Top Physics and Heavy Flavor measurements with ATLAS and CMS

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Carlos Escobar (University of Pittsburgh)
on behalf of the ATLAS and CMS Collaborations

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Top quark Physics

- Top quark mass measurements
- Top quark pair production
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  - Top quark pair + jets
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  - Spin correlations
- Single top quark measurements
  - Cross section
  - Cross section ratio
- Search for $t\bar{t}$ resonances

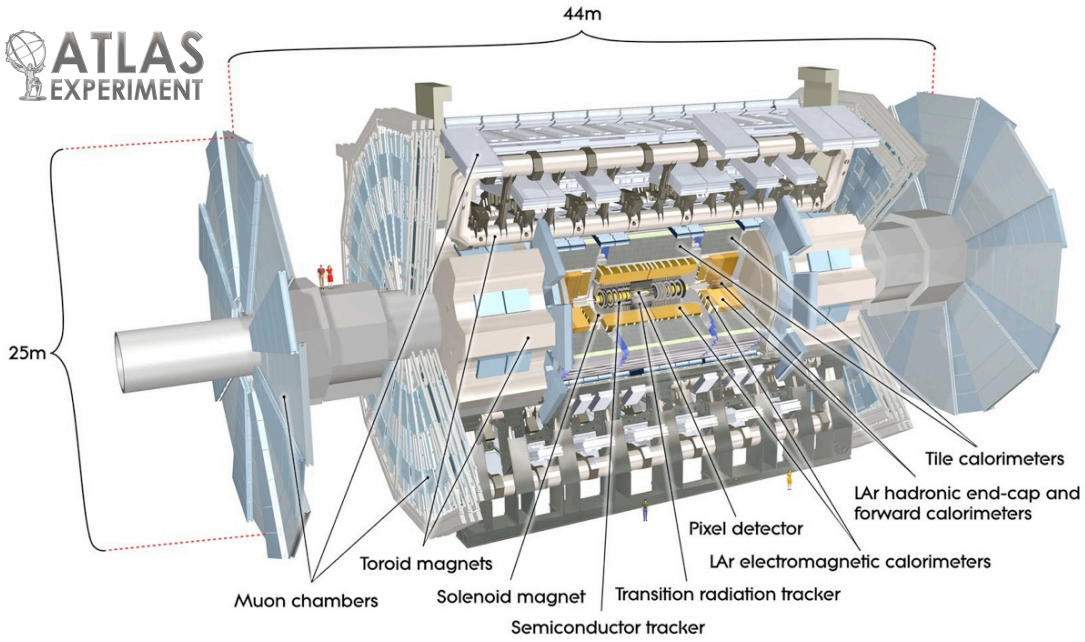
Heavy flavor measurements

- Mass, lifetime production cross section measurements
- Observations of new particles

This talk will cover **some of the latest analyses and some of the most important results** achieved by ATLAS and CMS **but not all**. Please, visit:

- ATLAS Public Results: *https://twiki.cern.ch/twiki/bin/view/AtlasPublic*
- CMS Public Results: *https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults*

ATLAS and CMS detectors

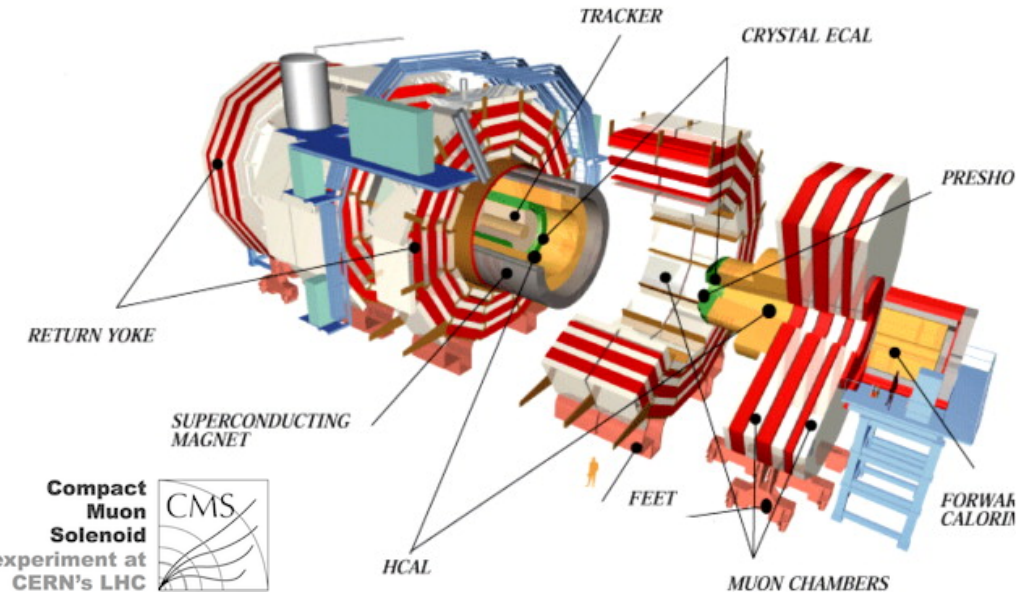


ATLAS (general purpose detector)

- Length: 44 m, diameter: 25 m
- Mass: ~7.0 ktons
- Two magnet fields:
  - Solenoid (ID): 2 T
  - Toroid (Muon System): 2-8 Tm

CMS (general purpose detector)

- Length: 21 m, diameter: 15 m
- Mass: ~ 12.5 ktons
- Solenoid: 4 T



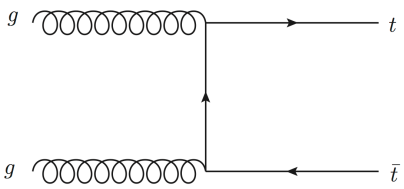
Top quark Physics Introduction

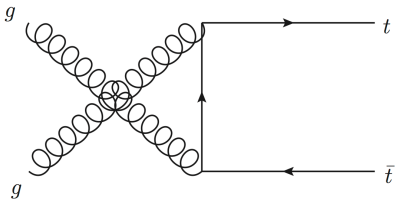
The top quark was discovered by the Tevatron experiments, *CDF* and *D0*, at Fermilab in 1995.

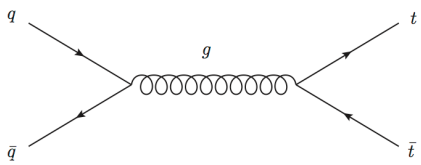
- Tevatron Run-II (10^{32} cm^{-2} s^{-1} @ 1.96 TeV): ~2 top pair every hour.

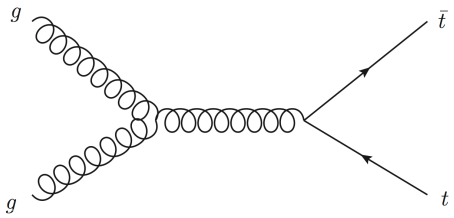
The LHC is a top quark factory:

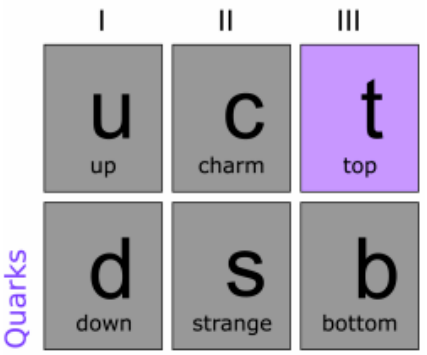
- At low luminosity (i.e. 10^{32} cm^{-2} s^{-1} @ 7 TeV): ~60 top pair every hour.
- At design luminosity (i.e. 10^{34} cm^{-2} s^{-1} @ 14 TeV): ~8 top pair every second.
- Top production is dominated by gluon fusion (85% $gg \rightarrow t\bar{t}$, 15% $q\bar{q} \rightarrow t\bar{t}$ @ 7 TeV)







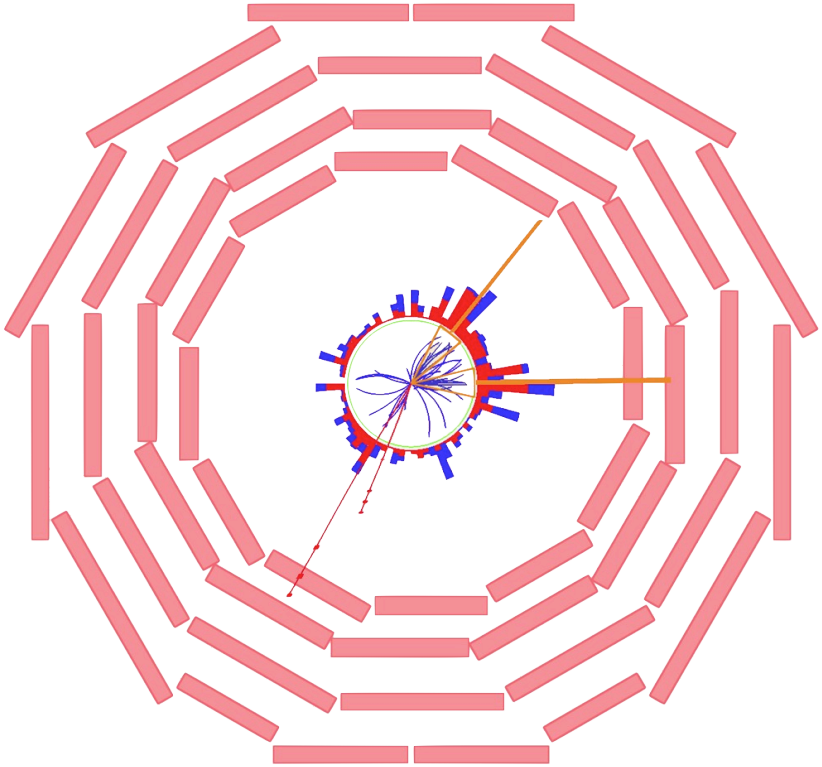




- Heaviest known elementary particle.
- Smallest cross-section of all of the SM particles.
- Short lifetime ($\tau_t \approx 5 \cdot 10^{-25}$ s) ⇒ top-quark decays into high p_T particles before hadronizing.
- Unique quark: only quark whose most of its properties can be directly measured!!!
- Production: top pairs and single top processes.

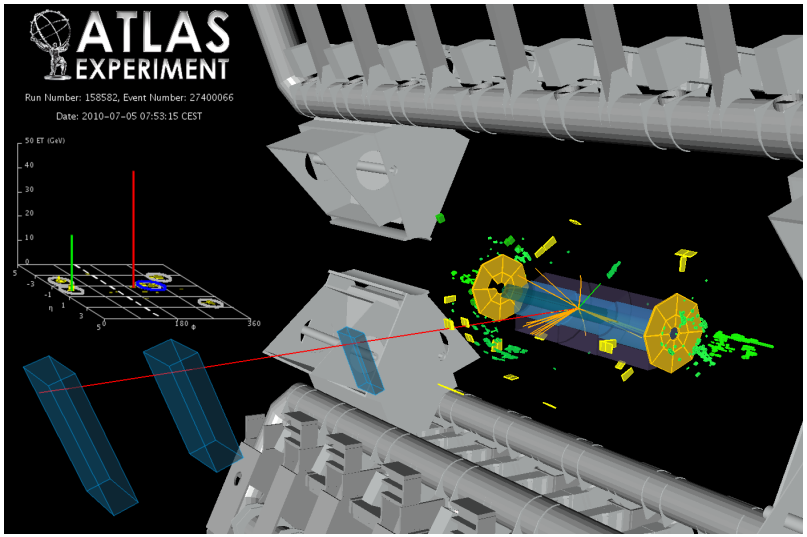
First top quark pair candidates @ LHC

Recorded: Jul 18 11:13:22 2010 CET
Run/Event: 140379 / 136650665



A candidate for production of a top quark pair in CMS, where both top quarks decay into a *W* and a *b*-quark, and both *W* particles decay into a μ and *ν*. This results in 2 μ (red tracks), 2 jets tagged as *b*-quark jets and missing energy (from the escaping neutrinos).

Recorded: Jul 7 07:53:15 2010 CET
Run/Event: 158582 / 27400066



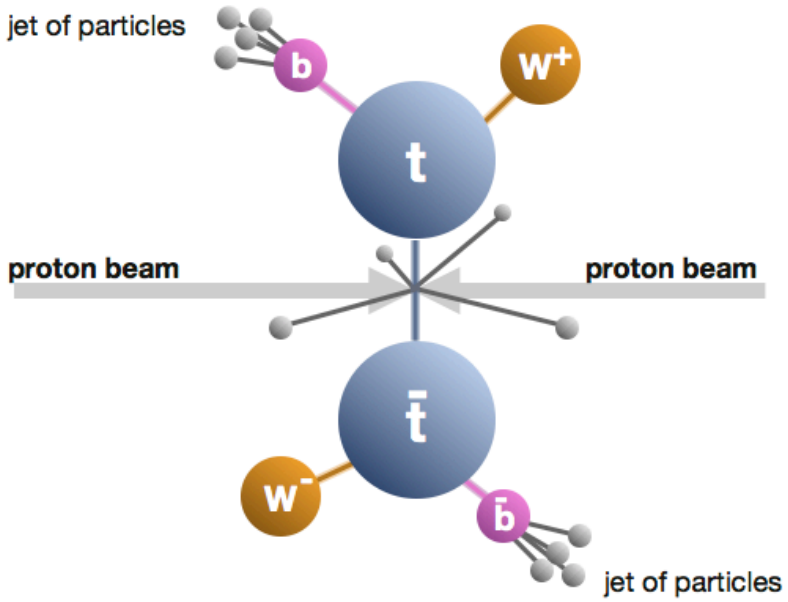
Event display of the *e*-*μ* dilepton candidate. The isolated *μ* track is shown in red, the isolated *e* is shown as a green track pointing to a green calorimeter energy cluster. The *b*-tagged jet is marked as a blue circle in the η-ϕ lego plot on the left side of the figure. The direction of the missing transverse energy is shown as a dashed line in the η-ϕ lego plot.

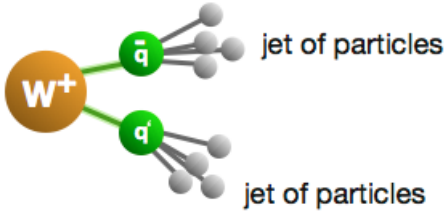
Top quark Physics Introduction

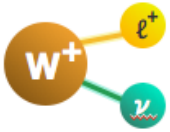
The top quark decays almost exclusively (>99%, i.e. $|V_{tb}| \approx 0.999$) to $t \rightarrow Wb$ (LO).

- *b*-quark will always hadronize generating a jet of particles.
- *W* decays define the final state topology.

Top quark pairs production

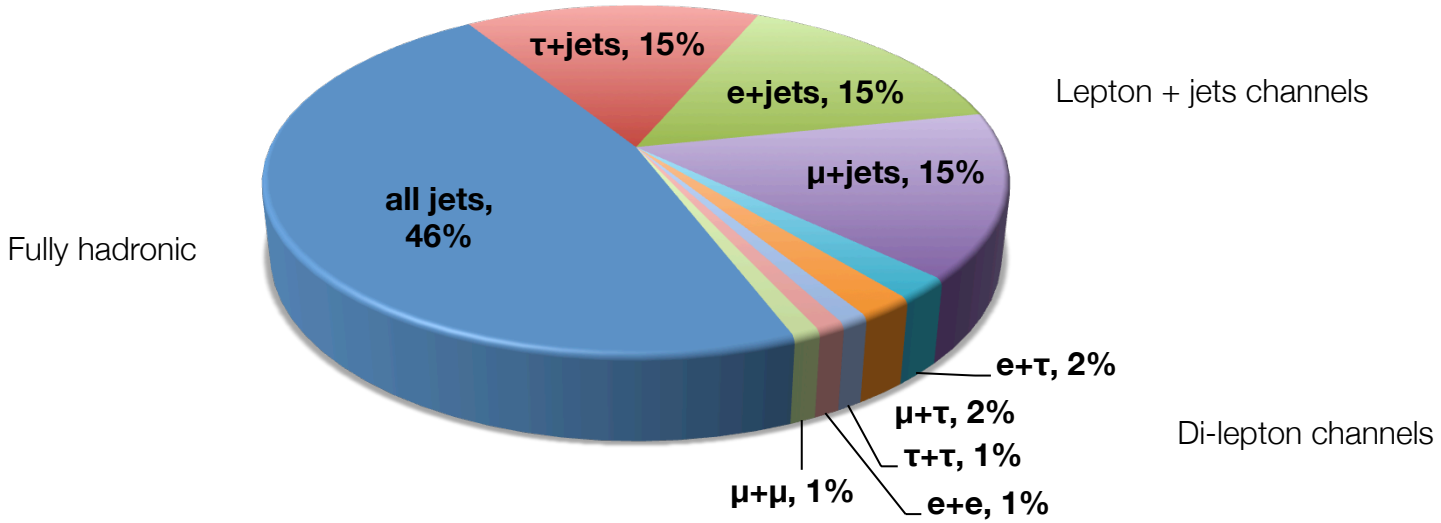






Top decay modes and selections

Top-quark pair branching ratios for different topologies



Fully hadronic channel (@ LO):

- Largest statistics: 6 high p_T jets in the final state (4 light jets and 2 b-jets).
- No leptons to trigger on. Important presence of multijets background (low S/B).

Di-lepton channel (@ LO):

- Clean in terms of trigger and selection: 2 high p_T isolated leptons and 2 high p_T b-jets.
- 2 neutrinos in the final state which can introduce reconstruction ambiguities due to the high E_T^{miss}.

Lepton + jets channel (@ LO):

- Large statistics: 4 high p_T jets in the final state (2 light jets and 2 b-jets) and 1 high p_T isolated lepton → high trigger efficiency and good multijets background rejection.
- 1 neutrino in the final state which is easy to reconstruct using E_T^{miss}.

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Heavy flavor measurements

- Mass, lifetime production cross section measurements
- Observations of new particles

Top-quark mass @ 7 TeV

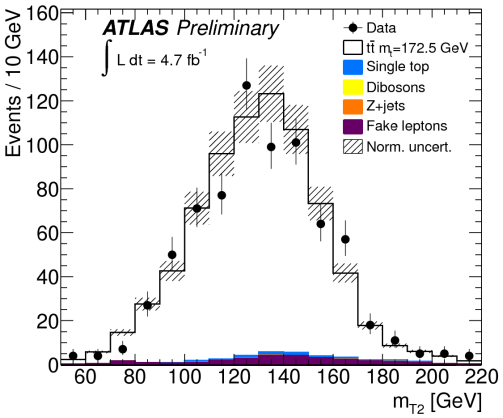
ATLAS 4.7 fb^{-1}
ATLAS-CONF-2012-082

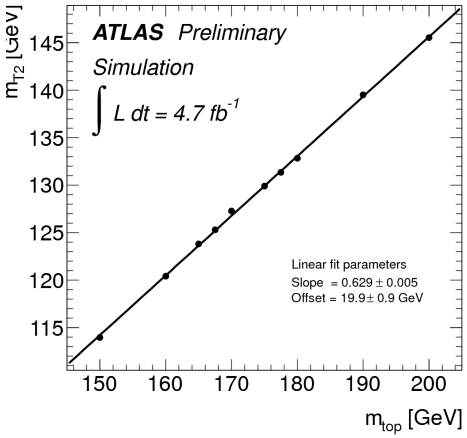
Di-lepton event selection

Based on the transverse mass (m_{T2}) measurement.

