Multi-boson production measurements with the CMS detector

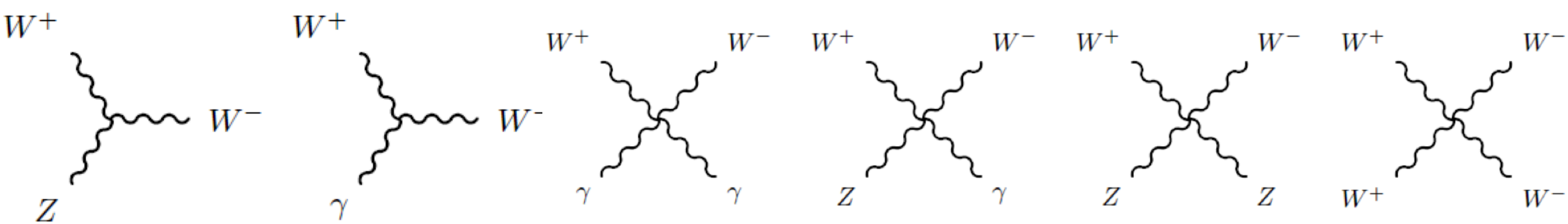
Gian Luca Pinna Angioni

Università degli Studi di Torino

INFN Torino
Istituto Nazionale di Fisica Nucleare

Physic motivation

- Interesting channels: ZZ,$W^{\pm}W^{\pm}$+jets, ZW, $WV\gamma$, $W^{+}W^{-}$,ecc.
- Studies on boson fermion couplings.
- Test of electroweak sector of SM.
  - Sensitive to the self-interaction between gauge bosons via triple/quadric gauge couplings (TGC,QGC).
  - Fundamental to establish if this Higgs boson really can preserve unitarity in the VV scattering amplitude at all energies.
  - <u>QCD process are dominant to EW !</u>

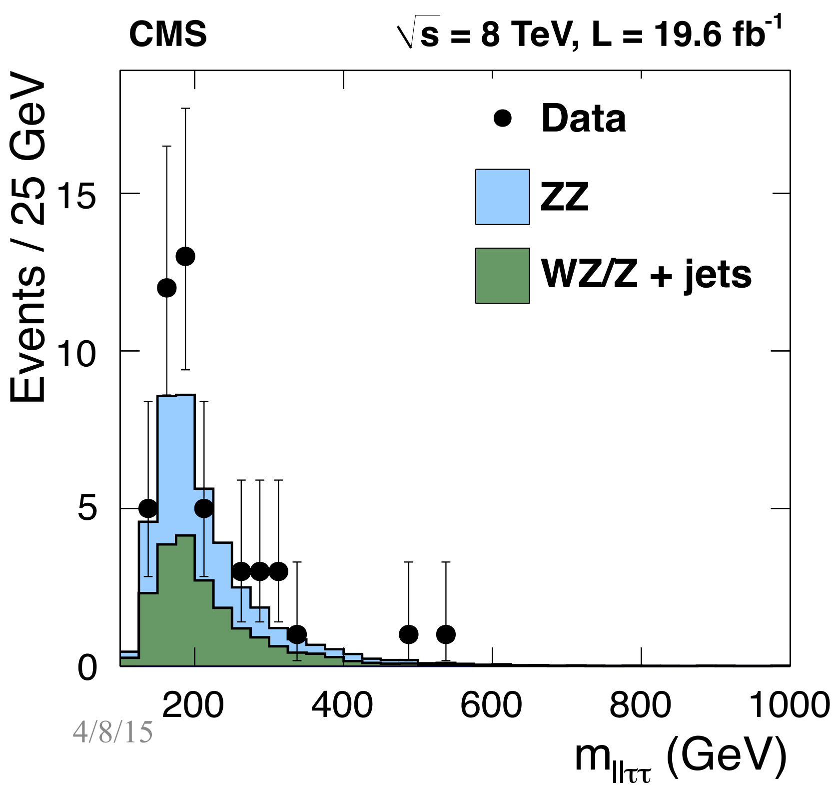


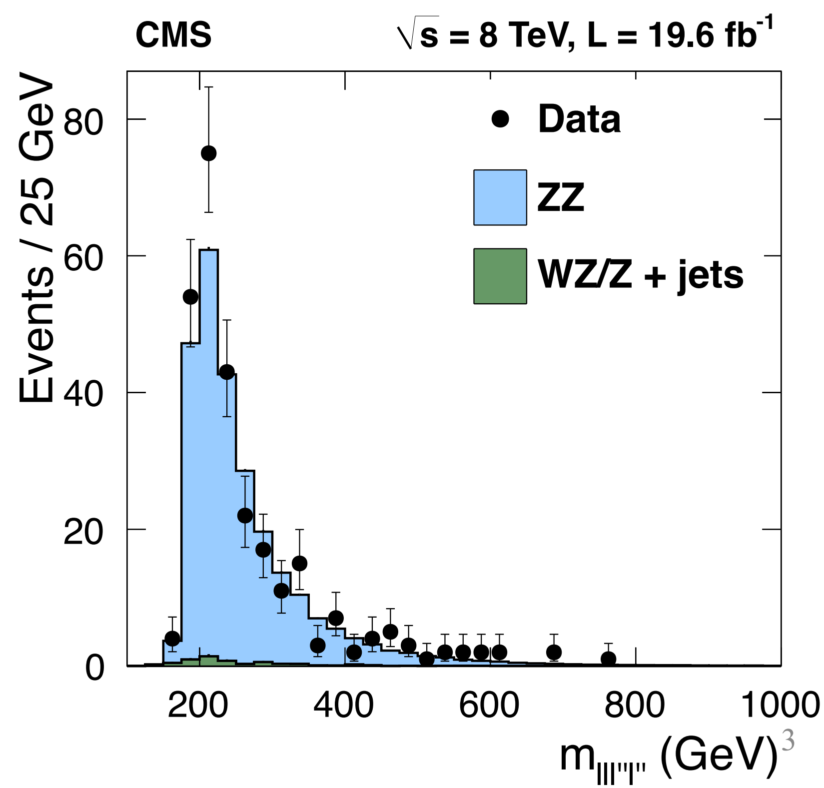
- Sensitive to anomalous triple/quadric couplings (aTGC,aQGC)
  - Analyzable through effective field theory
- Important background to Higgs and beyond-SM searches

ZZ$^{(*)}$→ 2ℓ2ℓ' (8 TeV)

Selection:
- Two opposite-sign same-flavor lepton pairs.
- ℓ = e, μ ℓ'=e, μ , τ
- τ reconstructed in both lepton and hadron decay

Background:
- Z+fake, ZW+fake, WWZ,tt + jets.
- Low in e,μ channels





$ZZ^{(*)} \rightarrow 2\ell 2\ell'$ (8 TeV)

