Top pair production at √s=8 TeV

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Intro & outline

- Production of top/antitop pair is an important topic
  - ➤ Sensitive to new physics
  - ➤ Perturbative QCD test in new phase space regions
  - ➤ Background to many Higgs or non SM searches

- Overview of ttbar at LHC and how to measure it
- Results from ATLAS and CMS at 8TeV
  - ➤ Inclusive cross-section
  - ➤ Differential cross-section

Top pair production at LHC

- 2 production modes
  - ➢ qqbar (~15% at 8TeV)
  - ➢ gluon fusion (~85% at 8TeV)
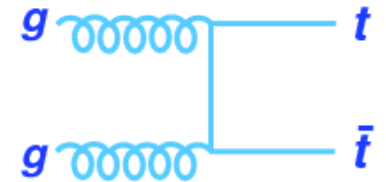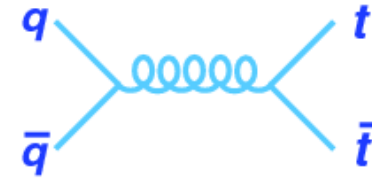
- Cross section calculated at NNLO+NNLL at 8TeV:

$$\sigma = 253^{+13}_{-15} \text{ pb } (\text{Scale+PDF uncertainties})$$

Top++ 2.0
(Czakon et al., c.f. ref slide 22)

- Pairs produced for 8TeV run :

$$\sim 20\text{fb}^{-1} \rightarrow \sim 5\ 000\ 000 \text{ pairs}$$

Analysis overview

Topology depends on W decays

- ➤ 2 charged leptons (dilepton)
- ➤ 1 charged lepton (single lepton)
- ➤ full hadronic

$$t \quad W^+ \quad l^+, q \quad \nu, \bar{q}' \quad b$$
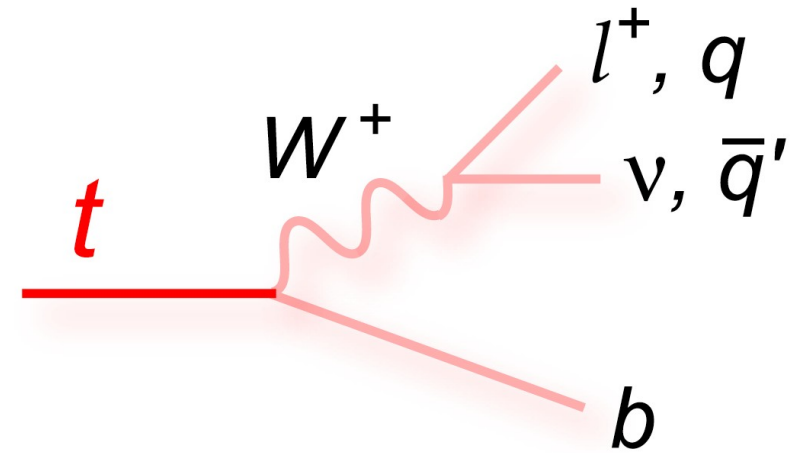
Analysis overview

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Top Pair Decay Channels

Analysis overview

Topology depends on W decays

- 2 charged leptons (dilepton)
- 1 charged lepton (single lepton)
- full hadronic

Tagging b quark jets
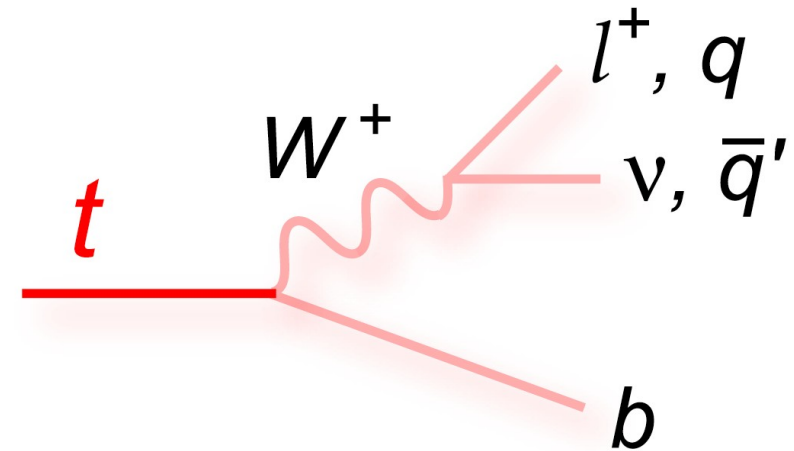
- important evt characteristic !
- typical (efficiency, mistag rate) working point :
    - 60 to 70 % efficiency
    - O(1%) mis-tag probability

W^+

t

l^+, q

$\nu, \bar{q}'$

b

Top Pair Decay Channels

Dilepton channels

- 3 sub-channels : µµ , ee, µe

- Typical event selection

  - ➢ 2 isolated leptons, $p_T > 20/25$ GeV

  - ➢ 1 or 2 b-tagged jets, $p_T > 25/30$ GeV

  - ➢ (in ee/µµ : veto evts with $m_{\ell\ell}$ around Z mass)

Backgrounds
<u>Clean channel</u> : bkg at ~1% level
- Single top
- WW, WZ
- Fake leptons (in W+jets,...)

