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TOP2016 Highlights: Properties+Mass

Hartmut Stadie

10 October 2016

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Outline

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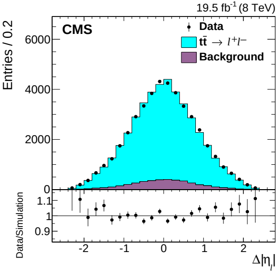
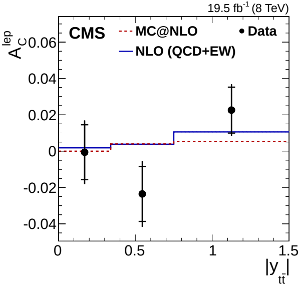
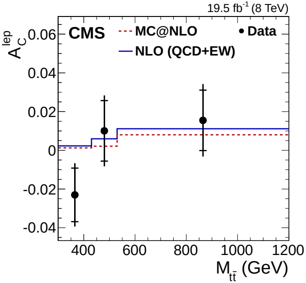
Charge asymmetry

- unfold in $t\bar{t}$ events with two leptons $\Delta|\eta_{t/\ell}| = |\eta_{t/\ell^+}| - |\eta_{\bar{t}/\ell^-}|$
- $A_C = \frac{N(\Delta|\eta|>0)-N(\Delta|\eta|<0)}{N(\Delta|\eta|>0)+N(\Delta|\eta|<0)}$
- result:
  $A_C^{\text{lep}} = 0.011 \pm 0.011 \pm 0.007(QCD + EW(NLO) : 0.0111 \pm 0.0004)$
  $A_C^{\text{lep}} = 0.003 \pm 0.006 \pm 0.003(QCD + EW(NLO) : 0.0064 \pm 0.0003)$







Phys. Lett. B 760 (2016) 365

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Spin Correlation

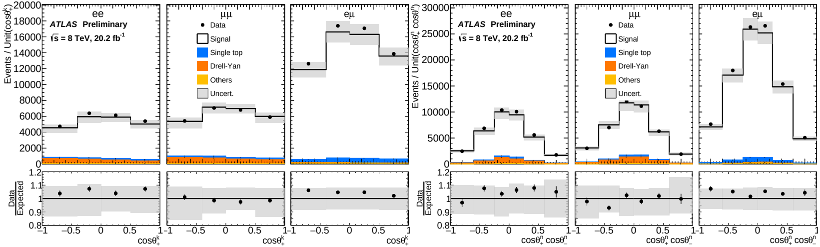
$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta^a_+\, d\cos\theta^b_-} = \frac{1}{4}\left(1 + B^a_+\cos\theta^a_+ + B^b_-\cos\theta^b_- - C(a,b)\cos\theta^a_+\cos\theta^b_-\right)$$

B,C: polarization, spin correlation

a,b: spin quantization axes

θ: angle between axis and momentum of decay particle in top quark rest frame

$+$,$-$: top quark or anti-quark



ATLAS-CONF-2016-099

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Spin Correlation

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_+^a\, d\cos\theta_-^b} = \frac{1}{4}\left(1 + B_+^a\cos\theta_+^a + B_-^b\cos\theta_-^b - C(a,b)\cos\theta_+^a\cos\theta_-^b\right)$$

B,C: polarization, spin correlation

a,b: spin quantization axes

θ: angle between axis and momentum of decay particle in top quark rest frame

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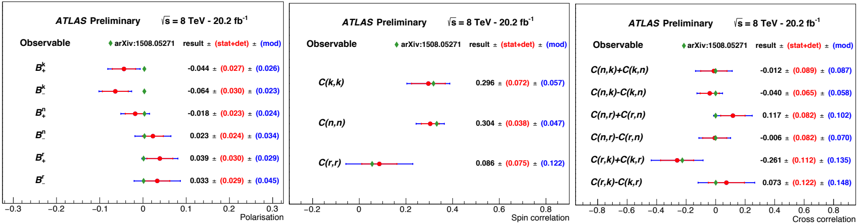

