Search for the Standard Model Higgs Boson in the γγ Channel with 4.9 fb^{-1} Data at 7 TeV with ATLAS

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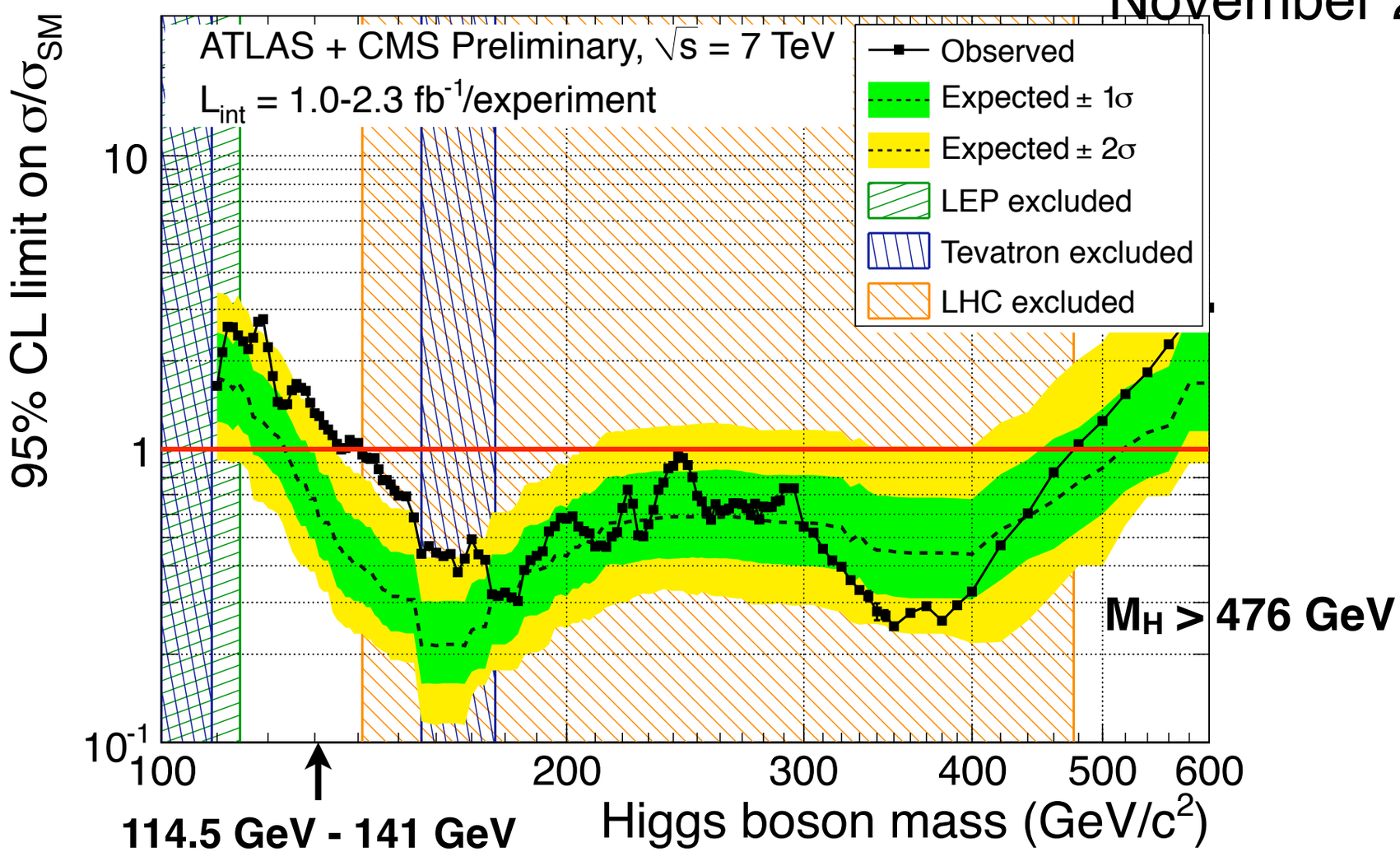
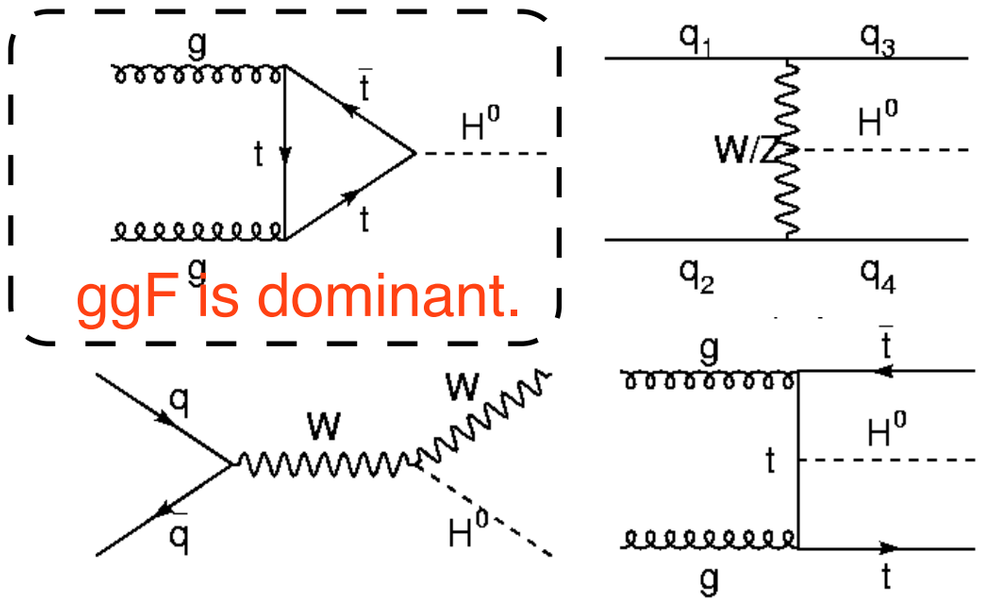
Introduction

Searches for a Higgs boson have been carried out by several experiments, namely, LEP, Tevatron and LHC.

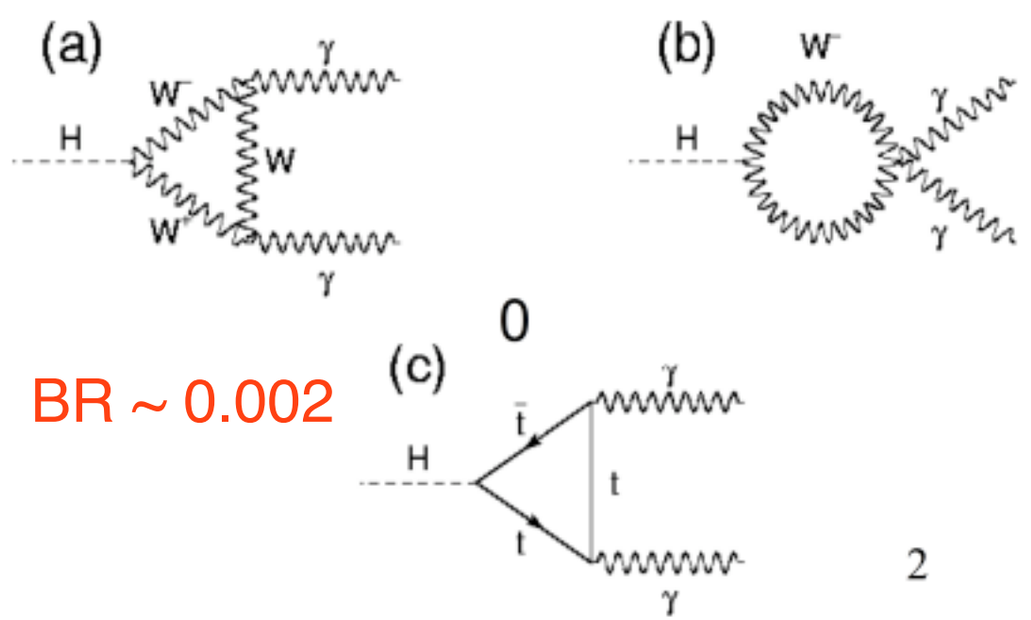


At the LHC, the Higgs to γγ channel is the one of the most sensitive channels in the low M_H region. In addition, it allows to reconstruct the Higgs mass.