Additional bkg in ee, µµ :
- DY

Additional bkg in µe :
- $Z \to \tau\tau \to \mu e$

Presented in this talk :

CMS inclusive x-section

- Using ee, µµ, eµ

- Counting measurement

CMS differential x-section

CMS ttbar+jets

Atlas inclusive x-section

- Using µe only

- Fit extracting σ and b jet acceptance

Single lepton channel

- Considering e+jets or μ+jets

- Typical event selection

  ➤ 1 isolated lepton, $p_T > 30/40\,GeV$

  ➤ veto 2nd lepton

  ➤ 3 or 4 jets, $p_T > 25/30\ GeV$

    – 1 or 2 b-tagged

  ➤ (E_{Tmiss} and $m_{WT} > 30\,GeV$)

- Can rebuild the tops kinematics

Backgrounds
- W/Z+jets
- Single top
- WW, WZ
- (Multijet)

Presented in this talk :

CMS differential x-section

- Against various kinematics vars

- Counting+unfolding

Atlas inclusive x-section

- Multivariate discriminant

- Signal & bkg template fit

  (Differential x-section at 7TeV)

Results :
inclusive cross section measurements

Atlas inclusive single lepton

- 1 or more b tagged jets, E_{Tmiss} cuts
- Use a multivariate discriminant
  - build from η_ℓ and "transformed aplanarity"
- Fit templates of signal & bkg
  - extract N_{tt} and W+jets normalization
- Main systematic uncertainties
  - MC modelling : 12 %
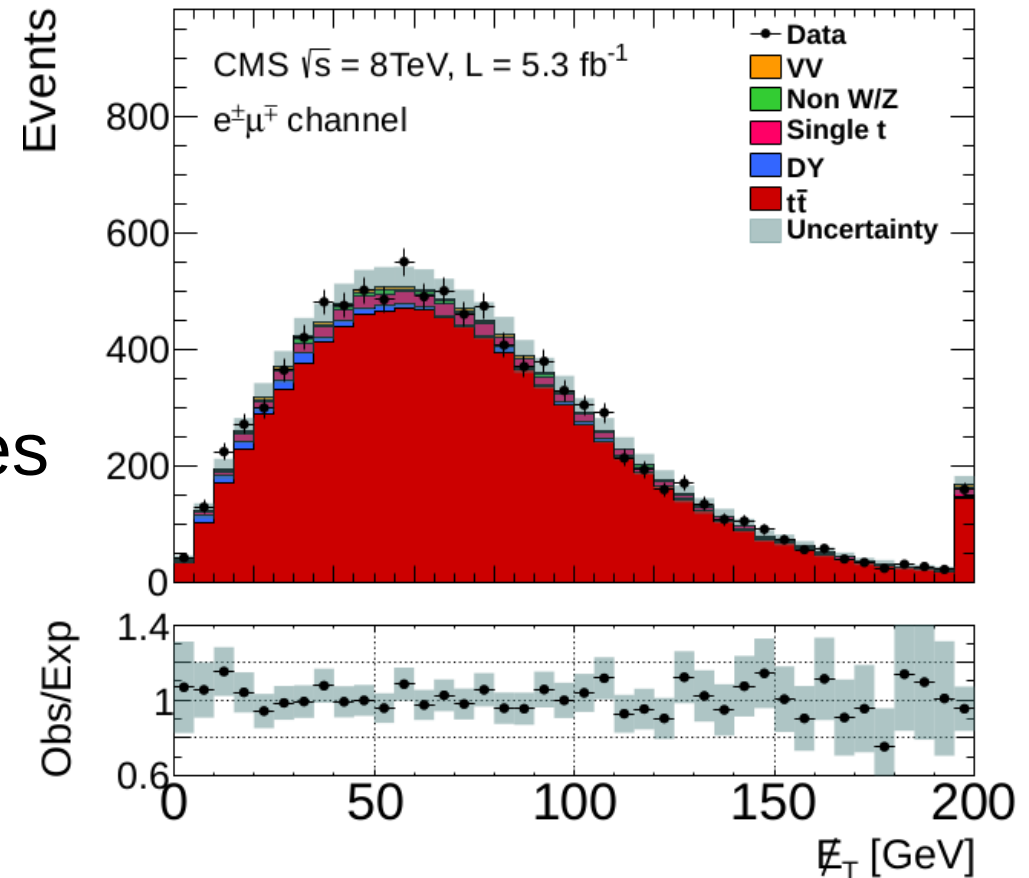 - Jet/E_{Tmiss} : 6 %
- Total uncertainty : **13.4 %**
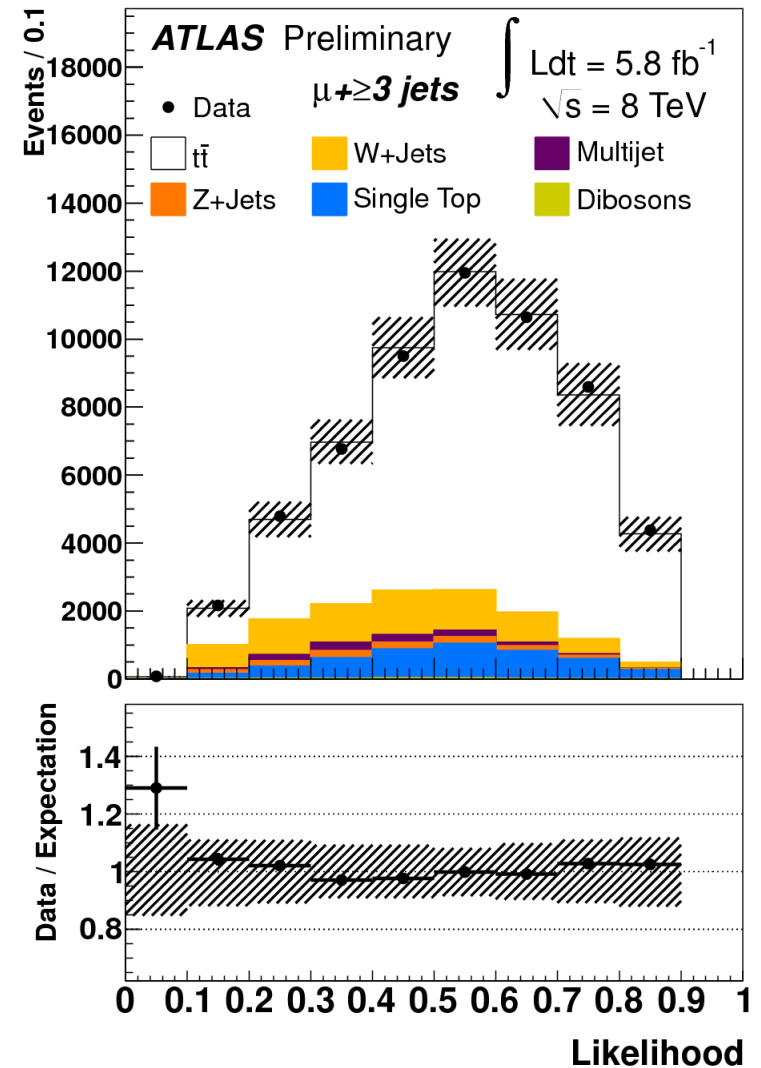
$$\sigma = 241 \pm 2(\text{stat}) \pm 31(\text{syst}) \pm 9(\text{lumi}) \text{ pb}$$

