13$^{\mathrm{th}}$ International Workshop on Top Quark Physics
14–18 September 2020

Measuring standard model parameters with top-quark cross sections

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on behalf of the ATLAS and CMS Collaborations

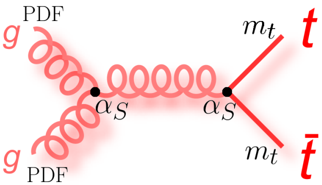
top quark production and QCD parameters

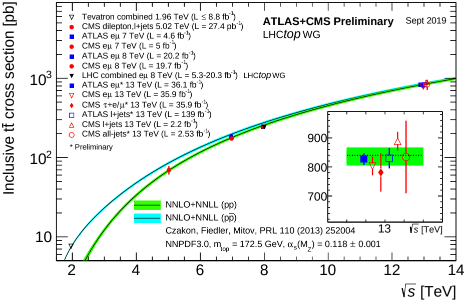
top quarks mainly produced in $t\bar{t}$ **pairs**

- gluon fusion → dominant at LHC

calculations of $\sigma_{t\bar{t}}$

- available up to NNLO+NNLL ($\simeq$ 5% precision)
- experimental precision currently superior to theoretical one





in pQCD, predictions for $\sigma_{t\bar{t}}$ depend on experimental inputs

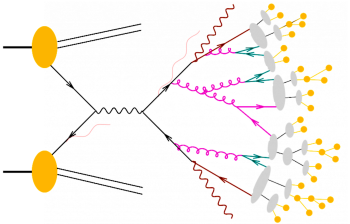
1. value of α_S
2. value of m_t (pole, $\overline{\mathrm{MS}}$, ...)
3. gluon (quark) PDF at high-x (up to $x \simeq 0.1$)

→ measurements of $\sigma_{t\bar{t}}$ can constrain QCD parameters

direct vs indirect measurement of m_t

direct measurement: reconstruct invariant mass of top quark decay products

- compare to MC templates generated with different values of m_t
- can reach precision of $\sim 0.5\,\text{GeV}$



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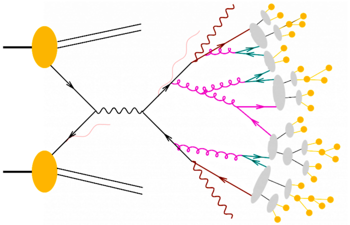
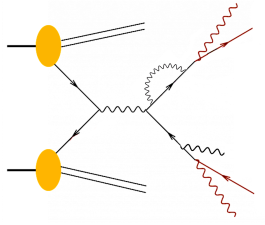


indirect determination: measure observable sensitive to m_{t} (e.g. $\sigma_{\mathrm{t\bar{t}}}$)

- compare measured $\sigma_{\mathrm{t\bar{t}}}$ to fixed-order calculations (inclusive, differential)
- m_{t} determined in well-defined scheme



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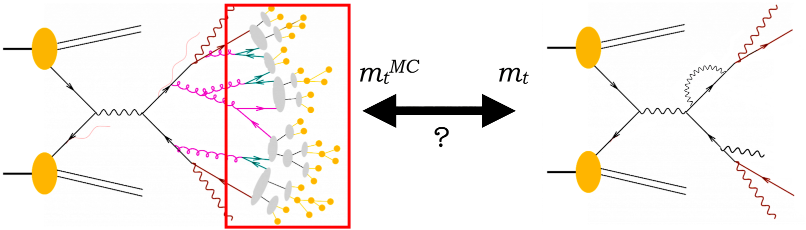


$$m_{\mathrm{t}}^{\mathrm{MC}} = m_{\mathrm{t}}^{\mathrm{pole}} \pm \Delta_{\mathrm{MC}}$$

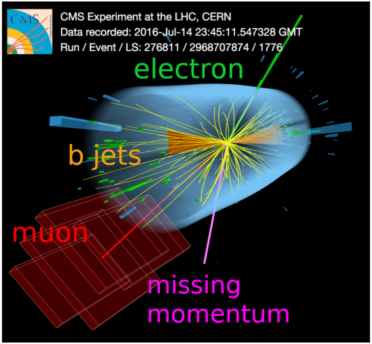
$\rightarrow$ Δ_{MC} includes non-perturbative effects that are difficult to estimate

e.g. PRL 117 (2016) 232001

visible phase space

1. detector geometry
2. selection of final-state objects

$$\sigma_{t\bar{t}}^{vis} \rightarrow \sigma_{t\bar{t}} = \frac{\sigma_{t\bar{t}}^{vis}}{A_{sel} \cdot \mathrm{BR}}$$



- acceptance A_{sel} depends on assumed m_t^{MC}
- potential problem when extracting m_t

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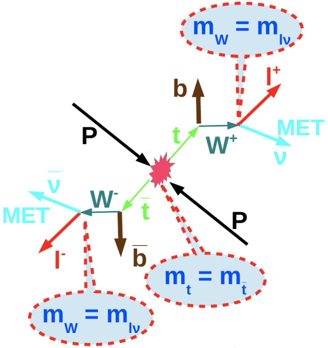

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kinematic top quark reconstruction

