

Top mass measurements at CMS

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Particle Physics Day 12.10.2023 Jyväskylä

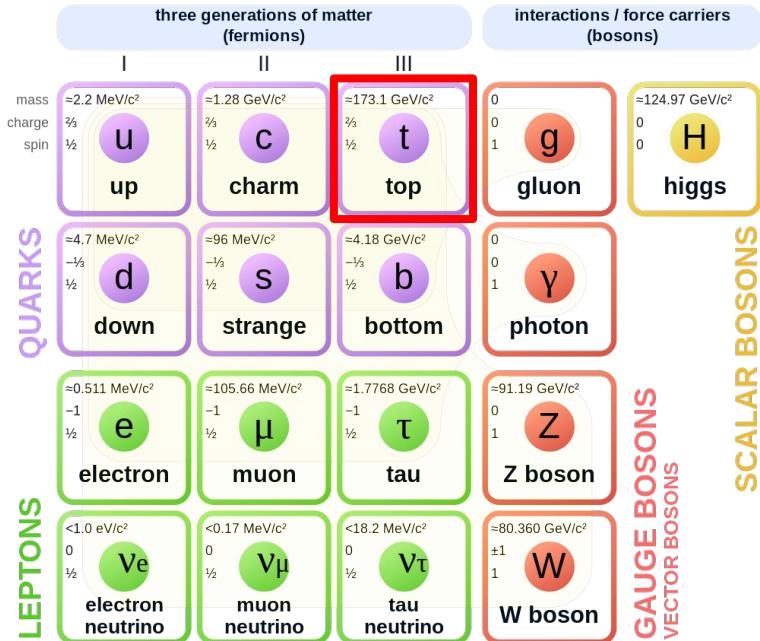


"Funded/Co-funded by the European Union (ERC, JEC4HL-LHC, 101043975). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Council. Neither the European Union nor the granting authority can be held responsible for them."

Motivation

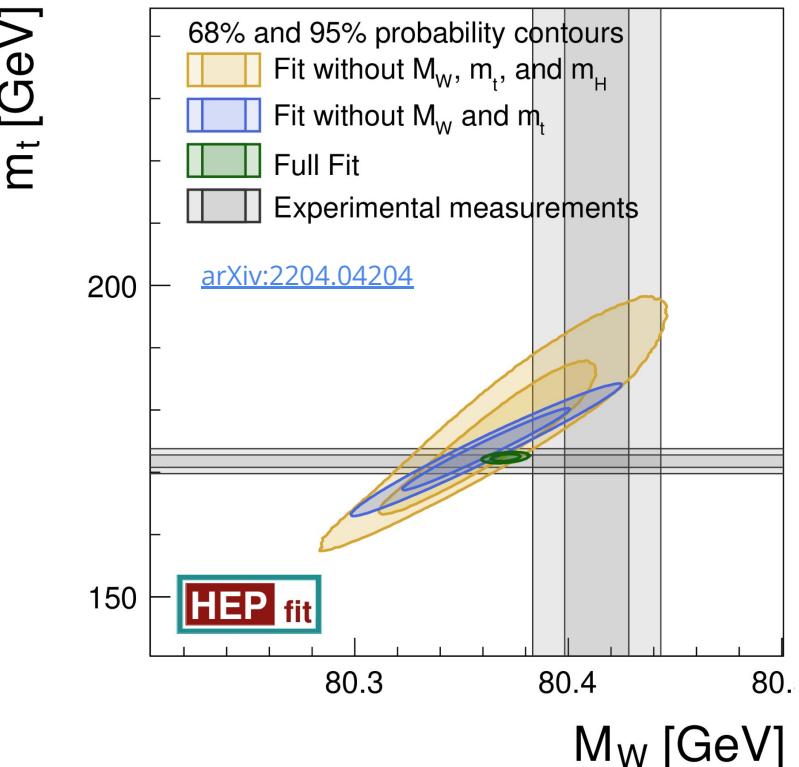
- Top quark is the heaviest elementary particle
 - top mass is a significant parameter in the SM
 - connection to Higgs physics and BSM physics

Standard Model of Elementary Particles



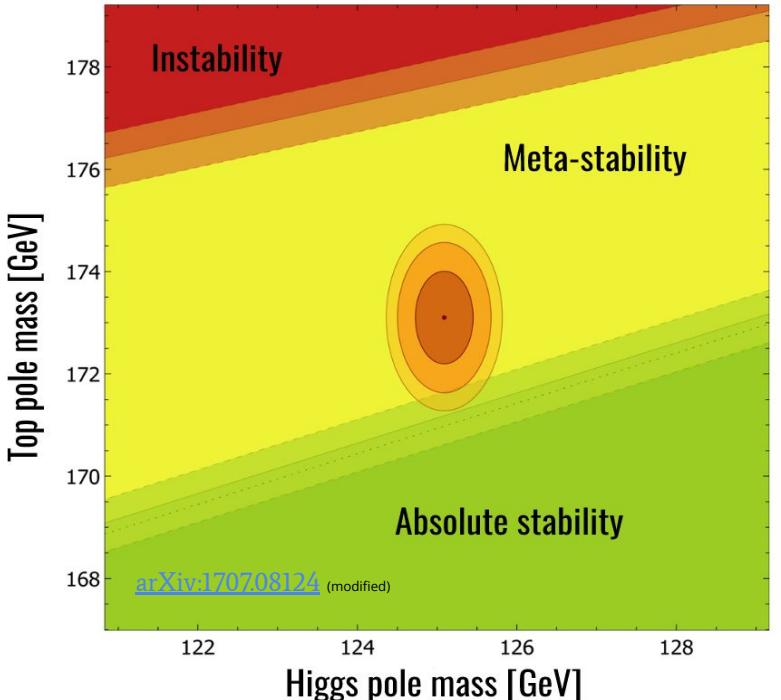
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- Global EW fits → SM consistency



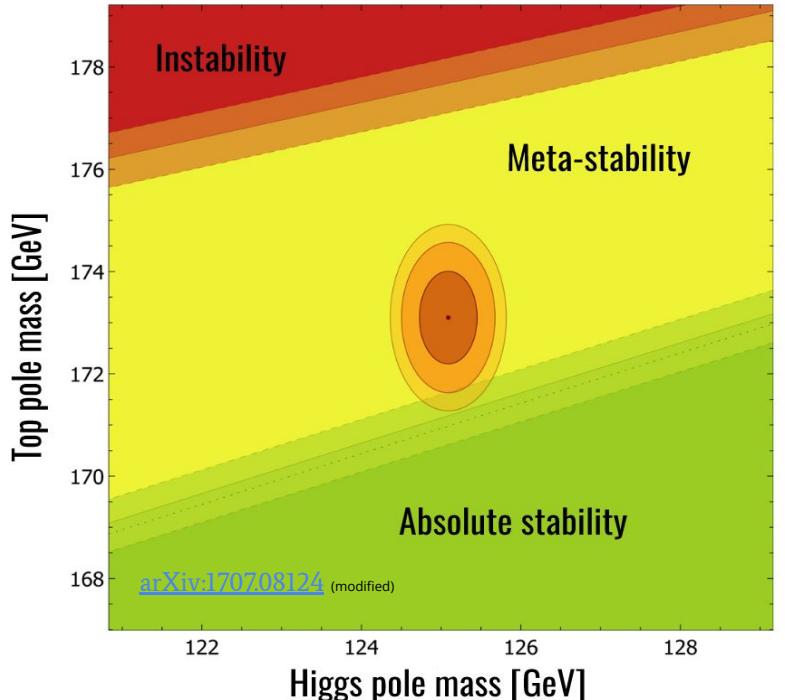
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- Top quark is the heaviest elementary particle
 - top mass is a significant parameter in the SM
 - connection to Higgs physics and BSM physics
- Global EW fits → SM consistency
- Stability of the EW vacuum
 - “To rule out absolute stability to 3σ confidence, the uncertainty on the top quark pole mass would have to be pushed below 250 MeV” [arxiv:1707.08124](https://arxiv.org/abs/1707.08124)



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- Global EW fits → SM consistency
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 - “To rule out absolute stability to 3σ confidence, the uncertainty on the top quark pole mass would have to be pushed below 250 MeV” [arxiv:1707.08124](https://arxiv.org/abs/1707.08124)
- Challenges
 - $t\bar{t}$ modelling
 - jet energy scale
 - b-quark fragmentation
 - final state radiation



Direct measurements m_t^{MC}

→ reconstruct invariant mass from decay products

ATLAS+CMS Preliminary
LHCtopWG

..... World comb. (Mar 2014) [2]
stat
total uncertainty

LHC comb. (Sep 2013) LHCtopWG

World comb. (Mar 2014)

ATLAS, I+jets

ATLAS, dilepton

ATLAS, all jets

ATLAS, single top

ATLAS, dilepton

ATLAS, all jets

ATLAS, I+jets

ATLAS comb. (Oct 2018)

ATLAS, leptonic invariant mass

ATLAS, dilepton (*)

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CMS, boosted

* Preliminary

m_{top} summary, $\sqrt{s} = 7\text{-}13 \text{ TeV}$

June 2023

total stat

$m_{\text{top}} \pm \text{total (stat} \pm \text{syst} \pm \text{recoil)}$

\sqrt{s} Ref.

