Top quark physics results from LHC

Cristina Ferro

NCU Taiwan

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Outline

Introduction

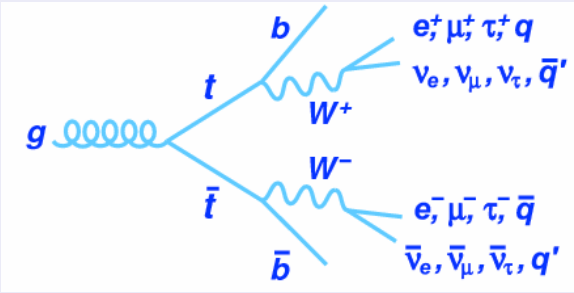
The Top physics is one of the main pillars of the physics program at the LHC.

- The top quark is the **heaviest particle** of the SM (173.20 $\pm$ 0.51 (stat) $\pm$ 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.

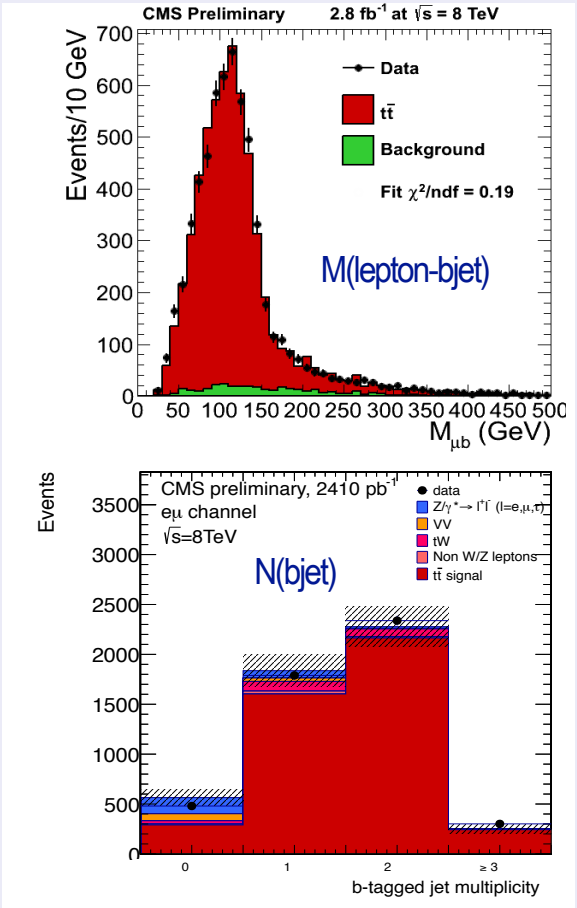
Cross section measurements

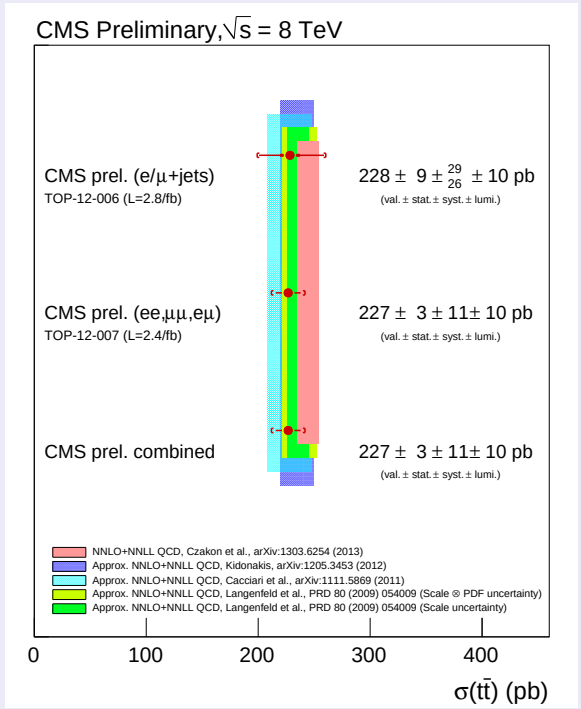
- Cross section measurements
  - Dileptonic and Semileptonic channel. CMS-PAS-TOP-12-007, CMS-PAS-TOP-12-006, CMS-PAS-TOP-12-011, ATLAS-CONF-2012-149

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



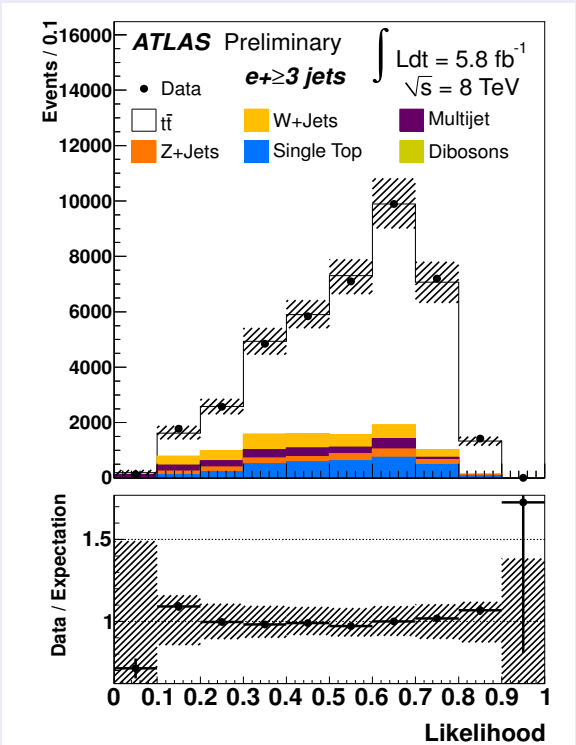
- $e^-\mu^-$+jets channel
  - Template fit to M_{lb}
  - QCD background shape from data
  - Systematics: b-tagging, jet energy scale.
- Dileptonic channel
  - Cut based analysis
  - High purity, High statistics
  - Systematics: lepton ID, jet energy scale.

