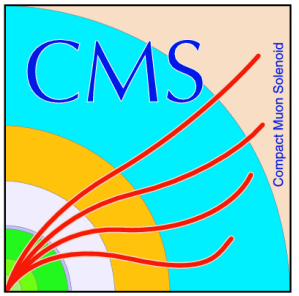
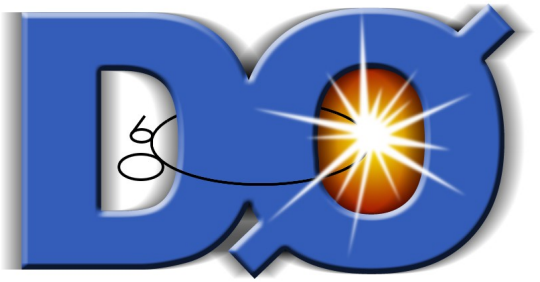
$t\bar{t}$ production: inclusive and differential cross section measurements

Matteo Negrini
INFN Bologna

On behalf of the ATLAS, CDF, CMS, and D0 collaborations





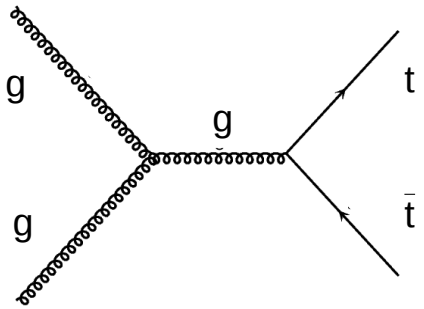
SM@LHC - Madrid 09/04/2014

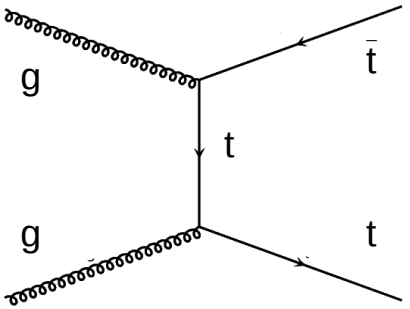
Introduction

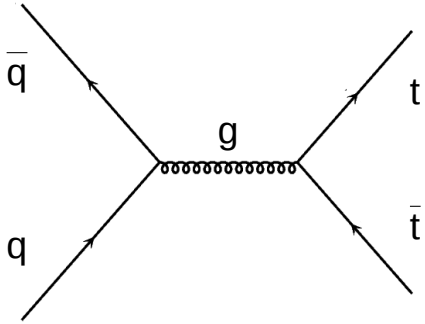
- Top quark physics plays a major role in the Tevatron and LHC physics program
  - Lifetime shorter than hadronization timescale
  - Yukawa coupling to Higgs boson ≈ 1
  - May strongly couple to new physics
  - One of major background sources for new physics searches
- Study of $t\bar{t}$ production is precision physics
  - Huge $t\bar{t}$ samples available at the LHC
  - Differential cross sections measured with unprecedented precision
  - Theoretical predictions on total cross section available at NNLO+NNLL

Top quark physics → tool for precision tests of the SM

Total $t\bar{t}$ production cross section





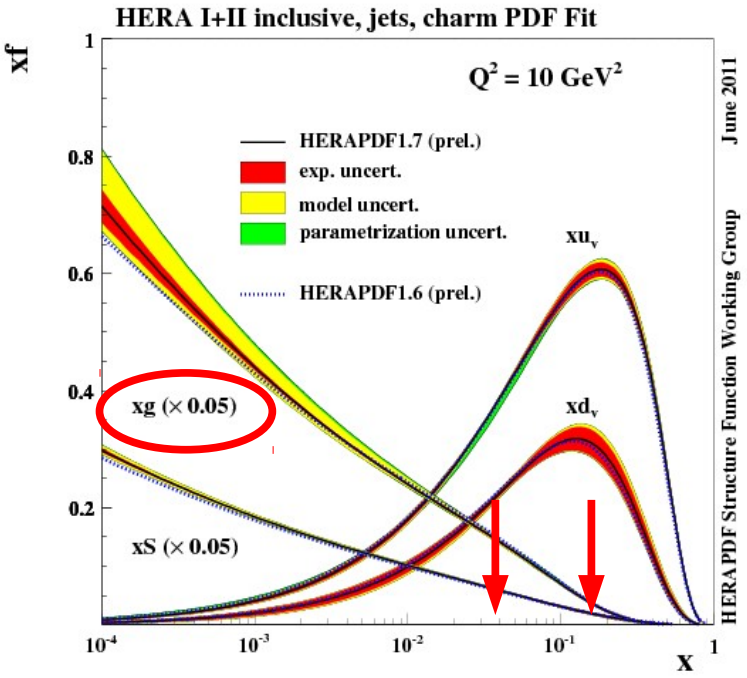


	gg	$q\bar{q}$
Tevatron ($p\bar{p}$ @ 2 TeV)	10%	90%
LHC (pp @ 8 TeV)	85%	15%
LHC (pp @ 14 TeV)	90%	10%

- Theoretical predictions at NNLO+NNLL
  - Uncertainty: ~2% (Tevatron), ~3% (LHC)
  - Comparable with experimental accuracy
- Main theoretical uncertainties: scale uncertainties, PDFs, α_s, m_t
- Sensitivity to PDFs
- $t\bar{t}$ production at the LHC testing large-x gluon PDFs

$$x^2 \approx \hat{s}/s \approx 4\,m_t^2/s$$

x ~ 0.18 (Tevatron)
x ~ 0.04 (LHC 8 TeV)