173.29 ± 0.95 (0.35 ± 0.88)	7 TeV [1]
173.34 ± 0.76 (0.36 ± 0.67)	1.96-7 TeV [2]
172.33 ± 1.27 (0.75 ± 1.02)	7 TeV [3]
173.79 ± 1.41 (0.54 ± 1.30)	7 TeV [3]
175.1 ± 1.8 (1.4 ± 1.2)	7 TeV [4]
172.2 ± 2.1 (0.7 ± 2.0)	8 TeV [5]
172.99 ± 0.85 (0.41 ± 0.74)	8 TeV [6]
173.72 ± 1.15 (0.55 ± 1.01)	8 TeV [7]
172.08 ± 0.91 (0.39 ± 0.82)	8 TeV [8]
172.69 ± 0.48 (0.25 ± 0.41)	7+8 TeV [8]
174.41 ± 0.81 (0.39 ± 0.66 ± 0.25)	13 TeV [9]
172.21 ± 0.80 (0.20 ± 0.67 ± 0.39)	13 TeV [10]
173.49 ± 1.06 (0.43 ± 0.97)	7 TeV [11]
172.50 ± 1.52 (0.43 ± 1.46)	7 TeV [12]
173.49 ± 1.41 (0.69 ± 1.23)	7 TeV [13]
172.35 ± 0.51 (0.16 ± 0.48)	8 TeV [14]
172.82 ± 1.23 (0.19 ± 1.22)	8 TeV [14]
172.32 ± 0.64 (0.25 ± 0.59)	8 TeV [14]
172.95 ± 1.22 (0.77 ± 0.95)	8 TeV [15]
172.44 ± 0.48 (0.13 ± 0.47)	7+8 TeV [14]
172.25 ± 0.63 (0.08 ± 0.62)	13 TeV [16]
172.33 ± 0.70 (0.14 ± 0.69)	13 TeV [17]
172.34 ± 0.73 (0.20 ± 0.70)	13 TeV [18]
172.13 ± 0.77 (0.32 ± 0.70)	13 TeV [19]
171.77 ± 0.37	13 TeV [20]
172.76 ± 0.81 (0.22 ± 0.78)	13 TeV [21]

[1] ATLAS-CONF-2013-102
[2] arXiv:1403.4427
[3] EPJC 75 (2015) 330
[4] EPJC 75 (2015) 158
[5] JHEP 12 (2015) 055
[6] PLB 761 (2016) 350
[7] JHEP 09 (2017) 118

[8] EPJC 79 (2019) 290
[9] arXiv:2209.0583
[10] ATLAS-CONF-2022-058
[11] JHEP 12 (2012) 105
[12] EPJC 75 (2015) 1902
[13] EPJC 74 (2014) 2758
[14] PRD 93 (2016) 072004
[15] arXiv:2302.01967
[16] arXiv:2211.01456

[17] EPJC 78 (2018) 891
[18] EPJC 79 (2019) 313
[19] EPJC 79 (2019) 150
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Indirect measurements m_t^{pole}

→ measure observable sensitive to mass e.g. cross-section

ATLAS+CMS Preliminary
LHCtopWG

m_{top} from cross-section measurements
June 2023

Ref.

$\sigma(t\bar{t})$ inclusive, NNLO+NNLL

ATLAS, 7+8 TeV	172.9 ^{+2.5} _{-2.6}	[1]
CMS, 7+8 TeV	173.8 ^{+1.7} _{-1.8}	[2]
CMS, 13 TeV	169.9 ^{+1.9} _{-2.1} (0.1 ± 1.5 ^{+1.2} _{-1.5})	[3]
ATLAS, 13 TeV	173.1 ^{+2.0} _{-2.1}	[4]
LHC comb., 7+8 TeV	173.4 ^{+1.8} _{-2.0}	[5]

$\sigma(t\bar{t}+1j)$ differential, NLO

ATLAS, 7 TeV	173.7 ^{+2.3} _{-2.1} (1.5 ± 1.4 ^{+1.0} _{-0.5})	[6]
CMS, 8 TeV (*)	169.9 ^{+4.5} _{-3.7} (1.1 ± 2.5 ^{+3.6} _{-3.1} ^{-1.6} _{-0.7})	[7]
ATLAS, 8 TeV	171.1 ^{+1.2} _{-1.0} (0.4 ± 0.9 ^{+0.7} _{-0.3})	[8]
CMS, 13 TeV	172.9 ^{+1.4} _{-1.3} (1.3 ± 0.5 ^{+0.5} _{-0.4})	[9]

$\sigma(t\bar{t})$ n-differential, NLO

ATLAS, n=1, 8 TeV	173.2 ^{+1.6} _{-1.6} ($0.9 \pm 0.8 \pm 1.2$)	[10]
CMS, n=3, 13 TeV	170.5 ^{± 0.8}	[11]

m_{top} from top quark decay

CMS, 7+8 TeV comb. [10]	[1] EPJC 74 (2014) 3109 [2] JHEP 08 (2016) 029 [3] EPJC 79 (2019) 368 [4] EPJC 80 (2020) 528 [5] arXiv:2205.13830	[6] JHEP 10 (2015) 121 [7] CMS-PAS-TOP-13-006 [8] JHEP 11 (2019) 150 [9] arXiv:2207.02270 [10] EPJC 77 (2017) 804 [11] EPJC 80 (2020) 658
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* Preliminary

155 160 165 170 175 180 185 190
 m_{top} [GeV]

170 175

175 180

180 185

[LHCWG summary plots](#)

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+8 TeV	$172.9^{+2.5}_{-2.6}$	[1]
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TeV	$169.9^{+1.9}_{-2.1} (0.1 \pm 1.5^{+1.2}_{-1.5})$	[3]
3 TeV	$173.1^{+2.0}_{-2.1}$	[4]
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differential, NLO

TeV	$173.7^{+2.3}_{-2.1} (1.5 \pm 1.4^{+1.0}_{-0.5})$	[6]
eV (*)	$169.9^{+4.5}_{-3.7} (1.1^{+2.5}_{-3.1} +3.6_{-1.6})$	[7]
TeV	$171.1^{+1.2}_{-1.0} (0.4 \pm 0.9^{+0.7}_{-0.3})$	[8]
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m_{top} from top quark decay

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- [362] EPJC 79 (2019) 313
- [363] EPJC 79 (2019) 313
- [364] EPJC 79 (2019) 313
- [365] EPJC 79 (2019) 313
- [366] EPJC 79 (2019) 313
- [367] EPJC 79 (2019) 313
- [368] EPJC 79 (2019) 313
- [369] EPJC 79 (2019) 313
- [370] EPJC 79 (2019) 313
- [371] EPJC 79 (2019) 313
- [372] EPJC 79 (2019) 313
- [373] EPJC 79 (2019) 313
- [374] EPJC 79 (2019) 313
- [375] EPJC 79 (2019) 313
- [376] EPJC 79 (2019) 313
- [377] EPJC 79 (2019) 313
- [378] EPJC 79 (2019) 313
- [379] EPJC 79 (2019) 313
- [380] EPJC 79 (2019) 313
- [381] EPJC 79 (2019) 313
- [382] EPJC 79 (2019) 313
- [383] EPJC 79 (2019) 313
- [384] EPJC 79 (2019) 313
- [385] EPJC 79 (2019) 313
- [386] EPJC 79 (2019) 313
- [387] EPJC 79 (2019) 313
- [388] EPJC 79 (2019) 313
- [389] EPJC 79 (2019

Direct measurements m_t^{MC}

→ reconstruct invariant mass from decay products

ATLAS+CMS Preliminary
LHCtopWG

..... World comb. (Mar 2014) [2]
stat
total uncertainty

LHC comb. (Sep 2013) LHCtopWG

World comb. (Mar 2014)

ATLAS, I+jets

ATLAS, dilepton

ATLAS, all jets

ATLAS, single top

ATLAS, dilepton

ATLAS, all jets

ATLAS, I+jets

ATLAS comb. (Oct 2018)

ATLAS, leptonic invariant mass

ATLAS, dilepton (*)

CMS, I+jets

CMS, dilepton

CMS, all jets

CMS, I+jets

CMS, dilepton

CMS, all jets

CMS, single top

CMS comb. (Sep 2015)

CMS, I+jets

CMS, dilepton

CMS, all jets

CMS, single top

CMS, I+jets

CMS, boosted

* Preliminary

m_{top} summary, $\sqrt{s} = 7\text{-}13 \text{ TeV}$

June 2023

total stat

m_{top} ± total (stat ± syst ± recoil)

\sqrt{s} Ref.

7 TeV [1]	173.29 ± 0.95 (0.35 ± 0.88)
1.96-7 TeV [2]	173.34 ± 0.76 (0.36 ± 0.67)
7 TeV [3]	172.33 ± 1.27 (0.75 ± 1.02)
7 TeV [3]	173.79 ± 1.41 (0.54 ± 1.30)
7 TeV [4]	175.1 ± 1.8 (1.4 ± 1.2)
8 TeV [5]	172.2 ± 2.1 (0.7 ± 2.0)
8 TeV [6]	172.99 ± 0.85 (0.41 ± 0.74)
8 TeV [7]	173.72 ± 1.15 (0.55 ± 1.01)
8 TeV [8]	172.08 ± 0.91 (0.39 ± 0.82)
7+8 TeV [8]	172.69 ± 0.48 (0.25 ± 0.41)
13 TeV [9]	174.41 ± 0.81 (0.39 ± 0.66 ± 0.25)
13 TeV [10]	172.21 ± 0.80 (0.20 ± 0.67 ± 0.39)
7 TeV [11]	173.49 ± 1.06 (0.43 ± 0.97)
7 TeV [12]	172.50 ± 1.52 (0.43 ± 1.46)
7 TeV [13]	173.49 ± 1.41 (0.69 ± 1.23)
8 TeV [14]	172.35 ± 0.51 (0.16 ± 0.48)
8 TeV [14]	172.82 ± 1.23 (0.19 ± 1.22)
8 TeV [14]	172.32 ± 0.64 (0.25 ± 0.59)
8 TeV [15]	172.95 ± 1.22 (0.77 ± 0.95)
7+8 TeV [14]	172.44 ± 0.48 (0.13 ± 0.47)
13 TeV [16]	172.25 ± 0.63 (0.08 ± 0.62)
13 TeV [17]	172.33 ± 0.70 (0.14 ± 0.69)
13 TeV [18]	172.34 ± 0.73 (0.20 ± 0.70)
13 TeV [19]	172.13 ± 0.77 (0.32 ± 0.70)
13 TeV [20]	171.77 ± 0.37
	172.76 ± 0.81 (0.22 ± 0.78)

[1] ATLAS-CONF-2013-102
[2] arXiv:1403.4427
[3] EPJC 75 (2015) 330
[4] EPJC 75 (2015) 158
[5] ATLAS-CONF-2014-055
[6] PLB 761 (2016) 350
[7] JHEP 09 (2017) 118

[8] EPJC 74 (2014) 280
[9] arXiv:2209.05583
[10] ATLAS-CONF-2022-058
[11] JHEP 12 (2014) 108
[12] EPJC 74 (2014) 2902
[13] EPJC 74 (2014) 2758
[14] PRD 93 (2016) 072004
[15] arXiv:2302.01967
[21] arXiv:2211.01456

[16] EPJC 77 (2017) 354
[17] EPJC 78 (2018) 891
[18] EPJC 79 (2019) 368
[19] EPJC 79 (2019) 313
[20] arXiv:2302.01967
[21] arXiv:2211.01456

[22] JHEP 08 (2016) 029
[23] CMS-PAS-TOP-13-006
[24] EPJC 80 (2020) 528
[25] arXiv:2205.13830
[26] JHEP 11 (2019) 150
[27] PRD 93 (2016) 072004
[28] arXiv:2207.02270
[29] EPJC 79 (2019) 290
[30] arXiv:2207.02270
[31] EPJC 77 (2017) 804
[32] EPJC 80 (2020) 658
[33] JHEP 08 (2016) 029
[34] PRD 93 (2016) 072004
[35] arXiv:2207.02270
[36] EPJC 79 (2019) 290
[37] CMS-PAS-TOP-13-006
[38] JHEP 11 (2019) 150
[39] PRD 93 (2016) 072004
[40] arXiv:2207.02270
[41] EPJC 77 (2017) 804
[42] EPJC 80 (2020) 658
[43] JHEP 08 (2016) 029
[44] PRD 93 (2016) 072004
[45] arXiv:2207.02270
[46] EPJC 79 (2019) 368
[47] EPJC 79 (2019) 313
[48] arXiv:2207.02270
[49] arXiv:2207.02270
[50] arXiv:2205.13830
[51] arXiv:2211.01456

Indirect measurements m_t^{pole}

→ measure observable sensitive to mass e.g. cross-section

ATLAS+CMS Preliminary
LHCtopWG

m_{top} from cross-section measurements
June 2023

Ref.

$\sigma(t\bar{t})$ inclusive, NNLO+NNLL

ATLAS, 7+8 TeV	172.9 ± 2.5	[1]
CMS, 7+8 TeV	173.8 ± 1.7	[2]
CMS, 13 TeV	169.9 ± 1.9 (0.1 ± 1.5 ± 1.2)	[3]
ATLAS, 13 TeV	173.1 ± 2.0	[4]
LHC comb., 7+8 TeV	173.4 ± 1.8	[5]

$\sigma(t\bar{t}+1j)$ differential, NLO

ATLAS, 7 TeV	173.7 ± 2.3 (1.5 ± 1.4 ± 1.0)	[6]
CMS, 8 TeV (*)	169.9 ± 4.5 (1.1 ± 2.5 ± 3.6)	[7]
ATLAS, 8 TeV	171.1 ± 1.2 (0.4 ± 0.9 ± 0.3)	[8]
CMS, 13 TeV	172.9 ± 1.4 (1.3 ± 0.5)	[9]

$\sigma(t\bar{t})$ n-differential, NLO

ATLAS, n=1, 8 TeV	173.2 ± 1.6 (0.9 ± 0.8 ± 1.2)	[10]
CMS, n=3, 13 TeV	170.5 ± 0.8	[11]

m_{top} from top quark decay

CMS, 7+8 TeV comb. [10]	[6] JHEP 10 (2015) 121
ATLAS, 7+8 TeV comb. [11]	[7] CMS-PAS-TOP-13-006
	[8] JHEP 11 (2019) 150
	[9] arXiv:2207.02270
	[10] EPJC 77 (2017) 804
	[11] EPJC 80 (2020) 658

* Preliminary

covered in this talk

[LHCWG summary plots](#)

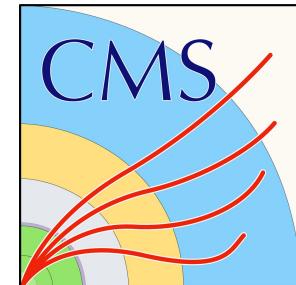
Direct measurements m_t^{MC}

→ reconstruct invariant mass from decay products

“Measurement of the top quark mass using a profile likelihood approach with the lepton+jets final states in proton-proton collisions at $\sqrt{s}=13 \text{ TeV}$ ”

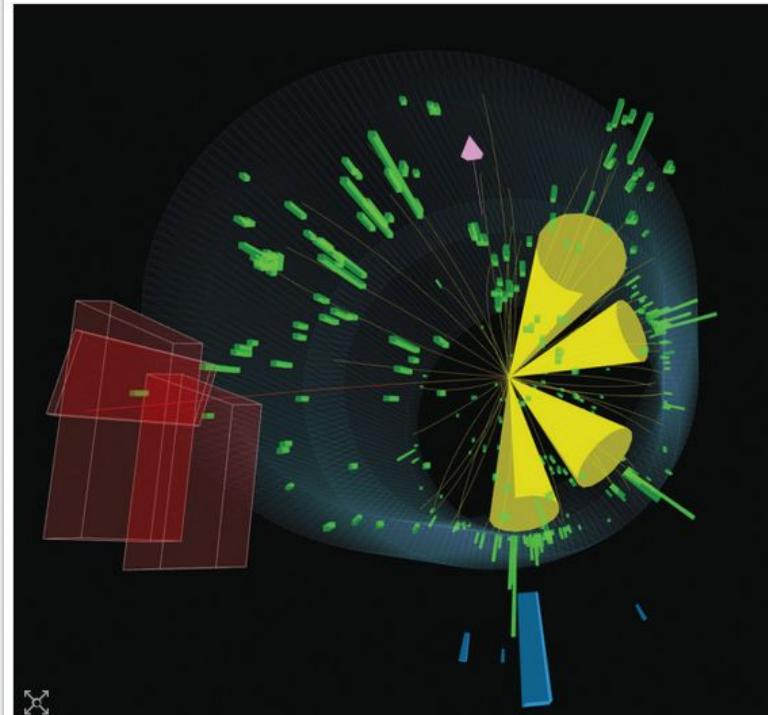
tt lepton+jets

[arXiv:2302.01967](https://arxiv.org/abs/2302.01967) (submitted to EPJC)



