Top-Quark Mass in ATLAS

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on behalf of ATLAS Collaboration

Top Quark Physics at the Precision Frontier
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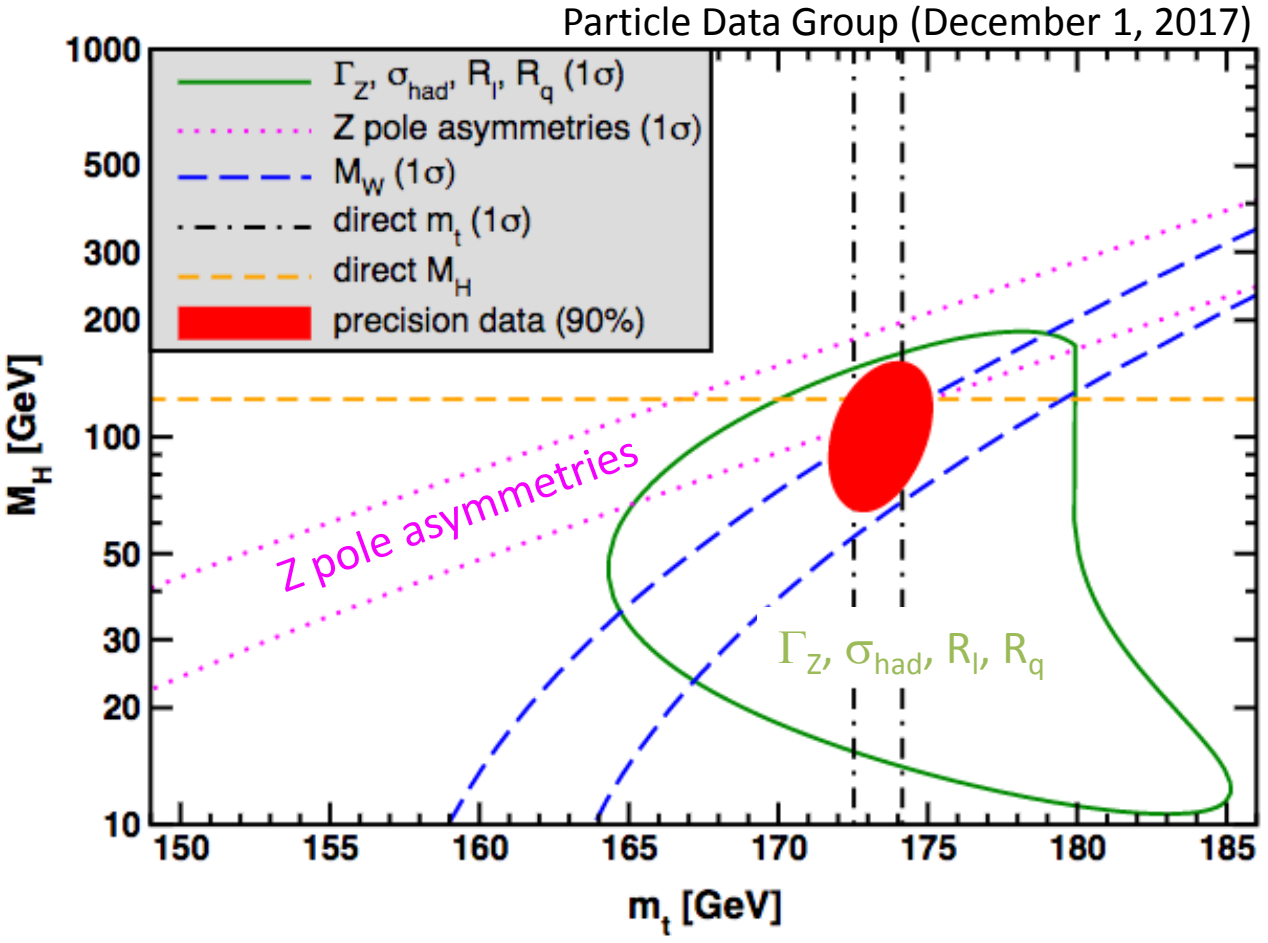
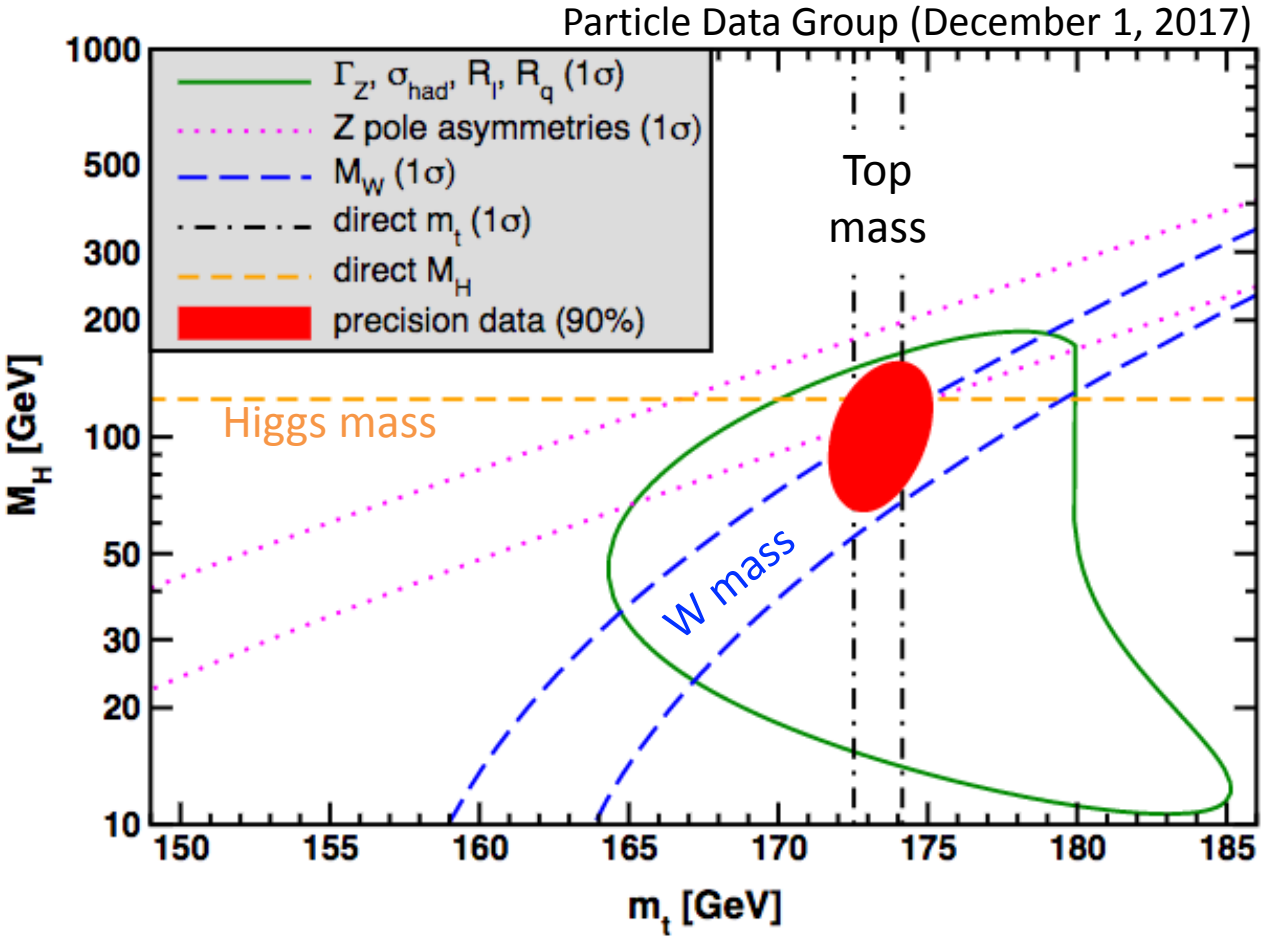
Fermilab

Electroweak and constraints on new physics



- Provides crucial info. for global fits of EW interactions, assessing the internal consistency of the SM and probing its extensions
- Affects the stability of the SM Higgs potential, which has cosmological implications

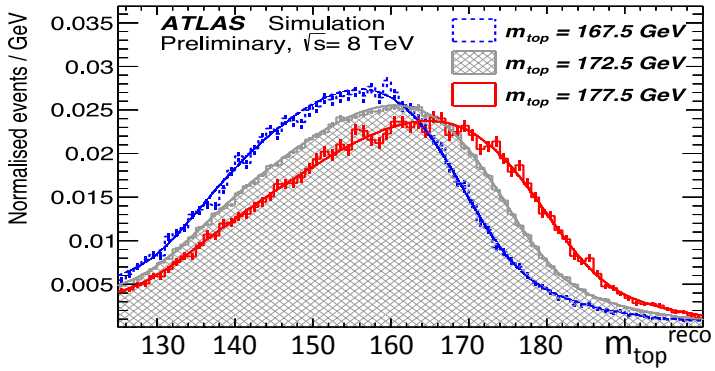
Electroweak and constraints on new physics

