Prospects for LHC top-quark-pair cross section combinations

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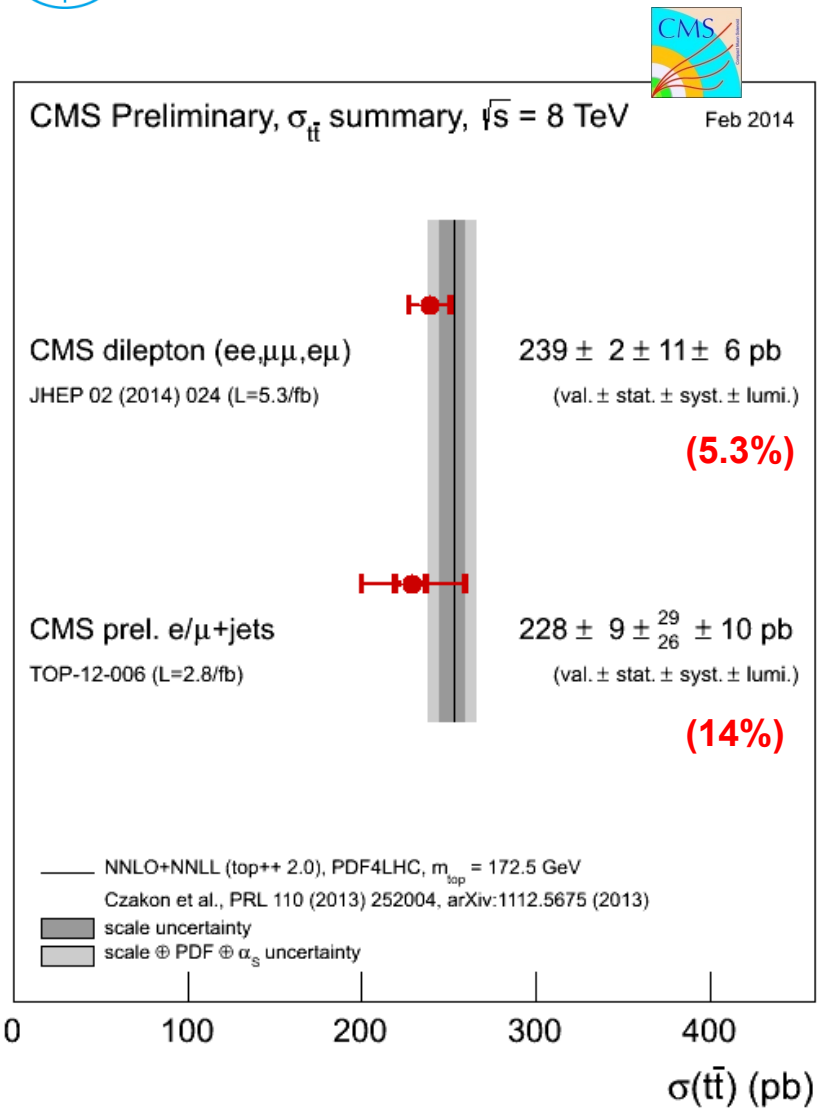
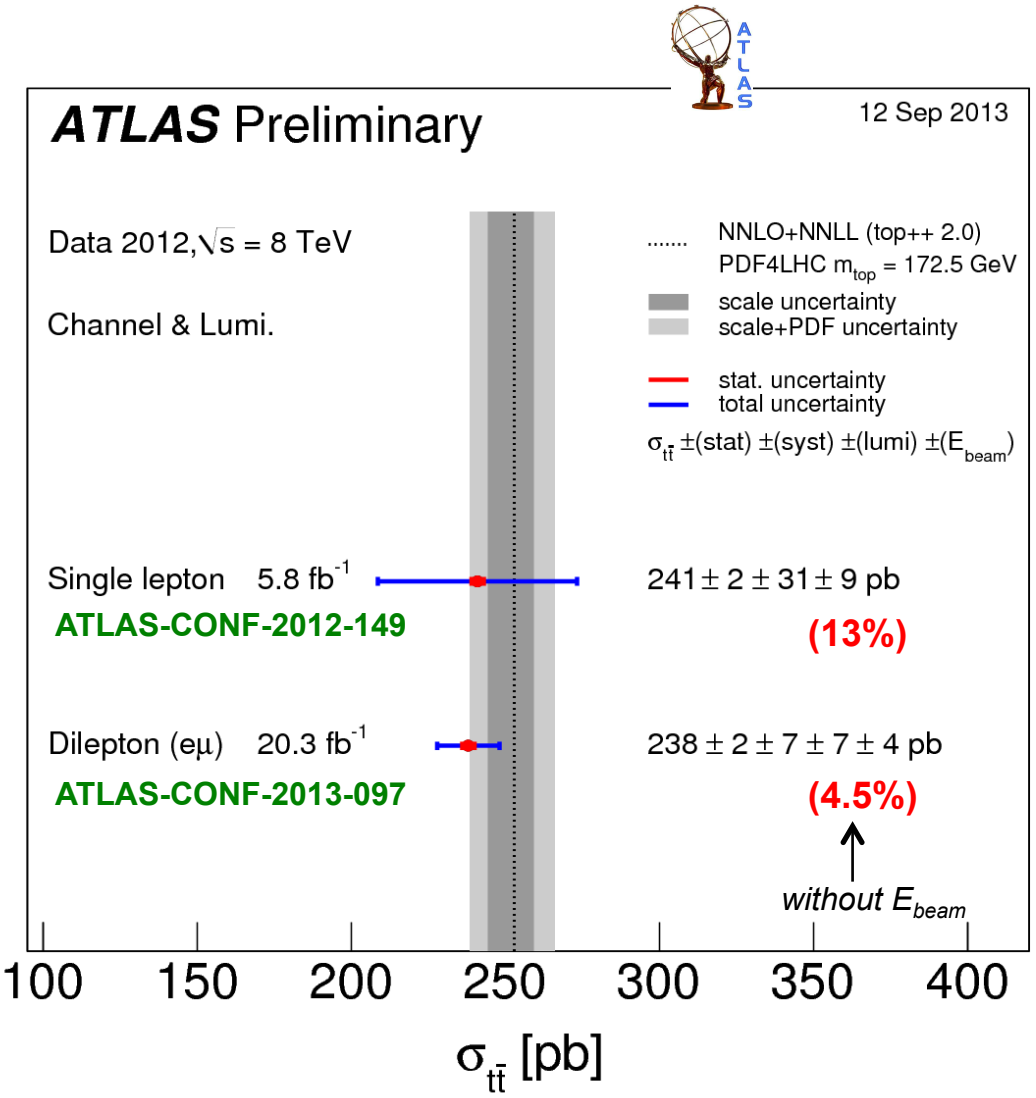
HELMHOLTZ GEMEINSCHAFT

