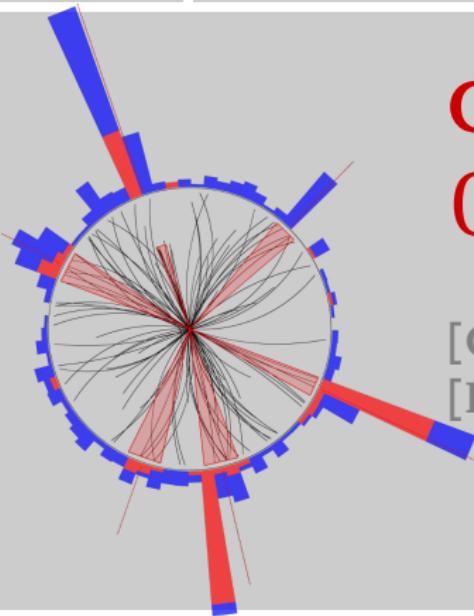




LHCtopWG open meeting

Tuesday 20th November, 2018



CMS top mass results (in Run II)

[CMS-PAS-TOP-17-008]

[EPJC 78 (2018), 891]

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on behalf of the CMS Collaboration

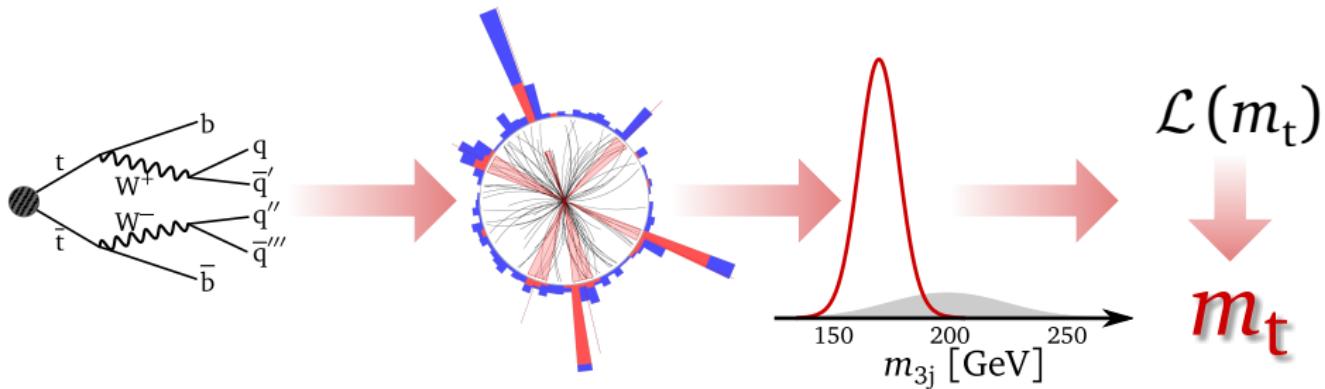


Universität Hamburg
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Two “direct” m_t measurements in Run II

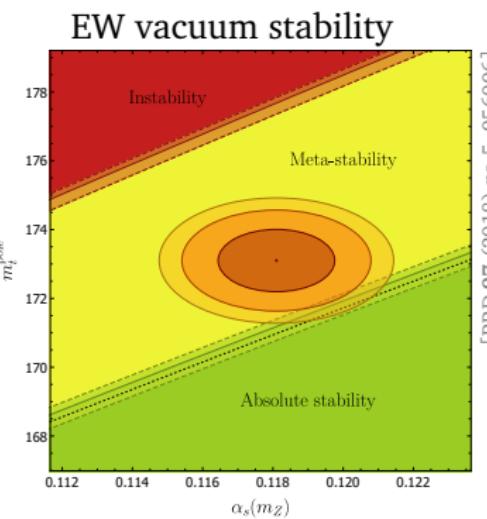
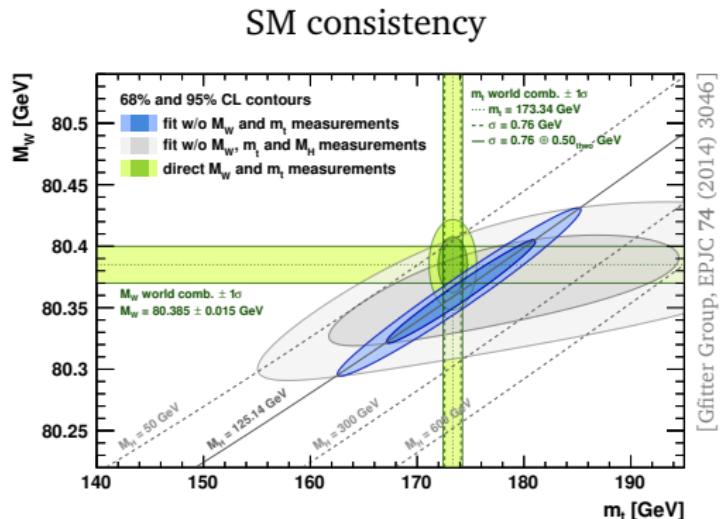
$\ell + \text{jets}$ EPJC 78 (2018), 891 [↗](#)
 all-jets CMS-PAS-TOP-17-008 [↗](#)

since last LHCtopWG meeting:
(published)
(new)

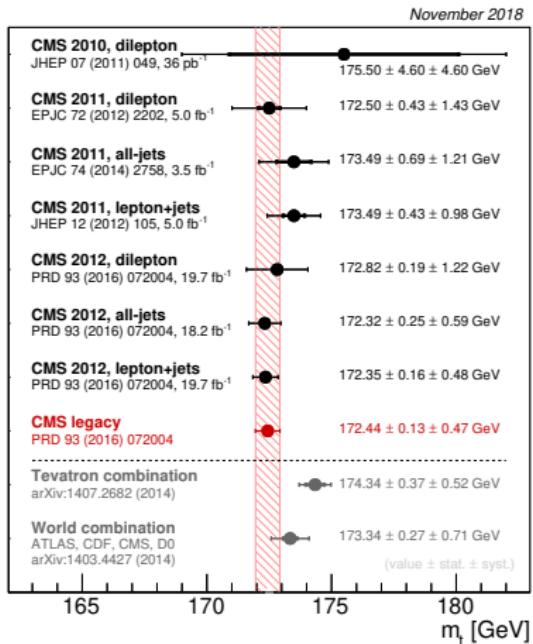


mass extraction from cross section: talk by Jan Kieseler

m_t : important SM parameter!



Previous measurements

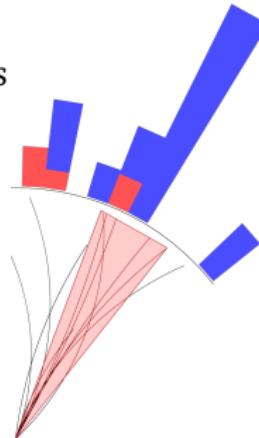


improvements w.r.t. Run I:

- $3 \times \sigma_{t\bar{t}}$
- $2 \times \mathcal{L}$
- 2016 dataset: $\mathcal{L} \approx 35.9 \text{ fb}^{-1}$
- NLO MC available for calibration
POWHEG v2 + PYTHIA8, CUETP8M2T4
- new theory models
esp. color reconnection

Jets

- clustered with anti- k_t algorithm ($D = 0.4$) from particle flow (PF) objects
- pileup subtraction using charged hadrons
- $p_T > 30 \text{ GeV}$
- $|\eta| < 2.4$
- $H_T = \sum_{\text{jets}} p_T$
- CSVv2 b tagger: medium/tight WP
 - efficiency $\approx 69/49 \%$
 - mistag rate $\approx 1/0.1 \%$



Muons

$p_T > 26 \text{ GeV}, |\eta| < 2.4$

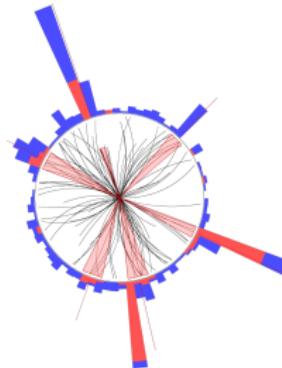
Electrons

$p_T > 34 \text{ GeV}, |\eta| < 2.1$

Event selection

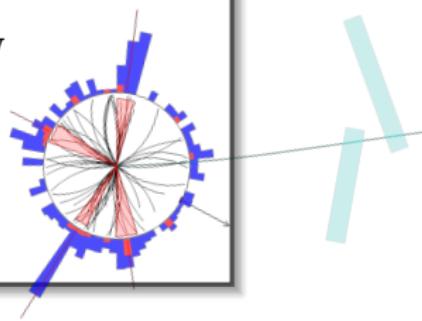
all-jets

- trigger: six jets, one b tag
- $H_T > 450 \text{ GeV}$
- six jets, $p_T > 40 \text{ GeV}$
- two tight b tags
- $\Delta R(b\bar{b}) > 2.0$

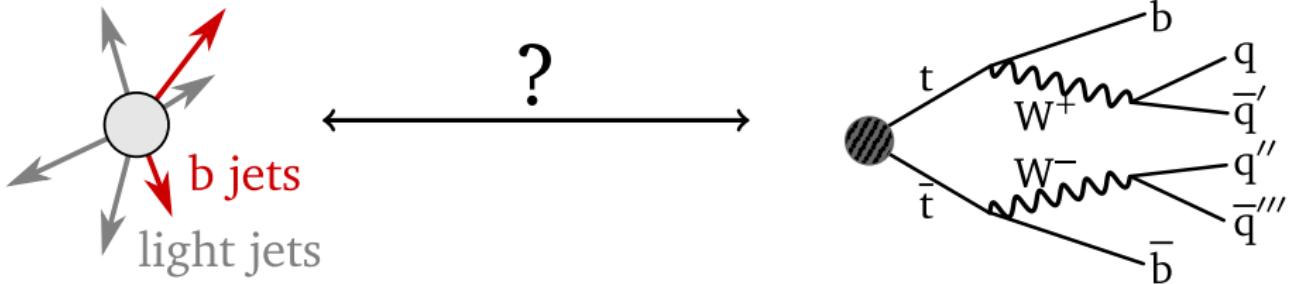


$\ell + \text{jets}$

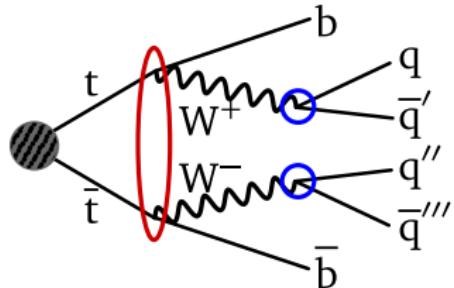
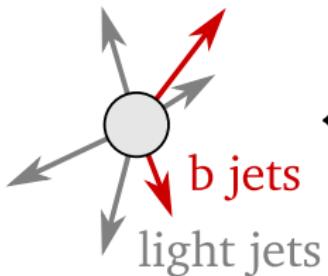
- trigger: isolated μ/e with $p_T > 24/32 \text{ GeV}$
- exactly one isolated lepton ($\ell = e, \mu$)
- four jets
- two medium b tags