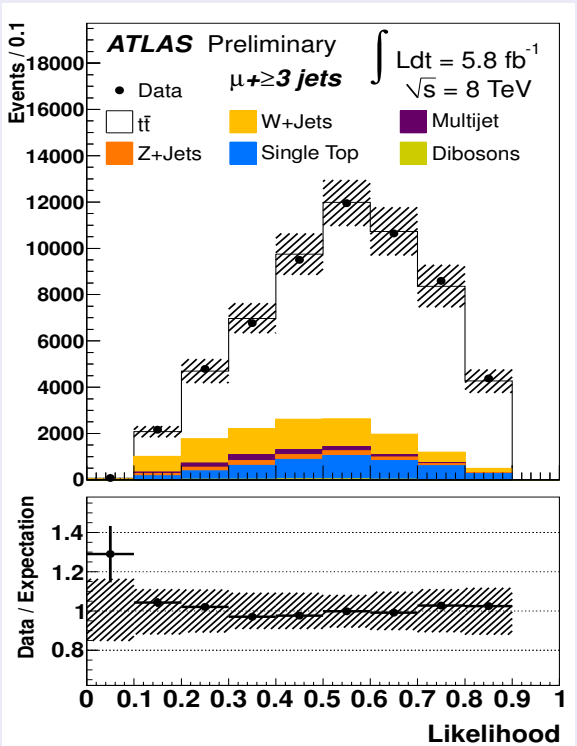




$t\bar{t}$ production cross section in the semileptonic channel ($\sqrt{s} = 8$ TeV ATLAS)

- Number of singal events obtained from data with a likelihood discriminant template fit. (Likelihood function obtained from projective likelihood method defined in the TMVA)
- Multijet bkg: matrix method form μ + jets channel, Jet-electron method (using simulated di-jet sample) for e+jets channel.
- Systematics: Jet and MET reconstruction, MC modeling of the signal.
- Result: $\sigma_{t\bar{t}} = 241 \pm 2$ (stat.) ± 31 (syst.) ± 9 (lumi.) pb.



