GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

LHC top pair cross section combination

ATLAS-CONF-2012-134
CMS PAS TOP-12-003

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FSP 101 ATLAS

PHYSICS AT THE TERA SCALE
Helmholtz-Alliance

Nov 29, 2012

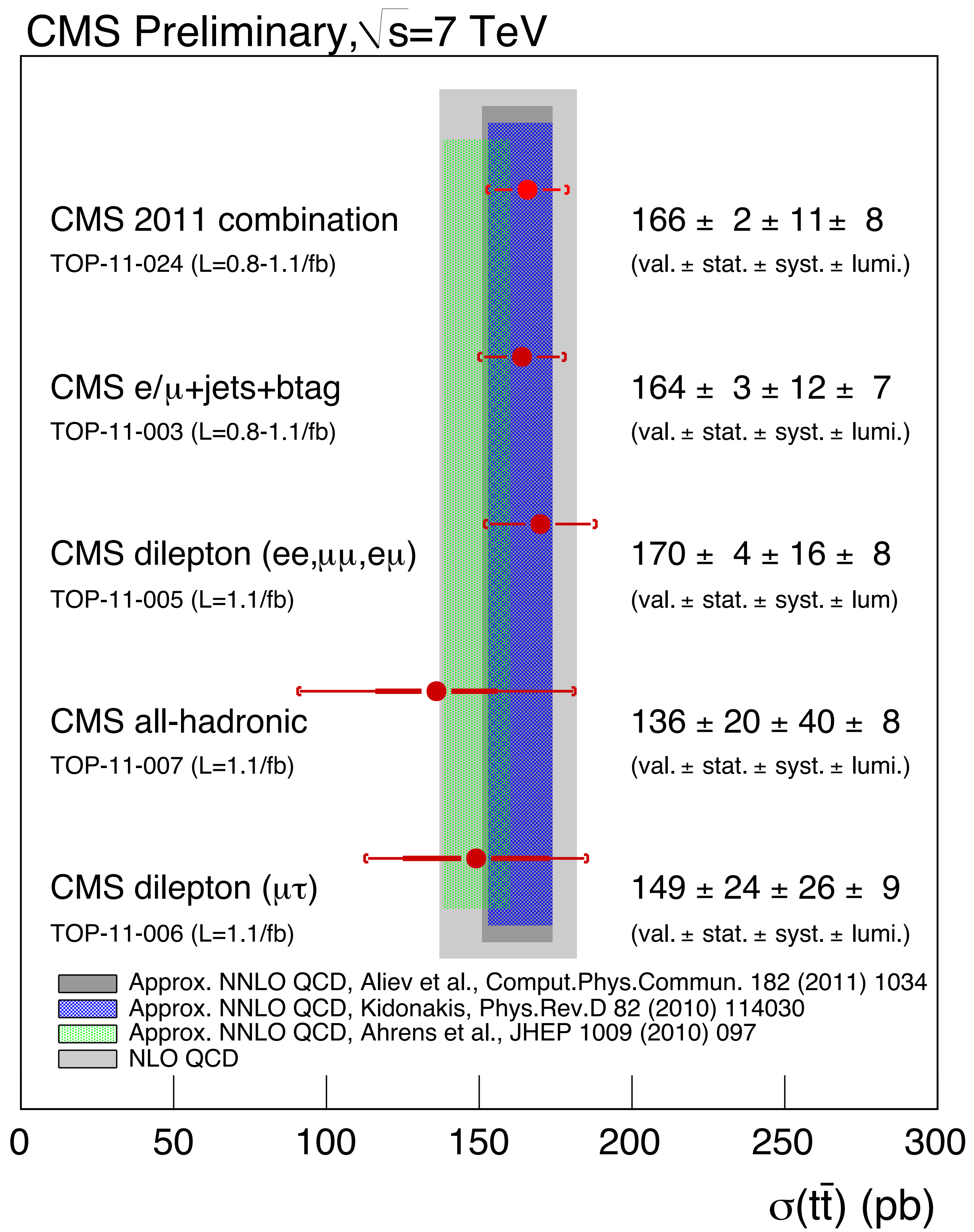
Outline

- Goal: combine CMS and ATLAS top pair cross section measurements
- What is included in the combination?
- Combination strategy and method
  - BLUE vs full likelihood
- Breakdown of systematic uncertainties
  - correlations of systematic uncertainties
- New measurements and future combination

CMS combination

- up to 1.1/fb
- 4 channels
- relative uncertainty 8%
- dominated by l+jets - 8.6% uncertainty

σ = 166 ± 2(stat) ± 11(syst) ± 8 (lumi)



CMS-PAS-TOP-11-024

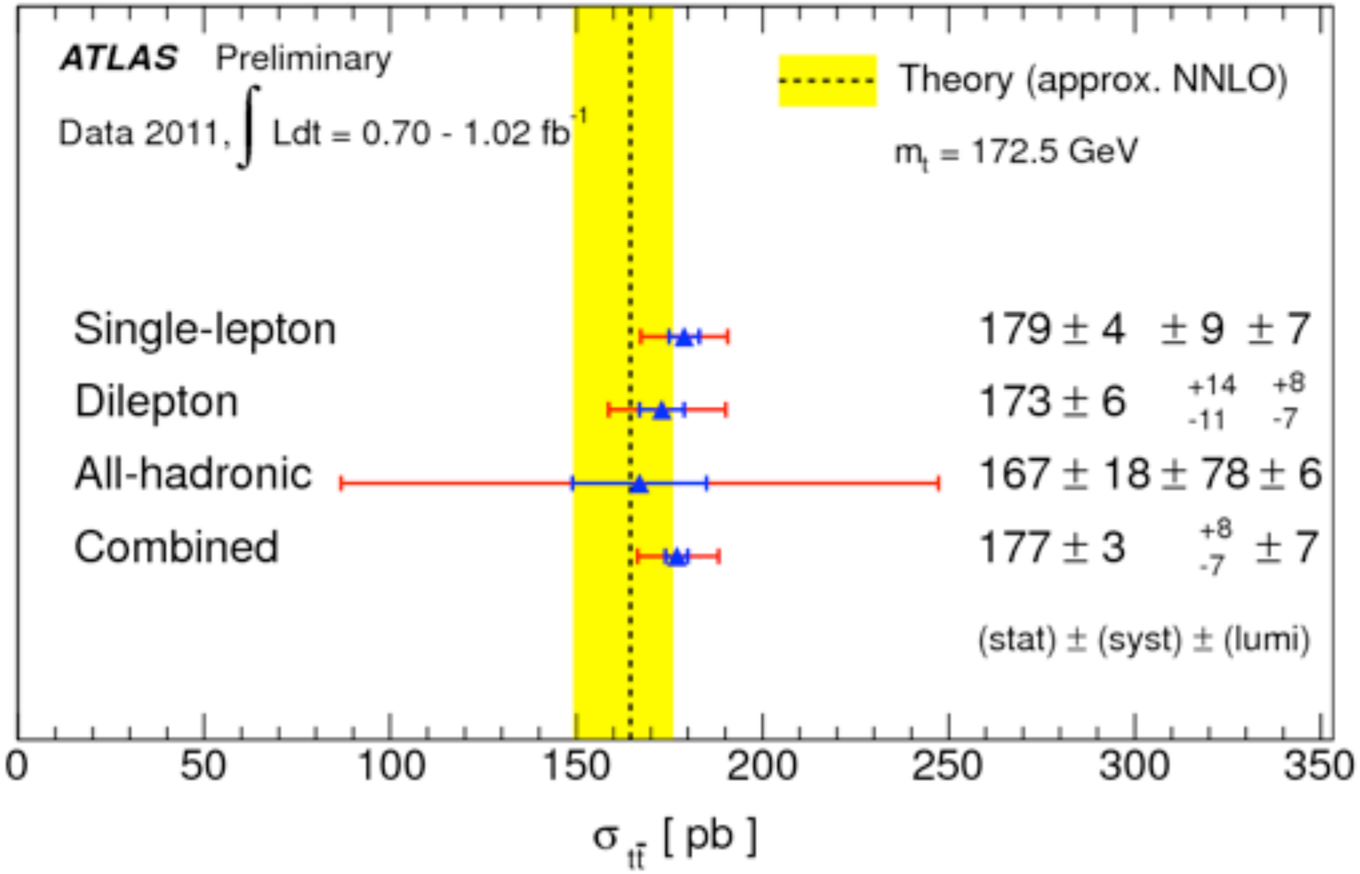
CMS combination method

- Techniques in individual channels
  - l+jets: binned profile likelihood fit
  - dilepton and μ+τ: cut and count
  - all hadronic: unbinned maximum likelihood fit to reconstructed m_{top}
- Combination: fitter used in l+jets extended to include other channels
  - channels using counting methods are modeled by histograms with one bin
  - results of unbinned LH fit are parameterized to be represented as a single bin in combined likelihood
  - not straightforward to extend to include ATLAS measurements
- Best Linear Unbiased Estimate method used as a cross check
  - results agree very well
    - central value differs by 0.7%
    - relative uncertainty is the same

