Dijet η distributions in pp and pPb at 5 TeV with CMS

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For the CMS Collaboration

Hard Probes 2016

Wuhan, China

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Introduction

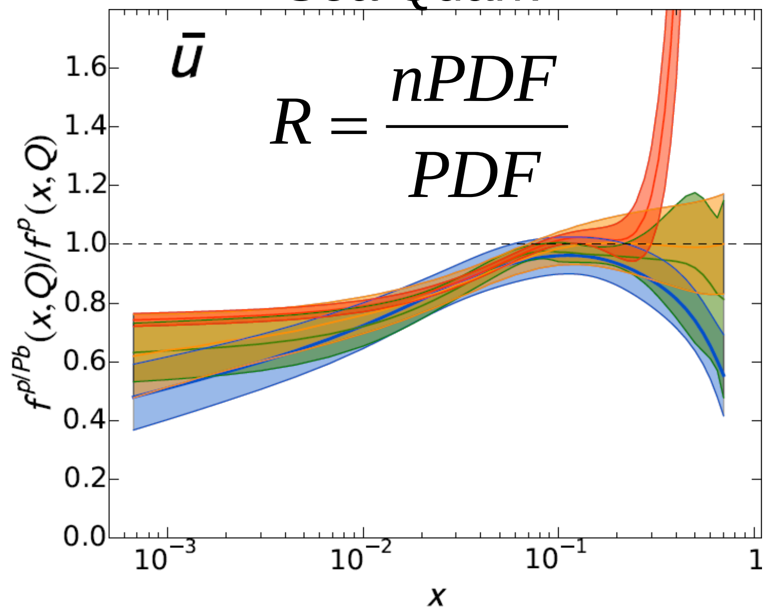
Nuclear Parton Distribution Functions (nPDF)

Deep Inelastic Scattering Data

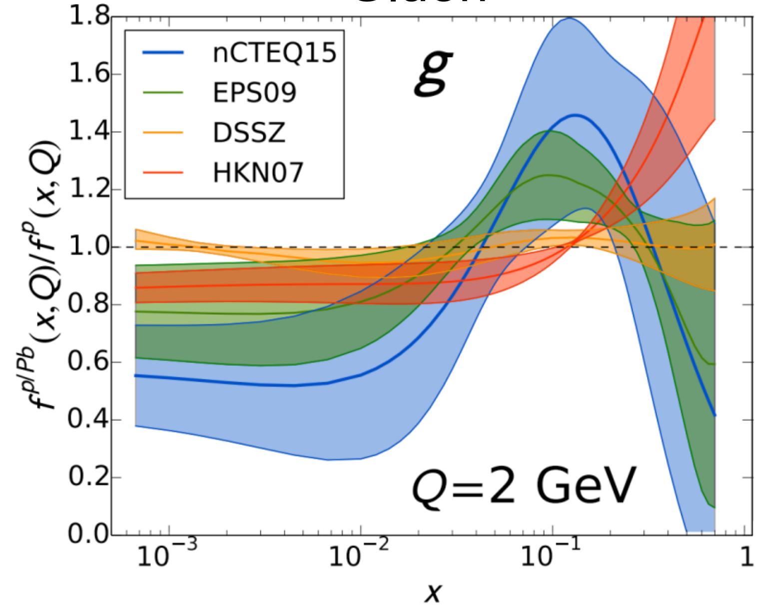
Drell-Yan Data

RHIC Pion Data

Sea Quark

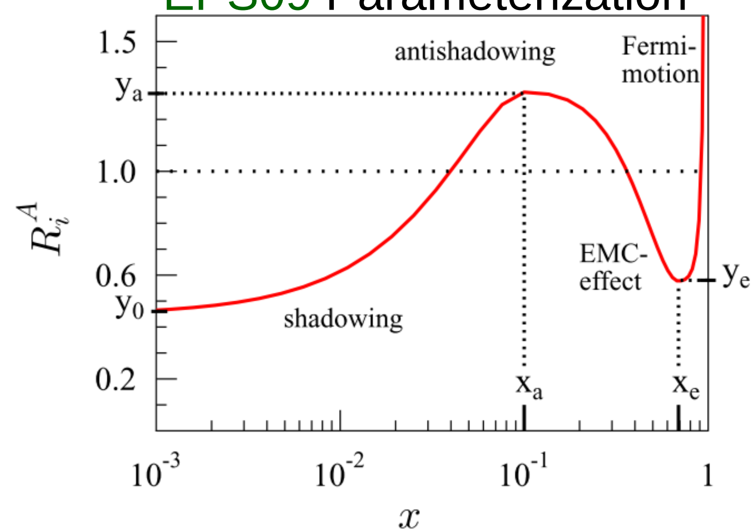


Gluon



	Q^2 cutoff	DIS	DY	PHENIX Pion	STAR Pion
HKN07	1	V	V		
EPS09	1.69	V	V	V	
DSSZ	1	V	V	V	V
nCTEQ15	4	V	V	V	V

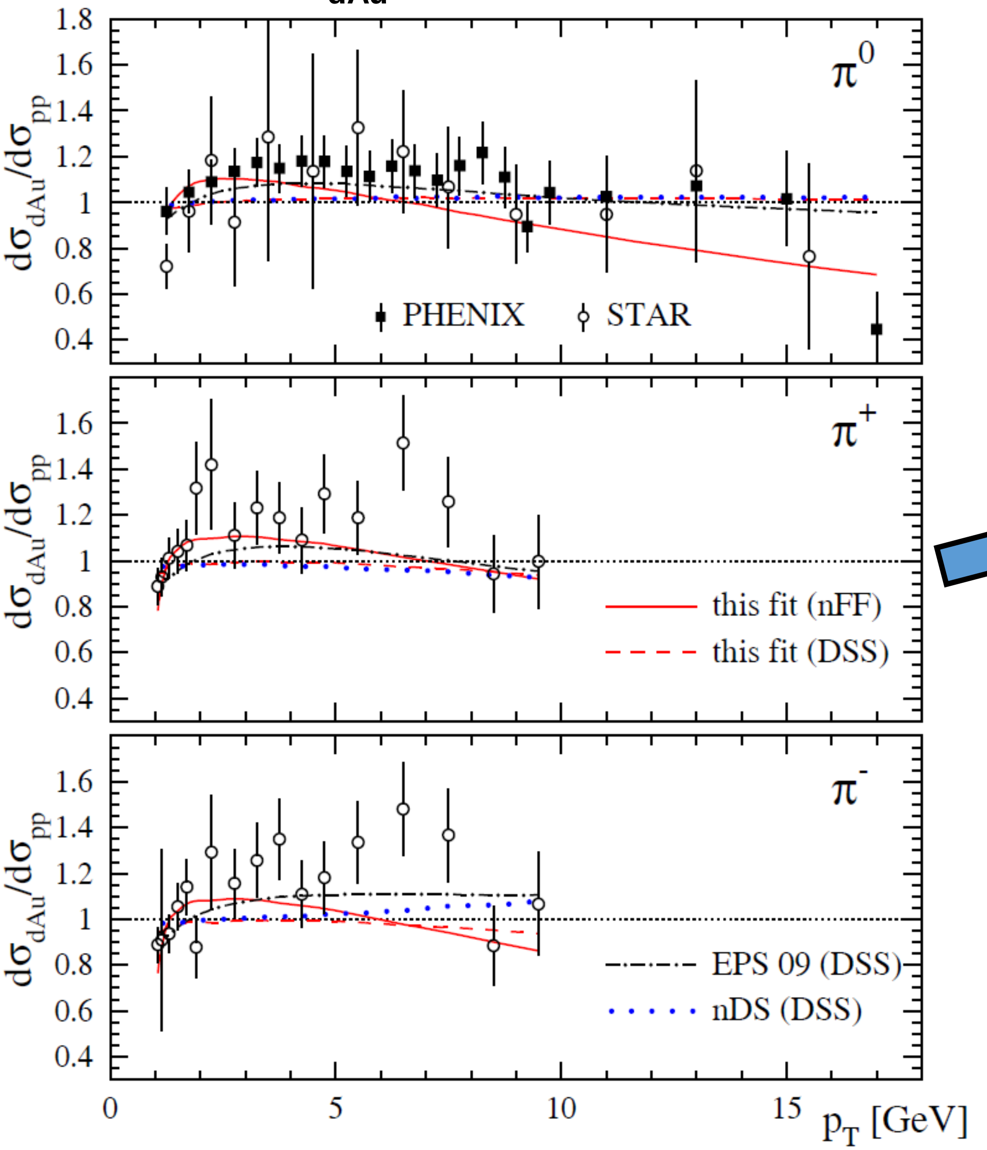
EPS09 Parameterization



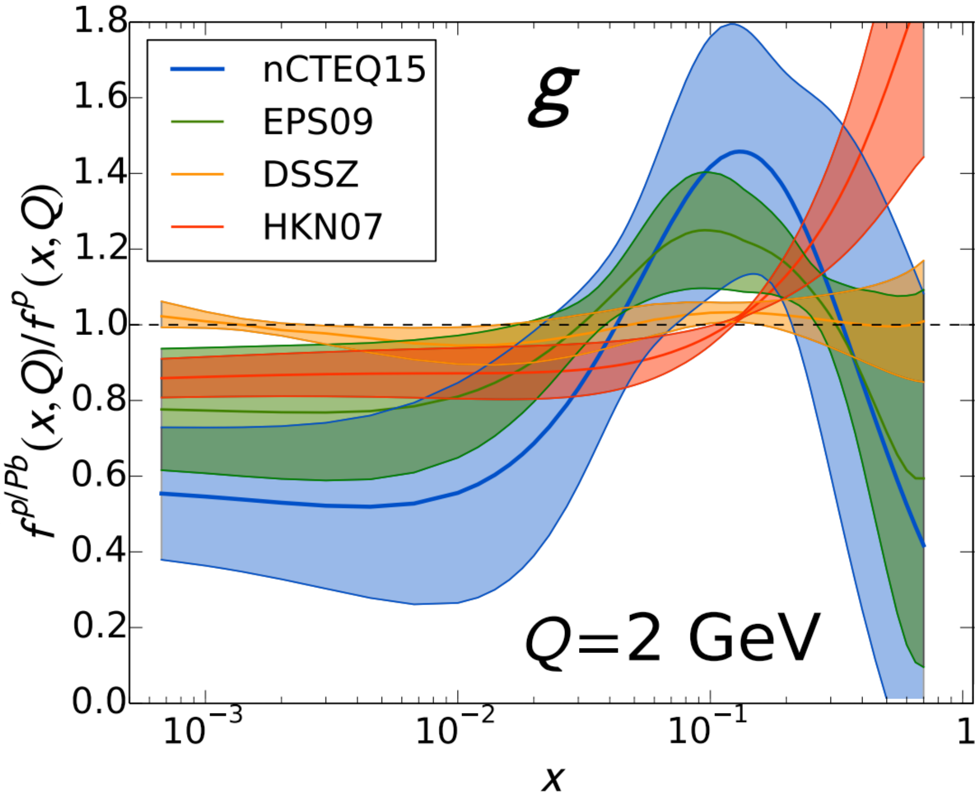
Different interpretation of the pion data

Hadron observables: sensitive to possible modifications of **fragmentation function** and **hadronization** → Different interpretation of the data!

