Universität Hamburg
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Federal Ministry of Education and Research

Inclusive & dijet production at 13 TeV

SM @ LHC Workshop | CERN, Geneva, Switzerland | 11–14 April 2022

Daniel Savoiu on behalf of the ATLAS, CMS & LHCb Collaborations

Jets at hadron colliders

QCD-induced jet production is **dominant process** at hadron colliders

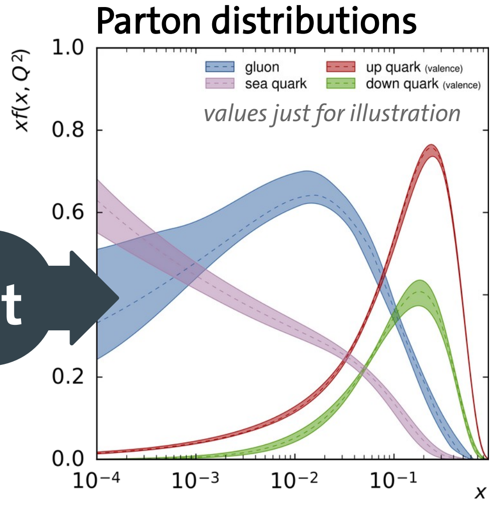
- high cross section → high statistical precision, low background
- valuable experimental input for probing **fundamental QCD parameters** (α_s), **PDFs**

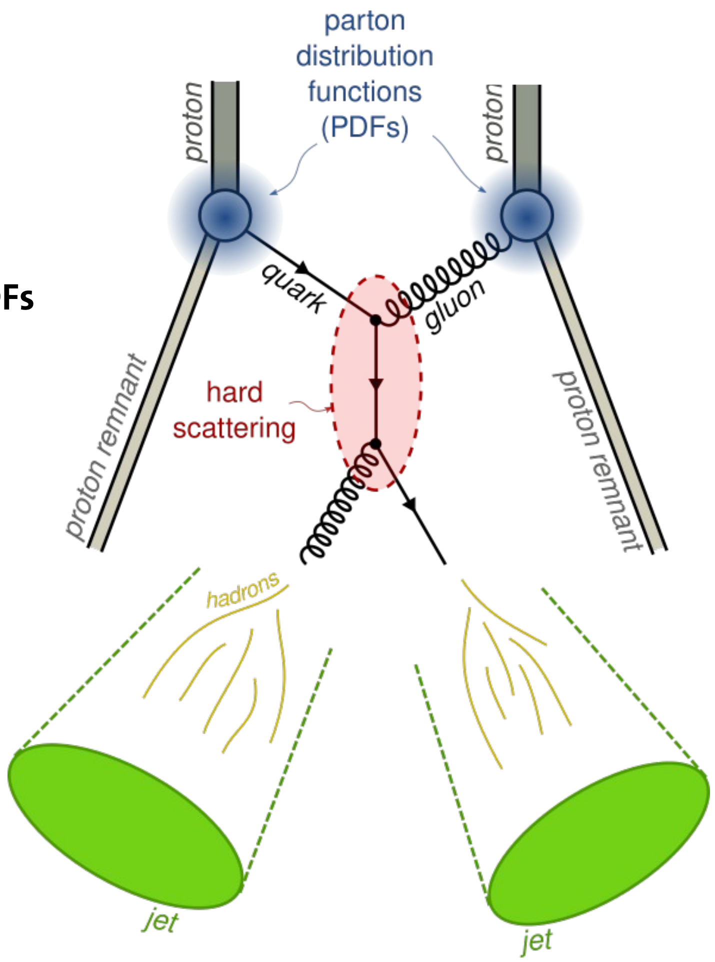
Inputs

precision measurements
LHC: **jet cross sections** at $\sqrt{s}$ = 13 TeV

fixed-order **theory**
state of the art: **NNLO pQCD**

Fit





this talk → focus on recent LHC results at 13 TeV for **inclusive jet** and **dijet** production

Jet measurements at $\sqrt{s}$ = 13 TeV

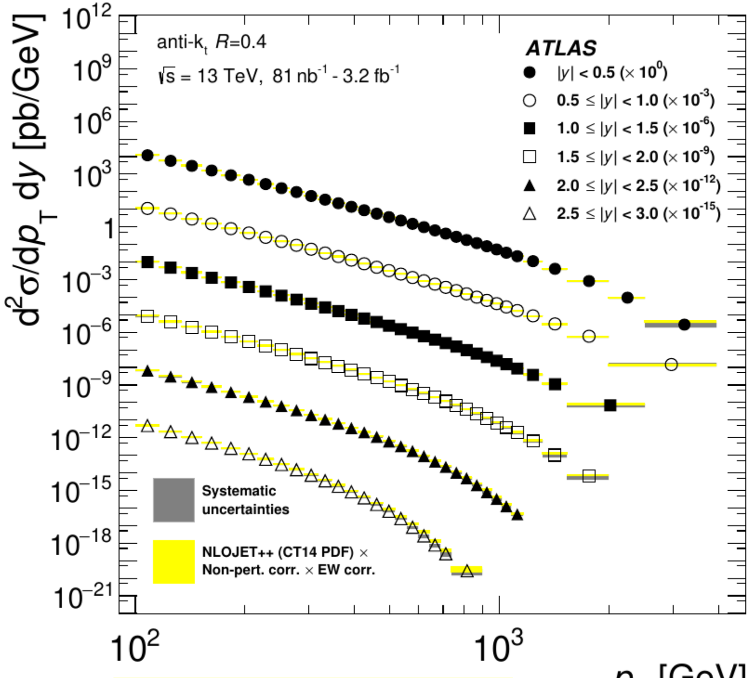
[1] *JHEP* **05** (2018) 195
arXiv:1711.02692

