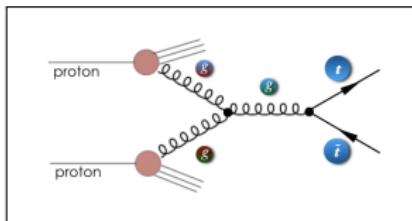


Top quark results from LHC

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on behalf of the
ATLAS, CMS and LHCb Collaborations



QCD@LHC 2016
Zurich, 24th August 2016

The top quark: why do we care?

- Top is the **heaviest** known fundamental particle

$$\lambda_t = \sqrt{2}m_t/v \sim 1 \text{ (special role in EWSB?)}$$

- Top quark is **short lived**

☞ decays before hadronization

- $\Lambda_{\text{QCD}}^{-1} \sim (100 \text{ MeV})^{-1} \sim 10^{-23} \text{ s}$

- $\Gamma_t^{\text{NLO}} = 1.42 \text{ GeV}$

$$\tau_t \sim 10^{-25} \text{ s} \ll 10^{-23} \text{ s}$$

- Top **decays** (almost exclusively) through $t \rightarrow bW$

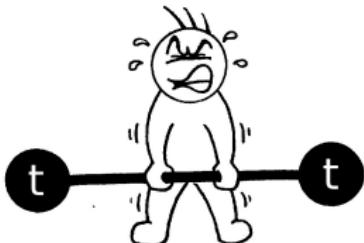
$$BR(t \rightarrow sW) \leq 0.18\%, BR(t \rightarrow dW) \leq 0.02\%$$

- The measurement of the top quark properties provides a powerful test of the SM

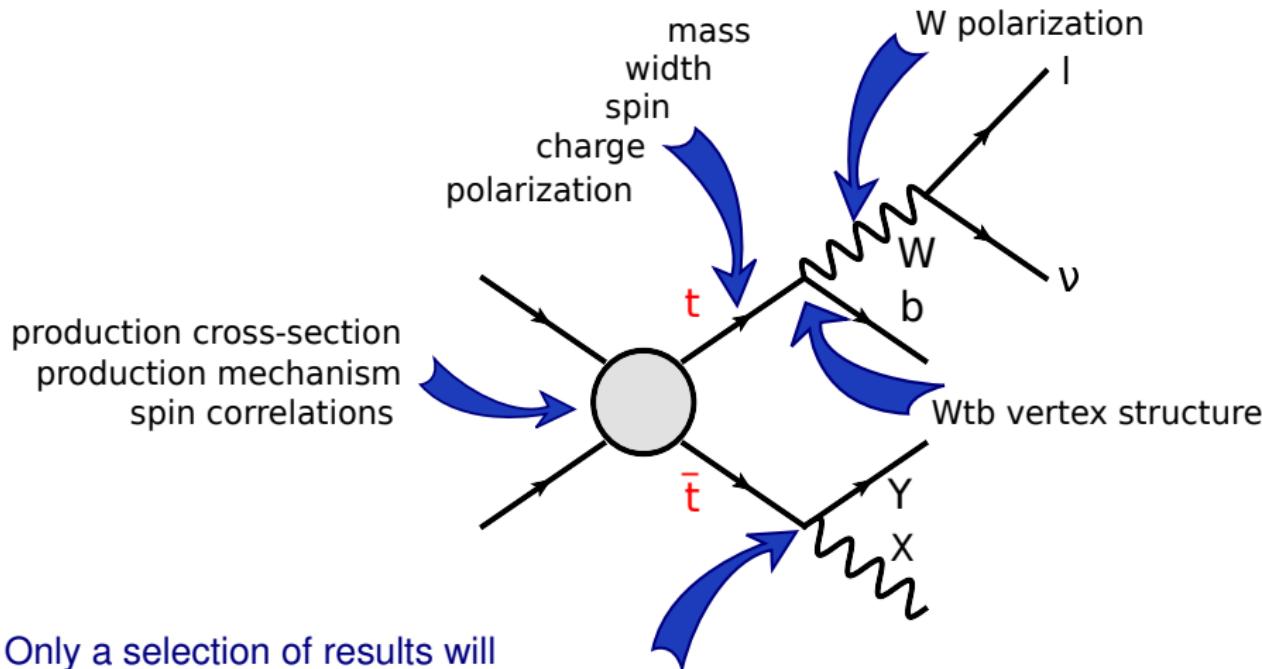
☞ precision **test of perturbative QCD to high orders** (at least NNLO needed to describe data!)

☞ soft radiation in production and decay: constrain the **modelling of parton shower and hadronization**

- Top quark might play a special role in new physics models



The top quark: why do we care?



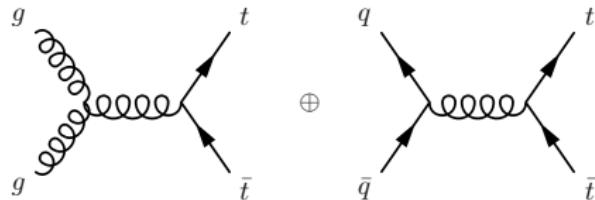
☞ Only a selection of results will be discussed in this talk (focusing mainly on the most recent ones)

branching ratios (Wtb, rare decays)
associated production (H, W, Z, γ)

Top quark production at the LHC

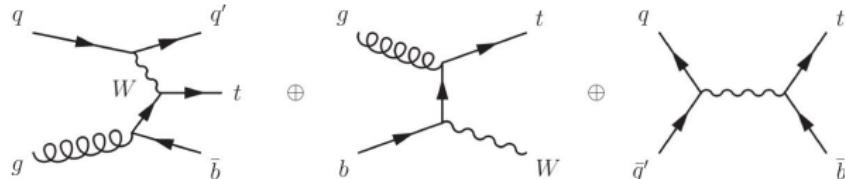
- LHC is a top factory:

pair production:



- dominant production mode
- at the LHC, mainly through gluon fusion
- $\sigma(t\bar{t})$: constrain gluon PDF, α_s and pole mass

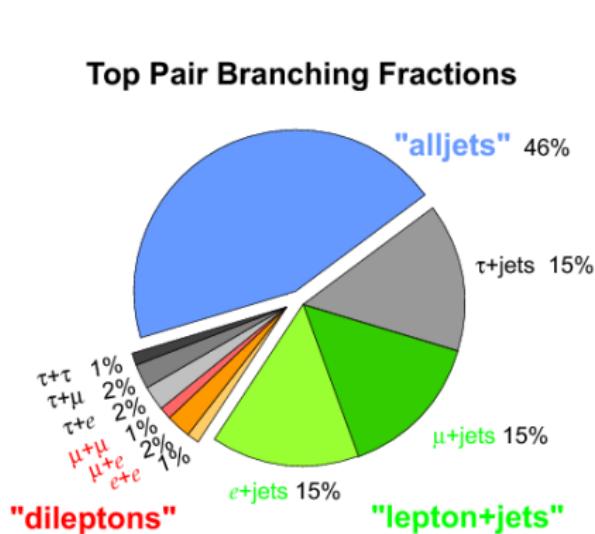
single production:



- EW production (sensitive to V_{tb})
- tW production: interference at higher orders with $t\bar{t}$

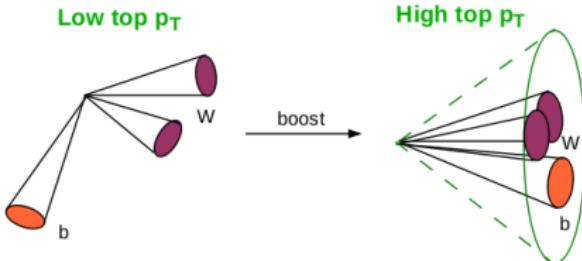
Different topologies available in $t\bar{t}$ events

- ☛ The decay of the W from the top quark defines the event topology
- ☛ Presence of b -tagged jets (from $t \rightarrow bW$ decay)

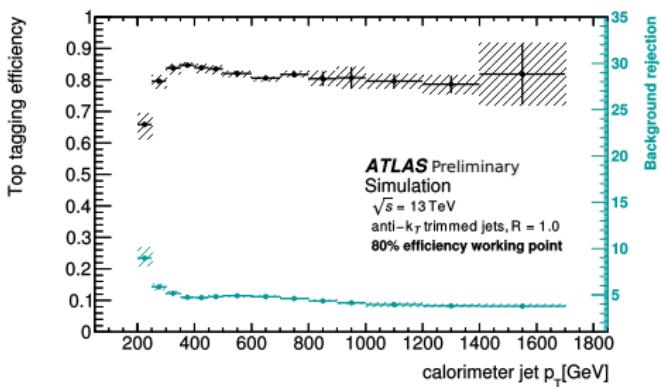


- $\ell + \text{jets}$:
 - high BR
 - reasonable S/B
 - dominant background: $W + \text{jets}$
- dileptonic:
 - small BR
 - excellent S/B
 - 3 main channels: ee , $e\mu$, $\mu\mu$
- all hadronic:
 - highest BR
 - large multi-jet background

Identifying top quarks: boosted topologies



[ATL-PHYS-PUB-2015-053]



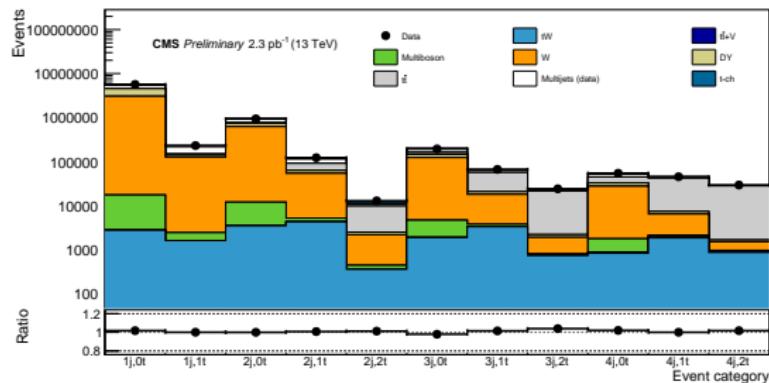
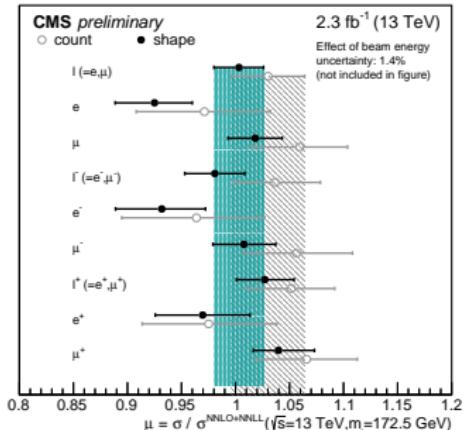
- $\Delta R_{\text{massive jet}} \sim \frac{2M}{p_T}$
- pile-up effects are important
 - ☛ important to mitigate its effect (trimming, soft drop)
- Development of t -tagging techniques targeting high- p_T top quarks

Inclusive $t\bar{t}$ production cross-section

$\sqrt{s} = 13 \text{ TeV}$

[CMS PAS TOP-16-006]

- $\ell = e, \mu + \text{jets topology}$
- $2 \times 2 \times 11$ categories ($N_{\text{jets}}, N_{\text{b-jets}}, e^\pm, \mu^\pm$)
- shape analysis [$M(\ell, b)$]



$$\sigma_{t\bar{t}} = 834.6 \pm 2.5 \text{ (stat)} \pm 22.8 \text{ (syst)} \pm 22.5 \text{ (lumi)} \text{ pb}$$

$$\left(\frac{\delta \sigma}{\sigma} \right) = 4\%$$

- Uncertainty dominated by systematics: $W+\text{jets}$ modelling and luminosity are the biggest sources

