Constraints on nuclear parton distribution functions with dijets in pp, pPb collisions at 5.02 TeV with the CMS detector

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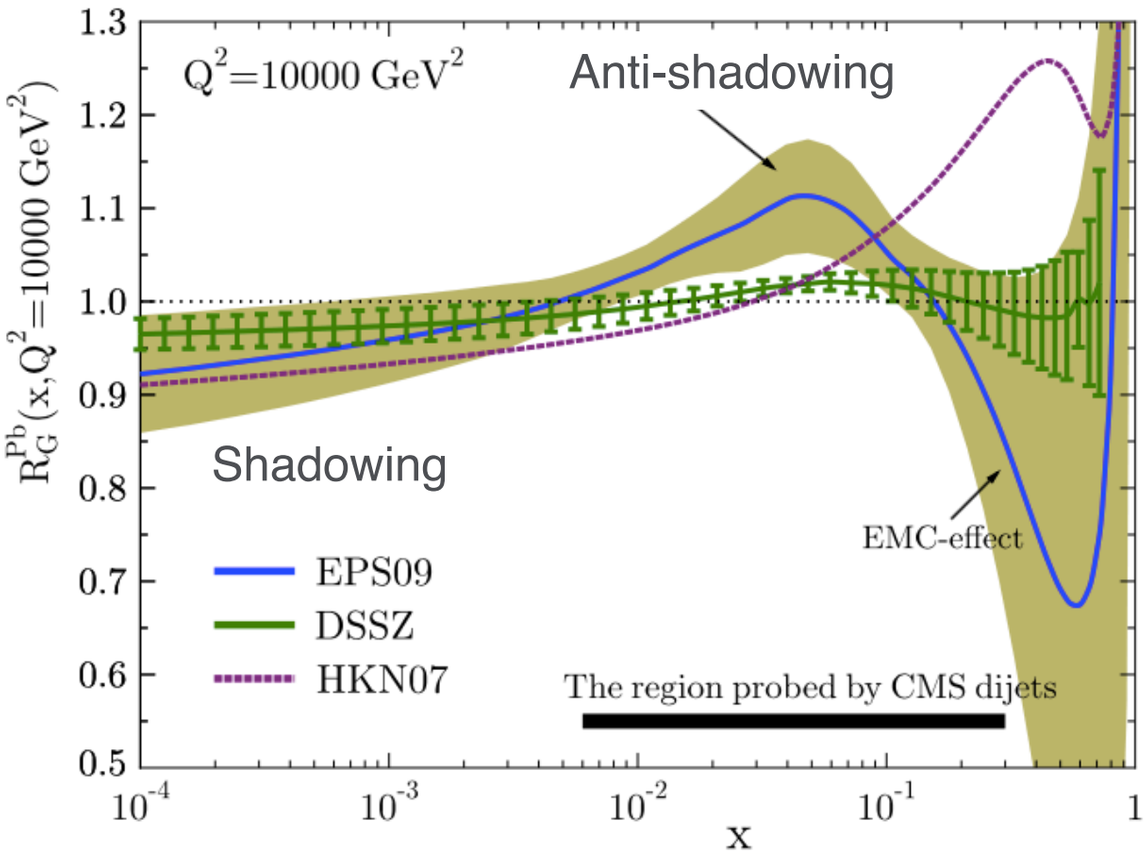
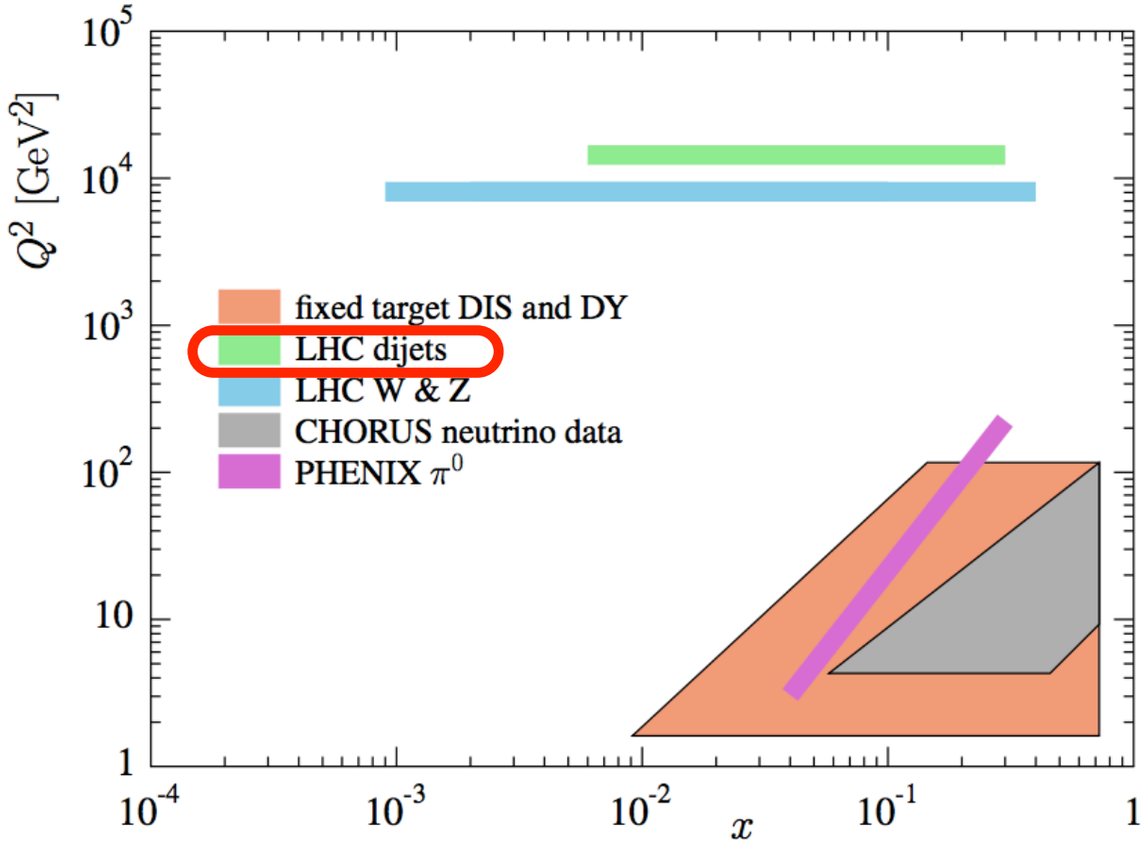
Introduction

- Understanding nPDF (nuclear parton distribution function) and initial state is one of the most important questions in high-energy nuclear physics
- CMS has a wide variety of processes to study nPDF
- Dijet η is sensitive to the gluon nPDF