RHIC **R_{dAu}** dAu 200 GeV/c



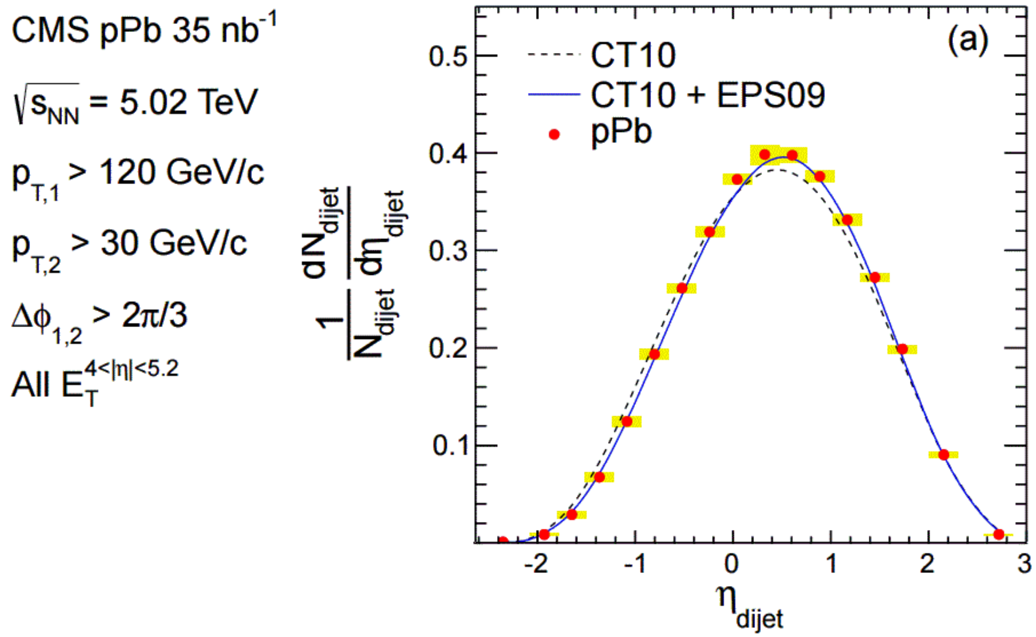
Gluon **R=nPDF/PDF**



- **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

Dijet pseudorapidity

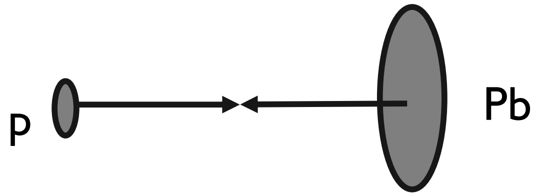
Idea: Angular distributions of high p_T dijets



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

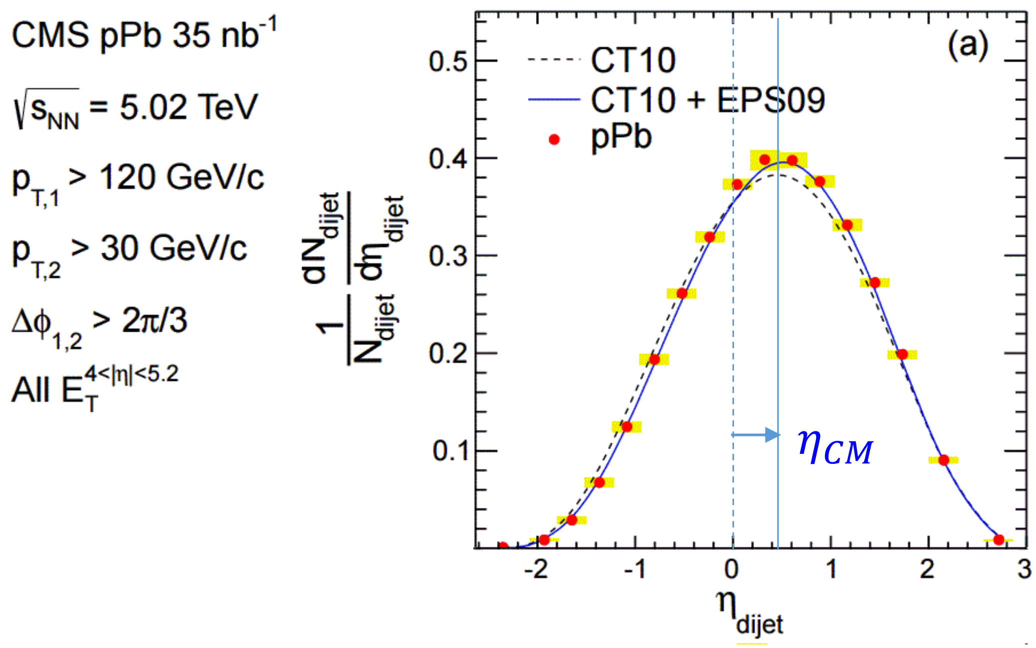
$$\propto 0.5 \log\left(\frac{x_p}{x_{Pb}}\right) + \eta_{CM}$$

- Less sensitive to fragmentation functions and hadronization effects
- Can be calculated with pQCD with small theoretical uncertainties
- Normalized distribution: lead to smaller theoretical and experimental uncertainties



Dijet pseudorapidity in the LAB Frame

Idea: Angular distributions of high p_T dijets

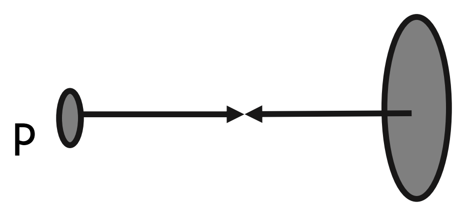


- $\eta_{dijet} = \dfrac{\eta_1+\eta_2}{2}$

$$\propto 0.5\log\left(\frac{x_p}{x_{Pb}}\right) + \eta_{CM}$$

Measurement in the lab frame

3.5 TeV

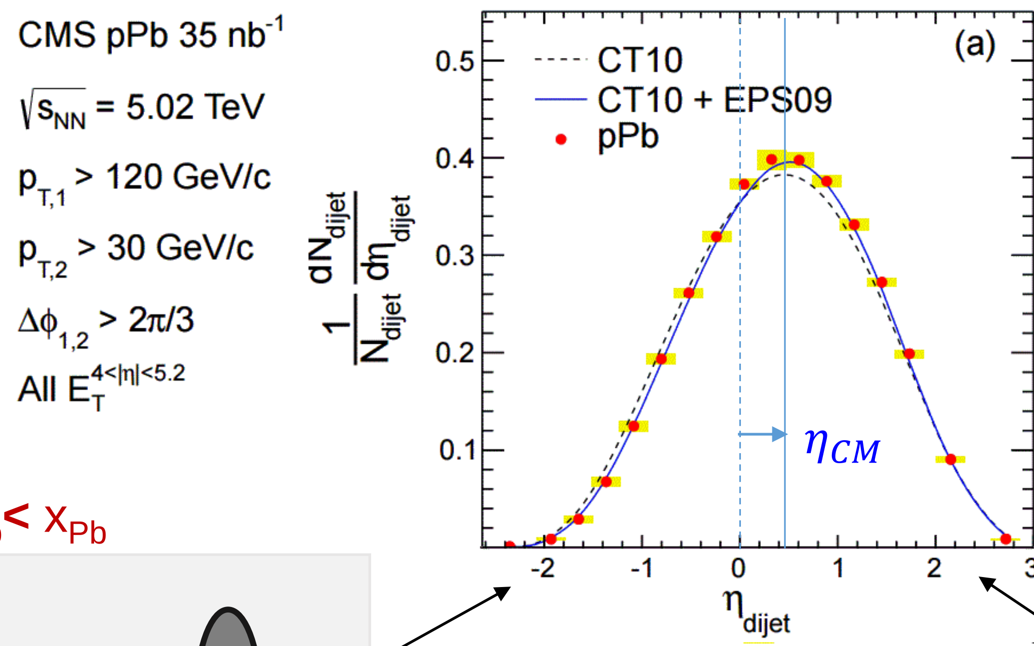


1.38 TeV

Distribution shift to positive value due to asymmetric proton and lead ion beam energy

Dijet pseudorapidity in the LAB Frame

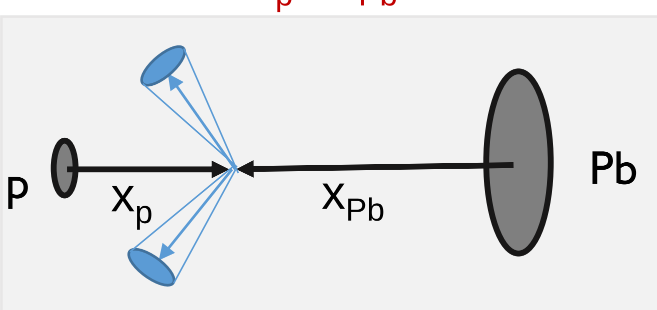
Idea: Angular distributions of high p_T dijets



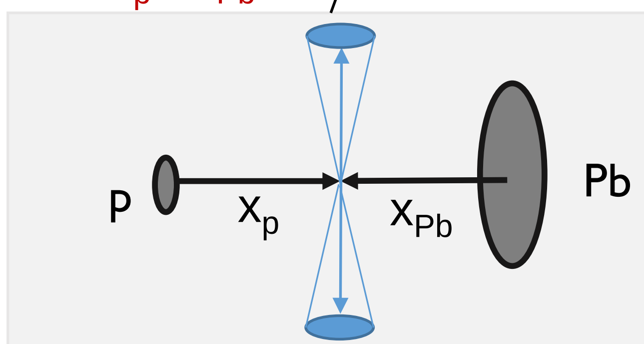
- $\eta_{dijet} = \dfrac{\eta_1+\eta_2}{2}$

