XXIXth Rencontres de Physique de la Vallée d'Aoste

Diboson and EWK physics at CMS

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On behalf of the CMS collaboration

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Outline

Diboson production:

ZZ->4l at 8TeV, CMS-PAS-SMP-13-005 => Phys. Lett. B 740 (2015)

ZZ->2l2ν at 7+8TeV, CMS-PAS-SMP-12-016

WZ->3l at 7+8TeV, CMS-PAS-SMP-12-006

VZ->2l2b at 8TeV, CMS-PAS-SMP-13-011 => Eur. Phys. J. C 74 (2014) 2973

γγ production, CMS-PAS-SMP-13-001 => Eur. Phys. J. C 74 (2014) 3129

Z(->ll)γ at 8TeV, CMS-PAS-SMP-13-014

Selection of the latest CMS results

+ Anomalous couplings:

ZZ->4l, ZZ->2l2ν, Z(->ll)γ

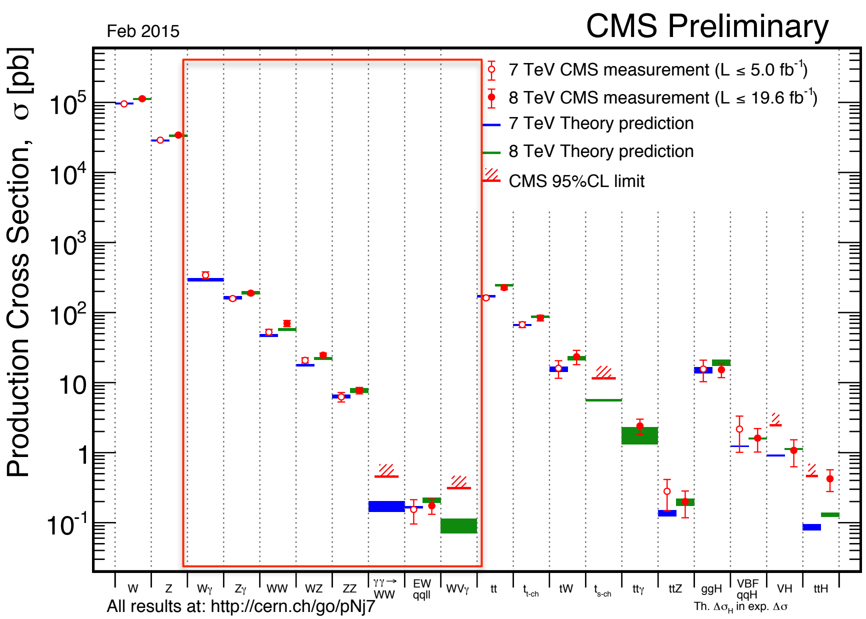
Selected electroweak results:

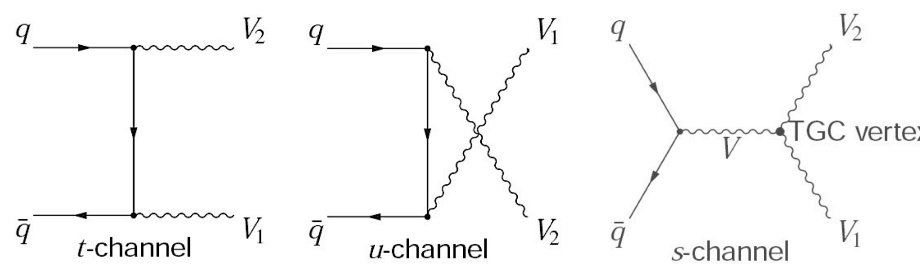
VBS: EWK WW with 2 jets, WZ with 2 jets, CMS-PAS-SMP-13-015 => Phys. Rev. Lett. 114 (2015) 051801

VBF: EWK Z with forward and backward jets, CMS-PAS-FSQ-12-035 => Eur. Phys. J. C 75 (2015) 66

Diboson production

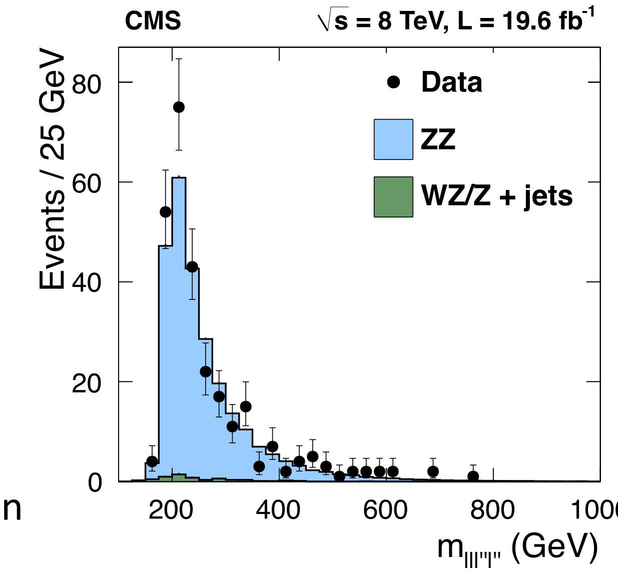
- Cross-section measurement is a fundamental test of the Standard Model (SM)
- Vector boson self-interaction result from the non-Abelian nature of SU(2)xU(1)
- Irreducible background for Higgs boson studies and many beyond SM searches
- Anomalous Triple and Quartic Gauge Couplings is a probe for the new physics
- CMS Collaboration has performed extensive studies of the diboson production





ZZ->4l cross section

- Inclusive and differential ZZ->lll'l' cross sections (l = e, μ; l' = e, μ, τ)
- Mutually exclusive sets of 4e, 4μ, 2e2μ and llττ, with 60 < m_Z <120
- Backgrounds: WZ+jets, Z+jets and ttbar, control data samples used
- Simultaneous fit to include all final states in cross section calculation
- Differential cross section measured, 4e, 4μ, 2e2μ decays combined
- The measured cross-sections show good agreement with the SM

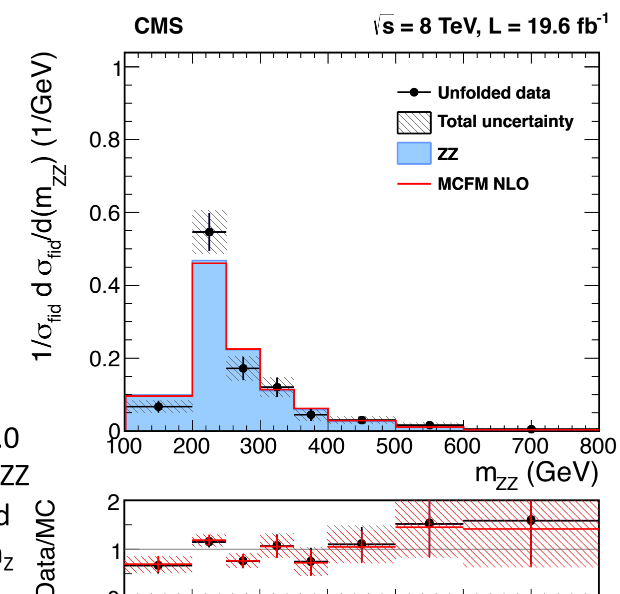


Decay channel	Total cross section, pb
4e	$7.2\,^{+1.0}_{-0.9}\,(\text{stat.})\,^{+0.6}_{-0.5}\,(\text{syst.}) \pm 0.4\,(\text{th.}) \pm 0.2\,(\text{lum.})$
4μ	$7.3\,^{+0.8}_{-0.8}\,(\text{stat.})\,^{+0.6}_{-0.5}\,(\text{syst.}) \pm 0.4\,(\text{th.}) \pm 0.2\,(\text{lum.})$
$2e2\mu$	$8.1\,^{+0.7}_{-0.6}\,(\text{stat.})\,^{+0.6}_{-0.5}\,(\text{syst.}) \pm 0.4\,(\text{th.}) \pm 0.2\,(\text{lum.})$
$\ell\ell\tau\tau$	$7.7\,^{+2.1}_{-1.9}\,(\text{stat.})\,^{+2.0}_{-1.8}\,(\text{syst.}) \pm 0.4\,(\text{th.}) \pm 0.2\,(\text{lum.})$
Combined	$7.7 \pm 0.5\,(\text{stat.})\,^{+0.5}_{-0.4}\,(\text{syst.}) \pm 0.4\,(\text{th.}) \pm 0.2\,(\text{lum.})$

Theoretical value of

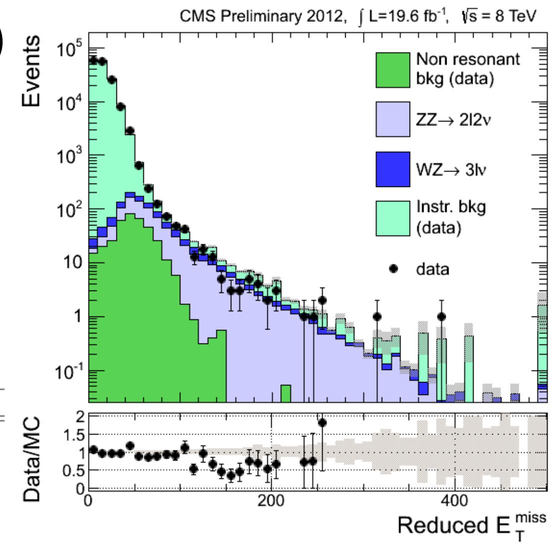
7.7 ± 0.6 pb

calculated with MCFM 6.0 at NLO qq->ZZ & LO gg->ZZ with MSTW2008 PDF and scales set to $\mu_R = \mu_F = m_Z$



ZZ->2l2ν cross section

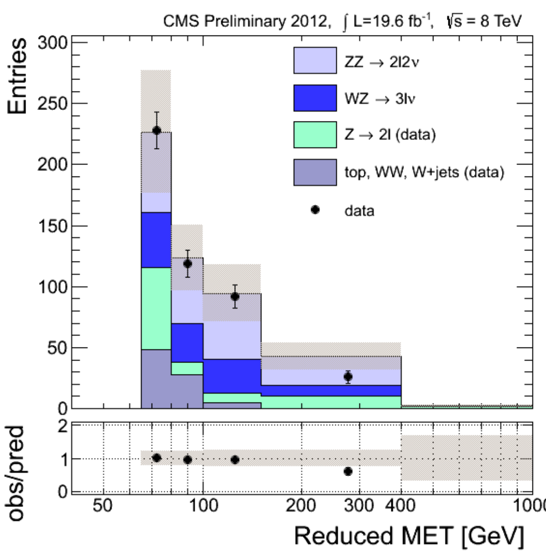
- Inclusive cross-section measurement, 7TeV ($4.9 fb^{-1}$) and 8TeV ($19.6 fb^{-1}$)
- BR is 6x larger than ZZ->4l, large background yields (DY, WW and top)
- MET reconstruction is crucial, distinctive hallmark w.r.p. to DY process
- Reduced MET variable applied, previously used at D0 & OPAL searches



$$\text{reduced-}E_{\mathrm{T}}^{\mathrm{miss}\,i} = -q_{\mathrm{T}}^{i} - R_{c/u}^{i}$$

$$B = E_{\mathrm{T}}^{\mathrm{miss}} / q_{\mathrm{T}}$$

Variable	Value
Dilepton invariant mass	$\lvert m(\ell\ell) - 91\rvert < 7.5$ GeV/c^2
Dilepton p_{T}	$q_{\mathrm{T}} > 45$ GeV/c
b-tag veto	based on vertex info. (for jet with $p_T > 20$ GeV/c)
Jet veto	no jets with $p_{\mathrm{T}} > 30$ GeV/c
Reduced $E_{\mathrm{T}}^{\mathrm{miss}}$	> 65 GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$ balance	$0.4 < B < 1.8$
$\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}$,jet)	> 0.5 rad
$\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}$,lept.)	> 0.2 rad
Lepton veto	no additional leptons (e/μ) with $p_{\mathrm{T}} > 10/3$ GeV/c



- The DY background is estimated from data using γ+jets control sample
- Non-resonant (WW and top) estimated from eμ events and Z mass SB
- Cross section extracted with a profile likelihood fit to the reduced MET

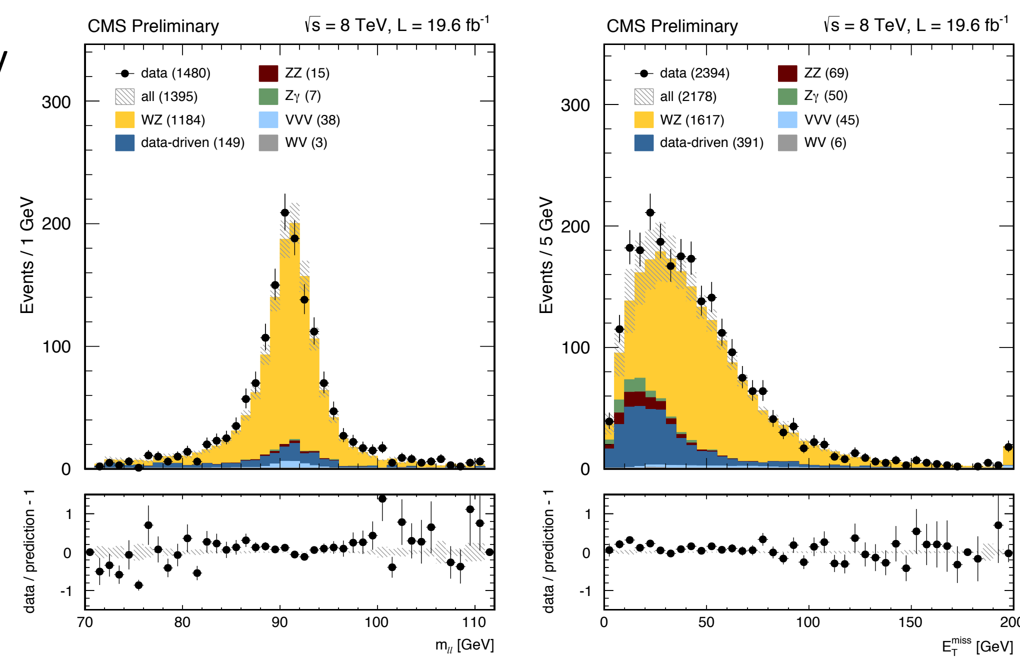
7TeV: $\sigma(\text{data}) = 5.0_{-1.4}^{+1.5}$ (stat)$_{-1.0}^{+1.3}$ (syst) ± 0.2 (lumi) pb
$\sigma(\text{NLO}) = 6.83_{-0.10}^{+0.13}$ pb

8TeV: $\sigma(\text{data}) = 6.8_{-0.8}^{+0.8}$ (stat)$_{-1.4}^{+1.8}$ (syst) ± 0.3 (lumi) pb
$\sigma(\text{NLO}) = 8.38_{-0.12}^{+0.15}$ pb

WZ->3lν cross section (1/2)

- Inclusive cross-section measurement in 3 leptons (e or μ) plus MET, 7TeV (4.9fb^{-1}) and 8TeV (19.6fb^{-1})
- Background contribution from events with 3 (real or fake) leptons, can be grouped into three classes:
  - non-peaking background: tt, QCD multijet and W+jets (the latter two are found to be negligible)
  - Z+fake lepton background: most important, include fake or non-iso leptons from jets or photons
  - Z+prompt lepton background: mainly from ZZ->4l, irreducible but small (reduced ZZ cross section)
- Prompt leptons: real, from heavy boson decay
- Fake leptons: leptons in jets or misID hadrons
- Z+jets and top from data, dedicated fake rate

sample	eee	eeμ	$\mu\mu$e	$\mu\mu\mu$
Z+jets	9.8 ± 4.4	16.9 ± 6.0	14.5 ± 5.4	13.8 ± 4.5
top	1.4 ± 0.4	2.7 ± 0.3	6.2 ± 0.7	9.1 ± 1.0
ZZ	2.4 ± 0.1	3.1 ± 0.1	3.9 ± 0.1	5.8 ± 0.1
Zγ	2.4 ± 0.9	0.4 ± 0.4	3.8 ± 1.2	0
WV	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	2.2 ± 0.7
VVV	6.1 ± 0.3	7.9 ± 0.3	10.4 ± 0.4	13.4 ± 0.4
WZ	193.9 ± 1.4	245.8 ± 1.6	315.9 ± 1.9	428.0 ± 2.2
total MC	216.0 ± 4.7	277.0 ± 6.3	354.9 ± 6.0	472.3 ± 5.2
data-driven	14.8 ± 1.4	27.1 ± 2.9	47.9 ± 3.4	59.0 ± 4.6
data	235	288	400	557

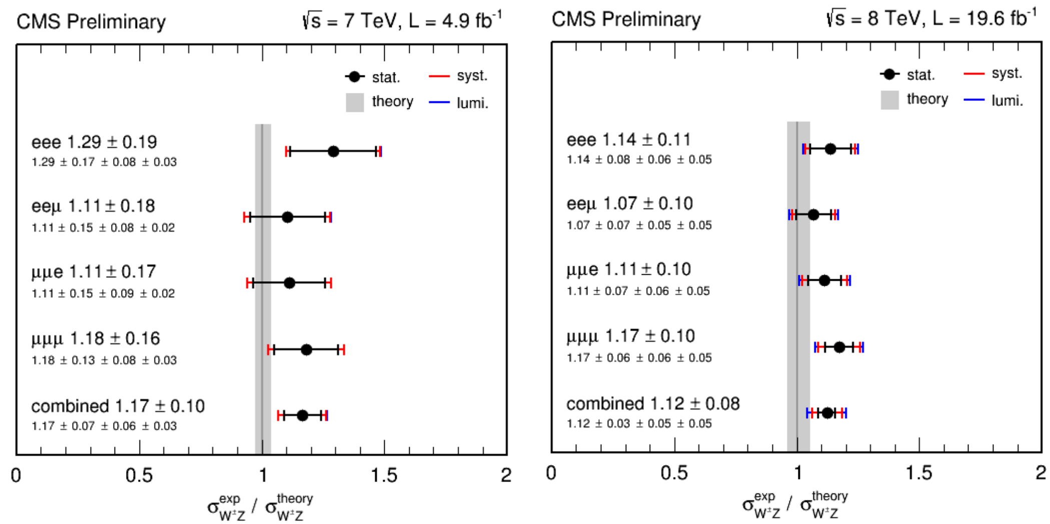


WZ->3lν cross section (2/2)

- Cross section estimated using expression:

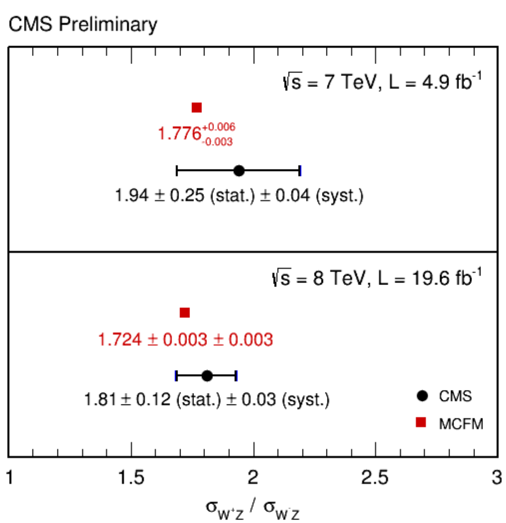
$$\sigma = \frac{N_{\mathrm{sig}}}{A \cdot \epsilon \cdot \mathcal{L}}$$

- Kinematical range: 71 < m(Z) < 111 GeV
- Individual channels combined with BLUE



- The measured values for the WZ production cross section at 7 and 8 TeV in this kinematical range are:

7TeV:	σ(data) = 20.76 ± 1.32 (stat.) ± 1.13 (syst.) ± 0.46 (lumi.) pb σ(NLO) = $17.8_{-0.5}^{+0.7}$ pb
8TeV:	σ(data) = 24.61 ± 0.76 (stat.) ± 1.13 (syst.) ± 1.08 (lumi.) pb σ(NLO) = $21.91_{-0.88}^{+1.17}$ pb

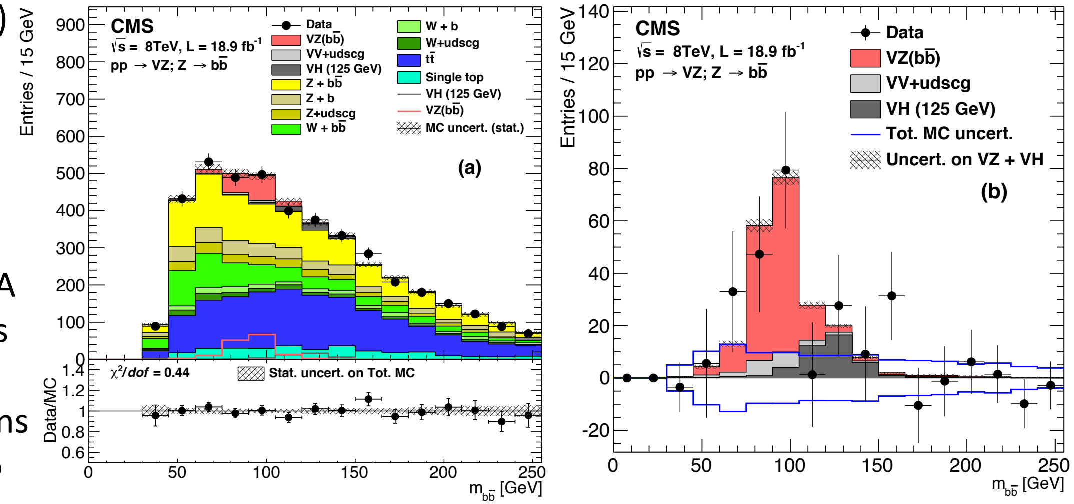


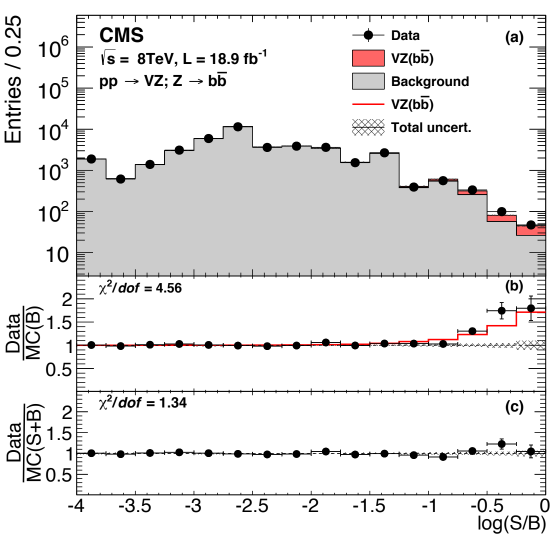
- The ratios of W^+Z to W^-Z production cross sections at 7 and 8 TeV are:

7TeV: σ(W^+Z)/σ(W^+Z) = 1.94 ± 0.25 (stat.) ± 0.04 (syst.),	SM: $1.776_{-0.003}^{+0.006}$
8TeV: σ(W^+Z)/σ(W^+Z) = 1.81 ± 0.12 (stat.) ± 0.03 (syst.),	SM: 1.724 ± 0.003

VZ->2l2b cross section

- Important test of SM, background for the VH(bb)
- Leptonic decays: W -> eν, μν; Z -> e^+e^-, $\mu^+\mu^-$, νν
- Analysis of final states with the 0, 1 or 2 leptons
- Two methods: first using fit to the output of MVA discriminant, second takes fit of the two jet mass
- MVA (BDT): events classified into different regions of W/Z pT, then sorted by the expected S/B ratio
- Two-jet mass analysis: a more restrictive selection





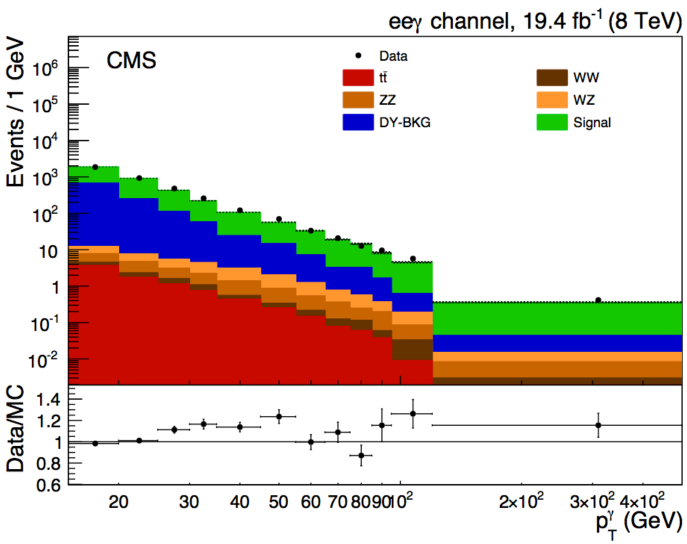
- Total cross sections determined from simultaneous fit to all final states
- MVA analysis: 6.3 σ (5.9 σ expected); m_{bb} analysis: 4.1 σ (4.6 σ expected)
- Measured cross sections (60 < M_Z < 120 GeV) consistent with SM@NLO:

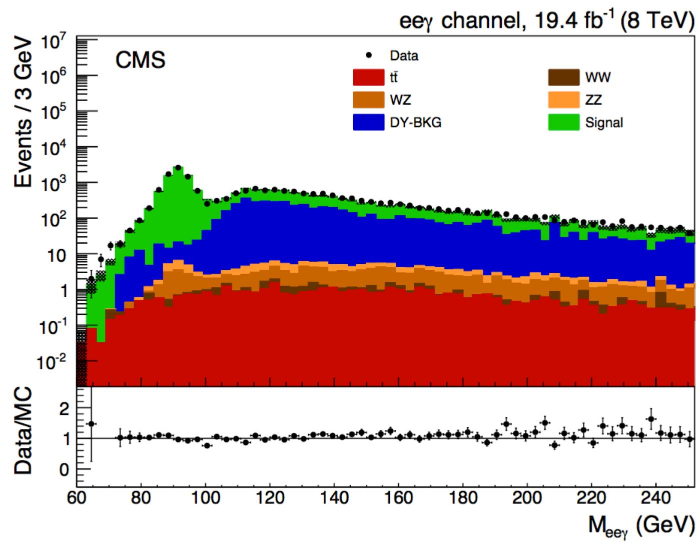
$$\sigma(pp \to WZ) = 30.7 \pm 9.3\,(\text{stat.}) \pm 7.1\,(\text{syst.}) \pm 4.1\,(\text{th.}) \pm 1.0\,(\text{lum.})\,\text{pb}$$
$$\sigma(pp \to WZ) = 22.3 \pm 1.1\,\text{pb} \quad \text{(MCFM NLO)}$$

$$\sigma(pp \to ZZ) = 6.5 \pm 1.7\,(\text{stat.}) \pm 1.0\,(\text{syst.}) \pm 0.9\,(\text{th.}) \pm 0.2\,(\text{lum.})\,\text{pb}$$
$$\sigma(pp \to ZZ) = 7.7 \pm 0.4\,\text{pb} \quad \text{(MCFM NLO)}$$

Zγ->llγ cross section (1/2)

- Measurement of the Zγ production cross section in electron and muon channels, with 19.5 fb^{-1} at 8 TeV
- Kinematic range: $p_T^l > 20$ GeV, $M_{ll} > 50$ GeV, $E_T^\gamma > 15$ GeV, $\Delta R(l,\gamma) > 0.7$, lept. and photon in fiducial area
- The dominant background is DY+jets: non-prompt photons from π^0 or η decays or misidentified hadrons
- Two template observables were used to measure the cross sections independently and then combined:
  - $\sigma_{i\eta i\eta}$: separation between two background photons have larger $\sigma_{i\eta i\eta}$ values than for single photons
  - $I_{\gamma,nfp}$: p_T sum of all photon-like PF objects in $\Delta R < 0.4$ around photon, no "footprint" of the photon



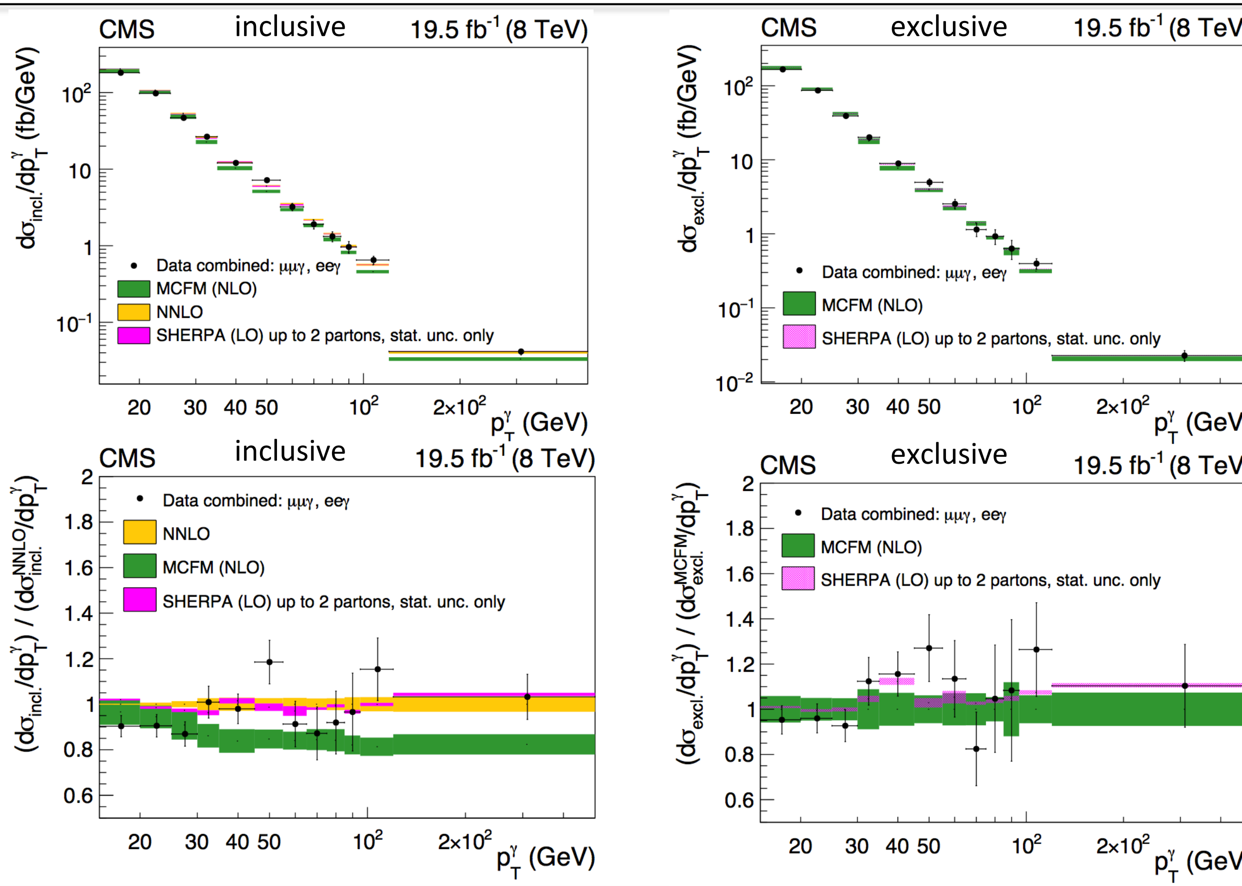


Zγ->llγ cross section (2/2)

- The overall inclusive cross section, from the combination of two template methods, is measured to be:

σ(incl) = 2063 ± 19 (stat.) ± 98 (syst.) ± 54 (lumi.) fb   σ(NLO) = 2100 ± 120 fb (MCFM)
σ(NNLO) = 2241 ± 22 fb (M. Grazzini et al. arXiv:1309.7000.)

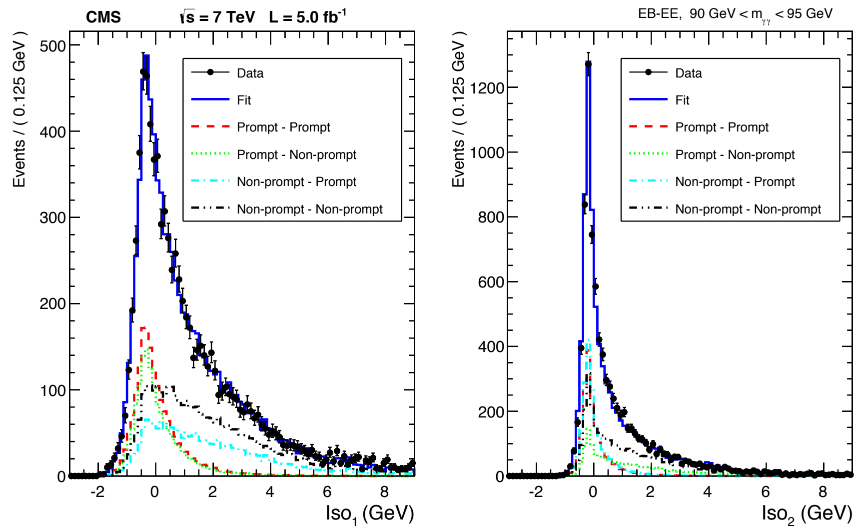
- The inclusive cross section shows better agreement at high p_T^γ with NNLO and SHERPA than with MCFM
- The exclusive cross section is measured without any accompanying jet with p_T > 30 GeV and |η| < 2.4
- The difference at high p_T^γ between MCFM (NLO) and SHERPA smaller than incl.
- No exc. NNLO calc. available
- Adding the exc. CS in all bins



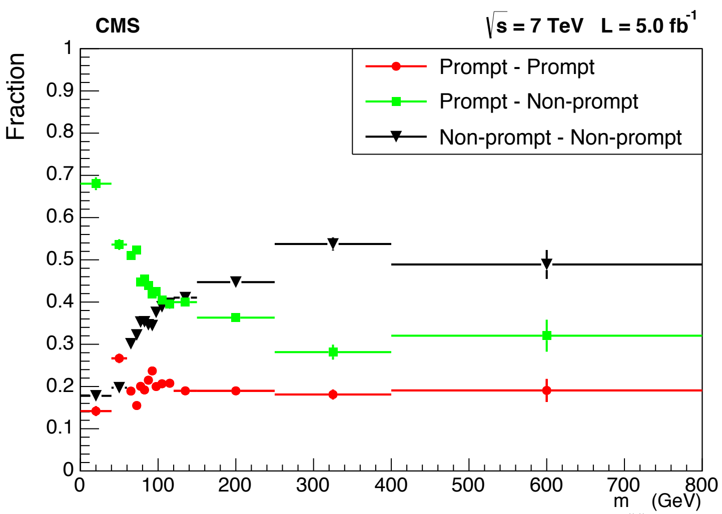
σ(excl) = 1770 ± 18 (stat.) ± 115 (syst.) ± 46 (lumi.) fb, σ(NLO) = 1800 ± 120 fb (MCFM)

Diphoton cross section (1/2)

- Measurement of diphoton production at 7 TeV, 5 fb^{-1}
- Major background for the H->γγ and BSM searches
- Main background from jets misidentified as photons
- Probed a phase space with asymmetric p_T selection to enhance sensitivity to the higher order diagrams:



(two isolated photons, $p_{T,\gamma1}$ > 40 GeV, $p_{T,\gamma2}$ > 25 GeV, $|\eta_\gamma|$ < 1.44 or 1.57 < $|\eta_\gamma|$ < 2.5, $\Delta R(\gamma_1, \gamma_2)$ > 0.45)

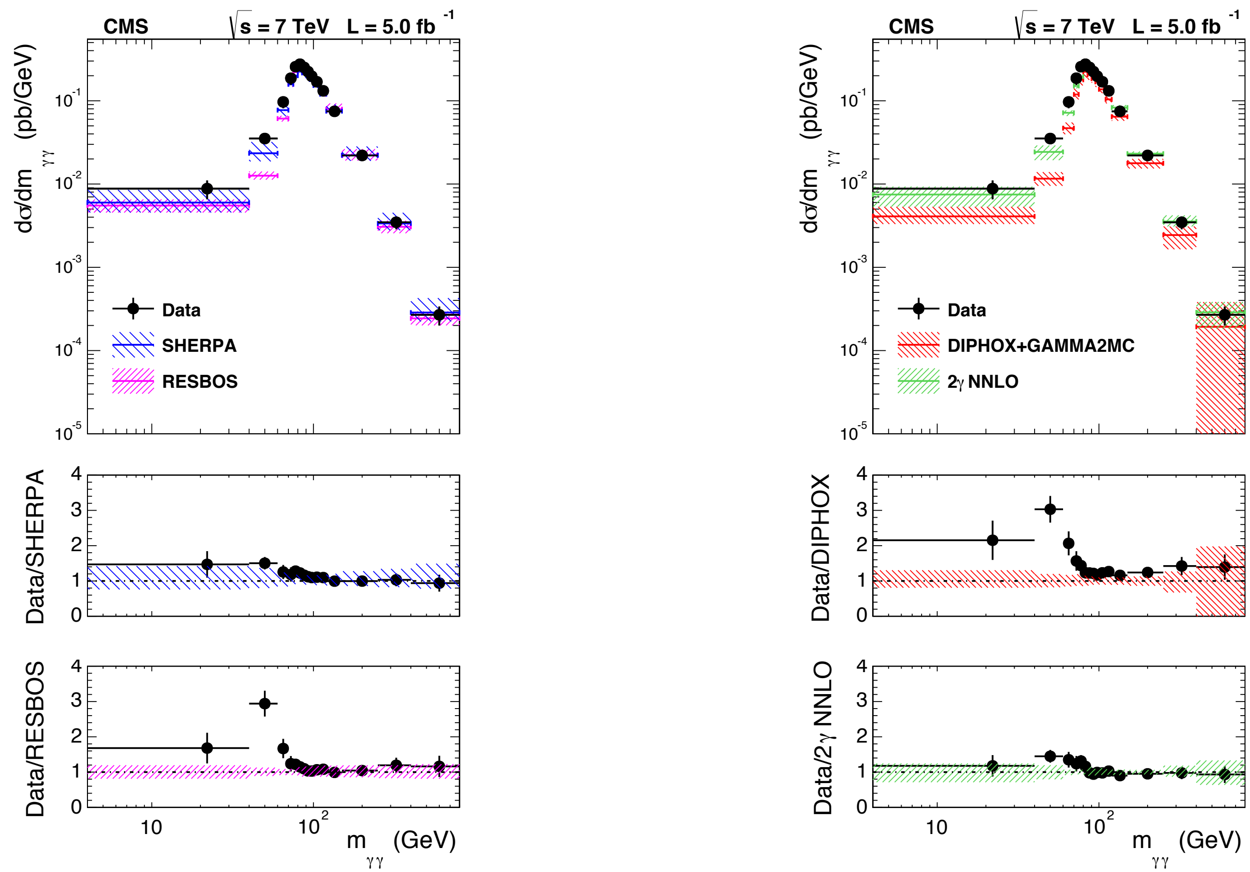


- Photon component of PF isolation is used as a discriminator
- Template shapes for signal and background built from data
- Binned maximum likelihood fit to statistically separate signal
- Total cross section measured in data for phase-space above:

σ(data) = 16.8 ± 0.2 (stat.) ± 1.8 (syst.) ± 0.4 (lumi.) pb
σ(2γNNLO) = $16.2_{-1.3}^{+1.5}$ (scale) pb

Diphoton cross section (2/2)

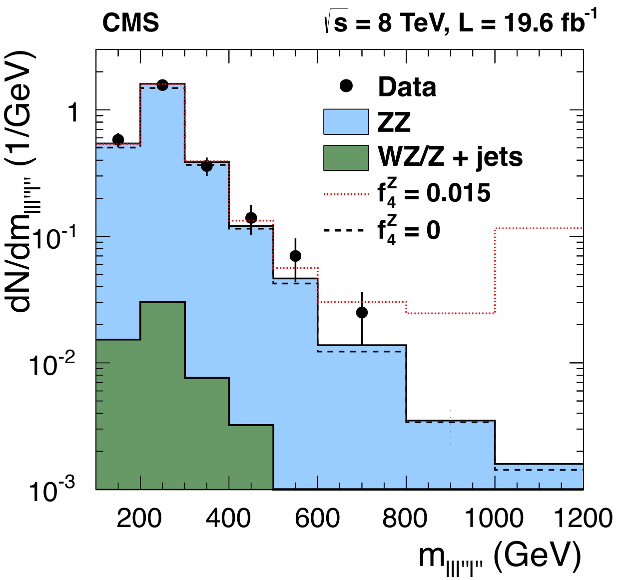
- The production cross section was measured differentially as a function of $m_{\gamma\gamma}$, $p_T^{\gamma\gamma}$, $\Delta\phi_{\gamma\gamma}$ and $\cos\theta^*$
- NNLO from 2γNNLO prediction show an improved agreement with data for kinematical distributions



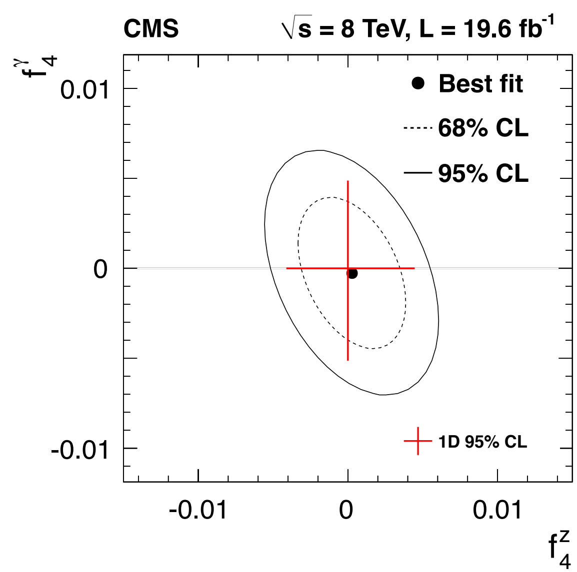
- Reasonable agreement from SHERPA at LO, since it includes up to 3 extra-jets at matrix-element level
- Still there is an excess in data at low $\Delta\phi_{\gamma\gamma}$, particularly sensitive to the missing higher order QCD effects

ZZ->4l aTGC searches

- Eff. Lagrangian for ZZZ and ZZγ ATGCs, parameters f_4^V and f_5^V (V=Z/γ) zero in the SM, no form factors



- The ATGC signal samples are produced with SHERPA generator
- Would be manifested as an increased yield of events at high m_{4l}
- The expected signal obtained from a grid of ATGC in $(f_{4(5)}^Z, f_{4(5)}^\gamma)$
- Cross section has quadratic dependence on coupling parameters



- The 1D limits and 2D contours are derived

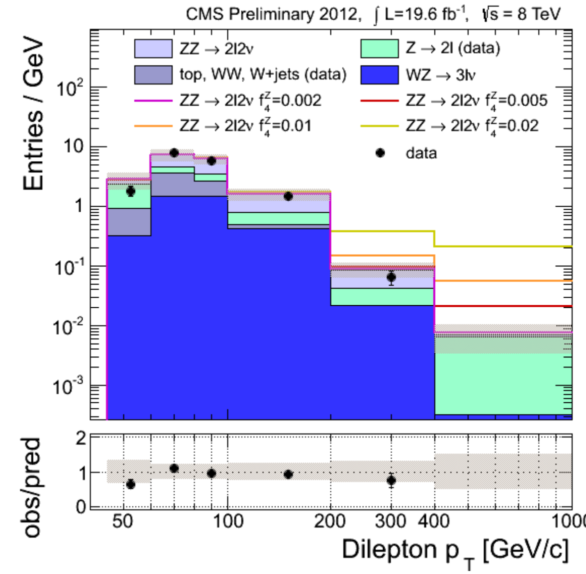
$$-0.004 < f_4^Z < 0.004, -0.005 < f_5^Z < 0.005$$

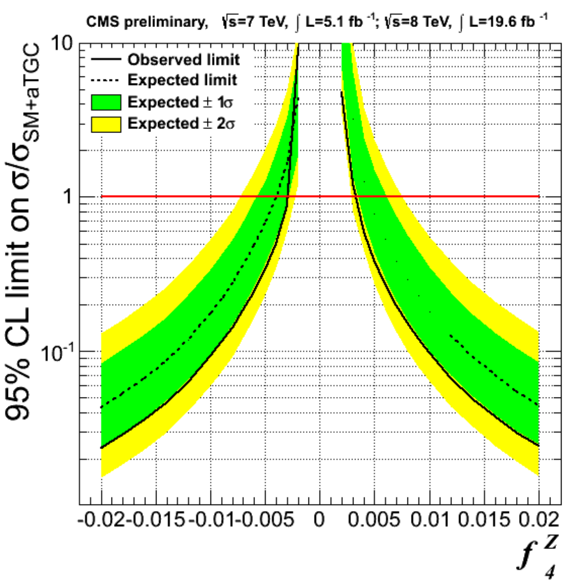
$$-0.004 < f_4^\gamma < 0.004, -0.005 < f_5^\gamma < 0.005$$

- Improved previous limits by a factor of 3-4

ZZ->2l2ν aTGC searches

- The ZZ production used to probe the existence of ZZZ and ZZγ ATGCs
- Eff. Lagrangian approach, anomalous coupling parameters f_4^V and f_5^V
- No form-factor scaling, following the CMS Collaboration prescription
- The limits were derived using 4.9 fb^{-1} at 7 TeV and 19.6 fb^{-1} at 8 TeV
- Dilepton p_T distribution is a good observable, sensitive to the ATGCs





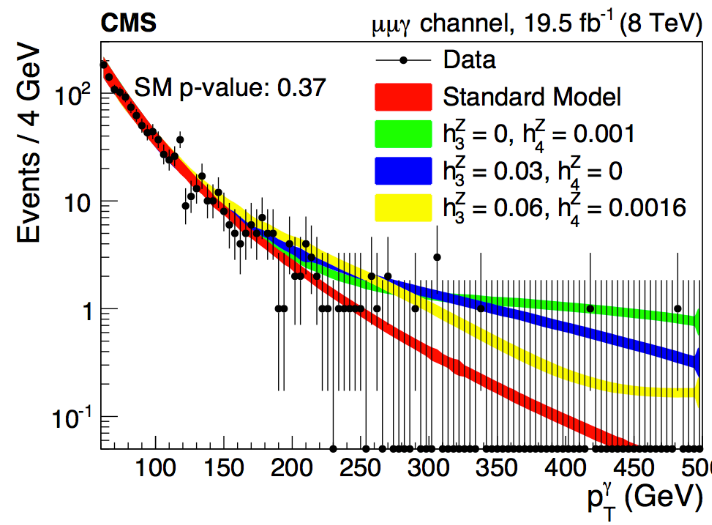
- The DY and non-resonant background estimated in data-driven way
- Modified frequentist construction CL_S used, binned profile likelihood
- One- dimensional limits on each of the 4 parameters, fixing other 3

Dataset	f_4^Z	f_4^γ	f_5^Z	f_5^γ
7 TeV	[-0.0088; 0.0085]	[-0.0098; 0.011]	[-0.0096; 0.0096]	[-0.011 ; 0.010]
8 TeV	[-0.0038; 0.0040]	[-0.0049; 0.0039]	[-0.0041; 0.0038]	[-0.0049; 0.0046]
Combined	[-0.0030; 0.0034]	[-0.0039; 0.0031]	[-0.0036; 0.0032]	[-0.0038; 0.0038]

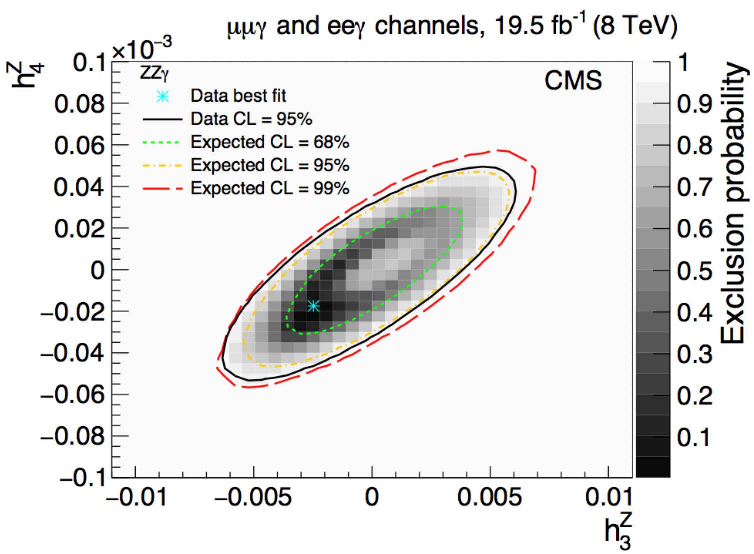
- Super-seeding the previous limits, 2l2ν better by 25% than 4l results

Zγ->llγ aTGC searches

- The ZZγ and Zγγ ATGCs using EFT dim 6 and dim 8 operators
- There are eight couplings: h_i^V, i=1..4 and V = Z/γ for ZZγ/Zγγ
- Eff. Lagrangian assume Λ well above, no form factors applied
- The existence of aTGC would enhance the high E_T^γ spectrum



- Unbinned profile likelihood ratio is used to find the best fitting aTGC model and corresponding 95% CL

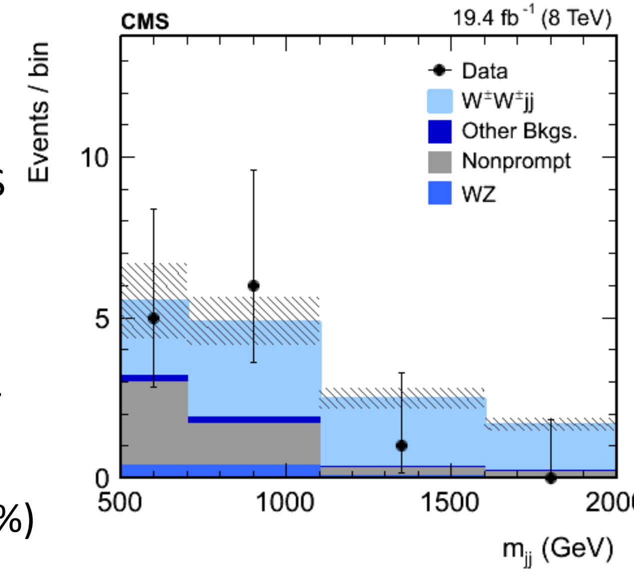


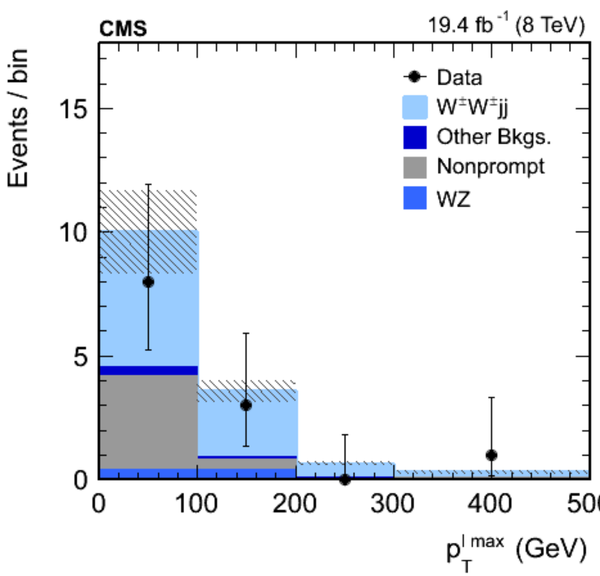
- Only the CP-even parameters, h_3^V and h_4^V, are considered
- The data are in good agreement with the SM expectations
- Limits on the strength of ZZγ and Zγγ ATGCs are extracted
- Improvement up to a factor of 3 w.r.p. to previous 7 TeV results

$$-3.8\cdot 10^{-3} < h_3^Z < 3.7\cdot 10^{-3}$$
$$-3.1\cdot 10^{-5} < h_4^Z < 3.0\cdot 10^{-5}$$
$$-4.6\cdot 10^{-3} < h_3^\gamma < 4.6\cdot 10^{-3}$$
$$-3.6\cdot 10^{-5} < h_4^\gamma < 3.5\cdot 10^{-5}$$

VBS : $W^{\pm} W^{\pm}$ and WZ production (1/2)

- A key process to probe the nature of the EWK symmetry breaking
- Higgs discovery suggests which mechanism could unitarize the VBS
- Many BSM scenarios predict enhancement in the VBS production
- Events with two SS leptons, two separated jets and moderate MET
- Signal receives contributions from EWK, QCD and interference (15%)





- Backgrounds from the non-prompt leptons (75%) and WZ->3lν (15%)
- Statistical analysis of event yields in 8 bins, 4 m_{jj} times 2 charge bins
- The cross section is extracted for a fiducial dilepton SS signal region

$p_T^l > 10$ GeV, $|\eta_l| < 2.5$, $p_t^{jet} > 20$ GeV, $|\eta_{jet}| < 5.0$, $m_{jj} > 300$ GeV, $|\Delta\eta_{jj}| > 2.5$

$\sigma(W^{\pm} W^{\pm}jj) = 4.0_{-2.0}^{+2.4}$ (stat)$_{-1.0}^{+1.1}$ (syst) fb, expectation: 5.8 ± 1.2 fb

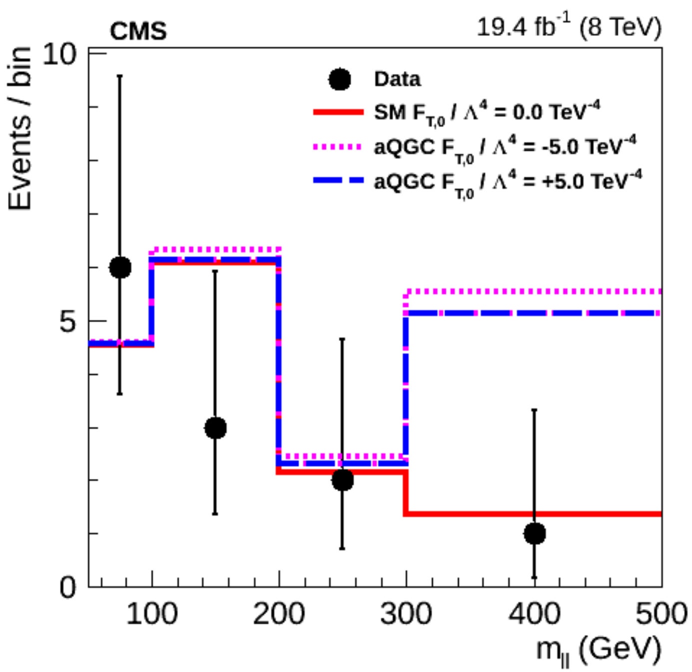
$\sigma(WZjj) = 10.8 \pm 4.0$ (stat) ± 1.3 (syst) fb, expectation: 14.4 ± 4.0 fb

- The observed (expected) significance for VBS process is 2.0 σ (3.1 σ)

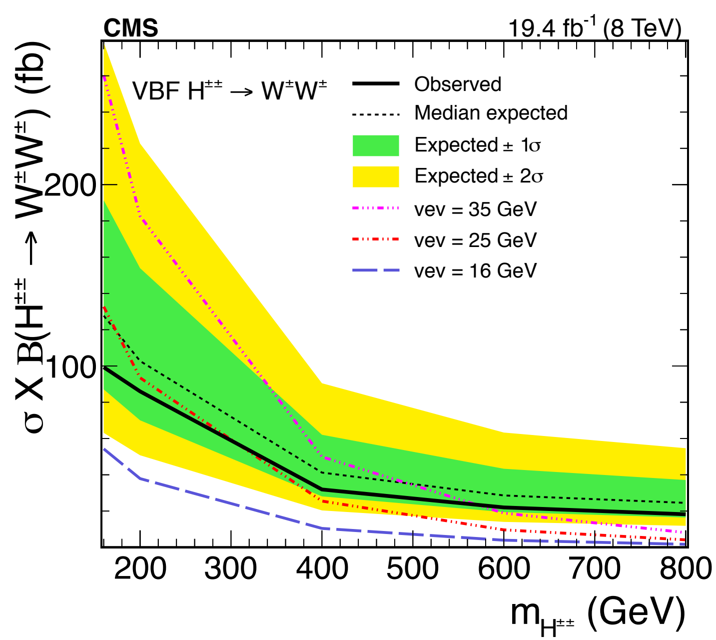
VBS : $W^{\pm} W^{\pm}$ and WZ production (2/2)

- There are various extensions of the SM that can alter the couplings of the vector bosons to each other
- Nine independent C and P conserving EFT dim 8 operators modify the quartic gauge boson couplings

Operator coefficient	Exp. lower	Exp. upper	Obs. lower	Obs. upper	Unitarity limit
$F_{S,0}/\Lambda^4$	−42	43	−38	40	0.016
$F_{S,1}/\Lambda^4$	−129	131	−118	120	0.050
$F_{M,0}/\Lambda^4$	−35	35	−33	32	80
$F_{M,1}/\Lambda^4$	−49	51	−44	47	205
$F_{M,6}/\Lambda^4$	−70	69	−65	63	160
$F_{M,7}/\Lambda^4$	−76	73	−70	66	105
$F_{T,0}/\Lambda^4$	−4.6	4.9	−4.2	4.6	0.027
$F_{T,1}/\Lambda^4$	−2.1	2.4	−1.9	2.2	0.022
$F_{T,2}/\Lambda^4$	−5.9	7.0	−5.2	6.4	0.08

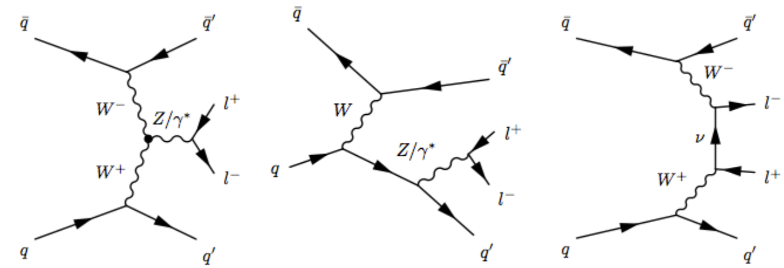


- Double charged Higgs bosons: VBF $H^{++} \rightarrow W^{\pm} W^{\pm}$
- The exclusion limits in Georgi-Machacek model



VBF : EWK Z production

- Zjj production is a mixture of EW and strong (ref: DY Zjj)
- EWK Zjj signal characterized by a large $\Delta\eta_{jj}$ and large M_{jj}
- Part of more general studies of VBS and VBF processes
- Two types of jets: "jet-plus-track" and "particle-flow"



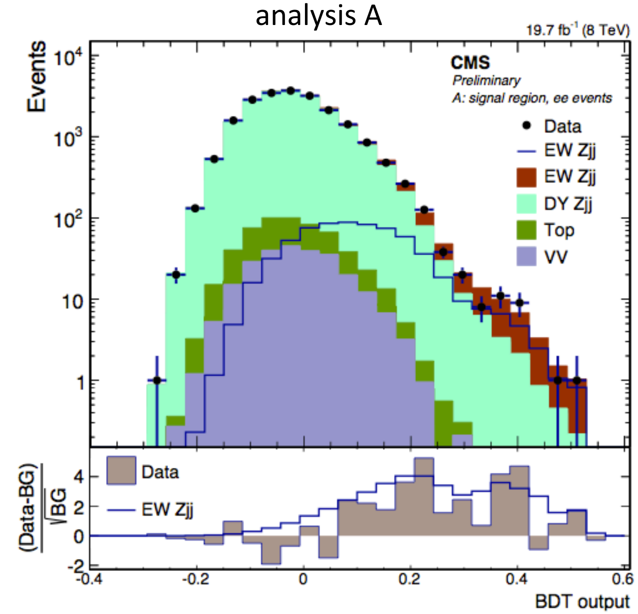
- Multivariate analyses used to provide separation of EW Zjj and DY Zjj from the inclusive lljj spectrum:

  A. μμ & ee (PF jets), dijet and Z kinematics as input to the MVA

  B. μμ (JPT jets), BDT: full kinematics of tagging jets and Z boson

  C. μμ & ee (PF jets), only dijet-related variables as input to MVA

analysis A



- Measured signal cross section is in a good agreement with the SM prediction at leading order (LO):

$$\sigma(\mathrm{EW}\ \ell\ell jj) = 174 \pm 15\,(\mathrm{stat}) \pm 40\,(\mathrm{syst})\,\mathrm{fb} = 174 \pm 42\,(\mathrm{total})\,\mathrm{fb} \qquad \sigma_{\mathrm{LO}}(\mathrm{EW}\ \ell\ell jj) = 208 \pm 18\,\mathrm{fb}$$

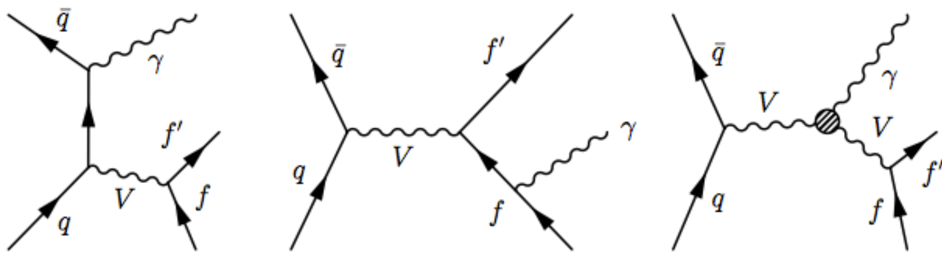
Summary

- CMS Collaboration has performed measurements of various diboson cross-sections
- Full 2011 (7 TeV) and 2012 (8 TeV) LHC Run I datasets were used in many searches
- Overall there is a good agreement of the measurements with the NLO expectation
- The importance of NNLO predictions is demonstrated in the modeling of $Z\gamma$ and $\gamma\gamma$
- Extensive searches for the anomalous gauge boson coupling have been performed
  - No signal was observed, the limits were extracted, many are the world-leading
- The EWK VBS and VBF processes were studied, an agreement with SM is observed
- Many opportunities and challenges ahead as the start of LHC Run II is approaching

Backup slides

Anomalous (Charged) Gauge Couplings

- The self-interaction of the electroweak gauge bosons present an important and sensitive probe of the SM
- Any deviation would be an indication of new physics



- Limits on the charged aTGC: WWγ and WWZ vertices
- The results from CMS approaching sensitivity of LEP

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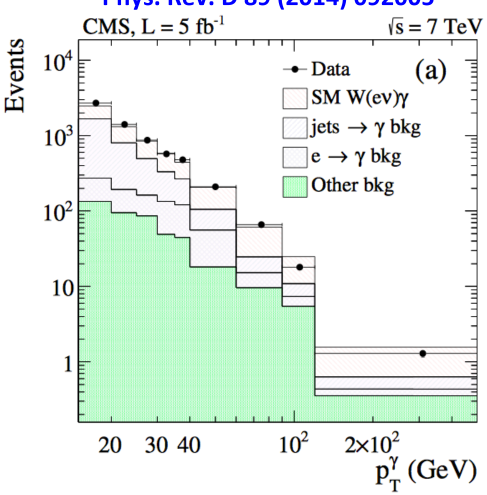

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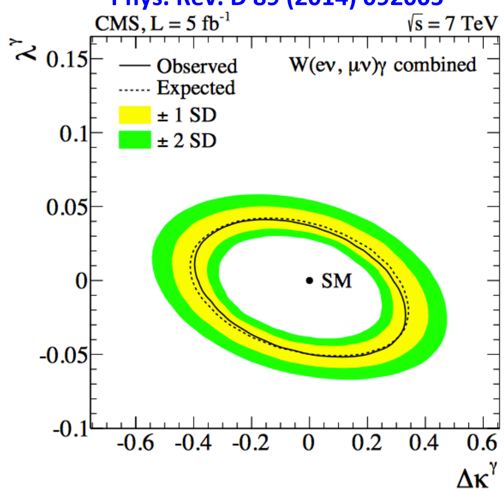
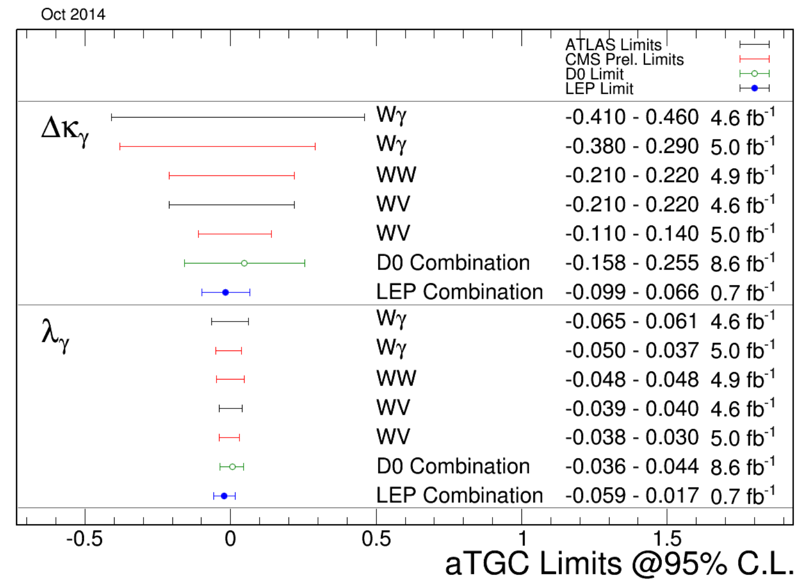
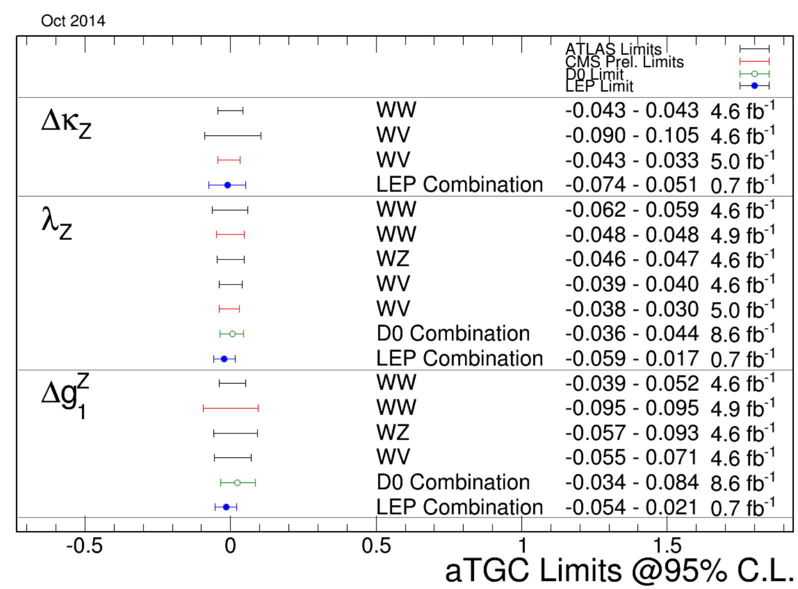
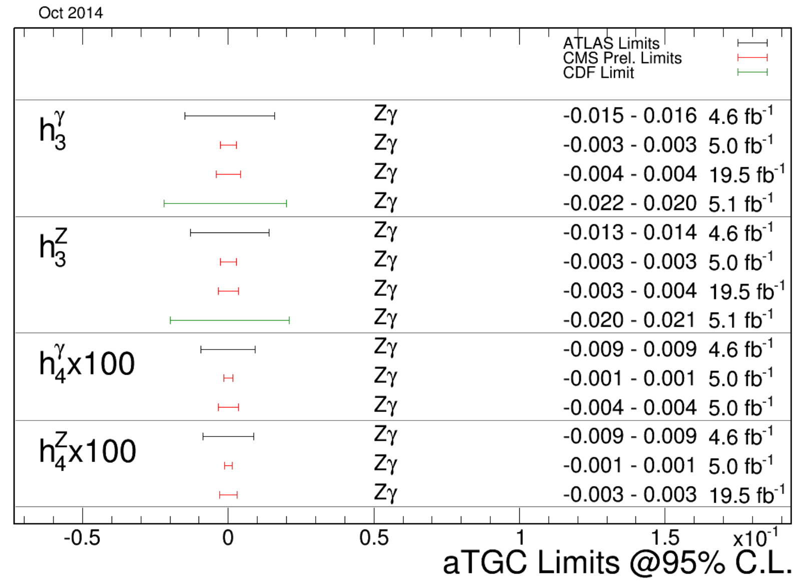




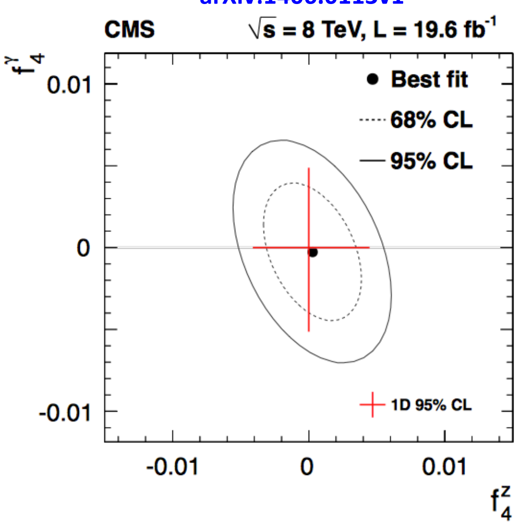


Anomalous (Neutral) Gauge Couplings

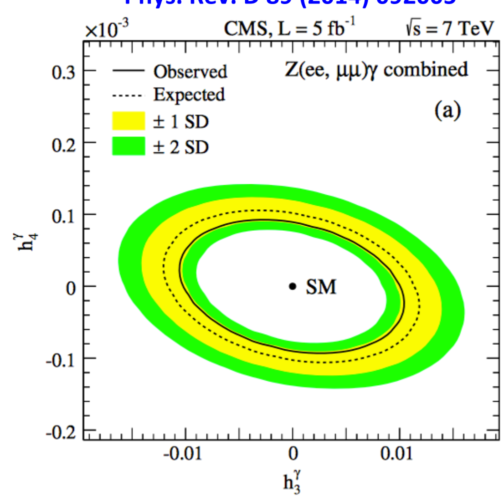
- Limits on the neutral aTGC: the ZZγ and Zγγ vertices
- In the SM neutral aTGC are equal to zero at tree level
- The limits are set for aTGC parameters: h_3,h_4 and f_4,f_5
- Several limits are at the world-best in the sensitivity

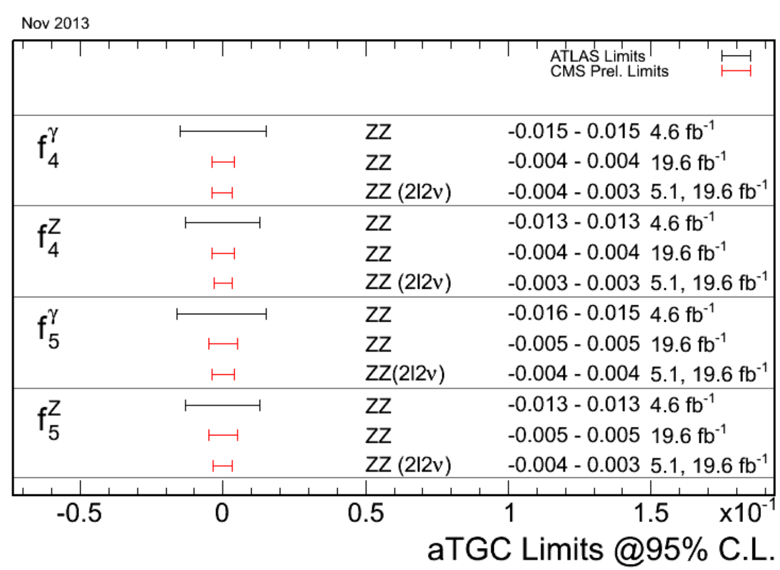


arXiv:1406.0113v1



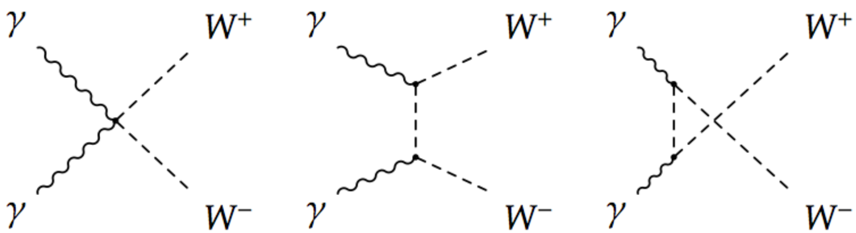
Phys. Rev. D 89 (2014) 092005





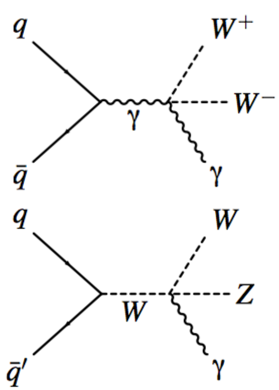
Anomalous Quartic Gauge Couplings

- Two photon production of a pair of W bosons is sensitive to anomalous quartic gauge couplings

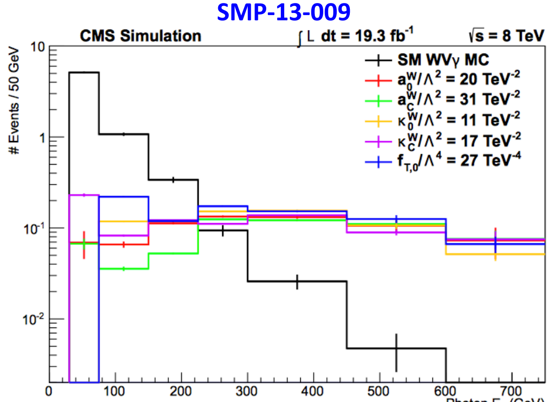


- Limits set by CMS are approximately two orders of magnitude more stringent than the LEP limits and about 20 times better than Tevatron results

- Search for aQGC through WVγ production, where W boson decays to leptons and V(W or Z) to jets

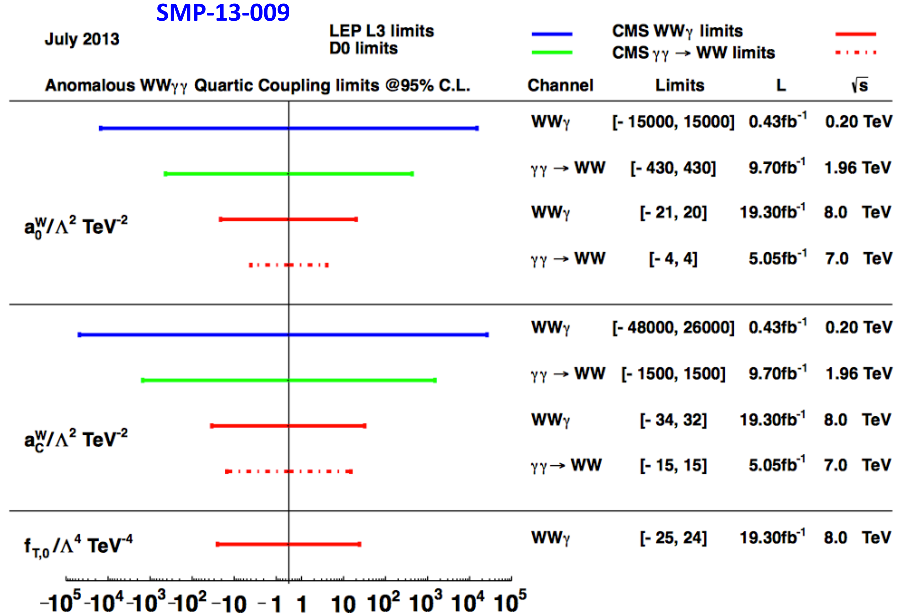


SMP-13-009



- First ever limits on anomalous WWZγ couplings

SMP-13-009



SMP-13-009

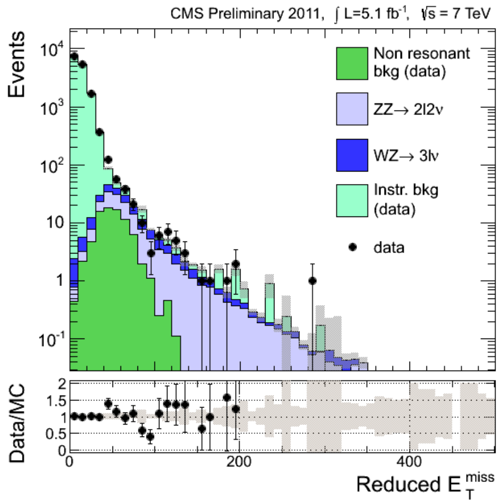
Observed Limits	Expected Limits
$-21\ (\text{TeV}^{-2}) < a_0^W/\Lambda^2 < 20\ (\text{TeV}^{-2})$	$-24\ (\text{TeV}^{-2}) < a_0^W/\Lambda^2 < 23\ (\text{TeV}^{-2})$
$-34\ (\text{TeV}^{-2}) < a_C^W/\Lambda^2 < 32\ (\text{TeV}^{-2})$	$-37\ (\text{TeV}^{-2}) < a_C^W/\Lambda^2 < 34\ (\text{TeV}^{-2})$
$-25\ (\text{TeV}^{-4}) < f_{T,0}/\Lambda^4 < 24\ (\text{TeV}^{-4})$	$-27\ (\text{TeV}^{-4}) < f_{T,0}/\Lambda^4 < 27\ (\text{TeV}^{-4})$
$-12\ (\text{TeV}^{-2}) < \kappa_0^W/\Lambda^2 < 10\ (\text{TeV}^{-2})$	$-12\ (\text{TeV}^{-2}) < \kappa_0^W/\Lambda^2 < 12\ (\text{TeV}^{-2})$
$-18\ (\text{TeV}^{-2}) < \kappa^W/\Lambda^2 < 17\ (\text{TeV}^{-2})$	$-19\ (\text{TeV}^{-2}) < \kappa^W/\Lambda^2 < 18\ (\text{TeV}^{-2})$

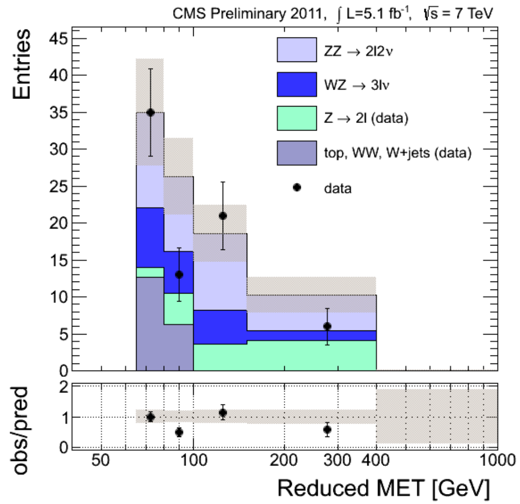
SMP-13-009

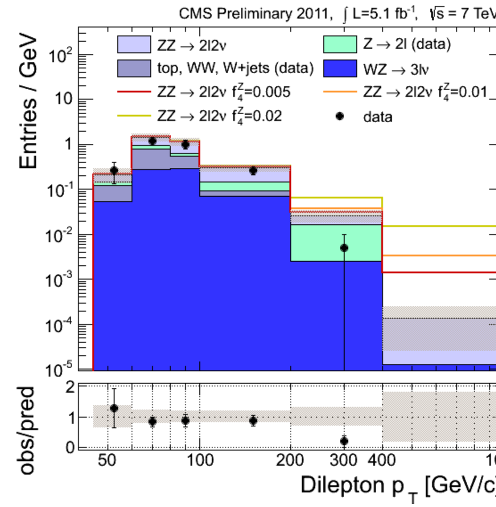
Observed Limits	Expected Limits
$-77\ (\text{TeV}^{-4}) < f_{M,0}/\Lambda^4 < 81\ (\text{TeV}^{-4})$	$-89\ (\text{TeV}^{-4}) < f_{M,0}/\Lambda^4 < 93\ (\text{TeV}^{-4})$
$-131\ (\text{TeV}^{-4}) < f_{M,1}/\Lambda^4 < 123\ (\text{TeV}^{-4})$	$-143\ (\text{TeV}^{-4}) < f_{M,1}/\Lambda^4 < 131\ (\text{TeV}^{-4})$
$-39\ (\text{TeV}^{-4}) < f_{M,2}/\Lambda^4 < 40\ (\text{TeV}^{-4})$	$-44\ (\text{TeV}^{-4}) < f_{M,2}/\Lambda^4 < 46\ (\text{TeV}^{-4})$
$-66\ (\text{TeV}^{-4}) < f_{M,3}/\Lambda^4 < 62\ (\text{TeV}^{-4})$	$-71\ (\text{TeV}^{-4}) < f_{M,3}/\Lambda^4 < 66\ (\text{TeV}^{-4})$

ZZ->2l2ν cross section

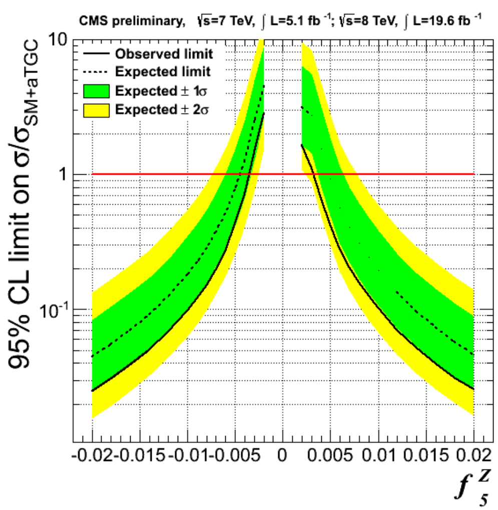
Results at 7TeV

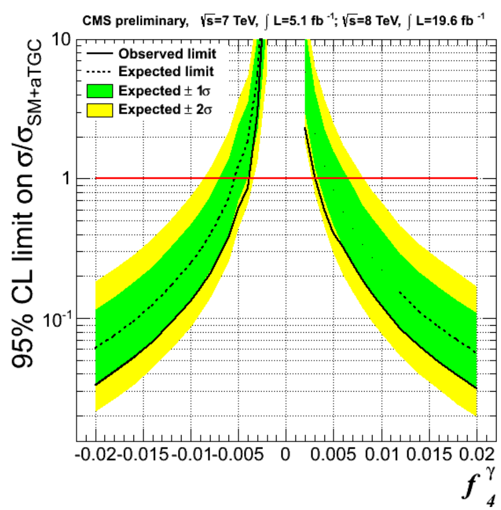


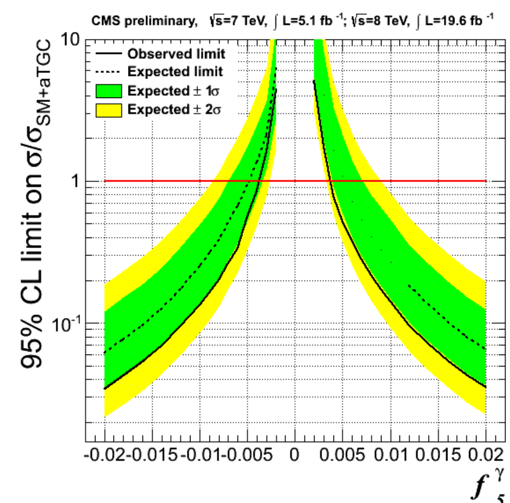




1D limits at 8TeV

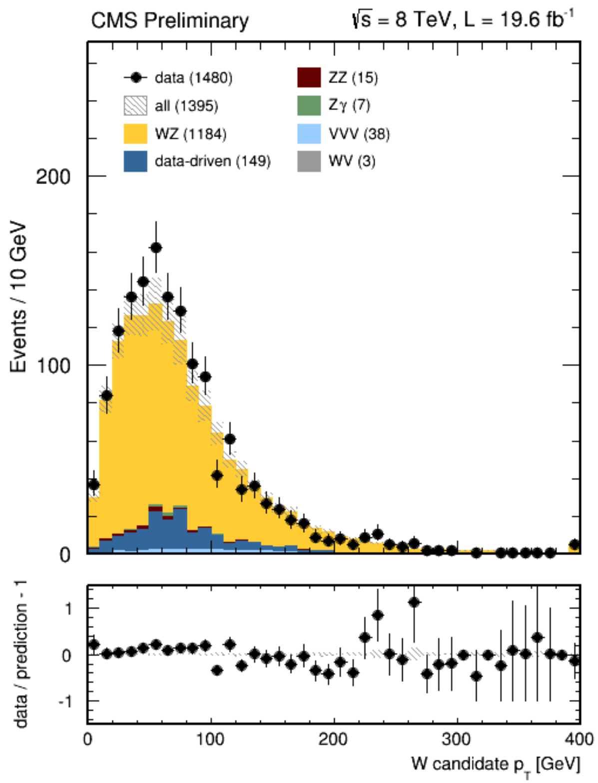




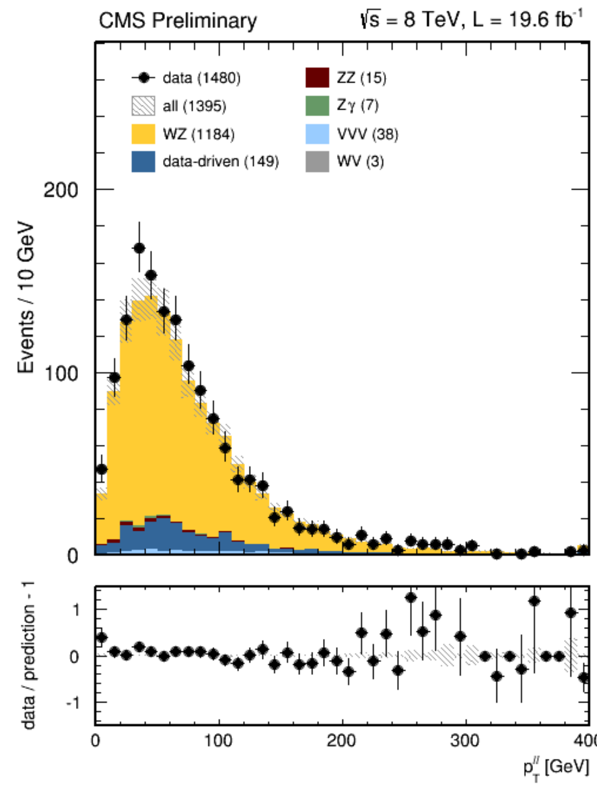


WZ->3lν cross section

Results at 8TeV



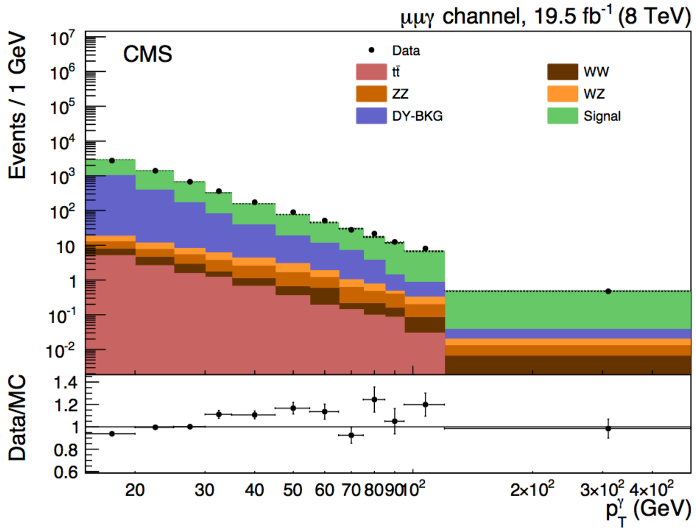
W boson p_T

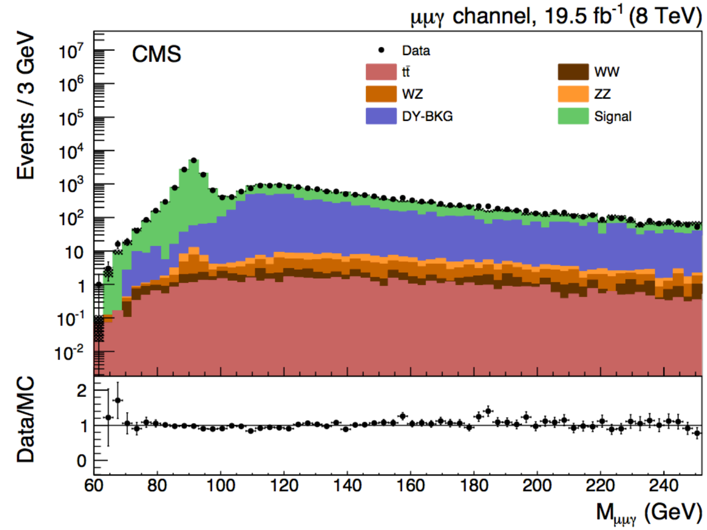


Z boson p_T

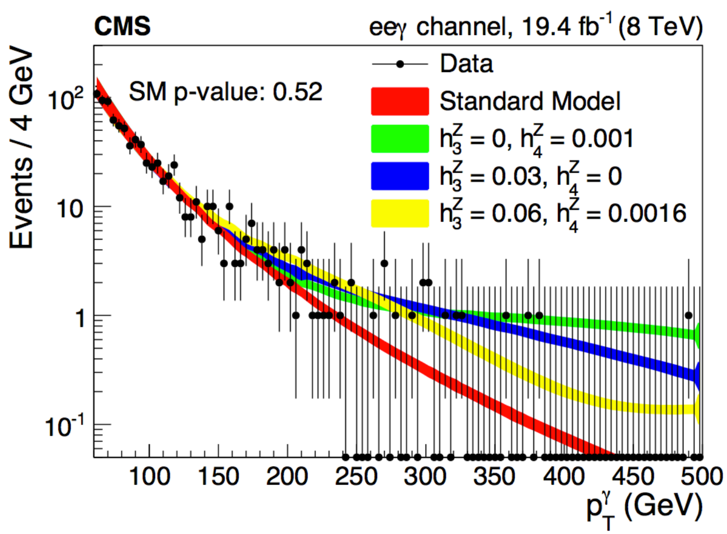
Zγ->llγ cross section

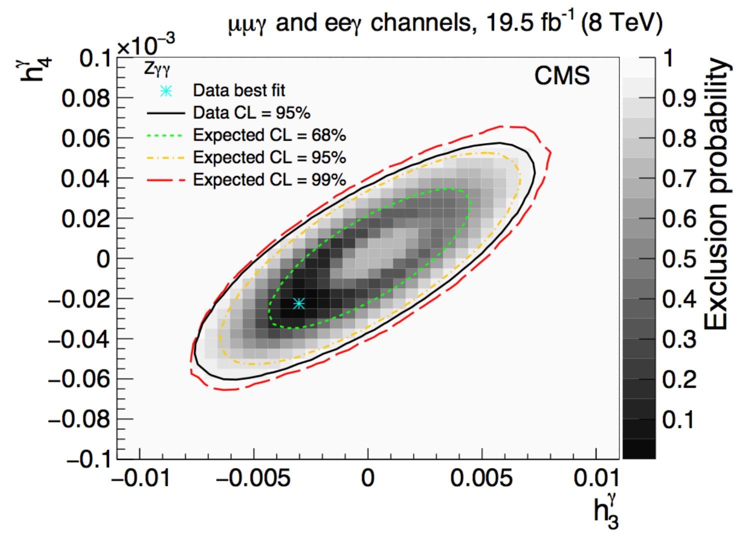
Z(μμ)γ results



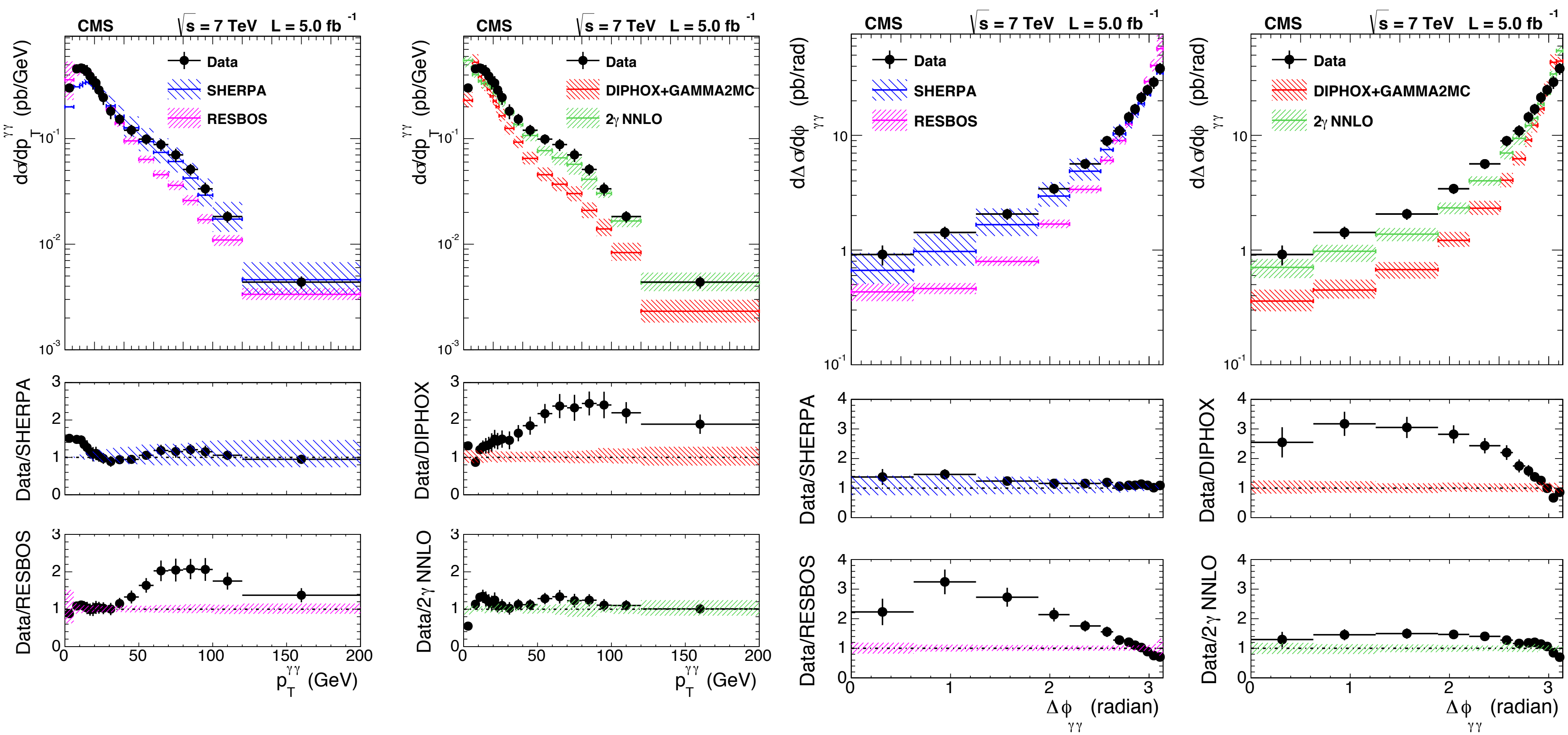


γ p_T & limits



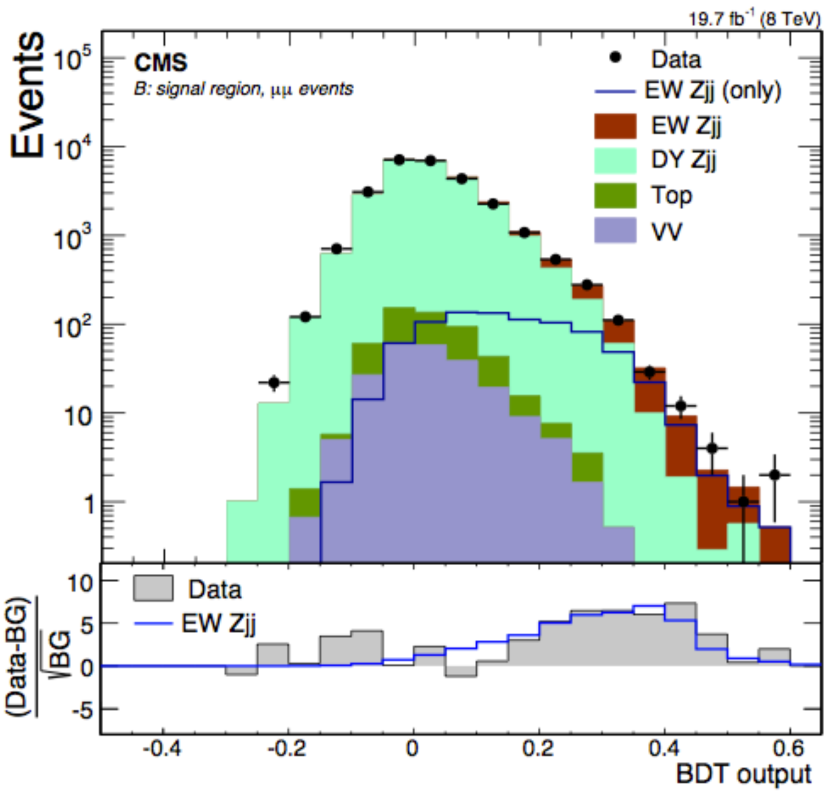


Diphoton cross section



VBF : EWK Z production

Analysis B



Analysis C