Cross-section based top quark mass measurements

15th International Workshop on Top-Quark Physics
05.09.2022, Durham (UK)

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on behalf of the CMS and ATLAS Collaborations

Why we still measure m_t

- **Important input to global electroweak fits**
- Related to EW vacuum stability at M_P scale
- Proportional to **t-H Yukawa coupling**
- Enters loops with $\sim m_t^2$ dependence

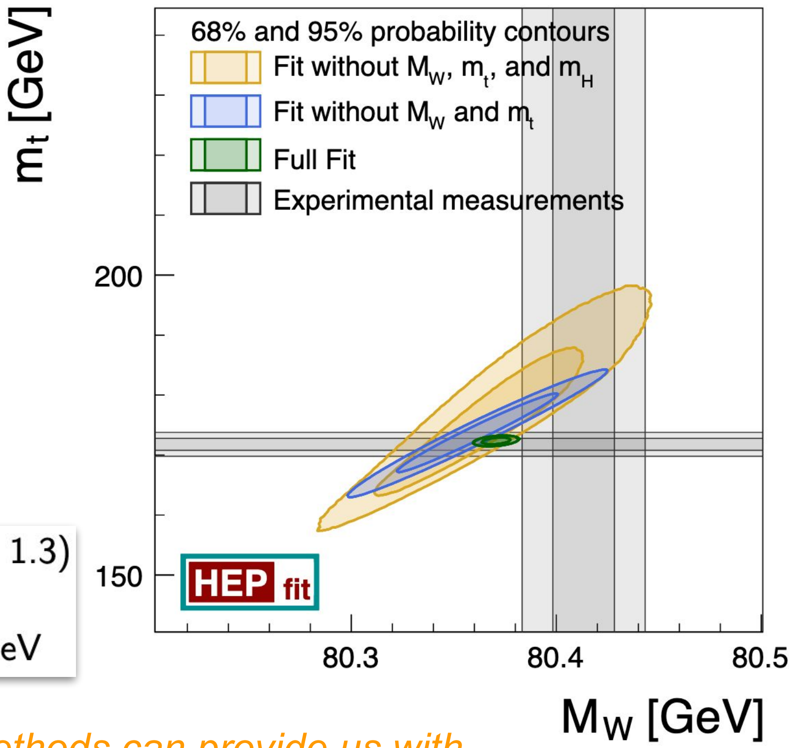
Not uniquely defined concept. Each definition:

- Theoretical or practical (dis-)advantages
- Experimentally determined with different techniques → complementarity

→ from PDG

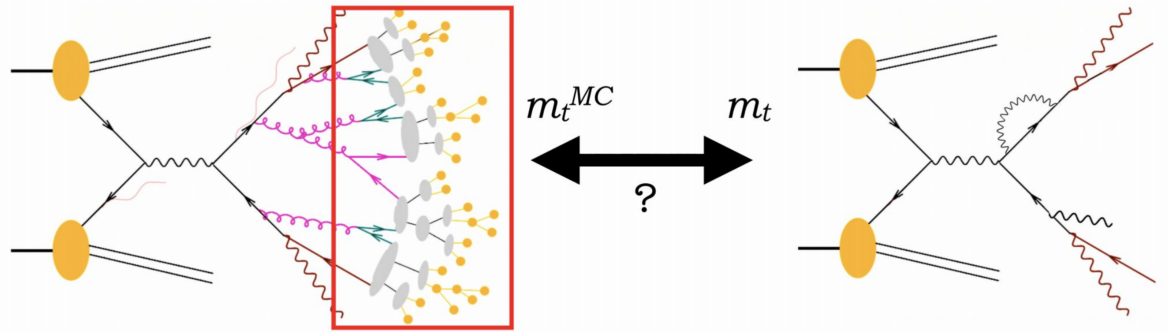
Mass (direct measurements) $m = 172.69 \pm 0.30$ GeV [a,b] (S = 1.3)
Mass (from cross-section measurements) $m = 162.5^{+2.1}_{-1.5}$ GeV [a]
Mass (Pole from cross-section measurements) $m = 172.5 \pm 0.7$ GeV

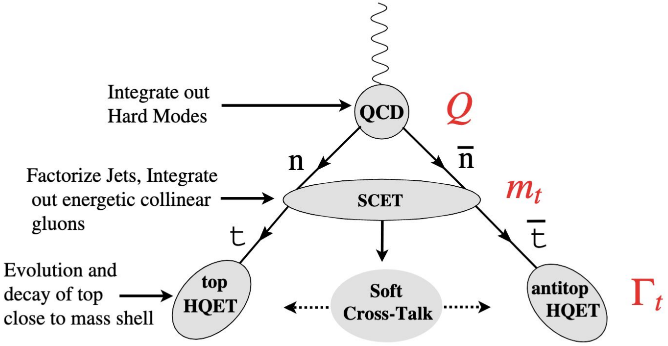
arXiv:2204.04204



Measuring m_t with different methods can provide us with information on the limits of the models we use

Classes of top quark mass measurements





"Direct" measurements: reconstruct invariant mass of top quark decay products

- Can be very precise (~0.3 GeV)
- Depends on the details of the MC simulation

→ see talk by M. Vanadia

"Indirect" measurements: measure observable directly sensitive to m_t (e.g. inclusive/differential σ_{tt})

- Compare to theory prediction in **well-defined renormalisation scheme** (pole, MS, MSR)
- Can be sensitive to soft-gluon effects at threshold, where mass sensitivity is the highest

"Third way": jet mass in boosted top decays can be calculated using SC-EFT

→ can provide info on relation between m_t^{MC} and m_t (MSR)

see talk by M. Villaplana + e.g. S.Fleming, A.Hoang, S.Mantry, I.Stewart: PRD 77 (2008) 074010

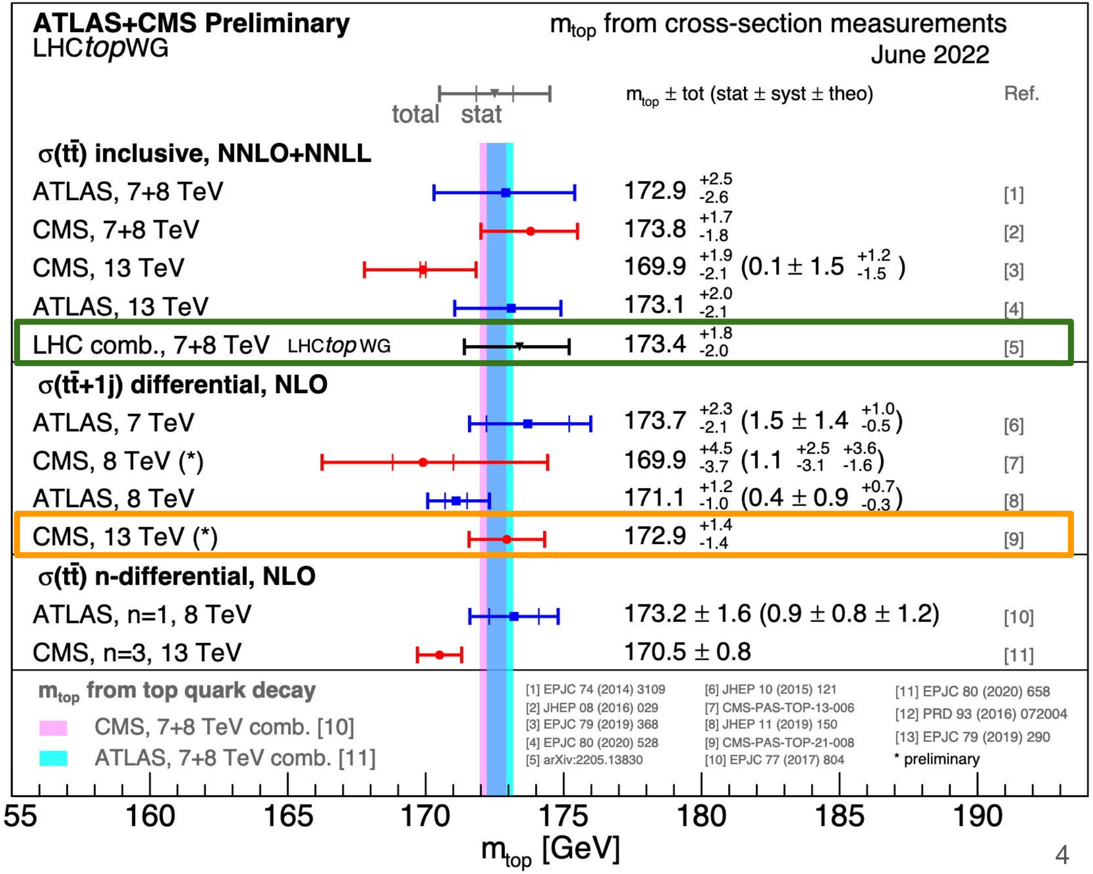
m_t from cross sections: where do we stand

1. New m_t^{pole} result from combined ATLAS+CMS inclusive σ_{tt} at 7+8 TeV

2. New m_t^{pole} measurement from tt+1jet invariant mass from CMS

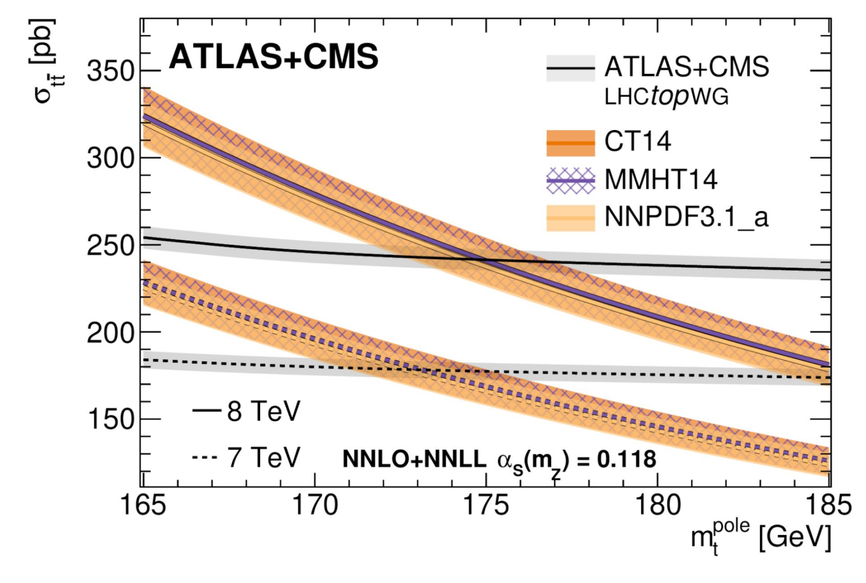
- Results obtained with different methods *overall in good agreement*

- CMS result from 3D cross section is the most precise result, to date, but *may be significantly affected by threshold effects*



Matteo M. Defranchis (CERN)

m_t^{pole} @NNLO from inclusive σ_{tt} at 7+8 TeV (LHC)