ATLAS combination

ATLAS-CONF-2012-024

- up to 1.1/fb
- 3 final channels
  - 4th channel was available (l+tau) but not included into combination due to overlap with l+jets
- relative uncertainty - 6.2%
- dominated by l+jets - 6.7%



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

Atlas combination method

- 6 channel combination is implemented as a product of individual likelihoods
  - approximation for the LH of l+jets channel

$$L_{\mathrm{comb}}(\sigma_{t\bar{t}}, \mathcal{L}, \vec{\alpha}) = L_{l+\mathrm{jets}}(\sigma_{t\bar{t}}, \mathcal{L}, \vec{\alpha}) \prod_{i\in\{ee,\mu\mu,e\mu\}} \mathrm{Pois}(N_i^{\mathrm{obs}} | N_{i,\mathrm{tot}}^{\mathrm{exp}}(\vec{\alpha})) \times \prod_{k\in\text{all-had bins}} \mathrm{Pois}(n_k \,|\, s_k(\vec{\alpha}) + b_k(\vec{\alpha})) \prod_{j\notin \text{l+jets sys}} \mathrm{Gaus}(0|\alpha_j, 1)\,.$$

- 89 parameters total
- 26 shared between l+jets and dilepton LH
- 12 common to all three channels

$\sigma = 177.4\,^{+11.1}_{-10.2}$ (total)

BLUE combination

- much simpler
- more approximations
  - symmetrized uncertainties
- excellent agreement with LH

$\sigma = 177.7 \pm 11.4$ (total)

LHC combination

- Performing combination of all individual channels from two experiments using likelihood technique is very complicated
- BLUE = Best Linear Unbiased Estimate

  L.Lyons, D.Gibaut, P.Clifford, NIM A270 (1988), A.Valassi, NIM A500 (2003)

  - calculates linear weighted sum of individual results with weights determined such that they minimize the total uncertainty on the combined result
  - takes into account statistical and systematic uncertainties and their correlations
- Advantages
  - allows combination of correlated measurements of one or more parameters
  - produces a fit χ^2 to evaluate consistency of inputs
  - fast and simple
  - well established technique used recently for the LHC top quark mass combination

Dealing with uncertainties

- Split in categories according to
  - physics origin
  - correlation between experiments
- Try to follow as close as possible
  - LHC top quark mass combination
    - ATLAS-CONF-2012-095
    - CMS PAS TOP-12-001

- Signal modelling uncertainties
- ATLAS
  - generator: MC@NLO vs Powheg (vs Alpgen for the recent results)
  - shower model: Powheg+Pythia vs Powheg+Herwig
  - ISR/FSR: ACER+Pythia with more/less radiation
  - PDF
- CMS
  - Q^2 variation in Madgraph
  - ME-PS matching
  - MC tune (for some analysis)
  - PDF

Mapping of uncertainties

Table 2: Mapping of the ATLAS and CMS systematic uncertainties

Category	ATLAS systematics	CMS systematics	correlation
Statistical			0
Detector simulation			0
	muon, electron identification jeteff, JER, MET btag-allHad trigger allHad	lepton efficiency, lepton selection pileup b-tagging trigger allHad τ fake, τ identification	
JES	JES	JES, bJES	0
Signal model			
MC	Generator	Generator, MC tune Jet and MET model, τ decay model	1
PS	Parton shower	ME-PS matching	1
Radiation	ISR/FSR	tt Q^2	1
PDF			1
	added for ATLAS	W branching	1
Background (data)			0
	QCD shape fake background multijet background Z pT model, DY normalization	QCD normalization DY normalization	
Background (MC)			1
	theoretical cross-sections W shape	cross sections of MC backgrounds W+jets Q^2	
Method	Monte Carlo statistics		
Luminosity			
	Bunch current	Bunch current	1
	Detector	Detector	0

- keep separate components as in LHC top mass combination
- test sensitivity to correlation

Top mass uncertainty is not considered

Inputs and result

	ATLAS	CMS	Correlation	LHC combination
Cross-section	177.0	165.8		173.3
Uncertainty				
Statistical	3.2	2.2	0	2.3
Jet Enegy Scale	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	0	1.6
W leptonic branching ratio	1.0	1.0	1	1.0
Luminosity				
Bunch current	5.3	5.1	1	5.3
Luminosity measurement	4.3	5.9	0	3.4
Total systematic	10.8	14.2		9.8
Total	11.3	14.4		10.1

ATLAS: 60% of total
CMS: 54% of total

σ = 173.3 ± 2.3 (stat) ± 9.8 (syst+lumi)
weights: 67% ATLAS, 33% CMS
probability - 47%, correlation - 30%

5.8% relative uncertainty,
7% improvement relative
to the most precise result

Cross checks

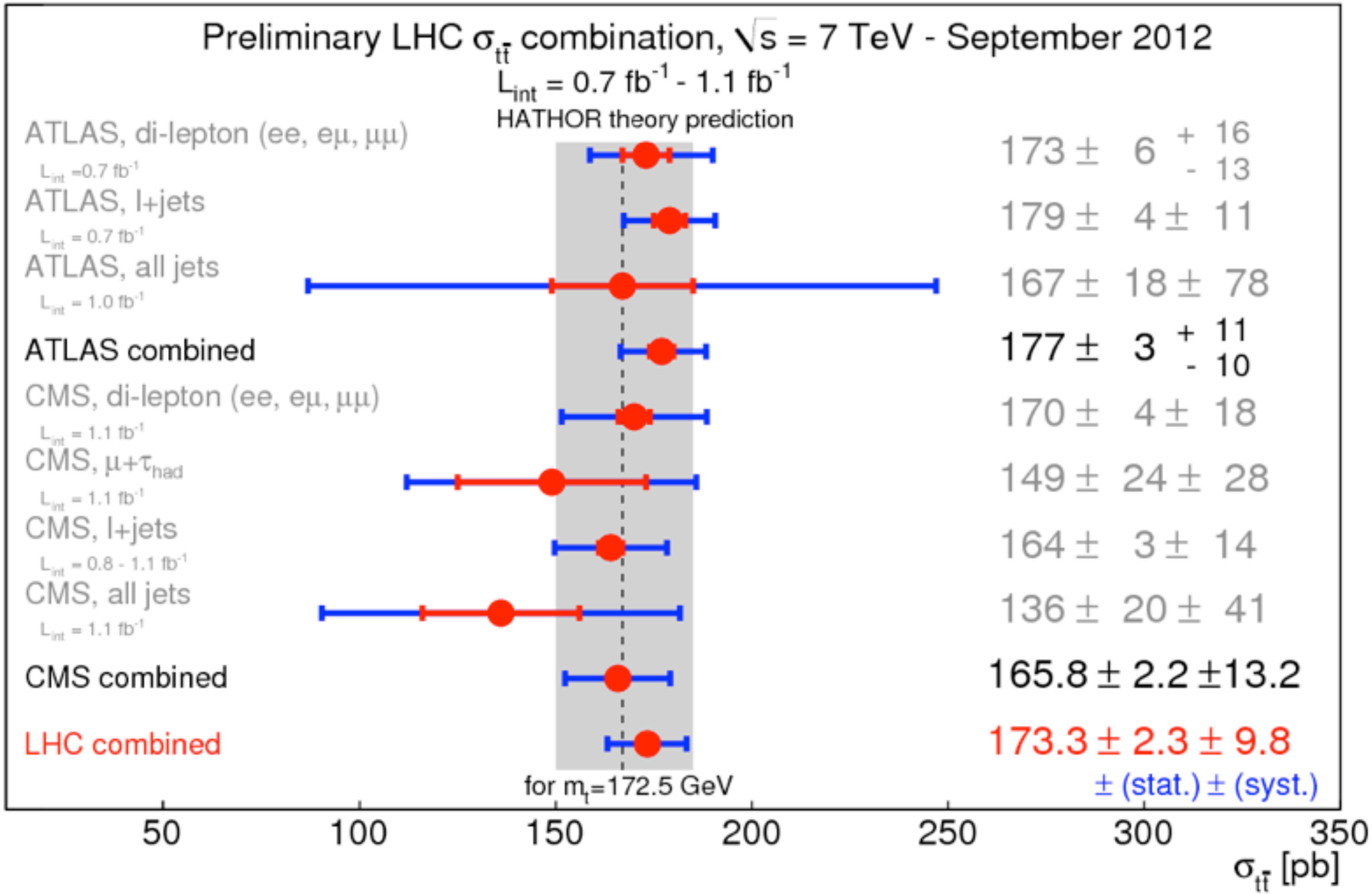
- Use Asymmetric Iterative BLUE (AIB):
  - http://home.fnal.gov/cplager/log/AIB
  - Important if combining the measurements where the magnitude of the uncertainty depends on the measurement itself
    - true for the cross section
  - uses the starting combined value to calculate the uncertainty
  - iterates until the starting value and the output are the same
  - Result of AIB and BLUE turned out to be identical within rounding
- Vary correlation between 0 and 1 and check the effect on combined cross section
  - Variation for JES and components of the signal model evaluated differently by CMS and ATLAS has negligible effect on the result
  - For luminosity uncertainty breakdown into correlated and uncorrelated part is critical
    - for extreme variation of correlation of total luminosity uncertainty between 0 and 1 cross section changes by 0.8 pb, uncertainty by 1.1% absolute, 12% relative

Breakdown in combination

summary talk by W. Kozanecki at "LHC Lumi Days 2012 workshop"

- ATLAS luminosity uncertainty on the combined cross section - 3.8%
  - 3% comes from bunch current and taken as fully correlated with CMS
  - 2.3% uncorrelated
- CMS luminosity uncertainty on the combined cross section - 4.7%
  - 3.1% comes from bunch current and taken fully correlated with ATLAS
  - 3.5% uncorrelated

Money plot



Preliminary LHC σ_tt̄ combination, √s = 7 TeV - September 2012
L_int = 0.7 fb^-1 - 1.1 fb^-1
HATHOR theory prediction
ATLAS, di-lepton (ee, eμ, μμ)
L_int =0.7 fb^-1
173 ± 6 + 16 - 13
ATLAS, l+jets
L_int = 0.7 fb^-1
179 ± 4 ± 11
ATLAS, all jets
L_int = 1.0 fb^-1
167 ± 18 ± 78
ATLAS combined
177 ± 3 + 11 - 10
CMS, di-lepton (ee, eμ, μμ)
L_int = 1.1 fb^-1
170 ± 4 ± 18
CMS, μ+τ_had
L_int = 1.1 fb^-1
149 ± 24 ± 28
CMS, l+jets
L_int = 0.8 - 1.1 fb^-1
164 ± 3 ± 14
CMS, all jets
L_int = 1.1 fb^-1
136 ± 20 ± 41
CMS combined
165.8 ± 2.2 ±13.2
LHC combined
173.3 ± 2.3 ± 9.8
for m_t=172.5 GeV
± (stat.) ± (syst.)
50
100
150
200
250
300
350
σ_tt̄ [pb]

Recent measurements at 7 TeV

- counting using soft muon tag
- ≥3 jets

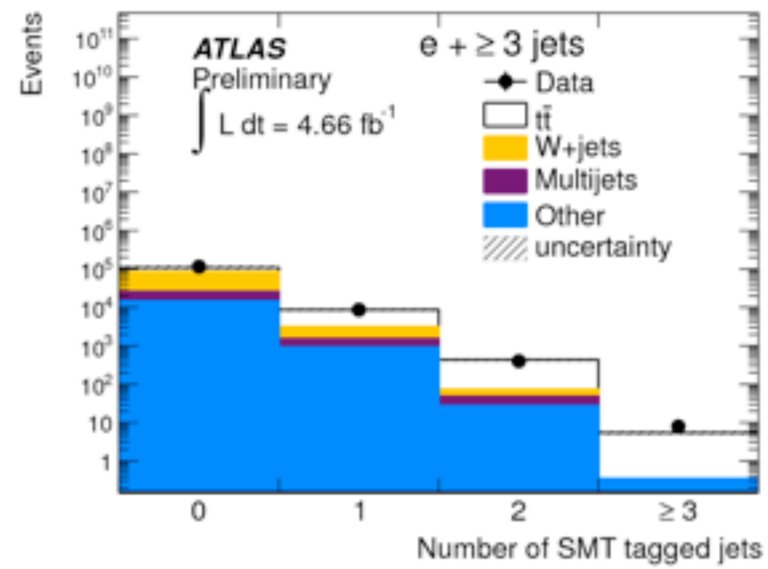
single lepton

4.7 fb^{-1}

ATLAS-CONF-2012-131

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

total uncertainty ~10.5%



- τ+jets, 1.7/fb, 23% — ATLAS-CONF-2012-032
- all hadronic, 4.7/fb, 37% — ATLAS-CONF-2012-031
- l+τ, 2/fb, 13.4% — Phys. Lett. B 717 (2012) 89-108

statistical correlation?

- count with b-tagging
- cross section extracted from the profile likelihood fit to Njets vs Nbtags distribution

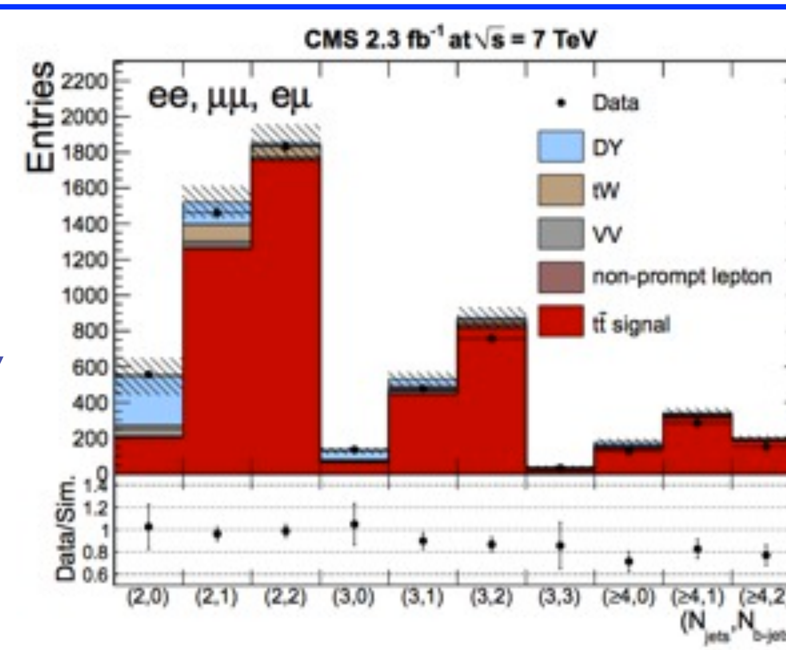
dilepton

2.3 fb^{-1}

$$\sigma_{t\bar{t}} = 161.9 \pm 2.5(\text{stat})\ ^{+5.1}_{-5.0}(\text{syst}) \pm 3.6\ (\text{lumi})\ \text{pb}$$

arXiv:1208.2671

total uncertainty ~5%



- τ+jets, 3.9/fb, 23% — CMS PAS TOP-11-004
- l+τ, 2.1/fb, 18% — *Phys. Rev. D* 85 (2012) 112007

The most precise single measurement

7 TeV measurements: systematics

single lepton

Source	Combined
Statistical Uncertainty	±1.0
Object selection	
Lepton energy resolution	+0.2 /-0.1
Lepton reco, ID, trigger	+1.7 /-1.8
Jet energy scale	+3.5 /-3.8
Jet energy resolution	±0.2
Jet reconstruction efficiency	±0.06
Jet vertex fraction	+1.2 /-1.4
E_T^{miss} uncertainty	±0.07
SMT muon reco, ID	±1.3
SMT muon χ^2_{match} efficiency	±0.6
Background estimates	
Multijet normalisation	± 4.4
W+jet normalisation	± 5.5
Other bkg normalisation	± 0.1
Other bkg systematics	+2.2 /-1.8
Signal simulation	
$b \to \mu X$ Branching ratio	+2.9 /-3.1
ISR/FSR	± 1.5
PDF	± 3.1
NLO generator	± 3.2
Parton shower	± 2.2
Total systematics	±10.5
Integrated luminosity	± 1.8