H. Paukkunen et al. / Nuclear Physics A 931 (2014) 331–336

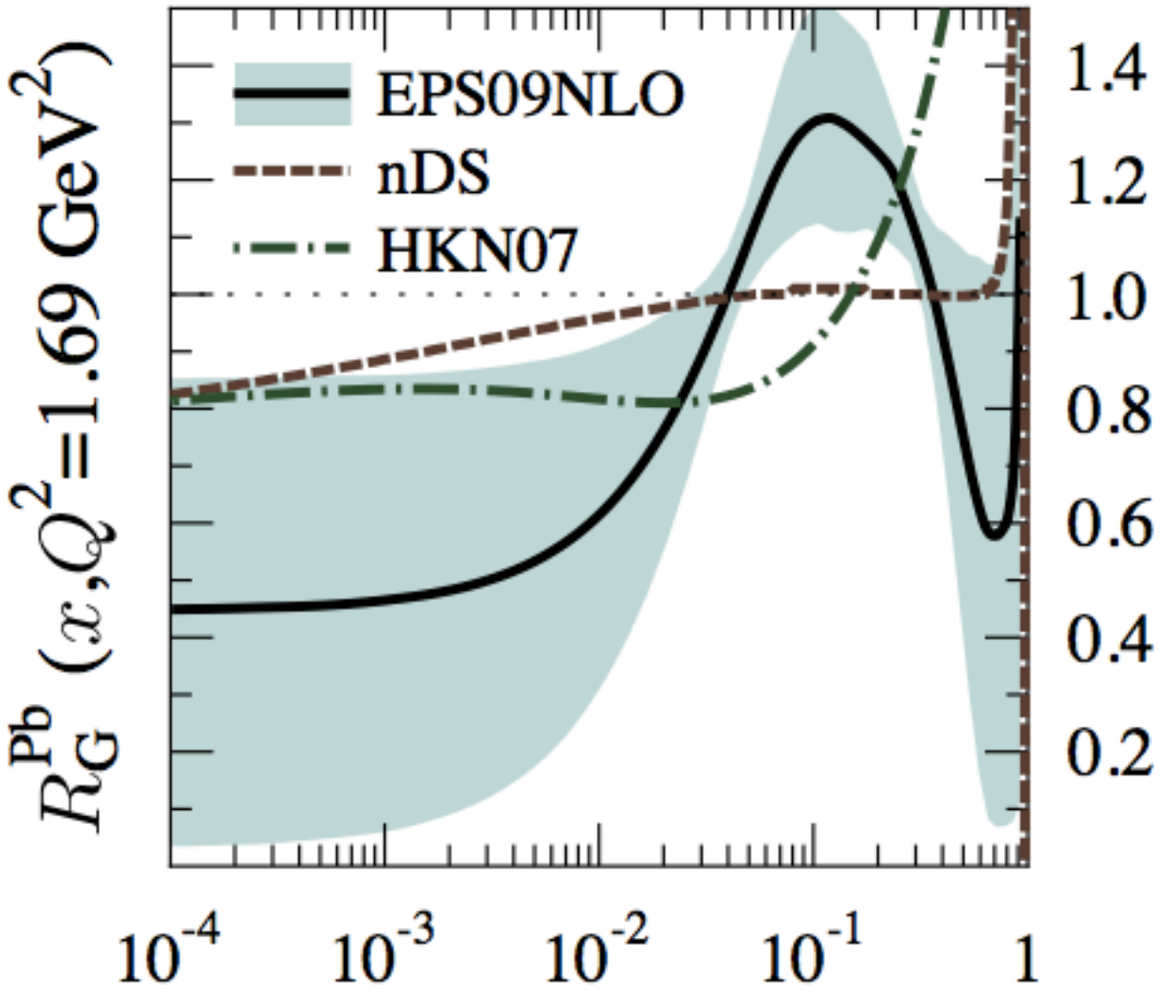


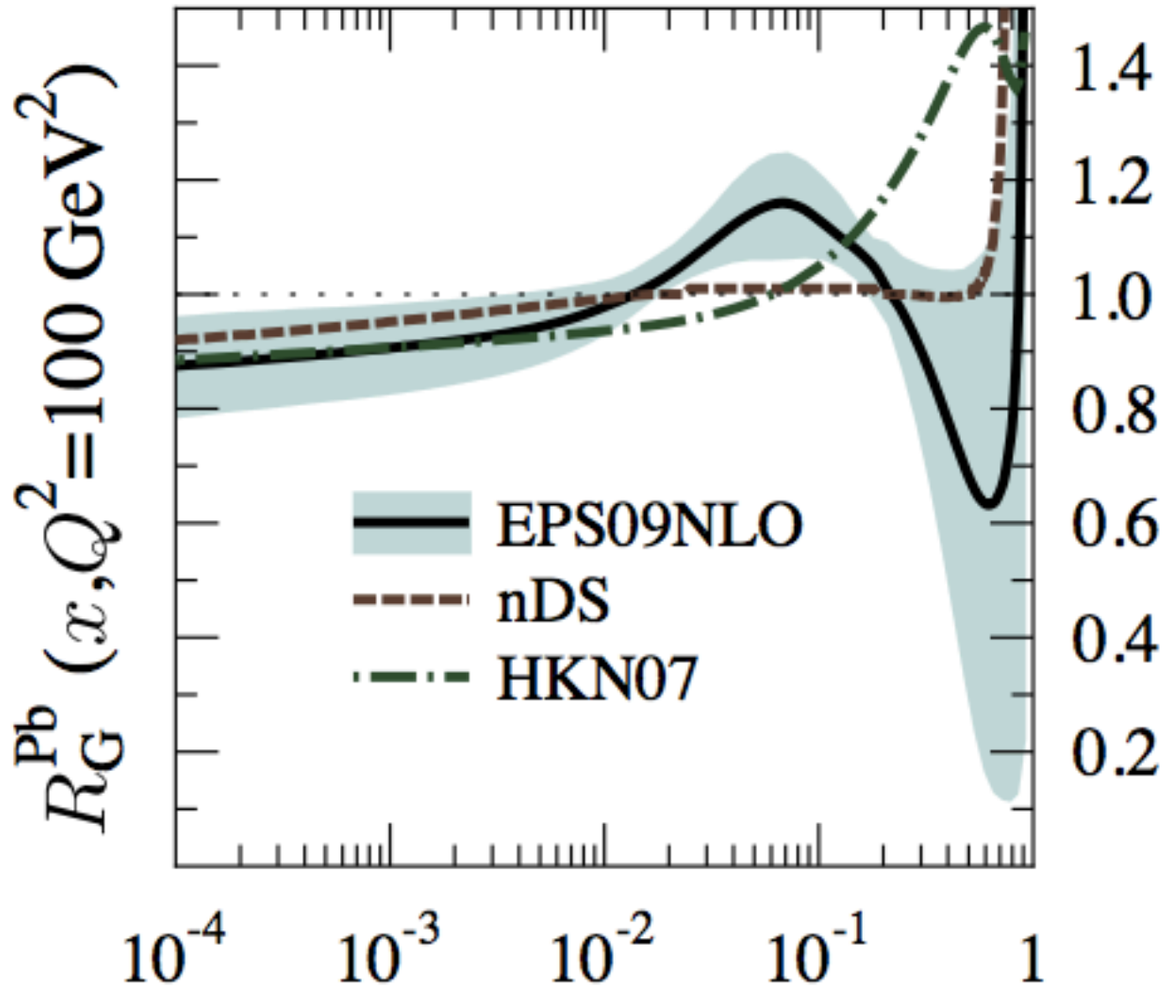
K.J. Eskola, et al. Eur. Phys. J. C (2017) 77: 163

$$R_i^A(x,Q^2) = \frac{f_i^{p/A}(x,Q^2)}{f_i^{p}(x,Q^2)}$$

* See talk by Hyunchul Kim on nPDF studies using other EW processes

Q^2 dependent nPDF





arxiv:1103.1471v2

- **The nuclear modifications depend on factorization scale (Q^2)**

nPDF parameterization

- **The PDF global analysis aims at finding the best possible parameter values -> a large set of experimental data from various hard processes are optimally described**