- estimate neutrino momenta using kinematic constraints (m_W and m_t^{MC})
- m_t^{MC}: large effect near threshold

$\to$ **mitigation strategies** discussed in this talk

Recent QCD results from $t\bar{t}$ cross sections in ATLAS and CMS

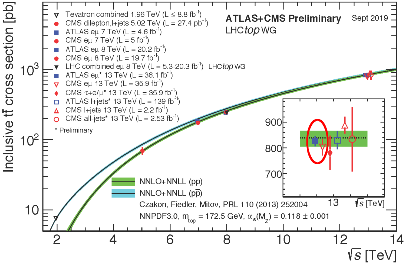
m_{t}^{pole} from inclusive $\sigma_{t\bar{t}}$ at $\sqrt{s} = 13$ TeV in ATLAS

EPJC 80 (2020) 528

$e^{\mp}\mu^{\pm}$ channel, 36.1 fb^{-1} (2015+2016)

- event count in bins of b-jet multiplicity
- significant improvements in lepton ID and luminosity determination

→ more details in Olga Bylund's talk



$$\sigma_{t\bar{t}}^{(e\mu)} = 826.4 \pm 3.6\,(\text{stat}) \pm 19.6\,(\text{syst})\ \text{pb}$$

$$\sigma_{t\bar{t}}^{\text{th}} = 832\ {}^{+20}_{-29}\ (\text{scale}) \pm 35\ (\text{PDF}+\alpha_S)\ \text{pb}$$

(Top++, NNLO+NNLL)

- total uncertainty of 2.4%, cfr:
  1. $\simeq$ 5% of theoretical prediction
  2. 4% of CMS result in $\ell^+\ell^-$ channels

→ most precise 13 TeV measurement

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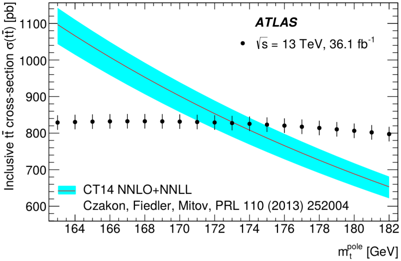


extraction of $m_t^{\rm pole}$

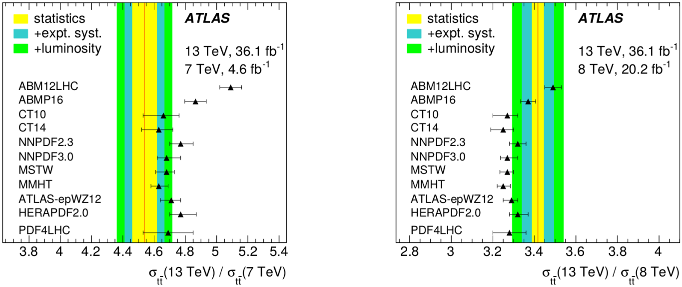
- NNLO+NNLL, CT14_nnlo PDFs
- dependence of measured $\sigma_{t\bar{t}}$ on $m_t^{\rm MC}$ accounted for, while $m_t^{\rm MC} = m_t^{\rm pole}$

$$m_t^{\rm pole} = 173.1\ ^{+2.0}_{-2.1}\ \text{GeV}$$

→ limited by QCD scale and PDF+α_S uncertainties

EPJC 80 (2020) 528

- $R^{t\bar{t}}_{13/8}$ and $R^{t\bar{t}}_{13/7}$ sensitive to PDFs
- cancellation of correlated uncertainties
- lower gluon density at high-x in ABM12 (lesser extent in ABMP16)



ATLAS cross section ratios

EPJC 80 (2020) 528

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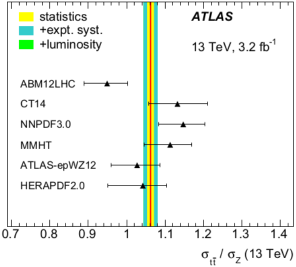
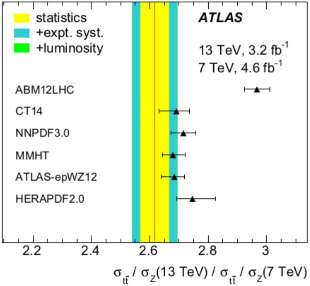
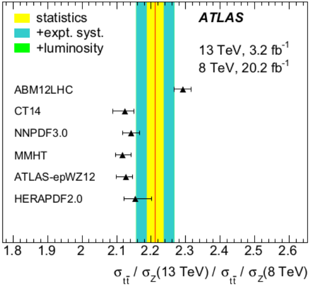
- cancellation of correlated uncertainties
- lower gluon density at high-x in ABM12 (lesser extent in ABMP16)
- luminosity uncertainty suppressed using $t\bar{t}/Z$ cross section (double) ratios



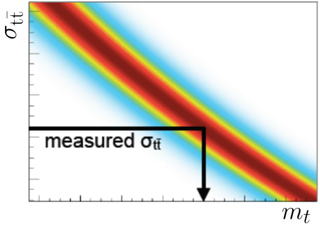




$m_t(m_t)$ and $\alpha_S(m_Z)$ from CMS $\sigma_{t\bar{t}}$ measurement at 13 TeV ($e^{\mp}\mu^{\pm}$)

