Karlsruher Institut für Technologie

Comparison of treatment of tt+b(b) background in ATLAS & CMS ttH searches

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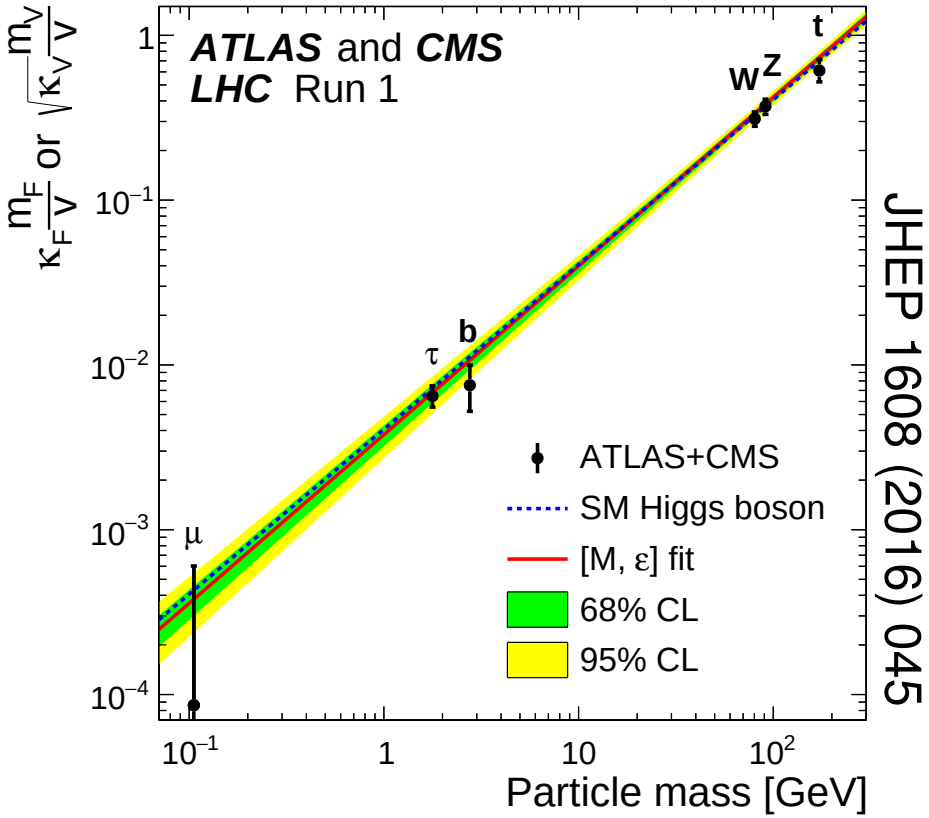
Karim El Morabit (CMS), Michele Pinamonti (ATLAS) | May 15th, 2017

INSTITUT FÜR EXPERIMENTELLE TEILCHENPHYSIK (ETP)

Introduction

- Higgs-boson: production and decay rates consistent with SM expectations
- Now to measure properties
  - Study e.g. Higgs Yukawa couplings to fermions
  - Best candidate: coupling to top quarks
  - Indirect access through gluon-fusion
  - Direct access through measurement of $t\bar{t}H$ production



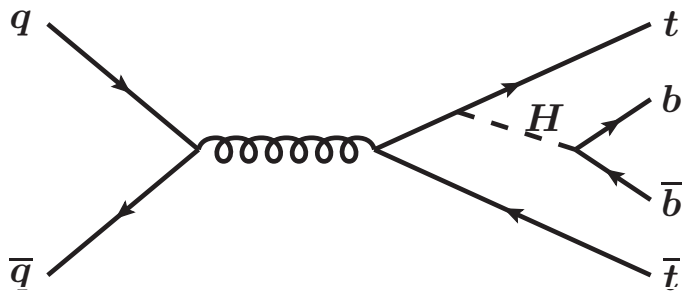
Recent $t\bar{t}H$ results at the LHC

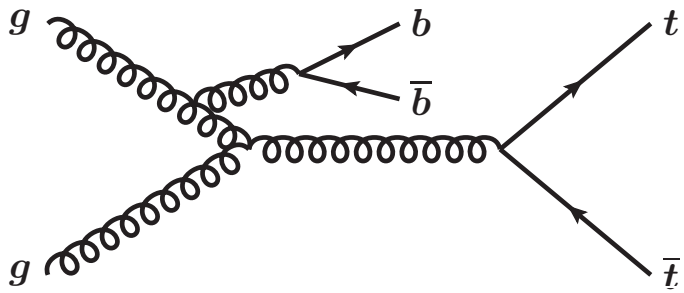
- Recent results from ATLAS and CMS
- $t\bar{t}H(b\bar{b})$ important channel
- Dominant uncertainty from $t\bar{t}$+b(b) modeling

