Measurement of the top-quark mass

in lepton+jets final states at CMS

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Bundesministerium
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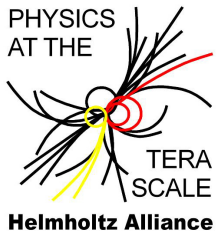
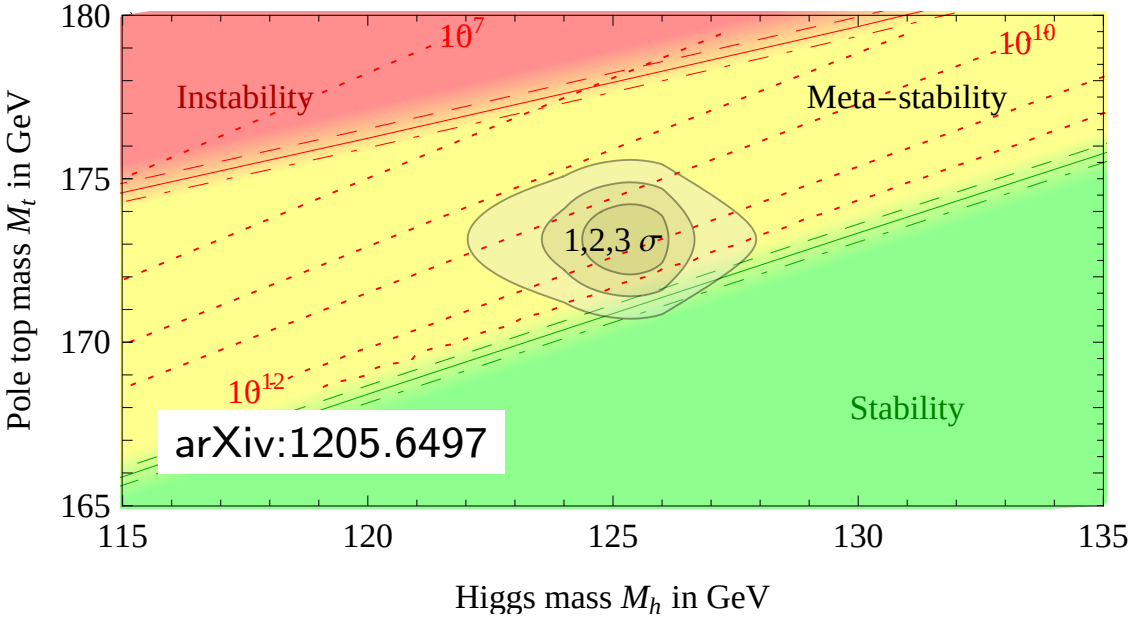
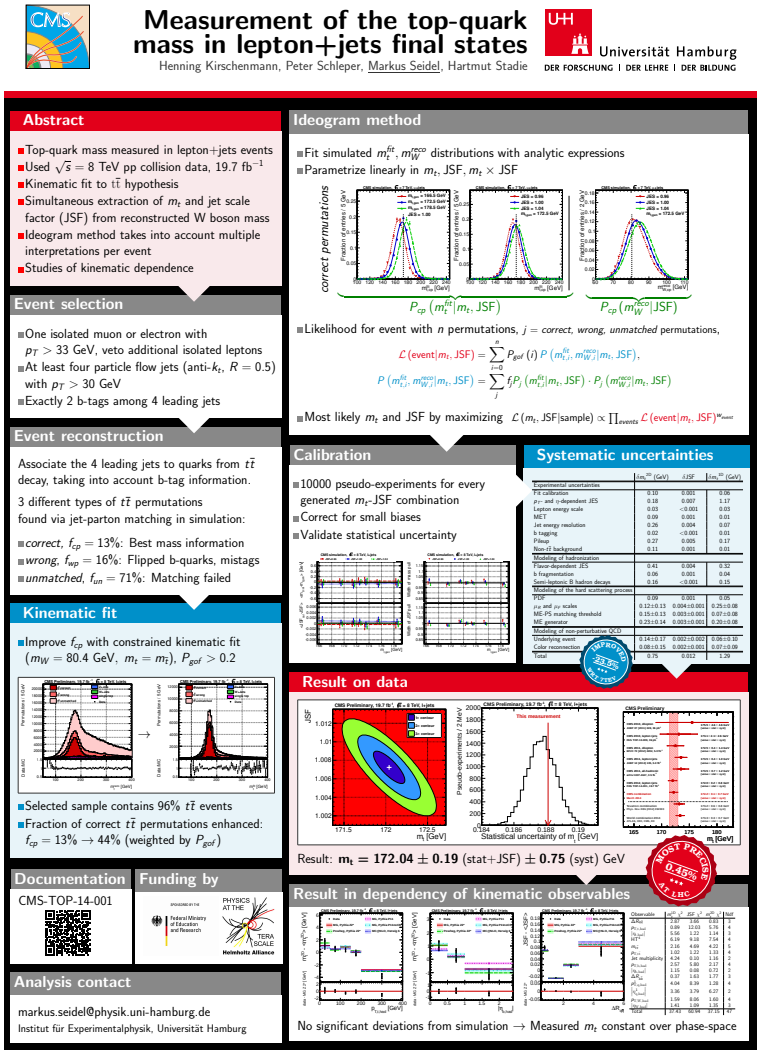


