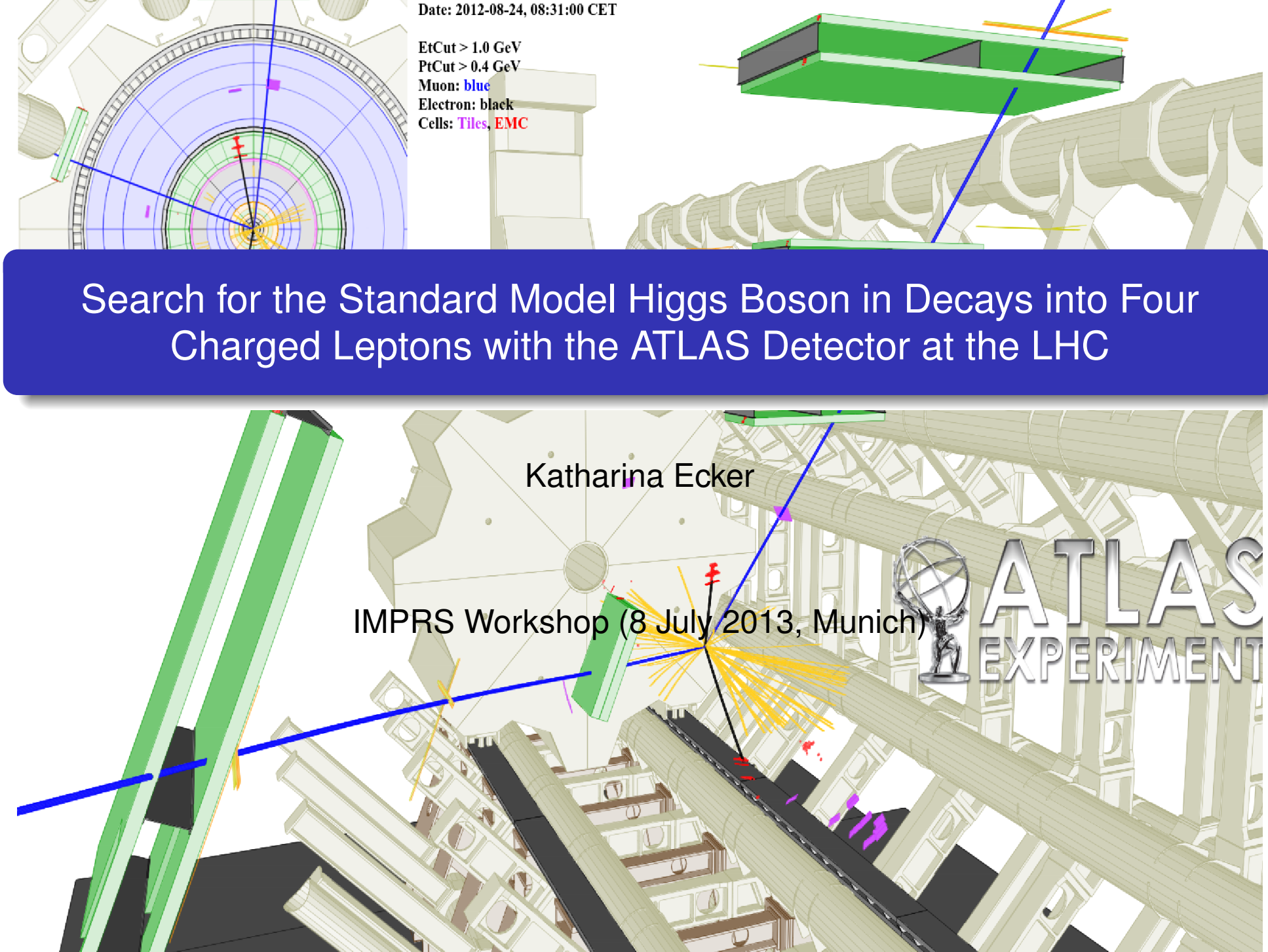


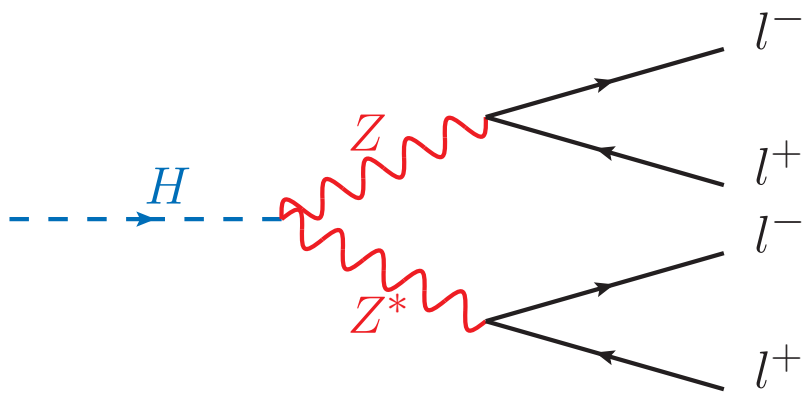
Search for the Standard Model Higgs Boson in Decays into Four Charged Leptons with the ATLAS Detector at the LHC

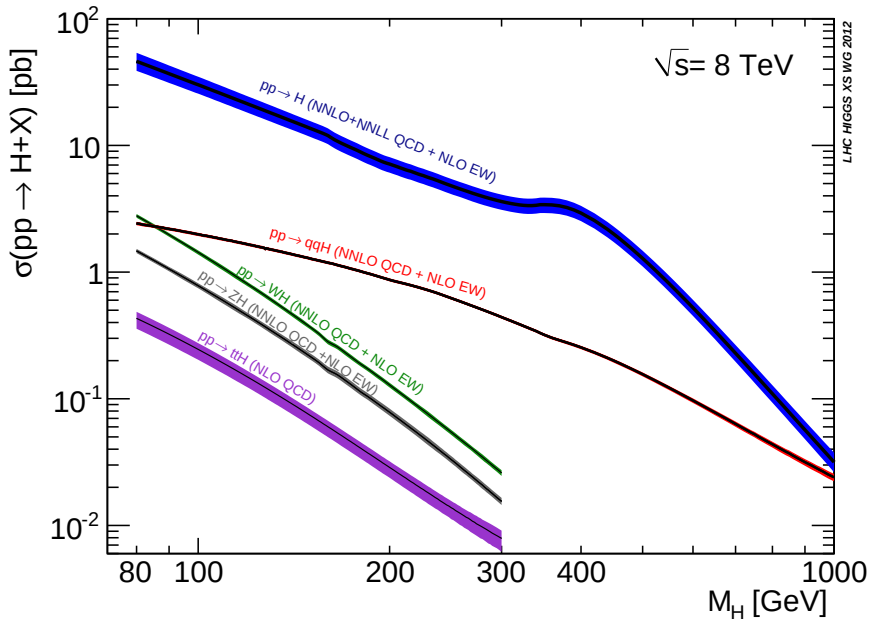
Katharina Ecker

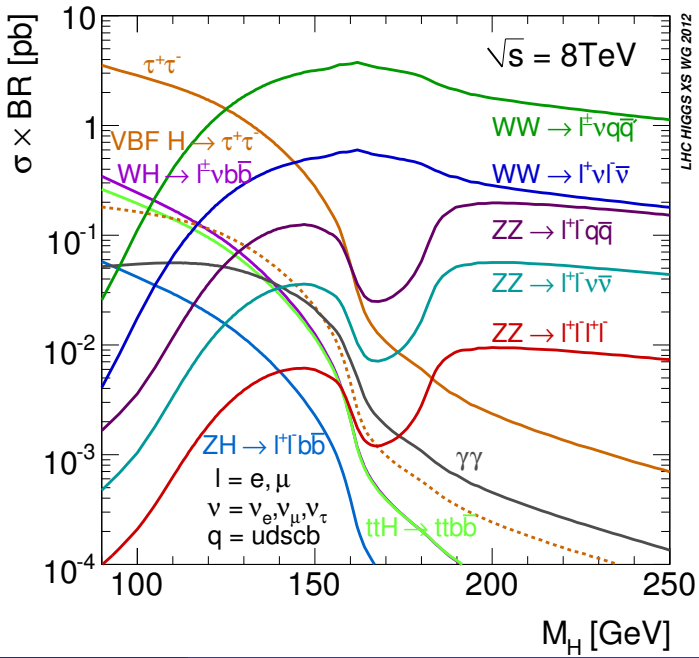
IMPRS Workshop (8 July 2013, Munich)

Introduction: The Higgs decay channel $H \to ZZ^* \to 4\ell$

- $H \to ZZ^* \to 4\ell$ $(\ell = \mu, e)$
  only search for muons and electrons
  $\to$ Final states 4μ, $4e$ und $2\mu 2e$



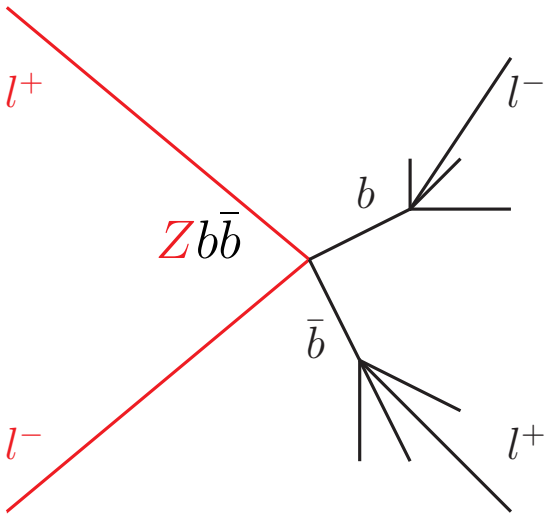


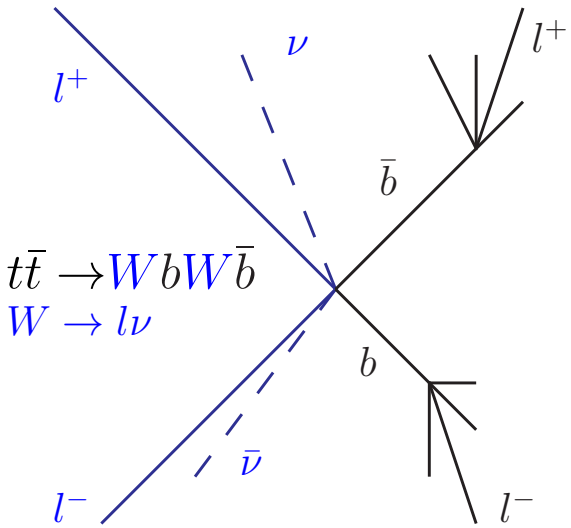


- Small branching ratio
  $\to$ High reconstruction efficiency of muons and electrons necessary
- Clear experimental signature

Backgrounds

1. Irreducible background: SM $ZZ^* \to 4\ell$
   Cannot be distinguished from signal
2. Reducible backgrounds:
   Can be reduced by analysis
   - $Z + jets$: Isolation cuts
   - $Z + b\bar{b}$: Isolation and impact parameter cuts
   - $t\bar{t}$: Isolation and impact parameter cuts

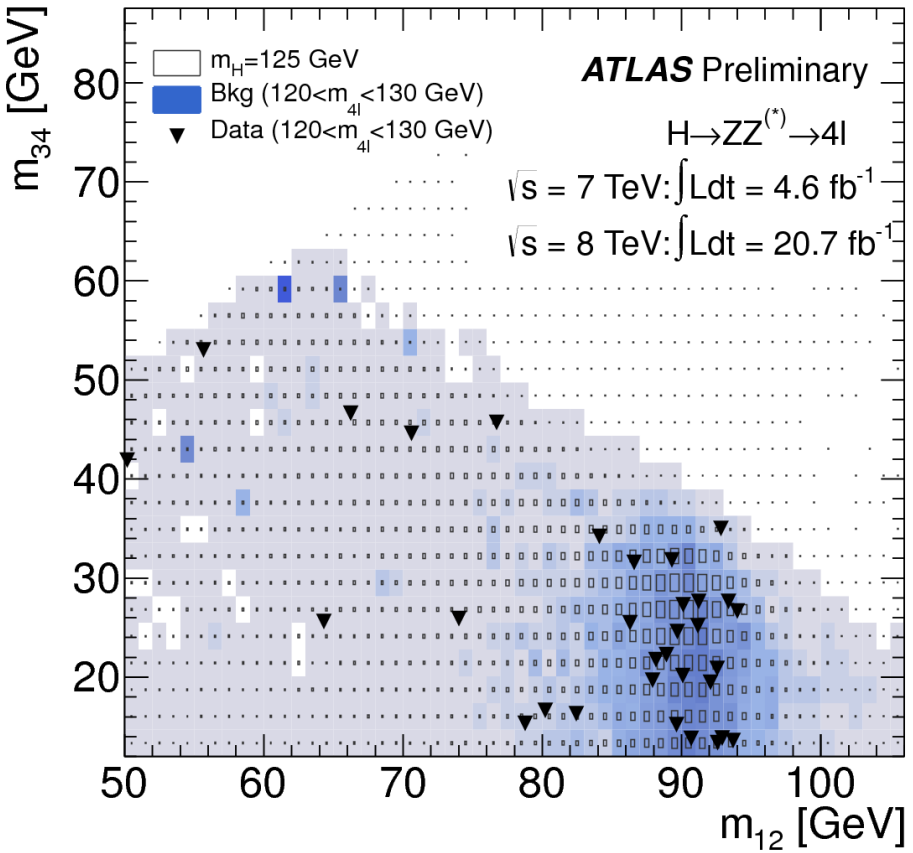




Selection

- Selection of 2 same flavour and oppositely charged electron or muon pairs
- Standard requirements for muons (electrons)
  $p_{T\,\ell 1,\ell 2,\ell 3,\ell 4} > 20, 15, 10, 6\ (7)$ GeV, $|\eta| < 2.7\ (2.47)$
- Reduction background: Isolated leptons, impact parameter cut
  $|z_0| < 10$ mm, $\frac{|d_0|}{\sigma_{d_0}} < 3.5\ (6.5)$

