Sermilab



Gauge boson self couplings



Gauge boson trilinear and quartic couplings emerge naturally from the non-abelian gauge symmetry of the standard model (SM).

• With $o(10^4)$ WW, $o(10^3)$ WZ, and o(10²) ZZ events, quickly approaching precision measurement of gauge couplings, already improved over LEP and Tevatron in most cases.

Measure coupling parameters in effective Lagrangian approach. In the case of charged trilinear couplings WWZ and WW_V

$\mathcal{L}_{anom} = ig_{WWZ}$	$\Delta g_1^Z (W^*_{\mu\nu} W^{\mu} Z^{\nu} - W_{\mu\nu} W^{*\mu} Z^{\nu}) + \Delta \kappa^Z W^*_{\mu} W^*_{\mu\nu} W^*_$	V
$+ i g_{WW\gamma}$	$\left[\Delta\kappa^{\gamma}W^{*}_{\mu}W_{\nu}\gamma^{\mu\nu} + \frac{\lambda^{\gamma}}{M^{2}_{W}}W^{*}_{\rho\mu}W^{\mu}_{\nu}\gamma^{\nu\rho}\right]$	

Five independent parameters: λ_Z , λ_V , $\Delta \kappa_Z$, $\Delta \kappa_V$, Δg_1^Z . Imposing SU(2) x U(1) gauge invariance reduces the number of independent parameters to three $\lambda_Z = \lambda_\gamma = \lambda$ (= 0 in SM) $\Delta \kappa_Z = \Delta g_1^Z - \Delta \kappa_\gamma \cdot \tan^2 \theta_W$ (= 0 in SM)

- A Neutral trilinear gauge couplings ZZ_{γ} , $Z_{\gamma\gamma}$, ZZZ are forbidden in SM
- Anomalous ZZ_{γ}, ZZZ couplings introduced by terms $f_4^{Z/\gamma}$ and $f_5^{Z/\gamma}$ in \mathcal{L}_{anom}
- Anomalous $Z_{\gamma\gamma}$ and ZZ_{γ} described by terms $h_3^{Z/\gamma}$ and $h_4^{Z/\gamma}$.

Trilinear couplings are getting highly constrained

Currently constrained within 3–9% for charged and within 1% for neutral aTGC. With 8 TeV data expect further improvement by a factor of few.



Example of effective Lagrangian (in "dimension 6 realization"):



Measure the coefficients a_0 and a_c from experimental data.

Constraints on Anomalous Gauge Boson Couplings

$$V_{\nu}Z^{\mu\nu} + \frac{\lambda^Z}{M_W^2} W^*_{\rho\mu} W^{\mu}_{\nu} Z^{\nu\rho} \bigg]$$

Limits on charged trilinear couplings*

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			ATLAS Limits H
Δ1/		Wγ	-0.410 - 0.460 4.6 fb ⁻¹
		Wγ	-0.380 - 0.290 5.0 fb ⁻¹
	lI	WW	-0.210 - 0.220 4.9 fb ⁻¹
	⊢−−−−− {	WV	-0.110 - 0.140 5.0 fb ⁻¹
	└────O───┤	D0 Combination	-0.158 - 0.255 8.6 fb ⁻¹
	⊢-●	LEP Combination	-0.099 - 0.066 0.7 fb ⁻¹
2	├	Wγ	-0.065 - 0.061 4.6 fb ⁻¹
\mathcal{N}_{γ}	⊢ {	Wγ	-0.050 - 0.037 5.0 fb ⁻¹
	⊢−−−1	WW	-0.048 - 0.048 4.9 fb ⁻¹
	⊢I	WV	-0.038 - 0.030 5.0 fb ⁻¹
	Ю	D0 Combination	-0.036 - 0.044 8.6 fb ⁻¹
	⊢●┥	LEP Combination	-0.059 - 0.017 0.7 fb ⁻¹
Δι	⊢	WW	-0.043 - 0.043 4.6 fb ⁻¹
ZKZ	┝━━┥	WV	-0.043 - 0.033 5.0 fb ⁻¹
	┝━━━┥	LEP Combination	-0.074 - 0.051 0.7 fb ⁻¹
λ	⊢—–I	WW	-0.062 - 0.059 4.6 fb ⁻¹
⁷ Z	⊢—-I	WW	-0.048 - 0.048 4.9 fb ⁻¹
	⊢–-I	WZ	-0.046 - 0.047 4.6 fb ⁻¹
	⊢ −1	WV	-0.038 - 0.030 5.0 fb ⁻¹
	FOH	D0 Combination	-0.036 - 0.044 8.6 fb ⁻¹
	H	LEP Combination	-0.059 - 0.017 0.7 fb ⁻¹
Δq^{Z}	⊢1	WW	-0.039 - 0.052 4.6 fb ⁻¹
-9_{1}	⊢−−−−−−	WW	-0.095 - 0.095 4.9 fb ⁻¹
	├	WZ	-0.057 - 0.093 4.6 fb ⁻¹
	H-0I	D0 Combination	-0.034 - 0.084 8.6 fb ⁻¹
		LEP Combination	-0.054 - 0.021 0.7 fb ⁻¹
			<u> </u>
-0.5	0 (
			$m_{1} = (\alpha) U h_{1} = (\alpha) U h_{2} = (\alpha) U $

