Physics at the Terascale meeting 2018

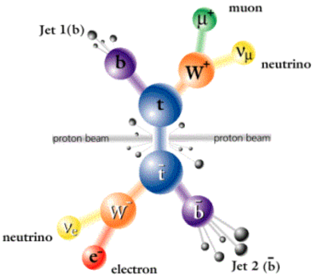
November 27, 2018

# Inclusive $\mathrm{t\bar{t}}$ cross section and determination of $\alpha_\mathrm{S}$ and $m_\mathrm{t}$ at 13 TeV in CMS

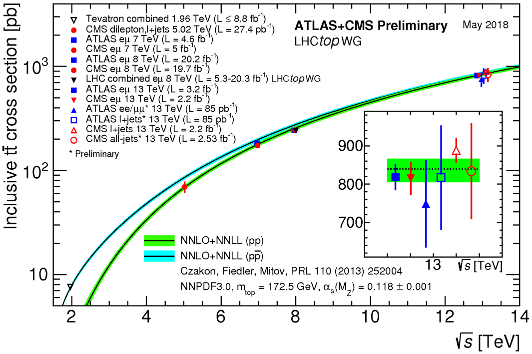
Matteo Defranchis (DESY)

on behalf of the CMS Collaboration

- CMS measurement of inclusive $\sigma_{t\bar{t}}$ at 13 TeV in di-lepton channels
- extraction of $\alpha_S$ and $m_t^{pole}$ at 7 and 8 TeV
- strategy of 13 TeV analysis
- CMS simultaneous measurement of inclusive $\sigma_{t\bar{t}}$ and $m_t^{MC}$ at 13 TeV
- extraction of $\alpha_S$ and $m_t(m_t)$ from inclusive $\sigma_{t\bar{t}}$



- can be used to constrain **gluon PDF** and extract **QCD parameters** like $m_{\mathrm{t}}$ and $\alpha_S$
- sensitive to **physics BSM**, e.g. $\tilde{\mathrm{t}}$ production (see talk by Juan Gonzalez)
- main **background** of several searches and measurements




$\simeq 15/\mathrm{s}$ $\mathrm{t\bar{t}}$ pairs produced at LHC

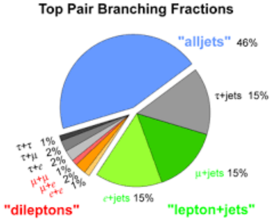
$\Rightarrow$ unique opportunity to study this process in detail and exploit its potential

- $\mathrm{t\bar{t}}$ production is well understood process on a wide range of energy
- first 13 TeV results with 35.9 $\mathrm{fb}^{-1}$ (2016) presented in this talk - by CMS Collaboration

- measurement is performed in the visible phase space where a **fiducial cross section** $\sigma_{t\bar{t}}^{\mathrm{vis}}$ is measured (systematic uncertainties can be constrained)
- observed $\sigma_{t\bar{t}}^{\mathrm{vis}}$ is extrapolated to full phase space to get **total cross section** $\sigma_{t\bar{t}}$ $\rightarrow$ introduces model dependence

$$\sigma_{t\bar{t}}^{\mathrm{vis}} = \frac{N_{\mathrm{data}} - N_{\mathrm{bkg}}}{\epsilon_{\mathrm{sel}} \cdot L_{\mathrm{int}}}$$

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




**"golden" decay channels** for $\sigma_{t\bar{t}}$ measurement

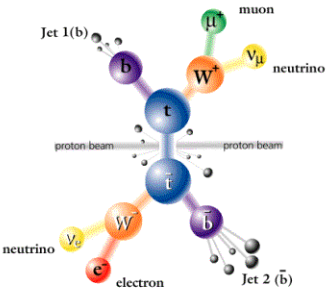
- di-leptonic channels, in particular $e\mu$
- l+jets channels ($l = e, \mu$)

$\rightarrow$ all-hadronic channel penalized by JES, modelling and b-tagging uncertainties

**triggers**: dilepton OR single lepton

## offline selection

- at least two opposite-charge leptons:
  $p_{T1} > 25\,\text{GeV}$, $p_{T2} > 20\,\text{GeV}$
  $|\eta| < 2,4$, $m_{ll} > 20\,\text{GeV}$
- jets: $p_T > 30\,\text{GeV}$ and $|\eta| < 2.4$
- b-tagging: CSVv2 Tight WP
  (0.1% mis-identification, 40% efficiency)




### same flavour channels

- at least one b tagged jet
- Z boson veto in region
  $76 < m_{\ell\ell} < 106$ GeV

→ events classified in mutually-exclusive categories according to lepton flavour, b-tag and jet multiplicity method: **template fit** to distributions of final state observables

- systematic uncertainties treated as **nuisance parameters** and constrained in the visible phase space (with exception of luminosity)
- events categorized in **bins of jet and b-tag multiplicities** in order to constrain modelling uncertainties and b-tagging efficiencies
- jet $p_T$ spectra are used to constrained JEC uncertainties

**extrapolation**

- result is extrapolated to the full phase space $\rightarrow$ total cross section
- systematic uncertainties on acceptance are not constrained
  $\rightarrow$ *you cannot measure what you do not see*

**binned Poisson Likelihood**

$$L = \prod_i \exp[\mu_i]\mu_i^{n_i}/n_i! \cdot \prod_m \pi(\lambda_m)$$

$$\mu_i = s_i(\sigma_{\mathrm{t\bar{t}}}^{\mathrm{vis}}, \vec{\lambda}) + \sum_k b_{k,i}^{\mathrm{MC}}(\vec{\lambda})$$

- $\vec{\lambda}$ is a set of nuisance parameters
- $\pi(\lambda_m)$ parametrizes the prior knowledge of $m^{\mathrm{th}}$ parameter

