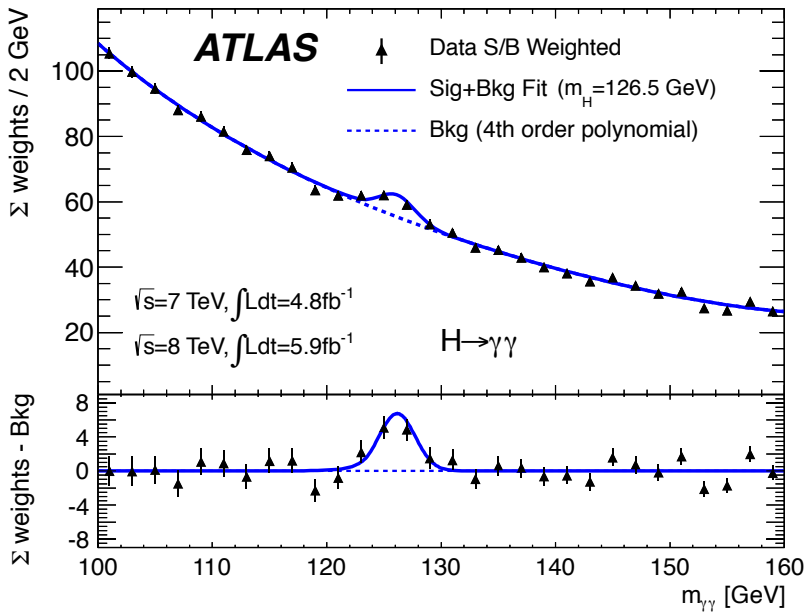
Observation of An Excess of Events in the Search for SM H → γγ with ATLAS Detector



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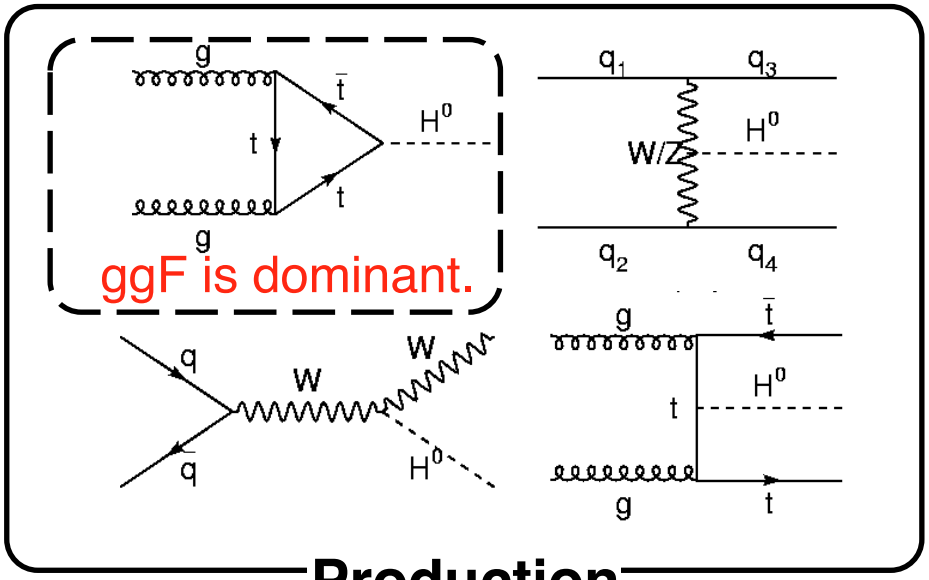
for the ATLAS Collaboration

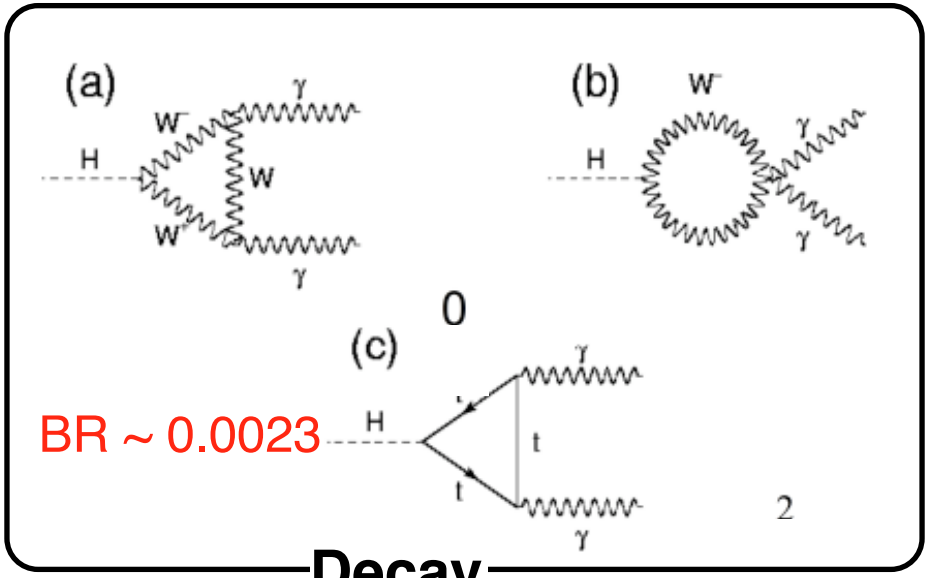
US LHC User Organization Annual Meeitng
Fermilab
October 18th – 20th 2012

Introduction



Production

7 TeV: 17.2 pb, 8 TeV: 22.0 pb

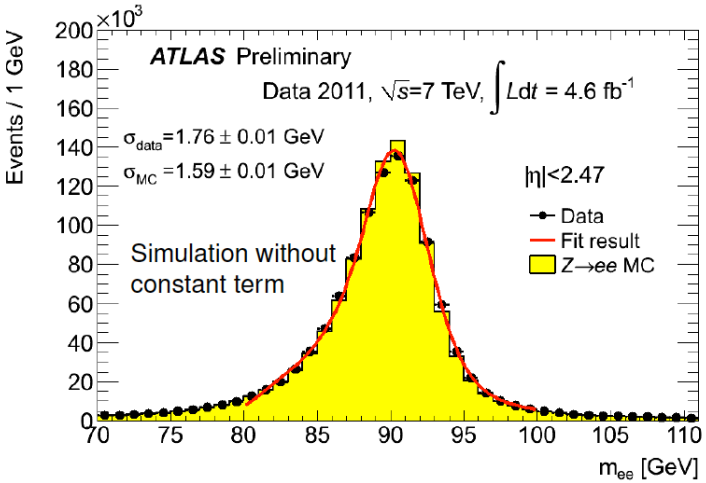


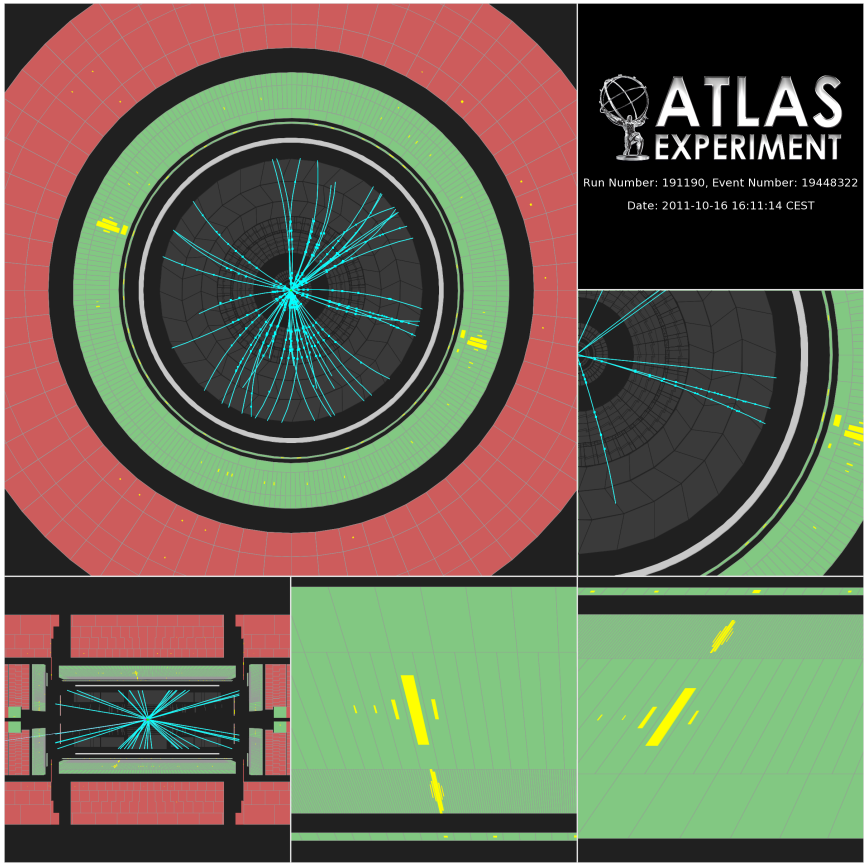
Decay

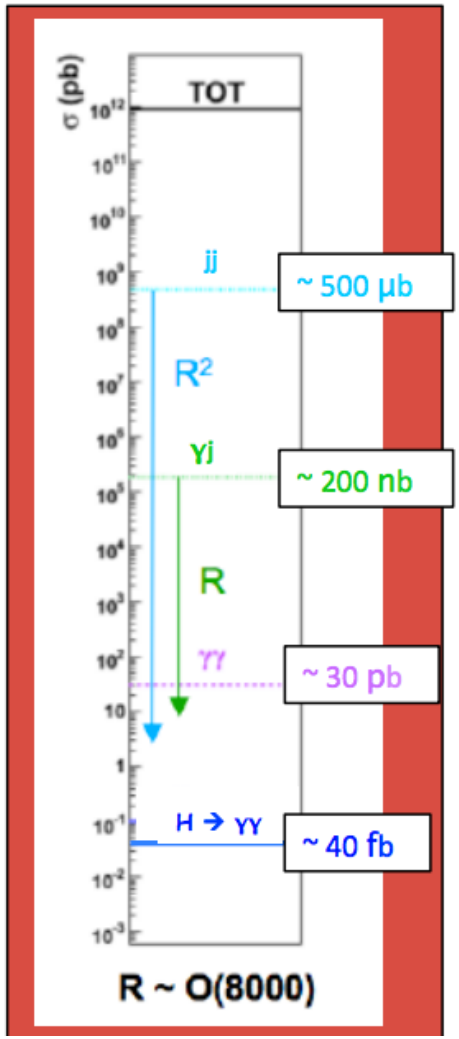
If a 126 GeV Standard Model Higgs boson exists in nature, then, for each experiment LHC would have already produced:

	luminosity	Higgs	Higgs → γγ
7 TeV	4.8 fb^{-1}	~82,000	~ 190
8 TeV	5.9 fb^{-1}	~131,000	~ 300

Highlights of ATLAS detector performance



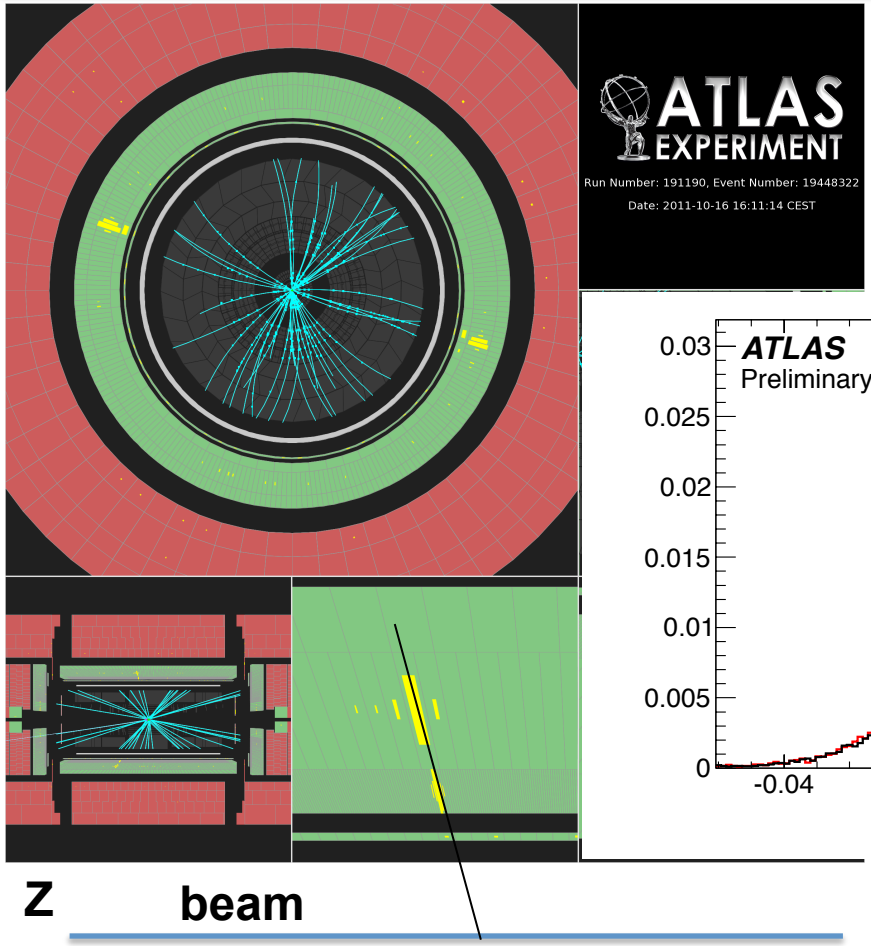




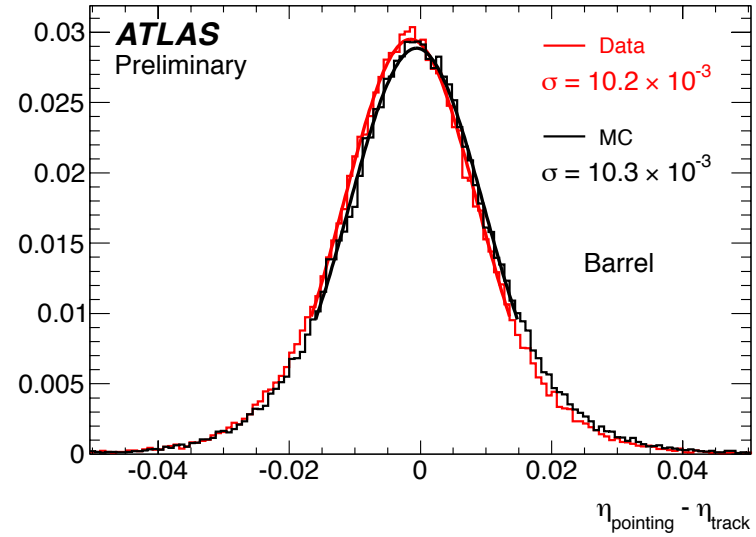
- Liquid Argon sampling calorimeter: 3 layers + presampler, covers |η|<3.2, precision measurement |η|<2.5

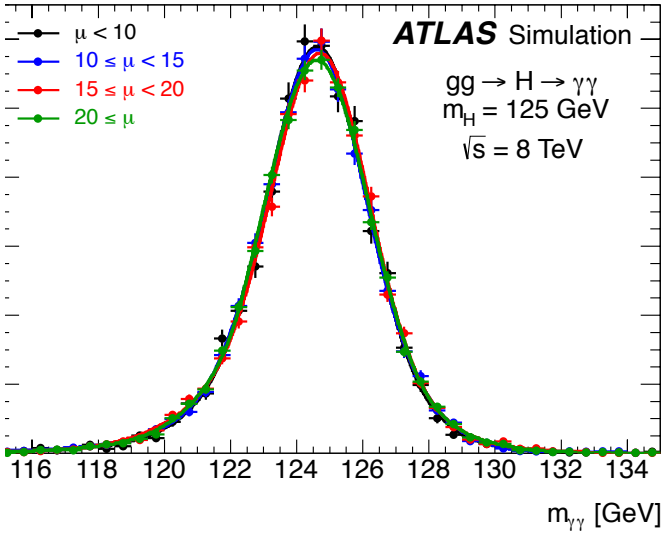
- Monte Carlo calibration, corrected with $Z \rightarrow e^+e^-$ data.
- Resolution of diphoton invariant mass(m_H = 125 GeV) is ~ 1.6 GeV.
- Fine granularity of calorimeter helps identify real photon over jet fakes.

Highlights of ATLAS detector performance



Multiply vertices in high pile-up condition. Interaction point(IP) spread ~ 5.6 cm, i.e., additional ~ 1 GeV contribution to resolution.



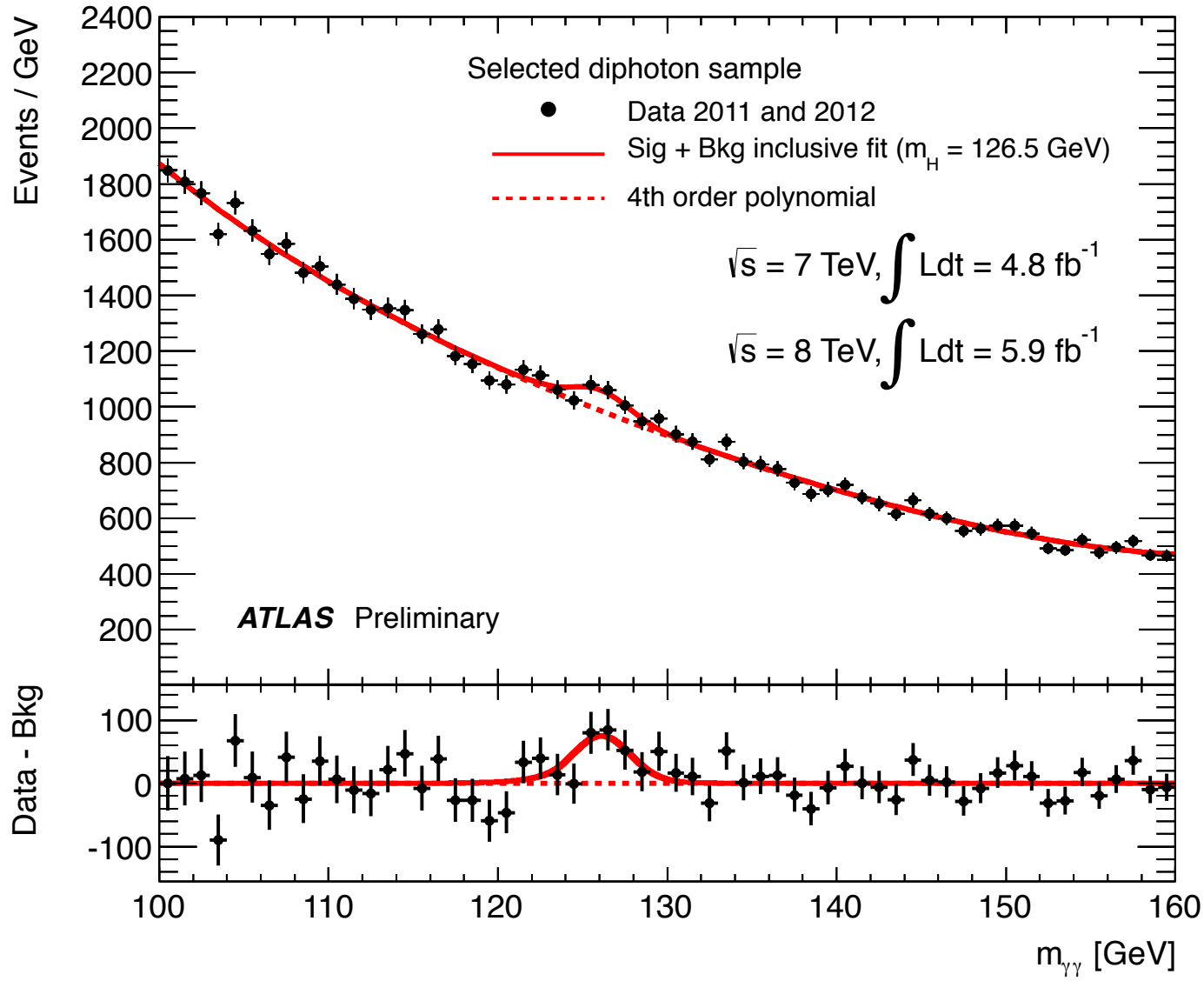


- **Calorimeter pointing**
  - use the longitudinal development of the shower to point back to the IP.
  - Position measurement contribution to the resolution is negligible.
  - Robust against pile-up.

Inclusive analysis: fit a single mass spectrum

Selection:
$p_T > 40, 30$ GeV;
$|\eta|<2.37$, not in calorimeter transition region;
Isolation < 4 GeV

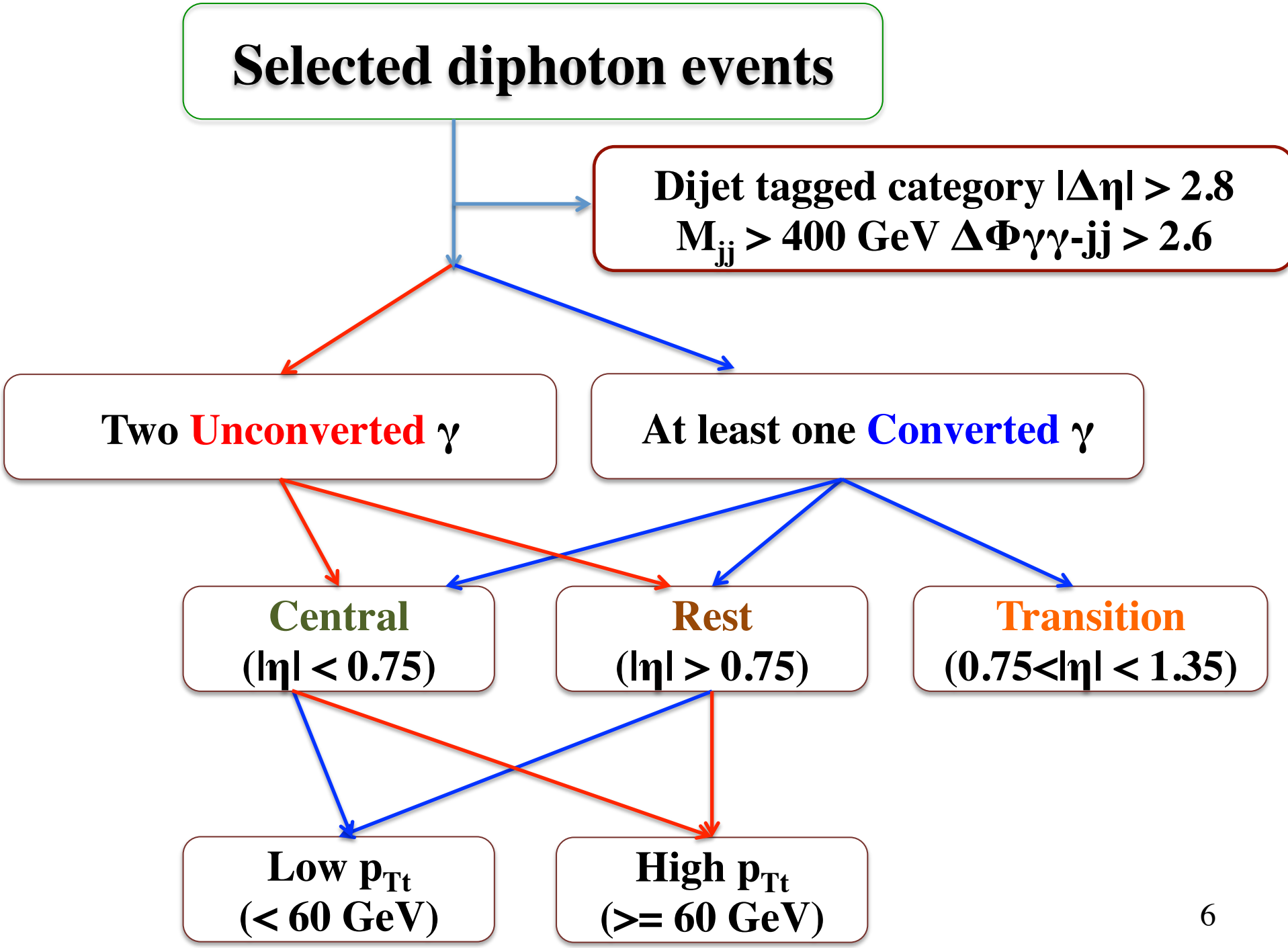
59039 candidates selected(23788 at 7 TeV and 35251 at 8 TeV)
Expected signal: 81 at 7 TeV and 114 at 8 TeV.



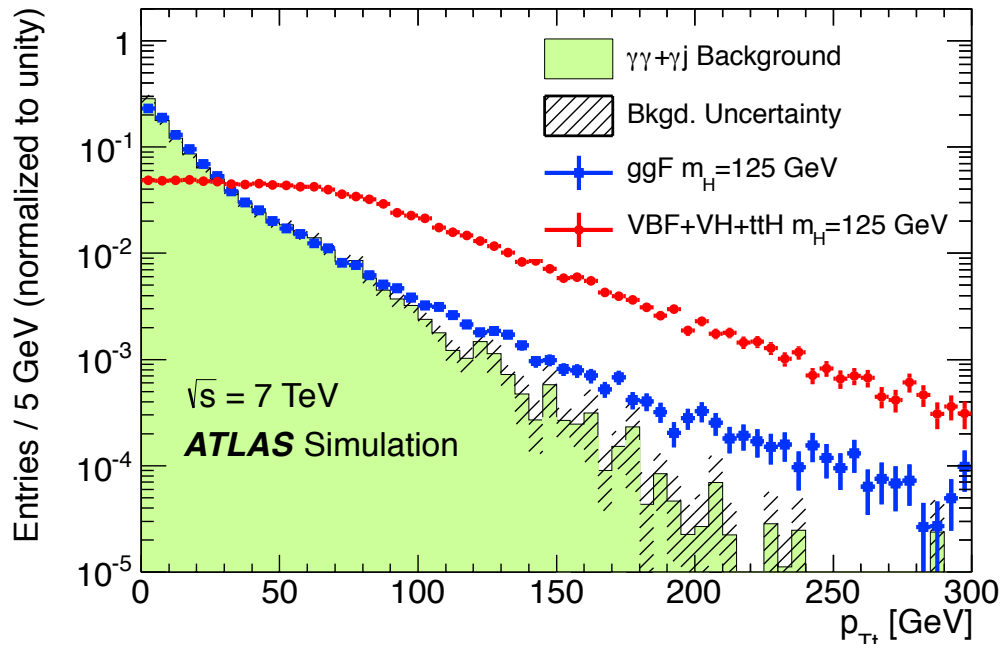
The inclusive analysis result: expected 1.9 σ, and observed 3.4 σ

The final result using a more sophisticated analysis: expected 2.4 σ, and observed 4.5 σ.

Categorization

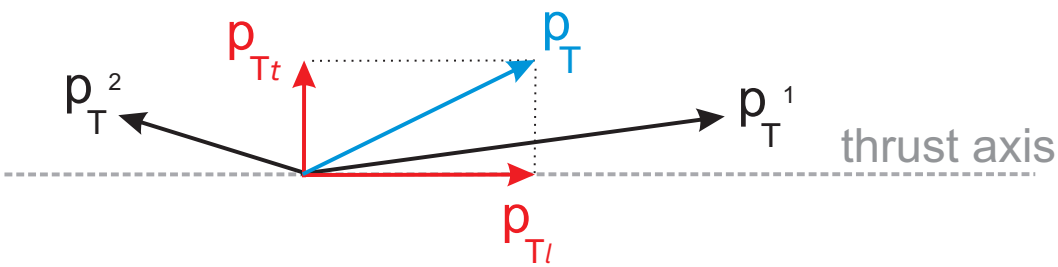


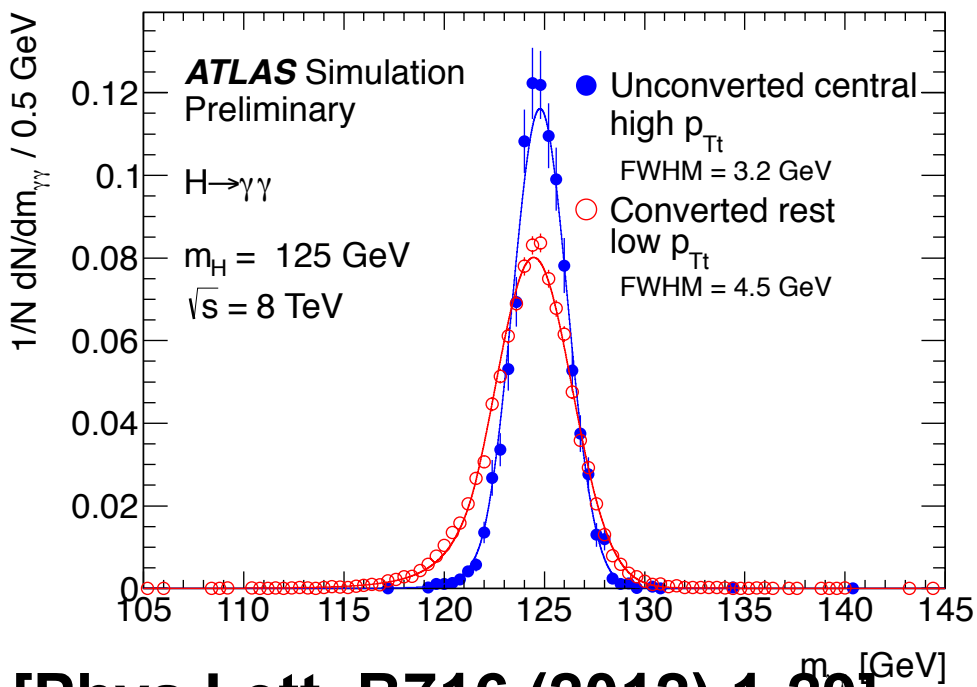
Categorization



High pTt

More signal like, especially for VH and VBF events.





Unconverted photon:

Better resolution

Converted photon:

Worse resolution, more fake photons($\pi^0 \rightarrow \gamma\gamma$)

Central Calorimeter region:

Better resolution

[Phys.Lett. B716 (2012) 1-29]

7

Combined likelihood: bring 10 categories together

Category	σ_{CB} [GeV]	FWHM [GeV]	Observed [N_{evt}]	S [N_{evt}]	B [N_{evt}]	S/B
Inclusive	1.63	3.87	3693	100.4	3635	
Unconverted central, low p_{Tt}	1.45	3.42	235	13.0	215	
Unconverted central, high p_{Tt}	1.37	3.23	15	2.3	14	0.16
Unconverted rest, low p_{Tt}	1.57	3.72	1131	28.3	1133	
Unconverted rest, high p_{Tt}	1.51	3.55	75	4.8	68	
Converted central, low p_{Tt}	1.67	3.94	208	8.2	193	
Converted central, high p_{Tt}	1.50	3.54	13	1.5	10	
Converted rest, low p_{Tt}	1.93	4.54	1350	24.6	1346	
Converted rest, high p_{Tt}	1.68	3.96	69	4.1	72	
Converted transition	2.65	6.24	880	11.7	845	0.014
2-jets	1.57	3.70	18	2.6	12	0.22

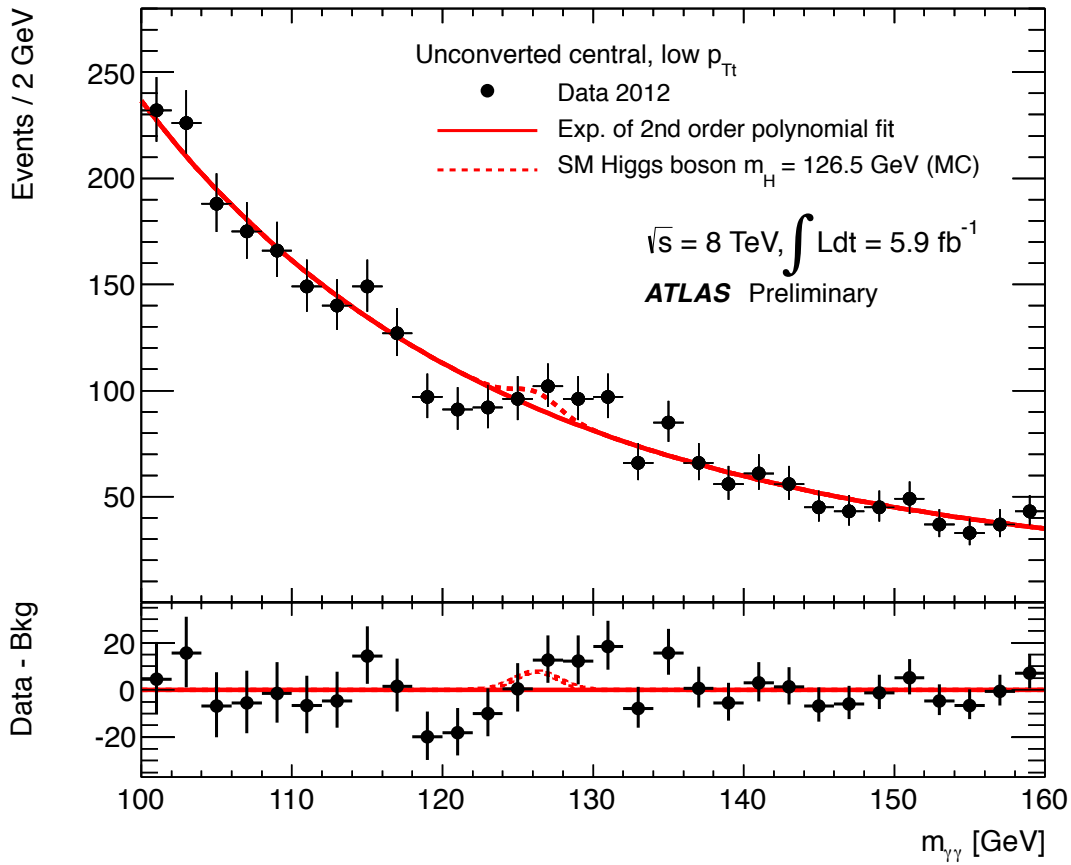
Resolution varies between 1.4 GeV and 2.6 GeV.

2-jets category offers the best S/B = 0.22, and in the other categories, the S/B varies between 0.16 and 0.014.

The fraction of VBF events in total signal events in 2-jets category is ~ 75 % in 7 TeV data, and ~ 68% in 8 TeV data

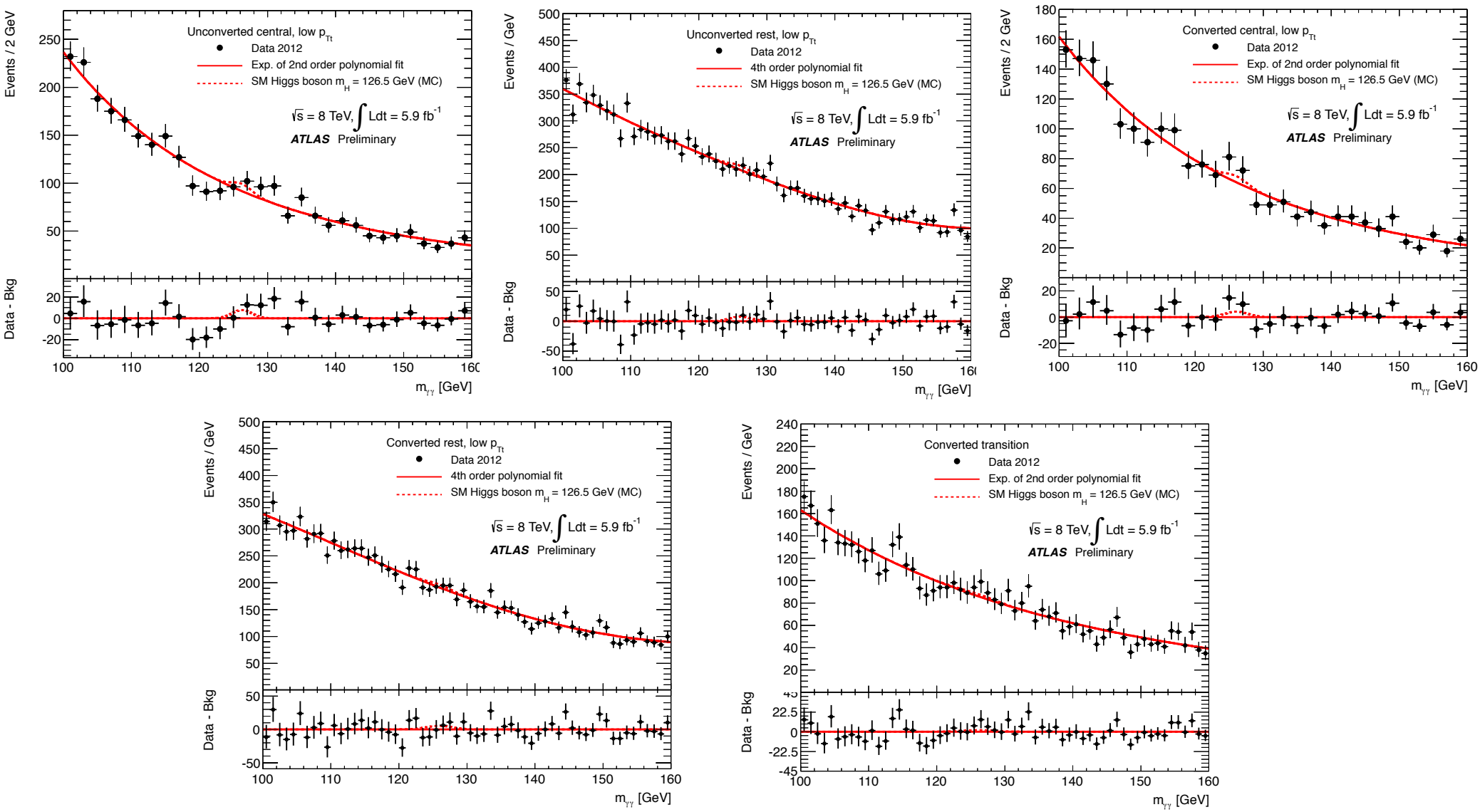
[Phys.Lett. B716 (2012) 1-29]

Background models



- Functional forms that fit data equally well can give different observed significance.
- Choices of background parameterizations were decided before looking at data.
- Use high statistics Monte Carlo sample to select background models that are flexible enough to fit data and still retain enough statistical power.

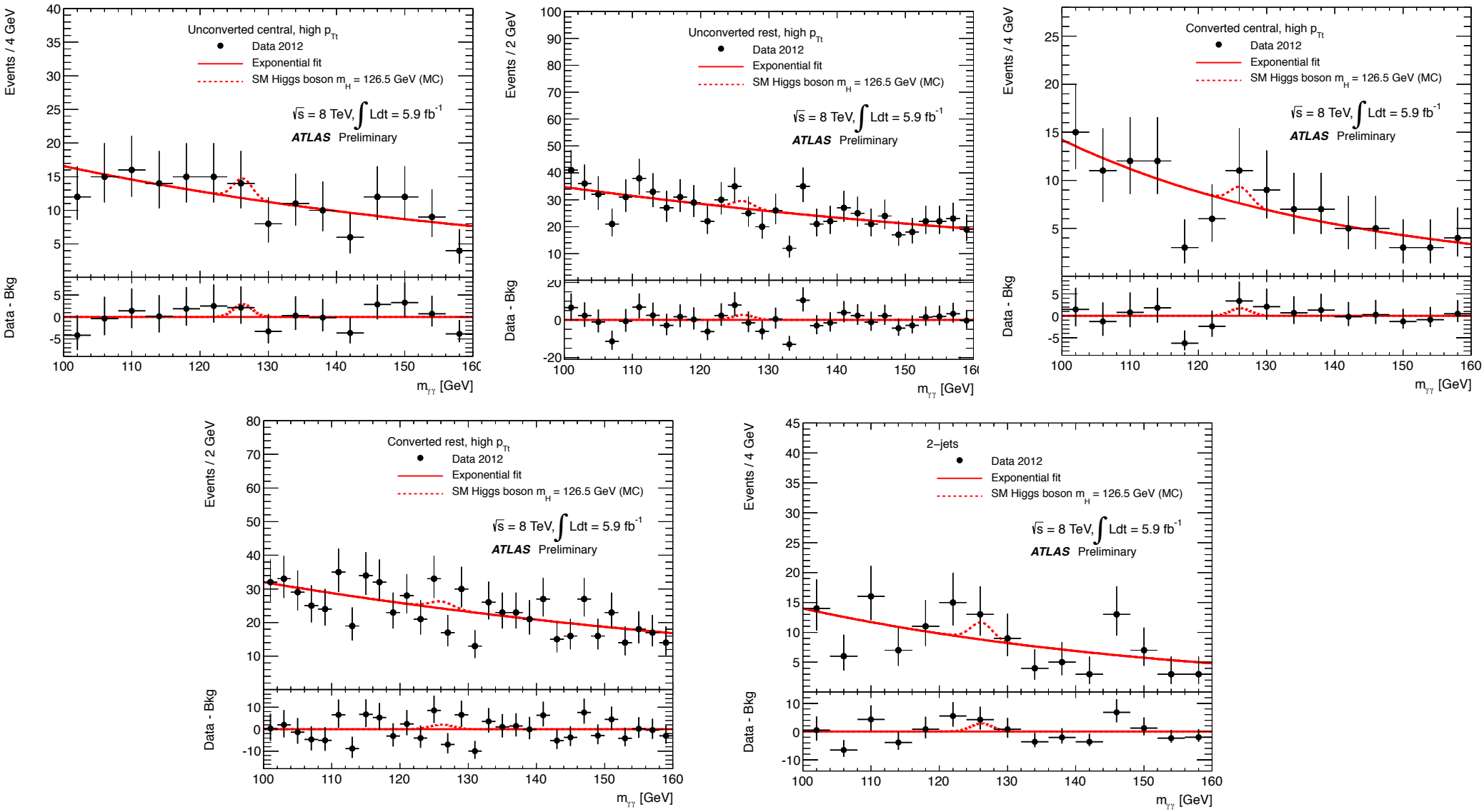
Invariant mass spectra (8 TeV data)



Categories with high statistics: low p_{Tt} categories and converted transition category

[Phys.Lett. B716 (2012) 1-29]

Invariant mass spectra (8 TeV data)

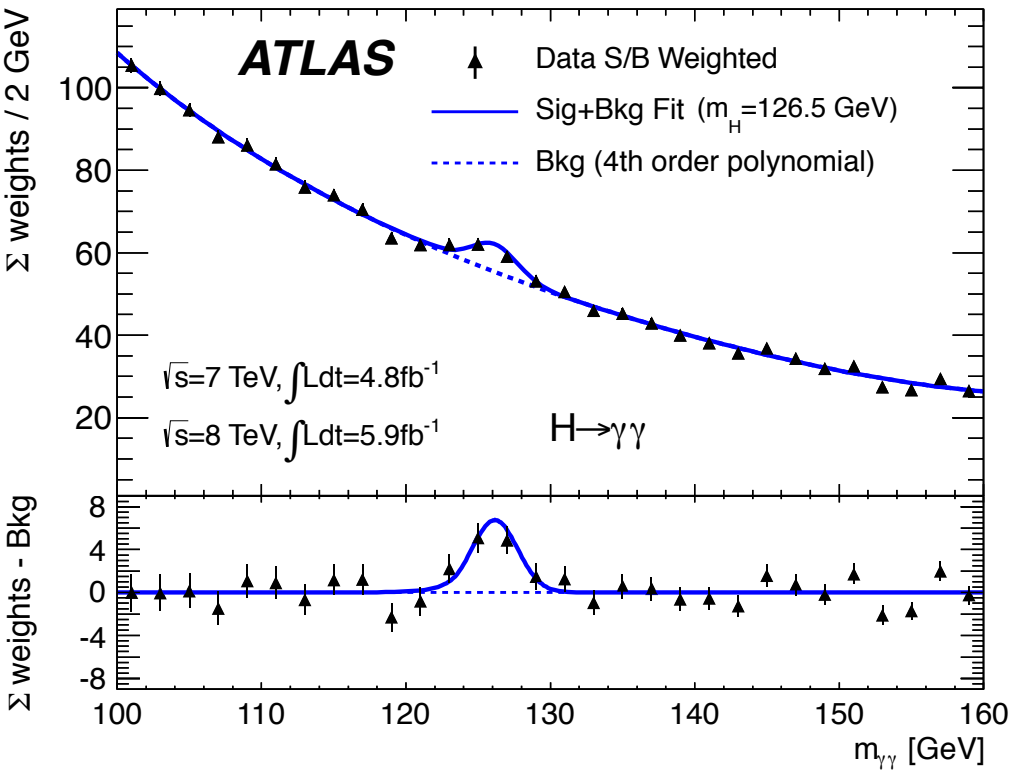


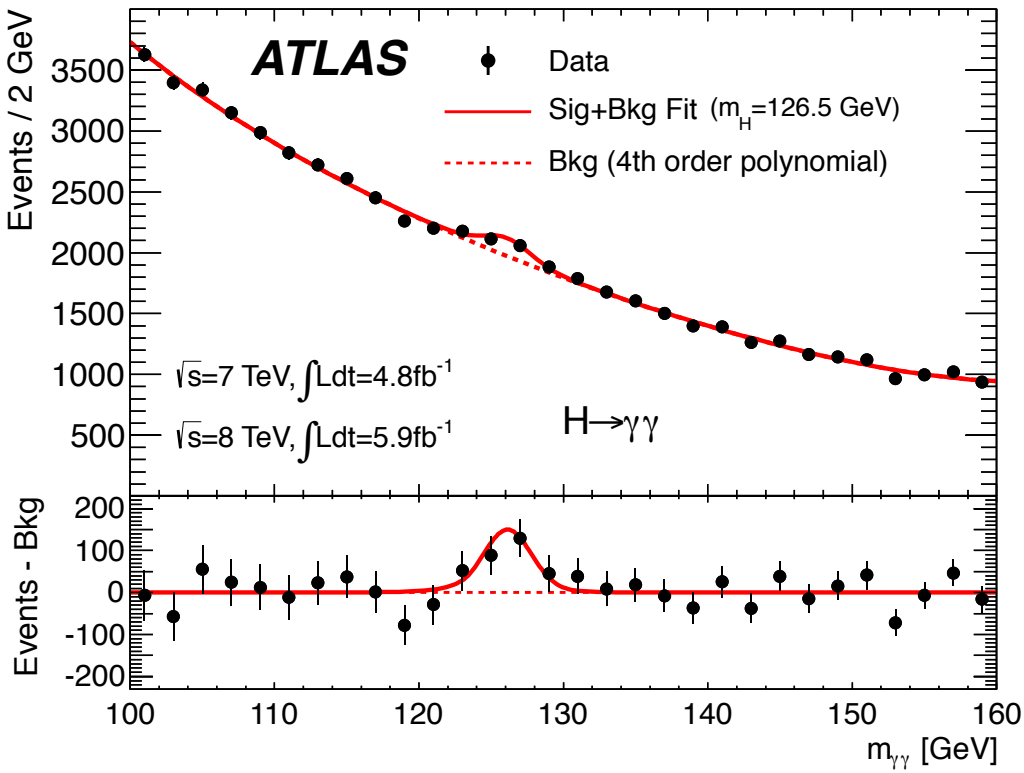
Categories with low statistics: high p_{Tt} categories and 2-jets category

[Phys.Lett. B716 (2012) 1-29]

Invariant mass spectra: combining 7 TeV and 8 TeV data

[Phys.Lett. B716 (2012) 1-29]





Left: sum of weighted 7 TeV and 8 TeV data, compared to a background fit.

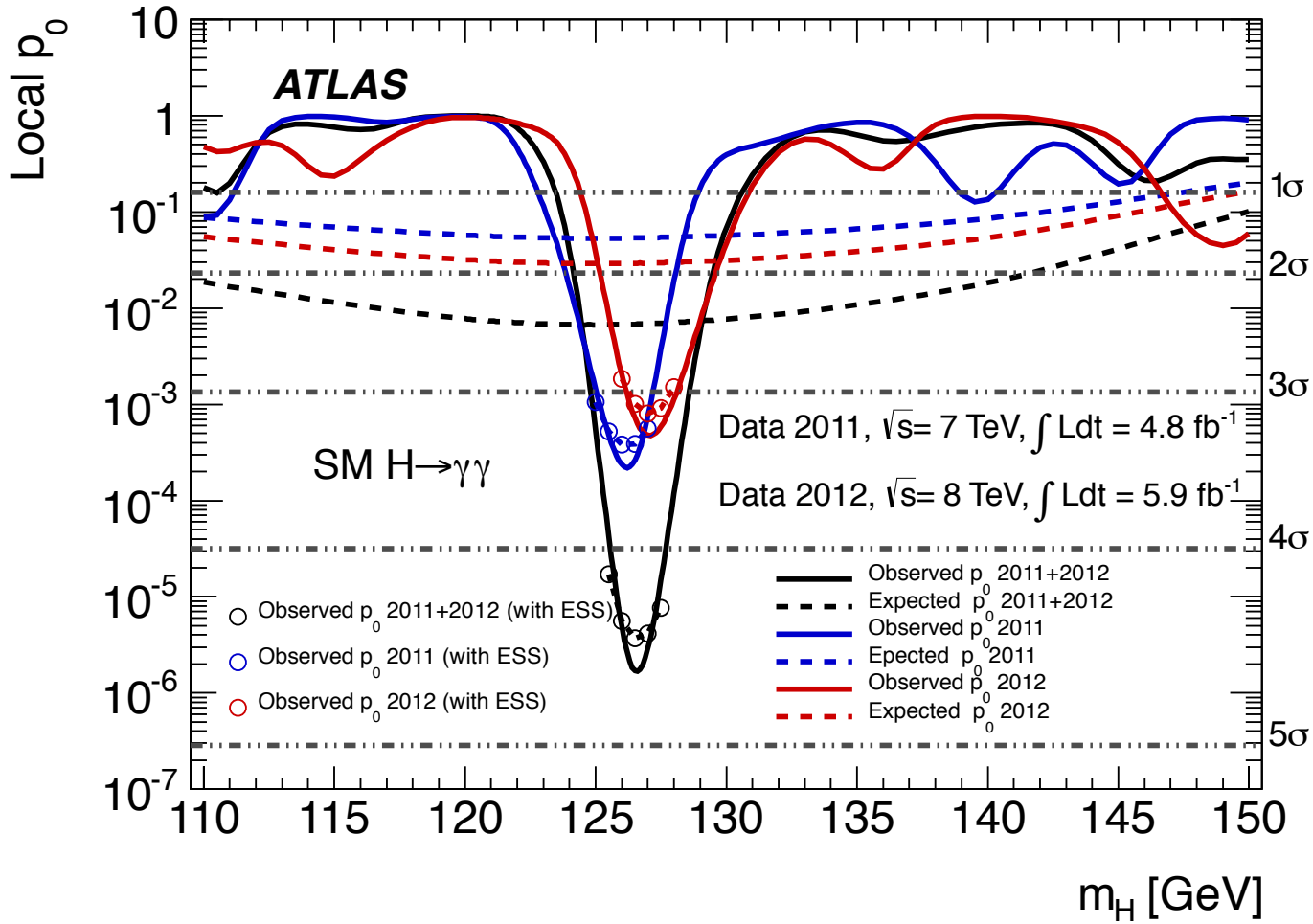
Right: sum of 7 TeV and 8 TeV data, compared to a background fit.

weight = ln(1+s_i/b_i), i is the index of category.

It reflects the power of categorization.

Significance

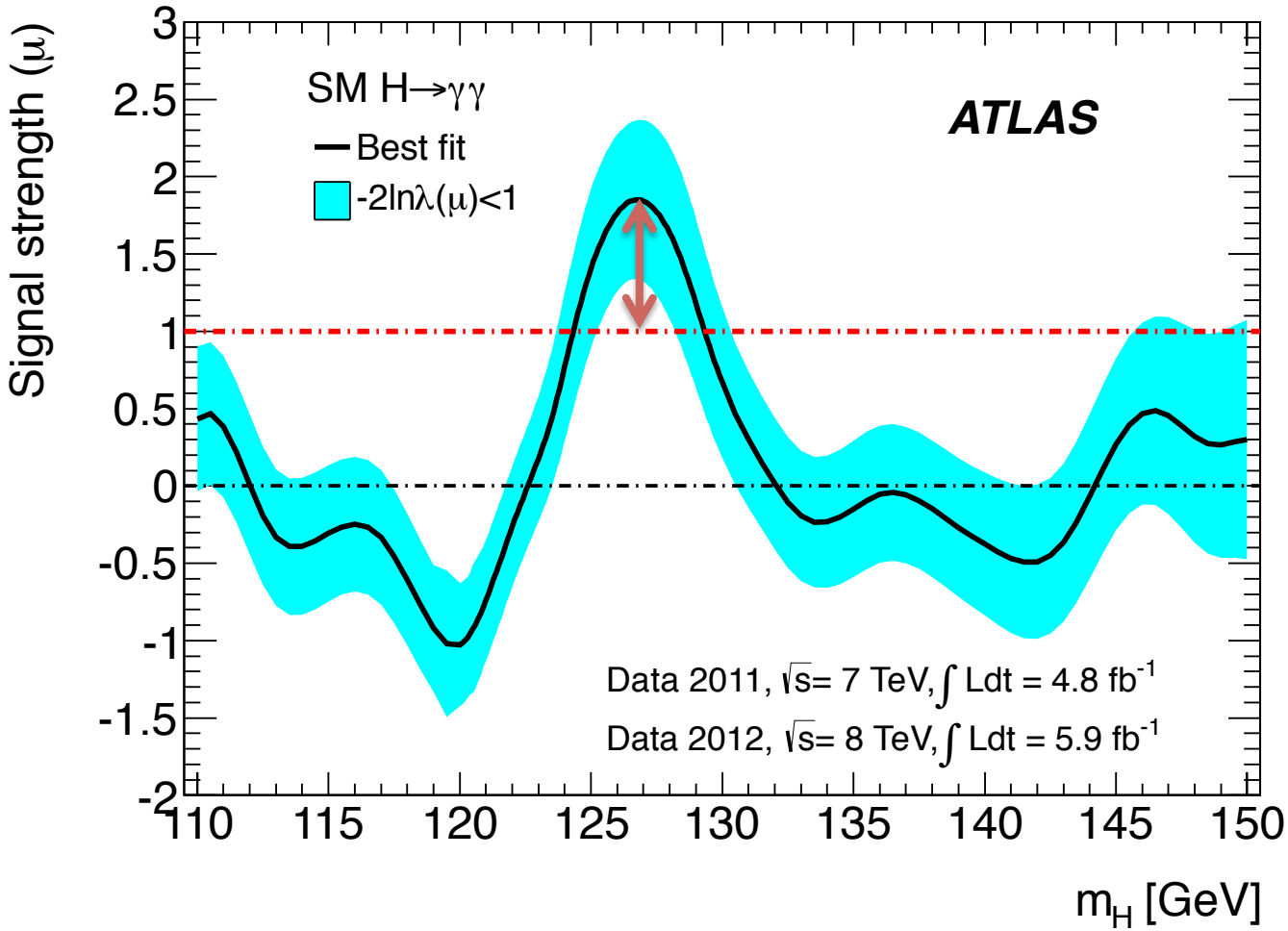
[Phys.Lett. B716 (2012) 1-29]



	m_H (GeV)	Expected Z (σ)	Observed Z (σ)
7 TeV	126.0	1.6	3.3
8 TeV	127.0	1.9	3.2
Combined	126.5	2.4	4.5

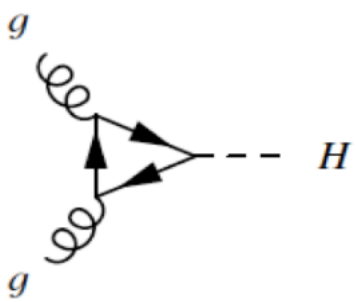
Signal strength

[Phys.Lett. B716 (2012) 1-29]



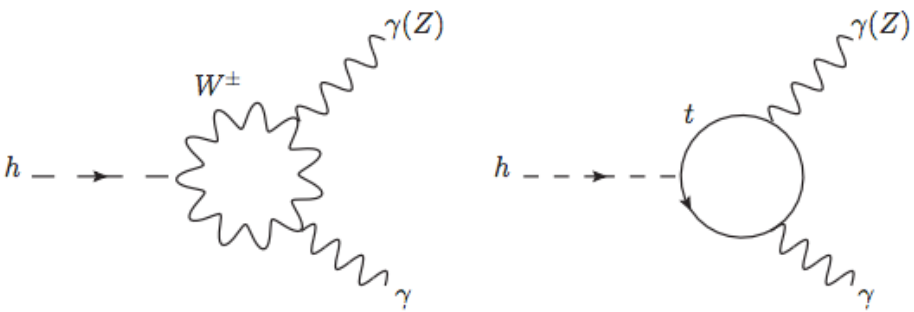
	m_H (GeV)	$\mu(\sigma/\sigma_{SM})$
2011	126.0	2.2 ± 0.8
2012	127.0	1.7 ± 0.6
Combined	126.5	1.8 ± 0.5

Simultaneous fit to all SM Higgs search results



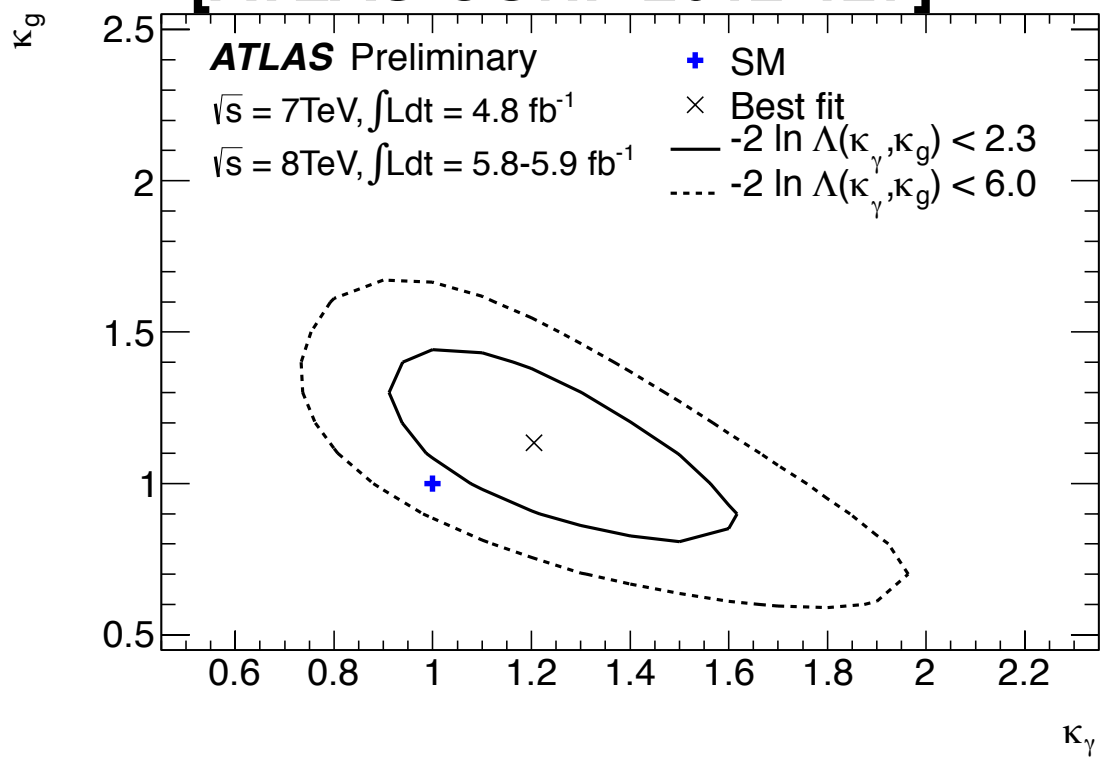
(a) $gg \to H$

$\varkappa_g$ quantifies the variation of the top-loop contribution wrt its SM value.



$\varkappa_\gamma$ quantifies the variation of the decay loop contribution wrt its SM value.

[ATLAS-CONF-2012-127]

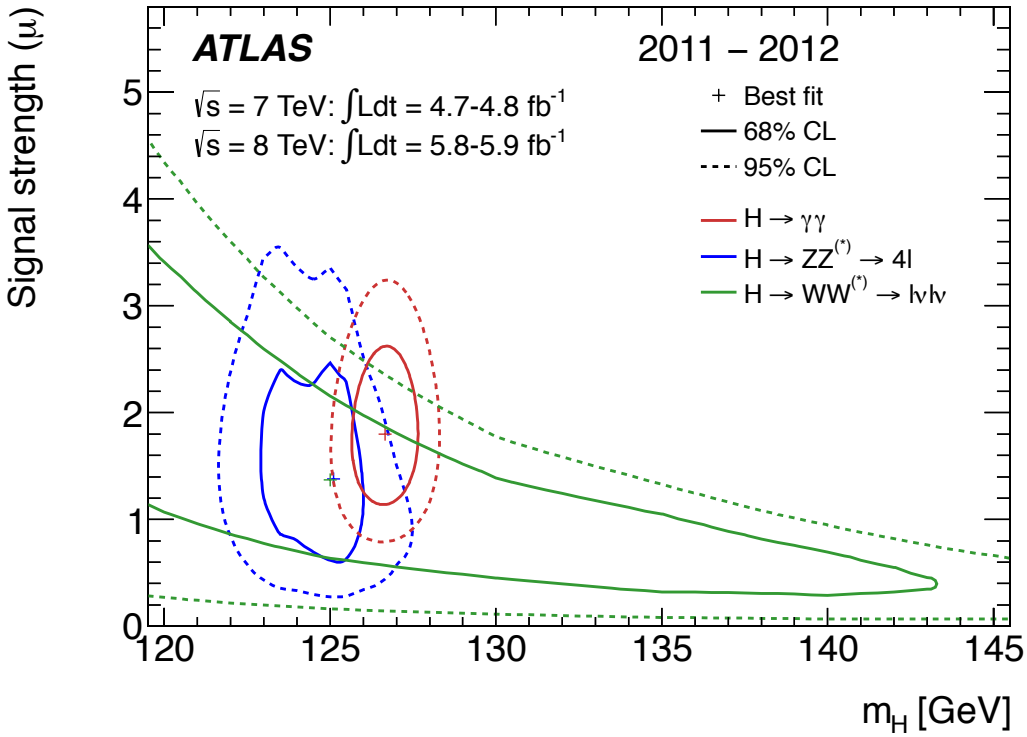


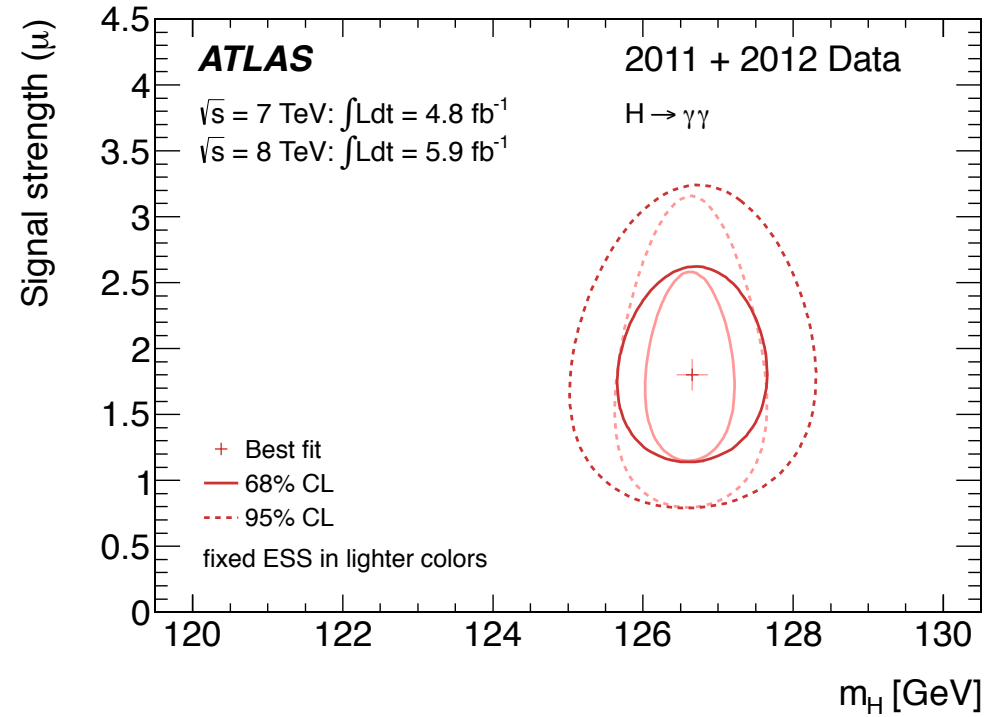
$\varkappa_\gamma \sim 1.2$, $\varkappa_g \sim 1.2$
(with large errors)

The other production modes are constrained by other Higgs search channels.

Determining the mass of the new particle

[Phys.Lett. B716 (2012) 1-29]





The mass measurement from combining $H \rightarrow \gamma\gamma$ and $H \rightarrow 4l$ leads to

$$\mathbf{m_H = 126.0 \pm 0.4(stat.) \pm 0.4(syst.)\ GeV}$$

The $H \rightarrow \gamma\gamma$ channel alone would give ~ 126.5 GeV, while the $H \rightarrow 4l$ channel alone would give ~125.0 GeV.

Energy scale systematics is the major systematic uncertainty.

Summary and outlook

A new particle is observed in the search for the Standard Model Higgs boson decaying to diphoton with the ATLAS detector.

The statistical significance of the excess is 4.5 σ, and its observed signal strength is 1.8 ± 0.5 times the a SM Higgs boson expectation with $m_H = 126.5$ GeV.

The new particle mass is determined to be

$$126.0 \pm 0.4(\text{stat.}) \pm 0.4\ (\text{syst.})\ \text{GeV}.$$

The next major update will be released for Hadron Collider Physics conference on Nov. 12th. Stay tuned!

References:

[Phys.Lett. B716 (2012) 1-29]

Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC. Phys.Lett. B716 (2012) 1-29

[ATLAS-CONF-2012-127]

Coupling properties of the new Higgs-like boson observed with the ATLAS detector at the LHC, ATLAS-CONF-2012-127

Systematic uncertainties(1)

Systematic uncertainties	$\sqrt{s}$ = 7 TeV [%]	$\sqrt{s}$ = 8 TeV [%]
Signal event yield		
Photon identification	±8.4	±10.8
Effect of pileup on photon rec/ID	±4	
Photon energy scale	±0.3	
Photon Isolation	±0.4	±0.5
Trigger	±1	
Higgs boson cross section (perturbative)	$gg \to H$: $^{+12}_{-8}$, VBF: ±0.3, WH: $^{+0.2}_{-0.8}$, ZH: $^{+1.4}_{-1.6}$, ttH: $^{+3}_{-9}$	$gg \to H$: $^{+7}_{-8}$, VBF: ±0.2, WH: $^{+0.2}_{-0.6}$, ZH: $^{+1.6}_{-1.5}$, ttH: $^{+4}_{-9}$
	$gg \to H + 2$ jets: ±25	
Higgs boson cross section (PDF+α_S)	$gg \to H$: $^{+8}_{-7}$, VBF: $^{+2.5}_{-2.1}$, VH: ±3.5, ttH: ±9	$gg \to H$: $^{+8}_{-7}$, VBF: $^{+2.6}_{-2.8}$, VH: ±3.5, ttH: ±8
Higgs boson branching ratio	±5	
Higgs boson p_T modeling	low p_{Tt}: ±1.1, high p_{Tt}: ∓12.5, 2-jets: ∓9	
Underlying Event (2-jets)	VBF: ±6, Others: ±30	
Luminosity	±1.8	±3.6

Systematic uncertainties(2)

Signal category migration		
Material	Unconv: ±4, Conv: ∓3.5	
Effect of pileup on photon rec/ID	Unconv: ±3, Conv: ∓2, 2-jets: ±2	Unconv: ±2, Conv: ∓2, 2-jets: ±12
Jet energy scale	low p_{Tt}	
	$gg \to H$: ±0.1, VBF: ±2.6, Others: ±0.1	$gg \to H$: ±0.1, VBF: ±2.3, Others: ±0.1
	high p_{Tt}	
	$gg \to H$: ±0.1, VBF: ±4, Others: ±0.1	$gg \to H$: ±0.1, VBF: ±4, Others: ±0.1
	2-jets	
	$gg \to H$: ∓19, VBF: ∓8, Others: ∓15	$gg \to H$: ∓18, VBF: ∓9, Others: ∓13
Jet-vertex-fraction		2-jets: ±13, Others: ∓0.3
Primary vertex selection	negligible	
Signal mass resolution		
Calorimeter energy resolution	±12	
Electron to photon extrapolation	±6	
Effect of pileup on energy resolution	±4	
Primary vertex selection	negligible	
Signal mass position		
Photon energy scale	±0.6	
Background modeling	see Table 3	

A VBF-like 2jets category

Select VBF-like events by requiring 2 jets with:

- $p_{T1,2} > 25$ GeV (2011), 30 GeV(2012)
- $|\eta|<4.5$
- $|\Delta\eta_{jj}| > 2.8$
- $M_{jj} > 400$ GeV
- $|\Delta\phi_{(\gamma\gamma\text{-}jj)}| > 2.6$

- **Selection was optimized to maximize 7 TeV search sensitivity.**

Purity of VBF events in selected signal events:

- **76.7% (7 TeV)**
- **68.4% (8 TeV)**