Measurements of nuclear parton distribution functions using dijets, forward jets, and photo-nuclear jets at the CMS detector

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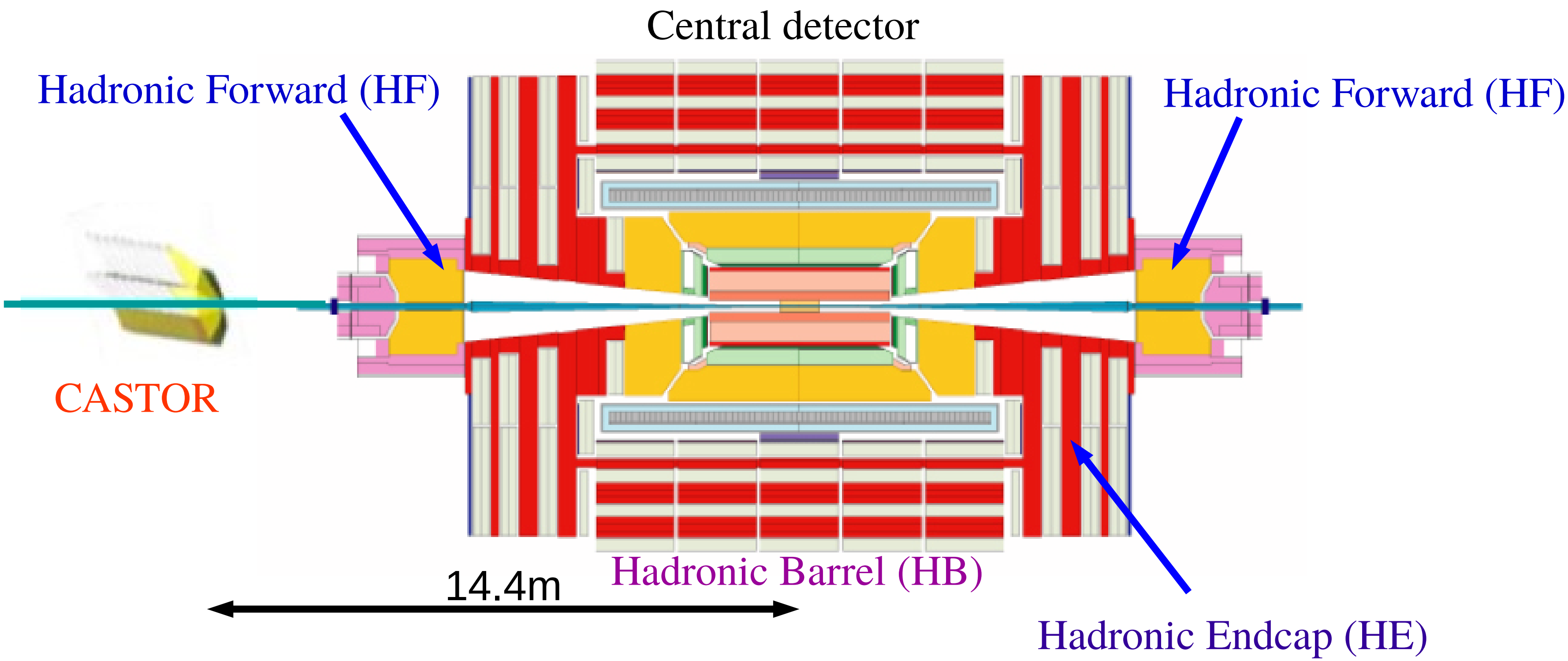
Outline

- Motivation to study processes with jets
- CMS Experiment is a perfect facility to study jet production
- Forward jets with CASTOR
  - Both pp @13 TeV and pPb @5 TeV measurements
- Dijet production in pp and pPb collisions
  - Constraining the nPDFs with heavy ion collisions
  - Prospects for further measurements at HL-LHC
- Outlook

Motivation

- Jet production has very high cross section, among other processes at LHC parton-parton scatterings
  - Important background for most measurements and searches at the LHC that must be modeled very precisely
- Scattering at large momentum transfer lead to jet production.
  - Such processes are described in QCD using parton distribution functions (PDFs)
  - Jet production is a useful tool to study the parton structure of hadrons
- Jet production in heavy-ion collisions can reveal signals of parton saturation
  - Knowledge of nPDFs is crucial in extracting QGP properties from the experimental data
  - Negligible final-state effects in pPb collisions

