Radiative Z decays in ATLAS and CMS

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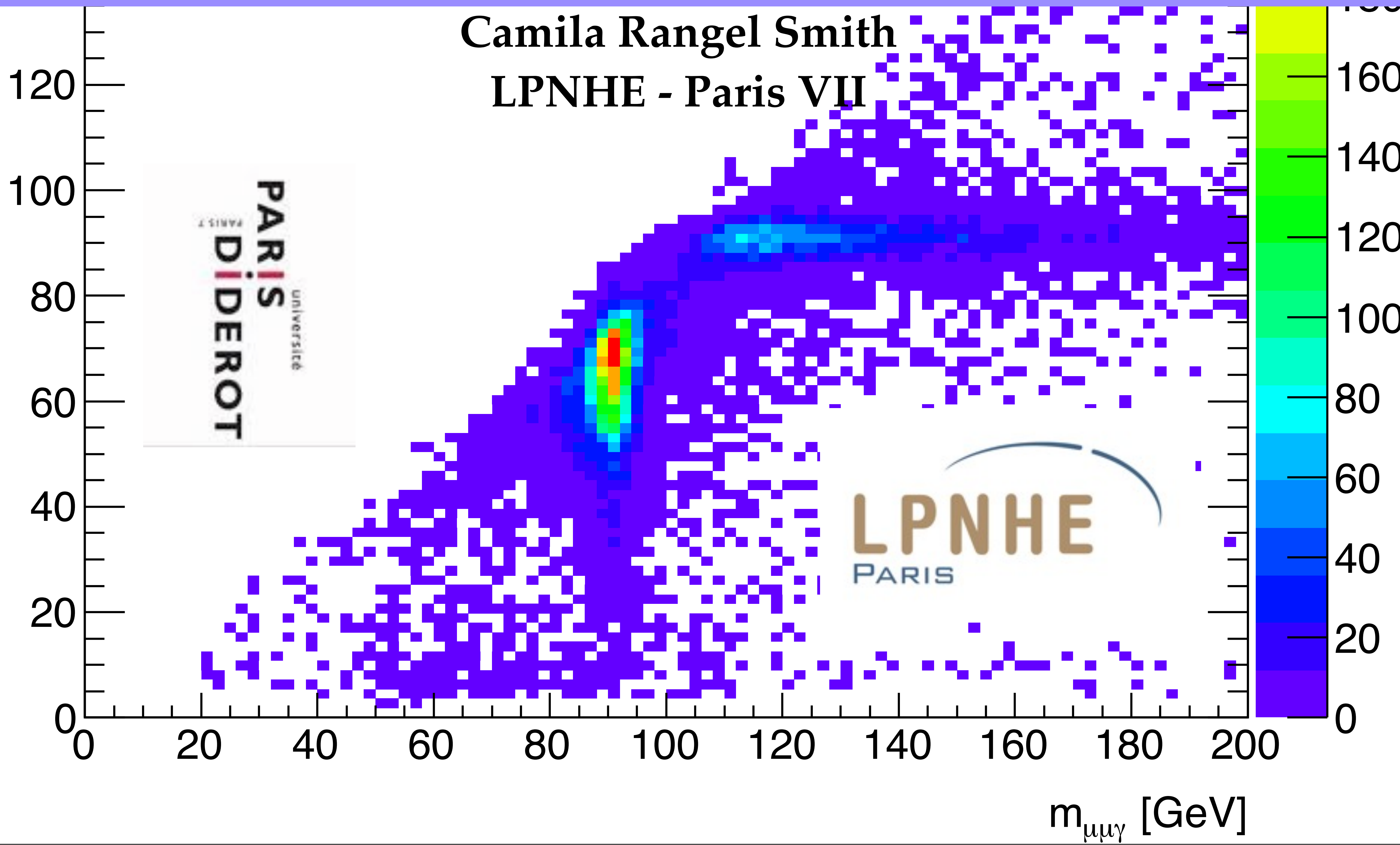
LPNHE - Paris VII



Topics of this talk:

Radiative Z decays are used both in physics and performance analysis:

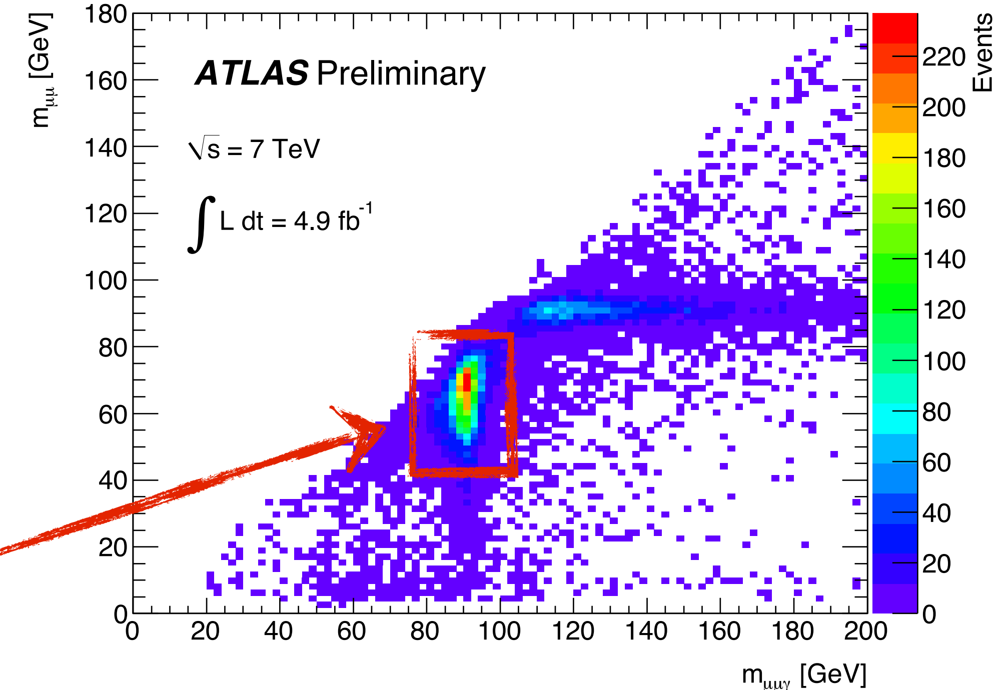
- Photon performance analyses with FSR Zγ:
  - Photon identification
  - Photon calibration
- Photon physics analysis:
  - SM Diboson Zγ Analysis (see H. Abreu's talk)
  - SM ISR Zγ as main background in the H-> Zγ analysis. This talk will show a glimpse of ATLAS and CMS results.

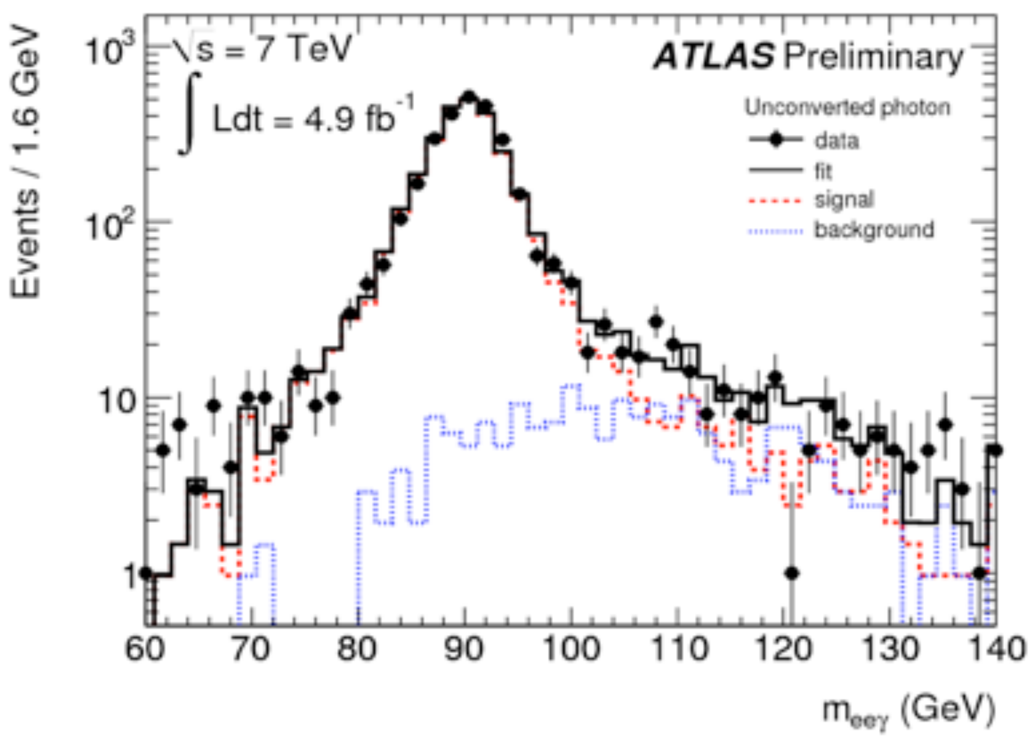
Photon performance with FSR Zγ

Photon performance with FSR Z decays

- Two opposite-charged leptons and an isolated photon.

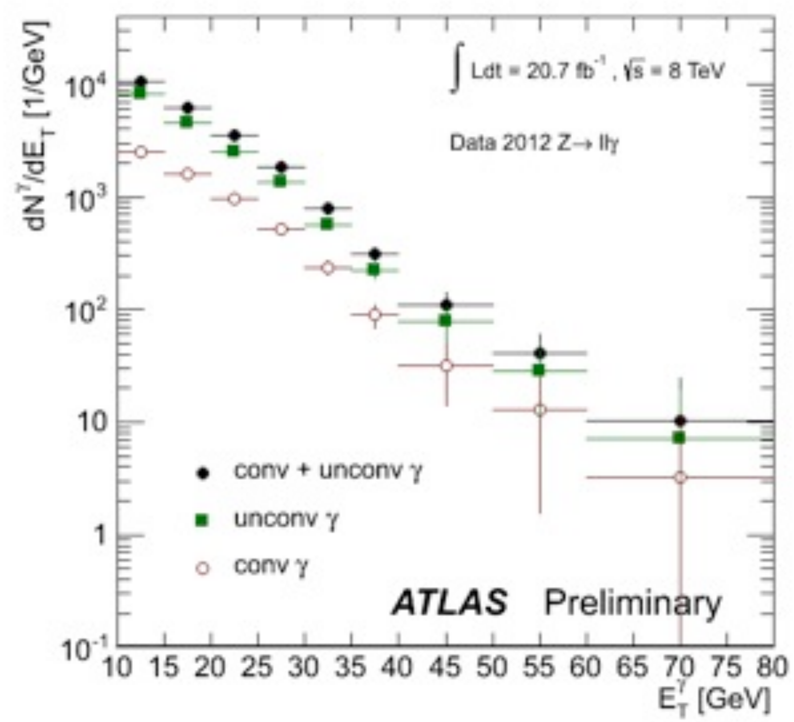
Three body invariant mass near to the Z mass, a rectangular cut applied to M_{ll}-$M_{ll\gamma}$ region.





The dataset is a high purity photon sample with a small contribution from Z+jets.

The photon sample is divided in unconverted photon and converted photons and cover the lower Et region.



Photon Identification efficiency

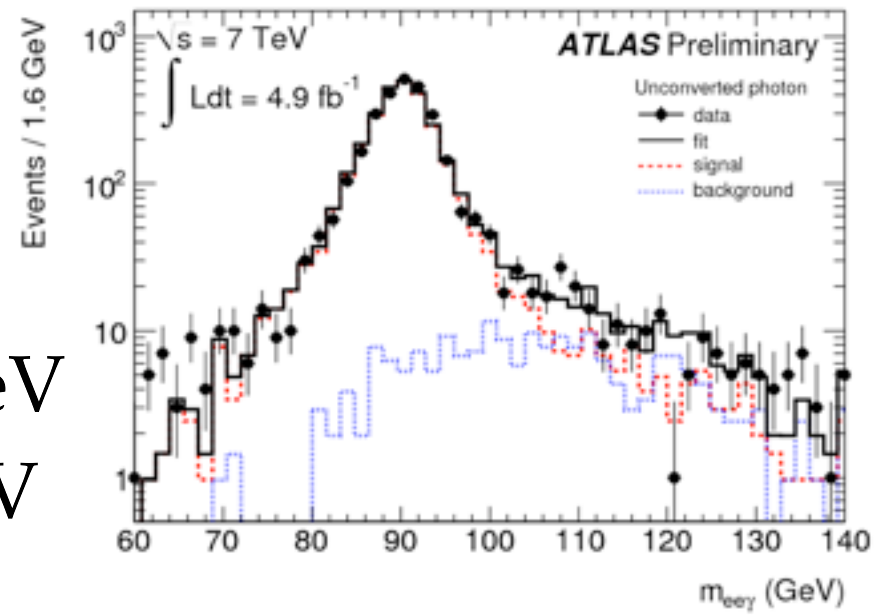
Event selection:

✓ $E_{t,photon}$ > 10 GeV (15 GeV in 2011)

✓ $|\eta_{photon}|$ <2.4

✓ 80 GeV < $M_{ll\gamma}$ < 96 GeV

✓ 40 GeV < M_{ll} < 83 GeV



Selected events (Before PID)	$Z\rightarrow ee\gamma$	$Z\rightarrow \mu\mu\gamma$
2011	3538	8700
2012	44026	73823

Purity estimation (Template fit):

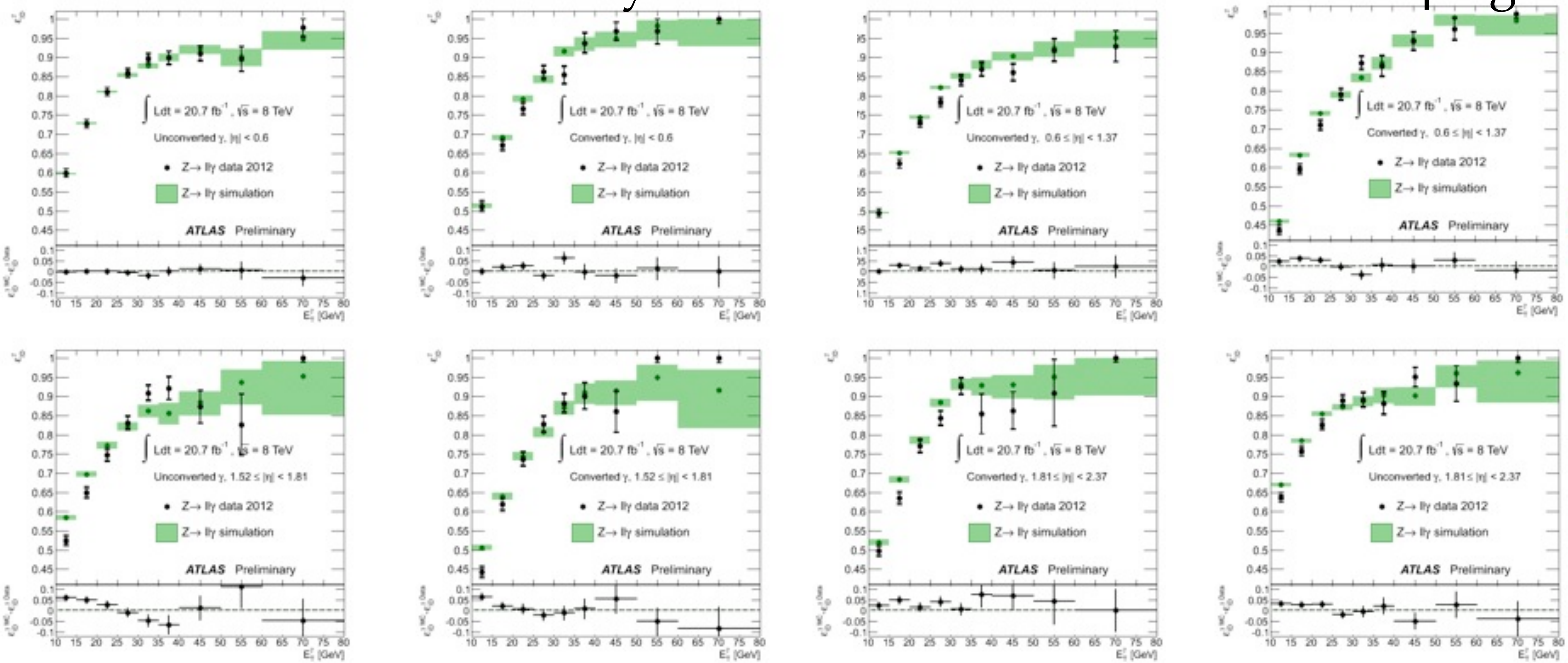
➡ $M_{ll\gamma}$ shape used as discriminant variable to estimate the Z+jet contamination.

➡ The sum of the $M_{ll\gamma}$ signal and background templates from MC, is fitted to the $M_{ll\gamma}$ distribution in the data by floating the relative normalization.The purity of this sample is estimated to be close to 90% for Et <15 GeV and improves to 98% for photon candidates with Et>15 GeV.

Reference: ATLAS-CONF-2012-123 at https://cds.cern.ch/record/1473426

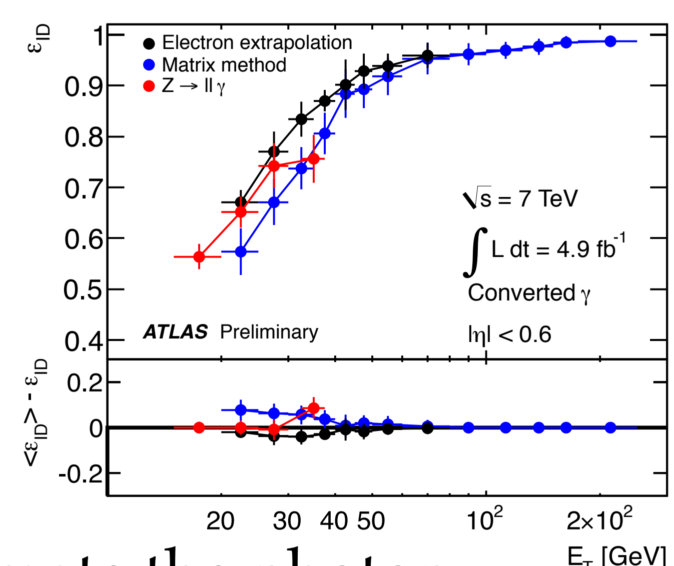
Photon Identification efficiency

The identification efficiency is measured in function of Et for η regions.



Systematic uncertainties comes from the non-100% purity of the sample, and the method to estimate it. As purity increases with Et, the systematics decreases.

Other 2 methods used in ATLAS for photonID (see E. Petit talk), these results agrees in the overlap region, and they essentially dominate at low Et.

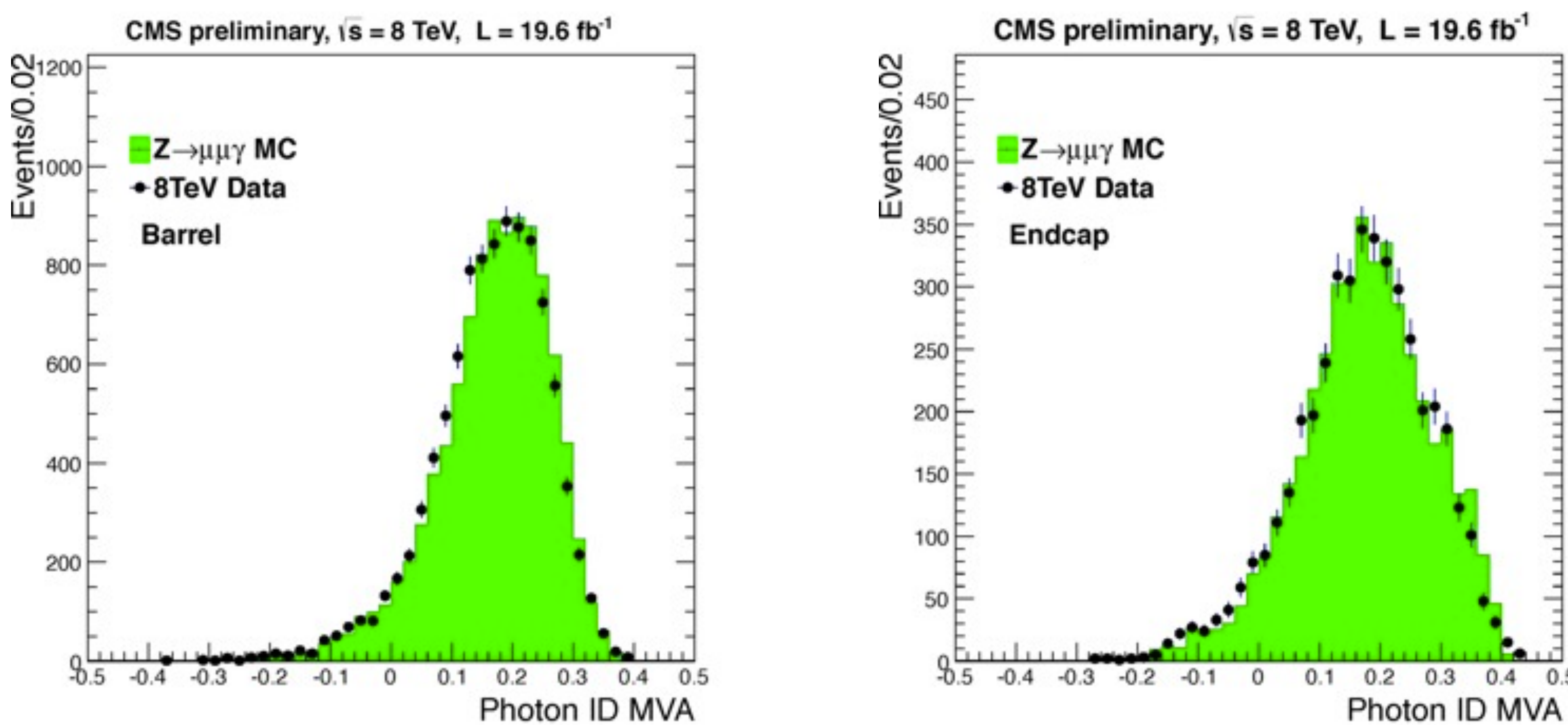


The FSR sample is also used to estimate the photon trigger efficiency, in addition to the bootstrap method.

CMS Photon Identification MVA

Photon ID is crucial for H→γγ .

MVA Photon ID is validated with the Z→μμγ sample.

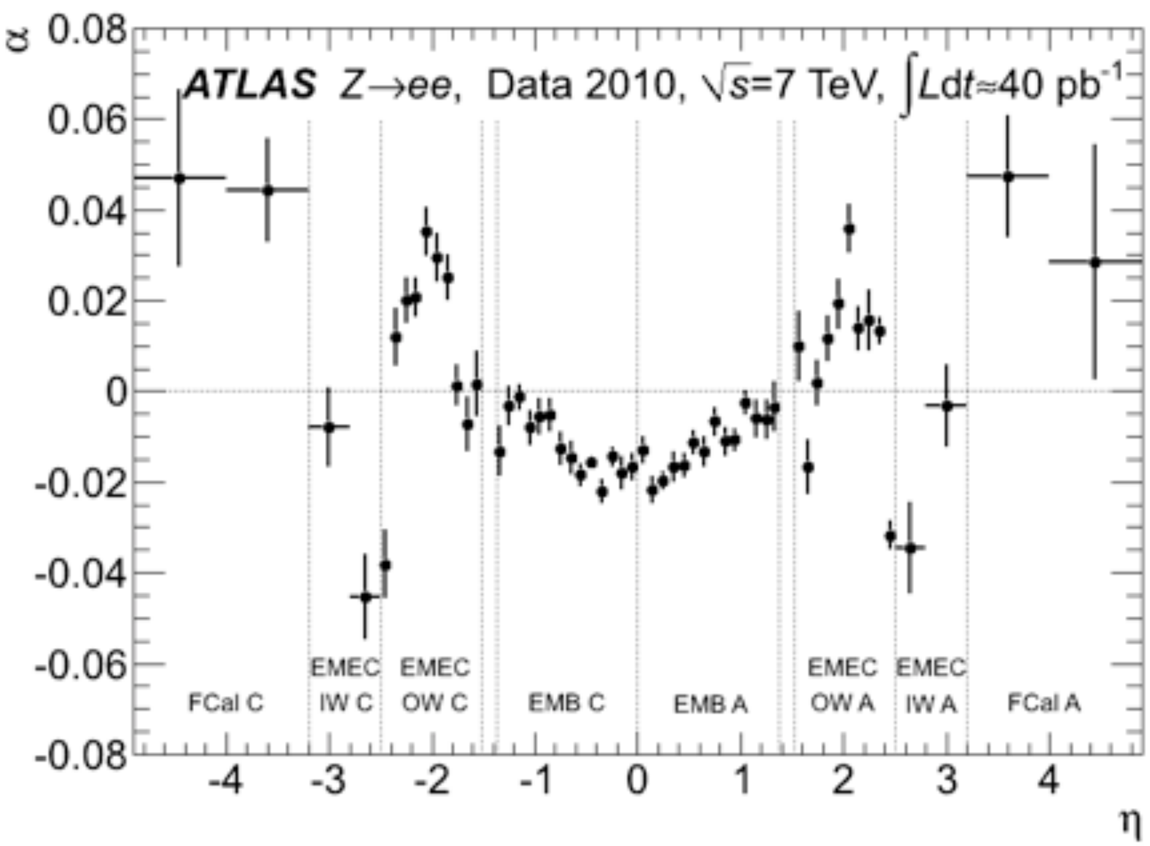


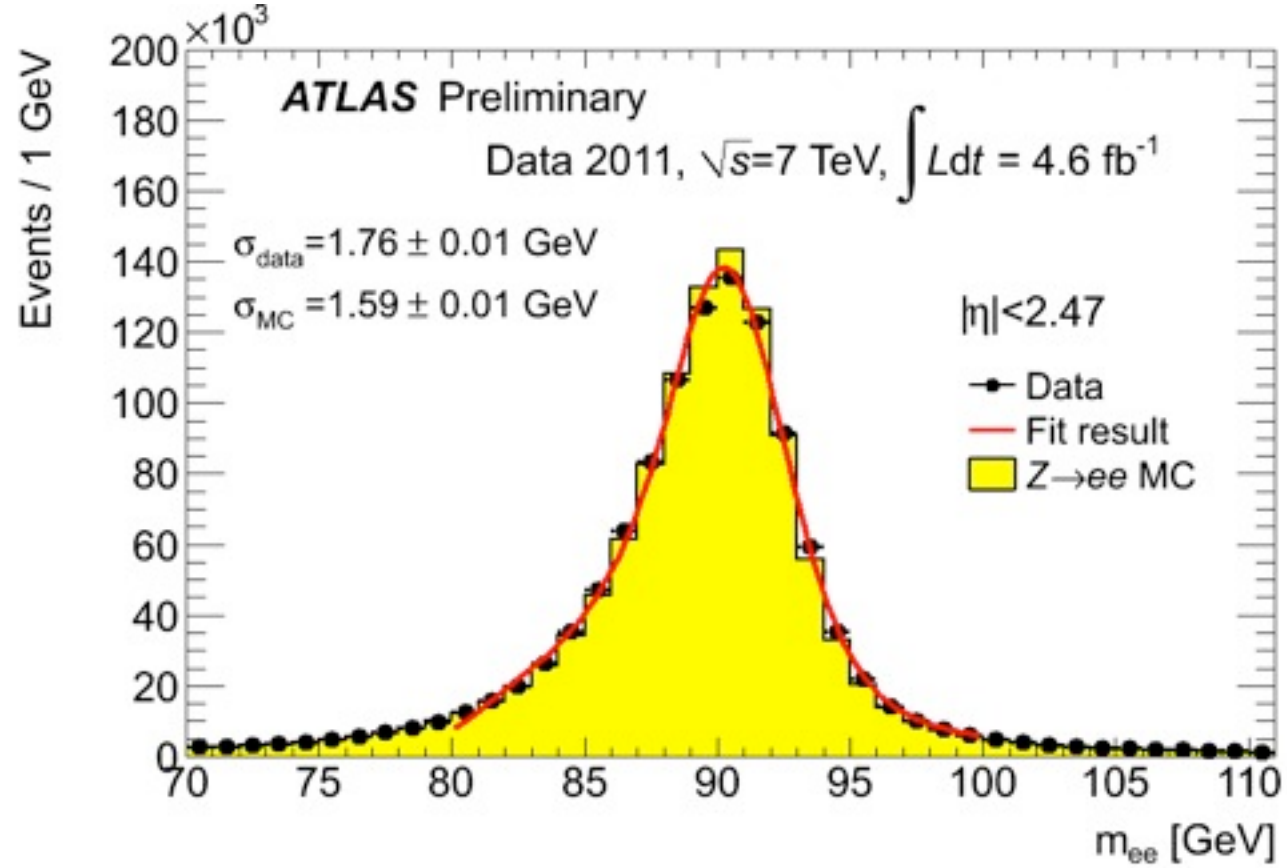
A comparison of the photon ID MVA score obtained with barrel and End-Cap in data and MC simulation.

Reference: https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13001TWiki#Photon_identification_MVA

Photon calibration

Z→ee in-situ calibration is used to correct the EM scale on data:





Electron to photon extrapolation extracted from MC simulation (more details in E. Petit talk).

Validation of calibration is performed using Z radiative decays.

Photon scales

From: $E_{MC} = E_{Data} / (1+\alpha)$

alpha can be extracted from our FSR sample

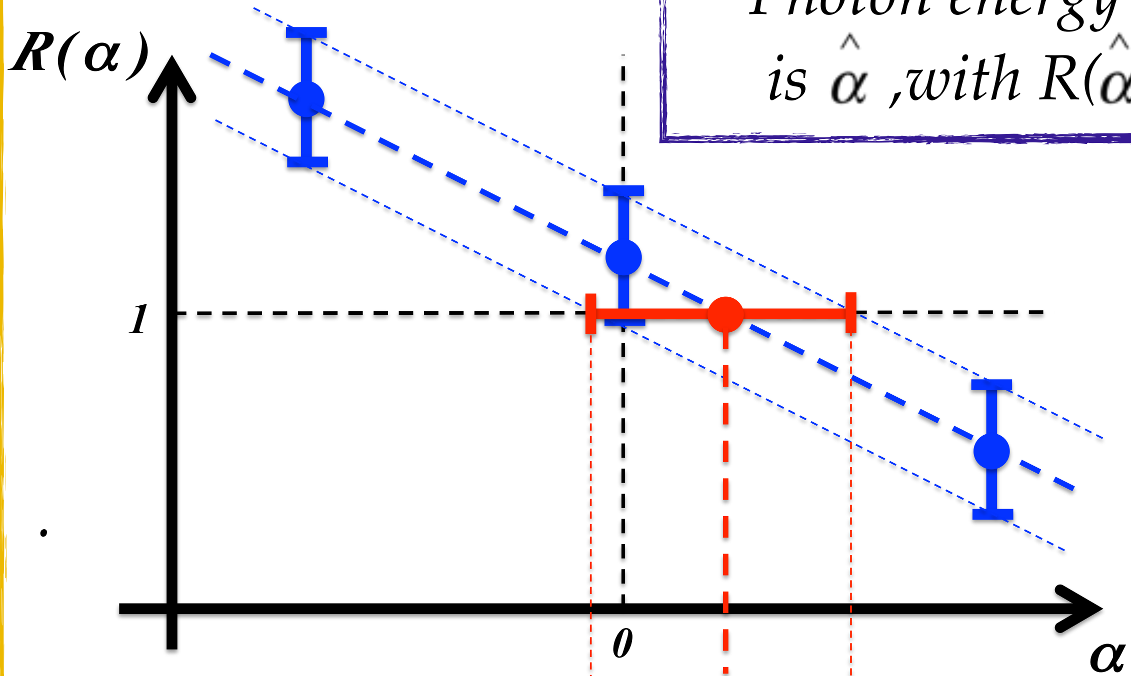
The ratio method:

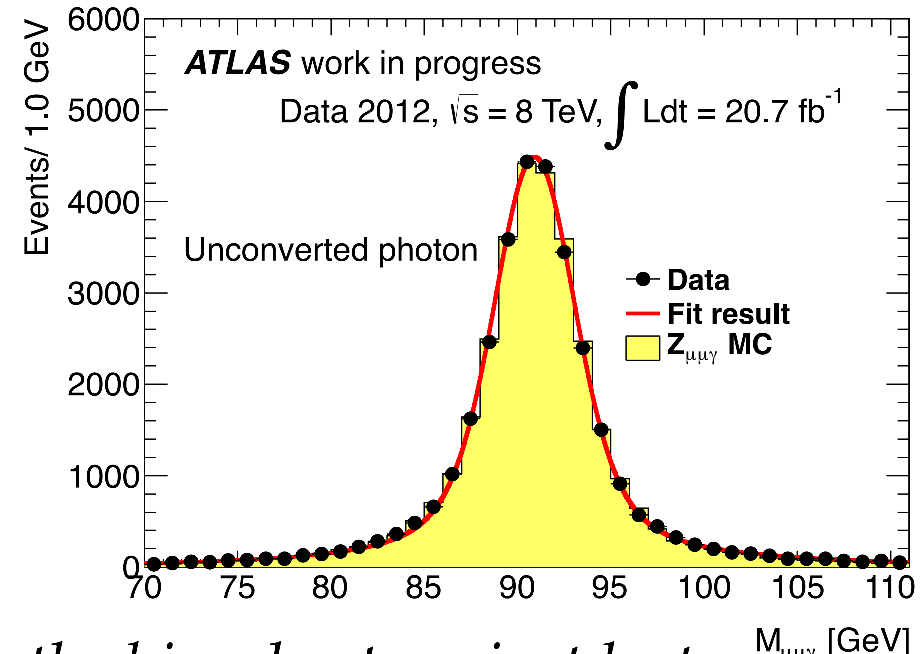
The photon energy in data is shifted by α and the three body invariant mass is recalculated. The mean value in of the FSR Z peak is fitted in both data and MC, and R is evaluated:

$$R(\alpha) = \frac{M(ll\gamma(\alpha))_{Data} / M(ll)_{Data}}{M(ll\gamma)_{MC} / M(ll)_{MC}}$$

where M(llγ) and M(ll) are the fitted mean value of the three-body and two body invariant mass.

Photon energy scale is $\hat{\alpha}$,with $R(\hat{\alpha})=1$

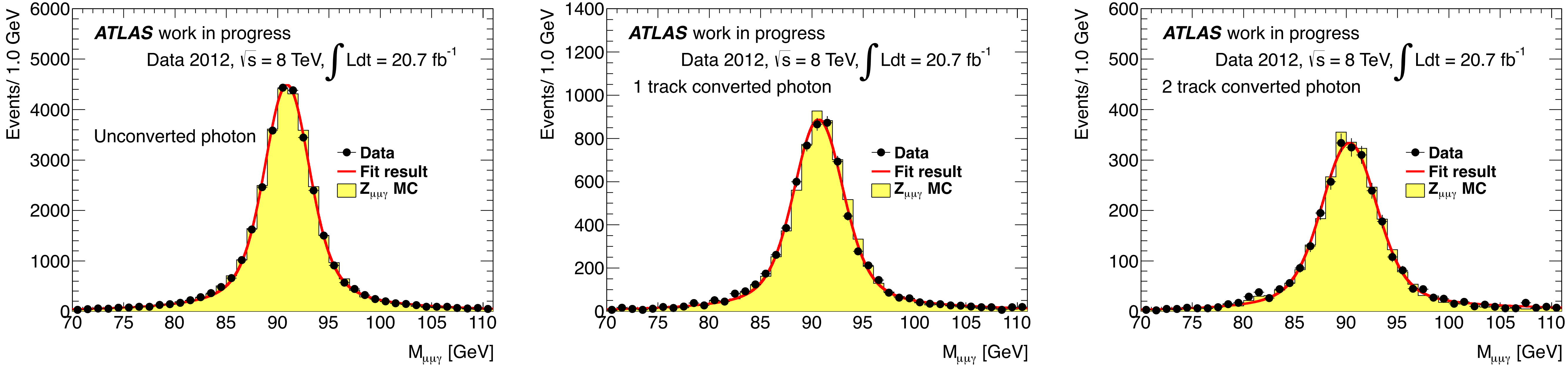




This method is robust against lepton scale uncertainties and against difference in the Z(llγ) and Z(ll) kinematics.

Photon scales with Z→μμγ

Tight photons Et > 10 GeV. Sample divided in unconverted photons and converted photons with one or two reconstructed tracks.



Photon type	Scale (α)	Stat. Error	Sys. Error
Unconv	0.0031	0.0011	0.0003
Conv 1trk	-0.0042	0.0027	0.0008
Conv 2trk	0.0019	0.0042	0.0008

Small systematics from muon scale uncertainties and fitting model.

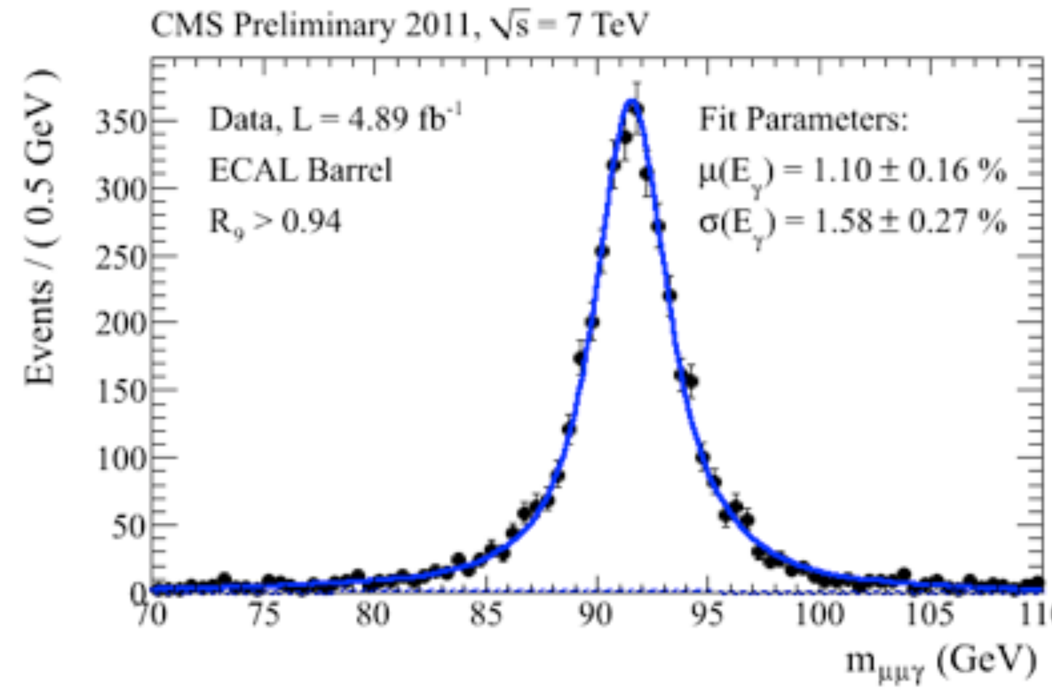
Z→eeγ channel gives compatible results.
The scales are in the range of the global EM scales uncertainties (a few per mil).

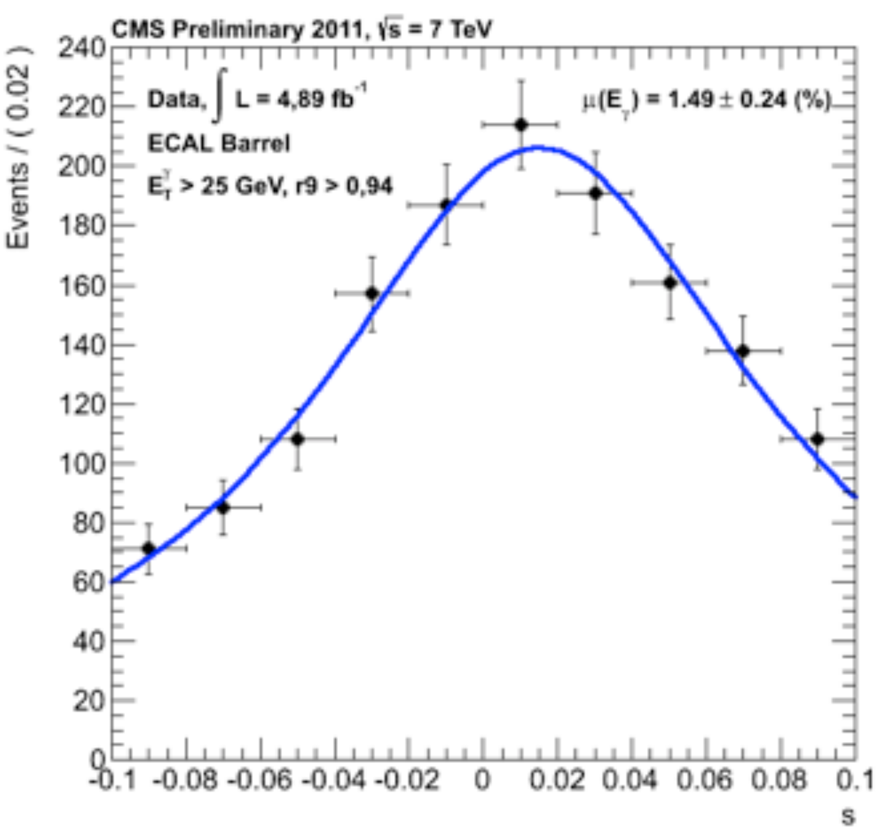
Photon scales with Z→μμγ in CMS

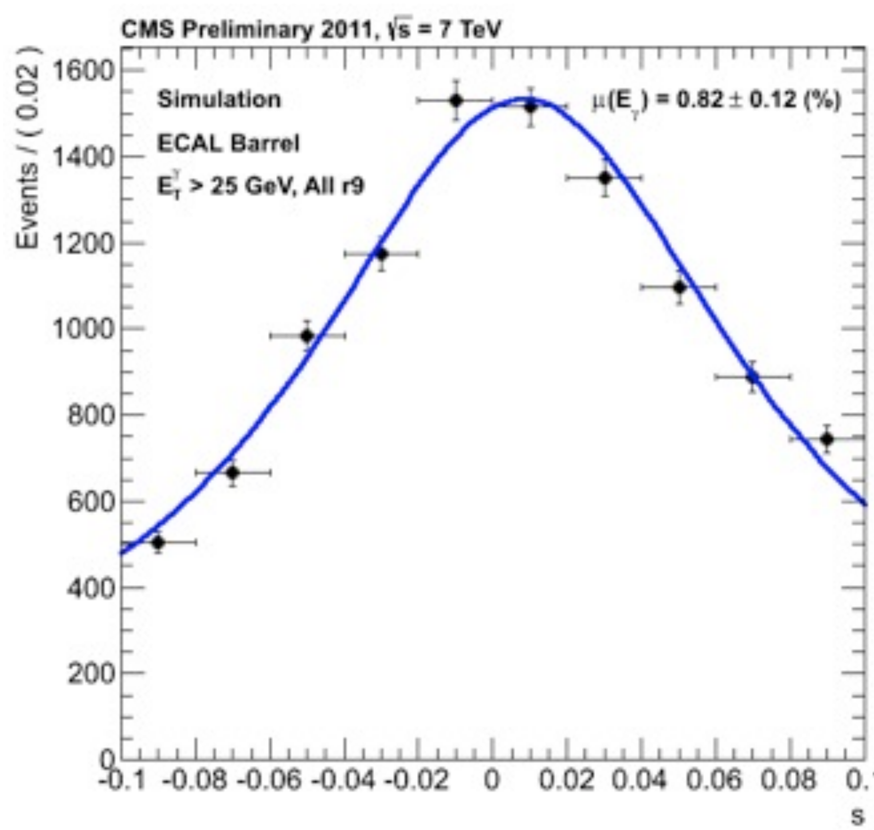
Sample based on the 2011 sample, photons with Et >25 GeV.

$$s = \frac{m^2_{\mu\mu\gamma} - m^2_{\mu\mu}}{m^2_{Z_0} - m^2_{\mu\mu}} - 1$$

Photon energy scale estimator, s.







The photon energy scale agrees to within 0.5% with an independent method.

Reference :**CMS-DP-2012/024**

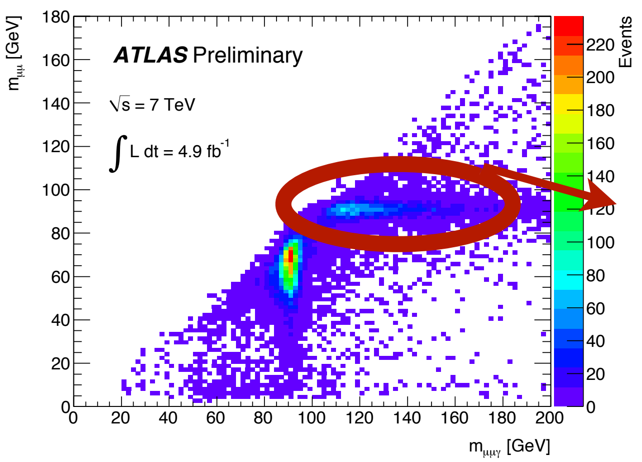
H→Zγ analysis

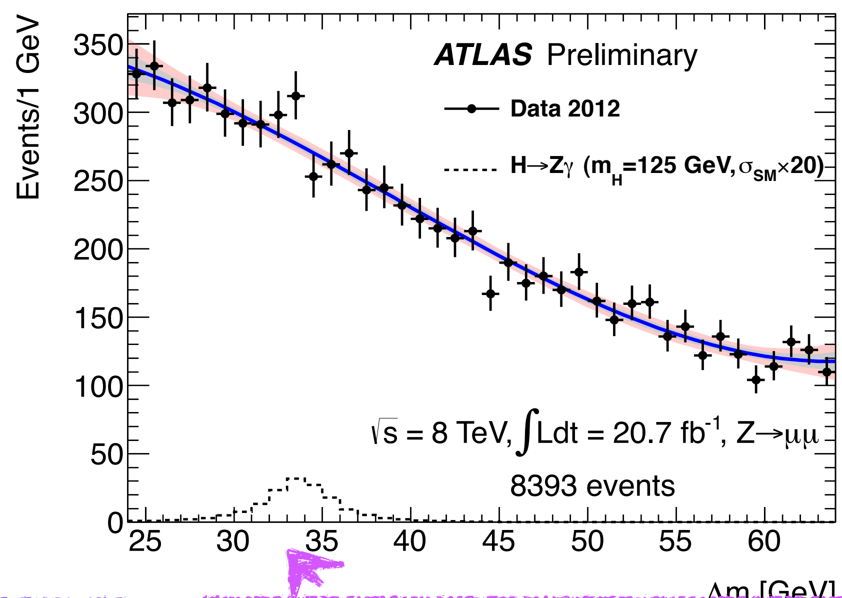
Data sample

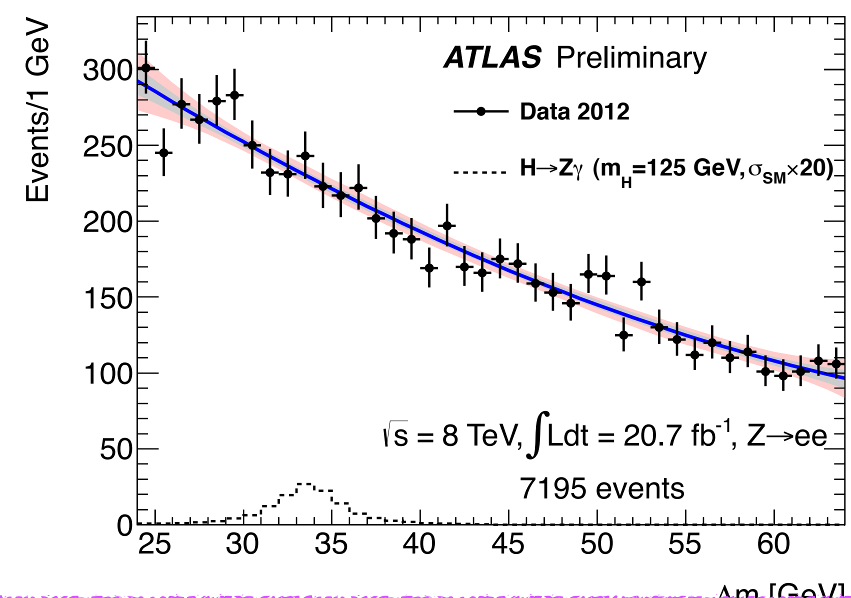
Main backgrounds comes from

SM Zγ (82% mainly ISR) followed by Z+jets (17%).

Analysis strategy very similar to H→γγ (see O.Davignon / F. Couderc talks).







The variable $\Delta M_{ll\gamma}$ ($M_{ll\gamma}$ - M_{ll}) is used as discriminant variable:

- ✓ Insensitive to lepton energy scale uncertainties.
- ✓ No contribution to the signal from FSR in H → μμ decays.

For the signal model, an analytical function of the mH valid in the whole $\Delta M_{ll\gamma}$ range is used for the limit extraction.

From the signal MC samples, the parameters that depend on mH are extracted from a simultaneous fit. For example:

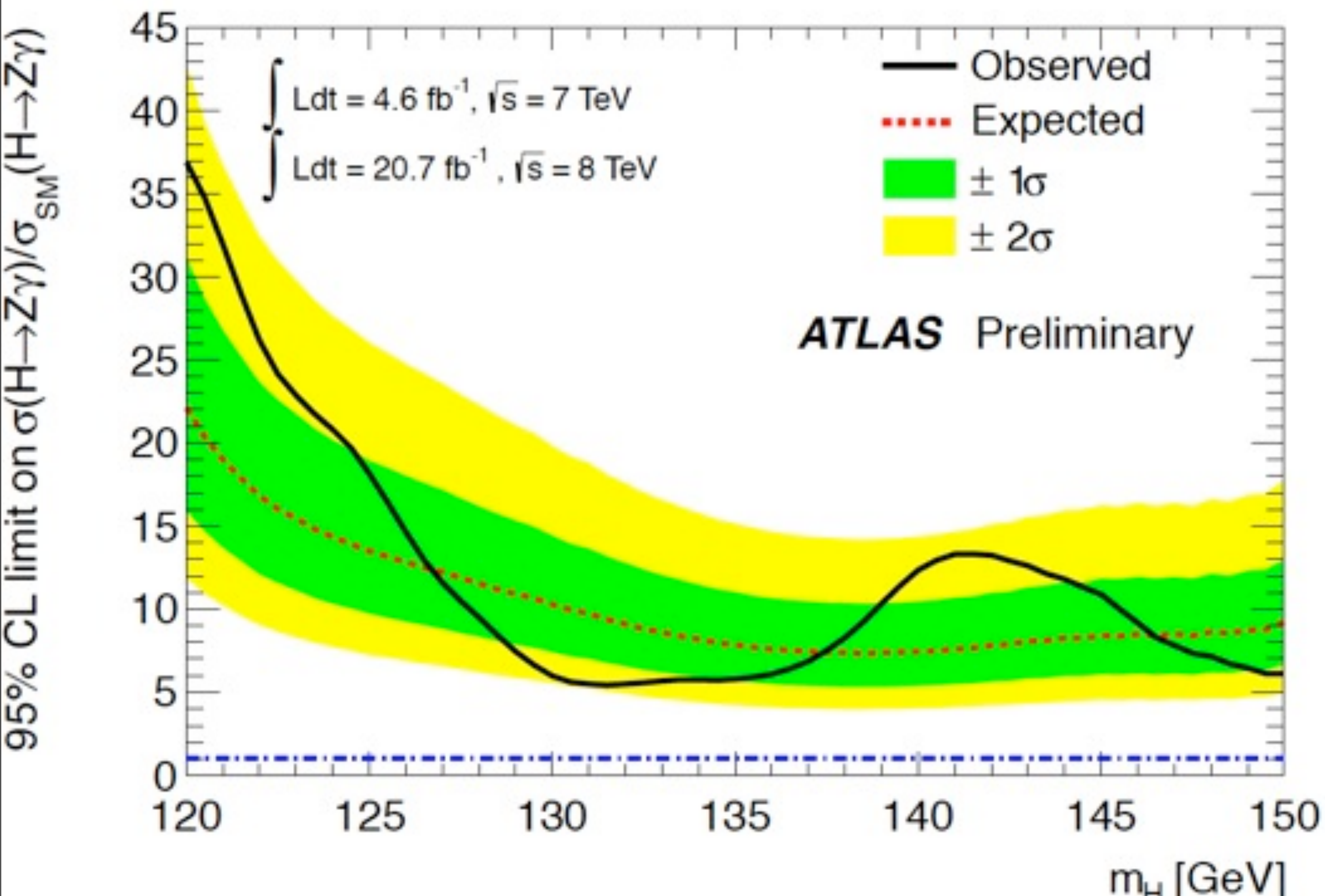
$$\sigma_{Signal}(M_{ll\gamma}) = \sigma_{125GeV} + \sigma_{slope} \times (M_{ll\gamma} - 125GeV)$$

This width function can also be validated with MC ISR sample.

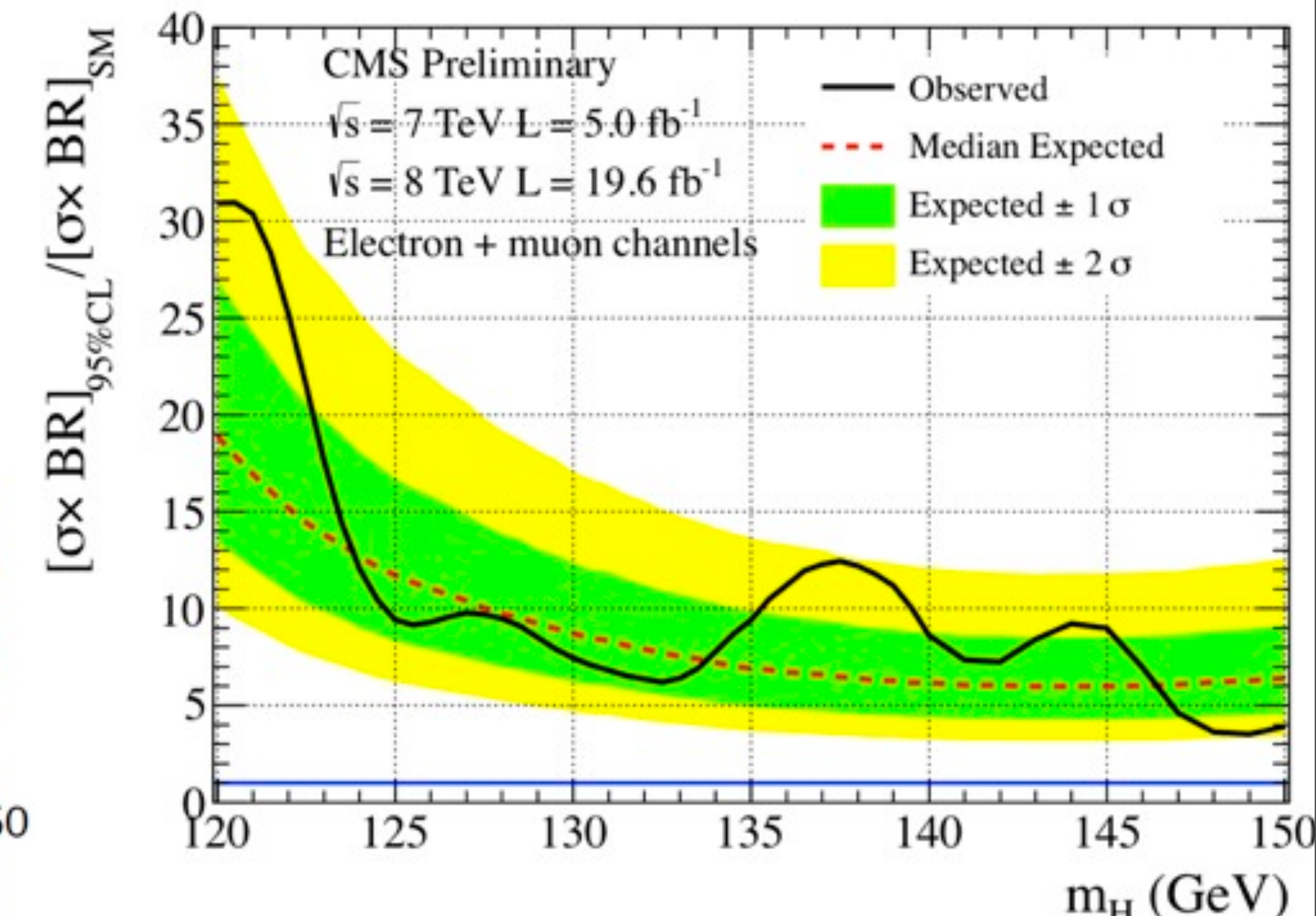
Results

In ATLAS at 125 GeV the expected and observed limits are 13.5 and 18.2 x SM, respectively.

✓ CMS at 125 GeV the expected and observed limits are ~12 and 9 x SM, respectively.



Reference: ATLAS-COM-CONF-2013-014 at https://cds.cern.ch/record/1516924?



Reference: CMS-HIG-13-006 at http://cms-physics.web.cern.ch/cms-physics/public/HIG-13-006-pas.pdf

Conclusions

- Photons from FSR Z decays are widely used in ATLAS and CMS performance studies.
  - These photons represents a high purity sample that covers the lower Et region up to 80 GeV.
  - Sample used for photon identification efficiency measurements and as a cross check to the $Z \rightarrow ee$ based photon calibration.
- Z Radiative decays in Initial State Radiation are the main background for the $H\rightarrow Z\gamma$ search.
  - First public results by ATLAS were presented. With the complete 7 TeV and 8 TeV data sample, at 125 GeV the expected and observed limits are 13.5 and 18.2 x SM, respectively. CMS presents compatible results.

Backup

- ## Plot description

  Energy scale estimator $s = \frac{m^2_{\mu\mu\gamma} - m^2_{\mu\mu}}{m^2_{Z^0} - m^2_{\mu\mu}} - 1$ from $Z^0 \rightarrow \mu\mu\gamma$ final states from 2011 Data and Simulation, where m_{Z^0} is the PDG value. Plots are shown for EB with R9 > 0.94, inclusive EB and inclusive EE categories (The variable R9 is defined as the ratio of the energy contained within the 3x3 array of crystals centered around the seed crystal of the supercluster to the total energy of the supercluster).

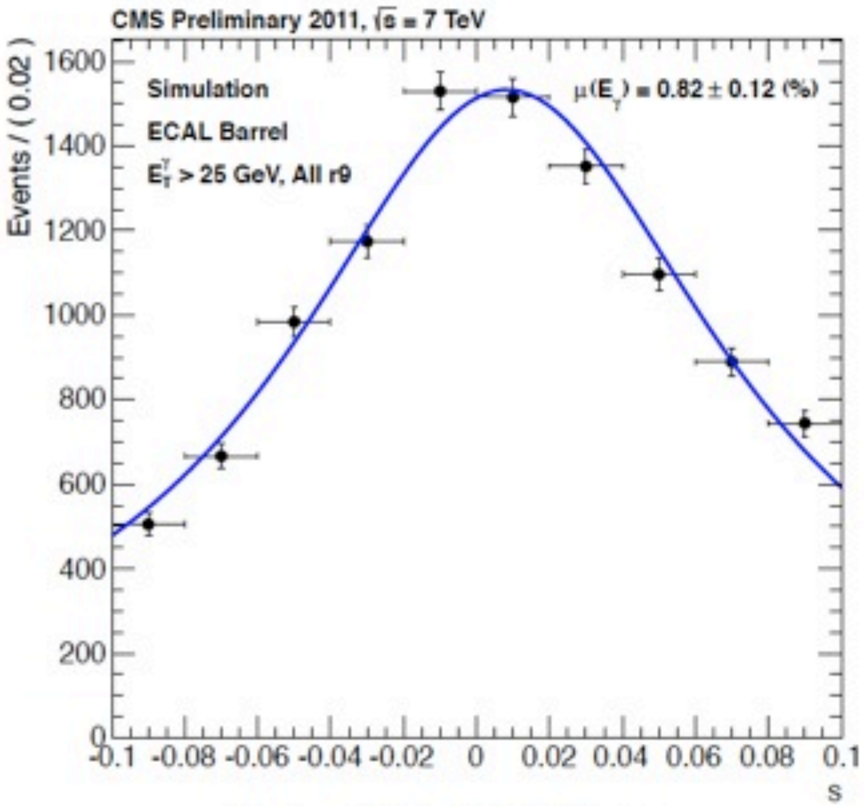
- ## Technical details

  Z decays where one of the final state leptons radiates a photon provide a source of clean photons, where the photon kinematics are constrained by the muon system. The photon transverse energy E_T is reconstructed from the muon kinematics and the Z mass constraint. The muon momenta have been corrected for biases arising from their dependence on E_T, η, ϕ, and charge using approved techniques. Only photons of $E_T > 25$ GeV are used. The purity of selected events is > 99 %. The mean E_T (E) of the photons is approximately 32 GeV (42 GeV in EB for high R9, 43 GeV in EB, 113 GeV in EE). The value of the energy scale estimator s(E_T) is calculated directly for each selected event, and the mean of the resulting distribution is extracted from an unbinned fit with a Voigtian (convolution of a Breit-Wigner with a Gaussian) function. Scale extraction is performed independently for data and simulation. Statistical uncertainties and systematic effects from the choice of fit range are quoted ; systematic effects from the muon momentum scale and kinematics are quoted for simulation.

- ## Conclusion

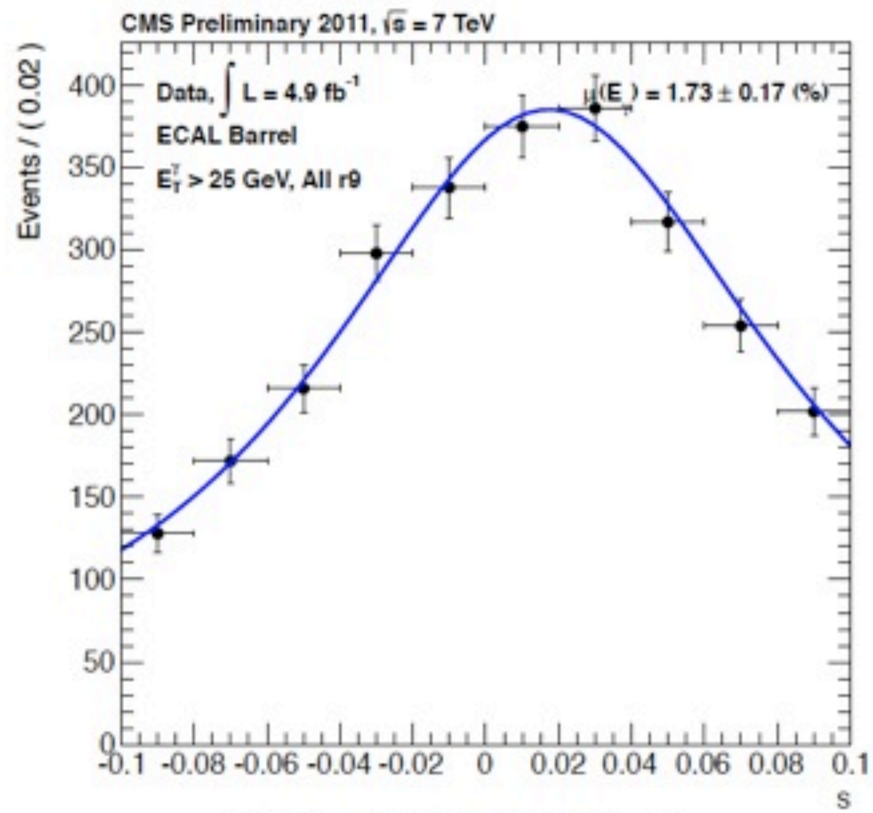
  The photon energy scale agrees to within 1.3 % between DATA and MC. The energy scale agrees to better than 0.5 % with that obtained using an independent method. The rate of selected events is found to be 1.12 / pb^{-1}.

s_{RECOMC}



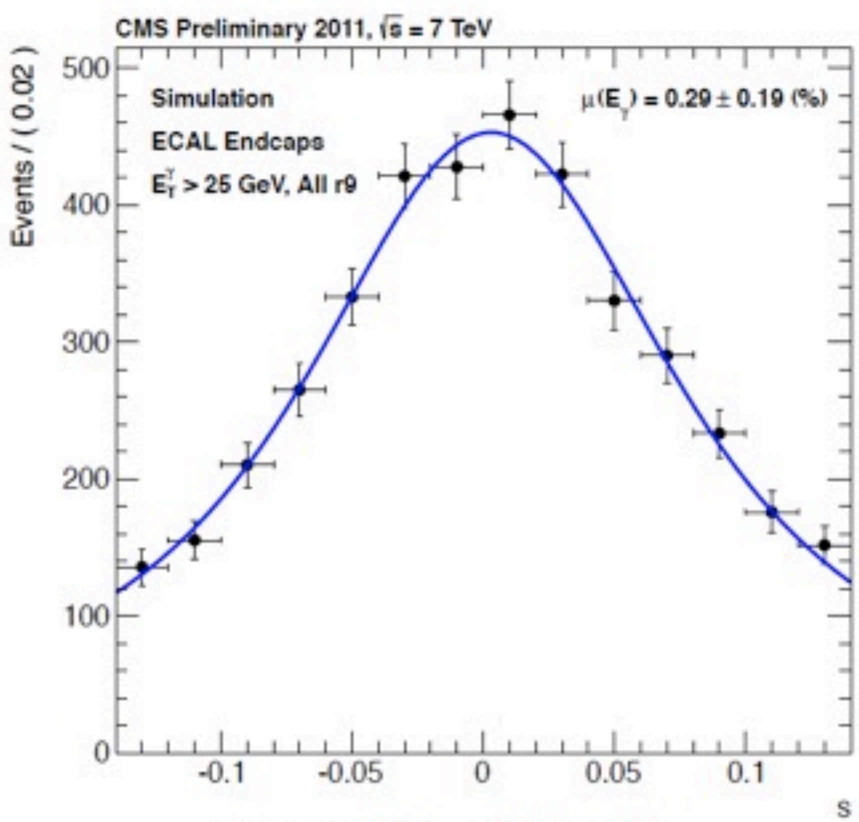
$\mu(E_\gamma) = 0.82 \pm 0.12$ (stat)
$\pm$ 0.10 (fit range) $\pm$ 0.02 (muons) %

$s_{RECOData}$



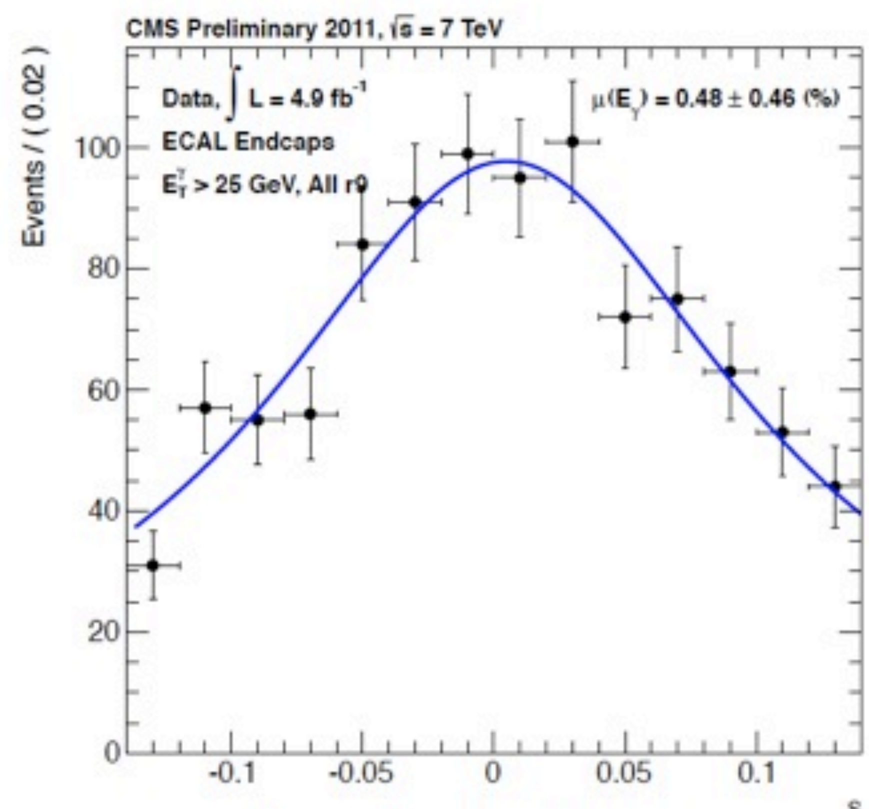
$\mu(E_\gamma) = 1.73 \pm 0.17$ (stat)
$\pm$ 0.16 (fit range) %

s_{RECOMC}



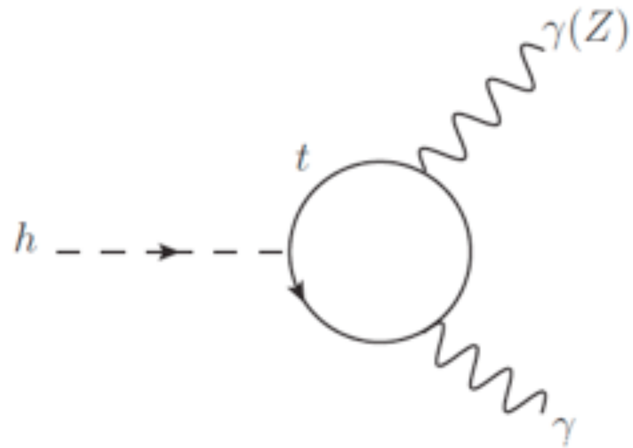
$\mu(E_\gamma) = 0.29 \pm 0.19$ (stat)
$\pm$ 0.05 (fit range) $\pm$ 0.03 (muons) %

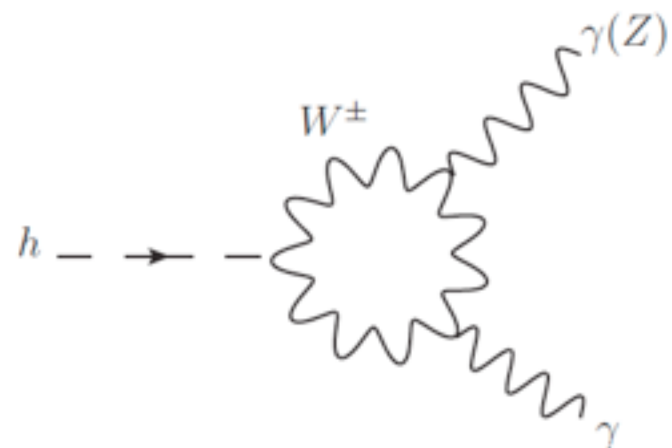
$s_{RECOData}$



$\mu(E_\gamma) = 0.48 \pm 0.46$ (stat)
$\pm$ 0.10 (fit range) %

Physics motivation

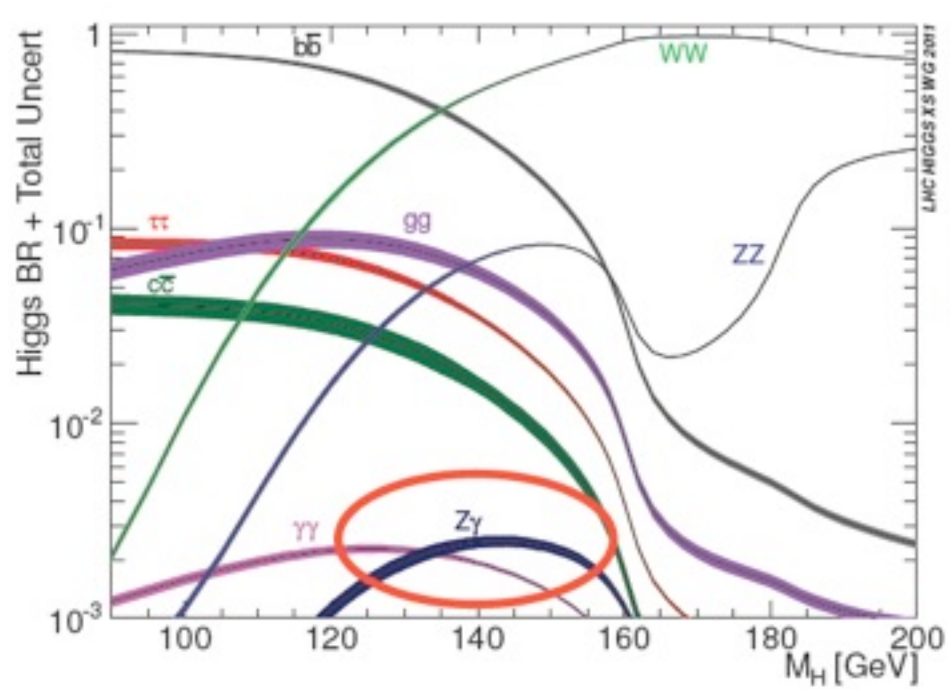


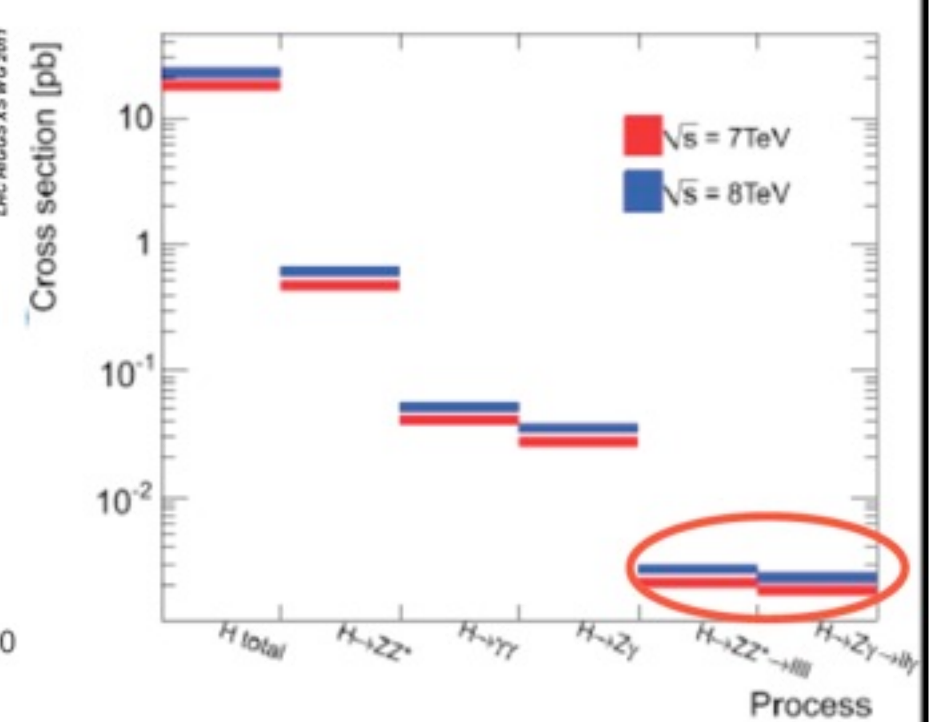


In SM, Zγ decay proceeds via top- and W-mediated loops.

New Physics could manifest through enhancement (or suppression) of the decay rate via contributions from new heavy charged particles in the loop.

The BF(Zγ) ~ BF(γγ), BF(Z→ll (e+μ)) ~ 6.7% gives yield comparable to H→4l.





Systematics

Theory sys.

$\sqrt{s}$	Systematic uncertainty (%)										
	$\sigma(gg \to H)$		σ(VBF)		$\sigma(WH)$		$\sigma(ZH)$		$\sigma(t\bar{t}H)$		$B(H \to Z\gamma)$
	scale	PDF	scale	PDF	scale	PDF	scale	PDF	scale	PDF	
7 TeV	$^{+7.1}_{-7.8}$	$^{+7.6}_{-7.1}$	± 0.3	$^{+2.5}_{-2.1}$	$^{+0.2}_{-0.8}$	± 3.5	$^{+1.4}_{-1.6}$	± 3.5	$^{+3.3}_{-9.3}$	± 8.5	$^{+9.0}_{-8.8}$
8 TeV	$^{+7.3}_{-7.9}$	$^{+7.5}_{-6.9}$	± 0.2	$^{+2.6}_{-2.8}$	$^{+0.1}_{-0.6}$	± 3.4	$^{+1.5}_{-1.4}$	± 3.5	$^{+3.9}_{-9.3}$	± 7.8	$^{+9.0}_{-8.8}$

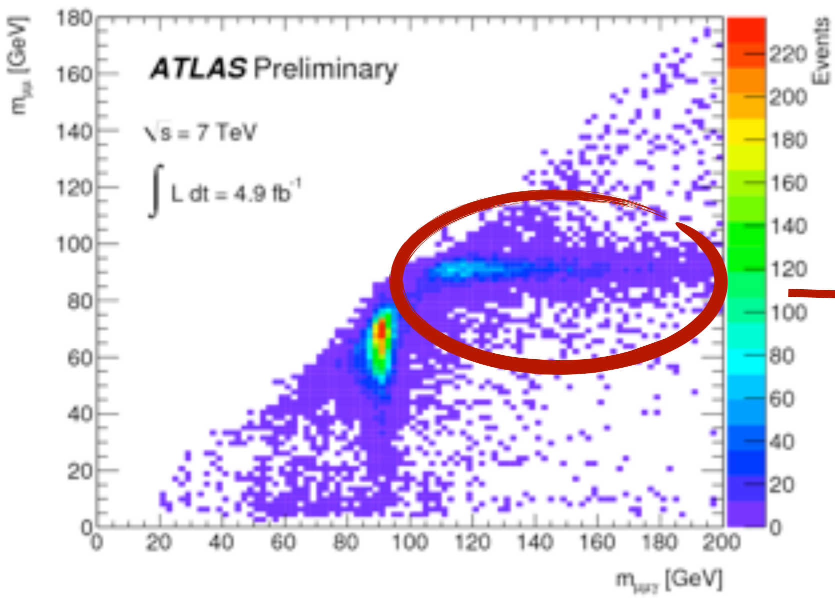
Systematic Uncertainty	$H \to Z(ee)\gamma(\%)$	$H \to Z(\mu\mu)\gamma(\%)$
Signal Yield		
Luminosity	3.6 (1.8)	3.6 (1.8)
Trigger efficiency	0.4 (0.2)	0.8 (0.7)
Acceptance of kinematic selection	4.0 (4.0)	4.0 (4.0)
γ identification efficiency	2.9 (2.9)	2.9 (2.9)
electron reconstruction and identification efficiency	2.7 (3.0)	
μ reconstruction and identification efficiency		0.6 (0.7)
e/γ energy scale	1.4 (0.3)	0.3 (0.2)
e/γ isolation	0.4 (0.3)	0.4 (0.2)
e/γ energy resolution	0.2 (0.2)	0.0 (0.0)
μ momentum scale		0.1 (0.1)
μ momentum resolution		0.0 (0.1)
Signal Δm resolution		
e/γ energy resolution	5.0 (5.0)	2.4 (2.4)
μ momentum resolution		0.0 (1.5)
Signal Δm peak position		
e/γ energy scale	0.2 (0.2) GeV	0.2 (0.2) GeV
μ momentum scale		negligible

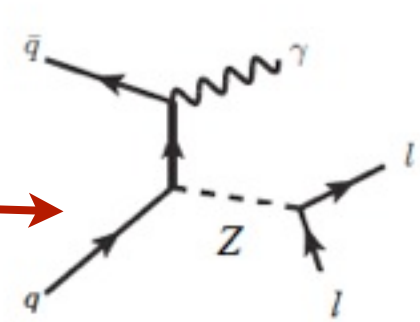
Experimental sys.

Backgrounds

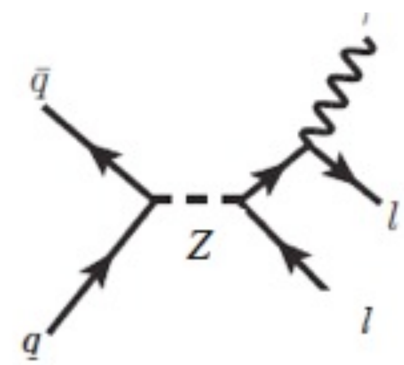
- Main background:

  Z+γ (80%)

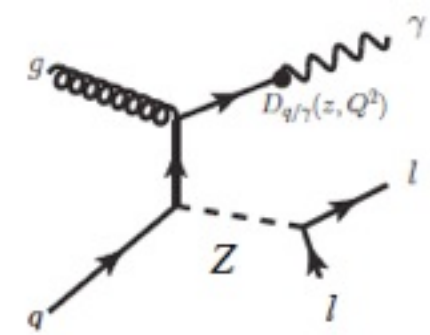




t,u channels



FSR



Fragmentation

Irreducible bkg, suppressed by photon Et cut (SM Zγ photons are softer).
$\Delta R_{l\gamma}$ (suppress FSR photons) and M(ll) M(llγ) cuts.

- Secondary background: Z+jets (16%)

Suppressed by Photon Identification and isolation criteria.

- Minor contribution from ttbar (4%) and negligible from WZ.

Selection overview

Lepton selection:

✓ Leptons with Pt > 10 to 15 GeV and |η|<2.4 to 2.7

Photon selection:

✓ Et > 15 GeV, isolated photons

✓ Photon identification criteria.

Z selection:

✓ Opposite charge leptons

✓ Mll > 65 GeV

✓ Mll > Mz - 10 GeV

For the analysis all 7 TeV (4.6 fb^{-1}) and 8 TeV (20.7 fb^{-1}) samples will be used.

Discriminant variable:

The search is performed in the range of 120-150 GeV, by fitting the observed distribution of a discriminating variable.

The three body invariant mass $M_{ll\gamma}$ and $\Delta M_{ll\gamma}$ ($M_{ll\gamma}$ - M_{ll}) where studied.

The variable $\Delta M_{ll\gamma}$ is chosen due to this two advantages:

✓ Unaffected by lepton energy scale uncertainties.

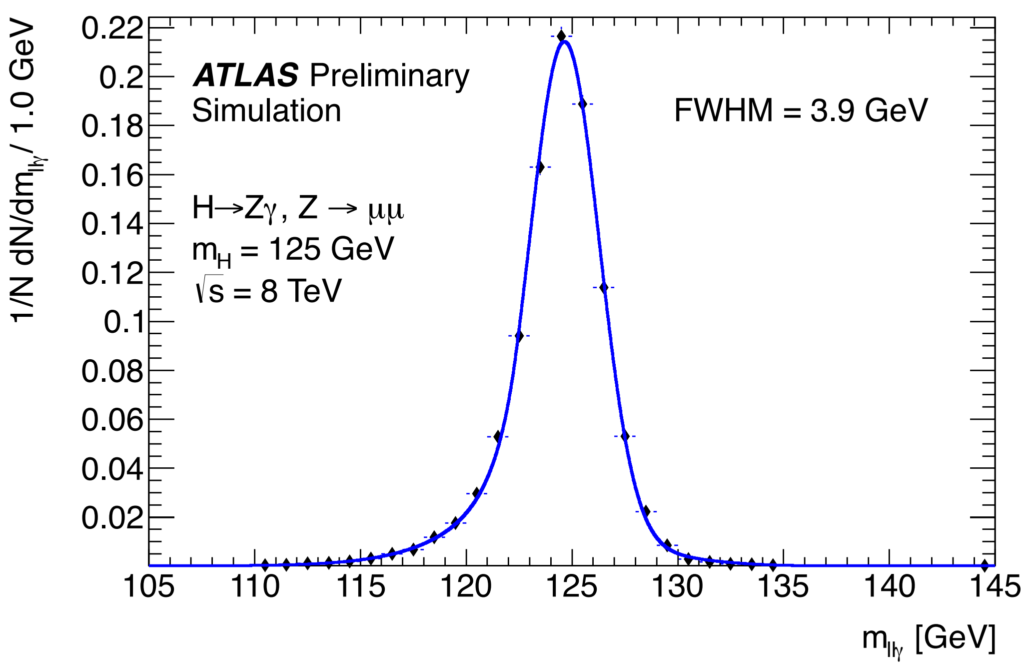
✓ Insensitive to the contribution to the signal from FSR in $H \rightarrow \mu\mu$ decays.

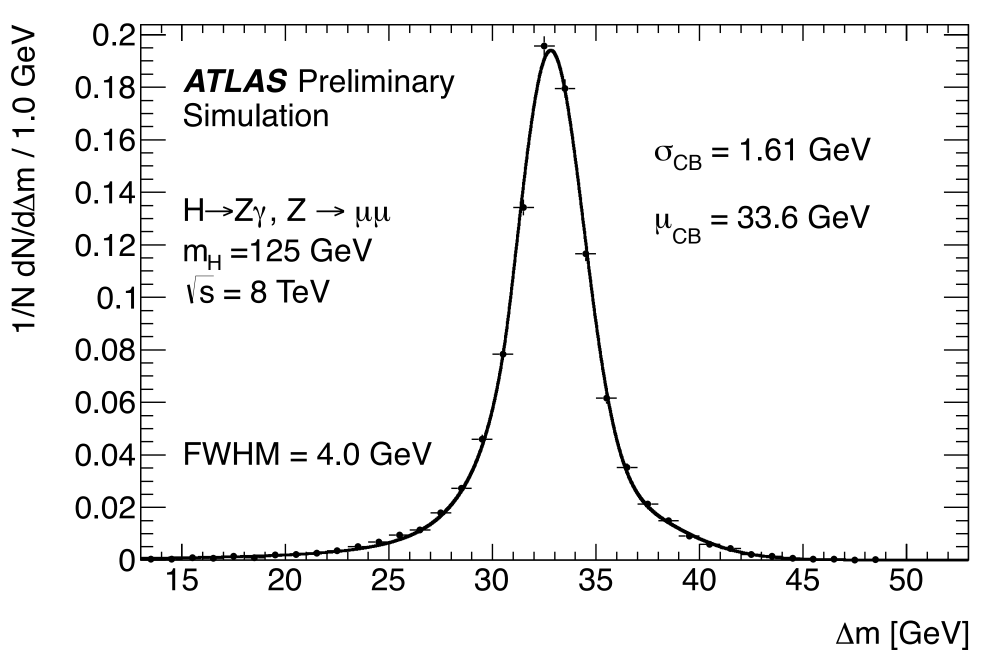
Reference: ATLAS-COM-CONF-2013-014 at https://cds.cern.ch/record/1516924?

Signal properties

15 Higgs events in 7 TeV + 8 TeV data sample at 125 GeV

m_H [GeV]	$Z \to ee$, 7 TeV ε [%]	$Z \to ee$, 7 TeV S	$Z \to \mu\mu$, 7 TeV ε [%]	$Z \to \mu\mu$, 7 TeV S	$Z \to ee$, 8 TeV ε [%]	$Z \to ee$, 8 TeV S	$Z \to \mu\mu$, 8 TeV ε [%]	$Z \to \mu\mu$, 8 TeV S
120	17.1	0.6	22.5	0.7	21.3	4.0	25.8	4.9
125	20.4	0.9	26.5	1.1	24.6	5.9	29.7	7.2
130	23.0	1.1	29.9	1.5	27.3	7.7	32.8	9.3
135	25.1	1.3	32.4	1.7	29.4	9.0	35.1	10.7
140	26.6	1.4	34.1	1.8	30.9	9.5	36.6	11.3
145	27.5	1.4	35.0	1.8	31.7	9.2	37.3	10.8
150	27.9	1.2	35.1	1.5	32.0	8.1	37.2	9.4





The global resolution model:

Both $M_{ll\gamma}$ and $\Delta M_{ll\gamma}$ distribution are modelled with a Crystal Ball + wide gaussian outlier.

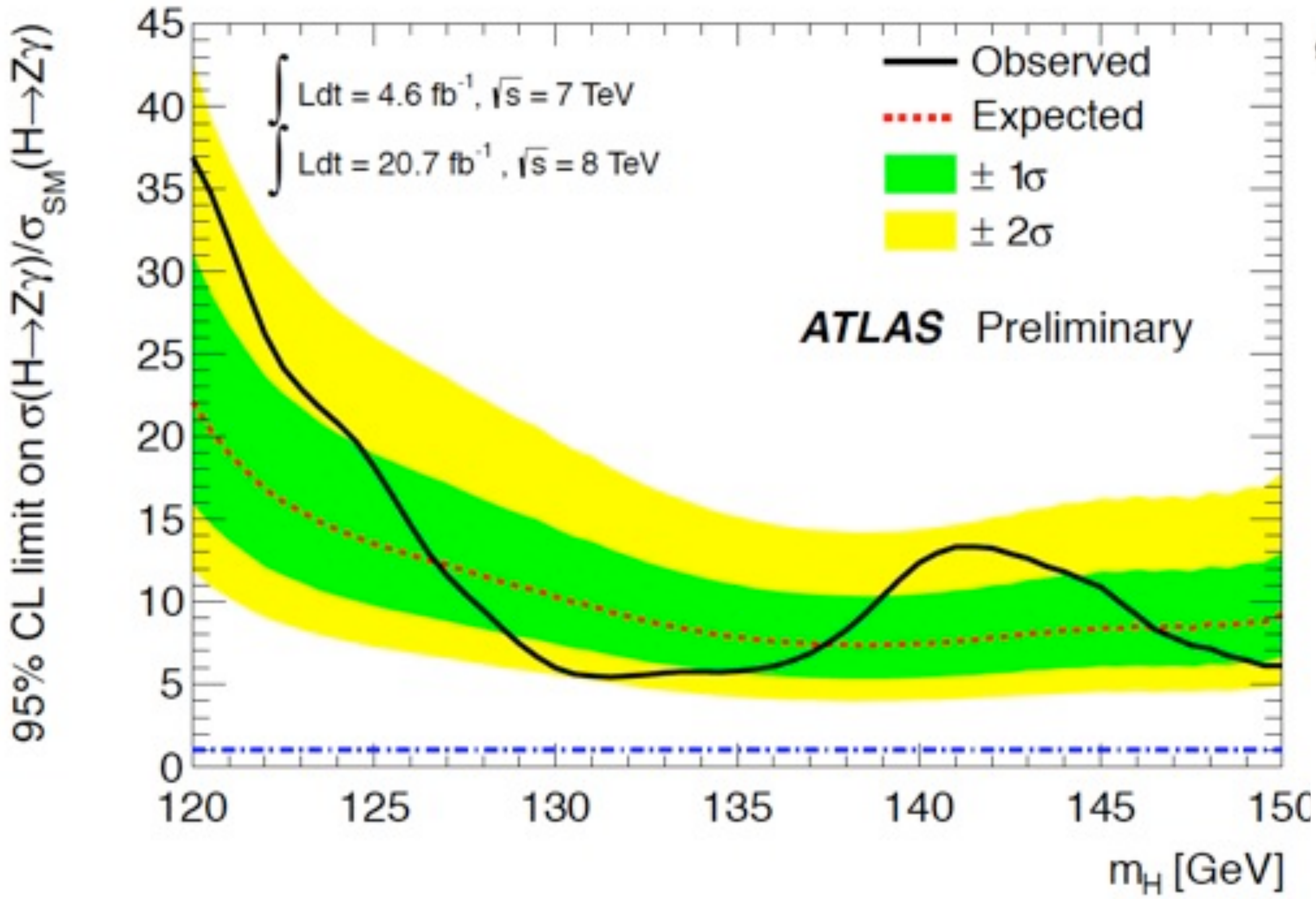
The limit extraction needs an analytical function of the Higgs mass (mH) with a full description of the signal in the whole mass range ($24 < \Delta M_{ll\gamma} < 64$ GeV).

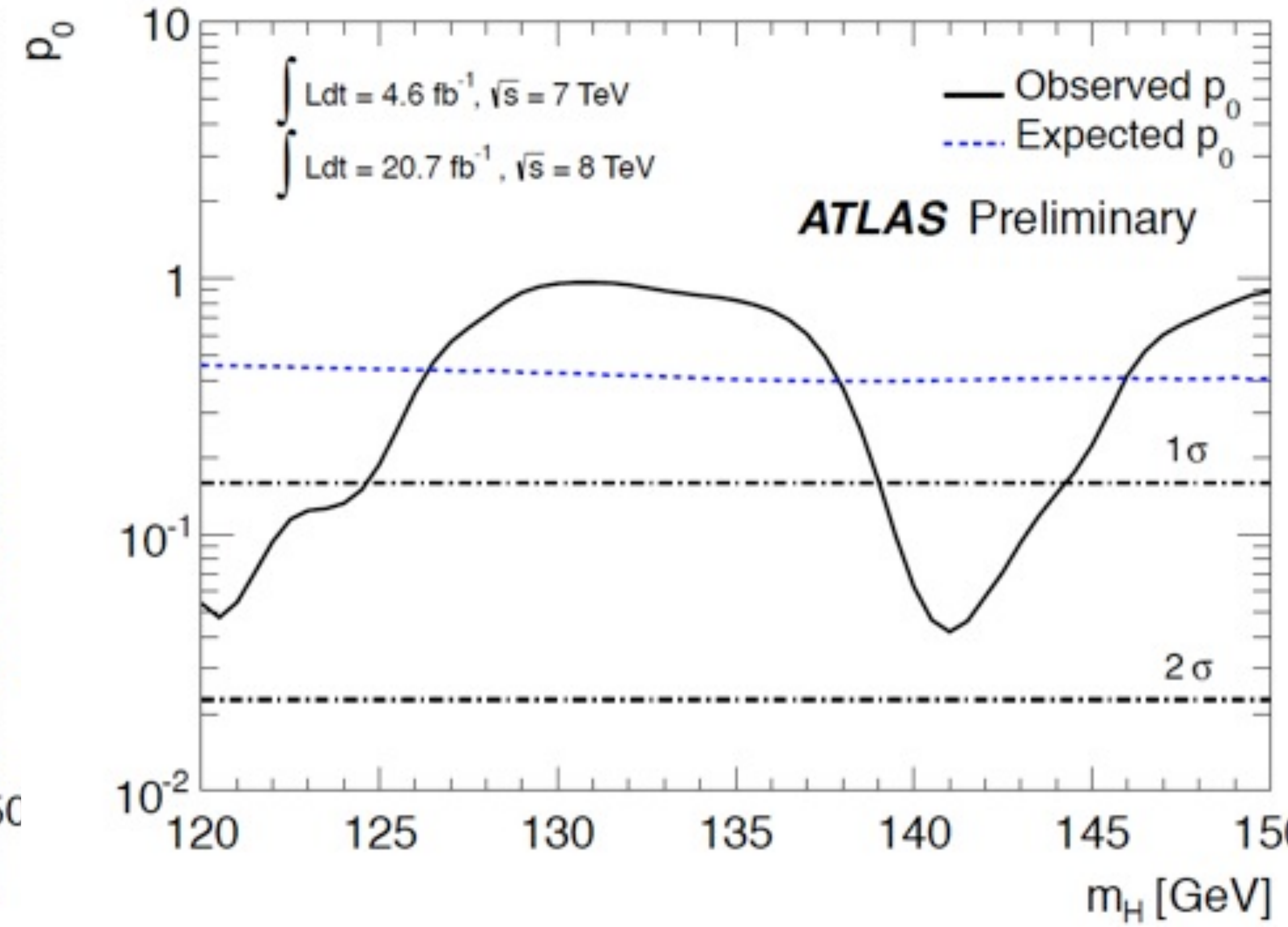
From the available signal MC samples at all mass points, the parameters that depend on mH are identified and extracted from a simultaneous fit. For example:

$$\sigma_{CB} = \sigma CB_{125GeV} + \sigma CB_{slope} \times (M(ll\gamma) - 125GeV)$$

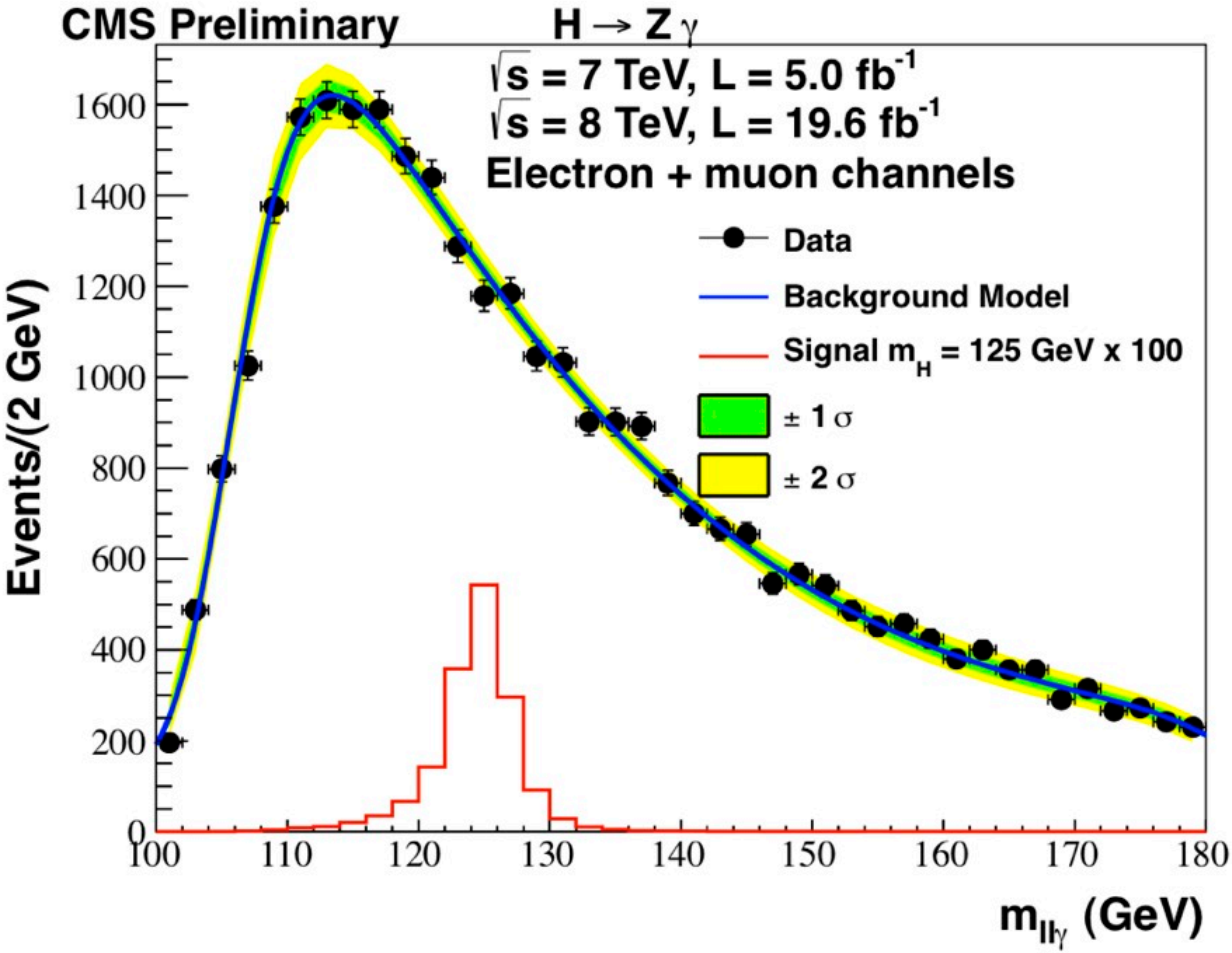
Results

At 125 GeV the expected and observed limits are 13.5 and 18.2 x SM, respectively. Statistical uncertainties are dominating: neglecting all systematic uncertainties, the observed (expected) 95% CL limit on the cross section at 125 GeV is 17.4 (12.9) x SM.





The expected p0 at mH = 125 GeV is 0.443, corresponding to a significance of 0.14 σ, while the observed one is 0.188 (0.89σ).



CMS Preliminary
H → Z γ
√s = 7 TeV, L = 5.0 fb-1
√s = 8 TeV, L = 19.6 fb-1
Electron + muon channels
Data
Background Model
Signal mH = 125 GeV x 100
± 1 σ
± 2 σ
Events/(2 GeV)
0
200
400
600
800
1000
1200
1400
1600
100
110
120
130
140
150
160
170
180
mllγ (GeV)

Table 2: Definition of the four event classes, the fraction of selected events for a signal with $m_{\mathrm{H}} = 125$ GeV produced by gluon-gluon fusion at 8 TeV and data in a narrow bin centred at 125 GeV. The expected mass resolution on the signal is also shown.

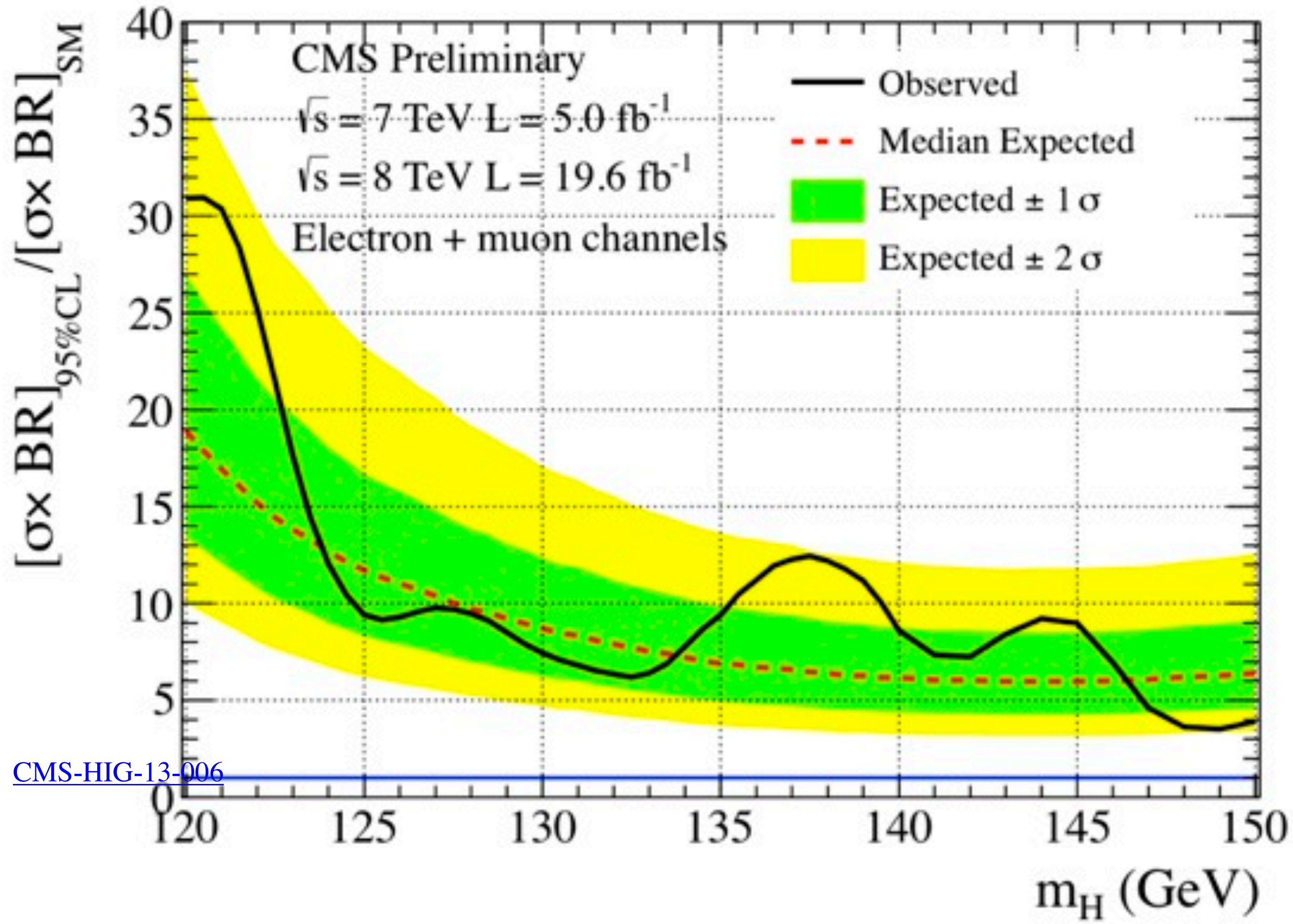
	$e^+e^-\gamma$	$\mu^+\mu^-\gamma$
	Event class 1	
	Photon $0 < \|\eta\| < 1.4442$ Both leptons $0 < \|\eta\| < 1.4442$ $R_9 > 0.94$	Photon $0 < \|\eta\| < 1.4442$ Both leptons $0 < \|\eta\| < 2.1$ and one lepton $0 < \|\eta\| < 0.9$ $R_9 > 0.94$
Data	17%	20%
Signal	30%	34%
σ_{eff}	1.9 GeV	1.6 GeV
FWHM	4.5 GeV	3.7 GeV
	Event class 2	
	Photon $0 < \|\eta\| < 1.4442$ Both leptons $0 < \|\eta\| < 1.4442$ $R_9 < 0.94$	Photon $0 < \|\eta\| < 1.4442$ Both leptons $0 < \|\eta\| < 2.1$ and one lepton $0 < \|\eta\| < 0.9$ $R_9 < 0.94$
Data	26%	31%
Signal	28%	31%
σ_{eff}	2.1 GeV	1.9 GeV
FWHM	5.0 GeV	4.6 GeV
	Event class 3	
	Photon $0 < \|\eta\| < 1.4442$ At least one lepton $1.4442 < \|\eta\| < 2.5$ No requirement on R_9	Photon $0 < \|\eta\| < 1.4442$ Both leptons in $\|\eta\| > 0.9$ or one lepton in $2.1 < \|\eta\| < 2.4$ No requirement on R_9
Data	26%	20%
Signal	23%	18%
σ_{eff}	3.1 GeV	2.1 GeV
FWHM	7.3 GeV	5.0 GeV
	Event class 4	
	Photon $1.566 < \|\eta\| < 2.5$ Both leptons $0 < \|\eta\| < 2.5$ No requirement on R_9	Photon $1.566 < \|\eta\| < 2.5$ Both leptons $0 < \|\eta\| < 2.4$ No requirement on R_9
Data	31%	29%
Signal	19%	17%
σ_{eff}	3.3 GeV	3.2 GeV
FWHM	7.8 GeV	7.5 GeV

Table 3: Separate sources of systematic uncertainties accounted for in the analysis of the 7 and 8 TeV data set. The magnitude of the variation of the source that has been applied to the signal model is shown.

Source	7 TeV	8 TeV
Integrated luminosity	2.2%	4.4%
Theory		
- Gluon-gluon fusion cross section (scale)	+12.5% -8.2%	+7.6% -8.2%
- Gluon-gluon fusion cross section (PDF)	+7.9% -7.7%	+7.6% -7.0%
- Vector boson fusion cross section (scale)	+0.5% -0.3%	+0.3% -0.8%
- Vector boson fusion cross section (PDF)	+2.7% -2.1%	+2.8% -2.6%
- W associate production (scale)	+0.7% -0.8%	+0.2% -0.7%
- W associate production (PDF)	+3.5% -3.5%	+3.5% -3.5%
- Z associate production (scale)	+1.7% -1.6%	+1.9% -1.7%
- Z associate production (PDF)	+3.7% -3.7%	+3.9% -9.7%
- Top pair associate production (scale)	+3.4% -9.4%	+3.9% -9.3%
- Top pair associate production (PDF)	+8.5% -8.5%	+7.9% -7.9%
Branching fraction	6.7%,9.4% -6.7%,-9.3%	6.7%,9.4% -6.7%,-9.3%
Trigger		
- Electron	0.5%	2.0%
- Muon	0.5%	3.5%
Selection		
- Photon Barrel	0.5%	0.6%
- Photon Endcap	1.0%	1.0%
- Electron	0.8%	0.8%
- Muon	0.7%	1.4%
Signal scale and resolution		
- Mean	1.0%	1.0%
- Sigma	5.0%	5.0%
Event migration	5.0%	5.0%
Pileup		
- Electron	0.6%	0.8%
- Muon	0.4%	0.4%

CMS Results

- ✓ Expecting about 16 events in 7 TeV + 8 TeV at 125 GeV.
- ✓ Four categories divide the events in terms of the pseudorapidity of the leptons/photon, and on the shower shape of the photon for one of the topologies.
- ✓ Four and five order polynomials are used to parametrize the background in the different categories.



- ✓ At 125 GeV the expected and observed limits are 12 and 9 x SM, respectively.

Reference: CMS-HIG-13-006 at http://cms-physics.web.cern.ch/cms-physics/public/HIG-13-006-pas.pdf