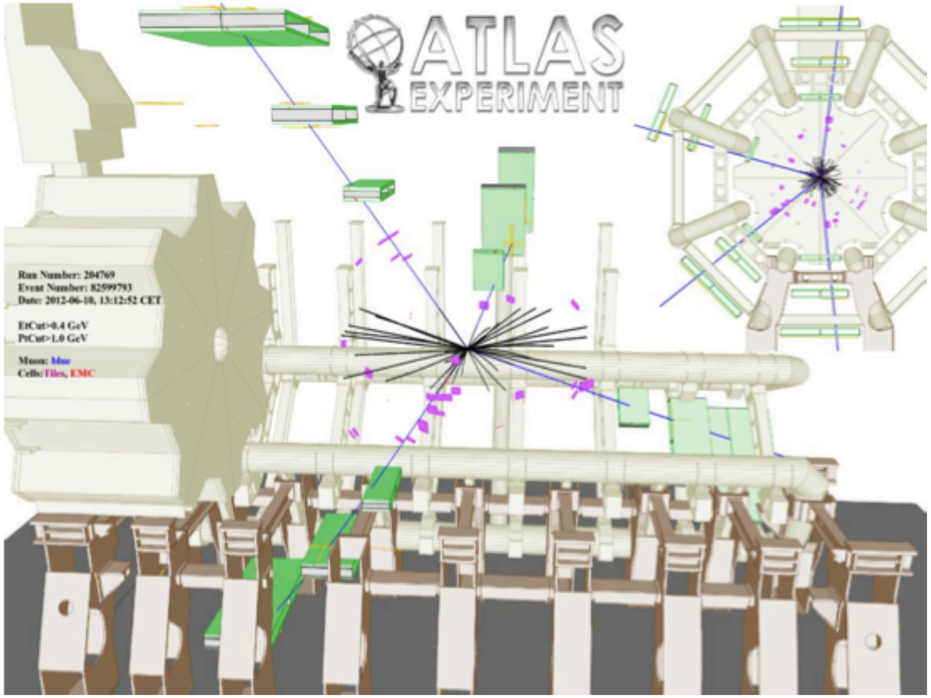
DESY LHC Discussion – August 06, 2012

SM Higgs searches at ATLAS

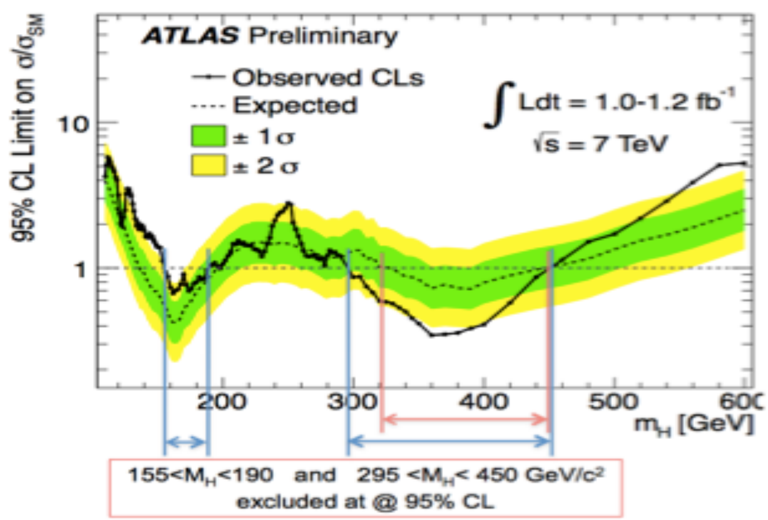


Marcos Jimenez Belenguer

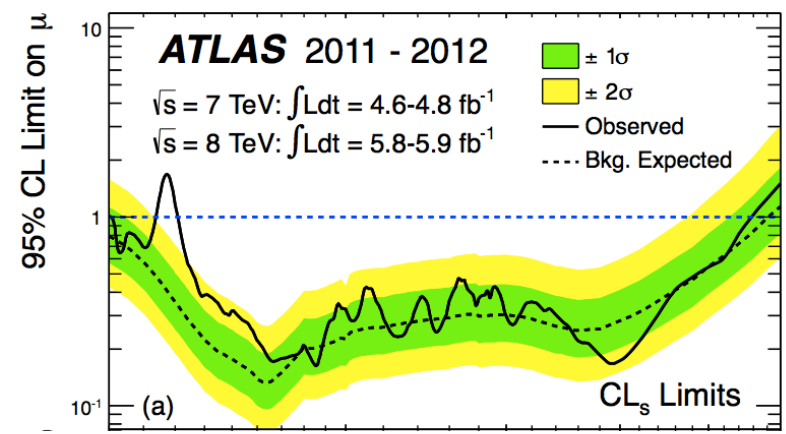
Abstract of paper made public on July 31st (last Tuesday) : http://arxiv.org/ps/1207.7214v1

Clear evidence for the production of a neutral boson with a measured mass of 126.0 ± 0.4 (stat) ± 0.4 (sys) GeV is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7 × 10–9, is compatible with the production and decay of the Standard Model Higgs boson.

Summer 2011

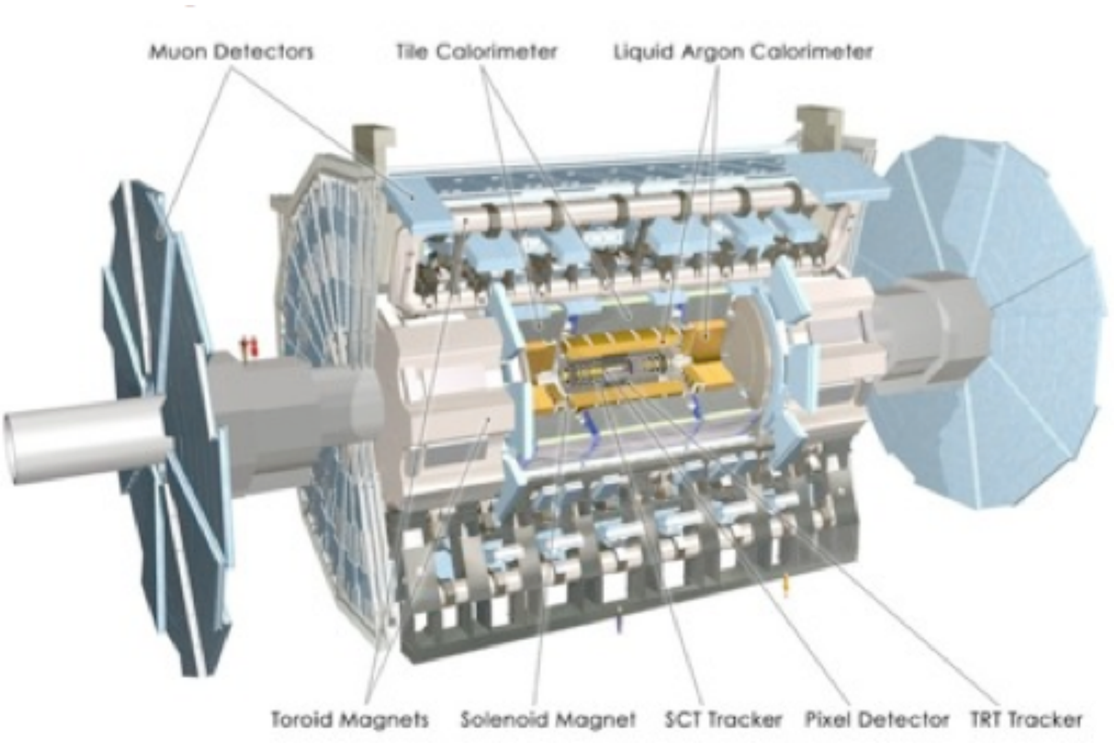


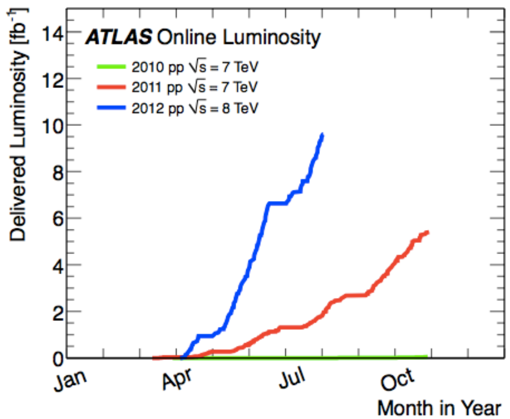
Summer 2012



- Higgs excluded at 95% confidence level in 111 < m_H < 600 [GeV] except in the 122 < m_H < 131 [GeV] where an excess of events with significance of 5.9 sigma is observed

Discovery of resonance made possible by this machine :





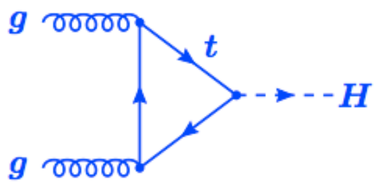
LHC is rapidily delivering more data. Expect up to 30 fb^{-1} by end of 2012 !!

→ ***The design of the ATLAS detector was partially driven to provide high sensitivity to Higgs production***

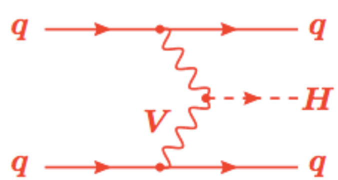
- Silicon Pixel (Si) and Silicon Microstrip detectors (SCT)
- Straw Tube Radiation Tracker (TRT) (immersed in solenoid producing 2 Tesla field)
- EMC (LAr detector) – very granular in eta and hadronic Calorimeters
- Muon tracking chambers (own magnetic field)

Standard Model Higgs Production Mechanisms

Dominant process: Gluon fusion

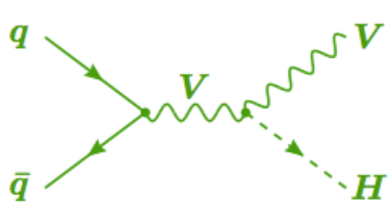


Vector boson fusion (VBF)

