Recent top mass results from CMS

Markus Seidel

CERN

Nov 17, 2015

Introduction

Recent measurements of m_t

- TOP-14-022
  Measurement of the top quark mass using proton-proton data at $\sqrt{s} = 7$ and 8 TeV
  submitted to PRD, arXiv:1509.04044
- TOP-15-002
  Measurement of the top-quark mass from the b jet energy spectrum
- TOP-14-011
  Measurement of the top-quark mass using the BEST-assisted R distribution in the muon + jets channel

Additional studies

- TOP-14-022
  m_t as function of kinematic observables
- Hadronization uncertainties in CMS
  incl. Sherpa Lund vs Cluster model

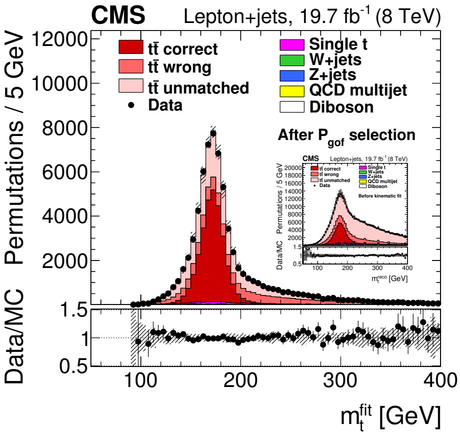
TOP-14-022 Standard methods “legacy” paper

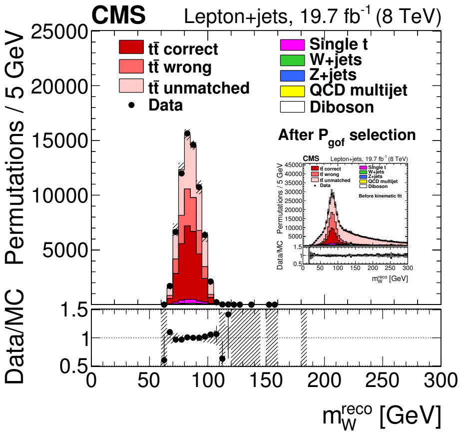
Paper contents

- Updated measurement in lepton+jets at 8 TeV — *using “hybrid” ideogram method incl. m_t as function of kinematics*
- Updated measurement in all-jets at 8 TeV — *using “hybrid” ideogram method*
- Updated measurement in dilepton at 8 TeV — *using AMWT method*
- Updated CMS combination 7 + 8 TeV — *including anti-correlation studies*

Selection and reconstruction

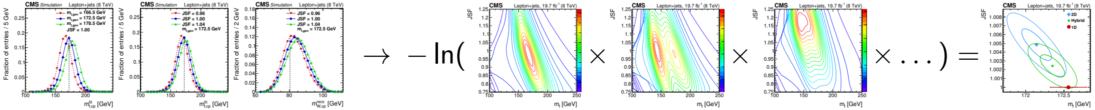
- Select $t\bar{t}$ lepton+jets events (exactly 1 e or μ, 4 jets, exactly 2 b tagged)
- Kinematic fit to $t\bar{t}$ hypothesis ($m_W = 80.4$ GeV, $m_t = m_{\bar{t}}$), require $P_{\text{gof}} > 0.2$
- Jet scale factor (JSF) extracted from W mass peak (*"2D" method*)



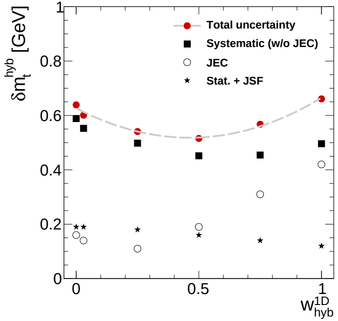


Hybrid ideogram method

Ideogram method: based on MC templates, uses multiple hypotheses per event



- Found anti-correlated uncertainties between 1D and 2D fits
  - JEC, JER, pileup, radiation, top p_T, ...
- Reason: Flat JSF overcorrects for uncertainties that mostly affect the light jets (due to flavor- and/or p_T-depency)
- Methods for improvement:
  - Use p_T-dependent JSF (CDF)
  - BLUE combination of 1D and 2D (ATLAS)
  - Weigh down JSF constraint
  - Add external JES constraint (D0, CMS)
- Trade-off between JEC and other unc., minimum in-between



