Precise measurements of top pair cross-section at LHC : electronic and muonic channels and combinations

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On behalf of the ATLAS and CMS collaborations

Introduction

- Why to perform precise measurements of the $t\bar{t}$ cross section ?
  - Test of perturbative QCD. Approximate NNLO cross section of 164^{+13}_{-10} pb @7TeV, 252^{+27}_{-29} pb @ 8 TeV (HATHOR, Comp.Phys.Commun. 182(2011)1034).
  - Search for new physics.
    - Deviations from SM prediction.
    - Precise estimate of $t\bar{t}$ background for Beyond Standard Model searches.

- High precision measurements become possible.
  - Large $t\bar{t}$ cross section and luminosity => measurements dominated by systematic uncertainties.
  - High statistics in control regions => allows to lower the systematics.

- How to be even more precise ?
  - Combinations of different channels (statistically independent, different systematic sources).
  - Combination of ATLAS and CMS measurements => TOPLHCWG.

Introduction (2)

- Most interesting channels for precise measurements :
  - Leptonic decay channels :
    - contain at least one muon or electron => efficient in QCD multi-jet rejection,
    - easier to trigger because of isolated high p_T leptons, better control of event selection (exploit efficient and pure lepton selection and identifications strategies),
    - presence of Missing E_T (MET) helps to reject backgrounds,
    - leads to lower systematics (less sensitive to the description of jets).
  - Have good signal over noise ratios : the more leptons, the less backgrounds. With luminosities, the dilepton channels start to be competitive with the l+jets channels (especially in the eμ channel).

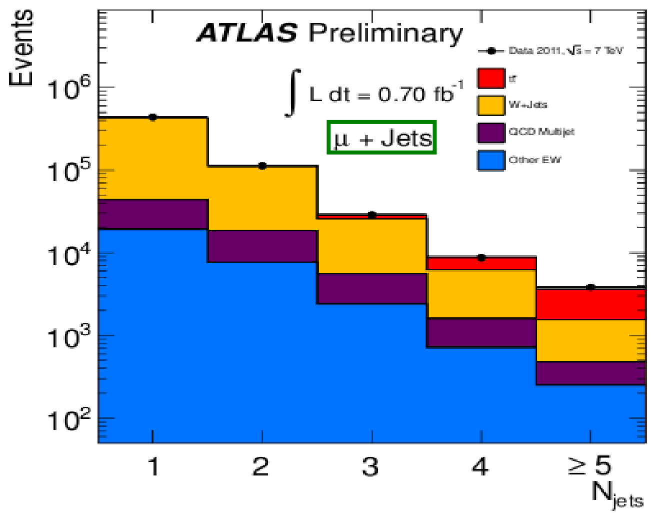
- "Golden channels" for precise top pair cross-section measurement :
  - Lepton+jets, with leptons being electrons or muons, high statistics, limited backgrounds mainly coming from W+jets, QCD multi-jets.
  - Dilepton, with leptons being electrons or muons, lower statistics but compensated by high lumi, low backgrounds mainly Z+jets or dibosons.

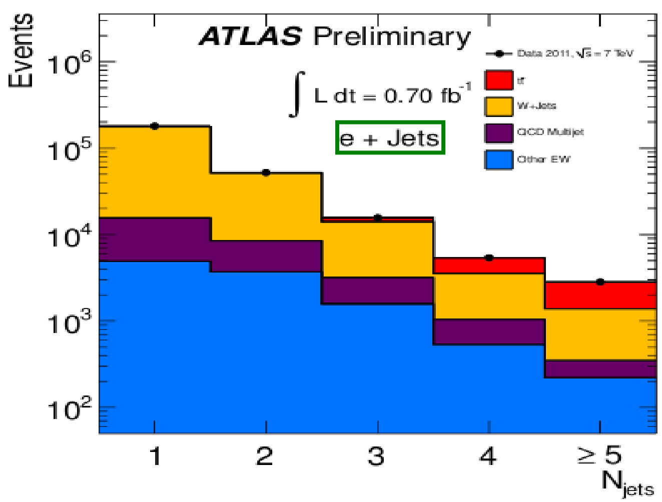
Top pair cross sections @7 TeV in the lepton+jets channel

Lepton+jets channel at ATLAS (1)

ATLAS-CONF-2011-121

- Luminosity = 0.70 fb^{-1}.
- Event selection:
  - Single lepton trigger.
  - = 1 reconstructed, isolated and identified lepton with E_T> 25 GeV for electrons (p_T>20 GeV for muons) and |η|<2.5.
  - ≥ 3 Jets with p_T>25 GeV and |η|<2.5.
  - MET> 35 GeV for electron+jet, 25 GeV for muon+jets
  - m_T(W)>25 GeV and MET+m_T(W) > 60 GeV.
- Corrections to the simulations :
  - Lepton efficiencies and resolutions compared to Z->ll events in data.

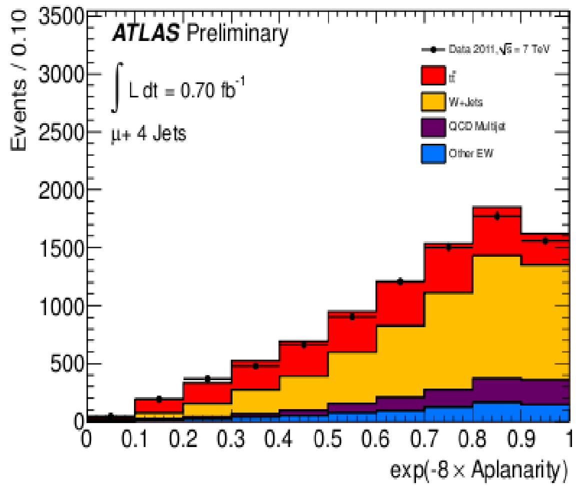


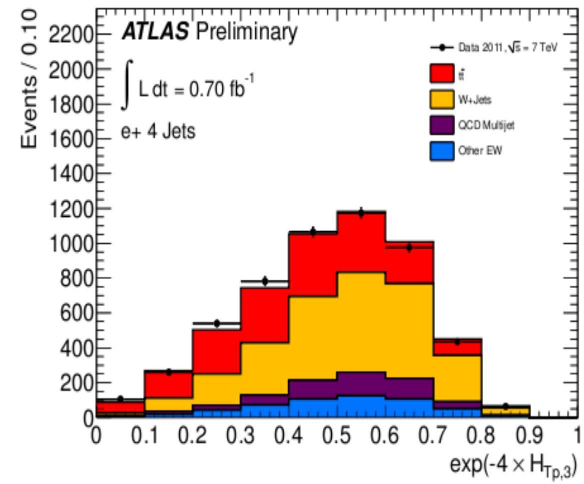


Lepton+jets channel at ATLAS (2)

ATLAS-CONF-2011-121

- Background determination from data :
  - W+jets : estimated using the charge asymmetry of W events,
  - QCD multi-jets : estimated using a Matrix Method.





- Other backgrounds (Z+jets, single top and diboson) are determined using simulations.

- Measurement strategy : maximum likelihood fit (profile) of a discriminating distributions. Combination of η_l, p_T of leading jet, Aplanarity (top events more "spherical"), $H_{T,3p}$(top events are more transverse).
- Likelihood defined as :

σ_{tt}, backgrounds — Detector-related syst.

$$\mathcal{L}(\vec{\beta},\vec{\delta}) = \prod_{k=1}^{120} \mathcal{P}(\mu_k, n_k) \times \prod_j \mathcal{G}(\beta_j, \Delta_j) \times \prod_i \mathcal{G}(\delta_i, 1)$$

Background normalization constrained by the fit

Poisson proba. density to observe n_k when μ_k is expected

Free parameters constrained by Gaussian distributions

Introduce sytematics as nuisance parameters

Lepton+jets channel at ATLAS (3)

Uncertainty	up (pb)	down (pb)	up (%)	down (%)
Statistical	3.9	−3.9	2.2	−2.2
Detector simulation				
Jets	3.2	−4.3	1.8	−2.4
Muon	4.1	−4.1	2.3	−2.3
Electron	2.7	−3.0	1.5	−1.7
E_T^{miss}	2.0	−1.6	1.1	−0.9
Signal model				
Generator*)	5.4	−5.4	3.0	−3.0
Hadronization*)	0.9	−0.9	0.5	−0.5
ISR/FSR	3.0	−2.3	1.7	−1.3
PDF*)	1.8	−1.8	1.0	−1.0
Background model				
QCD shape*)	0.7	−0.7	0.4	−0.4
W shape*)	0.9	−0.9	0.5	−0.5
Monte Carlo statistics*)	3.2	−3.2	1.8	−1.8
Systematic	9.0	−9.0	5.0	−5.0
Stat. & Syst.	9.8	−9.8	5.4	−5.4
Luminosity	6.6	−6.6	3.7	−3.7
Total	11.8	−11.8	6.6	−6.6

ATLAS-CONF-2011-121

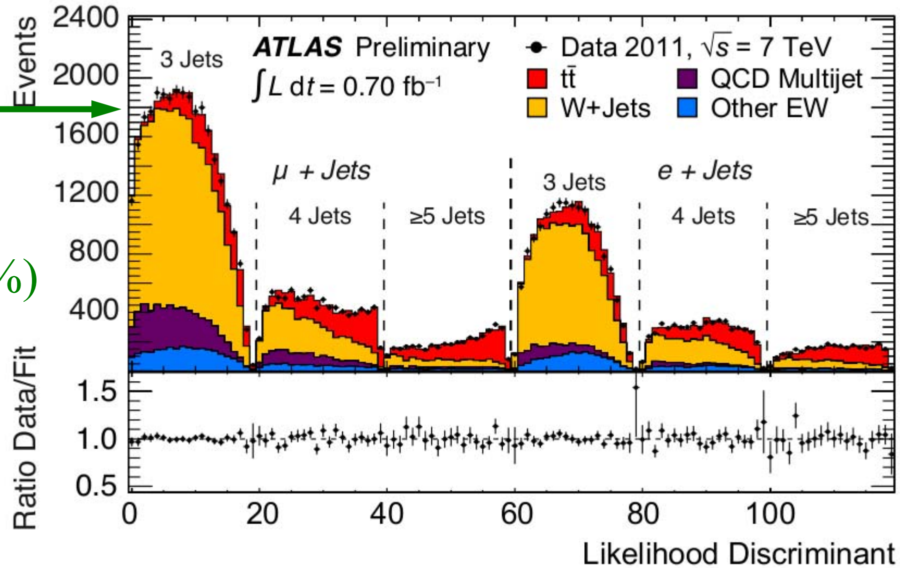
- Main uncertainties:
  - Dominated by systematic uncertainties.
  - Main systematics from luminosity (prelim.), generator (estimated by comparing MC@NLO and POWHEG), jet and muon selection.

- Discriminant after the fit.
- Measured cross section :

$$\sigma_{t\bar{t}} = 179.0 \pm 3.9\,(\text{stat}) \pm 9.0\,(\text{syst}) \pm 6.6\,(\text{lumi})\ \text{pb} \quad (7\%)$$

- Cross section dependence on the top-quark mass :

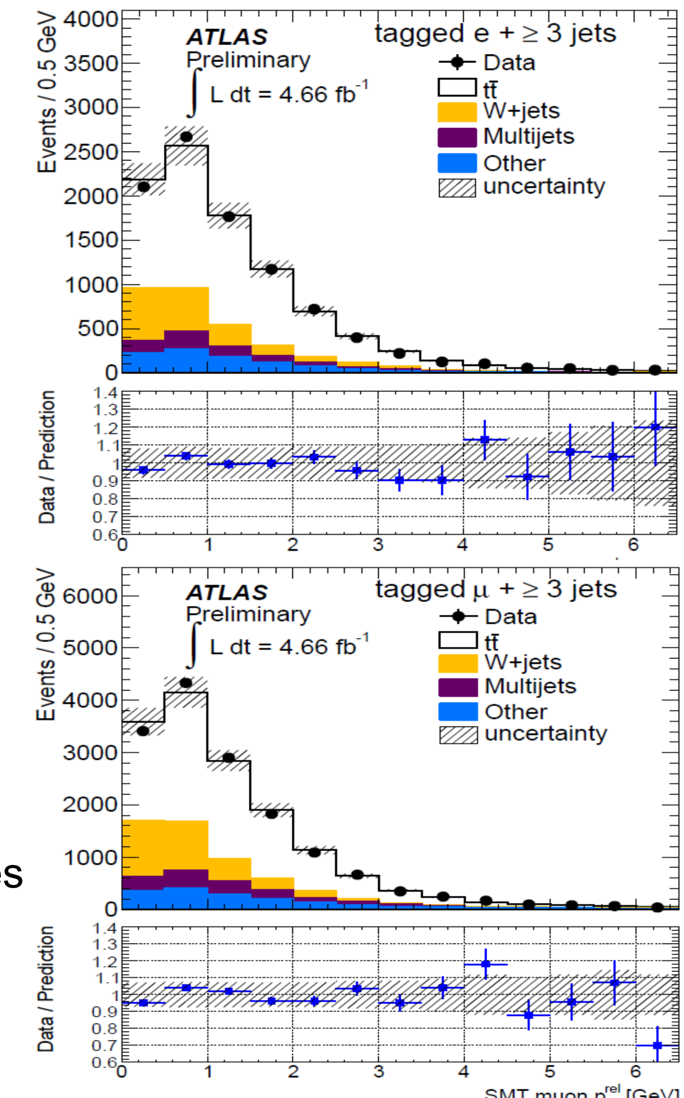
$$\sigma_{t\bar{t}} = 411.9 - 1.35 \times m_{top}(\text{GeV})\ \text{pb}.$$



Lepton+jets channel with semi-leptonic b-tagger at ATLAS (1)

NEW ATLAS-CONF-2012-131

- Complementary measurements using semi-leptonic decay of b-hadrons : leptons (e,μ) in b-jets (SMT tagger) in about 20% of the cases. Only μ in jets considered here.
- Luminosity : 4.66 fb^{-1}.
- Event selection :
  - similar events selection than ATLAS-CONF-2011-121 for trigger, lepton and jets.
  - MET> 30 GeV for electron+jet, 20 GeV for muon+jets.
  - $m_T(W)$>30 GeV for electron+jets, MET+$m_T(W)$ > 60 GeV for muon+jets.
  - ≥1 b-tagged jet with SMT.
- Corrections to the simulations :
  - Lepton trigger, reconstruction and selection efficiencies from Z events.
  - Detailed study of SMT performance in data.



