$t\bar{t}V$ and $t\bar{t}b\bar{b}$ backgrounds in $t\bar{t}H$ analyses

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Introduction

- Search for $t\bar{t}H$ associated production : an important step in LHC physics program
- Provides a direct measurement of the top-Higgs Yukawa coupling
- Not yet observed with available LHC data - hope to have it soon !
- An observation statement needs two things :
  - $\rightarrow$ a significant excess in data, given the expected background
  - $\rightarrow$ compatible with expected signal contribution
- In this talk, focus on the measurement of the following irreducible backgrounds :
  - $\rightarrow$ $t\bar{t} + b\bar{b}$ production, in the $t\bar{t}H \rightarrow b\bar{b}$ analyses
  - $\rightarrow$ $t\bar{t} + V$ production, in the $t\bar{t}H \rightarrow \mathrm{multilepton}$ analyses
- After coffee : reducible background (fake prompt lept.) in $t\bar{t}H \rightarrow \mathrm{multilepton}$ (Djamel)
  - $\rightarrow$ $t\bar{t}H \rightarrow b\bar{b}/\mathrm{multilepton}$ analyses covered by Royer, Kun, Xavier

Available analyses with LHC data

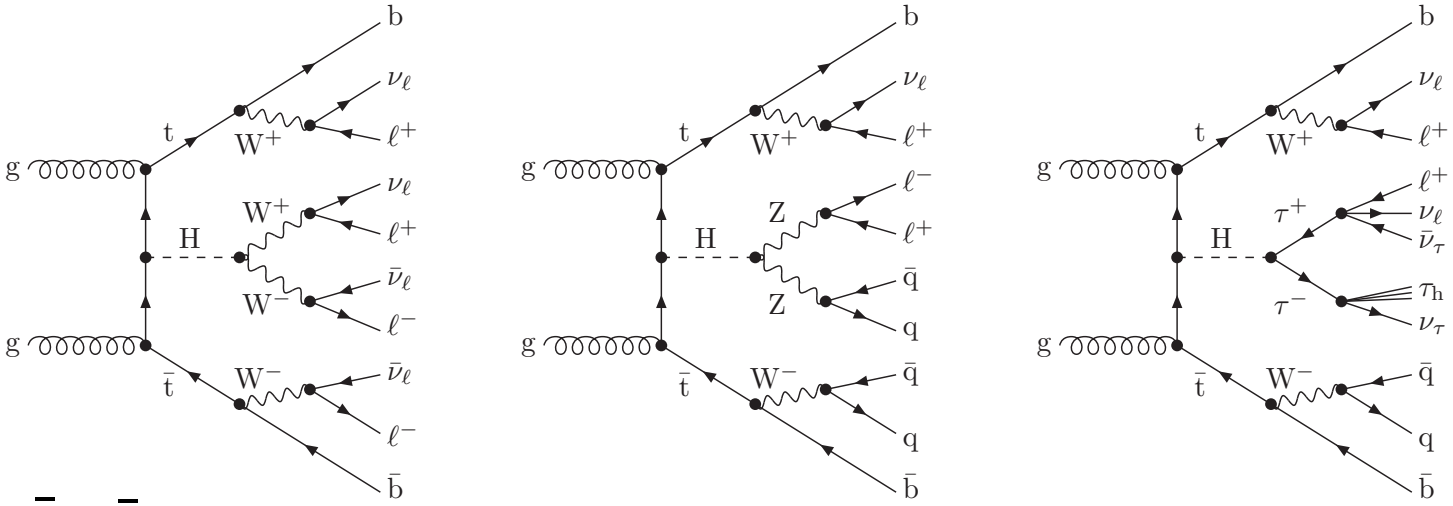
- Both ATLAS and CMS have published or preliminary results in the two channels

Experiment	Reference	CM energy	H decay	$t\bar{t}$ decay
ATLAS	Eur. Phys. J. C 75 (2015) 349	8 TeV	$b\bar{b}$	$1,2\ell$
ATLAS	arxiv:1604.03812	8 TeV	$b\bar{b}$	0ℓ
ATLAS	Phys. Lett. B 749 (2015) 519	8 TeV	WW,ZZ,$\tau\tau$	$1,2\ell$
CMS	JHEP 09 (2014) 087	7,8 TeV	$b\bar{b}$,WW,ZZ,$\tau\tau$	$1,2\ell$
CMS	Eur. Phys. J. C 75 (2015) 251	8 TeV	$b\bar{b}$	$1,2\ell$
CMS	CMS-PAS-HIG-15-008	13 TeV	WW,ZZ	$1,2\ell$
CMS	CMS-PAS-HIG-16-004	13 TeV	$b\bar{b}$	$1,2\ell$