**b-tagging efficiencies** determined *in situ* by exploiting the $\mathrm{t\bar{t}}$ topology:

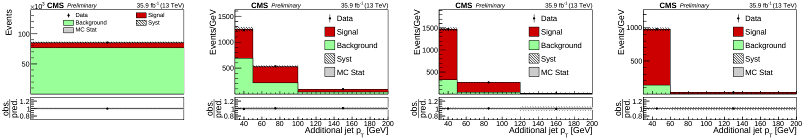
$$\begin{aligned} s_{1\mathrm{b}} &= \mathcal{L}\sigma_{\mathrm{t\bar{t}}}^{\mathrm{vis}}\epsilon_{\ell\ell} \cdot 2\epsilon_{\mathrm{b}}(1 - C_{\mathrm{b}}\epsilon_{\mathrm{b}}) \\ s_{2\mathrm{b}} &= \mathcal{L}\sigma_{\mathrm{t\bar{t}}}^{\mathrm{vis}}\epsilon_{\ell\ell} \cdot \epsilon_{\mathrm{b}}^2 C_{\mathrm{b}} \\ s_{\mathrm{other}} &= \mathcal{L}\sigma_{\mathrm{t\bar{t}}}^{\mathrm{vis}}\epsilon_{\ell\ell} \cdot (1 - 2\epsilon_{\mathrm{b}}(1 - C_{\mathrm{b}}\epsilon_{\mathrm{b}}) - C_{\mathrm{b}}\epsilon_{\mathrm{b}}^2) \end{aligned}$$

- $\epsilon_{\ell\ell}$ is the efficiency if the di-lepton selection
- $\epsilon_{\mathrm{b}}$ is the b-tagging efficiency
- $C_{\mathrm{b}}$ represents the residual correlation of tagging the two b-jets

# $t\bar{t}$ cross section results: post-fit distributions ($e^{\mp}\mu^{\pm}$ channel)

CMS-PAS-TOP-17-001

## 0 b-tags: 0,1,2,3 additional jets

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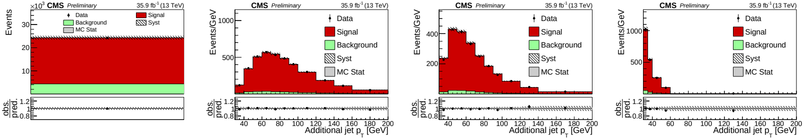
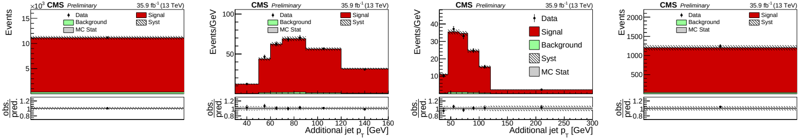



## 2 b-tags: 0,1,2,3 additional jets



CMS-PAS-TOP-17-001

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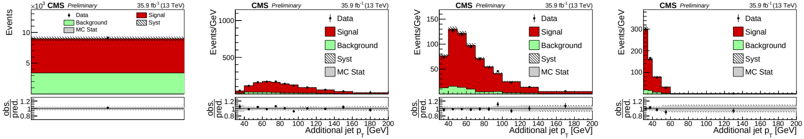
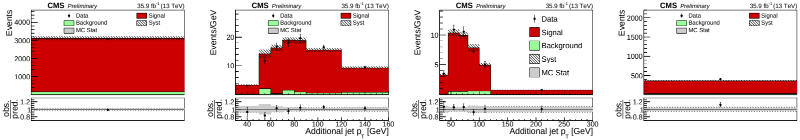



## 2 b-tags: 0,1,2,3 additional jets




→ at least one b-tagged jet required in same-flavour channels

# $t\bar{t}$ cross section results: post-fit distributions ($\mu^+\mu^-$ channel)

CMS-PAS-TOP-17-001

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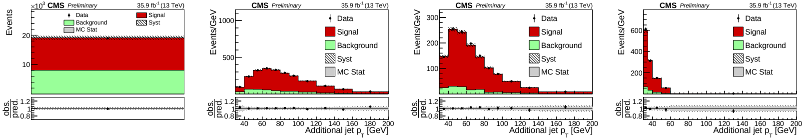
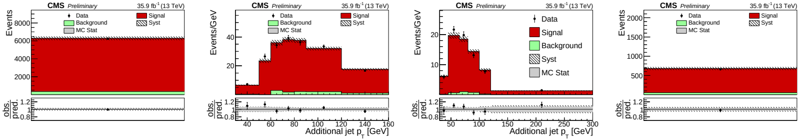



## 2 b-tags: 0,1,2,3 additional jets




→ at least one b-tagged jet required in same-flavour channels

# inclusive $\sigma_{t\bar{t}}$ result at 13 TeV - di-lepton channels

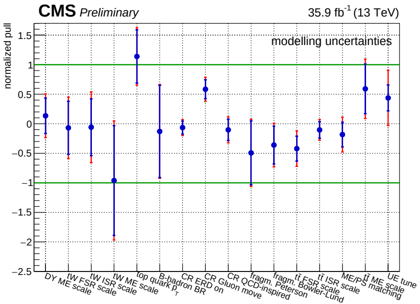
CMS-PAS-TOP-17-001

**visible $t\bar{t}$ cross section**

$\sigma_{t\bar{t}}^{\mathrm{vis}}$ = 25.61 $\pm$ 0.05 (stat) $\pm$ 0.75 (syst) $\pm$ 0.64 (lum) pb