Lepton+jets channel with semi-leptonic b-tagger at ATLAS (2)

NEW ATLAS-CONF-2012-131

- Analysis strategy : use a counting analysis.

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

- Main uncertainties :
  - W+jets and multijet background normalization, JES, generator.
  - More precise determination of luminosity.

- Compared to ATLAS-CONF-2011-121, more uncertainties mainly from the background estimates.

Source (≥ 3 Jets)	Relative cross section uncertainty [%] e+jets	μ+jets	Combined
Statistical Uncertainty	±1.5	±1.3	±1.0
Object selection			
Lepton energy resolution	+0.4 /-0.3	+0.2 /-0.1	+0.2 /-0.1
Lepton reco, ID, trigger	+2.4 /-2.5	+1.5 /-1.5	+1.7 /-1.8
Jet energy scale	+3.8 /-4.3	+3.2 /-3.6	+3.5 /-3.8
Jet energy resolution	±0.2	±0.5	±0.2
Jet reconstruction efficiency	±0.06	±0.06	±0.06
Jet vertex fraction	+1.2 /-1.4	+1.2 /-1.4	+1.2 /-1.4
E_T^{miss} uncertainty	±0.06	±0.08	±0.07
SMT muon reco, ID	±1.3	± 1.3	±1.3
SMT muon χ^2_{match} efficiency	±0.6	±0.6	±0.6
Background estimates			
Multijet normalisation	± 5.2	± 3.9	± 4.4
W+jet normalisation	± 5.2	± 5.7	± 5.5
Other bkg normalisation	± 0.2	± 0.2	± 0.1
Other bkg systematics	+1.6 /-1.5	+2.5 /-2.0	+2.2 /-1.8
Signal simulation			
$b \rightarrow \mu X$ Branching ratio	+2.9 /-3.0	+2.9 /-3.1	+2.9 /-3.1
ISR/FSR	± 2.4	± 0.9	± 1.5
PDF	± 3.2	± 3.0	± 3.1
NLO generator	± 3.2	± 3.2	± 3.2
Parton shower	± 2.2	± 2.2	± 2.2
Total systematics	±11.2	±10.2	±10.5
Integrated luminosity	± 1.8	± 1.8	± 1.8

Cross section measurements

$$\sigma_{t\bar{t}}^{e+jets} = 167 \pm 3(\text{stat.}) \pm 20(\text{syst.}) \pm 3(\text{lumi.})\ \text{pb}$$

$$\sigma_{t\bar{t}}^{\mu+jets} = 164 \pm 2(\text{stat.}) \pm 17(\text{syst.}) \pm 3(\text{lumi.})\ \text{pb}$$

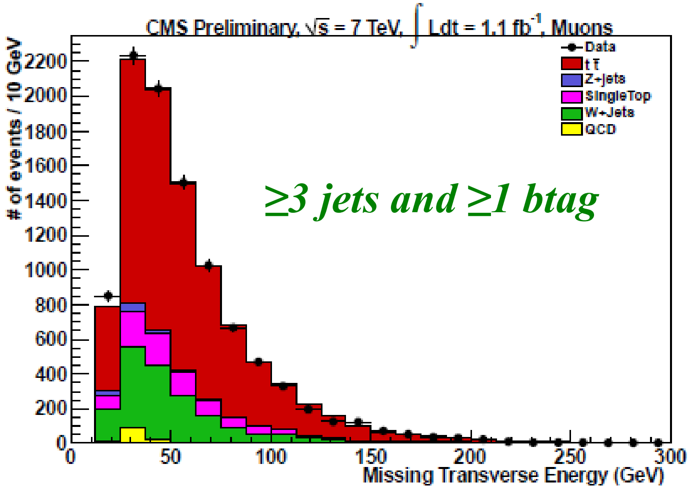
$$\sigma_{t\bar{t}} = 165 \pm 2(\text{stat.}) \pm 17(\text{syst.}) \pm 3(\text{lumi.})\ \text{pb}$$

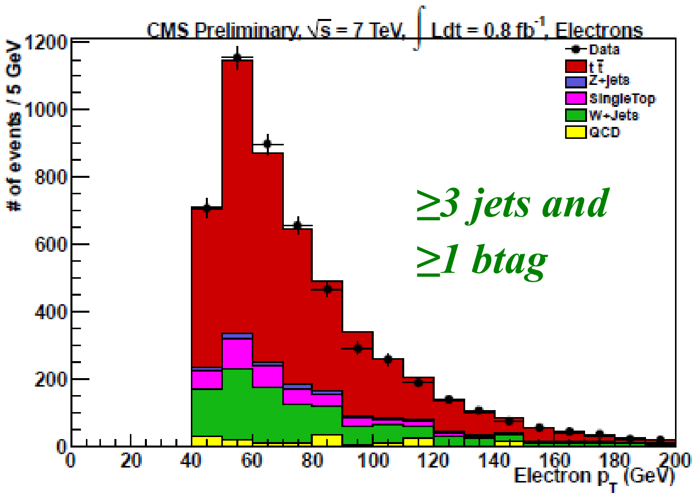
(11%)

Lepton+jets channel at CMS (1)

CMS PAS TOP-11-003

- Luminosity : 0.8-1.1 fb^{-1}
- Event selection :
  - Single lepton trigger selection.
  - =1 reconstructed, isolated and identified leptons with p_T>45 GeV (35 GeV) and |η|<2.5 (2.1) for electrons (muons). No other lepton with a looser isolation.
  - ≥ 1 jet with p_T > 30 GeV and |η|<2.4, possibly b-tagged (Simple Secondary Vertex tagger).
  - MET > 30 (20) GeV for the electron+jets (muon+jets) channels.
- Corrections to the simulation
  - Trigger and lepton efficiencies from data using Z events.



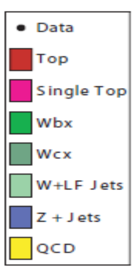


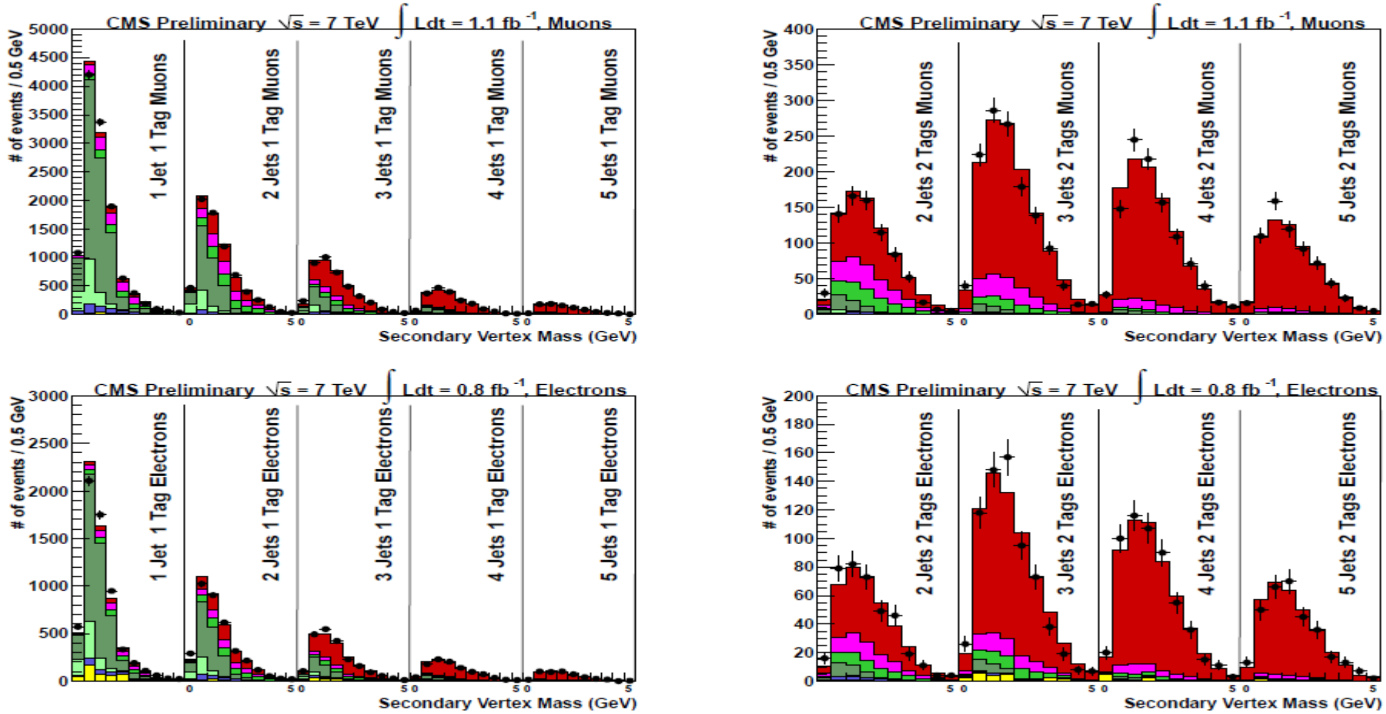
Lepton+jets channel at CMS (2)

CMS PAS TOP-11-003

- Cross section measurement based on a profile likelihood fit.
- Fitted distributions : Njets vs Nbjets vs Secondary Vertex mass.
- Nuisance parameters : JES/JER, b-tagging efficiency, W+jets ren./fac. scales.
- QCD shapes (μ+jets) and normalizations (μ+jets and e+jets) are extracted from control regions in data.
- Backgrounds : extracted from the fit but under constraints (shape and normalization).

Secondary vertex mass after the fit.





Lepton+jets channel at CMS (3)

CMS PAS TOP-11-003

Source	Muon Analysis	Electron Analysis	Combined Analysis
Quantity	Uncertainty (%)		
Lepton ID/reco/trigger	3.4	3	3.4
$\not{E}_T$ resolution due to unclustered energy	< 1	< 1	< 1
$t\bar{t}$ +jets Q^2 scale	2	2	2
ISR/FSR	2	2	2
ME to PS matching	2	2	2
Pile-up	2.5	2.6	2.6
PDF	3.4	3.4	3.4
Profile Likelihood Parameter	Uncertainty (%)		
Jet energy scale and resolution	4.2	4.2	3.1
b-tag efficiency	3.3	3.4	2.4
W+jets Q^2 scale	0.9	0.8	0.7
Combined	7.8	7.8	7.3

- Main uncertainties,
  - Dominated by systematics.
  - Main systematics from luminosity, JES/JER, lepton selection and PDF.
  - Different approach than ATLAS for generator systematics (variation of Q2 scale, matching threshold of MG).

Measured cross sections are :

μ+jets $\sigma_{t\bar{t}} = 163.2 \pm 3.4(\text{stat.}) \pm 12.7(\text{syst.}) \pm 7.3(\text{lum.})$ pb.

e+jets $\sigma_{t\bar{t}} = 163.0 \pm 4.4(\text{stat.}) \pm 12.7(\text{syst.}) \pm 7.3(\text{lum.})$ pb.

comb $\sigma_{t\bar{t}} = 164.4 \pm 2.8(\text{stat.}) \pm 11.9(\text{syst.}) \pm 7.4(\text{lum.})$ pb (9%)

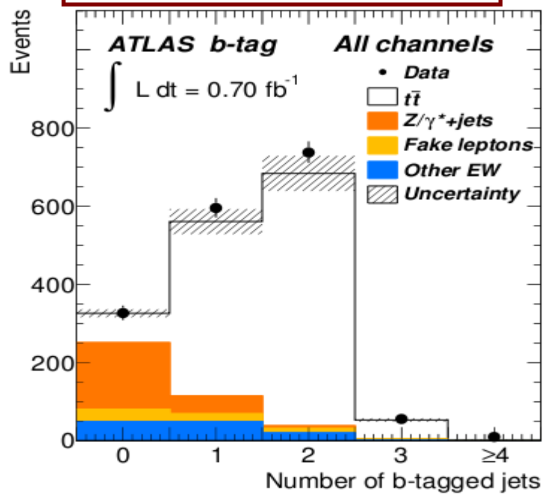
Cross check analysis using a combined cross section and b-tagging efficiency measurements leads to compatible results.