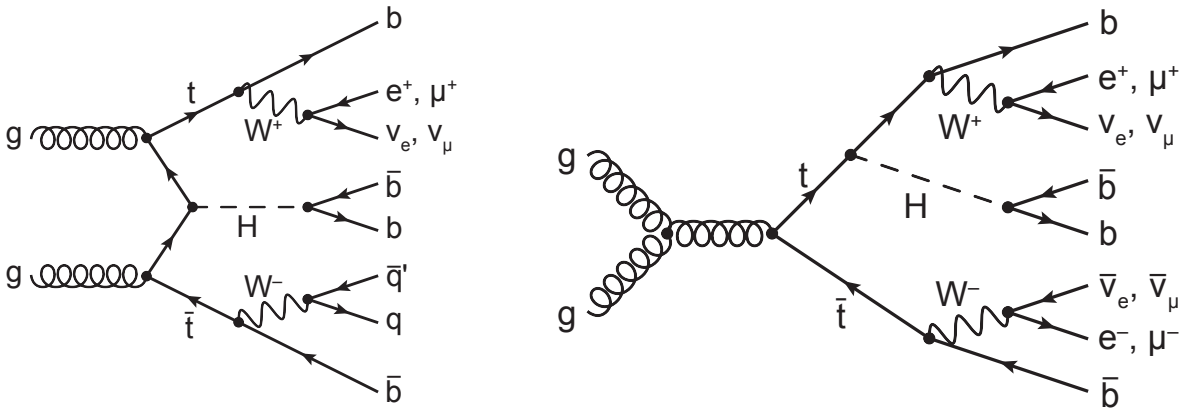
- Contributions of :
  - $\rightarrow$ IPHC/Strasbourg (CMS, $t\bar{t}H \rightarrow$ multilepton)
  - $\rightarrow$ LLR/Palaiseau (CMS, $t\bar{t}H \rightarrow$ multilepton & $t\bar{t}H \rightarrow b\bar{b}$)
  - $\rightarrow$ LPC/Clermont-Ferrand (ATLAS, $t\bar{t}H \rightarrow$ multilepton)
  - $\rightarrow$ CPPM/Marseille (ATLAS, $t\bar{t}H \rightarrow$ multilepton & $t\bar{t}H \rightarrow b\bar{b}$)
  - $\rightarrow$ CEA/Saclay (ATLAS, $t\bar{t}H \rightarrow b\bar{b}$ boosted)

$t\bar{t} + H$ final states

- $t\bar{t}H \rightarrow$ multilepton : at least two same-sign leptons
  - $\rightarrow$ one lepton from a top, one from $H \rightarrow ZZ/WW/\tau\tau$
  - $\rightarrow$ using hadronic taus

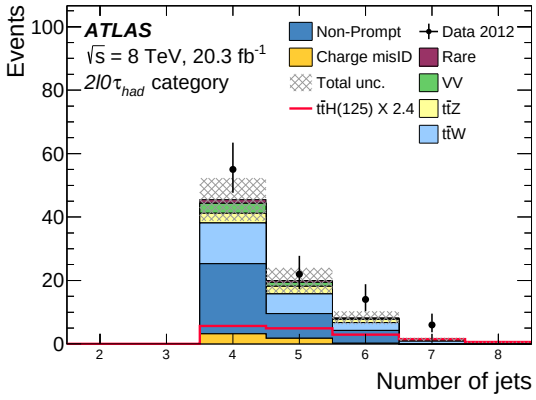


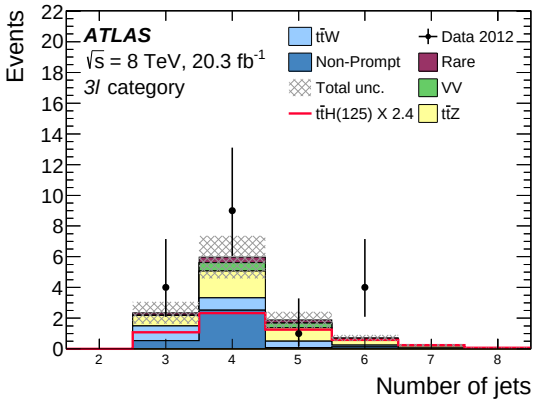
- $t\bar{t}H \rightarrow b\bar{b}$: $t\bar{t}$ pair + 2 b-jets from H decay
  - $\rightarrow$ mostly used channels : 1ℓ, 2ℓ (ℓ=e or μ)

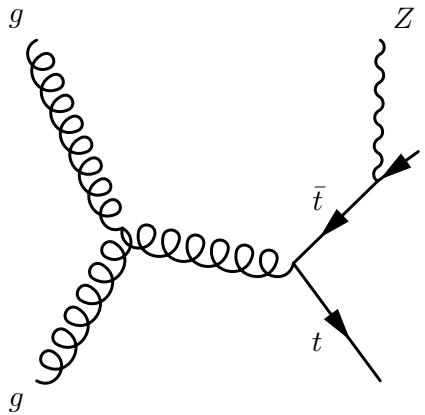


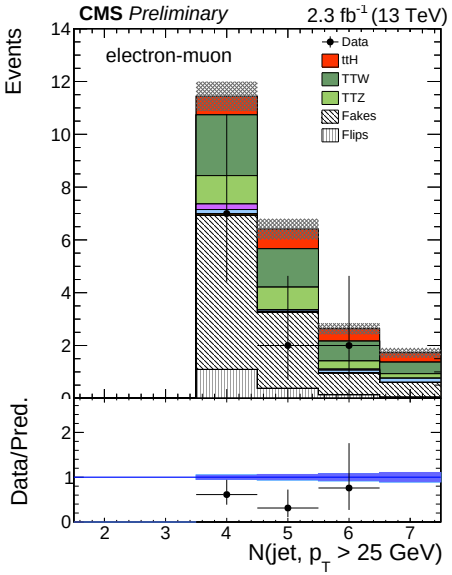
$t\bar{t} + V$: a background in the search of $t\bar{t}H \rightarrow$ multilepton