CMS inclusive dilepton

- Uses μμ, ee & μe

  - E_{Tmiss} cut in μμ, ee

- Counting experiment

  - combine 3 channels using BLUE method

- Main systematic uncertainties

  - jet energy

  - DY bkg (μμ, ee)

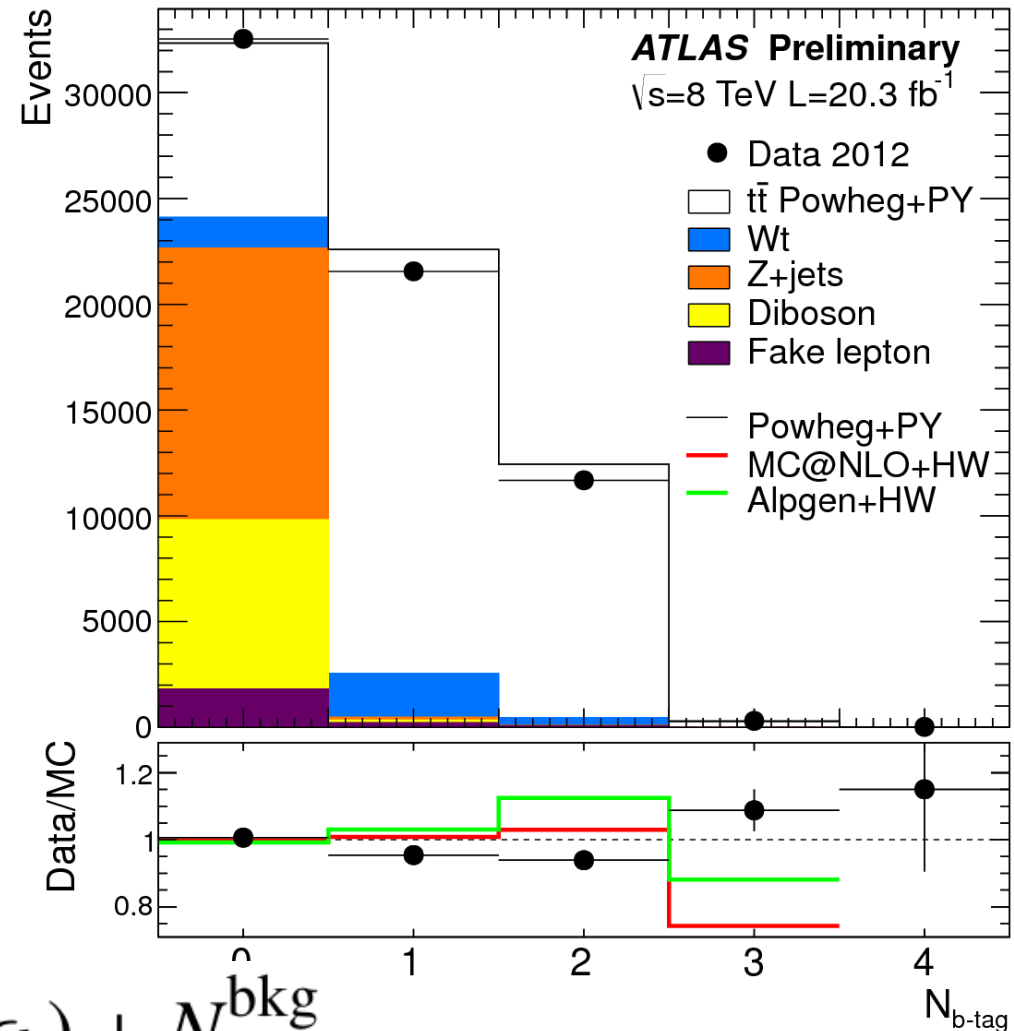 - QCD scales, lepton efficiencies

- Total uncertainty : **5.3 %**

$$\sigma = 239 \pm 2(\text{stat}) \pm 11(\text{syst}) \pm 6(\text{lumi}) \text{ pb}$$

Atlas inclusive dilepton

- **Only µe channel**
  - ➤ ~no DY, no E_{Tmiss} cut & uncertainty

- **Ask exactly 1 or 2 b jets**

- **Extract simultaneously σ and efficiency to select b-tag**
  - ➤ reduce b-tag, jet uncertainty

