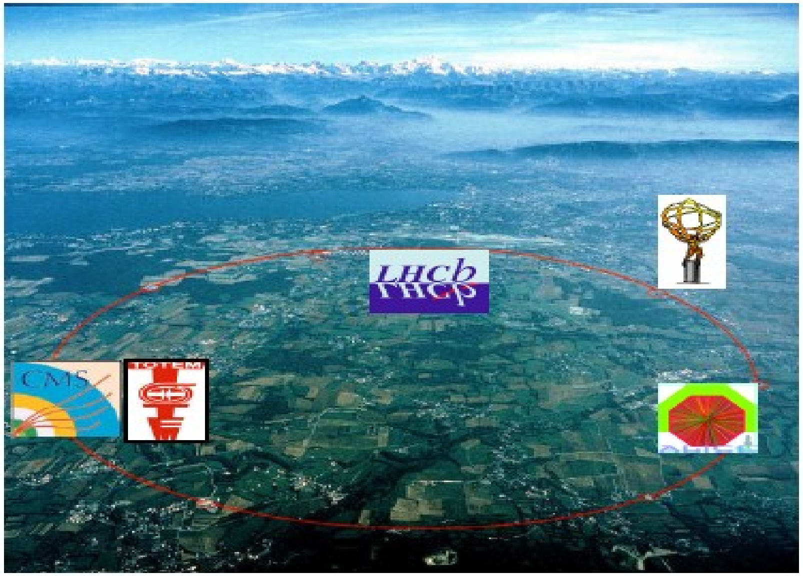
Physics Program

of the experiments at

Large Hadron Collider



Standard Model

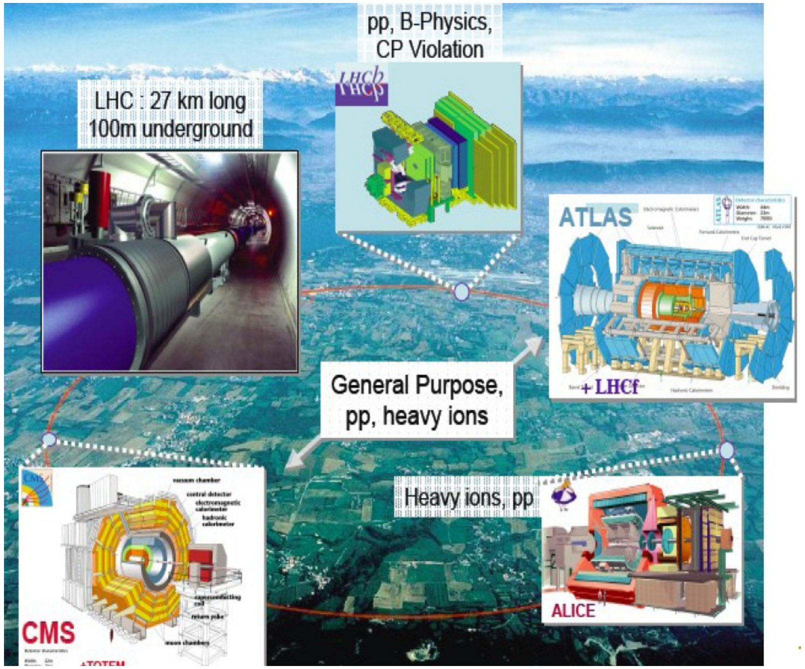
Higgs boson

Latest news

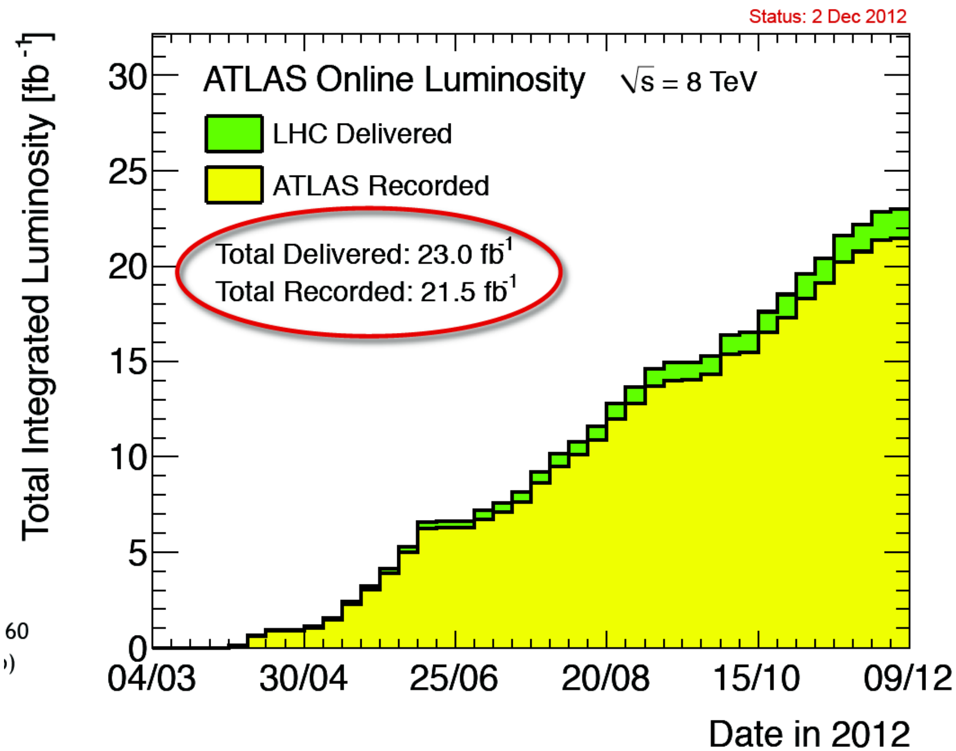
Today: CERN LHCC open session

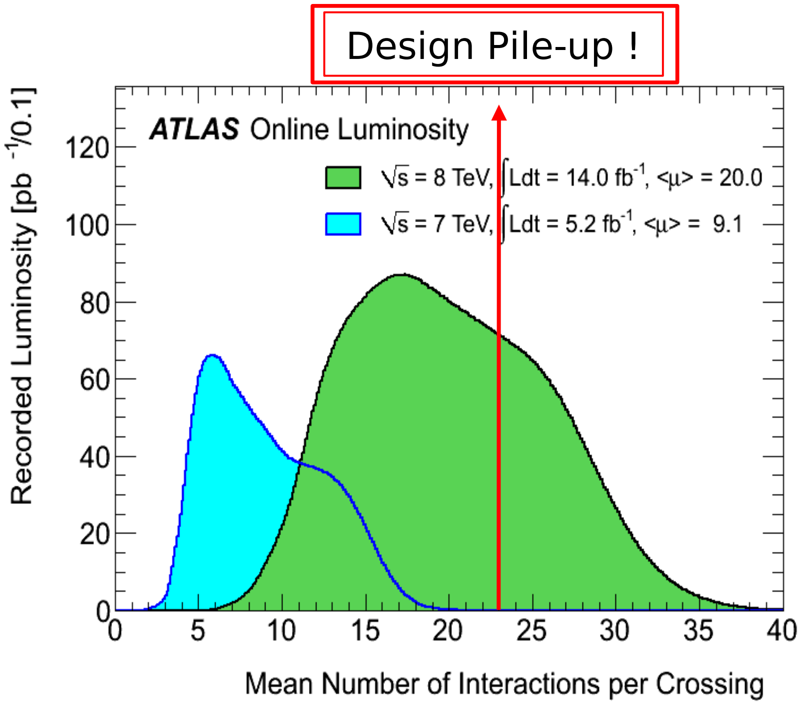
http://indico.cern.ch/conferenceDisplay.py?confId=216930

Living in incredibly exciting time for fundamental partcile physics!



Latest news





Excellent LHC performance in 2012

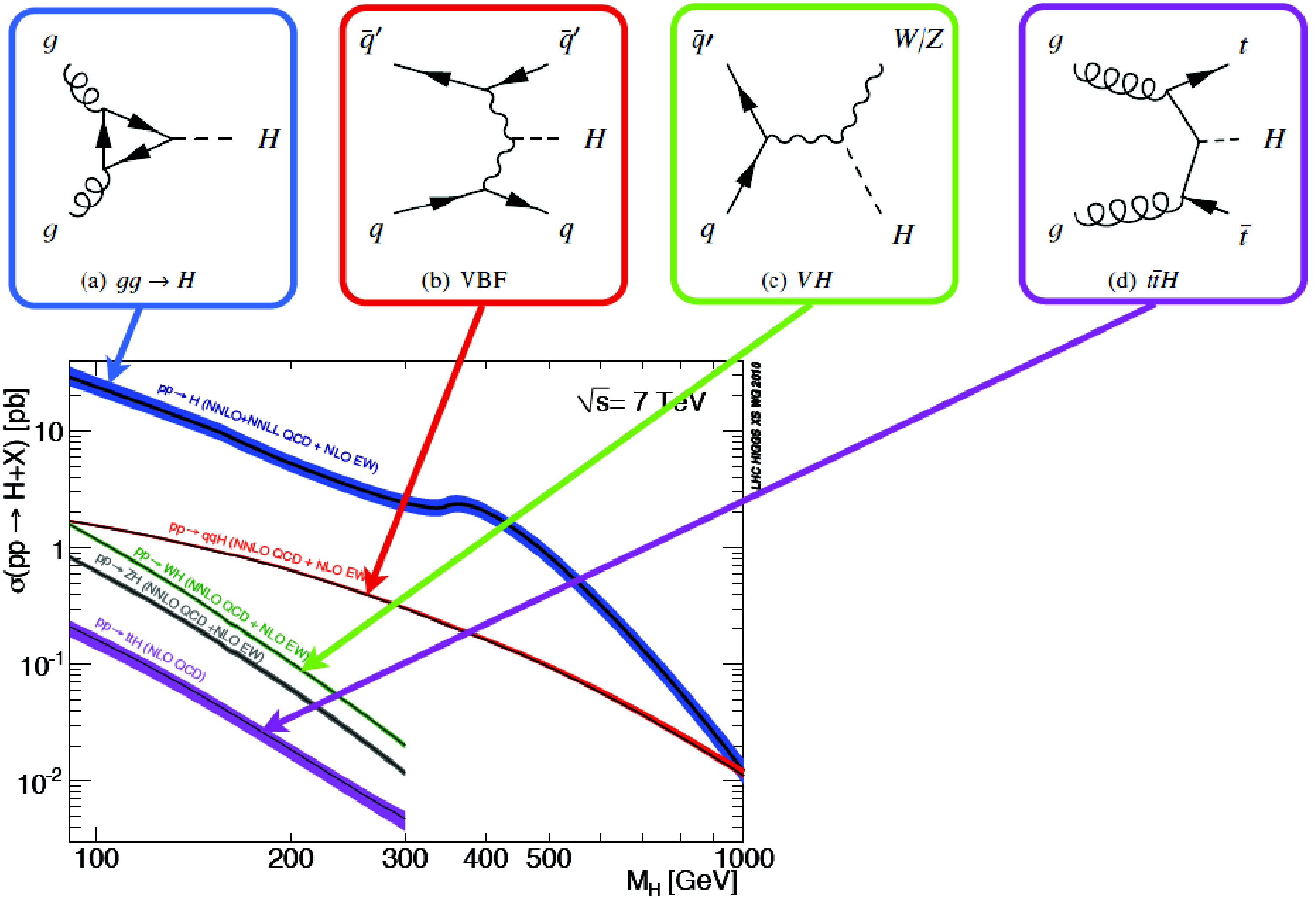
Lpeak up to 7.7x1033 cm-2 s-1 at 8 TeV

Lintegrated ~ 23 fb-1 delivered

LHC operated with 50ns bunch spacing:

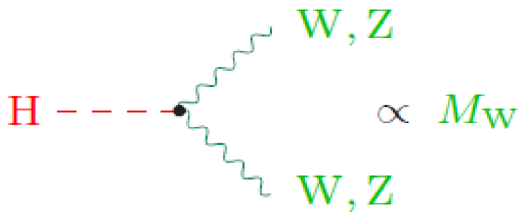
- 2012 pile-up conditions challenging

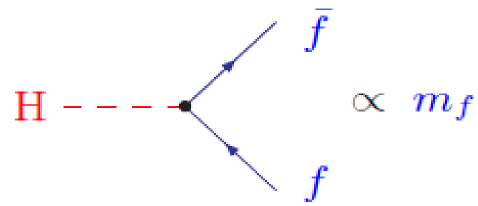
SM Higgs production at the LHC



Higgs production and decay at LHC

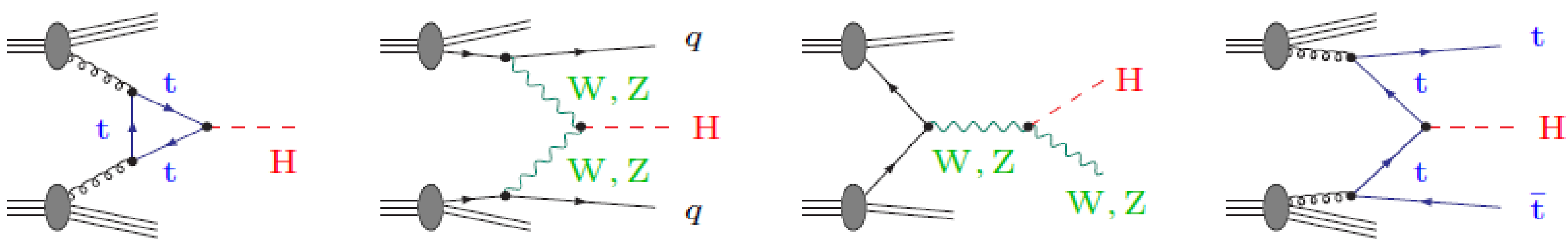
Higgs bosons couple proportional to particle masses:





$\Rightarrow$ Higgs production via couplings to W/Z bosons or top-quarks

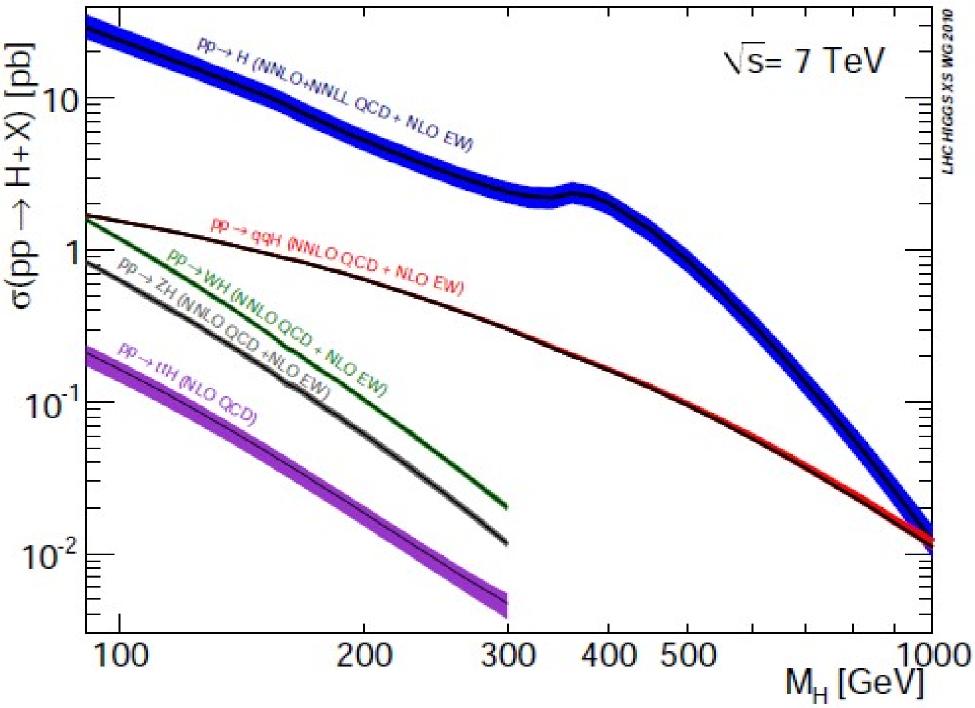
Production at hadron colliders ($p\bar{p}/pp$):



Decay channels for Higgs bosons of moderate mass ($M_H \lesssim 300\,\mathrm{GeV}$):

Higgs production and decay at LHC

SM Higgs XS predictions
for the LHC at $\sqrt{s} = 7\,\mathrm{TeV}$
LHC Higgs XS WG 2010



Rough numbers:

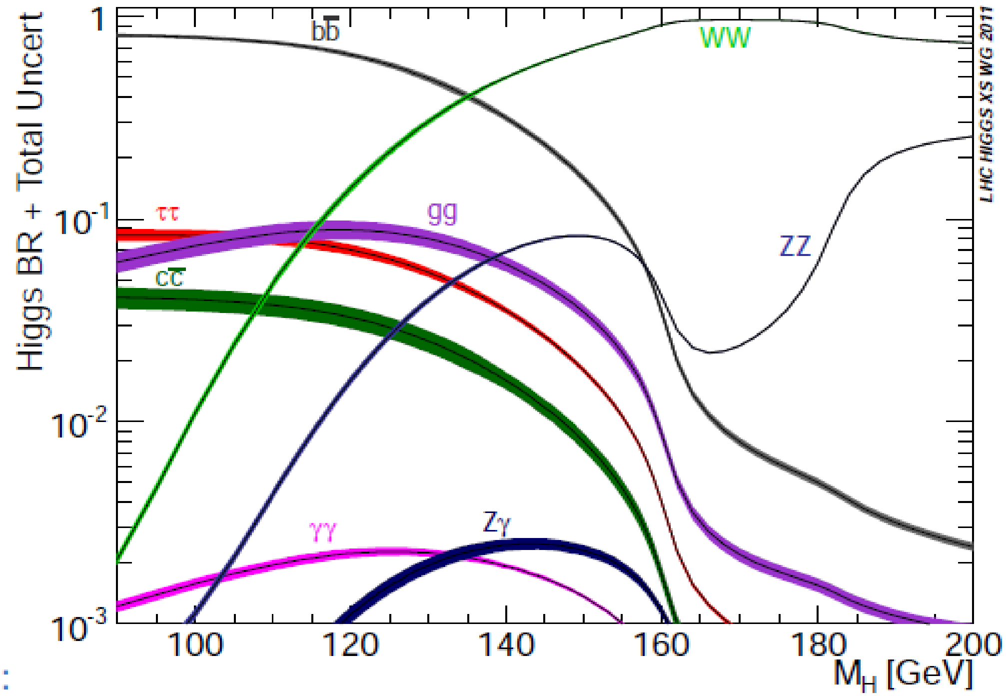
	M_{H}	Uncertainties scale	Uncertainties PDF4LHC	NLO/NNLO/NNLO+ QCD	EW
ggF	$< 500\,\mathrm{GeV}$	$6-10\%$	$8-10\%$	$>100\%$	5%
VBF	$< 500\,\mathrm{GeV}$	1%	$2-7\%$	5%	5%
WH	$< 200\,\mathrm{GeV}$	1%	$3-4\%$	30%	$5-10\%$
ZH	$< 200\,\mathrm{GeV}$	$1-2\%$	$3-4\%$	40%	5%
ttH	$< 200\,\mathrm{GeV}$	10%	9%	5%	?

EW corrections
$\sim \mathcal{O}$(uncertainties)

Higgs production and decay at LHC

At $L = 7\times10^{33}\ s^{-1}cm^{-2}$ and 8 TeV *pp* collisions, 560 Higgs bosons of mass 125 GeV ($\sigma_{pp\to H}$ = 22.3 pb) are produced in ATLAS and CMS per hour

Or: every 45 min. 1 $H\to\gamma\gamma$, need ~2 typical 160 pb^{-1} fills to produced one $H\to 4l$ ($l=e/\mu$)



Parametric + theoretical uncertainty:

M_H[GeV] H $\to$	$b\bar{b}$	$\tau^+\tau^-$	$c\bar{c}$	gg	$\gamma\gamma$	WW	ZZ
120	3%	6%	12%	10%	5%	5%	5%
150	4%	3%	10%	8%	2%	1%	1%
200	5%	3%	10%	8%	2%	$<0.1\%$	$<0.1\%$

$\leftarrow$ driven by δm_b via $\Gamma_{H\to b\bar{b}}$

EW corrections significant in predictions for $\Gamma_{H\to X}$ and $BR_{H\to X}$

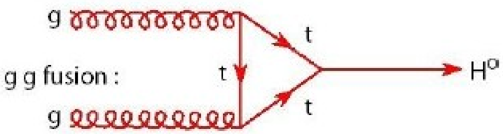
Higgs production and decay at LHC

For each coupling g_i, measure strength in "units" of SM value: $\kappa_i = g_i/g_{i,SM}$

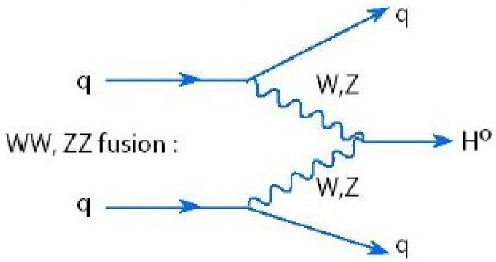
– Defined in analogy to signal strength $\mu = \sigma/\sigma_{SM}$

Production rate is proportional to squared coupling, g^2

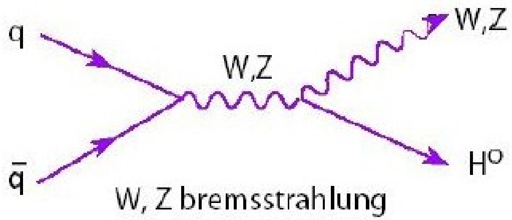
– Scaled each production mode *i* by factor κ_i^2



$\sim \kappa_g^2 \sim \kappa_t^2$ (loop coupling for gluons)

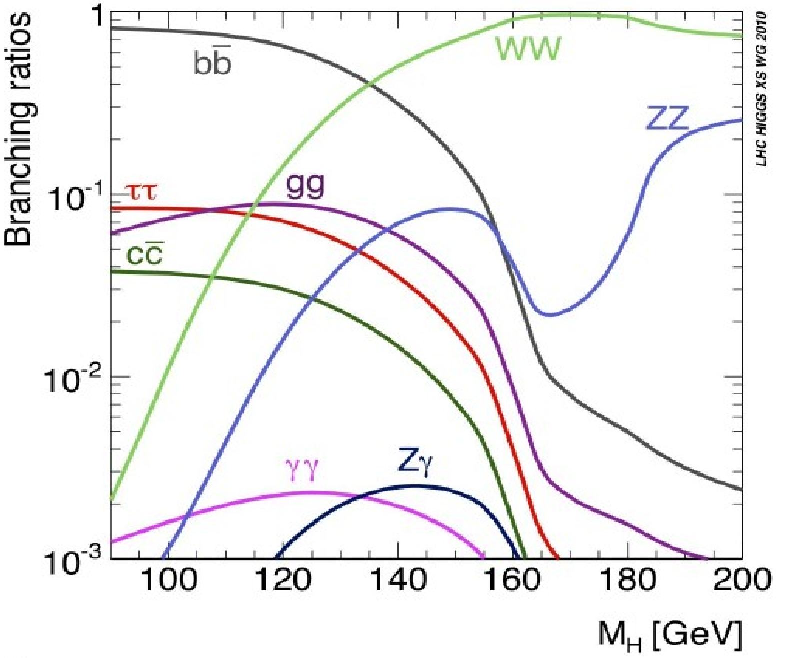


$\sim \kappa_{W,Z}^2$ (tree-level couplings)