- m_{T2} < 220 GeV (reject events with at least one wrongly identified b-jet: eff. 92%)

Calibration using MC samples with different input top-quark masses including all expected backgrounds



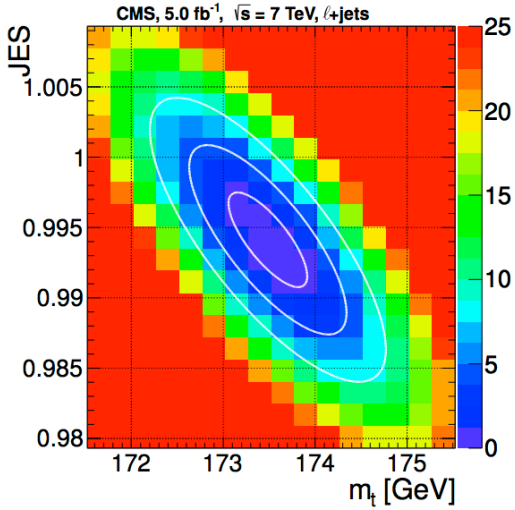


m_t (7TeV, 4.7 fb^{-1}) = 175.2
± 1.6 (stat.) $^{+3.1}_{-2.8}$ (syst.) GeV

CMS 5.0 fb^{-1}
CMS-TOP-PAS-11-015

Lepton + jets event selection

Kinematic fit to reconstruct the $t\bar{t}$ topology (all permutations are considered) and 2D likelihood functions for each event to estimate simultaneously both the top quark mass and the JES.



The ellipses correspond to statistical uncertainties on m_t and JES of one, two, and three standard deviations.

m_t (7TeV, 5.0 fb^{-1}) = 173.49
± 0.43 (stat.) ± 0.98 (syst.) GeV
JES = 0.994 ± 0.003 (stat.) ± 0.008 (syst.)

- Main backgrounds: *Z*+jets and *W*+jets and top production
- Main Systematics (ATLAS): JES, b-JES, Color recon. and MC modeling.
- Main Systematics (CMS): JES, b-JES, JER, Renorm. and factorization scale and Fit calib.

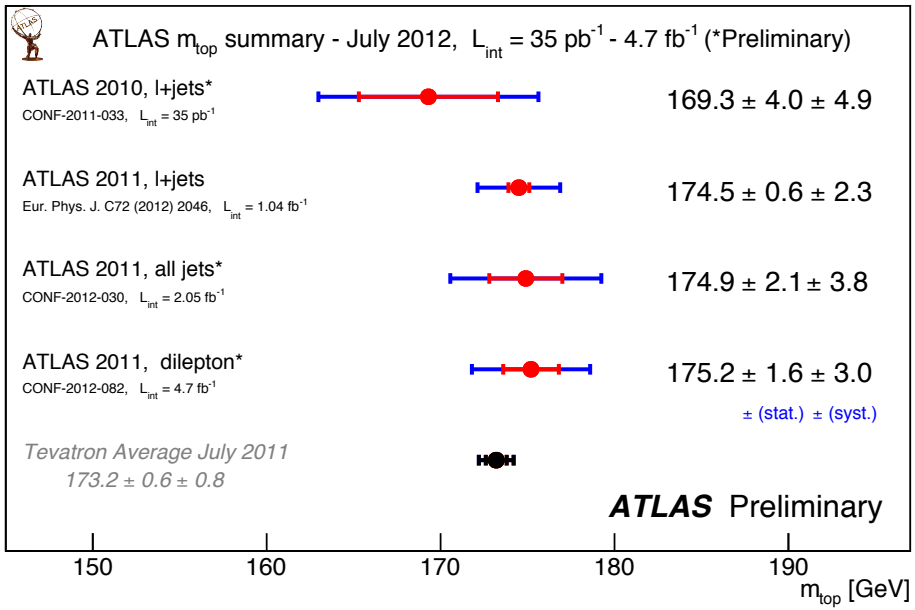
Top quark mass @ 7 TeV

Top quark mass is being measured in the 3 channels.

- The most precise top-quark measurements are from **lepton + jets** analyses.

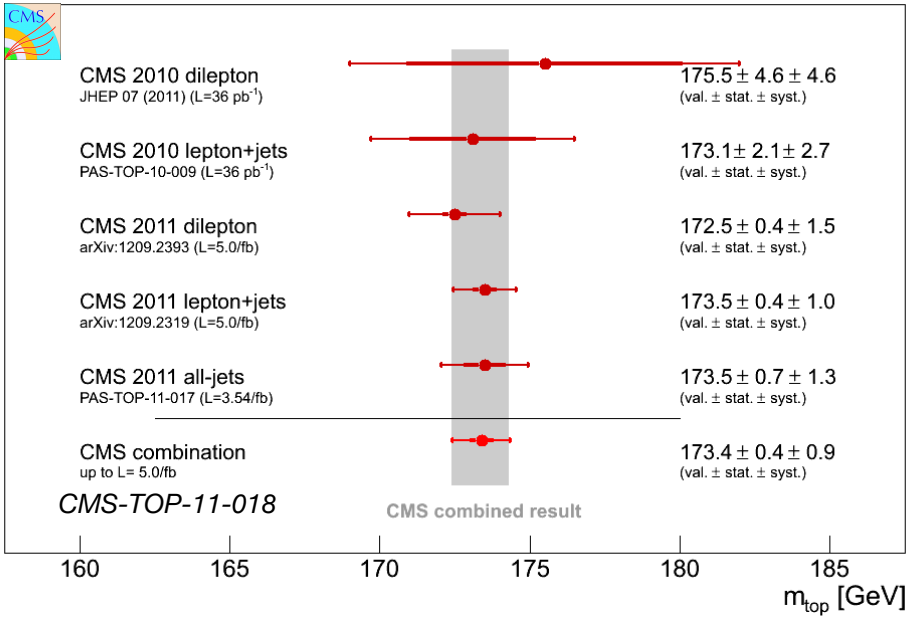
m_t (1.04 fb^{-1}) = 174.5 ± 0.6 (stat.) ± 2.3 (syst.) GeV

Eur. Phys. J. C72 (2012) 2046



m_t (5.0 fb^{-1}) = 173.4 ± 0.4 (stat.) ± 0.9 (syst.) GeV

CMS-TOP-11-018



ATLAS and CMS results are compatible between them as well as with CDF and D0 results:

m_t (Tevatron comb. 2012, 5.8 fb^{-1}) = 173.18 ± 0.56 (stat.) ± 0.75 (syst.) GeV

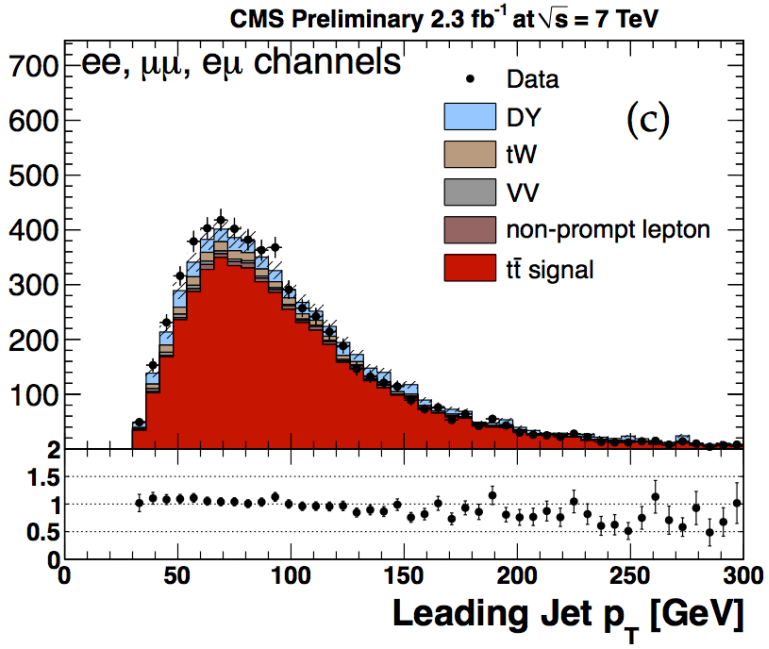
CDF and D0 5.8 fb^{-1}
arXiv:1207.1069 [hep-ex]

Top quark pair cross section @ 7 TeV

CMS 2.3 fb^{-1}
CMS-PAS-TOP-11-005

Di-lepton event selection

Cross section measurement using a profile likelihood ratio (and cut and count analysis as a cross-check).



$\sigma_{t\bar{t}}$ (7TeV, 2.3 fb^{-1}) = 161.9
± 2.5 (stat.) ± 5.1 (syst.) ± 3.6 (lumi.) pb

- Main Systematics: lepton efficiencies, *W* BR fraction and E_t^{miss} efficiency.

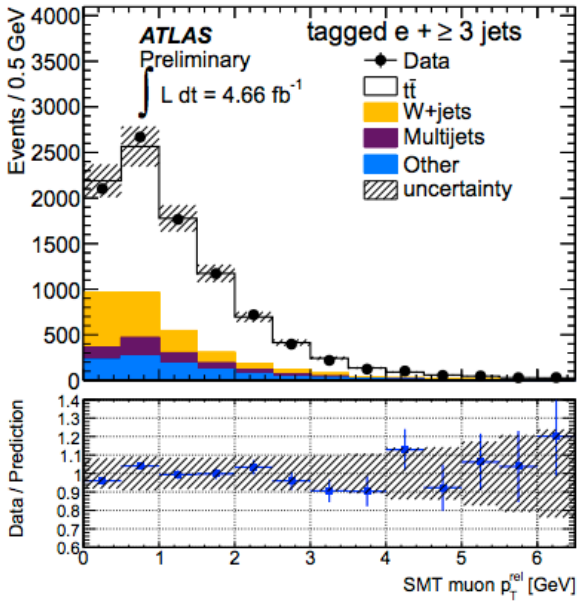
ATLAS 4.7 fb^{-1}
ATLAS-CONF-2012-131

Lepton + jets event selection

Soft Muon Tagging (SMT) technique: Semileptonic *b* decays are identified by a low p_T muon close to a jet.

Top quark pair cross section is computed with:

$$\sigma_{t\bar{t}} = \frac{N_{\text{data}} - N_{\text{bkg}}}{\int L\,dt \cdot \epsilon \cdot BR(\text{noFullHad})}$$



$\sigma_{t\bar{t}}$ (7TeV, 4.66 fb^{-1}) = 165
± 2 (stat.) ± 17 (syst.) ± 3 (lumi.) pb

- Main Systematics: JES, NLO generator, PDF and b→μX BR.

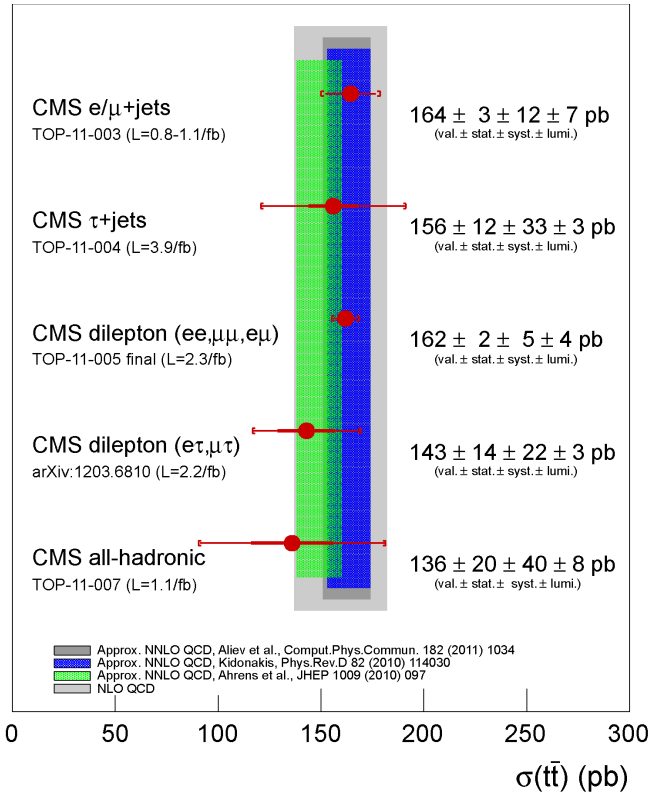
- Main backgrounds: multijets, *W*+jets and top production.

Top quark pair cross section @ 7 TeV

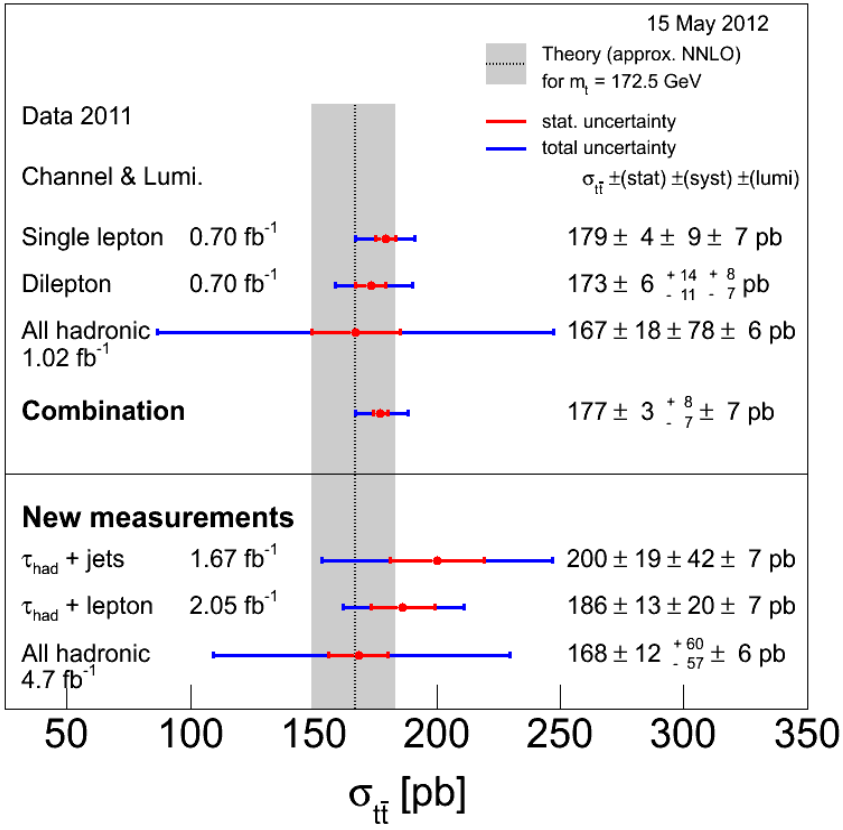
Top quark cross section is being measured in the various channels (lepton+jets, di-lepton, all-hadronic, τ+lepton, τ+jets, lepton+jets using semileptonic decays).

- The **most precise** top quark cross section measurement are from **di-lepton (CMS)** and **lepton + jets (ATLAS)** analyses.

$\sigma_{t\bar{t}}$ (7TeV, 2.3 fb^{-1}) = 162
± 2 (stat.) ± 5 (syst.) ± 4 (lumi.) pb



$\sigma_{t\bar{t}}$ (7TeV, 4.7 fb^{-1}) = 165
± 2 (stat.) ± 17 (syst.) ± 3 (lumi.) pb



ATLAS and CMS results are compatible between them and…
In agreement with SM prediction (approx. NNLO): $\sigma_{t\bar{t}}$ (7TeV) = 167 ± 18 pb.

HATHOR 1.2 ., Aliev et al, 2011, arXiv 1007.1327

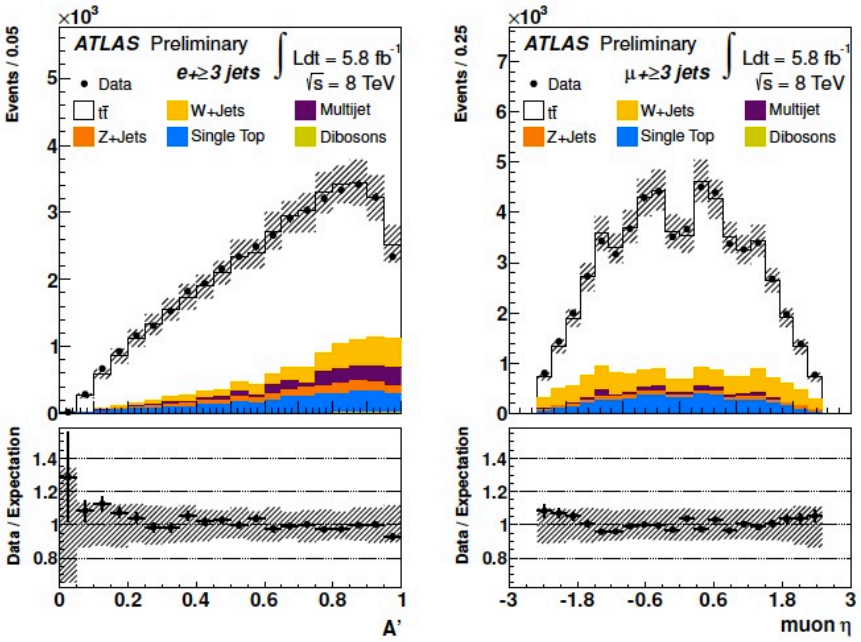
Top quark pair cross section @ 8 TeV

Lepton + jets analyses

ATLAS 5.8 fb^{-1}
ATLAS-CONF-2012-149

Similar to 7 TeV selection with few updates (p_T (e, μ) > 40 GeV) to reduce multijet background

Kinematic fit using likelihood discriminant function based on lepton η and transformed aplanarity (A'=e^{-8A}).

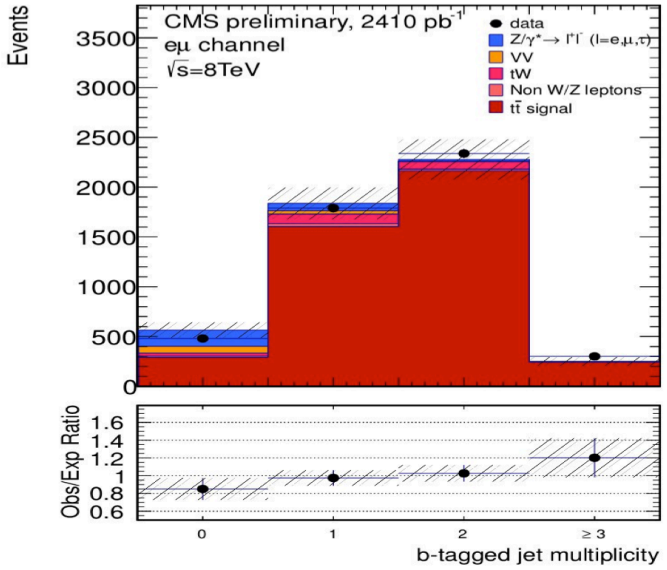


$\sigma_{t\bar{t}}$ (8TeV, 5.8 fb^{-1}) = 241
± 2 (stat.) ± 31 (syst.) ± 9 (lumi.) pb

- Main Systematics: MC modeling (generator, ISR/FSR), PDF, PS) and Jet/E_T^{miss} reconstruction.