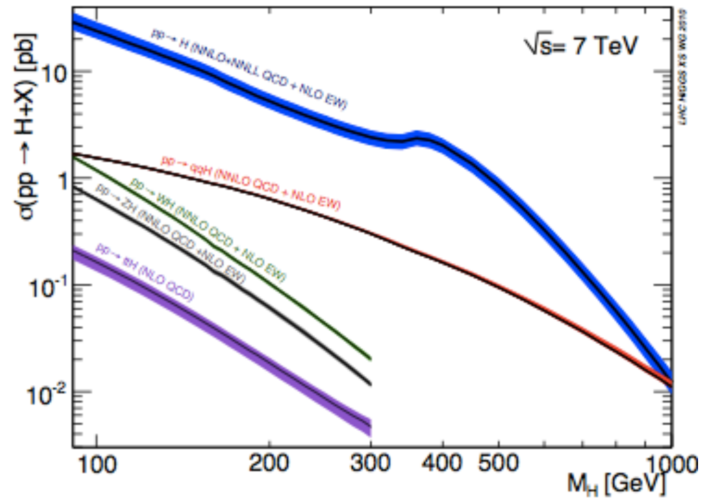


Distinct topology with forward jets

Associated production



Higgs production cross section at LHC

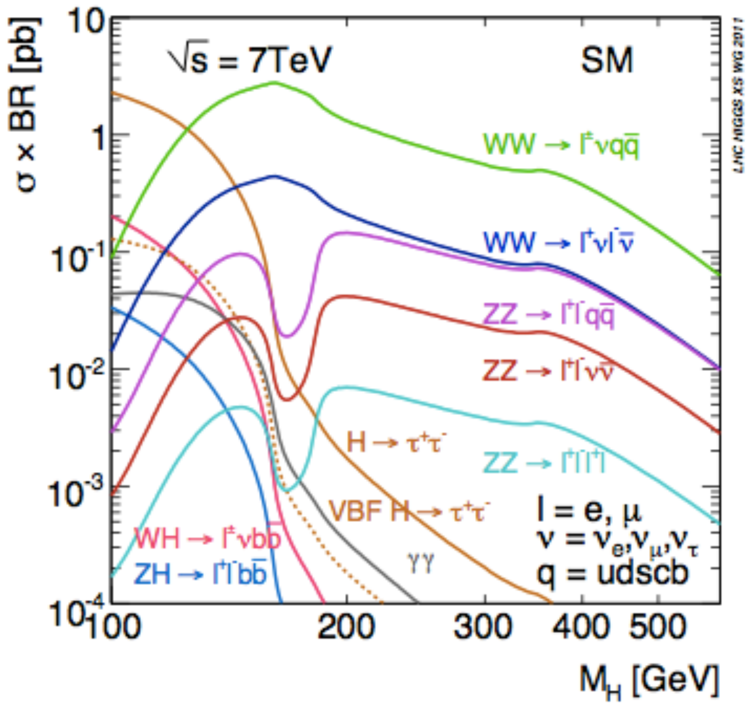


The SM predicts a specific admixture of Higgs production mechanisms – implicitly assumed in the display of the Higgs search results (will say more about this in later slides)

Example from expected number of H-> γγ signal events after acceptance (in %)

$\sqrt{s}$	Category	Events	$gg \to H$ [%]	VBF [%]	WH [%]	ZH [%]	$t\bar{t}H$ [%]
7 TeV	Inclusive	79.3	87.8	7.3	2.9	1.6	0.4

Standard Model Higgs Decay Channels



Intermediate m_H ($\gtrsim$ 130 GeV)

$H \to WW \to \ell\nu\ell\nu$, $H \to ZZ \to 4\ell$

Large m_H ($\gtrsim$ 200 GeV)

$H \to WW \to \ell\nu q\bar{q}$, $H \to ZZ \to \ell\ell\nu\nu$, $\ell\ell q\bar{q}$

Low mass ($\lesssim$ 140 GeV)

$H \to \gamma\gamma$

Rare decay, but distinct signal

$H \to \tau\tau$

Enhanced in MSSM, also contributes to SM search

$WH \to \ell\nu b\bar{b}$, $ZH \to \ell\ell b\bar{b}$

Important to study Higgs properties

Abstract of paper made public on July 31st :

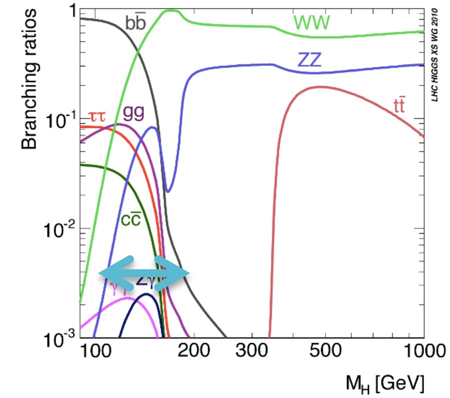
Individual searches in the channels *H*→ *ZZ* (*)→ 4l, *H*→ γγ and *H*→ *WW*(*)→ *eνμν* in the 8 TeV data are combined with previously published results of searches for *H*→*ZZ*(*), *WW*(*), *bb̄* and τ+τ− in the 7 TeV data and results from improved analyses of the *H*→ *ZZ*(*)→ 4l and *H*→ γγ channels in the 7 TeV data.

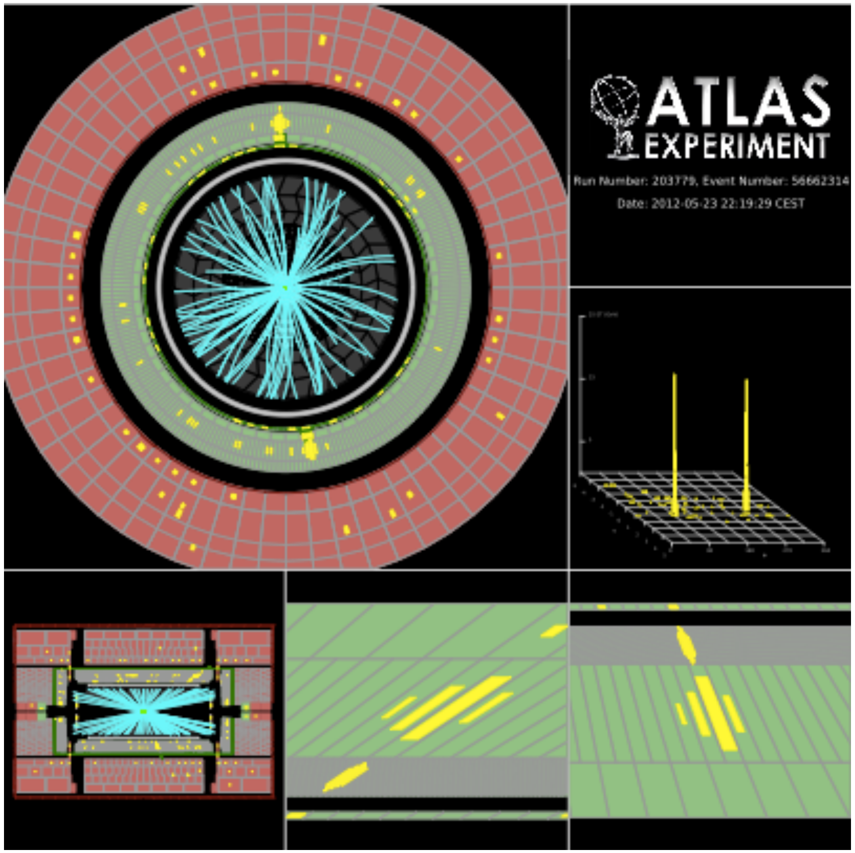
Channels used in 2012 combined result

Decay	m_H range (GeV)	arXiv
$H \to \gamma\gamma$	110-150 (*)	1202.1414
$H \to ZZ^{(*)} \to 4l$	110-600 (*)	1202.1415
$H \to ZZ \to llqq$	200-280-600	1206.2443
$H \to ZZ \to ll\nu\nu$	200-300-600	1205.6744
$H \to WW^{(*)} \to l\nu l\nu$	110-200-300-600	1206.0756
$H \to WW \to l\nu qq$	300-600	1206.6074
$H \to \tau\tau \to ll, l\tau_h, \tau_h\tau_h$	110-150	1206.5971
$VH \to l\nu bb, llbb, \nu\nu bb$	110-130	1207.0210

- **This presentation only covers** $H \to \gamma\gamma$ **and** $H \to ZZ^{(*)} \to 4l$ **(and some** $H \to WW^{(*)} \to l\nu l\nu$**)**
- **DESY is heavily involved in H->γγ channel, which along H->4l are the main players in the discovery of the new resonance**
- **Although of course the other channels also play important role in exclusion of high Higgs mass range**

Higgs → γ γ :: Event Signature



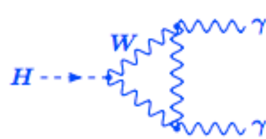


- **Simple signature**
  Two isolated photons in the final state (Pt1 > 40 GeV and Pt2 > 30 GeV)

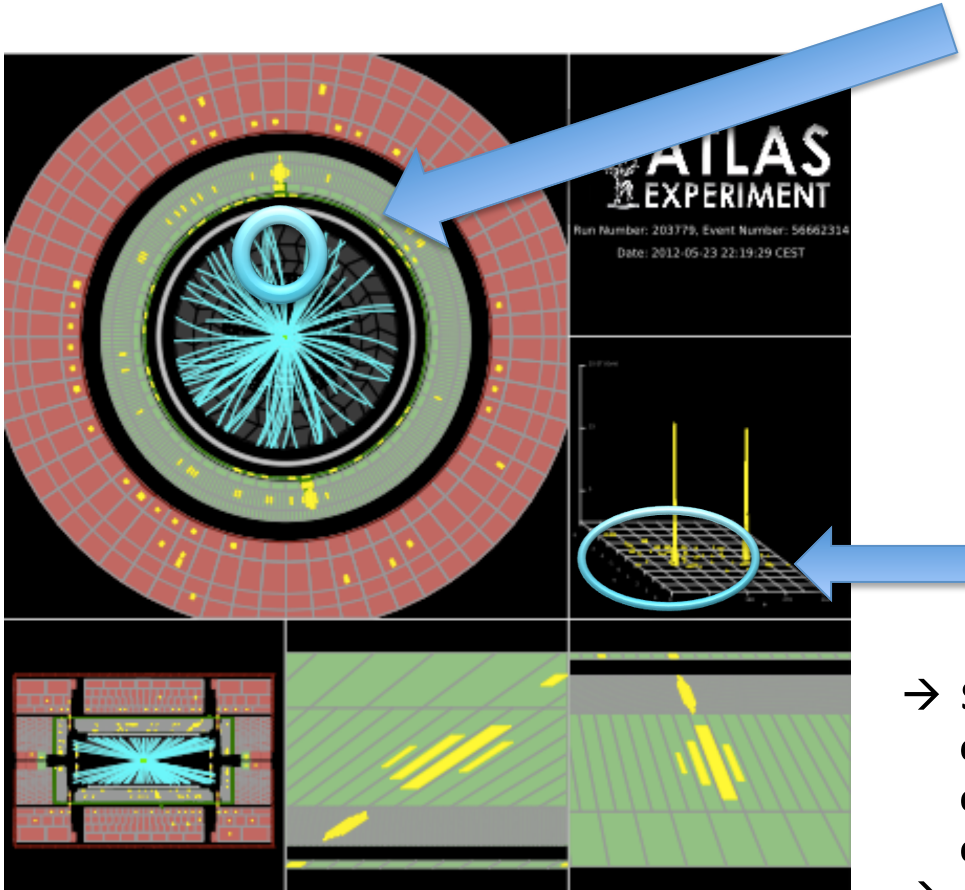
- **Improved 2011 + new 2012 analysis (4.8 + 5.9) fb^{-1}**
  Expect ~ 185 Higgs events from SM

- **Good position and energy resolution**
  Good invariant mass resolution (~1.6 GeV)

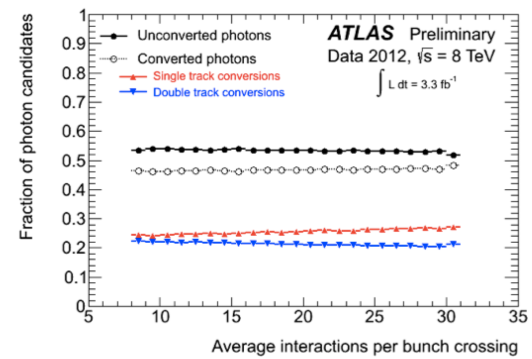
- **Produced via a top or W**



Higgs → γ γ :: Photon ID



- **Tracking information distinguish photon from electron : robust against pileup**

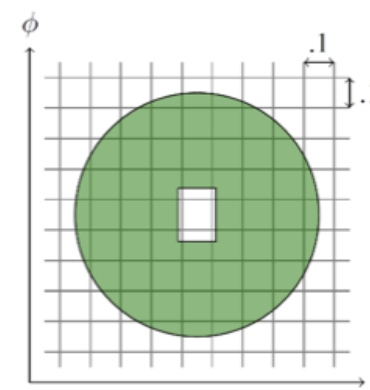


- **Calorimetric isolation**

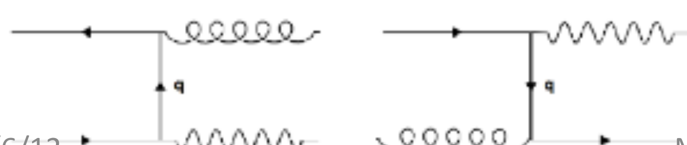
→ **Sum of energy calculated using topo-clusters in cone around cluster**

→ **Corrections for energy leakage outside cluster**

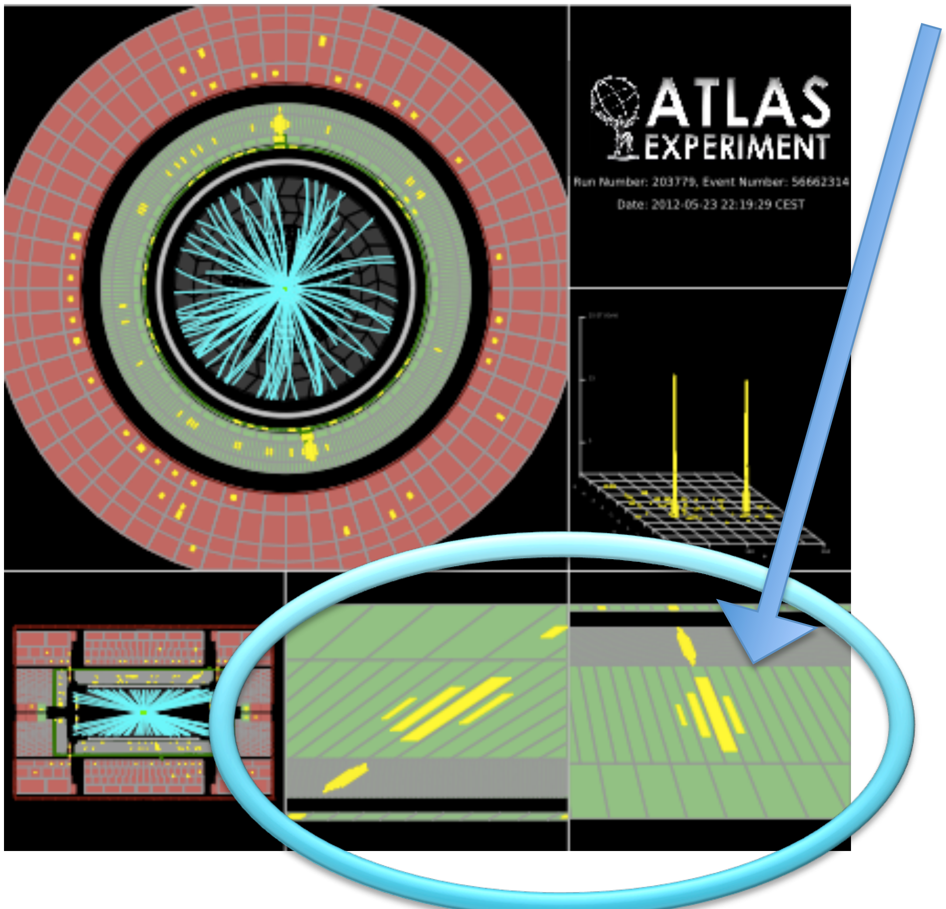
→ **Corrections for ambient energy from pileup/ underlying event**



Main QCD background



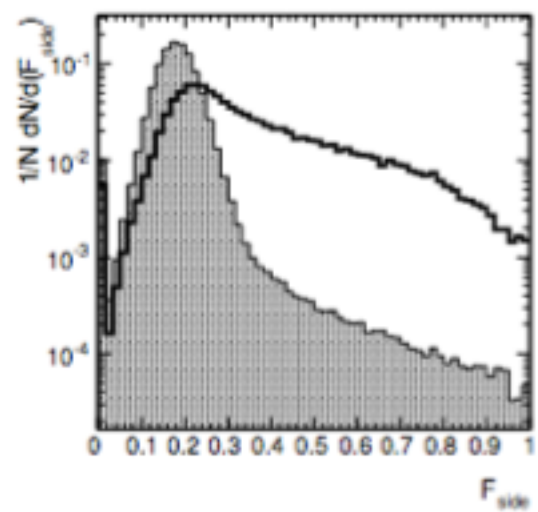
Higgs → γ γ :: Photon ID



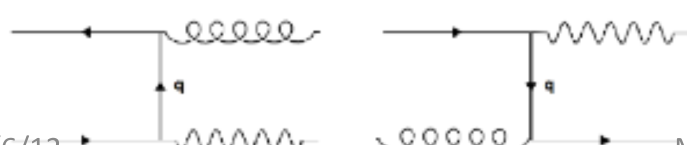
- **Shower shape distributions**

→ Neural Network developed for 2011. Re-optimized cut-based approach for 2012 : reject main QCD background

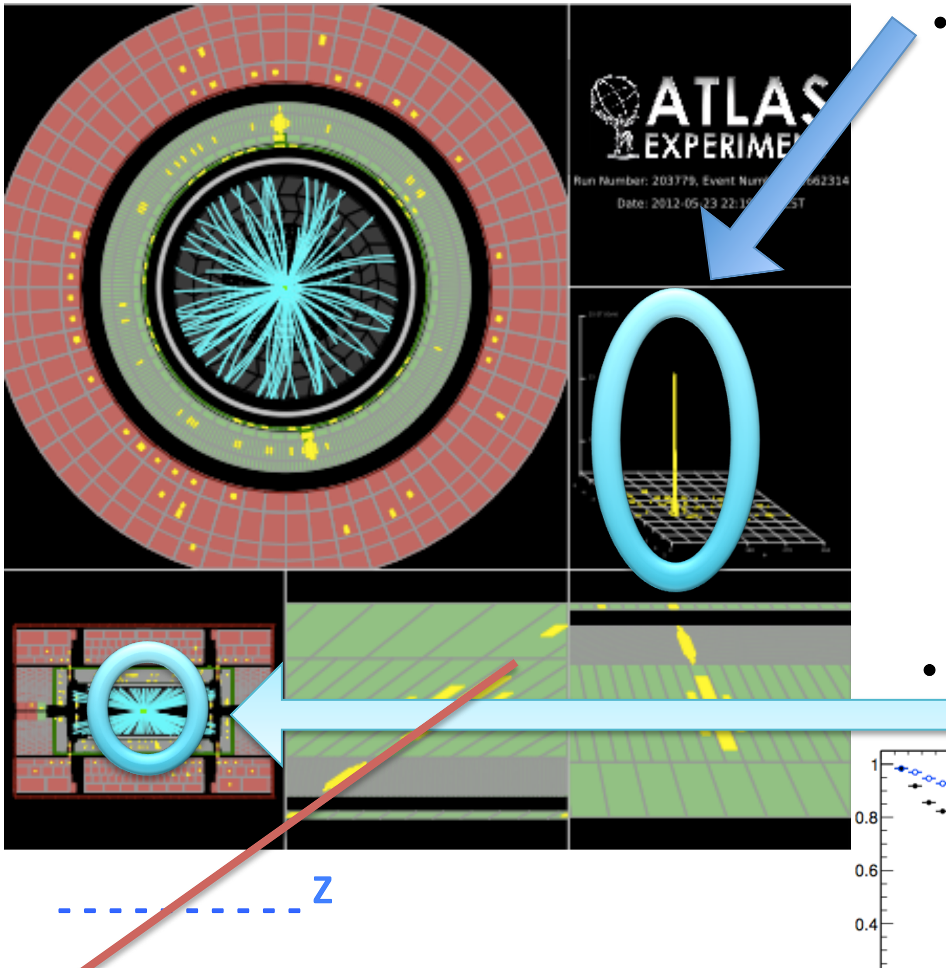
→ Photon ID efficiency cross-checked with data-driven methods : extrapolation from Z-> ee, radiative Z events and a sideband method



Main QCD background

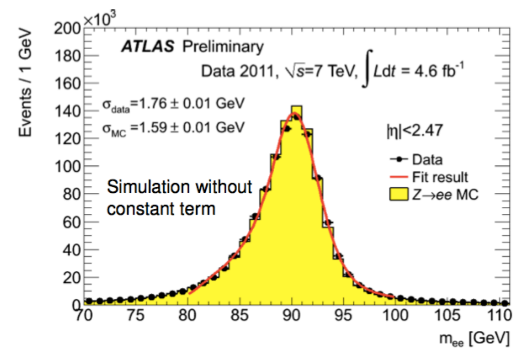


Higgs → γ γ :: Energy and position → $m_{\gamma\gamma}^2 = 2 * E_1 E_2 (1 - \cos \alpha)$

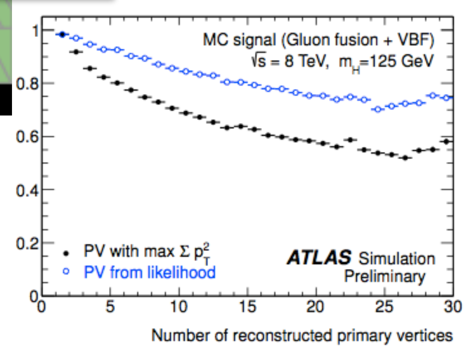


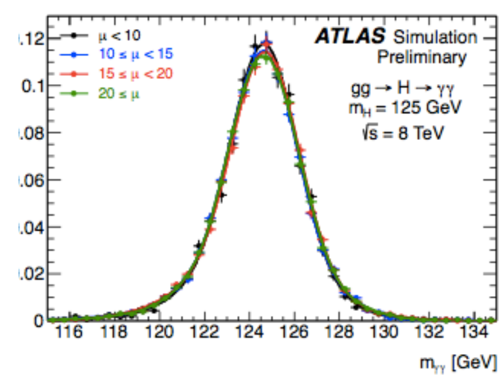
- **Cluster energy**

  → Energy calibration corrected using Z→ ee, W→ enu, J/Psi → ee…



- **Vertex position. Likelihood combination**





Z

→ **Calorimeter "pointing"**
→ **Σ tracks pT^2**
→ **Conversion vertex (only 2011)**