ATLAS-CONF-2012-131

dilepton

Uncertainty on $t\bar{t}$ signal

arXiv:1208.2671

Source	Without b tagging
Luminosity	2.2
Lepton efficiencies	1.7 (ee) / 1.7 ($\mu\mu$) / 1.0 (eμ)
Lepton energy scale	0.3
Jet energy scale	1.8
Jet energy resolution	0.5
$\not\!\!E_T$ efficiency	1.4
b tagging	-
Pileup	0.5
Scale of QCD (μ)	0.6
Matching partons to showers	0.6
W branching fraction	1.7

Very small modelling uncertainties

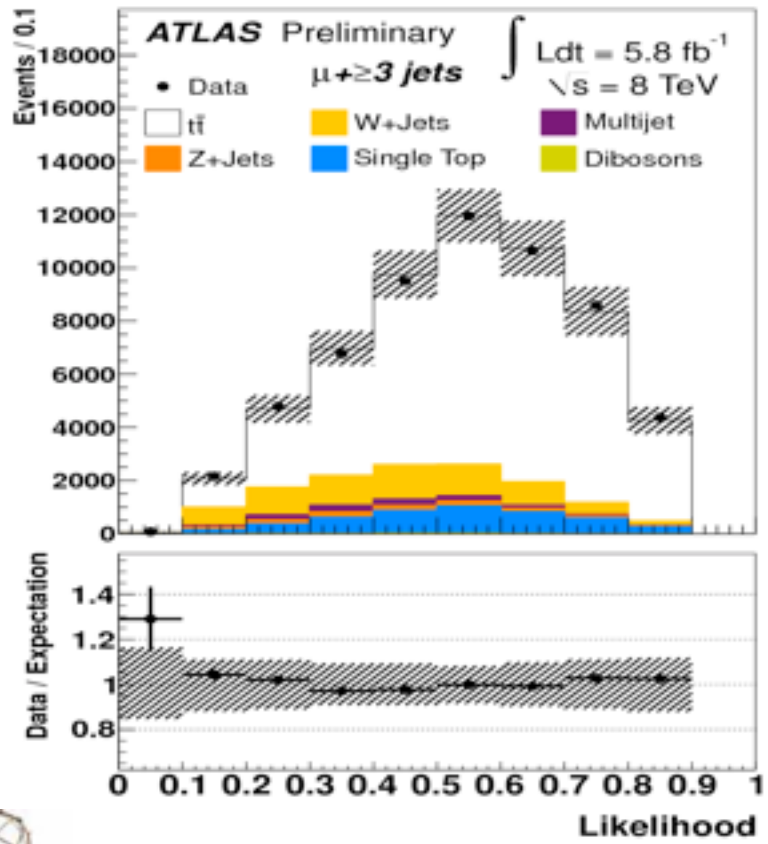
Only combined uncertainty on each background source is provided

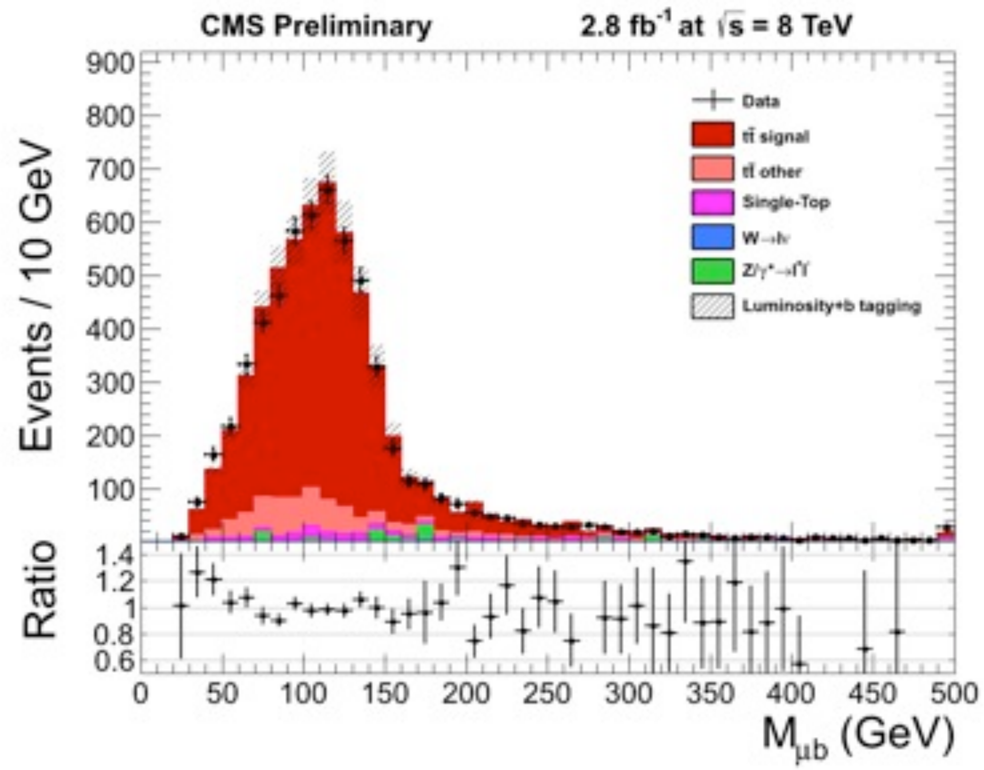
PDF uncertainty ?

No breakdown of uncertainties after the fit

A complete table is given for the counting cross check analysis

New measurements at 8 TeV





- ≥4 jets, ≥1 b-tag
- fit to M(lb)

CMS PAS TOP-12-006

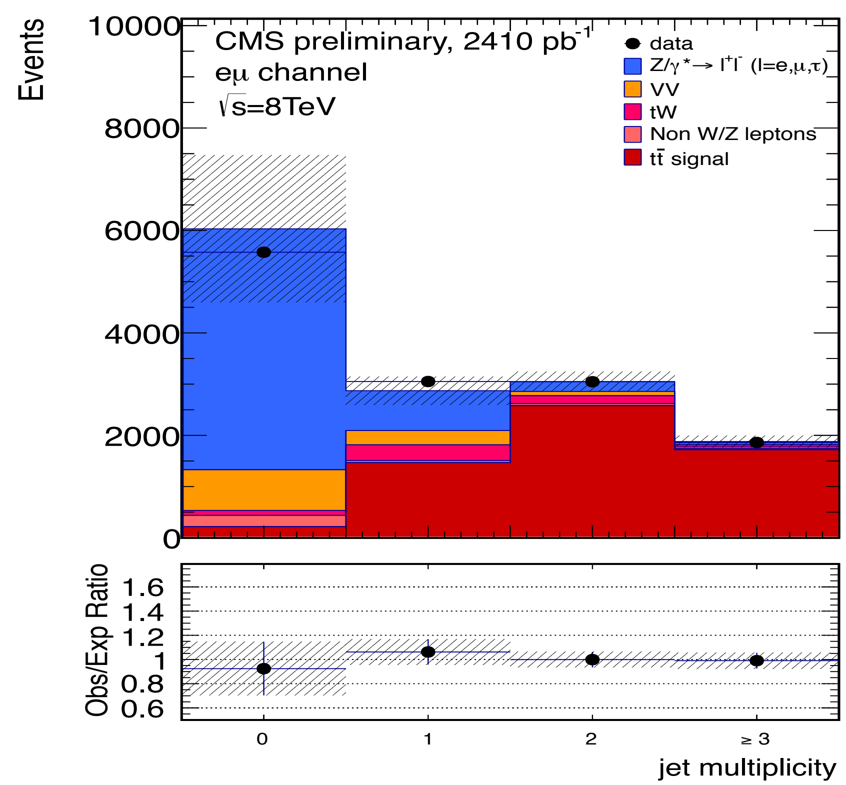
$$\sigma_{t\bar{t}}\,(\text{combined}) = 228.4 \pm 9.0\,(\text{stat.})\,^{+29.0}_{-26.0}\,(\text{syst.}) \pm 10.0\,(\text{lumi.})\ \text{pb}$$

- ≥3 jets, ≥1 b-tag
- multivariate discriminant
  - lepton η, aplanarity

ATLAS-CONF-2012-149

$\sigma_{t\bar{t}}$ =241±2(stat.)±31(syst)±9(lumi) pb

in l+jets comparable uncertainty between ATLAS and CMS



CMS PAS TOP-12-007

dilepton

- ≥2 jets, ≥1 b-tag
- counting

σ=227 ±3 (stat.) ±11 (syst.) ±10 (lumi.) pb

8 TeV measurements: systematics

ATLAS-CONF-2012-149

Source	$e+\geq 3$ jets	$\mu+\geq 3\,jets$	combined
Jet/MET reconstruction, calibration	6.7, -6.3	5.4, -4.6	5.9, -5.2
Lepton trigger, identification and reconstruction	2.4, -2.7	4.7, -4.2	2.7, -2.8
Background normalization and composition	1.9, -2.2	1.6, -1.5	1.8, -1.9
b-tagging efficiency	1.7, -1.3	1.9, -1.1	1.8, -1.2
MC modelling of the signal	±12	±11	±11
Total	±14	±13	±13

TABLE 1. Overview of the systematic uncertainties on the cross section measurement. Uncertainties marked with (*) are obtained from 7 TeV.

single lepton

generator	6%
shower	6%
ISR/FSR	4%
PDF	6%

CMS PAS TOP-12-006

single lepton

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 7TeV	0.9
Normalisation of data-driven multijet shape	0.9
b tagging efficiency measurement	8.0
Trigger Efficiency	-2.8 +3.2
Lepton selection	-2.4 +2.8
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
Luminosity	4.4
Total	+12.7 -11.4

dilepton

CMS PAS TOP-12-007

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

Summary cross section of measurements

exp	$\sqrt{s}$	channel	cross section
CMS	7	*combo*	166 ± 2(stat) ± 11(syst) ± 8 (lumi)
ATLAS	7	*combo*	177 ± 3 (stat) $^{+8}_{-7}$ (syst) ± 7 (lumi)
LHC	7	*combo*	173.3 ± 2.3 (stat) ± 9.8 (syst+lumi)
CMS	7	*dilepton*	161.9 ± 2.5(stat) $^{+5.1}_{-5.0}$(syst) ± 3.6 (lumi) pb
CMS	7	*tau+lep*	143±14(stat.)±22(syst)±3(lumi)
CMS	7	*tau+jets*	156±12(stat.)±33(syst)±3(lumi)
ATLAS	7	*l+jets*	165±2(stat.)±17(syst)±3(lumi)
ATLAS	7	*tau+jets*	200 ± 19(stat) ± 43(syst)
ATLAS	7	*tau+lep*	186±13(stat.)±20(syst)±7(lumi)
ATLAS	7	*all hadron*	168±12(stat.)+60−57(syst)±7(lumi)
ATLAS	8	*l+jets*	241±2(stat.)±31(syst)±9(lumi)
CMS	8	*l+jets*	228.4±9.0(stat.)+29.0−26.0(syst)±10.(lumi)
CMS	8	*dilepton*	227 ±3 (stat.) ±11 (syst.) ±10 (lumi.)

Conclusions and outlook

- Performed the first combination of top pair production cross section measurements by CMS and ATLAS

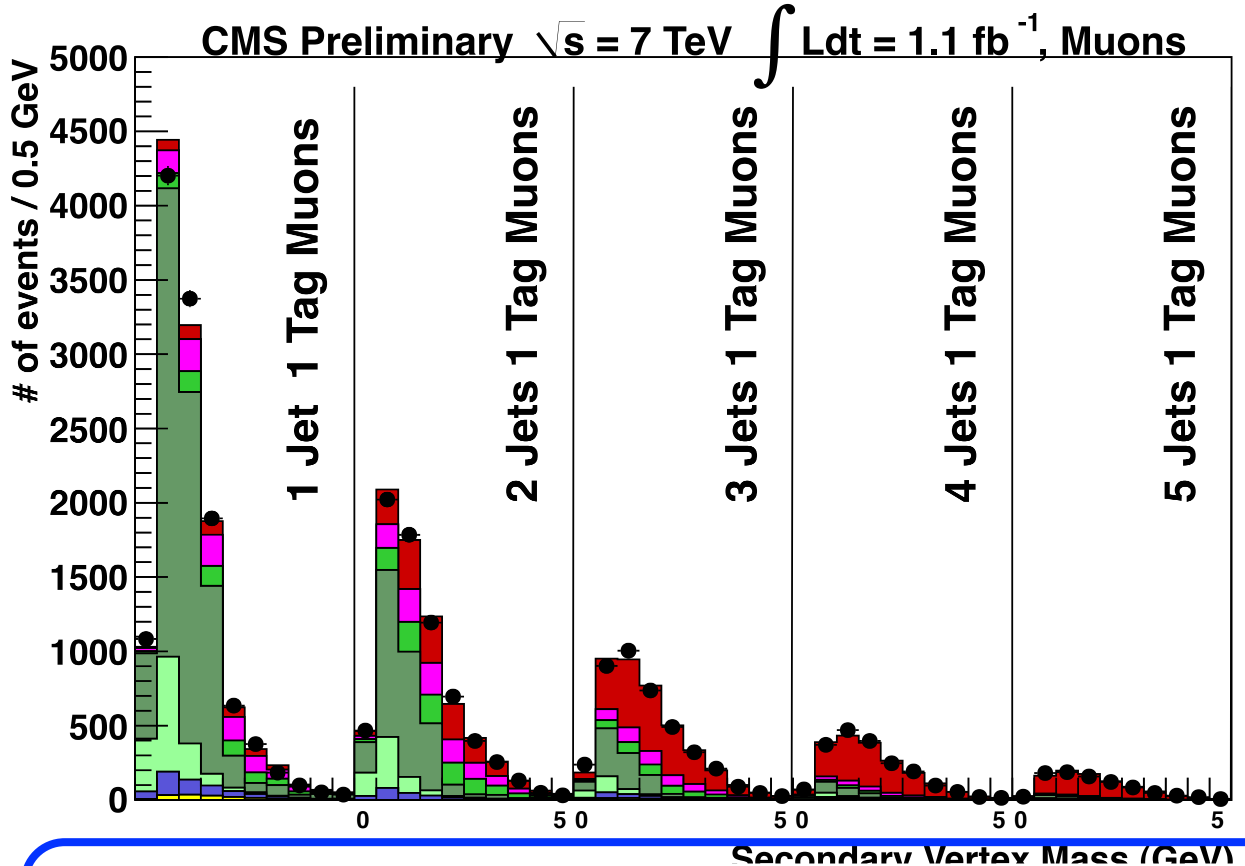
  σ = 173.3 ± 2.3 (stat) ± 9.8 (syst+lumi)

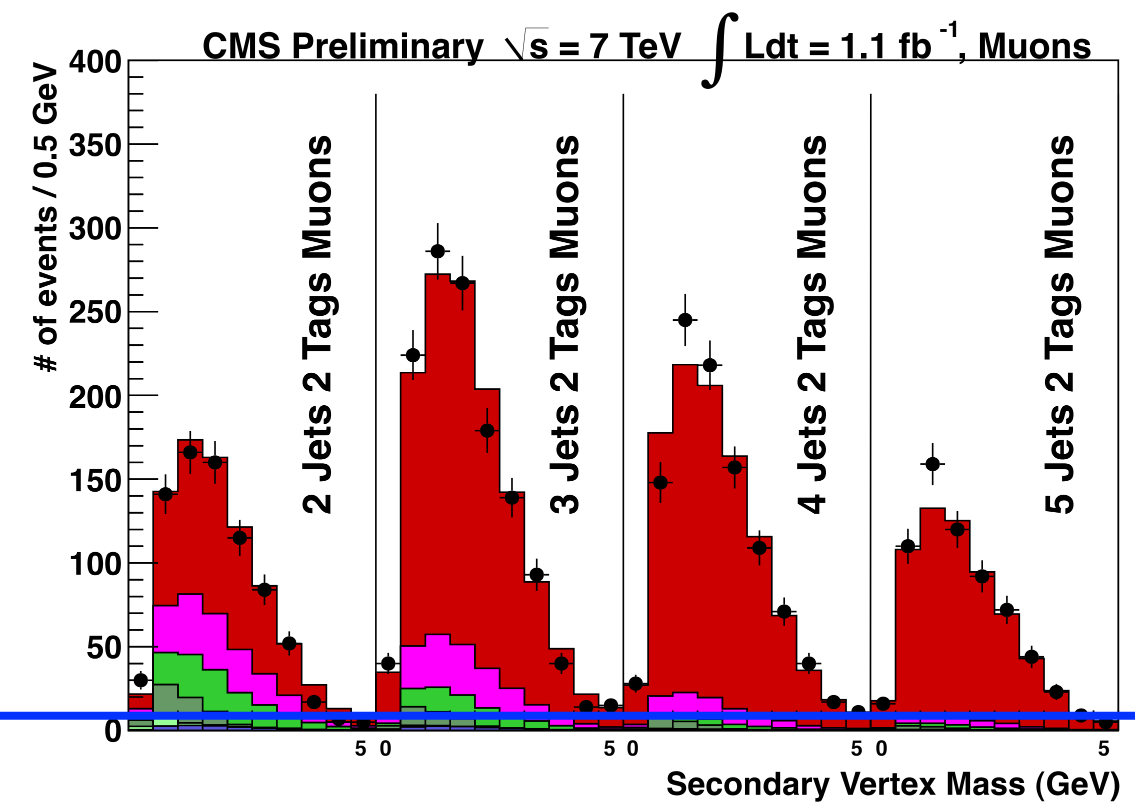
- Used BLUE method (as for top mass combinations)
- Luminosity correlation is of major importance in the current combination
  - luminosity uncertainty and correlation go down for full 2011 dataset
- New combinations can be performed for 7 and 8 TeV results
  - BLUE seems to be the best for practical reasons
  - it seems more practical to combine by channel
  - easier to update combination once new result is available
- Issues of future combinations
  - significant difference in treating modelling uncertainties by ATLAS and CMS
  - lack of information in public documents to perform combinations
  - some non-uniformity of quoting systematics even within the experiments

