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

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Hard Probes 2020: 1-5 June 2020, Austin, TX, USA
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
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 pseudorapidity is sensible to the low-x values
  \[ \chi \approx \frac{p_T}{\sqrt{s}} e^{\pm \eta} \approx 10^{-6} \quad \text{[} p_T = 10 \text{GeV} ; \eta = -6 ; \sqrt{s} = 13 \text{TeV} \]  

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

- 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*)

- 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 Pb$p$
  - MB trigger with track ($|\eta|<2.5$)
  - $E_{\text{tower}} > 4$ 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)

- 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

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

- pPb spectrum is well described by HIJING
- EPOS-LHC and QGSJETII.4 too soft
- Saturation models (KATIE and AAMQS) do not describe the data
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, \(|\eta_{\text{lab}}| < 3.0\), \(p_{T,1} > 90\) GeV, \(p_{T,2} > 20\) GeV, \(\Delta\phi_{1,2} = |\phi_1 - \phi_2| > 2\pi/3\)
- Ratios of the normalized pPb and pp \(\eta_{\text{dijet}}\) distributions (pPb/pp) are studied

\(<x_{\text{pb}}\rangle\) of a parton from lead ion

- \(\eta_{\text{dijet}} > 1.5\) – shadowing
- \(-0.5 < \eta_{\text{dijet}} < 1.5\) – antishadowing
- \(\eta_{\text{dijet}} < -0.5\) – EMC effect
Dijets in pp and pPb @ 5 TeV (PRL 121 (2018) 062002)

- pPb / pp < 1 in the small (EMC) and large (shadowing) $\eta_{\text{dijet}}$ 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 < |η| < 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 $3.0 < |\eta| < 5.2$:

Enhanced sensitivity to diffractive events.

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

Strong contribution from $\gamma p$ 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 $\eta_{\text{dijet}}$ 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 $\gamma p$ events in IPp+$\gamma p$ topology

Thank you very much for your attention!