**total $t\bar{t}$ cross section** (extrapolated)

$\sigma_{t\bar{t}}$ = 803 $\pm$ 2 (stat) $\pm$ 25 (syst) $\pm$ 20 (lum) pb




| Name | Contribution [%] |
|---|---|
| Trigger | 0.3 |
| Lepton ID/isolation | 2.0 |
| Electron energy scale | 0.1 |
| Muon energy scale | 0.1 |
| Jet energy scale | 0.4 |
| Jet energy resolution | 0.4 |
| b-tagging | 0.4 |
| Pile-up | 0.1 |
| $t\bar{t}$ ME scale | 0.2 |
| tW ME scale | 0.2 |
| DY ME scale | 0.1 |
| PDF | 1.1 |
| Top $p_T$ | 0.5 |
| ME/PS matching | 0.2 |
| UE tune | 0.3 |
| $t\bar{t}$ ISR scale | 0.4 |
| tW ISR scale | 0.1 |
| $t\bar{t}$ FSR scale | 0.8 |
| tW FSR scale | 0.1 |
| B-fragmentation | 0.7 |
| B-hadron BF | 0.1 |
| Color reconnection | 0.3 |
| DY background | 0.9 |
| tW background | 1.1 |
| Diboson background | 0.2 |
| W+jets background | 0.2 |
| $t\bar{t}$ background | 0.2 |
| Statistical | 0.2 |
| Luminosity | 2.5 |
| MC statistical | 1.1 |
| Total (vis) | 3.8 |
| $\sigma_{t\bar{t}}^{\mathrm{vis}}$ (13 TeV) | 25.61 pb |
| $t\bar{t}$ ME scale (extr) | $\mp^{0.3}_{0.1}$ |
| PDF (extr) | $\pm^{0.8}_{0.6}$ |
| Top $p_T$ (extr) | $\mp^{0.5}_{<0.1}$ |
| $t\bar{t}$ ISR scale (extr) | $\mp^{0.1}_{<0.1}$ |
| $t\bar{t}$ FSR scale (extr) | $\pm^{0.1}_{<0.1}$ |
| UE tune (extr) | $\mp^{<0.1}_{<0.1}$ |
| Total | $\pm^{4.0}_{4.0}$ |
| $\sigma_{t\bar{t}}$ (13 TeV) | 803 pb |

# inclusive $\sigma_{t\bar{t}}$ result at 13 TeV - di-lepton channels

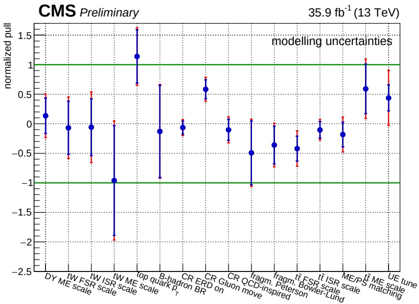
CMS-PAS-TOP-17-001

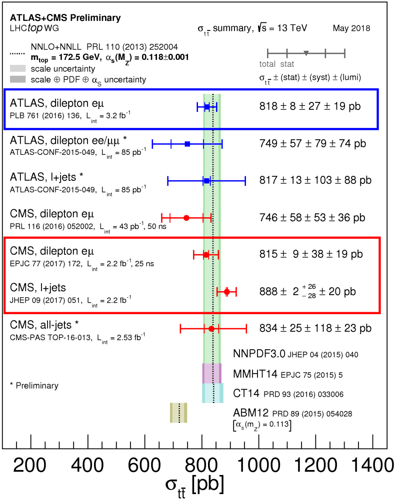
**visible $t\bar{t}$ cross section**

$\sigma_{t\bar{t}}^{\text{vis}}$=25.61 ± 0.05 (stat) ± 0.75 (syst) ± 0.64 (lum) pb

**total $t\bar{t}$ cross section** (extrapolated)

$\sigma_{t\bar{t}} = 803 \pm 2\,(\text{stat}) \pm 25\,(\text{syst}) \pm 20\,(\text{lum})$ pb

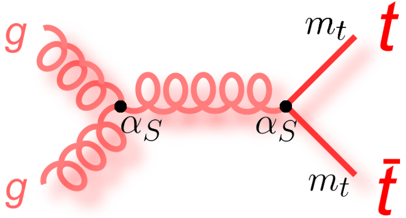


calculations of $t\bar{t}$ production depend on:

1. strong coupling $\alpha_S$
2. top quark mass $m_t$
3. gluon (quark) PDF in the proton

→ measurements of $\sigma_{t\bar{t}}$ can be used to constrain these parameters




**strong coupling**

- $\alpha_S$ known with sub-percent precision
- significant contribution to uncertainty for several QCD predictions
- can be measured at NNLO from $\sigma_{t\bar{t}}$

**top quark mass**

- consistency test of Standard Model
- can be determined in well defined scheme ($\overline{\mathrm{MS}}$, on-shell) from $\sigma_{t\bar{t}}$
- avoid interpretation problems of $m_t^{\mathrm{MC}}$

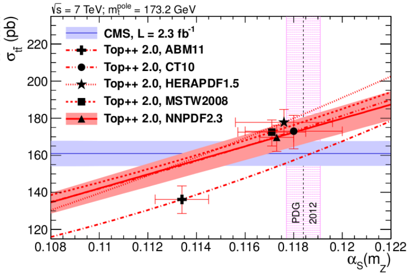
→ **NB:** $\alpha_S$ and $m_t$ cannot be determined simultaneously from inclusive $\sigma_{t\bar{t}}$

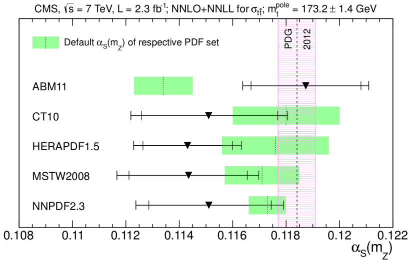
# determination of $\alpha_S(M_Z)$ from $\sigma_{t\bar{t}}$ at 7 TeV

