Universität Hamburg
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GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

Standard Reconstruction of the Top-Quark Mass at the LHC

Eike Schlieckau (Universität Hamburg)
on behalf of the ATLAS and CMS Collaborations
prepared with the help of Kevin Kröninger (TU Dortmund)

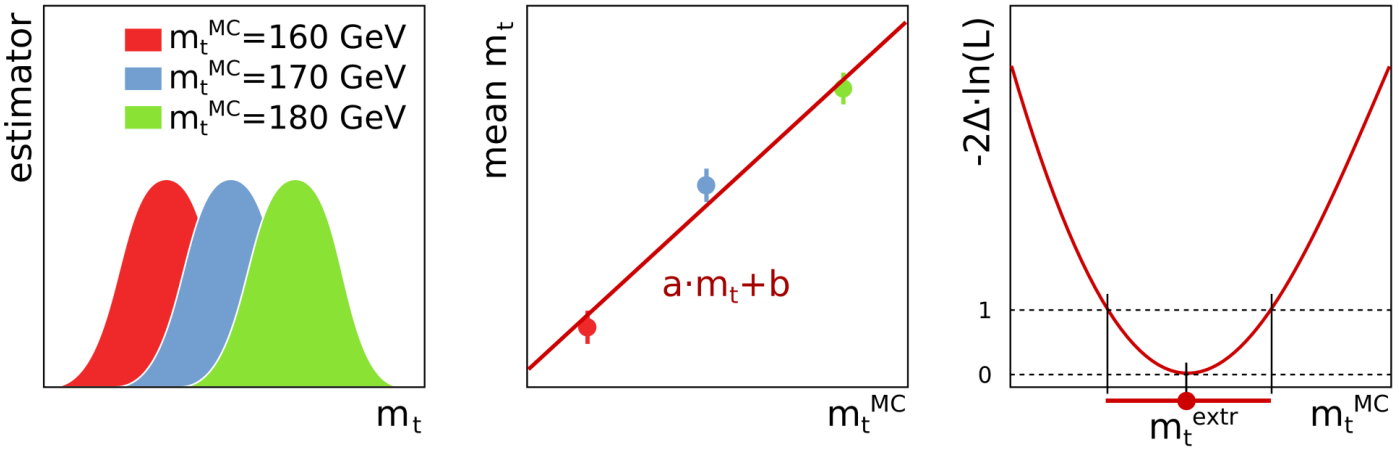
Standard Reconstruction

- Reconstruct invariant mass distributions from final state objects:
  - Leptons, jets, and missing transverse momentum
- Measured mass corresponds to definition used in MC
- All presented measurements on m_t^{MC}
  - Relation between theoretical well defined top-quark mass and m_t^{MC} to be determined
  - See talk by Andre Hoang (tomorrow 10am)

- For alternative mass measurements:
  - See talk by Stefanie Adomeit (today 2pm)

Measurement Method

- Build estimator for m_t (e.g. inv. mass of decay products)
- Parametrize estimator as function of m_t^{MC} (and possible other parameters)
- Possible per event combination of multiple estimators
- Ideogram method, CMS all-jets and l+jets
- Template method, all other measurements
- Perform maximum likelihood fit to data

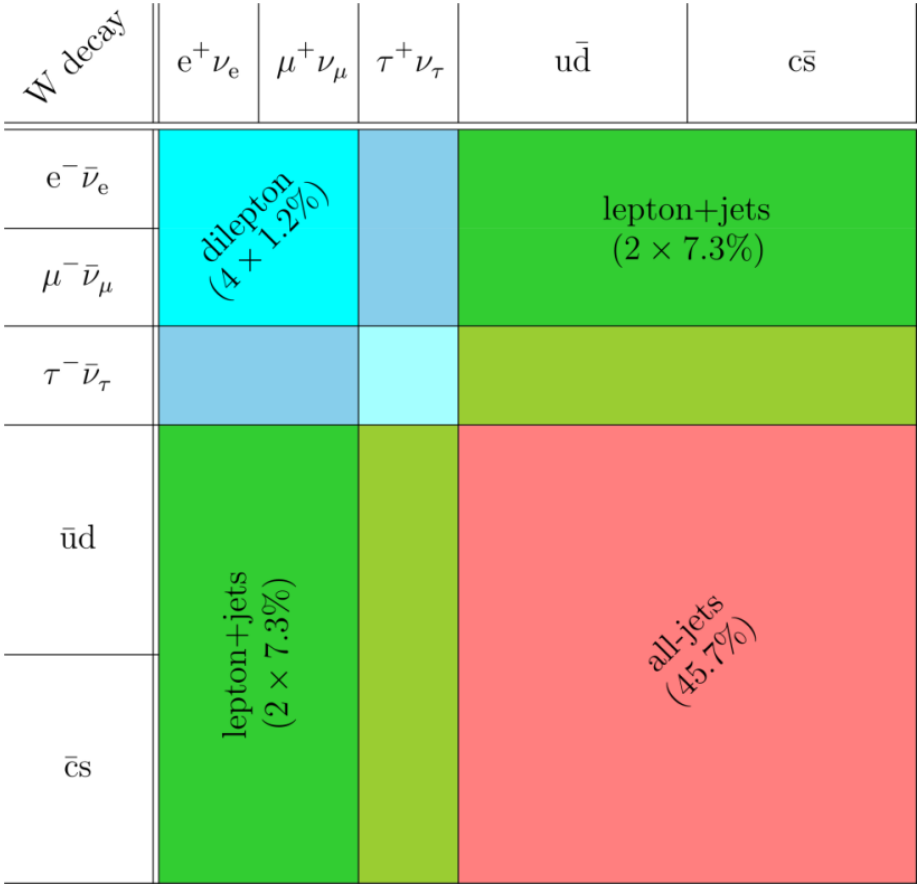


Datasets

- 7 TeV analyses based on 3.5 - 5.0 fb^{-1} from 2011
- 8 TeV analyses based on 18.2 - 19.7 fb^{-1} from 2012
- Produced number of top-quark pair events:
  - 2011: 800k, 2012: 5M, each number per experiment
- Cornerstones of measurements are understanding and minimizing impact of systematic uncertainties
  - See talks by:
    - Maria Costa (today 2:30pm, experimental uncertainties)
    - Markus Seidel (today 3:45pm, theoretical uncertainties)

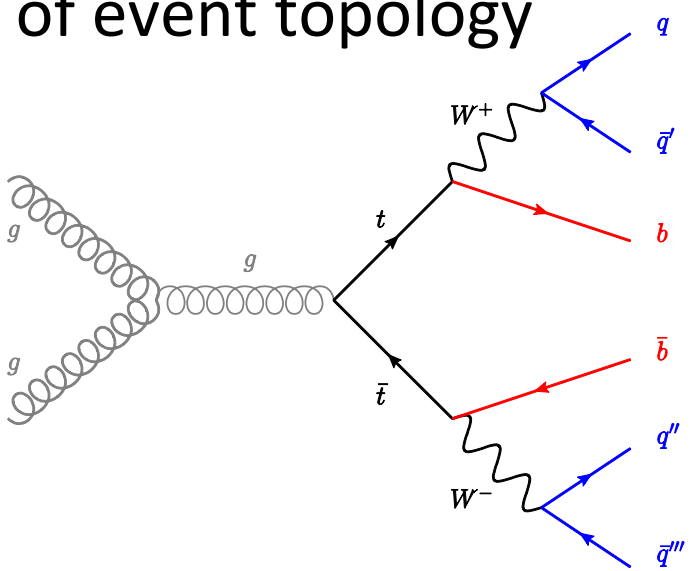
Overview of Measurements

- Alljets channel:
  - ATLAS @ 7 TeV
  - CMS @ 7 & 8 TeV
- Lepton+Jets channel:
  - ATLAS @ 7 TeV
  - CMS @ 7 & 8 TeV
- Dilepton channel:
  - ATLAS @ 7 TeV
  - CMS @ 7 & 8 TeV
- No measurements in final states with τ



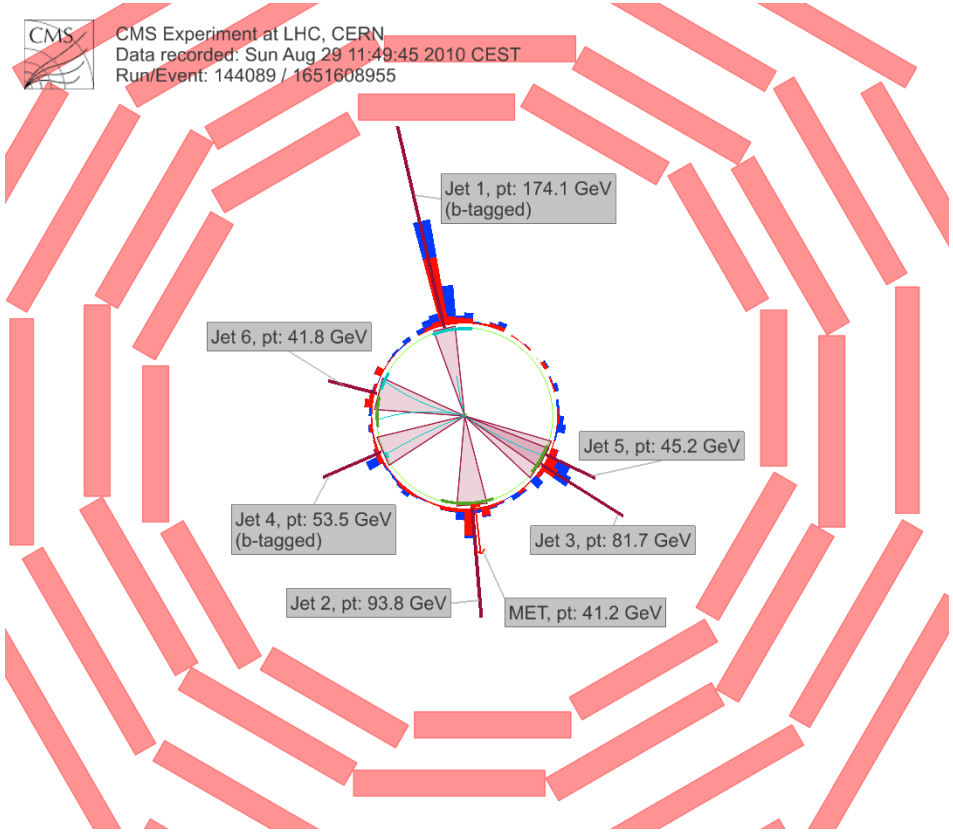
All-Jets Channel

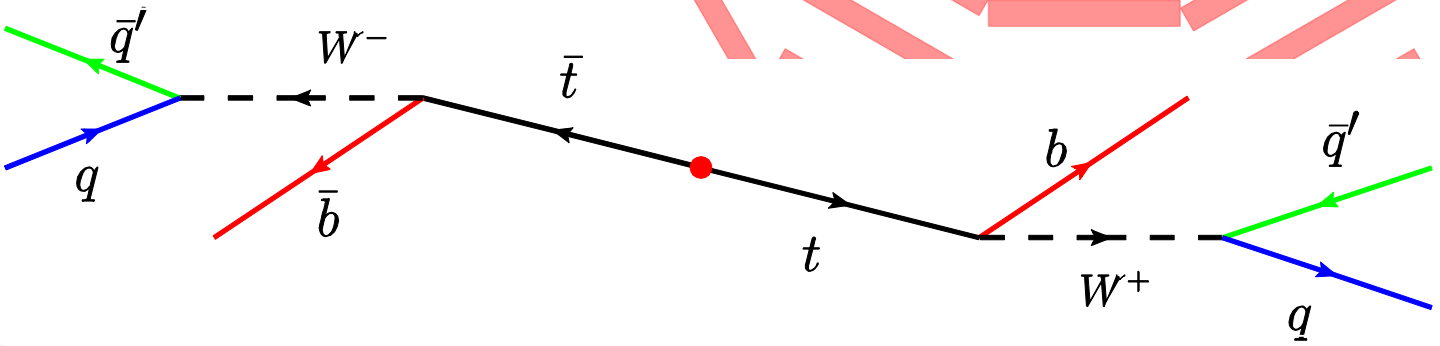
- Largest branching ratio (46%)
- 2 bottom quarks and 4 lighter quarks in the final state
  - Require 6 jets with 2 b tags (as clean as possible)
- Largest and worst predictable background (multijets)
  - Fully data-driven background prediction needed
- Background reduction with help of event topology
  - Kinematic Fit



Kinematic Fit

- Selected objects:
  - 4 untagged jets
  - 2 b-tagged jets





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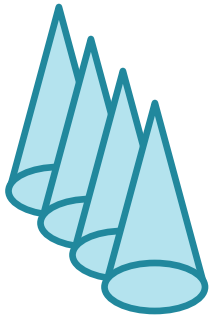
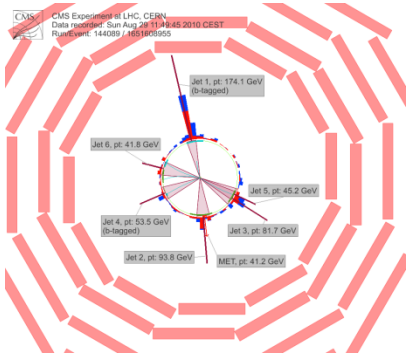
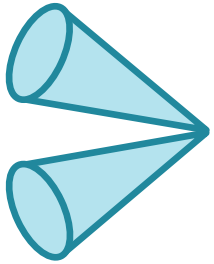
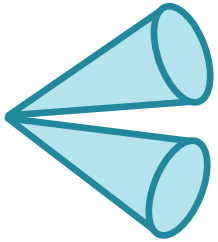




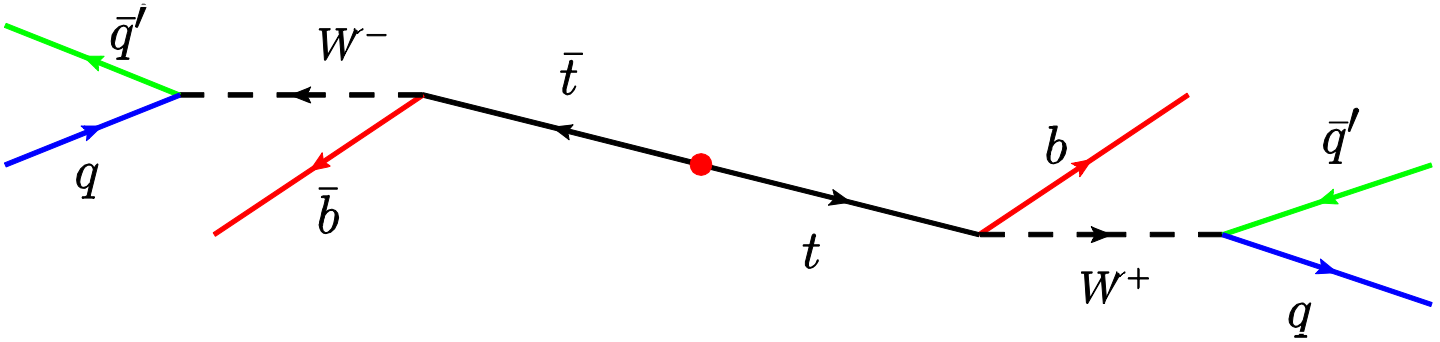
- Constraints:
  - 2x $m_{jj} = m_W$



= W boson &

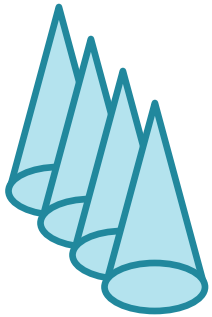


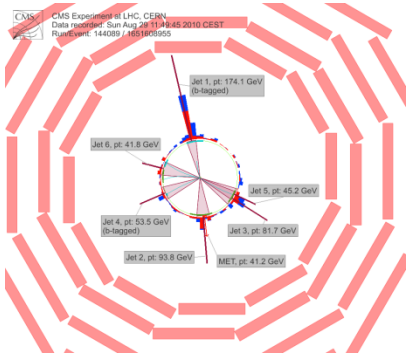
= W boson



Kinematic Fit

- Selected objects:
  - 4 untagged jets
  - 2 b-tagged jets





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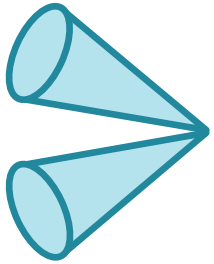
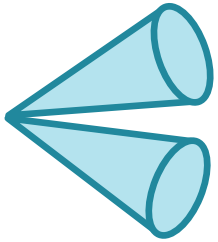


= W boson &



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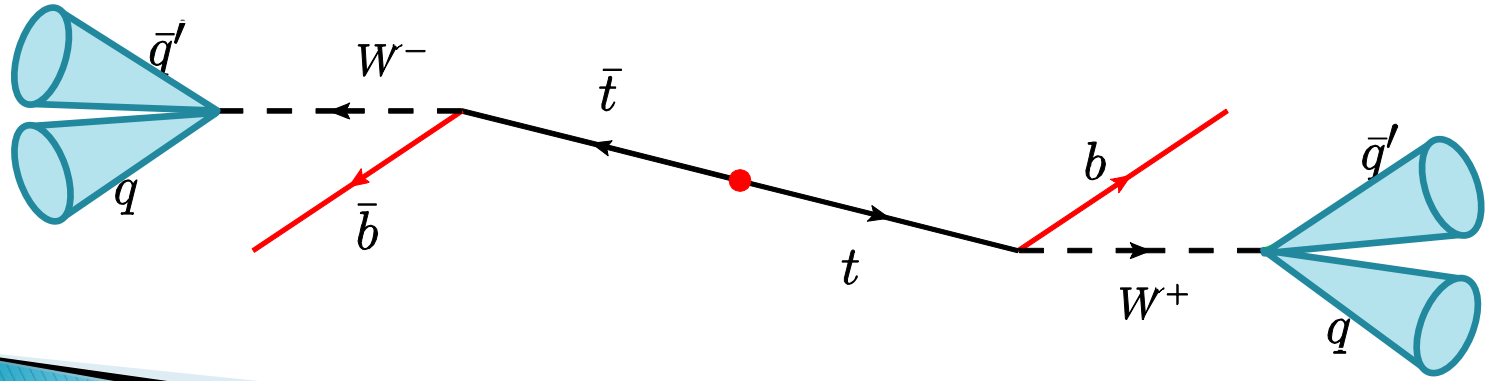

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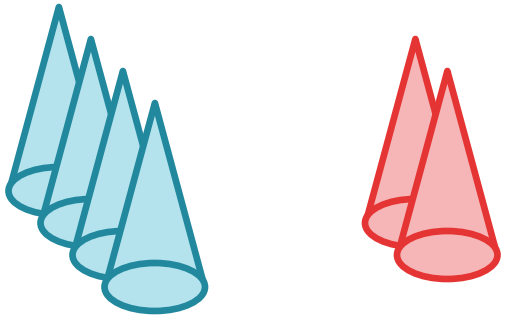
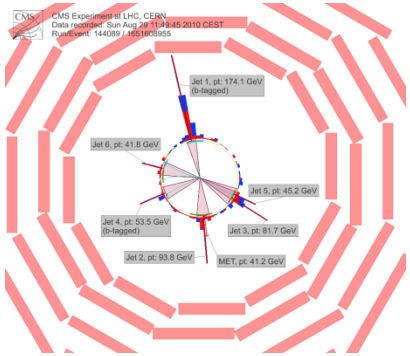
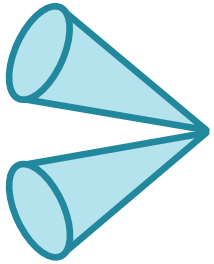
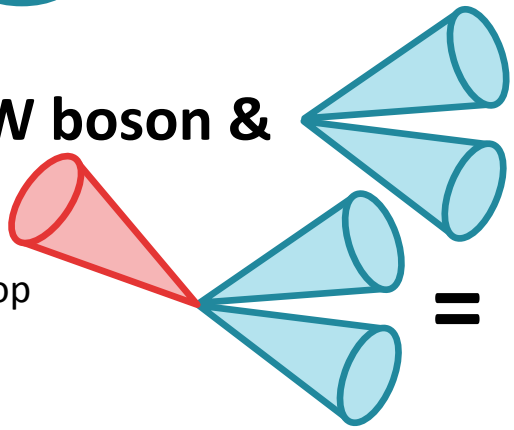




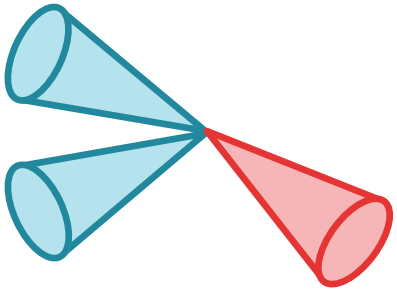
- Constraints:
  - 2x $m_{jj} = m_W$
  - $m_{top} = m_{jjb,1} = m_{jjb,2} = m_{antitop}$

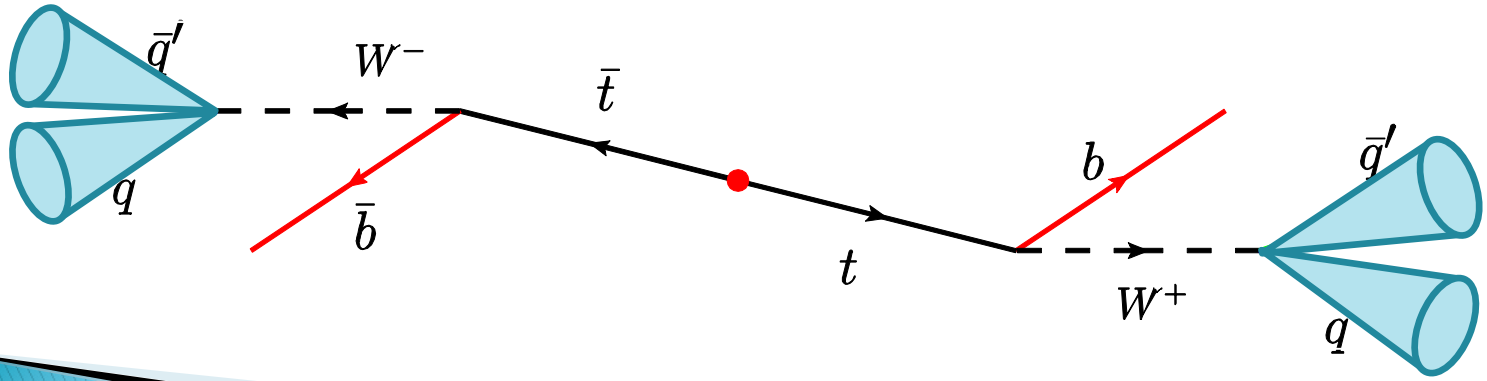


= W boson &



= W boson





Kinematic Fit

- Selected objects:
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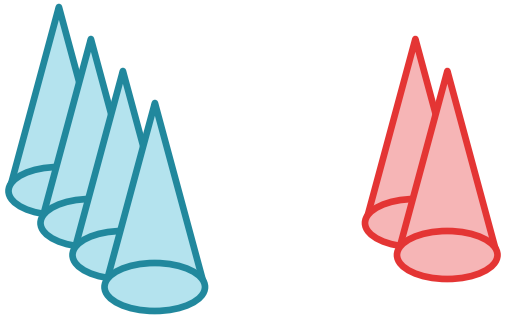