Kinematic fit



Kinematic fit

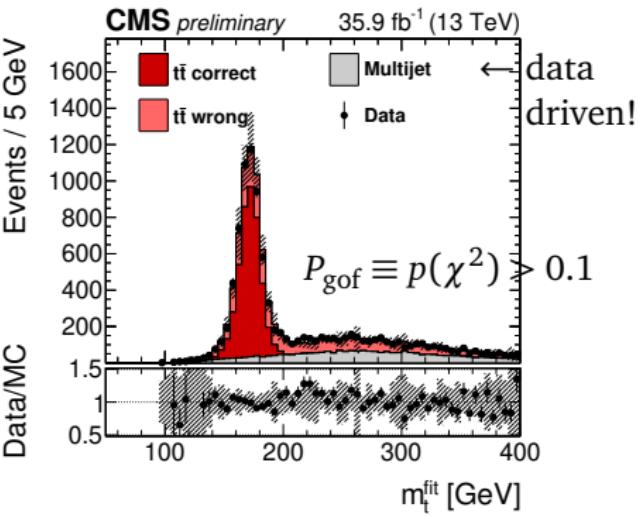


Minimize

$$\chi^2 = \sum_{j \in \text{jets}} \left[\frac{(p_{Tj}^{\text{reco}} - p_{Tj}^{\text{fit}})^2}{\sigma_{p_{Tj}}^2} + \frac{(\eta_j^{\text{reco}} - \eta_j^{\text{fit}})^2}{\sigma_{\eta_j}^2} + \frac{(\phi_j^{\text{reco}} - \phi_j^{\text{fit}})^2}{\sigma_{\phi_j}^2} \right]$$

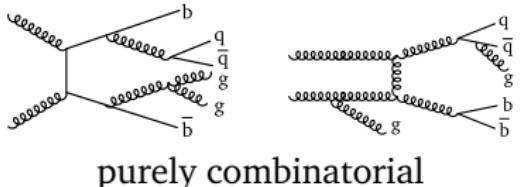
with constraints:

$$m_{W^+} = m_{W^-} = 80.4 \text{ GeV}, m_t = m_{\bar{t}}$$

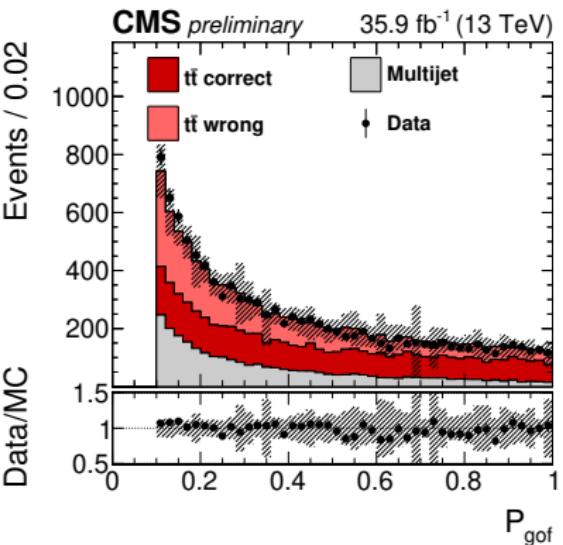
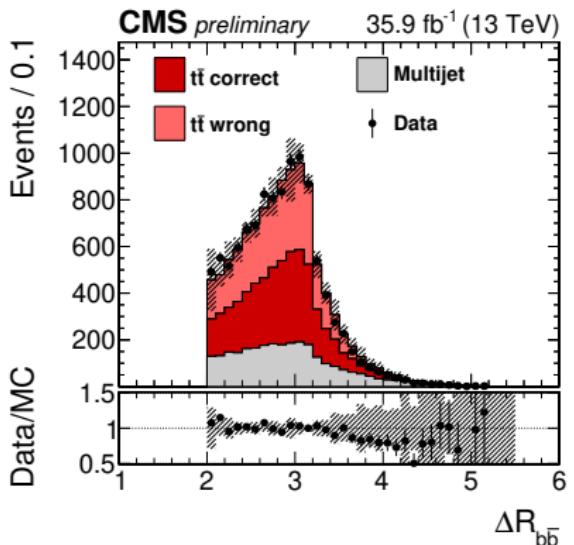
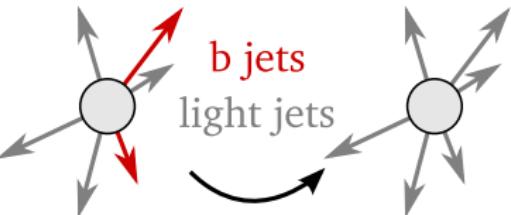


Background estimation

QCD multijet production



estimate from data in 0-b-tag region

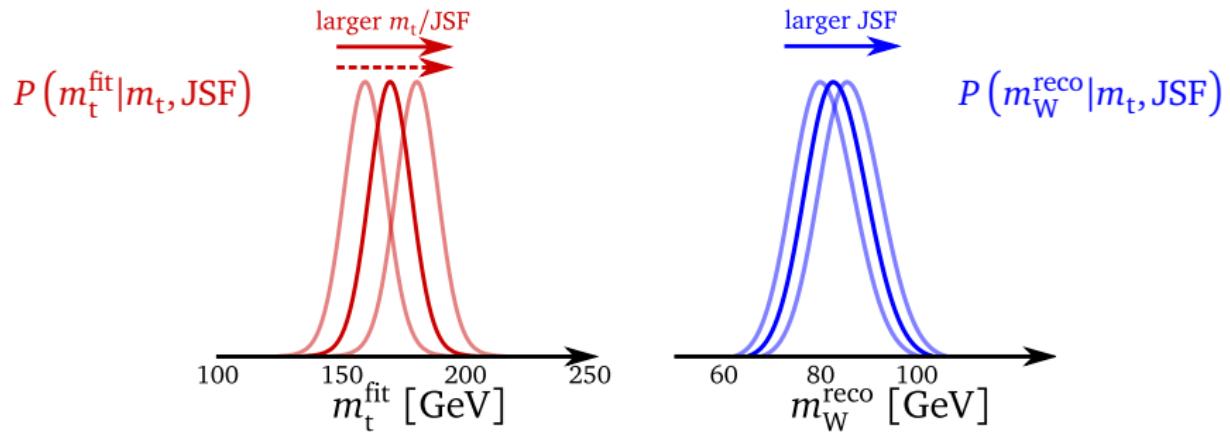


Mass extraction: ideogram method

Estimate m_t and additional jet scale factor (JSF)

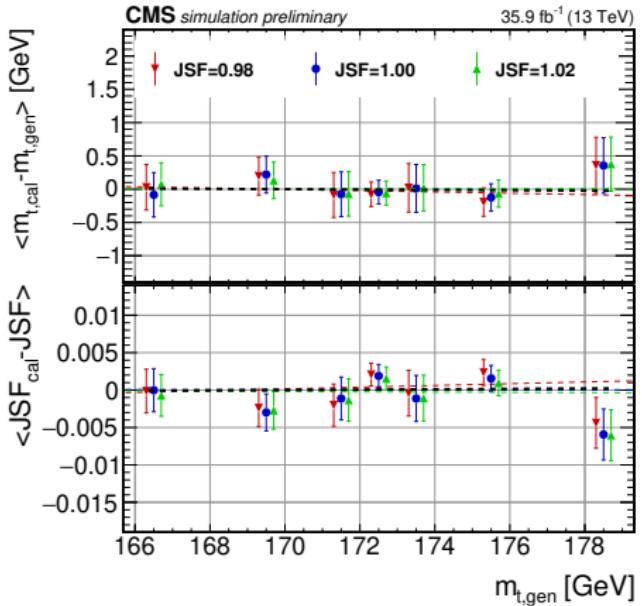
$$P(m_t, \text{JSF} | \text{sample}) \propto P(\text{JSF}) \cdot \mathcal{L}(\text{sample} | m_t, \text{JSF})$$

$$\mathcal{L}(\text{sample} | m_t, \text{JSF}) = \prod_{\text{events}} P(\text{event} | m_t, \text{JSF}) = \prod_{\text{events}} P(m_t^{\text{fit}}, m_W^{\text{reco}} | m_t, \text{JSF})$$



Calibration

perform pseudo-experiments for different generated m_t and JSF



pseudo-experiments also performed for systematic variations

Three versions of ideogram fit:

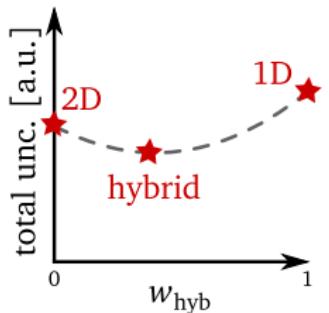
(1D)	only m_t free	$\mathcal{L}(\text{sample} m_t, \text{JSF} = 1)$
(2D)	m_t and JSF free	$\mathcal{L}(\text{sample} m_t, \text{JSF})$
(hybrid)	Gaussian JSF constraint	$\mathbf{P}(\text{JSF}) \cdot \mathcal{L}(\text{sample} m_t, \text{JSF})$

Width of JSF prior probability σ_c can be translated to a “hybrid weight”

$$w = \frac{\sigma_{2\text{D}}^2}{\sigma_{2\text{D}}^2 + \sigma_c^2}$$

“flat” prior: $\sigma_c \rightarrow \infty$: $w \rightarrow 0$ (2D method)

“ δ ” prior: $\sigma_c \rightarrow 0$: $w \rightarrow 1$ (1D method)

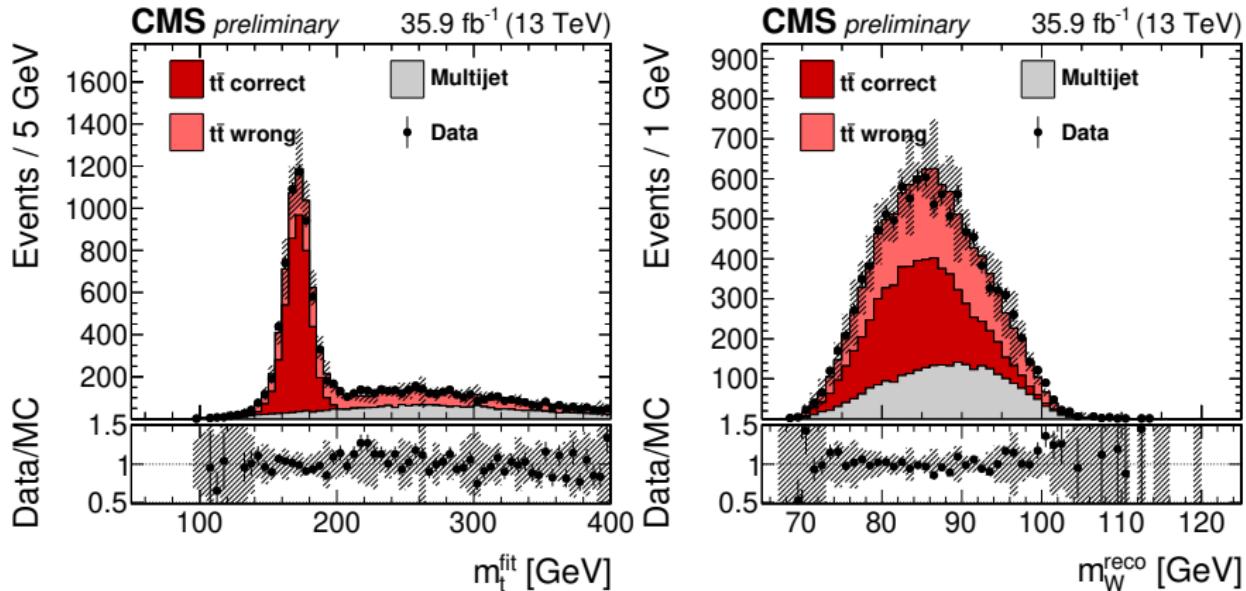


→ choose $w \in [0, 1]$, perform fit with $\sigma_c = \sigma_{2\text{D}} \sqrt{1/w - 1}$

optimal: $w = 0.3$

Result: all-jets

10 799 data events (75% $t\bar{t}$)



$$m_t = 172.34 \pm 0.20 \text{ (stat+JSF)} \pm 0.76 \text{ (syst) GeV}$$

Systematic uncertainties: all-jets

(selection)

	2D	1D	hybrid		
	δm_t^{2D} [GeV]	δJSF^{2D} [%]	δm_t^{1D} [GeV]	δm_t^{hyb} [GeV]	δJSF^{hyb} [%]

Example of cancellation for hybrid result

JEC ("Uncorrelated")	-0.17	-0.3	+0.69	+0.12	+0.2
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Expecting improvement for complete Run II

JEC Flavor	-0.35	+0.1	-0.31	-0.34	+0.0
- bottom	-0.29	-0.0	-0.29	-0.29	-0.0

Independent scale variations (simultaneous in Run I)

Ren. and fact. scale	0.05	0.0	0.04	0.04	0.0
ISR PS scale	$+0.17 \pm 0.17$	-0.2	$+0.13 \pm 0.12$	$+0.12 \pm 0.14$	-0.1
FSR PS scale	$+0.22 \pm 0.12$	-0.2	$+0.11 \pm 0.08$	$+0.18 \pm 0.11$	-0.1

NLO generator (LO in Run I)

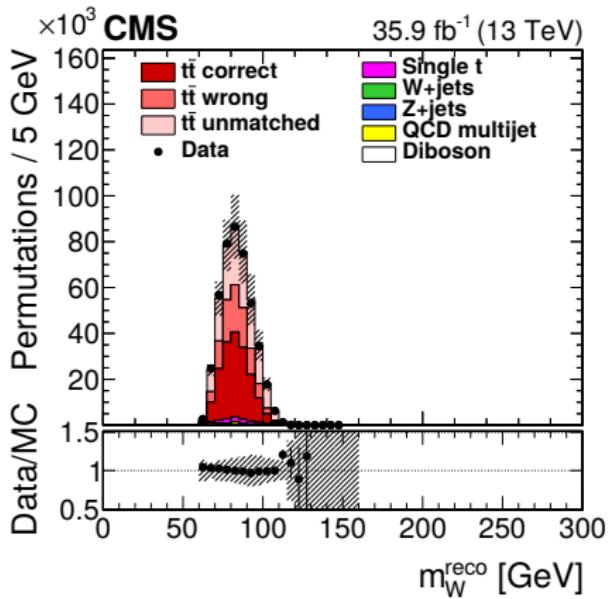
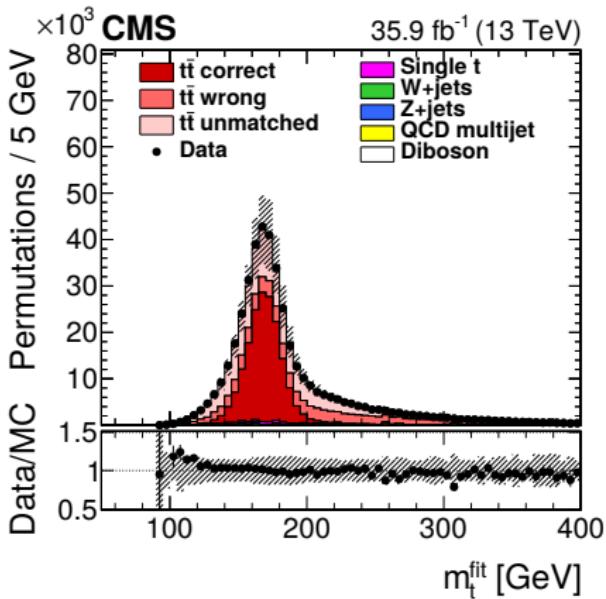
ME/PS matching	$+0.32 \pm 0.20$	-0.3	-0.05 ± 0.14	$+0.24 \pm 0.18$	-0.2
ME generator	$+0.29 \pm 0.34$	+0.1	$+0.36 \pm 0.24$	$+0.31 \pm 0.30$	+0.1

New color reconnection models

Early resonance decays	$+0.02 \pm 0.28$	+0.4	$+0.38 \pm 0.19$	$+0.13 \pm 0.24$	+0.3
CR modeling (max. shift)	$+0.41 \pm 0.29$	-0.4	-0.43 ± 0.20	-0.36 ± 0.25	-0.3
- "gluon move" (ERD on)	$+0.41 \pm 0.29$	-0.4	$+0.10 \pm 0.20$	$+0.32 \pm 0.25$	-0.3
- "QCD inspired" (ERD on)	-0.32 ± 0.29	-0.1	-0.43 ± 0.20	-0.36 ± 0.25	-0.1

Result: $\ell + \text{jets}$

161 496 data events



$$m_t = 172.25 \pm 0.08 (\text{stat+JSF}) \pm 0.62 (\text{syst}) \text{ GeV}$$

Systematic uncertainties: $\ell + \text{jets}$

(selection)

	2D δm_t^{2D} [GeV]	1D δm_t^{1D} [GeV]	hybrid δm_t^{hyb} [GeV]	$\delta \text{JSF}^{\text{hyb}}$ [%]
<i>Expecting improvement for complete Run II</i>				
JEC Flavor	-0.42	+0.1	-0.31	-0.39
- bottom	(-0.32)	(<0.1)	(-0.31)	(-0.32)
<i>Independent scale variations (simultaneous in Run I)</i>				
Ren. and fact. scales	0.02	0.1	0.02	0.01
ISR PS scale	$+0.07 \pm 0.09$	$+0.1$	$+0.10 \pm 0.05$	$+0.06 \pm 0.07$
FSR PS scale	$+0.24 \pm 0.06$	-0.4	-0.22 ± 0.04	$+0.13 \pm 0.05$
<i>NLO generator (LO in Run I)</i>				
ME/PS matching	-0.08 ± 0.09	+0.1	$+0.03 \pm 0.05$	-0.05 ± 0.07
ME generator	$+0.15 \pm 0.23$	+0.2	$+0.32 \pm 0.14$	$+0.20 \pm 0.19$
<i>New color reconnection models</i>				
Early resonance decays	-0.22 ± 0.09	+0.8	$+0.42 \pm 0.05$	-0.03 ± 0.07
Color reconnection	$+0.34 \pm 0.09$	-0.1	$+0.23 \pm 0.06$	$+0.31 \pm 0.08$
- "QCD inspired"	-0.11 ± 0.09	-0.1	-0.19 ± 0.06	-0.13 ± 0.08
- "gluon move"	$+0.34 \pm 0.09$	-0.1	$+0.23 \pm 0.06$	$+0.31 \pm 0.08$

modeling uncertainties description: Emry Clement @LHCtopWG Nov '17 

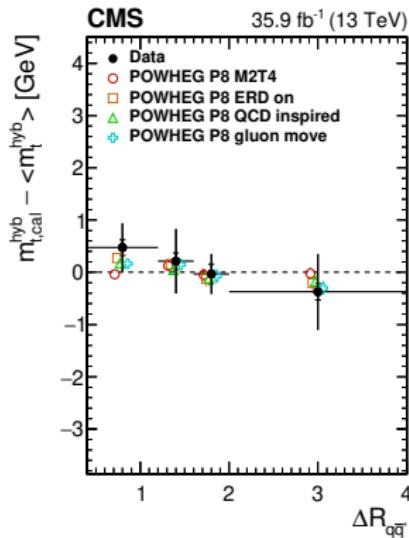
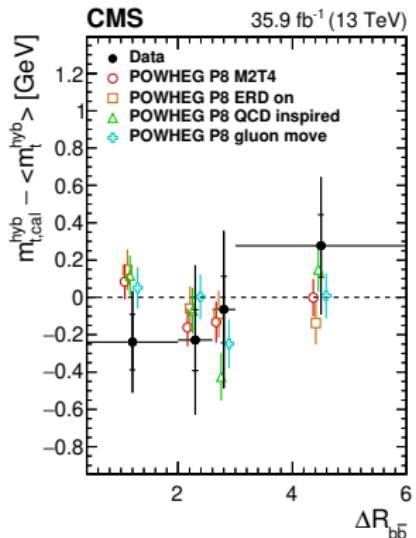
$\ell + \text{jets}$ differential: CR models

new color reconnection (CR) models available in PYTHIA8,
all with “early resonance decays” (ERD)

- default setup
- string formation beyond leading color (“QCD inspired”)
- gluons can be moved to another string (“gluon move”)

[JHEP 1508 (2015) 003]
[JHEP 1411 (2014) 043]

new UE tunes for all models [TOP-17-007]



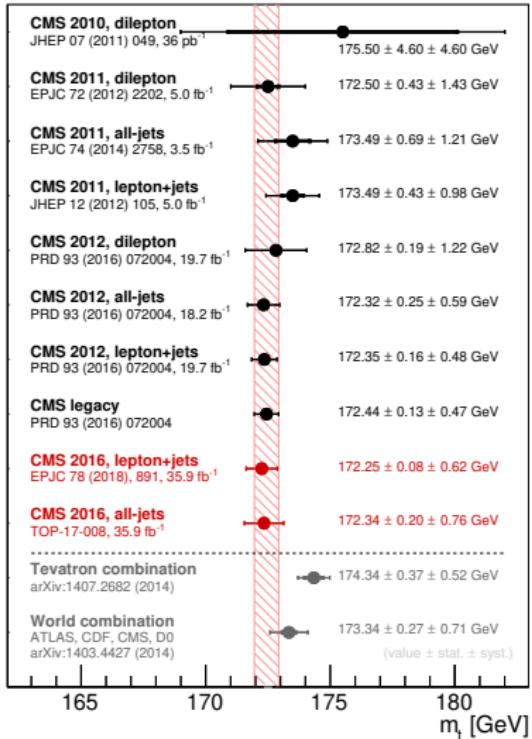
Discussion CR models

Model	χ^2 probability								
	$p_T^{t,\text{had}}$	$m_{t\bar{t}}$	$p_T^{t\bar{t}}$	N_{jets}	$p_T^{b,\text{had}}$	$ \eta^{b,\text{had}} $	$\Delta R_{b\bar{b}}$	$\Delta R_{q\bar{q}'}$	
POWHEG P8 M2T4	0.68	0.94	0.91	0.71	0.98	0.60	0.61	0.70	
POWHEG P8 ERD on	0.75	0.99	0.83	0.53	0.95	0.64	0.38	0.96	
POWHEG P8 QCD inspired	0.80	0.94	0.94	0.66	0.99	0.71	0.49	0.90	
POWHEG P8 gluon move	0.87	0.94	0.93	0.72	0.93	0.51	0.59	0.93	

- no significant discrepancy observed in any differential measurement
- more data might help to exclude models
- dedicated CR studies needed
- theory input necessary to judge which models are meaningful

Summary

November 2018



- two direct m_t measurements in Run II
- NLO generator for calibration
- results compatible with previous measurements
- new color reconnection models:
larger uncertainty than in Run I
→ dedicated analyses needed for future m_t measurements