	ATLAS	$(\mu = \sigma_{\mathrm{obs}}/\sigma_{\mathrm{SM}})$	CMS		$(\mu = \sigma_{\mathrm{obs}}/\sigma_{\mathrm{SM}})$
$t\bar{t}H$ (ZZ$\rightarrow$4l)	< 7.7	(JHEP 03(2018)095)	< 1.2		(JHEP 11(2017)047)
$t\bar{t}H$ ($\gamma\gamma$)	$0.5^{+0.6}_{-0.6}$	(HIGG-2016-21)	$2.2^{+0.9}_{-0.8}$		(HIG-16-040)
$t\bar{t}H$ (multileptons)	$1.6^{+0.5}_{-0.4}$	(PhysRevD.97.072003)	$1.2^{+0.5}_{-0.4}$		(HIG-17-018)
$t\bar{t}H$ (bb)	$0.8^{+0.6}_{-0.6}$	(PhysRevD.97.072016)	$0.7^{+0.5}_{-0.5}$	($\geq 1l$)	(HIG-17-026)
			$0.9^{+1.5}_{-1.5}$	(0l)	(HIG-17-022)
combination	$1.2^{+0.3}_{-0.3}$	(Phys.Rev.D.97.072003)	$1.1^{+0.3}_{-0.3}$		(HIG-17-035)

$t\bar{t}$+b(b) as dominant background

- Largest background for $t\bar{t}H(b\bar{b})$ searches:
  - $t\bar{t}$ +jets : $\sigma_{tt} = 832$ pb
- irreducible $t\bar{t}$+$b\bar{b}$ background: $\sigma_{t\bar{t}+b\bar{b}} = 4$ pb
- (Compare $t\bar{t}H$ cross section $\sigma_{ttH} = 0.51$ pb)
- $t\bar{t}$+hf modeling very challenging
  - Summary on status here
  - CMS 13 TeV measurement of inclusive $t\bar{t}$+$b\bar{b}$ cross section: precision $\approx 35\%$ 10.1016/j.physletb.2017.11.043
  - NLO precision $\approx 20\%$
  - Different MC predictions: significant kinematic differences





Phase space		$\sigma_{t\bar{t}b\bar{b}}$ [pb]
Visible	Measurement	$0.088 \pm 0.012 \pm 0.029$
	SM (POWHEG)	0.070 ± 0.009
Full	Measurement	$4.0 \pm 0.6 \pm 1.3$
	SM (POWHEG)	3.2 ± 0.4

10.1016/j.physletb.2017.11.043

$t\bar{t}$+b(b) as dominant uncertainty

- Most important systematics related to $t\bar{t}$+b(b) modeling

ATLAS

Uncertainty source	$\Delta\mu$	
$t\bar{t}+\geq 1b$ modeling	$+0.46$	-0.46
Background-model stat. unc.	$+0.29$	-0.31
b-tagging efficiency and mis-tag rates	$+0.16$	-0.16
Jet energy scale and resolution	$+0.14$	-0.14
$t\bar{t}H$ modeling	$+0.22$	-0.05
$t\bar{t}+\geq 1c$ modeling	$+0.09$	-0.11
JVT, pileup modeling	$+0.03$	-0.05
Other background modeling	$+0.08$	-0.08
$t\bar{t}+$ light modeling	$+0.06$	-0.03
Luminosity	$+0.03$	-0.02
Light lepton (e,μ) id., isolation, trigger	$+0.03$	-0.04
Total systematic uncertainty	$+0.57$	-0.54
$t\bar{t}+\geq 1b$ normalization	$+0.09$	-0.10
$tt+\geq 1c$ normalization	$+0.02$	-0.03
Intrinsic statistical uncertainty	$+0.21$	-0.20
Total statistical uncertainty	$+0.29$	-0.29
Total uncertainty	$+0.64$	-0.61

