Top quark mass measurements at the ATLAS experiment

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- 1D and 2D Template Methods
- Top Mass from Cross-Section
- All-hadronic Measurement
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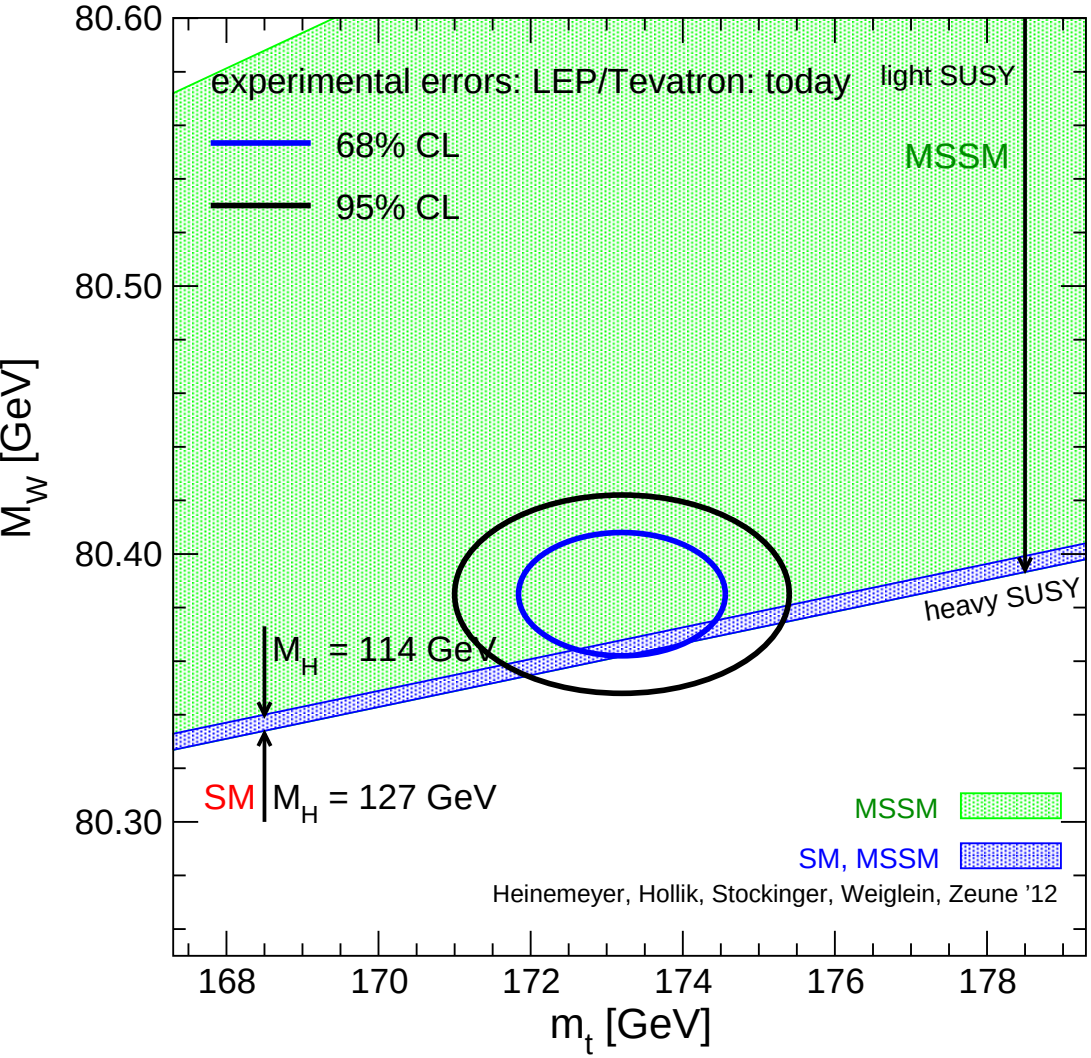
The Mass of the Top Quark



- The mass of the top quark has been measured with high precision ($< 1\%$) at CDF and D0
- It is an important quantity for standard model precision fits
- The top quark plays an important role in many extensions of the standard model

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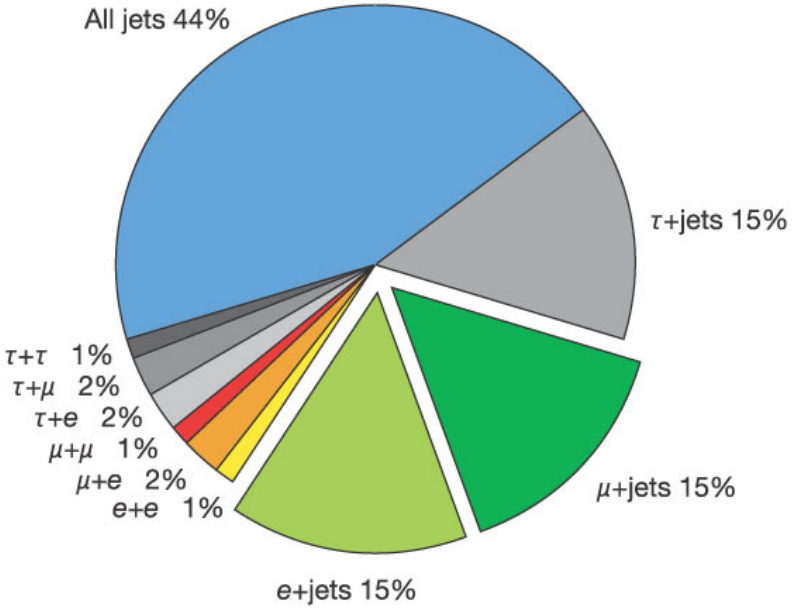
This Presentation

- Several measurements using 2010 and 2011 data
- Three use the lepton+jets decay channel of the top pair
- One additional measurement in the all-hadronic channel

Method	Year	$\mathcal{L}_{\text{Int.}}$
1D template fit	2011	$1\,\text{fb}^{-1}$
2D template fit	2011	$1\,\text{fb}^{-1}$
m_{top} from σ_{top}	2010	$35\,\text{pb}^{-1}$
All hadronic	2011	$2\,\text{fb}^{-1}$

- Combination of the two template measurements



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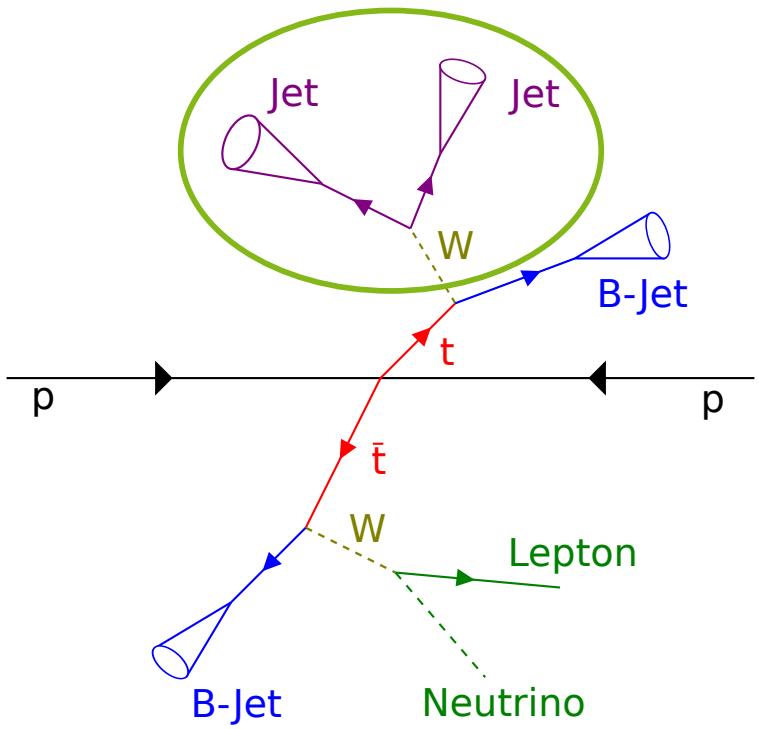
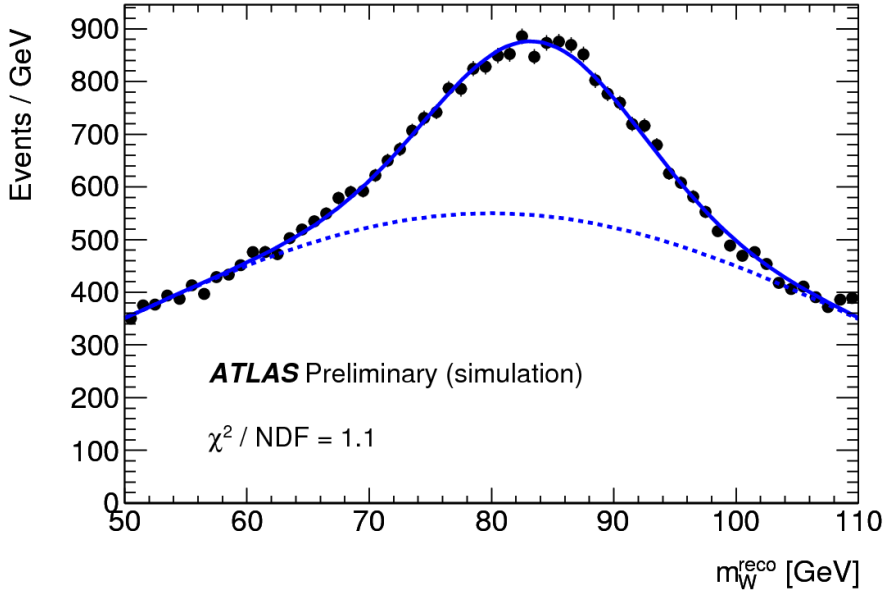
Description of the 2D Method

- Simultaneously determine m_{top} and a jet scale factor (JSF) with shape fits of invariant mass of top and W candidate
  - Build 2-jet mass of all untagged jets
  - Combine each 2-jet mass with each b-tagged jet, keep the combination with the highest p_T
  - Use well known mass and width of W to constrain α

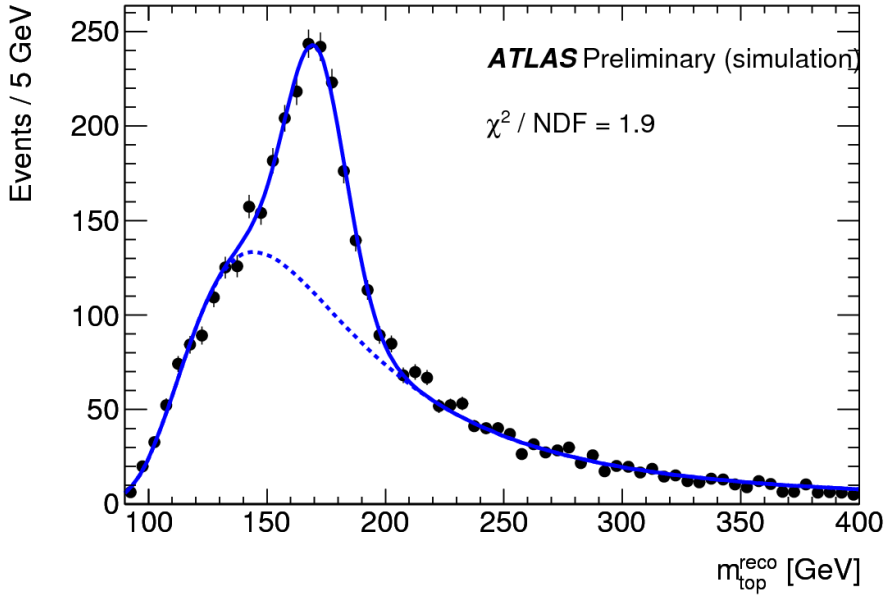


$$\chi^2(\alpha_1, \alpha_2) = \left[\frac{E_1(1-\alpha_1)}{\sigma_1}\right]^2 + \left[\frac{E_2(1-\alpha_2)}{\sigma_2}\right]^2 + \left[\frac{M_{12}(\alpha_1, \alpha_2) - m_W}{\Gamma_W}\right]^2$$

Signal and Background Parametrisations



Template	Signal	Background
m_W^{reco}	Gauss	Gauss
m_{top}^{reco}	Gauss	Landau



- Knowledge of $\alpha_{1,2}$ only propagated to m_{top}
- Retains full sensitivity to JSF in m_W but mediates effect of JES for m_{top}

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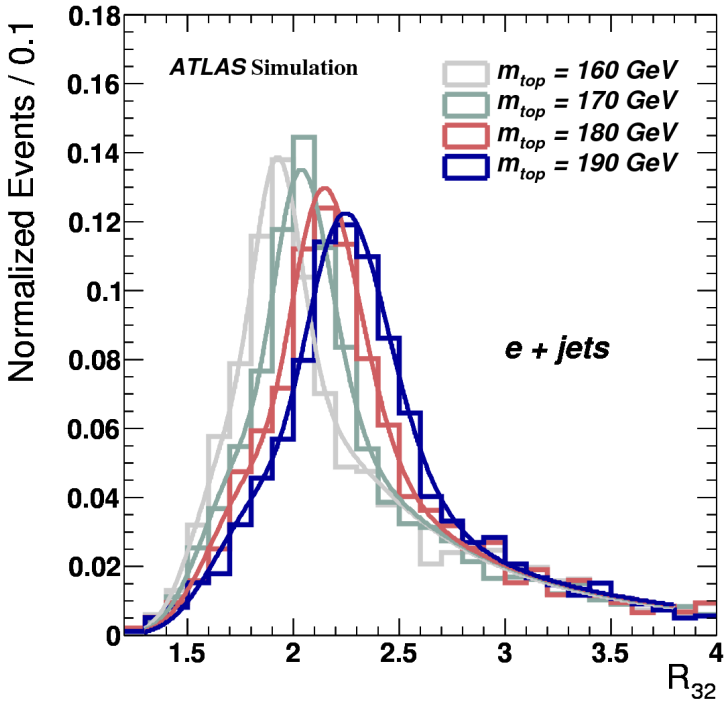
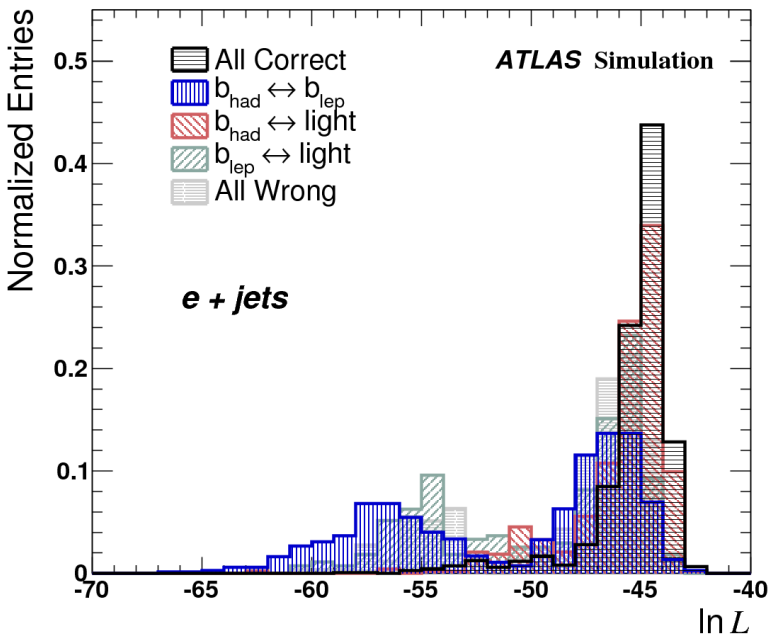
Description of the 1D Method

- Do a template fit to a variable which is less sensitive to JES
  - Use of $R_{32} = \frac{m_{\text{top}}^{\text{reco}}}{m_{\text{W}}^{\text{reco}}}$
  - The jet pair/triplet is chosen with a kinematic fit using the full event topology as well as b-tagging information





Systematic uncertainties

- Systematics are evaluated by changing the quantity by $\pm 1\sigma$
- Pseudoexperiments are performed to estimate each uncertainty

- Dominating uncertainties
  - Jet energy scales
  - Signal MC generator
  - Modelling of initial and final state radiation

Systematic	1d analysis Δm_{top} [GeV] e+jets	1d analysis Δm_{top} [GeV] μ+jets	2d analysis Δm_{top} [GeV] e+jets	2d analysis Δm_{top} [GeV] μ+jets
JSF	n.a.	n.a.	0.59	0.51
Method Calibration	0.07	<0.05	0.10	<0.05
Signal MC Generator	0.81	0.69	0.39	0.22
Hadronisation	0.33	0.52	0.20	0.06
Pileup	<0.05	<0.05	<0.05	<0.05
Underlying event	0.06	0.10	0.42	0.96
Color reconnection	0.47	0.74	0.32	1.04
ISR and FSR (signal)	1.45	1.40	1.04	0.95
Proton PDFs	0.22	0.09	0.10	0.10
W+jets background normalization	0.16	0.19	0.34	0.44
W+jets background shape	0.11	0.18	0.07	0.22
QCD background normalization	0.07	<0.05	0.25	0.33
QCD background shape	0.14	0.12	0.38	0.30
Jet energy scale	1.21	1.25	0.63	0.71
b-jet energy scale	1.09	1.21	1.61	1.53
b-tagging efficiency and mistag rate	0.21	0.13	0.31	0.26
Jet energy resolution	0.34	0.38	0.07	0.07
Jet reconstruction efficiency	0.08	0.11	<0.05	<0.05
Missing transverse energy	<0.05	<0.05	0.12	0.16
Total systematic uncertainty	2.46	2.56	2.31	2.57

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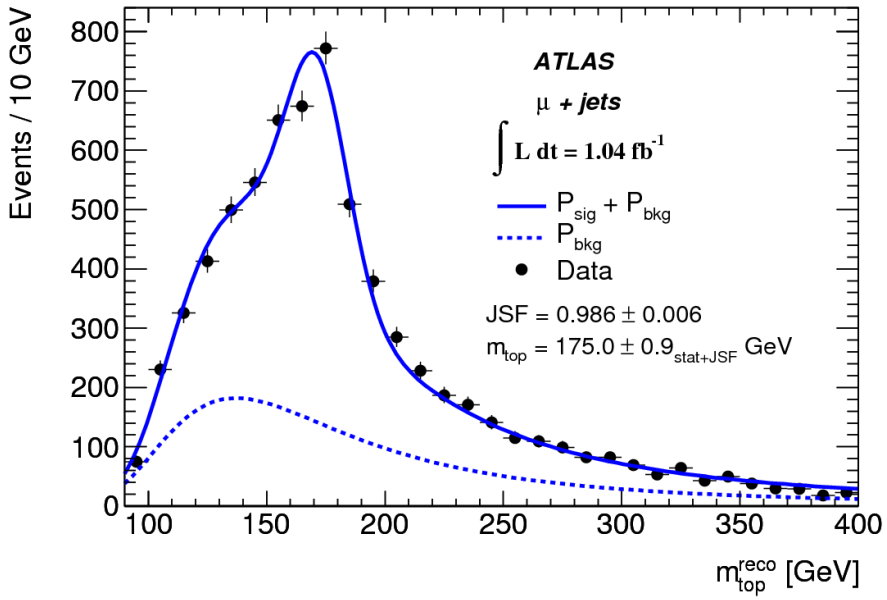
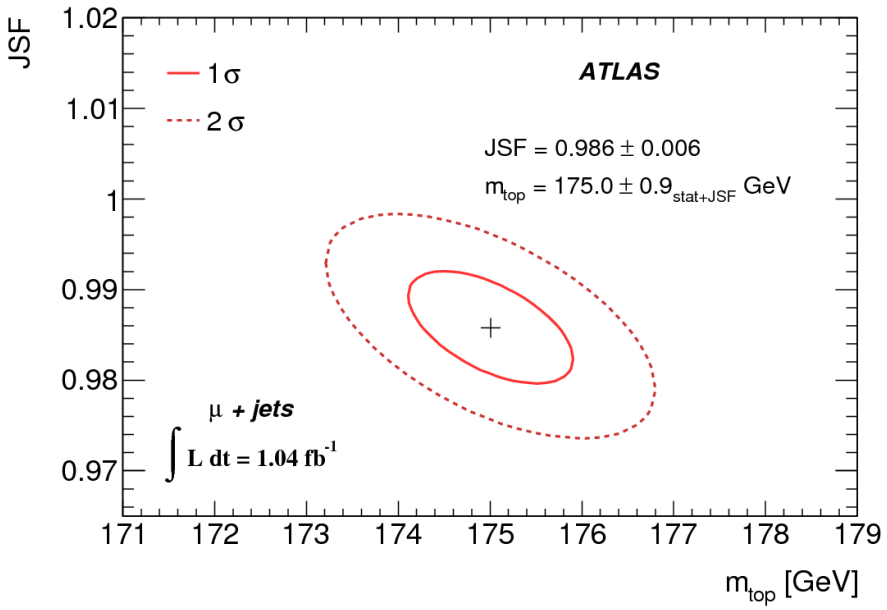
Results - 2D Template





- Both channels in good agreement with each other
- JSF modelled with an accuracy of 1%

	m_{top} [GeV]	JSF	ρ
electron	$174.3 \pm 1.0_{\text{stat}} \pm 2.2_{\text{syst}}$	0.985 ± 0.008	-0.6
muon	$175.0 \pm 0.9_{\text{stat}} \pm 2.5_{\text{syst}}$	0.986 ± 0.006	-0.6

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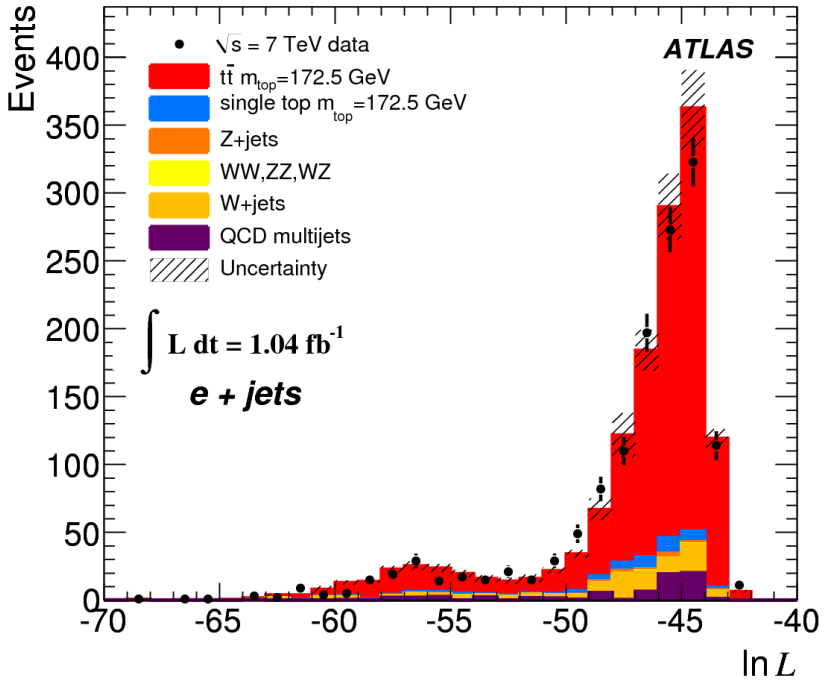
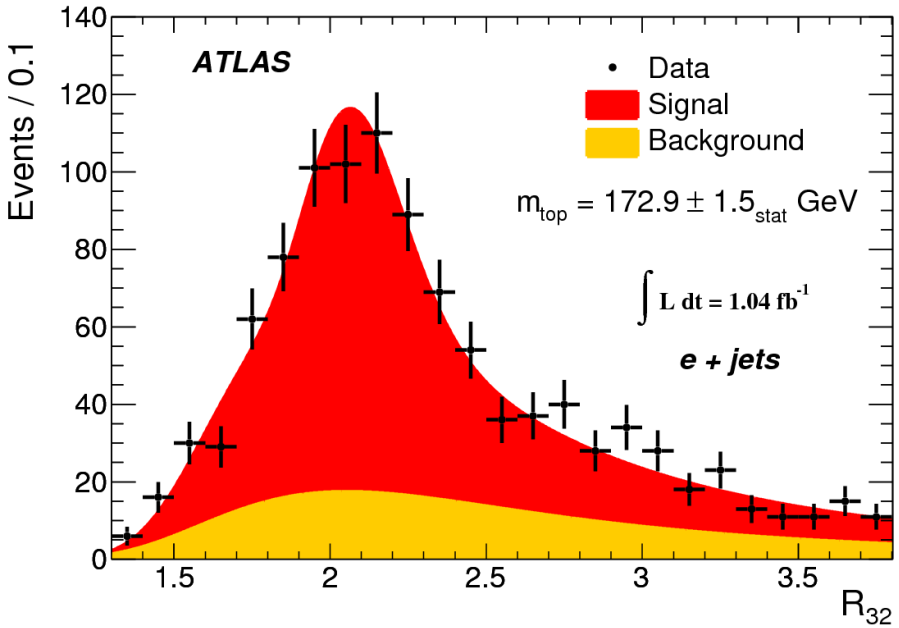
Results - 1D Template





- Good description of likelihood
- Results in agreement with each other

	m_{top} [GeV]
electron	$172.9 \pm 1.5_{\text{stat}} \pm 2.5_{\text{syst}}$
muon	$175.5 \pm 1.1_{\text{stat}} \pm 2.6_{\text{syst}}$

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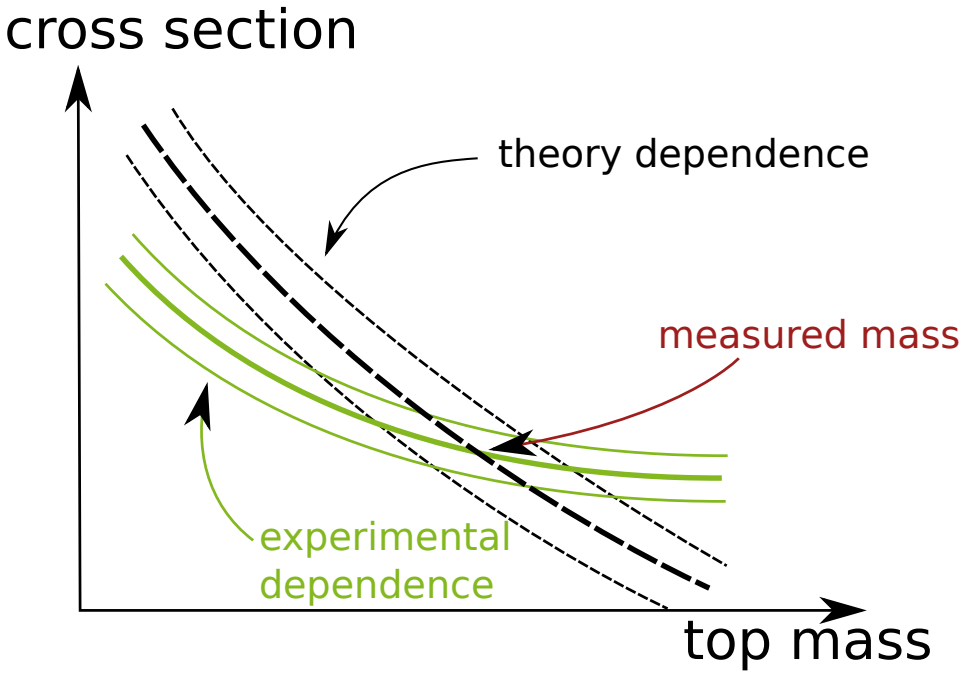
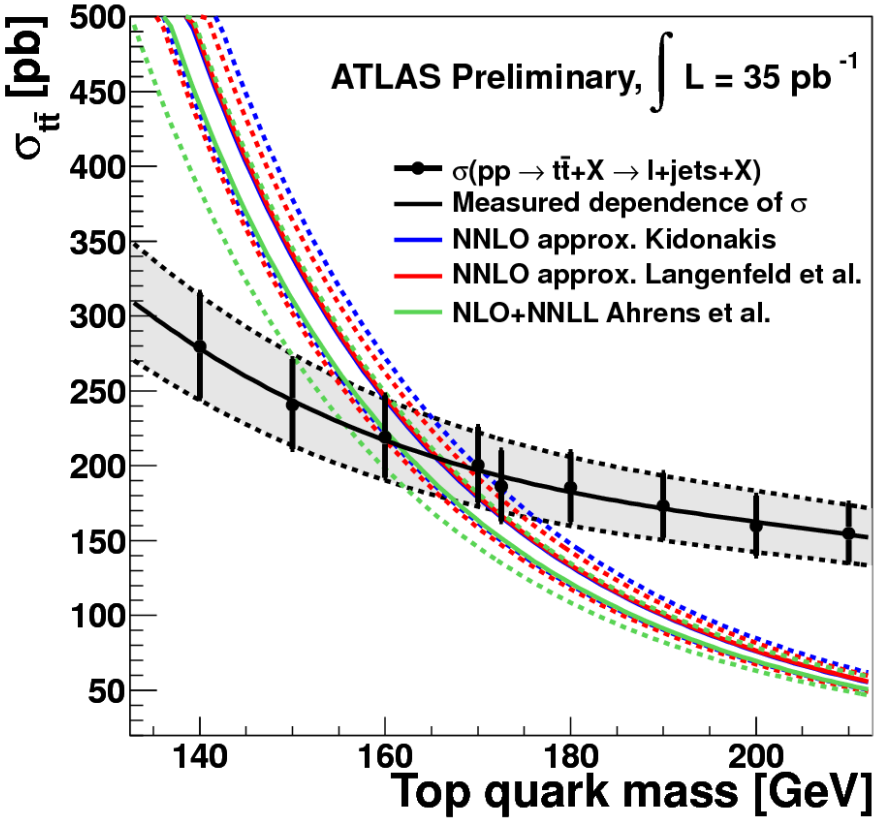
Description of the Method

- The top cross-section depends on the top mass
- Theory prediction has different dependence than measurement

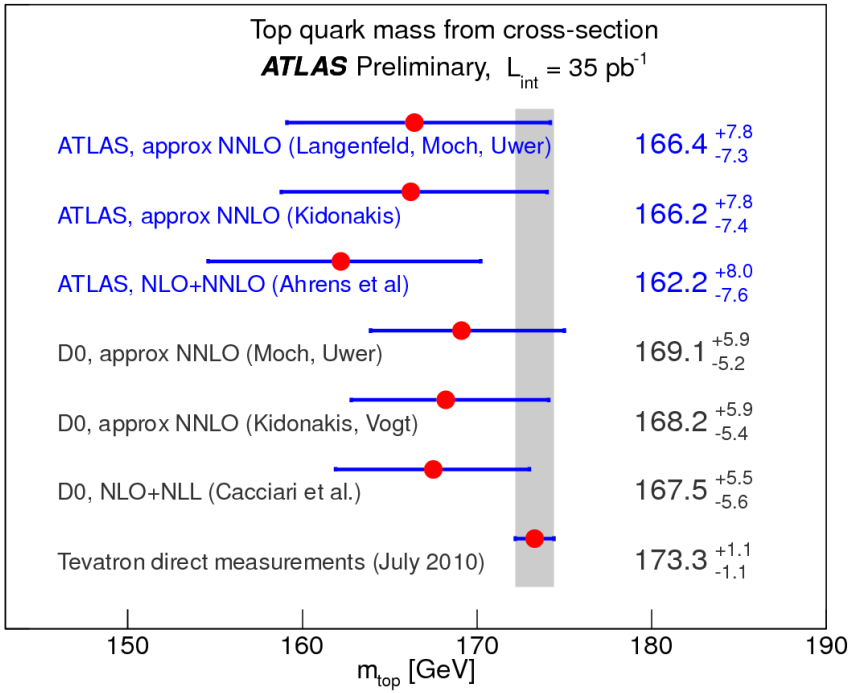
- Repeat cross-section measurement with multiple top mass hypotheseses
- Parametrize experimental and theory curves
- Extract well-defined pole mass instead of “MC generator mass”



Results



- Build uncorrelated likelihood $f(m_{\text{top}}) \propto \int f_{\text{th}}(\sigma \mid m_{\text{top}}) f_{\text{exp}}(\sigma \mid m_{\text{top}}) \mathrm{d}\sigma$
- The maximum of this likelihood determines the extracted $m_{\text{top}}^{\text{pole}}$



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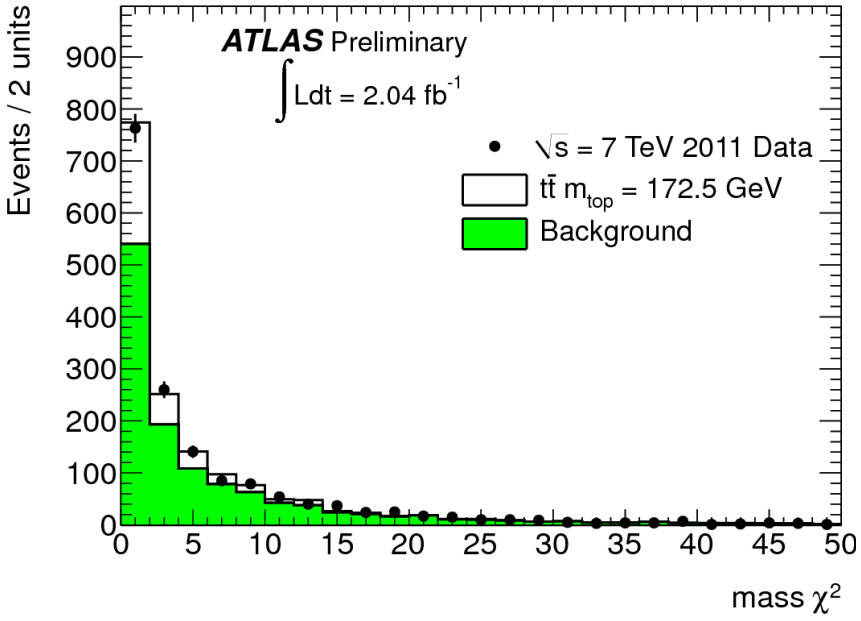
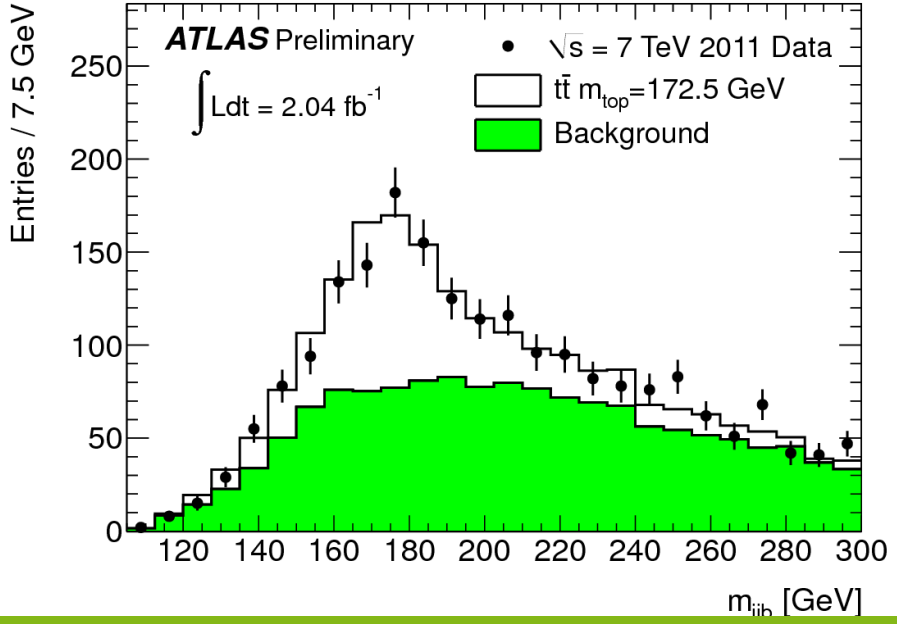
All-hadronic measurement

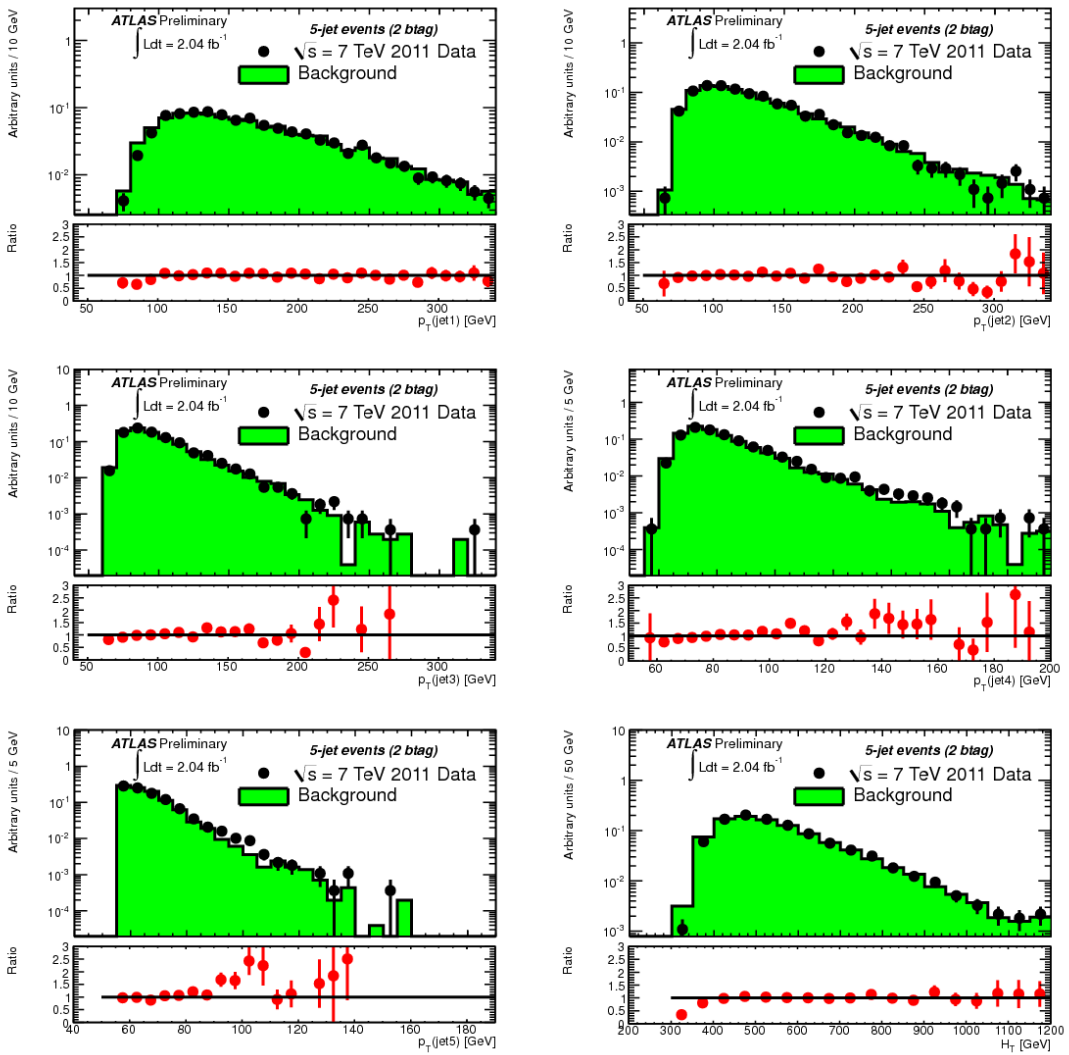


- Cut-based selection of candidate events
- χ^2-Fit to select correct pairs of jets
- Background from event mixing



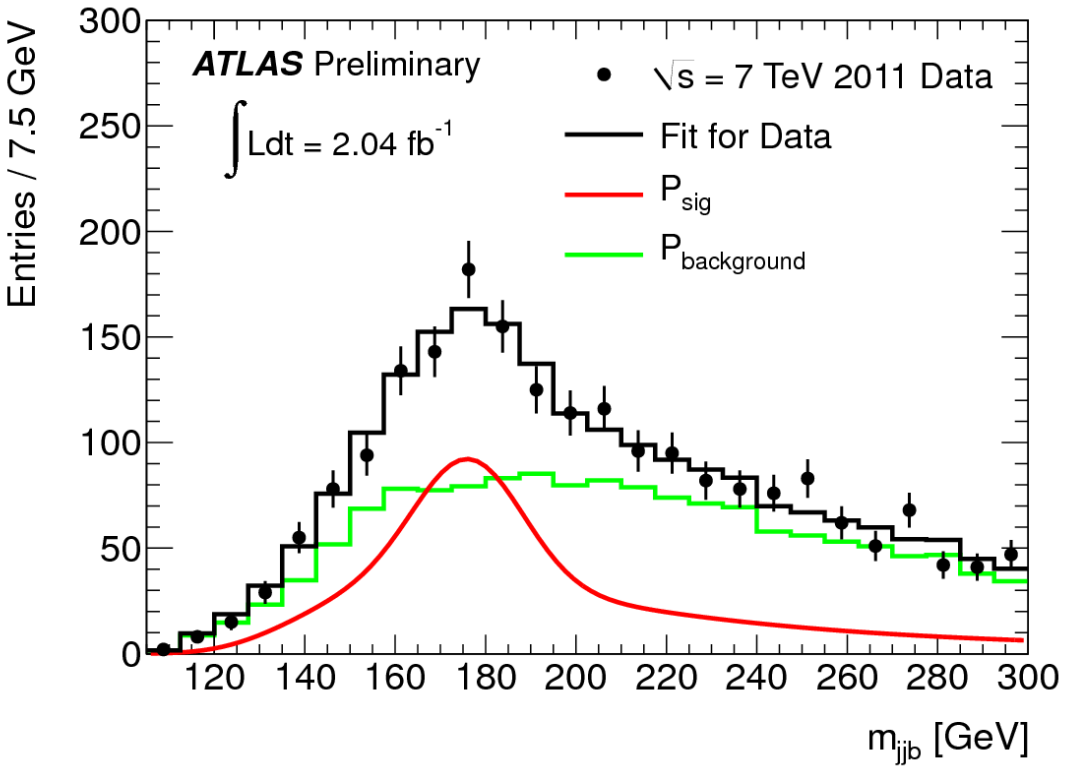
- Additional cut on the χ^2 to be lesser than 6
- Top peak clearly visible despite large multijet background before cuts

Event Mixing



- Use 5-jet data events and add a lower-p_T jet to the event
- Several validations, here with 4-jet to 5-jet
- Good description in the control regions

All-hadronic measurement: Result



- Template fit to extract top mass
- Fit result yields $m_{\text{top}} = 174.9 \pm 2.1_{\text{stat.}} \pm 3.8_{\text{syst.}}\ \text{GeV}$
- Dominating uncertainties are JES, Radiation and Modelling of the Background