CMS 2.4 fb^{-1}
CMS-TOP-PAS-12-007

Cut and count analysis.
Very small background contributions ⇒ High purity allows precision measurement with 6% overall uncertainty.



$\sigma_{t\bar{t}}$ (8TeV, 2.4 fb^{-1}) = 227
± 3 (stat.) ± 10 (syst.) ± 10 (lumi.) pb

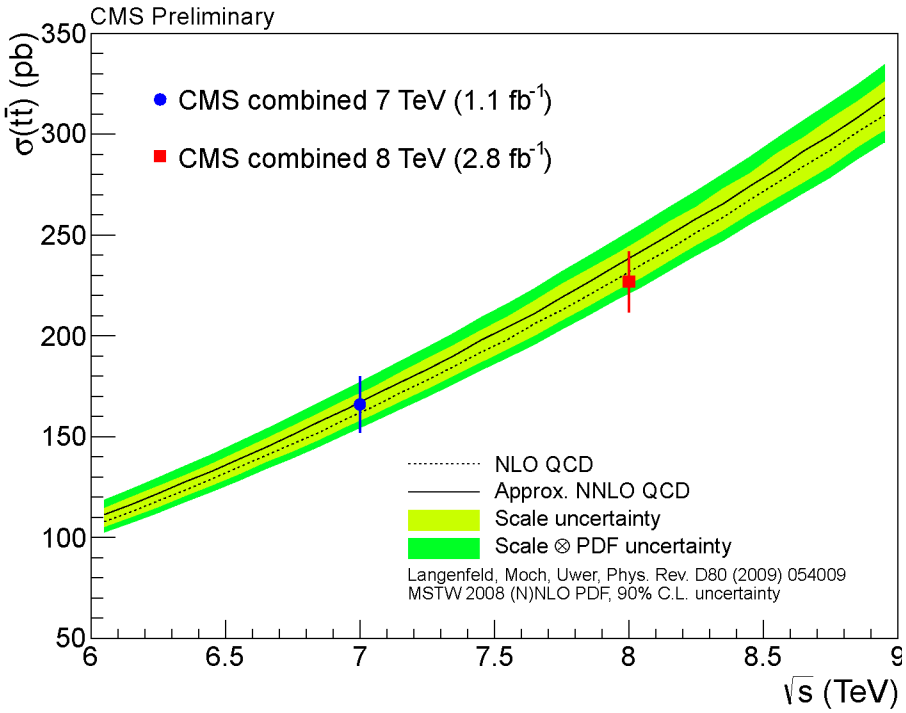
σ(8TeV)/σ(7TeV) = 1.41 ± 0.11

Main Systematics: JES (2.5%), lepton efficiencies (1.8%) and JER (1.7%).

Top quark pair cross sections @ 7 TeV and 8 TeV

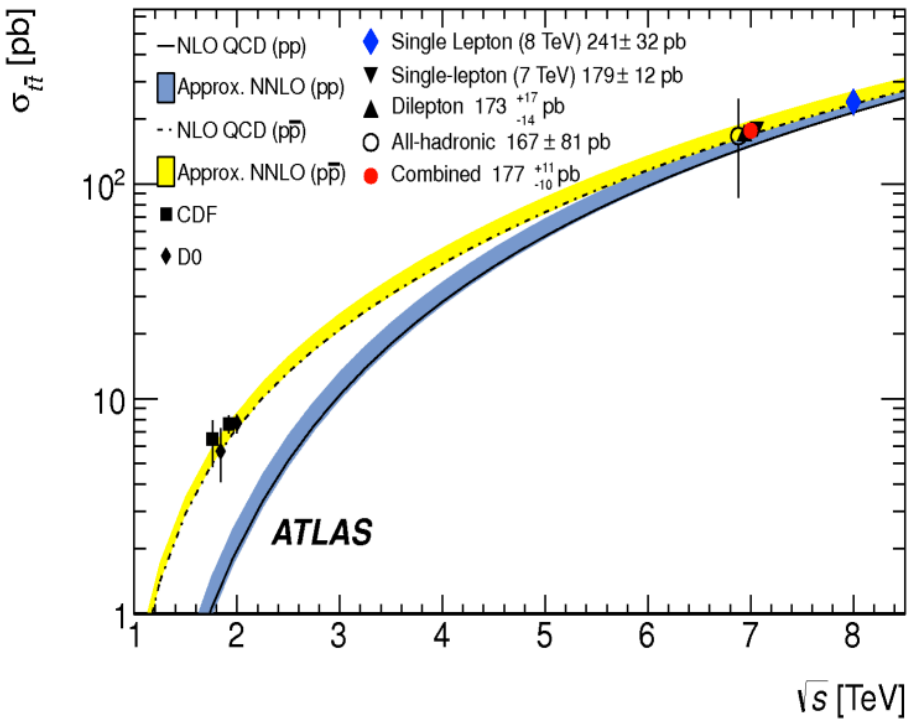
CMS-TOP-11-005
CMS-TOP-PAS-12-007

$\sigma_{t\bar{t}}$ (7TeV, 2.3 fb^{-1}) = 162 ± 2 (stat.) ± 9 (syst.) pb
$\sigma_{t\bar{t}}$ (8TeV, 2.4 fb^{-1}) = 227 ± 3 (stat.) ± 21 (syst.) pb



ATLAS-CONF-2012-131
ATLAS-CONF-2012-149

$\sigma_{t\bar{t}}$ (7TeV, 4.7 fb^{-1}) = 165 ± 2 (stat.) ± 20 (syst.) pb
$\sigma_{t\bar{t}}$ (8TeV, 4.7 fb^{-1}) = 241 ± 2 (stat.) ± 40 (syst.) pb



ATLAS and CMS results are compatible between them and…
In agreement with theoretical predictions (approx. NNLO):

- $\sigma_{t\bar{t}}$ (7TeV) = 167 ± 18 pb.
- $\sigma_{t\bar{t}}$ (8TeV) = 238^{+22}_{-24} pb

HATHOR 1.2 ., Aliev et al, 2011,
arXiv 1007.1327

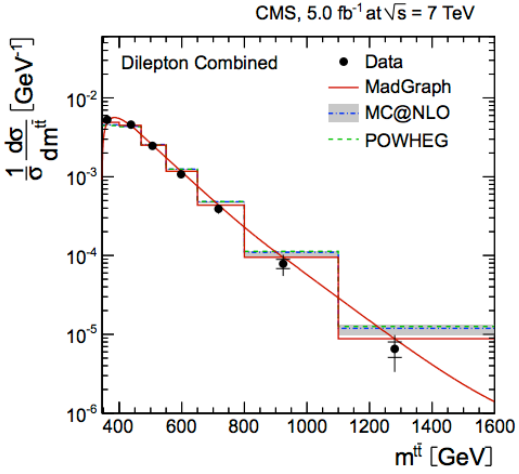
Top quark pair differential cross section @ 7 TeV

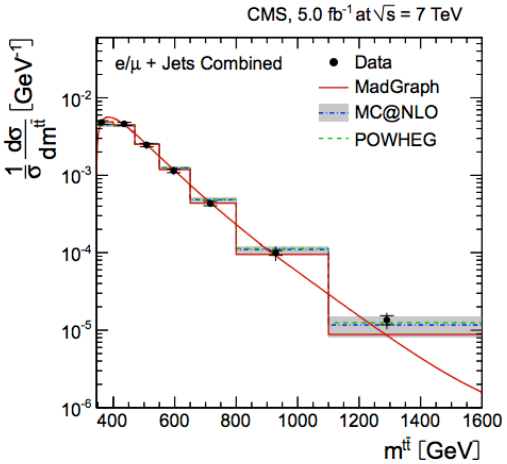
Relative diff. cross section derived as function of $m_{t\bar{t}}$, $p_T^{t\bar{t}}$ and $y_{t\bar{t}}$.

Top quarks reconstructed using a likelihood fit (lepton + jets) or probabilistic method (di-lepton).

CMS 5.0 fb^{-1}
arXiv:1211.2220, submitted to Eur. Phys. J. C

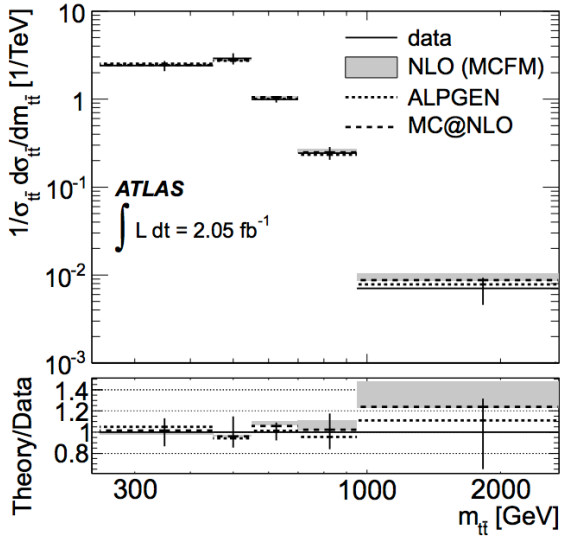
Di-lepton and lepton + jets analyses





ATLAS 2.05 fb^{-1}
arXiv:1207.5677, submitted to Eur. Phys. J. C

Lepton + jets analysis



- Unfold detector effects in data (MC migration matrix, no regularization used for ATLAS analysis)
- Correct for acceptance, luminosity and BR fraction.
- Measurements systematics dominated.

No significant deviation from SM expectations are observed.

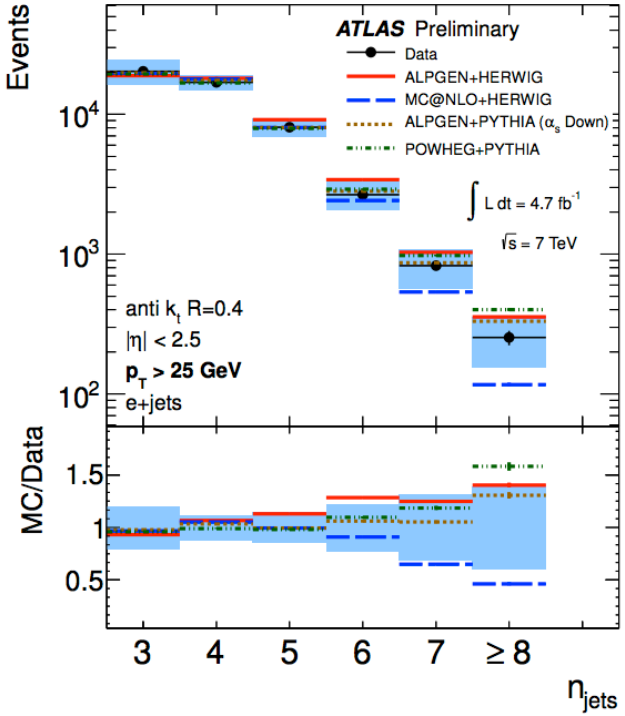
Top quark pair + jets @ 7 TeV

Additional jets in top pair production important for:

- QCD tests at NLO.
- Constraint MC generators ⇒ main source of systematic uncertainty in many top analyses.
- ISR/FSR assessment.
- Background to other signals (e.g. top-Higgs associate production).

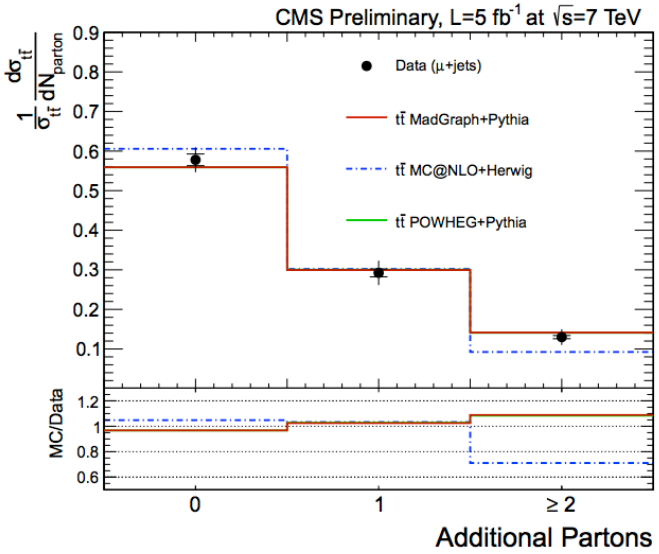
ATLAS 4.7 fb^{-1}
ATLAS-CONF-2012-155

Measurement done in a fiducial region matching the experimental acceptance.



CMS 5.0 fb^{-1}
CMS PAS-TOP-12-018

Additionally: top pair dσ in the number of radiated additional hard partons in the μ+jets channel.



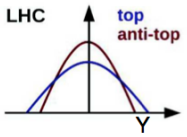
Studies performed for different p_T thresholds: 25, 40, 60, and 80 GeV

- Limited by systematic uncertainties, from background modeling (at lower jet multiplicities) to JES (at higher jet multiplicities).

Results are mostly compatible with various predictions (disagreement with MC@NLO+HERWIG).

Top quark pair Charge Asymmetry @ 7 TeV

Top pair production is symmetric at LO and slightly asymmetric at NLO because of $q\bar{q}$ annihilation production (top emitted preferentially in q direction).



CMS 5.0 fb^{-1}
CMS-TOP-11-030

ATLAS 4.7 fb^{-1}
ATLAS-TOP-CONF-2012-057

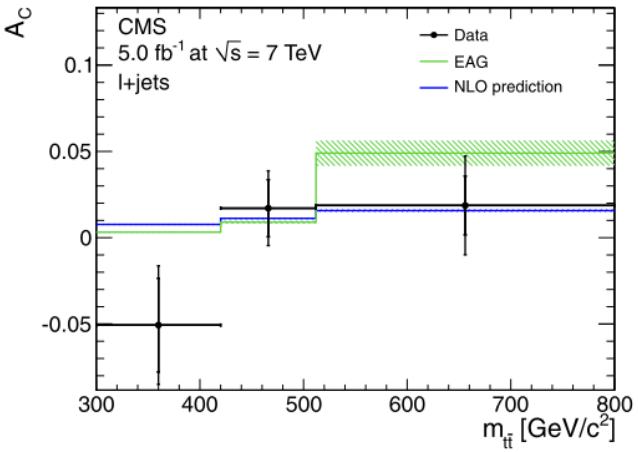
Lepton + jets event selection

- Inclusive $t\bar{t}$ charge asym. measurement.
- Diff. $t\bar{t}$ charge asym. measurements (y, p_T and $m_{t\bar{t}}$)

Di-lepton event selection

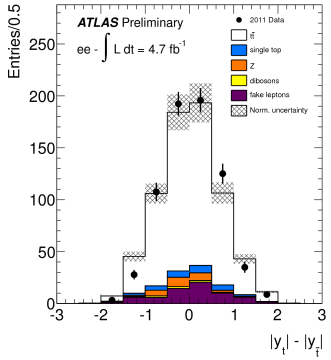
- Inclusive $t\bar{t}$ charge asym. measurement.
- Lepton (ee, $e\mu$ and $\mu\mu$) charge asymmetry measurement.

Likelihood fit to reconstruct the $t\bar{t}$ event topology. Background subtraction and unfolding (correct for acceptance and detector effects).



$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

FB asymmetry



$A^{\ell\ell}_C$ = 0.023 ± 0.012 (stat.) ± 0.008 (syst.)
$A^{\ell\ell}_C$ (SM using MC@NLO) = 0.004 ± 0.001

$A^{t\bar{t}}_C$ = 0.057 ± 0.024 (stat.) ± 0.015 (syst.)

$A^{t\bar{t}}_C$ = 0.004 ± 0.010 (stat.) ± 0.011 (syst.)
$A^{t\bar{t}}_C$(NLO) = 0.0115 ± 0.0006

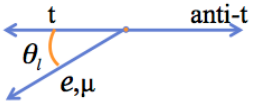
Combination (BLUE):
$A^{t\bar{t}}_C$ = 0.029 ± 0.018 (stat.) ± 0.014 (syst.)
$A^{t\bar{t}}_C$ (SM using MC@NLO) = 0.006 ± 0.002

- Main systematics: Signal and background modeling.

Inclusive and differential measurements are consistent with $A^{t\bar{t}}_C$=0 as well as with NLO predictions.

Top quark polarization @ 7 TeV

SM predicts non-polarized top quarks in top quark pair production
Parity conservation in QCD ⇒ deviation will be a hint of new physics (BSM).
Kinematic top pair decay reconstruction (top direction in top/anti-top center of mass frame).



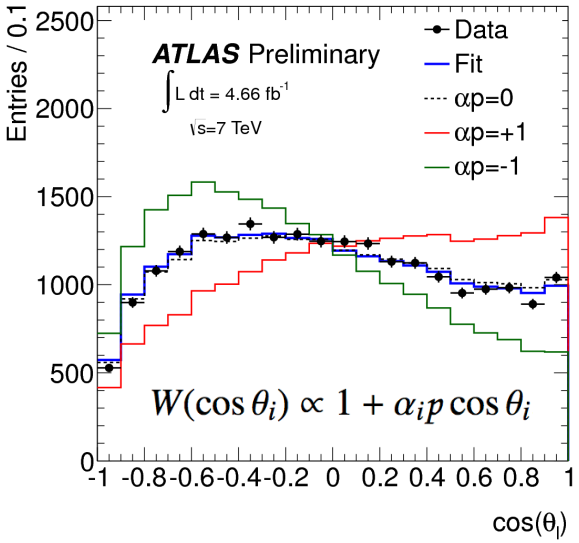
ATLAS 4.66 fb^{-1}
ATLAS-CONF-2012-133

Lepton + jets event selection

Fraction of positively polarized top quarks:

$$f = \frac{1}{2} + \frac{N(\cos\theta_l > 0) - N(\cos\theta_l < 0)}{N(\cos\theta_l > 0) + N(\cos\theta_l < 0)}$$

Template method



$\cos\theta_l$

Polar angle of charged lepton in parent top quark's rest frame

Degree of polarization:

$\alpha_l P = 2f - 1$

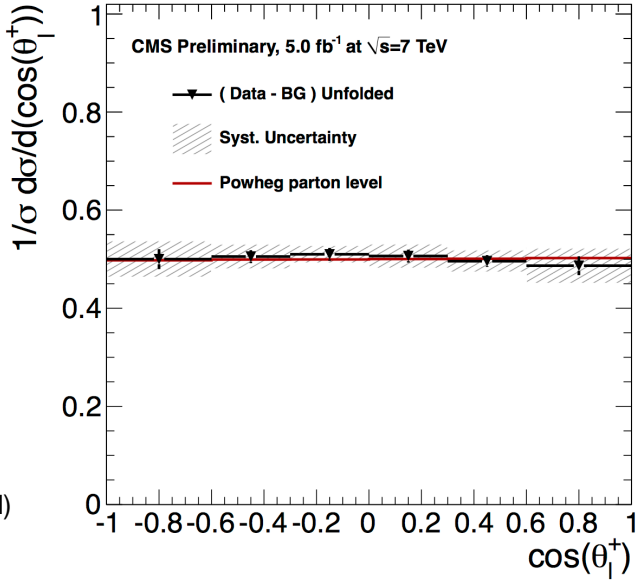
α_l = spin analyzing power = 1 (for SM)
P = degree of polarization along quantization axis

$f = 0.470 \pm 0.009\ (\text{stat})\ ^{+0.023}_{-0.032}\ (\text{syst})$

CMS 2.3 fb^{-1}
CMS-PAS-TOP-12-016

Di-lepton event selection

Kinematic top pair decay reconstruction (top direction in top/anti-top center of mass frame).
Analysis performed using positive leptons.



