Selection efficiency & mass resolution in the $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ decay channel at ATLAS

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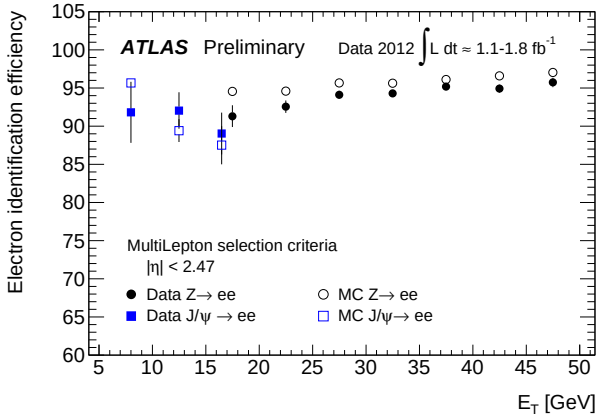
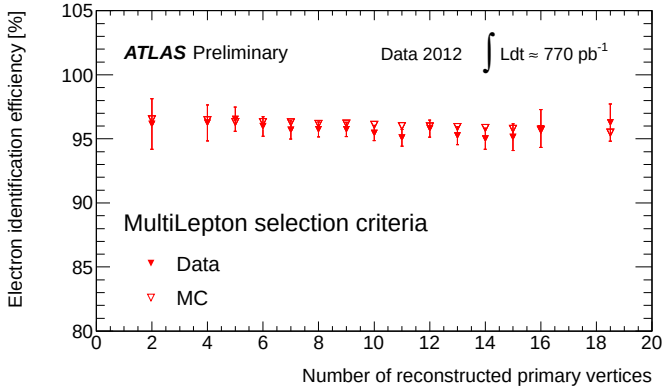
Introduction

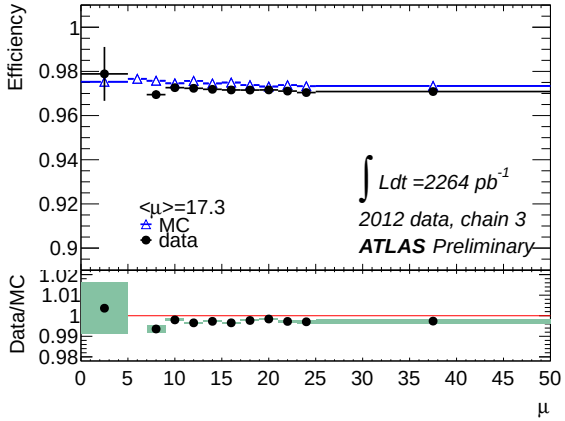
- Good muon/electron identification and reconstruction are essential to the $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ analysis
- Efficiencies must be robust against pile-up and measured down to $E_{\mathrm{T}} > 7$ for electrons and $p_{\mathrm{T}} > 6$ GeV for muons
- On top of the $H \rightarrow 4\ell$ lepton quality requirements additional isolation and impact parameter cuts are applied to further reduce backgrounds
- The efficiency of these extra criteria are studied for both data and Monte Carlo

Scale factor estimates for the additional isolation and impact parameter cuts specific to the $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ analysis are presented using 20.7 fb^{-1} of $\sqrt{s} = 8$ TeV data



[1]





[2]

Tag-and-Probe Selection

To estimate the efficiencies a Tag-and-Probe technique is applied to $Z \rightarrow e^+e^-$ and $Z \rightarrow \mu^+\mu^-$ events

Tag: tight requirements

- Combined muon / Multilepton e-ID
- Trigger matched
- $p_{\mathrm{T}} > 20$ GeV
- $z_0 < 10$ mm
- Track isolation: $\Sigma p_{\mathrm{T}}^{\Delta R=0.2}/p_{\mathrm{T}} < 0.05$
- $|\eta| < 1.37$ (electrons only)

Probe: looser requirements

- Combined muon / Multilepton e-ID
- $E_{\mathrm{T}} > 7$ GeV (electrons)
  $p_{\mathrm{T}} > 6$ GeV (muons)
- $z_0 < 10$ mm

Built pairs are opposite-sign leptons where $p_{\mathrm{T}}^{tag} > p_{\mathrm{T}}^{probe}$

Additional selection cuts

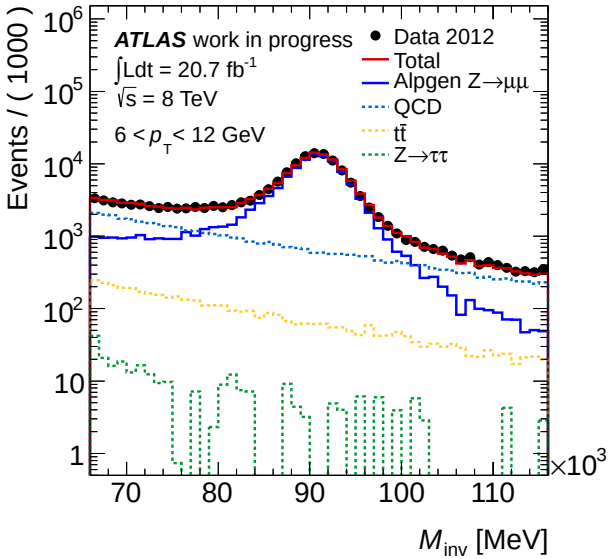
- Track isolation: $\Sigma p_{\mathrm{T}}^{\Delta R=0.2}/p_{\mathrm{T}} < 0.15$
- Calorimeter isolation: $\Sigma E_{\mathrm{T}}^{\Delta R=0.2}/E_{\mathrm{T}} < 0.3$ for muons 0.2 for electrons
- Impact parameter significance: $|\frac{d_0}{\sigma_{d_0}}| < 3.5$ for muons $|\frac{d_0}{\sigma_{d_0}}| < 6.5$ for electrons

Fitting Procedure

Aim: Perform binned fit to the Z invariant mass in different p_{T} / E_{T} and N_{vtx} bins using Monte Carlo signal templates and modelled backgrounds

Signal and background modelling

- Use Monte Carlo signal templates
- QCD background modelled by same-sign contribution in data with normalisation free in the fit
- $Z \rightarrow \tau\tau$ and $t\bar{t}$ templates from Monte Carlo are normalised to the integrated luminosity and fixed in fit



Efficiency

- Estimated using ± 5 GeV window around the Z with a fitting range 66-116 GeV

$$\epsilon = \frac{\text{signal after cuts}}{\text{signal before cuts}}$$

Systematics

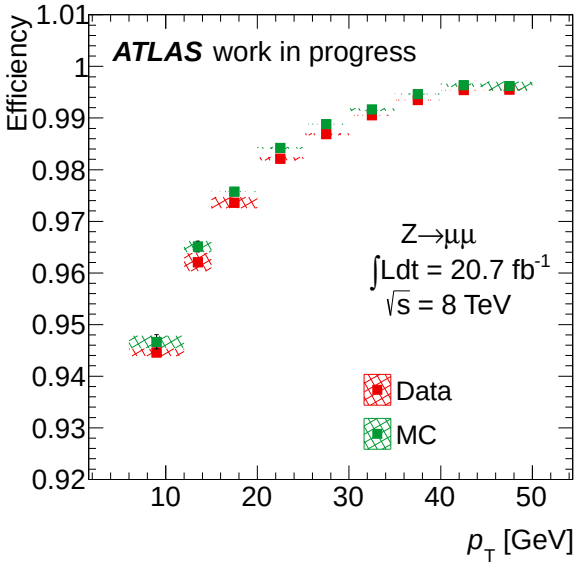
- Consider different efficiency windows, extended fit range and Monte Carlo signal templates