Backup

- Fit to secondary mass distribution in
  - njets = 1,2,3,4 and ≥5
  - nbtag = 1,2
- Profile likelihood fit
- 8% relative uncertainty
- dominant uncertainties:
  - luminosity
  - PDF
  - pileup

σ = 164 ± 3(stat) ± 12(syst) ± 7 (lumi)



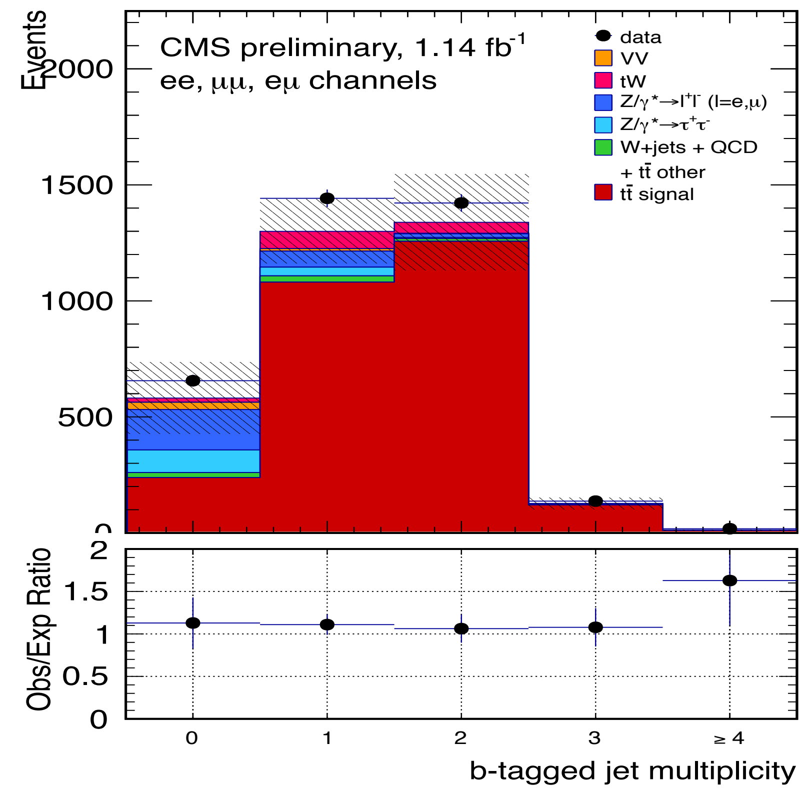


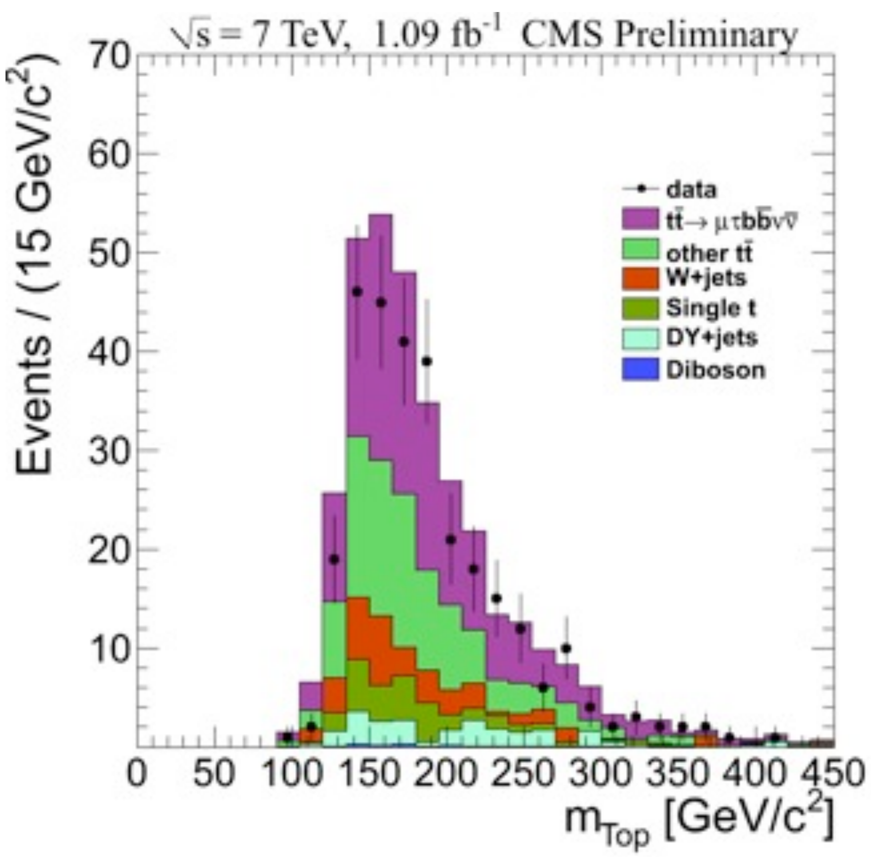
CMS dilepton channels

ee, μμ, eμ

- cut and count analysis
- dominant uncertainties:
  - b-tagging
  - pileup
  - lepton selection model