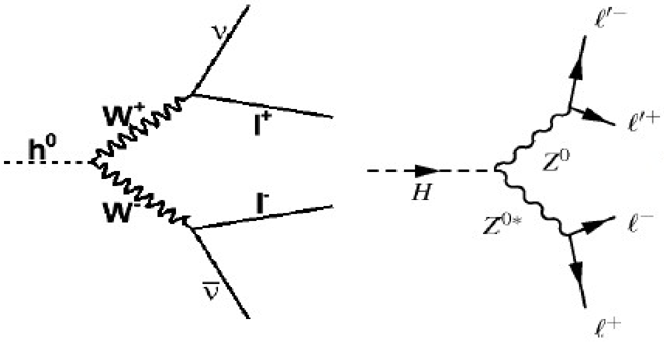


$\sim \kappa_{W,Z}^2$

Higgs production and decay at LHC

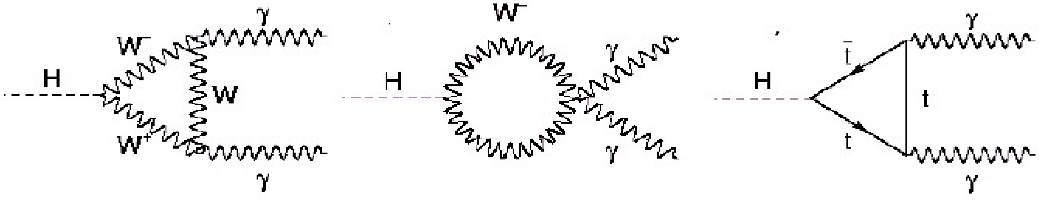


- Scaled each decay mode j by factor $\kappa_j^2 = g_j^2/g_{j,SM}^2$



$\sim \kappa_{W,Z}^2$

(tree-level couplings)



$\sim \kappa_\gamma^2 = |1.28\,\kappa_W - 0.28\,\kappa_t|^2$

(loop coupling for photons)

- Example:

$$(\sigma \cdot \mathrm{BR})(gg \to H \to \gamma\gamma) = \sigma_{SM}(gg \to H) \cdot \mathrm{BR}_{SM}(H \to \gamma\gamma) \cdot \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

SM Higgs decays

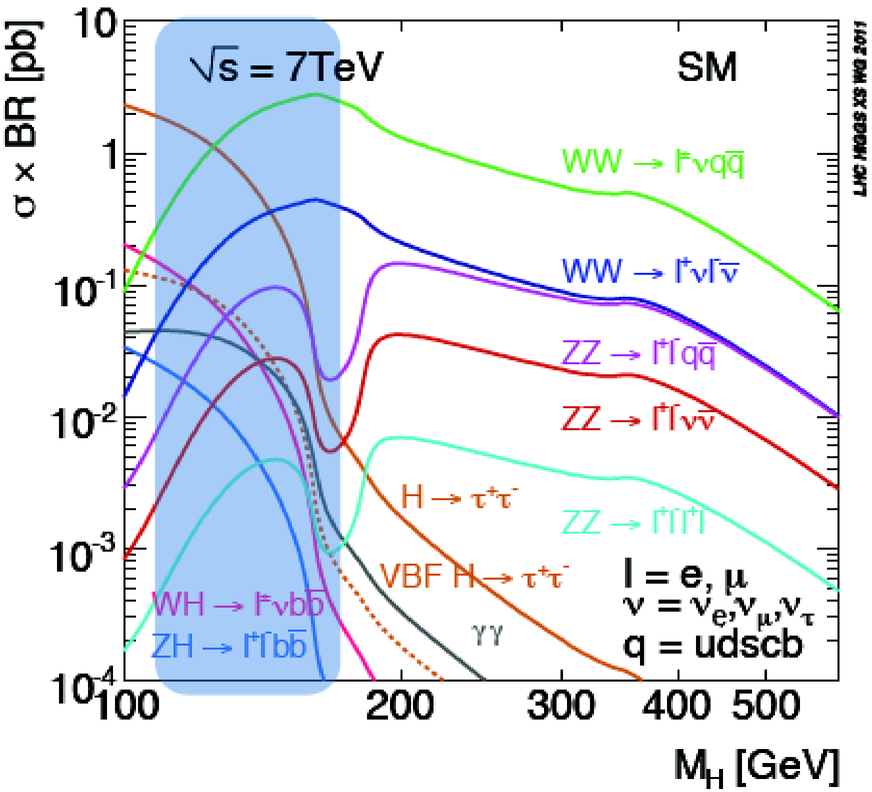
H→γγ

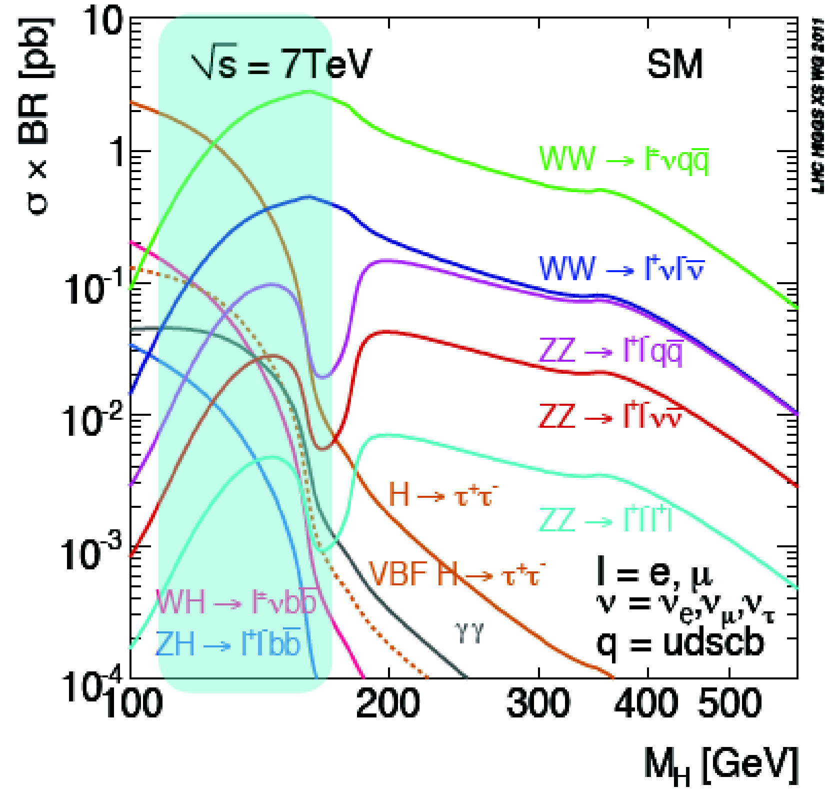
H→ZZ→llll

H→WW→lνlν

VH→bb

H→ττ





ATLAS results of 4-th July

- Searches performed in 12 channels in the range 110 GeV < m_H < 600 GeV

Updated with 2012 data

Higgs decay	Subsequent decay	Mass range [GeV]	L [fb^{-1}]	Publication (arXiv)
$H\rightarrow\gamma\gamma$		110-150	4.8 + 5.9	1202.1414
$H\rightarrow ZZ$	$lll'l'$	110-600	4.8 + 5.8	1202.1415
	$ll\nu\nu$	200-600	4.7	1205.6744
	$llqq$	200-600	4.7	1206.2443
$H\rightarrow WW$	$l\nu qq$	300-600	4.7	1206.6074
	$l\nu l\nu$	110-600	4.7	1206.0756
$H\rightarrow\tau\tau$	$ll4\nu$	110-150	4.7	1206.5971
	$l\tau_{had}3\nu$		4.7	
	$\tau_{had}\tau_{had}2\nu$		4.7	
$VH\rightarrow bb$	$l\nu bb$	110-130	4.7	1207.0210
	$llbb$		4.7	
	$\nu\nu bb$		4.6	

Definitions:

Global signal strength factor μ:

Scale factor on the total number of events predicted by the SM for the Higgs boson signal:

μ=0 - bgd only hypothesis

μ=1 - SM signal in addition to the bgd

Hypothesised values of μ tested with statistics based on profile likelihood ratio.

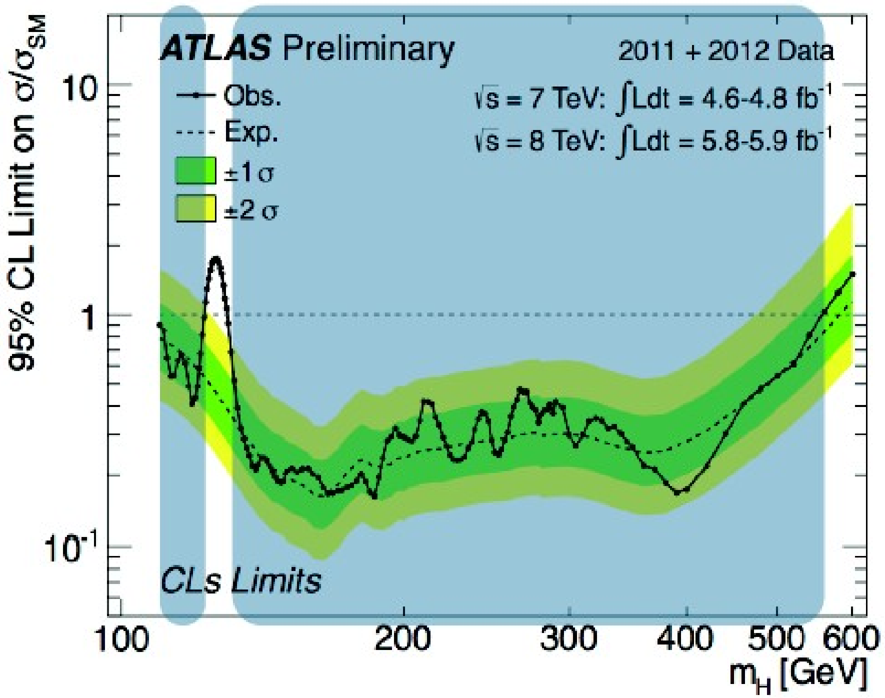
Local p_0:

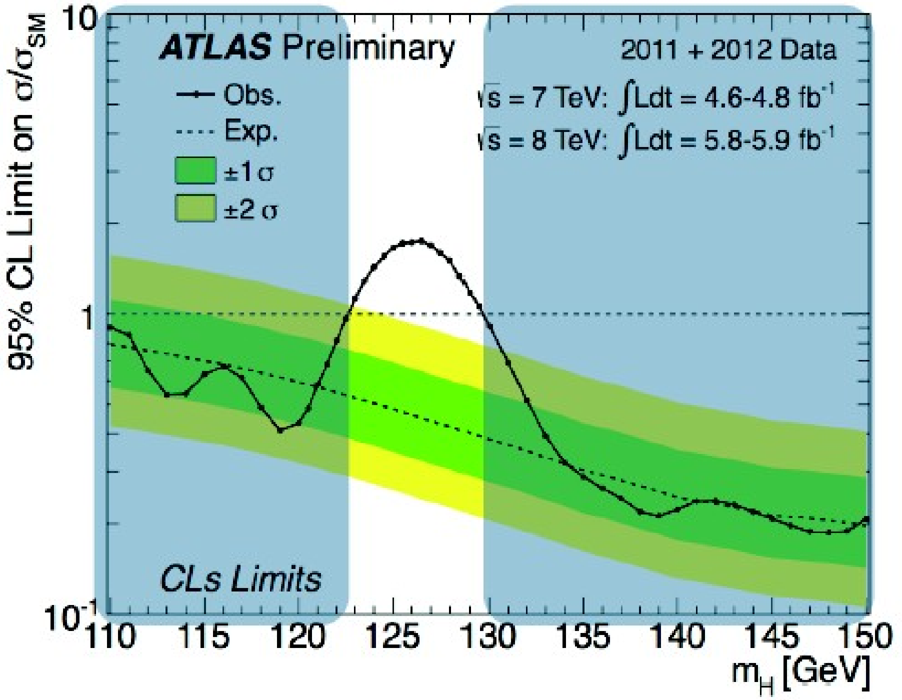
Probability that the background can produce a fluctuation greater than or equal to the excess observed in data. Equivalent in terms of number of standard deviations is called local significance.

95% CLs exclusion:

Value of μ is regarded as excluded at 95%CL when CLs is less than 5%. A SM Higgs boson with mass m_H is conisdered excluded at 95%CL when μ=1 is exluded at that mass.

ATLAS results of 4-th July



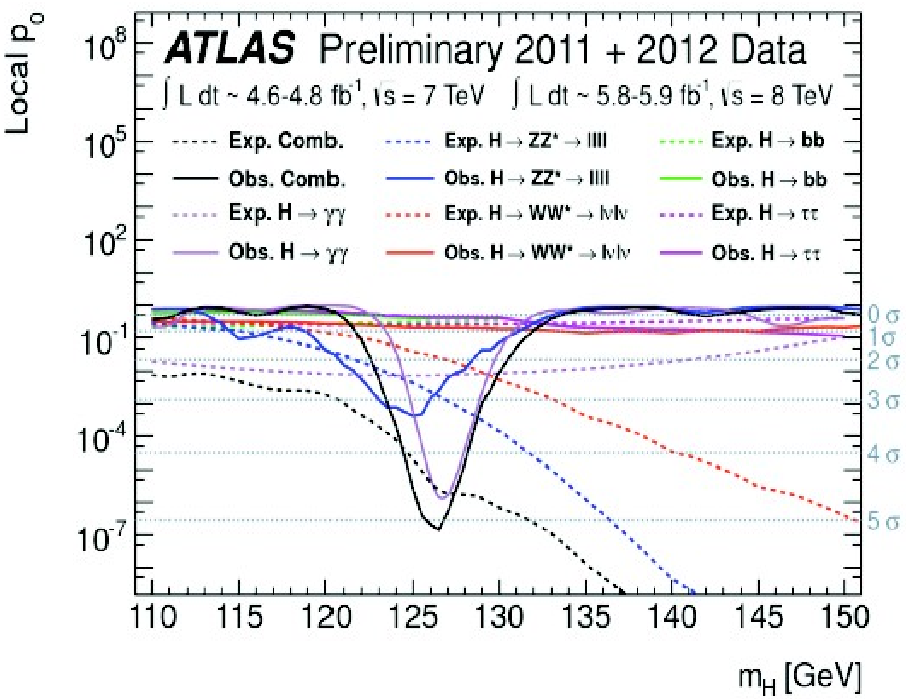


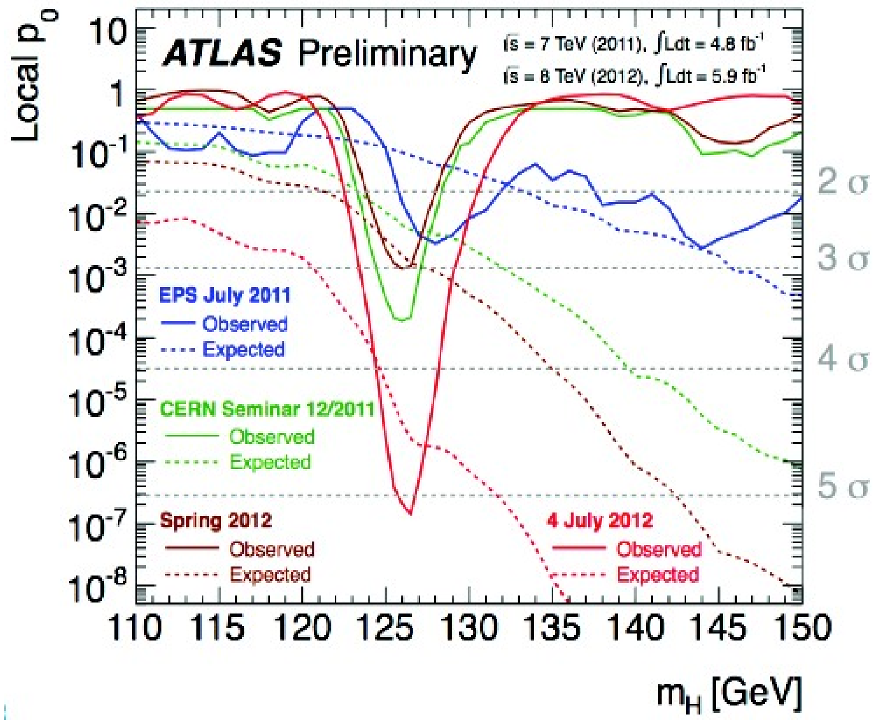
Excluded at 95% CL: 110-122.6 GeV, 129.7-558 GeV

Excluded at 99% CL: 111.7-121.7 GeV, 130.7-523 GeV

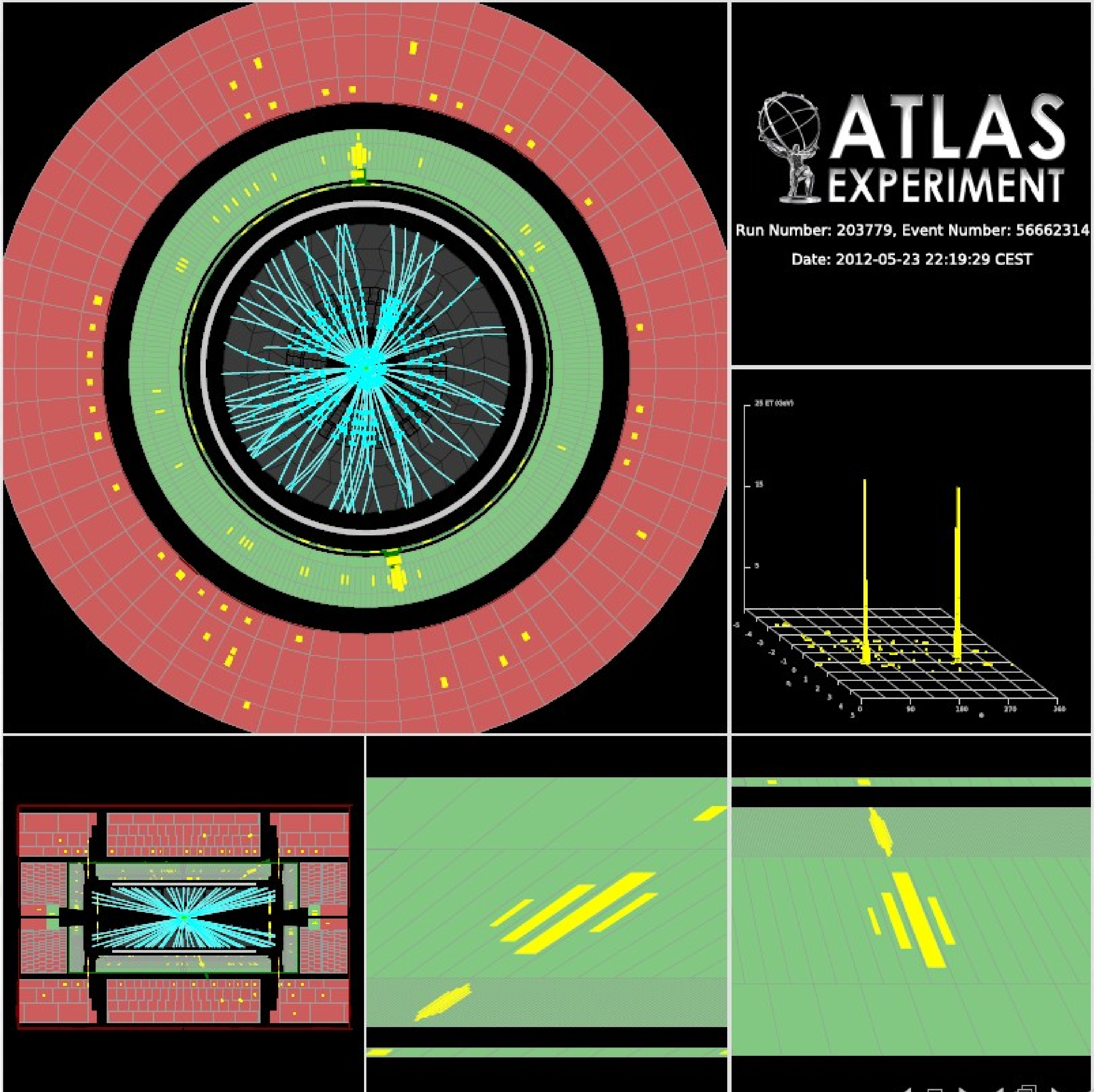
Expected exclusion at 95% CL (no signal): 110-582 GeV

ATLAS results of 4-th July





Excess consistent with
H->γγ and H->ZZ*->4l decays



$\sqrt{s} = 8$ TeV.

Leading γ:
$E_T = 62.2$ GeV,
$\eta = 0.39$

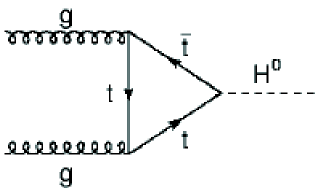
Subleading γ:
$E_T = 55.5$ GeV
$\eta = 1.18$

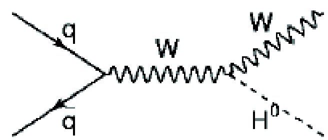
$m_{\gamma\gamma} = 126.9$ GeV.

Only reconstructed tracks with $P_T > 1$ GeV, hits in the pixel and SCT layers and TRT hits with a high threshold are shown.

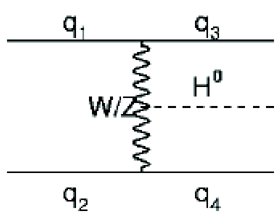
SM predictions for H->γγ

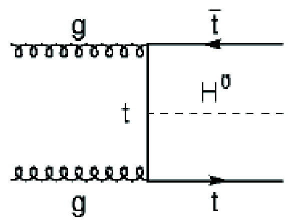
- **SM Higgs production channels**



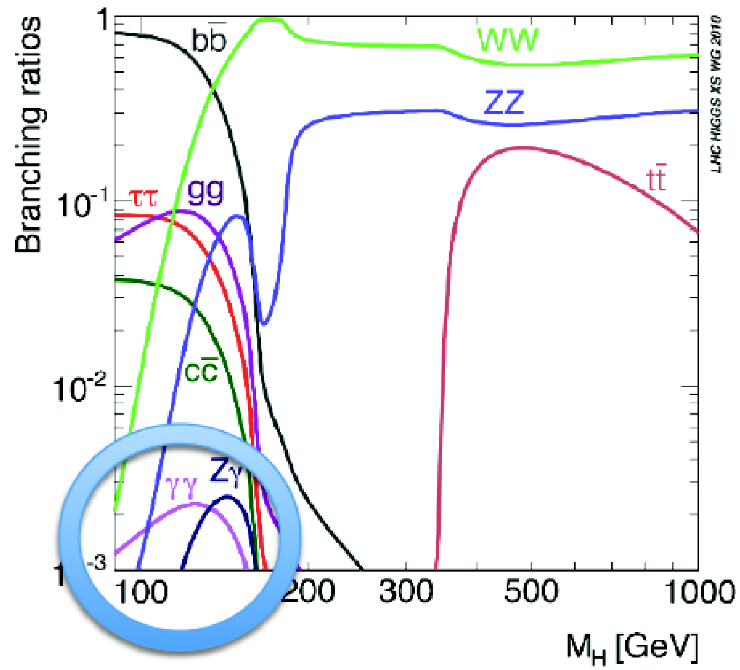


Gluon-gluon fusion (~87%)   Associated Higgs (< 5%)



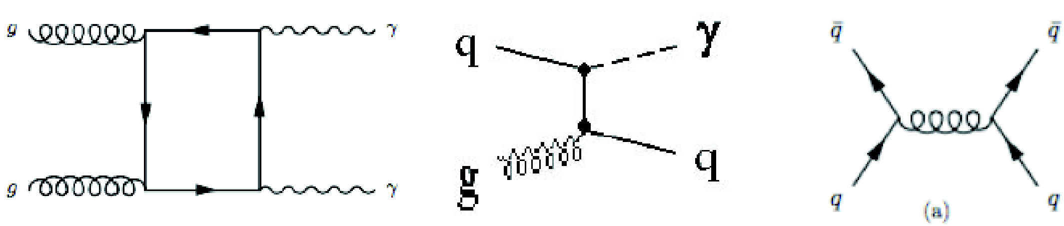


Vector-Boson Fusion (~7%)   ttH (< 5%)



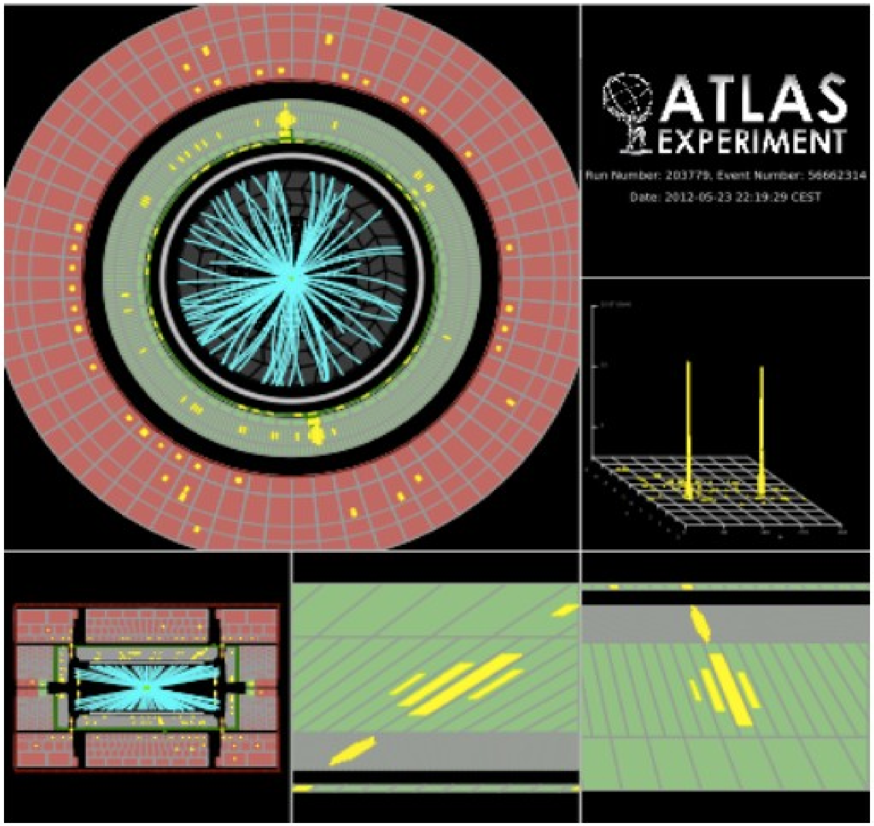
- **Branching fraction small** **but simple signature (two high p_T photons in final state)**

Main backgrounds to H→ γγ are SM diphoton, jet-γ and jet-jet events



- Signal expected as **narrow resonance over smooth decaying background**

H->γγ event signature



Simple event signature

- ❑ Two high pT photons
  $pT_1 > 40$ GeV and $pT_2 > 30$ GeV
- ❑ High trigger efficiency
  ~99%
- ❑ High event selection efficiency despite high jet-jet & γ-jet production
  ~40%
- ❑ High signal over background
  ~3-10 % (depending on sub-category)

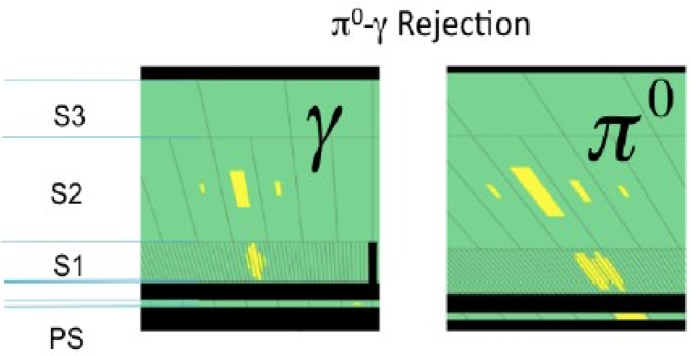
Invariant mass reconstruction $m_{\gamma\gamma}^2 = 2*E_1E_2(1 - \cos\alpha)$

- ❑ Good energy calibration
- ❑ Robust primary vertex reconstruction

→ Excellent invariant mass resolution ~1.6 GeV with 90% of events within ±2σ

Shower shapes and vertex reconstr.

Photon ID 2 – Photon shower shapes and background rejection

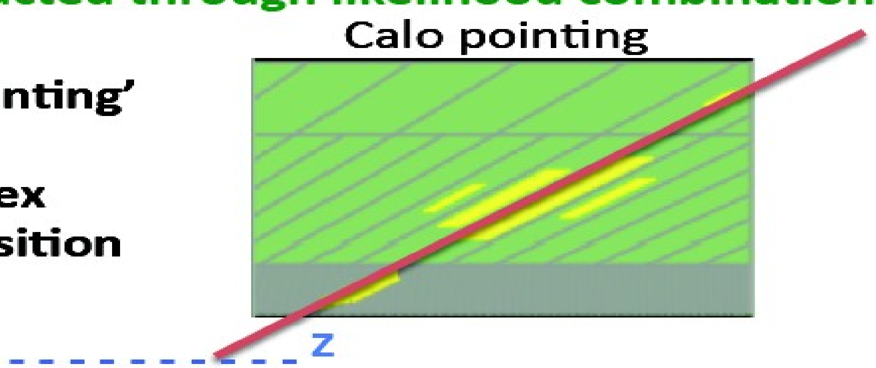


- Photons shower shape distributions in LAr sampling layers - different for signal and background (π^0)

Vertex Reconstruction

$$m_{\gamma\gamma}^2 = 2 * E_1 E_2 (1 - \cos \alpha)$$

- Vertex reconstructed through likelihood combination
  - Calorimeter 'pointing'
  - Σ tracks pT^2
  - Conversion vertex
  - Mean vertex position



Event categorization

Event categories based on eta, pTt, and conversion

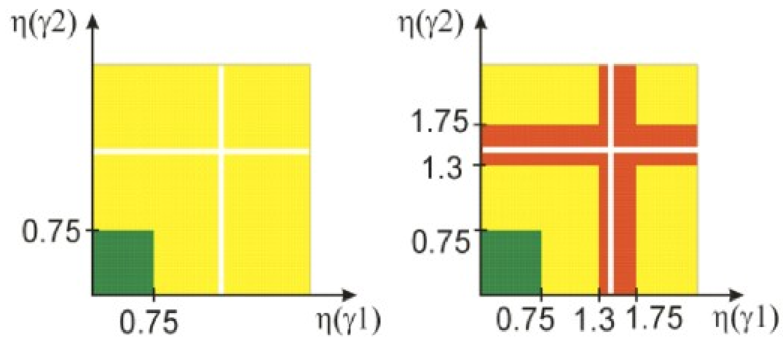
Both unconverted:

- Central
- Rest

At least one converted:

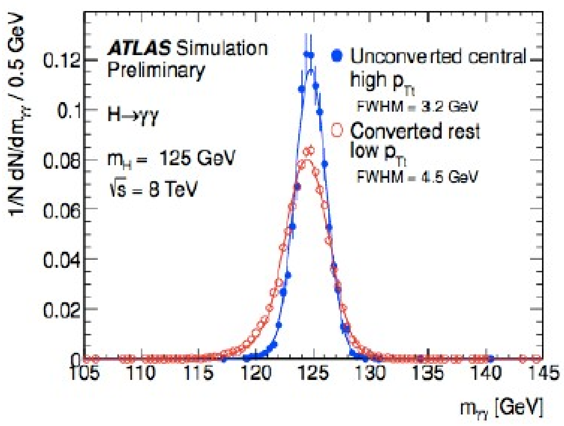
- Central
- Transition
- Rest

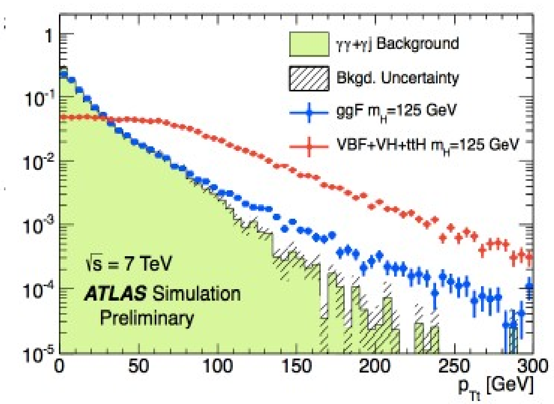
2 unconverted: >=1 converted:



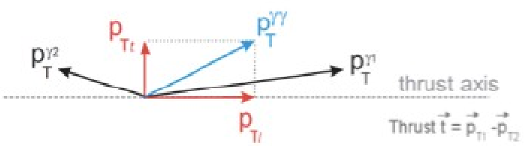
Resolution:

Good
Medium
Poor





Central and Rest divided into $p_{Tt} < 60$ GeV and $p_{Tt} > 60$ GeV



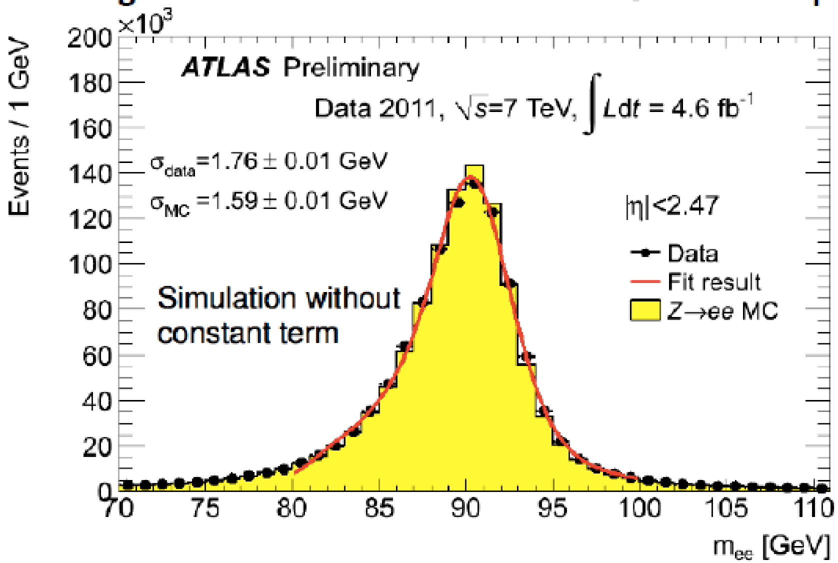
Energy calibration and resolution

$$m_{\gamma\gamma}^2 = 2 * E_1 E_2 (1 - \cos\alpha)$$

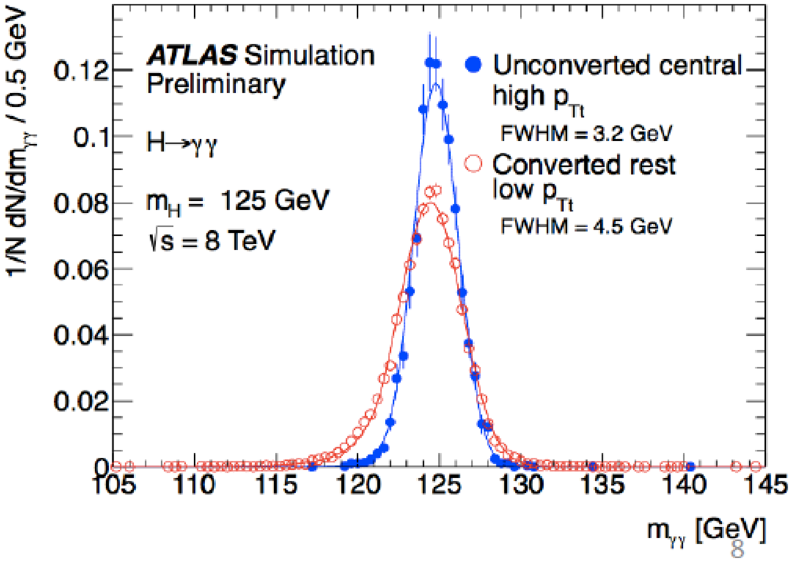
- MC based calibration improved with energy scale and resolution corrections based on in-situ analysis of Z→ee, W→eν and J/ψ → ee

- Energy scale at m_Z known to 0.3%, uniformity (constant term) 1% in barrel, 1.2 – 2.1% in endcap

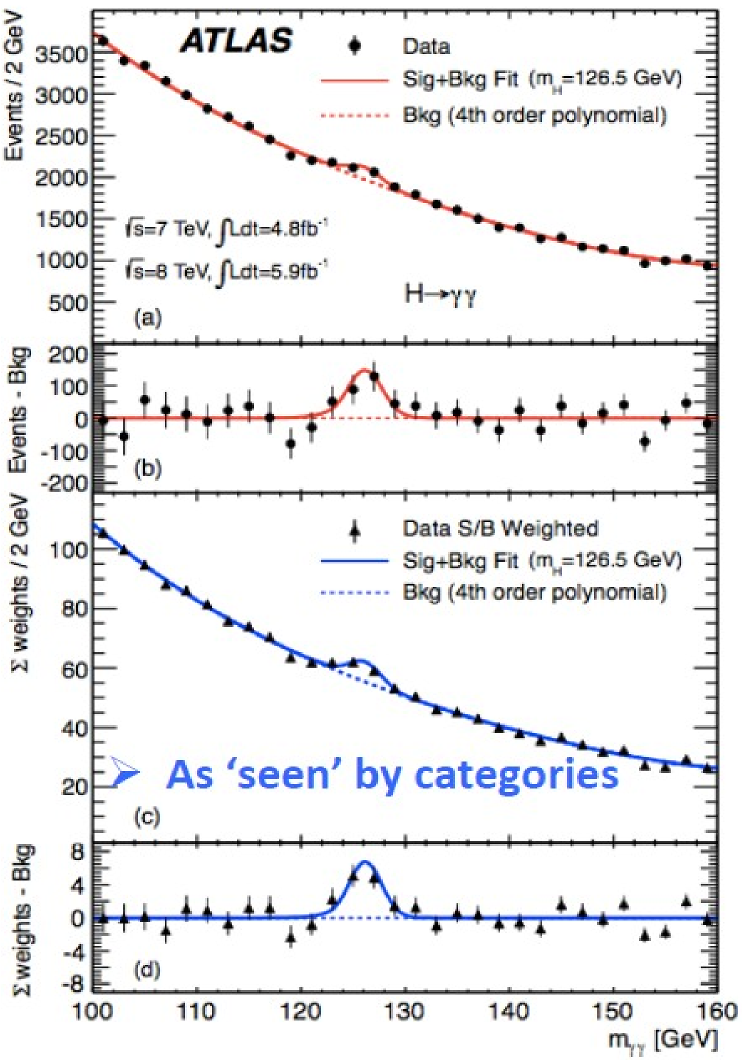
Agreement between data & MC Z→ee lineshape



Expected resolution of Higgs signal



Invariant mass distribution



➢ As 'seen' by categories

- ❑ Photon ID efficiency ~10%
- ❑ Energy resolution ~14% and mass scale ~0.6%
- ❑ Isolation < 1%
- ❑ Pileup 4%
- ❑ Lumi 1-3.6 % (2011-2012)
- ❑ Theory cross section
  - ~ up to 25% (for VBF contribution)
  - ~ up to 12% (in other ggF)
  - (underlying event ~5% and PTt dist up to 12% at hight PTt)

- ❑ Bkg Param (evts) 0.2-4.6 (0.3-6.8) for 2011(2012)

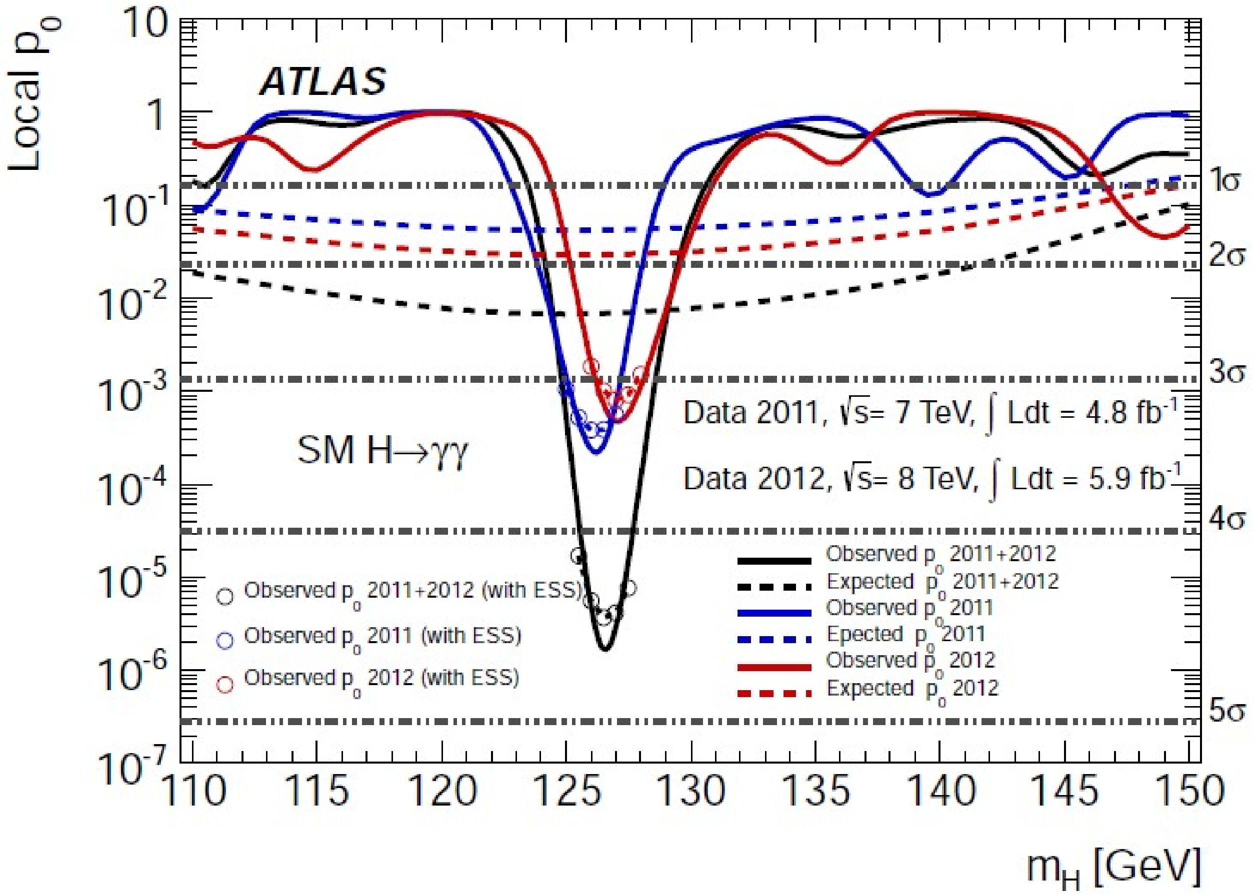
In VBF category

- ❑ Jet E-scale 9-10%
- ❑ Underl. Evt. 6-30%
- ❑ Higgs p_T up to 12.5%

23788 events (7 TeV) and 35251 events (8 TeV)

Background+signal fit, signal fixed at 126.5 GeV

Quantifying the excess p0



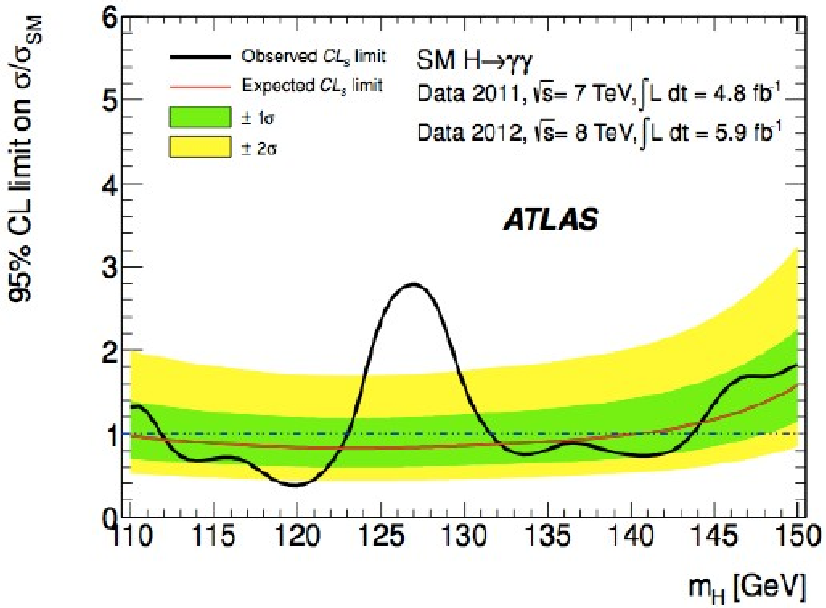
- Excess (m_H): 126.5 GeV
- Expected (local-significance): 2.5σ
- Observed (local-significance): 4.5σ
- Fitted signal strength: $\hat{\mu} = 1.8 \pm 0.5$

Signal strenght

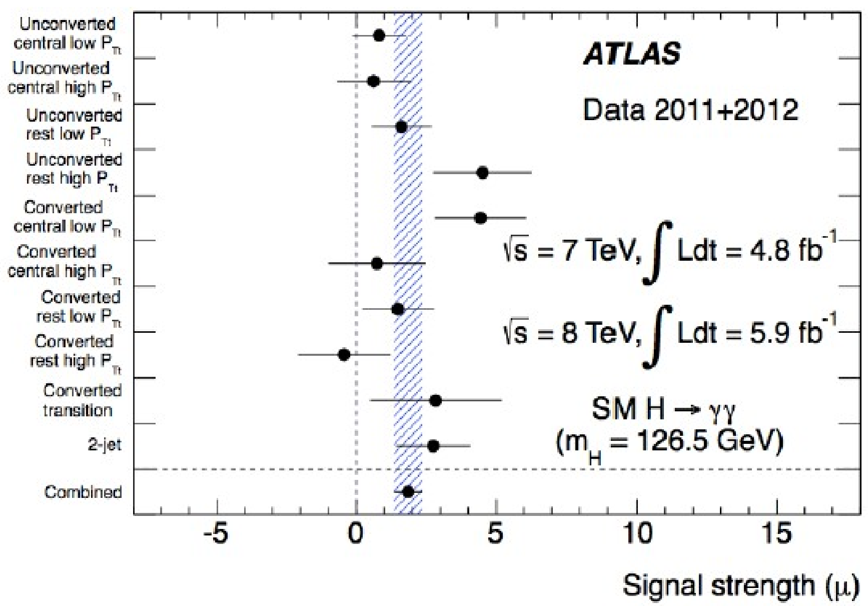
- SM hHggs excluded in the regions of **112 – 122.5 GeV and 132 – 143 GeV**
- Best fitted signal strength (wrt SM) for $m_{\gamma\gamma}$ = 126 of **μ = 1.8 ± 0.5**

- *Consistent results from different categories*

CL limit on σ/σ_{SM}

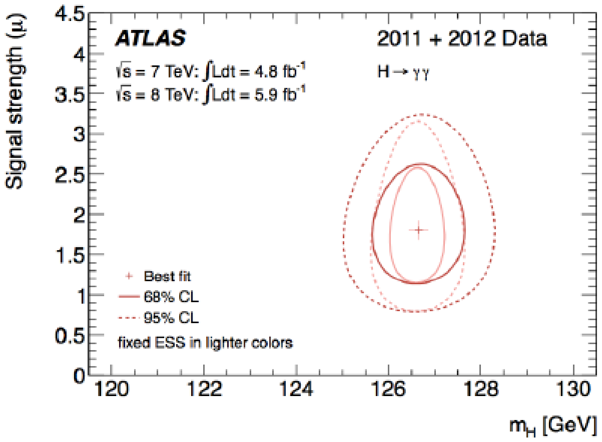


Signal Strength per Category



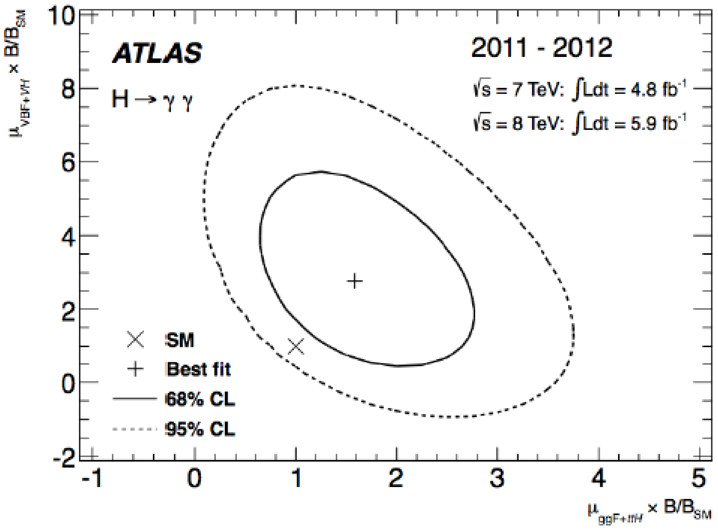
Properties of new resonance

- **Mass**
  → Likelihood contours in the (μ, mH) plane. Uncertainty on fit comparable for statistical and systematic uncertainty



