Studies of the initial state using jets and first study of diffraction with the CMS Experiment

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On behalf of the CMS Collaboration

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Outline

- Motivation
- 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 @5 TeV

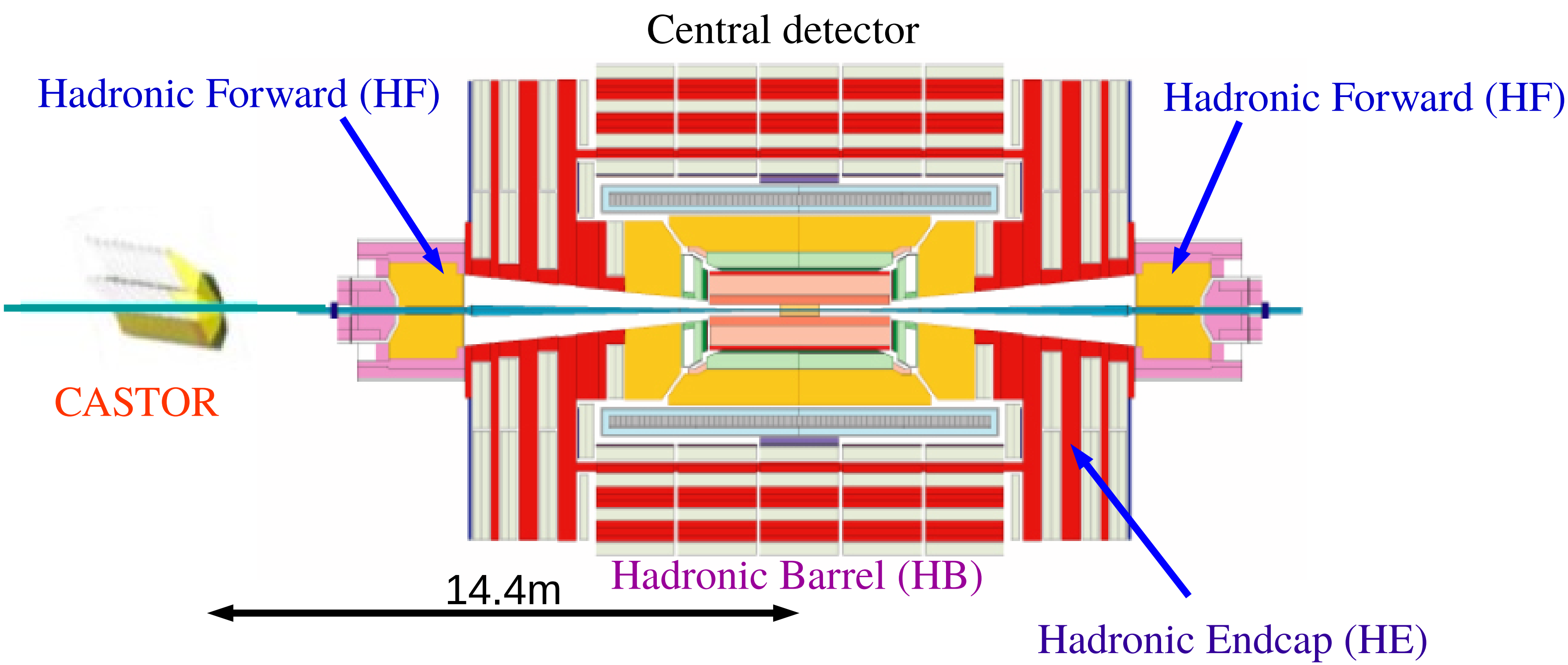
- Diffraction in pPb collisions @8 TeV

- Outlook

Motivation

- Jet production has very high cross section
  - Important background for most measurements and searches at the LHC
- 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 effect is pPb collisions
- Diffraction is sensitive to non-linear QCD effects
  - Cosmic ray MC tuning

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: $-6.6 < \eta < -5.2$

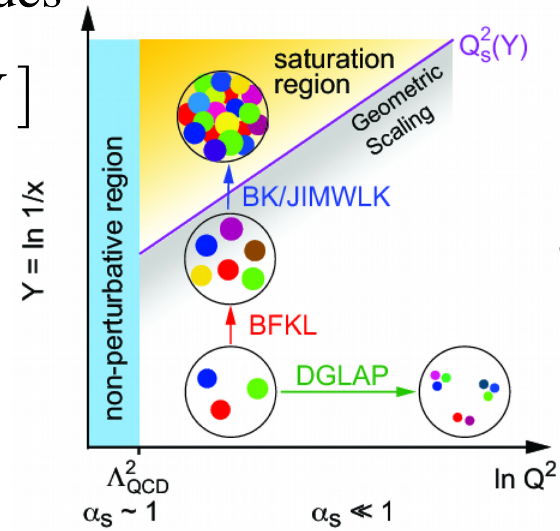
CMS offers perfect rapidity coverage to measure jets