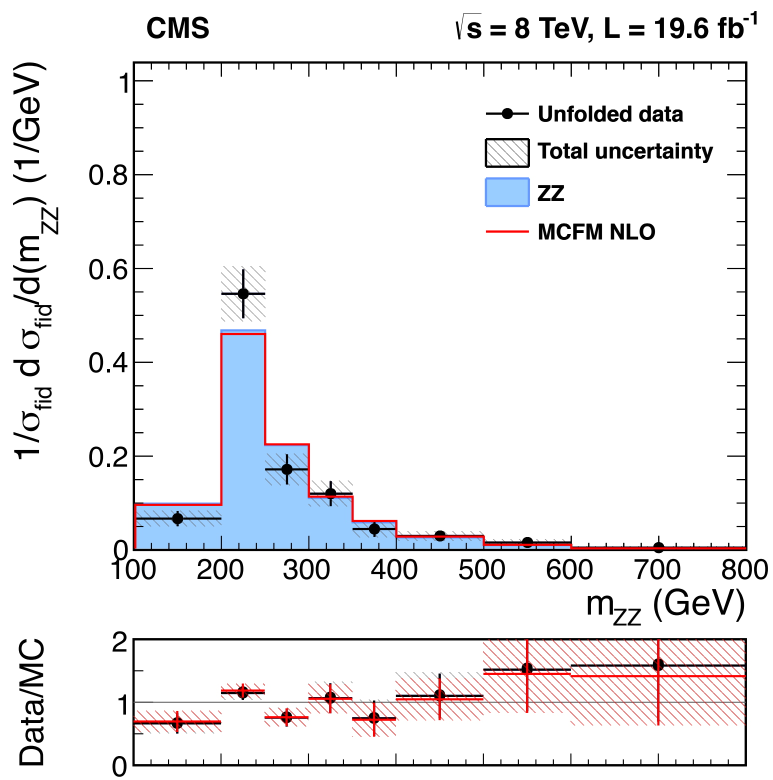
Cross section:

Fiducial region: 60 GeV<m_Z<120 GeV

- Measured separately in each final state and then combined through likelihood fit on number of events.
- Differential in mZZ, ZZp_T, Z_1p_T, $\ell_1 p_T$

Reference:

arXiv:1406.0113v2



L [fb^{-1}]	Experimental σ [pb]	Theory σ [pb]
19.6	$7.7_{-0.5}^{+0.5}$(stat)$_{-0.4}^{+0.5}$(syst)±0.4(theo)±0.2(lumi)	7.7±0.6

WVγ (8TeV) V=W,Z

Selections

- A γ plus a W in leptonic final state and a V in hadronic final state.
- Single tight lepton
- E_{miss}>35GeV
- M_T^W>30GeV
- E_T^γ>35GeV $|\eta^\gamma|$<1.44

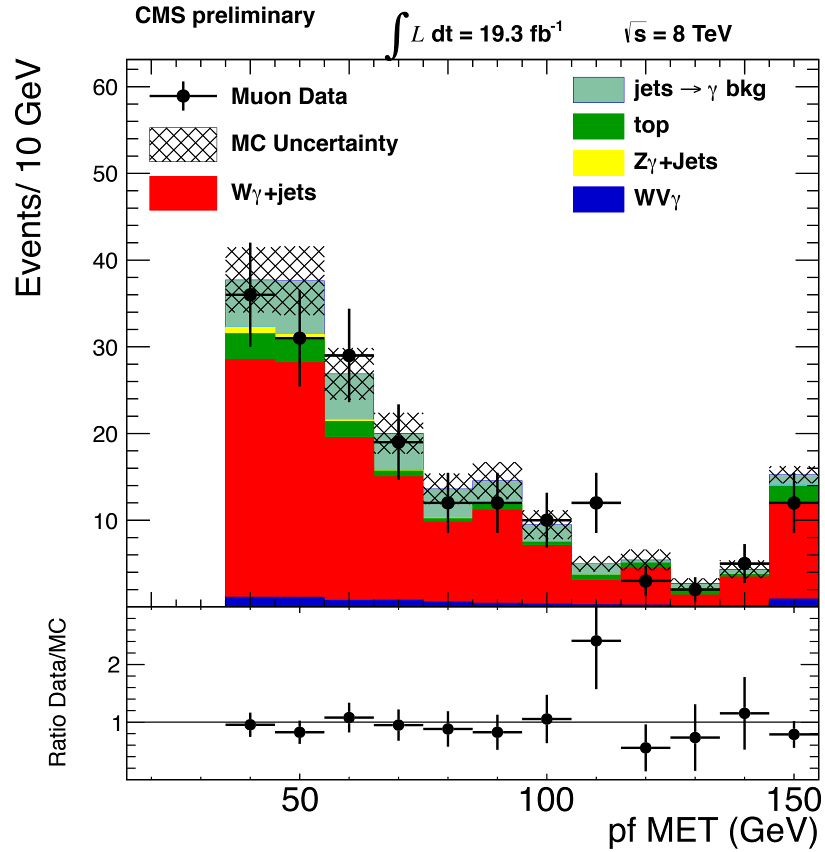
Background:

Wγ+jets,W+jets

Cross Section:

No excess above background predictions.

- Upper limit 311 fb by profile likelihood at 95% confidence level.
- ~3.4 times SM prediction 91.6±21.7 fb
- Expected limit of 403 fb



Reference:
arXiv:1404.4619

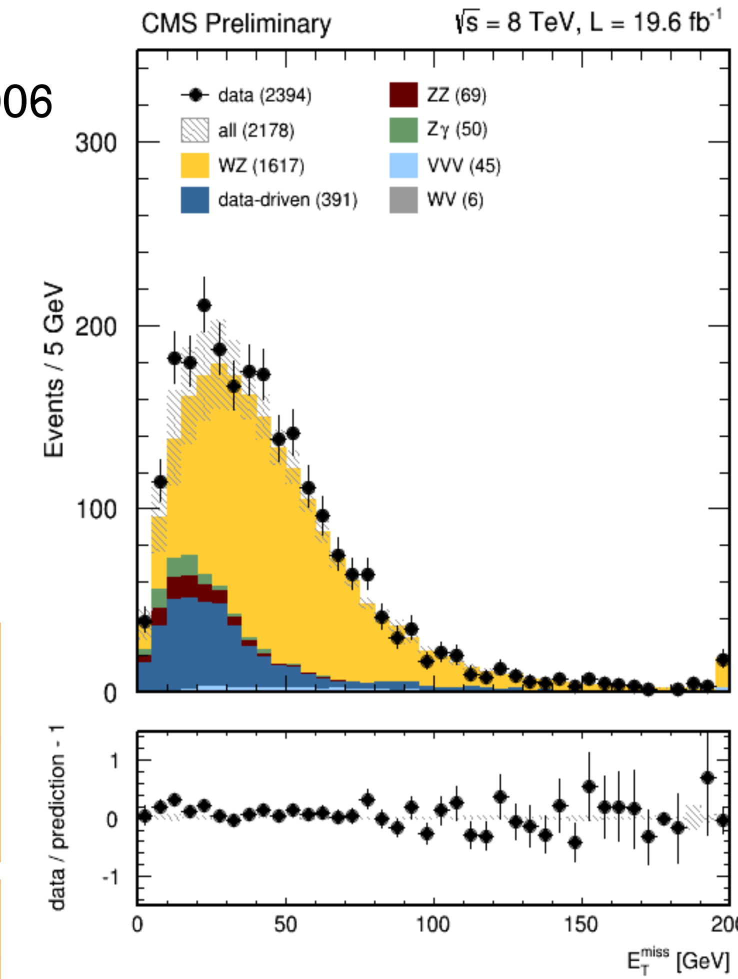
ZW→lllν (8 TeV)

