$Z + b\bar{b}$ Cross-section Measurements with the ATLAS detector

IOP Meeting

7th-9th April 2014

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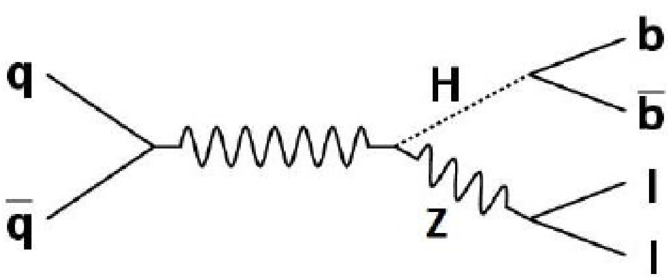
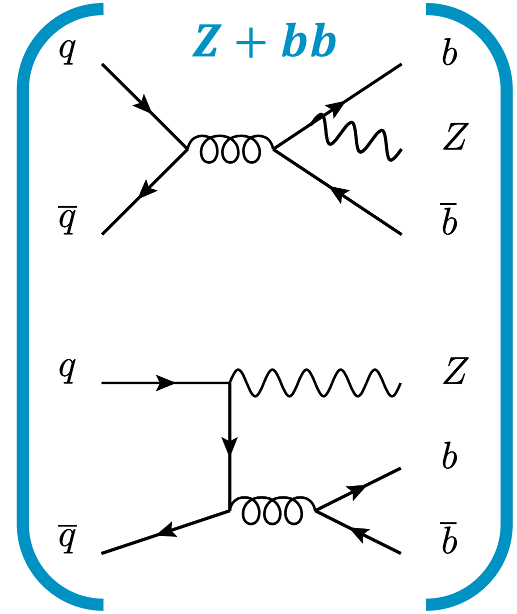
$Z + b\bar{b}$ Motivation

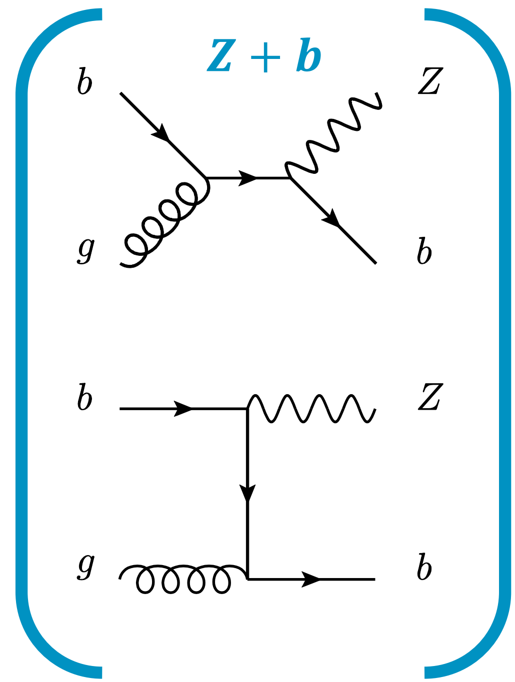
- First measurement of differential $Z + b\bar{b}$ cross section
  - Performed in conjunction with $Z + b$ analysis

- Provides opportunity to test perturbative QCD predictions
  - Compare several calculations
  - Potential parton density function (PDF) sensitivity
  - PDF 4/5 flavour number scheme discrimination (more sensitive for $Z + b$)

- $Z + b\bar{b}$ is a background to other interesting physics
  - Higgs production in $HZ \rightarrow Zb\bar{b}$ channel







Analysis Outline

- Measure $Z + b\bar{b}$ cross-section differentially in four variables: Zp_T, $Z|y|$, M_{bb} and ΔR_{bb} using 2011 data collected by ATLAS

Z Selection

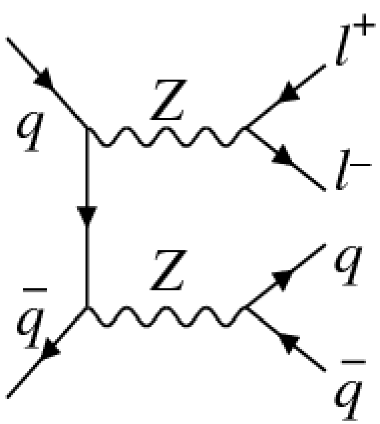
- Two opposite sign leptons ($\mu^+\mu^-$, e^+e^-)
- Lepton $p_T > 20\ GeV$
- $76 < M_{ll}(GeV) < 106$

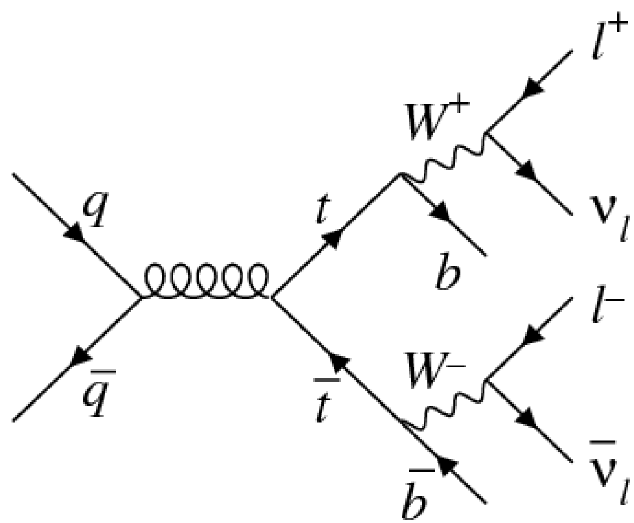
Jet Selection

- Two b-tagged jets
- $p_T > 20\ GeV$
- $|y| < 2.4$

Backgrounds

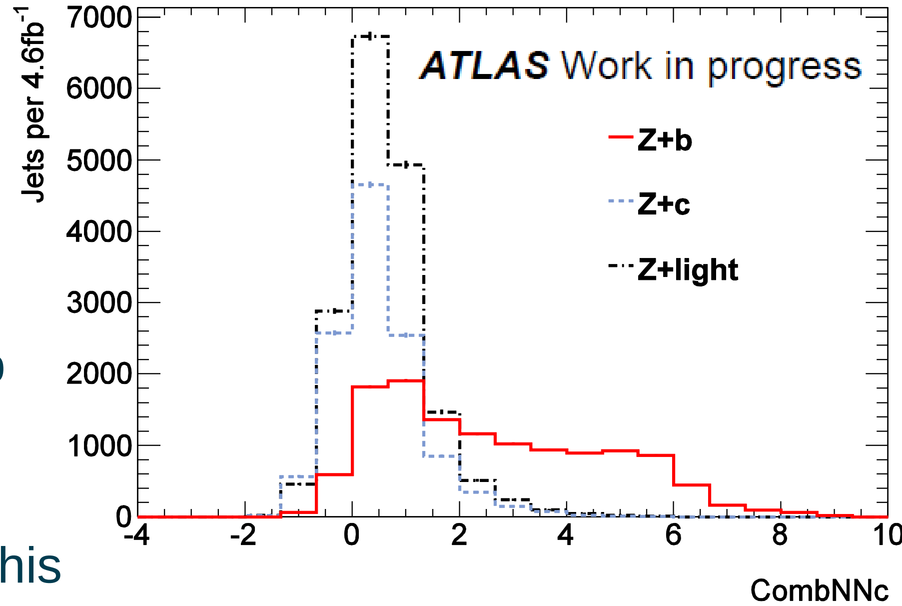
- Main backgrounds from:
  - Z + mis-tagged jets
  - $t\bar{t}$ & Diboson production
- Have $\not{E}_T < 70GeV$ cut to reduce $t\bar{t}$





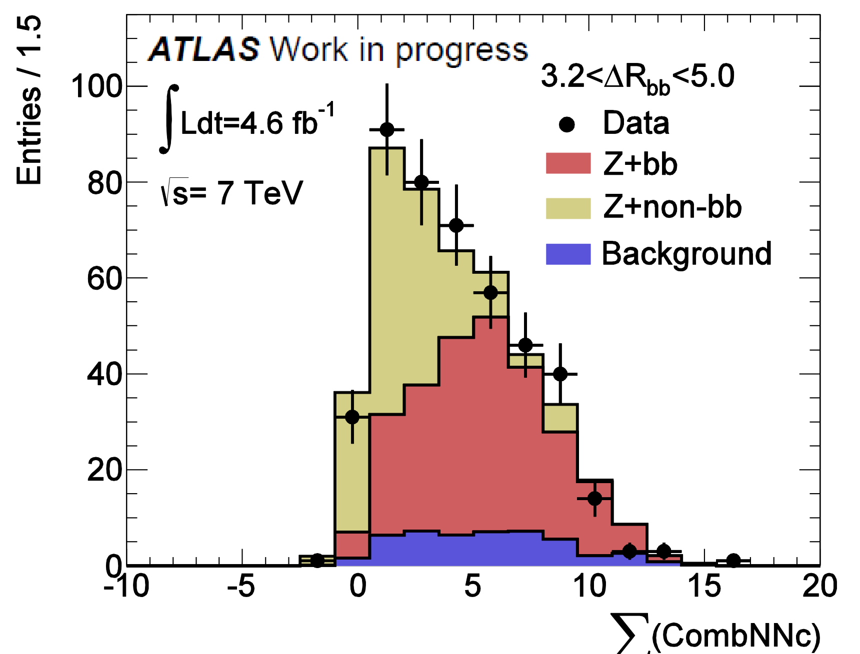
Extracting a $Z + b\bar{b}$ yield

- Extract yield by performing extended-likelihood fit, using jet flavour discriminating variable, CombNNc=$\ln(^{p_b}/_{p_c})$, where
  - p_b: probability jet is a b-jet
  - Sum over both tagged jets for $Z + b\bar{b}$
  - $\ln {}^{p_b}/_{p_c}$ has different shape for b and non-b jets



- Use Monte Carlo to construct templates of this variable for different jet flavours
  - Form bb and non-bb templates

- Fit to the data distribution of $\sum CombNNc$
  - Extract number of $Z + b\bar{b}$ events
  - Backgrounds included as a fixed template



- For differential cross sections perform fit in bins of the differential variable

Unfolding

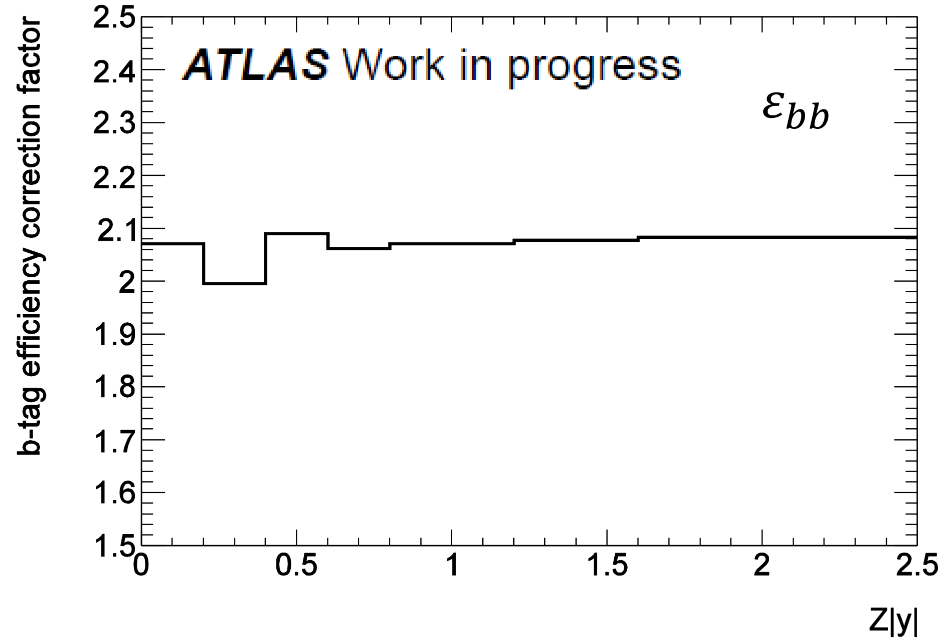
- Need to account for detector level effects on yield
  - Detector resolution, inefficiencies, acceptance etc.

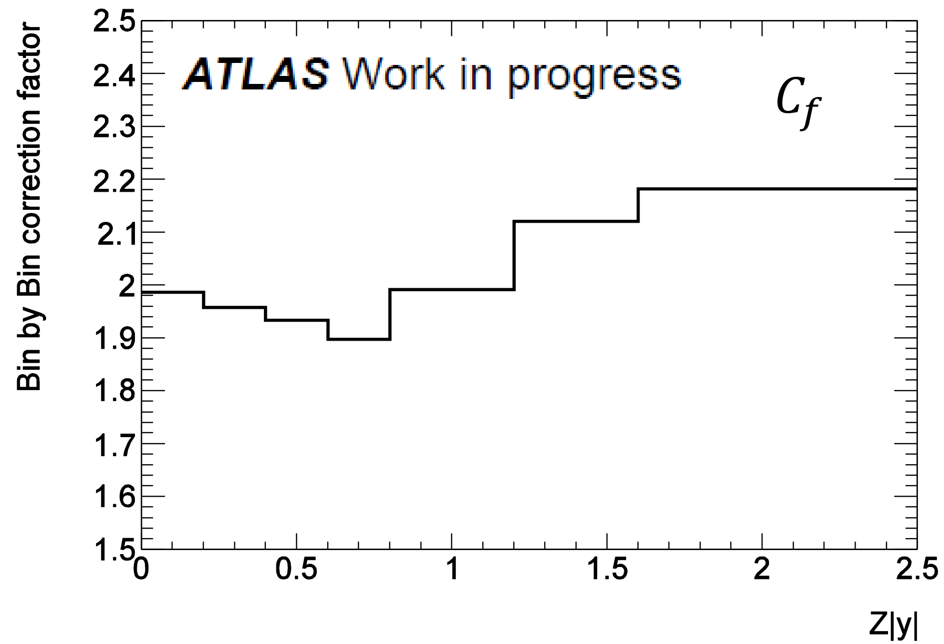
- Keep particle level selection close to detector event selection

- Split into two unfolding factors:
  - correction for b-tagging inefficiency, ε_{bb}
  - bin-by-bin correction factors, C_f

- Correct $Z + b\bar{b}$ yield, N_{bb}

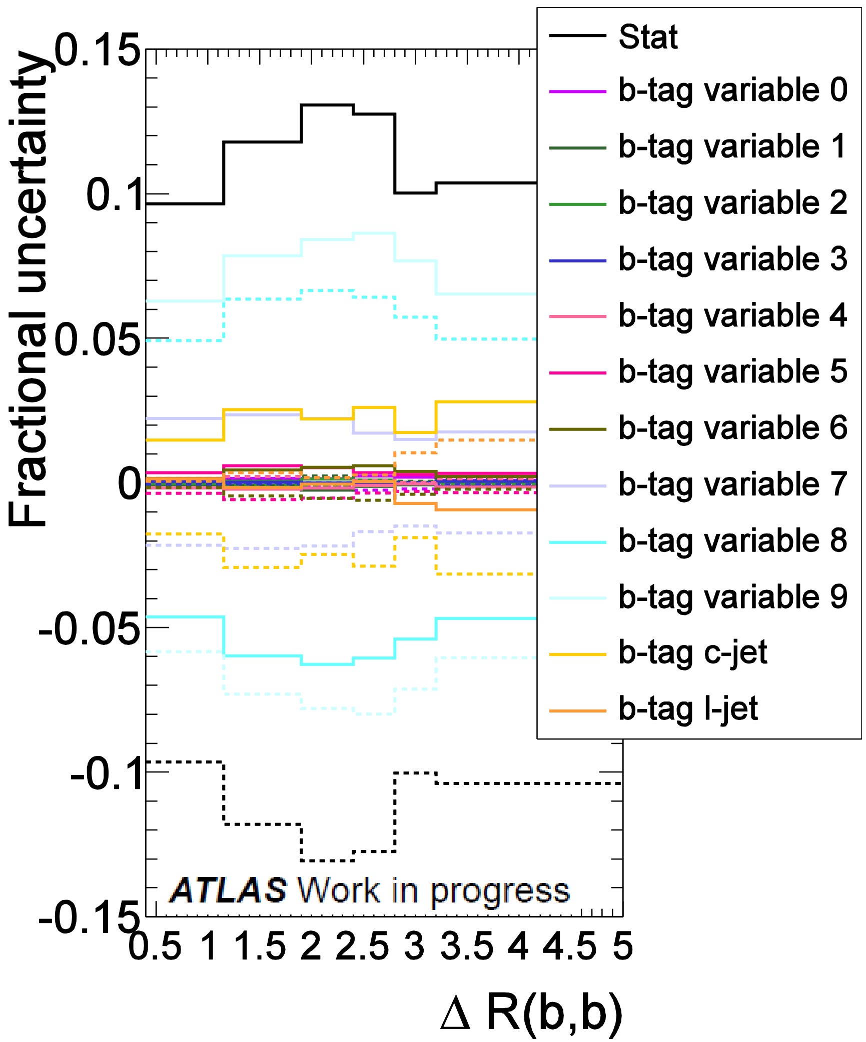
$$\sigma = \frac{N_{bb} \times C_f \times \varepsilon_{bb}}{\mathcal{L}}$$

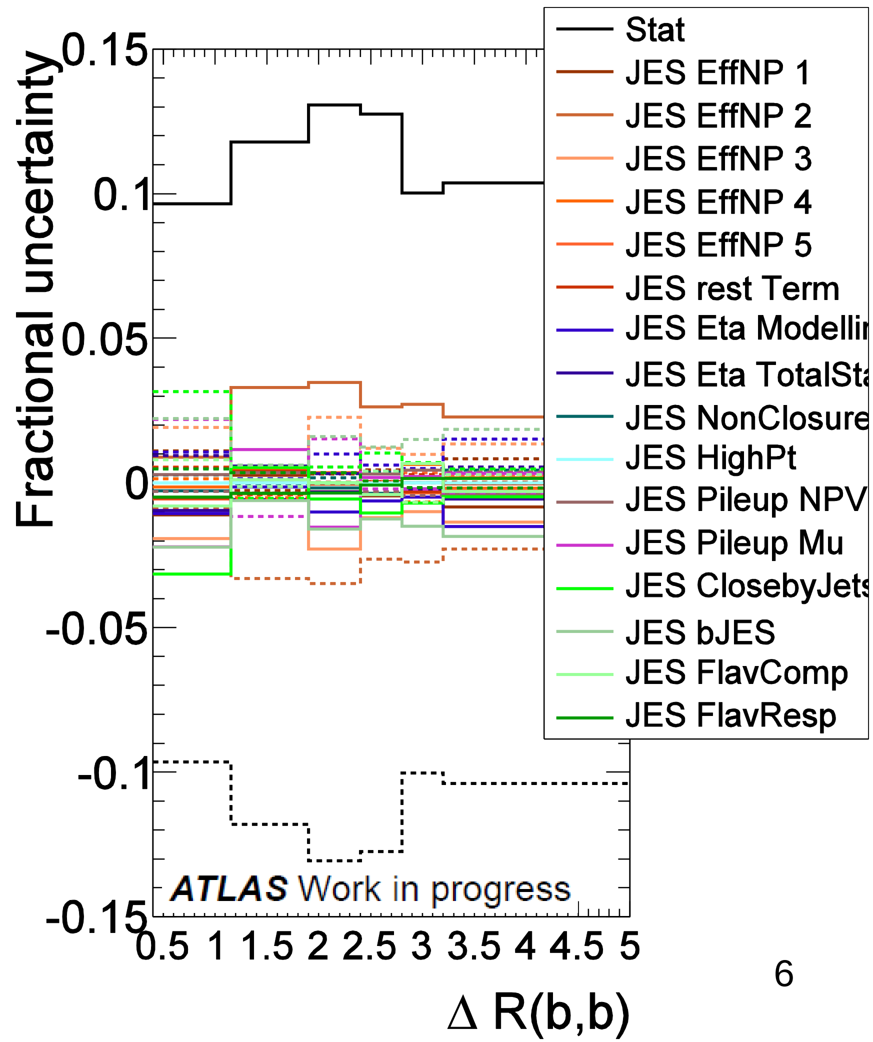




Systematics

- Systematics can affect the fit and the unfolding
- Each systematic source is varied independently & propagated through the analysis
  - ➢ Relative change from default is taken as uncertainty
  - ➢ b-tagging(left), Jet energy scale (right) and all other systematics (next slide)



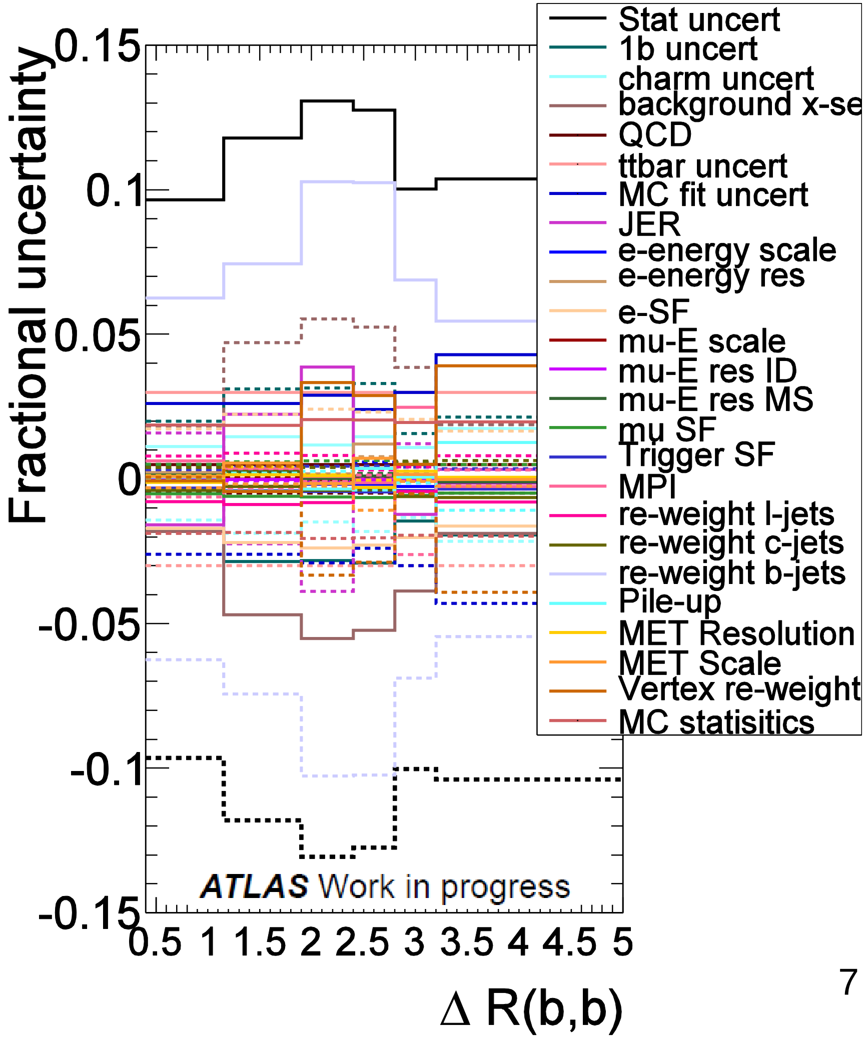


Systematics

- Systematics can affect the fit and the unfolding
- Each systematic source is varied independently & propagated through the analysis
  - ➢ Relative change from default is taken as uncertainty

- Dominant systematics:
  - ➢ b-tagging
  - ➢ b-template shape uncertainty

- Individual systematics all smaller than statistical uncertainty



Theory Predictions

Compare to NLO theory predictions:

- MCFM parton level NLO calculation
  - Corrected for non-perturbative effects
  - Corrected for QED final state radiation

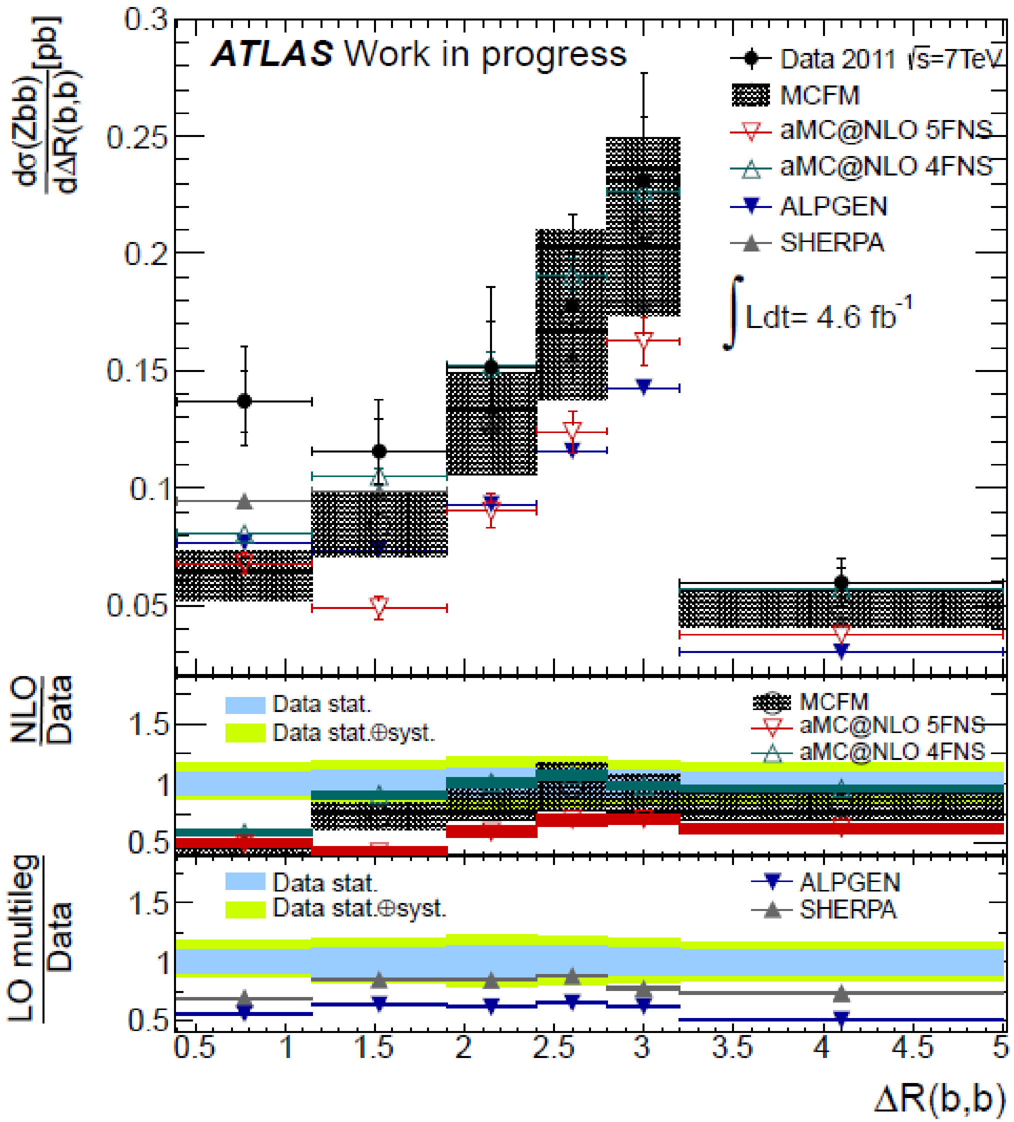
- aMC@NLO, NLO merged to parton shower
  - 4FNS (massive b-quark) and 5FNS calculations
  - Showered and hadronized with Herwig++

Compare to LO multi-leg predictions:

- Alpgen
- Sherpa

Comparison with theory predictions

- Example here shown comparison between data and theory for ΔR_{bb} distribution



Conclusions

- Have measured first differential cross sections for $\boldsymbol{Z + b\bar{b}}$ production using 2011 data

- Predictions agree reasonably well with data within uncertainties

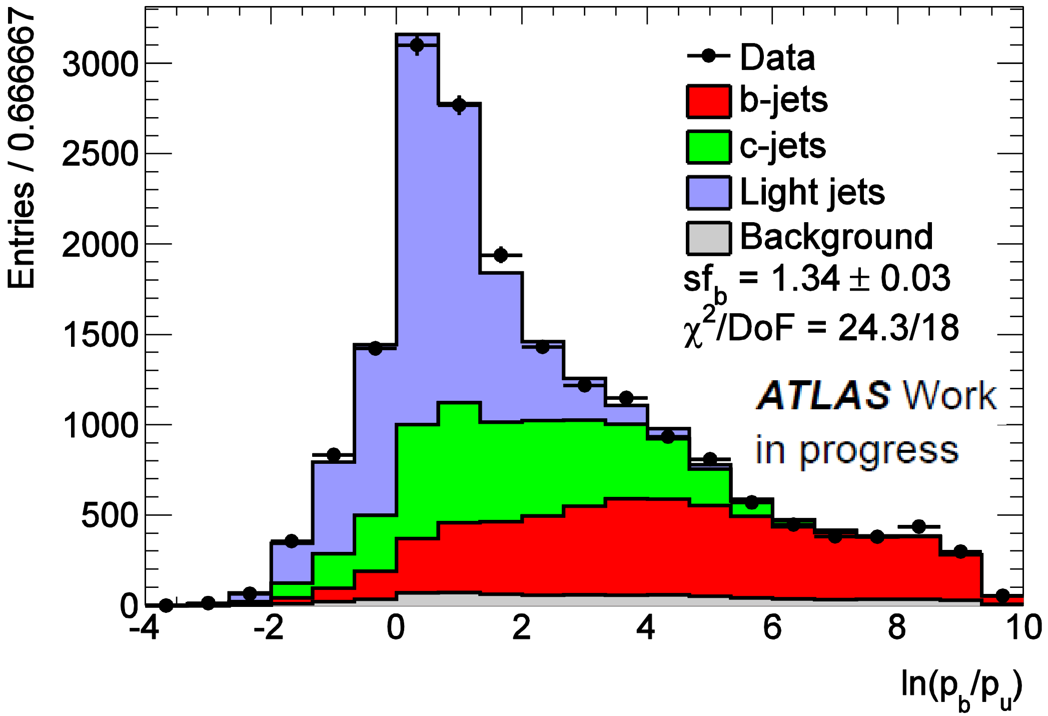
- With higher recorded luminosity in 2012 can improve the statistical precision of measurement

Backups

Fit Caveat: single-b scale factor

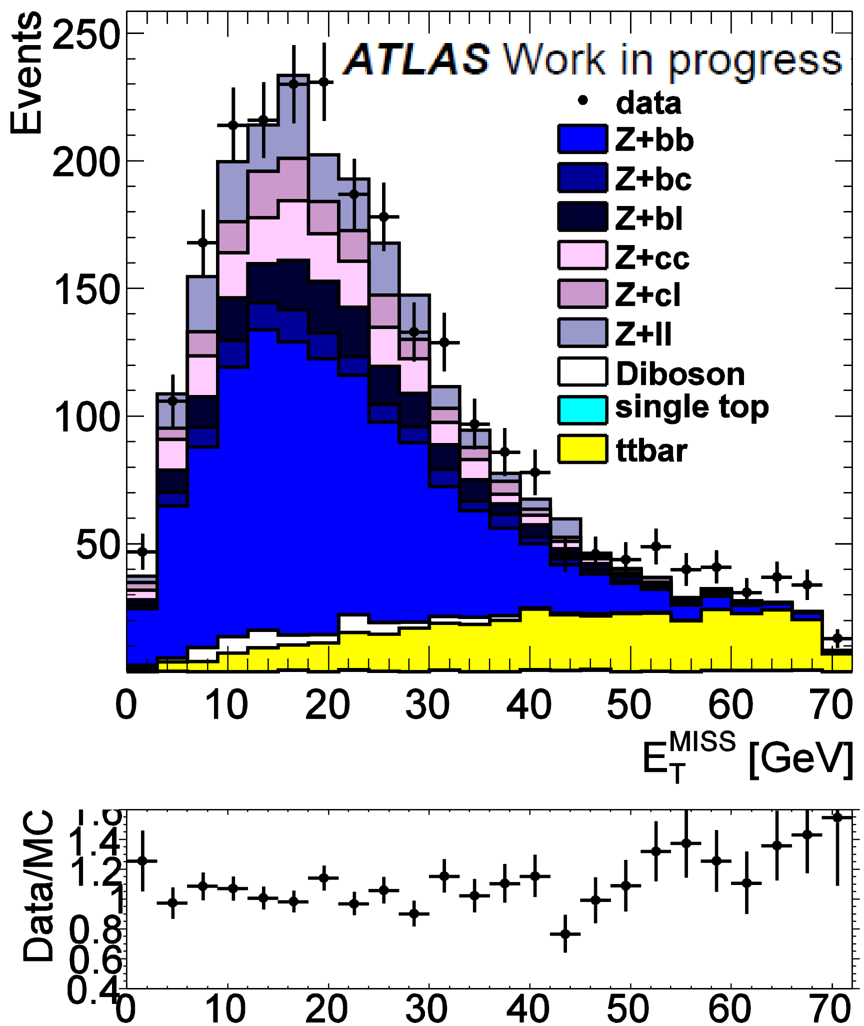
- As mentioned at beginning this analysis is in conjunction with Z+b analysis
- Found MC under predicts Z+b events
  - Need to adjust our Z+bc and Z+bl templates in $Z + b\bar{b}$ fit to account for this
- Define Control region Z+b+1jet, extra jet(s) not tagged
  - Extra (non-tagged) jet(s) to accurately represent our event kinematics
- Fit flavour discriminating variable for the tagged jet, $\ln(^{p_b}/_{p_u})$

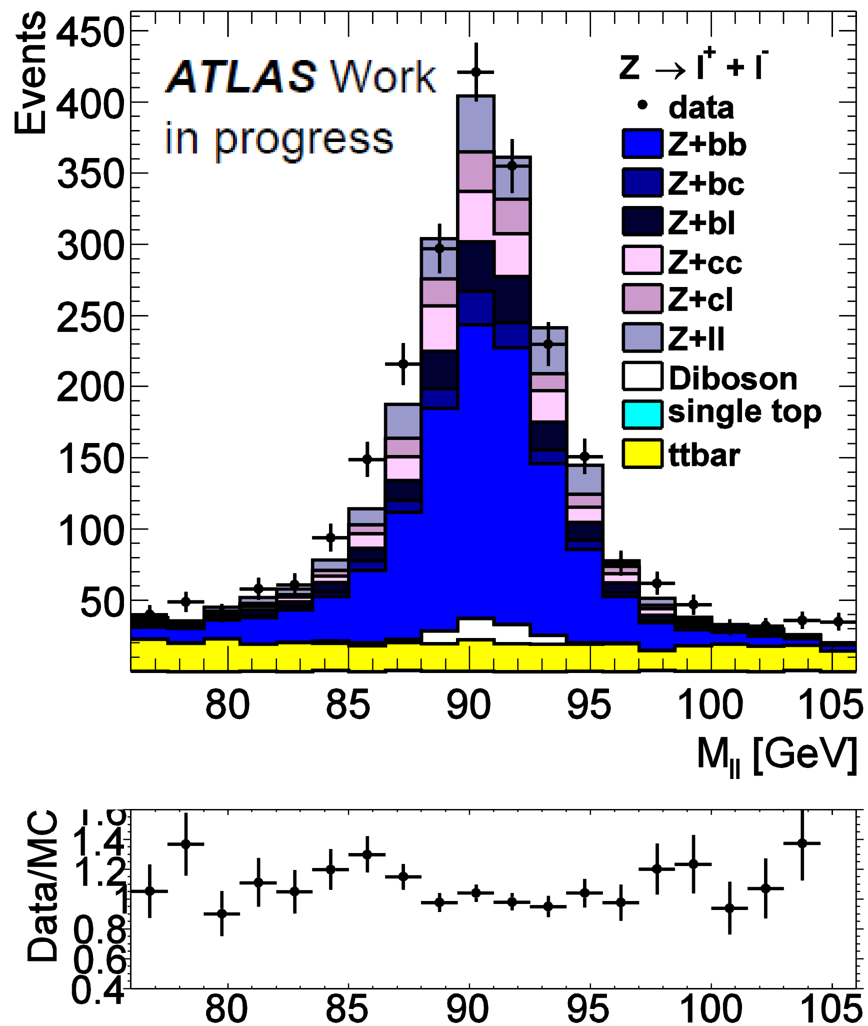
- Fit c-jets separately from light jets (also check Z+c contribution)
- Have to scale up Z+b contribution in MC to fit to data
- Find need to scale bc & bl contributions in $Z + b\bar{b}$ fit by 1.34



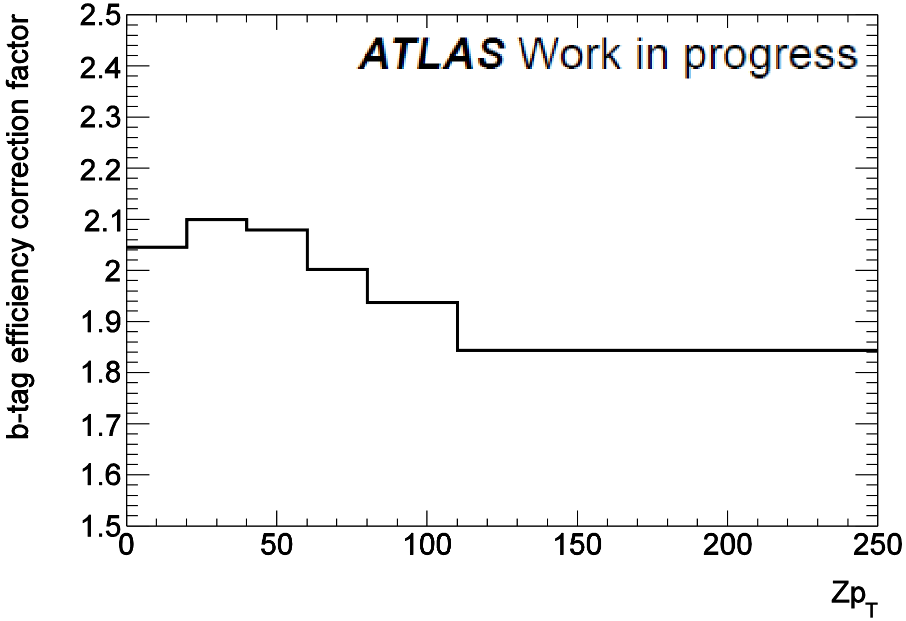
Control plots

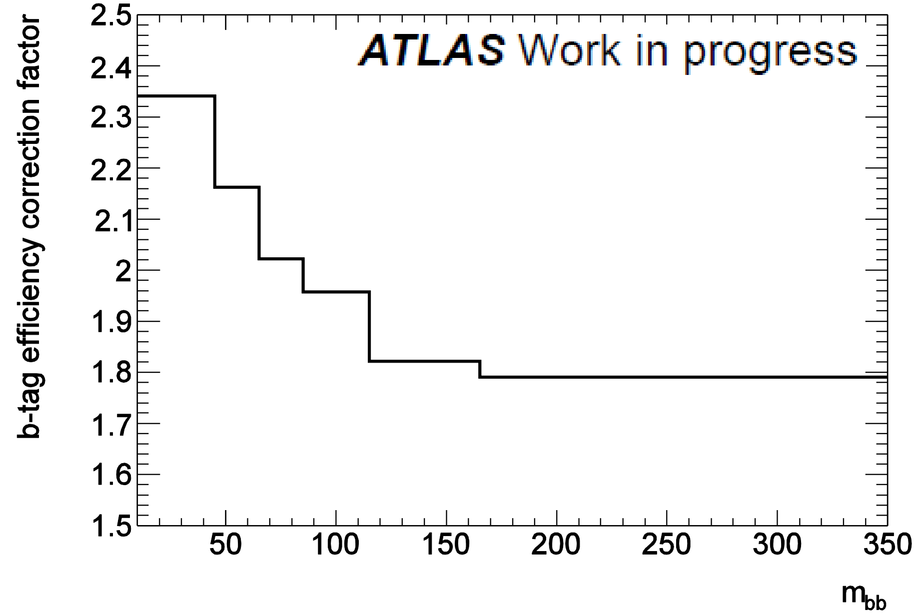
- The two lepton channels are combined before fitting
  - Increases available statistics
  - Lepton specific systematics small compared to shared systematics

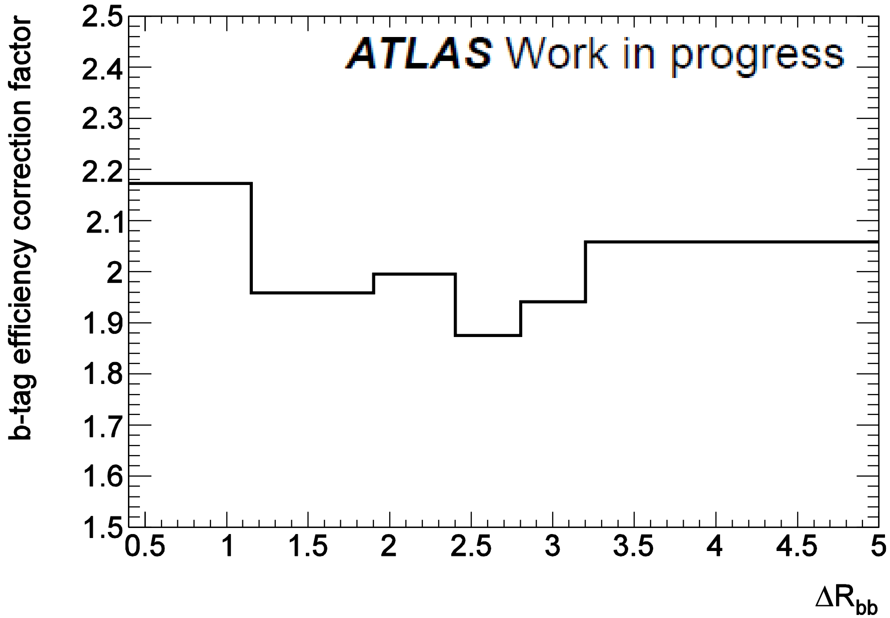




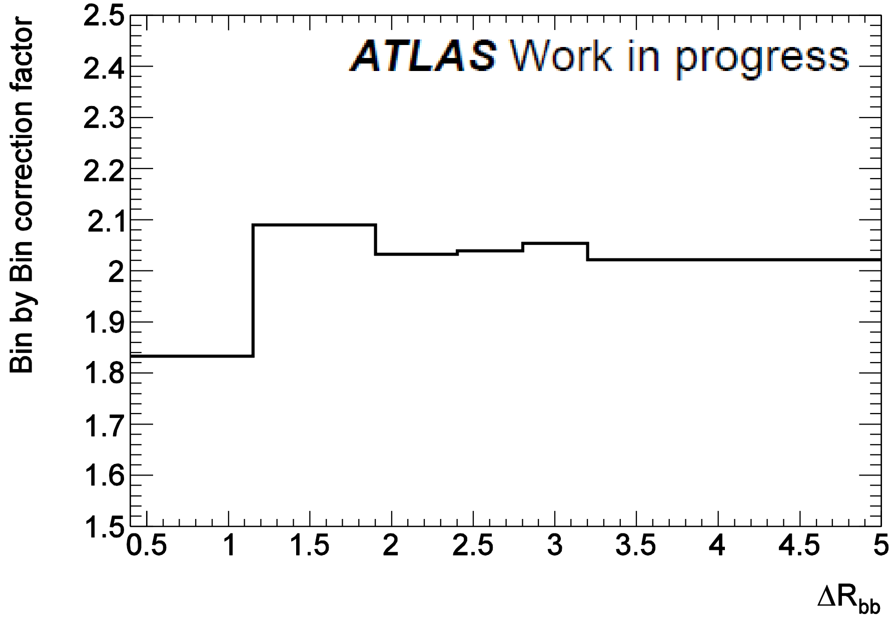
B-tag efficiency other variables

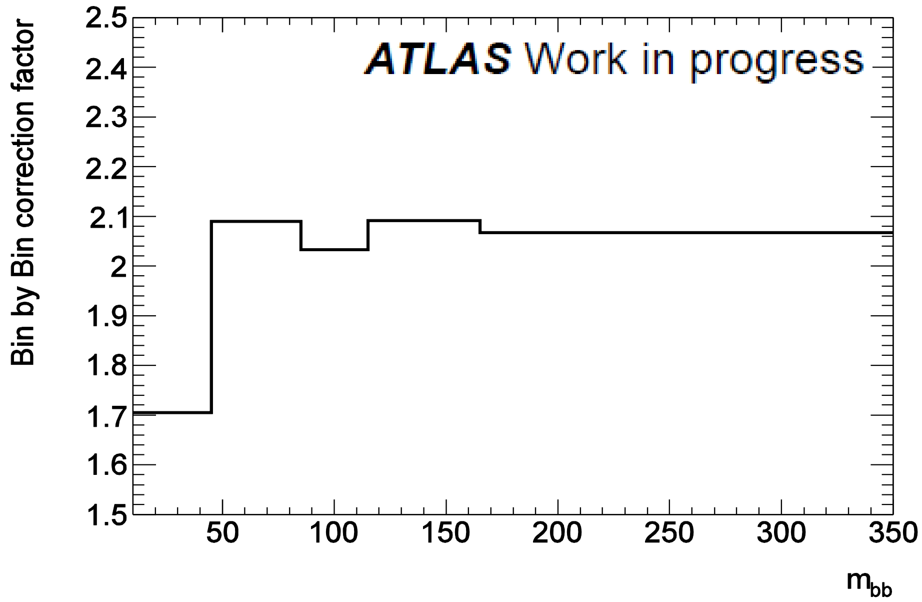


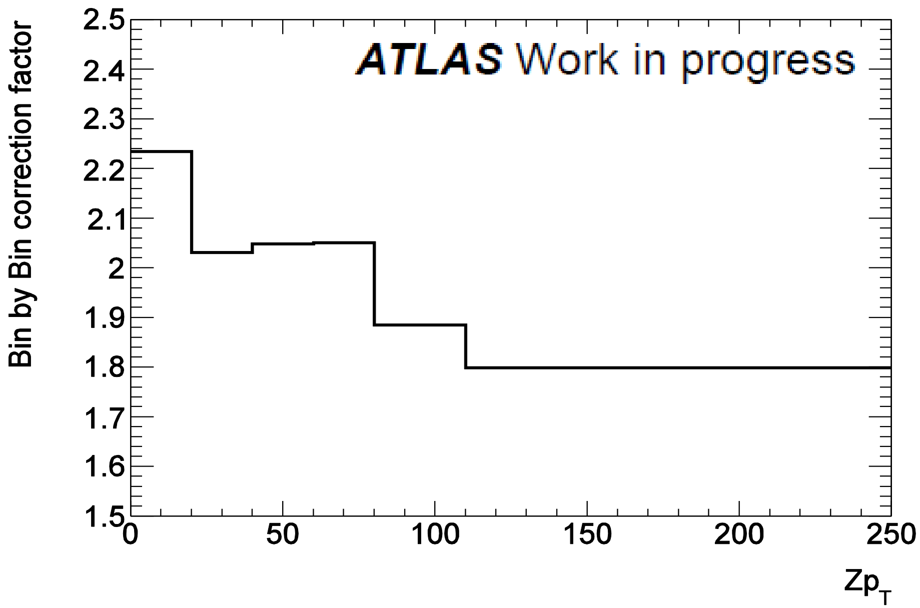




Correction factor other variables

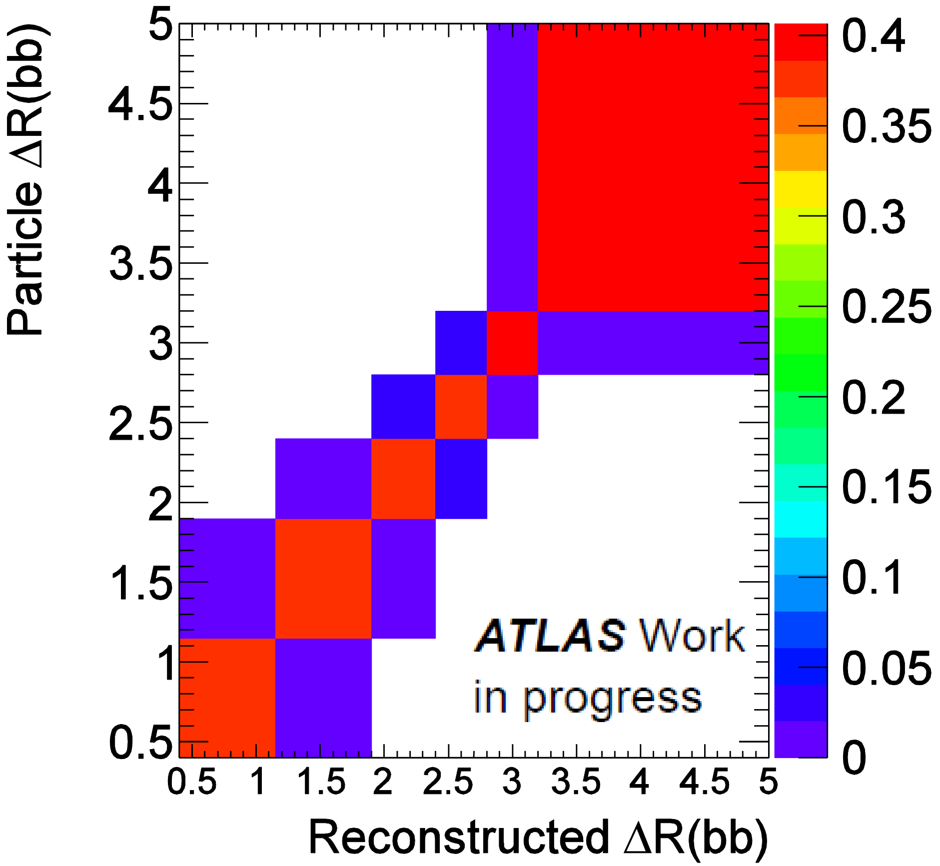






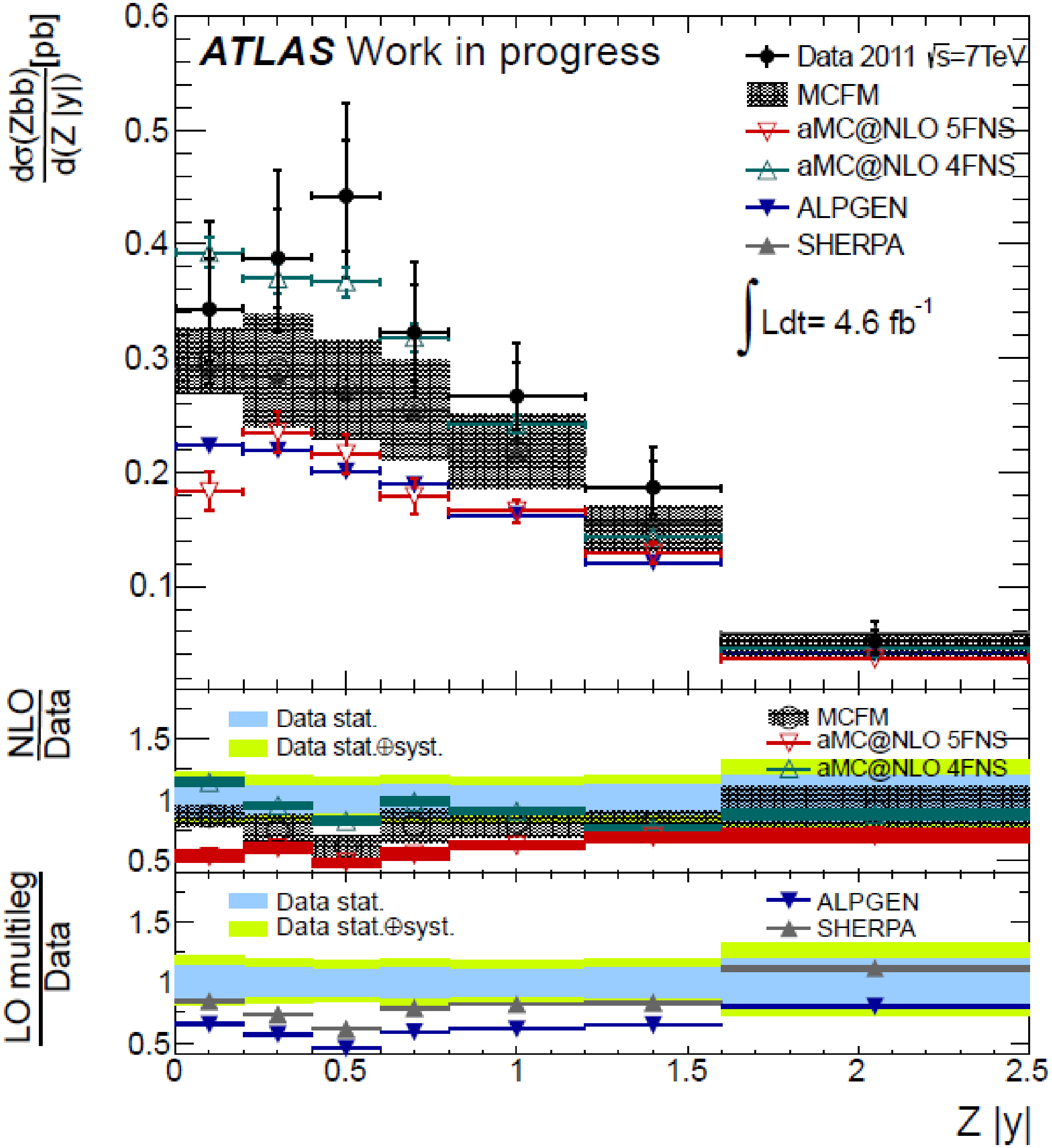
Unfolding

- Choose bin-by-bin unfolding by default
  - Have minimal migrations between bins
  - Results in diagonal migration matrix



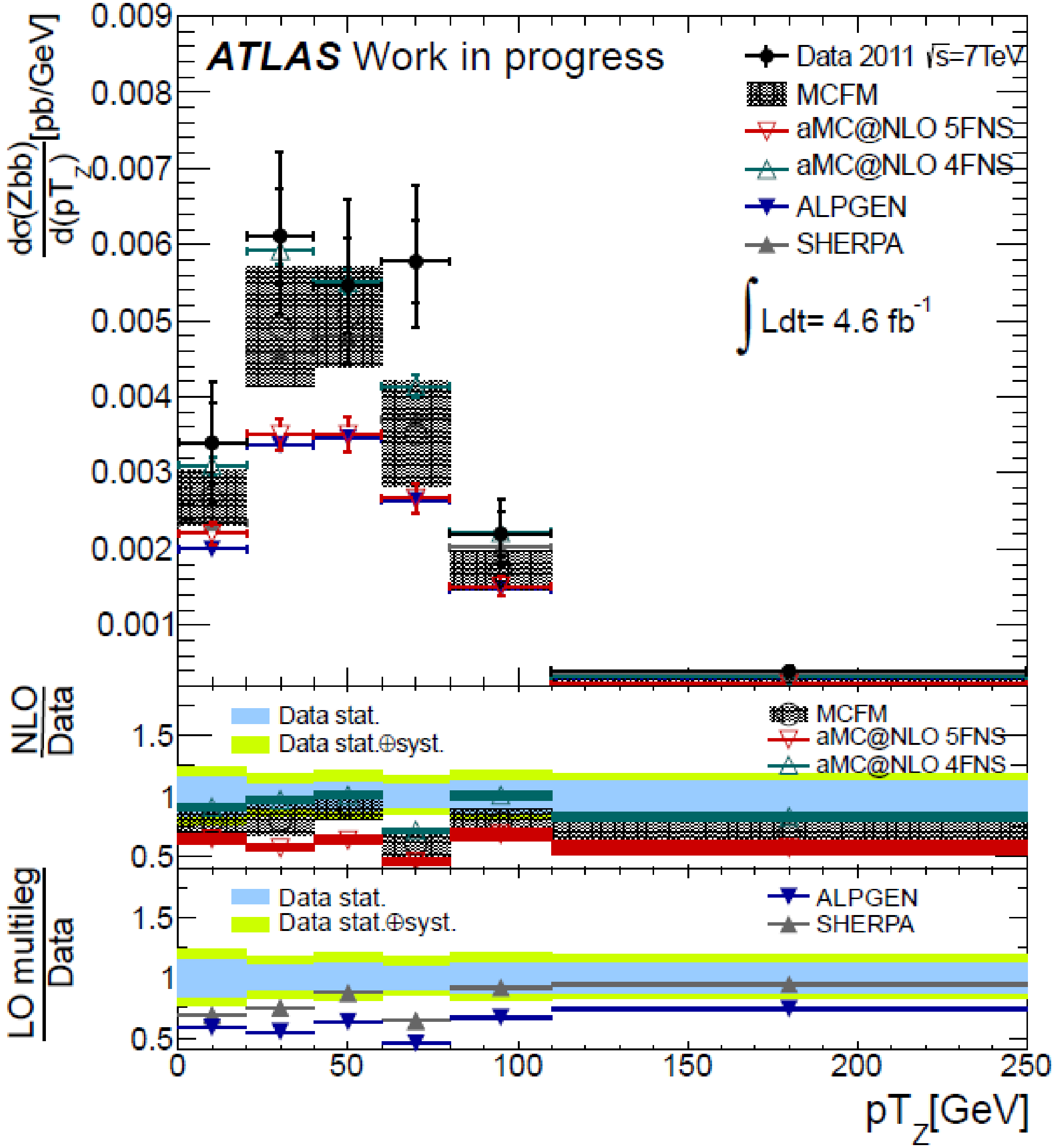
- Matrix shows probability particle level selection is reconstructed in certain detector level bin

Results $Z_{|y|}$



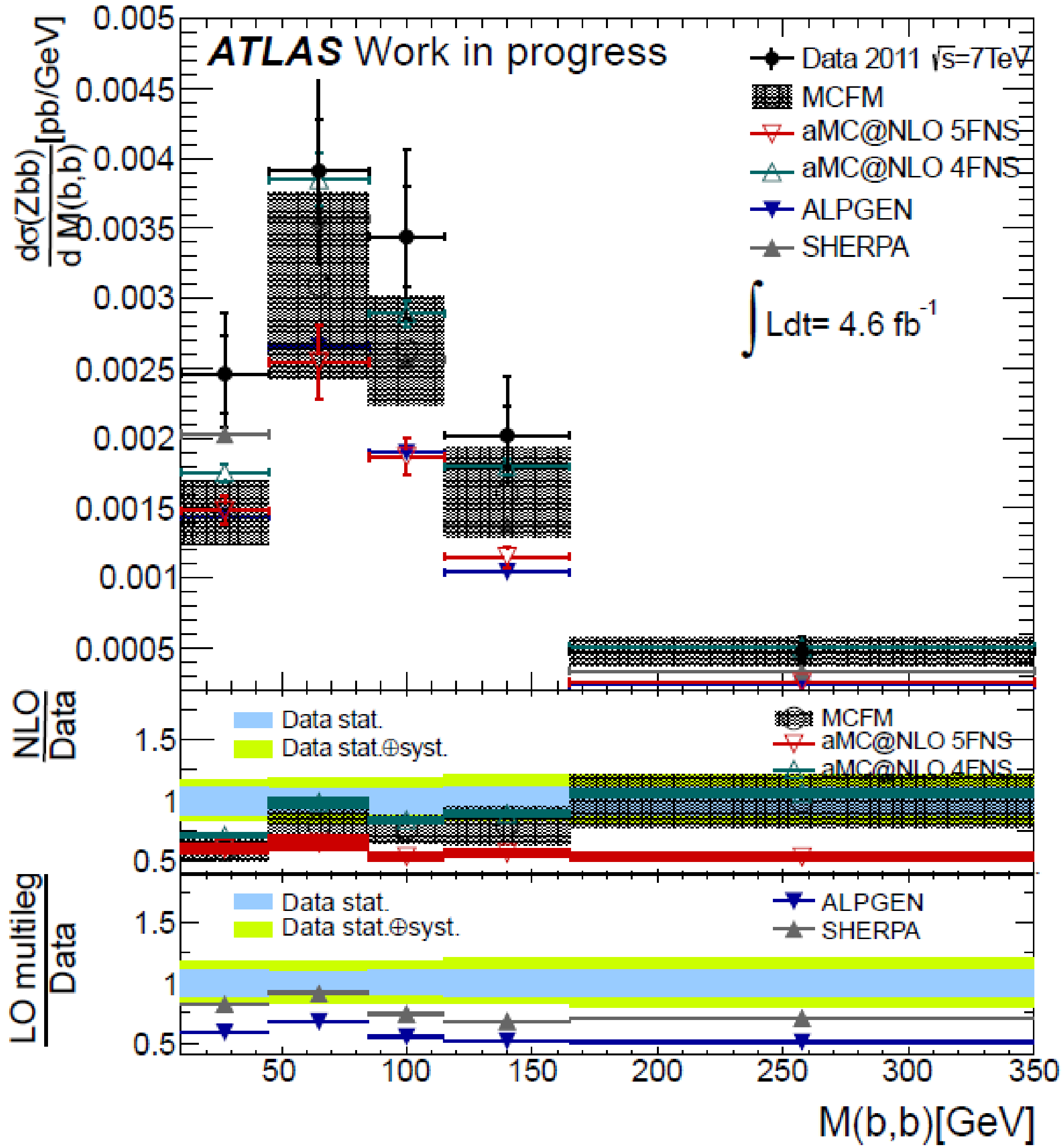
ATLAS Work in progress
Data 2011 √s=7TeV
MCFM
aMC@NLO 5FNS
aMC@NLO 4FNS
ALPGEN
SHERPA
∫Ldt= 4.6 fb⁻¹
dσ(Zbb)/d(Z |y|) [pb]
0.6
0.5
0.4
0.3
0.2
0.1
NLO/Data
Data stat.
Data stat.⊕syst.
MCFM
aMC@NLO 5FNS
aMC@NLO 4FNS
1.5
1
0.5
LO multileg/Data
Data stat.
Data stat.⊕syst.
ALPGEN
SHERPA
1.5
1
0.5
0
0.5
1
1.5
2
2.5
Z |y|

Results Zp_T



ATLAS Work in progress
Data 2011 √s=7TeV
MCFM
aMC@NLO 5FNS
aMC@NLO 4FNS
ALPGEN
SHERPA
∫Ldt= 4.6 fb⁻¹
dσ(Zbb)/d(pT_Z) [pb/GeV]
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
NLO/Data
Data stat.
Data stat.⊕syst.
MCFM
aMC@NLO 5FNS
aMC@NLO 4FNS
1.5
1
0.5
LO multileg/Data
Data stat.
Data stat.⊕syst.
ALPGEN
SHERPA
1.5
1
0.5
0
50
100
150
200
250
pT_Z[GeV]

Results M_{bb}



ATLAS Work in progress
Data 2011 √s=7TeV
MCFM
aMC@NLO 5FNS
aMC@NLO 4FNS
ALPGEN
SHERPA
∫Ldt= 4.6 fb-1
dσ(Zbb)/d M(b,b) [pb/GeV]
0.005
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
NLO/Data
Data stat.
Data stat.⊕syst.
MCFM
aMC@NLO 5FNS
aMC@NLO 4FNS
1.5
1
0.5
LO multileg/Data
Data stat.
Data stat.⊕syst.
ALPGEN
SHERPA
1.5
1
0.5
50
100
150
200
250
300
350
M(b,b)[GeV]

b-tagging

- B-tagging of jets makes use of tracks associated with the jets
  - Impact parameters
  - secondary vertices

- B-tagging scale factors are applied to MC so that b-tagging efficiency is the same as in data
- These scale factors have uncertainties associated
  - Different methods of deriving scale factors
  - Each with their sources of uncertainties
  - These uncertainties are then combined into single set of uncorrelated uncertainties