$P = -0.009 \pm 0.029\ (\text{stat.}) \pm 0.041\ (\text{syst.})$

Compatible with SM predictions: f (SM) = 0.5, P (SM) = 0
Main systematics: jet reconstruction and signal modeling.

Top quark pair spin correlations @ 7 TeV

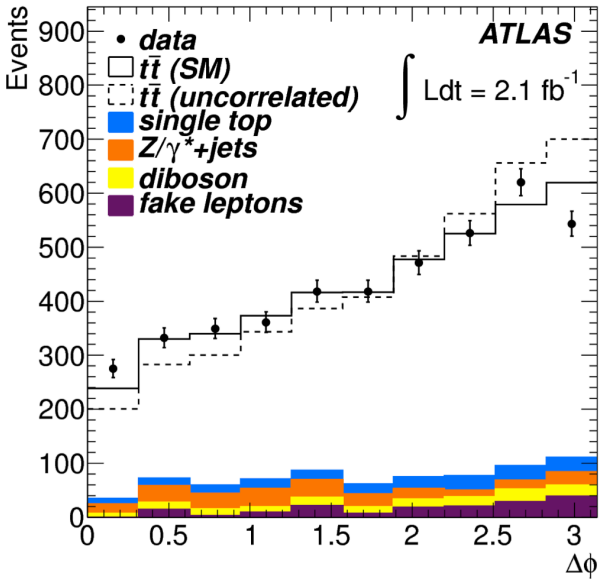
Di-lepton event selection

Spin correlations between top and anti-top.

gg fusion top pair production → *same helicity for top and anti-top*.

- Δφ between leptons (*e*/μ) in lab frame.
- Use helicity basis (*tt̄* rest frame) and "maximal basis".

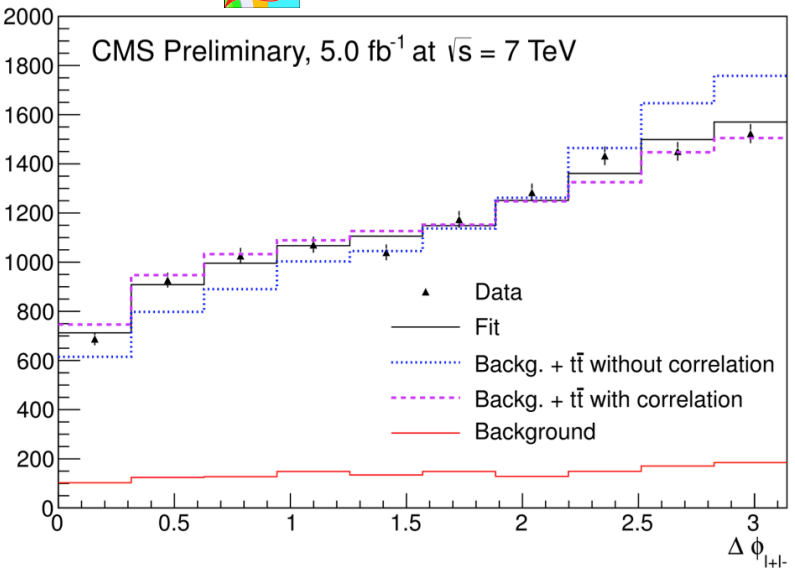
ATLAS 2.1 fb^{-1}
Phys. Rev. Lett. 108 (2012) 212001



$A_{helicity}$ = **0.40 ± 0.04 (stat.) $^{+0.08}_{-0.07}$ (syst.)**

$A_{maximal}$ = 0.57 ± 0.06 (stat.) $^{+0.12}_{-0.010}$ (syst.)

CMS 5.0 fb^{-1}
CMS-TOP-PAS-12-004



Binned maximum likelihood template fit for combined channels:

$A_{helicity}$ = **0.24 ± 0.02 (stat.) ± 0.08 (syst.)**

SM NLO prediction:
$A_{helicity}$ = 0.31
$A_{maximal}$ = 0.44

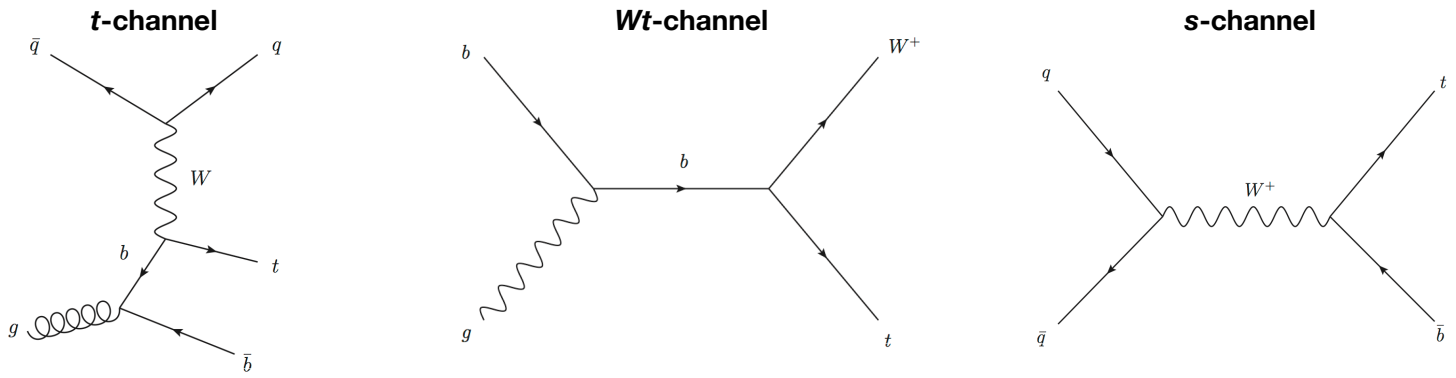
W. Nucl. Phys. B 837, 90 (2010)
WNucl. Phys. B 690, 81 (2004)

The hypothesis of **uncorrelated production is excluded with a significance of 5.1σ.**

- Main systematics: fake leptons

Single top-quark production @ LHC

Discovery of the production of **single top quarks** in 2009 by CDF and by D0.



Production via electroweak interaction

- 3 production mechanisms: ***t*-channel** (higher σ), ***s*-channel** and ***Wt*-channel**.

Motivations for studies of single top quark production

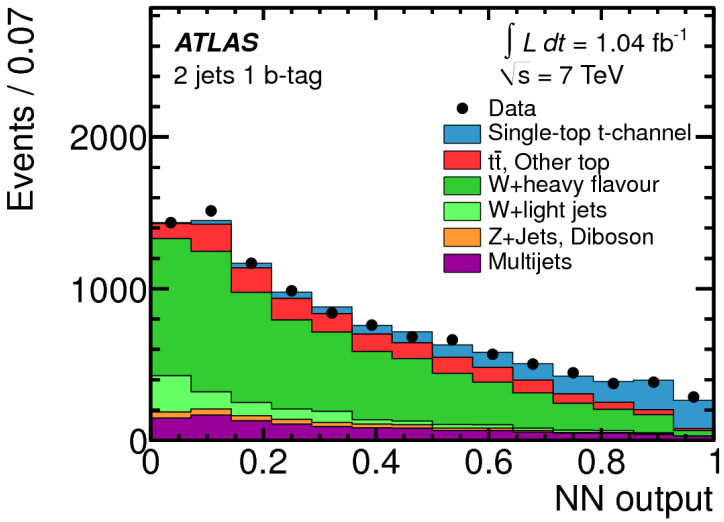
- Cross-section measurement allows to directly access a CKM matrix element: $\sigma \propto |V_{tb}|^2$
- Powerful probe for physics BSM related to EWSB
  - The 3 production modes are sensitive to different forms of new physics: cross-sections, polarization, anomalous couplings, 4th generation, FCNC, W', H+

Single top quark: *t*-channel cross section @ 7 TeV

Lepton + jets event selection

ATLAS 1.04 fb^{-1}
Phys. Lett. B717 (2012) 330-350

Multivariate analysis with maximum likelihood fit on NN output.

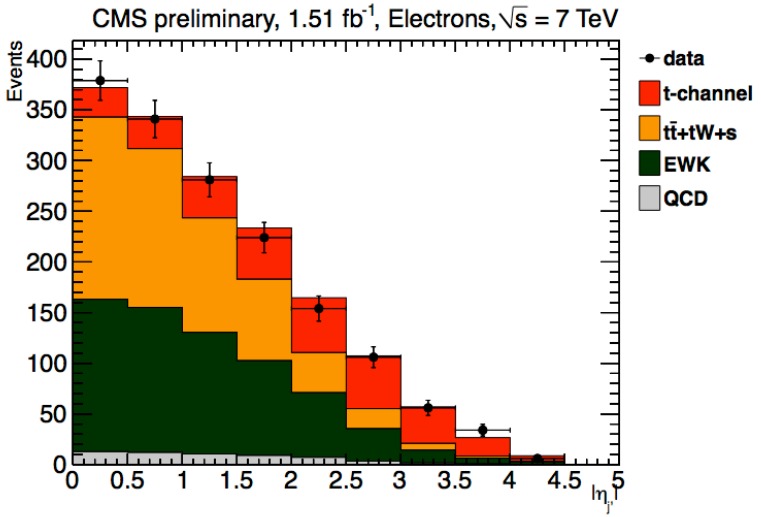


$\sigma_{t\text{-}ch}$ (7TeV) = 83 ± 4 (stat.) ± 20 (syst.) pb
$|V_{tb}|$ = 1.13 ± 0.14
0.75 < $|V_{tb}|$ < 1 @ 95% C.L.

Main Systs: ISR/FSR (14%) and b-tagging modeling (13%).

CMS 1.51 (e) 1.14 (μ) fb^{-1}
CMS-PAS-TOP-11-021

Maximum likelihood fit to the η distribution of the of the light jet.



$\sigma_{t\text{-}ch}$ (7TeV) = 70.2 ± 5.2 (stat.) ± 10.4 (syst.) ± 3.4 (lumi.) pb
$|V_{tb}|$ = 1.04 ± 0.09 (exp.) ± 0.02 (th.)

Main Systs: JES (9%) and *W*+jets (7%).

- Main backgrounds: *W*+jets and top production.

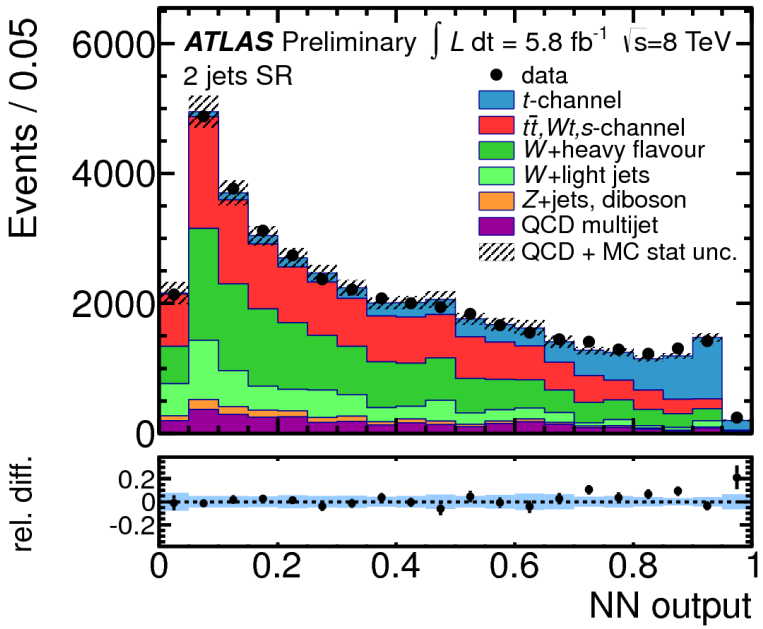
Both measurement are compatible with theoretical prediction: $\sigma_{t\text{-}ch}$ (7TeV) = 64.6 ± 2.4 pb

Single top quark: *t*-channel cross-section @ 8 TeV

Lepton + jets event selection

ATLAS 5.8 fb^{-1}
ATLAS-CONF-2012-132

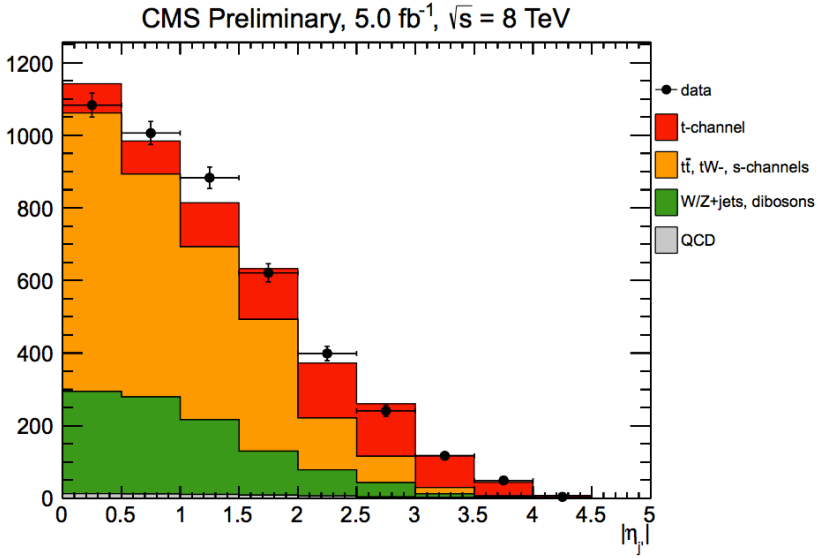
Multivariate analysis with maximum likelihood fit on NN output.



$\sigma_{t\text{-}ch}$ (8TeV) = 95 ± 2 (stat.) ± 18 (syst.) pb
$|V_{tb}|$ = 1.04 ± 0.11
0.80 < $|V_{tb}|$ < 1 @ 95% C.L.

CMS 5.0 fb^{-1}
CMS-PAS-TOP-12-011

Multivariate analysis exploiting the η distribution of the of the light jet and the m_t.



$\sigma_{t\text{-}ch}$ (8TeV) = 80.1 ± 5.7 (stat.) ± 15 (syst.) pb
$|V_{tb}|$ = 0.96 ± 0.08 (exp.) ± 0.02 (th.)
0.81 < $|V_{tb}|$ < 1 @ 95% C.L.

- Main backgrounds: *W*+jets and top production.

Both measurement are compatible with theoretical prediction: $\sigma_{t\text{-}ch}$ (8TeV) = 87.86 ± 3.4 pb

Single top quark: *t*-channel top/anti-top cross section ratio @ 7 TeV

Lepton + jets event selection

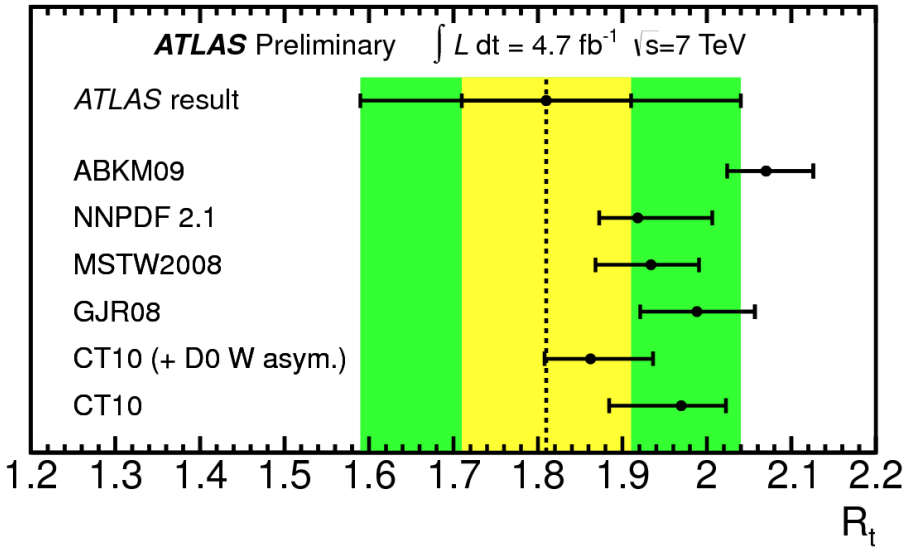
- Binned maximum likelihood fit to the output of NN, split according to the charge of the lepton.
- The ratio $R_t = \sigma_{t\text{-}ch}\,(t) \,/\, \sigma_{t\text{-}ch}\,(tbar)$ is sensitive to PDFs and new physics.

$\sigma_{t\text{-}ch}$ **(*t*, 7TeV) = 53.2 ± 1.7 (stat.) ± 10.6 (syst.) pb**
$\sigma_{t\text{-}ch}$ **(*tbar*, 7TeV) = 29.5 ± 7.5 (stat.) ± 1.7 (syst.) pb**

Extracted total cross-section in agreement with previous measurement

ATLAS 4.7 fb^{-1}
ATLAS-CONF-2012-056

Calculated Rt values for different NLO PDF sets



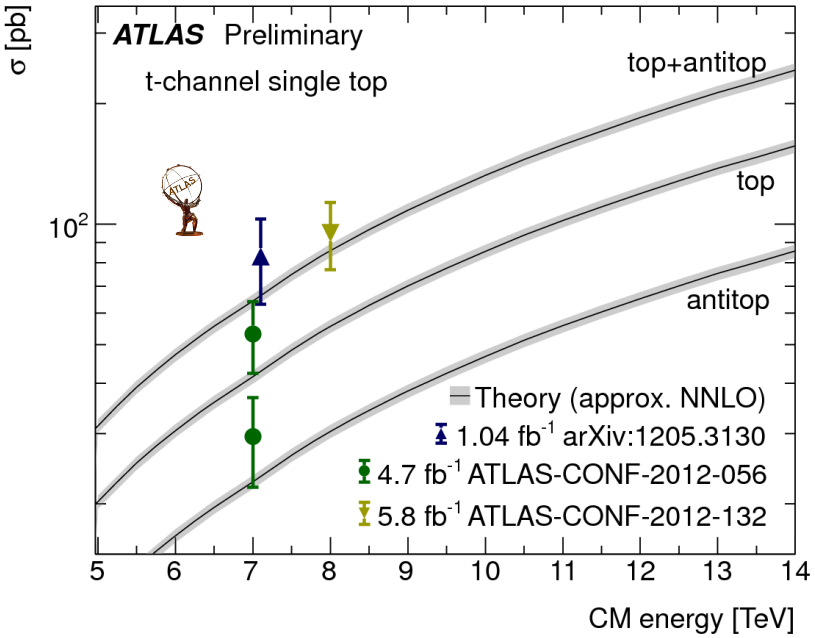
R_t (7TeV) = $\sigma_{t\text{-}ch}$ (*t*) / $\sigma_{t\text{-}ch}$ (*tbar*) = 1.81 ± 0.10 (stat.) ± 0.20 (syst.)

