Universität Hamburg
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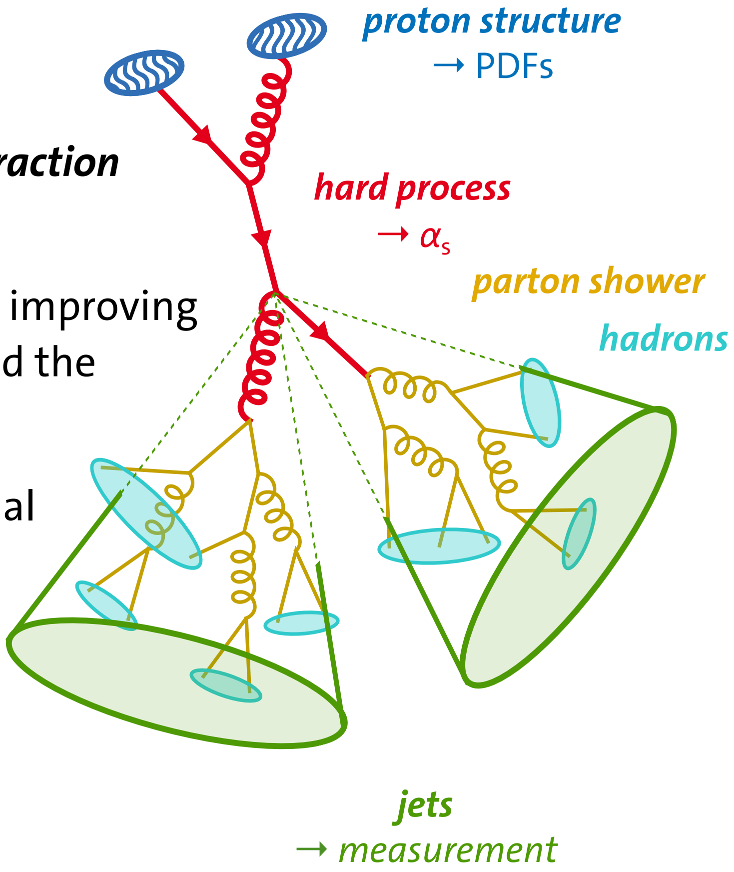
CMS jet measurements and constraints on PDFs and α_s

31st International Workshop on Deep Inelastic Scattering | 8–12 April 2024 | Grenoble, France

Daniel Savoiu on behalf of the CMS Collaboration

Jets & QCD at the LHC

- crucial for understanding ***proton structure*** & ***strong interaction*** up to the highest accessible energies
- measurements provide essential experimental input for improving the ***parton distribution functions*** (PDFs) of the proton and the ***strong coupling*** $\boldsymbol{\alpha_s}$
- many recent results from CMS, presenting only a personal selection today



Jet azimuthal correlations (preliminary)

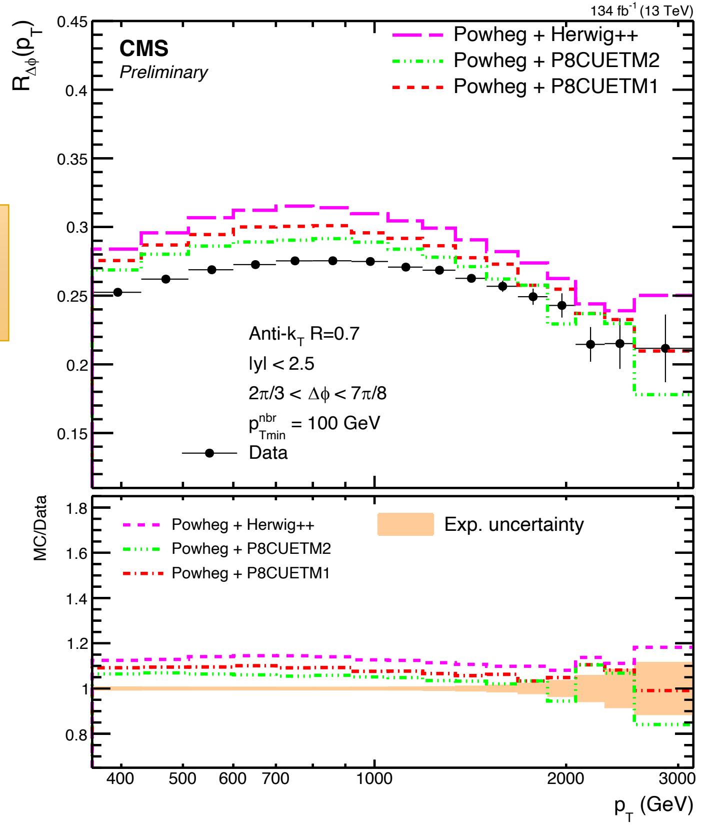
[arXiv:2305.16930]
[CMS-PAS-SMP-22-005]

- observable $R_{\Delta\phi}$ defined via the ***number of neighboring jets*** within a specified interval of ***angular distance Δφ***

$$R_{\Delta\phi}(p_{\mathrm{T}}) = \frac{\sum_{i=1}^{N_{\mathrm{jet}}(p_{\mathrm{T}})} N_{\mathrm{nbr}}^{(i)}(\Delta\phi, p_{\mathrm{Tmin}}^{\mathrm{nbr}})}{N_{\mathrm{jet}}(p_{\mathrm{T}})}$$

ratio observable
→ many systematic uncertainties cancel

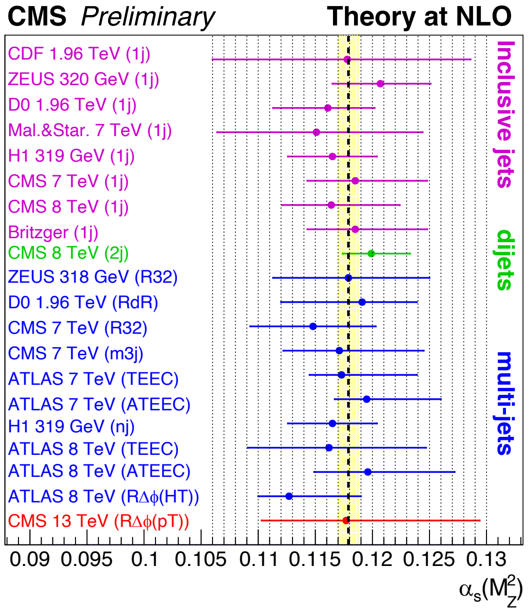
- interval $\left(\frac{2\pi}{3} < \Delta\phi < \frac{7\pi}{8}\right)$ separates dijet topologies from 3+ jets → ***sensitivity to $\alpha_s(m_Z)$***

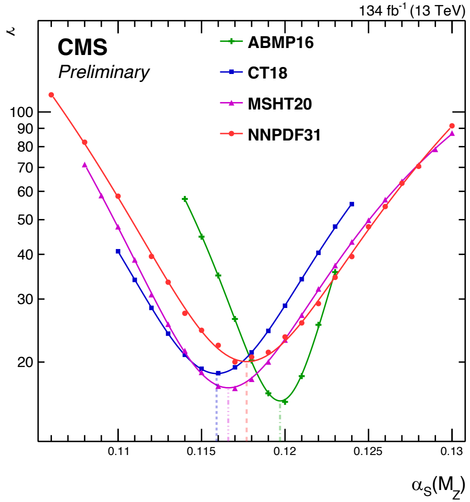


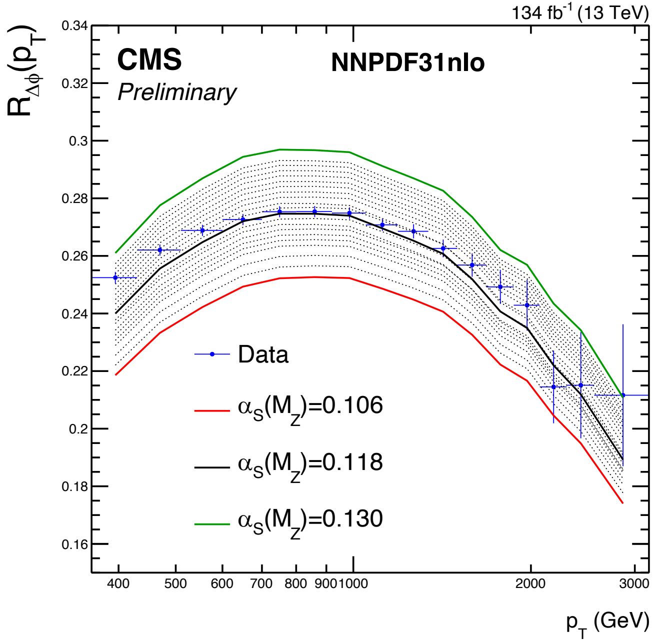
Jet azimuthal correlations (preliminary)

[arXiv:2305.16930]
[CMS-PAS-SMP-22-005]

- extraction of $\alpha_s(m_Z)$ from comparison to fixed-order pQCD predictions at ***NLO*** using several global PDF sets + nonperturbative & electroweak corrections





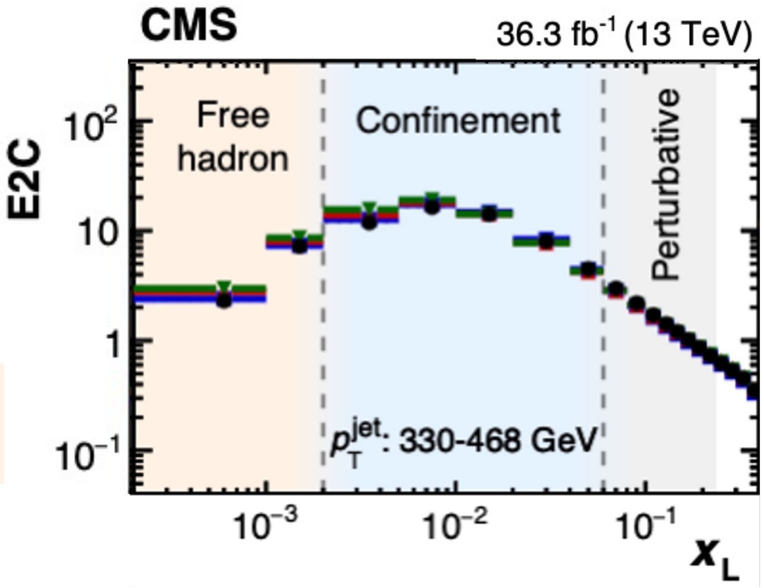


$$\alpha_s(m_Z)_{NLO} = 0.1177\ (13)_{exp}\ \left({}^{+116}_{-73}\right)_{theo.}$$

Energy correlators (EECs)

[arXiv:2402.13864]
Submitted to *PRL*

- ***substructure observables*** that describe the correlations of kinematic properties of particles inside jets, weighted by energy → E_iE_j/E^2 or $E_iE_jE_k/E^3$
- calculated based on ***pairs*** (E2C) or ***triplets*** (E3C) of constituent particles
- ordered by ***angular separation*** $\boldsymbol{x_L}$ → probe timescale of hadron formation



$$x_L = \sqrt{(\Delta\eta_{i,j})^2 + (\Delta\phi_{i,j})^2}$$

wide angle splittings, perturbation theory

small angle splittings, non-interacting hadrons

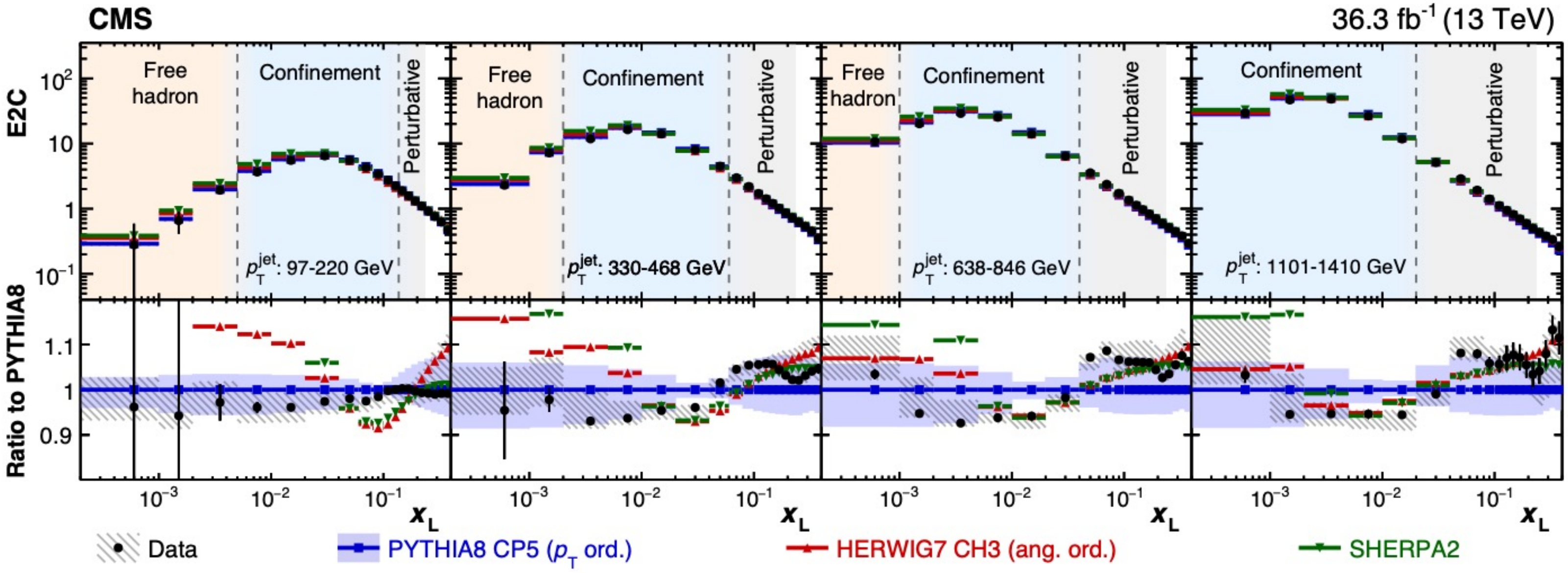
Energy correlators (EECs)

[arXiv:2402.13864]
Submitted to *PRL*

- EECs measured in bins of **jet p_T** and compared to predictions from MC generators *PYTHIA 8*, *Herwig 7* and *SHERPA 2*

best overall description (*PYTHIA 8*)

perform better in some regions (*Herwig 7* and *SHERPA 2*)

