Recent Diffractive and Exclusive Results from CMS

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On behalf of the CMS Collaboration
Outline

• Introduction
• Proton-proton collisions
  • Exclusive $\gamma\gamma \rightarrow W^+W^-$ production
  • Limits on anomalous quartic gauge couplings
  • Exclusive $\pi^+\pi^-$ production
    • Differential and integrated cross-sections
• Ongoing analyses and future prospects
  • Using CMS-TOTEM data to extend studies of central exclusive production
The CMS Experiment

LHC Runs
pp 7, 8, 13 TeV
Exclusive electroweak boson pairs
Motivation: Exclusive electroweak boson pairs

- The exclusive production of $W$ pairs is sensitive to anomalous quartic gauge couplings (aQGC)

- The electroweak sector of Standard Model predicts QGC

- Any deviation from SM expectations can reveal a sign of new physics

- Objective: Measure SM cross section and look for aQGC.

- aQGC are introduced via effective Lagrangian

$$\mathcal{L}_6^0 = \frac{-e^2}{8} \frac{a_0^W}{\Lambda^2} F_{\mu\nu} F^{\mu\nu} W^{+\alpha} W^{-\alpha}$$

$$\mathcal{L}_6^C = \frac{-e^2}{16} \frac{a^W_C}{\Lambda^2} F_{\mu\alpha} F^{\mu\beta} (W^{+\alpha} W^{-\beta} - W^{-\alpha} W^{+\beta})$$

Anomalous coupling constant for quartic vertex

$\Lambda$: Scale for New Physics
Exclusive $\gamma\gamma \rightarrow W^+ W^-$: event selection

- Exclusive production of $W$ pairs
  \[ p p \rightarrow p^{(*)} W^+ W^- p^{(*)} \]
  \[ p^{(*)}: \text{Elastic + Inelastic contributions} \]

- 2011 $pp$ collision data at 7 TeV with 5.05 fb$^{-1}$

- 2012 $pp$ collision data at 8 TeV with 19.7 fb$^{-1}$

- Offline exclusive $\gamma\gamma \rightarrow W^+ W^-$ signal selection
  - Opposite-sign $e\mu$ pair (final state) originating from common primary vertex
  - No extra tracks at $e\mu$ vertex
    to remove inclusive background
  - Invariant mass ($e\mu$) $> 20$ GeV
    to get rid of any low mass resonances
  - $p_T (e\mu) > 30$ GeV
    to suppress DY and $\gamma\gamma \rightarrow \tau^+ \tau^-$

- Proton dissociation factor from $\mu\mu$ sample
Exclusive $\gamma\gamma \to W^+ W^-$ production at 7 and 8 TeV

SM signal region: N extra tracks = 0, $p_T(e\mu) > 30$ GeV

Cross section times branching fraction

$$\sigma(pp \to p^*(*)W^+ W^-p^*(*) \to p^*(*)\mu^+\mu^-$ applied $$

- Expected Signal: $2.2 \pm 0.4$
- Expected bkg: $0.84 \pm 0.15$
- Observed: 2

- Expected Signal: $5.3 \pm 0.7$
- Expected bkg: $3.9 \pm 0.6$
- Observed: 13

SM Prediction: $4.0 \pm 0.7$ fb

The observed significance for 7 and 8 TeV combination is $3.4\sigma$
Exclusive $\gamma\gamma \rightarrow W^+W^-$: aQGC limit

- Used shape of $p_T$ (e\(\mu\)) distribution to search for sign of anomalous quartic gauge couplings
- $p_T$ (e\(\mu\)) > 100 GeV used at 7 TeV
- Two bins at 8 TeV:
  - $30 < p_T$ (e\(\mu\)) < 130 GeV
  - $p_T$ (e\(\mu\)) > 130 GeV
- Region outside solid line is excluded at 95% CL
- The most stringent limit so far, two orders of magnitude more stringent than LEP

