First measurement of the forward rapidity gap distribution in pPb collisions at 8 TeV

Ekaterina Kuznetsova (PNPI)
on behalf of the CMS collaboration

IS2021: The VI-th International Conference on the Initial Stages of High-Energy Nuclear Collisions,
10-15 Jan 2021, Weizmann Institute of Science, Rehavot (Israel)
Events with large rapidity gaps (LRG) in hadronic collisions

Non-diffractive (ND)

<table>
<thead>
<tr>
<th>+φ</th>
<th>+η</th>
</tr>
</thead>
<tbody>
<tr>
<td>-φ</td>
<td>-η</td>
</tr>
</tbody>
</table>

Diffractive production (Pomeron exchange in t-channel):

- **SD**: single diffractive
- **DD**: double diffractive
- **CD**: central diffractive

Events with LRG are also contributed by photon exchange processes. This contribution becomes significant for ions with large Z
Motivation

Inclusive diffractive production in hadronic collisions

- Relatively large contribution to the total cross-section
- Access to the Pomeron nature
- Access to processes at small $x$

Inclusive diffractive production in $pA$ collisions

- Cross sections of inelastic diffractive processes are very sensitive to nonlinear saturation effect
- Important information for precise cosmic ray shower modeling
- The most recent results before LHC are obtained by HELIOS for 27 GeV cme in 1991 (Z. Phys. C 49 (1991) 355)

As for $pp$ collisions, those measurements require good forward instrumentation of a detector

Recently measured at CMS for $pPb$ at $\sqrt{s_{NN}} = 8.16$ TeV: CMS-PAS-HIN-18-019
CMS detector

**Tracker**

- Pixel+SiStrip, Muon detectors

**Central calorimeters** $|\eta|<3$
- ECAL, HCAL

**Hadronic Forward Calorimeter (HF):**
- $2.9<|\eta|<5.2$
- in towers of $\Delta\eta \times \Delta\phi \sim 0.175 \times 175$

**Calorimetry + tracking $\rightarrow$ Particle Flow Objects**

+ Forward detectors available for AA/pA collision modes
  - (but not used in the baseline of our analysis for compatibility with pp results):
    - Castor $-6.6 < \eta < -5.2$
    - Zero Degree Calorimeter (ZDC): $|\eta| > 8.5$
Data and event topology

pPb/Pp run 2016: $\sqrt{s_{NN}} = 8.16$ TeV, low mean number of collisions per bunch (~0.15)
~6.4 $\mu$b$^{-1}$ in total

Goal: to obtain the differential cross section for events with large RG, for the IPPb and (IPp+\gamma p) topologies

STEP 1:
RG in the central detector area

STEP 2:
RG in the extended detector area

Larger RG – higher sensitivity to the diffractive production

Tracker
ECAL
HCAL
HF-
HF
HF+
\Delta\eta^F
\Delta\eta^F
\Delta\eta^F

or

Tracker
ECAL
HCAL
HF-
HF
HF+
\Delta\eta^F
\Delta\eta^F
\Delta\eta^F

or

Tracker
ECAL
HCAL
HF-
HF
HF+
\Delta\eta^F
\Delta\eta^F
\Delta\eta^F

or
Event selection

Analysis performed on inclusive Minimum Bias data
  + acceptance corrections are evaluated with Zero Bias data

- HF-based “Minimum Bias” data: require at least one tower of any of HF calorimeters to have at least 10 MeV deposition
  - large statistics, very inclusive but limited to the HF acceptance

- “Zero Bias” events triggered on beams crossing the interaction point, ensure inelastic collisions with a track, correct the tracker acceptance using Monte Carlo
  - total inelastic data set but low statistics
Rapidity Gap definition: thresholds depend on detector performance

- Theoretically the RG is defined as an acceptance region free of final state particles
- Practically we can not introduce the “zero” threshold due to finite detector sensitivity
- The thresholds should be as low as possible, but well above detector noise

- RG is defined in bins of $\eta=0.5$. Per every bin:

  for $|\eta|<2.5$:
  - No tracks with $P_T>200$ MeV
  - Total energy of all Particle Flow candidates < 6 GeV

  for $2.5<|\eta|<3$:
  - Total energy of all hadronic Particle Flow candidates < 13.4 GeV
Forward RG cross-section at reconstruction level (STEP1: $|\eta|<3$)

- EPOS does not account for the photoproduction contribution
- Larger data-MC deviation for the (IPp+γp) typologies, as expected
- EPOS predicts quite large contribution from non-diffractive events even for large RG
- To suppress the contribution from non-diffractive events, the analysis was extended to the HF acceptance

Compared to EPOS MC predictions
Expanding the Forward FG (STEP2)

- **Reweighing** according the fraction of events with **no detectable final state particles in the corresponding HF acceptance**.
  - The weighting coefficients are found comparing the HF energy spectra obtained for every considered FRG size to the noise spectrum of the corresponding HF.
- **Acceptance correction** for the total inelastic cross section
- **Unfolded** using EPOS MC

The FRG size is still counted from $|\eta|=3$, but the distributions correspond to the events with vetoed HF => “diffraction enhanced” data sample
Hadron level RG definition

• **RG at the central detector acceptance: the same as at the detector level**
  
  • RG is defined in bins of $\eta=0.5$. Per every bin:
    
    for $|\eta|<2.5$:
    • No tracks with $P_T>200$ MeV
    • Total energy of all Particle Flow candidates < 6 GeV

    for $2.5<|\eta|<3$
    • Total energy of all hadronic Particle Flow candidates<13.4 GeV

• **RG extension into the HF acceptance ($3<|\eta|<5$): no detectable particles**
Diffraction enhanced cross section at hadron level (STEP2)

Compared to EPOS MC predictions

Compared to QGSJET MC predictions

Both MC generators do not account for photon exchange processes
Diffraction enhanced cross section at hadron level

- Data are compared to EPOS, QGSJET and HIJING MC predictions (no contribution from $\gamma p$)

- Large difference between the data and MC in $\text{IPp} + \gamma p$ case is defined by the missing $\gamma p$ contribution in MC

- $\text{IPPb}$: EPOS provides the closest prediction, but still $\sim$2 times lower than the data

- In contrast to the data and other MC, HIJING demonstrates decrease of the differential cross section for large FRG
Additional studies: particle spectra at the RG edges

- IPp and γp events are topologically indistinguishable
- They have similar nature due to their “quasi-elasticity” and absence of the color exchange
- Due to lack of earlier experimental data, we do not have MC which can reliably describe inclusive photoproduction
- To use diffractive MC for data unfolding, the spectra of particles defining the RG size were studied

Number of tracks, their $p_T$ distributions and energy distribution of Particle Flow candidates in the pseudorapidity bin adjacent to the FRG: both HIJING and EPOS describe the data very well even for large FRG with high contribution of γp events
Additional studies: intact Pb event fraction in IPp+γp sample

- **Zero Degree Calorimeter**: is located behind the LHC dipole magnets.
- Sensitive to neutral particles in $|\eta|>8.5$ – perfect detector of neutrons originating in Pb break up

Though ZDC efficiency is known to be very high, we don’t know the precise value.

The fraction of intact Pb events is quite high (~80%) and does not depend on the FRG size
Summary

- Differential FRG cross section has been measured for the first time at the LHC energies for both pomeron-lead and pomeron-proton topologies

- Comparison to the EPOS, QGSJET and HIJING MC (IPPb):
  - neither of this generators can describe the absolute value of the cross-section
  - EPOS and QGSJET describe the distribution shape quite well
  - Pomeron-proton topology events are strongly contributed by the photon exchange events (γp) due to the large lead ion charge. The event signatures are indistinguishable for IPp and γp events
  - Those events (IPp+γp) have large probability to avoid lead break up, and this probability does not depend on the FRG size for large gap sizes

- The obtained results can be used for further MC generator tuning and improvement of the cosmic ray shower modeling
Weighting procedure
**Additional studies: intact Pb event fraction in IPp+γp sample**

- Zero Degree Calorimeter: located behind the LHC dipole magnets and is sensitive to neutral particles in $|\eta| > 8.5$ – perfect detector of neutrons originating from Pb break up.

---

**Diagram:**

- **BLIND**
  - **Tracker**
  - **ECAL**
  - **HF-**
  - **HF+**

**ZDC**

**Products of Pb break up**

**VS**

**BLIND**

- **Tracker**
- **ECAL**
- **HCAL**
- **HF-**
- **HF+**

**ZDC**

**EMPTY**

**Intact Pb (not detectable)**