Inclusive $t\bar{t}$ production cross-section

$\sqrt{s} = 13 \text{ TeV}$

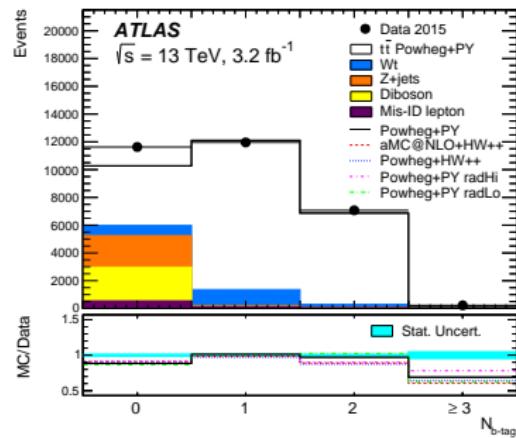
[arXiv:1606.02699]

- Cross-section and b-tagging efficiency extracted using $e\mu$ events with 1 or 2 b-tags:

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

$$N_2 = L \sigma_{t\bar{t}} \epsilon_{e\mu} C_b \epsilon_b^2 + N_2^{\text{bkg}}$$

- Selection requires 1 e , 1 μ and ≥ 1 b-tagged jets
- b-tagging efficiency absorbs systematic uncertainties due to b-tag and bJES
- Hadronization related uncertainties dominate



Event counts	N_1	N_2
Data	11958	7069
Single top	1140 ± 100	221 ± 68
Dibosons	34 ± 11	1 ± 0
$Z(\rightarrow \tau\tau \rightarrow e\mu) + \text{jets}$	37 ± 18	2 ± 1
Misidentified leptons	164 ± 65	116 ± 55
Total background	1370 ± 120	340 ± 88

$$\sigma_{t\bar{t}} = 818 \pm 8 \text{ (stat)} \pm 27 \text{ (syst)} \pm 19 \text{ (lumi)} \pm 12 \text{ (beam)} \text{ pb} \quad \left(\frac{\delta\sigma}{\sigma} = 4\% \right)$$

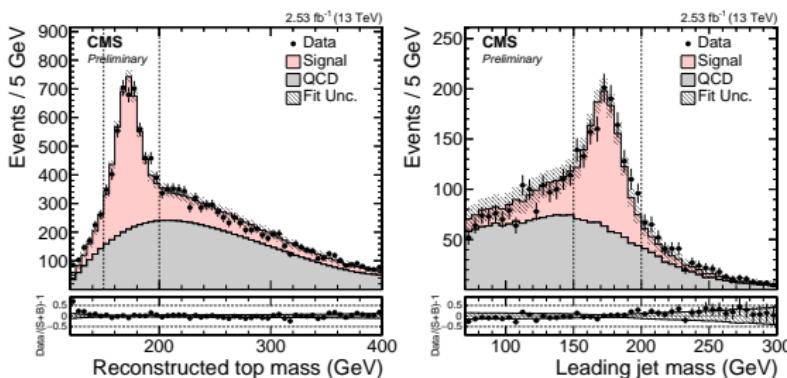
Inclusive $t\bar{t}$ production cross-section

$\sqrt{s} = 13 \text{ TeV}$

[CMS PAS TOP-16-013]

- Fully hadronic topology
- 2 approaches:
resolved (low top p_T) and
boosted (high top p_T)

Resolved	Boosted
<p>lepton veto AK4 jets $p_T > 30 \text{ GeV}$ and $\eta < 2.4$ $N_{\text{jets}} \geq 6$ $H_T > 500 \text{ GeV}$, $p_T^{(6)} > 45 \text{ GeV}$ at least two b-tagged jets $\Delta R_{bb} > 2.0$ kin. fit probability > 0.02 $150 < m_t < 200 \text{ GeV}$</p>	<p>lepton veto AK8 jets $p_T > 200 \text{ GeV}$, $\eta < 2.4$, $m_{SD} > 50 \text{ GeV}$ $N_{\text{jets}} \geq 2$ $p_T^{(1)} > 450 \text{ GeV}$ both jets should contain one b-tagged subjet $\mathcal{F} > 0$ $150 < m_{SD}^{(1)} < 200 \text{ GeV}$</p>

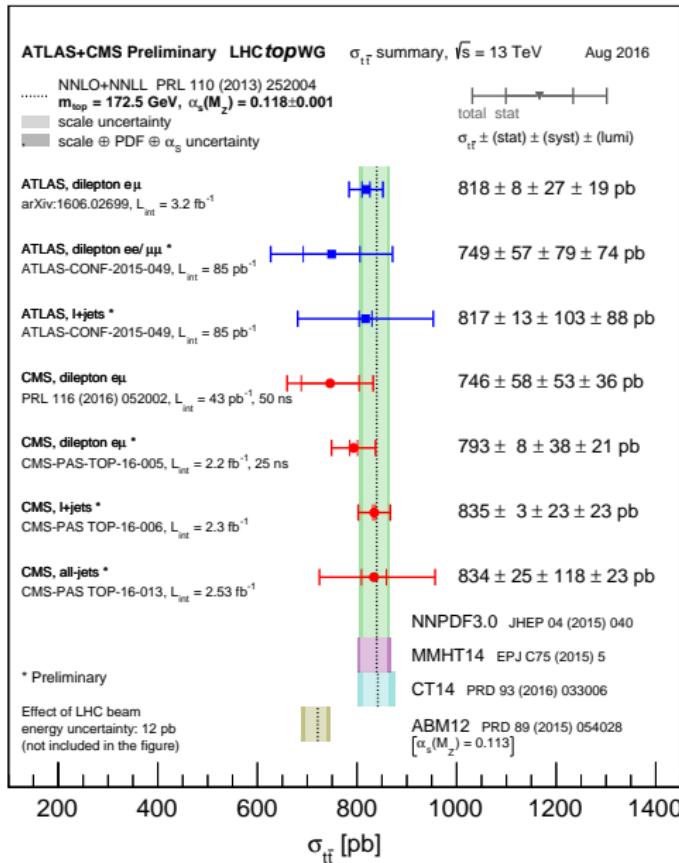


- Dominant systematic uncertainties: parton shower, b -tagging, JES (resolved)

$$\sigma_{t\bar{t}} = 834 \pm 25 \text{ (stat)} {}^{+118}_{-104} \text{ (syst)} \pm 23 \text{ (lumi)} \text{ pb} \quad \left(\frac{\delta\sigma}{\sigma} = 15\% \right)$$

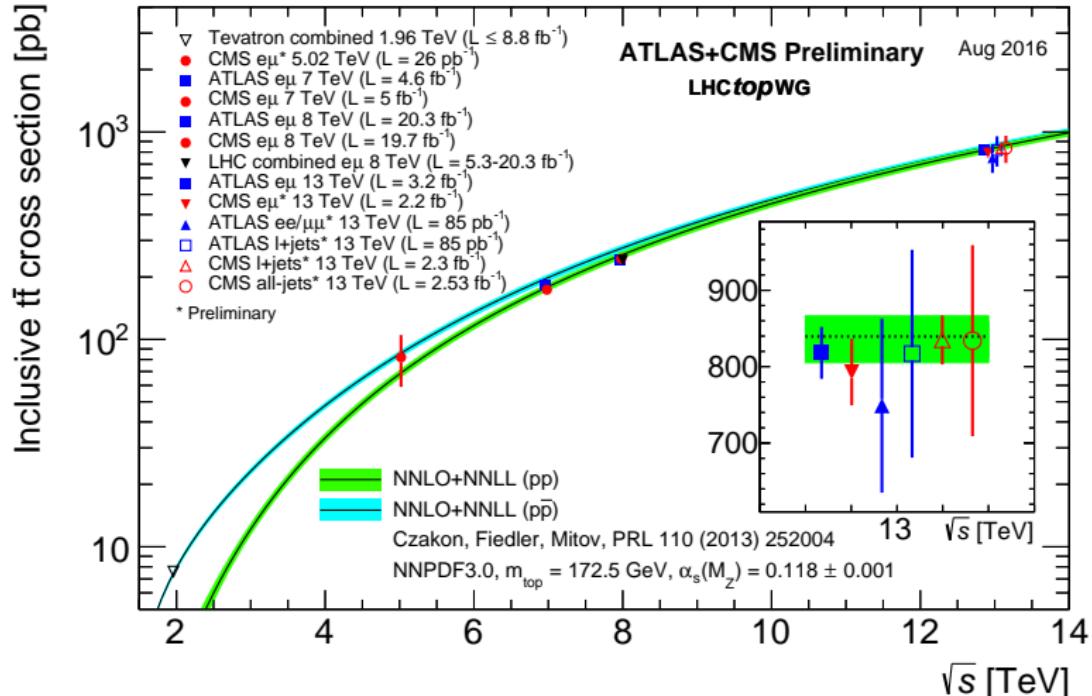
Inclusive $t\bar{t}$ production cross-section

$\sqrt{s} = 13 \text{ TeV}$



$$\left(\frac{\delta\sigma}{\sigma}\right)_{\text{theory}} = 6\%$$

Inclusive $t\bar{t}$ production cross-section



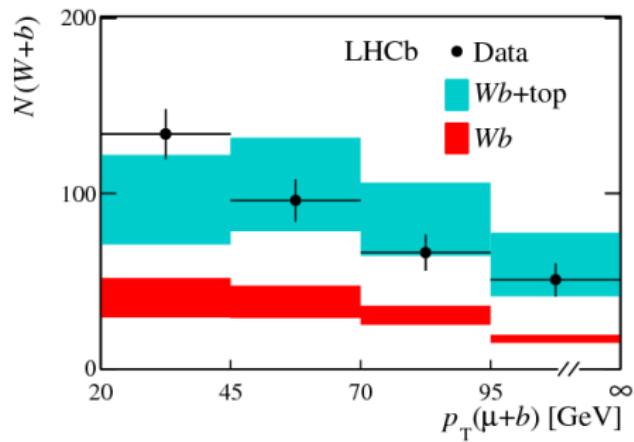
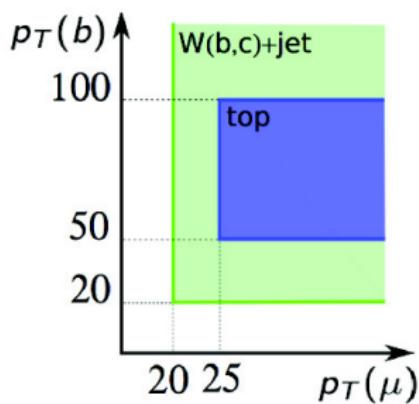
☞ Excellent agreement with the SM (NNLO+NNLL prediction)

Inclusive $t\bar{t}$ production cross-section in the forward region

$\sqrt{s} = 7, 8 \text{ TeV}$

[PRL 115 (2015) 112001]

- Forward t production different from central: qq and qg dominates over gg .
- NLO: $\sim 75\% t\bar{t}$ and about $\sim 25\%$ t-channel single t
- Constraint on large x gluon PDF
- Relies on the detection of an energetic, large $|\eta|$, muon



☞ First observation (5.4σ)

Inclusive $t\bar{t}$ production cross-section in the forward region

$\sqrt{s} = 8 \text{ TeV}$

[LHCb-PAPER-2016-038, in preparation]