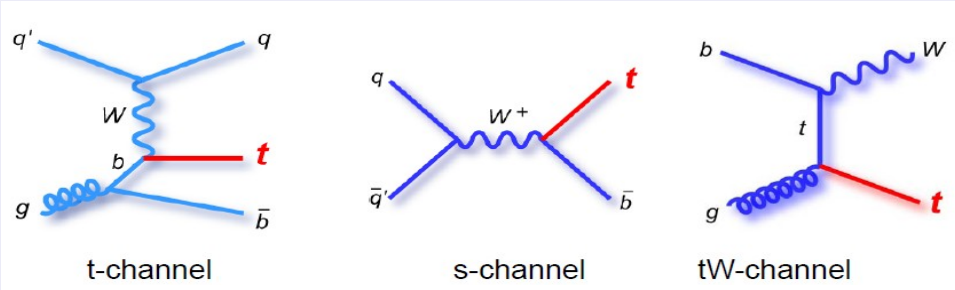


Cross section measurements

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

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

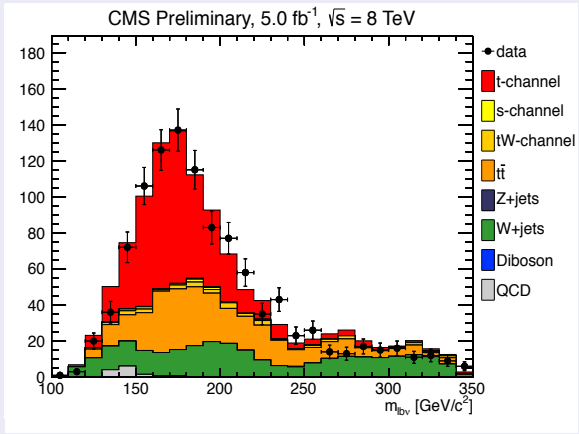
single-top production mechanisms



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

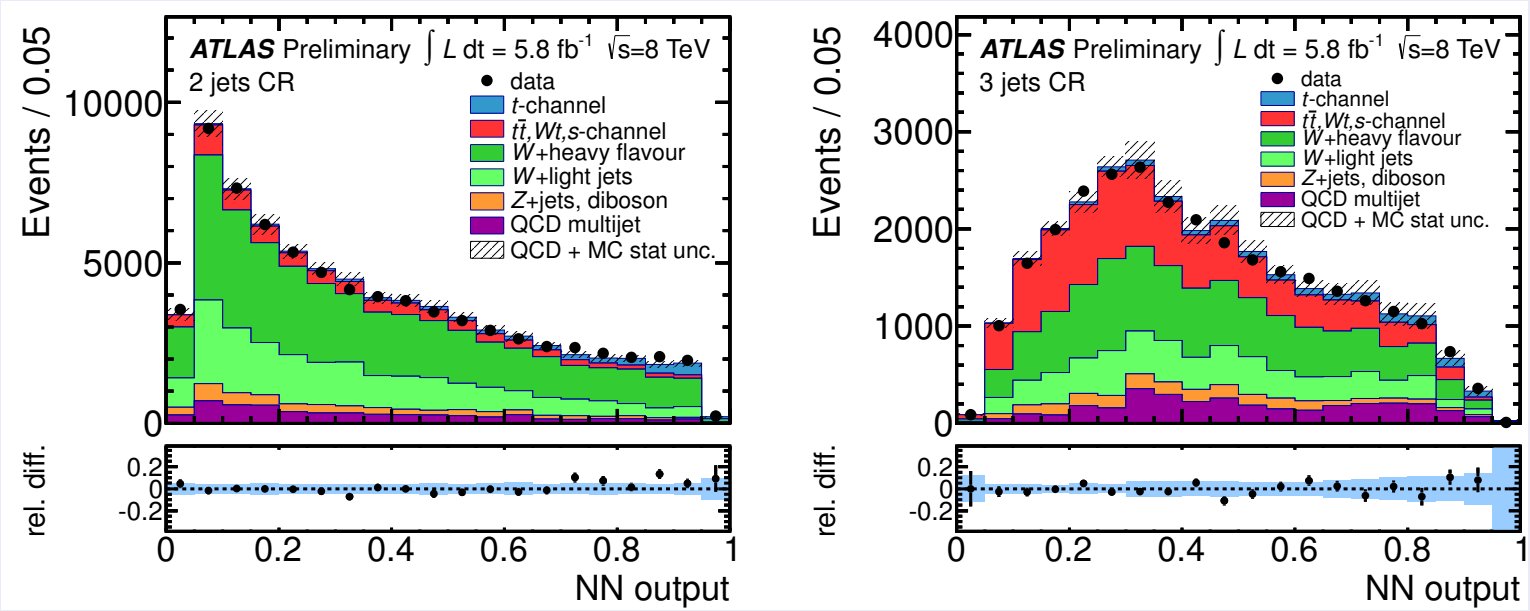


- $M_{lb\nu}$ distribution applying $|\eta_j| > 2.0$

  $\sigma_t^{t-ch} = 80.1 \pm 5.7(stat) \pm 11.0(syst) \pm 4.0(lumi)pb.$

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.



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

Cross section measurements

- Cross section measurements
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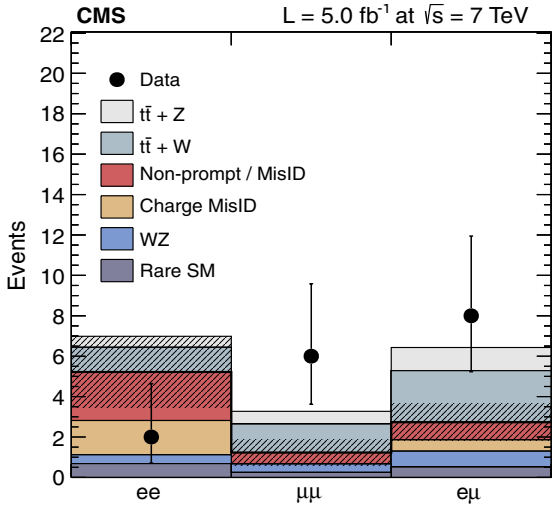
  - Single-top t-channel. CMS-PAS-TOP-12-011, ATLAS-CONF-2012-132
  - Measurement of Vector Boson Production associated with $t\bar{t}$ pairs at 7 TeV. Phys. Rev. Lett. 110 (2013) 172002

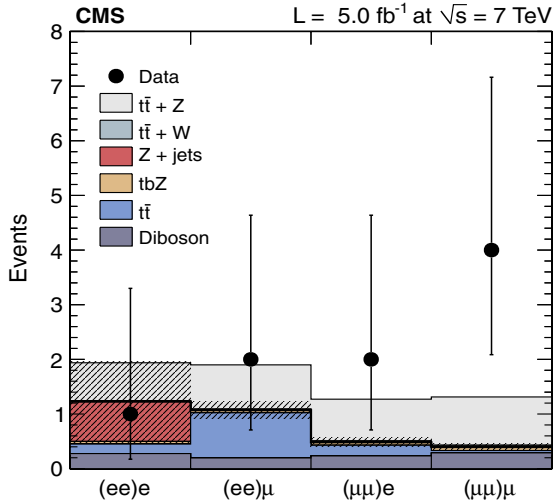
Measurement of Vector Boson Production associated with $t\bar{t}$ pairs

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

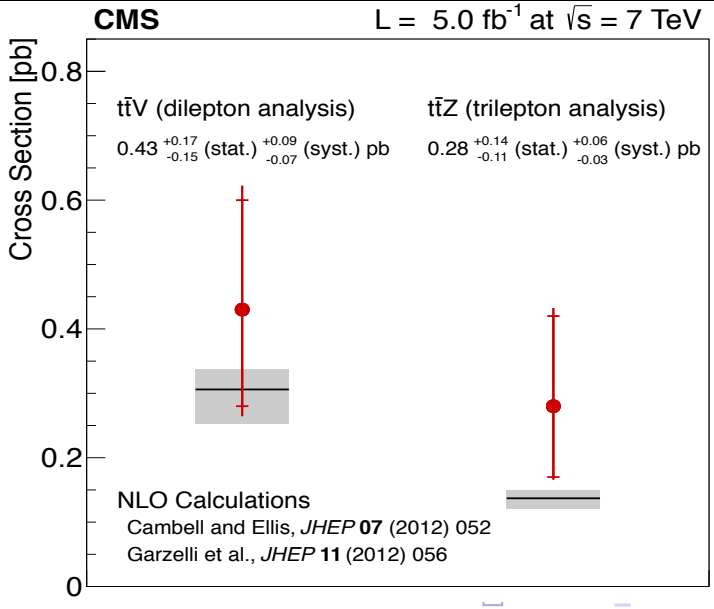
- Trilepton: $t\bar{t} + Z$ events



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



- Trilepton: $\sigma_{ttZ} = 0.30^{+0.14}_{-0.11}(stat)^{+0.04}_{-0.02}(syst)$
- Same-Sign dilepton : $\sigma_{ttV} = 0.45^{+0.17}_{-0.15}(stat)^{+0.06}_{-0.05}(syst)$



Cross section measurements

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  - Single-top t-channel. CMS-PAS-TOP-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-PAS-TOP-12-024