EPJC 79 (2019) 368

- 35.9 fb^{-1} (2016), $e^{\mp}\mu^{\pm}$ channel
- simultaneous measurement of $\sigma_{t\bar{t}}$ and m_t^{MC} → mitigation of dependence
- precision of 4.2% limited by luminosity (2.5%) and lepton IDs (2.2%)



$$\sigma_{t\bar{t}} = 815 \pm 2\,(\mathrm{stat}) \pm 29\,(\mathrm{syst}) \pm 20\,(\mathrm{lum})\ \mathrm{pb}$$

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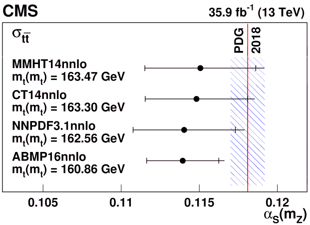
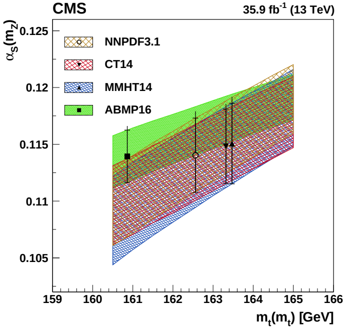
- values of $\alpha_S(m_Z)$ and $m_t(m_t)$ extracted using NNLO calculations in $\overline{\mathrm{MS}}$ scheme
  - most precise NNLO α_S result at hadron collider, and most precise $m_t(m_t)$ $\rightarrow$ 1.2%
- cannot obtain simultaneous information on α_S, m_t, and PDFs from inclusive $\sigma_{t\bar{t}}$

$\rightarrow$ need multi-differential measurement





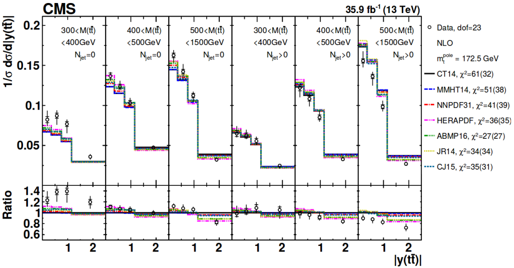
3D normalized $\sigma_{t\bar{t}}$ at 13 TeV ($\ell^+\ell^-$) and global QCD analysis (CMS)

arXiv:1904.05237

3D normalized cross section

1. $m_{t\bar{t}}$ → sensitive to m_t
2. $\mathrm{N_{jet}}$ → determine α_S
3. $y_{t\bar{t}}$ → info about PDFs

- reconstruction of $t\bar{t}$ system independent of m_t^{MC}
- parton-level cross section compared to NLO+PS



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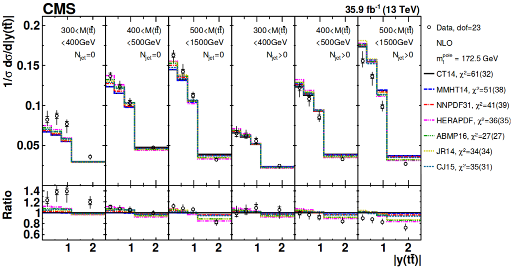
global fit to $t\bar{t}$ +HERA data

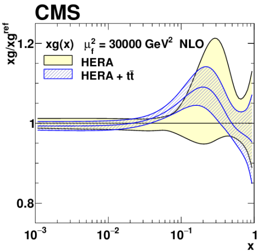
- simultaneous NLO fit of m_t^{pole}, α_S, and PDFs
- improvement in gluon PDF at high-x, reduced correlations

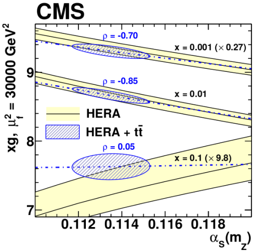
$$\alpha_S(m_Z) = 0.1135^{+0.0021}_{-0.0017}$$

$$m_t^{pole} = 170.5 \pm 0.8\,\mathrm{GeV}$$

$\rightarrow$ most precise result to date







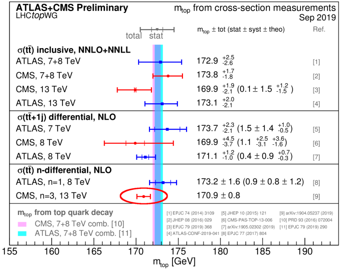
most sensitivity to m_{t} comes from threshold region ($m_{\mathrm{t\bar{t}}} \to 2m_{\mathrm{t}}$)

threshold effects

- important for this kind of analyses
- not captured by fixed-order calculations

however, QCD effects partly captured by

- fixed-order + parton showers
- all-order soft gluon resummation (effect up to +0.7 GeV on $m_{\mathrm{t}}^{\mathrm{pole}}$)



threshold effects in $t\bar{t}$ production

most sensitivity to m_t comes from threshold region ($m_{t\bar{t}} \to 2m_t$)