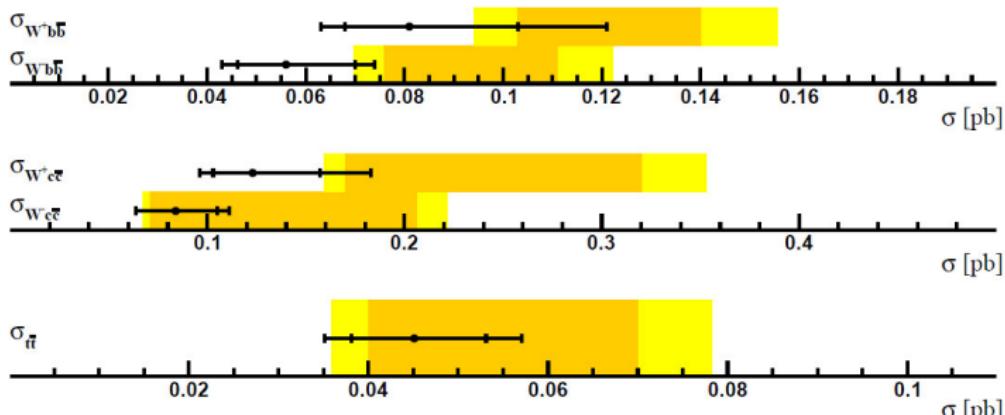
- High p_T , isolated, e or μ + 2 heavy-flavour tagged jets
- Moderate p_T cuts, tight $|\eta|$ cuts
- Relies on the use of m_{jj} and an MVA analysis
- Simultaneous fit of μ^- , μ^+ , e^- and e^+ samples
- Allows the measurement of $Wb\bar{b}$, $Wc\bar{c}$ and $t\bar{t}$ cross-sections

LHCb, $\sqrt{s} = 8 \text{ TeV}$

LHCb preliminary

• MCFM CT10

Data stat
Data tot

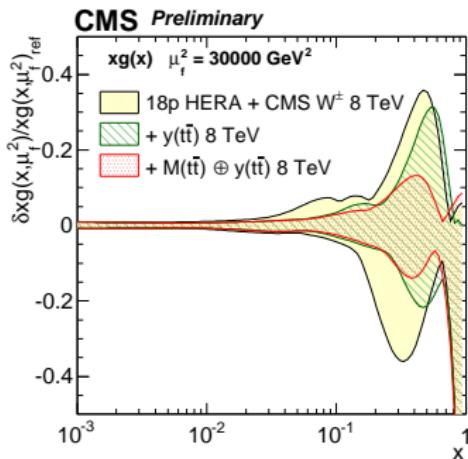
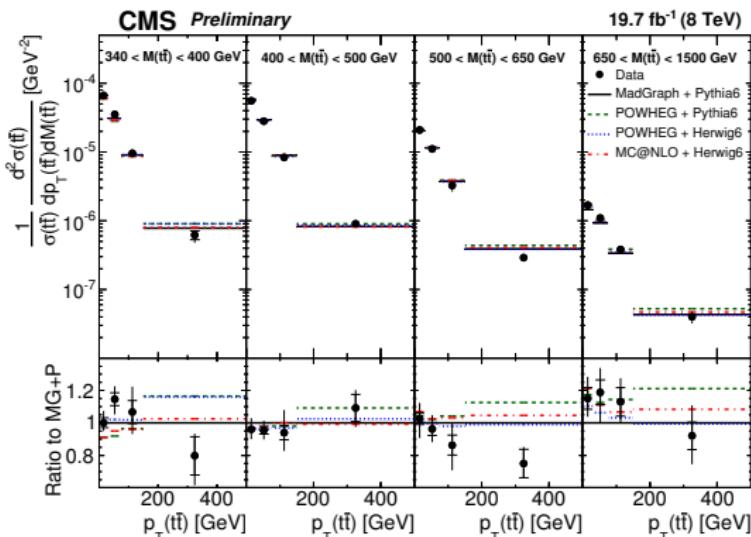


Differential $t\bar{t}$ production cross-section (parton level)

$\sqrt{s} = 8 \text{ TeV}$

[CMS PAS TOP-14-013]

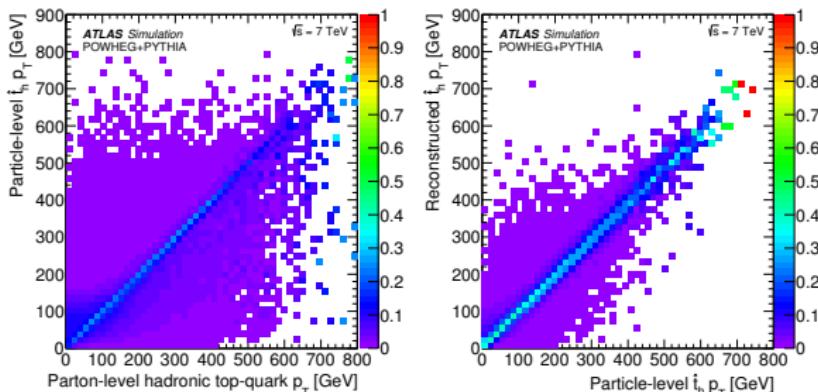
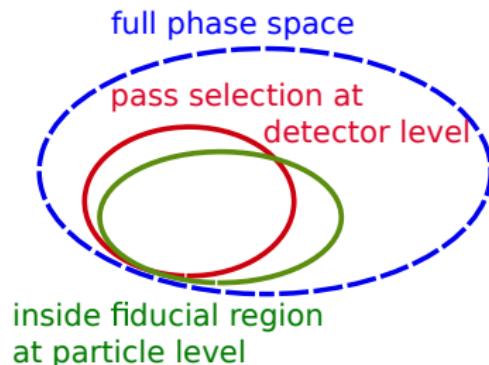
- Double differential cross sections: bin $t\bar{t}$ events in 2 variables:
e.g. $p_T(t\bar{t})$ vs. $y(t\bar{t})$, $p_T(y)$ vs. $y(t\bar{t})$, etc



- $m(t\bar{t})$ vs. $y(t\bar{t})$ especially sensitive to PDFs
(2D distributions provide stronger constraints than 1D)
- Significant reduction of the uncertainty at high- x

Particle level objects and pseudo-top quarks

- **parton level:** e.g. top quarks before decay, but after radiation
- **particle level:** stable particles ($\tau > 0.3 \times 10^{-10}$ s)
 - ☞ corrections to particle level allow to minimize the extrapolation and the theoretical uncertainty
- top quark proxy reconstructed from decay products after hadronization
[<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/ParticleLevelTopDefinitions>]



[JHEP06 (2015) 100]

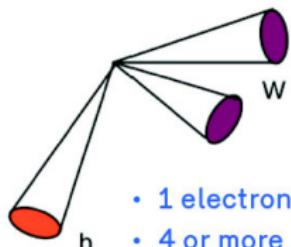
Differential $t\bar{t}$ production cross-section (particle level)

$\sqrt{s} = 13 \text{ TeV}$

[ATLAS-CONF-2016-040]

- Differential cross-sections in resolved and boosted $\ell+\text{jets}$ events and unfolded to particle level, in fiducial phase-space
- $p_T(t)$, $p_T(t\bar{t})$, $m(t\bar{t})$, $|y(t)|$, $|y(t\bar{t})|$

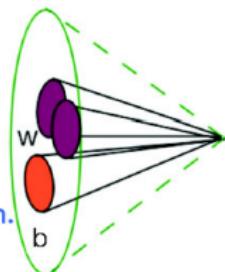
Resolved Top



- 1 electron or muon
- 4 or more jets
(at least 2 b-tagged)
- Hadronic and leptonic top reconstruction.

Boosted Top

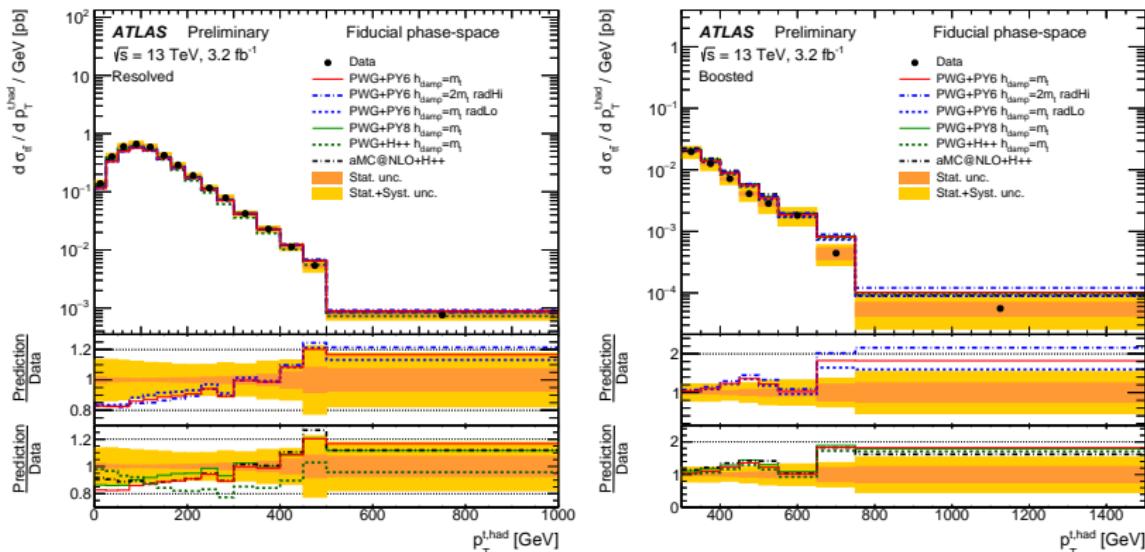
- 1 electron or muon
- 1 or more small-R jets
- 1 top-tagged large-R jet
- $\text{MET} > 20 \text{ GeV}$
- $\text{MET} + m_T(W) > 60 \text{ GeV}$
- Hadronic top reconstruction.
 $p_T(t) > 300 \text{ GeV}$
- Either small-R and large-R jets b-tagged (77% eff.).



Differential $t\bar{t}$ production cross-section (particle level)

$\sqrt{s} = 13 \text{ TeV}$

[ATLAS-CONF-2016-040]

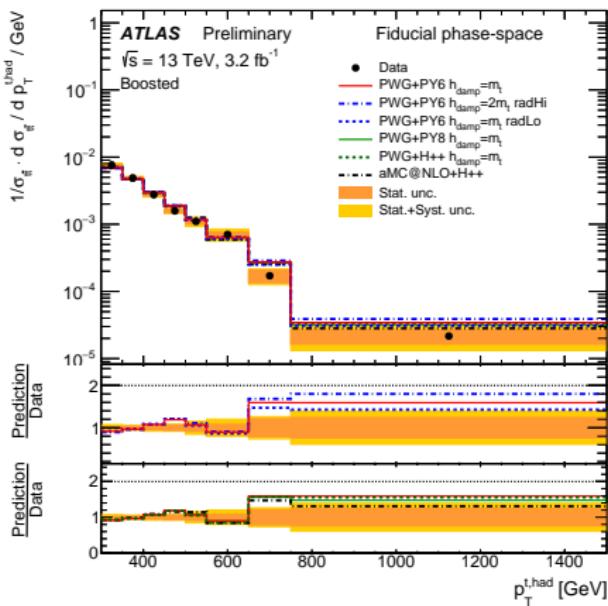
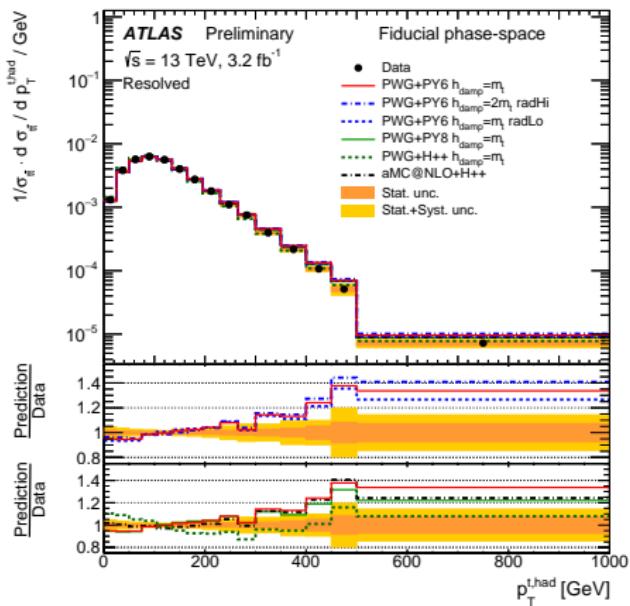


