

Top quark physics results from LHC

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1 Introduction

2 Cross section measurements

- $t\bar{t}$ dileptonic and semileptonic channels
- Single-top t-channel
- Measurement of Vector Boson Production associated with $t\bar{t}$ pairs at 7 TeV
- Measurement of the cross section ratio $\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}jj}$

3 Top quark Properties

- W polarization
- Top quark Mass
- Top anti-top mass difference

4 Conclusions

The Top physics is one of the main pillars of the physics program at the LHC.

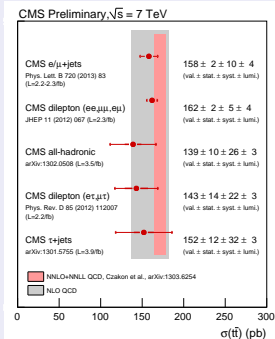
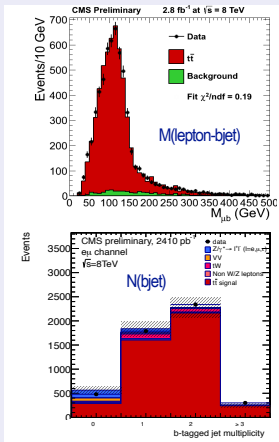
- The top quark is the **heaviest particle** of the SM (173.20 ± 0.51 (stat) ± 0.71 (syst) GeV, CDF Conf. note 10976, D0 Conf note 6381) \rightarrow **Yukawa coupling to the Higgs field close to 1** \rightarrow **Most interesting object to test the SM.**
- Top mass: fundamental parameter of SM and BSM Physics!
- Decay time of $O(10^{-24}$ s) shorter than the hadronization time scale \rightarrow **a unique possibility to study a “bare” quark free from hadronization effects.**
- The measurement of the ratio $\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}jj}$ is an important ingredient to understand if the Higgs particle is compatible with the SM or not.
- The measurement of the **W helicity fraction** as well as the measurement of the top anti-top mass difference can also suggest the presence of new physics.

- Cross section measurements

- ▶ Dileptonic and Semileptonic channel. CMS-TOP-PAS-12-007, CMS-TOP-PAS-006, CMS-PAS-TOP-12-011, ATLAS-CONF-2012-149

$t\bar{t}$ production cross section in the dilepton/semileptonic channel ($\sqrt{s} = 8$ TeV CMS)

- $e^- \mu^- + \text{jets}$ channel
 - ▶ Template fit to M_{lb}
 - ▶ QCD background shape from data
 - ▶ Systematics: b-tagging, jet energy scale.
- Dileptonic channel
 - ▶ Cut based analysis
 - ▶ High purity, High statistics
 - ▶ Systematics: lepton ID, jet energy scale.



$t\bar{t}$ production cross section in the semileptonic channel ($\sqrt{s} = 7$ TeV ATLAS)

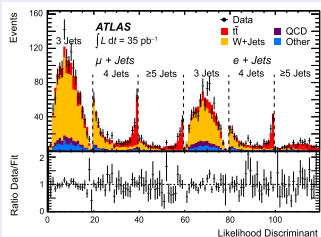
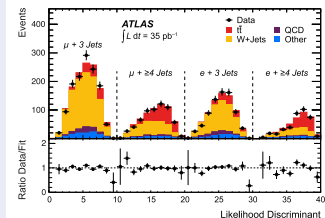
- $e^- \mu^- + \text{jets}$ channel
- two separate analyses:
 - ▶ **tagged analysis**
 - ▶ **untagged analysis**
- Multivariate analysis to separate signal from bkg.
- Fit to the likelihood output discriminant to extract signal.
- Systematics: JES, bkg modeling ISR/FSR.

- Untagged:

$$\sigma_{t\bar{t}} = 173 \pm 17(\text{stat})_{-16}^{+18}(\text{syst}) \pm 6(\text{lumi})\text{pb}$$

- Tagged:

$$\sigma_{t\bar{t}} = 187 \pm 17(\text{stat})_{-17}^{+18}(\text{syst}) \pm 6(\text{lumi})\text{pb}$$

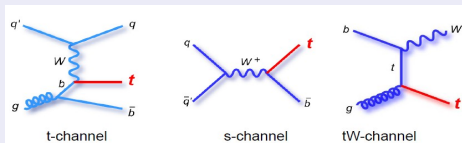


- Cross section measurement

- ▶ Dileptonic and Semileptonic channel. CMS-TOP-PAS-12-007, CMS-TOP-PAS-006, ATLAS-CONF-2012-149
- ▶ Single-top t-channel. CMS-TOP-PAS-12-011, ATLAS-CONF-2012-132

Measurement of single-top t-channel cross section (CMS)

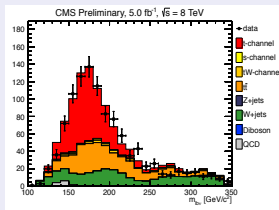
single-top production mechanisms



- The t-channel single-top process is expected to be the dominant one with a $\sigma_t^{th} = 87.2_{-0.7}^{+2.1}(\text{scale})_{-1.7}^{+1.5}(\text{PDF})\text{pb}$ at 8 TeV (for a $m_t = 173 \text{ GeV}/c^2$).
- Probe for new physics (FCNC).