- With and without ES uncertainty

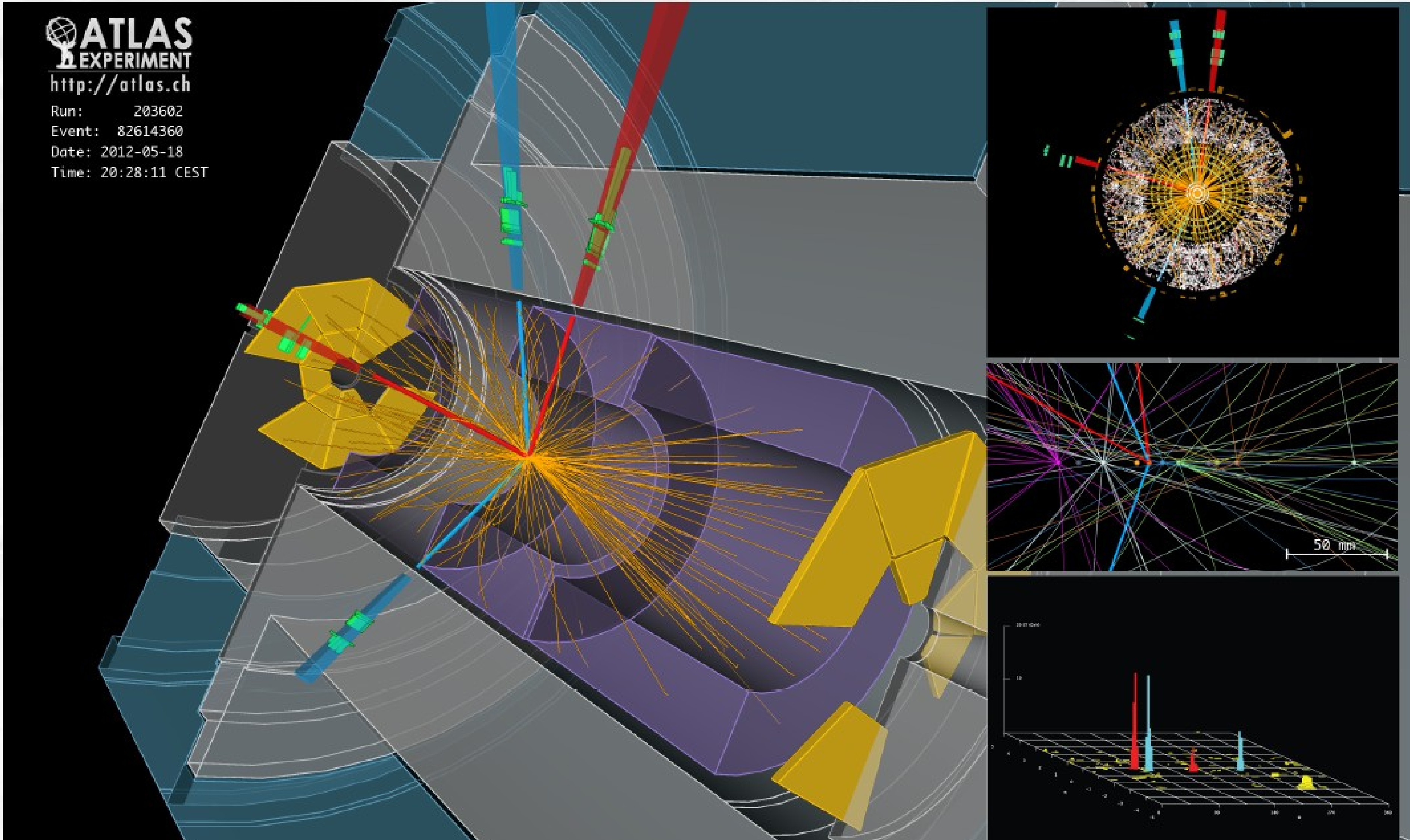
- **Couplings**
  → Constraints in the plane of μ (ggF+$t\bar{t}H$ $\times B/B_{SM}$) and μ (VBF+$VH \times B/B_{SM}$), where B is the branching ratio for $H \rightarrow \gamma\gamma$, can be obtained
  → The data are compatible with the SM at the 1.5 σ level
- Production modes merged due to similar couplings and small stats (with current data-set)



4e candidate. $m_{4\ell} = 124.6$ GeV, $m_{12} = 70.6$ GeV, $m_{34} = 44.7$ GeV.

e_1: $P_T = 24.9$ GeV, $\eta = -0.33$, $\phi = 1.98$ e_2: $P_T = 53.9$ GeV, $\eta = -0.40$, $\phi = 1.69$

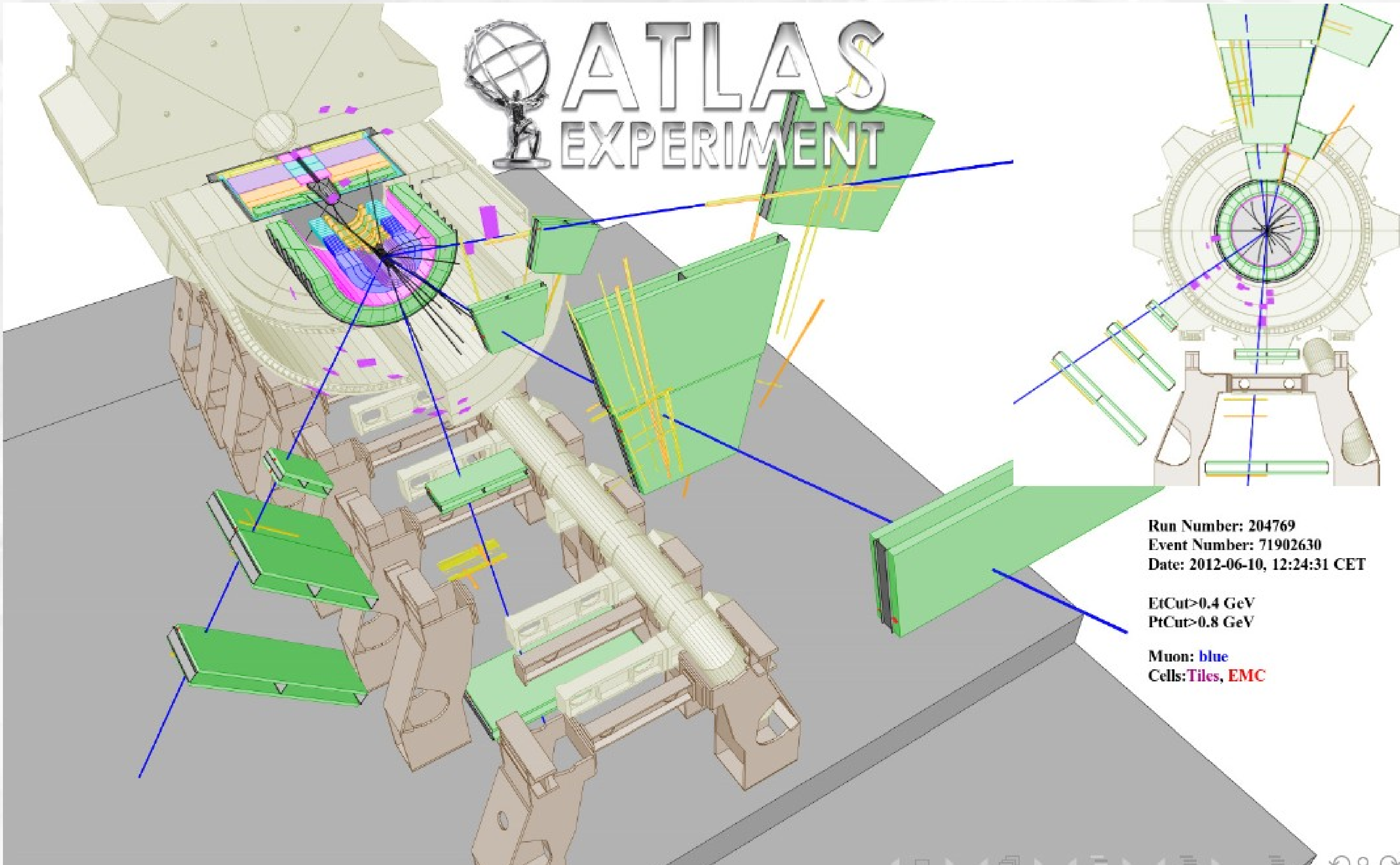
e_3: $P_T = 61.9$ GeV, $\eta = -0.12$, $\phi = 1.45$ e_4: $P_T = 17.8$ GeV, $\eta = -0.51$, $\phi = 2.84$



4μ candidate. $m_{4\ell} = 125.1$ GeV, $m_{12} = 86.3$ GeV, $m_{34} = 31.6$ GeV.

μ_1: $P_T = 36.1$ GeV, $\eta = 1.29$, $\phi = 1.33$ μ_2: $P_T = 47.5$ GeV, $\eta = 0.69$, $\phi = -1.65$

μ_3: $P_T = 26.4$ GeV, $\eta = 0.47$, $\phi = -2.51$ μ_4: $P_T = 71.7$ GeV, $\eta = 1.85$, $\phi = 1.65$

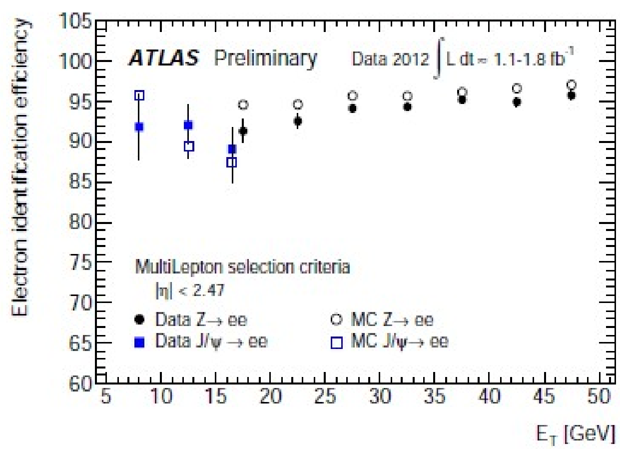


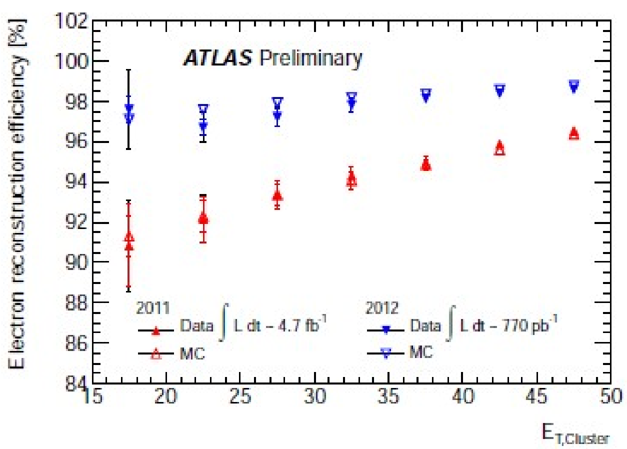
The golden channel

- 4-lepton (coming from Z decays: same-flavour, opposite charge) $\rightarrow$ very good resolution, high reconstruction and trigger efficiencies $\rightarrow$ mass peak can be reconstructed
- **Almost background free:** s/b between 0.9 ($4e$) and 1.6 4μ
- Very robust against systematic uncertainties
- Very small yield: signal cross section $\times$ branching ratio ($Z \rightarrow \ell\ell \sim 3\%$).
- Low P_T objects needed to maximise signal acceptance

Kinematic requirements:

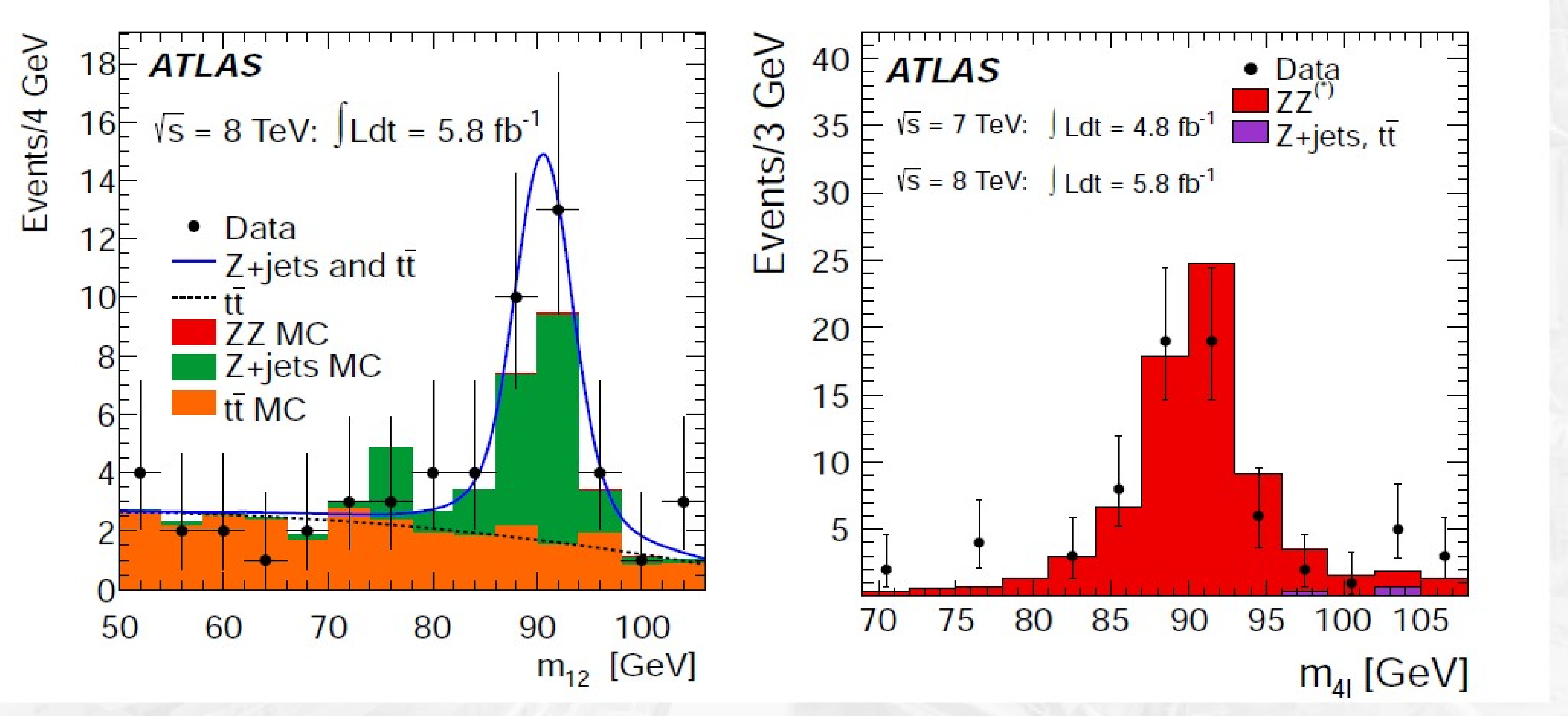
- Muons:
  $P_T > 6$ GeV,
  $|\eta| < 2.7$
- Electrons:
  $P_T > 7$ GeV,
  $|\eta| < 2.47$





The golden channel

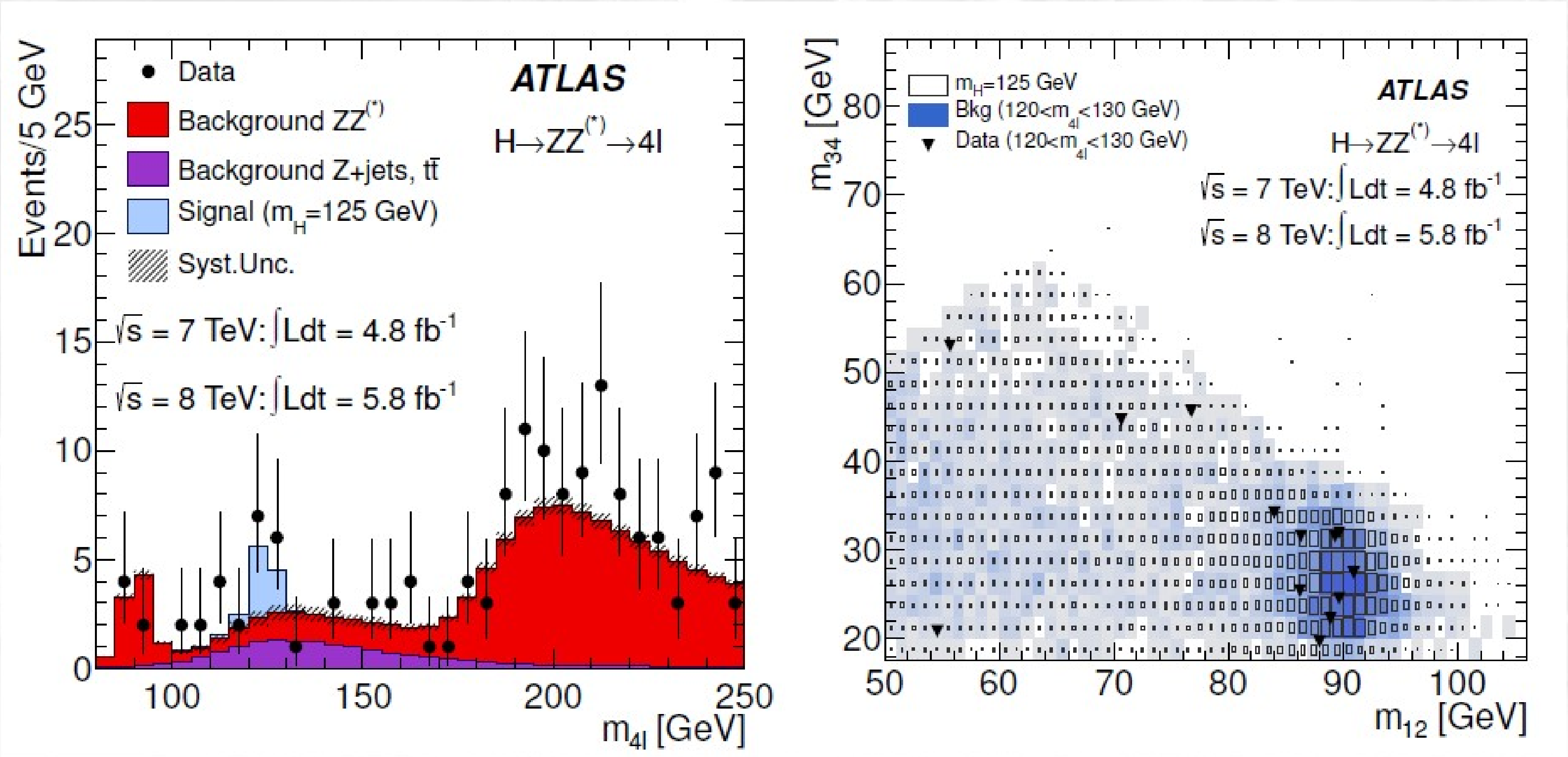
- Various control samples are used to measured contributions of reducible backgrounds (**Z+jets and $t\bar{t}$**), depending on the flavour of the sub-leading pair.
- Irreducible background (**ZZ**), constraint by fit on the full $m_{4\ell}$ range. Cross checked by the single-resonant production peak.



Inverted d_0 requirement for one of the two subleading leptons

Relaxed kinematic cuts

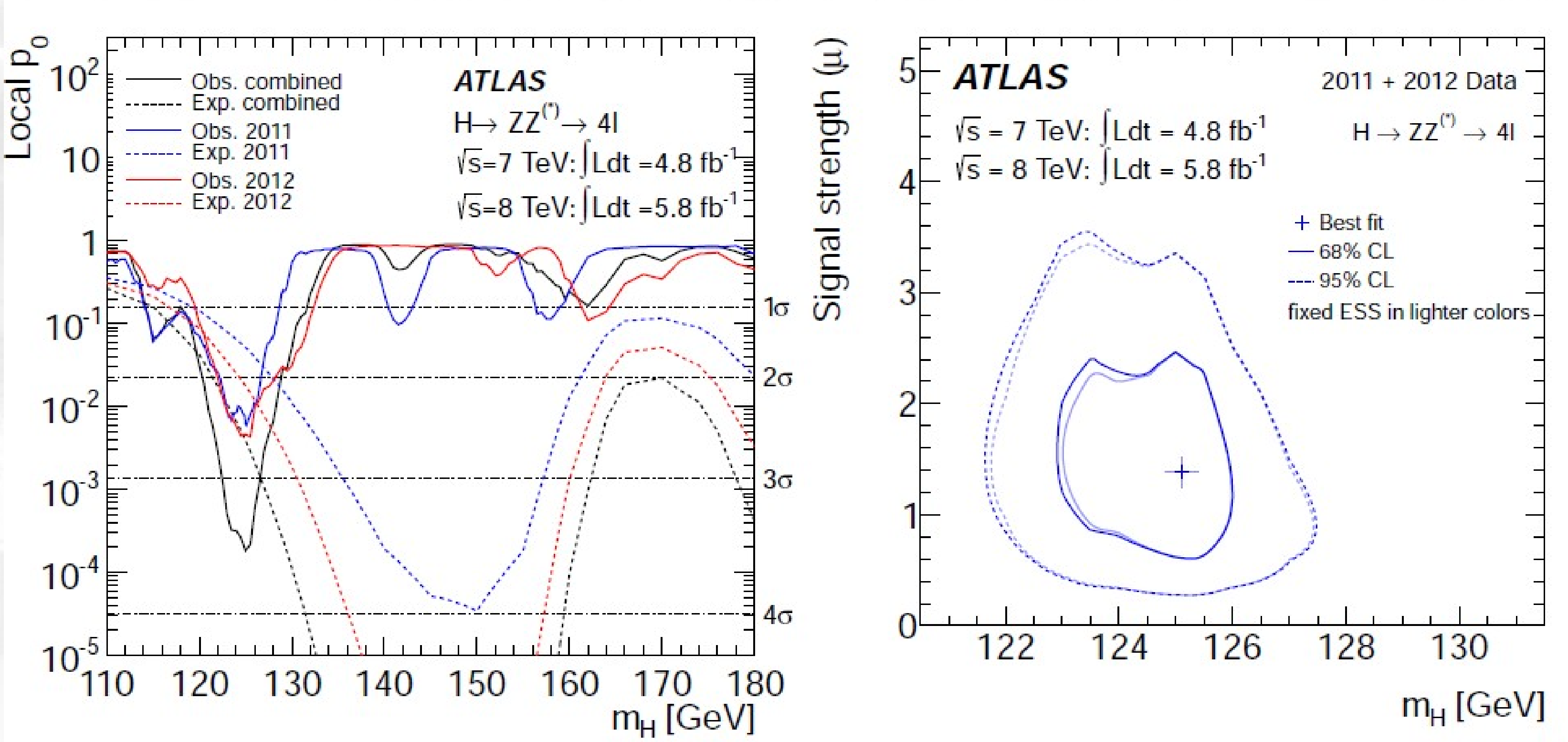
Final expected and observed yields



In a $m_{4\ell}$ window around 120-130 GeV:

	Signal	$ZZ^{(*)}$	$Z+$jets, $t\bar{t}$	Observed
4μ	2.09±0.30	1.12±0.05	0.13±0.04	6
$2e2\mu/2\mu2e$	2.29± 0.33	0.80±0.05	1.27±0.19	5
$4e$	0.90±0.14	0.44±0.04	1.09±0.20	2

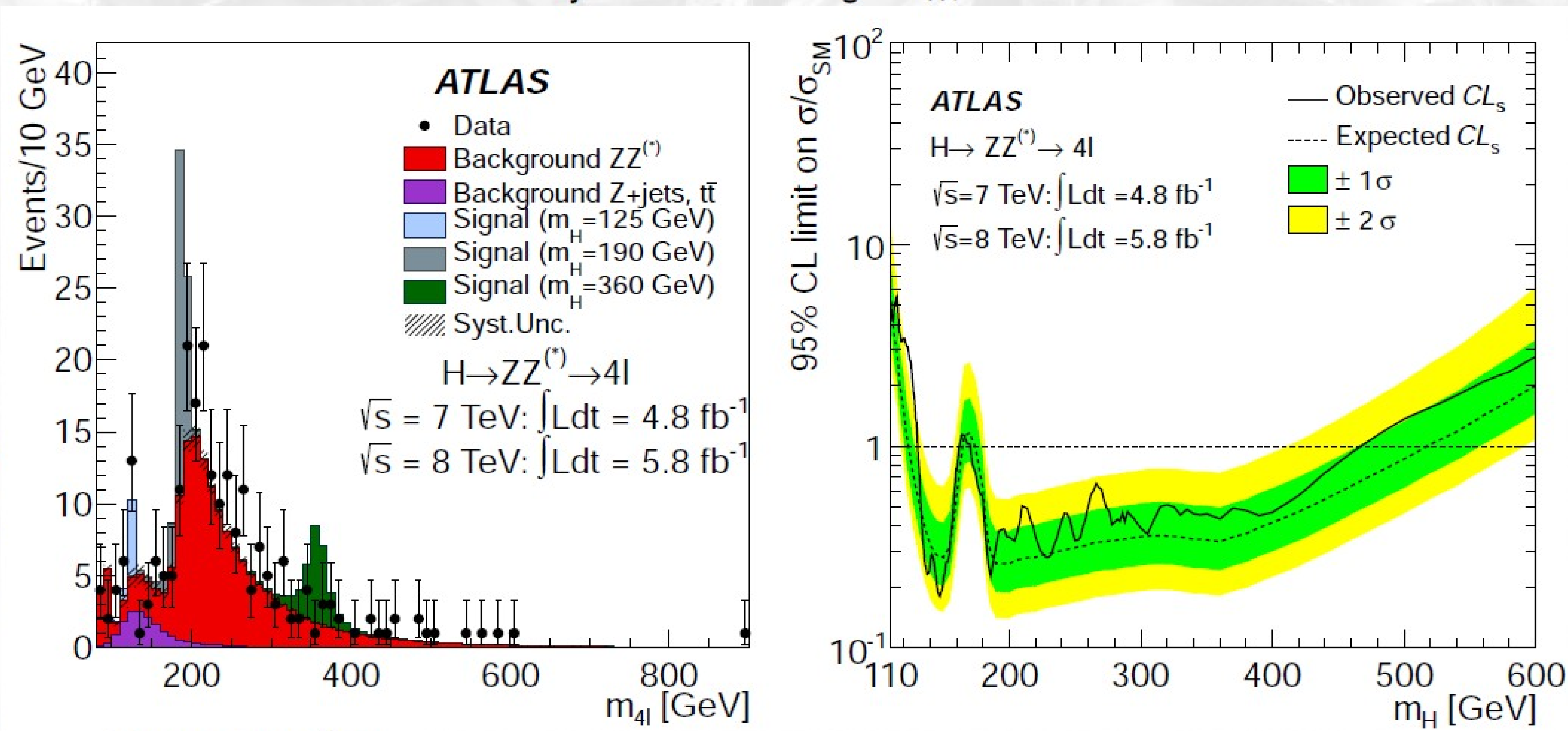
Quantifying the excess: p0



- Excess (m_H): 125 GeV
- Expected (local-significance): 2.7σ
- Observed (local-significance): 3.6σ
- $\hat{\mu}$ =1.2±0.6

Exploring large Higgs mass hypotheses

The 4ℓ channel is also very sensitive at high m_H, no excess found:



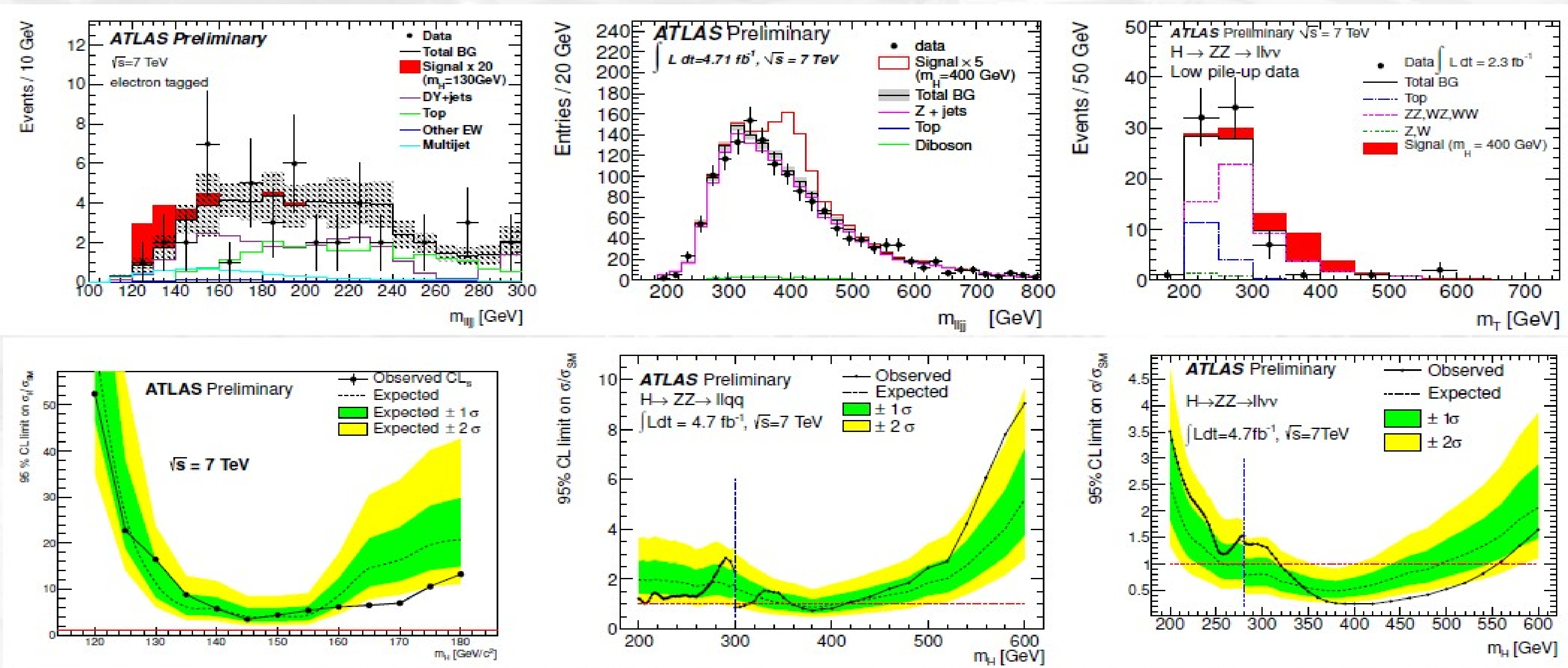
Documentation:

https://cdsweb.cern.ch/record/1460411/files/ATLAS-CONF-2012-092.pdf

Phys.Lett. B716 (2012) 1-29

Other ZZ channels

$H \to ZZ \to \ell^+\ell^- q\bar{q}$ and $H \to ZZ \to \ell^+\ell^- \nu\bar{\nu}$: 4.7 fb^{-1}



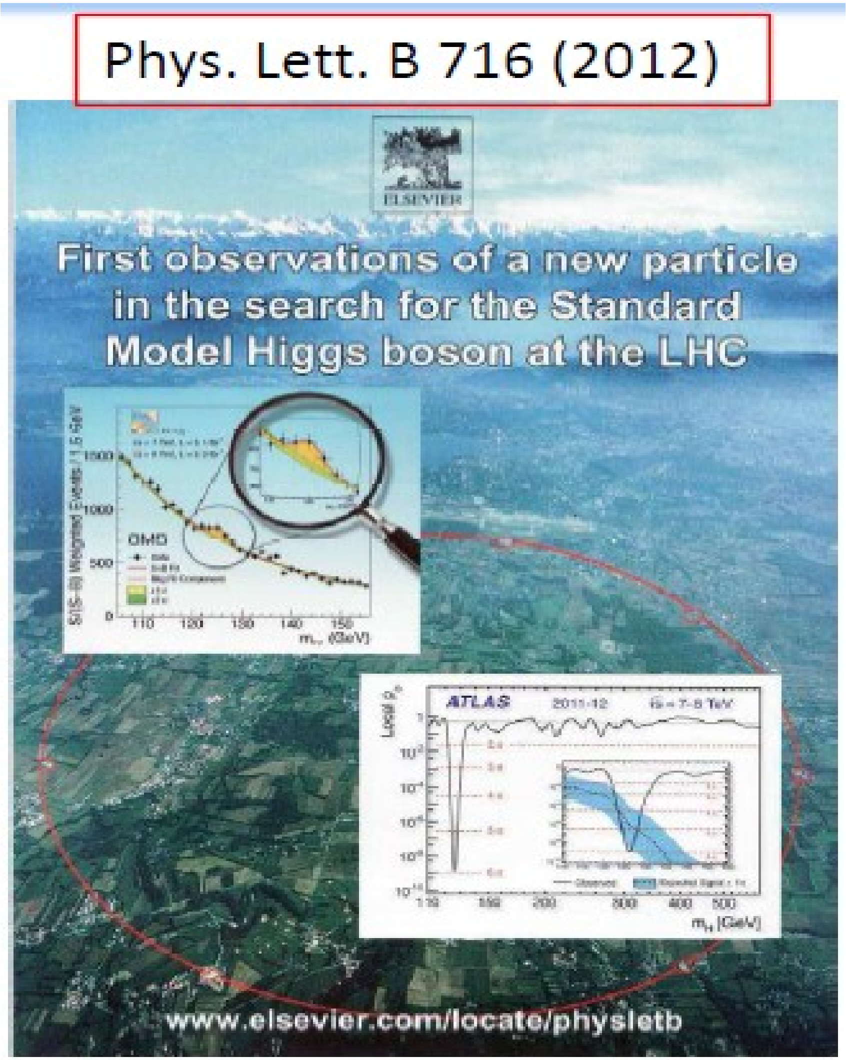
ATLAS-CONF-2012-163 Phys.Lett. B 717 (2012) 70-88 Phys. Lett. B 717 (2012) 29-48

- The $H \to ZZ$ decay allows us to explore a very wide region using many different topologies

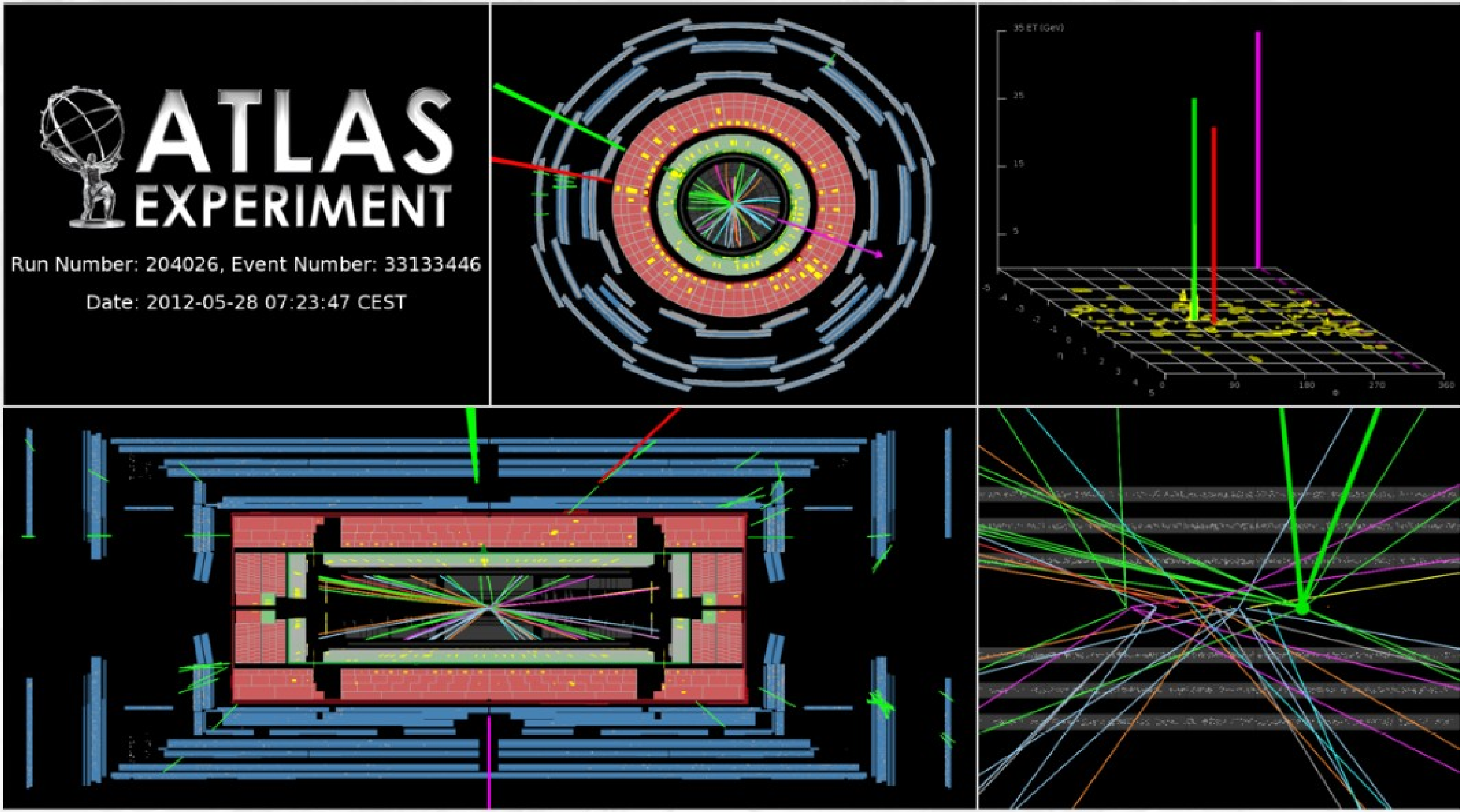
Since then……. (4-th July)

ATLAS

- The WW channel completed with 5.8fb^{-1} and released end of July, included in the SM Higgs published paper.



$\sqrt{s} = 8$ TeV - $e\mu$ - Zero jet - P_T^e =33 GeV and $P_T^\mu = 29$ GeV, $E_T^{miss,rel} = 35$ GeV, $m_T = 94$ GeV.



H->WW

Production:

$gg \to H$ + VBF + WH/ZH

Decay:

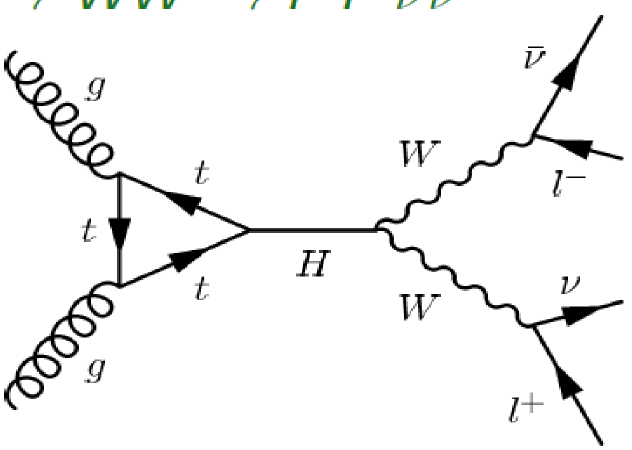
$H \to WW$

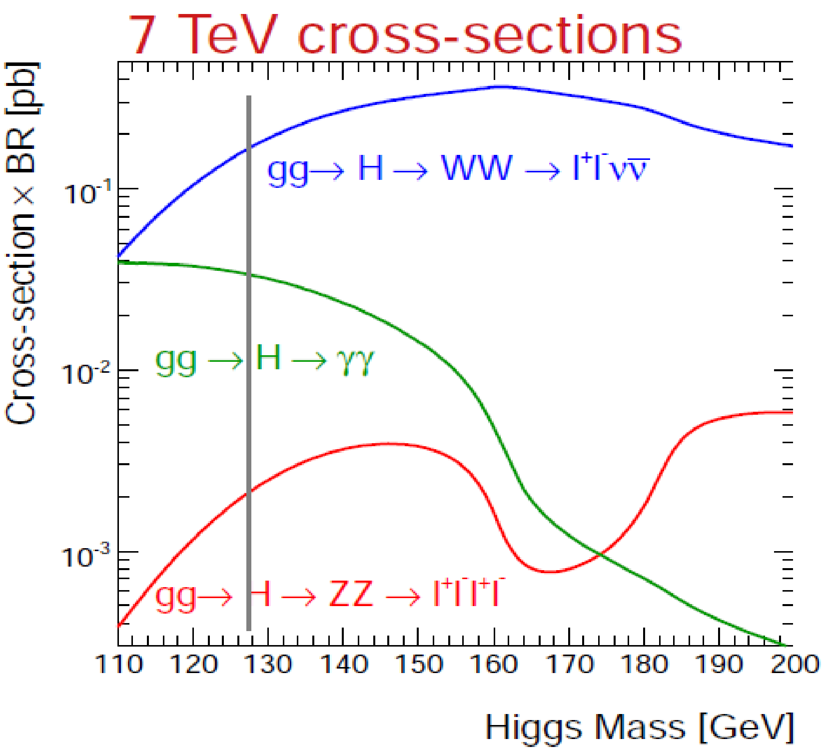
W Decays:

$W \to l^- \bar{\nu}$ twice

Looking for

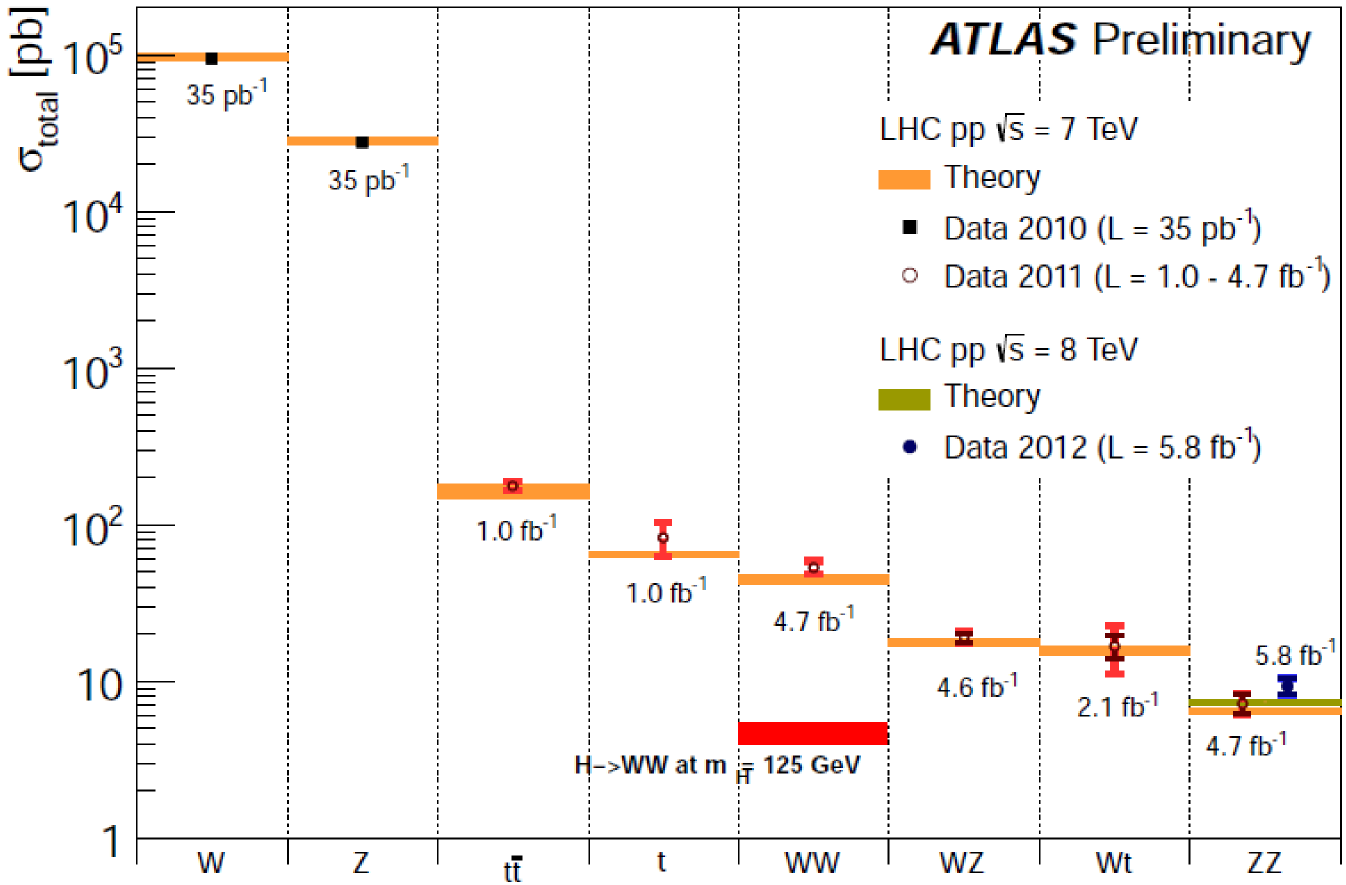
$H \to WW \to l^+ l^- \nu \bar{\nu}$





But…neutrinos mean we can't measure a mass peak

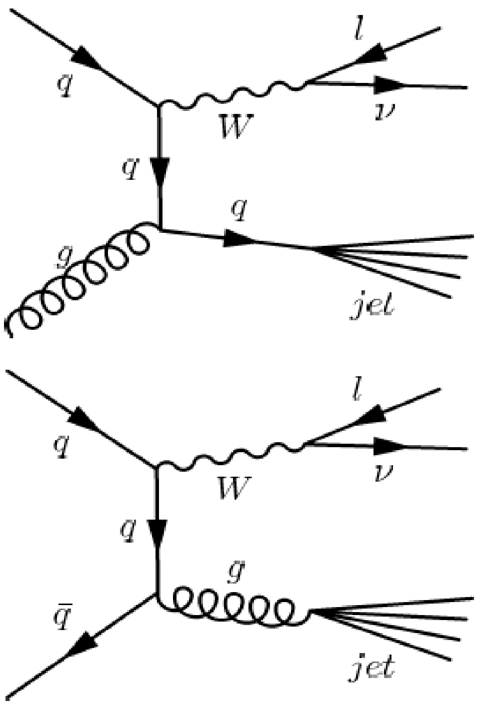
Background overwiew

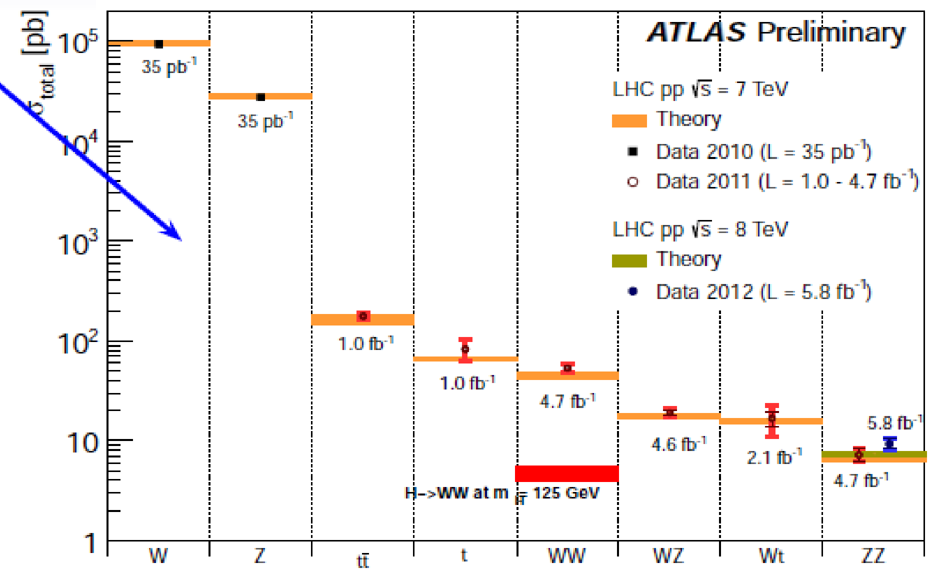


All of these are backgrounds plus $W\gamma$ and $W\gamma^*$

Backgrounds: W+jets

W+jets becomes $l\nu$+jet misidentified as a lepton





ATLAS $p_T^{lead} > 25$ GeV
$p_T^{sublead} > 15$ GeV

CMS $p_T^{lead} > 20$ GeV
$p_T^{sublead} > 10$ GeV

Lepton Identification and Isolation suppress W+jets by order 10^{-5}

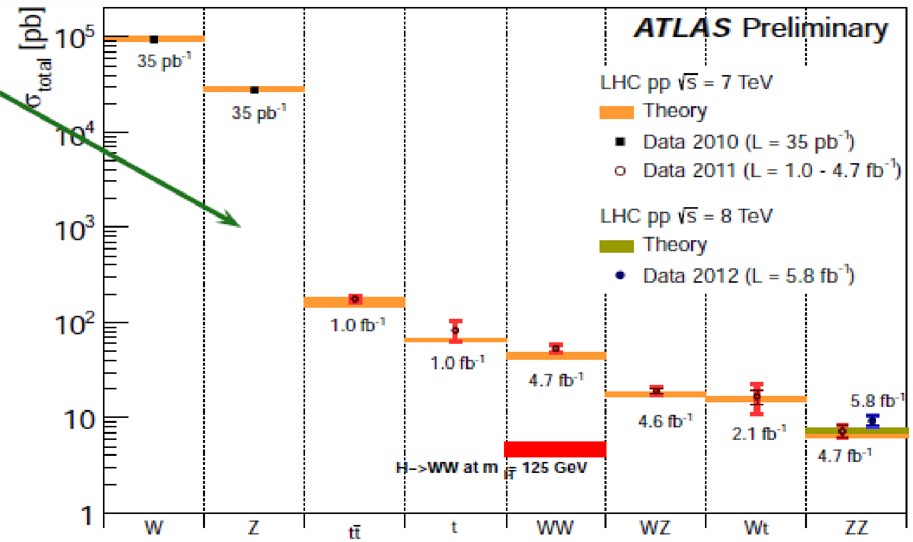
Remains one of the top two background systematics