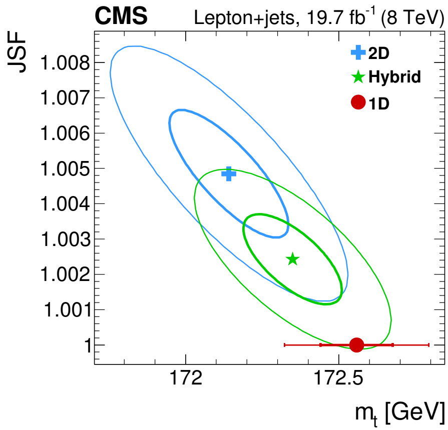
2D ←hybrid→ 1D

TOP-14-022 lepton+jets Result

- In-situ JSF and external constraint from γ/Z+jet have equal precision $\rightarrow$ equal weights
- Most precise result from hybrid fit (JSF+JEC)

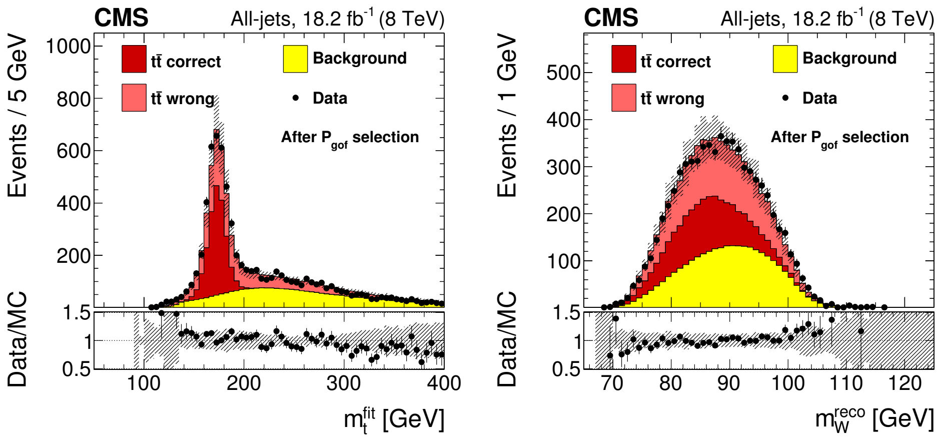
$$m_t^{\mathrm{hyb}} = 172.35 \pm 0.16\,(\mathrm{stat{+}JSF}) \pm 0.48\,(\mathrm{syst})\ \mathrm{GeV}$$

- Dominant uncertainty: flavor-dependent JEC
  cross-checked with $Z + b$ measurement



Selection and reconstruction

- Select $t\bar{t}$ all-jets events (6 jets, exactly 2 b tagged)
- Kinematic fit to $t\bar{t}$ hypothesis, require $P_{\mathrm{gof}} > 0.1, \Delta R_{b\bar{b}} > 2.0$
- QCD multijet background obtained from control sample (PAS: event mixing)
- Jet scale factor (JSF) extracted from W mass peak

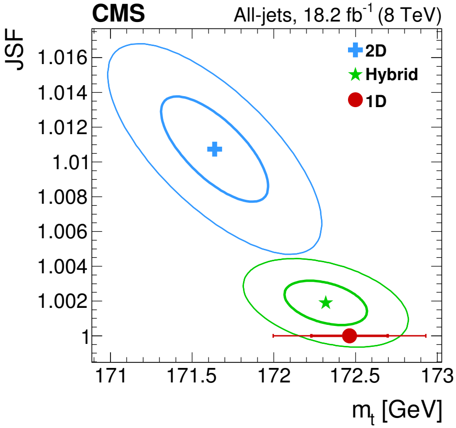


TOP-14-022 all-jets Result

- In-situ JSF gets large background uncertainty
  - hybrid fit closer to 1D
  - 2D fit compatible within systematic uncertainties (only stat. $2\Delta \log \mathcal{L} = \{1, 4\}$ contours are shown)
- Most precise result from hybrid fit (JSF+JEC)

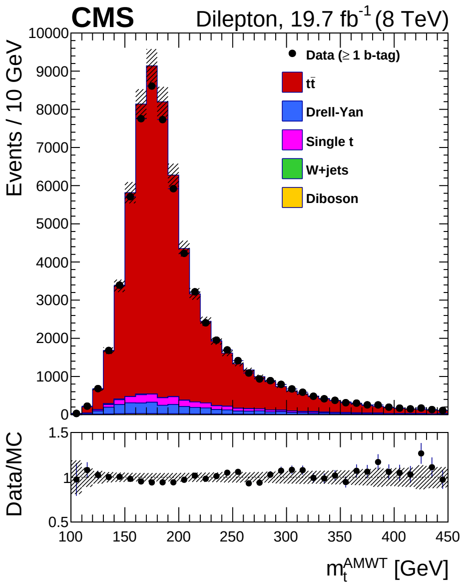
$$m_t^{\text{hyb}} = 172.32 \pm 0.25\,(\text{stat+JSF}) \pm 0.59\,(\text{syst})\ \text{GeV}$$

- Dominant uncertainties:
  JEC, flavor-dependent JEC, background



TOP-14-022 dilepton Selection and reconstruction

- Select $t\bar{t}$ dilepton events
  - 2 opposite-sign leptons
  - at least 2 b-tagged jets
  - for *ee* and $\mu\mu$: MET$>$ 40 GeV, $76 < m_{\ell\ell} < 106$ GeV
- AMWT method
  - Solve kinematic equations for $100 < m_{\mathrm{t}} < 600$ GeV $\rightarrow$ up to 8 solutions for neutrino momenta
  - Repeat 500$\times$ with object energies smeared within detector resolutions
  - Calculate matrix element weight for E_ℓ in top frame
  - Solution with highest average weight $\rightarrow m_{\mathrm{t}}^{\mathrm{AMWT}}$

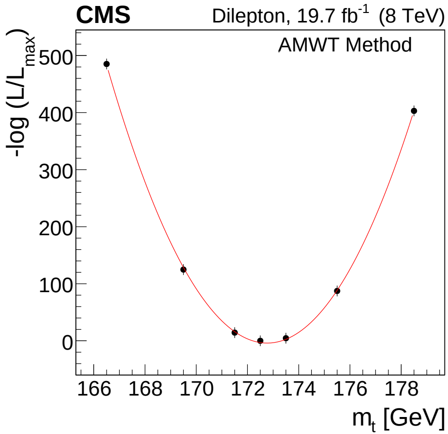


TOP-14-022 dilepton Result

- Result obtained from binned likelihood

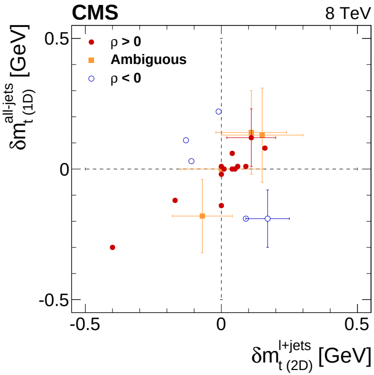
$$m_t = 172.82 \pm 0.19\,(\text{stat}) \pm 1.22\,(\text{syst})\ \text{GeV}$$

