Search for anomalous quartic $WW\gamma\gamma$ couplings in the dielectron and missing energy final state with the DØ detector

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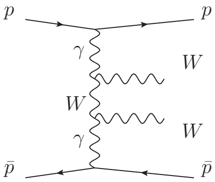
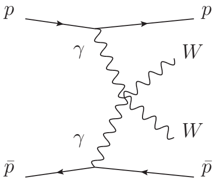
Outline

Two-photon interaction at the Tevatron

- Study of the QED process $p\bar{p} \to p\bar{p}WW$
- Very small cross section in the Standard Model ($\sigma_{p\bar{p}\to p\bar{p}WW} = 3$ fb at $\sqrt{s} = 1.96$ TeV).
- Sensitivity to beyond standard model effects, especially anomalous couplings (which can arise from e.g. models with extra dimensions).
- In this analysis we only study anomalous quartic gauge couplings (aQGCs), and not triple gauge couplings (TGCs).





Lagrangians

Effective lagrangian for aQGCs $WW\gamma\gamma$ (dim-6):

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

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

where $F_{\mu\nu}$ is the electromagnetic field strength tensor and $W_\alpha^\pm$ is the $W^\pm$ boson field.

Both anomalous parameters a_0^W and a_C^W are 0 in the SM.

Unitarity

If nothing is done, unitarity is violated at high energies. Introduce a form-factor: $a_0^W/\Lambda^2 \to \frac{a_0^W/\Lambda^2}{(1+W_{\gamma\gamma}^2/\Lambda^2)^2}$ where $\Lambda \sim$ scale of new physics (typical values from literature[a]: $\Lambda = 0.5$ TeV or 1 TeV).

[a] e.g. Eboli *et al.*, Phys. Rev. D **63**, 075008 (2001)

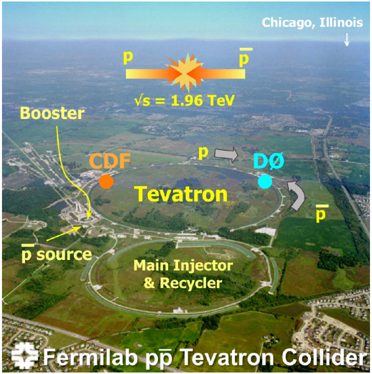
Previous results

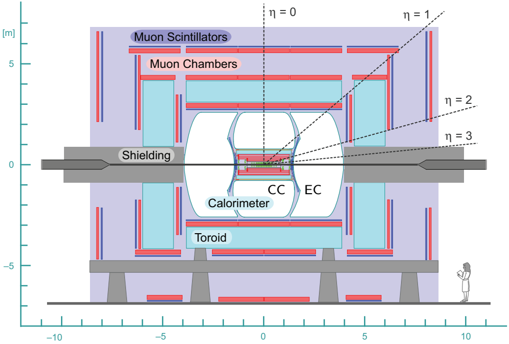
Current best published limits: OPAL

$$-0.020 < \quad a_0^W/\Lambda^2 \quad < 0.020\text{GeV}^{-2}$$
$$-0.052 < \quad a_C^W/\Lambda^2 \quad < 0.037\text{GeV}^{-2}$$

OPAL Collaboration, Phys. Rev. D **70**, 032005 (2004) [arXiv:hep-ex/0402021].

The DØ detector at the Tevatron



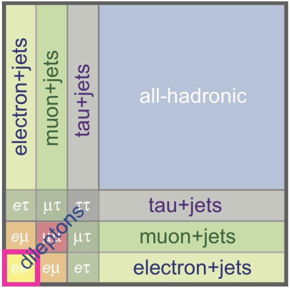


Strategy

Bulk of the analysis common with the DØ search for $H \to WW \to \ell\nu\ell\nu$ [1]

- Same final state ($WW \to \ell\nu\ell\nu$).
- $p\bar{p} \to WW$ cross section measured in the $H \to WW$ analysis.
- aQGC search specificities:
  - Only the $e\nu e\nu$ final state is considered.
  - Search optimized for the aQGC signal instead of the Higgs boson signal.