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however, QCD effects partly captured by

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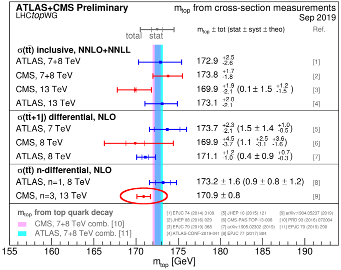
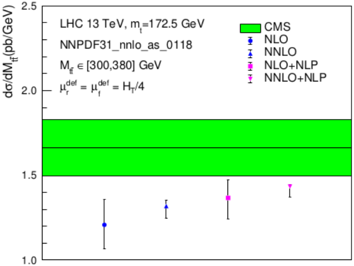
new study in JHEP 06 (2020) 158

- EFT approach used to include next-to-leading power (NLP) Coulomb corrections, to all orders in α_S
- better description of CMS data near the production threshold
- effect on m_t^{pole} up to +1.4 GeV

→ dedicated talk by Li Lin Yang





m_t from invariant mass of $t\bar{t}$ +1-jet system (ATLAS)

JHEP 11 (2019) 150

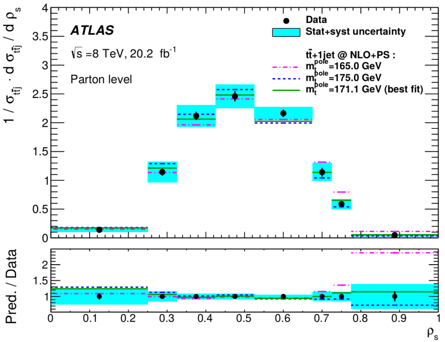
$$\rho_S = \frac{2m_0}{m_{t\bar{t}+1\text{-jet}}}, \quad m_0 = 170\,\text{GeV}$$

$\rightarrow$ sensitive to m_t at large ρ_S (production threshold)

- 20.2 fb^{-1} at $\sqrt{s} = 8$ TeV
- $t\bar{t} \rightarrow \ell$+jets ($\ell = e, \mu$)

method

- parton-level normalized differential cross section
- compared to NLO+PS predictions (on-shell, $\overline{\text{MS}}$)



- 3 times larger scale uncertainty in $\overline{\text{MS}}$ scheme (expected at threshold)

$m_t(m_t) = 162.9\,\text{GeV} \rightarrow m_t^{\text{pole}} = 170.9\,\text{GeV}$
$\Rightarrow$ consistent results

$$m_t^{\text{pole}} = 171.1 \pm 1.0\ (\text{exp})\ ^{+0.7}_{-0.3}\ (\text{th})\,\text{GeV}$$
$$m_t(m_t) = 162.9 \pm 1.1\ (\text{exp})\ ^{+2.1}_{-1.2}\ (\text{th})\,\text{GeV}$$

joint fit with HERA DIS data (ep)

- W, Z/γ^* (7 TeV) $\rightarrow$ quark PDFs
- $\mathrm{t\bar{t}}$ (8 TeV) $\rightarrow$ high-x gluon PDF

$\rightarrow$ focus on impact of $\mathrm{t\bar{t}}$ ATLAS data

PDF determination

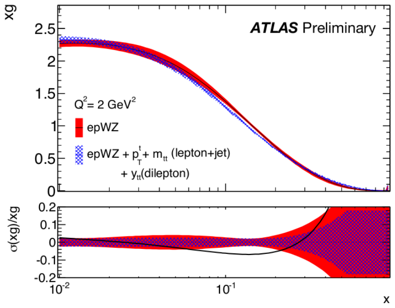
- general-mass variable-flavour-number scheme ($n_f \rightarrow n_f + 1$ transitions)
- NNLO QCD + NLO EW (xFitter)

sensitive distributions

1. $y_{\mathrm{t\bar{t}}}$ (dilepton)
2. $m_{\mathrm{t\bar{t}}}$ and p_{T}^{t} (ℓ+jets)

correlations between distributions determined with bootstrap method
$\Rightarrow p_{\mathrm{T}}^{t}, m_{\mathrm{t\bar{t}}}, y_{\mathrm{t\bar{t}}}$ used simultaneously

ATL-PHYS-PUB-2018-017



results

1. harder gluon distribution at high-x
2. reduced uncertainty at high-x

first investigation of the running of m_t (CMS)

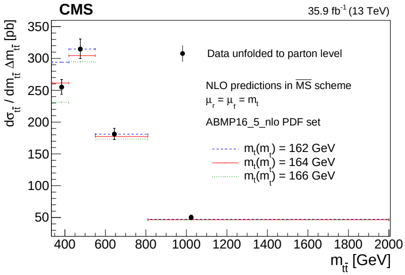
PLB 803 (2020) 135263

in $\overline{\mathrm{MS}}$ scheme, m_q dependence on scale μ described by RGE: $\frac{\mathrm{d}m_\mathrm{q}}{\mathrm{d}\mu^2} = -\gamma(\alpha_\mathrm{S})m_\mathrm{q}$

- probe of validity of pQCD
- sensitive to BSM contributions

method

- $m_\mathrm{t}(\mu)$ extracted at NLO vs $\mu = m_{\mathrm{t}\bar{\mathrm{t}}}$ from measurement of $\mathrm{d}\sigma_{\mathrm{t}\bar{\mathrm{t}}}/\mathrm{d}m_{\mathrm{t}\bar{\mathrm{t}}}$
- $\mathrm{d}\sigma_{\mathrm{t}\bar{\mathrm{t}}}/\mathrm{d}m_{\mathrm{t}\bar{\mathrm{t}}}$ determined at parton-level with maximum-likelihood unfolding (see Valentina Vecchio's talk)
- m_t^MC dependence incorporated in fit



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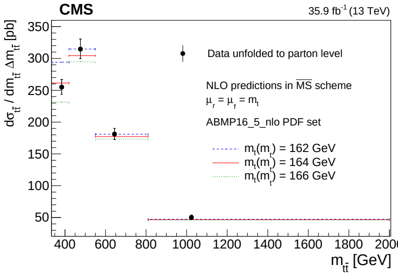
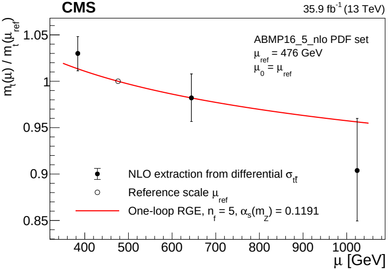
- m_t^{MC} dependence incorporated in fit
- slope: $r(\mu) = m_t(\mu)/m_t(\mu_{\mathrm{ref}})$
  1. cancellation of systematics
  2. solely depends on RGE

results

- good agreement with RGE
- no-running excluded at $> 95\%$ C.L.





running of m_t with "dynamic" scale

results of PLB 803 (2020) 135263
obtained with

- $\mu_\mathrm{r} = \mu_\mathrm{f} = \mu_m = m_\mathrm{t}$
- converting $m_\mathrm{t}(m_\mathrm{t}) \to m_\mathrm{t}(m_{\mathrm{t}\bar{\mathrm{t}}})$ using appropriate RGEs

in JHEP 08 (2020) 027 (see Stefano Catani's talk) it is argued that

- dynamic effect of $m_\mathrm{t}(\mu_m)$ should be included in the calculation
- best choice is $\mu_m = m_{\mathrm{t}\bar{\mathrm{t}}}/2$ (which approaches m_t at threshold)
- scale is set bin-by-bin (bbb)

results of PLB 803 (2020) 135263 obtained with

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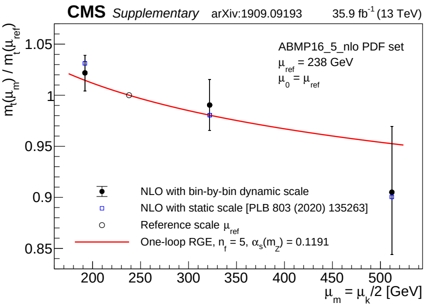
analysis of repeated at NLO with

1. $\mu_r = \mu_f = m_t$
2. $\mu_m = m_{t\bar{t}}/2$ (bbb)

$\to$ assess effect of μ_m alone

CMS public web page



- result qualitatively similar to original ones
- quantitative differences do not alter main conclusions of the paper
  1. good agreement with RGE
  2. no-running excluded at $> 95\%$ C.L.

$\to$ would benefit from NNLO calculation

non-QCD results from top quark measurements in ATLAS and CMS

$\rightarrow$ electroweak parameters

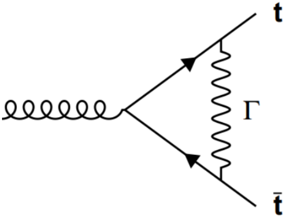
top quark Yukawa coupling from $t\bar{t}$ at 13 TeV (CMS)

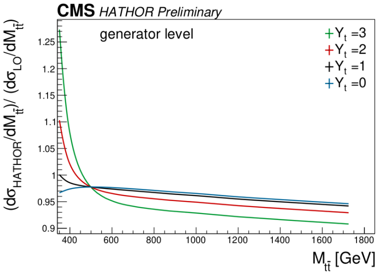
CMS-PAS-TOP-19-008

$m_{t\bar{t}}$ and $\Delta y_{t\bar{t}} = y_t - y_{\bar{t}}$ distributions altered by exchange of massive bosons (including H)

advantage: no assumption on other Higgs couplings

- approximate $\alpha_S^3\alpha$ EW corrections obtained with Hathor and applied to NLO MC





CMS-PAS-TOP-19-008

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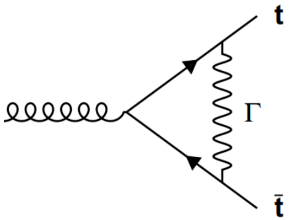


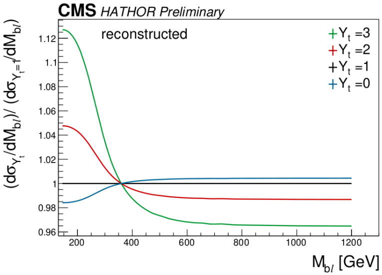
$\rightarrow$ 137 fb^{-1} at 13 TeV, $\ell\ell$ channel

- $M_{b\bar{b}\ell\bar{\ell}}$ and $|y_{b\bar{\ell}} - y_{\bar{b}\ell}|$ used as proxies for $m_{t\bar{t}}$, $\Delta y_{t\bar{t}}$ $\Rightarrow$ **no top reconstruction**
- profile likelihood fit to double-differential distributions

$$\mathcal{Y}_t = y_t^{\text{meas}}/y_t^{\text{SM}} = 1.16^{+0.24}_{-0.35}$$

ATLAS combination of Higgs results:
$\mathcal{Y}_t = 0.98 \pm 0.14$

$\rightarrow$ more details in Evan Ranken's talk



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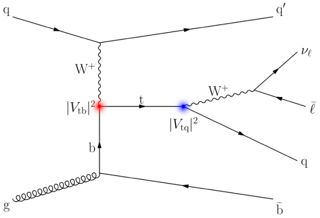
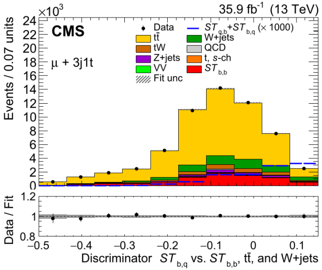
first **direct + model-independent** determination of $|V_{\rm tb}|$ and $|V_{\rm td}|^2 + |V_{\rm ts}|^2$

1. no assumption of unitarity
2. no assumption of no BSM physics

- CKM elements determined from signal strength of $\mathrm{ST}_{\rm b,b}$, $\mathrm{ST}_{\rm q,b}$, $\mathrm{ST}_{\rm b,q}$
- BDT trained in exclusive categories of jet and b-tagged jet multiplicity
- profile likelihood fit of BDT output





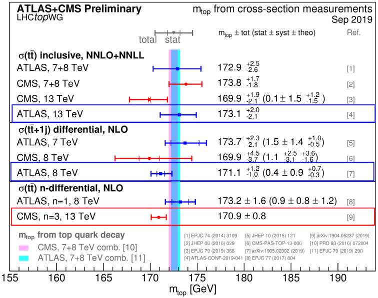
in the **BSM scenario** where $R_\Gamma = \Gamma_{\rm t}^{\rm obs}/\Gamma_{\rm t}$ is free:

$$|V_{\rm tb}| = 0.988 \pm 0.011\,(\text{stat+prof}) \pm 0.021\,(\text{nonprof})$$

$$|V_{\rm td}|^2 + |V_{\rm ts}|^2 = 0.06 \pm 0.05\,(\text{stat+prof}) \pm 0.04\,(\text{nonprof})$$

$$R_\Gamma = 0.99 \pm 0.42\,(\text{stat+prof}) \pm 0.03\,(\text{nonprof}).$$

→ precision on $|V_{\rm tb}|$ improved by 50% w.r.t previous CMS measurement in single-top



top and QCD parameters

- most recent m_{t} **results** using $\mathrm{t\bar{t}}$ cross sections (ATLAS & CMS)
- running of m_{t} in $\overline{\mathrm{MS}}$ scheme (CMS)
- **determination of** α_{S} from $\mathrm{t\bar{t}}$ (CMS)

PDF determination with $\mathrm{t\bar{t}}$ data

- PDF determination from $W, Z/\gamma^*, \mathrm{t\bar{t}}$ cross sections + HERA data (ATLAS)
- simultaneous fit of $m_{\mathrm{t}}^{\mathrm{pole}}$, α_{S}, and PDF with 3D $\sigma_{\mathrm{t\bar{t}}}$ at 13 TeV and HERA DIS data (CMS)

→ improvement in gluon PDF at high-x

top and EW sector (CMS)

- extraction of top Yukawa coupling $\mathrm{t\bar{t}}$ distributions at 13 TeV
- first model-independent extraction of CKM elements from t-ch. single top at 13 TeV → 50% improvement

Thank you for your attention

m_t^{pole} from inclusive $\sigma_{t\bar{t}}$ at 13 TeV (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	$172.1^{+3.1}_{-2.0}$

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	$^{+2.0}_{-2.1}$

$\alpha_S(m_Z)$, $m_t(m_t)$, m_t^{pole} from inclusive $\sigma_{t\bar{t}}$ at 13 TeV (CMS)

PDF set	$\alpha_S(m_Z)$
ABMP16	0.1139 ± 0.0023 (fit + PDF) $^{+0.0014}_{-0.0001}$ (scale)
NNPDF3.1	0.1140 ± 0.0033 (fit + PDF) $^{+0.0021}_{-0.0002}$ (scale)
CT14	0.1148 ± 0.0032 (fit + PDF) $^{+0.0018}_{-0.0002}$ (scale)
MMHT14	0.1151 ± 0.0035 (fit + PDF) $^{+0.0020}_{-0.0002}$ (scale)

	ABMP16	NNPDF3.1	CT14	MMHT14
m_t^{pole} [GeV]	170.37	172.5	173.3	174.2
RUNDEC loops	3	2	2	3
$m_t(m_t)$ [GeV]	160.86	162.56	163.30	163.47
$\alpha_S(m_Z)$	0.116	0.118	0.118	0.118
α_S range	0.112−0.120	0.108−0.124	0.111−0.123	0.108−0.128

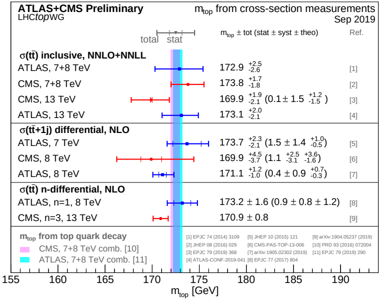
PDF set	$m_t(m_t)$ [GeV]
ABMP16	161.6 ± 1.6 (fit + PDF + α_S) $^{+0.1}_{-1.0}$ (scale)
NNPDF3.1	164.5 ± 1.6 (fit + PDF + α_S) $^{+0.1}_{-1.0}$ (scale)
CT14	165.0 ± 1.8 (fit + PDF + α_S) $^{+0.1}_{-1.0}$ (scale)
MMHT14	164.9 ± 1.8 (fit + PDF + α_S) $^{+0.1}_{-1.1}$ (scale)

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)

$\alpha_S(m_Z)$ and m_t^{pole} from 3D normalized $\sigma_{t\bar{t}}$ at 13 TeV (CMS)

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}	$Q^2_{\text{min}} = 5.0\,\text{GeV}^2$	$+0.0002$	$+0.1$
Q^2_{min}	$Q^2_{\text{min}} = 2.5\,\text{GeV}^2$	-0.0004	-0.1
M_c	$M_c = 1.49\,\text{GeV}$	$+0.0001$	0.0
M_c	$M_c = 1.37\,\text{GeV}$	0.0000	0.0
Total		${}^{+0.0002}_{-0.0004}$	${}^{+0.1}_{-0.1}$
	PDF parametrisation uncertainty		
$\mu^2_{f,0}$	$\mu^2_{f,0} = 2.2\,\text{GeV}^2$	-0.0001	0.0
$\mu^2_{f,0}$	$\mu^2_{f,0} = 1.6\,\text{GeV}^2$	$+0.0002$	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		${}^{+0.0011}_{-0.0005}$	${}^{+0.3}_{-0.3}$

m_t from $t\bar{t} + 1$-jet at 8 TeV (ATLAS)

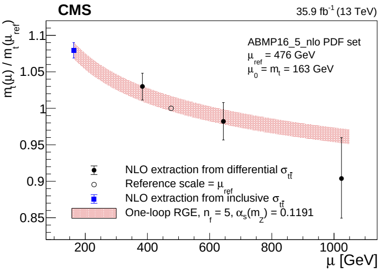


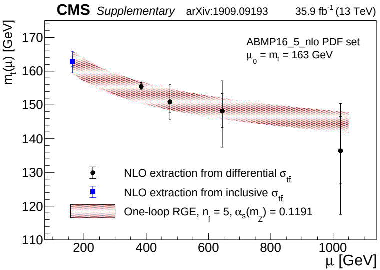
Mass scheme	m_t^{pole} [GeV]	$m_t(m_t)$ [GeV]
Value	**171.1**	**162.9**
Statistical uncertainty	**0.4**	**0.5**
Simulation uncertainties		
Shower and hadronisation	0.4	0.3
Colour reconnection	0.4	0.4
Underlying event	0.3	0.2
Signal Monte Carlo generator	0.2	0.2
Proton PDF	0.2	0.2
Initial- and final-state 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)**

PDFs from HERA DIS data + $W, Z/\gamma^*, t\bar{t}$ (ATLAS)

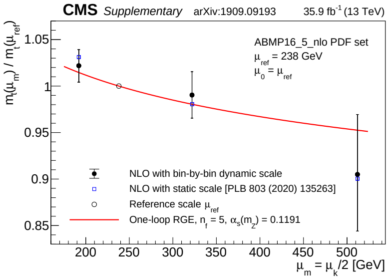
		lepton+jets p_T^t, m_{tt} and dilepton y_{tt} spectra
total χ^2/NDF		1253.8 / 1061
Partial χ^2/NDP	HERA	1149 / 1016
Partial χ^2/NDP	ATLAS $W, Z/\gamma^*$	78.9 / 55
Partial χ^2/NDP	ATLAS lepton+jets p_T^t, m_{tt}	16.0 / 15
Partial χ^2/NDP	ATLAS dilepton y_{tt}	5.4 / 5

running of m_t at 13 TeV (CMS)





running of m_t: fixed vs "dynamic" scale



observed running parametrized as

$$f(x, \mu) = x\,[r(\mu) - 1] + 1$$

such that

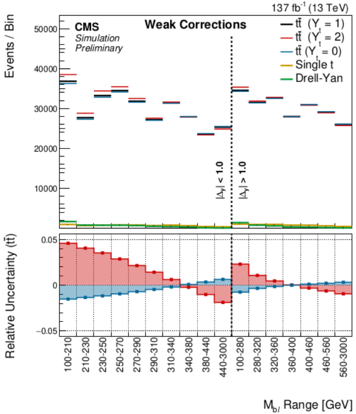
- $f(1, \mu) = r(\mu) \rightarrow$ RGE running
- $f(0, \mu) = 1 \rightarrow$ no running

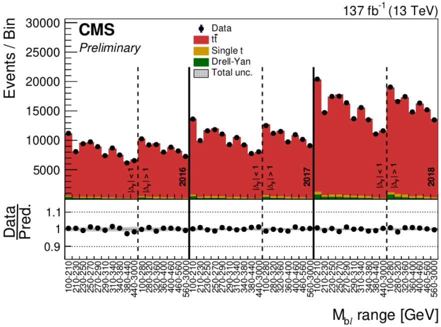
$\rightarrow$ best-fit value of x extracted via χ^2 fit of $f(x, \mu)$ to the ratios

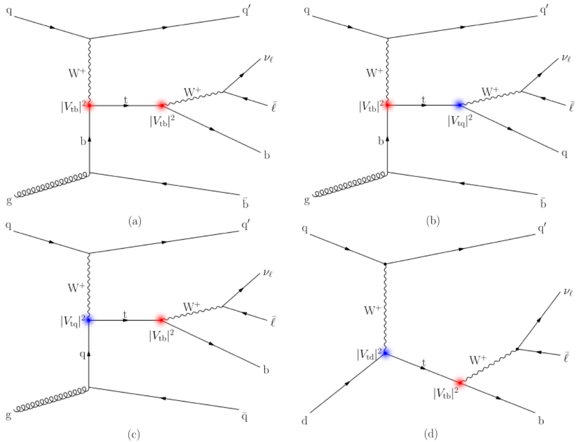
fixed scale: $\hat{x} = 2.05 \pm 0.61\ \text{(fit)}\ ^{+0.31}_{-0.55}\ (\text{PDF} + \alpha_S)\ ^{+0.24}_{-0.49}\ \text{(extr)}$

dynamic scale: $\hat{x} = 1.57 \pm 0.57\ \text{(fit)}\ ^{+0.28}_{-0.53}\ (\text{PDF} + \alpha_S)\ ^{+0.21}_{-0.46}\ \text{(extr)}$

top Yukawa from $t\bar{t}$ distributions at 13 TeV (CMS)







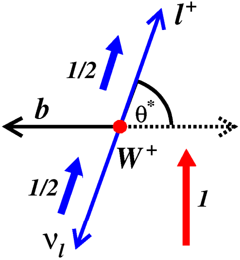
Category	Enriched in	Cross section × branching fraction	Feynman diagram
2j1t	$ST_{\mathrm{b,b}}$	$\sigma_{t\text{-ch,b}}\mathcal{B}(\mathrm{t}\to\mathrm{Wb})$	1a
3j1t	$ST_{\mathrm{b,q}}$, $ST_{\mathrm{q,b}}$	$\sigma_{t\text{-ch,b}}\mathcal{B}(\mathrm{t}\to\mathrm{Wq})$, $\sigma_{t\text{-ch,q}}\mathcal{B}(\mathrm{t}\to\mathrm{Wb})$	1b, 1c, 1d
3j2t	$ST_{\mathrm{b,b}}$	$\sigma_{t\text{-ch,b}}\mathcal{B}(\mathrm{t}\to\mathrm{Wb})$	1a

CKM elements from t-ch. single top at 13 TeV (CMS) - II

Treatment	Uncertainty	$\Delta\sigma_{ST_{b,b}}/\sigma$ (%)
Profiled	Lepton trigger and reconstruction	0.50
	Limited size of simulated event samples	3.13
	$t\bar{t}$ modelling	0.66
	Pileup	0.35
	QCD background normalisation	0.08
	W+jets composition	0.13
	Other backgrounds μ_R/μ_F	0.44
	PDF for background processes	0.42
	b tagging	0.73
	Total profiled	3.4
Nonprofiled	Integrated luminosity	2.5
	JER	2.8
	JES	8.0
	PDF for signal process	3.8
	Signal μ_R/μ_F	2.4
	ME-PS matching	3.7
	Parton shower scale	6.1
	Total nonprofiled	11.5
Total uncertainty		12.0

W polarization fractions F_0, F_L, F_R determined by

1. V-A structure of $\mathrm{t} \to \mathrm{Wb}$ vertex
2. m_t, m_W, m_b
3. possible anomalous couplings



$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta^*} = \frac{3}{4}\left(1-\cos^2\theta^*\right)F_0 + \frac{3}{8}\left(1-\cos\theta^*\right)^2 F_\mathrm{L} + \frac{3}{8}\left(1+\cos\theta^*\right)^2 F_\mathrm{R}$$

$\to$ experimental uncertainties ($3-5\%$) larger than theoretical ones (NNLO $\simeq 2\%$) $\Rightarrow$ **combination**

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- constraint: $F_R = 1 - F_L - F_0$
- improved precision of 25 (29)% for F_0 (F_L)
- almost doubled precision on F_R
- derived limits on anomalous coupling in EFT framework