11^{th} International Workshop on Top Quark Physics

September 17, 2018

Measurements of the inclusive $\mathrm{t\bar{t}}$ cross section at the ATLAS and CMS experiments

Matteo Defranchis, Deutsches Elektronen-Synchrotron (DESY)

on behalf of the ATLAS and CMS Collaborations

introduction

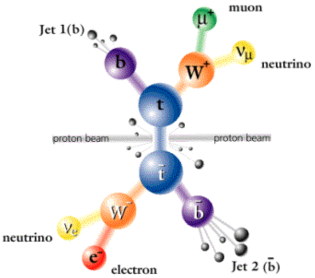
- motivation and strategy for cross section measurements

recent results by ATLAS and CMS

- ATLAS and CMS results in l+jets channels at 8 TeV and 13 TeV
- ATLAS result in $e\mu$ channel at 13 TeV and $\sigma_{\mathrm{t\bar{t}}}$ to σ_Z ratio
- first result at 5.02 TeV by CMS
- CMS observation of $\mathrm{t\bar{t}}$ production in pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16\ \mathrm{TeV}$

preliminary CMS results with 2016 dataset

- $\sigma_{\mathrm{t\bar{t}}}$ measurement in di-lepton channels
- combined measurement of $\sigma_{\mathrm{t\bar{t}}}$ and $m_{\mathrm{t}}^{\mathrm{MC}}$ in $e\mu$ channel



$t\bar{t}$ production mechanisms at LHC

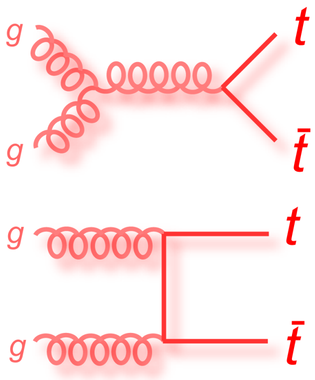
- gluon fusion (≃ 90%)
- $q\bar{q}$ annihilation (≃ 10%)

fixed order predictions at NNLO+NNLL
at $m_t = 172.5$ GeV (Top++v2.0, TWiki)

$\sqrt{s}$ [TeV]	$\sigma_{t\bar{t}}$ [pb]	uncert. [%]
7	177.3	6.8
8	252.9	6.5
13	831.8	6.1

→ uncertainty dominated by PDF+α_S

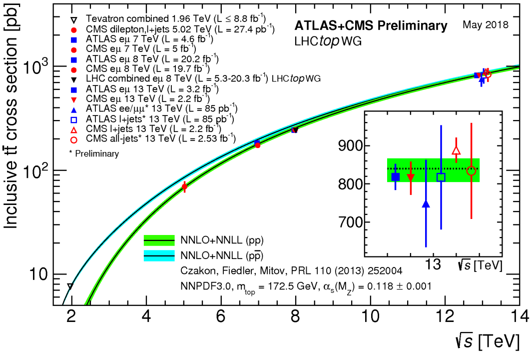
gluon fusion



- can be used to constrain **gluon PDF** and extract **QCD parameters** like m_{t} and α_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



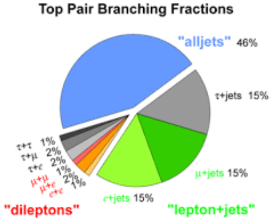
- $\mathrm{t\bar{t}}$ production is well understood process on a wide range of energy
- first 13 TeV results with 35.9 fb^{-1} (2016) presented in this talk - by CMS Collaboration

top pair production cross section: general procedure

- 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 introduction

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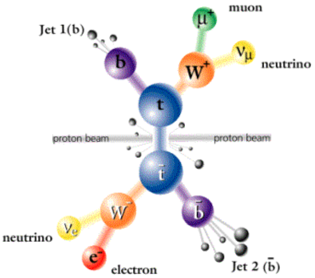
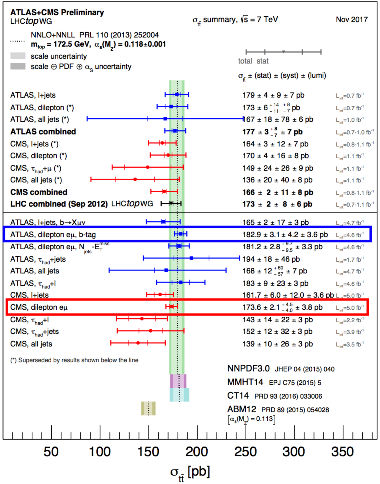


preliminary CMS results with 2016 dataset

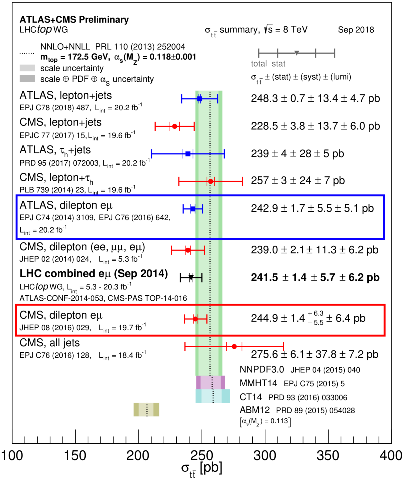
- $\sigma_{t\bar{t}}$ measurement in di-lepton channels
- combined measurement of $\sigma_{t\bar{t}}$ and m_t^{MC} in $e\mu$ channel

measurements of $\sigma_{t\bar{t}}$ at 7 and 8 TeV

$\sqrt{s} = 7$ TeV



$\sqrt{s} = 8$ TeV



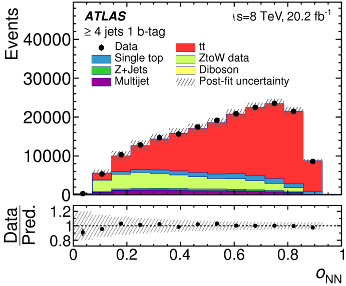
ATLAS measurement in l+jets channel at 8 TeV