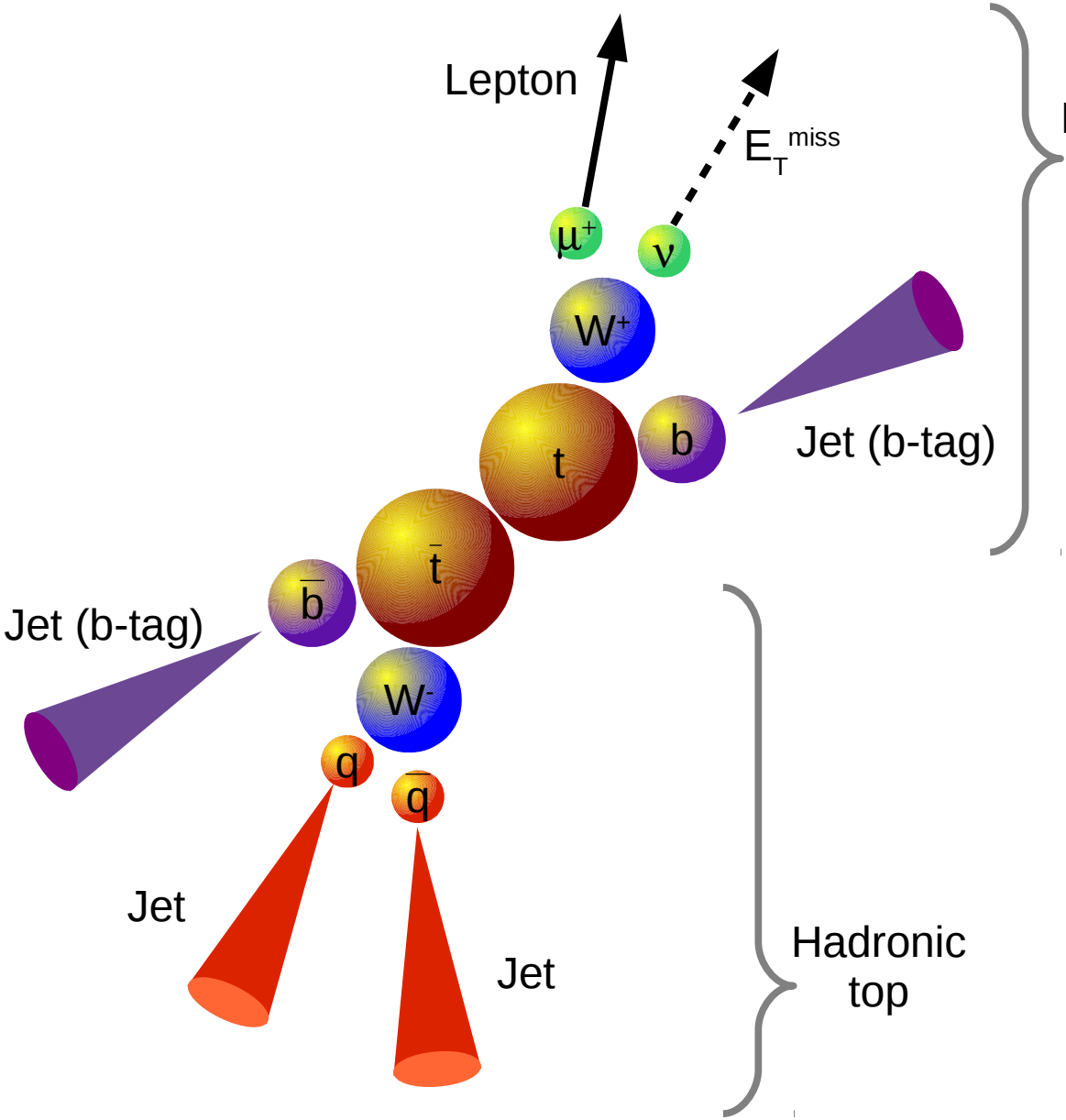


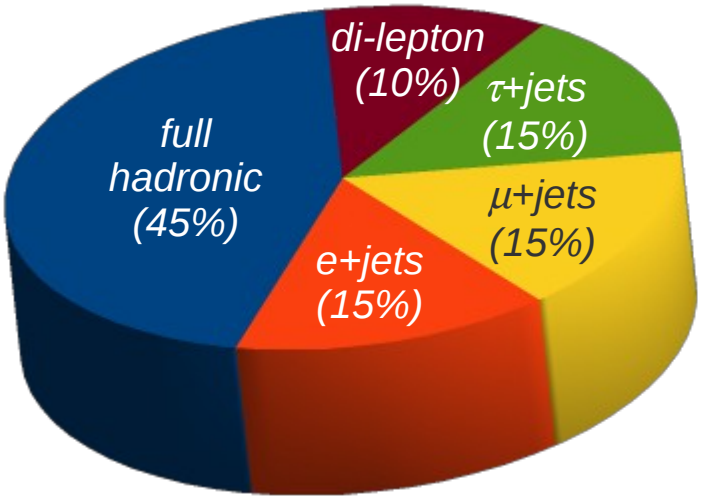
$\sigma(t\bar{t})$ theoretical predictions at NNLO+NNLL

Collider	$\sigma_{\rm tot}$ [pb]	scales [pb]	pdf [pb]
Tevatron	7.164	$^{+0.110(1.5\%)}_{-0.200(2.8\%)}$	$^{+0.169(2.4\%)}_{-0.122(1.7\%)}$
LHC 7 TeV	172.0	$^{+4.4(2.6\%)}_{-5.8(3.4\%)}$	$^{+4.7(2.7\%)}_{-4.8(2.8\%)}$
LHC 8 TeV	245.8	$^{+6.2(2.5\%)}_{-8.4(3.4\%)}$	$^{+6.2(2.5\%)}_{-6.4(2.6\%)}$
LHC 14 TeV	953.6	$^{+22.7(2.4\%)}_{-33.9(3.6\%)}$	$^{+16.2(1.7\%)}_{-17.8(1.9\%)}$

Czakon, Fiedler, Mitov, Phys.Rev.Lett 110, 252004 (2013)

Top quark signatures





Branching fractions for $t\bar{t}$ events

Analysis overview

l+jets

- one isolated lepton
- jets (≥4)
- missing E_T
- b-tagging
- kinematic fit

dilepton

- two isolated leptons
- jets (≥2)
- m_{ll} cuts to suppress quarkonia and Z
- missing E_T
- b-tagging
- kinematic assumptions

