$\gamma\gamma \rightarrow WW$ and Anomalous Quartic Gauge Couplings at CMS

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EPS-HEP
July 19, 2013
Quartic Gauge Couplings

• Fundamental prediction of the Standard Model electroweak sector
• Deviations from predictions would indicate new physics – typically parametrized in terms of Anomalous Quartic Gauge Couplings
• At the LHC, quartic couplings can be studied via:
  • Boson scattering – for example $\gamma\gamma \rightarrow WW$
  • Tri-boson production – for example $WWW\gamma$, $WZ\gamma$
  • Both types of analyses pursued in CMS
$\gamma\gamma \rightarrow WW$ at the LHC

- Large cross section for high-energy $\gamma\gamma$ interactions at the LHC
  - $\gamma\gamma \rightarrow WW$ process has never before been observed

- In an untagged analysis - protons may stay intact, or dissociate into an undetected low-mass system
  - Signal is the sum of both topologies: $pp \rightarrow p^{(*)}WWp^{(*)}$
\( \gamma\gamma \rightarrow WW \) analysis in CMS

- Search for \( \gamma\gamma \rightarrow WW \) performed using full 5fb\(^{-1} \) collected at 7TeV during 2011

- Consider only \( WW \rightarrow \mu e \) (+ neutrinos) final state for signal
  - Same flavor channels have much larger backgrounds – use \( \gamma\gamma \rightarrow \mu\mu \) as a control sample to constrain signal systematic and theory uncertainties

- “Exclusivity” defined by counting tracks on \( \mu e \) vertex – reduce sensitivity to pileup
  - Select events with 0 extra tracks and \( p_T(\mu e) > 30 \) GeV (SM signal region) and \( p_T(\mu e) > 100 \) GeV (AQGC search region)
$\gamma\gamma \rightarrow \mu\mu$ control samples

- Elastic-enriched selection with 0 extra tracks
  - Good agreement with predictions for $\gamma\gamma \rightarrow \mu\mu$ off the $Z$ peak (LPAIR MC)
  - Use this sample to bound systematics from exclusivity, pileup modelling

- Proton dissociation-enriched selection
  - Expect larger discrepancies from rescattering corrections not included in the MC simulation
  - Derive a total normalization factor for $(\text{elastic} + \text{proton-dissociation})/\text{elastic}$ from high-mass dimuon data

$$F = 3.23 \pm 0.53.$$
\[ \gamma\gamma \rightarrow WW \rightarrow \mu e \] backgrounds

- Background predictions are checked from sideband control regions in number of extra tracks and \( p_T(\mu e) \)

<table>
<thead>
<tr>
<th>Region</th>
<th>Background process</th>
<th>Data</th>
<th>Sum of backgrounds</th>
<th>( \gamma\gamma \rightarrow W^+W^- ) signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inclusive ( W^+W^- )</td>
<td>43</td>
<td>46.2 ± 1.7</td>
<td>1.0</td>
</tr>
<tr>
<td>2</td>
<td>Inclusive Drell-Yan ( \tau^+\tau^- )</td>
<td>182</td>
<td>256.7 ± 10.1</td>
<td>0.3</td>
</tr>
<tr>
<td>3</td>
<td>( \gamma\gamma \rightarrow \tau^+\tau^- )</td>
<td>4</td>
<td>2.6 ± 0.8</td>
<td>0.7</td>
</tr>
</tbody>
</table>

- Nominal background estimate: 0.84±0.15
- Consistent results obtained with several MC and data-driven (ABCD, same-sign events, tau-embedding) methods
For the SM signal region with $p_T(\mu e)>30\text{GeV}$:

- **Expected:**
  - $2.2\pm0.4$ (signal)
  - $0.84\pm0.15$ (bkg)
- **Observed:** 2 events
- Obtain a cross section times branching fraction and upper limit for a SM-like signal:

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

\[
\sigma(pp \to p^{(*)}W^+W^-p^{(*)} \to p^{(*)}\mu^\pm e^\mp p^{(*)}) < 10.6 \text{ fb}.
\]
AQGC search region

- For $p_T(\mu e) > 100$ GeV and 0 extra tracks
  - 0.14 events expected (SM)
  - 0 events observed

- Set a model-independent limit on the partial cross section times branching fraction

\[
\sigma(pp \to p^{(*)}W^+W^-p^{(*)} \to p^{(*)}\mu^\pm e^\mp p^{(*)}) < 1.9 \text{ fb.}
\]

