

Top quark mass measurements in Run-I from CMS

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Introduction

Content:

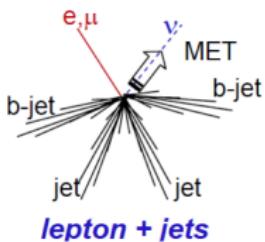
Published measurements for $\sqrt{s} = 8$ TeV data:

- ℓ +jets channel (M. Seidel (UHH))
- all-jets channel (E. Schlieckau (UHH))

Measurement:

- $t\bar{t}$ candidates
- up to 19.7 fb^{-1} data
- MADGRAPH+PYTHIA samples
- peak position of invariant mass of decay products
 - experimentally: best precision
 - difficult to simulate/relate to theory
(resonance+PS)

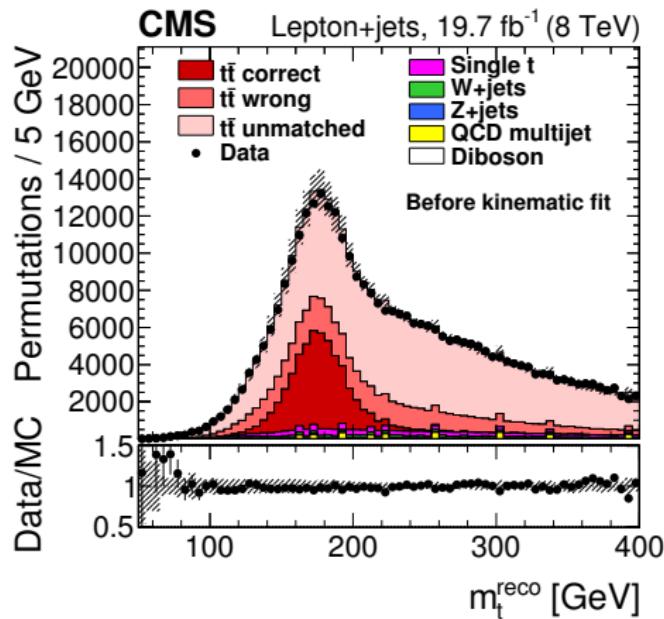
Top Mass Measurement in ℓ +jets Channel



selection:

- exactly **1 isolated e, μ** with
 $p_T > 33 \text{ GeV}, |\eta| < 2.1$
 (veto additional e, μ)
- **≥ 4 jets** with
 $p_T > 30 \text{ GeV}, |\eta| < 2.4$
- **= 2 jets with b-tag**

Estimated composition: 93% $t\bar{t}$, 2% W+jets, 4% single top, 1% other



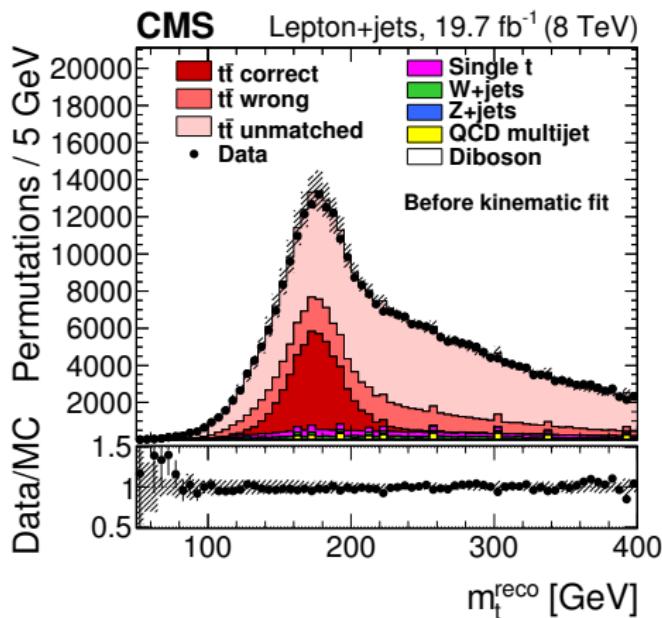
Kinematic Fit

- split in 3 permutation classes:

- correct
- wrong
flipped b -quarks, mistags
- unmatched
no unambiguous match

- kinematic fit:

- two untagged jets:
 $m_{jj} = 80.4 \text{ GeV}$
- lepton and neutrino (\not{E}_T)
 $m_{\ell\nu} = 80.4 \text{ GeV}$
- combine with two b -tagged jets:
 $m_{jjb_1} = m_{\ell\nu b_2}$



Kinematic Fit

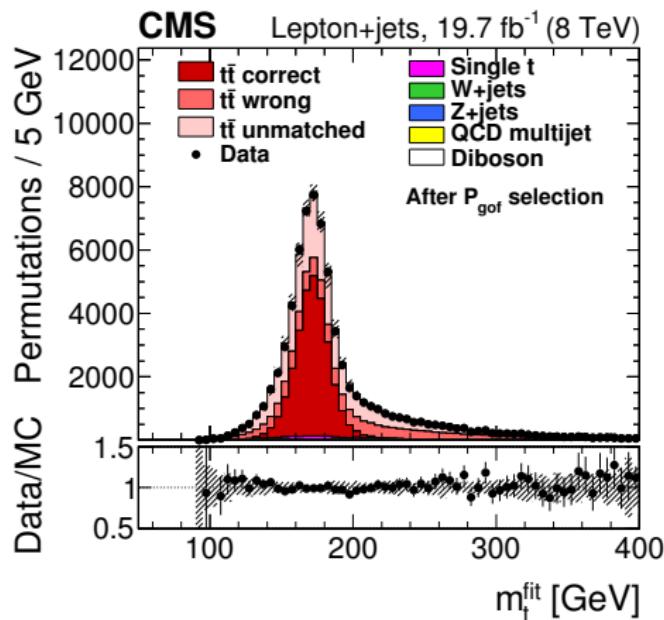
- split in 3 permutation classes:

- correct
- wrong
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- no unambiguous match

- kinematic fit:

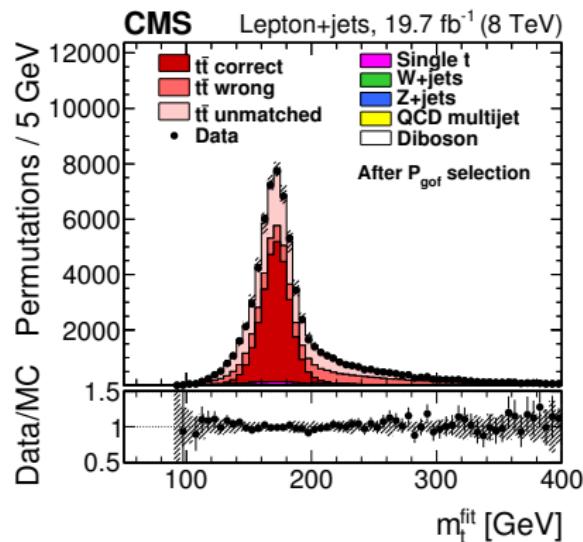
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$P_{\text{gof}} > 0.2$ & weight permutations by P_{gof} : $f_{cp} = 13\% \rightarrow 42\%$



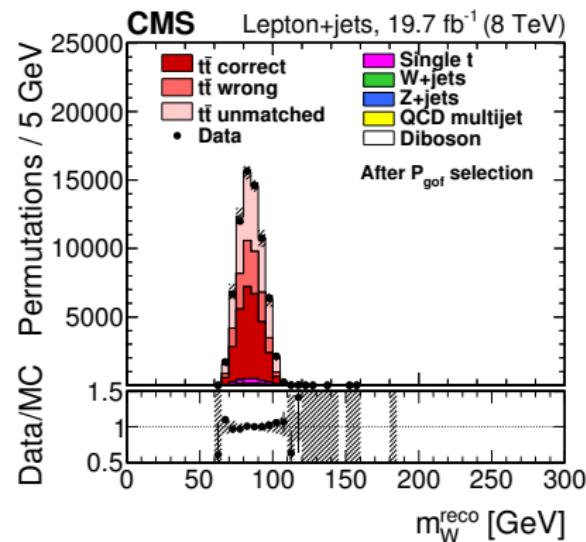
Ideogram Method

- simultaneous measurement of the top quark mass and jet energy scale factor(JSF)
- ideogram: $P(\text{event} | m_t, \text{JSF})$
- input: $m_{t,i}^{\text{fit}}$ and $m_{W,i}^{\text{reco}}$
- use all allowed permutations i per event



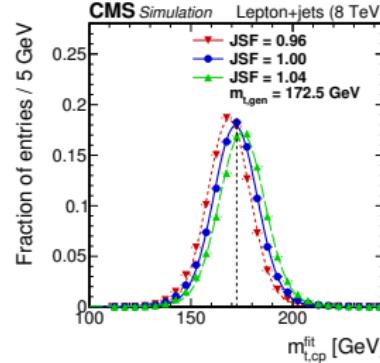
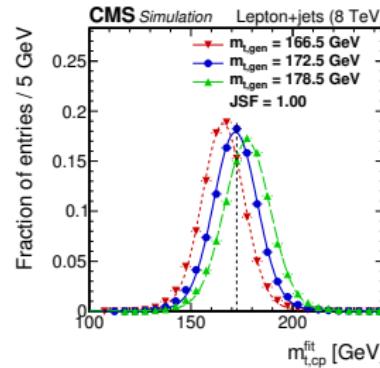
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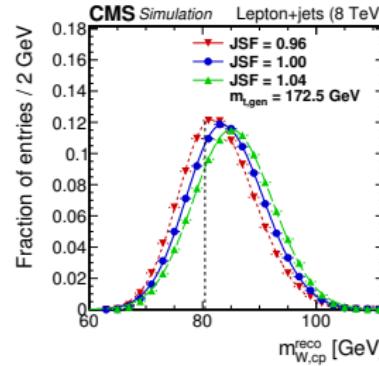
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- input: $m_{t,i}^{\text{fit}}$ and $m_{W,i}^{\text{reco}}$
- use all allowed permutations i per event
- $$P_i = \sum_j f_j P_j(m_{t,i}^{\text{fit}} | m_t, \text{JSF}) \cdot P_j(m_{W,i}^{\text{reco}} | m_t, \text{JSF})$$



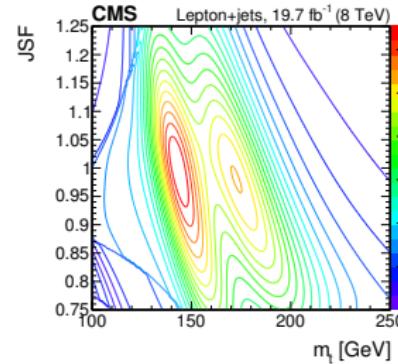
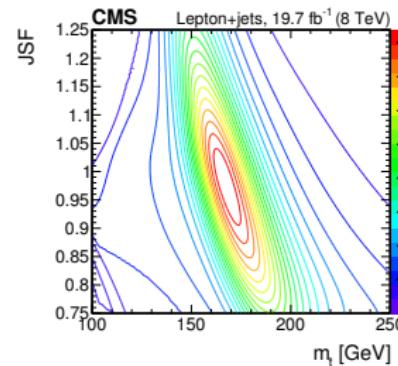
Ideogram Method

- simultaneous measurement of the top quark mass and jet energy scale factor(JSF)
- ideogram: $P(\text{event} | m_t, \text{JSF})$ no dependence on $m_{t,\text{gen}}$
- input: $m_{t,i}^{\text{fit}}$ and $m_{W,i}^{\text{reco}}$
- use all allowed permutations i per event
- $$P_i = \sum_j f_j P_j (m_{t,i}^{\text{fit}} | m_t, \text{JSF}) \cdot P_j (m_{W,i}^{\text{reco}} | m_t, \text{JSF})$$



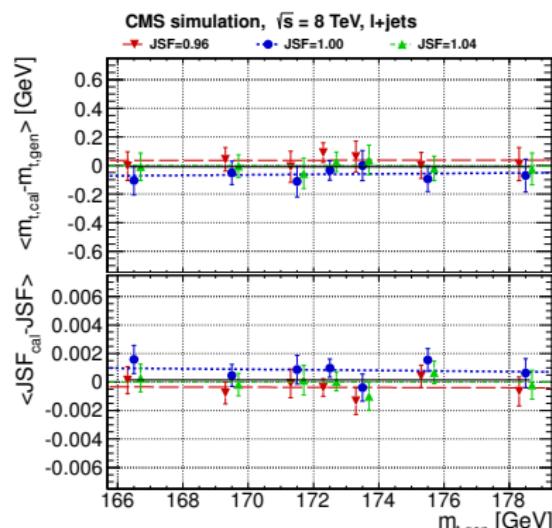
Ideogram Method

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- ideogram: $P(\text{event} | m_t, \text{JSF})$
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- use all allowed permutations i per event
- $$P_i = \sum_j f_j P_j (m_{t,i}^{\text{fit}} | m_t, \text{JSF}) \\ \cdot P_j (m_{W,i}^{\text{reco}} | m_t, \text{JSF})$$
- final ideogram: combine P_i and weight event by sum of fit probabilities



Ideogram Method

- simultaneous measurement of the top quark mass and jet energy scale factor(JSF)
- ideogram: $P(\text{event} | m_t, \text{JSF})$
- input: $m_{t,i}^{\text{fit}}$ and $m_{W,i}^{\text{reco}}$
- use all allowed permutations i per event
- $P_i = \sum_j f_j P_j \left(m_{t,i}^{\text{fit}} | m_t, \text{JSF} \right) \cdot P_j \left(m_{W,i}^{\text{reco}} | m_t, \text{JSF} \right)$
- final ideogram: combine P_i and weight event by sum of fit probabilities



- combine all ideograms and extract m_t and JSF after calibration

Hybrid Method

Study interplay of 2D and 1D(JSF=1) results

Shifts with sign:

	$\delta m_t^{2D}(\text{GeV})$	δJSF	$\delta m_t^{1D}(\text{GeV})$	$\delta m_t^{\text{hyb}}(\text{GeV})$
Ren. and fact. scales	$+0.17 \pm 0.08$	-0.004 ± 0.001	-0.24 ± 0.06	-0.09 ± 0.07
ME-PS matching threshold	$+0.11 \pm 0.09$	-0.002 ± 0.001	-0.07 ± 0.06	$+0.03 \pm 0.07$
Underlying event	$+0.15 \pm 0.15$	-0.002 ± 0.001	$+0.07 \pm 0.09$	$+0.08 \pm 0.11$

Observation:

JSF from m_W^{reco} gets larger shifts than needed for m_t^{fit} .
 i.e., m_W^{reco} stronger affected by modeling than m_t

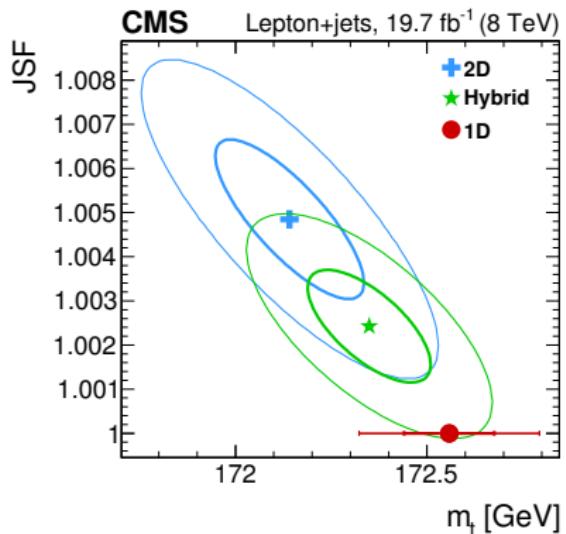
Solution: hybrid method

Add JSF-prior to likelihood to include jet calibration measurements

Result on Data

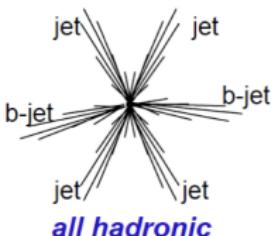
Result with 28 295 selected events in
 $\ell + \text{jets}$ channel, 19.7 fb^{-1}

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



	Δm_{top} (GeV)	
	2D	hyb
Method calibration	0.04	0.04
Jet energy corrections	0.11	0.16
Lepton energy scale	0.01	0.01
E_T scale	0.04	0.04
Jet energy resolution	0.11	0.03
b tagging	0.06	0.06
Pileup	0.12	0.04
Backgrounds	0.05	0.03
JEC: Flavor-dependent	0.40	0.34
b jet modeling	0.17	0.16
PDF	0.09	0.04
Ren. and fact. scales	0.17	0.09
ME-PS matching threshold	0.11	0.07
ME generator	0.11	0.12
Top quark p_T	0.16	0.02
Underlying event	0.15	0.11
Color reconnection modeling	0.13	0.09
Total systematic	0.59	0.48
Statistical	0.20	0.16
Total	0.62	0.51

Top Mass Measurement in all-jets Channel

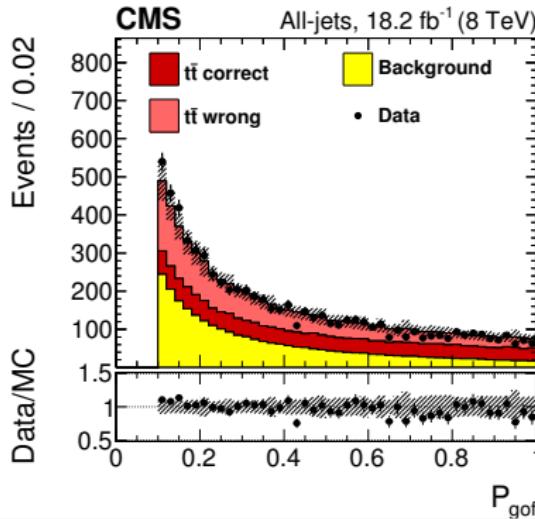


selection with p_T -ordered jets:

- six jets with $|\eta| < 2.4$ and $p_{T,4} > 60 \text{ GeV}$,
 $p_{T,5} > 30 \text{ GeV}$,
 $p_{T,6} > 30 \text{ GeV}$
- = 2 jets with b-tag

kinematic fit:

- 2×2 untagged jets: $m_{jj} = 80.4 \text{ GeV}$
- combine with two b -jets: $m_{jjb} = m_{j\bar{b}}$