Forward jets with CASTOR

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

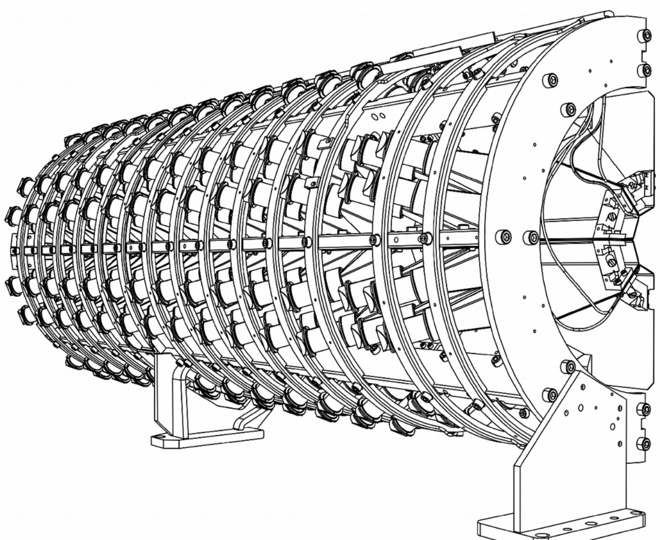
$$x \approx \frac{p_T}{\sqrt{s}} e^{\pm\eta} \approx 10^{-6} \quad [p_T = 10\,GeV\,; \eta = -6\,; \sqrt{s} = 13\,TeV]$$

- 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

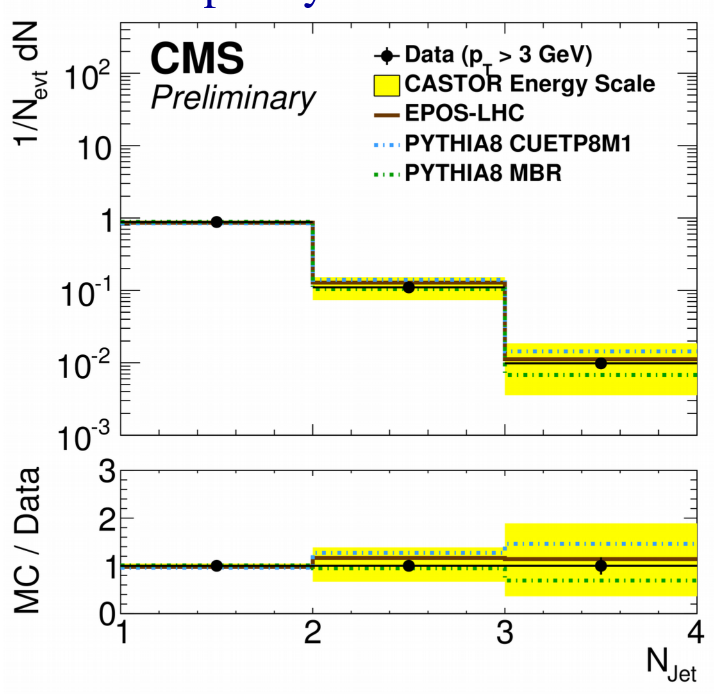
pp collisions @13 TeV (*FSQ-PAS-16-003*)

- Luminosity 0.21 nb^{-1}, low pile-up runs

- 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 $E\cosh(\eta)$, [$\eta = -5.9$]
  - E > 150 GeV or $p_T > 3$ GeV