Forward CMS Detectors



Hadron Barrel Calorimeter (HB): $|\eta| < 1.3$

Hadron Endcap Calorimeter (HE): $1.3 < |\eta| < 3.0$

Hadron Forward Calorimeter (HF): $3.0 < |\eta| < 5.2$

CASTOR Calorimeter: $-6.6 < \eta < -5.2$

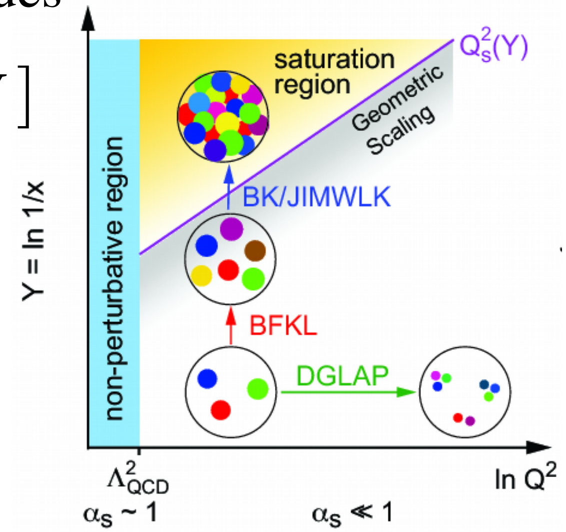
CMS offers perfect rapidity coverage to measure jets

Forward jets with CASTOR

- Very forward pseudorapidities are sensible to the low-x values

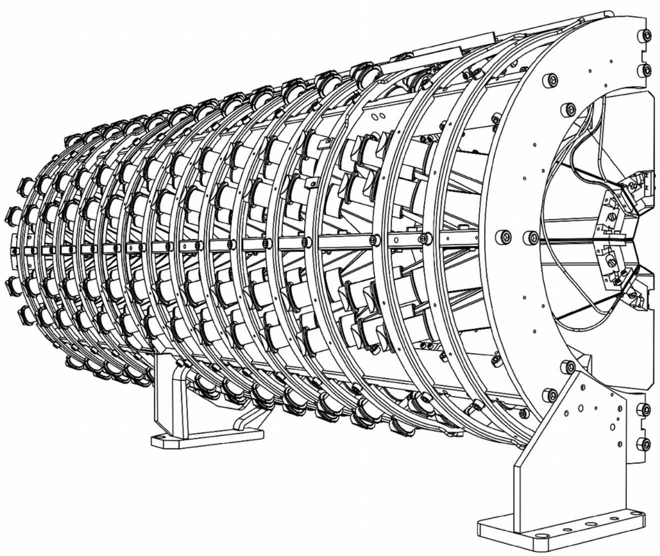
$$x \approx \frac{p_T}{\sqrt{s}} e^{\pm\eta} \approx 10^{-6} \quad [\, p_T = 10\,GeV\,; \eta = -6\,; \sqrt{s} = 13\,TeV\,]$$

- Breakdown of DGLAP evolution (as a function of Q^2)
  - Use of BFKL approach (evolution as a function of 1/x)
  - Access to nonlinear parton "saturation" regime (BK)



CASTOR Calorimeter: -6.6 < η < -5.2

- CASTOR is a sampling calorimeter using layers of quartz plates and tungsten absorbers
- CASTOR is segmented in 14 longitudinal and 16 azimuthal channels
- 15% energy scale uncertainty