	EPS09	DSSZ	nCTEQ15	EPPS16
Order in α_s	LO & NLO	NLO	NLO	NLO
NC DIS lA/ld	✓	✓	✓	✓
DY pA/pd	✓	✓	✓	✓
RHIC pions dAu/pp	✓	✓	✓	✓
νA DIS		✓		✓
πA DY	DATA as input			✓
LHC pPb W, Z			LHC DATA as input	✓
LHC pPb jets				✓
Q cut in DIS	1.3 GeV	1 GeV	2 GeV	1.3 GeV
datapoints	929	1579	708	1811
free parameters	15	25	16	20
error analysis	Hessian	Hessian	Hessian	Hessian
error tolerance $\Delta\chi^2$	50	30	35	52
Free proton PDFs	CTEQ6.1	MSTW2008	CTEQ6M-like	CT14
HQ treatment	ZM-VFNS	GM-VFNS	GM-VFNS	GM-VFNS
Flavour separation	no	no	valence	full
Weight data in χ^2	yes	no	no	no

arxiv:1802.05927

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νA DIS		✓		✓
πA DY	DATA as input			✓
LHC pPb W, Z			LHC DATA as input	✓
LHC pPb jets				✓

- **EPS09 & nCTEQ15 : hint of anti-shadowing of gluon nPDF**
- **DSSZ : modification of parton-to-pion fragmentation function in heavy ion collisions and no gluon anti-shadowing**
- **EPPS16 : LHC data from Z/W/dijets at 5 TeV pPb as input**

arxiv:1802.05927

Dijet pseudorapidity

- **Angular distributions of high p_T dijets are less sensitive to fragmentation functions and hadronization effects than hadron observables**

CMS pPb 35 nb^{-1}

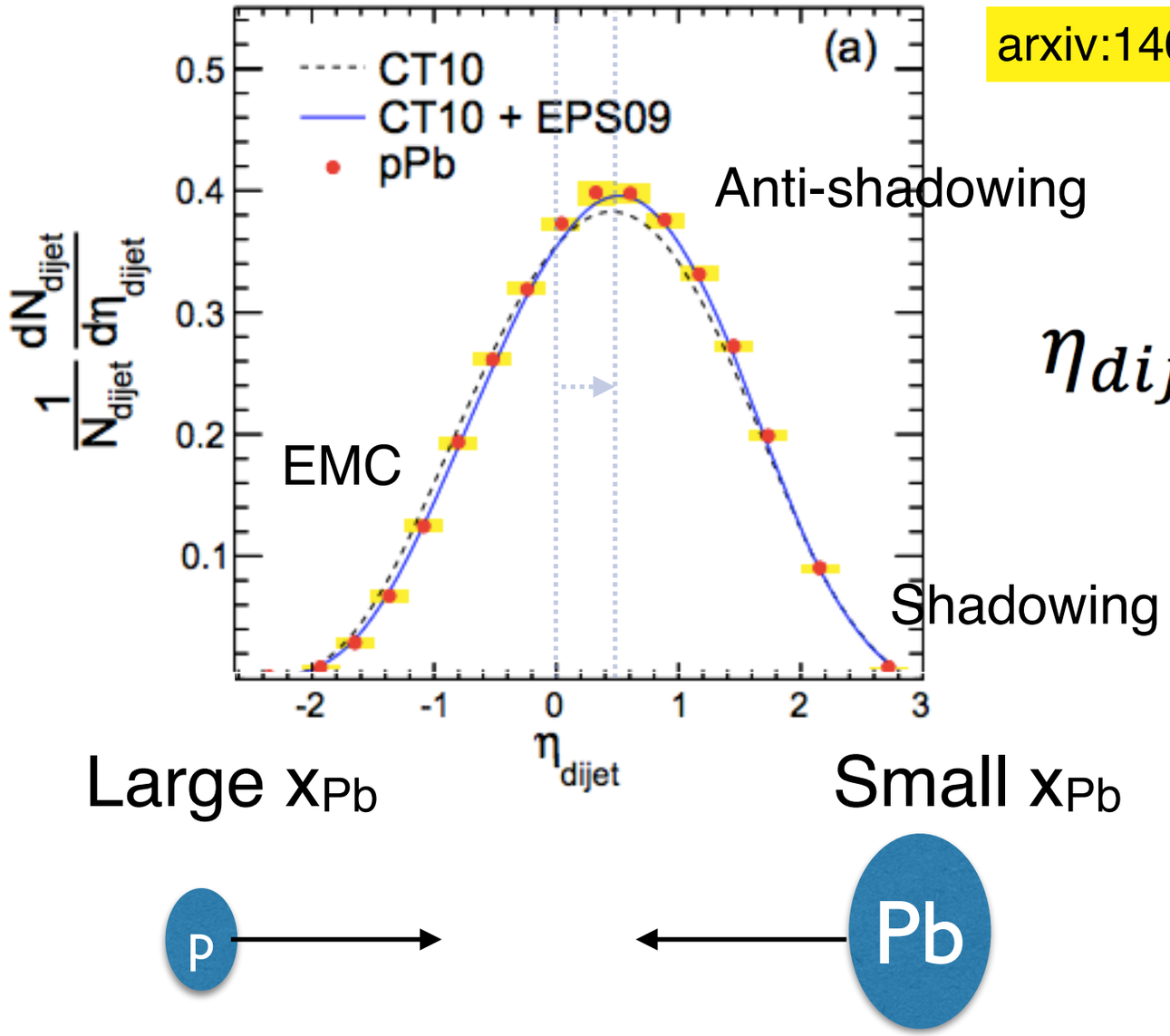
$\sqrt{s_{NN}}$ = 5.02 TeV

$p_{T,1}$ > 120 GeV/c

$p_{T,2}$ > 30 GeV/c

$\Delta\phi_{1,2} > 2\pi/3$

All $E_T^{4<|\eta|<5.2}$



arxiv:1401.4433

$$\eta_{dijet} = \frac{\eta_1+\eta_2}{2}$$

- **Distribution shifts to positive value due to asymmetric proton and lead ion beam energy**