- Dominant uncertainties: JES and b -tagging
- Trends of NLO predictions observed to be similar as in 8 TeV results
- Data tends to be softer than NLO MC at high $p_T(t)$ in both resolved and boosted cases

Differential $t\bar{t}$ production cross-section (particle level)

$\sqrt{s} = 13 \text{ TeV}$

[ATLAS-CONF-2016-040]



👉 Normalized distributions

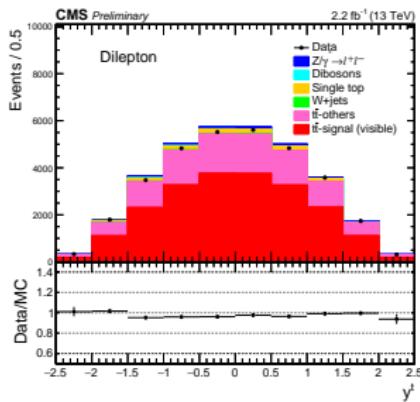
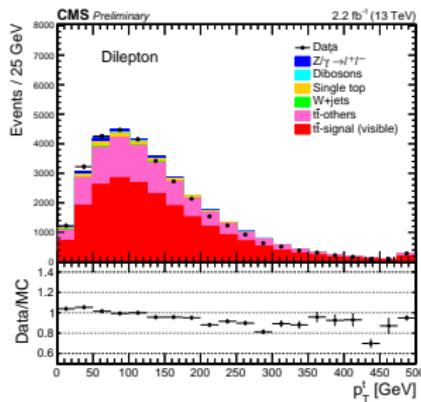
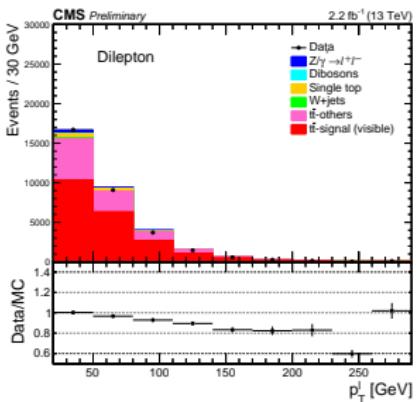
Differential $t\bar{t}$ production cross-section (particle level)

$\sqrt{s} = 13 \text{ TeV}$

[CMS PAS TOP-16-007]

- Dilepton topology:
 e^+e^- , $\mu^+\mu^-$, $e^\pm\mu^\mp$
- Fiducial measurement

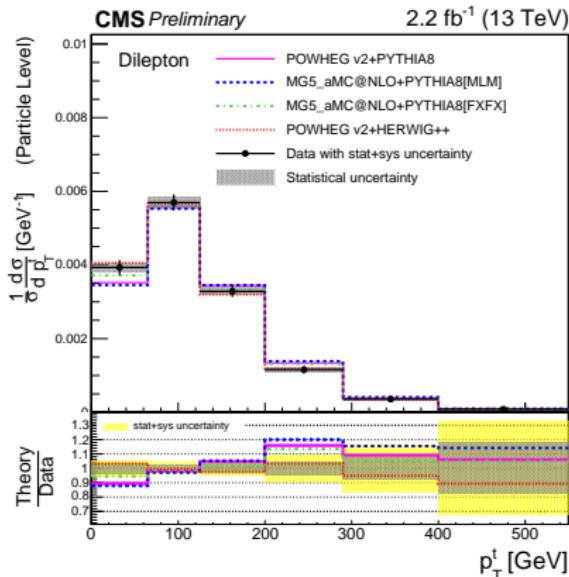
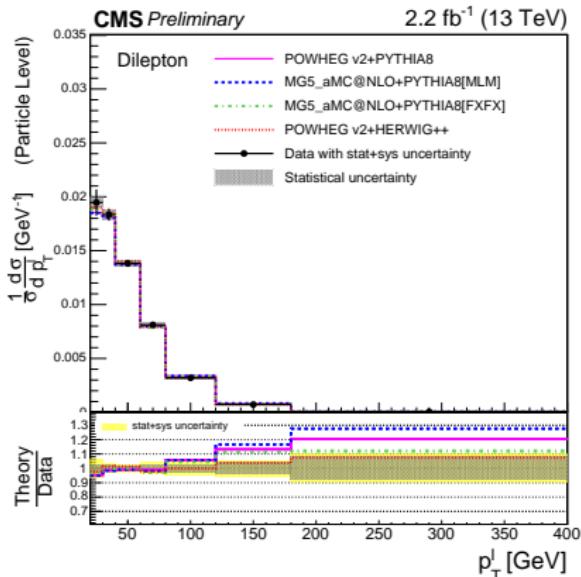
Object	Definition	Selection criteria
Prompt neutrino	neutrinos not from hadron decay	none
Dressed lepton	anti- k_T jet with a distance parameter of 0.1 using electrons, muons and photons not from hadron decay	$p_T > 20 \text{ GeV}$, $ \eta < 2.4$
b quark jet	anti- k_T jet with a distance parameter of 0.4 using all particles and ghost B hadrons not including any neutrinos nor particles used in dressed leptons	$p_T > 30 \text{ GeV}$, $ \eta < 2.4$ with ghost B hadrons



Differential $t\bar{t}$ production cross-section (particle level)

$\sqrt{s} = 13 \text{ TeV}$

[CMS PAS TOP-16-007]



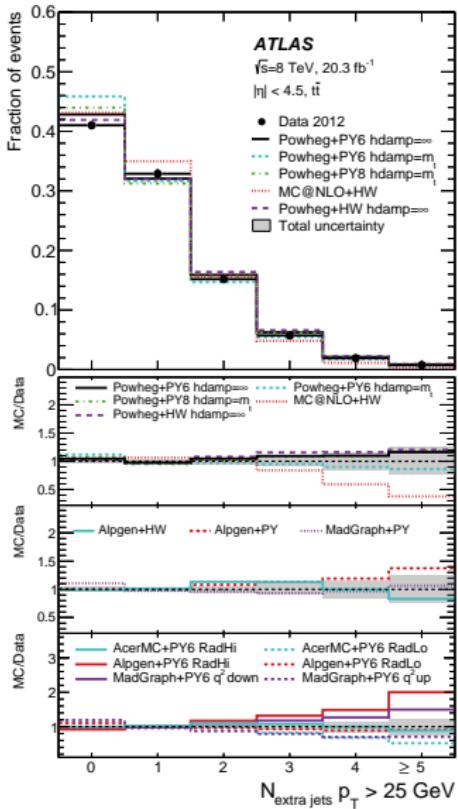
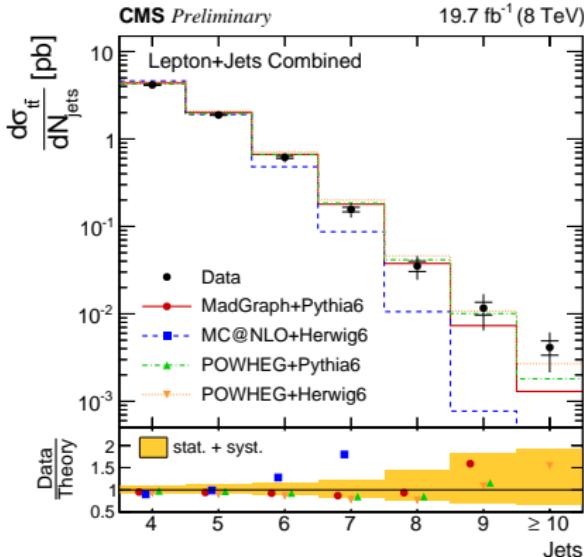
- Dominant uncertainties: MC modelling
- Similar trend on $p_T(t)$ observed

Additional jet activity in $t\bar{t}$ events

$\sqrt{s} = 8 \text{ TeV}$

[CMS PAS TOP-15-006] [arXiv:1606.09490]

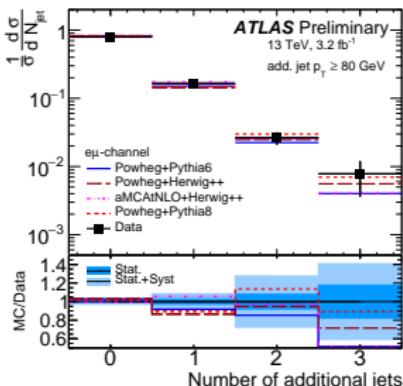
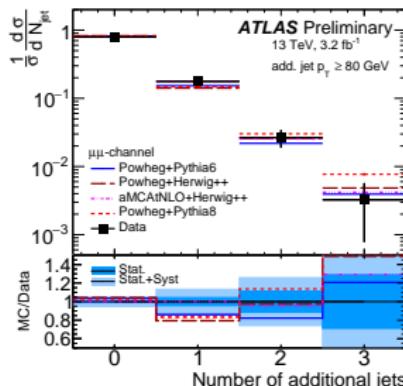
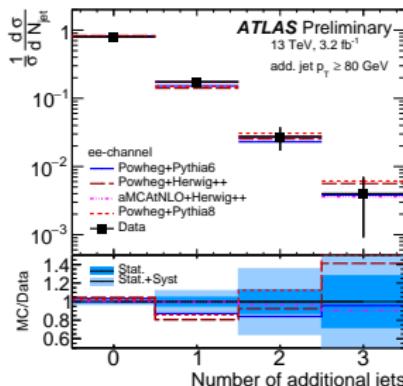
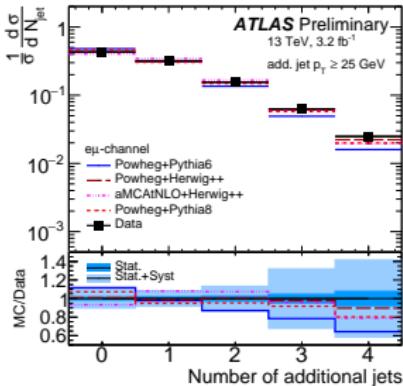
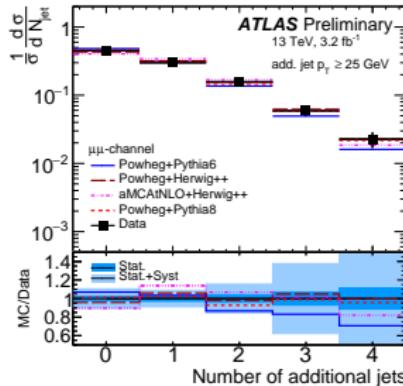
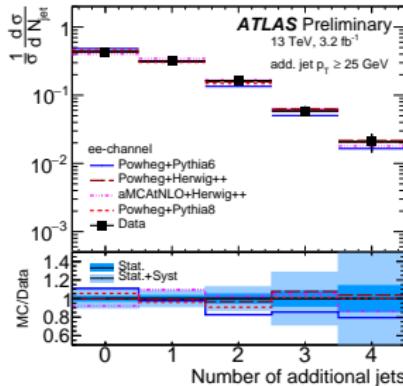
- Differential cross section for $t\bar{t}$ production as a function of jet multiplicity
- $\ell + \text{jets}$ (CMS) and dilepton $e^\pm \mu^\mp + b\bar{b}$ (ATLAS)