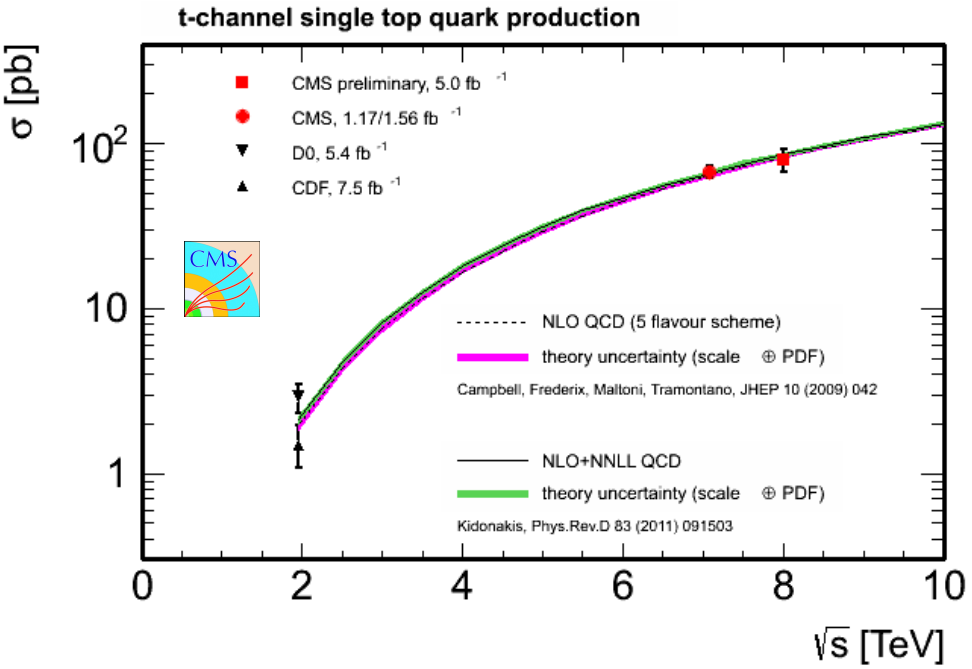
- Main backgrounds: multijets, *W*+jets and top pairs.
- Main Systematics: bkg normalization (5%), ISR/FSR (4%) and JES (4%).
- Ratio measurement reduces systematics mainly on lepton eff, JES and top MC gen.

The measurement is in agreement with the predictions that vary between R_t = [1.86, 2.07].

Single top quark *t*-channel cross-section

Precision achieved in the cross section measurements at 7 and 8 TeV is comparable with theoretical NLO and NNLO predictions.





$$\frac{\sigma_{t\text{-ch}}(8\ \text{TeV})}{\sigma_{t\text{-ch}}(7\ \text{TeV})} = 1.14 \pm 0.12\ (\text{stat.}) \pm 0.14(\text{syst.})$$

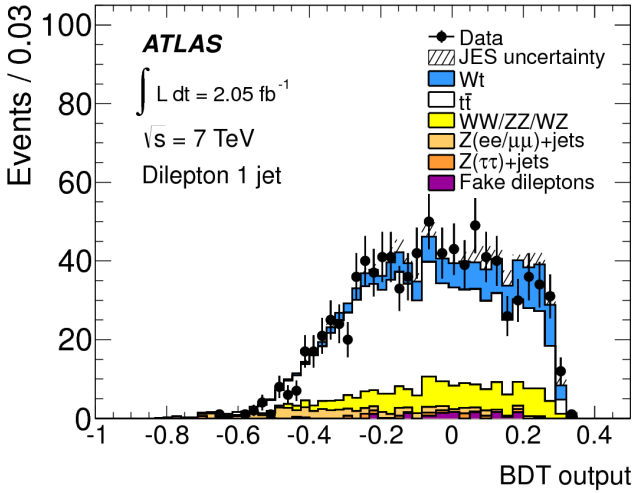
CMS 5.0 fb^{-1}
CMS-PAS-TOP-12-011

Single top quark: *Wt* associated production

Di-lepton event selection analyses

ATLAS 2.05 fb^{-1}
Phys. Lett. B716 (2012) 142-159

Multivariate analysis with profile likelihood fit on boosted decision tree (BDT) output.
Combined fit of 1-jet, 2-jet and ≥3-jets channels.

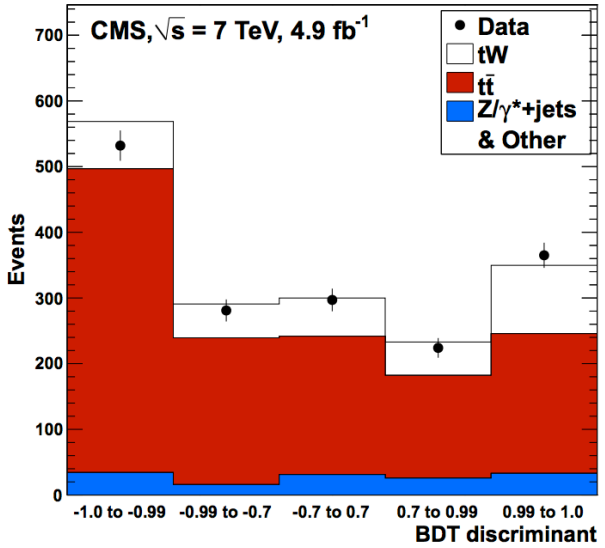


$\sigma_{Wt\text{-}ch}$ (7TeV) = 17 ± 3 (stat.) ± 5 (syst.) pb
$|V_{tb}|$ = 1.03 ± 0.19
3.3σ observed evidence (exp. 3.4σ)

Main Systematics: JES (16%), PS modeling (15%), data stats. (17%).

CMS 4.9 fb^{-1}
CMS-PAS-TOP-11-022

Multivariate analysis with on BDT output.
Combined fit of 1-jet, 2-jets channels.



$\sigma_{Wt\text{-}ch}$ (7TeV) = 16 ± 5 (stat. + syst.) pb
4.0σ observed evidence (exp. 1.8 ± 0.9 σ)

Main Systematics: b-tag (10%), Q^2 (15%), generator model (~9%).

- Main backgrounds: top production.

Both measurement are compatible with theoretical prediction: $\sigma_{Wt\text{-}ch}$ (theory) = 15.7 ± 1.1 pb

Search for resonances decaying to top quark pairs

High mass top pair resonances can lead to strongly boosted top decays:

- top decay products start to merge

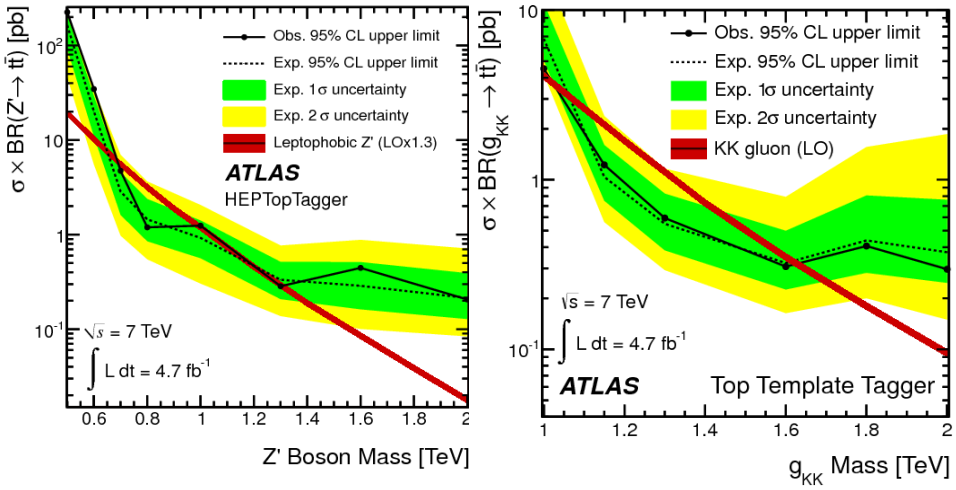
ATLAS 4.7 fb^{-1}
CERN-PH-EP-2012-291

CMS 5.0 fb^{-1}
CMS-PAS-TOP-11-010

Fully hadronic event selection

2 massive jets with large p_T with associated b-quark decay.
Two different methods:

- HEPTopTagger (fat-jets)
- Top Template Tagger (comparison with patterns of E deposition from MC decays).

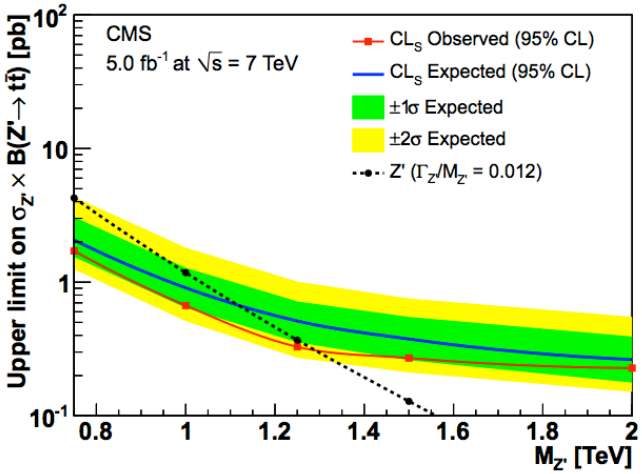


Exclusion mass limits (95% C.L.):

- **Z′ boson: 0.7 – 1 TeV**
- **Leptophobic topcolor Z′:1.28-1.32 TeV**
- **Kaluza-Klein gluons: 0.70-1.62 TeV**

Di-lepton event selection

A multivariate analysis, based on Bayesian Neural Network (BNN).



Exclusion limits (95% C.L.):

- **Z′ boson: 0.75 – 3 TeV**
- **Leptophobic topcolor Z′:1.3-1.9 TeV**

No evidence for a top pair resonance is observed.

Contents

Top quark Physics

- Top quark mass measurements
- Top quark pair production
  - Cross section
  - Differential cross section
  - Top quark pair + jets
  - Charge Asymmetry
  - Polarization
  - Spin correlations
- Single top quark measurements
  - Cross section
  - Cross section ratio
- Search for resonances

Very rich heavy flavor physics program for ATLAS and CMS which is impossible to be covered in this talk.

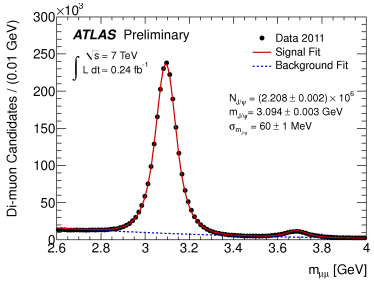
Heavy flavor measurements

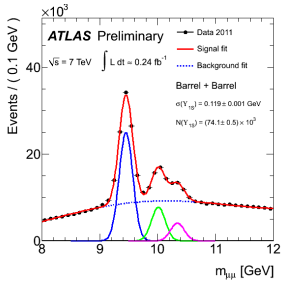
- Mass, lifetime production cross section measurements
- Observations of new particles

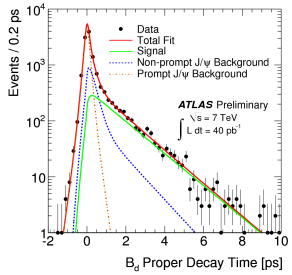
This talk will cover **some of the latest analyses and some of the most important results** achieved by ATLAS and CMS **but not all**. Please, visit:

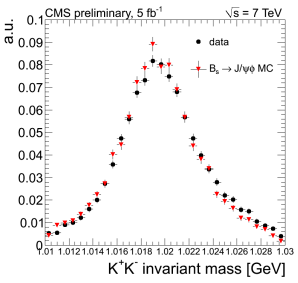
- ATLAS Public Results: *https://twiki.cern.ch/twiki/bin/view/AtlasPublic*
- CMS Public Results: *https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults*

Heavy flavor mass and lifetime measurements

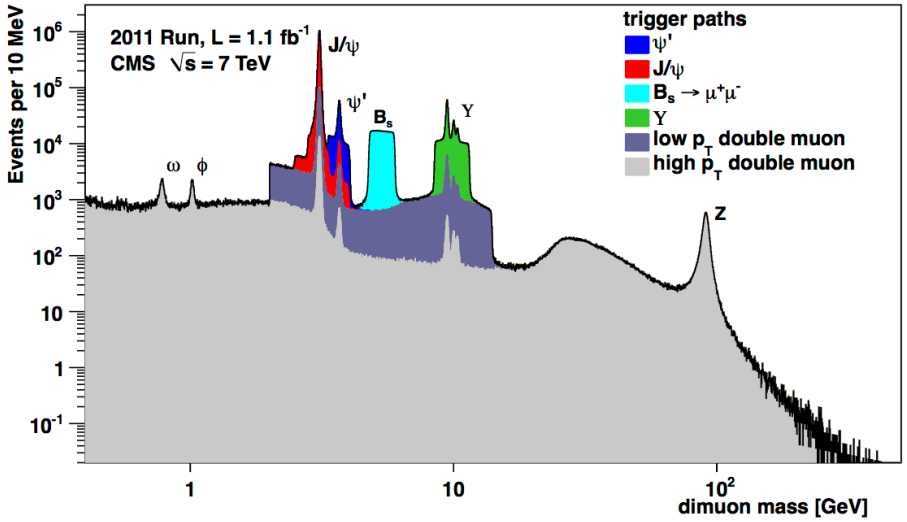


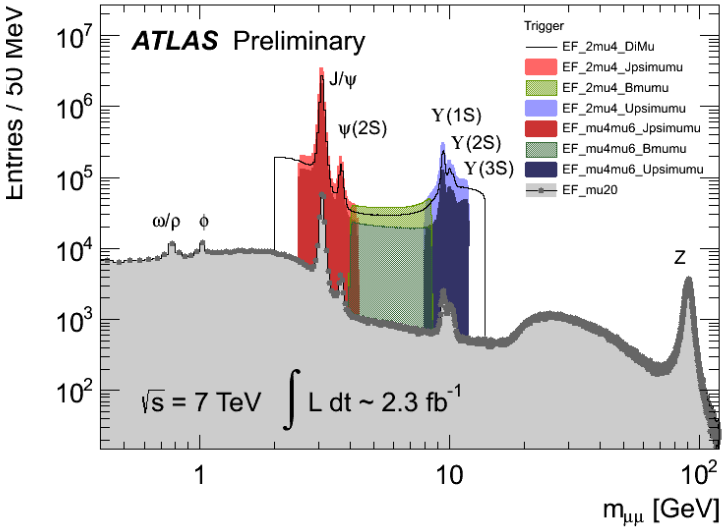






large etc….





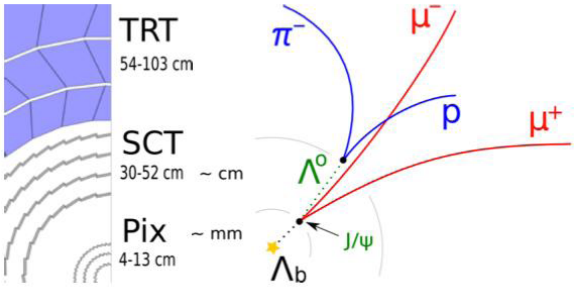
All mass and lifetimes measurements in the charm, onia and beauty production are consistent with PDG values.

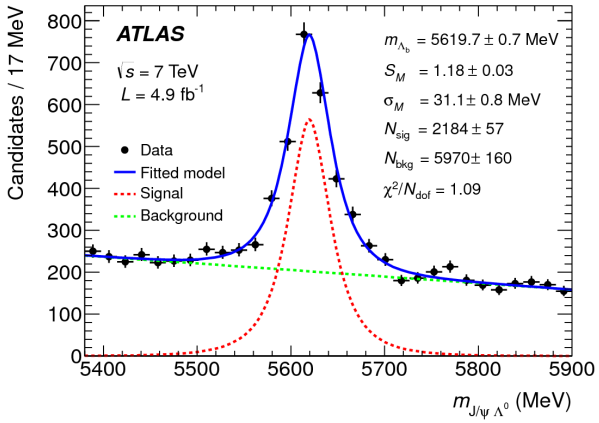
- Impossible to review all the measurements here so I will show you only one of the latest measurements.

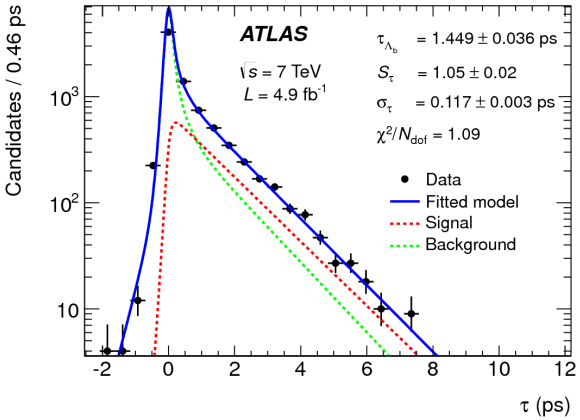
Λ_b (nS) lifetime and mass measurements

Measurement performed on the decay $\Lambda_b \rightarrow J/\psi\, \Lambda^0 \rightarrow \mu\mu\, p\pi$, with mass constraints.

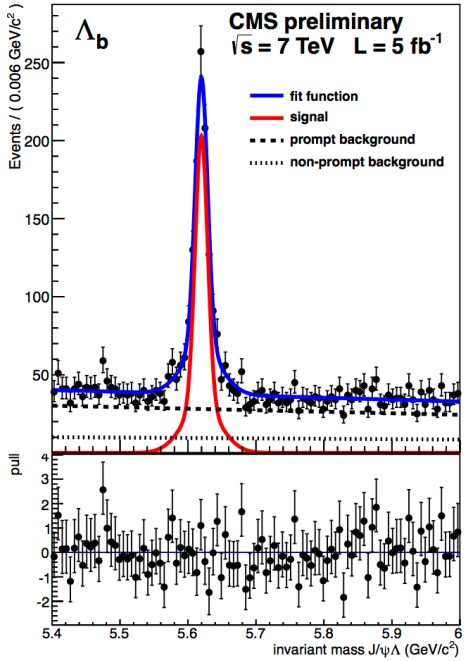
- Cross checks performed on mass and lifetime of B_0.