$\sigma = 170 \pm 4(\text{stat}) \pm 16(\text{syst}) \pm 8\ (\text{lumi})$





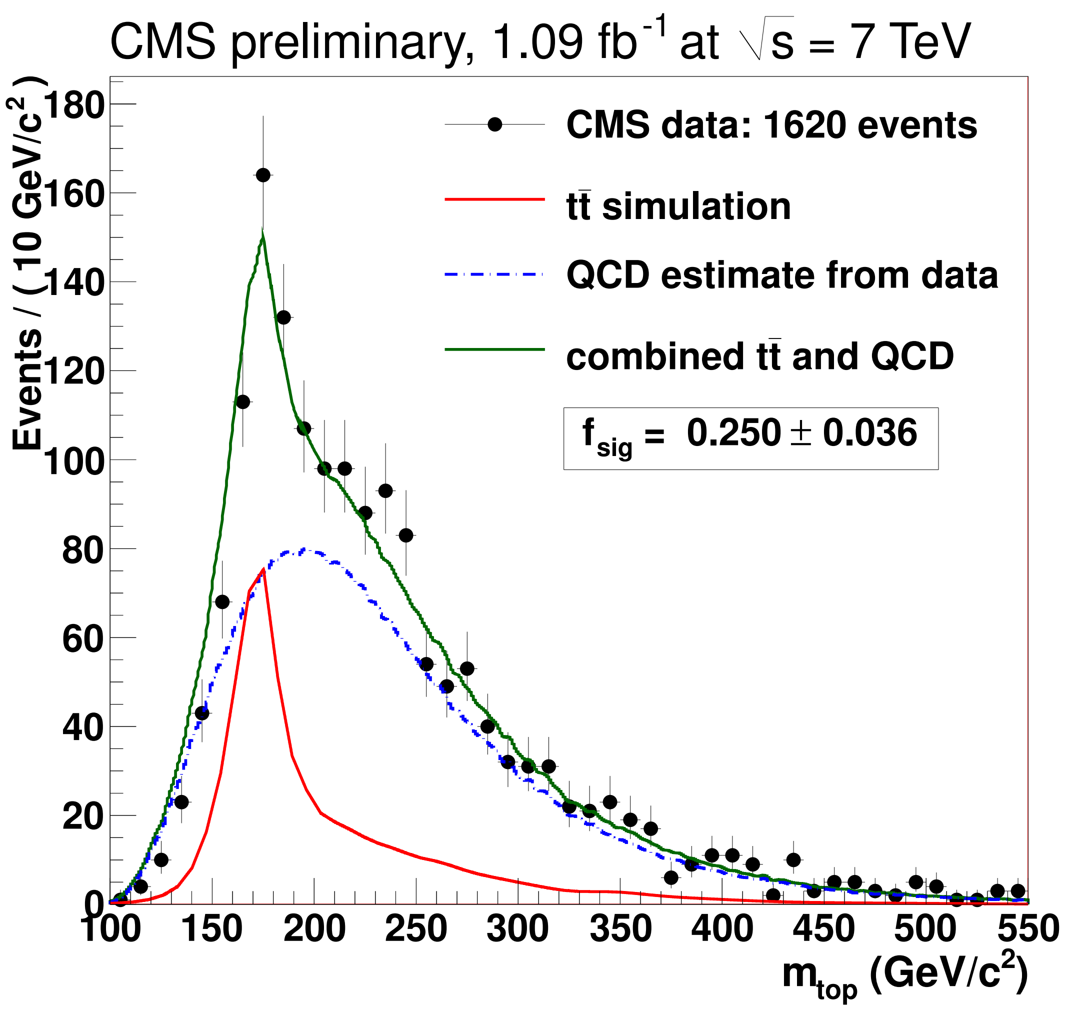
$\mu\tau_{had}$

- cut and count analysis
- dominant uncertainties:
  - τ fake background
  - τ identification
  - b-tagging
- overlap of events with l+jets channel has negligible effect on the combined result

$\sigma = 149 \pm 24(\text{stat}) \pm 26(\text{syst}) \pm 9\ (\text{lumi})$

CMS all hadronic channel

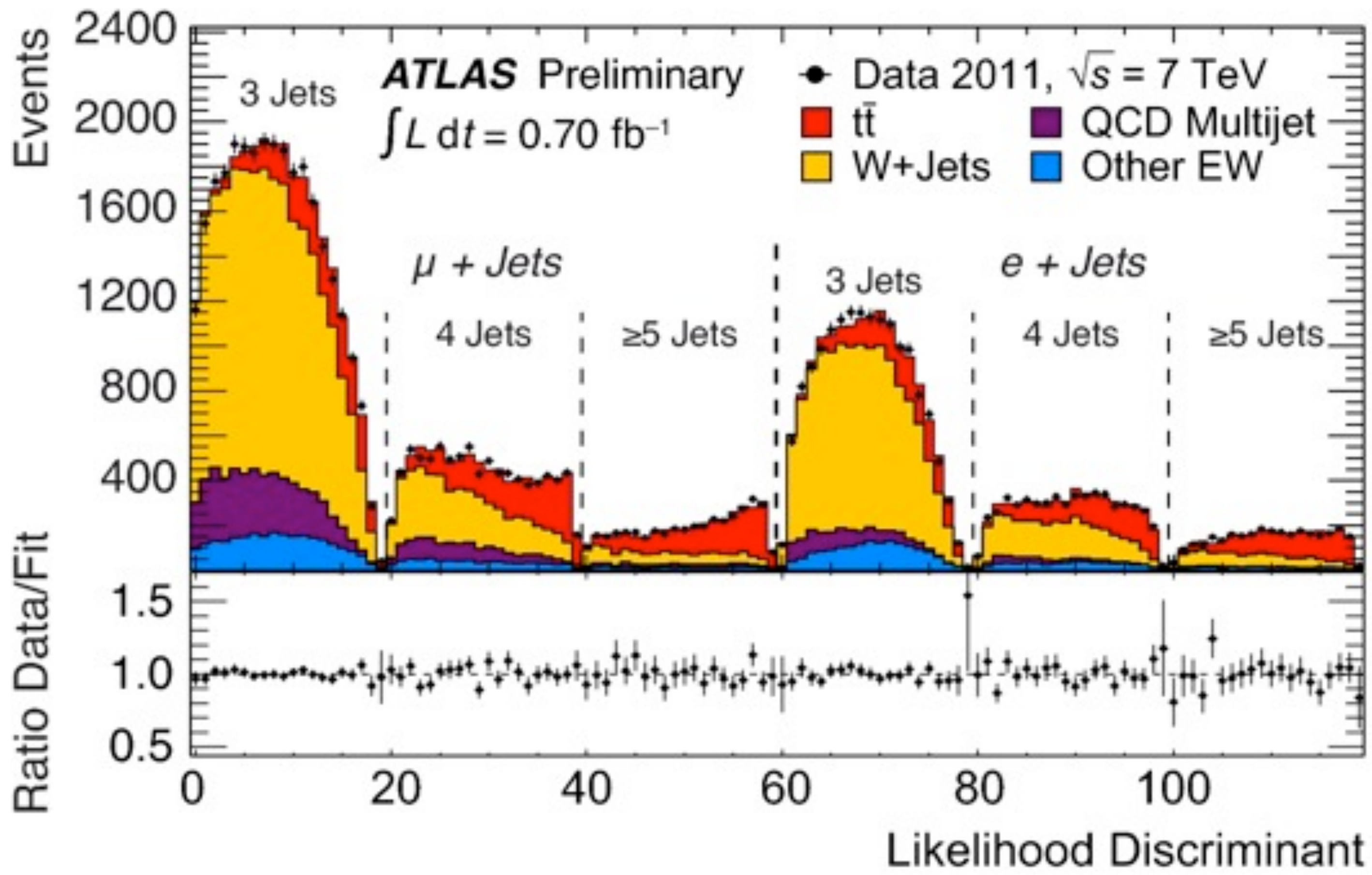
- unbinned maximum likelihood fit to the reconstructed top quark mass
- dominant uncertainties
  - b-tagging
  - JES
  - background model



σ = 136 ± 20(stat) ± 40(syst) ± 8 (lumi)

ATLAS: l+jets

- discriminant built of 4 kinematic variables
- simultaneous fit in
  - njets = 3,4 and ≥5
  - no b-tag requirement
- profile likelihood fit
- dominant uncertainties
  - generator
  - JES
  - muon identification

