The Measurement of Vγ Cross Sections at 7 TeV in CMS

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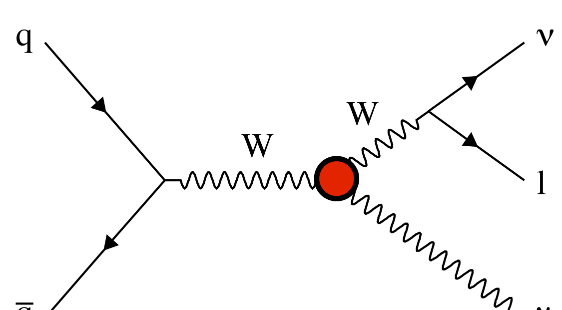
On behalf of CMS Collaboration

Outline

- Motivation
- Measurement of Wγ cross section with $E_T^{\gamma} > 10$ GeV and $\Delta R(\ell,\gamma) > 0.7$
- Measurement of Zγ cross section with $E_T^{\gamma} > 10$ GeV, $\Delta R(\ell,\gamma) > 0.7$, and $M_{\ell\ell} > 50$GeV
- Summary

Motivation

- The physics with diboson (WW, WZ, Wγ, Zγ) in the final state is an important test of Standard Model at high energy
  - Background for the new physics
  - Signature for new physics
  - Higgs, SUSY, Technicolor, Graviton ......
- The measurement of triple gauge couplings (TGCs) provides the search for new physics
  - Anomalous VVV (V= W/Z/γ) TGCs would lead different cross section and kinematic in diboson productions



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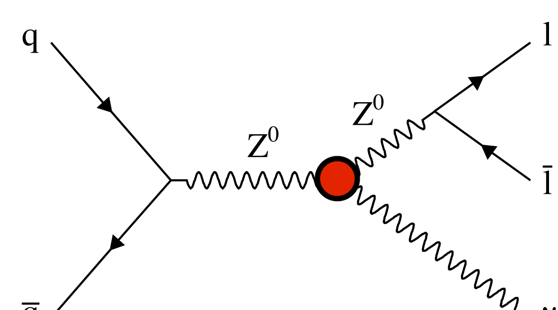

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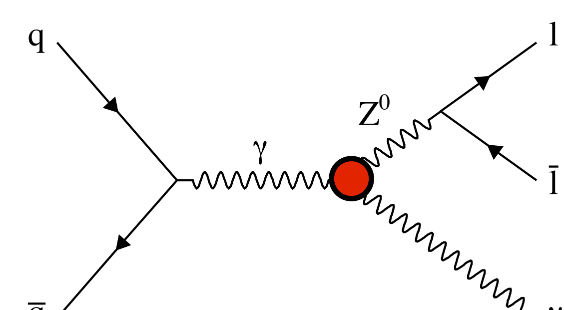

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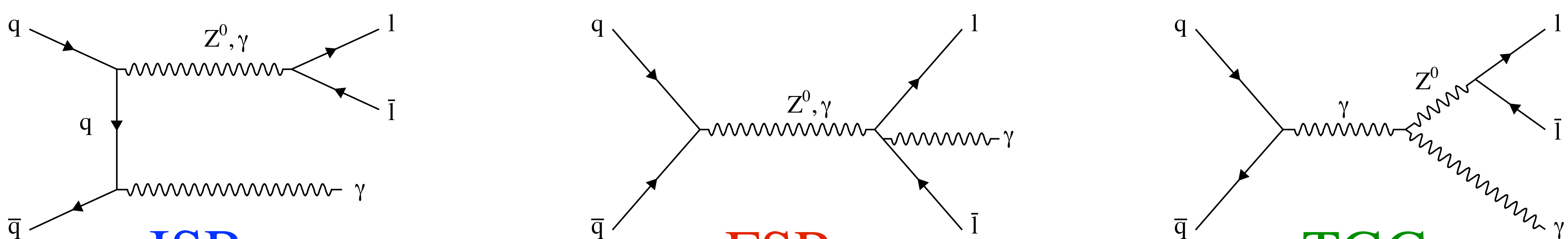
Wγ and Zγ Signatures

- Use leptonic W and Z boson decays
  - Four signatures: eνγ, μνγ, eeγ, and μμγ
- Three production mechanisms
  - Initial state radiation (ISR), final state radiation (FSR), and triple gauge coupling (TGC)



(ZZγ, Zγγ are forbidden in SM)

- FSR process can provide pure photon control sample
  - Photon energy scale and resolution
  - Photon selection efficiency
  - Photon signal template for background estimation using template method

Measurement of Wγ Cross Section with $E_T^{\gamma} > 10$ GeV and $\Delta R(\ell,\gamma) > 0.7$ with 36 pb^{-1}

$$\sigma \times \mathcal{BR}\,(W\gamma \rightarrow l\nu\gamma) = \frac{N_S}{\int \mathcal{L}\,dt \times \mathcal{A} \times \epsilon_{MC,W\gamma\rightarrow\ell\nu\gamma} \times \rho_{eff}},$$

- ➡ N_S: the number of estimated signal yields
- ➡ $\mathcal{A}$: the fiducial and kinematic acceptance
- ➡ ε_{MC}: the selection efficiency from MC simulation
- ➡ ρ_{eff}: the correction factor on MC efficiency
- ➡ $\int\mathcal{L}dt$: integrated luminosity

- ✦ Outline:
  - ✦ Resulting plots
  - ✦ Background estimation
  - ✦ Uncertainties
  - ✦ Estimated cross section

Event Selection

- HLT requirement:
  - Unprescaled single-electron triggers
    Unprescaled muon-electron triggers

$W\gamma \rightarrow e\nu\gamma$

- One good electron:
  - $P_T > 20$ GeV and $|\eta| < 2.5$
  - Pass EWK electron selection
  - Match to HLT object
- Veto 2nd electron with $P_T > 20$ GeV

$W\gamma \rightarrow \mu\nu\gamma$

- One good muon:
  - $P_T > 20$ GeV and $|\eta| < 2.1$
  - Pass EWK muon selection
  - Match to HLT object
- Veto 2nd muon with $P_T > 10$ GeV and $|\eta| < 2.4$

- MET > 25 GeV
- Select leading good photon:
  - $E_T > 10$ GeV and $|\eta| < 2.5$
  - Pass photon selection
  - $\Delta R(\ell, \gamma) > 0.7$

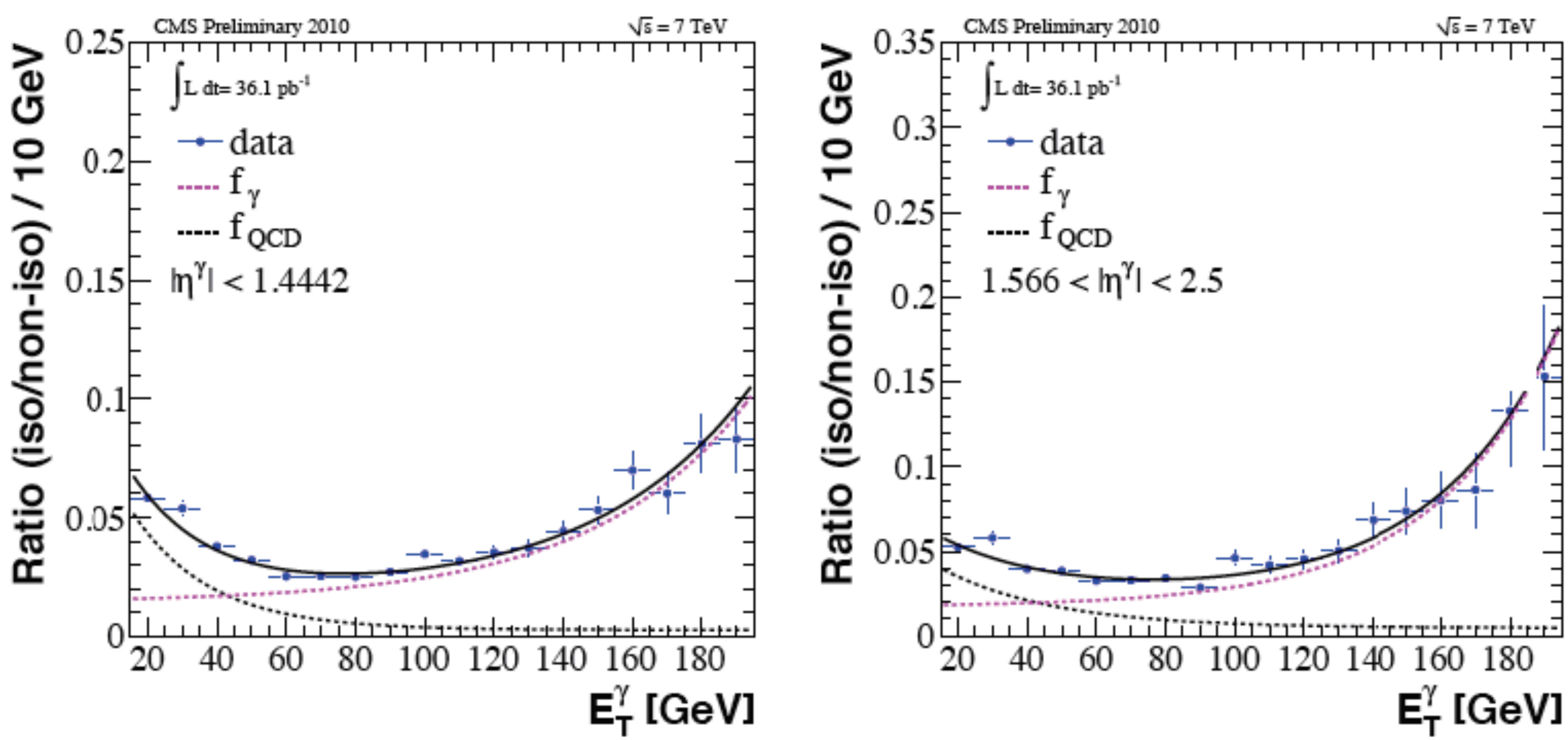
Backgrounds

- The major background is from W+jets:
  - Use "Ratio method" to estimate the photons faked from jets and use "Shape method" to cross check
- Other backgrounds:
  - An electron is misidentified as a photon
  - $W(\tau\nu_{\tau})\gamma$: τ decays to $e\nu$ or $\mu\nu$
  - $Z(\ell\ell)\gamma$: one lepton is not detected by detector
  - These are estimated using MC simulation

Background Estimation - Ratio Method

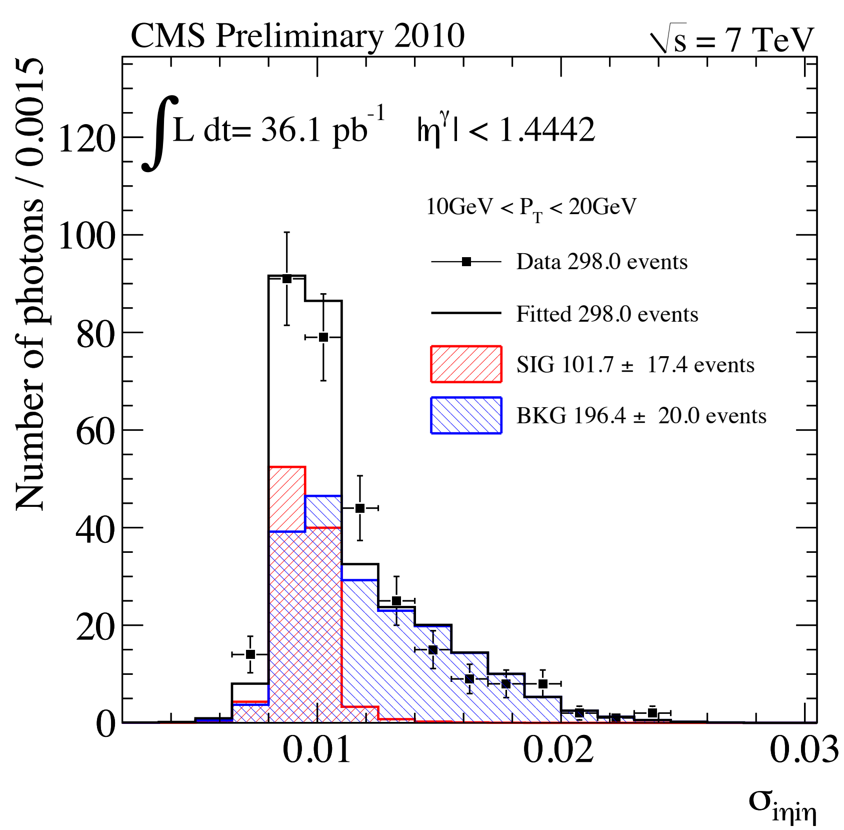
- Assume the ratio of isolated fake photon to non-isolated fake photon is the same for both V+jets and QCD samples
- Use QCD enriched sample to measure the ratio of isolated to non-isolated fake photons
- Estimated background =

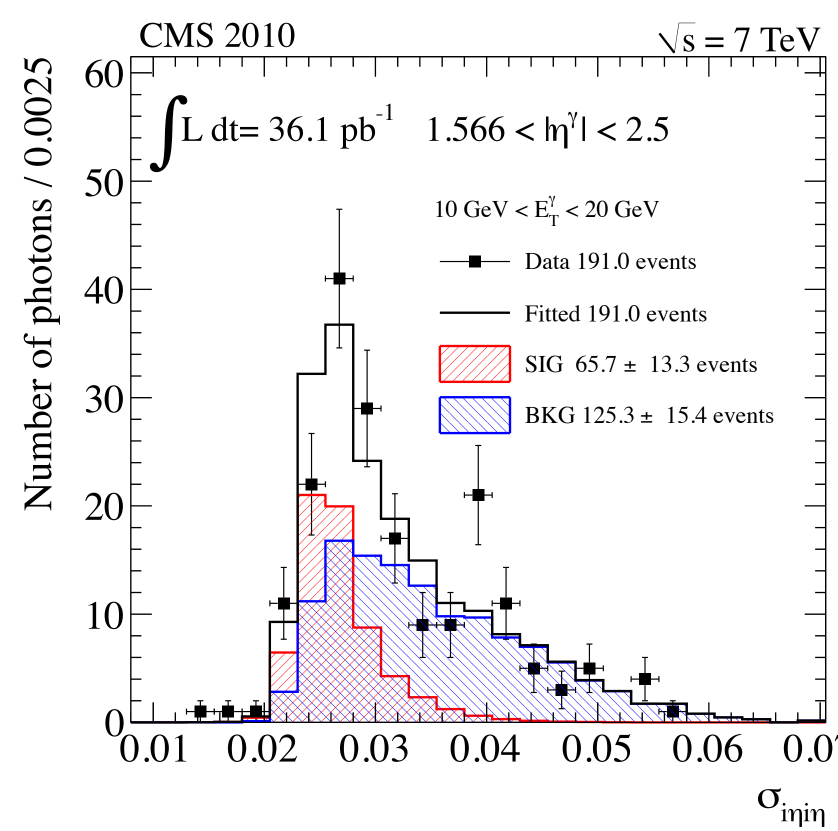
$$N_{V+\text{jets}} = \left(\frac{N_{\text{isolated }\gamma}}{N_{\text{non-isolated }\gamma}}\right)_{QCD} \times N_{V+\text{non-isolated }\gamma}$$



Background Estimation - Shape Method

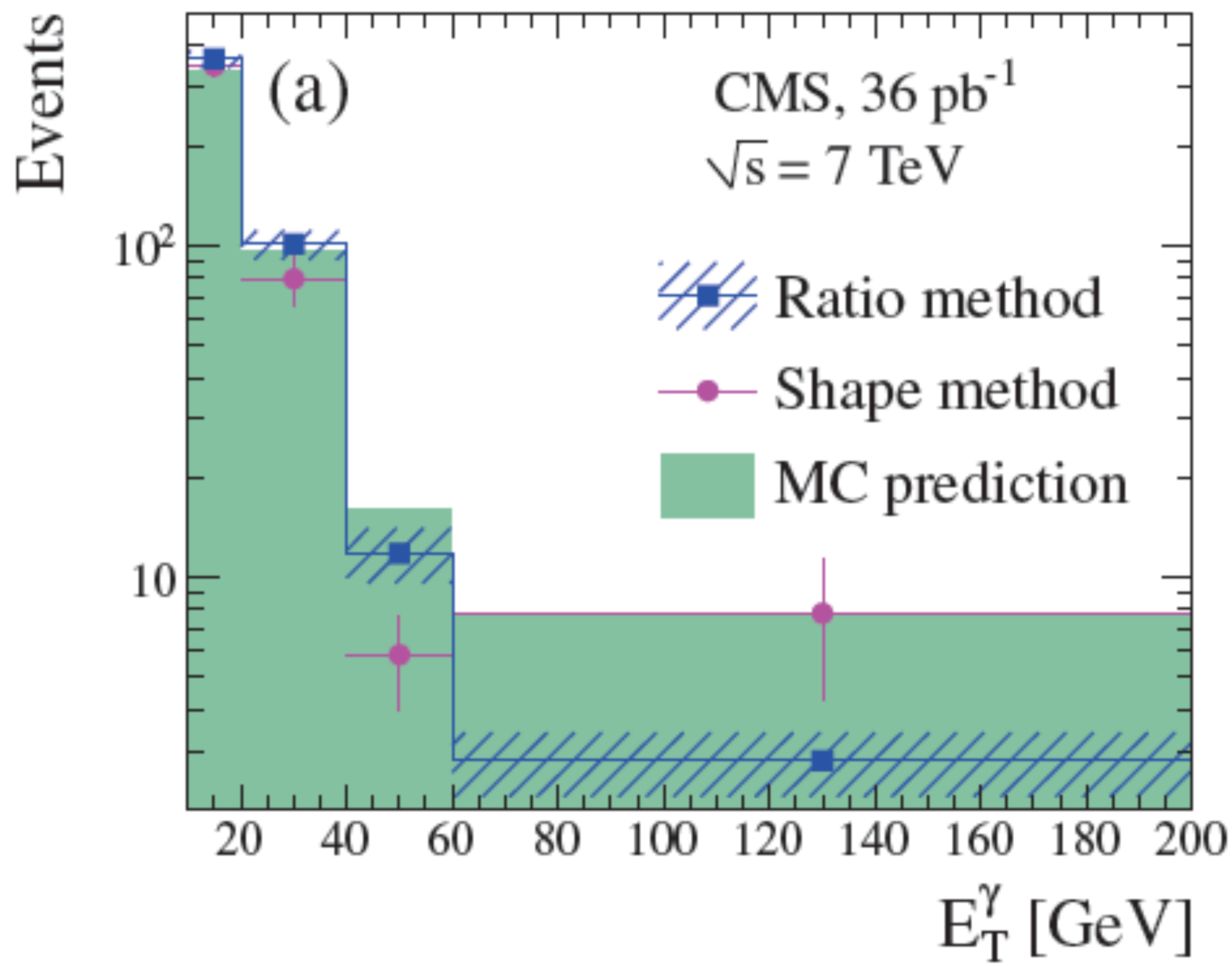
- Choose the shape of lateral energy deposition as a discriminant
- Signal templates are obtained from MC simulation
  - Use Zee data to extract correction
- Background templates are completely obtained from data-driven
  - Inverting isolation (sideband)
- The fit is performed using a binned extended maximum likelihood





Resulting Plots

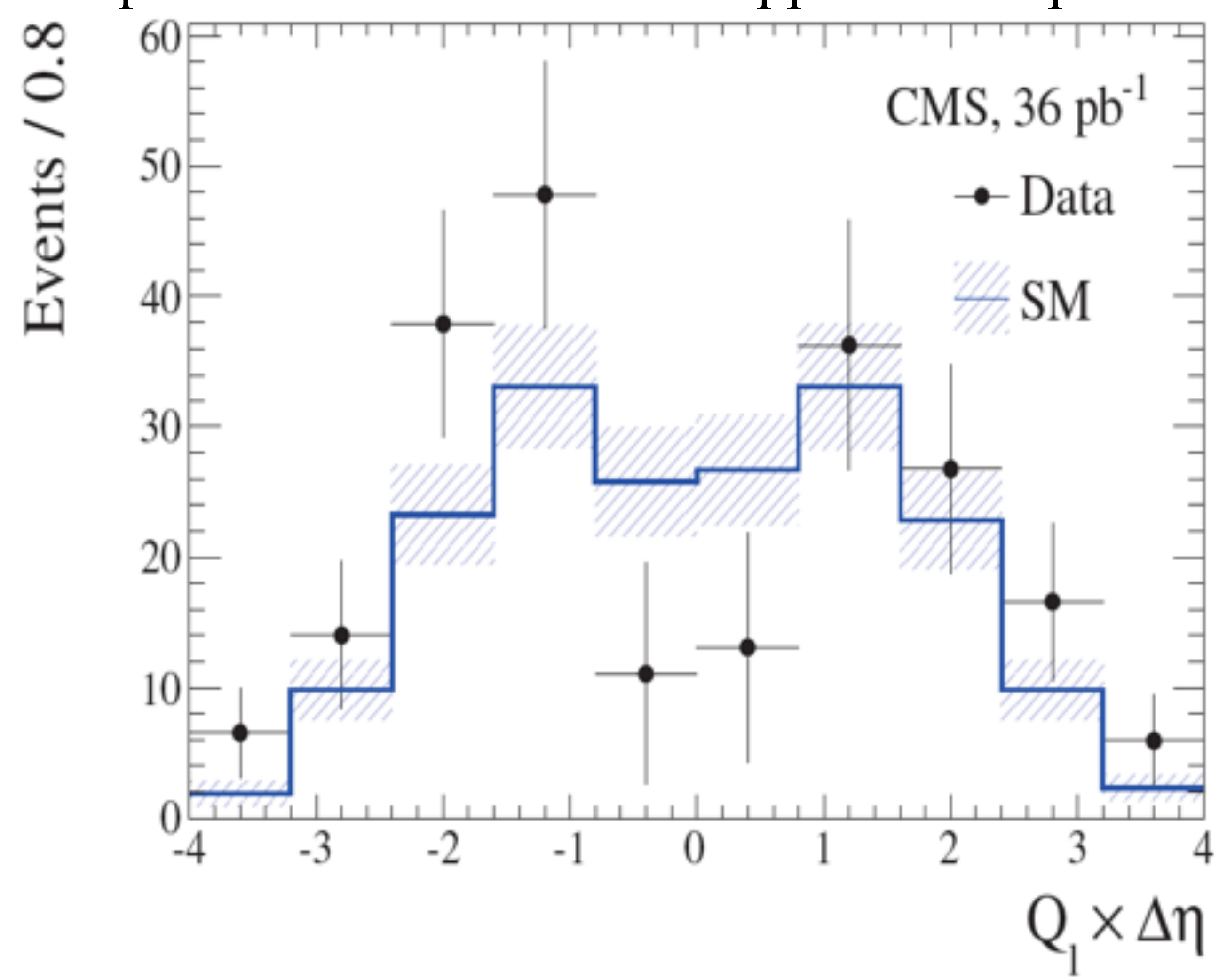
- Background estimation from shape method agrees with that from ratio method



Resulting Plots

- The tree-level Wγ production process interferes with each other, resulting in a radiation amplitude zero (RAZ) in the angular distribution of the photon
- Use charge-signed rapidity ($Q_l \times \Delta\eta$) to observe RAZ
- In the SM, the location of dip minimum is located at 0 for pp collisions
- The agreement between background-subtracted data and MC prediction is reasonable, with Kolmogorov-Smirnov test result of 57 %

Require $M_T^{W\gamma} > 90$ GeV to suppress FSR process



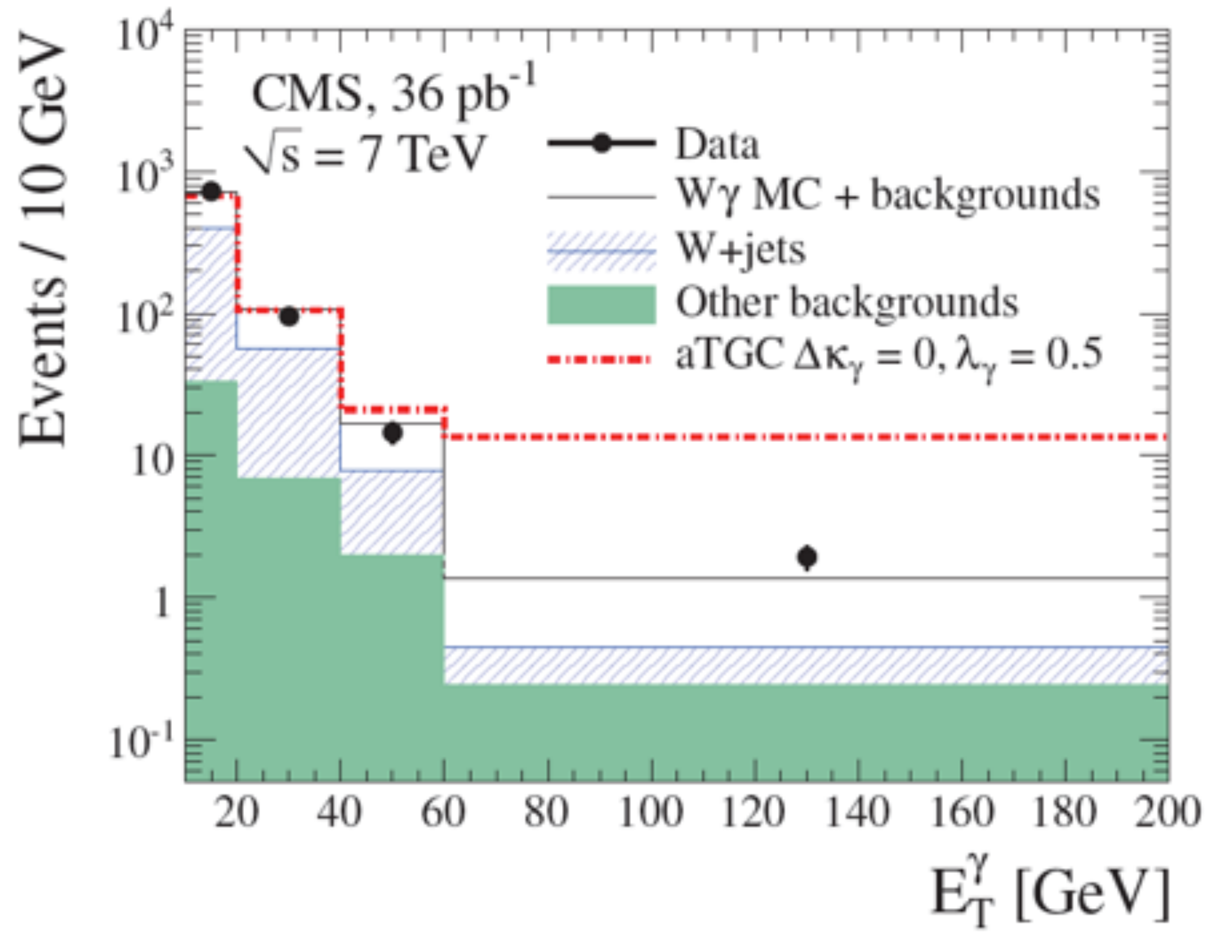
Summary of Uncertainties

- Three main categories of systematic uncertainty
  - Acceptance, efficiency, and background estimation

	$W\gamma \to e\nu\gamma$	$W\gamma \to \mu\nu\gamma$
Source	Effect on $A \cdot \epsilon_{MC}$	
Lepton energy scale	2.3%	1.0%
Lepton energy resolution	0.3%	0.2%
Photon energy scale	4.5%	4.2 %
Photon energy resolution	0.4%	0.7%
Pile-up	2.7%	2.3%
PDFs	2.0%	2.0%
Total uncertainty on $A \cdot \epsilon_{MC}$	6.1%	5.2%
	Effect on $\epsilon_{data}/\epsilon_{MC}$	
Trigger	0.1%	0.5%
Lepton identification and isolation	0.8%	0.3%
E_T^{miss} selection	0.7%	1.0%
Photon identification and isolation	1.2%	1.5%
Total uncertainty on $\epsilon_{data}/\epsilon_{MC}$	1.6%	1.9%
Background	6.3%	6.4%

Cross-section Measurement

- Theoretical NLO cross section: 49.4 ± 3.8 pb
- The estimated results:
  - $W\gamma \to e\nu\gamma$ with $E_T^\gamma > 10$ GeV and $\Delta R(\ell,\gamma) > 0.7$:
    57.1 ± 6.9 (stat.) ± 5.1 (syst.) ± 2.3 (lumi.) pb
  - $W\gamma \to \mu\nu\gamma$ with $E_T^\gamma > 10$ GeV and $\Delta R(\ell,\gamma) > 0.7$:
    55.4 ± 7.2 (stat.) ± 5.0 (syst.) ± 2.2 (lumi.) pb
  - $W\gamma \to \ell\nu\gamma$ (ℓ=e/μ) with $E_T^\gamma > 10$ GeV and $\Delta R(\ell,\gamma) > 0.7$:
    56.3 ± 5.0 (stat.) ± 5.0 (syst.) ± 2.3 (lumi.) pb



Measurement of Zγ Cross Section with $E_T^{\gamma} > 10$ GeV, $\Delta R(\ell,\gamma) > 0.7$ and $M_{\ell\ell} > 50$ GeV with 36 pb^{-1}

$$\sigma_{Z\gamma\to ll\gamma} = \frac{N_{observed} - N_{background}}{A \cdot \epsilon_{MC,Z\gamma\to ll\gamma} \cdot \rho_{eff} \cdot \int \mathcal{L}\, dt},$$

- ➡ $N_{observed}$: the number of observed yields
- ➡ $N_{background}$: the number of background yields
- ➡ $\mathcal{A}$: the fiducial and kinematic acceptance
- ➡ ε_{MC}: the selection efficiency from MC simulation
- ➡ ρ_{eff}: the correction factor on MC efficiency
- ➡ $\int \mathcal{L}dt$: integrated luminosity

- ✦ Outline:
  - ✦ Resulting plots
  - ✦ Background estimation
  - ✦ Uncertainties
  - ✦ Estimated cross section

Event Selection

- HLT requirement:
  - Unprescaled single-electron triggers
    Unprescaled muon-electron triggers

$Z\gamma \to ee\gamma$

- Two good electrons:
  - $P_T > 20$ GeV and $|\eta| < 2.5$
  - Pass EWK electron selection
- $M_{ee} > 50$ GeV

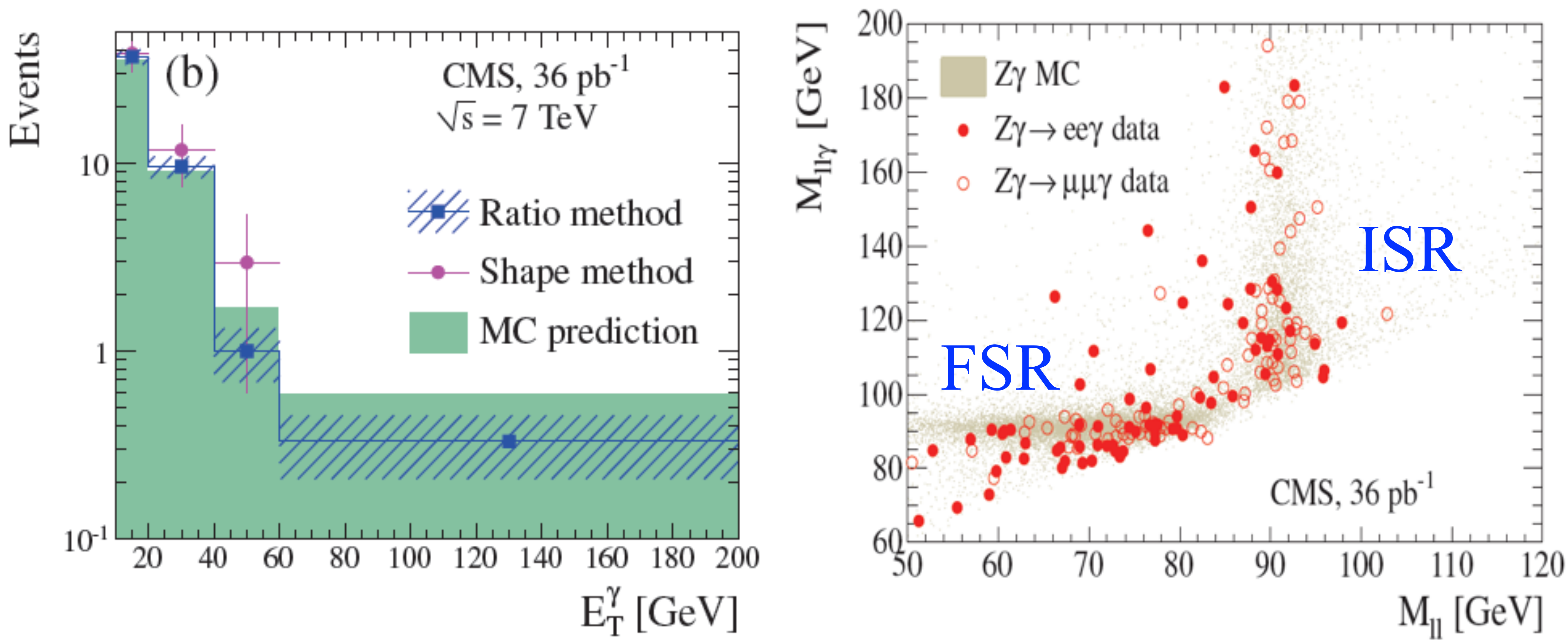
$Z\gamma \to \mu\mu\gamma$

- Two good muons:
  - $P_T > 20$ GeV and $|\eta| < 2.4$
  - Pass EWK muon selection
- $M_{\mu\mu} > 50$ GeV

- Select leading good photon:
  - $E_T > 10$ GeV and $|\eta| < 2.5$
  - Pass photon selection
  - $\Delta R(\ell, \gamma) > 0.7$

Resulting Plots

❖ Background estimation from shape method agrees with that from ratio method



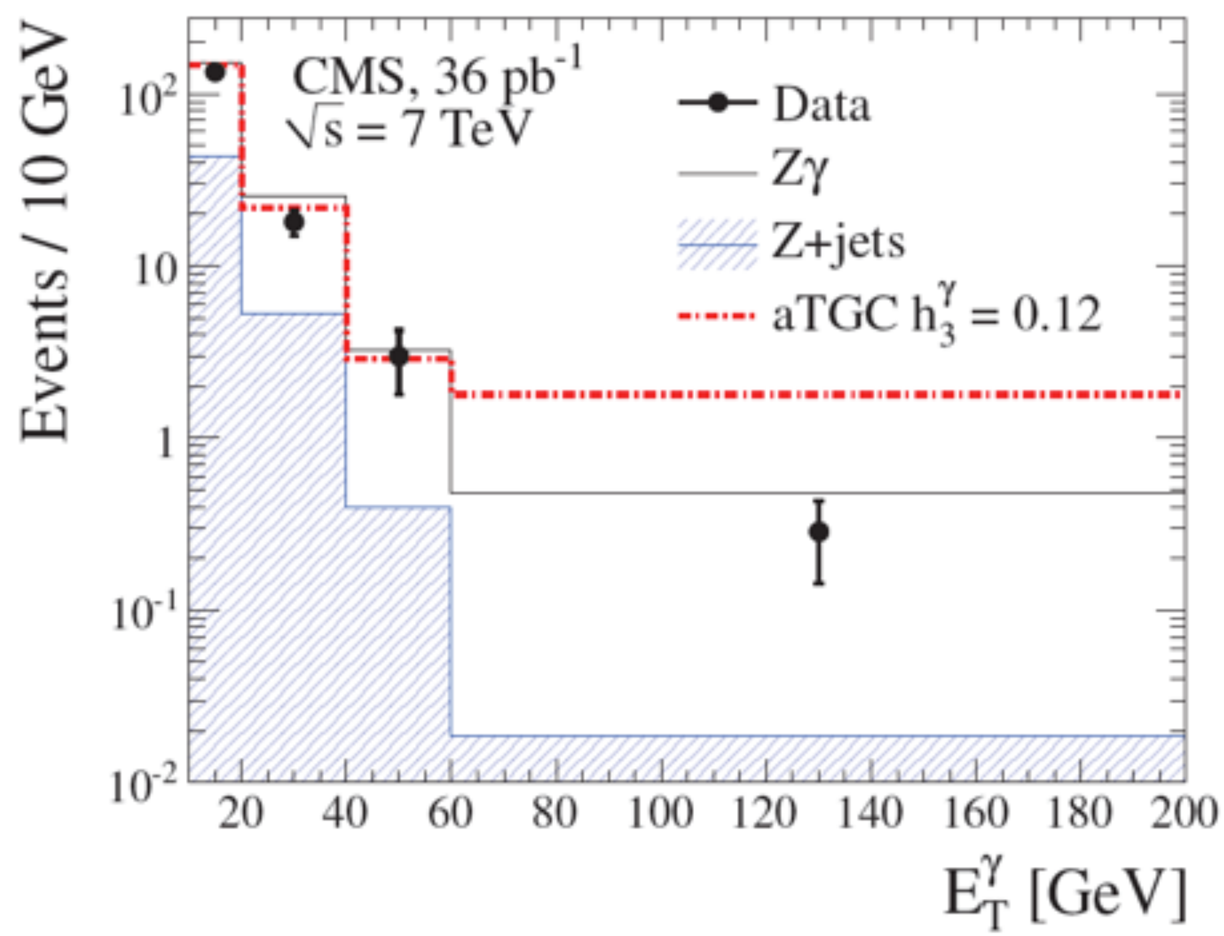
Summary of Uncertainties

- Three main categories of systematic uncertainty
  - Acceptance, efficiency, and background estimation

	$Z\gamma \to ee\gamma$	$Z\gamma \to \mu\mu\gamma$
Source	Effect on $A \cdot \epsilon_{MC}$	
Lepton energy scale	2.8%	1.5%
Lepton energy resolution	0.5%	0.4%
Photon energy scale	3.7%	3.0%
Photon energy resolution	1.7%	1.4%
Pile-up	2.3%	1.8%
PDFs	2.0%	2.0%
Total uncertainty on $A \cdot \epsilon_{MC}$	5.8%	4.3%
	Effect on $\epsilon_{data}/\epsilon_{MC}$	
Trigger	$< 0.1\%$	$< 0.1\%$
Lepton identification and isolation	1.1%	1.0%
E_T^{miss} selection	N/A	N/A
Photon identification and isolation	1.0%	1.0%
Total uncertainty on $\epsilon_{data}/\epsilon_{MC}$	1.6%	1.5%
Background	9.3%	11.4%

Cross-section Measurement

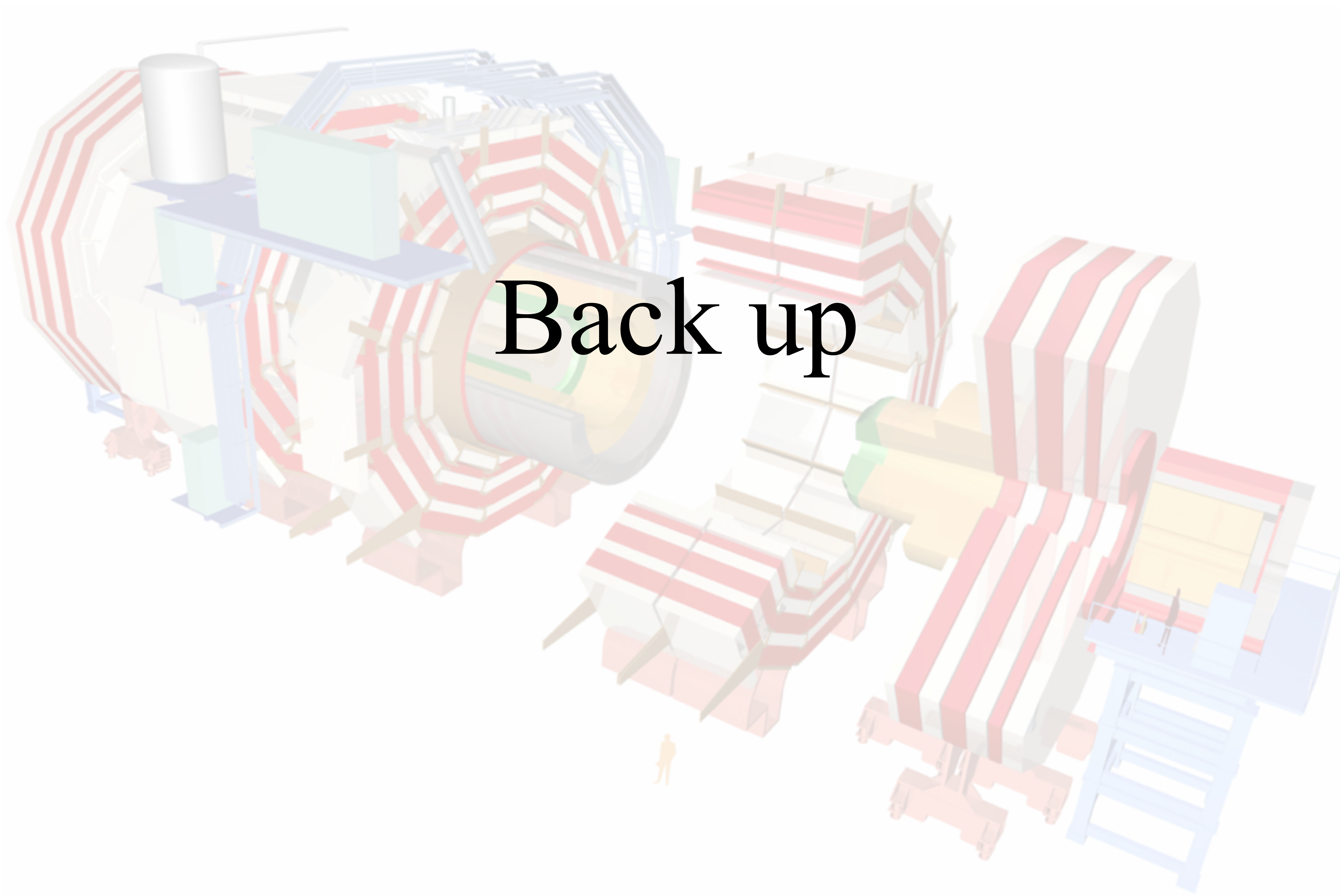
- Theoretical NLO cross section: 9.6 ± 0.4 pb
- The estimated results:
  - $Z\gamma \rightarrow ee\gamma$ with $E_T^\gamma > 10$ GeV, $\Delta R(e,\gamma) > 0.7$, and $M_{ee} > 50$ GeV:
    9.5 ± 1.4 (stat.) ± 0.7 (syst.) ± 0.4 (lumi.) pb
  - $Z\gamma \rightarrow \mu\mu\gamma$ with $E_T^\gamma > 10$ GeV, $\Delta R(\mu,\gamma) > 0.7$, and $M_{\mu\mu} > 50$ GeV:
    9.2 ± 1.4 (stat.) ± 0.6 (syst.) ± 0.4 (lumi.) pb
  - $Z\gamma \rightarrow \ell\ell\gamma$ (ℓ=e/μ) with $E_T^\gamma > 10$ GeV, $\Delta R(\ell,\gamma) > 0.7$, and $M_{\ell\ell} > 50$ GeV:
    9.4 ± 1.0 (stat.) ± 0.6 (syst.) ± 0.4 (lumi.) pb



Summary

- The measurements of $W\gamma$ and $Z\gamma$ cross sections are performed using 36 pb^{-1} data.
- $W\gamma \rightarrow \ell\nu\gamma$ (ℓ=e/μ) with $E_T^\gamma > 10$ GeV and $\Delta R(\ell,\gamma) > 0.7$:
  56.4 ± 5.0 (stat.) ± 5.0 (syst.) ± 2.3 (lumi.) pb
- $Z\gamma \rightarrow \ell\ell\gamma$ (ℓ=e/μ) with $E_T^\gamma > 10$GeV, $\Delta R(\ell,\gamma) > 0.7$, and $M_{\ell\ell} > 50$GeV:
  9.4 ± 1.0 (stat.) ± 0.6 (stat.) ± 0.4 (lumi.) pb
- All results are consistent with the standard model predictions.
- The results with 2011 full data (5 fb^{-1}) are being finalized.

Back up



Data and MC samples

- Data:
  - Integrated luminosity = 36 pb^{-1}

CMS Run	Dataset Name	Used by
	Data samples	
2010A	/EG/Run2010A-Nov4ReReco_v1/RECO	$W\gamma \to e\nu + \gamma$, $Z\gamma \to ee + \gamma$
2010B	/Electron/Run2010B-Nov4ReReco_v1/RECO	$W\gamma \to e\nu + \gamma$, $Z\gamma \to ee + \gamma$
2010A	/Mu/Run2010A-Nov4ReReco_v1/RECO	$W\gamma \to \mu\nu + \gamma$, $Z\gamma \to \mu\mu + \gamma$
2010B	/Mu/Run2010B-Nov4ReReco_v1/RECO	$W\gamma \to \mu\nu + \gamma$, $Z\gamma \to \mu\mu + \gamma$
	Samples used for background estimation	
2010A	/JetMETTau/Run2010A-Nov4ReReco_v1/RECO	all channels
2010A	/JetMET/Run2010A-Nov4ReReco_v1/RECO	all channels
2010B	/Jet/Run2010B-Nov4ReReco_v1/RECO	all channels

- MC:
  - Fall10 MC samples
  - Signal samples are generated using Madgraph

Process	$\sigma_{MadGraph}$, pb	σ_{NLO}, pb	Dataset Name (GEN-SIM-RECO data tier)
$W \to e\nu + \gamma$	100	121.24	/WGToENuG_TuneD6T_7TeV-madgraph
$W \to \mu\nu + \gamma$	100	121.24	/WGToMuNuG_TuneD6T_7TeV-madgraph
$Z \to ee + \gamma$	27	33.73	/ZGToEEG_TuneD6T_7TeV-madgraph
$Z \to \mu\mu + \gamma$	27	33.73	/ZGToMuMuG_TuneD6T_7TeV-madgraph

  - Background samples: Wjets, Zjets, WW, WZ, ZZ, QCD, PhotonJet, etc.
  - Detail list is in backup

MC Background Samples

Process	σ, pb	Dataset Name (GEN-SIM-RECO data tier)
$W \rightarrow l\nu + jets$	31314	/WJetsToLNu_TuneZ2_7TeV-madgraph-tauola
$Z \rightarrow ll + jets$	3048	/DYJetsToLL_TuneZ2_M-50_7TeV-madgraph-tauola
$t\bar{t} + jets$	157.5	/TTJets_TuneZ2_7TeV-madgraph-tauola
WW	43	/WWtoAnything_TuneZ2_7TeV-pythia6-tauola
WZ	18.2	/WZtoAnything_TuneZ2_7TeV-pythia6-tauola
ZZ	5.9	/ZZtoAnything_TuneZ2_7TeV-pythia6-tauola
$\gamma + jets(\hat{p_T} : 0 - 15)$	8.420×10^7	/G_Pt_0to15_TuneZ2_7TeV_pythia6
$\gamma + jets(\hat{p_T} : 15 - 30)$	1.717×10^5	/G_Pt_15to30_TuneZ2_7TeV_pythia6
$\gamma + jets(\hat{p_T} : 30 - 50)$	1.669×10^4	/G_Pt_30to50_TuneZ2_7TeV_pythia6
$\gamma + jets(\hat{p_T} : 50 - 80)$	2.722×10^3	/G_Pt_50to80_TuneZ2_7TeV_pythia6
$\gamma + jets(\hat{p_T} : 80 - 120)$	4.472×10^2	/G_Pt_80to120_TuneZ2_7TeV_pythia6
$\gamma + jets(\hat{p_T} : 120 - 170)$	8.417×10^1	/G_Pt_120to170_TuneZ2_7TeV_pythia6
$\gamma + jets(\hat{p_T} : 170 - 300)$	2.264×10^1	/G_Pt_170to300_TuneZ2_7TeV_pythia6
$\gamma + jets(\hat{p_T} : 300 - 470)$	1.493	/G_Pt_300to470_TuneZ2_7TeV_pythia6
$QCD(\hat{p_T} : 5 - 15)$	3.675×10^{10}	/QCD_Pt_5to15_TuneZ2_7TeV_pythia6
$QCD(\hat{p_T} : 15 - 30)$	8.159×10^8	/QCD_Pt_15to30_TuneZ2_7TeV_pythia6
$QCD(\hat{p_T} : 30 - 50)$	5.312×10^7	/QCD_Pt_30to50_TuneZ2_7TeV_pythia6
$QCD(\hat{p_T} : 50 - 80)$	6.359×10^6	/QCD_Pt_50to80_TuneZ2_7TeV_pythia6
$QCD(\hat{p_T} : 80 - 120)$	7.843×10^5	/QCD_Pt_80to120_TuneZ2_7TeV_pythia6
$QCD(\hat{p_T} : 120 - 170)$	1.151×10^5	/QCD_Pt_120to170_TuneZ2_7TeV_pythia6
$QCD(\hat{p_T} : 170 - 300)$	2.426×10^4	/QCD_Pt_170to300_TuneZ2_7TeV_pythia6
$QCD(\hat{p_T} : 300 - 470)$	1.168×10^3	/QCD_Pt_300to470_TuneZ2_7TeV_pythia6
$QCDEMEnriched(\hat{p_T} : 20 - 30)$	2.4544×10^6	/QCD_Pt-20to30_EMEnriched_TuneZ2_7TeV-pythia6
$QCDEMEnriched(\hat{p_T} : 30 - 80)$	3.8662×10^6	/QCD_Pt-30to80_EMEnriched_TuneZ2_7TeV-pythia6
$QCDEMEnriched(\hat{p_T} : 80 - 170)$	1.395×10^5	/QCD_Pt-80to170_EMEnriched_TuneZ2_7TeV-pythia6
$QCDMuEnriched(\hat{p_T} > 20, p_{T\mu} > 15$	84679.3	/QCD_Pt-20_MuEnrichedPt-15_TuneZ2_7TeV-pythia6
$QCDBCtoE(\hat{p_T} : 20 - 30)$	1.3216×10^5	/QCD_Pt-20to30_BCtoE_TuneZ2_7TeV-pythia6
$QCDBCtoE(\hat{p_T} : 30 - 80)$	1.36804×10^5	/QCD_Pt-30to80_BCtoE_TuneZ2_7TeV-pythia6
$QCDBCtoE(\hat{p_T} : 80 - 170)$	9.36×10^3	/QCD_Pt-80to170_BCtoE_TuneZ2_7TeV-pythia6

Electron Selection

- Pass identification, isolation and conversion rejection cuts
- Chose two working points, WP80 for Wγ and WP95 for Zγ
- WP80 is the same in VBTF

	WP95		WP80	
	Barrel	Endcap	Barrel	Endcap
$I_{\rm trk}/E_T$	0.15	0.08	0.09	0.04
$I_{\rm ECAL}/E_T$	2.0	0.06	0.07	0.05
$I_{\rm HCAL}/E_T$	0.12	0.05	0.10	0.025
Missing hits $\leq$	1	1	0	0
Dcot	–	–	0.02	0.02
Dist	–	–	0.02	0.02
$\sigma_{i\eta i\eta}$	0.01	0.03	0.01	0.03
$\Delta\phi_{in}$	0.8	0.7	0.06	0.03
$\Delta\eta_{in}$	0.007	0.01	0.004	0.007
H/E	0.15	0.07	0.04	0.025

Muon Selection

- Muon is reconstructed as a global and as a tracker muon
  - $\geqq$ 1 good muon chamber hit
  - $>$ 10 tracker hit
  - $\geqq$ 1 pixel hits
  - match to $\geqq$ 2 muon stations
  - chi2/ndf of global fit $<$ 10
  - $|d_{xy}| < 2$ mm (impact parameter in transverse plane)
- Relative combined isolation
  $\rightarrow (Iso_{TRK} + Iso_{ECAL} + Iso_{HCAL})/P_T < 0.15$
- These selections are the same in VBTF

Photon Selection

- Pass identification and isolation criteria
  - $Iso_{ECAL} < 4.2 + 0.006 \times P_T$
  - $Iso_{HCAL} < 2.2 + 0.0025 \times P_T$
  - $Iso_{TRK} < 2.0 + 0.001 \times P_T$
  - $H/E < 0.05$
  - $\sigma_{i\eta i\eta} < 0.013$ (EB), 0.03 (EE)
- No pixel seed matching
- This is recommended by EG POG
  https://twiki.cern.ch/twiki/bin/view/CMS/PhotonID