Backgrounds: Z+jets

Z+jets suppressed by:

Requiring transverse momentum imbalance (E_T^{miss})

- ATLAS calorimeter-only
- CMS calorimeter and track



$Z \to \tau\tau \to e\mu\nu\nu$ removed by Missing Energy away from leptons

ee and $\mu\mu$ require additional selection

- Directly vetoing Z peak for ee and $\mu\mu$ final states
- CMS: MVA using kinematics of leptons and E_T^{miss}

In 2012, poor E_T^{miss} resolution due to large pile-up

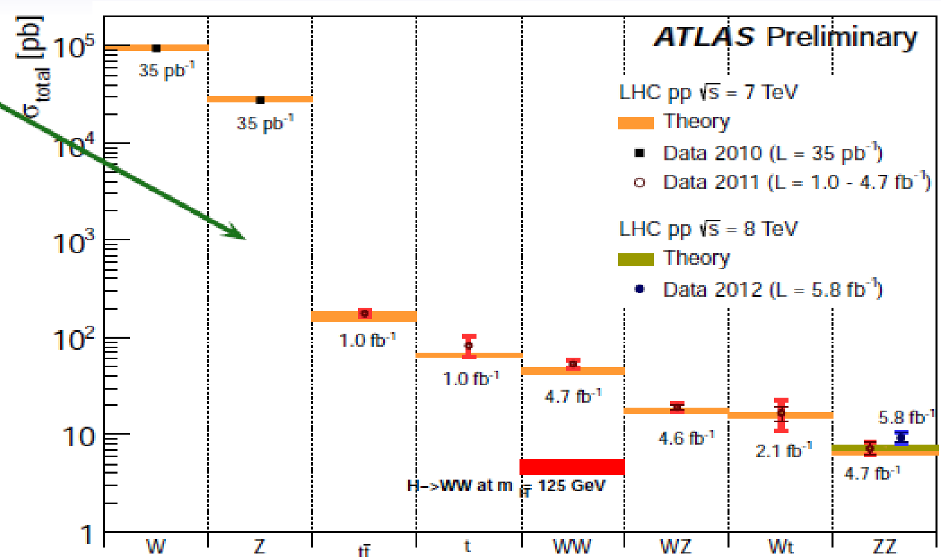
- ATLAS only $e\mu$ for 2012
- CMS still does ee and $\mu\mu$

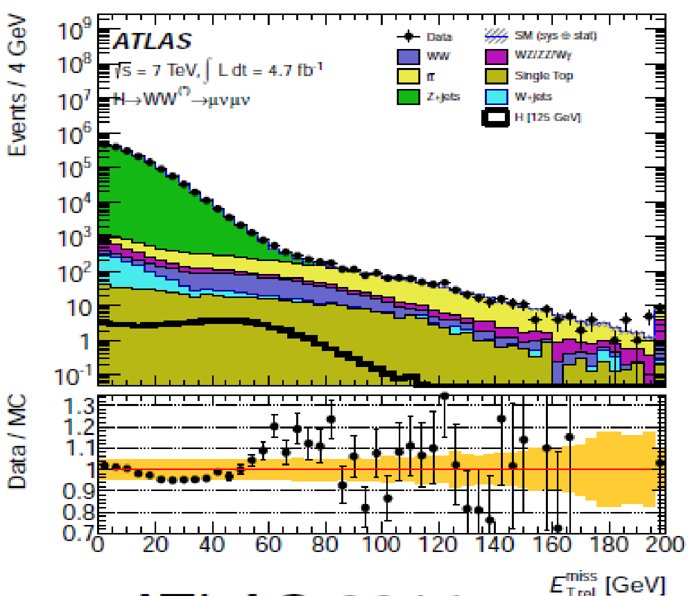
Backgrounds: Z+jets

Z+jets suppressed by:

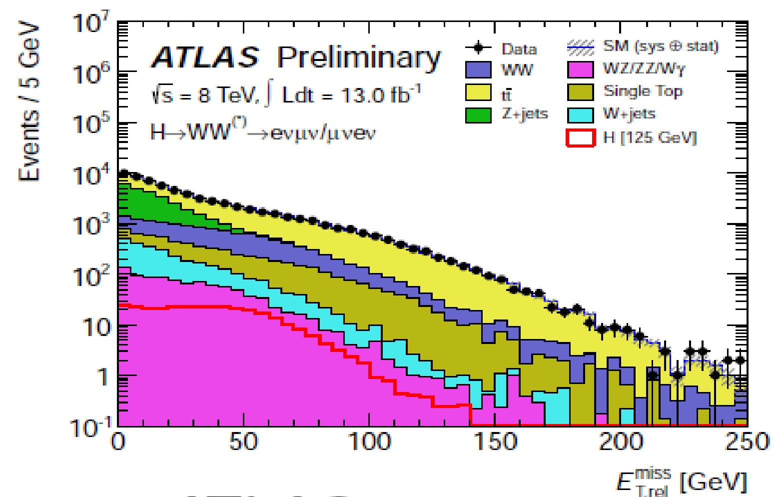
Requiring transverse momentum imbalance (E_T^{miss})

- ATLAS calorimeter-only
- CMS calorimeter and track





ATLAS 2011 $\mu\mu$

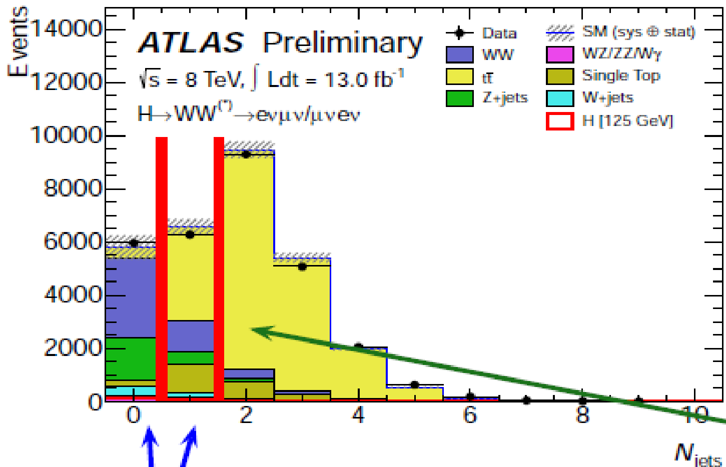


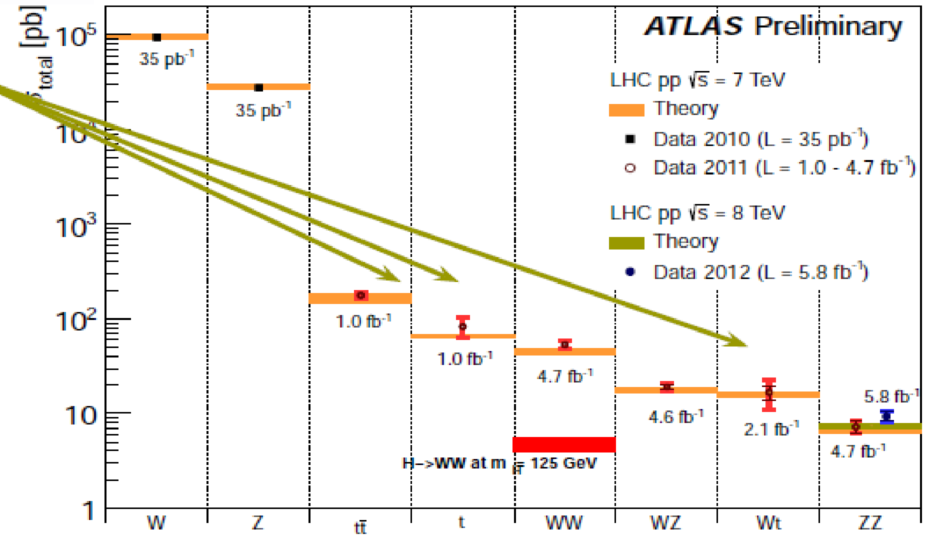
ATLAS 2012 $e\mu$

Backgrounds: top

$t\bar{t}$ and single top controlled by using jet bins

$p_T > 30$(CMS), 25(ATLAS) GeV





2-jet for VBF-only

Access HWW^2 coupling

0-jet and 1-jet for $gg \to H$

Access HWW×Hgg couplings

b-tag veto is applied to all jets within tracker volume

- CMS: $p_T > 10$ GeV plus soft-muon veto
- ATLAS: $p_T > 25$ GeV

Most of the sensitivity is 0-jet

Backgrounds: dibosons

$WW \to ll\nu\nu$

- Large irreducible
- See following slides

$WZ \to lll\nu$

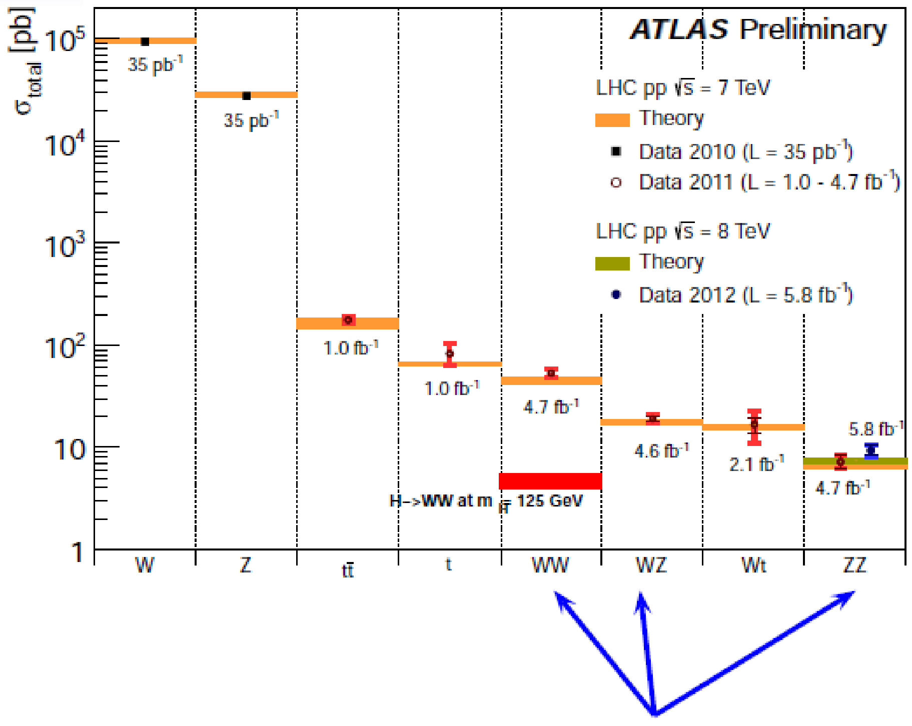
- Veto on third lepton

$W\gamma^* \to lll\nu$

- Isolation / Veto third lepton
- CMS validates rate with three lepton analysis

$W\gamma \to l\nu + \gamma$ conversion

- Conversion vetos in lepton id



$ZZ \to ll\nu\nu$

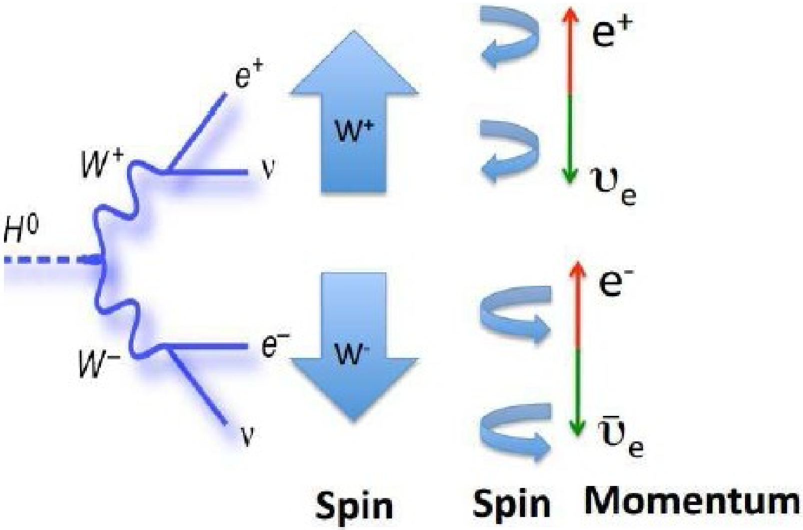
- Irreducible, but small

Separating gg->H->WW from qq->WW

The differences are subtle: spin and poorly measured mass

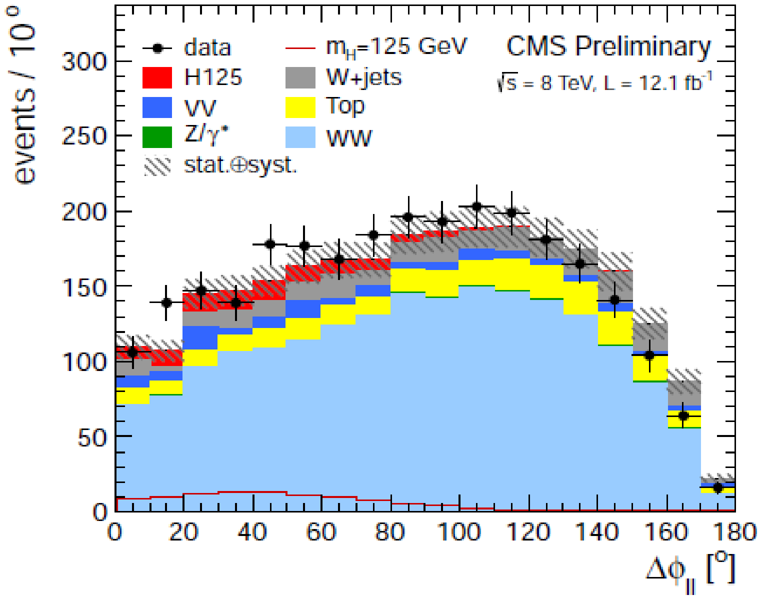
Spin

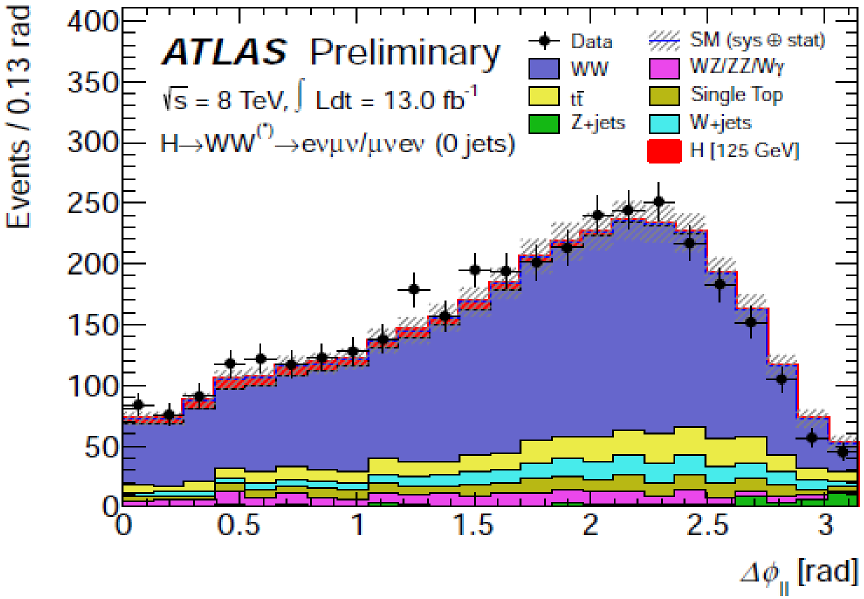
- Higgs is a spinless particle
- W has spin one
  - $\Rightarrow$ Ws must be spinning in opposite directions
- Parity Violation:
  - Positively charged leptons tend to go along W^+ spin direction
  - Negatively charged leptons tend to go away from W^- spin direction
  - $\Rightarrow$ charge leptons tend to go in the same direction



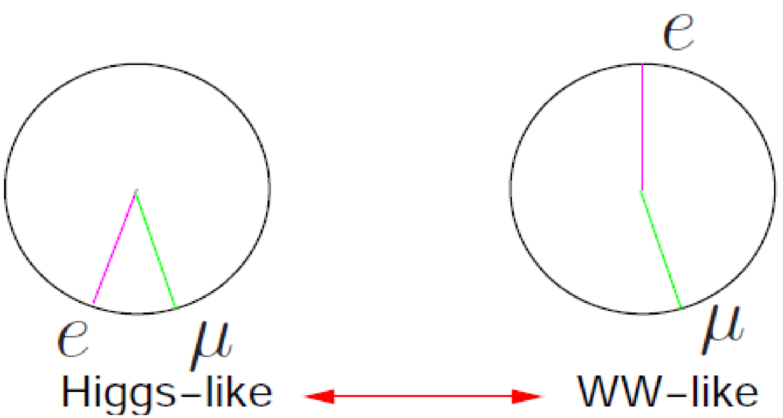
Separating gg->H->WW from qq->WW

Spin 0 → angle between leptons key discriminant



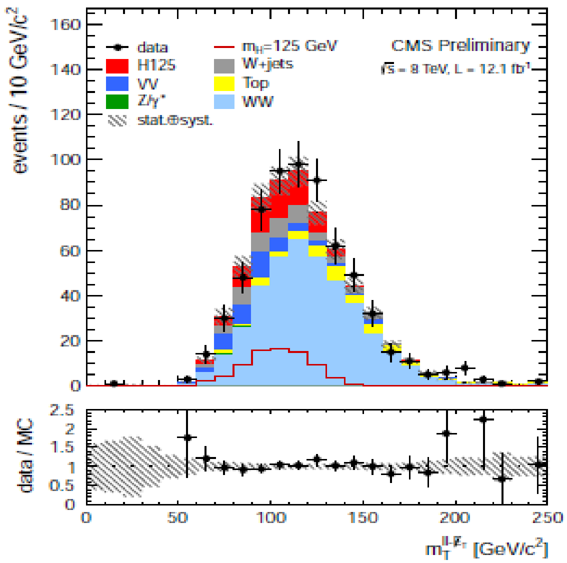


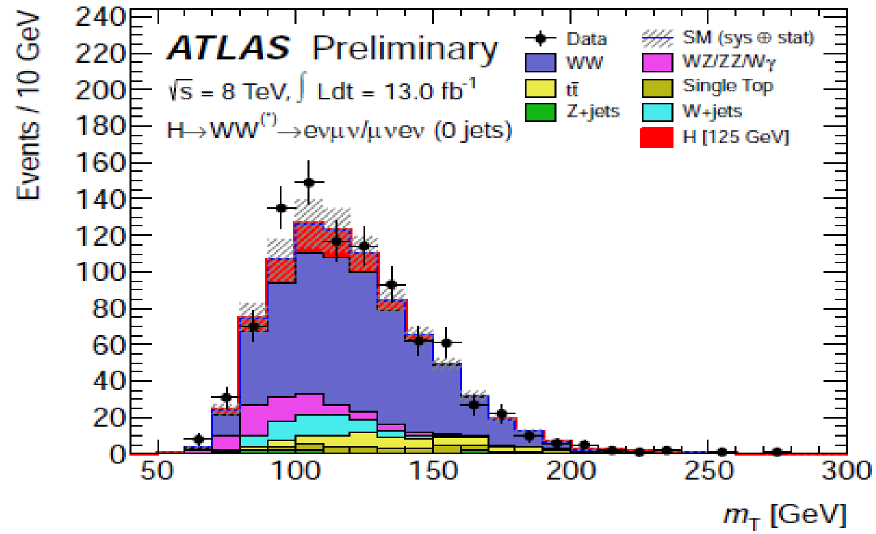
Plots are in 0-jet channel after a dilepton+E_T^{miss} selection



m_{ll} is also small because of small angle

Using the mass information: m_T variable





CMS: Fit in m_T vs m_{ll} for 0 and 1-jet $e\mu$, cuts for 0 and 1-jet $ee/\mu\mu$ and 2-jet

$$m_T^2 = 2|\vec{p}_T^{ll}||\vec{E}_T^{\mathrm{miss}}|(1 - cos\Delta\phi_{E_T^{\mathrm{miss}},ll})$$

