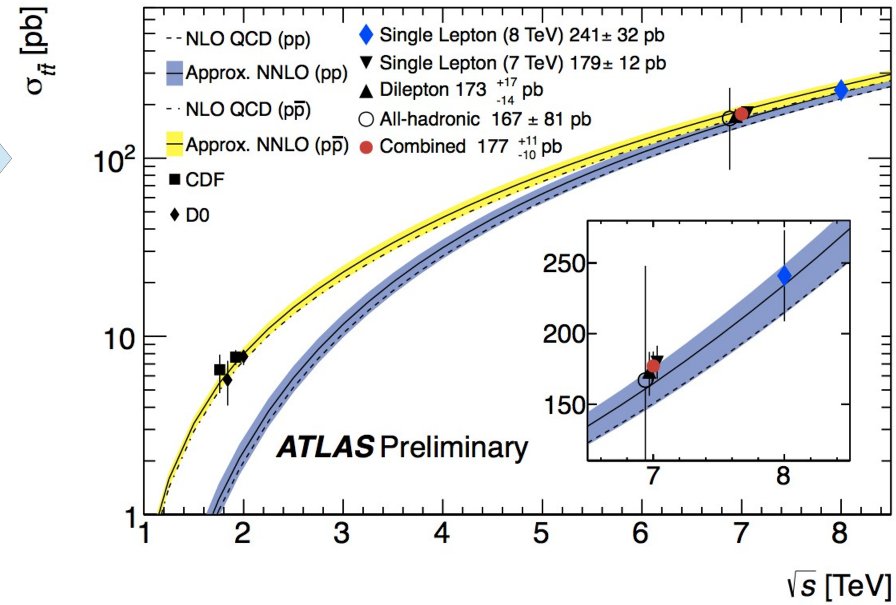
Top quark mass measurements in ATLAS

HEP 2013
Stockholm
18-24 July 2013

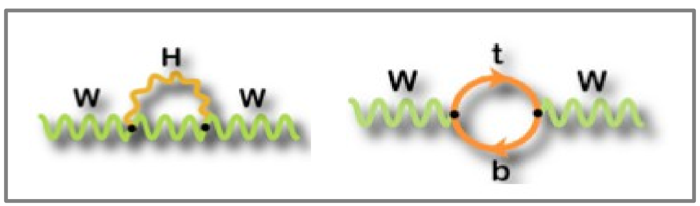
Gabriele Compostella (MPP-Munich)
on behalf of the ATLAS Collaboration

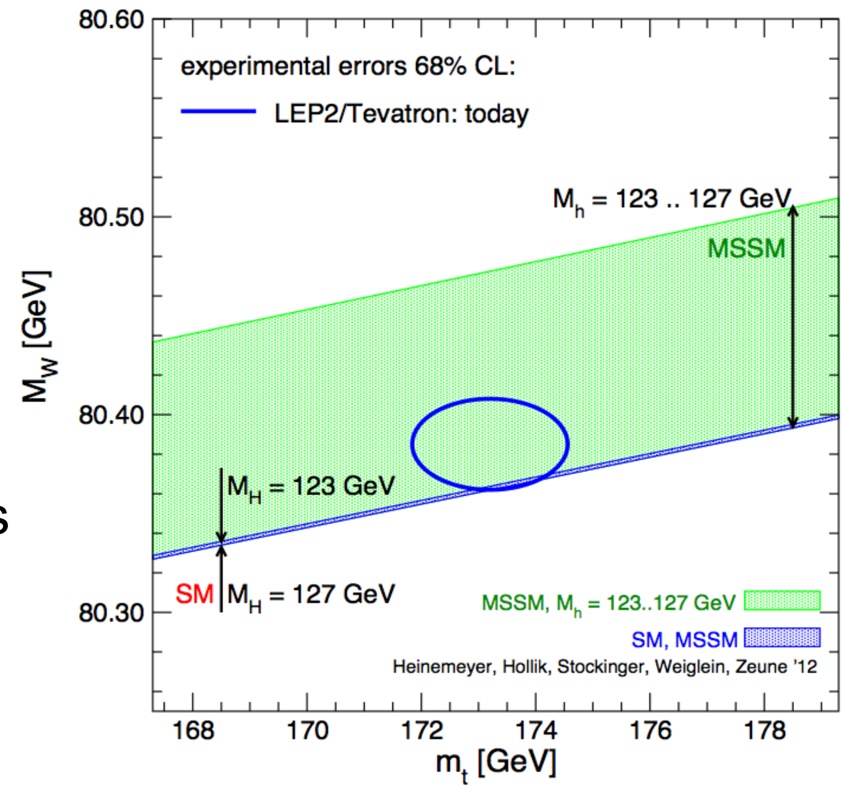
Photo by Werner Nystrand on flickr

LHC is a top quark factory, with a large pair production cross section, mainly via gluon fusion (85%)



- the top quark decays before hadronization, this provides a unique opportunity to study a "bare" quark
- the top quark mass m_{top} is a fundamental parameter of the SM
- m_{top} is related to m_W and m_H

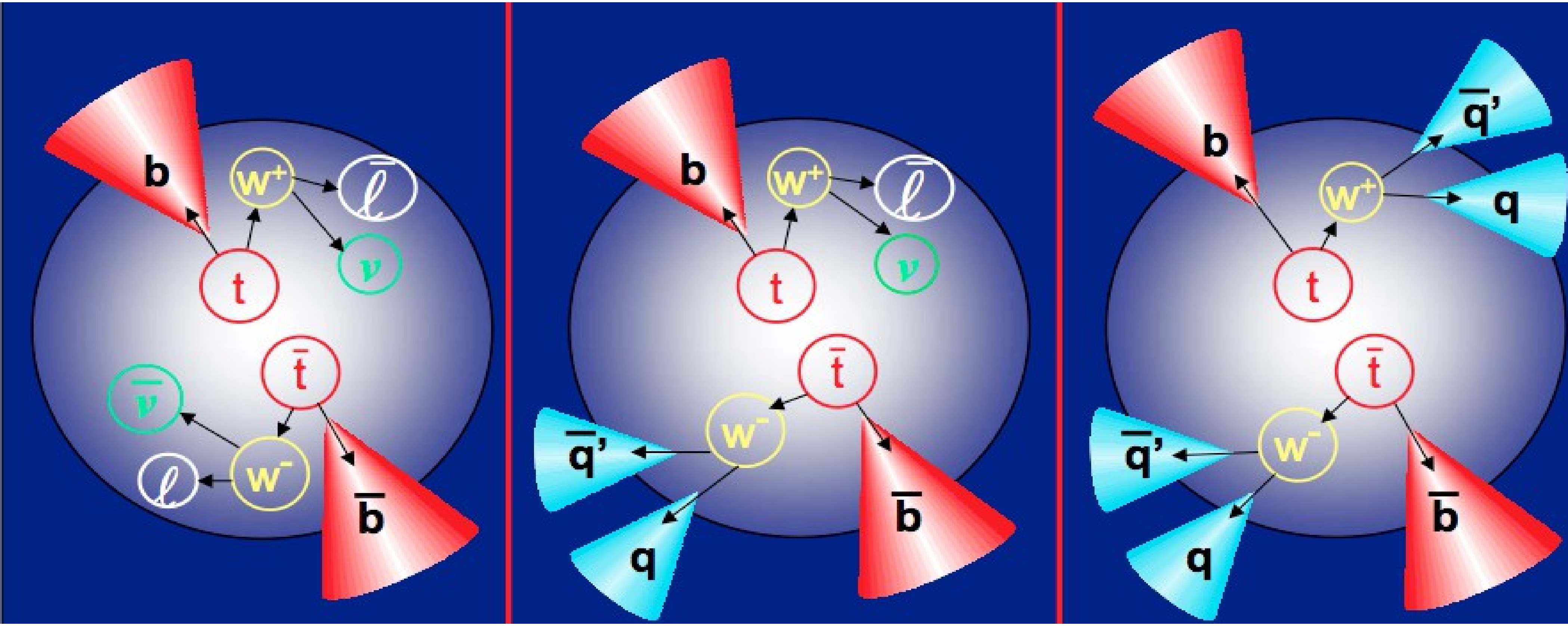




- a precise determination of m_{top}, m_W and m_H combined with EW precision measurements allows to perform a stringent test of SM and beyond SM models

Top quark decays almost exclusively to Wb, $t\bar{t}$ pair decay signatures categorized from W decays

Dilepton (e or μ) 6% | Lepton (e or μ) +jets 34% | All hadronic 46%

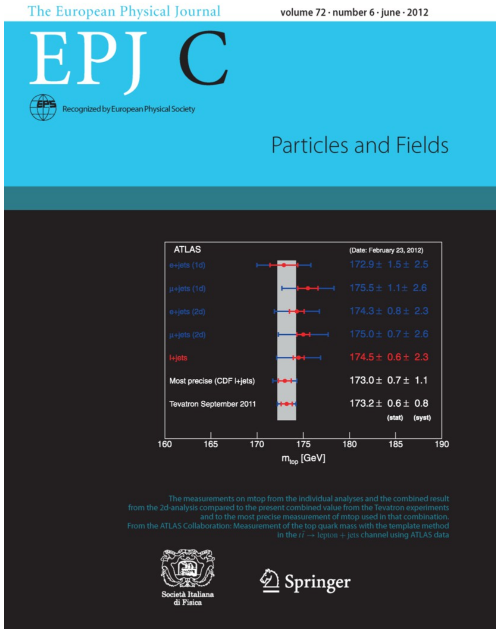


Dilepton	Lepton +jets	All hadronic
low rate, low background (mainly Drell-Yan)	higher rate, manageable background (mainly W+jets)	large rate, large background (mainly QCD)
High purity	*Golden Channel*	*Lowest purity*
2 high-p_T leptons + E_T^{miss}	*1 high-p_T lepton + E_T^{miss} + jets*	*6 Jets + b-tagging*

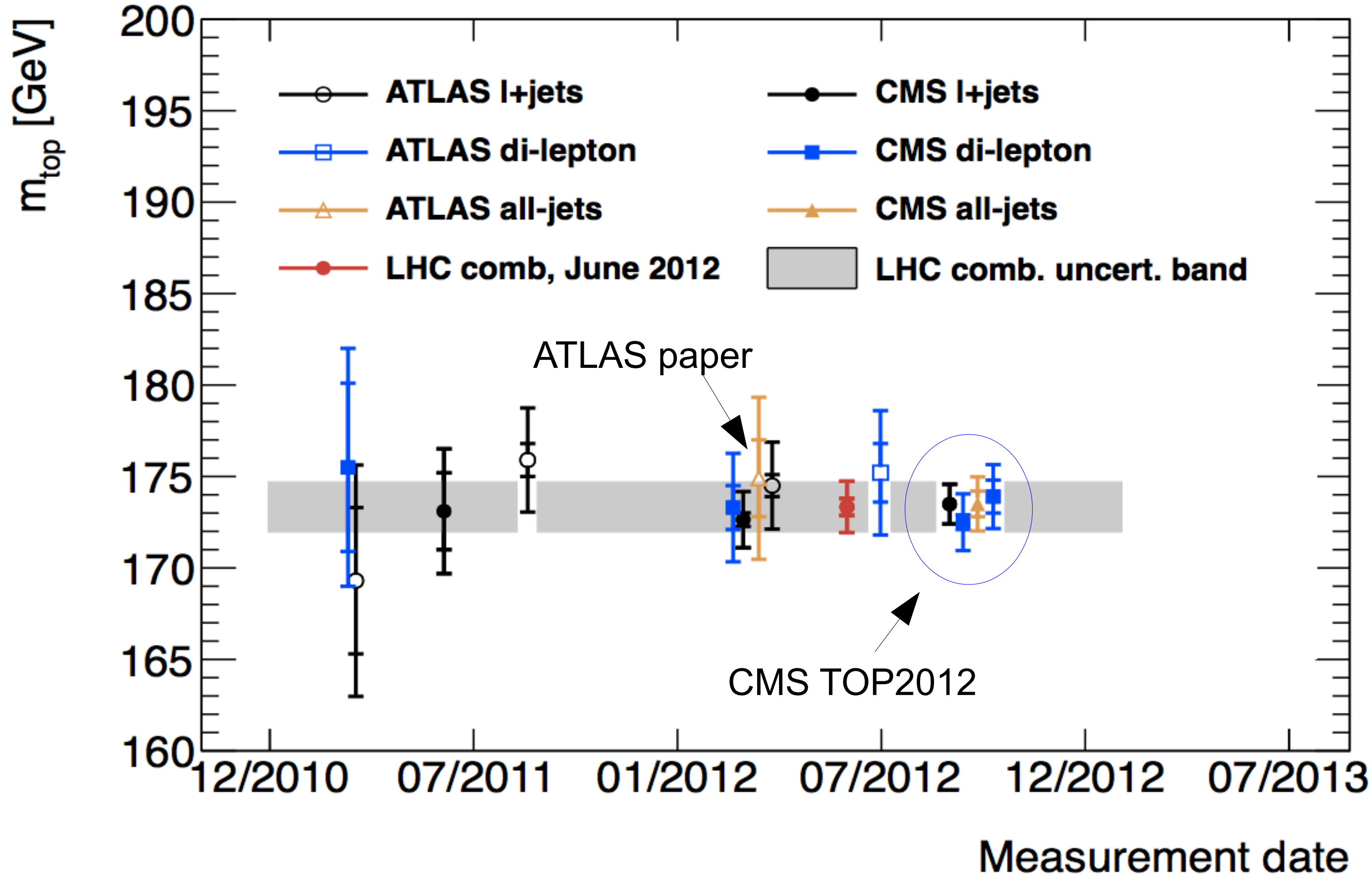
(other signatures involve at least one explicitely detected τ)

ATLAS has performed measurements of m_{top} in all 3 channels

Measurement of m_{top} in the lepton+jets channel



EPJC (2012) 72:2046



2012 lepton+jets ATLAS paper using $1fb^{-1}$ of data, based on the template method:

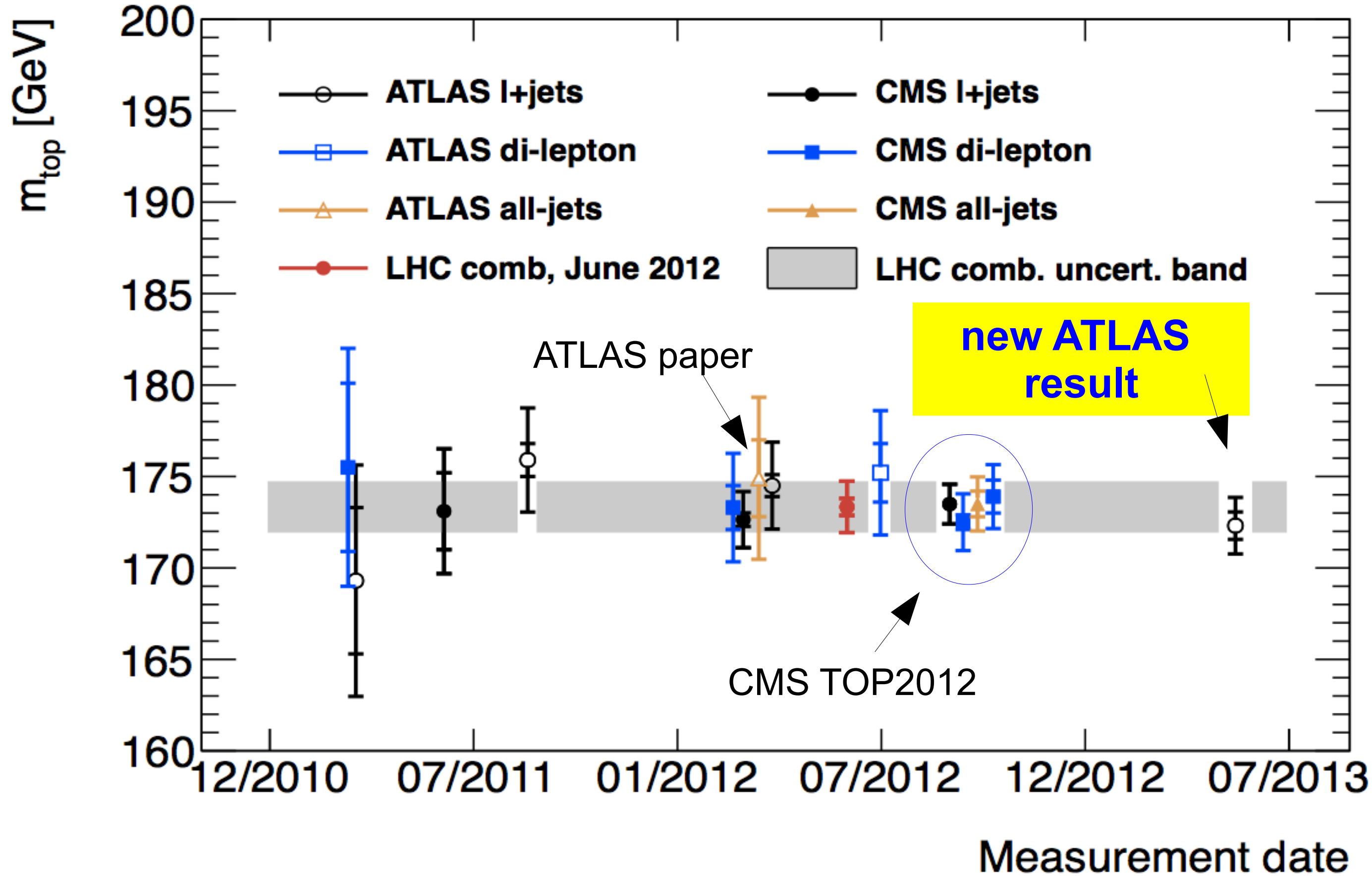
- fit m_{top} estimator in data to the sum of signal and background PDFs derived from simulation
- calibrate JES in-situ using m_W

Dominant uncertainties:

- ISR/FSR
- bJES/JES

(86% of total syst)

Measurement of m_{top} in the lepton+jets channel



What have we improved on since then?