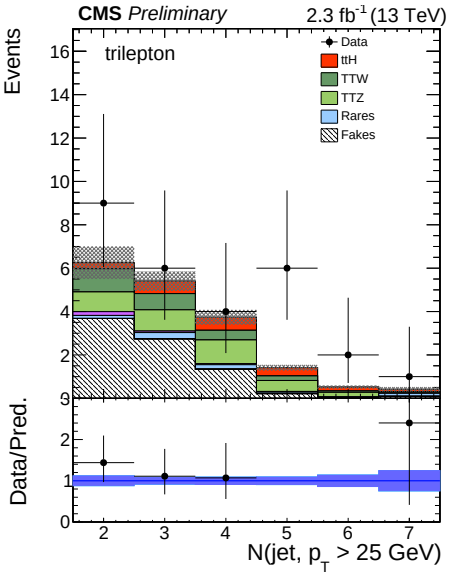
- $t\bar{t}H \rightarrow$ multilepton : irreducible background from $t\bar{t} + V$ production (V=W or Z)
- Can have at least two same-sign leptons, one from a top, one from a W or Z
- Second largest background - largest irreducible source

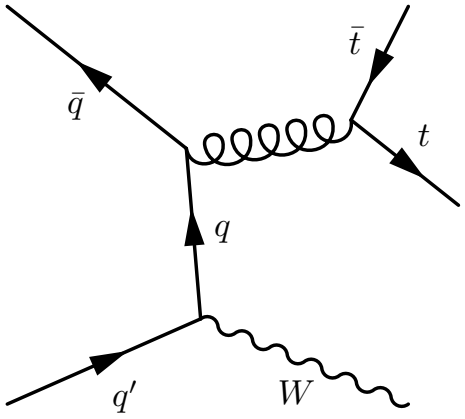






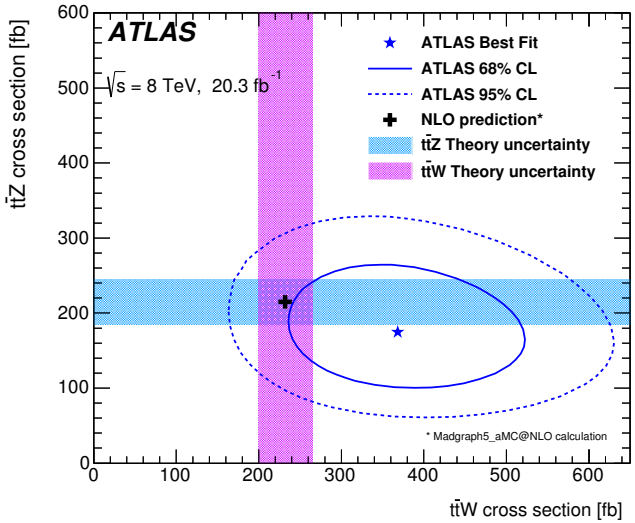


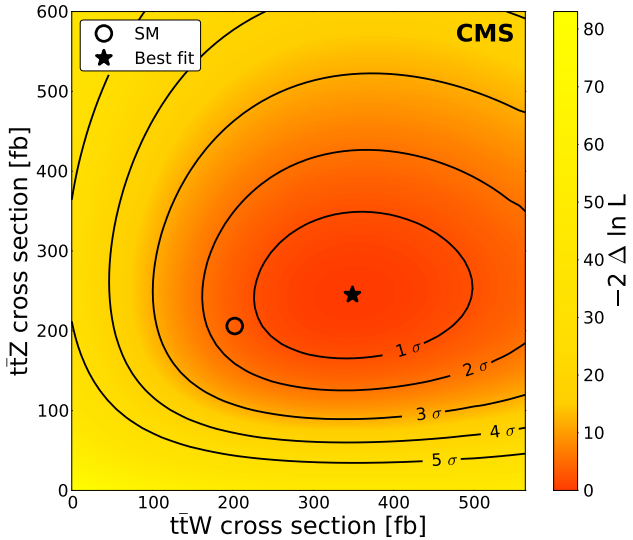




Measurements and predictions of $t\bar{t} + V$ cross-sections

- Both $t\bar{t} + W$ and $t\bar{t} + Z$ have been observed with 8 TeV data !





- At 8 TeV :

ATLAS	$\sigma_{t\bar{t}W} = 369^{+100}_{-91}$fb	$\sigma_{t\bar{t}Z} = 176^{+58}_{-52}$fb
CMS	$\sigma_{t\bar{t}W} = 382^{+117}_{-102}$fb	$\sigma_{t\bar{t}Z} = 242^{+65}_{-55}$fb
MG5_aMC@NLO	$\sigma_{t\bar{t}W} = 232 \pm 32$fb	$\sigma_{t\bar{t}Z} = 215 \pm 30$fb

- At 13 TeV :

ATLAS	$\sigma_{t\bar{t}W} = 1.4 \pm 0.8$pb	$\sigma_{t\bar{t}Z} = 0.9 \pm 0.3$pb
MG5_aMC@NLO	$\sigma_{t\bar{t}W} = 0.57 \pm 0.06$pb	$\sigma_{t\bar{t}Z} = 0.76 \pm 0.08$pb

- Measurements in agreement with predictions, but not yet competitive

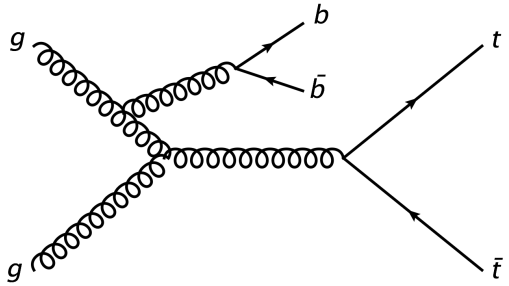
$t\bar{t} + V$ contributions in the $t\bar{t}H \rightarrow$ multilepton analyses