Helmholtz Alliance

Measuring the top-quark mass at the LHC



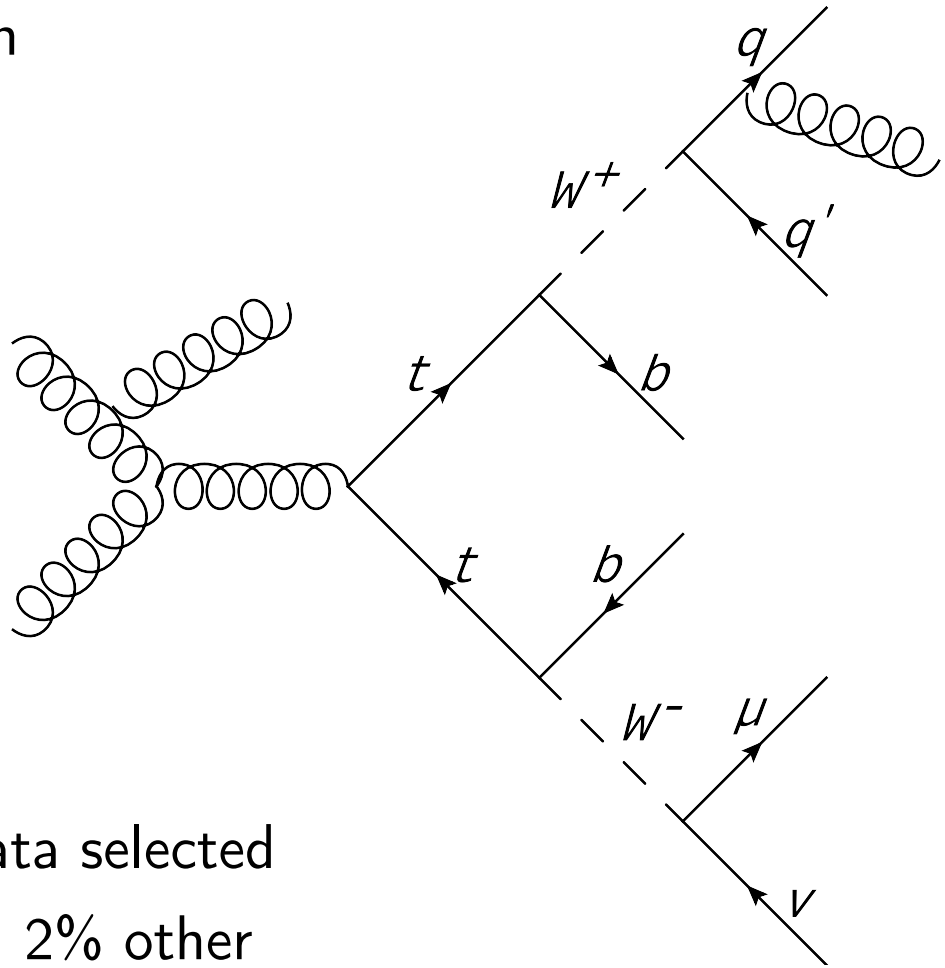
- Motivation: m_t is an important parameter of the Standard Model
- Preconditions:
  5M $t\bar{t}$ events at CMS in 2012 (8 TeV)
- Challenge: Treatment of systematic uncertainties below 1 GeV



Thank you for voting!