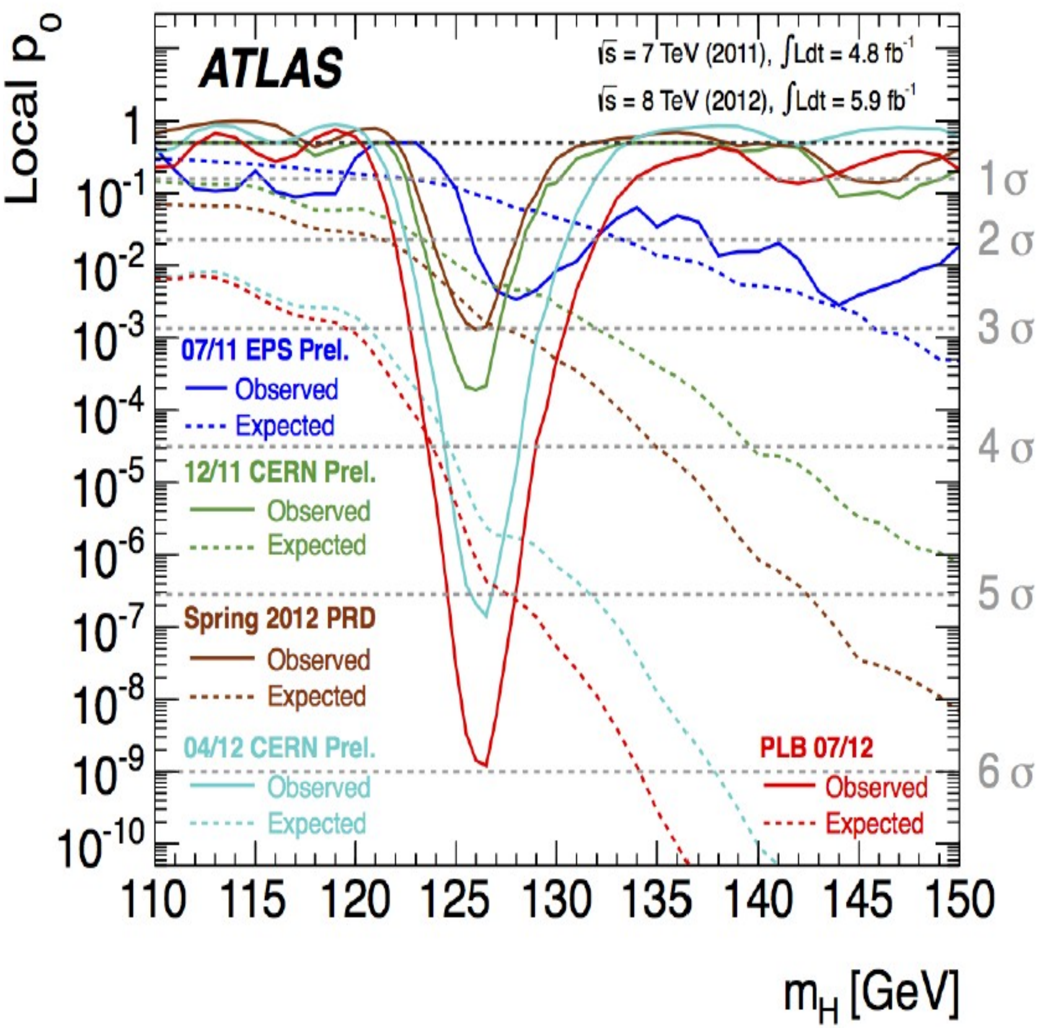
CMS cuts @ 125 GeV: $p_T^{lead} > 23$ GeV, $m_{ll} < 43$ GeV, $\Delta\phi_{ll} < 100°$, $80 < m_T < 123$

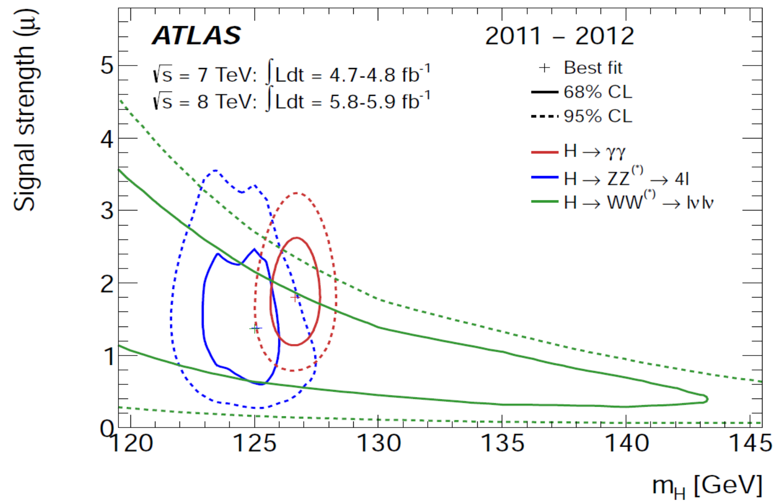
ATLAS: fits final m_T distribution after all other cuts

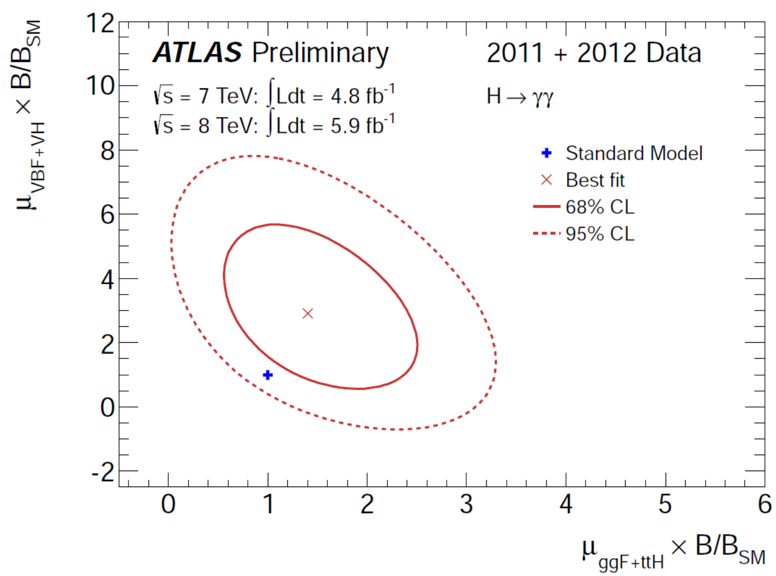
$$m_T^2 = \left[\sqrt{m_{ll}^2 + |\vec{p}_T^{ll}|^2} + |\vec{E}_T^{\mathrm{miss}}|\right]^2 - |\vec{p}_T^{ll} + \vec{E}_T^{\mathrm{miss}}|^2$$

ATLAS cuts: $p_T^{lead} > 25$ GeV, $m_{ll} < 50$ GeV, $\Delta\phi_{ll} < 1.8$

Standard Model Higgs







Since then……. (HCP conference)

ATLAS

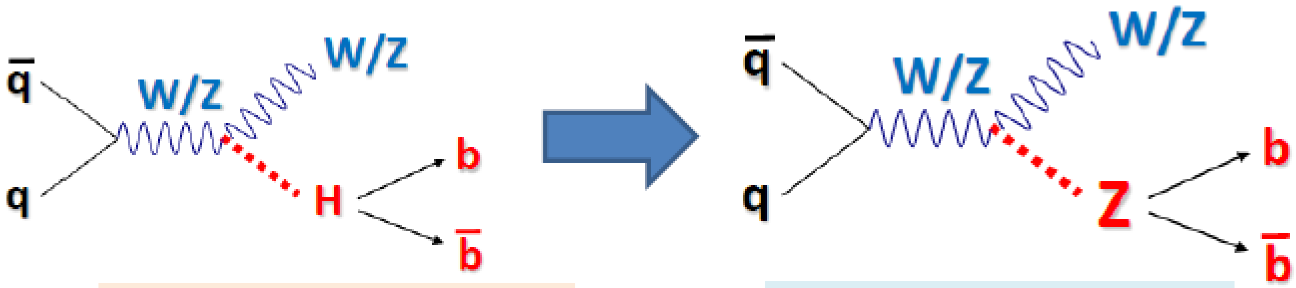
- Low mass channels with decay to WW, bb, $\tau\tau$ updated with ~13fb^{-1} (2012) and released for HCP conference.
- Update on combination for signal strength.

CMS

- Updated ZZ, WW, bb, $\tau\tau$ with ~12 fb^{-1} (2012).
- Updated combination, couplings and spin.

- **Tevatron**
- Update on H->bb analysis with 10fb^{-1}.

The TEVATRON update

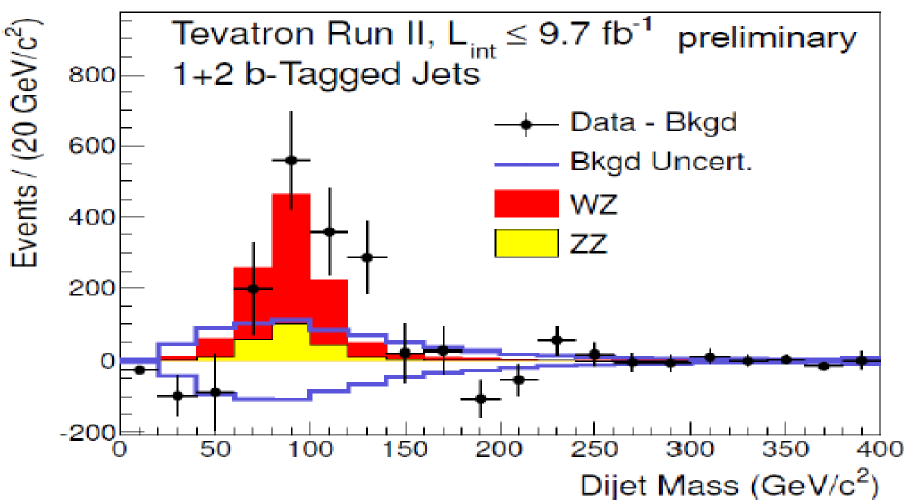


For m_H=115 GeV
Total VH: σ = 46 fb

Replace Z with H
Total VZ: σ = 213 fb

Z→bb yields is 5 times larger, but more W+jets at lower mass, also there is **BG from WW**.

Measure diboson cross section with **exactly the same** analysis procedure.



$\sigma(WZ+ZZ) = 3.0 \pm 0.9$ pb

(Fit performed with MVA output without Higgs signal)

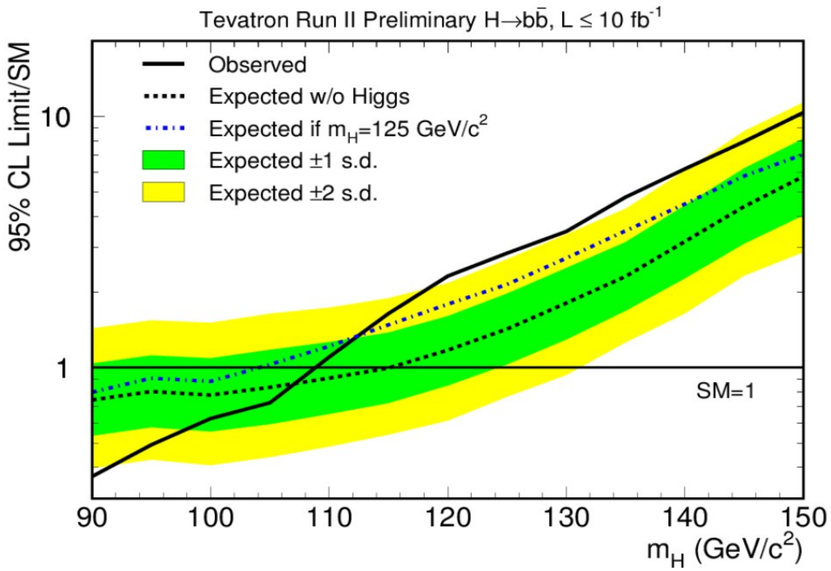
$\sigma(VZ)^{NLO}_{SM} = 4.4 \pm 0.3$ pb

The TEVATRON update

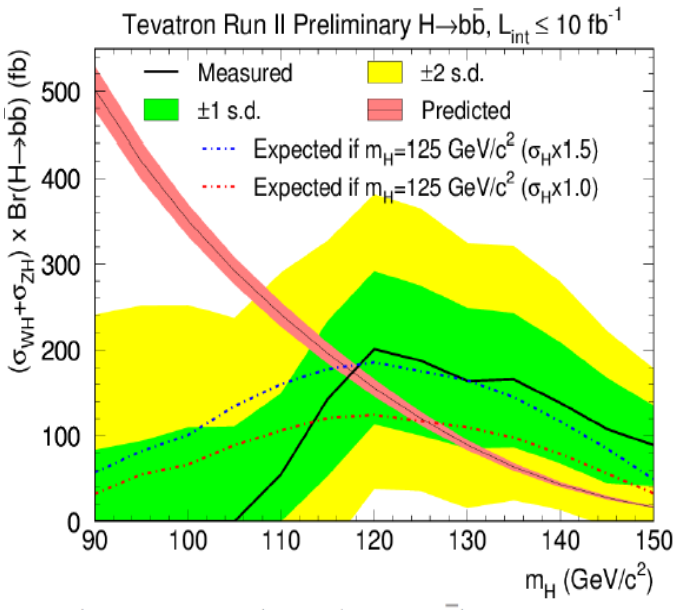
$\sigma(WH+ZH) \times Br(H \rightarrow b\bar{b})$

$= 0.19 \pm 0.09$ (stat+syst) pb

$\rightarrow \mu = 1.56 \pm^{0.72}_{0.73}$ @M_H=125GeV



95% CL SM Higgs limit ratio @M_H = 125 GeV
Exp : 1.4 Obs : 2.9



$\mu = 1.56 \pm^{0.72}_{0.73}$

$(\sigma_{WH}+\sigma_{ZH})\times\mathcal{B}(H\rightarrow b\bar{b}) = 0.19\pm0.09\ (\mathrm{stat}+\mathrm{syst})\ \mathrm{pb}$

SM expectation : 0.12 ± 0.01 pb

SM Higgs @ 125 GeV

ATLAS H->bb: analysis strategy

Search for Higgs decaying to pair of b-quarks

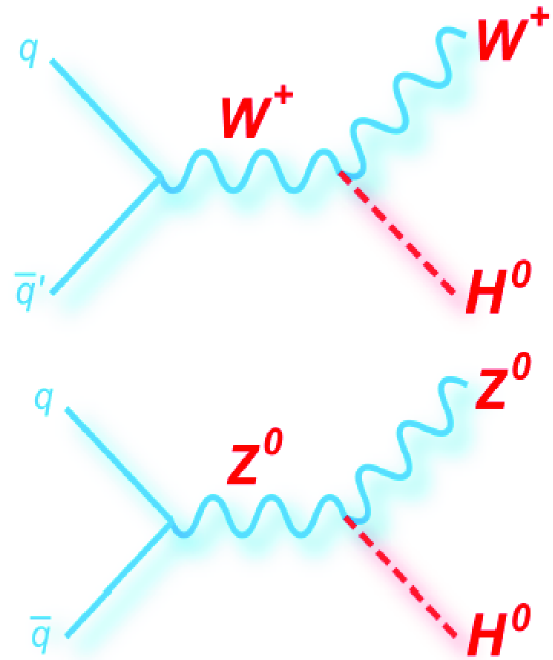
- Associated production to reduce backgrounds

The analysis is divided into three channels

- Two (llbb), one (lνbb) or zero (ννbb),) (l=e,μ)

Cuts common to all channels

- Two or three jets: 1st jet $p_T > 45$ GeV
  other jets $p_T > 20$ GeV
- Two b-tags: 70% efficiency per tag (mistag ~1%)



Two lepton

ZH → llbb
- No additional leptons
- $E_t^{miss} < 60$ GeV
- $83 < m_Z < 99$ GeV
- Single & di-lepton trigger

One lepton

WH → lνbb
- No additional leptons
- $E_t^{miss} > 25$ GeV
- $40 < M_T^W < 120$ GeV
- Single lepton trigger

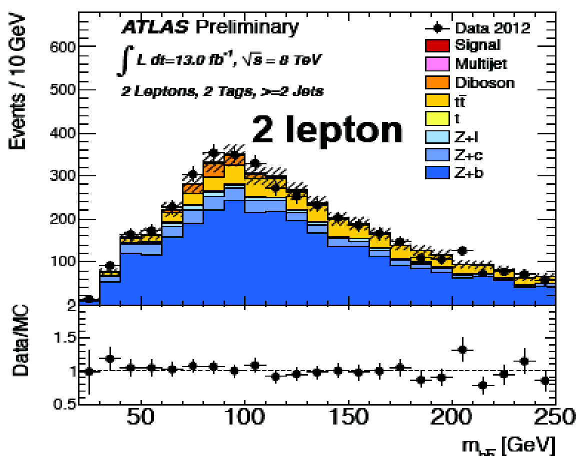
Zero lepton

ZH → ννbb
- No leptons
- $E_t^{miss} > 120$ GeV
- E_t^{miss} trigger

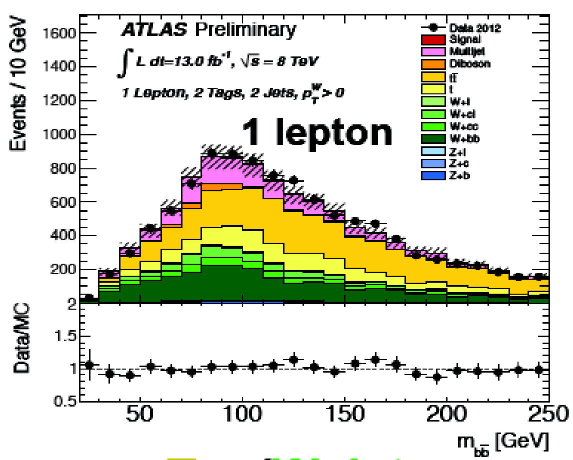
H->bb: backgrounds

- Signal: WH/ZH Pythia8
- Diboson WW/WZ/ZZ Herwig
- Multijet: Data driven
- Ttbar: MC@NLO
- Single Top Acer/MC@NLO
- W+b Powheg
- W+c/light-jets Alpgen
- Z+ b/c/light-jets Alpgen/Sherpa

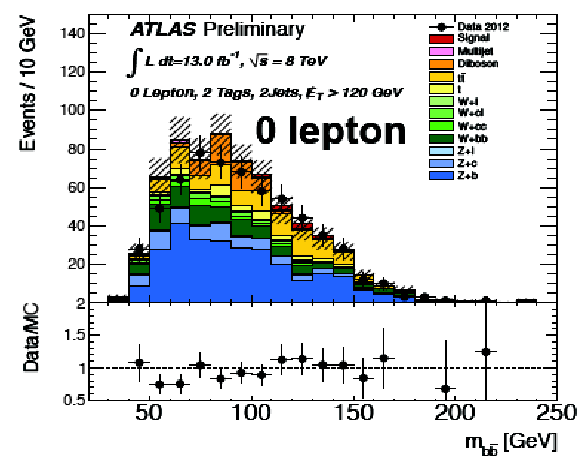
- Background shapes from simulation and normalised using data (flavour & signal fit)
- Multi-jet bkg determined by data-driven techniques
- WZ(Z→bb) & ZZ(Z→bb) resonant bkg normalisation and shape from simulation



Z+jets

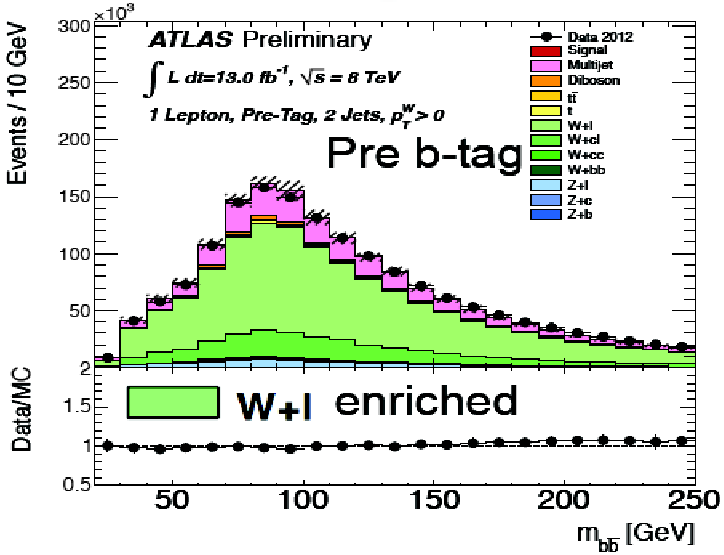


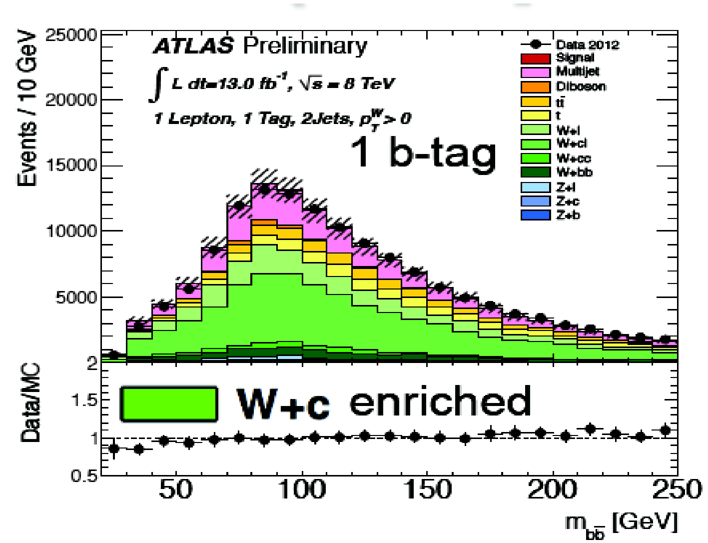
Top/W+jets

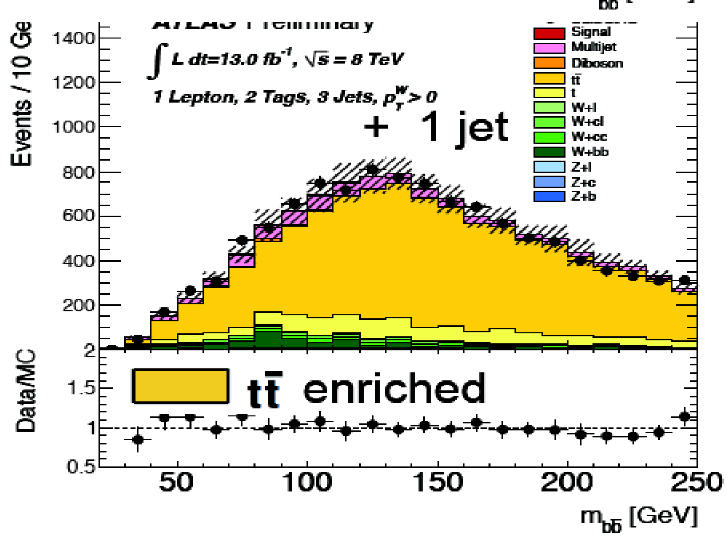


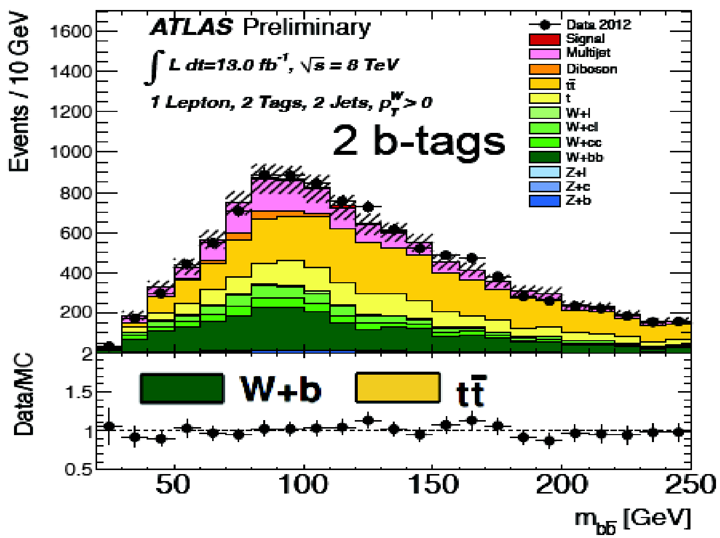
Z+jets/W+jets/Top

H->bb: example flavour fit









H->bb: systematic uncertainties

Main experimental uncertainties

b-tagging and **jet energy** dominate

- Jets: components (7 JES, 1 p_T^{Reco}, resol.)
- E_T^{miss} – scale and resolution
- bTagging – light, c & 6 p_T efficiency bins
- Top, W, Z background modelling
- Lepton/ Multijet / diboson / Luminosity
- MC statistics

Main theoretical uncertainties

- W/Z+jet m_{bb} and V pT
- BR(H→bb) @ mH=125 GeV
- Signal cross-sections include pT-dependent electroweak correction factors
- Single top/top normalisation
- W+c, Z+c

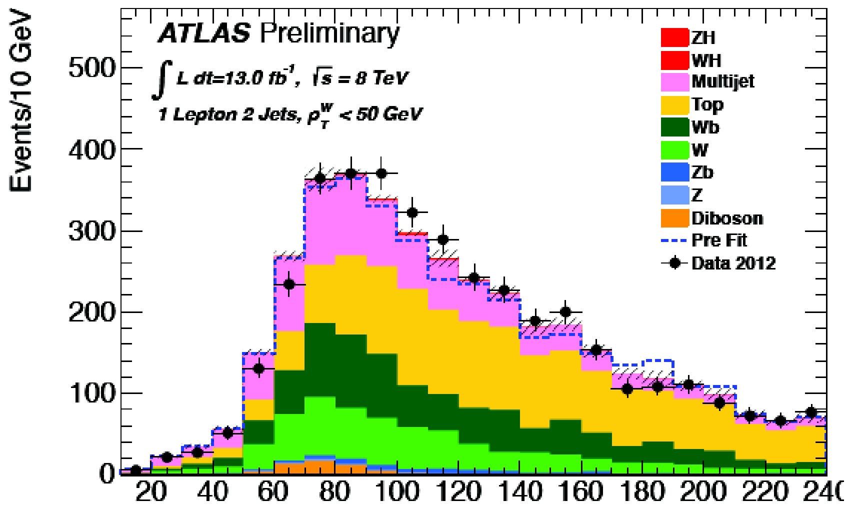
Uncertainty [%]	0 lepton	1 lepton	2 leptons
b-tagging	6.5	6.0	6.9
c-tagging	7.3	6.4	3.6
light tagging	2.1	2.2	2.8
Jet/Pile-up/E_T^{miss}	20	7.0	5.4
Lepton	0.0	2.1	1.8
Top modelling	2.7	4.1	0.5
W modelling	1.8	5.4	0.0
Z modelling	2.8	0.1	4.7
Diboson	0.8	0.3	0.5
Multijet	0.6	2.6	0.0
Luminosity	3.6	3.6	3.6
Statistical	8.3	3.6	6.6
Total	25	15	14

Background systematics (after cuts)

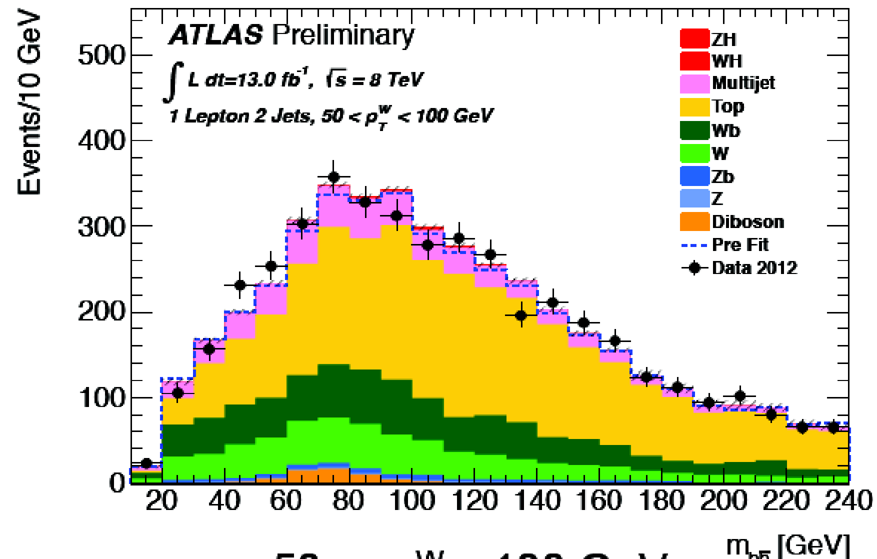
Uncertainty [%]	0 lepton		1 lepton	2 leptons
	ZH	*WH*	*WH*	*ZH*
b-tagging	8.9	9.0	8.8	8.6
Jet/Pile-up/E_T^{miss}	19	25	6.7	4.2
Lepton	0.0	0.0	2.1	1.8
$H \to bb$ BR	3.3	3.3	3.3	3.3
VH p_T-dependence	5.3	8.1	7.6	5.0
VH theory PDF	3.5	3.5	3.5	3.5
VH theory scale	1.6	0.4	0.4	1.6
Statistical	4.9	18	4.1	2.6
Luminosity	3.6	3.6	3.6	3.6
Total	24	34	16	13

Signal systematics (after cuts)

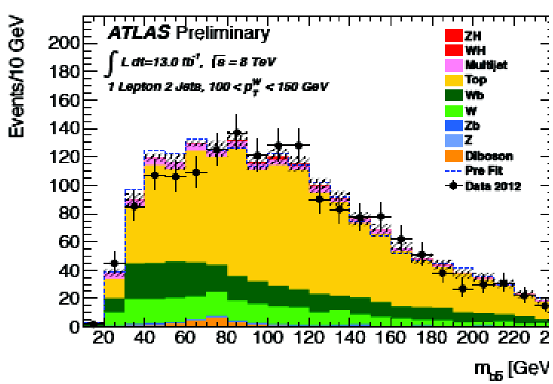
H->bb: m_{bb} distribution (1 lepton)



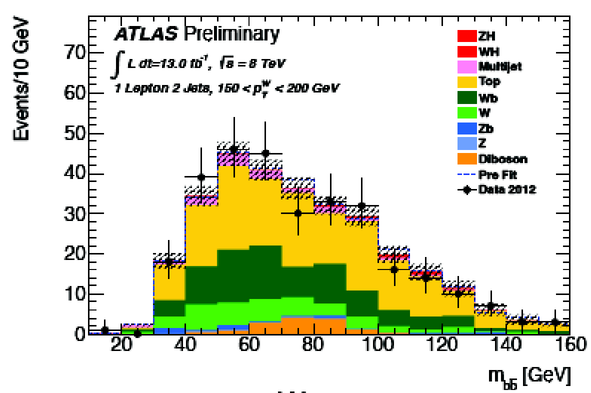
$p_T^W < 50$ GeV



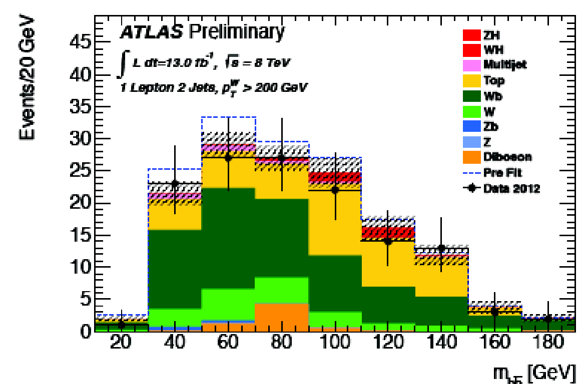
$50 < p_T^W < 100$ GeV



$100 < p_T^W < 100$ GeV



$150 < p_T^W < 200$ GeV



$p_T^W > 200$ GeV

H->bb: Diboson production

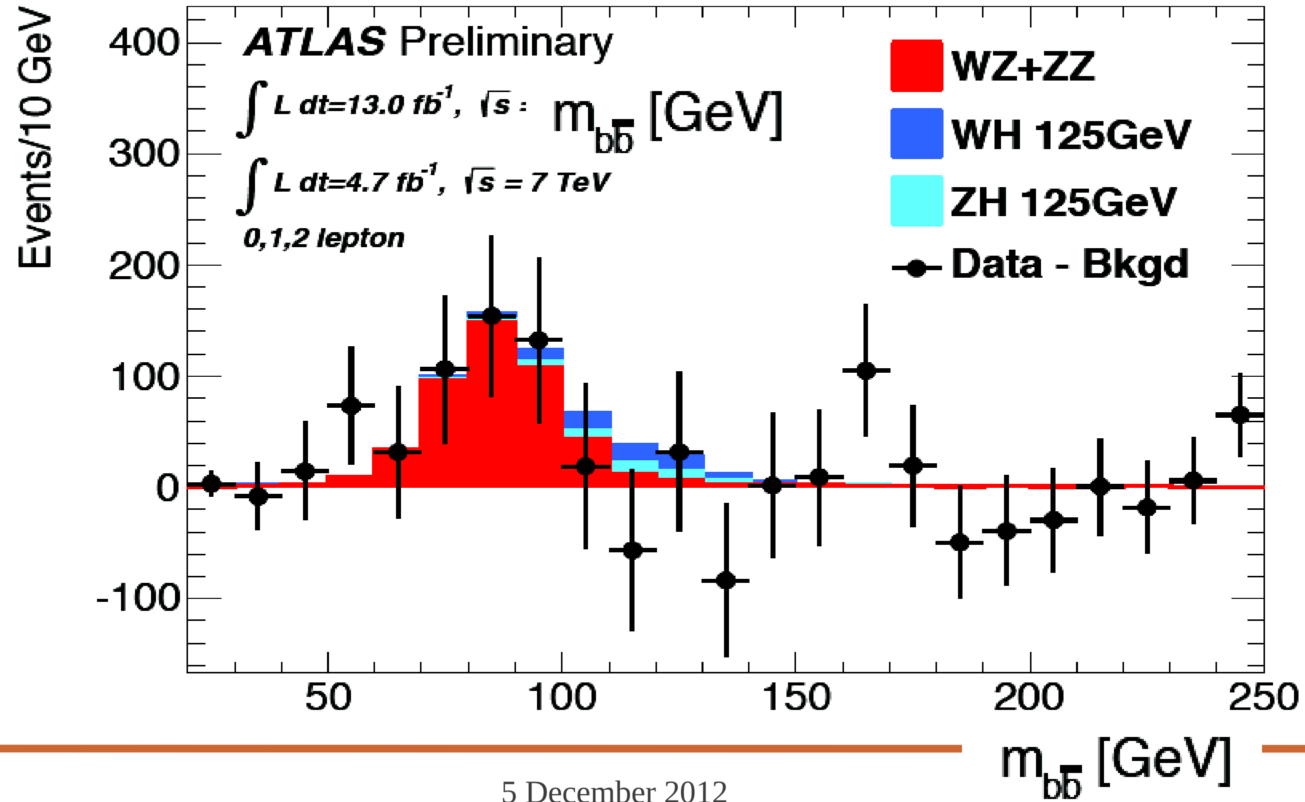
WZ & ZZ production with $Z \rightarrow b\bar{b}$ similar signature, but 5 times larger cross-section

Perform a separate fit to search for it and to validate the analysis procedure

- Profile likelihood fit performed (with full systematics)
- All backgrounds (except diboson) subtracted
- Uses full $p_T^{W,Z}$ range, done individually for each channel & year (see backup)

Clear excess is observed in data at expected mass (all lepton channels combined)

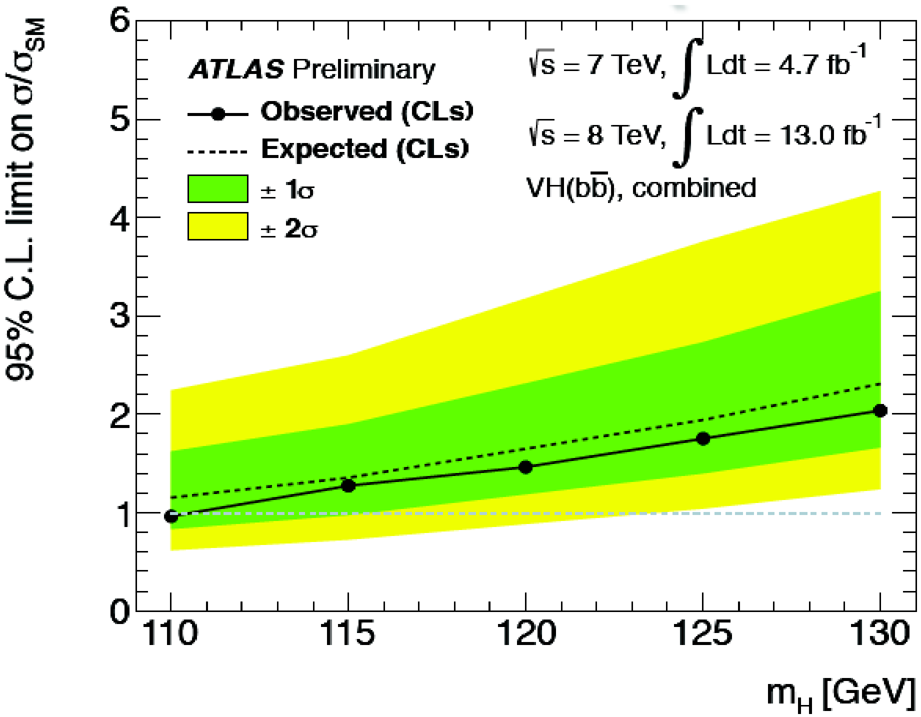
Results: $\sigma/\sigma_{SM} = \mu_D = 1.09 \pm 0.20$ (stat) ± 0.22 (syst). The significance is 4.0σ

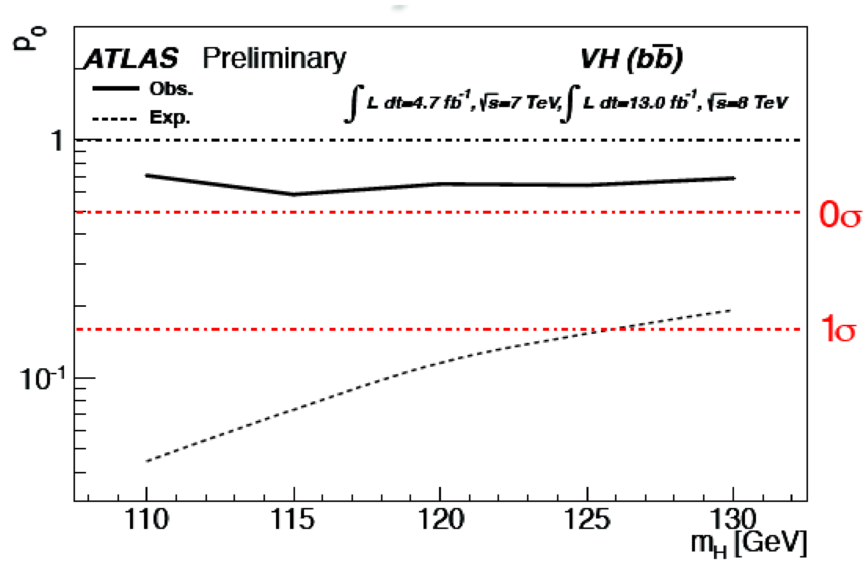


H->bb: Expected and observed events

	0-lepton, 2 jet			0-lepton, 3 jet			1-lepton					2-lepton				
Bin	E_T^{miss} [GeV]						p_T^W [GeV]					p_T^Z [GeV]				
	120-160	160-200	>200	120-160	160-200	>200	0-50	50-100	100-150	150-200	> 200	0-50	50-100	100-150	150-200	>200
ZH	2.9	2.1	2.6	0.8	0.8	1.1	0.3	0.4	0.1	0.0	0.0	4.7	6.8	4.0	1.5	1.4
WH	0.8	0.4	0.4	0.2	0.2	0.2	10.6	12.9	7.5	3.6	3.6	0.0	0.0	0.0	0.0	0.0
Top	89	25	8	92	25	10	1440	2276	1120	147	43	230	310	84	3	0
$W + c$,light	30	10	5	9	3	2	580	585	209	36	17	0	0	0	0	0
$W + b$	35	13	13	8	3	2	770	778	288	77	64	0	0	0	0	0
$Z + c$,light	35	14	14	8	5	8	17	17	4	1	0	201	230	91	12	15
$Z + b$	144	51	43	41	22	16	50	63	13	5	1	1010	1180	469	75	51
Diboson	23	11	10	4	4	3	53	59	23	13	7	37	39	16	6	4
Multijet	3	1	1	1	1	0	890	522	68	14	3	12	3	0	0	0
Total Bkg.	361 ± 29	127 ± 11	98 ± 12	164 ± 13	63 ± 8	42 ± 5	3810 ± 150	4310 ± 86	1730 ± 90	297 ± 27	138 ± 14	1500 ± 90	1770 ± 110	665 ± 47	97 ± 12	72 ± 12
Data	342	131	90	175	65	32	3821	4301	1697	297	132	1485	1773	657	100	69

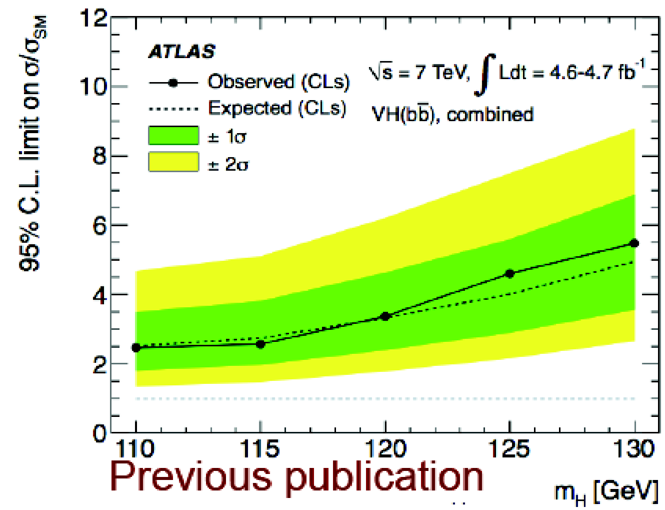
H->bb: Expected and observed events





- Observed (expected) limit at m_H =125 GeV
  - 1.8 (1.9) x SM prediction
  - $\sigma/\sigma_{SM} = \mu = -0.4 \pm 0.7(\text{stat.}) \pm 0.8(\text{syst.})$
- Observed (expected) p_0 value: 0.64 (0.15)
- Exclusion at m_H ~ 110 GeV

More than doubled the analysis sensitivity ➡



Previous publication

http://arxiv.org/abs/1207.0210

ATLAS: update on combination

Higgs Boson Decay	Subsequent Decay	Sub-Channels	$\int L\, dt$ [fb^{-1}]
		2011 $\sqrt{s}$ =7 TeV	
$H \rightarrow ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	4.8
$H \rightarrow \gamma\gamma$	–	10 categories $\{p_{Tt} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet}\}$	4.8
$H \rightarrow \tau\tau$	$\tau_{lep}\tau_{lep}$	$\{e\mu\} \otimes \{\text{0-jet}\} \oplus \{\ell\ell\} \otimes \{\text{1-jet, 2-jet, boosted}, VH\}$	4.7
	$\tau_{lep}\tau_{had}$	$\{e, \mu\} \otimes \{\text{0-jet, 1-jet, boosted, 2-jet}\}$	4.7
	$\tau_{had}\tau_{had}$	$\{\text{boosted, 2-jet}\}$	4.7
$VH \rightarrow Vbb$	$Z \rightarrow \nu\nu$	$E_T^{miss} \in \{120-160, 160-200, \geq 200 \text{ GeV}\} \otimes \{\text{2-jet, 3-jet}\}$	4.6
	$W \rightarrow \ell\nu$	$p_T^W \in \{< 50, 50-100, 100-150, 150-200, \geq 200 \text{ GeV}\}$	4.7
	$Z \rightarrow \ell\ell$	$p_T^Z \in \{< 50, 50-100, 100-150, 150-200, \geq 200 \text{ GeV}\}$	4.7
		2012 $\sqrt{s}$ =8 TeV	
$H \rightarrow ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	5.8
$H \rightarrow \gamma\gamma$	–	10 categories $\{p_{Tt} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet}\}$	5.9
$H \rightarrow WW^{(*)}$	$e\nu\mu\nu$	$\{e\mu, \mu e\} \otimes \{\text{0-jet, 1-jet}\}$	13
$H \rightarrow \tau\tau$	$\tau_{lep}\tau_{lep}$	$\{\ell\ell\} \otimes \{\text{1-jet, 2-jet, boosted}, VH\}$	13
	$\tau_{lep}\tau_{had}$	$\{e, \mu\} \otimes \{\text{0-jet, 1-jet, boosted, 2-jet}\}$	13
	$\tau_{had}\tau_{had}$	$\{\text{boosted, 2-jet}\}$	13
$VH \rightarrow Vbb$	$Z \rightarrow \nu\nu$	$E_T^{miss} \in \{120-160, 160-200, \geq 200 \text{ GeV}\} \otimes \{\text{2-jet, 3-jet}\}$	13
	$W \rightarrow \ell\nu$	$p_T^W \in \{< 50, 50-100, 100-150, 150-200, \geq 200 \text{ GeV}\}$	13
	$Z \rightarrow \ell\ell$	$p_T^Z \in \{< 50, 50-100, 100-150, 150-200, \geq 200 \text{ GeV}\}$	13

Channels entering HCP combination

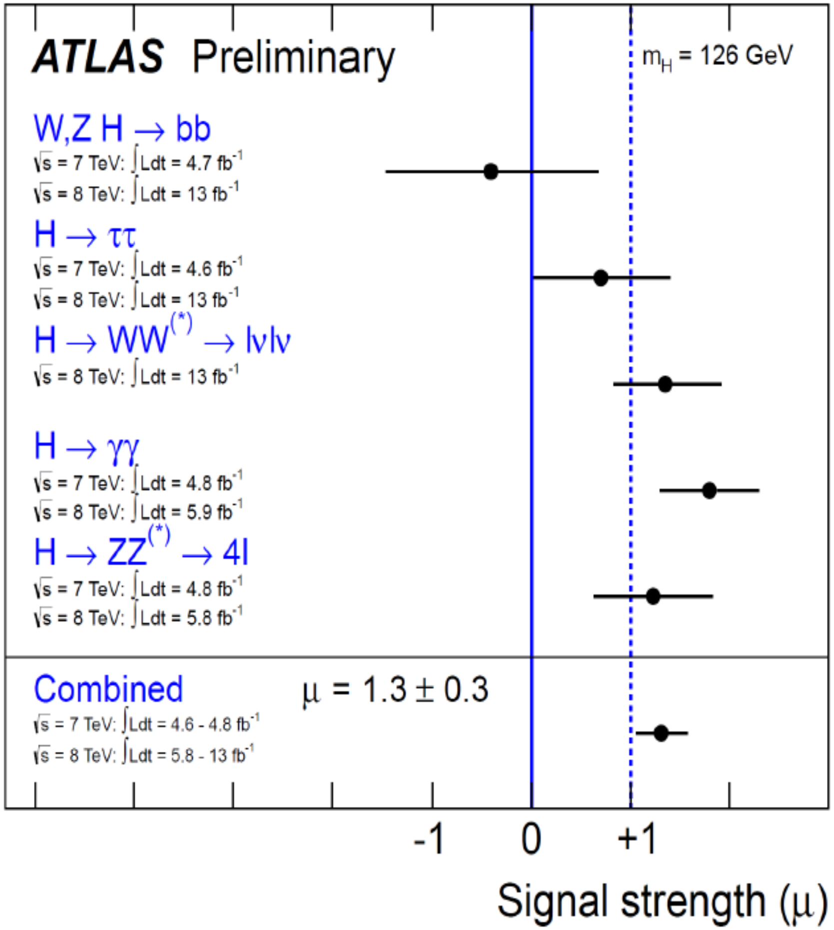
Best–fit Higgs mass m_H :

126.0 ± 0.4 (stat) ± 0.4 (syst) GeV

Best-fit signal strength:

μ = 1.3 ± 0.3

Couplings measurement not updated for HCP: uncertainies of 20-30%



Next topics

- 12.12 - **Higgs (part II)**
- 19.12 - **SUSY**
- 9.1 – other searches for New Physics
- 16.1 - B-physics programme
- 23.1 – heavy ion programme