Recent CMS and CMS-TOTEM results on diffraction and exclusive production

Olivér Surányi

on behalf of CMS Collaboration

Eötvös Loránd University
Wigner RCP
Budapest, Hungary

24th June 2019
Introduction

Many important questions in diffraction and exclusive physics!

- Pomeron structure
- Soft survival effects
- BFKL dynamics
- Low mass resonances
- Glueballs
The Forward Detectors of CMS experiment
● **NEW**: Exclusive dipion production at 5.02 and 13 TeV  
CMS-PAS-FSQ-16-006

● Diffractive dijets with proton tagging at 8 TeV  
CMS-PAS-FSQ-12-033

● Dijets with a large rapidity gap between jets at 7 TeV  

● Inelastic cross section at 13 TeV  
JHEP **1807**, 161 (2018)
Exclusive dipion production at 5.02 and 13 TeV
Motivation

- Restricted quantum numbers.
- Filter certain low mass resonances.
- Gluon-rich environment in DPE → glueball search.

Double pomeron exchange (DPE)

\[ I^G(J^{PC}) = 0^+(J^{++}), \text{ } J \text{ is even} \]

Vector meson photoproduction

\[ I(J^{PC}) = 0, 1(1^{--}) \]
Dataset, trigger, event selections

**Dataset:** low-pileup data in 2015 at
- $\sqrt{s} = 5.02$ TeV, $522 \, \mu b^{-1}$
- $\sqrt{s} = 13$ TeV, $258 \, \mu b^{-1}$

**Trigger:** random bunch-crossings (zero bias events)

**Event selection:**
- Two tracks, passing high purity criteria.
- Single interaction vertex.
- No activity in calorimeters, except $3\sigma$ cone around track hits.
- $\pi$ identification via $dE/dx$
- $p_T(\pi) > 0.2$ GeV, $|\eta(\pi)| < 2.4$. 
Particle identification

- Separate $\pi$ and $K$ candidates
- $p$-slices fitted with Gaussians
- High $\pi$ identification efficiency $\rightarrow$ large $K$ contamination, treated in the analysis
Multihadron background estimation

- Using a sample with extra calorimeter hits
- Background distribution from events with 2 – 5 extra calorimeter hits
- Normalization based on same sign distribution
- Systematic uncertainties from varying control region

CMS Preliminary 258 $\mu$b$^{-1}$ (13 TeV)

OS tracks
- Identified pion pair
- Background in 0 bin
- Background in 2-5 bin

Number of extra towers over threshold

Corrected yield

Oliver Suranyi

Recent CMS and CMS-TOTEM results on diffraction and exclusive production
Results

- **STARLIGHT**: exclusive $\rho(770)$ photoproduction.
- **DIME MC**: DPE continuum contribution.
- No simulation describes certain low mass resonances ($f_0$ and $f_2$).
- Total exclusive $\pi^+\pi^-$ cross section in $p_T(\pi) > 0.2$ GeV, $|\eta| < 2.4$:
  \[
  \sigma(\sqrt{s} = 5.02 \text{ TeV}) = 19.6 \pm 0.4 \text{ (stat.)} \pm 3.3 \text{ (syst.)} \pm 0.01 \text{ (lumi.)} \mu b
  \]
  \[
  \sigma(\sqrt{s} = 13 \text{ TeV}) = 19.0 \pm 0.6 \text{ (stat.)} \pm 3.2 \text{ (syst.)} \pm 0.01 \text{ (lumi.)} \mu b
  \]
Results – invariant mass distribution

- Enhancement in $\rho(770)$ region
- Sharp drop at around 1 GeV
  - Indication of $f_0(980)$ resonance
  - Interference between resonance and continuum
- Significant peak at $f_2(1270)$
- Dime MC overestimates 1500 MeV region
Results – mass fits

- Fits with interfering Breit-Wigners
- Convolution with Gaussian to model resolution
- Resonance yields extracted
Results – resonance yields