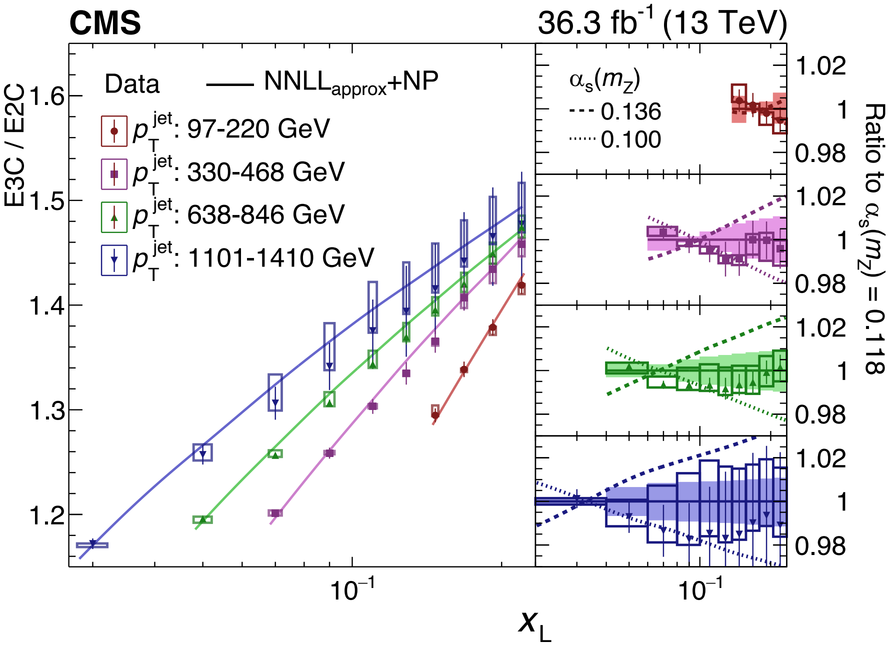


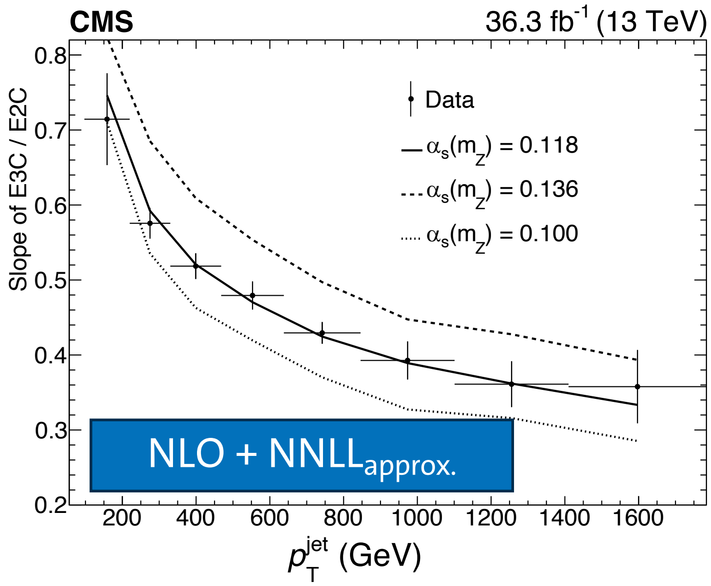
Strong coupling from EECs

[arXiv:2402.13864]
Submitted to *PRL*

ratio of E3C and E2C sensitive to $\alpha_s(m_Z)$:

- approx. linear in $\alpha_s \ln x_L$
- PDF dependence largely suppressed





NLO + NNLL$_{approx.}$

$$\alpha_s(m_Z)_{EEC} = 0.1229 \; \left({}^{+14}_{-12}\right)_{stat.} \; \left({}^{+23}_{-36}\right)_{exp.} \; \left({}^{+30}_{-33}\right)_{theo.}$$

most precise $\alpha_s(m_Z)$ from substructure

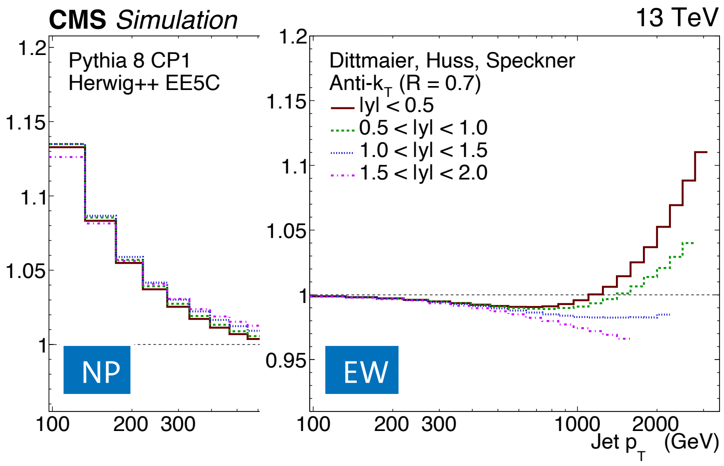
Inclusive jet production at $\sqrt{s} = 13$ TeV

[arXiv:2111.10431]
[JHEP 02 (2022) 142]
+ addendum [JHEP 12 (2022) 035]

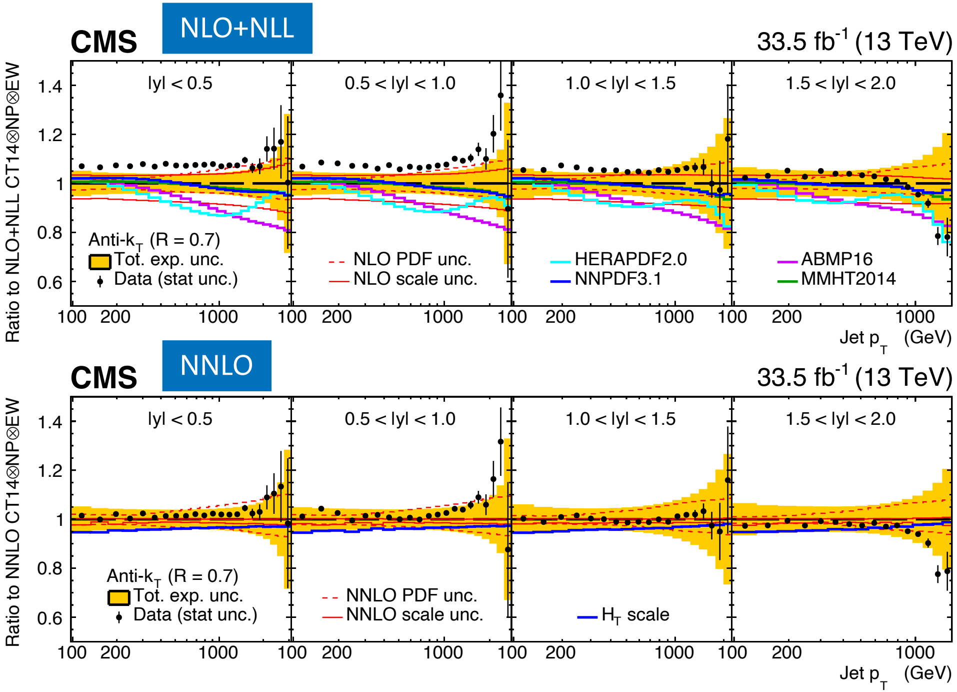
comparison to fixed-order pQCD theory at **NNLO** and **NLO+NLL**

+ corrections for non-perturbative (***NP***) and electroweak (***EW***) contributions

improved agreement at **NNLO**



corrections of >10% in certain phase space regions



Inclusive jet production at $\sqrt{s}$ = 13 TeV

[arXiv:2111.10431]
[JHEP 02 (2022) 142]
+ addendum [JHEP 12 (2022) 035]