- EPOS-LHC and PYTHIA8 used for correction

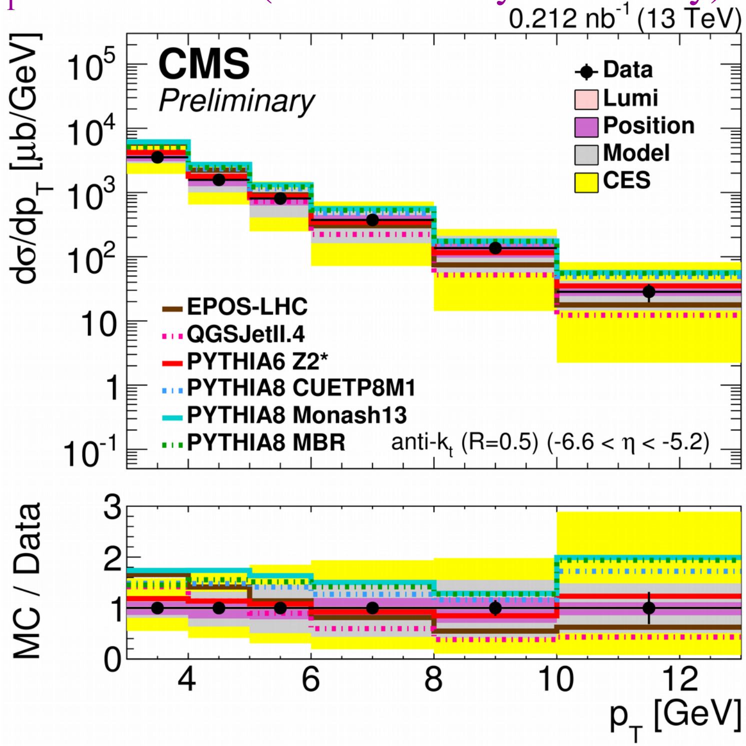
Jet multiplicity @ detector level



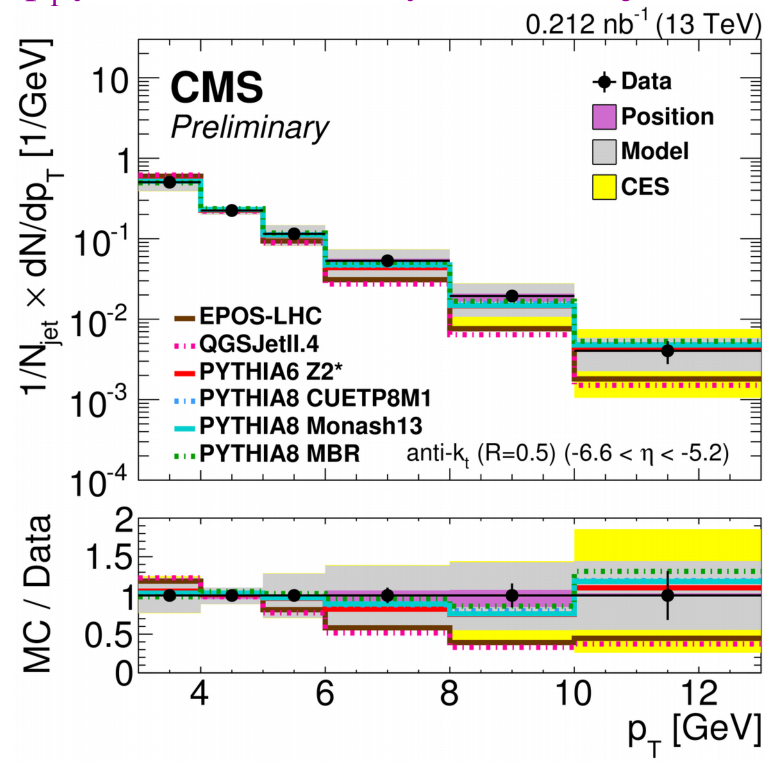
Forward jets with CASTOR: Results

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

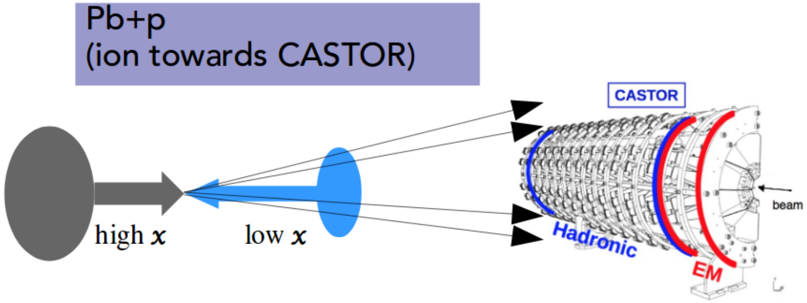
- EPOS-LHC and QGSJetII.4 softer than the data
- All PYTHIA versions reproduce the shape well

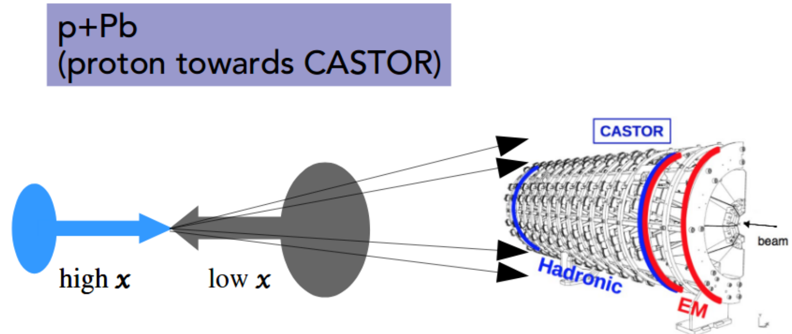
Presented differential spectra have only a moderate sensitivity to the underlying PDF

Forward jets with CASTOR in pPb

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

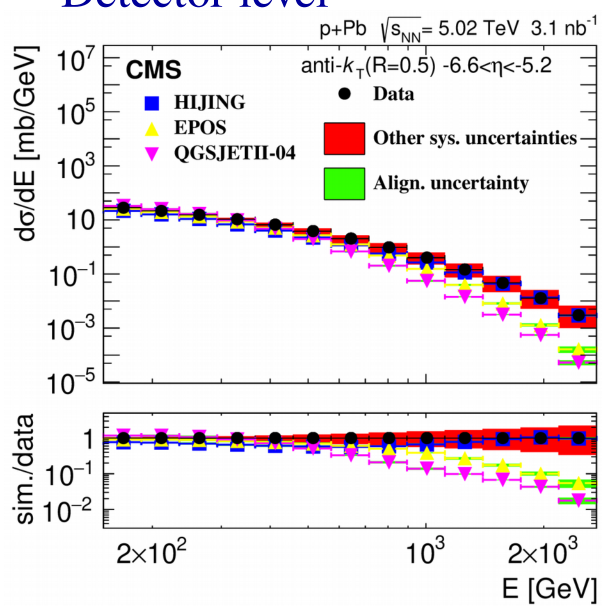
- 3.13 nb^{-1} for pPb and 6.71 nb^{-1} for Pbp
  - MB trigger with track ($|\eta|<2.5$)
  - E_{tower} > 4 GeV in HF+ and HF- ($3.0<|\eta|<5.2$)
  - Anti-k_T jets with R=0.5
  - $-6.6 < \eta < -5.2$
- All results shown in lab frame





