Measurements of the properties of the Higgs boson in the four lepton decay channel with the ATLAS detector

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Introduction

Discovery in July 2012 via bosonic channels (Phys. Lett. B716):

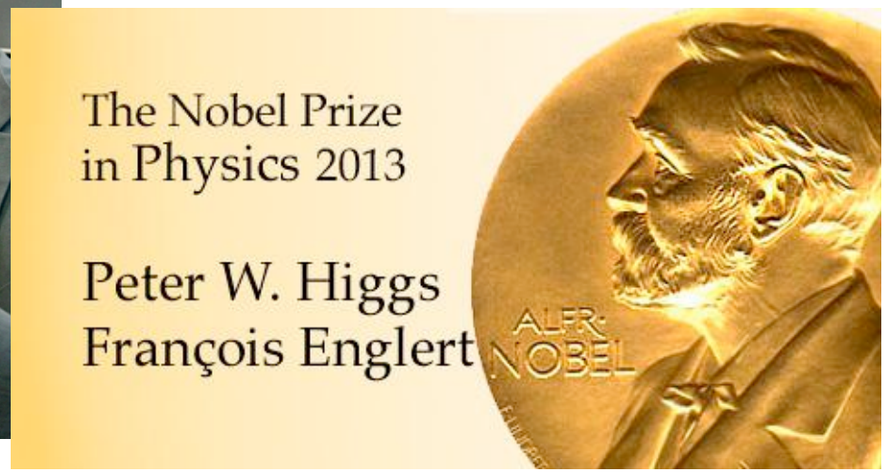
$H \rightarrow ZZ^* \rightarrow 4\ell$, $H \rightarrow \gamma\gamma$, $H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$

Property measurement (Phys. Lett. B726):
- Production and coupling measurement
- Spin / CP

New combined mass measurement with

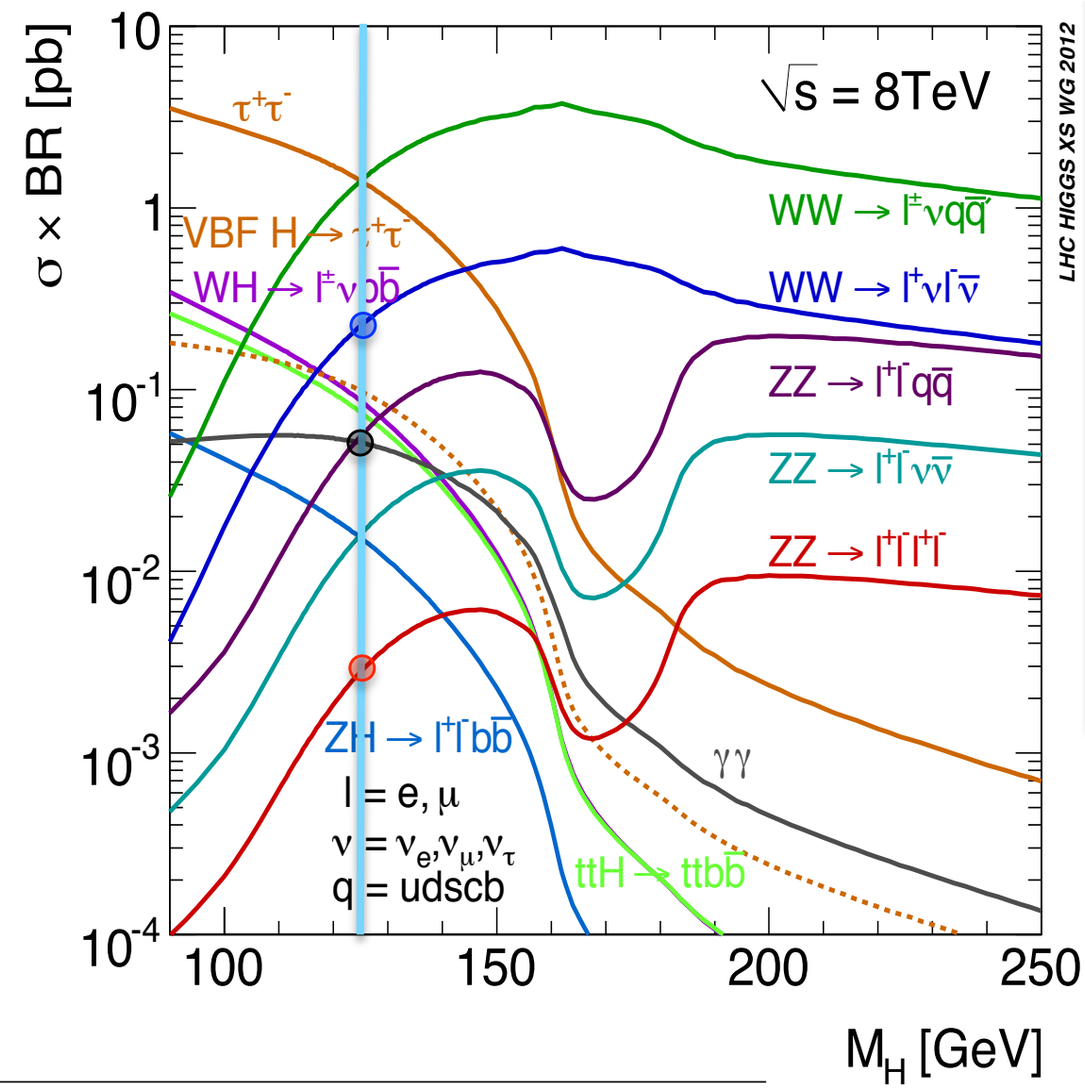
$H \rightarrow ZZ^* \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$

(submitted to Phys. Review D)



The Golden Channel

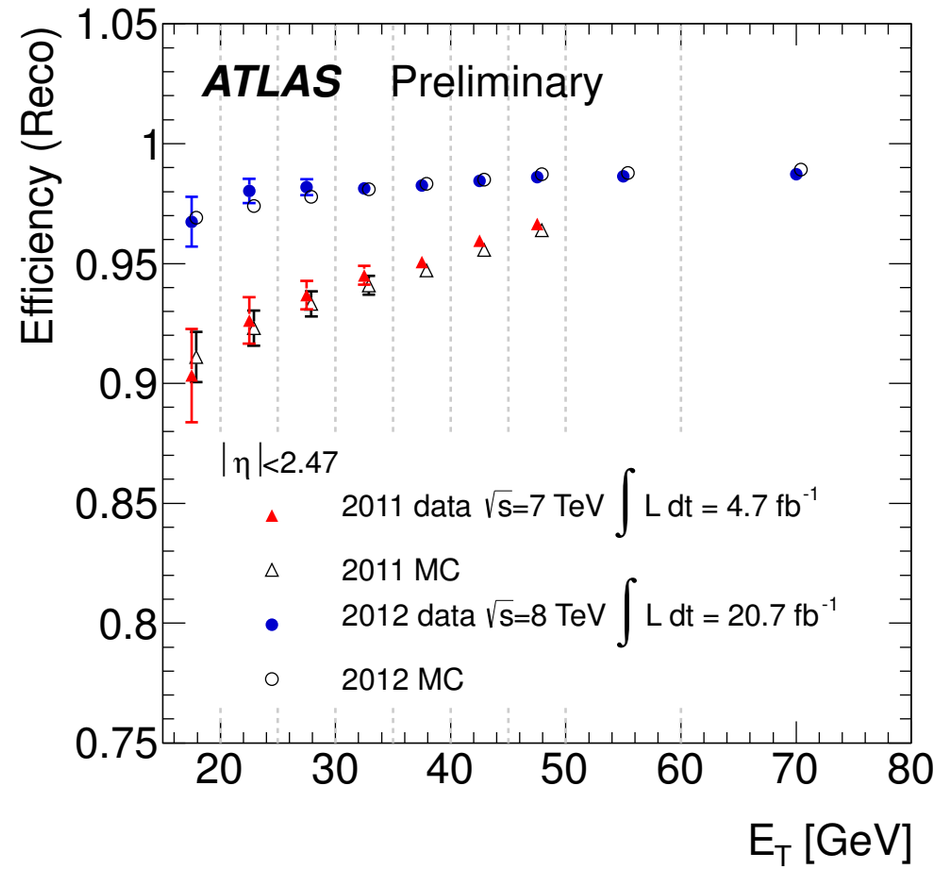
- S/B ~ 2 in mass window 120–130 GeV
- Excellent mass resolution: 1.6 (2.2) GeV 4μ (4e) final state
- Very low $\sigma \cdot$ BR ~ 2.9 fb for m_H=125.5 GeV @ 8 TeV
- Recent improvements in analysis
  - likelihood method for electron identification
  - MVA-based electromagnetic calibration
  - E/p combination
  - BDT for ZZ* discrimation



Final state	Signal full mass range	Signal	ZZ^*	Z + jets, $t\bar{t}$	s/b	Expected	Observed
			$\sqrt{s}$ = 7 TeV and $\sqrt{s}$ = 8 TeV				
4μ	6.80 ± 0.67	6.20 ± 0.61	2.82 ± 0.14	0.79 ± 0.13	1.7	9.81 ± 0.64	14
$2e2\mu$	4.58 ± 0.45	4.04 ± 0.40	1.99 ± 0.10	0.69 ± 0.11	1.5	6.72 ± 0.42	9
$2\mu 2e$	3.56 ± 0.36	3.15 ± 0.32	1.38 ± 0.08	0.72 ± 0.12	1.5	5.24 ± 0.35	6
$4e$	3.25 ± 0.34	2.77 ± 0.29	1.22 ± 0.08	0.76 ± 0.11	1.4	4.75 ± 0.32	8
Total	18.2 ± 1.8	16.2 ± 1.6	7.41 ± 0.40	2.95 ± 0.33	1.6	26.5 ± 1.7	37

Event Selection (1)

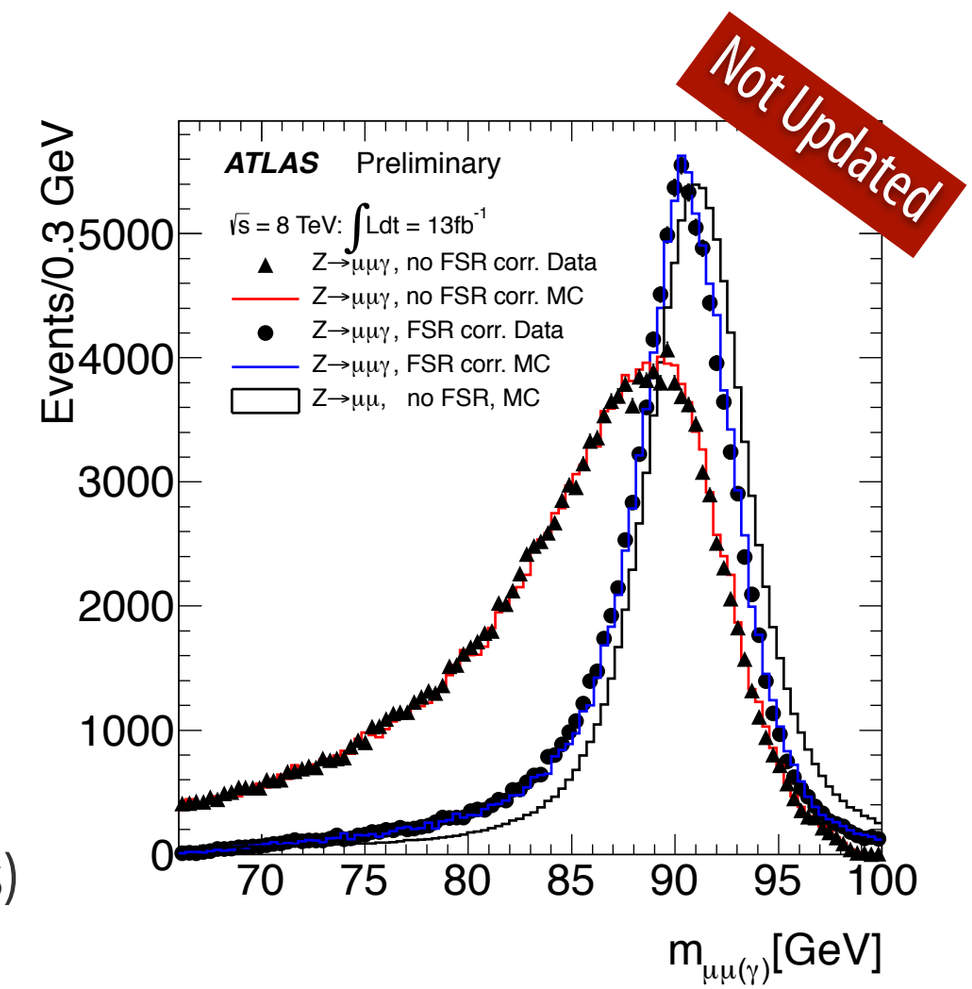
- Electrons:
  - E_T>7 GeV, |η|<2.47
  - improved reconstruction algorithm with higher efficiency in 2012
  - likelihood-based selection (cut-based for 7 TeV)
- Muons:
  - p_T>6 GeV, |η|<2.7
- Quality and cleaning cuts; e-e, e-μ, e-jet overlap removal
- Quadruplets: 2 SF OS lepton pairs
  - p_{T1}>20 GeV, p_{T2}>15 GeV, p_{T3}>10 GeV
- Single- and dilepton trigger object(s) matched to the lepton(s)



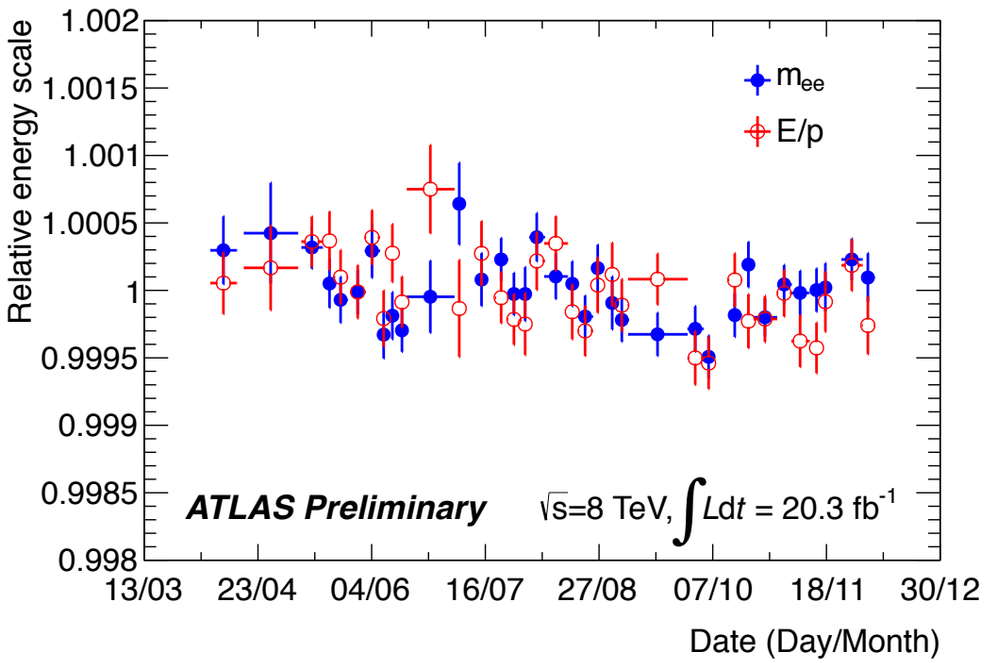
Event Selection (2)

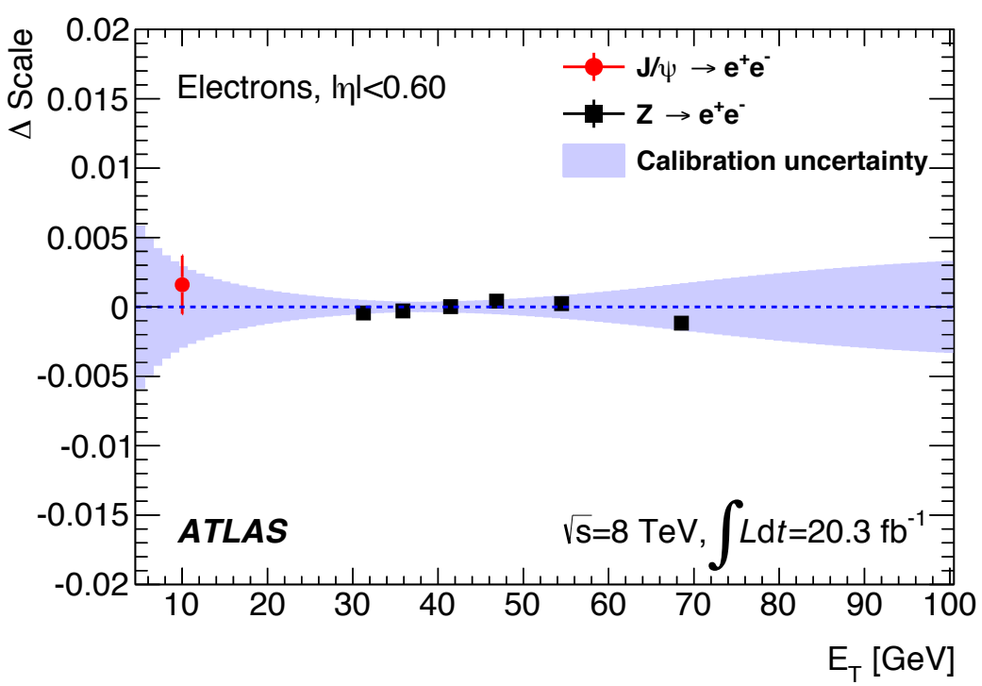
- Select lepton pair with the mass closest to the Z boson mass : Z_1
  - Leading pair: $50 < m_{12} < 106$ GeV
- Among remaining pairs, select the next-closest to m_Z : Z_2
  - Subleading pair: $m_{min} < m_{34} < 115$ GeV, $m_{min} = 12$ (50) for $m4l \leq 140$ (≥ 190) GeV
- $\Delta R > 0.1$ (0.2) between same (opposite) flavour leptons
- Relative track isolation in cone $\Delta R = 0.2$: $I_{track} < 0.15$
- Relative calorimeter isolation in cone $\Delta R = 0.2$: typically $I_{calo} < 0.3$
- $|d_0/\sigma(d_0)| < 3.5$ (6.5) for muons (electrons)
- FSR recovery
  - collinear FSR for leading dimuon pairs (~4% of events)
  - far FSR with high E_T for leading dimuon and dielectrons (~1% of events)

Overall accepance
for $m_H = 125$ GeV @ 8 TeV:
39% 4μ, 27% 2e2μ and 20% 4e



New electron calibration

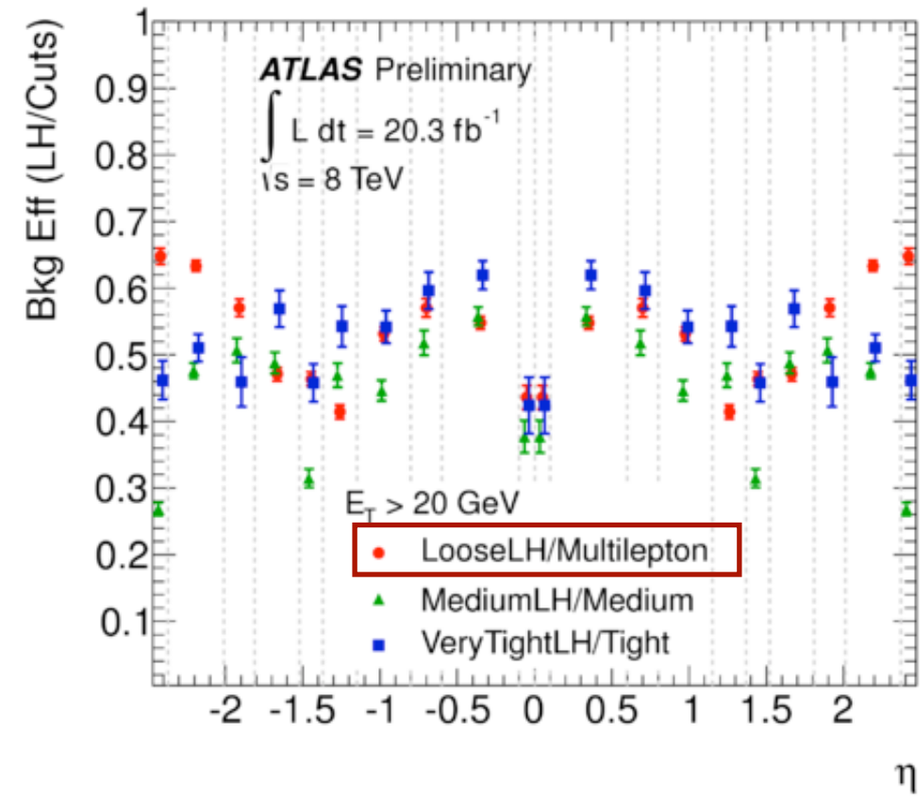


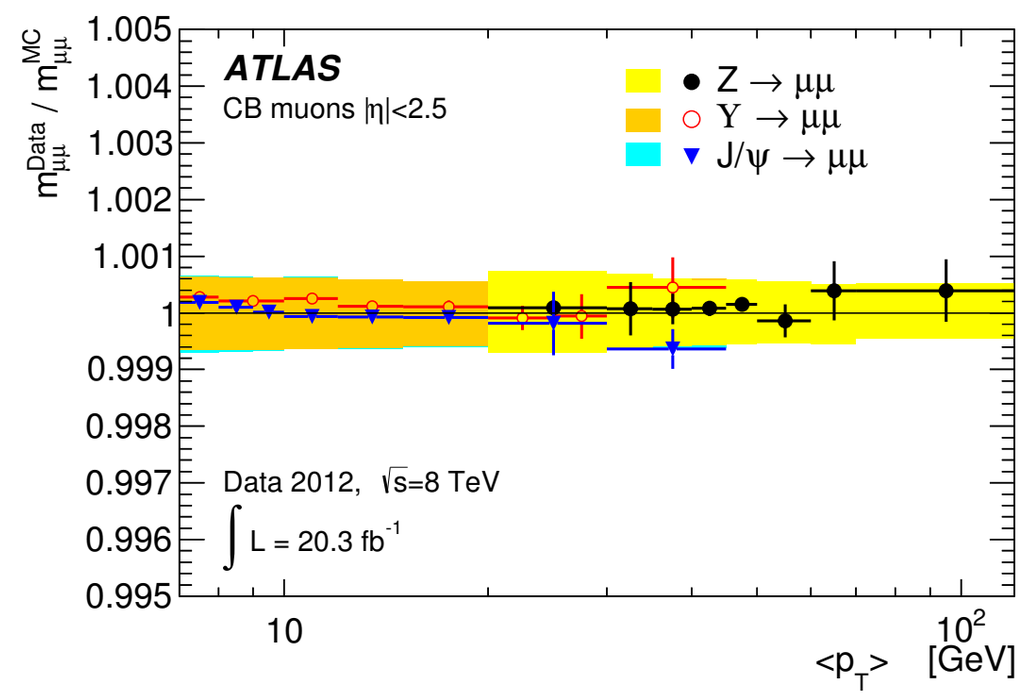


- Intercalibration of calorimeter layers using Z → μμ events
  - 1-2% for EM layers 1 & 2
- Accurate knowledge of material in front of EM calorimeter
  - Constrain inactive material (2-5 X_0) to ~2-10% X_0
- EM cluster energy correction via MVA regression
- Energy scale and resolution extracted with Z → ee and J/ψ → ee
  - Good data/MC agreement after corrections
- Response stable at ~0.05% vs time and pileup

Leptons improvements

- New electron likelihood-based identification selection
  - same signal efficiency as cut-based
  - improves rejection of light-flavor jets and photon conversions by a factor ~2
- New electron combined fit of the track momentum and cluster energy
  - for $E_T < 30$ GeV and when track momentum and cluster energy are consistent
  - improves m4ℓ resolution in 4e and 2μ2e channels by ~4%
- Improved muon momentum scale and resolution corrections
  - determined using $Z \to \mu\mu$ and $J/\psi \to \mu\mu$, checked with $\Upsilon \to \mu\mu$
  - momentum scale uncertainties: 0.05% in barrel, up to 0.2% for $|\eta| > 2$

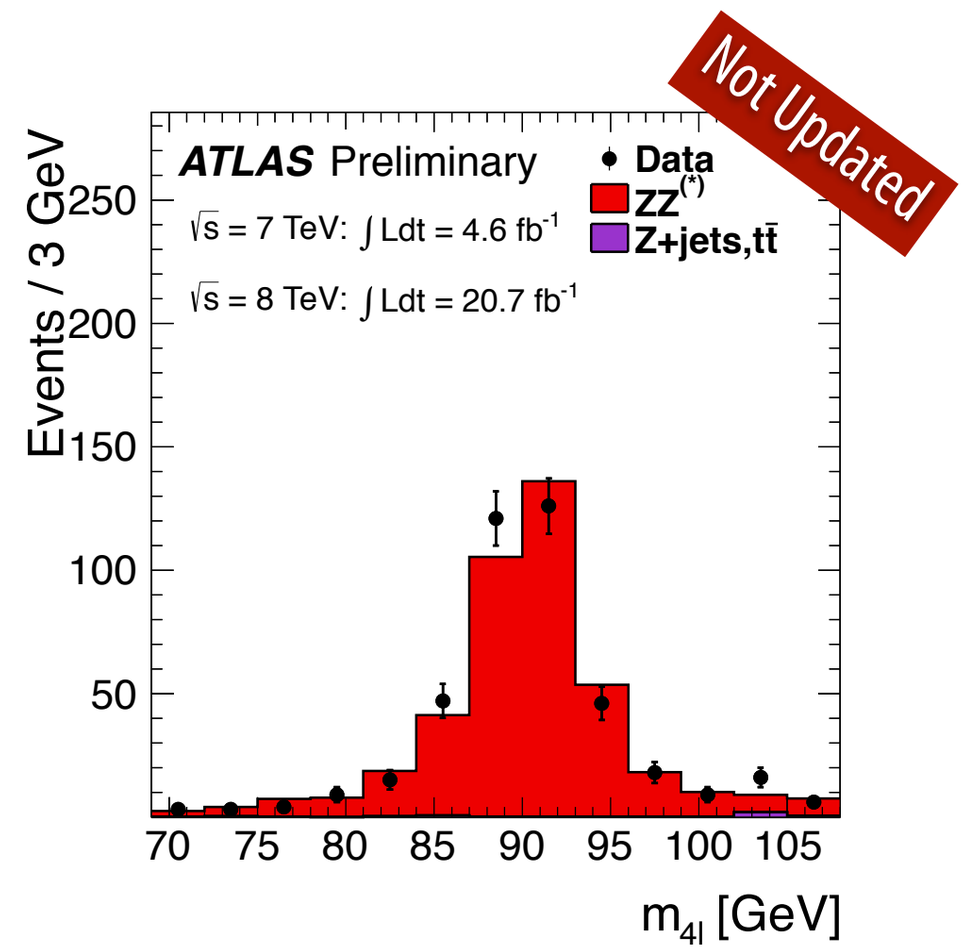




Background estimation (1)

- Irreducible background: ZZ*
  - main source of background
  - estimated from MC (POWHEG+gg2ZZ+SHERPA)
  - normalized to MCFM cross-section

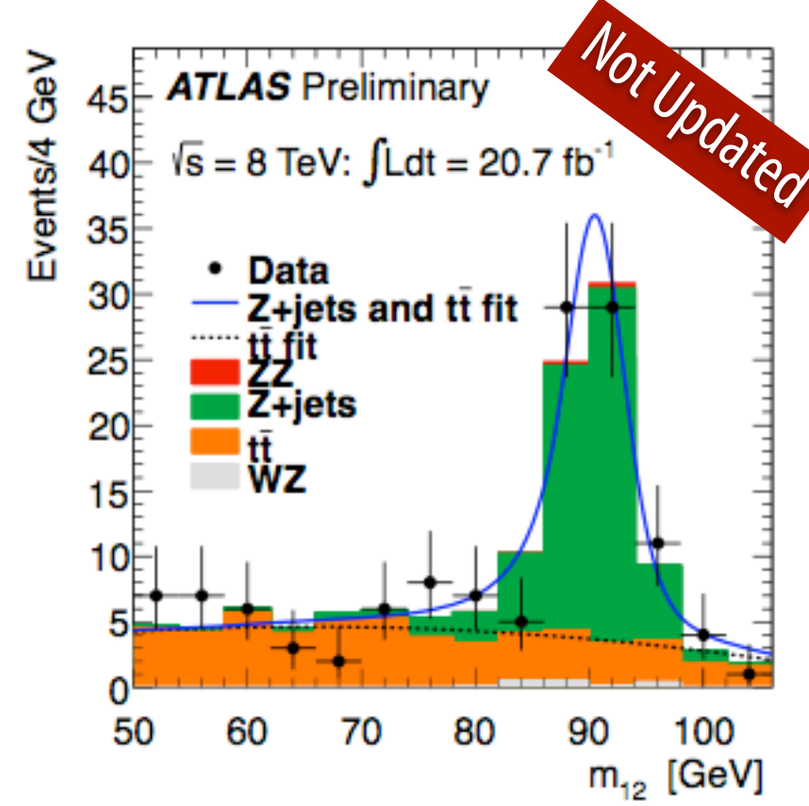
Events in 120-130 GeV:
7.41 ± 0.40



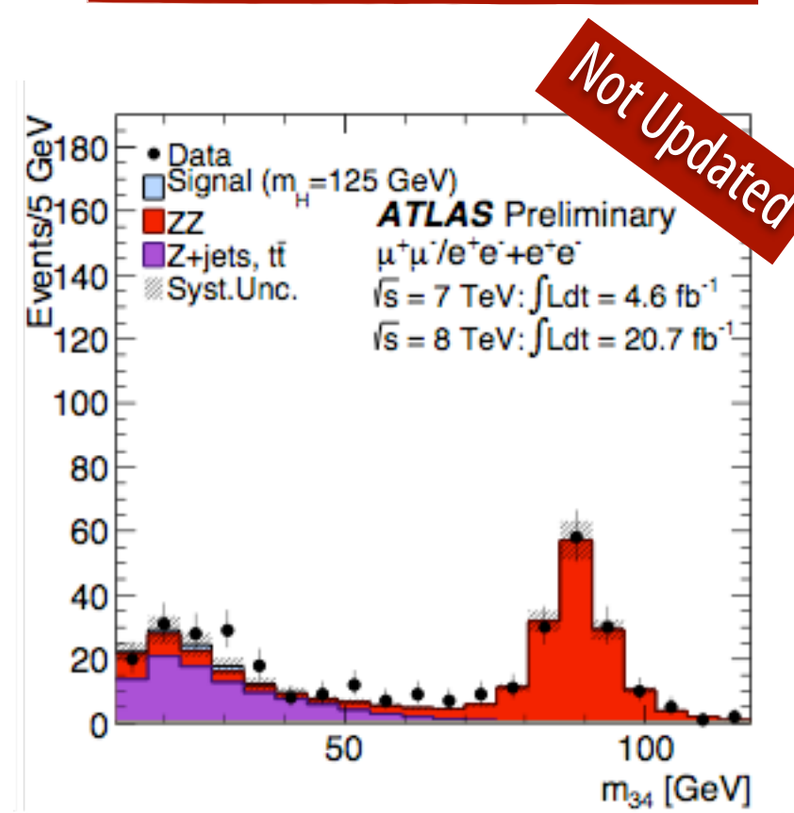
- To reduce impact of the ZZ*background on the fitted mass use BDT discriminant
  - p_T of four lepton system
  - η of four lepton system
  - matrix element based kinematic discriminant $D_{ZZ^*} = \ln\left(\frac{|M_{sig}|^2}{|M_{ZZ}|^2}\right)$

Background estimation (2)

- Reducible backgrounds: Z+jets (including Z+bb) and tt
  - estimated separately for final states with subleading muons and electrons
  - data-driven methods
- $\ell\ell+\mu\mu$ channels
  - Four CRs are fitted simultaneously to extract each component of the reducible background
  - Fitted yields extrapolated to signal region using efficiencies from simulation
  - Small contribution from WZ decays estimated using simulation
- $\ell\ell+ee$ channels
  - $3\ell+X$ CR - full selection on 3ℓ, relaxed ID on X, SS
  - fit to hits in B-layer and TRT threshold
  - fitted yields extrapolated to the signal region using efficiencies from Z+X

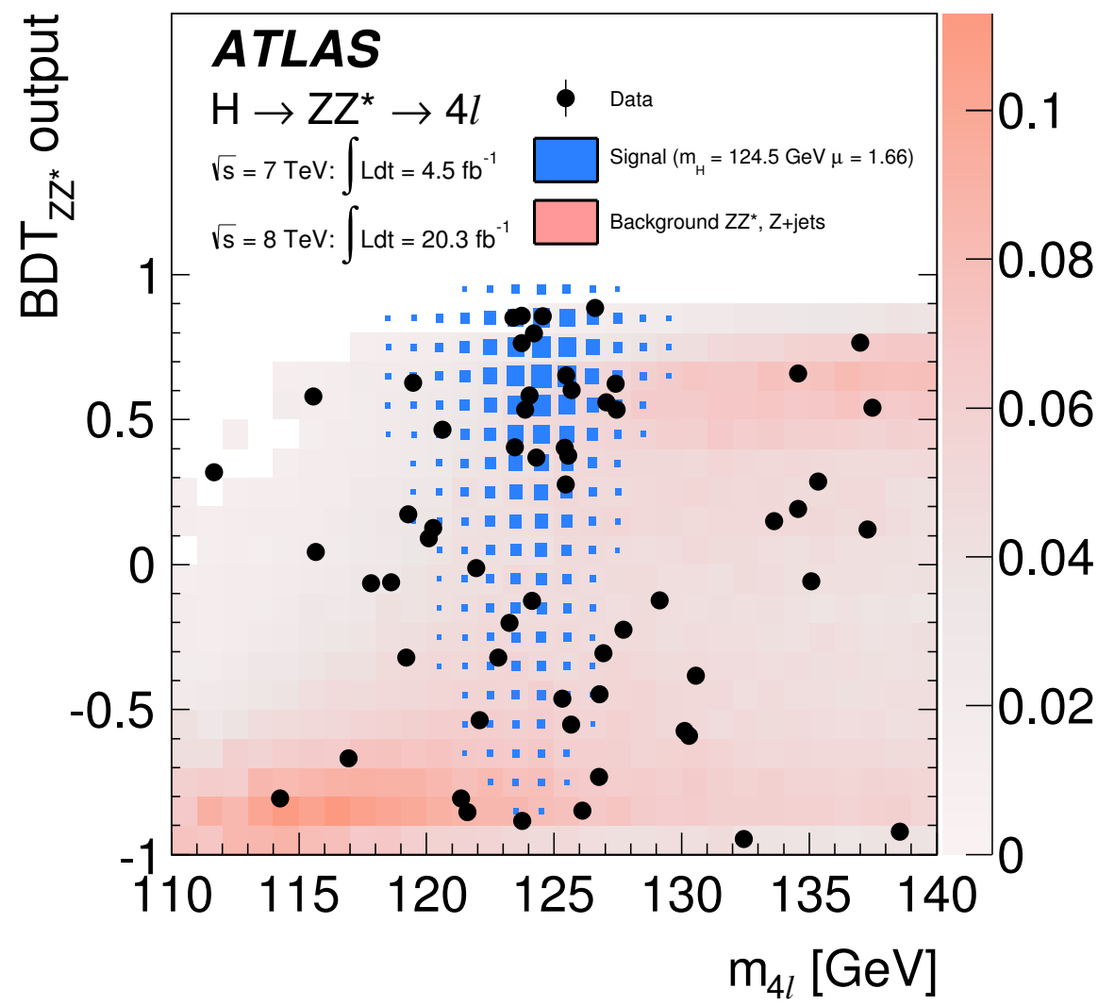


Total estimate in 120-130 GeV: 2.95 ± 0.33

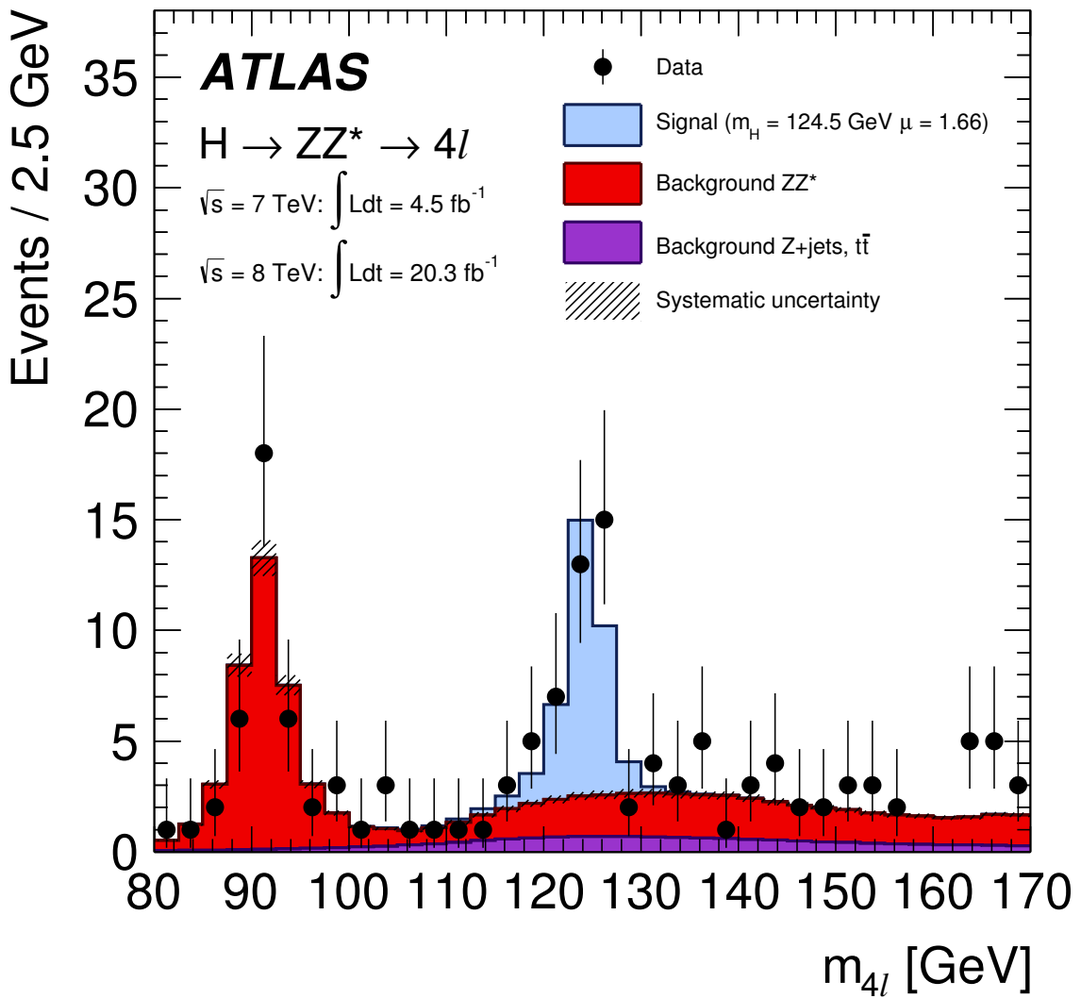


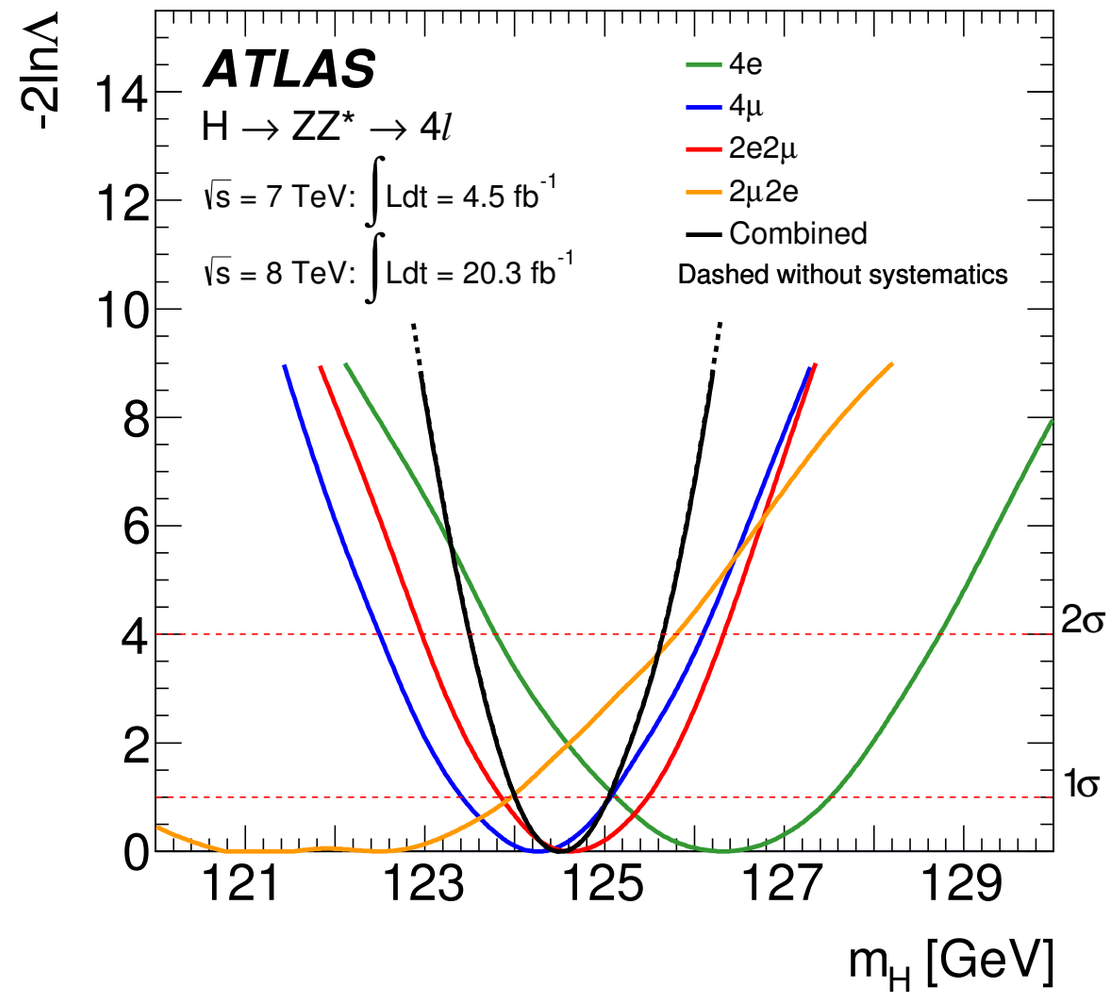
Mass measurement

- Kinematic fit used to constrain m_{Z1} to the Z pole mass within the experimental resolution
  - improvement on the $m_{4\ell}$ resolution of ~15%
- Two-dimensional fit to $m_{4\ell}$ and BDT_{ZZ^*}
  - ~8% improvement over simple $m_{4\ell}$ fit
- Signal model based on smoothed simulation distributions
  - templates parameterized as a function of m_H
- 26.5 events expected, 37 observed



Results



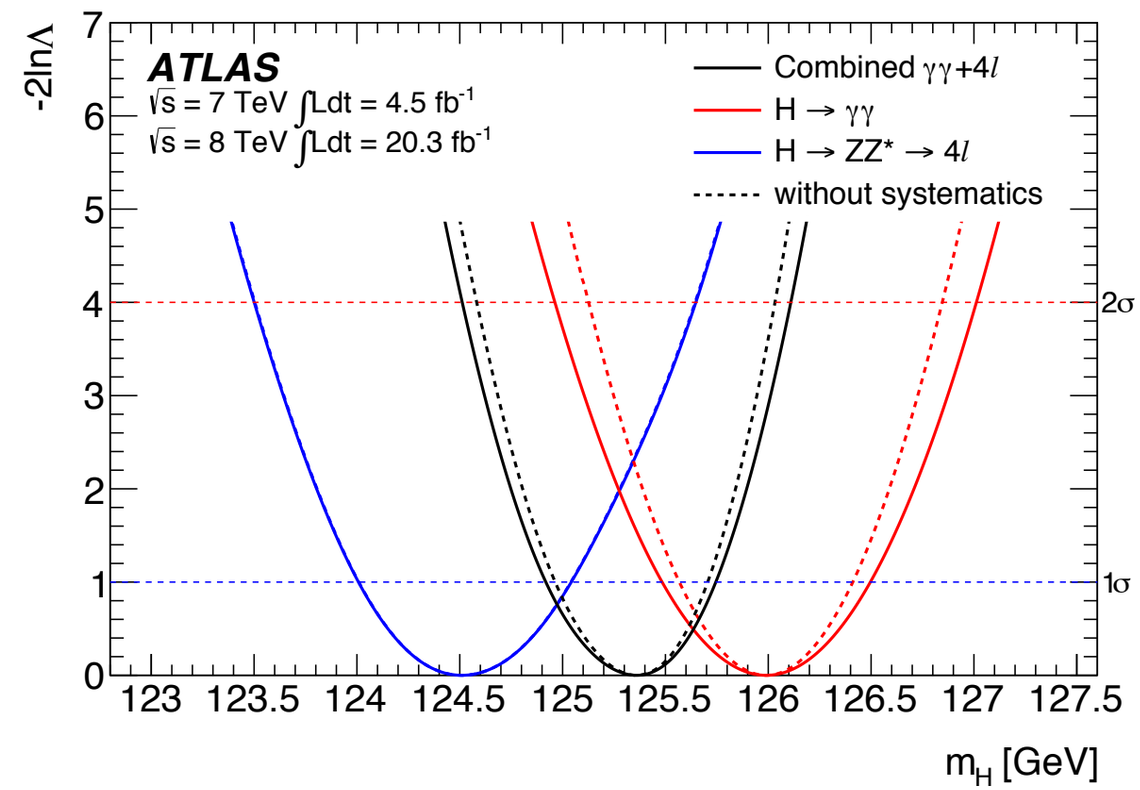


$$m_H = 124.51 \pm 0.52\ (\text{stat}) \pm 0.06\ (\text{syst})\ \text{GeV}$$

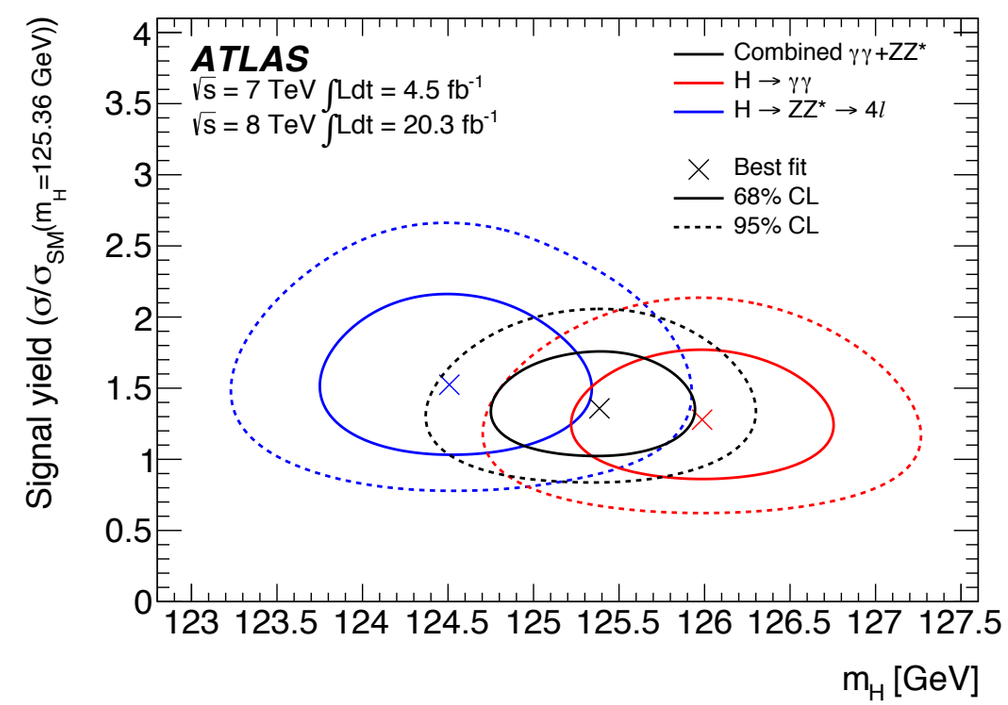
previous result: $m_H = 124.3\ ^{+0.6}_{-0.5}\ (\text{stat})\ ^{+0.5}_{-0.3}\ (\text{syst})\ \text{GeV}$

Combination with H→$\gamma\gamma$

- New mass measurement just made public
- Total uncertainty reduced by ~40%
  - Systematics reduced by factor ~3
- Compatibility between channels: 2σ (4.8%)
  - 2.5σ previously



Channel	Mass measurement [GeV]
$H \to \gamma\gamma$	$125.98 \pm 0.42\,(\text{stat}) \pm 0.28\,(\text{syst}) = 125.98 \pm 0.50$
$H \to ZZ^* \to 4\ell$	$124.51 \pm 0.52\,(\text{stat}) \pm 0.06\,(\text{syst}) = 124.51 \pm 0.52$
Combined	$125.36 \pm 0.37\,(\text{stat}) \pm 0.18\,(\text{syst}) = 125.36 \pm 0.41$



Conclusions

- Analysis improved under many aspects, mainly on lepton performance
  - electron calibration, identification, energy measurement
  - muon calibration and smearing
- New $H \rightarrow ZZ^* \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ combined mass measurement recently released
  - $m_H = 125.36 \pm 0.37$ (stat) ± 0.18 (syst) GeV
  - channels compatible with each other to within 2σ
- Other new results in the $H \rightarrow ZZ^* \rightarrow 4\ell$ channel coming soon
  - Measurements of the inclusive and differential fiducial cross section
  - Measurements of the Higgs boson production and couplings
  - Measurement of the spin/CP properties
- Getting ready for Run II ....

Backup Slides

Other numbers

- Direct Higgs width measurement
  - Event-by-event modelling of detector resolution
  - Per-lepton resolution functions use sum of 2(3) Gaussians for muons (electrons)
  - 95% CL : $\Gamma_H < 2.6$ GeV (exp. limit 6.2 for $\mu=1$)
- Signal strenght: $\mu = 1.66 +0.45 -0.38$
- Old combined mass measurement:
  - $mH = 125.49 \pm 0.24$ (stat) $+ 0.50 -0.58$ (syst) GeV