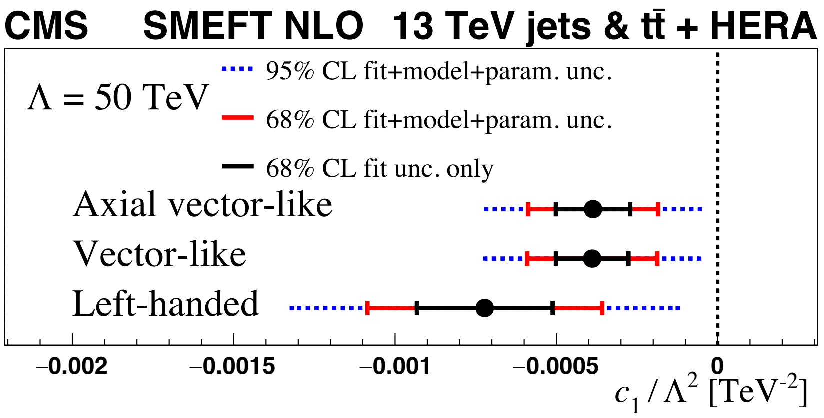
- determination of PDFs & $\alpha_s(m_Z)$ up to ***NNLO***

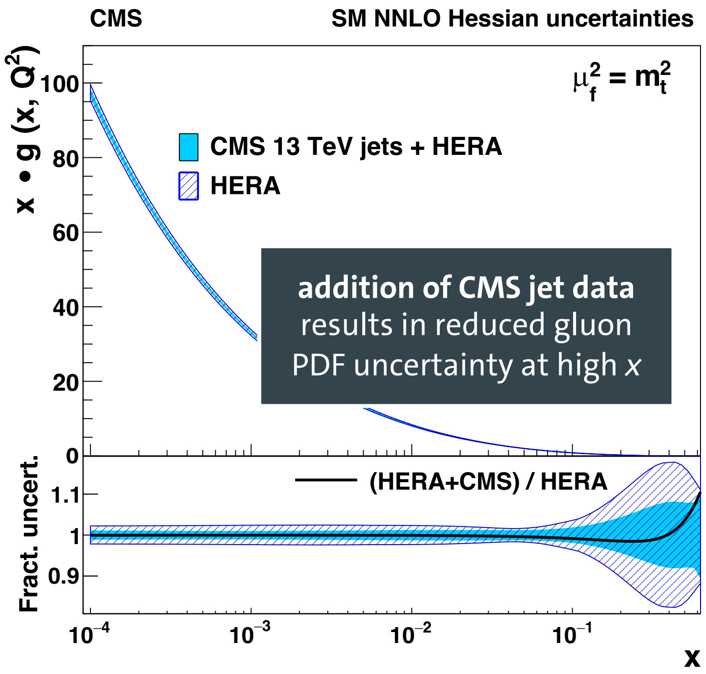
$$\alpha_s(m_Z)_{\text{NNLO}} = 0.1166\ (14)_{\text{fit}}\ (7)_{\text{model}}\ (4)_{\text{scale}}\ (1)_{\text{param.}}$$

↳ $\chi^2 / n_{\text{dof}} = 1302 / 1118$

most precise value of $\alpha_s(m_Z)$ obtained from jet cross sections

- with $t\bar{t}$ data: limits on ***Wilson coefficients*** for four-quark contact interactions



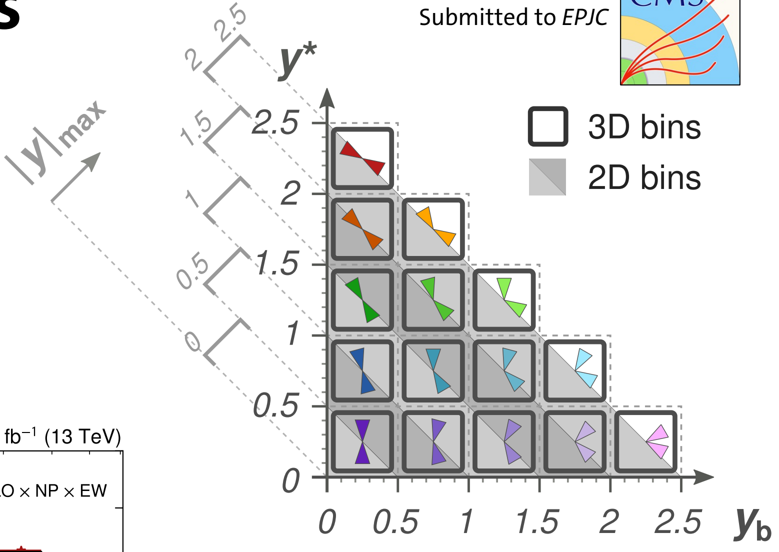


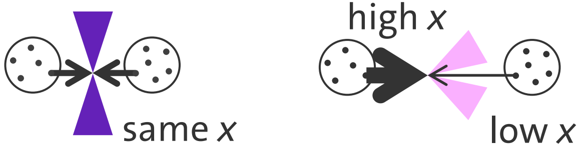
addition of CMS jet data results in reduced gluon PDF uncertainty at high x

Multidifferential dijet cross sections

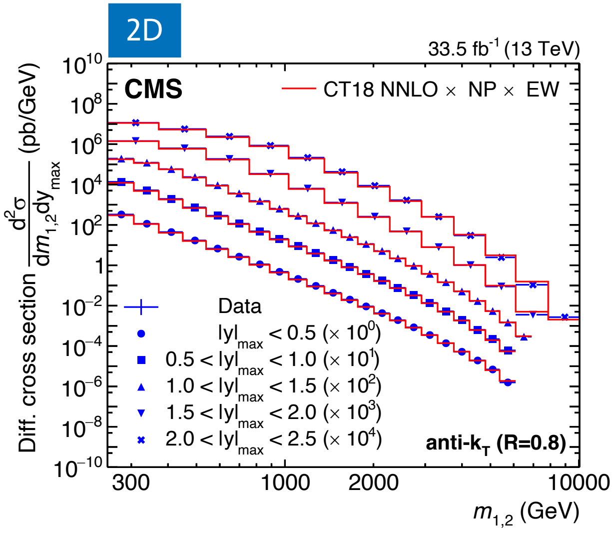
[arXiv:2312.16669]
Submitted to *EPJC*

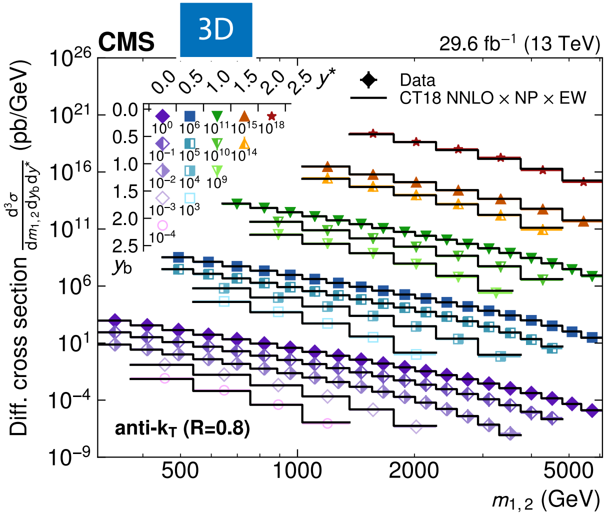
- **double- & triple-differential** cross section measured as a function of **dijet invariant mass $m_{1,2}$** for anti-k_T jets with R = **0.4** & **0.8**
- data compared to fixed-order theory at **NNLO** pQCD from ***NNLOJET*** + ***fastNLO***





disentangle regions of different **momentum fractions *x*** carried by partons → PDF fits





