Top pair inclusive and differential cross sections at LHC

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Outline

Inclusive $t\bar{t}$ cross section measurements

- CMS: $t\bar{t}$ cross section using $t\bar{t} \to e + \mu+$jets dilepton channel at 8 TeV
- ATLAS: $t\bar{t}$ cross section using $t\bar{t} \to e + \mu+$jets dilepton channel at 7 TeV and 8 TeV
- LHC combination: $t\bar{t} \to e + \mu+$jets dilepton channel at 8 TeV
- CMS: $t\bar{t}$ cross section measured in $e\tau/\mu\tau$ channel at 8 TeV

Differential $t\bar{t}$ cross section measurements

- ATLAS: differential $t\bar{t}$ cross-section at $\sqrt{s}=$ 7 TeV as a function of pseudo-top-quark observables
- CMS: Measurement of the differential ttbar cross section in the lepton+jets and dilepton channels at 8 TeV
- ATLAS: boosted differential $t\bar{t}$ cross section measurements at 8 TeV

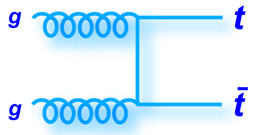
Summary and outlook

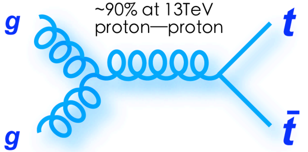
- What do we learn from the measurements?

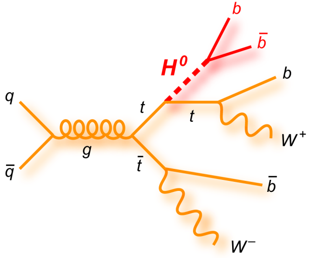
Motivation

- Top quarks are mostly produced through $t\bar{t}$.
- Precise tests of perturbative QCD: theoretical prediction of inclusive $\sigma_{t\bar{t}} = \boxed{177^{+10}_{-11}\ \text{pb}}$ @7 TeV, $\boxed{253^{+13}_{-15}\ \text{pb}}$ @8 TeV with $m_t = 172.5$ GeV (full NNLO+NNLL soft gluon terms with top++2.0)

- Precise $\sigma_{t\bar{t}}$ measurements are directly sensitive to PDF (especially large-x gluon PDF) and useful to constrain / tune Monte Carlo (MC) modeling.
- Precise understanding of top-quark related backgrounds to new physics search, e.g. associated production of dark matter and $t\bar{t}$.
- Search for new physics associated with top quark (talk given by Davide Gerbaudo).







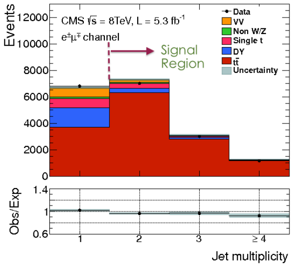
Inclusive $t\bar{t}$ cross sections in LHC

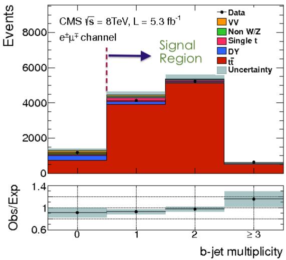
- Method of cut-and-count applied to data corresponding to 5.3fb^{-1}, @8 TeV.
- Backgrounds: single top and diboson (estimated with MC), Z+jets and fake leptons (data driven).
- Purity of signal about ~90%.

Event selection:

1. Dilepton trigger thresholds of p_T >17 GeV and >8 GeV
2. Opposite charge $e^{\pm}\mu^{\mp}$
3. $\geq$2 jets & $\geq$1 b-tagged jets.