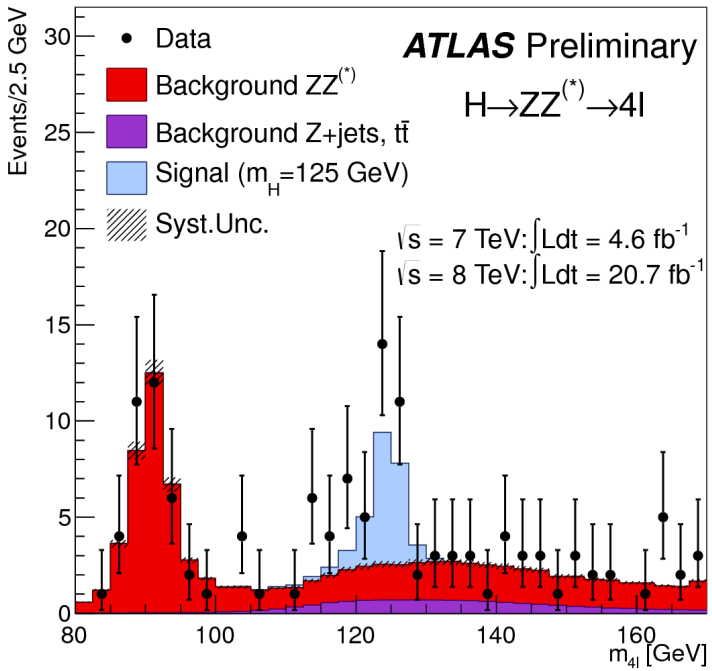
- For $M_H < 2M_Z$:
  Distinction between lepton pairs from on-shell Z and off-shell Z^*:
  $\rightarrow$ 4 channels: 4μ, $4e$, $2\mu 2e$ and $2e2\mu$
  m_{12}: Invariant mass of leading lepton pair
  m_{34}: Invariant mass of sub-leading lepton pair

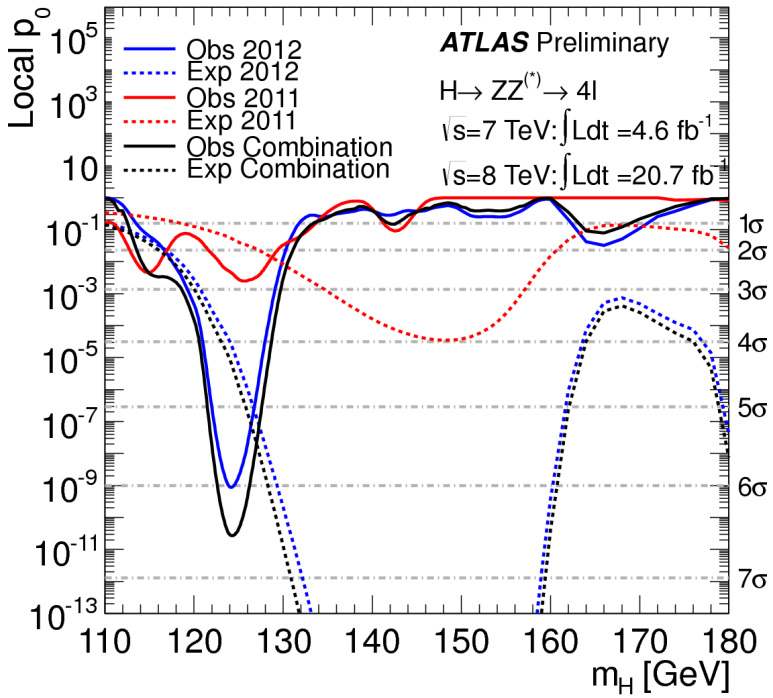


2011 and 2012 candidates

Number of expected and observed events for $(120 < m_{4\ell} < 130)$ GeV:

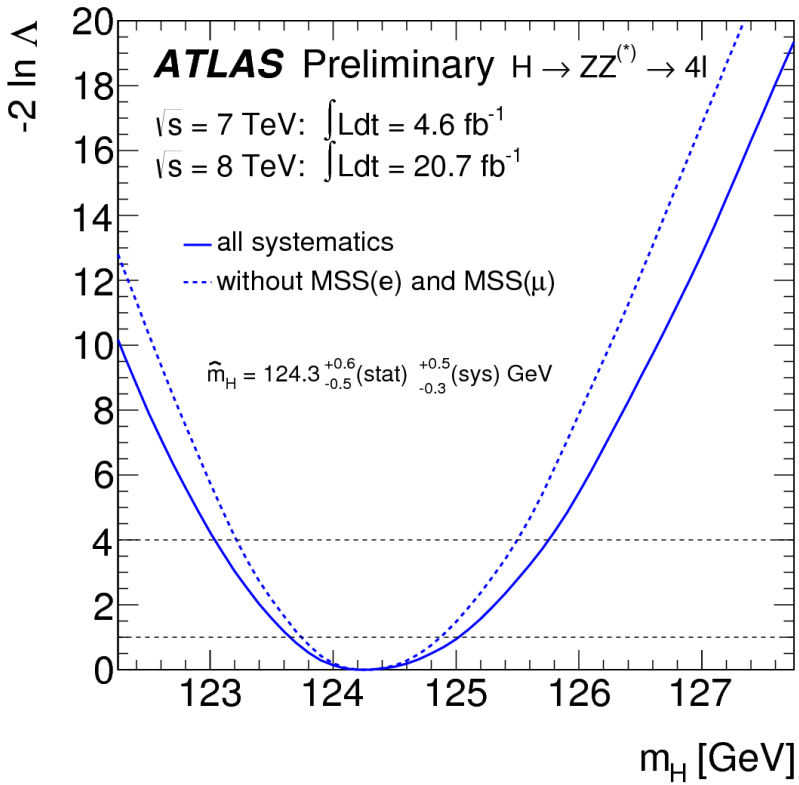
	Signal (m_H=125 GeV)	ZZ^*	$Z+$jets, $t\bar{t}$	Expected bkg	Observed
4μ	6.3 ± 0.8	2.8 ± 0.1	0.55 ± 0.15	3.33 ± 0.25	13
$2\mu 2e$	3.0 ± 0.4	1.4 ± 0.1	1.56 ± 0.33	2.96 ± 0.43	5
$2e2\mu$	4.0 ± 0.5	2.1 ± 0.1	0.55 ± 0.17	2.65 ± 0.27	8
$4e$	2.6 ± 0.4	1.2 ± 0.1	1.11 ± 0.28	2.31 ± 0.38	6
total	15.9 ± 2.1	7.4 ± 0.4	3.74 ± 0.93	11.14 ± 1.33	32