WW Branching Ratios (BR)



Experimental signature

Two high-p_T electrons and missing transverse energy.

[1] arXiv:1301.1243 [hep-ex] (2013), accepted by Phys. Rev. D.

Signal and background modeling

Photon exchange and double pomeron exchange processes

- Signal: $p\bar{p} \to p\bar{p}WW$ through photon exchange, with aQGCs.
- Backgrounds: WW and $\ell\ell$ production through photon exchange or double pomeron exchange (DPE).
- Processes modeled using Forward Physics Monte-Carlo (FPMC).

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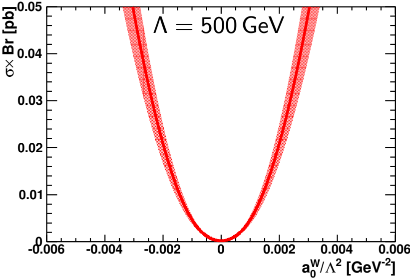
Non-diffractive backgrounds

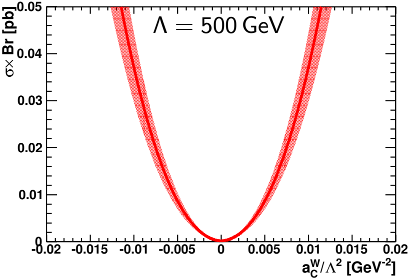
- Physics backgrounds: Z/γ^*+jets, $t\bar{t}$, diboson (WW, WZ, ZZ).
- Instrumental backgrounds: W+jets, multijet.
- Modeled using PYTHIA or ALPGEN + PYTHIA.
  - Multijet background fully determined from data.

Signal cross section

Cross sections

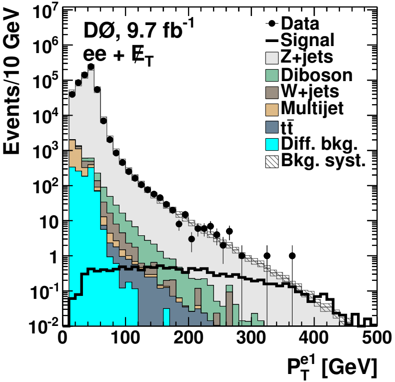
- In the SM: $\sigma_{p\bar{p}\rightarrow p\bar{p}WW} = 3\,\text{fb}$ ($\rightarrow$ 0.1 event after event selection).
- $10 - 100$ times enhancement with anomalous couplings.





Preselection

$a_0^W/\Lambda^2 = 5 \times 10^{-4}$ GeV^{-2}, no f.f.



Preselection

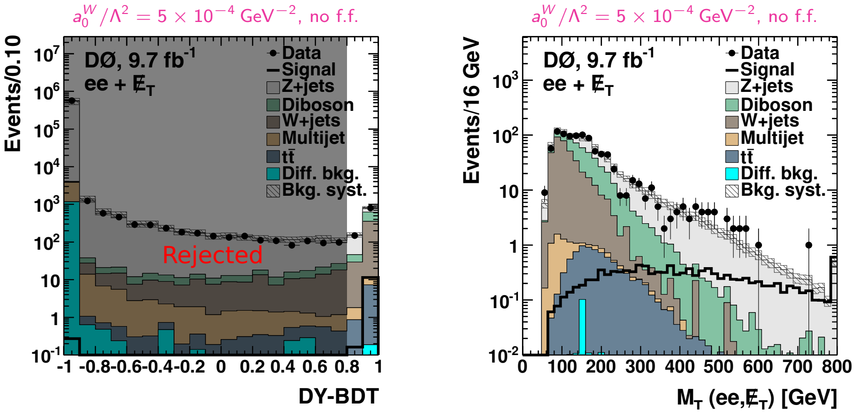
- Two opposite-sign electrons with $p_T^{1(2)} > 15(10)$ GeV.
- In the CC ($|\eta_D| < 1.1$) or the EC ($1.5 < |\eta_D| < 2.5$).
  - At least one electron in the CC.
- $M_{ee} > 15$ GeV.
- No jet above 20 GeV.