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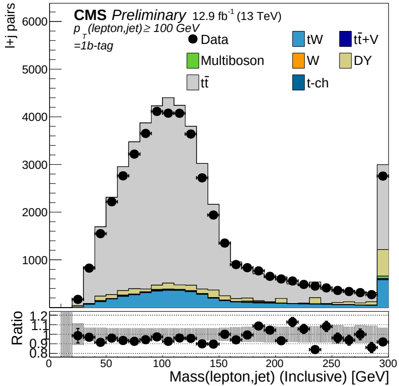
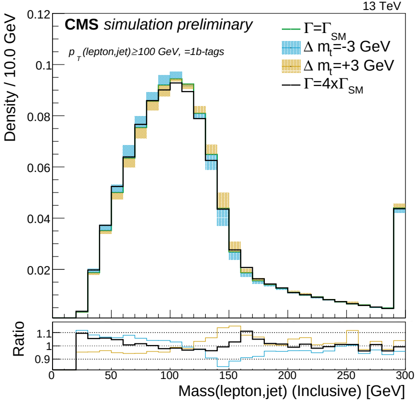
Top quark width I

- dilepton $t\bar{t}$ selection in 12.9 fb^{-1} 13 TeV data
- observable: $m_{\ell b}$





CMS PAS TOP-16-019

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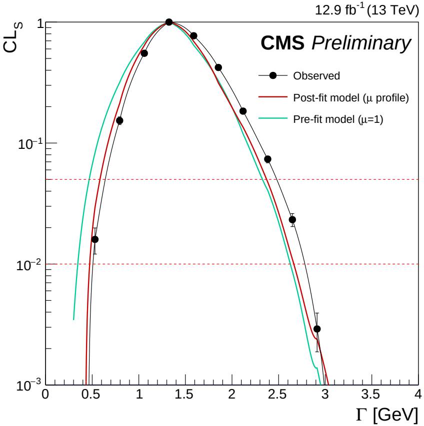
Top quark width II

Method:

- likelihood for different Γ_t with nuisances
- limit on SM width with CL_S

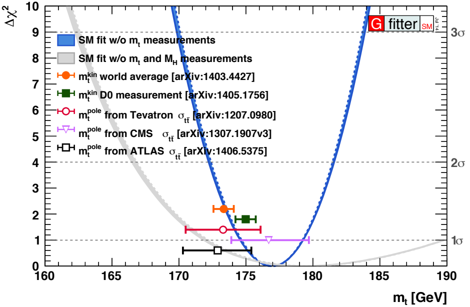
Result:

measured: $0.6 \leq \Gamma_t \leq 2.5$ GeV @ 95% CL
expected: $0.6 \leq \Gamma_t \leq 2.4$ GeV @ 95% CL
CDF: $\Gamma_t \leq 6.38$ GeV @ 95% CL (PRL 111 (2012) 202001)

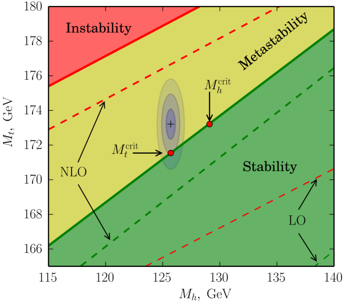


CMS PAS TOP-16-019

Top mass



(Gfitter)



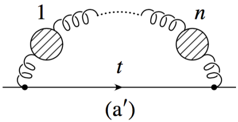
(Bednyakov, 1609.02503)

Top mass measurements

- colored object: pole mass not well defined
- direct measurements rely on MC (parton shower), not theo. computable
- indirect measurements experimentally less precise

Top mass ambiguity

- Pole mass defined by an asymptotic series

$\sum_{n=0}^{\infty}$ 

$$\Sigma^{(1)}(m_R, a) = \frac{16 m_R}{3\beta_0} \sum_{n=0}^{\infty} c_n a^{n+1}$$

$$c_n \overset{n\to\infty}{\longrightarrow} e^{-C/2} 2^n n!$$

$$a \equiv \frac{\beta_0 \alpha_s(m_R)}{4\pi}$$

- **Renormalon ambiguity: the series is not Borel summable**
- Ambiguity proportional to Λ_{QCD} , but with what coefficient ?
- Relation to MS mass up to 4-loops

$$m_P = 163.643 + 7.557 + 1.617 + 0.501 + (0.195 \pm 0.005)\,\text{GeV}$$

Marquard, Smirnov, Smirnov, Steinhauser `15

- Most recent estimate of the ambiguity

$$\delta^{(5+)} m_P = 0.250^{+0.015}_{-0.038}\,(N) \pm 0.001\,(c_4) \pm 0.010\,(\alpha_s) \pm 0.071\,(\text{ambiguity})\,\text{GeV}$$