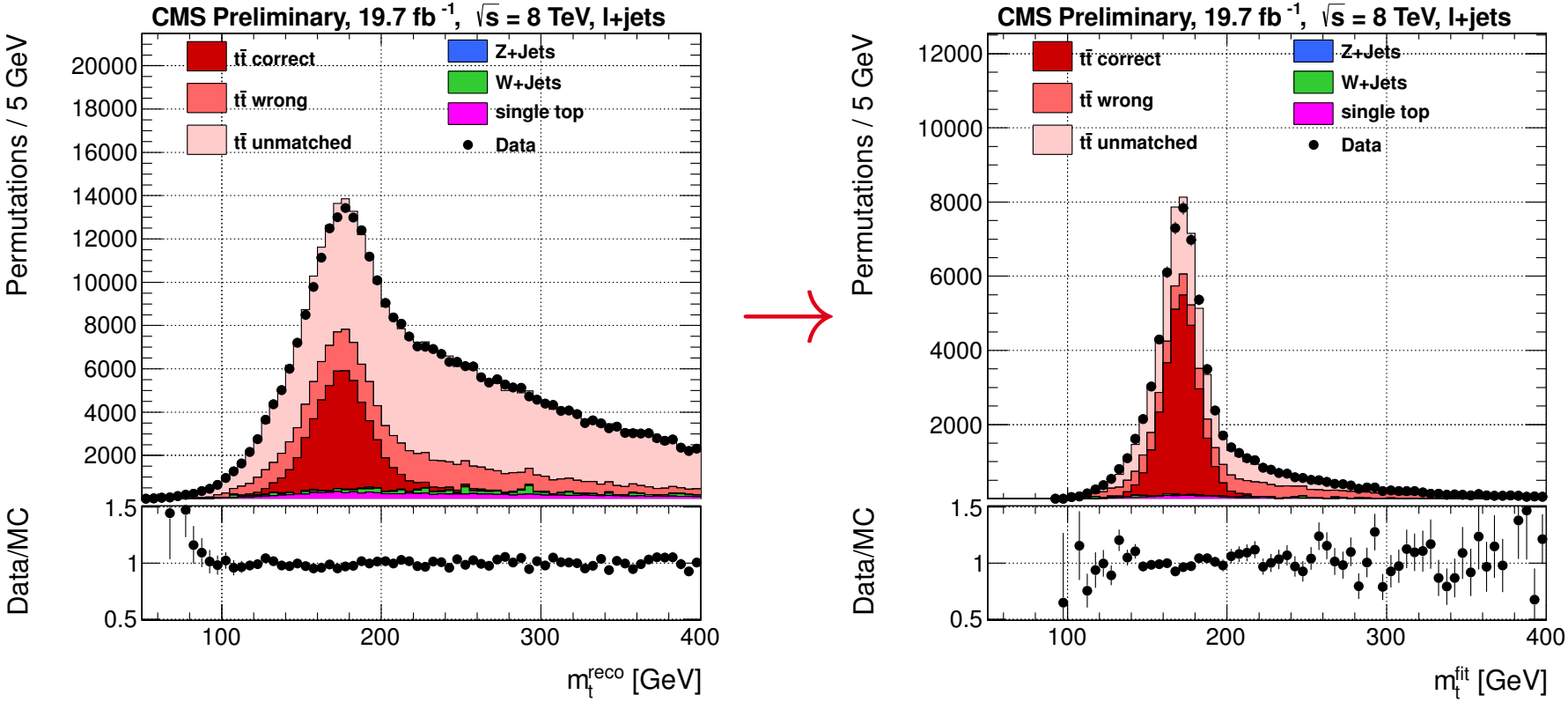
Event selection: lepton+jets final state

- Trigger for isolated muon or electron ($p_T > 24/27$ GeV)
- Exactly 1 isolated lepton with $p_T > 33$ GeV, $|\eta| < 2.1$ (veto additional isolated e, μ)
- ≥ 4 "particle flow" jets (anti-k_t, $R = 0.5$) with $p_T > 30$ 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, $m_t = m_{\bar{t}}$)