CMS detector

Jet : reconstructed in Tracker+Ecal+Hcal

CMS DETECTOR

Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

STEEL RETURN YOKE
12,500 tonnes

SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A

MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

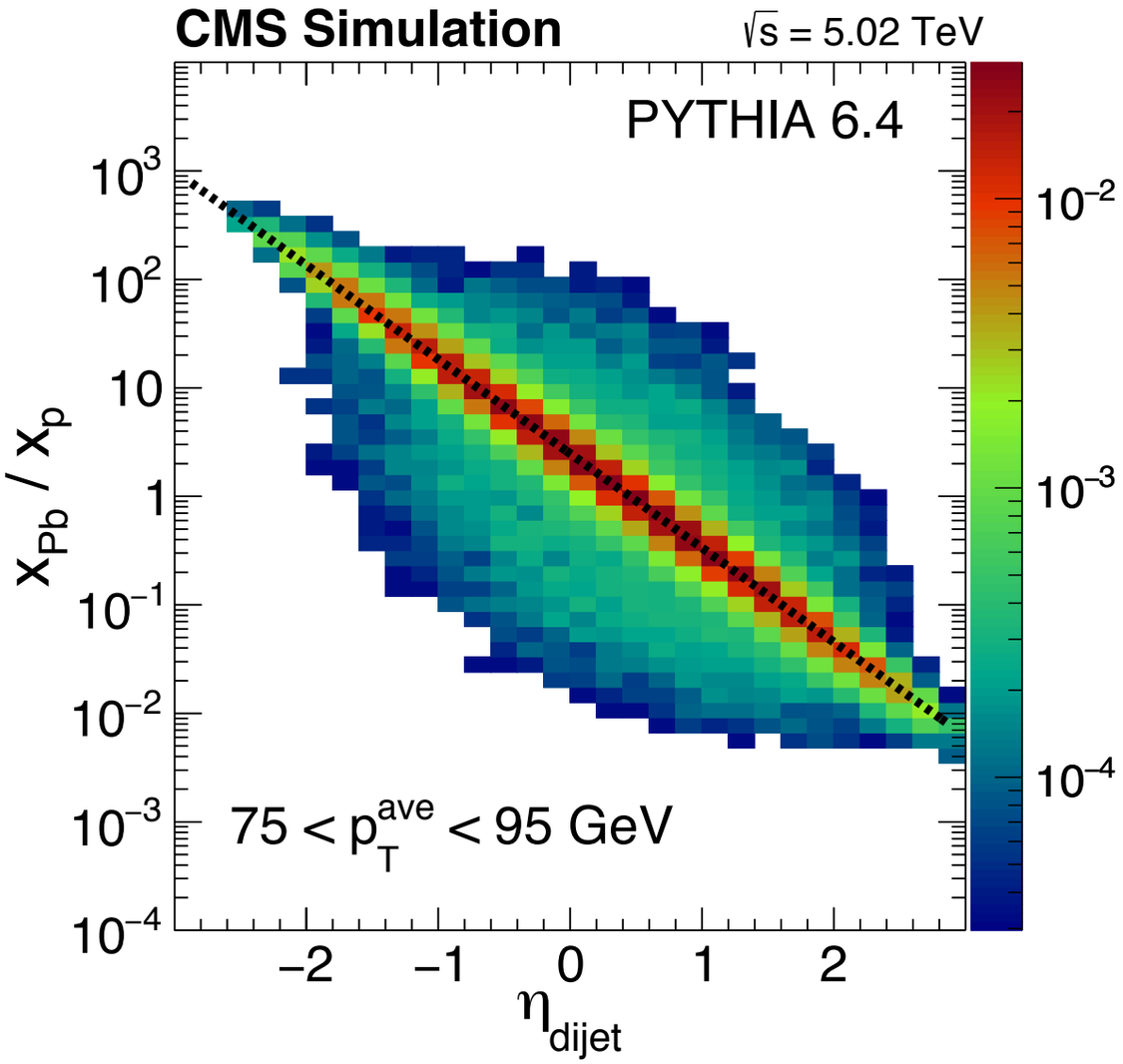
PRESHOWER
Silicon strips ~16m² ~137,000 channels

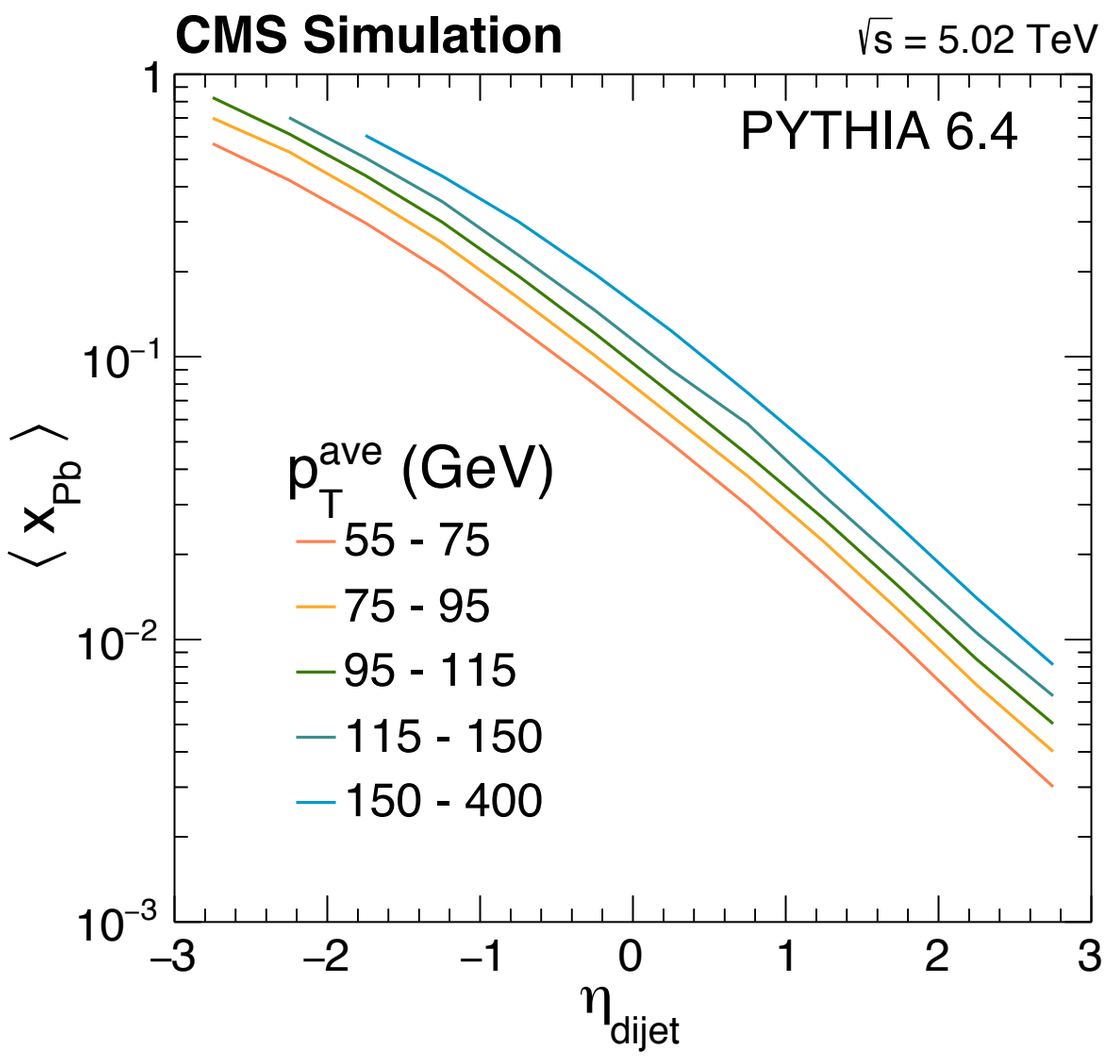
FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating $PbWO_4$ crystals

HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

Relation between η_{dijet} and x_{Pb}





$$\eta_{\mathrm{dijet}} = (\eta_1 + \eta_2)/2$$

$$p_{\mathrm{T}}^{\mathrm{ave}} = (p_{\mathrm{T},1} + p_{\mathrm{T},2})/2$$

- η_{dijet} **distributions are sensitive to nPDF effects**
- **Factorization scale is proportional to** $p_{\mathrm{T}}^{\mathrm{ave}}$