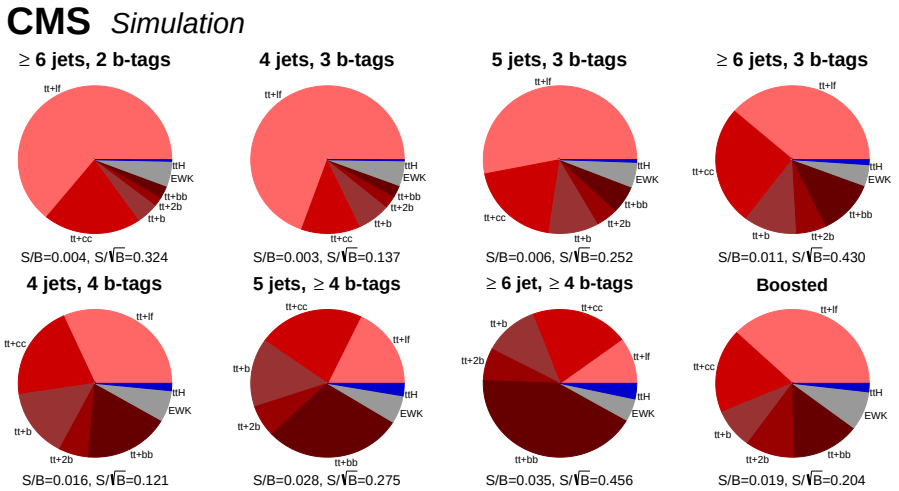
- Uncertainties on inclusive cross-sections : $< 14\%$
- Measured $\mu_{t\bar{t}H}$ can be expressed as a function of $\sigma_{t\bar{t}W}$ and $\sigma_{t\bar{t}Z}$ (ATLAS)
  - $\rightarrow$ usefull for interpretation of results
- In ATLAS 8 TeV analysis, following systematics on acceptance are considered :
  - $\rightarrow$ comparisons of MC generators : 5 – 23%
  - $\rightarrow$ QCD scale : 1.3 – 6.7
  - $\rightarrow$ PDF : 0.9 – 4.8%
- In CMS 13 TeV analysis, variation of factorisation and renormalisation scales
  - $\rightarrow$ effect on acceptance : 2 – 4%

Source	$\Delta\mu$	
$2\ell 0\tau_{\text{had}}$ non-prompt muon transfer factor	+0.38	−0.35
$t\bar{t}W$ acceptance	+0.26	−0.21
$t\bar{t}H$ inclusive cross section	+0.28	−0.15
Jet energy scale	+0.24	−0.18
$2\ell 0\tau_{\text{had}}$ non-prompt electron transfer factor	+0.26	−0.16
$t\bar{t}H$ acceptance	+0.22	−0.15
$t\bar{t}Z$ inclusive cross section	+0.19	−0.17
$t\bar{t}W$ inclusive cross section	+0.18	−0.15
Muon isolation efficiency	+0.19	−0.14
Luminosity	+0.18	−0.14

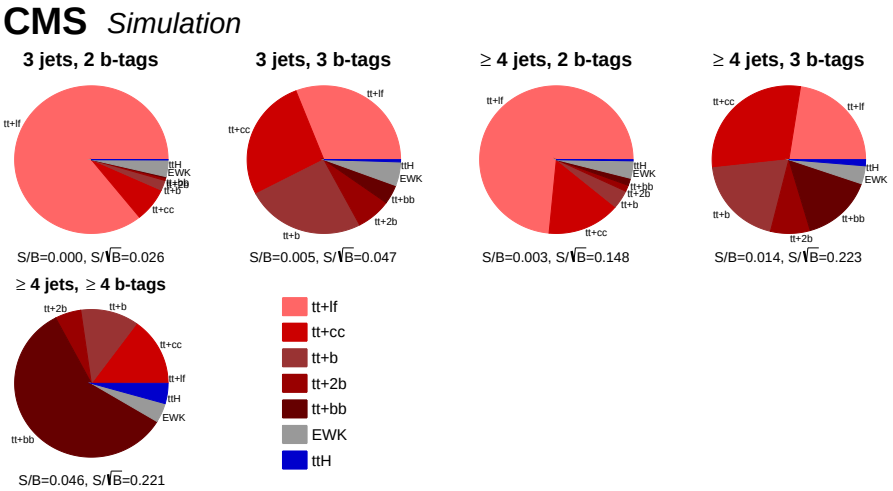
$t\bar{t} + b\bar{b}$: a background in the search of $t\bar{t}H \to b\bar{b}$

- $t\bar{t}H \to b\bar{b}$: irreducible background from $t\bar{t} + b\bar{b}$ production
- Additional $b\bar{b}$ pair from gluon radiation
  - $\to$ + electroweak contribution ($Z \to b\bar{b}$)
- QCD at two energy scales
  - $\to$ large uncertainties on predictions





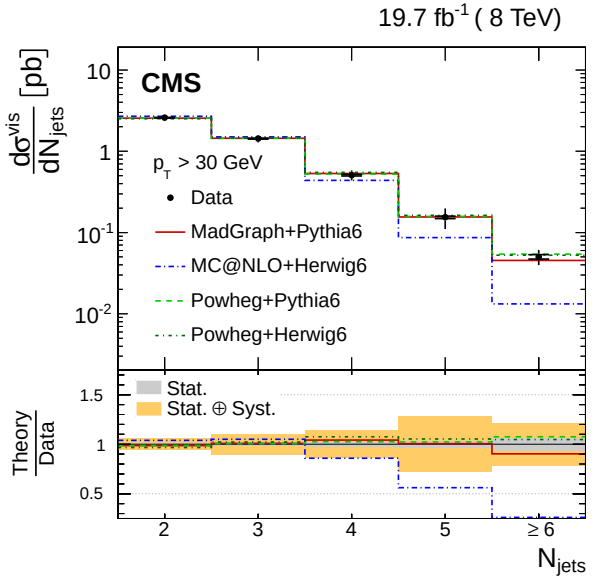
ℓ+jets regions

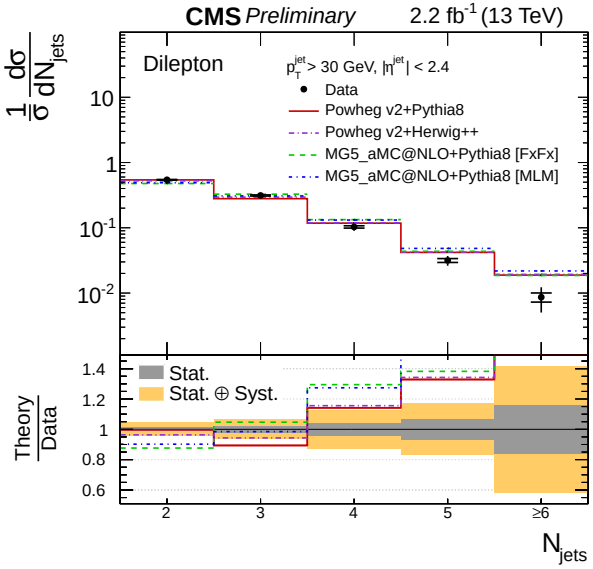


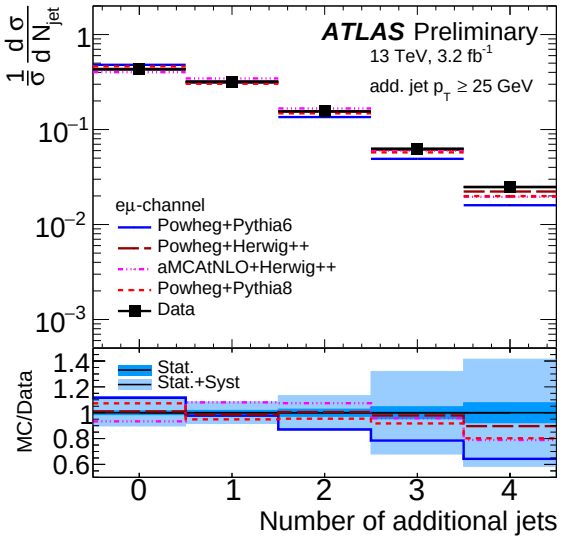
dilepton regions

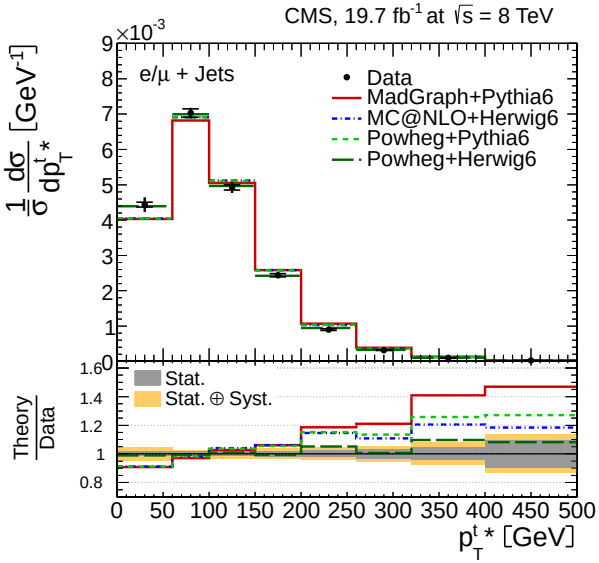
Measurements of $t\bar{t}+$jets differential cross-sections

- $t\bar{t}+b\bar{b}$ is a sub-process of $t\bar{t}+jets$ - first step : need to model N_{jets} well