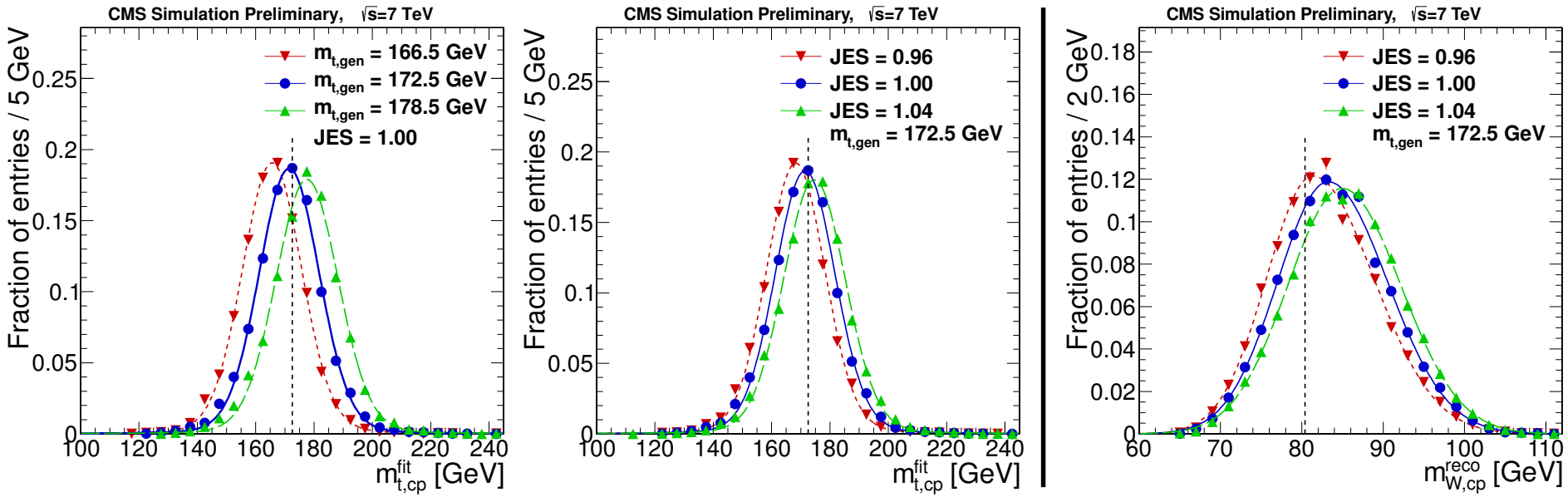


- Select $P_{gof} > 0.2 \rightarrow$ 28 750 events in 19.7 fb^{-1} 8 TeV data, 96.4% $t\bar{t}$, 2.2% single-top, 1.2% W+jets, 0.2% other
- $t\bar{t}$ composition: 42.0% correct, 20.8% wrong, 37.1% unmatched

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^{fit}, m_W^{reco} distributions with analytical expressions
- Parametrize linearly in m_t, JSF, $m_t \times$ JSF

Example: *correct permutations*



$P_{cp}\left(m_t^{\mathrm{fit}} | m_t, \mathrm{JSF}\right)$ $\qquad$ $P_{cp}\left(m_W^{\mathrm{reco}} | \mathrm{JSF}\right)$