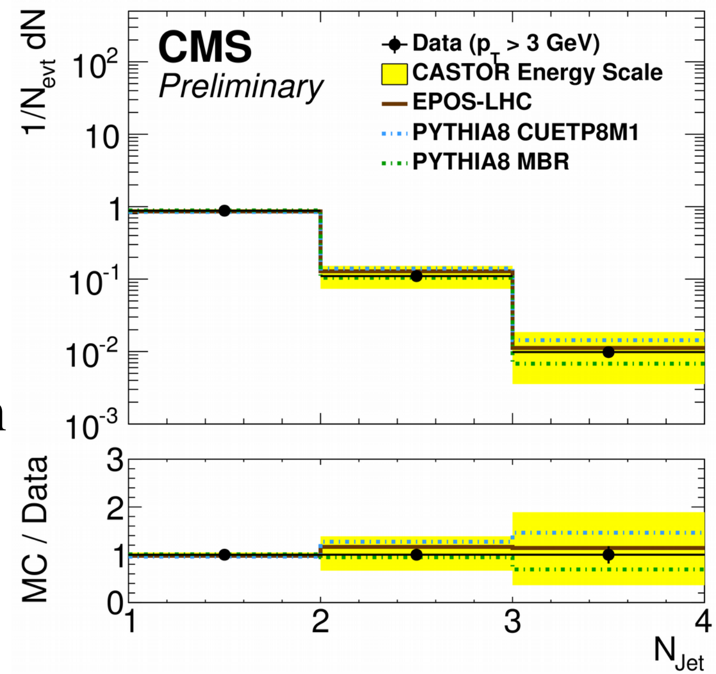
Forward jets with CASTOR: Analysis strategy

pp collisions @13 TeV (*FSQ-PAS-16-003*)

- Luminosity 0.212 nb^{-1}

- Fully corrected inclusive jet cross sections and jet yields normalized to number of visible jets as function of jet p_T
  - Anti-k_T jets with R=0.5
  - $-6.6 < \eta < -5.2$
  - p_T unfolded from E•coshη, [$\eta = -5.9$]
  - Low pile-up runs
  - E > 150 GeV or p_T > 3 GeV
- EPOS-LHC and PYTHIA8 used for correction