ATLAS EXPERIMENT

1 inclusive jet cross section

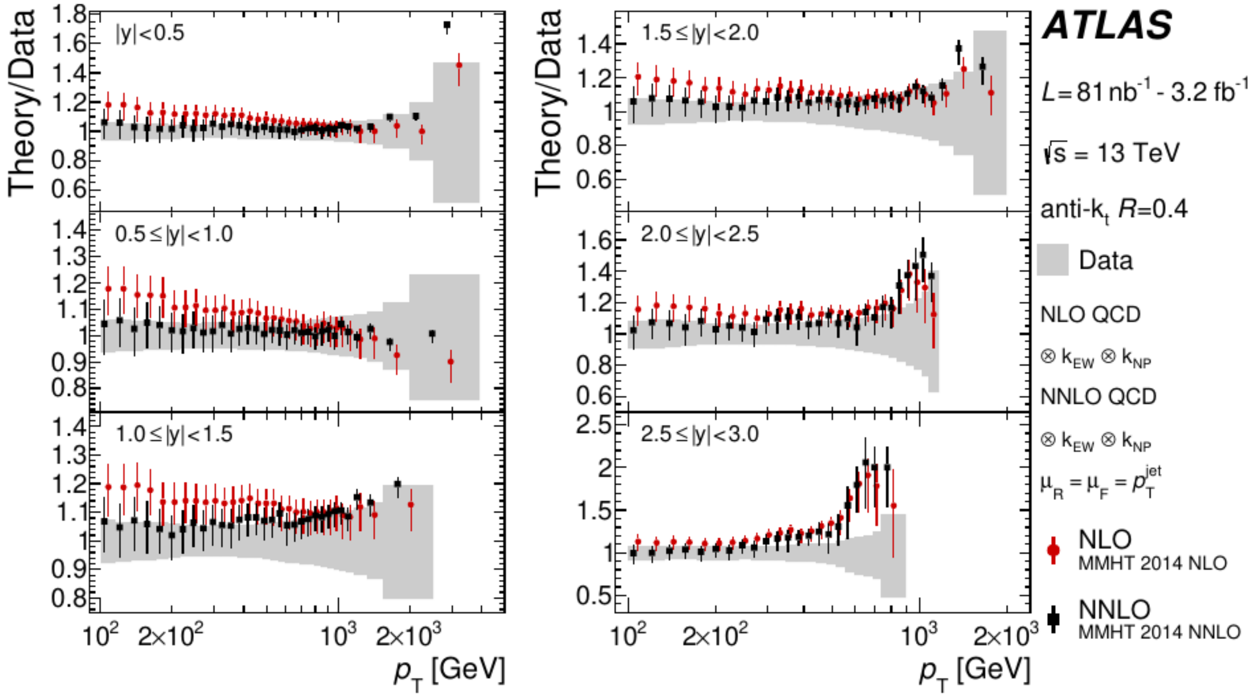
double-differential cross section in **jet p_T** and **absolute jet rapidity $|y|$**

- 2015 data (3.2 fb^{-1})
- anti-k_T jets (R = 0.4)



range: 100 GeV – 3.5 TeV

compare **8 TeV**: 70 GeV – 2.5 TeV [*JHEP* **09** (2017) 020]



comparison to pQCD theory at **NLO** & **NNLO**

Jet measurements at $\sqrt{s}$ = 13 TeV

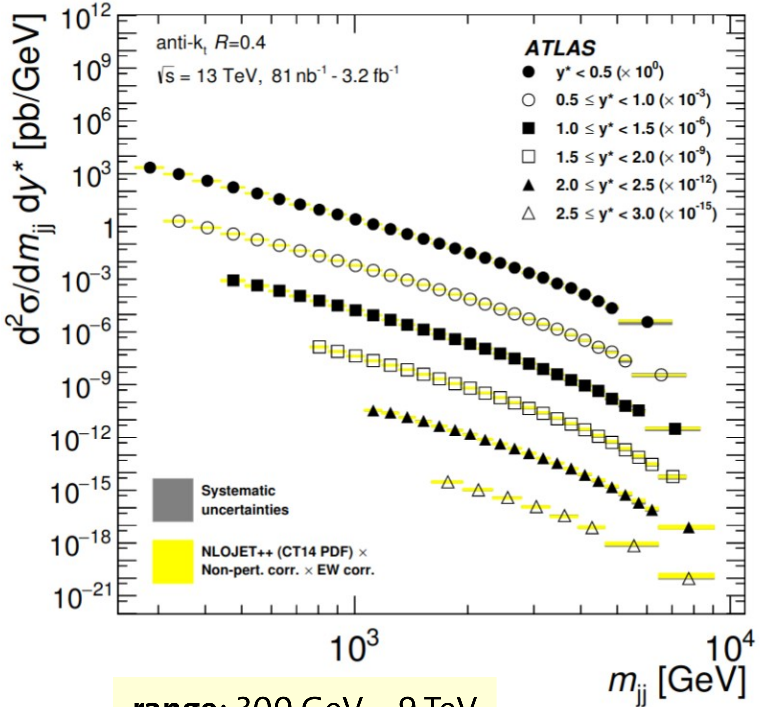
[1] *JHEP* **05** (2018) 195
arXiv:1711.02692