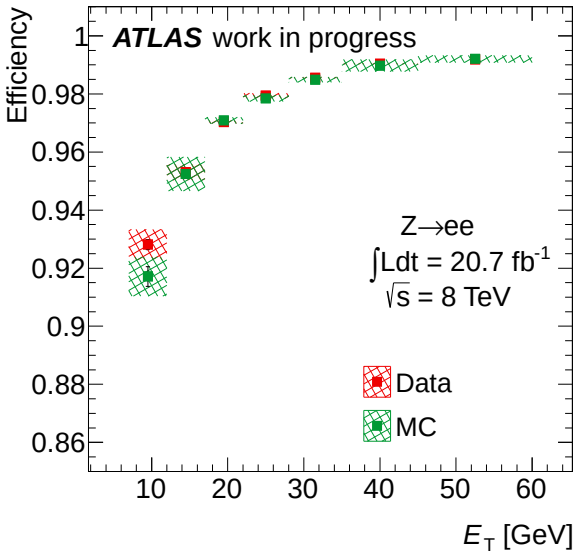
Efficiency Results

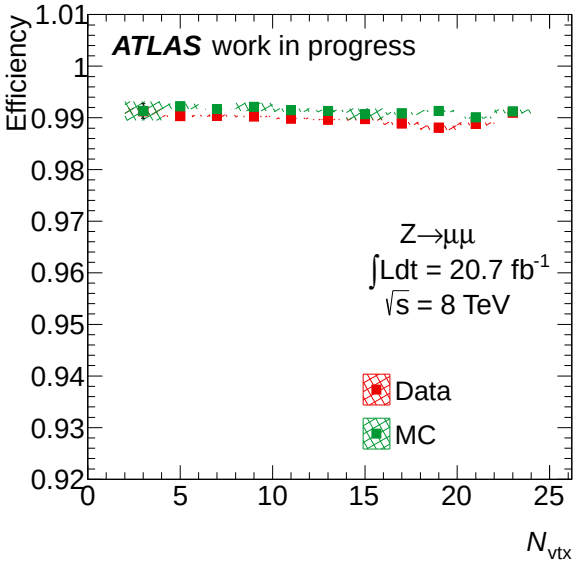
The efficiency results after all cuts are applied

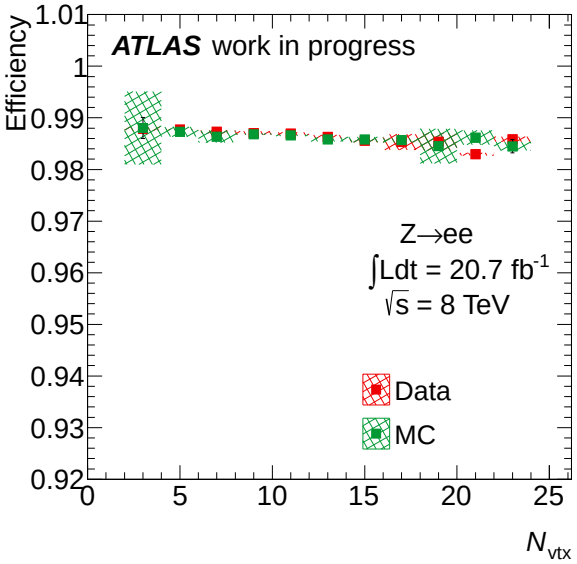
p_T / E_T bins

Largest effect comes from the calorimeter isolation









N_{vtx} bins

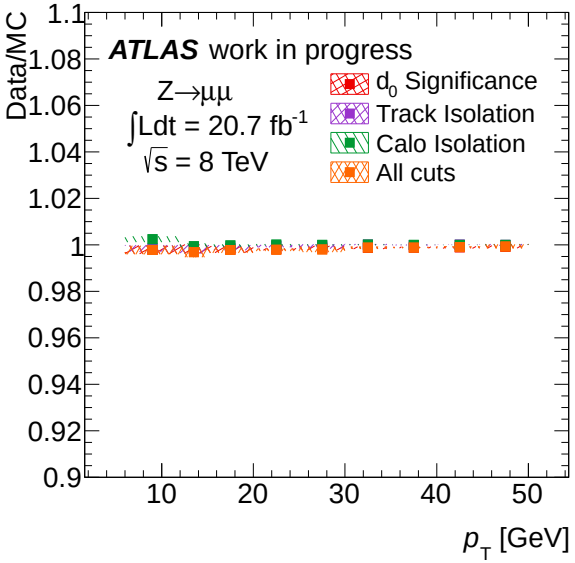
Efficiencies relatively stable with increased pile-up