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

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

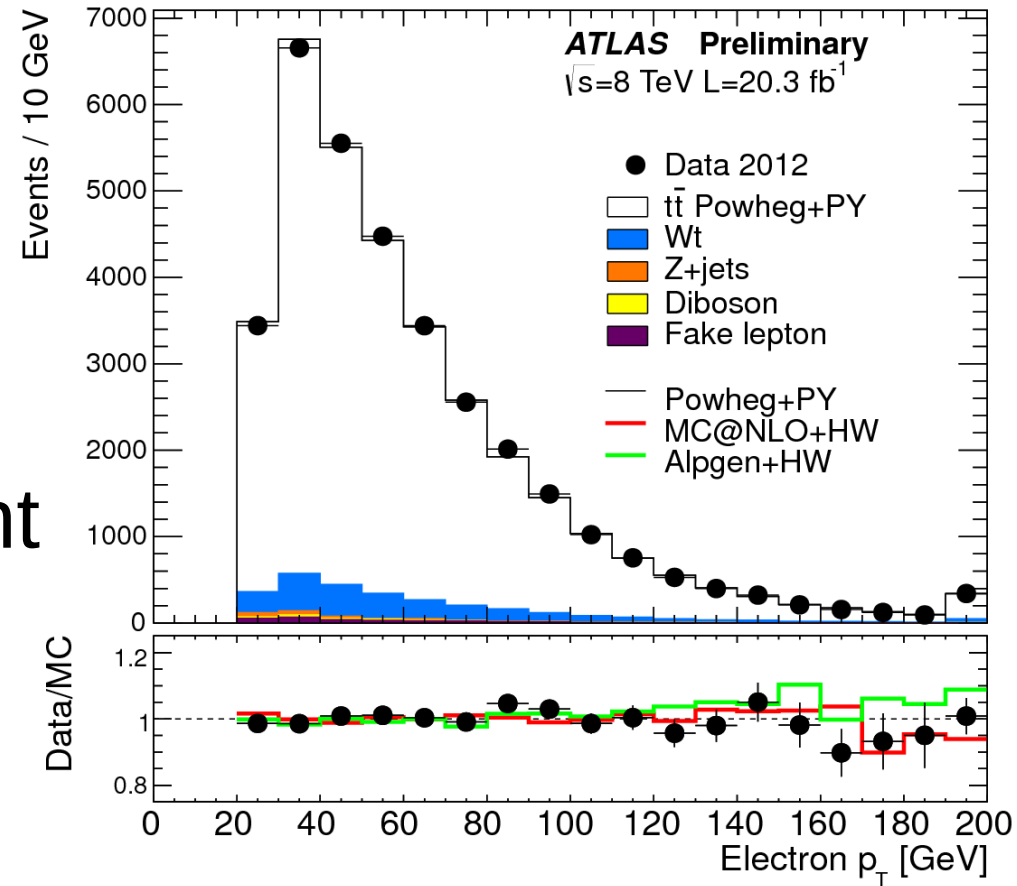# Atlas inclusive dilepton (2)

- **Main systematic**
  - ➤ electron ID
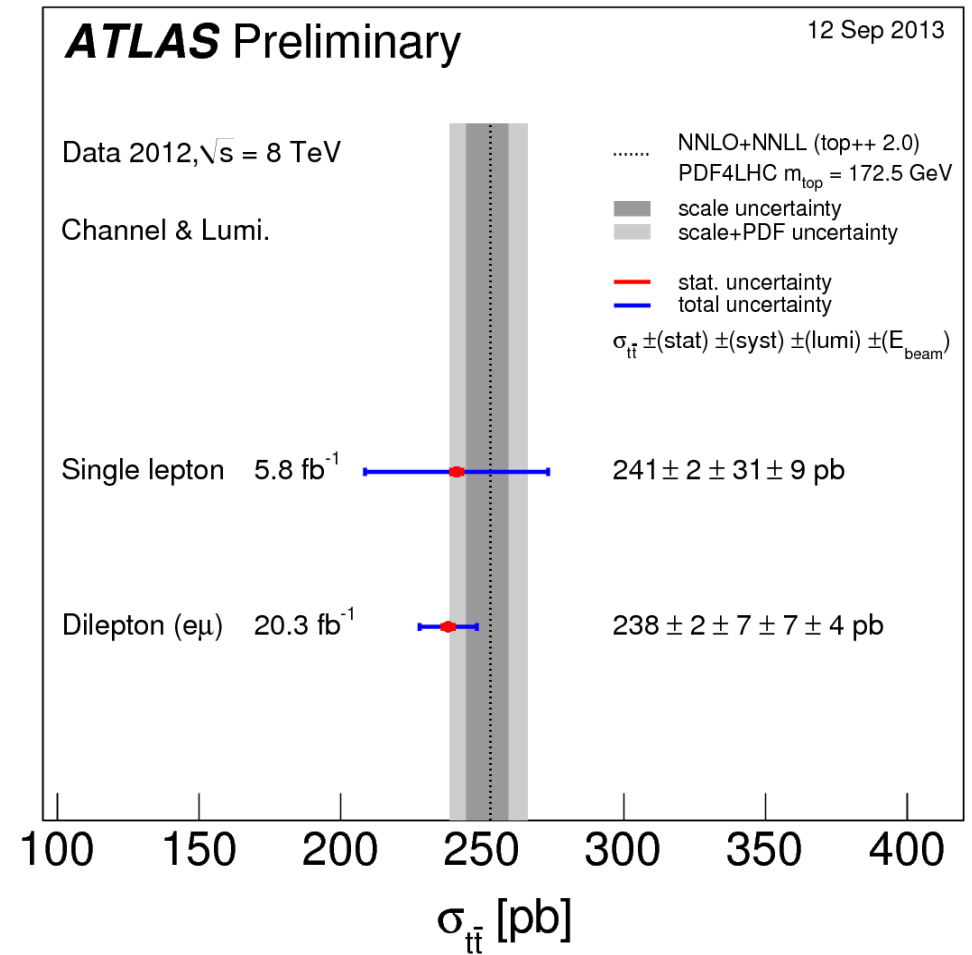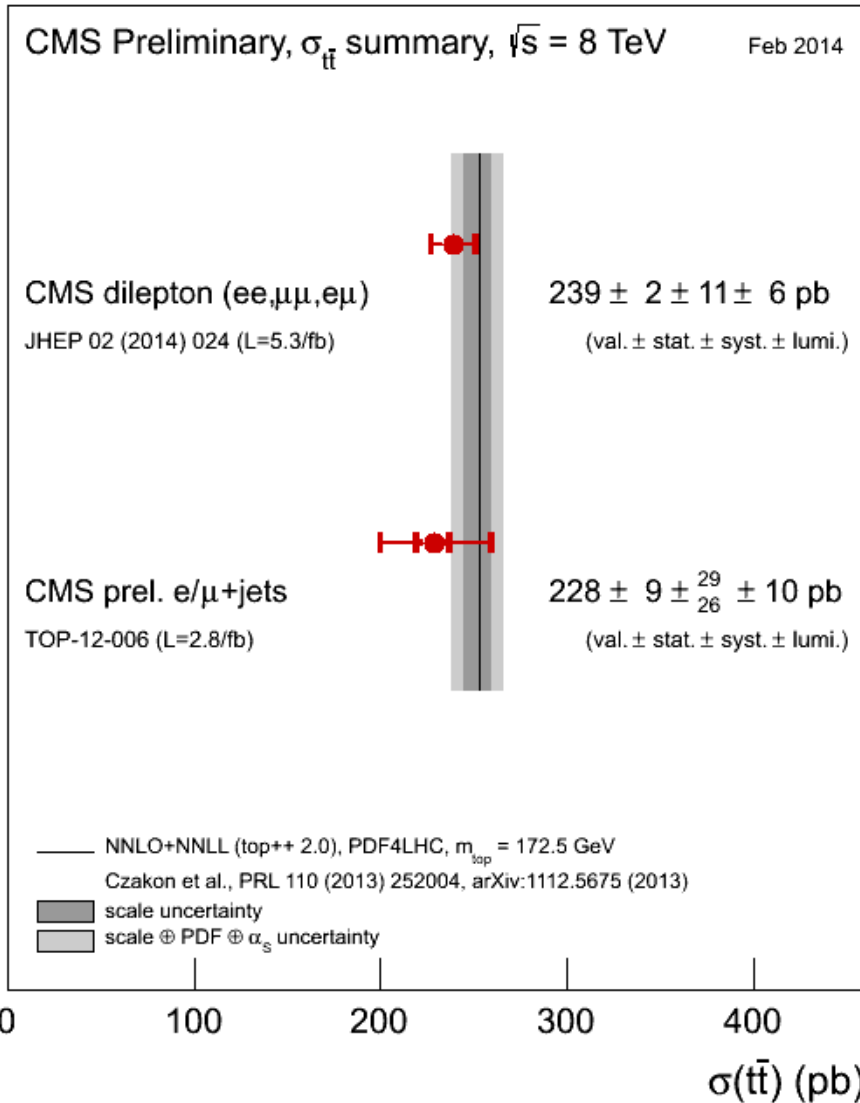 - ➤ ISR/FSR
  - ➤ PDF