<table>
<thead>
<tr>
<th>Resonance</th>
<th>$\sigma_{pp \rightarrow p' p' X \rightarrow p' p' \pi^+ \pi^-}$ [µb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_0(500)$</td>
<td>$1.7 \pm 0.7$ (stat.) $\pm 0.2$ (syst.) $\pm 0.04$ (lumi.)</td>
</tr>
<tr>
<td>$\rho^0(770)$</td>
<td>$3.2 \pm 0.7$ (stat.) $\pm 0.3$ (syst.) $\pm 0.1$ (lumi.)</td>
</tr>
<tr>
<td>$f_0(980)$</td>
<td>$0.3 \pm 0.1$ (stat.) $\pm 0.03$ (syst.) $\pm 0.01$ (lumi.)</td>
</tr>
<tr>
<td>$f_2(1270)$</td>
<td>$1.9 \pm 0.5$ (stat.) $\pm 0.2$ (syst.) $\pm 0.04$ (lumi.)</td>
</tr>
</tbody>
</table>

$\sqrt{s} = 5.02$ TeV

$\sqrt{s} = 13$ TeV

| $f_0(500)$ | $1.4 \pm 0.5$ (stat.) $\pm 0.2$ (syst.) $\pm 0.03$ (lumi.) |
| $\rho^0(770)$ | $2.8 \pm 0.8$ (stat.) $\pm 0.3$ (syst.) $\pm 0.1$ (lumi.) |
| $f_0(980)$ | $0.6 \pm 0.2$ (stat.) $\pm 0.1$ (syst.) $\pm 0.01$ (lumi.) |
| $f_2(1270)$ | $2.0 \pm 0.7$ (stat.) $\pm 0.2$ (syst.) $\pm 0.05$ (lumi.) |

STARlight results for $\rho^0(770)$:

- 5.02 TeV: 2.3 µb
- 13 TeV: 3.0 µb
Diffractive dijets with proton tagging at 8 TeV
Motivation

- Single diffraction
- Rapidity gap around proton
- Factorization theorem: Convolution of diffractive PDFs and + pQCD
- Spoiled by soft rescattering
Diffractive dijets with proton tagging at 8 TeV

**TOTEM Roman Pots**

- Small tracking detectors, detect beam protons
- 147 m and 220 m from IP
- 4-momentum transfer squared:
  \[ t = (p_f - p_i)^2 \]

- Fractional momentum loss:
  \[ \xi_{\text{TOTEM}} = 1 - \frac{|p_f|}{p_i} \]
  \[ \xi_{\text{CMS}}^\pm = \frac{\sum (E_i^\pm p_z^i)}{\sqrt{s}} \]
**Dataset, trigger, event selection**

**Dataset:** low pileup pp at $\sqrt{s} = 8$ TeV, special beam optics: $\beta^* = 90$ m, 37.5 nb$^{-1}$

**Trigger:** dijets with $p_T > 20$ GeV

**Event selections:**
- At least two jets with $p_T > 40$ GeV and $|\eta| < 4.4$
- At least one reconstructed primary vertex
- At least one proton in RP
  - $0 < x_{RP} < 7$ mm and $8.4 < |y_{RP}| < 27$ mm
- Rejecting elastic events
- Kinematic cuts:
  - $0.03 < |t| < 1.0$ GeV$^2$ and $0 < \xi_{TOTEM} < 0.1$
Background to diffractive dijets

- Background distribution from zero bias events
- To suppress background: $\xi_{CMS} - \xi_{TOTEM} \leq 0$
Unfolded with iterative d’Agostini method
Pythia 8 DG and Pomwig gives good description
Pythia 8 4C and CUETP8M1 predicts higher contribution
Cross section in the kinematic region:

$$\sigma_{jj}^{pX} = 21.7 \pm 0.9 \text{ (stat)} ^{+3.0}_{-3.3} \text{ (syst)} \pm 0.9 \text{ (lumi) nb}$$
Results

- Ratio of SD dijet versus inclusive dijet cross section
- Generally large deviation at low-\(x\)
- Pomwig and Pythia 8 DG gives better description
- Cross section decreased compared to CDF – feature already seen in CDF
Dijets with a large rapidity gap between jets at 7 TeV
Motivation

- Two jets with large $p_T$
- pQCD, described by DGLAP equations
- Large rapidity gap between jets:
  - BFKL equations give better description
- Color singlet exchange (CSE)
  ⇒ Described by pomeron
Dataset, trigger

**Dataset:** low pileup data at $\sqrt{s} = 7\text{ TeV}$ (2010), 8 pb$^{-1}$

**Trigger:**

- Dijet with $p_T > 15$ and 30 GeV
- Single jet with $p_T > 70$ GeV
Event selections

- At least two jets
- Maximum one vertex with $|z| < 24$ cm
- Rejecting beam-scraping events
- Two leading jets in $1.5 < |\eta_{\text{jet}}| < 4.7$
- Leading jets with opposite $\eta$ sign
Dijets with a large rapidity gap between jets at 7 TeV

Track multiplicity in rapidity gap

- Pythia 6 with $Z_2^*$: LO DGLAP, non-CSE
- Herwig 6: LL BFKL, only CSE
- CSE fraction is measured
- Two methods to estimate non-CSE:
  - NBD fit on $N_{\text{track}}$ distribution
  - Using same side jets
**Results**

- **Factor of 2 decrease compared to** $\sqrt{s} = 1.8$ TeV
  - Expected from Tevatron scaling
  - Stronger contribution from rescattering

- **Mueller and Tang (MT) LL model** does not reproduce the rise with $p_{T,\text{jet2}}$ and underestimates the fraction of CSE events

- **Ekstedt, Enberg and Ingelman (EII) NLL model** gives better agreement
Results

- In three $p_T^{jet,2}$ bins
- MT model does not reproduce the rise with $\Delta \eta_{jj}$ and underestimates the fraction of CSE events
- EEI model with MPI and soft color interaction reproduces rise $\Delta \eta_{jj}$
- Other EEI settings provide decreasing trend
Inelastic cross section at 13 TeV
Motivation

- $\sigma_{\text{inel}}$: fundamental observable in high-energy particle, nuclear and cosmic ray physics
- Input for phenomenological hadronic interaction models
- Used in tuning of MC generators
- Crucial ingredient for Glauber models
- Important in estimation of pileup
Inelastic cross section at 13 TeV

Dataset, trigger, event selection

**Dataset:** low pileup datasets at $\sqrt{s} = 13$ TeV in 2015, with magnets on: $40.8 \, \mu b^{-1}$, with magnets off: $28.0 \, \mu b^{-1}$

**Trigger:** random bunch crossings (zero bias) + single/no bunch triggers for calorimeter noise study

**Event selection:**
- Energy deposit larger than 5 GeV in HF
- OR larger than 5 GeV in CASTOR (only in $B = 0$ T)
- At stable particle level:
  - $\xi > 10^{-6}$ (HF only)
  - $\xi_X > 10^{-6}$, $\xi_Y > 10^{-7}$ (HF+CASTOR)

\[ \xi_{X,Y} = \frac{M_{X,Y}^2}{s} \quad \xi = \max(\xi_X, \xi_Y) \]
Results

- Pileup correction applied bunch-by-bunch
- Correction for detector effects based on MC samples
- Fully corrected inelastic cross section:

\[ \sigma(\xi > 10^{-6}) = 67.5 \pm 0.8 \text{ (syst)} \pm 1.6 \text{ (lumi)} \text{ mb} \]

\[ \sigma(\xi_X > 10^{-6} \text{ or } \xi_Y > 10^{-7}) = 68.6 \pm 0.5 \text{ (syst)} \pm 1.6 \text{ (lumi)} \text{ mb} \]
**NEW:** Exclusive dipion production at 5.02 and 13 TeV

- $f_0(500)$, $\rho(770)$, $f_0(980)$ and $f_2(1270)$ resonances observed
- Total and resonant cross sections measured

**Diffractive dijets with proton tagging at 8 TeV:**

- Joint measurement of CMS and TOTEM
- Test of survival probability in different MC
- Scaling with $\sqrt{s}$ as expected from CDF

**Dijets with a large rapidity gap between jets at 7 TeV:**

- BFKL dynamics tested
- Scaling with $\sqrt{s}$ as expected from CDF

**Inelastic cross section at 13 TeV:**

- Cross sections in fiducial regions:

  $$\sigma(\xi > 10^{-6}) = 67.5 \pm 0.8 \text{ (syst)} \pm 1.6 \text{ (lumi)} \text{ mb}$$
  $$\sigma(\xi_X > 10^{-6} \text{ or } \xi_Y > 10^{-7}) = 68.6 \pm 0.5 \text{ (syst)} \pm 1.6 \text{ (lumi)} \text{ mb}$$

- Results consistent with ATLAS result
Thank you for your attention!