$$\propto 0.5\log\left(\frac{x_p}{x_{Pb}}\right) + \eta_{CM}$$

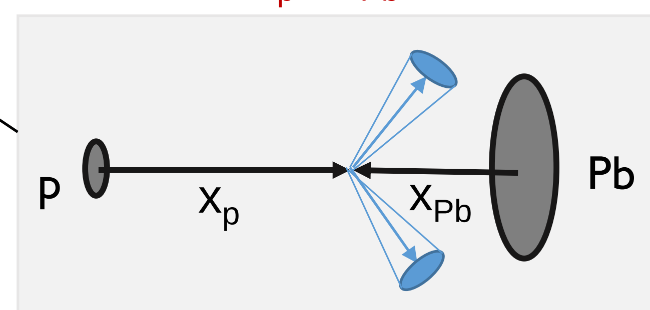
$x_p < x_{Pb}$



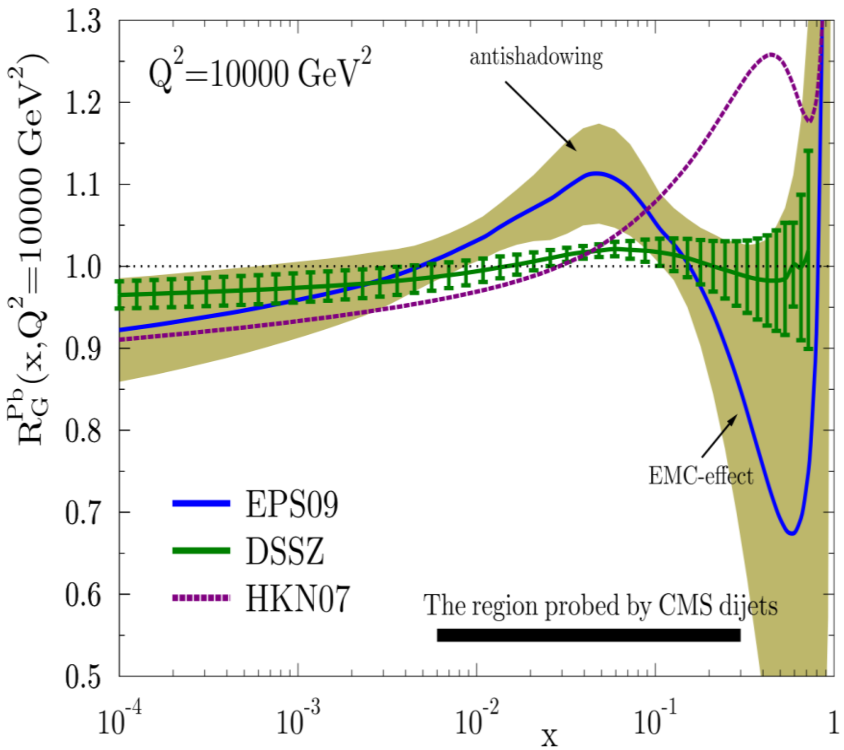
$x_p \sim x_{Pb}$

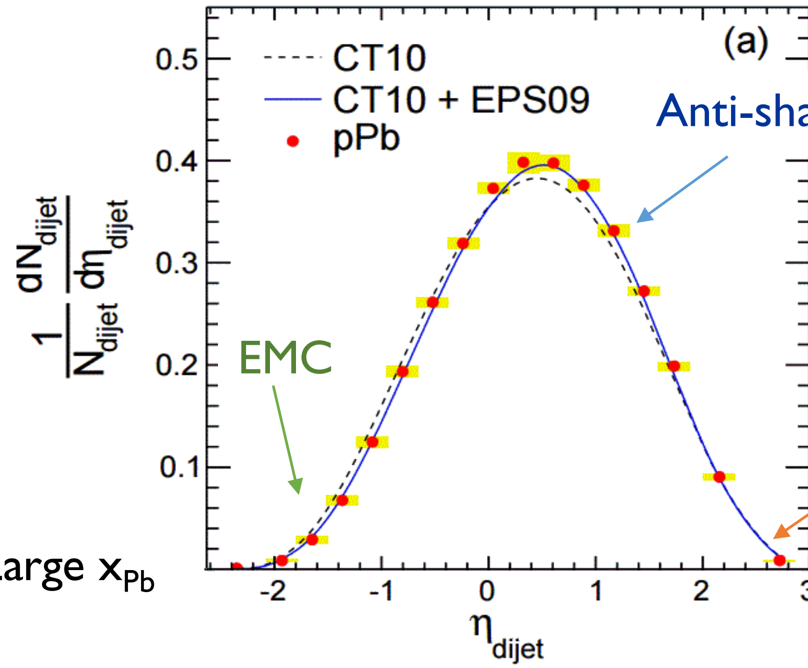


$x_p > x_{Pb}$



Mapping onto regions of x_{Pb}





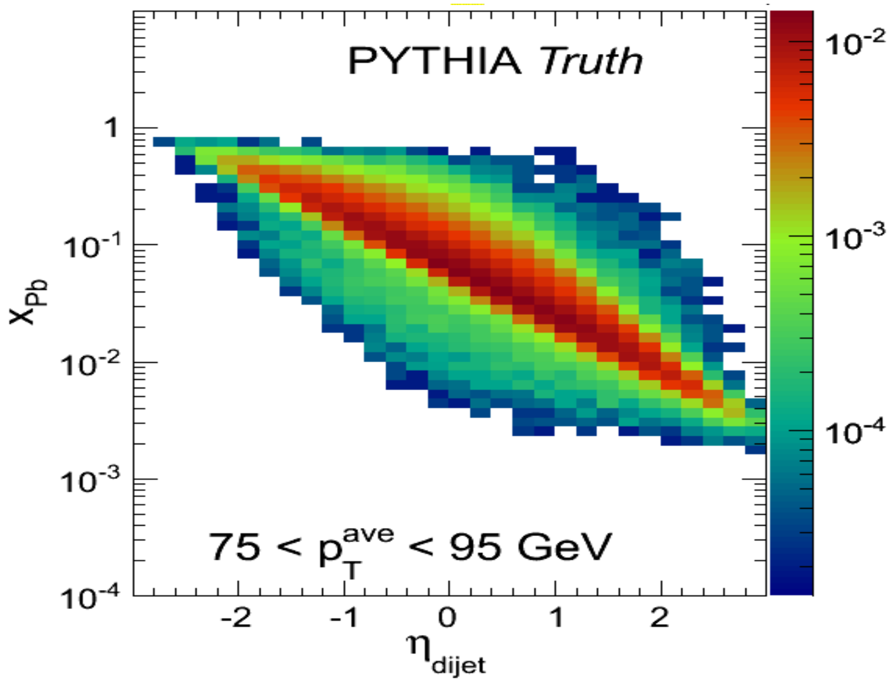
Large x_{Pb}

Small x_{Pb}

EMC

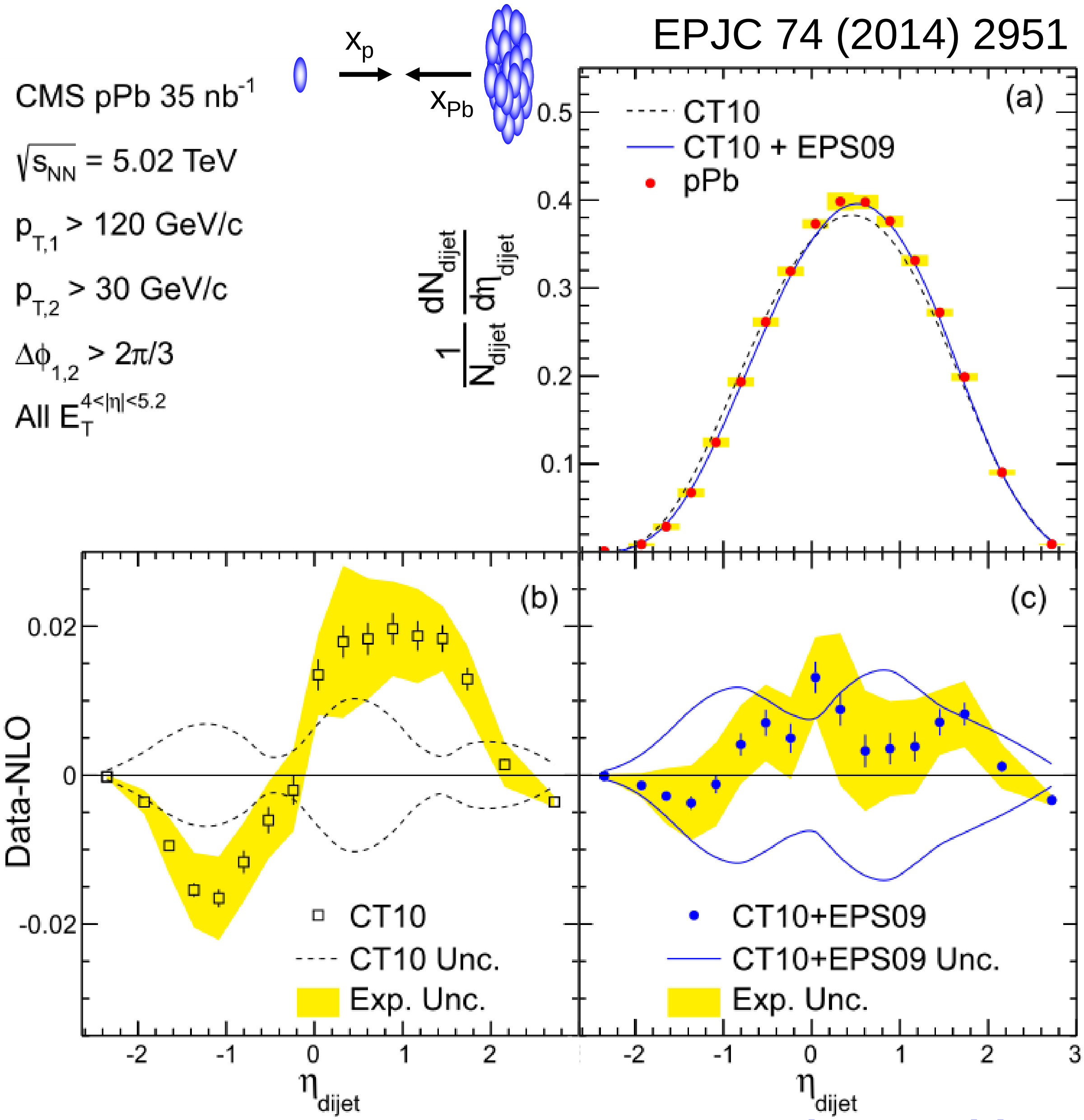
Anti-shadowing

Shadowing

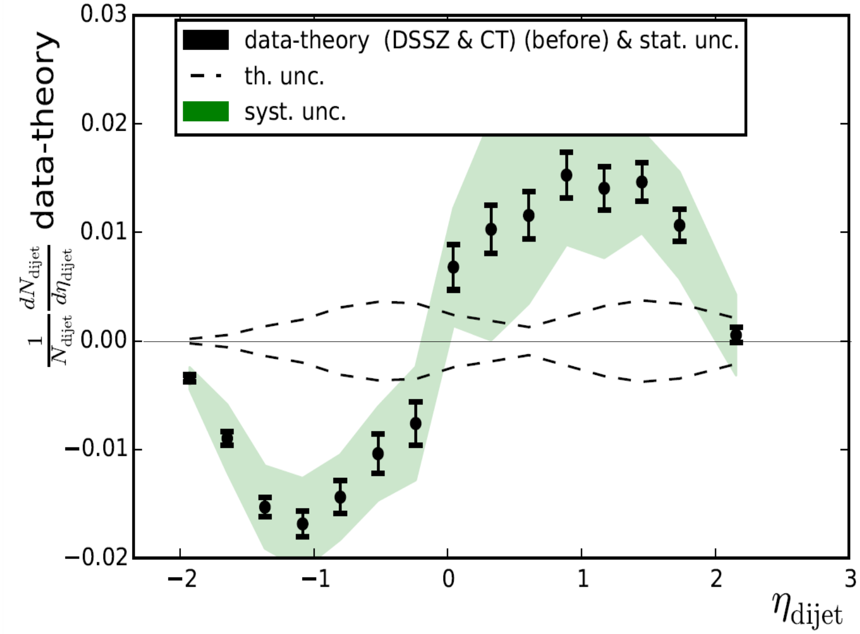


Dijet Rapidity Measurement $\eta_{dijet} = (\eta_1 + \eta_2)/2$

EPJC 74 (2014) 2951



N. Armesto, H. Paukkunen, J. M. Penin, C. A. Salgado, P. Zurita
arXiv:1512.01528, **EPJC 76 (2016) 218**



Inconsistent with CT10 (nucleon PDF)

Consistent with CT10+EPS09

Inconsistent with DSSZ

Good agreement with EPS09

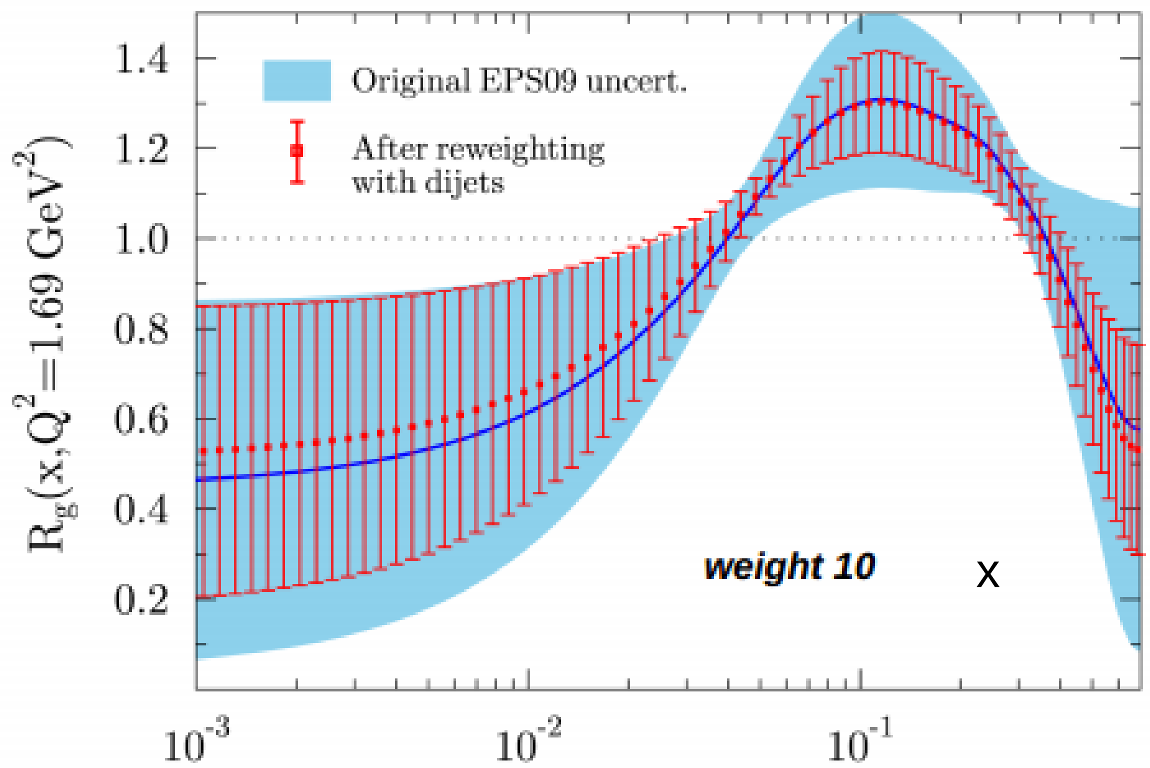
After reweighting with dijet data:
EPS09 central value doesn't change significantly but errors shrink

PDF + nPDF	χ^2 dijets$_{\mathrm{CMS}}$ (15)
CT10+DSSZ	94.441
CT10+EPS09	10.526
CT10 only	116.187
MSTW2008+DSSZ	56.365
MSTW2008+EPS09	5.522
MSTW2008 only	67.763

Using a different proton PDF changes χ^2 significantly

N. Armesto, H. Paukkunen, J. M. Penin, C. A. Salgado, P. Zurita
arXiv:1512.01528, **EPJC 76 (2016) 218**

New constraint on the gluon nPDF!!