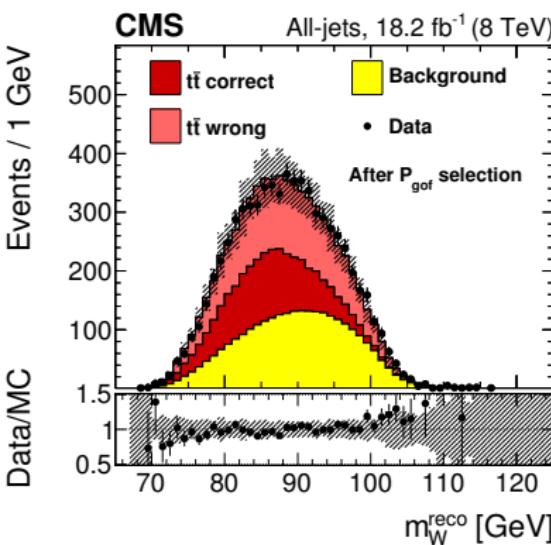
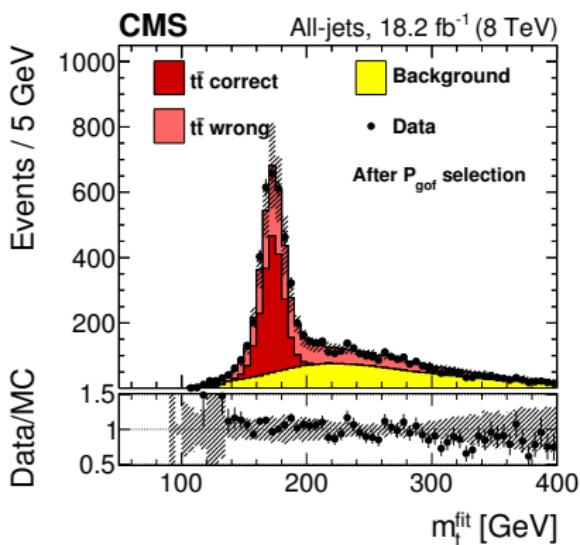


$P_{\text{gof}} > 0.1$ and $\Delta R_{b\bar{b}} > 2.0$: $f_{\text{sig}} = 61\%$; bkg from data w/o b-tag req.

Mass extraction

Use similar ideogram method as for $\ell + \text{jets}$

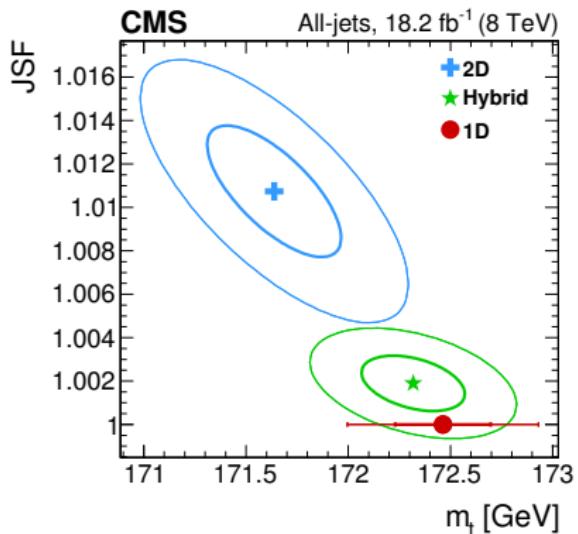
fit parameters: m_t , JSF, f_{sig} , f_{cp}



Result on Data

Result with 7049 selected events,
 18.2 fb^{-1}

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



	Δm_{top}	(GeV)
	2D	hyb
Method calibration	0.06	0.06
Jet energy corrections	0.07	0.26
Jet energy resolution	0.10	0.02
b tagging	0.02	0.02
Pileup	0.09	0.01
Backgrounds	0.61	0.20
Trigger	0.04	0.01
JEC: Flavor-dependent	0.34	0.32
b jet modeling	0.16	0.14
PDF	0.06	0.03
Ren. and fact. scales	0.29	0.12
ME-PS matching threshold	0.18	0.13
ME generator	0.20	0.16
Top quark p_T	0.04	0.04
Underlying event	0.27	0.18
Color reconnection modeling	0.35	0.16
Total systematic	0.95	0.59
Statistical	0.33	0.25
Total	1.01	0.64

Summary

- m_t in $\ell + \text{jets}$ and all-jets channels for $\sqrt{s} = 8 \text{ TeV}$
TOP-14-022
(<http://arxiv.org/abs/1509.04044>)
- modeling uncertainties constrained by 2D fit with JSF prior (hybrid)
- new CMS combination with dilepton channel and $\sqrt{s} = 7 \text{ TeV}$:

$$m_t = 172.44 \pm 0.13 \text{ (stat.)} \\ \pm 0.47 \text{ (syst.) GeV}$$