- **Very precise measurement**
  - ➤ **4.5%** (without beam)
  - ➤ exp. uncertainty smaller than theory (>5%)

σ = 237.7 ±1.7(stat) ±7.4(syst) ±7.4(lumi) ±4.0(beam) pb

Inclusive measurement summary

Atlas and CMS measurements compatible & compatible with predictions

P.A. Delsart, LPSC, Grenoble

Inclusive measurement summary

Atlas and CMS measurements compatible & compatible with predictions
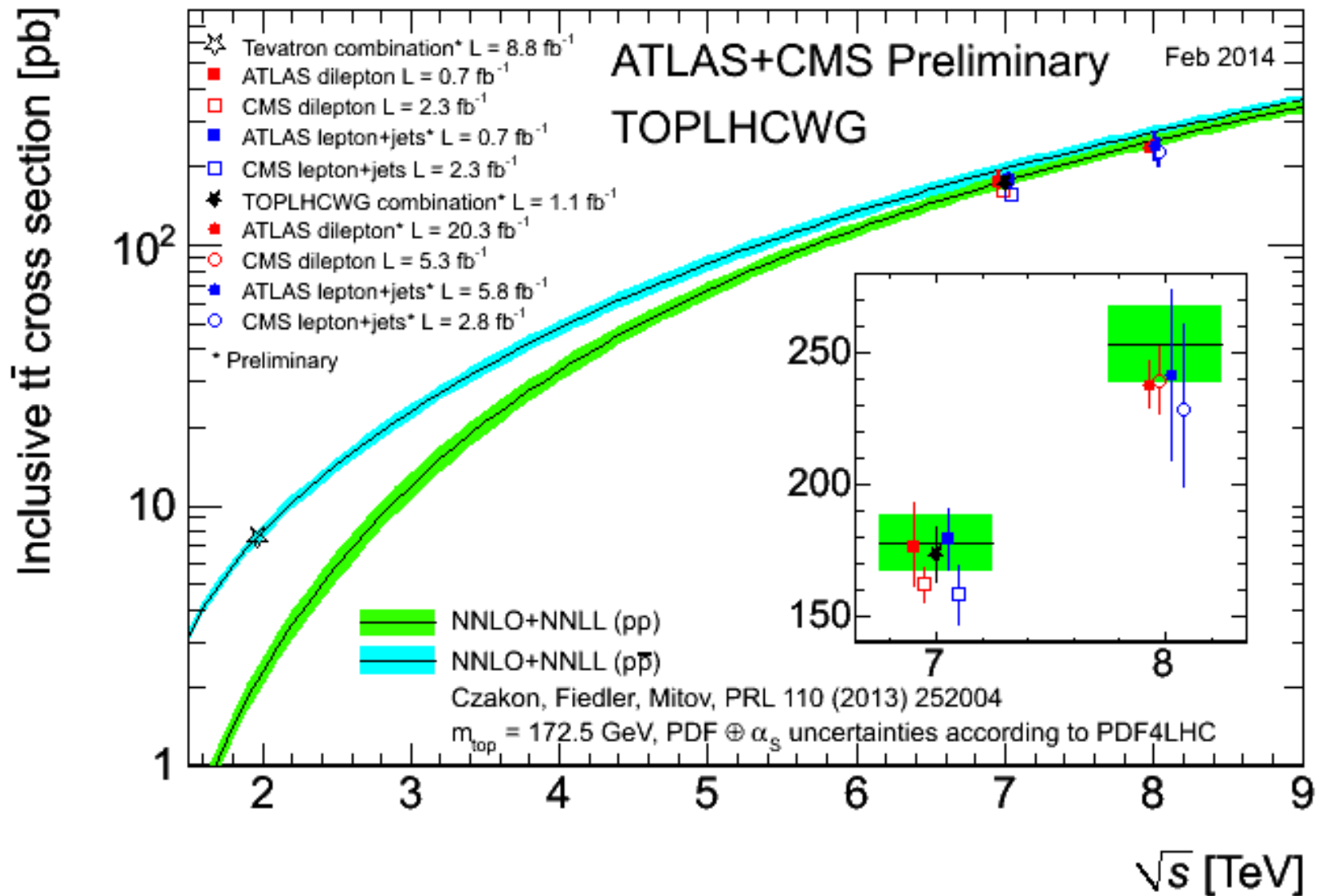
Results :
differential cross section measurements