H. Paukkunen, K. J. Eskola, C. Salgado
arXiv:1408.4563 NPA 931 (2014) 331

Motivates the measurements with pp data

What's new at HP2016?

- First paper: *Asymmetric jet p_T selection* used to search for jet quenching in pPb [EPJC 74 (2014) 2951]

- Update: Switch to *Balanced dijet selection* reduces the contribution of three jet events making the correlation between $\boldsymbol{\eta_{dijet}}$ and **x** better
[CMS-PAS-HIN-16-003]

- pp reference data at 5 TeV: L ~25.8 pb^{-1}:
  - Cancellation of uncertainties (pPb and pp)
  - **(pPb – pp)** or **pPb/pp**: less sensitive to the pp baseline calculation

- Measurement of dijet η as a function of $p_T^{ave} = \frac{p_{T,1}+p_{T,2}}{2} \propto Q$
  - Test nPDF at different Q^2 scale

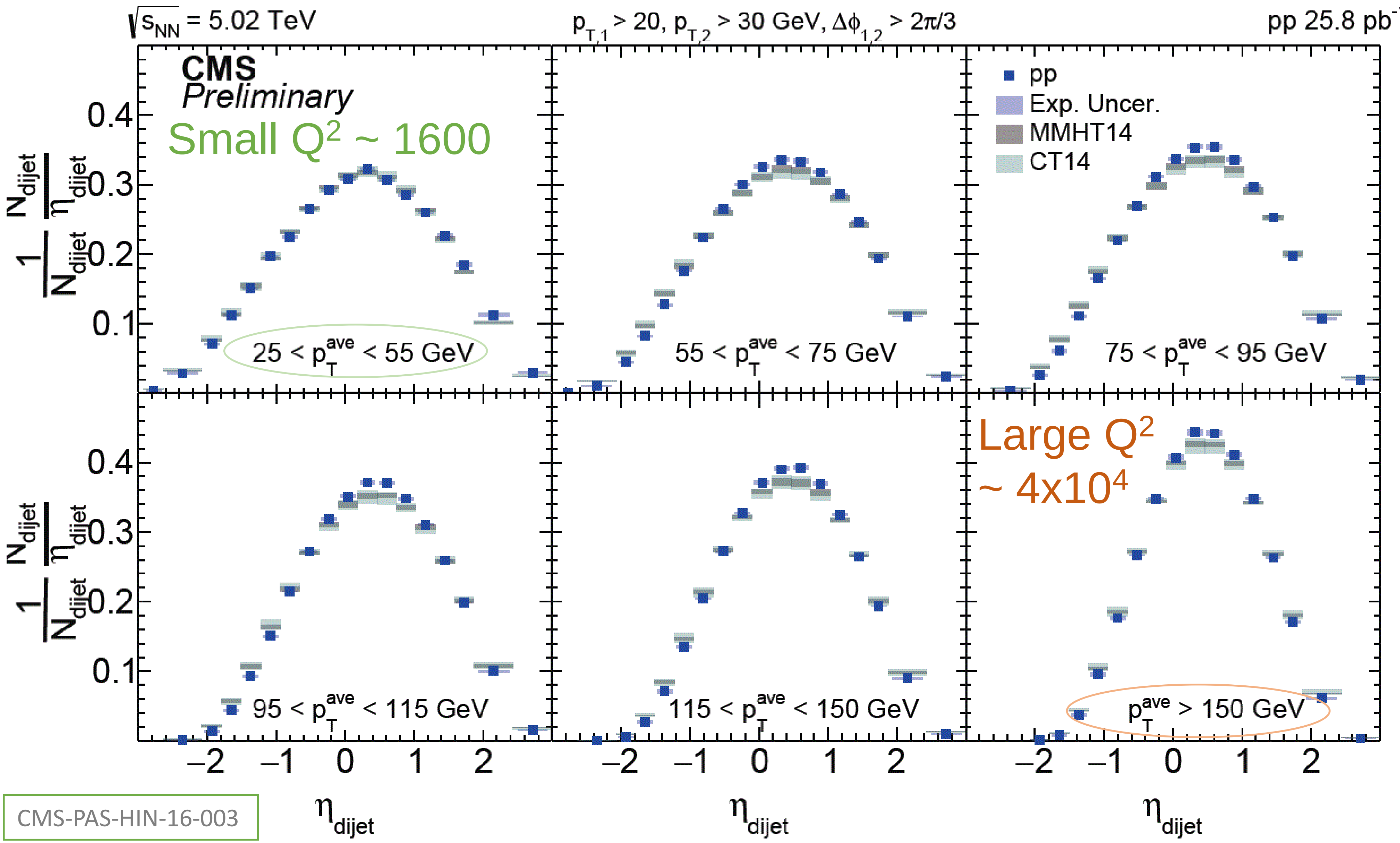
- Results are compared to NLO calculations from *N. Nestor, H. Hannu, P. Zurita and C. A. Salgado*

Dijet Kinematics Selection

- Jets reconstruction:
  - Anti-k_T R = 0.3 particle-flow jets using both tracker and calorimeter information.
  - pPb analysis: $|\eta_{Lab}| < 3$
  - pp: $-3.465 < |\eta_{Lab}| < 2.535$ to compare with the pPb data
  - No UE subtraction
  - Data-driven energy correction using dijet, photon-jet and Z-jet

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

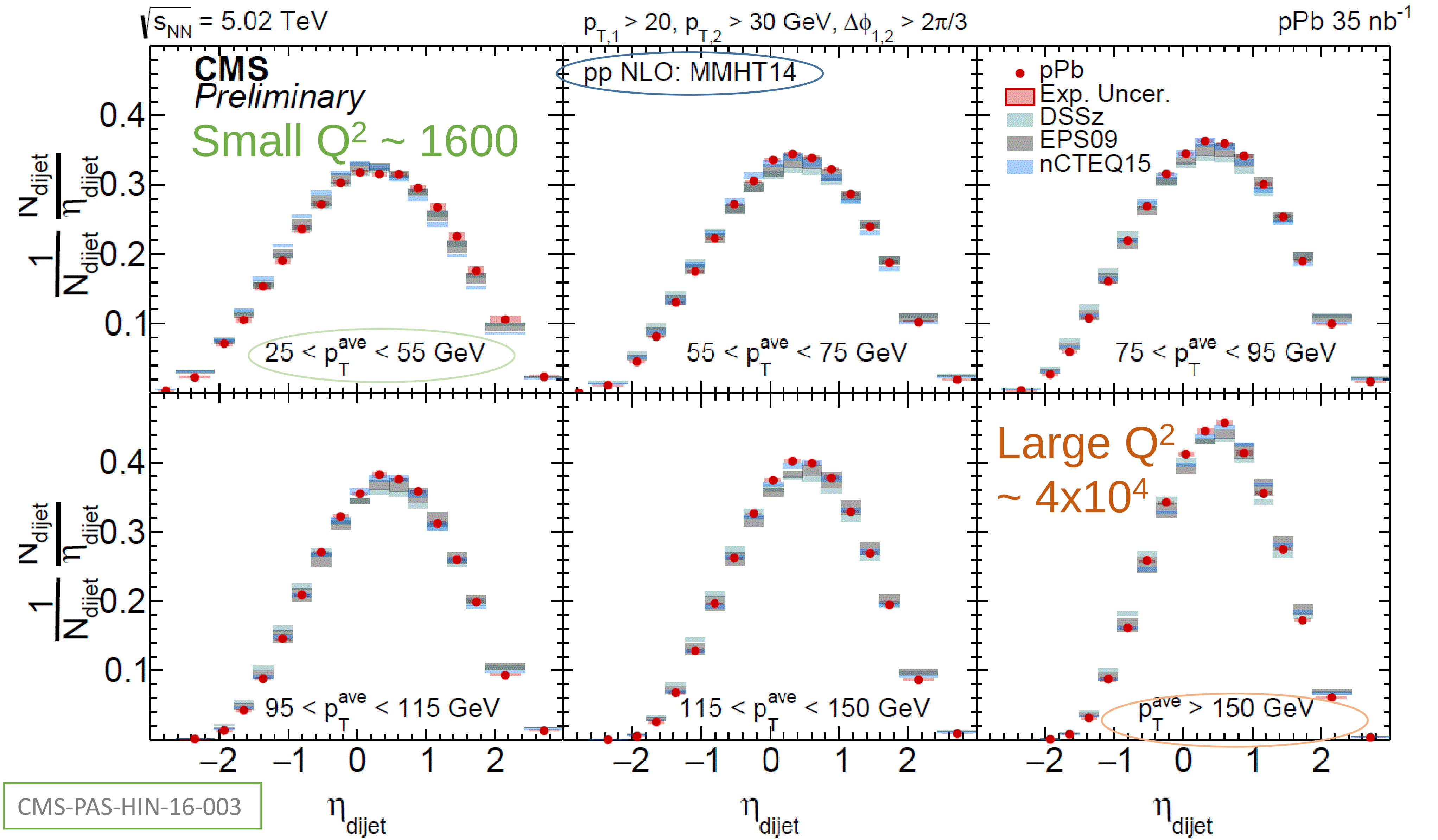
Dijet η in pp vs. p_T^{ave} (boosted to match pPb)



CMS-PAS-HIN-16-003

- NLO calculations with both **CT14** and **MMHT14** PDFs are **too wide** compared to data
- **MMHT14** gives a slightly better description of pp data

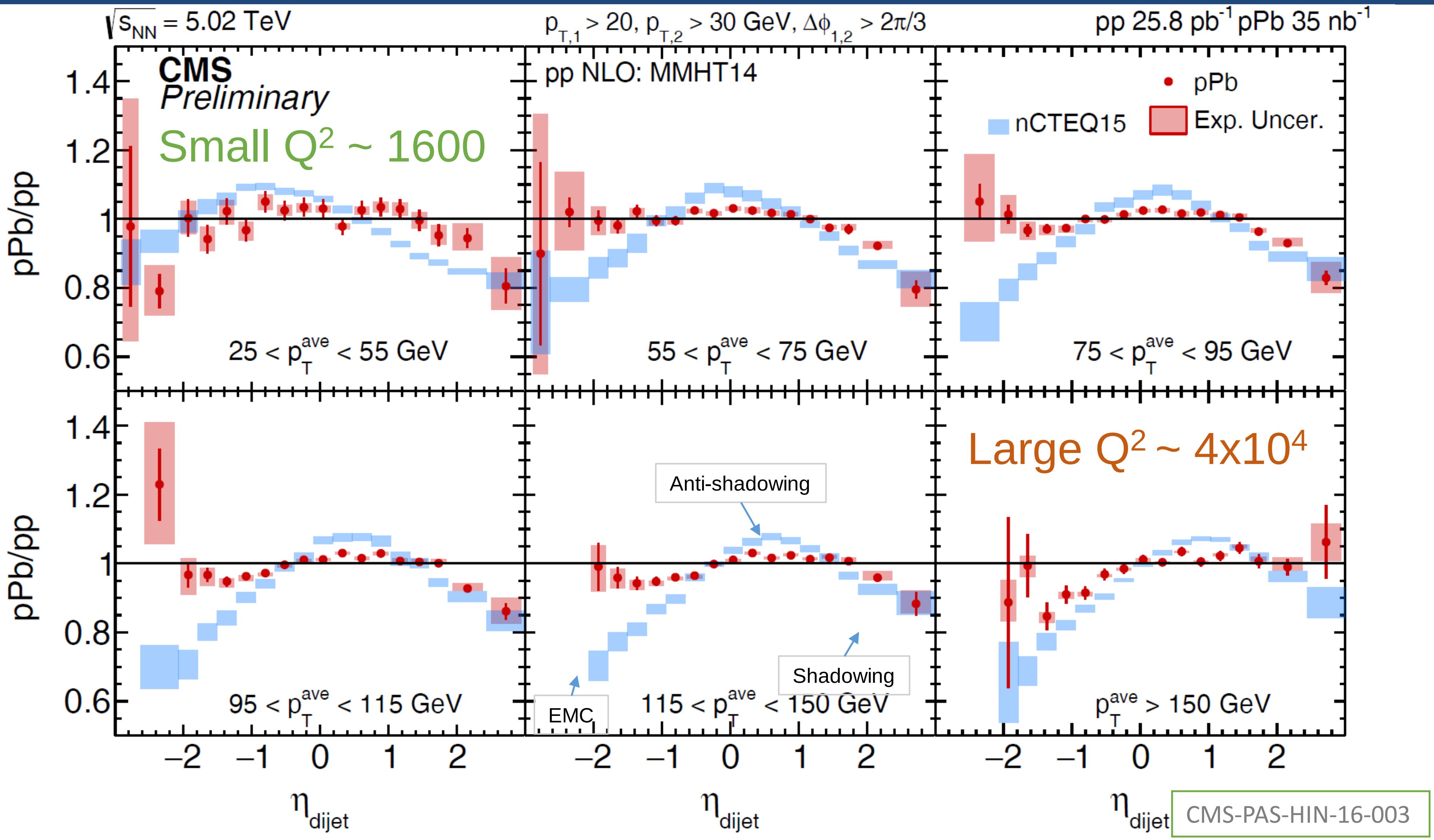
Dijet η in **pPb** vs. p_T^{ave}



CMS-PAS-HIN-16-003

- NLO calculations with nucleon PDF + nuclear effects are closer to pPb data.
- However, the discrepancy found in *pp is hidden in this comparison*

