Search for Higgs->Zγ and 2012 project summary

Giovanni Marchiori, Yanwen Liu, Kun Liu
LPNHE(Paris) and USTC(China)

27/03/2013
FCPPL workshop @ Nanjing

Introduction

- Search for $H \rightarrow Z\gamma$

  -- Motivation

  -- Data sets and event selection

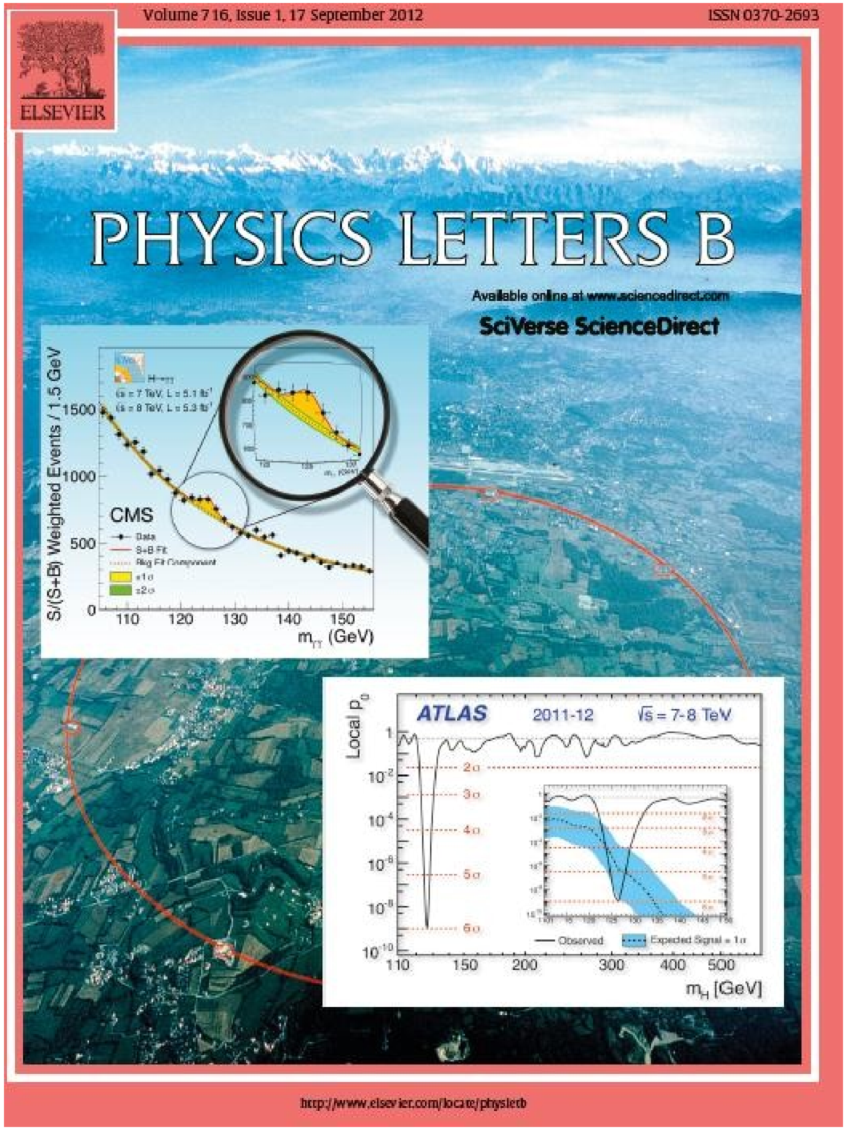
  -- Data-driven background decomposition

  -- Limit extraction

  -- Conclusion

- Summary of activities during year 2012

- Higgs-like particle have been discovered both in ATLAS/CMS on diboson channels : $\gamma\gamma$, $ZZ^{(*)}$, $WW^{(*)}$



- Properties of new particle ?
- Standard Model Scalar?

- Why $H \rightarrow Z\gamma$?

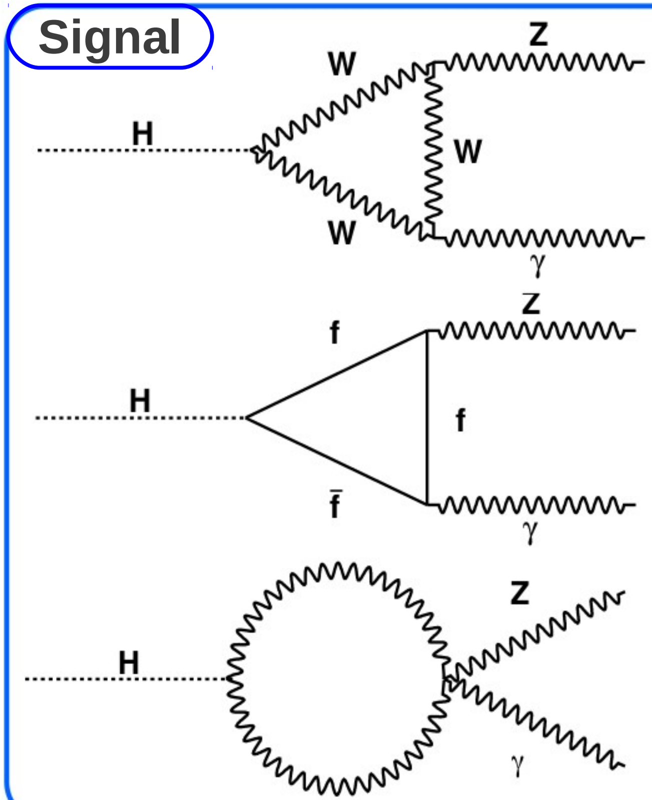
  -- decay rate can help determine whether the the new boson is SM Higgs boson