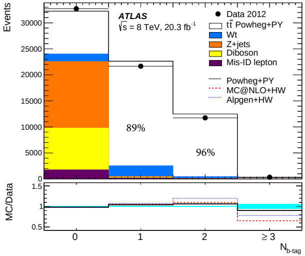
- Dominant systematic uncertainties: $t\bar{t}$ modeling (3%), Jet Energy Scale (2%), lepton efficiencies (2%)

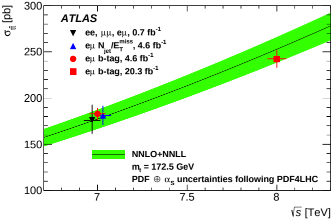




Result: $\sigma_{t\bar{t}} = 239.0 \pm 2.6(\text{stat.}) \pm 11.4(\text{syst.}) \pm 6.2(\text{lumi.})$ pb @8 TeV consistent with theoretical prediction

- Selection of $t\bar{t}$ in $e\mu$ final state: single lepton e or μ trigger, opposite charge $e^{\pm}\mu^{\mp}$, exactly 1 or 2 b-tagged jets.
- Simultaneously fit $\sigma_{t\bar{t}}$ and ϵ_b to reduce jet related systematic. (ϵ_b: combined probability of jet acceptance, reconstruction and b-tag.)
- Besides simultaneous fit, measuring the lepton isolation in data helps reduce $t\bar{t}$ modeling systematic.





- Method: $t\bar{t}$ cross section is extracted with

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

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

- Systematic: luminosity(2-3%), beam energy(~1.8%), tt modelling(~1.4%), PDF(~1.1%).

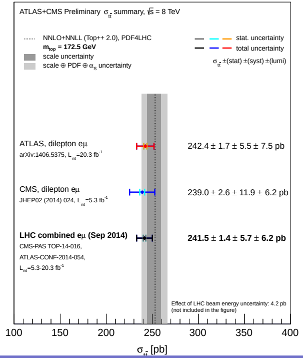
$$\sigma_{t\bar{t}}=\mathbf{182.9}\pm\mathbf{3.1}(\text{stat.})\pm\mathbf{4.2}(\text{syst.})\pm\mathbf{3.6}(\text{lumi.})\pm 3.3(\text{beam})\ \text{pb} \quad @7\ \text{TeV}$$

$$\sigma_{t\bar{t}}=\mathbf{242.4}\pm\mathbf{1.7}(\text{stat.})\pm\mathbf{5.5}(\text{syst.})\pm\mathbf{7.5}(\text{lumi.})\pm 4.2(\text{beam})\ \text{pb} \quad @8\ \text{TeV}$$

- Total uncertainty (4%) of the measurement < theoretical uncertainty (6%).

- The combination is performed in TopLHC working group using the Best Linear Unbiased Estimator (BLUE) method.
- Results stable against variations of the correlations between the systematic uncertainties w.r.t the input assumptions. (beam modeling correlation tested at 0. 0.3 0.6 1.0 gives result difference up to 0.3 pb.)
- Lower uncertainties in ATLAS measurement thanks to: Trigger (single lepton), Jet Related (simultaneous fit), $t\bar{t}$ modeling (simultaneous fit & lepton isolation measured in $t\bar{t}$ data).
- Combination improves uncertainty (3.5%) given in the ATLAS measurement (3.9%).

	ATLAS	CMS	correlation	Combination
Cross section [pb]	242.4	239.0		241.5
Uncertainty [pb]				
Statistical	1.7	2.6	0	1.4
Trigger	0.4	3.6	0	1.0
Lepton scale and resolution	1.2	0.2	0	0.9
Lepton identification	1.7	4.0	0	1.6
Jet resolution	1.2	3.0	0	1.2
b-tagging	1.0	1.7	0	0.8
UncorrJES	0.6	4.3	0	1.2
FlavourJES	0.9	2.9	1	1.4
Signal model: Scale	0.7	5.6	0.5	1.9
Signal model: Radiation		3.8		1.0
Signal model: Generator/PS	3.0	3.3	0.5	2.7
Signal model: PDF	2.7	0.5	1	2.1
Bkg: Lepton mis-ID	0.8	1.9	0	0.8
Bkg: Single top quark	2.0	2.3	1	2.1
Beam modelling	2.9	5.0	1	3.5
Luminosity determination	6.9	3.6	0	5.1
Total systematic	9.3	13.4		8.4
Total	9.4	13.6		8.5