Ideogram method

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

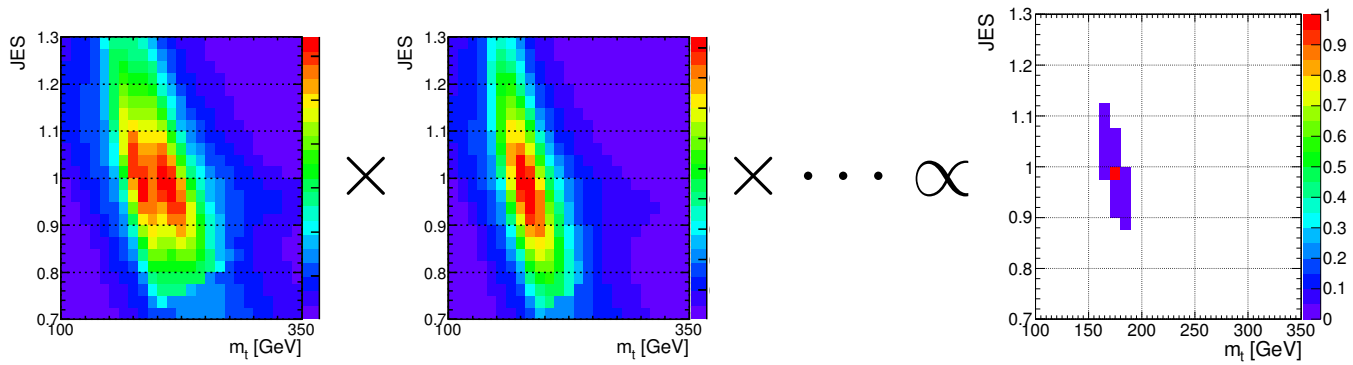
$$\mathcal{L}\left(\text{event}|m_t, \text{JSF}\right) = \sum_{i=0}^{n} P_{gof}\left(i\right) P\left(m_{t,i}^{fit}, m_{W,i}^{reco}|m_t, \text{JSF}\right),$$

$$P\left(m_{t,i}^{fit}, m_{W,i}^{reco}|m_t, \text{JSF}\right) = \sum_{j} f_j P_j\left(m_{t,i}^{fit}|m_t, \text{JSF}\right) \cdot P_j\left(m_{W,i}^{reco}|m_t, \text{JSF}\right)$$

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

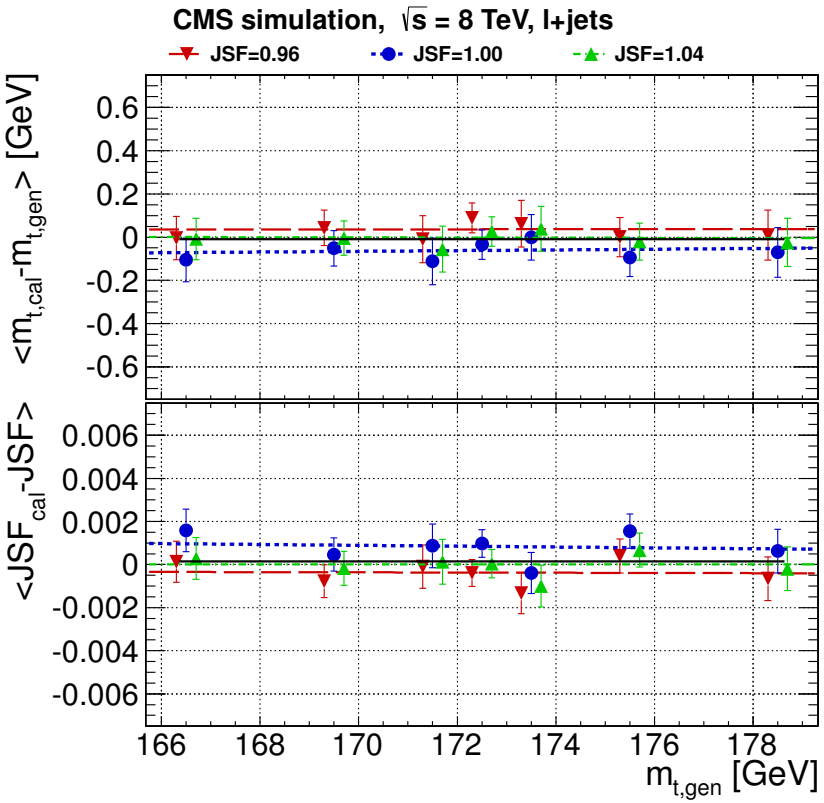
$$\mathcal{L}\left(m_t, \text{JSF}|\text{sample}\right) \propto \prod_{\text{events}} \mathcal{L}\left(\text{event}|m_t, \text{JSF}\right)^{w_{\text{event}}}$$