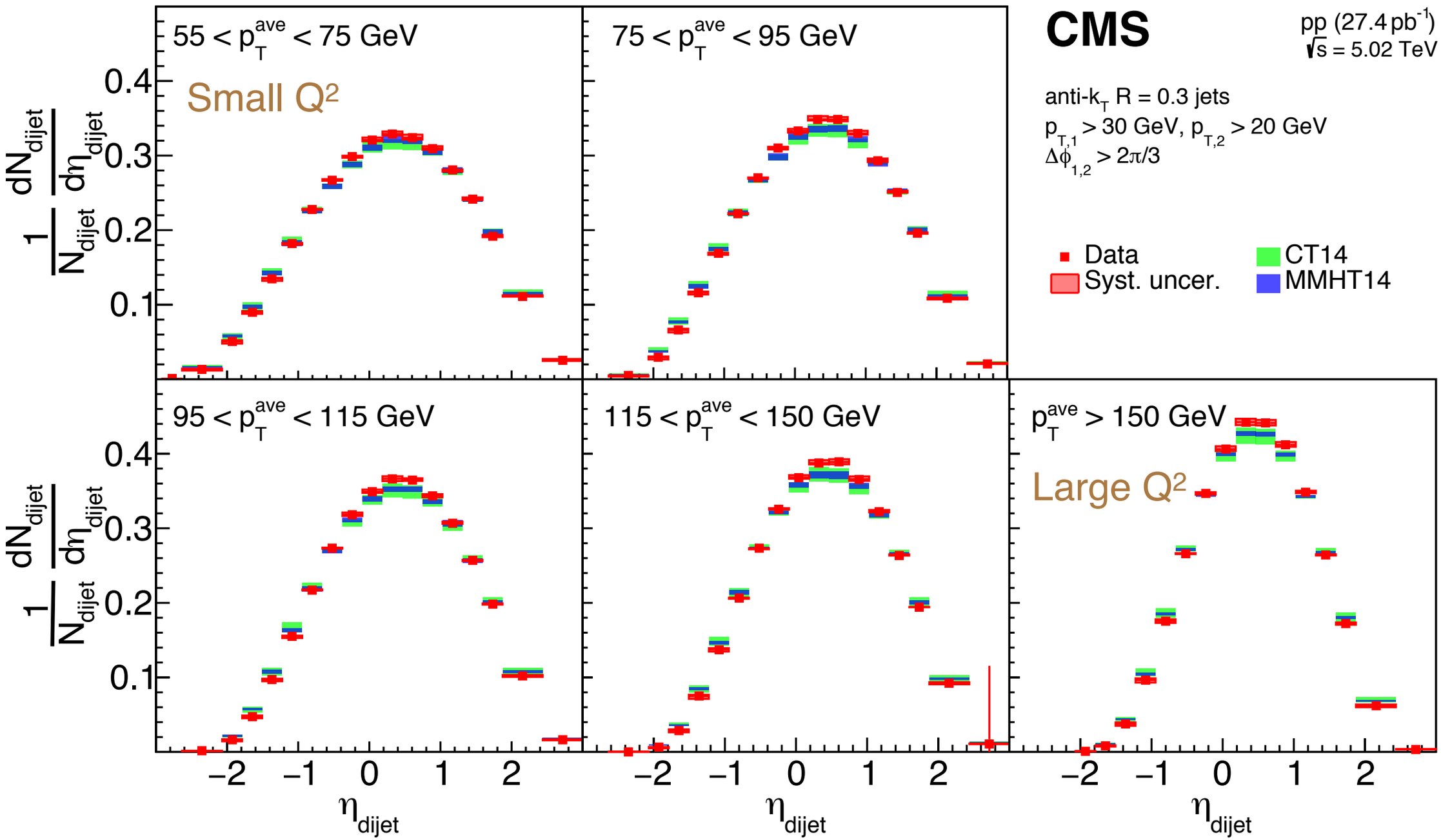
Dijet Kinematics Selection

- **Jet reconstruction**
  - Anti-k_T R = 0.3 particle-flow jets
  - pPb : $|\eta_{lab}| < 3$
  - pp : $-3.465 < |\eta_{lab}| < 2.535$ to compare with the pPb data
  - No underlying event subtraction
  - Data-driven energy correction using dijet, photon-jet and Z-jet

- **Dijet selection**
  - $p_{T,1} > 30$ GeV
  - $p_{T,2} > 20$ GeV
  - $\Delta\phi > 2\pi/3$
  - p_T^{ave} intervals ($p_T^{ave} = \frac{p_{T,1}+p_{T,2}}{2} \propto Q$)
    - 25, 55, 75, 95, 115, 150, 400 GeV
    - Vary the Q^2 by ~ a factor of 30

Comparison of pp data with NLO

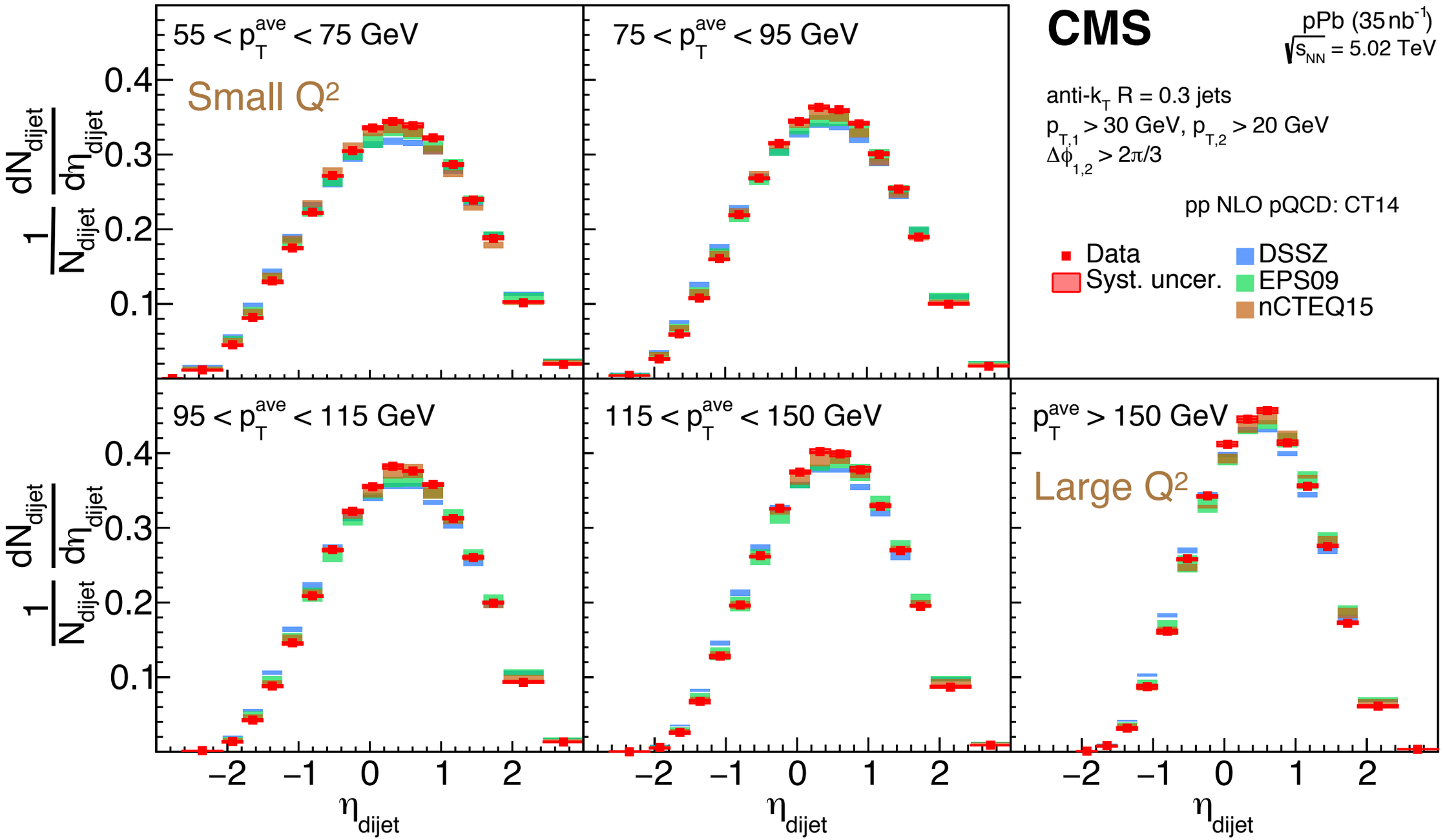
pp collisions



- **Data is narrower compared to NLO calculations (both CT14 and MMHT14)**

Comparison of pPb data with NLO (CT14)