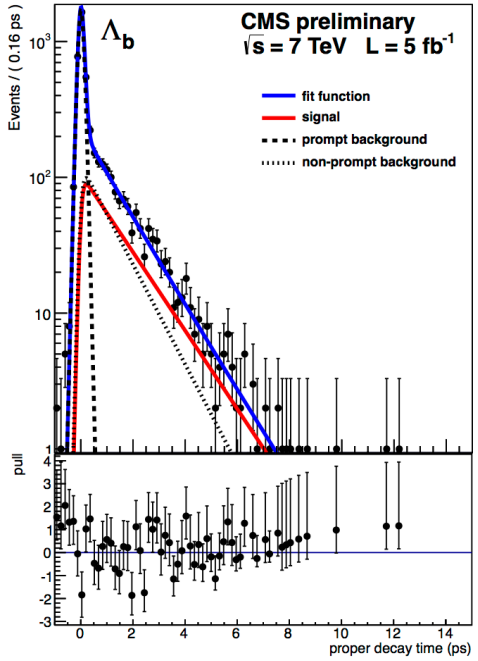






ATLAS 4.9 fb^{-1}
arXiv:1207.2284





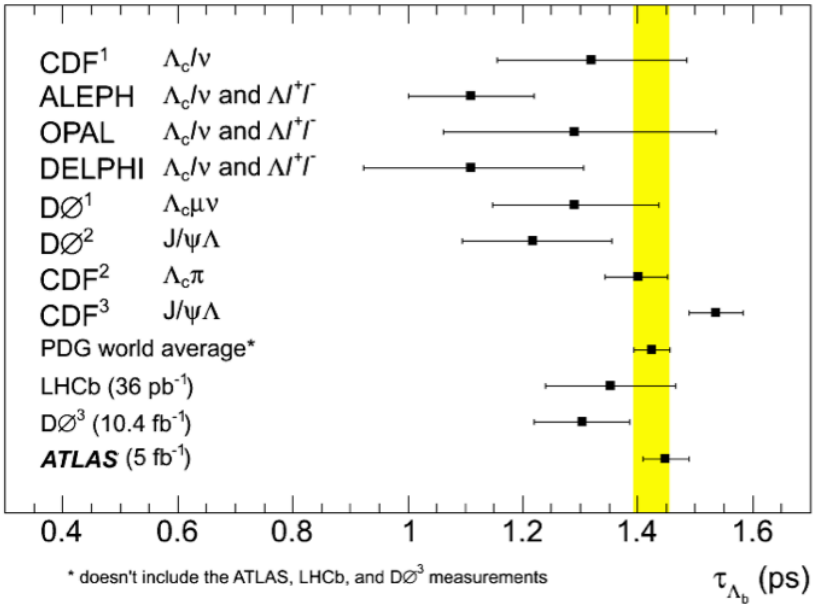
- The results are compatible and competitive with previous best measurements:

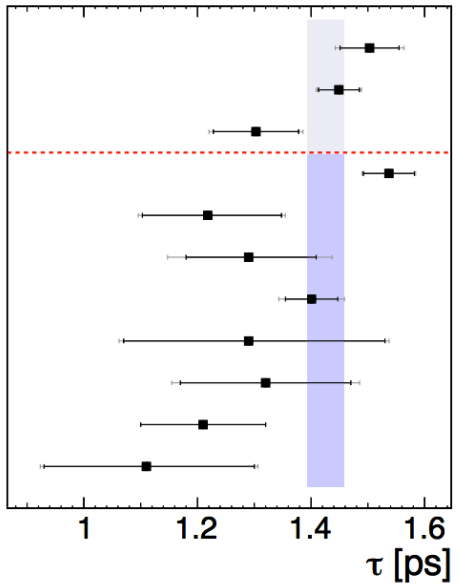
CMS 5.0 fb^{-1}
CMS BPH-11-013

$m(\Lambda_b)$ = 5619.7 ± 0.7 (stat.) ± 1.1 (syst.) MeV
$\tau(\Lambda_b)$ = 1.449 ± 0.036 (stat.) ± 0.017 (syst.) ps

$\tau(\Lambda_b)$ = 1.503 ± 0.052 (stat.) ± 0.031 (syst.) ps

Λ_b (nS) lifetime and mass measurements

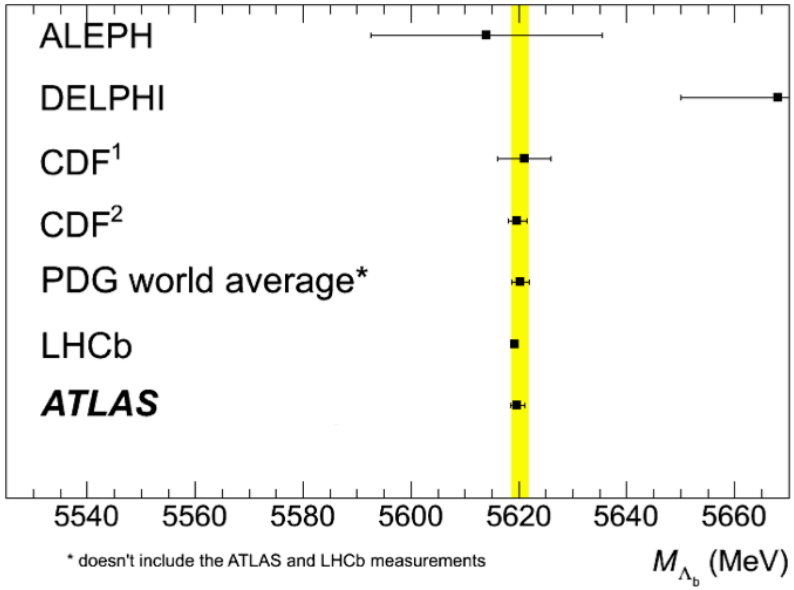




Experiment	Period	Channel
CMS prel.	(2011)	$J/\psi\Lambda$
ATLAS	(2011)	$J/\psi\Lambda$
D0	(02-11)	$J/\psi\Lambda$
CDF2	(02-09)	$J/\psi\Lambda$
D0	(02-06)	$J/\psi\Lambda$
D0	(02-06)	$\Lambda_c^+\mu$
CDF2	(02-06)	$\Lambda_c^+\pi$
OPAL	(90-95)	$\Lambda_c^+ l$, $\Lambda l^- l^+$
CDF1	(91-95)	$\Lambda_c^+ l$
ALEPH	(91-95)	Λl
DELPHI	(91-94)	$\Lambda_c^+ l$

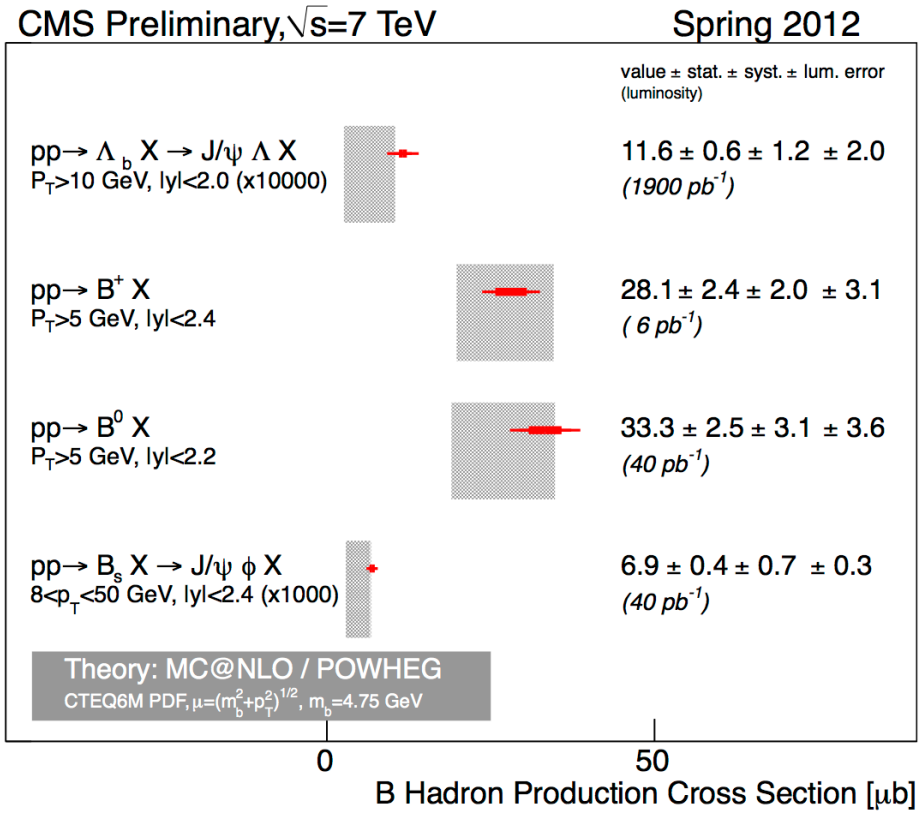
errors in black: statistical only
errors in grey: syst. added in quadrature
band: current best value (PDG)
---- values below used for best value

J. Beringer et al. (Particle Data Group)
Phys. Rev. D86, 010001 (2012)



Λ_b (nS) lifetime and mass measurements are consistent with PDG values.

Production cross section measurements



Cross section measurements mostly in agreement with NLO predictions.

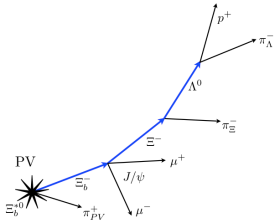
Observation of new particle states

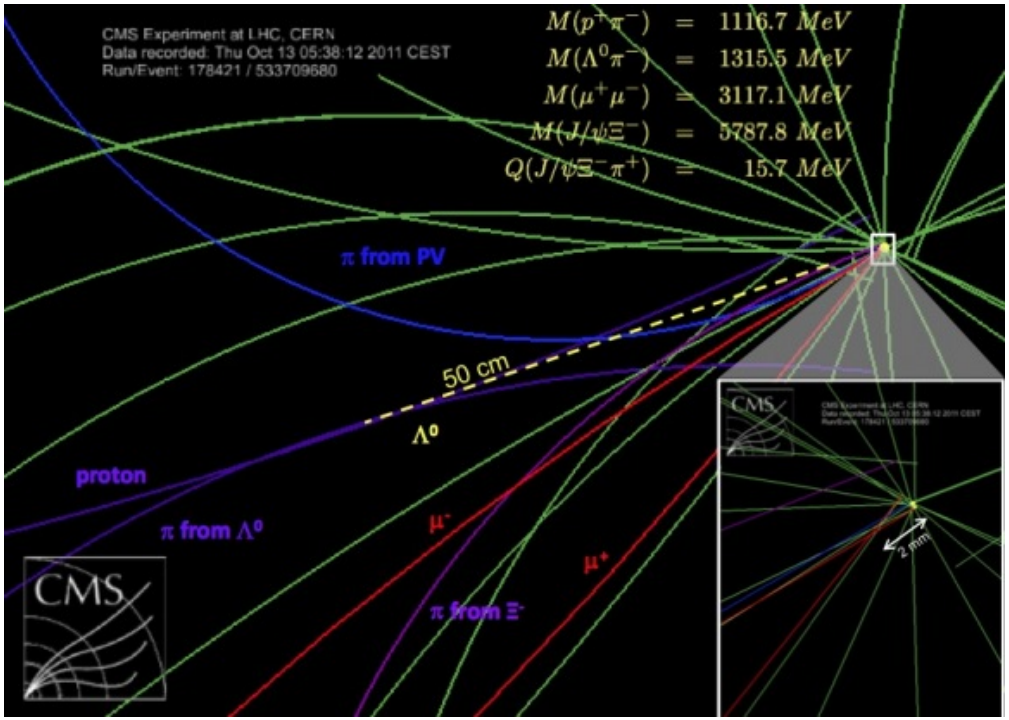
New baryon Ξ_b^{0*}

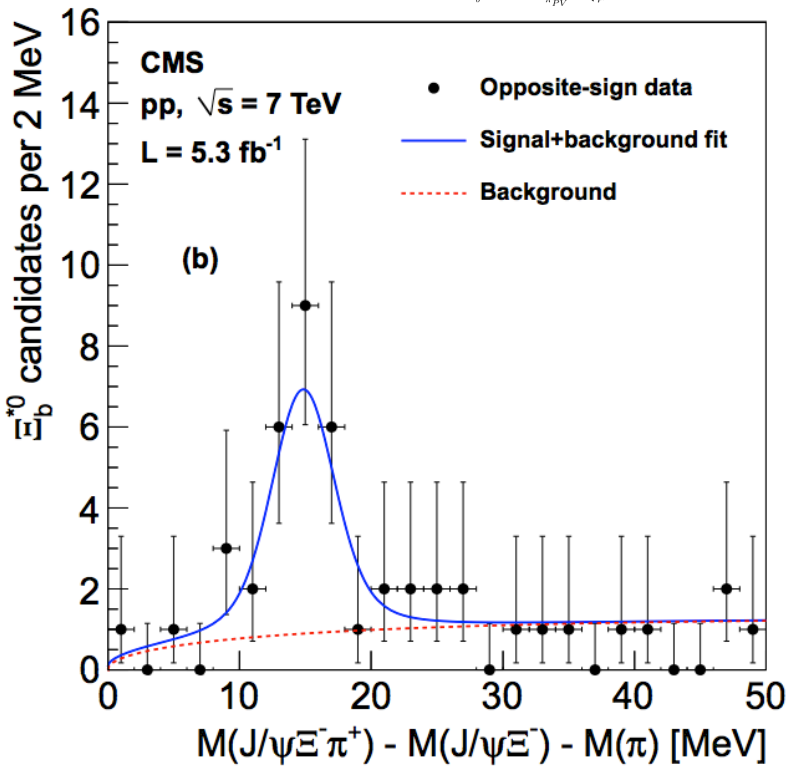
Its ground state is Ξ_b (u, s, b)

$\Xi_b^{0*} \rightarrow \Xi_b^- \pi^+$

CMS 5.3 fb^{-1}
CMS-BPH-12-001







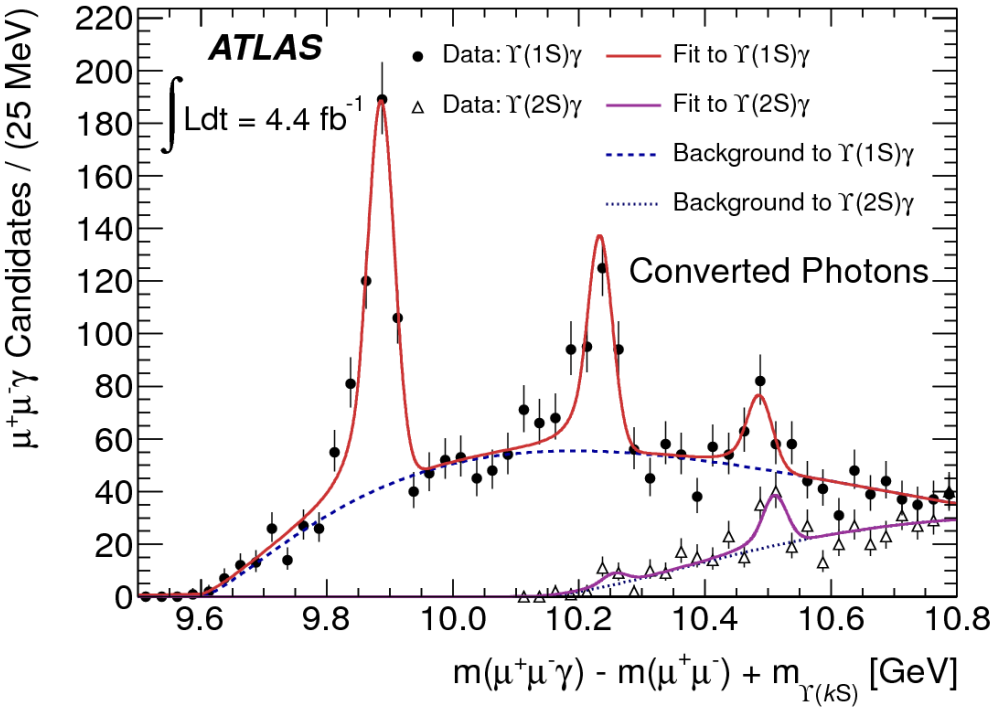
A peak is observed in the distribution of the $m(\Xi_b^- \pi^+) - [\, m(\Xi_b^-) + m(\pi^+)\,]$ with a significance exceeding 5σ.

$m(\Xi_b^{0*}) = 5745.0 \pm 0.7$ (stat.) ± 0.3 (syst.) ± 2.7 (PDG) MeV

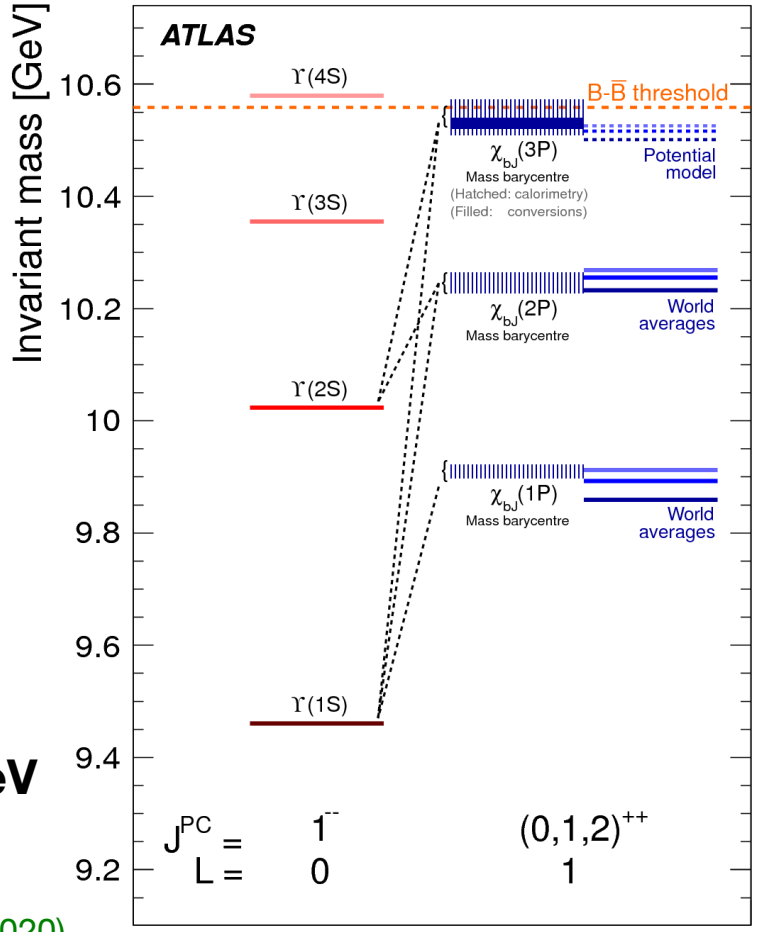
New χ_b ($b\bar{b}$) quarkonium state

Search for radiative decays of χ_b (nP) → Υ(iS)γ → $\mu^+\mu^-\gamma$ with i=1,2.
Mass balance built as m($\mu\mu\gamma$) – [m($\mu\mu$) + m (Υ(iS))] and fitted.

ATLAS 4.4 fb^{-1}
Phys. Rev. Lett. 108 (2012) 152001



Observed bottomonium radiative decays in ATLAS, L = 4.4 fb^{-1}



m (χ_b) = 10.530 ± 0.005 (stat.) ± 0.009 (syst.) GeV
Interpretation as 3P state of χ_b with significance of 6σ.