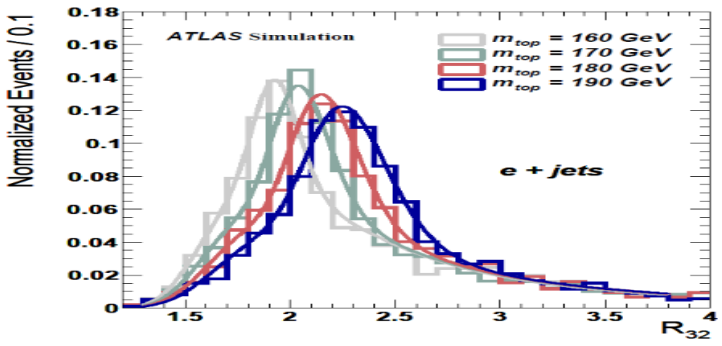


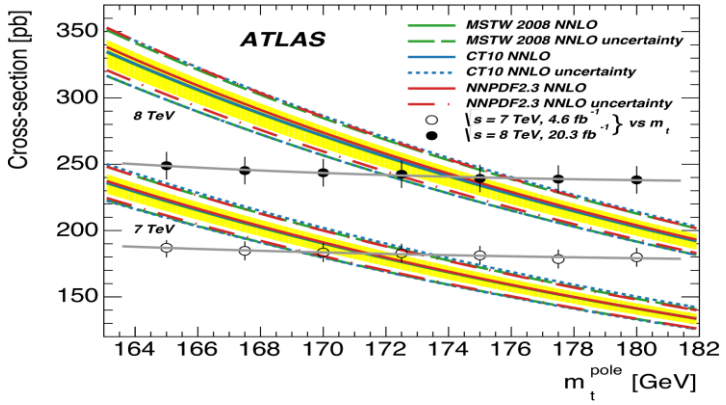
- Provides crucial info. for global fits of EW interactions, assessing the internal consistency of the SM and probing its extensions
- Affects the stability of the SM Higgs potential, which has cosmological implications

Definition of top mass; Measurement methods

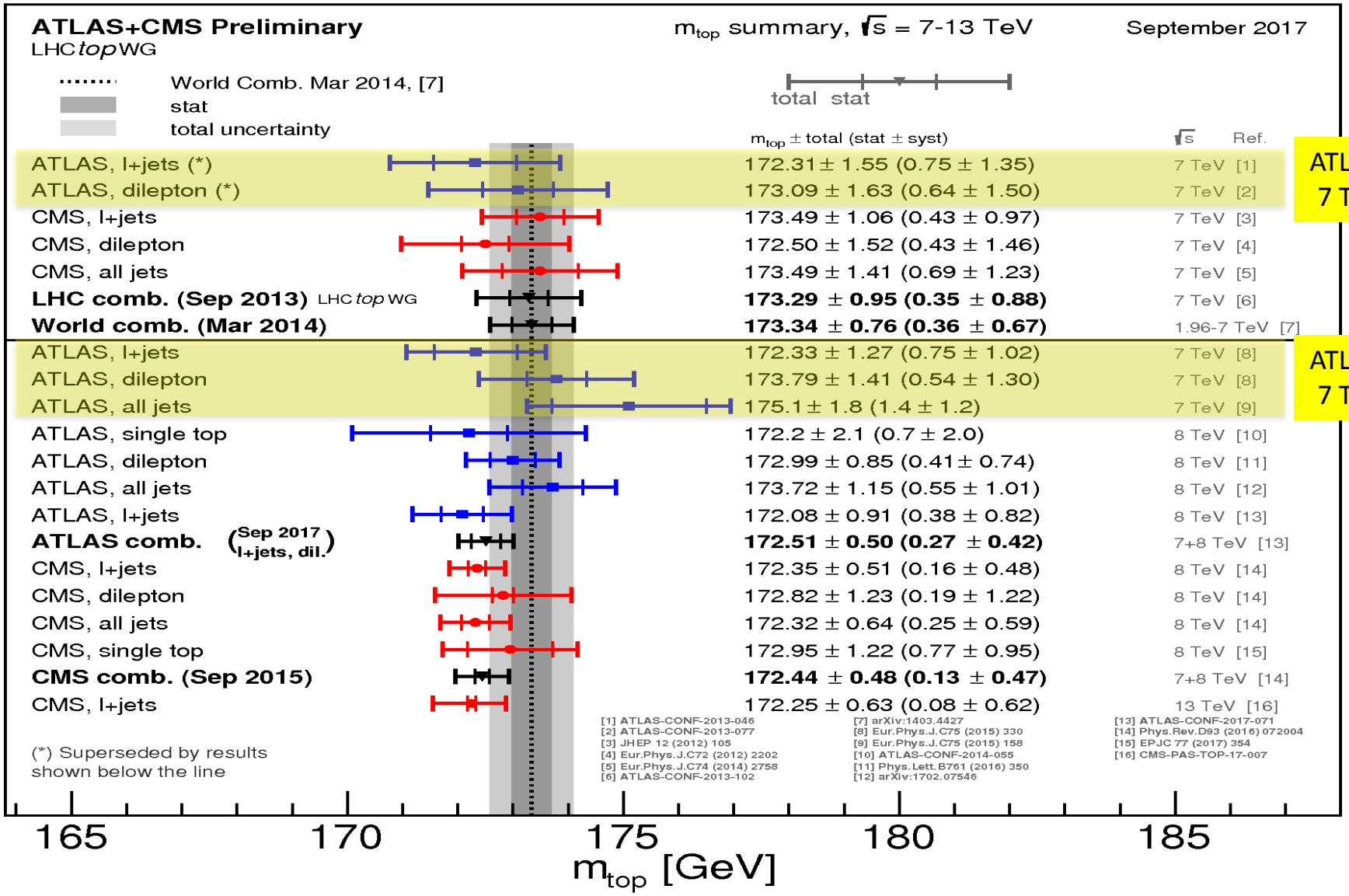
- "Top mass" = Top MC mass
  - Standard
    - Reconstruct top-pair system
    - Reconstruct "top mass" distribution
    - MC samples w/ various m_{top} values
    - m_{top} that gives the best fit to data
  - Alternative
    - Use variables sensitive on m_{top}
    - Different systematic uncertainties
- Top-quark pole mass
  - σ_{tt} depends on top "pole" mass
  - $\Delta\sigma_{tt} / \sigma_{tt} \sim 5\% \rightarrow \Delta m_{top} / m_{top} \sim 1\%$







ATLAS + CMS: top-MC mass measurements

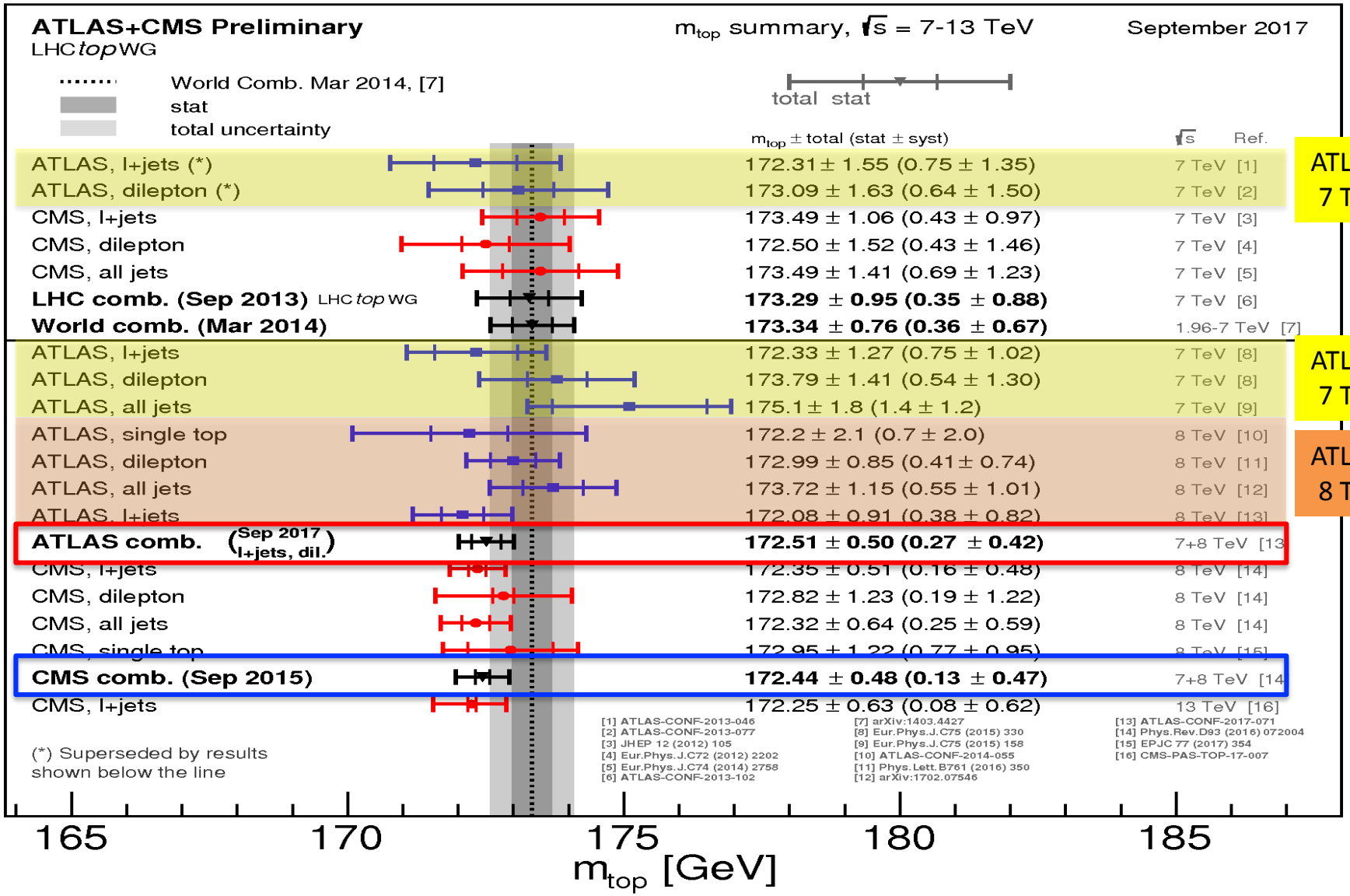


ATLAS 7 TeV

ATLAS 7 TeV

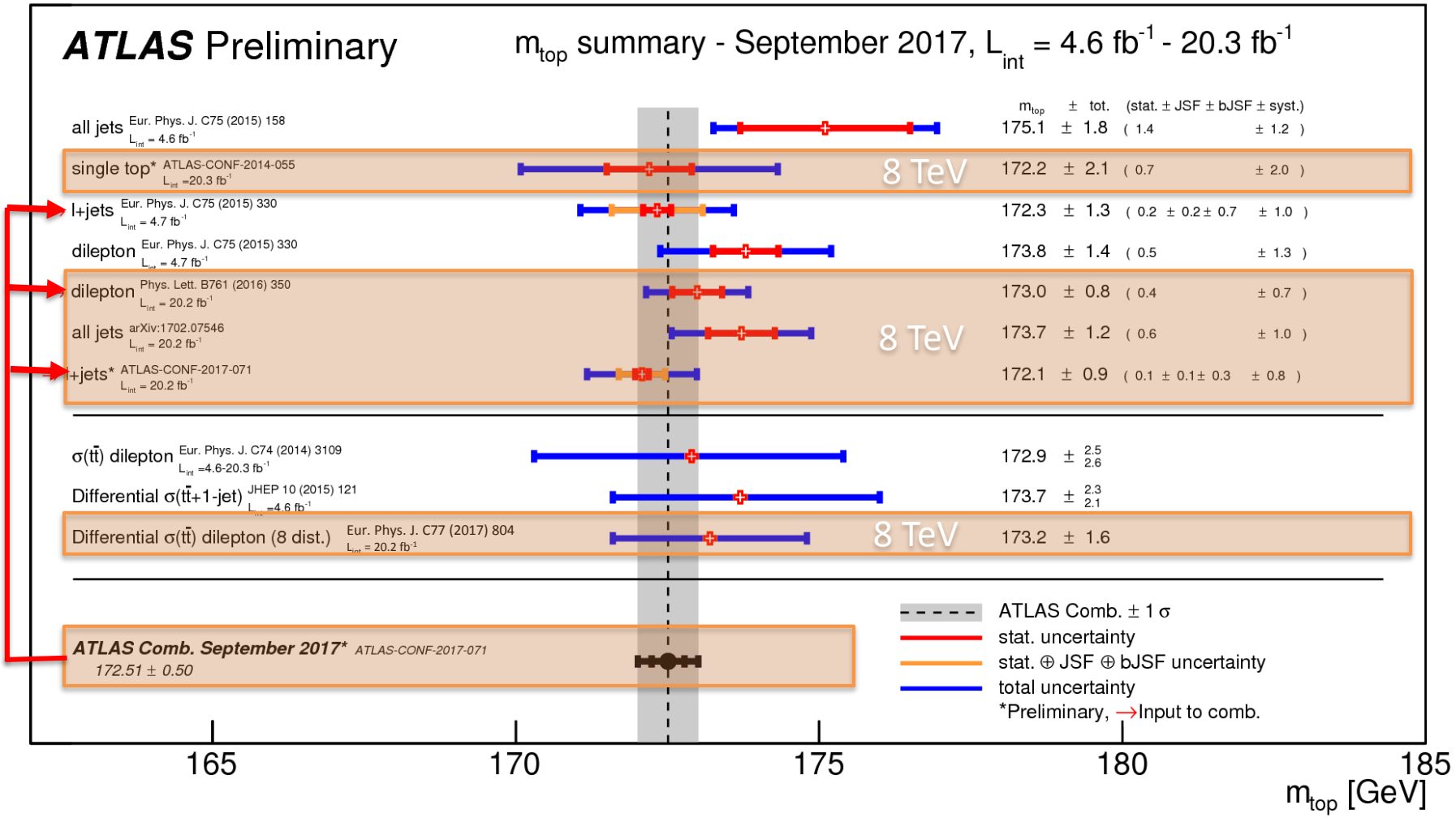
Dominated by systematic uncertainties → influenced strategies for 8 TeV analysis

ATLAS + CMS: top-MC mass measurements



~0.5 GeV uncertainty → needs a better understanding of MC and pole mass relations

ATLAS: top mass measurements



Top mass: 7 TeV → 8 TeV

Better knowledge
jet energy scale and *b*-jet energy scale

Optimization procedure to reduce the systematic uncertainty
(jet energy scale and theory modeling)
trading between statistical and systematic uncertainty

Direct Top Mass (top pair)

(lepton = e, μ)

	All jets WWbb → qqqqbb	Lepton + jets WWbb → lνqqbb	Di-lepton WWbb → llννbb
Branching Ratio	46% (multi-jet bgrnd)	30%	4% (clean)
Triggers	5 jets (p_T > 55 GeV)	e, μ (p_T > 24 GeV)	
Pre-selection (all central objects)	0 lepton (e, μ) $\not{E}_T$ < 60 GeV 5 jets (p_T > 60 GeV) others (p_T > 25 GeV) 2 *b*-tagged jets	1 lepton (e, μ) $p_T^{e,\mu}$ > 25 GeV $\not{E}_T$ > 30(e),20(μ) GeV 4 jets (p_T > 25 GeV) 1 or 2 *b*-tagged jets	2 leptons (e, μ) $p_T^{e,\mu}$ > 25 GeV $\not{E}_T$ > 25 GeV 2 jets (p_T > 25 GeV) 1 or 2 *b*-tagged jets
b-tagging	ε_b = 59% (tight) Rejection:~13(c),~330(u/d/s)	ε_b = 70% Rejection: ~5 (c), ~140 (u/d/s)	

Direct Top Mass (top pair)

(lepton = e, μ)

	All jets WWbb → qqqqbb	Lepton + jets WWbb → lνqqbb	Di-lepton WWbb → ll$\nu\nu$bb
Top pair event reconstruction (jet to parton matching)	*b*-tagged jets → *b* quarks un-tagged jets → light (*b*) quarks $m_{qq} = m_W$, $m_{top1} = m_{top2}$		*b*-tagged jets → *b* quarks
	χ^2	event-likelihood	min($<m_{lb}>$)
Final selection • Reduce background • Correct jet-parton matching • Better resolution • Lower syst. uncertainty	$\Delta\phi(b_1,b_2) > 1.5$ $<\Delta\phi(b,W)> < 2$	Boosted decision tree (BDT) > -0.05 2 *b*-tagged jets	$p_{T,lb} > 120$ GeV
# of events	12,900	38,054	9,426
Signal events	See next slides	Top pair: 97.6% Single top: 2.4%	Top pair: 94.6% Single top: 3.6%
Background events		Total: 1.0% W + jets: 0.8% (data driven)	Total: 0.6% Fake lepton:0.3% (data driven)

All-jets top mass at 8 TeV

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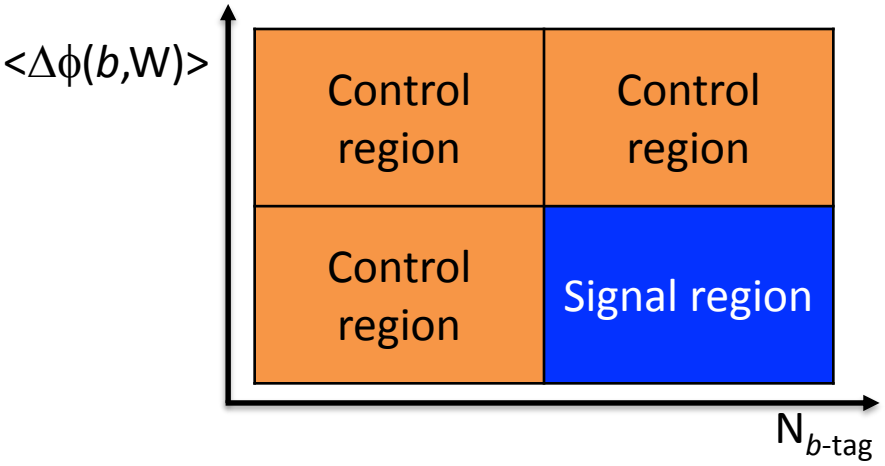
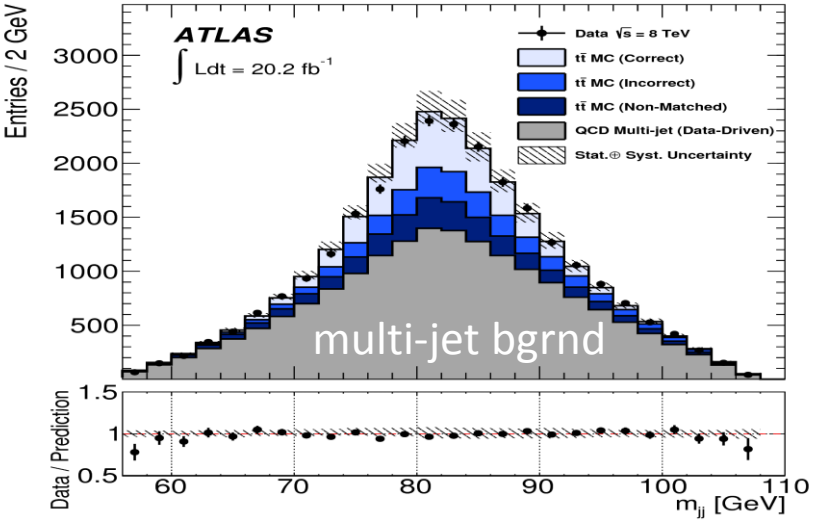
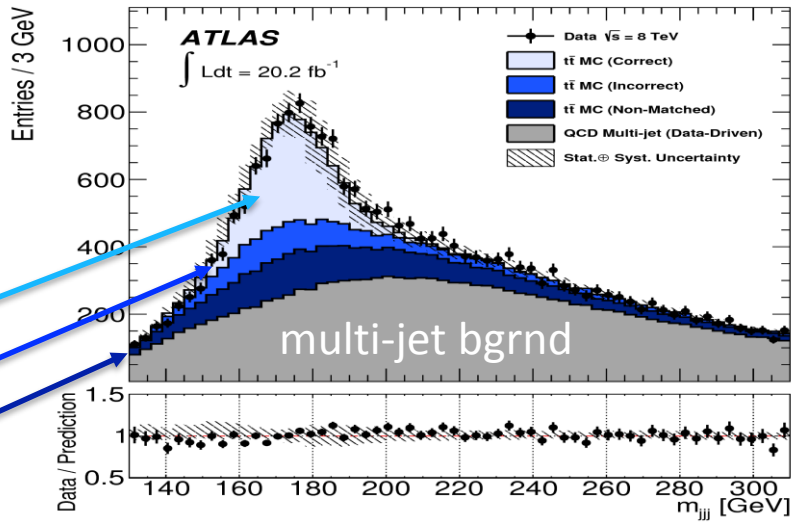
- Challenge: multi-jets bgrnd
  - Estimate (data driven)
  - Control regions for normalization and shape







Signal: Jet-parton assignment

Correctly matched

Incorrectly matched

Not matched

All-jets top mass at 8 TeV

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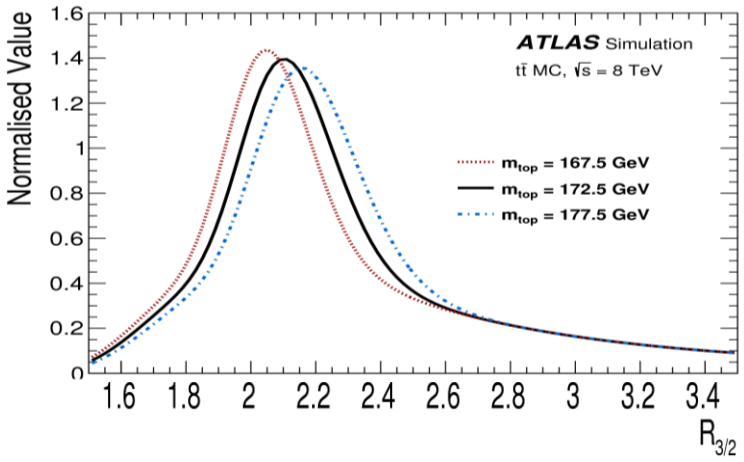
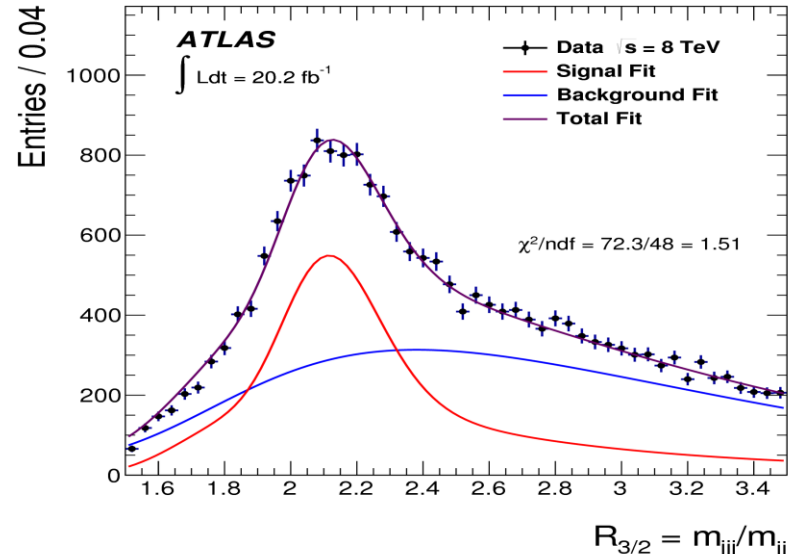
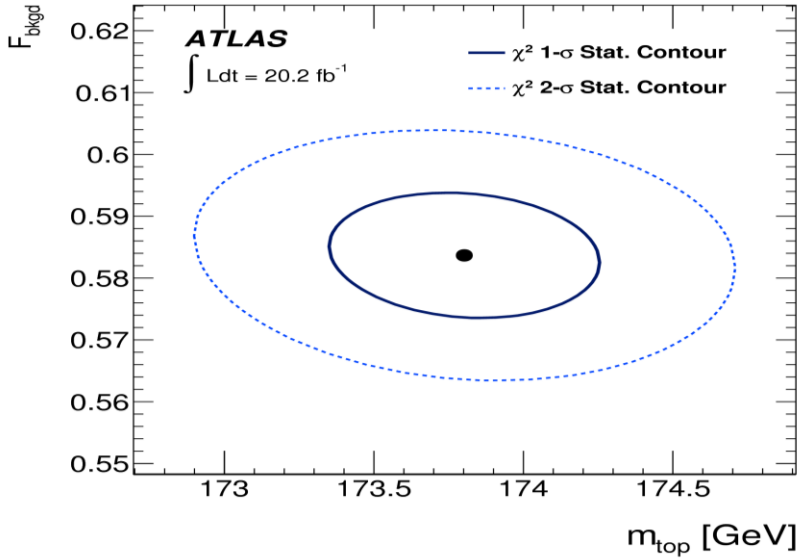
- Template fit
  - $R_{3/2} = m_{qqb} / m_{qq}$
  - Partially cancel syst. effects common to m_{top} and m_W



- Binned min. χ^2 approach
- Dominant syst. uncertainties
  - Jet energy scale (JES)
  - Hadronization modeling
  - Relative *b*-to-light-jet E scale (*b*JES)





Di-lepton top mass at 8 TeV

- Optimize to minimize the total uncertainty in m_{top}
  - Trading between stat. vs syst.
  - $p_{T,lb} = p_T$(lepton, *b*-jet) > 120 GeV
- Template fit
  - m_{lb}^{reco}
- Unbinned maximum-likelihood fit to data
- Dominant syst. uncertainties
  - Jet energy scale (JES)
  - Relative *b*-to-light-jet energy scale (*b*JES)

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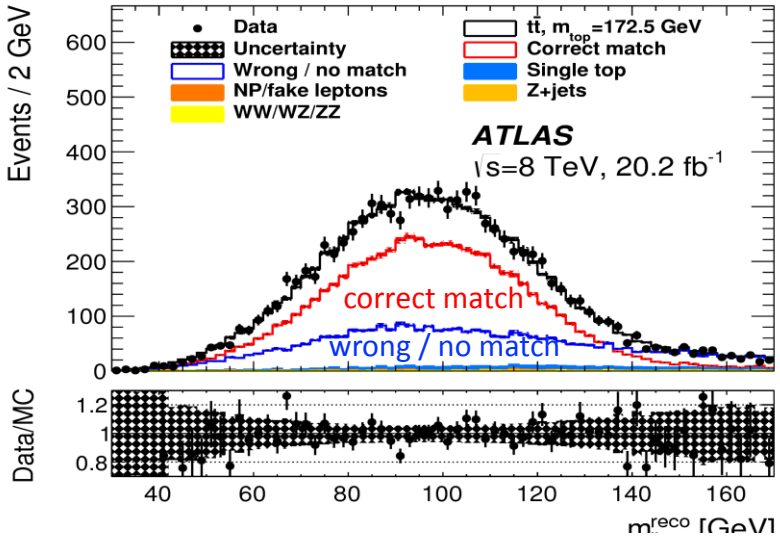
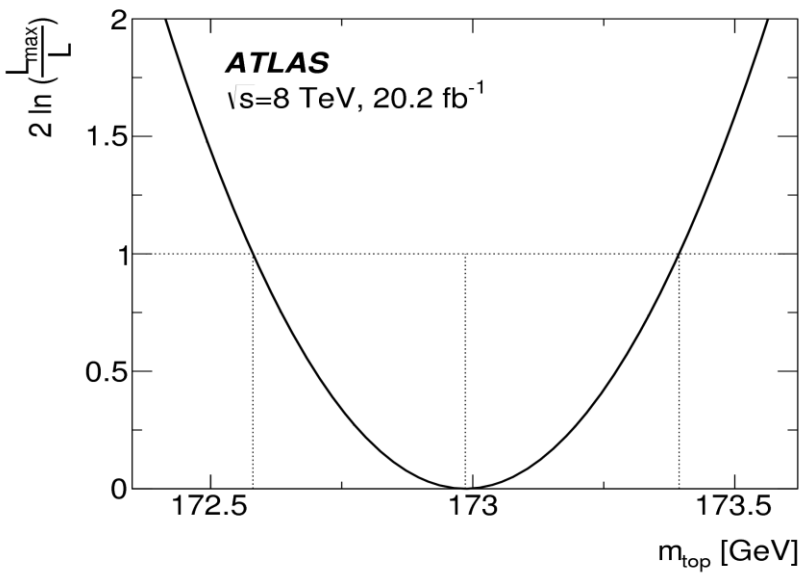
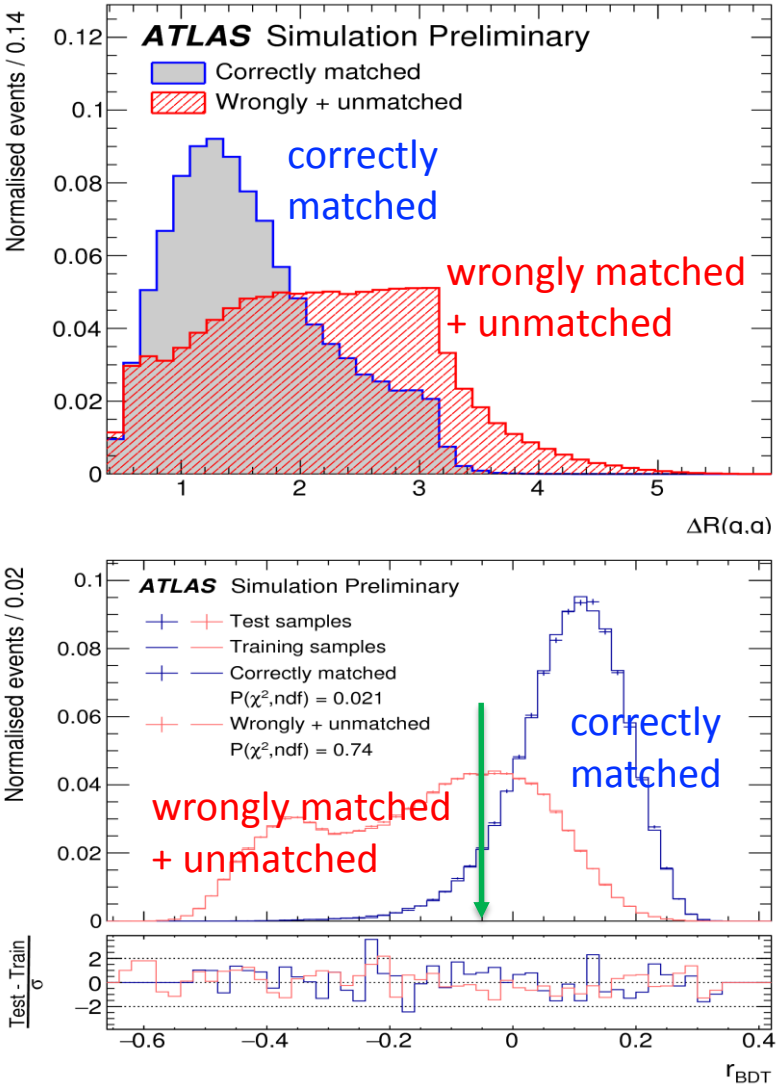




Lepton+jets top mass at 8 TeV

ATLAS-CONF-2017-071

- BDT to minimize the total uncertainty in m_{top}
  - Distinguishes events with a correct jet-to-parton matching
  - 12 input variables
    - $\Delta R(q_1,q_2)$: untag.-jets to W
    - $p_T(W_{had})$, $p_T(top_{had})$…
  - BDT > -0.05
    - Remove 60% signal (wrongly matched or unmatched)
    - Remove 90% of W+jets



Lepton+jets top mass at 8 TeV

- Template fit
- Simultaneous measurement of m_{top}, JES and *b*JES
  - M_{top}^{reco}
  - $m_{W(q1,q2)}$
  - $R_{bq}^{reco} = (p_T^{b1}+p_T^{b2}) / (p_T^{q1}+p_T^{q2})$
- Reduces the sizeable JES and *b*JES induced uncertainties
- Unbinned likelihood fit
- Dominant syst. uncertainty
  - JES
  - *b*-tagging

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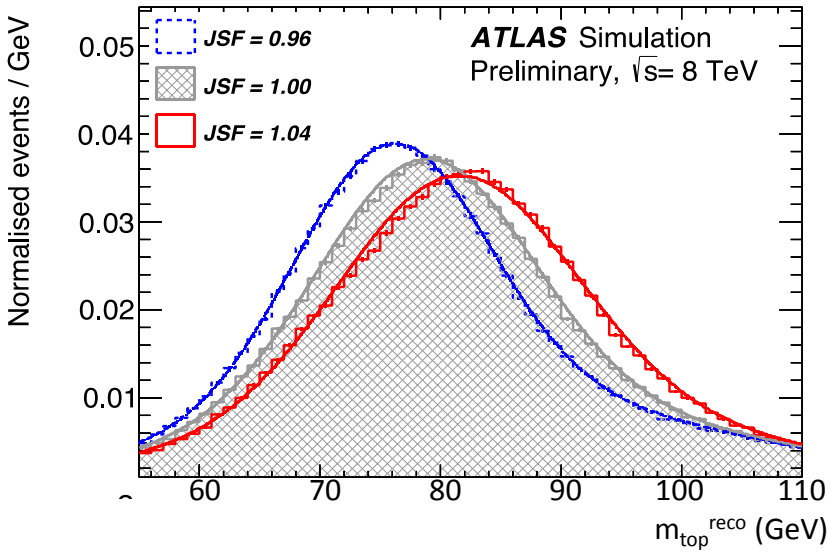
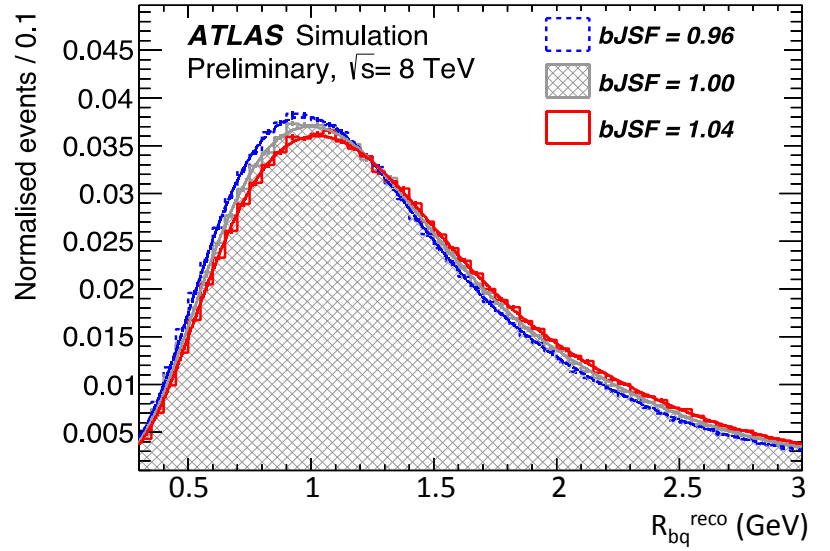
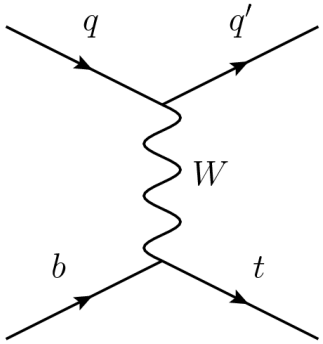




Top mass with single top events

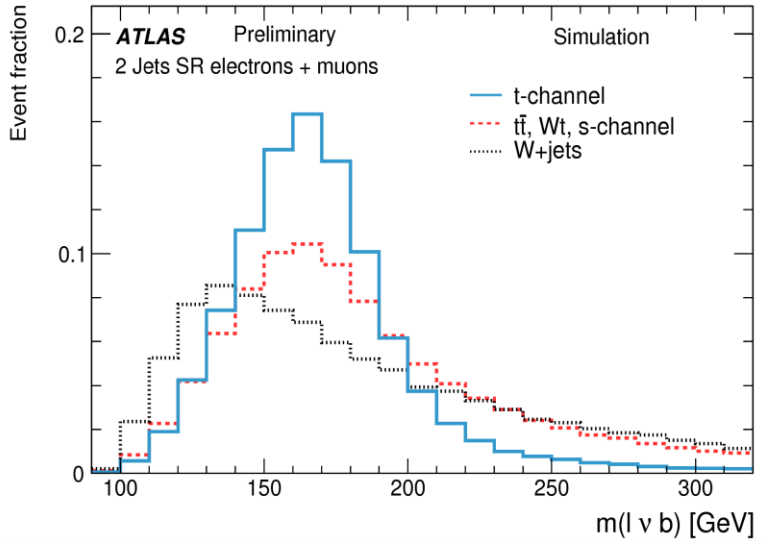
- *t*-channel dominant
  - 1 lepton (e, μ)
  - 1 neutrino
  - 1 *b* quark
  - 1 light quark

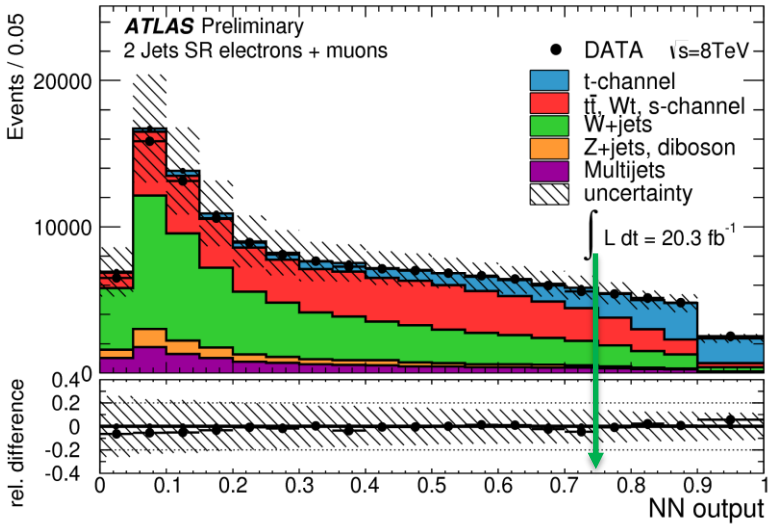


- Compared to top-pair
  - Weak int.s → different color flow
  - Lower Q^2
  - Less jet-parton ambiguities
  - Less jet multiplicity → large bgrnd
  - Different systematics

- Neutral network
  - Multivariate analysis technique
  - 12 variables including $m_{l\nu b}$, m_{jb}, …
  - $NN_{output} > 0.75$

ATLAS-CONF-2014-055





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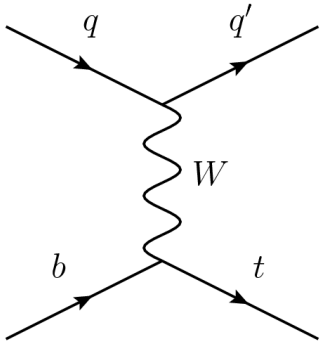
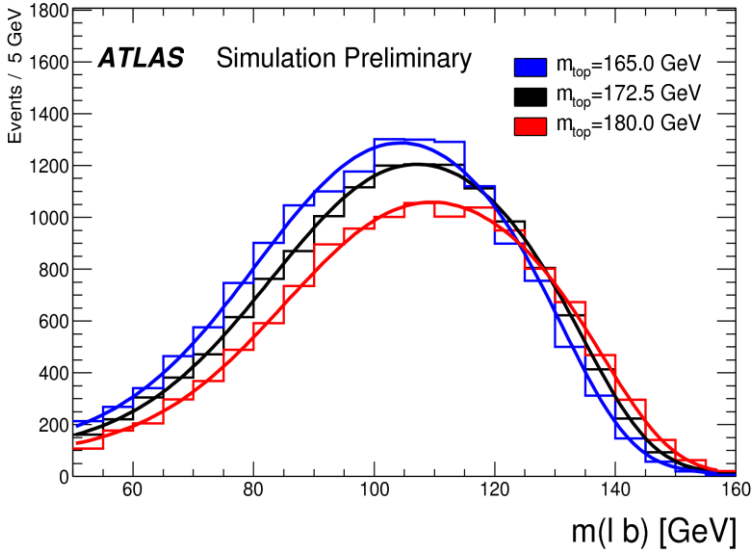
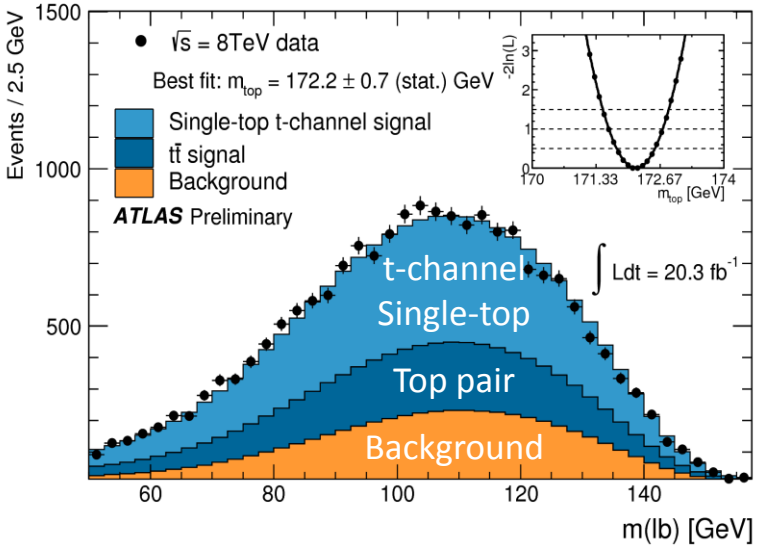


- Selected events
  - Data: 19,833 events
  - Signal + background
    - Top pair: 26%
    - Background: 28%

- Template fit to m_{lb}
- Binned maximum likelihood
- Dominant syst. uncertainty
  - JES

ATLAS-CONF-2014-055

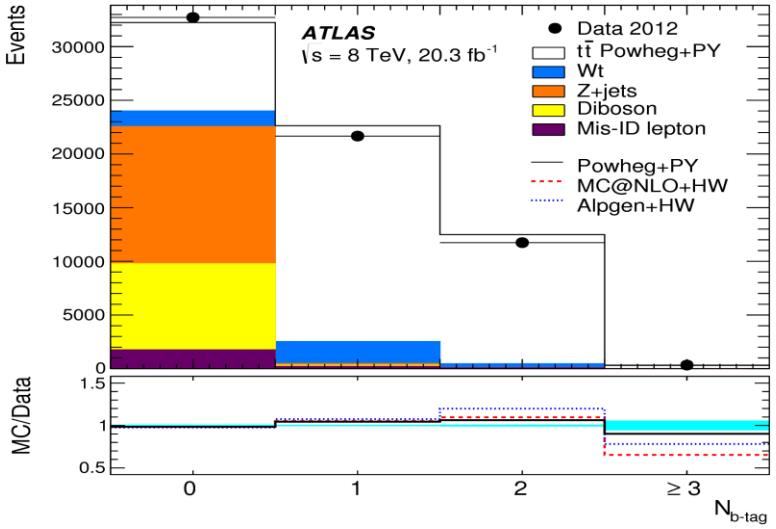


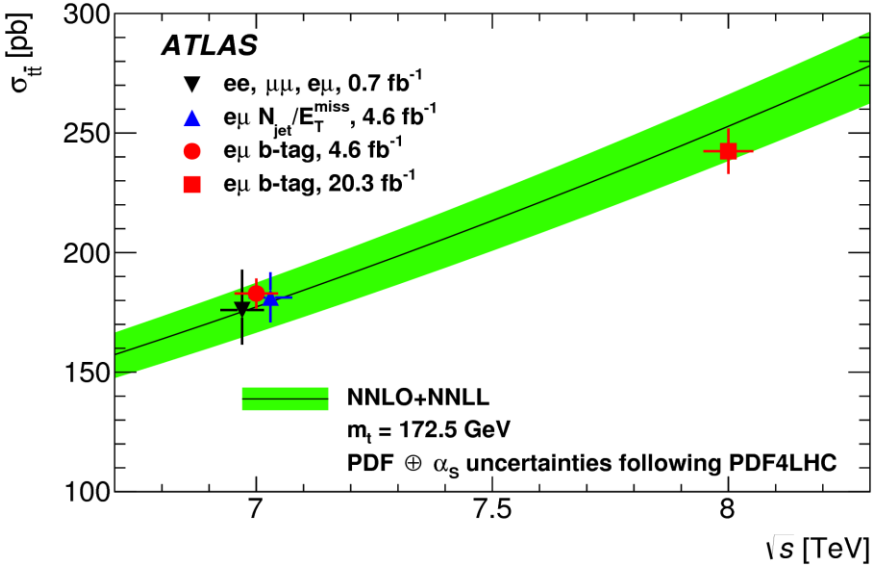


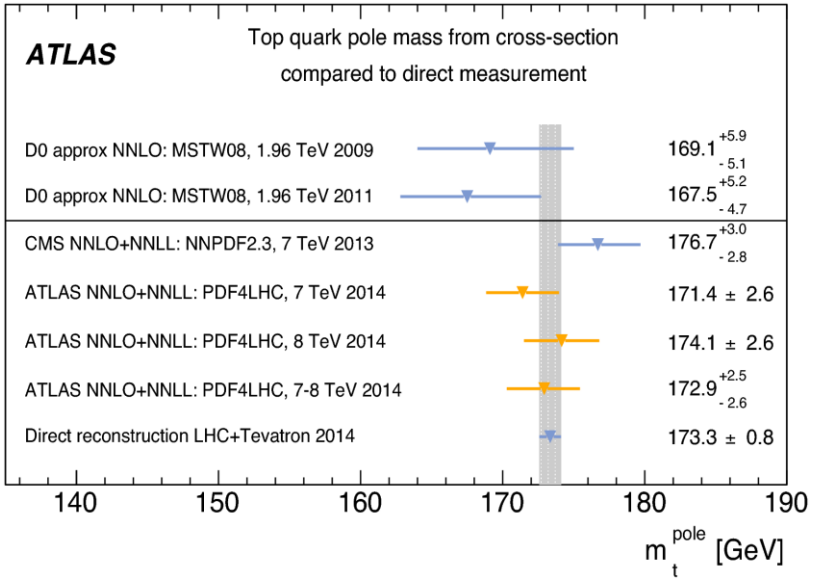
Top-pole mass

- Top pair cross sec.: sensitive to
  - Gluon PDFs,
  - Top mass
  - Physics beyond the SM
- Di-lepton channel
  - e + μ + 1 or 2 *b*-jets
  - Main background: *Wt*
- Extracted top-pole mass from σ_{tt}

Eur. Phys. J. C74 (2014) 3109



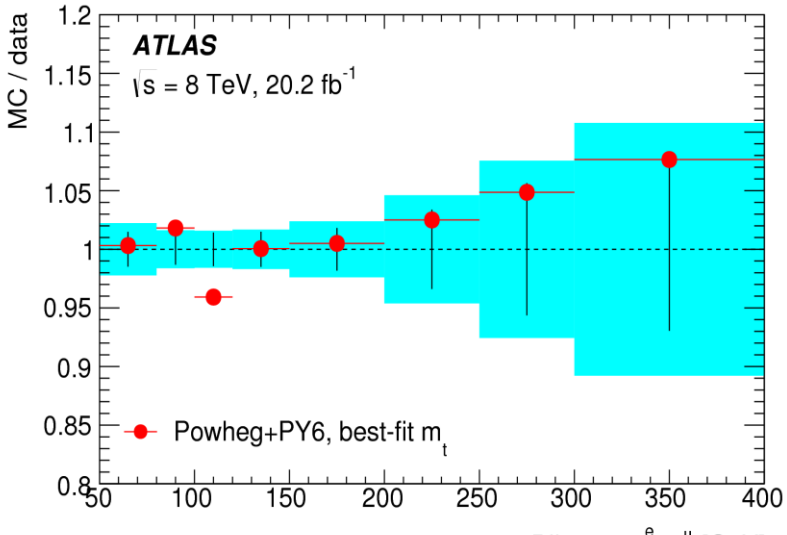


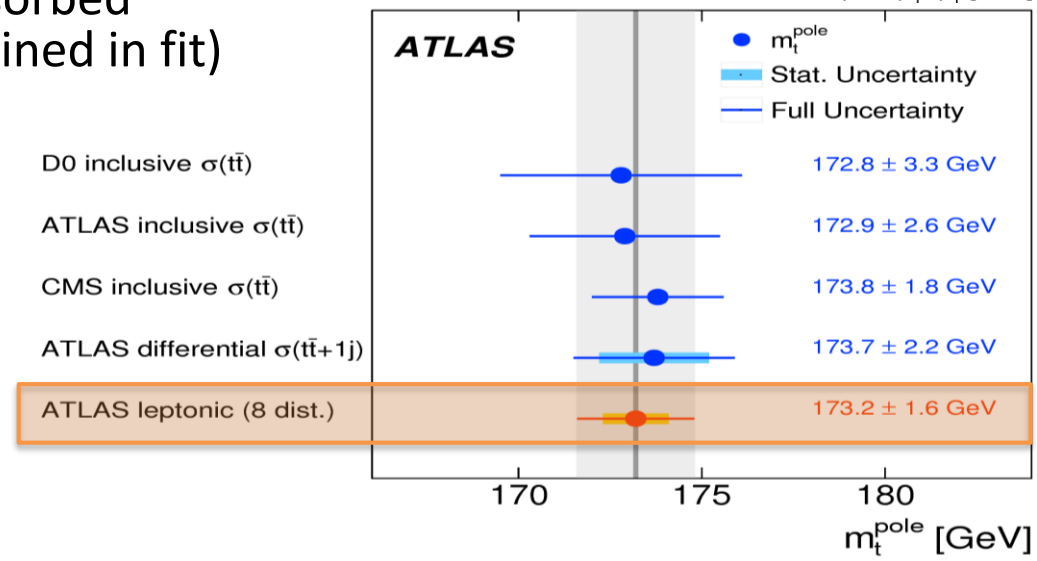


Top-pole mass

- Differential cross sections
  - 1 lepton or 2-lepton system
  - Less sensitive to hadronic part
- m_{top}: p_T^{l}, $p_T^{e\mu}$, $m^{e\mu}$, $p_T^{e}+p_T^{\mu}$, $E^{e}+E^{\mu}$
- PDF/QCD scales: $|\eta^{l}|$, $|y^{e\mu}|$, $\Delta\phi^{e\mu}$
- Fit to fixed order QCD predictions (NLO) from the MCFM program
  - Missing NNLO corr.s absorbed in scale uncert. (constrained in fit)
- δm_{top}^{pole} = ± 0.9 (stat)
  ± 0.8 (syst)
  ± 1.2 (theo)
- Dominant: QCD scales

Eur. Phys. J. C77 (2017) 804





Top mass measurements in ATLAS at 8 TeV

(GeV)

	Dilepton	L+jets	All-jets	Single top	$d\sigma_{tt}/dx$
Top mass	MC mass				pole mass
	172.99	172.08	173.72	172.2	173.2
Statistical uncertainty	0.41	0.39	0.55	0.7	0.9
Dominant syst. uncertainty	JES:0.54 *b*JES:0.30	JES:0.54 *b*-tagging:0.38	JES:0.60 Hadronization:0.64	JES:1.5 Hadronization:0.7	QCD scale: 1.0
Total sys. uncertainty	0.74	0.82	1.01	2.0	1.4
Total uncertainty	0.84	0.91	1.15	2.1	1.6

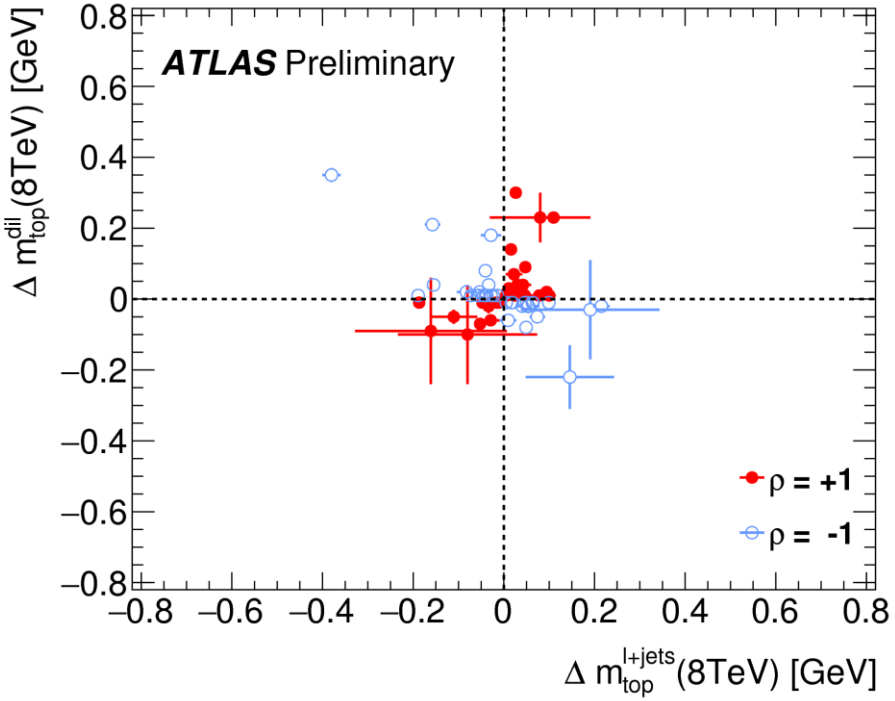
ATLAS top mass combination

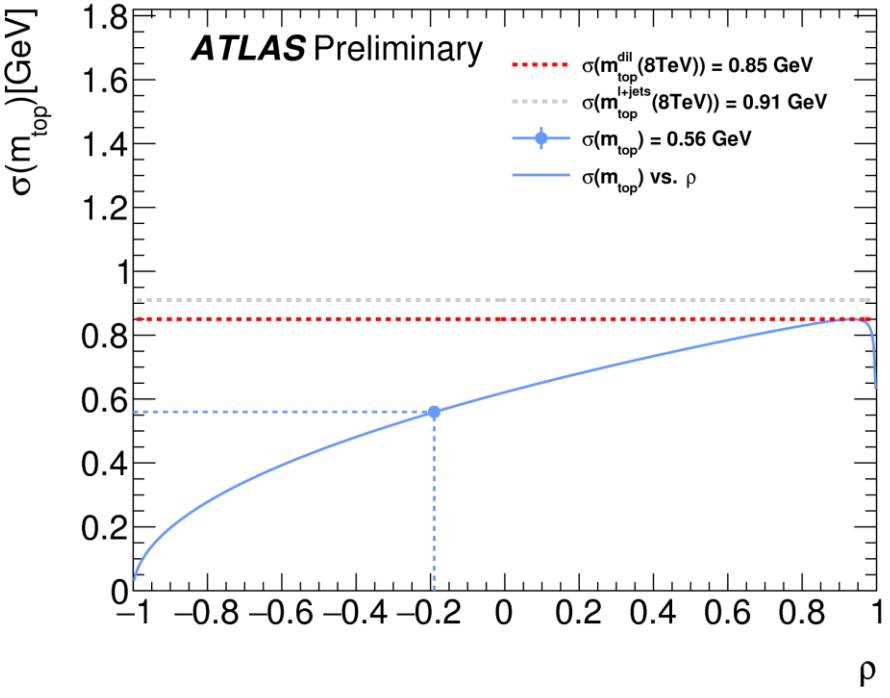
Performed using the best linear unbiased estimate (BLUE) method:

Central values

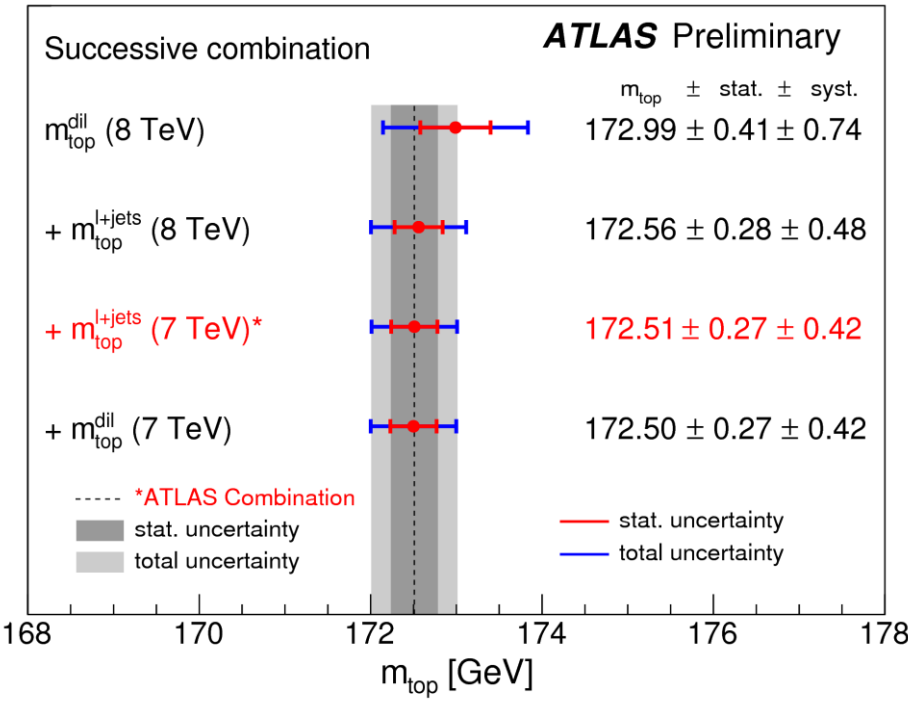
Uncertainties

Correlations ρ of the estimators for each uncertainty

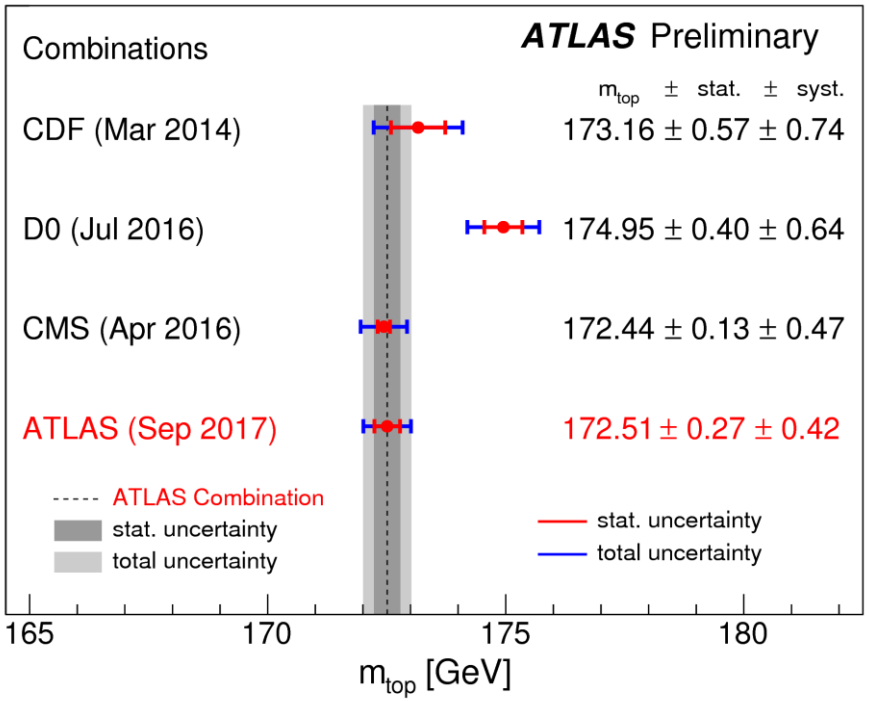




ATLAS top mass combination



Combined result when successively adding results to the most precise one



Combined result per experiment

Conclusions

- ATLAS has made a number of measurements of the top quark mass at 7 and 8 TeV
- Top-MC mass (Standard & Alternative)
  - Best individual measurements
    - Reduced the total uncertainty by trading stat. for syst. precision
    - Di-lepton channel: 0.84 GeV at 8 TeV
    - Lepton+jets channel: 0.91 GeV at 8 TeV
  - ATLAS combination
    - Care was taken to minimize & properly evaluate the correlations between individual measurements
    - $m_{top} = 172.51 \pm 0.50$ GeV
- Top-pole mass via differential cross sections of top pair
  - $m_{top}^{pole} = 173.2 \pm 1.6$ GeV: consistent with m_{top} measurements