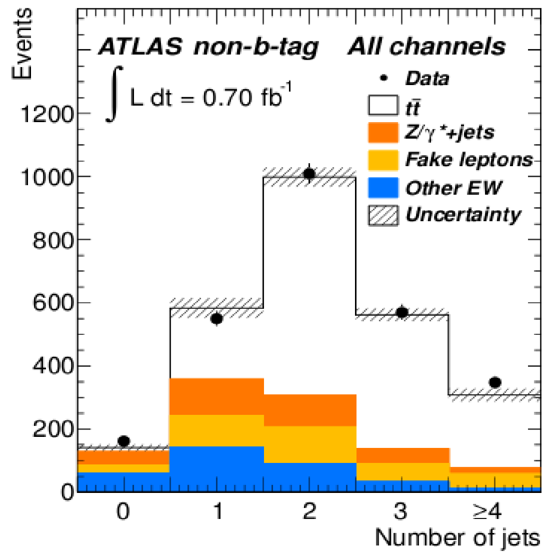
Top pair cross section @7 TeV dilepton channel

Dilepton channel at ATLAS (1)

JHEP05 (2012) 059

- Luminosity : 0.70 fb^{-1}
- Event selection :
  - Single lepton trigger,
  - 2 reconstructed, isolated and identified electrons (p_T>25 GeV, |η|<2.5) or muons (p_T>20 GeV, |η|<2.5) with opposite charges (LL candidates).
  - OR 1 lepton and 1 isolated track with p_T>25 GeV with opposite charge (LT candidate) with a dedicated selection.
  - ≥2 jets with p_T>25 GeV and |η|<2.5 **(2nd selection including b-tagging).**
  - For ee, μμ => m_{ll}>15 GeV, MET > 60 GeV **(>40 GeV)** and $|m_{ll}-m_Z|$ > 10 GeV.
  - For eμ, H_T (sum p_T of selected objects) > 130 GeV.
- Corrections to the simulation
  - Trigger, lepton and track efficiencies from data using Z->ll events.
  - Lepton momentum scale and resolution from Z events.





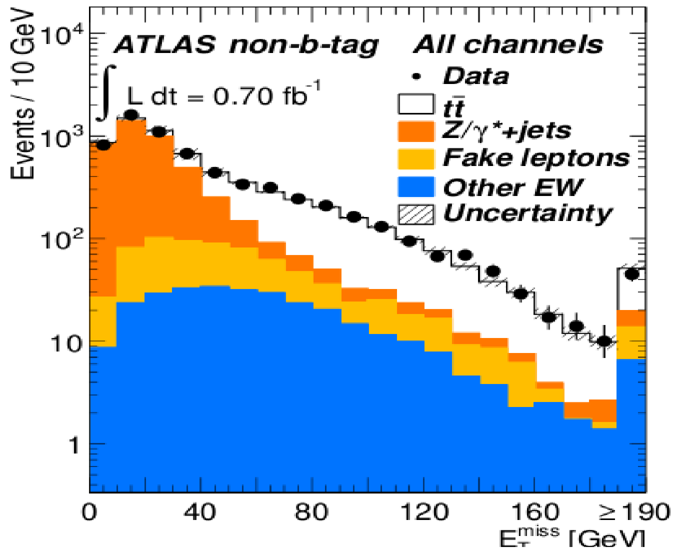
Dilepton channel at ATLAS (2)

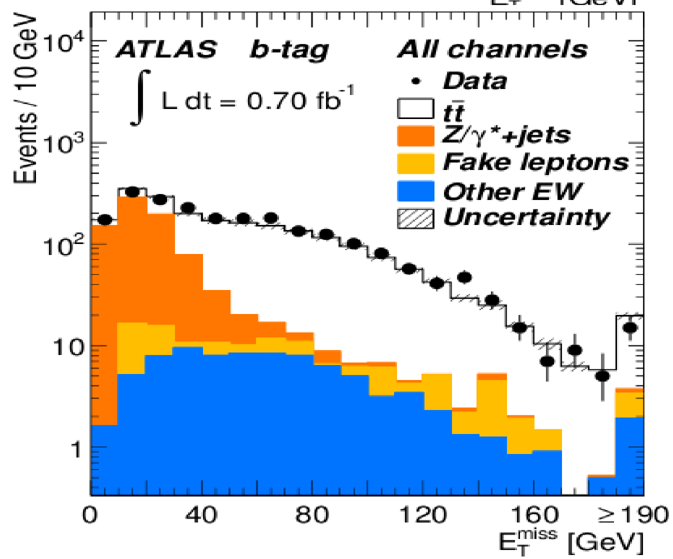
JHEP05 (2012) 059

- Cross section measurement based on a profile likelihood method (event yields).

- Main background sources : Drell-Yan (DY) events for ee and μμ channels. Events with fake leptons. Diboson events.

- Background determination :
  - DY estimated using data : a control region (within the Z mass peak and with relaxed MET cuts). Non DY events are removed in the control region using simulations.
  - $t\bar{t}$ lepton+jets, W+jets from data: events with mis-identified (fake) leptons are estimated using an extended Matrix Method.
  - Lepton-track events : estimate the probability of a jet to fake a track from γ+jets events. Apply fake probability to W+jets events to estimate the fake track-lepton contribution.
  - Other backgrounds (single top, Z→ττ, diboson) are determined from simulation.





Dilepton channel at ATLAS (3)

JHEP05 (2012) 059

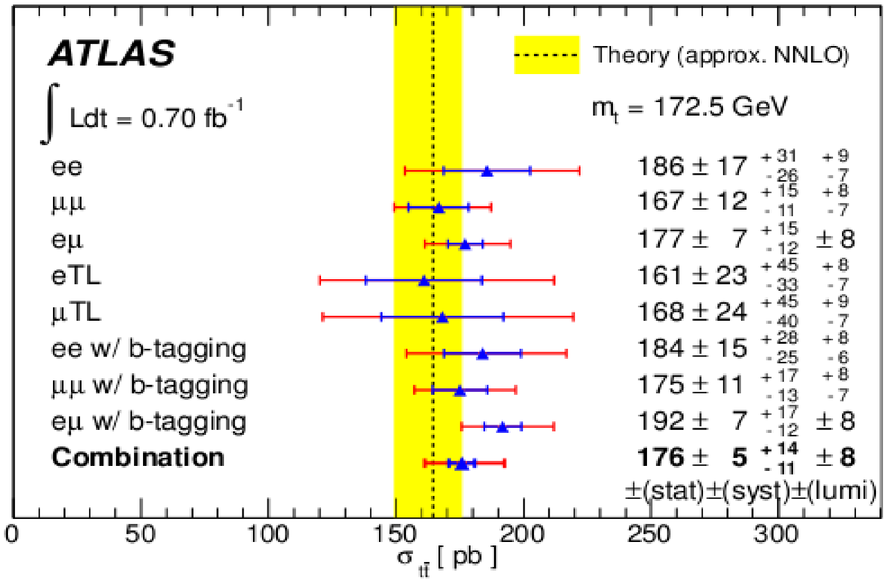
Uncertainties $\Delta\sigma/\sigma[\%]$	ee	$\mu\mu$	$e\mu$	eTL	μTL	Combined
Data statistics	± 8.1	± 6.1	± 3.9	± 14.1	± 14.2	± 2.9
Luminosity	$+4.4/-3.8$	$+4.4/-3.9$	± 4.2	$+5.1/-4.2$	$+5.4/-4.4$	± 4.3
MC statistics	± 1.6	± 1.2	± 0.8	± 5.5	± 4.6	$+0.7/-0.6$
Lepton uncertainties	$+6.2/-5.4$	$+2.9/-1.3$	± 3.1	± 4.1	$+1.8/-1.6$	$+2.6/-2.2$
Track leptons	—	—	—	± 4.4	± 1.9	$+0.3/-0.2$
Jet/E_T^{miss} uncertainties	$+5.7/-5.7$	$+6.4/-3.5$	$+4.7/-3.2$	$+14.8/-6.4$	± 13.1	$+4.4/-3.4$
b-tagging uncertainties	$+1.2/-1.0$	± 0.7	—	—	—	$+0.4/-0.0$
Z/γ^*+ jets evaluation	± 0.4	$+0.5/-0.0$	—	± 6.2	$+2.4/-2.7$	$+0.3/-0.2$
Fake lepton evaluation	± 3.3	$1.5/-1.3$	± 3.0	± 13.7	± 15.1	± 1.7
Generator	$+12/-11$	$+4.5/-4.3$	$+4.8/-4.5$	$+14/-11$	$+14/-13$	$+5.1/-4.9$
All syst.(except lumi.)	$+16.4/-14.4$	$+8.8/-6.4$	$+8.2/-6.8$	$+27.9/-20.7$	$+26.5/-23.7$	$+8.0/-6.5$
Stat. + syst.	$+18.9/-16.9$	$+11.6/-9.5$	$+10.1/-8.8$	$+31.8/-25.2$	$+30.7/-27.8$	$+9.6/-8.2$

- Main uncertainties :
  - Dominated by systematics.
  - Main systematics : luminosity, jet/MET and generator uncertainties.

Combined cross section measurement

$$\sigma_{t\bar{t}} = 176 \pm 5(\text{stat.})^{+14}_{-11}(\text{syst.}) \pm 8(\text{lumi.})\ \text{pb.}$$

(10%)

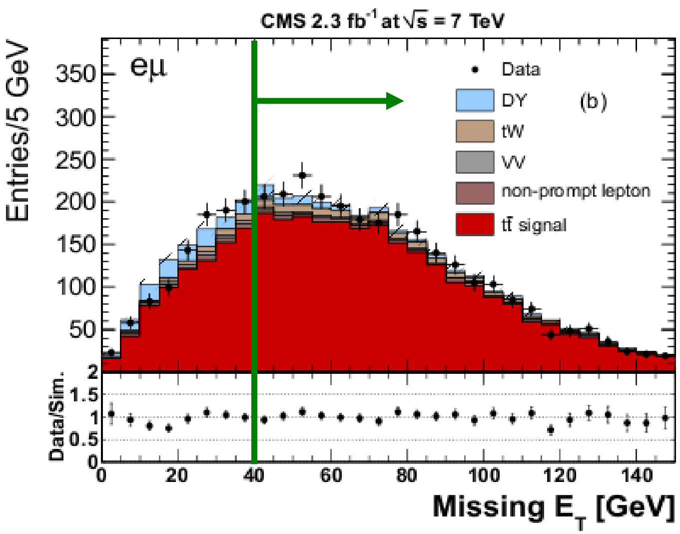


Dilepton channel at CMS (1)

arXiv:1208.2671

- Luminosity : 2.3 fb^{-1}
- Event selection :
  - Dilepton trigger : E_T(electrons) > 8-17 GeV, p_T(muons) > 7-17 GeV.
  - 2 reconstructed, isolated and identified leptons with opposite charges, p_T>20 GeV and |η|<2.5 for electrons (2.1 for muons).
  - m_{ll}>20 GeV (ee, μμ, eμ channels) and $|m_{ll}-m_Z|$> 15 GeV (ee, μμ channels) .
  - MET > 40 GeV for ee, μμ channels, no MET cut for the eμ channel.
  - ≥2 jets with p_T>30 GeV and |η|<2.5.
  - ≥1b-tagged jets (Combined Secondary Vertex).

- Selection efficiency
  - Dilepton trigger efficiency estimated using an independent sample triggered by the MET.
  - Lepton selection efficiencies estimated from Z→ll events.
  - MET selections estimated from the eμ channel.



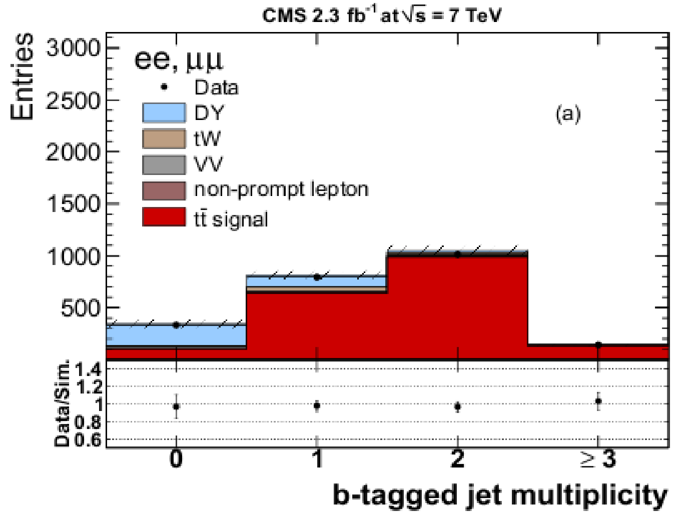
Dilepton channel at CMS (2)

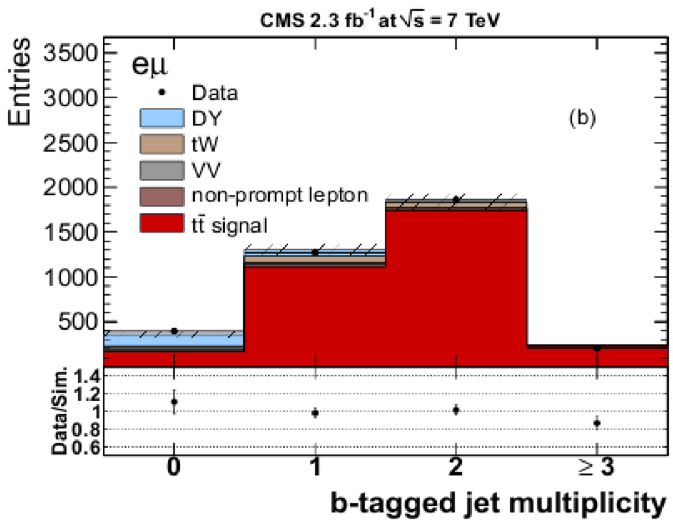
arXiv:1208.2671

- Cross section is measured from a profile likelihood ratio using the Njets vs NBjets distribution.