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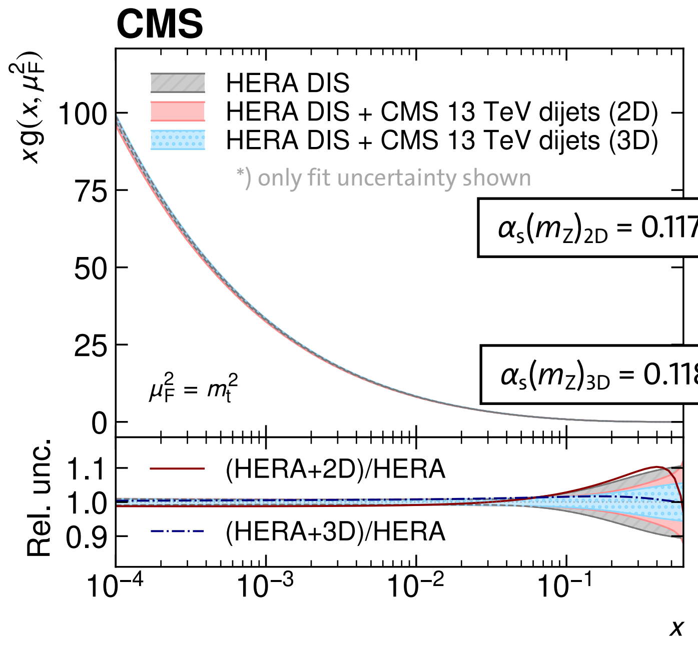
PDFs and $\alpha_s(m_Z)$ determined simultaneously in fits to CMS dijet & HERA DIS data

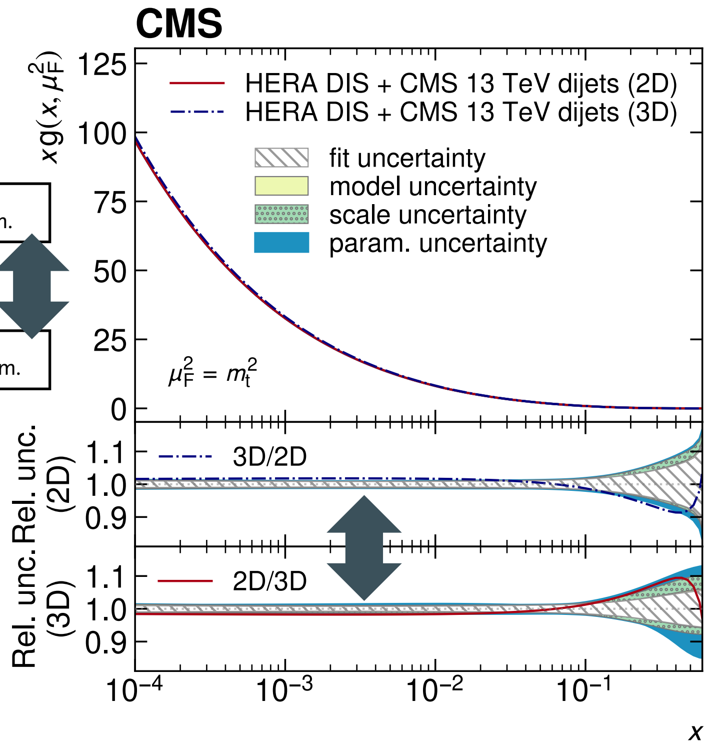


$\alpha_s(m_Z)_{2D} = 0.1179\ (15)_{fit}\ (8)_{model}\ (8)_{scale}\ (1)_{param.}$

↳ $\chi^2 / n_{dof} = 1232 / 1081$

$\alpha_s(m_Z)_{3D} = 0.1181\ (13)_{fit}\ (9)_{model}\ (6)_{scale}\ (2)_{param.}$

↳ $\chi^2 / n_{dof} = 1339 / 1109$



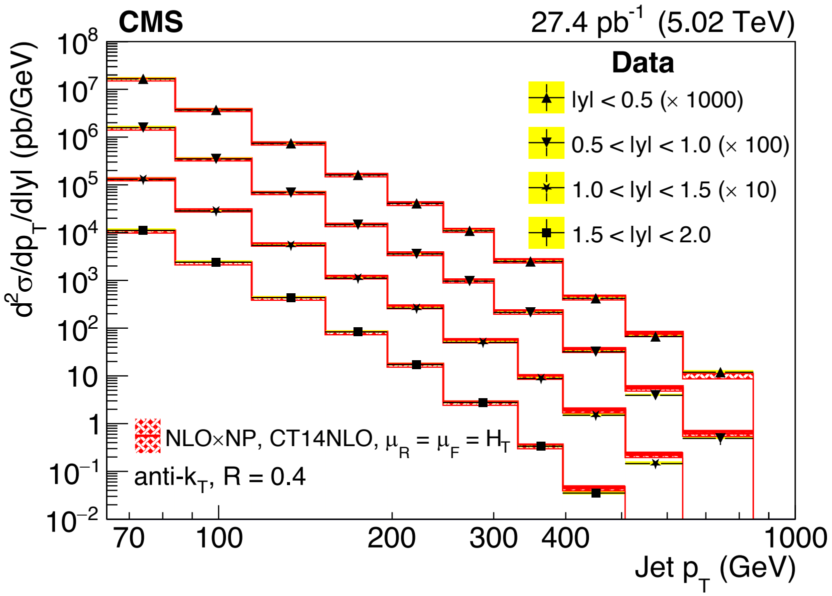
- gluon PDF uncertainty reduced at $x > 0.3$
- 2D & 3D fits largely compatible

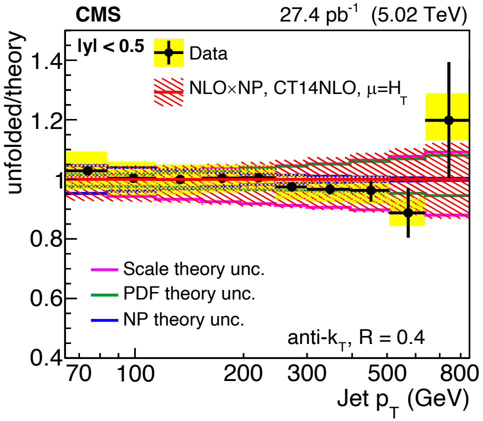
Inclusive jet production at $\sqrt{s} = 5.02$ TeV

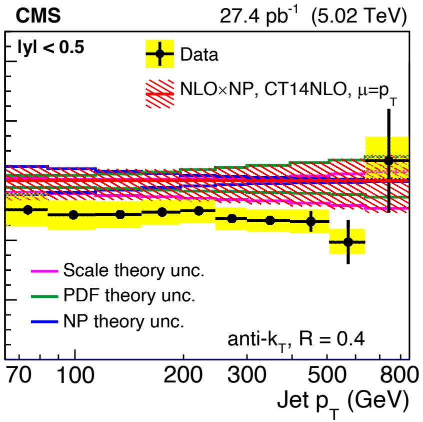
[arXiv:2401.11355]
Submitted to *JHEP*

complementary measurement at lower center-of-mass energy using anti-k_T jets with $R = 0.4$

- data/theory agreement studied for ***NLO*** & ***NNLO*** pQCD, different ***PDFs***, different central ***scale choices*** (H_T, p_T^{jet})
- can be used as an input to future QCD fits



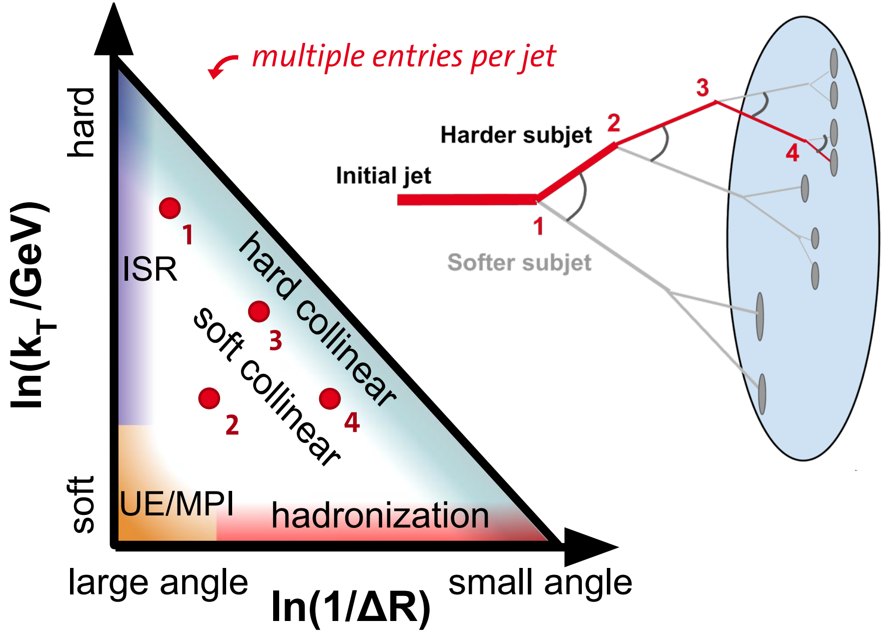




Primary *Lund* plane density

[arXiv:2312.16343]
Submitted to *JHEP*

- Lund jet plane represents phase space of emissions inside jets
  - **anti-k_T** jets are declustered iteratively using ***Cambridge–Aachen*** algorithm
  - density of emissions measured as a function of **ln(k_T / GeV)** and **ln(1 / ΔR)**:



$$\frac{1}{N_{\text{jets}}}\frac{\mathrm{d}^2 N_{\text{emissions}}}{\mathrm{d}\ln(k_T)\,\mathrm{d}\ln(R/\Delta R)}$$

$$\approx \frac{2}{\pi} C_R \alpha_S(k_T)$$

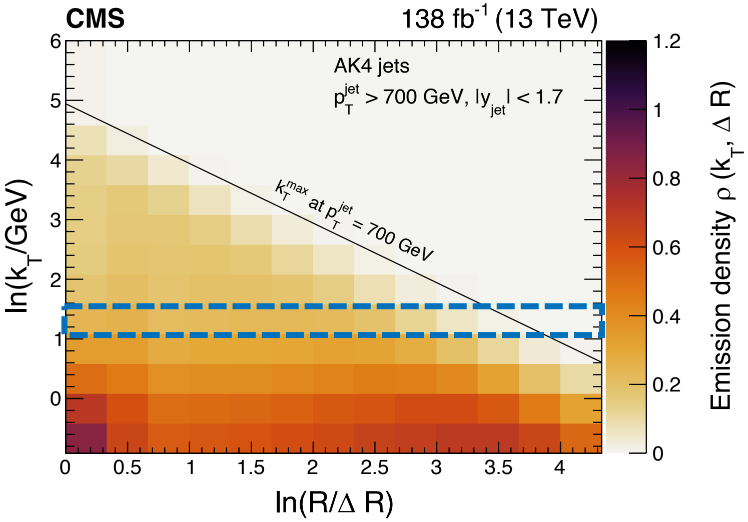
Applications

- improve modeling of ***parton shower***, ***hadronization***, underlying event, ...
- heavy-flavor tagging due to unique signatures of boosted color-singlets

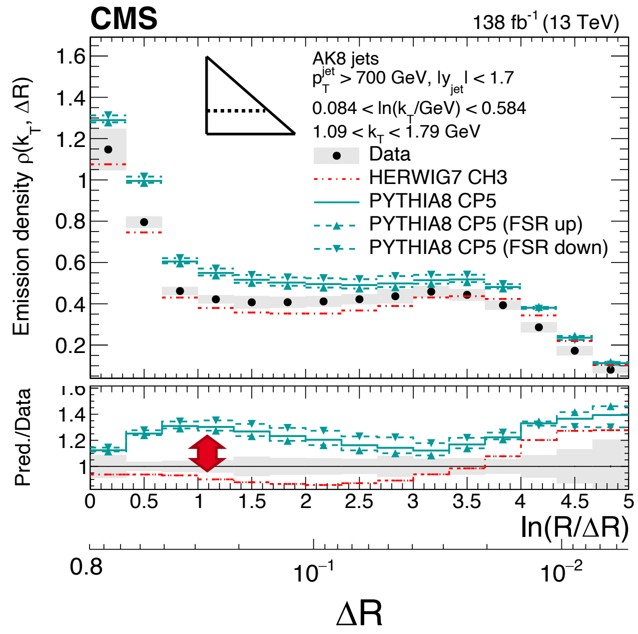
Primary *Lund* plane density

- measured for both small (R = 0.4) and large-radius jets (R = 0.8) with p_T > 700 GeV & |y| < 1.7, using only ***charged constituents***
- test performance of different **generators**, **tunes**, **parton showers**

[arXiv:2312.16343]
Submitted to *JHEP*



ΔR slice



- measurement can be used as input for ***MC tuning***

Summary

- presented recent jet measurements from the ***CMS*** Collaboration
- diverse measurement programs, targeting large range of observables, such as **jet cross sections**, **jet substructure, event shapes**
- measurements provide essential input for determinations of **strong coupling $\alpha_s(m_Z)$** and **parton distributions**, together with theory predictions up to **NNLO** accuracy

Thank you for your attention! Questions?

Backup

Inclusive jet production @ 5.02 TeV

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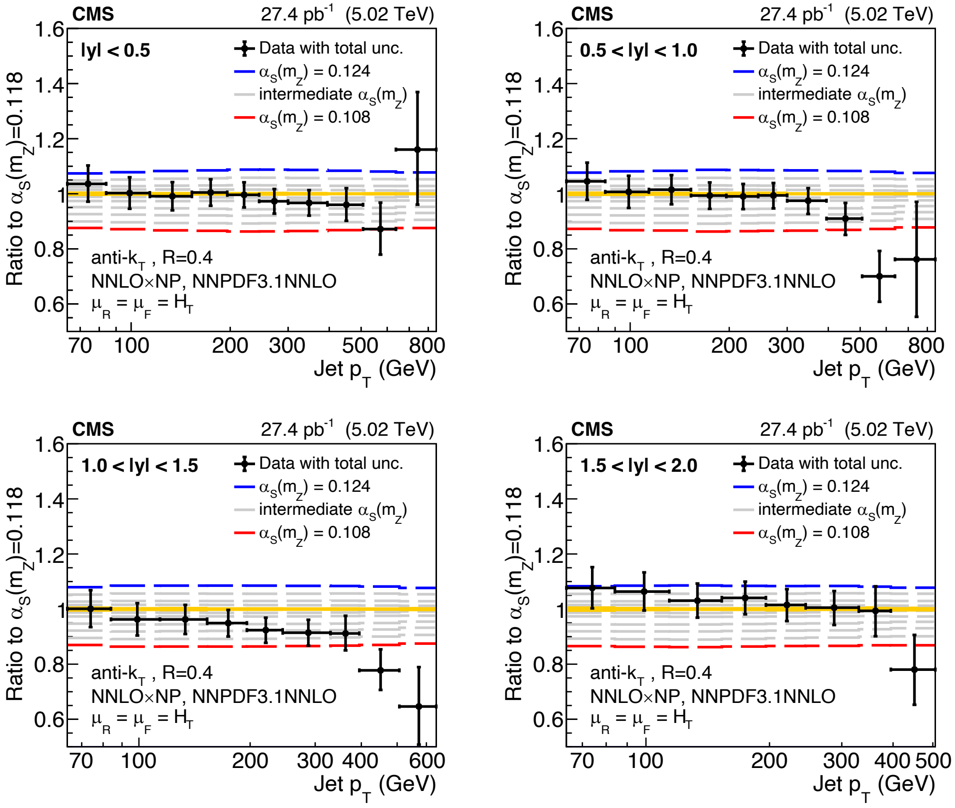