Expectation from aQGCs

- Boosted WW pair.
- Similar effects from a_0^W/Λ^2 and a_C^W/Λ^2.

Z/γ^*+jets rejection

Dominant Z/γ^*+jets background rejected thanks to a cut on a Boosted Decision Tree (BDT).



Event yields

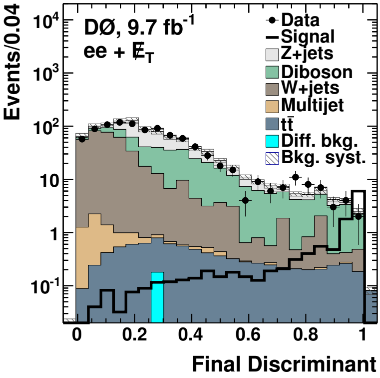
	Preselection	Final selection
Data	572700	946
Total background	576576 ± 11532	983 ± 108
Signal ($a_0^W/\Lambda^2 = 5 \times 10^{-4}$ GeV^{-2}, no f.f.)	12.2	11.6
$Z/\gamma^* \to ee$	566800	291
$Z/\gamma^* \to \tau\tau$	4726	22
$t\bar{t}$	15	8
W+jets	623	370
Diboson	517	287
Multijet	2716	5.4
Diff. bkg. (γ exch. and DPE)	1180	0.2

Final discriminant

A second BDT is used as final discriminant.

- The same BDT is used for both a_0^W/Λ^2 and a_C^W/Λ^2.

$a_0^W/\Lambda^2 = 5 \times 10^{-4}$ GeV^{-2}, no f.f.



Systematic uncertainties

Source	Uncertainty (%)
Z/γ^*+jets xsec.	6
W+jets xsec.	16
diboson xsec.	6
$t\bar{t}$ xsec.	7
Multijet norm.	30
$\not\!\!E_T$ modeling	4-5
Photon exchange and DPE norm.	100
Signal xsec.	20
Jet energy scale	4
Jet resolution	0.5
Jet identification	2
Jet association to $p\bar{p}$ vertex	2
W+jets modeling	10
WW modeling	< 1
W, Z p_T modeling	< 1

1D limits

Table: Expected and observed 95% C.L upper limits on $|a_0^W/\Lambda^2|$, assuming a_C^W is zero and for different assumptions about the form factor.

Cutoff	Expected upper limit [GeV^{-2}]	Observed upper limit [GeV^{-2}]
No form factor	0.00043	0.00043
$\Lambda = 1$ TeV	0.00092	0.00089
$\Lambda = 0.5$ TeV	0.0025	0.0025

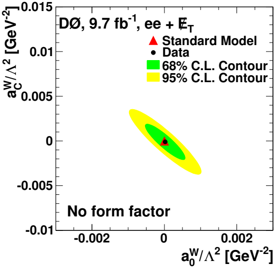
Table: Expected and observed 95% C.L upper limits on $|a_C^W/\Lambda^2|$, assuming a_0^W is zero and for different assumptions about the form factor.