Higgs → γ γ :: Event Categorization (improve sensitivity of search)

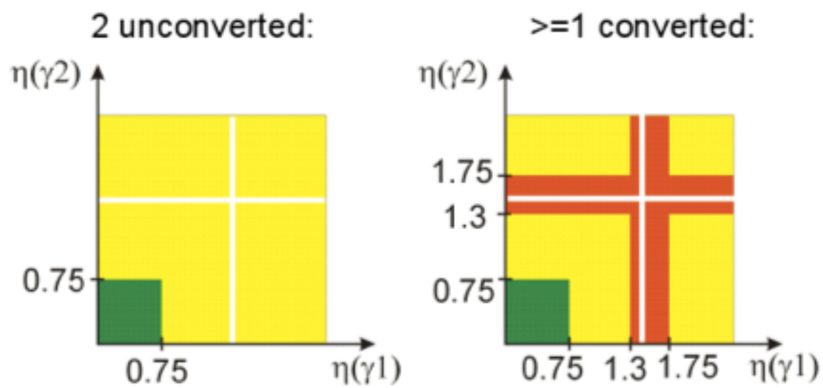
Event categories based on eta, pTt, and conversion, (2-jets properties – next slide)

Both unconverted:

- Central
- Rest

At least one converted:

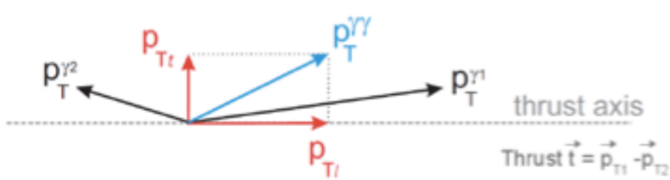
- Central
- Transition
- Rest

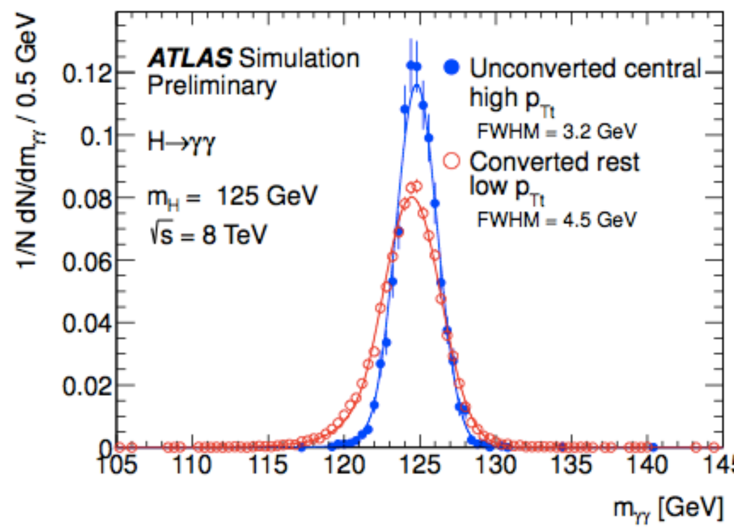


Resolution:

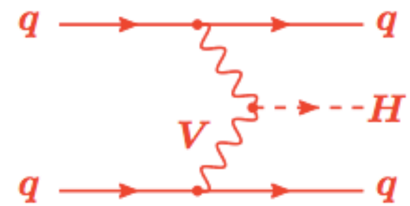
Good
Medium
Poor

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



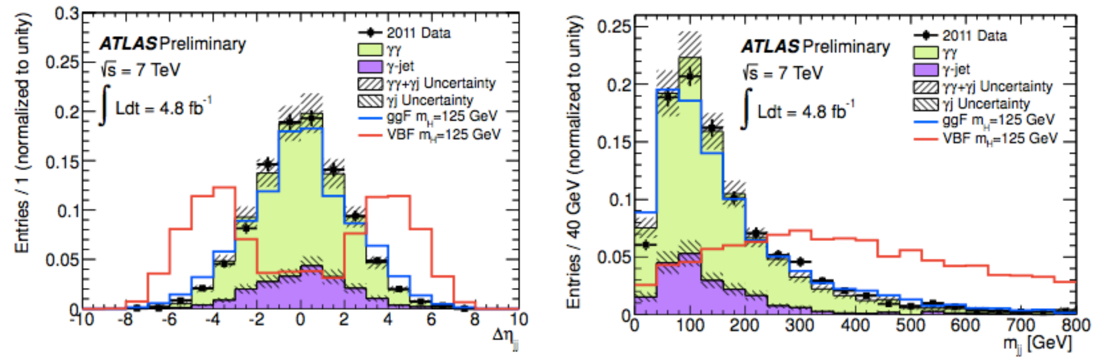


Higgs → γ γ :: Event Categorization (VBF - enriched)



This is bound to be very relevant in determining properties of resonance :

- 2 jets with $|\eta| < 4.5$, with |JVF|*> 0.75 and $p_T > 25\,\mathrm{GeV}$
  - ⋆ Tightened to $p_T > 30\,\mathrm{GeV}$ for $|\eta| > 2.5$ for $\sqrt{s} = 8\,\mathrm{TeV}$
- Jet separation $\Delta\eta_{jj} > 2.8$
- Invariant mass $M_{jj} > 400\,\mathrm{GeV}$
- $|\Delta\phi_{jj-\gamma\gamma}| > 2.6$

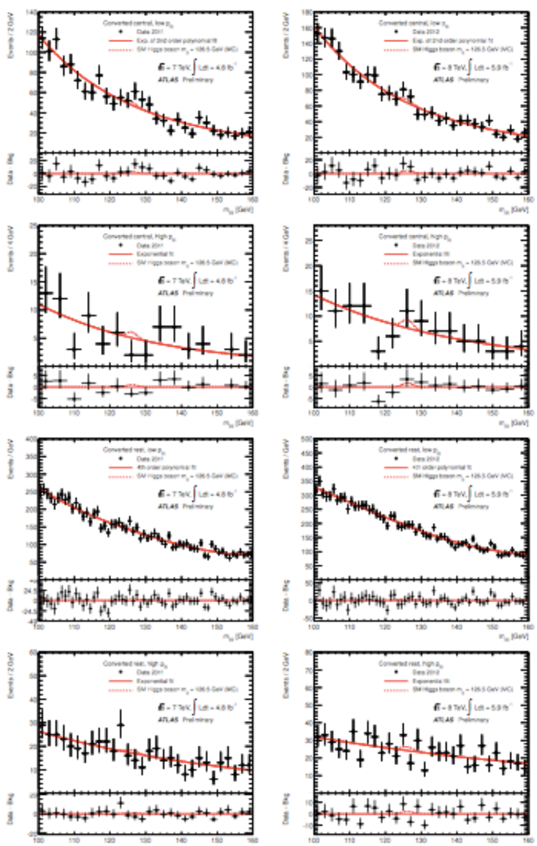


- ***Cuts are not as tight as they could in order to have enough statistics for background fits***
- ***This category requires good primary vertex resolution in order to select jets properly and also a good primary vertex selection***
- ***Expected fraction of gg→ H events in 2-jet category***

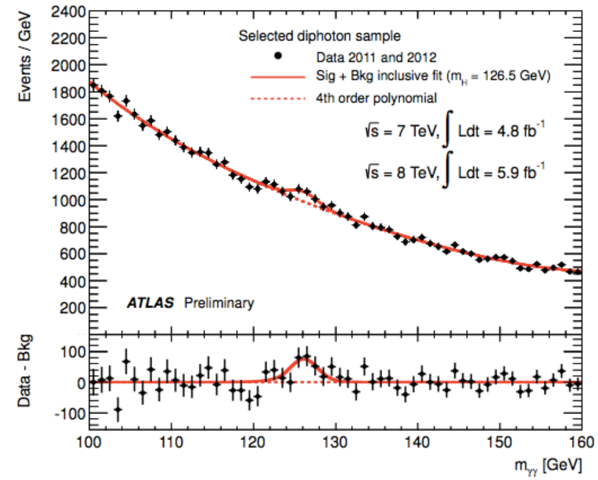
	7 TeV	8 TeV
VBF	77%	68%
$gg \to H$	23%	30%