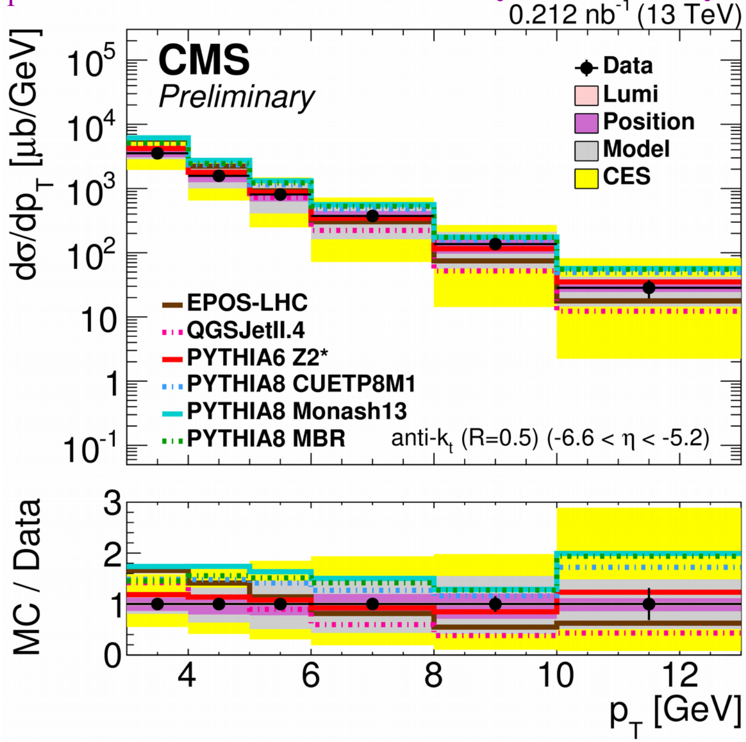
Jet multiplicity @ detector level



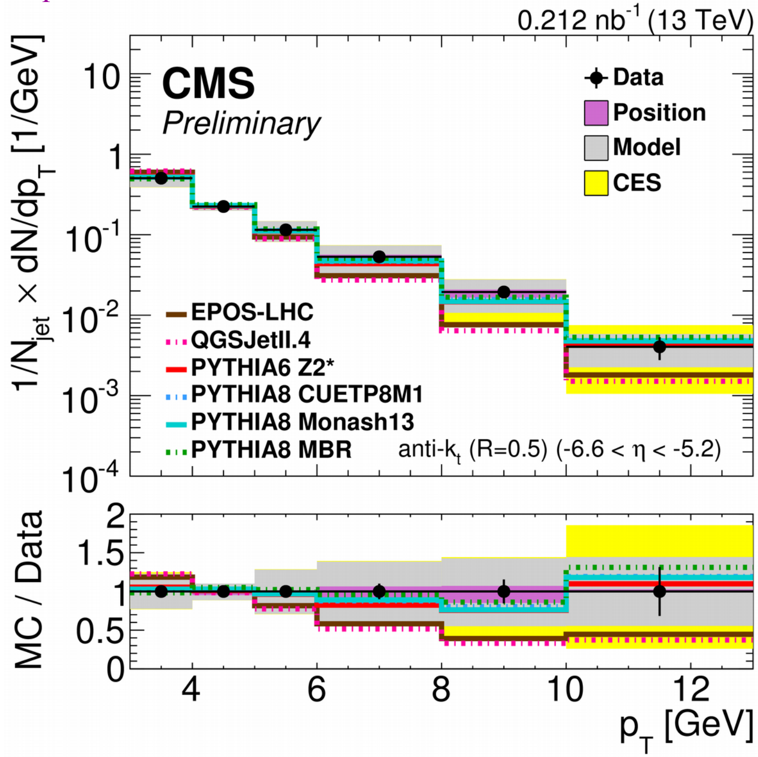
Forward jets with CASTOR: Results

pp collisions @13 TeV (*FSQ-PAS-16-003*)

Jet p_T cross section (normalized by Luminosity)



Jet p_T yield (normalized by number of jets)



- EPOS-LHC and QGSJetII.4 lower than the data
- PYTHIA overpredicts the cross section

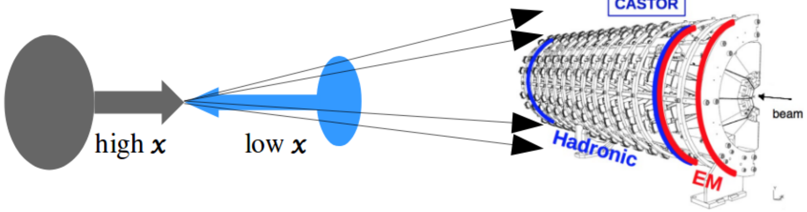
- EPOS-LHC and QGSJetII.4 softer than the data
- All PYTHIA versions reproduce the shape well

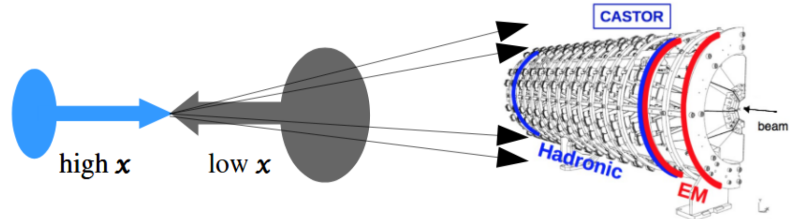
Presented differential spectra have only a moderate sensitivity to the underlying PDF

Forward jets with CASTOR in pPb

pPb collisions @5 TeV (*JHEP 05 (2019) 043*)

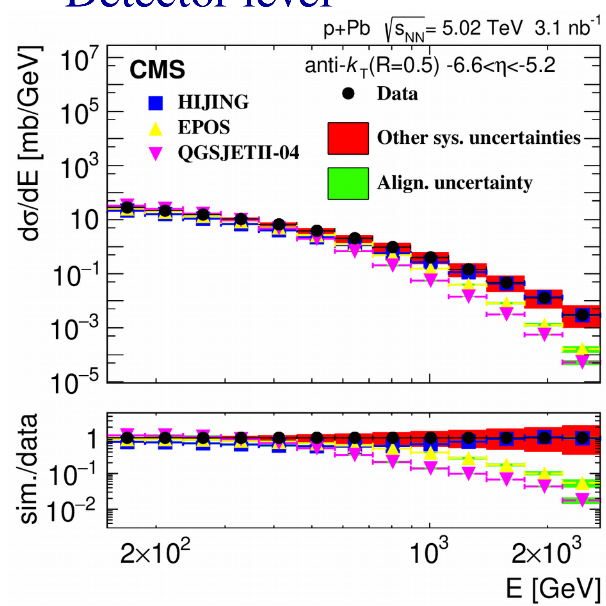
- 3.13 nb^{-1} for pPb and 6.71 nb^{-1} for Pbp
  - MB trigger with track ($|\eta|<2.5$)
  - E_{tower} > 4 GeV in HF+ and HF- ($3.0<|\eta|<5.2$)
  - Anti-k_T jets with R=0.5
  - $-6.6 < \eta < -5.2$
- All results shown in lab frame