<table>
<thead>
<tr>
<th>Dimension-6 AQGC parameter</th>
<th>7 TeV ($\times 10^{-4}$ GeV$^{-2}$)</th>
<th>8 TeV ($\times 10^{-4}$ GeV$^{-2}$)</th>
<th>7+8 TeV ($\times 10^{-4}$ GeV$^{-2}$)</th>
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</thead>
<tbody>
<tr>
<td>$a_W^W / \Lambda^2$ ($\Lambda_{\text{cutoff}} = 500$ GeV)</td>
<td>$-1.5 &lt; a_W^W / \Lambda^2 &lt; 1.5$</td>
<td>$-1.1 &lt; a_W^W / \Lambda^2 &lt; 1.0$</td>
<td>$-0.9 &lt; a_W^W / \Lambda^2 &lt; 0.9$</td>
</tr>
<tr>
<td>$a_C^W / \Lambda^2$ ($\Lambda_{\text{cutoff}} = 500$ GeV)</td>
<td>$-5 &lt; a_C^W / \Lambda^2 &lt; 5$</td>
<td>$-4.2 &lt; a_C^W / \Lambda^2 &lt; 3.4$</td>
<td>$-3.6 &lt; a_C^W / \Lambda^2 &lt; 3.0$</td>
</tr>
</tbody>
</table>
Exclusive $\pi^+\pi^-$ production
Exclusive $\pi^+\pi^-$ production: Experimental signature

- Exclusive production of hadrons at central rapidities phenomenologically described in terms of “DPE” Double Pomeron Exchange when the mass of central system is low, or pertubatively in “CEP”

- **Experimental signature:**
  - Only two opposite sign tracks ($\pi^\pm$) from the same primary vertex
  - No additional signal in calorimeters
  - $p_T(\pi) > 0.2$ GeV
  - $|y(\pi)| < 2$
Exclusive $\pi^+\pi^-$ production: Background estimation

- **Signal:** (Zero-bin with opposite-sign (OS) events)

- **Background:**
  - Make “data-driven”
  - Both normalization and shape for different distributions
  - OS and SS data for $2 \leq N_{extra} \leq 10$ are very well described with NBD
  - Extrapolation to $N_{extra} = 0$ is used
  - Use the same procedure on same-sign (SS) events (purely background)
Exclusive $\pi^+\pi^-$ production: Signal distribution

- Signal events ($N_{\text{extra}} = 0$)

- Background events obtained by scaling the events in the region $2 \leq N_{\text{extra}} \leq 10$ according to the amount predicted by the NBD for $N_{\text{extra}} = 0$

**Background is $\pi^+\pi^-$ events but with additional activity**
Exclusive $\pi^+\pi^-$ production: Results $d\sigma/dM$

**CMS-FSQ-12-004**  **arXiv:1706.08310**

**Differential cross section:**

- with $p_T(\pi) > 0.2$ GeV and $|y(\pi)| < 2$
- Compared to the predictions of DPE production from the **Dime MC** (red/green curves), and **STARLIGHT** (dash). (Here: Dime MC & Starlight are stacked)
- The shaded blue band shows the overall systematic uncertainty, and the thin error bar indicates the statistical uncertainty
- The results are plotted on a linear scale (left) and a logarithmic scale (right)
Exclusive $\pi^+\pi^-$ production: Results $d\sigma/dp_T$, $d\sigma/dy$

Differential cross sections as a function of $p_T$ and rapidity:

- with $p_T(\pi) > 0.2$ GeV and $|y(\pi)| < 2$

- Compared to the predictions of DPE production from the Dime MC (red/green curves), and STARLIGHT (dash).

- (Here: Dime MC & Starlight are stacked) The shaded blue band shows the overall systematic uncertainty, and the thin error bar indicates the statistical uncertainty.