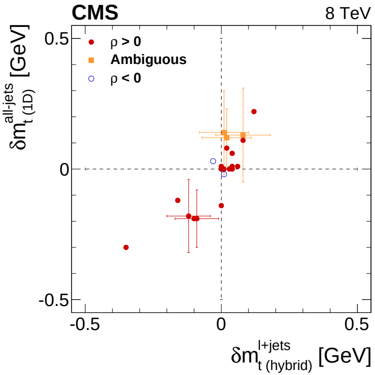
- Dominant uncertainties
  - 0.75 GeV scale variation (μ_R, μ_F)
  - 0.69 GeV b fragmentation

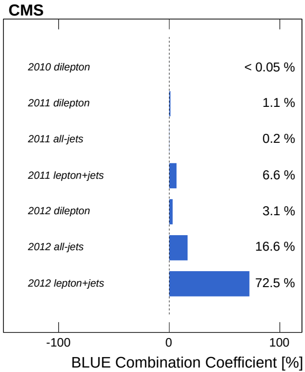


TOP-14-022 combination

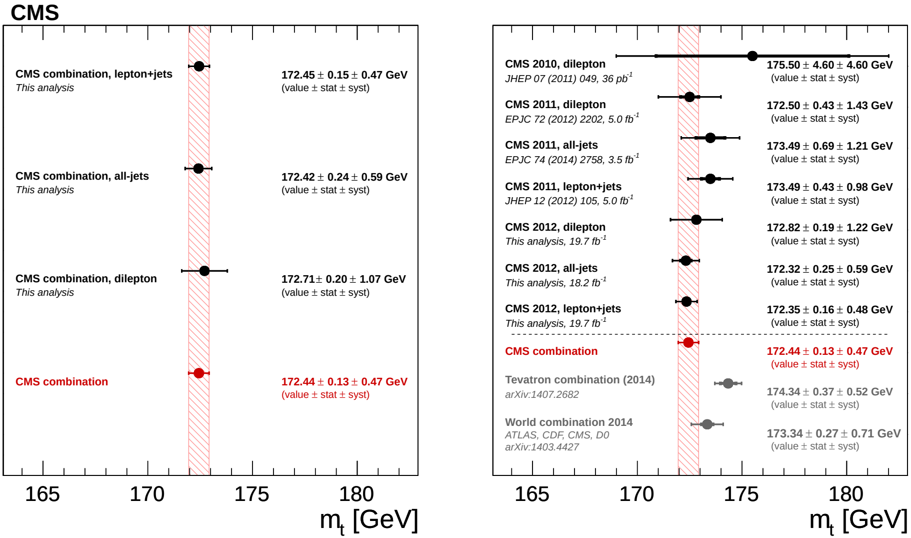
- Measurements combined with BLUE
- Pileup uncertainty uncorrelated between 7 and 8 TeV
- Anti-correlations are minimized by hybrid fits → no negative correlations assigned
- Use constraint $\rho < \sigma_i/\sigma_j$ → avoid negative coefficients, slightly larger uncertainty







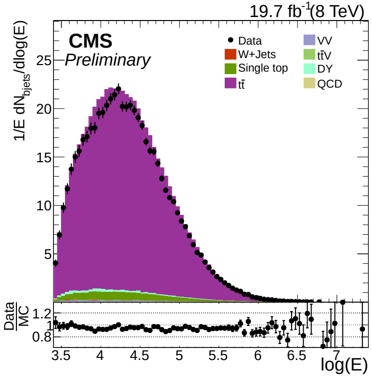
TOP-14-022 combination Result

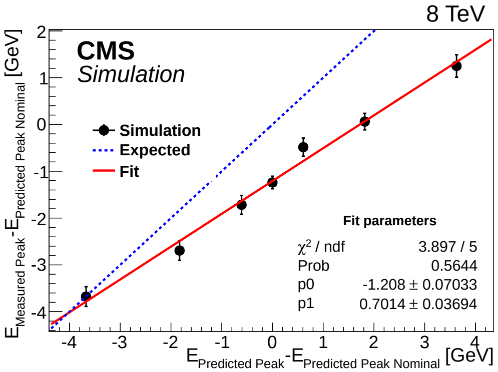


$m_t = 172.44 \pm 0.13\,(\text{stat}) \pm 0.47\,(\text{syst})\ \text{GeV}$ with $\chi^2/\text{ndf} = 2.5/6$