- Complementary measurement : simple counting analysis.

- Background determination :
  - $Z \rightarrow ll$ in the ee and μμ channels : using the expected ratio of events outside and inside the Z mass cut. Ratio taken from simulation but corrected using control region in data.
  - $Z \rightarrow \tau\tau \rightarrow e\mu$ from a template fit of the m_{ll} distribution.
  - Fake-lepton backgrounds (dominated by $t\bar{t}$ l+jets) estimated using an extended Matrix Method.
  - Other backgrounds (single top, diboson) estimated from simulation.





Dilepton channel at CMS (3)

arXiv:1208.2671

Source	Counting experiment	Uncertainty on $\sigma_{t\bar{t}}$(pb)
Diboson		0.4
Single top		2.3
Drell-Yan		1.0
Non-W/Z leptons		0.6
Lepton efficiencies		1.7
Lepton energy scale		0.5
Jet energy scale		2.8
Jet energy resolution		0.5
$\not\!\!E_T$ efficiency		1.9
b-tagging		1.1
Pileup		0.7
Scale of QCD (μ)		1.0
Matching partons to showers		1.0
W branching fraction		2.7
Total systematic		5.6
Integrated luminosity		3.6
Statistical		2.6

- With higher luminosity, lower statistical uncertainty and better control of systematics.
- More precise luminosity calculation using pixel.
- Main uncertainties :
  - Luminosity, JES, W Branching ratio,

Cross section measurements.

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	$161.9 \pm 2.5^{+5.1}_{-5.0} \pm 3.6$	$161.0 \pm 2.6 \pm 5.6 \pm 3.6$

(5%)

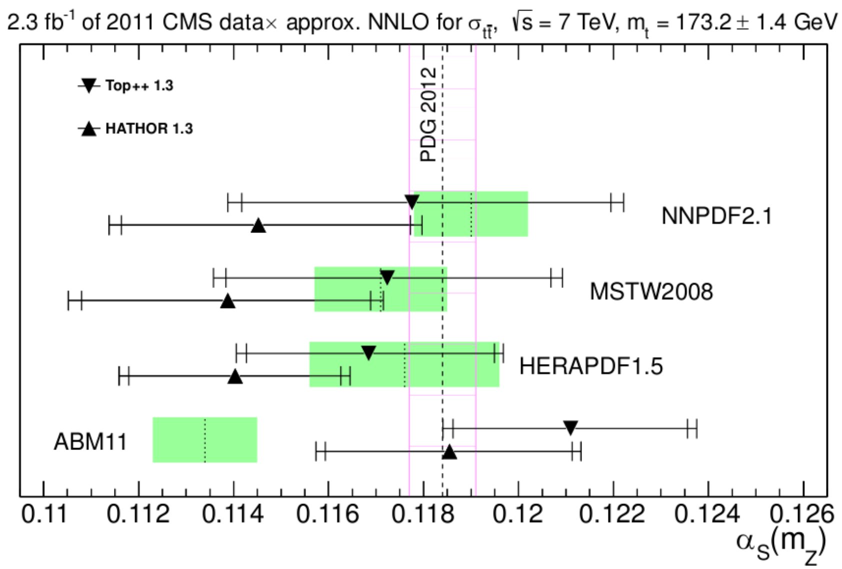
- Combination done with the likelihood fit (with σ_{tt} as a single parameter), a Best Linear Unbiased Estimate (BLUE, Nucl.Instrim.Meth. A270 (1988) 110) method for the counting analysis.
- Combination dominated by the eμ channel (more statistic, less backgrounds, no MET selection).
- Very good agreement with the counting analysis.
- Top mass dependence : $\sigma_{t\bar{t}}/\sigma_{t\bar{t}}(m_t = 172.5) = 1.00 - 0.008 \times (m_t - 172.5) - 0.000137 \times (m_t - 172.5)^2.$

Top mass uncertainty at WA : 1.4 pb

α_S from top pair cross section

New CMS PAS TOP-12-022

Using arXiv:1208.2671		Most likely value	Uncertainty Total	Uncertainty From δm_t
Top++ 1.3	with NNPDF2.1	0.1178	$^{+0.0045}_{-0.0039}$	$^{+0.0015}_{-0.0015}$
HATHOR 1.3		0.1145	$^{+0.0034}_{-0.0031}$	$^{+0.0013}_{-0.0013}$
Top++ 1.3	with MSTW2008	0.1172	$^{+0.0037}_{-0.0037}$	$^{+0.0013}_{-0.0014}$
HATHOR 1.3		0.1139	$^{+0.0033}_{-0.0034}$	$^{+0.0013}_{-0.0013}$
Top++ 1.3	with HERAPDF1.5	0.1168	$^{+0.0028}_{-0.0028}$	$^{+0.0010}_{-0.0011}$
HATHOR 1.3		0.1140	$^{+0.0024}_{-0.0024}$	$^{+0.0010}_{-0.0010}$
Top++ 1.3	with ABM11	0.1211	$^{+0.0027}_{-0.0027}$	$^{+0.0010}_{-0.0010}$
HATHOR 1.3		0.1185	$^{+0.0028}_{-0.0028}$	$^{+0.0010}_{-0.0010}$



- High precision measurement of the top pair cross section can be used to determine the strong coupling constant $\alpha_s(m_Z)$.
- Dependence of the $t\bar{t}$ cross section on α_s and correlations with m_t determined with Top++ and HATHOR and for various PDF sets.
- α_s determined from the maximization of a likelihood function :

$$L(\alpha_S) = \int f_{\mathrm{exp}}(\sigma_{t\bar{t}}|\alpha_S)\, f_{\mathrm{th}}(\sigma_{t\bar{t}}|\alpha_S)\, d\sigma_{t\bar{t}}.$$

Gaussian term, experimental measurement

Convolution of a Gaussian (PDF) and a rectangular function (ren./fact. scales)

LHC combination at 7TeV

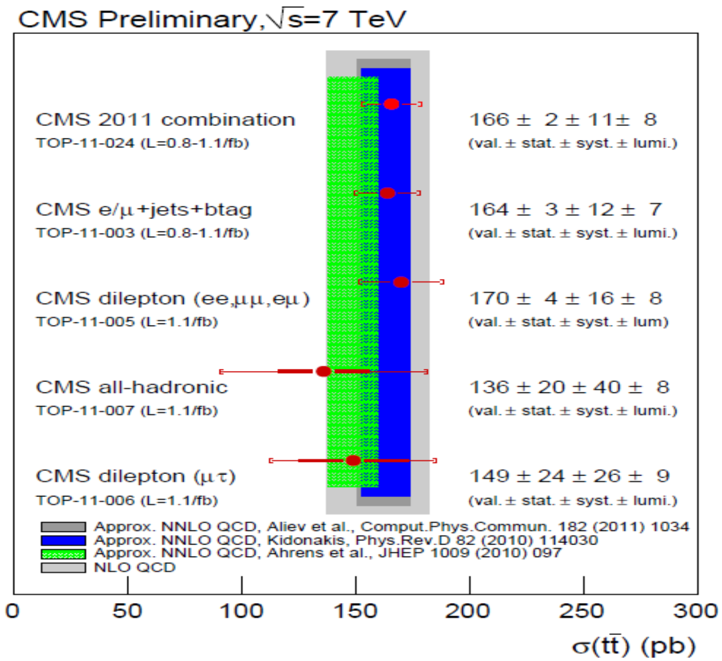
- Combination of channels within the same experiment : statistically uncorrelated, some systematics uncorrelated.
- Combination of LHC results : statistically uncorrelated, more systematics uncorrelated.
- **TOPLHCWG combinations done with 0.7-1.1 fb^{-1}** (first attempt), also including results presented in the previous talk (Gia Khoriauli).

ATLAS and CMS combinations @7TeV

CMS PAS TOP-11-024

- CMS combination using 0.8-1.1 fb^{-1}.
- Combination done using a binned maximum likelihood (TOP-11-003). Gain 21% of stat. and 11% of syst. uncertainty compared to the l+jets channel.
- Combination cross-checked with a BLUE method : agree within 1%, 3% less precise.

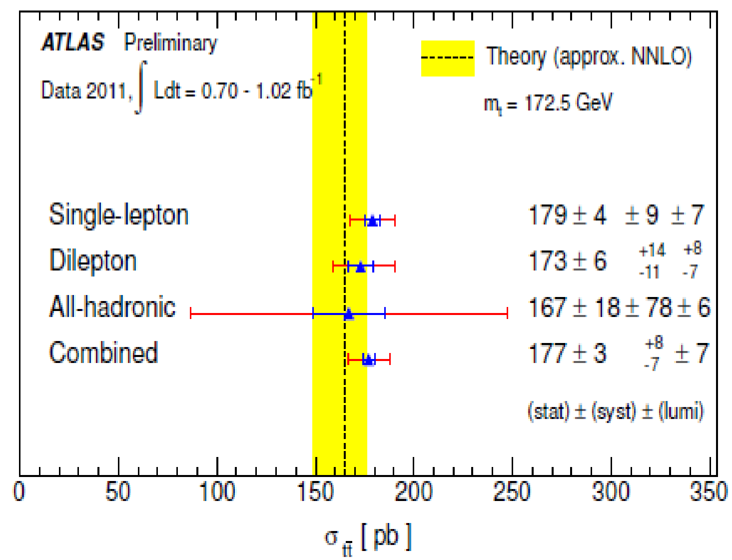
$$\sigma_{t\bar{t}} = 165.8 \pm 2.2(\text{stat.}) \pm 10.6(\text{syst.}) \pm 7.8(\text{lumi.})\ \text{pb}$$



ATLAS-CONF-2012-024

- ATLAS combination using 0.7-1.0 fb^{-1}.
- Combination done using a profile likelihood ratio method.
- Gain 25% of stat. and 11% of syst. uncertainties compared to the l+jets channel .

$$\hat{\sigma}_{t\bar{t}} = 177 \pm 3\ (\text{stat.})\ {}^{+8}_{-7}\ (\text{syst.}) \pm 7\ (\text{lumi.})\ \text{pb}$$



LHC Combination @7TeV

- LHC combination from TOPLHCWG working group : combination of the ATLAS and CMS combinations (ATLAS-CONF-2012-134, CMS PAS TOP-12-003).

- BLUE method used : simple and compatible results with likelihood based methods.

- Type of uncertainties and their correlations :
  - Detector modeling : uncorrelated.
  - JES : uncorrelated (assumption tested).
  - Signal modeling : fully correlated (assumption tested).
  - Backgrounds estimated from data : uncorrelated.
  - Backgrounds estimated from simulation : fully correlated.
  - Luminosity : partially correlated, bunch charge uncertainty (fully correlated, 3% for ATLAS, 3.1% for CMS) or detector related uncertainty (uncorrelated 2.4% for ATLAS, 3.6% for CMS).

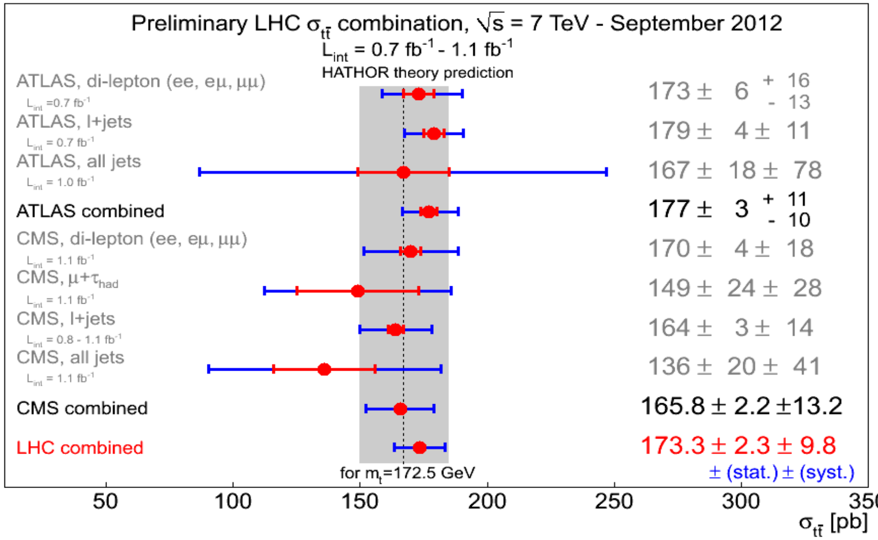
LHC Combination @7TeV

	ATLAS	CMS	Correlation	LHC combination
Cross-section	177.0	165.8		173.3
Uncertainty				
Statistical	3.2	2.2	0	2.3
JES	2.7	3.5	0	2.1
Detector model	5.3	8.8	0	4.6
Signal model				
Monte-Carlo	4.2	1.1	1	3.1
Parton shower	1.3	2.2	1	1.6
Radiation	0.8	4.1	1	1.9
PDF	1.9	4.1	1	2.6
Background from data	1.5	3.4	0	1.6
Background from MC	1.6	1.6	1	1.6
Method	2.4	n/e	1	1.6
W leptonic branching	1.0	1.0	1	1.0
Luminosity				
Bunch current	5.3	5.1	1	5.3
Detector effects	4.3	5.9	0	3.4
Total systematic	10.8	14.2		9.8
Total	11.3	14.4		10.1

- ATLAS+CMS combined cross section measurements.
- Total correlations between the measurements : 30%.
- Combined $t\bar{t}$ cross section uncertainty becomes 5.8% (around 10 pb) => gain about 7% w.r.t. the most precise measurement.