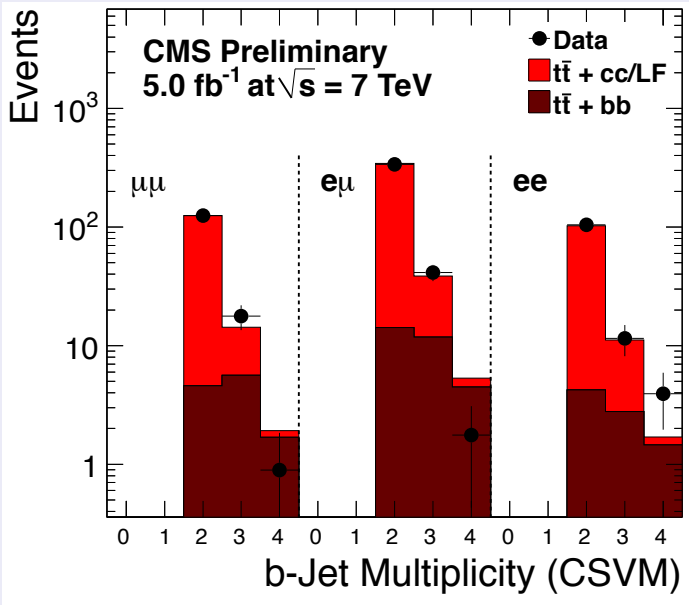
Measurement of the cross section ratio R=$\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}jj}$

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
- $\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}jj} =$ $3.6 \pm 1.1(stat) \pm 0.9(syst)\%$.
- MC predictions: 1.2% MADGRAPH, 1.3% POWHEG



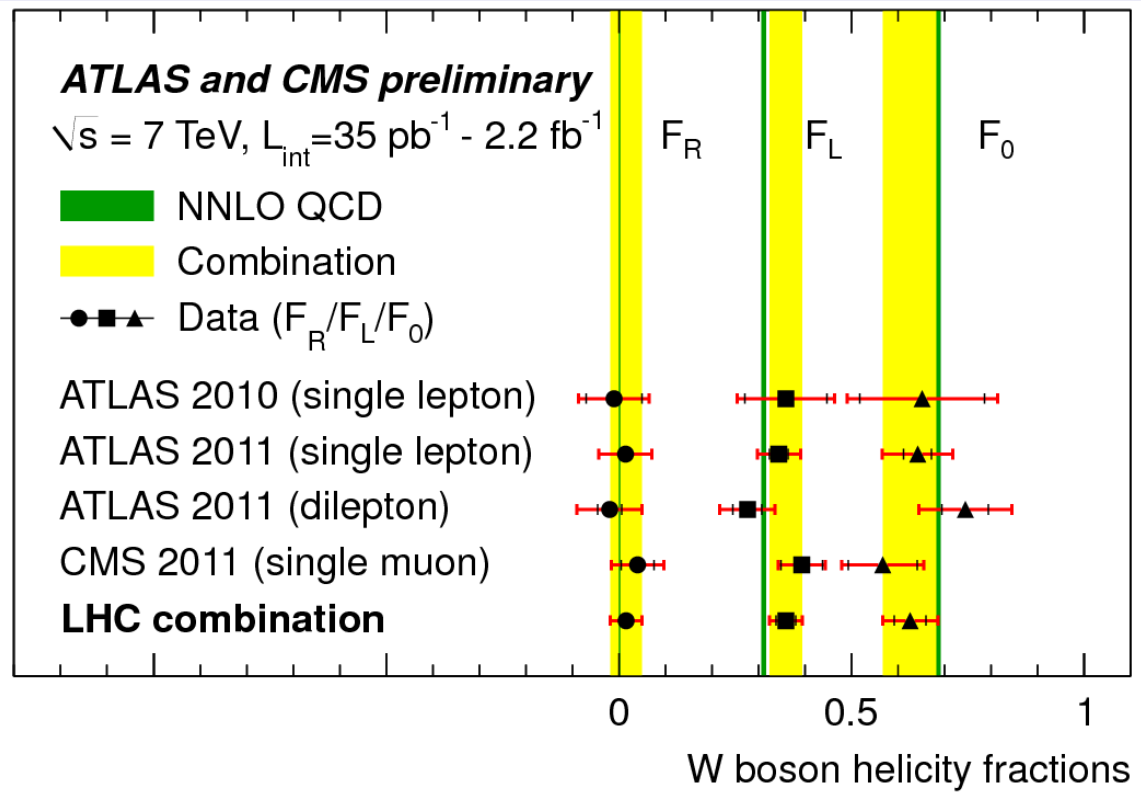
Top quark Properties

- Top quark Properties
  - W polarization

W Polarization

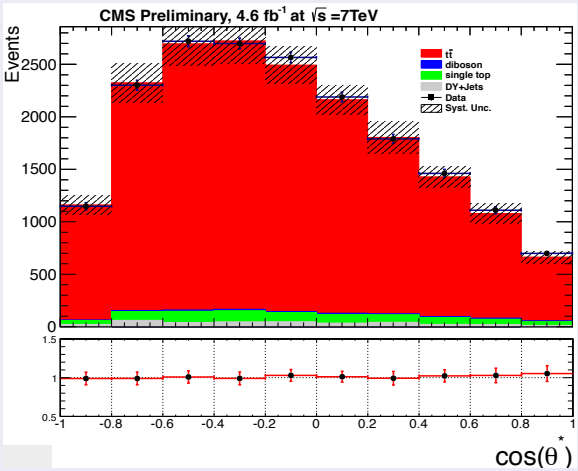
- θ^* disribution (angle between the p(lepton) in W rest frame and p(W).)
- Test V-A structure of tWb-vertex, possible BSM contribution modify elicity fractions: F_0, F_L, F_R.

Combined results ATLAS+CMS using 2010 and 2011 data

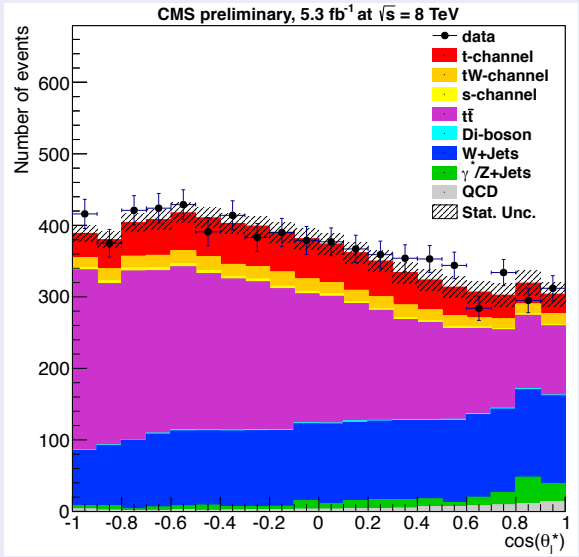


W polarization with 2012 data at 8 TeV (CMS)

Dilepton channel



Single-top t-ch



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

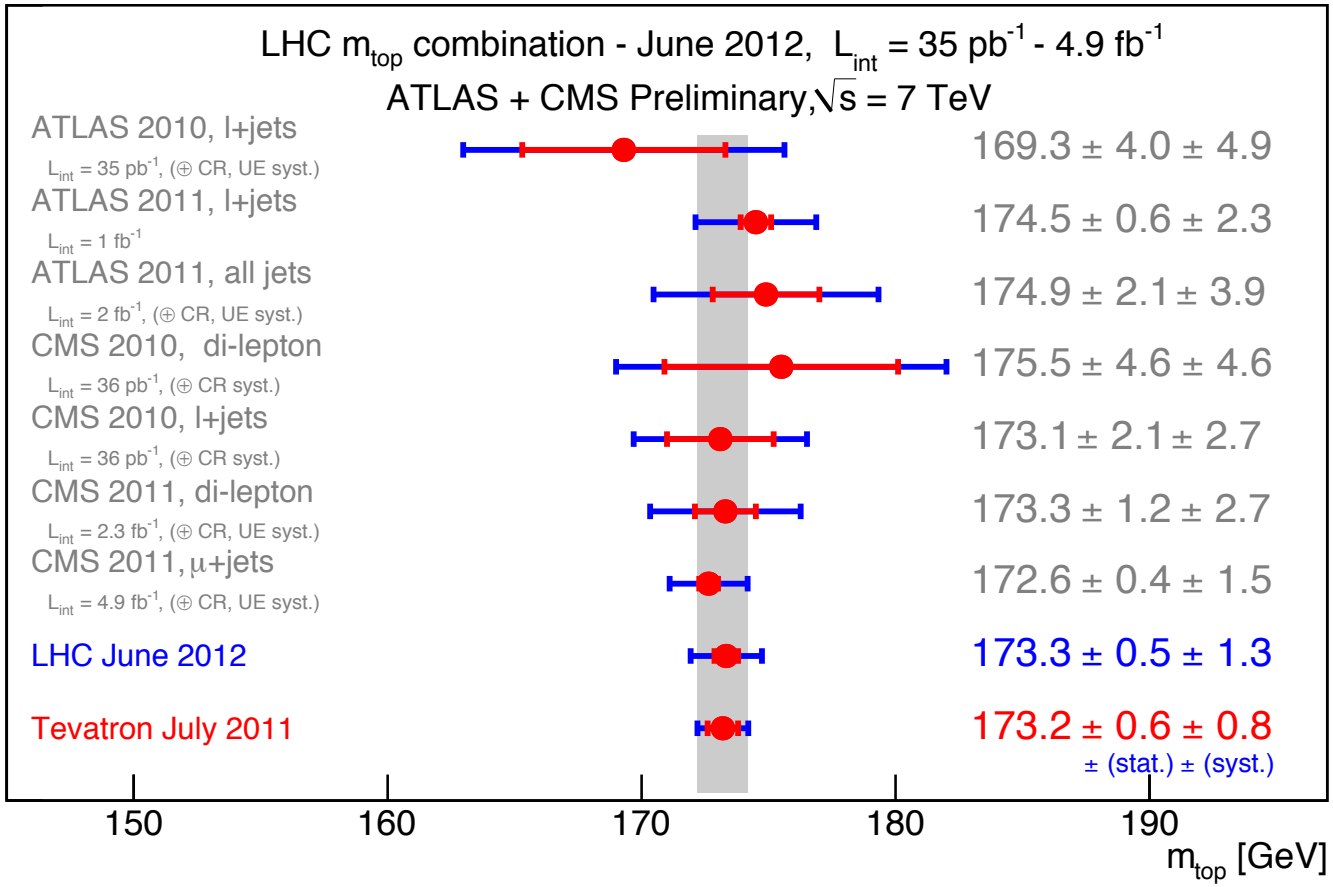
$$F_L = 0.293 \pm 0.069(\text{stat.}) \pm 0.030(\text{syst.}),$$
$$F_0 = 0.713 \pm 0.114(\text{stat.}) \pm 0.023(\text{syst.}),$$
$$F_R = -0.006 \pm 0.057(\text{stat.}) \pm 0.027(\text{syst.}).$$

Top quark Properties

- 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 $\mu^{\pm}$
- 4 jets, 2-btags

Analysis ("2D-ideogram")