Additional jet activity in $t\bar{t}$ events

$\sqrt{s} = 13 \text{ TeV}$

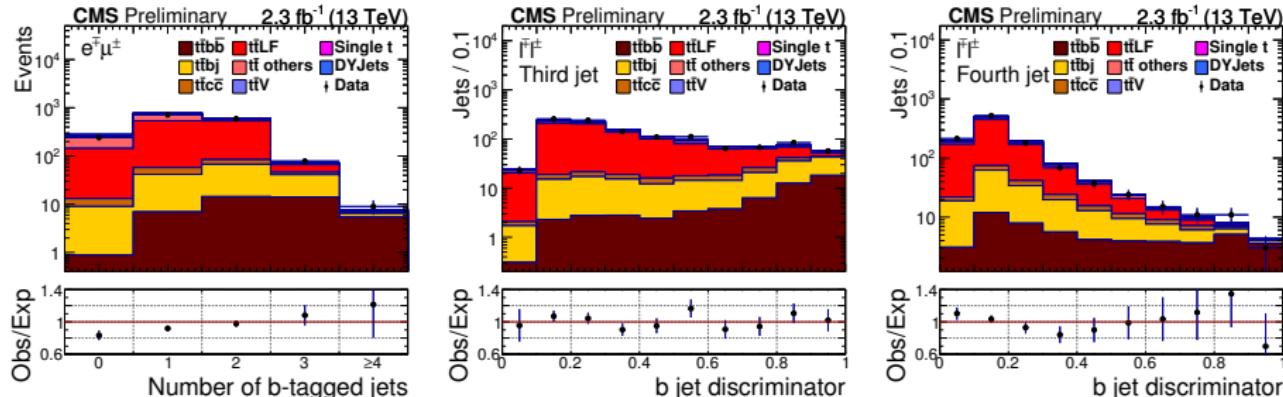
[ATLAS-CONF-2015-065] dilepton events with 2 b -tagged jets



$\sigma(t\bar{t}bb)/\sigma(t\bar{t}jj)$ ratio

$\sqrt{s} = 13 \text{ TeV}$

[CMS PAS TOP-16-010] dilepton events

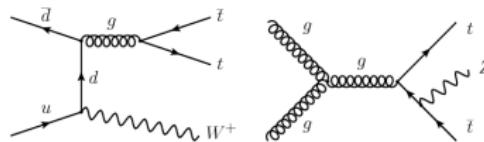


Phase Space	$\sigma_{t\bar{t}bb} [\text{pb}]$	$\sigma_{t\bar{t}jj} [\text{pb}]$	$\sigma_{t\bar{t}bb}/\sigma_{t\bar{t}jj}$
Measurement			
Visible	$0.085 \pm 0.012 \pm 0.029$	$3.5 \pm 0.1 \pm 0.7$	$0.024 \pm 0.003 \pm 0.007$
Full	$3.9 \pm 0.6 \pm 1.3$	$176 \pm 5 \pm 33$	$0.022 \pm 0.003 \pm 0.006$
Simulation (POWHEG)			
Visible	0.070 ± 0.009	5.1 ± 0.5	0.014 ± 0.001
Full	3.2 ± 0.4	257 ± 26	0.012 ± 0.001

$t\bar{t}W$ and $t\bar{t}Z$ production

$\sqrt{s} = 13 \text{ TeV}$

[ATLAS-CONF-2016-003]

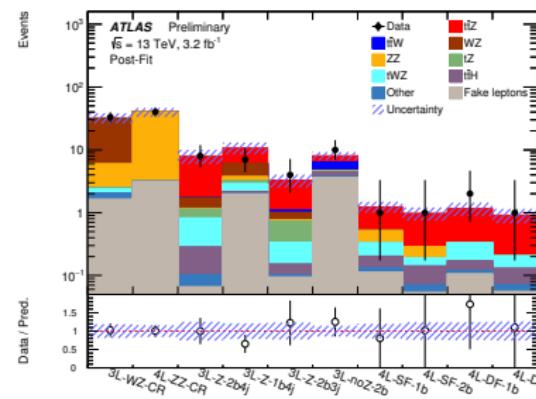
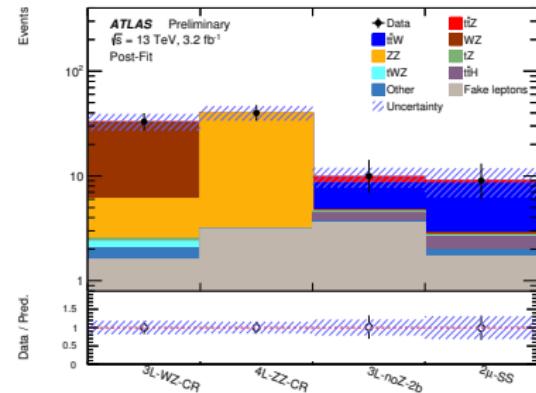


- Final states with either 2 SS- μ or 3, 4 $\ell = e\mu$
- 2 control regions (WZ and ZZ)
- 2 (8) signal regions used for the $t\bar{t}W$ ($t\bar{t}Z$) fits

Process	$t\bar{t}$ decay	Boson decay	Channel
$t\bar{t}W^\pm$	$(\mu^\pm \nu b)(q\bar{q}b)$ $(\ell^\pm \nu b)(\ell^\mp \nu b)$	$\mu^\pm \nu$ $\ell^\pm \nu$	SS dimuon Trilepton
$t\bar{t}Z$	$(\ell^\pm \nu b)(q\bar{q}b)$ $(\ell^\pm \nu b)(\ell^\mp \nu b)$	$\ell^+\ell^-$ $\ell^+\ell^-$	Trilepton Tetralepton

$$\sigma(t\bar{t}W) = 1.4 \pm 0.8$$

$$\sigma(t\bar{t}Z) = 0.9 \pm 0.3$$

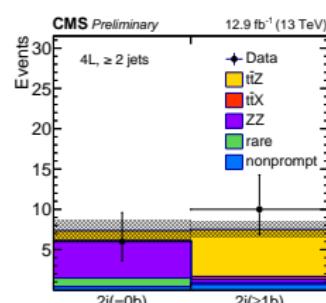
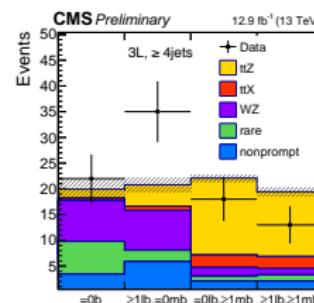
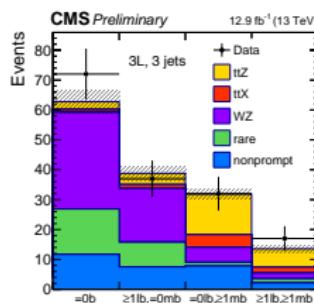
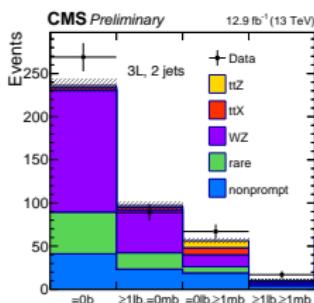
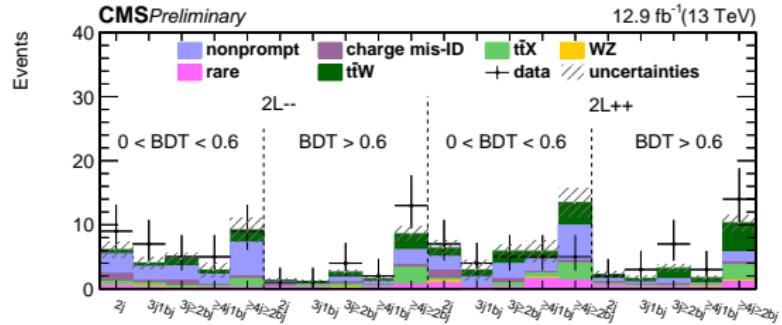


$t\bar{t}W$ and $t\bar{t}Z$ production

$\sqrt{s} = 13 \text{ TeV}$

[CMS PAS TOP-16-017]

- $t\bar{t}W$ measured in 2 SS leptons events (BDT used)
- $t\bar{t}Z$ measured in 3 or 4 leptons events



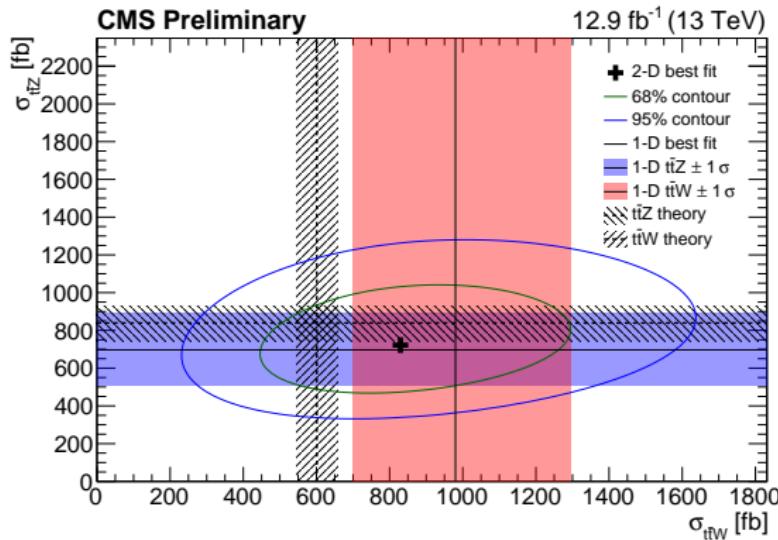
$t\bar{t}W$ and $t\bar{t}Z$ production

$\sqrt{s} = 13 \text{ TeV}$

[CMS PAS TOP-16-017]

$$\sigma(t\bar{t}W) = 0.98^{+0.23}_{-0.22} \text{ (stat)}^{+0.22}_{-0.18} \text{ (syst)}$$

$$\sigma(t\bar{t}Z) = 0.70^{+0.16}_{-0.15} \text{ (stat)}^{+0.14}_{-0.12} \text{ (syst)}$$



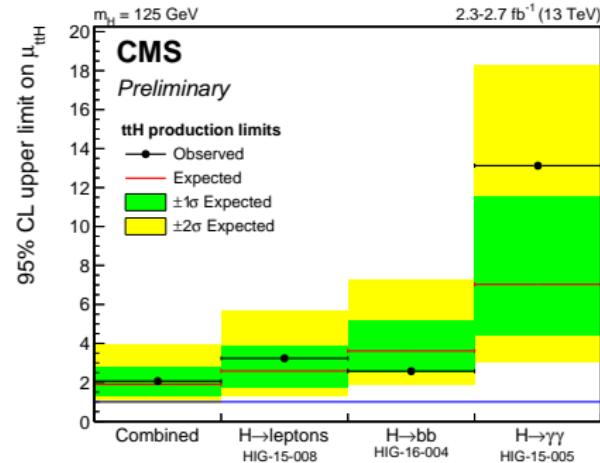
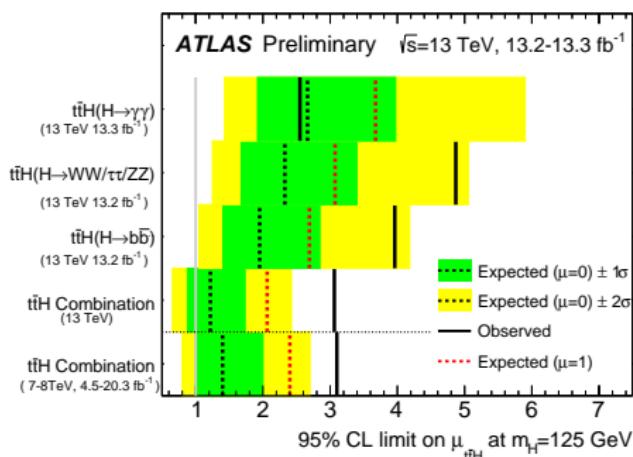
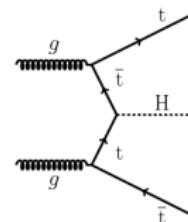
Channel	Expected significance	Observed significance
$2\ell ss$ analysis ($t\bar{t}W$)	2.6	3.9
3ℓ analysis ($t\bar{t}Z$)	5.4	3.8
4ℓ analysis ($t\bar{t}Z$)	2.4	2.8
3ℓ and 4ℓ combined ($t\bar{t}Z$)	5.8	4.6

$t\bar{t}H$ production

$\sqrt{s} = 13 \text{ TeV}$

[ATLAS-CONF-2016-068]

[<https://twiki.cern.ch/twiki/bin/view/CMSPublic/TTHCombMoriond2016>]



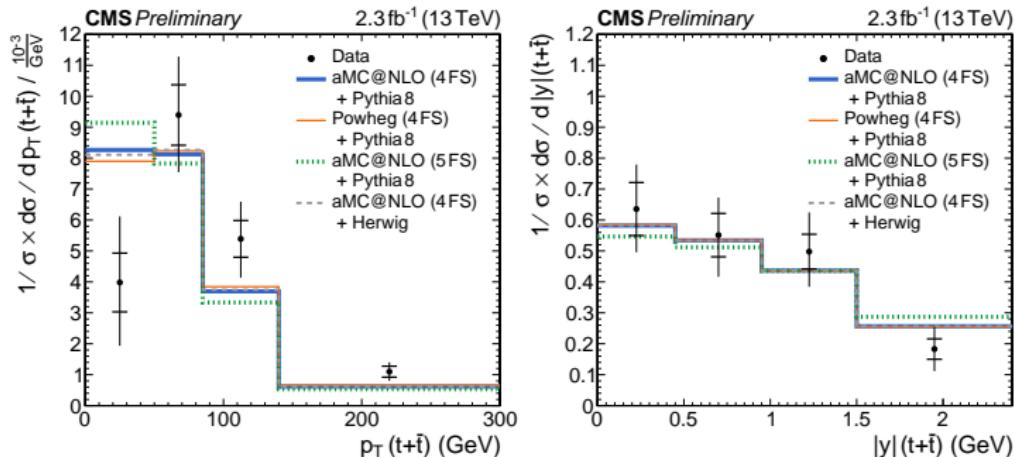
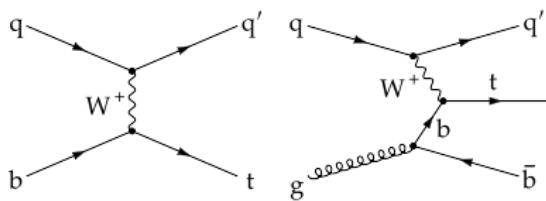
☞ 13 TeV sensitivity already surpasses the 8 TeV one

Single t production: t -channel differential cross-section

$\sqrt{s} = 13 \text{ TeV}$

[CMS PAS TOP-16-004]

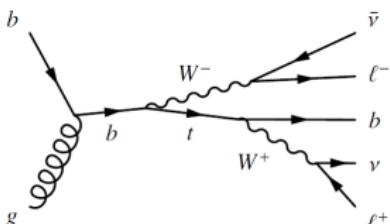
- single muon topology ($\mu, \geq 1 b\text{-jet}, \geq 1 \text{ fwd jet, MET}$)
- BDT used ($t\bar{t}$ and $W+\text{jets}$ rejection)
- Unfolding $p_T(t + \bar{t})$ and $|y|(t + \bar{t})$ to parton level



Single t production: Wt -channel inclusive cross-section

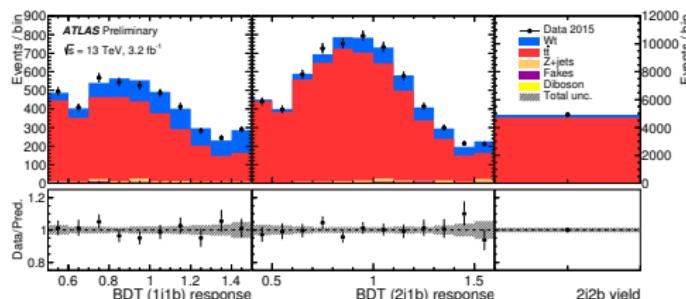
$\sqrt{s} = 13 \text{ TeV}$

[ATLAS-CONF-2016-065]



At least one jet with $p_T > 25 \text{ GeV}$	
Exactly two leptons of opposite charge with $p_T > 20 \text{ GeV}$	
At least one lepton with $p_T > 25 \text{ GeV}$, veto if third lepton with $p_T > 20 \text{ GeV}$	
At least one lepton matched to the trigger object	
Different flavour	$E_T^{\text{miss}} > 50 \text{ GeV},$ if $m_{\ell\ell} < 80 \text{ GeV}$ $E_T^{\text{miss}} > 20 \text{ GeV},$ if $m_{\ell\ell} > 80 \text{ GeV}$
Same flavour	$E_T^{\text{miss}} > 40 \text{ GeV},$ always veto, if $m_{\ell\ell} < 40 \text{ GeV}$ $4E_T^{\text{miss}} > 5m_{\ell\ell},$ if $40 \text{ GeV} < m_{\ell\ell} < 81 \text{ GeV}$ veto, if $81 \text{ GeV} < m_{\ell\ell} < 101 \text{ GeV}$ $2m_{\ell\ell} + E_T^{\text{miss}} > 300 \text{ GeV},$ if $m_{\ell\ell} > 101 \text{ GeV}$

- BDT shape used in 2 regions (1j1b and 2j1b) and single bin in 2j2b

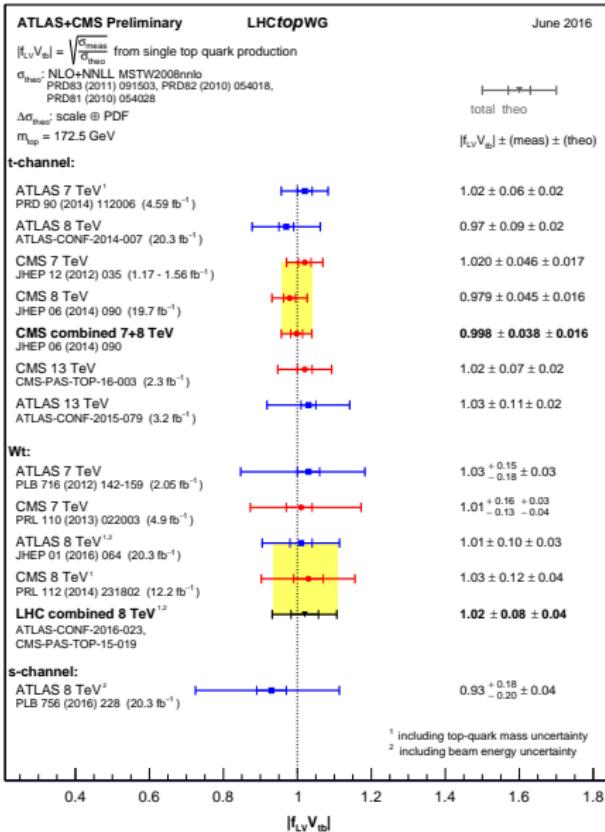
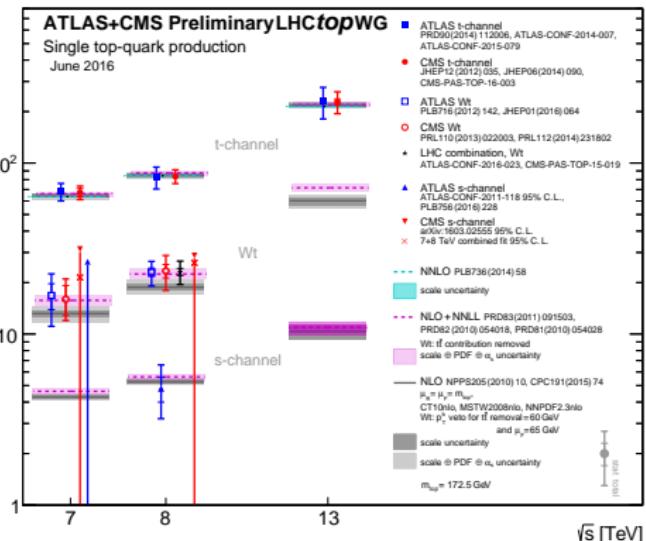


$$\sigma(Wt) = 94 \pm 10 (\text{stat})^{+28}_{-23} (\text{syst})$$

☞ main uncertainties:
MC modelling
(NLO ME, ISR/FSR, PS)

Single t production: inclusive cross-sections and V_{tb}

Inclusive cross-section [pb]

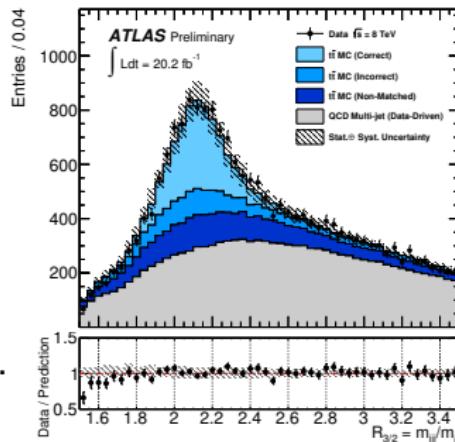
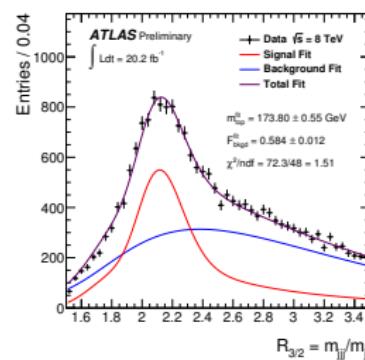
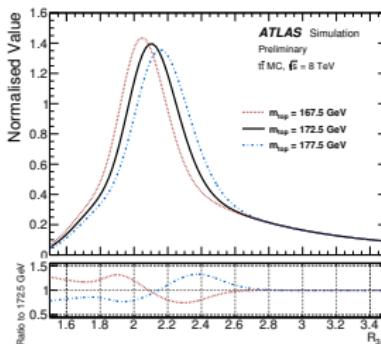


Top quark mass measurement in the fully hadronic channel

$\sqrt{s} = 8 \text{ TeV}$

[ATLAS-CONF-2016-064]

- Multijet trigger
- low MET
- $\geq 2 b$ -tagged jets
- χ^2 -method for the event reconstruction
- data-driven evaluation of the multijet bkgd.



$$m_t = 173.80 \pm 0.55 \text{ (stat)} \pm 1.01 \text{ (syst)} \text{ GeV}$$

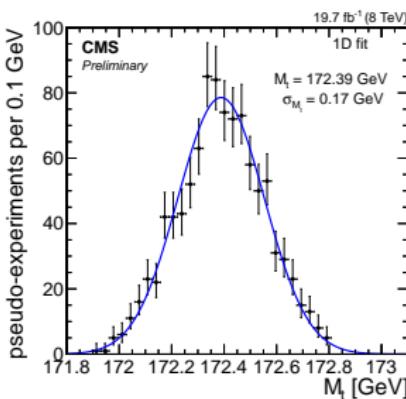
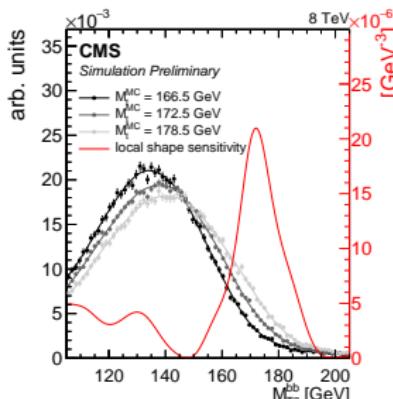
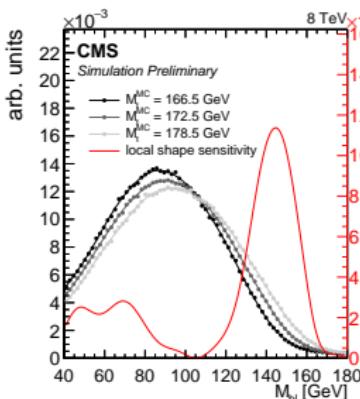
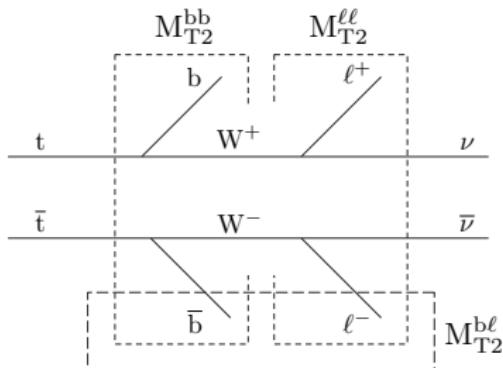
Top quark mass measurement using alternative observables

$\sqrt{s} = 8 \text{ TeV}$

[CMS PAS TOP-15-008]

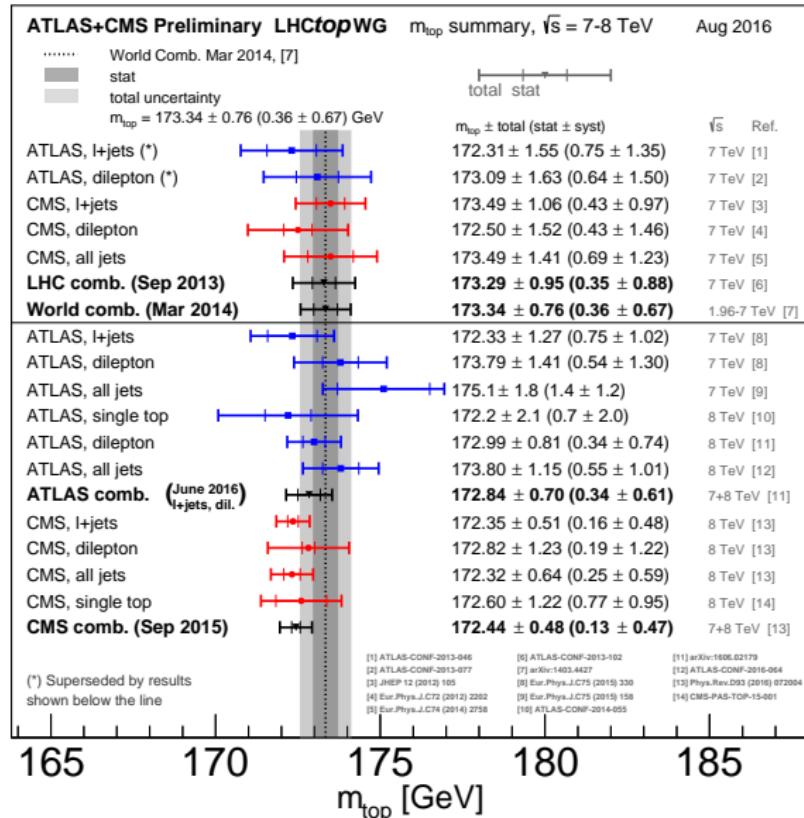
- Alternative observables in $\ell^+ \ell^-$ events:

- $M_{b\ell} = \sqrt{(p_b + p_\ell)^2}$
- $M_{T2} = \min_{\vec{p}_T^a + \vec{p}_T^b = \vec{p}_T^{\text{miss}}} [\max M_T^a, M_T^b]$



$$m_t = 172.39 \pm 0.17 \text{ (stat)} {}^{+0.91}_{-0.95} \text{ (syst) GeV}$$

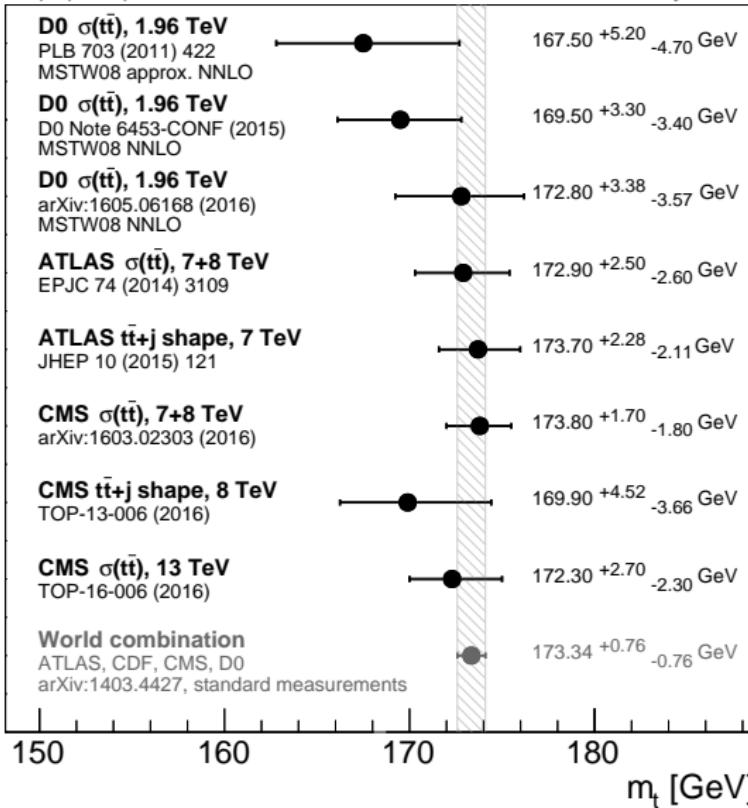
Top quark mass: summary of the direct measurements



Top mass from the $t\bar{t}$ production cross-section

Top-quark pole mass measurements

July 2016



Summary

- With the LHC data the top quark physics has entered in a precision era
- The top-quark observables constitute a powerful test of the SM (and perturbative QCD): NNLO precision is required to describe data
- Differential measurements play a very important role
- Pseudo-top definitions and fiducial particle level measurements allow to reduce the uncertainty related to the MC-based extrapolation to parton level results in the full phase-space
- Many measurements dominated by systematics, but not all:
 - rare processes
 - differential measurements
- No evidence for physics beyond the SM (yet?)

Backup Slides

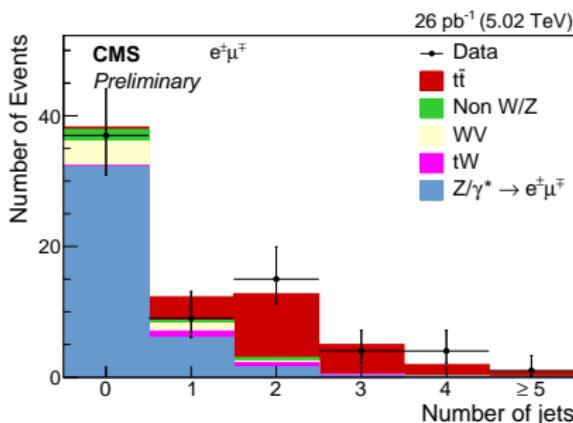
Inclusive $t\bar{t}$ production cross-section

$\sqrt{s} = 5.02 \text{ TeV}$

[CMS PAS TOP-16-015]

- Event selection:

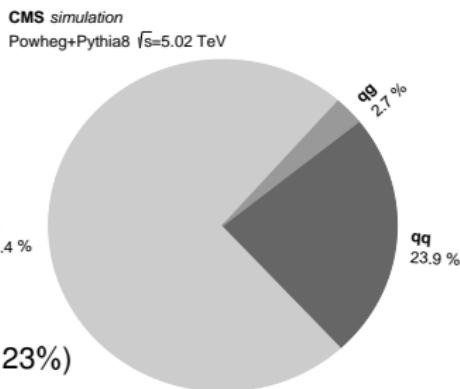
- ≥ 2 OFOS leptons ($e^\pm \mu^\mp$)
- ≥ 2 jets ($\text{anti-}k_T, R = 0.4$)



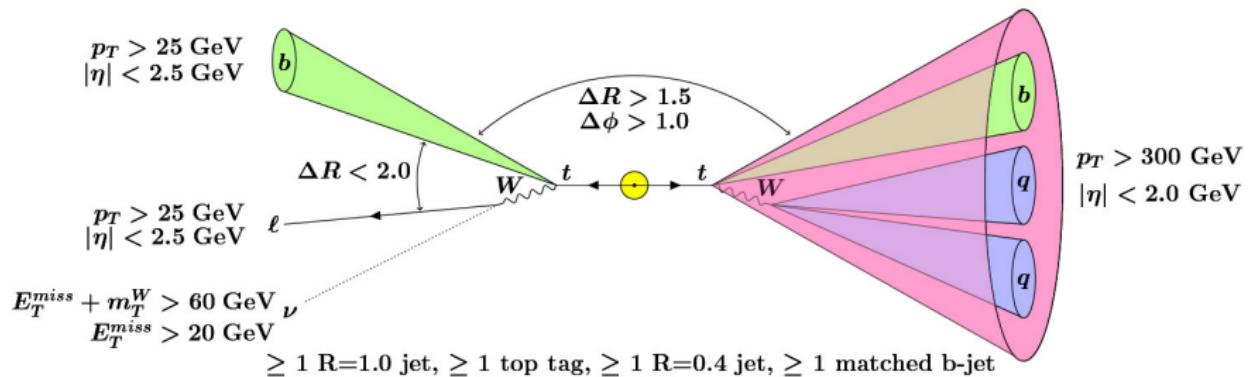
$$\sigma_{t\bar{t}} = 82 \pm 20 \text{ (stat)} \pm 5 \text{ (syst)} \pm 10 \text{ (lumi)} \text{ pb} \quad (\frac{\delta\sigma}{\sigma} = 23\%)$$

- ☞ reference for future heavy ions measurement
- ☞ uncertainty statistically dominated

Source	Number of events $e^\pm \mu^\mp$
Drell-Yan	1.6 ± 0.4
Non W/Z	1.0 ± 0.9
tW	0.89 ± 0.02
WV	0.41 ± 0.02
Total background	3.9 ± 0.8
Signal ($t\bar{t} \rightarrow e \mu$)	17.0 ± 0.2
Data	24



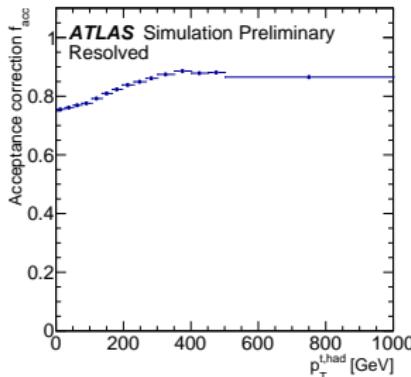
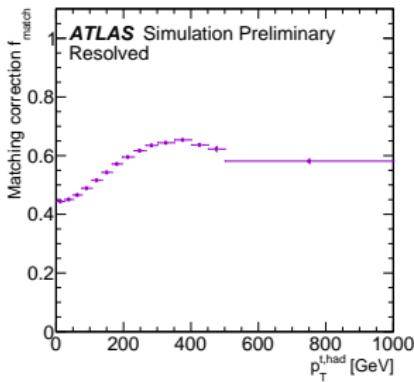
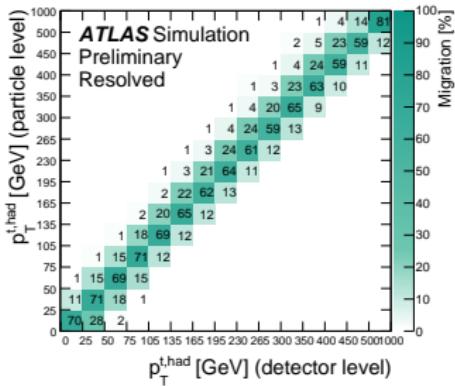
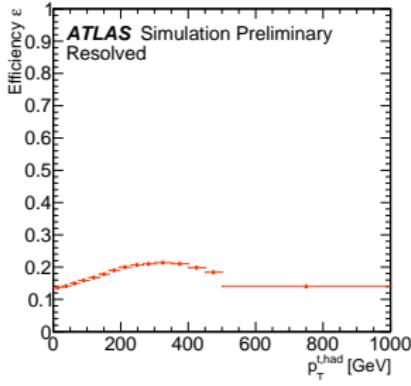
Boosted topology in $\ell + \text{jets}$ events