- The results are plotted on a logarithmic scale (top) and a linear scale (bottom).

$$\sigma_{\pi^+\pi^-} = 26.5 \pm 0.3\,(stat) \pm 5.0\,(syst) \pm 1.1\,(lumi)\,\mu b$$
Future prospects
Joint CMS-TOTEM $\beta^*=90\text{m}$ runs in October 2015
About 0.4/pb of low-pileup ($\mu = 0.06-0.15$) data at 13 TeV
Events with central system in CMS and diffractive protons in TOTEM Roman Pots
Separate DAQ systems with trigger exchange
CMS and TOTEM data reconstructed separately, then merged offline (event by event based on the same orbit and bunch crossing)
Dedicated CMS track reconstruction tune, to assure high track-finding efficiency for low-$p_T$ tracks and high vertex-finding efficiency for 2-track events

**Trigger:** Two scattered protons in the TOTEM Roman Pots (RP), no activity in the TOTEM T2 telescopes, at least 5 clusters in the CMS pixel detector
Transverse momenta \( p_Y \) of the scattered protons detected in Roman Pots (TOTEM) vs transverse momenta of two pion tracks measured in the central tracking system (CMS) for the \( pp \rightarrow pp\pi^+\pi^- \) production. Events on the diagonal correspond to the exclusive \( \pi^+\pi^- \) production.

Adding tagged protons from TOTEM greatly helps to select exclusive \( pp \rightarrow pp\pi^+\pi^- \) process with no proton-dissociation.

The three distinct regions along the \( p_Y^\text{TOTEM} \) axis correspond to the top-top, diagonal and bottom-bottom proton configurations.
Summary
• Exclusive $\gamma\gamma \rightarrow W^+ W^-$
  • 2 events observed at 7 Tev, 13 events observed at 8 Tev in SM region
  • No indication of aQGC found
• Exclusive $\pi^+ \pi^-$
  • Differential cross-sections above exclusive $\pi^+ \pi^- + \rho$ photoproduction predictions for high-pt
  • The invariant mass spectrum shows some features not included in the purely non-resonant predictions
• Using combined CMS-Totem data provides a very clean sample with no proton-dissociation background
• More exciting exclusive results to be presented this year
  • Not only in pp data, but also in pPb data and in PbPb!

Thank you for your attention!
Additional slides
Requirements of the transverse momentum balance $|p_Y^{CMS} + p_Y^{TOTEM}| < 2\sigma_{dpY}$ and $|p_X^{CMS} + p_X^{TOTEM}| < 2\sigma_{dpX}$ are applied to reject background and select events of central exclusive production, $pp \rightarrow ppX$ with $X = \pi^+\pi^-, K^+K^-, \pi^+\pi^-\pi^+\pi^-, K^+K^-K^+K^-$, …
Future prospects: Joint CMS-TOTEM run @13 TeV

Left: the x position of the event vertex for pp->ppπ⁺π⁻ events reconstructed from an extrapolation of the proton tracks measured in the right (z>0) vs left (z<0) TOTEM Roman Pot.

Right: The CMS vs TOTEM measurement of the x position of the event vertex for pp->ppπ⁺π⁻ events. The CMS value is measured in the CMS reference frame, while the TOTEM value is measured in the LHC reference frame.

The β*=90m optics has parallel-to-point focusing for the y plane – the RP measurement in y has no sensitivity on the vertex (only on the scattering angle).
Requirements of the vertex compatibility $|x_{VTX}^{p\text{ right}} - x_{VTX}^{p\text{ left}}| < 2\sigma_{TOTEM \ dx_{VTX}}$ and $|x_{VTX}^{CMS} - x_{VTX}^{TOTEM} - x_0| < 2\sigma_{dx_{VTX}}$ are applied to reject background and select events of central exclusive production, $pp \rightarrow ppX$ with $X=\pi^+\pi^-, K^+K^-, \pi^+\pi^-\pi^+\pi^-, K^+K^-K^+K^-, \ldots$. 

Future prospects: Joint CMS-TOTEM run @13 TeV