l+jets main backgrounds

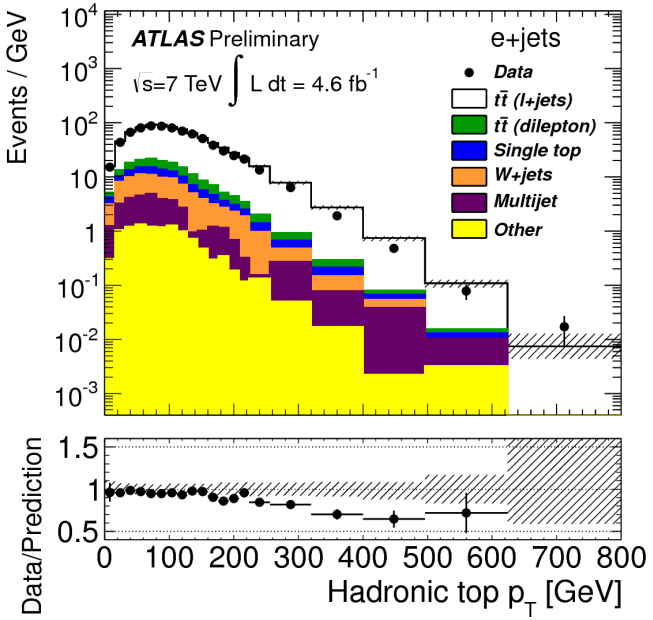
- W+jets
- multijet QCD
- single top

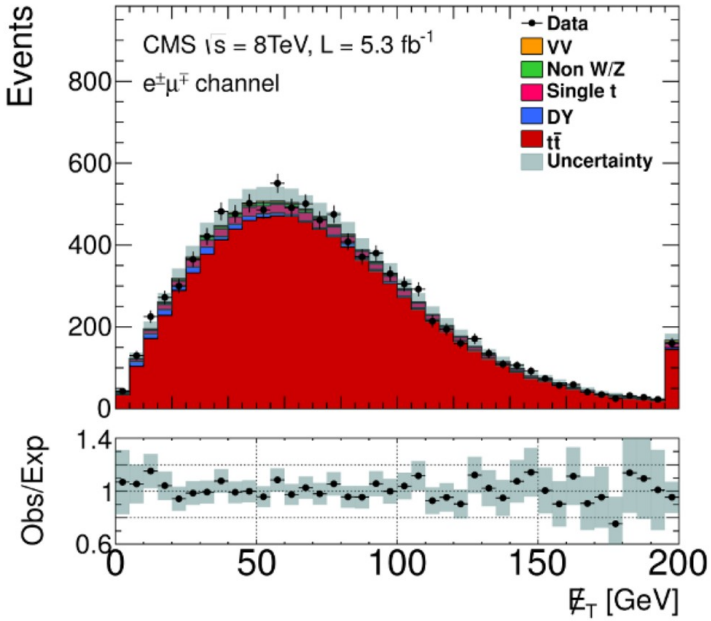
dilepton main backgrounds

- Z/γ + jets
- diboson
- single top

typical systematic uncertainties

- Detector modeling (JES, JER, lepton efficiency, b-tagging)
- Signal modeling (generator, IFSR, PDFs)
- Background modeling



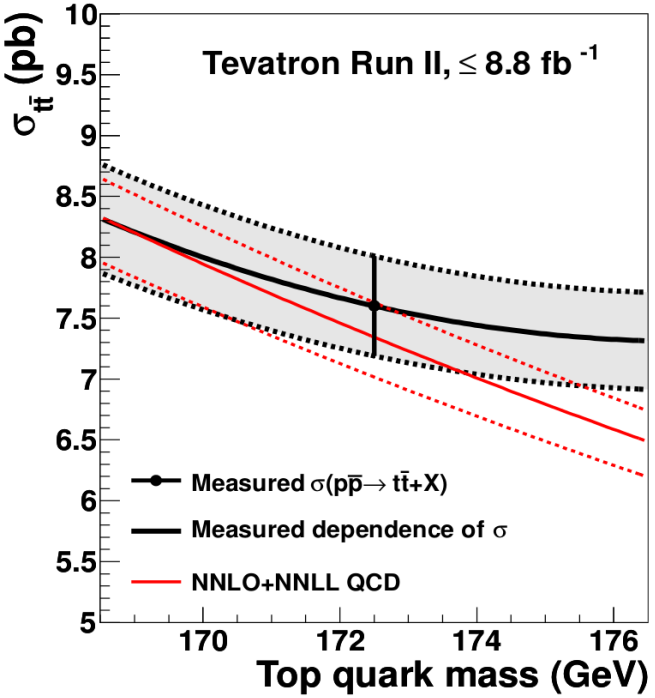


$\sigma(t\bar{t})$ at the Tevatron

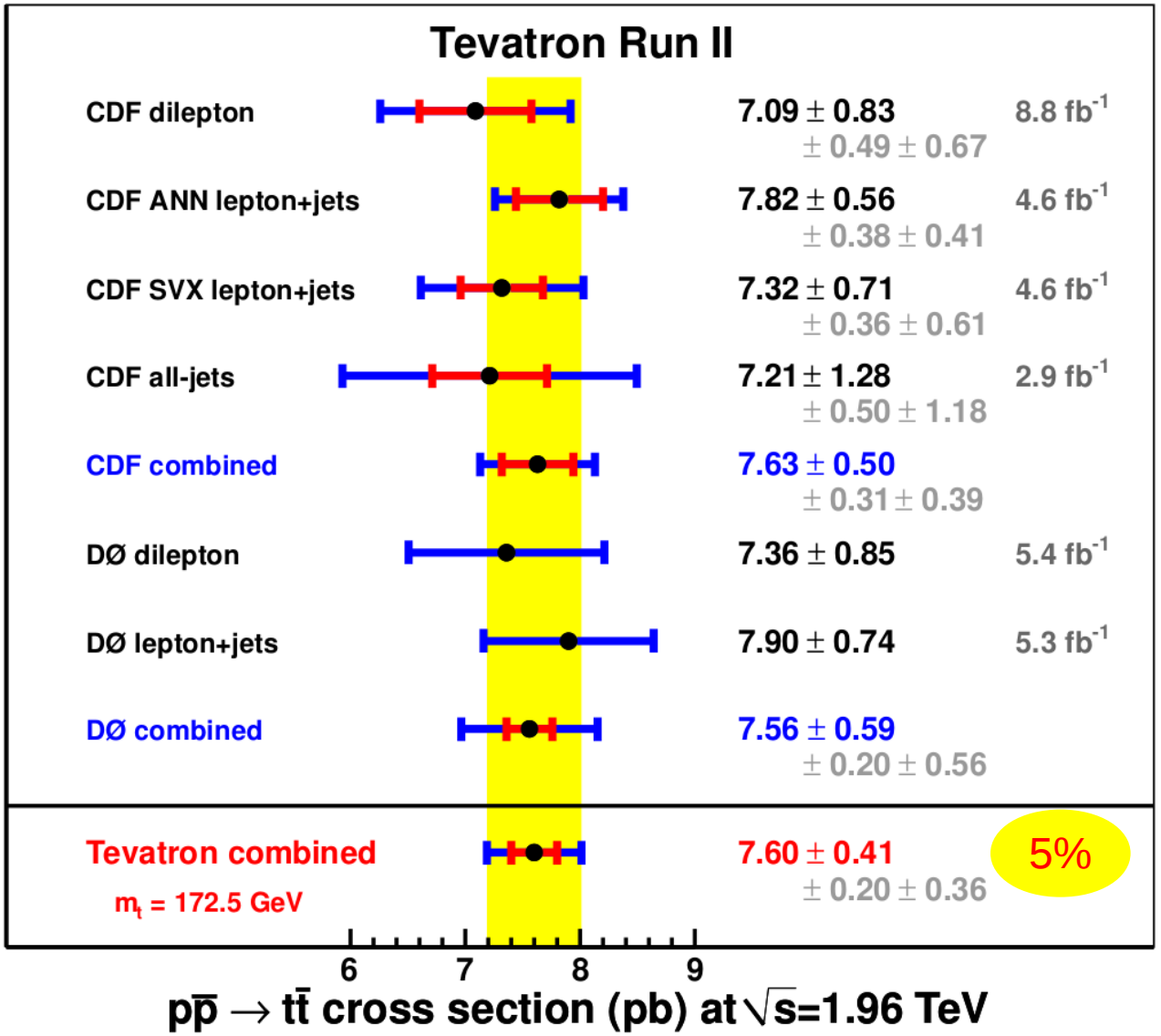
Combination of different measurements with BLUE

