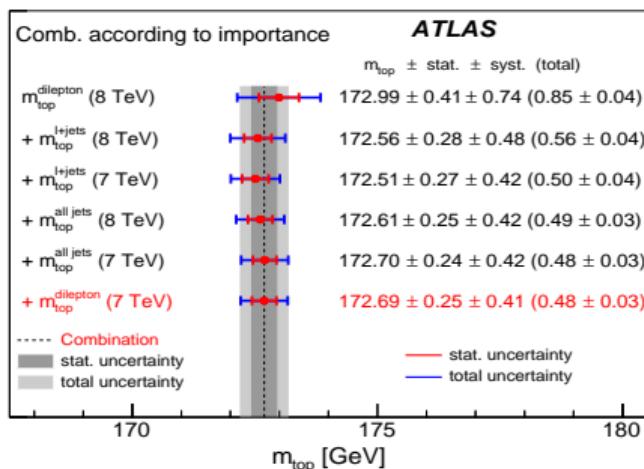
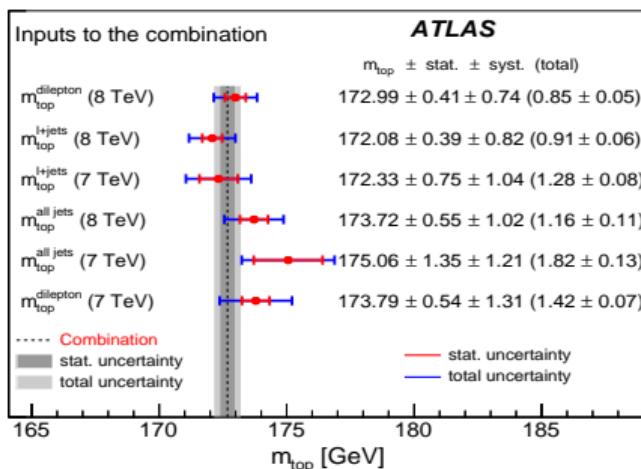


Top mass in ATLAS



Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Ben Pearson (MPP Munich)
on behalf of the ATLAS Collaboration



Outline

Brief review of earlier Run-1 m_{top} analyses included in the combination

- Measurements in $t\bar{t}$ decay channels with 0,1,2 leptons
 - ▶ $t\bar{t} \rightarrow$ all-jets
 - ★ at 7 TeV ▶ Eur. Phys. J. C75 (2015) 158
 - ★ at 8 TeV ▶ JHEP 09 (2017) 118 ← Brief review in this Talk
 - ▶ $t\bar{t} \rightarrow$ lepton+jets ($\ell + \text{jets}$)
 - ★ at 7 TeV ▶ Eur. Phys. J. C75 (2015) 330
 - ▶ $t\bar{t} \rightarrow$ dilepton
 - ★ at 7 TeV ▶ Eur. Phys. J. C75 (2015) 330
 - ★ at 8 TeV ▶ Phys. Lett. B761 (2016) 350 ← Brief review in this Talk

Most recent top mass result from ATLAS ▶ arXiv:1810.01772

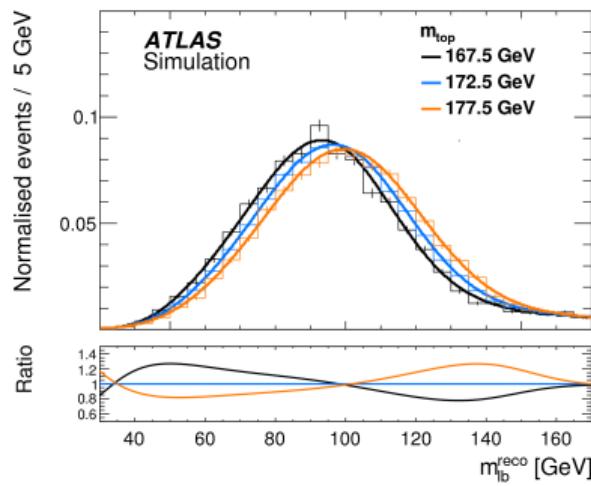
- **New** measurement of m_{top} in the $t\bar{t} \rightarrow$ lepton+jets channel at 8 TeV
- **New** combination of Run-1 ATLAS m_{top} measurements

Brief review: template methods

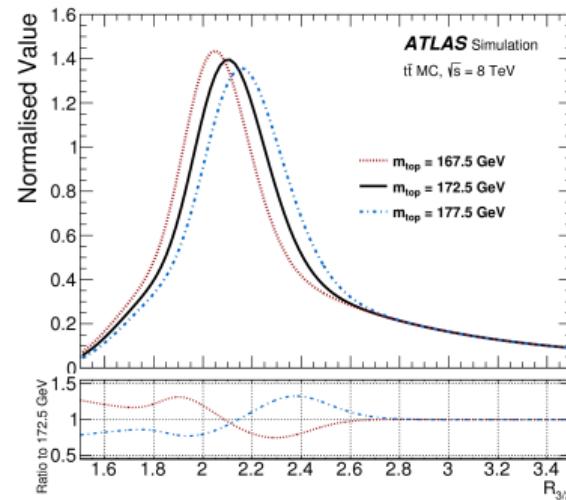
All m_{top} measurements included in the ATLAS combination use the template method

- Distributions of variables that are sensitive to m_{top} are fit to analytical functions at several discrete values of the input m_{top}
- These functions are then parameterized as functions of the input m_{top}

Dilepton: m_{lb}



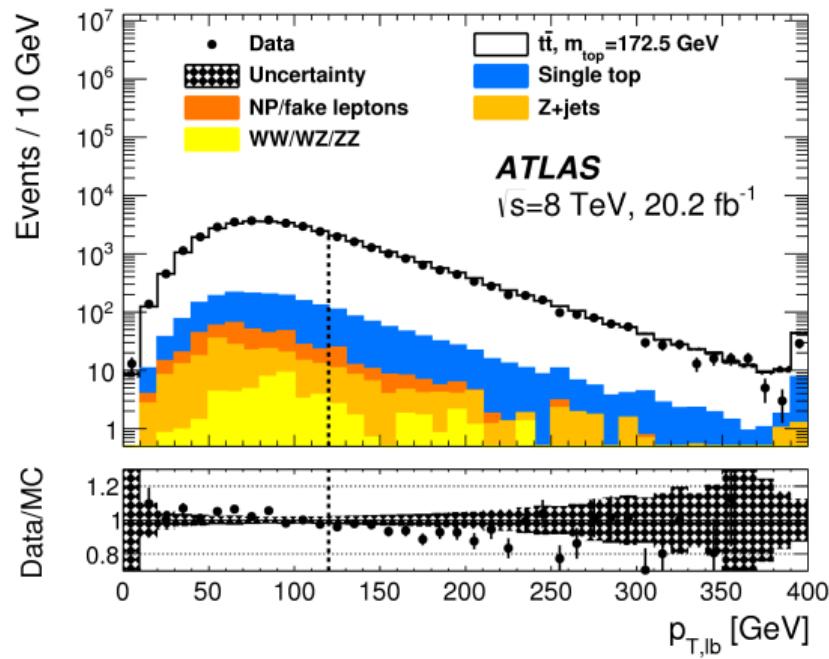
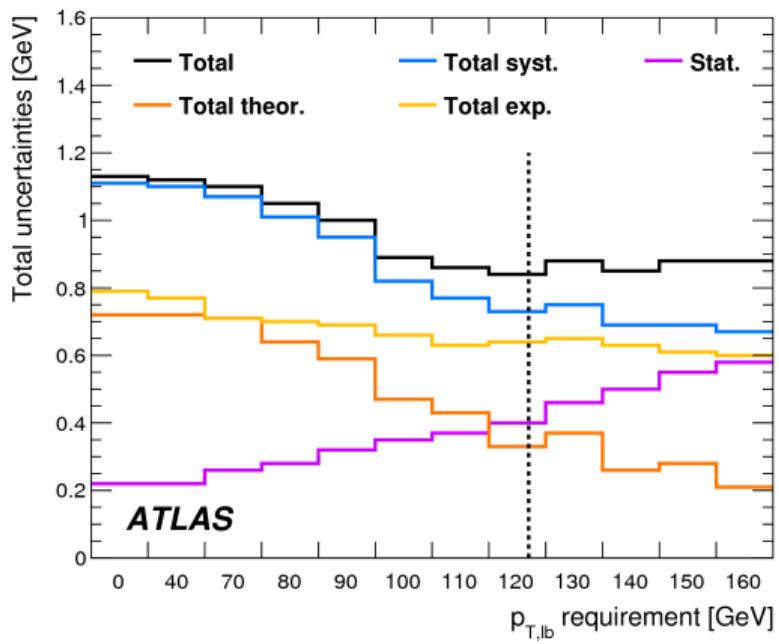
All-jets: $R_{3/2} = m_{jjj}/m_{jj}$



Brief review: optimization strategies

• Dilepton

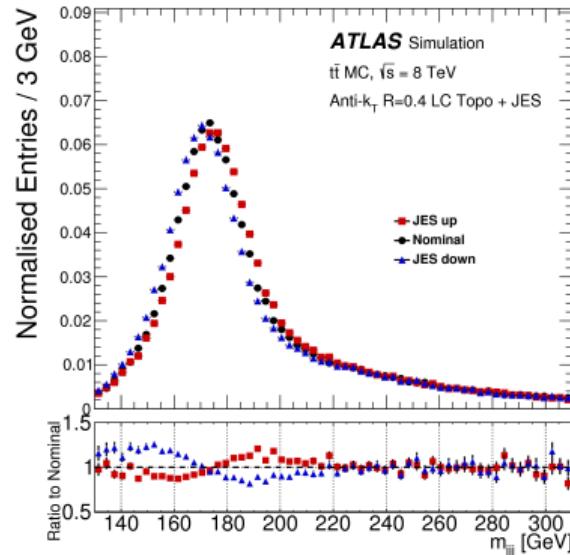
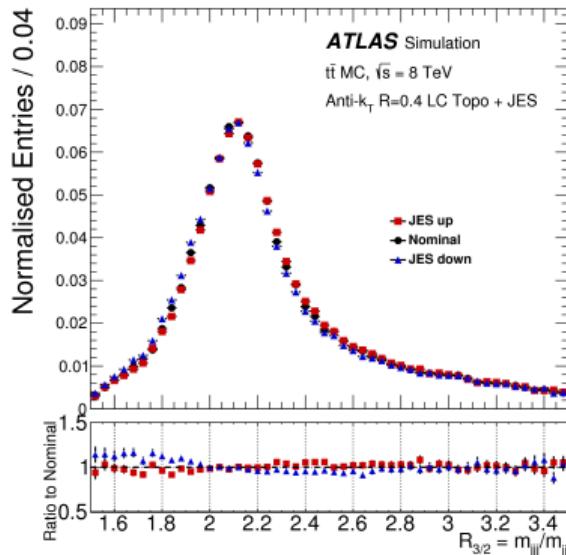
- Optimize a cut on $p_{T,lb}$ to minimize the total uncertainty



Brief review: optimization strategies

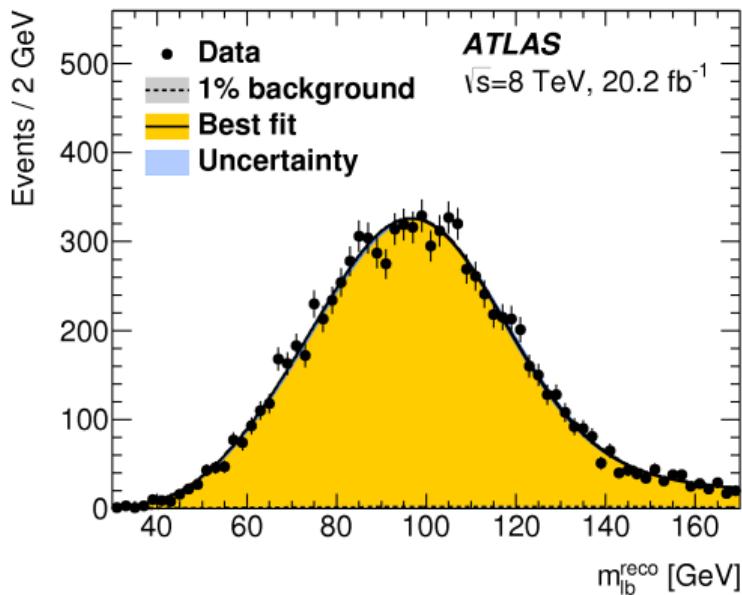
- Dilepton
 - ▶ Optimize a cut on p_{T,l_b} to minimize the total uncertainty

- All-jets
 - ▶ Use the $R_{3/2}$ distribution as the estimator for m_{top} instead of m_{jjj}
 - ★ more protected from variations in the JES: $R_{3/2} = \frac{m_{qqb}}{m_{qq}} \propto \frac{\text{JES} * \text{bJES}}{\text{JES}}$



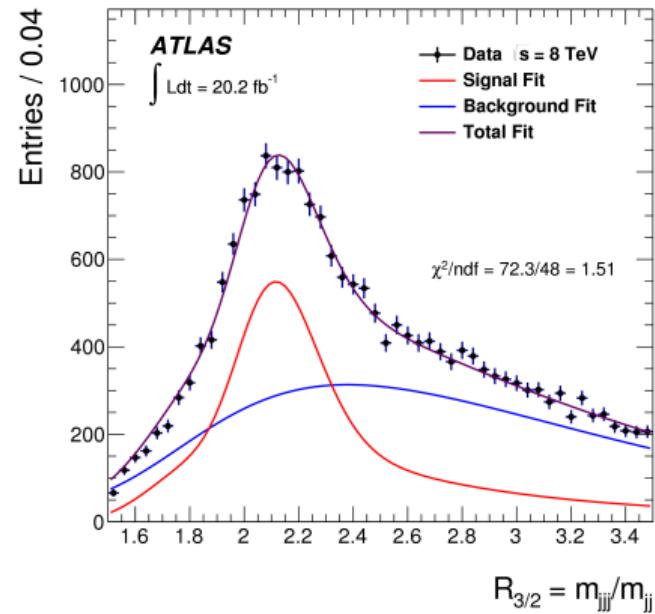
Brief review: results in data

Dilepton: unbinned max-LH



$$m_{\text{top}}^{\text{dilepton}} = 172.99 \pm 0.41(\text{stat}) \text{ GeV}$$

All-jets: binned min- χ^2



$$m_{\text{top}}^{\text{all-jets}} = 173.72 \pm 0.55(\text{stat}) \text{ GeV}$$

Brief review: systematic uncertainties (Δm_{top} [GeV])

• Dilepton

- ▶ JES (0.54), relative b -to-light JES (0.30), hadronisation (0.22), and ISR/FSR (0.23)
- ▶ Total uncertainty: **0.84 GeV (0.49%)**

| | $\sqrt{s} = 7 \text{ TeV}$ | $\sqrt{s} = 8 \text{ TeV}$ | |
|---|-------------------------------------|-------------------------------------|-----------------|
| $m_{\text{top}}^{\ell+\text{jets}}$ [GeV] | $m_{\text{top}}^{\text{dil}}$ [GeV] | $m_{\text{top}}^{\text{dil}}$ [GeV] | |
| Results | 172.33 | 173.79 | 172.99 |
| Statistics | 0.75 | 0.54 | 0.41 |
| Method | 0.11 ± 0.10 | 0.09 ± 0.07 | 0.05 ± 0.07 |
| Signal Monte Carlo generator | 0.22 ± 0.21 | 0.26 ± 0.16 | 0.09 ± 0.15 |
| Hadronisation | 0.18 ± 0.12 | 0.53 ± 0.09 | 0.22 ± 0.09 |
| Initial- and final-state QCD radiation | 0.32 ± 0.06 | 0.47 ± 0.05 | 0.23 ± 0.07 |
| Underlying event | 0.15 ± 0.07 | 0.05 ± 0.05 | 0.10 ± 0.14 |
| Colour reconnection | 0.11 ± 0.07 | 0.14 ± 0.05 | 0.03 ± 0.14 |
| Parton distribution function | 0.25 ± 0.00 | 0.11 ± 0.00 | 0.05 ± 0.00 |
| Background normalisation | 0.10 ± 0.00 | 0.04 ± 0.00 | 0.03 ± 0.00 |
| $W/Z+\text{jets}$ shape | 0.29 ± 0.00 | 0.00 ± 0.00 | 0 |
| Fake leptons shape | 0.05 ± 0.00 | 0.01 ± 0.00 | 0.08 ± 0.00 |
| Jet energy scale | 0.58 ± 0.11 | 0.75 ± 0.08 | 0.54 ± 0.04 |
| Relative b -to-light-jet energy scale | 0.06 ± 0.03 | 0.68 ± 0.02 | 0.30 ± 0.01 |
| Jet energy resolution | 0.22 ± 0.11 | 0.19 ± 0.04 | 0.09 ± 0.05 |
| Jet reconstruction efficiency | 0.12 ± 0.00 | 0.07 ± 0.00 | 0.01 ± 0.00 |
| Jet vertex fraction | 0.01 ± 0.00 | 0.00 ± 0.00 | 0.02 ± 0.00 |
| b -tagging | 0.50 ± 0.00 | 0.07 ± 0.00 | 0.03 ± 0.02 |
| Leptons | 0.04 ± 0.00 | 0.13 ± 0.00 | 0.14 ± 0.01 |
| $E_{\text{T}}^{\text{miss}}$ | 0.15 ± 0.04 | 0.04 ± 0.03 | 0.01 ± 0.01 |
| Pile-up | 0.02 ± 0.01 | 0.01 ± 0.00 | 0.05 ± 0.01 |
| Total systematic uncertainty | 1.03 ± 0.31 | 1.31 ± 0.23 | 0.74 ± 0.29 |
| Total | 1.27 ± 0.33 | 1.41 ± 0.24 | 0.84 ± 0.29 |

Brief review: systematic uncertainties (Δm_{top} [GeV])

- Dilepton

- ▶ JES (0.54), relative b -to-light JES (0.30), hadronisation (0.22), and ISR/FSR (0.23)
- ▶ Total uncertainty: **0.84 GeV** (0.49%)

- All-jets

- ▶ JES (0.60), hadronisation (0.64), and bJES (0.34)
- ▶ Total uncertainty: **1.15 GeV** (0.66%)

| Source of uncertainty | Δm_{top} [GeV] |
|--|-------------------------------|
| Monte Carlo generator | 0.18 ± 0.21 |
| Hadronisation modelling | 0.64 ± 0.15 |
| Parton distribution functions | 0.04 ± 0.00 |
| Initial/final-state radiation | 0.10 ± 0.28 |
| Underlying event | 0.13 ± 0.16 |
| Colour reconnection | 0.12 ± 0.16 |
| Bias in template method | 0.06 |
| Signal and bkgd parameterisation | 0.09 |
| Non all-hadronic $t\bar{t}$ contribution | 0.06 |
| ABCD method <i>vs.</i> ABCDEF method | 0.16 |
| Trigger efficiency | 0.08 ± 0.01 |
| Lepton/ E_T^{miss} calibration | 0.02 ± 0.01 |
| Overall flavour-tagging | 0.10 ± 0.00 |
| Jet energy scale (JES) | 0.60 ± 0.05 |
| b-jet energy scale (bJES) | 0.34 ± 0.02 |
| Jet energy resolution | 0.10 ± 0.04 |
| Jet vertex fraction | 0.03 ± 0.01 |
| Total systematic uncertainty | 1.01 |
| Total statistical uncertainty | 0.55 |
| Total uncertainty | 1.15 |

8 TeV lepton+jets analysis strategy

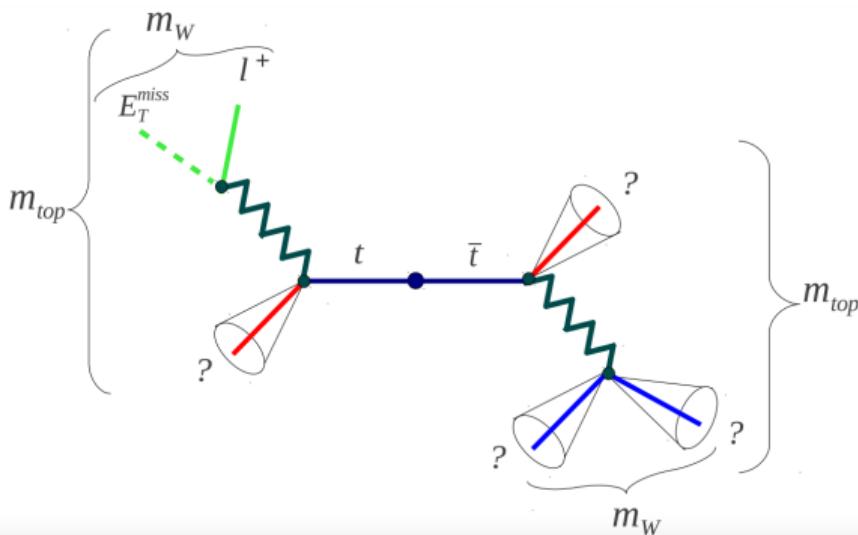
- Use the 3-D template method developed for the 7 TeV lepton+jets analysis
 - ▶ Templates constructed for $m_{\text{top}}^{\text{reco}}$, m_W^{reco} , and R_{bq}^{reco}

$$R_{bq}^{\text{reco}} = \frac{p_T^{b_{\text{had}}} + p_T^{b_{\text{lep}}}}{p_T^{q_1} + p_T^{q_2}}, \text{ where } q_1 \text{ and } q_2 \text{ are the light jets assigned to the } W \text{ boson}$$

- A 3D unbinned maximum likelihood fit of these templates is applied to the observed data to extract the measured m_{top} , JSF, and bJSF
- The simultaneous measurement of m_{top} with a jet energy scale factor (JSF) and a relative b -to-light-jet energy scale factor (bJSF) reduces the sizable JES and bJES uncertainties in m_{top}

8 TeV lepton+jets event selection and reconstruction

- Require **one** high- p_T electron or muon along with **at least four** high- p_T central jets
 - ▶ Exactly **two** of these jets must be ***b*-tagged**
- Use a kinematic likelihood fitter (KLFitter) for jet-parton assignment and to obtain $m_{\text{top}}^{\text{reco}}$



- $m_{\text{top}}^{\text{reco}}$ reconstructed within the KLFitter
- m_W^{reco} and R_{bq}^{reco} use the chosen jet permutation from KLFitter, but the original jet momentum 4-vectors
 - ▶ to retain the maximum sensitivity to JES and bJES

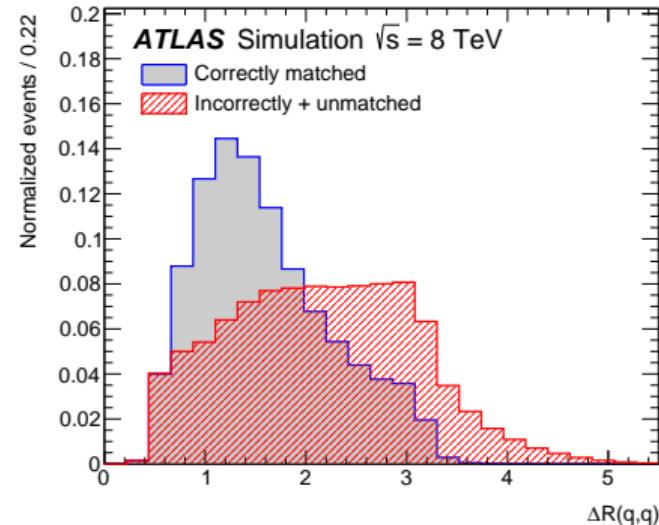
8 TeV lepton+jets BDT strategy

Idea:

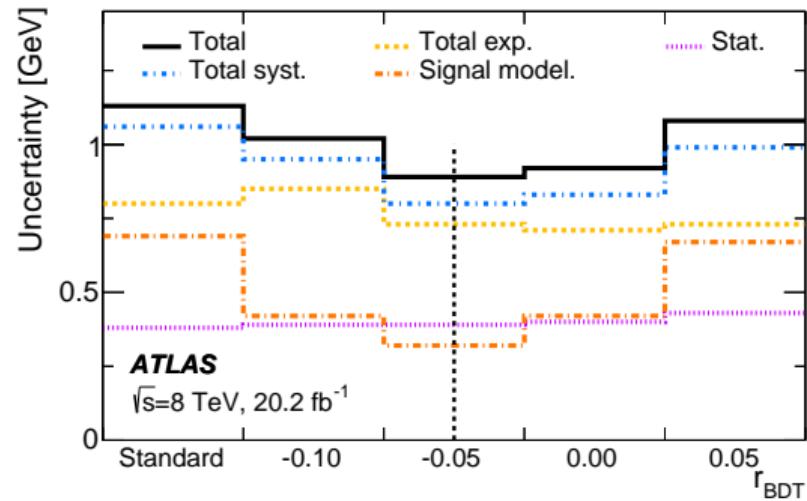
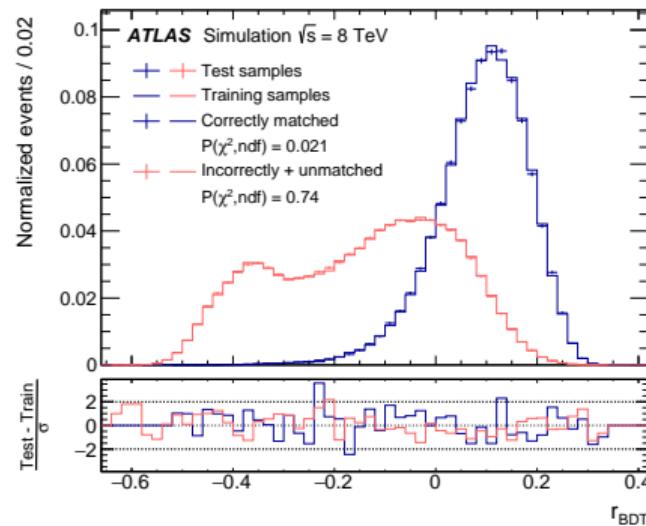
- Remove incorrectly/un-matched events, expected to have larger systematic uncertainties

Method:

- Train a BDT algorithm to distinguish these events from correctly matched events
- Require a minimum BDT output (r_{BDT})
- 13 variables are used as inputs to the BDT
- The two with by far the greatest separation power are
 - ▶ the KLFitter likelihood of the best permutation
 - ▶ the angular separation of the two untagged jets from the hadronically decaying W boson ($\Delta R(q, q)$)



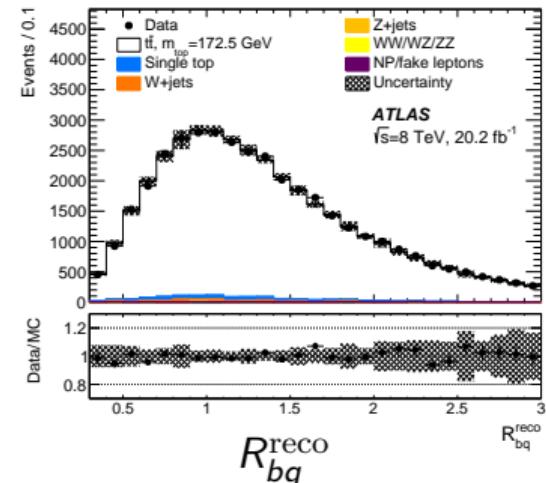
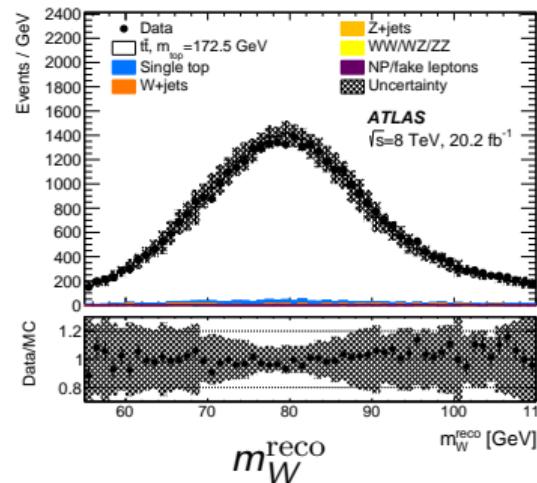
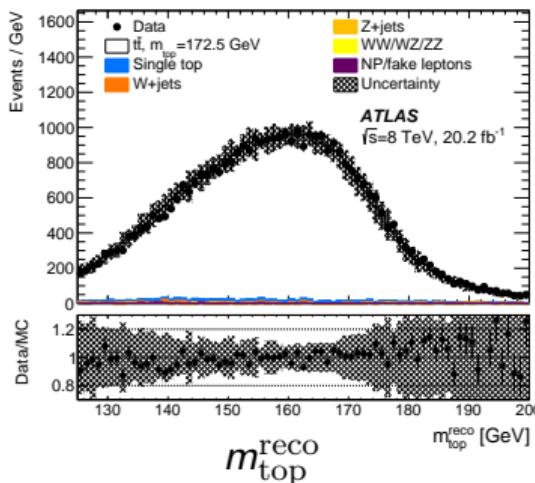
8 TeV lepton+jets BDT training and cut



- The BDT is trained on $t\bar{t}$ signal MC
 - ▶ Good separation of the event categories
- A scan of the cut on r_{BDT} around the crossing point of 0 is performed
 - ▶ Run complete analysis for each point in the scan to compare the total uncertainty in m_{top}
- A cut of $r_{\text{BDT}} \geq -0.05$ results in the smallest total uncertainty

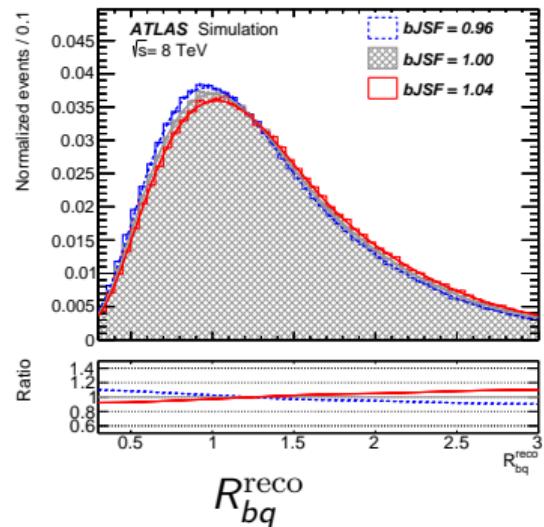
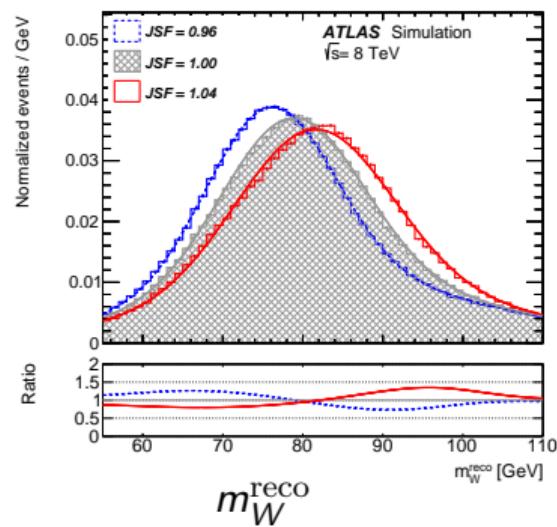
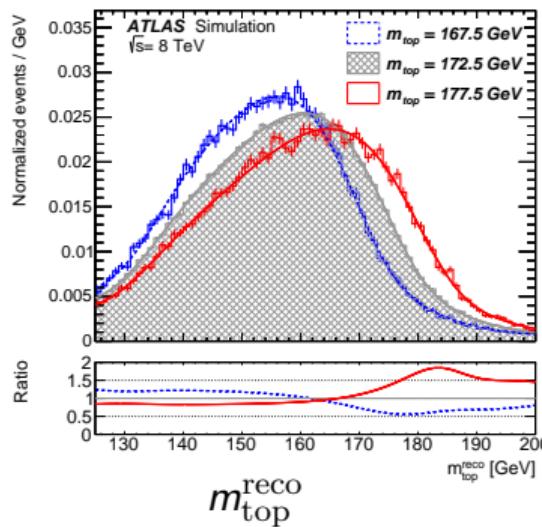
8 TeV lepton+jets data/MC agreement

- After applying the r_{BDT} cut, the background fraction is only 1%
- Single-top-quark production is included in signal
 - ▶ resulting in a background independent of m_{top}
- Distributions of fit variables agree well with data within uncertainties
 - ▶ MC simulation is normalised to the data and only shape uncertainties remain in the band



8 TeV lepton+jets template fit

- Simulated distributions of $m_{\text{top}}^{\text{reco}}$, m_W^{reco} , and R_{bq}^{reco} are fit to analytical functions which are parameterised as functions of the input m_{top} , JSF, and bJSF depending on sensitivity
 - $m_{\text{top}}^{\text{reco}}$ ($m_{\text{top}}, \text{JSF}, \text{bJSF}$), m_W^{reco} (JSF), R_{bq}^{reco} ($m_{\text{top}}, \text{JSF}, \text{bJSF}$)



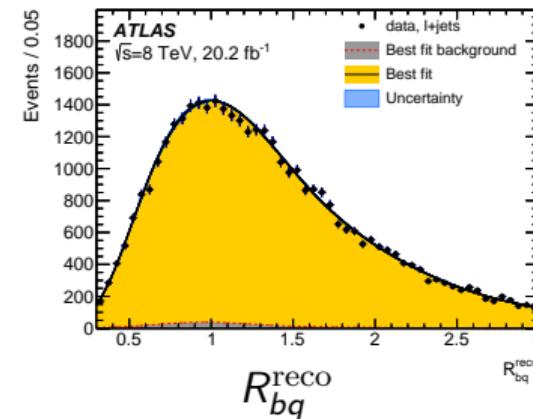
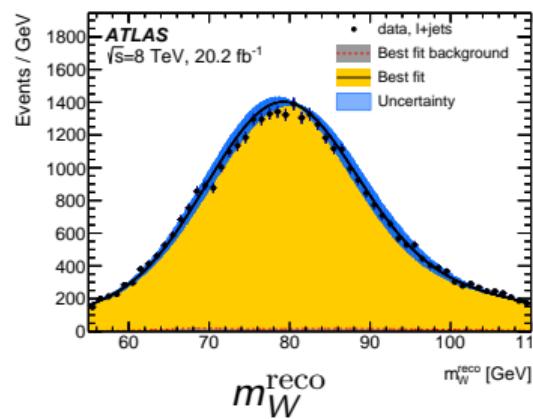
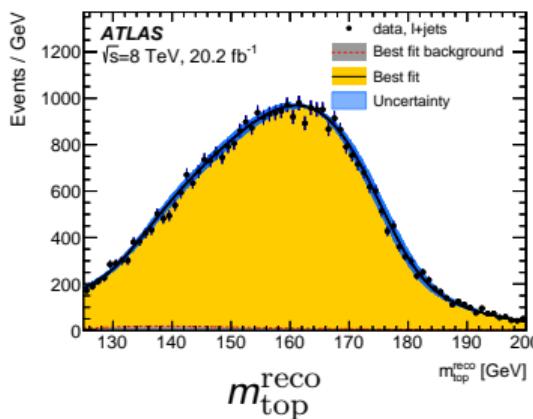
8 TeV lepton+jets result in data

- The 3D unbinned maximum likelihood fit to the data results in:

$$m_{\text{top}} = 172.08 \pm 0.39(\text{stat}) \text{ GeV}$$

$$\text{JSF} = 1.005 \pm 0.001(\text{stat})$$

$$\text{bJSF} = 1.008 \pm 0.005(\text{stat})$$



- Including systematic uncertainties, the result is:

$$m_{\text{top}} = 172.08 \pm 0.39(\text{stat}) \pm 0.82(\text{syst}) \text{ GeV} = 172.08 \pm 0.91 \text{ GeV}$$

8 TeV lepton+jets uncertainties in m_{top}

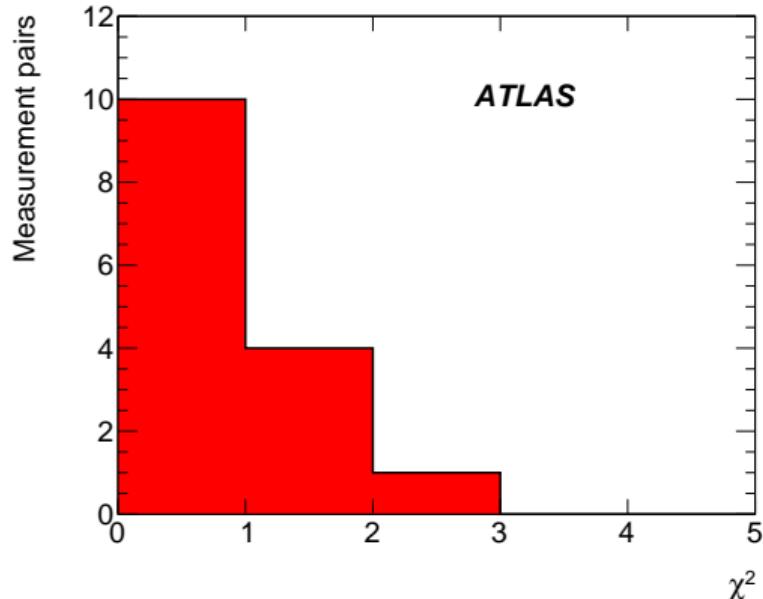
- Dominant sources of uncertainty
 - ▶ JES (0.54 GeV) and *b*-tagging (0.38 GeV)
- Total uncertainty reduced with BDT sel.
 - ▶ **19%** improvement over no BDT at 8 TeV
 - ▶ Reduces theory modelling uncertainties
 - ▶ Also improves resolution in m_{top} as seen by the scaling of the stat. unc.
 - ★ With no improvement in resolution:
 $\sigma_{\text{BDT}}^{\text{stat}} = \sigma_{\text{std}}^{\text{stat}} \sqrt{N_{\text{std}}/N_{\text{BDT}}} = 0.60$
as compared to 0.39
 - ▶ Altogether, a **29%** improvement over the 7 TeV lepton+jets measurement
- Given the new result, an updated ATLAS combination is performed

| | $\sqrt{s} = 7 \text{ TeV}$ | $\sqrt{s} = 8 \text{ TeV}$ | |
|--|----------------------------|----------------------------|-----------------|
| Event selection | Standard | Standard | BDT |
| m_{top} result [GeV] | 172.33 | 171.90 | 172.08 |
| Statistics | 0.75 | 0.38 | 0.39 |
| - Stat. comp. (m_{top}) | 0.23 | 0.12 | 0.11 |
| - Stat. comp. (JSF) | 0.25 | 0.11 | 0.11 |
| - Stat. comp. (bJSF) | 0.67 | 0.34 | 0.35 |
| Method | 0.11 ± 0.10 | 0.04 ± 0.11 | 0.13 ± 0.11 |
| Signal Monte Carlo generator | 0.22 ± 0.21 | 0.50 ± 0.17 | 0.16 ± 0.17 |
| Hadronization | 0.18 ± 0.12 | 0.05 ± 0.10 | 0.15 ± 0.10 |
| Initial- and final-state QCD radiation | 0.32 ± 0.06 | 0.28 ± 0.11 | 0.08 ± 0.11 |
| Underlying event | 0.15 ± 0.07 | 0.08 ± 0.15 | 0.08 ± 0.15 |
| Colour reconnection | 0.11 ± 0.07 | 0.37 ± 0.15 | 0.19 ± 0.15 |
| Parton distribution function | 0.25 ± 0.00 | 0.08 ± 0.00 | 0.09 ± 0.00 |
| Background normalization | 0.10 ± 0.00 | 0.04 ± 0.00 | 0.08 ± 0.00 |
| $W+\text{jets}$ shape | 0.29 ± 0.00 | 0.05 ± 0.00 | 0.11 ± 0.00 |
| Fake leptons shape | 0.05 ± 0.00 | 0 | 0 |
| Jet energy scale | 0.58 ± 0.11 | 0.63 ± 0.02 | 0.54 ± 0.02 |
| Relative <i>b</i> -to-light-jet energy scale | 0.06 ± 0.03 | 0.05 ± 0.01 | 0.03 ± 0.01 |
| Jet energy resolution | 0.22 ± 0.11 | 0.23 ± 0.03 | 0.20 ± 0.04 |
| Jet reconstruction efficiency | 0.12 ± 0.00 | 0.04 ± 0.01 | 0.02 ± 0.01 |
| Jet vertex fraction | 0.01 ± 0.00 | 0.13 ± 0.01 | 0.09 ± 0.01 |
| <i>b</i> -tagging | 0.50 ± 0.00 | 0.37 ± 0.00 | 0.38 ± 0.00 |
| Leptons | 0.04 ± 0.00 | 0.16 ± 0.01 | 0.16 ± 0.01 |
| Missing transverse momentum | 0.15 ± 0.04 | 0.08 ± 0.01 | 0.05 ± 0.01 |
| Pile-up | 0.02 ± 0.01 | 0.14 ± 0.01 | 0.15 ± 0.01 |
| Total systematic uncertainty | 1.04 ± 0.08 | 1.07 ± 0.10 | 0.82 ± 0.06 |
| Total | 1.28 ± 0.08 | 1.13 ± 0.10 | 0.91 ± 0.06 |

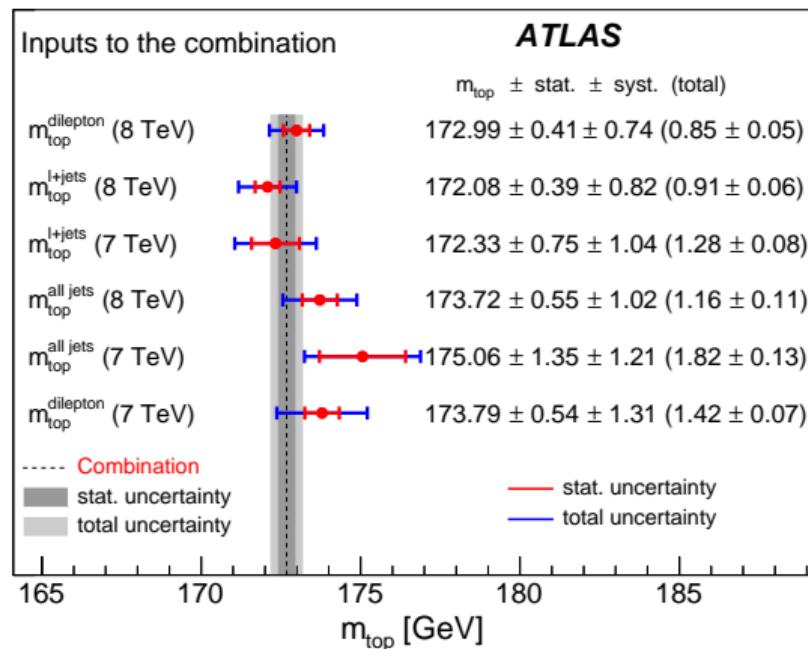
Combination: compatibility of input measurements

- Verify compatibility of measurements before performing a combination via:

$$\chi_{ij}^2 = \frac{(x_i - x_j)^2}{\sigma_i^2 + \sigma_j^2 - 2\rho_{ij}\sigma_i\sigma_j}$$

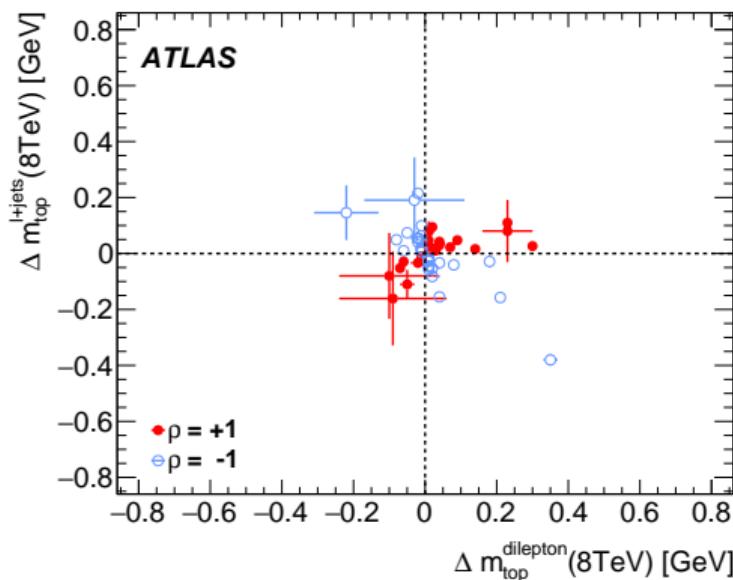


- Good χ^2 probabilities observed for all pairs of measurements
 - Smallest probability: 15%

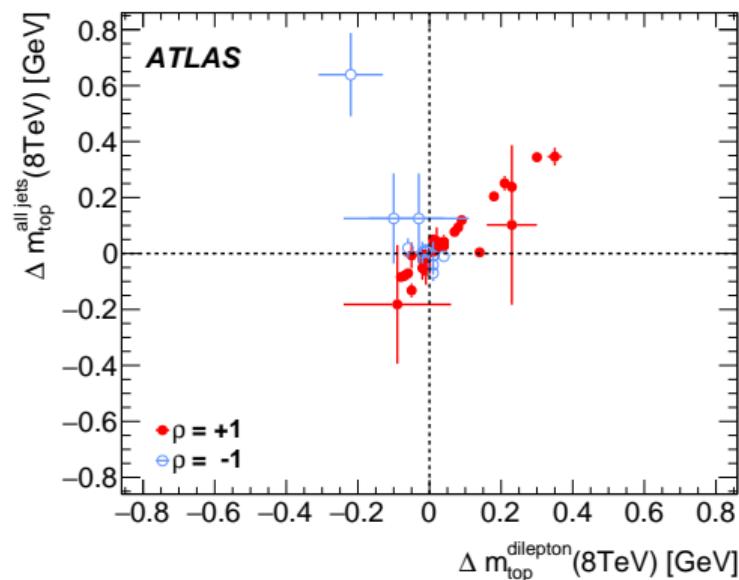


Combination: correlations of pairs of estimators

dilepton (8 TeV) vs. lepton+jets (8 TeV)

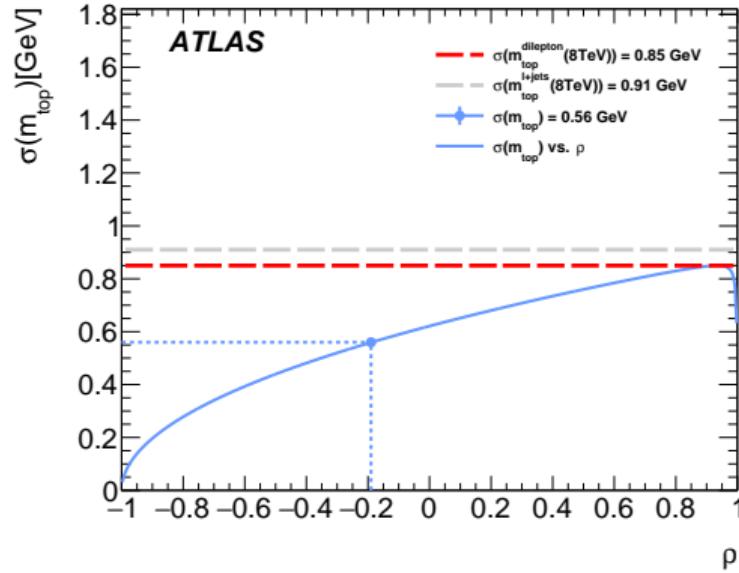
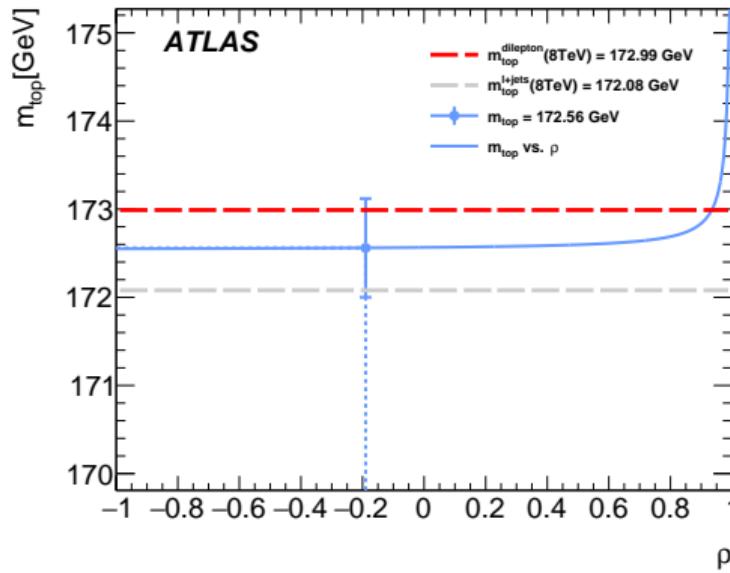


dilepton (8 TeV) vs. all-jets (8 TeV)



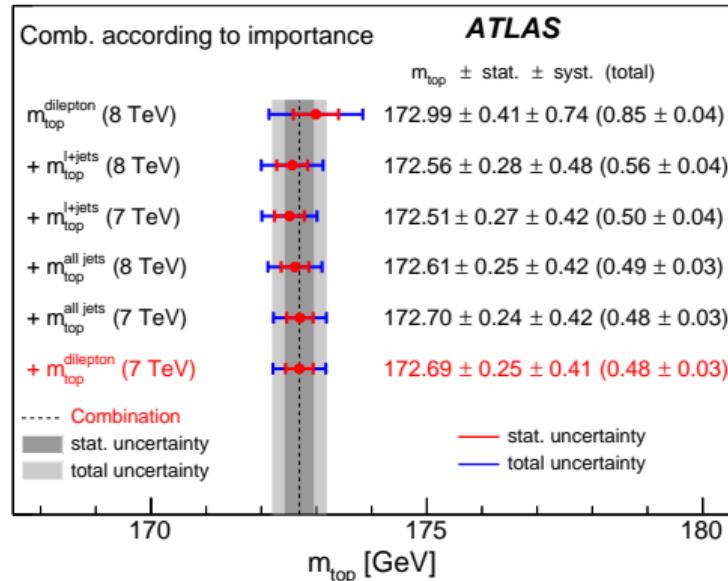
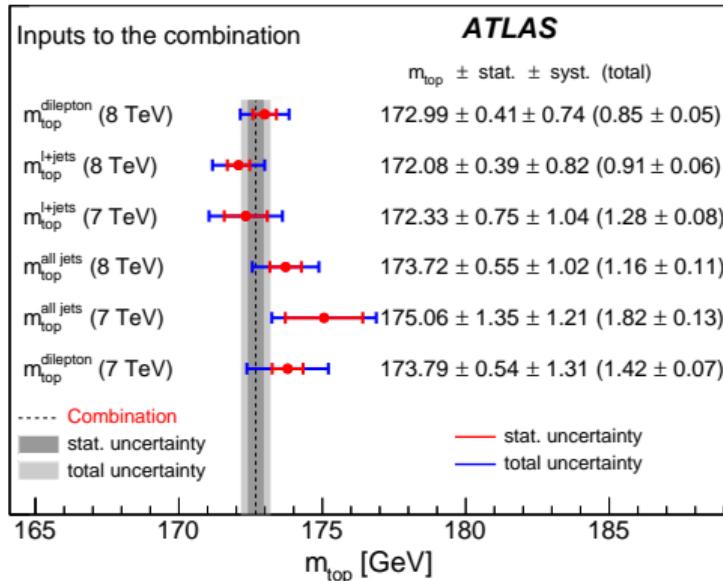
- Pairwise Δm_{top} when simultaneously varying a pair of measurements for each syst. unc.
- The correlations of the estimators for each uncertainty component are evaluated
- The combination is performed using the **BLUE** method

Combination: example of two most precise measurements



- Combined value (left) and uncertainty (right) in the combination of the 8 TeV $\ell + \text{jets}$ and dilepton measurements as a function of their total correlation (blue line)
- The red and gray lines indicate the pair of input values (left) and uncertainties (right)
- The uncertainty in the combined m_{top} strongly depends on the total correlation

Combination: result



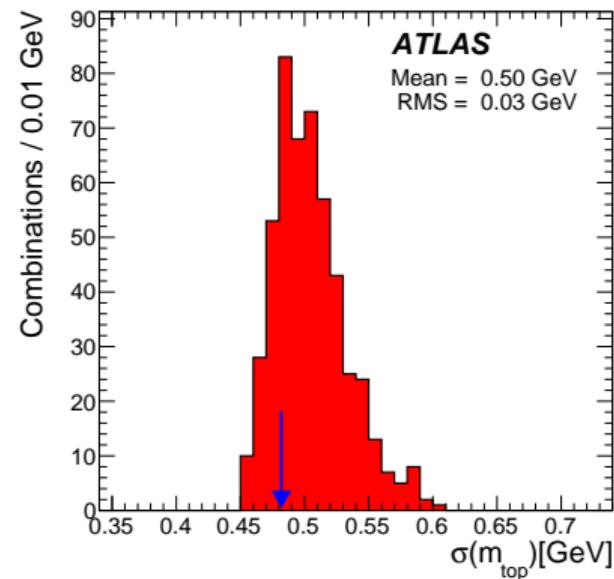
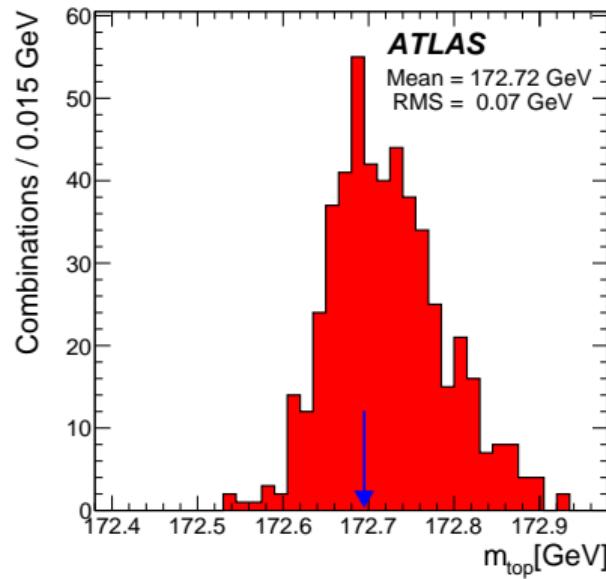
This combination results in a relative precision of **0.28%**:

$$m_{\text{top}} = 172.69 \pm 0.25(\text{stat}) \pm 0.41(\text{syst}) \text{ GeV} = 172.69 \pm 0.48 \text{ GeV}$$

- a **44%** improvement w.r.t. the most precise single input measurement
- a **31%** improvement w.r.t. the previous ATLAS combination

Combination: stability

- Analyze the stability of the combined result using 500 pseudo-combinations
 - Randomly vary each systematic uncertainty within its statistical precision
 - Consequently re-evaluate their correlations
 - Arrows indicate the values of the original combination



Conclusions and remarks

- Direct measurements of m_{top} have been made using the Run-1 ATLAS data in the various $t\bar{t}$ decay channels
- **New** measurement of m_{top} in the $t\bar{t} \rightarrow \text{lepton+jets}$ channel at 8 TeV
 - ▶ $m_{\text{top}}^{\text{l+jets}} = 172.08 \pm 0.39(\text{stat}) \pm 0.82(\text{syst}) \text{ GeV}$
 - ★ With a total uncertainty of $0.91 \pm 0.06 \text{ GeV}$
- **New** ATLAS combination of m_{top}
 - ▶ $m_{\text{top}}^{\text{comb}} = 172.69 \pm 0.25(\text{stat}) \pm 0.41(\text{syst}) \text{ GeV}$
 - ★ With a total uncertainty of $0.48 \pm 0.03 \text{ GeV}$
- Take-away messages from Run-1 ATLAS combination
 - ▶ The two LHC combinations of m_{top} are **consistent** and have **comparable precision**
 - ▶ The ability to **evaluate the correlation** between individual measurements is critical
 - ★ Important to include statistical precision of all systematic uncertainties
 - ▶ **Minimizing these correlations** has a large impact on the final uncertainty

Additional Material

Combination: input measurement uncertainties

| | | $\sqrt{s} = 7 \text{ TeV}$ | | | $\sqrt{s} = 8 \text{ TeV}$ | | |
|-----|---|--|---|--|--|---|--|
| | | $m_{\text{top}}^{\text{dilepton}}$ [GeV] | $m_{\text{top}}^{\ell+\text{jets}}$ [GeV] | $m_{\text{top}}^{\text{all jets}}$ [GeV] | $m_{\text{top}}^{\text{dilepton}}$ [GeV] | $m_{\text{top}}^{\ell+\text{jets}}$ [GeV] | $m_{\text{top}}^{\text{all jets}}$ [GeV] |
| k | Results ($i = 0 \dots, 5$) | 173.79 | 172.33 | 175.06 | 172.99 | 172.08 | 173.72 |
| 0 | Statistics | 0.54 | 0.75 0.23 0.25 0.67 | 1.35 | 0.41 | 0.39 0.11 0.11 0.35 | 0.55 |
| 1 | Method | 0.09 ± 0.07 | 0.11 ± 0.10 | 0.42 ± 0.01 | 0.05 ± 0.07 | 0.13 ± 0.11 | 0.11 |
| 2 | Signal Monte Carlo generator | 0.26 ± 0.16 | 0.22 ± 0.21 | 0.30 ± 0.30 | 0.09 ± 0.15 | 0.16 ± 0.17 | 0.18 ± 0.21 |
| 3 | Hadronization | 0.53 ± 0.09 | 0.18 ± 0.12 | 0.50 ± 0.15 | 0.22 ± 0.09 | 0.15 ± 0.10 | 0.64 ± 0.15 |
| 4 | Initial- and final-state QCD radiation | 0.47 ± 0.05 | 0.32 ± 0.06 | 0.22 ± 0.11 | 0.23 ± 0.07 | 0.08 ± 0.11 | 0.10 ± 0.28 |
| 5 | Underlying event | 0.05 ± 0.05 | 0.15 ± 0.07 | 0.08 ± 0.10 | 0.10 ± 0.14 | 0.08 ± 0.15 | 0.12 ± 0.16 |
| 6 | Colour reconnection | 0.14 ± 0.05 | 0.11 ± 0.07 | 0.22 ± 0.10 | 0.03 ± 0.14 | 0.19 ± 0.15 | 0.12 ± 0.16 |
| 7 | Parton distribution function | 0.10 ± 0.00 | 0.25 ± 0.00 | 0.09 ± 0.00 | 0.05 ± 0.00 | 0.09 ± 0.00 | 0.09 ± 0.00 |
| 8 | Background normalization | 0.04 ± 0.00 | 0.10 ± 0.00 | 0 | 0.03 ± 0.00 | 0.08 ± 0.00 | 0 |
| 9 | $W/Z+\text{jets}$ shape | 0.00 ± 0.00 | 0.29 ± 0.00 | 0 | 0 | 0.11 ± 0.00 | 0 |
| 10 | Fake leptons shape | 0.01 ± 0.00 | 0.05 ± 0.00 | 0 | 0.07 ± 0.00 | 0 | 0 |
| 11 | Data-driven all-jets background | 0 | 0 | 0.35 ± 0.21 | 0 | 0 | 0.17 |
| 12 | Jet energy scale | 0.76 ± 0.09 | 0.58 ± 0.11 | 0.50 ± 0.05 | 0.54 ± 0.04 | 0.54 ± 0.02 | 0.60 ± 0.03 |
| 13 | Relative b -to-light-jet energy scale | 0.68 ± 0.02 | 0.06 ± 0.03 | 0.62 ± 0.05 | 0.30 ± 0.01 | 0.03 ± 0.01 | 0.34 ± 0.02 |
| 14 | Jet energy resolution | 0.19 ± 0.04 | 0.22 ± 0.11 | 0.01 ± 0.08 | 0.09 ± 0.05 | 0.20 ± 0.04 | 0.10 ± 0.04 |
| 15 | Jet reconstruction efficiency | 0.07 ± 0.00 | 0.12 ± 0.00 | 0.01 ± 0.01 | 0.01 ± 0.00 | 0.02 ± 0.01 | 0 |
| 16 | Jet vertex fraction | 0.00 ± 0.00 | 0.01 ± 0.00 | 0.01 ± 0.01 | 0.02 ± 0.00 | 0.09 ± 0.01 | 0.03 ± 0.01 |
| 17 | b -tagging | 0.07 ± 0.00 | 0.50 ± 0.00 | 0.16 ± 0.00 | 0.04 ± 0.02 | 0.38 ± 0.00 | 0.10 ± 0.00 |
| 18 | Leptons | 0.13 ± 0.00 | 0.04 ± 0.00 | 0 | 0.14 ± 0.01 | 0.16 ± 0.01 | 0.01 ± 0.00 |
| 19 | Missing transverse momentum | 0.04 ± 0.03 | 0.15 ± 0.04 | 0.02 ± 0.05 | 0.01 ± 0.01 | 0.05 ± 0.01 | 0.01 ± 0.01 |
| 20 | Pile-up | 0.01 ± 0.00 | 0.02 ± 0.01 | 0.02 ± 0.00 | 0.05 ± 0.01 | 0.15 ± 0.01 | 0.01 ± 0.00 |
| 21 | Trigger | 0 | 0 | 0.01 ± 0.01 | 0 | 0 | 0.08 ± 0.01 |
| 22 | Fast vs. full simulation | 0 | 0 | 0.24 ± 0.18 | 0 | 0 | 0 |
| | Total systematic uncertainty | 1.31 ± 0.07 | 1.04 ± 0.08 | 1.21 ± 0.13 | 0.74 ± 0.05 | 0.82 ± 0.06 | 1.02 ± 0.11 |
| | Total | 1.42 ± 0.07 | 1.28 ± 0.08 | 1.82 ± 0.13 | 0.85 ± 0.05 | 0.91 ± 0.06 | 1.16 ± 0.11 |

Combination: input measurement pairwise correlations

| k | $m_{\text{top}}^{\text{dilepton}}$ 7 TeV $i = 0$ | | | | | $m_{\text{top}}^{\ell+\text{jets}}$ 7 TeV $i = 1$ | | | | $m_{\text{top}}^{\text{all jets}}$ 7 TeV $i = 2$ | | | $m_{\text{top}}^{\text{dilepton}}$ 8 TeV $i = 3$ | $m_{\text{top}}^{\ell+\text{jets}}$ 8 TeV $i = 4$ | |
|---------------|---|-------------|-------------|-------------|-------------|--|-------------|-------------|-------------|---|-------------|-------------|---|--|-------------|
| | ρ_{01} | ρ_{02} | ρ_{03} | ρ_{04} | ρ_{05} | ρ_{12} | ρ_{13} | ρ_{14} | ρ_{15} | ρ_{23} | ρ_{24} | ρ_{25} | ρ_{34} | ρ_{35} | ρ_{45} |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1.00 | -1.00 | 1.00 | 1.00 | 1.00 | -1.00 | 1.00 | 1.00 | 1.00 | -1.00 | -1.00 | -1.00 | 1.00 | 1.00 | 1.00 |
| 3 | 1.00 | 1.00 | 1.00 | -1.00 | -1.00 | 1.00 | 1.00 | -1.00 | -1.00 | 1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 1.00 |
| 4 | -1.00 | 1.00 | 1.00 | 1.00 | 1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 5 | -1.00 | 1.00 | 1.00 | 1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 1.00 | 1.00 | 1.00 | -1.00 | 1.00 | -1.00 | -1.00 |
| 6 | -1.00 | 1.00 | 1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 1.00 | 1.00 | 1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 1.00 |
| 7 | 0.53 | 0.22 | -0.02 | 0.72 | -0.61 | -0.36 | -0.32 | 0.72 | -0.81 | 0.41 | -0.05 | 0.27 | -0.48 | 0.40 | -0.76 |
| 8 | 1.00 | 0 | 0.31 | -0.77 | 0 | 0 | 0.31 | -0.74 | 0 | 0 | 0 | 0 | -0.06 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0.20 | 0 | 0 | 0 | 0 | 0 | 0.27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 12 | -0.24 | 0.86 | 0.36 | 0.18 | 0.36 | 0.10 | 0.04 | -0.29 | 0.13 | 0.41 | 0.09 | 0.42 | -0.54 | 0.98 | -0.57 |
| 13 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 14 | -1.00 | 1.00 | 0 | 0 | 0 | -1.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0.22 | -0.07 | -0.17 |
| 15 | 1.00 | 1.00 | 1.00 | 1.00 | 0 | 1.00 | 1.00 | 1.00 | 0 | 1.00 | 1.00 | 0 | 1.00 | 0 | 0 |
| 16 | -1.00 | 1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 1.00 | 1.00 | 1.00 | -1.00 | -1.00 | -1.00 | 1.00 | 1.00 | 1.00 |
| 17 | -0.80 | -0.03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.23 | 1 | 1 |
| 18 | -0.35 | 0 | 0.93 | -0.08 | 0.42 | 0 | -0.51 | -0.17 | 0.02 | 0 | 0 | 0 | 0.11 | 0.28 | -0.36 |
| 19 | 0.00 | -0.26 | -0.26 | -0.12 | 0.04 | 0.84 | 0.26 | 0.22 | 0.16 | 0 | 0 | 0 | 0.97 | 0.86 | 0.96 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.00 | 0 | 0 | 0 |
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | -0.07 | 0.42 | 0.52 | 0.06 | 0.08 | -0.01 | -0.00 | -0.07 | -0.02 | 0.29 | -0.06 | -0.01 | -0.19 | 0.32 | 0.00 |
| χ_{ij}^2 | 0.55 | 0.51 | 0.44 | 1.09 | 0.00 | 1.50 | 0.18 | 0.02 | 0.64 | 1.37 | 2.06 | 0.39 | 0.45 | 0.37 | 1.25 |

Combination: results for selected combinations

| | $m_{\text{top}}^{\text{7TeV}}$ [GeV] | $m_{\text{top}}^{\text{8TeV}}$ [GeV] | $m_{\text{top}}^{\text{dilepton}}$ [GeV] | $m_{\text{top}}^{\ell+\text{jets}}$ [GeV] | $m_{\text{top}}^{\text{all jets}}$ [GeV] | $m_{\text{top}}^{(3)}$ [GeV] | m_{top} [GeV] |
|---|--------------------------------------|--------------------------------------|--|---|--|------------------------------|------------------------|
| Results | 173.20 | 172.68 | 172.98 | 172.13 | 174.08 | 172.51 | 172.69 |
| Statistics | 0.46 | 0.26 | 0.39 | 0.37 | 0.56 | 0.27 | 0.25 |
| Method | 0.08 | 0.06 | 0.05 | 0.10 | 0.14 | 0.06 | 0.06 |
| Signal Monte Carlo generator | 0.17 | 0.13 | 0.12 | 0.15 | 0.03 | 0.14 | 0.12 |
| Hadronization | 0.35 | 0.04 | 0.18 | 0.03 | 0.32 | 0.07 | 0.00 |
| Initial- and final-state QCD radiation | 0.03 | 0.15 | 0.26 | 0.07 | 0.13 | 0.07 | 0.07 |
| Underlying event | 0.05 | 0.07 | 0.10 | 0.01 | 0.06 | 0.05 | 0.03 |
| Colour reconnection | 0.02 | 0.08 | 0.02 | 0.16 | 0.02 | 0.08 | 0.08 |
| Parton distribution function | 0.15 | 0.03 | 0.05 | 0.13 | 0.08 | 0.07 | 0.05 |
| Background normalization | 0.07 | 0.04 | 0.03 | 0.04 | 0.00 | 0.03 | 0.02 |
| $W/Z+\text{jets}$ shape | 0.15 | 0.05 | 0.01 | 0.12 | 0.00 | 0.07 | 0.06 |
| Fake leptons shape | 0.03 | 0.03 | 0.07 | 0.02 | 0.00 | 0.03 | 0.03 |
| Data-driven all-jets background | 0.04 | 0.02 | 0.01 | 0.01 | 0.22 | 0 | 0.03 |
| Jet energy scale | 0.40 | 0.27 | 0.53 | 0.34 | 0.51 | 0.21 | 0.22 |
| Relative b -to-light-jet energy scale | 0.35 | 0.19 | 0.32 | 0.01 | 0.41 | 0.15 | 0.17 |
| Jet energy resolution | 0.04 | 0.10 | 0.09 | 0.16 | 0.07 | 0.10 | 0.09 |
| Jet reconstruction efficiency | 0.09 | 0.01 | 0.01 | 0.05 | 0.00 | 0.03 | 0.03 |
| Jet vertex fraction | 0.00 | 0.05 | 0.02 | 0.07 | 0.02 | 0.05 | 0.05 |
| b -tagging | 0.24 | 0.18 | 0.05 | 0.30 | 0.09 | 0.17 | 0.17 |
| Leptons | 0.04 | 0.10 | 0.14 | 0.11 | 0.01 | 0.09 | 0.08 |
| Missing transverse momentum | 0.08 | 0.03 | 0.01 | 0.07 | 0.01 | 0.04 | 0.04 |
| Pile-up | 0.01 | 0.07 | 0.05 | 0.10 | 0.01 | 0.06 | 0.06 |
| Trigger | 0.00 | 0.01 | 0.00 | 0.00 | 0.06 | 0 | 0.01 |
| Fast vs. full simulation | 0.03 | 0 | 0.01 | 0.01 | 0.07 | 0 | 0.01 |
| Total systematic uncertainty | 0.76 ± 0.04 | 0.48 ± 0.04 | 0.74 ± 0.04 | 0.61 ± 0.04 | 0.80 ± 0.05 | 0.42 ± 0.04 | 0.41 ± 0.03 |
| Total | 0.89 ± 0.04 | 0.54 ± 0.04 | 0.84 ± 0.04 | 0.71 ± 0.04 | 0.98 ± 0.05 | 0.50 ± 0.04 | 0.48 ± 0.03 |

8 TeV lepton+jets: Table of BDT input variables

| Separation | Description |
|------------|---|
| 31% | Logarithm of the event likelihood of the best permutation, $\ln L$ |
| 13% | ΔR of the two untagged jets q_1 and q_2 from the hadronically decaying W boson, $\Delta R(q, q)$ |
| 5.0% | p_T of the hadronically decaying W boson |
| 4.3% | p_T of the hadronically decaying top quark |
| 4.2% | Relative event probability of the best permutation |
| 2.0% | p_T of the reconstructed $t\bar{t}$ system |
| 1.7% | p_T of the semi-leptonically decaying top quark |
| 1.2% | Transverse mass of the leptonically decaying W boson |
| 0.3% | p_T of the leptonically decaying W boson |
| 0.3% | Number of jets |
| 0.2% | ΔR of the reconstructed b -tagged jets |
| 0.2% | Missing transverse momentum |
| 0.1% | p_T of the lepton |

8 TeV lepton+jets: data/MC agreement in BDT output