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

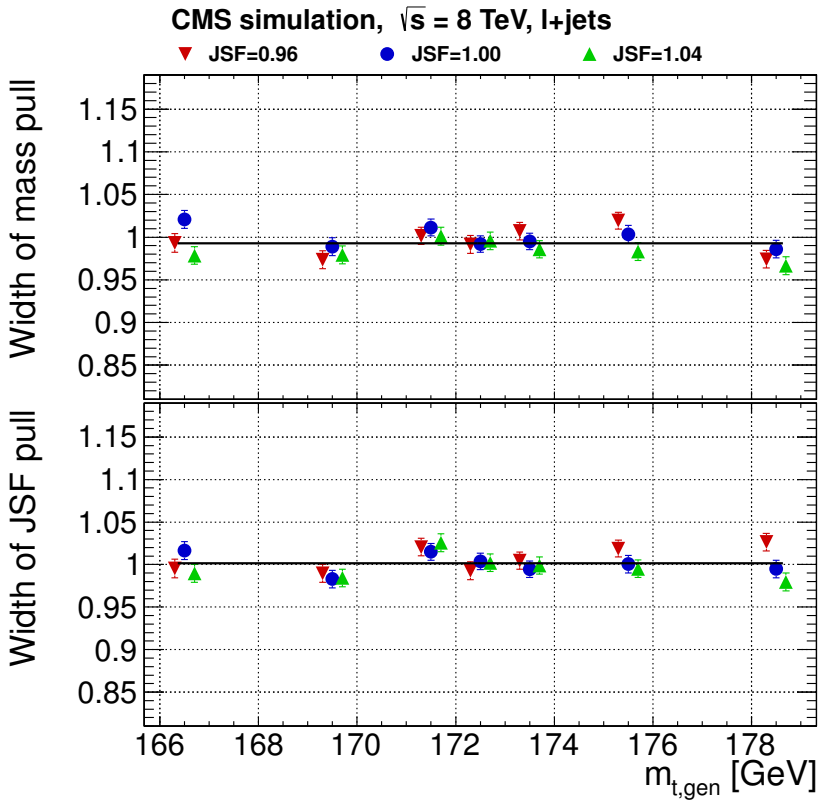


Calibration and validation

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



$$\text{bias} = \text{extr} - \text{gen}$$



$$\text{pull} = (\text{extr} - \text{gen})/\sigma_{\text{stat}}$$

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	$<$0.001	0.15
Modeling of the hard scattering process			
PDF	0.09	0.001	0.05
μ_R and μ_F scales	0.12$\pm$0.13	0.004$\pm$0.001	0.25$\pm$0.08
ME-PS matching threshold	0.15$\pm$0.13	0.003$\pm$0.001	0.07$\pm$0.08
ME generator	0.23$\pm$0.14	0.003$\pm$0.001	0.20$\pm$0.08
Modeling of non-perturbative QCD			
Underlying event	0.14$\pm$0.17	0.002$\pm$0.002	0.06$\pm$0.10
Color reconnection	0.08$\pm$0.15	0.002$\pm$0.001	0.07$\pm$0.09
Total	0.75	0.012	1.29

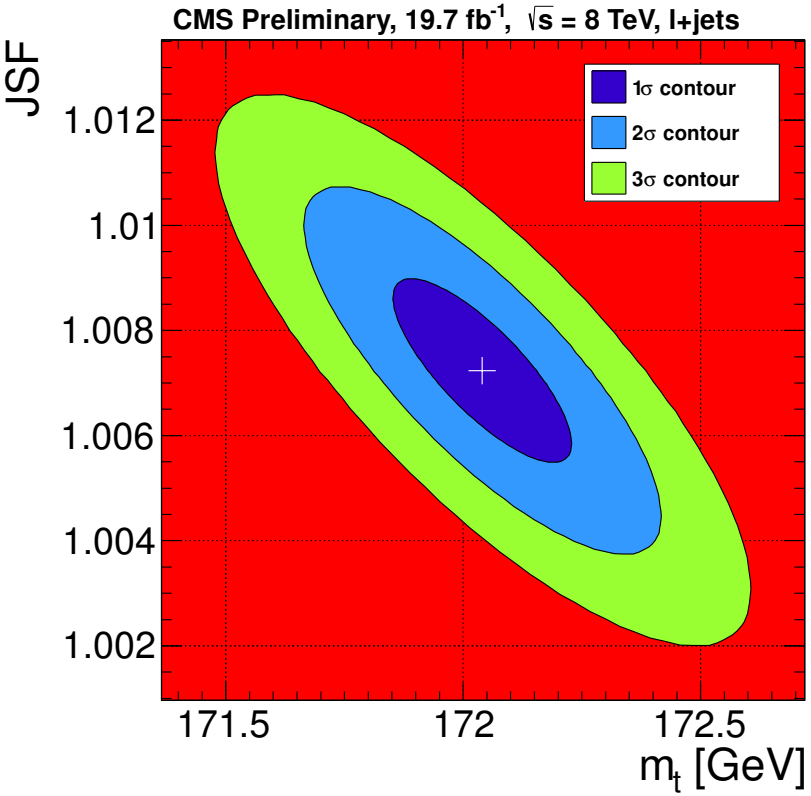
- Uncertainty reduced by 41.9% wrt to "1D" measurement
- Uncertainty reduced by 23.5% wrt to 7 TeV measurement (new flavour studies, larger simulated samples)