For $p_T(\mu e) > 20$ GeV, $|\eta(\mu e)| < 2.4$, $p_T(\mu e) > 100$ GeV
Interpret results in terms of LEP-like “dimension-6” $\gamma\gamma WW$ AQGC's

- Strong unitarity violation for high-energy $\gamma\gamma$ interactions – give limits both with and without form factors ($\Lambda = 500 \text{ GeV}$) to preserve unitarity

Limits are $\sim 100x$ beyond LEP, $\sim 20x$ beyond Tevatron (with $\Lambda = 500 \text{ GeV}$)

No-FF limits are $\sim 100x$ beyond Tevatron (with no form factor)
WZγ and WWγ at CMS

- New - first LHC search for WVγ tri-boson production (where V = W or Z decaying to dijets)
  - Analysis performed in the lepton + dijet + photon + missing E_T final state
  - Based on the full 20fb⁻¹ dataset collected at 8 TeV

- Cross section limits obtained are 3.4x the Standard Model prediction
- Photon p_T is used as the variable to set limits on AQGC's
  - For additional details see talk by Chia-Ming Kuo
WVγ AQGC limits

- Interpret results in terms of both dimension-6 and dimension-8 (linear) anomalous \(WWγγ\) and \(WWZγ\) couplings
  - No form factors used

- Limits on \(WWγγ\) couplings are significantly beyond Tevatron
- First limits on the (CP-conserving) \(WWZγ\) couplings \(κ^W_C, κ^W_0\)

\[
\begin{align*}
-21 < a_0^W / \Lambda^2 &< 20 \text{ TeV}^{-2}, \\
-34 < a_C^W / \Lambda^2 &< 32 \text{ TeV}^{-2}, \\
-25 < f_{T,0} / \Lambda^4 &< 24 \text{ TeV}^{-4}, \\
-12 < κ_0^W / \Lambda^2 &< 10 \text{ TeV}^{-2}, \\
-18 < κ_C^W / \Lambda^2 &< 17 \text{ TeV}^{-2}.
\end{align*}
\]
Summary

- The investigation of quartic gauge boson couplings at the LHC is underway
- CMS has searched for $\gamma\gamma \rightarrow WW$ production in the $e\mu$ final state using 5fb$^{-1}$ collected at 7 TeV
  - For the SM signal region with $p_T(\mu e) > 30$GeV: 2 events observed, with $2.2\pm0.4$ signal, $0.84\pm0.15$ background expected
  - Limits on anomalous quartic $\gamma WW$ couplings are ~20-100x more stringent than previous results obtained at LEP/Tevatron
- CMS has searched for $WW\gamma$ and $WZ\gamma$ production in the lepton + photon + dijets + missing $E_T$ final state using 20fb$^{-1}$ collected at 8 TeV
  - Limits are set on the CP-conserving anomalous quartic $WWZ\gamma$ couplings $\kappa_c^W$, $\kappa_0^W$ for the first time

arXiv:1305.5596, To appear in JHEP ($\gamma\gamma \rightarrow WW$)
CMS PAS-SMP-13-009 ($WV\gamma$)
Additional material
Exclusive $\gamma\gamma$

- First search for exclusive diboson production at 7 TeV by CMS
  - Expected to be dominated by strong Central Exclusive Production
  - Based on 36pb$^{-1}$ collected in 2010

- 0 events observed - limits set on exclusive plus quasi-exclusive $pp \rightarrow p(*)\gamma\gamma p(*)$
  - Start to exclude upper end of theory predictions

JHEP 1211 (2012) 080
- Standard candle processes used to validate exclusivity selection
- Measured in both $\mu\mu$ and $ee$ channels in 2010 data
- Reasonable agreement with LPAIR MC in shapes and normalization
Life with pileup

- ~9 interactions/crossing in 2011 data
- Use tracking/vertexing selection to discriminate multiple interactions in the same bunch crossing

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ12010
$\gamma\gamma \rightarrow \mu\mu$ control samples (I)

- Elastic-enriched selection with 0 extra tracks
  - Good agreement with predictions for $\gamma\gamma \rightarrow \mu\mu$ off the Z peak (LPAIR MC)
  - Use this sample to bound systematics from exclusivity, pileup modelling

- On the Z peak
  - Yields consistent with expected residual Drell-Yan background