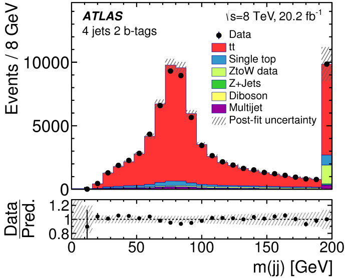
Eur. Phys. J. C 78 (2018) 487

- exactly one electron or muon, ≥ 4 jets, ≥ 1 b-tagged jet
- events split in 3 disjoint regions (different sensitivities to backgrounds and systematics + constrain b-tagging efficiencies)
  1. **SR1**: ≥ 4 jets, 1 b-tag
  2. **SR2**: 4 jets, 2 b-tags $\rightarrow$ **very pure in $t\bar{t}$**
  3. **SR3**: ≥ 4 jets, ≥ 2 b-tags (excluding SR2)
- simultaneous fit of $\sigma_{t\bar{t}}$, b-tagging efficiencies and global jet energy scale factor
- NN using kinematic variables used to separate backgrounds in SR1 and SR3
- m(jj) from W in SR2, sensitive to JES

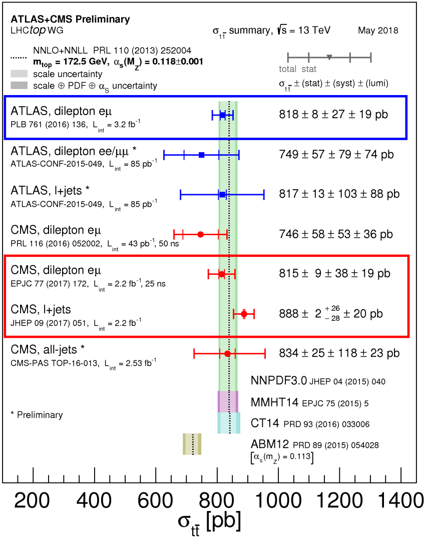
$$\sigma_{t\bar{t}} = 248.3 \pm 0.7\,(\text{stat}) \pm 13.4\,(\text{syst}) \pm 4.7\,(\text{lum})\ \text{pb}$$

$\rightarrow$ limited by PDF in extrapolation (high-x gluon)





status of $t\bar{t}$ cross section measurements at 13 TeV



wide range of measurements by ATLAS and CMS in different decay channels

- all measurements performed with $\lesssim 3.2\ \text{fb}^{-1}$ from 2015 LHC run
- measurements in $e\mu$ and lepton+jets channels are outstanding

- ATLAS benefits from higher integrated luminosity and reduced lepton ID uncertainties
- overall comparable precision between the two experiments

common limitation

- uncertainty on integrated luminosity ($\simeq$ 2.3% for both experiments)

CMS measurement in the lepton+jets channel at 13 TeV

likelihood fit with systematic uncertainties as nuisance parameters $\rightarrow$ constrained *in-situ*

- events split in **44 orthogonal categories** of jet and b-tagged jet multiplicity, lepton charge and lepton flavour
  - 1, 2, 3, $\geq$ 4 jets
  - 0, 1, $\geq$ 2 b-tagged jets
- $m_{\mathrm{lb}}^{\mathrm{min}}$ distribution used to discriminate $\mathrm{t\bar{t}}$ from backgrounds (W+jets, QCD multi-jet)
- dependence of $m_{\mathrm{lb}}^{\mathrm{min}}$ on m_{t} taken into account

main systematic uncertainties

- W+jets normalization (1.6 %)
- b-jet identification efficiency (1.3 %)

$$\sigma_{\mathrm{t\bar{t}}} = 888 \pm 2\,(\mathrm{stat}) \pm^{26}_{28}\,(\mathrm{syst}) \pm 20\,(\mathrm{lum})\,\mathrm{pb}$$

$$\sigma_{\mathrm{t\bar{t}}}^{\mathrm{vis}} = 208.2 \pm 0.4\,(\mathrm{stat}) \pm^{5.5}_{4.9}\,(\mathrm{syst}) \pm 4.8\,(\mathrm{lum})\,\mathrm{pb}$$

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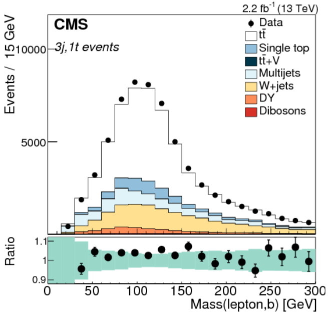

result used to **extract top pole mass** using Top++

$$m_{\mathrm{t}} = 170.6 \pm 2.7\,\mathrm{GeV}$$

ATLAS measurement in the $e\mu$ channel at 13 TeV

Phys. Lett. B761 (2016) 136

- select events with exactly 1,2 b-tags
- simultaneously determine **b-tagging efficiency from data** → reduce uncertainty

$$N_1 = L\sigma_{t\bar{t}}\epsilon_{e\mu}2\epsilon_b(1 - C_b\epsilon_b) + N_1^{bkg}$$
$$N_2 = L\sigma_{t\bar{t}}\epsilon_{e\mu}C_b\epsilon_b^2 + N_2^{bkg}$$

express number of events in each b-tag multiplicity category in terms of $\sigma_{t\bar{t}}$ and

1. b-tagging efficiency ϵ_b
2. residual correlation between two jets C_b
3. efficiency of selecting $e\mu$ in $t\bar{t}$ event $\epsilon_{e\mu}$

$$\sigma_{t\bar{t}} = 818 \pm 8\,(\text{stat}) \pm 27\,(\text{syst}) \pm 19\,(\text{lum}) \pm 12\,(\text{beam})\ \text{pb}$$

Uncertainty (inclusive $\sigma_{t\bar{t}}$)	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ [%]
Data statistics	0.9
$t\bar{t}$ NLO modelling	0.8
$t\bar{t}$ hadronisation	2.8
Initial- and final-state radiation	0.4
$t\bar{t}$ heavy-flavour production	0.4
Parton distribution functions	0.5
Single-top modelling	0.3
Single-top/$t\bar{t}$ interference	0.6
Single-top Wt cross-section	0.5
Diboson modelling	0.1
Diboson cross-sections	0.0
Z+jets extrapolation	0.2
Electron energy scale/resolution	0.2
Electron identification	0.3
Electron isolation	0.4
Muon momentum scale/resolution	0.0
Muon identification	0.4
Muon isolation	0.3
Lepton trigger	0.2
Jet energy scale	0.3
Jet energy resolution	0.2
b-tagging	0.3
Misidentified leptons	0.6
Analysis systematics	3.3
Integrated luminosity	2.3
LHC beam energy	1.5
Total uncertainty	4.4

$\sigma_{t\bar{t}}$ to σ_Z ratio by ATLAS at 13 TeV

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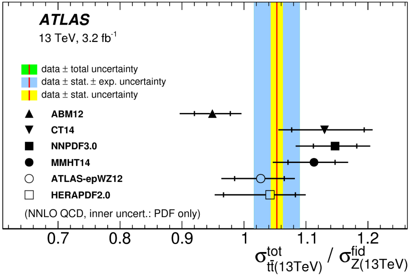
result in $e\mu$ channel used to extract the $\sigma_{t\bar{t}}$ to σ_Z ratio at 13 TeV

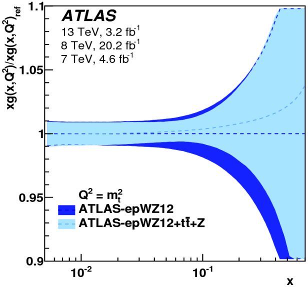
- cancellation of systematics
- σ_Z measured at sub-percent level (excluding integrated luminosity)
- sensitive to **gluon-to-quark PDF ratio**

- measurement of σ_Z ($Z \to \ell\ell$) fully synchronized with $t\bar{t}$ lepton selection (trigger, visible phase space)
- careful evaluation of correlations improves cancellation of systematics

$$\sigma_Z = 779 \pm 3\,(\text{stat}) \pm 6\,(\text{syst}) \pm 16\,(\text{lum})\,\text{pb}$$

$$\sigma_Z^{\text{NNLO}} = 744\,^{+22}_{-28}\,(\text{tot})\,\text{pb}$$





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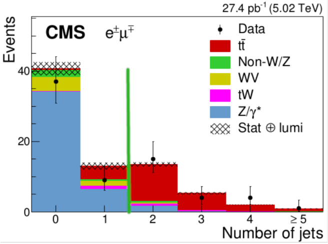
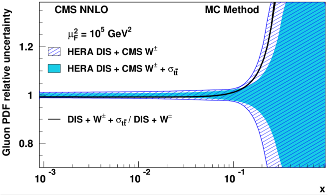
first ever measurement at 5.02 TeV

- low pile-up run from 2015 (PU $\simeq$ 1.4)
- integrated luminosity of 27.4 pb^{-1}
- $e^{\mp}\mu^{\pm}$, $\mu^{+}\mu^{-}$ and l+jets final states
  1. di-lepton: cut&count
  2. l+jets: fit to b-jet categories
- limited by **statistical uncertainty**



$$\sigma_{t\bar{t}} = 69.5 \pm 6.1\,(\text{stat}) \pm 5.6\,(\text{syst}) \pm 1.6\,(\text{lum})\ \text{pb}$$
$$\sigma_{t\bar{t}}^{\text{NNLO}} = 68.9 \pm^{1.9}_{2.3}\,(\text{scale}) \pm 2.3\,(\text{PDF}) \pm^{1.4}_{1.0}\,(\alpha_S)\ \text{pb}$$

- excellent agreement with prediction
- used to **constrain gluon PDF** at high momentum fraction



→ moderate improvement in uncertainty

CMS observation of $t\bar{t}$ production in pPb collisions at 8.16 TeV

Phys. Rev. Lett. 119, 242001 (2017)

- 174 nb^{-1} at $\sqrt{s_{NN}} = 8.16$ TeV (2016)
- l+jets channels considered ($l = e, \mu$)
- **probe of nuclear PDF at high Bjorken-x**

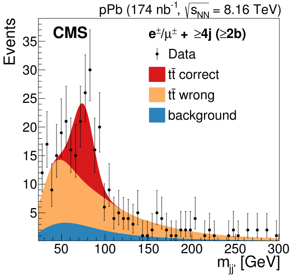
strategy

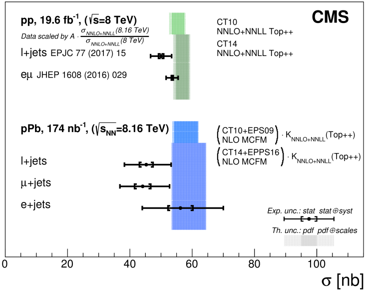
- likelihood fit of $m(j, j')$ from W decays
- categories of b-tags (0, 1, ≥ 2)
- simultaneously with b-tagging efficiency and global jet energy scale factor

results

- significance of $t\bar{t}$ signal above 5σ
- leading syst: b-tagging efficiency (13%)

$$\sigma_{t\bar{t}}^{\mu+\text{jets}} = 44 \pm 3\,(\text{stat}) \pm 8\,(\text{syst})\ \text{nb}$$
$$\sigma_{t\bar{t}}^{e+\text{jets}} = 56 \pm 4\,(\text{stat}) \pm 13\,(\text{syst})\ \text{nb}$$





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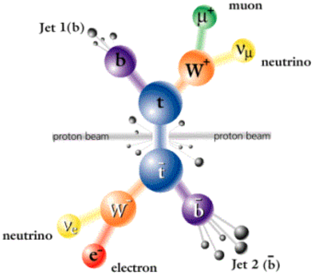


measurement performed with **two different approaches**:

a) inclusive $\mathrm{t\bar{t}}$ cross section **at fixed top mass** (172.5 GeV)

- simultaneously in $\mathrm{e}^+\mathrm{e}^-$, $\mathrm{e}^\mp\mu^\pm$ and $\mu^+\mu^-$ channels

→ push the measurement in the di-lepton channel to the **precision regime** by exploiting statistical power of 2016 dataset

b) simultaneous measurement of $\boldsymbol{\sigma_{\mathrm{t\bar{t}}}}$ **and top MC mass** (m_t^MC)

- performed in $\mathrm{e}^\mp\mu^\pm$ channel only

→ cross section determined at **optimal mass point** 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

1. jet $\mathrm{p_T}$ spectra are used to constrained JEC uncertainties
2. $m_{\mathrm{lb}}^{\mathrm{min}}$ distribution used to constrain $m_{\mathrm{t}}^{\mathrm{MC}}$ (in $\sigma_{\mathrm{t\bar{t}}} + m_{\mathrm{t}}^{\mathrm{MC}}$ fit)

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*

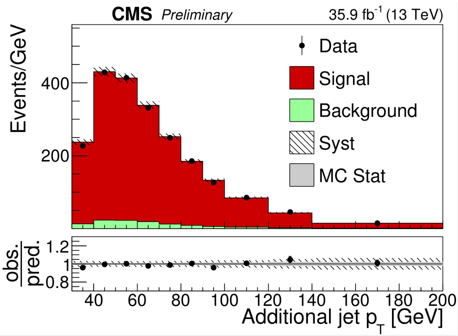
CMS-PAS-TOP-17-001

visible $t\bar{t}$ cross section

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

CMS result with 35.9 fb^{-1} at 13 TeV - $e\mu$, ee, $\mu\mu$ channels

CMS-PAS-TOP-17-001

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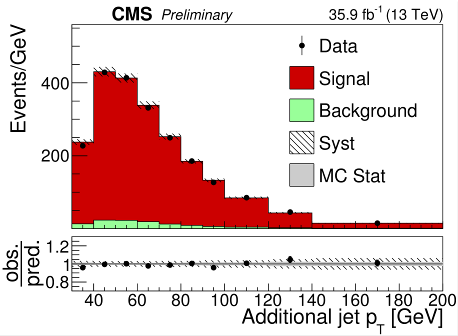
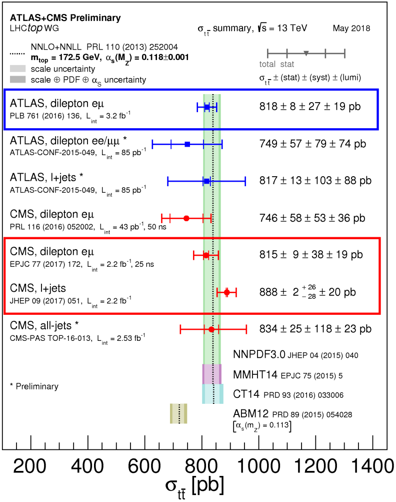




CMS combined measurement of $\sigma_{t\bar{t}}$ and m_t^{MC} at 13 TeV

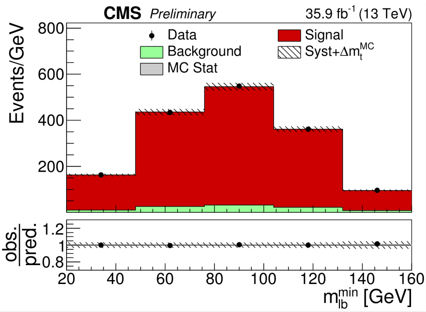
CMS-PAS-TOP-17-001

total $t\bar{t}$ cross section

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

top MC mass

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



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

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CMS-PAS-TOP-17-001

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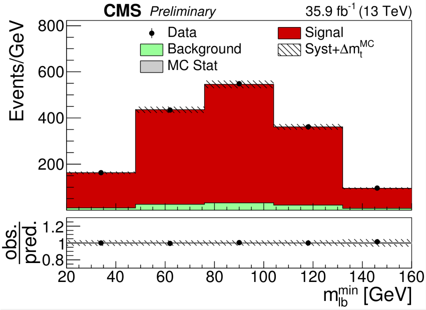

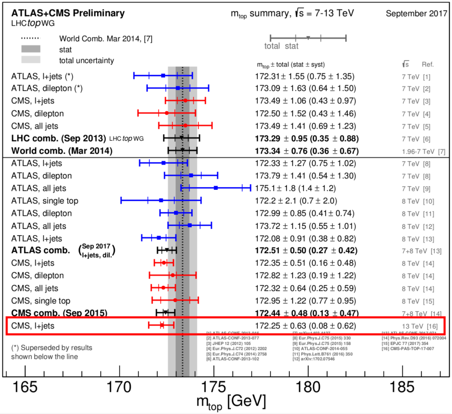

recent results from ATLAS and CMS

- overview of recent measurements from ATLAS and CMS at 8 and 13 TeV
- advantages, limitations and applications of each method highlighted
- CMS measurement at 5.02 TeV illustrated $\rightarrow$ constrain gluon PDF at high momentum fraction
- CMS observation of $\mathrm{t\bar{t}}$ production in pPb collisions at 8.16 TeV

preliminary results by CMS with 35.9 fb^{-1}

- measurement of $\sigma_{\mathrm{t\bar{t}}}$ at fixed mass point in $\mathrm{e}^{\mp}\mu^{\pm}$, $\mathrm{e^+e^-}$ and $\mu^+\mu^-$ channels
- simultaneous determination of $\sigma_{\mathrm{t\bar{t}}}$ and $m_{\mathrm{t}}^{\mathrm{MC}}$ in $\mathrm{e}^{\mp}\mu^{\pm}$ channel

$\rightarrow$ all results show competitive precision with respect to previous measurements

summary and conclusions

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- simultaneous determination of $\sigma_{\mathrm{t\bar{t}}}$ and $m_{\mathrm{t}}^{\mathrm{MC}}$ in $\mathrm{e}^{\mp}\mu^{\pm}$ channel

$\rightarrow$ all results show competitive precision with respect to previous measurements

further preliminary results by CMS

- cross section result from simultaneous fit of $\sigma_{\mathrm{t\bar{t}}}$ and $m_{\mathrm{t}}^{\mathrm{MC}}$ used to determine α_S and m_{t}
- will be presented at CMS joker talk on Wednesday

Thank you for your attention

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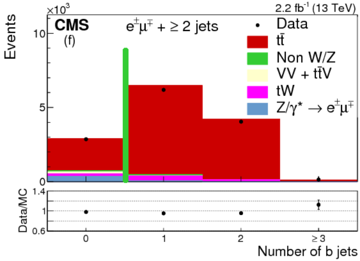
- **cut&count method**
- events with ≥ 2 jets, ≥ 1 b-tagged $\rightarrow$ high signal purity
- measurement limited by lepton efficiencies
- significant contribution from JES and choice of NLO gen. (powheg vs aMC@NLO)

$$\sigma_{t\bar{t}} = 815 \pm 9\,(\text{stat}) \pm 38\,(\text{syst}) \pm 19\,(\text{lum})\ \text{pb}$$



Source	$\Delta\sigma_{t\bar{t}}$ (pb)	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Experimental		
Trigger efficiencies	9.9	1.2
Lepton efficiencies	18.9	2.3
Lepton energy scale	<1	≤0.1
Jet energy scale	17.4	2.1
Jet energy resolution	0.8	0.1
b tagging	11.0	1.3
Mistagging	<1	≤0.1
Pileup	1.5	0.2
Modeling		
μ_F and μ_R scales	<1	<0.1
$t\bar{t}$ NLO generator	17.3	2.1
$t\bar{t}$ hadronization	6.0	0.7
Parton shower scale	6.5	0.8
PDF	4.9	0.6
Background		
Single top quark	11.8	1.5
VV	<1	≤0.1
Drell–Yan	<1	≤0.1
Non-W/Z leptons	2.6	0.3
$t\bar{t}$V	<1	≤0.1
Total systematic (no integrated luminosity)	37.8	4.6
Integrated luminosity	18.8	2.3
Statistical	8.5	1.0
Total	43.0	5.3

ATLAS measurement in $\ell\ell$ and lepton+jets channels (preliminary)

ATLAS-CONF-2015-049

preliminary results with **early 2015 data** (85 pb^{-1}, 50 ns bunch spacing)

lepton+jets

- suffers from limited knowledge of systematics
- especially JES and integrated luminosity

$$\sigma_{t\bar{t}} = 817 \pm 13\,(\text{stat}) \pm 103\,(\text{syst}) \pm 88\,(\text{lum})\text{ pb}$$

***ee* and $\mu\mu$ channels**

- simultaneous fit with b-tagging efficiency (as in $e\mu$)
- heavily penalized by data statistics

$$\sigma_{t\bar{t}} = 749 \pm 57\,(\text{stat}) \pm 79\,(\text{syst}) \pm 74\,(\text{lum})\text{ pb}$$

→ results not as competitive, but useful complement to the precise result in the $e\mu$ channel

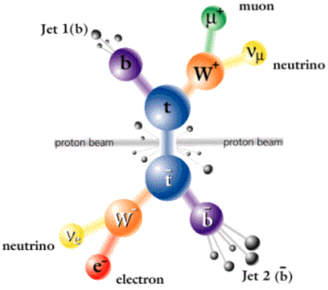
lepton+jets

Uncertainty	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Data statistics	1.5
$t\bar{t}$ NLO modelling	0.6
$t\bar{t}$ hadronisation	4.1
Initial/final state radiation	1.9
PDF	0.7
Single top cross-section	0.3
Diboson cross-sections	0.2
Z+jets cross-section	1.0
W+jets method statistics	1.7
W+jets modelling	1.0
Electron energy scale/resolution	0.1
Electron identification	2.1
Electron isolation	0.4
Electron trigger	2.8
Muon momentum scale/resolution	0.1
Muon identification	0.2
Muon isolation	0.3
Muon trigger	1.2
E_T^{miss} scale/resolution	0.4
Jet energy scale	$^{+10}_{-8}$
Jet energy resolution	0.6
b-tagging	4.1
NP & fakes	1.8
Analysis systematics	$^{+13}_{-11}$
Integrated luminosity	$^{+11}_{-9}$
Total uncertainty	$^{+17}_{-14}$

triggers: dilepton OR single lepton

offline selection

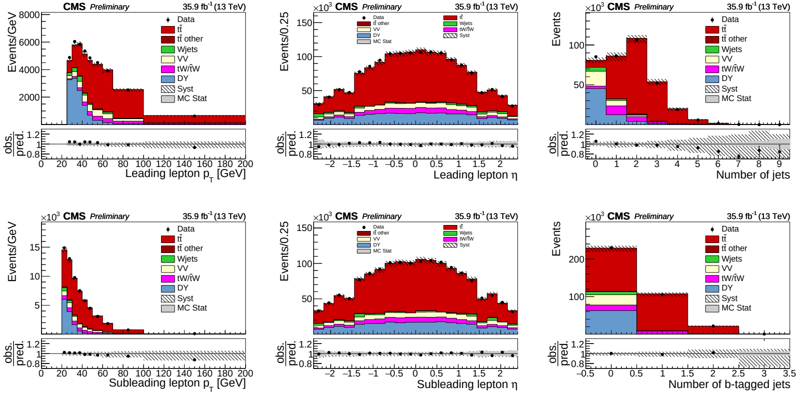
- at least two opposite-charge leptons:
  $p_{T1} > 25$ GeV, $p_{T2} > 20$ GeV
  $|\eta| < 2,4$, $m_{ll} > 20$ GeV
  Z-veto in e^+e^- $\mu^+\mu^-$ channels
- jets: $p_T > 30$ GeV and $|\eta| < 2.4$
- b-tagging: CSVv2 Tight WP
  (at least one b-tagged jet in same-flavour channels)



→ events classified in mutually-exclusive categories according to lepton flavour, b-tag and jet multiplicity

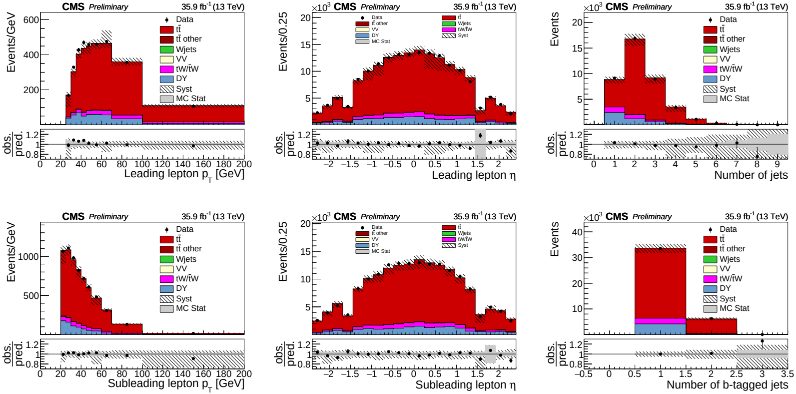
control distributions ($e^{\mp}\mu^{\pm}$ channel)

CMS-PAS-TOP-17-001



control distributions (e^+e^- channel)

CMS-PAS-TOP-17-001



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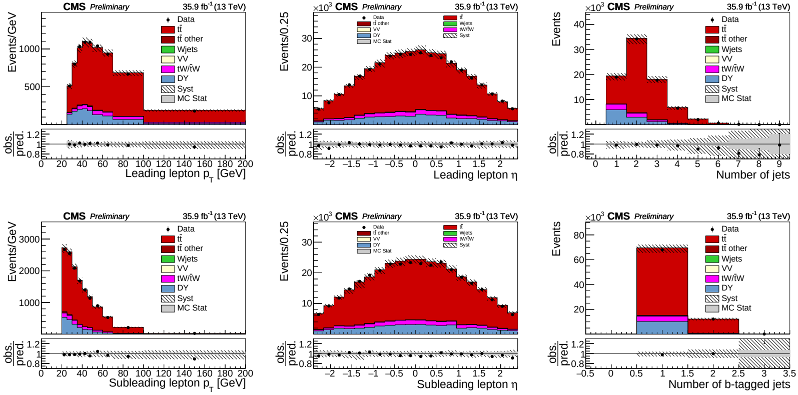

template fit to distributions of final state observables

- systematic uncertainties treated as nuisance parameters and constrained *in situ* (with exception of luminosity)
- events categorized in bins of jet and b-tag multiplicity in order to constrain modelling systematics and b-tagging efficiency
- jet $\mathrm{p_T}$ spectra are used to constrained JEC uncertainties

binned Poisson Likelihood

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

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

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

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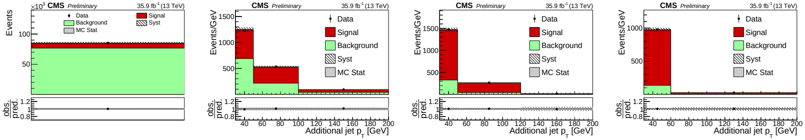
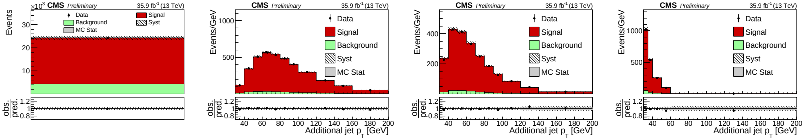
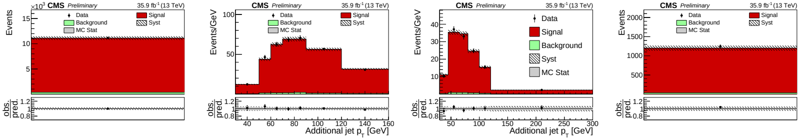
0 b-tags: 0,1,2,3 additional jets



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



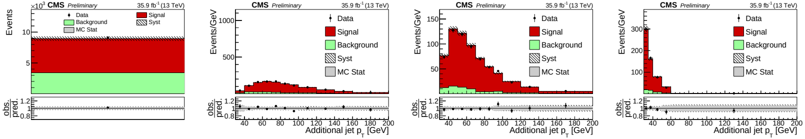
2 b-tags: 0,1,2,3 additional jets



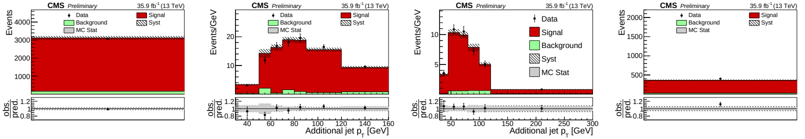
$t\bar{t}$ cross section results: post-fit distributions (e^+e^- channel)

CMS-PAS-TOP-17-001

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



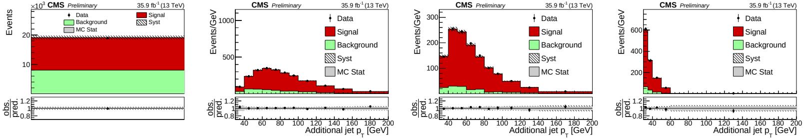
2 b-tags: 0,1,2,3 additional jets



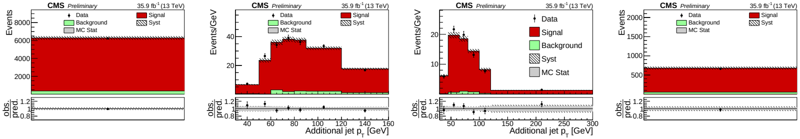
→ at least one b-tagged jet required in same-flavour channels

CMS-PAS-TOP-17-001

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



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

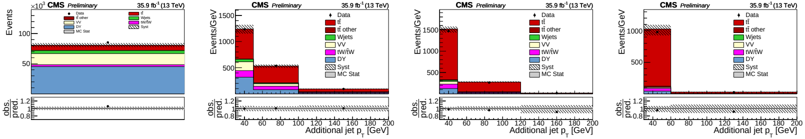


→ at least one b-tagged jet required in same-flavour channels

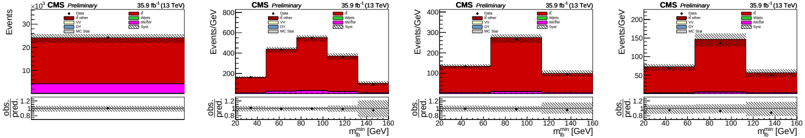
combined $\sigma_{t\bar{t}}$ and m_t^{MC} results: pre-fit distributions ($e^{\mp}\mu^{\pm}$ only)

CMS-PAS-TOP-17-001

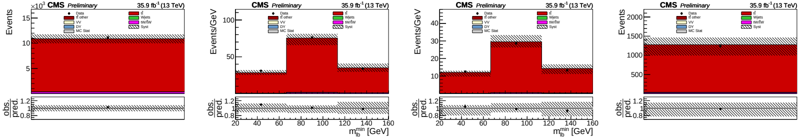
0 b-tags: 0,1,2,3 additional jets



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

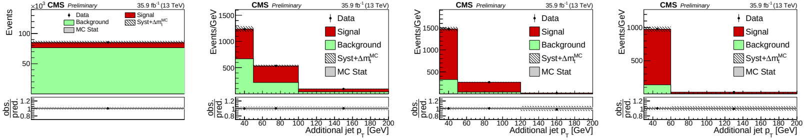


2 b-tags: 0,1,2,3 additional jets

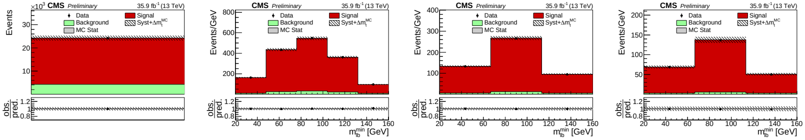


CMS-PAS-TOP-17-001

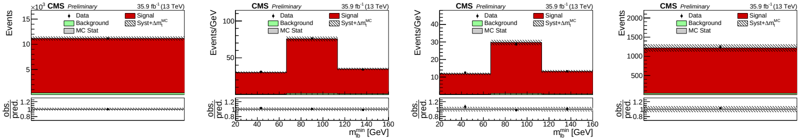
0 b-tags: 0,1,2,3 additional jets



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

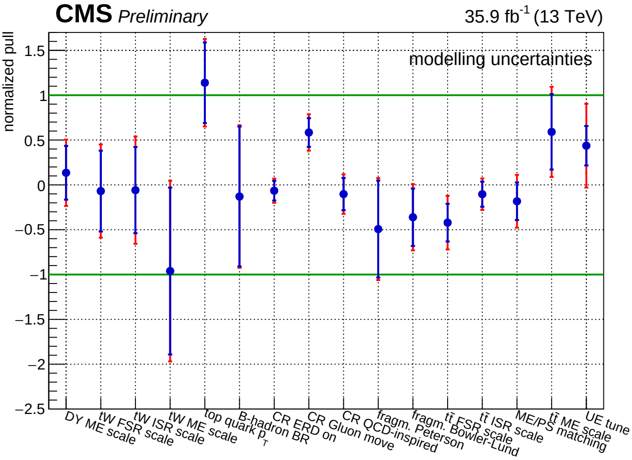


2 b-tags: 0,1,2,3 additional jets



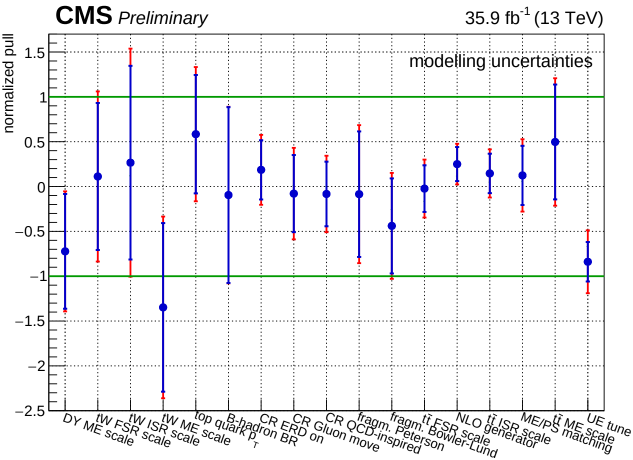
pulls and constraints of modelling uncertainties: $\sigma_{t\bar{t}}$

CMS-PAS-TOP-17-001



pulls and constraints of modelling uncertainties: $\sigma_{t\bar{t}} + m_t^{MC}$

CMS-PAS-TOP-17-001



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

$$s_{1b} = \mathcal{L}\sigma^{vis}_{t\bar{t}}\epsilon_{\ell\ell}\cdot 2\epsilon_b(1 - C_b\epsilon_b) \quad (1)$$

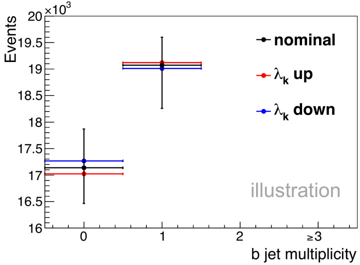
$$s_{2b} = \mathcal{L}\sigma^{vis}_{t\bar{t}}\epsilon_{\ell\ell}\cdot \epsilon_b^2 C_b \quad (2)$$

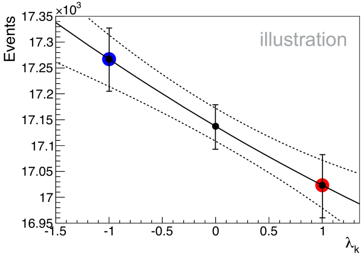
$$s_{other} = \mathcal{L}\sigma^{vis}_{t\bar{t}}\epsilon_{\ell\ell}\cdot (1 - 2\epsilon_b(1 - C_b\epsilon_b) - C_b\epsilon_b^2) \quad (3)$$

- $\epsilon_{\ell\ell}$ is the efficiency of the full selection
- ϵ_b is the b-tagging efficiency
- C_b represents the residual correlation of tagging the two b-jets

→ all parameters are derived by the simulation and depend on the 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 $\lambda_{\rm k} = 0$, $+1$ and -1 respectively





procedure to assess impact of MC stats in CMS-PAS-TOP-17-001

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

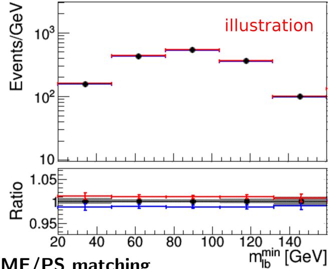
- by re-weighting events (e.g. ME scale)
- with alternative MC samples (e.g. ME/PS matching)

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