  -- sensitive to potential new particles decay into $Z\gamma$

Physical interest of the measurement

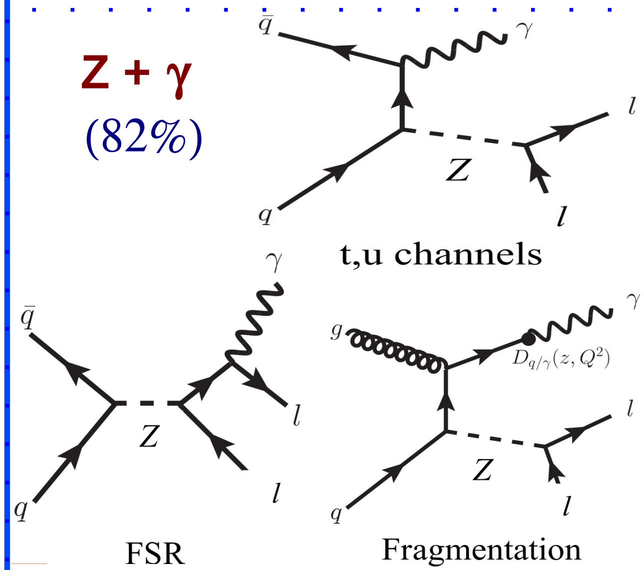
- In Standard Model, $H \to Z\gamma$ proceeds through loops(mostly W-loop)

Signal

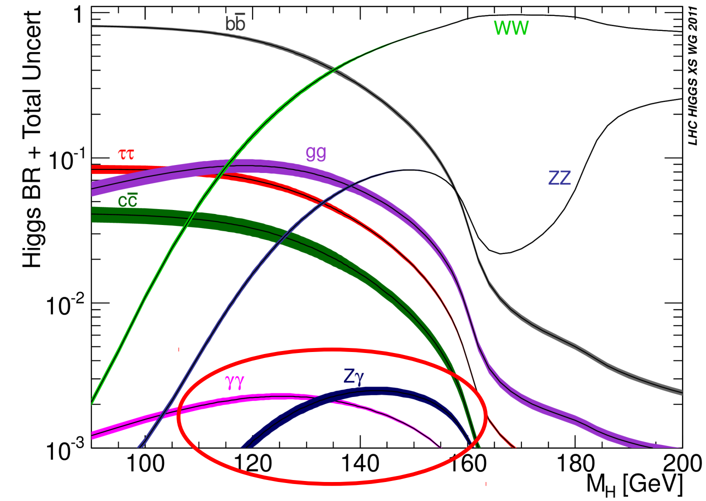


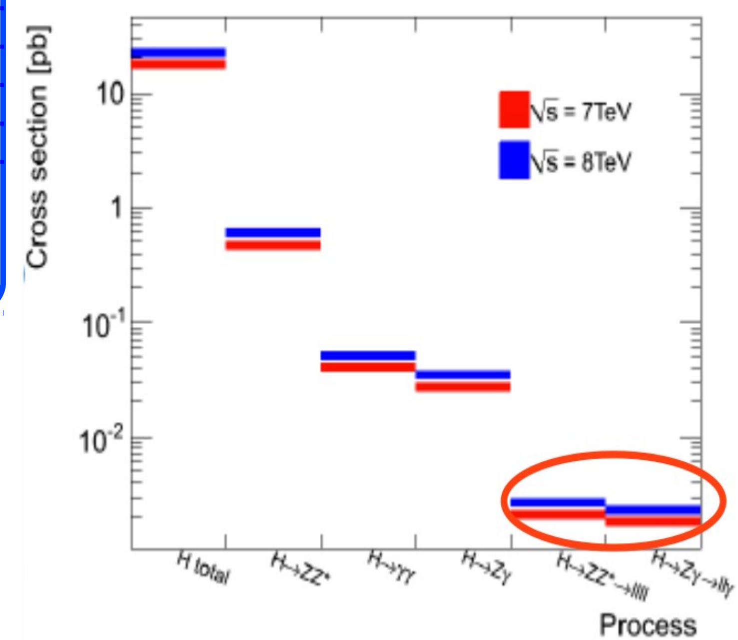
Background

Z + γ (82%)



Z + jet (17%): suppressed by photon ID+ isolation cuts





- $BF(H \to Z\gamma) \sim BF(H \to \gamma\gamma)$, $BF(Z \to ll) \sim 6.7\%$ gives yields comparable to $H \to ZZ^{(*)} \to llll$ (expect ~15 events in full 2011+ 2012 data for $m_H = 125$ GeV)

Data sets and event selection

Data sets

full 2011 + 2012 data sets
-- 7 TeV : 4.6 fb^{-1}
-- 8 TeV : 20.7 fb^{-1}

Signal simulation

Powheg+Pythia8: ggF and VBF processes 115-150GeV in steps of 5 GeV ,@7 and 8TeV
MCFM+Pythia8 : ggF @ 8TeV, for syst. Studies

Background simulation

Full simulation : Z+ γ (Sherpa, up to 3 jets), Z+ jets (Alpgen/Sherpa, up to 5 jets)
ttbar (MC@ NLO), WZ (Powheg + Pythia or Sherpa)

- **Event selection** (details in backup):