Combined cross section measurement

$$\sigma_{t\bar{t}} = 173.3 \pm 2.3(\text{stat.}) \pm 9.8(\text{syst.})\ \text{pb}$$



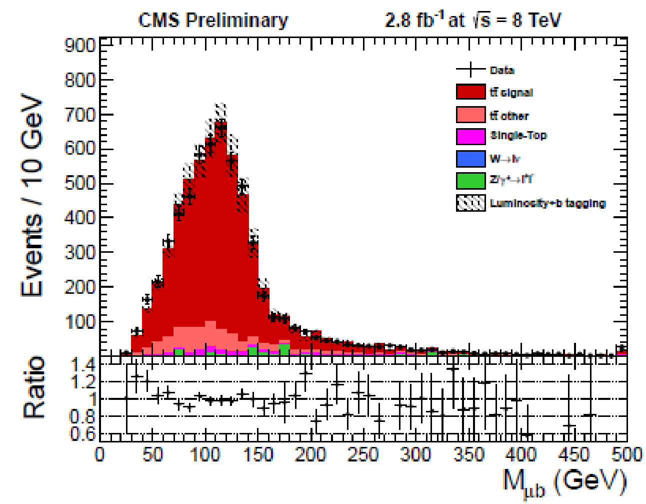
Better results are expected with new measurements : more statistics, better lumi. systematic.

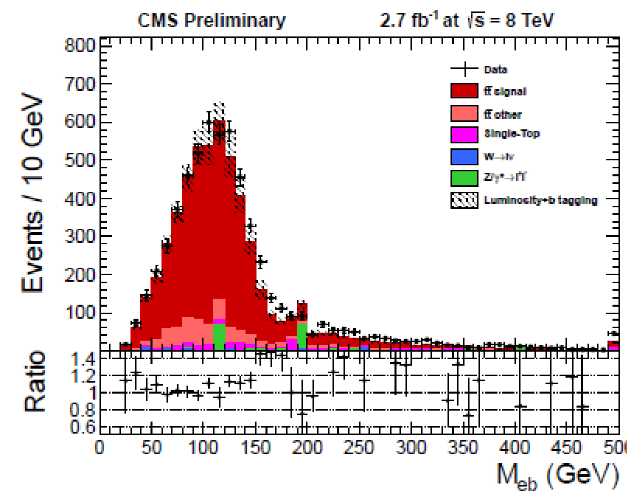
Top pair cross section @ 8 TeV

Lepton +jets channel at CMS (1)

CMS PAS TOP-12-006

- Luminosity : 2.8 fb^{-1}.
- Event selection :
  - Lepton+jets trigger : ≥ 1 lepton with p_T> 17-20 GeV for muons (25 GeV for electrons) and ≥ 3 jets with p_T > 30 GeV.
  - Exactly 1 lepton with p_T>26 GeV (30 GeV) and $|\eta|<2.1$ (2.5) for muons (electrons).
  - Events with another leptons with loose isolation rejected.
  - ≥4 jets with p_T >45, 45, 35, 35 GeV and $|\eta|<2.5$.
  - ≥1 b-tagged jet using the Jet Probability tagger.
- Selection efficiencies :
  - Trigger and lepton selection efficiencies determined from Z->ll data.





Lepton +jets channel at CMS (2)

- Analysis strategy :
  - Estimate the number of $t\bar{t}$ events from a template fit of the M_{lb} distribution.
  - The templates for $t\bar{t}$, single-top and W/Z+jets taken from simulation.
  - QCD template from data in a control region (inverting isolation cut on lepton).
- Cross-check analysis : different selection and using the M3 variable, similar results.
- Main uncertainties:
  - B-tagging efficiency, generator, JES, luminosity

Systematic	Combined fit $\delta\sigma_{t\bar{t}}$ (%)	
Jet Energy Scale	+4.3	-5.0
Jet Energy Resolution	+0.5	-1.1
Pileup	+0.7	-0.7
Background Composition	+0.1	-0.1
W + Jets template shape from unweighted 7 TeV	+0.9	-0.9
Normalisation of data-driven multijet shape	+0.9	-0.9
b tagging efficiency measurement	+8.0	-8.0
Trigger Efficiency	+3.2	-2.8
Lepton selection	+2.8	-2.4
Factorization scale (*)	+6.2	-2.1
ME-PS Matching threshold (*)	+4.6	-3.1
PDF uncertainties (*)	+1.6	-2.0
Top Quark Mass (*)	+0.3	-1.4
Total	+12.7	-11.4
Luminosity	+4.4	-4.4

Combined cross section measurements.

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

(14%)

Dilepton channel at CMS

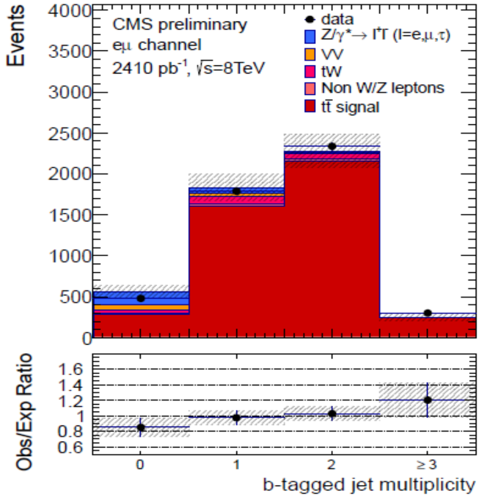
- Luminosity : 2.4 fb-1.
- Events selection, backgrounds determination and selection efficiencies as the 7 TeV measurement.
- Different fake lepton estimation : using like sign lepton selection.
- Counting experiment.
- Main systematics :
  - Luminosity, JES, lepton efficiency.

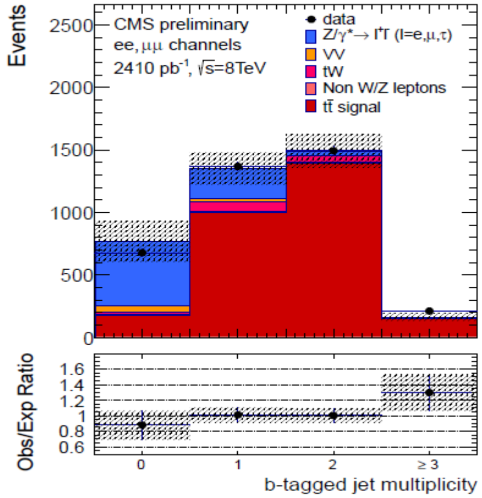
Combined cross section measurement.

$$\sigma_{t\bar{t}} = 227 \pm 3\ (\text{stat.}) \pm 11\ (\text{syst.}) \pm 10\ (\text{lumi})\ \text{pb}$$

(7%)

Source	Cont. to the $\sigma_{t\bar{t}}$(pb)	Cont. to the $\sigma_{t\bar{t}}$(%)
VV	0.3	0.1
Single top - tW	2.2	1.0
Non W/Z leptons	3.2	1.4
Drell-Yan	1.6	0.7
Lepton efficiencies	4.0	1.8
LES	0.7	0.3
JES	5.7	2.5
JER	3.8	1.7
B-tagging	2.0	0.9
pileup	3.3	1.5
Branching ratio	3.9	1.7
Event Q^2 scale	1.6	0.7
Matching	1.6	0.7
Total Systematic	10.7	4.7
Luminosity	10.0	4.4
Statistics	3.1	1.4





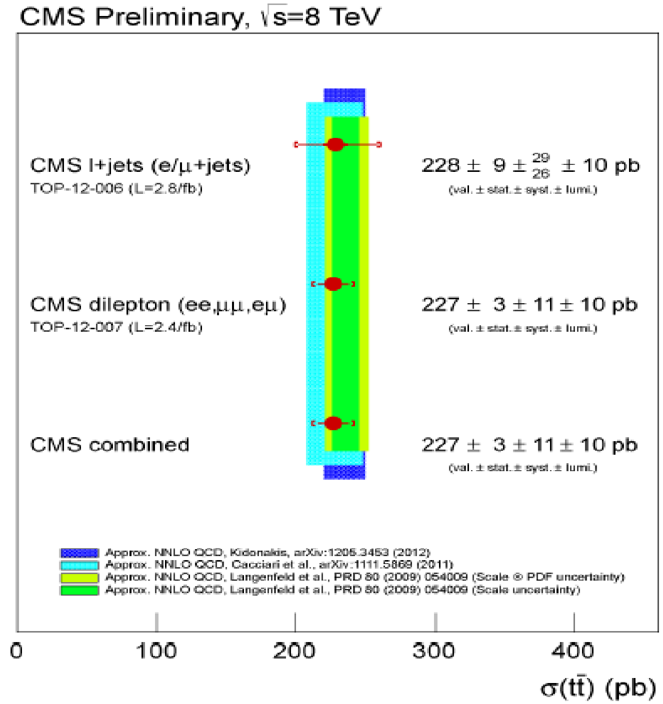
CMS PAS TOP-12-007

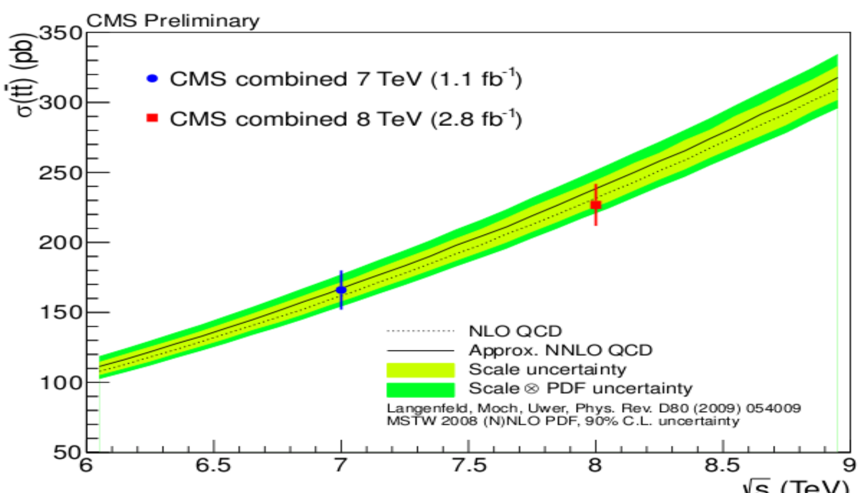
CMS combination at 8 TeV

- Combination of the CMS 8 TeV measurements, using a BLUE method.
- Combination dominated by the dilepton measurement.

Combined cross section measurement.

$$\sigma_{t\bar{t}} = 227 \pm 3\,(\text{stat.}) \pm 11\,(\text{syst.}) \pm 10\,(\text{lumi})\ \text{pb}.$$





- Ratio of the 8TeV (combination) and 7TeV cross sections (dilepton at 2.3 fb^{-1}).
- Lot of systematic uncertainties cancel out.
- is found to be 1.41±0.10.

Summary

- High luminosity allows to perform high precision measurements of $t\bar{t}$ cross section.
- **<u>All measurements performed at 7 and 8 TeV are compatible</u>** within the uncertainties, and are compatible with theoretical calculations.
- For the same luminosities (about 1 fb^{-1}), ATLAS and CMS measurements have similar precisions : uncertainty of 11.4 pb (6.4%) for ATLAS, 14.4 pb (8.7%) for CMS.
- Combining ATLAS and CMS results allows to go to an uncertainty as low as 10 pb.
- With higher luminosities, very high precision can be reached : 7 pb (<5%, CMS) in the dilepton channel.
- Similar precisions can be reached with the 8 TeV data, despite the high multiplicity of pileup events : 15 pb (<7%).
- Cross-section measurements start to be more precise than approximate NNLO calculations.

Backups

ATLAS-CONF-2011-121

Table 1: Selected events in the e + jets channel split up according to the jet multiplicity. The W + jets background is obtained from a data-driven method exploiting the charge asymmetry in W boson production. The total uncertainty is shown for QCD multijet background determined from data and statistical ones for all other contributions.

	1 Jet	2 Jet	3 Jet	4 Jet	≥ 5 jet
$t\bar{t}$	225±15	1005±32	1934±44	1835±43	1463±38
W+jets (DD)	161600±400	43170±210	10840±100	2486±50	1032±32
QCD multijet (DD)	11000±5000	4800±2400	1600±800	510±250	177±89
Single Top	571±24	711±27	391±20	156±13	65±8
Z+jets	3732±61	2444±49	996±32	333±18	146±12
Diboson (WW,WZ,ZZ)	599±25	538±23	178±13	45±7	10±3
Total Predicted	177000±5000	52600±2400	15900±800	5360±260	2892±100
Data Observed	179469	51820	15614	5398	2812

ATLAS-CONF-2011-121

Table 2: Selected events in the μ + jets channel split up according to the jet multiplicity. The W + jets background is obtained from a data-driven method exploiting the charge asymmetry in W boson production. The total uncertainty is shown for QCD multijet background determined from data and statistical ones for all other contributions.

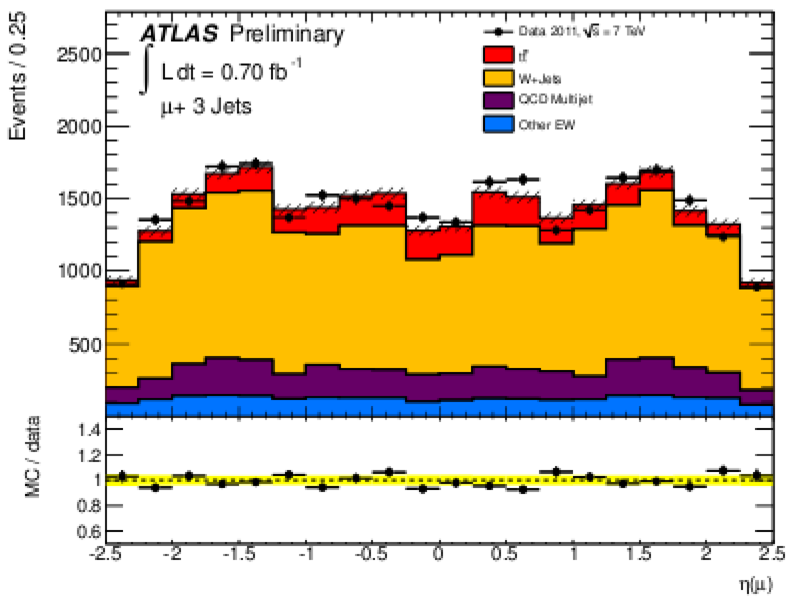
	1 Jet	2 Jet	3 Jet	4 Jet	$\geq$ 5 jet
$t\bar{t}$	319±18	1342±37	2734±52	2714±52	2030±45
W+jets (DD)	383200±600	93440±310	20140±140	4644±68	1082±33
QCD multijet (DD)	25000±12000	11000±6000	3200±1600	900±400	290±150
Single Top	996±32	1148±34	594±24	210±15	84±9
Z+jets	17270±130	5492±74	1510±39	436±21	149±12
Diboson (WW,WZ,ZZ)	1093±33	1009±32	308±18	69±8	18±4
Total Predicted	428000±12000	113000±6000	28400±1600	8900±400	3660±160
Data Observed	433931	111741	28643	8680	3814

- Aplanarity : smallest eigen value of M_{ij}

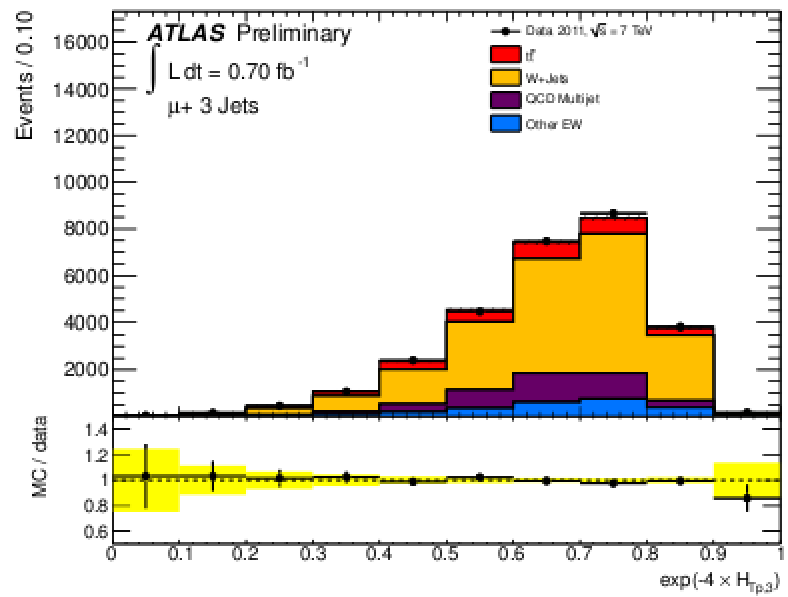
ATLAS-CONF-2011-121

$$M_{ij} = \frac{\sum_{k=1}^{N'_{\text{objects}}} p_{ik} p_{jk}}{\sum_{k=1}^{N'_{\text{objects}}} p_k^2},$$

$$H_{\text{T,3p}} = \frac{\sum_{i=3}^{N_{\text{jets}}} |p_{\text{T},i}|}{\sum_{j=1}^{N_{\text{objects}}} |p_{z,j}|},$$

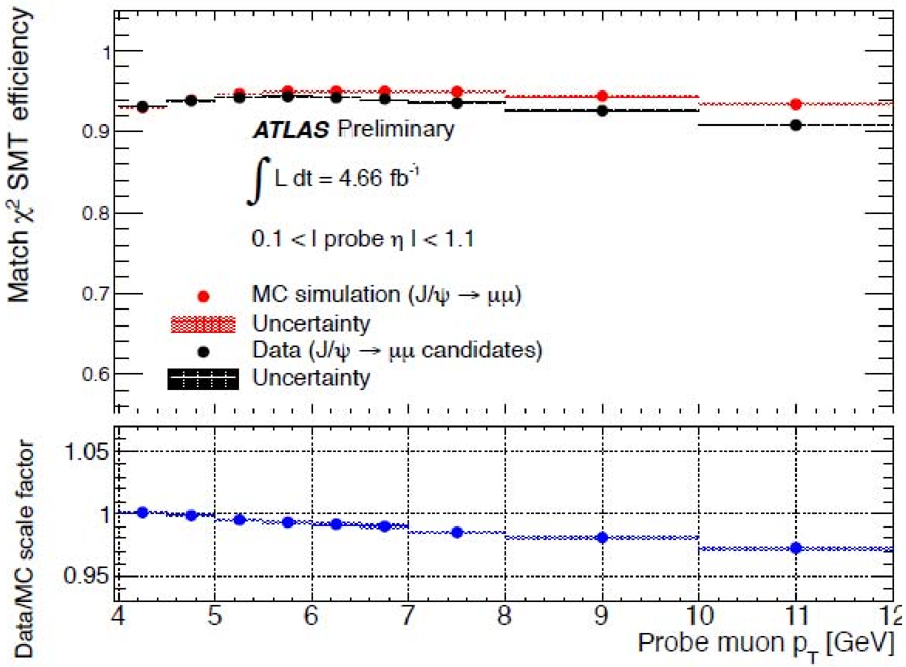


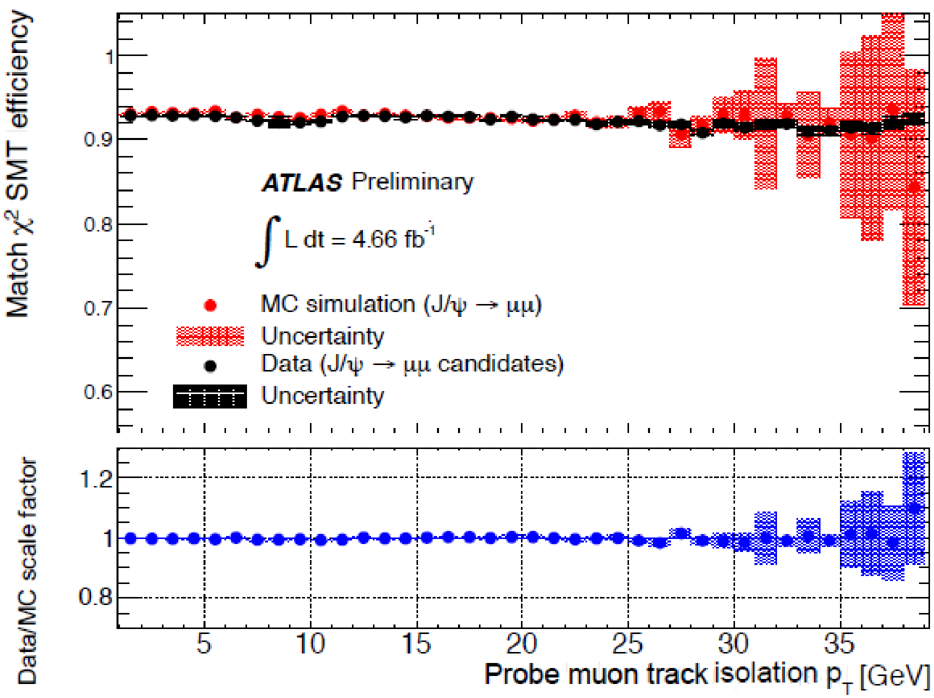
(a) η^ℓ



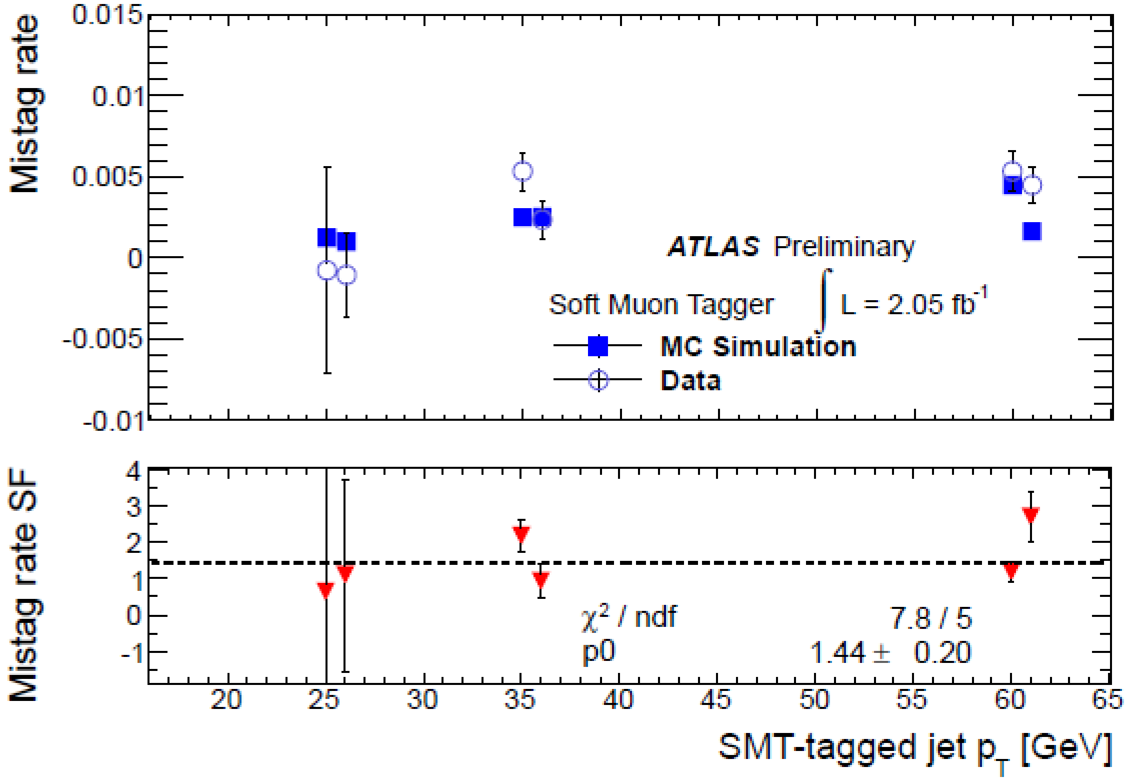
(b) $\exp[-4 \times H_{\text{T,3p}}]$

ATLAS-CONF-2012-131





ATLAS-CONF-2012-131



Systematic	Electron channel (%)	Muon channel (%)
Heavy flavour fractions	17	15
Normalisation	9	7
b-tagging	5	5
Jet energy scale	3	3
$b \rightarrow \mu X$ Branching ratio	2	2
Jet energy resolution	1	2
Total	20	18

Table 7: Source of uncertainties, in percent, on the tagged W+jets background estimate.

	e+jets		**μ+jets**	
Sample	**Pretag**	**Tagged**	**Pretag**	**Tagged**
Data(4.66 fb^{-1})	124424	9165	227318	14940
$t\bar{t}$ MC	31900±1300	5980±350	52100±1600	9100±500
W+jets DD	59300±5400	1640±330	117200±9300	2900±500
Multijet DD	16200±8100	620±310	27000±5400	1310±350
Z+jets MC	9900^{+2500}_{-1400}	$270\pm^{+40}_{-30}$	11500^{+2400}_{-1600}	780^{+140}_{-100}
Single Top MC	4300±400	630±60	7200±600	980±80
DiBoson MC	1190^{+220}_{-180}	40±10	2030^{+350}_{-300}	60±10
$t\bar{t}$ MC + Backgrounds	123000±10000	9200±600	217000±12000	15100±800
Measured $t\bar{t}$		6000±500		8900±600

Table 9: Observed and estimated event yields in the pretag and tagged samples. The multijet and W+jets backgrounds are evaluated with Data Driven (DD) techniques whilst signal $t\bar{t}$ and all other backgrounds are evaluated with Monte Carlo (MC) simulation. Uncertainties are quoted as the sum of the statistical and systematic uncertainties.