Beneke, Marquard, Nason, Steinhauser arXiv:1605.03609

Czakon

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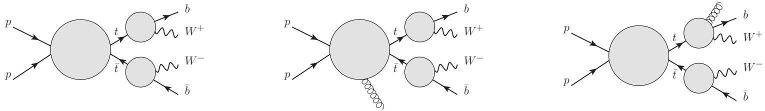
Top mass and MC I

Monte Carlo simulations with higher-order $pp \to WWb\bar{b}$ matrix elements

- well defined m_t^{pole} input (no MC mass!)
- systematic precision improvements in $m_t^{\text{pole}} \leftrightarrow$ observables



Resonance aware Powheg matching [Jezo and Nason, 1509.09071]

- **guiding principle:** respects on-shellness and all-order factorisation of top production×decay for $\Gamma_t \to 0$

$\Rightarrow$ assign radiation to top production or decays consistent with $\Gamma_t \to 0$ limit

$\Rightarrow$ modified NLO+PS approach to preserve resonance virtualities at all stages

see analogous approach in MC@NLO [Frederix et al, 1603.01178]

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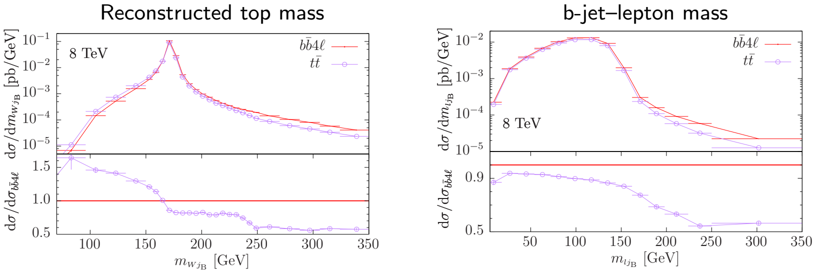
New MC: $t\bar{t} \to b\bar{b}4\ell$



$t\bar{t} \to b\bar{b}4\ell$ wrt $t\bar{t}$

- difference in peak position of m_{Wb}
- difference in tail $m_{\mathrm{b}\ell}$

Better modeling uncertainties in top mass observables in dilepton channel

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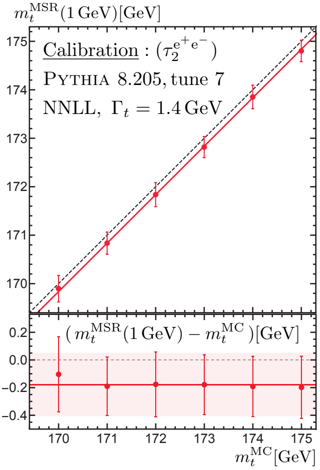
Top mass and MC II

Method:

compare hadron level QCD prediction of 2-jettiness in e^+e^- with MC

$m_t^{\mathrm{MC}} = 173\,\mathrm{GeV} \quad (\tau_2^{e^+e^-})$

mass	order	central	perturb.	incompatibility	total
$m_{t,1\,\mathrm{GeV}}^{\mathrm{MSR}}$	NLL	172.80	0.26	0.14	0.29
$m_{t,1\,\mathrm{GeV}}^{\mathrm{MSR}}$	$\mathrm{N^2LL}$	172.82	0.19	0.11	0.22
m_t^{pole}	NLL	172.10	0.34	0.16	0.38
m_t^{pole}	$\mathrm{N^2LL}$	172.43	0.18	0.22	0.28



1608.01318, Preisser

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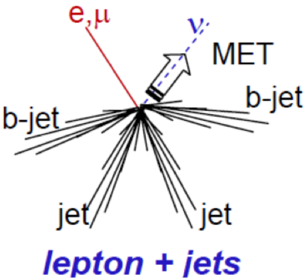
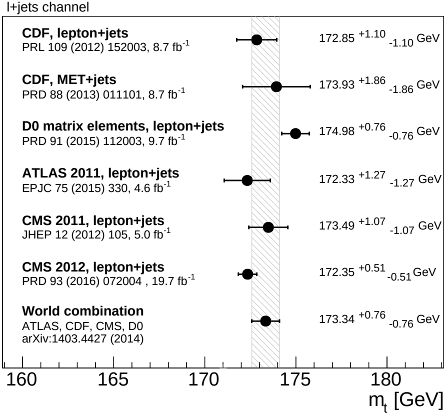
ℓ+jets Channel





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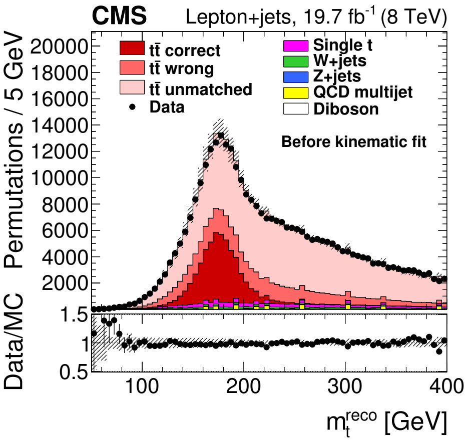
Kinematic Fit

- split in 3 permutation classes:
  - correct
  - wrong
    flipped *b*-quarks, mistags
  - unmatched
    no unambiguous match
- kinematic fit:
  - two untagged jets:
    $m_{\mathrm{jj}} = 80.4$ GeV
  - lepton and neutrino ($\not{E}_T$)
    $m_{\ell\nu} = 80.4$ GeV
  - combine with two b-tagged jets:
    $m_{\mathrm{jjb}_1} = m_{\ell\nu\mathrm{b}_2}$



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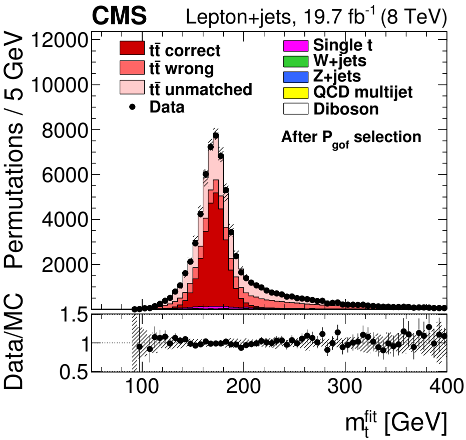

$P_{\mathrm{gof}} > 0.2$ & weight permutations by P_{gof}: $f_{cp} = 13\% \rightarrow 44\%$

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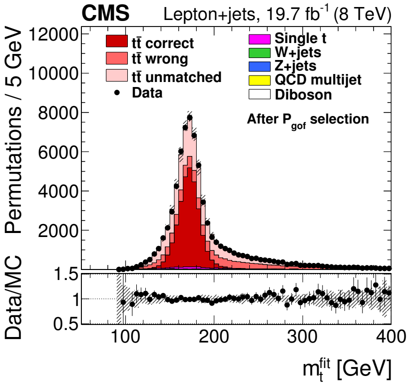
Ideogram Method

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



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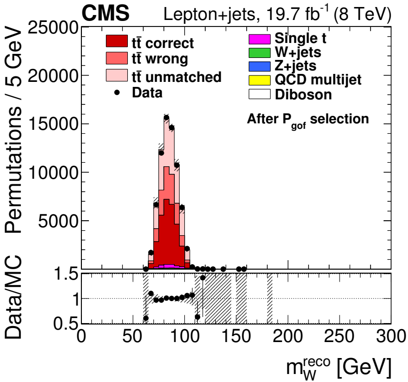

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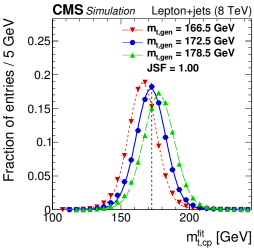
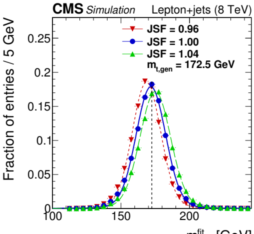
- input: $m^\text{fit}_{t,i}$ and $m^\text{reco}_{\text{W},i}$
- use all allowed permutations i per event
- $P_i = \sum_j f_j P_j \left(m^\text{fit}_{t,i}|m_\text{t}, \text{JSF}\right) \cdot P_j\left(m^\text{reco}_{\text{W},i}|m_\text{t}, \text{JSF}\right)$





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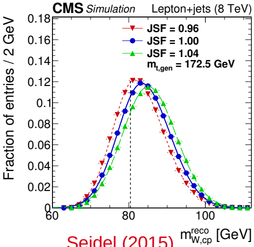
no dependence on $m_{\text{t,gen}}$



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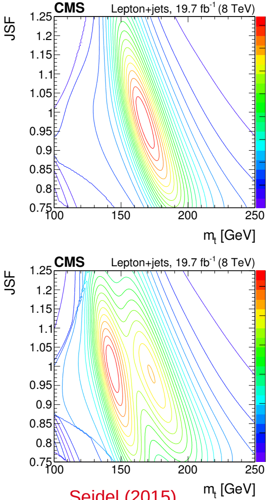
- final ideogram: combine P_i and weight event by sum of fit probabilities



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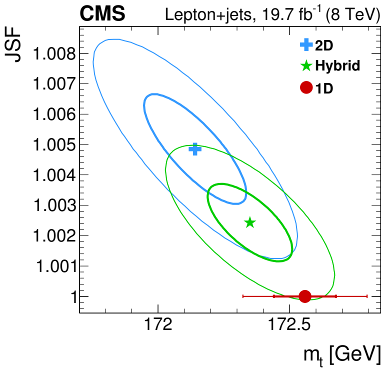

- combine all ideograms and extract m_t and JSF after calibration

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Hybrid Method

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

Shifts with sign:

	δm_t^{2D}(GeV)	δJSF	δm_t^{1D}(GeV)	δm_t^{hyb}(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

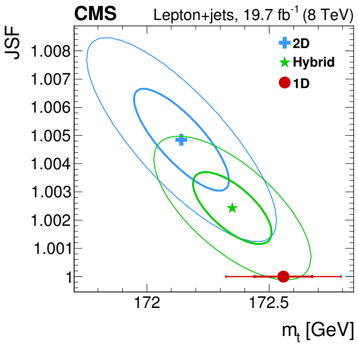
Solution: hybrid method

Add JSF-prior to likelihood to include jet calibration measurements

Result on Data

Result with 28 295 selected events in ℓ+jets channel, 19.7 fb^{-1}

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



	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

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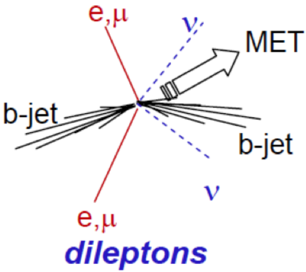
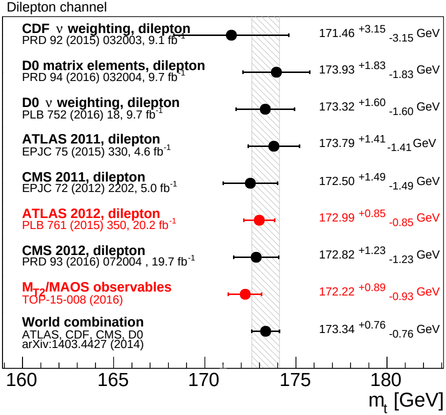
Dilepton channel





New ATLAS and CMS results with run 1 data

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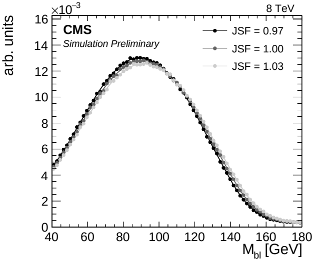
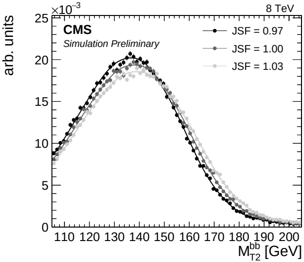
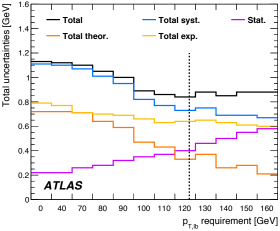
Dilepton channel





- ATLAS optimize selection:
  $m_t = 172.99 \pm 0.41\,(\text{stat.}) \pm 0.74\,(\text{syst.})$ GeV
- CMS 2D hybrid:
  $m_t = 172.22 \pm 0.18\,(\text{stat.})\,^{+0.89}_{-0.93}\,(\text{syst.})$ GeV



Phys.Lett. B761 (2016) 350, CMS PAS TOP-15-008

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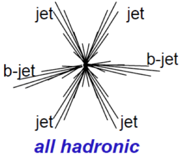
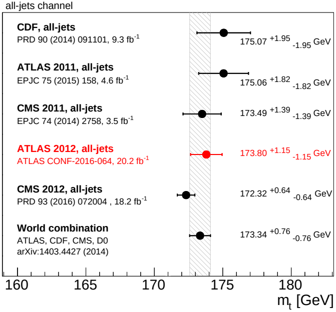
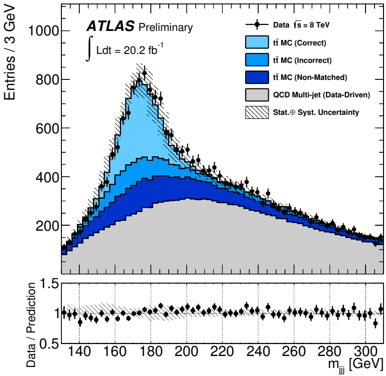
All-jets channel







main uncertainties (GeV):
PS(hadr.) 0.64, JES 0.60, stat 0.55,
bJES 0.34

ATLAS-CONF-2016-064

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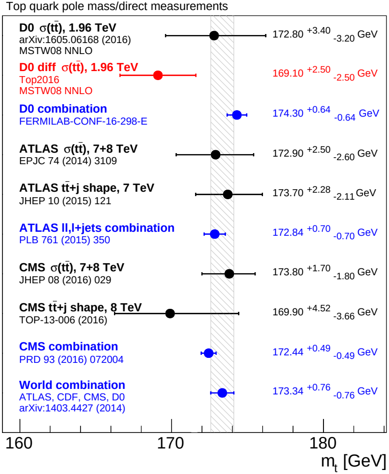
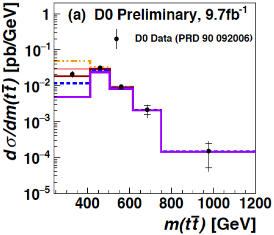
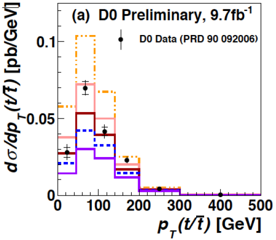
Mass from σ







D0 prel.

Conclusions

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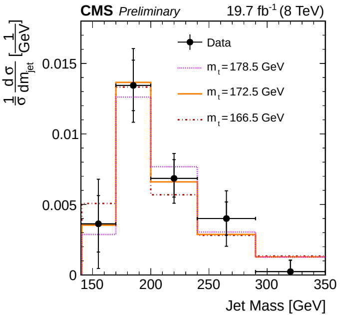
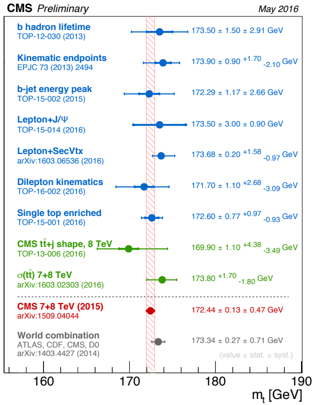
Summary

- test of $t\bar{t}$ production mechanism
- direct measurement of mass and width
- crucial: theory understanding, MC

repeat successful program from run 1





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