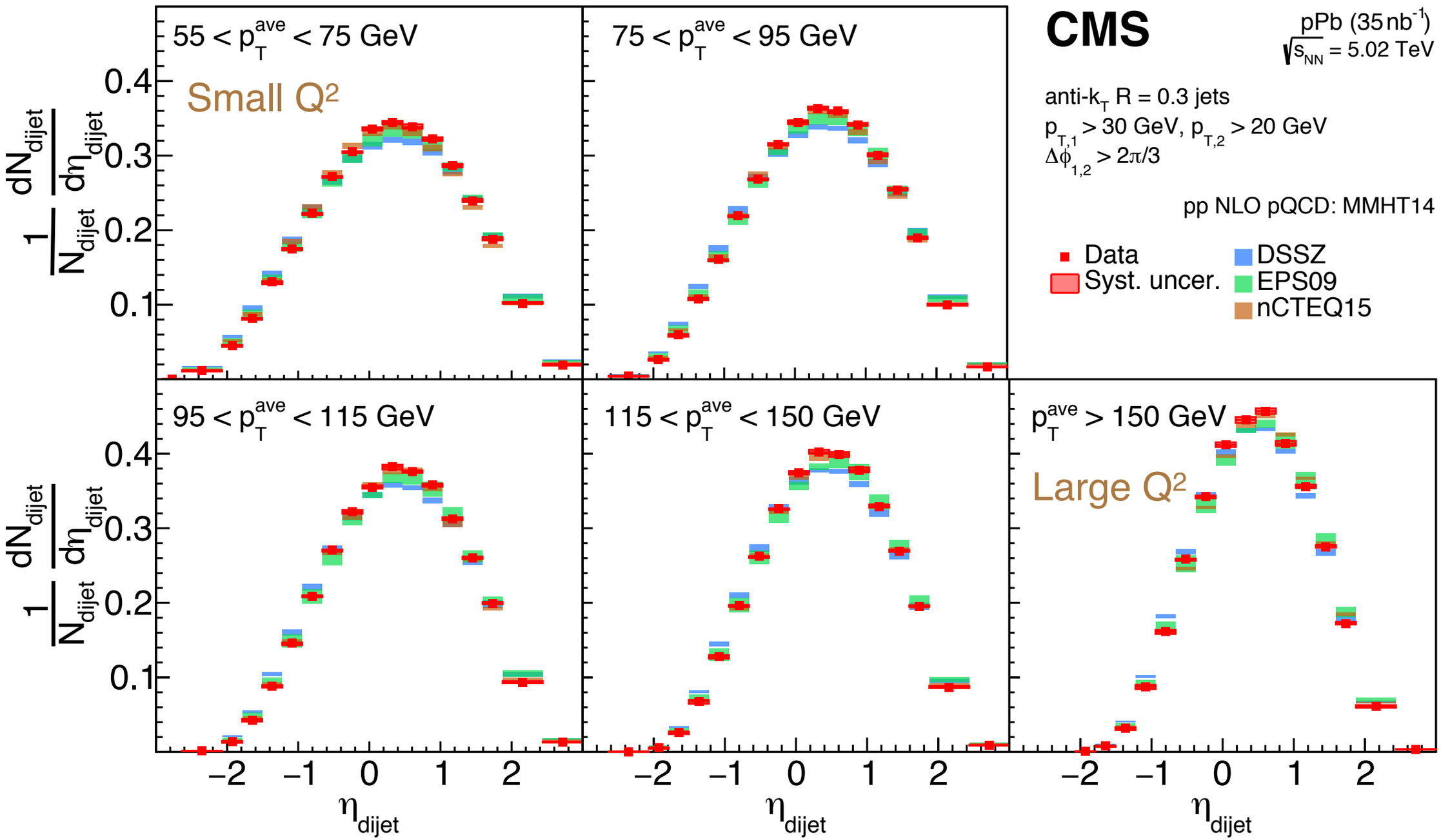
pPb collisions and pp NLO pQCD: CT14



- **better agreement between DATA and NLO calculations than pp**
  - -> However, there is the hidden effect of pp

Comparison of pPb data with NLO (MMHT14)

