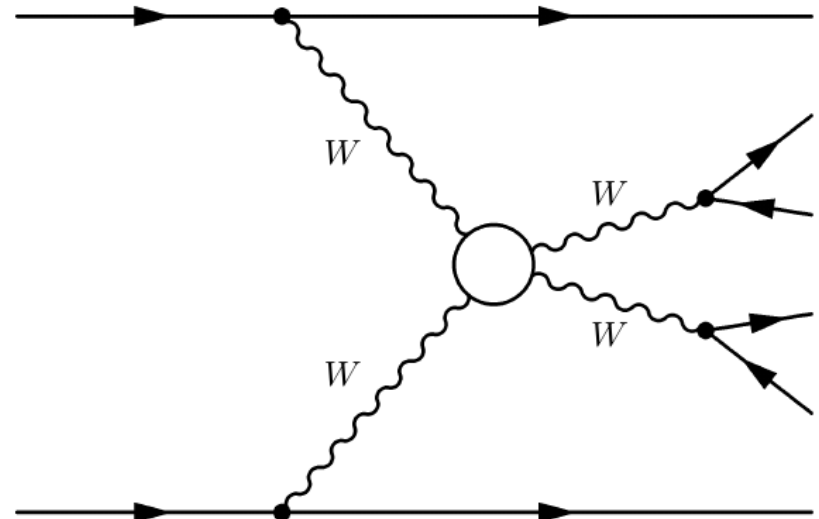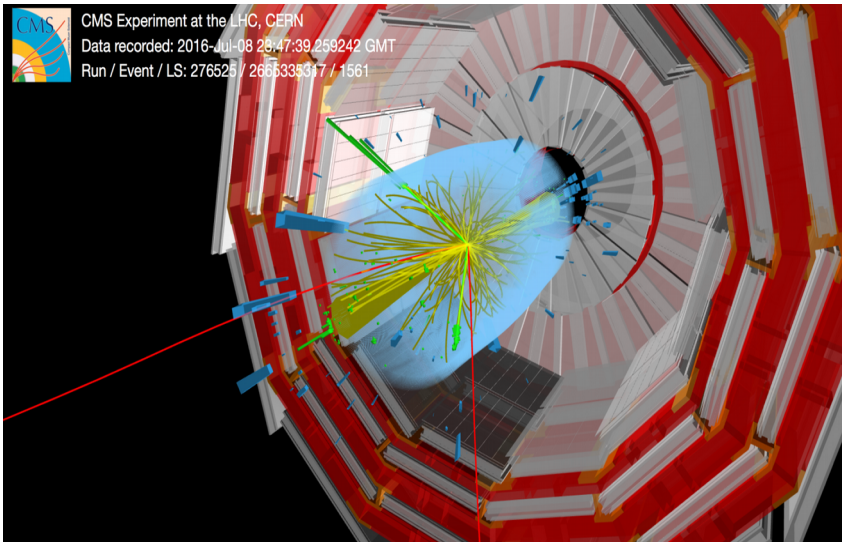# Combination Studies
Max Neukum
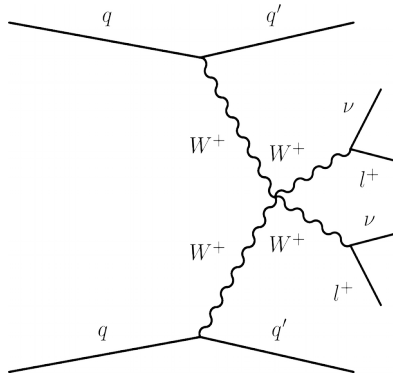
VBSCan 2nd annual meeting
21st June 2018

Institute of Experimental Particle Physics, Karlsruhe Institute of Technology
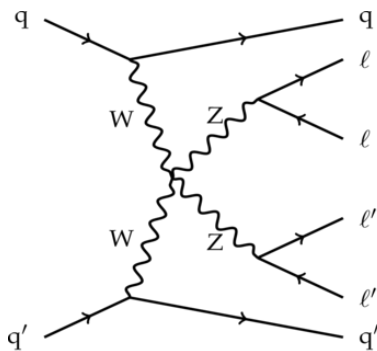
www.kit.edu
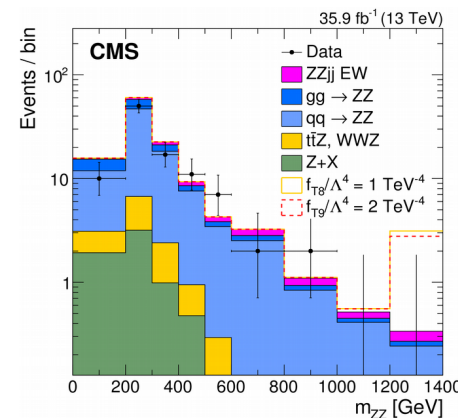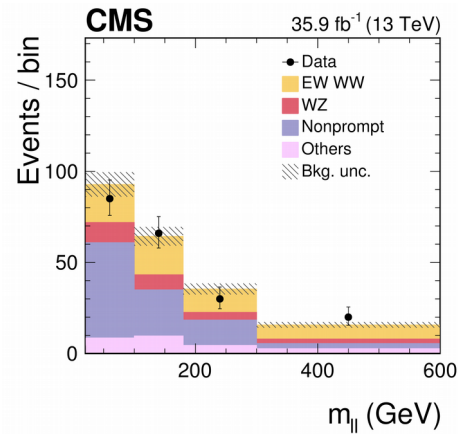
Combination Studies

- 95% CL limits on EFT parameters in quartic vertices

- Combine different channels

ArXiv:1709.05822 [hep-ex]

ArXiv:1708.02812 [hep-ex]

	Observed limits (TeV $^{-4}$)	Expected limits (TeV $^{-4}$)
f_{S0}/Λ^4	$[-7.7, 7.7]$	$[-7.0, 7.2]$
f_{S1}/Λ^4	$[-21.6, 21.8]$	$[-19.9, 20.2]$
f_{M0}/Λ^4	$[-6.0, 5.9]$	$[-5.6, 5.5]$
f_{M1}/Λ^4	$[-8.7, 9.1]$	$[-7.9, 8.5]$
f_{M6}/Λ^4	$[-11.9, 11.8]$	$[-11.1, 11.0]$
f_{M7}/Λ^4	$[-13.3, 12.9]$	$[-12.4, 11.8]$
f_{T0}/Λ^4	$[-0.62, 0.65]$	$[-0.58, 0.61]$
f_{T1}/Λ^4	$[-0.28, 0.31]$	$[-0.26, 0.29]$
f_{T2}/Λ^4	$[-0.89, 1.02]$	$[-0.80, 0.95]$

Coupling	Exp. lower	Exp. upper	Obs. lower	Obs. upper	Unitarity bound
f_{T0}/Λ^4	-0.53	0.51	-0.46	0.44	2.5
f_{T1}/Λ^4	-0.72	0.71	-0.61	0.61	2.3
f_{T2}/Λ^4	-1.4	1.4	-1.2	1.2	2.4
f_{T8}/Λ^4	-0.99	0.99	-0.84	0.84	2.8
f_{T9}/Λ^4	-2.1	2.1	-1.8	1.8	2.9

Effective Field Theory

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{f_i^{(6)}}{\Lambda^2} \mathcal{O}_i^{(6)} + \sum_i \frac{f_i^{(8)}}{\Lambda^4} \mathcal{O}_i^{(8)} + \dots$$

- Theory invalid beyond UV cut-off Λ, no renormalization

- Include higher (mass-) dimension operators

- For E < Λ, use first relevant order

- aTGC: dimension-6   aQGC: dimension-8

	WWWW	WWZZ	ZZZZ	WWAZ	WWAA	ZZZA	ZZAA	ZAAA	AAAA
$\mathcal{L}_{S,0}$, $\mathcal{L}_{S,1}$	X	X	X	O	O	O	O	O	O
$\mathcal{L}_{M,0}$, $\mathcal{L}_{M,1}$, $\mathcal{L}_{M,6}$, $\mathcal{L}_{M,7}$	X	X	X	X	X	X	X	O	O
$\mathcal{L}_{M,2}$, $\mathcal{L}_{M,3}$, $\mathcal{L}_{M,4}$, $\mathcal{L}_{M,5}$	O	X	X	X	X	X	X	O	O
$\mathcal{L}_{T,0}$, $\mathcal{L}_{T,1}$, $\mathcal{L}_{T,2}$	X	X	X	X	X	X	X	X	X
$\mathcal{L}_{T,5}$, $\mathcal{L}_{T,6}$, $\mathcal{L}_{T,7}$	O	X	X	X	X	X	X	X	X
$\mathcal{L}_{T,9}$, $\mathcal{L}_{T,9}$	O	O	X	O	O	X	X	X	X

Table 1: Quartic vertices modified by each dimension-8 operator are marked with X.
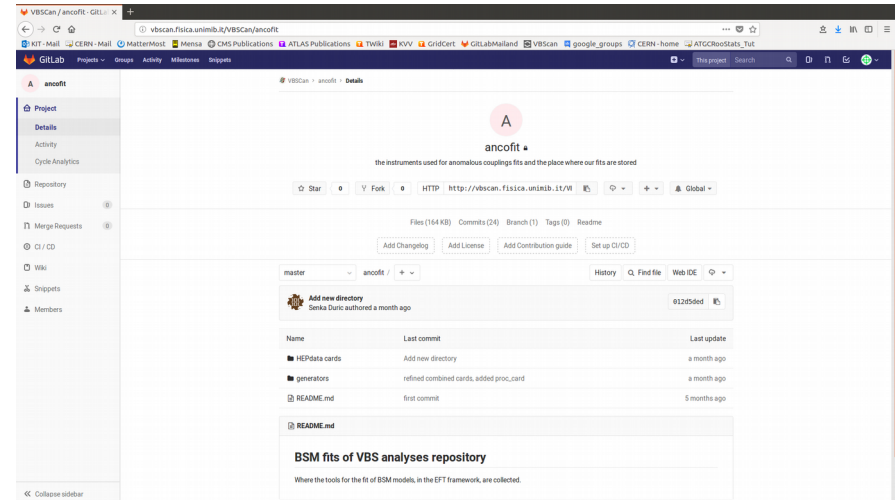
[O. Éboli et al.]

Signal Model (1)

- MG5 cards on GitLab:

  process_card

  run_card

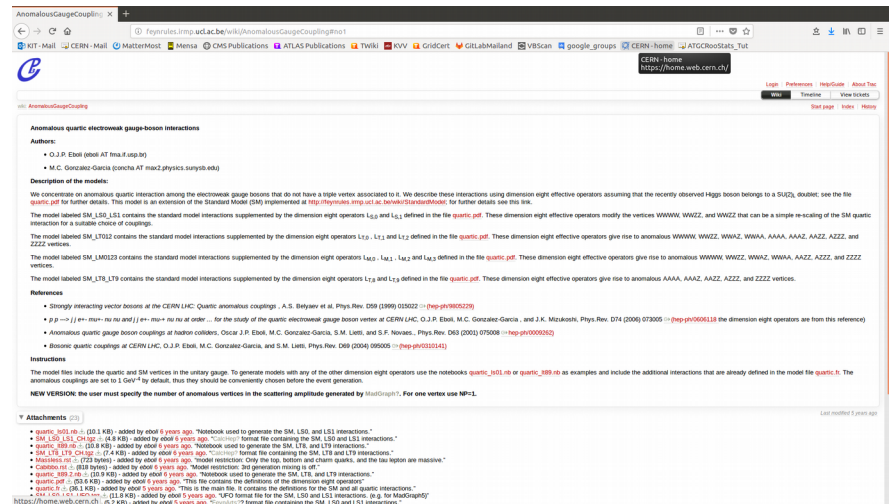- Fact. & Ren. Scales:

  dynamical_scale_choice=3

  $$\sum \frac{m_T}{2}$$

- Systematic Unc. (μ_F, μ_R, pdf):

  MG build-in "systematics"

- aQGC model from feynrules

http://vbscan.fisica.unimib.it/VBSCan/ancofit

http://feynrules.irmp.ucl.ac.be/wiki/AnomalousGaugeCoupling

Signal Model (2)

- Start small:
  - MG sample for: f_{s0}, f_{s1}, f_{s2}
  - look at WW – channel only
  - begin with constraints on f_{s0}

- Easy to reduce 2D to 1D:
  - Use "Reweight" to generate 2D grids

- Quadratically fit 1D, 2D, ...

Observation of electroweak production of same-sign W boson pairs in the two jet and two same-sign lepton final state in proton-proton collisions at 13 TeV

The CMS Collaboration[*]

Abstract

The first observation of electroweak production of same-sign W boson pairs in proton-proton collisions is reported. The data sample corresponds to an integrated luminosity of $35.9\,\text{fb}^{-1}$ collected at a center-of-mass energy of 13 TeV with the CMS detector at the LHC. Events are selected by requiring exactly two leptons (electrons or muons) of the same charge, moderate missing transverse momentum, and two jets with a large rapidity separation and a large dijet mass. The observed significance of the signal is 5.5 standard deviations, where a significance of 5.7 standard deviations is expected based on the standard model. The ratio of measured event yields to that expected from the standard model at leading-order is 0.90 ± 0.22. A cross section measurement in a fiducial region is reported. Bounds are given on the structure of quartic vector boson interactions in the framework of dimension-eight effective field theory operators and on the production of doubly charged Higgs bosons.
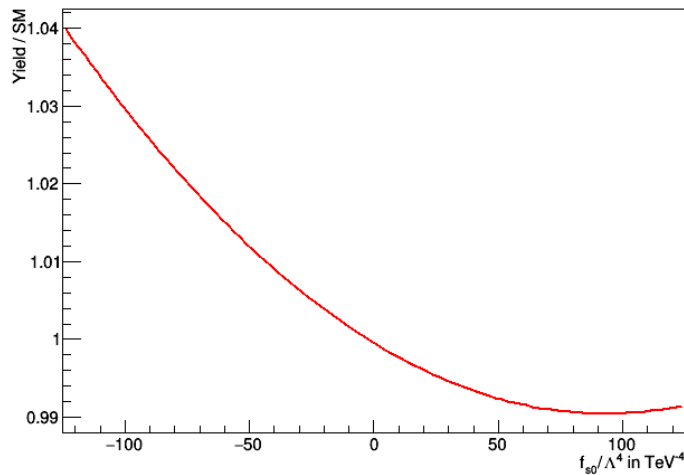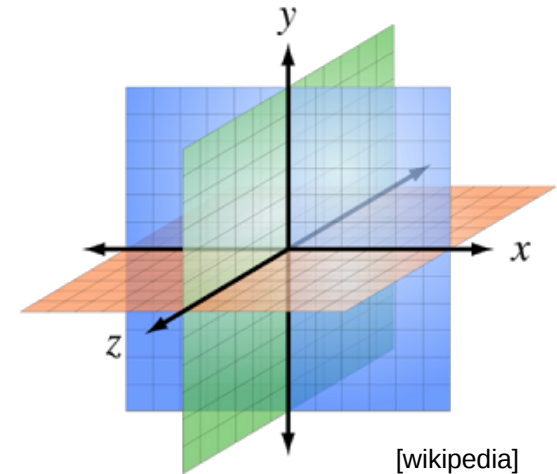
MadGraph: Reweight Grid

- 3 5x5 grids:

  25 + (25-5) + (25-5-4) = 61 weights

- 2D Fit for each bin:

  weight on $f_{s0} - f_{s1} -$ plane

- Results for 1D Fit (f_{s0}) :
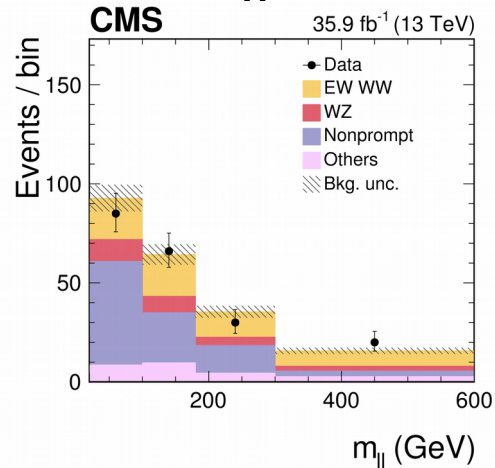

[wikipedia]

20 GeV < m_{ll} < 100 GeV

400 GeV < m_{ll}

HEPdata (CMS WW paper)

- Data & Background

Process	Data	WW EWK	WW QCD	WZ	ZZ	Triboson	Wrong-sign	Wgamma	WW DPS	Non-prompt
Mjj/Mll [GeV/GeV]	Yields of two dimensional dijet-dilepton mass distribution									
500-800/20-100	47	4.968 +1.253 -1.253	0.551 +0.154 -0.154	4.61 +1.167 -1.167	0.042 +0.011 -0.011	0.932 +0.352 -0.352	0.725 +0.294 -0.294	1.308 +0.593 -0.593	0.244 +0.04 -0.04	30.856 +4.811 -4.811
800-1100/20-100	19	4.314 +1.062 -1.062	0.22 +0.068 -0.068	3.39 +0.864 -0.864	0.015 +0.005 -0.005	0.463 +0.265 -0.265	0.1 +0.097 -0.097	0.908 +0.484 -0.484	0.056 +0.019 -0.019	12.668 +2.721 -2.721
1100-1500/20-100	10	4.396 +1.067 -1.067	0.114 +0.04 -0.04	1.812 +0.555 -0.555	0.008 +0.002 -0.002	0.334 +0.134 -0.134	0.352 +0.205 -0.205	1.2 +0.493 -0.493	0.03 +0.012 -0.012	5.398 +1.603 -1.603
1500-inf/20-100	9	7.213 +1.695 -1.695	0.05 +0.023 -0.023	1.255 +0.405 -0.405	0.005 +0.002 -0.002	0.108 +0.101 -0.101	0.598 +0.477 -0.477	0.201 +0.207 -0.207	0.027 +0.012 -0.012	3.344 +1.267 -1.267
500-800/100-180	26	4.766 +1.212 -1.212	0.851 +0.21 -0.21	3.397 +0.861 -0.861	0.027 +0.007 -0.007	1.377 +0.293 -0.293	0.954 +0.353 -0.353	0.787 +0.376 -0.376	0.11 +0.023 -0.023	13.149 +2.97 -2.97
800-1100/100-180	22	3.929 +0.958 -0.958	0.386 +0.12 -0.12	2.493 +0.625 -0.625	0.014 +0.004 -0.004	0.256 +0.195 -0.195	0.877 +0.389 -0.389	1.017 +0.567 -0.567	0.051 +0.016 -0.016	9.628 +2.214 -2.214
1100-1500/100-180	7	4.289 +1.038 -1.038	0.217 +0.069 -0.069	1.197 +0.367 -0.367	0.006 +0.002 -0.002	0.3 +0.103 -0.103	0.115 +0.076 -0.076	1.438 +0.543 -0.543	0.02 +0.011 -0.011	1.608 +1.096 -1.096
1500-inf/100-180	11	8.097 +1.882 -1.882	0.144 +0.051 -0.051	1.224 +0.381 -0.381	0.005 +0.001 -0.001	0.156 +0.046 -0.046	0.107 +0.09 -0.09	0.453 +0.375 -0.375	0.012 +0.008 -0.008	0.892 +1.401 -1.401

- Uncertainties & Efficiency

Source	Value (%)
Integrated luminosity	2.5
Muon selection	2
Electron selection	2
Jet energy scale	3
PDFs	4
QCD scales	10

Mll [GeV]	Efficiency (%)
20-100	38
100-200	51
200-300	62
300-400	66
400-inf	66

Statistics Tool (CMS internal)
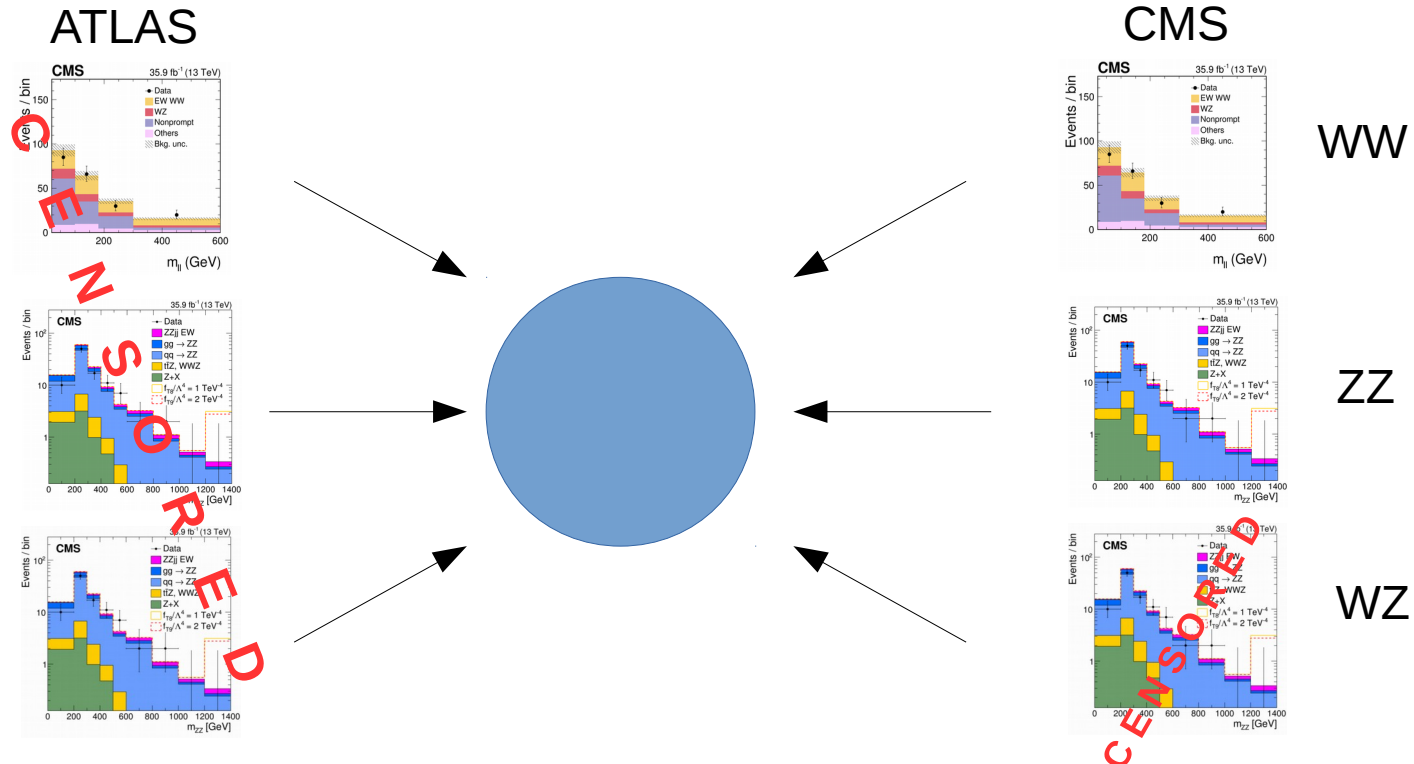
- https://twiki.cern.ch/twiki/bin/view/CMS/ATGCRooStats

- Based on Higgs combination tool

- Setting limits on aGC parameters

- Fit the produced grids quadratically (1D, 2D, 3D)

- Data & Background from paper

- DeltaNLL & 95% CL limits

- Machinery is running

- Missing: cuts on m_{ll}, efficiencies,
  systematic uncertainties, ...

Outlook

- Implement cuts, efficiencies, systematic uncertainties, ….

- Reproduce bounds given in paper

- Combine different channels: WW, ZZ, WZ (Atlas & CMS)

ATLAS

CMS

WW

ZZ

WZ

Backup Slides