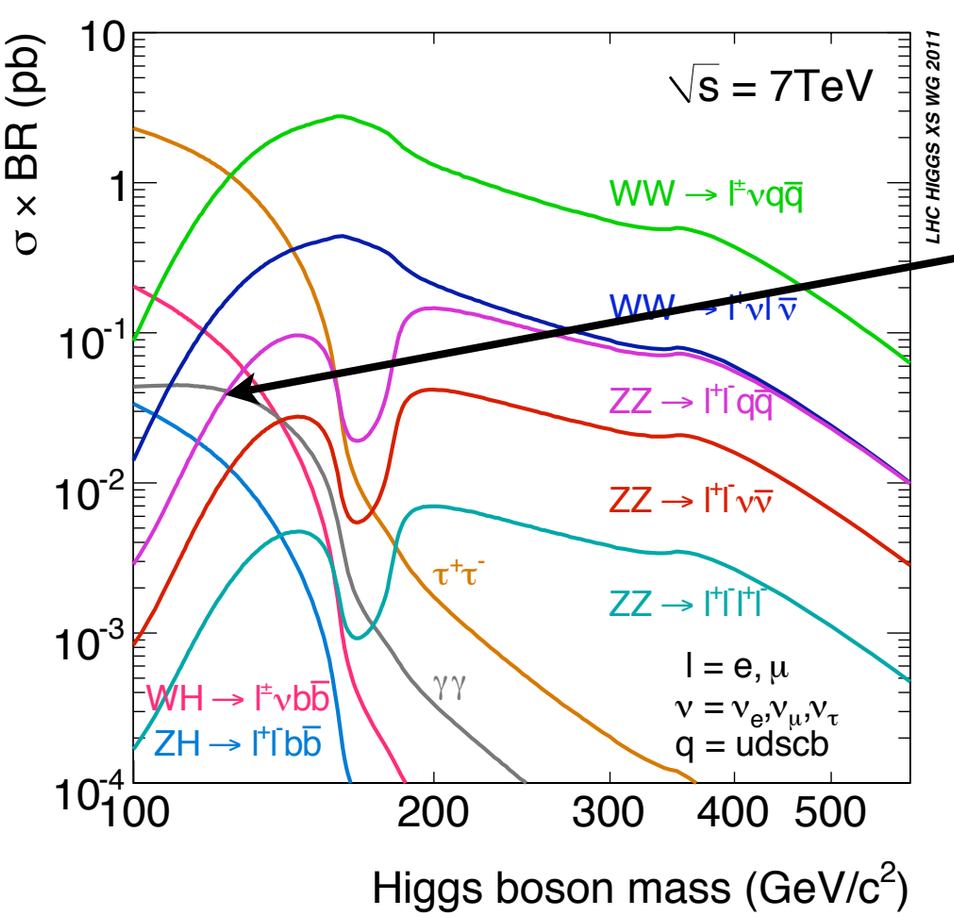
Production and decay



Production



Decay

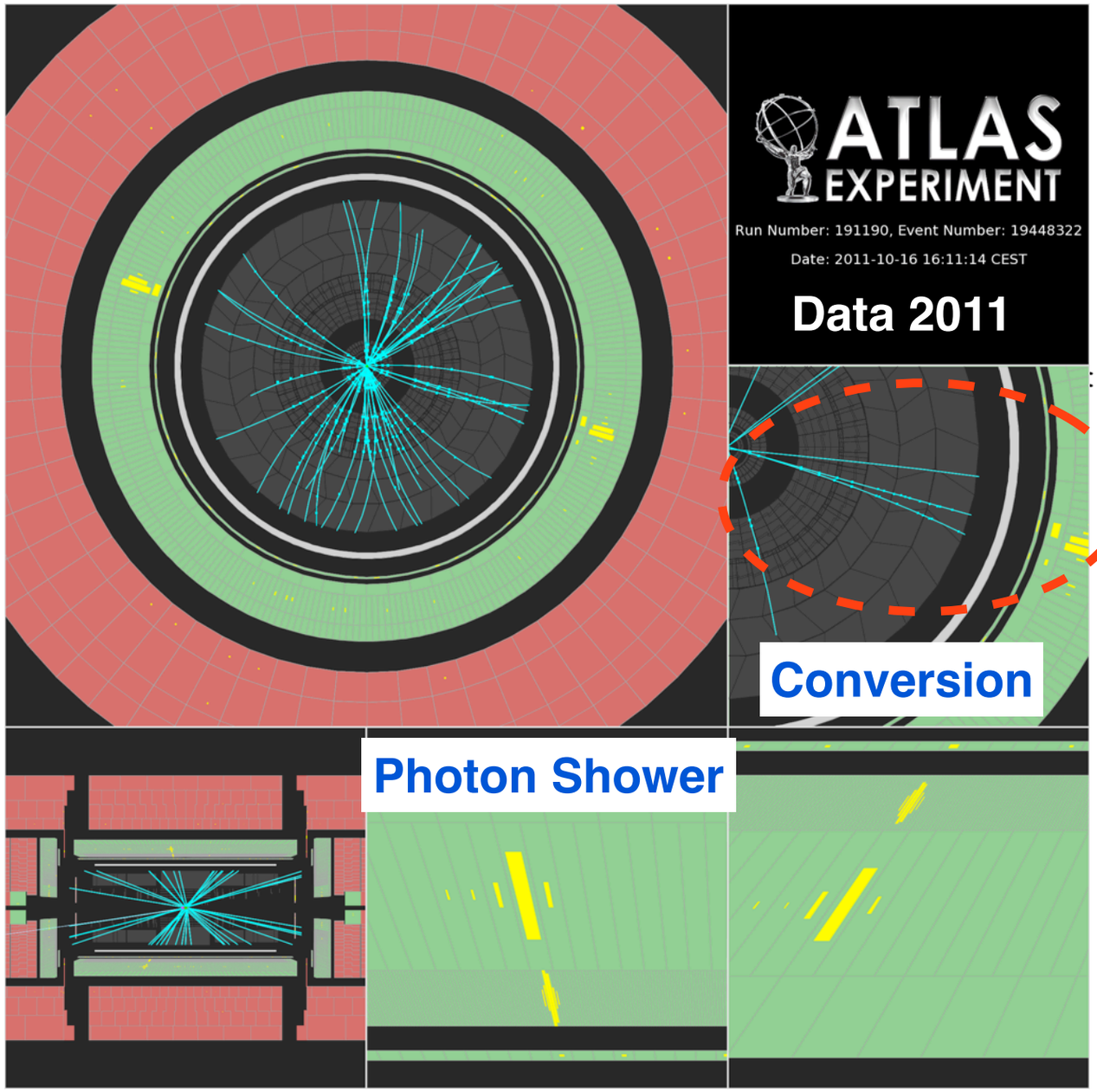


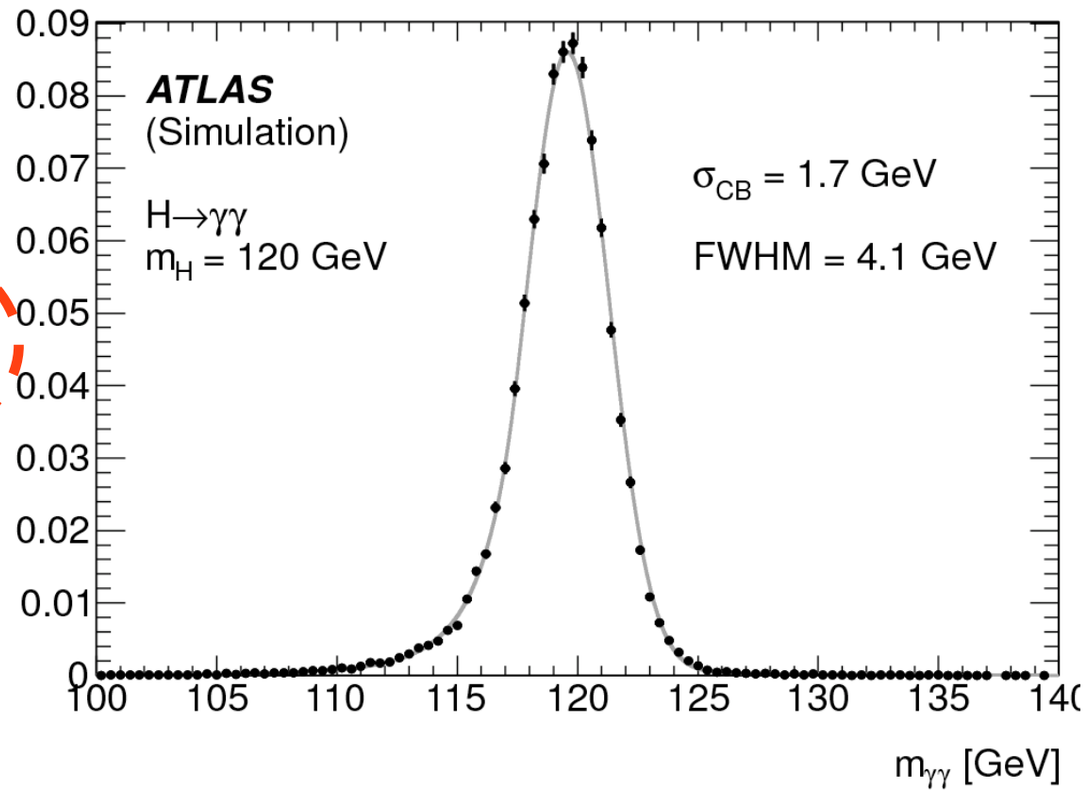
σBR ~ 40 fb for M_H ~ 125 GeV

The loop-induced decay is unique for Higgs to γγ.