BACKUP

Systematic uncertainties: all-jets

	2D	1D	hybrid		
	δm_t^{2D} [GeV]	δJSF^{2D} [%]	δm_t^{1D} [GeV]	δm_t^{hyb} [GeV]	δJSF^{hyb} [%]
<i>Experimental uncertainties</i>					
Method calibration	0.06	0.2	0.06	0.06	0.2
JEC (quad. sum)	0.18	0.3	0.73	0.15	0.2
- Intercalibration	-0.04	-0.1	+0.12	-0.04	-0.1
- MPFIinSitu	-0.03	-0.0	+0.22	+0.08	+0.1
- Uncorrelated	-0.17	-0.3	+0.69	+0.12	+0.2
Jet energy resolution	-0.12	+0.4	+0.18	-0.03	+0.3
b tagging	0.02	0.0	0.01	0.02	0.0
Pileup	-0.06	+0.1	+0.00	-0.04	+0.1
Background	0.10	0.1	0.03	0.07	0.1
Trigger	+0.04	-0.1	-0.04	+0.02	-0.1
<i>Modeling of hadronization</i>					
JEC Flavor (linear sum)	-0.35	+0.1	-0.31	-0.34	+0.0
- light quarks (uds)	+0.10	-0.1	-0.01	+0.07	-0.1
- charm	+0.03	-0.0	-0.01	+0.02	-0.0
- bottom	-0.29	-0.0	-0.29	-0.29	-0.0
- gluon	-0.19	+0.2	+0.03	-0.13	+0.2
b jet modeling (quad. sum)	0.09	0.0	0.09	0.09	0.0
- b frag. Bowler-Lund	-0.07	+0.0	-0.07	-0.07	+0.0
- b frag. Peterson	-0.05	+0.0	-0.04	-0.05	+0.0
- semi-leptonic B decays	-0.03	-0.0	-0.03	-0.03	-0.0
<i>Modeling of perturbative QCD</i>					
PDF	0.01	0.0	0.01	0.01	0.0
Ren. and fact. scale	0.05	0.0	0.04	0.04	0.0
ME/PS matching	+0.32±0.20	-0.3	-0.05±0.14	+0.24±0.18	-0.2
ME generator	+0.29±0.34	+0.1	+0.36±0.24	+0.31±0.30	+0.1
ISR PS scale	+0.17±0.17	-0.2	+0.13±0.12	+0.12±0.14	-0.1
FSR PS scale	+0.22±0.12	-0.2	+0.11±0.08	+0.18±0.11	-0.1
Top quark p_T	+0.03	-0.0	+0.02	+0.03	-0.0
<i>Modeling of soft QCD</i>					
Underlying event	+0.16±0.19	-0.3	-0.07±0.14	+0.10±0.17	-0.2
Early resonance decays	+0.02±0.28	+0.4	+0.38±0.19	+0.13±0.24	+0.3
CR modeling (max. shift)	+0.41±0.29	-0.4	-0.43±0.20	-0.36±0.25	-0.3
- "gluon move" (ERD on)	+0.41±0.29	-0.4	+0.10±0.20	+0.32±0.25	-0.3
- "QCD inspired" (ERD on)	-0.32±0.29	-0.1	-0.43±0.20	-0.36±0.25	-0.1
Total systematic	0.88	1.0	1.10	0.76	0.7
Statistical (expected)	0.21	0.2	0.16	0.20	0.1
Total (expected)	0.91	1.0	1.11	0.79	0.7

Systematic uncertainties: $\ell + \text{jets}$

	2D approach	1D approach	Hybrid	
	δm_t^{2D} [GeV]	$\delta \text{JSF}^{\text{2D}}$ [%]	δm_t^{1D} [GeV]	δm_t^{hyb} [GeV]
<i>Experimental uncertainties</i>				
Method calibration	0.05	<0.1	0.05	0.05
JEC (quad. sum)	0.13	0.2	0.83	0.18
- InterCalibration	(−0.02)	(<0.1)	(+0.16)	(+0.04)
- MPFInSitu	(−0.01)	(<0.1)	(+0.23)	(+0.07)
- Uncorrelated	(−0.13)	(+0.2)	(+0.78)	(+0.16)
Jet energy resolution	−0.20	+0.3	+0.09	−0.12
b tagging	+0.03	<0.1	+0.01	+0.03
Pileup	−0.08	+0.1	+0.02	−0.05
Non- $t\bar{t}$ background	+0.04	−0.1	−0.02	+0.02
−0.1				
<i>Modeling uncertainties</i>				
JEC Flavor (linear sum)	−0.42	+0.1	−0.31	−0.39
- light quarks (uds)	(+0.10)	(−0.1)	(−0.01)	(+0.06)
- charm	(+0.02)	(<0.1)	(−0.01)	(+0.01)
- bottom	(−0.32)	(<0.1)	(−0.31)	(−0.32)
- gluon	(−0.22)	(+0.3)	(+0.02)	(−0.15)
b jet modeling (quad. sum)	0.13	0.1	0.09	0.12
- b frag. Bowler-Lund	(−0.07)	(+0.1)	(−0.01)	(−0.05)
- b frag. Peterson	(+0.04)	(−0.1)	(+0.05)	(+0.04)
- semileptonic B decays	(+0.11)	(<0.1)	(+0.08)	(+0.10)
PDF	0.02	<0.1	0.02	0.02
Ren. and fact. scales	0.02	0.1	0.02	0.01
ME/PS matching	-0.08 ± 0.09	+0.1	$+0.03 \pm 0.05$	-0.05 ± 0.07
ME generator	$+0.15 \pm 0.23$	+0.2	$+0.32 \pm 0.14$	$+0.20 \pm 0.19$
ISR PS scale	$+0.07 \pm 0.09$	+0.1	$+0.10 \pm 0.05$	$+0.06 \pm 0.07$
FSR PS scale	$+0.24 \pm 0.06$	−0.4	-0.22 ± 0.04	$+0.13 \pm 0.05$
Top quark p_T	+0.02	−0.1	−0.06	−0.01
Underlying event	-0.10 ± 0.08	+0.1	$+0.01 \pm 0.05$	-0.07 ± 0.07
Early resonance decays	-0.22 ± 0.09	+0.8	$+0.42 \pm 0.05$	-0.03 ± 0.07
Color reconnection	$+0.34 \pm 0.09$	−0.1	$+0.23 \pm 0.06$	$+0.31 \pm 0.08$
Total systematic	0.75	1.1	1.10	0.62
Statistical (expected)	0.09	0.1	0.06	0.08
Total (expected)	0.76	1.1	1.10	0.63
				0.8

Compatibility of different models with the differential measurement of the top quark mass. For each variable and model, the probability of the cumulative χ^2 is computed. The setup with POWHEG v2 + HERWIG++ does not use ME corrections to the top quark decay and shows large deviations from the data.