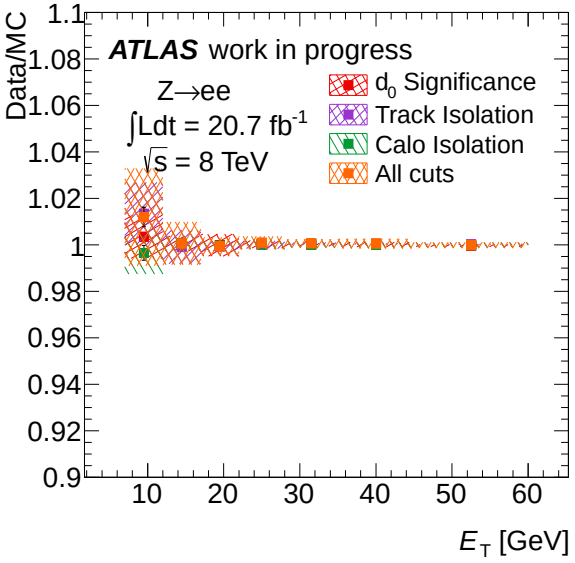
Scale Factor Results

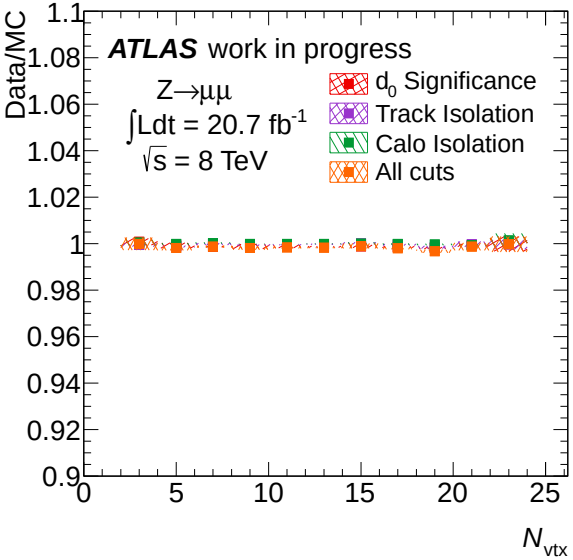
The scale factor results for each of the cuts and all combined

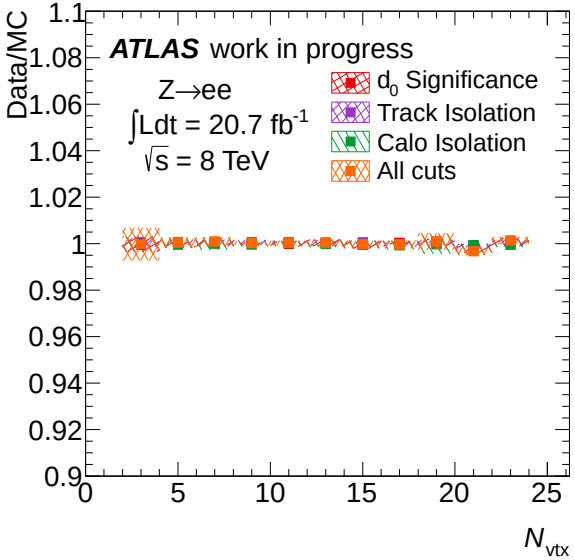
p_T / E_T bins

Largest systematics seen in lowest E_T bins for electrons









N_{vtx} bins

Whole range modelled well by Monte Carlo

In general all values are consistent with unity within uncertainity

Mass Resolution

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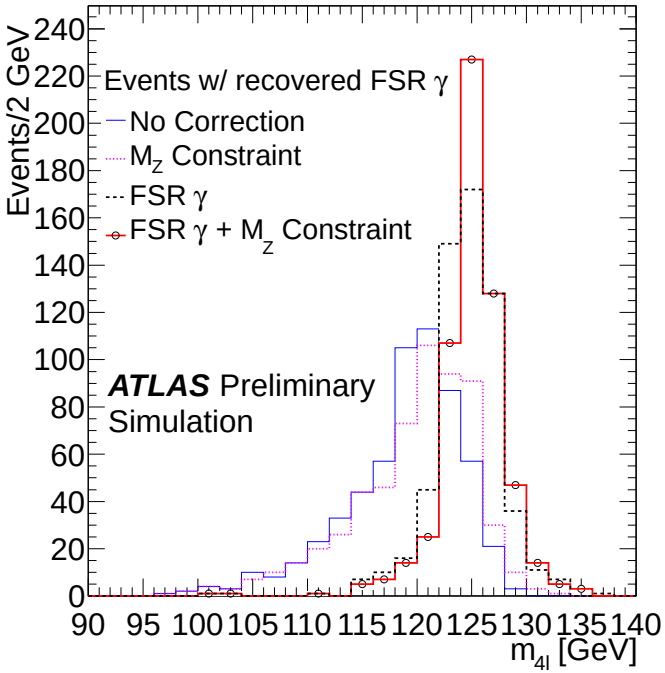
The $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ high mass resolution makes it ideal to perform a mass measurement

FSR Recovery

- Correct invariant mass of Z for losses through final-state radiation
- Applied to all di-muon Z_1 candidates with $66 < m_{12} < 89$ GeV and a reconstructed photon $E_{\mathrm{T}} > 1$ GeV close to a muon track
- Expect around 70% efficiency with an 85% purity

Z-mass Constraint

- Applied to the leading di-lepton for $m_{4\ell} <$ 190 GeV and both dileptons above this
- Gives improvement for all channels without chaning the ZZ background shape
- Accounts for the Z line-shape and the uncertainity on the di-lepton mass



Simulated $H \rightarrow ZZ^{(*)} \rightarrow 4\mu$ events with recovered FSR γ

$\sim$4% of simulated events have FSR γ

Mass Fit

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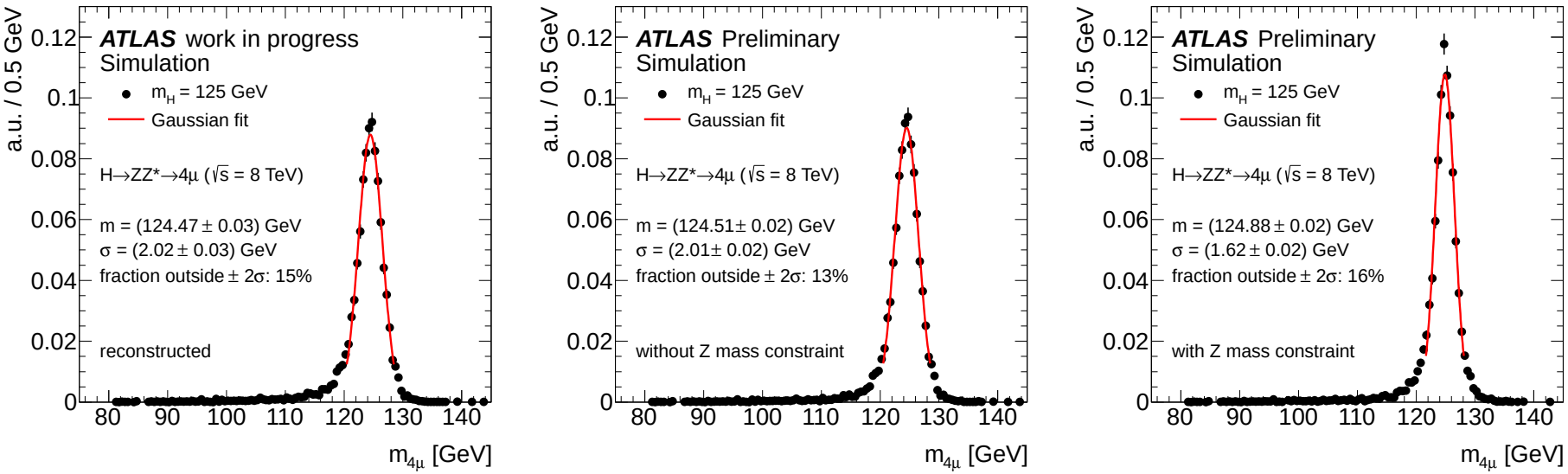
- Study the invariant mass distribution for simulated $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ events
- PowHeg generated ggH events for $m_H = 125$ GeV at $\sqrt{s} = 8$ TeV
- Perform Gaussian fit in the range:
  - -2σ to 2σ for the 4μ channel
  - -1.5σ to 2.5σ for the 2μ2e/2e2μ/4e channels
- The slightly lower mean arises from radiative losses which are most significant in channels containing electrons



Reconstruction $\rightarrow$ + FSR Recovery $\rightarrow$ + Z-mass Constraint

Mass Resolution Results

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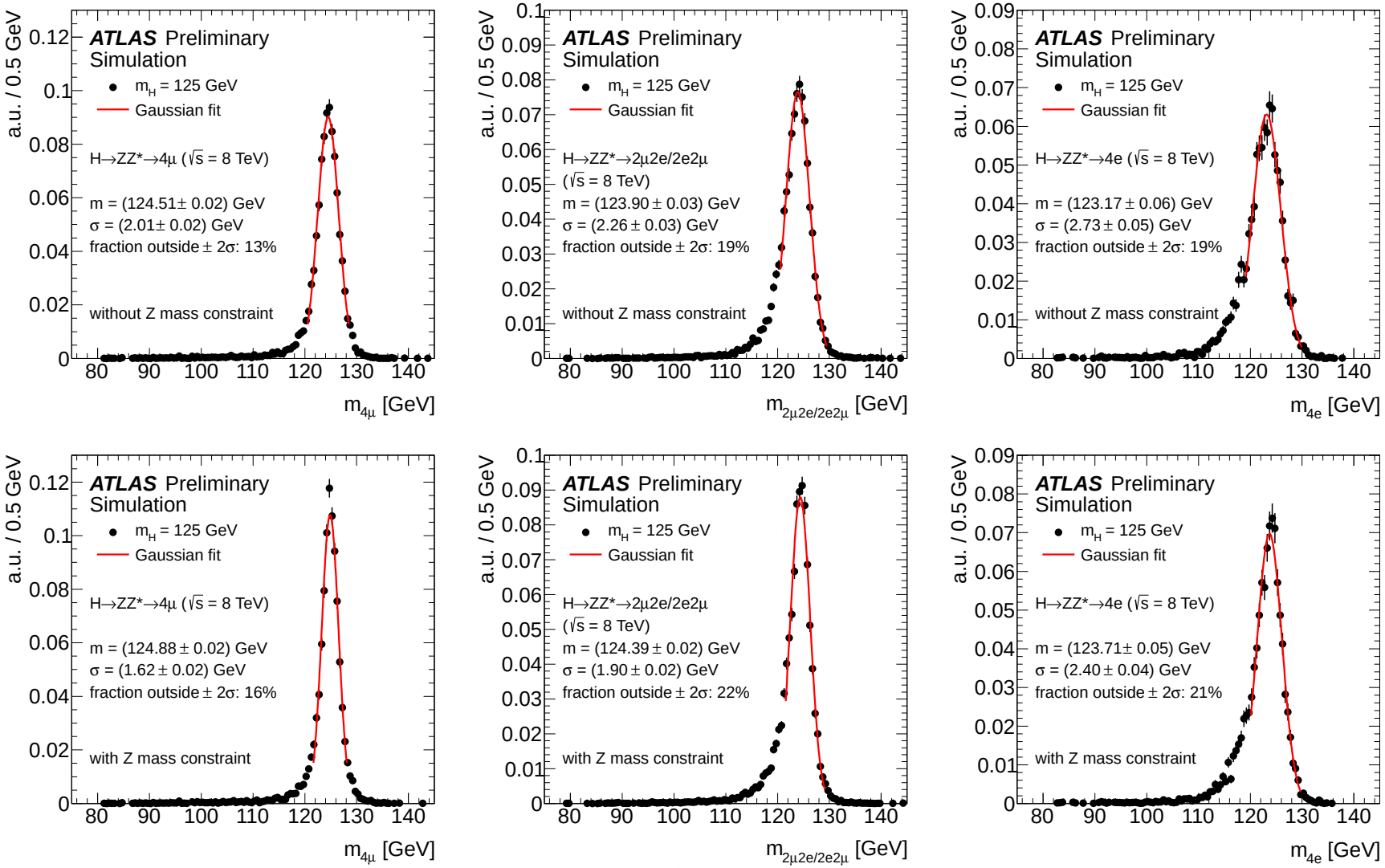
- Invariant mass distributions for simulated $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ events before (top) and after (bottom) the Z-mass constraint



4μ $2\mu 2e/2e2\mu$ $4e$

Mass Measurement

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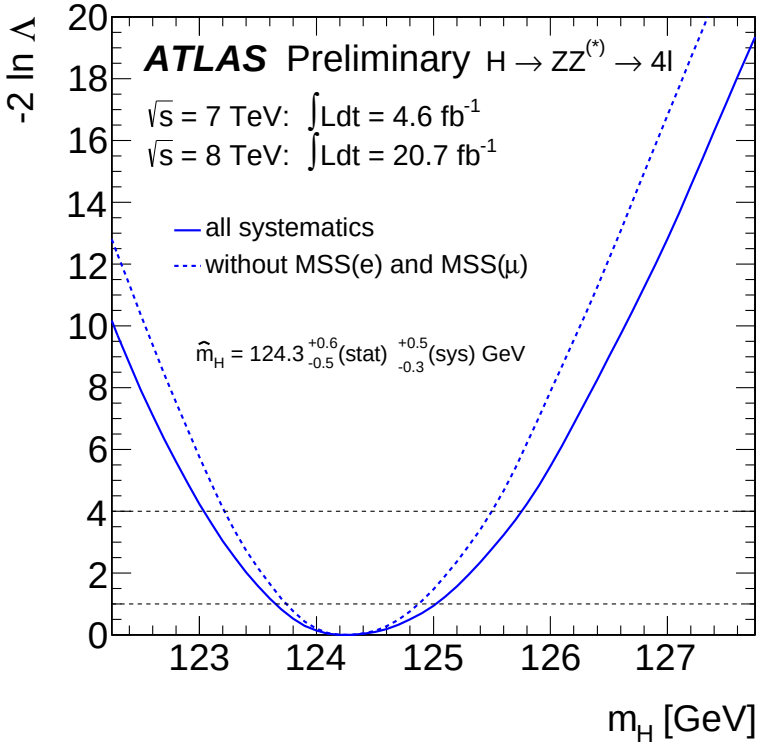
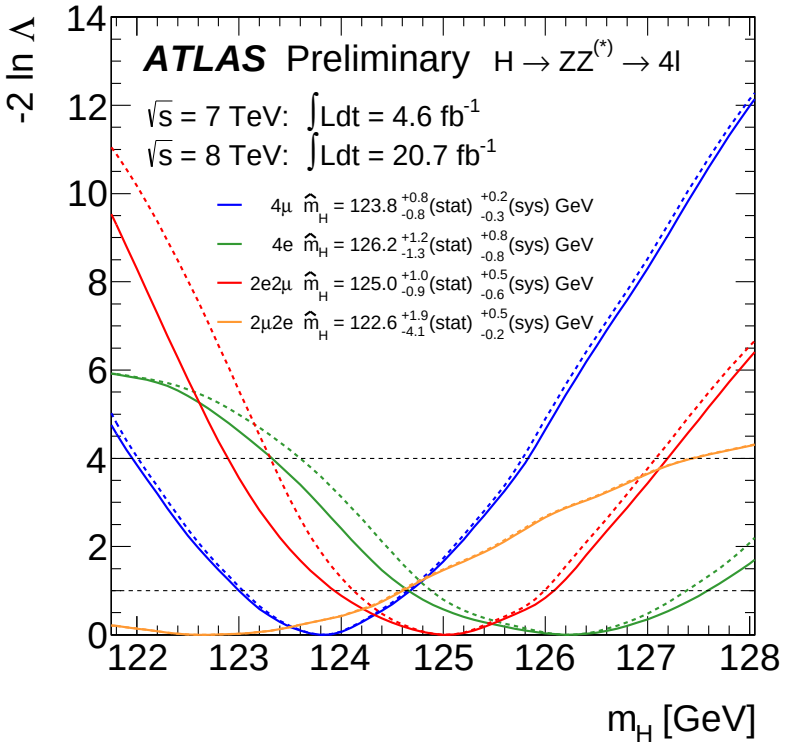
- Profile likelihood vs m_H with and without mass scale systematics
- There is resonably good agreement between the individual channels within their total uncertainties
- The 4μ channel currently drives the measurement
- Best fit $m_H = 124.3^{+0.6}_{-0.5}\,(\mathrm{stat})^{+0.5}_{-0.3}\,(\mathrm{syst})\,\mathrm{GeV}$





Summary

Selection efficiency

- The Monte Carlo models well the selection effects and all scale factors are consistent with unity within uncertainties

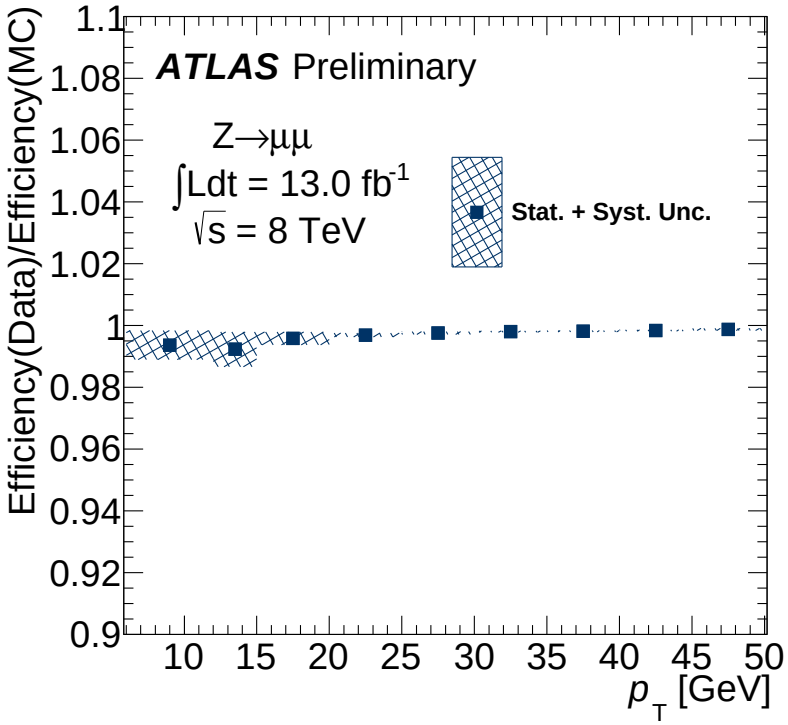
Mass resolution

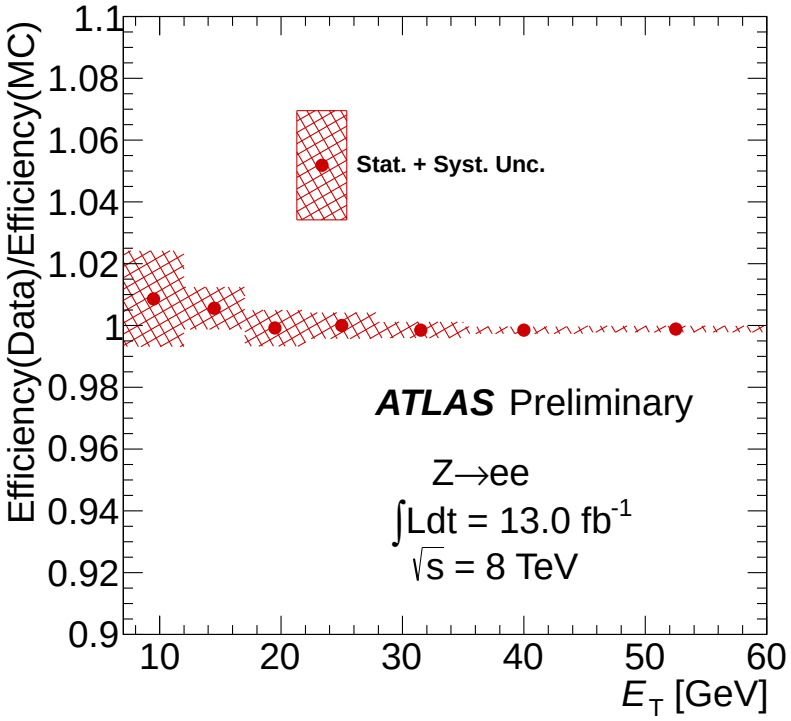
- The Z-mass constraint offers a substantial improvement in the mass resolution in all final states
- Future possibility is to perform a mass measurement exploting the resolution in different detector categories

Backup

Scale Factors

- Scale Factors vs p_{T} / E_{T} with total uncertainties for 13.0 fb^{-1} of $\sqrt{s} = 8$ TeV data





References

Talk:

- ATLAS-COM-PHYS-2011-783 - Electron identification efficiency
- ATL-COM-PHYS-2012-716 - Muon reconstruction
- ATLAS-CONF-2013-013 - Moriond

Other material:

- ATLAS-CONF-2012-092 - ICHEP
- arXiv:1207.7214 - Higgs discovery paper
- ATLAS-CONF-2012-169 - CERN Council Seminar
- ATLAS-CONF-2012-143 - Reconstruction of FSR