WW, Wγ and Zγ production at CMS

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On behalf of the CMS Collaboration

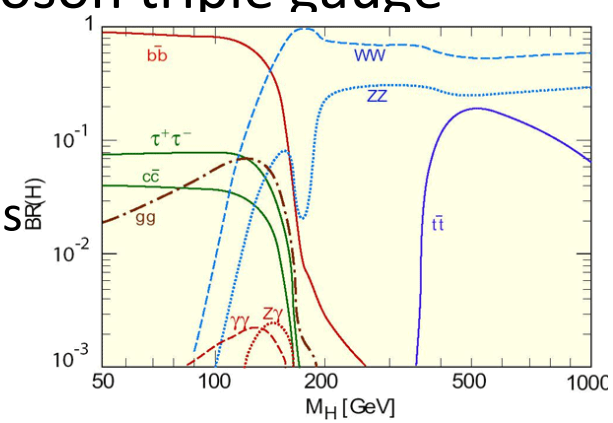
Overview

- Overview of studies in these slides:
  - ❑ WW→ 2ℓ2ν (1.1 fb^{-1} CMS Data) ***M. Marionneau EPS-HEP 2011***
  - ❑ Wγ
  - ❑ Zγ
  - ❑ Anomalous TGC

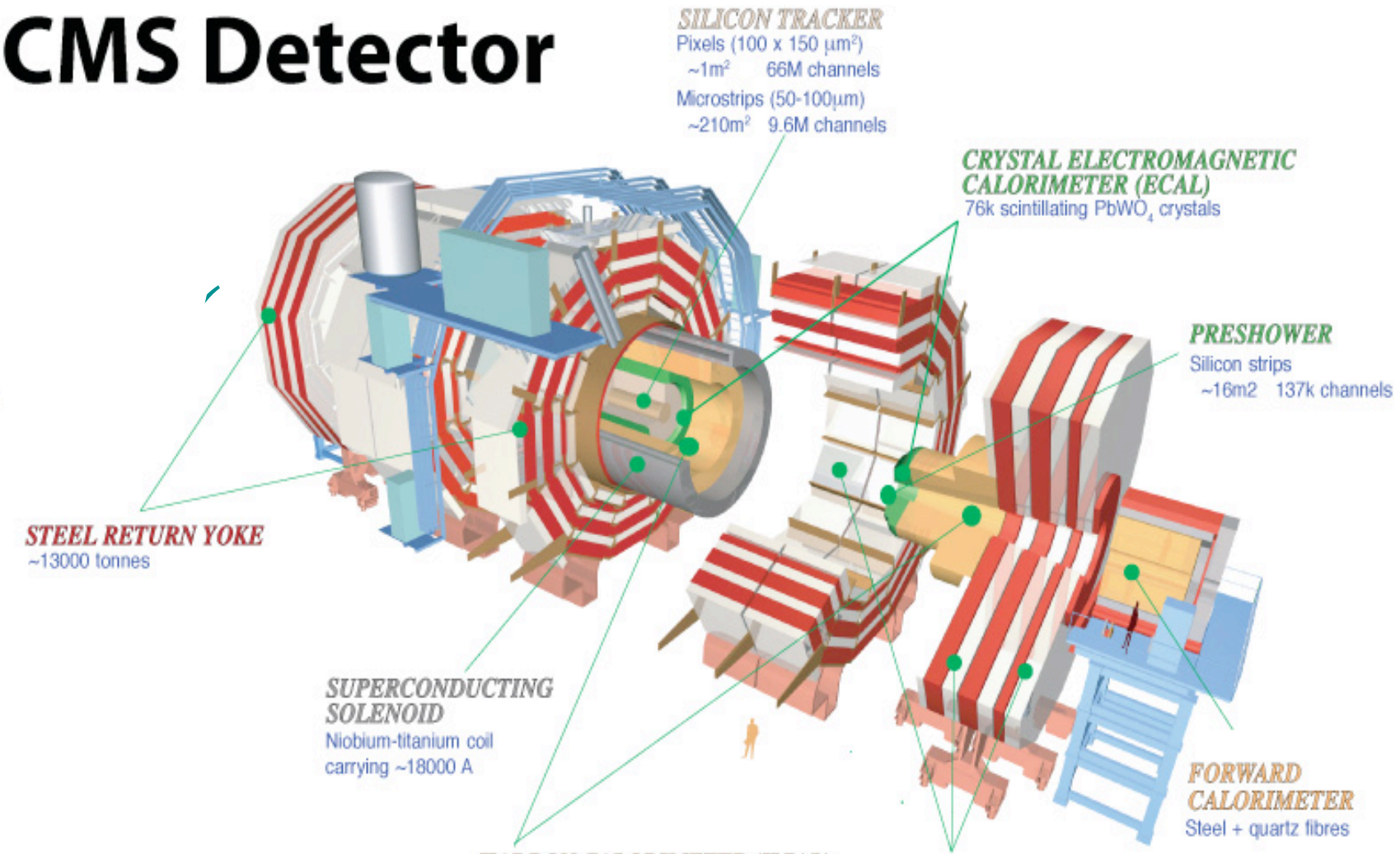
  Phys. Lett. B701 535-555,2011

  Phys. Lett. B699 25-47,2011
- Only fully leptonic modes are considered (Z →ℓℓ & W→ℓν)
- These are important fundamentals test of the Standard Model because:
  - ◆ Self interaction between electroweak boson triple gauge couplings (TGCs)
  - ◆ Probe for new physics
    - (enhancement of diboson production cross s
    - Resonances with diboson final states

    (these slides have been synchronized to EPS)



CMS Detector



Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

$WW \rightarrow 2\ell 2\nu$ signal & background

Signal selection:

- ✧ Two isolated high PT leptons
- ✧ Leading lepton $P_T > 20$ GeV with lepton $P_T > 10$ GeV
- ✧ Significant Missing Transverse Energy

W+jet/background reduction

- ❖ Jet-veto and application of b-tagging algorithm

WZ/ZZ reduction

- ❖ Veto third lepton

$Z \rightarrow \tau\tau$, missing E_T along the lepton axes

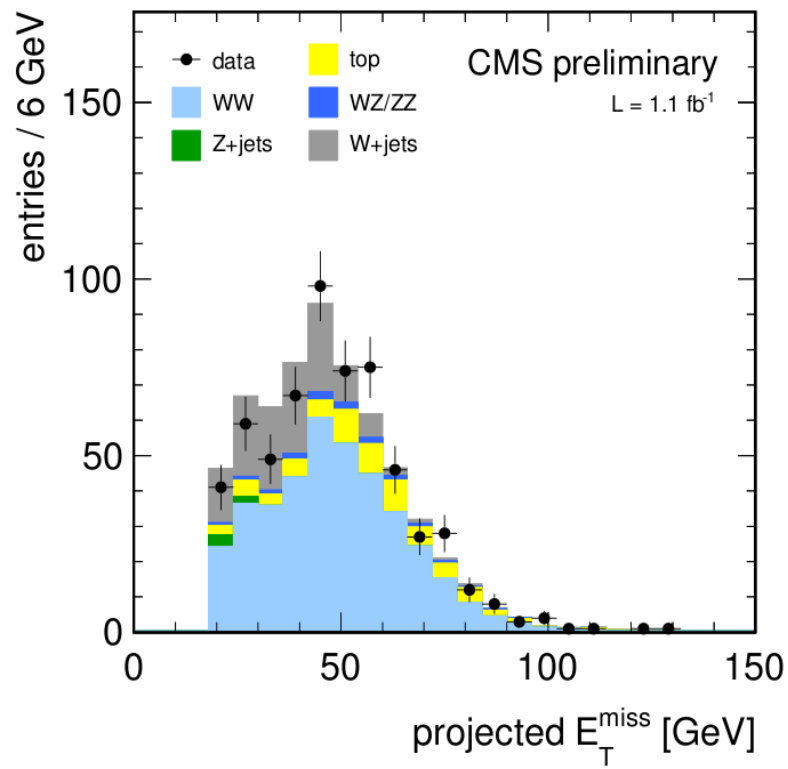
- ❖ projection along the transverse axis of the nearest lepton

Fake missing E_T in 2+jet events :

- ❖ MET treatment against pile-up
- ❖ Missing $E_T > 40$ (20) GeV for ee/μμ (eμ) final state

Drell-Yan background reduction :

- ❖ Veto on $m_{\ell\ell} < 12$ GeV
- ❖ Veto on $76 < m_{\ell\ell} < 106$ GeV for events with same flavor leptons
- ❖ $\Delta\phi$(di-lepton, remaining jet $p_T > 15$ GeV) < 165°



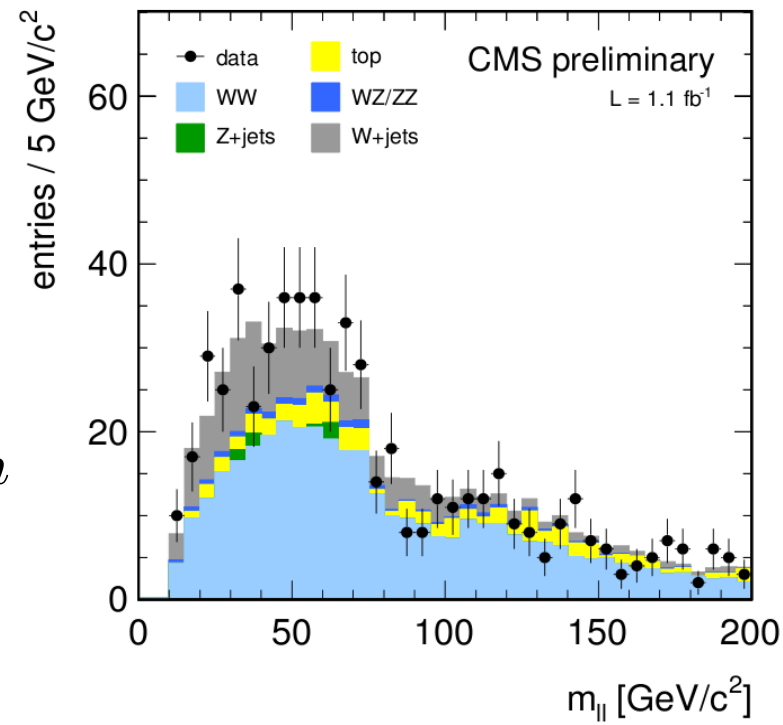
Background & Efficiency

Background components:

- Major Backgrounds
  - QCD / W+jet
  - Top
  - Z/WZ/ZZ

  Data Driven
- Smaller backgrounds
  - Wγ
  - $Z \rightarrow \tau\tau$
  - non resonant WZ/ZZ

  MC Simulation



Efficiencies

- Tag & Probe for lepton efficiencies
- Jet veto: simulation + correction with a Z+jet control sample
- Selection Missing ET

Total Efficiency(ε) = 6.7 ± 0.5 %

WW Results & Uncertainties

Sample	Yield
$qq \rightarrow W^+W^-$	349.7 ± 30.3
$gg \rightarrow W^+W^-$	17.2 ± 1.6
W + jets	106.9 ± 38.9
ttbar + tW	63.8 ± 15.9
$Z / \gamma^* \rightarrow \ell\ell$ + WZ + ZZ	12.2 ± 5.3
$Z / \gamma^* \rightarrow \tau\tau$	1.6 ± 0.4
WZ/ZZ not in $Z / \gamma^* \rightarrow \ell\ell$	8.5 ± 0.9
$W + \gamma$	8.7 ± 1.7
Signal + Background	568.6 ± 52.2
Data	626

Major Uncertainties	
Background Estimation	~ 20%
W+jet	36%
top	25%
Signal efficiency	~ 10%
Lepton efficiencies	1.5 – 2.5%
Missing E_T Resoultion	2.0%
Jet counting	5.5%

New result with 1.1 fb^{-1} (2011)

$$\sigma_{W^+W^-} = 55.3 \pm 3.3\,(\text{stat}) \pm 7.6\,(\text{syst}) \pm 3.3\,(\text{lumi})\ \text{pb}$$

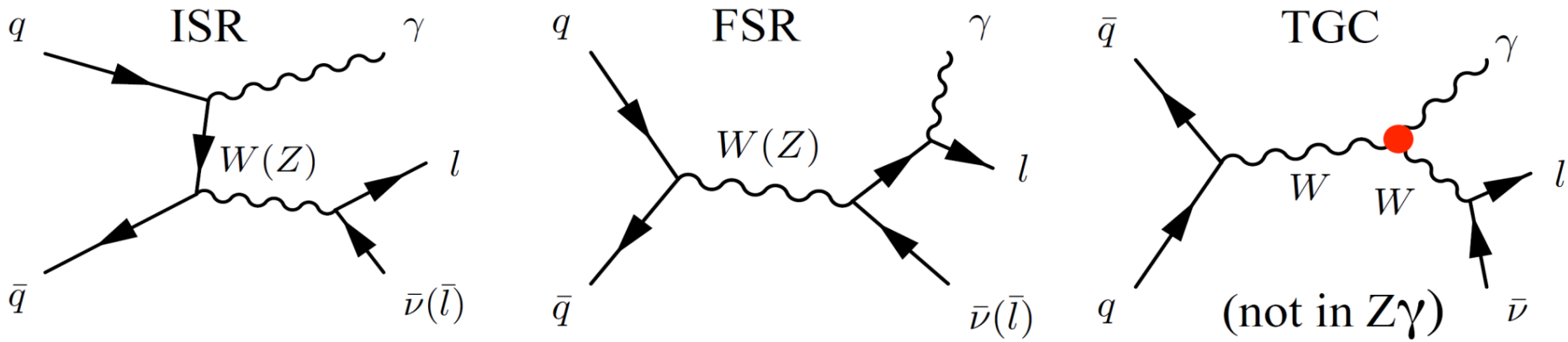
Previous with 36 fb^{-1} (2010)

$$\sigma_{W^+W^-} = 41.1 \pm 15.3\,(\text{stat}) \pm 5.8\,(\text{syst}) \pm 4.5\,(\text{lumi})\ \text{pb}.$$

NLO prediction

43.0 ± 2.1 ($qq \rightarrow W^+W^-$) + 1.46 pb ($gg \rightarrow WW$)

$W\gamma$ and $Z\gamma$ Study

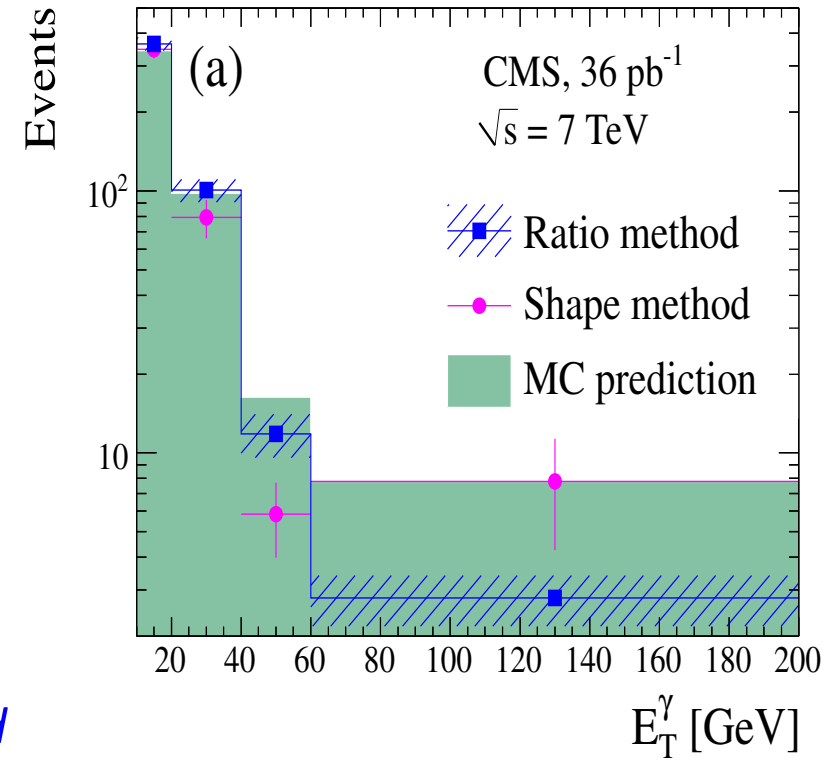


$W\gamma$ and $Z\gamma$ production in the SM:

- *Final states appearing in several new physics scenarios (fermiophobic Higgs, SUSY, ...)*
- *Allows tests of the triple-gauge coupling structure of the SM and a search for anomalous couplings*
- *Any deviation of TGCs from their predicted SM values could be an indication for new physics (NP) beyond the SM and could give us some clues about the electroweak symmetry breaking mechanism (EWSB)*

$W\gamma$ Selection

- *We use 36 pb^{-1} Data in 2010*
- *W selection :*
  - *isolated lepton $p_T > 20$ GeV*
  - *Missing $E_T > 25$ GeV*
- *Photon selection :*
  - *$E_T > 10$ GeV*
  - *$\Delta R(\ell,\gamma) > 0.7$ (avoid soft γ divergence)*
- *Veto additional lepton*
- *Dominant background : W + jet*
  - *rejected with tight isolation on photon*
  - *Estimated with two data-driven method*



- *shower shape variable distribution fit with templated PDFs + signal component extraction*
- *Use of ratio between number of isolated / non-isolated Photon, computed on a QCD control sample*
- *Other backgrounds are estimated with MonteCarlo simulation*

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)