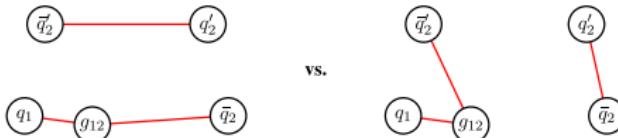
Model	χ^2 probability							
	$p_T^{t,\text{had}}$	$m_{t\bar{t}}$	$p_T^{t\bar{t}}$	N_{jets}	$p_T^{b,\text{had}}$	$ \eta^{b,\text{had}} $	$\Delta R_{b\bar{b}}$	$\Delta R_{q\bar{q}'}$
POWHEG P8 M2T4	0.68	0.94	0.91	0.71	0.98	0.60	0.61	0.70
MG5 P8 [FxFx] M2T4	0.98	0.78	0.93	0.94	0.80	0.35	0.94	0.91
MG5 P8 [MLM] M1	0.48	0.84	0.99	0.41	0.98	0.17	0.71	0.61
POWHEG H++ EE5C	0.07	2×10^{-13}	0.52	0.72	2×10^{-4}	0.55	0.36	2×10^{-5}
POWHEG P8 ERD on	0.75	0.99	0.83	0.53	0.95	0.64	0.38	0.96
POWHEG P8 QCD inspired	0.80	0.94	0.94	0.66	0.99	0.71	0.49	0.90
POWHEG P8 gluon move	0.87	0.94	0.93	0.72	0.93	0.51	0.59	0.93

default model

- probability for parton pair to reconnect
- low- p_T pairs more likely to reconnect

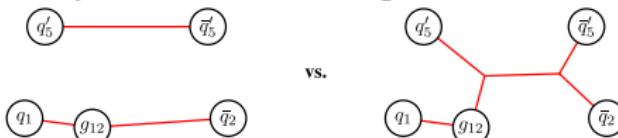
QCD inspired

- can reconnect all pairs of QCD dipoles considering QCD color rules



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- also junction structures possible:



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gluon move

- gluons (= “kinks”) can be moved from one color string to another one to minimize string length

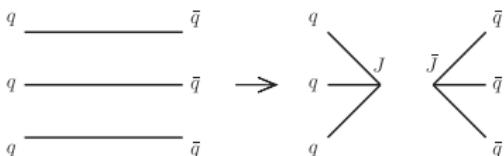
CR models: QCD inspired



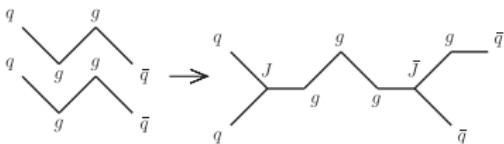
(a) Type I: ordinary dipole-style reconnection



(b) Type II: junction-style reconnection



(c) Type III: baryon-style junction reconnection



(d) Type IV: zipper-style junction reconnection

CR models: gluon move

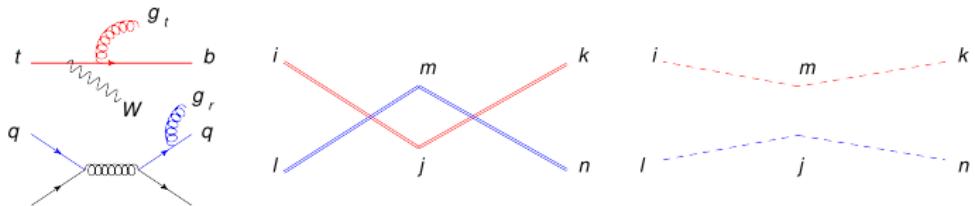


Figure 1. An example of a gluon emitted from a top decay product g_t exchanging colors with a gluon from another interaction g_r . A possible string configuration for this final state is shown on the right. The gluons g_t, g_r are identified with the kinks j, m respectively, while the top and bottom quarks and the incoming and outgoing q from the additional interaction are identified with the string endpoints i, k, l and n respectively. The double lines indicate the configuration that results from the perturbative color flow and the dashed lines indicate a configuration with a smaller λ , resulting from the exchange of colors and anticolors between gluons j and m .

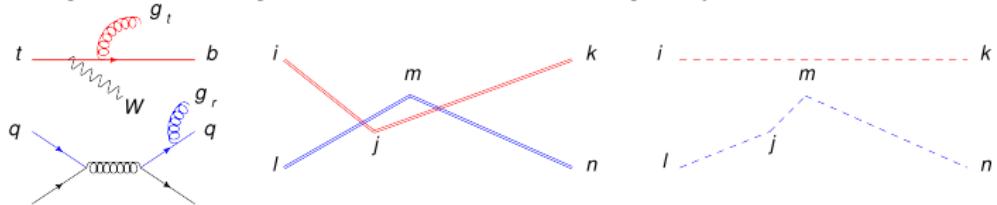


Figure 2. In the ‘move’ model, a gluon j originally attached to string piece ik can be moved to a different string piece lm if it leads to a smaller total string length λ . Solid lines indicate the original configuration and dashed lines indicate the resulting configuration after moving the gluon.