Recent forward physics and diffraction results from CMS

Gabor Veres (CERN) on behalf of the CMS Collaboration

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Outline

- CMS: forward instrumentation
- Diffraction:
  - single- and double-diffractive (RG) cross sections
  - DD-dominated sample: xsec using a central rapidity gap
  - forward rapidity gap cross sections
- Hard color-singlet exchange (CSE):
  - dijet events with a large rapidity gap
  - fraction of CSE events measured
    - as a function of the subleading jet $p_T$
    - as a function of the rapidity gap
CMS and TOTEM Experiments

- Excellent instrumentation at high $\eta$ ("forward")

Common data taking during low-PU runs in 2012

BSC*: Beam Scintillator Counters (in front of HF) $3.2 < |\eta| < 4.7$ (Run 1)
Soft diffraction at 7 TeV

- Diffraction: \( \sim 22\% \) of inelastic cross section (14 mb/64.5 mb)
- Large rapidity gap (LRG). Pomeron: color singlet
- Predictions based on Regge theory, extrapolations to LHC
- Important to improve models, event generators, MB and UE predictions, etc.
- SD and DD separated with CASTOR: \(-6.6<\eta<-5.2\)

\( p \rightarrow X \) (a) non-diffractive (ND)
\( p \rightarrow \not{P} \rightarrow X \) (b) single dissociation (SD)
\( p \rightarrow \not{P} \rightarrow \not{P} \rightarrow Y \) (c) double dissociation (DD)
\( p \rightarrow \not{P} \rightarrow \not{P} \rightarrow X \) (d) central diffraction (CD)
Models, MC simulations

Used for corrections: resolutions, acceptance, migration, etc.

- **PYTHIA 8.165**: inelastic events
- **PYTHIA-MBR**: extract cross sections (extrapolation to low mass). Phenomenological renormalized Regge model. Successful at CDF. DD ↓15%
- **PYTHIA 8 4C**: Schuler-Sjostrand model, diffractive cross section adjusted: SD ↓10%, and DD ↓12%

- **M_X, M_Y**: separated by the largest rapidity gap

- **Data:**
  - 2010, 16.2/μb, pileup=0.14
  - trigger: zero bias + any BSC hit (and at least 2 Particle Flow objects). Acceptance: 90% if M_X or M_Y >12.6 GeV
  - no vertex required
Diffractive topologies

\[ \Delta \eta^0 = \eta^0_{\text{max}} - \eta^0_{\text{min}} \]

Detector level:
- ND
- FG1
- FG2
- CG

Generator level:
- ND
- SD1
- DD
- SD2
- DD
- DD

Experimental categories:
- conceptual categories

\[ a) \quad \eta_{\text{min}} \quad \eta_{\text{max}} \]

\[ b) \quad \eta_{\text{min}} \quad \eta_{\text{max}} \]

\[ c) \quad \eta_{\text{min}} \quad \eta_{\text{max}} \]

\[ d) \quad \eta_{\text{min}} \quad \eta_{\text{max}} \]

\[ e) \quad \eta_{\text{min}} \quad \eta_{\text{max}} \]

\[ f) \quad \eta_{\text{min}} \quad \eta^0_{\text{min}} \quad \eta^0_{\text{max}} \quad \eta_{\text{max}} \]
$\eta_{\text{min}}$ and $\Delta \eta^0$ distributions

- Distribution of $\eta_{\text{min}}$ and $\Delta \eta^0$ in the selected events:
  - ND: exponential suppression of rapidity gap
  - large gaps: dominated by diffractive events
  - cuts to enhance SD and DD: $\eta_{\text{min}} > -1$ and $\Delta \eta^0 > 3$.  

**PRD 92, 012003**
Acceptance

Based on PYTHIA 8 MBR for true DD events:

- Trigger selection
- FG2 with CASTOR tag
- CG selection
The forward rapidity gap xsec is measured vs $\xi_X$:

Experimentally, this is approximated by (using PF objects in the detector, where the dissociated system is in the + or - side):

$$\zeta_X = \frac{M_X^2}{s}$$

$$\zeta^\pm = \frac{\sum(E^i \mp p^i_z)}{\sqrt{s}}$$

The correlation of reconstructed and generated variables for SD2 events:

(correction using MBR)

$7\ \text{TeV}$

CMS Simulation

$\log_{10}\xi_X$
ξ distributions in the FG2 sample

- FG2 sample: SD dominates
- FG2 sample, with empty CASTOR: SD dominates
- FG2 sample, with some energy in CASTOR: DD dominates

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gabor.veres@cern.ch
Forward Gap cross sections

FG2 sample. Unfolded, pileup and acceptance corrected.

**SD “enhanced”:**
empty CASTOR.

**DD “enhanced”:**
with CASTOR tag

Integrals:

- **SD “enhanced”:**
  - empty CASTOR: $2.99 \pm 0.02\,(\text{stat})^{+0.32}_{-0.29}\,(\text{syst})\,\text{mb}$

- **DD “enhanced”:**
  - with CASTOR tag: $1.18 \pm 0.02\,(\text{stat}) \pm 0.13\,(\text{syst})\,\text{mb}$

PYTHIA 8 MBR gives the best description of the data.
Double diffractive-enhanced xsec

Variables: \[ \Delta \eta = -\log \xi \]

Detector level: \( \Delta \eta^0 = \eta_{\text{max}}^0 - \eta_{\text{min}}^0 \)

Correction to translate between the two: from MC (MBR)

Integral: \( 0.58 \pm 0.01 \text{ (stat)}^{+0.13}_{-0.11} \text{ (syst)} \text{ mb} \)
Total diffractive cross sections at 7 TeV

- Background subtraction.
  - Main bg sources:
    - no-CASTOR: DD
    - CASTOR: ND

Measurements extrapolated to total single (SD) and double (DD) diffractive cross sections:
  - using PYTHIA 8 MBR
  - extrapolation around a factor of 2 needed

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Rapidity gap cross section

Forward rapidity gap: largest distance between detector edge ($|\eta|=4.7$) and first Particle Flow object: $\Delta\eta^F$

Correction for bg (circulating beams), migrations.

$PU=0.0066$. Particle level cut: $p_T>200$ MeV/c, $|\eta|<4.7$. 

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**Graphs:**

- Left graph: CMS data with different theoretical predictions.
- Right graph: CMS and ATLAS data comparison.

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Dijets with large rapidity gap, 7 TeV

- Dijet production: normally quark or gluon exchange → color field → hadron production between the two jets (in η)
- BFKL model: experimentally accessible with two jets with large rapidity gap, and no particles between them.
- Color singlet exchange (CSE): Pomeron or gluon ladder

Data:
- jets: $p_T > 40$ GeV, $1.5 < |\eta| < 4.5$
- particles (veto): $|\eta| < 1$, $p_T > 200$ MeV
- Data: 2010, 8/pb, pileup = 1.16 - 1.60
- vertex: 0 or 1

MC:
- dijets: PYTHIA 6 Z2* (LO DGLAP), MPI, ISR, FSR
Charged particle multiplicity in the gap

Multiplicity measured in the gap:

Data shows large excess at 0 particles. Not described by DGLAP, but HERWIG6 reproduces it.
CSE event features

- Jet $p_T$ distributions (in events with a gap) are described by HERWIG6.

- Dijets with a gap are more back-to-back.
CSE fraction

- **Definition:**
  
  \[ f_{\text{CSE}} = \frac{N_{\text{events}}(S) - N_{\text{bkg}}(S)}{N_{\text{events}}} \]

- **Background subtraction:**
  - “same-sign” sample: jets in the same \( \eta \) hemisphere
  - Negative Binomial fit to the “opposite sign” sample

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CMS-PAS-12-001
CSE fraction vs. subleading jet $p_T$

- Factor of $\sim 2$ lower than at Tevatron at 1.8 TeV
  - (stronger rescattering at high energy)
- Modest increase with subleading jet $p_T$
CSE fraction vs. rapidity gap

- Fraction increases with $\Delta \eta$
- Muller-Tang model does not reproduce this increase and underestimates the data
Summary

- CMS has an **active** forward and diffractive physics program
- CMS forward instrumentation is unique, complemented by the TOTEM experiment and the CASTOR calorimeter
  - a joint physics program and data taking is underway
  - CT-PPS will take off next year: tagging diffraction and CEP at high luminosity. Common CMS-TOTEM data with Roman Pot coincidences this year (next week).
- SD and DD cross sections measured at 7 TeV
  - gap cross sections measured as a function of “fractional proton momentum loss” and central and forward gap width
- Jet-gap-jet events at 7 TeV:
  - first time at the LHC
  - dijet events with a gap are **not consistent with** LO DGLAP
  - CSE observed.
  - **CSE fraction** rises with $p_T^2$ and decreases with energy
END