Top quark weighs in with unparalleled precision

1 July 2022



Top marks The classic signature of a top-quark pair at the LHC is four jets (yellow cones), one muon (red line and boxes) and missing energy from a neutrino (pink arrow). Credit: CMS

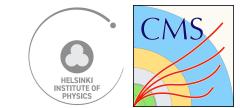
<https://cerncourier.com/a/top-quark-weighs-in-with-unparalleled-precision/>

Event selection

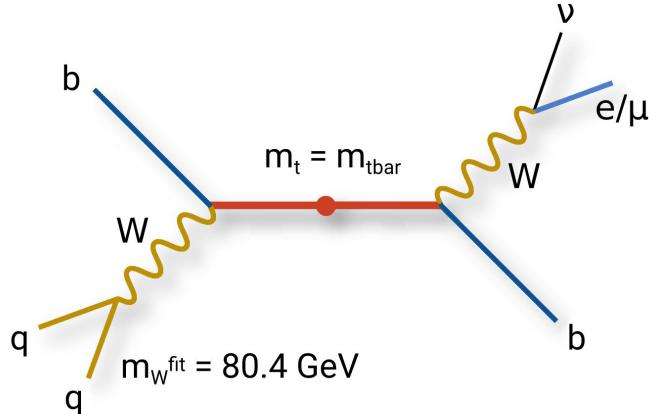
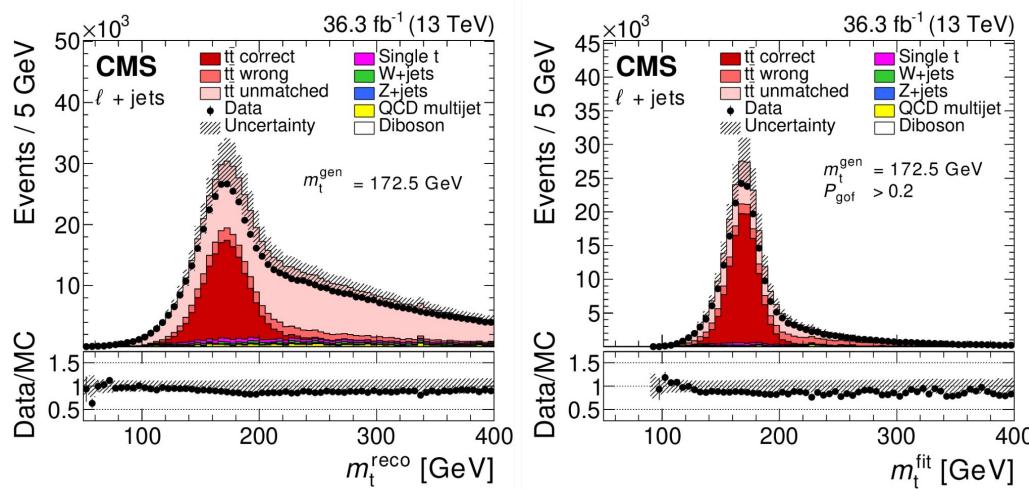
arXiv:2302.01967 (submitted to EPJC)

$t\bar{t}$ lepton+jets

Run2 2016 36.3 fb^{-1} 13 TeV



- Exactly one muon/electron
- 2 b-jets
 - correct assignment challenging
- 2 light quark jets from W
 - boosted W's introduce complications



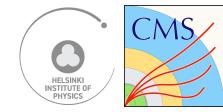
- **Kinematic fit**
 - best event hypothesis chosen from χ^2 minimization
 - based on parton-object resolution functions
 - constraints
 - $m_W^{\text{fit}} = 80.4$ GeV
 - $m_t^{\text{hadr}} = m_t^{\text{lept}}$
 - $P_{\text{gof}} = \exp(-\chi^2/2) > 0.2$ used as a default cut

Profiled maximum-likelihood fit

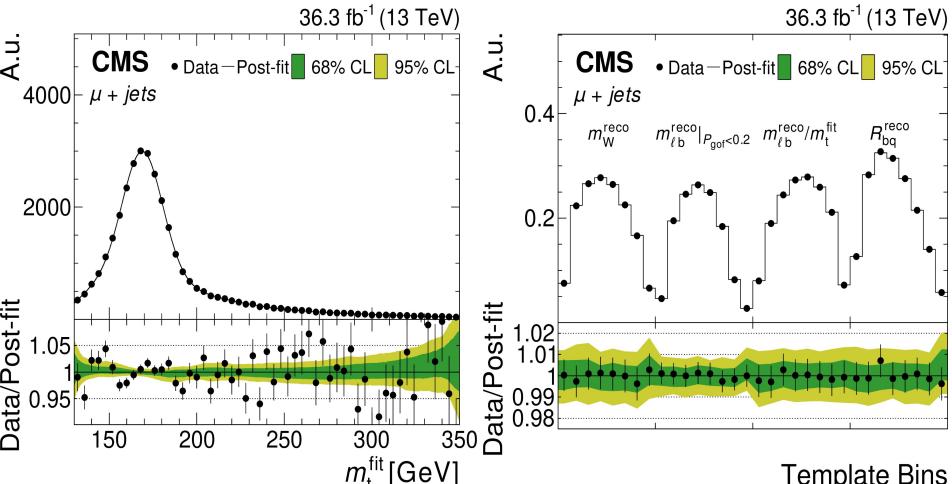
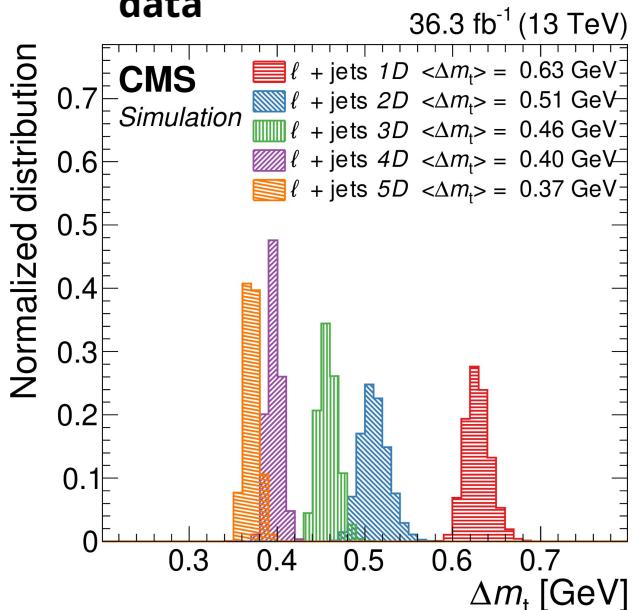
[arXiv:2302.01967](https://arxiv.org/abs/2302.01967) (submitted to EPJC)

$t\bar{t}$ lepton+jets

Run2 2016 36.3fb^{-1} 13 TeV



- m_t^{MC} from profiled maximum-likelihood fit using 5 observables
- Nuisance parameters for syst. uncertainties
- Possible to constrain systematics with data



$$\begin{aligned} m_t^{\text{fit}} \\ m_W^{\text{reco}} \\ R_{b\bar{q}}^{\text{reco}} = (p_T^{b1} + p_T^{b2}) / (p_T^{q1} + p_T^{q2}) \\ m_{lb}^{\text{red}} = m_{lb}^{\text{reco}} / m_t^{\text{fit}} \\ m_{lb}^{\text{reco}} (P_{\text{gof}} < 0.2) \end{aligned}$$

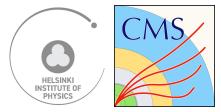
- for m_t
 → light quark JES
 → b-JES
 → for lep syst.
 → for full statistics
- } parametrized
 } binned

Results

arXiv:2302.01967 (submitted to EPJC)

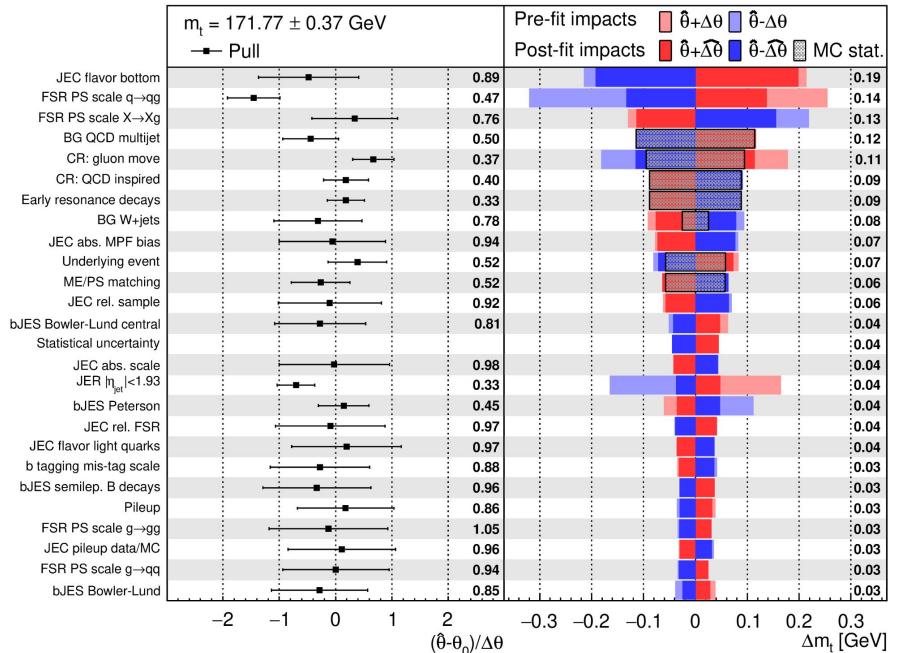
$t\bar{t}$ lepton+jets

Run2 2016 36.3fb^{-1} 13 TeV



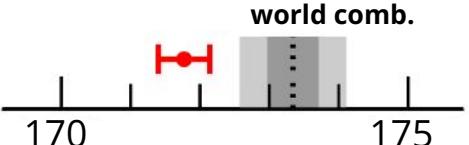
CMS

36.3 fb^{-1} (13 TeV)



- Most precise individual result to date $171.77 \pm 0.37 \text{ GeV}$
 - statistical uncertainty in data: 0.04 GeV

$m_t = 171.77 \pm 0.37 \text{ GeV}$

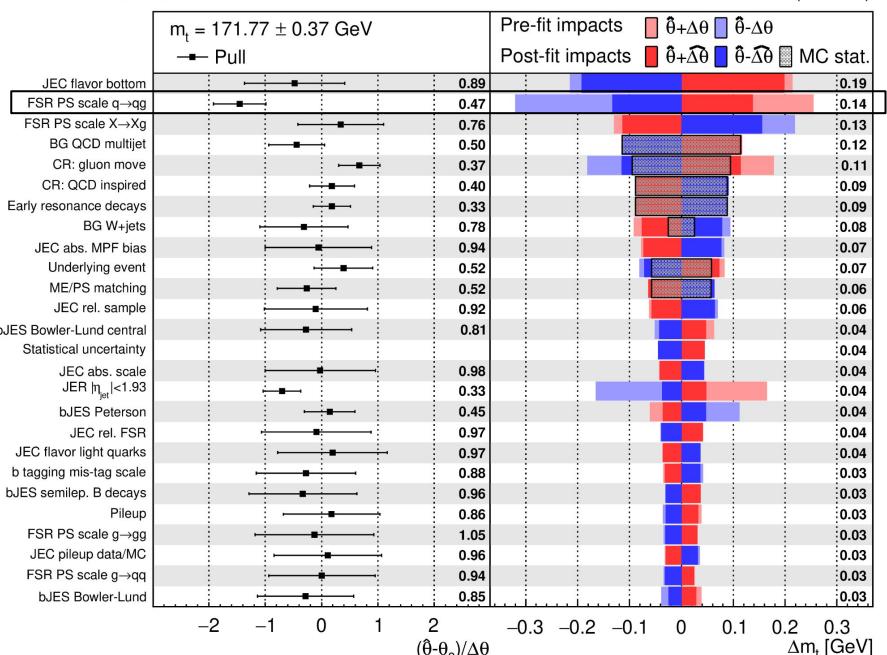


Dominant uncertainties

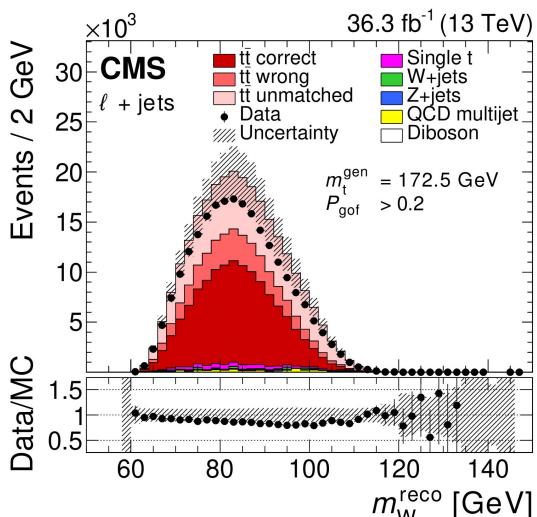
- b JEC
- q FSR scale
- b FSR scale

Results

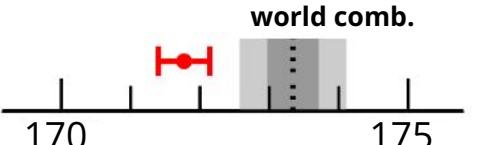
CMS



- Most precise individual result to date $171.77 \pm 0.37 \text{ GeV}$
 - statistical uncertainty in data: 0.04 GeV
- qFSR $\sim -1.5 \sigma$
→ related to m_W^{reco} peak



$m_t = 171.77 \pm 0.37 \text{ GeV}$

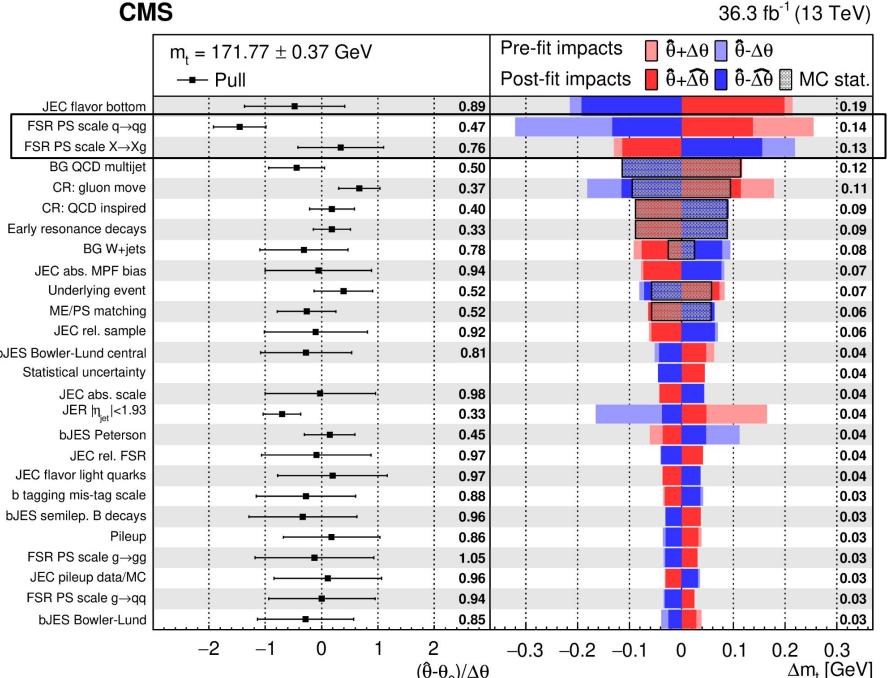


Dominant uncertainties

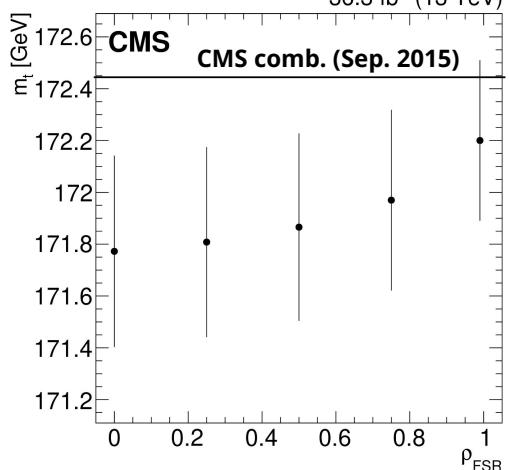
- b JEC
- q FSR scale
- b FSR scale

Results

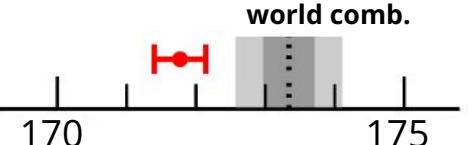
CMS



- Most precise individual result to date $171.77 \pm 0.37 \text{ GeV}$
 - statistical uncertainty in data: 0.04 GeV
- qFSR $\sim -1.5 \sigma$
 - related to m_W^{reco} peak
- qFSR and bFSR pulls in opposite direction
 - treated fully decorrelated
 - $\rho=0$



$m_t = 171.77 \pm 0.37 \text{ GeV}$



Dominant uncertainties

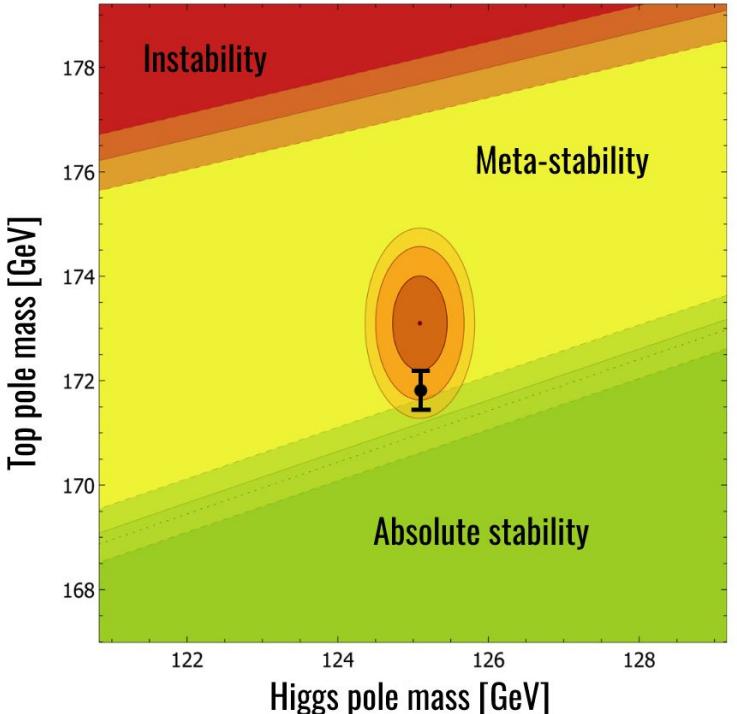
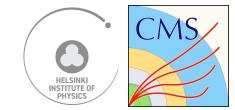
- b JEC
- q FSR scale
- b FSR scale

Results

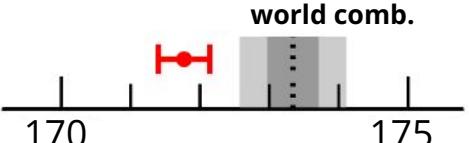
arXiv:2302.01967 (submitted to EPJC)

$t\bar{t}$ lepton+jets

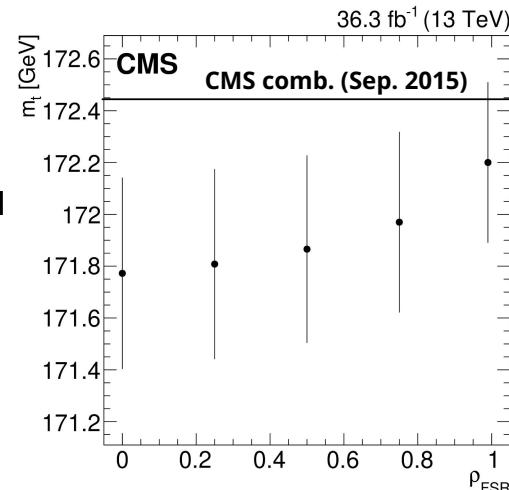
Run2 2016 36.3fb^{-1} 13 TeV



$m_t = 171.77 \pm 0.37 \text{ GeV}$



- Most precise individual result to date $171.77 \pm 0.37 \text{ GeV}$
 - statistical uncertainty in data: 0.04 GeV
- qFSR $\sim -1.5 \sigma$
→ related to m_W^{reco} peak
- qFSR and bFSR pulls in opposite direction
→ treated fully decorrelated
 $\rho=0$



Dominant uncertainties

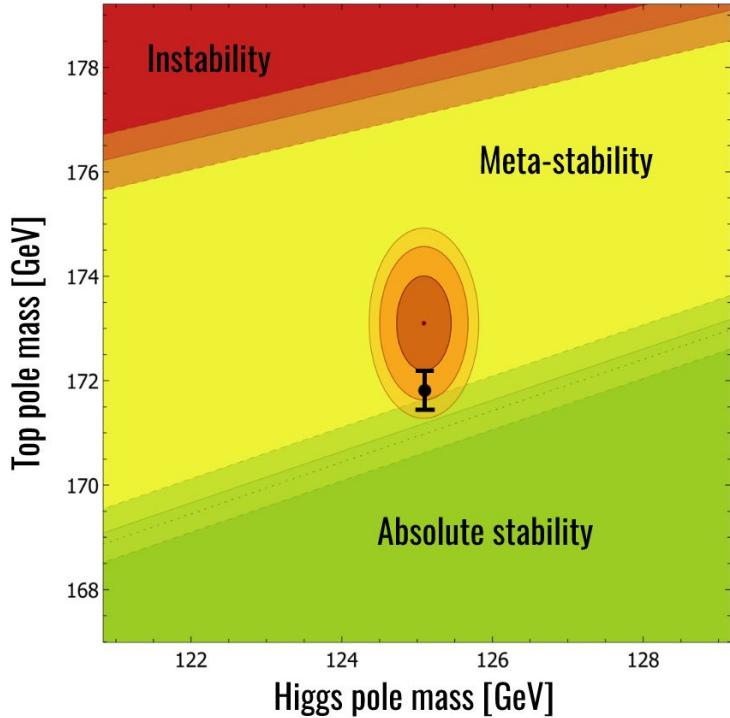
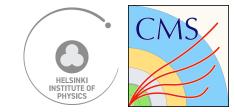
- b JEC
- q FSR scale
- b FSR scale

Results

arXiv:2302.01967 (submitted to EPJC)

$t\bar{t}$ lepton+jets

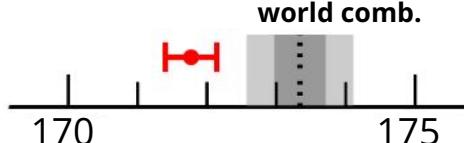
Run2 2016 36.3fb^{-1} 13 TeV



Our analysis in Helsinki extends this by including data from 2017-2018

$\sim 100 \text{ fb}^{-1} \rightarrow$ around 3 times more than 2016

$m_t = 171.77 \pm 0.37 \text{ GeV}$



Dominant uncertainties

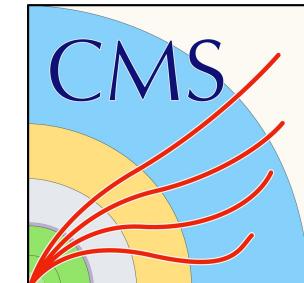
- b JEC
- q FSR scale
- b FSR scale

Indirect measurements m_t^{pole}
→ measure observable sensitive to mass e.g. cross-section

“Measurement of the top quark pole mass using $t\bar{t}$ +jet events in the dilepton final state in proton-proton collisions at $\sqrt{s} = 13 \text{ TeV}$ ”

$t\bar{t}+1j$ pole mass

[JHEP 07 \(2023\) 077](#)

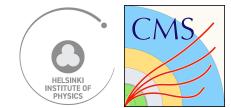


$t\bar{t}+1$ jet in dilepton channel

JHEP 07 (2023) 077

$t\bar{t}+1$ j pole mass

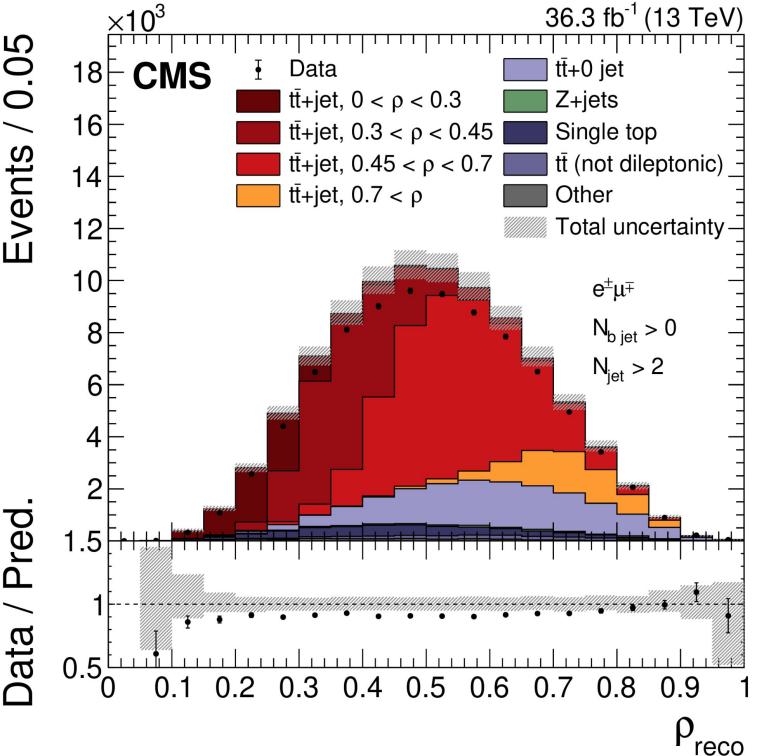
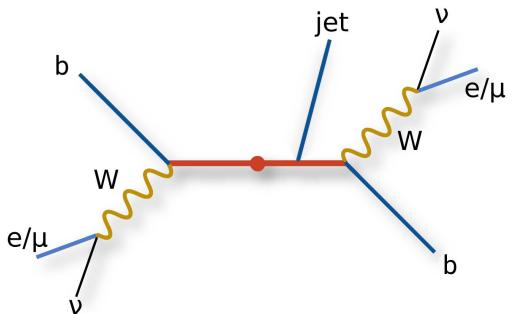
Run2 2016 36.3 fb^{-1} 13 TeV



- Normalised differential cross section measured at detector level and unfolded using maximum likelihood method with profiled nuisance parameters
- As a function of ρ

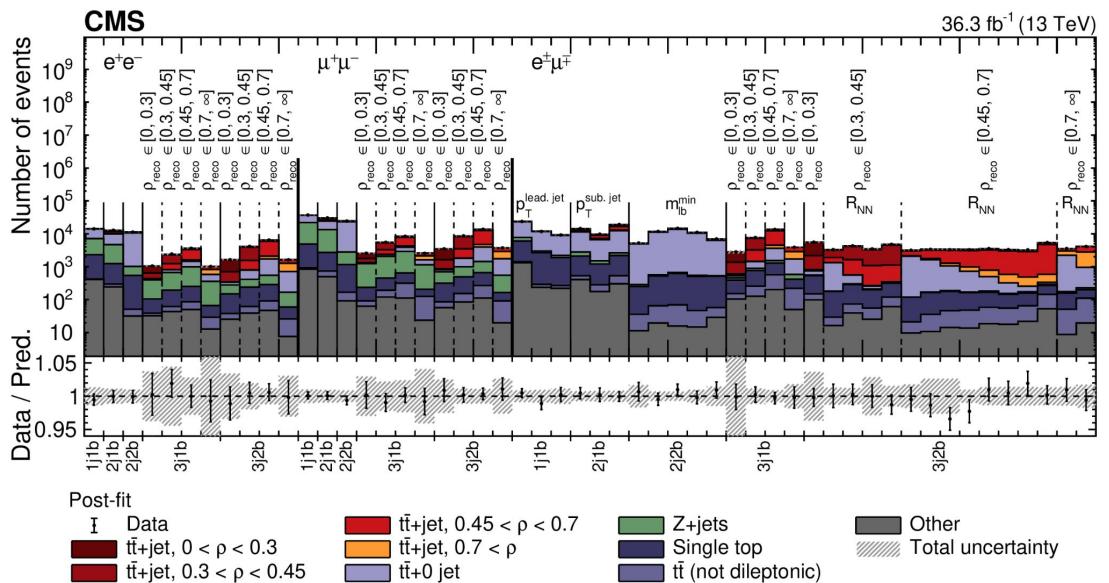
$$\rho = \frac{2m_0}{m_{t\bar{t}+\text{jet}}}$$

- m_0 scaling constant = 170 GeV

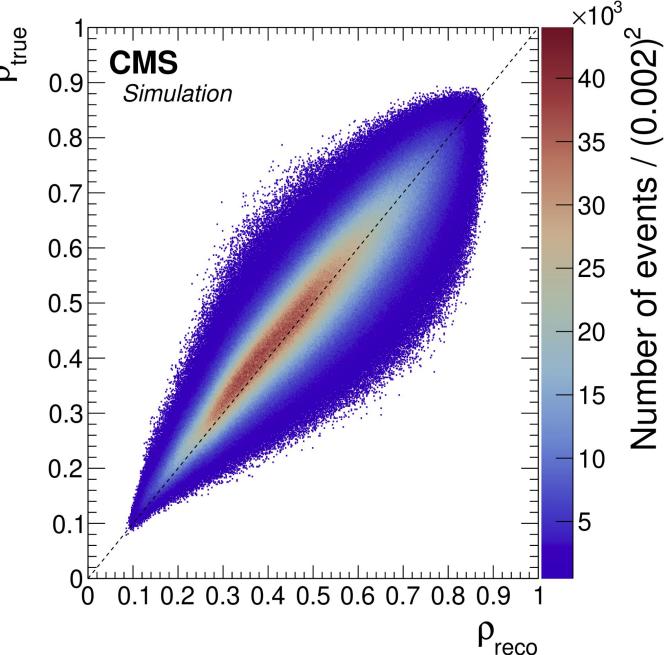
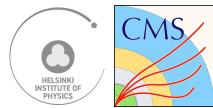


ρ reconstruction

- Regression NN
 - target variable is parton-level ρ
 - ~ 100 variables from which **10 most relevant selected**
- Event classifier developed using the same interface as for regression NN with three output classes $t\bar{t}$ +jet, Z+jets, $t\bar{t}$ +0jets



JHEP 07 (2023) 077
 $t\bar{t}+1j$ pole mass
 Run2 2016 36.3 fb^{-1} 13 TeV



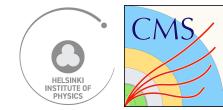
- Event categories based on jet and b-jet multiplicities

Results

JHEP 07 (2023) 077

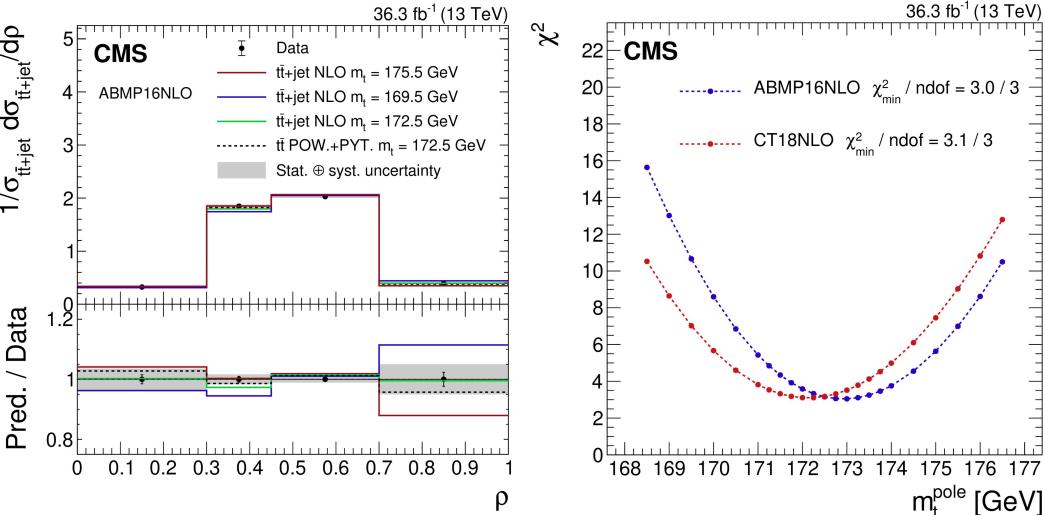
$t\bar{t}+1j$ pole mass

Run2 2016 36.3 fb^{-1} 13 TeV



- m_t^{pole} from χ^2 fit of the normalized differential cross section at NLO, where m_t^{MC} as a free parameter
- No assumptions on the relationship between $m_t^{\text{MC}} \leftrightarrow m_t^{\text{pole}}$
- In good agreement with m_t^{pole} $t\bar{t}+\text{jet}$ measurement by ATLAS at 8 TeV

[arXiv:1905.02302](https://arxiv.org/abs/1905.02302)



$$\text{ABMP16NLO: } m_t^{\text{pole}} = 172.93 \pm 1.26 \text{ (fit)} {}^{+0.51}_{-0.43} \text{ (scale)} \text{ GeV}$$

$$\text{CT18NLO: } m_t^{\text{pole}} = 172.13 \pm 1.34 \text{ (fit)} {}^{+0.50}_{-0.40} \text{ (scale)} \text{ GeV}$$

$m_t^{\text{pole}} = 172.93 \pm 1.36 \text{ GeV}$



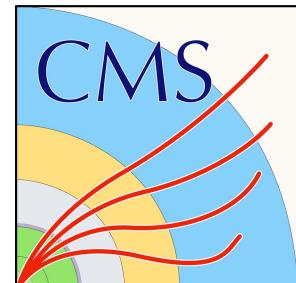
Dominant uncertainties

- Jet energy scale
- Background normalisation
- Electron identification

“Combination of measurements of the top quark mass
from data collected by the ATLAS and CMS
experiments at $\sqrt{s} = 7$ and 8 TeV”

ATLAS + CMS Run1 combination

[ATLAS-CONF-2023-066](#)

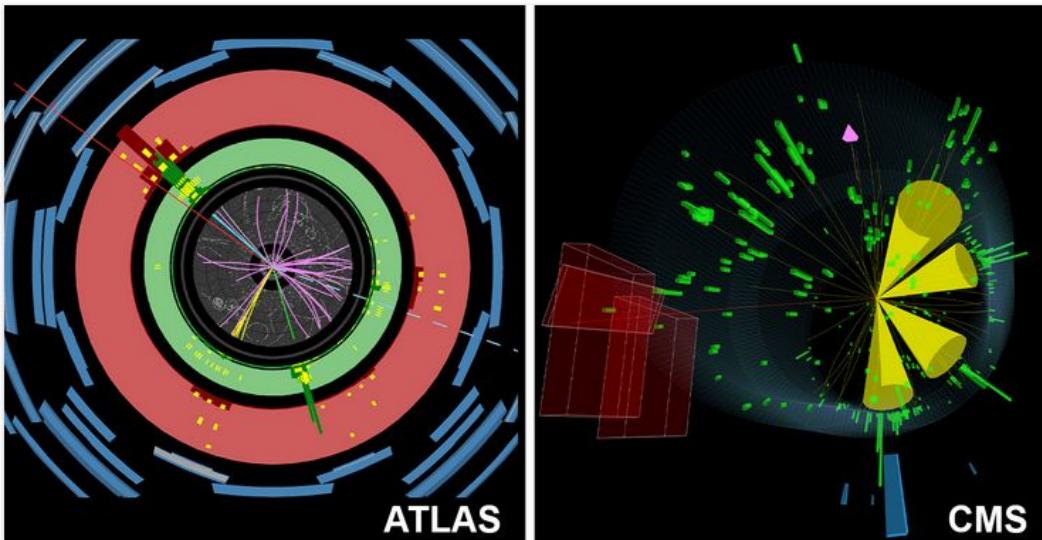


ATLAS and CMS unite to weigh in on the top quark

The new result combines 15 previous measurements to give the most precise determination of the top-quark mass to date

11 OCTOBRE, 2023

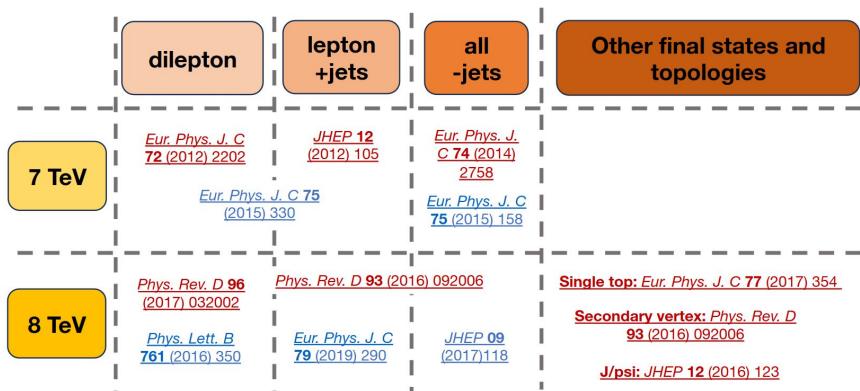
<https://home.cern/fr/node/188765>



Collision event displays of top-quark production from ATLAS (left) and CMS (right). (Image: ATLAS/CMS/CERN)

Run1 combination

- 15 input measurements by ATLAS and CMS
 - direct measurements → m_t^{MC}
- **BLUE** = Best Linear Unbiased Estimator
 - to properly handle correlations in systematics
 - 25 categories - correlations between pairs of measurements evaluated within experiment
 - then correlation ρ between ATLAS and CMS
 - Uncorrelated: $\rho = 0$
 - Partially correlated: $\rho = 0.5$
 - Strongly correlated: $\rho = 0.85$



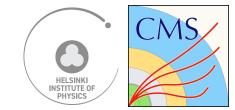
Uncertainty category	ρ	Scan range	$\Delta m_t/2$ [MeV]	$\Delta \sigma_{m_t}/2$ [MeV]
LHC JES 1	0	—	—	—
LHC JES 2	0	[−0.25, +0.25]	8	7
LHC JES 3	0.5	[+0.25, +0.75]	1	<1
LHC b-JES	0.85	[+0.5, +1]	26	5
LHC g-JES	0.85	[+0.5, +1]	2	<1
LHC l-JES	0	[−0.25, +0.25]	1	<1
CMS JES 1	—	—	—	—
JER	0	[−0.25, +0.25]	5	1
Leptons	0	[−0.25, +0.25]	2	2
b tagging	0.5	[+0.25, +0.75]	1	1
p_T^{miss}	0	[−0.25, +0.25]	<1	<1
Pileup	0.85	[+0.5, +1]	2	<1
Trigger	0	[−0.25, +0.25]	<1	<1
ME generator	0.5	[+0.25, +0.75]	<1	4
LHC radiation	0.5	[+0.25, +0.75]	7	1
LHC hadronization	0.5	[+0.25, +0.75]	1	<1
CMS B hadron BR	—	—	—	—
Color reconnection	0.5	[+0.25, +0.75]	3	1
Underlying event	0.5	[+0.25, +0.75]	1	<1
PDF	0.85	[+0.5, +1]	1	<1
Top quark p_T	—	—	—	—
Background (data)	0	[−0.25, +0.25]	8	2
Background (MC)	0.85	[+0.5, +1]	2	<1
Method	0	—	—	—
Other	0	—	—	—

Most precise m_t measurement to date

ATLAS-CONF-2023-066

ATLAS + CMS Run1 combination

Run1 7,8 TeV



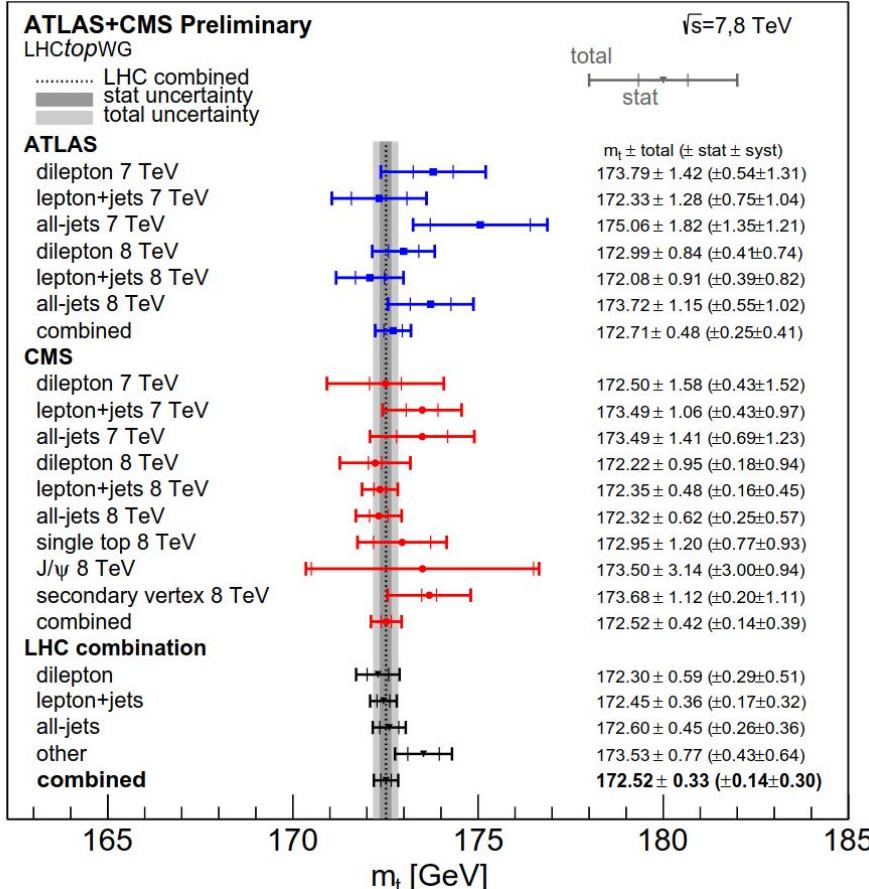
ATLAS
 $172.71 \pm 0.25 \text{ (stat)} \pm 0.41 \text{ (syst)}$

CMS
 $172.52 \pm 0.14 \text{ (stat)} \pm 0.39 \text{ (syst)}$

$172.52 \pm 0.33 \text{ GeV}$

Dominant uncertainties

- b-JES
- b-tagging
- ME generator
- JES



Summary

- m_t measurements by CMS with increasing **precision** and **understanding** of systematics
- Three measurements introduced
 - m_t^{MC} $t\bar{t}$ lepton+jets $171.77 \pm 0.37 \text{ GeV}$
 - m_t^{pole} $t\bar{t}+1j$ pole mass $172.93 \pm 1.36 \text{ GeV}$
 - Run1 combination $172.52 \pm 0.33 \text{ GeV}$
- Stability of the EW vacuum
 - “To rule out absolute stability to 3σ confidence, the uncertainty on the top quark pole mass would have to be pushed below 250 MeV” [arxiv:1707.08124](https://arxiv.org/abs/1707.08124)
- Top mass interpretation problem
 - $m_t^{\text{MC}} \rightarrow m_t^{\text{pole}}$