(PhysRevD.97.072016)

CMS

Uncertainty source	$\pm\Delta\mu$ (observed)	$\pm\Delta\mu$ (expected)
Total experimental	$+0.15/-0.16$	$+0.19/-0.17$
b tagging	$+0.11/-0.14$	$+0.12/-0.11$
jet energy scale and resolution	$+0.06/-0.07$	$+0.13/-0.11$
Total theory	$+0.28/-0.29$	$+0.32/-0.29$
$t\bar{t}$+hf cross section and parton shower	$+0.24/-0.28$	$+0.28/-0.28$
Size of the simulated samples	$+0.14/-0.15$	$+0.16/-0.16$
Total systematic	$+0.38/-0.38$	$+0.45/-0.42$
Statistical	$+0.24/-0.24$	$+0.27/-0.27$
Total	$+0.45/-0.45$	$+0.53/-0.49$

(HIG-17-026)

$t\bar{t}$+hf definition

- Both ATLAS and CMS split $t\bar{t}$ into subprocesses based on
  - flavor of additional jets at particle level
  - number of hadrons inside additional jets
- **additional jets** are jets not coming from the t or W decays

	ATLAS	CMS
Particle level jet p_T cuts	15 GeV	20 GeV
Particle level jet $\|\eta\|$ cuts	< 2.5	< 2.4
Hadron p_T cut	5 GeV	no cut
jet-hadron matching	$\Delta R < 0.4$	ghost hadron

$t\bar{t}$+hf definition

ATLAS

- Classify jets as
  - **b(B)-jets**: contain 1($\geq$ 2) b-hadrons
  - **c(C)-jets**: contain 1($\geq$ 2) c-hadrons
- Classify events as
  - **$t\bar{t}$+$\geq$1b** : $\geq$ 1 b- or B-jet
    - **$t\bar{t}$+b** : 1 b-jet
    - **$t\bar{t}$+b$\bar{b}$** : 2 b-jets
    - **$t\bar{t}$+B** : 1 B-jet
    - **$t\bar{t}$+b (MPI/FSR)** : jets from FSR or MPI
    - **$t\bar{t}$+$\geq$3b** : else
  - **$t\bar{t}$+$\geq$1c** : $\geq$ 1 c- or C-jet
  - **$t\bar{t}$ + light flavor**

CMS

- Classify events as
  - **$t\bar{t}$+b$\bar{b}$** : $\geq$ 2 jets containing $\geq$ 1 b-hadrons each
  - **$t\bar{t}$+b** : 1 jet containing 1 b-hadron
  - **$t\bar{t}$+2b** : 1 jet containing $\geq$ 2 b-hadrons
  - **$t\bar{t}$+c$\bar{c}$** : $\geq$ 1 jets containing c-hadrons
  - **$t\bar{t}$ + light flavor** : else

Analysis strategies

- Analysis in 1*l* (LJ) and 2*l* (DL) channels (leptons = μ/e)
- Select events compatible with $t\bar{t}H(b\bar{b})$
- Create categories enriched in signal and background events
- Use MVA and ME-methods to separate signal from background
- Extract signal strength in combined template fit

Event selection

	LJ		DL	
	ATLAS	CMS	ATLAS	CMS
leading lepton p_T cut (GeV)	27	30(26) for $e(\mu)$	27	25
subleading/veto lepton p_T cut (GeV)	10	15 for $e(\mu)$	15(10) $ee(\mu\mu, e\mu)$	15
lepton $\lvert\eta\rvert$ cut	<2.5	<2.1	<2.5	<2.4
m_{ll} cut (GeV)	-	-	15	20
m_{ll} Z window veto	-	-	83 — 99	76 — 106
τ_{had} veto	>2	-	>1	-
MET cut (GeV)	-	20	-	40
Ak4 jet p_T cut (GeV)	25	30	25	25 (30 for at least 2)
Ak4 jet $\lvert\eta\rvert$ cut	2.5	2.4	2.5	2.4
N jets	5	4	3	4
N b-tags @ medium (very tight) WP	3(2)	3	2	3
Ak10 jet p_T for Higgs(Top) (GeV)	200(250)	-	-	-