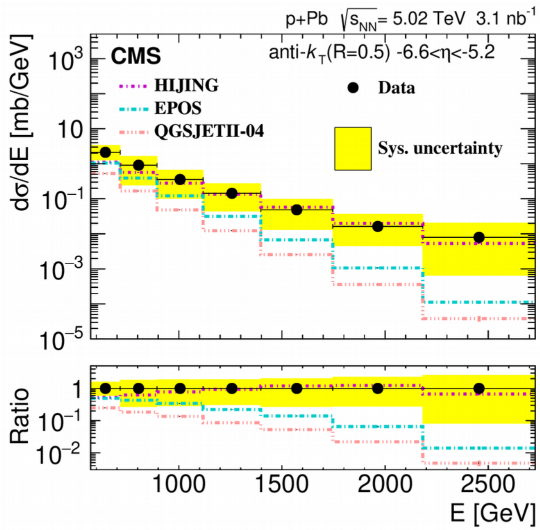
- *HIJING v1.383 (used for constructing the response matrix)*
  - DGLAP parton evolution via PYTHIA
  - Saturation effects via nuclear shadowing
- EPOS-LHC
  - Combination of parton model with pomeron exchange
  - Saturation is modeled through pomeron-pomeron interactions
- QGSJETII-04
  - Similar to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

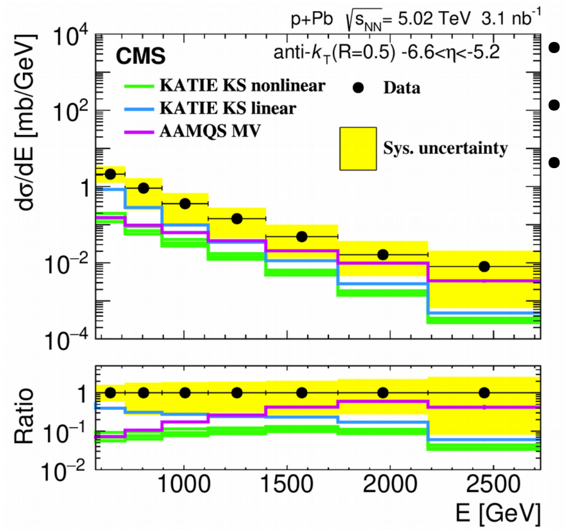
Detector level



Forward jets with CASTOR in pPb: Results

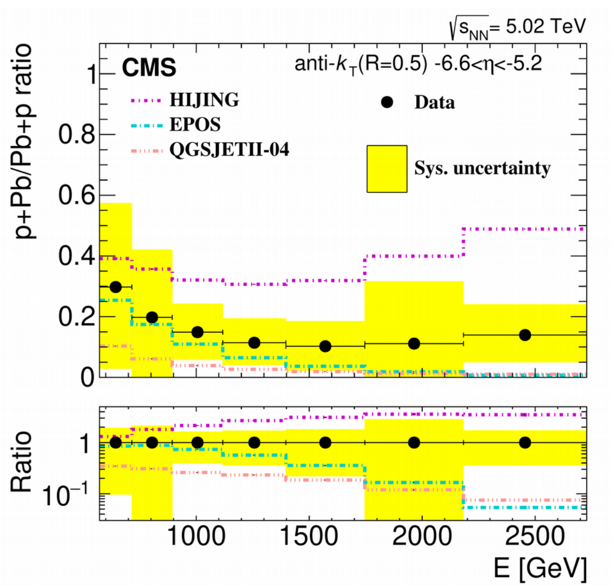
pPb collisions @5 TeV (*JHEP 05 (2019) 043*)





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

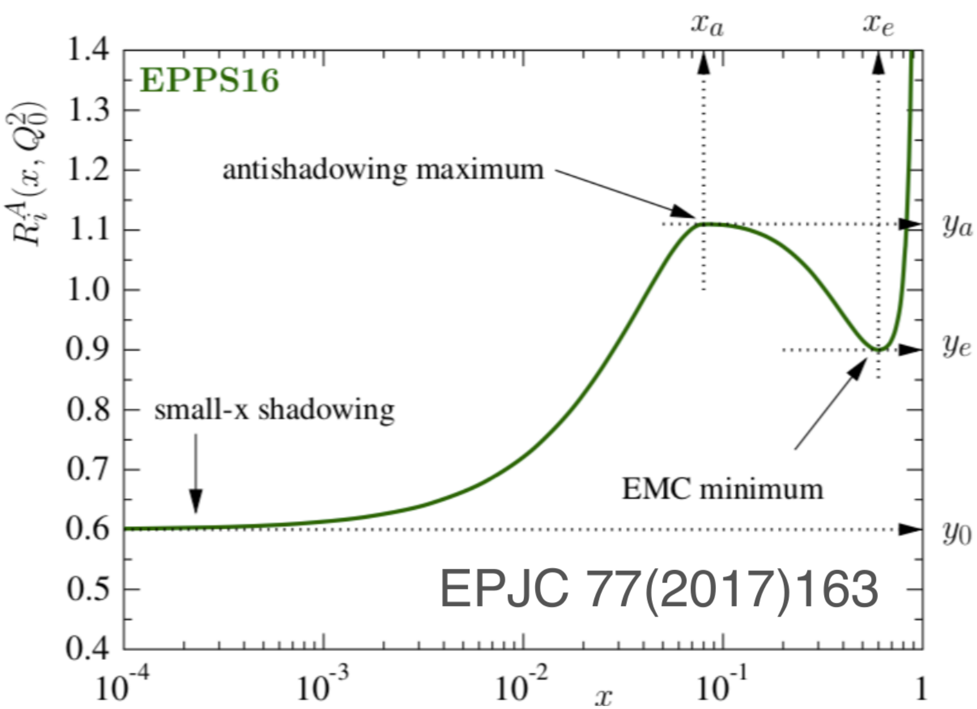
Cancellation of energy scale uncertainty in pPb/Pbp ratio allows better discrimination between data and models

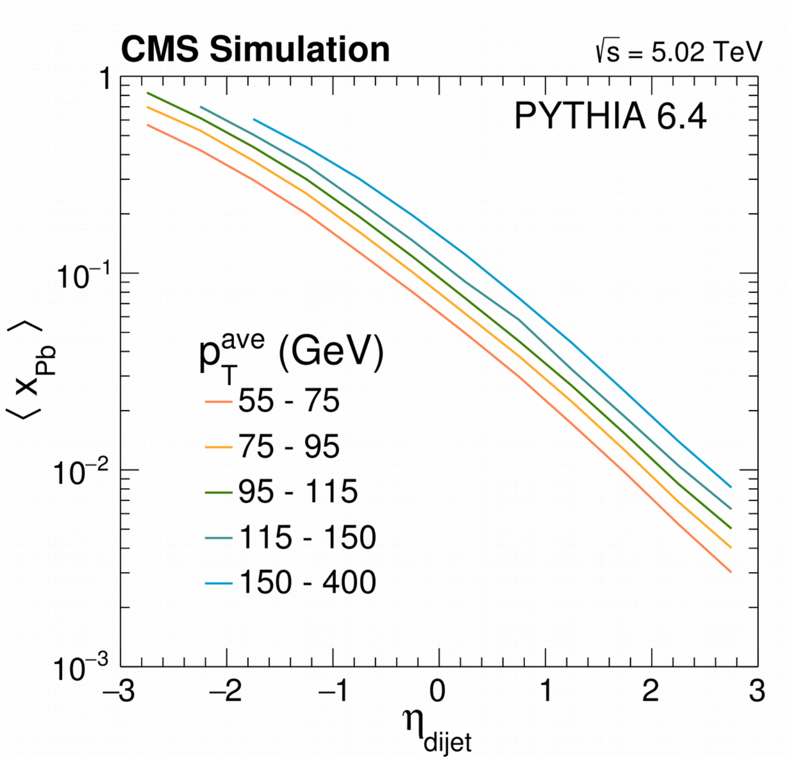


- None of the models describe the pPb/Pbp ratio
  - HIJING describes the shape well but is off in normalization (due to the poor Pb+p description)
  - EPOS-LHC describes the lower energy part of the ratio well, but fails to describe the shape at high energies
  - QGSJETII-04 significantly fail to describe 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
- PF-jets with R=0.3, $|\eta_{lab}| < 3.0$, $p_{T,1} > 90$ GeV, $p_{T,2} > 20$ GeV, $\Delta\varphi_{1,2} = |\varphi_1 - \varphi_2| > 2\pi/3$
- Ratios of the normalized pPb and pp η_{dijet} distributions (pPb/pp) are studied





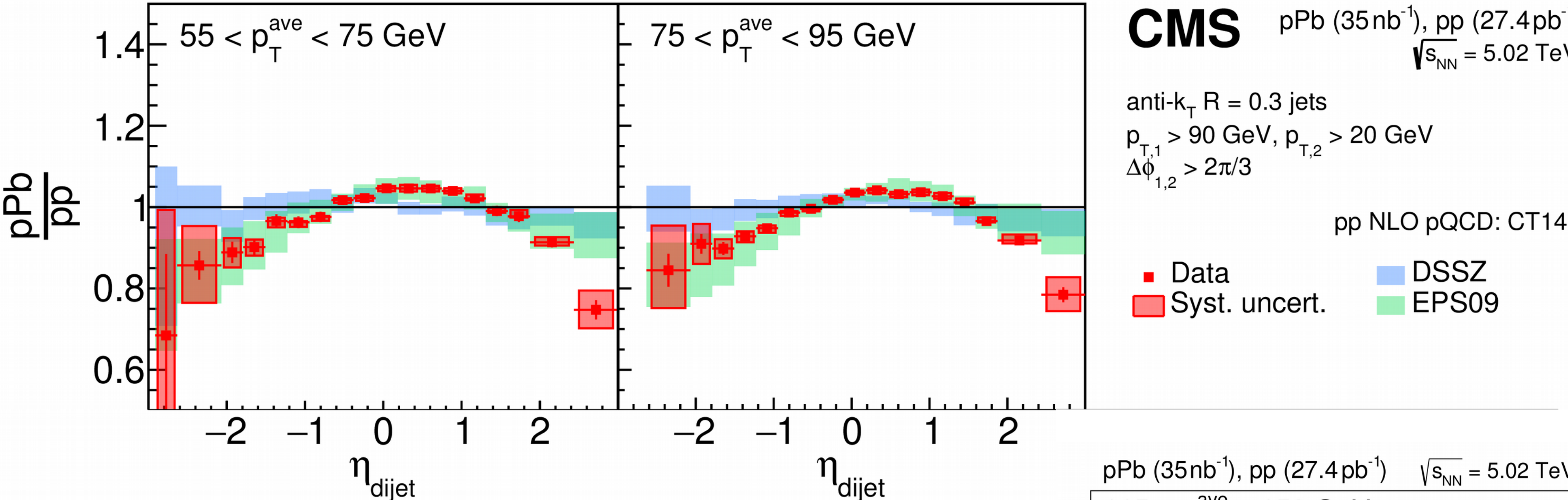
$<x_{Pb}>$ of a parton from lead ion

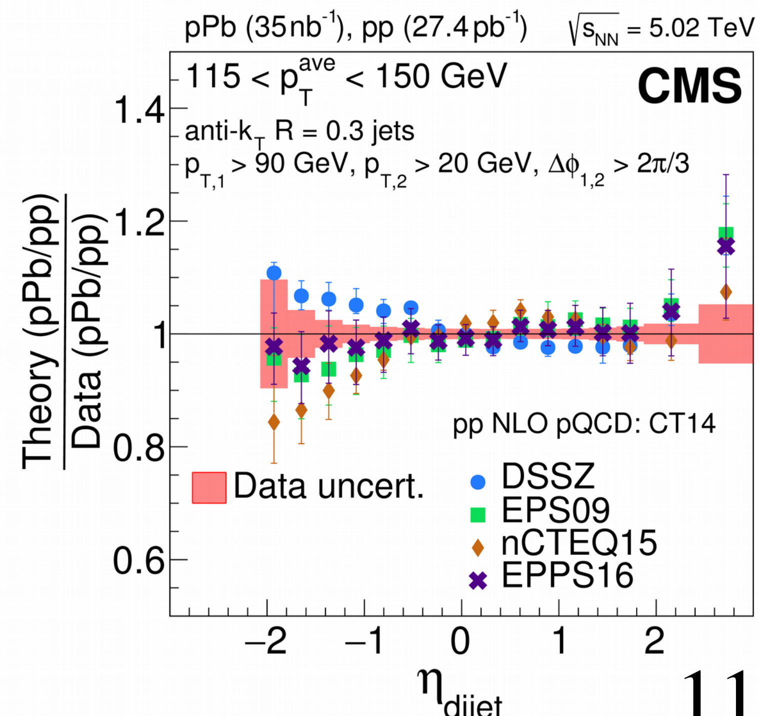
$\eta_{dijet} > 1.5$ – shadowing

$-0.5 < \eta_{dijet} < 1.5$ – antishadowing

$\eta_{dijet} < -0.5$ – EMC effect

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

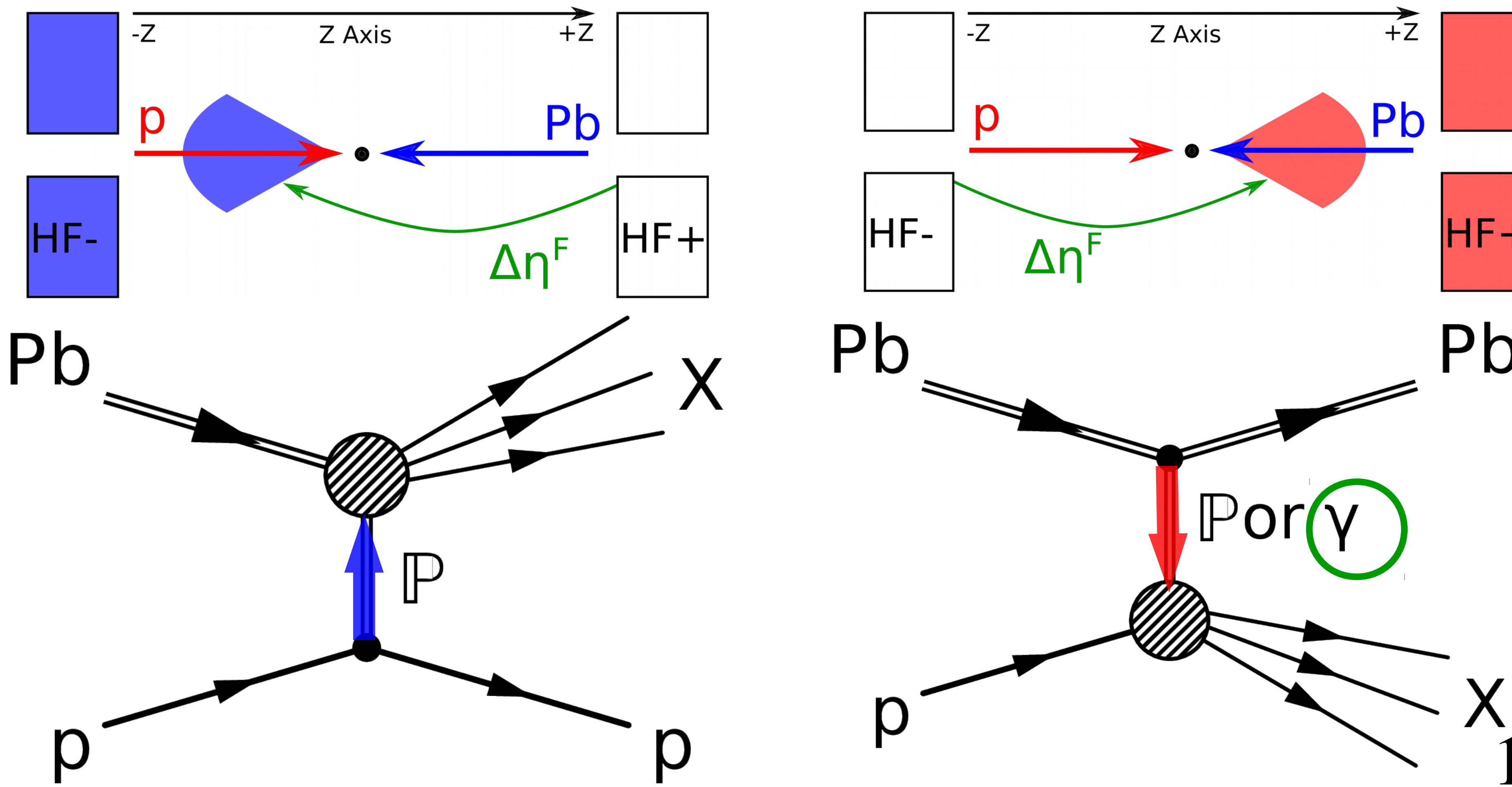




- pPb / pp < 1 in the small (EMC) and large (shadowing) η_{dijet} regions.
- DSSZ and EPS09 can't describe in the full rapidity region
- The first evidence that the gluon PDF at large Bjorken x in lead ions is strongly suppressed

Diffraction in pPb @8 TeV (CMS-PAS-HIN-18-019)

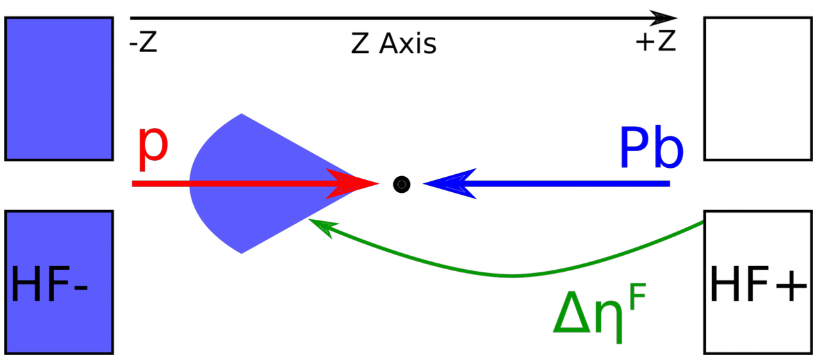
- 3.9 μb^{-1} for pPb and 2.5 μb^{-1} for Pbp
- MB events, at least one HF tower > 10 GeV (3.0 < $|\eta|$ < 5.2)
- Single Diffractive (SD) IPPb and IPp events are characterized by large rapidity gaps

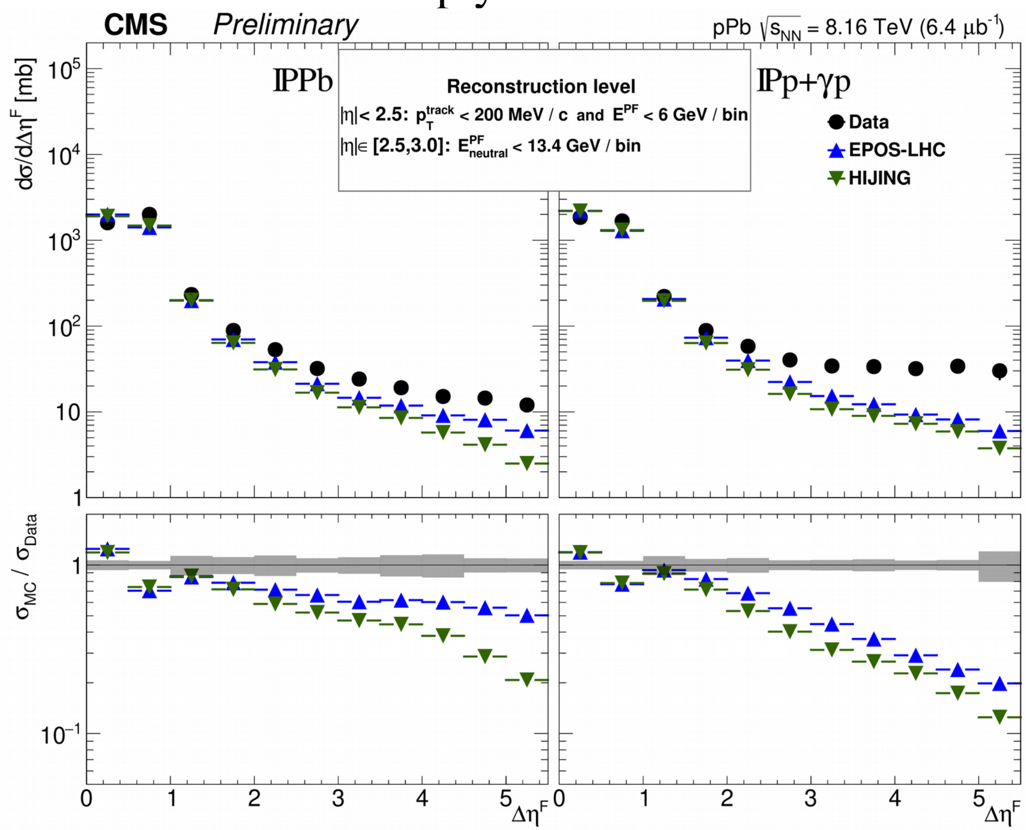


Diffraction in pPb @8 TeV (CMS-PAS-HIN-18-019)

- Central detector $|\eta| < 3.0$ divided into 12 bins in rapidity
- No track with $p_T > 200$ MeV, total energy of PF-candidates below 6 GeV for $|\eta| < 2.5$
- Neutral hadron PF-candidates below 13.4 GeV for $2.5 < |\eta| < 3.0$

Rapidity Gap $\Delta\eta^F$ is the distance from $\eta = 3.0$ to the first non empty bin



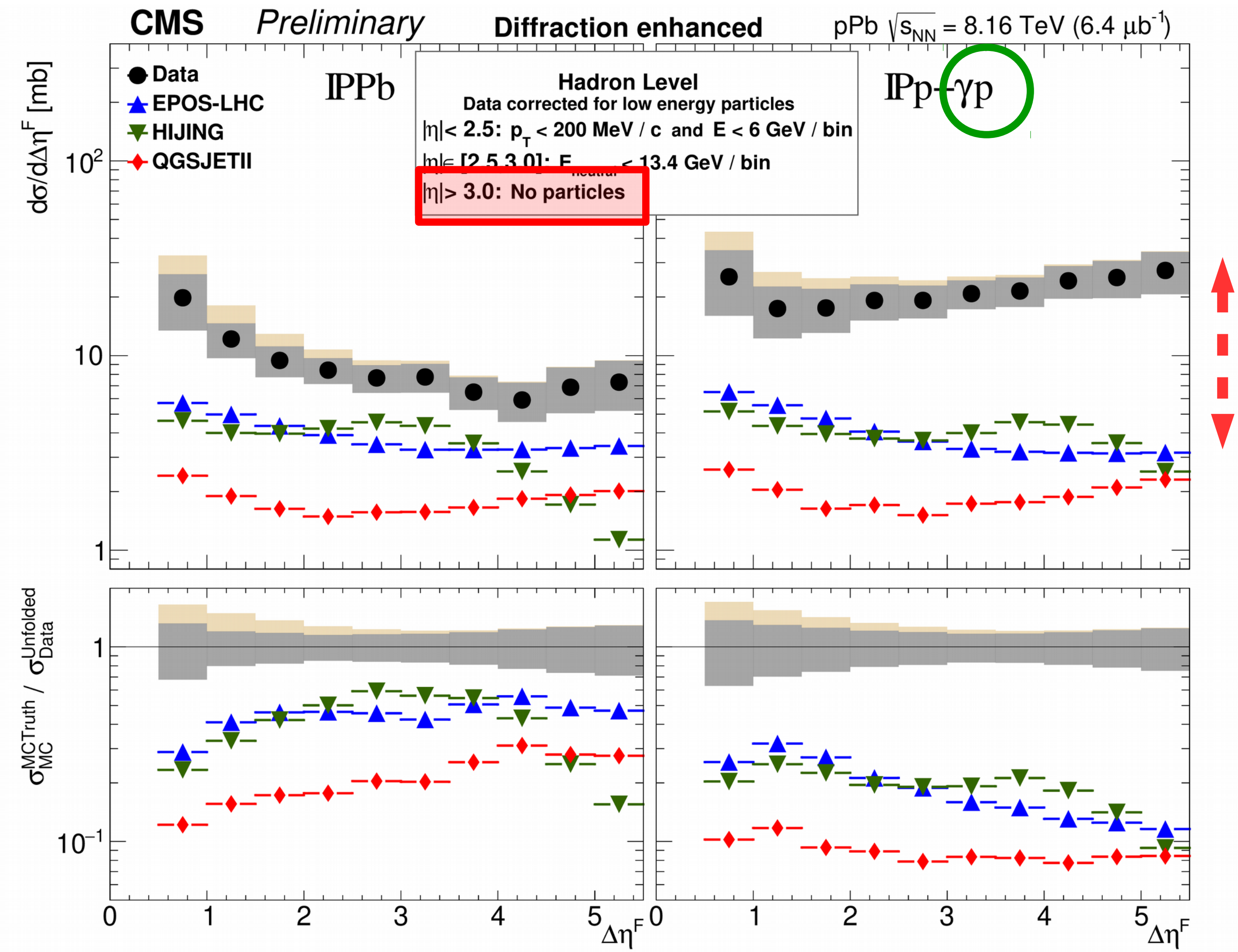


$\Delta\eta^F < 2$ are dominated by non-diffractive events

Diffraction in pPb @8 TeV (CMS-PAS-HIN-18-019)

Extended rapidity gap to the HF calorimeter 3.0 < |η| < 5.2:

Enhanced sensitivity to diffractive events.



EPOS-LHC and QGSJET II below the data, but describe its shape

Strong contribution from γp events

Summary

- 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
- First measurement of diffraction in pPb collisions
  - Strong contribution from γp events in IPp+γp topology

Thank you very much for your attention!