P.A. Delsart, LPSC, Grenoble

CMS differential cross section

- **Results with dilepton and single lepton channels**
  - μμ, ee, μe and μ+jets, e+jets

- **Kinematic fits performed evt by evt to reconstruct top kinematics**

- **Normalized cross section extracted from distributions of variables**
  - variables : kinematics of lepton, jets, top, ttbar system
  - unfolding method account for efficiencies and migrations

- **Systematic evaluated for each bins & variables**
  - correlations between channel and bins taken into account
  - uncertainties correlated across all bins cancel out due to normalization

P.A. Delsart, LPSC, Grenoble
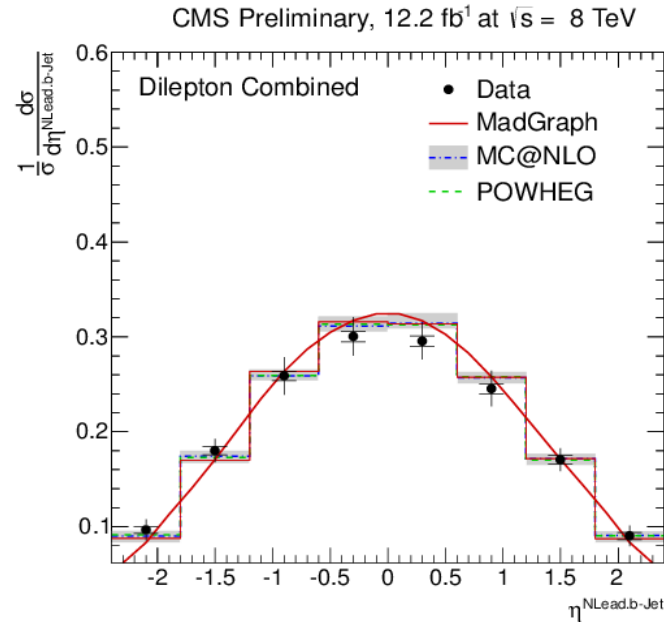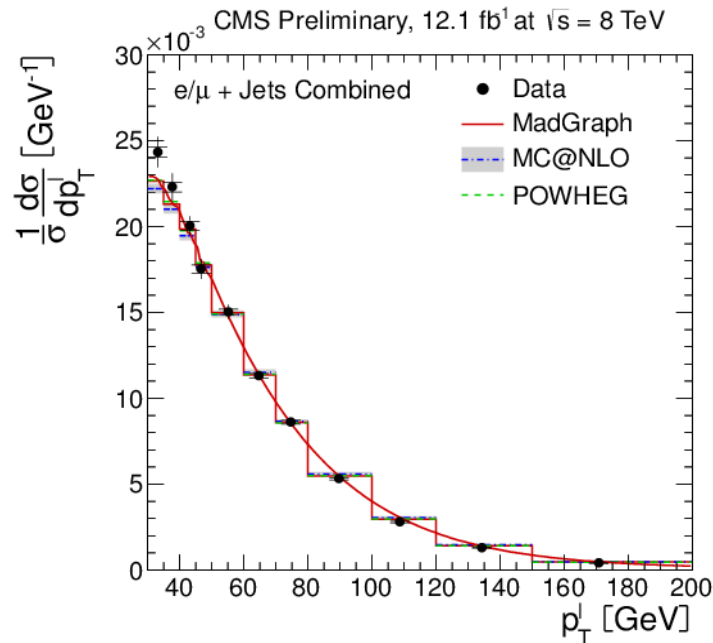
# CMS differential cross section