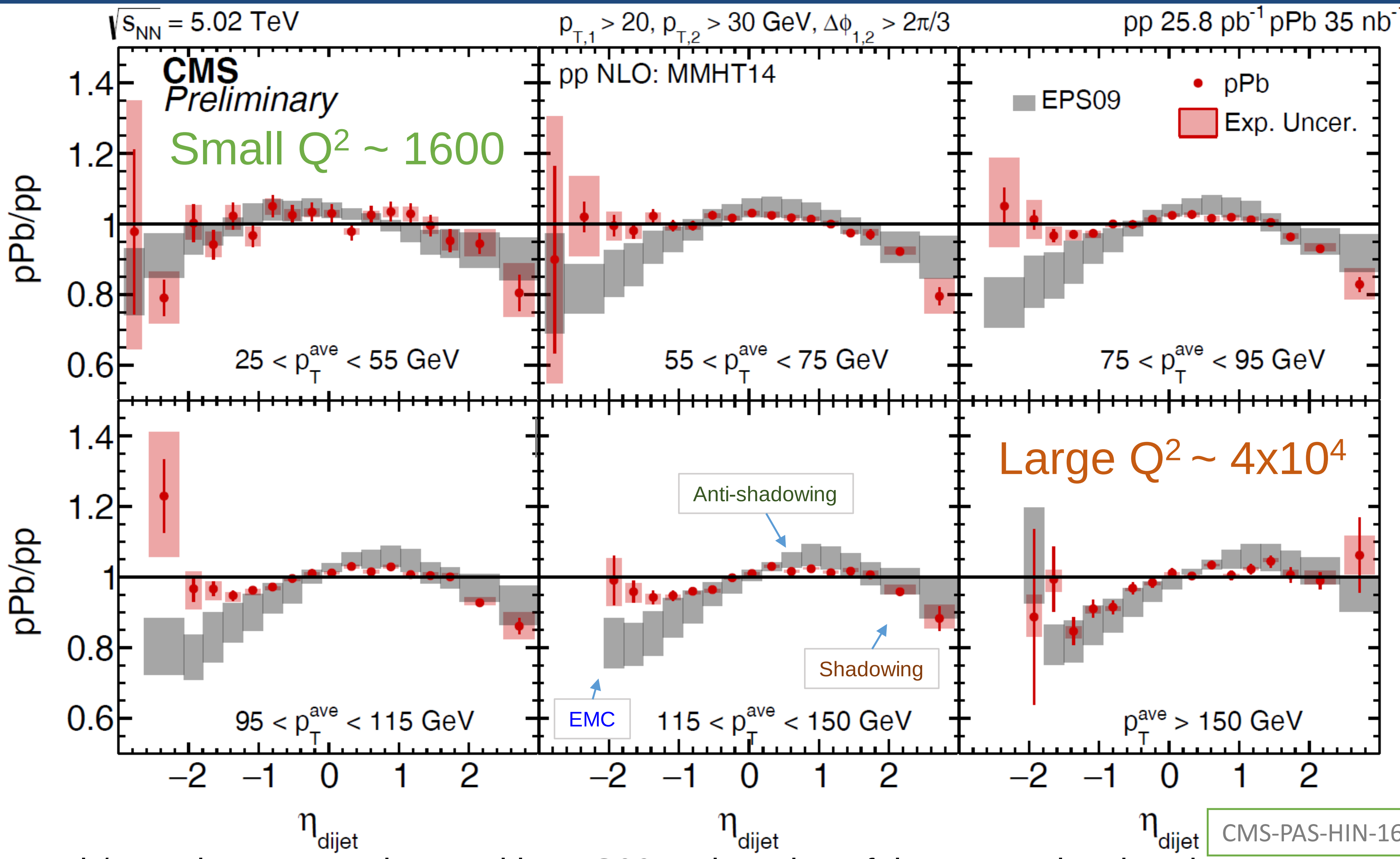
Ratio of pPb and pp vs. p_T^{ave}



CMS-PAS-HIN-16-003

- pPb/pp ratios are compared to NLO calculations with nCTEQ15.
- The data and NLO calculations are not in agreement in all p_T^{ave} bins

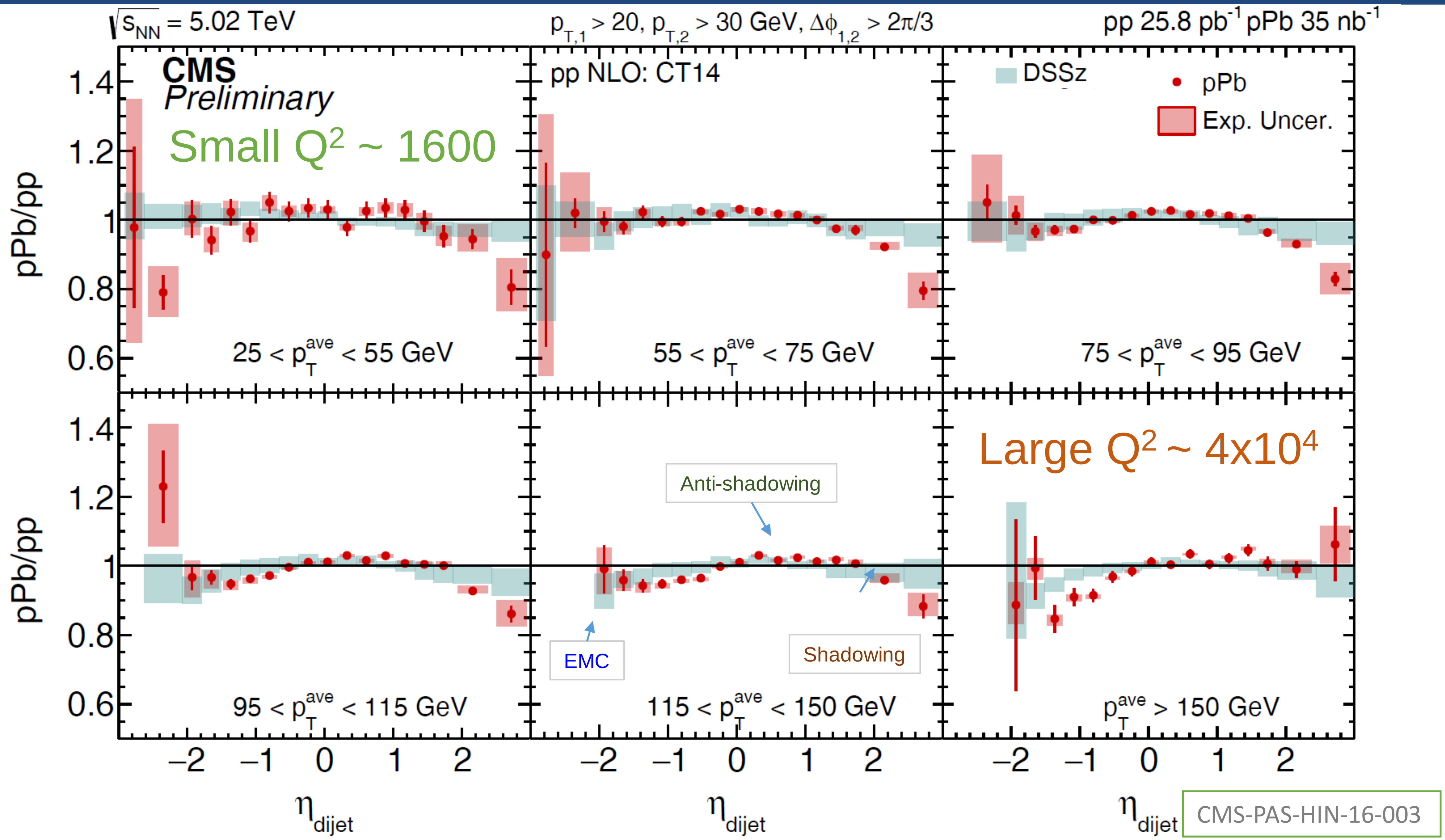
Ratio of pPb and pp vs. p_T^{ave}



CMS-PAS-HIN-16-003

- pPb/pp ratios are consistent with EPS09 at the edge of the uncertainty band in the **anti-shadowing** and **shadowing** region
- At low p_T and in the EMC region data starts to deviate from EPS09

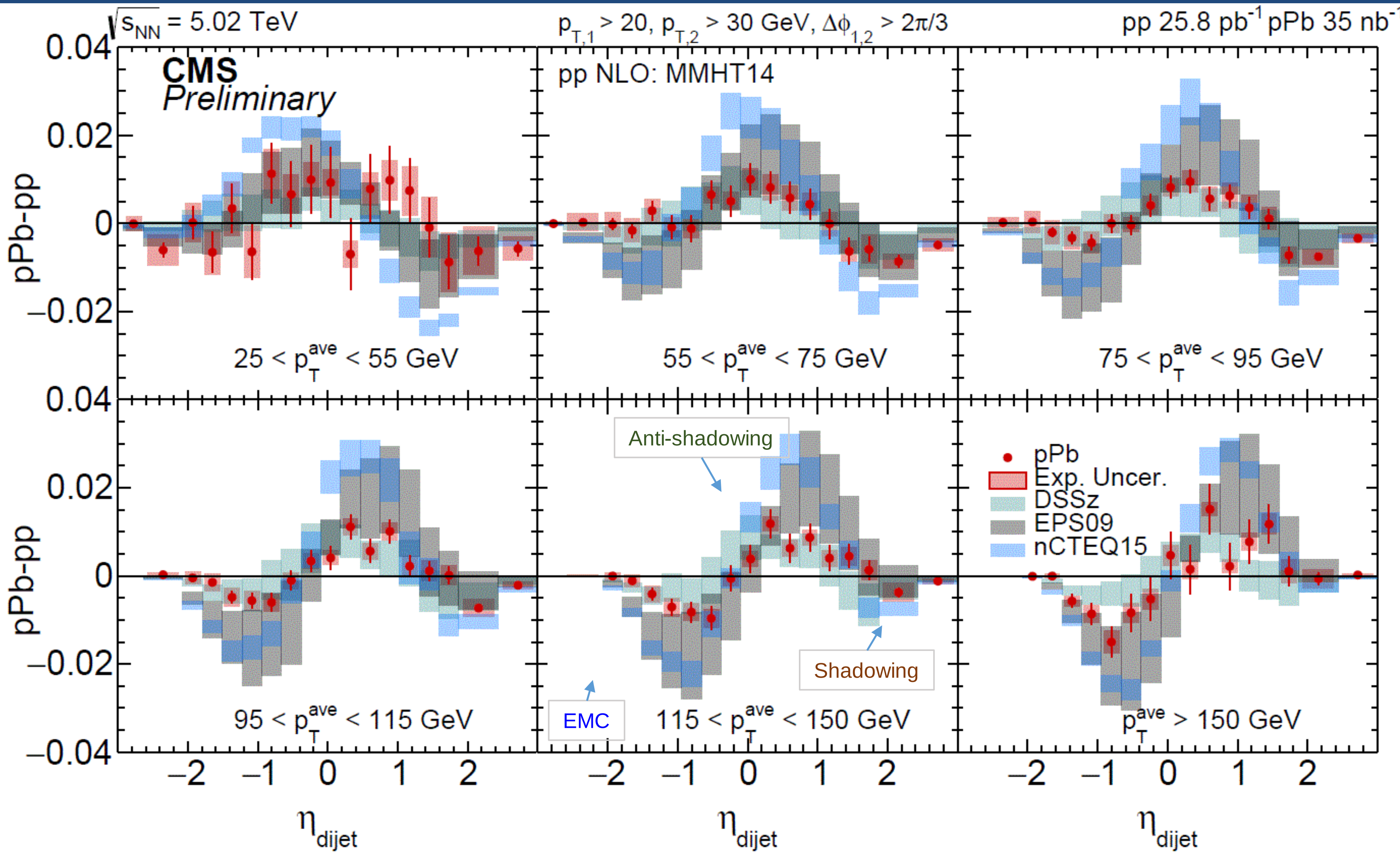
Ratio of pPb and pp vs. p_T^{ave}



CMS-PAS-HIN-16-003

- At low p_T and in the forward direction (EMC region) data starts to deviate from EPS09 and agree with DSSZ
- Data and theoretical uncertainties are large in this region