Confirmed by D0 (arXiv:1203.6034) and LHCb (LHCb-CONF-2012-020)

Conclusions

This talk will cover **some of the latest analyses and some of the most important results** achieved by ATLAS and CMS **but not all**. Please, visit:

- ATLAS Public Results: *https://twiki.cern.ch/twiki/bin/view/AtlasPublic*
- CMS Public Results: *https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults*

Conclusions

ATLAS and CMS have a very rich top quark and heavy flavor physics program.

- This could never be a complete summary!

After the discovery of the top quark at the Tevatron and its “re-discovery” at the LHC, the era of **precision measurements** of its properties has come!

- High production cross section at LHC: top factory!
- Measurements being performed at 7 TeV and 8 TeV.

Top quark physics can answer fundamental questions.

- SM precision measurements.
- Production mechanism: mass, cross section, $|V_{tb}|$ and angular distributions, etc…
- Direct search for resonances.
- Top production is background for most of searches and Higgs production.
- Top quark measurements as a powerful probe of physics BSM.

Heavy Flavor:

- Mass and lifetime measurements.
- Observations of new states.
- Inclusive and exclusive production cross sections.
- Test of BSM phenomena.

Conclusions

So far no hint of new physics or discrepancies from SM.

- In good agreement with SM predictions.
- Generally current precisions are comparable to theoretical predictions.

All measurements are limited by systematic uncertainties.

- New data being analyzed, need to improve our understanding of detector (calibrations) and MC simulation of fundamental processes.
- Higher energy collisions will come with higher pile-up, but not a show stopper.

Looking forward to calibrate and refine the analysis using full statistics at 8 TeV!

- Stay tuned!

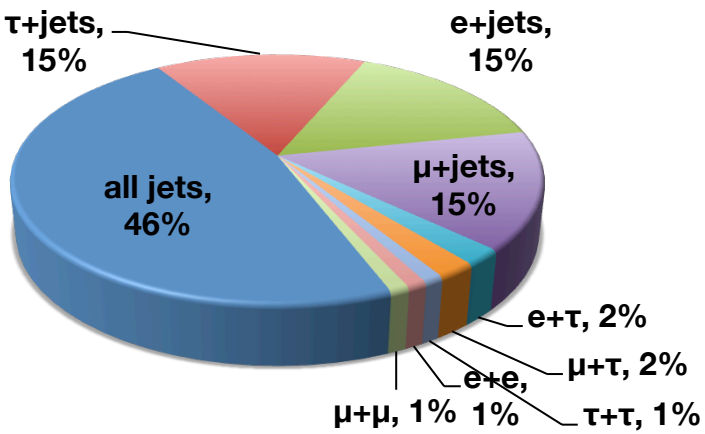
Thank you very much for your attention!

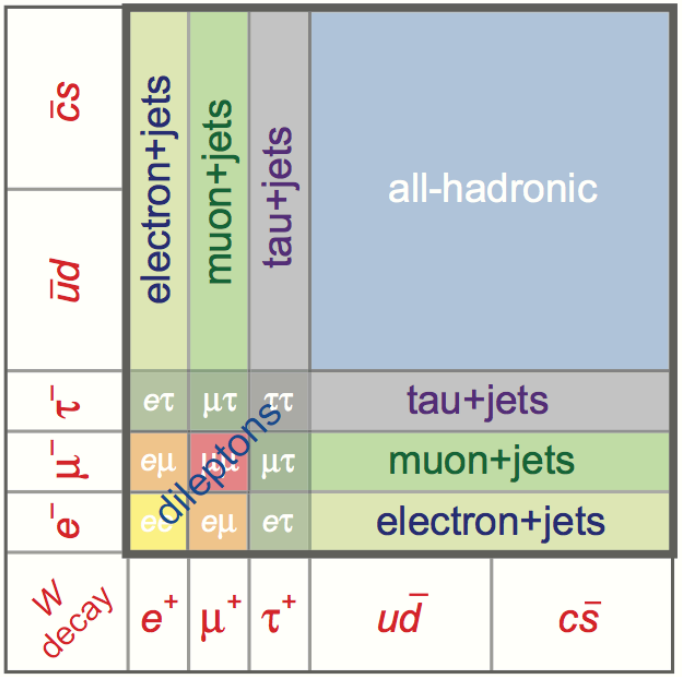
Backup slides

Carlos Escobar (University of Pittsburgh)
on behalf of the ATLAS and CMS Collaborations

Top decay modes and selections

Top-quark pair branching ratios for different topologies





Fully hadronic channel (@ LO):

- Largest statistics: 6 high p_T jets in the final state (4 light jets and 2 b-jets).
- No leptons to trigger on. Important presence of multijets background (low S/B).

Di-lepton channel (@ LO):

- Clean in terms of trigger and selection: 2 high p_T isolated leptons and 2 high p_T b-jets.
- 2 neutrinos in the final state which can introduce reconstruction ambiguities due to the high E_T^{miss}.

Lepton + jets channel (@ LO):

- Large statistics: 4 high p_T jets in the final state (2 light jets and 2 b-jets) and 1 high p_T isolated lepton → high trigger efficiency and good multijets background rejection.
- 1 neutrino in the final state which is easy to reconstruct using E_T^{miss}.

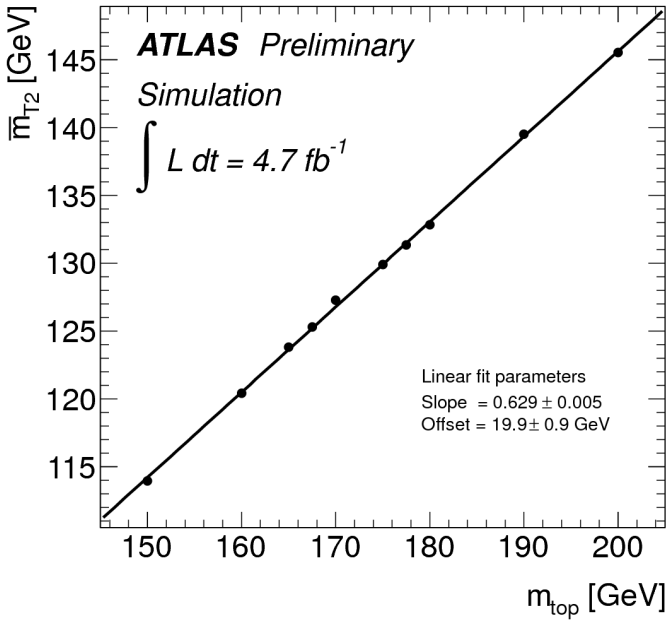
ATLAS 4.7 fb^{-1}
ATLAS-CONF-2012-082

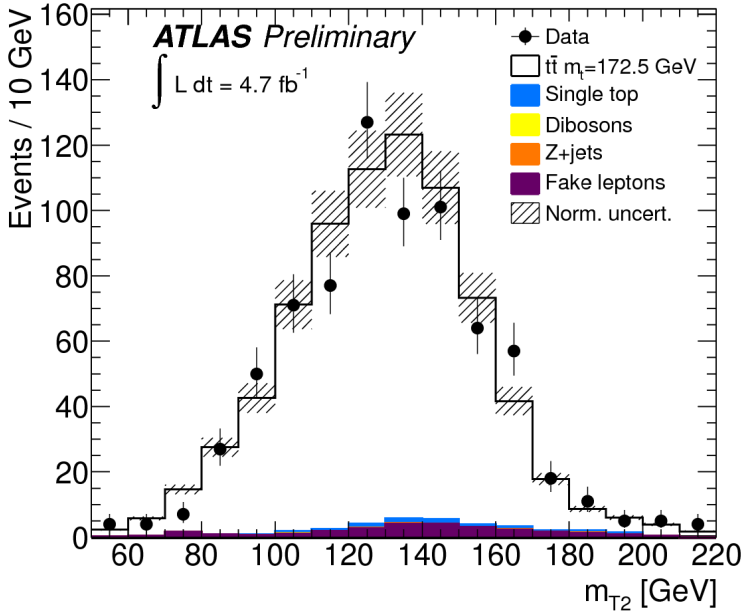
Di-lepton event selection

Based on the transverse mass (m_{T2}) measurement.

- m_{T2} < 220 GeV (reject events with at least one wrongly identified b-jet: eff. 92%)

Calibration using MC samples with different input top-quark masses including all expected backgrounds





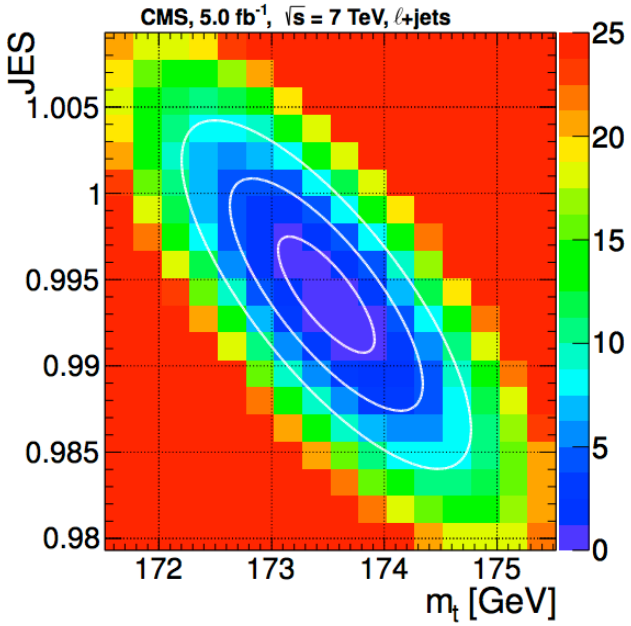
m_t (7TeV, 4.7 fb^{-1}) = 175.2 ± 1.6 (stat.) $^{+3.1}_{-2.8}$ (syst.) GeV

- Main backgrounds: *Z*+jets and fake leptons from *W*+jets and top production
- Main Systematics: JES, b-jet Energy Scale, Color reconnection and MC modeling.

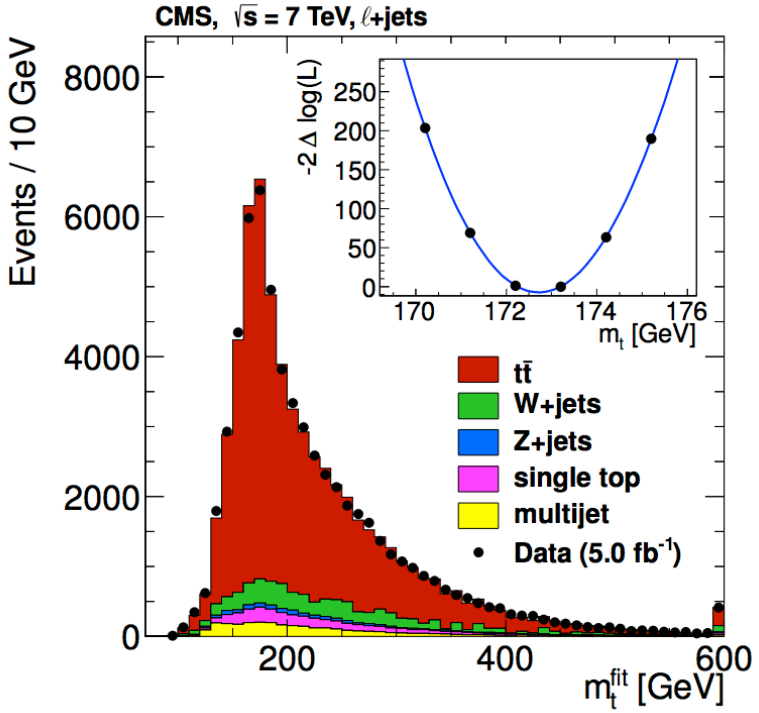
CMS 5.0 fb^{-1}
CMS-TOP-PAS-11-015

Lepton + jets event selection

The analysis employs a kinematic fit of the decay products to a $t\bar{t}$ hypothesis (all permutations are considered) and 2D likelihood functions for each event to estimate simultaneously both the top quark mass and the JES.



The ellipses correspond to statistical uncertainties on m_t and JES of one, two, and three standard deviations.



m_t (7TeV, 5.0 fb^{-1}) = 173.49 ± 0.43 (stat.) ± 0.98 (syst.) GeV
JES = 0.994 ± 0.003 (stat.) ± 0.008 (syst.)

- Main backgrounds: multijets, *W*+jets and top production.
- Main Systematics: JES, b-JES, JER, Renorm. and factorization scale and Fit calib.

CMS 5.0 fb^{-1}
Eur. Phys. J. C72 (2012) 2202

Dileptonic channel

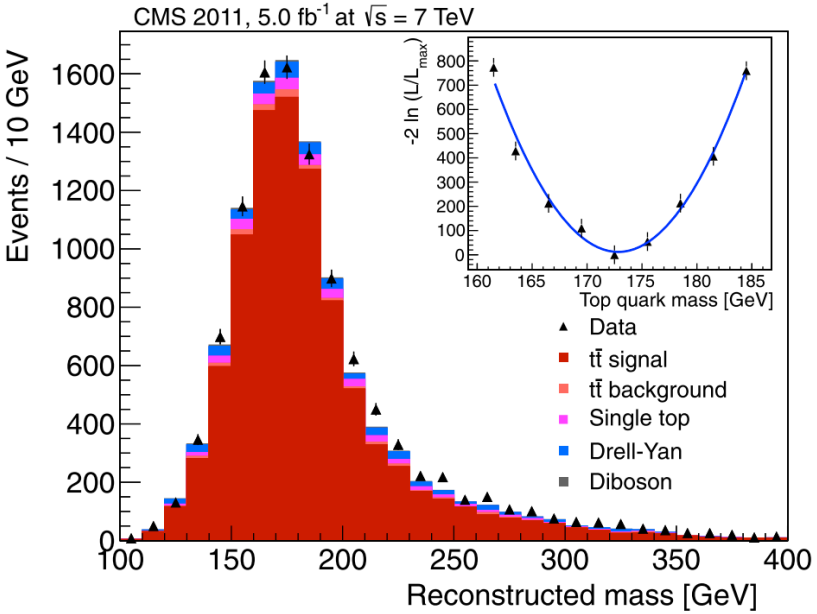
The top-quark mass is reconstructed with an Analytical Matrix Weighting Technique (AMWT) using distributions derived from simulated samples.

A maximum-likelihood fit is used to derive the top-quark mass.

Event selection:

- 2 leptons (e, μ) (p_T>20 GeV), at least 2 jets (p_T > 30 GeV) being at least 1 of them tagged.
- E_T^{miss} > 40 GeV

Main backgrounds: *Z*+jets and fake leptons from *W*+jets and top production



m_t (CMS, 5.0 fb^{-1}) = 172.5 ± 0.4 (stat.) ± 1.5 (syst.) GeV

Main Systematics: Jet Energy Scale, b-jet Energy Scale, Renorm. and factorization scale and Fit calib.

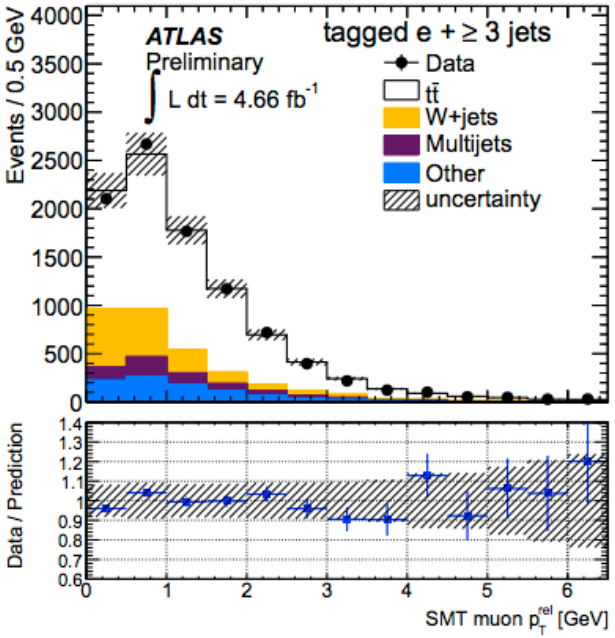
Lepton + jets event selection

Semileptonic *b* decays are identified by a lower p_T muon close to a jet:

- Soft Muon Tagging (SMT) technique.

Top quark pair cross section is computed with:

$$\sigma_{t\bar{t}} = \frac{N_{\text{data}} - N_{\text{bkg}}}{\int L\,dt \cdot \epsilon \cdot BR(\text{noFullHad})}$$



σ_{tt} (7TeV, 4.66 fb^{-1}) = 165 ± 2 (stat.) ± 17 (syst.) ± 3 (lumi.) pb

- Main backgrounds: multijets, *W*+jets and top production.
- Main Systematics: JES, NLO generator, PDF and b→μX BR.

Dileptonic channel

Cross section measurement using a profile likelihood ratio (counting analysis as a cross-check).

Event selection:

- 2 leptons (e, μ) (p_T>20 GeV), at least 2 jets (p_T > 30 GeV) being at least 1 of them tagged.

Main backgrounds: multijets, *W*+jets and top production.

The measured $\sigma_{t\bar{t}}$ depends on the value of the top quark mass used to simulate $t\bar{t}$ events:

$$\sigma_{t\bar{t}}/\sigma_{t\bar{t}}(m_t = 172.5) = 1.00 - 0.008 \times (m_t - 172.5) - 0.000137 \times (m_t - 172.5)^2$$

Channel	PLR method	Counting analysis
ee	$168.0 \pm 6.6^{+7.6}_{-7.0} \pm 3.7$	$165.9 \pm 6.4 \pm 7.0 \pm 3.6$
$\mu\mu$	$156.3 \pm 5.6^{+7.7}_{-6.6} \pm 3.5$	$153.8 \pm 5.4 \pm 6.6 \pm 3.4$
eμ	$161.9 \pm 3.1^{+5.8}_{-5.4} \pm 3.6$	$161.6 \pm 3.1 \pm 5.6 \pm 3.6$
Combined	$161.9 \pm 2.5^{+5.1}_{-5.0} \pm 3.6$	$161.0 \pm 2.6 \pm 5.6 \pm 3.6$

$\sigma_{t\bar{t}}$ (7TeV, 2.3 fb^{-1}) = 161.9 ± 2.5 (stat.) ± 5.1 (syst.) ± 3.6 (syst.) pb

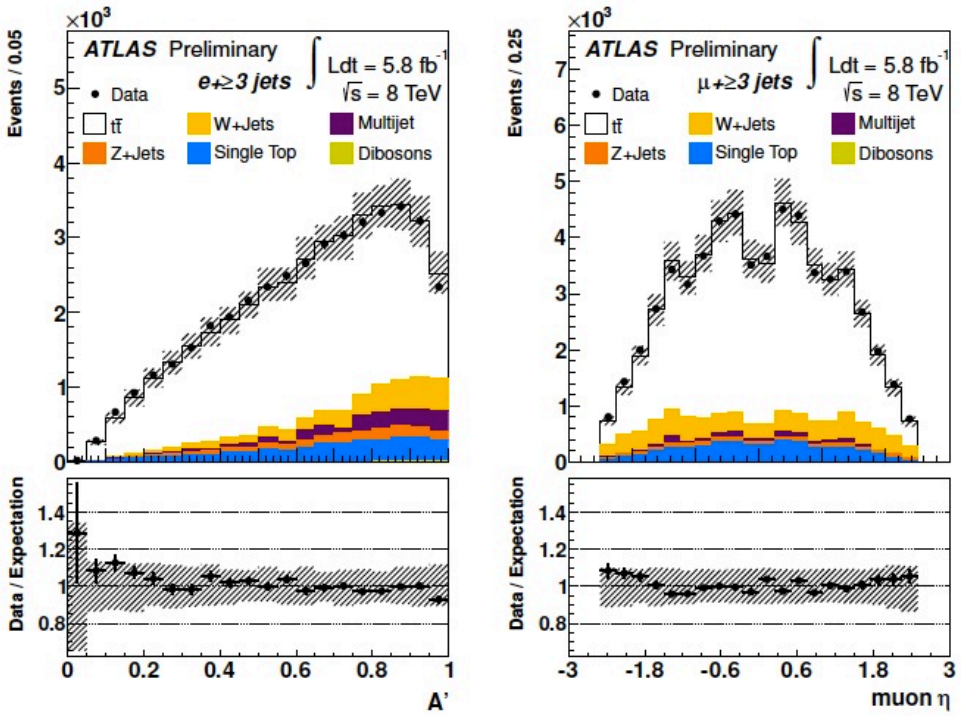
Main Systematics: lepton efficiencies, *W* BR fraction and E_T^{miss} efficiency.