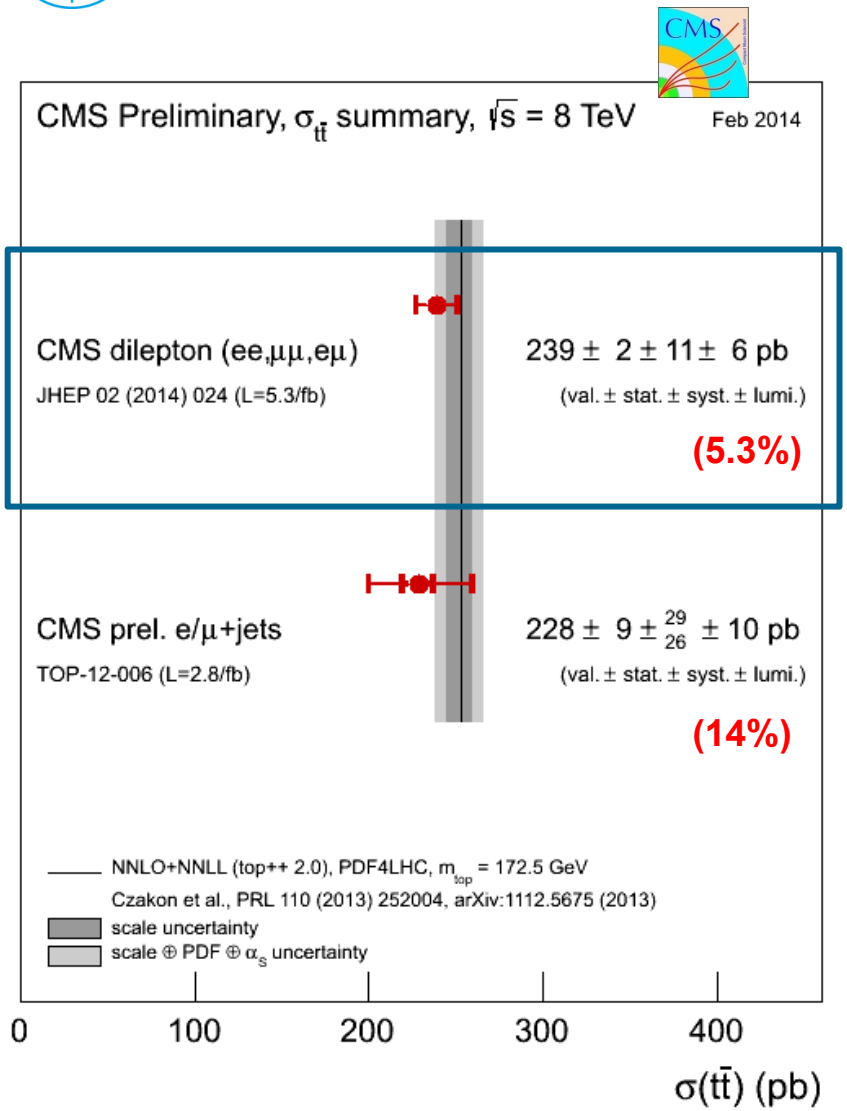
DESY

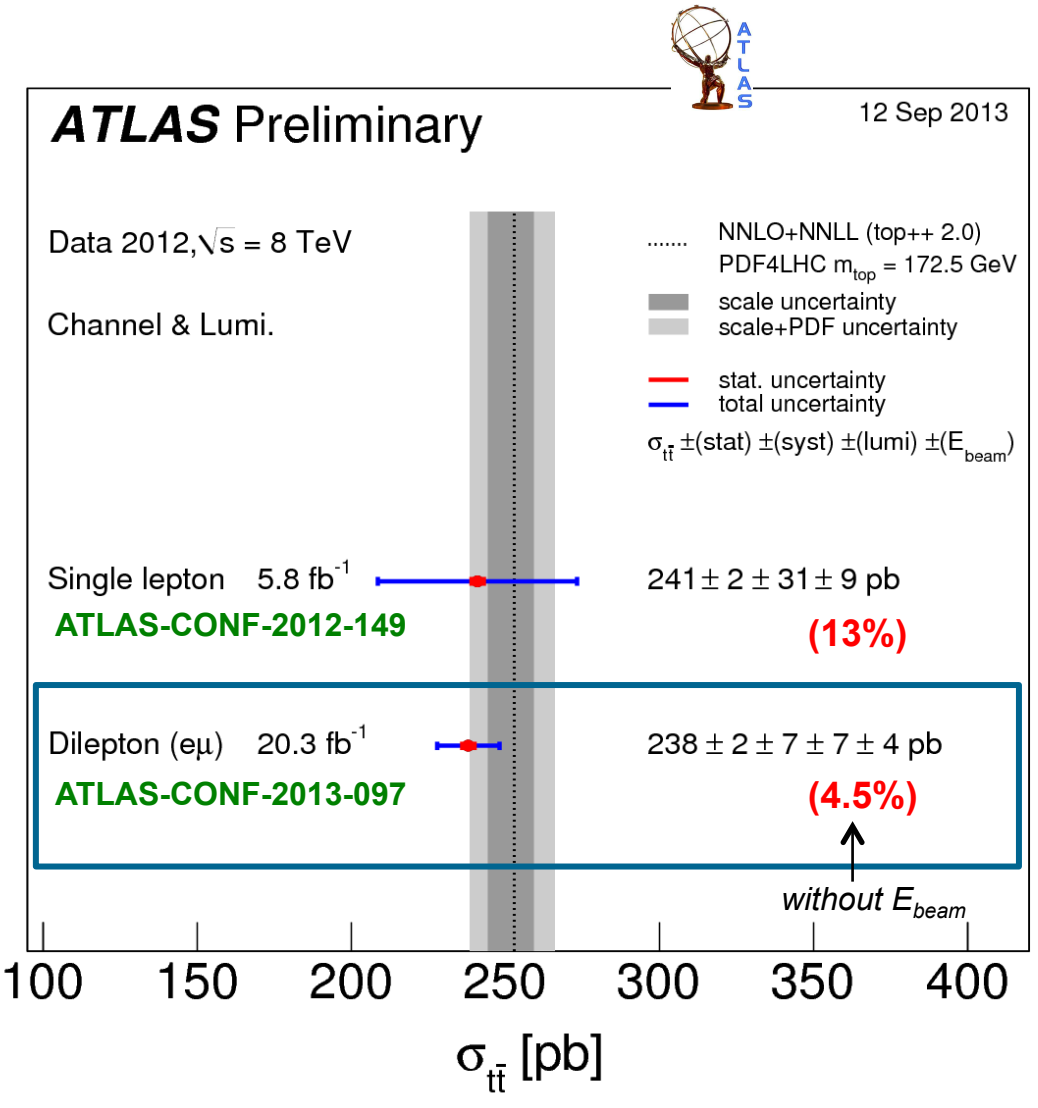
ATLAS & CMS measurements at 8 TeV





ATLAS & CMS measurements at 8 TeV





Focus on CMS and ATLAS results in the dilepton channels

σ(tt̄) in dileptons @ 8 TeV: CMS

ee, μμ, eμ channels, L = 5.3 fb^{-1}: JHEP 02 (2014) 024