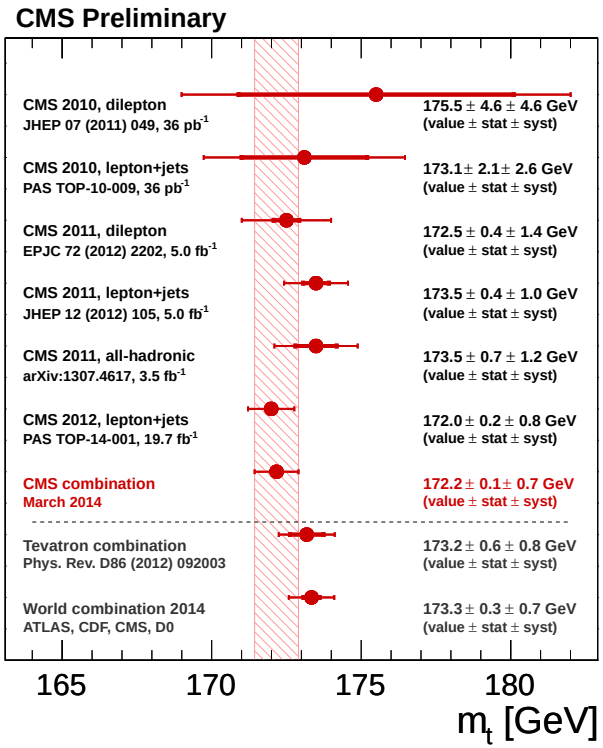
Top-quark mass result

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

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

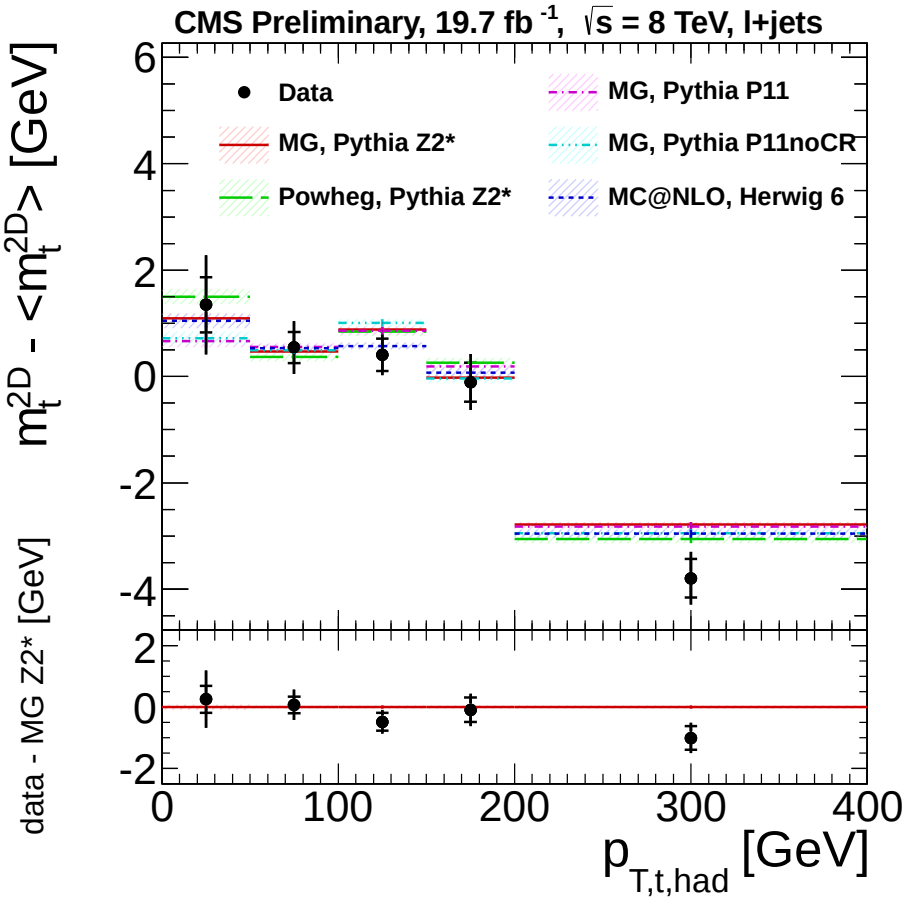
$$m_t^{\text{1D}} = 172.66 \pm 0.11\ (\text{stat}) \pm 1.29\ (\text{syst})\ \text{GeV}$$