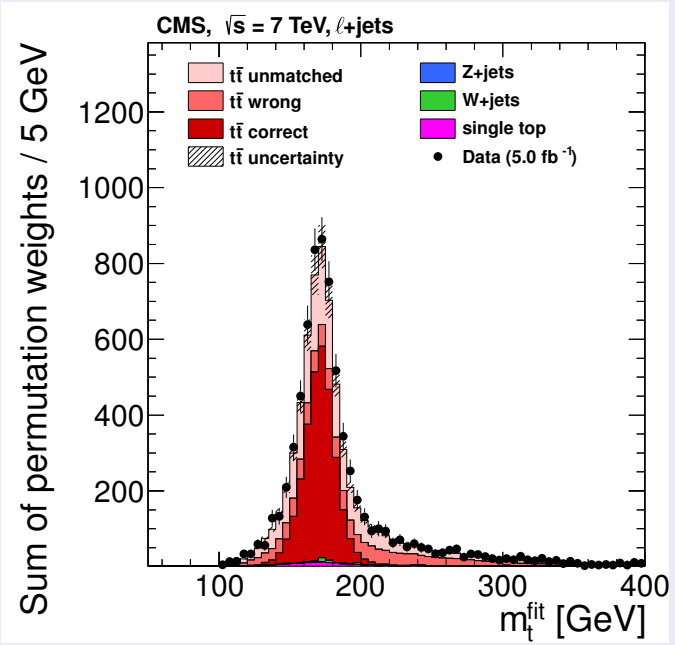
- Reconstruct top mass from kinematic fit (P_{gof})
- **2D max. likelihood fit of the mass and JES** using W mass costraint.
- weight each fit solution by P_{gof} to reduce impact of events without correct permutations.

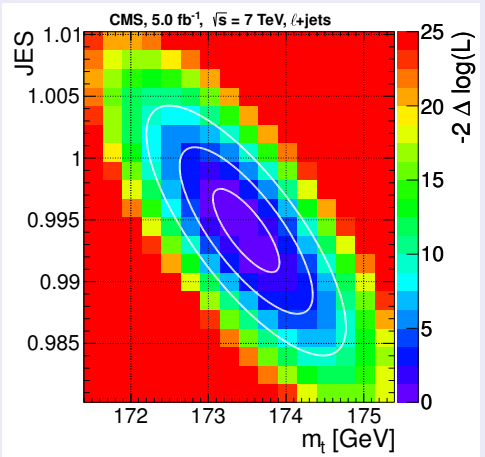
Systematics

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

Result

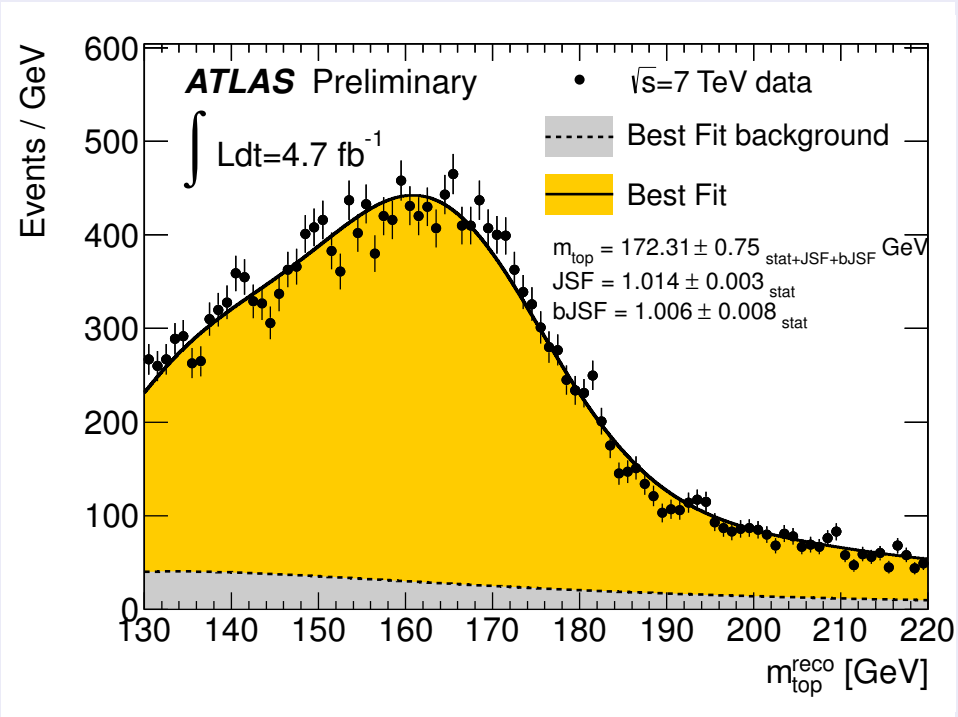
- $m_{top} = 173.5 \pm 0.4_{stat+JES} \pm 1.0_{syst}$ GeV





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

- Top quark Properties
  - W polarization
  - Top quark mass
  - Top anti-top mass difference: CMS-PAS-TOP-12-031

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,

e- + jets $m_t = -325 \pm 294$ (stat.) MeV,

The results for Δm_t are compatible with the expectation from the hypothesis of CPT symmetry.

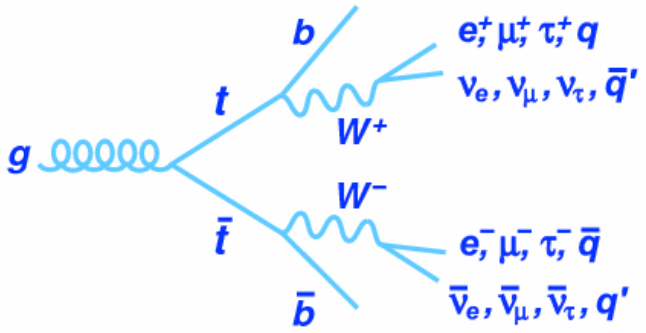
combined $m_t = -272 \pm 196$ (stat.) ± 122 (syst.) MeV.

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

Conclusions

- 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 precison 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 $\rightarrow$ we are preparing the new data taking at 14 TeV.

$t\bar{t}$ production cross section in the dilepton channel (pp collisions at $\sqrt{s} = 8$ TeV) (I)



- Total integrated luminosity of $2.4 fb^{-1}$.
- data triggered by requiring one or two leptons (e^-, μ^-).

Offline selection

- At least one good Primary Vertex (PV).
- At least one pair of **oppositely charged** and **isolated leptons**. $\mu^-(e^-)$: $p_T > 20$ GeV, $|\eta| < 2.4(2.5)$.
- At least two jets with $p_T > 30$ GeV, $|\eta| < 2.5$ are required. No overlap with selected $\mu^-(e^-)$. At least one jet has to be b-tagged.

Background estimation

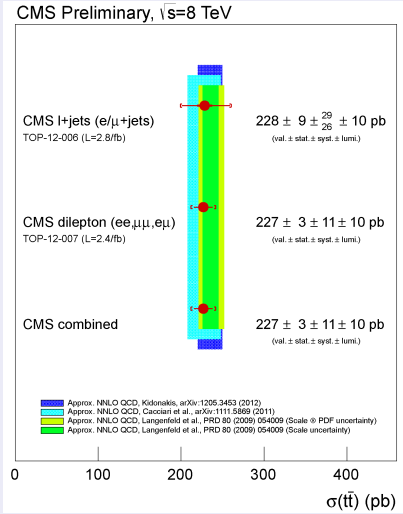
- Dilepton candidates with $M_{ll} < 20$ GeV are removed $\rightarrow$ to remove heavy flavour resonances and Drell-Yen processes.
- M_{ll} have to be outside a ± 15 GeV window centered at the Z mass.
- E_T^{miss} >40 GeV is required to reduce the QCD background contribution.
- The residual contribution of QCD and Drell-Yan processes are estimated on data.

$t\bar{t}$ production cross section in the dilepton channel (pp collisions at $\sqrt{s} = 8$ TeV) (II)

Cross section extraction

$$\sigma_{t\bar{t}} = \frac{N - N_B}{A * L}$$

- Cut based analysis.
  N is the number of events observed in data.
  N_B is the number of estimated background events.
- The measurements is performed in the three channels separately ($ee, \mu\mu, e\mu$) and then combined.
- Theoretical prediction at 8 TeV: 225.2 pb.



Measurements of $t\bar{t}$ cross section production

- Measurements of $t\bar{t}$ cross section production
  - Dileptonic channel
  - Semileptonic channel. CMS-TOP-PAS-12-006

$t\bar{t}$ production cross section in the e^-/μ+jets channel (pp collisions at $\sqrt{s} = 8$ TeV) (I)

- data are collected with a single lepton plus three-jets trigger. Total integrated luminosity of $2.8 fb^{-1}$.

offline selection

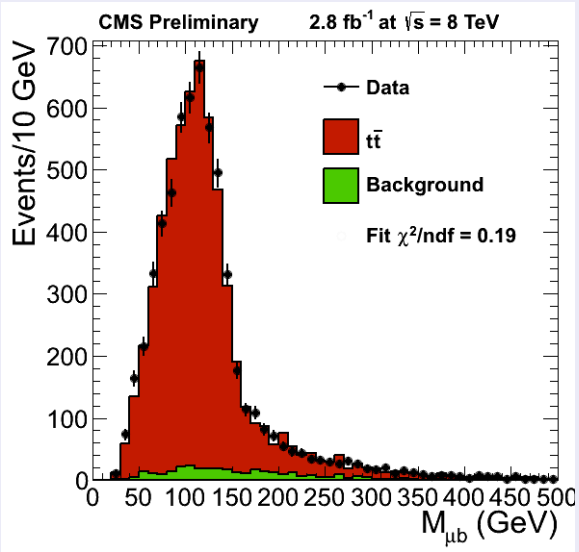
- At least one good PV.
- **Only one isolated lepton** compatible with the reconstructed PV. $\mu^-(e^-)$: $p_T > 26(30)$ GeV, $|\eta| < 2.1(2.5)$. (to reject Z and top quark pairs decaying into dileptons.)
- At least four jets with p_T >45, 45, 35, 35 GeV are required. At least one of them has to be b-tagged.

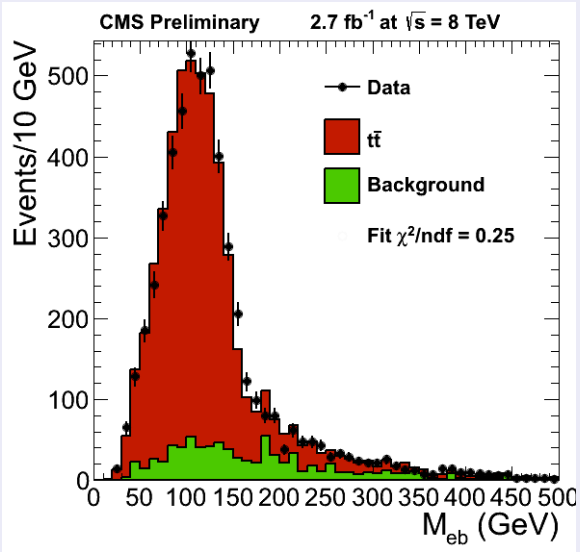
Background estimation and analysis strategy

- The main QCD background process is modeled on data. The other smaller contributions are taken from simulation.
- The number of signal events is extracted with a binned maximum likelihood fit of templates describing signal and bgk processes to the data sample passing the final selection. The M_{lb} distribution has been fitted.