  -- Object quality requirement

  -- Single-/di-lepton(e,μ) triggers

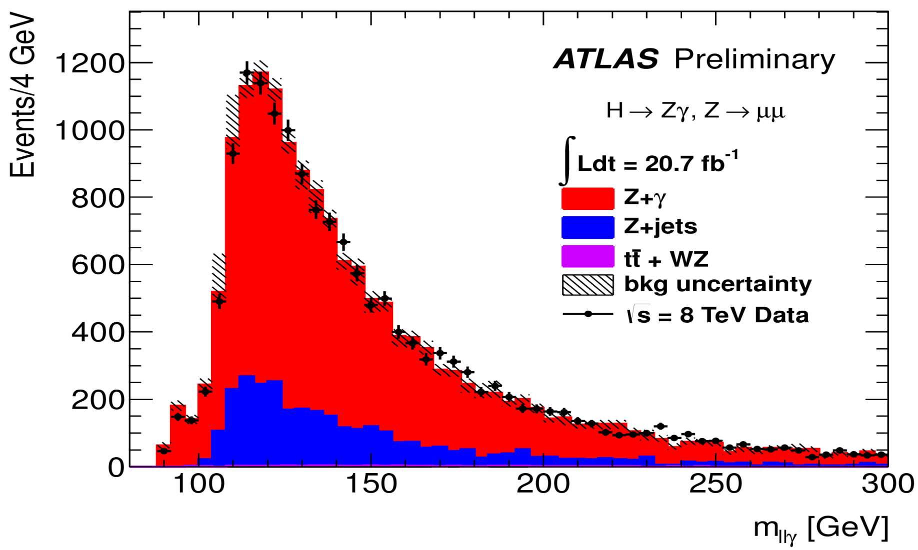
  -- Primary vertex requirement

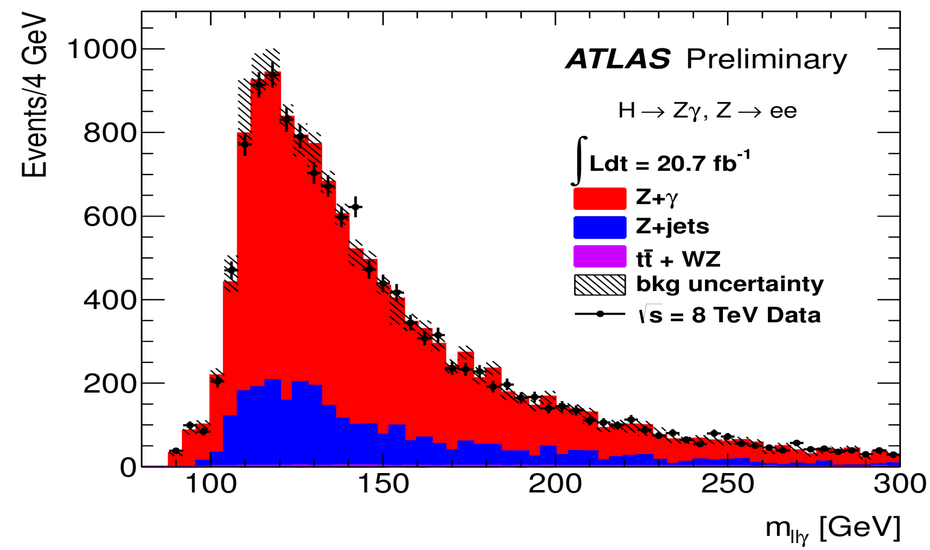
  -- Lepton E_T > 10GeV + kinematic and isolation requirements

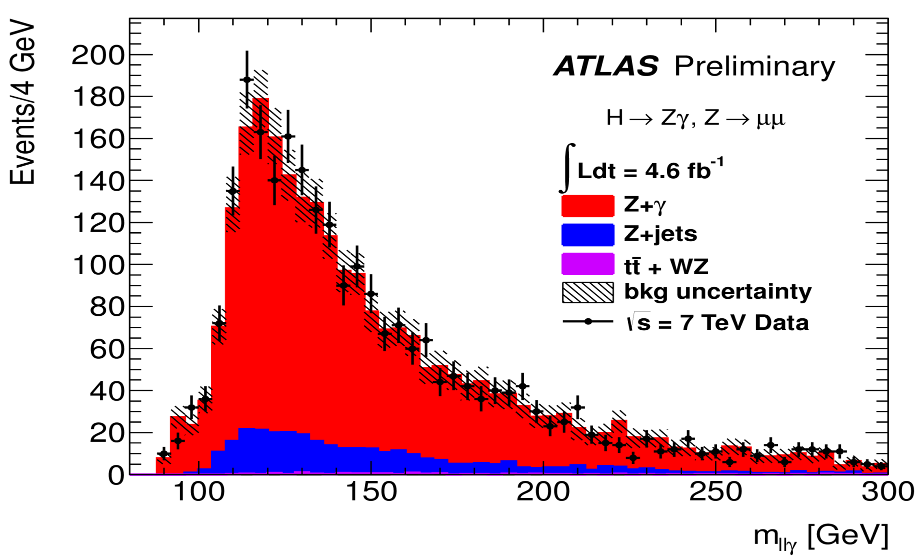
  -- Photon E_T > 15 GeV + kinematic and isolation requirements

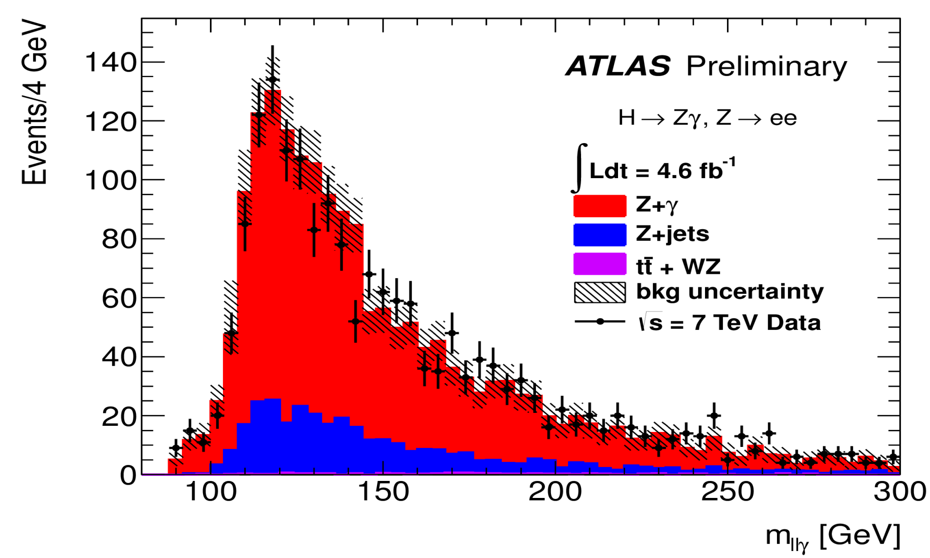
  -- Requirements for Z boson candidate

- **Data-driven background decomposition:** using two-dimensional sideband method to discriminate Z+γ vs Z+jet in data and using MC to estimate tt+WZ bkg.









Limit extraction

- **Set 95% C.L. limit** on production cross section times BF normalized to SM expectation and **p-values** for the compatibility of the data with background-only hypothesis by using likelihood-based statistical tests.