Analysis strategies

ATLAS

- Categorization
  - Has boosted Higgs and top candidate
  - Multiplicity of jets and b-tags at different WPs
- Results in
  - Boosted category
  - Signal categories enriched in $t\bar{t}H$ and $t\bar{t}+b\bar{b}$
  - Control categories enriched in $t\bar{t}+b$, $t\bar{t}+\geq 1c$ and $t\bar{t}+lf$
- MVAs (BDTs, LHDs) and ME-methods to separate signal/background in signal+boosted categories
- Fit MVA discriminants in signal+boosted and kinematic variables in control categories

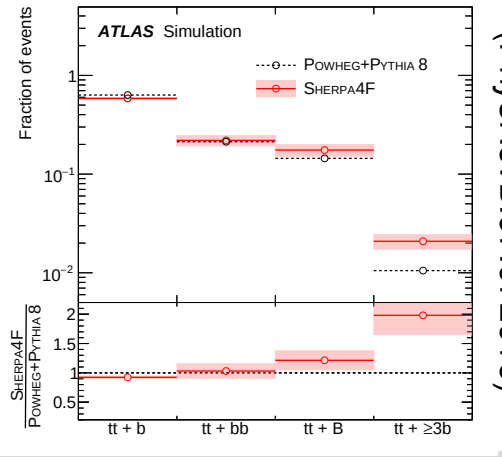
CMS

- Categorization
  - DL: b-tag multiplicity
  - LJ:
    - jet multiplicity
    - output of multiclass DNN (used ME-method as input)
- Results in
  - categories enriched in $t\bar{t}H$, $t\bar{t}+b\bar{b}$, $t\bar{t}+b$, $t\bar{t}+2b$, $t\bar{t}+c\bar{c}$ and $t\bar{t}+lf$
- DL: combination of BDT and ME-method
- DNN outputs to separate $t\bar{t}H$ or $t\bar{t}$ +X from rest in corresponding category (e.g. $t\bar{t}+c\bar{c}$ vs rest in $t\bar{t}+c\bar{c}$ enriched categories)
- Fit BDT/MEM or DNN discriminants

Nominal $t\bar{t}$+$\geq$1b predictions

ATLAS

- $t\bar{t}$ prediction: $t\bar{t}$ +jets sample generated with Powheg+Pythia8 (tune: A14, NNPDF3.0)
- Normalized to NNLO+NNLL $\sigma_{tt} = 832$ pb
- Rescale relative contributions of $t\bar{t}$+$b\bar{b}$, $t\bar{t}$+b, $t\bar{t}$+B and $t\bar{t}$+$\geq$3b to match prediction from Sherpa+OpenLoops (4F) $t\bar{t}$+$b\bar{b}$ sample (CT10 PDF)
- $\Rightarrow$ overall $t\bar{t}$+$\geq$1b fraction taken from Powheg+Pythia8
- Freely floating normalization of $t\bar{t}$+$\geq$1b and $t\bar{t}$+$\geq$1c in final fit



(PhysRevD.97.072016)

CMS

- $t\bar{t}$ prediction: $t\bar{t}$ +jets sample generated with Powheg+Pythia8 (tune: CUETP8M2T4, NNPDF3.0)
- Normalized to NNLO+NNLL $\sigma_{tt} = 832$ pb
- $t\bar{t}$ sample split into $t\bar{t}$ subprocesses
- $\Rightarrow$ Shape and normalization for $t\bar{t}$+b(b) taken from Powheg+Pythia8
- Each $t\bar{t}$ subprocess is treated independent in the final template fit
- $t\bar{t}$+b(b) normalizaton **not** freely floating in fit