TOP-15-002 m_t from b-jet energy spectrum

- Select $t\bar{t}$ dilepton $e\mu$ events (2 opposite sign leptons, 1 or 2 b-tagged jets)
- E_b peak position sensitive to m_t [PRD 88 (2013) 057701]
- Biased by selection and reconstruction effects $\rightarrow$ MC calibration needed



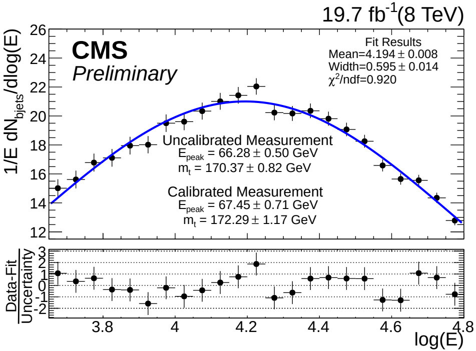


TOP-15-002 Result

- Result from fit to $\log(E)$

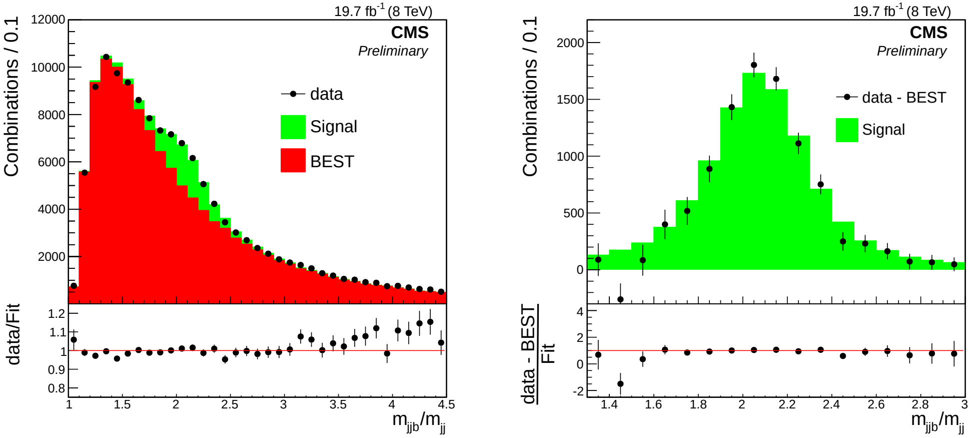
  $m_t = 172.29 \pm 1.17\,(\text{stat}) \pm 2.66\,(\text{syst})$ GeV

- Dominant uncertainties
  - 1.17 GeV statistics
  - 0.74 GeV JEC (pre-final 2012)
  - 0.91 GeV ME generator
  - 0.91 GeV top p_T
- Used Z+b jet calibration JME-13-001
  - central value compatible with 1
  - uncertainty reduced by 60%