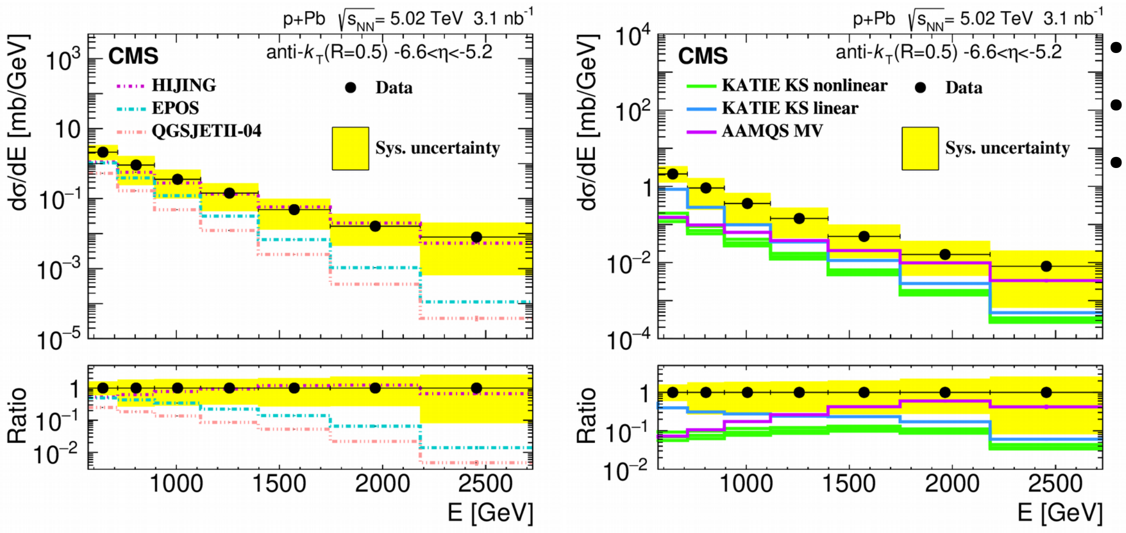
- *HIJING v1.383 (used for constructing the response matrix)*
  - DGLAP parton evolution via PYTHIA
  - Saturation effects via nuclear shadowing
- EPOS-LHC
  - Combination of parton model with pomeron exchange
  - Saturation is modeled through pomeron-pomeron interactions
- QGSJETII-04
  - Similar to EPOS but implements saturation via pomeron self-interactions

Detector level



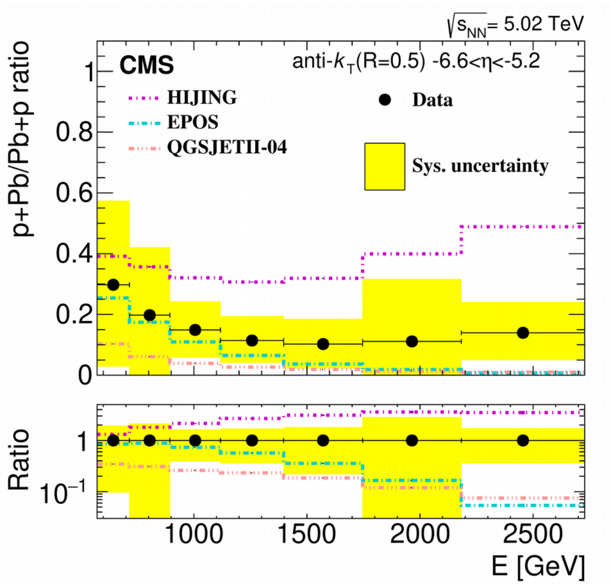
Forward jets with CASTOR in pPb: Results

pPb collisions @5 TeV (*JHEP 05 (2019) 043*)



- pPb spectrum is well described by HIJING
- EPOS-LHC and QGSJETII.4 too soft
- Saturation models (KATIE and AAMQS) do not describe the data

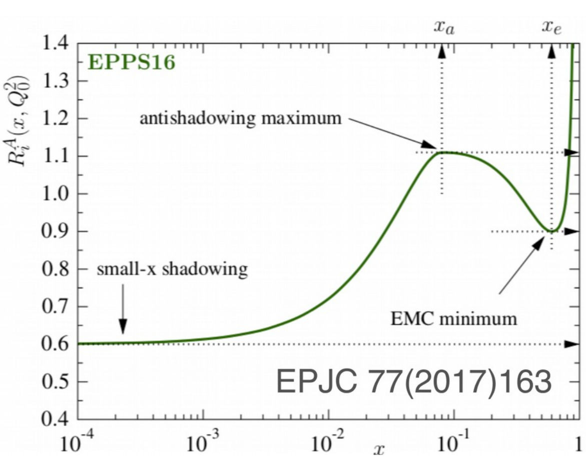
Cancellation of energy scale uncertainty in pPb/Pbp ratio allows better discrimination between data and models

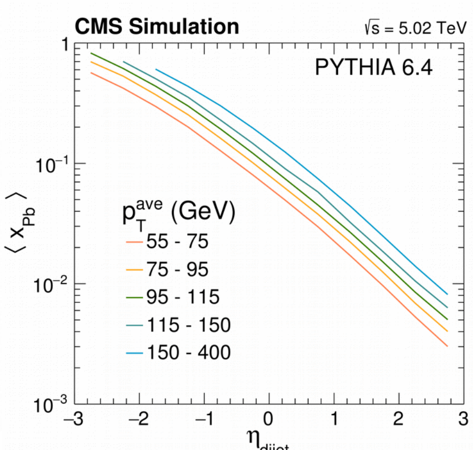


- None of the models describe the pPb/Pbp ratio
  - HIJING describes the shape well but is off in normalization (due to the poor Pb+p description)
  - EPOS-LHC describes the lower energy part of the ratio well, but fails to describe the shape at high energies
  - QGSJETII-04 significantly fail to describe both the shape and the normalization of the pPb/Pbp ratio

Dijets in pp and pPb @5 TeV

- 35 nb^{-1} for pPb and 27.4 pb^{-1} for pp
- Ratios of the normalized pPb and pp η_{dijet} distributions (pPb/pp) are studied
- Event selection:
  - Singe Jet Trigger (p_T > 40, 60, 80 GeV)
  - At least one HF tower > 3 GeV for pPb ($3.0<|\eta|<5.2$)
  - Primary vertex with ≥ 2 tracks
  - PF-jets using the anti-k_t algorithm with R=0.3
  - $|\eta_{lab}| < 3.0$, $p_{T,1} > 90$ GeV, $p_{T,2} > 20$ GeV, $\Delta\varphi_{1,2} = |\varphi_1-\varphi_2| > 2\pi/3$