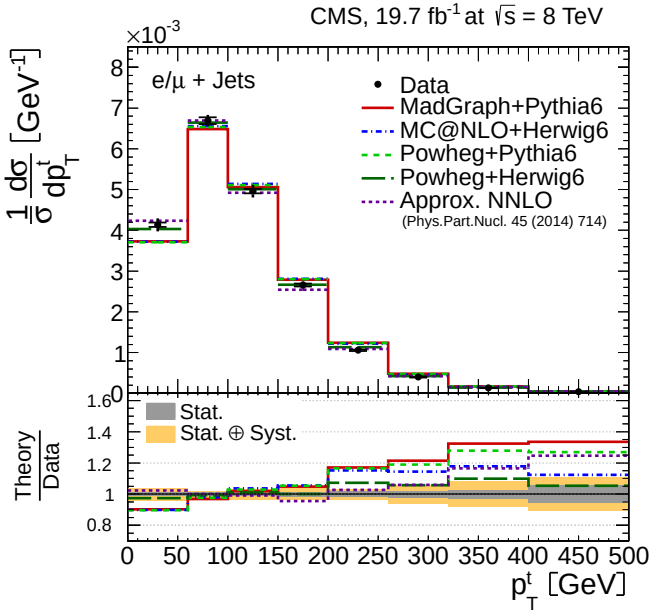


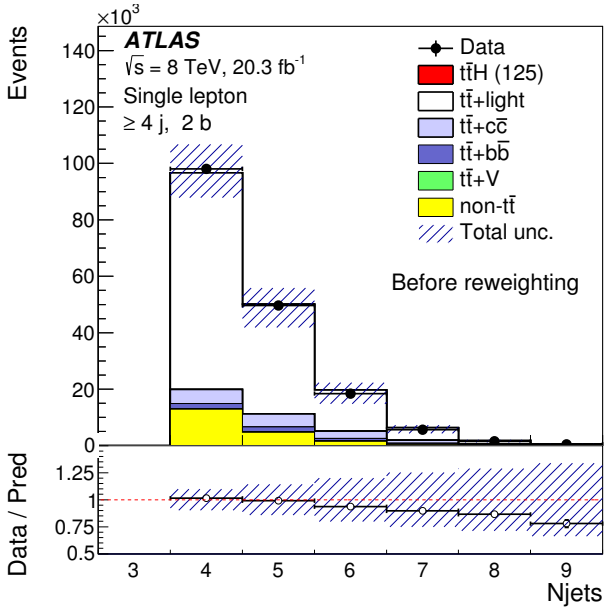


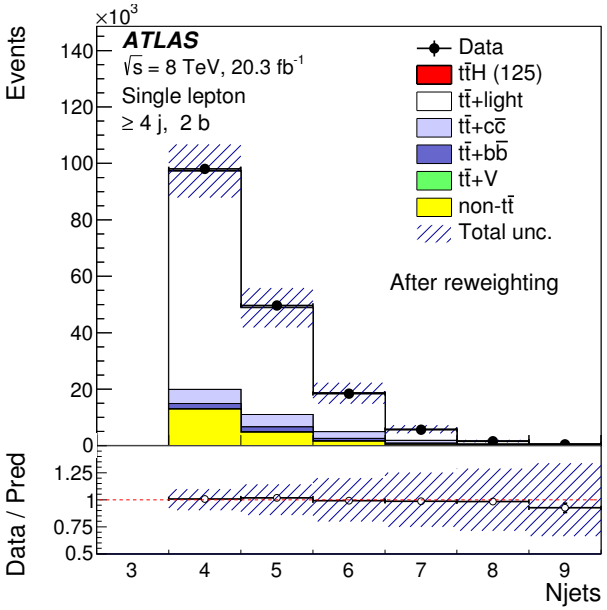
- Different MC settings can lead to very different N_{jets} !
- Modelling of N_{jets} and top kinematics related
- Many tunable parameters affecting these variables
  - → ME generator
  - → showering generator
  - → matching scheme and parameters
  - → additional partons in ME (LO or NLO)
- Also : NNLO - predictions available, no generator yet

Handling the $t\bar{t} + \mathrm{jets}$ mismodelling(s)

- Correction applied in CMS 8 TeV analysis
  - → use a reweighting function based on the $\mathrm{p_T}(t)$ distribution
  - → systematic uncertainty : remove or double the correction
- Correction applied in ATLAS 8 TeV analysis
  - → reweighting of $t\bar{t} + c\bar{c}$ and $t\bar{t} + \mathrm{light}$ contributions to improve $\mathrm{N_{jets}}$ and $\mathrm{H_T}$
  - → using $\mathrm{p_T}(t\bar{t})$ and $\mathrm{p_T}(t)$ 7 TeV cross-section measurement compared to 7 TeV prediction
  - → systematic uncertainty : doing or not this correction - separate for $t\bar{t} + c\bar{c}$ and $t\bar{t} + \mathrm{light}$