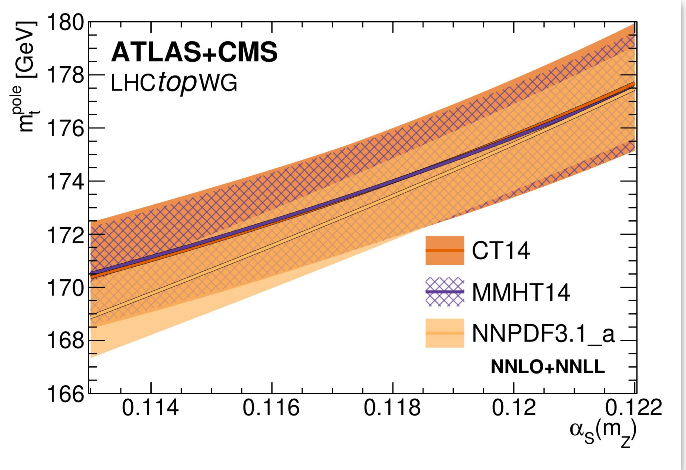


PDF set	m_t^{pole}	$\alpha_s(m_Z)$
	($\alpha_s = 0.118 \pm 0.001$)	($m_t = 172.5 \pm 1.0$ GeV)
CT14	$174.0\ ^{+2.3}_{-2.3}$ GeV	$0.1161\ ^{+0.0030}_{-0.0033}$
MMHT2014	$174.0\ ^{+2.1}_{-2.3}$ GeV	$0.1160\ ^{+0.0031}_{-0.0030}$
NNPDF3.1_a	$173.4\ ^{+1.8}_{-2.0}$ GeV	$0.1170\ ^{+0.0021}_{-0.0018}$

NEW

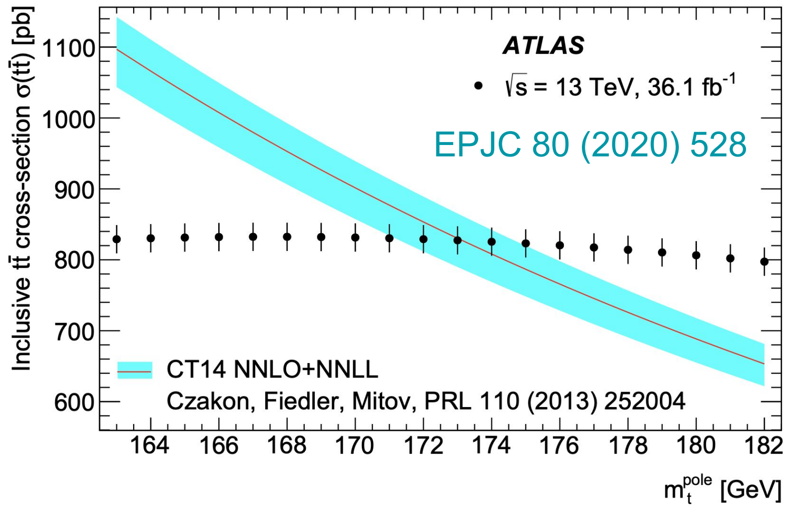
arXiv:2205.13830

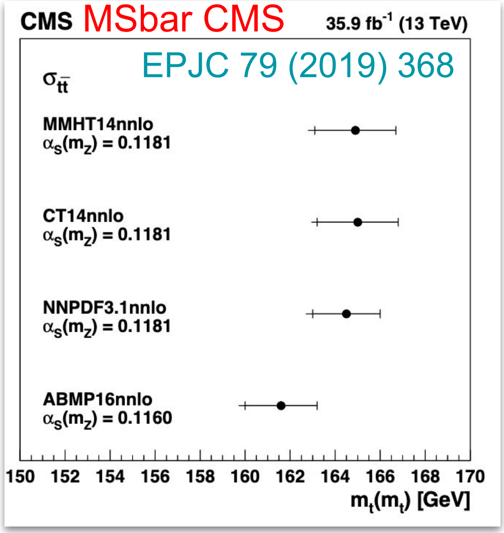
- Simultaneous fit of NNLO+NNLL (Top++) prediction to combined 7+8 TeV σ_{tt}
- Residual experimental dependence on m_t (acceptance) taken into account
- **NB.** extracted values of m_t^{pole} crucially depends on assumed value of α_S



→ see talk by P. Hansen

m_t @NNLO from inclusive σ_{tt} at 13 TeV (eμ)





Very similar m_t^{pole} results by ATLAS and CMS, also in terms of syst.

Smaller scale uncert. in MSbar result from CMS, despite absence of soft-gluon corrections

pole ATLAS

PDF set	m_t^{pole} (GeV)
CT14	$173.1^{+2.0}_{-2.1}$
NNPDF3.1_notop	$172.9^{+1.7}_{-1.7}$
CT10	$172.1^{+2.0}_{-2.0}$
MSTW	$172.3^{+2.0}_{-2.1}$
NNPDF2.3	$173.4^{+1.9}_{-1.9}$
PDF4LHC	$172.1^{+3.1}_{-2.0}$

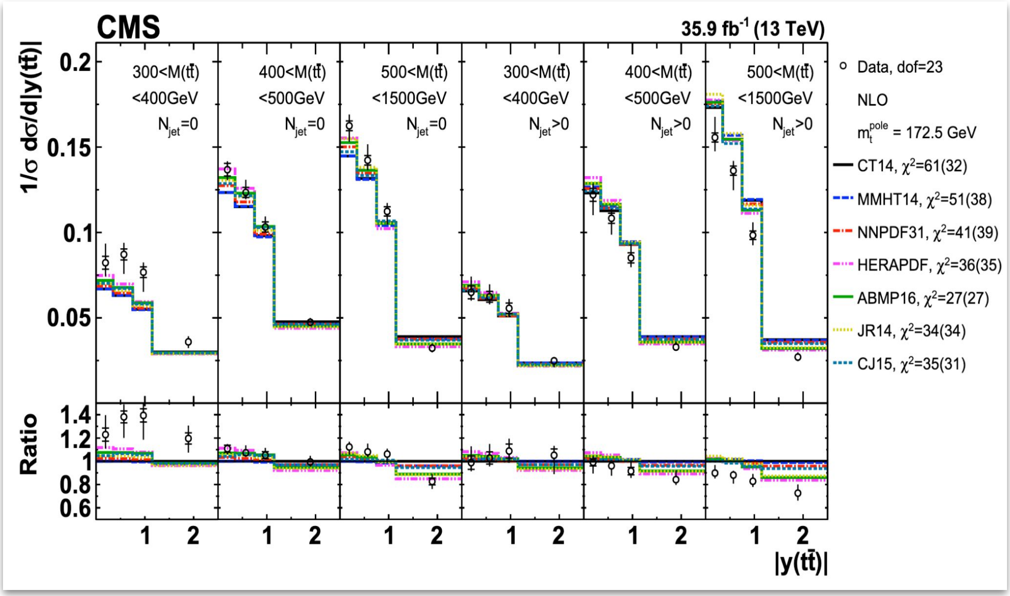
pole CMS

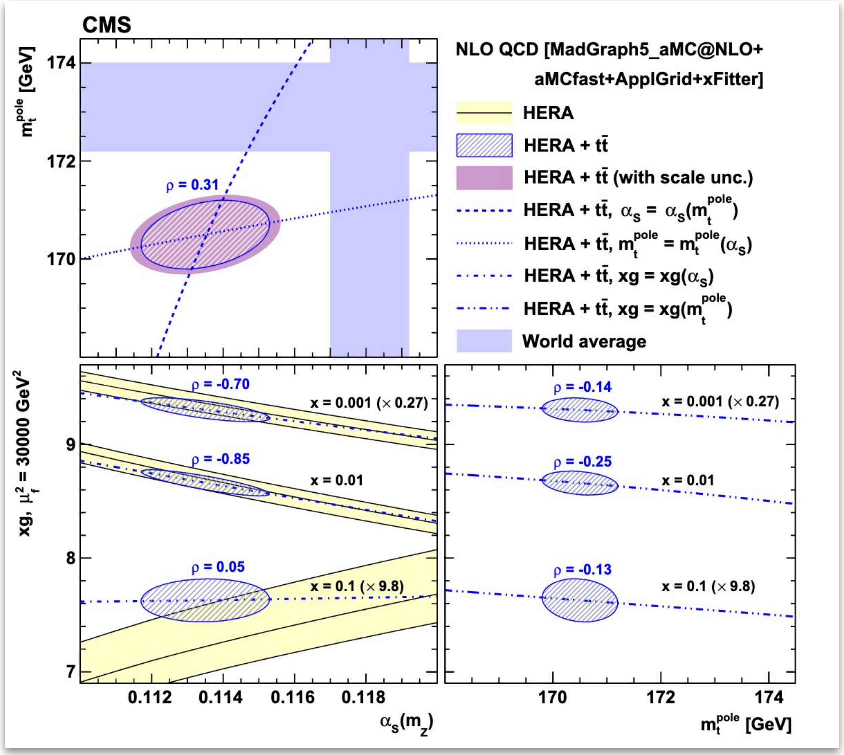
PDF set	m_t^{pole} [GeV]
ABMP16	169.9 ± 1.8 (fit + PDF + α_S) $^{+0.8}_{-1.2}$ (scale)
NNPDF3.1	173.2 ± 1.9 (fit + PDF + α_S) $^{+0.9}_{-1.3}$ (scale)
CT14	173.7 ± 2.0 (fit + PDF + α_S) $^{+0.9}_{-1.4}$ (scale)
MMHT14	173.6 ± 1.9 (fit + PDF + α_S) $^{+0.9}_{-1.4}$ (scale)

→ results again dependent on chosen value for α_S

m_t^{pole} @NLO from CMS 3D result at 13 TeV (ℓℓ)

EPJC 80 (2020) 658





- Simultaneous fit @NLO of m_t^{pole}, α_S, and PDFs in combination with HERA data
- Most precise result of m_t^{pole} to date
- Impact of threshold effects unknown

$$m_t^{pole} = 170.5 \pm 0.7\,(\text{fit}) \pm 0.1\,(\text{model})^{+0.0}_{-0.1}\,(\text{param}) \pm 0.3\,(\text{scale})\ \text{GeV} = 170.5 \pm 0.8(\text{total})\ \text{GeV}$$

How big are threshold effects?

JHEP 06 (2020) 158

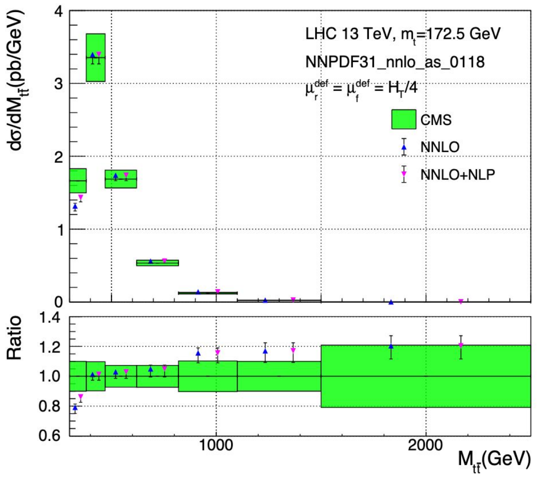
Short answer: we don't really know

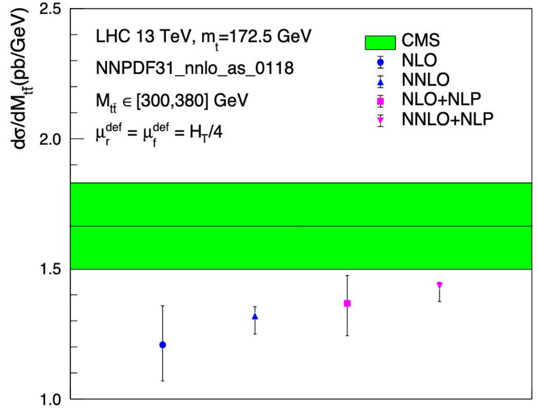
A study by Li Lin Yang et. al. based on next-to-leading power resummation suggests that the effect in the CMS 3D analysis (previous slide) can be as large as +1.4 GeV

This would lead to m_t^{pole} = 171.9 ± 0.8 GeV, in better agreement with other pole mass measurement

However, there is no consensus in the theory community on the presented NNLO+NLP results, and therefore we do not have a conclusive answer on the issue

- This is currently the **limiting factor** of indirect m_t measurement at threshold at the LHC
- Hard to think of consistent ways to assess the size of such uncertainty in the absence of a calculation





m_t @NLO from tt+1jet at 8 TeV in ATLAS (ℓ+jets)

JHEP 11 (2019) 150

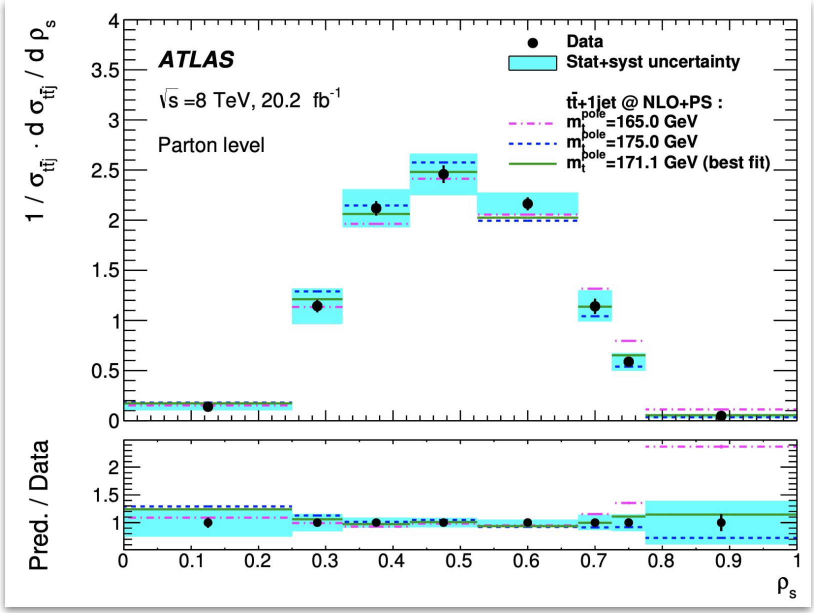
Invariant mass of tt+1jet system sensitive to value of m_t near the production threshold

$$\mathcal{R}(m_t^{\text{pole}}, \rho_s) = \frac{1}{\sigma_{t\bar{t}+1\text{-jet}}} \cdot \frac{d\sigma_{t\bar{t}+1\text{-jet}}}{d\rho_s},$$

$$\rho_s = \frac{2m_0}{m_{t\bar{t}+1\text{-jet}}}$$

- Normalised differential cross section unfolded to the parton level
  → normalisation mitigates α_S dependence

- Compared to dedicated NLO+PS predictions in pole and MS schemes
  → PS approximates threshold effects: *does it affect the mass definition?*



$$m_t^{\text{pole}} = 171.1 \pm 0.4\ (\text{stat}) \pm 0.9\ (\text{syst})\ ^{+0.7}_{-0.3}\ (\text{theo})\ \text{GeV}$$

$$m_t(m_t) = 162.9 \pm 0.5\ (\text{stat}) \pm 1.0\ (\text{syst})\ ^{+2.1}_{-1.2}\ (\text{theo})\ \text{GeV}$$

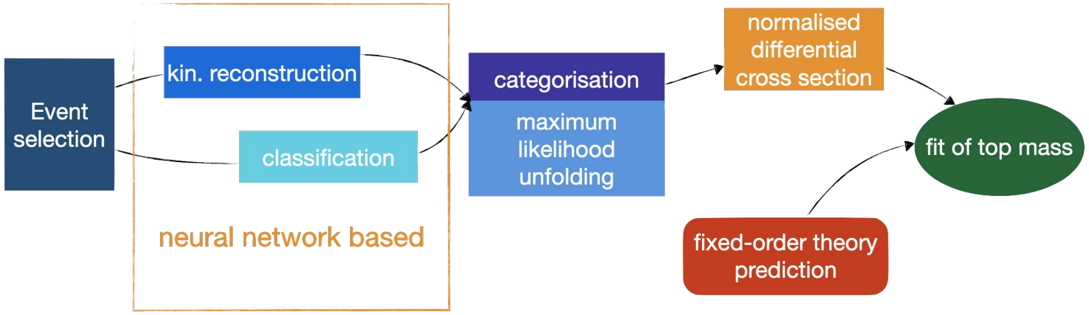
Larger scale uncertainties in MSbar scheme at threshold (contrary to inclusive σ_{tt})

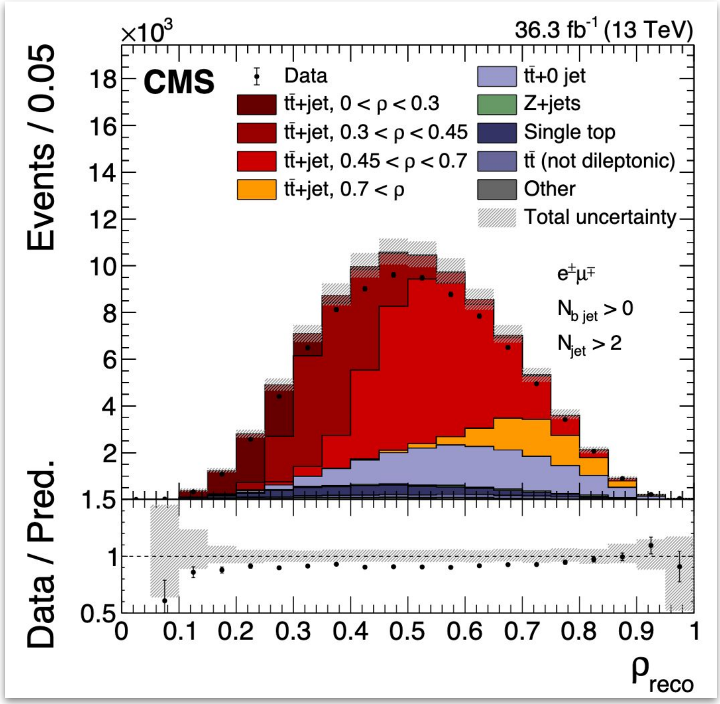
m_t @NLO from tt+1jet at 13 TeV in CMS (ℓℓ)

NEW

arXiv:2207.02270

- First result of this type at 13 TeV
- NN techniques to optimally reconstruct ρ variable and categorise processes
- **Maximum-likelihood unfolding** to reduce impact of systematic uncertainties



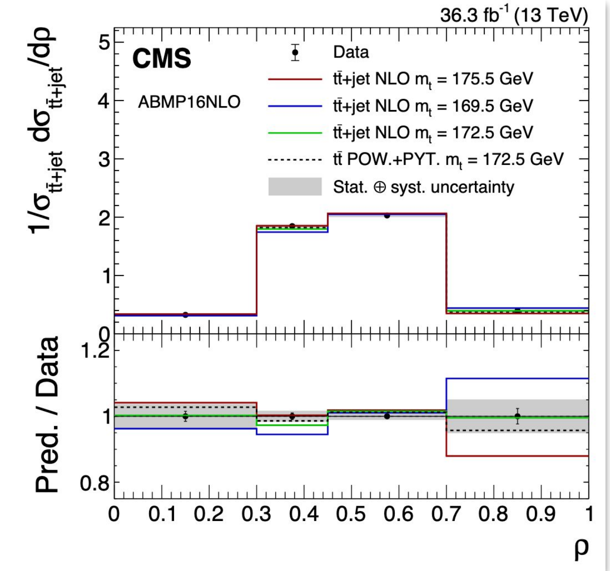


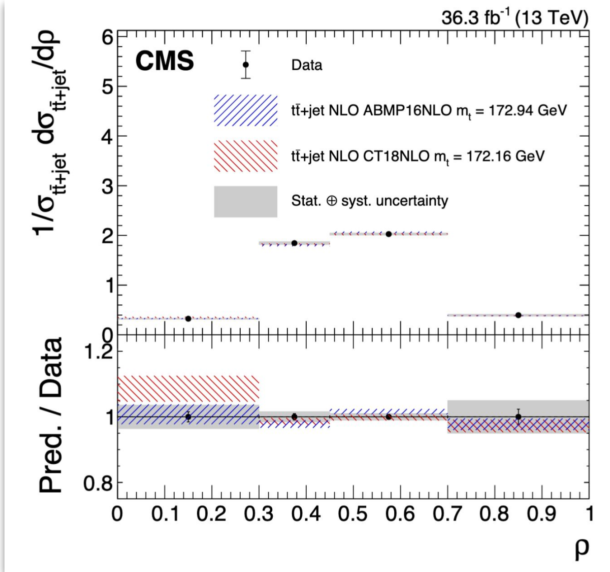
m_t @NLO from tt+1jet at 13 TeV in CMS (ℓℓ) NEW

arXiv:2207.02270

- m_t^{pole} extracted by fitting NLO predictions to normalised differential cross section
- Good agreement between data and predictions with both CT18 and ABMP16 PDFs
- Milder experimental dependence on m_t and larger PDF uncertainties wrt 8 TeV

→ more details in talk by Sebastian Wuchterl





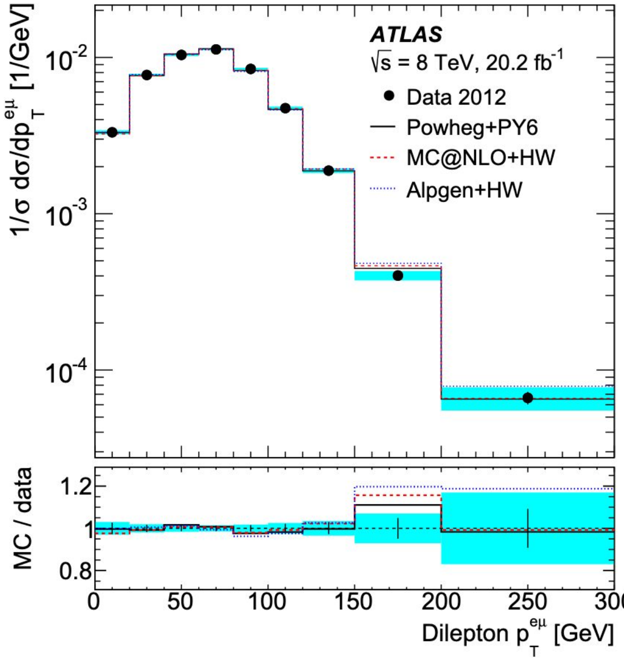
ABMP16: $$m_t^{pole} = 172.94 \pm 1.27\,(\text{fit})\,^{+0.51}_{-0.43}\,(\text{scale})\,\text{GeV}$$