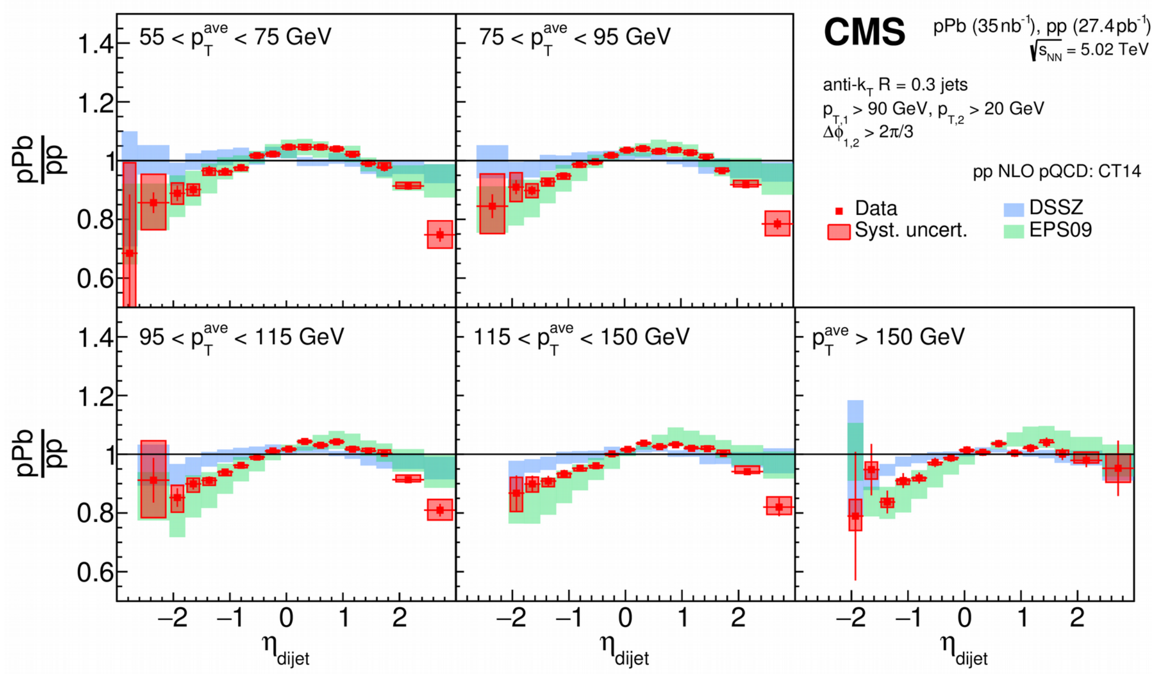


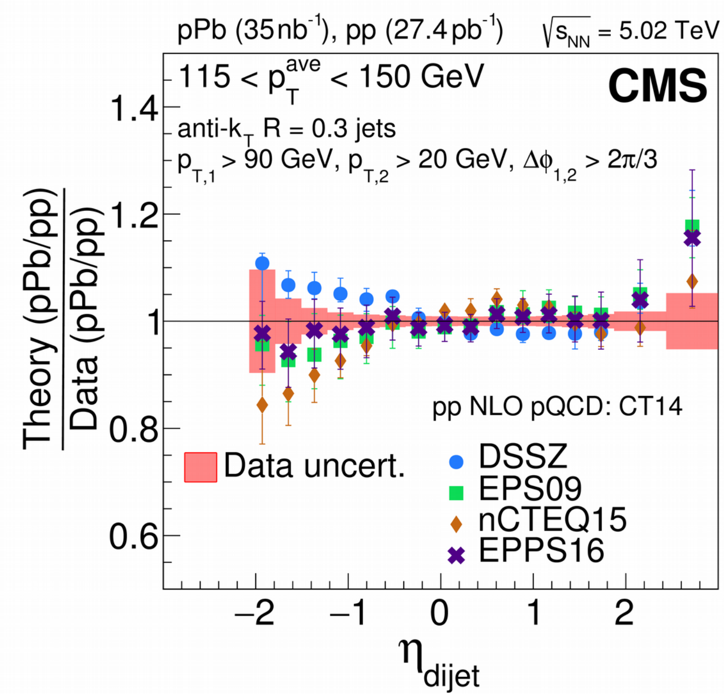


<x_{Pb}> of a parton from lead ion

- $\eta_{dijet} > 1.5$ – shadowing
- $-0.5 < \eta_{dijet} < 1.5$ – antishadowing
- $\eta_{dijet} < -0.5$ – EMC effect

Dijets in pp and pPb @5 TeV (PRL 121 (2018) 062002)



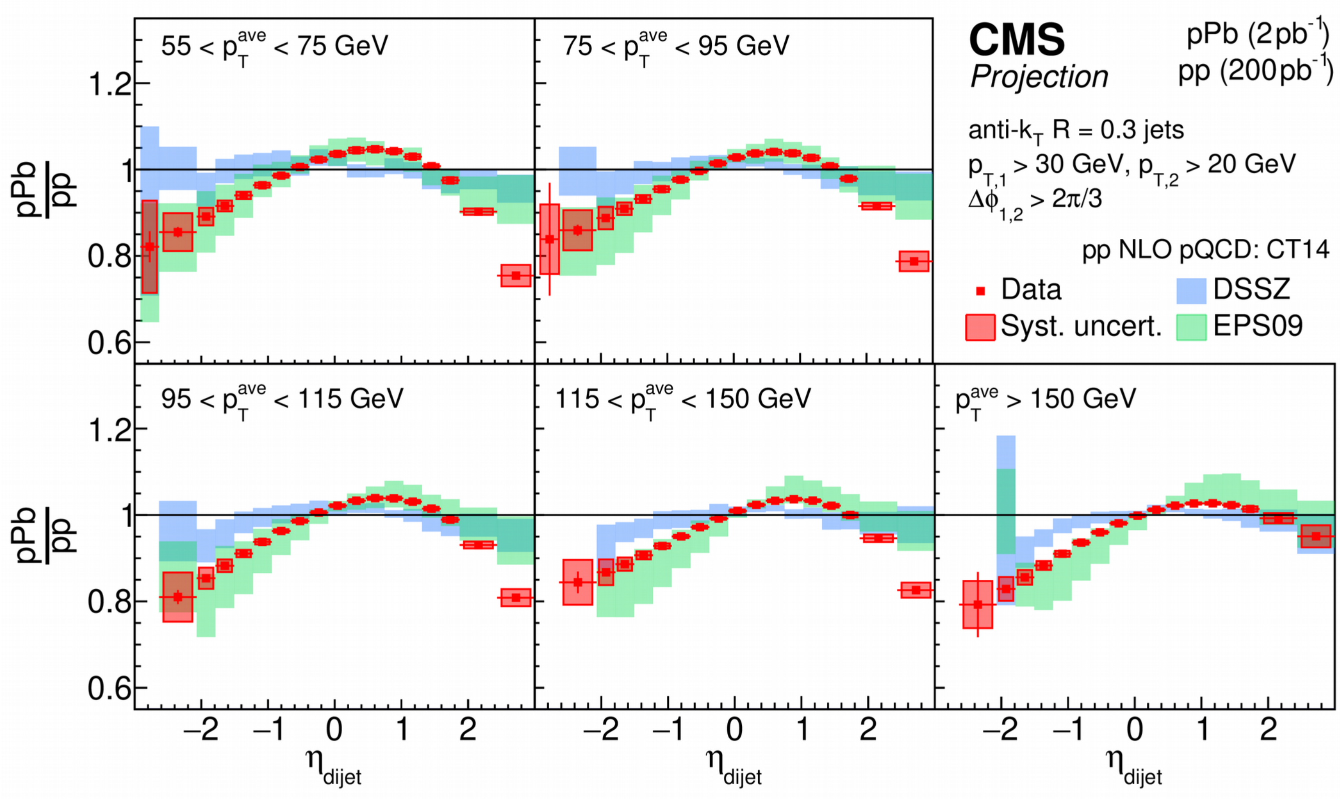


- The ratios of pPb and pp data are seen to deviate significantly from unity in the small (EMC) and large (shadowing) η_{dijet} regions.
- Neither DSSZ, nor EPS09 can describe in the full rapidity region
- For $\eta_{dijet} < -1$, which is sensitive to the gluon EMC effect, NLO pQCD calculations with EPS09 nPDF match the data
- The first evidence that the gluon PDF at large Bjorken x in lead ions is strongly suppressed

Dijets in pp and pPb @8.8 TeV (FTR-18-027)

Projection

- 2 pb^{-1} for pPb collisions
- Extension towards lower η_{dijet} values



Summary

- CMS Experiment is a perfect facility to study jet production
- Forward jets with CASTOR
  - Both pp @13 TeV and pPb @5 TeV have been measured
    - Moderate sensitivity to the underlying PDF in **pp**
    - No model is able to describe all aspects of the **pPb** data
- Dijet production in pp and pPb collisions
  - Significant modifications of the η_{dijet} distributions are observed in pPb data
  - The first evidence that the gluon PDF at large x in lead ions is suppressed
  - Projectionss for further measurements at HL-LHC have been presented

Thank you very much for your attention!