Higgs → γ γ :: Results I

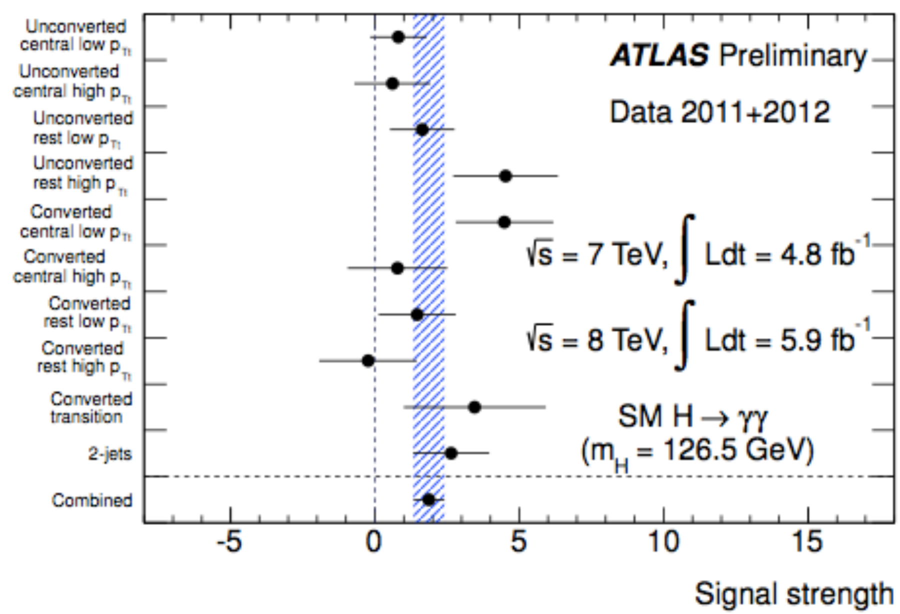
- From each category a mγγ dist



Inclusive m γγ

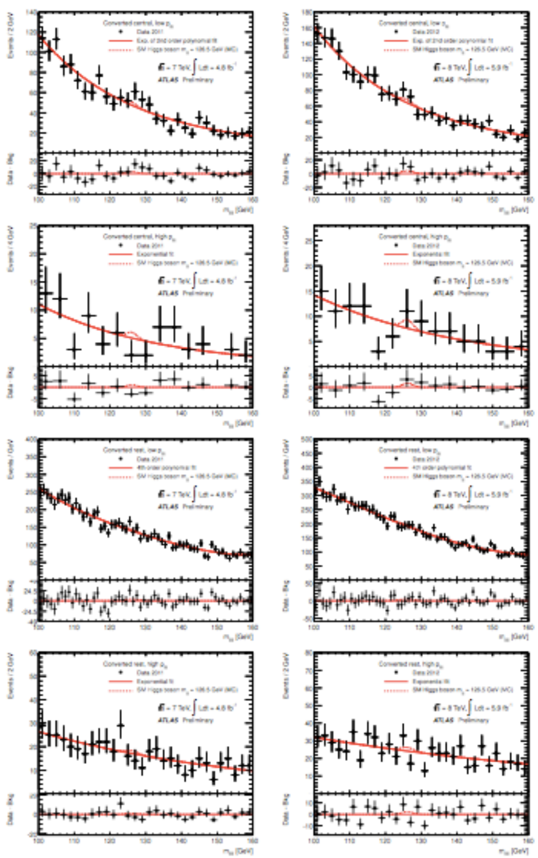


Signal Strength of each category

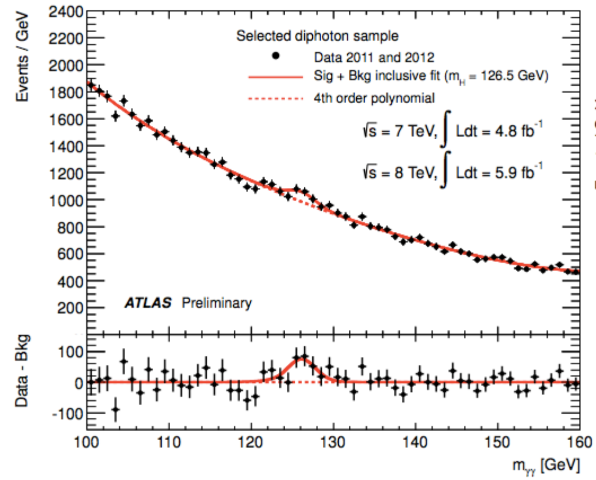


Higgs → γ γ :: Results II

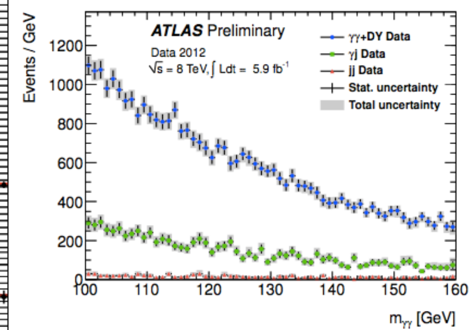
From each category a mγγ dist



Inclusive m γγ

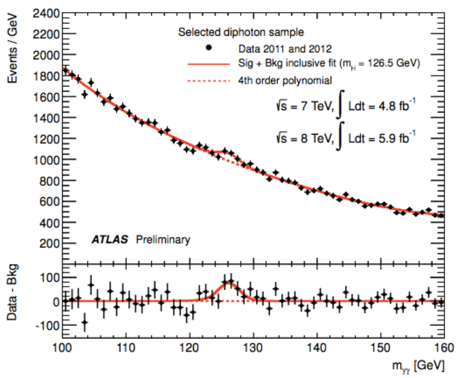


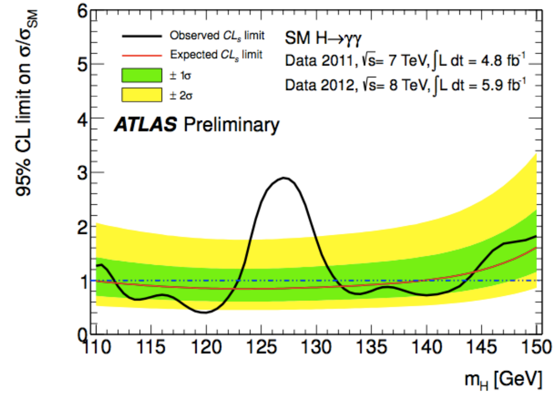
Bkg decomposition in 2012

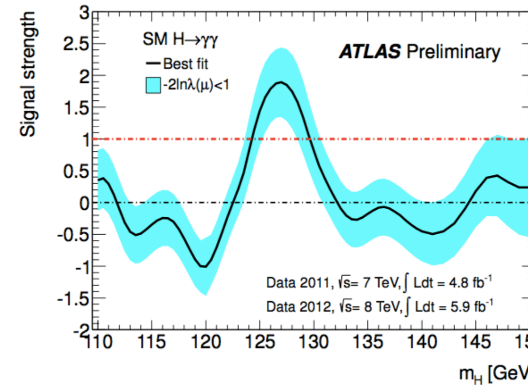


- Background is parametrized using function flexible enough to describe shape well but with limited parameters such that it is not unconstrained
- The model used is tailored to the shape in each category (exponential, Bernstein polynomial, etc…)
- Signal is described by CB + broad gaussian to account for detector resolution effects
- Background decomposition is also studied using data-driven methods

Higgs → γ γ :: Results III



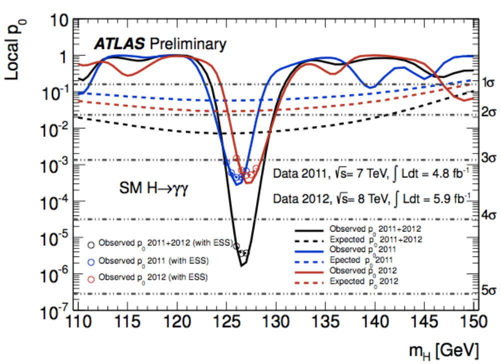


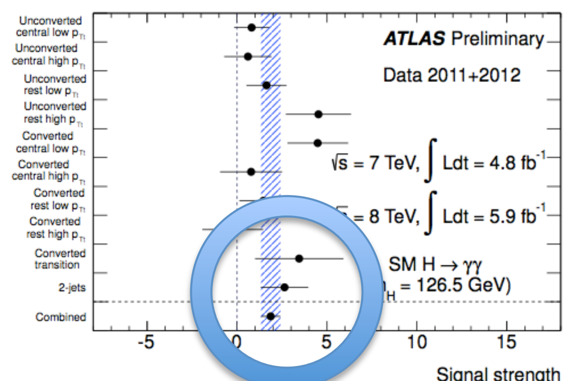


Local p0 value lowest at 126.5 with a value of $2x10^{-6}$ and local significance of 4.5 σ

SM Higgs excluded in ~112 < mγγ < 145 [GeV] region except in 122.5 < mγγ < 132 [GeV]

Best fit of signal strength μ is at 126.5 with 1.9 σ strength



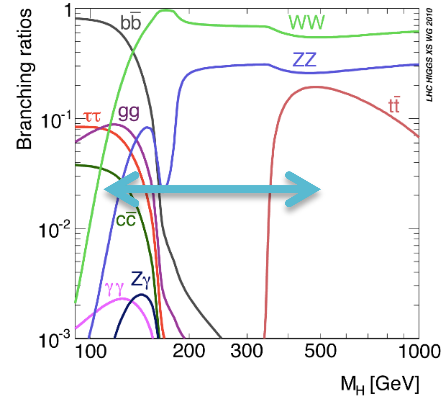


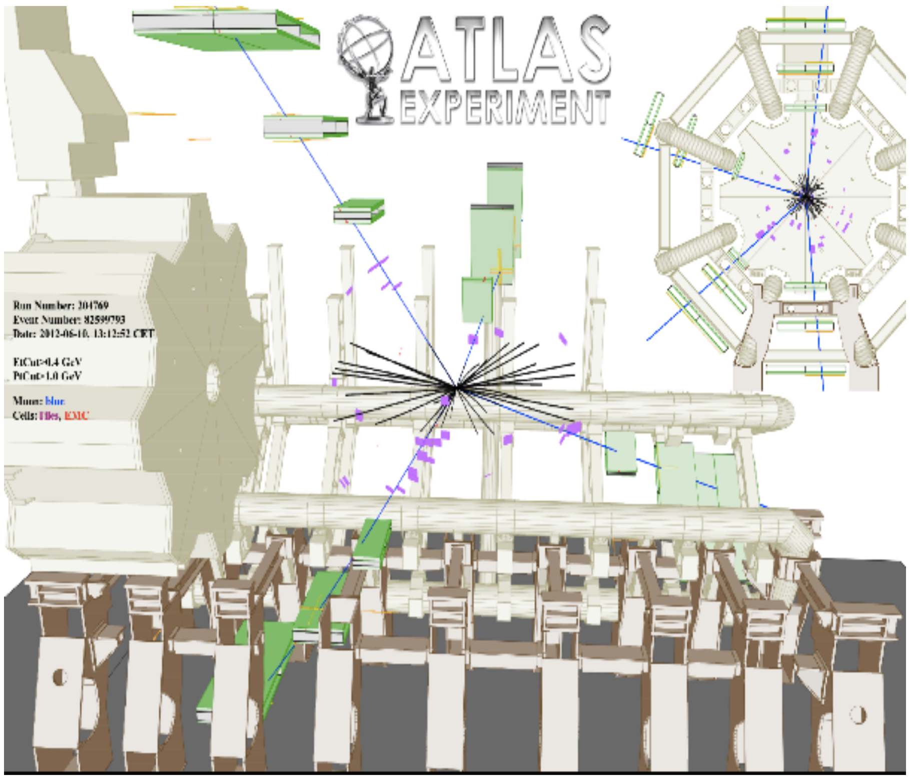
Caution : Signal strength is with respect to SM Higgs, where the ggH, 2-jet, HZ,HW productions are assumed…

Despite low events, 2-jet (VBF enriched) category has high signal strength

H→ ZZ → 4l Channel :: Event signature

H->ZZ-> 4 muon candidate



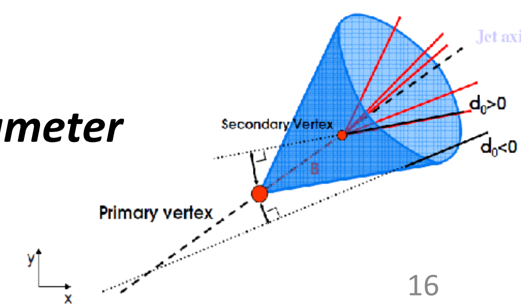


- ***Essentially select 4 isolated leptons such that one or two pair invariant mass is close to Z mass***
- ***Same flavour, opposite charge pairs***

Selection	Original	Optimised
Lepton p_T (e/μ)	20,20,7,7	20,15,10,7/6
m_{12} selection	$\|m_{12}-m_Z\|<15$	$50<m_{12}<106$

$m_{4\ell}$ (GeV)	≤120	130	150	160	165	180	≥190
m_{34} threshold (GeV)	17.5	22.5	30	30	35	40	50

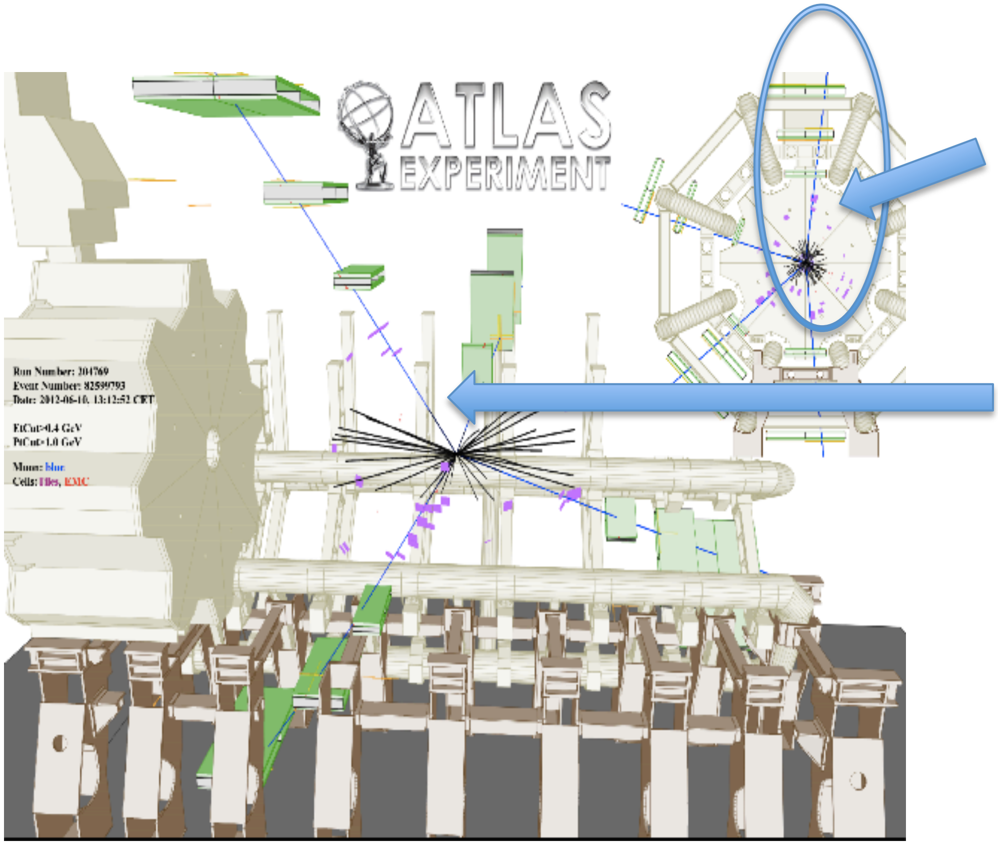
- ***Cut on impact parameter***



Main background : SM ZZ*, Zbb…

H→ ZZ → 4l Channel :: muon ID

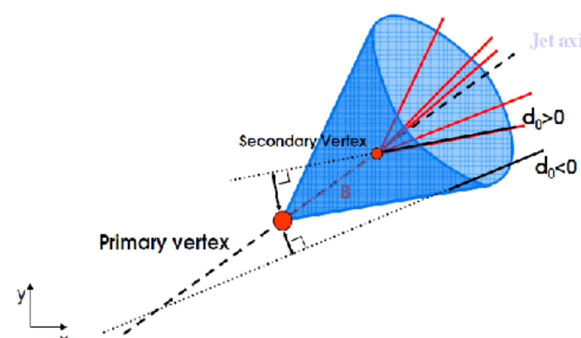
H->ZZ-> 4 muon candidate



Signal signature for single muons

- **Match between ID and MS tracks**
- **pT reconstructed by combining ID and MS track info (cut on pT > 6 GeV)**

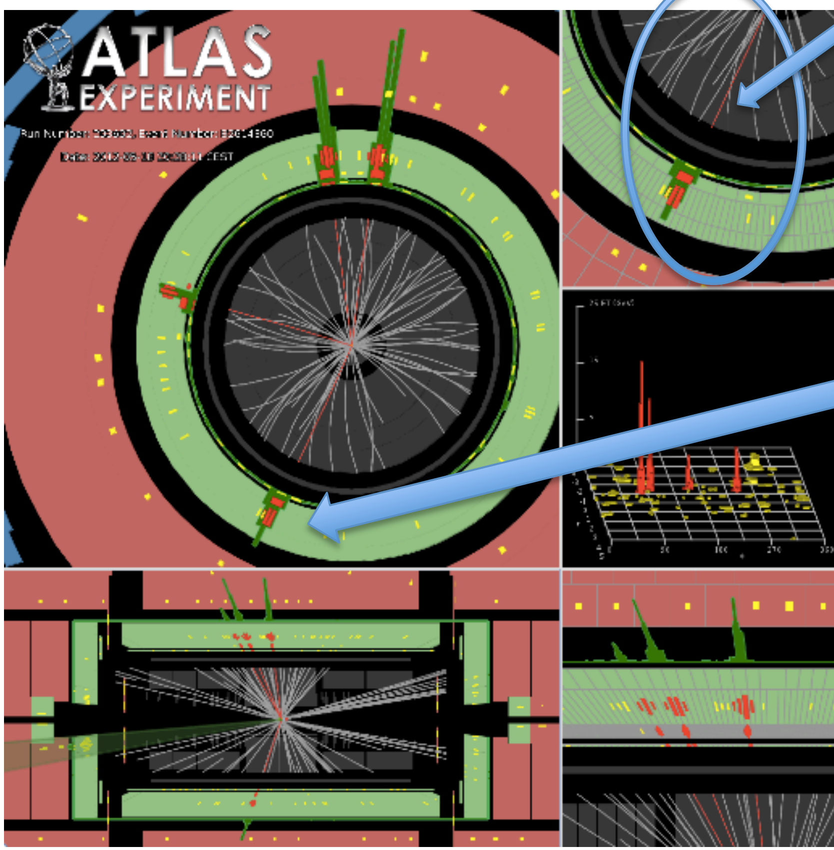
- **Track isolation (sum of pT of all tracks in a cone around the electron track must be below certain threshold):**



Main background : SM ZZ*, Zbb…

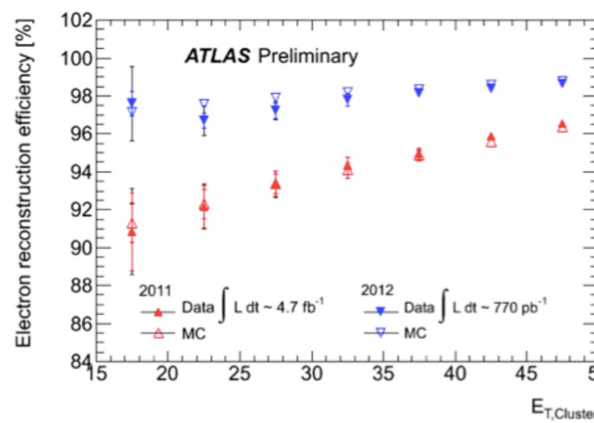
H→ ZZ → 4l Channel :: electron ID

H->ZZ-> 4 electron candidate



Signal signature for single electrons

- **EM Cluster match to ID track**
- **pT reconstructed from track direction at vertex and energy in Lar (cut on pt > 7 GeV)**
- **EM shower shapes must match those expected for electrons**
- **Track isolation (previous slide)**
- **Calorimeter isolation (sum of Et of all topoclusters in calorimeter – similar to photon isolation in previous slide)**



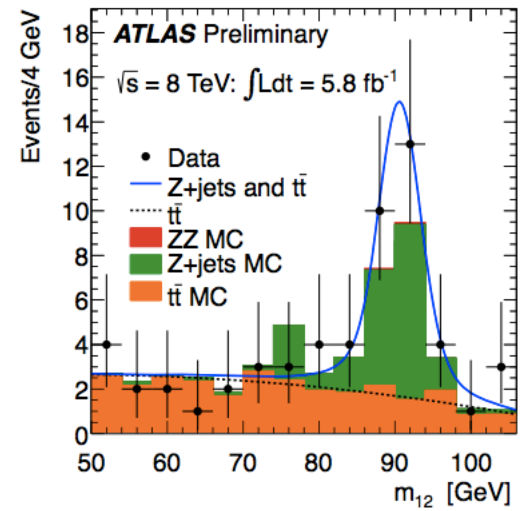
Main background : SM ZZ*, Zbb…

- **ID efficiency robust to pileup**

H→ ZZ → 4l Channel :: Background estimates

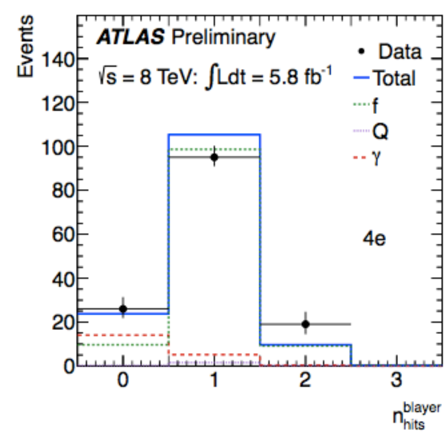
ZZ → ee + muon muon channel

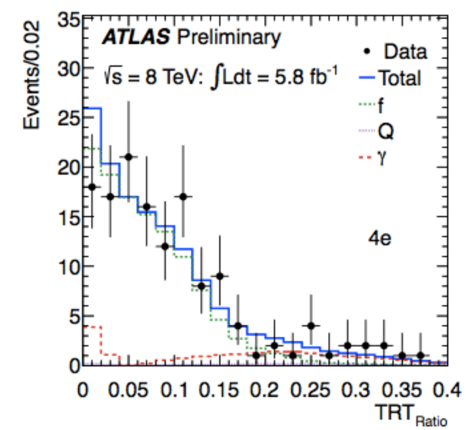
- No isolation (leading lepton) and reverse impact parameter (for another lepton)
- Fitted background is extrapolated to signal region using MC



ZZ → ll + ee

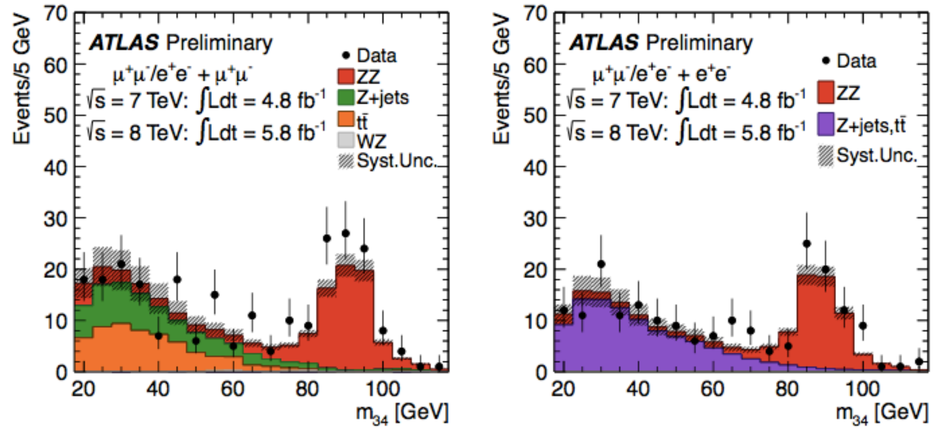
- Electrons can be faked by jets, photon conversions, and heavy flavour semi-leptonic decays → Dedicated studies for each case.
- The cuts in one of the electrons are loosened and b-layer hits, TRT hits are fitted using MC templates



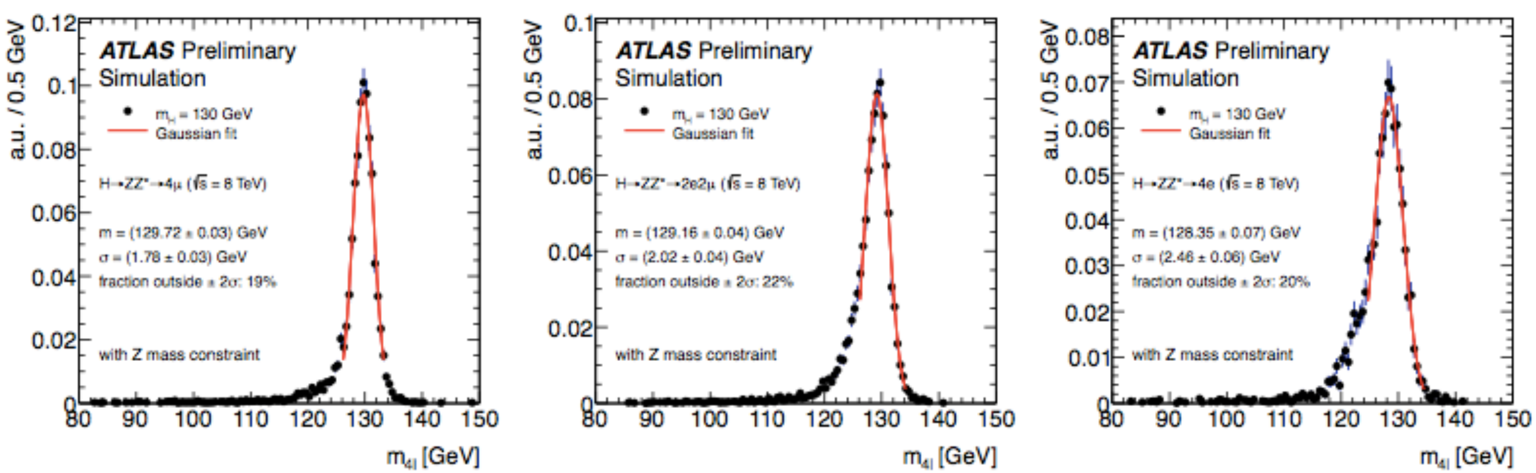


H→ ZZ → 4l Channel :: Background II and Signal resolution

- *Invariant mass of pairs well described at low and high pT*
- *Control samples obtained by relaxing isolation and impact parameter as described in previous slide*

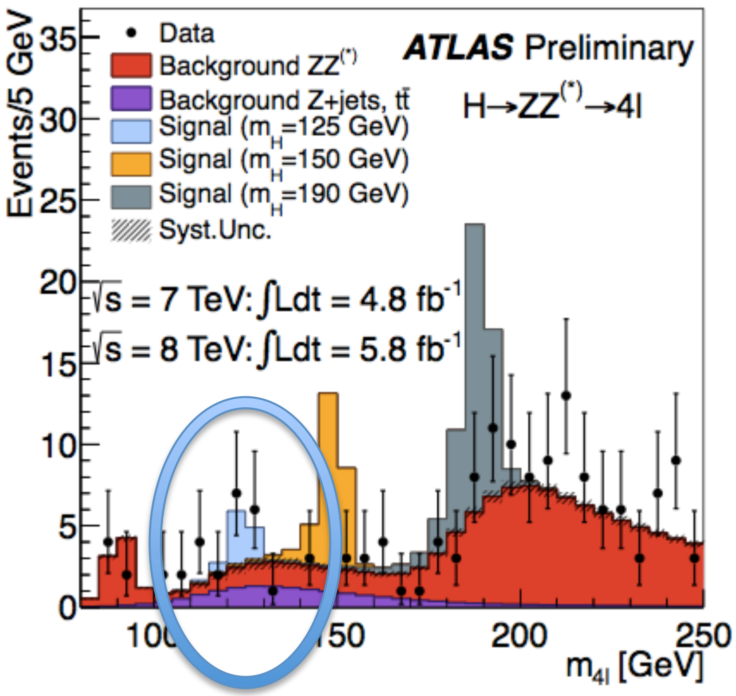


- ***Basically all that is left to do is reconstruct invariant mass and look for a peak***
- ***Good invariant mass resolution***

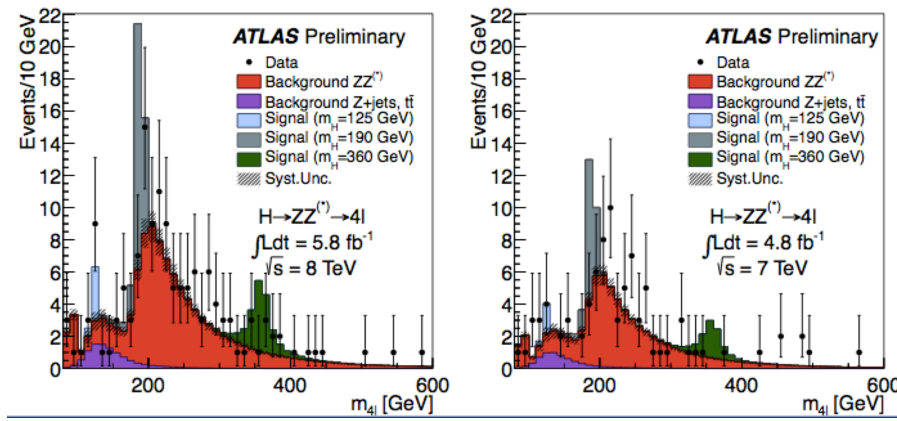


H→ ZZ → 4l Channel :: Results I

→ Excess observed at ~125 GeV, while no excess is observed in the range: 131 < m4l < 460 [GeV] is essentially excluded



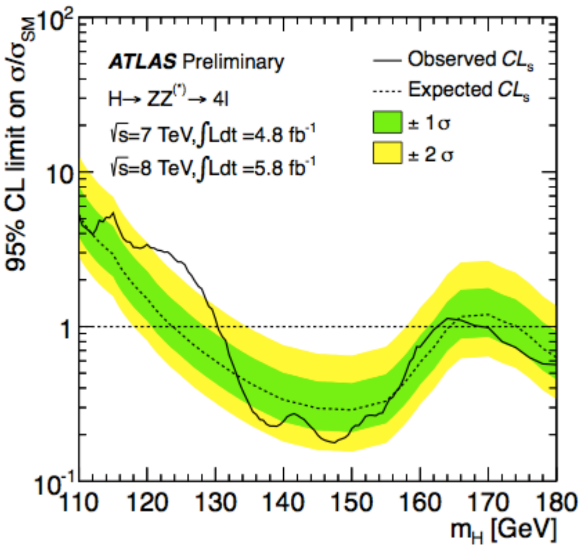
- Separately for 2011 and 2012, over the whole invariant mass range

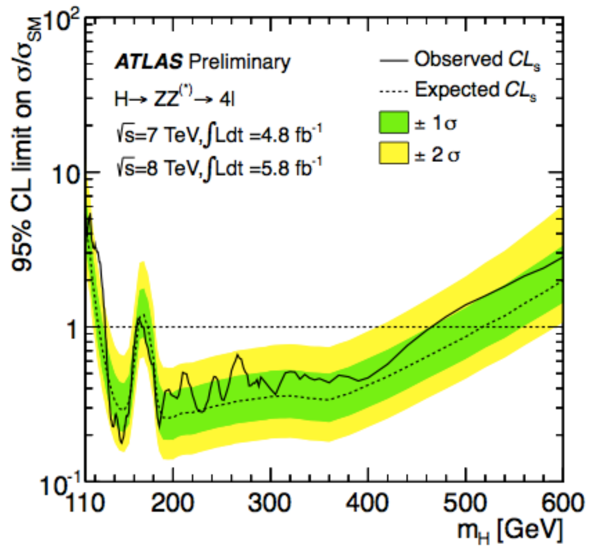


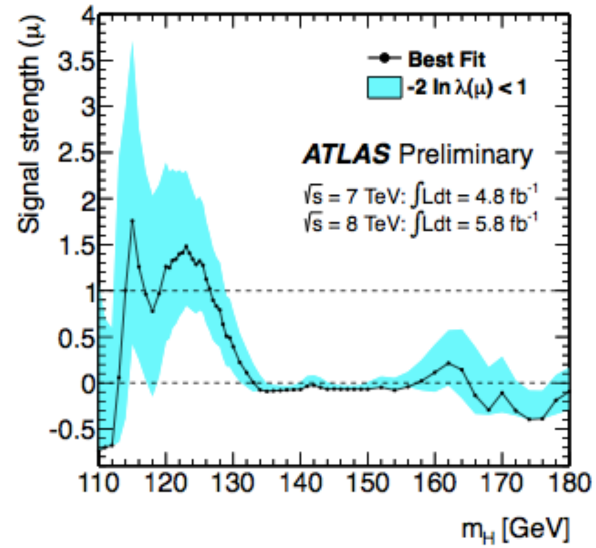
- Event counts of signal and expected background in range 120 < m4l < 130 [GeV]

7+8 TeV	4μ	2e2μ	4e
Background	1.3±0.1	2.2±0.2	1.6±0.2
Data	6	5	2
m_H=125 GeV	2.1±0.3	2.3±0.3	0.9±0.1
S/B	1.6	1.0	0.6

H→ ZZ → 4l Channel :: Results II

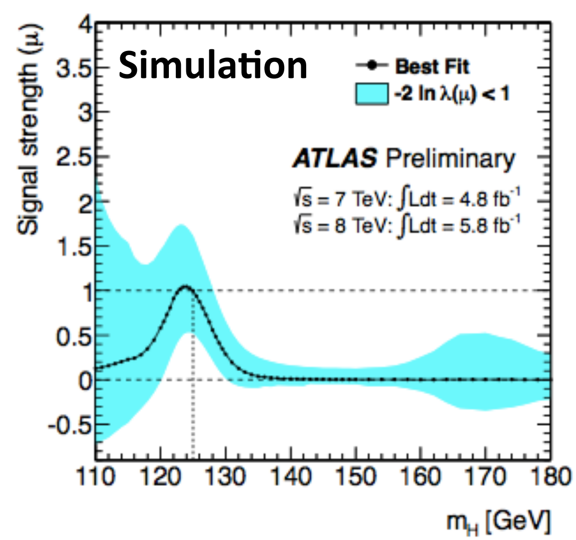




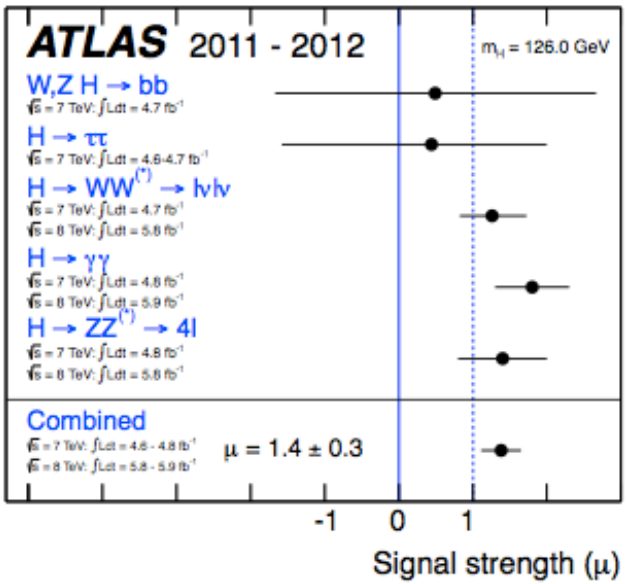


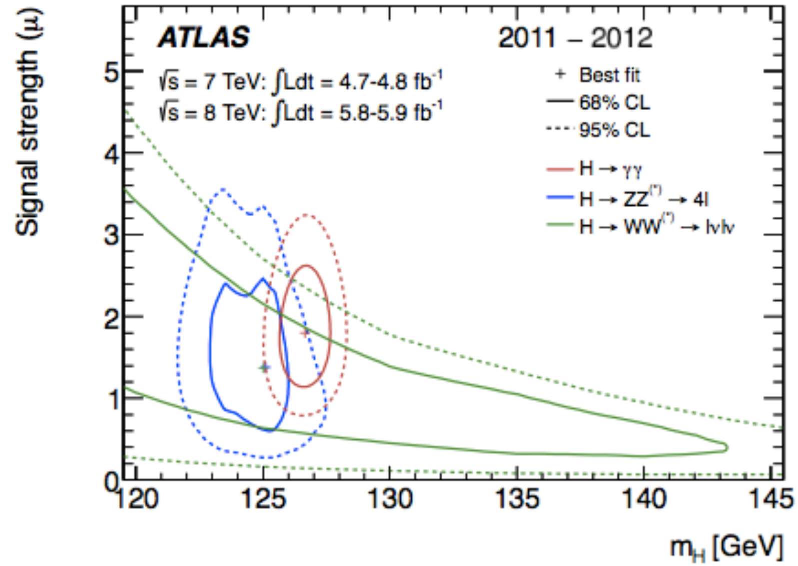
- Golden channel single-handedly excludes large m_H range while revealing an excess at ~125 GeV

- The excess is (slightly) larger than what would be expected from a SM Higgs, but consistent with errors



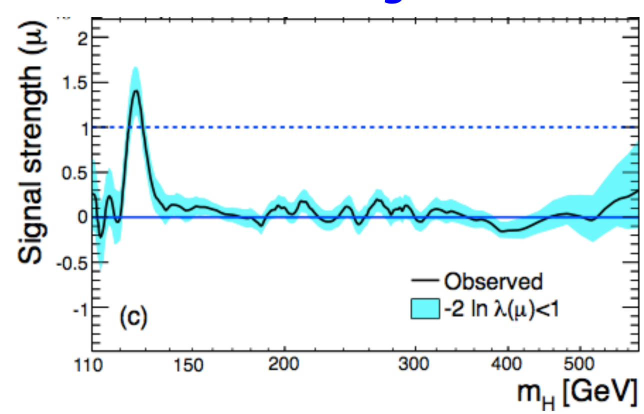
Back to combined results http://arxiv.org/ps/1207.7214v1





→ Other channels also contribute to combination with varying strengths

→ Results of H→ γγ and H→ 4l are consistent within 2 sigma

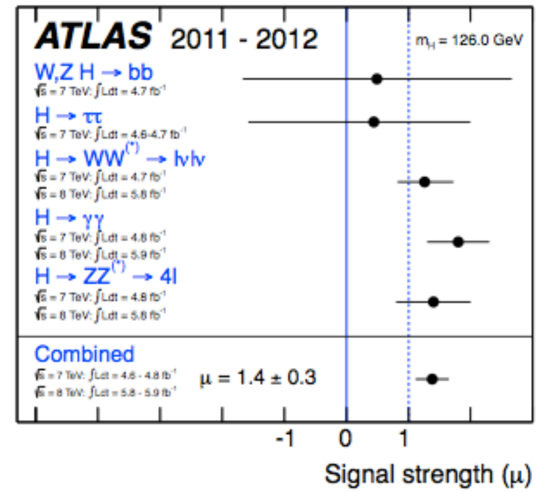


Resonance has been established at 126.5 [GeV] with 5σ local significance

Expected SM local significance is 4.6σ

Next steps – measure properties of particle I

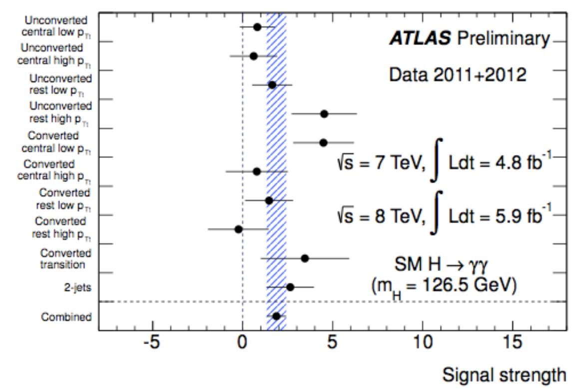
First steps



- ***Improve mass measurement***
  → Improve energy calibration of electrons and photons

- ***Measure cross section x branching ratio***
  → Improve photon and electron ID efficiency

Constrain couplings



- ***Improve measurement of signal strength*** *for different final states*

- ***Improve sensitivity to different production modes***

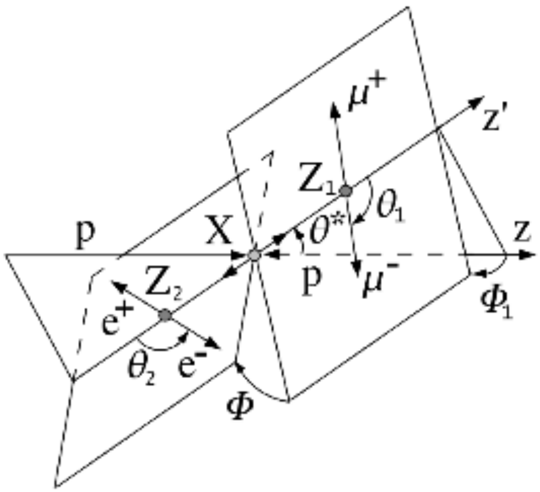
Next steps – measure properties of particle II

- *Dermine Spin and CP of resonance*

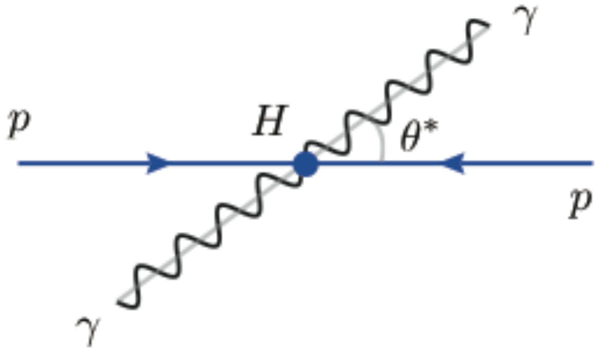
→ ***SM*** → ***Spin = 0, Scalar***
→ ***MSSM*** → ***Can be CP-odd scalar particle***

→ ***Note that decay in 2-photon channel indicates Spin = 0, 2 and decay into 2 fermions indicates Spin = 0, 1 → some indication that Spin = 0***

We can define angles in H→ 4 lepton that are sensitive to both CP and Spin



In H→ 2 gamma channel theta gives Spin



Next steps – determine properties of particle III

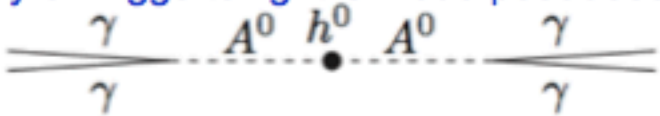
Other properties will likely take longer…

- ***Set limits on resonance width → requires very good knowledge of energy resolution***
- ***Higgs self-coupling (low cross section)***
- ***Running of Higgs coupling ?***

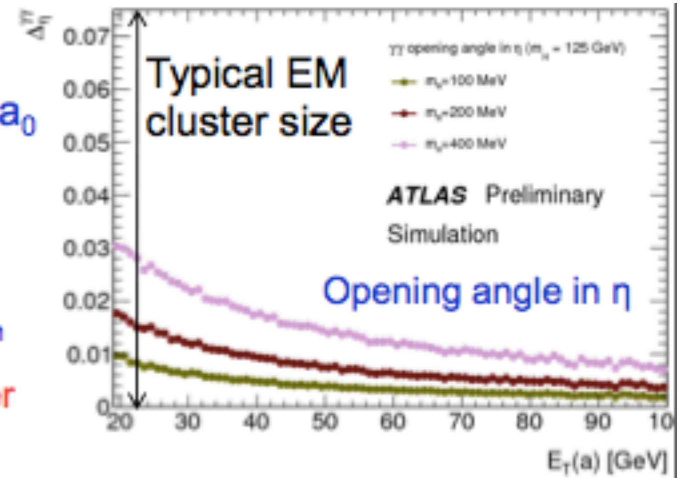
IMPUT FROM THEORETICAL COMMUNITY IS VERY IMPORTANT AT THIS POINT… ! ☺

Next step – Possible hidden processes in signal

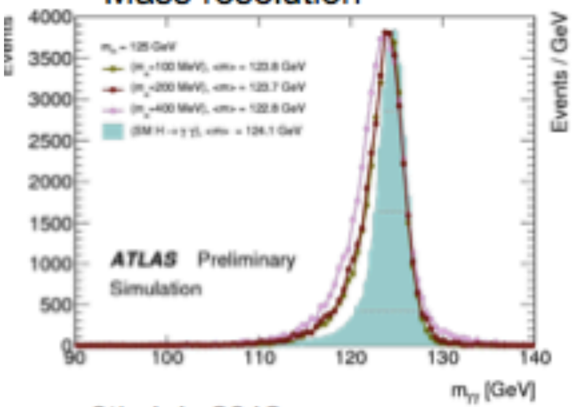
- Interest in other models with similar signature
  - Decay of Higgs to light CP-odd pseudoscalars $H \to a_0 a_0$



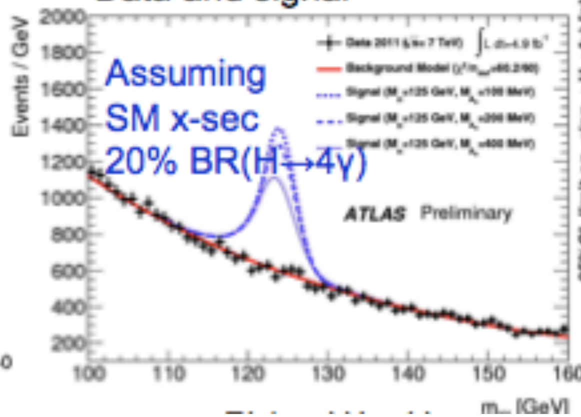
  - a_0 decays to two very collimated photons with small separation, mimics $H \to \gamma\gamma$ with slightly degraded resl^n
    - Relax photon identification for broader (merged) shower
    - Applicable for a_0 decays <~0.5m, 100<m(a_0)<400 MeV
  - No signal observed, set limits on $\sigma \times BR(H \to 4\gamma)$



Mass resolution



Data and signal



Limit with m_a=200 MeV