CMS jet measurements and constraints on PDFs and α_s

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Low-x 2023,
Leros Island, Greece

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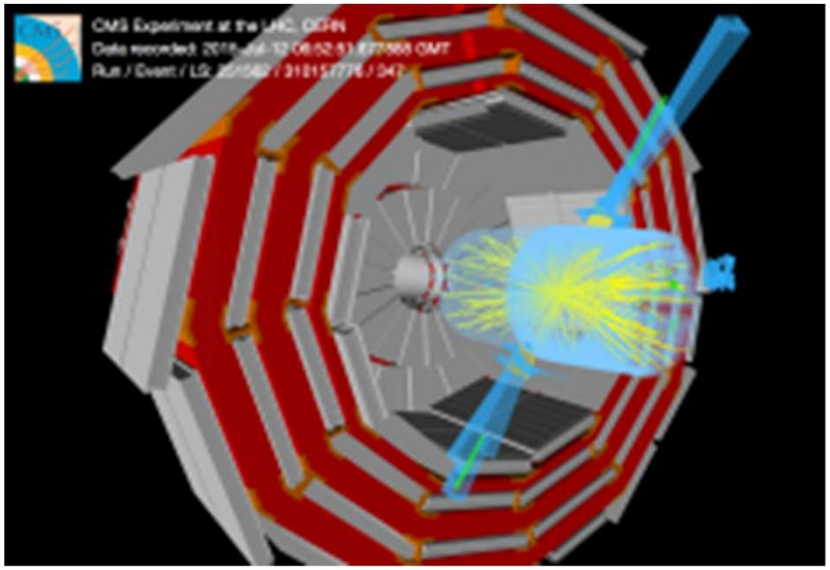
on behalf of the **CMS** collaboration

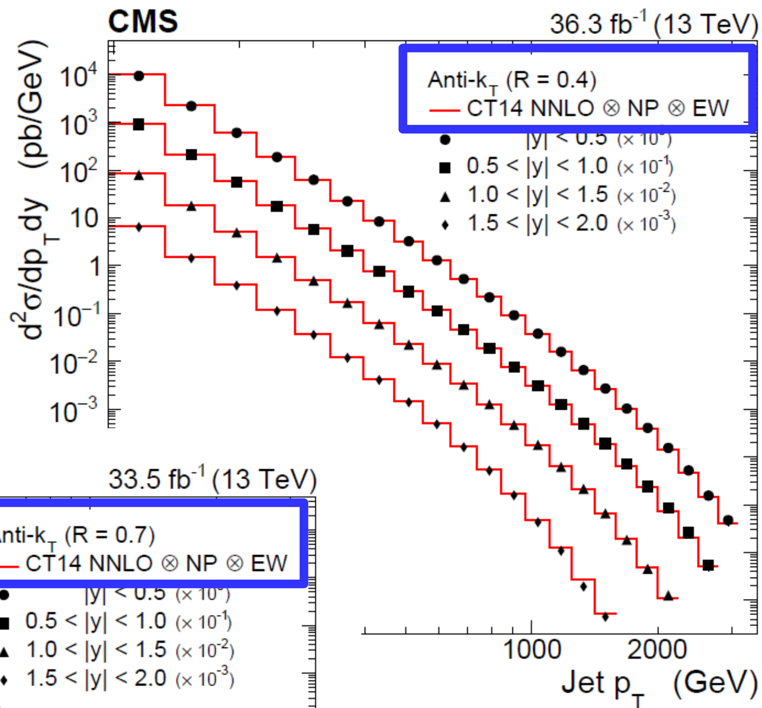


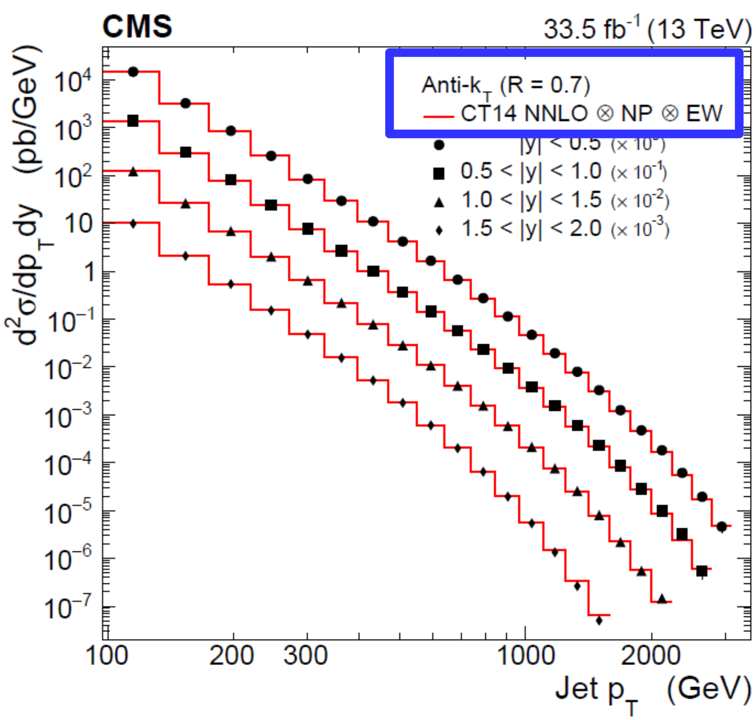
Outline:
- inclusive jets, PDFs and α_s
- dijets, PDFs and α_s
- multijets, jet multiplicity, multiparton interactions
- azimuthal correlations and α_s, α_s running
- conclusions

Double differential inclusive jet cross sections

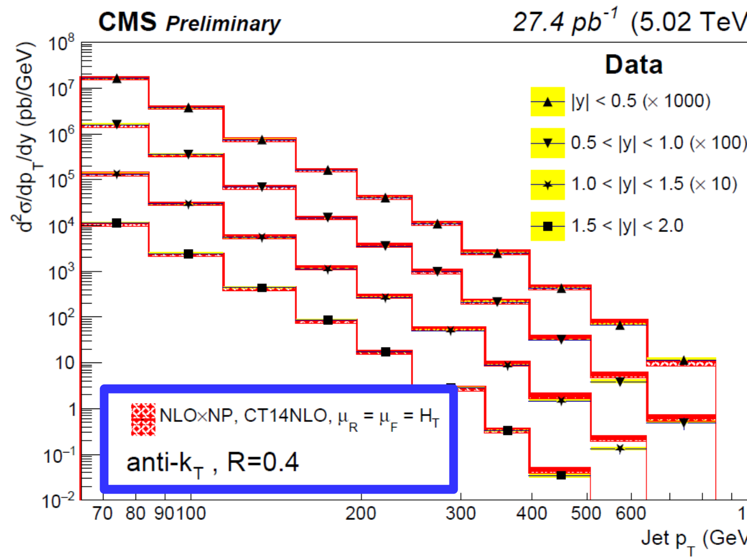
CMS, JHEP 02 (2022) 142 + Addendum JHEP 12 (2022) 035 CMS PAS SMP-21-009

13 TeV





5 TeV



Predictions describe data well over wide p_T and $|y|$ range

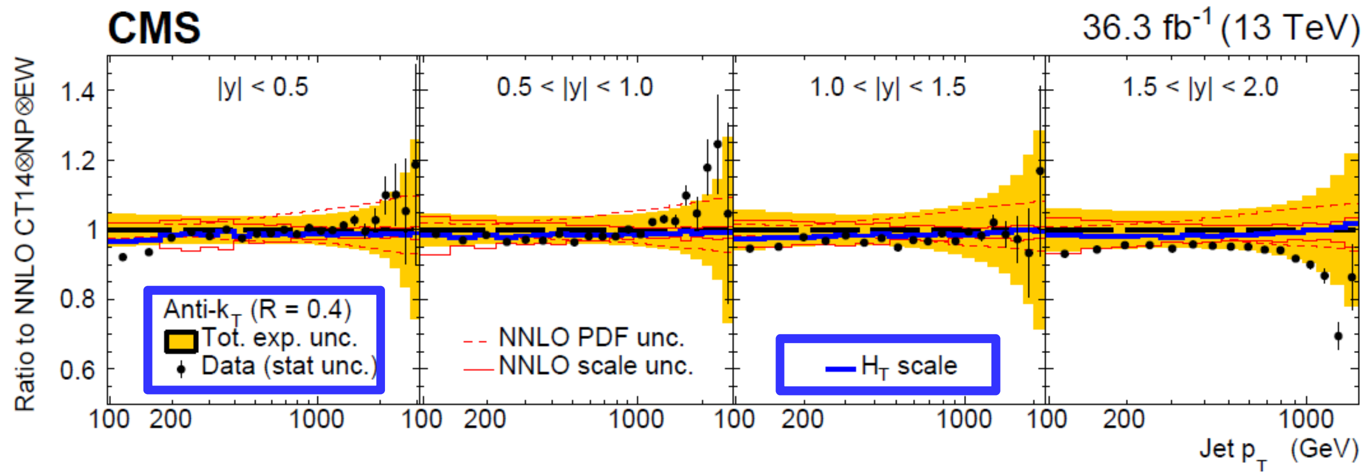
multiparton and hadronization corrections included
partial NLO EW corrections included (see backup)
13 TeV Addendum:
NNLO updated from k-factors to full theory grid

Double differential inclusive jet cross sections

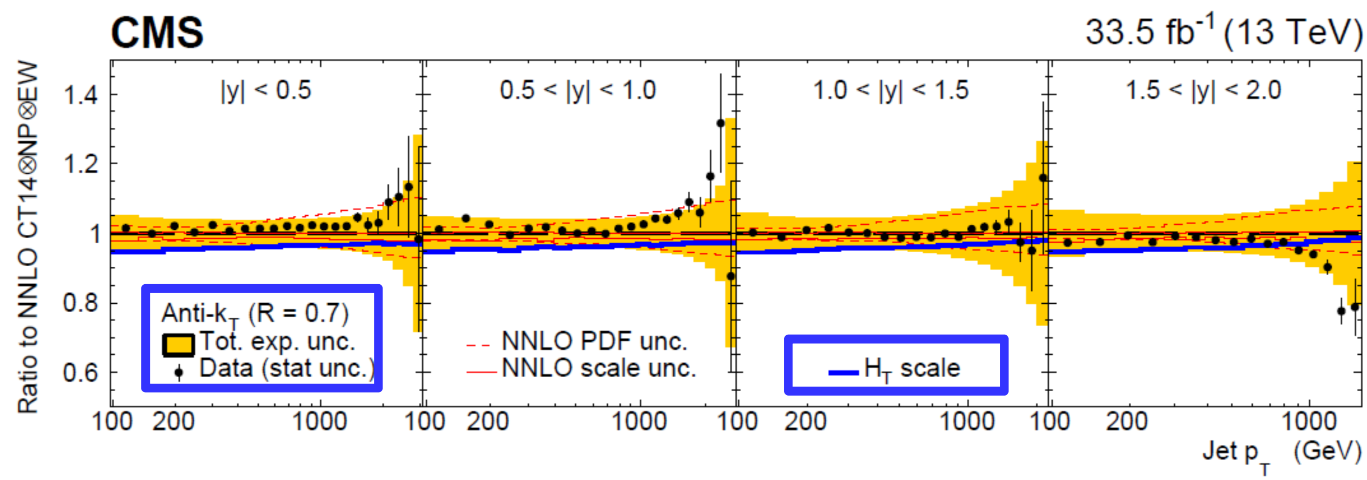
CMS, JHEP 02 (2022) 142 + Addendum JHEP 12 (2022) 035

13 TeV

comparison to NNLO



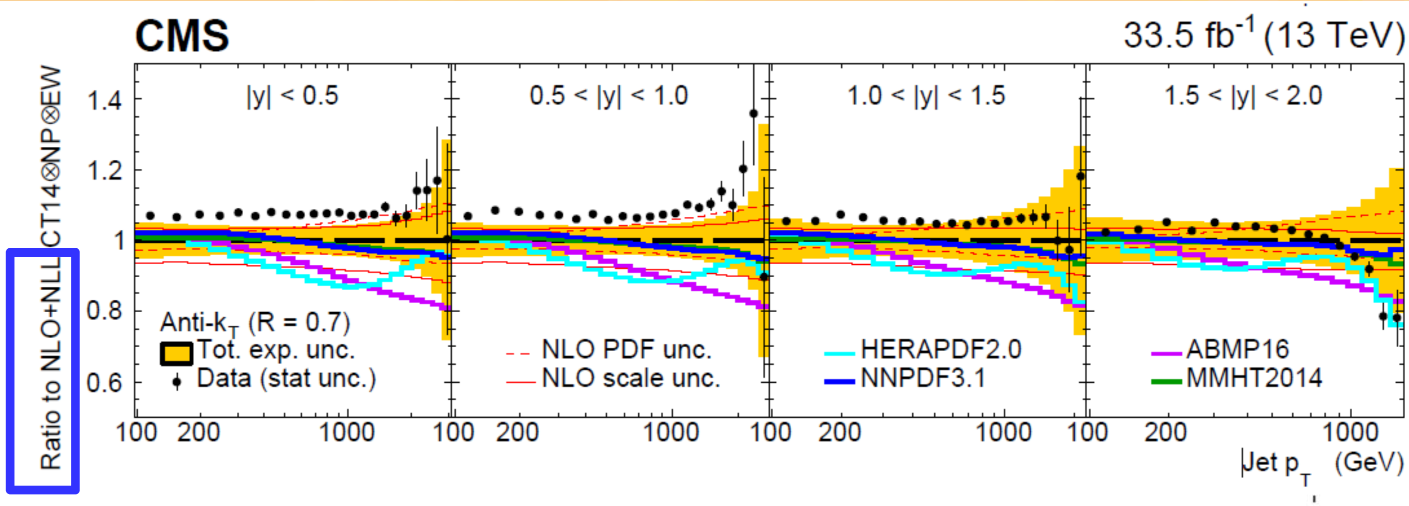
different jet radii & scales



R=0.7 slightly better suited for NNLO fit than R=0.4
(less 'out of cone' effect)
QCD scale jet p_T better suited than scale event H_T

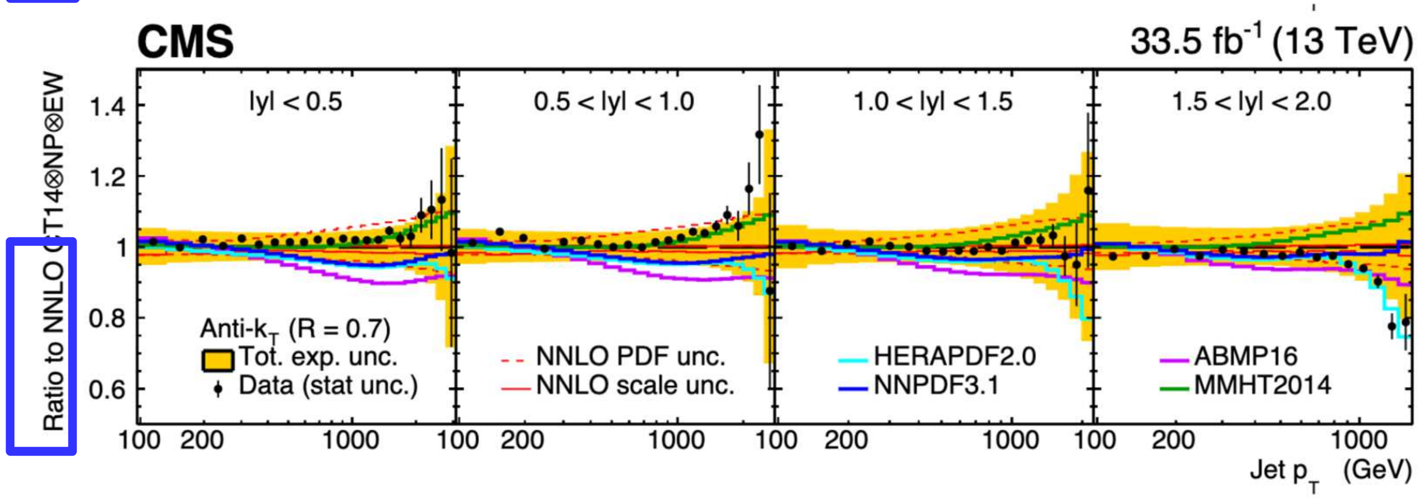
Double differential inclusive jet cross sections

CMS, JHEP 02 (2022) 142 + Addendum JHEP 12 (2022) 035



NLO vs. NNLO,

different PDFs



NNLO describes data much better than NLO,
but still sizeable PDF dependence -> can fit PDF

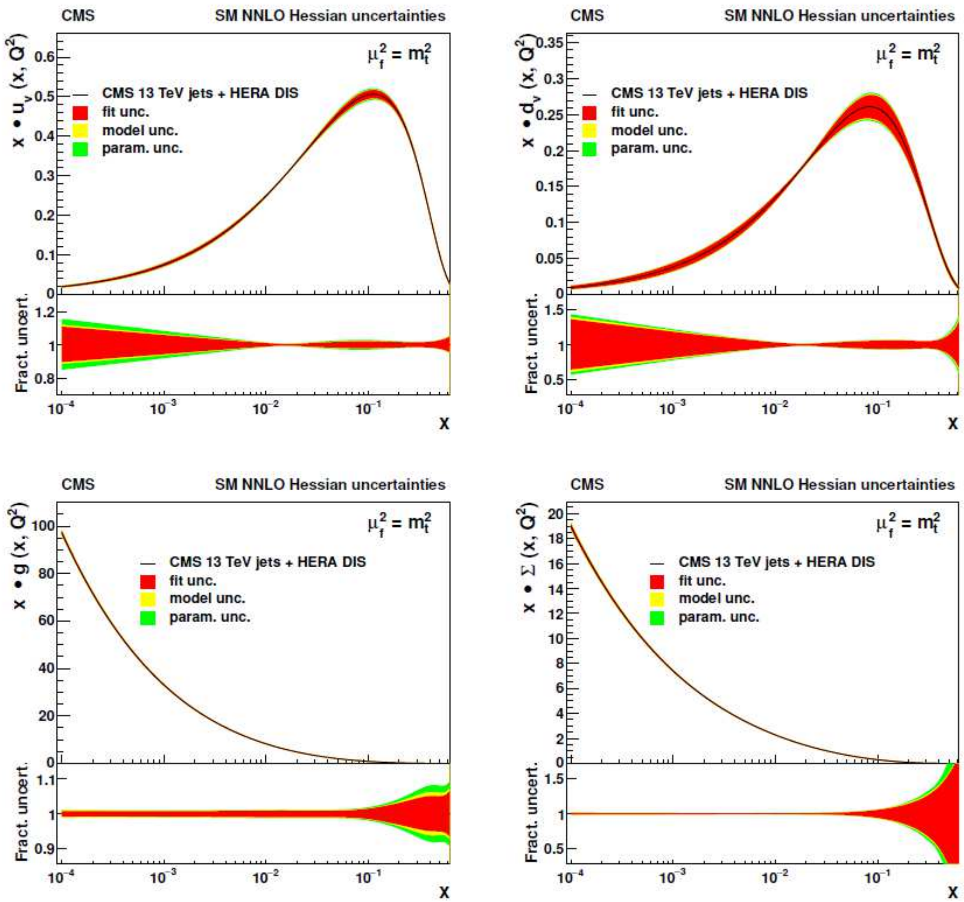
QCD fit @NNLO, R=0.7 (xFitter): PDF + α_s

CMS, JHEP 02 (2022) 142 + Addendum JHEP 12 (2022) 035

- **Full QCD fit at NNLO:** inclusive DIS cross sections (HERA) [arXiv:1506.06042] + CMS inclusive jets at 13 TeV [arXiv:2111.10431]
- **NNLO fast grids NNLOJet+applFast** [D. Britzger et al., EPJC 82 (2022) 930, arXiv:2207.13735]

good fit:

Data sets		HERA+CMS Partial χ^2/N_{dp}
HERA I+II neutral current	e^+p, $E_p = 920$ GeV	376/332
HERA I+II neutral current	e^+p, $E_p = 820$ GeV	60/63
HERA I+II neutral current	e^+p, $E_p = 575$ GeV	202/234
HERA I+II neutral current	e^+p, $E_p = 460$ GeV	209/187
HERA I+II neutral current	e^-p, $E_p = 920$ GeV	227/159
HERA I+II charged current	e^+p, $E_p = 920$ GeV	46/39
HERA I+II charged current	e^-p, $E_p = 920$ GeV	56/42
CMS inclusive jets 13 TeV	$0.0 < \|y\| < 0.5$	8.6/22
	$0.5 < \|y\| < 1.0$	23/21
	$1.0 < \|y\| < 1.5$	13/19
	$1.5 < \|y\| < 2.0$	14/16
Correlated χ^2		81
Global χ^2/N_{dof}		1302/1118



$\alpha_s(m_Z) = 0.1166 \pm 0.0018$

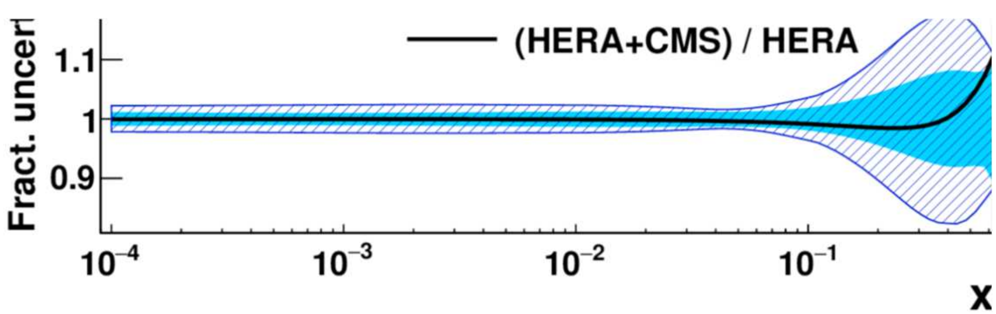
(.0014 fit, .0007 model, .0004 scale, .0001 param)

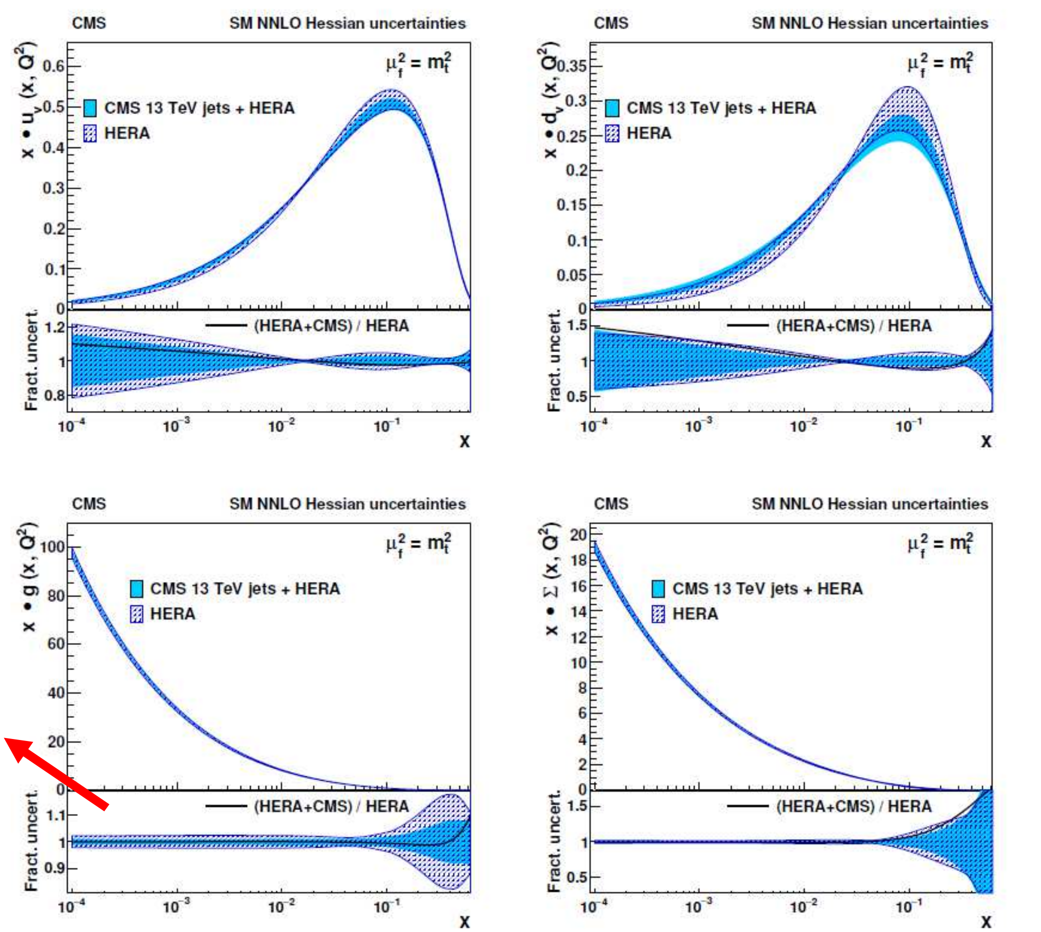
QCD fit @NNLO, comparison to HERA only

CMS, JHEP 02 (2022) 142 + Addendum JHEP 12 (2022) 035

- **Full QCD fit at NNLO:** inclusive DIS cross sections (HERA) [arXiv:1506.06042]
  + CMS inclusive jets at 13 TeV [arXiv:2111.10431]
- **NNLO fast grids NNLOJet+applFast** [D. Britzger et al., EPJC 82 (2022) 930, arXiv:2207.13735]

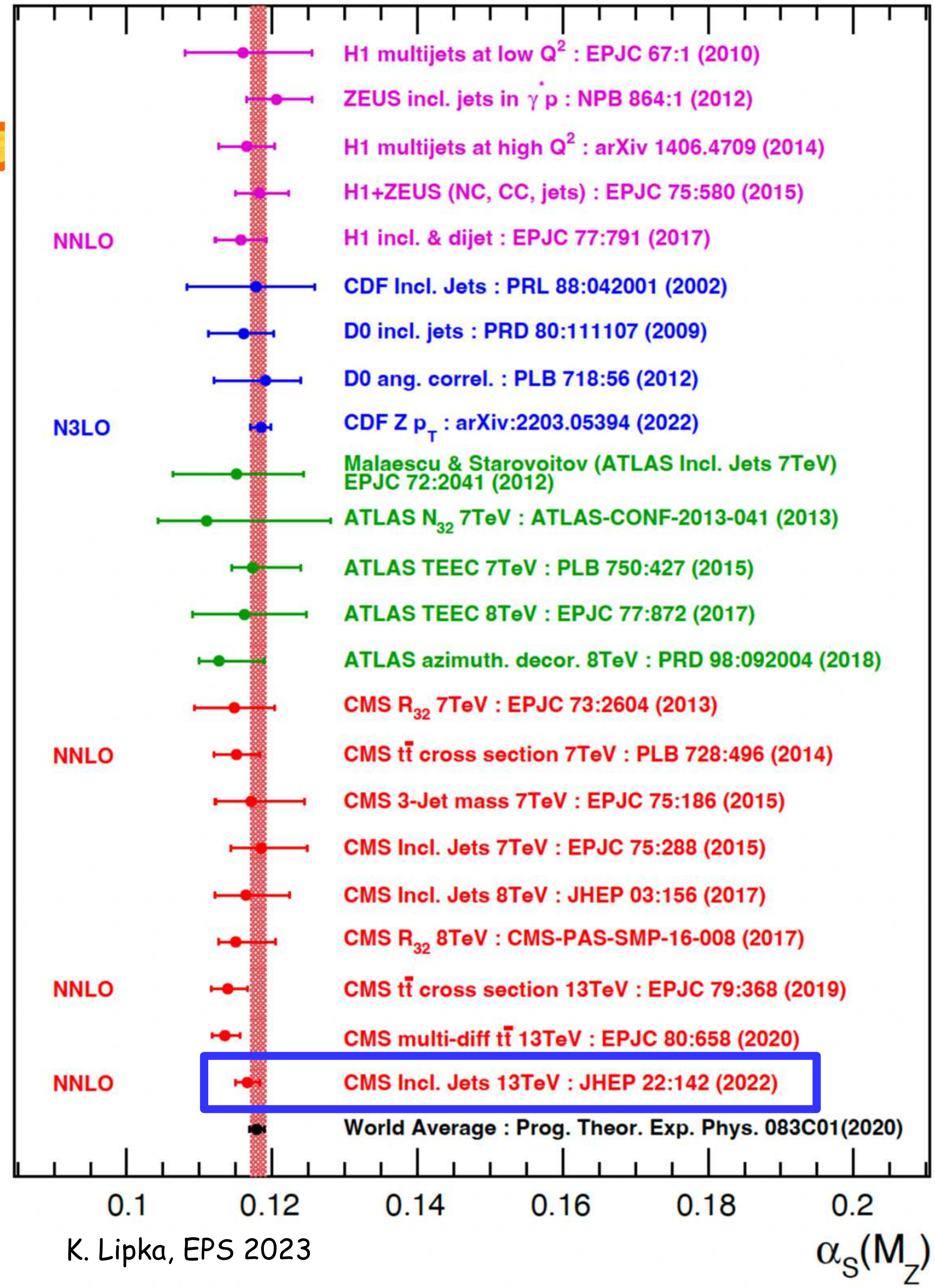
strong reduction of uncertainty on gluon distribution





α_s from jets

summary

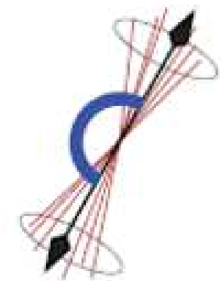


$\alpha_s(m_Z)$ = 0.1166 ± 0.0018

most precise α_s from jet measurements

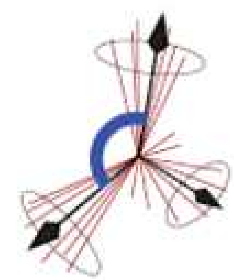
Motivation: Why study multijets?

- **inclusive jet measurements** dominated by dijets: 2 back-to-back final state partons (LO QCD configuration, $O(a_s^2)$)



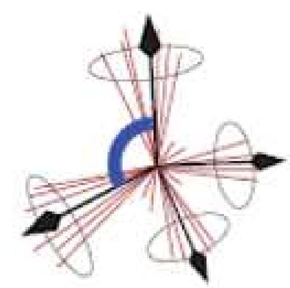
$\Delta\varphi_{dijet} = \pi$

- production of **third jet**
-> radiation of third parton (NLO QCD configuration, $O(a_s^3)$, is effectively LO),
-> decorrelation in dijet azimuthal angle (but angle between two leading jets remains > 2/3 π)



$\Delta\varphi_{dijet} < \pi$

- **four-jet** final state requires two additional parton radiations (at least $O(a_s^4)$)
-> **excellent probe for higher order QCD corrections** (angle between two leading jets can go down to 0)

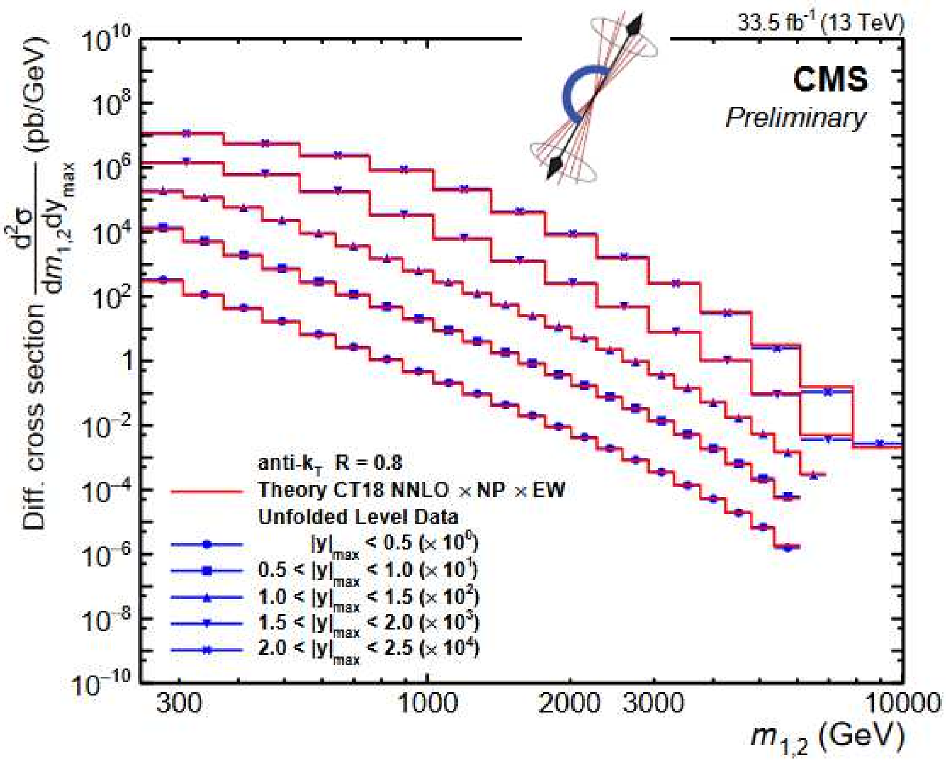


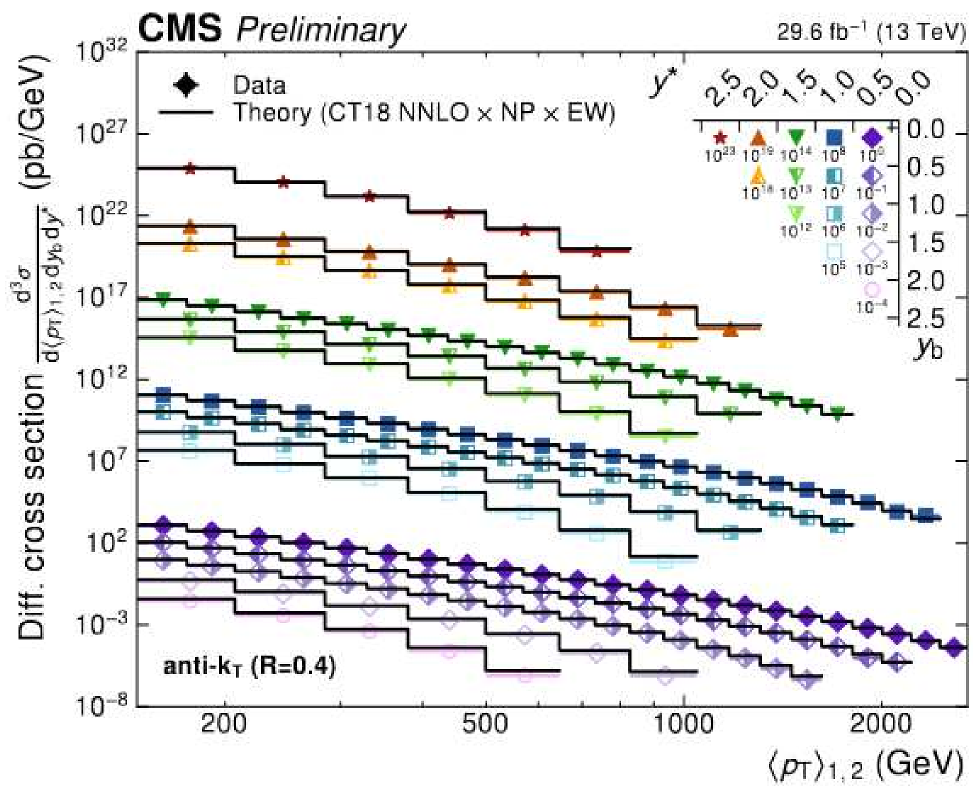
$\Delta\varphi_{dijet} << \pi$

Double/triple differential dijet cross sections

CMS PAS SMP-21-008, preliminary

2D: m_{12} and $|y|_{max}$ 3D: m_{12} or $\langle p_T \rangle_{12}$, $y^* = |\Delta y_{12}|/2$, y_{boost}





R=0.4 or 0.8

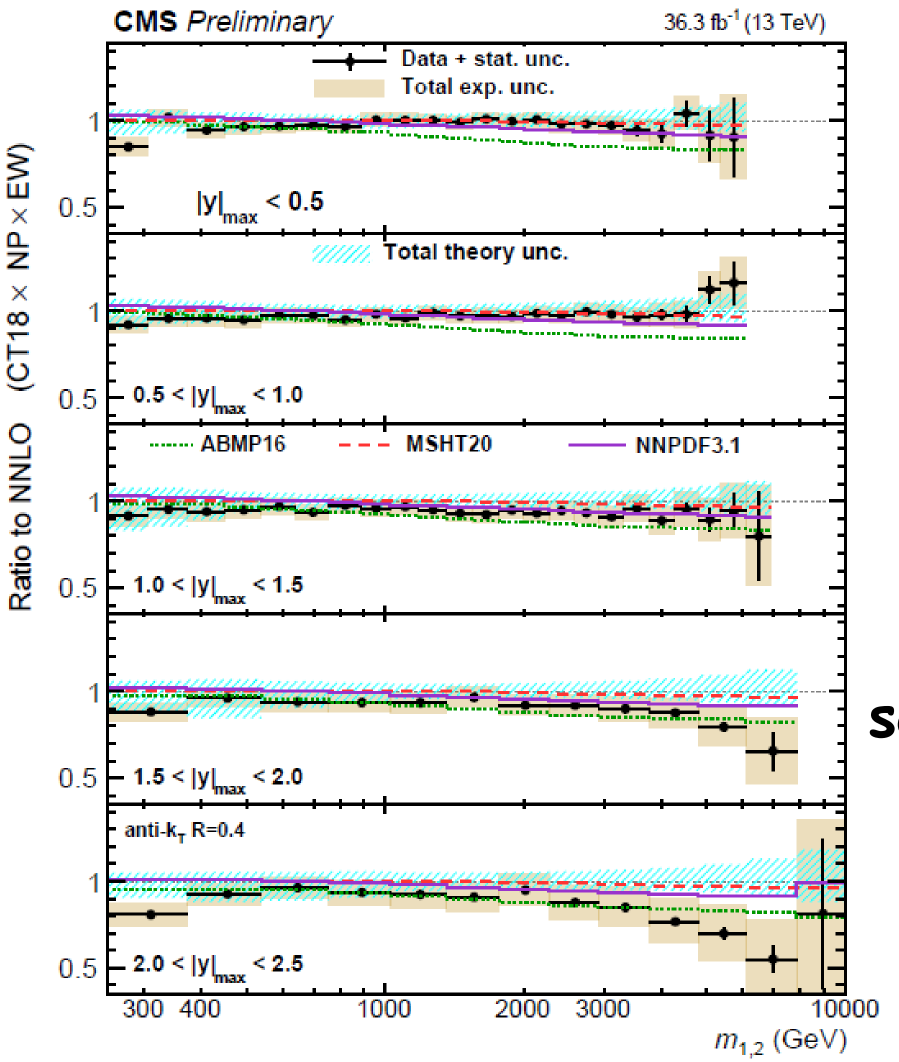
NNLO predictions reasonably describe data

multiparton and hadronization corrections included
partial NLO EW corrections included

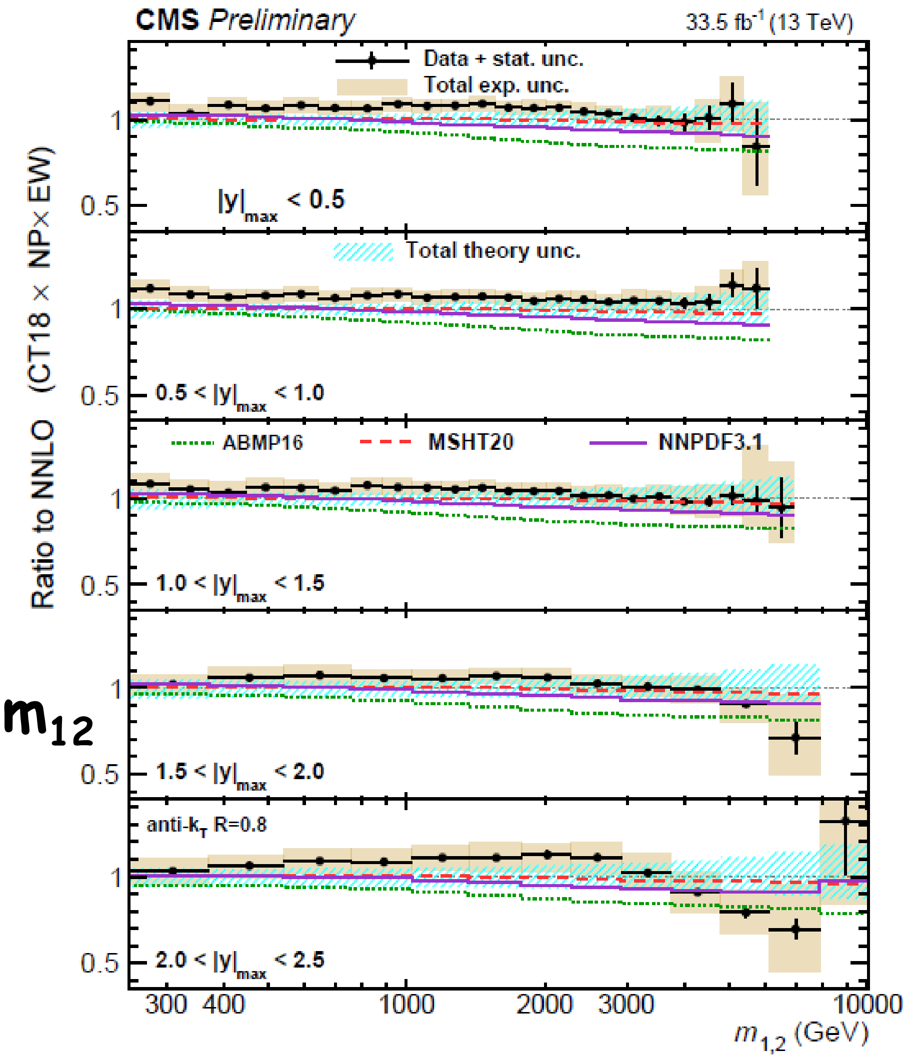
Double differential dijets, ratio to NNLO

CMS PAS SMP-21-008, preliminary

R=0.4 2-dim: m_{12} and $|y|_{max}$ R=0.8



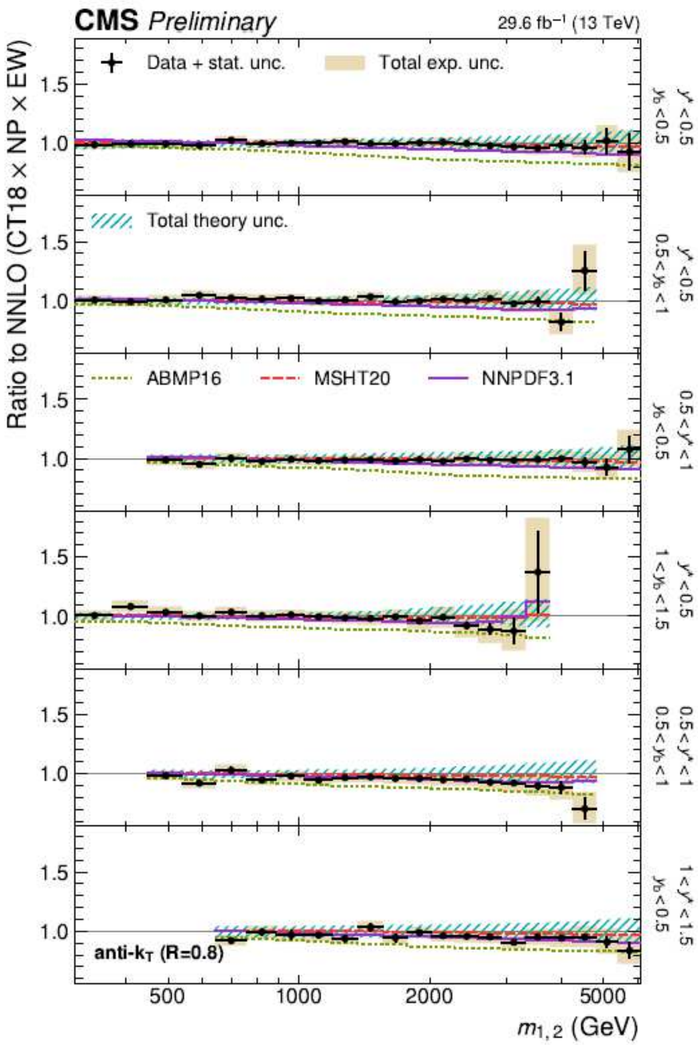
scale: m_{12}



Triple differential dijets, ratio to NNLO

CMS PAS SMP-21-008, preliminary

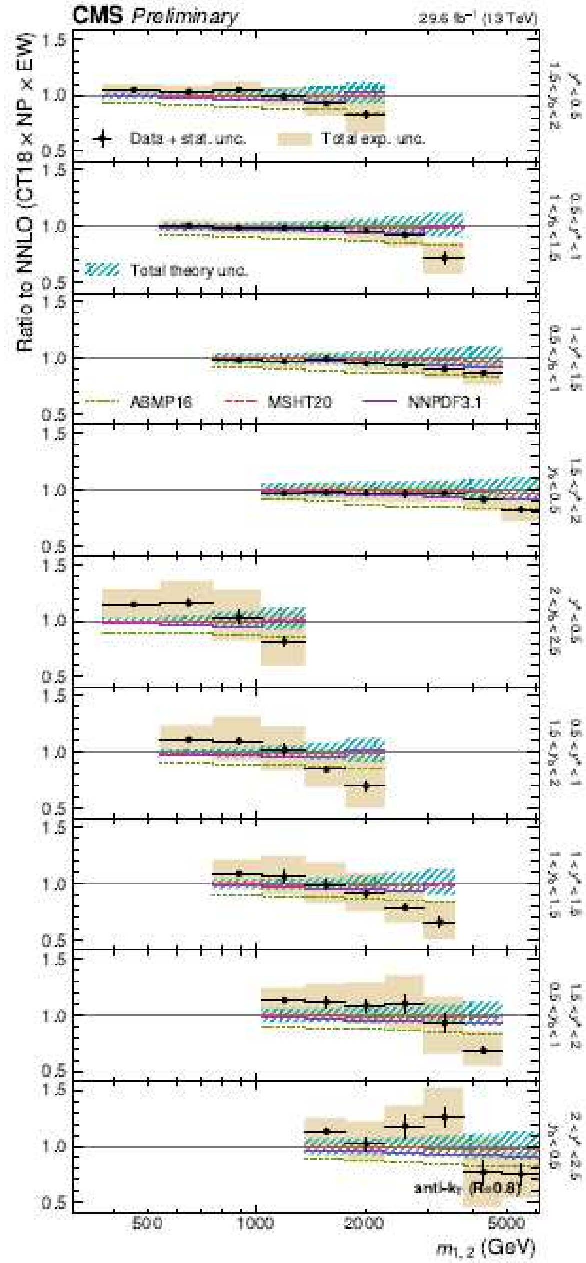
3-dim: m_{12}, $y^*=|\Delta y_{12}|/2$, y_{boost}



R=0.8

scale: m_{12}

15 2-dim y bins

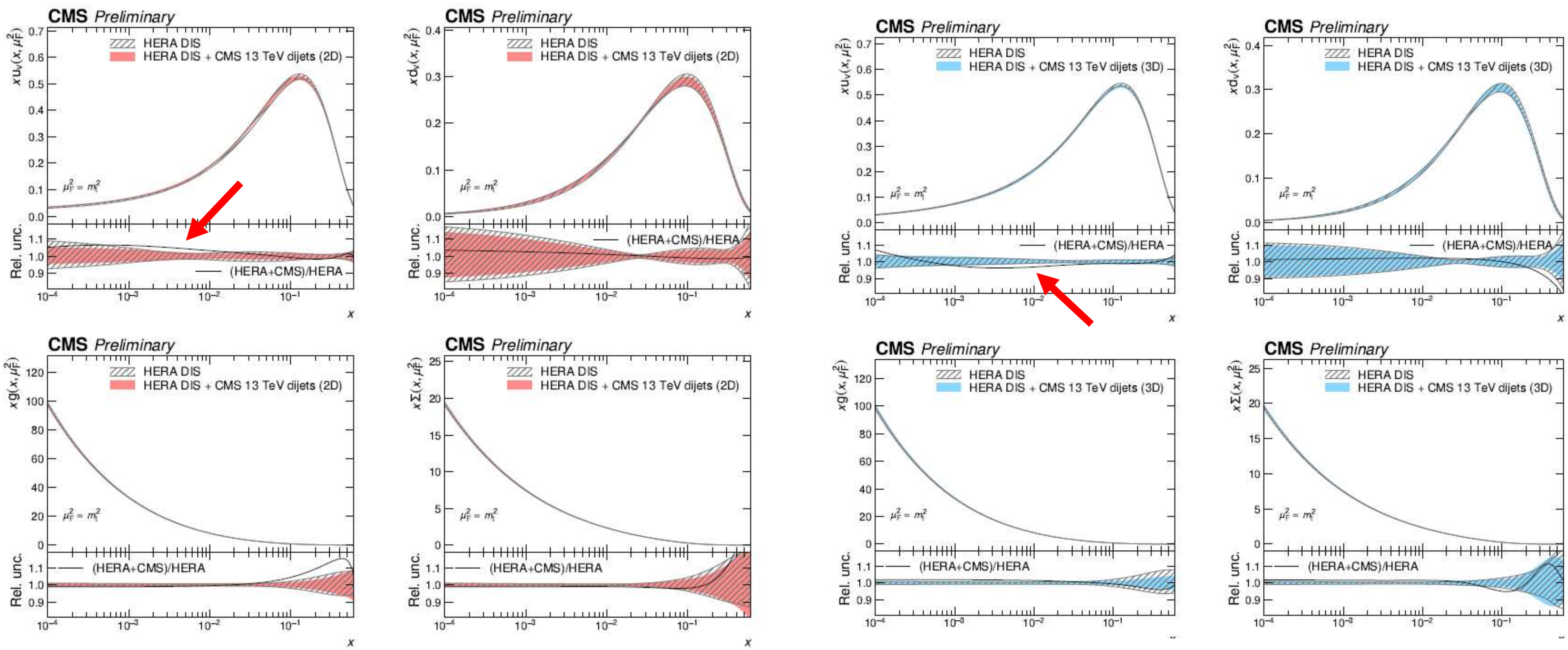


QCD fit @NNLO, R=0.8 (xFitter): PDF + α_s

CMS PAS SMP-21-008, preliminary

- **QCD fit at NNLO:** inclusive DIS cross sections (HERA) [arXiv:1506.06042]

2D + CMS dijets at 13 TeV **3D**



PDF uncertainty reduction smaller than for inclusive jets

Different solutions for u valence quarks for 2D and 3D

larger than inclusive jets

$\alpha_s(m_Z)$ = 0.1201 ± 0.0021

(.0012 fit, .0008 model, .0008 scale, .0005 param)

$\alpha_s(m_Z)$ = 0.1201 ± 0.0020

(.0010 fit, .0008 model, .0005 scale, .0006 param)

4 jets from double parton interactions

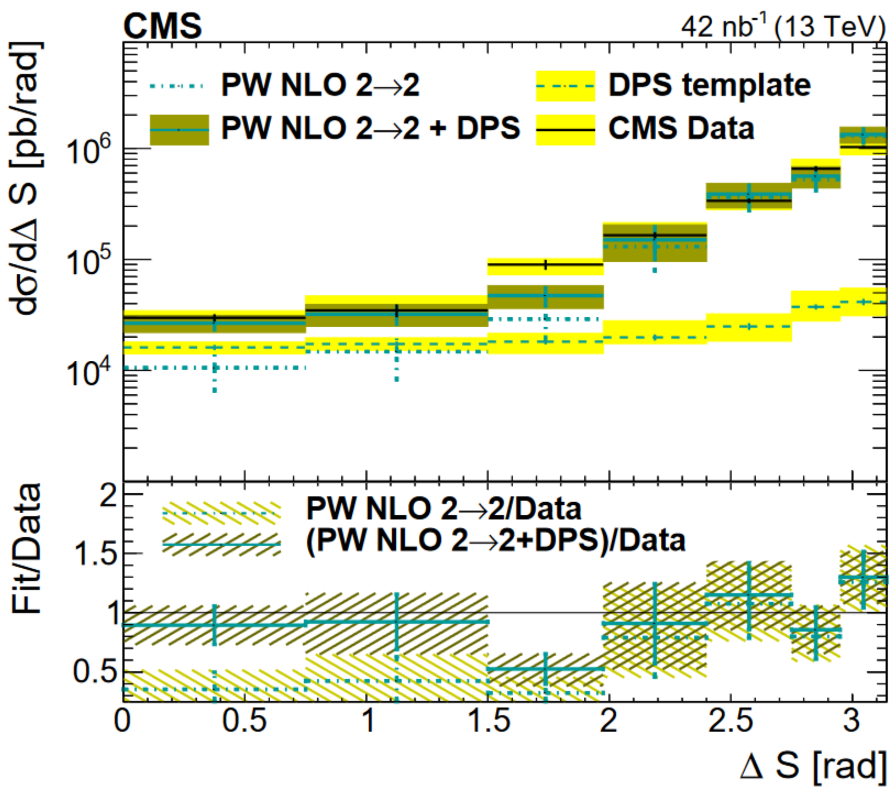
CMS, JHEP 01 (2022) 177

Compare 2-jet and 4-jet cross sections for p_T>30 and 50 GeV

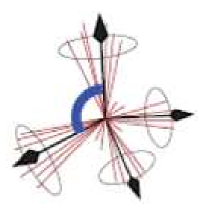
4-jet p_T/angular correlator

$$\Delta S = \arccos\left(\frac{(\vec{p}_{T,1}+\vec{p}_{T,2})\cdot(\vec{p}_{T,3}+\vec{p}_{T,4})}{|\vec{p}_{T,1}+\vec{p}_{T,2}|\,|\vec{p}_{T,3}+\vec{p}_{T,4}|}\right).$$

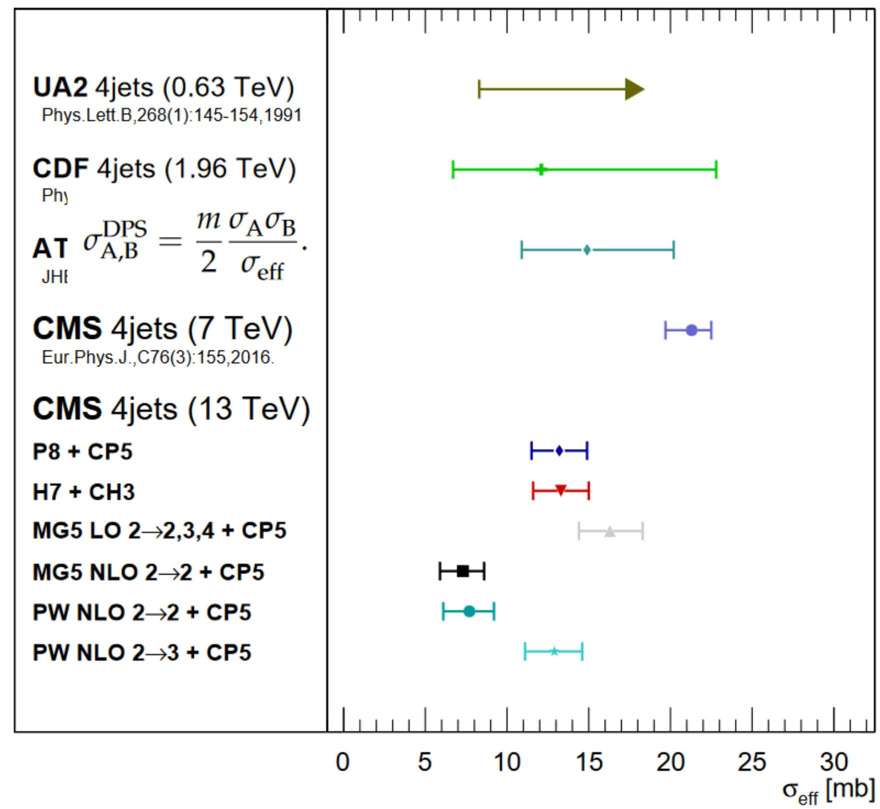
σ_{eff}: $$\sigma^{DPS}_{A,B} = \frac{m}{2}\frac{\sigma_A \sigma_B}{\sigma_{eff}}.$$



R = 0.4



σ_{eff} meas

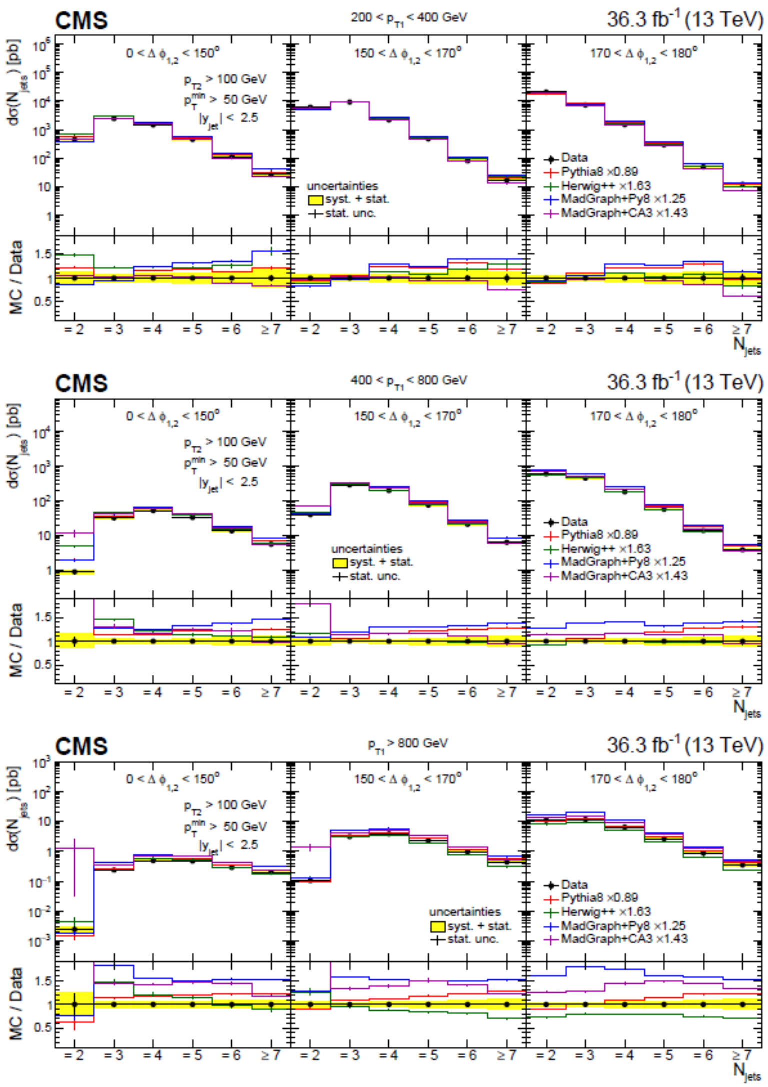


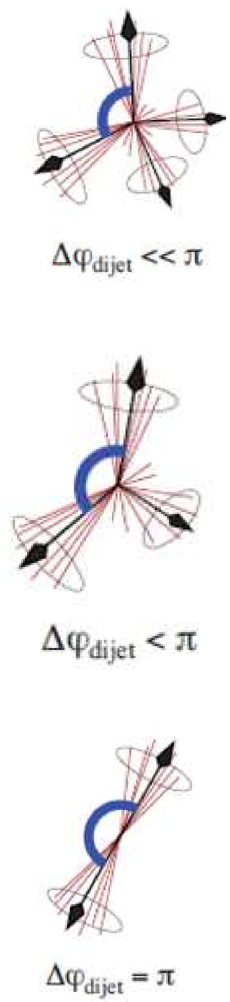
DPS contribution to 4-jet cross section small but non-negligible

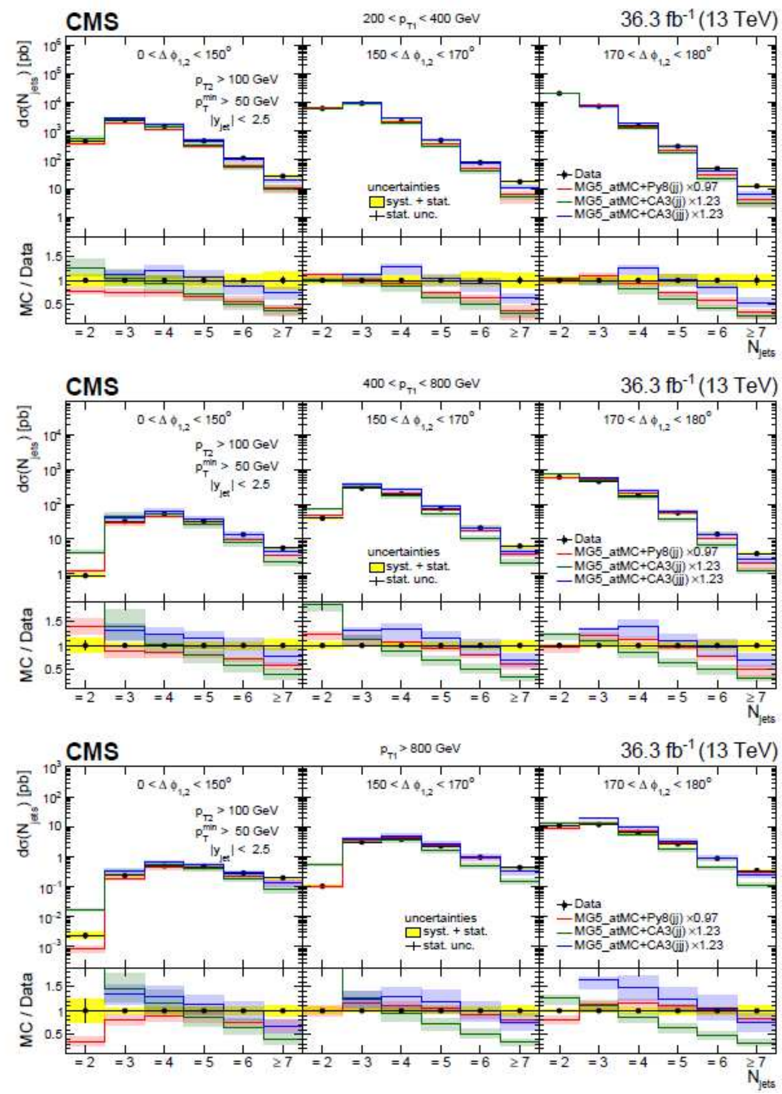
σ_{eff} model dependent and in qualitative agreement with earlier determinations.

Multi-jet **multiplicity** (up to 7+) vs. $\Delta\phi$ of jet$_{1,2}$

CMS, arXiv:2210.13557







up to 7 jets! sometimes, scaled LO+PS models (left) still describe the data better than NLO+PS models (right). (PS models might need to be retuned for NLO)

Cross sections vs. p_T for 1st, 2nd, 3rd, 4th jet

CMS, arXiv:2210.13557

>=2 jet events with

p_{T1}>200 GeV and p_{T2}>100 GeV:

NLO does a good job for 1st and 2nd jet

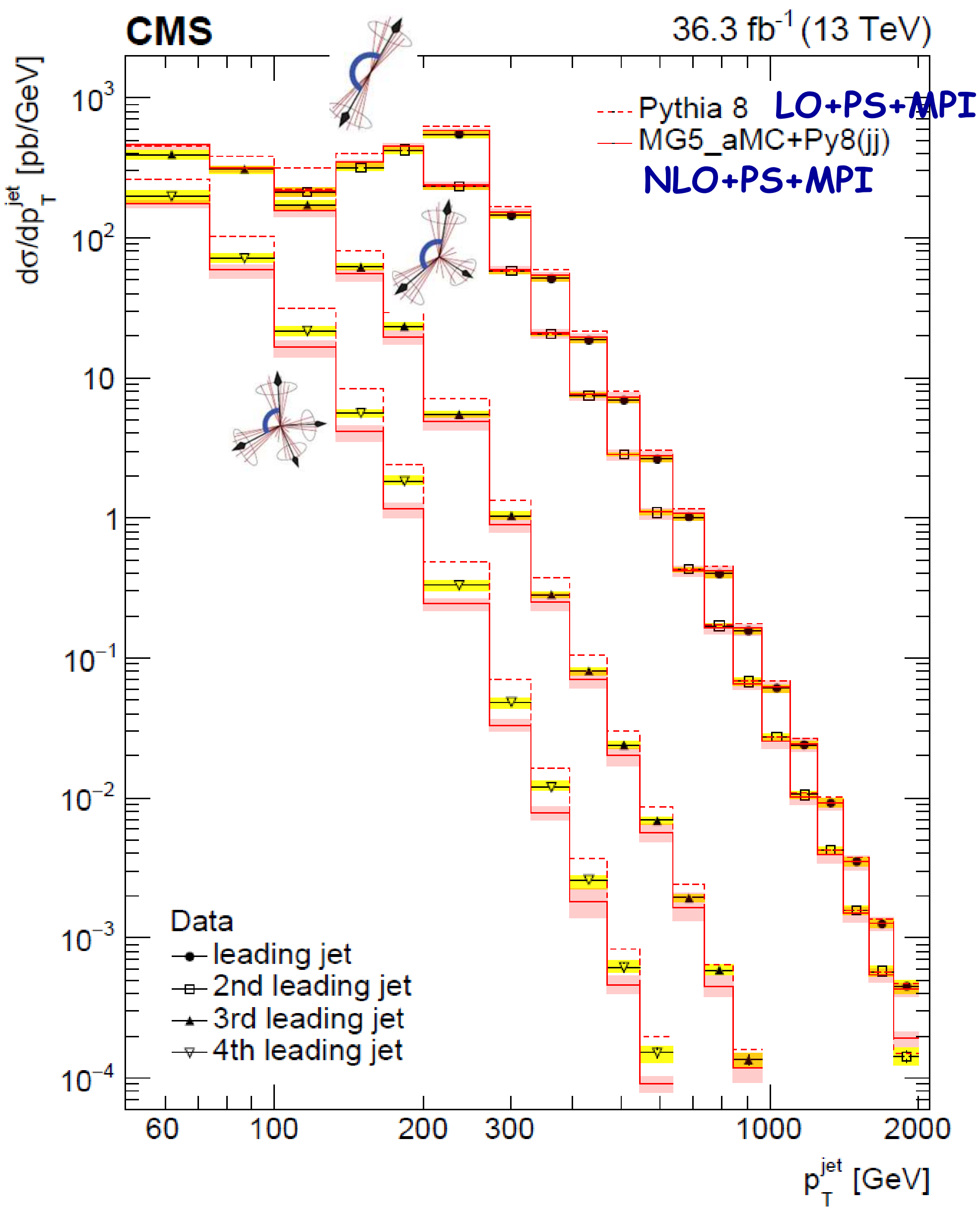
(PS mostly subleading).

for jet multiplicities >=3 and >=4,

data tend to lie between the

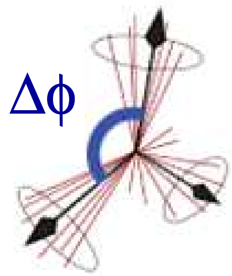
LO+PS and NLO+PS predictions,

both including MPI models.



Azimuthal correlations between jets, full Run 2

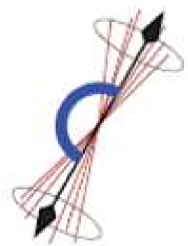
CMS-PAS-SMP-22-005, preliminary, brand new



number of neighbours > 100 GeV

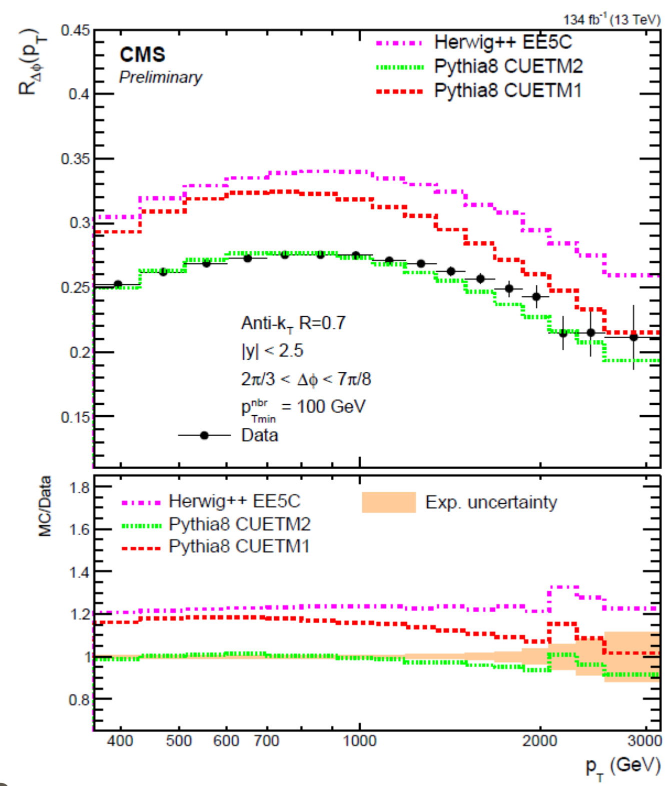
used for detector unfolding

$$R_{\Delta\phi}(p_T) = \frac{2/3\,\pi < \Delta\phi < 7/8\,\pi}{\text{incl.}} = \frac{\sum_{i=1}^{N_{\rm jet}(p_T)} N_{\rm nbr}^{(i)}(\Delta\phi, p_{\rm Tmin}^{\rm nbr})}{N_{\rm jet}(p_T)} = \frac{\sum_{n=0}^{\infty} n N(p_T, n)}{\sum_{n=0}^{\infty} N(p_T, n)}$$



incl.

$\sim \dfrac{\alpha_s^{\,3}}{\alpha_s^{\,2}}$



well described by LO+LL CUETM2 PYTHIA tune

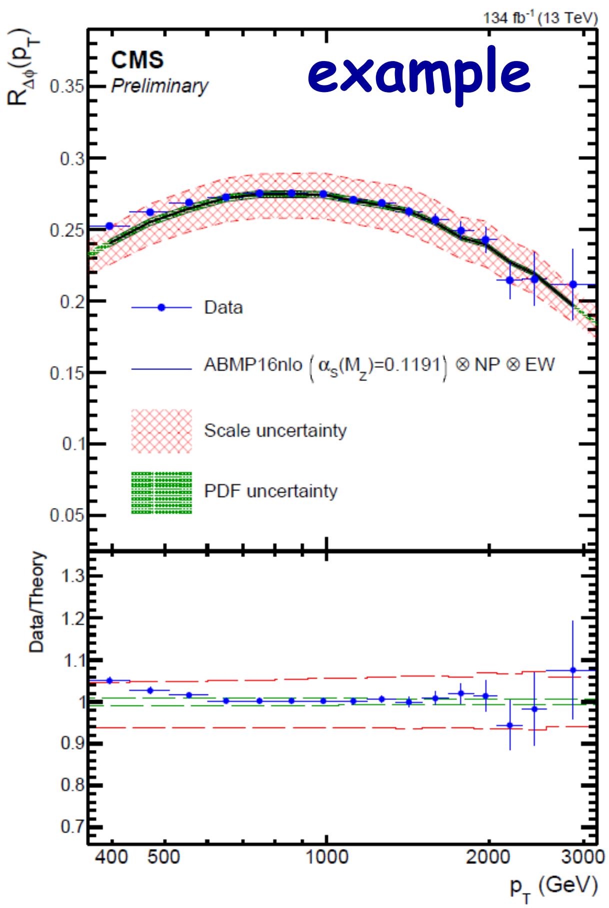
PDF effects partially cancel

Azimuthal correlations between jets, full Run 2

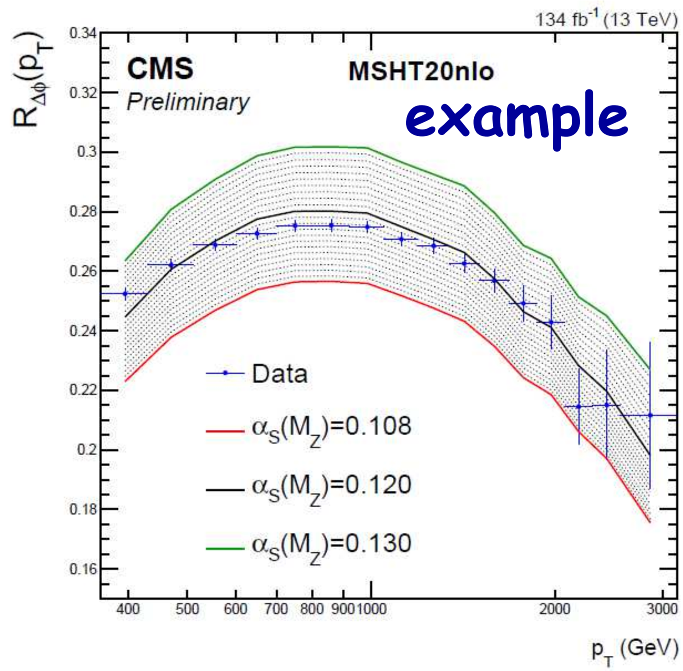
CMS-PAS-SMP-22-005, preliminary, brand new

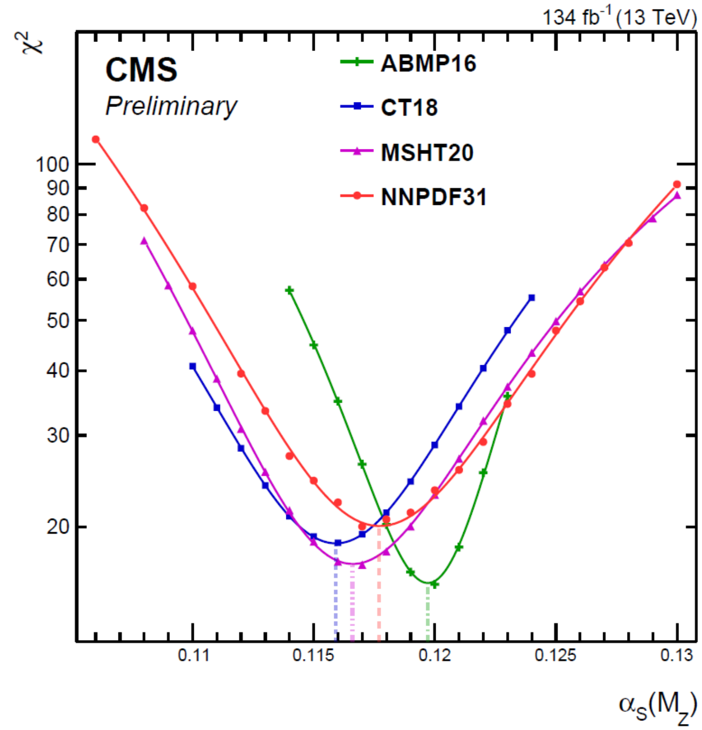
well described

by NLO QCD



perform **NLO α_s fit** (fixed PDF)



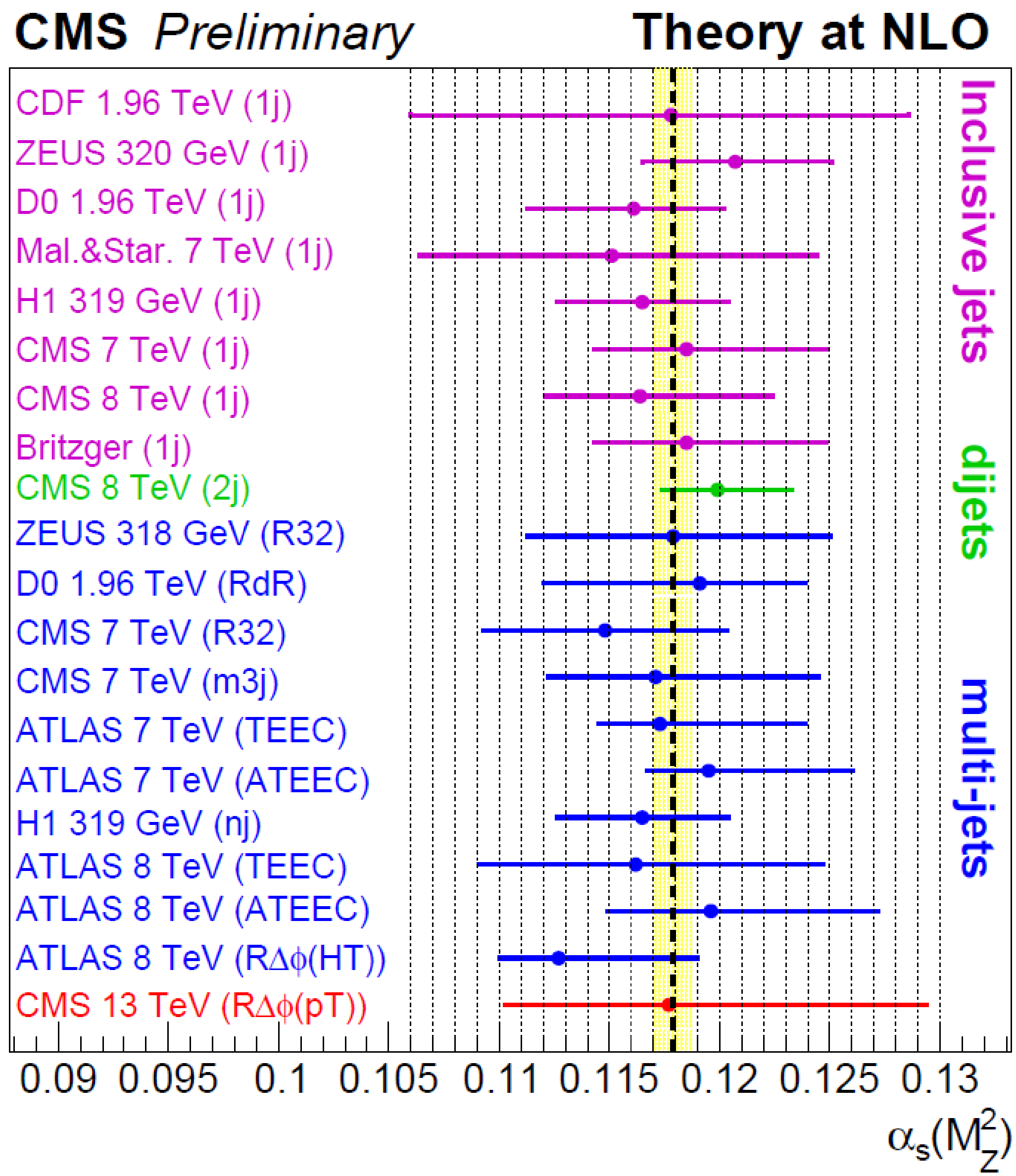


$\alpha_s(m_Z)$ = 0.1177 +0.0117 -0.0074

(+.0114 scale, .0013 exp, .0011 NP, .0010 PDF, .0020 PDF choice, .0003 EW)
-.0068

Comparison with other NLO jet measurements

CMS-PAS-SMP-22-005



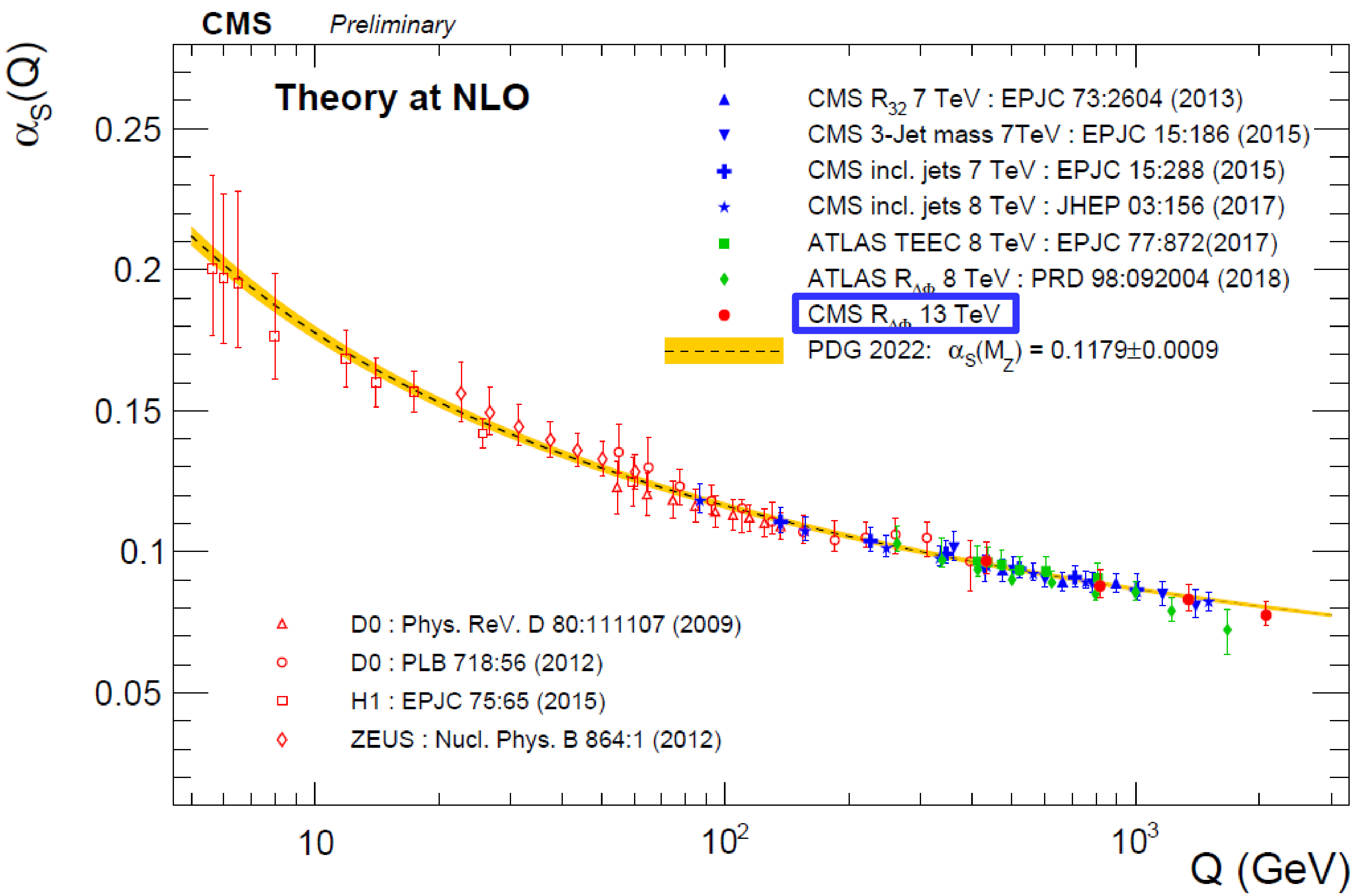
consistent

$\alpha_s(m_Z) = 0.1177$

$+0.0117 \; -0.0074$

Running of α_s

CMS-PAS-SMP-22-005



repeat analysis in different p_T ranges

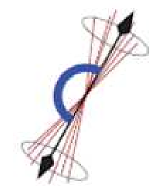
Running of α_s consistent with QCD up to the highest accessible scale (2 TeV)

Conclusions

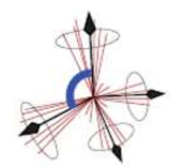
- **Inclusive single jet production in CMS was used to derive the most precise α_s determination from jets,**

  $$\alpha_s(m_Z) = 0.1166 \pm 0.0018$$

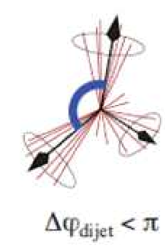
  and significant constraints on the gluon PDF in a combined NNLO PDF+α_s fit including HERA data.



- **Dijet cross sections at 13 TeV have recently also been measured and the corresponding preliminary NNLO PDF+α_s fit gives results which are partially complementary to the inclusive jet results.**



- **Double parton interactions are established to contribute significantly to four-jet production, and multi-jet distributions with up to 7 Jets are reasonably described by LO+LL and NLO+LL MC models including MPI.**



- **The measurement and NLO QCD fit of azimuthal jet correlations allows the extraction of α_s and a cross check of its running up to the highest scale in CMS (2 TeV).**

Backup

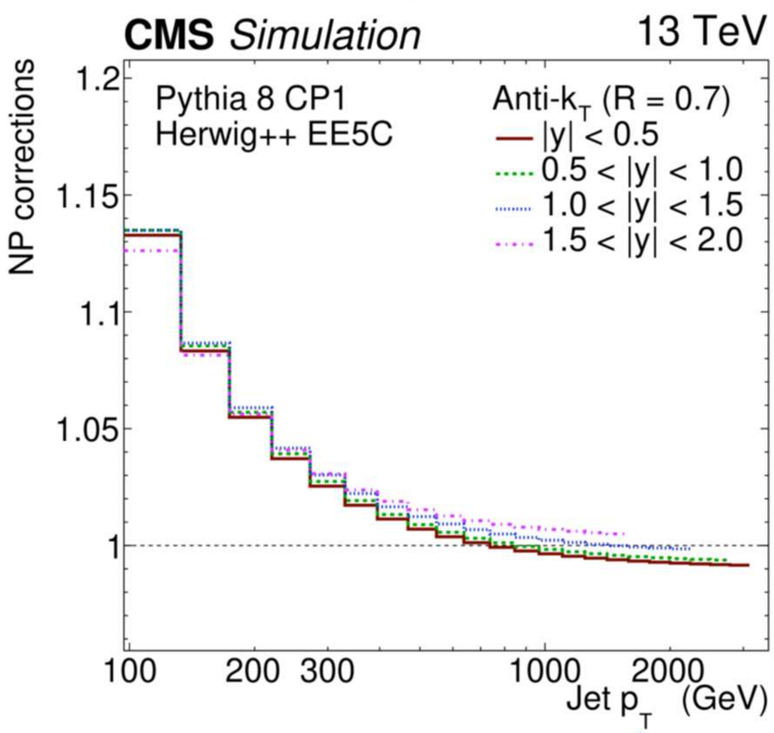
Double differential inclusive jet cross sections

CMS, JHEP 02 (2022) 142 + Addendum JHEP 12 (2022) 035

corrections to NNLO predictions

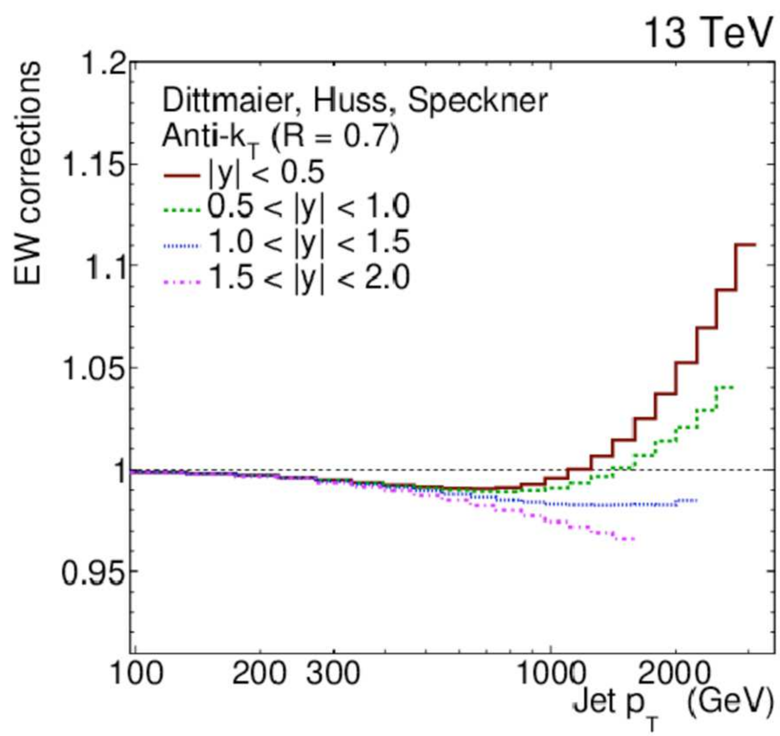
nonperturbative corr.

$$\mathrm{NP}_i = \frac{\sigma_i^{\mathrm{MC}}(\mathrm{PS}\ \&\ \mathrm{MPI}\ \&\ \mathrm{HAD})}{\sigma_i^{\mathrm{MC}}(\mathrm{PS})},$$



use average + envelope
HERWIG & PYTHIA

partial NLO EW corrections



significant at high p_T