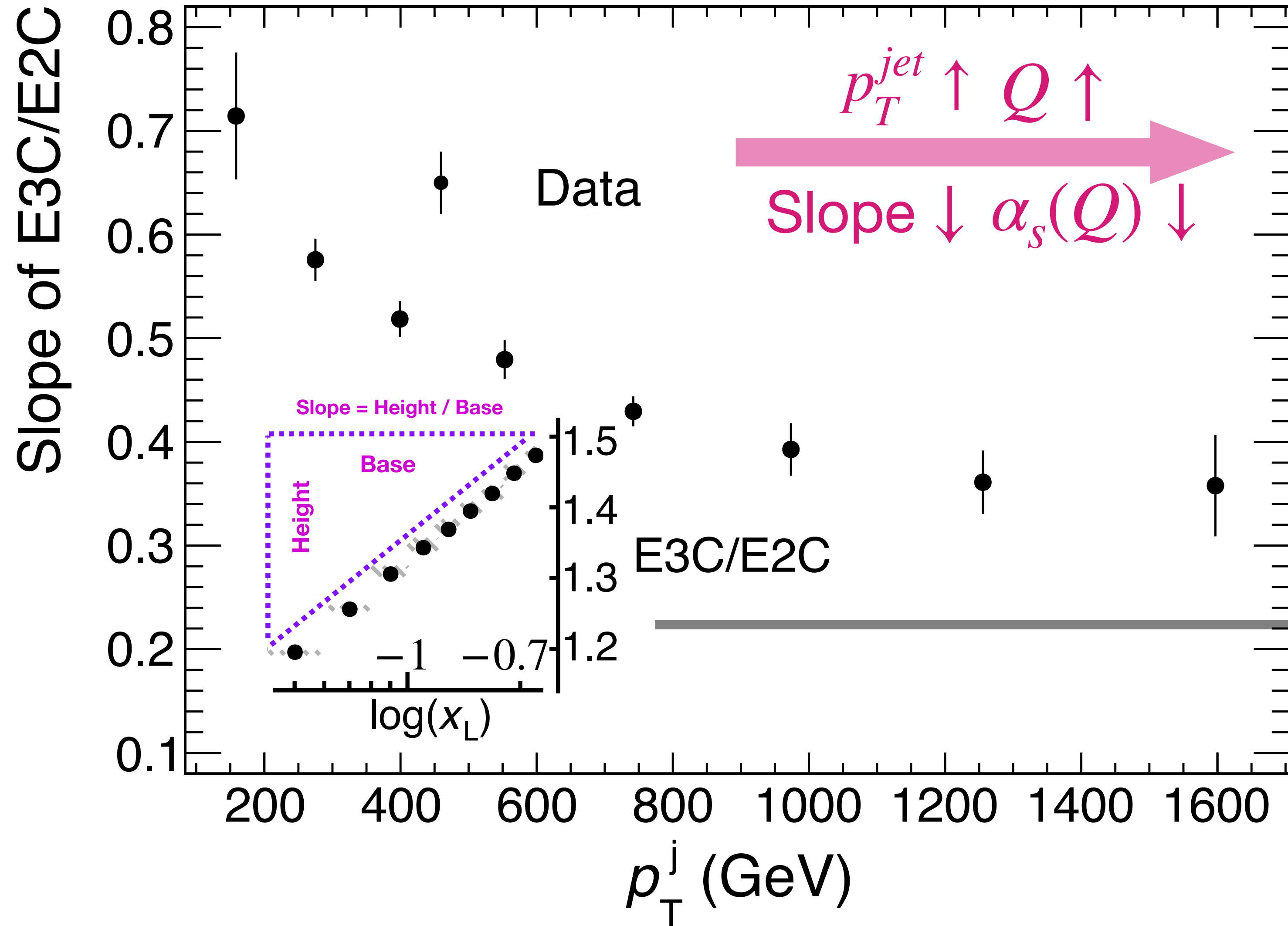
E3C/E2C



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

Direct observation of asymptotic freedom

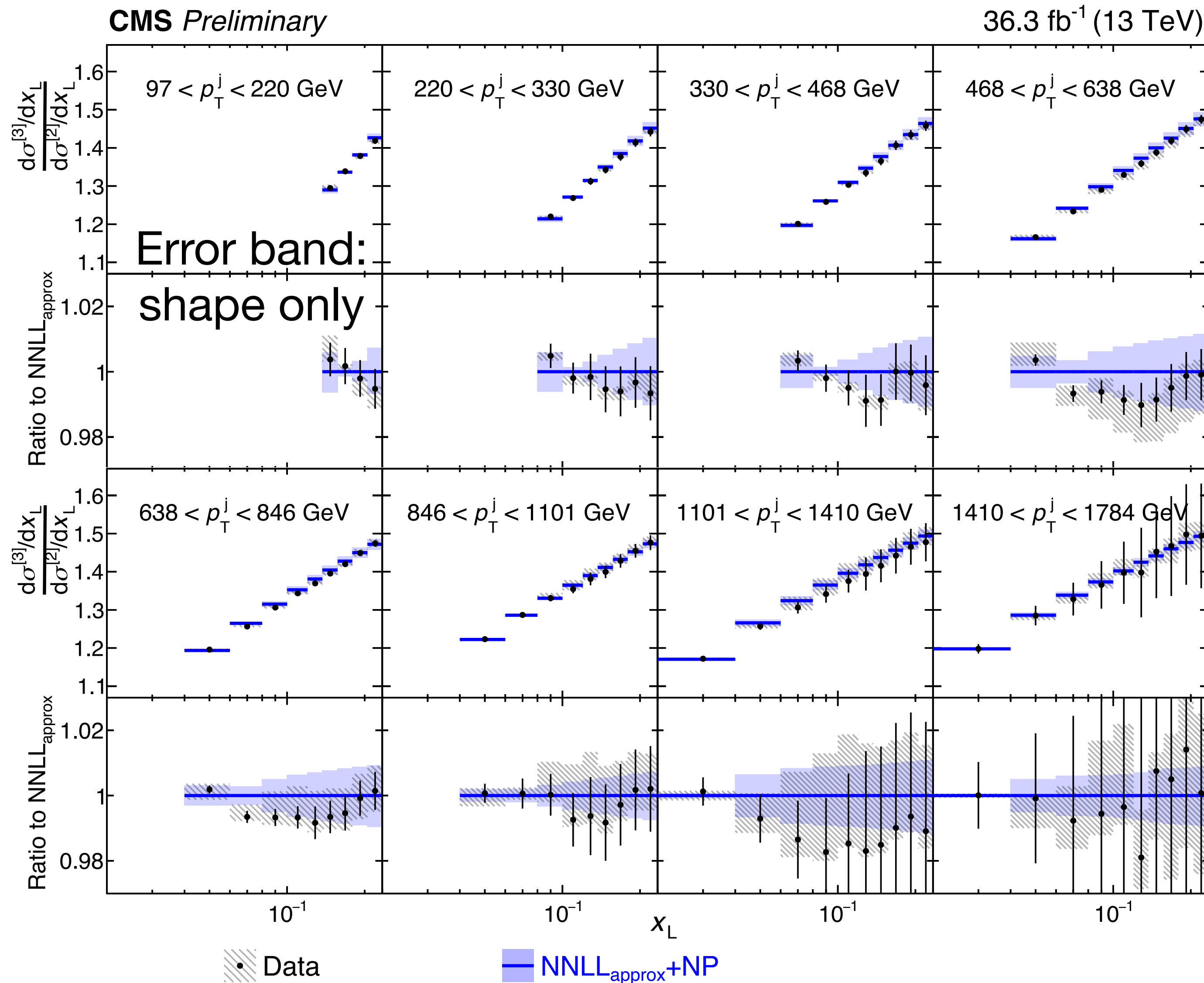
CMS Preliminary 36.3 fb⁻¹ (13 TeV)



$$\frac{\Delta}{\text{---}} \propto \alpha_s(Q) \ln x_L + O(\alpha_s^2)$$