CT18: $$m_t^{pole} = 172.16 \pm 1.35\,(\text{fit})\,^{+0.50}_{-0.40}\,(\text{scale})\,\text{GeV}.$$

Differential measurements sensitive to jet-related syst. + kin. reco

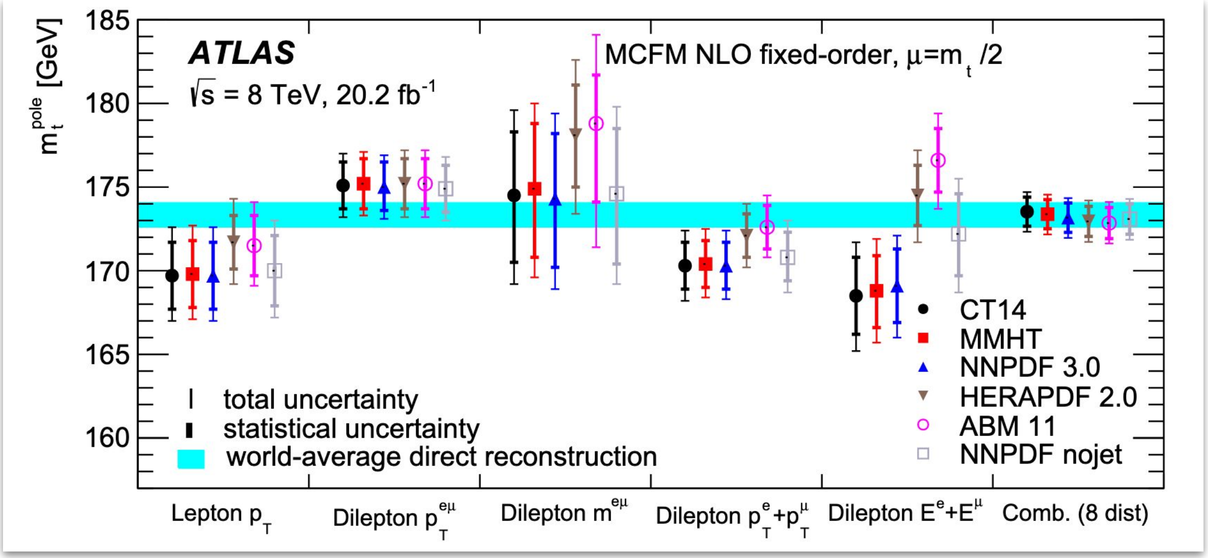
m_t^{pole} from leptonic obs. @ NLO, ATLAS 8 TeV

EPJC 77 (2017) 804



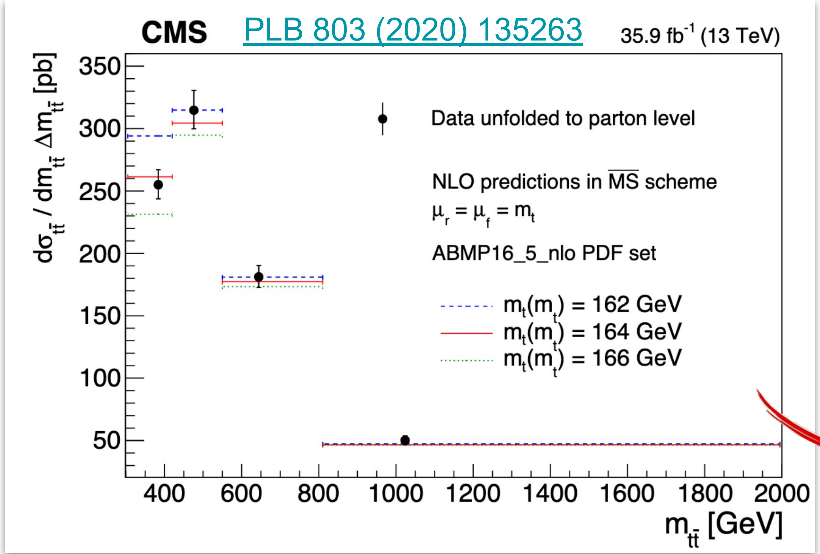
m_t^{pole} = 173.2 ± 0.9 (stat) ± 0.8 (exp) ± 1.2 (th) GeV

- Only make use of leptonic observables, which are less sensitive to jet syst. + no kinematic reconstruction
- Individual / simultaneous fits to NLO MCFM prediction
- PDF and QCD uncertainties profiled as nuisance parameters with gaussian priors → can be pulled / constrained

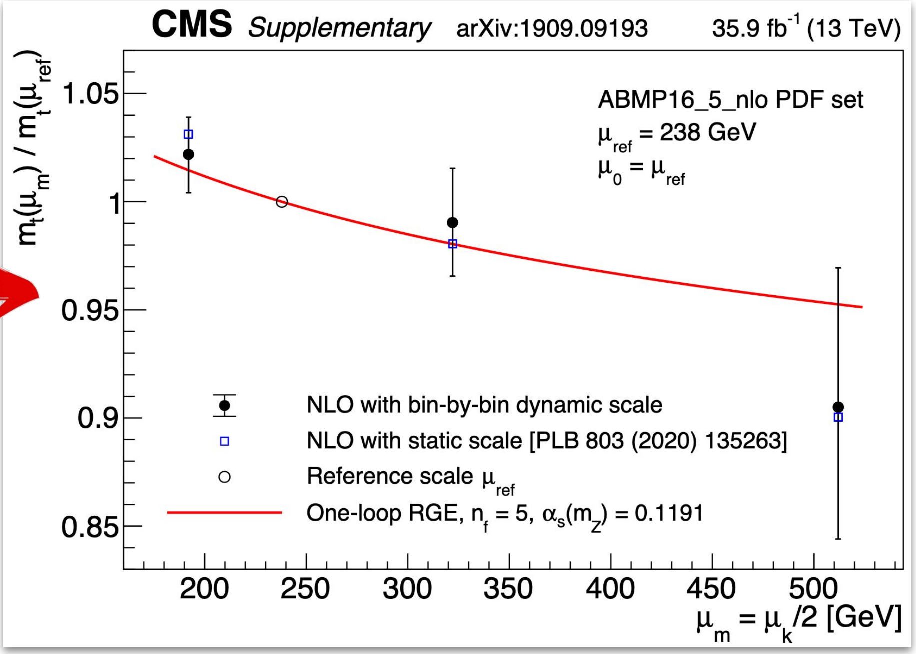


NNLO calculations now available: M.Czakon, A.Mitov, R.Poncelet JHEP 05 (2021) 212
→ see talk by R. Poncelet

Running of m_t @ NLO with 13 TeV data in CMS



- In $\overline{\text{MS}}$ scheme $m_t = m_t(\mu_m) \rightarrow$ running (similar to α_S)
- $m_t(\mu_m)$ extracted as a function of energy scale μ_m



Result compared to theoretical predictions in the MS scheme at NLO (MCFM) with fixed QCD scales ($\mu_r = \mu_f = \mu_m = m_t$) or with **bin-by-bin dynamic scales** ($\mu_r = \mu_f = m_t$, $\mu_m = m_{tt}/2$)

Choice of dynamic scales following JHEP 08 (2020) 027

Good agreement with QCD running @ 1 loop

NNLO prediction in MS scheme using Matrix

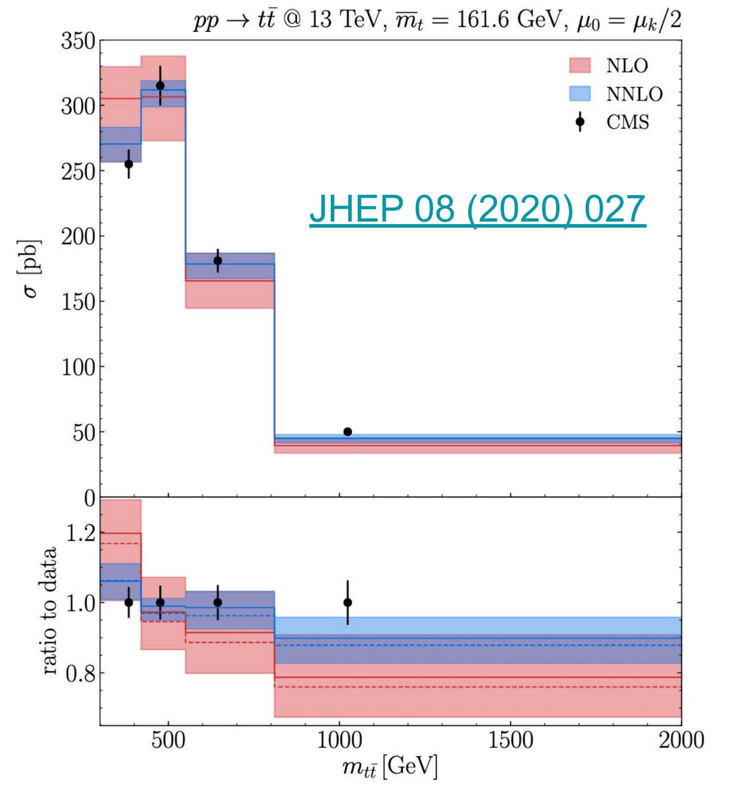
- First differential prediction of this kind, implemented in *Matrix* framework
- Significant reduction of scale uncertainties
- Possibility to set scale dynamically bin-by-bin -> extract directly $m_t(\mu_m)$

Choice for dynamic scale: $\mu_m = m_{tt}/2$, since $m_{tt}/2 \rightarrow m_t$ near the production threshold

$\rightarrow$ can be used together with CMS data to perform first extraction of m_t running @ NNLO

Limitation: non-negligible numerical uncertainties due to limited resources when producing several mass points and PDF variations for QCD fit

S.Catani, S.Devoto, M.Grazzini, S.Kallweit, J.Mazzitelli



JHEP 08 (2020) 027

m_t running @NNLO with CMS 13 TeV data

NEW

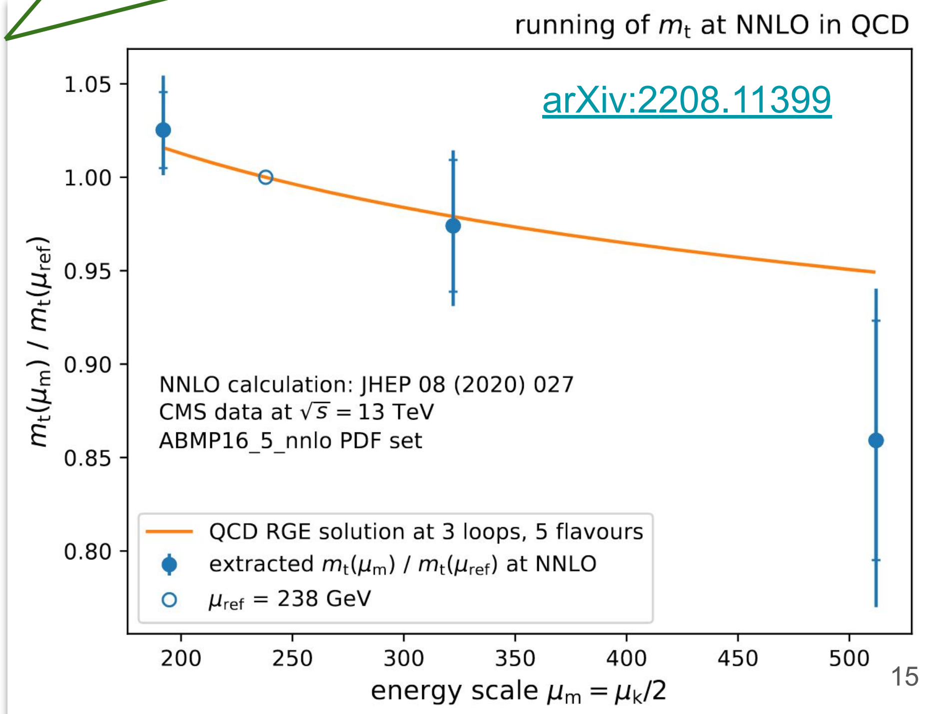
$$\chi^2(\vec{m},\vec{j},\vec{\eta}) = \vec{\Delta}^{\mathrm{T}}(\vec{m},\vec{j},\vec{\eta})\, C_{\mathrm{exp}}^{-1}\, \vec{\Delta}(\vec{m},\vec{j},\vec{\eta}) + \sum_{p=1}^{\mathrm{nPDF}} j_p^2 + \sum_{t=1}^{\mathrm{nPred}} \eta_t^2$$

data - theory masses PDFs numerical priors

MD, J.Kieseler, K.Lipka, J.Mazzitelli

- **CMS cross section rescaled** to match new measurement of integrated luminosity
- Significantly improved fit procedure, which takes into account numerical uncertainties in the calculation at their correlations

- Good agreement with QCD RGE solution at 3 loops (as in NNLO calculation)
- Consistent results with NLO analysis

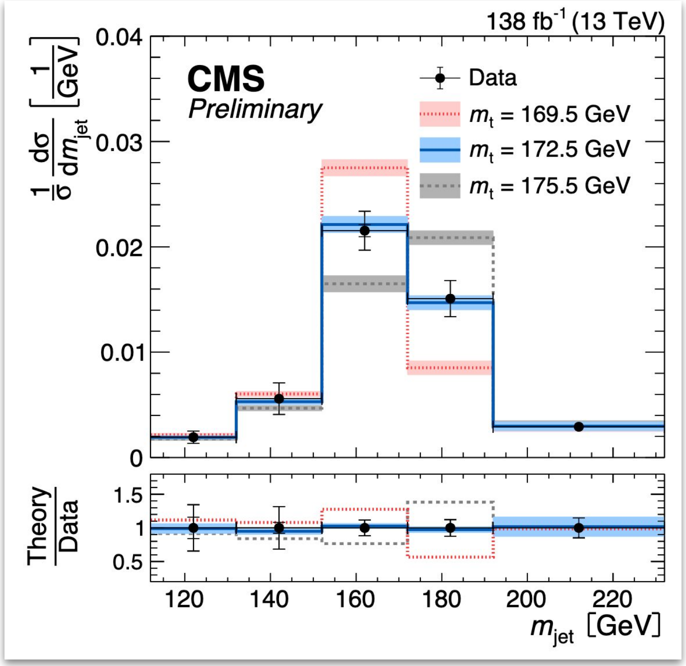


m_t from boosted m_{jet} at 13 TeV in CMS

NEW

CMS-PAS-TOP-21-012

- Analysis makes use of XCone exclusive algorithm to reconstruct jets and sub-jets → improved resolution
- Dedicated calibration of FSR using substructure variables, and dedicated jet mass calibration
- x3 improvement over CMS 2016 analysis!



As analytic calculations for m_{jet} are not yet available, m_t extraction is demonstrated using Powheg simulation

Comparable precision to direct measurement, but with different sensitivity to systematics uncertainties

More details in talks by M. Vanadia and D. Schwarz + poster by R. Kogler

Source	Uncertainty [GeV]
Statistical uncertainty	0.22
Experimental uncertainty	0.57
JER	0.40
JMS	0.27
JMS flavour	0.27
JES	0.10
Model uncertainty	0.48
Choice of m_{top}	0.37
CR	0.19
h_{damp}	0.19
FSR	0.02

$$m_t = 172.76 \pm 0.22\,(\text{stat}) \pm 0.57\,(\text{exp}) \pm 0.48\,(\text{model}) \pm 0.24\,(\text{theo})\,\text{GeV}$$
$$= 172.76 \pm 0.81\,\text{GeV}.$$

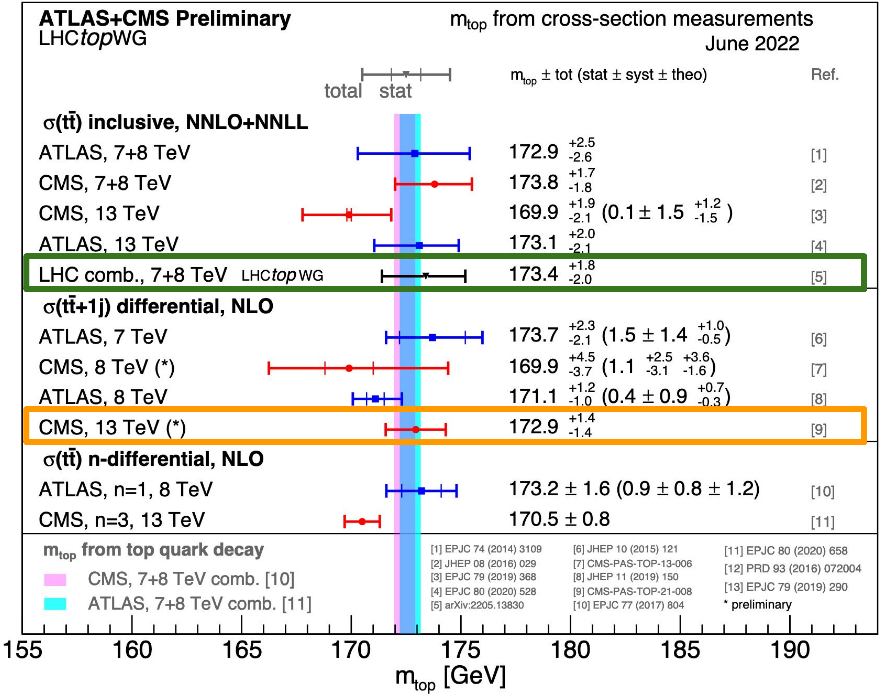
Summary

Presented most recent and most precise cross-section based measurements of m_t
→ advantage of a clear theoretical interpretation

- Results from inclusive σ_{tt} strongly depend on the assumed value of α_S
- Results from differential measurements rely on poorly understood threshold region

→ **theoretical advances needed in order to obtain accurate and unambiguous results**

Presented first measurement of *m_t running at NNLO* + precise extraction of *m_t from boosted jet mass* distribution in CMS



Thank you!

mt from LHC 7+8 TeV combination

$$\chi^2 = \frac{1}{1-\rho^2}\Big(\Delta(7\ \text{TeV})^2 + \Delta(8\ \text{TeV})^2 - 2\rho\Delta(7\ \text{TeV})\Delta(8\ \text{TeV})\Big),\ \text{with}$$

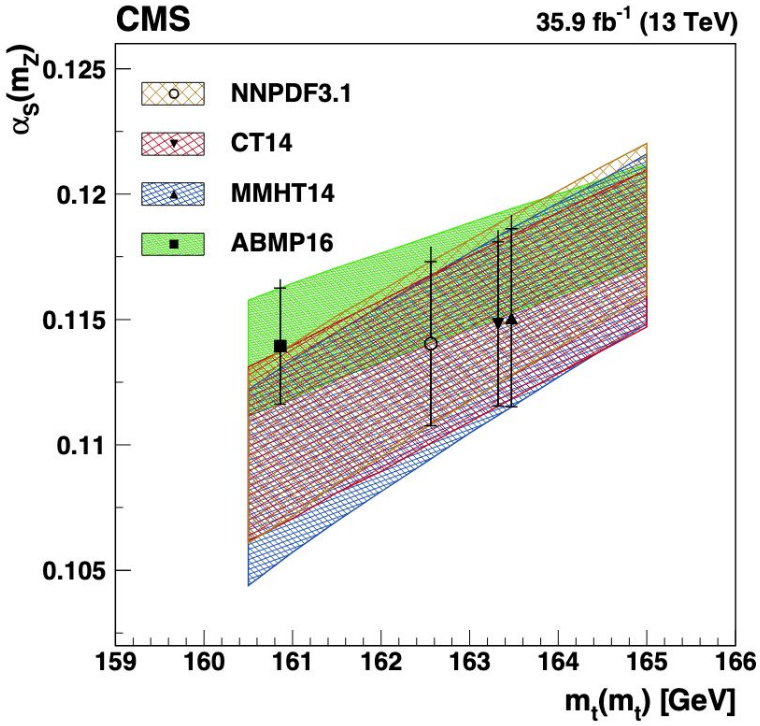
$$\Delta = \frac{\sigma_{t\bar{t}}(m_t^{\text{pole}}) - \sigma_{t\bar{t}}^{\text{p}}(m_t^{\text{pole}}, \alpha_{\text{s}}(m_Z))}{\delta},$$

ATLAS pole mass from inclusive @13 TeV

Uncertainty source	Δm_t^{pole} (GeV)
Data statistics	0.2
Analysis systematics	0.6
Integrated luminosity	0.8
Beam energy	0.1
PDF+α_S	$^{+1.5}_{-1.4}$
QCD scales	$^{+1.0}_{-1.5}$
Total uncertainty	$^{+2.0}_{-2.1}$

CMS inclusive 13 TeV

PDF set	$m_t(m_t)$ [GeV]
ABMP16	$161.6 \pm 1.6\,(\text{fit} + \text{PDF} + \alpha_S)\,^{+0.1}_{-1.0}\,(\text{scale})$
NNPDF3.1	$164.5 \pm 1.6\,(\text{fit} + \text{PDF} + \alpha_S)\,^{+0.1}_{-1.0}\,(\text{scale})$
CT14	$165.0 \pm 1.8\,(\text{fit} + \text{PDF} + \alpha_S)\,^{+0.1}_{-1.0}\,(\text{scale})$
MMHT14	$164.9 \pm 1.8\,(\text{fit} + \text{PDF} + \alpha_S)\,^{+0.1}_{-1.1}\,(\text{scale})$



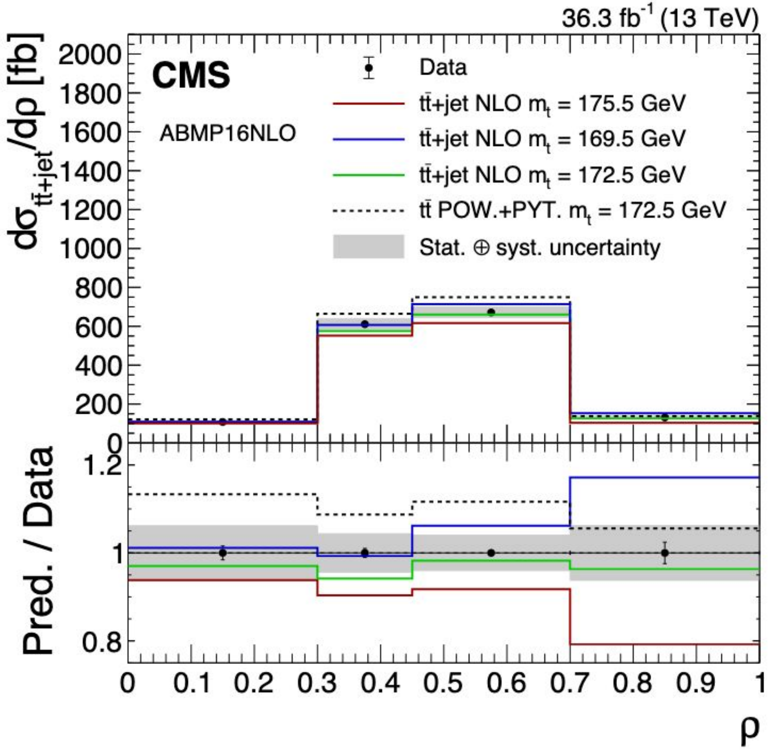
CMS 3D impacts

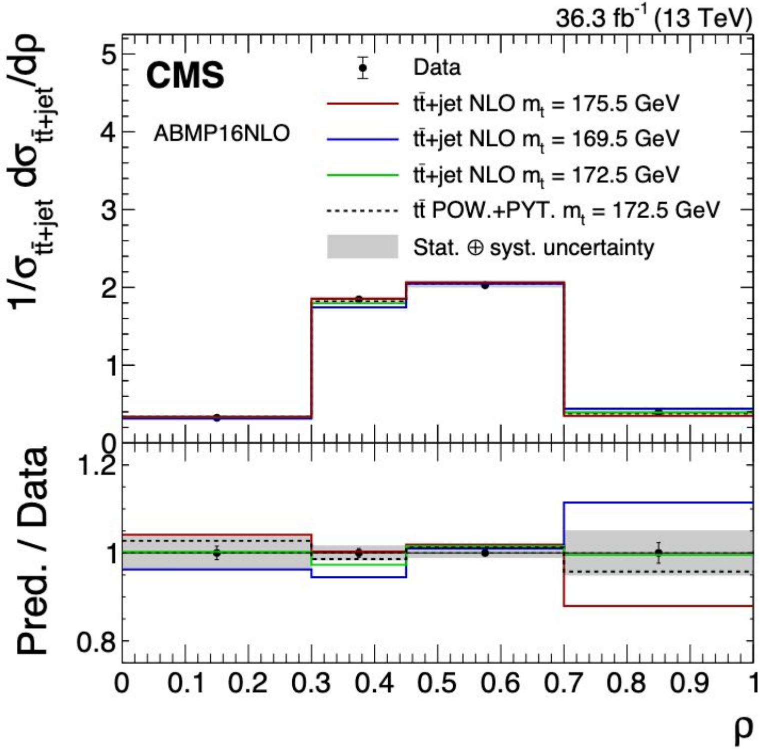
Parameter	Variation	$\alpha_S(m_Z)$	m_t^{pole} [GeV]
Fit uncertainty			
Total	$\Delta\chi^2 = 1$	± 0.0016	± 0.7
Model uncertainty			
f_s	$f_s = 0.5$	$+0.0001$	0.0
f_s	$f_s = 0.3$	0.0000	0.0
Q^2_{min}	$Q^2_{min} = 5.0\,\mathrm{GeV}^2$	$+0.0002$	$+0.1$
Q^2_{min}	$Q^2_{min} = 2.5\,\mathrm{GeV}^2$	-0.0004	-0.1
M_c	$M_c = 1.49\,\mathrm{GeV}$	$+0.0001$	0.0
M_c	$M_c = 1.37\,\mathrm{GeV}$	0.0000	0.0
Total		$^{+0.0002}_{-0.0004}$	$^{+0.1}_{-0.1}$
PDF parametrisation uncertainty			
$\mu^2_{f,0}$	$\mu^2_{f,0} = 2.2\,\mathrm{GeV}^2$	-0.0001	0.0
$\mu^2_{f,0}$	$\mu^2_{f,0} = 1.6\,\mathrm{GeV}^2$	$+0.0002$	0.0
A'_g	set to 0	$+0.0002$	-0.1
E_g	set to 0	$+0.0008$	0.0
Total		$^{+0.0008}_{-0.0001}$	-0.1
Scale uncertainty			
μ_r variation	$\mu_r = H'$	$+0.0004$	-0.2
μ_r variation	$\mu_r = H'/4$	$+0.0007$	$+0.1$
μ_f variation	$\mu_f = H'$	-0.0002	$+0.3$
μ_f variation	$\mu_f = H'/4$	$+0.0001$	-0.3
$\mu_{r,f}$ variation	$\mu_{r,f} = H'$	$+0.0004$	$+0.1$
$\mu_{r,f}$ variation	$\mu_{r,f} = H'/4$	$+0.0011$	-0.2
Alternative $\mu_{r,f}$	$\mu_{r,f} = H/2$	-0.0005	$+0.1$
Total		$^{+0.0011}_{-0.0005}$	$^{+0.3}_{-0.3}$

ATLAS tt+1jet 8 TeV

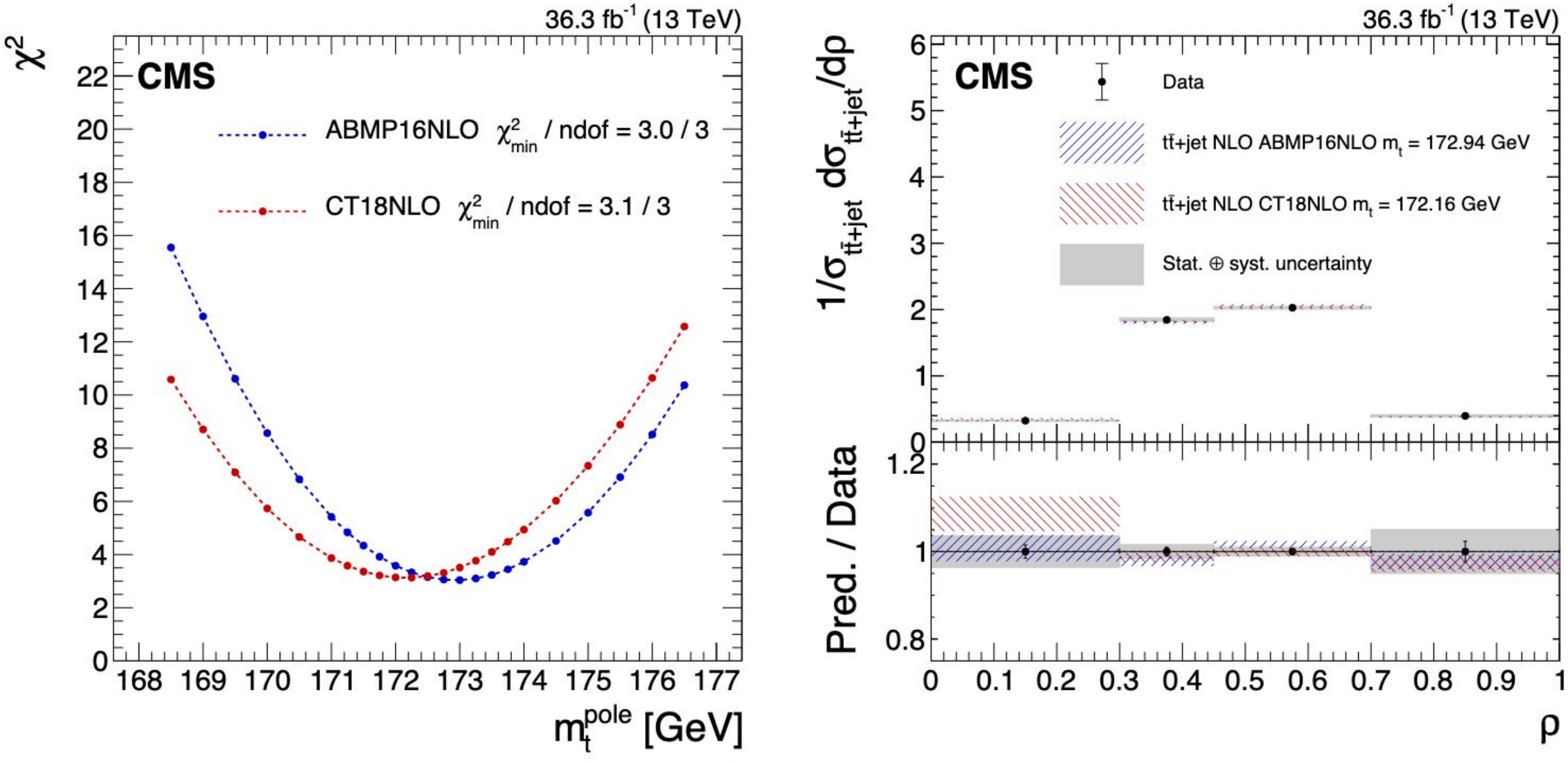
Mass scheme	m_t^{pole} [GeV]	$m_t(m_t)$ [GeV]
Value	**171.1**	**162.9**
Statistical uncertainty	**0.4**	**0.5**
Simulation uncertainties		
Shower and hadronisation	0.4	0.3
Colour reconnection	0.4	0.4
Underlying event	0.3	0.2
Signal Monte Carlo generator	0.2	0.2
Proton PDF	0.2	0.2
Initial- and final-state radiation	0.2	0.2
Monte Carlo statistics	0.2	0.2
Background	<0.1	<0.1
Detector response uncertainties		
Jet energy scale (including b-jets)	0.4	0.4
Jet energy resolution	0.2	0.2
Missing transverse momentum	0.1	0.1
b-tagging efficiency and mistag	0.1	0.1
Jet reconstruction efficiency	<0.1	<0.1
Lepton	<0.1	<0.1
Method uncertainties		
Unfolding modelling	0.2	0.2
Fit parameterisation	0.2	0.2
Total experimental systematic	**0.9**	**1.0**
Scale variations	(+0.6, −0.2)	(+2.1, −1.2)
Theory PDF$\oplus\alpha_s$	0.2	0.4
Total theory uncertainty	(**+0.7**, −0.3)	(**+2.1**, −1.2)
Total uncertainty	(**+1.2**, −1.1)	(**+2.3**, −1.6)

CMS tt+1j CMS 13 TeV

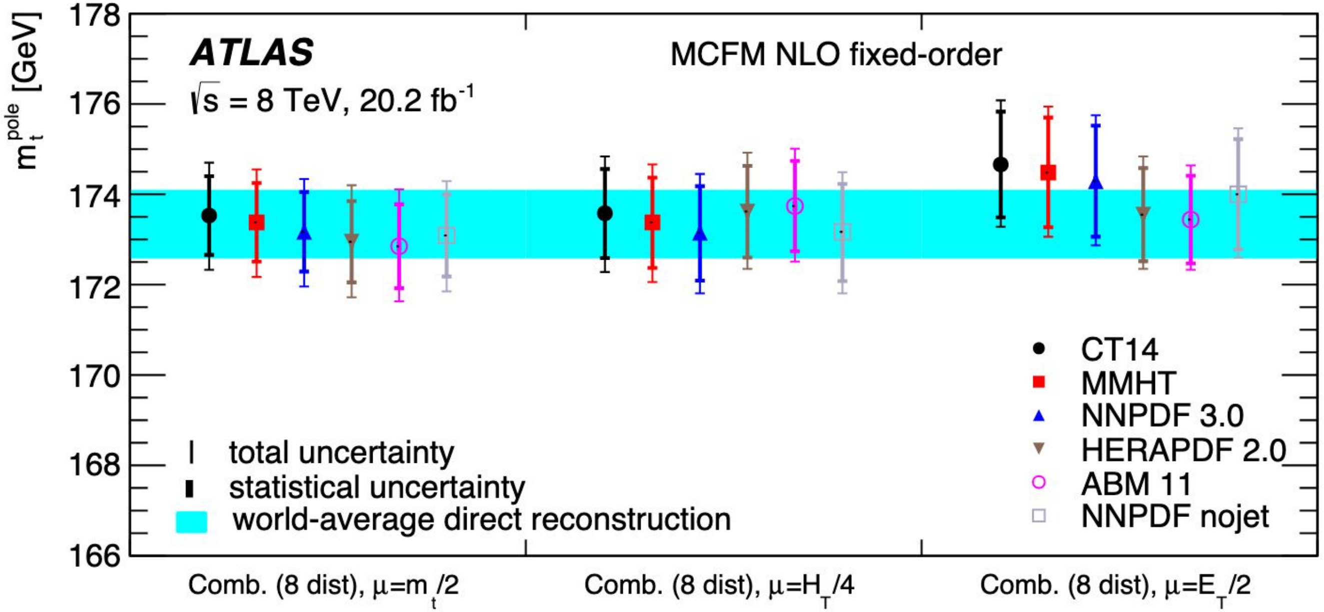




CMS tt+1j CMS 13 TeV



ATLAS leptonic observables 8 TeV



ATLAS leptonic observables 8 TeV

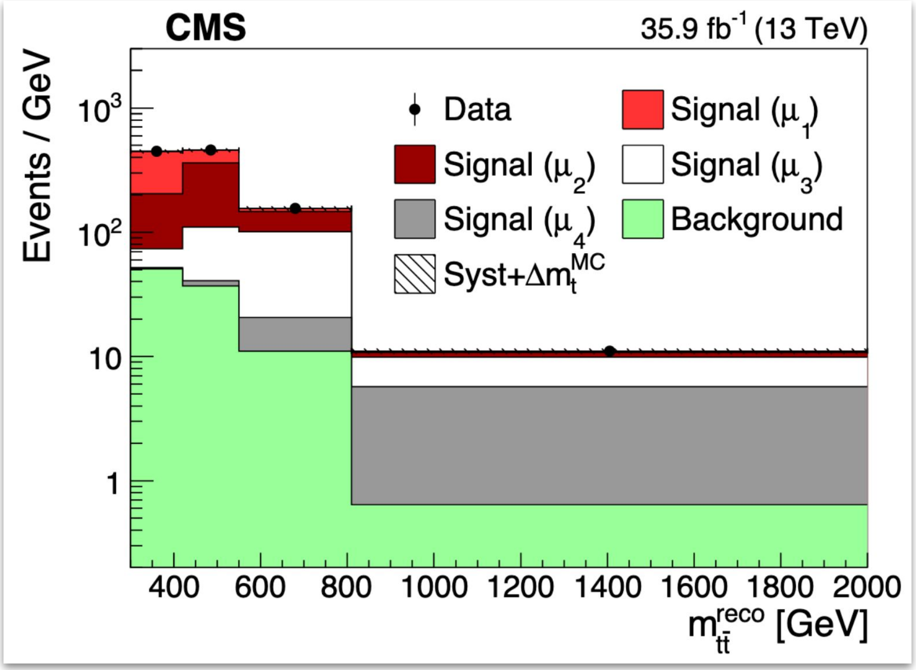
$$\chi^2(\mathbf{b}_{\text{exp}}, \mathbf{b}_{\text{th}}) = \sum_i \frac{\left(\varsigma_i^{\text{exp}} + \sum_j \gamma_{ij}^{\text{exp}} b_{j,\text{exp}} - \varsigma_i^{\text{th}} - \sum_k \gamma_{ik}^{\text{th}} b_{k,\text{th}}\right)^2}{d_{ii}^2} + \sum_j {b_{j,\text{exp}}}^2 + \sum_k {b_{k,\text{th}}}^2 + L\,,$$

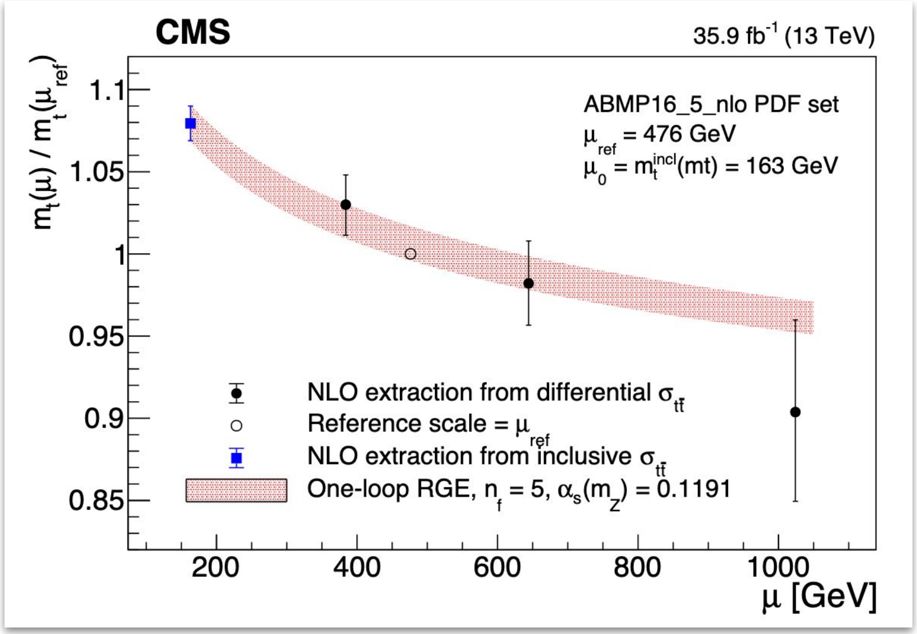
The χ^2 for the consistency of each prediction with the data was calculated using Eq. (9), incorporating both PDF and QCD scale uncertainties into the theoretical uncertainties represented by the nuisance parameters $\mathbf{b}_{\text{th}}$.

ATLAS leptonic observables 8 TeV

	CT14	MMHT	NNPDF 3.0	HERAPDF 2.0	ABM 11	NNPDF nojet
$\mu_F = \mu_R = m_t/2$						
χ^2/N_{dof}	71/68	70/68	67/68	67/68	71/68	64/68
m_t^{pole} [GeV]	173.5 ± 1.2	173.4 ± 1.2	173.2 ± 1.2	172.9 ± 1.2	$172.8^{+1.3}_{-1.2}$	173.1 ± 1.2
Data statistics	± 0.9	± 0.9	± 0.9	± 0.9	± 0.9	± 0.9
Expt. systematic	$^{+0.7}_{-0.8}$	± 0.8	± 0.8	± 0.9	$^{+0.9}_{-0.8}$	± 0.8
PDF uncertainty	± 0.1	± 0.1	$^{+0.1}_{-0.2}$	± 0.1	± 0.1	± 0.4
QCD scales	± 0.1	± 0.1	$^{+0.1}_{-0.0}$	± 0.1	± 0.1	± 0.0
$\mu_F = \mu_R = H_T/4$						
χ^2/N_{dof}	69/68	67/68	64/68	61/68	66/68	60/68
m_t^{pole} [GeV]	173.6 ± 1.3	173.4 ± 1.3	173.2 ± 1.3	173.6 ± 1.3	$173.7^{+1.3}_{-1.2}$	$173.2^{+1.3}_{-1.4}$
$\mu_F = \mu_R = E_T/2$						
χ^2/N_{dof}	71/68	70/68	66/68	64/68	68/68	64/68
m_t^{pole} [GeV]	174.7 ± 1.4	$174.5^{+1.5}_{-1.4}$	$174.3^{+1.5}_{-1.4}$	$173.6^{+1.3}_{-1.2}$	$173.4^{+1.2}_{-1.1}$	$174.0^{+1.5}_{-1.4}$

Running m_t CMS, likelihood unfolding





NNLO running: fit strategy

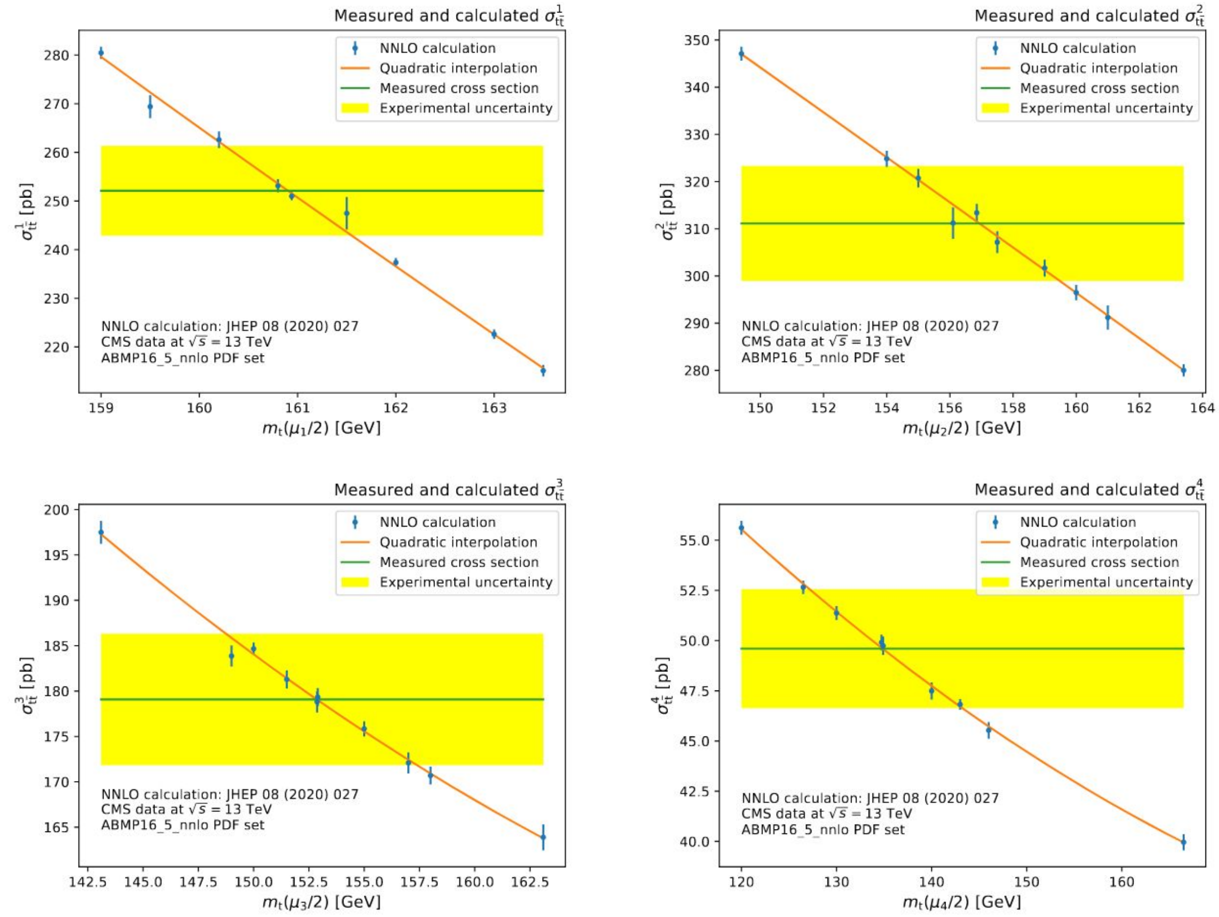
$$\chi^2(\vec{m},\vec{j},\vec{\eta}) = \vec{\Delta}^{\mathrm{T}}(\vec{m},\vec{j},\vec{\eta})\, C_{\mathrm{exp}}^{-1}\, \vec{\Delta}(\vec{m},\vec{j},\vec{\eta}) + \sum_{p=1}^{\mathrm{nPDF}} j_p^2 + \sum_{t=1}^{\mathrm{nPred}} \eta_t^2$$

$$\Delta_k(m_k,\vec{j},\vec{\eta}) = \sigma_{\mathrm{exp}}^k - \sigma_{\mathrm{th}}^k(m_k,\vec{j},\vec{\eta})$$

$$\sigma_{\mathrm{th}}^t(\eta_t) = \sigma_{\mathrm{th}}^t(1+\eta_t\delta_{\mathrm{num}}^t)$$

$$\sigma_{\mathrm{th}}^{m,k}(\vec{j},\vec{\eta}) = \sigma_{\mathrm{th}}^{m,k}(\eta_{m,k}) \prod_{p=1}^{\mathrm{nPDF}} \left[1 + j_p\left(\frac{\sigma_{\mathrm{th}}^{p,k}(\eta_{p,k})}{\sigma_{\mathrm{th}}^{m_0,k}(\eta_{m_0,k})} - 1\right)\right]$$

Running NNLO: interpolation



Running m_t @ NLO vs NNLO

NLO:

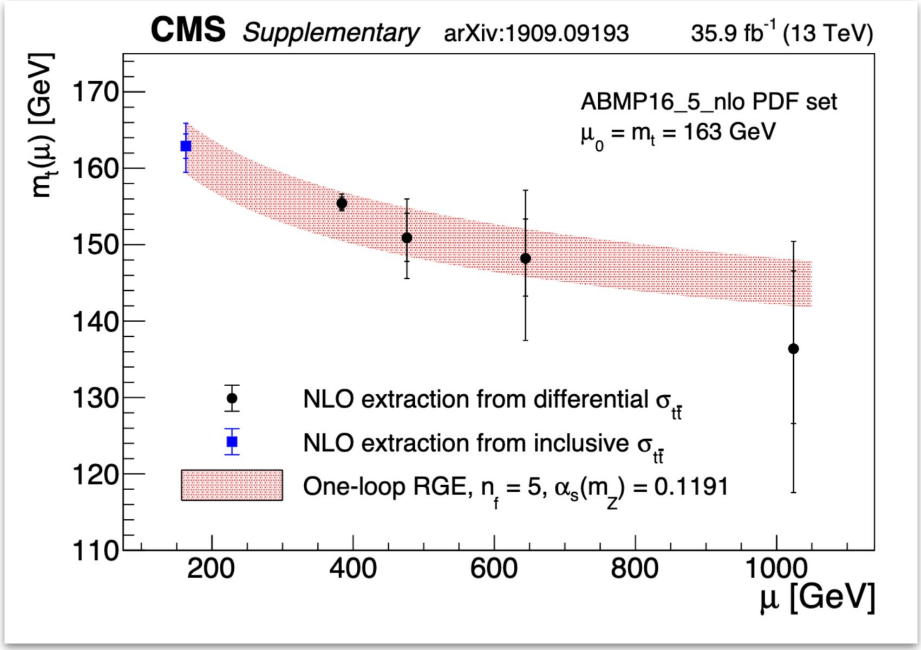
$$m_t(\mu_1) = 155.4 \pm 0.8\,(\text{fit}) \pm 0.2\,(\text{PDF+}\alpha_S) \pm 0.1\,(\text{extr})\,^{+0.9}_{-0.6}\,(\text{scale}),$$
$$m_t(\mu_2) = 150.9 \pm 3.0\,(\text{fit})\,^{+1.1}_{-0.7}\,(\text{PDF+}\alpha_S)\,^{+0.4}_{-0.5}\,(\text{extr})\,^{+3.9}_{-4.3}\,(\text{scale}),$$
$$m_t(\mu_3) = 148.2 \pm 4.6\,(\text{fit})\,^{+2.0}_{-1.4}\,(\text{PDF+}\alpha_S)\,^{+0.9}_{-1.0}\,(\text{extr})\,^{+7.3}_{-9.5}\,(\text{scale}),$$
$$m_t(\mu_4) = 136.4 \pm 9.0\,(\text{fit})\,^{+3.8}_{-3.0}\,(\text{PDF+}\alpha_S)\,^{+2.8}_{-2.3}\,(\text{extr})\,^{+9.6}_{-16.1}\,(\text{scale}).$$

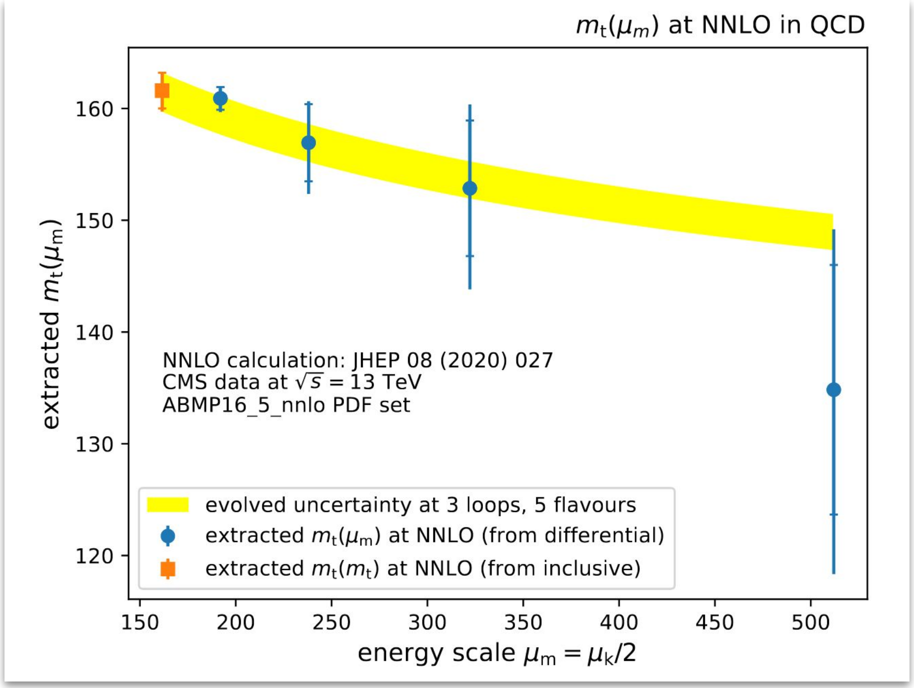
N.B. different choices of central scales, central values not comparable!

NNLO:

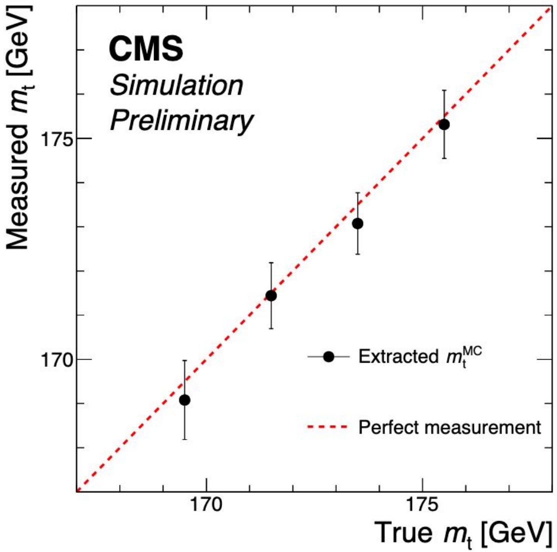
$\mu_k/2$ [GeV]	$m_t(\mu_k/2)$ [GeV]	exp [GeV]	PDF+num [GeV]	scale [GeV]
192	160.90	0.61	0.81	$+0.13, -0.69$
238	156.9	2.5	2.4	$+1.4, -3.0$
322	152.9	4.2	4.4	$+4.4, -6.7$
512	134.8	8.7	7.0	$+9.0, -12.2$

Running m_t @ NLO vs NNLO





Boosted m_{jet} CMS



Source	Uncertainty [GeV]
Total	0.81
Statistical	0.22
Experimental total	0.57
Jet energy resolution	0.40
Jet mass scale	0.27
Jet mass scale flavour	0.27
Jet energy scale	0.09
Pileup	0.08
MC statistics	0.07
Additional XCone corrections	0.03
Backgrounds	0.01
Model total	0.48
Choice of m_t	0.37
h_{damp}	0.19
Colour reconnection	0.19
Underlying event tune	0.12
μ_F, μ_R scales	0.07
ISR	0.06
FSR	0.03
Theory total	0.24
FSR	0.14
Underlying event tune	0.13
Colour reconnection	0.10
μ_F, μ_R scales	0.06
h_{damp}	0.06
ISR	0.06