Assuming m_t=172.5 GeV

Good agreement among all channels and with NNLO+NNLL predictions



arXiv:1309.7570



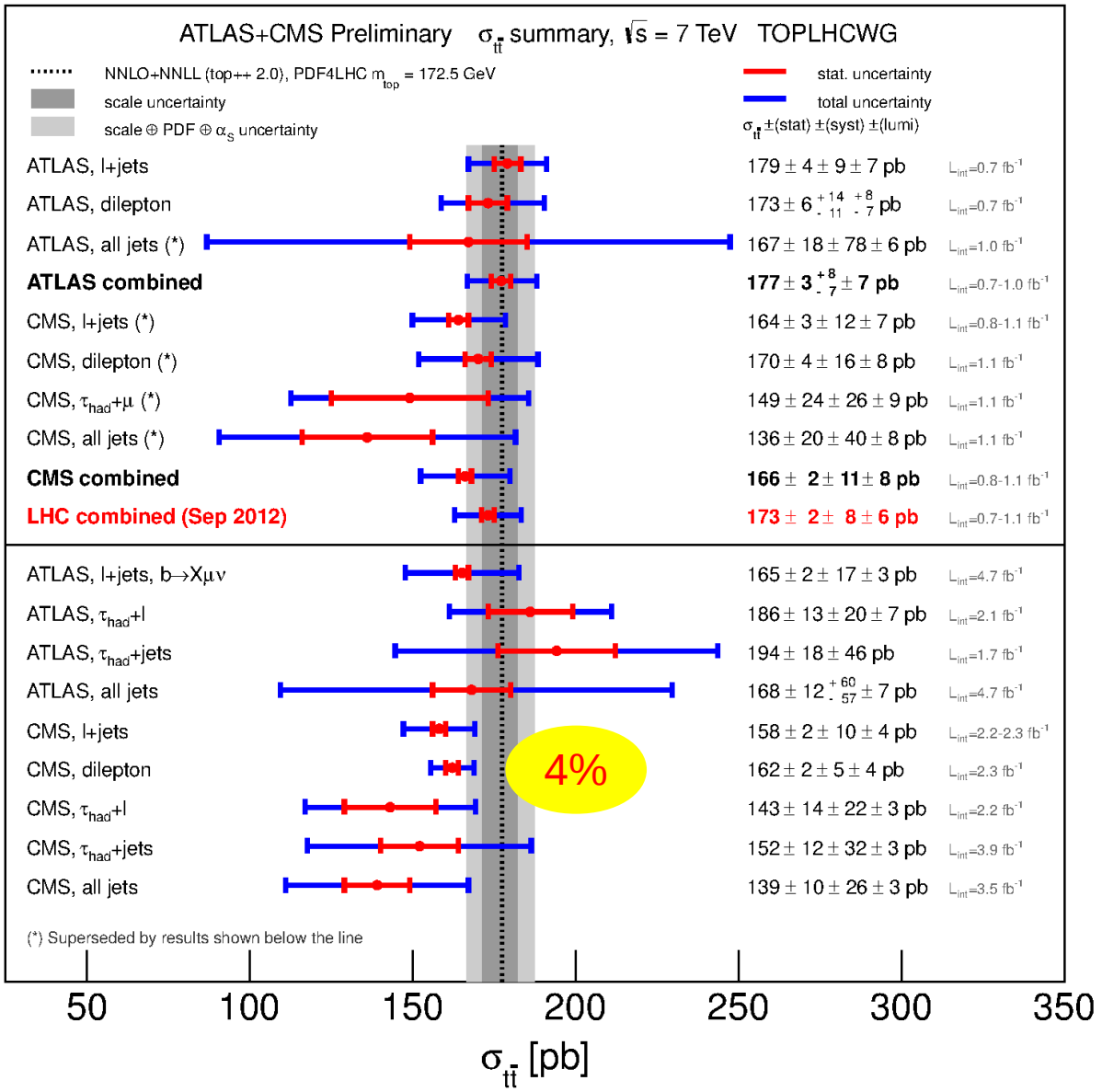
$\sigma(t\bar{t})$ at the LHC - $\sqrt{s}$=7 TeV