- Use dilepton triggers (p_T > 17 GeV, 8 GeV)
- Event selection:

  2 OS iso leptons, p_T > 20 GeV, $|\eta|$ < 2.5 (2.1 for μ)
  ≥ 2 jets, p_T > 30 GeV, $|\eta|$ < 2.5
  ≥ 1 b-tag

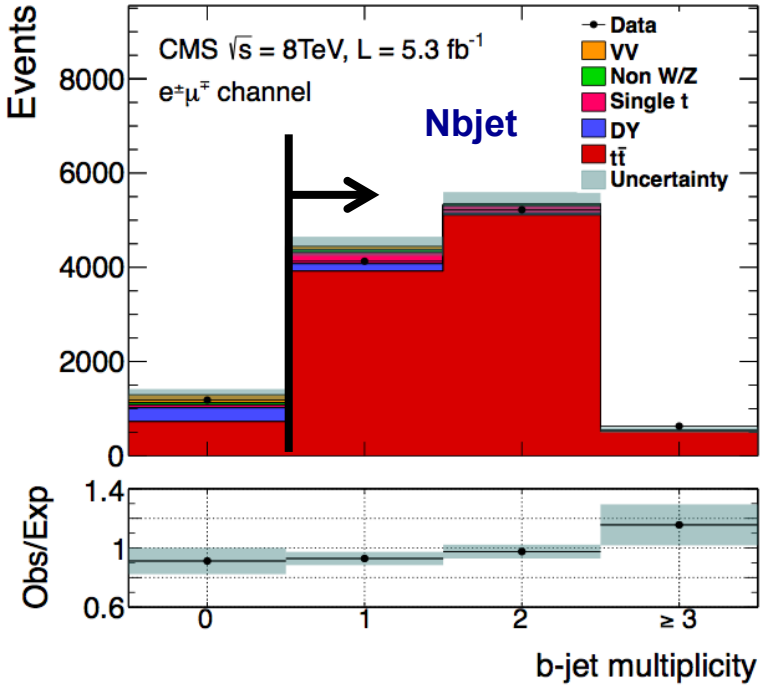
  E_T^{miss} > 40 GeV for ee, μμ; veto Z-mass region

- Reference signal tt̄ MC: MadGraph+Pythia
- Main BGs estimated from data
  - Z+jets from m(ll) in Z-mass window
  - Non-Z/W leptons from 'tight-to-loose' method. Fake and prompt rates estimated using samples enriched in QCD dijet events and Z→ll events, respectively
- Cross section: cut-&-count

$$\sigma_{t\bar{t}} = 239.0 \pm 2.1\,(\text{stat.}) \pm 11.3\,(\text{syst.}) \pm 6.2\,(\text{lum.})\,\text{pb}$$

(5.3%)

Main syst: Q^2 scale, matching, lepton efficiencies, JES



- Per channel: $\sigma_{t\bar{t}}$ (pb)

ee :	$244.3 \pm 5.2 \pm 18.6 \pm 6.4$
μμ :	$235.3 \pm 4.5 \pm 18.6 \pm 6.1$
eμ :	$239.0 \pm 2.6 \pm 11.4 \pm 6.2$

σ(tt̄) in dileptons @ 8 TeV: ATLAS

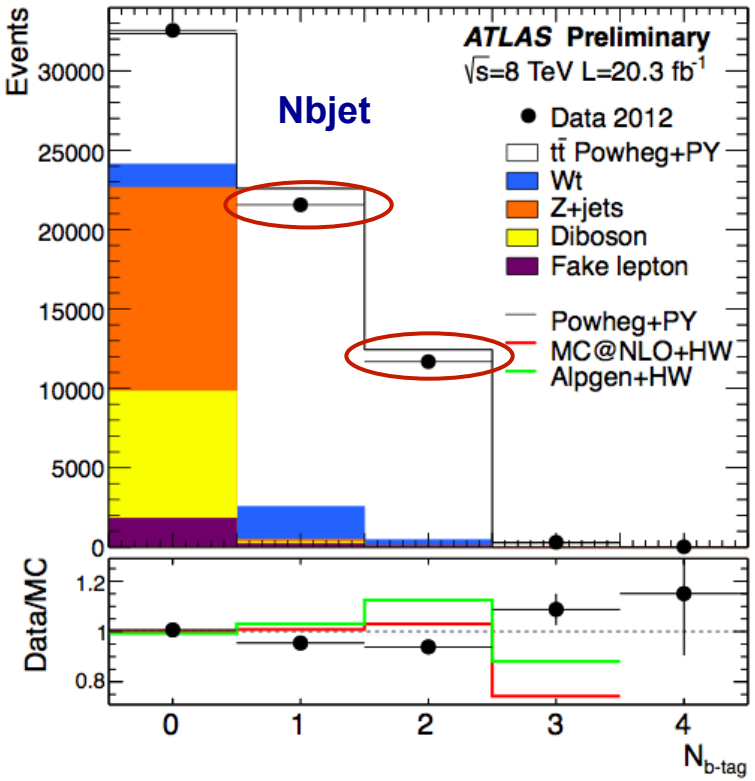
eμ channel, L = 20.3 fb^{-1}: ATLAS-CONF-2013-097

- Use single-lepton triggers (p_T > 24 GeV)
- Event selection:

  1 OS iso μe pair, p_T > 25 GeV, |η| < 2.47 (2.5 for μ)
  ≥ 1 jet, p_T > 25 GeV, |η| < 2.5
  1 or 2 b-tags
- Reference signal tt̄ MC: Powheg+Pythia
- Main BGs estimated from data
  - Fake leptons from SS lepton sample
  - Z+jets from Z→μμ sample
- Cut-&-count: in-situ determination of b-tag efficiency from b-tag multiplicity distribution

$$N_1 = L\sigma_{t\bar{t}}\,\epsilon_{e\mu}2\epsilon_b(1 - C_b\epsilon_b) + N_1^{\mathrm{bkg}}$$

$$N_2 = L\sigma_{t\bar{t}}\,\epsilon_{e\mu}C_b\epsilon_b^{\,2} + N_2^{\mathrm{bkg}}$$



- ε_b: product of b-tagging efficiency & jet kinematic acceptance for tt evts
- $\varepsilon_{\mu e}$: leptonic acceptance
- C_b: tagging correlation

$$\sigma_{t\bar{t}} = 237.7 \pm 1.7\ (\mathrm{stat}) \pm 7.4\ (\mathrm{syst}) \pm 7.4\ (\mathrm{lumi}) \pm 4.0\ (\mathrm{beam\ energy})\ \mathrm{pb}$$

(4.5%, *without* E_{beam})

Main syst: signal model, ISR/FSR, eID

σ(tt̄) in the eμ channel @ 8 TeV

- Consider only eμ channels as input for the combination:

ATLAS (4.5%)	CMS (5.5%)
237.7 ± 1.7 (stat) ± 7.4 (syst) ± 7.4 (lumi) pb	239.0 ± 2.6 (stat) ± 11.4 (syst) ± 6.2 (lumi) pb

- Systematic uncertainties evaluated by repeating the full analysis for each source
  - Individual contributions are added in quadrature yielding the total systematic uncertainty
- Difference in size of uncertainties
  - Statistics: fraction (CMS) vs. full (ATLAS) dataset at 8 TeV
  - Systematics: smaller for ATLAS due to different analysis approach
  - ATLAS quotes, separately, an uncertainty on the LHC beam energy calibration
- Top mass dependence available

Systematic uncertainties

Uncertainty	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)	$\Delta\sigma_{t\bar{t}}$ (pb)
Data statistics	0.72	1.7
$t\bar{t}$ modelling	1.52	3.6
Initial/final state radiation	1.23	2.9
Parton density functions	1.09	2.6
QCD scale choices	0.30	0.7
Single-top modelling	0.38	0.9
Single-top/$t\bar{t}$ interference	0.15	0.4
Single-top Wt cross-section	0.70	1.7
Diboson modelling	0.42	1.0
Diboson cross-sections	0.03	0.1
Z+jets extrapolation	0.05	0.1
Electron energy scale/resolution	0.48	1.1
Electron identification/isolation	1.42	3.4
Muon momentum scale/resolution	0.05	0.1
Muon identification/isolation	0.52	1.2
Lepton trigger	0.16	0.4
Jet energy scale	0.49	1.2
Jet energy resolution	0.59	1.4
Jet reconstruction/vertex fraction	0.04	0.1
b-tagging	0.42	1.0
Pileup modelling	0.28	0.7
Misidentified leptons	0.38	0.9
Total systematic	3.12	7.4
Integrated luminosity	3.11	7.4
LHC beam energy	1.70	4.0
Total uncertainty	4.77	11.3

SG model, **BG from MC**, **detector**, **BG from data**, **luminosity**

Source	$e^{\pm}\mu^{\mp}$ (pb)
Trigger efficiencies	3.6
Lepton efficiencies	4.0
Lepton energy scale	0.2
Jet energy scale	5.2
Jet energy resolution	3.0
b-jet tagging	1.7
Pileup	2.0
Scale (μ_F and μ_R)	5.6
Matching partons to showers	3.8
Single top quark	2.3
VV	0.5
Drell–Yan	1.5
Non-W/Z leptons	1.9
Total systematic	11.4
Integrated luminosity	6.2
Statistical	2.6

Hadronisation: 3.2 pb (quoted in the text)

LHC combination @ 8 TeV

(4.5%)

237.7 ± 1.7 (stat) ± 7.4 (syst) ± 7.4 (lumi) pb

(5.5%)

239.0 ± 2.6 (stat) ± 11.4 (syst) ± 6.2 (lumi) pb

- Use BLUE method (ROOT implementation from R. Nisius, http://blue.hepforge.org/)
- Type of uncertainties and assumed correlation, based on 7 TeV combination:
  - **Detector simulation**: correl. 0
    - Finer breakdown of JES and correlations now available for ATLAS & CMS
  - **Background from data**: correl. 0
  - **Background from simulation**: correl. 1
  - **Signal modelling**: correl. 1
  - **Luminosity**: correlations available
  - ATLAS beam energy uncertainty not considered

Summary: ATLAS & CMS total-$\mathcal{L}$ uncertainties

	ATLAS	CMS
100% correlated btwn ATLAS & CMS	1.1 % *at most*	2.1 % *at most*
Uncorrelated btwn ATLAS & CMS	2.5 % *at least*	1.5% *at least*
Total	**2.8%**	**2.6 %**

W. Kozanecki,LHC-wide luminosity meeting (LLCMWG), 31.03.14

Signal model systematics

No straightforward mapping of signal systematic effects, mainly due to using NLO (ATLAS) vs LO multileg (CMS) generators:

- tt modelling:
  - Powheg-PY vs. MC@NLO-HW

  → Varies both generator & frag/had model

  → Can result in artificial cancellation of effects

- ISR/FSR:
  - Difference btwn 2 AcerMC+PY samples with different tunes

- QCD scale: ($Q^2 = m_{top}^2 + p_{T,top}^2$)
  - Difference btwn 2 Powheg-PY samples with varied (separately) μ_R and μ_F
  - Variation only in ME
  - Evaluated at generator level

- Hadronisation:
  - Powheg-PY vs. Powheg-HW

  → Assumed to be partially covered by JES uncertainty

- ME-PS matching:
  - Difference btwn 2 MadGraph+PY samples with different parameter

  → ISR/FSR accounted for

- QCD scale: ($Q^2 = m_{top}^2 + \Sigma p_T^2$, sum over add partons)
  - Difference btwn 2 MadGraph-PY samples with varied (simultaneously) μ_R and μ_F
  - Variation in ME and PS

  → ISR/FSR accounted for

Effects are not 100% correlated, assumptions have to be tested

Preliminary mapping of uncertainties

Category		ATLAS		CMS	Correl.
	Info	$\mu^{\pm}e^{\mp}$(pb)	Info	$\mu^{\pm}e^{\mp}$(pb)	ρ_{LHC}
$\sigma_{t\bar{t}}$		237.7		239.0	
Stat.		1.7		2.6	0
Detector					
	eES/reso	1.1	LES	0.2	0
	μES/reso	0.1			
	μID/iso	1.2	lep eff	4.0	0
	eleID/iso	3.4			
	trigger	0.4	trigger	3.6	0
	JES	1.2	JES	5.2	0
	JER	1.4	JER	3.0	0
	jet reco/vtx frac	0.1			
	btag	1.0	btag	1.7	0
	pileup	0.7	pileup	2.0	0

Work in progress

Related sources (shown in same colour) are added in quadrature

Will be evaluated following the recommendations from the TOPLHCWG

- Detector simulation: large differences between ATLAS & CMS for some sources (e.g. trigger, JES/JER) due to different analysis approach

Preliminary mapping of uncertainties

Category		ATLAS		CMS	Correl.
	Info	$\mu^{\pm}e^{\mp}$(pb)	Info	$\mu^{\pm}e^{\mp}$(pb)	ρ_{LHC}
$\sigma_{t\bar{t}}$		237.7		239.0	
Stat.		1.7		2.6	0
Detector					
	eES/reso	1.1	LES	0.2	0
	μES/reso	0.1			
	μID/iso	1.2	lep eff	4.0	0
	eleID/iso	3.4			
	trigger	0.4	trigger	3.6	0
	JES	1.2	JES	5.2	0
	JER	1.4	JER	3.0	0
	jet reco/vtx frac	0.1			
	btag	1.0	btag	1.7	0
	pileup	0.7	pileup	2.0	0
SG model					1
	$t\bar{t}$ model	3.6	Had	3.3	
	ISR/FSR	2.9	Match	3.8	
	Scale	0.7	Scale	5.6	
	PDF	2.6			

Work in progress

Related sources (shown in same colour) are added in quadrature

- Signal modelling: differences between ATLAS & CMS mainly due to use of different order generators, effects not 100% correlated

Preliminary mapping of uncertainties

Category		ATLAS		CMS	Correl.
	Info	$\mu^{\pm}e^{\mp}$(pb)	Info	$\mu^{\pm}e^{\mp}$(pb)	ρ_{LHC}
$\sigma_{t\bar{t}}$		237.7		239.0	
Stat.		1.7		2.6	0
Detector					
	eES/reso	1.1	LES	0.2	0
	μES/reso	0.1			
	μID/iso	1.2	lep eff	4.0	0
	eleID/iso	3.4			
	trigger	0.4	trigger	3.6	0
	JES	1.2	JES	5.2	0
	JER	1.4	JER	3.0	0
	jet reco/vtx frac	0.1			
	btag	1.0	btag	1.7	0
	pileup	0.7	pileup	2.0	0
SG model					1
	$t\bar{t}$ model	3.6	Had	3.3	
	ISR/FSR	2.9	Match	3.8	
	Scale	0.7	Scale	5.6	
	PDF	2.6			
BG from MC					1
	t: model	0.9			
	t: interf	0.4	t	2.3	
	t: σ_{tW}	1.7			
	VV: model	1.0	VV	0.5	
	VV: σ_{VV}	0.1			
BG from data					0
	Zjets	0.1	Zjets	1.5	
	misID lep	0.9	Non-W/Z lep	1.9	
Luminosity		7.4		6.2	
Total syst.		7.4		11.8	

Work in progress

Related sources (shown in same colour) are added in quadrature

Prospects for updated 7 TeV combination

- Several CMS results after combination, most precise:
  - Dileptons (2.3 fb^{-1}): **JHEP 11 (2012) 067**

    161.9 ± 2.5 (stat) +5.1/-5.0 (syst) ± 3.6 (lumi) pb **(4.2%)** → More precise than 7 TeV LHC combination
  - L+jets (2.3 fb^{-1}): **PLB 720 (2013) 83**

    158.1 ± 2.1 (stat) ± 10.2 (syst) ± 3.5 (lumi) pb **(7%)**
- ATLAS result after combination: **ATLAS-CONF-2012-131**
  - L+jets, soft muon tag (4.7 fb^{-1}):

    165 ± 2 (stat) ± 17 (syst) ± 3 (lumi) pb **(10.5%)** → Partial overlap with l+jets analysis used in 7 TeV LHC combination
- ATLAS has several updates in preparation
- Possible 7 TeV LHC combination update using CMS updated results and upcoming ATLAS results

Conclusions & Outlook

- LHC combination of 8 TeV results in the $e\mu$ channel with BLUE feasible
- First attempt at mapping uncertainties between ATLAS & CMS
  - Different treatment of signal modelling uncertainties by ATLAS and CMS
  - Work needs to be done to determine correlations
- Combination of current 8 TeV results aiming at TOP2014
  - CMS 'LHC Run I legacy' dilepton result with 20 fb^{-1} in preparation
- Top mass dependence provided by ATLAS & CMS will allow 8 TeV cross section results to be quoted at any (reasonable) top mass value
- Awaiting ATLAS new results to update the 7 TeV LHC combination

Additional information

Systematic uncertainties

SG model, BG from MC, detector, BG from data

Uncertainty	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)	$\Delta\sigma_{t\bar{t}}$ (pb)
Data statistics	0.72	1.7
$t\bar{t}$ modelling	1.52	3.6
Initial/final state radiation	1.23	2.9
Parton density functions	1.09	2.6
QCD scale choices	0.30	0.7
Single-top modelling	0.38	0.9
Single-top/$t\bar{t}$ interference	0.15	0.4
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Misidentified leptons	0.38	0.9
Total systematic	3.12	7.4
Integrated luminosity	3.11	7.4
LHC beam energy	1.70	4.0
Total uncertainty	4.77	11.3

Source	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$ (pb)
Trigger efficiencies	4.1	3.0	3.6
Lepton efficiencies	5.8	5.6	4.0
Lepton energy scale	0.6	0.3	0.2
Jet energy scale	10.3	10.8	5.2
Jet energy resolution	3.2	4.0	3.0
b-jet tagging	1.9	1.9	1.7
Pileup	1.7	1.5	2.0
Scale (μ_F and μ_R)	5.7	5.5	5.6
Matching partons to showers	3.9	3.8	3.8
Single top quark	2.6	2.4	2.3
VV	0.7	0.7	0.5
Drell–Yan	10.8	10.3	1.5
Non-W/Z leptons	0.9	3.2	1.9
Total systematic	18.6	18.6	11.4
Integrated luminosity	6.4	6.1	6.2
Statistical	5.2	4.5	2.6

σ(tt̄) results @ 8 TeV in l+jets

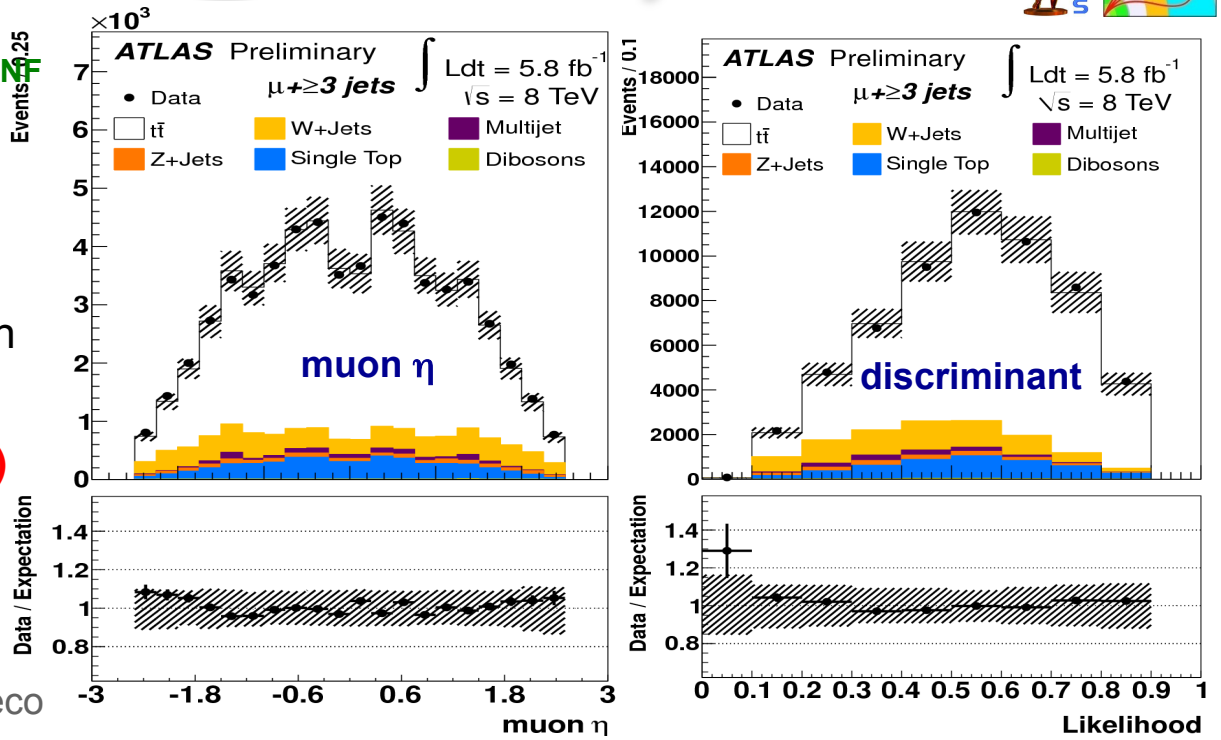
ATLAS (L = 5.8 fb^{-1}): ATLAS-CONF -2012-149

1 isolated high-p_T μ/e, ≥ 3 jets, ≥ 1 b-tagged jet

- Likelihood discriminant fit for tt signal and W+jets normalisation
- Discriminant based on aplanarity and lepton η (13%)

$$\sigma_{tt} = 241 \pm 2\,(\text{stat}) \pm 31\,(\text{syst}) \pm 9\,(\text{lumi})\ \text{pb}$$