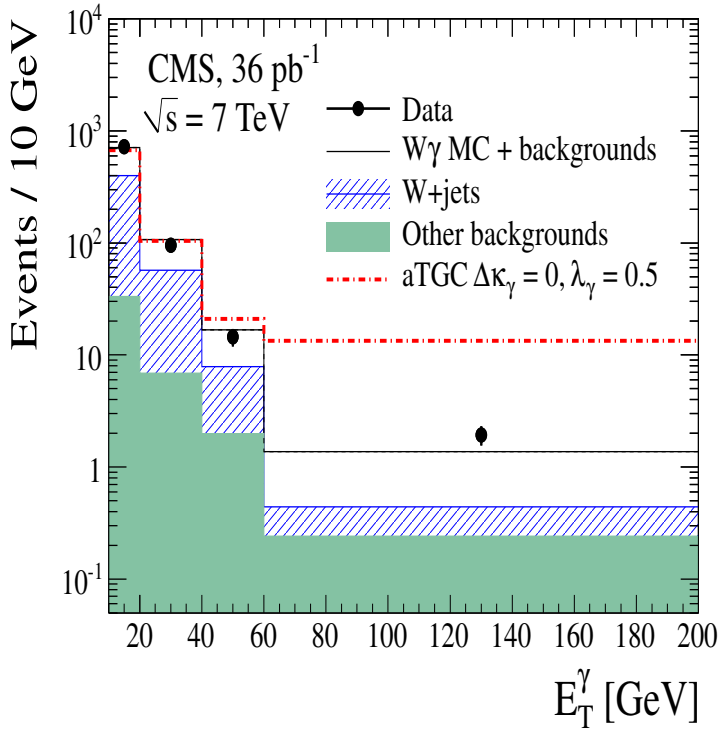
$W\gamma$ Results

- *Major systematic uncertainties:*

	uncertainty	main sources
$A.\epsilon$	$5.2 - 6.1\%$	PDFs / energy scales
ρ	$1.6 - 1.9\%$	γ ID-Isolation / E_T^{miss} selection
backgrounds	6.3%	W + jet

- *Selected events*

process	$N_{bkg}^{e\nu}$	$N_{bkg}^{\mu\nu}$
W+jet	$220 \pm 16 \pm 14$	$261 \pm 19 \pm 16$
other backgrounds	7.7 ± 0.5	16.4 ± 1.0
all data	452	520



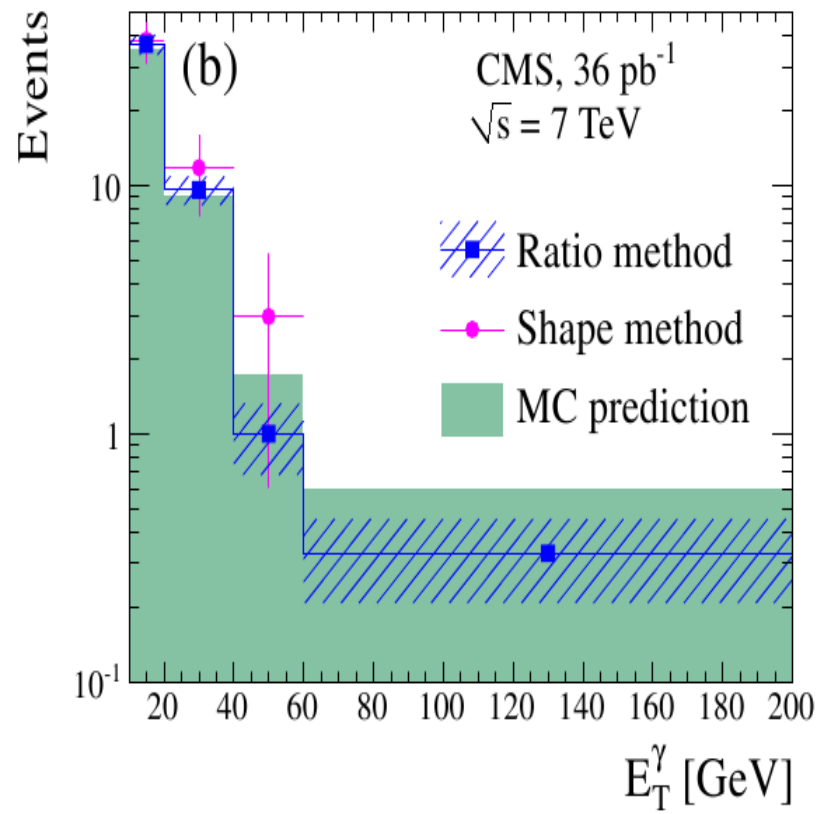
- *Small τ background estimated using MC*

$\sigma(pp \to W\gamma \to e\nu\gamma)$ = 56.7 ± 6.9 (stat.) ± 5.1 (syst.) ± 6.2 (lumi.) pb
$\sigma(pp \to W\gamma \to \mu\nu\gamma)$ = 55.0 ± 7.2 (stat.) ± 5.0 (syst.) ± 6.1 (lumi.) pb
$\sigma(pp \to W\gamma \to l\nu\gamma)$ = 55.9 ± 5.0 (stat.) ± 5.0 (syst.) ± 6.1 (lumi.) pb
$\sigma(pp \to W\gamma \to l\nu\gamma)$ = 49.4 ± 3.0 pb (NLO)

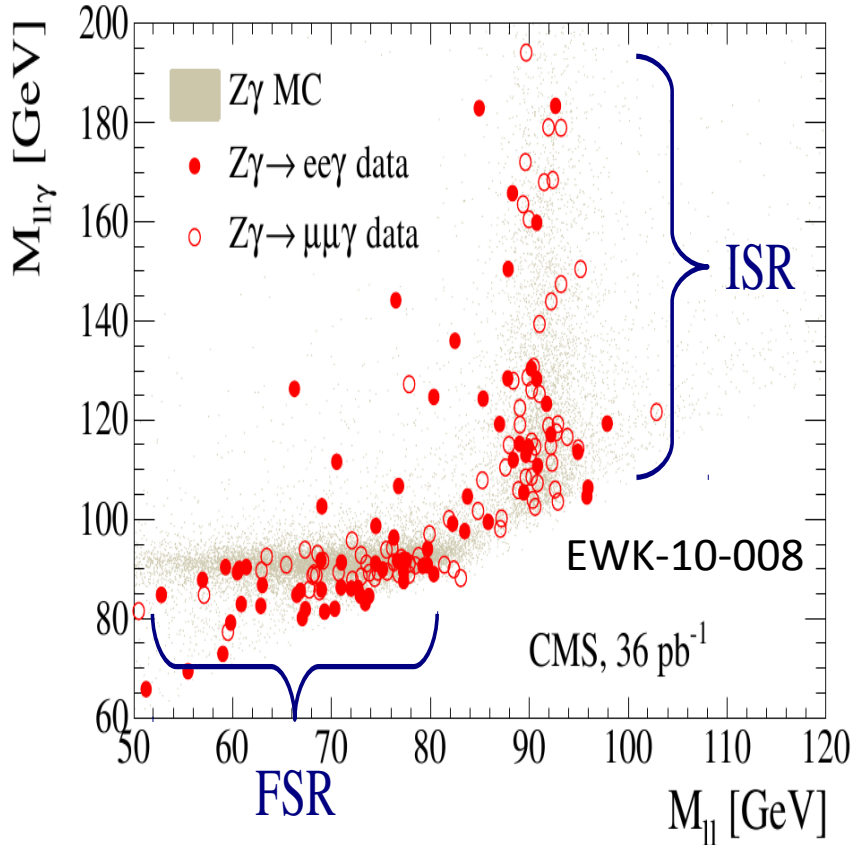
$Z\gamma$ event selection

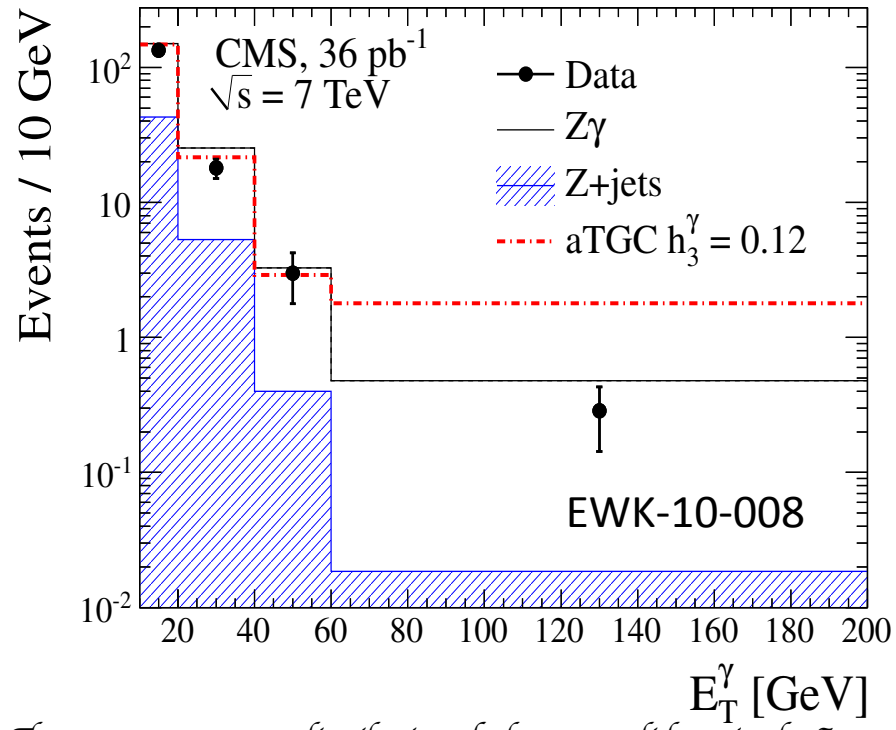
- *Z selection :*
  - two isolated lepton with $p_T > 20$ GeV
  - $m_{\ell\ell} > 50$ GeV
- *Photon selection :*
  - ET > 10 GeV
  - $\Delta R(\ell, \gamma) > 0.7$
- Large background contribution from Z + jet process using the same data driven estimation as for $W\gamma$
- Other minor backgrounds estimated with simulation
- Major systematic uncertainties:

	uncertainty	main sources
$A.\epsilon$	$4.3 - 5.8\%$	PDFs / energy scales
ρ	1.5%	γ / lepton ID-Isolation
backgrounds	$9.3 - 11.4\%$	Z + jet



Results of Zγ





The transverse energy distribution of photon candidates in the Zγ channel in data is shown with black circles with error bars; the expected signal plus background is shown as a solid black histogram, while the contribution from misidentified jets is given as a hatched blue histogram. A typical aTGC signal is given as a red dot-and-line histogram. The last bin includes overflows.

Characteristics Initial & Final State Radiation in the plot $M_{\ell\ell}$ and $M_{\ell\ell\gamma}$ in Zγ study

$\sigma(pp \to Z\gamma \to ee\gamma)$ = 9.4 ± 1.4 (stat.) ± 0.7 (syst.) ± 1.0 (lumi.) pb
$\sigma(pp \to Z\gamma \to \mu\mu\gamma)$ = 9.2 ± 1.4 (stat.) ± 0.6 (syst.) ± 1.0 (lumi.) pb
$\sigma(pp \to Z\gamma \to ll\gamma)$ = 9.3 ± 1.0 (stat.) ± 0.6 (syst.) ± 1.0 (lumi.) pb
$\sigma(pp \to Z\gamma \to ll\gamma)$ = 9.6 ± 0.4 pb (NLO)

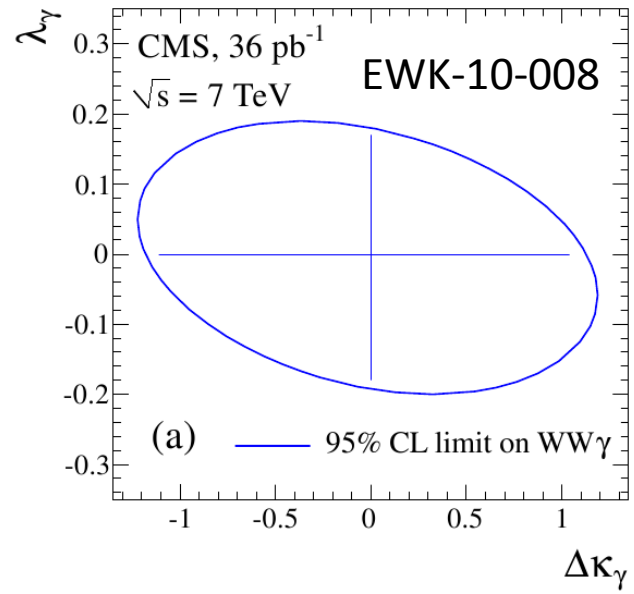
Anomalous TGC Limits

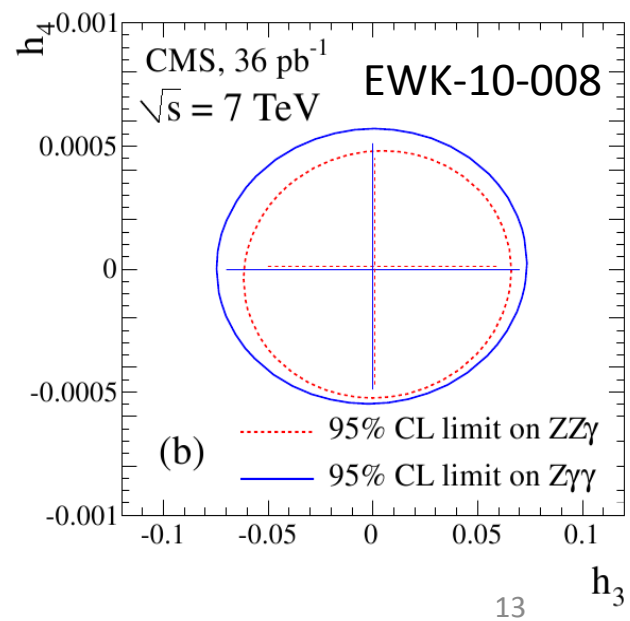
- Deviation to SM modeled by an effective Lagrangian
  - No "energy-scale" dependent form-factor
  - SU(2)xU(1) gauge invariance
  - No C/P-violating parameters
- Two parameters for WWγ :
  - $\Delta\kappa_\gamma = 1-\kappa_\gamma$ (**SM $\kappa_\gamma = 1$**),
  - $\lambda_\gamma=\lambda_Z$ (**SM = 0**)
- ZVγ (V=Z, γ) :

  $h_3 = 0$, $h_4 = 0$ (at tree level in SM)
- Limits obtained by using a profile likelihood based on the E_T spectrum of the photon.
- aTGC is generated using Baur and Sherpa MC

WWγ	ZZγ	Zγγ
$-1.11 < \Delta\kappa_\gamma < 1.04$	$-0.05 < h_3 < 0.06$	$-0.07 < h_3 < 0.07$
$-0.18 < \lambda_\gamma < 0.17$	$-0.0005 < h_4 < 0.0005$	$-0.0005 < h_4 < 0.0006$

- Competitive to Tevatron





Summary

- *The cross-section measurement of $W\gamma$, $Z\gamma$ and WW for a center of mass energy of 7 TeV has been done with 36 pb^{-1} with CMS and we updated WW with 1.1 fb^{-1}*
- *All results show good agreement with the SM predictions and with most of the state of the art MC predictions*
- *CMS Measurements of anomalous triple gauge boson couplings competitive to Tevatron and LEP*
- *More golden opportunities and new exciting results with increasing integrated luminosity*

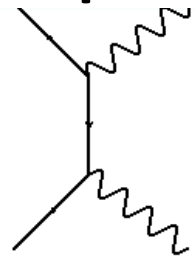
Back Up Slides

$V\gamma$ Systematic Uncertainties

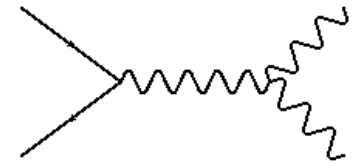
	$W\gamma \to e\nu\gamma$	$W\gamma \to \mu\nu\gamma$	$Z\gamma \to ee\gamma$	$Z\gamma \to \mu\mu\gamma$
Source	Effect on $A \cdot \epsilon_{MC}$			
Lepton energy scale	2.3%	1.0%	2.8%	1.5%
Lepton energy resolution	0.3%	0.2%	0.5%	0.4%
Photon energy scale	4.5%	4.2 %	3.7%	3.0%
Photon energy resolution	0.4%	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%			

Radiation Amplitude Zero(RAZ)

Destructive interferences between following diagrams



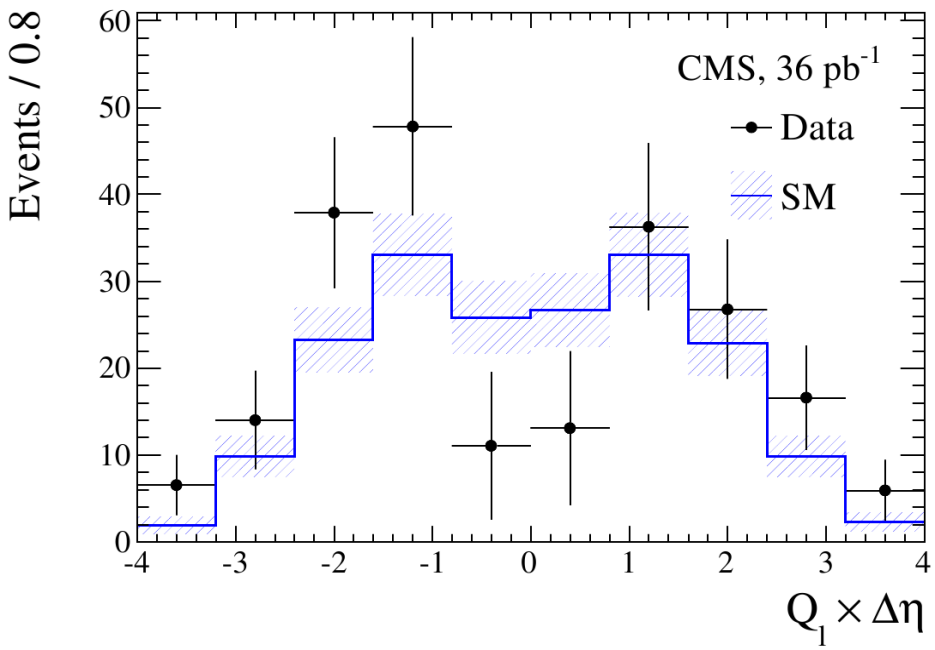
and



Already observed by D0 using the "charge-signed rapidity" : $Q_l.\Delta\eta(l,\gamma)$

For pp collision : minimum located at $Q_l.\Delta\eta(l,\gamma) = 0$

FSR $W\gamma$ radiation amplitude reduced by requiring $M_T(l, \gamma, MET) > 90$ GeV.



Background is subtracted

Kolmogorov-Smirnov probability of 57 %