LHC first combination

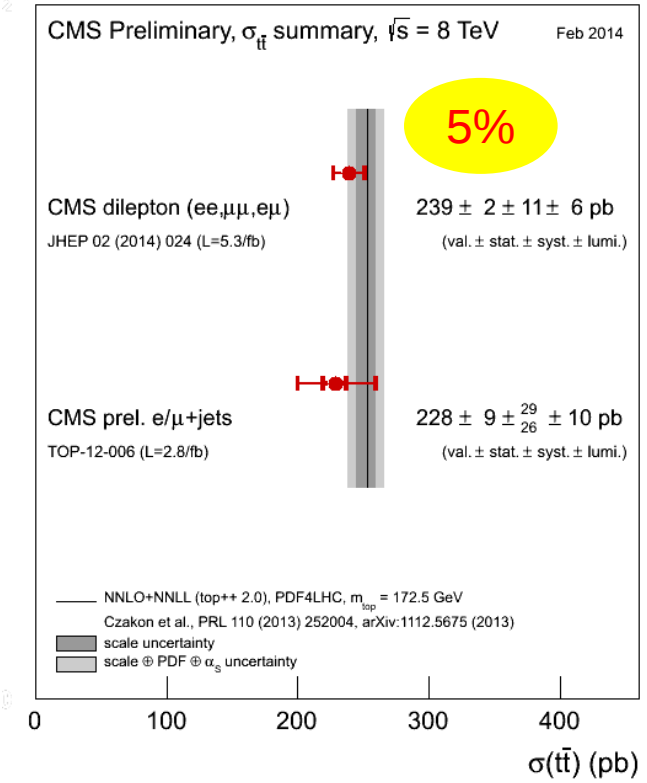
Recent results not included in the combination

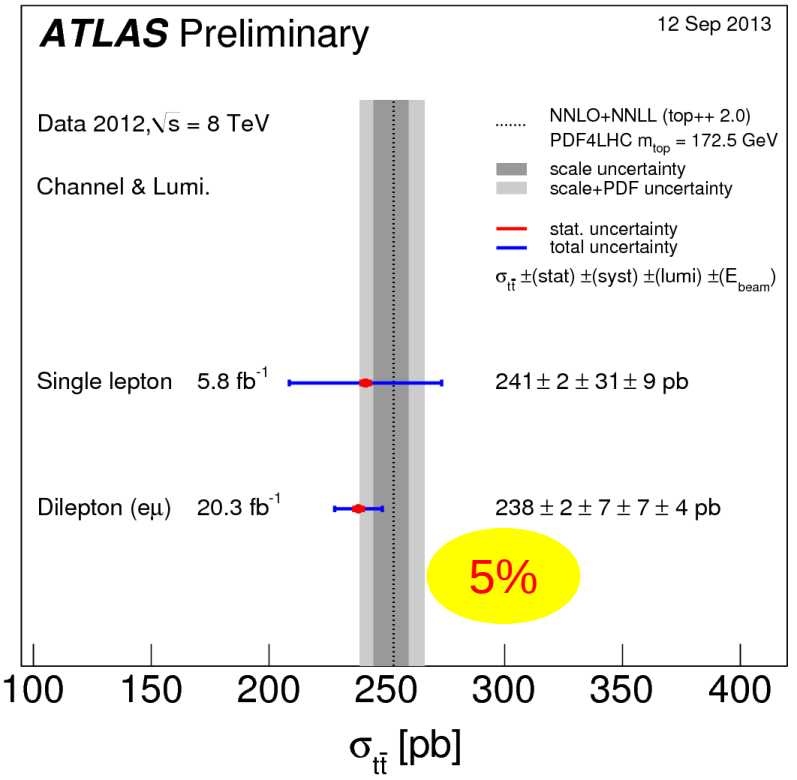
Uncertainty dominated by systematics

NNLO+NNLL predictions agree with all measurements within experimental and theoretical uncertainties



$\sigma(t\bar{t})$ at the LHC - $\sqrt{s}$=8 TeV



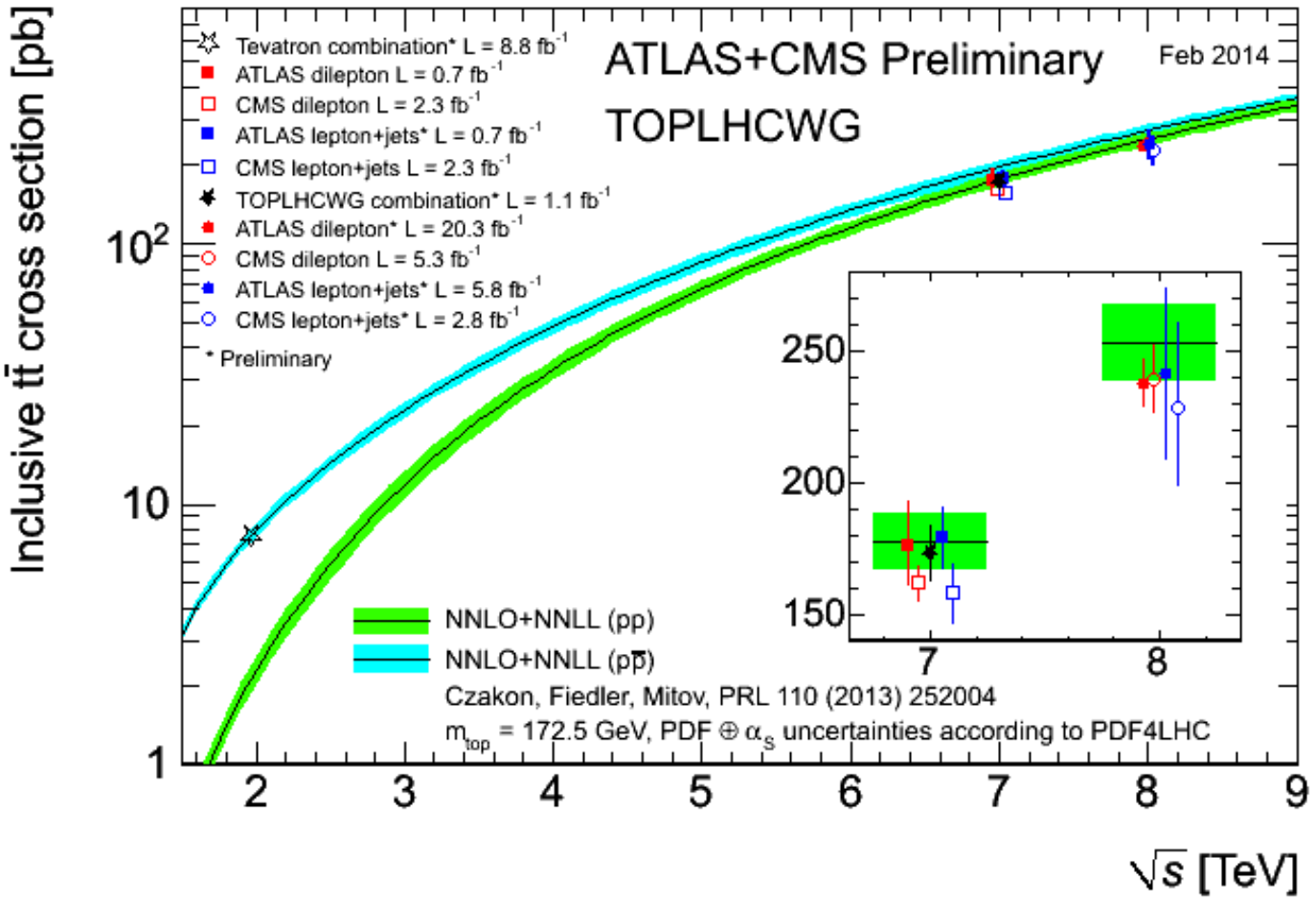


All measurements dominated by systematics

Single measurements in the dilepton channel at 5% accuracy

NNLO+NNLL predictions agree with all measurements within experimental and theoretical uncertainties