Main syst: signal modelling, jet/E_T^{miss} reco



CMS (L = 2.8 fb^{-1}): CMS-PAS TOP-12-006

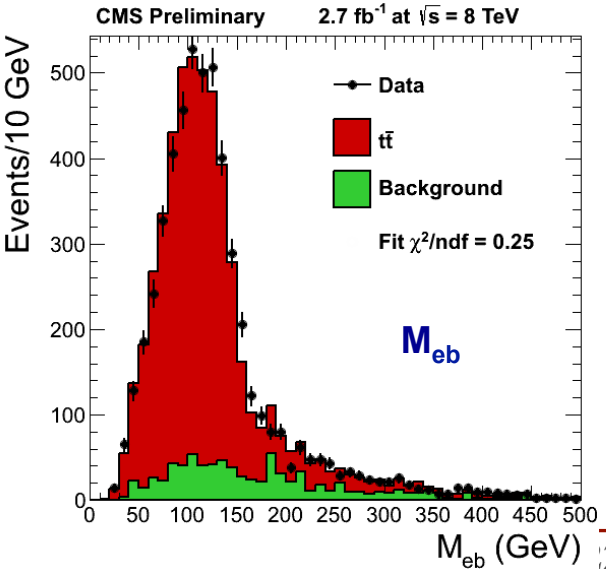
1 isolated high-p_T μ/e, ≥ 4 jets, ≥ 1 b-tag

- Template fit to M_{lb} distribution
  - tt, single-top, W/Z+jets templates from simulation
  - QCD from sideband with non-isolated leptons

(14%)

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

Main syst: JES, btag, Q^2 and matching scales



Systematic uncertainties in l+jets @ 8 TeV

ATLAS-CONF-2012-149

Source	e+ ≥3 jets	μ+ ≥ 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

Includes JES

No breakdown of BG from data ?

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

Lumi: 3.6%

CMS-PAS TOP-12-006

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

SG model,
BG from MC,
detector,
BG from data

Include scale variations in W+jets sample

First $\sigma(t\bar{t})$ combination at LHC (7 TeV)

	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 & CMS combination:**

$$\sigma_{tt} = 173.3 \pm 2.3\ (\text{stat}) \pm 9.9\ (\text{syst})\ \text{pb}$$ **(5.8%)**

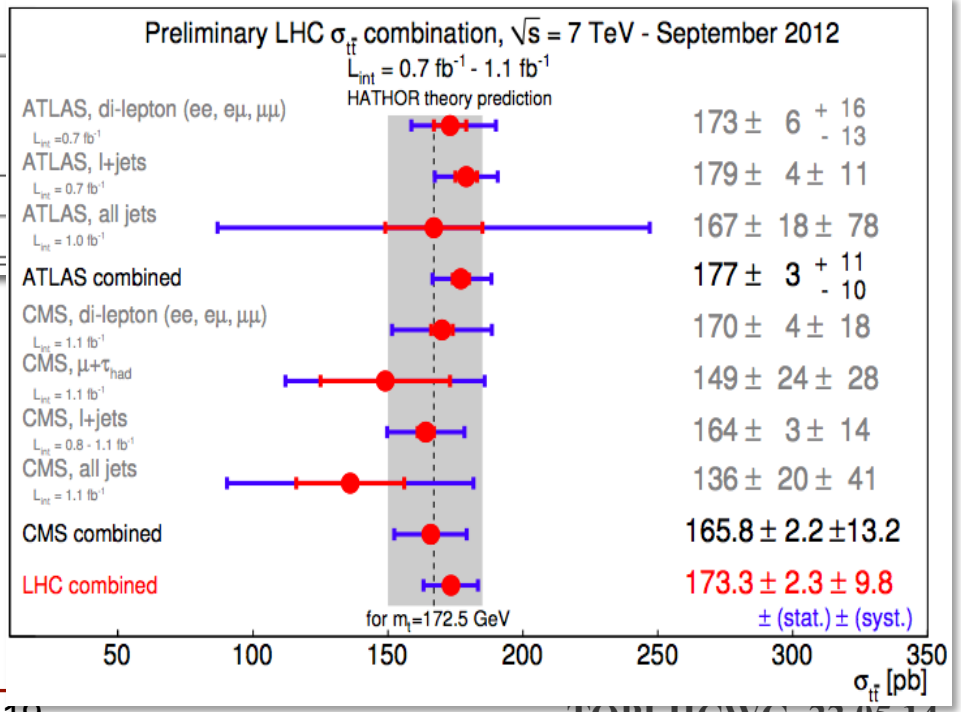
- Weights: 67% ATLAS, 33% CMS
  probability: 47% ; correlation: 30%

7% improvement wrt most precise result

Full NNLO+NNLL: [arXiv:1303.6254]

$$\sigma_{tt} = 172.0\ ^{+4.4}_{-5.8}\ (\text{scales})\ ^{+4.7}_{-4.8}\ (\text{pdf})\ \text{pb}$$ **(~3%)**

- ATLAS & CMS treat signal modelling uncertainties differently !, e.g.:
  - Radiation: Q^2 variation (CMS) vs. ISR/FSR variation (ATLAS)
  - Shower model: ME-PS matching (CMS) vs. Powheg+PY/HW (ATLAS)



Mapping of uncertainties (7 TeV)

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 Detector	Bunch current Detector	1 0