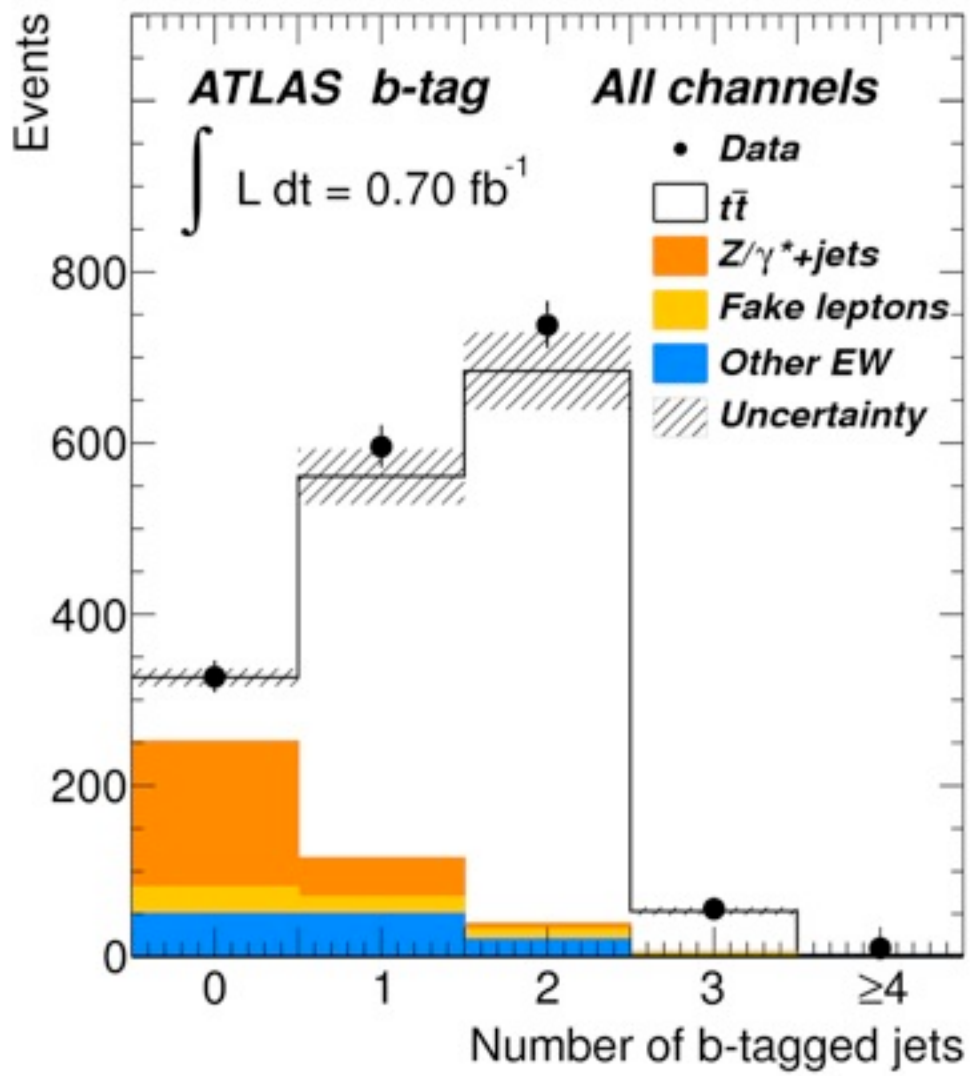


σ = 179 ± 4 (stat) ± 9 (syst) ± 7 (lumi)

ATLAS dilepton channel

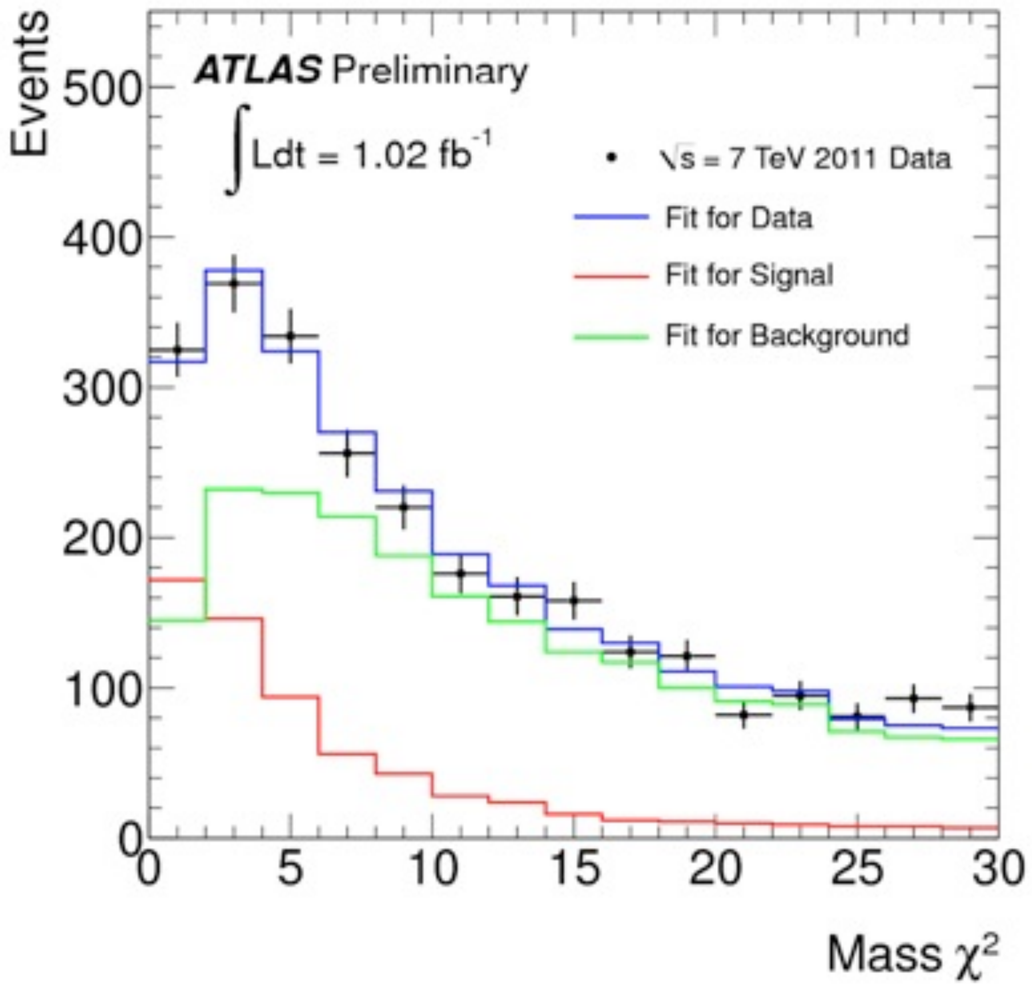
- cut and count in 3 pretag samples
  - combination does not include l+track channels due to significant overlap with l+jets
- profile likelihood used to combine individual channels
- dominant uncertainties:
  - generator
  - JES
  - lepton identification

$$\sigma = 173 \pm 6\ (\text{stat})\ ^{+14}_{-11}\ (\text{syst})\ ^{+8}_{-7}\ (\text{lumi})$$



ATLAS all hadronic

- Binned likelihood fit to the reconstructed χ^2 top quark mass distribution
- Dominating uncertainties
  - JES
  - b-tagging
  - ISR/FSR



σ = 167 ± 18 (stat) ± 78 (syst) ± 6 (lumi)

What is the correlation?

summary talk by W. Kozanecki at "LHC Lumi Days 2012 workshop"

Systematic uncertainties on σ_{vis} (*pp* @ 7 TeV, vdM scans)

ATLAS 3.0%

CMS 3.1%

	ATLAS-CONF-2011-116 (2 fb^{-1}) May 2011 vdM %	ATL Upd 2011 5 fb^{-1}, projected May 2011 vdM %	ATL est. 2012 for precision vdM scan	CMS 2011 pp 7 TeV May 2011 vdM %	ALICE 2011 pp 2.76 TeV Mar 2011 vdM %	LHCb 2011 pp 7 TeV Oct 2011 vdM %
DCCT calibration	2.73	0.23			0.4	0.23
FBCT bunch-by-bunch fractions	1.30	0.20			?	0.05
Ghost charge & satellites	0.18	0.18			0.4	0.39
Subtotal, bunch-charge product	*3.0*	*0.35*		*3.10*	*0.64*	*0.46*
Statistical	0.04	0.04		0?	0?	0.15
Beam centering	0.10	0.10		?	0	0
Beam position jitter	0.30	0.30	*depend*	?	?	?
ε growth & other non-reproducibility	0.40	0.77	*on*	1.34	0.64	1.06
Bunch-to-bunch σ_{vis} consistency	0.40	0.55		2 bunches	?	-> inflate stat err
Fit model	0.80	0.29		0	?	0.29
Background subtraction	N/A	0.31	*beam*	N/A	0.30	0
Reference $\mathcal{L}_{sp}$	NC	0.30		only 1 det/alg	only 1 det/alg	only 1 det/alg
Dynamic beta	NC	0.80	*conditions*	?	1.00	0.80
Linear x-y coupling	negligible	negligible?		?	0.60	0.01
Non-linear transverse correlations	0.50	0.50		?	?	?
μ-dependence during vdM scan	0.50	0.50		?	negligible	no effect seen
Length scale calibration	0.30	0.30		0.50	1.41	0.14
ID lengh scale	0.30	0.30		?	?	?
Instrumental issues (e.g. BCM H/V)	0.70	0.70		-	-	-
Subtotal, calibration-scan syst.	*1.5*	*1.75*		*1.43*	*1.96*	*1.38*
Total syst. uncertainty on σ_{vis}	***3.4***	***1.8***		***3.4 (1.5?)***	***2.1***	***1.5***

The numbers are the systematic uncertainties (%) as reported by each experiment (and regrouped to fit roughly in the same descriptive scheme)

"?" reflect this speaker's ignorance as to how this uncertainty was treated; it does not necessarily imply that it was ignored in the analysis – only that it was unclear where to find it.

https://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=162948