$\sigma(t\bar{t})$: the full picture



Excellent agreement with measurements of NNLO+NNLL theoretical predictions in the whole √s range

Comparable experimental and theoretical uncertainties

Differential cross sections

- Measurement of $d\sigma/dX$
  - X = kinematic quantities of top quark, $t\bar{t}$ system, leptons, jets, missing E_T
- Test predictions in different regions of phase space
  - Monte Carlo generators at NLO (or multi-leg LO)
  - Approximate NNLO calculation

Ahrens, Ferroglia, Neubert, Pecjak, Yang, JHEP 09, 097 (2010)

Kidonakis, Phys. Rev. D 82, 114030 (2010)

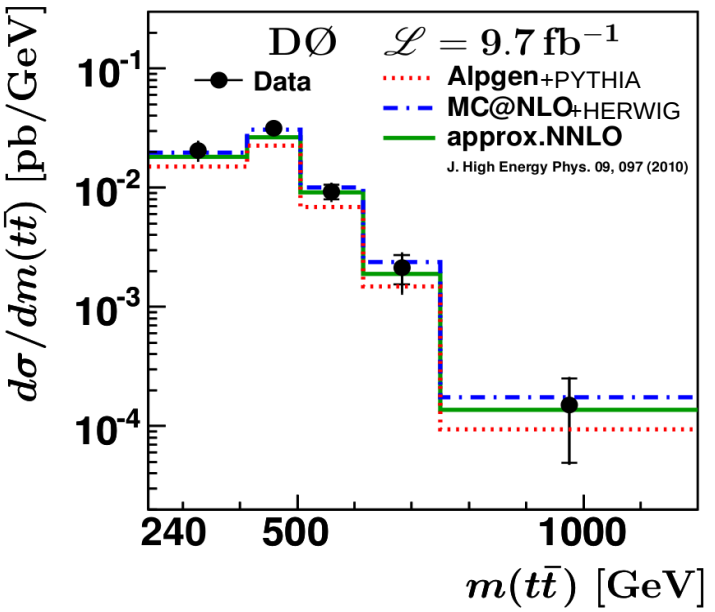
- Measurement definitions
  - correction to parton or particle level
  - extrapolation to full or visible phase space
- Test of PDFs
- Sensitivity to new physics

dσ/dX at the Tevatron

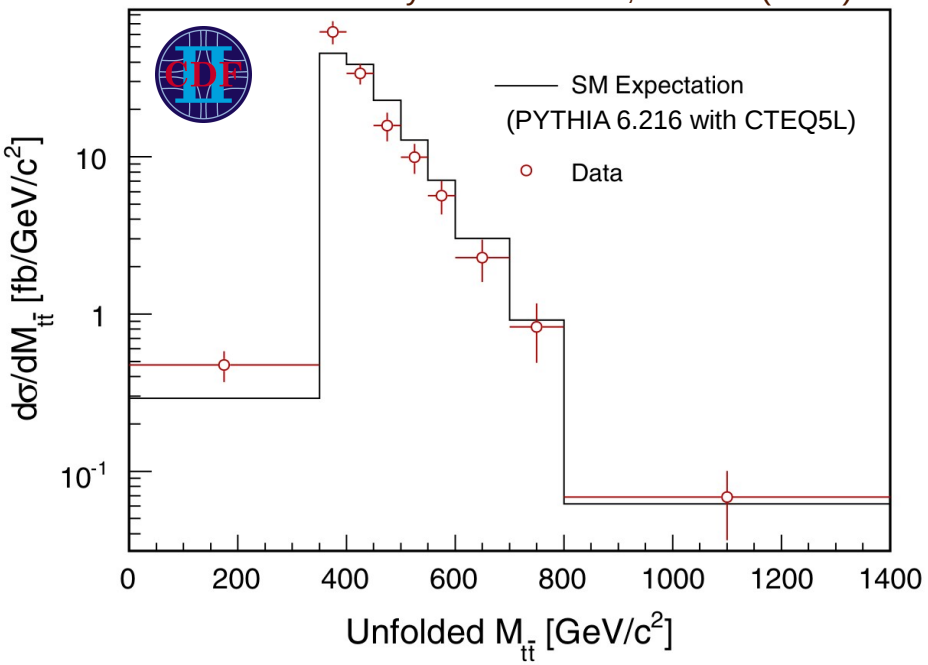
arXiv:1401.5785

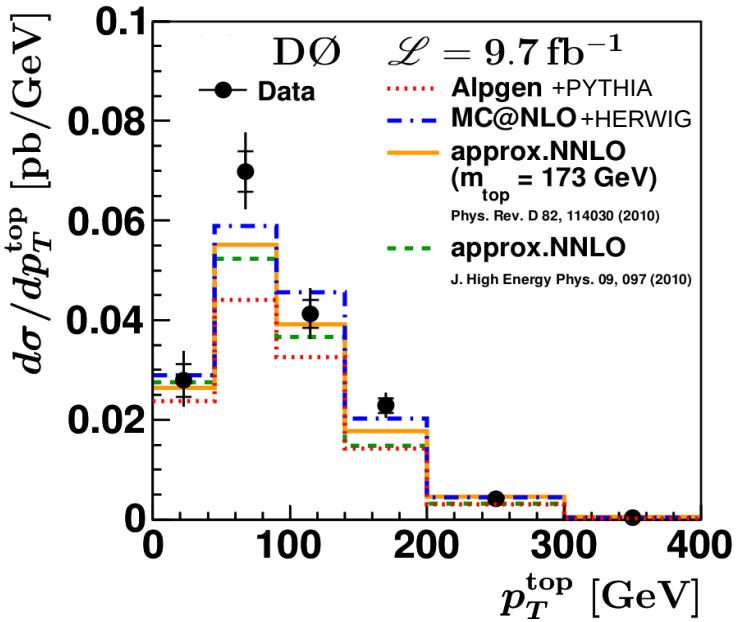
- Measurement of parton-level cross sections
- Extrapolation to full phase space
- Systematic uncertainty on each point typically ~10% (or larger)
  Main contributions: JES, PDFs