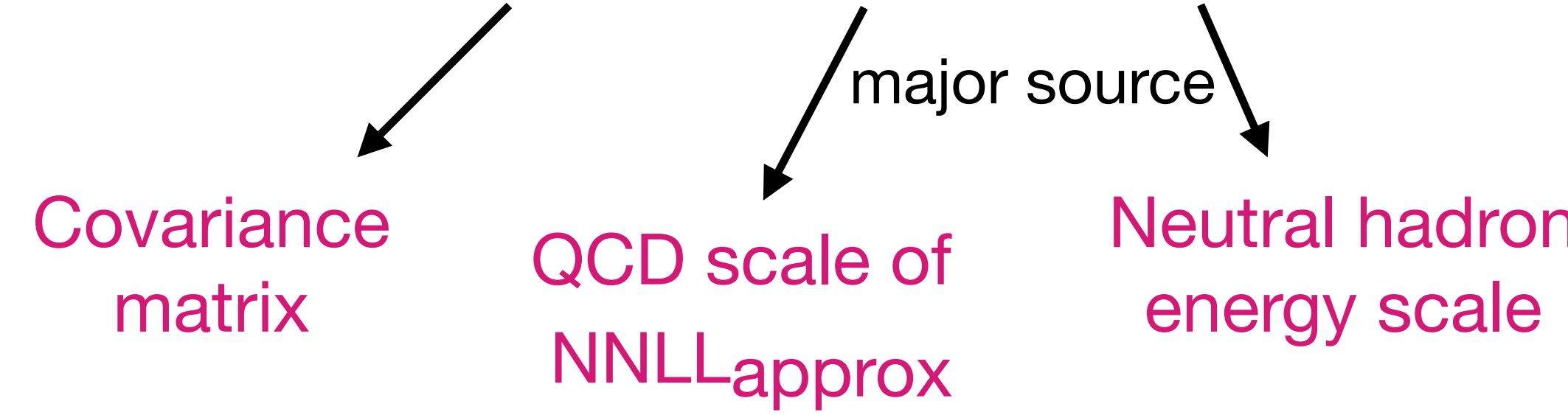
Data point: slope fitted
in a p_T^{jet} region

Unfolded E3C/E2C vs NNLL-approx



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

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



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