ISR/FSR: Reduced the parameter range used for estimating ISR/FSR systematics, improvement based on jet-veto analysis Eur.Phys.J. C72 (2012) 2043

JES: improved baseline uncertainty ATLAS-CONF-2013-004

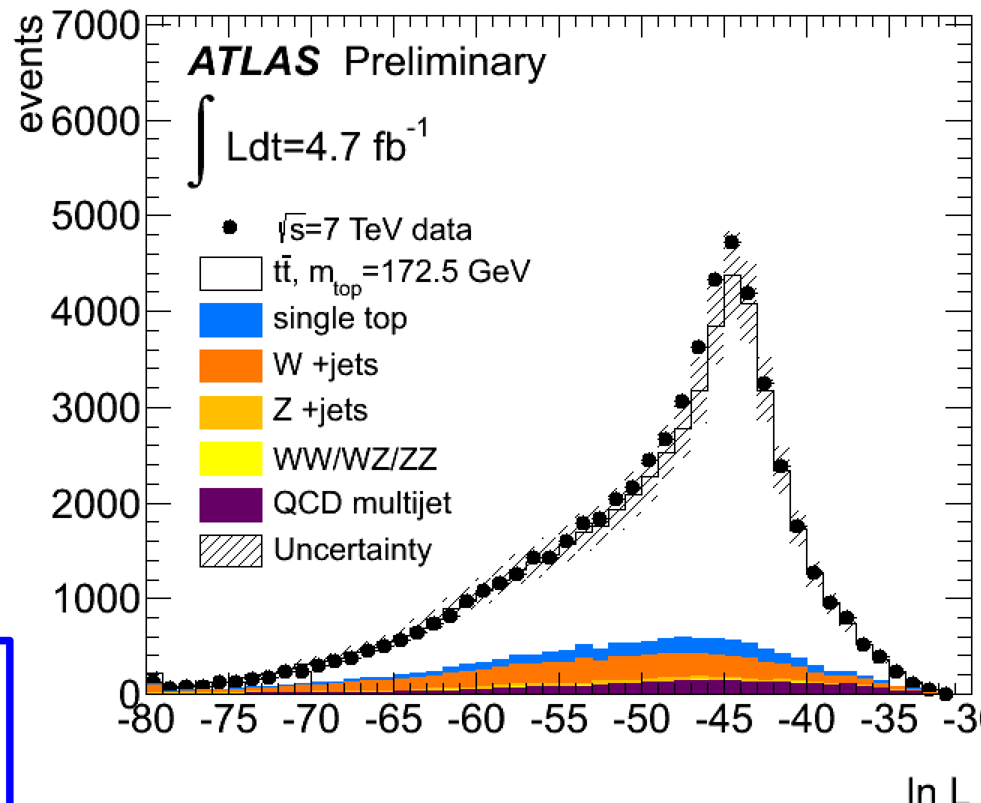
bJES: 40% reduction of the MC based bJES uncertainty ATLAS-CONF-2013-002

MC Generators: moved to Powheg+Pythia P2011C for default top quark MC, extensive study of generators and their tunes for top quark physics ATL-PHYS-PUB-2013-005

Lepton+jets events are reconstructed using a Kinematical Likelihood Fitter (KLFitter):

- Choose the object topology that best fits the top quark pair decay hypothesis
- Reconstructed objects are mapped to the response of partons from the hard scattering via LO transfer functions ($\mathcal{T}$)
- Apply Breit Wigner ($\mathcal{B}$) constraints (Γ_{top} and Γ_W) for m_{top}^{reco} and m_W^{reco} (for both had/lep sides), constraining m_W^{reco} to m_W^{PDG}
- Reduce combinatorics by introducing b-tag information in the likelihood (W_{btag})

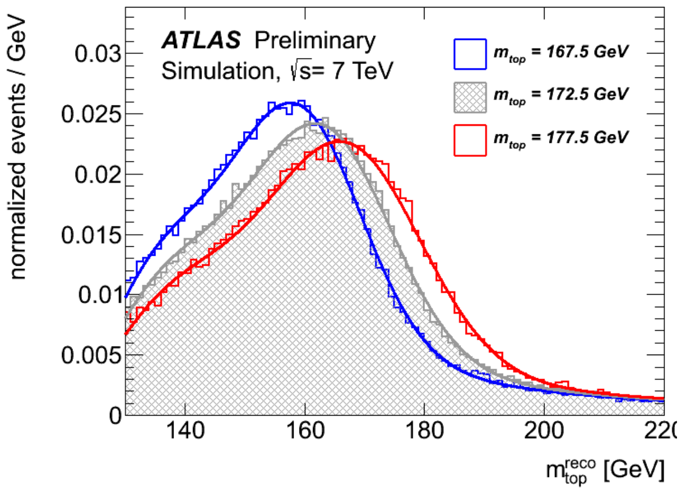
$$
\begin{aligned}
L \; = \; & \mathcal{T}\left(E_{\text{jet}_1}|\hat{E}_{b_{\text{had}}}\right)\cdot\mathcal{T}\left(E_{\text{jet}_2}|\hat{E}_{b_\ell}\right)\cdot\mathcal{T}\left(E_{\text{jet}_3}|\hat{E}_{q_1}\right)\cdot \\
& \mathcal{T}\left(E_{\text{jet}_4}|\hat{E}_{q_2}\right)\cdot\mathcal{T}\left(E_x^{\text{miss}}|\hat{p}_{x,\nu}\right)\cdot\mathcal{T}\left(E_y^{\text{miss}}|\hat{p}_{y,\nu}\right)\cdot \\
& \left\{\begin{array}{ll}\mathcal{T}\left(E_e|\hat{E}_e\right) & \text{e+jets} \\ \mathcal{T}\left(p_{\text{T},\mu}|\hat{p}_{\text{T},\mu}\right) & \mu\text{+jets}\end{array}\right\}\cdot \\
& \mathcal{B}\left[m(q_1\,q_2)|m_W,\Gamma_W\right]\cdot\mathcal{B}\left[m(\ell\,\nu)|m_W,\Gamma_W\right]\cdot \\
& \mathcal{B}\left[m(q_1\,q_2\,b_{\text{had}})|m_{\text{top}}^{\text{reco}},\Gamma_{\text{top}}\right]\cdot \\
& \mathcal{B}\left[m(\ell\,\nu\,b_\ell)|m_{\text{top}}^{\text{reco}},\Gamma_{\text{top}}\right]\cdot W_{\text{btag}}\,.
\end{aligned}
$$



- reconstructed top quark mass m_{top}^{reco}
- assignment of jets to partons
  (correct assignment in >70% of the cases)

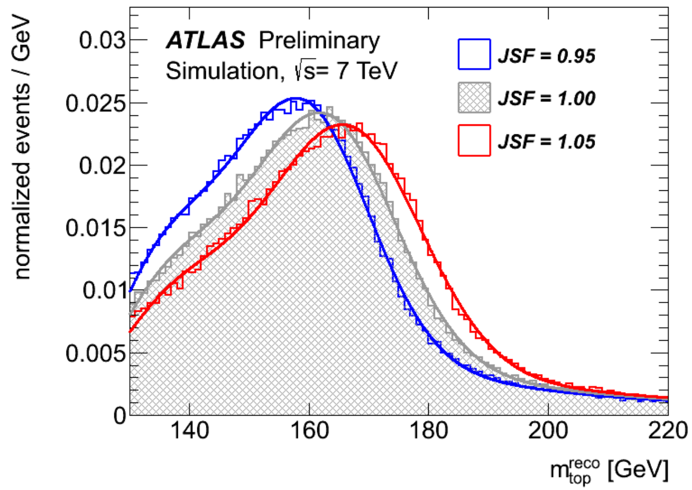
m_{top}^{reco} signal PDFs from top-antitop MC, as a function of:

input m_{top}



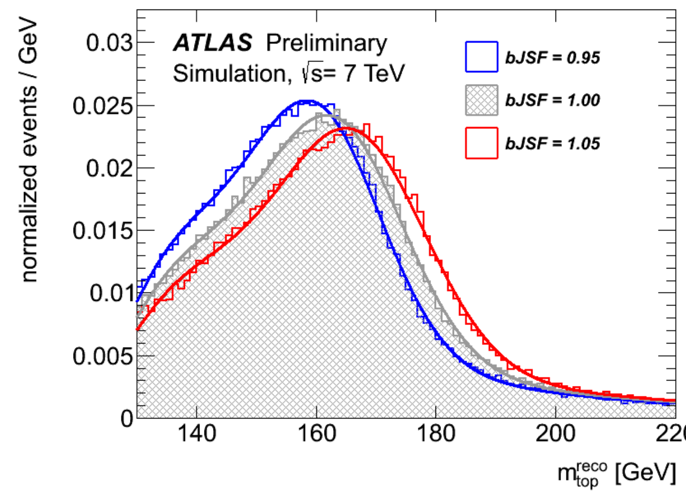
Good sensitivity to the underlying top quark mass.

JES



Large dependence on the jet energy scale → large systematics!

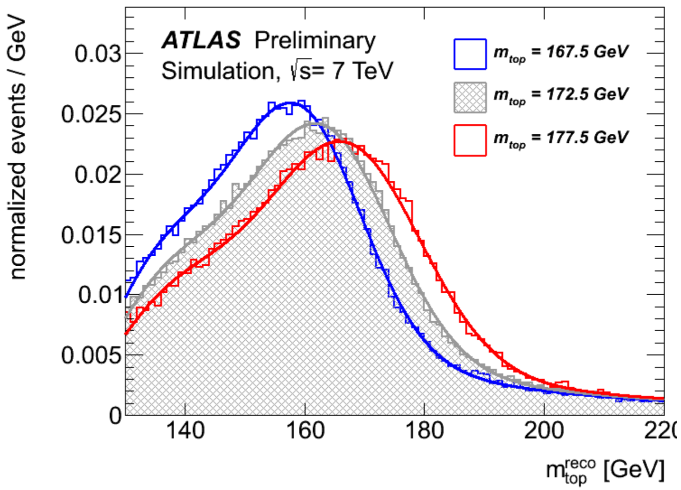
bJES



Large dependence on the b-jet energy scale → large systematics!

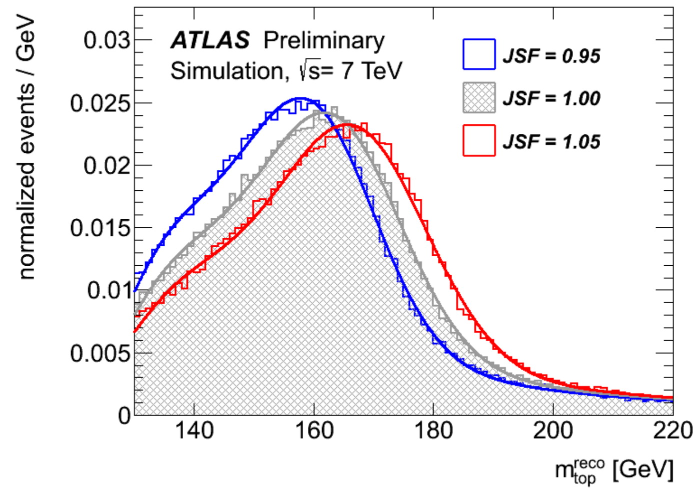
m_{top}^{reco} signal PDFs from top-antitop MC, as a function of:

input m_{top}

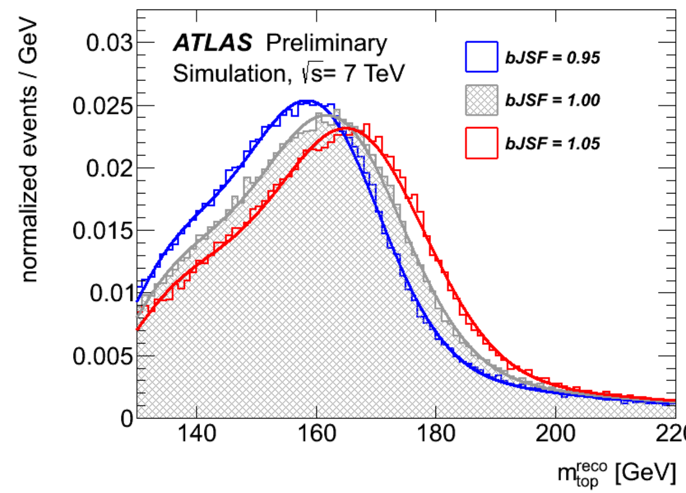


Good sensitivity to the underlying top quark mass.

JES

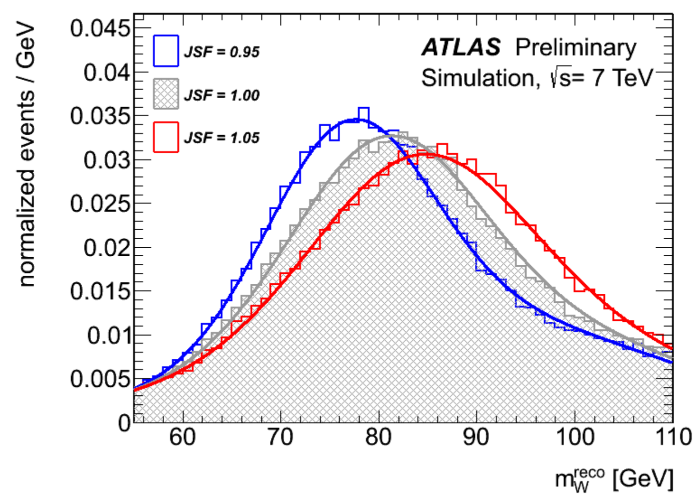


bJES



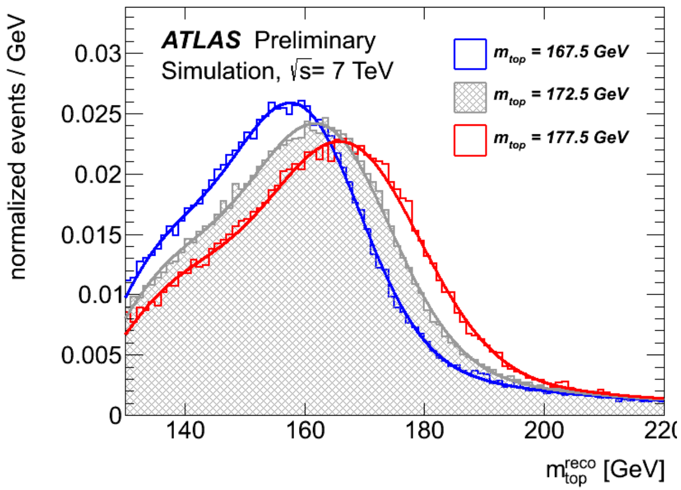
Large dependence on the b-jet energy scale → large systematics!