Good overall agreement of predictions with measurements



Phys.Rev.Lett 102, 222003 (2009)

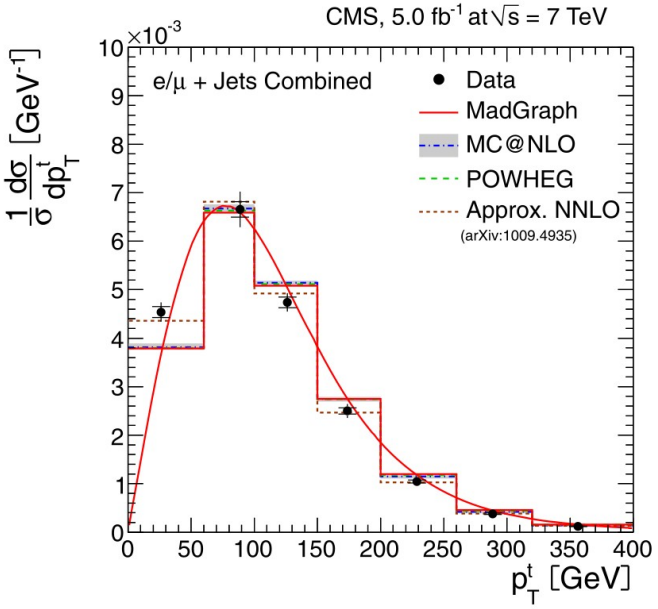


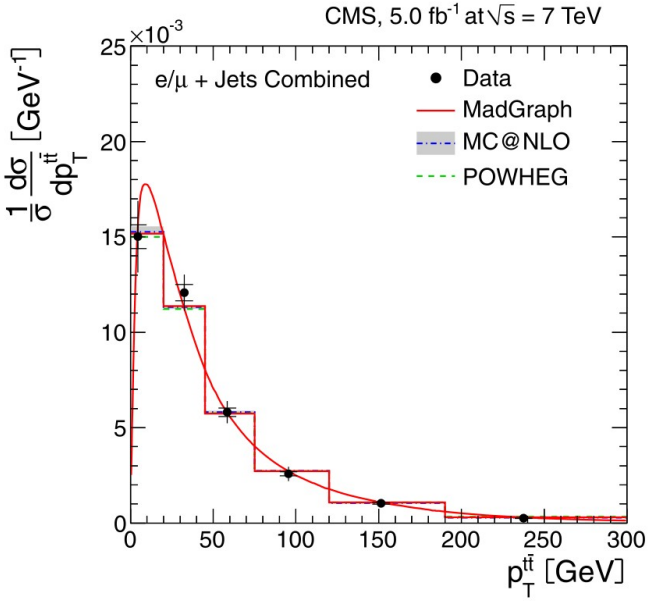


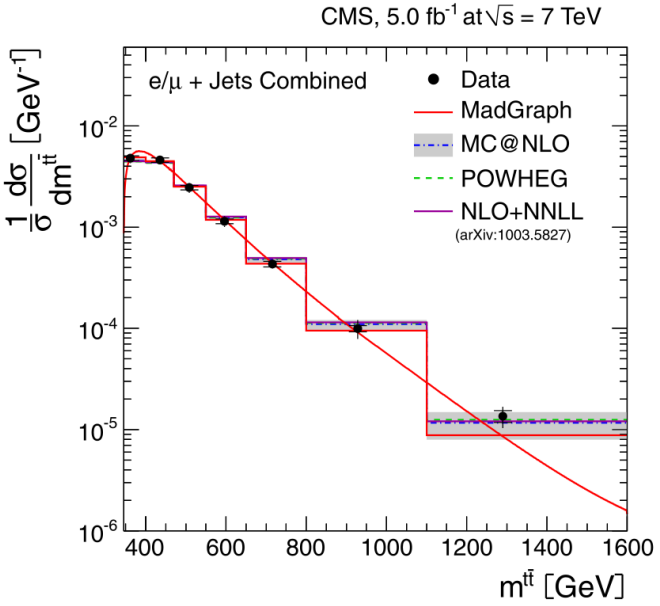
$1/\sigma\, d\sigma/dX$ at CMS - 7 TeV

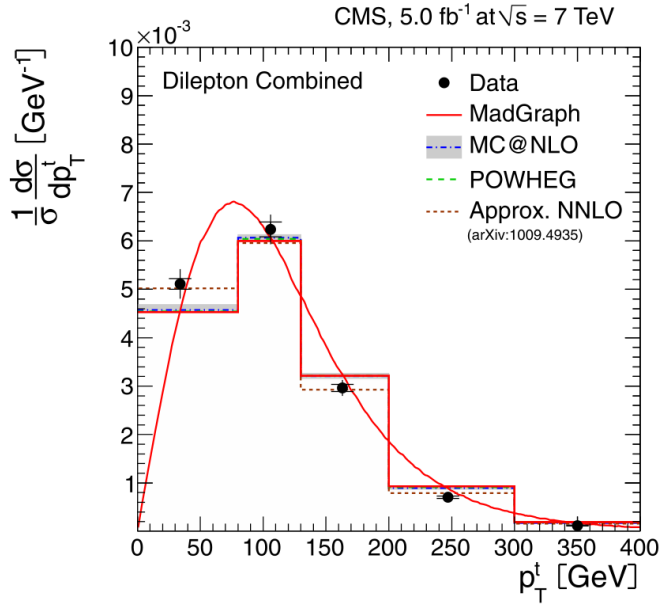
Measurement of inclusive parton-level cross sections