2 dijet cross section

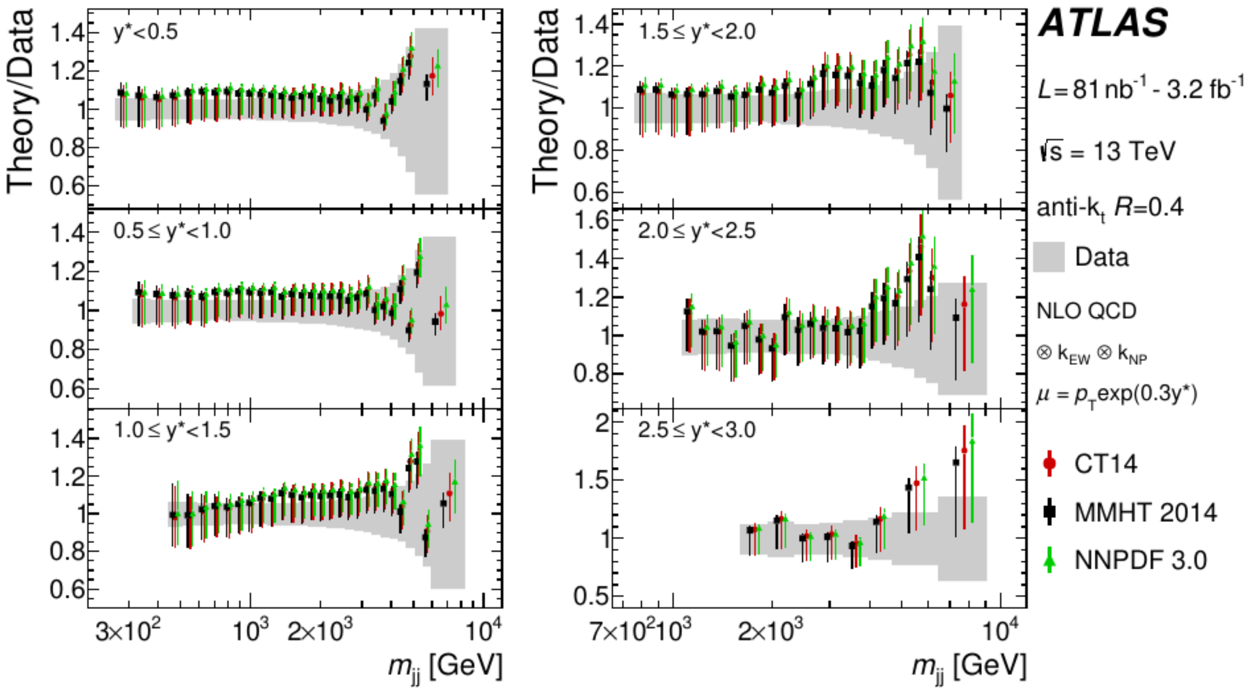
$y^* = \frac{1}{2}|y_1 - y_2|$

double-differential cross section in **dijet invariant mass m_{jj}** and **dijet rapidity separation y^***

- 2015 data (3.2 fb^{-1})
- anti-k_T jets (R = 0.4)



range: 300 GeV – 9 TeV



comparison to pQCD theory at **NLO** with various **global PDF sets**

PDF fits

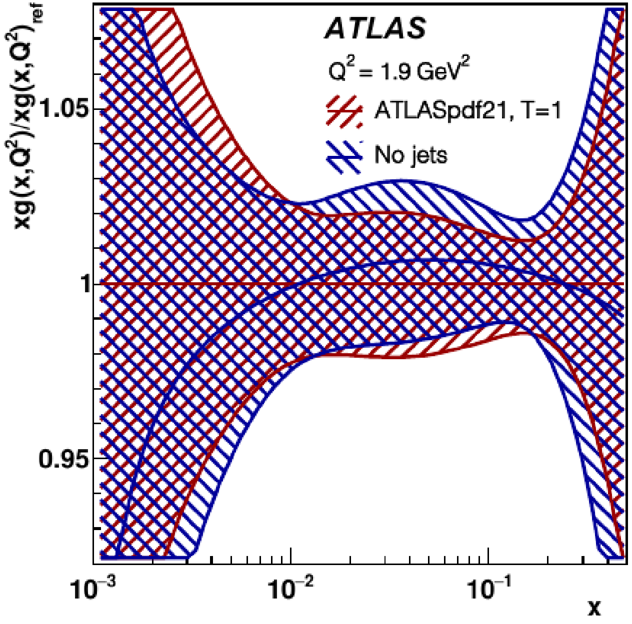
[2] CERN-EP-2021-239
arXiv:2112.11266

ATLAS EXPERIMENT

extensive studies of PDFs using various ATLAS data sets

Data set	$\sqrt{s}$ [TeV]	Luminosity [fb^{-1}]	Decay channel	Observables entering the fit
Inclusive $W, Z/\gamma^*$ [9]	7	4.6	e, μ combined	η_ℓ (W), y_Z (Z)
Inclusive Z/γ^* [13]	8	20.2	e, μ combined	$\cos\theta^*$ in bins of $y_{\ell\ell}, m_{\ell\ell}$
Inclusive W [12]	8	20.2	μ	η_μ
$W^\pm$ + jets [24]	8	20.2	e	p_T^W
Z + jets [25]	8	20.2	e	p_T^{jet} in bins of $\lvert y^{jet}\rvert$
$t\bar{t}$ [26, 27]	8	20.2	lepton + jets, dilepton	$m_{t\bar{t}}, p_T^t, y_{t\bar{t}}$
$t\bar{t}$ [15]	13	36	lepton + jets	$m_{t\bar{t}}, p_T^t, y_t, y_{t\bar{t}}^b$
Inclusive isolated γ [14]	8, 13	20.2, 3.2	-	E_T^γ in bins of η^γ
Inclusive jets [16–18]	7, 8, 13	4.5, 20.2, 3.2	-	p_T^{jet} in bins of $\lvert y^{jet}\rvert$

gluon PDF resulting from ATLAS analysis
(**with** & **without** inclusive jet data)



main impact of inclusive jet data is on gluon PDF

- decreased uncertainty & mild preference for harder gluon at high x

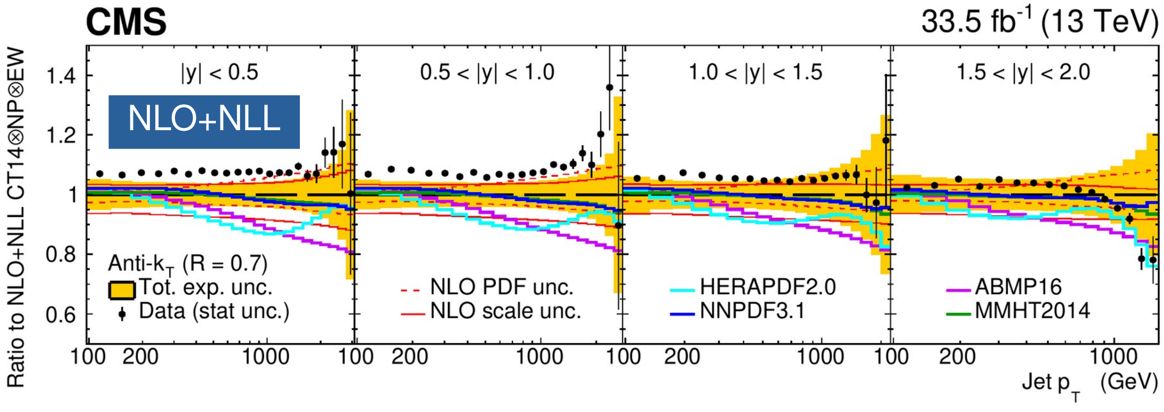
more details in Eimear's talk ▸

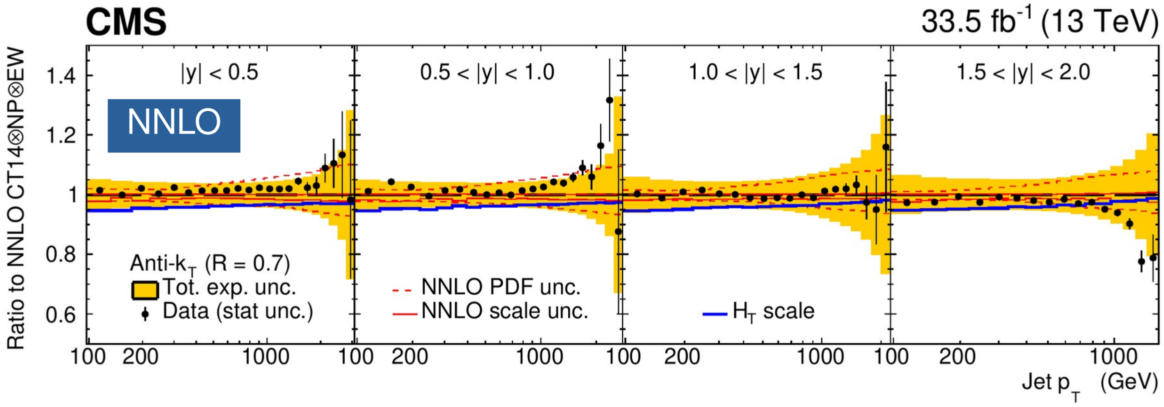
Inclusive jet cross section at $\sqrt{s}$ = 13 TeV

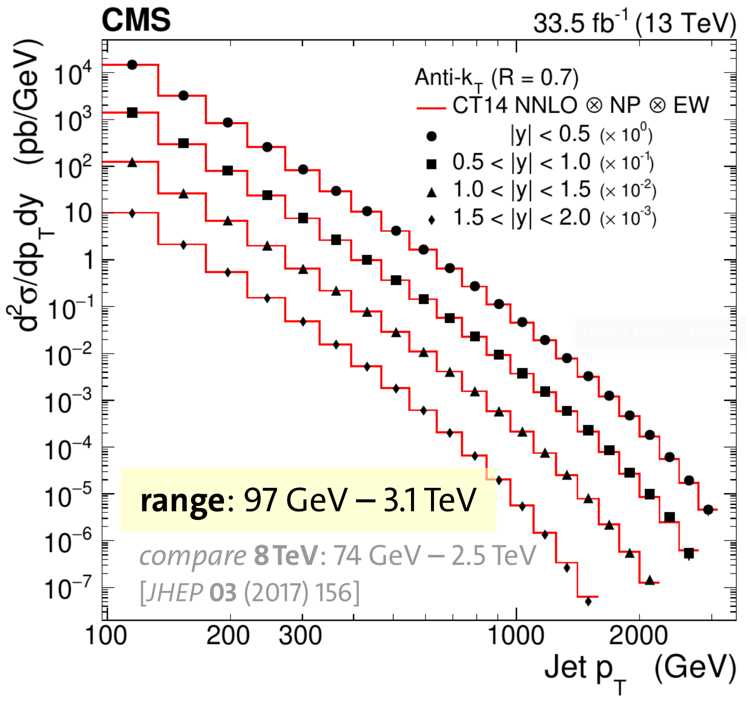
[3] *JHEP* **02** (2022) 142
arXiv:2111.10431

double-differential in **jet p_T** and **absolute jet rapidity |*y*|**

- anti-k_T jets (R = 0.4 & R = 0.7)







range: 97 GeV – 3.1 TeV

compare **8 TeV**: 74 GeV – 2.5 TeV
[*JHEP* **03** (2017) 156]

comparison to pQCD theory

- improved description at NNLO
- tension between global PDFs at high p_T

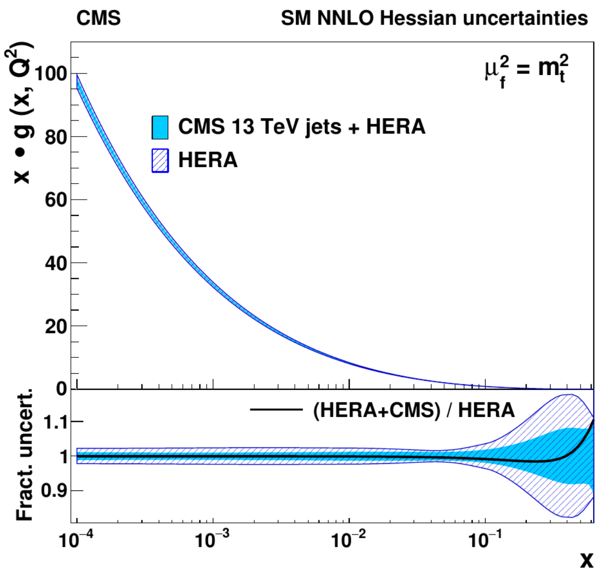
QCD analysis

SMEFT constraints

[3] *JHEP* **02** (2022) 142
arXiv:2111.10431

PDF + $\alpha_s(m_Z)$ fit at NNLO

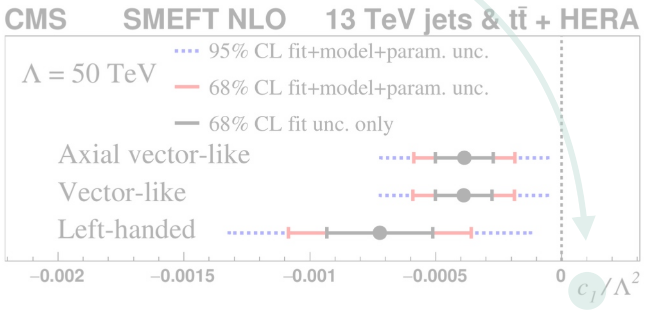
HERA + CMS inclusive jet data



$\alpha_s(m_Z) = 0.1170 \pm 0.0014$ (fit)
± 0.0004 (model)
± 0.0008 (scale)
± 0.0001 (parametrization)

constrain *Wilson coefficients* for SM extensions involving four-quark contact interactions (CI)

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \frac{2\pi}{\Lambda^2} \sum_{n\in\{1,3,5\}} c_n O_n$$



$m_t^{(\text{pole})}$ [GeV] $= 170.4 \pm 0.6$ (fit)
± 0.1 (model)
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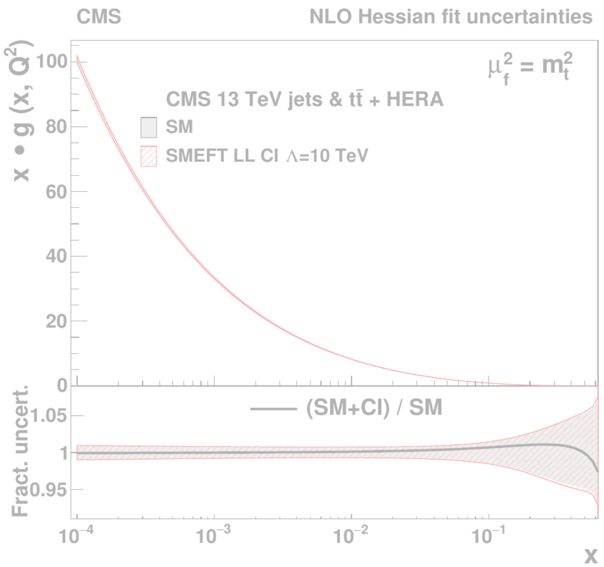
more details in Eimear's talk ▸

PDF + $\alpha_s(m_Z)$ + $m_t^{(\text{pole})}$ fit at NLO

simultaneous fit to jet and tt̄ data



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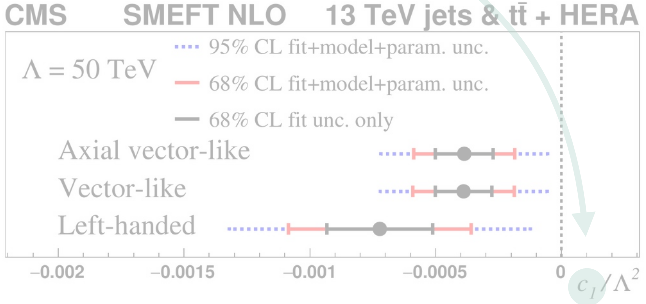

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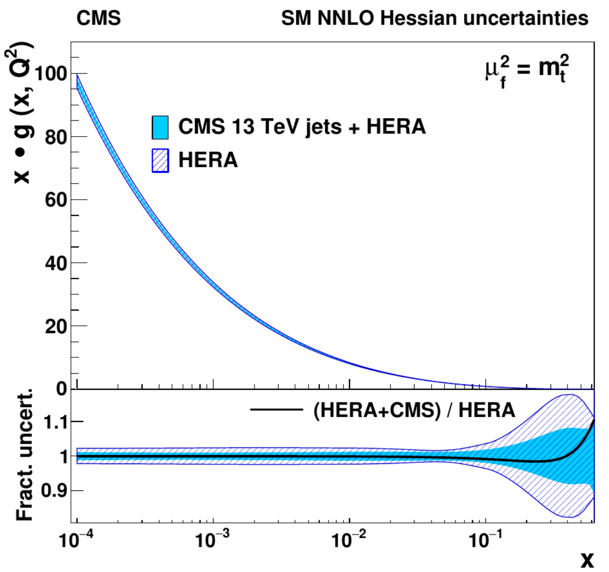

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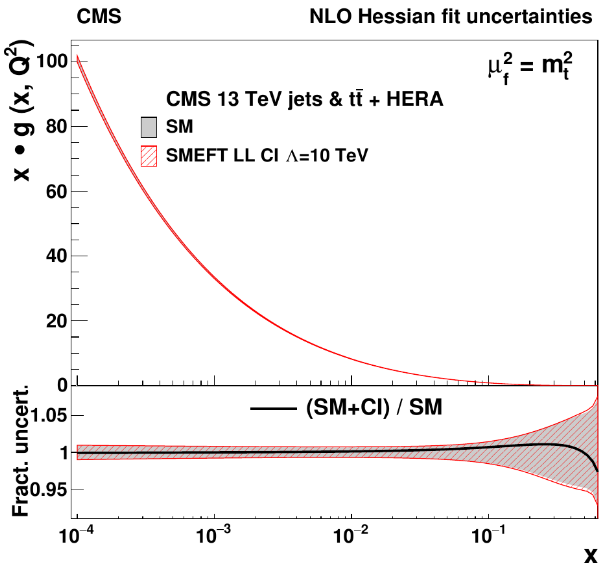

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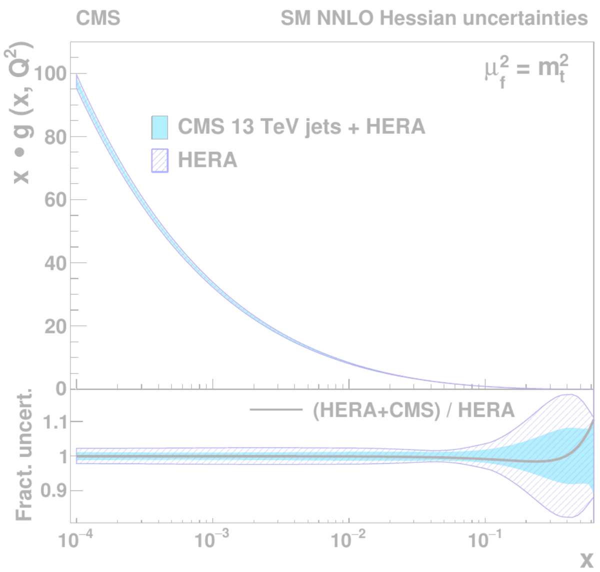

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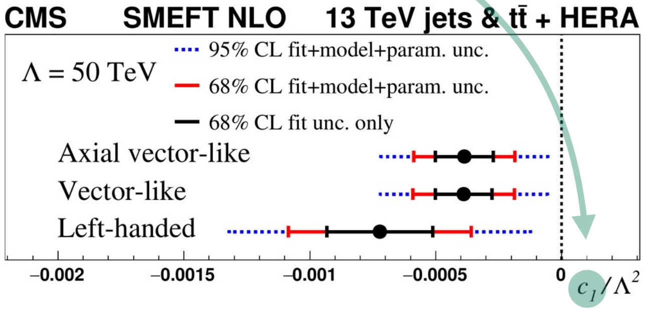

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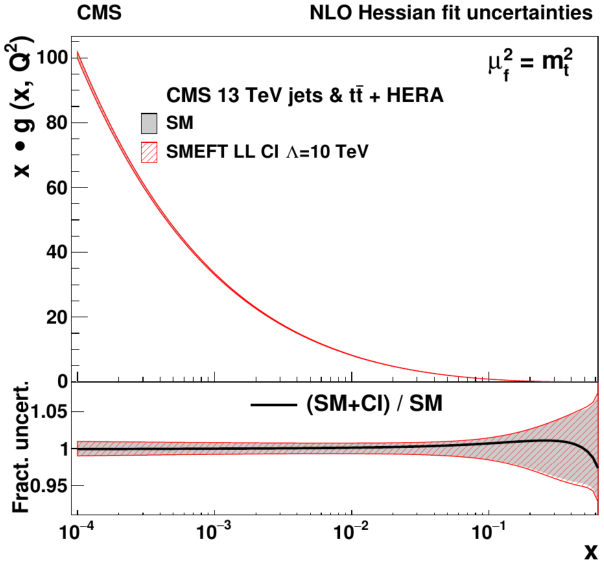

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$b\bar{b}$ and $c\bar{c}$ dijet production

[4] *JHEP* **2102** (2021) 023
arXiv:2010.09437

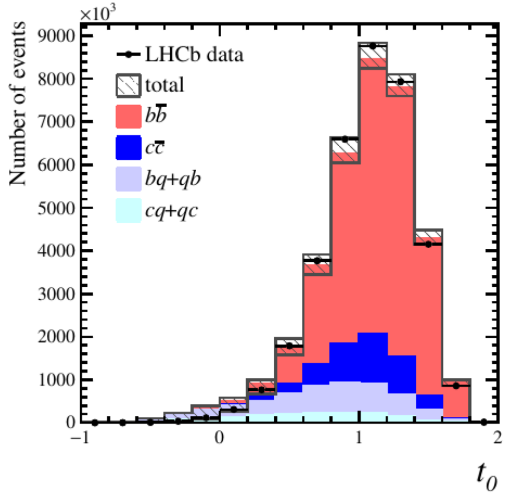
probe of heavy-flavor dijets in the forward region at LHCb

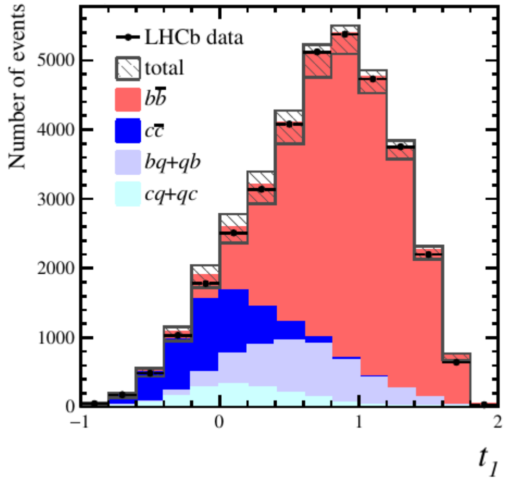
fiducial phase space

- $2.2 < \text{jet } \eta < 4.2$
- jet $p_T > 20\,\text{GeV}$
- dijet $|\Delta\phi| > 1.5$

flavor tagging

- boosted decision trees (BDTs) distinguish between dijet events from light & heavy quarks (t_0) and $b\bar{b}$ & $c\bar{c}$ quark pairs (t_1)





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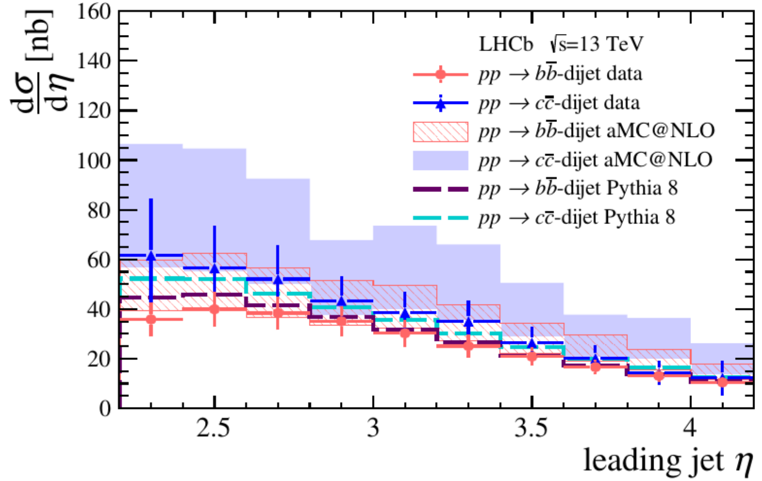
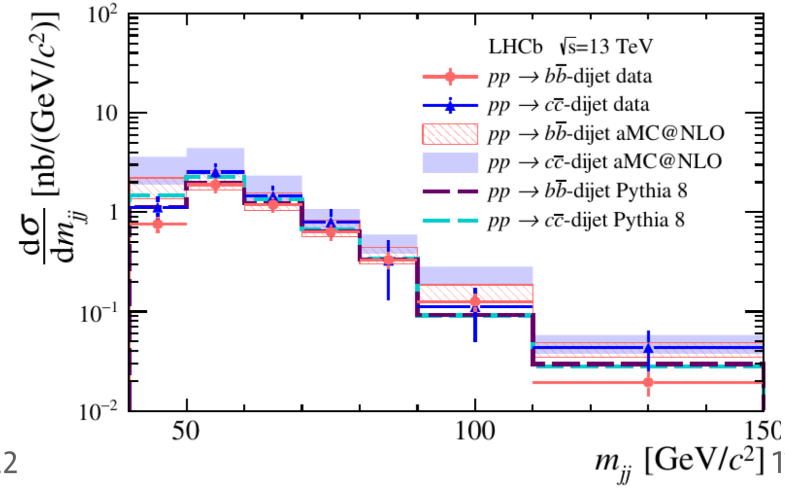
total & differential cross section measurements

- $\sigma(pp \to b\bar{b}\text{-dijet} + X)$ [nb] $= 53.0 \pm 9.5$ (stat. + syst. no lumi) ± 2.1 (lumi)
- $\sigma(pp \to c\bar{c}\text{-dijet} + X)$ [nb] $= 72.6 \pm 16.1$ (stat. + syst. no lumi) ± 2.9 (lumi)





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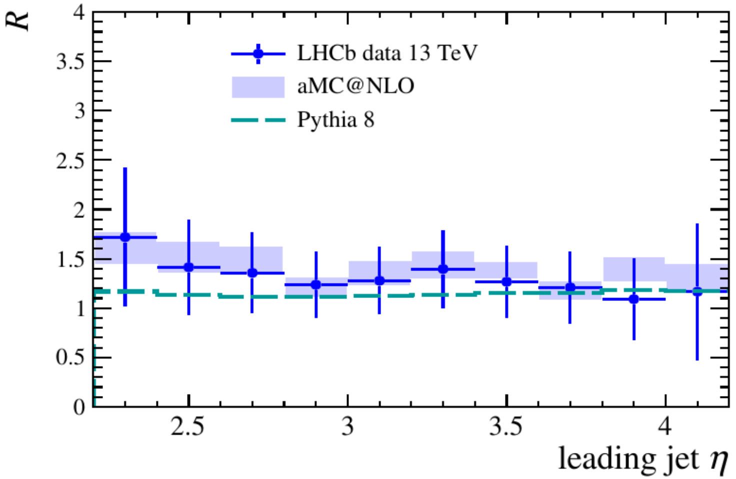
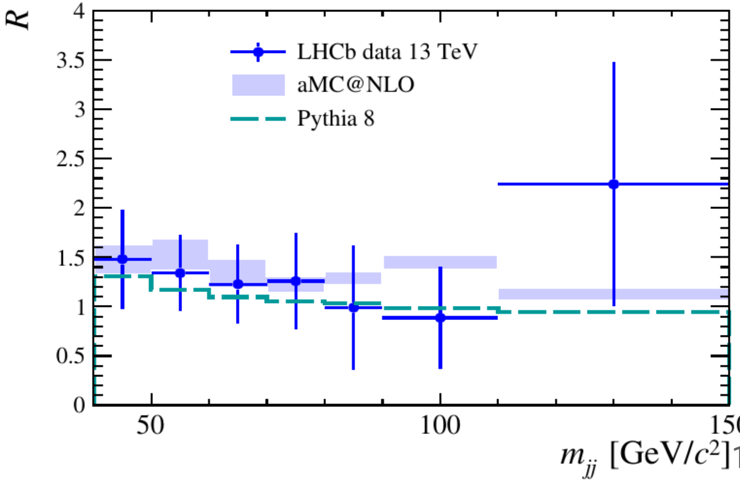
fiducial cross section ratio

- $$R = \frac{\sigma(pp \to c\bar{c}\text{-dijet} + X)}{\sigma(pp \to b\bar{b}\text{-dijet} + X)} = 1.37 \pm 0.27 \text{ (stat. + syst.)}$$





Summary

an overview of recent results from the LHC on **inclusive jet** & **dijet** production at 13 TeV has been presented

ATLAS

- inclusive jet & dijet cross sections (3.2 fb^{-1}, $R = 0.4$)
- extensive set of PDF studies with diverse ATLAS data, including jet cross sections at 7, 8 & 13 TeV

CMS

- inclusive jet cross sections (33.5 fb^{-1}, $R = 0.4$ & 0.7)
- QCD analysis → PDF+α_s determinations at NNLO | fit of jets+$t\bar{t}$ data at NLO | constraints on SMEFT

LHCb

- cross section measurements for $b\bar{b}$- & $c\bar{c}$-dijet pairs in forward region ($2.2 < \eta < 4.2$) | c/b flavor ratio R
- first direct differential measurement of $c\bar{c}$-dijet production

Thank you for your attention!

References

[1] ATLAS Collaboration, "*Measurement of inclusive jet and dijet cross-sections in proton-proton collisions at $\sqrt{s} = 13\,\text{TeV}$*", *JHEP* **05** (2018) 195, doi:10.1007/JHEP05(2018)195, arXiv:1711.02692, CERN-EP-2017-157, INSPIRE ID 1634970. All figures including auxiliary figures are available at https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2016-03;

[2] ATLAS Collaboration, "*Determination of the parton distribution functions of the proton using diverse ATLAS data from* pp *collisions at $\sqrt{s} = 7$, 8 and 13 TeV*", 2021, arXiv:2112.11266, CERN-EP-2021-239, INSPIRE ID 1994965. Submitted to EPJC. All figures including auxiliary figures are available at http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2020-32;

[3] CMS Collaboration, "*Measurement and QCD analysis of double-differential inclusive jet cross sections in pp collisions at $\sqrt{s} = 13\,\text{TeV}$*", *JHEP* **02** (2022) 142, doi:10.1007/JHEP02(2022)142, arXiv:2111.10431, CMS-SMP-20-011, CERN-EP-2021-221, http://cds.cern.ch/record/2791017, INSPIRE ID 1972986. All figures and tables can be found at http://cms-results.web.cern.ch/cms-results/public-results/publications/SMP-20-011 (CMS Public Pages);

[4] LHCb Collaboration, "*Measurement of differential bb- and cc-dijet cross-sections in the forward region of* pp *collisions at $\sqrt{s} = 13\,\text{TeV}$*", *JHEP* **2102** (2021) 023, doi:10.1007/JHEP02(2021)023, arXiv:2010.09437, LHCb-PAPER-2020-018, CERN-EP-2020-174, http://cds.cern.ch/record/2742421, INSPIRE ID 1823739, All figures and tables can be found at https://lhcbproject.web.cern.ch/lhcbproject/Publications/LHCbProjectPublic/LHCb-PAPER-2020-018.html;