Use the light quark jets from W to determine a global jet energy scale factor (JSF) reducing the uncertainty on m_{top} from the JES
→ 2d fit, using as m_W^{reco} as additional observable



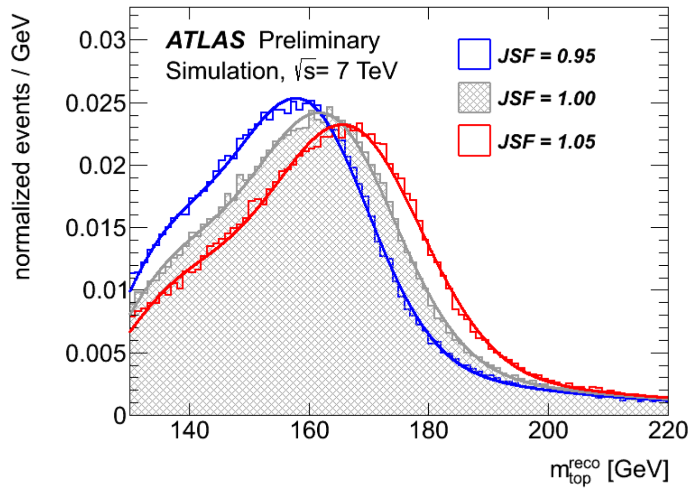
m_{top}^{reco} signal PDFs from top-antitop MC, as a function of:

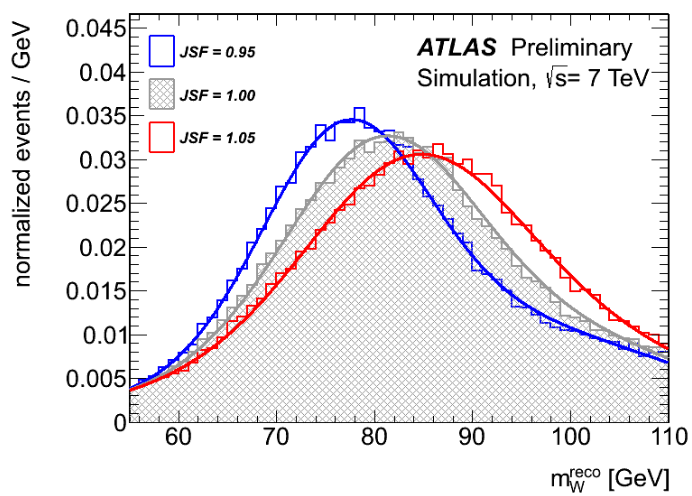
input m_{top}



Good sensitivity to the underlying top quark mass.

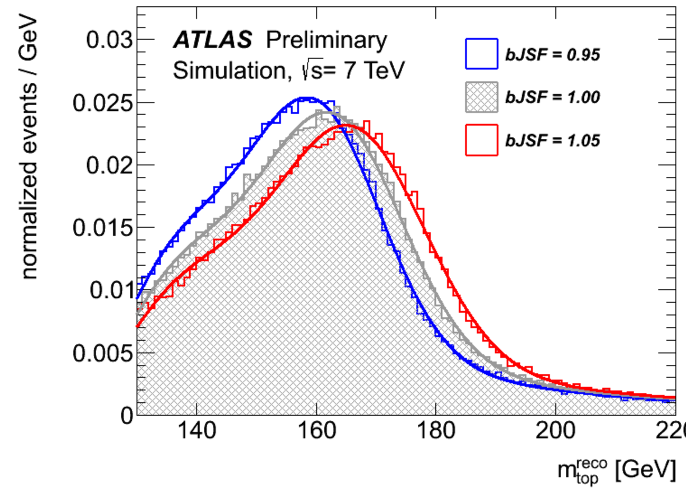
JES





Reduced JES uncertainty

bJES



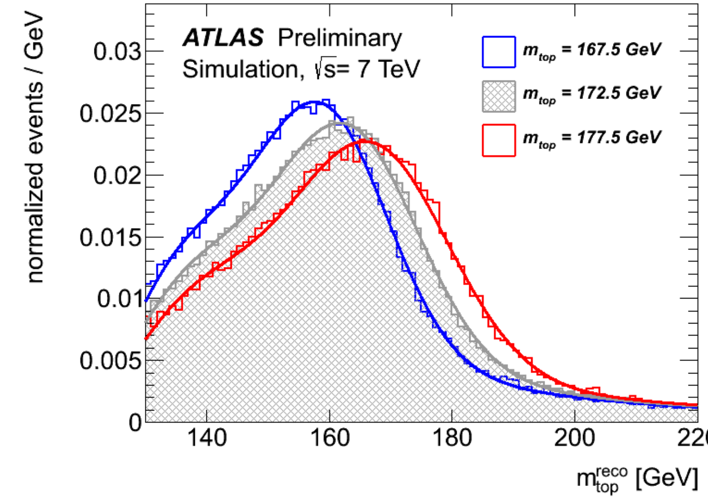
Large dependence on the b-jet energy scale → large systematics!

What can we do about it?

3d template method (3d analysis)

- Extend the 2d analysis with a 3rd dimension to reduce the bJES uncertainty using data

$$\left\{\begin{array}{l} P_{m_{top}^{reco}}(m_{top}, JSF, bJSF) \\ P_{m_{W}^{reco}}(JSF) \\ P_{R_{lb}^{reco}}(m_{top}, bJSF) \end{array}\right.$$

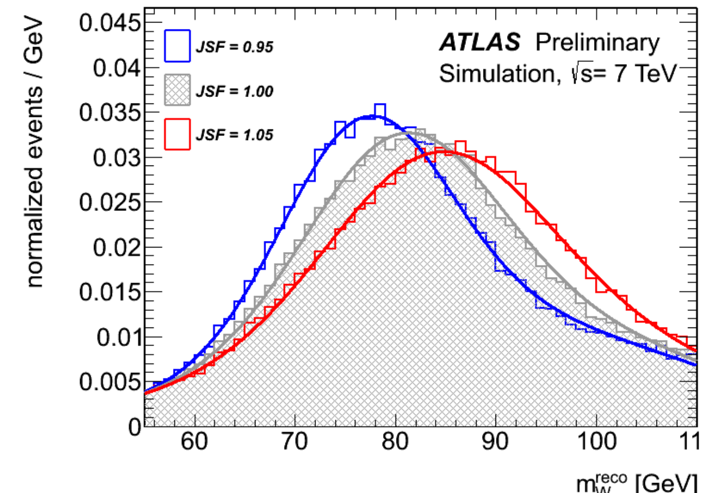


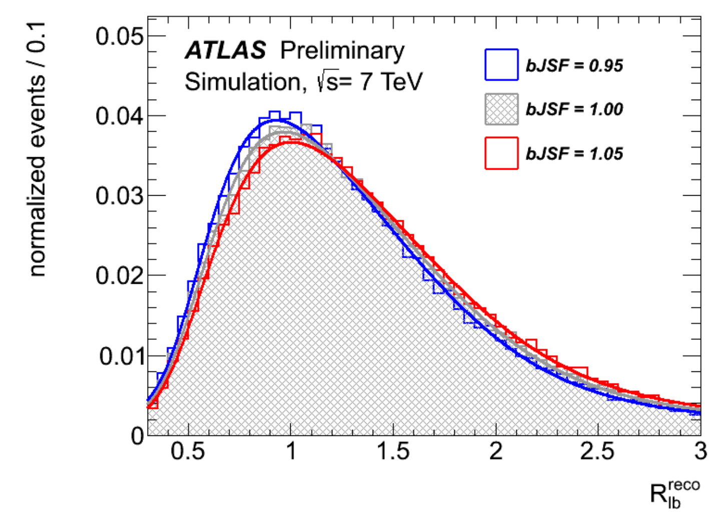
- The 3rd variable is defined to be sensitive to the relative b-to-light jets energy scale (bJSF):

2 b-tag events: $$R_{lb}^{reco} = \frac{p_T^{b-tag,1} + p_T^{b-tag,2}}{p_T^{light,1} + p_T^{light,2}}$$

1 b-tag events: $$R_{lb}^{reco} = \frac{p_T^{b-tag}}{(p_T^{light,1} + p_T^{light,2})/2}$$

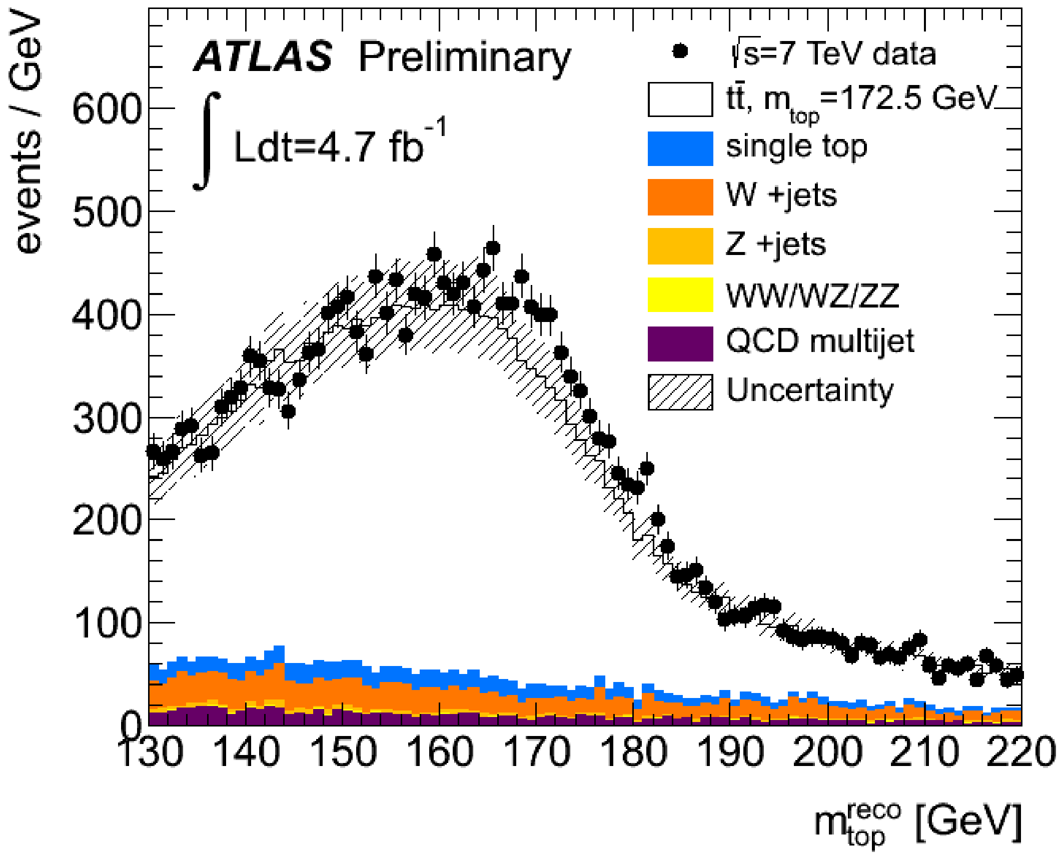
light jets = jets assigned to the W boson decay by the reconstruction algorithm

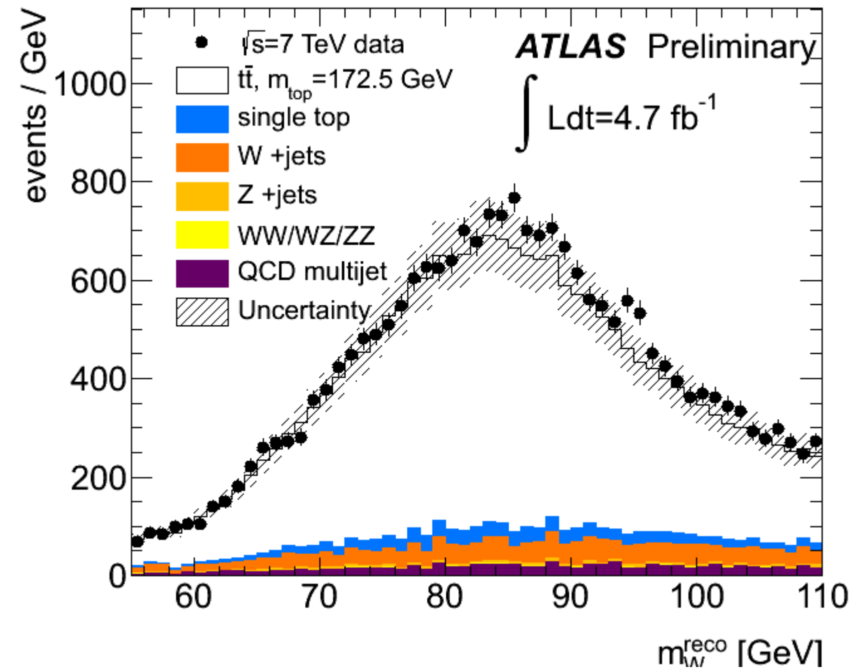


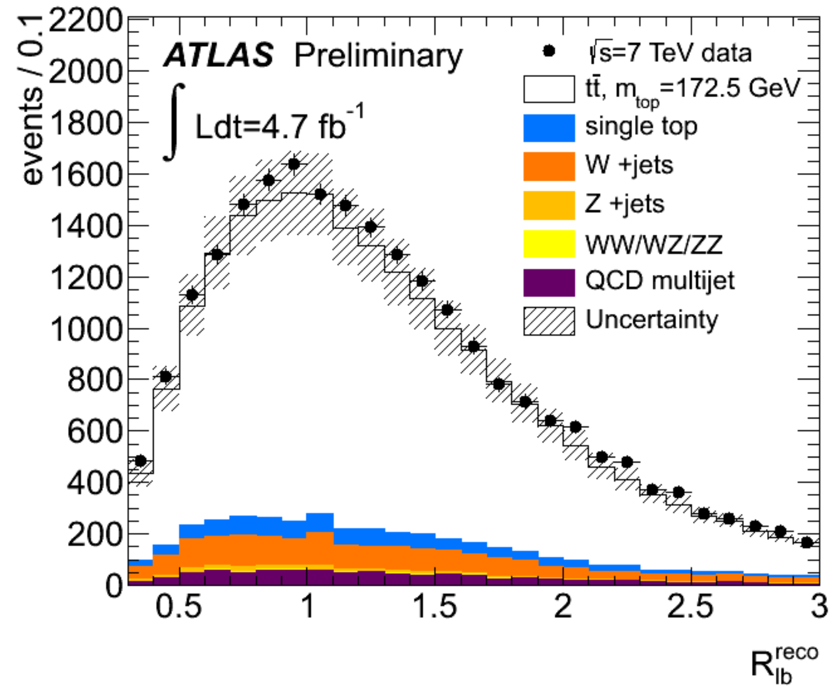


Events with = 1 or ≥ 2 b-tagged jets are treated separately: different sensitivity / resolution

Distributions before any fit



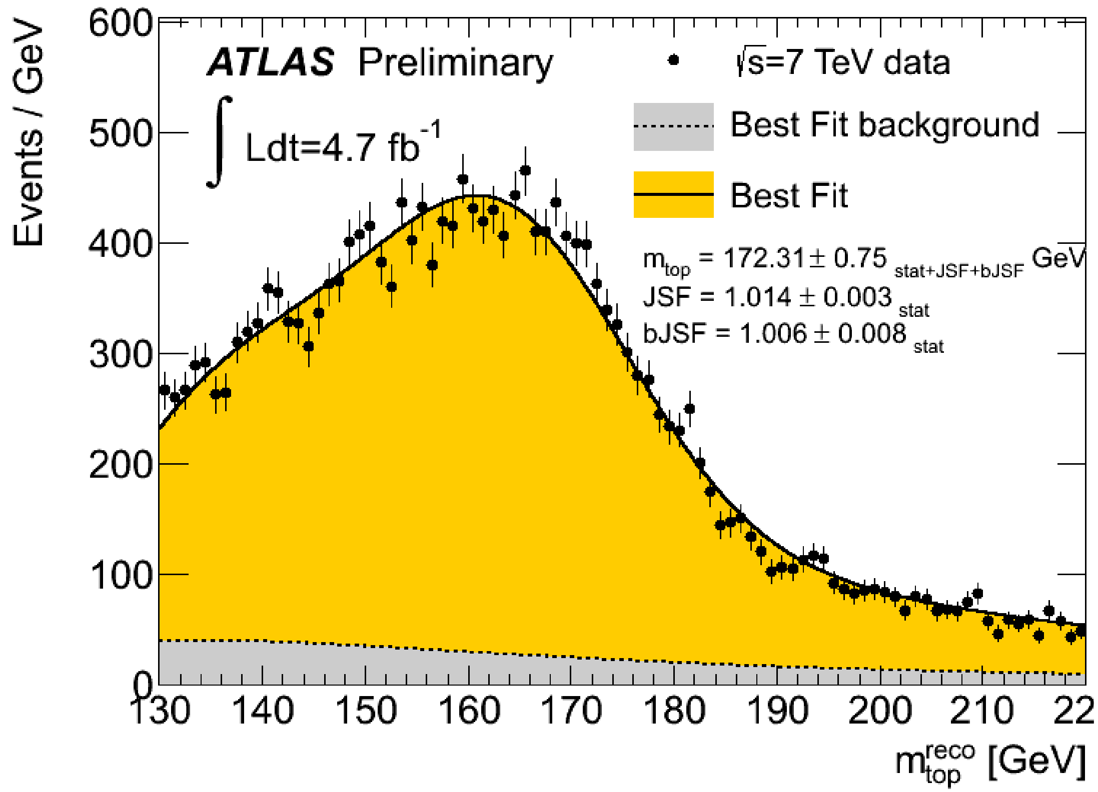




events with ≥1 b-tags

The shape differences between data and predictions are what we use to measure m_{top} with an unbinned likelihood fit, using the template parameterizations as PDFs

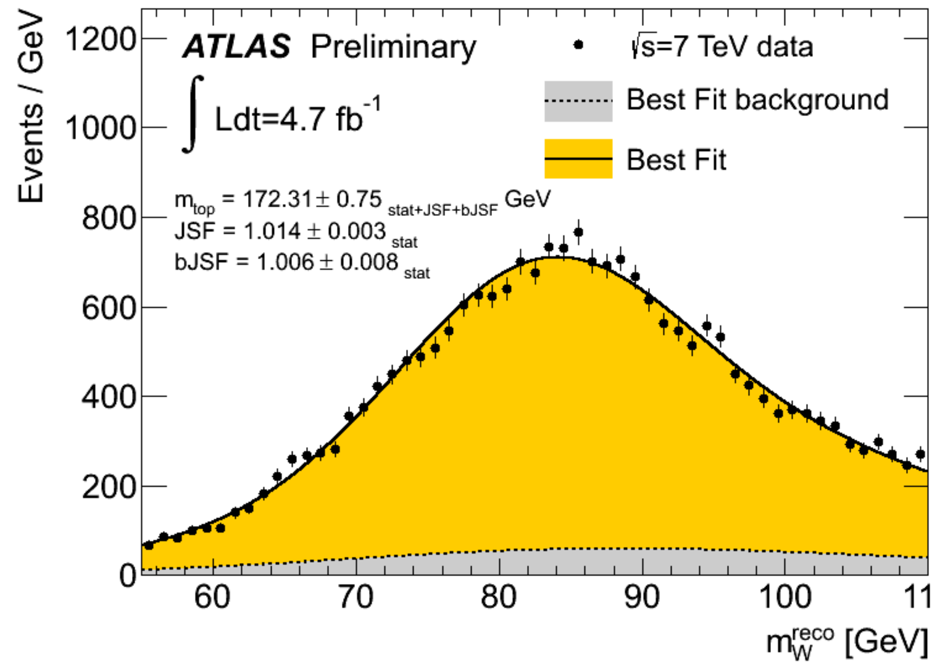
Best fit to data

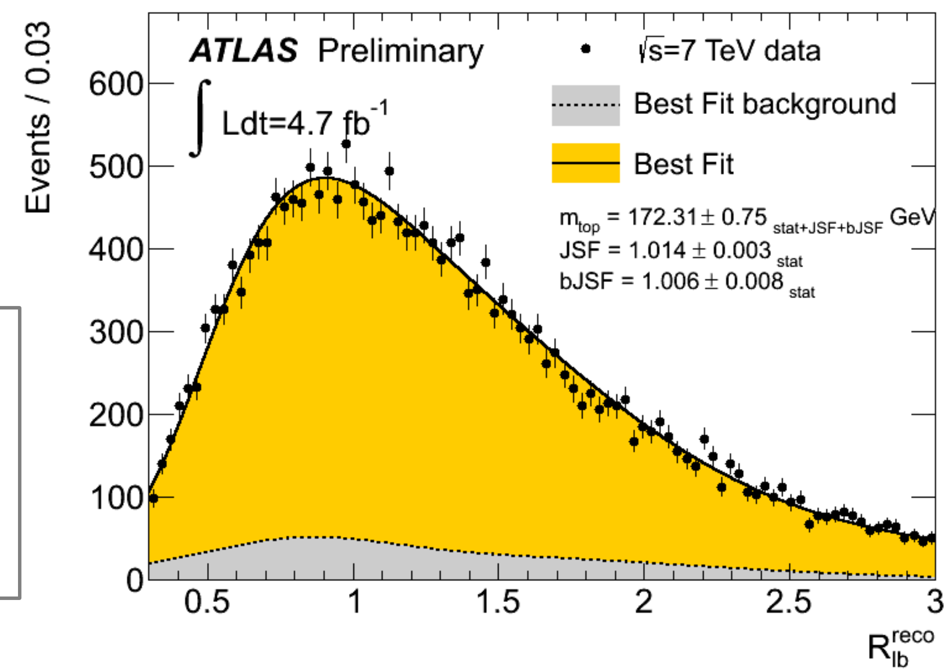


events with ≥1 b-tags

$$m_{top} = 172.31 \pm 0.75_{(\mathrm{stat}\oplus\mathrm{JSF}\oplus\mathrm{bJSF})}\,\mathrm{GeV}$$
$$\mathrm{JSF} = 1.014 \pm 0.003_{(\mathrm{stat})}$$
$$\mathrm{bJSF} = 1.006 \pm 0.008_{(\mathrm{stat})}$$

(statistical uncertainties only)





	2d-analysis		3d-analysis		
	m_{top} [GeV]	JSF	m_{top} [GeV]	JSF	bJSF
Measured value	172.80	1.014	172.31	1.014	1.006
Data statistics	0.23	0.003	0.23	0.003	0.008
Jet energy scale factor (stat. comp.)	0.27	n/a	0.27	n/a	n/a
bJet energy scale factor (stat. comp.)	n/a	n/a	0.67	n/a	n/a
Method calibration	0.13	0.002	0.13	0.002	0.003
Signal MC generator	0.36	0.005	0.19	0.005	0.002
Hadronisation	1.30	0.008	0.27	0.008	0.013
Underlying event	0.02	0.001	0.12	0.001	0.002
Colour reconnection	0.03	0.001	0.32	0.001	0.004
ISR and FSR (signal only)	0.96	0.017	0.45	0.017	0.006
Proton PDF	0.09	0.000	0.17	0.000	0.001
single top normalisation	0.00	0.000	0.00	0.000	0.000
W+jets background	0.02	0.000	0.03	0.000	0.000
QCD multijet background	0.04	0.000	0.10	0.000	0.001
Jet energy scale	0.60	0.005	0.79	0.004	0.007
b-jet energy scale	0.92	0.000	0.08	0.000	0.002
Jet energy resolution	0.22	0.006	0.22	0.006	0.000
Jet reconstruction efficiency	0.03	0.000	0.05	0.000	0.000
b-tagging efficiency and mistag rate	0.17	0.001	0.81	0.001	0.011
Lepton energy scale	0.03	0.000	0.04	0.000	0.000
Missing transverse momentum	0.01	0.000	0.03	0.000	0.000
Pile-up	0.03	0.000	0.03	0.000	0.001
Total systematic uncertainty	2.02	0.021	1.35	0.021	0.020
Total uncertainty	2.05	0.021	1.55	0.021	0.022

The same analysis is performed also by switching off the 3rd dimension of the fit (bJSF fixed to unity), to highlight the improvements w.r.t. the 2d analysis

Systematic uncertainties

	2d-analysis		3d-analysis		
	m_{top} [GeV]	JSF	m_{top} [GeV]	JSF	bJSF
Measured value	172.80	1.014	172.31	1.014	1.006
Data statistics	0.23	0.003	0.23	0.003	0.008
Jet energy scale factor (stat. comp.)	0.27	n/a	0.27	n/a	n/a
bJet energy scale factor (stat. comp.)	n/a	n/a	0.67	n/a	n/a
Method calibration	0.13	0.002	0.13	0.002	0.003
Signal MC generator	0.36	0.005	0.19	0.005	0.002
Hadronisation	1.30	0.008	0.27	0.008	0.013
Underlying event	0.02	0.001	0.12	0.001	0.002
Colour reconnection	0.03	0.001	0.32	0.001	0.004
ISR and FSR (signal only)	0.96	0.017	0.45	0.017	0.006
Proton PDF	0.09	0.000	0.17	0.000	0.001
single top normalisation	0.00	0.000	0.00	0.000	0.000
W+jets background	0.02	0.000	0.03	0.000	0.000
QCD multijet background	0.04	0.000	0.10	0.000	0.001
Jet energy scale	0.60	0.005	0.79	0.004	0.007
b-jet energy scale	0.92	0.000	0.08	0.000	0.002
Jet energy resolution	0.22	0.006	0.22	0.006	0.000
Jet reconstruction efficiency	0.03	0.000	0.05	0.000	0.000
b-tagging efficiency and mistag rate	0.17	0.001	0.81	0.001	0.011
Lepton energy scale	0.03	0.000	0.04	0.000	0.000
Missing transverse momentum	0.01	0.000	0.03	0.000	0.000
Pile-up	0.03	0.000	0.03	0.000	0.001
Total systematic uncertainty	2.02	0.021	1.35	0.021	0.020
Total uncertainty	2.05	0.021	1.55	0.021	0.022

Statistical components:

the extra statistical uncertainties on m_{top} introduced by the simultaneous JSF (bJSF) fits

→ the 3d analysis has a larger statistical component due to the increased dimensionality of the fit (extra 0.67 GeV)

...more than compensated by the reduced bJES uncertainty (thanks to the 3^{rd} dimension)

Systematic uncertainties

	2d-analysis		3d-analysis		
	m_{top} [GeV]	JSF	m_{top} [GeV]	JSF	bJSF
Measured value	172.80	1.014	172.31	1.014	1.006
Data statistics	0.23	0.003	0.23	0.003	0.008
Jet energy scale factor (stat. comp.)	0.27	n/a	0.27	n/a	n/a
bJet energy scale factor (stat. comp.)	n/a	n/a	0.67	n/a	n/a
Method calibration	0.13	0.002	0.13	0.002	0.003
Signal MC generator	0.36	0.005	0.19	0.005	0.002
Hadronisation	1.30	0.008	0.27	0.008	0.013
Underlying event	0.02	0.001	0.12	0.001	0.002
Colour reconnection	0.03	0.001	0.32	0.001	0.004
ISR and FSR (signal only)	0.96	0.017	0.45	0.017	0.006
Proton PDF	0.09	0.000	0.17	0.000	0.001
single top normalisation	0.00	0.000	0.00	0.000	0.000
W+jets background	0.02	0.000	0.03	0.000	0.000
QCD multijet background	0.04	0.000	0.10	0.000	0.001
Jet energy scale	0.60	0.005	0.79	0.004	0.007
b-jet energy scale	0.92	0.000	0.08	0.000	0.002
Jet energy resolution	0.22	0.006	0.22	0.006	0.000
Jet reconstruction efficiency	0.03	0.000	0.05	0.000	0.000
b-tagging efficiency and mistag rate	0.17	0.001	0.81	0.001	0.011
Lepton energy scale	0.03	0.000	0.04	0.000	0.000
Missing transverse momentum	0.01	0.000	0.03	0.000	0.000
Pile-up	0.03	0.000	0.03	0.000	0.001
Total systematic uncertainty	2.02	0.021	1.35	0.021	0.020
Total uncertainty	2.05	0.021	1.55	0.021	0.022

MC modelling:
dominant uncertainties are reduced due to the additional fit of the bJSF

	2d-analysis		3d-analysis		
	m_{top} [GeV]	JSF	m_{top} [GeV]	JSF	bJSF
Measured value	172.80	1.014	172.31	1.014	1.006
Data statistics	0.23	0.003	0.23	0.003	0.008
Jet energy scale factor (stat. comp.)	0.27	n/a	0.27	n/a	n/a
bJet energy scale factor (stat. comp.)	n/a	n/a	0.67	n/a	n/a
Method calibration	0.13	0.002	0.13	0.002	0.003
Signal MC generator	0.36	0.005	0.19	0.005	0.002
Hadronisation	1.30	0.008	0.27	0.008	0.013
Underlying event	0.02	0.001	0.12	0.001	0.002
Colour reconnection	0.03	0.001	0.32	0.001	0.004
ISR and FSR (signal only)	0.96	0.017	0.45	0.017	0.006
Proton PDF	0.09	0.000	0.17	0.000	0.001
single top normalisation	0.00	0.000	0.00	0.000	0.000
W+jets background	0.02	0.000	0.03	0.000	0.000
QCD multijet background	0.04	0.000	0.10	0.000	0.001
Jet energy scale	0.60	0.005	0.79	0.004	0.007
b-jet energy scale	0.92	0.000	0.08	0.000	0.002
Jet energy resolution	0.22	0.006	0.22	0.006	0.000
Jet reconstruction efficiency	0.03	0.000	0.05	0.000	0.000
b-tagging efficiency and mistag rate	0.17	0.001	0.81	0.001	0.011
Lepton energy scale	0.03	0.000	0.04	0.000	0.000
Missing transverse momentum	0.01	0.000	0.03	0.000	0.000
Pile-up	0.03	0.000	0.03	0.000	0.001
Total systematic uncertainty	2.02	0.021	1.35	0.021	0.020
Total uncertainty	2.05	0.021	1.55	0.021	0.022

Residual JES uncertainty:

- despite the in-situ m_W calibration
- introduced by the p_T dependence of the JES uncertainty, not recoverable by a global JSF

b-tagging uncertainty:

- the 3d analysis has a larger sensitivity to b-tagging systematics, related to the p_T dependence of the SF uncertainties, affecting the shape of R_{lb}^{reco}

Systematic uncertainties

	2d-analysis		3d-analysis		
	m_{top} [GeV]	JSF	m_{top} [GeV]	JSF	bJSF
Measured value	172.80	1.014	172.31	1.014	1.006
Data statistics	0.23	0.003	0.23	0.003	0.008
Jet energy scale factor (stat. comp.)	0.27	n/a	0.27	n/a	n/a
bJet energy scale factor (stat. comp.)	n/a	n/a	0.67	n/a	n/a
Method calibration	0.13	0.002	0.13	0.002	0.003
Signal MC generator	0.36	0.005	0.19	0.005	0.002
Hadronisation	1.30	0.008	0.27	0.008	0.013
Underlying event	0.02	0.001	0.12	0.001	0.002
Colour reconnection	0.03	0.001	0.32	0.001	0.004
ISR and FSR (signal only)	0.96	0.017	0.45	0.017	0.006
Proton PDF	0.09	0.000	0.17	0.000	0.001
single top normalisation	0.00	0.000	0.00	0.000	0.000
W+jets background	0.02	0.000	0.03	0.000	0.000
QCD multijet background	0.04	0.000	0.10	0.000	0.001
Jet energy scale	0.60	0.005	0.79	0.004	0.007
b-jet energy scale	0.92	0.000	0.08	0.000	0.002
Jet energy resolution	0.22	0.006	0.22	0.006	0.000
Jet reconstruction efficiency	0.03	0.000	0.05	0.000	0.000
b-tagging efficiency and mistag rate	0.17	0.001	0.81	0.001	0.011
Lepton energy scale	0.03	0.000	0.04	0.000	0.000
Missing transverse momentum	0.01	0.000	0.03	0.000	0.000
Pile-up	0.03	0.000	0.03	0.000	0.001
Total systematic uncertainty	2.02	0.021	1.35	0.021	0.020
Total uncertainty	2.05	0.021	1.55	0.021	0.022

Summary:

- 3d analysis has a reduced total uncertainty by 0.5 GeV
- The so far dominating bJES uncertainty has been absorbed by the bJSF and its statistical uncertainty, that will scale with luminosity

More info: ATLAS-CONF-2013-046

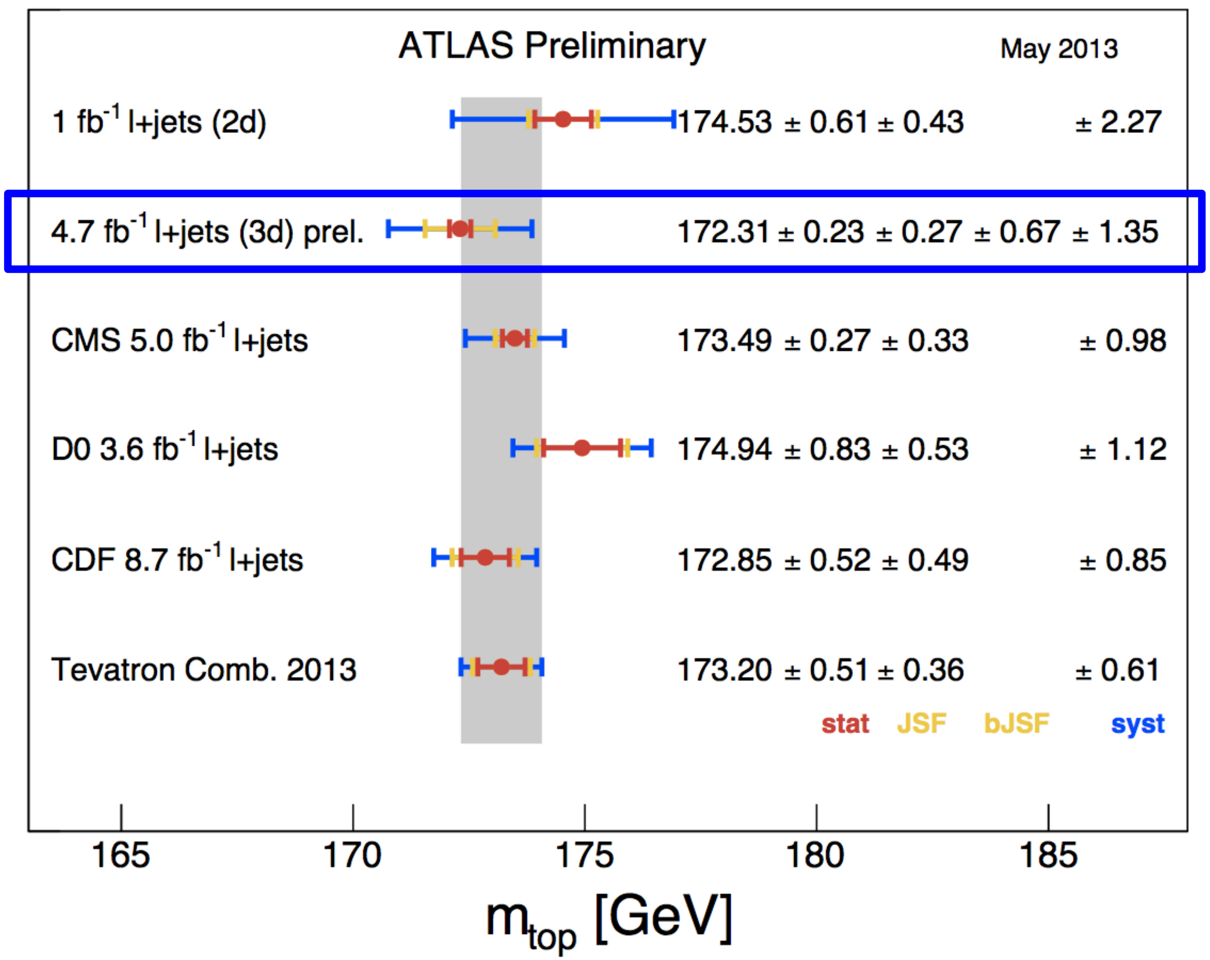
The final measurement is:

$$
\begin{aligned}
m_{top} &= 172.31 \pm 0.75\ (\text{stat} + \text{JSF} + \text{bJSF}) \pm 1.35\ (\text{syst})\ \text{GeV}, \\
\text{JSF} &= 1.014 \pm 0.003\ (\text{stat}) \pm 0.021\ (\text{syst}), \\
\text{bJSF} &= 1.006 \pm 0.008\ (\text{stat}) \pm 0.020\ (\text{syst}).
\end{aligned}
$$

Compared to ATLAS 1fb^{-1} paper, uncertainty has been reduced from 2.4 GeV to 1.5 GeV (~40%), thanks to improvements in both the analysis and the MC modelling

Total uncertainty dominated by:

- residual JES
- b-tagging syst



Measurement of m_{top} in the dilepton channel

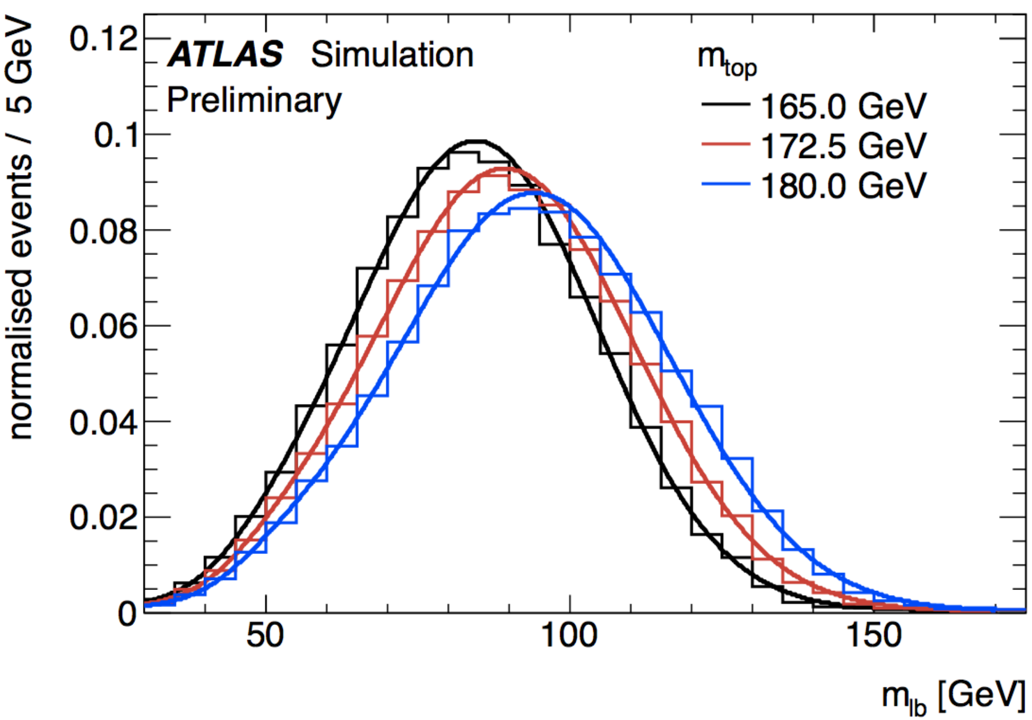
- Select events with exactly 2 charged leptons (e, μ), E_T^{miss} and exactly 2 b-tagged jets
- Almost a background free sample! (background < 3%)

Use the template method with the m_{lb} observable as an estimator for m_{top}:

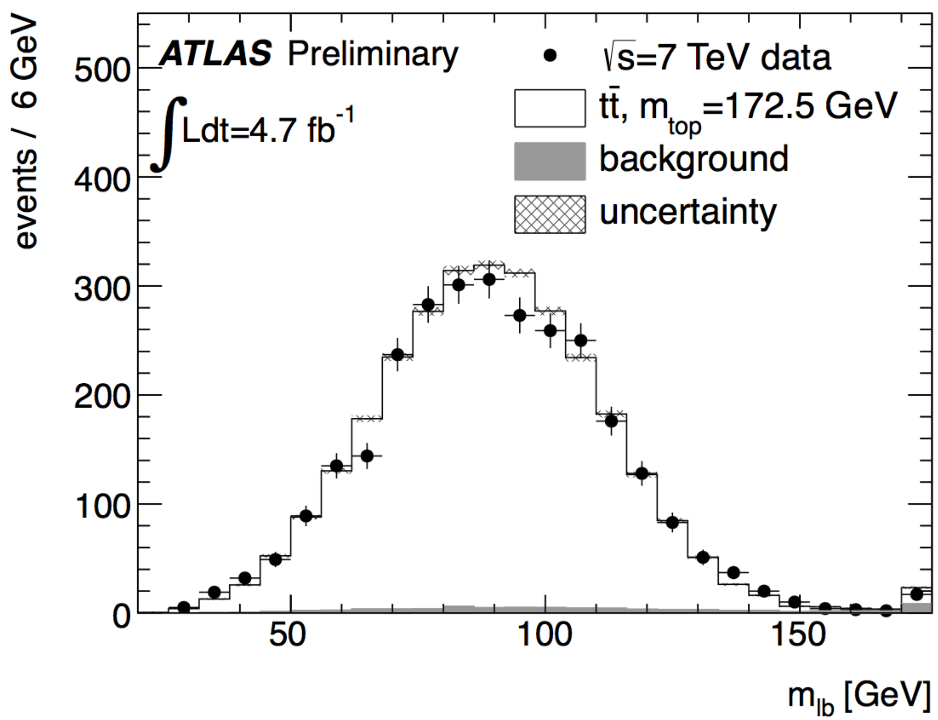
- average invariant mass of the charged lepton - b-tagged jet systems
- b-tagged jet to lepton assignment by taking the pairing with minimum average m_{lb}

→ correct assignment in ~77% of the cases

m_{lb} signal PDF from top-antitop MC:

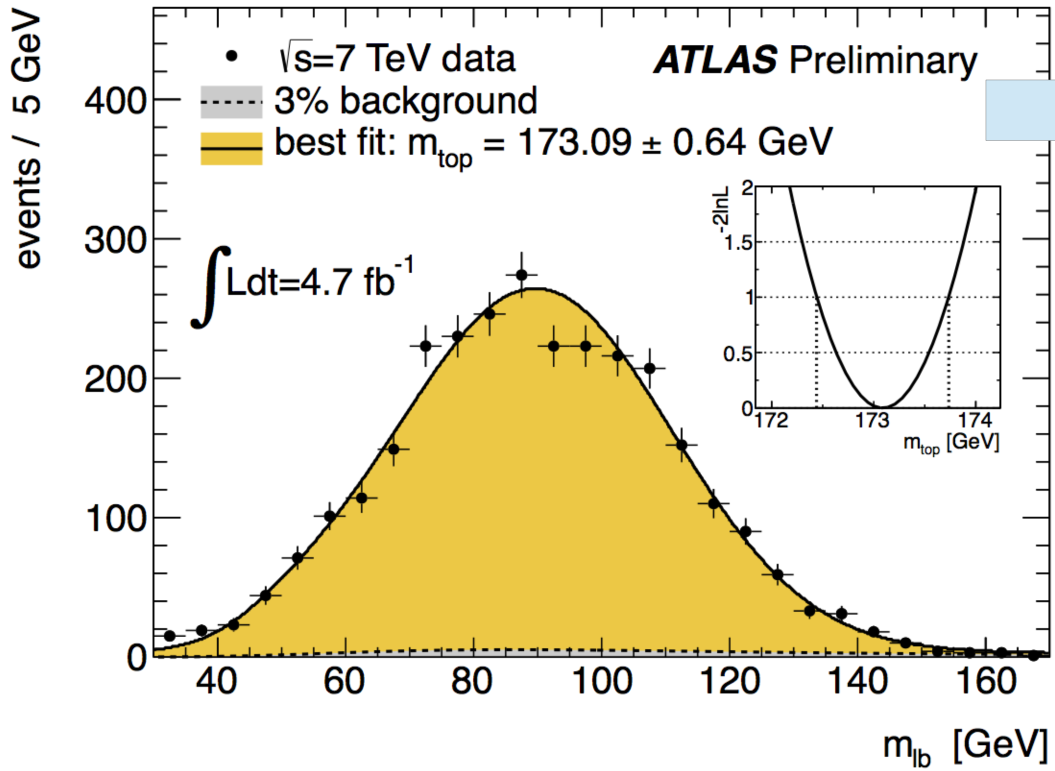


m_{lb} in 4.7 fb^{-1} of 2011 $\sqrt{s}$=7 TeV ATLAS data:



Results on 2011 √s=7 TeV ATLAS data

Best fit to data



by far largest contributions to the total uncertainty on m_{top} from JES and bJES (80% of the total)
expected since no in-situ calibration of the jet energy scales is used

Systematic uncertainties

Description	Value [GeV]
Measured value	173.09
Statistical uncertainty	0.64
Method calibration	0.07
Signal MC generator	0.20
Hadronisation	0.44
Underlying event	0.42
Colour reconnection	0.29
ISR/FSR	0.37
Proton PDF	0.12
Background	0.14
Jet energy scale	0.89
b-jet energy scale	0.71
b-tagging efficiency and mistag rate	0.46
Jet energy resolution	0.21
Missing transverse momentum	0.05
Pile-up	0.01
Electron uncertainties	0.11
Muon uncertainties	0.05
Total systematic uncertainty	1.50
Total uncertainty	1.63

dilepton summary

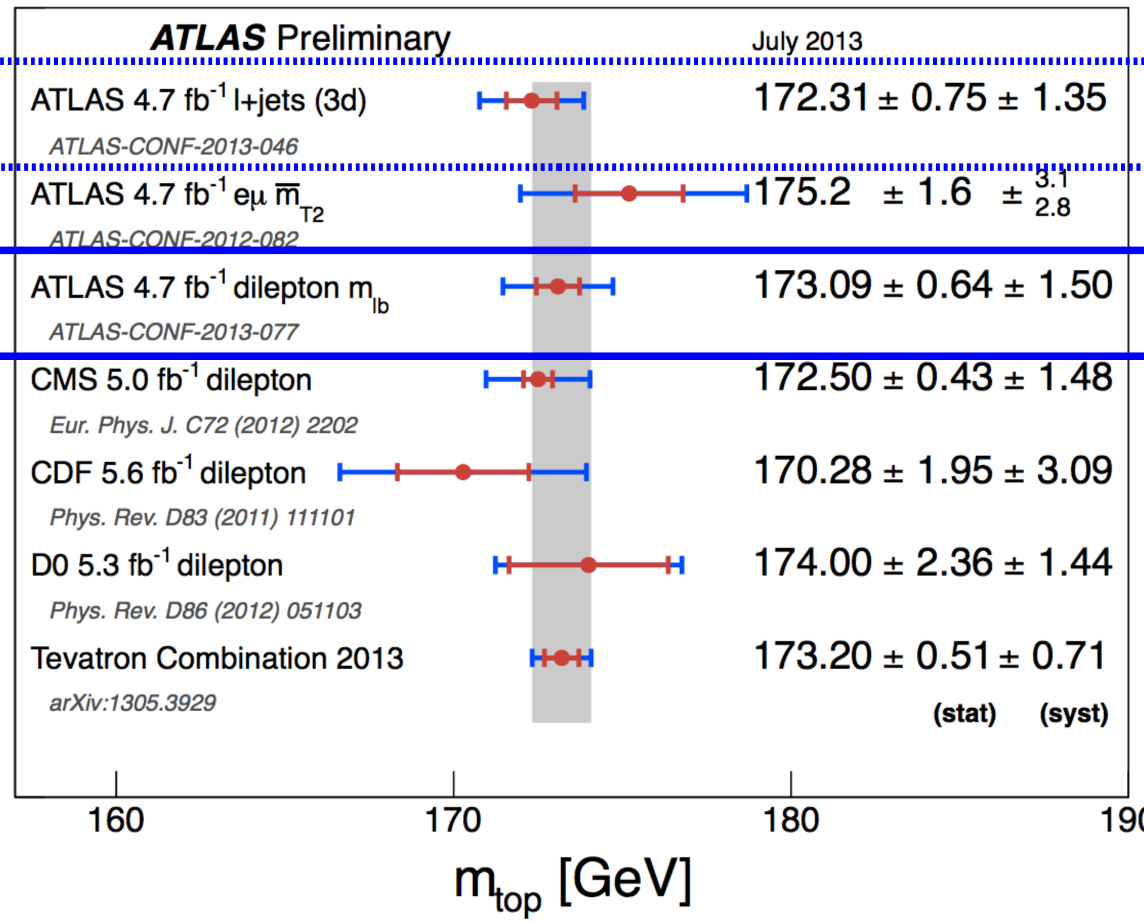
More info: [ATLAS-CONF-2013-077]

The final measurement is:

$$m_{top} = 173.09 \pm 0.64\ (\text{stat}) \pm 1.50\ (\text{syst})\ \text{GeV}$$

Uncertainty reduced from 3.5 GeV to 1.6 GeV with respect to previous ATLAS result in the *eμ* channel

Precision better than 1%, competitive with m_{top} from the ATLAS lepton+jets 3d analysis



Measurement of m_{top} in the all-hadronic channel

At least 6 jets (p_T>55 GeV, 6th jet p_T>30 GeV), exactly 2 b-tagged jets
Veto events with prompt leptons, require low E_T^{miss}
Jet to parton assignments using a χ^2 fit
→ use the template method with m_{jjb} as estimator for m_{top}

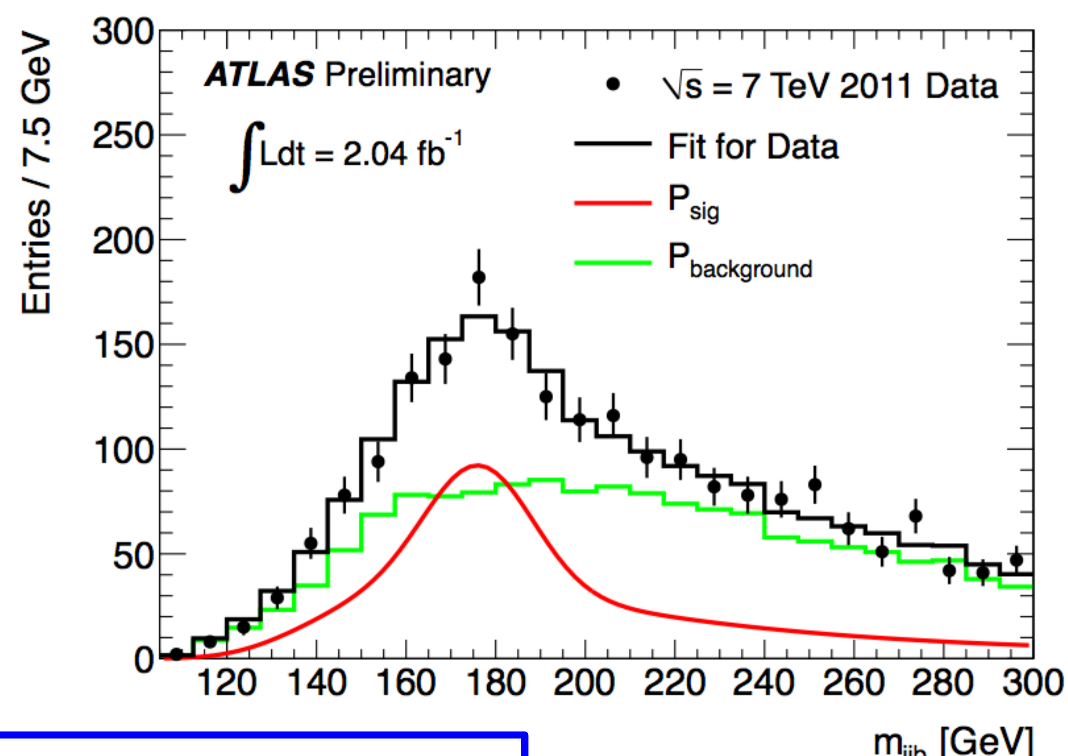
Data driven QCD multijet background using an event/jet mixing algorithm

More info: [ATLAS-CONF-2012-30]

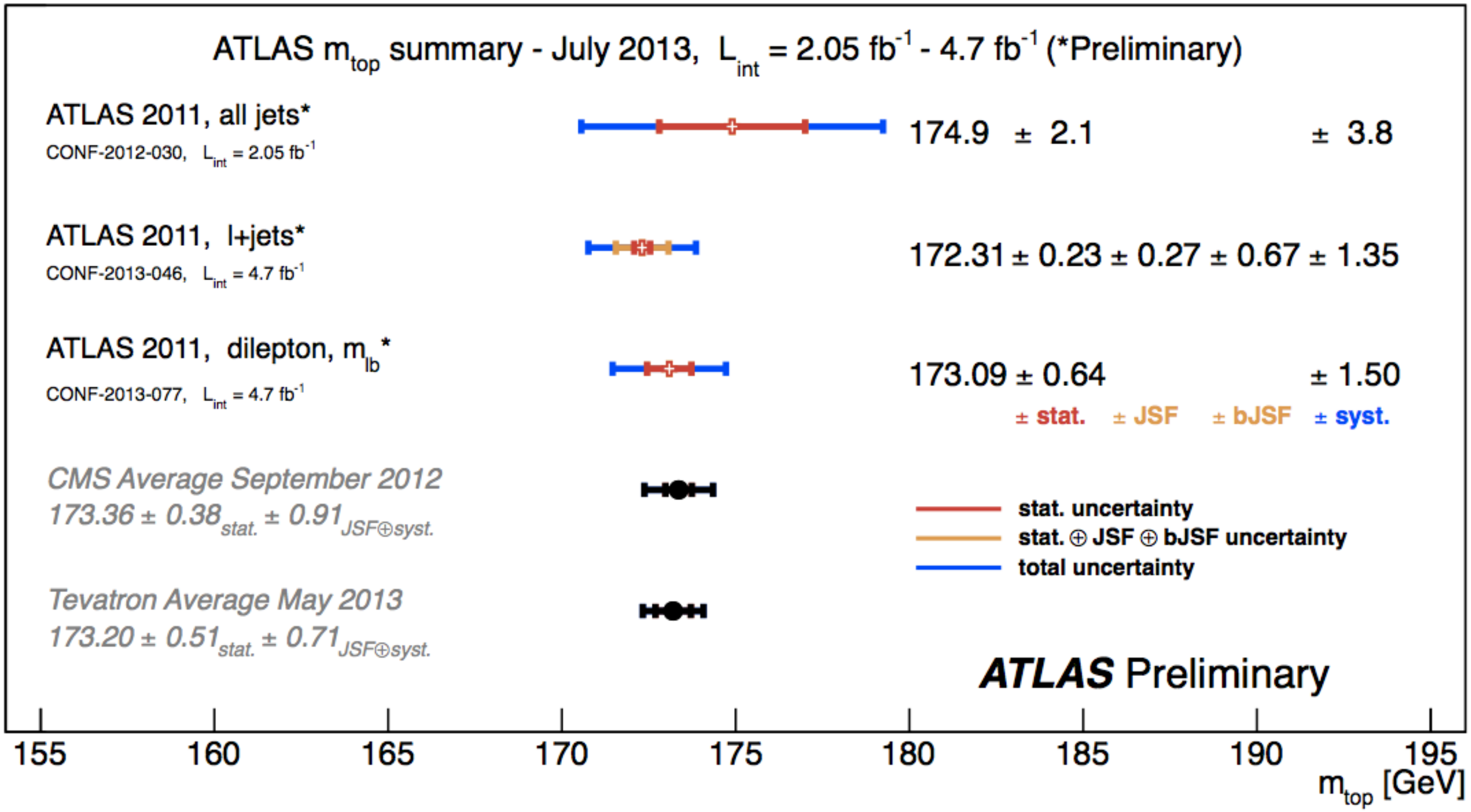
Result on 2.04 fb^{-1} of 2011 $\sqrt{s}$=7 TeV ATLAS data

Systematic uncertainties dominated by JES, bJES, ISR/FSR, and background modelling

This measurement does not yet take advantage of the latest ATLAS improvements in MC modelling, JES and bJES



$$m_t = 174.9 \pm 2.1\ (\text{stat.}) \pm 3.8\ (\text{syst.})\ \text{GeV}$$



- Individual m_{top} measurements at ATLAS have reached a precision better than 1%, thanks to:
  - improvements in the analysis methods
  - better understanding of the detector performance and MC simulation

- Expect improved precision in the next LHC combination (competitive with Tevatron)

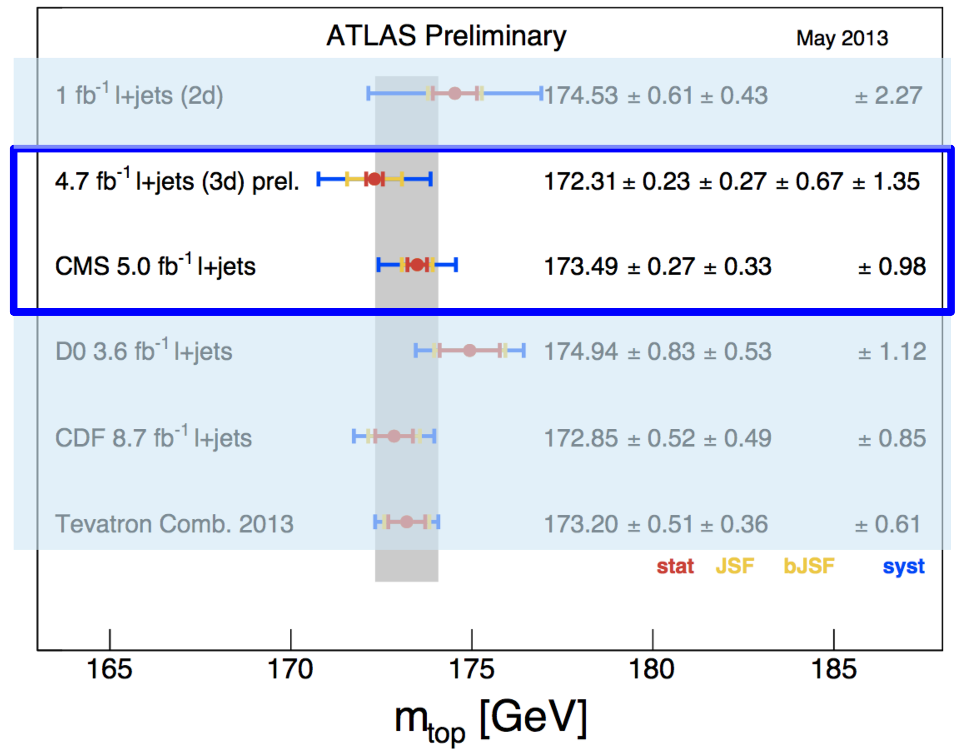
http://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults

- Backup -

lepton+jets m_{top}: ATLAS vs CMS comparison

Tevatron	ATLAS	CMS	ATLAS 2011 l+jets	CMS 2011 l+jets
Measured m_{top}			172.31	173.49
	Jet Scale Factor	Jet Scale Factor	0.27	0.33
	bJet Scale Factor		0.67	
iJES	Sum	Sum	0.72	0.33
bJES	JES_{b-jet}	JES_{b-jet}	0.08	0.61
dJES	$JES_{light-jet}$	$JES_{light-jet}$	0.79	0.28
Lepton p_T Scale			0.04	0.02
MC	MC Generator	MC Generator	0.19	
	Hadronisation		0.27	
	Sum	Sum	0.33	
Rad	ISR/FSR	ISR/FSR	0.45	
		Q-Scale		0.24
		Jet-Parton Scale		0.18
	Sum	Sum	0.45	0.30
CR	Colour Recon.		0.32	0.54
PDF	Proton PDF	Proton PDF	0.17	0.07
	Jet Energy Res.	Jet Energy Res.	0.22	0.23
	Jet Rec. Eff.		0.05	
	b-tagging	b-tagging	0.81	0.12
	E_T^{miss}	E_T^{miss}	0.03	0.06
DetMod	Sum	Sum	0.84	0.27
Underlying Event			0.12	0.15
BGMC				0.13
BGData			0.10	
Method	Method Calib.	Method Calib.	0.13	0.06
MHI	Pile-up	Pile-up	0.03	0.07
		Statistics	0.23	0.27
		Rest	1.53	1.03
		Total Uncertainty	1.55	1.07

Summary table of public 2011 LHC m_{top} measurements in the lepton+jets channel, likely to drive the next LHC combination



Systematics categorized according to the first LHC combination
CMS measurement from:
[JHEP (2012) 2012:105]

lepton+jets m_{top}: ATLAS vs CMS comparison

Uncertainty Categories			ATLAS / CMS	
Tevatron	ATLAS	CMS	2011 l+jets	2011 l+jets
Measured m_{top}			172.31	173.49
	Jet Scale Factor	Jet Scale Factor	0.27	0.33
	bJet Scale Factor		0.67	
iJES	Sum	Sum	0.72	0.33
bJES	JES_{b-jet}	JES_{b-jet}	0.08	0.61
dJES	$JES_{light-jet}$	$JES_{light-jet}$	0.79	0.28
Lepton p_T Scale			0.04	0.02
MC	MC Generator	MC Generator	0.19	
	Hadronisation		0.27	
	Sum	Sum	0.33	
Rad	ISR/FSR	ISR/FSR	0.45	
		Q-Scale		0.24
		Jet-Parton Scale		0.18
	Sum	Sum	0.45	0.30
CR	Colour Recon.		0.32	0.54
PDF	Proton PDF	Proton PDF	0.17	0.07
	Jet Energy Res.	Jet Energy Res.	0.22	0.23
	Jet Rec. Eff.		0.05	
	b-tagging	b-tagging	0.81	0.12
	E_T^{miss}	E_T^{miss}	0.03	0.06
DetMod	Sum	Sum	0.84	0.27
Underlying Event			0.12	0.15
BGMC				0.13
BGData			0.10	
Method	Method Calib.	Method Calib.	0.13	0.06
MHI	Pile-up	Pile-up	0.03	0.07
		Statistics	0.23	0.27
		Rest	1.53	1.03
		Total Uncertainty	1.55	1.07

Statistical sensitivity

- extra statistical uncertainties on m_{top} introduced by the simultaneous JSF/bJSF fits
- Scale with luminosity, uncorrelated between experiments
- Similar sensitivity to JSF from the in-situ m_W fits (0.27 vs 0.33 GeV)
- ATLAS has larger JES stat component (iJES) due to the increased dimensionality of the fit (extra 0.67 GeV)

Similar statistical sensitivity to m_{top} (corresponds to a 1d fit)

lepton+jets m_{top}: ATLAS vs CMS comparison

Uncertainty Categories			ATLAS / CMS	
Tevatron	ATLAS	CMS	2011 l+jets	2011 l+jets
Measured m_{top}			172.31	173.49
	Jet Scale Factor	Jet Scale Factor	0.27	0.33
	bJet Scale Factor		0.67	
iJES	Sum	Sum	0.72	0.33
bJES	JES_{b-jet}	JES_{b-jet}	0.08	0.61
dJES	$JES_{light-jet}$	$JES_{light-jet}$	0.79	0.28
Lepton p_{T} Scale			0.04	0.02
MC	MC Generator	MC Generator	0.19	
	Hadronisation		0.27	
	Sum	Sum	0.33	
Rad	ISR/FSR	ISR/FSR	0.45	
		Q-Scale		0.24
		Jet-Parton Scale		0.18
	Sum	Sum	0.45	0.30
CR	Colour Recon.		0.32	0.54
PDF	Proton PDF	Proton PDF	0.17	0.07
	Jet Energy Res.	Jet Energy Res.	0.22	0.23
	Jet Rec. Eff.		0.05	
	b-tagging	b-tagging	0.81	0.12
	$E_{\mathrm{T}}^{\mathrm{miss}}$	$E_{\mathrm{T}}^{\mathrm{miss}}$	0.03	0.06
DetMod	Sum	Sum	0.84	0.27
Underlying Event			0.12	0.15
BGMC				0.13
BGData			0.10	
Method	Method Calib.	Method Calib.	0.13	0.06
MHI	Pile-up	Pile-up	0.03	0.07
		Statistics	0.23	0.27
		Rest	1.53	1.03
		Total Uncertainty	1.55	1.07

Reduced bJES uncertainty thanks to 3rd dimension in the fit

Uncertainty Categories			ATLAS / CMS	
Tevatron	ATLAS	CMS	2011 *l*+jets	2011 *l*+jets
Measured m_{top}			172.31	173.49
	Jet Scale Factor	Jet Scale Factor	0.27	0.33
	bJet Scale Factor		0.67	
iJES	Sum	Sum	0.72	0.33
bJES	JES_{b-jet}	JES_{b-jet}	0.08	0.61
dJES	$JES_{light-jet}$	$JES_{light-jet}$	0.79	0.28
Lepton p_T Scale			0.04	0.02
MC	MC Generator	MC Generator	0.19	
	Hadronisation		0.27	
	Sum	Sum	0.33	
Rad	ISR/FSR	ISR/FSR	0.45	
		Q-Scale		0.24
		Jet-Parton Scale		0.18
	Sum	Sum	0.45	0.30
CR	Colour Recon.		0.32	0.54
PDF	Proton PDF	Proton PDF	0.17	0.07
	Jet Energy Res.	Jet Energy Res.	0.22	0.23
	Jet Rec. Eff.		0.05	
	b-tagging	*b*-tagging	0.81	0.12
	E_T^{miss}	E_T^{miss}	0.03	0.06
DetMod	Sum	Sum	0.84	0.27
Underlying Event			0.12	0.15
BGMC				0.13
BGData			0.10	
Method	Method Calib.	Method Calib.	0.13	0.06
MHI	Pile-up	Pile-up	0.03	0.07
		Statistics	0.23	0.27
		Rest	1.53	1.03
		Total Uncertainty	1.55	1.07

Different residual JES uncertainties, despite the in-situ m_W calibration

More pronounced p_T dependence of the JES uncertainty for ATLAS, softer jet p_T requirements

Uncertainty Categories			ATLAS / CMS	
Tevatron	ATLAS	CMS	2011 l+jets	2011 l+jets
Measured m_{top}			172.31	173.49
	Jet Scale Factor	Jet Scale Factor	0.27	0.33
	bJet Scale Factor		0.67	
iJES	Sum	Sum	0.72	0.33
bJES	JES_{b-jet}	JES_{b-jet}	0.08	0.61
dJES	$JES_{light-jet}$	$JES_{light-jet}$	0.79	0.28
Lepton p_T Scale			0.04	0.02
MC	MC Generator	MC Generator	0.19	
	Hadronisation		0.27	
	Sum	Sum	0.33	
Rad	ISR/FSR	ISR/FSR	0.45	
		Q-Scale		0.24
		Jet-Parton Scale		0.18
	Sum	Sum	0.45	0.30
CR	Colour Recon.		0.32	0.54
PDF	Proton PDF	Proton PDF	0.17	0.07
	Jet Energy Res.	Jet Energy Res.	0.22	0.23
	Jet Rec. Eff.		0.05	
	b-tagging	b-tagging	0.81	0.12
	E_T^{miss}	E_T^{miss}	0.03	0.06
DetMod	Sum	Sum	0.84	0.27
Underlying Event			0.12	0.15
BGMC				0.13
BGData			0.10	
Method	Method Calib.	Method Calib.	0.13	0.06
MHI	Pile-up	Pile-up	0.03	0.07
		Statistics	0.23	0.27
		Rest	1.53	1.03
		Total Uncertainty	1.55	1.07

MC generator and hadronization (Pythia/Herwig) uncertainties:

Not dominant uncertainties for ATLAS 3d analysis but could be large depending on the analysis

Within CMS:

- the MC generator systematics are found to be small (but are not documented for all the current public results)
- Hadronization systematics are meant to be covered by the JES uncertainty

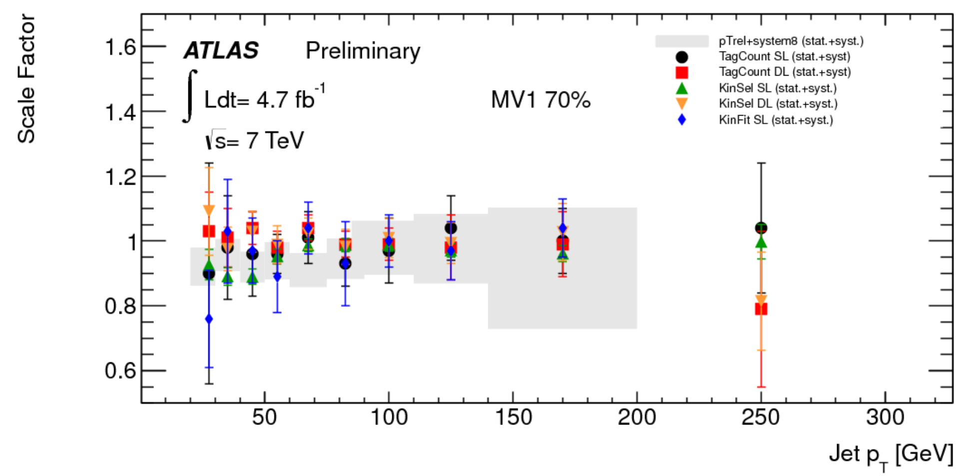
Harmonized treatment is under discussion in the TOP-LHC-WG for the next LHC combination

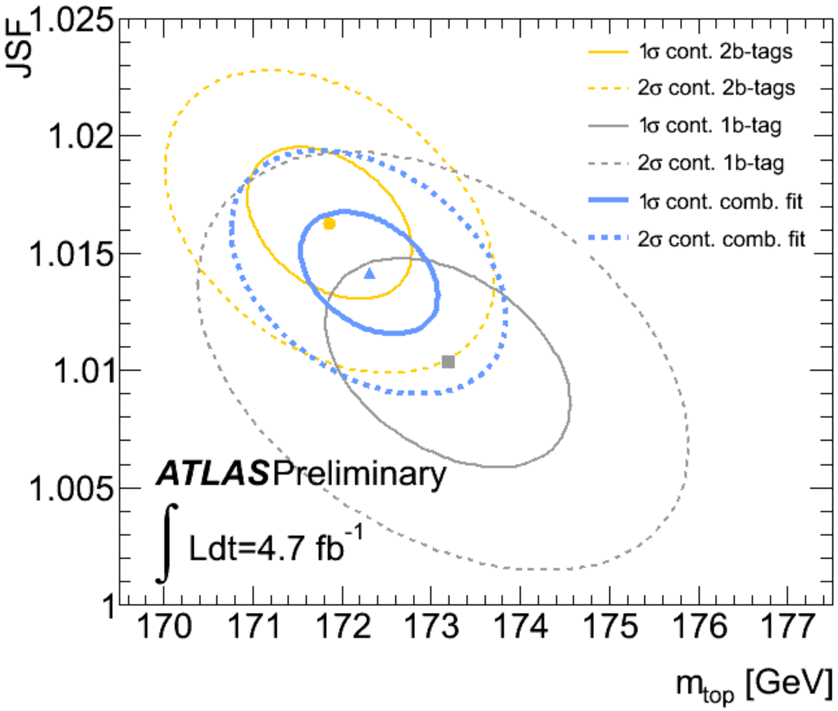
Need to evaluate possible double counting effects between the hadronization and JES systematics

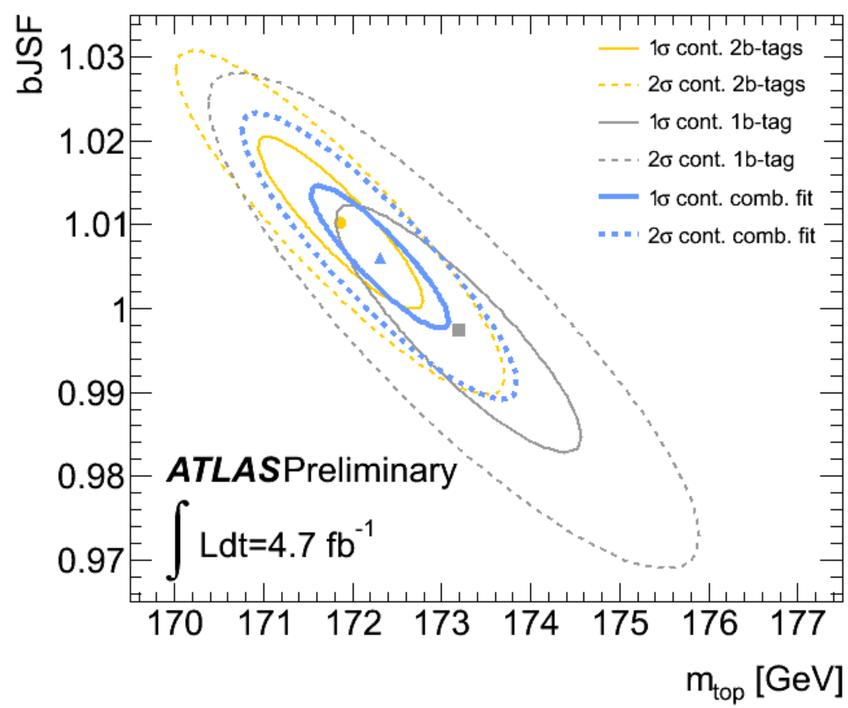
lepton+jets m_{top}: ATLAS vs CMS comparison

Uncertainty Categories			ATLAS / CMS	
Tevatron	ATLAS	CMS	2011 l+jets	2011 l+jets
Measured m_{top}			172.31	173.49
	Jet Scale Factor	Jet Scale Factor	0.27	0.33
	bJet Scale Factor		0.67	
iJES	Sum	Sum	0.72	0.33
bJES	JES_{b-jet}	JES_{b-jet}	0.08	0.61
dJES	$JES_{light-jet}$	$JES_{light-jet}$	0.79	0.28
Lepton p_T Scale			0.04	0.02
MC	MC Generator	MC Generator	0.19	
	Hadronisation		0.27	
	Sum	Sum	0.33	
Rad	ISR/FSR	ISR/FSR	0.45	
		Q-Scale		0.24
		Jet-Parton Scale		0.18
	Sum	Sum	0.45	0.30
CR	Colour Recon.		0.32	0.54
PDF	Proton PDF	Proton PDF	0.17	0.07
	Jet Energy Res.	Jet Energy Res.	0.22	0.23
	Jet Rec. Eff.		0.05	
	b-tagging	b-tagging	0.81	0.12
	E_T^{miss}	E_T^{miss}	0.03	0.06
DetMod	Sum	Sum	0.84	0.27
Underlying Event			0.12	0.15
BGMC				0.13
BGData			0.10	
Method	Method Calib.	Method Calib.	0.13	0.06
MHI	Pile-up	Pile-up	0.03	0.07
		Statistics	0.23	0.27
		Rest	1.53	1.03
		Total Uncertainty	1.55	1.07

ATLAS 3d analysis has a larger sensitivity to b-tag systematics, mainly due to p_T dependence of the b-tagging SF uncertainties, that affect the shape of R_{lb}^{reco}





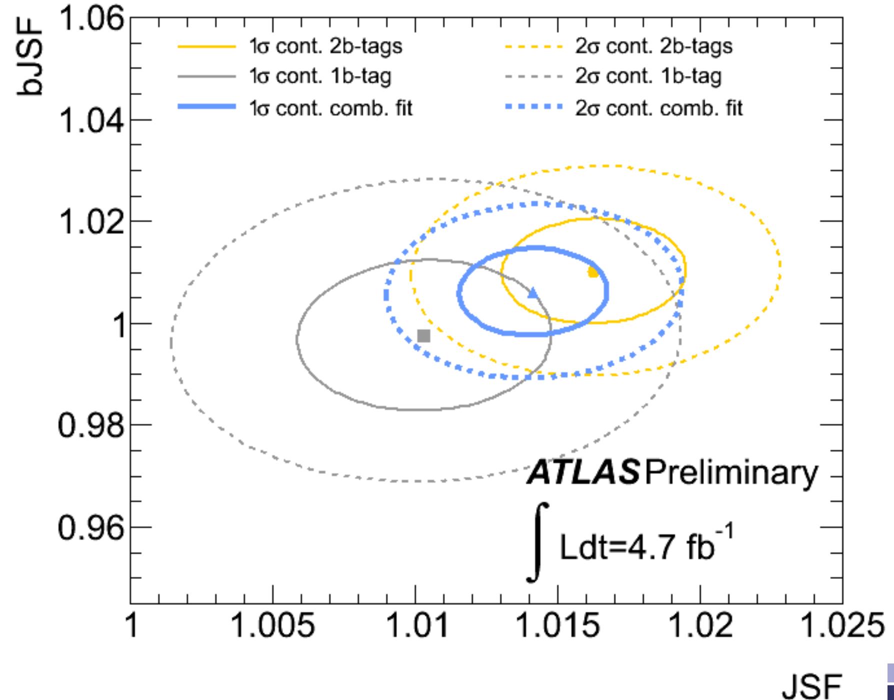


Results of the fits for
1b-tag / ≥ 2b-tags / combined
show very good consistency

Contour plots
m_{top} vs JSF/bJSF and JSF vs bJSF

JSF and bJSF (almost) uncorrelated

(statistical uncertainties only)



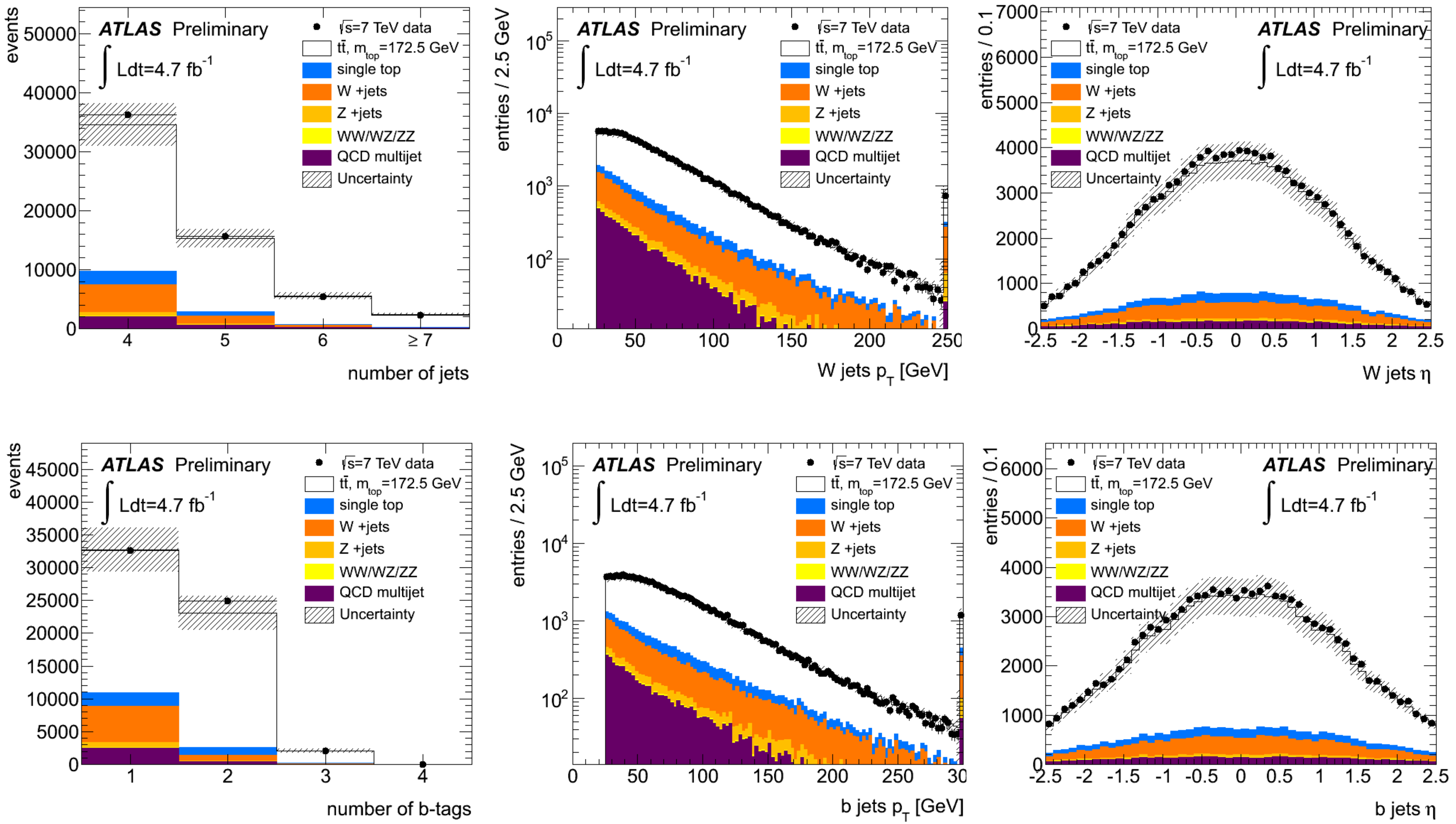
Standard top-pair selection for the l+jets channel:

- Exactly one charged lepton, matching trigger and within good detector acceptance, with $E_T \geq 25$ ($p_T \geq 20$) GeV for electrons (muons)

- ≥ 4 anti-kt4 EM+JES jets with $p_T \geq 25$ GeV, $|\eta| < 2.5$, $|JVF| \geq 0.75$
- ≥ 1 b-tag jet (MV1 @ 70% efficiency)

- To suppress backgrounds:
  - e+jets: $E_T^{miss} \geq 30$ GeV, $m_W^T \geq 30$ GeV
  - μ+jets: $E_T^{miss} \geq 20$ GeV, $E_T^{miss} + m_W^T \geq 60$ GeV

MC samples are corrected by applying scale factors (SF) to match data. The b-tagging SF is derived from dijet and dilepton top pair decay events to have a reduced p_T dependence of its uncertainty.



uncertainty band includes: statistical uncertainty, luminositi, b-tagging uncertainties,
10% uncertainty on top antitop cross section, 30% on W+jets normalization, 50% on QCD normalization

Perform an unbinned likelihood fit using the following function:

$$\mathcal{L}_{\text{shape}}(m_{\text{top}}^{\text{reco}}, m_{\text{W}}^{\text{reco}}, R_{\text{lb}}^{\text{reco}} | m_{\text{top}}, \text{JSF}, \text{bJSF}, n_{\text{bkg}}) = \prod_{i=1}^{N} P_{\text{top}}(m_{\text{top}}^{\text{reco}} | m_{\text{top}}, \text{JSF}, \text{bJSF}, n_{\text{bkg}})_i \times P_{\text{W}}(m_{\text{W}}^{\text{reco}} | \text{JSF}, n_{\text{bkg}})_i \times P_{\mathcal{R}_{\text{lb}}}(R_{\text{lb}}^{\text{reco}} | m_{\text{top}}, \text{bJSF}, n_{\text{bkg}})_i$$

Performance of the fitting procedure has been verified using pseudo-experiments:
- pull (mean, width) = (0,1)
- the residual deviations from this are used to estimate the method calibration uncertainty

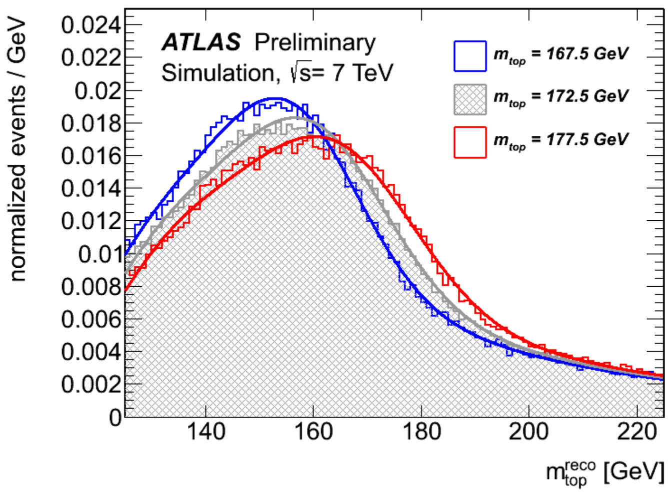
lepton+jets: template parameterization 1/2

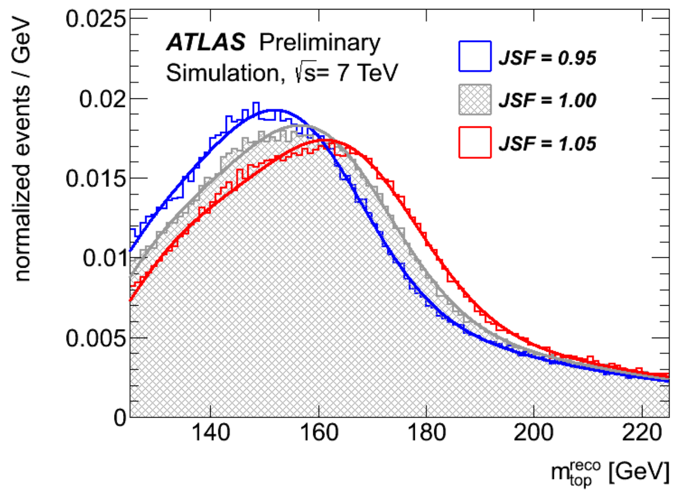
Parameterize the probability density functions of the reconstructed observables:

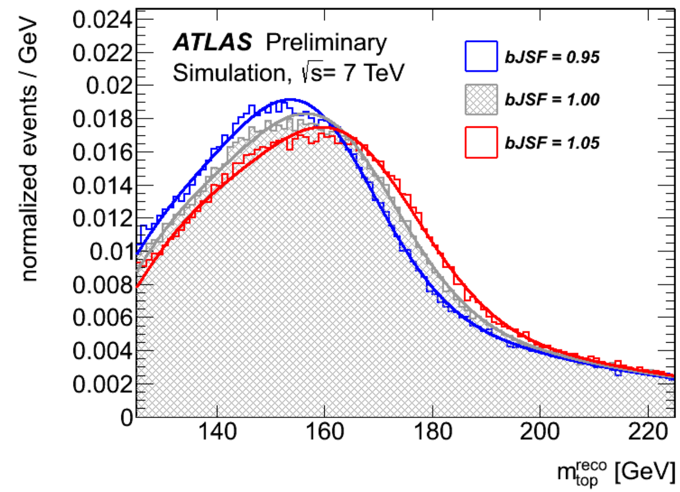
- m_{top}^{reco} as function of m_{top}, JSF^{in} and $bJSF^{in}$

Fit parameters depend linearly on m_{top}, JSF^{in} and $bJSF^{in}$
Parameterization done separately for signal/background and 1 b-tag/ ≥2b-tags samples
single top considered in signal, background m_{top} independent

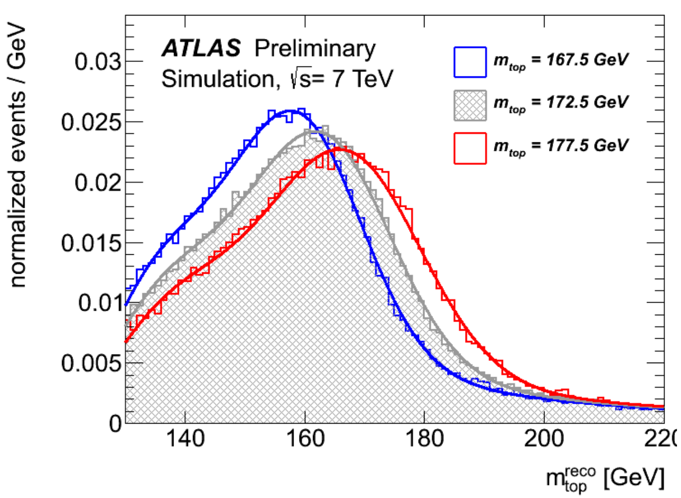
events with 1 b-tag

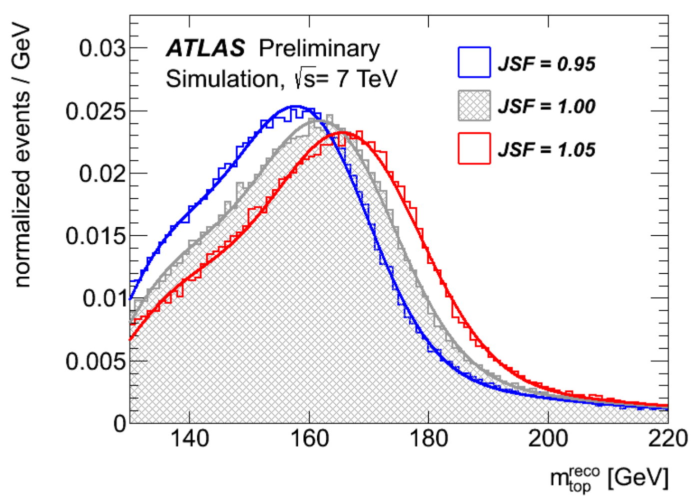


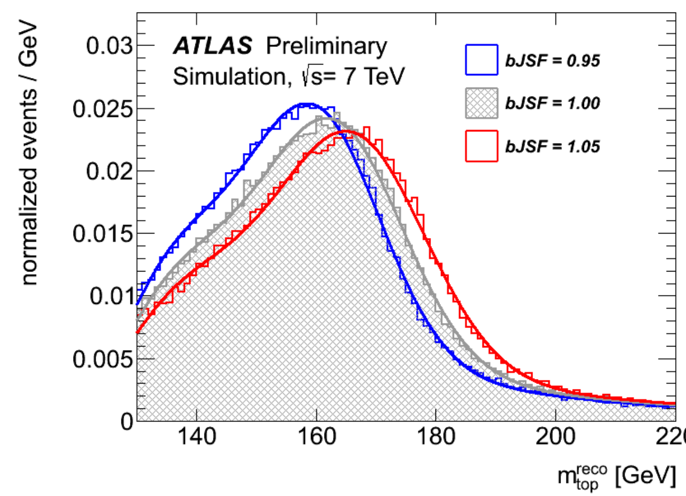




events with ≥2b-tags







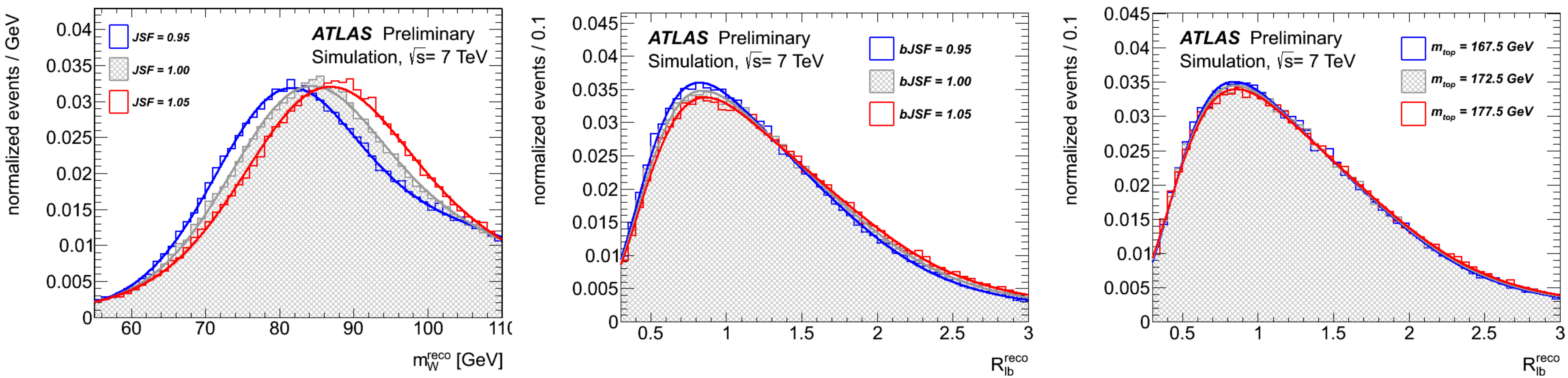
lepton+jets: template parameterization 2/2

Parameterize the probability density functions of the reconstructed observables:

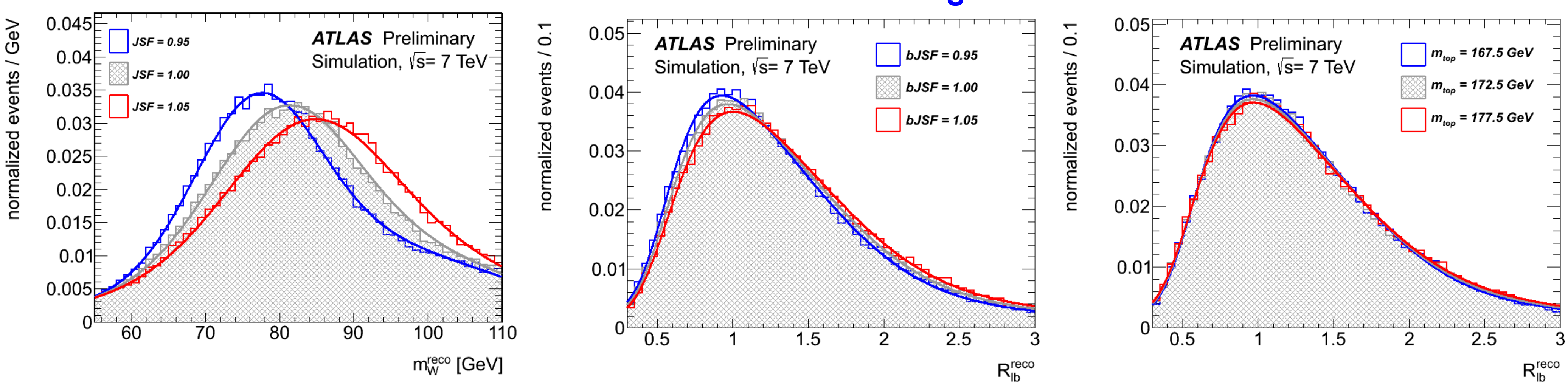
- m_{top}^{reco} as function of m_{top}, JSF^{in} and $bJSF^{in}$
- m_W^{reco} as function of JSF^{in}
- R_{lb}^{reco} as function of $bJSF^{in}$ and m_{top}

Fit parameters depend linearly on m_{top}, JSF^{in} and $bJSF^{in}$
Parameterization done separately for signal/background and 1 b-tag/ ≥2b-tags samples
single top considered in signal, background m_{top} independent

events with 1 b-tag



events with ≥2b-tags



Standard top-pair selection in the dileptonic channel:

- Two oppositely charged isolated leptons within good detector acceptance, with $E_T \geq 25$ ($p_T \geq 20$) GeV for electrons (muons)

- $\geq$ 2 anti-kt4 EM+JES jets with $p_T \geq 25$ GeV, $|\eta| < 2.5$, $|JVF| \geq 0.75$
- Exactly 2 b-tagged jets (MV1 @ 70% efficiency)

- To suppress backgrounds:
  - e^+e^-, $\mu^+\mu^-$:
    - $E_T^{miss} \geq 60$ GeV,
    - Z boson mass window exclusion: m_{e+e-}, $m_{\mu+\mu-} \neq 91 \pm 10$ GeV
  - eμ :
    - $H_T \geq 130$ GeV

- All reco-object scale factors are applied
- di-jet based b-tagging scale factors are used

Almost a background free sample. Background < 3%