Selection:
- Fully leptonic final states (eee,eeμ,eμμ,μμμ).
- Lepton + E^T_{miss} forming W.

Reference:
CMS-PAS-SMP-12-006

Background:
- Z+fake (jet,γ)
- Irreducible ZZ

Cross section:
- Fiducial region: $71<M_Z<111$GeV



L [fb^{-1}]	Experimental σ [pb]	Theory σ [pb]
19.6	24.61±0.76(stat)±1.13(exp) ±1.08(lum)	$21.91^{+1.17}_{-0.88}$

Discovery future projection (Run2)		
	3 σ	5 σ
SM EW scattering	75 fb-1	185 fb-1

W^+W^+, W^-W^- and VBS in $\ell\ell$+jets

Process:

W^+W^+, W^-W^-

Selection:

Two high p_T leptons.

Two jets E_T>30 GeV, m_{jj}>500GeV and large rapidity separation

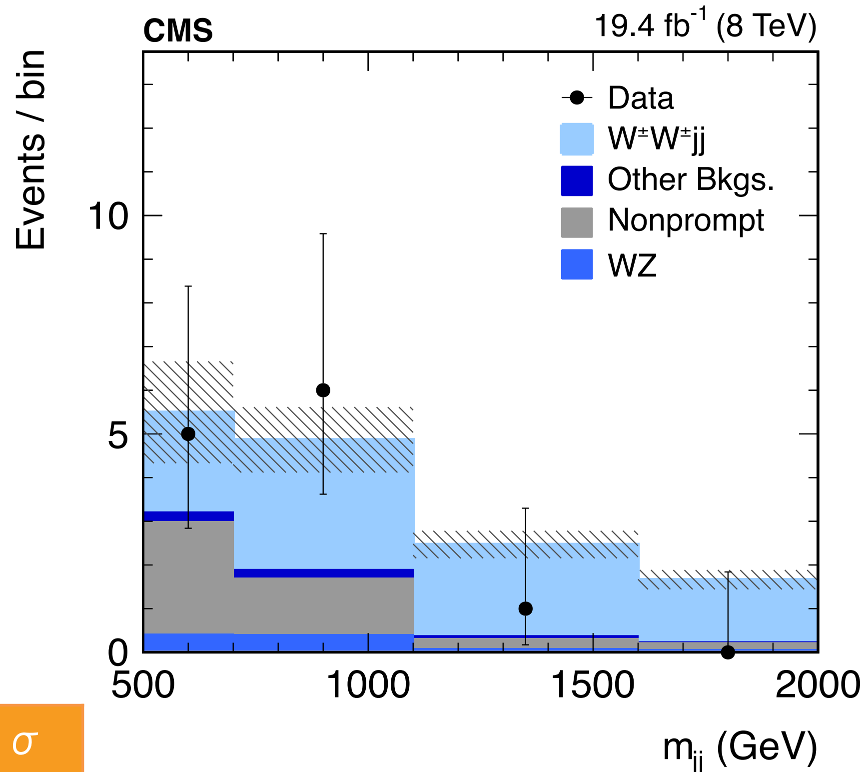
Background:

DY,WZ,tt, fake

Cross section:

Fiducial region: , $m_{jj}>300$, $|\Delta\eta_{jj}|>2.5$,s $p_T^{\ell}>10$, $|\eta_\ell|<2.5$, $p_T^{jet}>20$ GeV, $|\eta_{jet}|<5$.

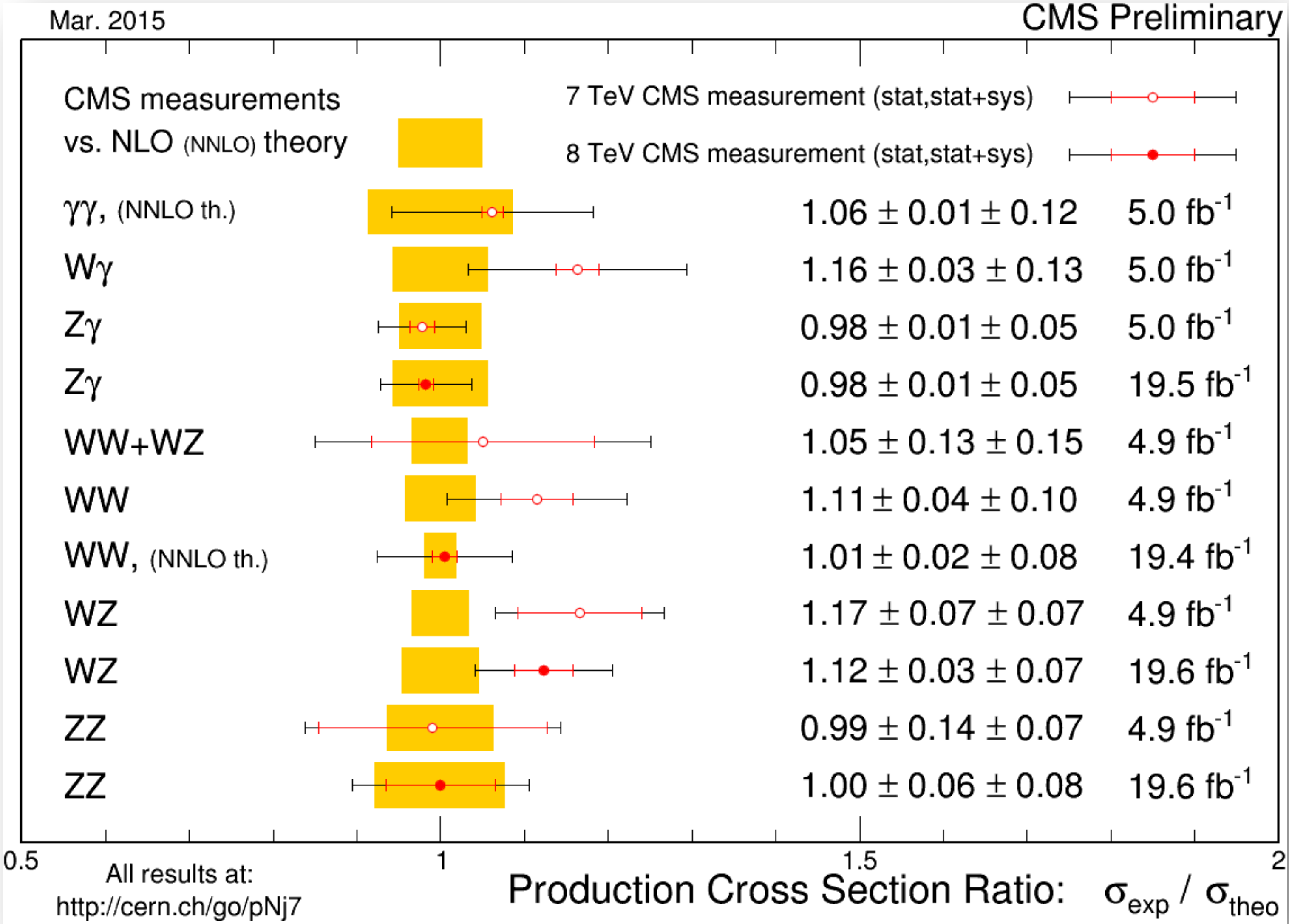
L [fb^{-1}]	Experimental σ [fb]	Theory σ [fb]
19.6	$4.0^{+2.4}_{-2.0}$(stat)$^{+1.1}_{-1.0}$(syst)	5.8±1.2