TOP-14-011 Top mass using BEST

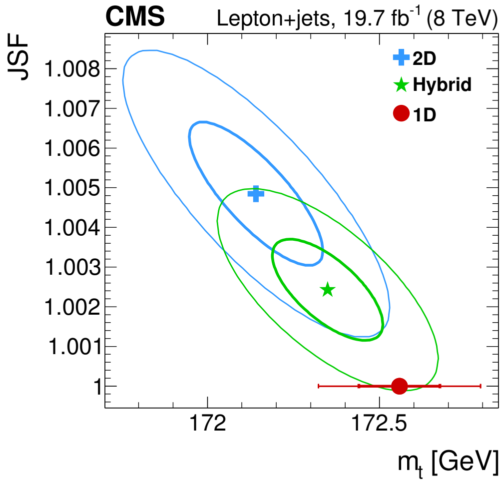
- Select $t\bar{t}$ lepton+jets events (exactly 1 μ, ≥ 4 jets, ≥ 2 b tagged)
- Estimation of comb. background using Bi-Event Subtraction Technique (BEST)



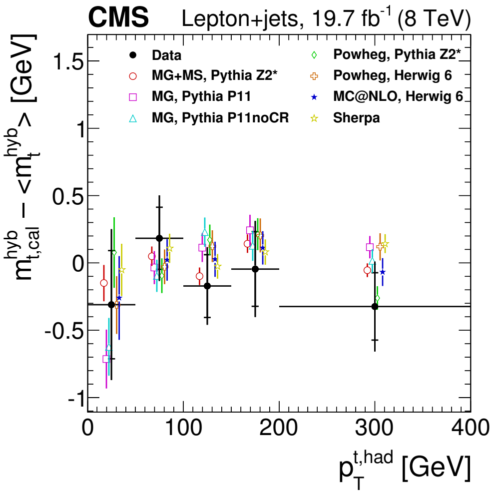
- Result from fit to $R = m_{jjb}/m_{jj}$: $m_t = 172.61 \pm 0.57\,(\text{stat}) \pm 0.90\,(\text{syst})$ GeV

TOP-14-022 lepton+jets m_t as function of kinematic observables

- Measure m_t on subsets depending on kinematic observables
- Subtract value of inclusive measurements
- Compare data to models, difference should be flat



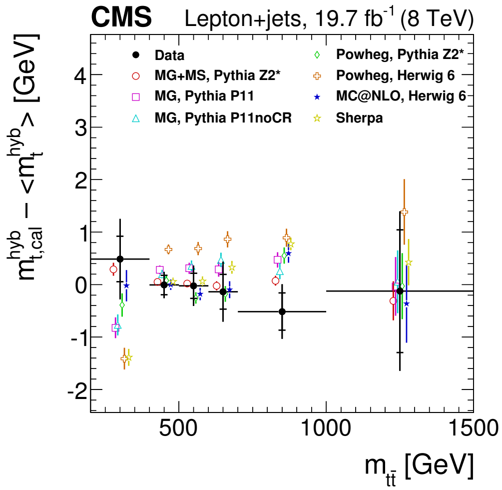
→



TOP-14-022 lepton+jets m_t as function of kinematic observables

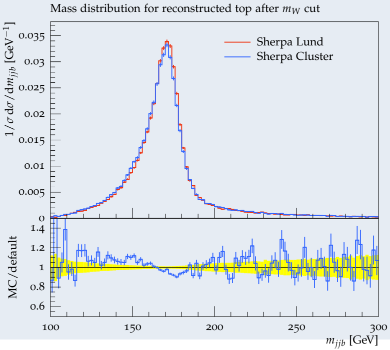
- Included 8 observables: $p_{T,t}$, $p_{T,b}$, $|\eta_b|$, $m_{t\bar{t}}$, $p_{T,t\bar{t}}$, $\Delta R_{q\bar{q}}$, $\Delta R_{b\bar{b}}$, number of jets
- Quantified overall agreement by $\chi^2 = \sum (\text{data - sim})^2 / (\sigma^2_{\text{data}} + \sigma^2_{\text{sim}})$
- Summed χ^2 for different generators

Simulation	χ^2	σ
MG + Pythia 6 Z2*	17.55	0.10
MG + Pythia 6 P11	37.68	1.73
MG + Pythia 6 P11noCR	31.57	1.15
Powheg + Pythia 6 Z2*	19.70	0.20
Powheg + Herwig 6	76.48	4.84
MC@NLO + Herwig 6	20.47	0.24
Sherpa	46.79	2.56

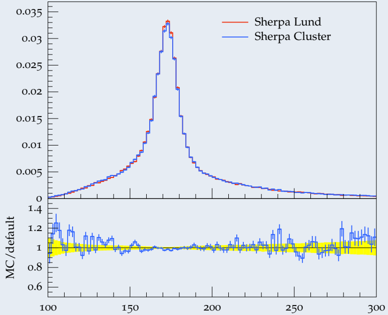


Hadronization model → particle-level comparison in Sherpa

$m_{jjb} \approx m_t$ (from jets w/o neutrinos)



$m_{jjb} \approx m_t$ (from jets with neutrinos)



Difference in BR $B \to \ell\nu X$

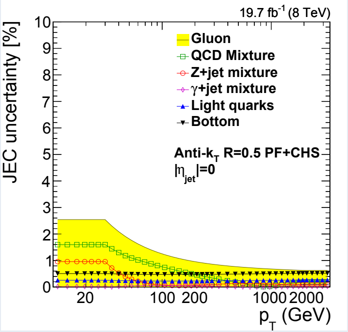
- Sherpa Lund: 0.247
- Sherpa Cluster: 0.287
- PDG: 0.239 – 0.268

Hadronization model...

- has small effect on IR-safe observables
- affects analyses by jet composition (particle types and momenta)

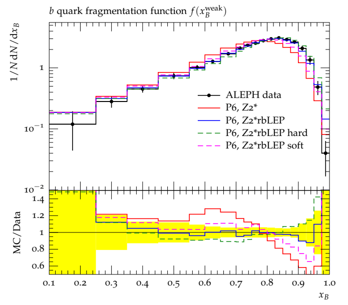
Hadronization uncertainties in CMS

JEC: Flavor



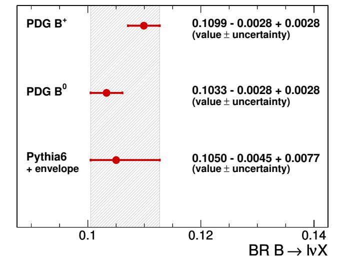
- Pythia 6 vs. Herwig++ for each jet flavor

b fragmentation



- Retune to LEP data using Professor framework
- Take full difference between Z2* and Z2*rbLEP

B hadron decays



- Neutrinos in b jets → lower response
- Vary BR to cover PDG values for $B^{+/0}$

- Ask our data: **JME-13-001** Direct measurement of b jet response using $Z + b$ events

Conclusions

- Very good agreement of default MC MadGraph+Pythia 6 Z2* with CMS Run1 data
  - m_t in dependence of kinematics, differential cross sections, jet multiplicity
  - Exception: top p_T $\rightarrow$ included as uncertainty
- Very precise final 2012 JEC + detailed breakdown of hadronization uncertainties

$$\downarrow$$

- Obtained a set of most precise measurements in each analysis channel, yielding a combined Run1 result of

$$m_t = 172.44 \pm 0.13\,(\mathrm{stat}) \pm 0.47\,(\mathrm{syst})\ \mathrm{GeV}$$

- Alternative mass extractions in good agreement with main result

Additional material

New NLO tools for Run2

- For m_t: accurate description of decay products more important than n^{th} extra jet
- Currently ME corrections "off" recommended for NLO matching?

"Gedanken"experiment in e^+e^- at $\sqrt{s} = 350\,\text{GeV}$

- Select dilepton events, look at additional jets
- No contribution from UE and ISR
- Large effect from ME corrections that are implemented in Pythia and Herwig for top decays

$\rightarrow$ need clarification from theory on correct procedure for NLO matching + ME corrections

$t\bar{t}$ dilepton 3-jet events, min $\Delta R\,(b, j)$