Sensitivity to anomalous quartic gauge couplings in $\gamma\gamma$ interactions at LHC

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On behalf of the Louvain Photon Group

• Introduction: LHC as a $\gamma\gamma$ collider
• Detection of two-photon exclusive pair production
• Sensitivity to aQGCs: $\gamma\gamma$WW and $\gamma\gamma$ZZ case
• Summary/Outlook

Europhysics Conference on High Energy Physics

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LHC as a $\gamma\gamma$ collider

V.M. Budnev et al. 
*Phys. Rept.* 15, 181

\[
\sigma(\ pp \rightarrow (\gamma\gamma \rightarrow X)\ pp )
\]

Low $\gamma$ virtuality (typical $Q^2 \sim 0.01\text{GeV}^2$) $\Rightarrow$

- factorization to
  - long distance photon exchange
  - short distance $\gamma\gamma \rightarrow X$ interaction
LHC as a $\gamma\gamma$ collider

Main detector acceptance cuts:
- $p_T(\mu) > 3$ GeV, $|\eta| < 2.5$

**CMS / ATLAS**

**RP acceptance:** HECTOR

- $120$ GeV < tagged $E_\gamma$ < $900$ GeV
  - RP 220m
- $20$ GeV < tagged $E_\gamma$ < $120$ GeV
  - RP 420m

\[
\sigma_{\gamma\gamma} = \int \sigma(W_{\gamma\gamma}) \frac{dL_{\gamma\gamma}}{dW_{\gamma\gamma}} dW_{\gamma\gamma}
\]
LHC as a $\gamma\gamma$ collider

- $\gamma\gamma \to \mu\mu$ first $\gamma\gamma$ process to be seen
- $\gamma\gamma \to W^+W^-$ very interesting SM process 108 fb
- New physics!

<table>
<thead>
<tr>
<th>Processes</th>
<th>[fb]</th>
<th>Generator</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma\gamma \to \mu\mu$</td>
<td>72,500</td>
<td>LPAIR pt &gt; 2 GeV $</td>
</tr>
<tr>
<td>$\gamma\gamma \to WW$</td>
<td>108</td>
<td></td>
</tr>
<tr>
<td>$\to FF$ (m=100 GeV)</td>
<td>4.06</td>
<td>MadGraph</td>
</tr>
<tr>
<td>$\to FF$ (m=200 GeV)</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>$\to SS$ (m=100 GeV)</td>
<td>0.68</td>
<td>MadEvent</td>
</tr>
<tr>
<td>$\to SS$ (m=200 GeV)</td>
<td>0.07</td>
<td></td>
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Moreover:
- Lepton final states
- Clear signature – background suppression

Cross sections for $\gamma\gamma$ processes as a function of the minimal $\gamma\gamma$ cms energy $W_0$
we use Lagrangian for genuine anomalous quartic vector boson couplings which conserves C, P as well as local U(1)_{SM} and SU(2)_{C}

\[ L_6^0 = -\frac{e^2}{8} \frac{\alpha_0^W}{\Lambda^2} F_{\mu\nu} F^{\mu\nu} W^+ W^- - \frac{e^2}{16 \cos^2 \theta_W} \frac{\alpha_0^Z}{\Lambda^2} F_{\mu\nu} F^{\mu\nu} Z^+ Z^- \]

\[ L_6^C = -\frac{e^2}{16} \frac{\alpha_C^W}{\Lambda^2} F_{\mu\alpha} F^{\mu\beta} (W^+ W^- + W^- W^+) - \frac{e^2}{16 \cos^2 \theta_W} \frac{\alpha_C^Z}{\Lambda^2} F_{\mu\alpha} F^{\mu\beta} Z^+ Z^- \]

This gives a general auxiliary formula for a cross section (total or differential, with or without cuts) as a function of the anomalous parameters:

\[ \sigma = \sigma_{SM} + \sigma_0 a_0 + \sigma_0 a_0^2 + \sigma_C a_C + \sigma_{CC} a_C^2 + \sigma_{0C} a_0 a_C \]
Detector acceptance

Simple event counting in the main detector with a two leptons (e or $\mu$) signature within the acceptance cuts:

- $|\eta| < 2.5$
- $p_T > 10 \text{ GeV}$

- WW : $\gamma \gamma \rightarrow W^+ W^- \rightarrow l^+ l^- \nu_l \bar{\nu}_l$
- ZZ : $\gamma \gamma \rightarrow ZZ \rightarrow l^+ l^- jj$ (no cuts on jets)

for a background we assume:

- WW : only SM $\gamma \gamma \rightarrow WW$
- ZZ : no background – as no tree level SM $\gamma \gamma \rightarrow ZZ$

Note: CEP of WW is $< 1 \text{ fb}$
Setting limits on aQGCs

\[ \text{if } N_{\text{obs}} = \sigma_{\text{cuts}}^{SM} \cdot L, \ \text{CL}=95\% \]

\[ \sum_{k=0}^{N_{\text{obs}}} P_{\text{Poisson}}(\lambda^{up} = \sigma^{up} \cdot L ; \ k) = 1 - CL \]

The calculated cross section CL=95% upper limits are:

<table>
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<th>$\gamma \gamma \rightarrow WW$</th>
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<td>$\sigma_{\text{cuts}}^{SM} = 4.081$ fb</td>
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can be easily converted to the limit on the anomalous quartic couplings

![Graph showing limits on $a_0^Z/\Lambda^2$ and $a_0^W/\Lambda^2$ for $\gamma\gamma \rightarrow WW$ and $\gamma\gamma \rightarrow ZZ$.]
Setting limits on aQGCs

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can be easily converted to the limit on the anomalous quartic couplings.
Setting limits on aQGCs

\[
\begin{align*}
\sigma_{WW} & \quad L=1\text{fb}^{-1} \\
\sigma_{ZZ} & \quad L=10\text{fb}^{-1}
\end{align*}
\]

\[
\begin{array}{|c|c|c|}
\hline
\text{Coupling} & \text{Limits [GeV}^3\text{]} \ & \text{L=1fb}^{-1} \ & \text{L=10fb}^{-1} \\
\hline
\left| a_0^Z / \Lambda^2 \right| & 0.49 \cdot 10^{-6} & 0.16 \cdot 10^{-6} \\
\left| a_0^W / \Lambda^2 \right| & 0.54 \cdot 10^{-6} & 0.27 \cdot 10^{-6} \\
\left| a_C^Z / \Lambda^2 \right| & 1.84 \cdot 10^{-6} & 0.58 \cdot 10^{-6} \\
\left| a_C^W / \Lambda^2 \right| & 2.02 \cdot 10^{-6} & 0.99 \cdot 10^{-6} \\
\hline
\end{array}
\]
So far no constrains on $W$ were applied → need to watch unitarity bounds!

Anomalous enhancement mostly at high $W_{\gamma\gamma}$ mass
In non elastic scattering partial wave function $a_L$:

$$a_L = \frac{1}{32\pi} \int_{-1}^{1} M(\sqrt{s}, \cos \Theta, a_0, a_C) \cdot P_L(\cos \Theta) d\cos \Theta$$

must satisfy:

$$\beta \sum_{pol} |a_L(\sqrt{s}, a_0, a_C)|^2 < \left( \frac{1}{2} \right)^2$$
Unitarity bounds

\[ a \rightarrow \frac{a}{\left(1 + \frac{W^2_{\gamma \gamma}}{\Lambda^2}\right)^2} \]

Limits including form-factor:
\[ a_0^w/\Lambda^2 < 2.5 \cdot 10^{-6} \text{ GeV}^2 \]
\[ a_z^w/\Lambda^2 < 9 \cdot 10^{-6} \text{ GeV}^2 \]

whilst LEP:
\[ a_0^w/\Lambda^2 < 2.0 \cdot 10^2 \text{ GeV}^2 \]
\[ a_z^w/\Lambda^2 < 3.7 \cdot 10^2 \text{ GeV}^2 \]

for \( L = 10 \text{ fb}^{-1} \)

Improvement of \(~4000\)
Differential distributions

- use of leptons $p_T$ and/or $\eta$ distributions – discriminating power

**differential cross section:**
- SM
- anomalous $a_0^{W/\Lambda^2} = 0.54 \cdot 10^{-6}$, $a_c^{W/\Lambda^2} = 0$ [GeV$^{-2}$]

\[ \gamma\gamma \rightarrow W^- W^+ \]

Definitely a lot of space for improvements, but can it be done at very high luminosity?
Event pileup

In preceding discussion no event pileup was assumed so full exclusivity condition could be applied: Apart from two leptons, no activity in central detectors (including calorimeters)

Very powerful condition, leaves no non-exclusive backgrounds (beautifully applied at Tevatron: see 5 papers by CDF) BUT cannot be used if two events occur in the same bunch crossing → large loss of luminosity by requesting single event BX…

Solution 1:

Use track-based exclusivity, allow only two leptons and NO more tracks from the vertex (Note: only charged particlers and ±2.5 rapidity units vs ±5 for calorimeters)
Works well for medium luminosities, up to $2.10^{33}$ cm$^{-2}$s$^{-1}$

Solution 1+2:

Apply track exclusivity and require detection in the forward detectors + z-vertex matching from time difference measurements in ToF detectors (GasToF)

See FP420 talk for details
Exclusive dileptons at high $\mathcal{L}$

N. Schul at SUSY'09: Assume 10 ps ToF resolution

Low lumi, exclusivity

High lumi, exclusivity

Low lumi, exclusivity + Gastof

High lumi, exclusivity + Gastof
LHC is a powerful photon-photon collider (1% pp luminosity available for $\gamma\gamma$ collisions at energies above 200 GeV)

Exclusive two-photon WW and ZZ production provides stringent tests if SM

Exclusive dilepton events from leptonic W and Z decays will allow to improve LEP quartic gauge couplings limits by orders of magnitudes already with small integrated LHC luminosity

To be able to study the exclusive production at nominal LHC luminosity novel, very forward proton detectors are mandatory!