pPb – pp vs. p_T^{ave}

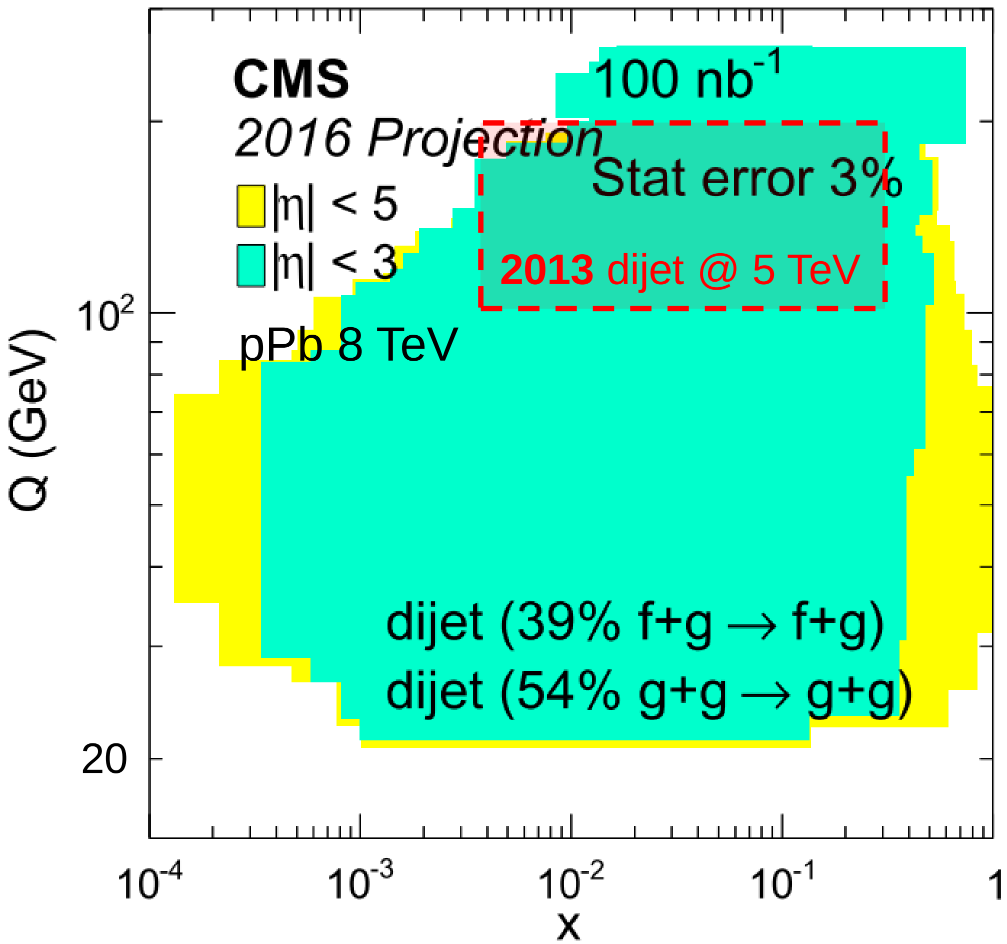


- At mid-rapidity: better agreement with EPS09 (slightly more anti-shadowing compared to data) and discrepancy nCTEQ15
- Similar to the conclusion from pPb / pp ratios

CMS-PAS-HIN-16-003

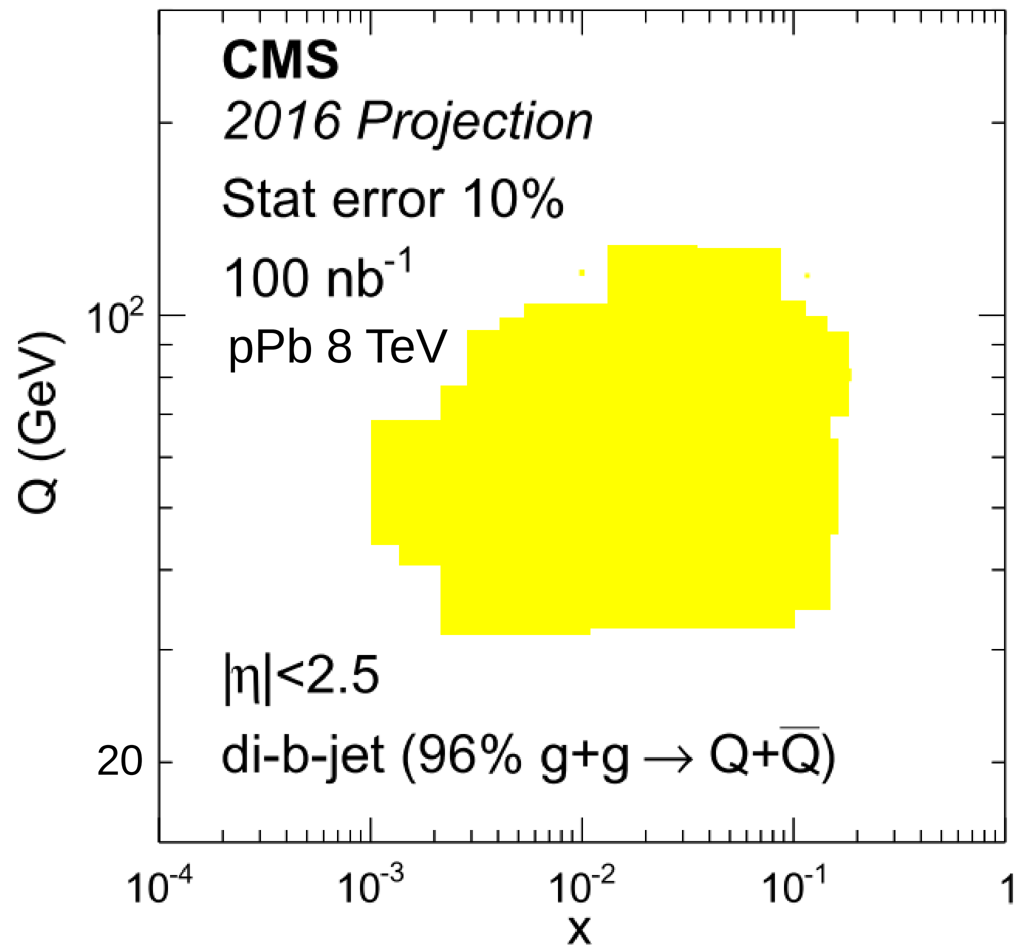
Outlook: 2016 pPb run at 8 TeV

(Forward) Dijet



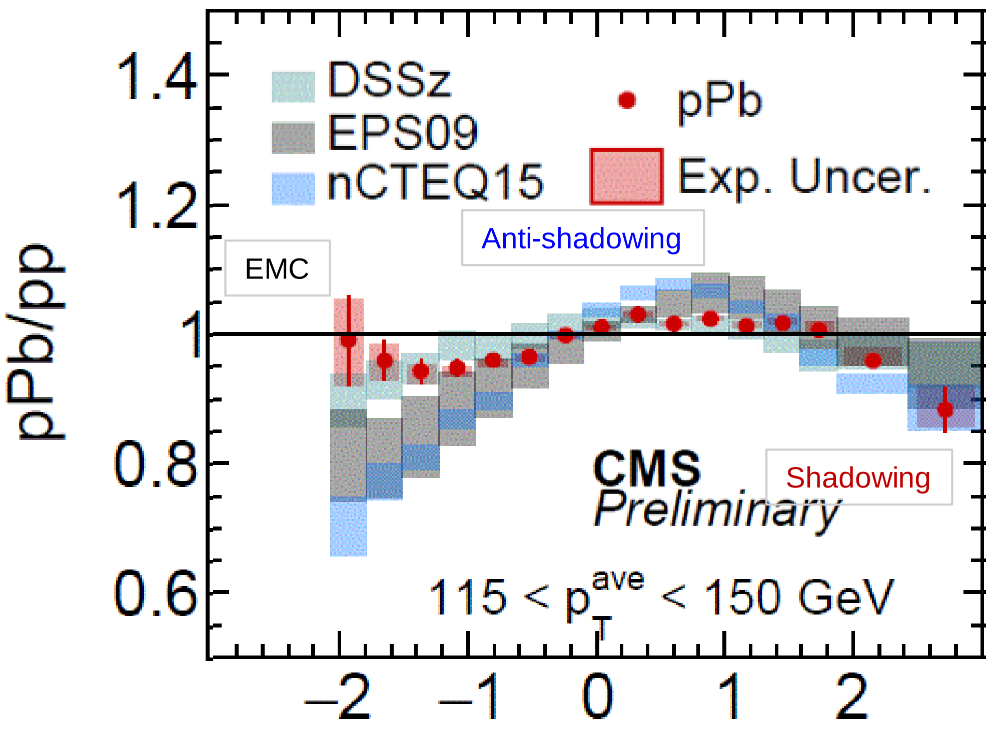
Lower x reach with 100/nb 8 TeV pPb data