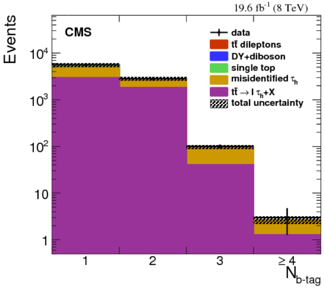


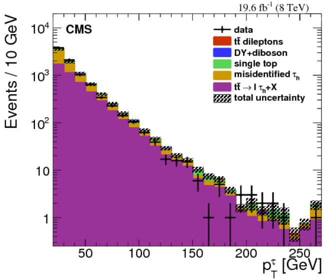
CMS: Inclusive $t\bar{t}$ cross section in $e\tau/\mu\tau$ [PLB 739 (2014) 23]

- Measurement in $t\bar{t} \to (\ell\nu)(\tau\nu)b\bar{b}$ with hadronic decay of τ (τ_h) using 19.6fb^{-1} data @8 TeV.
- Sensitive to light charged Higgs ($m_{H^+} < m_{top}$) where $t\bar{t} \to H^+ bW^- \bar{b}$ with $H^+ \to \tau^+\nu$.
- Large background contamination ($\sim$45%); Dominant: mis-identified τ_h from $t\bar{t} \to \ell$+jets and W+jets.

- The probability $w(\text{jet} \to \tau_h)$ measured as a function of jet p_{T}, η and width (R_{jet}) in simulated events and data (in good agreement).
- Leading systematic uncertainties: τ_h identification (6.0%); τ_h mis-identified background (4.3%); modeling: factorization/renormalization scale (2.9%); luminosity (2.6%); τ_h energy scale (2.5%).

- Result (@8 TeV):
  $\sigma_{t\bar{t}} = 257 \pm 3(\text{stat.}) \pm 24(\text{syst.}) \pm 7(\text{lumi.})$ pb.
  (ATLAS measurement in the same decay mode @7 TeV 2.05fb^{-1}: $\sim$13% total uncertainty.)





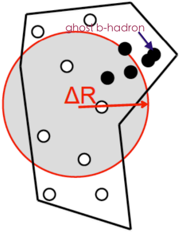
Differential $t\bar{t}$ cross sections in LHC

- Pseudo-top-quarks are defined with particle level objects in MC.

Particle objects (based on stable particles, $\tau_0 > 0.3 \times 10^{-10} s$):

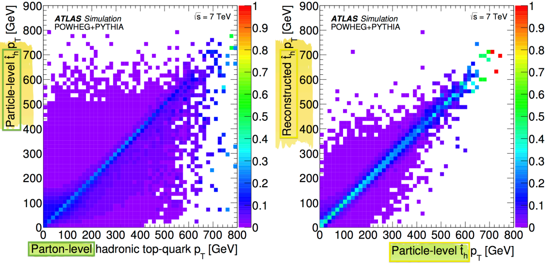
- Leptons: e/μ dressed with photons around R=0.1; E_T^{miss}: sum of all neutrinos;
- Jets: built from all stable particles but μ, e and γ not from hadrons; b-jet: ghost-matching[1].

[1] A b-hadron can be included in the jet finding as a particle with an infinitely small momentum (a 'ghost'). The presence of this b-hadron in the jet defines the jet flavour.



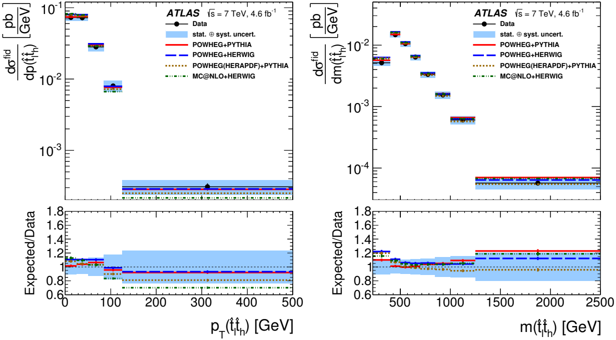
WHY particle level objects:

- Unambiguously compared to MC generator predictions (less MC dependent).
- Minimize the correction from reconstruction (detector) level objects.



pseudo-top-quark ($\hat{t}$):