Uncertainties on $t\bar{t}$

ATLAS

- Rate uncertainties on NNLO cross section correlated between $t\bar{t}$+$\geq$1b, $t\bar{t}$+$\geq$1c and $t\bar{t}$+lf
- All other uncertainties uncorrelated between $t\bar{t}$+$\geq$1b, $t\bar{t}$+$\geq$1c and $t\bar{t}$+lf
- Uncertainties due to general MC and PS generator choices (uncorrelated for $t\bar{t}$+$\geq$1b $t\bar{t}$+$\geq$1c and $t\bar{t}$+lf)
  - PS & hadronization: nominal prediction vs. Powheg+Herwig7
  - NLO event generator: nominal prediction vs. Sherpa+OpenLoops (5F) $t\bar{t}$ +jets sample
  - ISR/FSR : variation of μ_{F} and μ_{F}, hdamp and tune in nominal Powheg+Pythia8 sample
- Additional uncertainty of $t\bar{t}$+$\geq$1c by comparing
  - MG5_aMC@NLO+Herwig++ (3F) $t\bar{t}$+c$\bar{c}$ vs (5F) $t\bar{t}$ +jets shapes

CMS

- Rate uncertainties on NNLO cross section correlated among all $t\bar{t}$ subprocesses
- Shape uncertainty from NNPDF3.0 PDF set used in MC generation
  - Envelope of PDF replicas
  - Correlated among $t\bar{t}$ subprocesses and $t\bar{t}$H
- Shape uncertainty from variation of μ_{F} and μ_{R} at ME level by reweighting $t\bar{t}$ sample
  - Correlated among $t\bar{t}$ subprocesses
- Uncertainties on PS generation by variation of parameters controlling ISR, FSR, ME-PS matching and underlying event
  - Derived from additional $t\bar{t}$ samples with varied parameters
  - Small sample size: estimated as jet-multiplicity dependent rate changes
  - Uncorrelated for each $t\bar{t}$ subprocess

Uncertainties on $t\bar{t}+\geq 1b$

ATLAS

- Uncertainty on $t\bar{t}+\geq 1b$: comparison of nominal Powheg+Pythia8 $t\bar{t}$ vs Sherpa+OpenLoops (4F) $t\bar{t}+b\bar{b}$ shapes
- Uncertainties on relative fractions of $t\bar{t}+b\bar{b}$, $t\bar{t}+b$, $t\bar{t}+B$ and $t\bar{t}+\geq 3b$: variation of Sherpa+OpenLoops 4F $t\bar{t}+b\bar{b}$ sample
  - Variation of μ_{R}
  - Change resum. scale $\mu_{\mathrm{Q}} = H_{\mathrm{T}}/2 \Rightarrow \mu_{\mathrm{CMMPS}}$
  - Set $\mu_{\mathrm{Q}} = \mu_{\mathrm{R}} = \mu_{\mathrm{F}} = \mu_{\mathrm{CMMPS}}$
  - Vary shower recoil scheme
  - Vary UE tune
  - Compare MSTW vs CT10 PDF
  - Compare NNPDF vs CT10 PDF
- Large difference of $t\bar{t}+\geq 3b$ left uncovered $\Rightarrow$ additional 50% rate uncertainty
- Uncertainties on $t\bar{t}+b$ (MPI/FSR) partially contained in other uncertainties. But add additional 50% rate

CMS

- Additional 50% rate on each $t\bar{t}+b\bar{b}$, $t\bar{t}+2b$ $t\bar{t}+b$ and $t\bar{t}+c\bar{c}$ subprocess, uncorrelated
  - Conservative compared to prediction and measurement
  - Verified that model is robust and bias free by performing toy studies with
    - varied a-priory uncertainty
    - varied $t\bar{t}+b\bar{b}$ rate in pseudo-data by 30%
    - varied $t\bar{t}+b\bar{b}$ rate in background template by 30%
    - letting $t\bar{t}+b\bar{b}$ normalization float freely in fit

Model Validation

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ATLAS

- Fit model validated with pseudo-data from Powheg +Pythia6
  $\Rightarrow$ No bias in fitted signal observed
- Comparisons with alternative $t\bar{t}+\geq 1b$ systematic models & correlation schemes

CMS

- Fit model validated with Sherpa+OpenLoops (4F) $t\bar{t}+b\bar{b}$ sample
  - Create pseudo-data where sum of $t\bar{t}+b\bar{b}$, $t\bar{t}+b$ and $t\bar{t}+2b$ is replaced by Sherpa+OpenLoops (4F) $t\bar{t}+b\bar{b}$ prediction
  - Normalization of Sherpa+OpenLoops $t\bar{t}+b\bar{b}$ taken from Powheg+Pythia8 prediction in each analysis category
    $\Rightarrow$ only shape differences

Summary

- Compared treatment of $t\bar{t}$+b(b) in $t\bar{t}H(b\bar{b})$ searches by ATLAS and CMS
- Different definition of $t\bar{t}$+b(b) and other $t\bar{t}$ subprocesses

ATLAS

- Nominal prediction
  - $t\bar{t}$ Powheg+Pythia8
  - relative $t\bar{t}$+b(b) fractions rescaled to Sherpa+OpenLoops
- Uncertainties
  - Comparison of different ME, PS generators, several settings/effects varied at the same time
  - Separate norm. uncertainties on $t\bar{t}+\geq$1b subprocesses, correlated

CMS

- Nominal prediction
  - $t\bar{t}$ Powheg+Pythia8
  - $t\bar{t}$+b(b) from nominal $t\bar{t}$
- Uncertainties
  - Variation of single parameters of nominal $t\bar{t}$ prediction
  - Additional 50% normalization uncertainty on $t\bar{t}$ subprocesses, uncorrelated

- **Both validate the fit models with independent MC predictions**

Backup

ATLAS ttH(bb) lep. systematics

Systematic uncertainty	Type	Comp.
Experimental uncertainties		
Luminosity	N	1
Pileup modeling	SN	1
Physics Objects		
Electron	SN	6
Muon	SN	15
Taus	SN	3
Jet energy scale	SN	20
Jet energy resolution	SN	2
Jet vertex tagger	SN	1
$E_{\mathrm{T}}^{\mathrm{miss}}$	SN	3
b-tagging		
Efficiency	SN	30
Mis-tag rate (c)	SN	15
Mis-tag rate (light)	SN	80
Mis-tag rate (extrapolation $c \to \tau$)	SN	1
Signal and background modeling		
Signal		
$t\bar{t}H$ cross-section	N	2
H branching fractions	N	3
$t\bar{t}H$ modeling	SN	1
$t\bar{t}$ Background		
$t\bar{t}$ cross-section	N	1
$t\bar{t}+\geq$1c normalization	N (free floating)	1
$t\bar{t}+\geq$1b normalization	N (free floating)	1
$t\bar{t}+$light modeling	SN	3
$t\bar{t}+\geq$1c modeling	SN	4
$t\bar{t}+\geq$1b modeling	SN	13
Other Backgrounds		
$t\bar{t}W$ cross-section	N	2
$t\bar{t}Z$ cross-section	N	2
$t\bar{t}W$ modeling	SN	1
$t\bar{t}Z$ modeling	SN	1
Single top cross-section	N	3
Single top modeling	SN	5
W+jets normalization	N	3
Z+jets normalization	N	3
Diboson normalization	N	1
Fakes and non-prompt normalization	N	7
$t\bar{t}t\bar{t}$ cross-section	N	1
Small background cross-sections	N	9

ATLAS ttH(bb) lep. systematics HF

Systematic source	Description	$t\bar{t}$ categories
$t\bar{t}$ cross-section	Up or down by 6%	All, correlated
$k(t\bar{t}+\geq 1c)$	Free-floating $t\bar{t}+\geq 1c$ normalization	$t\bar{t}+\geq 1c$
$k(t\bar{t}+\geq 1b)$	Free-floating $t\bar{t}+\geq 1b$ normalization	$t\bar{t}+\geq 1b$
Sherpa5F vs. nominal	Related to the choice of NLO event generator	All, uncorrelated
PS & hadronization	Powheg+Herwig 7 vs. Powheg+Pythia 8	All, uncorrelated
ISR / FSR	Variations of μ_{R}, μ_{F}, h_{damp} and A14 Var3c parameters	All, uncorrelated
$t\bar{t}+\geq 1c$ ME vs. inclusive	MG5_aMC@NLO+Herwig++: ME prediction (3F) vs. incl. (5F)	$t\bar{t}+\geq 1c$
$t\bar{t}+\geq 1b$ Sherpa4F vs. nominal	Comparison of $t\bar{t}+b\bar{b}$ NLO (4F) vs. Powheg+Pythia 8 (5F)	$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 1b$ renorm. scale	Up or down by a factor of two	$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 1b$ resumm. scale	Vary μ_{Q} from $H_{\mathrm{T}}/2$ to μ_{CMMPS}	$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 1b$ global scales	Set μ_{Q}, μ_{R}, and μ_{F} to μ_{CMMPS}	$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 1b$ shower recoil scheme	Alternative model scheme	$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 1b$ PDF (MSTW)	MSTW vs. CT10	$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 1b$ PDF (NNPDF)	NNPDF vs. CT10	$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 1b$ UE	Alternative set of tuned parameters for the underlying event	$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 1b$ MPI	Up or down by 50%	$t\bar{t}+\geq 1b$
$t\bar{t}+\geq 3b$ normalization	Up or down by 50%	$t\bar{t}+\geq 1b$