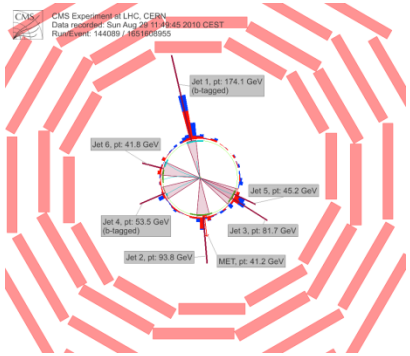

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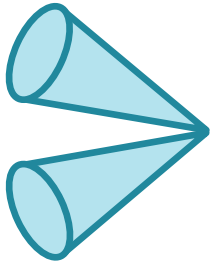
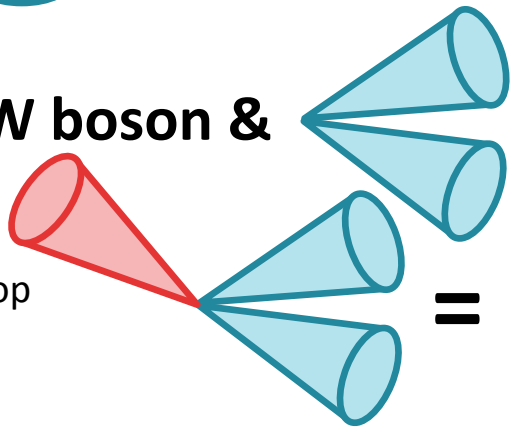
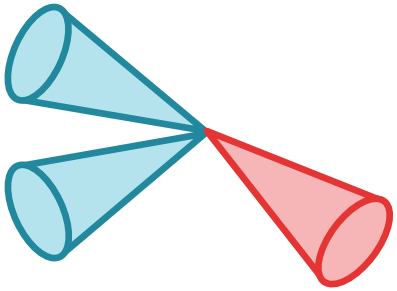
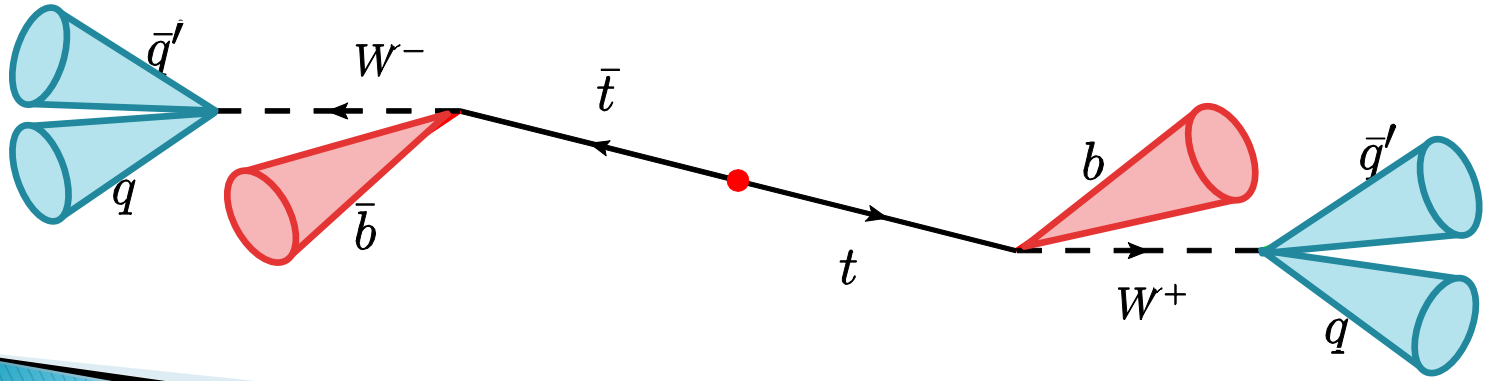


= W boson &



= W boson

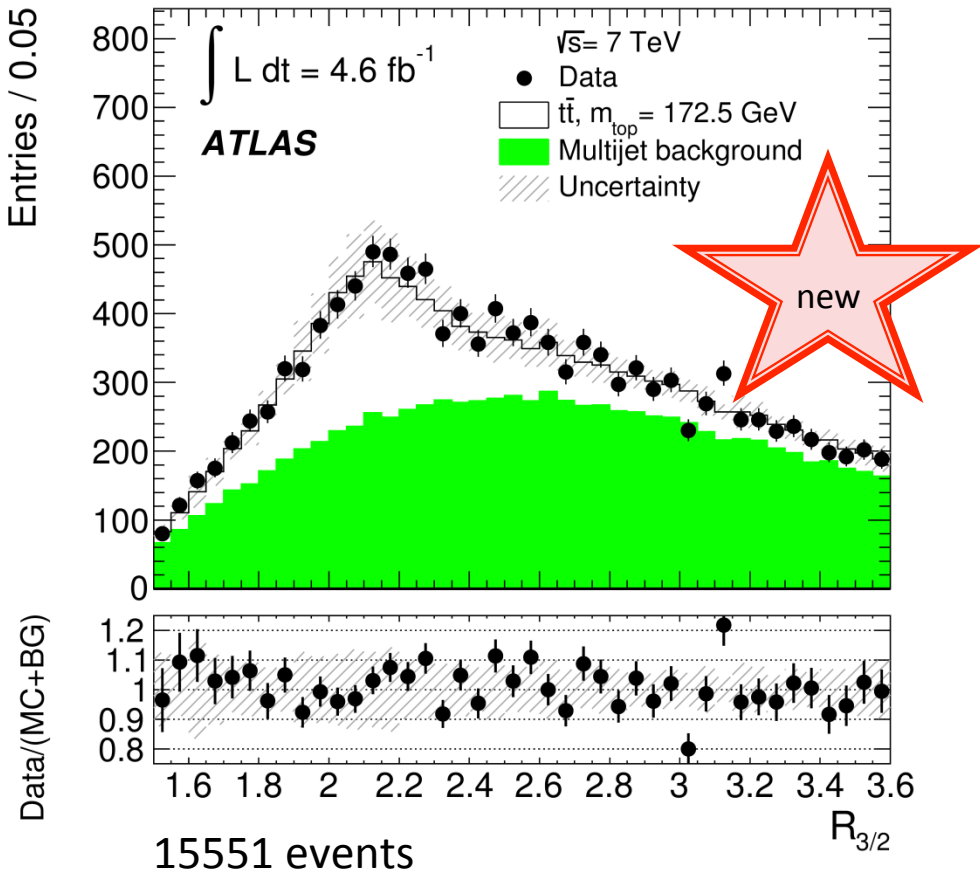




All-Jets Top-Quark Mass @ ATLAS 7 TeV

- Kinematic fit for jet-parton assignment
- Background: ABCD method
- Reduce JES uncertainty:
  - $R_{3/2} = m_{jjj} / m_{jj}$

arXiv:1409.0832
Submitted to: EPJC



15551 events

m_t = 175.1 ± 1.9 GeV (1.06%)

Source	Unc. [GeV]
JES+PU	0.52
bJES+Had	0.80
Detector modelling	0.17
Signal modelling	0.51
Background	0.35
Method	0.42
Syst.	1.22
Stat.	1.40
Total	1.86

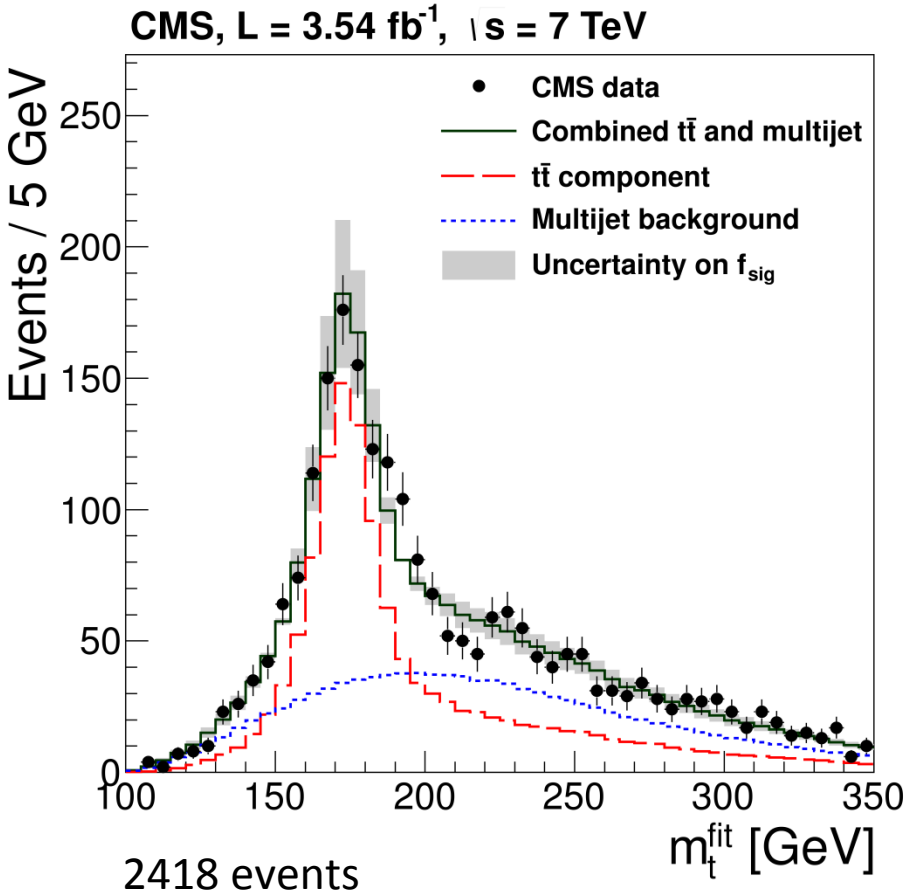
bJES: 0.62
Had: 0.50

All-Jets Top-Quark Mass @ CMS 7 TeV

- Kinematic fit
- Background: event mixing
- Tighter selection than ATLAS
  - Less events
  - Narrower peak

EPJC74 (2014) 2758

Source	Unc. [GeV]
JES+PU	0.97
bJES+Had	0.49
Detector modelling	0.29
Signal modelling	0.46
Background	0.13
Method	0.13
Syst.	1.23
Stat.	0.69
Total	1.41



m_t = 173.49 ± 1.41 GeV (0.81%)

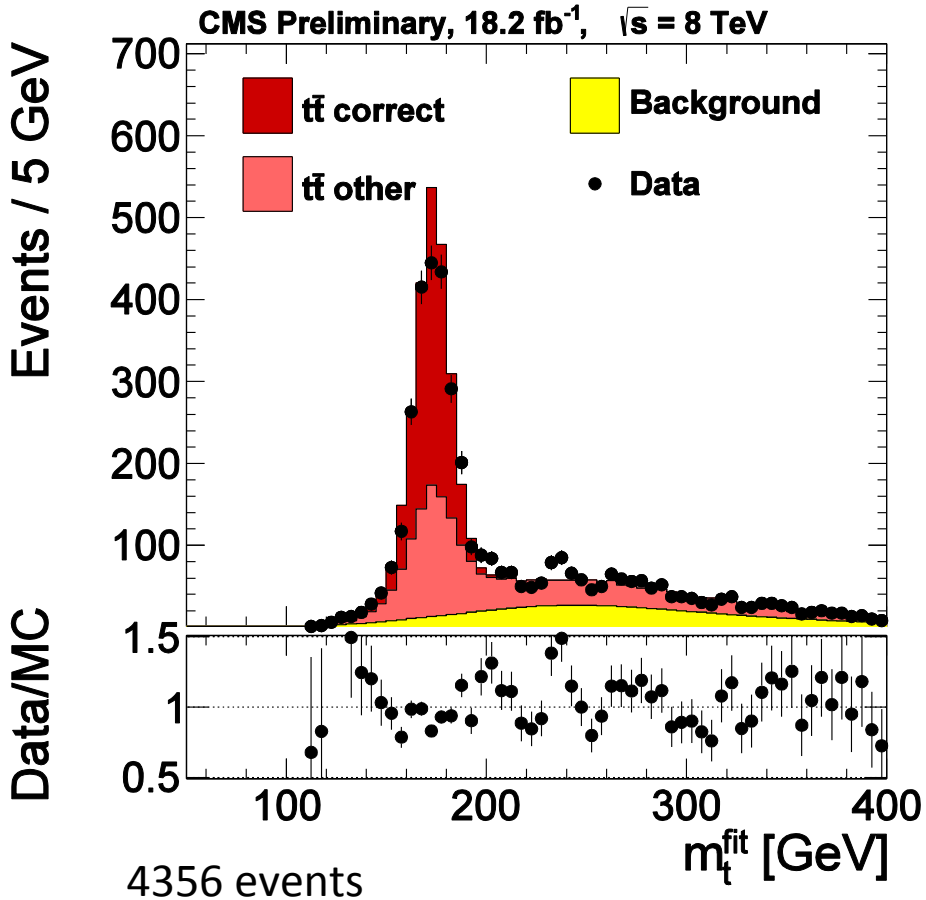
All-Jets Top-Quark Mass @ CMS 8 TeV

- Improved reconstruction
- Switch to 2D fit with JES scale factor (JSF)
- Fit signal and correct permutation fractions

JES+PU: 0.42
JSF: 0.24

Source	Unc. [GeV]
JES+PU+JSF	0.48
bJES+Had	0.39
Detector modelling	0.21
Signal modelling	0.52
Background	0.22
Method	0.06
Syst.	0.86
Stat. (m_t only)	0.27
Total	0.90

CMS-PAS-TOP-14-002



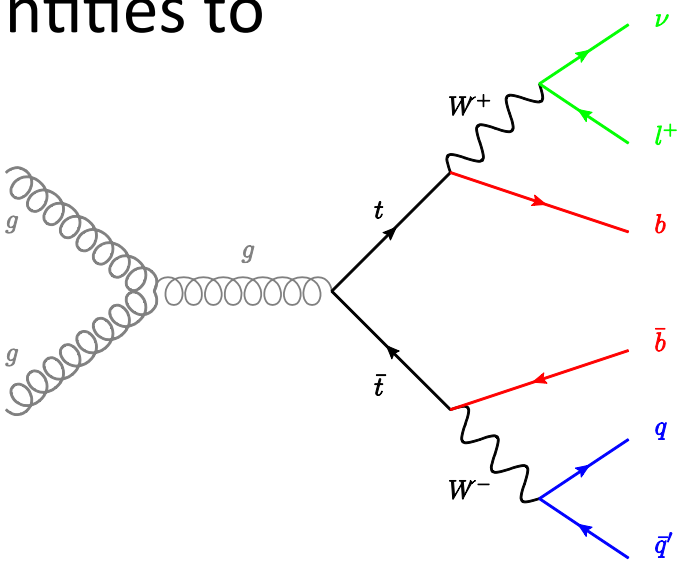
4356 events

m_t = 172.08 ± 0.90 GeV (0.53%)

JSF = 1.007 ± 0.011

Lepton+Jets Channel

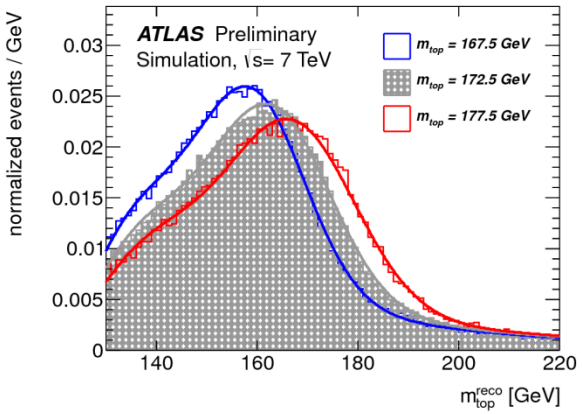
- Moderate branching ratio (29% for e / μ final states)
- 2 bottom and lighter quarks, 1 charged lepton and an undetectable neutrino in the final state
  - Require 1 isolated e or μ and 4 jets with 1-2 b tags
- Moderate and well predictable backgrounds (W+jets, t)
- In-situ measuring additional quantities to reduce dominant systematics
  - JES scale factor (JSF) (used by CMS and ATLAS)
  - Bottom JES scale factor (bJSF) (used by ATLAS only)



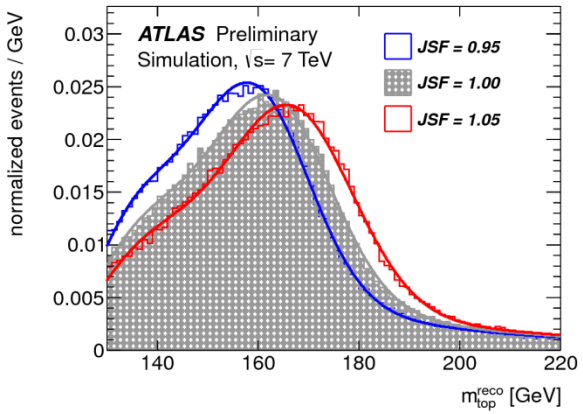
Simultaneous Extraction: m_t, JSF, bJSF

- Reconstructed top-quark mass has strong dependence on jet energy scale of bottom and lighter jets
  - Find quantities to in-situ measure both energy scale

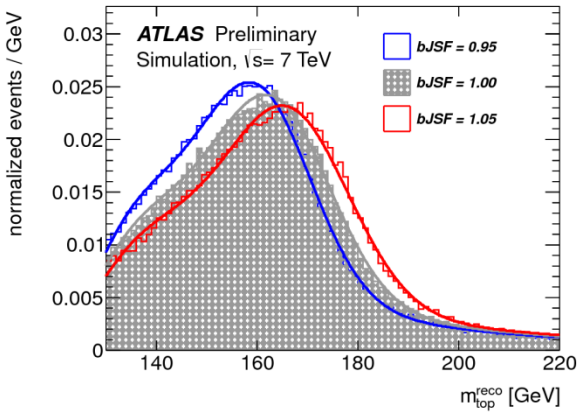
m_{top} variation



JSF variation



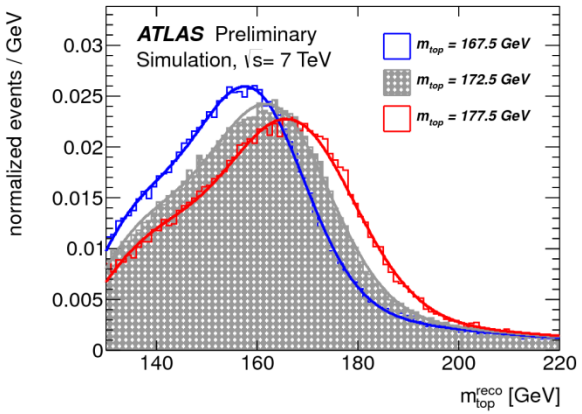
bJSF variation



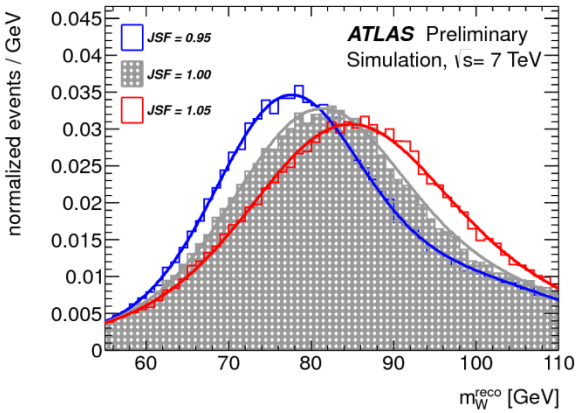
Simultaneous Extraction: m_t, JSF, bJSF

- Reconstructed top-quark mass has strong dependence on jet energy scale of bottom and lighter jets
  - Find quantities to in-situ measure both energy scale
  - Reconstructed mass of W boson (m_W^{reco}) to constrain light jets

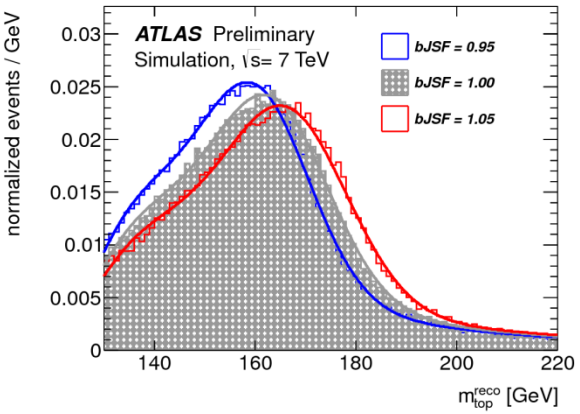
m_{top} variation



JSF variation



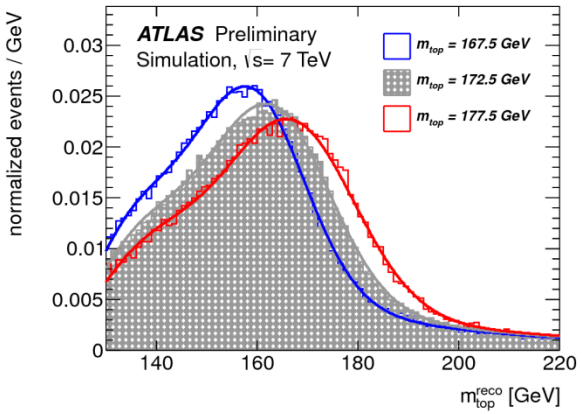
bJSF variation



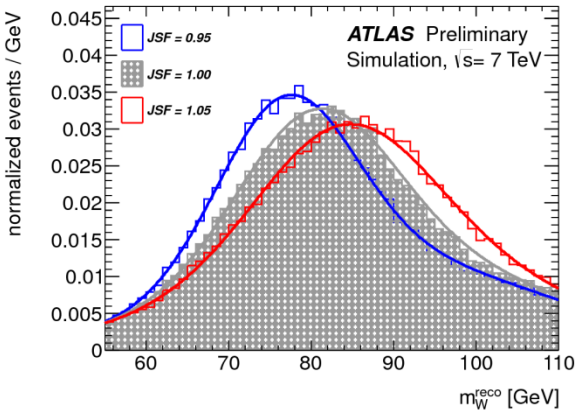
Simultaneous Extraction: m_t, JSF, bJSF

- Reconstructed top-quark mass has strong dependence on jet energy scale of bottom and lighter jets
  - Find quantities to in-situ measure both energy scale
  - Reconstructed mass of W boson (m_W^{reco}) to constrain light jets
  - Ratio of $p_T^{b\text{-tag}}$ over $p_T^{untagged}$ (R_{lb}^{reco}) to constrain bottom jets

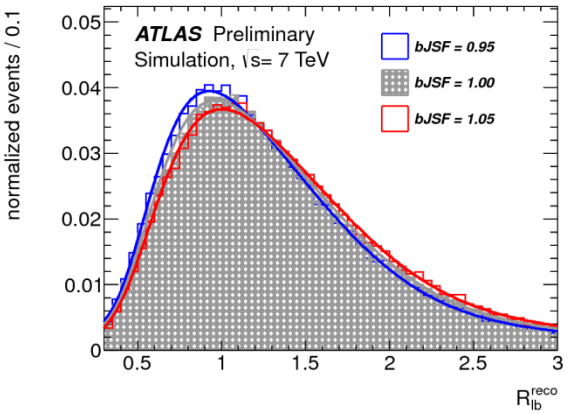
m_{top} variation



JSF variation



bJSF variation



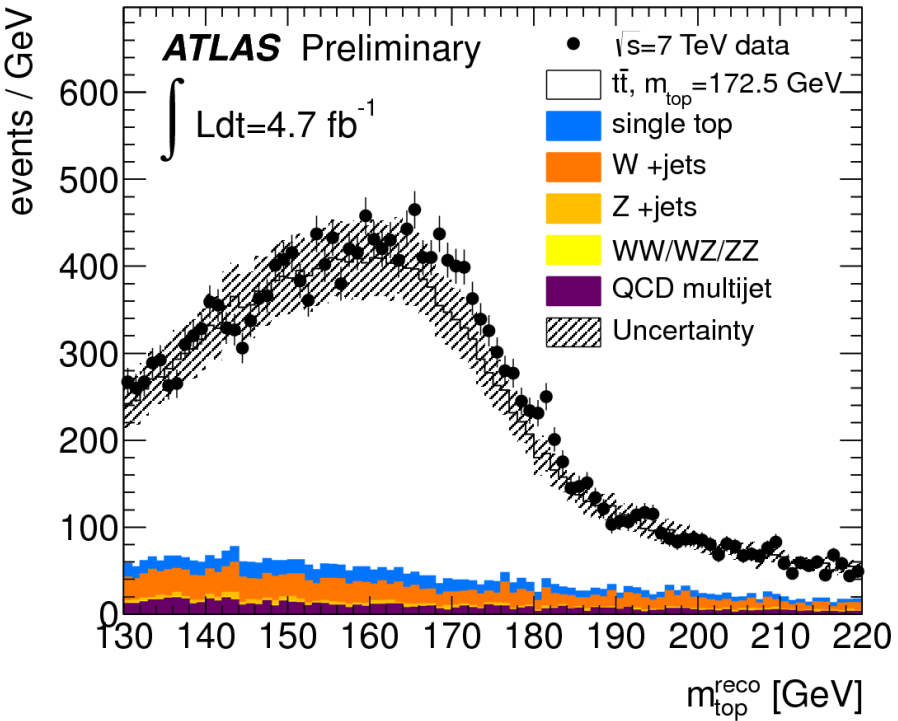
l+Jets Top-Quark Mass @ ATLAS 7 TeV

- Changes from 2D → 3D result
  - Reduced bJES & hadr. uncertainties
    - 1.59 GeV → 0.73 GeV
  - Increased b-tagging unc.
    - 0.17 GeV → 0.81 GeV

ATLAS-CONF-2013-046

JES+PU: 0.79
JSF: 0.27
bJES: 0.08
Had: 0.27
bJSF: 0.67

Source	Unc. [GeV]
JES+PU+JSF	0.83
bJES+Had+bJSF	0.73
Detector modelling	0.84
Signal modelling	0.62
Background	0.10
Method	0.13
Syst.	1.53
Stat. (m_t only)	0.23
Total	1.55



22878 events

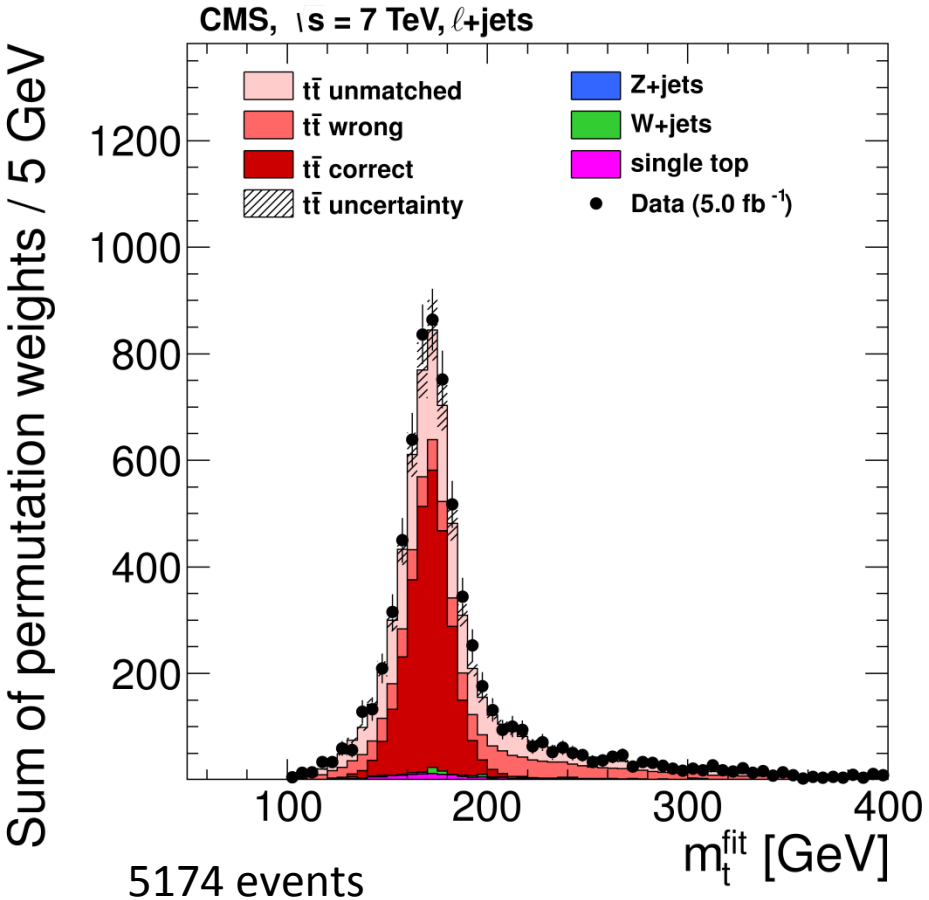
m_t = 172.31 ± 1.55 GeV (0.90%)

JSF = 1.014 ± 0.021; bJSF = 1.006 ± 0.022

l+Jets Top-Quark Mass @ CMS 7 TeV

- Kinematic fit
- In-situ measure JSF
- Use ideogram with all permutations

JHEP 12 (2012) 105



5174 events

m_t = 173.49 ± 1.06 GeV (0.61%)

JSF = 0.994 ± 0.009

JES+PU: 0.27
JSF: 0.33

Source	Unc. [GeV]
JES+PU+JSF	0.43
bJES+Had	0.61
Detector modelling	0.27
Signal modelling	0.64
Background	0.13
Method	0.06
Syst.	1.03
Stat. (m_t only)	0.27
Total	1.06

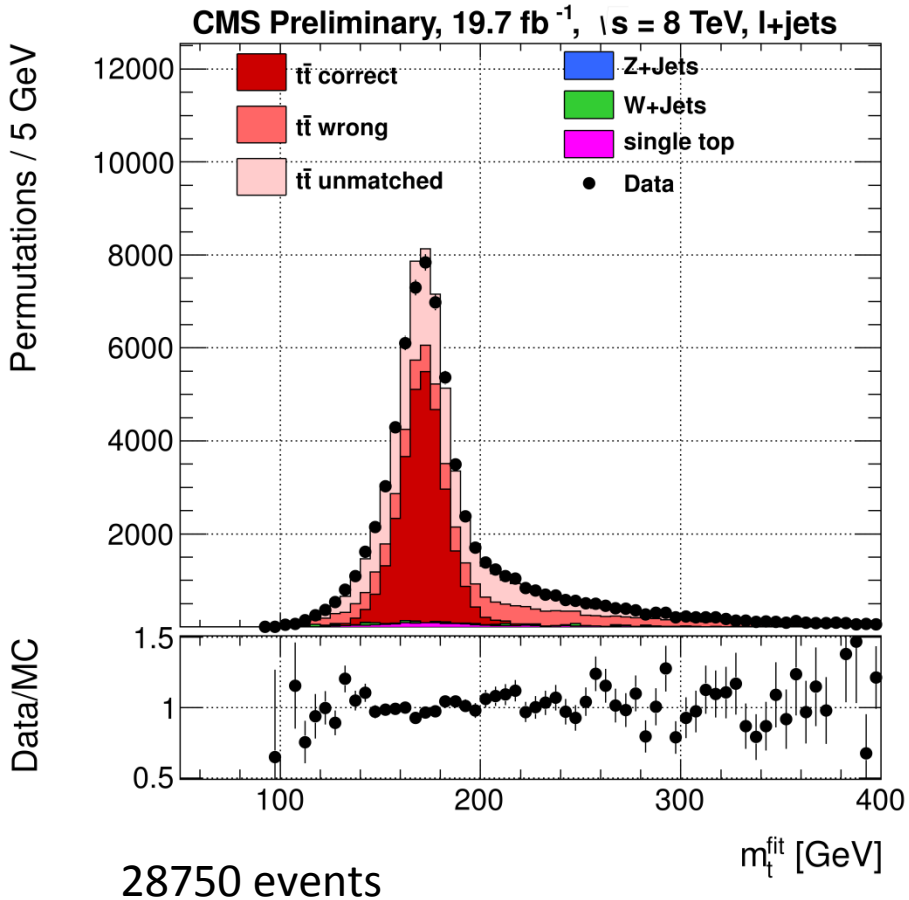
l+Jets Top-Quark Mass @ CMS 8 TeV

- Larger dataset and simulated samples
- Refined treatment of hadronisation and bJES uncertainties

JES+PU: 0.32
JSF: 0.15

Source	Unc. [GeV]
JES+PU+JSF	0.36
bJES+Had	0.44
Detector modelling	0.28
Signal modelling	0.39
Background	0.11
Method	0.10
Syst.	0.76
Stat. (m_t only)	0.11
Total	0.77

CMS-PAS-TOP-14-001



28750 events

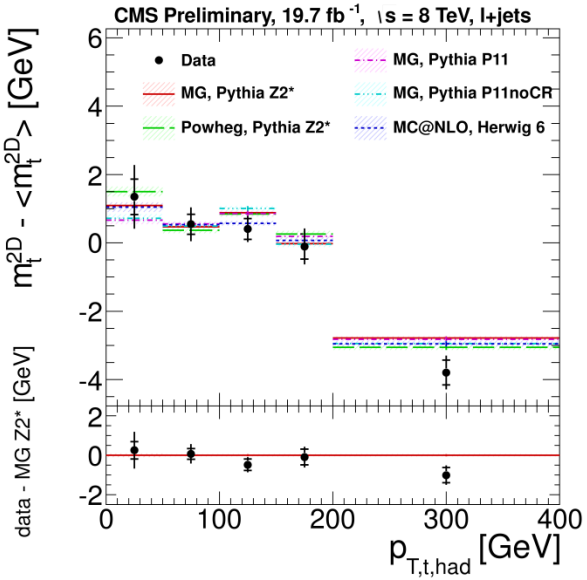
m_t = 172.04 ± 0.77 GeV (0.45%)

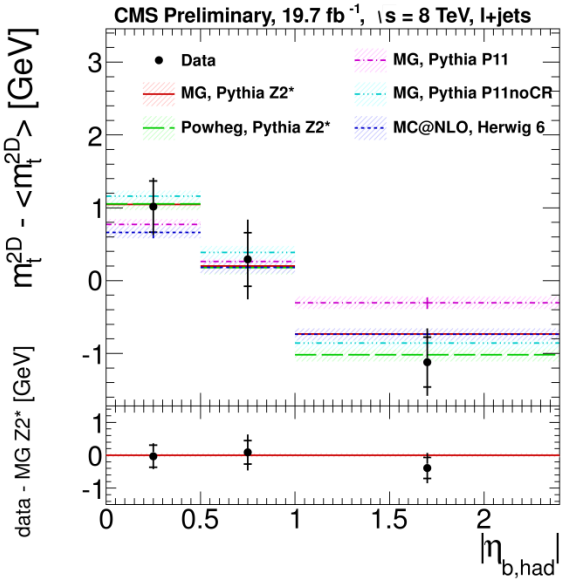
JSF = 1.007 ± 0.012

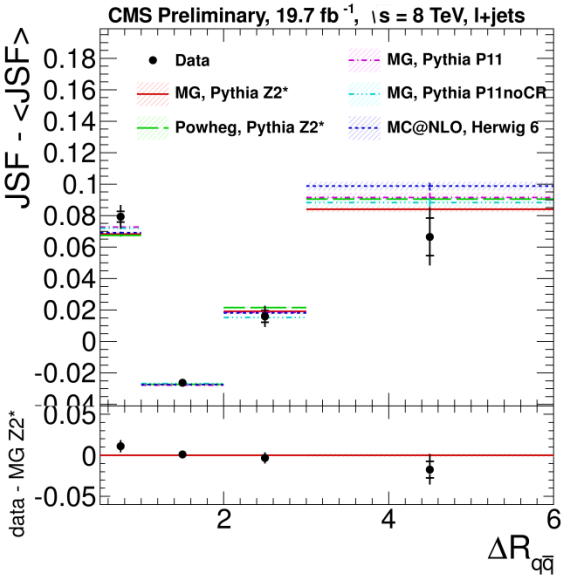
l+Jets Top-Quark Mass @ CMS 8 TeV

CMS-PAS-TOP-14-001

- Top mass vs. kinematic variables
- Data well-described
- χ^2 between data and MadGraph+Pythia Z2*
  - m_t: χ^2/ndf = 37/47 → P(χ^2,ndf) = 85%
  - JSF: χ^2/ndf = 61/47 → P(χ^2,ndf) = 8.3%

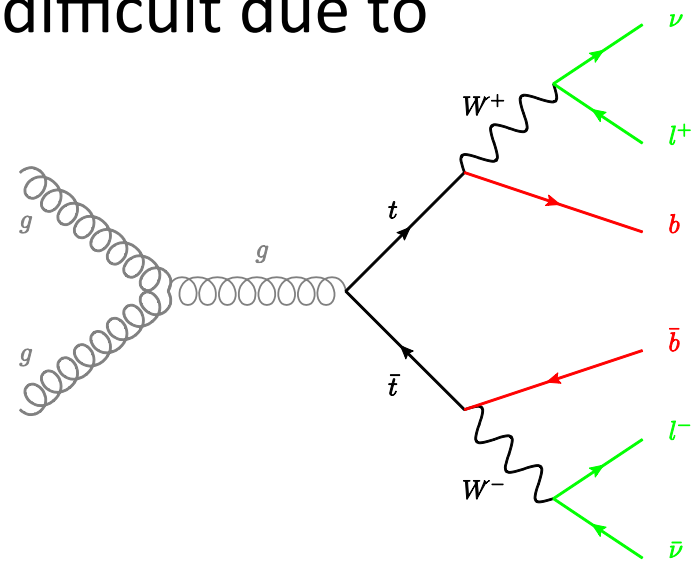






Dilepton Channel

- Small branching ratio (5% for ee / eμ / μμ final states)
- 2 bottom, 2 charged leptons and 2 undetectable neutrinos in the final state
  - Require 2 isolated e / μ, MET and 2 jets with up to 2 b tags
- Low and well predictable backgrounds (mainly Z+jets)
- Top-quark mass reconstruction difficult due to 2 undetectable neutrinos
  - Invariant mass of visible decay products: m_{lb}
  - Analytic Matrix Weighting Technique (AMWT)



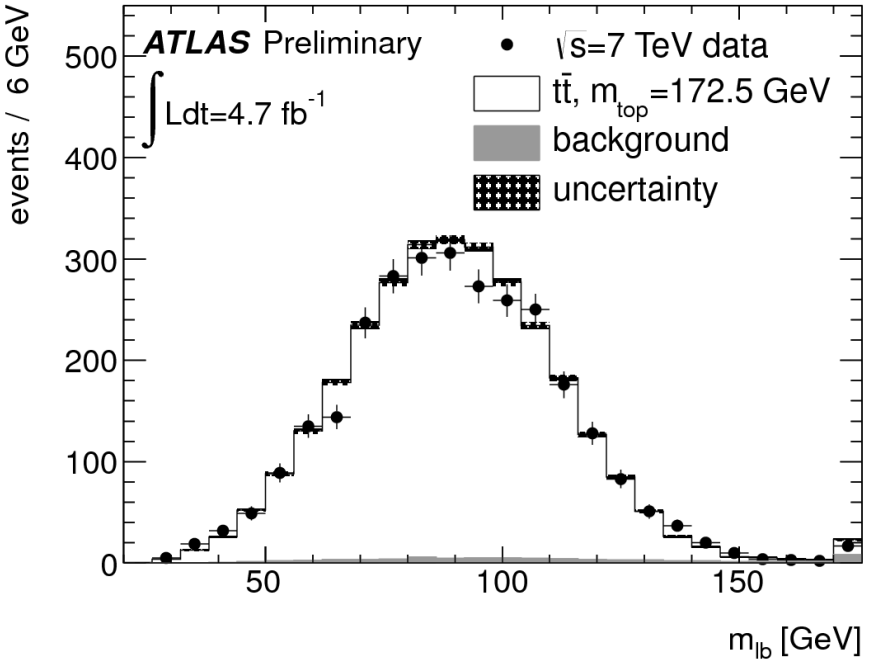
Dilepton Top-Quark Mass @ ATLAS 7 TeV

- Use m_{lb} as top-mass estimator
  - m_{lb}: invariant mass of lepton and b jet
  - No kinematic fitting

ATLAS-CONF-2013-077

Source	Unc. [GeV]
JES+PU	0.88
bJES+Had	0.84
Detector modelling	0.52
Signal modelling	0.67
Background	0.14
Method	0.07
Syst.	1.49
Stat.	0.64
Total	1.62

bJES: 0.71
Had: 0.44



2913 events

m_t = 173.09 ± 1.62 GeV (0.94%)

Analytic Matrix Weighting Technique

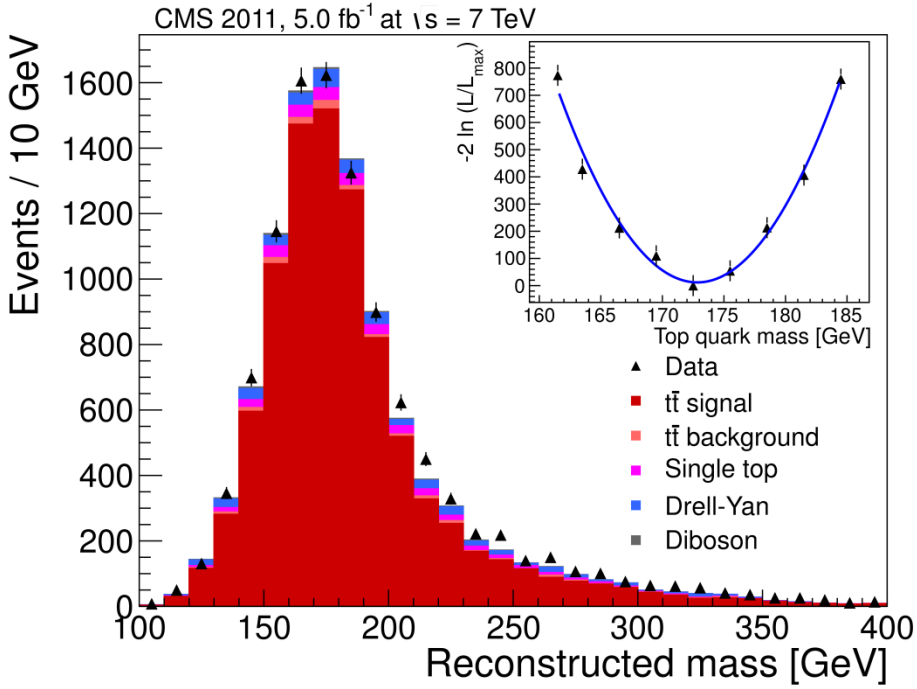
- Under-constrained system due to two neutrinos
- Constraining with help of W-boson and top-quark masses leads to (up to) eight possible solutions
- Scan over top-quark masses from 100 to 600 GeV
  - Repeat this with smeared jets
  - Assign weight for each solution
  - Sum weights of all solutions for each mass hypothesis
  - Use reconstructed mass with highest average weight

Dilepton Top-Quark Mass @ CMS 7 TeV

- AMWT to reconstruct top-quark mass

EPJC72 (2012) 2202

Source	Unc. [GeV]
JES+PU	0.98
bJES+Had	0.76
Detector modelling	0.25
Signal modelling	0.61
Background	0.05
Method	0.40
Syst.	1.46
Stat.	0.43
Total	1.52



11627 events

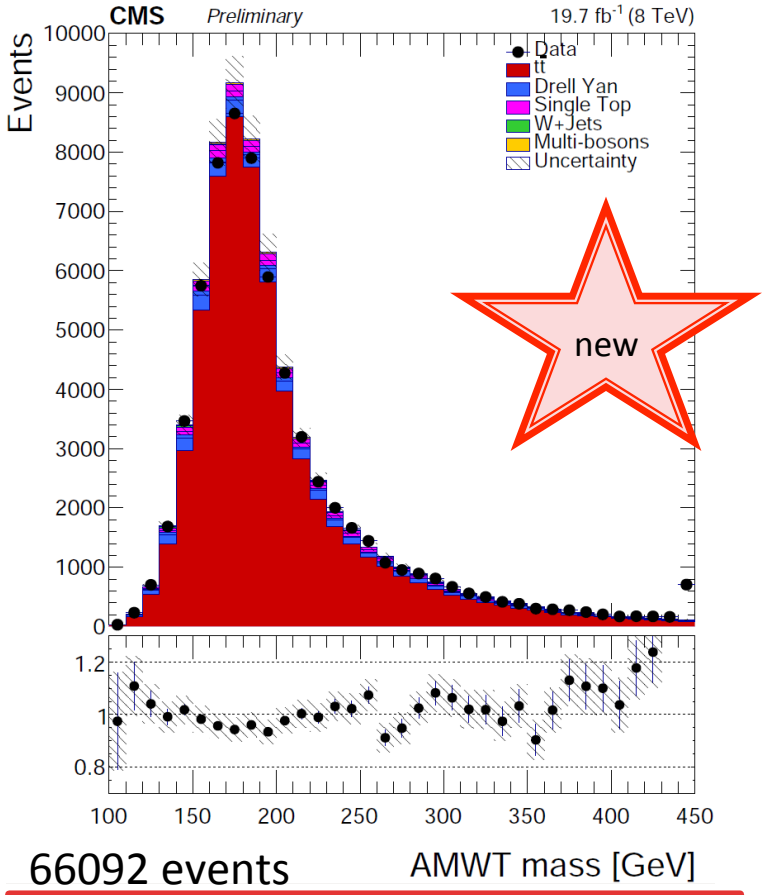
m_t = 172.50 ± 1.52 GeV (0.88%)

Dilepton Top-Quark Mass @ CMS 8 TeV

- AMWT to reconstruct top-quark mass
- Blinded analysis

CMS-PAS-TOP-14-010

Source	Unc. [GeV]
JES+PU	0.69
bJES+Had	0.69
Detector modelling	0.17
Signal modelling	0.99
Background	0.02
Method	0.03
Syst.	1.40
Stat.	0.17
Total	1.41



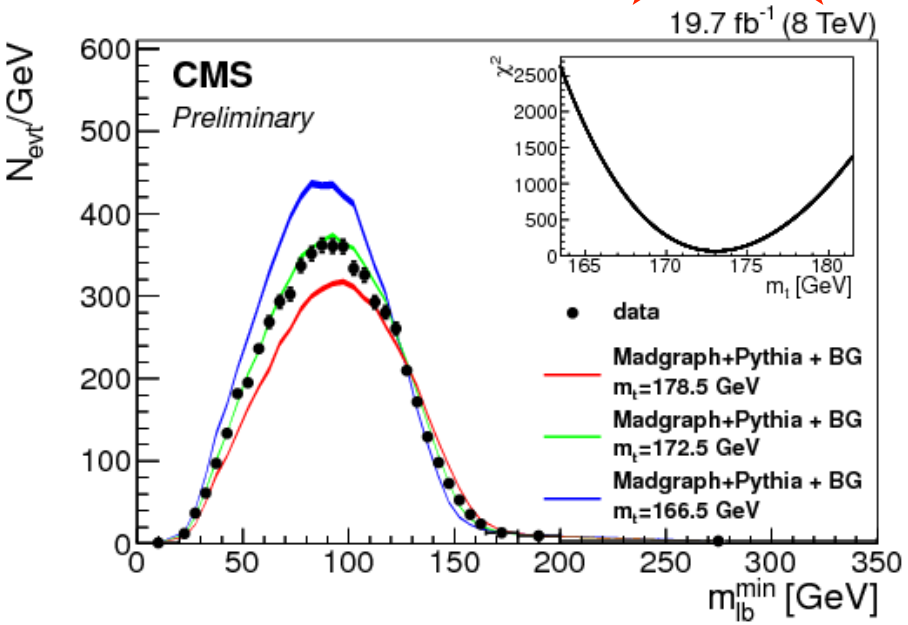
m_t = 172.47 ± 1.41 GeV (0.81%)

Dilepton Top-Quark Mass @ CMS 8 TeV

- Use minimal m_{lb} as top-mass estimator
- Blinded analysis
- Extraction of m_t possible using MCFM
  - Yields: 171.4 ± 1.1 GeV

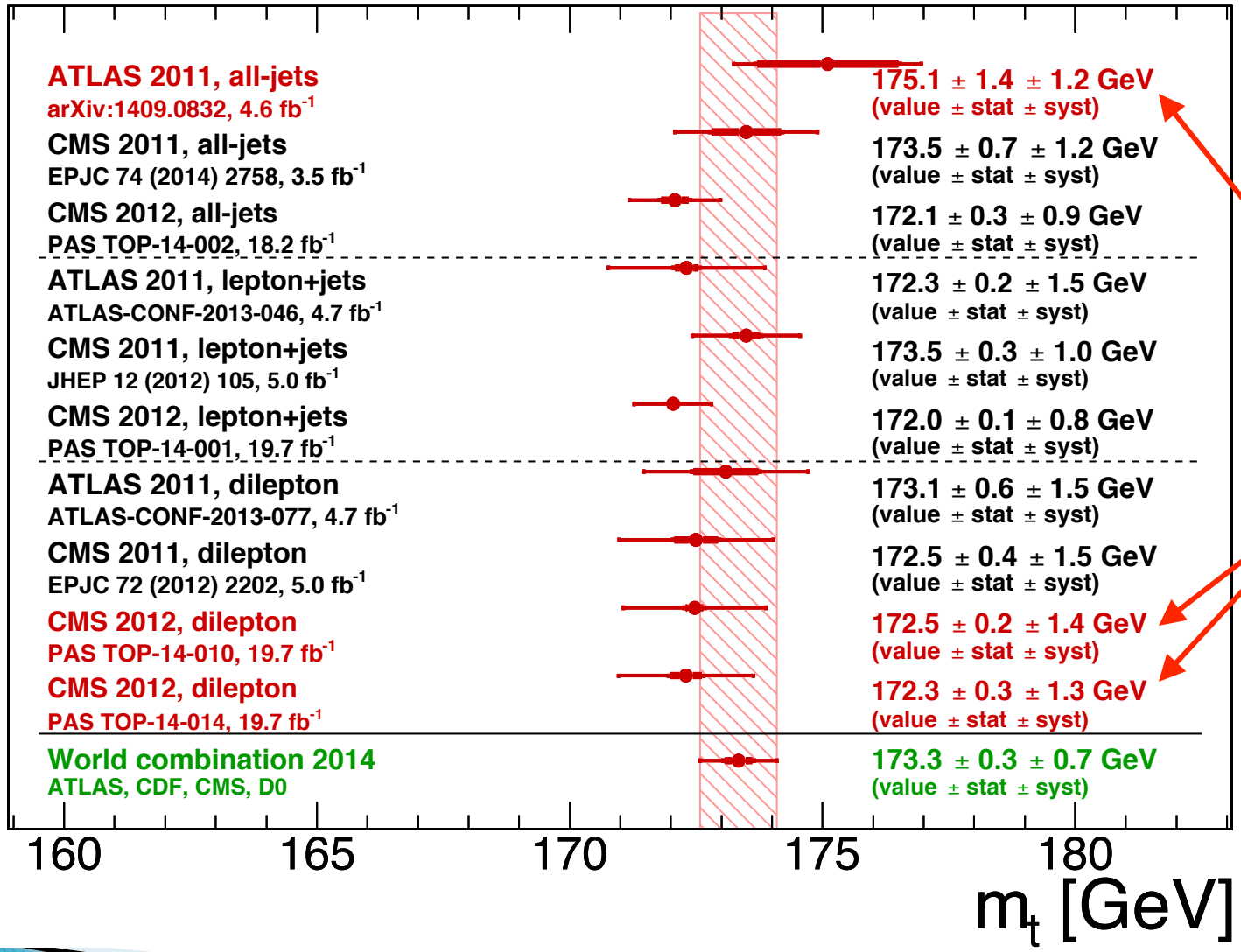
CMS-PAS-TOP-14-014

Source	Unc. [GeV]
JES+PU	0.43
bJES+Had	0.72
Detector modelling	0.31
Signal modelling	0.99
Background	0.12
Method	0.07
Syst.	1.29
Stat.	0.32
Total	1.33



m_t = 172.3 ± 1.33 GeV (0.77%)

Comparison of All Results



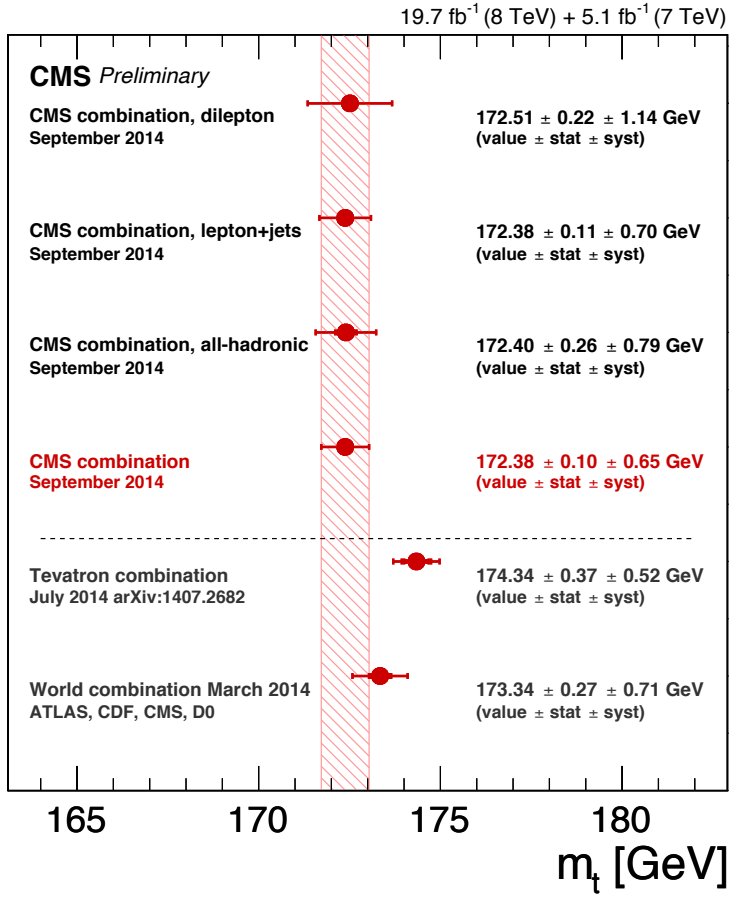
CMS Top-Mass Combination

- Combination of all standard CMS top-mass results
- Consistent between all decay channels

JES+PU: 0.25
JSF: 0.10

Source	Unc. [GeV]
JES+PU+JSF	0.27
bJES+Had	0.39
Detector modelling	0.19
Signal modelling	0.38
Background	0.09
Method	0.05
Syst.	0.65
Stat.	0.10
Total	0.65

CMS-PAS-TOP-14-015



m_t = 172.38 ± 0.65 GeV (0.38%)

Summary

- Precision further increasing for m_t^{MC} at the LHC
  - Reached precision below 1 GeV
- All measurements are systematically limited
  - 7 → 8 TeV @ CMS showed that larger datasets helped to reduce systematic uncertainties
- Combination of results are presented tomorrow
  - See talks by:
    - Giorgio Cortiana (tomorrow 9am, LHC combination)
    - Yvonne Peters (tomorrow 9:30am, Tevatron and world combination)

Back Up

All-Jets Top-Quark Mass @ ATLAS 7 TeV

arXiv:1409.0832

Signal modelling:	Δm_t [GeV]
Method calibration	0.42
Trigger	0.01
Signal MC generator	0.30
Hadronisation	0.50
Fast simulation	0.24
Colour reconnection	0.22
Underlying event	0.08
ISR and FSR	0.22
Proton PDF	0.09
Pile-up	0.02

Background modelling:	Δm_t [GeV]
Multijet background	0.35

Jet measurements:	Δm_t [GeV]
Jet energy scale	0.51
b-jet energy scale	0.62
Jet energy resolution	0.01
Jet reconstruction efficiency	0.01
b-tag efficiency and mistag rate	0.17
Soft contributions to missing energy	0.02
JVF scale factors	0.02

Total systematic uncertainty	1.22

	Δm_t [GeV]
Statistics and method	0.09
Physics modelling	0.31
Detector description	0.36
Mixed detector and modelling	0.05
Single high-p_{T} particle	0.02
Relative non-closure in MC	0.04
Pile-up	0.03
Close-by jets	0.02
Flavour composition and response	0.10

Jet energy scale	0.51
b-jet energy scale	0.62

All-Jets Top-Quark Mass @ CMS 7 TeV

EPJC74 (2014) 2758	1D analysis	2D analysis	
	δ_{m_t} (GeV)	δ_{m_t} (GeV)	δ_{JES}
Fit calibration	**0.13**	**0.14**	**0.001**
Jet energy scale	**0.97** $\pm$ 0.06	0.09 $\pm$ **0.10**	**0.002** $\pm$ 0.001
b-JES	**0.49** $\pm$ 0.06	**0.52** $\pm$ 0.10	**0.001** $\pm$ 0.001
Jet energy resolution	**0.15** $\pm$ 0.06	**0.13** $\pm$ 0.10	**0.003** $\pm$ 0.001
b tagging	0.05 $\pm$ **0.06**	0.04 $\pm$ **0.10**	**0.001** $\pm$ 0.001
Trigger	**0.24** $\pm$ 0.06	**0.26** $\pm$ 0.10	**0.006** $\pm$ 0.001
Pileup	0.05 $\pm$ **0.06**	0.09 $\pm$ **0.10**	**0.001** $\pm$ 0.001
Parton distribution functions	0.03 $\pm$ **0.06**	0.07 $\pm$ **0.10**	**0.001** $\pm$ 0.001
Renormalization and factorization scale	0.08 $\pm$ **0.22**	0.31 $\pm$ **0.34**	**0.005** $\pm$ 0.003
ME-PS matching threshold	**0.24** $\pm$ 0.22	0.29 $\pm$ **0.34**	0.001 $\pm$ **0.003**
Underlying event	**0.20** $\pm$ 0.12	**0.42** $\pm$ 0.20	**0.004** $\pm$ 0.002
Color reconnection effects	0.04 $\pm$ **0.15**	**0.58** $\pm$ 0.25	**0.006** $\pm$ 0.002
Multijet background	**0.13** $\pm$ 0.06	**0.60** $\pm$ 0.10	**0.006** $\pm$ 0.001
Total	1.21	1.23	0.013

All-Jets Top-Quark Mass @ CMS 8 TeV

CMS-PAS-TOP-14-002	δm_t^{2D} (GeV)	δJSF	δm_t^{1D} (GeV)
Experimental uncertainties			
Fit calibration	0.06	<0.001	0.06
p_T- and η-dependent JES	0.28	0.006	0.86
Jet energy resolution	0.10	0.001	0.01
b tagging	0.02	<0.001	<0.01
Pileup	0.31	0.001	0.30
Calorimeter JES of trigger confirmation	0.18	0.003	0.07
Non-$t\bar{t}$ background	0.22	0.002	0.08
Modeling of hadronization			
Flavor-dependent JSF	0.36	0.004	0.30
b fragmentation	0.07	0.001	0.03
Semi-leptonic B hadron decays	0.12	<0.001	0.12
Modeling of the hard scattering process			
PDF	0.02	<0.001	0.01
Renormalization and factorization scales	0.19±0.19	0.004±0.002	0.18±0.14
ME-PS matching threshold	0.20±0.19	0.002±0.002	0.09±0.14
ME generator	0.09±0.21	0.003±0.002	0.17±0.15
Modeling of non-perturbative QCD			
Underlying event	0.13±0.28	0.000±0.002	0.11±0.20
Color reconnection modeling	0.00±0.25	0.000±0.002	0.03±0.18
Total	0.83	0.011	1.05

l+Jets Top-Quark Mass @ ATLAS 7 TeV

ATLAS-CONF-2013-046

	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

l+Jets Top-Quark Mass @ CMS 7 TeV

JHEP 12 (2012) 105	μ+jets		e+jets		ℓ+jets	
	$\delta^{\mu}_{m_t}$ (GeV)	$\delta^{\mu}_{\mathrm{JES}}$	$\delta^{\mathrm{e}}_{m_t}$ (GeV)	$\delta^{\mathrm{e}}_{\mathrm{JES}}$	$\delta^{\ell}_{m_t}$ (GeV)	$\delta^{\ell}_{\mathrm{JES}}$
Fit calibration	0.08	0.001	0.09	0.001	0.06	0.001
b-JES	0.60	0.000	0.62	0.000	0.61	0.000
p_{T}- and η-dependent JES	0.30	0.001	0.28	0.001	0.28	0.001
Lepton energy scale	0.03	0.000	0.04	0.000	0.02	0.000
Missing transverse momentum	0.05	0.000	0.07	0.000	0.06	0.000
Jet energy resolution	0.22	0.004	0.24	0.004	0.23	0.004
b tagging	0.11	0.001	0.15	0.001	0.12	0.001
Pileup	0.07	0.002	0.08	0.001	0.07	0.001
Non-$\mathrm{t\bar{t}}$ background	0.10	0.001	0.16	0.000	0.13	0.001
Parton distribution functions	0.07	0.001	0.07	0.001	0.07	0.001
Renormalization and factorization scales	0.23	0.004	0.41	0.005	0.24	0.004
ME-PS matching threshold	0.17	0.000	0.15	0.001	0.18	0.001
Underlying event	0.26	0.002	0.24	0.001	0.15	0.002
Color reconnection effects	0.66	0.004	0.39	0.003	0.54	0.004
Total	1.06	0.008	1.00	0.007	0.98	0.008

l+Jets Top-Quark Mass @ CMS 8 TeV

CMS-PAS-TOP-14-001	δm_t^{2D} (GeV)	δJSF	δm_t^{1D} (GeV)
Experimental uncertainties			
Fit calibration	0.10	0.001	0.06
p_T- and η-dependent JES	0.18	0.007	1.17
Lepton energy scale	0.03	<0.001	0.03
MET	0.09	0.001	0.01
Jet energy resolution	0.26	0.004	0.07
b tagging	0.02	<0.001	0.01
Pileup	0.27	0.005	0.17
Non-$t\bar{t}$ background	0.11	0.001	0.01
Modeling of hadronization			
Flavor-dependent JSF	0.41	0.004	0.32
b fragmentation	0.06	0.001	0.04
Semi-leptonic B hadron decays	0.16	<0.001	0.15
Modeling of the hard scattering process			
PDF	0.09	0.001	0.05
Renormalization and factorization scales	0.12±0.13	0.004±0.001	0.25±0.08
ME-PS matching threshold	0.15±0.13	0.003±0.001	0.07±0.08
ME generator	0.23±0.14	0.003±0.001	0.20±0.08
Modeling of non-perturbative QCD			
Underlying event	0.14±0.17	0.002±0.002	0.06±0.10
Color reconnection modeling	0.08±0.15	0.002±0.001	0.07±0.09
Total	0.75	0.012	1.29

Dilepton Top-Quark Mass @ ATLAS 7 TeV

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

ATLAS-CONF-2013-077

Dilepton Top-Quark Mass @ CMS 7 TeV

EPJC72 (2012) 2202

Source	Δm_t (GeV)
Jet energy scale	$^{+0.90}_{-0.97}$
b-jet energy scale	$^{+0.76}_{-0.66}$
Jet energy resolution	± 0.14
Lepton energy scale	± 0.14
Unclustered E_T^{miss}	± 0.12
b-tagging efficiency	± 0.05
Mistag rate	± 0.08
Fit calibration	± 0.40
Background normalization	± 0.05
Matching scale	± 0.19
Renormalisation and factorisation scale	± 0.55
Pileup	± 0.11
PDFs	± 0.09
Underlying event	± 0.26
Colour reconnection	± 0.13
Monte Carlo generator	± 0.04
Total	± 1.48

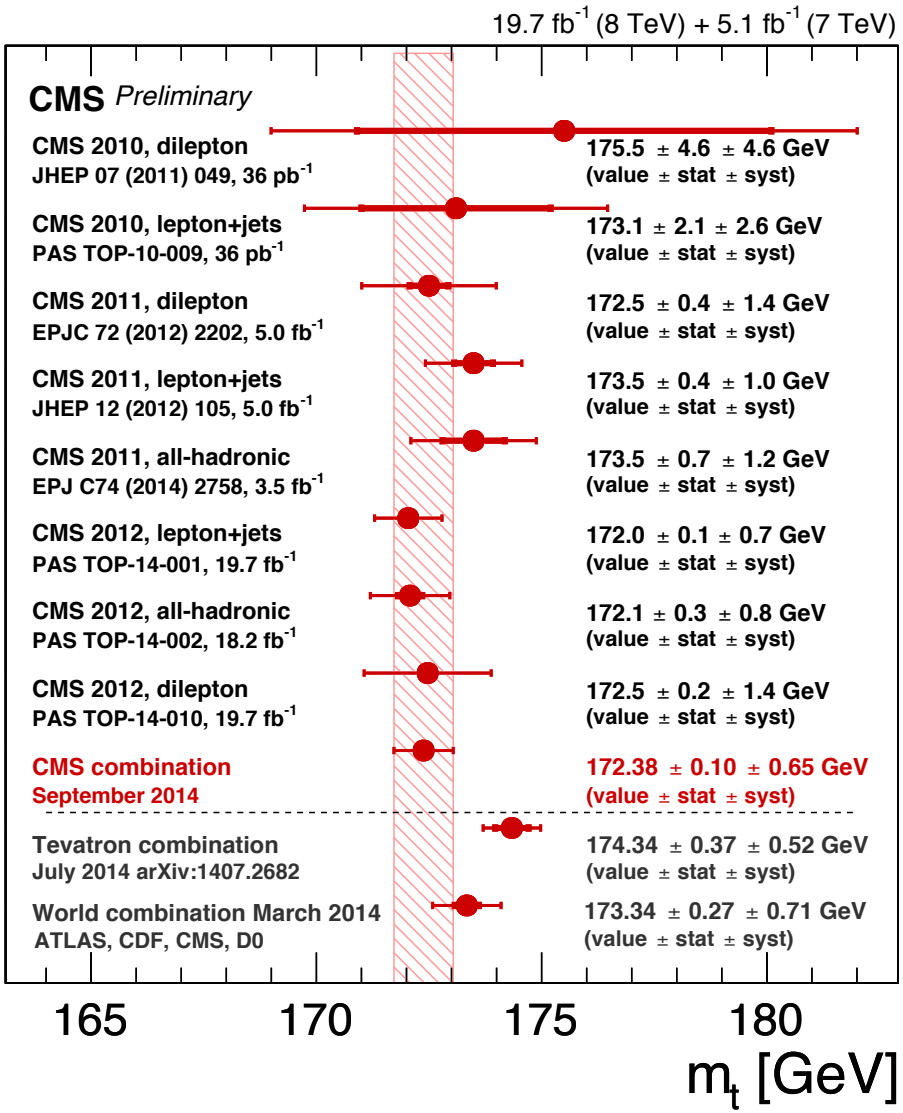
Dilepton Top-Quark Mass @ CMS 8 TeV

CMS-PAS-TOP-14-010

Source of uncertainty	δm_t(GeV)
Experimental uncertainties	
Fit calibration	0.03
p_T- and η-dependent JES	0.61
Lepton energy scale	0.12
Unclustered $\not{E}_T$	0.07
Jet energy resolution	0.09
b tagging	0.04
Pile-up	0.15
Non-$t\bar{t}$ background	0.02
Modeling of hadronization	
Flavor-dependent jet energy scale	0.28
b fragmentation	0.67
Semi-leptonic B hadron decays	0.18
Modeling of the hard scattering process	
PDF	0.18
Renormalization and factorization scales	0.87
ME-PS matching threshold	0.13
ME generator	0.37
Modeling of non-perturbative QCD	
Underlying event	0.04
Color reconnection modeling	0.16
Total	1.40

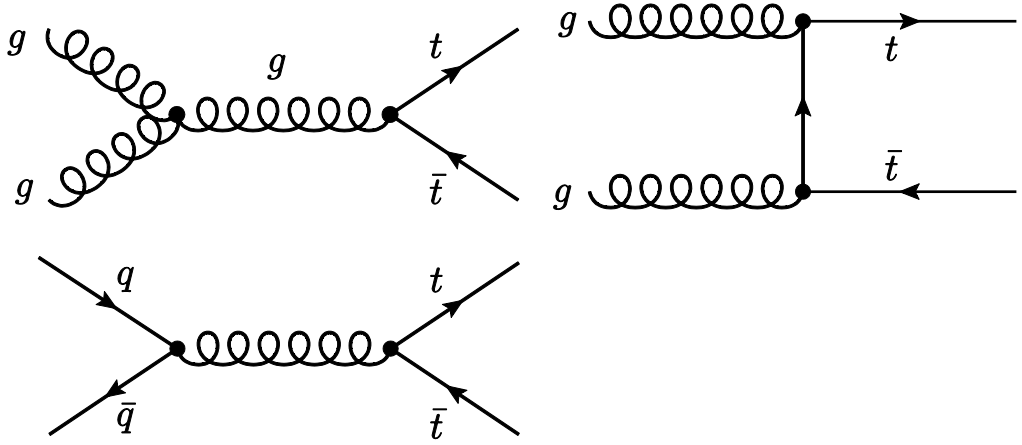
CMS Top-Mass Combination

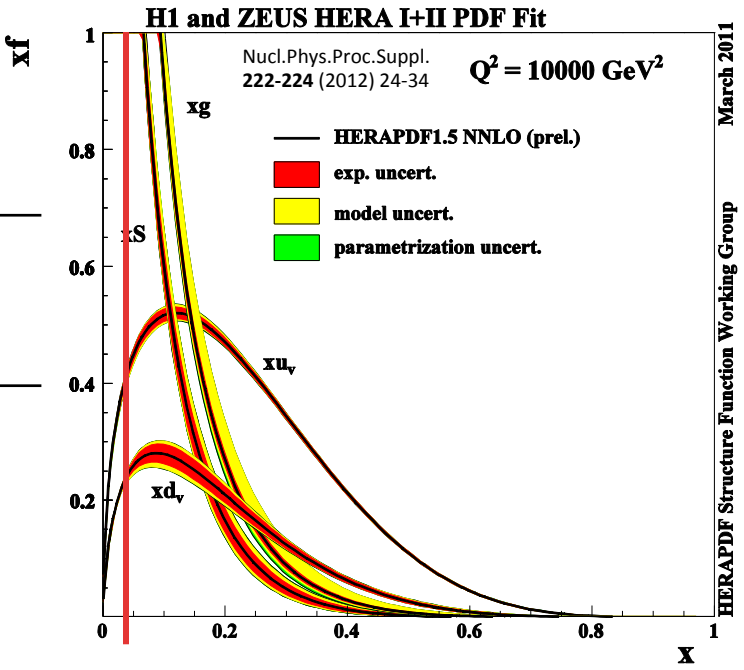
CMS-PAS-TOP-14-015



Top Quark – Production

- Mainly produced in pairs via fusion of 2 gluons due to PDFs ($x_1 x_2 \approx 0.04^2$ at LHC)
- Cross section (NNLO, Phys.Rev.Lett **110** (2013) 252004):
  - @7 TeV: 172 ± 8 pb
  - @8 TeV: 246 ± 11 pb





Ideogram Method

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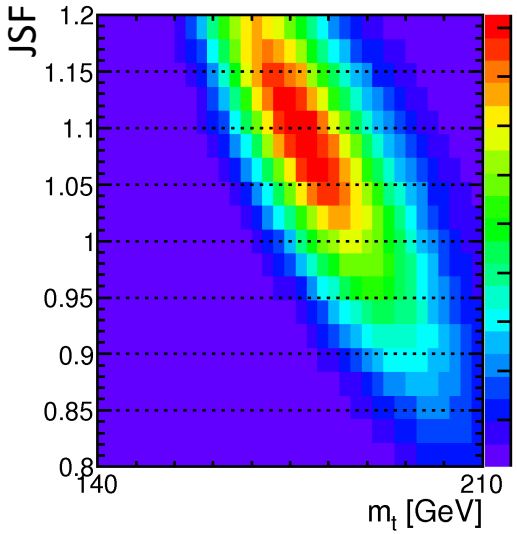
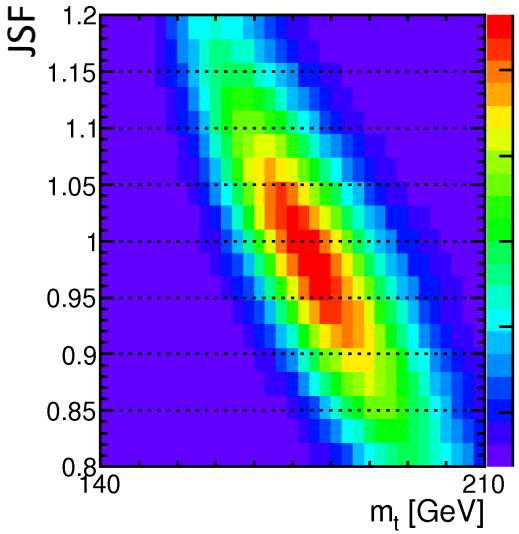


x



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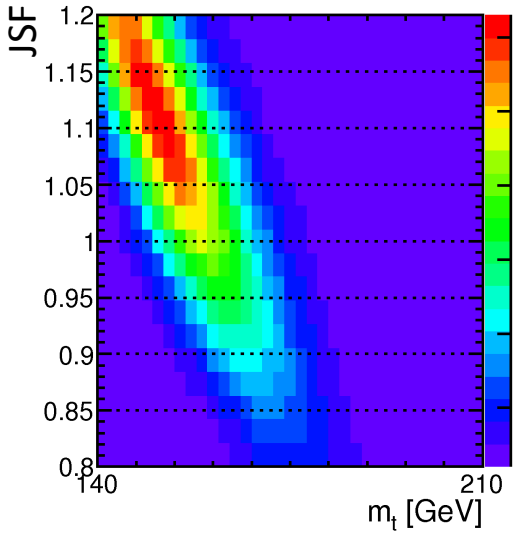

x ...) =