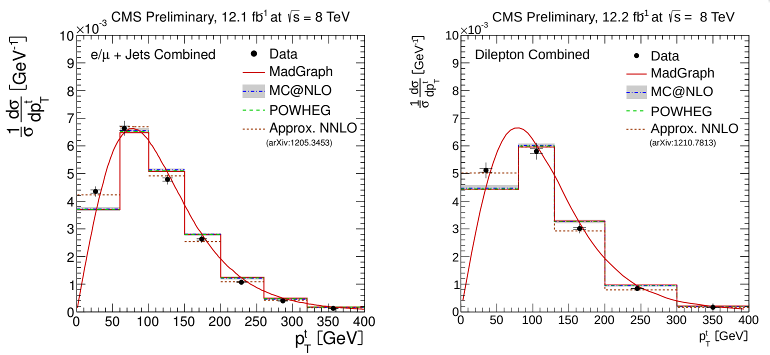
- Defined with particle level objects for leptonic $\hat{t}_\ell$ and hadronic $\hat{t}_h$ in $t\bar{t}$ ℓ+jets channel.
- Closely related to the top-quark parton provided by pQCD.

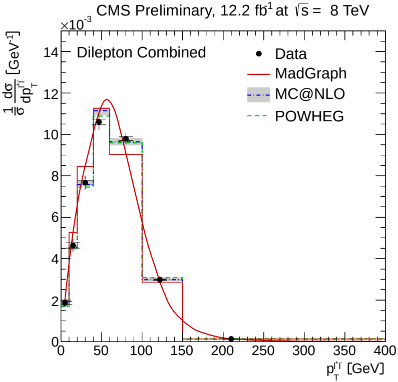


- Differential σ measured as a function of kinematics of $\hat{t}_h$, $\hat{t}_\ell$ and system($\hat{t}_h, \hat{t}_\ell$) using 7 TeV, 4.6 fb^{-1} data.
- MC@NLO provides softer distributions, the generator configuration disfavored.
- POWHEG(HERAPDF)+PYTHIA provides the best representation, except for low m($\hat{t}_h, \hat{t}_\ell$), all MC predicts higher.

Similar measurement in ℓ+jets and dilepton channels

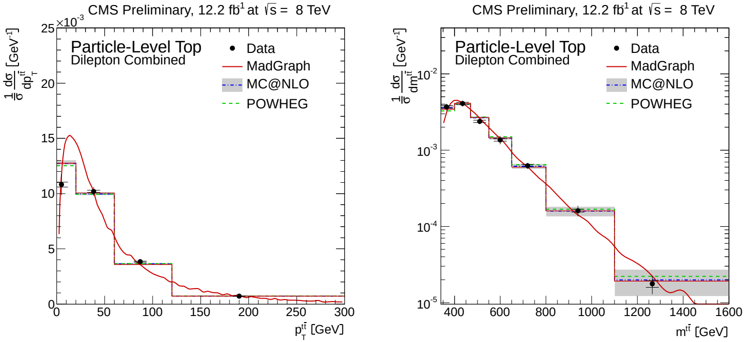
- The differential cross section determined as a function of the kinematic properties of the leptons, the *b*-jets at particle level and the top quarks, top quark pair at parton level.
  - Particle leptons: final state particle, required to be from W decay
  - Particle jets: obtained after clustering all but the prompt particles with anti-kt R = 0.5
  - Particle *b*-jets: checking particles clustered in the jet and at least one decay product of a *B*-hadron found
- At parton level, the unfolded distributions are extended to the full phase space in order to allow for direct comparisons with theory.
- Good agreement found for approx. NNLO compared to data.



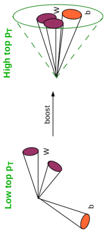


- Better agreement of POWHEG+PYTHIA and MC@NLO + HERWIG found in $p_T^{\ell^+\ell^-}$ for taking into account the $t\bar{t}$ spin correlation.

- Pseudo-top: defined by decay products of the top-quark at particle level
- Extension of differential cross section analysis in dileptonic channel
- MC predicts more events in low $p_{\mathrm{T}}^{t\bar{t}}$ region (similar to ATLAS result).