Differential $t\bar{t}$ production cross-section (particle level)

$\sqrt{s} = 13 \text{ TeV}$

[ATLAS-CONF-2016-040]



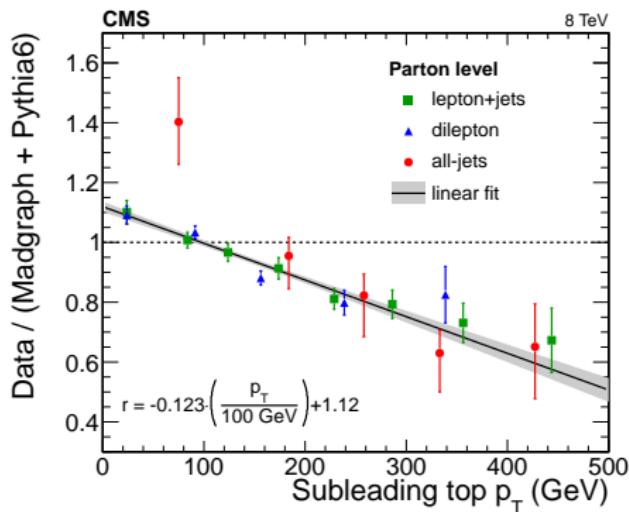
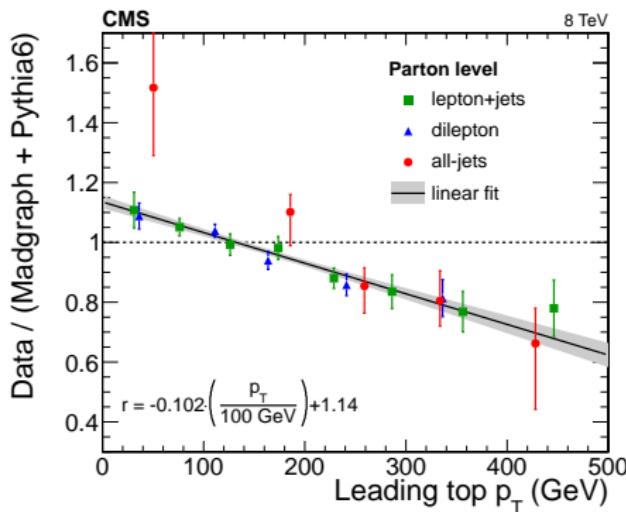
Unfolding procedure:

$$\frac{d\sigma^{\text{fid}}}{dX^i} \equiv \frac{1}{\mathcal{L} X^i} \frac{1}{\epsilon^i} \sum_j \mathcal{M}_{ij}^{-1} f_{\text{match}}^j f_{\text{acc}}^j (N_{\text{reco}}^j - N_{\text{bkg}}^j)$$

Top quark p_T mismodelling at 8 TeV

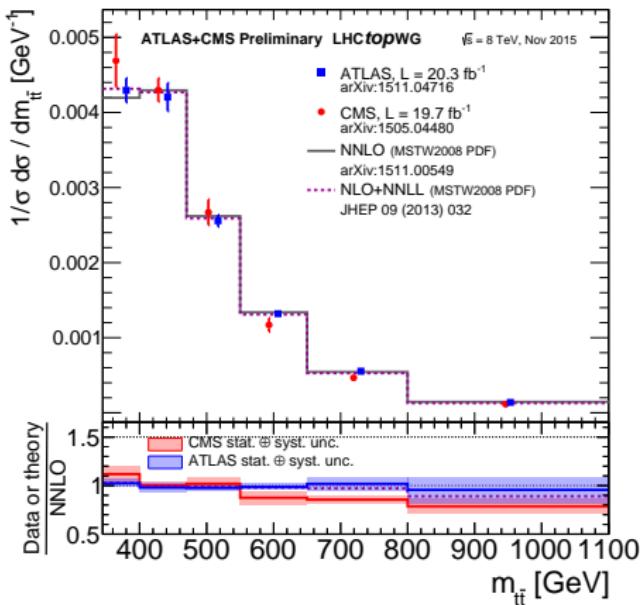
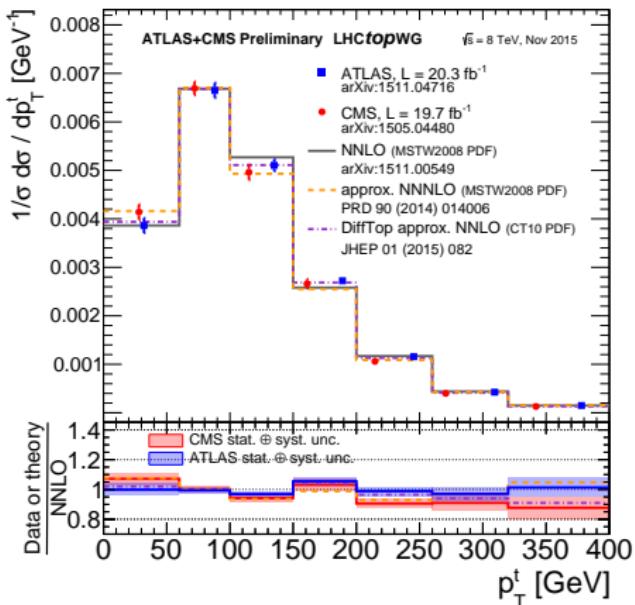
$\sqrt{s} = 8 \text{ TeV}$

[CMS PAS TOP-14-018]



Top quark p_T mismodelling at 8 TeV

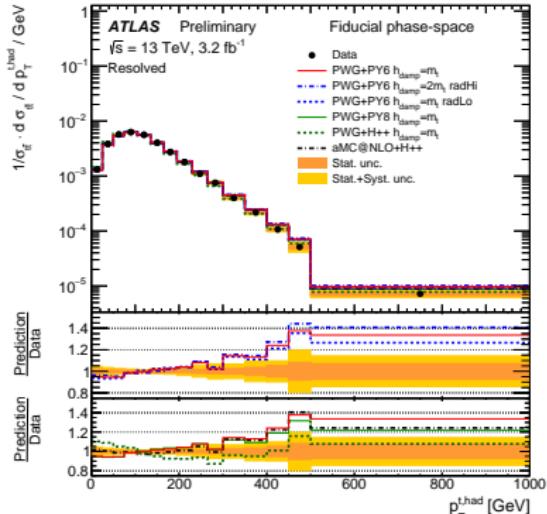
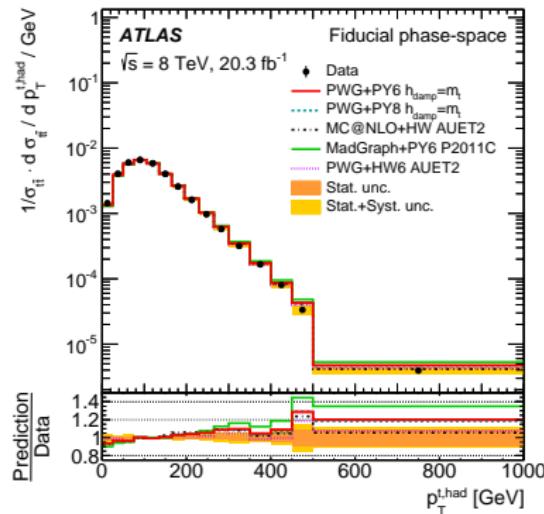
$\sqrt{s} = 8 \text{ TeV}$



Top quark p_T mismodelling at 8 and 13 TeV

$\sqrt{s} = 8/13 \text{ TeV}$

[ATLAS-CONF-2016-040]



- Similar trends in Powheg + Pythia 8 at 13 TeV compared to 8 TeV
- Powheg + Herwig++ agrees better with data at 8 TeV than at 13 TeV
- Comparable total uncertainty sizes at both energies
- NNLO corrections appear to bring $p_T(t)$ into agreement

Additional jet activity in $t\bar{t}$ events

$\sqrt{s} = 8 \text{ TeV}$

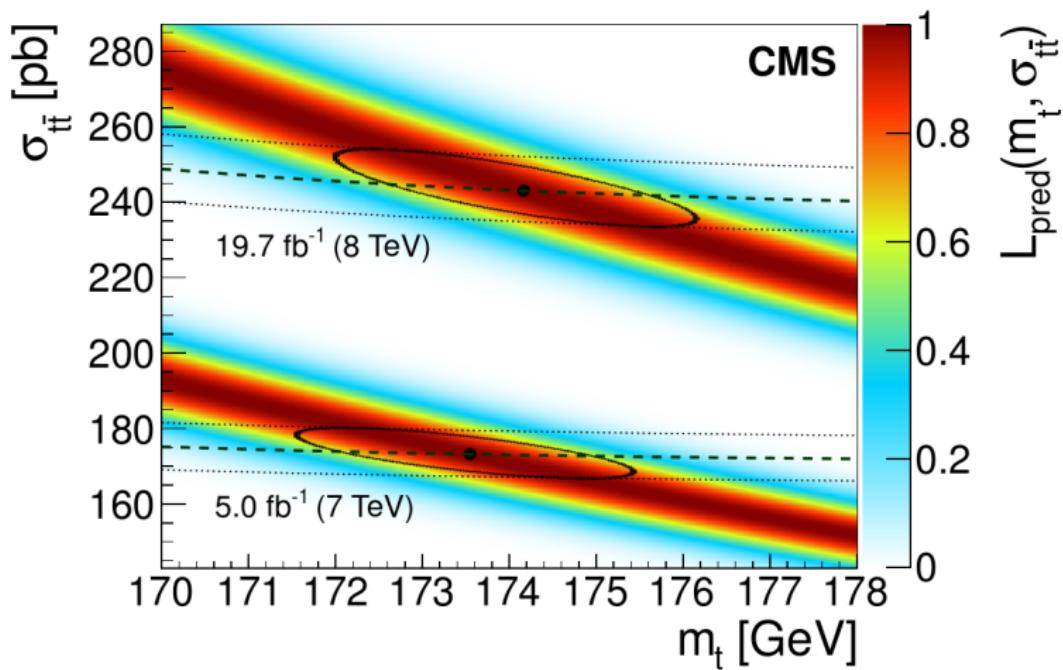
[CMS PAS TOP-15-006]

	$d\sigma/dN$ [pb]	Stat.	Exp.	Theo.	Total	Prediction [pb]
$t\bar{t} + \geq 0 \text{ jets}$	239.9	0.3%	6.2%	11.2%	13.0%	$252.9^{+2.5\%}_{-3.4\%}(\text{scale}) \pm 4.6\%(\text{PDF}+\alpha_s)$
$t\bar{t} + \geq 1 \text{ jet}$	81.4	0.5%	7.2%	11.7%	14.0%	-
$t\bar{t} + \geq 2 \text{ jets}$	20.1	0.8%	8.5%	13.6%	16.3%	$20.97^{+15.5\%}_{-13.3\%}(\text{scale})$
$t\bar{t} + \geq 3 \text{ jets}$	4.06	1.6%	10.3%	18.4%	21.3%	-
$t\bar{t} + \geq 4 \text{ jets}$	0.71	3.4%	13.1%	30.5%	33.4%	-

Top quark pole mass from $\sigma(t\bar{t})$

$\sqrt{s} = 7, 8 \text{ TeV}$

[JHEP 08 (2016) 029]



Top quark mass: alternative measurements