CMS PAS TOP-11-003

Table 1: Inputs to the profile likelihood, along with constraints. All values are in percent.

Quantity	Constraint (%)
b-tag Efficiency Scale Factor	100 ± 10
b-tag Mistag Scale Factor	100 ± 10
Jet energy scale relative to nominal	$100 \pm\ 3$ (η,p_T dependent)
W+jets renormalization/factorization scales	100^{+100}_{-50}
W+jets background normalization	unconstrained
QCD background normalization	100 ± 100
Single-top background normalization	100 ± 30
Z+jets background normalization	100 ± 30

Table 2: The fitted number of top and background events in the likelihood fit for muon + jets with least 1 b-tag. Here Wbx, Wcx, and Wqq represent W+b jets, W+c jets, and W+light flavor events, respectively.

	Data	Total Fit	Top	SingleTop	Wbx	Wcx	Wqq	ZJets	QCD
1 Jet 1 Tag	11934	11924.8	419.4	889.9	582.3	7718.9	1486.1	358.5	469.8
2 Jets 1 Tag	7026	7071.6	1479.9	904.5	860.2	2813.4	673.1	223.6	116.9
3 Jets 1 Tag	4067	4015.4	2084.5	408.8	320.5	816.6	213.7	88.1	83.2
4 Jets 1 Tag	1933	1916.0	1395.7	129.2	76.8	187.7	57.7	25.6	43.3
5 Jets 1 Tag	854	878.7	738.1	40.4	21.6	51.6	9.6	11.1	6.3
2 Jets $\geq$ 2 Tags	777	782.5	446.9	153.8	111.4	51.0	8.8	10.6	0.0
3 Jets $\geq$ 2 Tags	1297	1295.4	1053.5	138.6	64.3	28.0	2.0	9.0	0.0
4 Jets $\geq$ 2 Tags	1044	1050.0	955.3	59.3	16.2	15.5	0.9	2.8	0.0
5 Jets $\geq$ 2 Tags	650	642.0	601.1	24.6	9.0	5.6	0.0	1.7	0.0
Total	29582	29576.6	9174.4	2749.0	2062.2	11688.3	2452.0	731.0	719.6

CMS PAS TOP-11-003

Table 4: The fitted number of top and background events in the likelihood fit for electron + jets with least 1 b-tag. Here Wbx, Wcx, and Wqq represent W+b jets, W+c jets, and W+light flavor events, respectively.

	Data	Total Pred	Top	SingleTop	Wbx	Wcx	Wqq	ZJets	QCD
1 Jet 1 Tag	6119	6076.6	220.2	314.6	413.7	3789.7	872.1	213.1	253.2
2 Jets 1 Tag	3586	3661.7	764.4	358.0	620.8	1380.3	383.6	152.5	2.2
3 Jets 1 Tag	2142	2120.5	1066.3	187.9	235.2	351.8	97.1	60.2	121.9
4 Jets 1 Tag	1026	1004.9	723.5	65.2	53.0	90.2	35.3	19.4	18.4
5 Jets 1 Tag	475	474.9	386.5	20.1	21.9	21.1	7.8	6.3	11.0
2 Jets $\geq$ 2 Tags	383	373.5	220.0	58.9	60.4	22.9	1.4	9.9	0.1
3 Jets $\geq$ 2 Tags	689	690.7	527.5	58.7	59.6	18.1	0.8	5.7	20.3
4 Jets $\geq$ 2 Tags	553	549.1	485.2	29.3	19.2	3.8	1.1	2.9	7.7
5 Jets $\geq$ 2 Tags	319	329.6	305.7	12.9	6.5	1.1	0.3	1.3	1.8
Total	15292	15281.5	4699.2	1105.6	1490.4	5679.0	1399.5	471.2	436.6

CMS PAS TOP-11-003

Table 5: Correlation matrix of the fit to the combined electron and muon data samples with at least one b-tag.

	Top	SingleTop	Wbx	Wcx	Wqq	Zjets	Q^2	btag	JES	lftag
Top	1.000	-0.285	-0.180	0.288	0.032	0.074	-0.135	-0.627	-0.835	0.002
SingleTop	-0.285	1.000	-0.731	0.049	0.047	-0.041	0.069	-0.104	0.134	-0.006
Wbx	-0.180	-0.731	1.000	0.068	0.123	-0.145	0.295	0.195	0.269	-0.002
Wcx	0.288	0.049	0.068	1.000	0.053	0.034	0.673	-0.428	-0.204	-0.011
Wqq	0.032	0.047	0.123	0.053	1.000	-0.139	0.311	-0.058	-0.048	-0.763
ZJets	0.074	-0.041	-0.145	0.034	-0.139	1.000	0.129	0.000	-0.100	0.002
Q^2	-0.135	0.069	0.295	0.673	0.311	0.129	1.000	-0.022	0.231	-0.016
btag	-0.627	-0.104	0.195	-0.428	-0.058	0.000	-0.022	1.000	0.460	-0.011
jes	-0.835	0.134	0.269	-0.204	-0.048	-0.100	0.231	0.460	1.000	0.003
lftag	0.002	-0.006	-0.002	-0.011	-0.763	0.002	-0.016	-0.011	0.003	1.000

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	ee	$\mu\mu$	$e\mu$	eTL	μTL	b-tag ee	b-tag $\mu\mu$	b-tag $e\mu$
Z/γ^*+ jets	$4.0^{+2.5}_{-1.2}$	$14.4^{+5.4}_{-4.2}$	-	$24.3^{+10.7}_{-9.4}$	$22.0^{+5.3}_{-5.8}$	$9.8^{+1.7}_{-1.3}$	$20.3^{+1.8}_{-2.8}$	–
$Z/\gamma^* \to \tau\tau$+jets	4.9 ± 2.6	11.0 ± 5.0	43 ± 16	$17.0^{+8.4}_{-7.6}$	25 ± 11	$1.8^{+1.1}_{-1.2}$	$7.6^{+3.3}_{-3.6}$	$9.5^{+4.2}_{-3.9}$
Fake leptons	4.0 ± 5.0	6.3 ± 4.1	44 ± 24	74 ± 15	85 ± 17	7.5 ± 6.5	4.9 ± 3.1	20 ± 13
Single top quark	$6.4^{+1.2}_{-1.1}$	$16.0^{+1.9}_{-2.2}$	41.1 ± 5.5	$5.7^{+1.0}_{-0.9}$	$6.3^{+0.8}_{-1.1}$	$7.3^{+1.3}_{-1.1}$	$16.2^{+2.2}_{-2.3}$	$33.5^{+4.8}_{-4.7}$
Diboson	5.9 ± 1.1	$8.7^{+1.2}_{-1.5}$	32.9 ± 4.9	$5.9^{+0.9}_{-0.8}$	$4.8^{+0.6}_{-0.7}$	2.2 ± 0.7	$2.6^{+0.9}_{-0.6}$	$8.8^{+1.7}_{-1.6}$
Total background	25.2 ± 6.4	56.5 ± 9.4	161 ± 34	126^{+20}_{-19}	142 ± 21	28.6 ± 6.9	$51.6^{+5.6}_{-5.9}$	71.6 ± 14.1
Predicted $t\bar{t}$	124 ± 17	241^{+15}_{-18}	746 ± 42	112^{+16}_{-18}	110^{+17}_{-16}	159^{+17}_{-21}	304^{+26}_{-35}	675^{+57}_{-75}
Total	149 ± 18	298^{+17}_{-20}	907 ± 54	239 ± 26	253 ± 27	188^{+18}_{-22}	356^{+27}_{-35}	746^{+59}_{-76}
Observed	165	301	963	236	255	201	365	834

Table 1. Breakdown of the expected $t\bar{t}$ signal and background events in the signal region compared to the observed event yields, for each of the dilepton channels. All systematic uncertainties are included, and correlations between different background sources are taken into account, when calculating the total background uncertainty. The largest contribution to the line labeled 'Fake leptons' comes from W+jets events.

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Table 1: Estimated number of W-like (N_W) and MJ-like (N_{MJ}) background events in data before and after b tagging.

	Before b tagging			Requiring ≥1 b-tagged jet		
	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$
N_W	7.8 ± 5.9	14.9 ± 7.1	63.8 ± 16.8	1.8 ± 4.8	9.8 ± 5.6	42.4 ± 14.6
N_{MJ}	0.7 ± 0.6	0.4 ± 0.3	21.1 ± 10.0	0.6 ± 0.5	0.2 ± 0.1	7.5 ± 3.9

Table 2: Summary of the relative (%) systematic uncertainties on the number of signal $t\bar{t}$ events, after applying the full selection criteria, both, before b tagging and with at least one b-tagged jet in the event. Combined uncertainties are listed for the sum of contributions from the three dilepton channels, except for lepton efficiencies, which are given separately for e^+e^-, $\mu^+\mu^-$, and $e^\pm\mu^\mp$ events.

	Uncertainty on number of $t\bar{t}$ events (%)	
Source	Without b tagging	≥1 b-tagged jet
Luminosity	2.2	2.2
Lepton efficiencies	1.7 (ee) / 1.7 ($\mu\mu$) / 1.0 (eμ)	1.7 (ee) / 1.7 ($\mu\mu$) / 1.0 (eμ)
Lepton energy scale	0.3	0.3
Jet energy scale	1.8	1.9
Jet energy resolution	0.5	0.3
$\not{E}_T$ efficiency	1.4	1.3
b tagging	-	0.7
Pileup	0.5	0.5
Scale of QCD (μ)	0.6	0.6
Matching partons to showers	0.6	0.6
W branching fraction	1.7	1.7

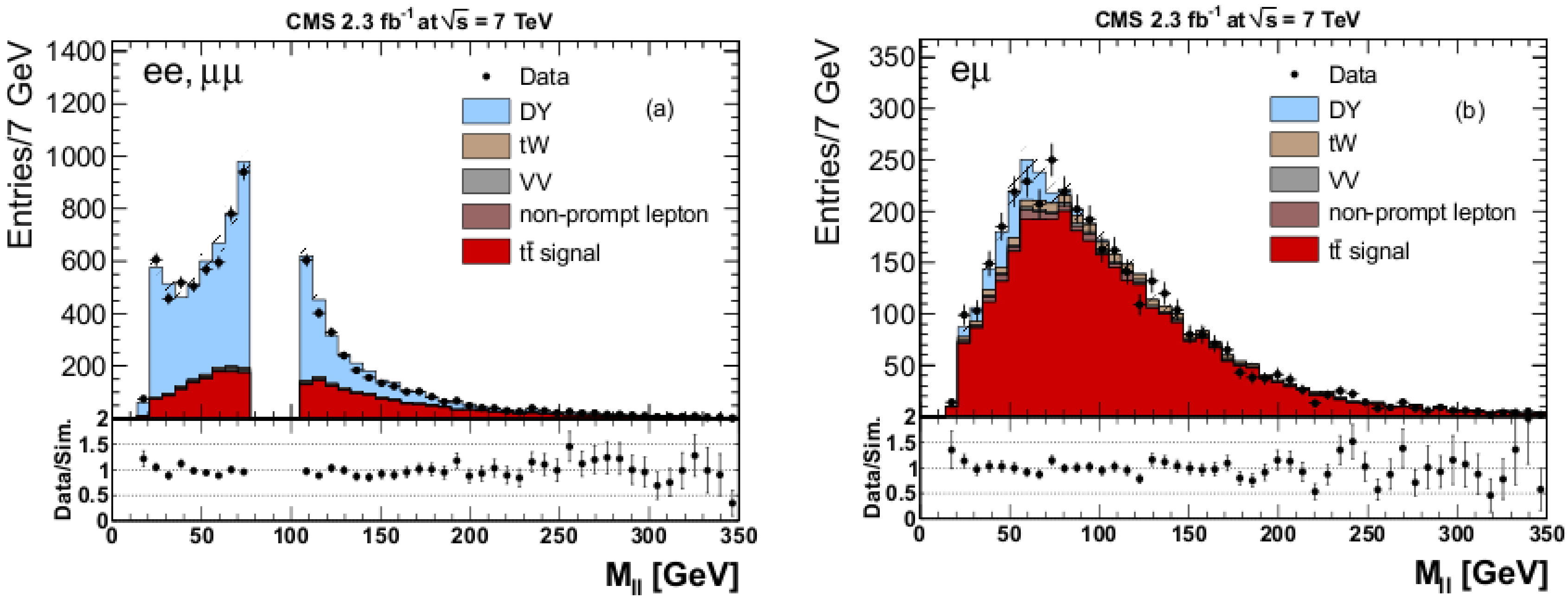


Figure 3: Same as Fig. 1, but for the dilepton invariant-mass distribution of (a) the sum of the e^+e^- and $\mu^+\mu^-$ channels, and (b) the $e^\pm\mu^\mp$ channel. The gap in the former distribution reflects the requirement that removes dileptons from Z decay.

arXiv:1208.2671

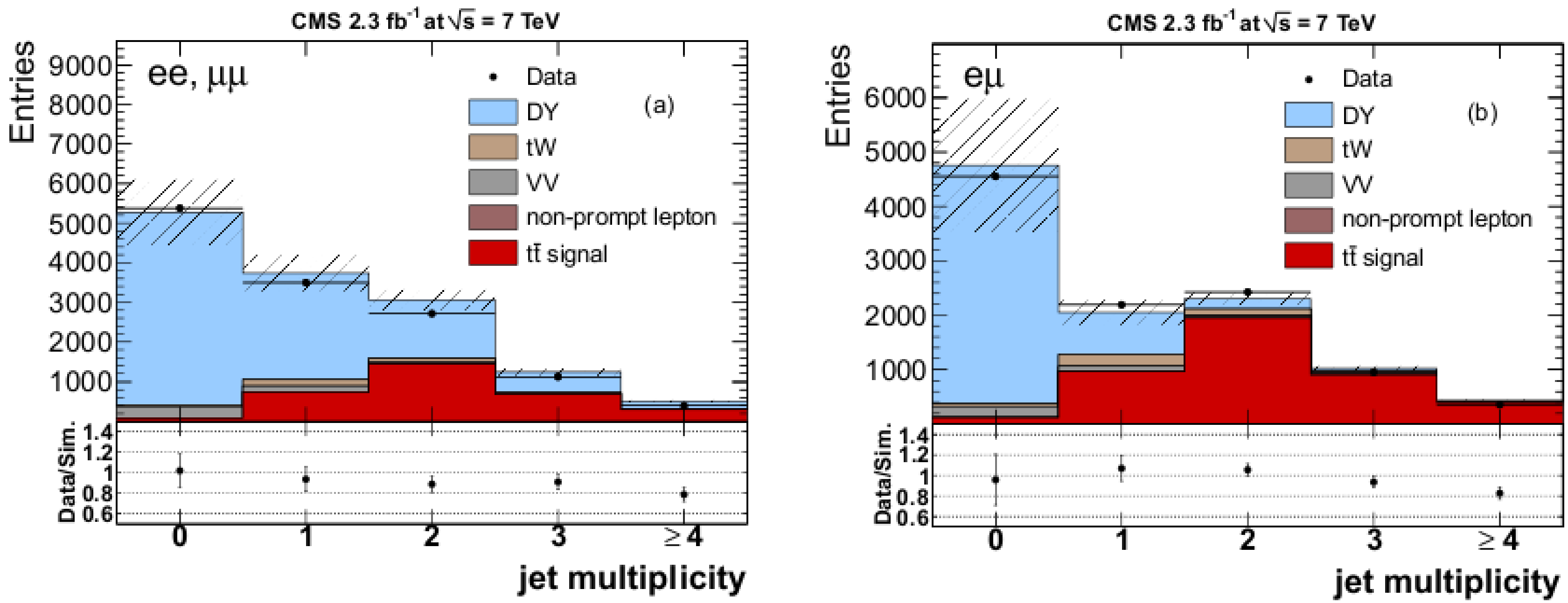
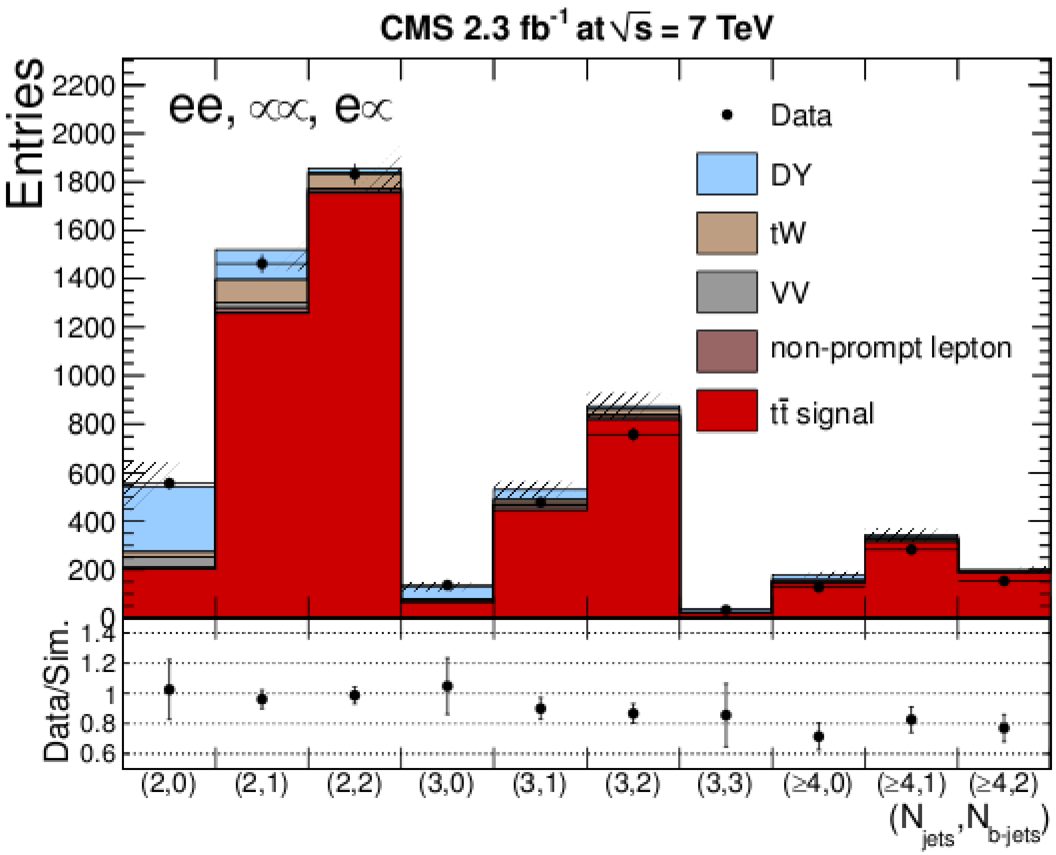


Figure 5: The jet multiplicity for events passing the dilepton and $\not{E}_T$ criteria, but before the b-tagging requirement, for (a) the sum of e^+e^- and $\mu^+\mu^-$ channels, and (b) the $e^\pm\mu^\mp$ channel.

arXiv:1208.2671



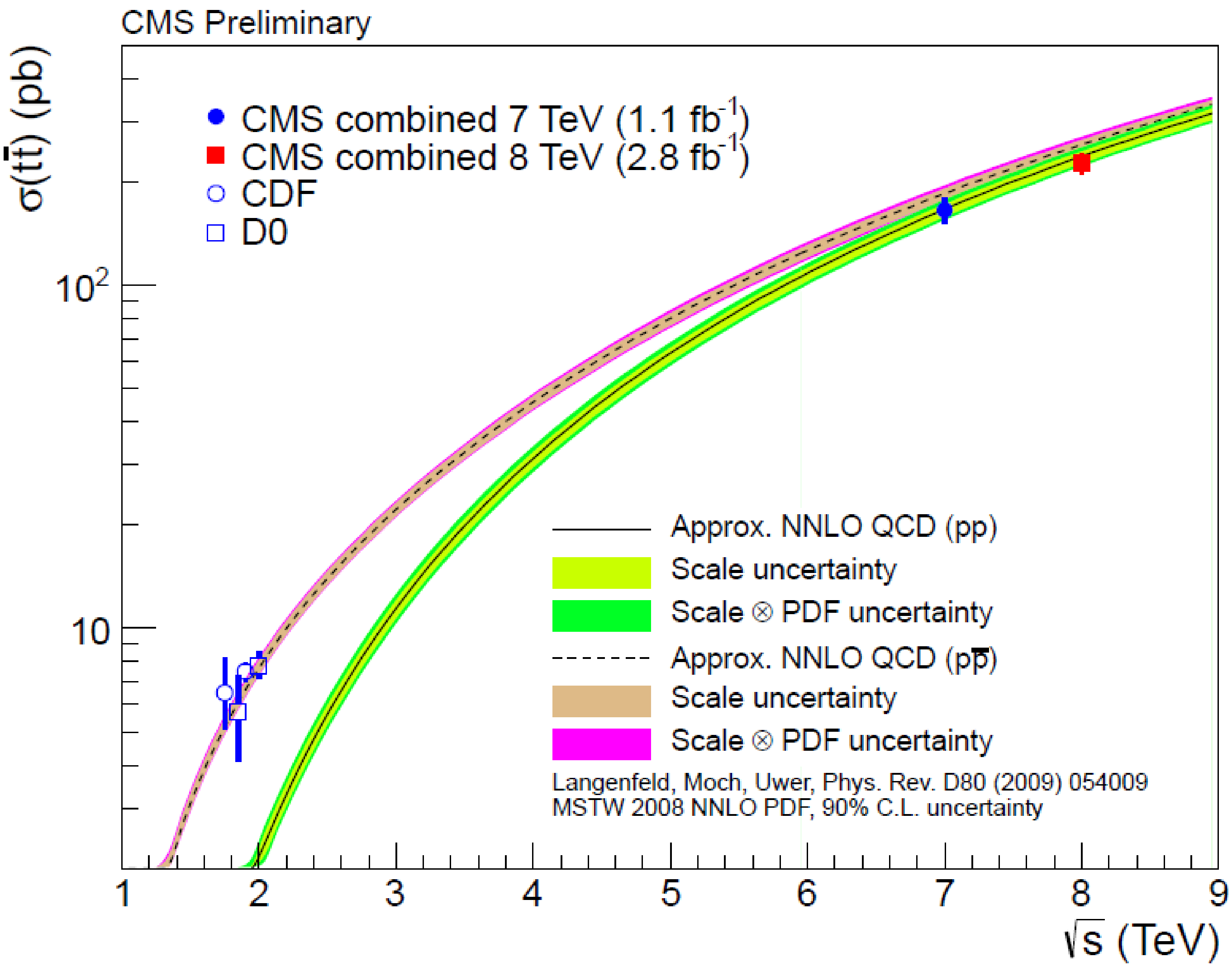
arXiv:1208.2671

Table 3: Number of dilepton events in the e^+e^-, $\mu^+\mu^-$, and $e^\pm\mu^\mp$channels after applying the event-selection criteria: (a) without requiring a b-tagged jet, and (b) requiring at least one b-tagged jet. The results are given for the individual sources of background, $t\bar{t}$ signal for $\sigma_{t\bar{t}}$ = 164 pb, and the data. The uncertainties reflect statistical and systematic uncertainties added in quadrature. Panel (c) gives the $t\bar{t}$ acceptance multiplied by the selection efficiency and by the branching fractions B (in %) of $t\bar{t}$ to two-lepton states, estimated using $t\bar{t}$ simulated events.

	(a) Number of events Without b-tagging selection		
Source	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$
Drell-Yan	136±29	217±45	220±46
Nonprompt leptons	9±6	15±7	85±20
Diboson	14±4	16±4	55±13
Single top	42±9	53±11	156±32
Total background	200±33	301±48	515±72
$t\bar{t}$ signal	801±34	1041±43	3253±126
Total predicted	1001±47	1342±65	3768±145
Data	1021	1259	3734

	(b) $\geq$ 1b-tagged jet		
Source	$\mu^+\mu^-$	e^+e^-	$e^\pm\mu^\mp$
Drell-Yan	62±16	82±21	89±19
Nonprompt leptons	2.4±4.8	10.0±5.5	50±15
Diboson	5.7±1.4	6.1±1.5	22.3±5.3
Single top	37.5±7.8	47.0±9.8	140±29
Total background	107±18	145±23	301±38
$t\bar{t}$ signal	759±33	991±42	3082±122
Total predicted	866±37	1135±48	3384±128
Data	875	1074	3339

	(c) $t\bar{t}$ acceptance × eff. × B (%)		
b-tagging selection	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$
No selection	0.22±0.01	0.28±0.01	0.87±0.04
$\geq$ 1b-tagged jet	0.20±0.01	0.27±0.01	0.83±0.04



CMS Preliminary
σ(tt̄) (pb)
CMS combined 7 TeV (1.1 fb-1)
CMS combined 8 TeV (2.8 fb-1)
CDF
D0
10²
10
Approx. NNLO QCD (pp)
Scale uncertainty
Scale ⊗ PDF uncertainty
Approx. NNLO QCD (pp̄)
Scale uncertainty
Scale ⊗ PDF uncertainty
Langenfeld, Moch, Uwer, Phys. Rev. D80 (2009) 054009
MSTW 2008 NNLO PDF, 90% C.L. uncertainty
1
2
3
4
5
6
7
8
9
√s (TeV)

Data-driven from ATLAS

- W-charge asymmetry method.

$$N_{W^+} + N_{W^-} = \frac{N^{MC}_{W^+} + N^{MC}_{W^-}}{N^{MC}_{W^+} - N^{MC}_{W^-}}(D^+ - D^-) = \frac{r_{MC}+1}{r_{MC}-1}(D^+ - D^-)$$

From data

Charge asymmetry from MC

- Matrix method

$$N^{loose} = N^{loose}_{real} + N^{loose}_{fake}$$

$$N^{std} = r N^{loose}_{real} + f N^{loose}_{fake}$$

From Z->ll in events

From region enriched in QCD