- **Unbinned likelihood** :

  -- $\Delta m = M_{ll\gamma} - M_{ll}$ as discriminating variable(insensitive to possible $H \rightarrow ll\gamma$ bkg:~5%)

  -- 4 categories based on lepton flavor and $\sqrt{s}$ @ 7 TeV or 8 TeV

Full Likelihood function →

$$L\left(\mu, \theta = \bigcup_{c=1}^{n_{cat}} \theta_c \middle| x = \bigcup x_c\right) = \prod_{c=1}^{n_{cat}} L_c(\mu, \theta_c | x_c)$$

Likelihood function in each category →

$$L_c(\mu, \theta_c | x_c) = e^{-N'_c} N_c'^{N_c} \prod_{k=1}^{N_c} \mathscr{L}_c(x_k | \mu, \theta_c)$$

Likelihood function in each event →

Signal PDF

Background PDF

$$\mathscr{L}_c(x|\mu, \theta_c) = \frac{N_{\mathrm{signal},c}(\mu, \theta_c^{norm})}{N_{\mathrm{signal},c} + N_{\mathrm{bkg},c}} f_{\mathrm{signal},c}(x|\theta_c^{shape}) + \frac{N_{\mathrm{bkg},c}}{N_{\mathrm{signal},c} + N_{\mathrm{bkg},c}} f_{\mathrm{bkg},c}(x|\theta_c^{bkg})$$

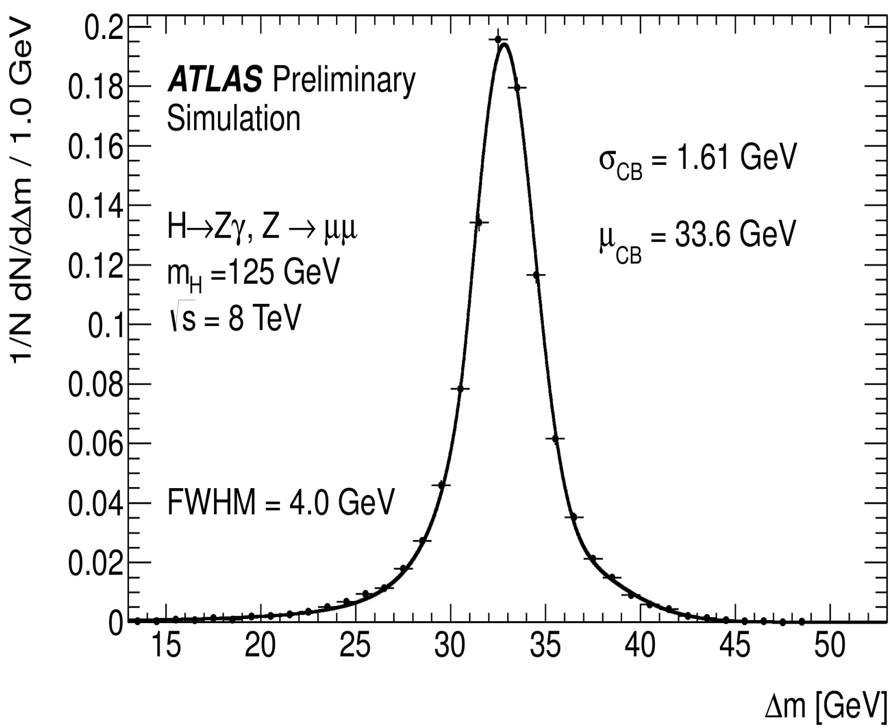
Signal parameters ($f_{\text{signal},c}(x|\theta_c^{shape})$)

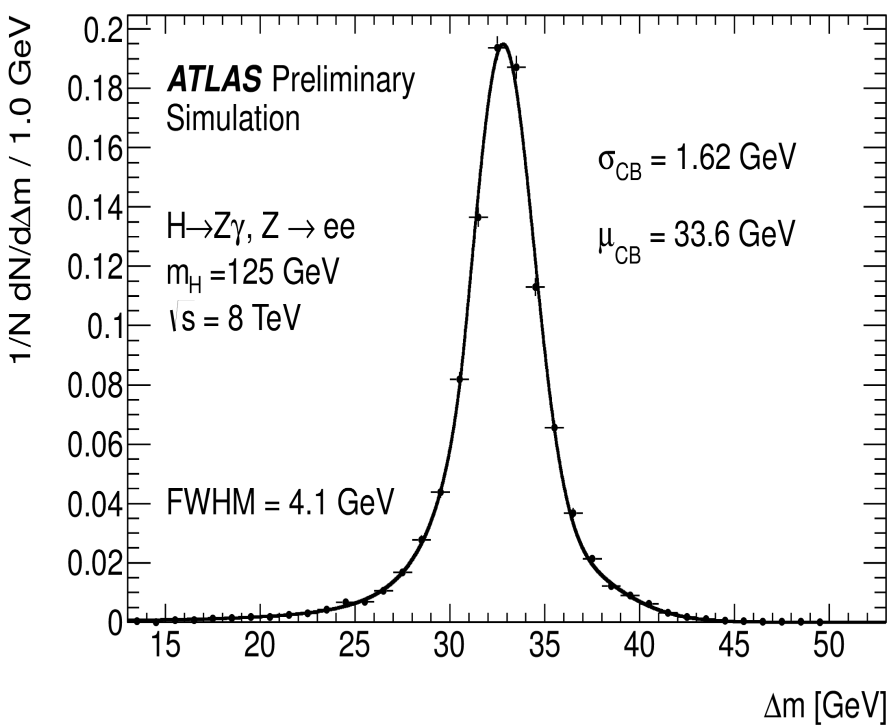
- **Expected signal yields**: $N_{i,\ell}(m_H) = \int \mathscr{L} dt \times \sigma_i(m_H) \times \mathscr{B}_{H\to Z\gamma}(m_H) \times \mathscr{B}_{Z\to\ell\ell} \times \varepsilon_{i,\ell}(m_H)$

  -- Higgs BF and x-section from theory

  -- efficiency for production from signal MC plus parabolic interpolation for ggF and VBF processes. And use average of ggF and VBF efficiency for VH,ttH

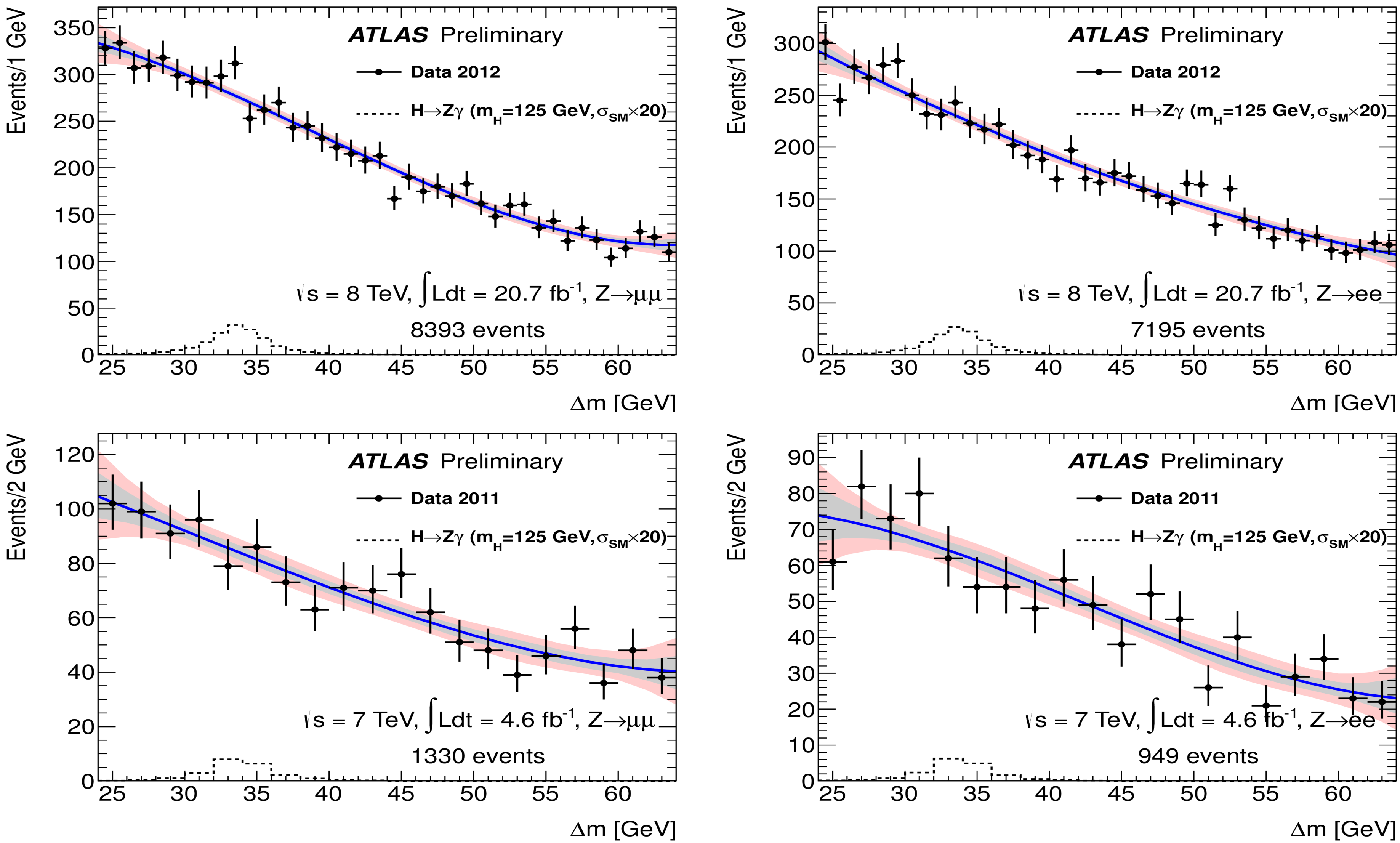
- **Signal model** : Crystal-Ball + Gaussian, global fit of the parameters vs m_H .





Background model ($f_{\mathrm{bkg},c}(x|\theta_c^{bkg})$)

- Choose background model and fit region which minimises σ_N and does not introduce too large bias(spurious signal) on the fitted signal
- Chosen fit range + model : 24< Δm < 64 GeV, 3rd degree polynomial



Systematic uncertainties at $m_H = 125$ GeV

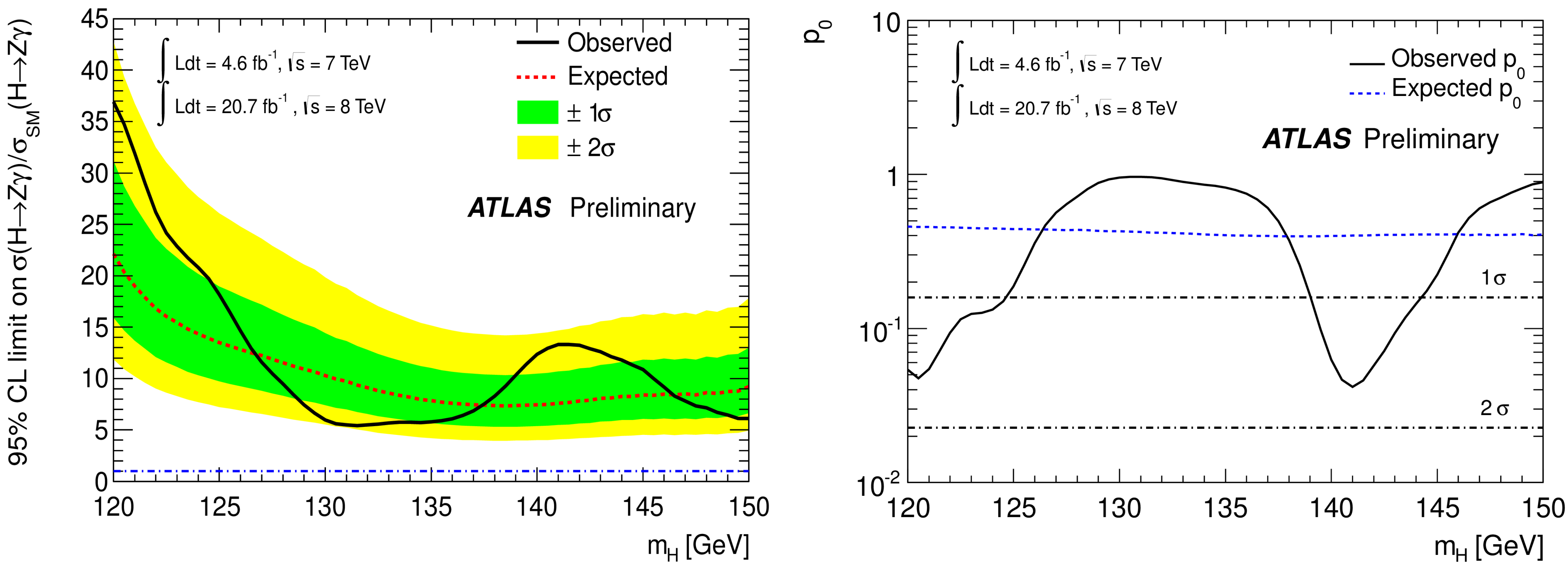
- **Theory uncertainty** on x-section and Higgs BF from Higgs@LHC x-section WG
- **Experiment uncertainties**:

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

- **Taking into account the bias from background modeling** ("spurious signal")

Results with 4.6 fb^{-1} @ 7TeV + 20.7 fb^{-1} @ 8TeV

- **Total number of nuisance parameters** : 39



- **Observed (expected) upper limit** at 125GeV : 18.2xSM (13.5xSM)
- **Observed (expected) significance** at 125GeV : 0.14 **σ** (0.89 **σ**)
- **Maximum upward fluctuation at 141 GeV** : 1.7 **σ**

Conclusion

- A search for $H \rightarrow Z\gamma$ performed with 4.6 fb^{-1} @ 7TeV + 20.7 fb^{-1} @ 8TeV
- For $120 < m_H < 150$ GeV :

  -- expected limits vary between 7.3 and 22.1xSM

  -- observed limits vary between 5.4 and 36.9xSM
- At 125 GeV :

  -- the observed (expected) limits are 18.2xSM (13.5xSM)

  -- the observed (expected) local significance is 0.89σ (0.14σ)
- The biggest local excess of 1.7σ significance is found at 141 GeV

List of all projects for 2012

- Photon performance

  -- Proposed di-photon medium trigger

  -- Photon trigger efficiency measurement

  -- Photon Identification efficiency measurement

- Physics studies

  -- Measurement of the SM isolated photon pair production cross section

  -- Observation of a new particle in search for the Standard Model Higgs boson

  -- Measurements of the propeties of the Higgs-like boson in two photon decay channel with 25 fb^{-1} of proton-proton collision data

  -- Search for Standard Model Higgs boson in the $H \rightarrow Z\gamma$ decay model with 7TeV and 8 TeV data

Photon performance

- **Proposed di-photon medium triggers for the 2012 data taking**: re-optimized criteria on loose trigger to be more robust against pile up, and adding loose cut on strip variable(Eratio) to reduce trigger rate
  - -- EF_2g20vh_medium : for SM di-photon x-section measurement
  - -- EF_g30_medium_g20_medium : as backup trigger for $H \rightarrow \gamma\gamma$ analysis
- **Photon trigger efficiency measurement** using photons from radiative Z decays : public note on the trigger efficiency measurement is in preparation
  - -- EF_g35_loose_g25_loose : 99.40% ± 0.23% (used in $H \rightarrow \gamma\gamma$ Moriond results)
  - -- EF_g30_medium_g20_medium : 99.01% +0.21% / - 0.22%
  - -- EF_2g20vh_medium : 98.74% ± 0.16 %
- **Photon identification efficiency measurement:** performed two data-driven measurements with two alternative techniques.
  - -- conference note for 2011 data: http://cds.cern.ch/record/1473426
  - -- paper in preparation both for 2011/2012 data: (one summary talk at Higgs $\rightarrow \gamma\gamma$ workshop) https://indico.cern.ch/getFile.py/access?contribId=8&sessionId=2&resId=0&materialId=slides&confId=214002
  - -- Poster was shown in LHCC 2013 : https://indico.cern.ch/getFile.py/access?contribId=149&sessionId=8&resId=0&materialId=slides&confId=238337

- Measurement of the SM isolated photon pair production cross section @ 7TeV : JHEP01(2013)086

  -- mainly contributed by Giovanni M.(editor), Lydia R.(editor),Sandrine L. and Kun L.

- Observation of a new particle in search for Standard Model Higgs boson

  Phys. Lett. B 716 (2012) 1-29 , our main contribution :

  -- trigger efficiency and photon identification efficiency measurement

  -- data-driven background decomposition

- Search for Standard Model Higgs boson in the $H \rightarrow Z\gamma$ decay mode with 7TeV and 8TeV data : ATLAS-CONF-2013-009 (https://cds.cern.ch/record/1523683)

  -- mainly contributed by Giovanni M.(editor) and Kun L.(supporting note editor)

Back up

- Use lowest-threshold unprescaled lepton/dilepton triggers

Year/period	Electron triggers	Muon triggers
2011 B-I	e20_medium	mu18_MG
	2e12_medium	2mu10_loose
2011 J	e20_medium	mu18_MG_medium
	2e12_medium	2mu10_loose
2011 K	e22_medium	mu18_MG_medium
	2e12T_medium	2mu10_loose
2011 L-M	e22vh_medium1	mu18_MG_medium
	2e12Tvh_medium	2mu10_loose
	e24vhi_medium1	mu24i_tight
2012	e60_medium1	mu36_tight
	2e12Tvh_loose1	mu18_tight_mu8_EFFS

- Trigger requirement is the logical OR of the various chains used

- Efficiency relative to offline > 98% for $ee\gamma$, 92% for $\mu\mu\gamma$ (calo/standalone muons not triggering + acceptance of muon trigger in barrel)

Event selection (II) -- Leptons

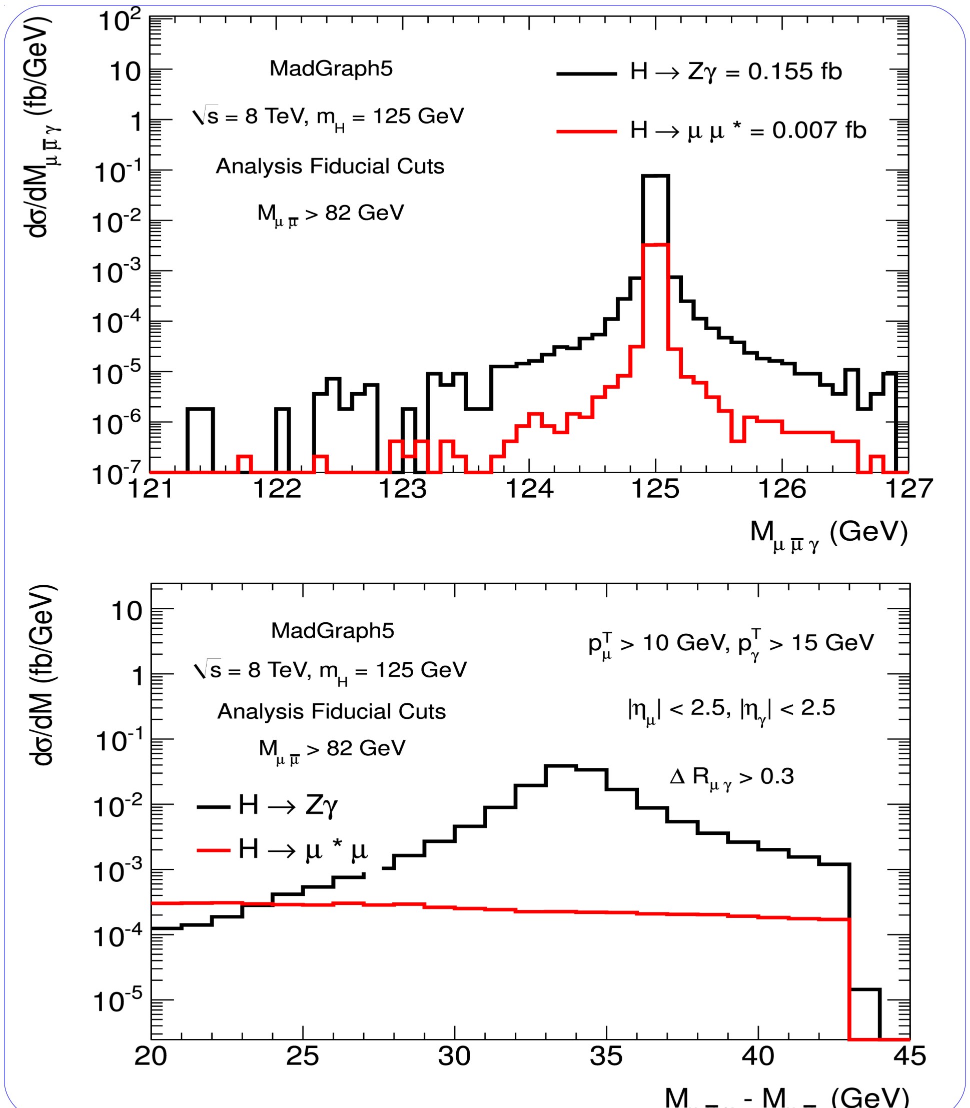
- Similar to $H \to 4l$
- Muons:
  - staco (stand-alone + segment-tagged + combined) or calo, passing tight ID
  - $p_T > 10$ GeV (15 GeV for calo), $|\eta| < 2.7$ (0.1 for calo)
  - recommended MCP cuts on hits in B-layer, pixel, SCT, TRT, MS
  - impact parameter: $|d_0| < 1$ mm , $|z_0| < 10$ mm
  - overlaps: remove duplicate muons reconstructed by different algos
- Electrons:
  - std. author, pass e/γ object quality (OQ) cuts, loose++ ID and hit in B-layer
  - $E_T > 10$ GeV, $|\eta| < 2.47$
  - overlaps: resolve e/m overlaps (same ID track), remove 2nd electron overlapping with higher-p_T electron
  - $|z_0| < 10$ mm

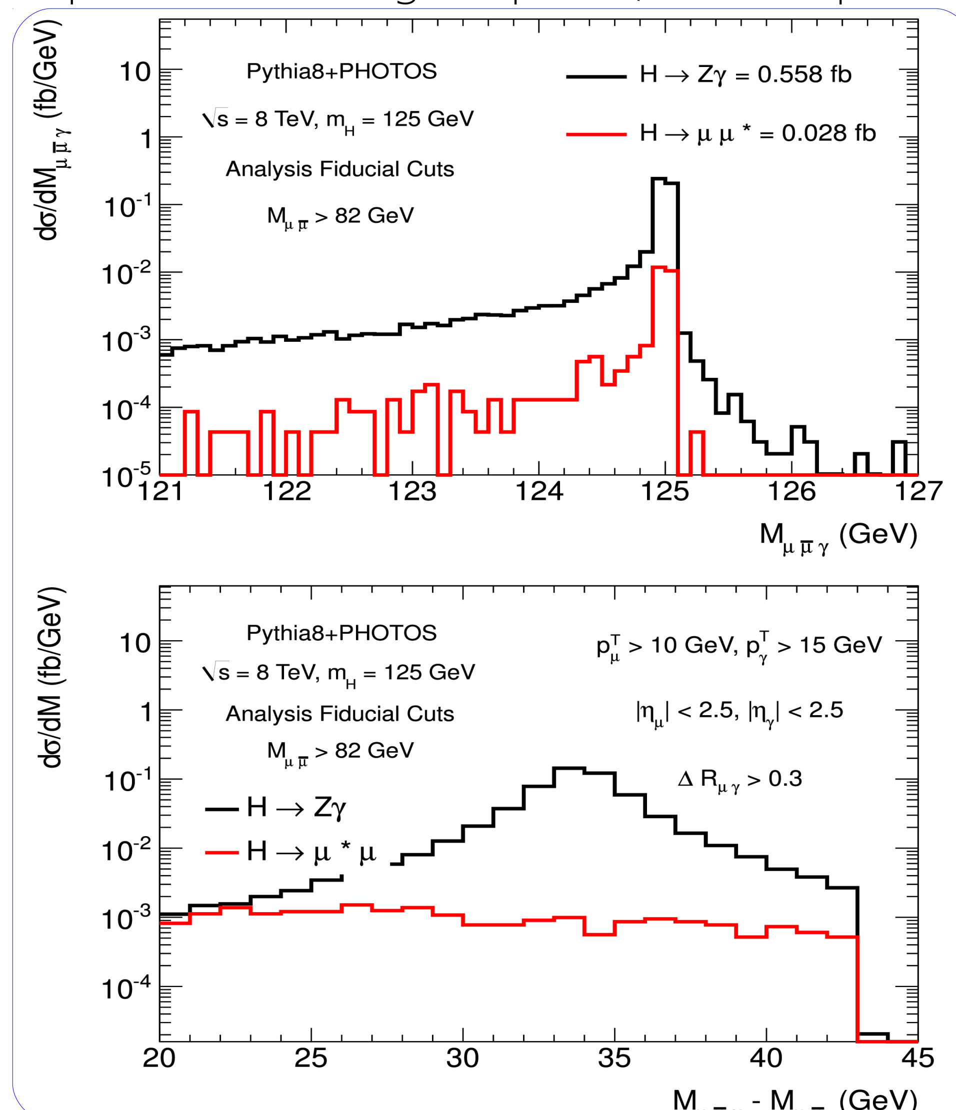
Event selection (III) -- photon and Z

- Photon: selection similar to $H \to \gamma\gamma$ (but lower threshold and no track isolation)
  - $E_T^\gamma > 15$ GeV, $|\eta^\gamma| < 2.37$ (remove $1.37 < |\eta^\gamma| < 1.52$), $\Delta R_{l\gamma} > 0.3$
  - pass e/γ OQ and photon cleaning requirements
  - tight ID (cut-based)
  - calorimeter isolation (based on topocluster) in cone $\Delta R = 0.4 < 4$ GeV
    - corrected for UE+pileup and out-of-cluster leakage
  - keep highest-E_T photon
- Z:
  - two same-flavor, opposite-sign leptons (at least one staco μ for μμ)
  - keep pair with m_{ll} closest to m_Z, require $m_{ll} > m_Z - 10$GeV (suppresses Drell-Yan and bkg from internal photon conversion in $H \to \gamma\gamma^*$)
  - match reco leptons to trigger objects
  - isolation in calorimeter ($E_T^{cone20}/p_T < 0.15 - 0.3$) and in tracker ($p_T^{cone20}/p_T < 0.15$, removing contribution from the other lepton in cone)
  - d_0 significance < 3.5 (μ, except standalone) or < 6.5 (e)

Background modeling

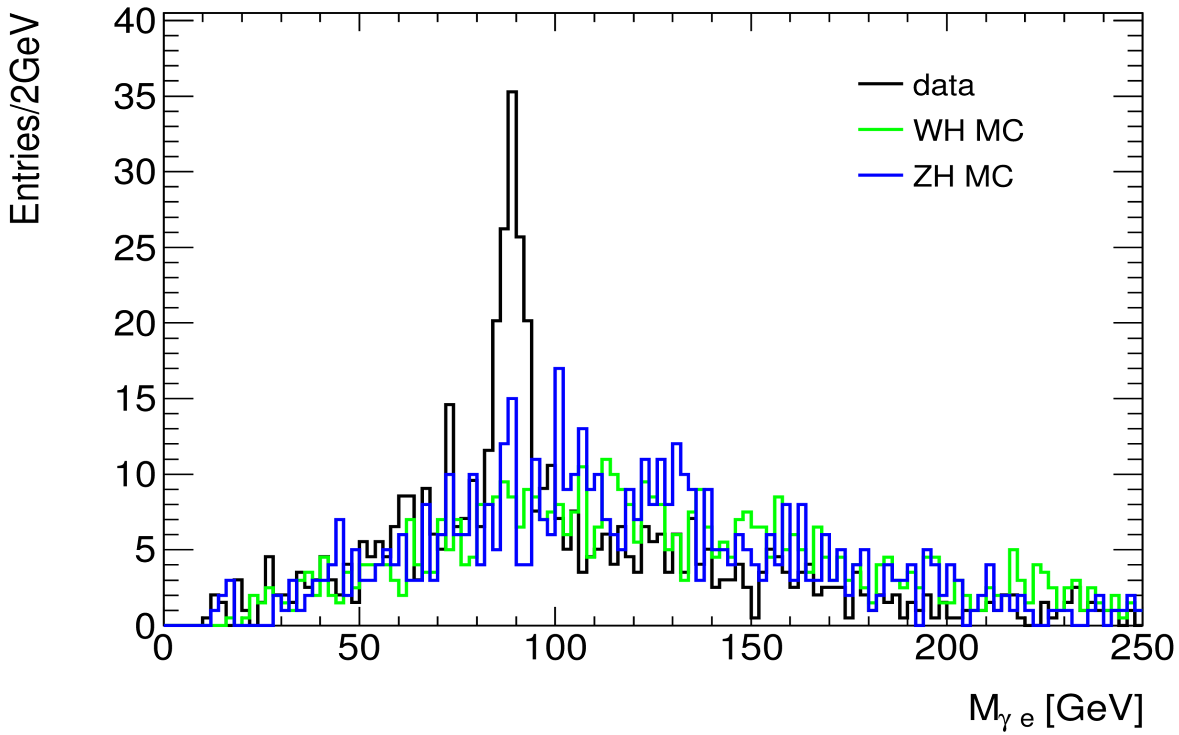
- Using Mllγ as discriminating variable, ~10% contamination of H → μ⁺μ⁻ is not negligible and peaks under signal peak(upper plots), while using Mllγ-Mll, the contamination is much smaller and does not peak under signal peak(bottom plots).





Z mass window remove in VH category in $H \rightarrow \gamma\gamma$ Moriond analysis

- VH category selection improvement from HCP to Moriond: we proposed Z mass window remove in this category by adding selection on $Me\gamma$ to enhance WH/ZH signal's fraction.



- This selection gives 20% improvement on the error of μ_{VH}, which is the important improvement for μ_{VH} measurement.