Reference:
arXiv:1410.6315

Obs(exp) significance for VBS = 1.9(3.0) σ

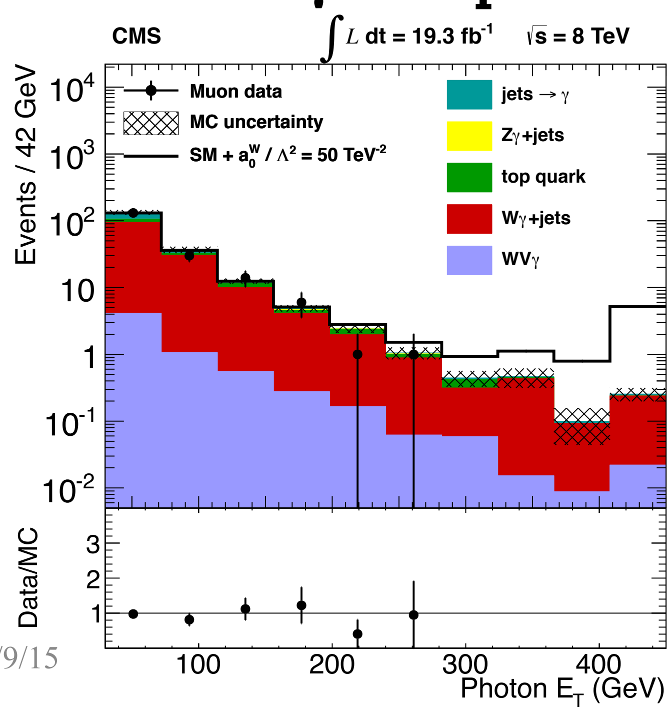
Multi boson measurements



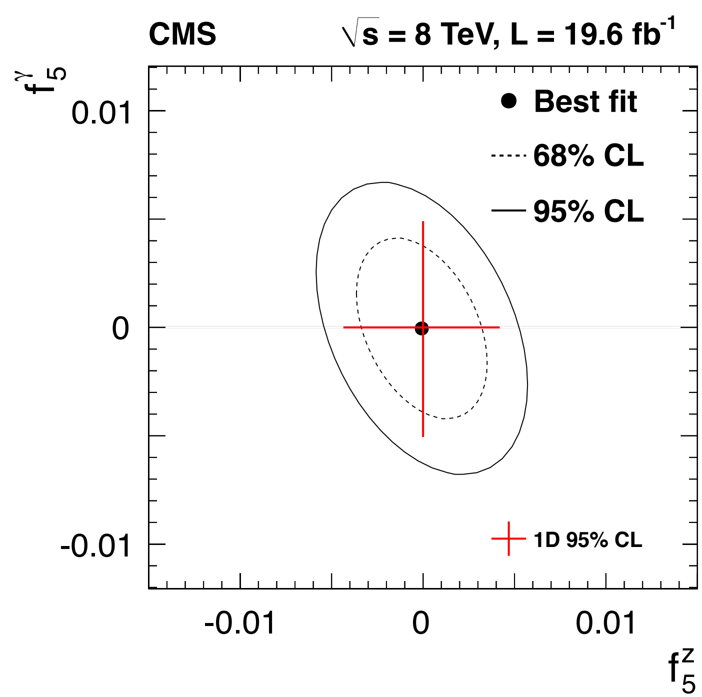
Anomalous coupling

- Possibility to test BSM physic adding new triple and quadruple terms/ operators with different dimension to the SM Lagrangian. (aTGC,aQGC)
- This new terms are introduced using an effective field theory.
- Expected variation in both yield and shape distributions.
- Anomalous coupling tested in almost every channel.
- **Limits set on this operators show no deviations from the SM**

WVγ example



ZZ example



Conclusion

- All possible multi-boson measurements have been done at CMS.
  - cross-sections measured: no significant deviations from the SM
  - limits set on aTGCs and aQGCs: show no deviations from the SM
- This measurements are the one of the most important measure for the next run at LHC.
  - Good prospective for 300 and 3000 fb^{-1}

Backup Slides

Analysis common features

Selection common features:

Prompt leptons in all analysis.

- Requested isolated leptons in a cone $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\Phi)^2}$ around leptons.
  - Values and features depend on the analysis
- The measured energy in the cone is corrected for the contribution from pile-up events.
- Leptons compatible with primary vertex (highest Σp^2_T vertex)
- Fake leptons background measured with a data driven method.

$W^+W^- \rightarrow l\nu l\nu$ (8TeV)

Selection:

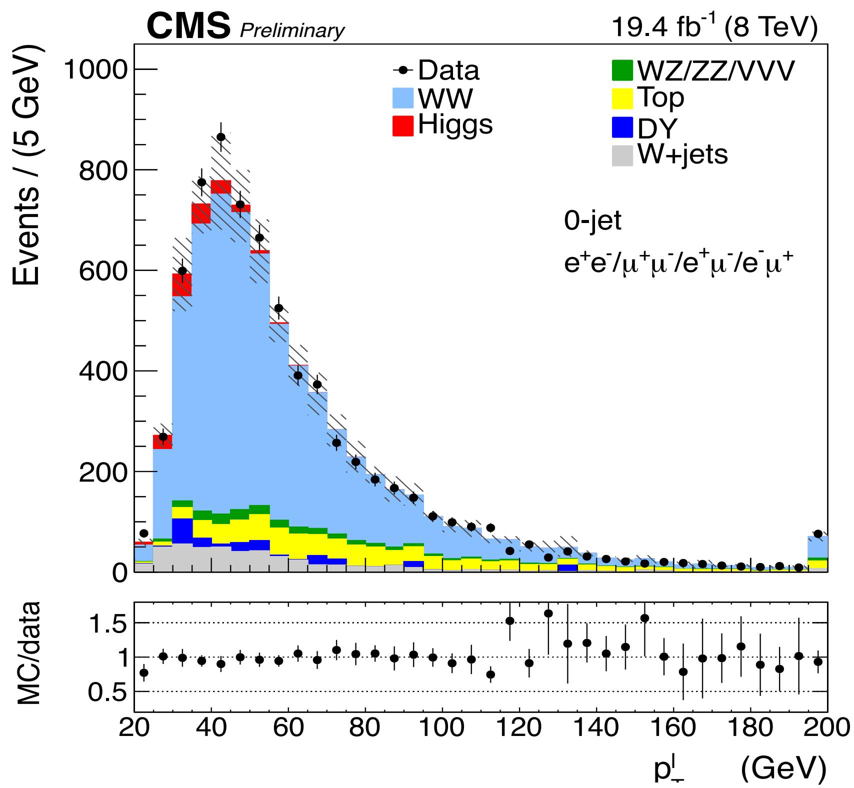
- Opposite-sign high p_T leptons.
- High missing energy.
- Small high p_T jets numbers.

Background:

W+jets, tt,tW, WZ,ZZ

Cross section:

Cross section measured separatelly in 4 category (flavor, jet numbers) and combined trough likelihood fit.



Event category		W^+W^- production cross section (pb.)
0-jet category	Different-flavor	59.7 ± 1.1 (stat.) ± 3.3 (exp.) ± 3.5 (th.) ± 1.6 (lum.)
	Same-flavor	64.3 ± 2.1 (stat.) ± 4.6 (exp.) ± 4.3 (th.) ± 1.7 (lum.)
1-jet category	Different-flavor	59.1 ± 2.8 (stat.) ± 6.0 (exp.) ± 6.2 (th.) ± 1.6 (lum.)
	Same-flavor	65.1 ± 5.5 (stat.) ± 8.3 (exp.) ± 8.0 (th.) ± 1.7 (lum.)

L [fb^{-1}]	Experimental σ [pb]	Theory σ [pb]
19.4	60.1±0.9(stat)±3.2(exp)±3.1(th)±1.6(lum)	$59.8^{+1.3}_{-1.1}$

$W^+W^- \to l\nu l\nu$ (8TeV)

Selection:

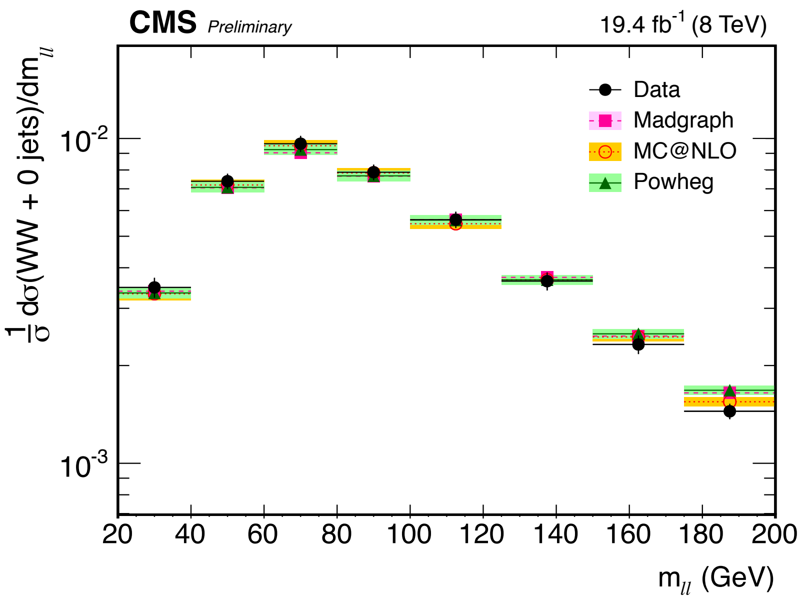
- Opposite-sign high p_T leptons.
- High missing energy.
- Small high p_T jets numbers.

Background:

W+jets, tt,tW, WZ,ZZ

Cross section:

Cross section measured separatelly in 4 category (flavor, jet numbers) and combined trough likelihood fit.



Reference:
CMS-PAS-SMP-14-016

Event category		W^+W^- production cross section (pb.)
0-jet category	Different-flavor	59.7 ± 1.1 (stat.) ± 3.3 (exp.) ± 3.5 (th.) ± 1.6 (lum.)
	Same-flavor	64.3 ± 2.1 (stat.) ± 4.6 (exp.) ± 4.3 (th.) ± 1.7 (lum.)
1-jet category	Different-flavor	59.1 ± 2.8 (stat.) ± 6.0 (exp.) ± 6.2 (th.) ± 1.6 (lum.)
	Same-flavor	65.1 ± 5.5 (stat.) ± 8.3 (exp.) ± 8.0 (th.) ± 1.7 (lum.)

L [fb^{-1}]	Experimental σ [pb]	Theory σ [pb]
19.4	60.1±0.9(stat)±3.2(exp)±3.1(th)±1.6(lum)	$59.8^{+1.3}_{-1.1}$