$t\bar{t}$ production cross section in the e^-/μ+jets channel (pp collisions at $\sqrt{s} = 8$ TeV) (II)

Cross section extraction



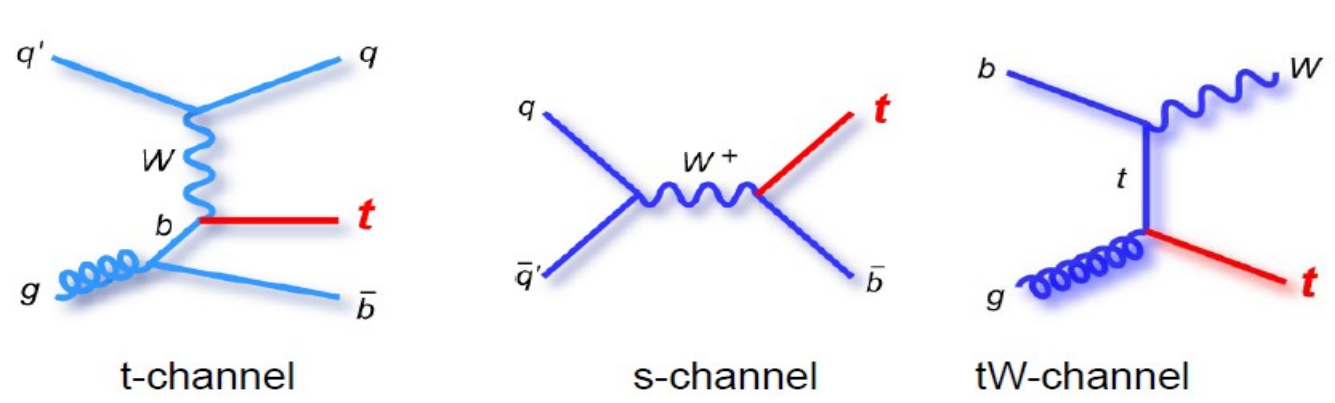


Final results

$$\sigma_{t\bar{t}}(\mu + jets) = 229.9 \pm 11.1\ (\text{stat.})^{+27.6}_{-29.0}\ (\text{syst.}) \pm 10.1\ (\text{lum.})\ \text{pb},$$
$$\sigma_{t\bar{t}}(e + jets) = 227.3 \pm 12.2\ (\text{stat.})^{+35.5}_{-30.0}\ (\text{syst.}) \pm 10.0\ (\text{lum.})\ \text{pb},$$
$$\sigma_{t\bar{t}}(combined) = 228.4 \pm 9.0\ (\text{stat.})^{+29.0}_{-26.0}\ (\text{syst.}) \pm 10.0\ (\text{lum.})\ \text{pb},$$

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

single-top production mechanisms



- The t-channel single-top process is expected to be the dominant one with a $\sigma_t^{th} = 87.2^{+2.1}_{-0.7}(scale)^{+1.5}_{-1.7}(PDF)$pb at 8 TeV (for a $m_t = 173$ GeV/c^2).
- Data collected with a single Muon trigger. Total integrated luminosity of $5 fb^{-1}$.

Offline selection

- Only one isolated muon with $p_T > 26$ and $|\eta| < 2.1$. Veto on the presence of electrons.
- The selected muon has to be compatible with the mass of the W (m_T^W >50 GeV/c^2)
- b-tagging is applied to reduce the huge background of W+jets events.
- A signal region (SR) is define by requiring two jets with $p_T > 40$ and 1 of these b-tagged.
- Control regions (CRs): if more than 2 jets or more than 1 b-tagged jet are present.

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

- This measurement is a key ingredient to test the SM validity. Two analysis separately:
  - **exclusive search of trilepton events produced in $t\bar{t} + Z$ decays**
  - **inclusive search for same sign dilepton events produced in $t\bar{t} + V$ decays (V=W or Z).**

Dataset and trigger

- Data are collected with a dilepton trigger. Total integrated luminosity: $4.98 fb^{-1}$, (7 TeV).

Trilepton analysis: offline selection

- two opposite-charge, same-flavor leptons with $p_T > 20$ GeV and $81 < m_{ll} < 101$ GeV
- transverse momentum of the Z > 35 GeV
- third lepton with $p_T >$10 GeV
- at least three jets with $p_T > 20$ GeV and $|\eta| < 2.4$, two of them b-tagged.
- $H_T >$120 GeV. H_T is the scalar sum of all jets in the event with $p_T >$20 and $|\eta| <$2.4.

Same-sign dilepton analysis: offline selection

- two same charged and isolated leptons with $p_{T1,T2} > 55$, 30 GeV
- at least three jets with $p_T > 20$ GeV. At least one b-tagged.
- $H_T >$100 GeV

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

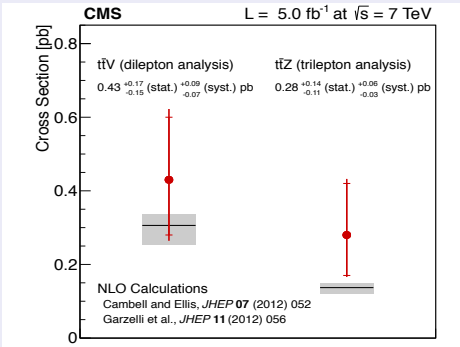
Background estimation

- for both analysis the main background processes, coming from $t\bar{t}$ production, Z +hard jets, and diboson productions, are modeled on data applying a specific selection.

Final results

- Trilepton analysis: $\sigma_{ttZ} = 0.30^{+0.14}_{-0.11}(stat)^{+0.04}_{-0.02}(syst)$
- Same-Sign dilepton analysis: $\sigma_{ttV} = 0.45^{+0.17}_{-0.15}(stat)^{+0.06}_{-0.05}(syst)$

Combination



- Measurement of the $t\bar{t}$V production cross section: the cross section from the trilepton channel (right), from the same sign dilepton channel (left) are compared to the NLO calculation (black line).
- Internal error bars represent the statistical component of the uncertainty.