CMS analysis at 8 TeV

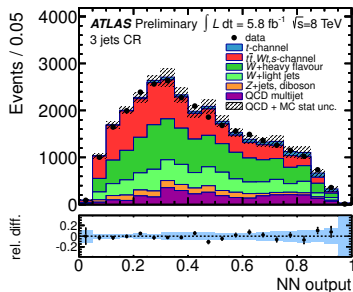
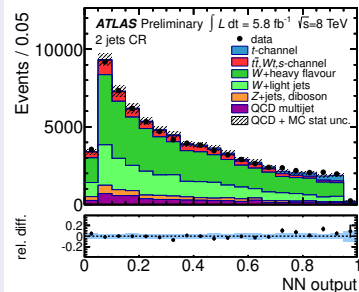
- Leptonic channel.
- Signal extraction: maximum likelihood fit to the $|\eta_j|$ **distribution**.
- Main bkg: from data in CRs.



- $M_{lb\nu}$ distribution applying $|\eta_j| > 2.0$
 $\sigma_t^{t-ch} = 80.1 \pm 5.7(\text{stat}) \pm 11.0(\text{syst}) \pm 4.0(\text{lumi})\text{pb}$.

Measurement of single-top t-channel cross section (ATLAS)

- Leptonic channel.
- **Multivariate analysis**
- Signal extraction: **maximum likelihood fit to the NNoutput distribution.**
- Two separate analyses: 2 or 3 jets.
- Signal region: 1 b-tagged jet
- Control region: no b-tagged jets
- Systematics: JES, b-tagging, ISR/FSR.



$$\sigma_{t\bar{t}} = 95 \pm 2(\text{stat.}) \pm 18(\text{syst.}) \text{ pb}$$

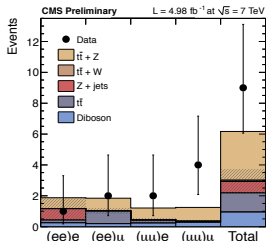
- Cross section measurements

- ▶ Dileptonic and Semileptonic channel. CMS-TOP-PAS-12-007, CMS-TOP-PAS-006, ATLAS-CONF-2012-149
- ▶ Single-top t-channel. CMS-TOP-PAS-12-011, ATLAS-CONF-2012-132
- ▶ Measurement of Vector Boson Production associated with $t\bar{t}$ pairs at 7 TeV. CERN preprint: CERN-PH-EP-2013-033

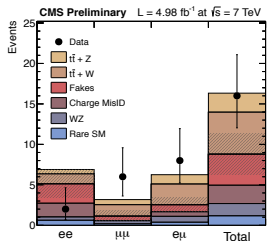
Measurement of Vector Boson Production associated with $t\bar{t}$ pairs

- Key ingredient to test the SM validity. First measurements of the direct ttZ coupling.

- Trilepton: $t\bar{t} + Z$ events



- Same-sign dilepton: $t\bar{t} + V$ events

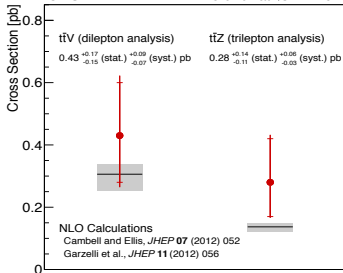


- Trilepton: $\sigma_{ttZ} = 0.30^{+0.14}_{-0.11}(\text{stat})^{+0.04}_{-0.02}(\text{syst})$

- Same-Sign dilepton :

$$\sigma_{ttV} = 0.45^{+0.17}_{-0.15}(\text{stat})^{+0.06}_{-0.05}(\text{syst})$$

CMS $L = 5.0 \text{ fb}^{-1}$ at $\sqrt{s} = 7 \text{ TeV}$



- Cross section measurements

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- ▶ Single-top t-channel. CMS-TOP-PAS-12-011, ATLAS-CONF-2012-132
- ▶ Measurement of Vector Boson Production associated with $t\bar{t}$ pairs at 7 TeV. CERN preprint: CERN-PH-EP-2013-033
- ▶ Measurement of the cross section ratio $\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}jj}$. CMS-TOP-PAS-12-024

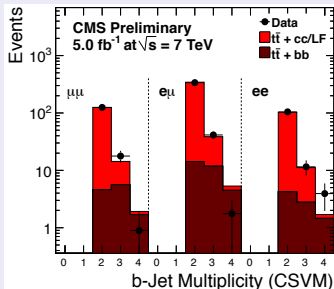
Measurement of the cross section ratio $R = \sigma_{t\bar{t}b\bar{b}} / \sigma_{t\bar{t}jj}$

Motivations

- $t\bar{t}H$ is one of the most promising channels for the direct measurement of the top quark Yukawa coupling with the H boson.
- If the new observed particle is the SM Higgs boson \rightarrow it decays mainly into $b\bar{b}$ in the final state.
- Because of the irreducible non-resonant background from the production of $t\bar{t}$ pair in association with $b\bar{b}$, the $t\bar{t}b\bar{b}$ final state has not yet been observed.
- For the first time we measured the cross section ratio $\sigma_{t\bar{t}b\bar{b}} / \sigma_{t\bar{t}jj}$.

Analysis

- $t\bar{t}$ decaying dileptonically.
- Fit to b-tagging jet-multiplicity to extract signal from bkg.
- Systematics: fake b-fraction
- $\sigma_{t\bar{t}b\bar{b}} / \sigma_{t\bar{t}jj} = 3.6 \pm 1.1(\text{stat}) \pm 0.9(\text{syst})\%$.
- MC predictions: 1.2% MADGRAPH, 1.3% POWHEG

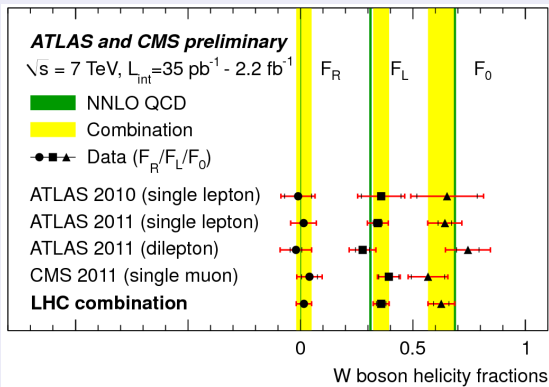


- Top quark Properties
 - ▶ **W polarization**

W Polarization

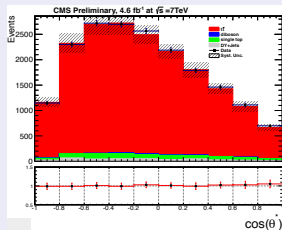
- θ^* distribution (angle between the $p(\text{lepton})$ in W rest frame and $p(W)$.)
- Test V-A structure of tWb -vertex, possible BSM contribution modify elicity fractions: F_0 , F_L , F_R .

Combined results ATLAS+CMS using 2010 and 2011 data

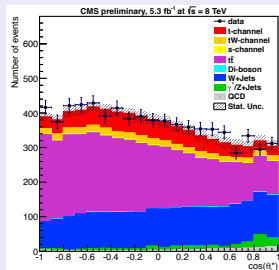


W polarization with 2012 data at 8 TeV (CMS)

Dilepton channel



Single-top t-ch



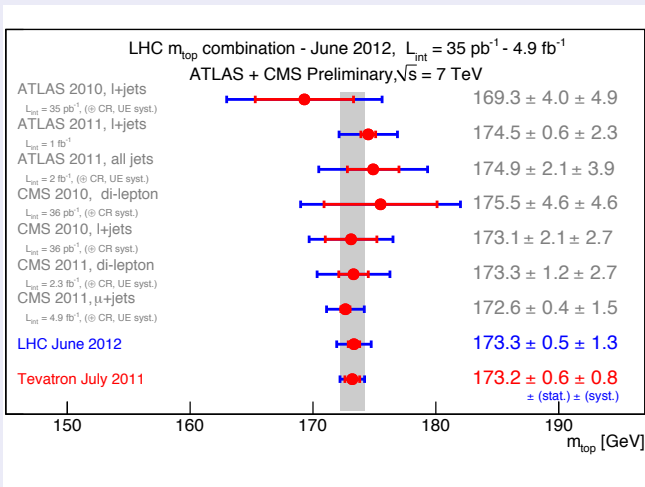
$$F_L = 0.288 \pm 0.035(\text{stat}) \pm 0.040(\text{syst})$$
$$F_0 = 0.698 \pm 0.057(\text{stat}) \pm 0.063(\text{syst})$$
$$F_R = 0.014 \pm 0.027(\text{stat}) \pm 0.042(\text{syst})$$

$$F_L = 0.293 \pm 0.069(\text{stat.}) \pm 0.030(\text{syst.}),$$
$$F_0 = 0.713 \pm 0.114(\text{stat.}) \pm 0.023(\text{syst.}),$$
$$F_R = -0.006 \pm 0.057(\text{stat.}) \pm 0.027(\text{syst.}).$$