W+W-→lvlv (8TeV) Fiducials region

Fiducial region cross section

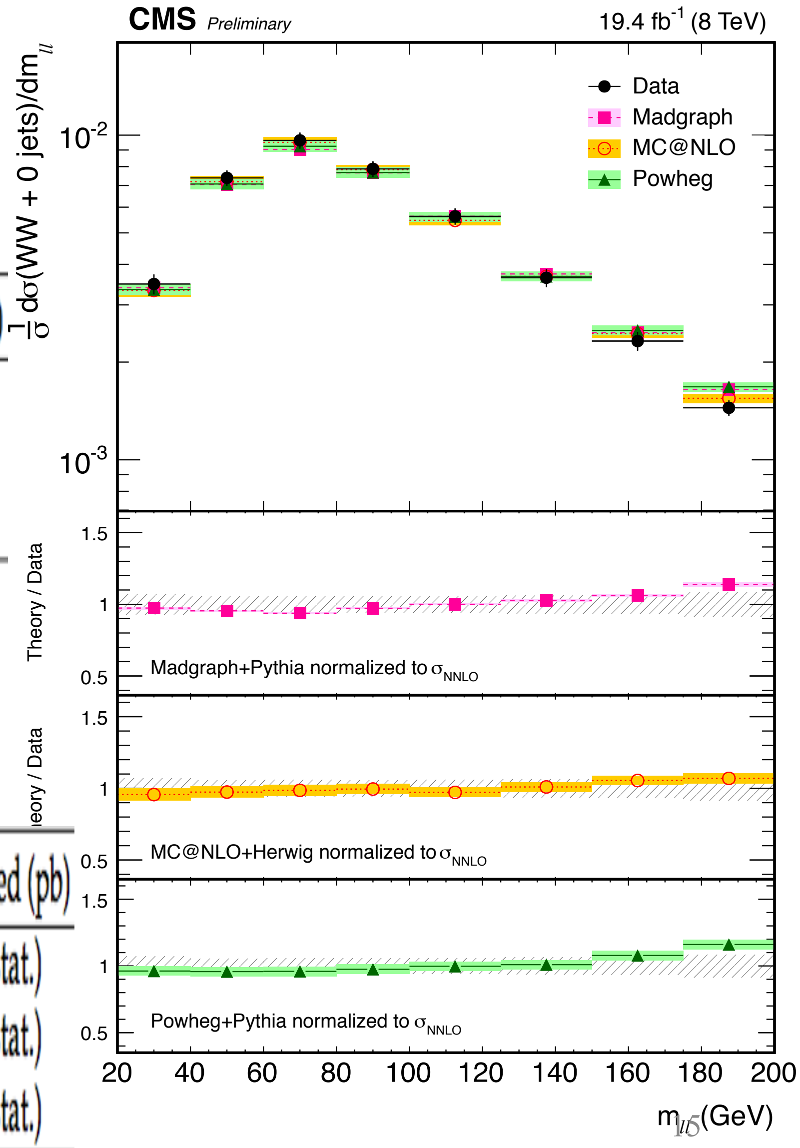
Fiducial region defined by a jet veto $|\eta^{jet}| < 4.7$ and different pT threshold categories.

p_T^{jet} threshold (GeV)	σ_{0jet} measured (pb)	σ_{0jet} predicted (pb)
20	$36.2 \pm 0.6\,(\text{stat.}) \pm 2.1\,(\text{exp.}) \pm 1.1\,(\text{th.}) \pm 0.9\,(\text{lum.})$	$36.7 \pm 0.1\,(\text{stat.})$
25	$40.8 \pm 0.7\,(\text{stat.}) \pm 2.3\,(\text{exp.}) \pm 1.3\,(\text{th.}) \pm 1.1\,(\text{lum.})$	$40.9 \pm 0.1\,(\text{stat.})$
30	$44.0 \pm 0.7\,(\text{stat.}) \pm 2.5\,(\text{exp.}) \pm 1.4\,(\text{th.}) \pm 1.1\,(\text{lum.})$	$43.9 \pm 0.1\,(\text{stat.})$

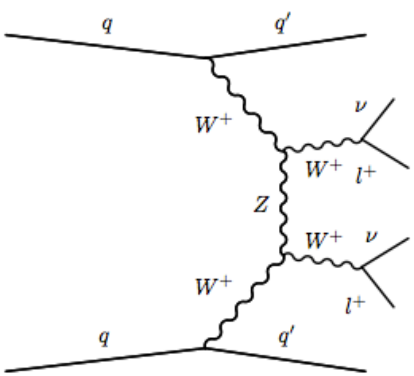
Fiducial region cross section 2

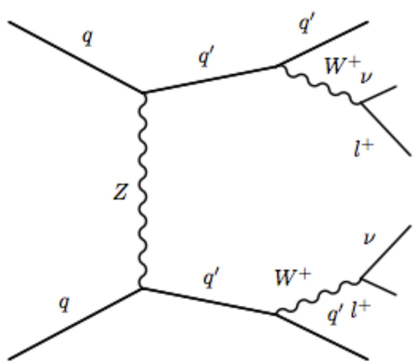
Fiducial region defined by a jet veto $|\eta^{jet}| < 4.7$ and different pT threshold categories and $p_T^{\ell} > 20$ GeV.

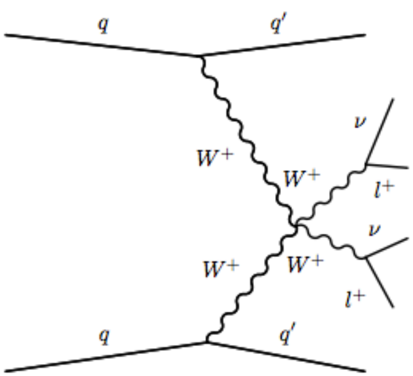
p_T^{jet} threshold (GeV)	$\sigma_{0jet,W\to\ell\nu}$ measured (pb)	$\sigma_{0jet,W\to\ell\nu}$ predicted (pb)
20	$0.223 \pm 0.004\,(\text{stat.}) \pm 0.013\,(\text{exp.}) \pm 0.007\,(\text{th.}) \pm 0.006\,(\text{lum.})$	$0.228 \pm 0.001\,(\text{stat.})$
25	$0.253 \pm 0.005\,(\text{stat.}) \pm 0.014\,(\text{exp.}) \pm 0.008\,(\text{th.}) \pm 0.007\,(\text{lum.})$	$0.254 \pm 0.001\,(\text{stat.})$
30	$0.273 \pm 0.005\,(\text{stat.}) \pm 0.015\,(\text{exp.}) \pm 0.009\,(\text{th.}) \pm 0.007\,(\text{lum.})$	$0.274 \pm 0.001\,(\text{stat.})$