ATLAS ttH(bb) lep. systematics impact

Uncertainty source	$\Delta\mu$	
$t\bar{t} + \geq 1b$ modeling	$+0.46$	-0.46
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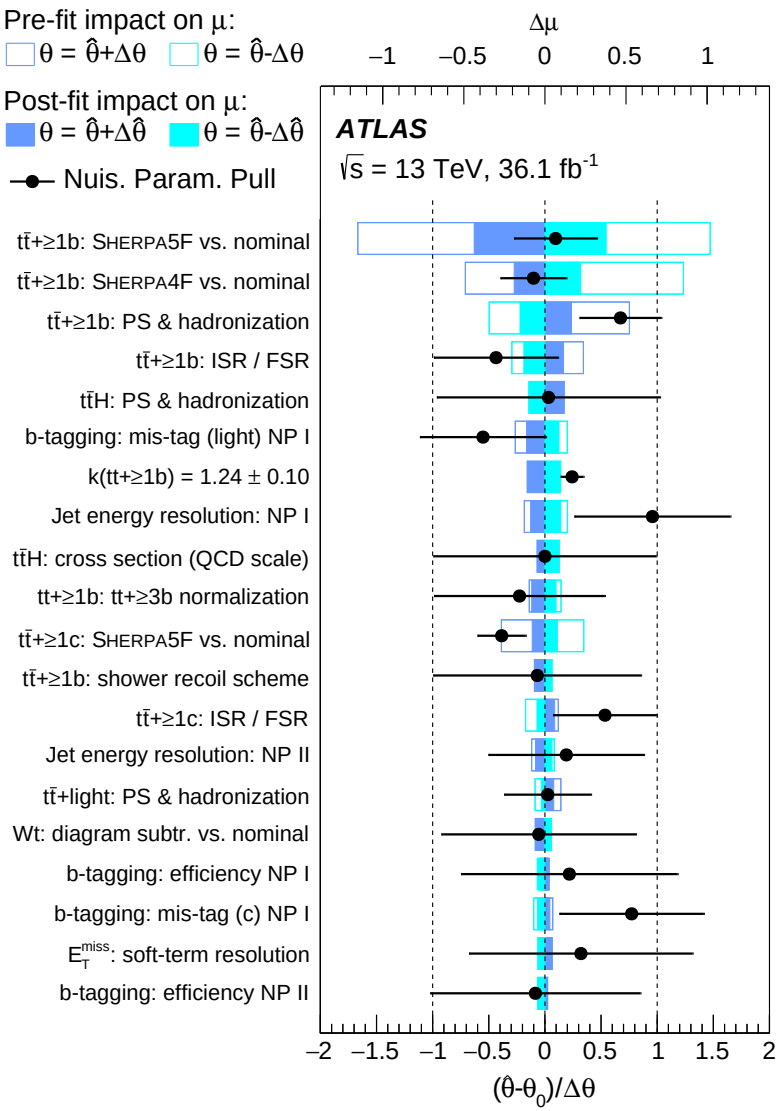
Light lepton (e, μ) id., isolation, trigger	$+0.03$	-0.04
Total systematic uncertainty	$+0.57$	-0.54
$t\bar{t} + \geq 1b$ normalization	$+0.09$	-0.10
$t\bar{t} + \geq 1c$ normalization	$+0.02$	-0.03
Intrinsic statistical uncertainty	$+0.21$	-0.20
Total statistical uncertainty	$+0.29$	-0.29
Total uncertainty	$+0.64$	-0.61

ATLAS ttH(bb) lep. systematics impact



CMS ttH(bb) lep. systematics

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Source	Type	Remarks
Integrated luminosity	rate	Signal and all backgrounds
Lepton identification/isolation	shape	Signal and all backgrounds
Trigger efficiency	shape	Signal and all backgrounds
Pileup	shape	Signal and all backgrounds
Jet energy scale	shape	Signal and all backgrounds
Jet energy resolution	shape	Signal and all backgrounds
b tag hf fraction	shape	Signal and all backgrounds
b tag hf stats (linear)	shape	Signal and all backgrounds
b tag hf stats (quadratic)	shape	Signal and all backgrounds
b tag lf fraction	shape	Signal and all backgrounds
b tag lf stats (linear)	shape	Signal and all backgrounds
b tag lf stats (quadratic)	shape	Signal and all backgrounds
b tag charm (linear)	shape	Signal and all backgrounds
b tag charm (quadratic)	shape	Signal and all backgrounds
Renorm./fact. scales ($t\bar{t}H$)	rate	Scale uncertainty of NLO $t\bar{t}H$ prediction
Renorm./fact. scales ($t\bar{t}$)	rate	Scale uncertainty of NLO $t\bar{t}$ prediction
Renorm./fact. scales ($t\bar{t}$+hf)	rate	Additional 50% rate uncertainty of $t\bar{t}$+hf predictions
Renorm./fact. scales (t)	rate	Scale uncertainty of NLO single t prediction
Renorm./fact. scales (V)	rate	Scale uncertainty of NNLO W and Z prediction
Renorm./fact. scales (VV)	rate	Scale uncertainty of NLO diboson prediction
PDF (gg)	rate	PDF uncertainty for gg initiated processes except $t\bar{t}H$
PDF (gg $t\bar{t}H$)	rate	PDF uncertainty for $t\bar{t}H$
PDF ($q\bar{q}$)	rate	PDF uncertainty of $q\bar{q}$ initiated processes ($t\bar{t}$+W,W,Z)
PDF (qg)	rate	PDF uncertainty of qg initiated processes (single t)
μ_R scale ($t\bar{t}$)	shape	Renormalisation scale uncertainty of the $t\bar{t}$ ME generator, independent for additional jet flavours
μ_F scale ($t\bar{t}$)	shape	Factorisation scale uncertainty of the $t\bar{t}$ ME generator, independent for additional jet flavours
PS scale: ISR ($t\bar{t}$)	rate	Initial state radiation uncertainty of the PS (for $t\bar{t}$ events), jet multiplicity dependent rate uncertainty, independent for additional jet flavours
PS scale: FSR ($t\bar{t}$)	rate	Final state radiation uncertainty (for $t\bar{t}$ events), jet multiplicity dependent rate uncertainty, independent for additional jet flavours
ME-PS matching ($t\bar{t}$)	rate	NLO ME to PS matching, *hdamp* [**?**] (for $t\bar{t}$ events), jet multiplicity dependent rate uncertainty, independent for additional jet flavours
Underlying event ($t\bar{t}$)	rate	Underlying event (for $t\bar{t}$ events), jet multiplicity dependent rate uncertainty, independent for additional jet flavours
NNPDF3.0NLO ($t\bar{t}H$, $t\bar{t}$)	shape	Based on the NNPDF replicas, same for $t\bar{t}H$ and additional jet flavours
Bin-by-bin event count	shape	Statistical uncertainty of the signal and background prediction due to the limited sample size

CMS ttH(bb) lep. systematics impact

Uncertainty source	$\pm\Delta\mu$ (observed)	$\pm\Delta\mu$ (expected)
Total experimental	$+0.15/-0.16$	$+0.19/-0.17$
b tagging	$+0.11/-0.14$	$+0.12/-0.11$
jet energy scale and resolution	$+0.06/-0.07$	$+0.13/-0.11$
Total theory	$+0.28/-0.29$	$+0.32/-0.29$
$t\bar{t}$+hf cross section and parton shower	$+0.24/-0.28$	$+0.28/-0.28$
Size of the simulated samples	$+0.14/-0.15$	$+0.16/-0.16$
Total systematic	$+0.38/-0.38$	$+0.45/-0.42$
Statistical	$+0.24/-0.24$	$+0.27/-0.27$
Total	$+0.45/-0.45$	$+0.53/-0.49$

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