- Top quark Properties
 - ▶ W polarization
 - ▶ Top quark mass: [JHEP 12\(2012\) 105 \[arXiv:1209.2319\]](#), [ATLAS-CONF-2013-046](#)

Top quark mass LHC Combination

CMS PAS TOP-12-001, ATLAS-CONF-2012-095



Direct Mass: Lepton+ jets. (CMS)

Signature

- 1 e^\pm or 1 μ^\pm
- 4 jets, 2-btags

Analysis (“2D-ideogram”)

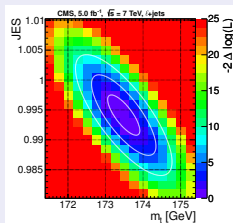
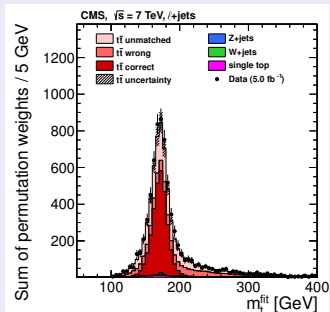
- Reconstruct top mass from kinematic fit (P_{gof})
- **2D max. likelihood fit of the mass and JES** using W mass constraint.
- weight each fit solution by P_{gof} to reduce impact of events without correct permutations.

Systematics

- main one: b-jet energy scale (0.61).

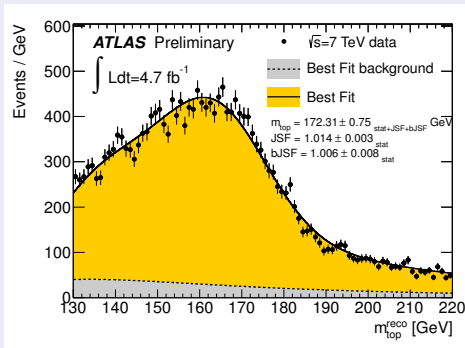
Result

- $m_{top} = 173.5 \pm 0.4_{stat+JES} \pm 1.0_{syst} \text{ GeV}$



Direct Mass: ATLAS

- 3D template analysis in lepton+jets channel. 2011 data at 7TeV have been used.
 - ▶ it allows to reduce drastically the JES and bJES uncertainty
- Top mass extracted using an unbinned likelihood fit to data
- insitu determination of the JSF and bJSF
- $m_{top} = 172.31 \pm 0.75(stat + JSF + bJSF) \pm 1.35(syst) GeV$



- Top quark Properties
 - ▶ W polarization
 - ▶ Top quark mass
 - ▶ Top anti-top mass difference

Measurement of the top anti-top mass difference in pp collisions at 8 TeV (CMS)

Motivation

- **CPT invariance implies equality of particle and anti-particle masses.**
- Several extensions of the SM include CPT violation effects.
- The top quark is unique for this kind of CPT test in the quark sector for two main reasons:
 - ▶ it decays before hadronization.
 - ▶ large dataset due to the large top quark cross section production at LHC

analysis

- $t\bar{t}$ semileptonic channel.
- Idiogram method used to reconstruct the m_t .

Final Results

+ jets	$m_t = -230 \pm 264$ (stat.) MeV,	The results for Δm_t are compatible with the expectation from the hypothesis of CPT symmetry.
e^- + jets	$m_t = -325 \pm 294$ (stat.) MeV,	
combined	$m_t = -272 \pm 196$ (stat.) ± 122 (syst.) MeV.	

This is more precise by at least a factor two than any of the previous public results.

- Top quark physics: Key to QCD, electro-weak and New Physics
- A wealth of measurements available from ATLAS and CMS (7 and 8 TeV).
- **For the first time the ratio $R = \sigma_{t\bar{t}b\bar{b}} / \sigma_{t\bar{t}jj}$ and the cross section of the top pairs produced in association with Vector bosons have been measured.**
- Top mass measured by both collaboration: Tevatron precision already reached. Altogether **LHC has a number of measurements that explore top quark mass systematics in a sophisticated way, aiming to go beyond the present systematic limitation.**
- Many measurements have not been presented: CP violation, FCNC, differential cross, spin correlation, charge...
- Still no hints of new physics → we are preparing the new data taking at 14 TeV.