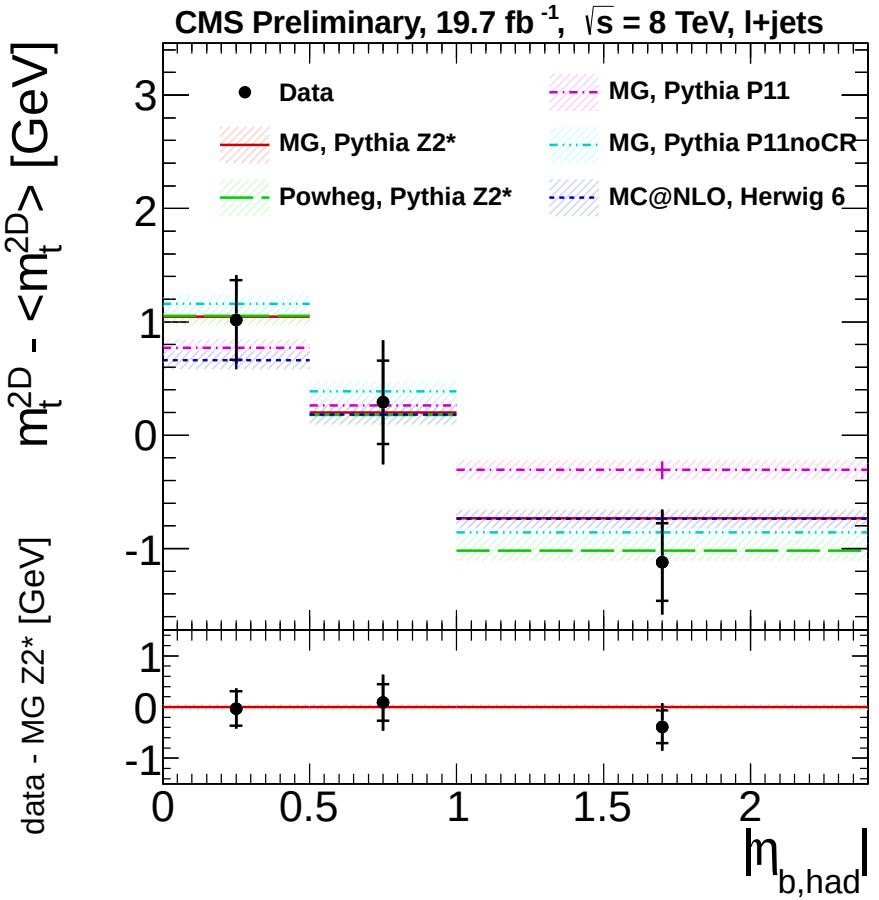




Measurement of dependency on event kinematics

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





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

Summary

- Measured the top-quark mass at 8 TeV:

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

- 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