Semileptonic channel

Selection similar to the one at 7 TeV with few updates to cope with a higher pile-up.

- p_T (e, μ) > 40 GeV

Kinematic fit using likelihood discriminant function based on lepton η and transformed aplanarity (A'=e^{-8A}).



$m_{tt̄}$ (ATLAS, 5.8 fb^{-1}) = 241 ± 2 (stat.) ± 31 (syst.) ± 9 (lumi.) pb

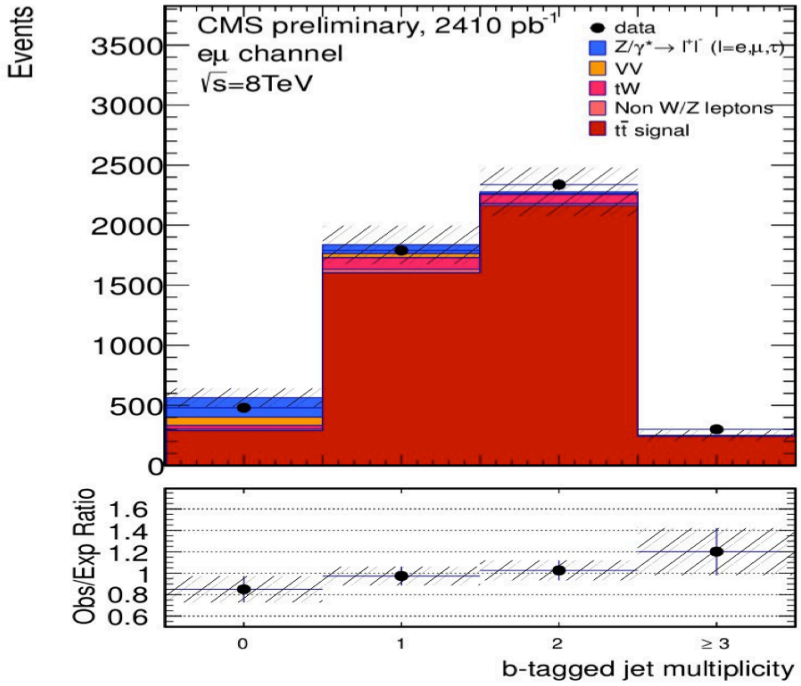
Main Systematics: MC modeling (generator, ISR/FSR), PDF, PS) and Jet/E_T^{miss} reconstruction.

CMS 2.4 fb^{-1}
CMS-TOP-PAS-12-007

Semileptonic channel

Counting experiment.

Very small background contributions ⇒ High purity allows precision measurement with 6% overall uncertainty.



σ_{tt} (CMS, 2.4 fb^{-1}) = 227 ± 3 (stat.) ± 10 (syst.) ± 10 (syst.) pb

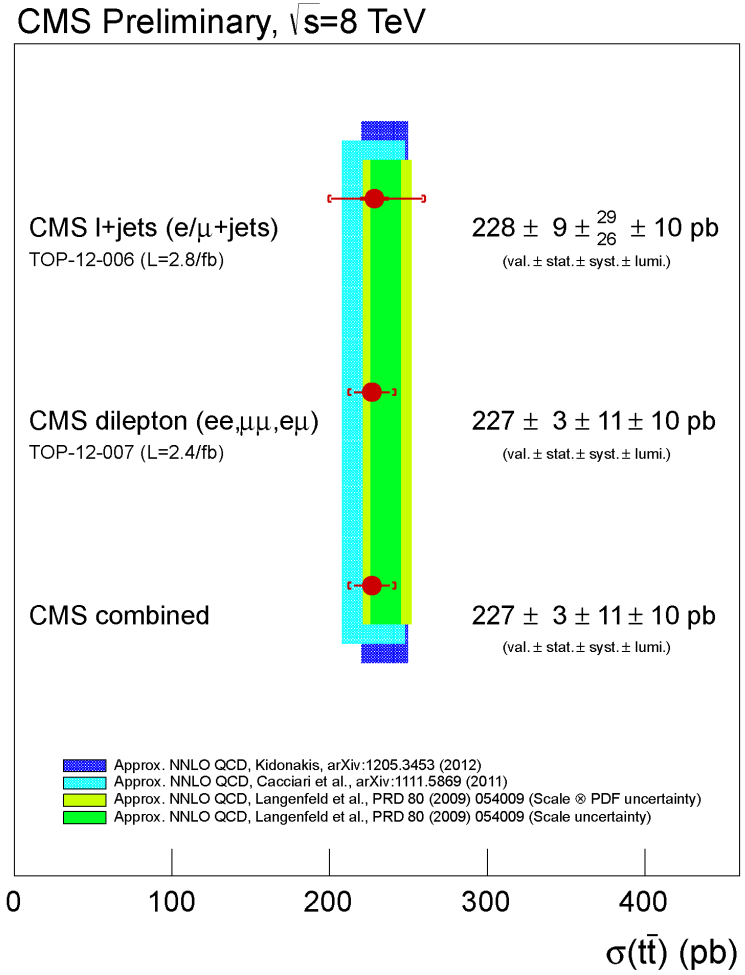
cross section ratio: σ(8TeV)/σ(7TeV) = 1.41 ± 0.11

Main Systematics: JES (2.5%), lepton efficiencies (1.8%) and JER (1.7%).

Top quark pair cross section @ 8 TeV

Top quark cross section is being measured in the lepton + jets and di-lepton channels.

$\sigma_{t\bar{t}}$ (8TeV, 2.4 fb^{-1}) = 227 ± 3 (stat.) ± 21 (syst.) pb



$\sigma_{t\bar{t}}$ (8TeV, 4.7 fb^{-1}) = 241 ± 2 (stat.) ± 40 (syst.) pb

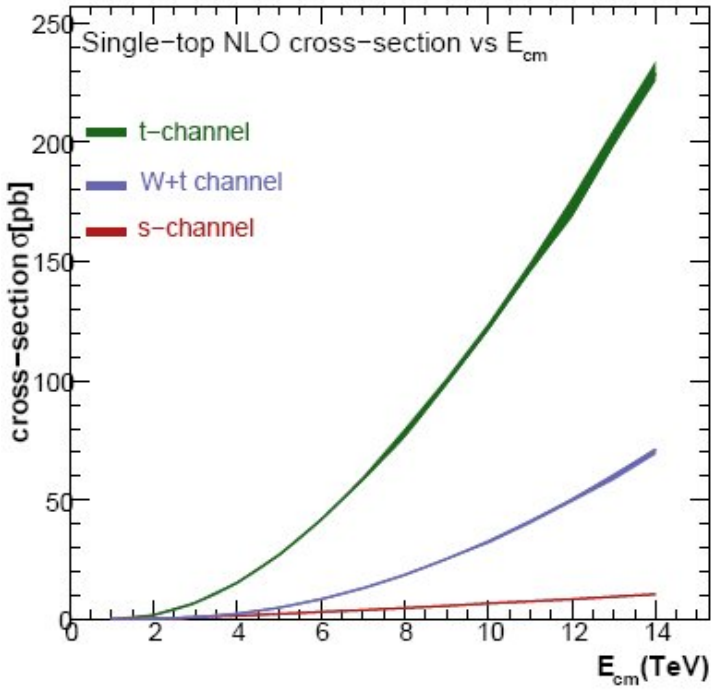
No plot available yet for ATLAS

ATLAS and CMS measurements are in agreement with theoretical prediction: $\sigma_{t\bar{t}}$ (theory) = 238 ± 24 pb

HATHOR, Comput. Phys. Commun., 182 (2011) 1034

Single top quark cross-sections for the different channels

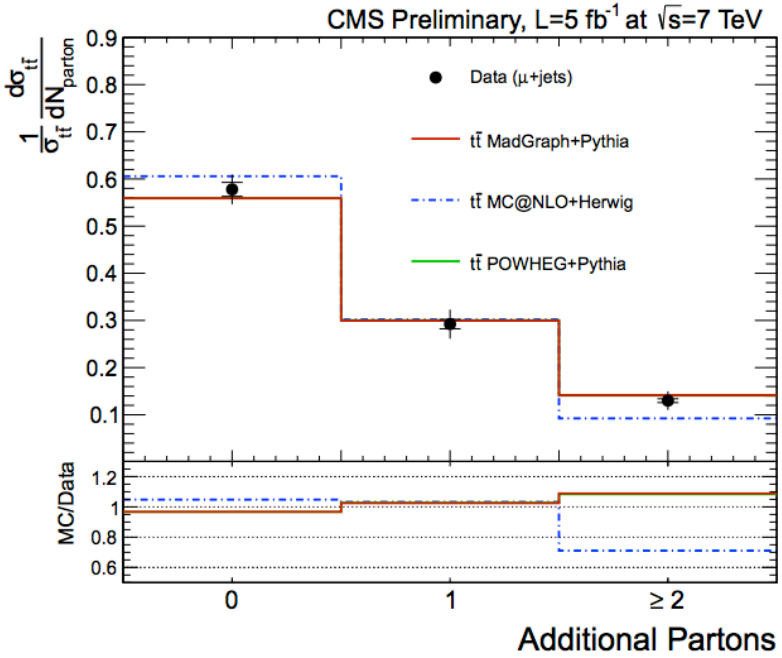
t, *s* and *Wt* cross sections predicted at NLO using the MCFM generator.

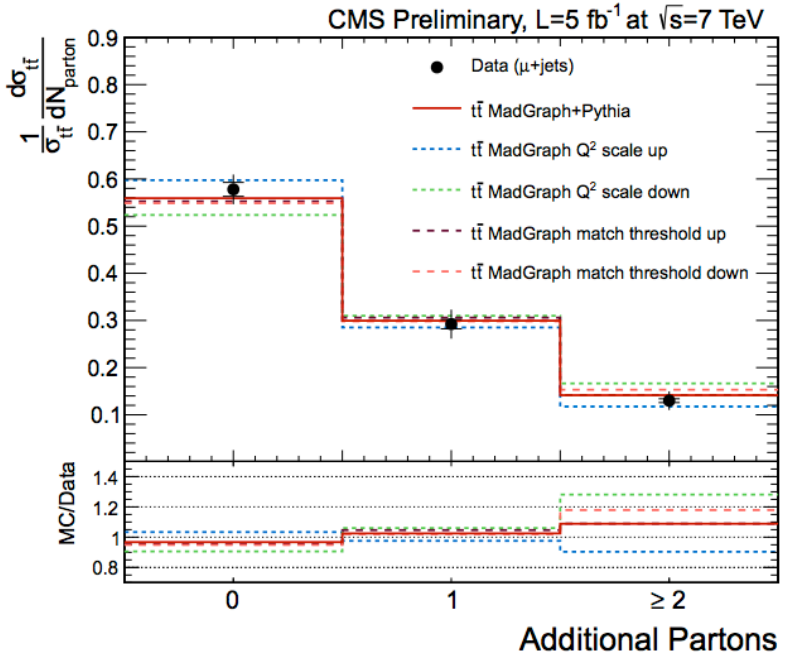


CMS 5.0 fb^{-1}
CMS PAS-TOP-12-018

Equivalent measurement in CMS.

Additionally, the measurement of the **top quark pair differential cross section in the number of radiated additional hard partons** in the muon + jets channel is presented. The measured fractions of events with $t\bar{t}$ + 0, 1, and ≥ 2 additional partons are in good agreement with different MC predictions.

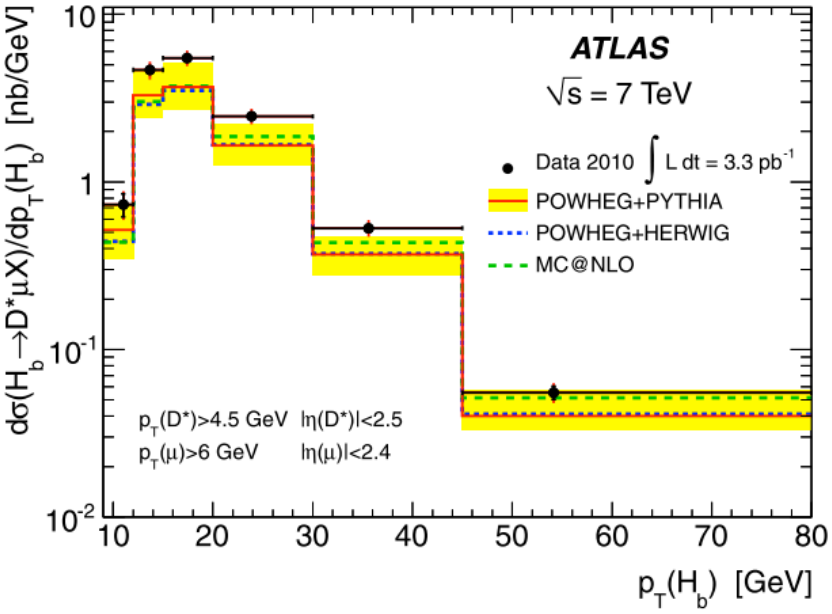


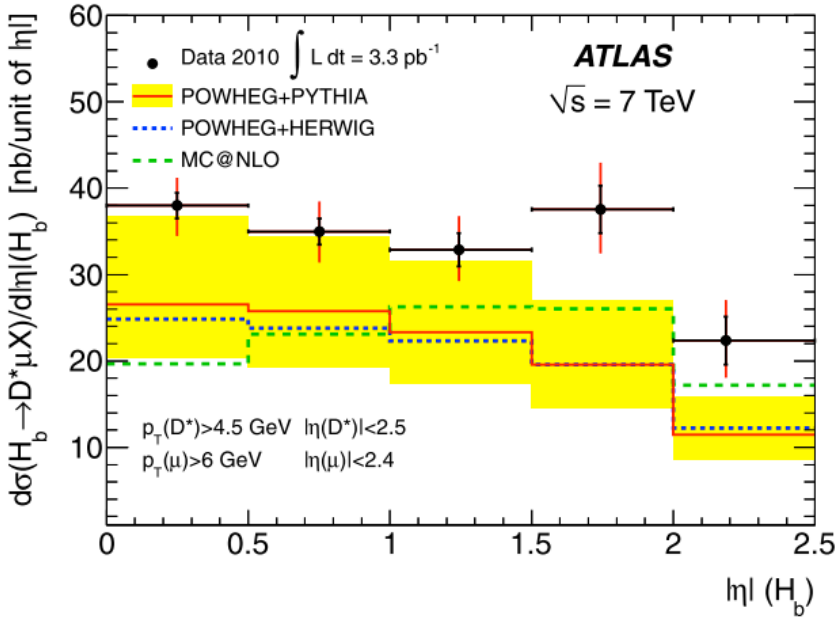


B hadron production cross section

ATLAS 3.3 fb^{-1}
Nucl. Phys. B864 (2012) 341-381

b-hadron production cross section estimated using decays to $D^{*+}\mu^{-}X$ final states.





Search for resonances decaying to top quark pairs

High mass top pair resonances can lead to strongly boosted top decays:

- top decay products start to merge

ATLAS 4.7 fb^{-1}
ATLAS-CONF-012-136

CMS 5.0 fb^{-1}
CMS-PAS-TOP-11-010

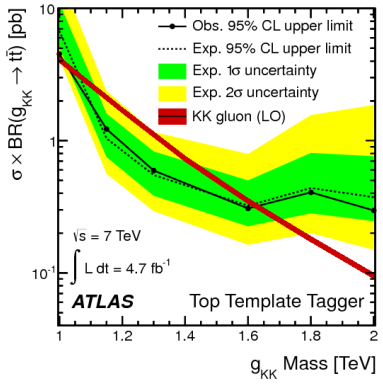
Semileptonic channel
Use a combination of resolved (standard) and boosted (ΔR=1.0 cone jets for hadronic top) reco schemes.

Exclusion limits (95% C.L.):

- **Z′ boson: 0.7 – 2 TeV**
- **Leptophobic topcolor Z′:<1.7 TeV**
- **Kaluza-Klein gluons: <1.9 TeV**

ATLAS 4.7 fb^{-1}
CERN-PH-EP-2012-291

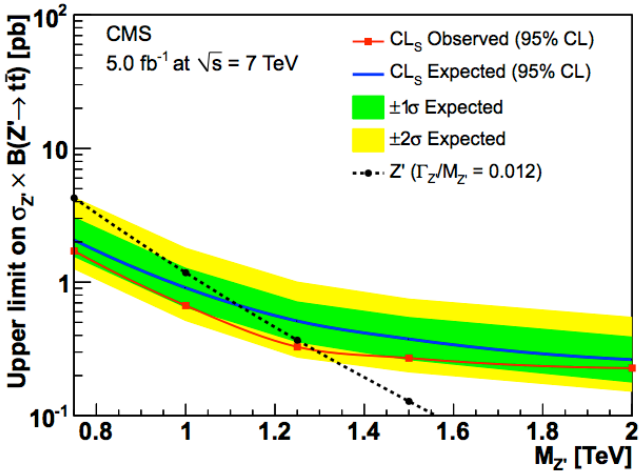
Fully hadronic channel
2 massive jets with large p_T with associated b-quark decay.
Two different methods: HEPTopTagger (fat-jets) and Top Template Tagger (comparison with patterns of E deposition from MC decays).



Exclusion mass limits (95% C.L.):

- **Z′ boson: 0.7 – 1 TeV**
- **Leptophobic topcolor Z′:1.28-1.32 TeV**
- **Kaluza-Klein gluons: 0.70-1.62 TeV**

Dileptonic channel
A multivariate analysis, based on Bayesian Neural Network (BNN).



Exclusion limits (95% C.L.):

- **Z′ boson: 0.75 – 3 TeV**
- **Leptophobic topcolor Z′:1.3-1.9 TeV**

No evidence for atop pair resonance is observed.