BSM physics could affect both Higgs productions and decays, i.e. Fermiophobic Higgs, MSSM Higgs, etc.

Signature





The resolution for a diphoton event with $M_{\gamma\gamma} \sim 120$GeV is ~ 2 GeV, with ~ 14% uncertainty.

~ 60% of diphoton candidates have at least one converted photon, which has been calibrated separately.

Selected sample

Selection:

$E_{T\gamma 1}$ > 40 GeV , $E_{T\gamma 2}$ > 25 GeV

|η| < 2.37, and not between (1.37, 1.52)

Isolation energy < 5 GeV

Photon identification

22489 candidate events were selected.

Expected number of signal events for M_H = 125GeV ~ 70 (~13% experimental uncertainty, ~15% theoretical uncertainty)

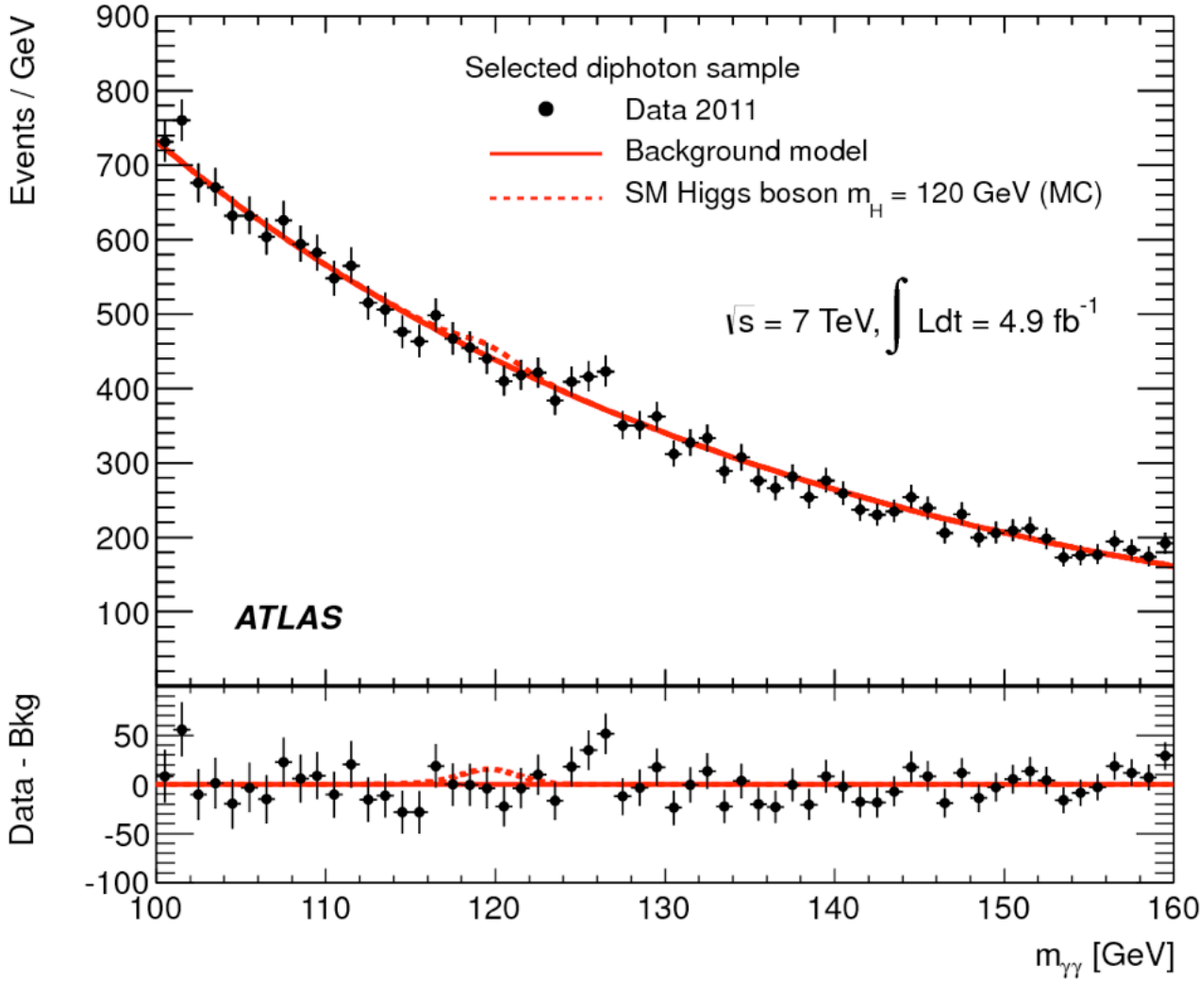
Backgrounds are:

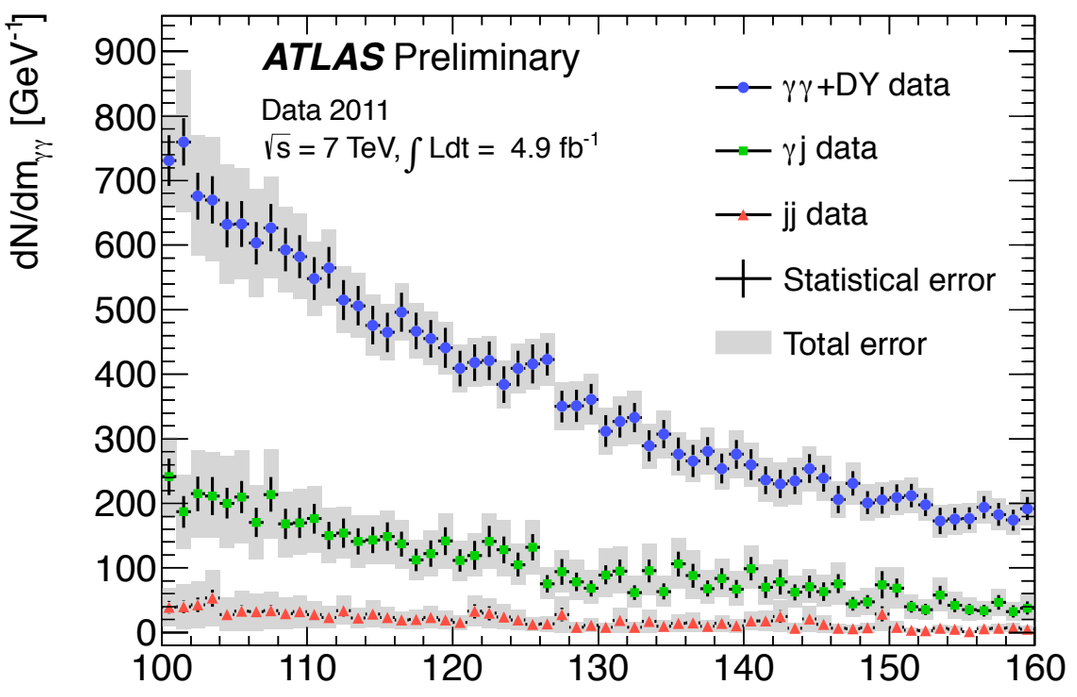
SM γγ production(~71%)

γ+jets (~23%)

dijet (~5%)

Drell Yan (~0.7%)





Search strategy

Categorization of events

Divide the sample into categories that have different S/B and invariant mass resolution.

Using more detailed information improves sensitivity.

Variables used to categorize events

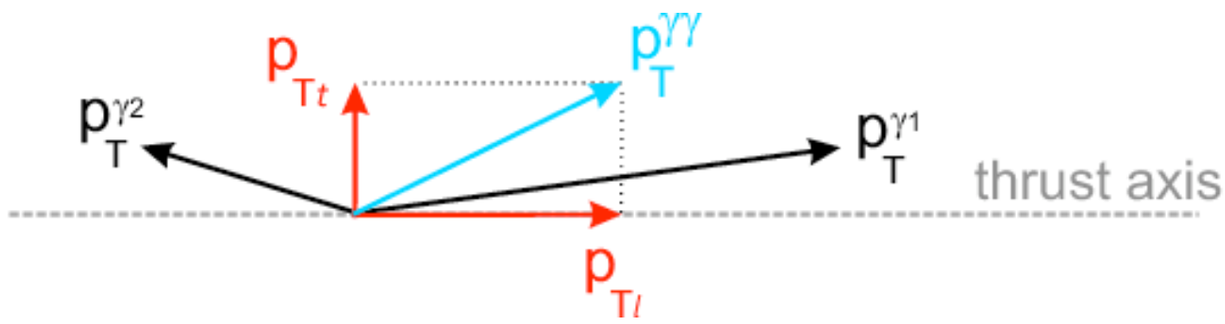
Conversion status : difference in σ_m and background rejection.

η of photon candidate(calorimeter regions) : difference in σ_m

p_{Tt} (transverse component of $p_{T\gamma\gamma}$ wrt thrust axis) :

ggF, a larger tail compared to background.

high p_{Tt} for VBF and VH



Conversion

|η|

High: $p_{Tt} > 40GeV$

Low : $p_{Tt} < 40GeV$

All

Unconverted

central
|η| < 0.75

Low:s/b= 0.05,σ_m=1.4GeV

HI: s/b = 0.11,σ_m=1.4GeV

rest
at least one γ |η| > 0.75

Low: s/b = 0.02,σ_m=1.7GeV

HI: s/b = 0.04,σ_m=1.6GeV

Converted

central
|η| < 0.75

Low: s/b = 0.03,σ_m=1.6GeV

HI:s/b = 0.08,σ_m=1.5GeV

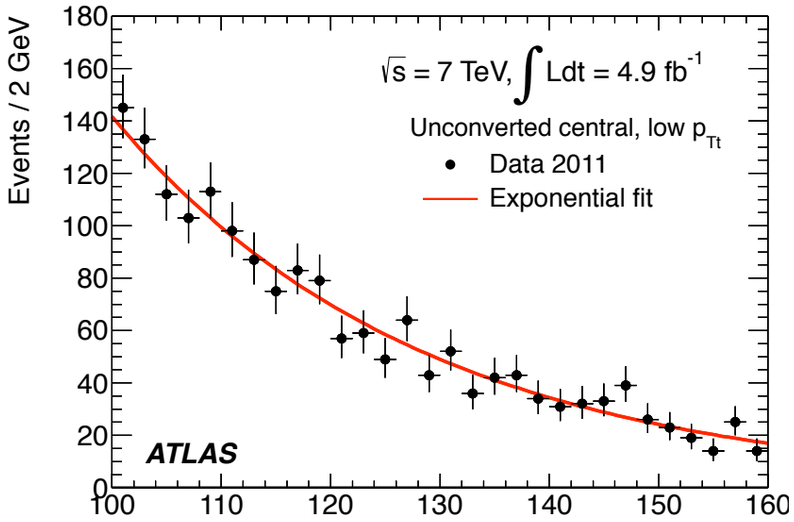
rest
at lease one γ |η| > 0.75; no γ has 1.3<|η| < 1.75

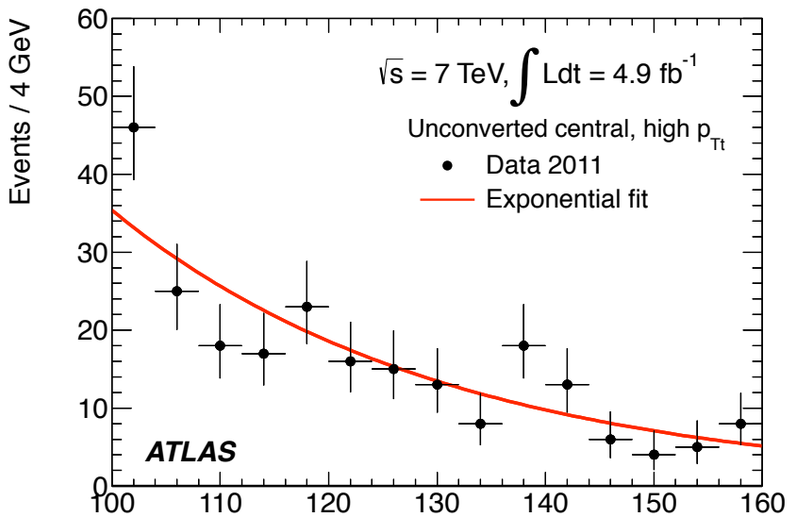
Low: s/b = 0.01,σ_m=2.0GeV

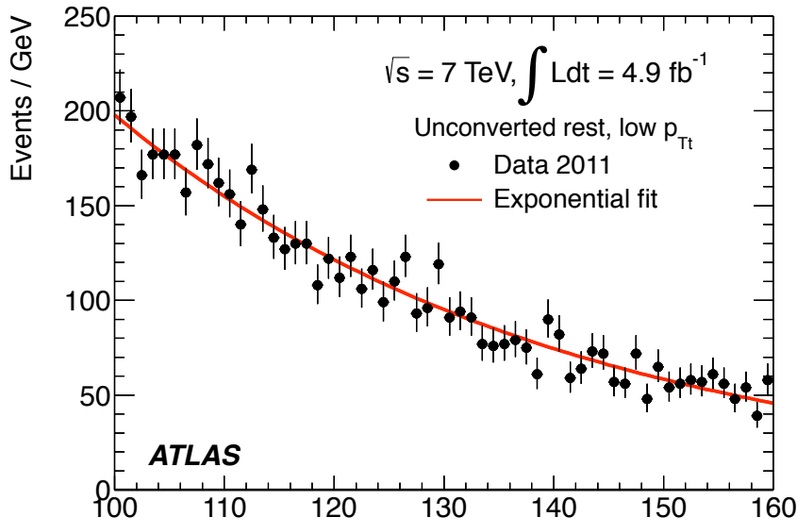
HI: s/b = 0.03,σ_m=1.9GeV

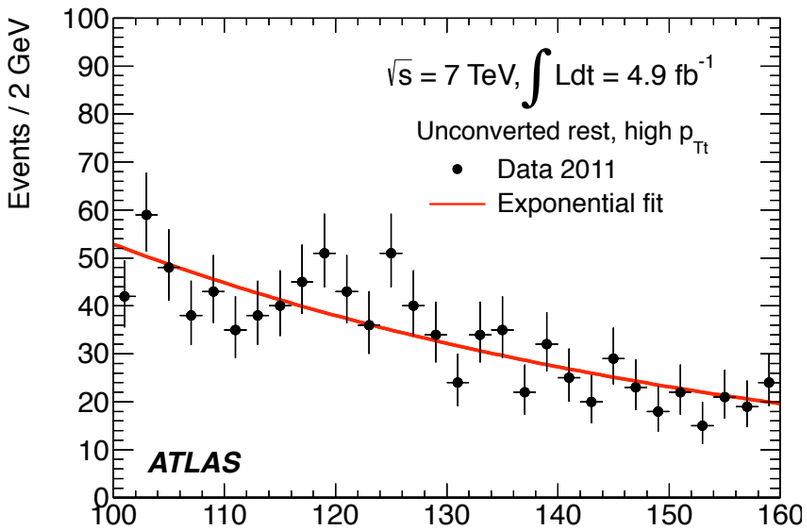
transition
at least one γ has 1.3<|η| < 1.75

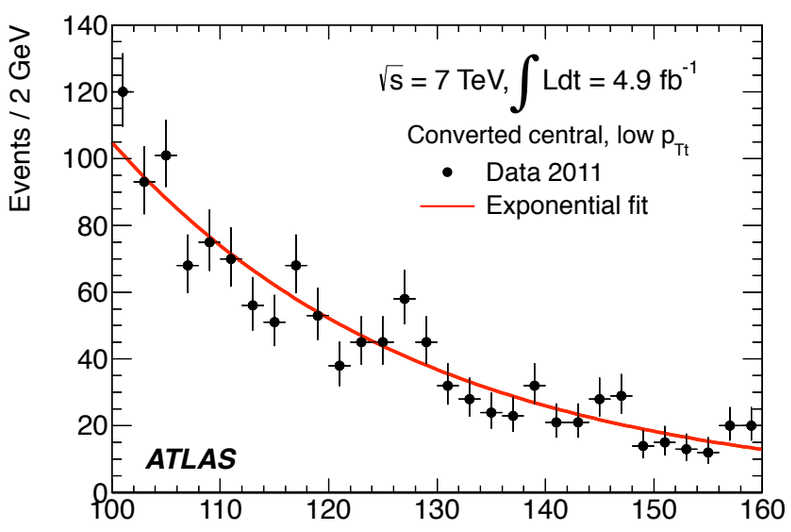
No cut: s/b = 0.01, σ_m=2.3GeV

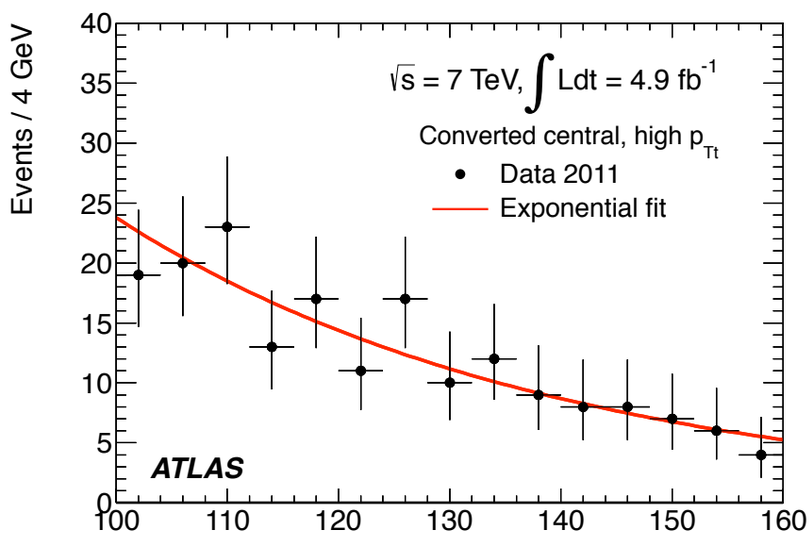


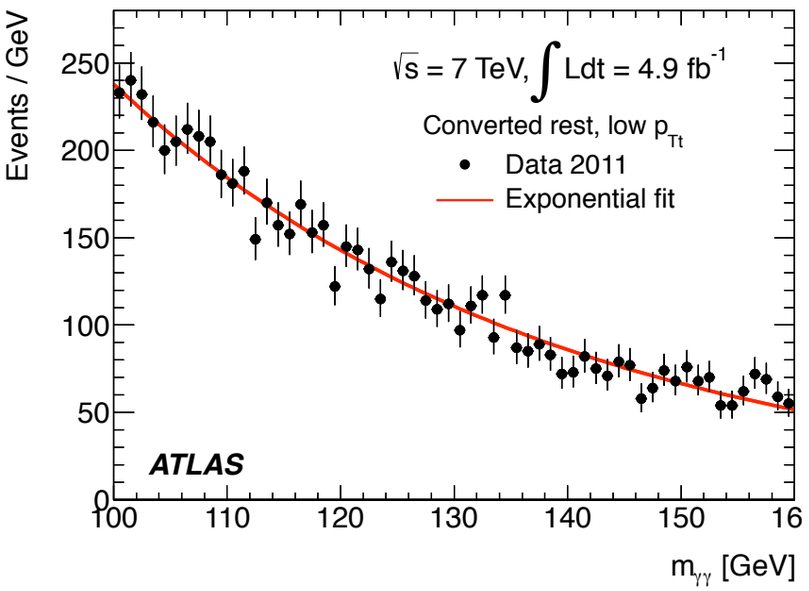


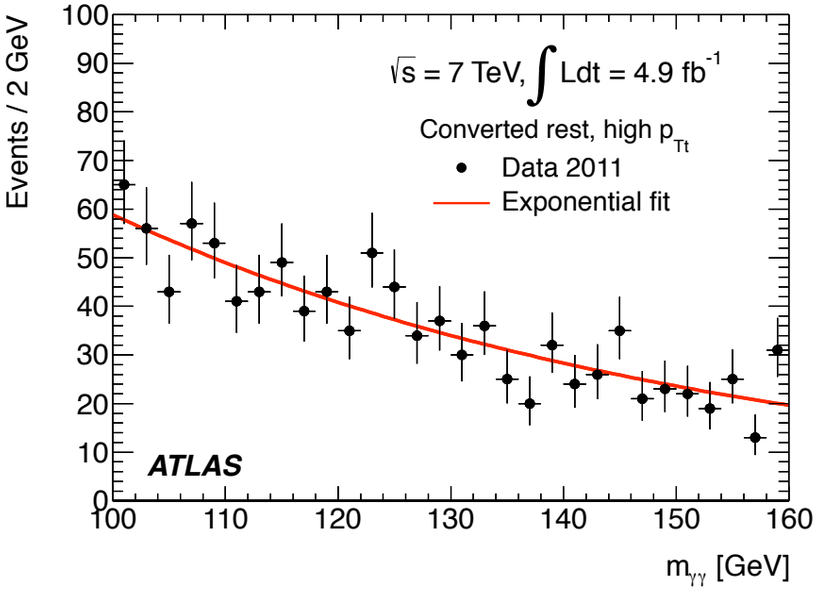


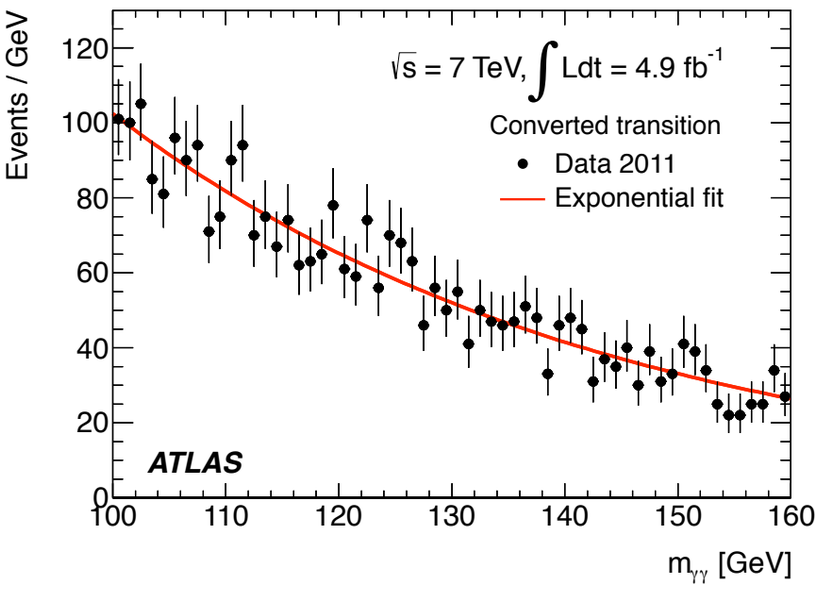






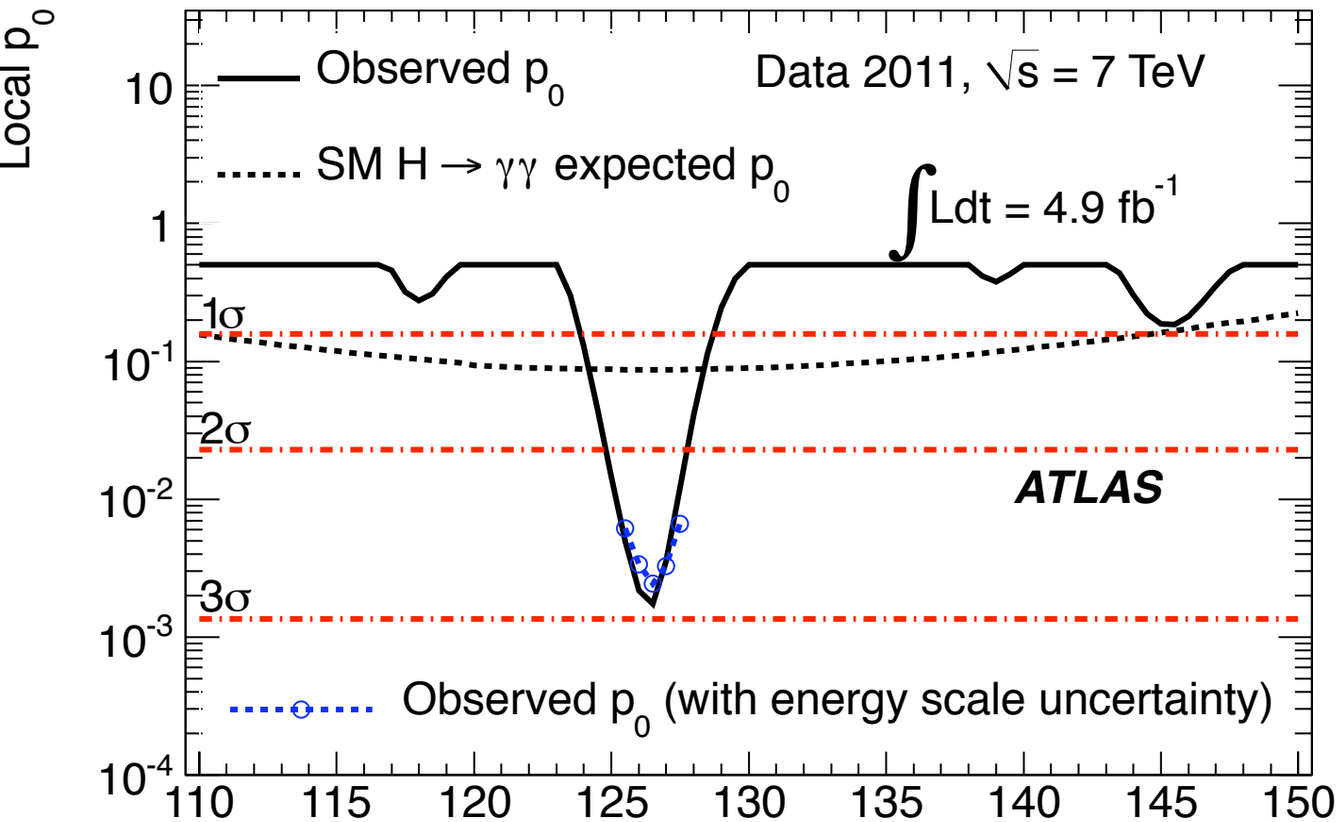


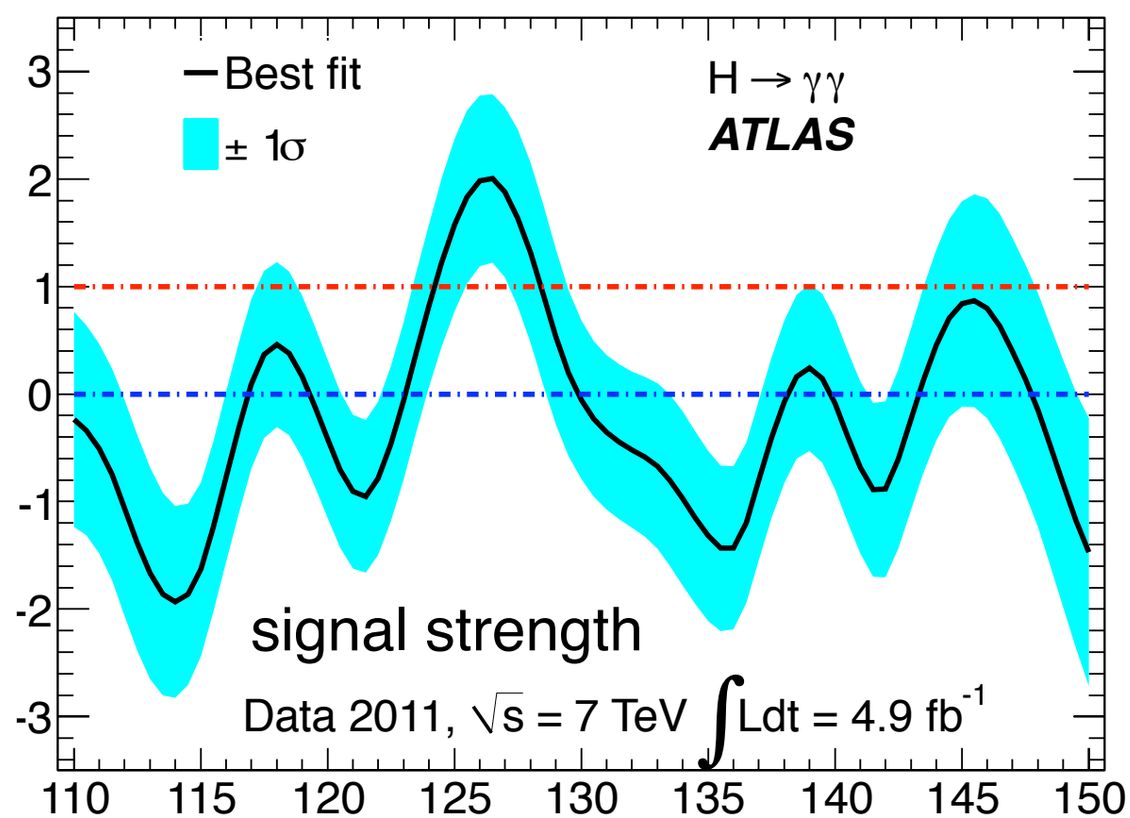




Combined $m_{\gamma\gamma}$ likelihood function of 9 categories is used to interpret the data.

Significance of excess





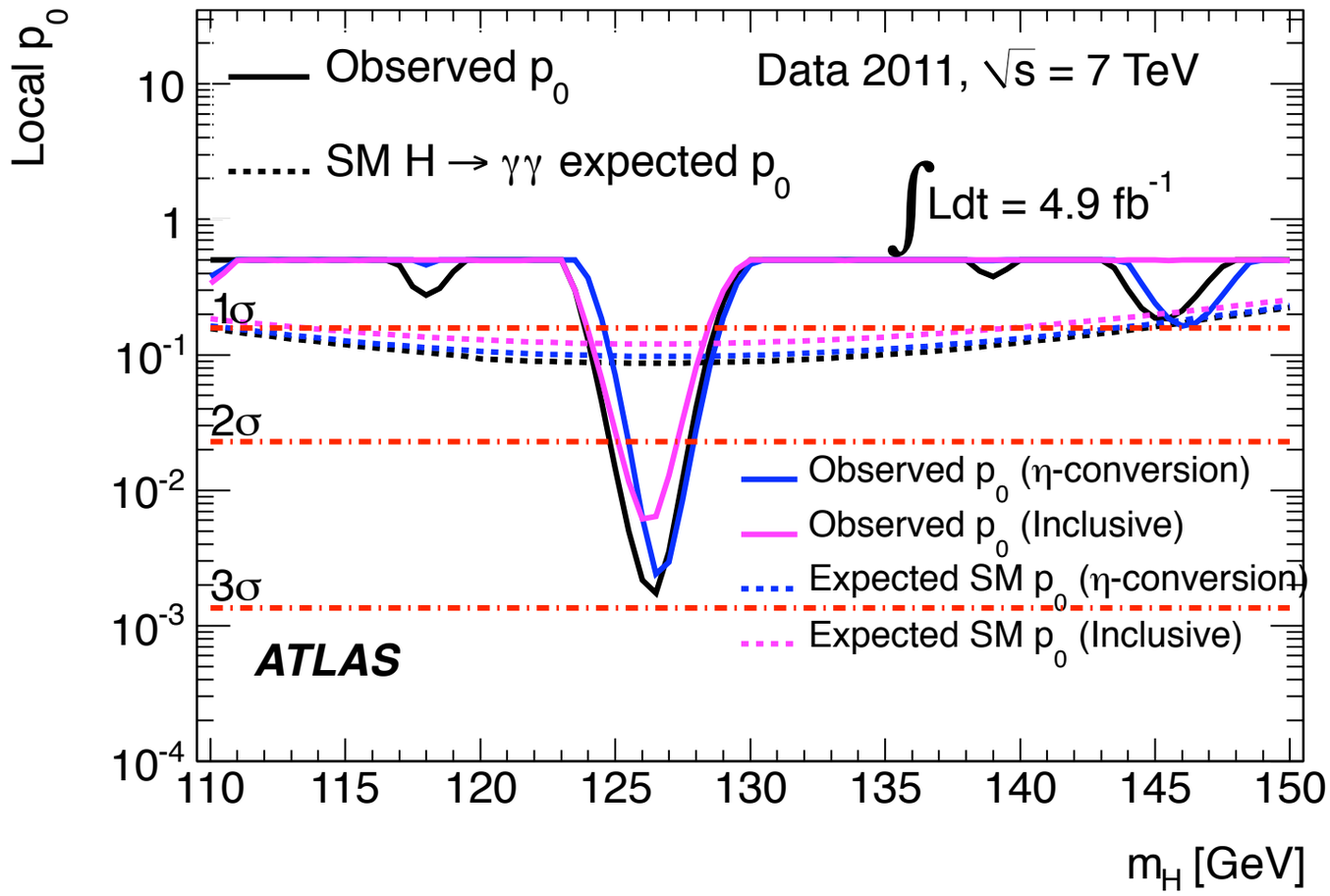
The search is carried out between 110 GeV and 150 GeV with a step of 0.5GeV.

The largest excess : 2.8σ at 126.5GeV, μ ~ 2.0 times SM prediction.

The significance drops to 1.5σ, if look elsewhere effect is considered.
(the probability of such excess appearing anywhere in the mass range investigated)

This channel looked in isolation is not significant enough.

Improvement due to categorization

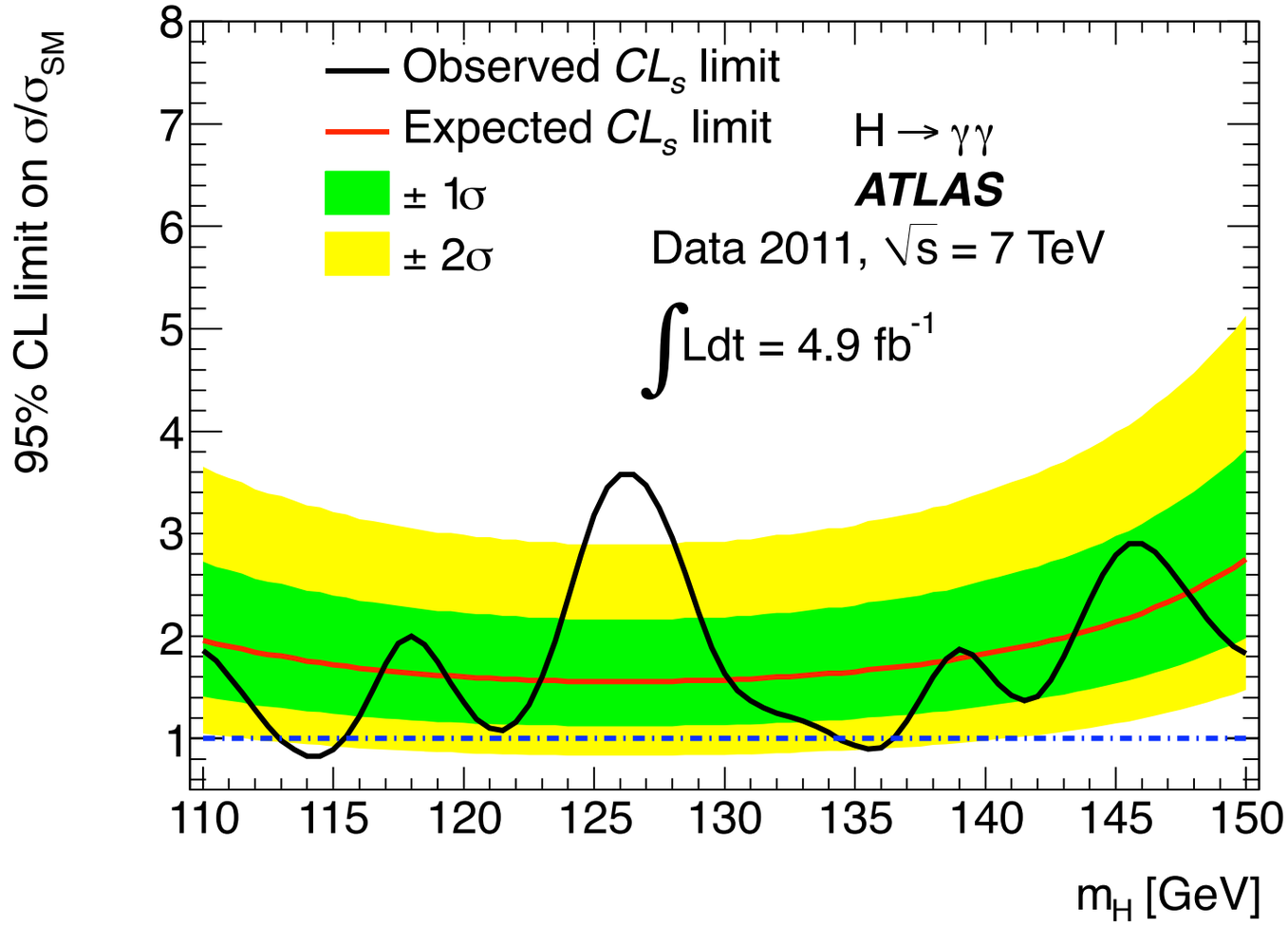


The data is also interpreted by only using η-conversion categorization, or without any categorization.

The expected significance is improved due to categorization.

Interesting hint: the observation happens to be also improved by categorization.

Limit on Higgs boson cross section

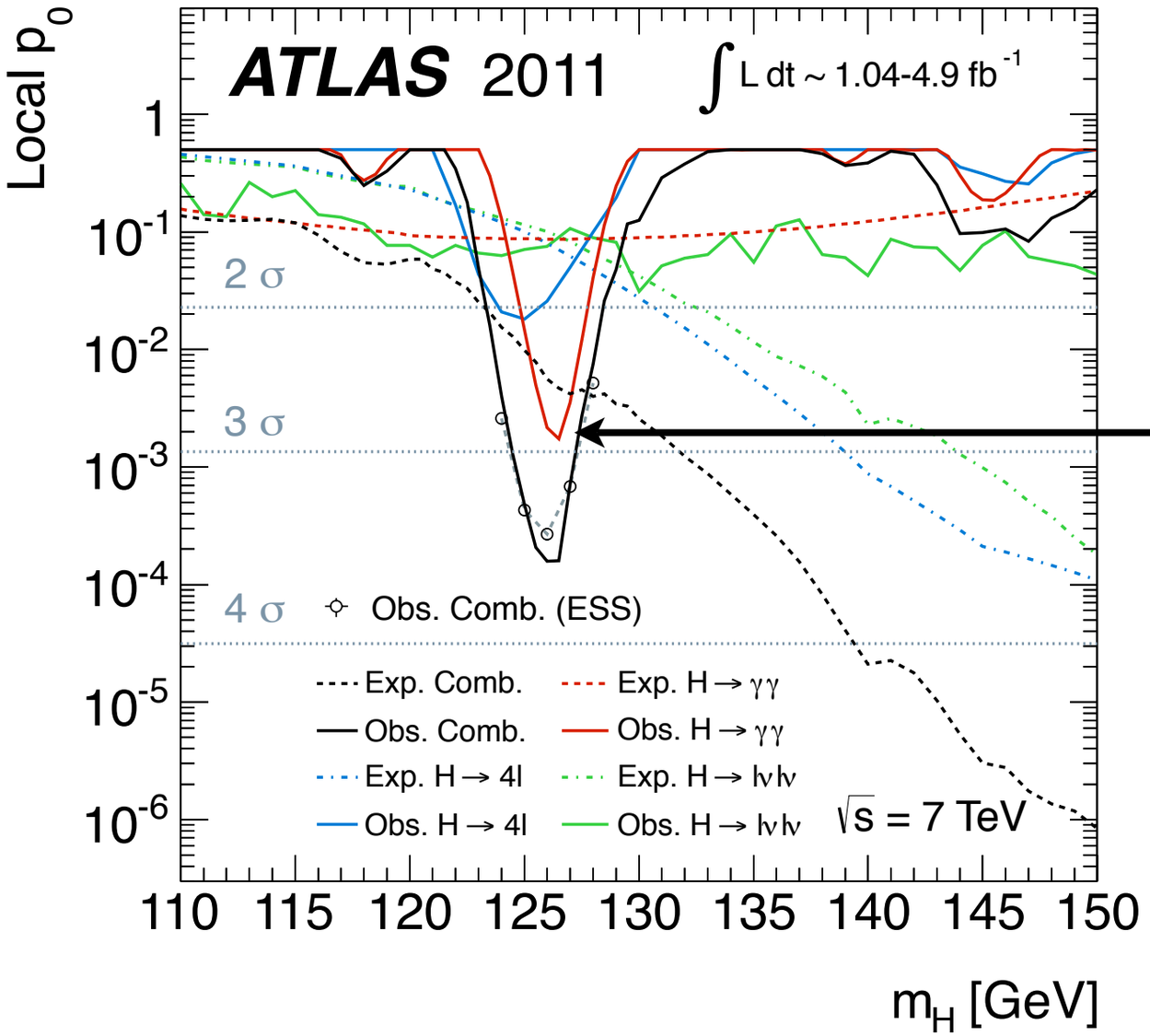


The expected limit is around 1.6 times the SM cross section for $M_H < 130$ GeV, and up to 2.7 for the full mass range.

The observed limit lies between 0.84 and 3.6 times the SM cross section.

A SM Higgs boson is excluded at 95% CL in the mass ranges of 113 - 115 GeV and 134.5 - 136 GeV.

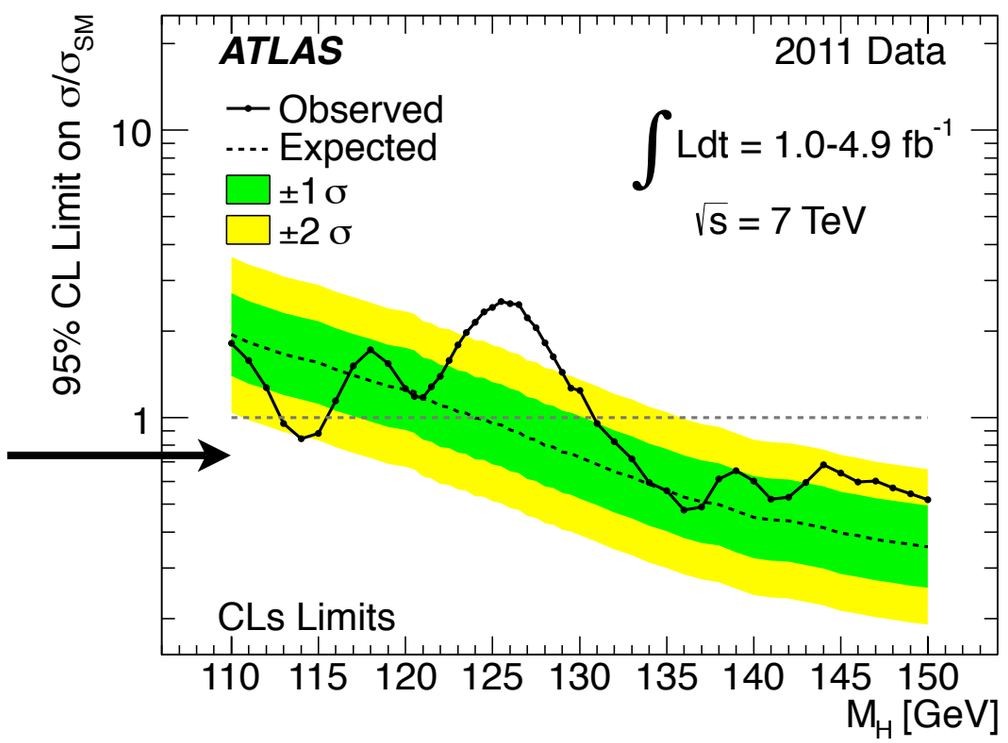
In the big picture



The major channels, γγ(4.9 fb-1), 4l(4.9 fb-1), and lvlv(2.05 fb-1) have comparable sensitivities around 126GeV.

The γγ excess is in coincidence with a smaller 4l excess, leading to a 3.5σ excess in the Higgs combination.

The exclusion between 112.9 GeV and 115.5 GeV is helped by the γγ channel.



Conclusion

- 2011 data gave us very exciting results:
  - Higgs to γγ channel starts excluding SM Higgs boson in certain mass ranges (113 - 115 GeV and 134.5 - 136 GeV).
  - An excess at 126.5 GeV, with 2.8σ local significance is found. It's in coincidence with a smaller excess from 4l channel, leading to a 3.5σ excess in the combination of Higgs searches.
- Outlook for 2012:
  - Further improve our analysis.
  - Given the expectation of collecting 20 fb^{-1} data at 8 TeV in 2012, a complete exclusion of low mass *SM* Higgs boson or a possible observation of *SM* Higgs is within the reach of the γγ channel.

Back up

Breakdown of categories

Category	σ_{CB}	FWHM	$\mathrm{N_S}$	$\mathrm{N_D}$	S/B
Unconverted central, low p_{Tt}	1.4	3.4	9.1	1763	0.05
Unconverted central, high p_{Tt}	1.4	3.3	2.6	235	0.11
Unconverted rest, low p_{Tt}	1.7	4.0	17.7	6234	0.02
Unconverted rest, high p_{Tt}	1.6	3.9	4.7	1006	0.04
Converted central, low p_{Tt}	1.6	3.9	6.0	1318	0.03
Converted central, high p_{Tt}	1.5	3.6	1.7	184	0.08
Converted rest, low p_{Tt}	2.0	4.7	17.0	7311	0.01
Converted rest, high p_{Tt}	1.9	4.5	4.8	1072	0.03
Converted transition	2.3	5.9	8.5	3366	0.01
All categories	1.7	4.1	72.1	22489	0.02

The statistical treatment

Profiled likelihood ratio is used to calculate p_0-value/significance of excess, and the limit on signal strength μ (σ/σ_{SM})

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

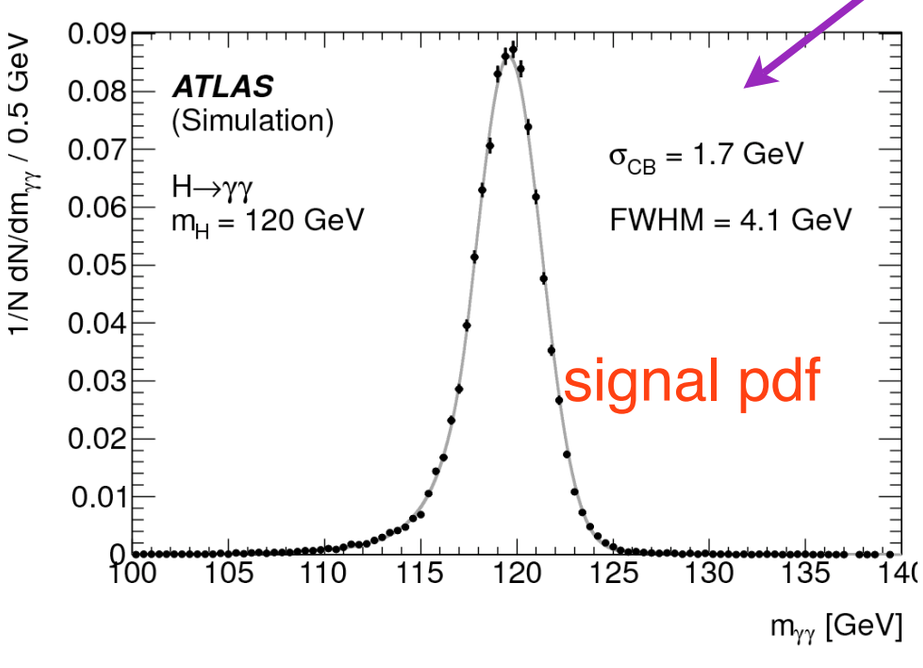
μS+B hypothesis (μ fixed) conditioned ML fit

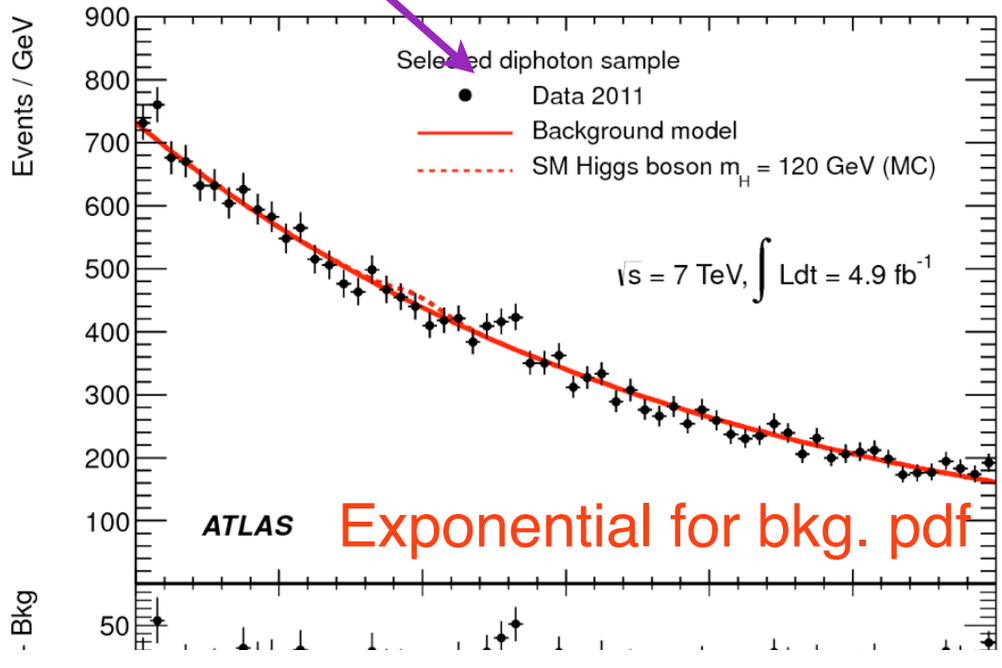
μS+B hypothesis (μ free) unconditioned ML fit

The unconditional fit is the same for both discovery and exclusion.

In the conditional fit, μ = 0, for discovery, and μ = μ_{test}.

$$f_{s+b}(m_{\gamma\gamma}) = n_s f_s(m_{\gamma\gamma}) + n_b f_b(m_{\gamma\gamma})$$





Systematic uncertainties

Signal event yield	
Photon reconstruction and identification	$\pm 11\%$
Effect of pileup on photon identification	$\pm 4\%$
Isolation cut efficiency	$\pm 5\%$
Trigger efficiency	$\pm 1\%$
Higgs boson cross section (scales)	$^{+12}_{-8}\%$
Higgs boson cross section (PDF+α_s)	$\pm 8\%$
Higgs boson p_{T} modeling	$\pm 1\%$
Luminosity	$\pm 3.9\%$
Signal mass resolution	
Calorimeter energy resolution	$\pm 12\%$
Photon energy calibration	$\pm 6\%$
Effect of pileup on energy resolution	$\pm 3\%$
Photon angular resolution	$\pm 1\%$
Signal mass position	
Photon energy scale	± 0.7 GeV
Signal category migration	
Higgs boson p_{T} modeling	$\pm 8\%$
Conversion rate	$\pm 4.5\%$
Background model	$\pm\,(0.1 - 7.9)$ events