The Top Quark Mass in the Muon+Jets Final State at $\sqrt{s} = 13$ TeV in 2015 Data

CMS PAS TOP-16-022

55th Course of the ISSP, Erice

Christoph Garbers, Nataliia Kovalchuk, Johannes Lange, Peter Schleper, Markus Seidel, Hartmut Stadie, Fred Stober

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The CMS experiment

slides from *Highlights from CMS* by I. Melzer-Pellmann

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**LHC is a top factory**

~2 million ttbar pairs per week in Run2 (>2 fb\(^{-1}\)/week)

New precise measurement of CMS at 5 TeV:
- Reference for future Heavy Ion studies with tops at same √s/nucleon
- Improving the knowledge of gluon PDFs at high x

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**Top mass measurement**

Dominant measurement at 8 TeV, but precision improved by 13 TeV data

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June 20, 2017 Christoph Garbers
The Top Quark

- Standard Model particle
- Heaviest measured particle
- $\tau_{\text{decay\, (top)}} \approx 5 \times 10^{-25} \text{ s}$
  $\ll \tau_{\text{hadronisation}}$
  $\Rightarrow$ spin correlation conserved
- Decays in 68.5% hadronic, else
  in $b$ quark + lepton + neutrino
- Precision measurement for
  global fits

30% of $t\bar{t}$ decays into
$e, \mu +$ jets

Optimal channel
- Branching ratio
- Easy to trigger
- Only one $\nu$
Analysis Steps

- selection
- kinematic fit
- construct estimator for top mass
  - using maximum likelihood
  - parameterize templates in $m_t$ and jet energy scale factor $JSF$
  - calibrate on MC
- systematic uncertainties
- evaluate on data

Run I Result:
2015 CMS-TOP-14-022

$m_t = 172.35 \pm 0.16 \pm 0.48$ GeV

awaiting improvement due to higher crosssection, higher luminosity, NLO MC, ...
MC and Data

data: 2.2 fb$^{-1}$ Run 2 2015

**signal MC:** powheg + pythia8 (tuned)
- default **top quark mass** 172.5 GeV
- additional top-quark mass 169.5 GeV, 173.5 GeV, 175.5 GeV, and 178.5 GeV used for template fit

**background MC:**
- W+Jets
- Single (anti)top
- Z+Jets
- Diboson
- QCD multijet

plus additional samples for systematic uncertainties
Selection

1 muon + 4 jets

- High-Level-Trigger: isolated muon with $p_T > 20$ GeV
- **muon selection:** $p_T > 25$ GeV and $|\eta| < 2.1$
  - relative isolation
- veto on events with additional leptons
- **jet selection:** anti-$k_t$, $R = 0.4$
  - at least 4 jets with each $p_T > 30$ GeV, $|\eta| < 2.4$
  - $\Delta R($muon,jet$) > 0.3$
- **b-tagging:** CSVv2M 1% mis-tag, 70% efficiency
  - at least two b-tags in selected jets

<table>
<thead>
<tr>
<th>event yield</th>
<th>before b-tagging</th>
<th>with b-tagging</th>
</tr>
</thead>
<tbody>
<tr>
<td>data</td>
<td>112 732</td>
<td>29 406</td>
</tr>
<tr>
<td>estimated signal frac.</td>
<td>61.4%</td>
<td>90.9%</td>
</tr>
</tbody>
</table>
Kinematic Fit

fitting the kinematics to a $t\bar{t}$ hypothesis

- four leading jets, containing two b-tagged jets
- $m_{t_{hadr}}^{fit} = m_{t_{lept}}^{fit}$, $m_{W}^{fit} = 80.4 \text{ GeV}$, $p_T$ balance
- try different jet-parton assignments
  - $\{b_{had}, W_{had}\} \rightarrow t_{hadr}$ ($t\bar{t}$ correct)
  - wrong jets, e.g. $\{b_{lept}, W_{had}\} \rightarrow t_{hadr}$ ($t\bar{t}$ wrong)
  - matching to other jets / matching did not work ($t\bar{t}$ unmatched)

use goodness-of-fit $P_{gof} = \exp(-\frac{1}{2}\chi^2)$

<table>
<thead>
<tr>
<th></th>
<th>baseline</th>
<th>final $P_{gof} &gt; 0.2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}$ correct</td>
<td>14.8 %</td>
<td>43.8 %</td>
</tr>
<tr>
<td>$t\bar{t}$ wrong</td>
<td>8.9 %</td>
<td>22.3 %</td>
</tr>
<tr>
<td>$t\bar{t}$ unmatched</td>
<td>76.4 %</td>
<td>33.9 %</td>
</tr>
</tbody>
</table>

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14,327 permutations of 5,798 event candidates estimated $f_{\text{sig}} = 95.9\%$
Ideogram Method

Likelihood fit of the $(m_t^{\text{fit}}, m_W^{\text{reco}})$ data to 2D $(m_t \times \text{JSF})$ templates derived from simulation.

Illustration by M. Seidel
Approaches

- **2D approach:** in-situ $m_t$ and JSF measurement

- **1D approach:** JSF fixed to unity (with jet energy correction from $\gamma/Z + \text{jet}$)

- **hybrid/final approach:** combination of 2D and 1D with the same weight
Result: 2D and 1D approach

\[ m_t^{1D} = 172.44 \pm 0.27 \text{ (stat)} \pm 1.02 \text{ (syst)} \text{ GeV} \]

\[ m_t^{2D} = 172.80 \pm 0.44 \text{ (stat+JSF)} \pm 1.10 \text{ (syst)} \text{ GeV} \]

\[ \text{JSF} = 0.996 \pm 0.004 \text{ (stat)} \pm 0.015 \text{ (syst)} \]
Result hybrid approach

$$m_t^{hyb} = 172.62 \pm 0.38 \text{ (stat+JSF)} \pm 0.70 \text{ (syst)} \text{ GeV}$$

$$\approx m_t^{pole} \text{ within } O(1 \text{ GeV}) \text{ (arXiv:1408.6080 Moch et al. 2014), or few 100 MeV (arXiv:1608.01318 Butenschoen et al. 2016)}$$

$$JSF^{hyb} = 0.998 \pm 0.003 \text{ (stat)} \pm 0.010 \text{ (syst)}$$
### Biggest Systematic Uncertainties

<table>
<thead>
<tr>
<th>Source</th>
<th>$\delta m^\text{hyb}_t$ [GeV]</th>
<th>$\delta \text{JSF}^\text{hyb}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>JEC: Uncorrelated non-pileup</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>JEC: Flavor bottom</td>
<td>0.32</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>PS $Q^2$ scale</td>
<td>0.23</td>
<td>0.001</td>
</tr>
<tr>
<td>Underlying event</td>
<td>0.18</td>
<td>0.007</td>
</tr>
<tr>
<td>Color reconnection modeling</td>
<td>0.22</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Underlying event and color reconnection modeling uncertainties still preliminary, currently reestimated for 2016 data.
Summary

lepton+jets channel

CDF, lepton+jets
PRL 109 (2012) 152003, 8.7 fb⁻¹

D0 matrix element, lepton+jets
PRD 91 (2015) 112003, 9.7 fb⁻¹

ATLAS 2011, lepton+jets
EPJC 75 (2015) 330, 4.6 fb⁻¹

CMS 2011, lepton+jets
JHEP 12 (2012) 105, 5.0 fb⁻¹

CMS 2012, lepton+jets
PRD 93 (2016) 072004, 19.7 fb⁻¹

CMS 2015 prel., lepton+jets
TOP-16-22 (2017), 2.2 fb⁻¹

CMS Run 1 combination
PRD 93 (2016) 072004

World combination
ATLAS, CDF, CMS, D0

172.85 +1.10 -1.10 GeV
174.98 +0.76 -0.76 GeV
172.33 +1.27 -1.27 GeV
173.49 +1.07 -1.07 GeV
172.35 +0.51 -0.51 GeV
172.62 +0.80 -0.80 GeV
172.44 +0.49 -0.49 GeV
173.34 +0.76 -0.76 GeV

CMS PAS TOP-16-022

first Run2 top quark mass result
confirms √s = 8 TeV

CMS analyses

good reference for Run 2 analyses to come

June 20, 2017
Christoph Garbers
Thank you for your attention!