General : good agreement with theory
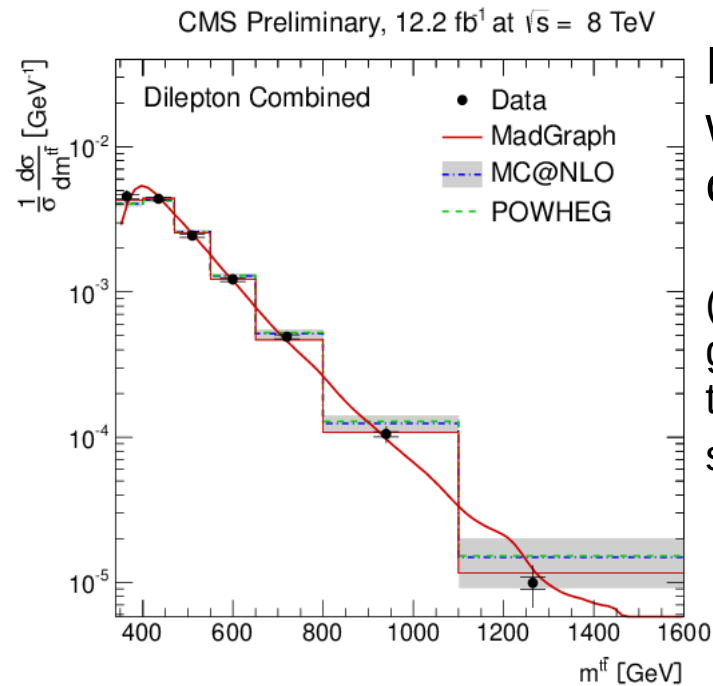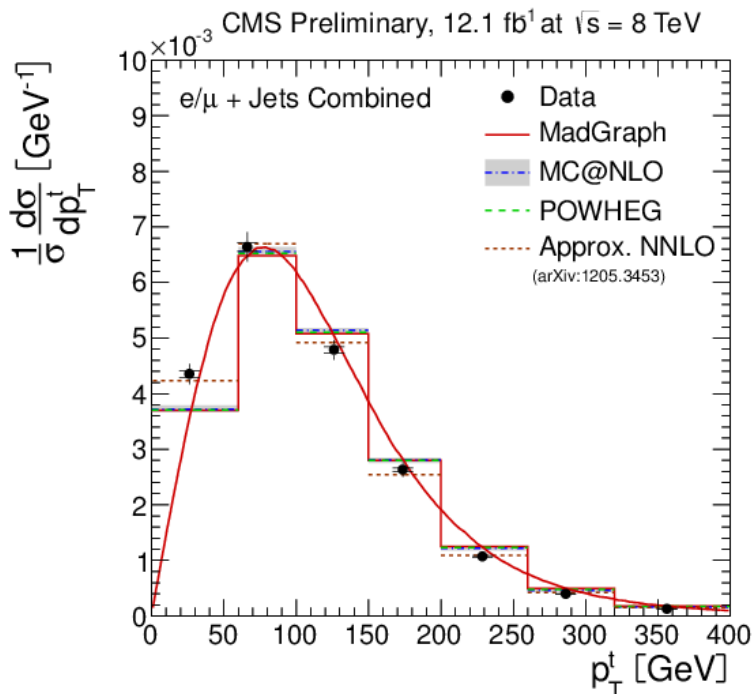
Data best described with approx NNLO calculations

(discrepancy w.r.t generators & ATLAS at low top quark p_T, see also next slide)

Atlas differential cross section (7TeV)