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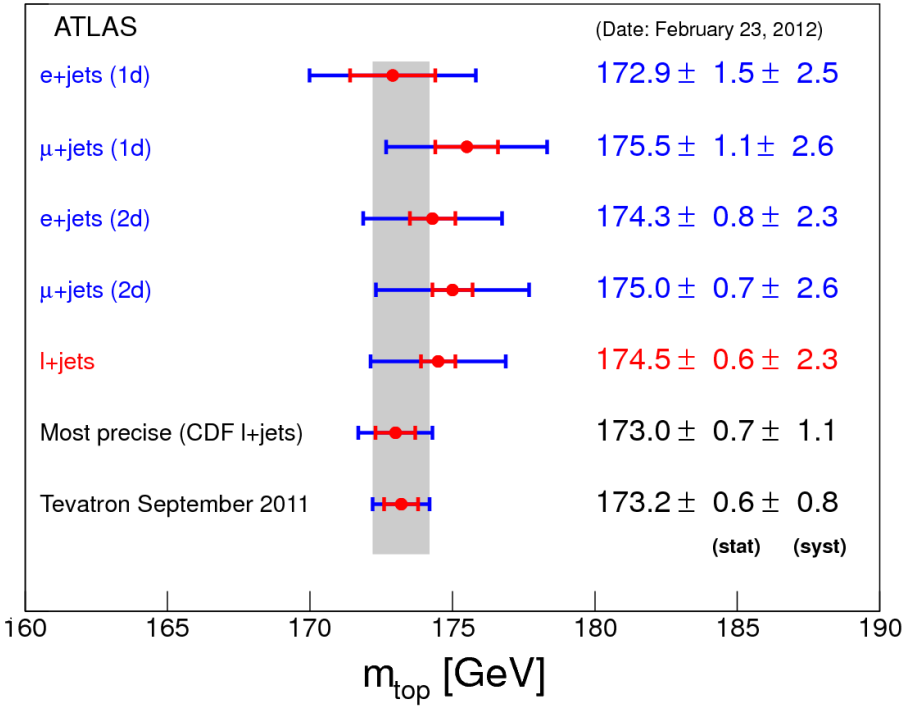
Combination & Outlook



- Combine presented template measurement with each other
- Result compatible with other measurements
- ATLAS measurements take full list of systematics into account

- We need to improve our understanding of the systematic uncertainties (ongoing!)
- Stay tuned for new results from ATLAS

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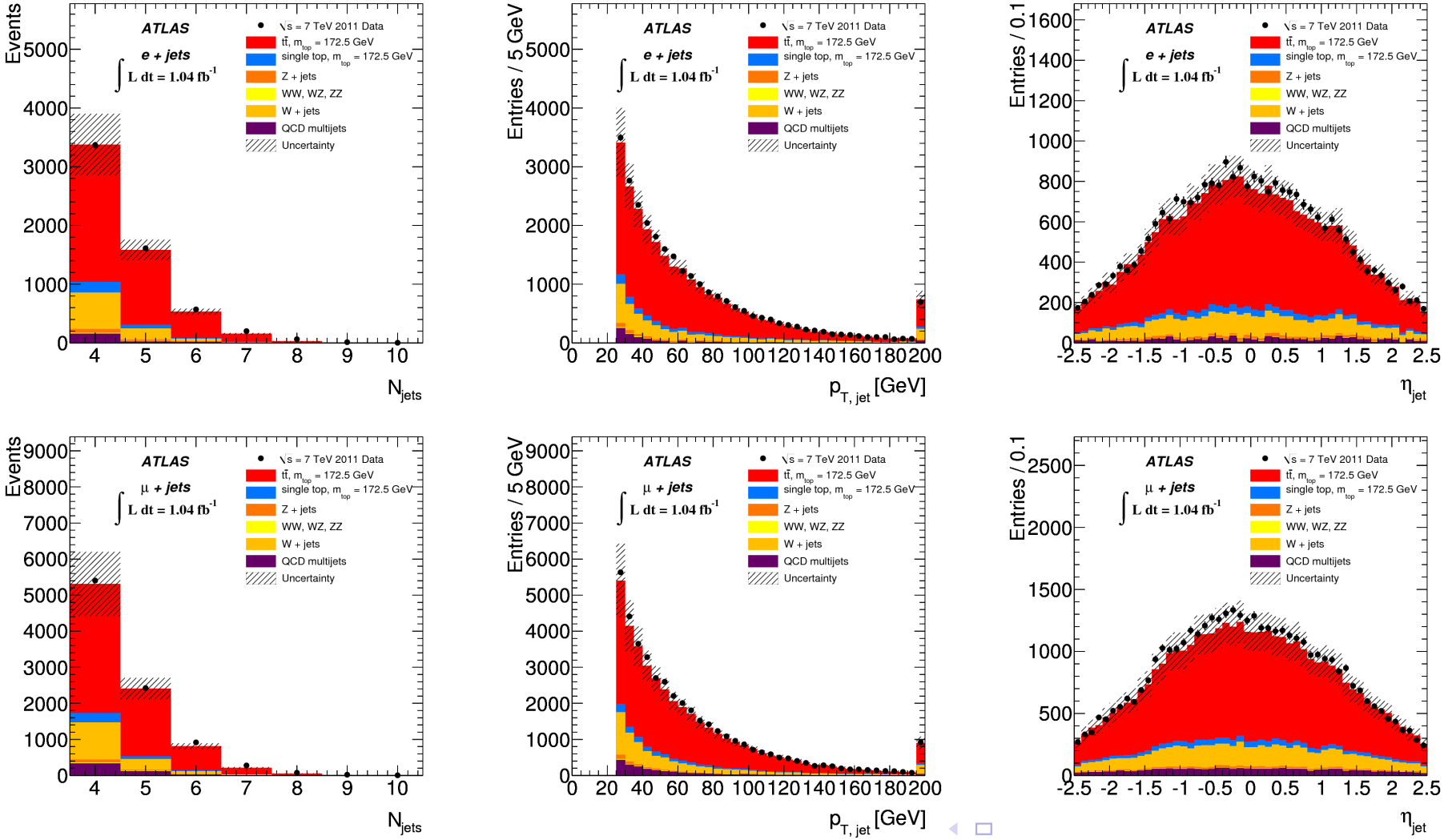
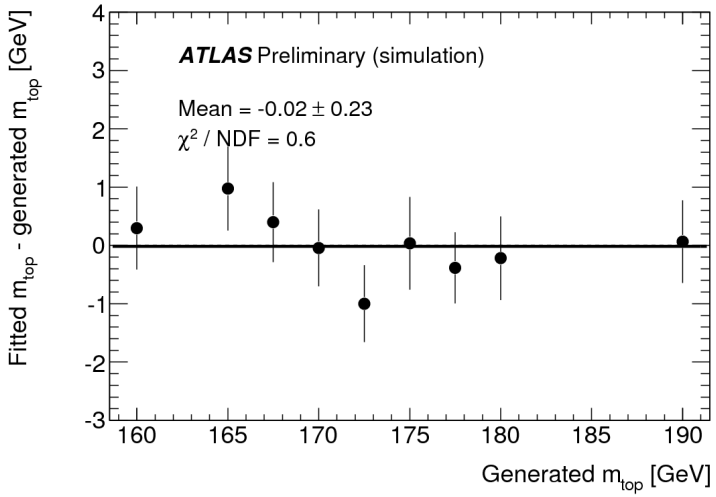
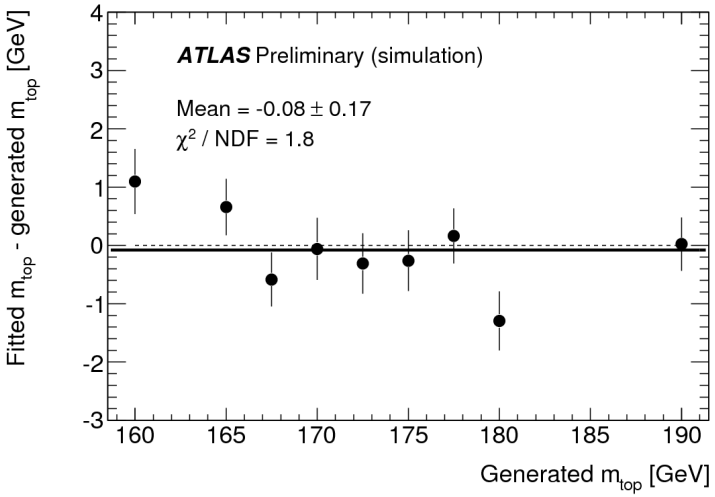
Backup

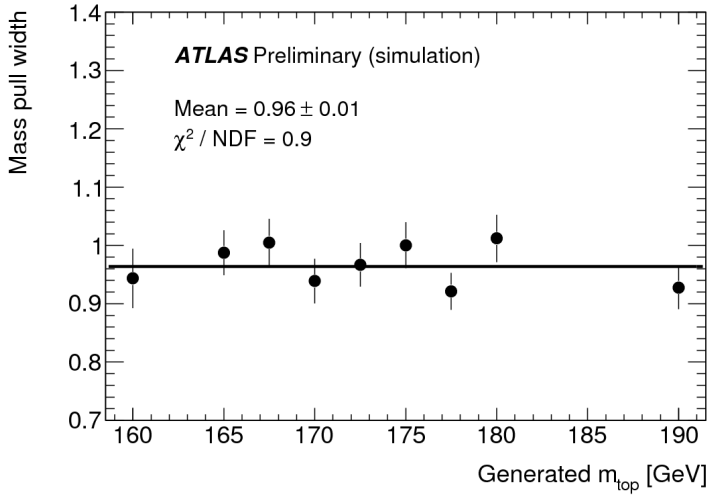
Template Methods - Control Plots

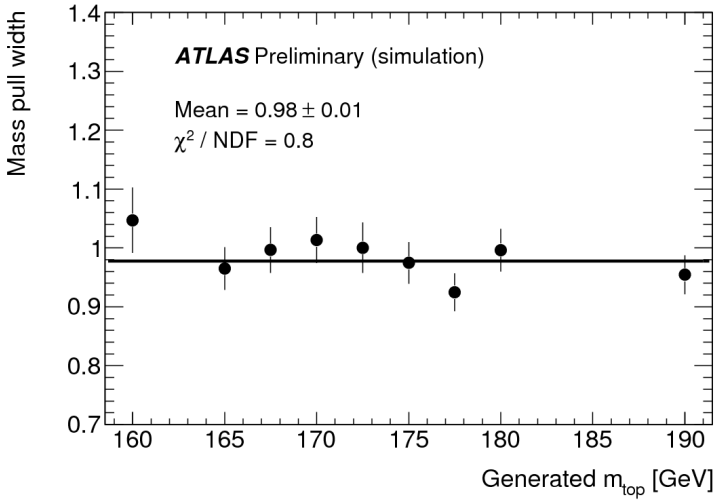


2D template - Verification of the fit

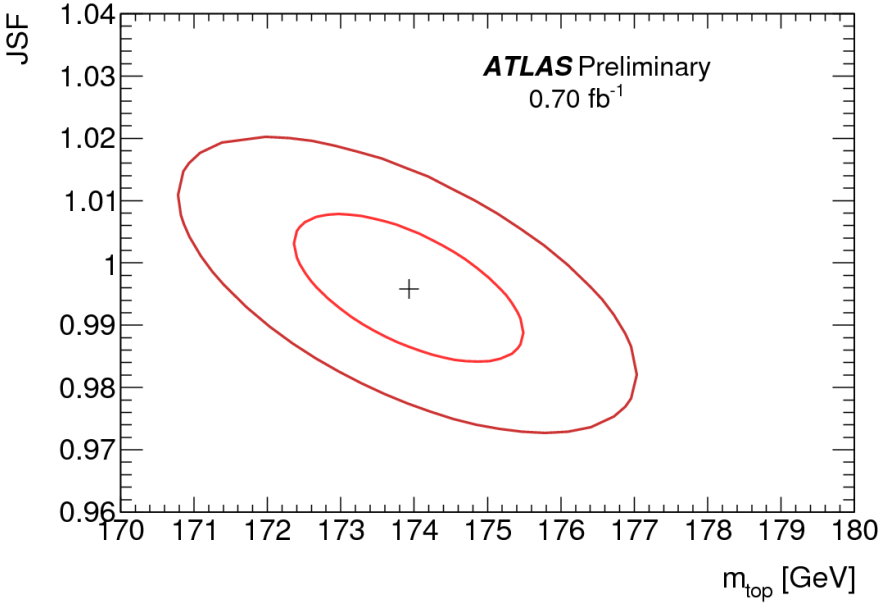


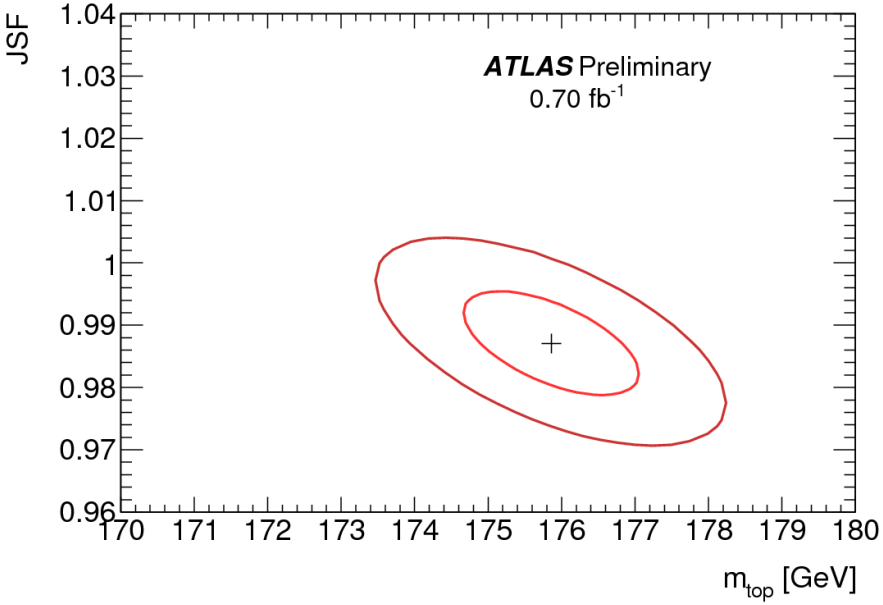






2D template - Correlation between JSF and top mass

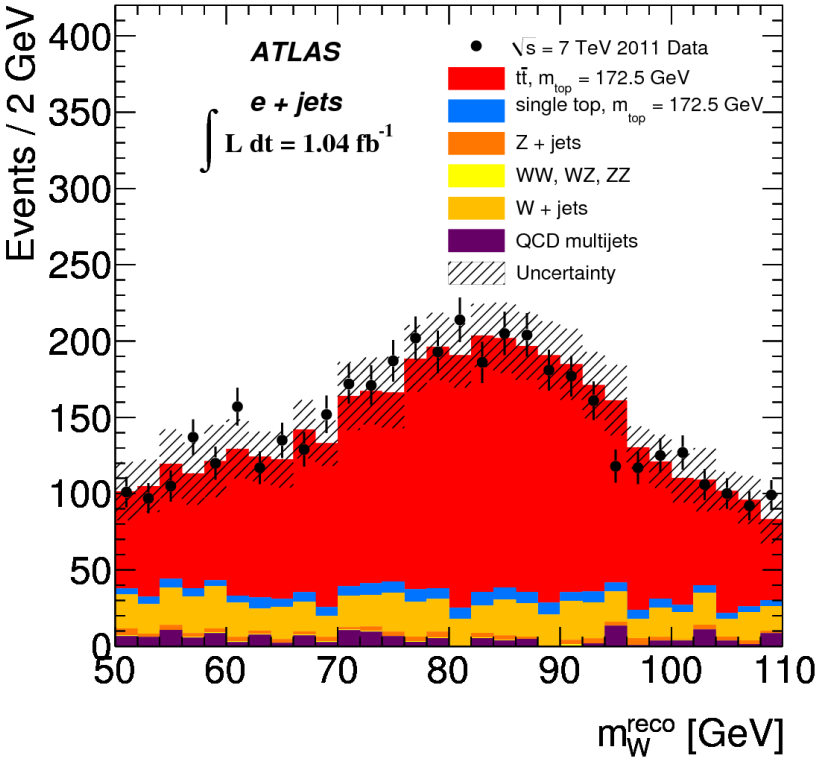


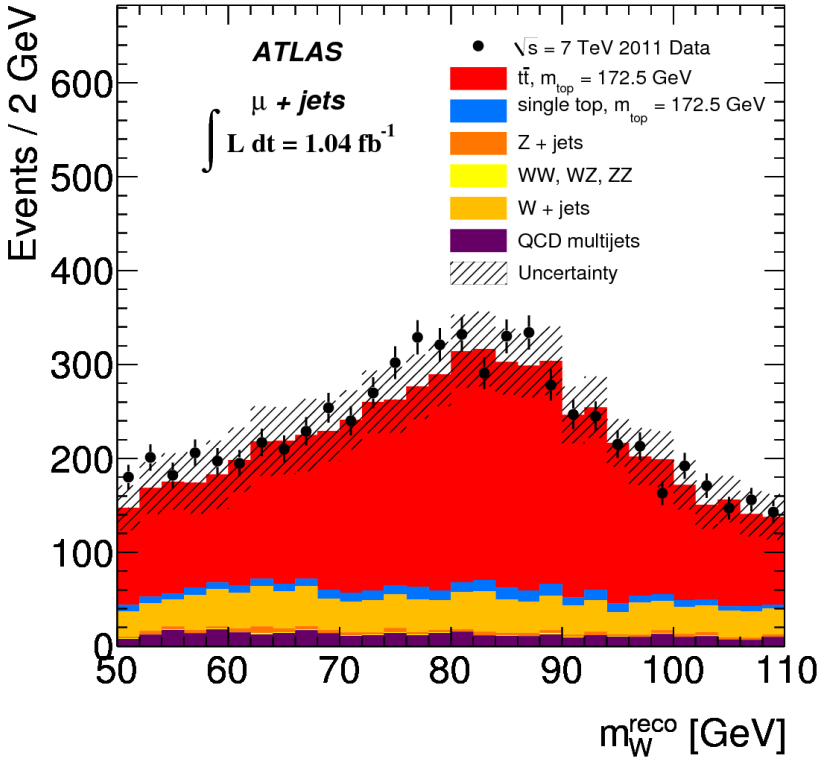


- Correlation coefficient is -0.6 in both channels

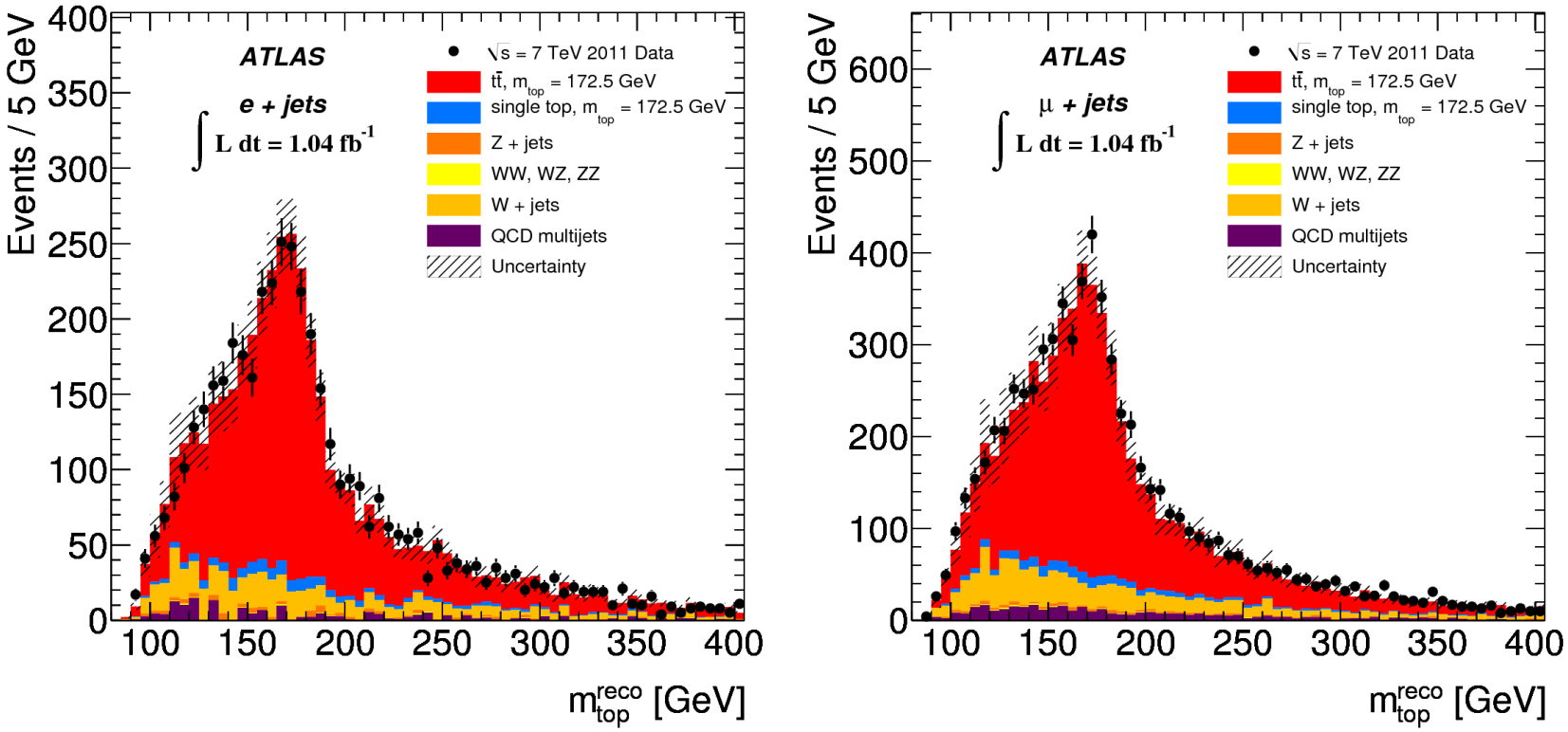
Invariant Mass of *W* Candidates

- *W* peak visible
- Knowledge of $\alpha_{1,2}$ not propagated to *W* mass
- Allows to obtain full sensitivity to the JSF





Invariant Mass of the Top Candidates



- Depends on m_{top} and JSF
- Knowledge of $\alpha_{1,2}$ propagated to mediate effect of JES

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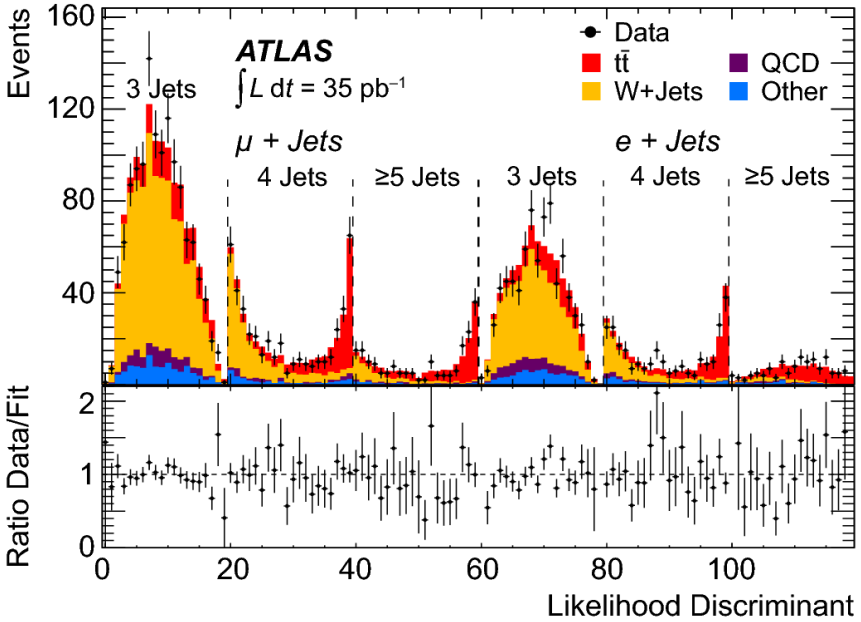
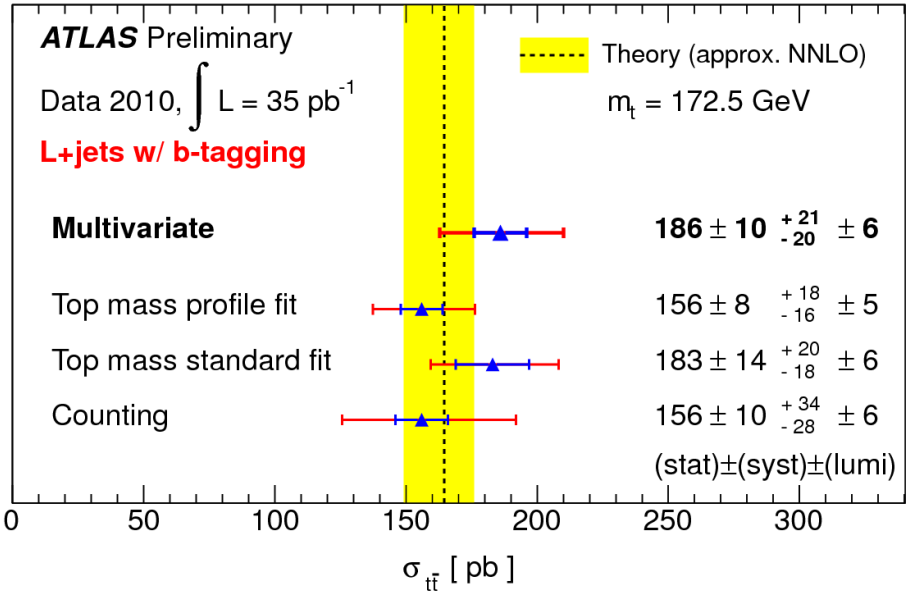
Measurement of the Cross-Section



- Multivariate analysis using lepton, jet and b-tagging information
- Result has precision of 13 % @ $m_{\text{top}} = 172.5\,\text{GeV}$



- Repeat analysis for different mass hypothesis between 140 GeV and 210 GeV of the MC generator (MC@NLO)
- Assume that relative uncertainty is independent of the top mass

Systematics of the method

- There are additional uncertainties on top of the ones from the cross-section measurement

- The theory has uncertainties due to PDFs and scales, they are added linearily
- Assumption on the scale of the relative uncertainty
- Identifying the MC mass with the pole mass, it is added linearily

Systematic	Δm_{top} [GeV]
Theory	$^{+2.4}_{-4.0}$
Scale of $\Delta\sigma_{\text{top}}$	± 2.2
$m_{\text{top}}^{\text{MC}} \equiv m_{\text{top}}^{\text{pole}}(\pm 1\text{ GeV})$	∓ 0.4
$m_{\text{top}}^{\text{MC}} \equiv m_{\text{top}}^{\text{pole}}(\pm 2\text{ GeV})$	∓ 0.8
$m_{\text{top}}^{\text{MC}} \equiv m_{\text{top}}^{\text{pole}}(\pm 5\text{ GeV})$	$^{-2.3}_{+1.9}$

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