Phys. Lett. B 728 (2013) 496

- using CMS measurement at 7 TeV in dilepton channel with 2.3 fb$^{-1}$, 4.1% accuracy (JHEP 11 (2012) 067)
- theory prediction with Top++2.0, NNLO+NNLL precision
- several different PDF sets considered
- $\alpha_S(M_Z)$ varied consistently in calculation and PDF
- experimental dependence of $\sigma_{t\bar{t}}$ on $\alpha_S(M_Z)$ found to be negligible
- assumed $m_t^{\text{pole}} = 173.2 \pm 1.4$ GeV (Tevatron average $\oplus$ 1 GeV to account for difference between $m_t^{\text{pole}}$ and $m_t^{\text{MC}}$)

$$\alpha_S(M_Z) = 0.1151\ ^{+0.0028}_{-0.0027} \quad \text{(NNPDF2.3)}$$



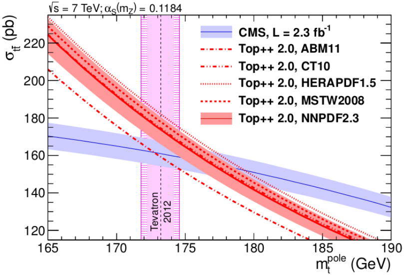
Phys. Lett. B 728 (2013) 496

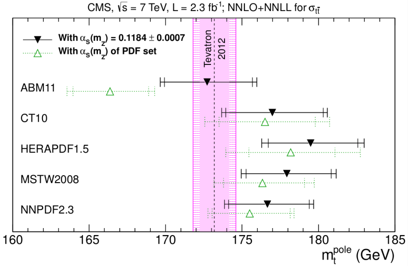
- same procedure used to extract $m_t^{pole}$
- assumed world average strong coupling: $\alpha_S(M_Z) = 0.1184 \pm 0.0007$
- measured $\sigma_{t\bar{t}}$ depends on $m_t^{MC}$ through acceptance corrections
- effect has to be taken into account

**assumption**: $m_t^{pole} = m_t^{MC} \pm 1\,\text{GeV}$

- additional uncertainty corresponding to 1 GeV added to measured $\sigma_{t\bar{t}}$

$$m_t^{pole} = 176.7\ ^{+3.0}_{-2.8}\ \text{GeV} \quad \text{(NNPDF2.3)}$$

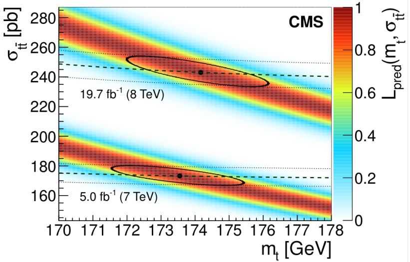


JHEP 08 (2016) 029

- simultaneous measurement of $\sigma_{t\bar{t}}$ at 7 and 8 TeV with template fit of final state distributions
- similar $m_t^{\rm pole}$ determination as in 7 TeV measurement
- $m_t^{\rm pole}$ determined separately from $\sigma_{t\bar{t}}$ at 7 and 8 TeV
- results combined taking correlations into account

| | $m_t$ [ GeV ] |
|---|---|
| NNPDF3.0 | $173.8^{+1.7}_{-1.8}$ |
| MMHT2014 | $174.1^{+1.8}_{-2.0}$ |
| CT14 | $174.3^{+2.1}_{-2.2}$ |




| | $m_t$ [ GeV ] | |
|---|---|---|
| | 7 TeV | 8 TeV |
| NNPDF3.0 | $173.5^{+1.9}_{-2.0}$ | $174.2^{+2.0}_{-2.2}$ |
| MMHT2014 | $173.9^{+2.0}_{-2.1}$ | $174.4^{+2.1}_{-2.3}$ |
| CT14 | $174.1^{+2.2}_{-2.4}$ | $174.6^{+2.3}_{-2.5}$ |

- simultaneous fit of $\sigma_{\mathrm{t\bar{t}}}$ and $m_{\mathrm{t}}^{\mathrm{MC}}$
- $\sigma_{\mathrm{t\bar{t}}}$ determined at **optimal mass point**

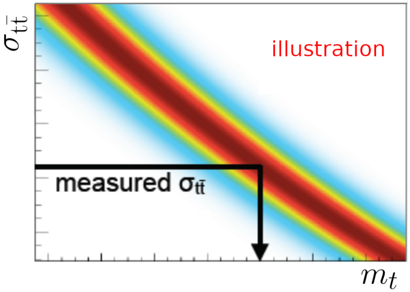
$\rightarrow$ with this approach:

- dependence of $\sigma_{\mathrm{t\bar{t}}}$ on $m_{\mathrm{t}}^{\mathrm{MC}}$ mitigated
- uncertainty on $\sigma_{\mathrm{t\bar{t}}}$ includes contribution from $m_{\mathrm{t}}^{\mathrm{MC}}$
- no assumption on relation between $m_{\mathrm{t}}^{\mathrm{MC}}$ and $m_{\mathrm{t}}$ needs to be made

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

- Hathor2.0 at NNLO precision
- several NNLO PDF sets considered
- $\overline{\mathrm{MS}}$ scheme adopted for $m_{\mathrm{t}}$
  $\rightarrow$ faster perturbative convergence
  (see EPJC 74 (2014) 11 3167)
- soft gluon resummation not included

PRL 116 (2016) 16 162001




CMS-PAS-TOP-17-001

**measurement results**

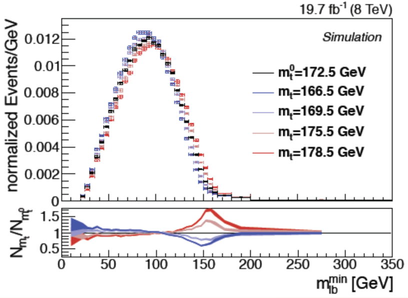
$\sigma_{\mathrm{t\bar{t}}} = 815 \pm 2\,(\mathrm{stat}) \pm 29\,(\mathrm{syst}) \pm 20\,(\mathrm{lum})$ pb

$m_{\mathrm{t}}^{\mathrm{MC}} = 172.33 \pm 0.14\,(\mathrm{stat})\, ^{+0.66}_{-0.72}\,(\mathrm{syst})$ GeV

- same fit strategy as in $\sigma_{t\bar{t}}$ measurement presented before
- only $e^{\mp}\mu^{\pm}$ channel considered

- introduce dependence of templates on top mass
- $m_{lb}^{min}$ distribution used to constrain $m_t^{MC}$

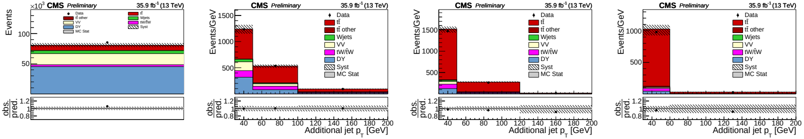
$m_{lb}^{min}$ = minimum invariant mass between reconstructed lepton and b-jet (sensitive to $m_t^{MC}$ through end point of spectrum)



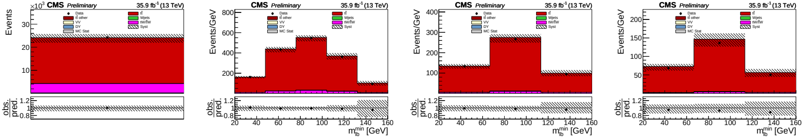
# pre-fit distributions

CMS-PAS-TOP-17-001

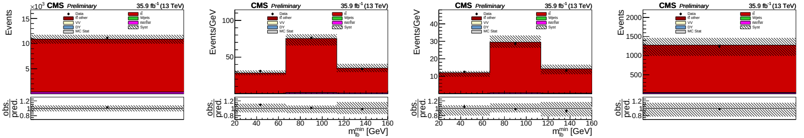
## 0 b-tags: 0,1,2,3 additional jets




## 1 b-tag: 0,1,2,3 additional jets




## 2 b-tags: 0,1,2,3 additional jets



# results for $\sigma_{t\bar{t}}$ and $m_t^{MC}$

**total $t\bar{t}$ cross section**

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

**top MC mass**

$m_t^{MC} = 172.33 \pm 0.14\,(\text{stat}) \pm^{0.66}_{0.72}\,(\text{syst})$ GeV

**main systematic uncertainties on $\sigma_{t\bar{t}}$**

- integrated luminosity (2.5%)
- lepton identification (2.2%)

**main systematic uncertainties on $m_t^{MC}$**

- jet energy scale (570 MeV)
- statistics of simulation (360 MeV)

| Name | Contribution [%] |
|---|---|
| Trigger | 0.4 |
| Lepton ID/isolation | 2.2 |
| Electron energy scale | 0.2 |
| Muon energy scale | 0.2 |
| Jet energy scale | 0.7 |
| Jet energy resolution | 0.5 |
| b tagging | 0.3 |
| Pileup | 0.3 |
| $t\bar{t}$ ME scale | 0.5 |
| tW ME scale | 0.7 |
| DY ME scale | 0.2 |
| NLO generator | 1.2 |
| PDF | 1.1 |
| $m_t^{MC}$ | 0.4 |
| Top quark $p_T$ | 0.5 |
| ME/PS matching | 0.2 |
| UE tune | 0.3 |
| $t\bar{t}$ ISR scale | 0.4 |
| tW ISR scale | 0.4 |
| $t\bar{t}$ FSR scale | 1.1 |
| tW FSR scale | 0.2 |
| B-Fragmentation | 1.0 |
| B-hadron BF | 0.2 |
| Colour reconnection | 0.4 |
| DY background | 0.8 |
| tW background | 1.1 |
| Diboson background | 0.3 |
| W+jets background | 0.3 |
| $t\bar{t}$ background | 0.2 |
| Statistical | 0.2 |
| Luminosity | 2.5 |
| MC Statistical | 1.2 |
| Total vis | 4.2 |
| $\sigma_{t\bar{t}}$(13 TeV) vis | 12.86 pb |
| $t\bar{t}$ ME scale (extr) | $\mp^{0.4}_{<0.1}$ |
| PDF (extr) | $\pm^{0.8}_{0.6}$ |
| Top quark $p_T$ (extr) | $\pm^{0.2}_{0.3}$ |
| $t\bar{t}$ ISR scale (extr) | $\mp^{0.2}_{<0.1}$ |
| $t\bar{t}$ FSR scale (extr) | $\pm^{0.1}_{0.1}$ |
| UE tune (extr) | $\mp^{<0.1}_{<0.1}$ |
| $m_t^{MC}$ (extr) | $\mp^{0.2}_{0.3}$ |
| Total | $\pm^{4.3}_{4.2}$ |
| $\sigma_{t\bar{t}}$(13 TeV) | 815 pb |

**total $t\bar{t}$ cross section**

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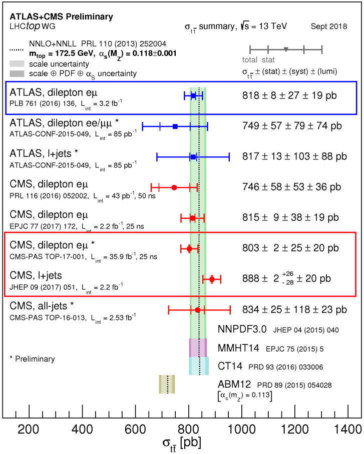
- statistics of simulation (360 MeV)



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**main systematic uncertainties on $\sigma_{t\bar{t}}$**

- integrated luminosity (2.5%)
- lepton identification (2.2%)

**main systematic uncertainties on $m_t^{MC}$**

- jet energy scale (570 MeV)
- statistics of simulation (360 MeV)

| Name | Contribution [GeV] |
|---|---|
| Trigger | 0.02 |
| Lepton ID/isolation | 0.02 |
| Electron energy scale | 0.10 |
| Muon energy scale | 0.03 |
| Jet energy scale | 0.57 |
| Jet energy resolution | 0.09 |
| b tagging | 0.12 |
| Pileup | 0.09 |
| $t\bar{t}$ ME scale | 0.18 |
| tW ME scale | 0.02 |
| DY ME scale | 0.06 |
| NLO generator | 0.14 |
| PDF | 0.05 |
| $\sigma_{t\bar{t}}$ | 0.09 |
| Top quark $p_T$ | 0.04 |
| ME/PS matching | 0.16 |
| UE tune | 0.03 |
| $t\bar{t}$ ISR scale | 0.16 |
| tW ISR scale | 0.02 |
| $t\bar{t}$ FSR scale | 0.07 |
| tW FSR scale | 0.02 |
| B-Fragmentation | 0.11 |
| B-hadron BF | 0.07 |
| Colour reconnection | 0.17 |
| DY background | 0.24 |
| tW background | 0.13 |
| Diboson background | 0.02 |
| W+jets background | 0.04 |
| $t\bar{t}$ background | 0.02 |
| Statistical | 0.14 |
| Total Stat+Syst | $\pm^{0.57}_{0.64}$ |
| MC Statistical | 0.36 |
| Total | $\pm^{0.68}_{0.73}$ |
| $m_t^{MC}$ | 172.33 |

# results for $\sigma_{t\bar{t}}$ and $m_t^{MC}$

**total $t\bar{t}$ cross section**

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

**top MC mass**

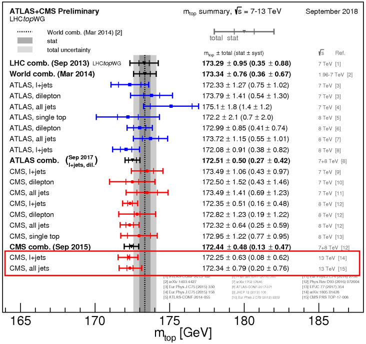
$m_t^{MC} = 172.33 \pm 0.14\,(\text{stat}) \pm^{0.66}_{0.72}\,(\text{syst})$ GeV

**main systematic uncertainties on $\sigma_{t\bar{t}}$**

- integrated luminosity (2.5%)
- lepton identification (2.2%)

**main systematic uncertainties on $m_t^{MC}$**

- jet energy scale (570 MeV)
- statistics of simulation (360 MeV)



# extraction of $\alpha_S(M_Z)$ from $\sigma_{t\bar{t}}$ at 13 TeV

CMS-PAS-TOP-17-001

parameters determined from data-theory $\chi^2$ using xFitter framework

$\alpha_S$ and $m_t$ cannot be determined simultaneously
$\Rightarrow$ $m_t$ fixed to native value of PDF

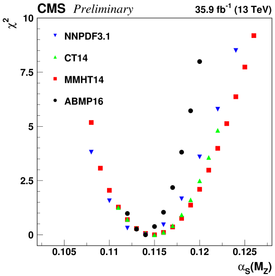
**uncertainties**

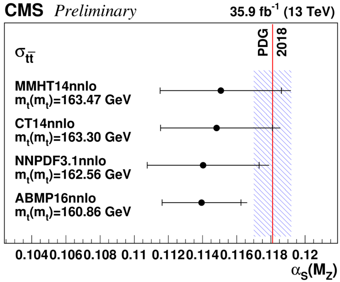
- experimental: from $\sigma_{t\bar{t}}$ measurement
- PDF: from eigenvectors
- independent $\mu_r$, $\mu_f$ variations by factor 2

**results**

- challenging precision on $\alpha_S(M_Z)$, most precise from hadronic processes to date
- better precision with ABMP16

$$\alpha_S(M_Z) = 0.1139\ ^{+0.0027}_{-0.0023} \quad \text{(ABMP16)}$$



CMS-PAS-TOP-17-001

parameters determined from data-theory $\chi^2$ using xFitter framework

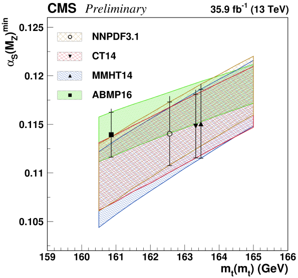
$\alpha_S$ and $m_t$ cannot be determined simultaneously
$\Rightarrow$ $m_t$ fixed to native value of PDF

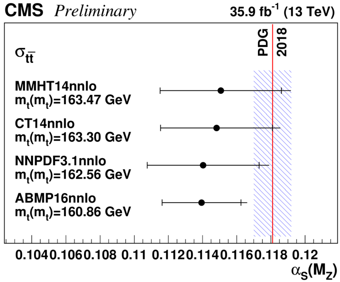
**uncertainties**

- experimental: from $\sigma_{t\bar{t}}$ measurement
- PDF: from eigenvectors
- independent $\mu_r$, $\mu_f$ variations by factor 2

**results**

- dependence of extracted $\alpha_S$ vs $m_t$ investigated $\rightarrow$ linear
- somehow flatter in case of ABMP16



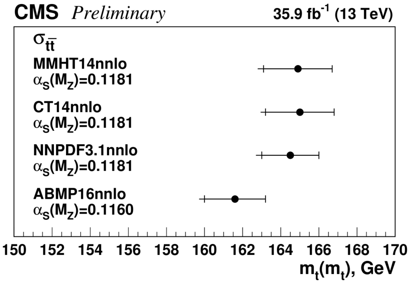
CMS-PAS-TOP-17-001

- same procedure used to extract top mass in $\overline{\mathrm{MS}}$ scheme, $m_t(m_t)$
- $\alpha_S(M_Z)$ fixed at native values of PDF

**results**

- first consistent determination of $m_t(m_t)$ (uncertainty $\simeq 1.2\%$)
- lower $m_t$ result with ABMP16 due to lower $\alpha_S(M_Z)$ in PDF determination

$$m_t(m_t) = 161.6\ ^{+1.6}_{-1.9}\ \text{GeV}\ (\text{ABMP16})$$



CMS-PAS-TOP-17-001

- same procedure used to extract top mass in $\overline{\text{MS}}$ scheme, $m_t(m_t)$
- $\alpha_S(M_Z)$ fixed at native values of PDF

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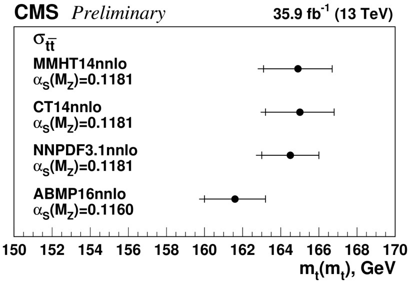
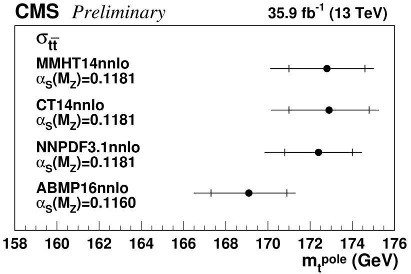
$$m_t(m_t) = 161.6 \,^{+1.6}_{-1.9}\ \text{GeV (ABMP16)}$$

**pole mass $m_t^{\text{pole}}$**

- missing soft gluon resummation $\Rightarrow$ for illustration purposes only
- results consistent with previous measurements



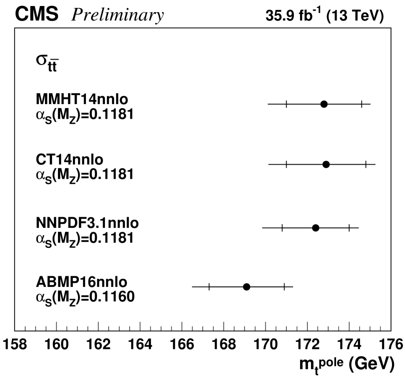



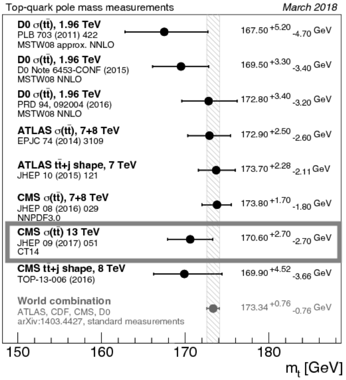
**preliminary CMS results at 13 TeV** presented

- measurement of $\sigma_{\mathrm{t\bar{t}}}$ in all di-lepton channels at fixed mass point
- simultaneous measurement of $\sigma_{\mathrm{t\bar{t}}}$ and $m_{\mathrm{t}}^{\mathrm{MC}}$
- extraction of $\alpha_{\mathrm{S}}$ and $m_{\mathrm{t}}(m_{\mathrm{t}})$ from inclusive $\sigma_{\mathrm{t\bar{t}}}$ using Hathor calculation with top quark mass in $\overline{\mathrm{MS}}$ scheme
- extraction of $m_{\mathrm{t}}^{\mathrm{pole}}$ for illustration (will be performed with Top++ for final publication)

# Thank you for your attention

# determination of $m_t^{\text{pole}}$ from $\sigma_{t\bar{t}}$ at 13 TeV




$$m_t^{\text{pole}} = 172.9\ ^{+2.4}_{-2.8}\ \text{GeV} \quad \text{(CT14)}$$

- results consistent with previous measurements at Tevatron and LHC

# numerical values for $\alpha_S(M_Z)$ with Hathor2.0

CMS-PAS-TOP-17-001

**top quark mass in $\overline{\text{MS}}$ scheme**

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

**top quark mass in on-shell scheme**

| PDF set (NNLO) | $\alpha_S^{min}(M_Z)$ |
|---|---|
| ABMP16 | $0.1164 \pm 0.0021$ (fit + PDF) $^{+0.0024}_{-0.0014}$ (scale) |
| NNPDF3.1 | $0.1184 \pm 0.0027$ (fit + PDF) $^{+0.0037}_{-0.0021}$ (scale) |
| CT14 | $0.1186 \pm 0.0028$ (fit + PDF) $^{+0.0034}_{-0.0019}$ (scale) |
| MMHT14 | $0.1205 \pm 0.0029$ (fit + PDF) $^{+0.0037}_{-0.0021}$ (scale) |

CMS-PAS-TOP-17-001

**top quark $\overline{\mathrm{MS}}$ mass**

| PDF set (NNLO) | $m_t(m_t)$ [ GeV ] |
|---|---|
| ABMP16 | $161.6 \pm 1.6\ (\mathrm{fit + PDF} + \alpha_S)\ ^{+0.1}_{-1.0}\ (\mathrm{scale})$ |
| NNPDF3.1 | $164.5 \pm 1.5\ (\mathrm{fit + PDF} + \alpha_S)\ ^{+0.1}_{-1.0}\ (\mathrm{scale})$ |
| CT14 | $165.0 \pm 1.7\ (\mathrm{fit + PDF}) \pm 0.6\ (\alpha_S)\ ^{+0.1}_{-1.0}\ (\mathrm{scale})$ |
| MMHT14 | $164.9 \pm 1.7\ (\mathrm{fit + PDF}) \pm 0.5\ (\alpha_S)\ ^{+0.1}_{-1.1}\ (\mathrm{scale})$ |

**top quark pole mass**

| PDF set (NNLO) | $m_t^{\mathrm{pole}}$ [ GeV ] |
|---|---|
| ABMP16 | $169.1 \pm 1.8\ (\mathrm{fit + PDF} + \alpha_S)\ ^{+1.3}_{-1.9}\ (\mathrm{scale})$ |
| NNPDF3.1 | $172.4 \pm 1.6\ (\mathrm{fit + PDF} + \alpha_S)\ ^{+1.3}_{-2.0}\ (\mathrm{scale})$ |
| CT14 | $172.9 \pm 1.8\ (\mathrm{fit + PDF}) \pm 0.7\ (\alpha_S)\ ^{+1.4}_{-2.0}\ (\mathrm{scale})$ |
| MMHT14 | $172.8 \pm 1.7\ (\mathrm{fit + PDF}) \pm 0.6\ (\alpha_S)\ ^{+1.3}_{-2.0}\ (\mathrm{scale})$ |

# $\alpha_S(M_Z)$ and $m_t$ in different PDF sets

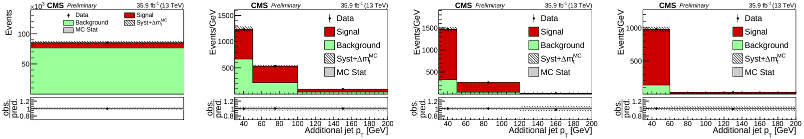
CMS-PAS-TOP-17-001

| PDF set (NNLO) | ABMP16 | NNPDF3.1 | CT14 | MMHT14 |
|---|---|---|---|---|
| $m_t^{pole}$ | 170.37 GeV | 172.5 GeV | 173.3 GeV | 174.2 GeV |
| RunDec conversion | 3 loops | 2 loops | 2 loops | 3 loops |
| $m_t(m_t)$ | 160.86 GeV | 162.56 GeV | 163.30 GeV | 163.47 GeV |
| $\alpha_S(m_Z)$ | 0.116 | 0.118 | 0.118 | 0.118 |
| $\alpha_S$ range | 0.112–0.120 | 0.108–0.124 | 0.111–0.123 | 0.108–0.128 |

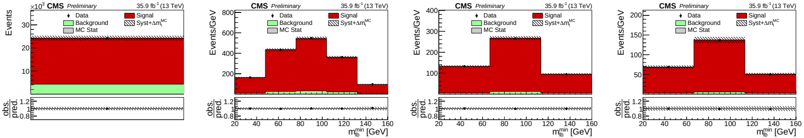
# combined $\sigma_{t\bar{t}}$ and $m_t^{MC}$ results: post-fit distributions

CMS-PAS-TOP-17-001

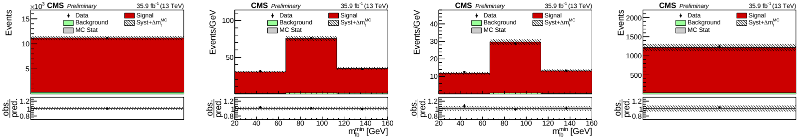
## 0 b-tags: 0,1,2,3 additional jets




## 1 b-tag: 0,1,2,3 additional jets

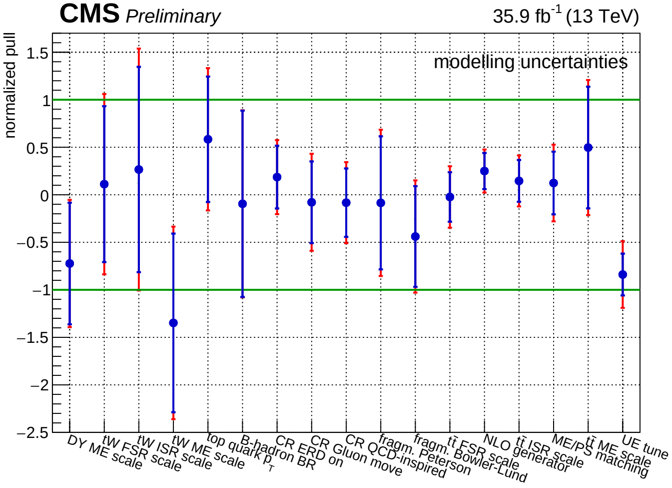



## 2 b-tags: 0,1,2,3 additional jets



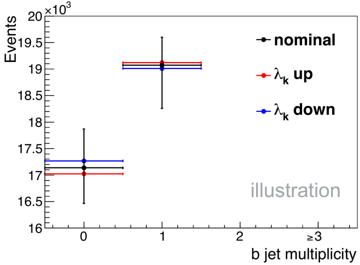
# pulls and constraints of modelling uncertainties

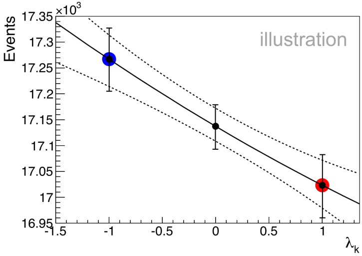
CMS-PAS-TOP-17-001



# parametrization of systematic uncertainties

- templates corresponding to systematic variations are derived by varying parameters in analysis within their prior uncertainty or by using alternative samples
- in each bin, the dependency on the nuisance parameters is modelled with a second order polynomial
- if the variation is one-sided (comparison between two alternative models) a linear dependence is assumed
- nominal, up and down variations correspond to $\lambda_k = 0$, $+1$ and -1 respectively



# procedure to assess impact of MC statistics

**general idea**: effect of systematics on fit distributions is modelled with templates obtained either

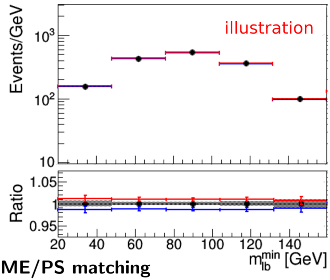
- by re-weighting events (e.g. ME scale)
- with alternative MC samples (e.g. ME/PS matching)

1. **re-weighting**: stats of nominal templates and varied templates are fully correlated
2. **alternative samples:** fully uncorrelated

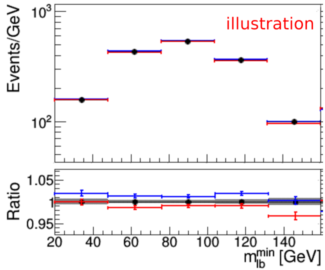
**procedure**

- produce **toy templates** where each bin is Poisson-smeared according to its MC stats
- fully consistent treatment of correlations between statistical uncertainties in the MC
  - throw individual toys for nominal and alternative samples and re-derive template dependencies
- **simultaneously for all the nuisance parameters**
- repeat fit to data points and assess effect on results (mass, cross section) and nuisances
- **estimates the impact of any possible MC fluctuation**

**ME scale**




**ME/PS matching**



CMS-PAS-TOP-17-001