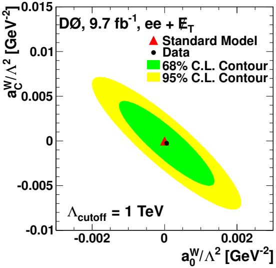
Cutoff	Expected upper limit [GeV^{-2}]	Observed upper limit [GeV^{-2}]
No form factor	0.0016	0.0015
$\Lambda = 1$ TeV	0.0033	0.0033
$\Lambda = 0.5$ TeV	0.0090	0.0092

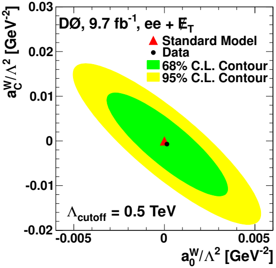
2D limits

Procedure

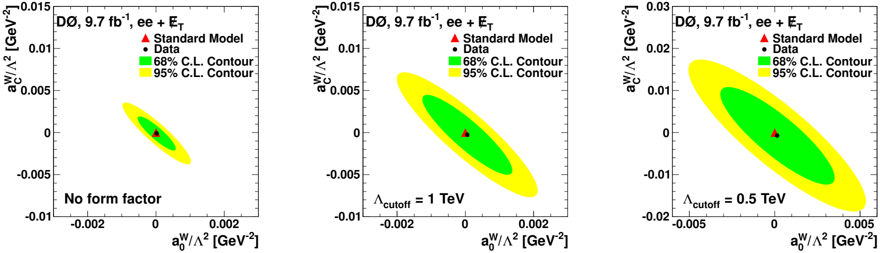
Based on the upper limit on the signal cross section obtained in the single parameter limits.







Conclusion



Probing new physics in the EW sector

New constraints on anomalous $WW\gamma\gamma$ quartic gauge boson couplings (a factor 4 to 8 more stringent than current best published limits):

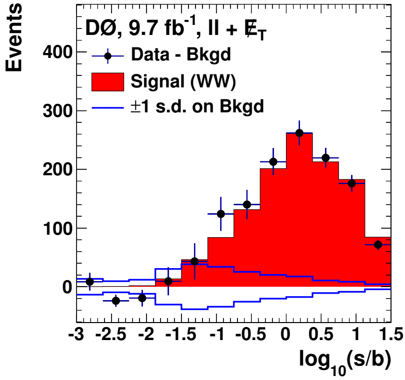
$$|a_0^W/\Lambda^2| < 0.0025\,\mathrm{GeV}^{-2} \qquad (a_C^W/\Lambda^2 = 0, \Lambda = 0.5\,\mathrm{TeV})$$

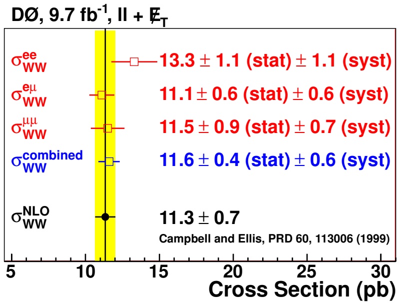
$$|a_C^W/\Lambda^2| < 0.0092\,\mathrm{GeV}^{-2} \qquad (a_0^W/\Lambda^2 = 0, \Lambda = 0.5\,\mathrm{TeV})$$

See 1305.1258 [hep-ex] (submitted to Phys. Rev. D – Rapid Communications) for more information.

Additional material

WW cross section in the $H \to WW$ analysis





CMS result

Current best limits: CMS Preliminary

Without form-factor:

$$-2.8 \times 10^{-6} < \quad a_0^W/\Lambda^2 \quad < 2.8 \times 10^{-6}\,\mathrm{GeV}^{-2}$$

$$-1.02 \times 10^{-5} < \quad a_C^W/\Lambda^2 \quad < 1.02 \times 10^{-5}\,\mathrm{GeV}^{-2}$$

With a form-factor with $\Lambda = 500\,\mathrm{GeV}$:

$$-0.00017 < \quad a_0^W/\Lambda^2 \quad < 0.00017\,\mathrm{GeV}^{-2}$$

$$-0.0006 < \quad a_C^W/\Lambda^2 \quad < 0.0006\,\mathrm{GeV}^{-2}$$

(CMS-PAS-FSQ-12-010).