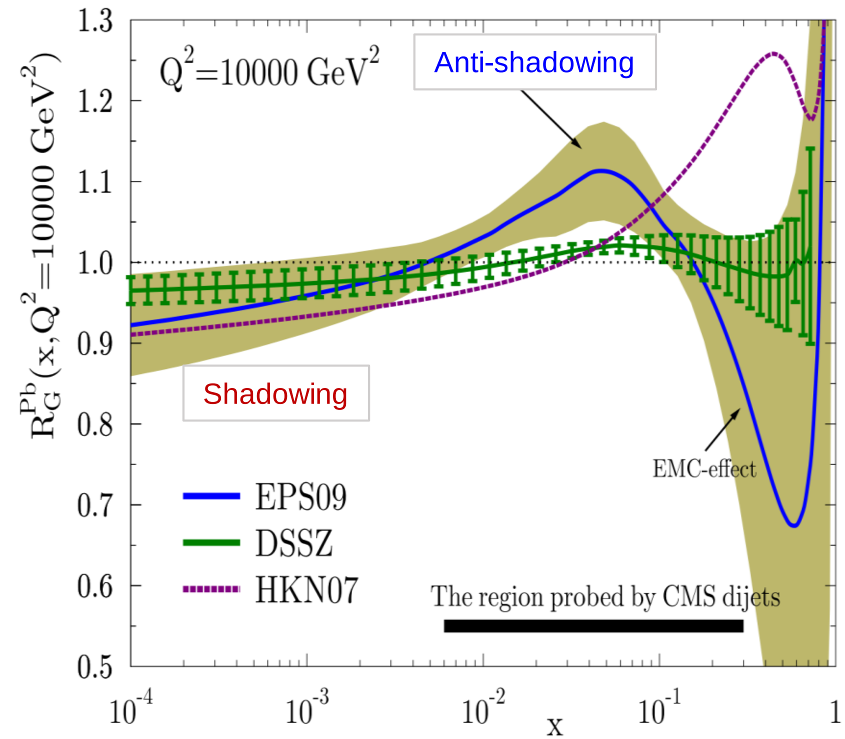
Doubly b-tagged jet



Di-b-jets are from gluon-gluon scattering

Summary



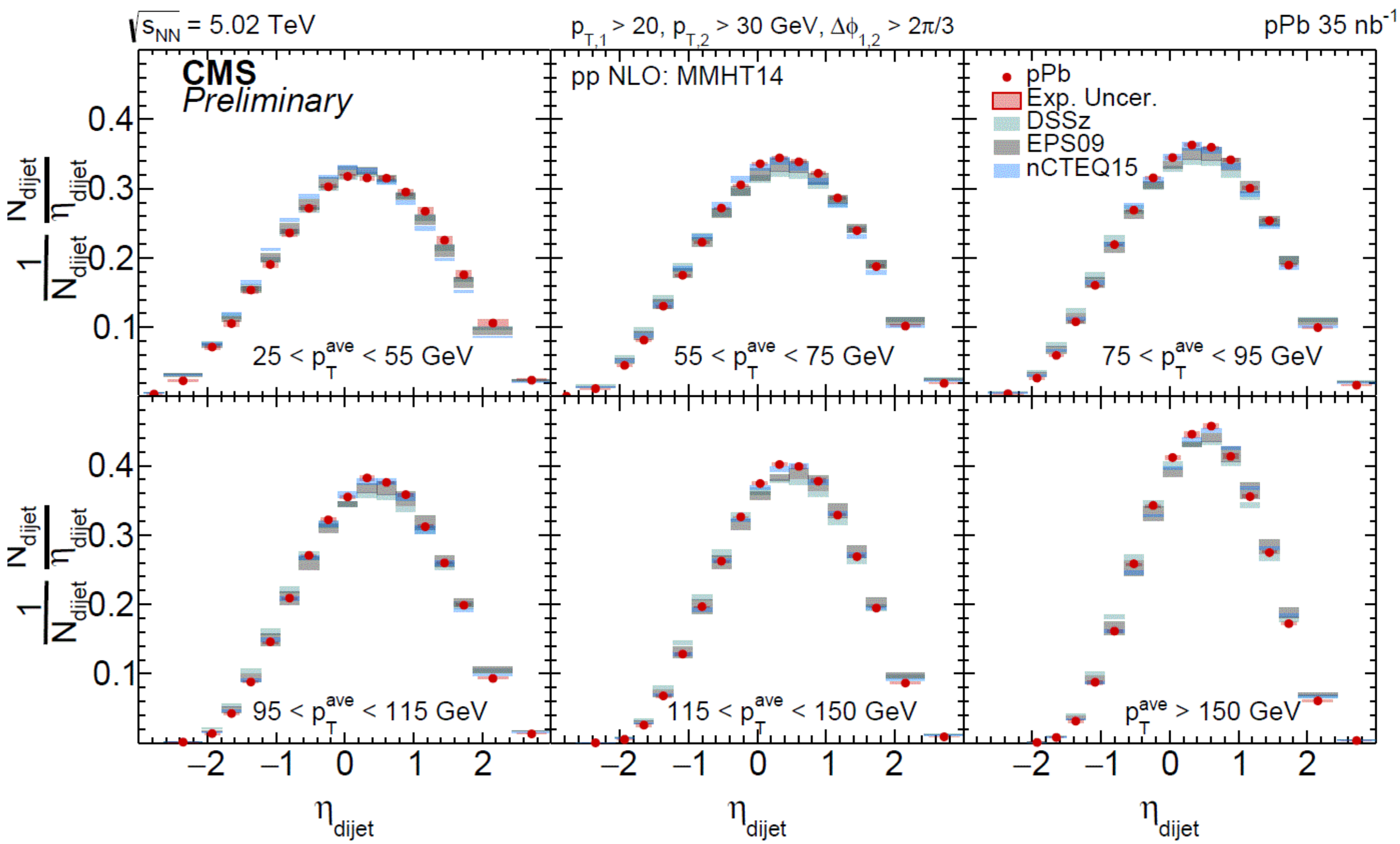


CMS-PAS-HIN-16-003

- Precision measurements of dijet η in pp and pPb from CMS
  - Data from pp collisions and NLO calculations are not in good agreement
- *Ratios of pPb and pp reference:* Reduce the dependence of the nPDF extraction on the pp NLO calculation and experimental uncertainties
- Significant modifications of dijet η in pPb observed. The data in different p_T^{ave} bins provide strong constraints on the (gluon) nPDF

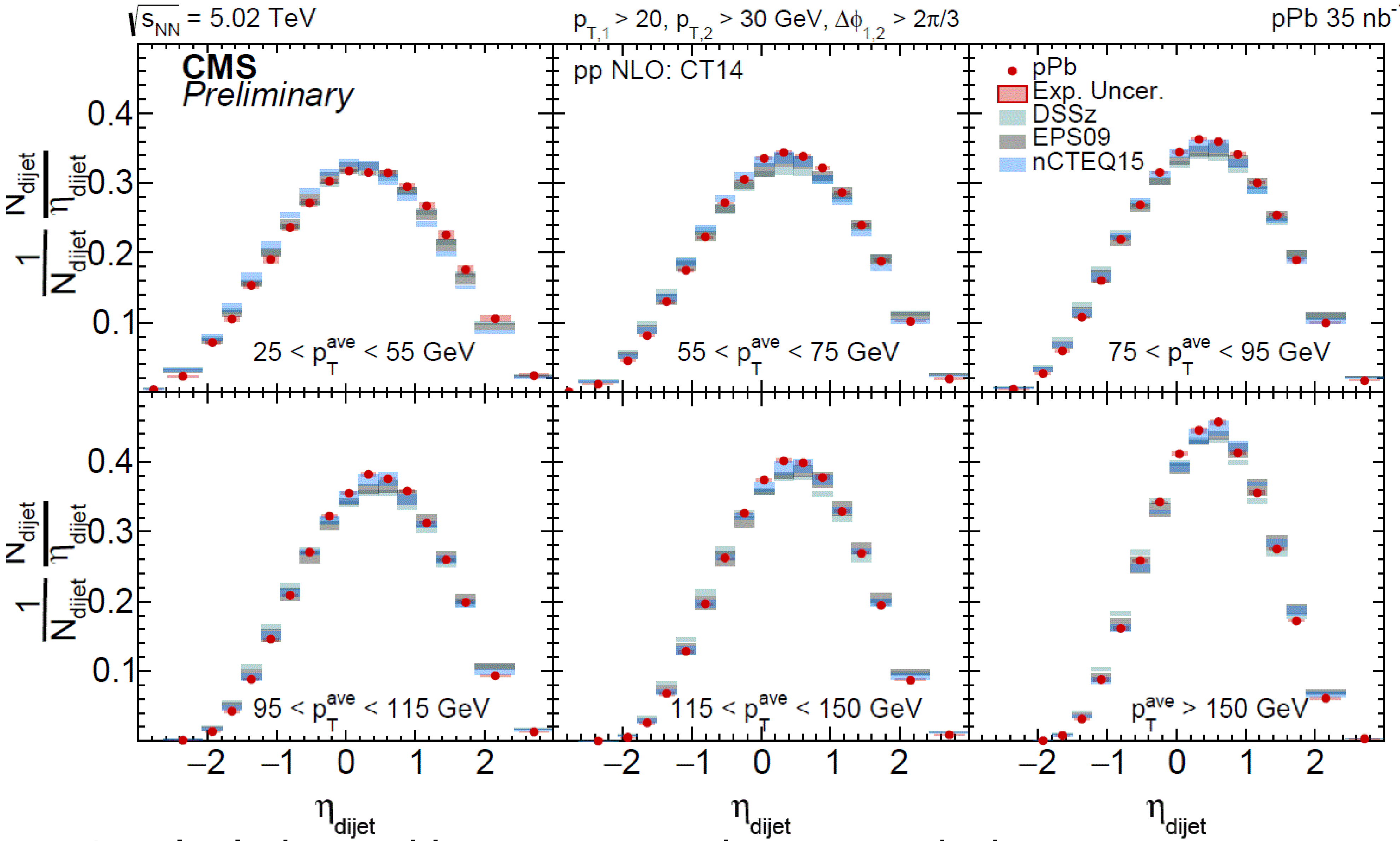
- Backup slides

Dijet η in pPb



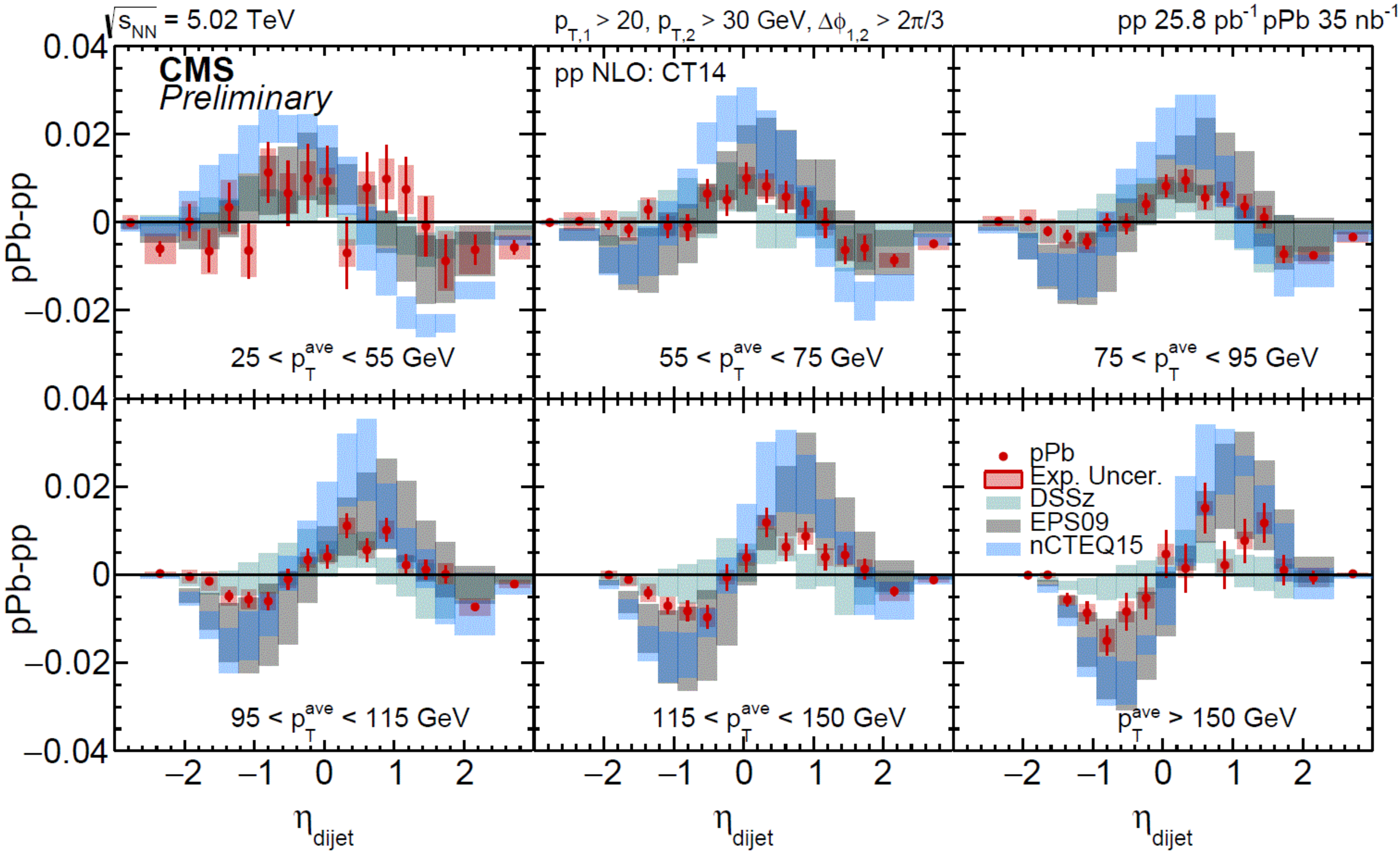
- Narrower distributions in MMHT14 are also reflected in nPDF calculations which use it as a baseline
- To reduce the dependence on proton PDF take ratios and differences of pPb and pp data and compare afterwards

Dijet η in pPb (CT14 basedline)



