CMS results on exclusive and diffractive production

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for the CMS collaboration
The setting: CMS@LHC

- High energy and high luminosity
  - Allows high statistics precision measurements, and sensitivity to “rare” processes (hard diffraction, exclusive production)
  - But high luminosity comes with high “pileup” – average 2-8 in 2010/2011, 21 in 2012
  - Low pileup needed for some analysis

- Good detector coverage
  - Tracking to $|\eta| < 2.4$
  - Hadronic calorimeter (HF) to $|\eta| < 5$
  - Forward calorimeters (cover $-6.6 < \eta < -5.2$ (CASTOR) and $|\eta| > 8.1$ (ZDC)
Overview

- Studying the exclusive production at CMS
  - Standard candle $\gamma \gamma \rightarrow \mu \mu$
  - WW
- Measurement of diffraction dissociation
  - SD
  - DD
- Many other interesting results not covered here
  - [https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ](https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ)
Studying the exclusive production

CMS-PAS-FWD-10-005
CMS-PAS-FSQ-12-010
Exclusive production $pp \rightarrow p\mu\mu p$
  - Well known QED like “Standard Candle”

Largest “background” from $\gamma\gamma \rightarrow \mu\mu$ with proton dissociation
  - $pp \rightarrow p\mu\mu Y$, or $pp \rightarrow X\mu\mu Y$ with proton remnants undetected
  - Can be used to control background for other exclusive searches
Measurement of $\gamma\gamma \rightarrow \mu\mu$

- Measure in two kinematic regions
  - Elastic
    - $|\Delta p_T(\ell^+\ell^-)| < 1.0$ GeV (momentum balance)
    - $1-|\Delta \phi(\ell^+\ell^-)/\pi| < 0.1$ (back to back leptons)
  - Inelastic -> opposite requirements

Dissociation dominates
Inelastic $\gamma\gamma\to\mu\mu$

- Deficit seen mostly in inelastic region due to rescattering effects not modeled by LPAIR

- A correction factor is estimated for high mass dimuons

<table>
<thead>
<tr>
<th>Region</th>
<th>Data</th>
<th>Simulation</th>
<th>Data/Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic</td>
<td>820</td>
<td>906 ± 9</td>
<td>0.91 ± 0.03</td>
</tr>
<tr>
<td>Dissociation</td>
<td>1312</td>
<td>1830 ± 17</td>
<td>0.72 ± 0.02</td>
</tr>
<tr>
<td>Total</td>
<td>2132</td>
<td>2736 ± 19</td>
<td>0.78 ± 0.02</td>
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</tbody>
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$$F = \frac{N_{\mu\mu} \text{ data} - N_{DY}}{N_{\text{elastic}}} \left| m(\mu^+\mu^-)>160 \text{ GeV} \right|$$

$F = 3.23 \pm 0.53$.

- This factor can be applied to the predicted cross section for $\gamma\gamma\to W^+W^-$. 

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Exclusive $\gamma\gamma \rightarrow WW$

- Triple and quartic coupling in SM
  - Any deviation can signal new physics
- BSM contributions via effective Lagrangian

$$L_6^0 = \frac{-e^2 a_0^W}{8} F_{\mu\nu} F^{\mu\nu} W^{+\alpha} W^-_{\alpha} - \frac{e^2}{16 \cos^2 \Theta_W} a_0^Z \frac{F_{\mu\nu} F^{\mu\nu} Z^{\alpha} Z_{\alpha}}{\Lambda^2},$$

$$L_6^C = \frac{-e^2 a_0^W}{16} F_{\mu\alpha} F^{\mu\beta} (W^{+\alpha} W^-_{\beta} - W^{-\alpha} W^+_{\beta}) - \frac{e^2}{16 \cos^2 \Theta_W} \frac{a_0^Z F_{\mu\alpha} F^{\mu\beta} Z^{\alpha} Z_{\beta}}{\Lambda^2},$$

$\Lambda$: scale for New Physics

- Form factors introduced to preserve unitarity
  - $W_W$: $\gamma\gamma$ center of mass energy
  - $\Lambda_{\text{cutoff}}$: energy cutoff scale ($\Lambda_{\text{cutoff}} \rightarrow \infty = \text{no form factor}$)
Event selection $\gamma\gamma \rightarrow WW$

- Elastic and proton-dissociative contributions
  - $pp \rightarrow p W^+ W^- p$
  - $pp \rightarrow p^{(*)} W^+ W^- p^{(*)}$
- Unlike-flavor dilepton decay channel: $\gamma\gamma \rightarrow W^+ W^- \rightarrow \mu^- e^+ \nu \bar{\nu}$
  - Avoid large backgrounds
- Data sample – 5.05 fb$^{-1}$ @ 7 TeV
  - Signal $p_T(\mu^- e^+) > 30$ GeV $\rightarrow$ avoid $\tau^+ \tau^-$
  - AQGC Searches $p_T(\mu^- e^+) > 100$ GeV
SM signal $\gamma\gamma \rightarrow WW$

- Includes dissociation correction from $\gamma\gamma \rightarrow \mu\mu$

\[
\sigma(pp \rightarrow p^{(s)}(\gamma\gamma \rightarrow W^+W^-)p^{(s)}) \times BR(W^\pm \rightarrow \mu^{\pm}v, e^{\pm}v) = 2.2^{+3.3}_{-2.0} \text{ (stat.)} \text{ fb} \quad (\text{SM prediction } 4.0 \pm 0.7 \text{ fb})
\]
Search for AQGC $\gamma\gamma \rightarrow WW$

- Upper limit @ 95% CL

$$\sigma(pp \rightarrow p^{(*)}(\gamma\gamma \rightarrow W^+W^-)p^{(*)}) \times BR(W^\pm \rightarrow \mu^\pm\nu, e^\pm\nu) < 1.9 \text{ fb}$$
95% CL intervals $\gamma \gamma \rightarrow WW$
Diffractive Dissociation @ 7 TeV

CMS PAS FSQ 12-005
Measurement of diffractive dissociation

- Data sample – 16.5 μb⁻¹ low pileup (μ=0.14) @ 7 TeV
  - Minimum bias trigger
    - Hit in both BPTX and either BSC

- Offline selection
  - Large Rapidity Gap (LRG) tagging
  - At least 2 PF objects in BSC acceptance
  - No vertex requirement (low mass)

- MC simulation
  - PYTHIA8-MBR – Minimum Bias Rockefeller model
  - PYTHIA8-4C – for systematic studies
Experimental Topologies

- Based on the LRG position
Detector level distributions

- Proton fractional momentum loss $\xi = M^2 x/s$
  - $M^2 x$ – Mass of the dissociated system

- At detector level it is reconstructed as $\xi = \sum E_i - p_i^2/\sqrt{s}$
  - Sum over all PF objects
  - $\xi$ corrected (MC) for undetected particles (low E, low $\eta$)

Castor tag selects low mass systems $M_x \approx 3.2$ GeV
Separate SD & DD
Measurements: SD cross section

\[ \frac{d\sigma^{SD}}{d \log_{10} \xi} = \frac{N_{noCASTOR}^{data} - (N_{DD} + N_{CD} + N_{ND})^{MC}}{acc \cdot L \cdot (\Delta \log_{10} \xi)_{bin}} \]

- SD falling behaviour well modeled by PYTHIA8-MBR
- PYTHIA8-4C and PYTHIA 6 do not follow the data trend
- Integrating over \(-5.5 < \log_{10} \xi < -2.5\) (X 2)
  \[ \sigma_{vis}^{SD} = 4.27 \pm 0.04 \text{ (stat)} \pm 0.65^{+0.58}_{-0.58} \text{ (syst)} \text{ mb} \]

- Systematic dominated by energy scale and background subtraction
Measurements: DD cross section

- Integrating over $\Delta\eta > 3$ and $M_{x,y} > 10$ GeV
  
  $\sigma_{\text{vis}}^{\text{DD}} = 0.93 \pm 0.01$ (stat) $\pm 0.26_{-0.22}^{+0.26}$ (syst) mb
Measurements: LRG cross section

- Difficult to measure the whole $M_x \rightarrow$ measure size of LRG
  - Inclusive – measure the largest forward gap $\Delta \eta_F = \max(4.7 - \eta_{\text{max}}, 4.7 + \eta_{\text{min}})$
  - largest gap between each edge of the detector and the position in $\eta$ of the first particle moving away from the edge

\[
\frac{d\sigma(\Delta \eta_F)}{d\Delta \eta_F} = \frac{A(\Delta \eta_F) \cdot N(\Delta \eta_F) - N_{\text{BG}}(\Delta \eta_F)}{\Delta \eta_{\text{bin}} \cdot \epsilon(\Delta \eta_F) \times \mathcal{L}}
\]
Measurements: LRG cross section

Unfolded and fully corrected distribution compared to MC

Exponential suppression (ND)

Diffractive plateau $\sim 1\text{mb}/\Delta\eta_F$

Best description of the data by PYTHIA8-MBR with smaller intercept
Measurements: LRG cross section

Comparison with ATLAS

- Different hadron level definition: $|\eta| < 4.7$ (CMS) vs $|\eta| < 4.9$ (ATLAS) → up to 5% effect

- Unfolding based on different MCs: PYTHIA8-MBR (CMS) vs PYTHIA8 (ATLAS) → up to 10% effect

→ Agreement within uncertainties

→ CMS result extends ATLAS measurement by 0.4 unit of gap size
Conclusions

- CMS measured exclusive and diffractive processes at the LHC

- Exclusive processes
  - Standard candle $\gamma\gamma \rightarrow \mu\mu$ used to correct for proton dissociation
  - Search for $\gamma\gamma \rightarrow WW \rightarrow$ two potential candidates $\rightarrow$ agreement with SM

\[
\sigma(pp \rightarrow p^*(W^+W^-p^*) \rightarrow p^*(\mu\pm e\mp p^*)) = 2.2^{+3.3}_{-2.0} \text{ fb},
\]

- AQGC limits two orders of magnitude more stringent than LEP and Tevatron

- Diffractive cross sections measured at 7 TeV
  - $\sigma^{SD}_{8u} = 4.27 \pm 0.04 \text{(stat.)} \pm 0.65 / -0.58 \text{(syst.)} \text{ mb for } -5.5 < \log \xi < -2.5$
  - $\sigma^{DD}_{8u} = 0.93 \pm 0.01 \text{(stat.)} \pm 0.26 / -0.22 \text{(syst.)} \text{ mb for } \Delta \eta > 3, M_x > 10 \text{ GeV}, M_y > 10 \text{ GeV}$

- Good agreement with ATLAS on LRG cross section

- More results coming soon
Extra
Luminosity and Pile-up

- The integrated luminosity ($L$) is based on the Van der Meer scans
- The uncertainty of the luminosity is 4%: dominates the systematic uncertainties of this analysis
- Number of collisions per bunch crossing follows Poisson - Average $\lambda$ (pile-up)

\[
F_{\text{pileup}} = \frac{\sum_{i=1}^{\infty} iP(i, \lambda)}{\sum_{i=1}^{\infty} (1 - (1 - \epsilon_{\text{inel}})^i)P(i, \lambda)} \cdot \epsilon_{\text{inel}} = \frac{\epsilon_{\text{inel}} \lambda}{\sum_{i=1}^{\infty} (1 - (1 - \epsilon_{\text{inel}})^i)P(i, \lambda)}
\]

\[
= 1 + \frac{1}{2} \lambda \epsilon_{\text{inel}} + \frac{1}{12} \lambda^2 \epsilon_{\text{inel}}^2 + O(\lambda^3)
\]

- Correction factor – accounts for multiple collisions being counted as one.
LHC as a small x machine

- **LHC can access lowest x values**
  - for central W/Z production at 7 TeV: $x \sim 0.01$
  - 14 TeV: $x \sim 0.005$
  - at forward rapidities ($\eta \sim 5$):
    - 7 TeV: $x \sim 6 \cdot 10^{-5}$
    - 14 TeV: $x \sim 3 \cdot 10^{-5}$
  - for central jets with $p_t > 20$ GeV:
    - 7 TeV: $x \sim 0.006$
    - 14 TeV: $x \sim 0.003$
  - at forward rapidities ($\eta \sim 5$):
    - 7 TeV: $x \sim 4 \cdot 10^{-5}$
    - 14 TeV: $x \sim 2 \cdot 10^{-5}$