pPb collisions and pp NLO pQCD: MMHT14



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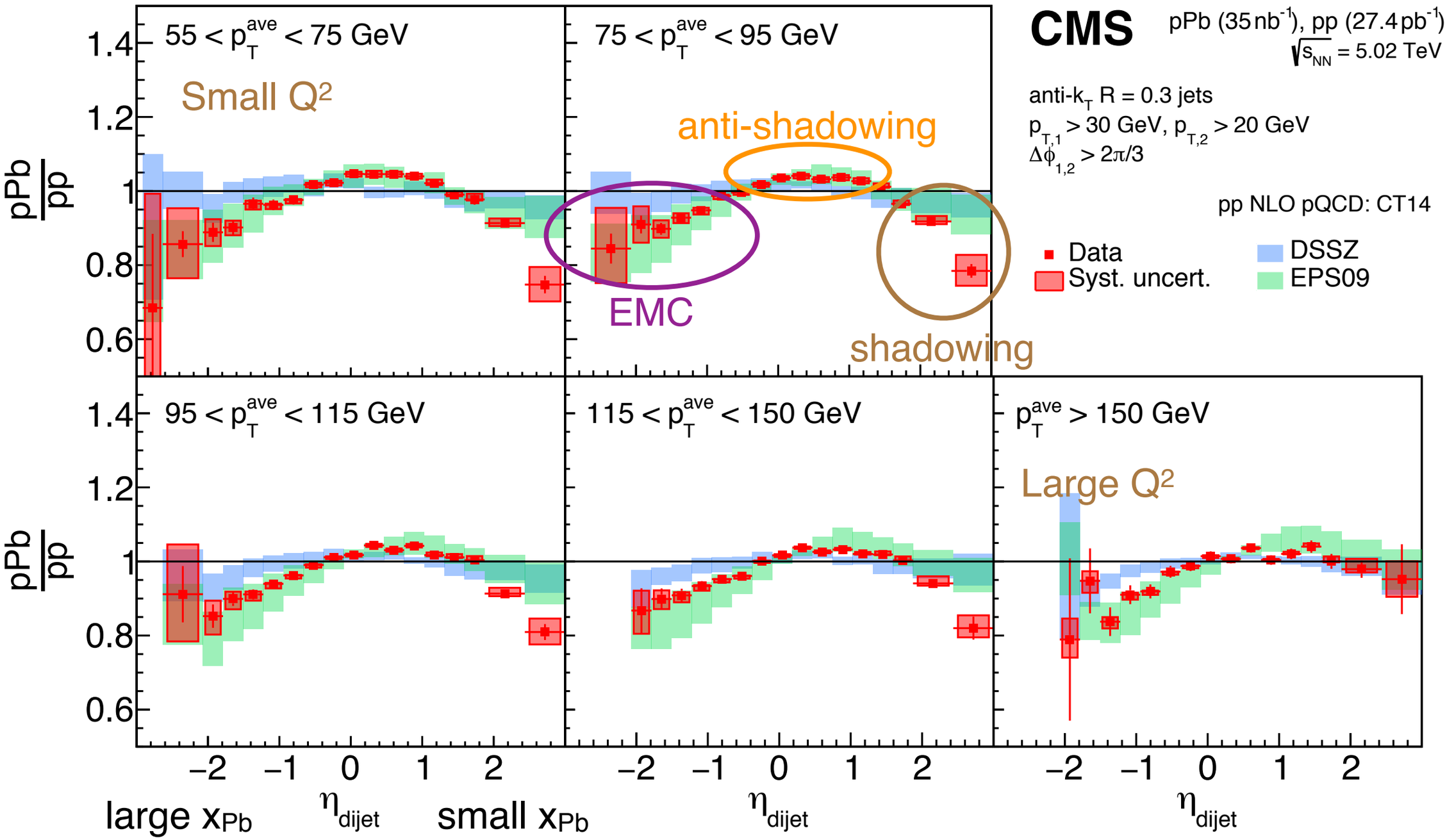
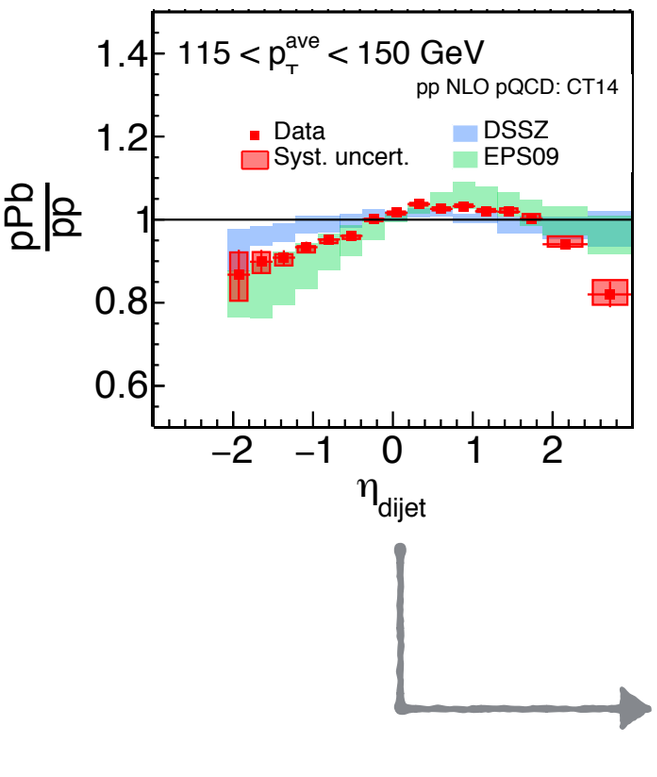
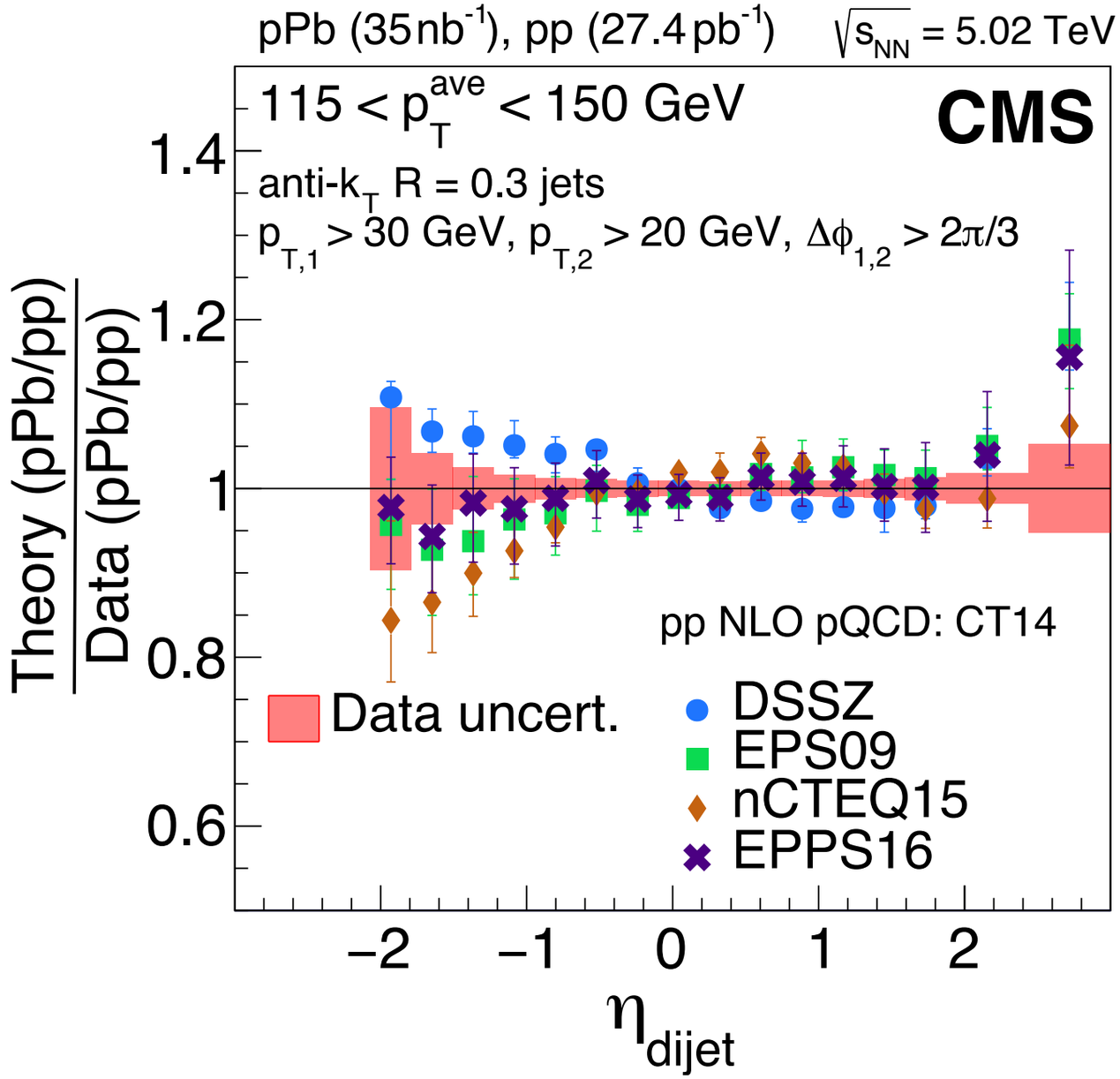
Ratio of pPb and pp



- **pPb/pp ratios deviate from unity in the small (EMC) and large (shadowing) dijet η region**

Ratio of pPb and pp comparison of DATA with NLO





* EPPS16 uses pPb dijet η as input

* χ^2 test
for $115 < p_T^{ave} < 150$ GeV

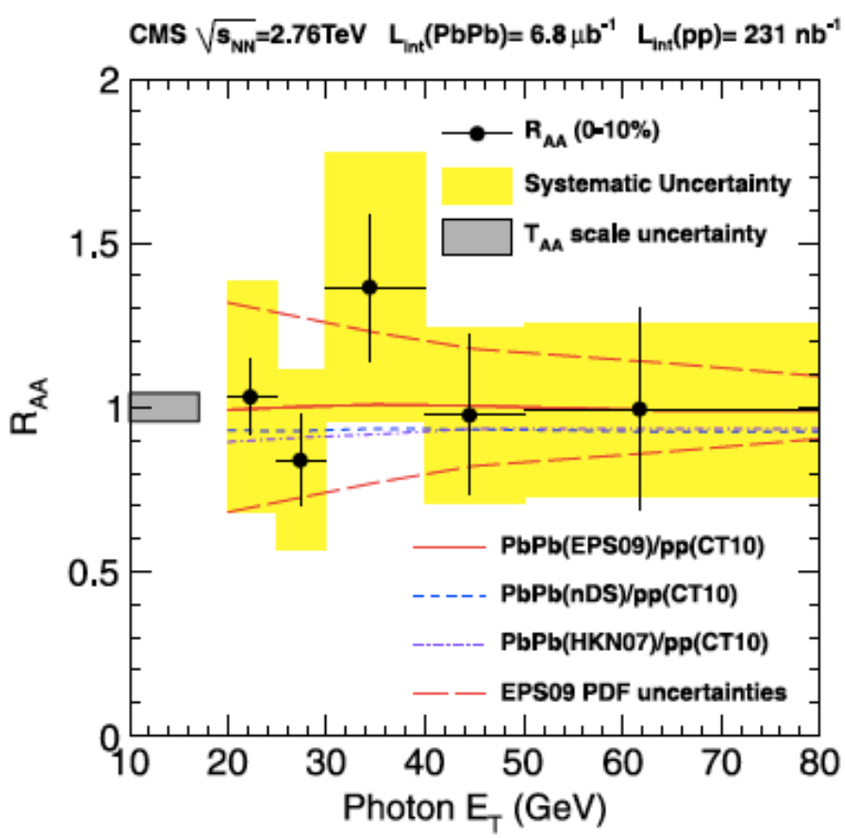
	p value
EPS09	0.19
DSSZ	$< 10^{-8}$
nCTEQ15	$< 10^{-8}$