Wide set of other models will be studied (SU(2) gauge symmetric, Higgsless scenarios, etc.)

Stay Tuned!
A Higgs Boson without the Mess

Particle physicists at CERN's Large Hadron Collider (LHC) hope to discover the Higgs boson amid the froth of particles born from proton-proton collisions. Results in the 19 June Physical Review Letters show that there may be a way to cut through some of that froth. An experiment at Fermilab's proton-antiproton collider in Illinois has identified a rare process that produces matter from the intense field of the strong nuclear force but leaves the proton and antiproton intact. There's a chance the same basic interaction could give LHC physicists a cleaner look at the Higgs.

A proton is always surrounded by a swarm of ghostly virtual photons and gluons associated with the fields of the electromagnetic and strong nuclear forces. Researchers have predicted that when two protons (or a proton and an antiproton) fly past one another at close range, within a Higgs machine. If CERN's Large Hadron Collider (LHC) can create Higgs bosons, a handful may appear in rare "exclusive" reactions that don't destroy the colliding protons—similar to a reaction now observed at Fermilab. CERN's ATLAS and CMS teams are considering adding equipment to their detectors (CMS shown here) to look for such events (click image to enlarge).
Two-photon physics

MSSM: 100 fb-1 (no pileup)

Large rates for WW

arXiv:0807.1121

(Light) SUSY case

Figure 3. Distribution of missing invariant mass $W_{\text{miss}}$ for the LM1 MSSM benchmark for the integrated luminosity $L = 100$ fb$^{-1}$. It starts at about $2m_{\text{LSP}}$ for SUSY, at zero for the $WW$ background.

$$W_{\text{miss}} = \sqrt{E_{\text{miss}}^2 - P_{\text{miss}}^2}$$

Brief history:
Ohnemus & Zerwas ’93
Piotrzkowski ’00, ’01

Forward detectors crucial for kinematics reconstruction (charged dilepton states only!):

Unique contribution!
Accidental overlays

Additional background arises from **accidental coincidence** where the detected system $X$ in the central detector and the forward protons in VFD do not come from the same vertex:

At the LHC, $<N_{\text{pile-up}}>$ is

- ~5 events for $L = 2*10^{33}$ cm$^{-2}$ s$^{-1}$
- ~25 events for $L = 1*10^{34}$ cm$^{-2}$ s$^{-1}$

* Single diffraction (pp$\to$Xp)
  \[ \sigma = 14.30 \text{ mb} \]
  \[ \varepsilon_{FP220} = 15\% \]
  \[ \varepsilon_{FP420} = 12\% \]
  \[ \Rightarrow \sigma_{VFD} = 3.8 \text{ mb} \]

* Double diffraction (pp$\to$X)
  \[ \sigma = 10.21 \text{ mb} \]
  \[ \varepsilon_{FP220} = 1.3\% \]
  \[ \varepsilon_{FP420} = 0.02\% \]
  \[ \Rightarrow \sigma_{VFD} = 0.13 \text{ mb} \]

* Non-Diffractive inelastic (pp$\to$X)
  \[ \sigma = 54.71 \text{ mb} \]
  \[ \varepsilon_{FP220} = 0.33\% \]
  \[ \varepsilon_{FP420} < 0.01\% \]
  \[ \Rightarrow \sigma_{VFD,\text{TOT}} = 0.18 \text{ mb} \]

\[ \Rightarrow \text{Global: } \varepsilon_{FP240} = 2.165\% \]
\[ \varepsilon_{FP420} = 3.015\% \]
\[ \Rightarrow \sigma_{VFD,\text{TOT}} = 4.10 \text{ mb} \]

Use timing for background suppression
Taken on 14/1/2009

- CMS
- Q6
- ~240m from IP5

Quench resistors
To alcove
Moving Hamburg pipe concept

Successfully used at HERA: Robust and simple design, + easy access to detectors

Motorization and movement control to be cloned from LHC collimator design
Calibration with exclusive di-muons

Calibration procedure itself can be very well controlled using Upsilon signal!

BOTTOMLINE:
Exclusive low-mass dimuons crucial for FP420
Problem: Same signature (one or two very forward protons) has also central diffraction (i.e. pomeron-pomeron scattering) in strong interactions

Both processes weakly interfere, and transverse momentum of the scattered protons are in average much softer in two-photon case

\begin{align*}
\langle Q^2 \rangle &< 0.01 \text{ GeV}^2 \\
\end{align*}

a) 'true' distributions; b) distributions smeared due to beam intrinsic $p_T$; all plots normalized for $p_T^2 < 2 \text{ GeV}^2$

$p_T$ gives powerful separation handle provided that size of $\gamma\gamma$ and pomeron-pomeron cross-sections are not too different

Assuming ultimate $p_T$ resolution $\approx 100 \text{ MeV}$; i.e. neglecting detector effects

16/07/09