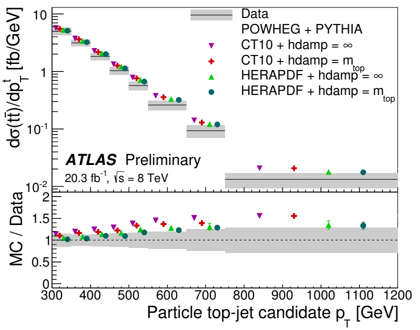
ATLAS: boosted differential $\sigma_{t\bar{t}}$ [ATLAS-CONF-2014-057]



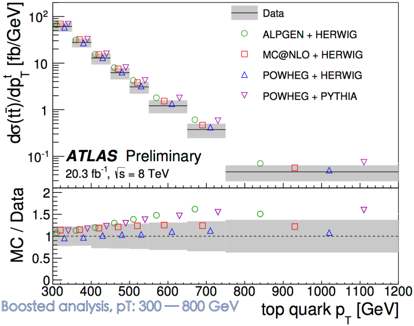
differential measurement for boosted top:

- High top-quark p_T spectrum is sensitive to several BSM mechanisms of $t\bar{t}$ production. Test SM at TeV scale using $t\bar{t}$ events.
- First differential σ measurement using boosted reconstruction techniques (hadronic top quark decay reconstructed as a single large-R jet, identified with sub-structure) in ℓ+jets channel.
  - $t\bar{t}$ selection efficiency increases at high top quark p_T and
  - Kinematic reach into the TeV range

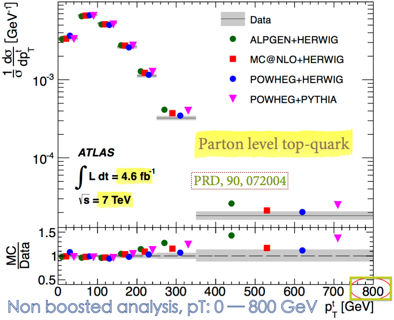
- Unfold to fiducial phase-space (at particle level) and at full phase-space (at parton level).
- Results at particle level have lower uncertainty. Using HERAPDF instead of CT10 improves data/MC agreement by up to 20%.
- Tuning POWHEG $h_{damp} = m_{top}$ over $h_{damp} = \infty$ improves data/MC agreement by up to 10%.



ATLAS: boosted differential $\sigma_{t\bar{t}}$ [ATLAS-CONF-2014-057 ➦]



Boosted analysis, pT: 300 — 800 GeV



Non boosted analysis, pT: 0 — 800 GeV

- Simulation predicts harder spectrum than data observation in all MC samples.
- Results of parton level top-p_T are consistent with the measurement using 7 TeV data.

Summary and outlook

Top pair production become unique and powerful handle to test/constrain SM at LHC

- Experimental uncertainties close to / lower than latest theoretical predictions.
- Measurements show slight preference on HeraPDF. CT10 is working fairly OK.
- All MC generators predict more events at high p_{T} of top-quark than observed in data.

Large efforts have been made to get optimized results

- The LHC combination including ATLAS and CMS reduces the overall uncertainty.
- Special technique employed to boosted objects to increase the sensitivity in high p_{T} top phase space.

Prospects for more results in Run I and Run II

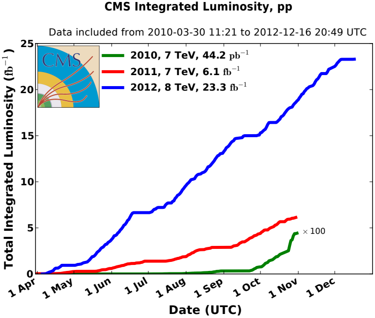
- Run I: still interesting final results to come, stay tuned.
- Run II: coming very soon, in 2015 at **13 TeV**.

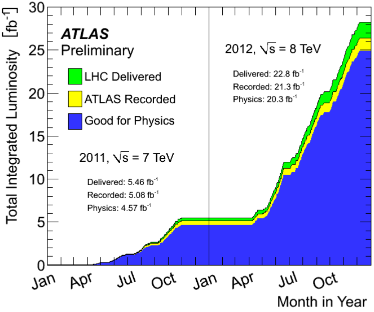
What kind of **'top'** are we going to reach if we keep ascending ?

Thank you!

ATLAS and CMS data taking during 2010 - 2012

- ATLAS and CMS had successful data taking during 2010 - 2012.
- LHC is a top-factory. Plenty of interesting physics results published.
- Results shown in the following slides based on data taken in 2011 (@7 TeV) and 2012 (@8 TeV) proton–proton collisions.





ATLAS pseudo-top-quark measurement