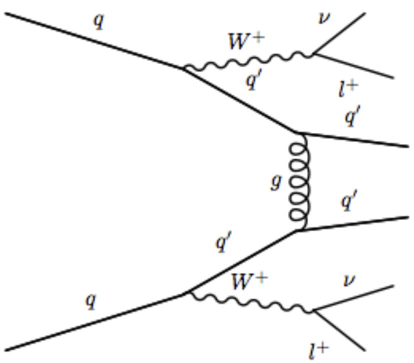


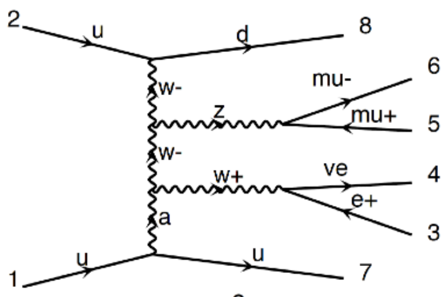
WW/WZ+jets diagrams

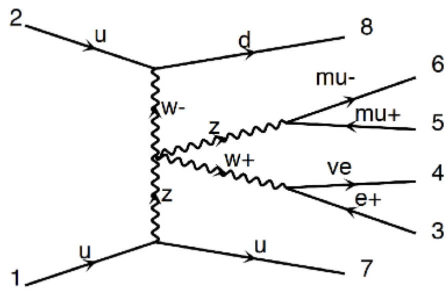


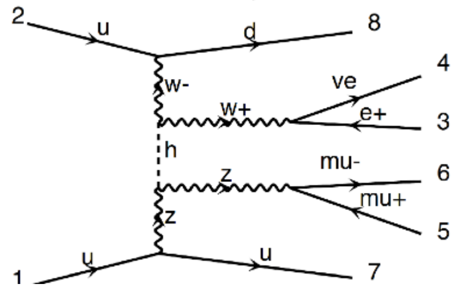








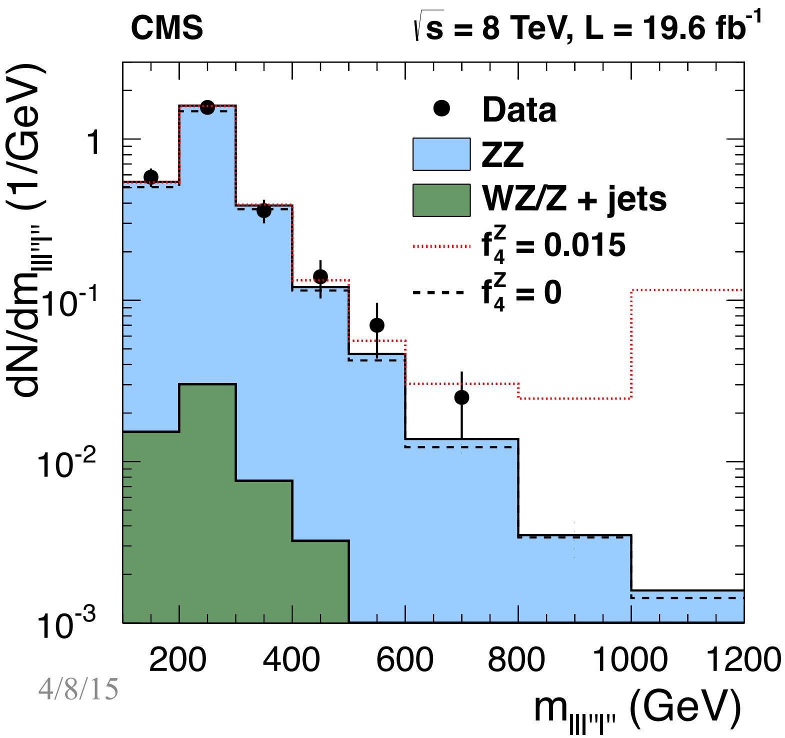


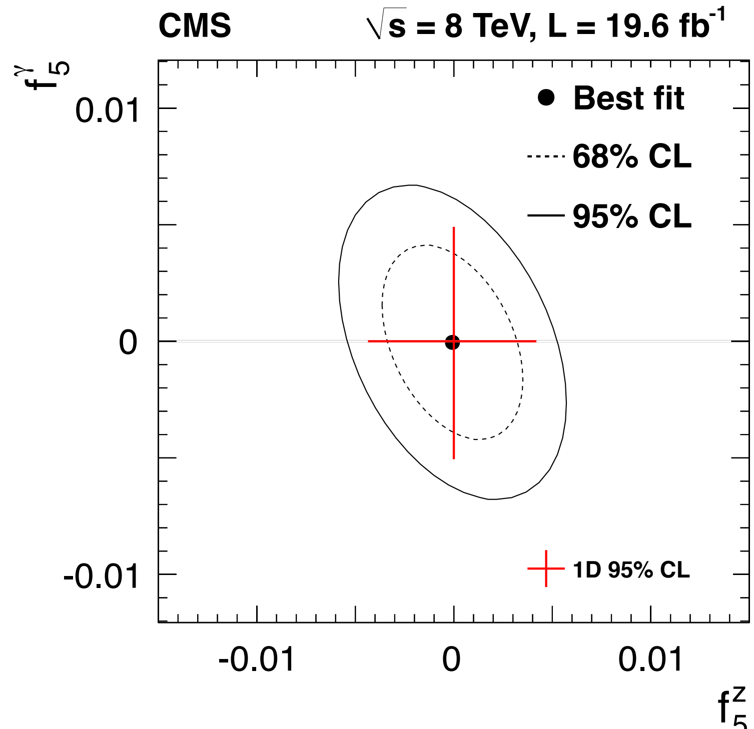


ZZ Anomalous coupling

- Anomalous tri-linear couplings ZZZ ZZγ introduced with an effective Lagrangian.
- Parameterized by two CP-violating (f_4^V) and two CP-conserving (f_5^V) complex parameter. V=Z,gamma
- One-dimensional fits for each parameter performed to obtain 95% CL:

$$-0.004 < f_4^Z < 0.004,\ -0.005 < f_5^Z < 0.005,\ -0.004 < f_4^\gamma < 0.004,\ -0.005 < f_5^\gamma < 0.005.$$





W^+W^- Anomalous coupling

- BSM processes parameterized by series of higher-dimensional operators that are the low-energy description of interactions mediated by unknown massive fields. (E.g. Fermi Lagrangian).

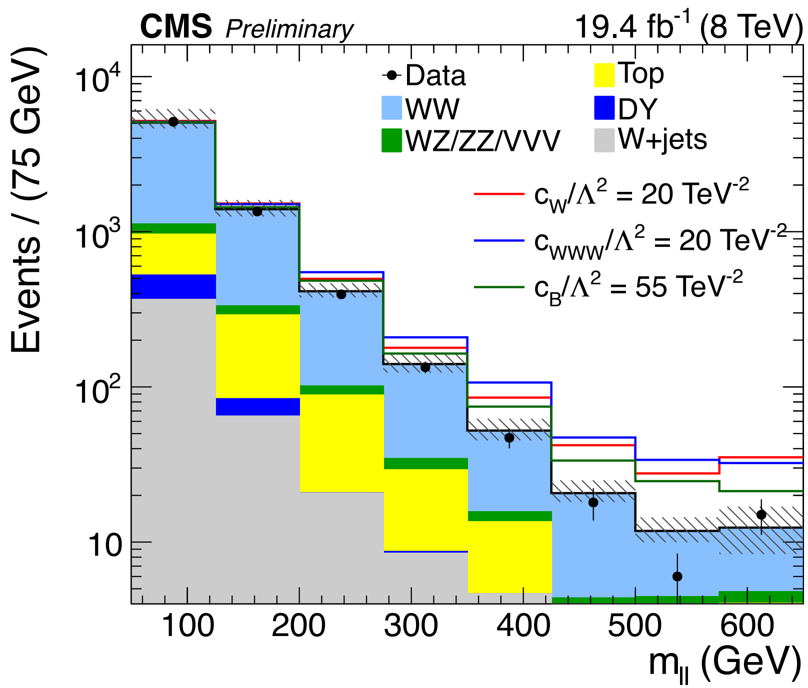
- Considering only C and P conserving operators and mass scale of new physic Λ large enough we have the following 6 dimension operators:

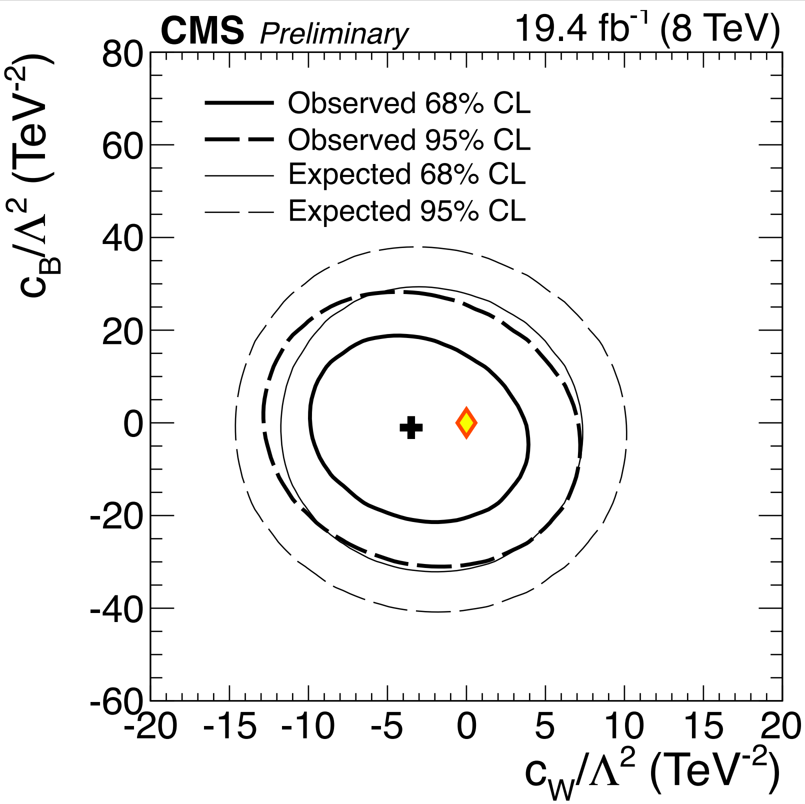
$$\mathcal{O}_{WWW} = \frac{c_{WWW}}{\Lambda^2}\mathrm{Tr}[W_{\mu\nu}W^{\nu\rho}W_{\rho}{}^{\mu}],$$
$$\mathcal{O}_{W} = \frac{c_{W}}{\Lambda^2}(D^{\mu}\Phi)^{\dagger}W_{\mu\nu}(D^{\nu}\Phi),$$
$$\mathcal{O}_{B} = \frac{c_{B}}{\Lambda^2}(D^{\mu}\Phi)^{\dagger}B_{\mu\nu}(D^{\nu}\Phi).$$

A binned Poisson log-likelihood computed on the invariant mass of the two charged leptons.

W^+W^- Anomalous coupling

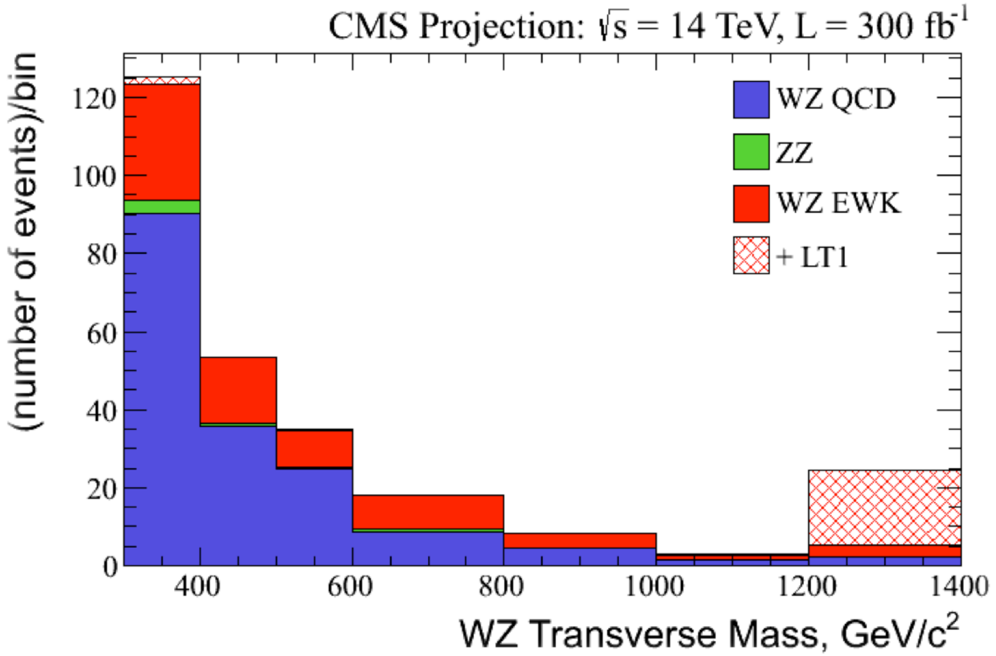
Coupling constant	This result (TeV^{-2})	This result 95% interval (TeV^{-2})	World average (TeV^{-2})
c_{WWW}/Λ^2	$0.1^{+3.2}_{-3.2}$	$[-5.7, 5.9]$	-5.5 ± 4.8 (from λ_γ)
c_W/Λ^2	$-3.6^{+5.0}_{-4.5}$	$[-11.4, 5.4]$	$-3.9^{+3.9}_{-4.8}$ (from g_1^Z)
c_B/Λ^2	$-3.2^{+15.0}_{-14.5}$	$[-29.2, 23.9]$	$-1.7^{+13.6}_{-13.9}$ (from κ_γ and g_1^Z)





Future projection WZ

- 300 fb-1 (Phase 1) with 50 pile-up event and similar detector
- 3000 fb-1 (Phase 2) with 140 pile-up events and with the detector upgrade (new tracker and Ecal, mu-detection down to $\eta < 4$)



$$L_{T1} = (f_{T1}/\Lambda^4) Tr[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}] Tr[\hat{W}_{\mu\beta}\hat{W}^{\alpha\nu}]$$

Significance	3σ	5σ
SM EWK scattering discovery	75 fb^{-1}	185 fb^{-1}
f_{T1}/Λ^4 at 300 fb^{-1} f_{T1}/Λ^4 at 3000 fb^{-1}	0.8 TeV^{-4} 0.45 TeV^{-4}	1.0 TeV^{-4} 0.55 TeV^{-4}