Wγ and Zγ Production in 7 TeV pp collisions at CMS

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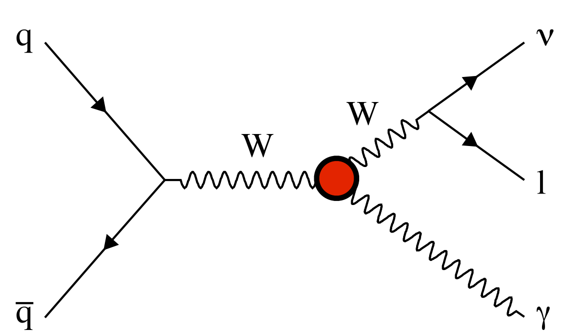
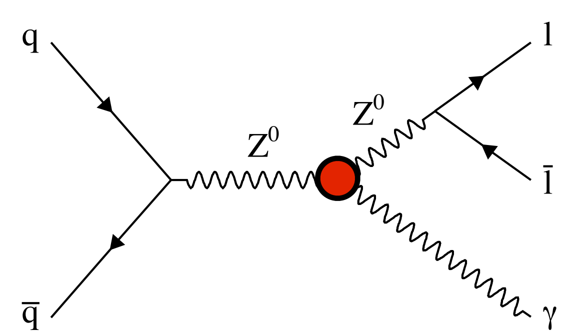
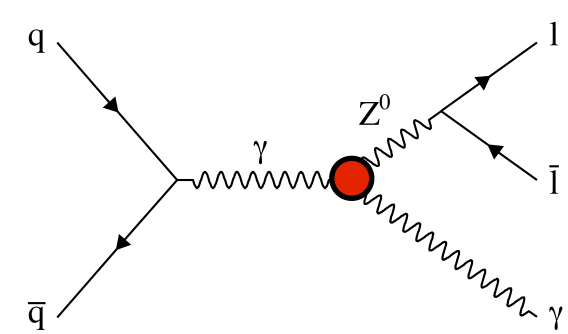
Motivation

- The physics with diboson (WW, WZ, $W\gamma$, $Z\gamma$, ZZ) in the final state is an important test of Standard Model at high energy
  - Signature for new physics
    - Higgs, SUSY, extra-dimensions, Technicolor, ...
  - Background for the new physics
- 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



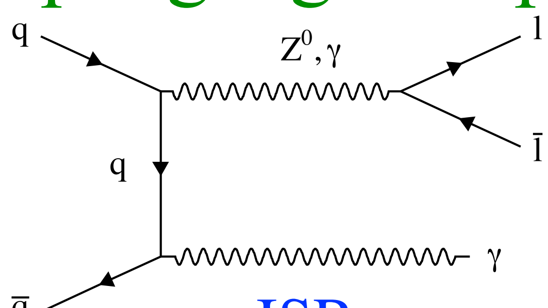




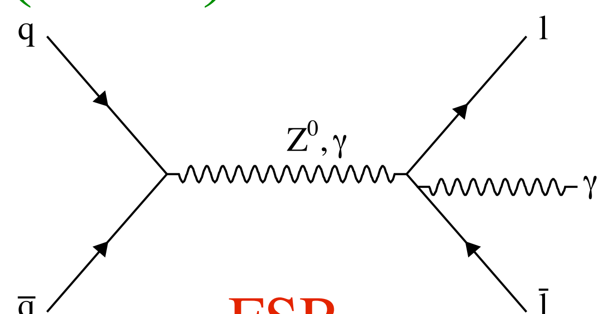
($ZZ\gamma$, $Z\gamma\gamma$ are forbidden in SM)

Wγ and Zγ Signatures

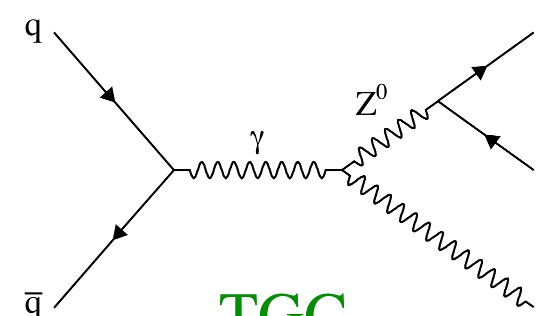
- Use leptonic W and Z boson decays: eνγ, μνγ, eeγ, μμγ, and ννγ
- Three production mechanisms
  - Initial state radiation (ISR), final state radiation (FSR), and triple gauge coupling (TGC)



ISR

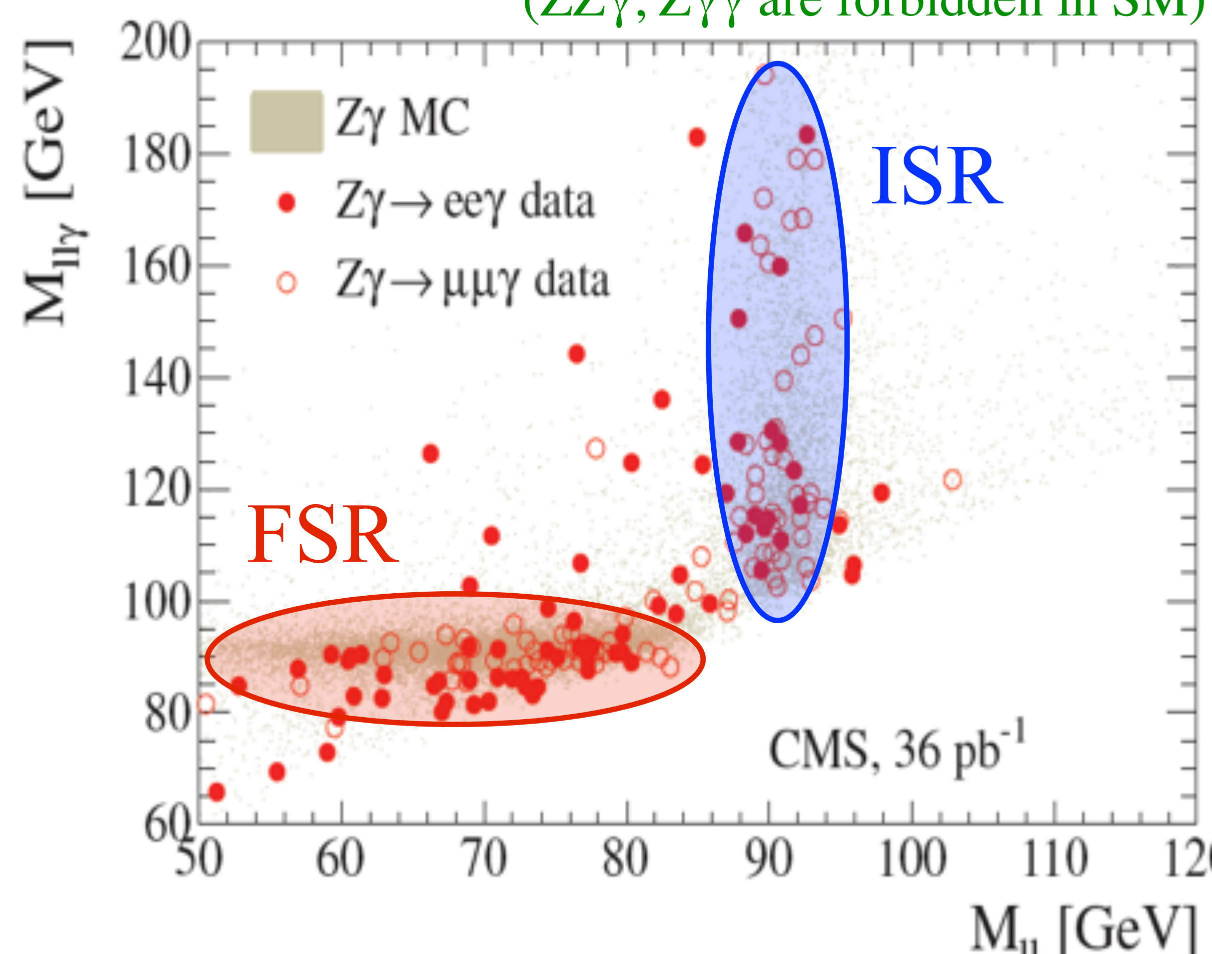


FSR



TGC (ZZγ, Zγγ are forbidden in SM)

  - FSR $Z\rightarrow\ell\ell\gamma$ process can provide pure photon control sample
    - Photon energy scale and resolution



Event Selection

- Measurements of cross section and aTGC for Wγ and Zγ with charged lepton decay channel are based on 36 pb^{-1} (**Phys. Lett. B 701, 535 (2011)**)
- Search of new physics in final state containing γ+MET (related to Z$\gamma\rightarrow\nu\nu\gamma$) is based on 5 fb^{-1} (**arXiv:1204.0821v1**)

W$\gamma\rightarrow\ell\nu\gamma$

- One good lepton with $P_T > 20$ GeV
- no 2nd lepton
- MET > 25 GeV
- One good photon with $E_T > 10$ GeV and $\Delta R(\ell, \gamma) > 0.7$

Z$\gamma\rightarrow\ell\ell\gamma$

- Two good leptons with $P_T > 20$ GeV
- Dilepton mass > 50 GeV
- One good photon with $E_T > 10$ GeV and $\Delta R(\ell, \gamma) > 0.7$

γ+MET (Z$\gamma\rightarrow\nu\nu\gamma$)

- One good photon with $E_T > 145$ GeV
- MET > 130 GeV
- No other objects (jet, lepton, etc)

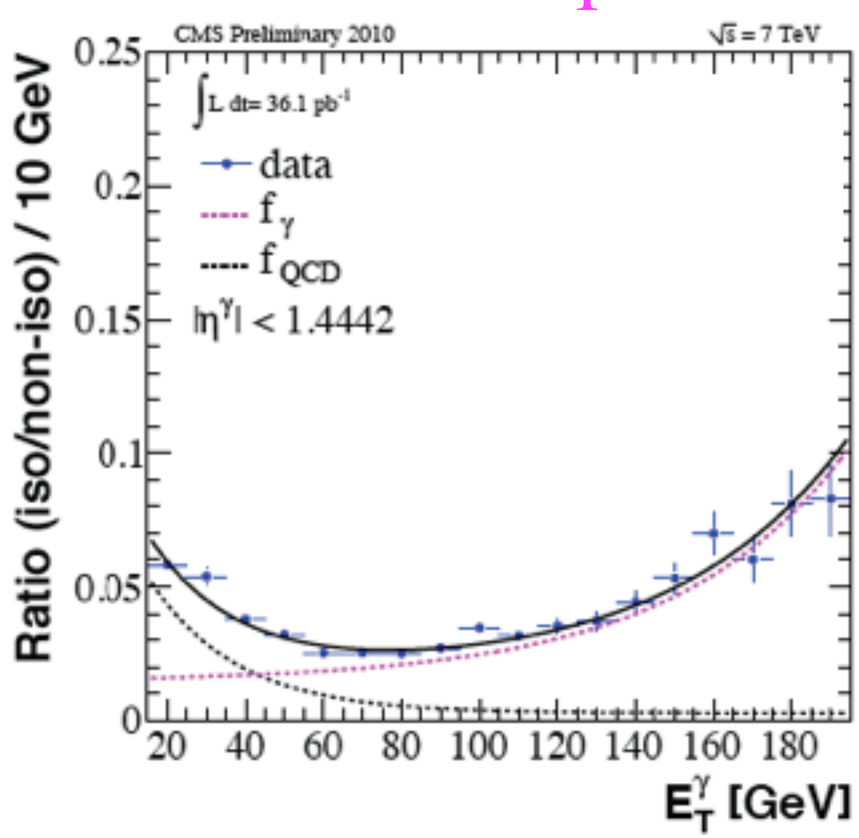
- Standard selection criteria for leptons and photons (centrally supported in CMS)

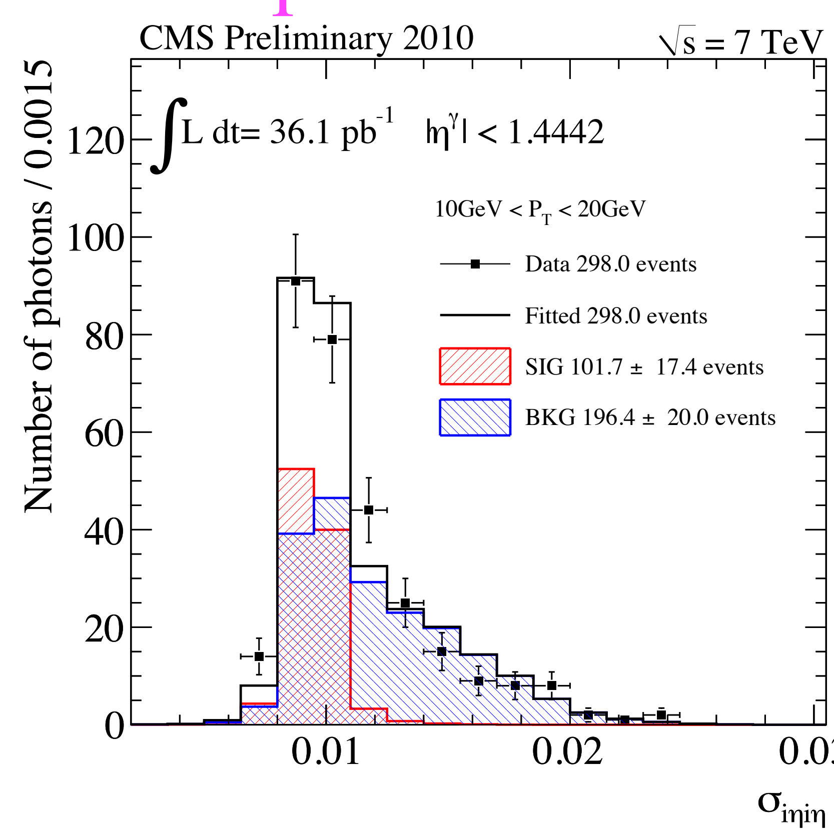
Backgrounds (1)

- The major backgrounds are from processes with jets misidentified as photons
- Two methods to estimate backgrounds from data directly
  - Ratio method: use QCD enriched sample to determine the ratio of isolated fake photon to non-isolated fake photon

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

  - Shape method: choose the shape of lateral energy deposition as a discriminant and then perform two-component fit



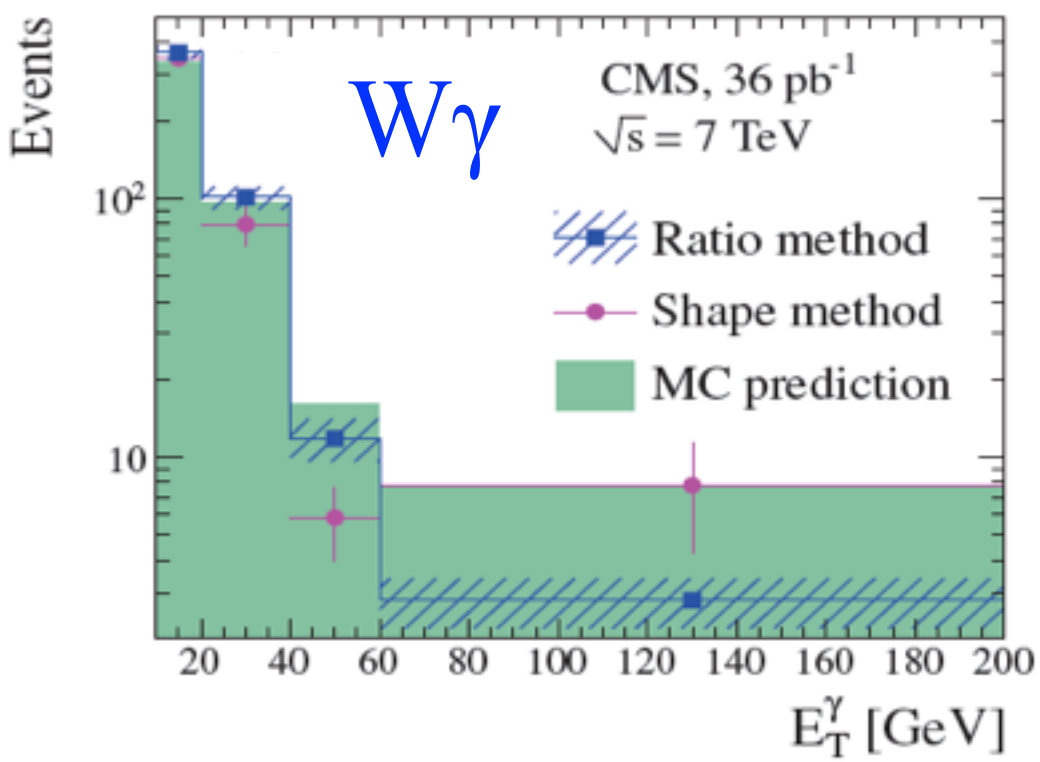


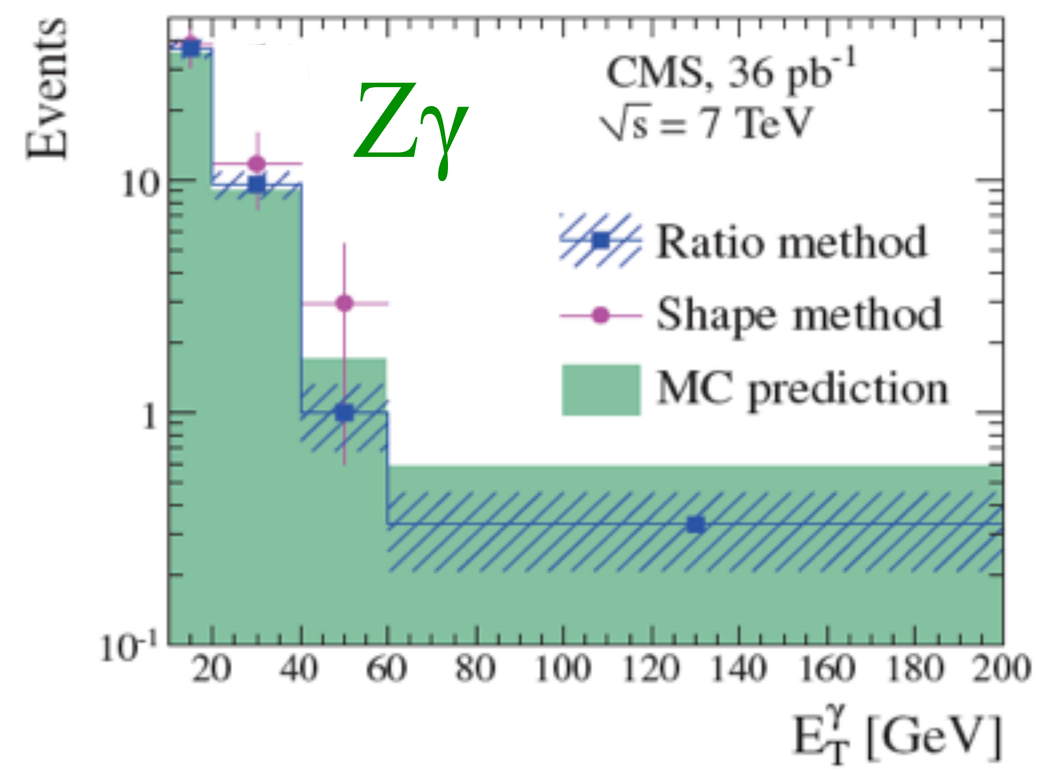
Backgrounds (2)

- The major backgrounds are from processes with jets misidentified as photons
- Two methods to estimate backgrounds from data directly
  - Ratio method: use QCD enriched sample to determine the ratio of isolated fake photon to non-isolated fake photon

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

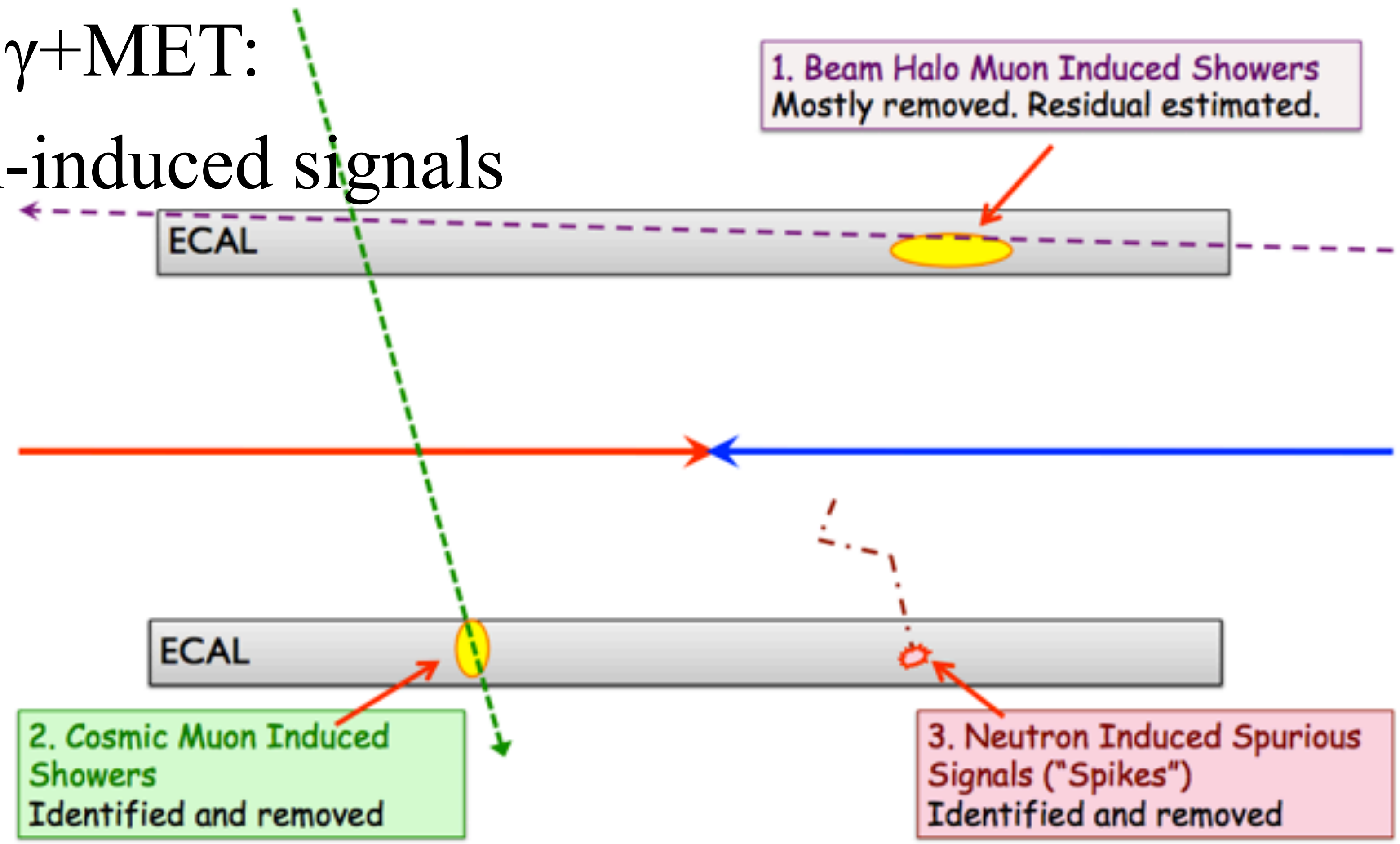
  - Shape method: choose the shape of lateral energy deposition as a discriminant and then perform two-component fit





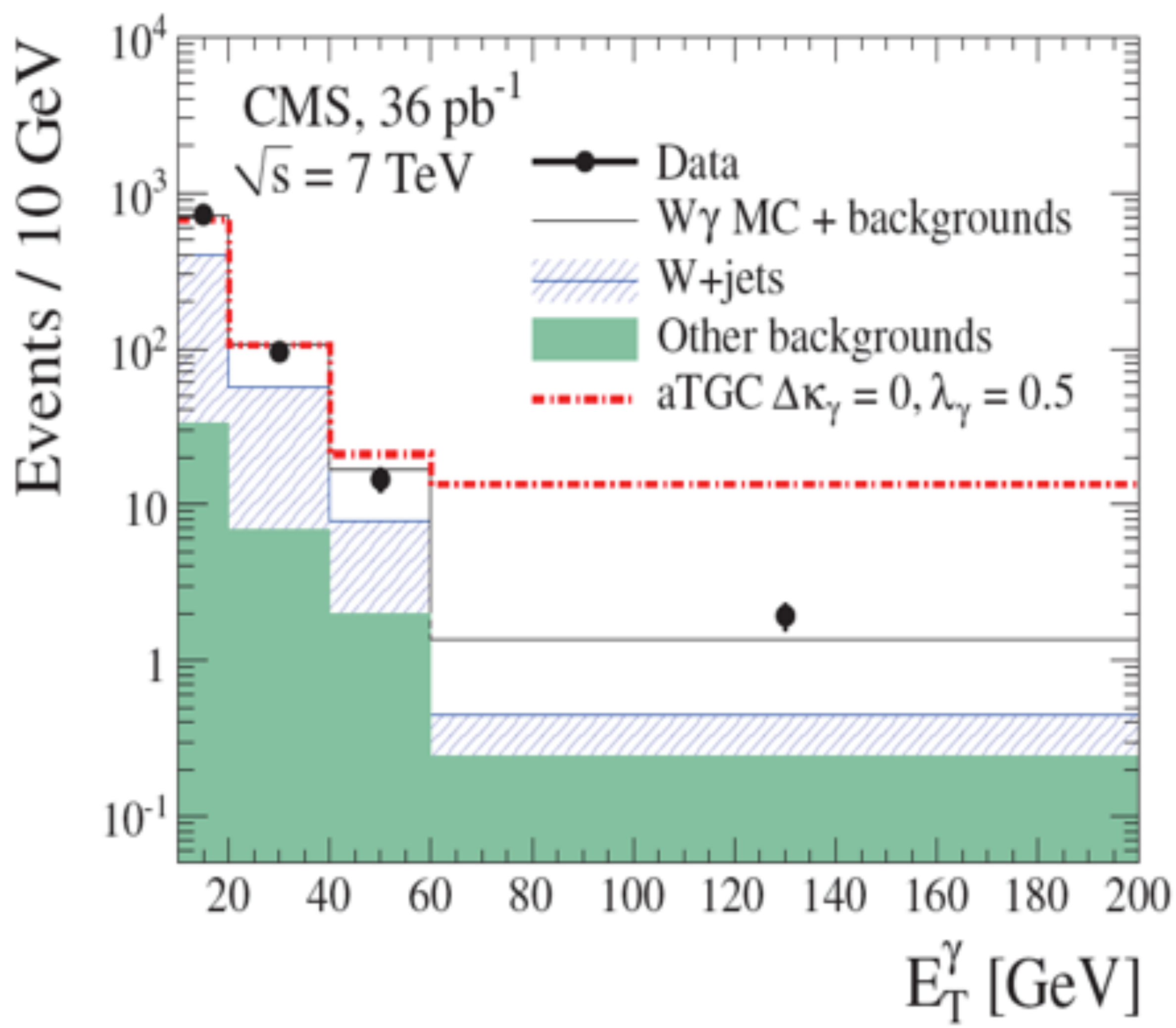
Backgrounds (3)

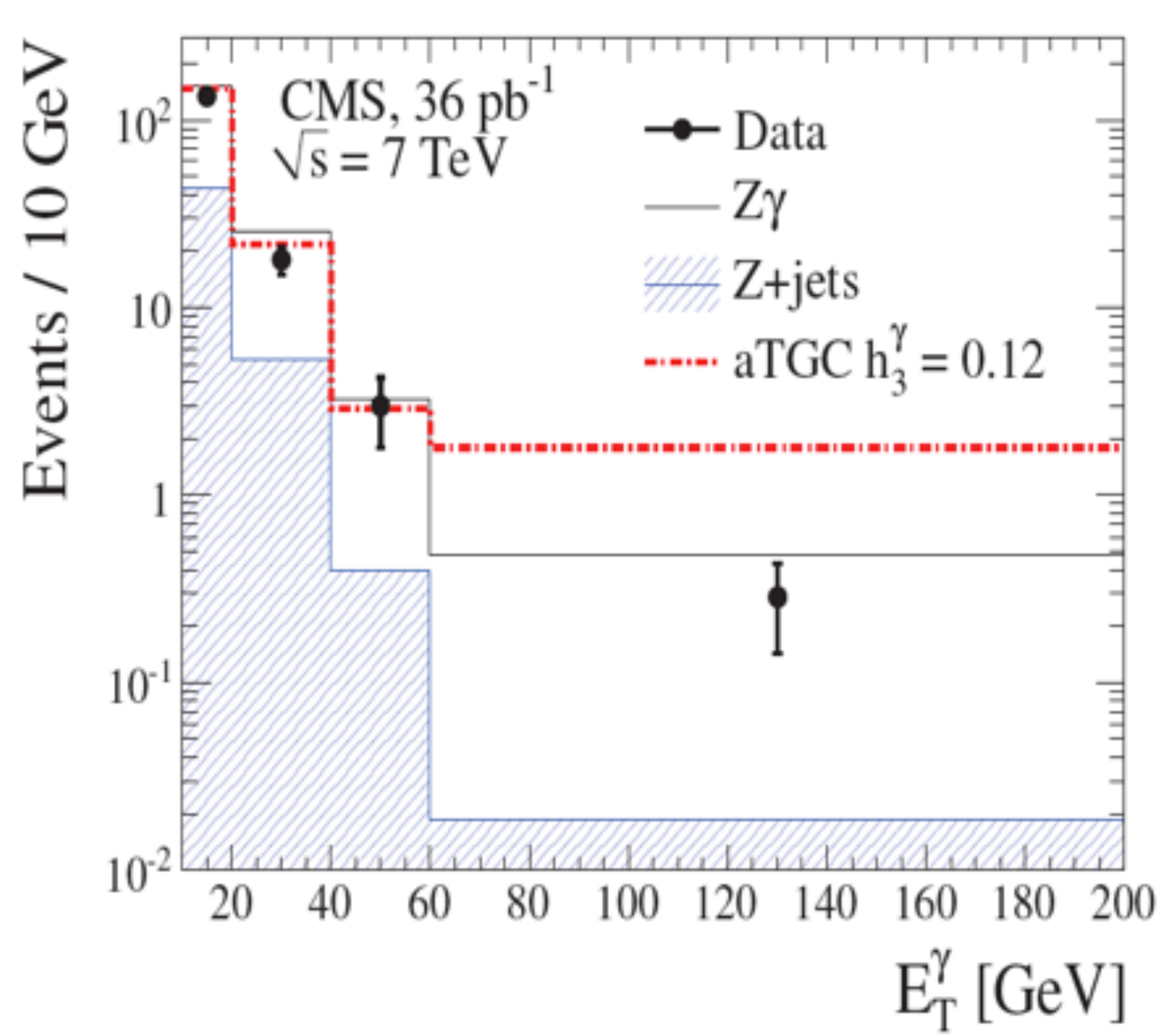
- Other prompt backgrounds for γ+MET:
  - W→eν in which electron is mis-identified as photon
    - Estimated from data
  - γ + jet that jet is mis-measured yielding MET
  - Wγ→ℓνγ with charged lepton is not reconstructed
    - Above two backgrounds are estimated from MC
- Non-collision backgrounds for γ+MET:
  - Beam halo, cosmics, neutron-induced signals
    - Estimated from data



Results: W($\ell\nu$)γ and Z($\ell\ell$)γ

- Measured cross section agrees with NLO prediction:
  - NLO prediction is from Baur NLO generator and MCFM
  - $W\gamma \rightarrow \ell\nu\gamma$ (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   49.4 ± 3.8 pb (NLO)
  - $Z\gamma \rightarrow \ell\ell\gamma$ (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   9.6 ± 0.4 pb (NLO)

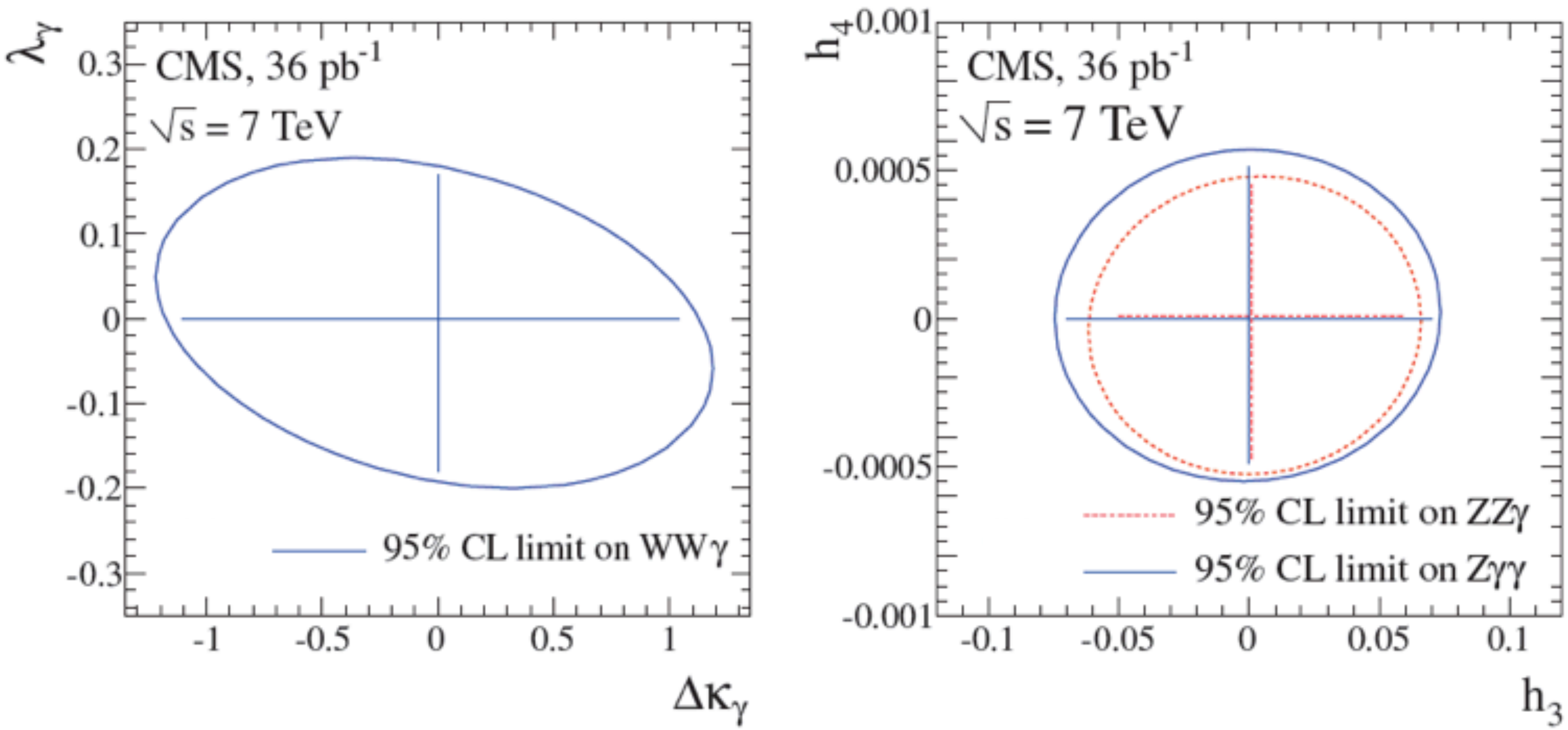




aTGC Results

- CMS uses form-factorless normalization: no energy-dependent assumption is made
- Use Sherpa/Madgraph to simulate aTGC signal
- Use E_T^{γ} as a sensitive observable to extract limits on aTGC

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

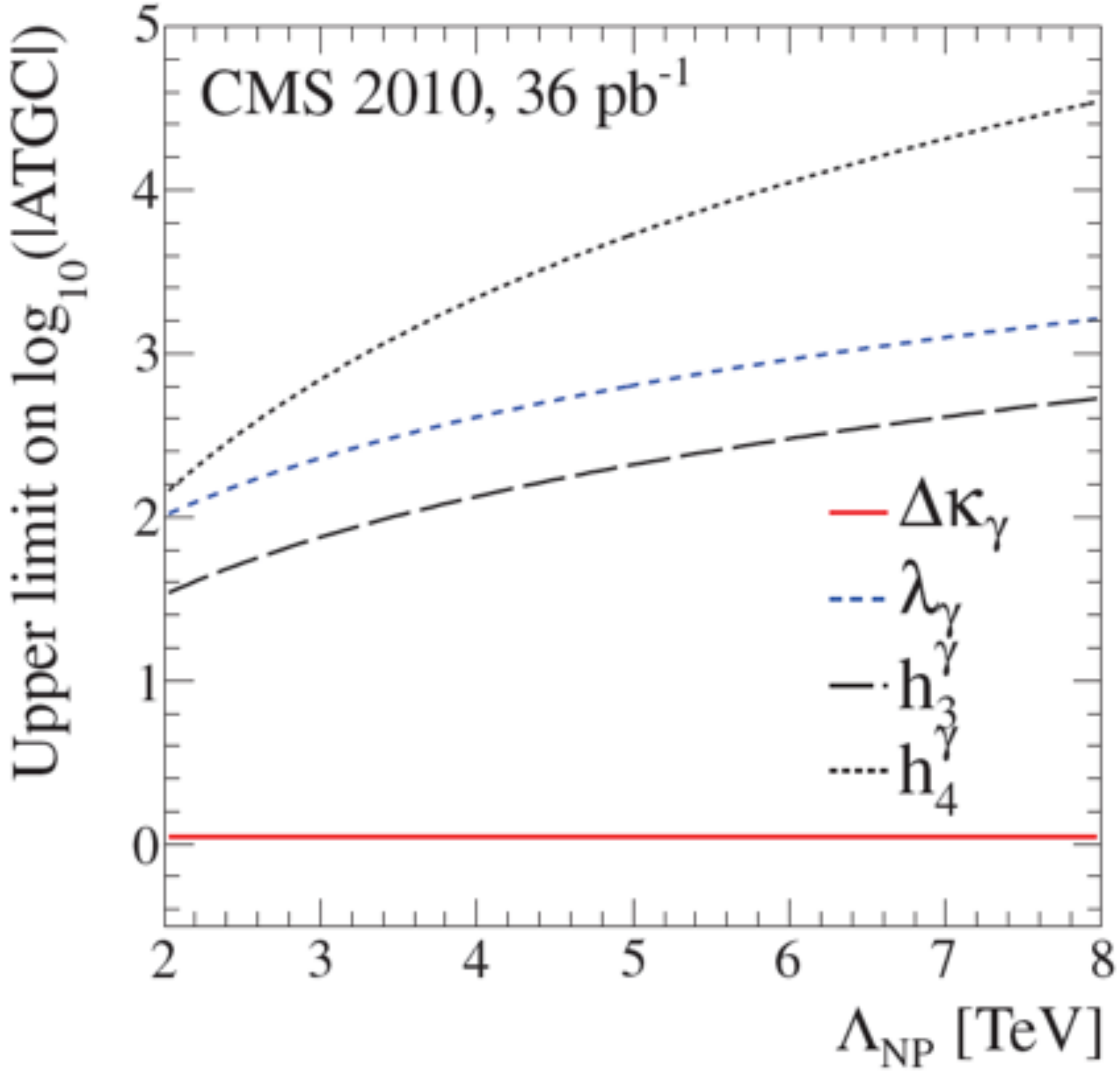


Different Interpretation

- Normalization of the couplings in the Lagrangian is arbitrary

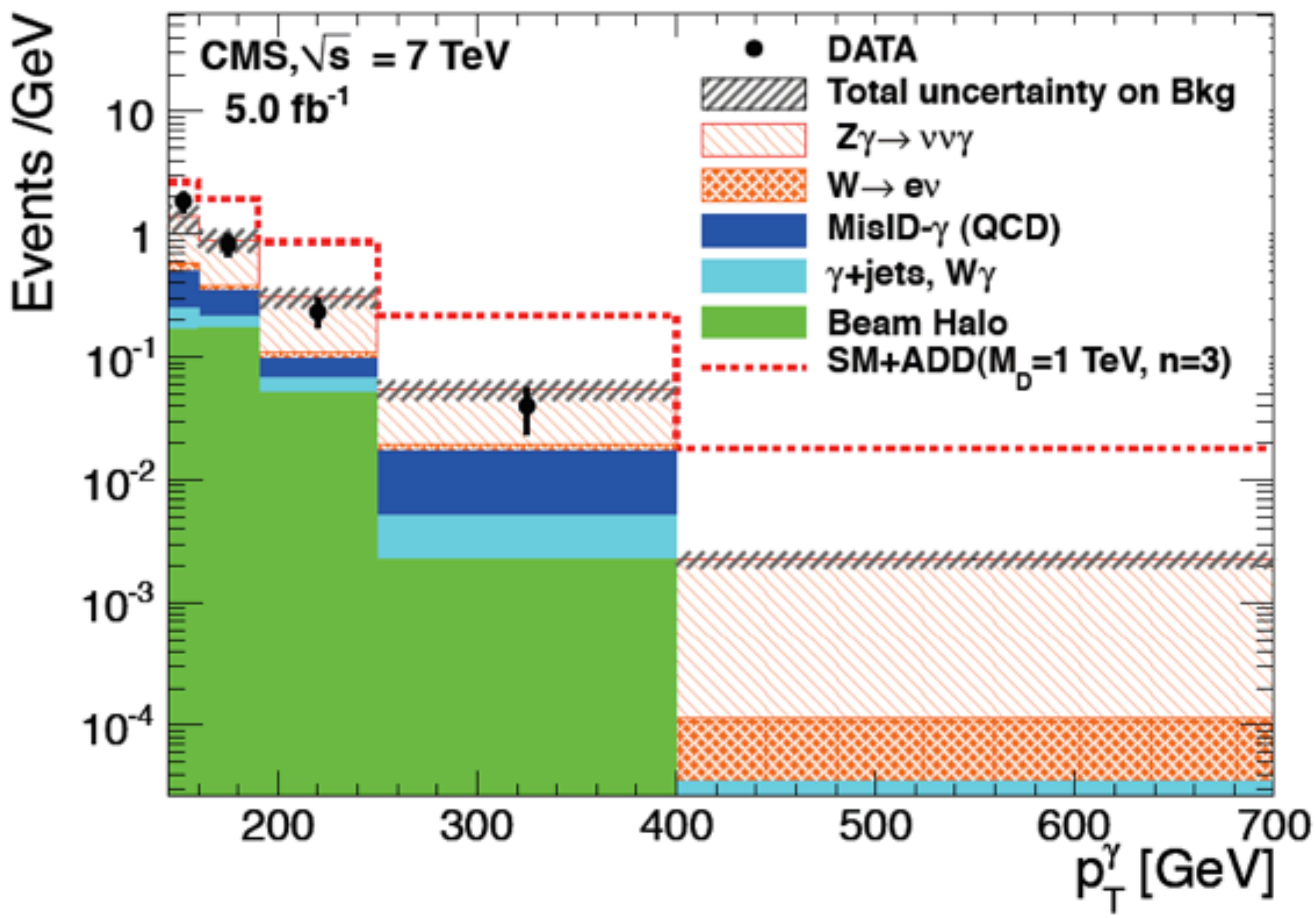
$$\mathcal{L}_{WW\gamma} = -ie[(W^{\dagger}_{\mu\nu}W^{\mu}A^{\nu} - W^{\dagger}_{\mu}W^{\mu\nu}A_{\nu}) + \kappa W^{\dagger}_{\mu}W_{\nu}F^{\mu\nu} + \frac{\lambda}{M_W^2}W^{\dagger}_{\lambda\mu}W^{\mu}_{\nu}F^{\nu\lambda}]$$

- Redefine couplings:
  - $\frac{\alpha}{M_V^n} \rightarrow \frac{\alpha}{\Lambda_{NP}^n}$
  - Λ_{NP} is characteristic energy scale of new physics



Results: Zγ→ννγ

❖ Good agreement between data and SM prediction



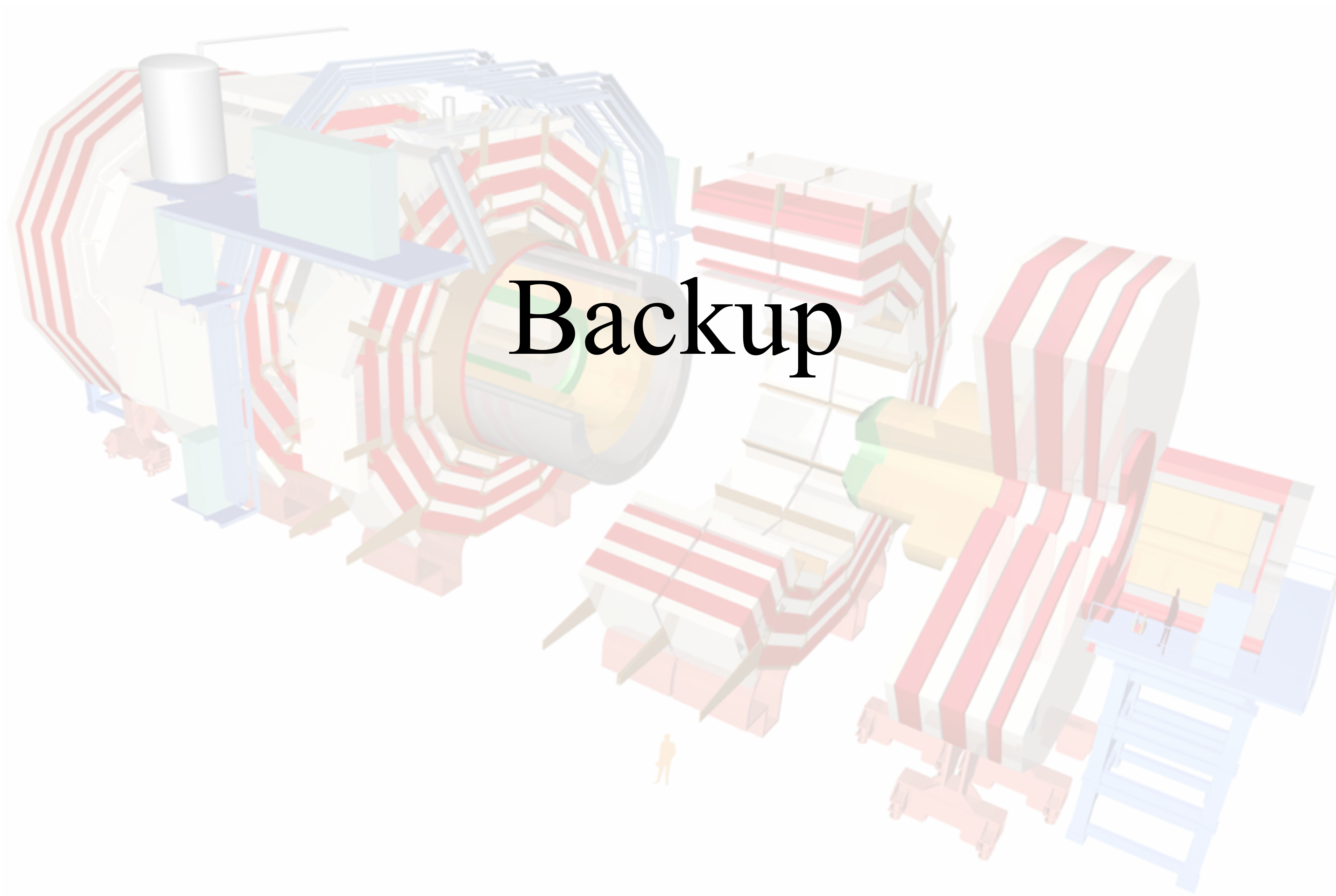
Source	Estimate
jet → γ	11.2 ± 2.8
beam halo	11.1 ± 5.6
e → γ	3.5 ± 1.5
Wγ and γ+jet	4.1 ± 1.0
Z(νν)γ	45.3 ± 6.8
Total	**75.1 ± 9.4**
Data	**73**

❖ The results are finalizing in terms of Z(νν)γ cross section and aTGC measurement

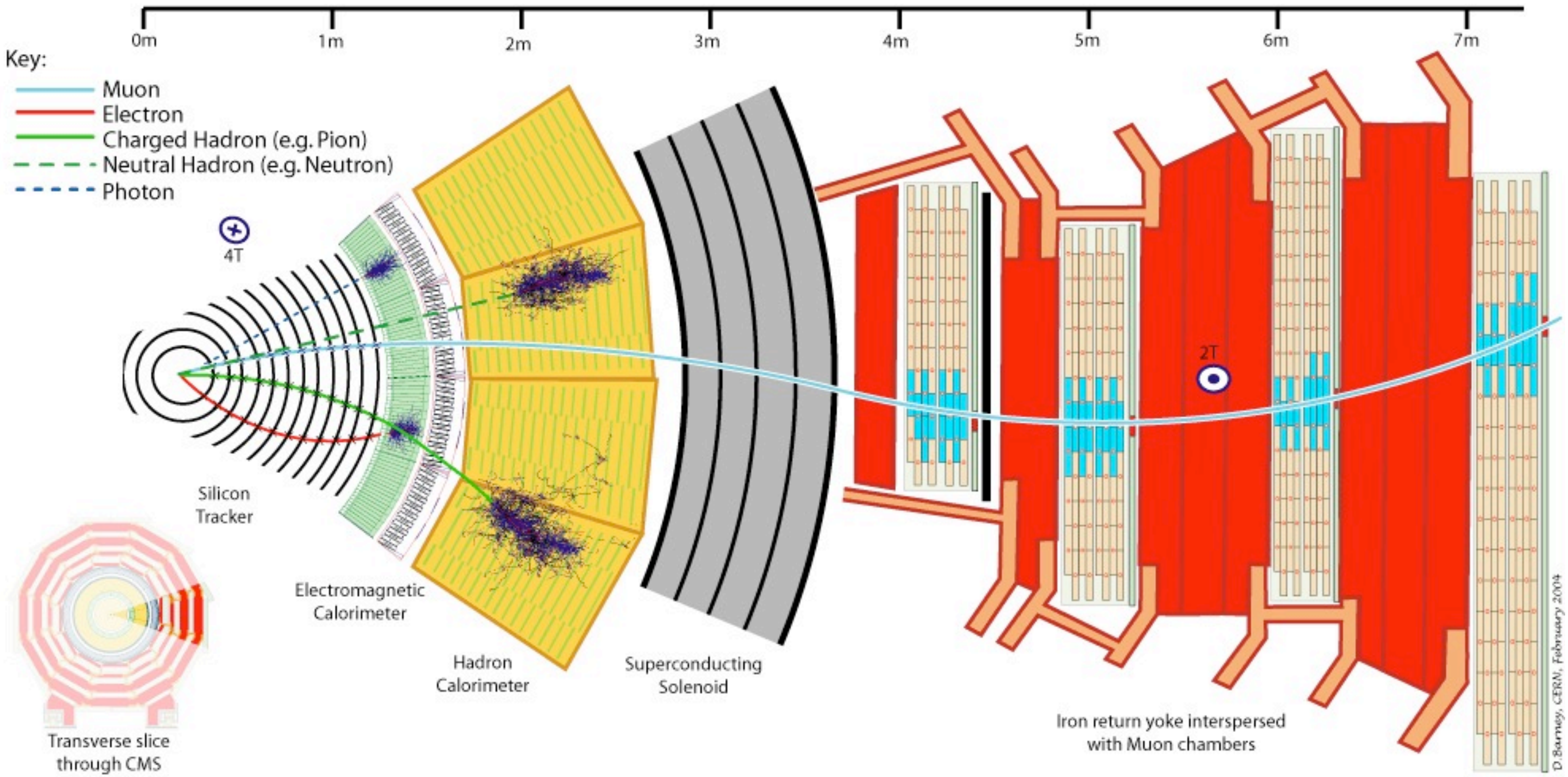
Summary

- The results of Wγ and Zγ with charged lepton decay channels are performed using 36 pb^{-1} data.
  - Measured cross section is consistent with SM prediction and there is no evidence for aTGC.
- First results of γ+MET with 5 fb^{-1} data are being finalized in terms of $Z(\nu\nu)\gamma$ cross section and aTGC measurement.
- Combined Vγ results with 5 fb^{-1} data are being finalized.

Backup



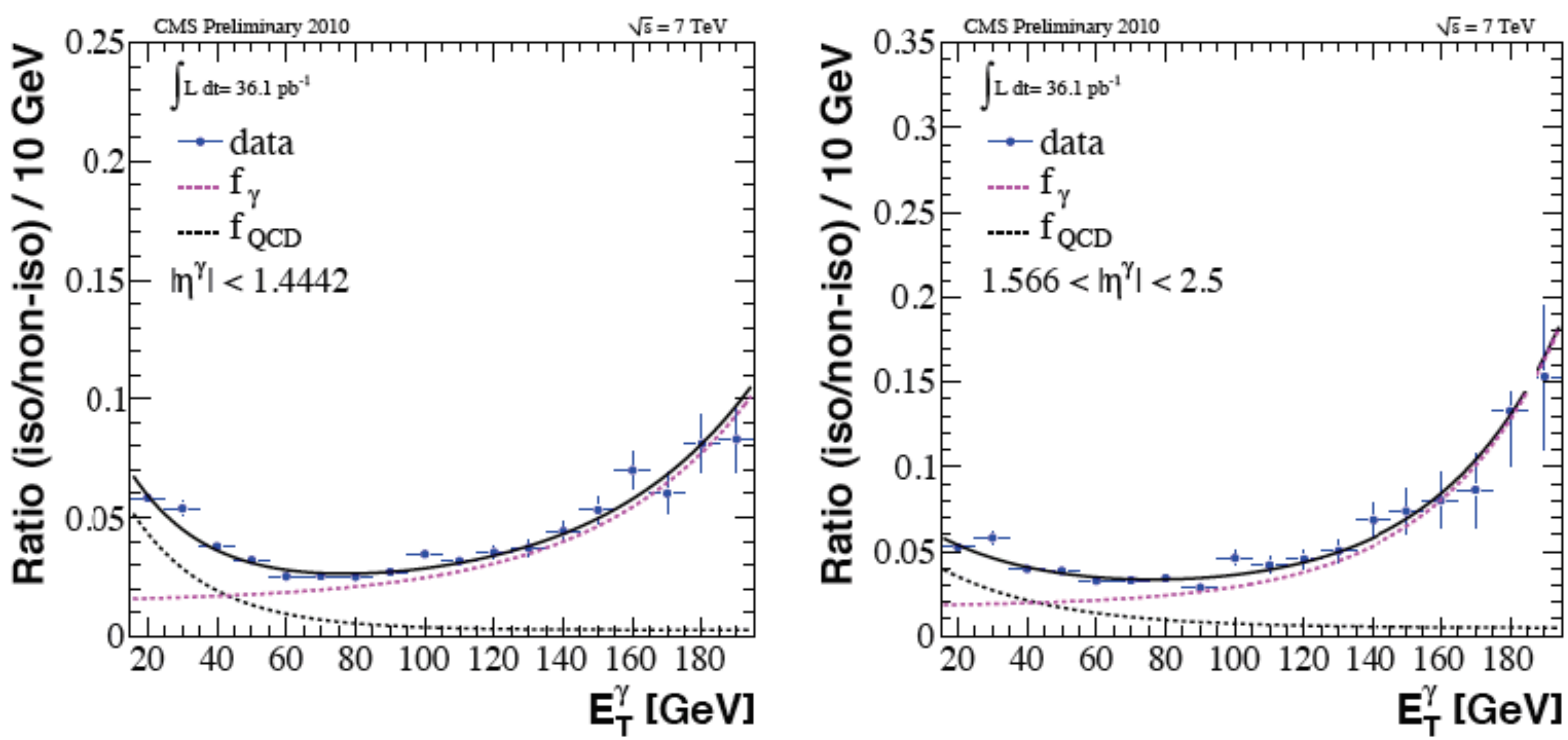
CMS Detector



Background Estimation - Ratio Method

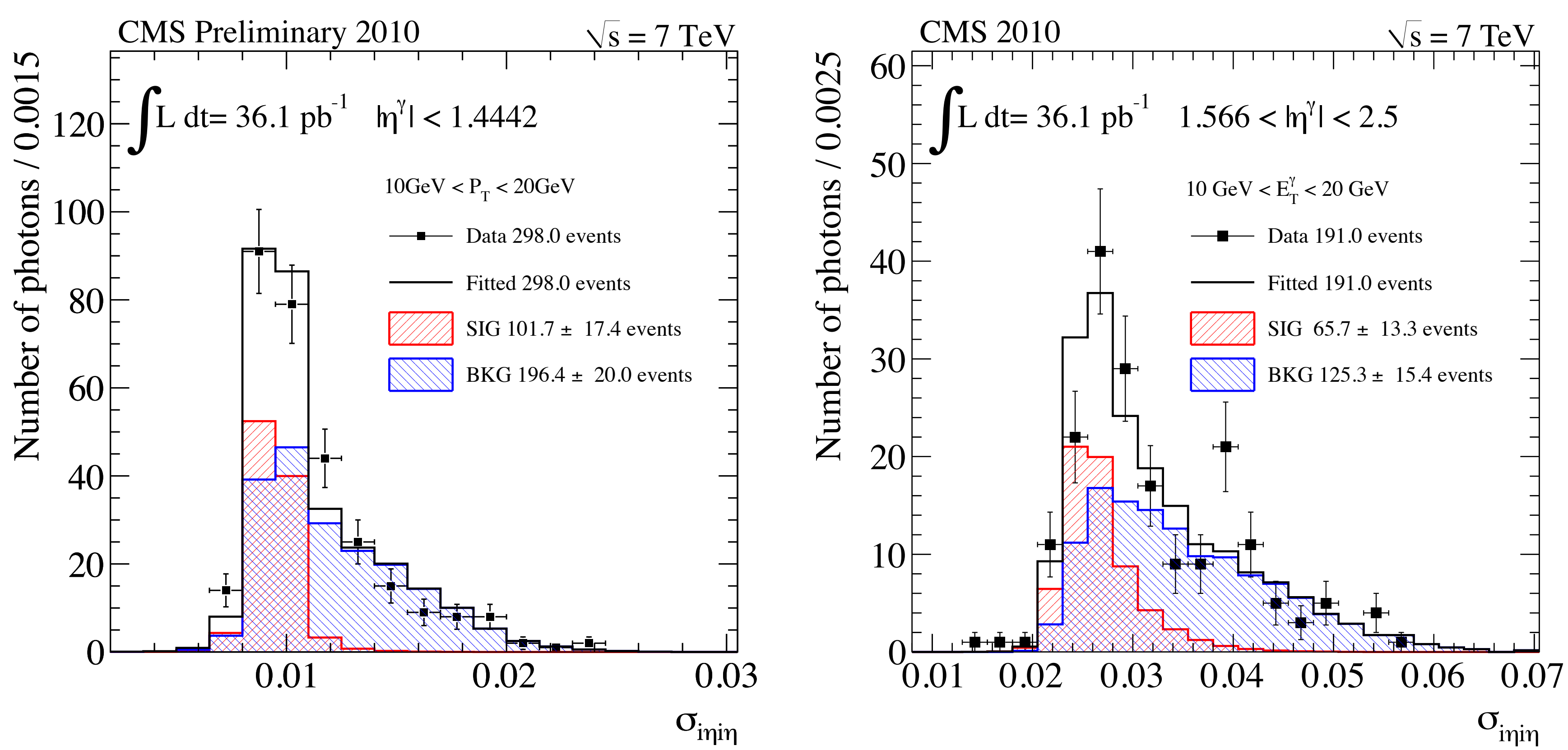
- Use QCD enriched sample to measure the ratio of isolated to non-isolated fake photons
- Estimated background =

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



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



Summary of Uncertainties

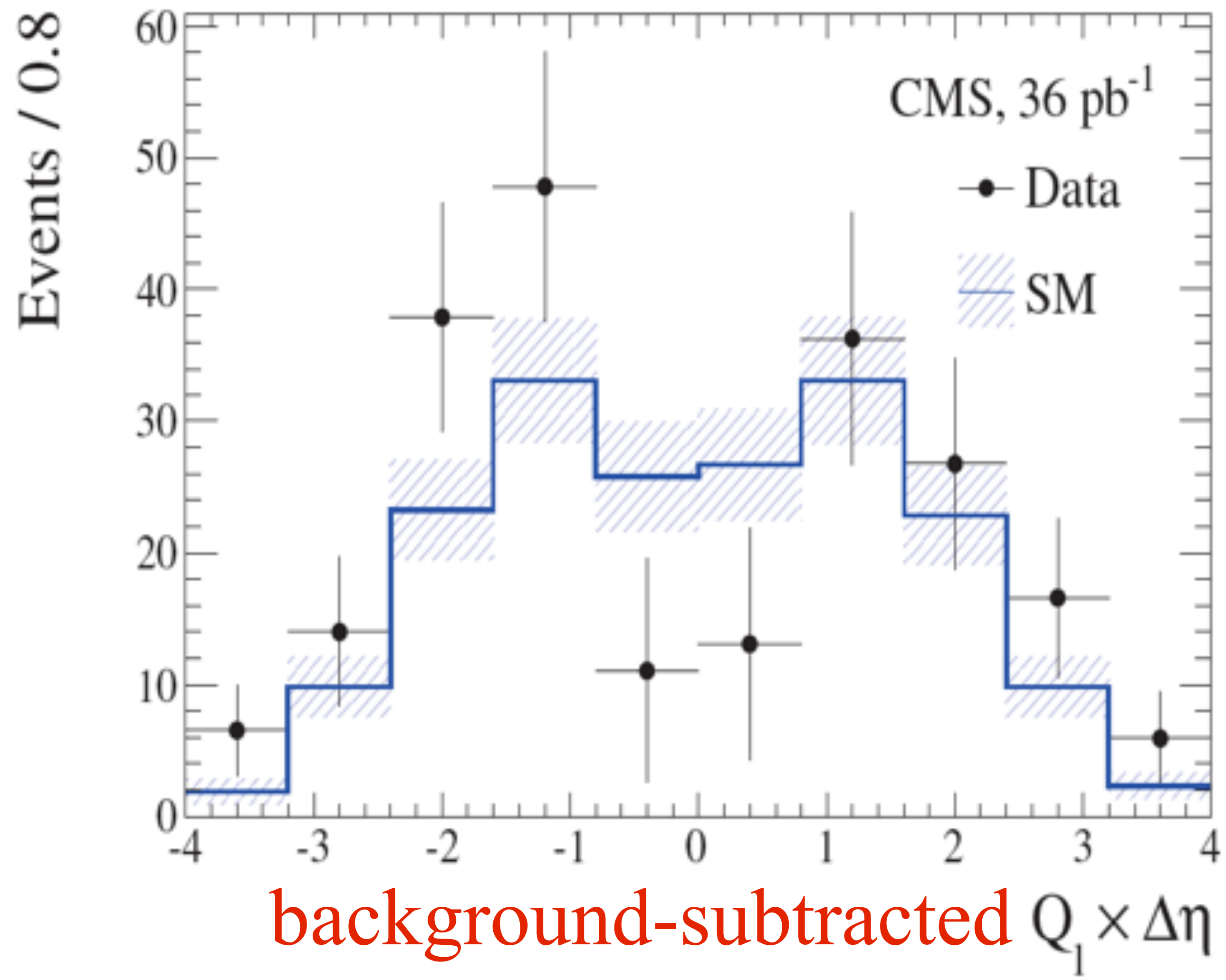
- Three main categories of systematic uncertainty
  - Acceptance, efficiency, and background estimation

	$W\gamma \to e\nu\gamma$	$W\gamma \to \mu\nu\gamma$	$Z\gamma \to ee\gamma$	$Z\gamma \to \mu\mu\gamma$
Source	Effect on $A \cdot \epsilon_{\mathrm{MC}}$			
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 $A \cdot \epsilon_{\mathrm{MC}}$	6.1%	5.2%	5.8%	4.3%
	Effect on $\epsilon_{\mathrm{data}}/\epsilon_{\mathrm{MC}}$			
Trigger	0.1%	0.5%	$< 0.1\%$	$< 0.1\%$
Lepton identification and isolation	0.8%	0.3%	1.1%	1.0%
$E_{\mathrm{T}}^{\mathrm{miss}}$ selection	0.7%	1.0%	N/A	N/A
Photon identification and isolation	1.2%	1.5%	1.0%	1.0%
Total uncertainty on $\epsilon_{\mathrm{data}}/\epsilon_{\mathrm{MC}}$	1.6%	1.9%	1.6%	1.5%
Background	6.3%	6.4%	9.3%	11.4%

Radiation Amplitude Zero: Wγ

- 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
- Anomalous Wγ production can result in a flat distribution
- 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



aTGC limits on WWγ

- The direct comparison between LHC and Tevatron is difficult because we are using different normalization of couplings

	ATLAS $\Lambda = \infty$ 1 fb^{-1} (arXiv:1205.2531)	CMS $\Lambda = \infty$ 36 pb^{-1} (Phys. Lett. B 701, 535)	CDF $\Lambda = 1.5$ TeV 200 pb^{-1} (Phys. Rev. D76, 111103)	D0 $\Lambda = 2$ TeV 4.2 fb^{-1} (Phys. Rev. Lett. 107, 241803)
$\Delta\kappa_\gamma$	[-0.33, 0.37]	[-1.11, 1.04]		[-0.4, 0.4]
λ_γ	[-0.060, 0.060]	[-0.18, 0.17]		[-0.08, 0.07]

aTGC limits on ZZγ/Zγγ

- The direct comparison between LHC and Tevatron is difficult because we are using different normalization of couplings

	ATLAS $\Lambda = \infty$ 1 fb^{-1} (arXiv:1205.2531)	CMS $\Lambda = \infty$ 1 fb^{-1} (Phys. Lett. B 701, 535)	CDF Λ = 1.5 TeV 5.1 fb^{-1} (Phys. Rev. Lett.107:051802)	D0 Λ = 1.5 TeV 6.2 fb^{-1} (Phys. Rev. D 85, 052001)
h_3^Z	[-0.022, 0.026]	[-0.05, 0.06]	[-0.020, 0.021]	[-0.026, 0.026]
h_4^Z	[-0.00022, 0.00021]	[-0.0005, 0.0005]	[-0.0009, 0.0009]	[0.0013, 0.0013]
h_3^γ	[-0.028, 0.027]	[-0.07, 0.07]	[-0.022, 0.020]	[-0.027, 0.027]
h_4^γ	[-0.00021, 0.00021]	[-0.0005, 0.0006]	[-0.0008, 0.0008]	[-0.0014, 0.0014]