Multidifferential dijet cross sections

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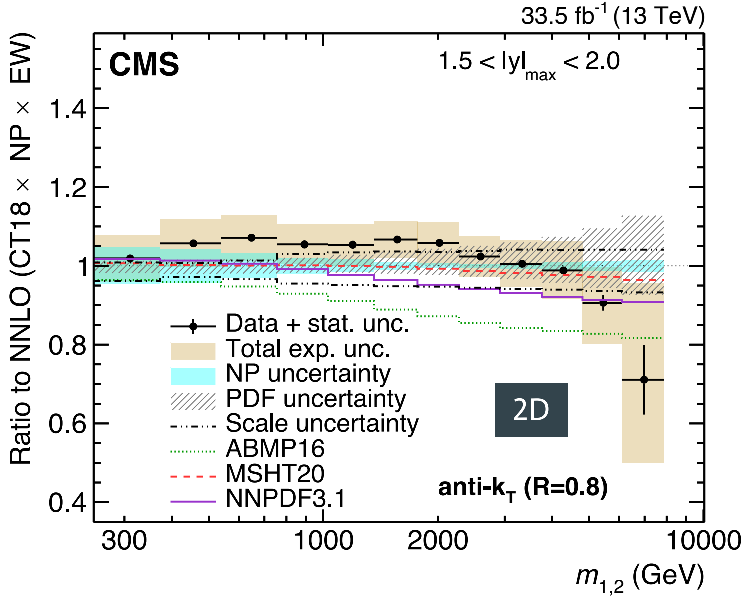
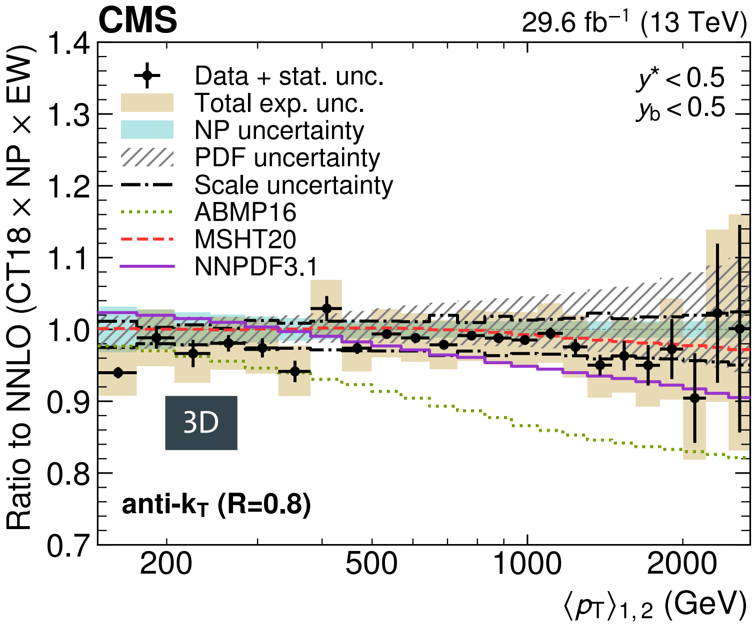
comparison to fixed-order theory predictions @ **NNLO** × nonperturbative, electroweak corrections





- in general, data are well described by theory (shown here: $R = 0.8$)

Inclusive jet production @ 13 TeV

[arXiv:2111.10431]
[JHEP 02 (2022) 142]
+ addendum [JHEP 12 (2022) 035]

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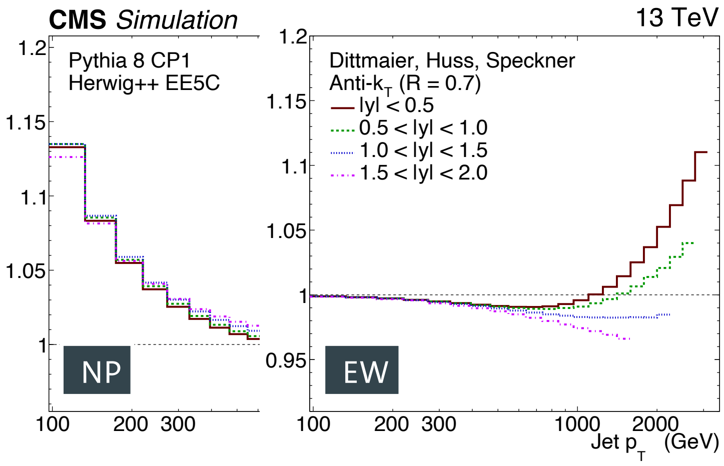

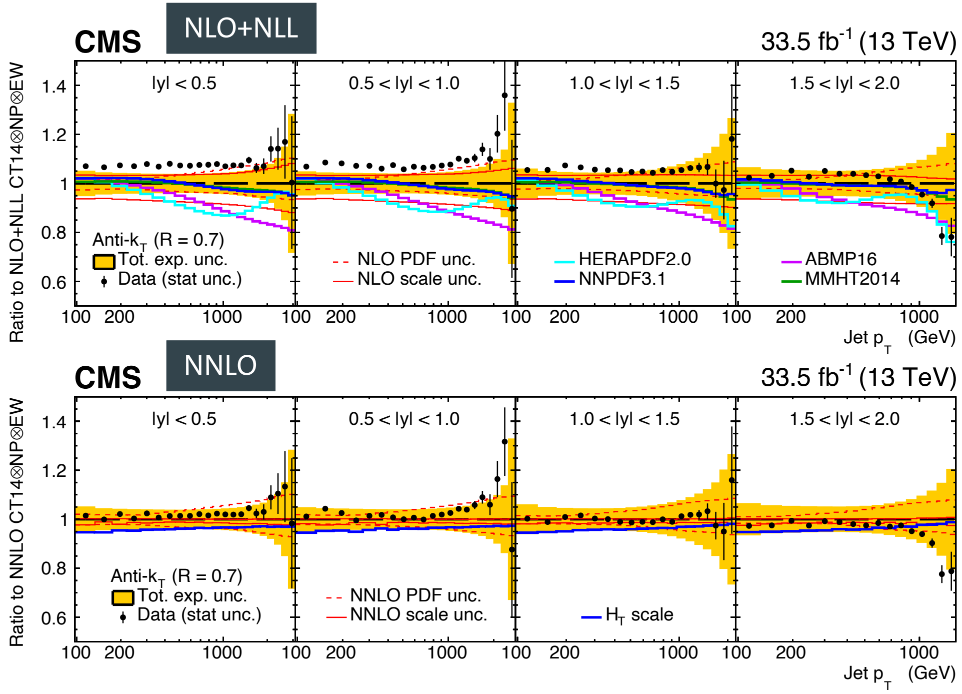

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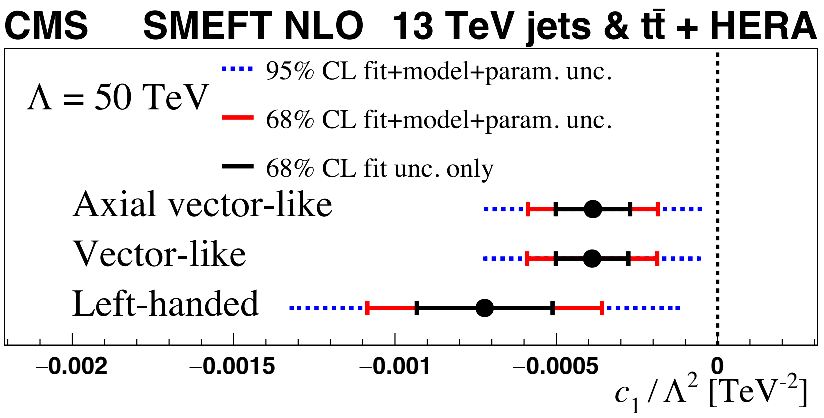
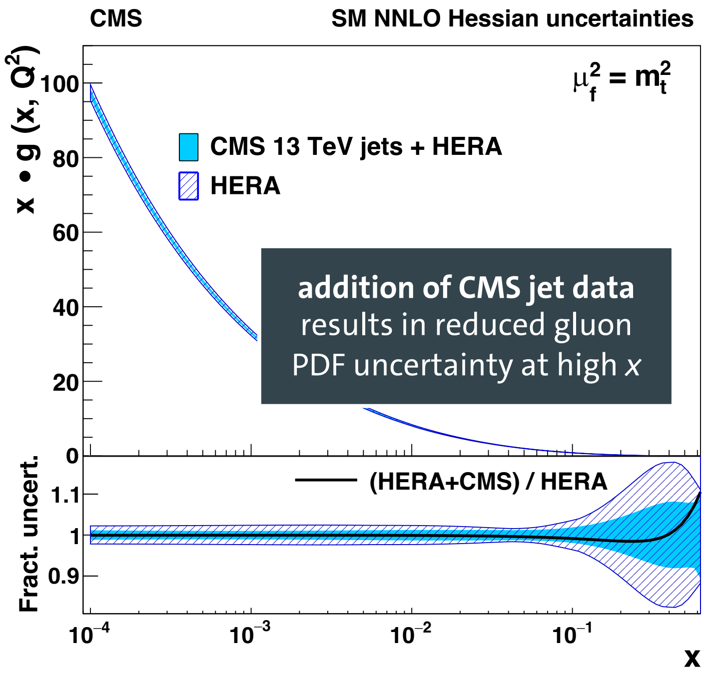
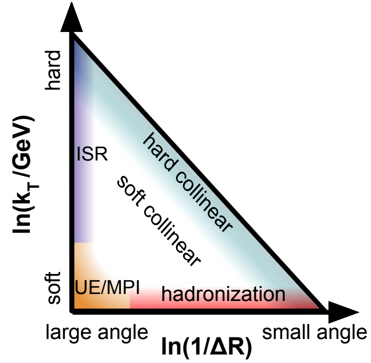
- with ***$t\bar{t}$*** data: limits on ***Wilson coefficients*** for four-quark contact interactions

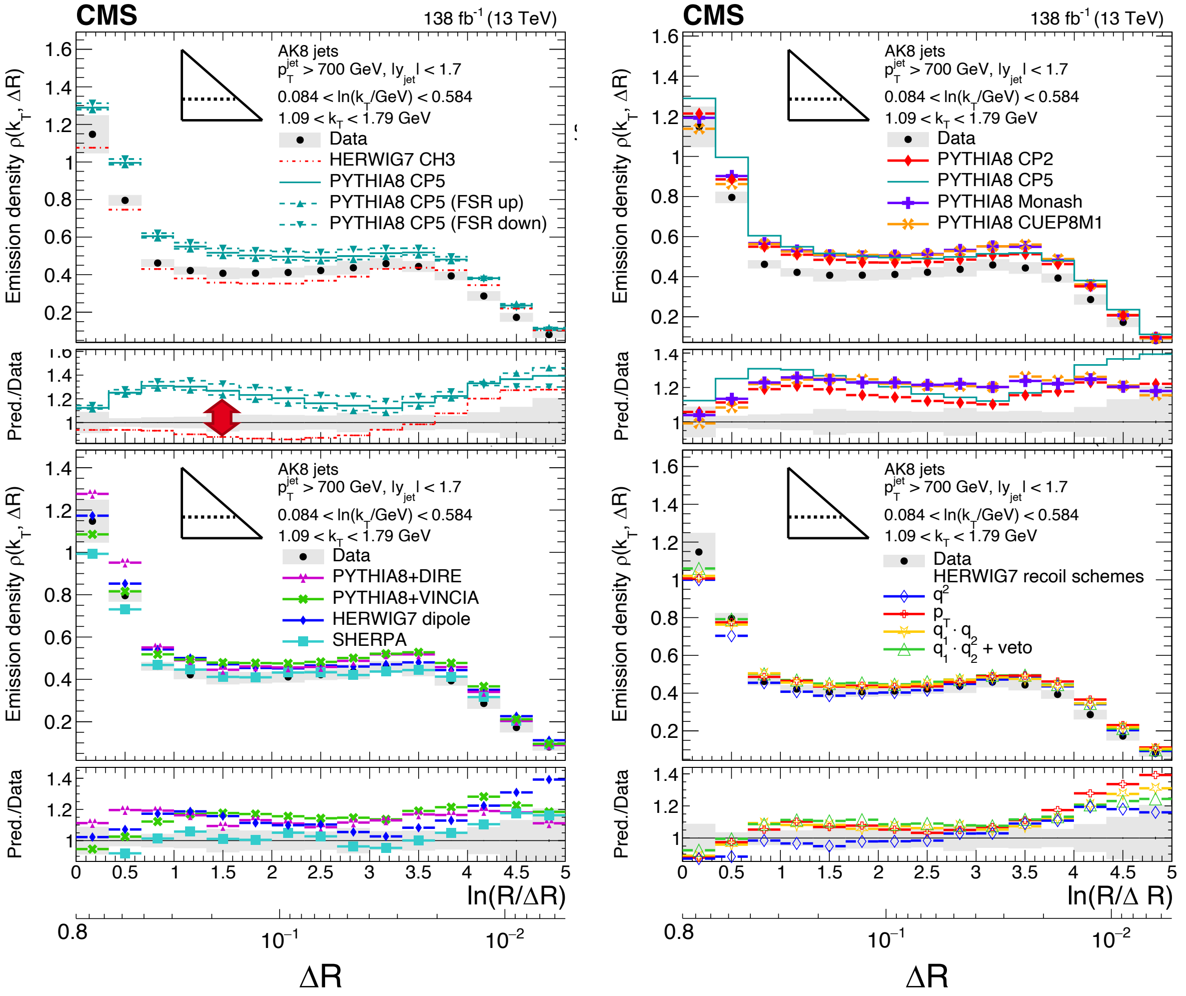




Primary *Lund* plane density

- test performance of different **generators, tunes, parton showers**
- measurement can be used as an input to further improve these models





Primary *Lund* plane density

[arXiv:2312.16343]
Submitted to *JHEP*

- comparison to predictions in the ***soft and collinear*** limit using the one-loop β function for the running of α_s
- qualitative description of emission density as a function of emission k_T