Production of W,Z bosons in association with photons at the LHC

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Outline:

- *Motivation.*

- *Production Cross-Section Measurements*
  - *Event Selections*
  - *Data-Driven Methods*
  - *Photon criteria efficiency*
  - *Differential cross-section results.*

- *Search for Anomalous Triple Gauge Couplings* in *Wγ and Zγ*

- *Summary*

Publics results :

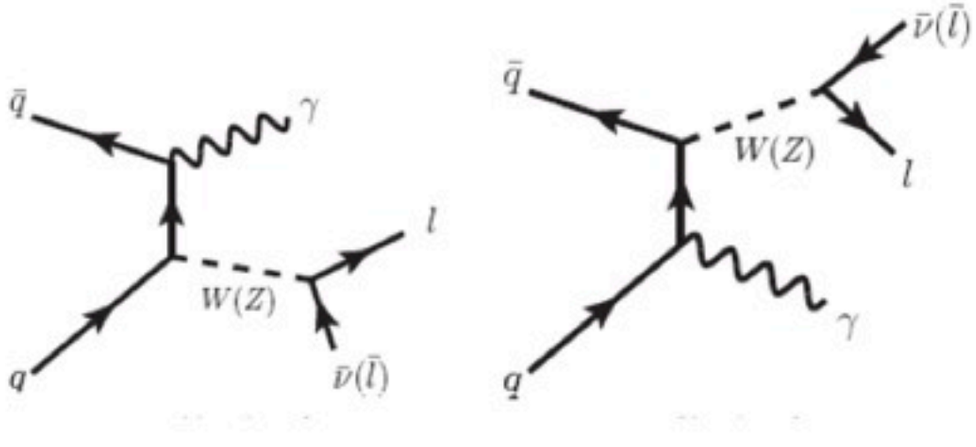
CMS: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEWK11009
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP12020

ATLAS: http://arxiv.org/pdf/1302.1283.pdf

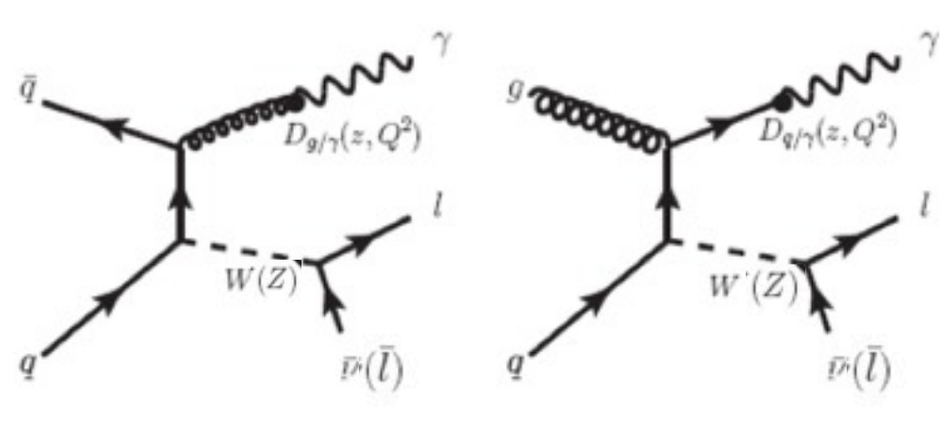
EW bosons + direct photons:

- *signal photon* is composed of "*direct (of hard scatter)*" and *fragmentation*.

direct production component:



fragmentation production component:



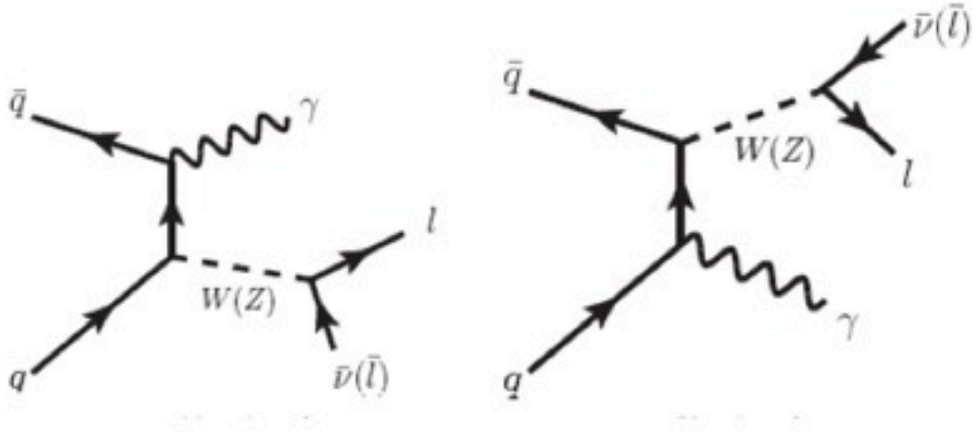
- Physics interest :

- *test of perturbative QCD*
- *Highest cross sections among all diboson processes.*
- *probing the WWγ TGC*
- *probing the existence of ZZγ and Zγγ*
  (forbidden at tree level in the Standard Model)
- *main background in Wγ/Zγ resonance searches (Higgs, LSTC)*

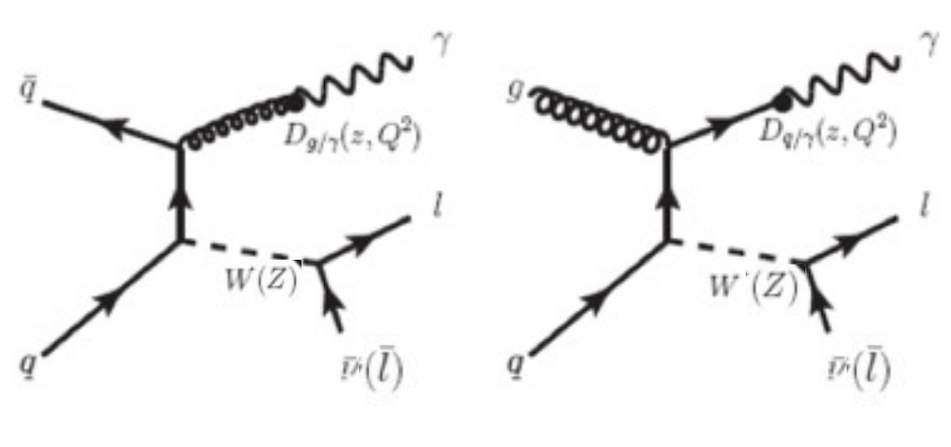
EW bosons + direct photons:

- *signal photon* is composed of "*direct (of hard scatter)*" and *fragmentation*.

direct production component:



fragmentation production component:



- Background for this analyses :

- **Wγ** : *W+jets, γ+jets, Z+jets, ttbar, Single top and Dibosons.*
- **Zγ** : *Z+jets, ttbar and Dibosons.*

- Background are estimated by using Data-driven techniques

Cross section measurements ingredients:

The measurement of the cross section is given canonically by the formula:

$$\sigma = \frac{N_{\mathrm{sig}}}{A_{\ell\nu\gamma(\ell\ell\gamma)} \cdot \epsilon \cdot \mathcal{L}}$$

- N_{sig} : *is the number of observed signal events*
- A : *is the geometric and kinematic acceptance*
- ϵ : *is the selection efficiency for events in the acceptance*
- $\mathcal{L}$: *is the integrated luminosity (~5 fb^{-1} with 7 TeV data)*

Event selections:

$W+\gamma$ $\qquad$ $Z+\gamma$

- **High p_T good identified and isolated leptons**
- **Applied cut in the invariant (transverse) mass**

- High MET cut
- Veto event with second high quality lepton.
- *Z* veto for *e* channel: *Mass window cut*

- Large MET cut (*invisible channel*)
- Two opposite charged leptons

- **Good quality and isolated photon high E_T photons**
- ***$\Delta R(lepton,\gamma) > 0.7$ (Suppress FSR)***

- ***High p_T Jets are selected***

Background Estimations:

After to have selected the *Z(W)* boson, background are computed respect to the photon signal candidate (in both experiments, *ATLAS* and *CMS*).

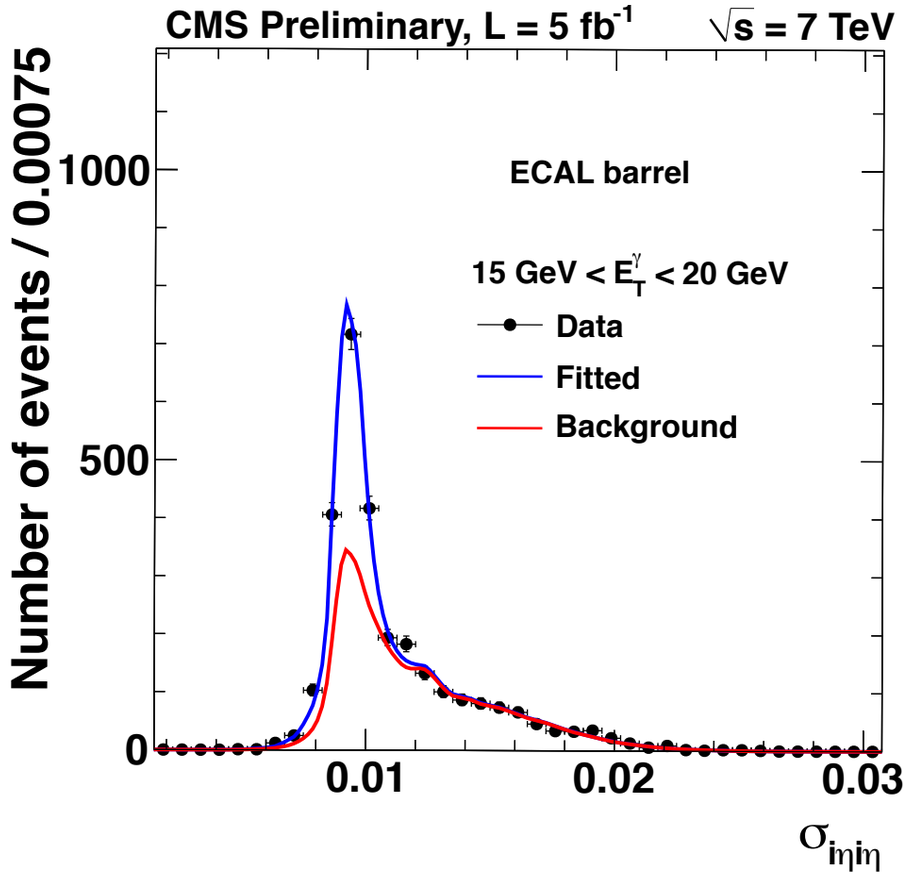
CMS:

$\sigma_{i\eta i\eta}$: quantifies the spread along η of the energy deposits in the central part of super-cluster.

$$\sigma^2_{i\eta i\eta} = \frac{\sum^{5\times5} w_i \left(\eta_i - \bar{\eta}_{5\times5}\right)^2}{\sum_i^{5\times5} w_i}$$

$$, w_i = \max\left(0, 4.7 + \ln\frac{E_i}{E_{5\times5}}\right)$$

Wγ analysis



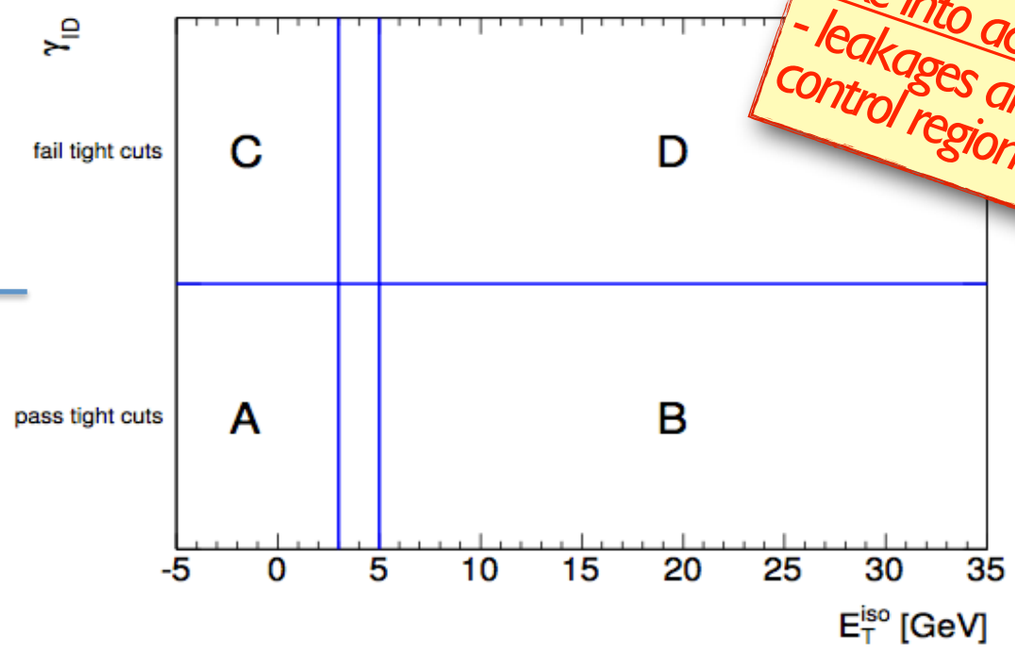
- *The signal shape from MC validated with data.*
- *The background template were made from jet-enriched data. (as a function of the track isolation energy)*

Background Estimations:

After to have selected the *Z(W)* boson, background are computed respect to the photon signal candidate.

ATLAS:

Two dimensional sideband method



take into account:
- leakages and correlations between control regions

We need to define the different control regions

A→ Signal Region : quality tight + Isolated (TopoIsol < 6 GeV)
B→ Background : quality tight + Non-Isolated (TopoIsol > 7 GeV)
C→ Background : quality Non-tight + Isolated (TopoIsol < 6 GeV)
D→ Background : quality Non-tight + Non-Isolated (TopoIsol > 7 GeV)

Z(W)+jets, γ+jets ***background estimations***

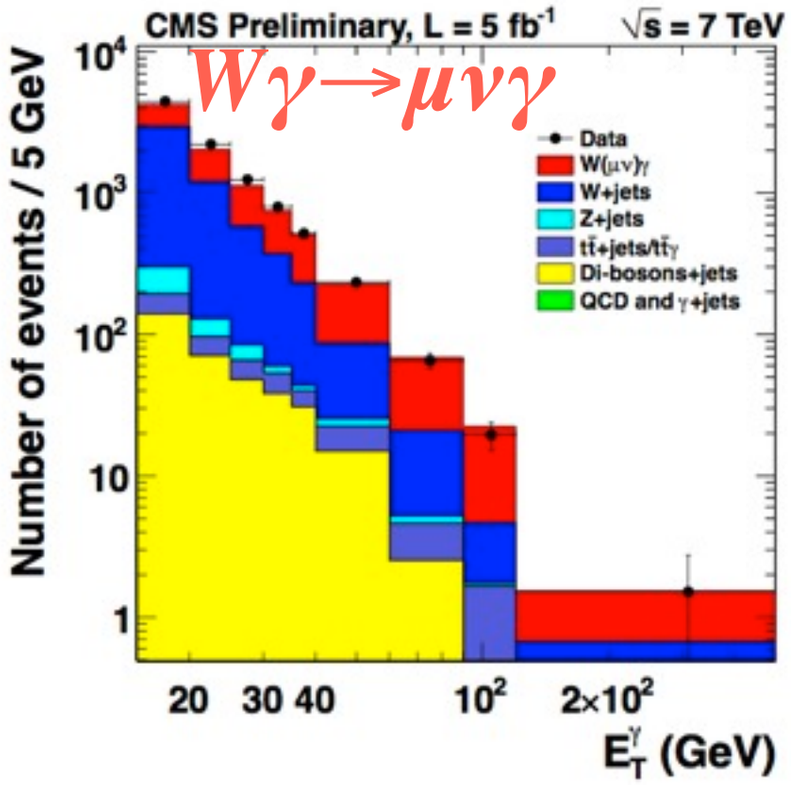
Purity definition:

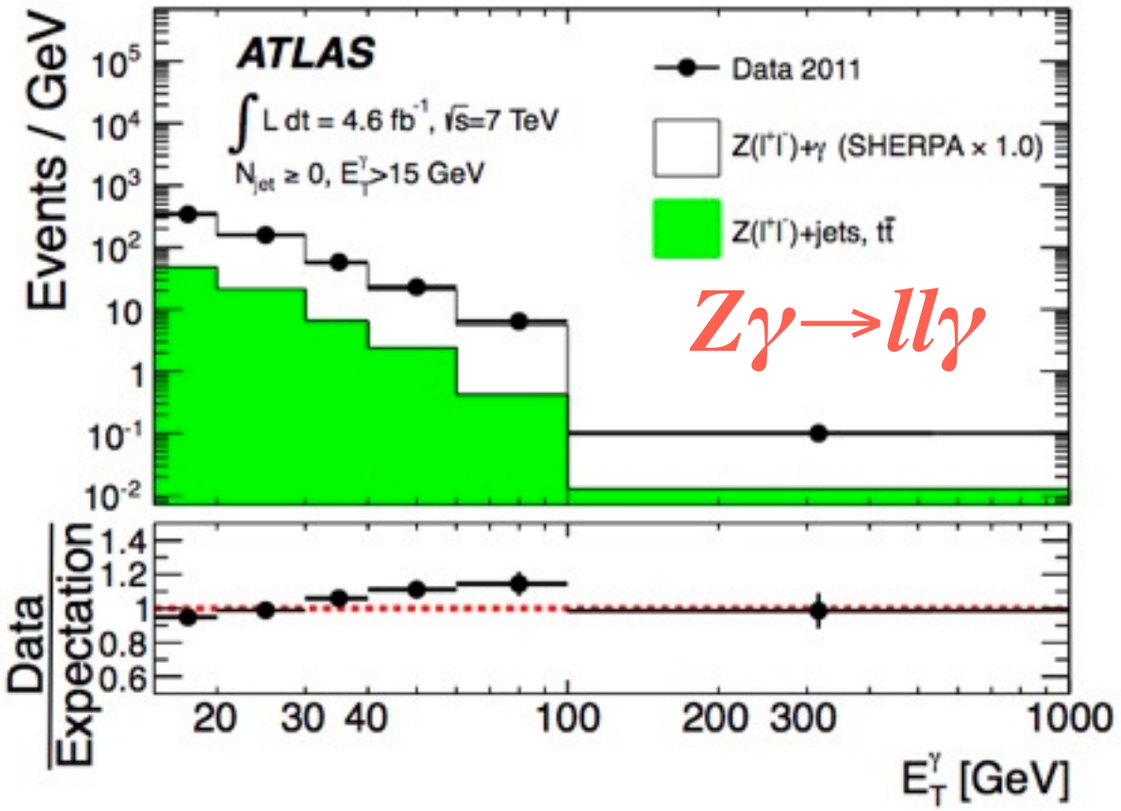
$$P = \frac{N_A - N_A^{Z/W/\gamma jets} - N_A^{EW}}{N_A}$$

N_A = *Observed data in signal region*

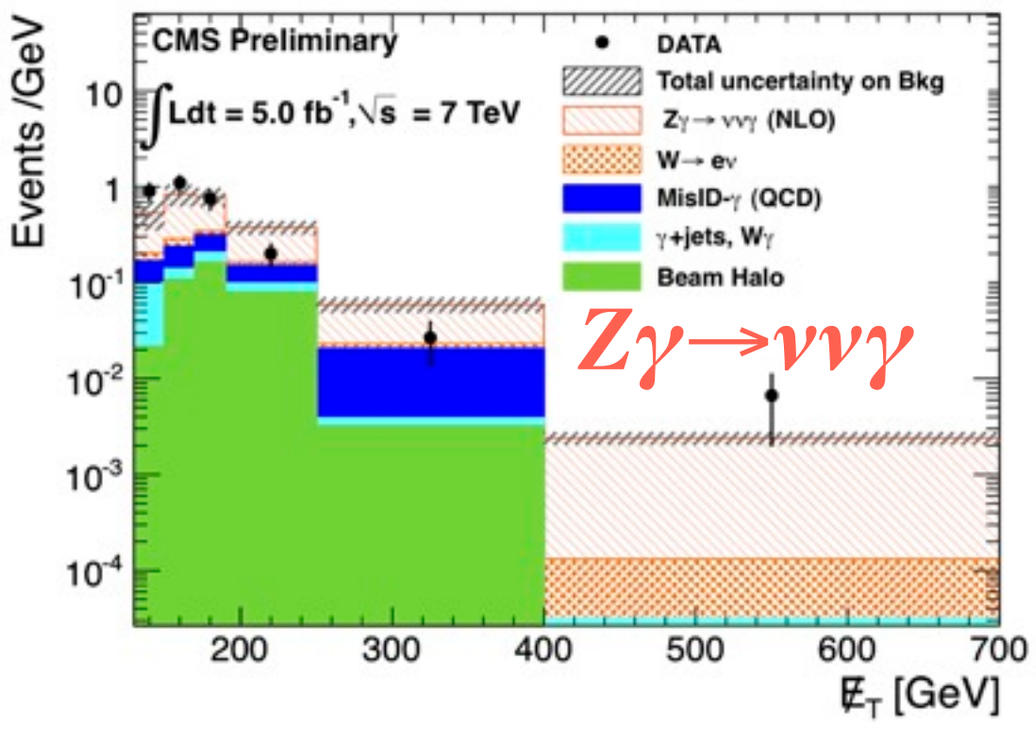
Data/MC comparison plots:

photon E_T distributions:





MET distributions:



- Good Data/MC agreement in photon E_T distributions.

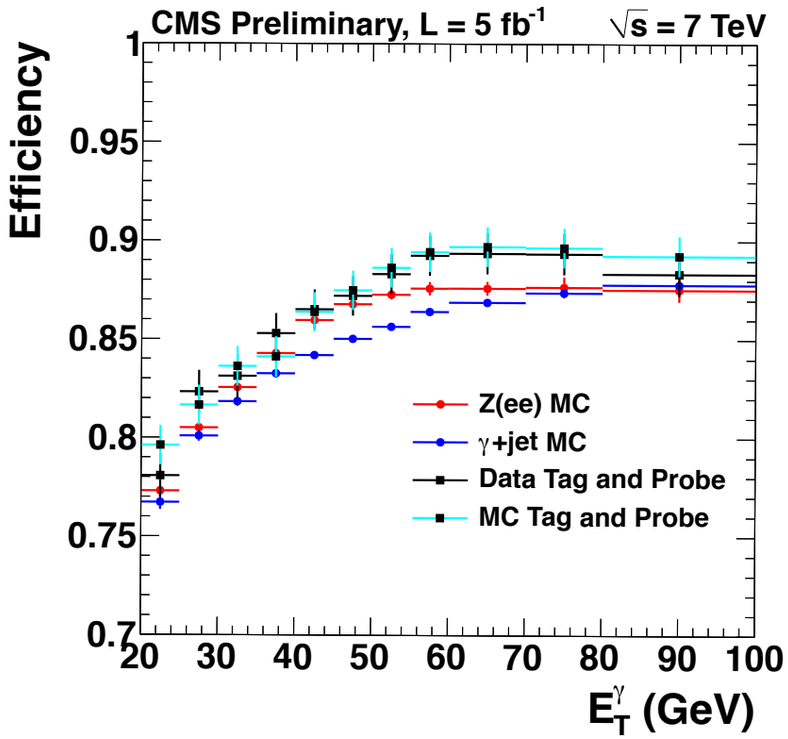
- Also nice agreement, in other key variables. For example, $M_{ll\gamma}$ and M_T .

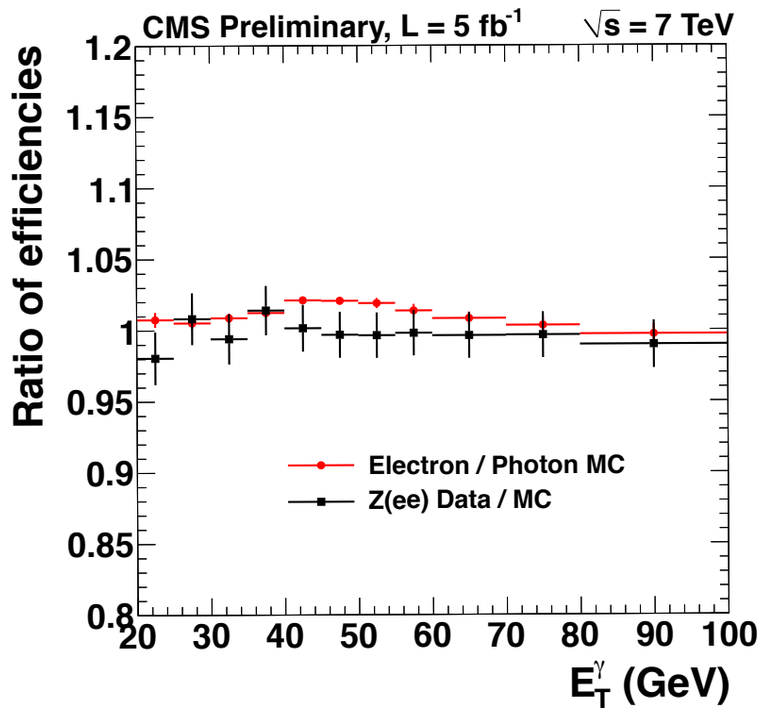
Photon criteria efficiency:

CMS:

- *Exploit the similarity between photons and electrons.*

  - Use tag-and-probe technique with $Z \rightarrow ee$ events.





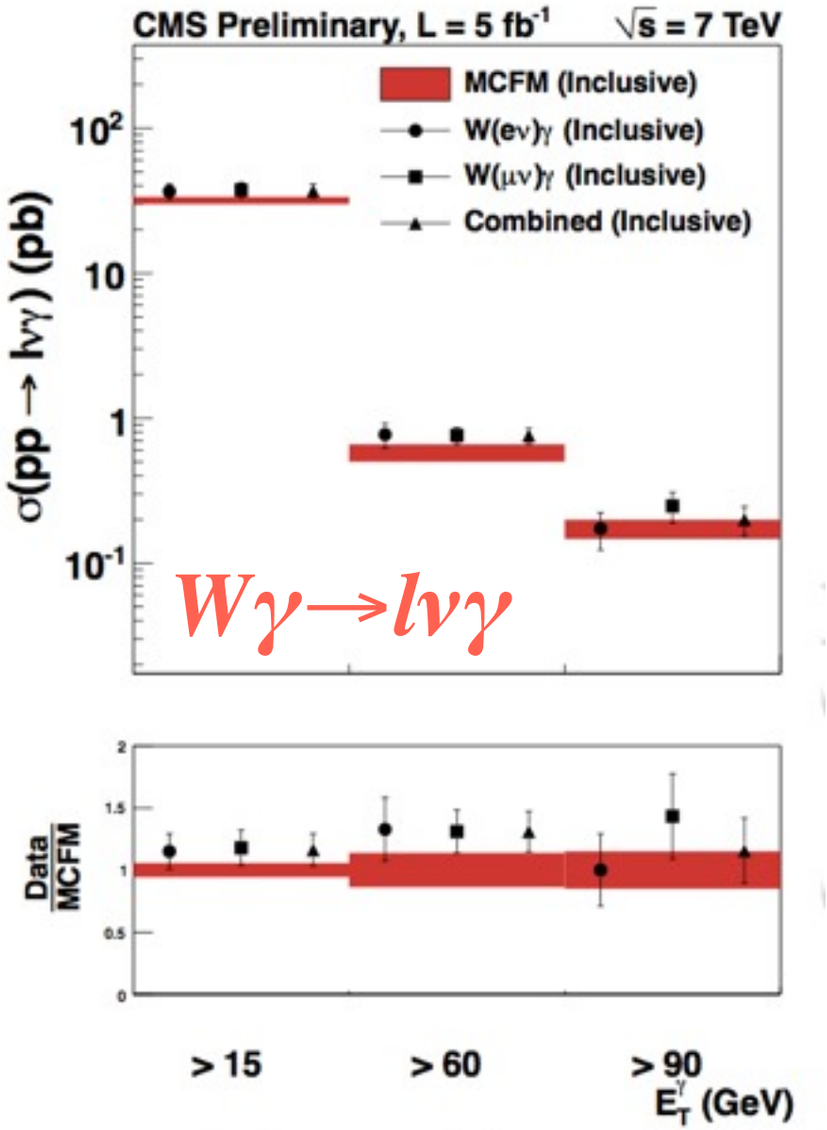
ATLAS:

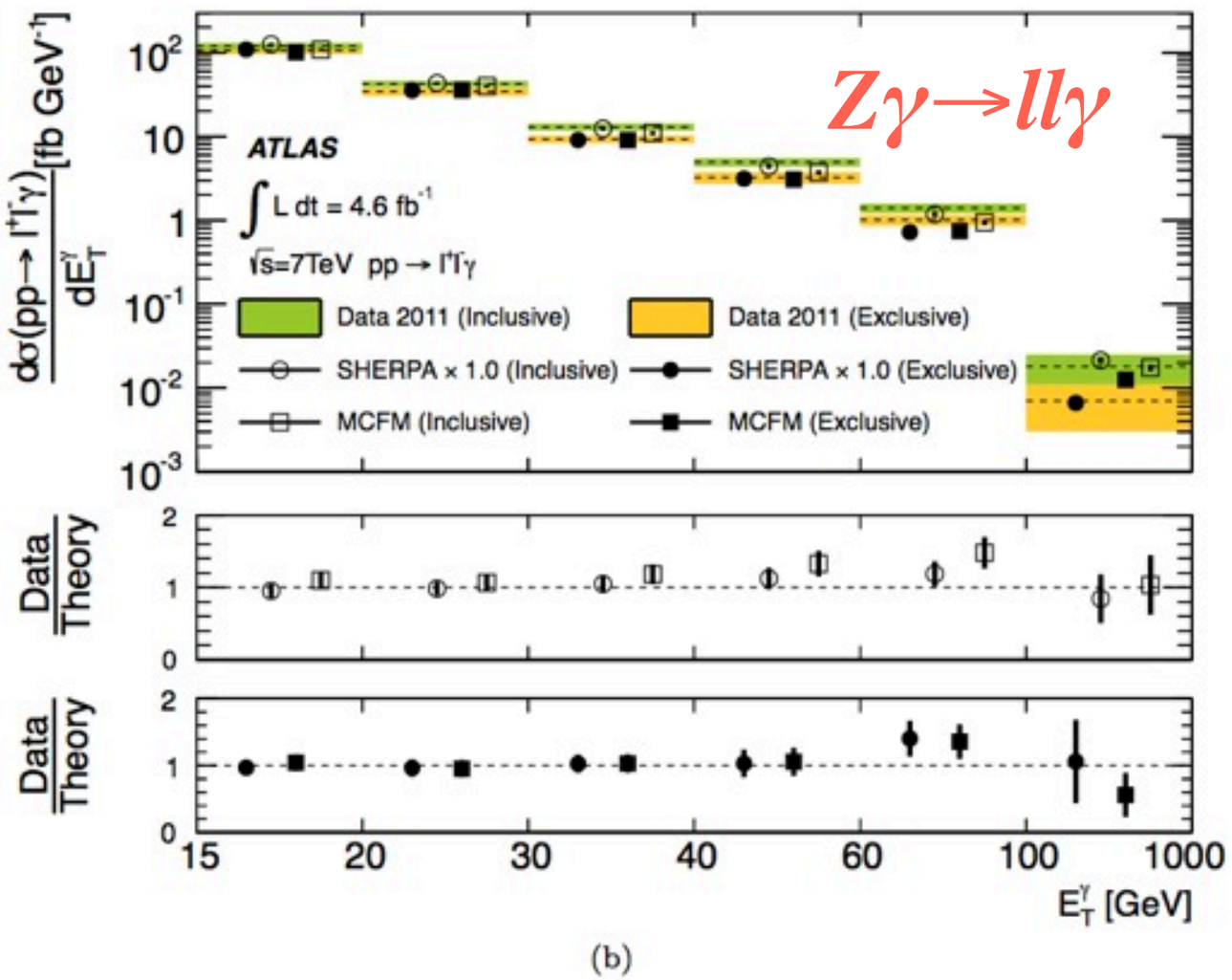
- Using signal MC samples. Shower shape distributions are corrected to account small discrepancies between data and simulation.

- bigger than ~50% at E_T [15-20] GeV and around 90% at E_T [40-60] GeV

- Systematics are the difference between corrected nominal and efficiency from pure photon sample from radiative Z decays in data.

Production cross section measurements:





- *Inclusive cross sections above the theory (MCFM NLO) Wγ*
- *Fair agreement for Zγ*
- *Cross sections are compatibles between the two experiments at high E_T photon . (Equivalent selection and bin size)*

Production cross section measurements:

$Z\gamma \rightarrow \nu\nu\gamma$

CMS: photons with transverse energy of 145 GeV with in the pseudorapidity $|\eta| < 1.4$

21.3 ± 4.2 (stat.) ± 4.3 (syst.) ± 0.5 (lumi.) fb

theoretical prediction from **BAUR** : *21.9 ± 1.1 fb*

ATLAS: photons with transverse energy of 90 GeV

0.133 ± 0.013 (stat.) ± 0.020 (syst.) ± 0.005 (lumi.) pb

theoretical prediction from **MCFM** : *0.156 ± 0.012 pb*

Systematics in cross section measurements:

ATLAS:

- *Photon identification uncertainty is found around* ***6%*** *for all Vg measurements.*

- *Isolation efficiency is found to be less than* ***3%****.*

- *ABCD method less than* ***9%****.*

- *Jet energy scale and Jet energy resolution:*
  - *Exclusive* ***lvγ*** *smaller than* ***4%****.*
  - *Exclusive* ***llγ*** *and* ***vvγ*** *smaller than* ***3%****.*

CMS:

- *Muon p_T scale, Electron and Photon energy scale ~**3%** in the signal yield for all Vg measurements.*

- *Acceptance and efficiencies ~**5.5%** and ~**1.4%** for Wγ and Zγ, respectively.*

- *Template method ~**8%** and ~**5%** for Wγ and Zγ, respectively.*

Anomalous couplings:

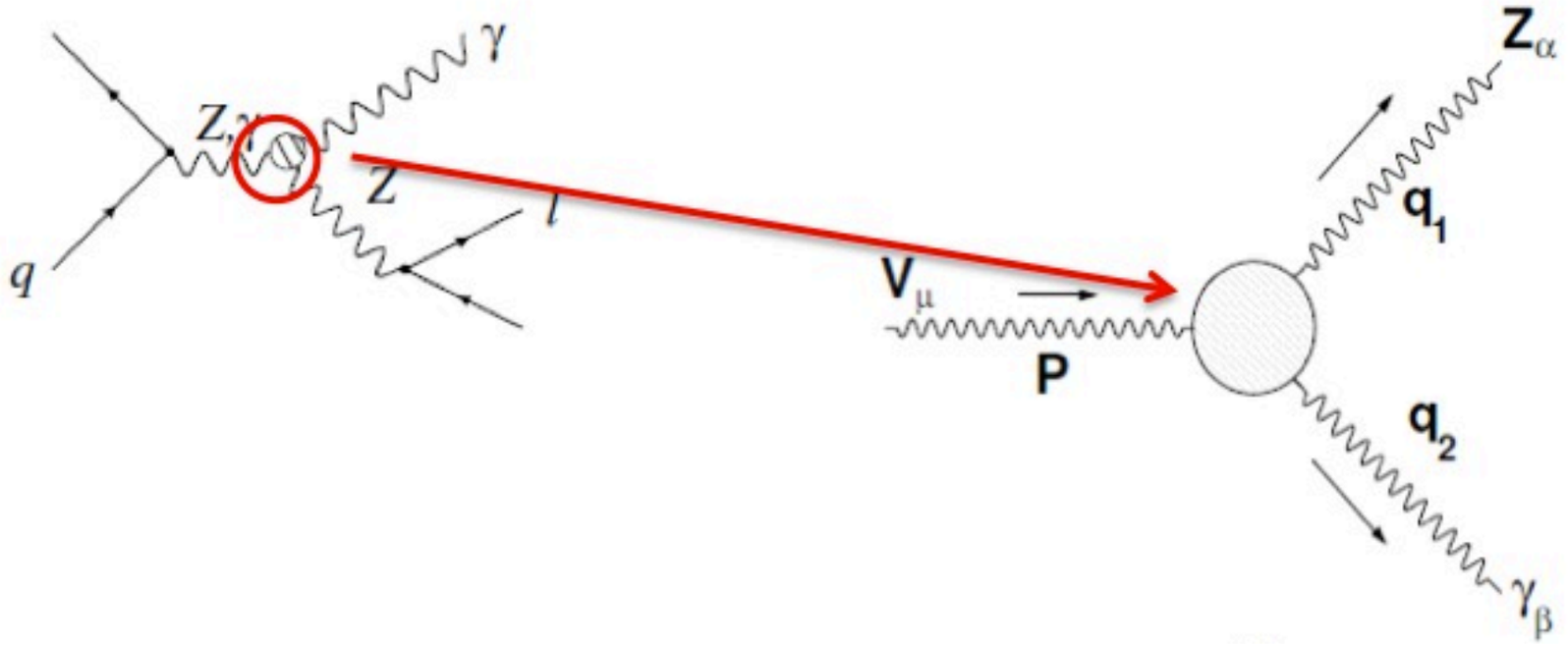
Anomalous Triple Gauge Couplings (aTGC):

- The triple gauge couplings (through ZZγ and Zγγ vertex) in Zγ process vanish in the SM.
  - *Contributions form anomalous couplings will increase the Zγ x-secs. and yield photons of higher energy than in the SM process.*

$$\Gamma^{\alpha\beta\mu}_{ZZ\gamma}(q_1,q_2,P) = \frac{P^2-q_1^2}{m_Z^2}(h_1^Z(q_2^\mu g^{\alpha\beta}-q_2^\alpha g^{\mu\beta})+$$

$$\frac{h_2^Z}{m_Z^2}P^\alpha[(P\cdot q_2)g^{\mu\beta}-q_2^\mu P^\beta]+$$

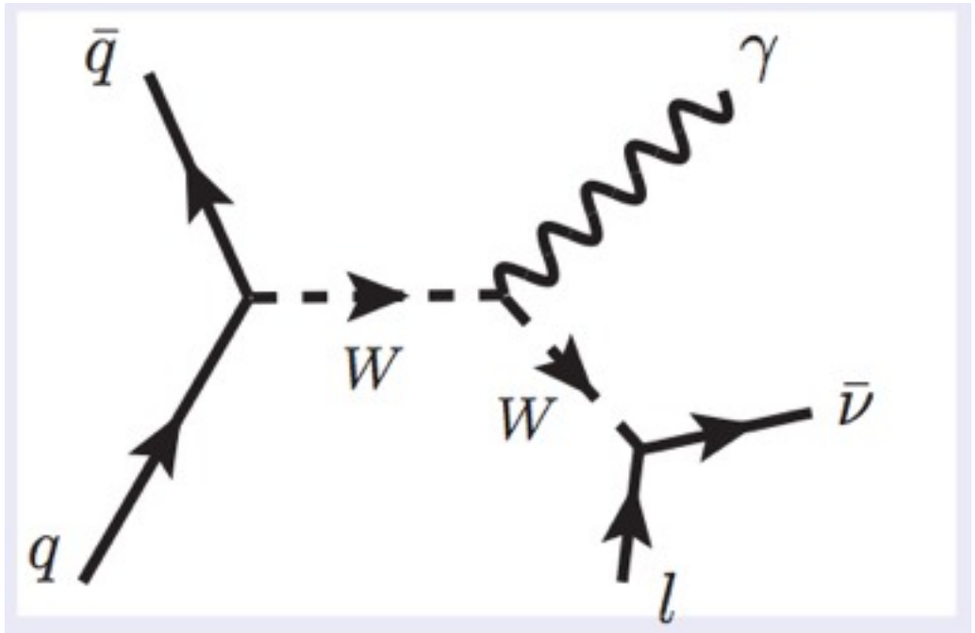
$$h_3^Z\epsilon^{\mu\alpha\beta\rho}q_{2\rho}+\frac{h_4^Z}{m_Z^2}P^\alpha\epsilon^{\mu\beta\rho\sigma}P_\rho q_{2\sigma}),$$



- By assuming CP conservation, $h_3^{Z/\gamma}$ and $h_4^{Z/\gamma}$ are chosen as aTGC parameters.

Triple Gauge Couplings (TGC):

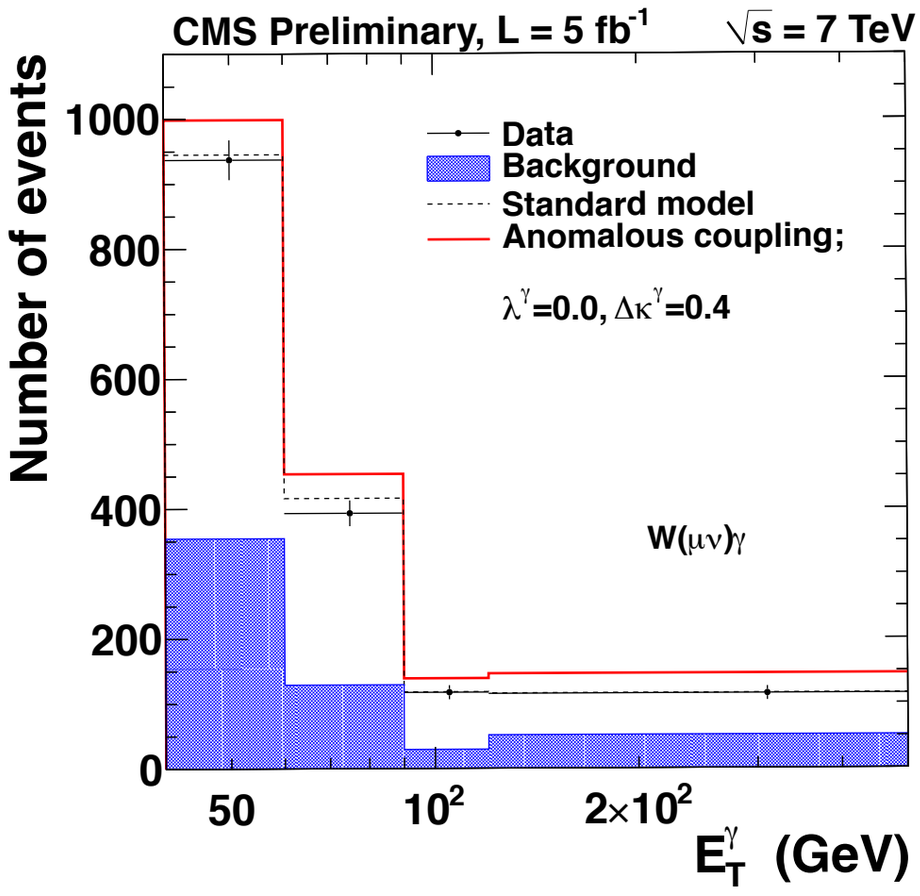
- The triple gauge couplings (through WWγ vertex) in Wγ process vanish in the SM.
  - *Contributions form anomalous couplings will increase the Wγ x-secs. and yield photons of higher energy than in the SM process.*



$$\frac{\mathcal{L}_{WWV}}{g_{WWV}} = ig_1^V (W^\dagger_{\mu\nu} W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu}) + i\kappa_V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{i\lambda_V}{M_W^2} W^\dagger_{\delta\mu} W^\mu_\nu V^{\nu\delta}$$

- Assuming C and P conservation only two independent parameters remain $\Delta\kappa_\gamma = \kappa_\gamma - 1$ and λ_γ.

Limits on Anomalous Couplings :



•CMS results:

	$\Delta\kappa_\gamma$	λ_γ
$W\gamma \to \ell\nu\gamma$	[-0.38, 0.29]	[-0.050, 0.037]

•ATLAS results:

	Measured	Expected
processes	$pp \to \ell\nu\gamma$	
Λ	∞	∞
$\Delta\kappa_\gamma$	$(-0.41, 0.46)$	$(-0.38, 0.43)$
λ_γ	$(-0.065, 0.061)$	$(-0.060, 0.056)$

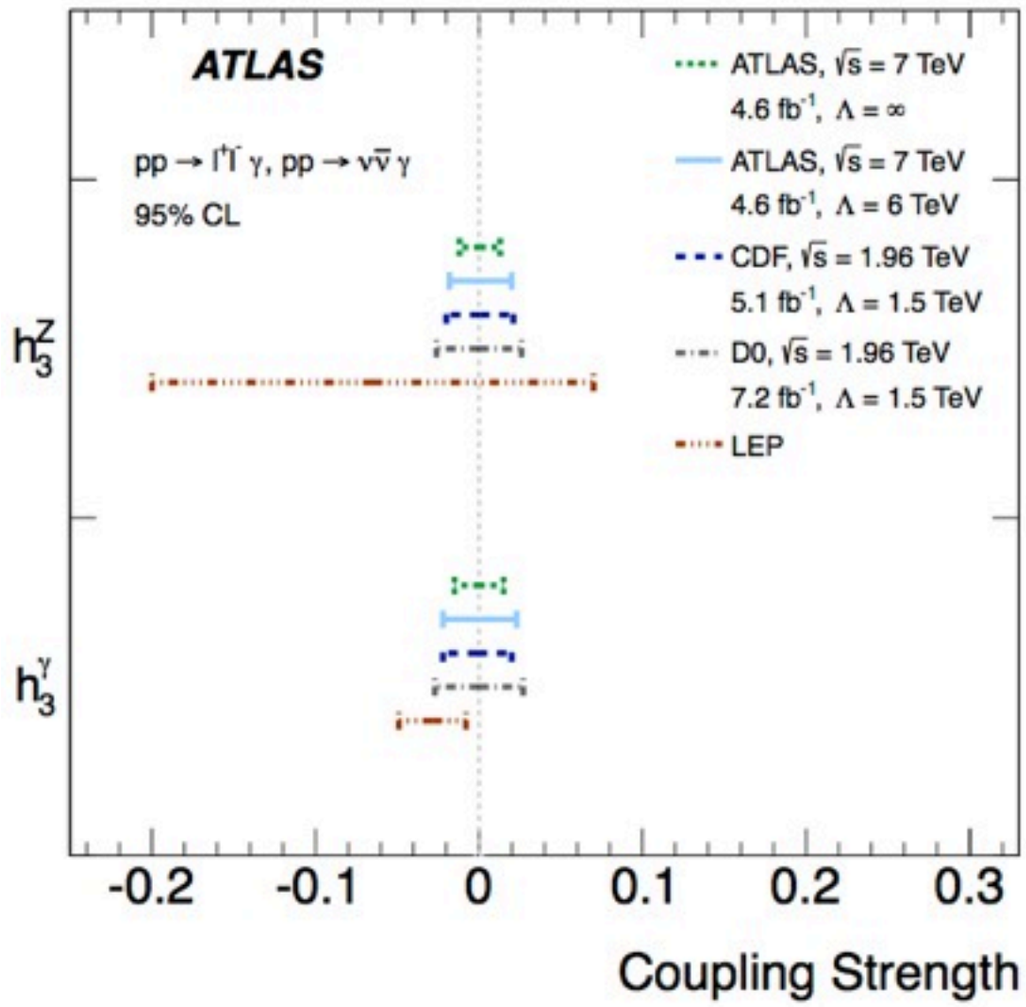
limits on aTGCs at 95% C.L. for Wγ

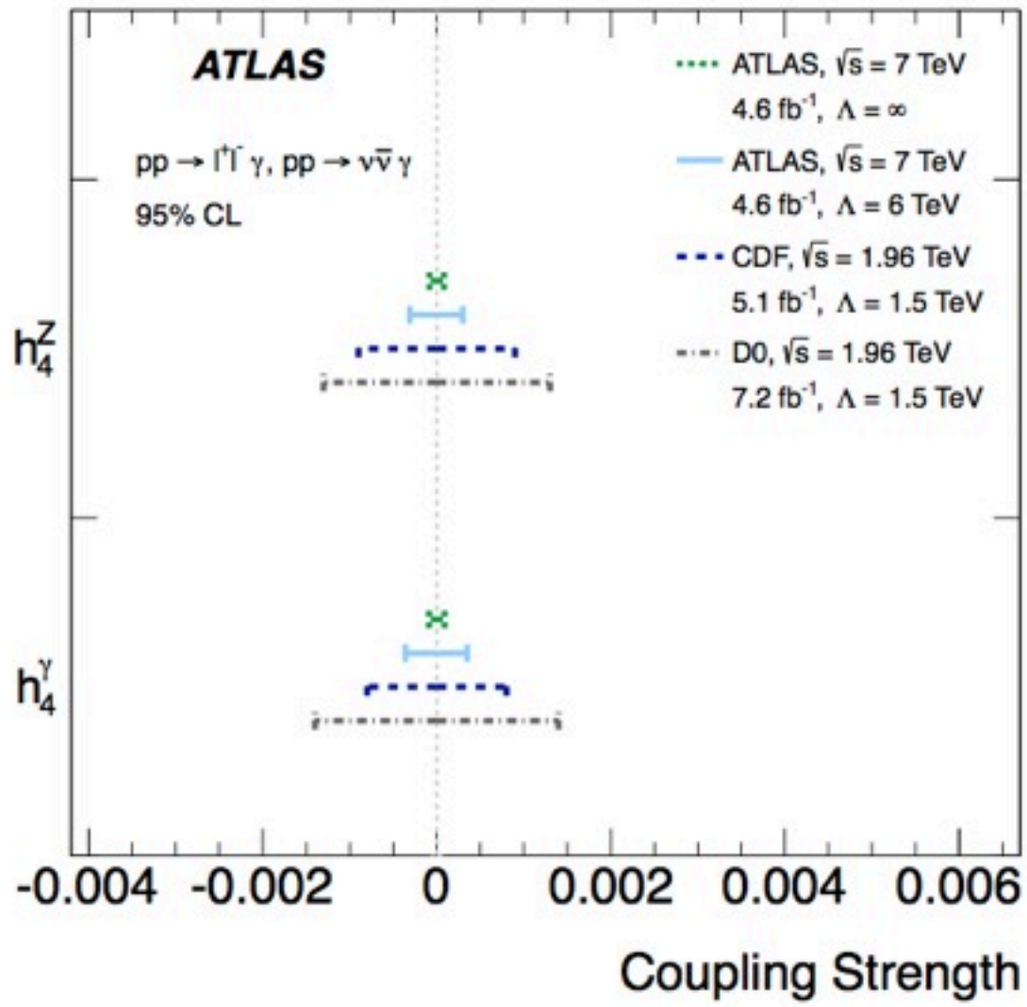
• The limits on a given aTGC parameter are extracted from a Frequentist Profile Likelihood test

• Measurements performed in the last exclusive E_T photon bin [100GeV - 1TeV] . Better sensibility .

•No deviations from SM predictions observed.

Limits on Anomalous Couplings :





- No deviations from SM predictions observed.

- Limits are comparable to LEP and Tevatron results, with different form factors.

- ATLAS and CMS results are compatibles.

Summary:

- Production cross section measurements performed for $W(\nu e, \nu\mu)\gamma$ and $Z(e\,e, \mu\,\mu, \nu\,\nu)\gamma$ using ~5fb^{-1} of collected data with the ATLAS and CMS detector.

- Differential cross sections agree with Standard Model predictions from multi leg MC generators.

- Exclusive measurements in $W\gamma$ and $Z\gamma$ are used to constraint aTGCs. No deviations from SM predictions observed.

- Compatible measurements in both collaborations.

Event selections (ATLAS):

$W+\gamma$ ⟵ PV, GRL .. ,single lepton trigger⟶(period) ⟶ $Z+\gamma$

- isolated good electron "tight++"
or isolated comb. muon p_T>25GeV
- $MET > 25$ GeV
- Transverse mass $M_T(l,MET)$>40GeV
- Veto event with second lepton:
  - *medium++ electron*
  - *combined muon* p_T>20GeV
- Z veto for e channel: $|M(e,\gamma)-M_Z|$>15GeV

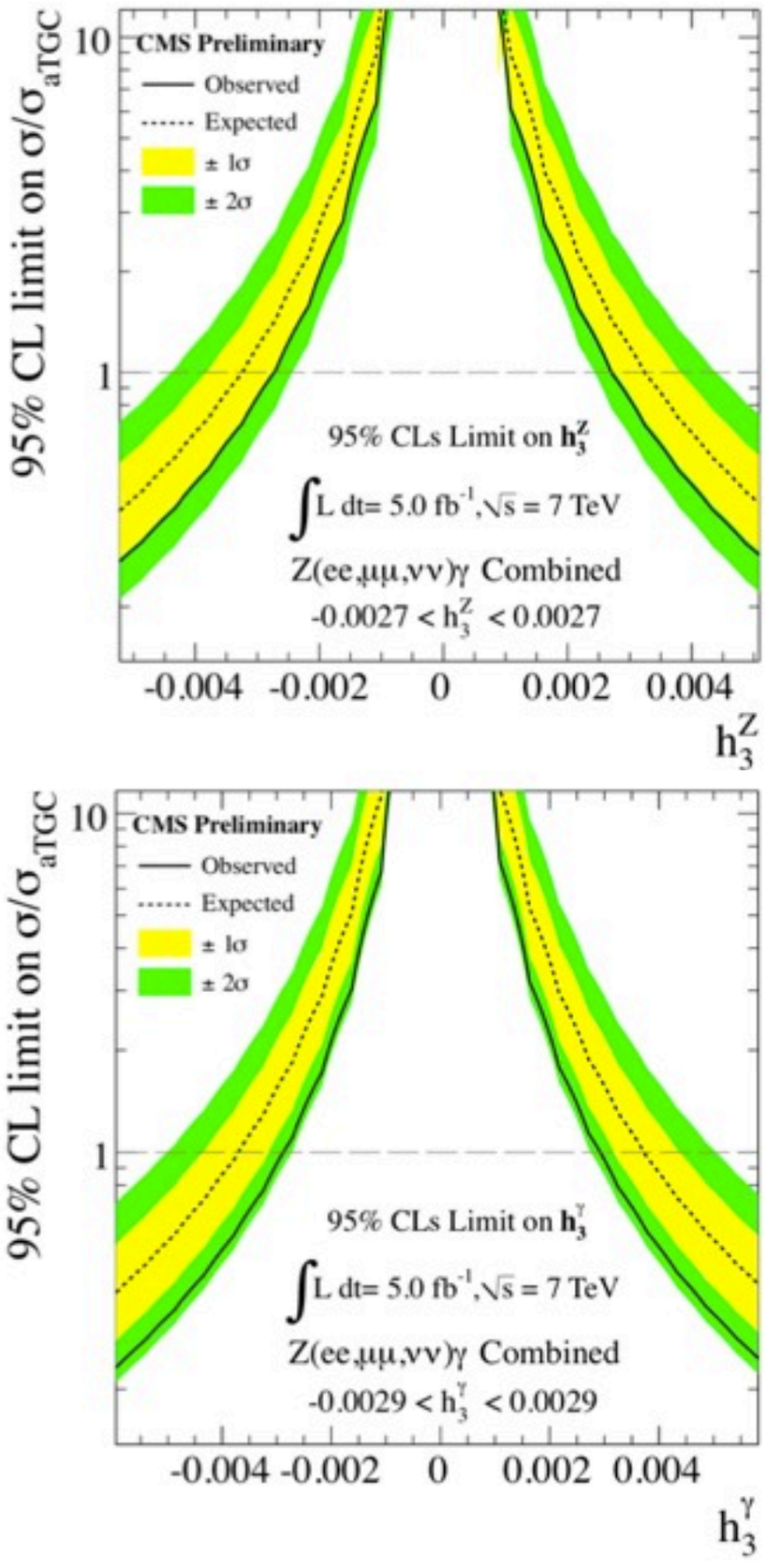
- isolated good electron "medium++"
or isolated comb. muon p_T>25GeV
- Two opposite charged leptons
- $M_{l^+l^-}$>40GeV

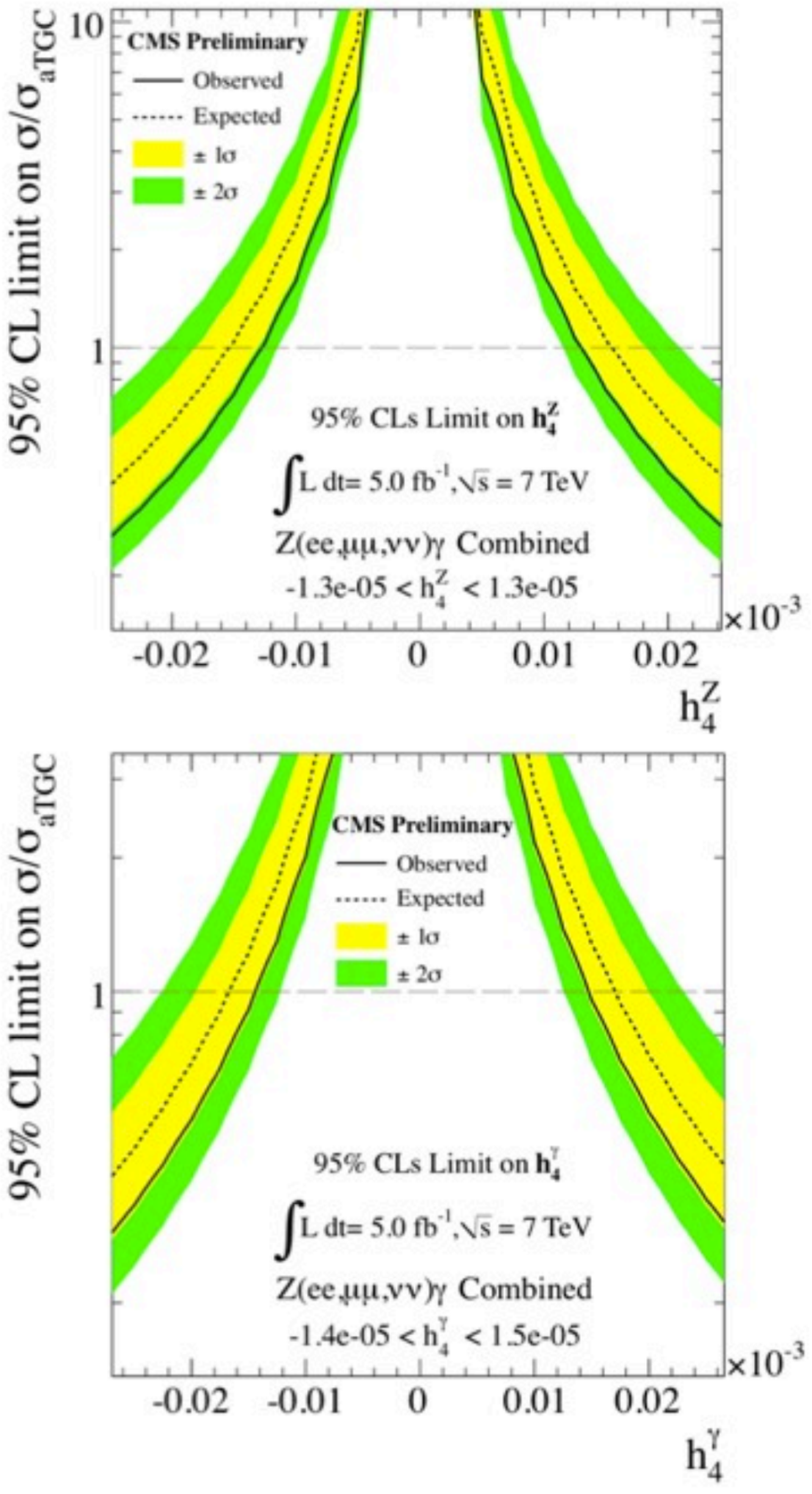
Tight photon, p_T>15GeV, $|\eta| < 2.37$ excl. crack region,
isolated $(E_T Cone30<6GeV)$ and $\Delta R(lepton,\gamma) > 0.7$

Jet Selection cuts(AntiKt4Topo)
p_T>30GeV, $|\eta|$<4.4 and $\Delta R(lepton/\gamma,jet) > 0.3$

to provide measurements in the following bins (differential measurements)
$N_{jet}\geq 0$, $N_{jet}=0$, E^{γ}_T :{15-20, 20-30, 30-40, 40-60, 60-100, 100-1000} GeV

ATGC CMS Zg:


CMS Preliminary
Observed
Expected
± 1σ
± 2σ
95% CL limit on σ/σ_aTGC
95% CLs Limit on h_3^Z
∫L dt= 5.0 fb^-1, √s = 7 TeV
Z(ee,μμ,νν)γ Combined
-0.0027 < h_3^Z < 0.0027
h_3^Z


CMS Preliminary
Observed
Expected
± 1σ
± 2σ
95% CL limit on σ/σ_aTGC
95% CLs Limit on h_4^Z
∫L dt= 5.0 fb^-1, √s = 7 TeV
Z(ee,μμ,νν)γ Combined
-1.3e-05 < h_4^Z < 1.3e-05
×10^-3
h_4^Z

CMS Preliminary
Observed
Expected
± 1σ
± 2σ
95% CL limit on σ/σ_aTGC
95% CLs Limit on h_3^γ
∫L dt= 5.0 fb^-1, √s = 7 TeV
Z(ee,μμ,νν)γ Combined
-0.0029 < h_3^γ < 0.0029
h_3^γ

CMS Preliminary
Observed
Expected
± 1σ
± 2σ
95% CL limit on σ/σ_aTGC
95% CLs Limit on h_4^γ
∫L dt= 5.0 fb^-1, √s = 7 TeV
Z(ee,μμ,νν)γ Combined
-1.4e-05 < h_4^γ < 1.5e-05
×10^-3
h_4^γ

ATGC ATLAS Wg: