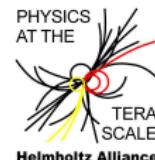


Measurement of the top-quark mass in lepton+jets final states at CMS

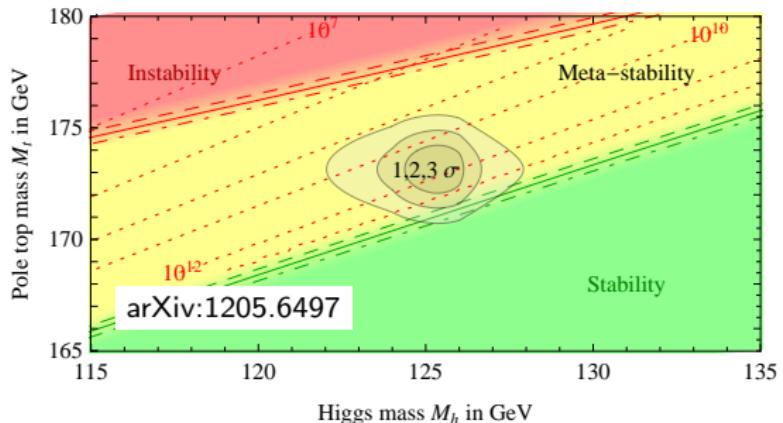
Peter Schleper, Markus Seidel, Hartmut Stadie

Universität Hamburg

Aug 29, 2014



Measuring the top-quark mass at the LHC



- **Motivation:** m_t is an important parameter of the Standard Model
- **Preconditions:**
5M $t\bar{t}$ events at CMS in 2012 (8 TeV)
- **Challenge:** Treatment of systematic uncertainties below 1 GeV

Measurement of the top-quark mass in lepton+jets final states

Henning Kieser, Peter Schleper, Markus Seidel, Hartmut Stöde

Abstract

- Top-quark mass measured in lepton+jets events
- Used $\sqrt{s} = 8$ TeV pp collision, 20.7 fb^{-1}
- Analysis based on $t\bar{t}$ hypothesis
- Simultaneous fit of m_t and jet scale factor (JSF) from reconstructed W boson mass
- Likelihood method takes into account multiple interpretations per event
- Studies of kinematic dependence

Event selection

- One isolated muon or electron with $p_T > 20$ GeV, veto additional isolated leptons
- At least four jets (anti- k_t , $R = 0.5$) with $p_T > 20$ GeV
- Exactly 2 b-tags among 4 leading jets

Event reconstruction

- Associate the 4 leading jets to quarks from $t\bar{t}$ decay, taking into account b-tag information
- 3 different types of $t\bar{t}$ permutations found via jet-parton matching in simulation:
 - correct: $\ell_{\text{tag}} = 33\%$: Best mass information
 - wrong: $\ell_{\text{tag}} = 18\%$: Flipped b-quarks, mistag
 - unmatched: $\ell_{\text{tag}} = 71\%$: Matching failed

Kinematic fit

- Improve ℓ_{tag} with constrained kinematic fit ($m_W = 80.4$ GeV, $m = m_t$), $P_{\text{jet}} > 0.2$
- Selected sample contains 98% $t\bar{t}$ events
- Fraction of correct $t\bar{t}$ permutations enhanced: $\ell_{\text{tag}} = 13\% \rightarrow 44\%$ (weighted by P_{jet})

Documentation

Funding by

Analysis contact

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Histogram method

- Fit simulated m_t , JSF distributions with analytic expressions
- Parameterize linearly in m_t , JSF, $m_t \times \text{JSF}$

Calibration

- 10000 pseudo-experiments for every generated m_t , JSF combination
- Correct for all biases
- Validate statistical uncertainty

Systematic uncertainties

Result on data

$m_t = 172.04 \pm 0.19 \text{ (stat+JSF)} \pm 0.75 \text{ (sys) GeV}$

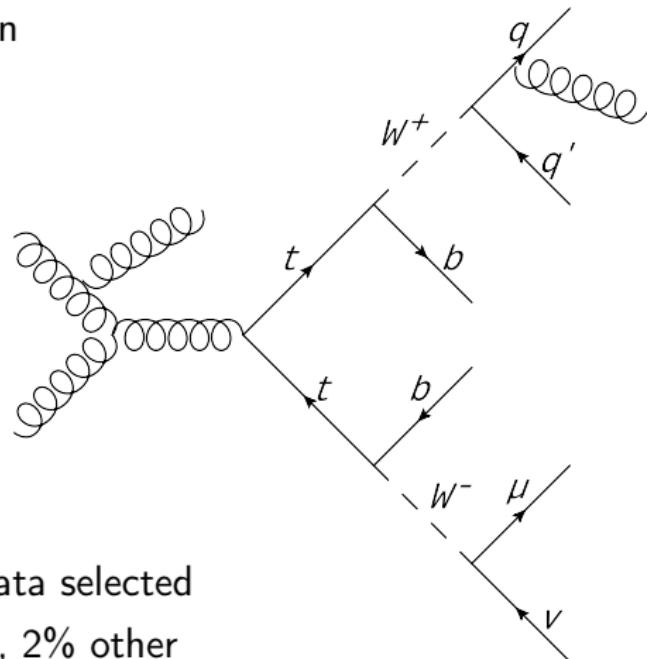
Result in dependency of kinematic observables

No significant deviations from simulation → Measured m_t constant over phase-space

Thank you for voting!

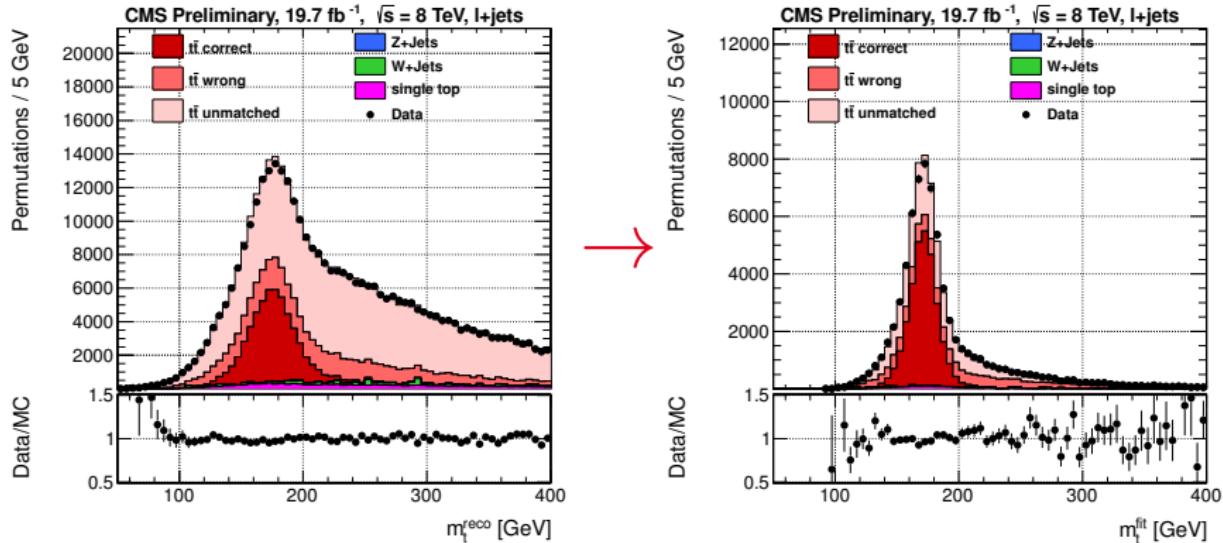
Event selection: lepton+jets final state

- Trigger for isolated muon or electron ($p_T > 24/27 \text{ GeV}$)
- Exactly 1 isolated lepton with $p_T > 33 \text{ GeV}$, $|\eta| < 2.1$ (veto additional isolated e, μ)
- ≥ 4 “particle flow” jets (anti- k_t , $R = 0.5$) with $p_T > 30 \text{ GeV}$, $|\eta| < 2.4$
- ≥ 2 jets b-tagged among the 4 leading jets
- 108 205 events in 19.7 fb^{-1} 2012 data selected
- 94% $t\bar{t}$, 4% single-top, 2% W+jets, 2% other



Event reconstruction

- Assign 4 leading jets to partons from $t\bar{t}$ decay, 2 b-jet assignments
- Perform constrained kinematic fit ($m_W = 80.4$ GeV, $m_t = m_{\bar{t}}$)

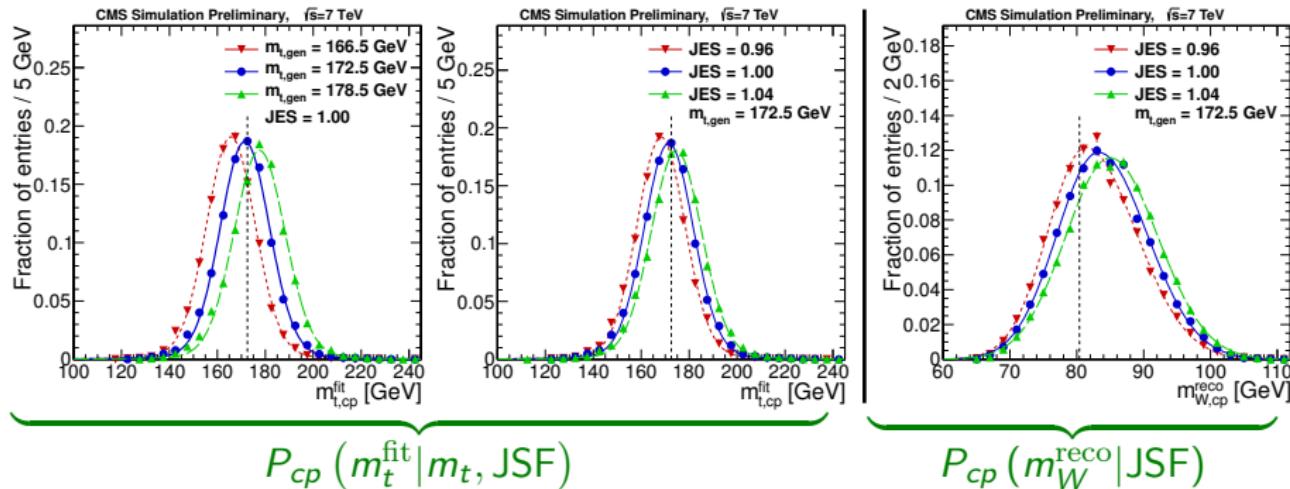


- Select $P_{gof} > 0.2 \rightarrow 28750$ events in 19.7 fb^{-1} 8 TeV data,
96.4% $t\bar{t}$, 2.2% single-top, 1.2% W+jets, 0.2% other
- $t\bar{t}$ composition: 42.0% correct, 20.8% wrong, 37.1% unmatched

Ideogram method: probability densities

- Simulated samples with
 - 7 different top masses: 166.5–178.5 GeV
(MadGraph+MadSpin+Pythia6 Z2*, 246M events in total)
 - 3 different JSF: 0.96, 1.00, 1.04 (scaled jet energies in simulation)
- Fit $m_t^{\text{fit}}, m_W^{\text{reco}}$ distributions with analytical expressions
- Parametrize linearly in $m_t, \text{JSF}, m_t \times \text{JSF}$

Example: correct permutations



Ideogram method

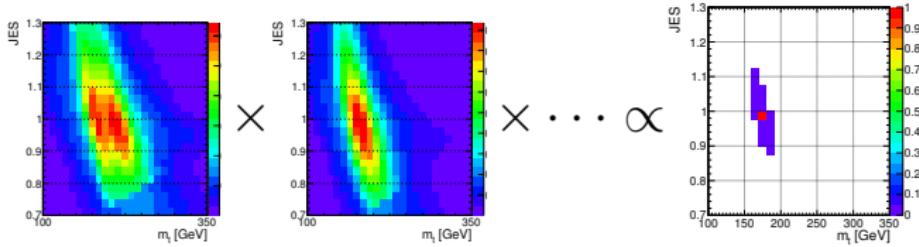
- Calculate likelihood for event with n permutations, j denotes *correct*, *wrong* and *unmatched* permutations

$$\begin{aligned}\mathcal{L}(\text{event}|m_t, \text{JSF}) &= \sum_{i=0}^n P_{\text{gof}}(i) P\left(m_{t,i}^{\text{fit}}, m_{W,i}^{\text{reco}}|m_t, \text{JSF}\right), \\ P\left(m_{t,i}^{\text{fit}}, m_{W,i}^{\text{reco}}|m_t, \text{JSF}\right) &= \sum_j f_j P_j\left(m_{t,i}^{\text{fit}}|m_t, \text{JSF}\right) \cdot P_j\left(m_{W,i}^{\text{reco}}|m_t, \text{JSF}\right)\end{aligned}$$

- Most likely m_t^{2D} and JSF by maximizing

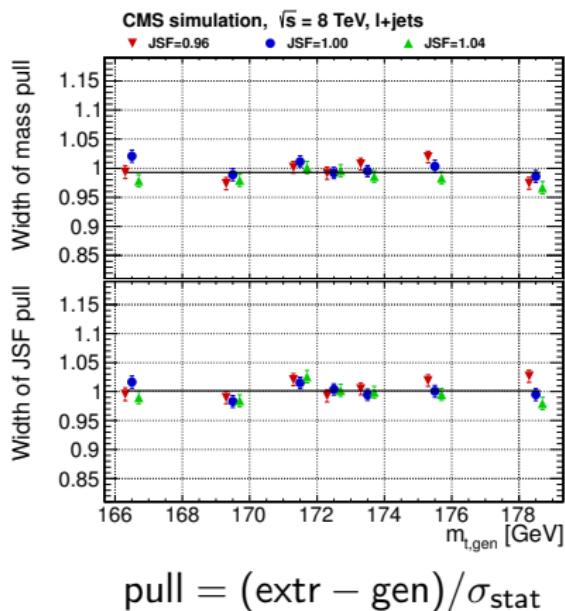
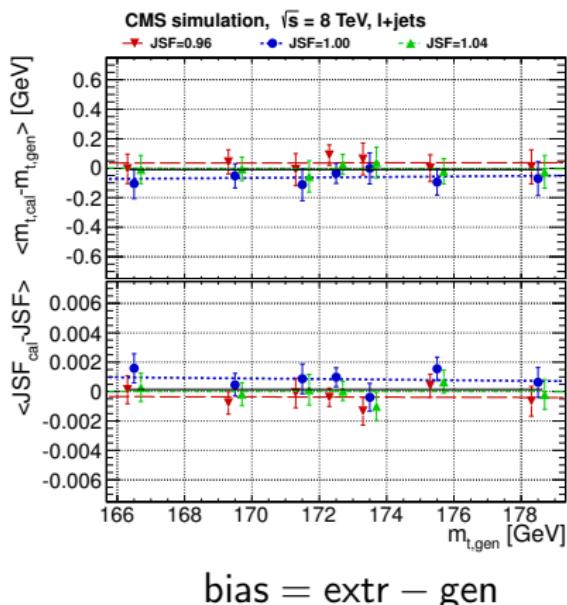
$$\mathcal{L}(m_t, \text{JSF}|\text{sample}) \propto \prod_{\text{events}} \mathcal{L}(\text{event}|m_t, \text{JSF})^{w_{\text{event}}}$$

- Can also obtain m_t^{1D} from $\mathcal{L}(m_t, \text{JSF} = 1|\text{sample})$



Calibration and validation

- 10 000 pseudo-experiments for every generated m_t -JSF combination
- Validation plots after small corrections ($< 1 \text{ GeV}/1\%$)
- Expected statistical uncertainty: 0.188 GeV



Systematic uncertainties

	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 JES	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
μ_R and μ_F 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	0.08±0.15	0.002±0.001	0.07±0.09
Total	0.75	0.012	1.29

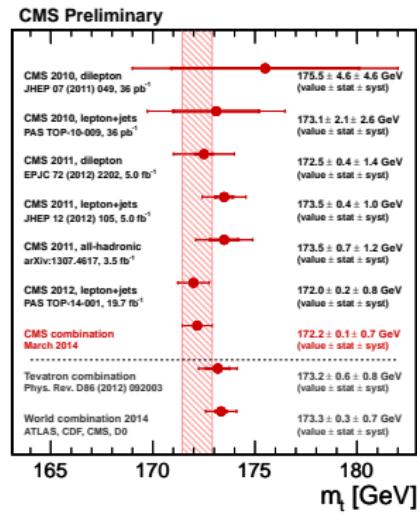
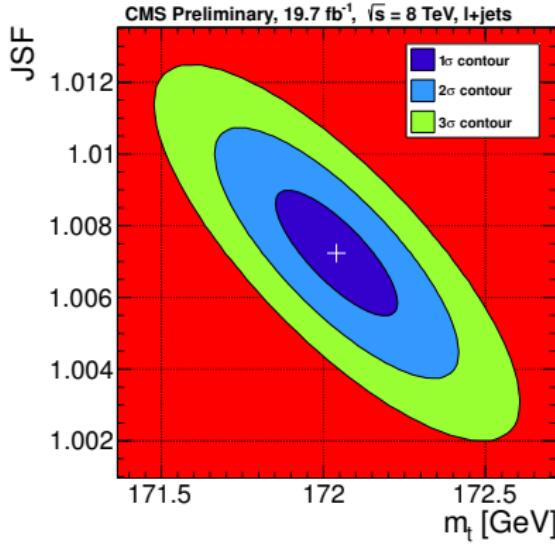
- Uncertainty reduced by 41.9% wrt to “1D” measurement
- Uncertainty reduced by 23.5% wrt to 7 TeV measurement
(new flavour studies, larger simulated samples)

Top-quark mass result

$$m_t = 172.04 \pm 0.19 \text{ (stat+JSF)} \pm 0.75 \text{ (syst) GeV}$$

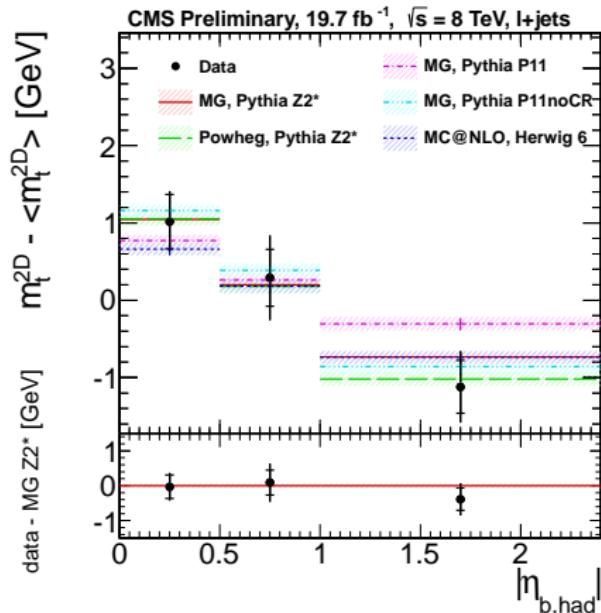
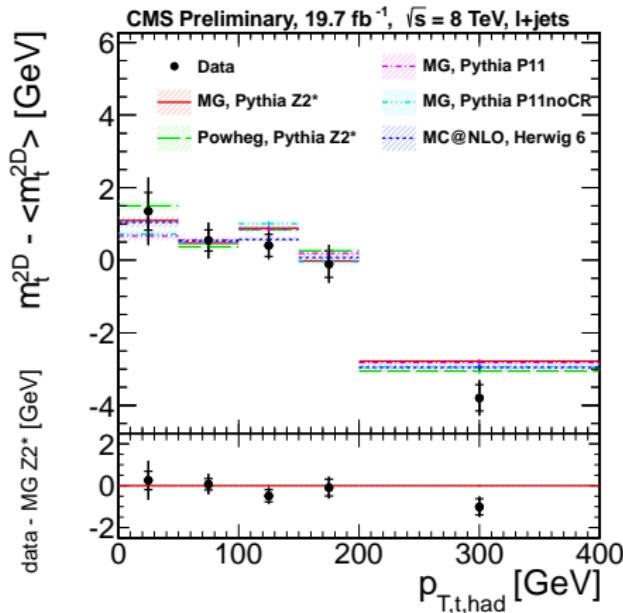
$$\text{JSF} = 1.007 \pm 0.002 \text{ (stat)} \pm 0.012 \text{ (syst)}$$

$$m_t^{1D} = 172.66 \pm 0.11 \text{ (stat)} \pm 1.29 \text{ (syst) GeV}$$



Measurement of dependency on event kinematics

- Measure on **subsets** depending on kinematics observables
- Compare to models, data-MC difference should be flat



- Tested 14 observables, compared data vs. MadGraph+Pythia Z2*
 $m_t^{2D} \chi^2/\text{ndf} = 35.85/47 \rightarrow P(\chi^2, \text{ndf}) = 0.88$

Summary

- Measured the top-quark mass at 8 TeV:

$$\begin{aligned}m_t^{\text{2D}} &= 172.04 \pm 0.19 \text{ (stat+JSF)} \pm 0.75 \text{ (syst) GeV} \\ \text{JSF} &= 1.007 \pm 0.002 \text{ (stat)} \pm 0.012 \text{ (syst)}\end{aligned}$$

- Measurement of dependency on event kinematics

- No significant deviations from simulation
 - Measured m_t constant over phase-space

Documentation

- Public document CMS PAS TOP-14-001