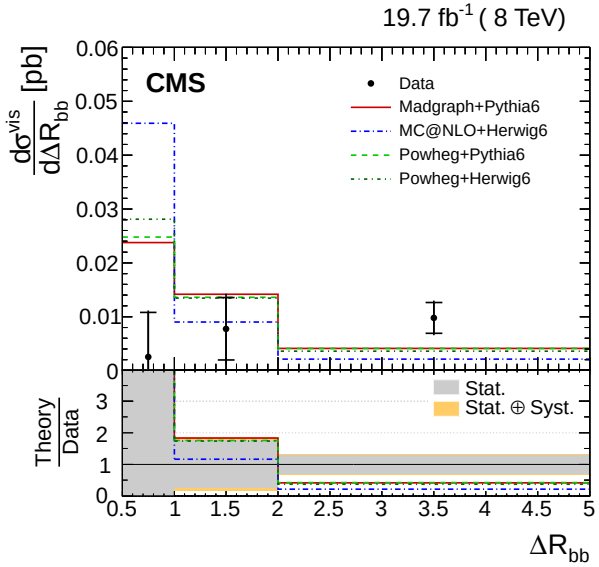


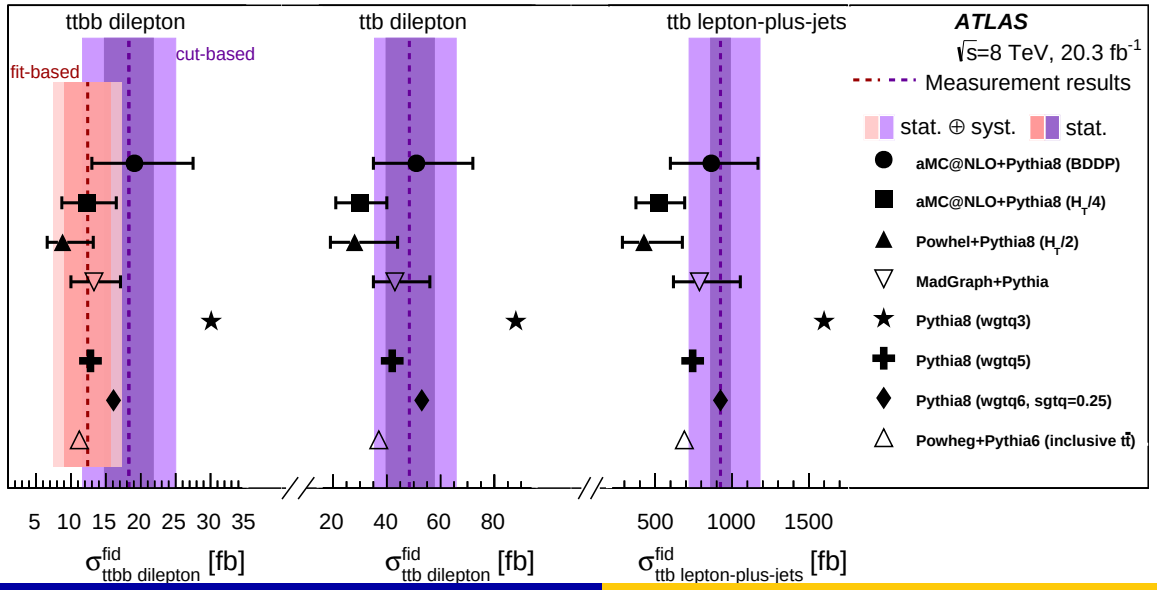


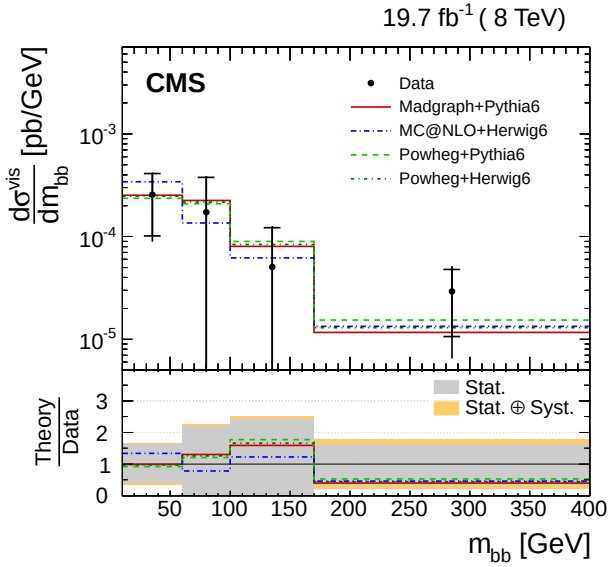


Measurements of $t\bar{t} + b\bar{b}$ cross-sections

- Various 8 TeV cross-section measurements :
  - → $\sigma_{t\bar{t}b\bar{b}/t\bar{t}jj}$ with $p_T(j) > 20$ GeV (CMS)
  - → differential parton-level cross-sections (CMS)
  - → $\sigma_{t\bar{t}+HF}$ in three particle-level fiductial regions (ATLAS)
- Could help to chose the best generator
  - → many settings to vary - scales, $g \to b\bar{b}$ splitting, PDF
  - → effects can be huge
- Not used in $t\bar{t}H \to b\bar{b}$ searches
  - → different fiducial regions - need more categories