Limits on neutral trilinear couplings*

Feb 2013			
			ATLAS Limits H
h ₃ γ		Ζγ	-0.015 - 0.016 4.6 fb ⁻¹
	н	Ζγ	-0.003 - 0.003 5.0 fb ⁻¹
	├ ────┤	Ζγ	-0.022 - 0.020 5.1 fb ⁻¹
h ₃ ^Z	⊢−−−−− 1	Ζγ	-0.013 - 0.014 4.6 fb ⁻¹
	н	Ζγ	-0.003 - 0.003 5.0 fb ⁻¹
		Ζγ	-0.020 - 0.021 5.1 fb ⁻¹
h_4^{γ} x100	├ ────┤	Ζγ	-0.009 - 0.009 4.6 fb ⁻¹
	Н	Ζγ	-0.001 - 0.001 5.0 fb ⁻¹
h ₄ z100	⊢1	Ζγ	-0.009 - 0.009 4.6 fb ⁻¹
	Н	Ζγ	-0.001 - 0.001 5.0 fb ⁻¹
f_4^{γ}	⊢−−−−− I	ZZ	-0.015 - 0.015 4.6 fb ⁻¹
		ZZ	-0.013 - 0.015 5.0 fb ⁻¹
f_4^Z	├ ────┤	ZZ	-0.013 - 0.013 4.6 fb ⁻¹
	⊢−−−− 1	ZZ	-0.011 - 0.012 5.0 fb ⁻¹
f_5^{γ}	├ ─────┤	ZZ	-0.016 - 0.015 4.6 fb ⁻¹
	├ ────┤	ZZ	-0.014 - 0.014 5.0 fb ⁻¹
f_5^Z		ZZ	-0.013 - 0.013 4.6 fb ⁻¹
	 	ZZ	-0.012 - 0.012 5.0 fb ⁻¹
-0.5	0	0.5	1 1.5 x10 ⁻

* Some information is repeated twice.

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aTGC Limits @95% C.L.

First measurement in scattering topology: $\gamma\gamma \rightarrow WW$





References

- 1305.5596 (2013).

Summary

- limits, in some cases by orders of magnitude



1. <u>https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMPaTGC</u> 2. <u>https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults</u>

3. LEP Combination: arXiv:1302.3415, D0 combination: arXiv:1208.5458 4. CMS Collaboration, "Study of exclusive two-photon production of W+W- pairs in pp collisions at 7 TeV and constraints on anomalous quartic couplings", CMS arXiv:

5. K. Mishra, report in the LHC Electroweak Working Group Meeting (April 16, 2013) https://indico.cern.ch/conferenceOtherViews.py?confld=245037

Study of gauge boson couplings is a rich physics program •LHC data sufficient for sensitivity to SM and anomalous couplings •New excitement after the discovery of a light Higgs boson Starting to set serious constraints on gauge boson couplings •Already broke new ground with 7/8 TeV data by exceeding previous