- ## Similar analysis

- ## Also good agreement data/theory

- ## Exception : **top quark p_T**

  - general trend : data softer than predictions at p_T>200GeV

  - disagreement smaller when compared to NLO or NLO+NNLL calculations

  - trend also seen by CMS
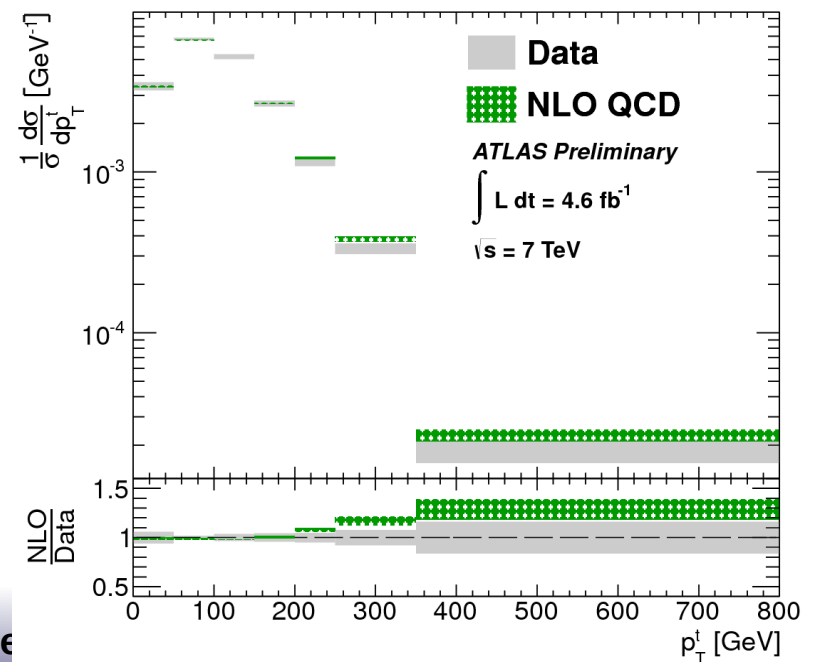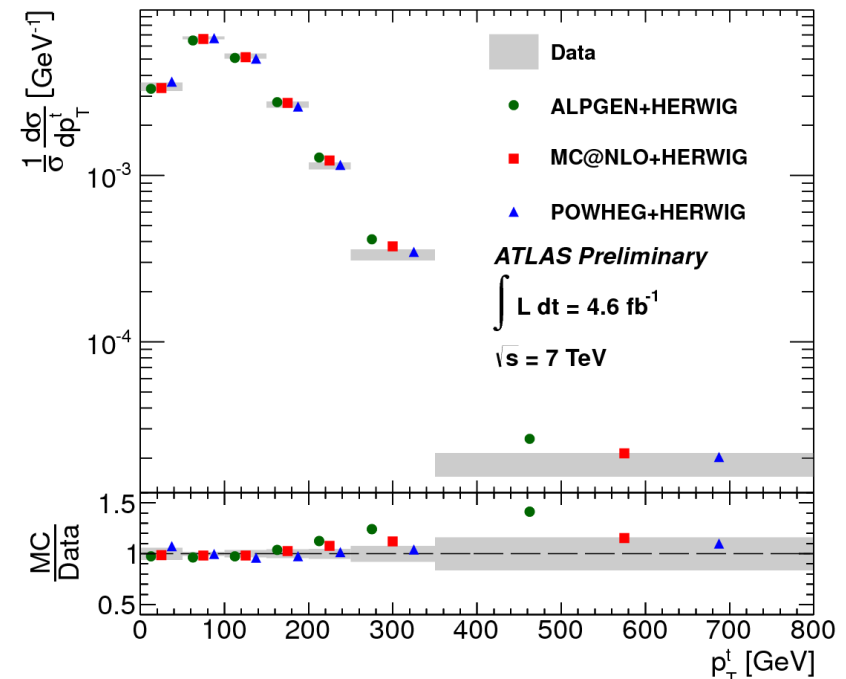
ATLAS-CONF-2013-099
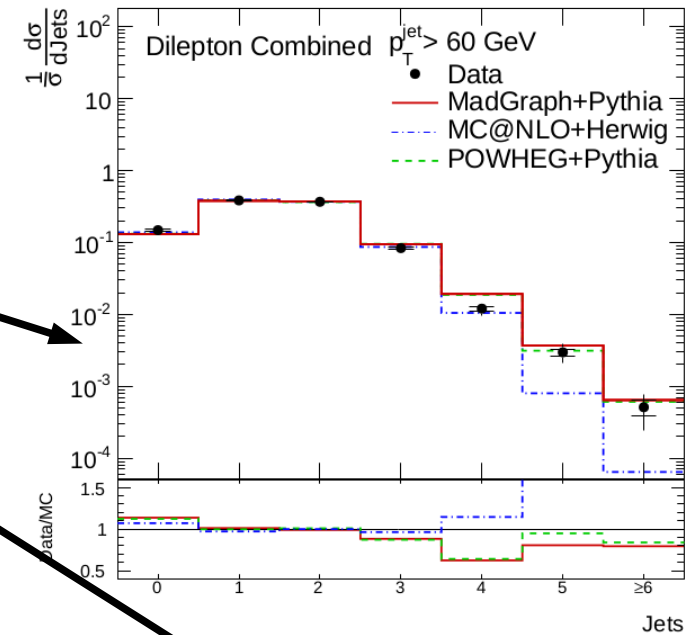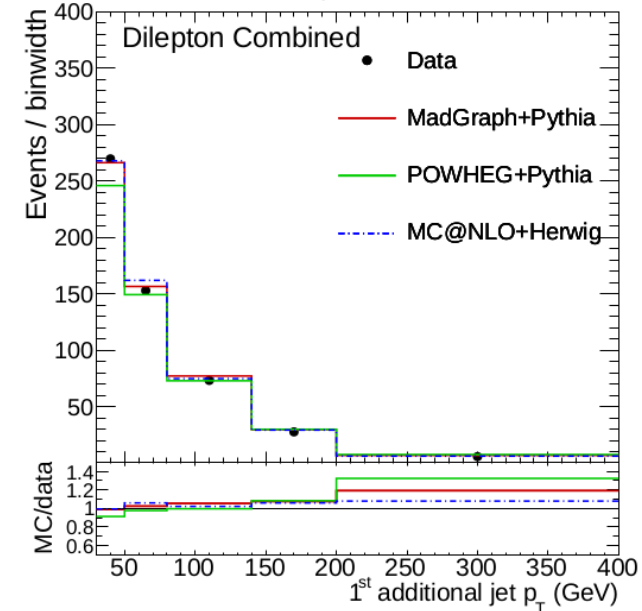
Other results : ttbar+jets

- Dilepton channel
- Studied additional jet observables
  - Normalized x-section vs multiplicity
  - Additional jets kinematics
  - gap fraction
- Compared several generators & tunes
  - reasonable agreement with data
  - MC@NLO underestimates jet multiplicity

- Similar ATLAS study at 7TeV
  - Similar conclusions

ATLAS-CONF-2012-155

Conclusions

- Atlas & CMS performed several ttbar cross-section measurements
  - various channels
  - Experimental uncertainties at level of theoretical ones

Measurements compatible with predictions

- Differential cross section results by CMS (and ATLAS at 7Tev)
  - dileptons and single lepton channel
  - general good agreement with theory

(small discrepancies in top quark p_T under discussions)

- Associated production results available
  - presented ttbar+jets
- Not covered here but available results :
  - ttbar+bb, ttbar+gamma, ...

- Next
  - Getting ready for run 2 and √s=13TeV

References

NNLO+NNLL xsection calculations : $\sigma = 252.9 \pm 11.7^{+6.7}_{-8.6}\mathrm{pb}$

[1] M. Cacciari et al., Top-pair production at hadron colliders with next-to-next-to-leading logarithmic soft-gluon resummation, Phys. Lett. B710 (2012) 612-622, arXiv:1111.5869 [hep-ph]

[2] P. Bärnreuther et al., Percent Level Precision Physics at the Tevatron: First Genuine NNLO QCD Corrections to qqbar →ttbar, Phys. Rev. Lett. 109 (2012) 132001, arXiv:1204.5201 [hep-ph]

[3] M. Czakon and A. Mitov., NNLO corrections to top-pair production at hadron colliders: the all-fermionic scattering channels, [[http://link.springer.com/article/10.1007%2FJHEP12%282012%29054][JHEP 1212 (2012) 054]], arXiv:1207.0236 [hep-ph]

[4] M. Czakon, A. Mitov., NNLO corrections to top pair production at hadron colliders: the quark-gluon reaction JHEP 1301 (2013) 080, arXiv:1210.6832 [hep-ph]

[5] M. Czakon, P. Fiedler, A. Mitov., The total top quark pair production cross-section at hadron colliders through $O(\alpha^4)$, Phys. Rev. Lett. 110 (2013) 252004, arXiv:1303.6254 [hep-ph]

[6] M. Czakon and A. Mitov, Top++: a program for the calculation of the top-pair cross-section at hadron colliders, arXiv:1112.5675 [hep-ph]

ATLAS & CMS references
See note & article numbers on result slides.

Access them from

ATLAS : https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults
CMS : https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP