Search for the Higgs Boson in the $H \rightarrow \gamma\gamma$ channel

Background studies, statistical analysis and results

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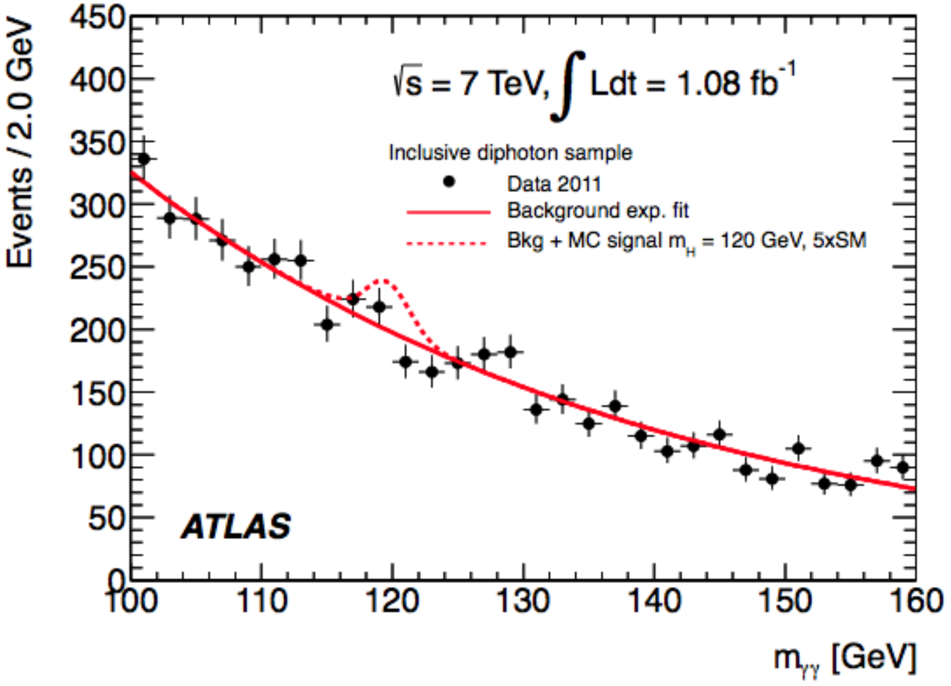
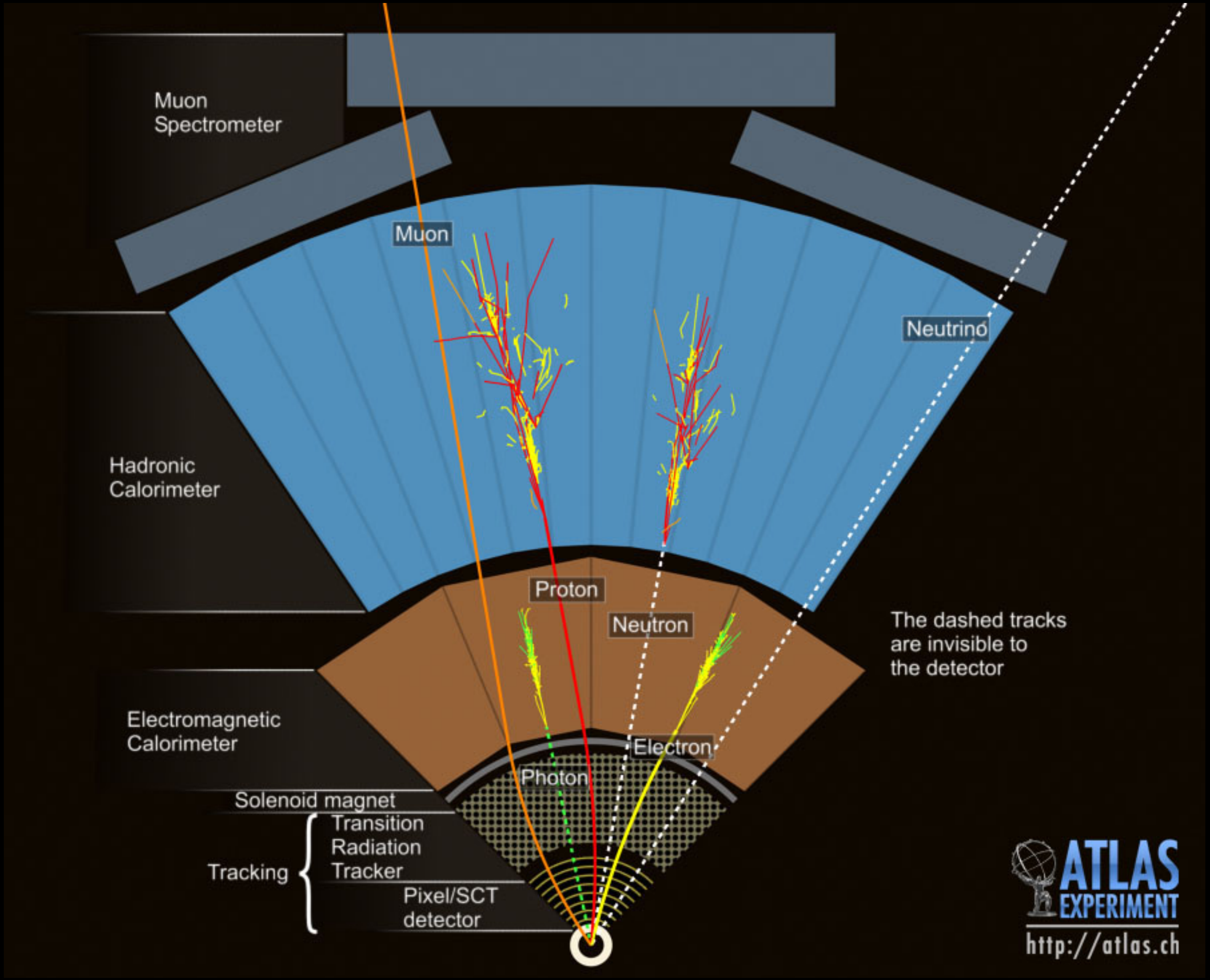


- Background studies
- Signal studies (O. Davignon)
- Statistical analysis and results
- Perspectives (O. Davignon)

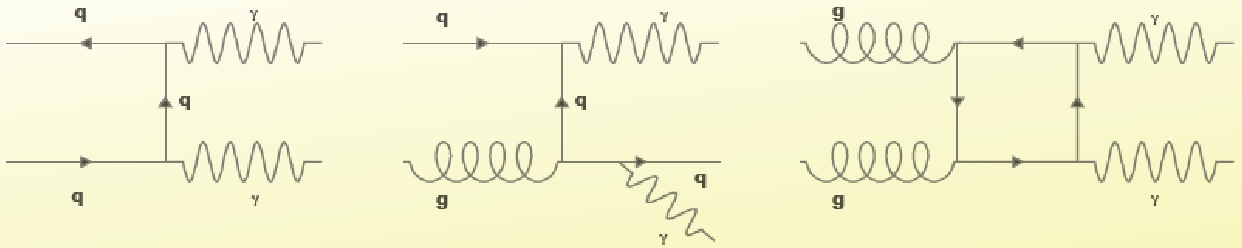
Particles through ATLAS



BACKGROUND

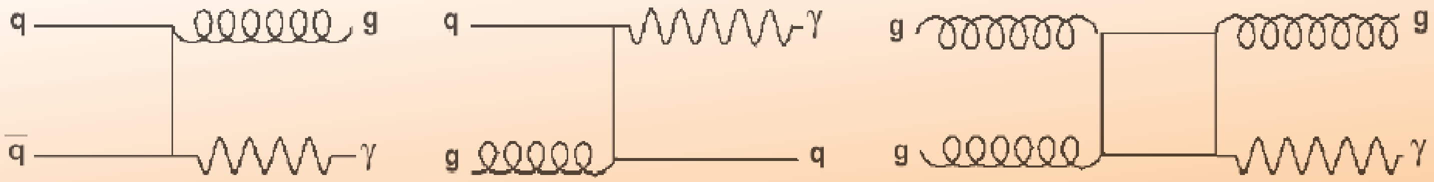
Background processes

- Irreducible: diphoton QCD production:

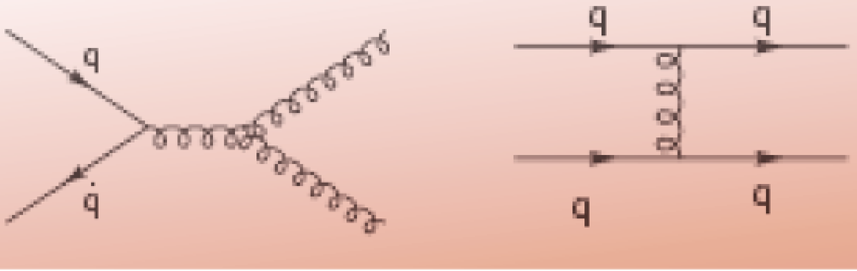


- Reducible: One or two jets fragmenting into a leading neutral hadron (mainly π^0) faking photons. Jet rejection O(5000).

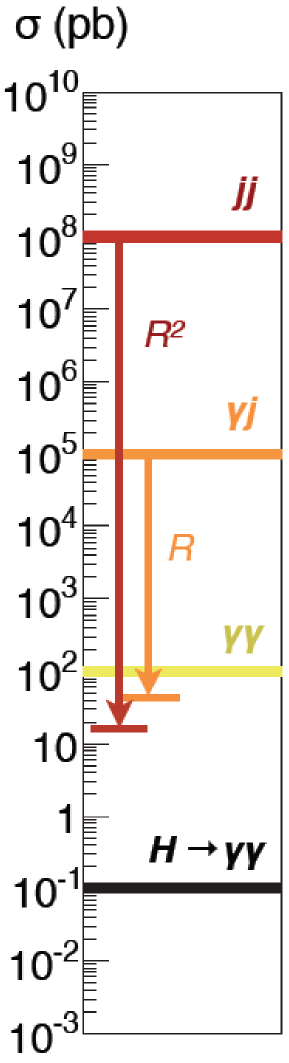
  - Gamma-jet events



  - Dijet events

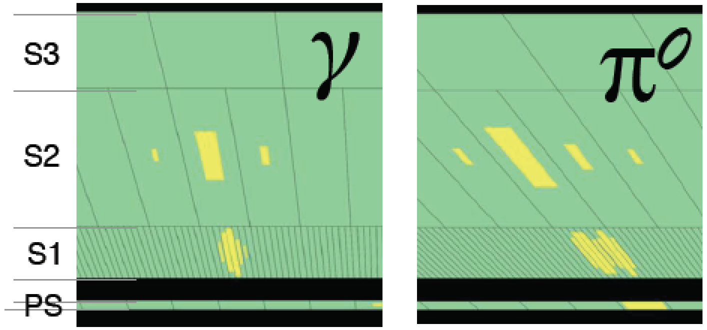


- Drell-Yan events, when both electrons are misidentified as converted photons.



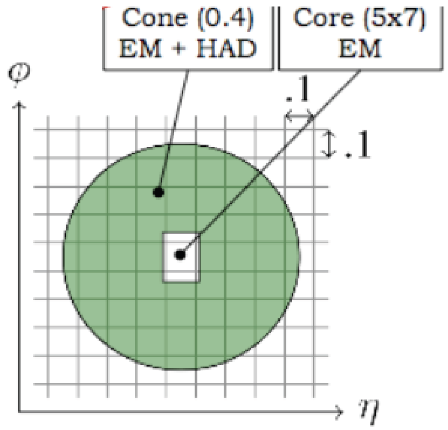
Event selection

- Start with a 20 GeV diphoton trigger (EF_2g20_loose).
- Use Egamma GRL for central electrons and photons.
- Require at least one PV ($N_{tracks} \geq 3$)
- At least two photons:
  - $E_{\perp 1} > 40$ and $E_{\perp 2} > 25$ GeV
  - $|\eta| < 1.37$ & $1.52 < |\eta| < 2.37$
  - LAr cleaning and object quality
  - Shower shape photon ID (isEM tight)
  - Calorimetric isolation ($E_{\perp}^{isol} < 5$GeV)



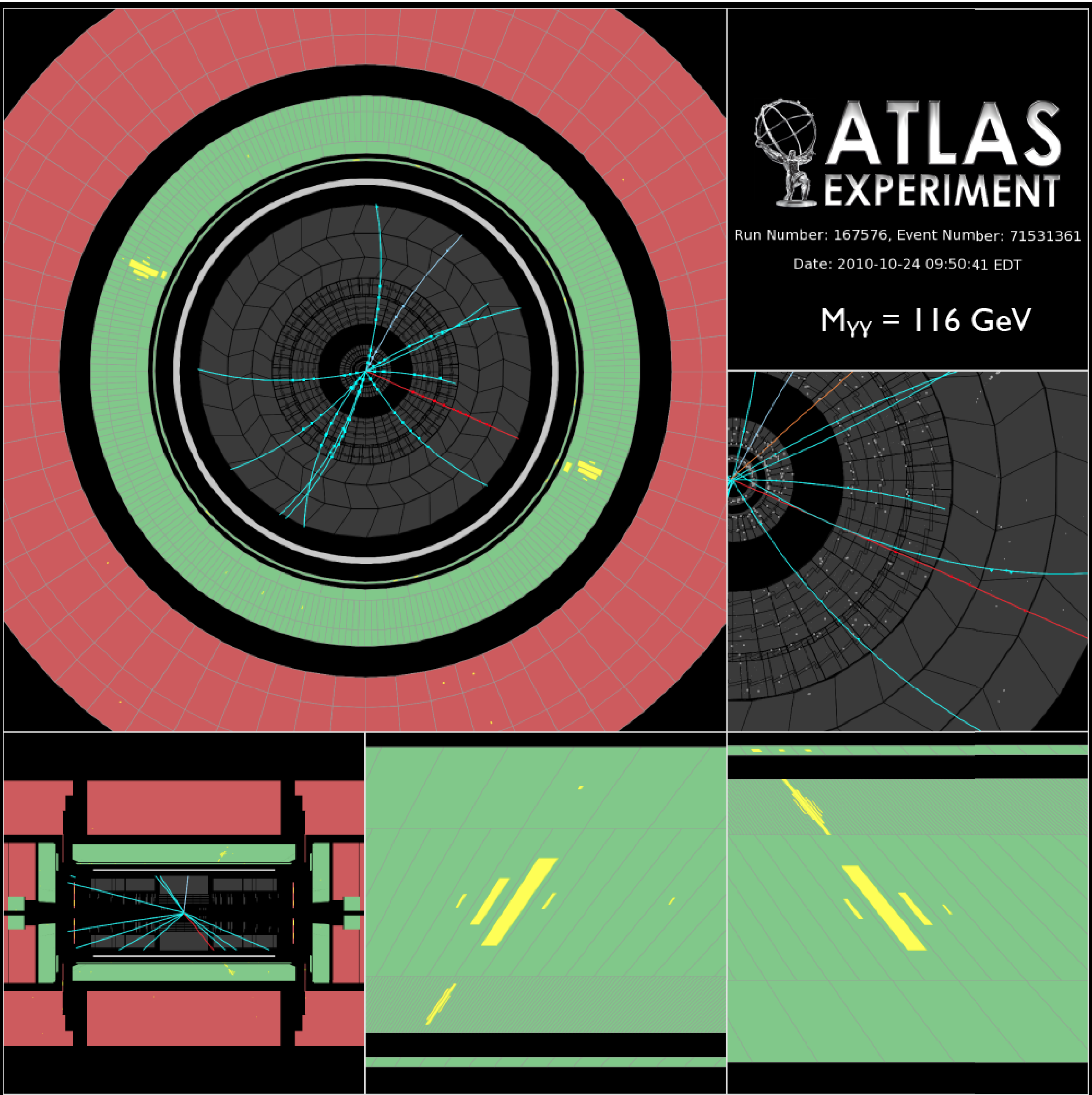
Shower shape based **photon ID:**

- Energy leakage to HCal
- 3 S2 discriminant variables
- 5 var. exploiting the S1 high granularity

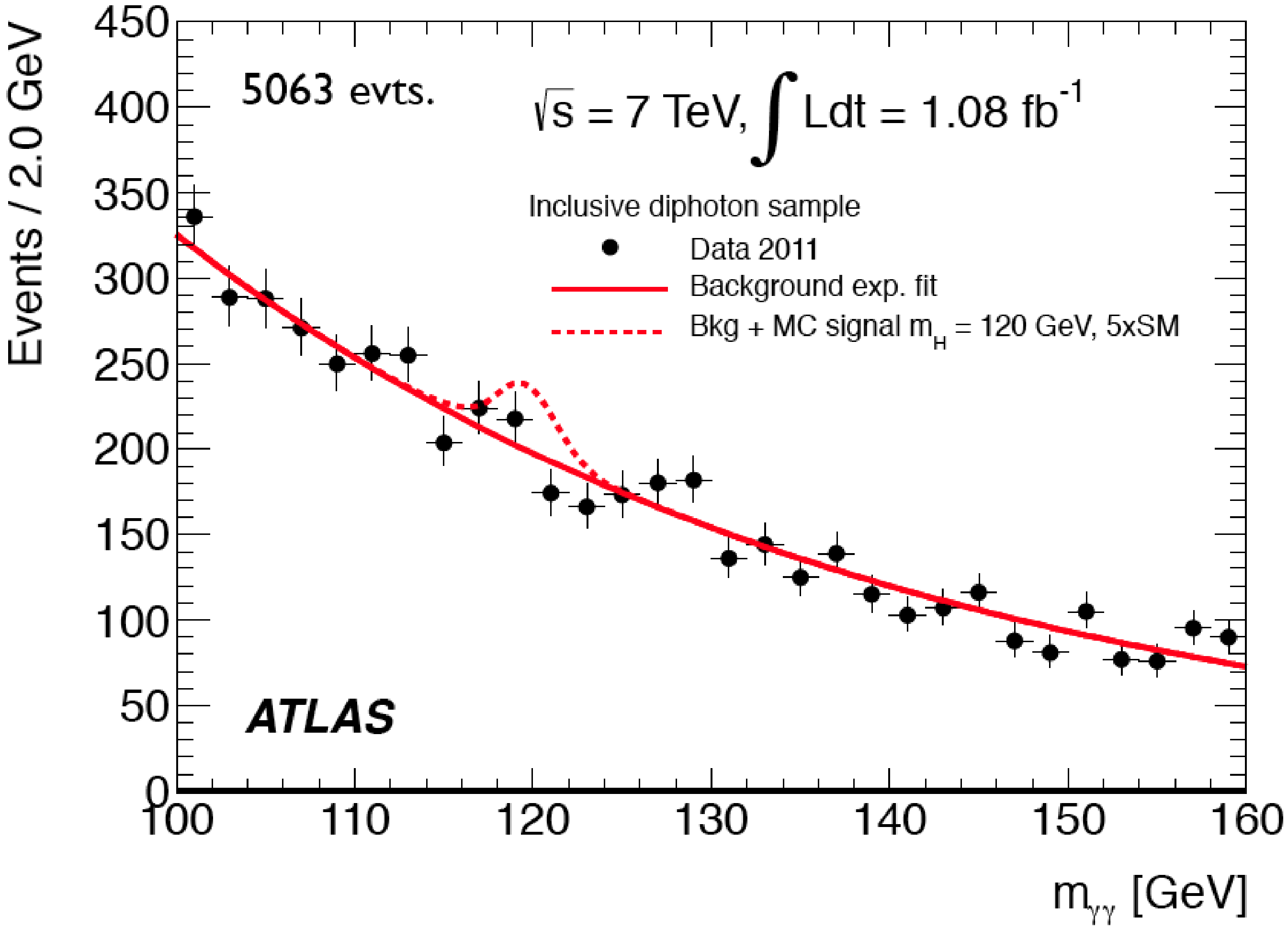


Calorimetric isolation:

- Sum of $E_{\perp}$ of calo cells in a cone (0.4), excluding the cluster cells.
- Out-of-(inner)-cone leakage corrections.
- Ambient energy correction event per event (to reduce the effects of underlying event and pile-up).


ATLAS EXPERIMENT
Run Number: 167576, Event Number: 71531361
Date: 2010-10-24 09:50:41 EDT
$M_{\gamma\gamma}$ = 116 GeV

Diphoton invariant mass distribution

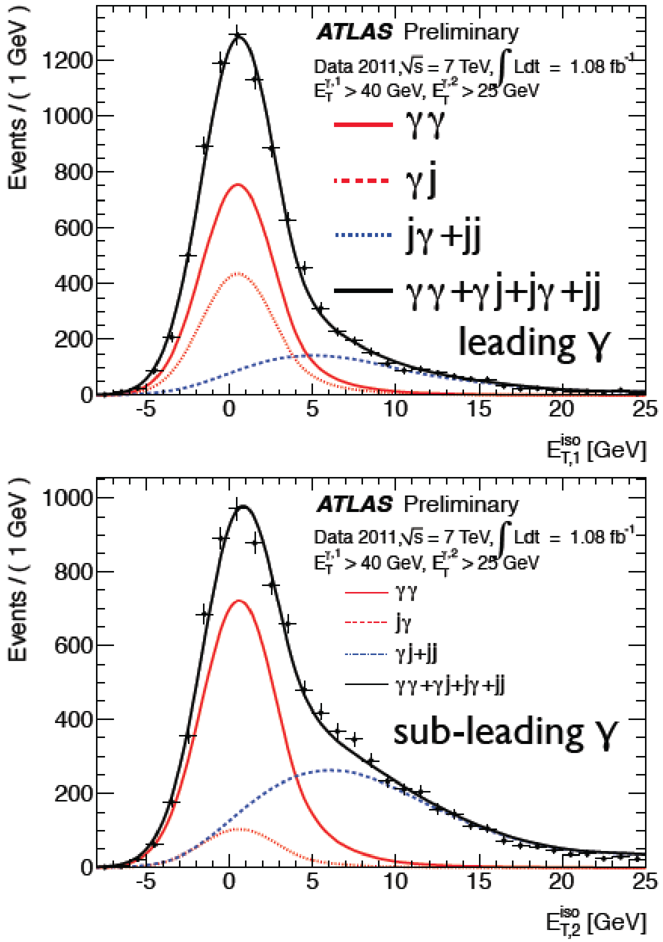


- The H→γγ channel has an important amount of background w.r.t. the expected signal.
- This background has a smooth decreasing shape.

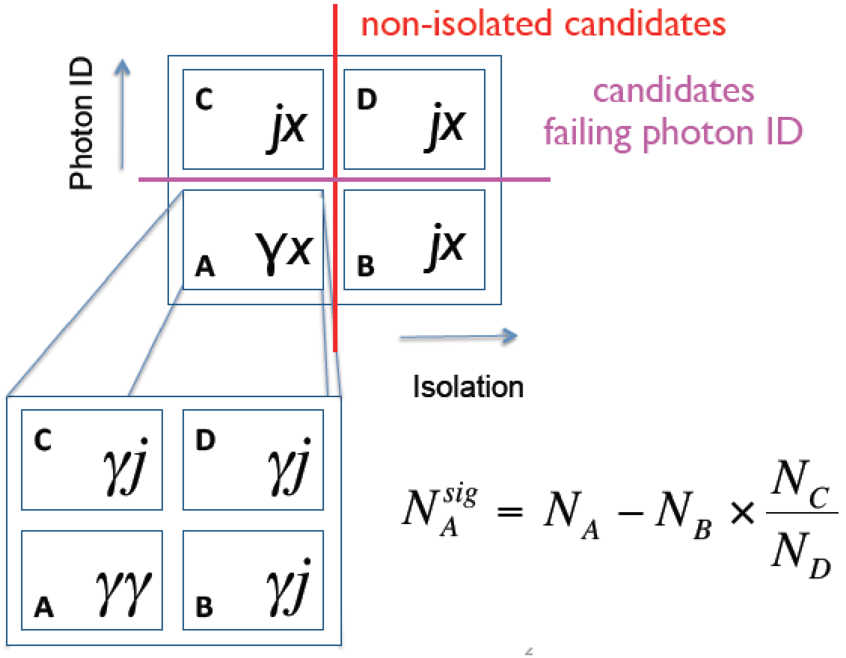
Background decomposition

Extraction of 4 background components, γγ, γ-jet, jet-γ and jet-jet, through different data-driven methods.

2D fit of the two photons calo-isolation distributions (PDFs obtained from data)



2x2D sideband, one for the leading and another one for the sub-leading.



$$N_A^{sig} = N_A - N_B \times \frac{N_C}{N_D}$$

2D sideband: define two sidebands, and so 4 region, 3 dominated by bkg., count the events and extrapolate the background by rule of three.

Drell-Yan background

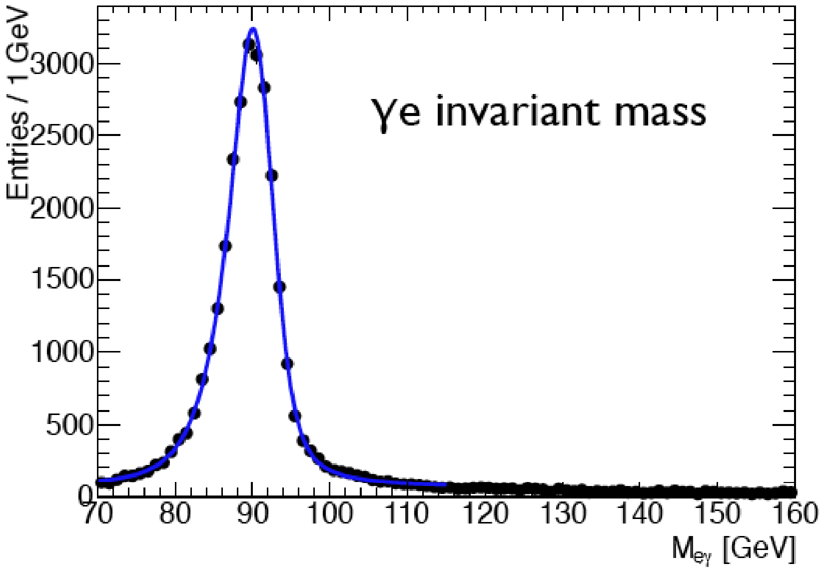
- After counting the number of $Z \rightarrow ee$ events reconstructed as ee and eγ events the **electrons mis-ID rates** is estimated to be:

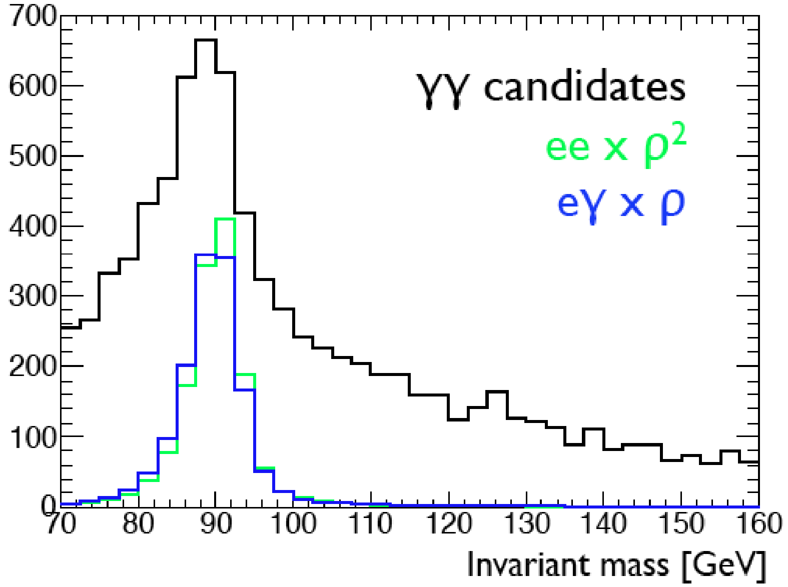
  ρ = 9.68 ± 0.05 ± 0.78 %

- The expected background is extrapolated from the e^+e^- mass spectrum and ρ

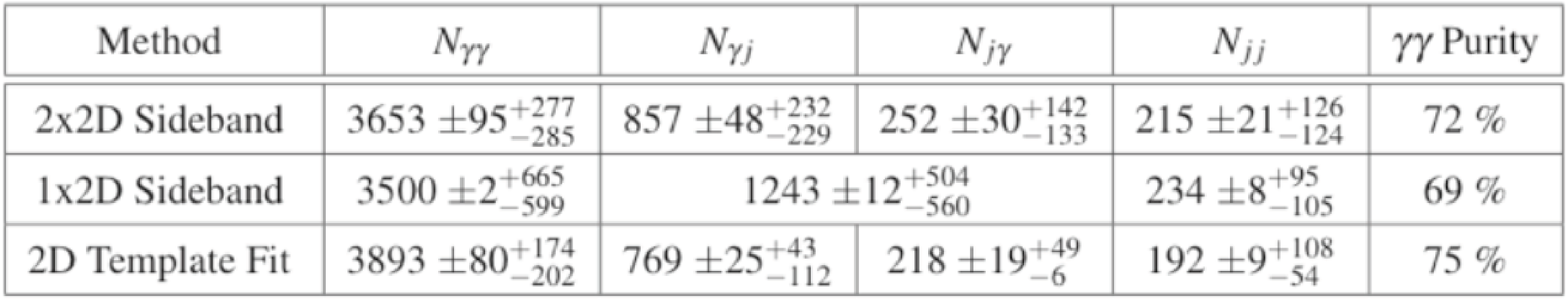
- For 1.08 fb^{-1}, the expected number of evts. in the mass window 100 and 160 GeV is:

  85.8 ± 0.9 ± 13.8



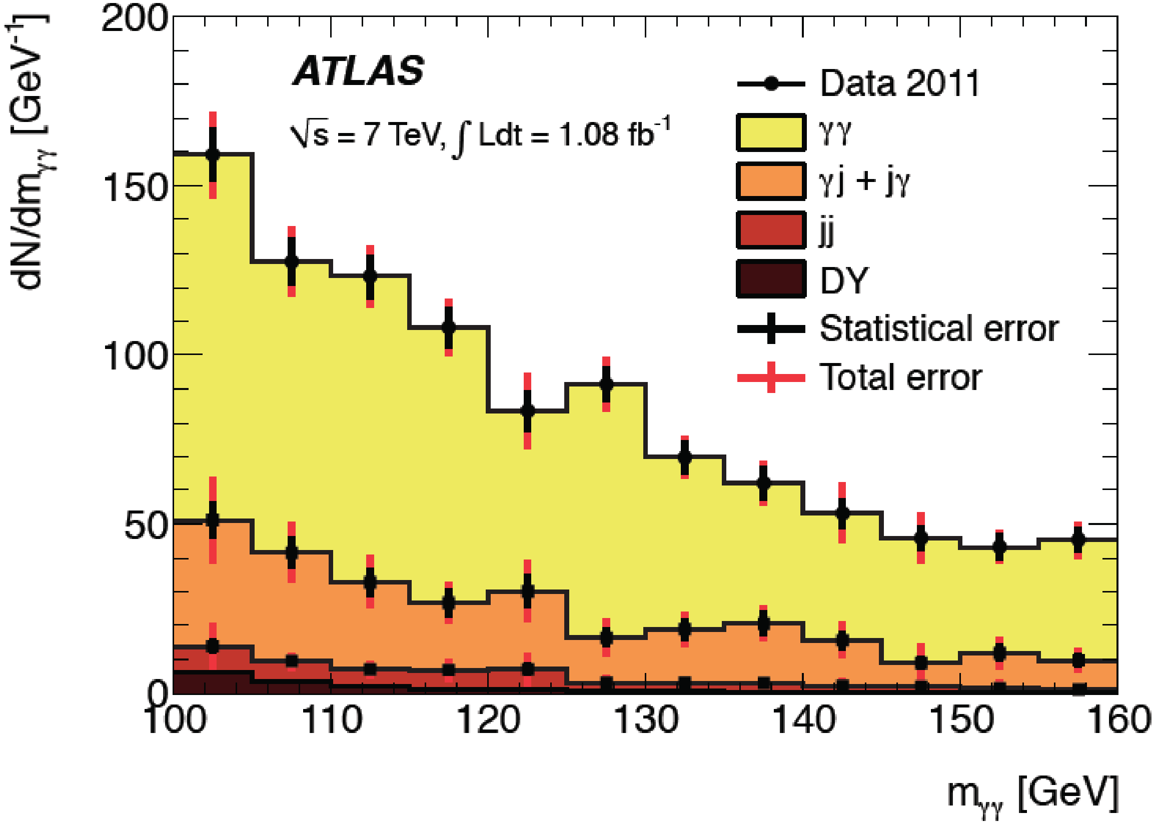


Background decomposition results



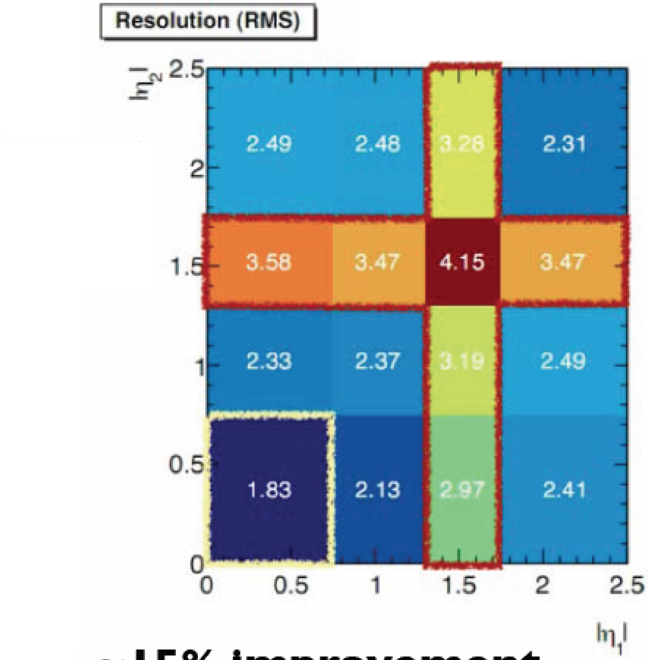
Method	$N_{\gamma\gamma}$	$N_{\gamma j}$	$N_{j\gamma}$	N_{jj}	$\gamma\gamma$ Purity
2x2D Sideband	$3653 \pm 95^{+277}_{-285}$	$857 \pm 48^{+232}_{-229}$	$252 \pm 30^{+142}_{-133}$	$215 \pm 21^{+126}_{-124}$	72 %
1x2D Sideband	$3500 \pm 2^{+665}_{-599}$	$1243 \pm 12^{+504}_{-560}$		$234 \pm 8^{+95}_{-105}$	69 %
2D Template Fit	$3893 \pm 80^{+174}_{-202}$	$769 \pm 25^{+43}_{-112}$	$218 \pm 19^{+49}_{-6}$	$192 \pm 9^{+108}_{-54}$	75 %

- Good agreement between the different methods is observed.
- ~70% diphoton pure sample!!
- The background composition is extracted as a function of the mass bin by bin.



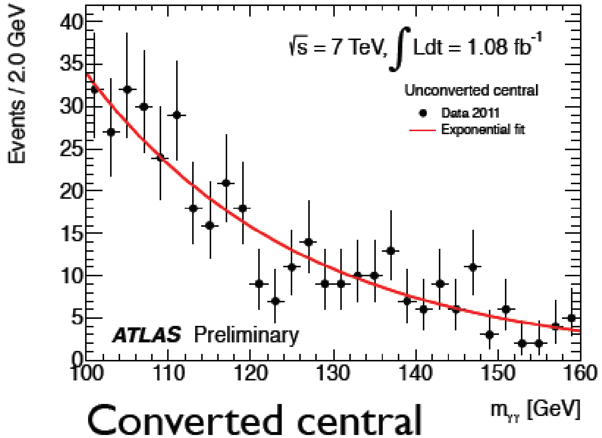
Conversion-η categories

Resolution motivated categorization.

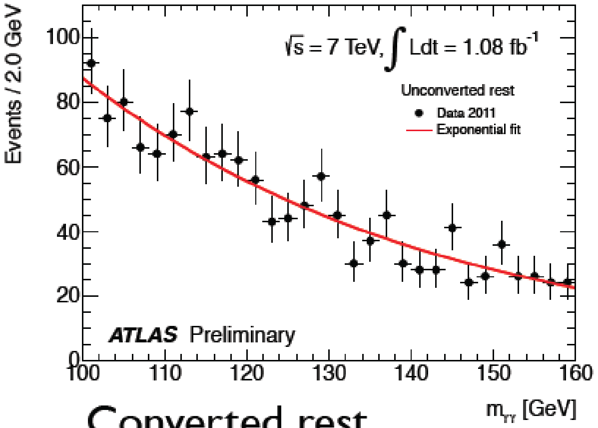


~15% improvement

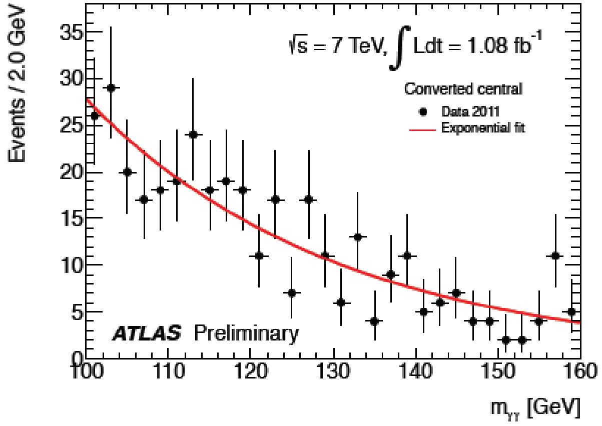
Unconverted central



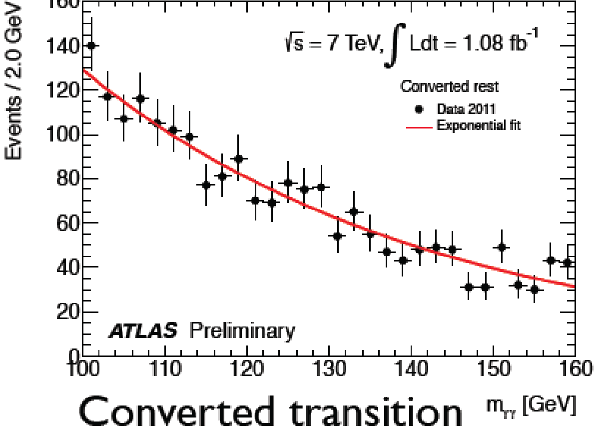
Unconverted rest



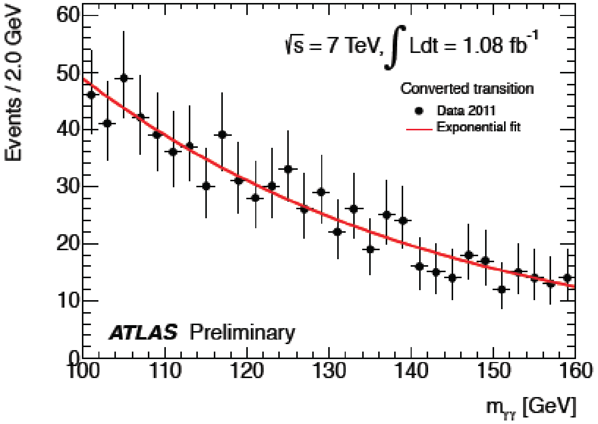
Converted central



Converted rest



Converted transition

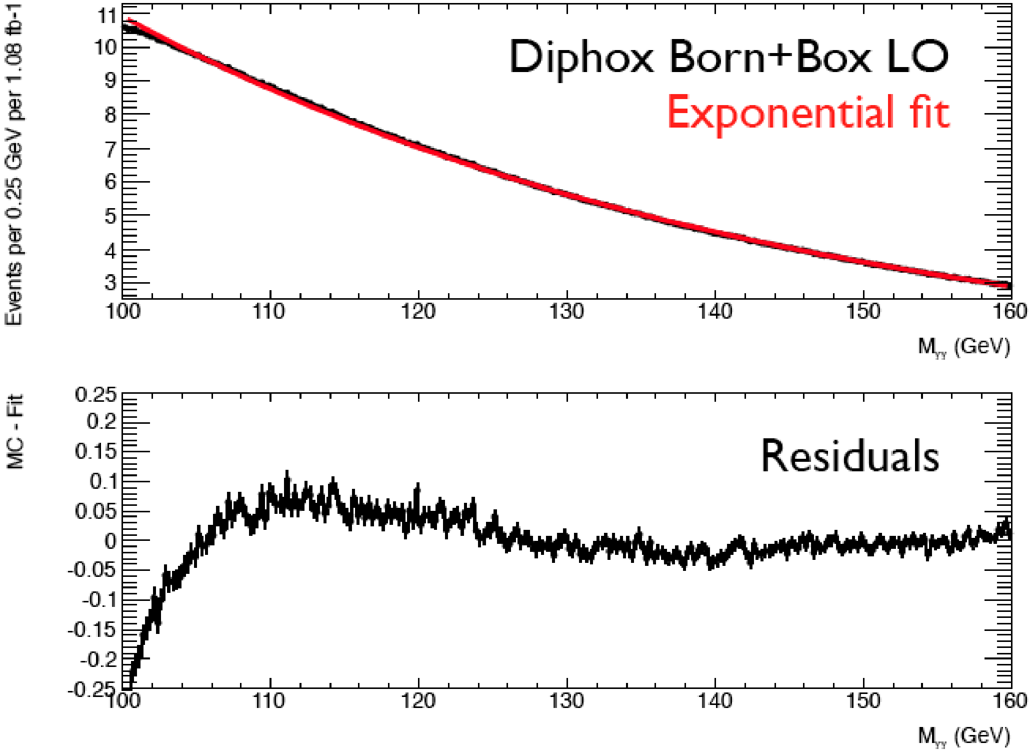


Central: both photons |η| < 0.75
Transition: at least one photon 1.3 < |η| < 1.75

Even if it was a resolution motivated categorization, large part of the gain is due to different Sig/Bkg.
Already exploiting kinematic differences between signal and background.

Background parameterization

- For the moment using a single exponential function.
- Systematic bias from the model choice has been estimated:
  - Fitting large diphoton MC samples (Diphox) and looking at the residuals.
  - Fitting toys pseudo experiments with signal plus exp. background model:
    - Bkg toys generated taking Diphox distribution or different functional forms fitted over data.
    - Adding 50 signal events at 120 GeV.
    - Then fitting with S+B model.
- A systematic uncertainty of ±3 - ±5 events is considered on the fitted signal rate, depending on the mass hypothesis.
- The fitting function will have to be revisited with the increasing data.



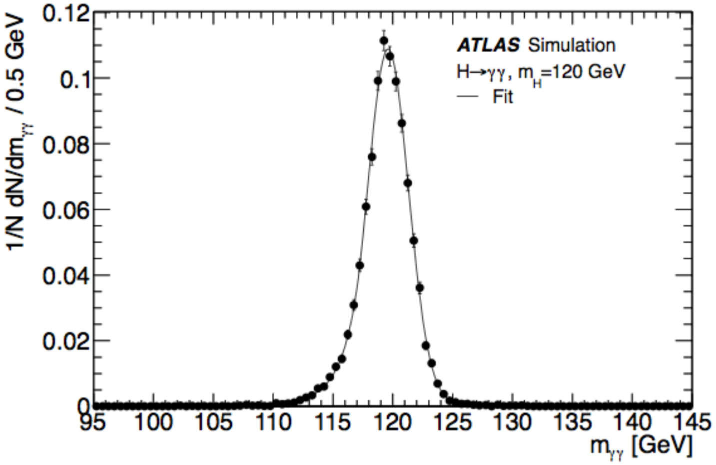
Statistical analysis and results

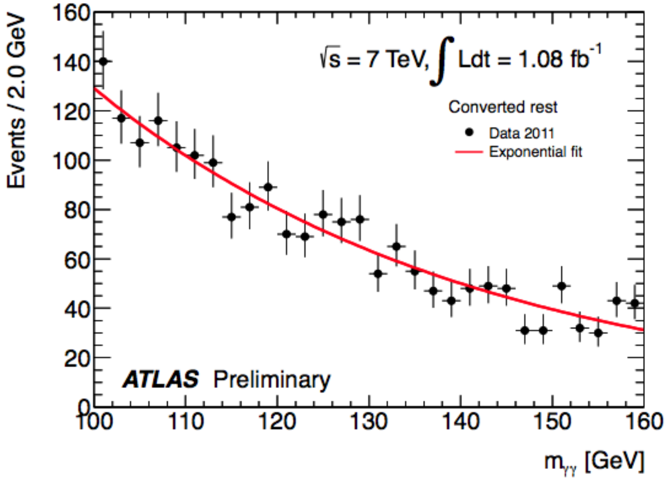
Limit setting

- Observed limits
  1. Construct the likelihood function

$$\mathcal{L}(\text{data}\,|\,\mu,\theta) = k^{-1}\prod_i(\mu S f_s(x_i) + B f_b(x_i)) \cdot e^{-(\mu S+B)}$$

X_i = Observable ($m_{\gamma\gamma}$)
S = N_{sig} expected
B = N_{bkg} expected
μ = signal scale factor





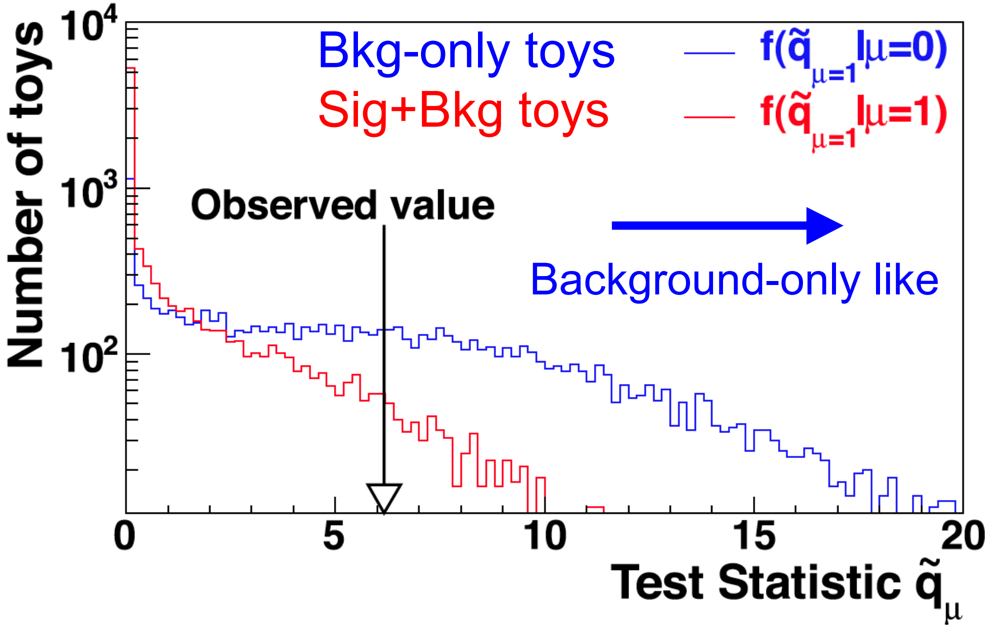
Limit setting

- Observed limits
  2. Compare the compatibility of the *data* with the *background-only* and *signal+background* hypotheses (for given m_H and μ values)

μ fixed

$$\tilde{q}_\mu = -2\ln\frac{\mathcal{L}(\text{data}|\mu,\hat{\hat{\theta}}_\mu)}{\mathcal{L}(\text{data}|\hat{\mu},\hat{\theta})}, \qquad 0 \le \hat{\mu} \le \mu$$

μ free

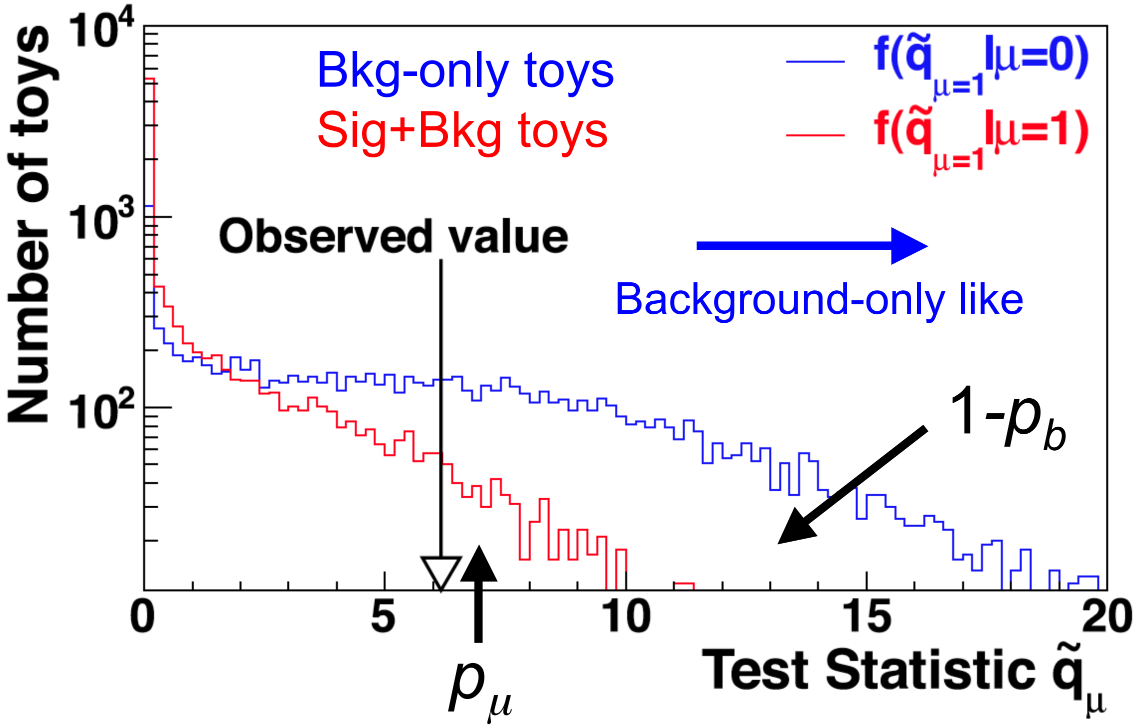


Limit setting

- Observed limits

2. Compute $CL_s(\mu)$

$$CL_s(\mu) = \frac{p_\mu}{1 - p_b}$$

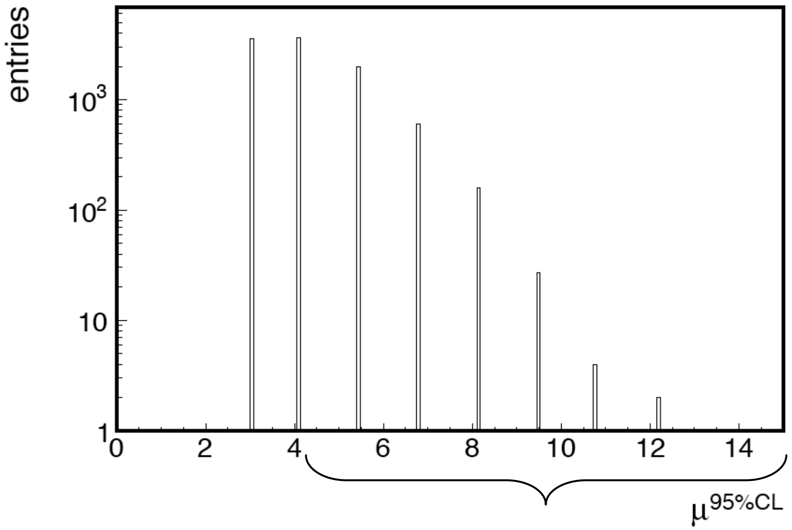


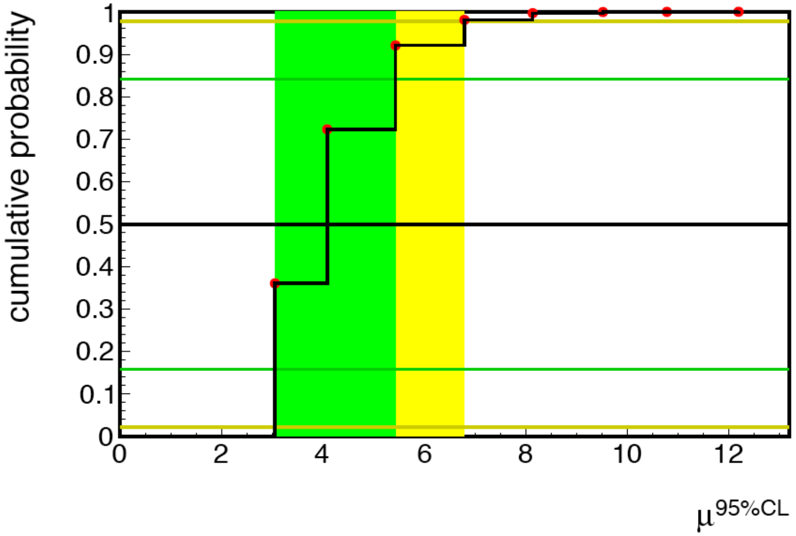
If, for $\mu = 1$, $CL_s \leq \alpha$, we would state that the SM Higgs boson is excluded with $(1\text{-}\ \alpha)$ CL_s confidence level

Then, we adjust μ until we reach $CL_s = 0.05 \Rightarrow \mu^{95\%CL}$

Limit setting

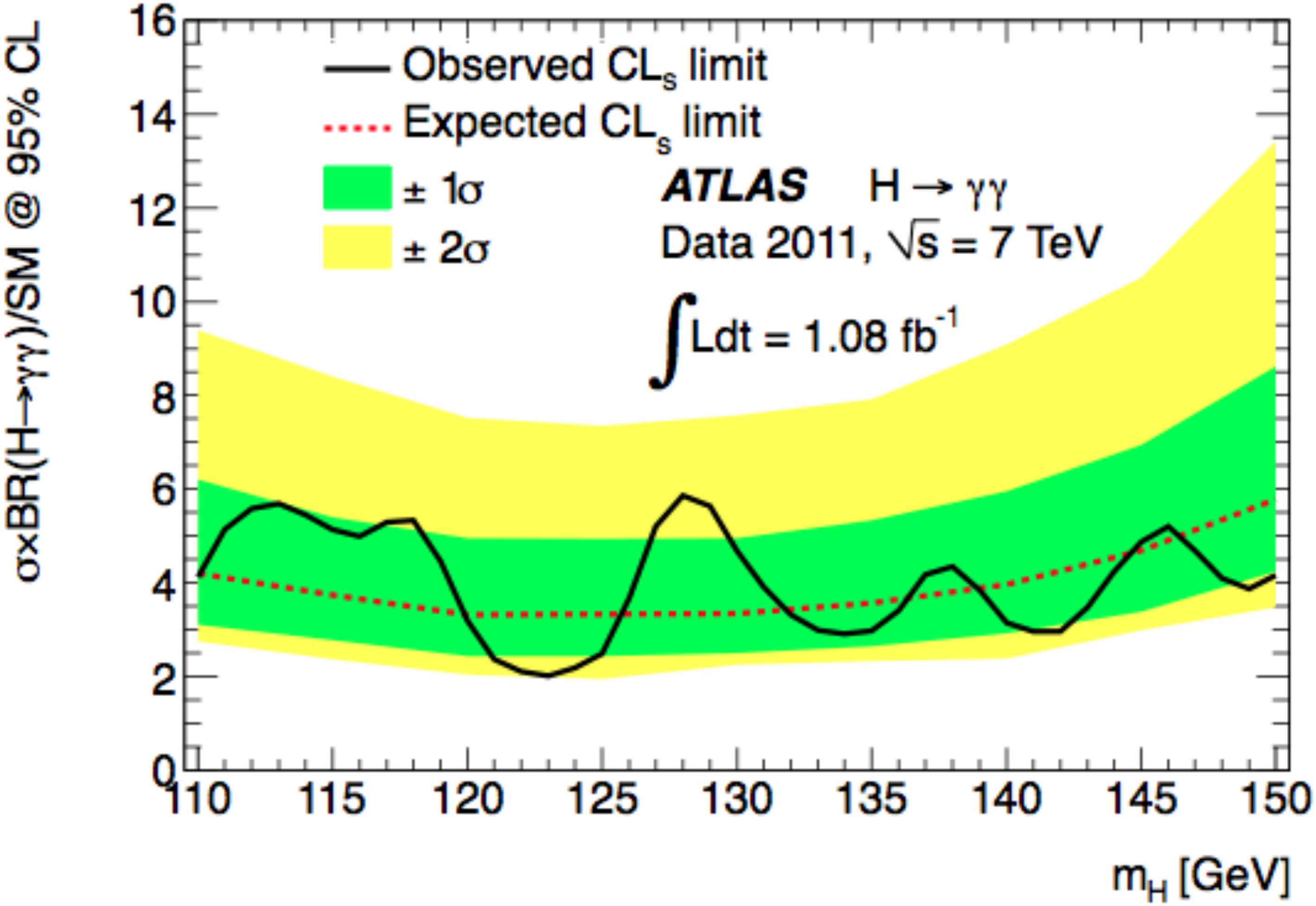
- Expected limits
  - Generate a large set of background-only pseudo-data and calculate CLs and $\mu^{95\%CL}$ for each of them.
  - Build a cumulative probability distribution starting from cero.
  - The point at which the cumulative probability distribution crosses the 50% line is the median expected value
    ($\pm 1\sigma \Rightarrow$ 16% and 84%; $\pm 2\sigma \Rightarrow$ 2.5% and 97.5%).





50% of the times we would exclude a signal of 4xSM cross-section

Exclusion limits



The variations of the observed limit, between 2 and 5.8 SM, are consistent with the expected statistical fluctuations around the median limit.

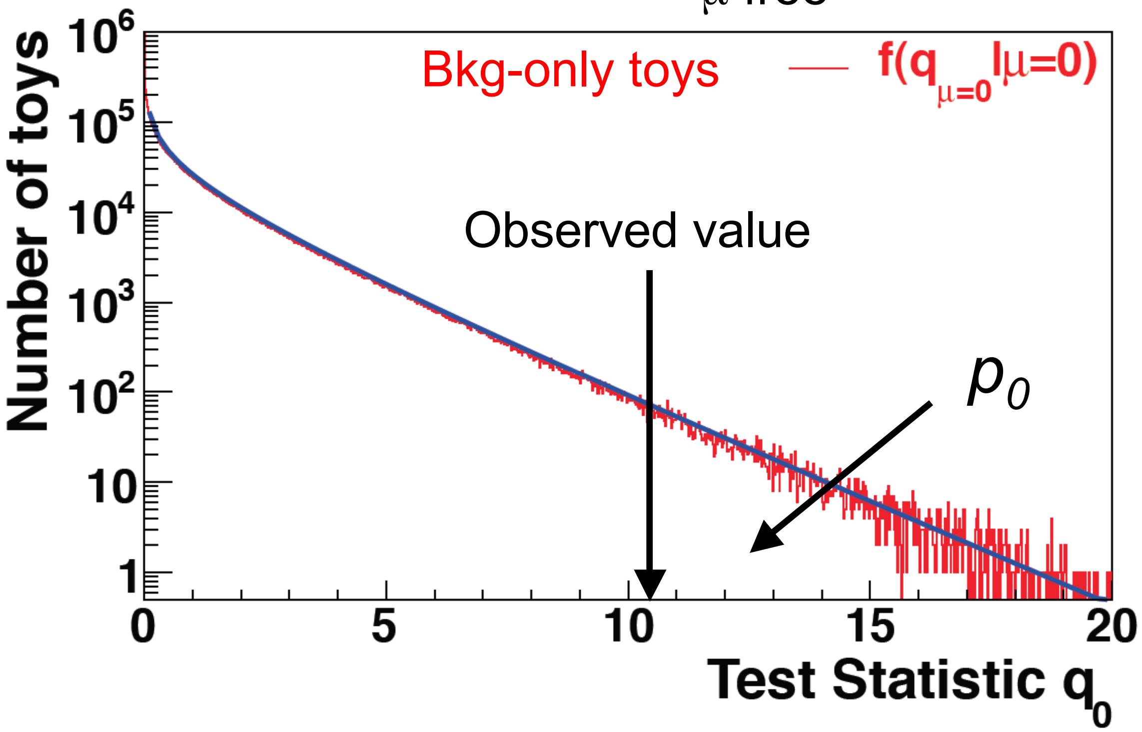
Quantifying an excess of events

- Use the probability ***p_0*** for the background to fluctuate and give an excess of events as large or larger than the observed one.

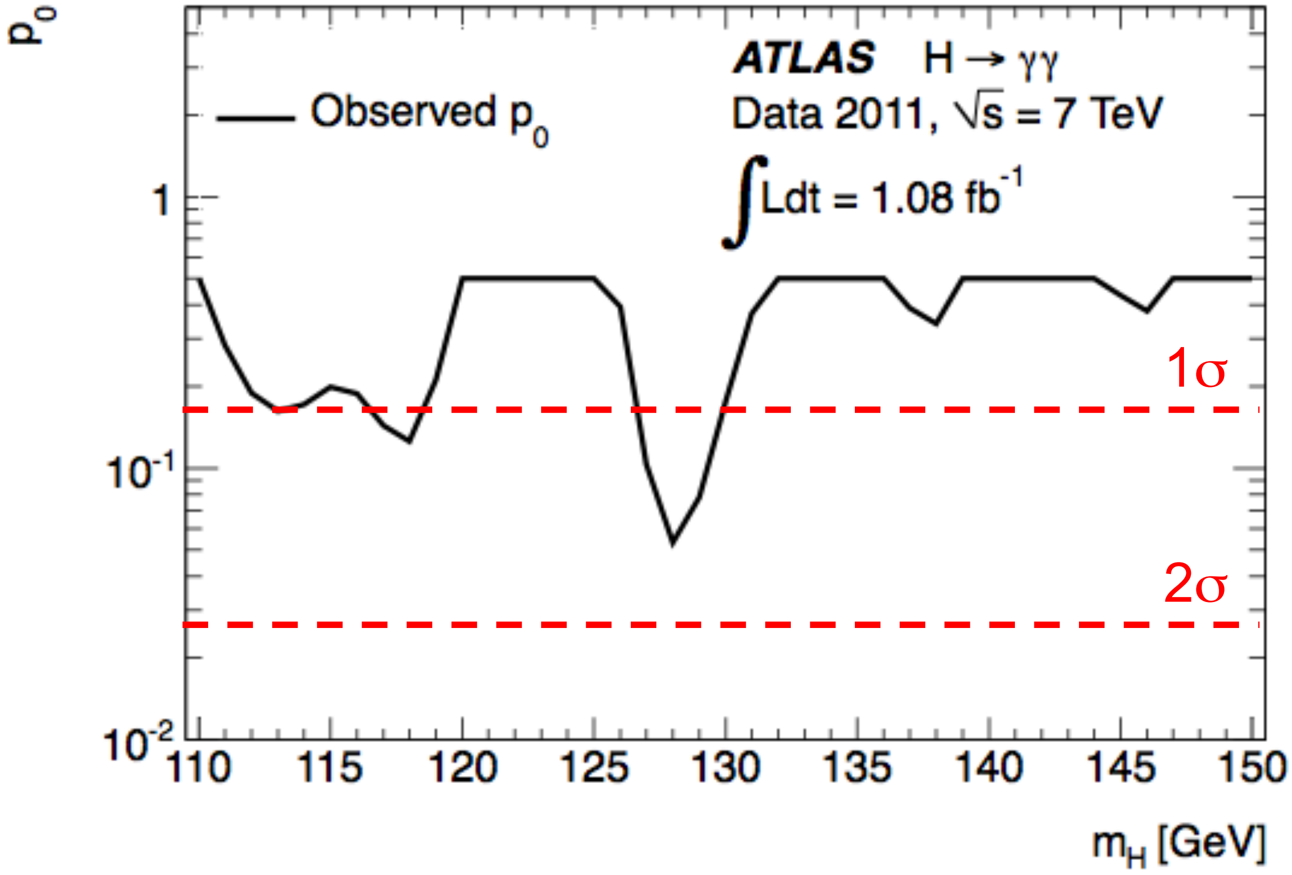
μ=0 fixed

$$q_0 \;=\; -2\ln \frac{\mathcal{L}(\text{data}|0,\hat{\hat{\theta}}_0)}{\mathcal{L}(\text{data}|\hat{\mu},\hat{\hat{\theta}})} \quad \text{and } \hat{\mu} \geq 0$$

μ free



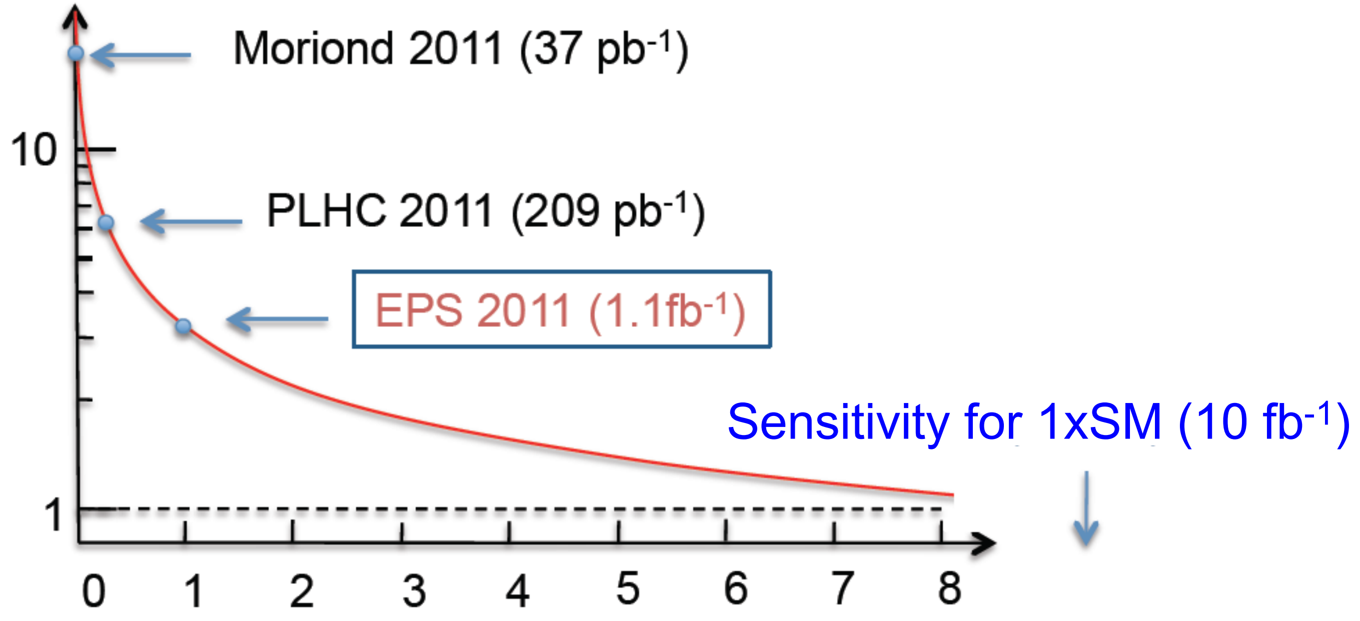
Quantifying an excess of events



No excess is found in the diphoton invariant mass distribution.

Conclusion

- No significant excess observed and limits are set in agreement with the sensitivity.



Next week results with 5fb^{-1} of luminosity will be published!

Backup

Systematic uncertainties

On signal yield

Source	(per event)
Photon identification efficiency	±10%
Pile-Up	±4%
Isolation	±3%
Luminosity	±3.7%
trigger efficiency	±1%
Modelling pT(H)	±1%
Total	**±12%**

On mass resolution

Source	(per event)
Energy Resolution	±12%
Energy Calibration	±6%
Pile-Up	±3%
Angle Measurement	±1%
Total	**±14%**

Theoretical Uncertainty: +20-15%

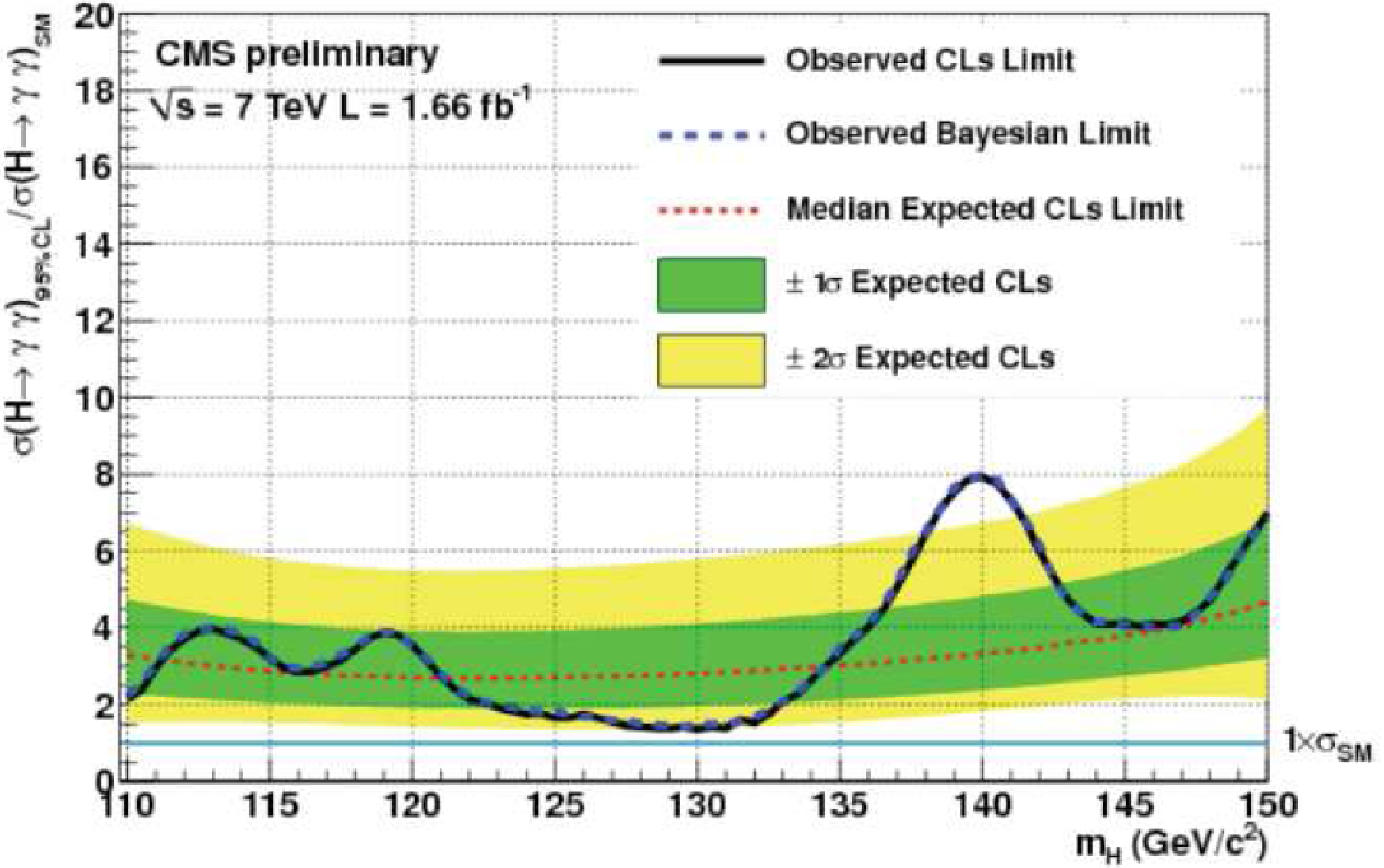
Background modelling:

+5 -3 events for 110-150 GeV

This uncertainty is propagated in each category proportionally to the number of background events.

All the systematic uncertainties are taken as fully correlated between the different categories. The impact of uncorrelated systematics and migration of events between categories was found to be negligible.

CMS results


CMS preliminary
$\sqrt{s}$ = 7 TeV L = 1.66 fb^{-1}
Observed CLs Limit
Observed Bayesian Limit
Median Expected CLs Limit
± 1σ Expected CLs
± 2σ Expected CLs
1×σ$_{SM}$
$\sigma(H\to\gamma\gamma)_{95\%CL}/\sigma(H\to\gamma\gamma)_{SM}$
m_H (GeV/c^2)
0
2
4
6
8
10
12
14
16
18
20
110
115
120
125
130
135
140
145
150