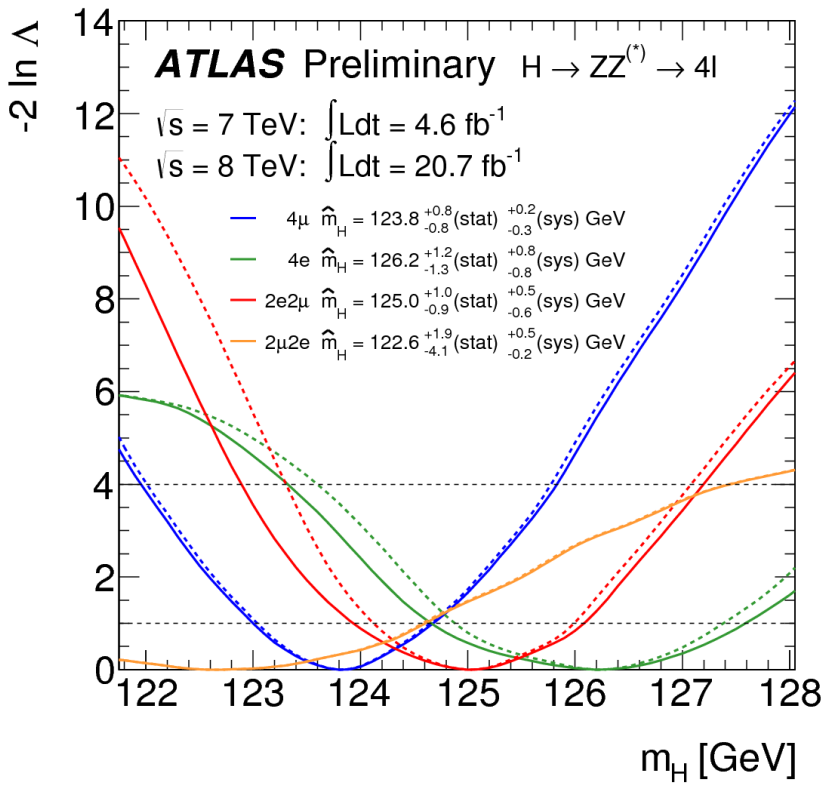




Higgs mass measurement with the ATLAS detector

- Two decay channels are available for the Higgs mass measurement: $H \to ZZ^* \to 4\ell$ and $H \to \gamma\gamma$
- ATLAS baseline method for the Higgs mass measurement: Fit of the mass distributions with simulation based template histograms *"MC templates"*





- Alternative method: Mass measurement in the $H \to ZZ^* \to 4\ell$ channel with convolution method

Higgs mass measurement in the $H \to ZZ^* \to 4\ell$ channel with convolution method

- Fit function: $F(m_{4\ell}, \sigma_{m_{4\ell}}) = \int g(m_{gen}, M_H)\, T(m_{4\ell} - m_{gen}, \sigma_{m_{4\ell}})\, \mathrm{d}m_{gen}$

  with

  Higgs signal at generator level $g(m_{gen}, M_H)$

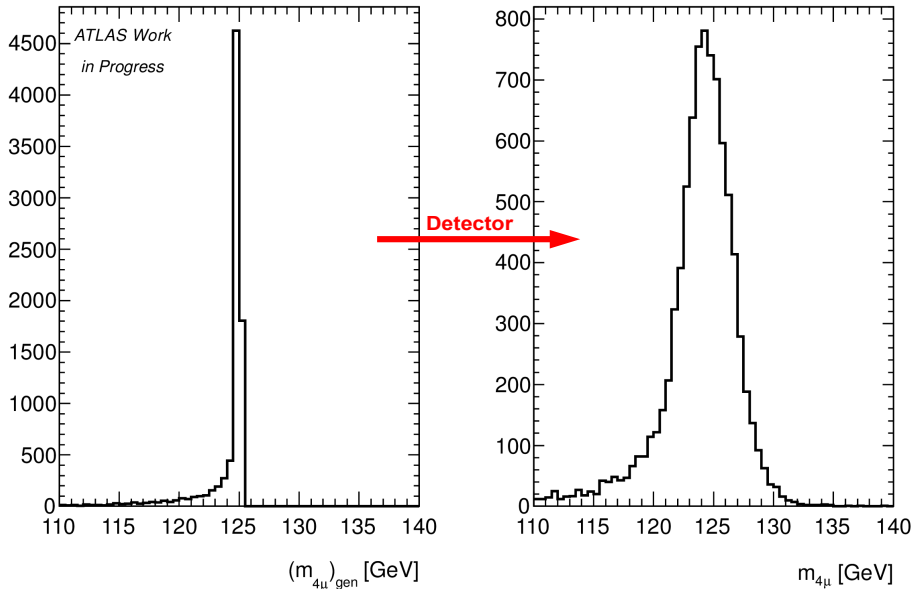
  $m_{4\ell}$ resolution function $T(m_{4\ell} - m_{gen}, \sigma_{m_{4\ell}})$

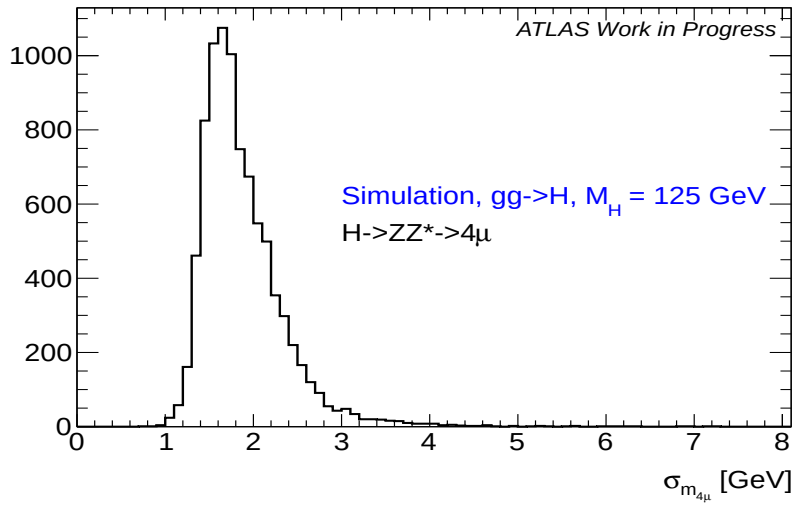
- Two observables: $m_{4\ell}$ and $\sigma_{m_{4\ell}}$

  Event by event variation of the mass measurement error

  $\sigma_{m_{4\ell}} = \sigma_{m_{4\ell}}(p_1, p_2, p_3, p_4, \sigma_{p_1}, \sigma_{p_2}, \sigma_{p_3}, \sigma_{p_4})$

  $\to$ Use of $\sigma_{m_{4\ell}}$ per event is beneficial in the fit for low statistics





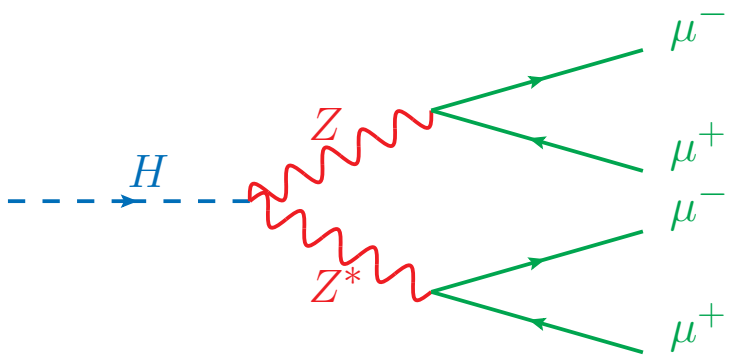
Higgs mass measurement in the $H \to ZZ^* \to 4\mu$ channel with convolution method

- Shape of $m_{4\ell}$ resolution function $T(m_{4\ell} - m_{gen}, \sigma_{m_{4\ell}})$ is dependent on flavour of final state leptons:

  For muons $H \to 4\mu$: Mass resolution function is Gaussian
  For electrons $H \to 4e/2e2\mu/2\mu2e$: Mass resolution function is non Gaussian due to electron Bremsstrahlung

$\Rightarrow$ Only considered $H \to ZZ^* \to 4\mu$ channel in the following!

- Fit function for $H \to ZZ^* \to 4\mu$ events:



$$F(m_{4\mu}, \sigma_{m_{4\mu}}) = \int g(m_{gen}, M_H) \cdot T(m_{4\mu} - m_{gen}, \sigma_{m_{4\mu}})\, \mathrm{d}m_{gen}$$

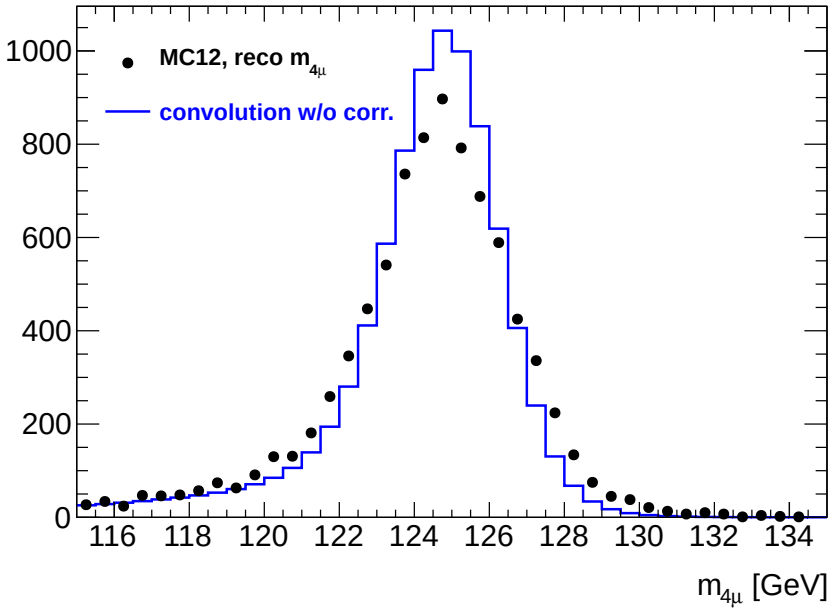
with Gaussian mass resolution function:

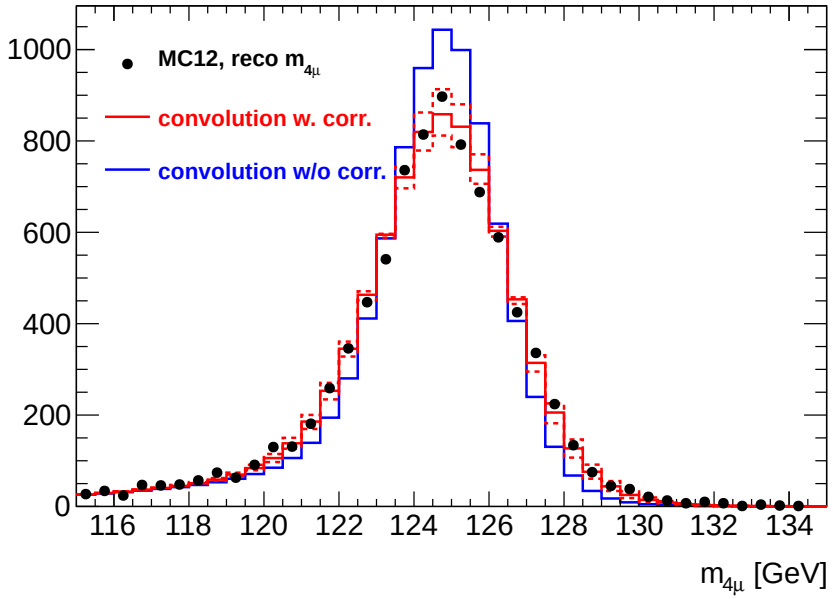
$$T(m_{4\mu} - m_{gen}, \sigma_{m_{4\mu}}) = \frac{1}{\sqrt{2\pi}\sigma_{m_{4\mu}}} e^{-\frac{1}{2} \cdot \frac{(m_{4\mu} - m_{gen})^2}{(\sigma_{m_{4\mu}})^2}}$$

Higgs mass measurement in the $H \to ZZ^* \to 4\mu$ channel with convolution method

Test of the convolution model

- Comparison convolution model with $m_{4\mu}$ distribution from MC simulation:





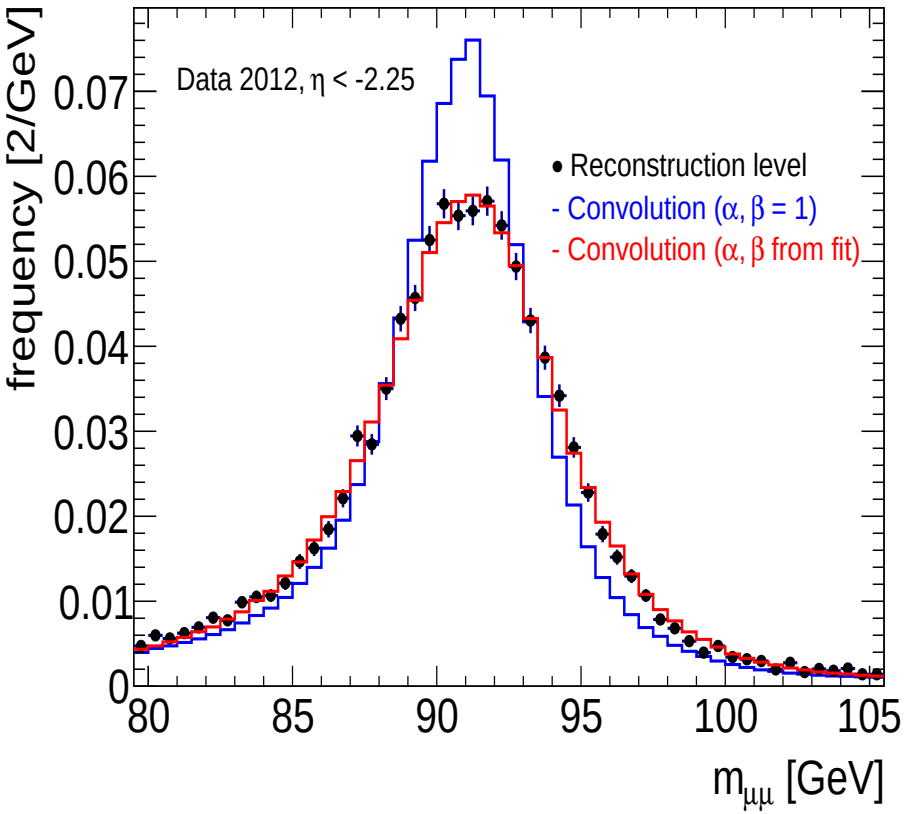
- Mass errors $\sigma_{m_{4\mu}}$ are underestimated and need to be scaled
  $\Rightarrow$ Correction of $m_{4\mu}$ and $\sigma_{m_{4\mu}}$ with scaling factors α and β

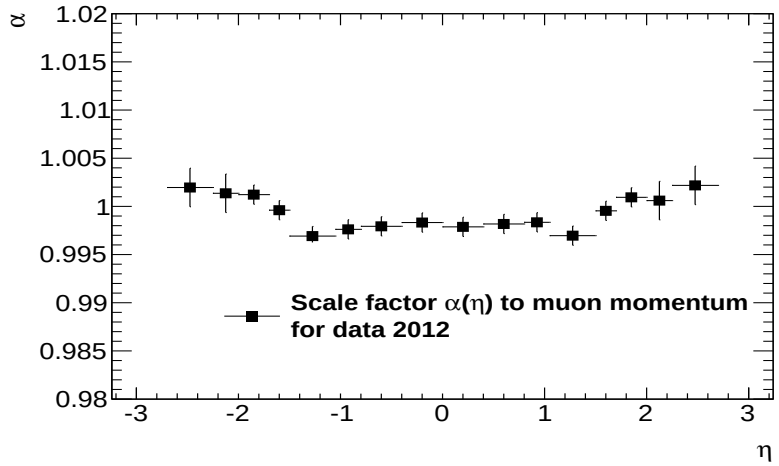
$$T(m_{4\mu} - m_{gen}, \sigma_{m_{4\mu}}) = \frac{1}{\sqrt{2\pi}\beta\sigma_{m_{4\mu}}} e^{-\frac{1}{2}\cdot\frac{(m_{4\mu}-\alpha\cdot m_{gen})^2}{(\beta\sigma_{m_{4\mu}})^2}}$$

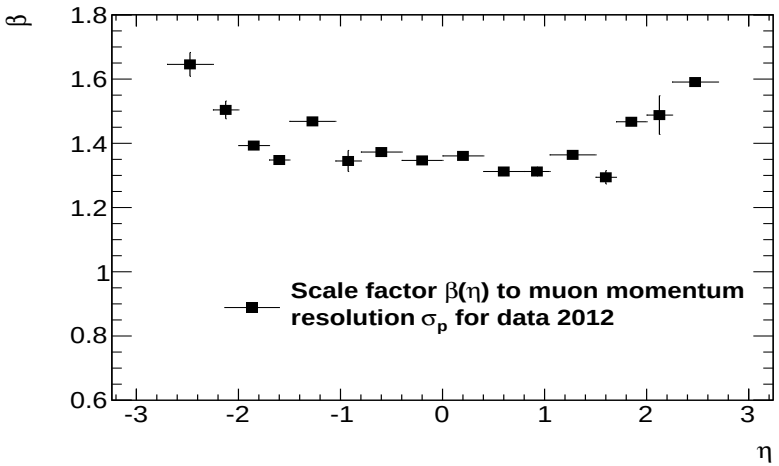
Higgs mass measurement in the $H \to ZZ^* \to 4\mu$ channel with convolution method

Calibration of $m_{4\mu}$ and $\sigma_{m_{4\mu}}$

- Nominal mass $m_{4\mu}$ and mass error $\sigma_{m_{4\mu}}$ are corrected with scale factors α and β
- Determination of scale factors α and β with $Z \to \mu^+\mu^-$ events



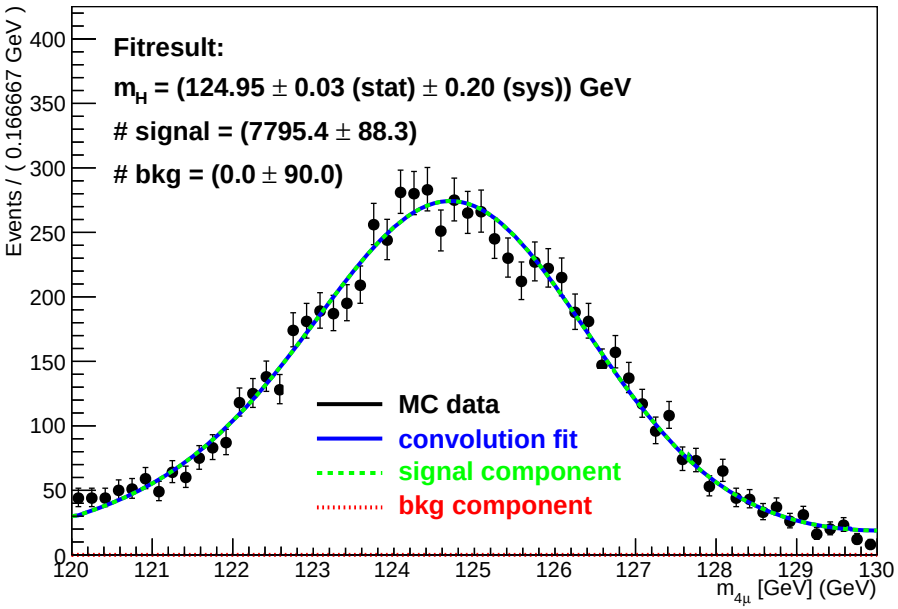


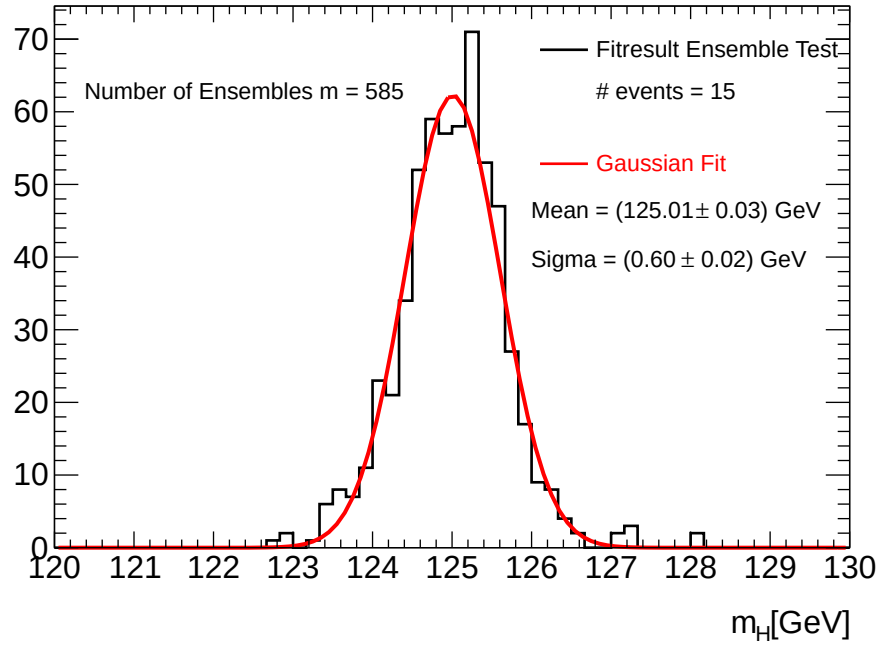


Higgs mass measurement in the $H \to ZZ^* \to 4\mu$ channel with convolution method

Test of the convolution method with Monte Carlo simulation

- Testing the convolution method with Monte Carlo simulation of a Higgs boson with $m_H = 125\ \mathrm{GeV}$





- Result of the test:

  $\to$ The fit works also for low statistics

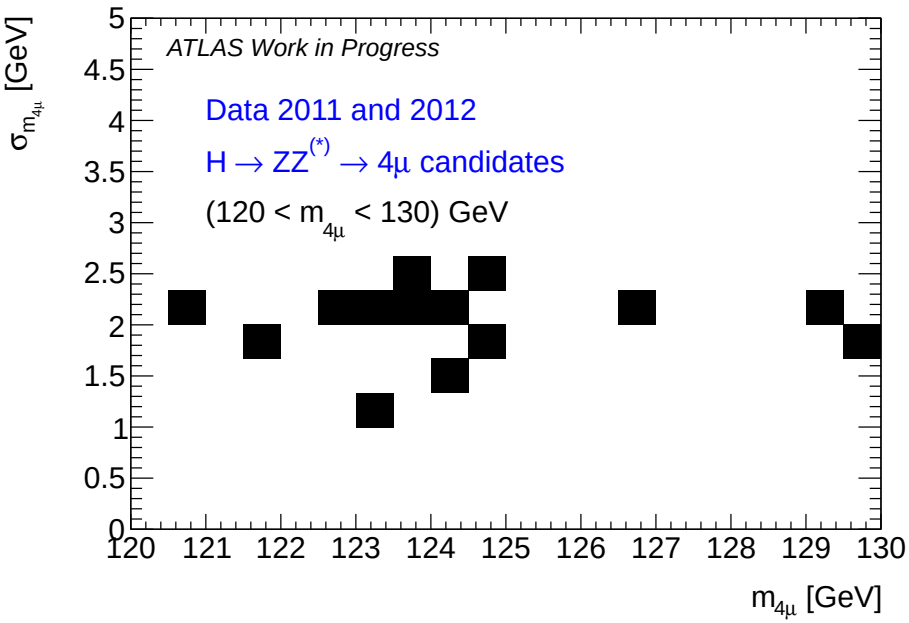
  $\to$ There is no bias in the fit and the expected mass resolution is about 0.6 GeV

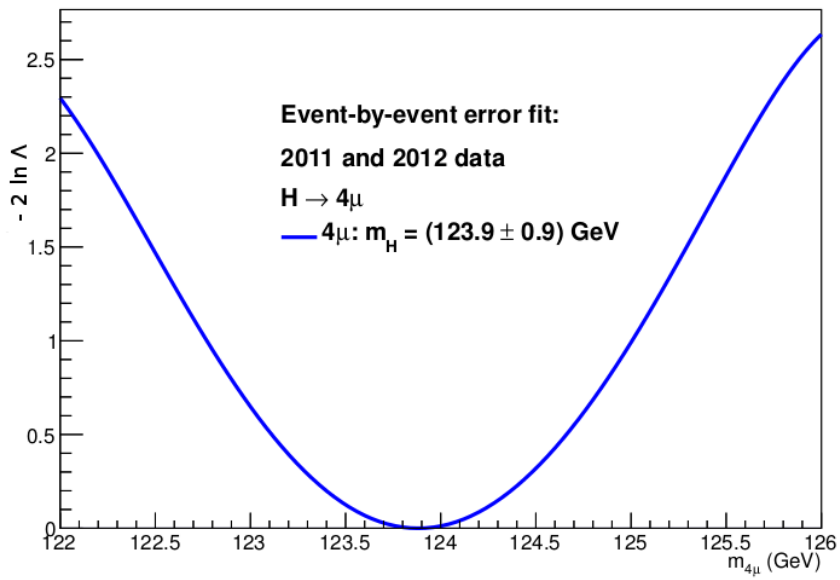
Result Higgs mass measurement in the $H \to ZZ^* \to 4\mu$ channel with convolution method

Applying the fit with the convolution method to 2011 and 2012 $H \to ZZ^* \to 4\mu$ data candidates:

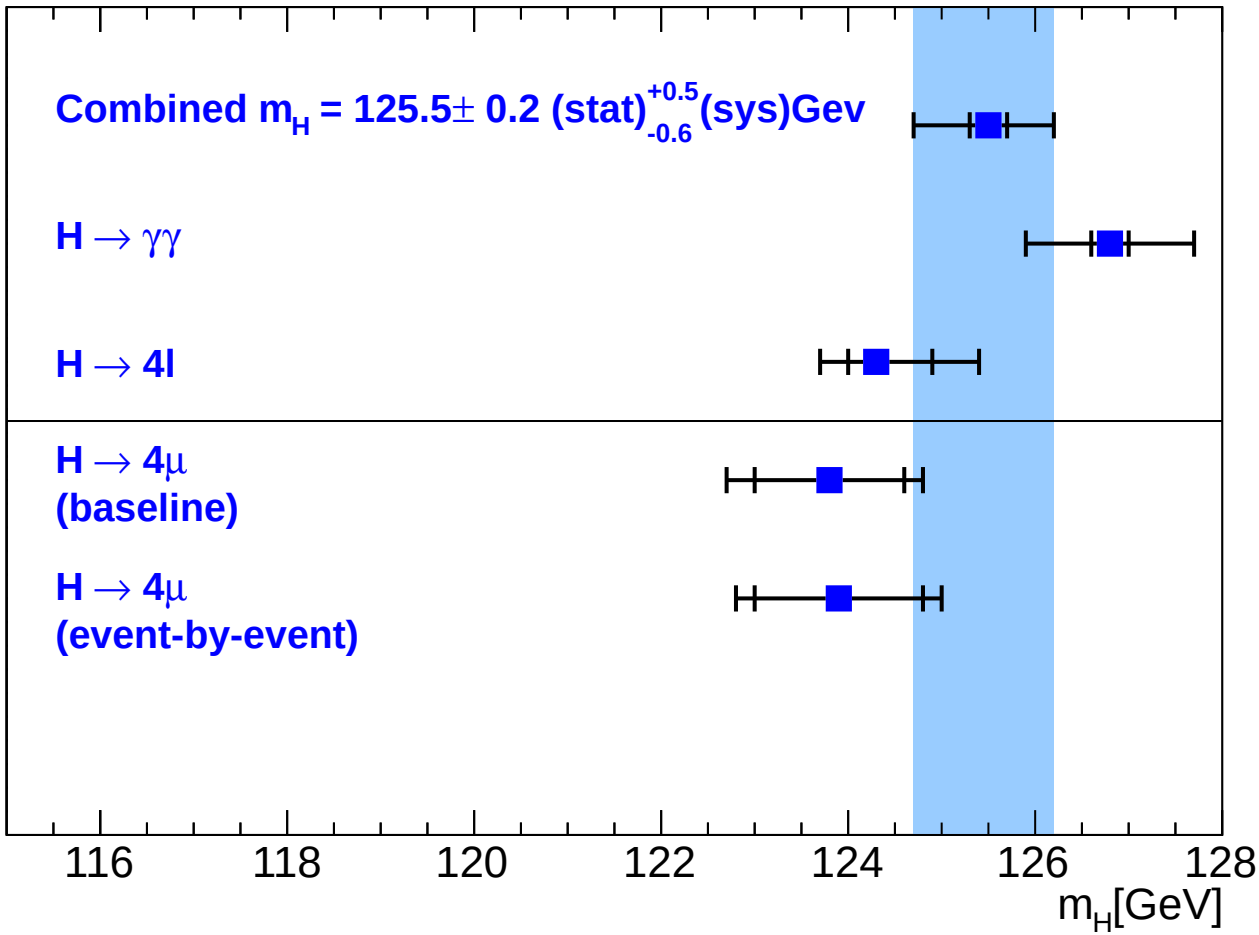
- Baseline method: $123.8^{+0.8}_{-0.8}(\text{stat})^{+0.2}_{-0.3}(\text{sys})$ GeV
- Convolution method: $123.9 \pm 0.9(\text{stat}) \pm 0.2(\text{sys})$ GeV

$\to$ *Mass measurements with baseline and convolution method are compatible*





Result Higgs mass measurement with the ATLAS detector



Conclusions

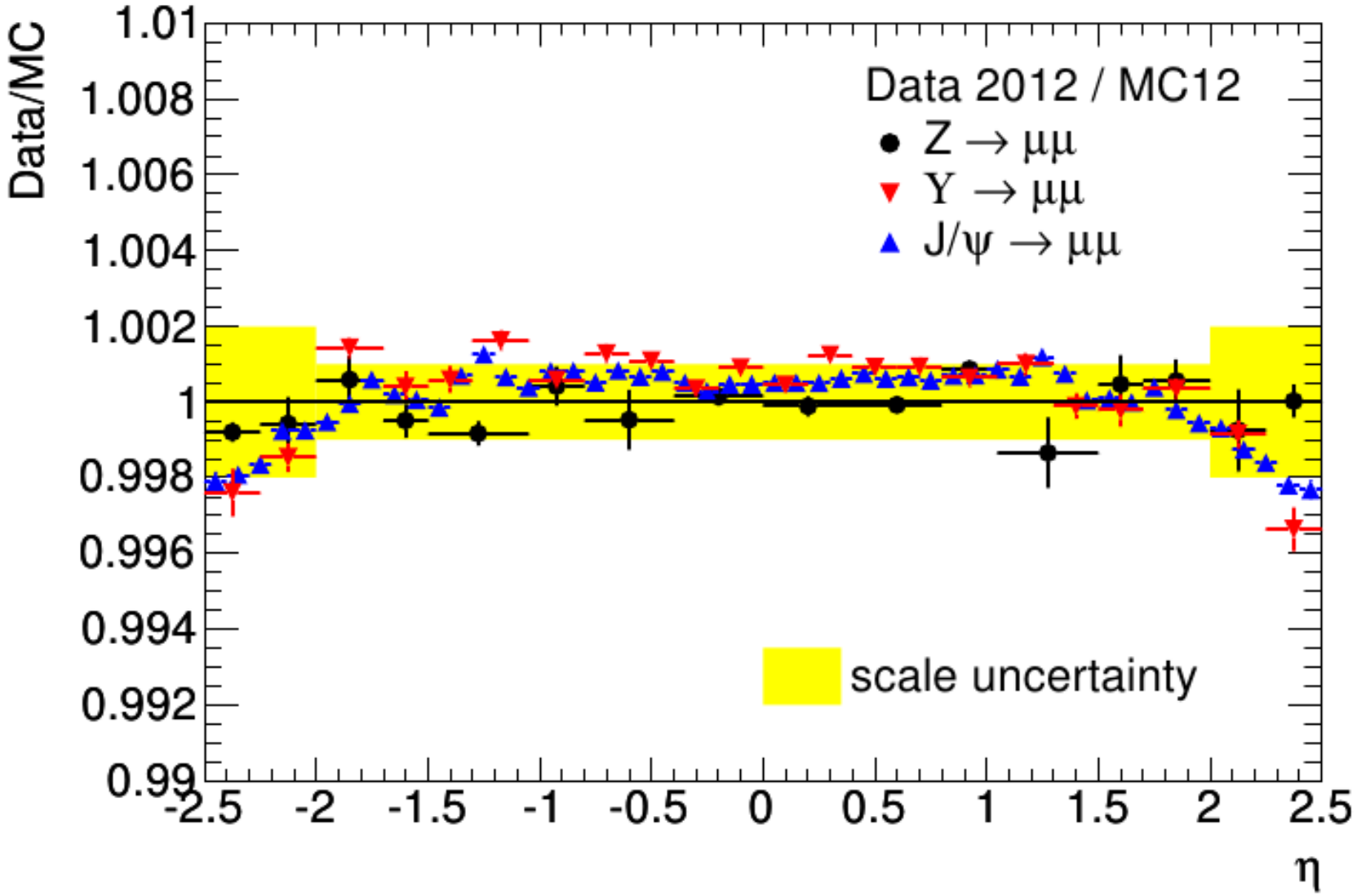
- The $H \to ZZ^* \to 4\ell$ decay channel provides very clear experimental signature and allows a precise measurement of the Higgs boson mass
- It was one of the Higgs discovery channels in 2012 and has now a significance of 6.6 σ
- Higgs mass measured with the $H \to ZZ^* \to 4\ell$ channel:
  $M_H = 124.3^{+0.6}_{-0.5}(\text{stat})^{+0.5}_{-0.3}(\text{sys})\ \text{GeV}$
- Alternative method, the convolution method with only $H \to ZZ^* \to 4\mu$ events:
  $M_H = 123.9 \pm 0.9(\text{stat}) \pm 0.2(\text{sys})\ \text{GeV}$

- Outlook $H \to ZZ^* \to 4\ell$ channel: Precise measurement of Spin and CP of the Higgs boson with 14 TeV data of the LHC upgrade

Backup Slides

Backup

Muon momentum scale systematics



Backup

Z boson decay into four leptons