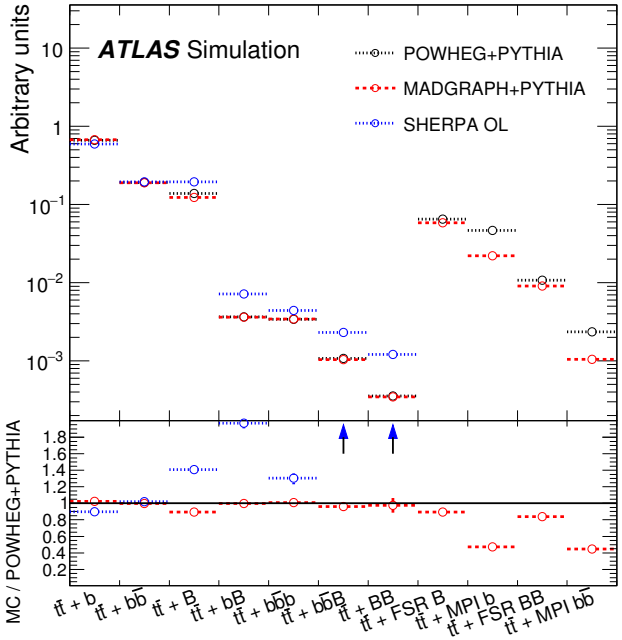


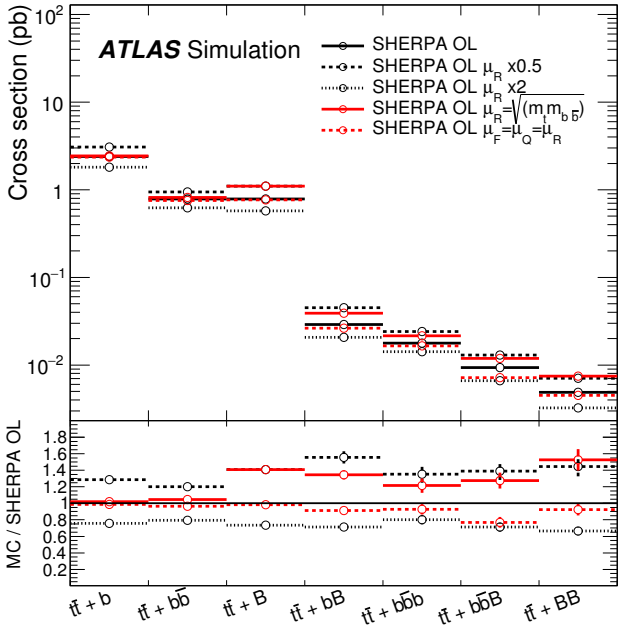




Handling the $t\bar{t} + b\bar{b}$ contribution

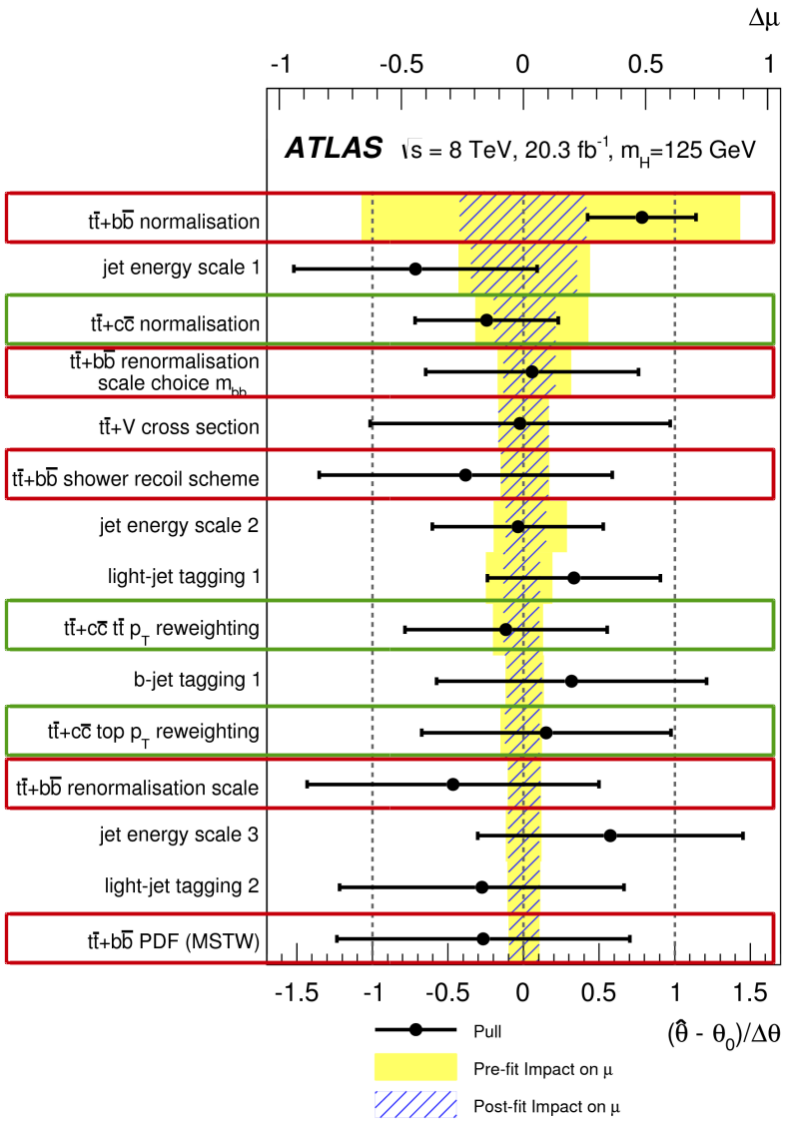
- In both experiments : 50% uncertainties on $t\bar{t} + b\bar{b}$ cross-section
  - → ATLAS decorrelates $t\bar{t} + b\bar{b}$ and $t\bar{t} + c\bar{c}$
  - → CMS : uncorrelated (decorrelated) for $t\bar{t} + b\bar{b}$, $t\bar{t} + b$, and $t\bar{t} + c\bar{c}$ at 8 (13) TeV
- Specific MC/MC correction on $t\bar{t} + b\bar{b}$ fractions in ATLAS 8 TeV analysis
  - → reweighting of nominal Powheg+Pythia6 to Sherpa OpenLoops (fully merged NLO)
  - → contribution subdivided in finer categories, each reweighted using kinematic variables
  - → uncertainties : 3 scales variations, shower recoil model, PDF choice
- No specific correction on $t\bar{t} + b\bar{b}$ fractions in CMS 8 & 13 TeV analyses
  - → $t\bar{t}$ uncerts. (ME and radiation scales, PDFs, $\mathrm{p_T}(t)$ reweight.) propagated to all categories





Effect of $t\bar{t} + \mathrm{HF}$ uncertainties on $t\bar{t}H \to b\bar{b}$

- $t\bar{t} + \mathrm{HF}$ uncertainties are dominant
  - $\to$ ATLAS : 8 out of the 15 largest sources
- $t\bar{t} + b\bar{b}/c\bar{c}$ normalisation constrained a lot
  - $\to$ same conclusions for ATLAS and CMS
- High correlation between μ_{sig} and $t\bar{t} + b\bar{b}$ norm.
  - $\to$ CMS 8 TeV : $\rho = -0.4$
  - $\to$ limit 4% better if this uncert. is removed



Conclusions

- $t\bar{t}H$ is a nice example of rare top-quark production mode to search for !
- Irreducible background sources from the other $t\bar{t}+X$ production modes
- $t\bar{t}+V$ relatively easy to deal with - predictions seem reliable and precise enough
  - $\rightarrow$ in the future : could take advantage of measurements when they become competitive
  - $\rightarrow$ not discussed in this talk : impact of $t\bar{t}+V \rightarrow q\bar{q}$ in $t\bar{t}H \rightarrow b\bar{b}$ search (also easy)
- $t\bar{t}+b\bar{b}$ (and $t\bar{t}+\mathrm{jets}$ in general) more challenging
  - $\rightarrow$ difficult to predict - large uncertainties
  - $\rightarrow$ heavily constrained in likelihood fits
  - $\rightarrow$ measurements could be used to have better MC - also for HF fractions