DiBoson production at CMS

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on behalf of the **CMS Collaboration**
23rd Rencontres de Blois

Outlook

- Introduction
- Diboson processes – Vγ and WW
  - Signal and selection
  - Background estimation
  - Cross-section measurements
- Search for aTGC
- Conclusions and Summary

Introduction

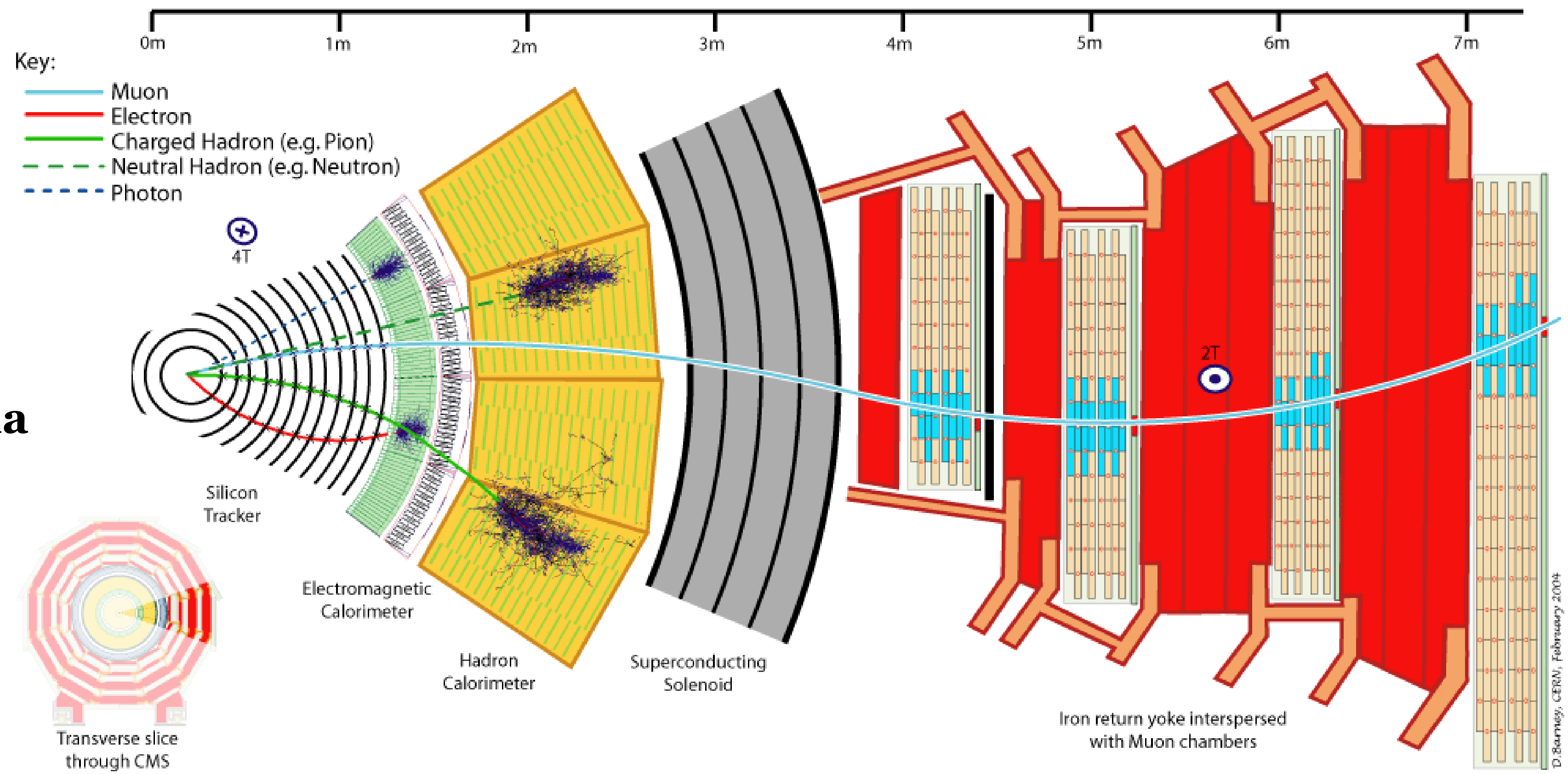
- Cross section measurement for diboson processes at CMS for **L_{int} = 36 /pb**
  - Wγ, Zγ and WW
  - Here not shown for WZ, ZZ : not enough luminosity

- Test of the Standard Model at 7 TeV
  - Measurement of the self-interaction boson coupling could be a candle of new physics

- Important backgrounds for New Physics searches
  - Vγ final state similar to those of BSM scenarios (SUSY, fermiophobic Higgs …)
  - WW irreducible for some Higgs searches (HWW)

CMS

B = 4 Tesla



Muon
Tracker + Muon System

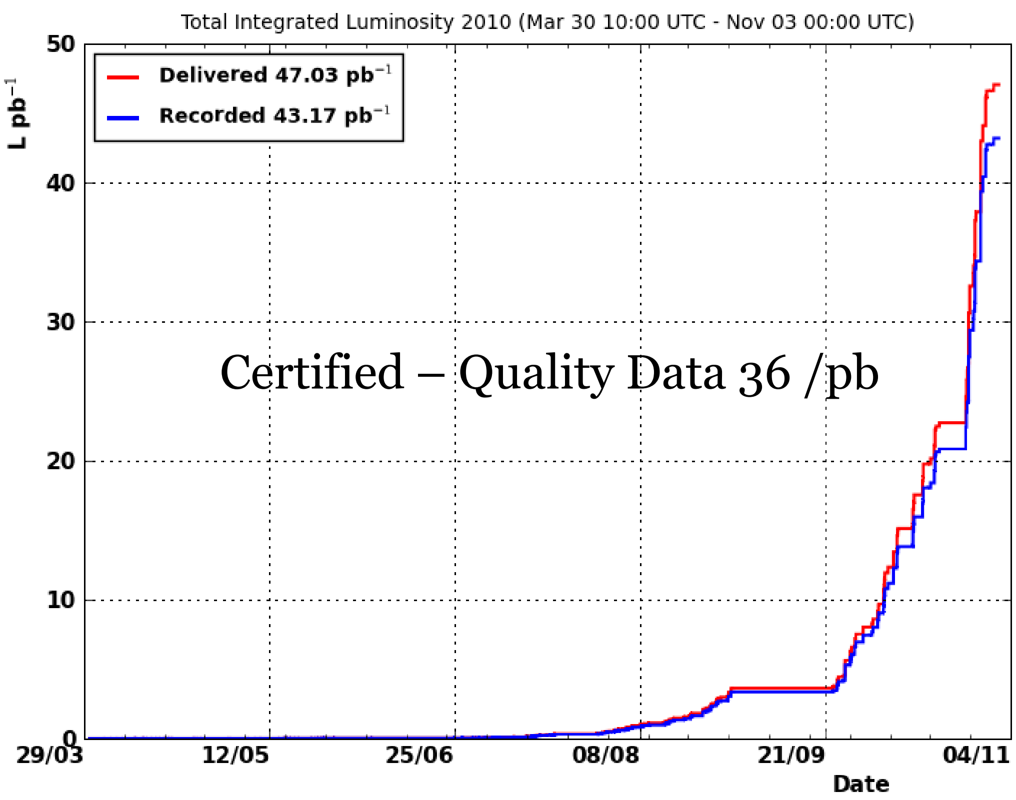
Electron
Tracker + Electromagnetic Cal.

Charged Hadron
Tracker + Hadron Cal.

Neutral Hadron
Hadron Cal.

Photon
Electromagnetic Cal.

CMS



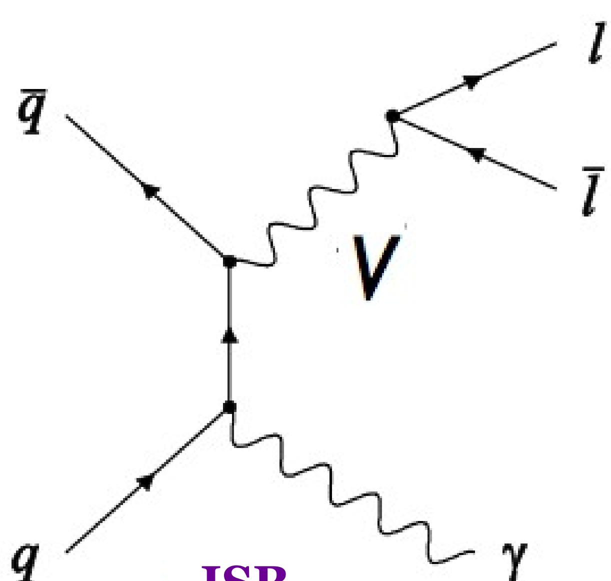
- Compact Detector
  - Tracker
  - Calorimeters
    - Hadronic
    - Electromagnetic
  - Muon System
- pp collisions at CMS with L_{int} = 36 /pb
- **> 90 % recording efficiency**
- **> 98 % operational detector**

Vγ Cross-section

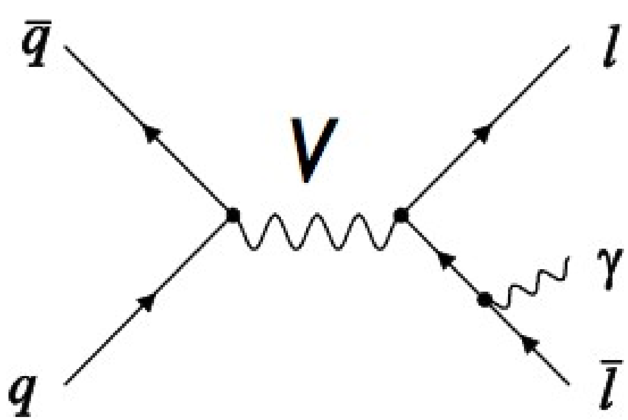
CMS – EWK – 10 – 008

DiBoson processes

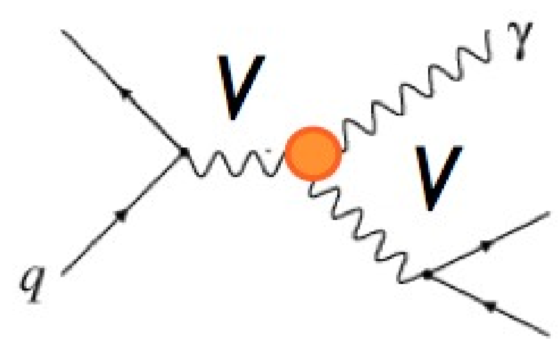
- $V\gamma$ (V = W,Z) Production modes
  - Final State Radiation (FSR)
  - Initial State Radiation (ISR)
  - Photon produced in s-channel via Trilinear Gauge Couplings (TGC)



ISR



FSR



TGC

Signal and Selection

- **Trigger:** Events selected using single lepton trigger
- **Vγ (V = W,Z) Signatures:** Only consider leptonic V decays
  - W→μνγ, W→eνγ, Z→μμγ, Z→eeγ

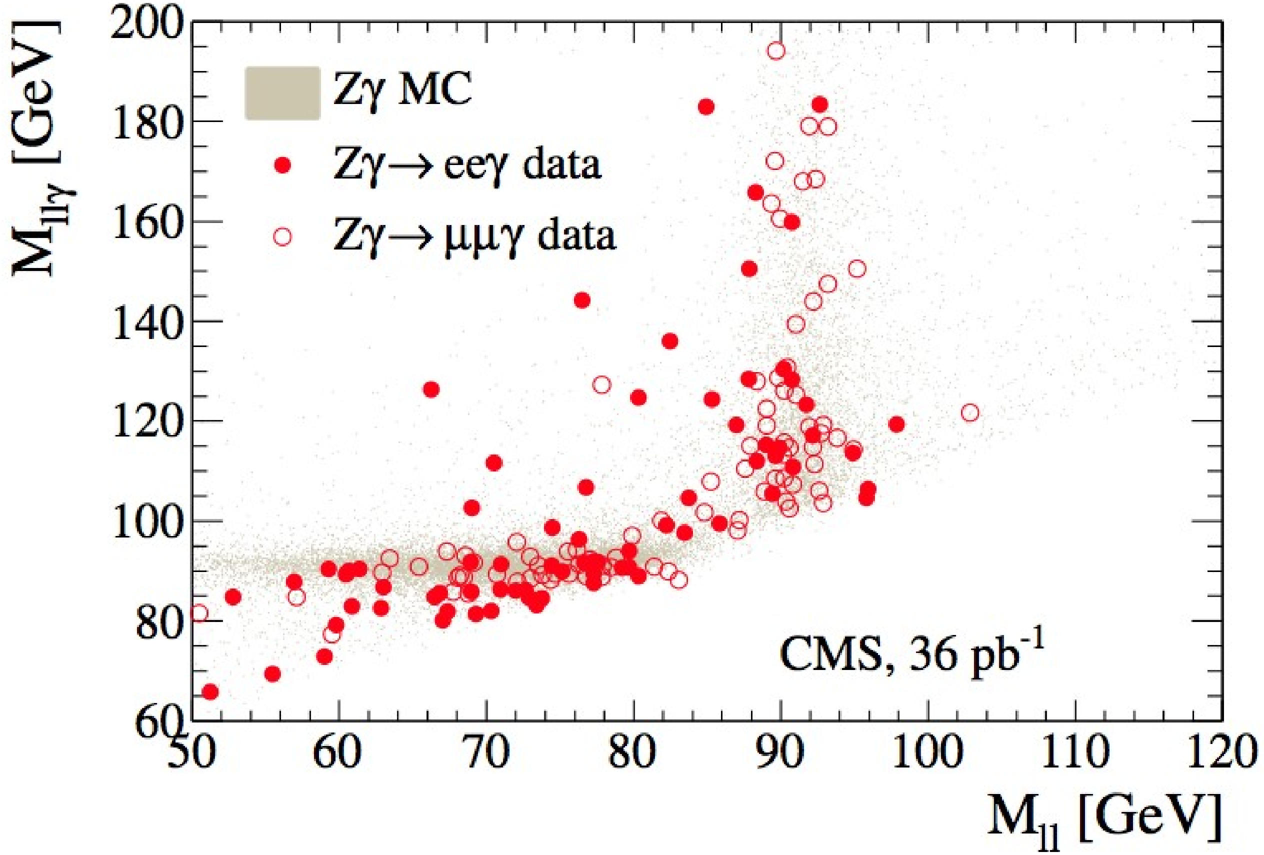
Wγ Selection

- Lepton with p_T > 20 GeV
  - No 2nd lepton
- Missing E_T > 25 GeV
- Photon
  - E_T > 10 GeV
  - $\Delta R(l,\gamma) > 0.7$

Zγ Selection

- 2 Leptons p_T > 20 GeV
- M_{ll} > 50 GeV
- Photon
  - E_T > 10 GeV
  - $\Delta R(l,\gamma) > 0.7$

Signal and Selection



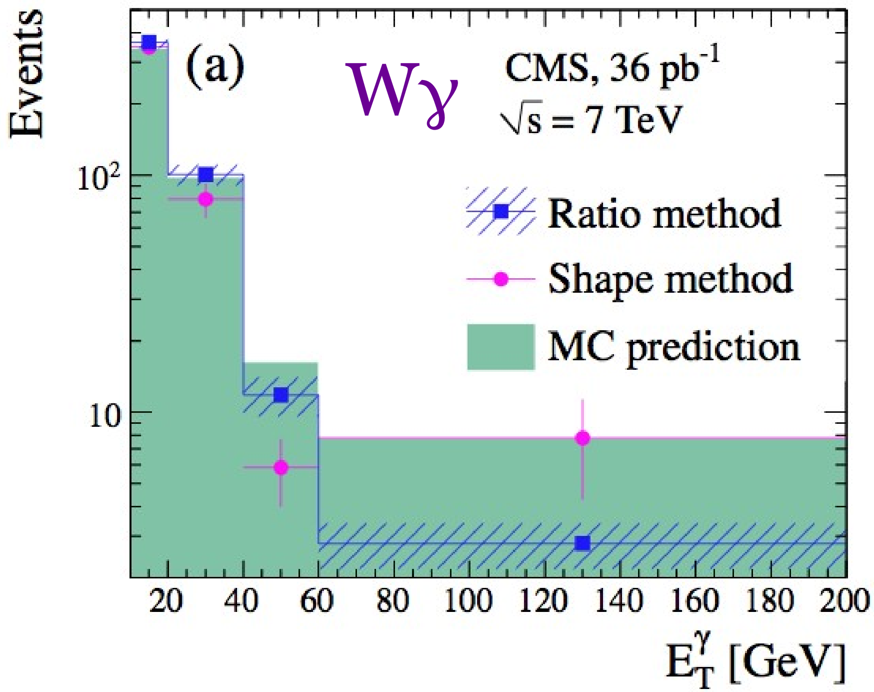
- $M_{ll\gamma} \simeq M_Z \rightarrow$ FSR events
- $M_{ll} \simeq M_Z \rightarrow$ ISR events

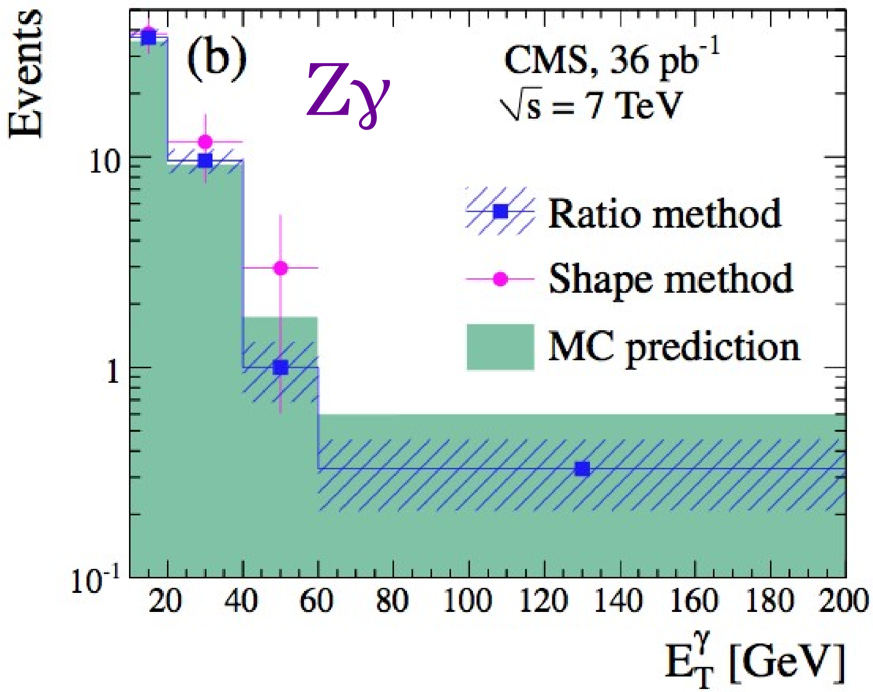
Background Estimation

- Vγ main backgrounds: W+jets and Z+jets processes where one jet is misidentified as a lepton
- Data Driven Methods
  - ***Ratio***
    - Measure isolated to non-isolated photons ratio from QCD on Data
    - At high E_T major contribution from γ+jets is corrected
  - ***Template***
    - Exploit the different lateral energy profile
    - Choose this variable as template to separate real γ from fakeable jets

Background Estimation

• Background from misidentified jet as a function of the photon candidate E_T agrees well between ratio and shape methods and MC prediction





Background Estimation

Background estimations for Vγ analysis for 36 /pb

W→μνγ

W+jets	261 ± 19 (stat.) ± 16 (syst.)
Zγ, others	16.4 ± 1.0 (MC)

W→eνγ

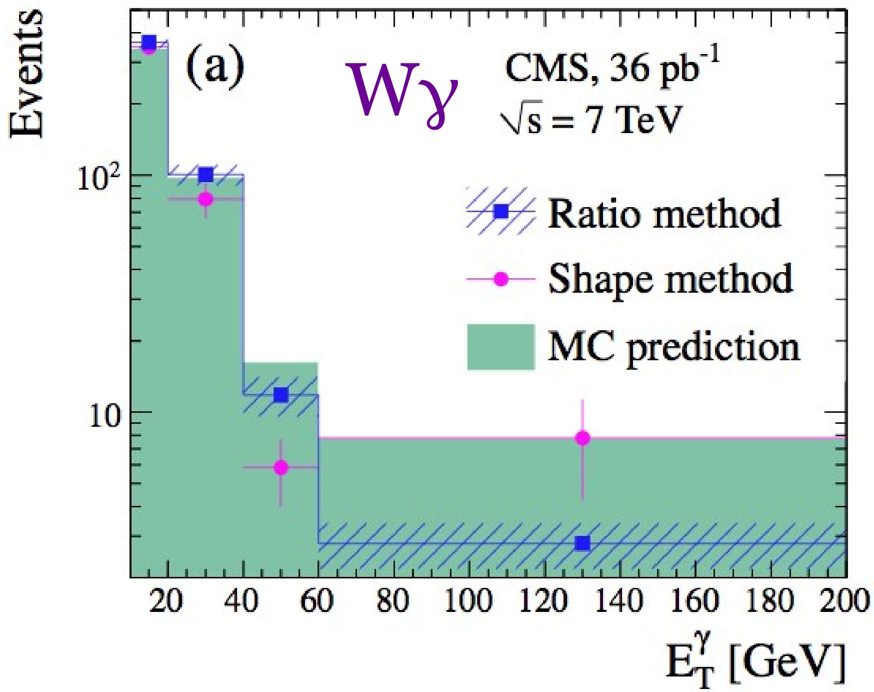
W+jets	220 ± 16 (stat.) ± 14 (syst.)
Zγ, others	7.7 ± 0.5 (MC)

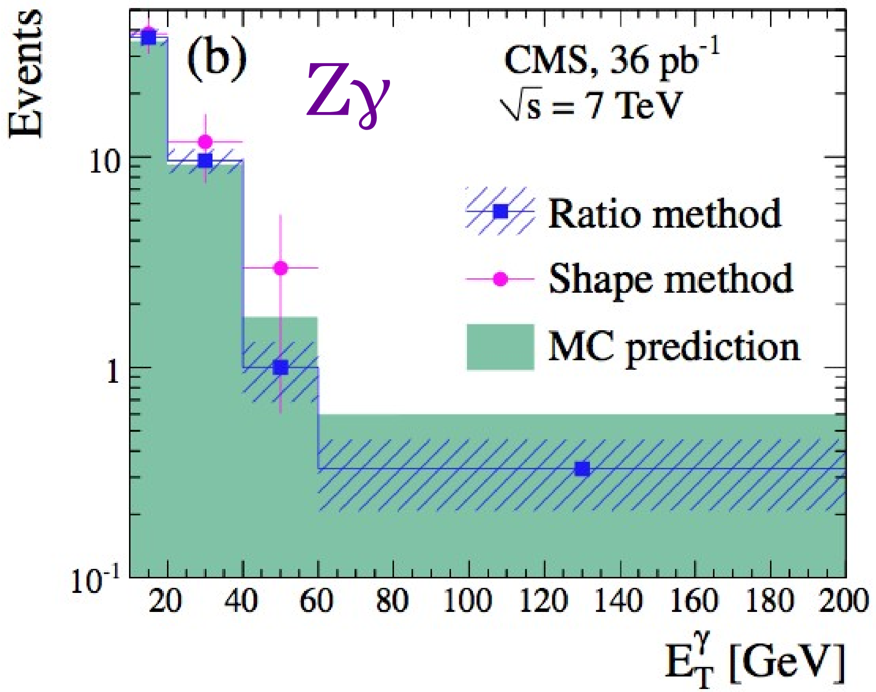
Z→μμγ

Z+jets	27.3 ± 2.2 (stat.) ± 2.3 (syst.)
γ+jets, etc.	< 1.0 (MC)

Z→eeγ

Z+jets	20.5 ± 1.7 (stat.) ± 1.9 (syst.)
γ+jets, etc.	< 1.0 (MC)





Cross-section measurement

- Calculate cross-section

$$\sigma = \frac{N_{observed} - N_{background}}{A\, \varepsilon_{MC}\, \rho\, L_{int}}$$

  - $N_{observed}$: yield on data
  - $N_{background}$: background estimation from MC and Data Driven methods
  - $A\varepsilon_{MC}$: CMS acceptance and efficiency from MC prediction
  - ρ: Scale factors Data/MC to correct efficiencies
    - Tag and probe, Jet veto …
  - L_{int}: Integrated luminosity (36 /pb)

Cross-section measurement

Vγ systematics

	$W\gamma \to e\nu\gamma$	$W\gamma \to \mu\nu\gamma$	$Z\gamma \to ee\gamma$	$Z\gamma \to \mu\mu\gamma$
Source	Effect on $A \cdot \epsilon_{MC}$			
Lepton energy scale	2.3%	1.0%	2.8%	1.5%
Lepton energy resolution	0.3%	0.2%	0.5%	0.4%
Photon energy scale	4.5%	4.2 %	3.7%	3.0%
Photon energy resolution	0.4%	0.7%	1.7%	1.4%
Pile-up	2.7%	2.3%	2.3%	1.8%
PDFs	2.0%	2.0%	2.0%	2.0%
Total uncertainty on $A \cdot \epsilon_{MC}$	6.1%	5.2%	5.8%	4.3%
	Effect on $\epsilon_{data}/\epsilon_{MC}$			
Trigger	0.1%	0.5%	$< 0.1\%$	$< 0.1\%$
Lepton identification and isolation	0.8%	0.3%	1.1%	1.0%
E_T^{miss} selection	0.7%	1.0%	N/A	N/A
Photon identification and isolation	1.2%	1.5%	1.0%	1.0%
Total uncertainty on $\epsilon_{data}/\epsilon_{MC}$	1.6%	1.9%	1.6%	1.5%
Background	6.3%	6.4%	9.3%	11.4%
Luminosity	4%			

Cross-section measurement

$W \to \mu\nu\gamma$

Observed 520 events
W+jets 261 ± 19 (stat.) ± 16 (syst.)
Zγ, others 16.4 ± 1.0

$W \to e\nu\gamma$

Observed 452 events
W+jets 220 ± 16 (stat.) ± 14 (syst.)
Zγ, others 7.7 ± 0.5

$Z \to \mu\mu\gamma$

Observed 90 events
Z+jets 27.3 ± 2.2 (stat.) ± 2.3 (syst.)
γ+jets, etc. < 1.0

$Z \to ee\gamma$

Observed 81 events
Z+jets 20.5 ± 1.7 (stat.) ± 1.9 (syst.)
γ+jets, etc. < 1.0

$\sigma(pp \to W\gamma+X)\cdot B(W\to\mu\nu) = 55.4 \pm 7.2\,(\text{stat.}) \pm 5.0\,(\text{syst.}) \pm 2.2\,(\text{lumi.})$ pb
$\sigma(pp \to W\gamma+X)\cdot B(W\to e\nu) = 57.1 \pm 6.9\,(\text{stat.}) \pm 5.1\,(\text{syst.}) \pm 2.3\,(\text{lumi.})$ pb
$\sigma(pp \to W\gamma+X)\cdot B(W\to l\nu) = 56.3 \pm 5.0\,(\text{stat.}) \pm 5.0\,(\text{syst.}) \pm 2.3\,(\text{lumi.})$ pb

$\sigma(pp \to Z\gamma+X)\cdot B(Z\to\mu\mu) = 9.2 \pm 1.4\,(\text{stat.}) \pm 0.6\,(\text{syst.}) \pm 0.4\,(\text{lumi.})$ pb
$\sigma(pp \to Z\gamma+X)\cdot B(Z\to ee) = 9.5 \pm 1.4\,(\text{stat.}) \pm 0.7\,(\text{syst.}) \pm 0.4\,(\text{lumi.})$ pb
$\sigma(pp \to Z\gamma+X)\cdot B(Z\to ll) = 9.4 \pm 1.0\,(\text{stat.}) \pm 0.6\,(\text{syst.}) \pm 0.4\,(\text{lumi.})$ pb

Cross-section measurement

W→μνγ

Observed 520 events

W+jets 261 ± 19 (stat.) ± 16 (syst.)

Zγ, others 16.4 ± 1.0

W→eνγ

Observed 452 events

W+jets 220 ± 16 (stat.) ± 14 (syst.)

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Z→μμγ

Observed 90 events

Z+jets 27.3 ± 2.2 (stat.) ± 2.3 (syst.)

γ+jets, etc. < 1.0

Z→eeγ

Observed 81 events

Z+jets 20.5 ± 1.7 (stat.) ± 1.9 (syst.)

γ+jets, etc. < 1.0

Theorical Prediction : σ(pp →Wγ+X)·B(W→*l*ν) = 49.4 ± 3.8 pb (NLO)

σ(pp →Wγ+X)·B(W→*l*ν) = 56.3 ± 5.0 (stat.) ± 5.0 (syst.) ± 2.3 (lumi.) pb

Theorical Prediction : σ(pp →Zγ+X)·B(Z→*ll*) = 9.6 ± 0.4 pb (NLO)

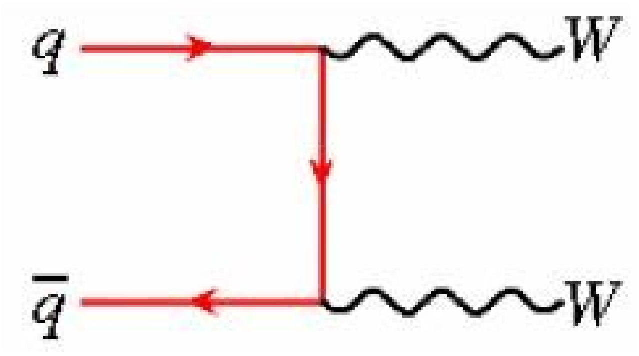
σ(pp →Zγ+X)·B(Z→*ll*) = 9.4 ± 1.0 (stat.) ± 0.6 (syst.) ± 0.4 (lumi.) pb

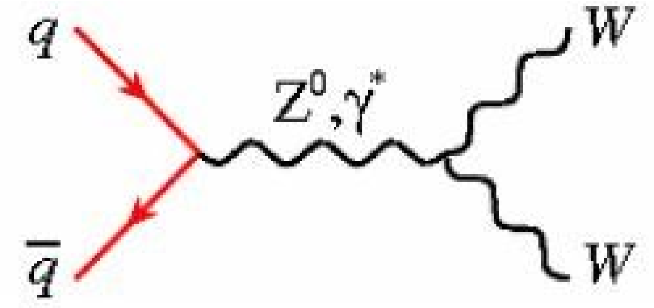
WW Cross-section

CMS – EWK – 10 – 009

DiBoson processes

- WW Production
  - t-channel and s-channel





Signal and Selection

- **Trigger:** Events selected using single lepton trigger
- **WW Signatures:** Only consider leptonic W decays
  - $WW \rightarrow ll\,\nu\nu$ (l = e, μ)

WW Selection

- 2 Leptons with $p_T > 20$ GeV and opposite charge
  - No 3rd lepton
- Missing E_T cuts && Z peak veto
- No hadronic activity
  - Central jet veto, no soft muons (from b's)
  - No extra b-tagged jets below the veto

Background Estimation

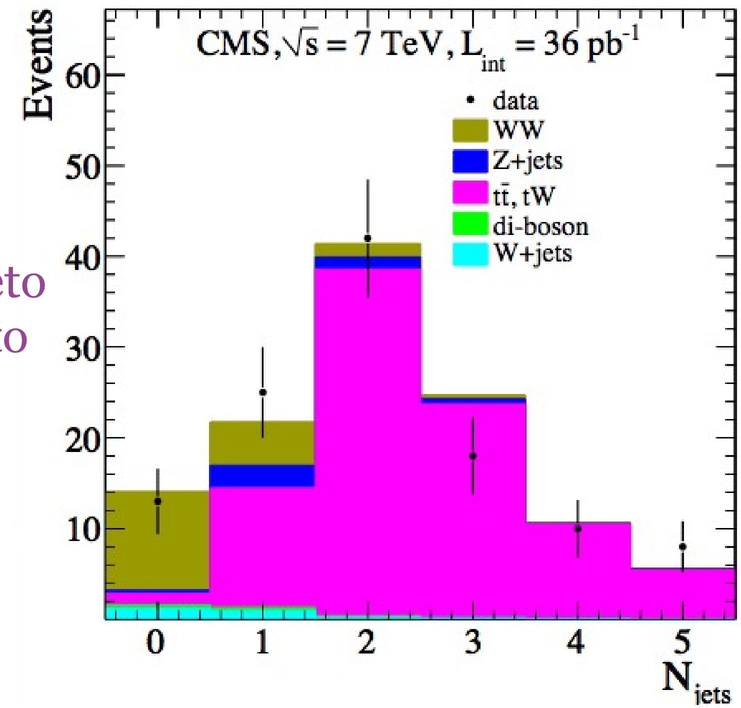
- WW main backgrounds: Z+jets, top, W+jets, WZ and ZZ
- Detailed studies using both data driven methods and MC prediction
- Data Driven Methods
  - ***Fake rate estimation***
    - FR as the ratio of the loosely selected lepton-like from a jet enriched sample that pass all the selection criteria
  - ***Z estimation – R in/out Method***
    - Ratio $R^{ll}_{in/out}$ of events Z window from MC
    - Contribution from Z:

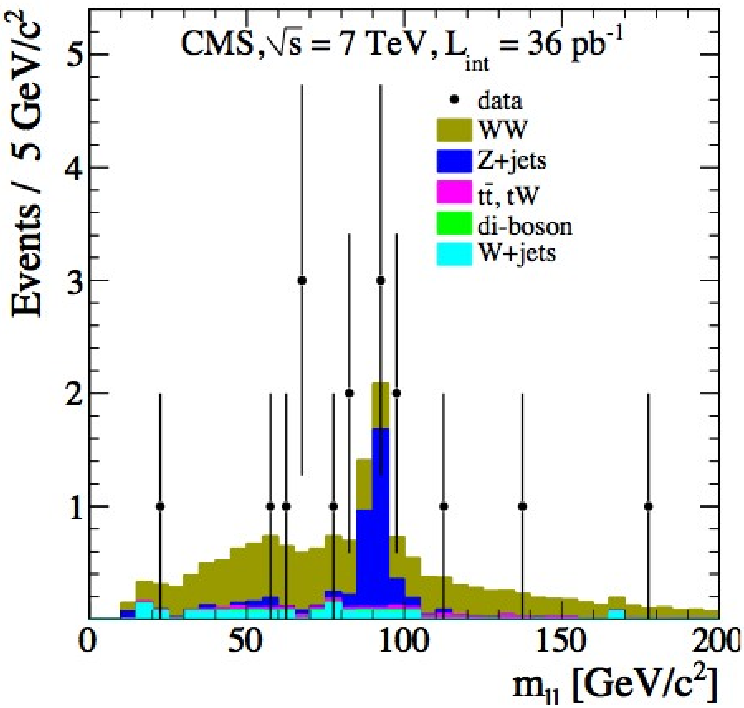
$$N^{ll,exp}_{out} = R^{ll}_{in/out}(N^{ll}_{in} - N^{non\text{-}Z}_{in})$$

Background Estimation

- MC Predictions
  - ***Top background***
    - Veto events with a soft muon
    - Jet Veto/Veto events with > 0 b-tag jet below threshold

No Jet Veto
No Z Veto





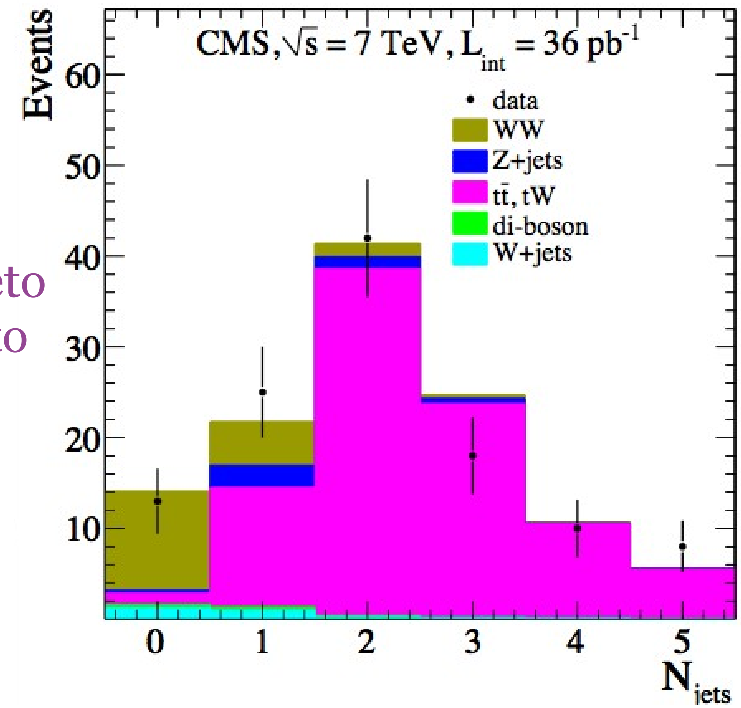
No Z Veto

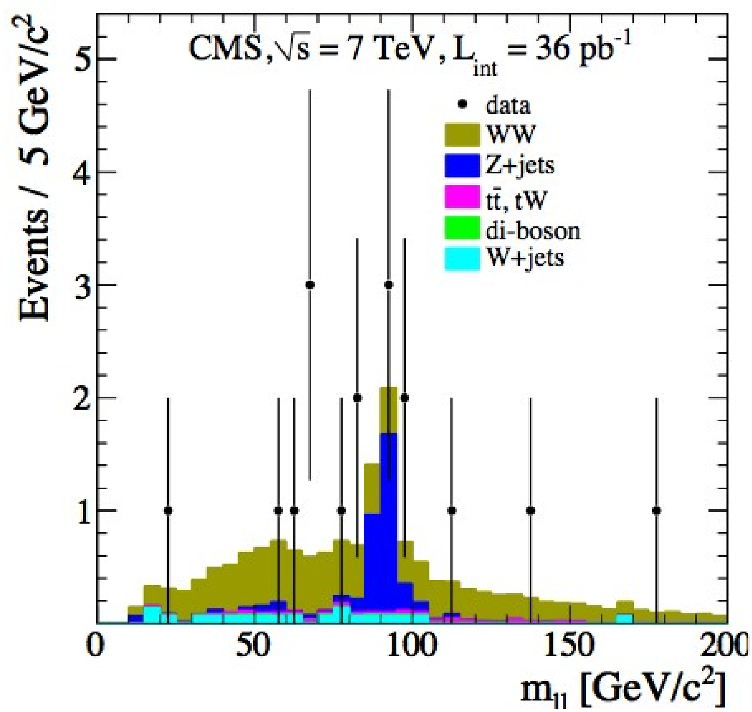
Background Estimation

Background estimations for WW analysis for 36 /pb

Process	Events
W+jets + QCD	$1.70 \pm 0.40 \pm 0.70$
$t\bar{t}$ + tW	$0.77 \pm 0.05 \pm 0.77$
$W\gamma$	$0.31 \pm 0.04 \pm 0.05$
$Z + WZ + ZZ \rightarrow e^+e^- / \mu^+\mu^-$	$0.20 \pm 0.20 \pm 0.30$
WZ + ZZ, leptons not from the same boson	$0.22 \pm 0.01 \pm 0.04$
$Z/\gamma^* \rightarrow \tau^+\tau^-$	$0.09 \pm 0.05 \pm 0.09$
Total	$3.29 \pm 0.45 \pm 1.09$

No Jet Veto
No Z Veto





No Z Veto

Cross-section measurement

WW SF/systematics

	Scale Factor (Data/MC)
Muon Efficiencies T&P	consistent with 1
Electron Efficiencies T&P	(96.9 ± 1.9) % Barrel (99.2 ± 2.6) % Endcap
Jet Veto $\varepsilon^{Data}_{WW} = \varepsilon^{MC}_{WW} \cdot \varepsilon^{Data}_{Z} / \varepsilon^{MC}_{Z}$	consistent with 1

	Systematic
Jet Veto SF	0.3 % (ε^{Data}_{Z}) & 5.5 % ($\varepsilon^{MC}_{WW}/\varepsilon^{MC}_{Z}$)
PDF	2 – 4 %
Lepton efficiencies	1 – 4 %

Luminosity 11%

Cross-section measurement

$WW \to ll\nu\nu$

	$\mu^+\mu^-$	e^+e^-	$\mu^\pm e^\mp$	ll
Observed	**1**	**2**	**10**	**13**
Expected	**2.7 ± 0.1**	**2.3 ± 0.2**	**8.5 ± 0.3**	**13.5 ± 0.3**

Theorical Prediction : $\sigma(pp \to WW)$ = 43.0 ± 2.0 pb (NLO)

$\sigma(pp \to WW)$ = 41.1 ± 15.3 (stat.) ± 5.8 (syst.) ± 4.5 (lumi.) pb

Theorical Prediction : $\sigma WW/\sigma W = (4.45 \pm 0.30) \cdot 10^{-4}$

$\sigma WW/\sigma W = (4.46 \pm 1.66\,(stat.) \pm 0.64\,(syst.)) \cdot 10^{-4}$

Search for aTGC

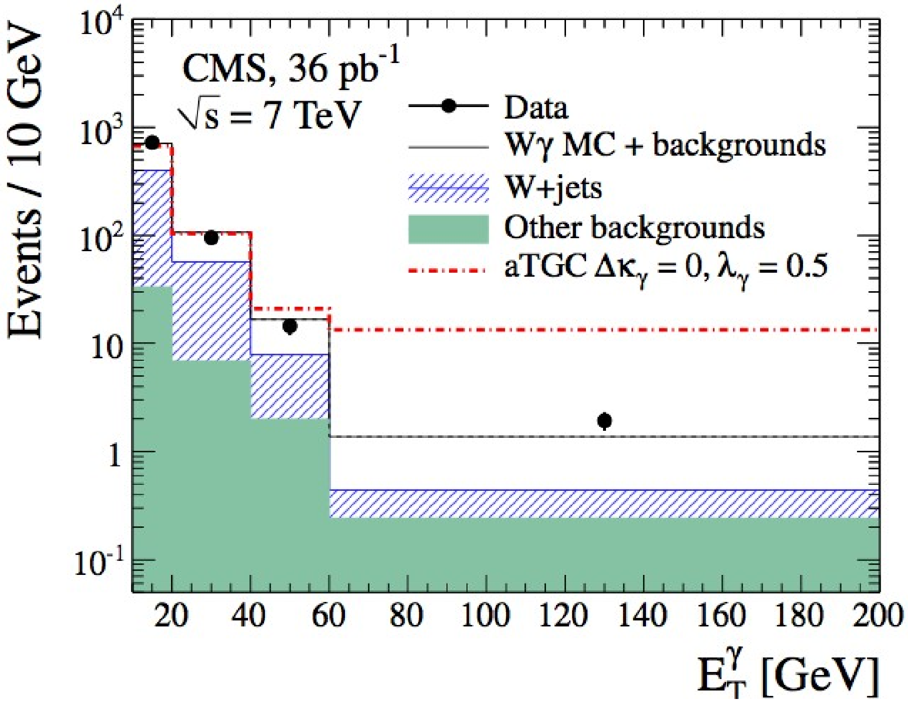
Search for aTGC

- TGC: self interaction between gauge bosons via trilinear couplings
- Direct consequence of the non-Abelian *SU(2)xU(1)* gauge symmetry
- The value of these couplings are fully fixed in the SM by the gauge structure of the Lagrangian:
  - Any deviation of the strength of the TGC could indicate new physics
    - i.e. production of new particles that decay to W/Z γ
    - i.e. new interactions that increase the TGC
- Previous aTGC searches at LEP and Tevatron
  - Results consistent with SM
- New regime of energy at the LHC – test of the bosonic region

Limits on anomalous couplings

- **WWγ Assumptions:** CP symmetry and *SU(2)xU(1)* gauge symmetry
  - Measure deviation of k_γ ($\Delta k_\gamma = k_\gamma - 1$) and λ_γ from Wγ production
- **ZZγ and Zγγ Assumptions:** Couplings h^V_i, with i = 3,4 and V = Z,γ
  - CP-even couplings. $h^V_i = 0$ at tree level in SM
- aTGC enlarge SM cross-section production → excess of events with high momentum bosons
  - Use photon E_T as it is more precise than measuring W or Z
  - Define Likelihood in terms of the TGC parameters. Minimize

Limits on anomalous couplings



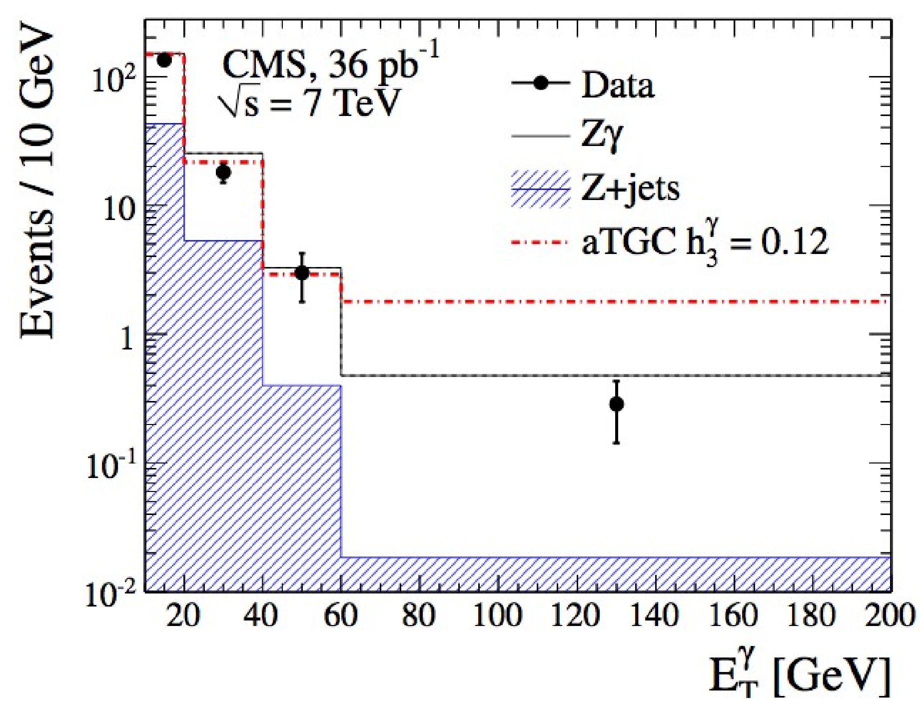


Table One dimensional 95% CL limits on $WW\gamma$, $ZZ\gamma$, and $Z\gamma\gamma$ aTGCs.

$WW\gamma$	$ZZ\gamma$	$Z\gamma\gamma$
$-1.11 < \Delta\kappa_\gamma < 1.04$	$-0.05 < h_3 < 0.06$	$-0.07 < h_3 < 0.07$
$-0.18 < \lambda_\gamma < 0.17$	$-0.0005 < h_4 < 0.0005$	$-0.0005 < h_4 < 0.0006$

Set 95 % C.L. limits on Wγ and ZVγ aTGC

Conclusions

• The cross-section measurement of Wγ, Zγ and WW for a center of mass energy of 7 TeV has been done with 36 /pb with CMS

Wγ

$\sigma(pp \rightarrow W\gamma+X)\cdot B(W\rightarrow l\nu) = 56.3 \pm 5.0$ (stat.) ± 5.0 (syst.) ± 2.3 (lumi.) pb

$\sigma(pp \rightarrow W\gamma+X)\cdot B(W\rightarrow l\nu) = 49.4 \pm 3.8$ pb (NLO)

Zγ

$\sigma(pp \rightarrow Z\gamma+X)\cdot B(Z\rightarrow ll) = 9.4 \pm 1.0$ (stat.) ± 0.6 (syst.) ± 0.4 (lumi.) pb

$\sigma(pp \rightarrow Z\gamma+X)\cdot B(Z\rightarrow ll) = 9.6 \pm 0.4$ pb (NLO)

WW

$\sigma(pp \rightarrow WW) = 41.1 \pm 15.3$ (stat.) ± 5.8 (syst.) ± 4.5 (lumi.) pb

$\sigma(pp \rightarrow WW) = 43.0 \pm 2.0$ pb (NLO)

Conclusions

- The cross-section measurement of Wγ, Zγ and WW for a center of mass energy of 7 TeV has been done with 36 /pb with CMS

- Good agreement between measurements and theoretical predictions
  - First measurement of diboson processes at 7 TeV!

- Study of the anomalous TGC
  - Set 95 % C.L. limits on WWγ and ZVγ aTGC
  - Results compatible with SM. Found no evidence of aTGC
  - Extend the previous results of vector boson self-interaction at lower energies

Back Up Slides

Limits on WWγ anomalous couplings

- Assumptions
  - #1 : CP symmetry.Remaining parameters for WWγ and WWZ couplings are

$$k_Z, k_\gamma, \lambda_Z, \lambda_\gamma, g^Z_1$$

$$\text{SM} : \lambda_Z = \lambda_\gamma = 0 \text{ and } k_Z = k_\gamma = g^Z_1 = 1$$

  - #2: *SU(2)xU(1)* gauge symmetry

$$\Delta k_Z = \Delta g^Z_1 - \Delta k_\gamma \cdot \tan^2\theta_W \text{ and } \lambda = \lambda_Z = \lambda_\gamma$$

Measure the deviation of k_γ ($\Delta k_\gamma = k_\gamma - 1$) and λ_γ from Wγ production

Limits on anomalous couplings

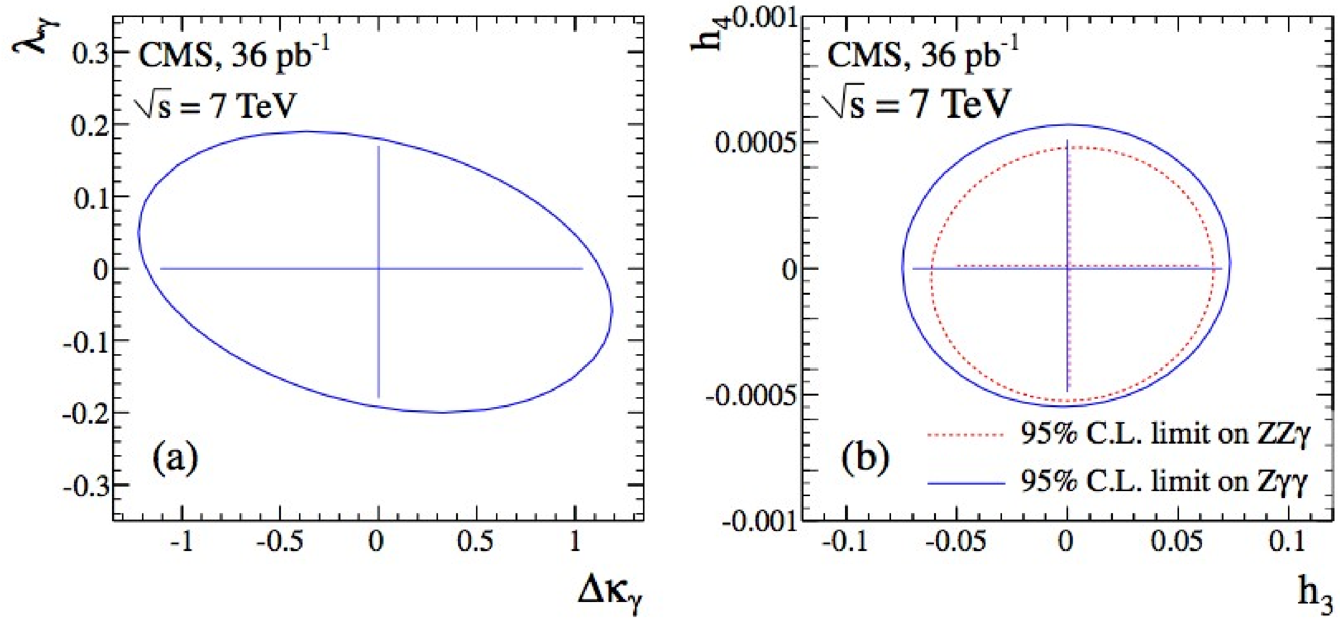


Figure 6: Two-dimensional 95% CL limit contours (a) for the WWγ vertex couplings λ_γ and $\Delta\kappa_\gamma$ (blue line), and (b) for the ZZγ (red dashed line) and Z$\gamma\gamma$ (blue solid line) vertex couplings h_3 and h_4 assuming no energy dependence on the couplings. One-dimensional 95% CL limits on individual couplings are given as solid black lines.