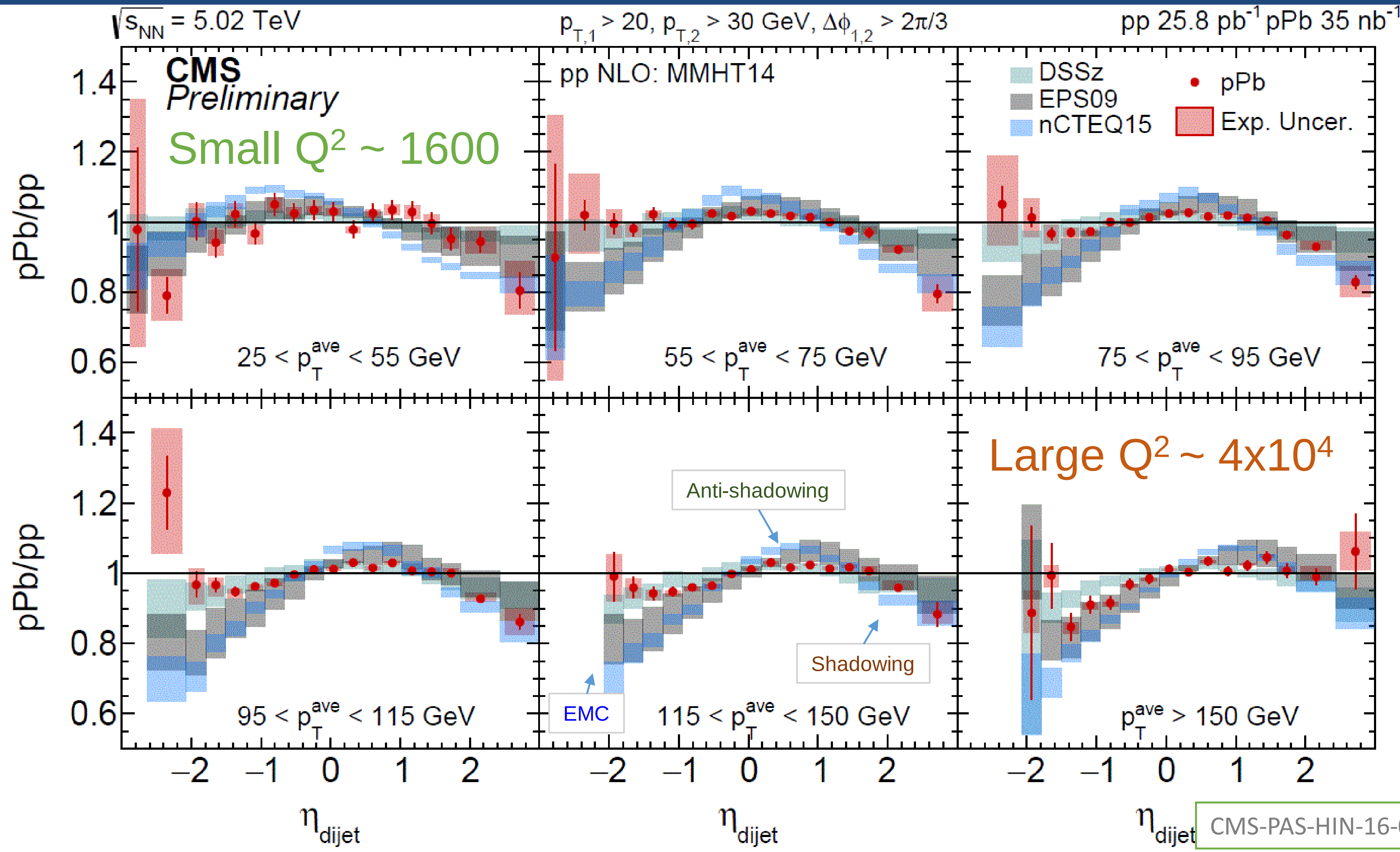
- NLO calculations with nPDFs are closer to pPb data.
- However, the discrepancy found in *pp is hidden in this comparison*

pPb – pp



- Anti-shadowing region. Similar evolution in NLO and data vs p_T^{ave}
- At mid-rapidity: Agreement with EPS09 and discrepancy with DSSZ and nCTEQ15

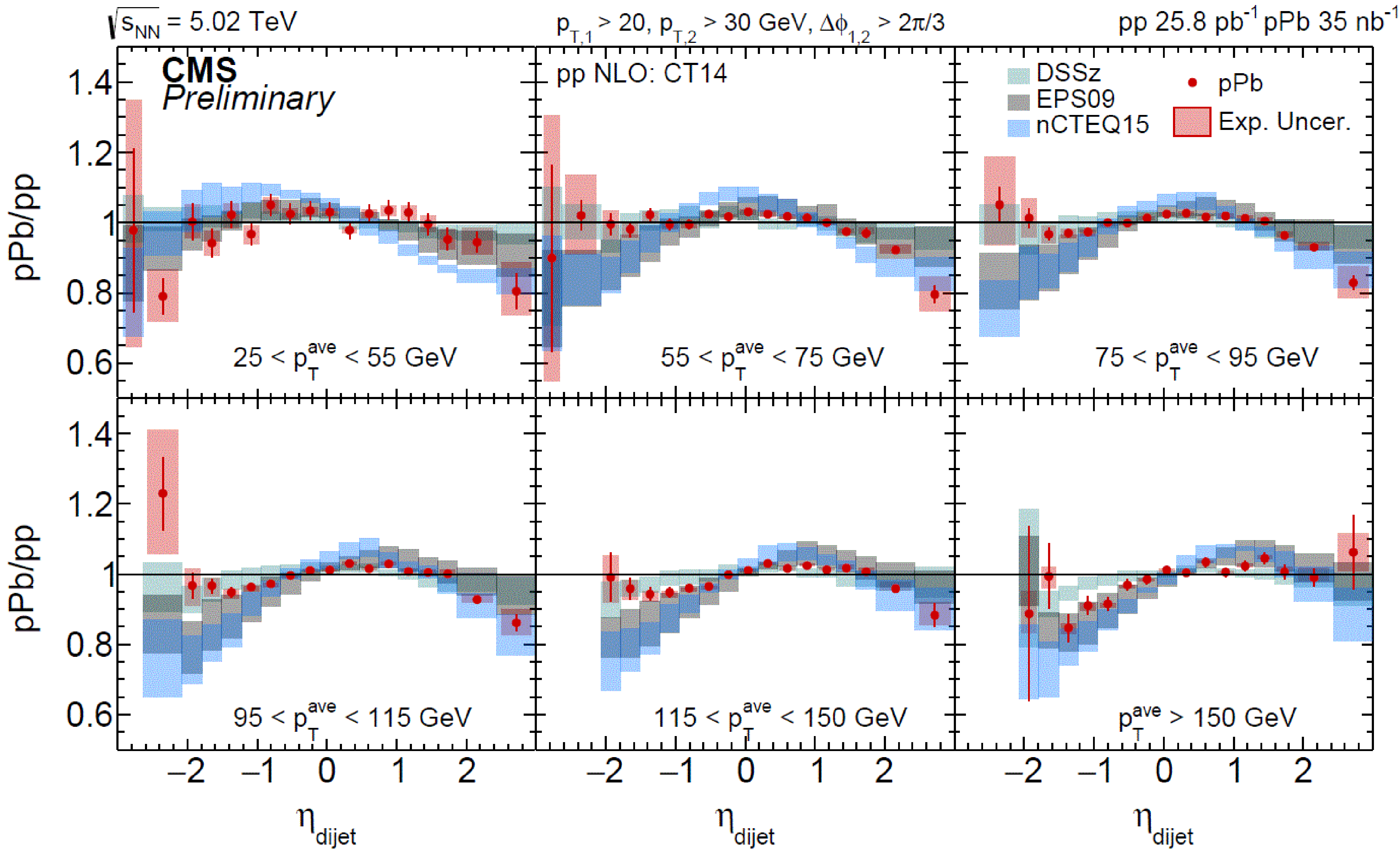
Ratio of pPb and pp vs. p_T^{ave}



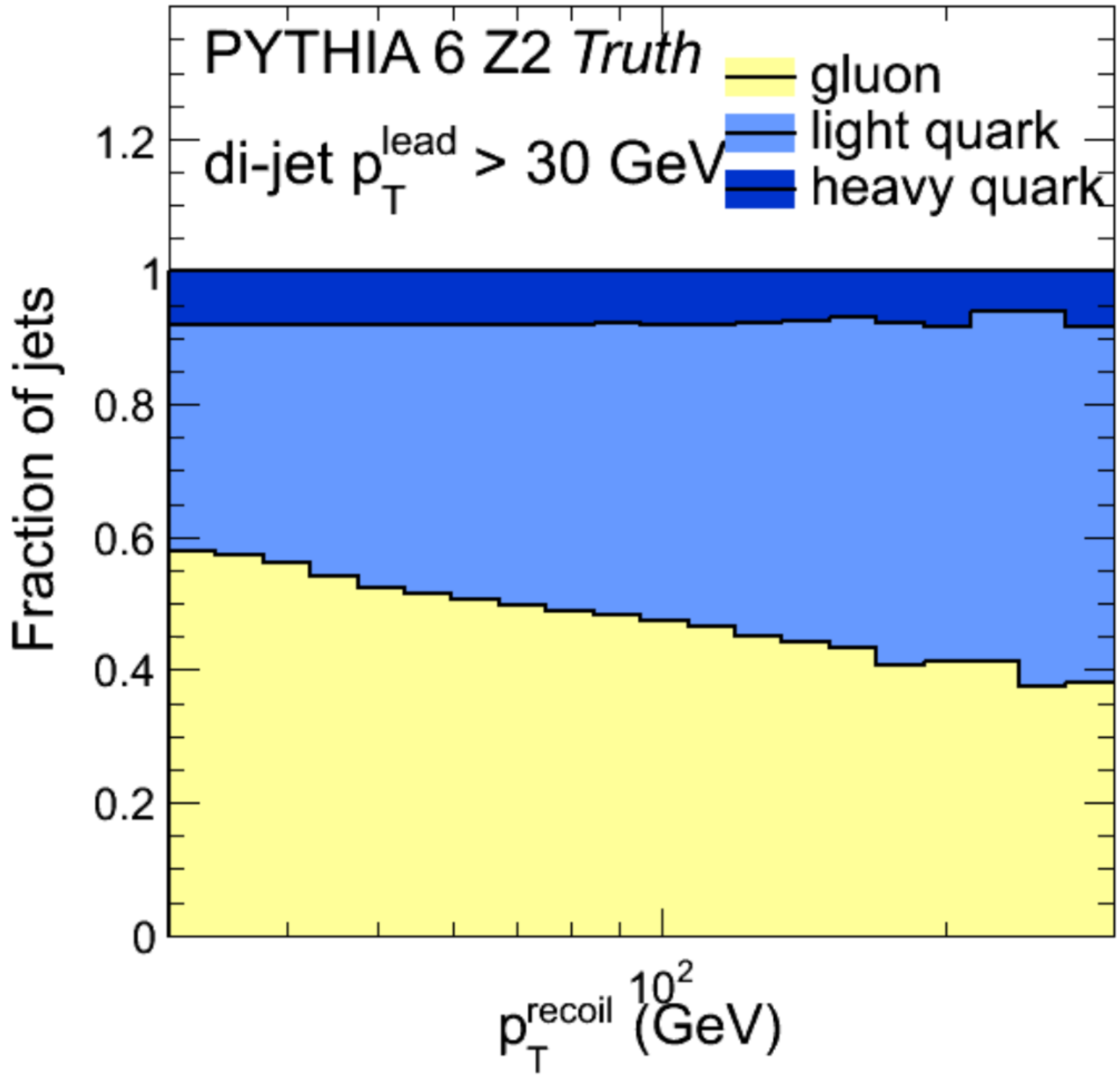
CMS-PAS-HIN-16-003

- At low p_T and in the forward direction (EMC region) data starts to deviate from EPS09 and agree with DSSZ
- Data and theoretical uncertainties are large in this region

Ratio of pPb and pp



- At low p_T and in the forward direction (EMC region) data starts to deviate from EPS09, agrees better with DSSZ
- The systematic uncertainties and theoretical uncertainties are large in this region


PYTHIA 6 Z2 Truth
di-jet p_T^{lead} > 30 GeV
gluon
light quark
heavy quark
Fraction of jets
1.2
1
0.8
0.6
0.4
0.2
0
10^2
p_T^{recoil} (GeV)