- **Based on a statistical analysis, the EPS09 nPDF provides the best overall agreement with the data.**

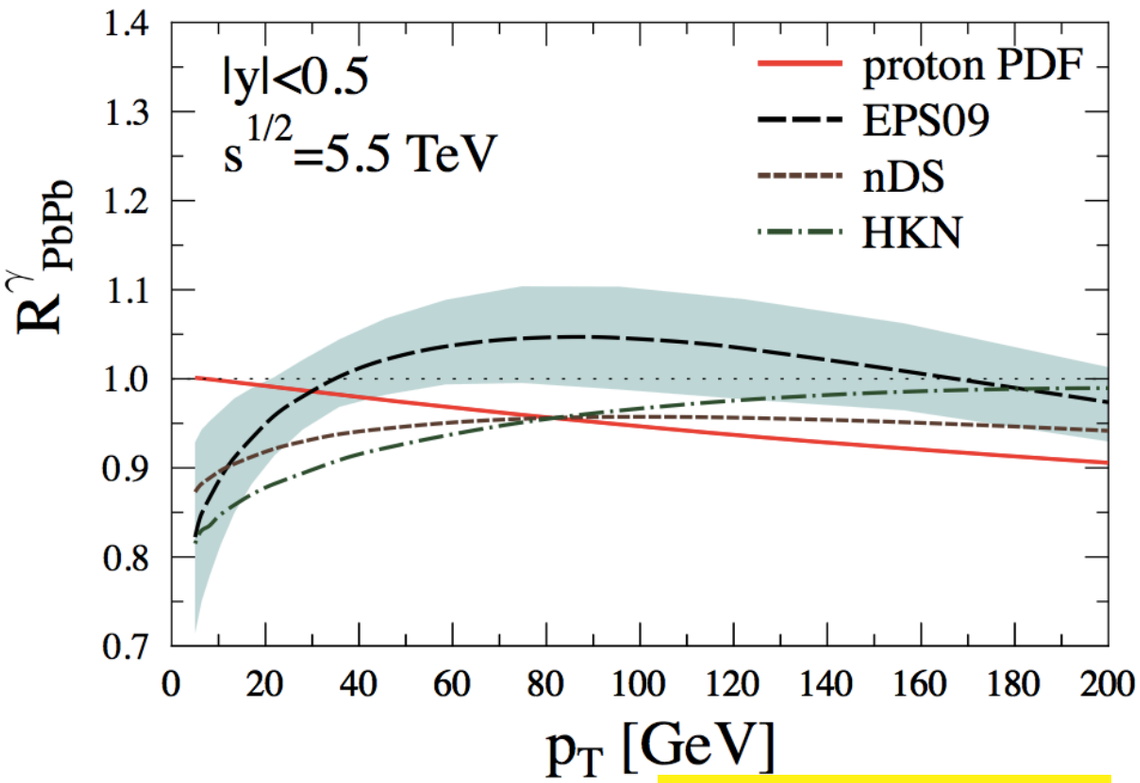
Outlook : prompt photons for nPDF study

- **Constraint nPDF with prompt photons**
  - The production of inclusive and isolated prompt photons in hadronic collisions is a process that is known – along with jet production – to carry direct information on the gluon PDF

- **Baseline for Nuclear Modification Factor(R_{AA}) of other particles**
  - as a clean probe which does not interact with the QCD medium.

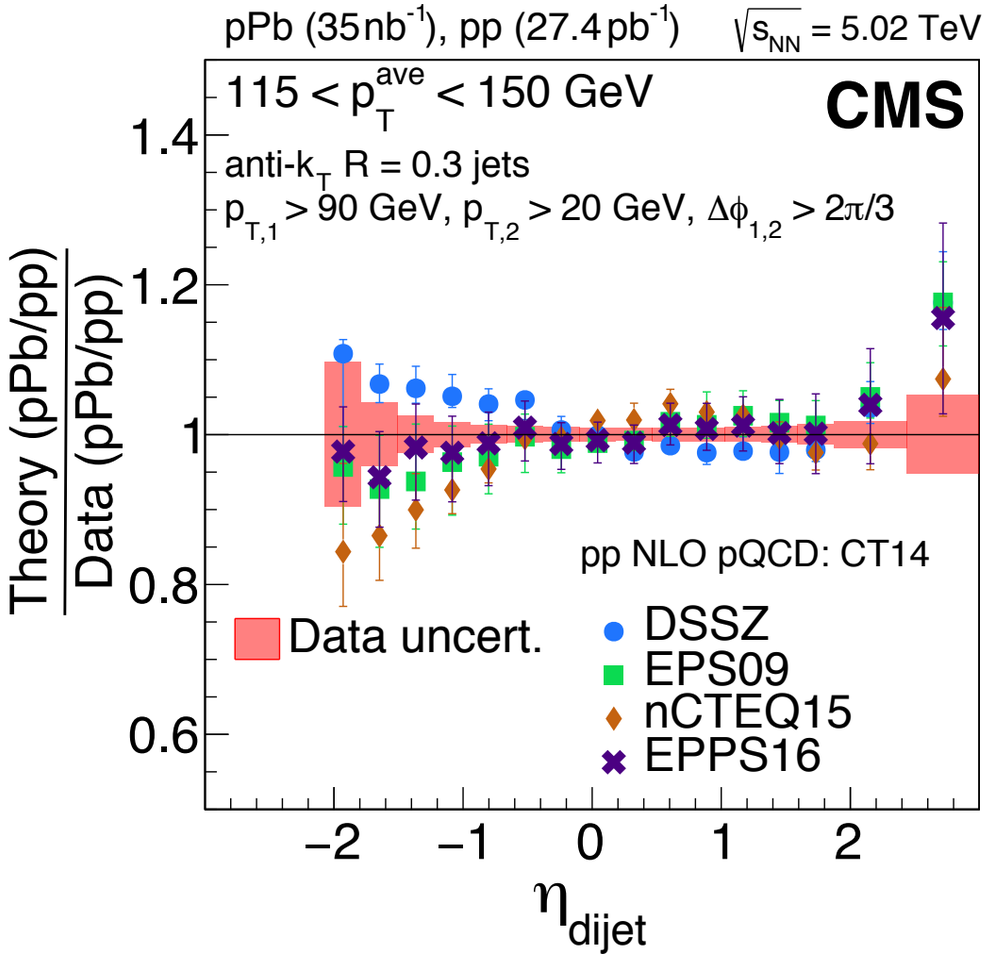


PLB 710 (2012) 256–277



JHEP04(2011)055

Summary



- **Precision measurements of dijet pseudorapidity for different p_T^{ave} bins in pp and pPb from CMS provide strong constraints on the (gluon) nPDF**
- **Based on a statistical analysis, the EPS09 nPDF provides the best overall agreement with the data.**
- **Prompt photon measurements will be able to provide constraints on the nPDF**

Thank you for the attention !