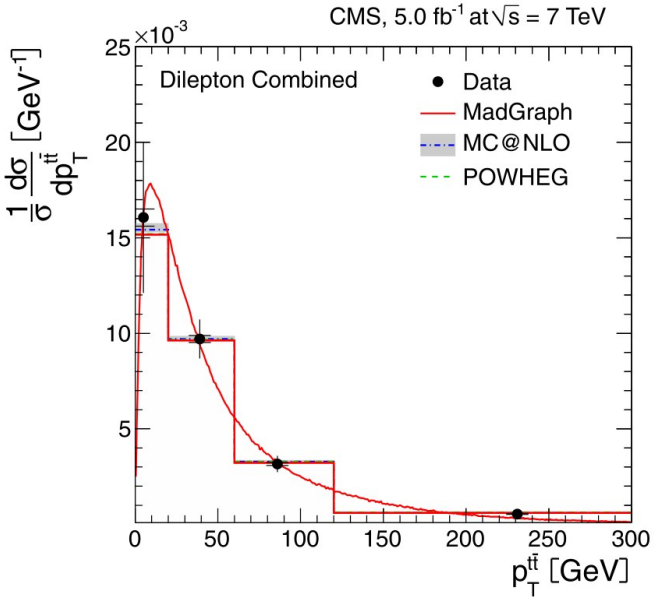
Eur. Phys. J. C 73, 2339 (2013)

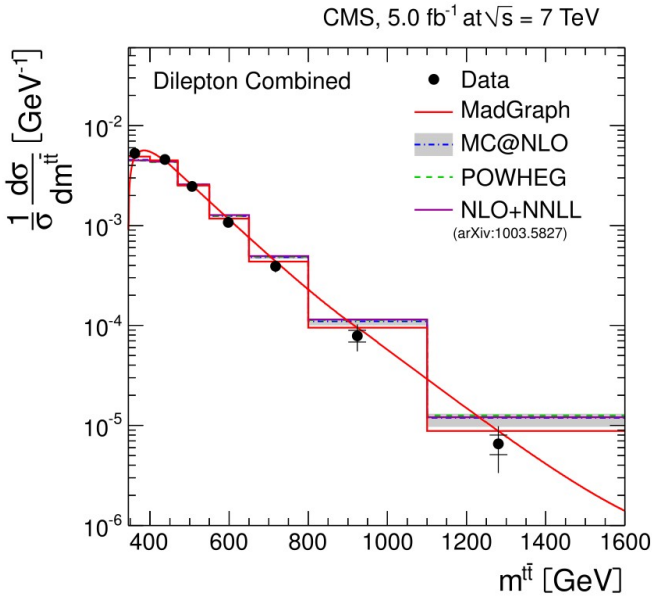








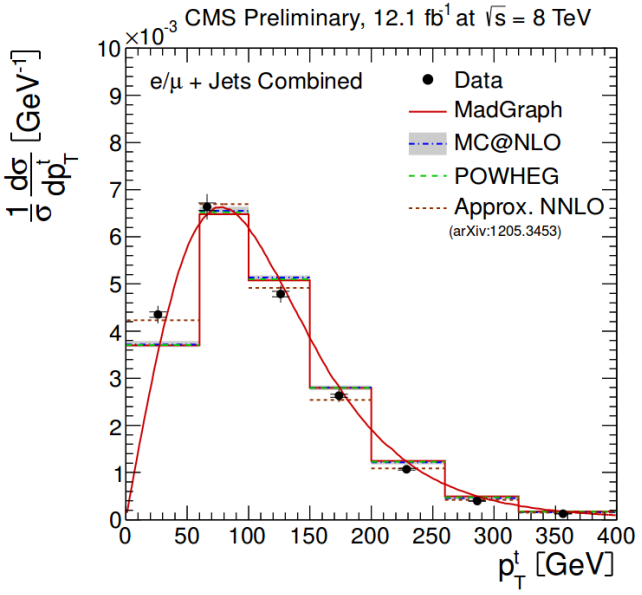


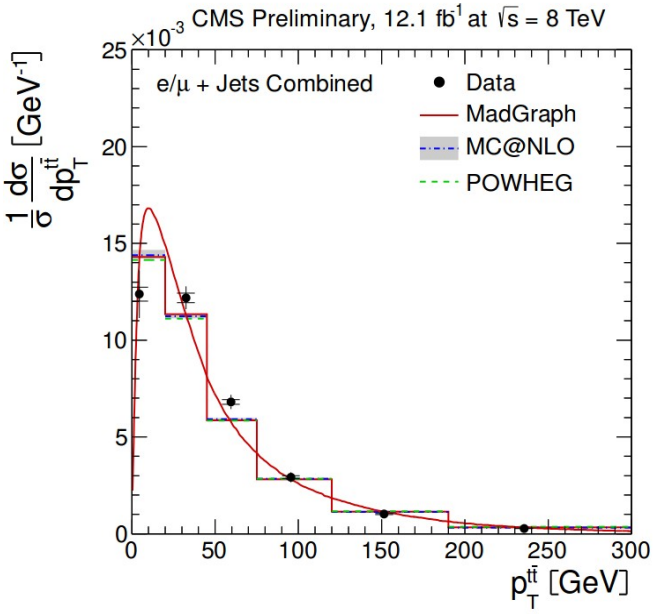


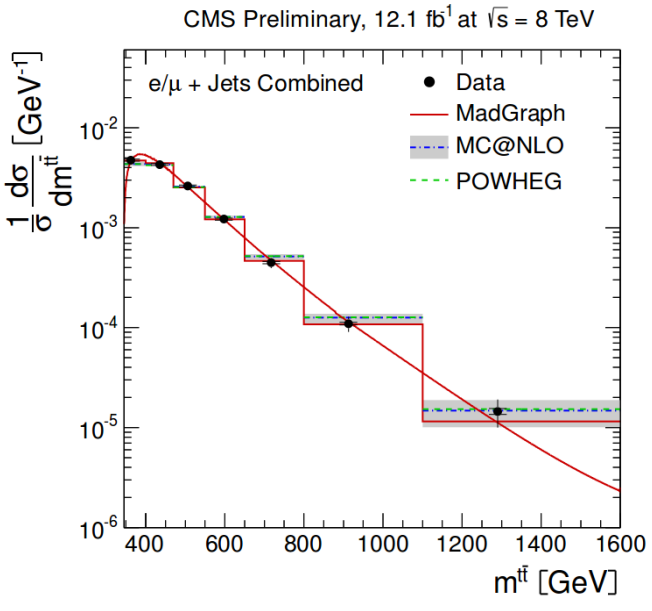
$1/\sigma\, d\sigma/dX$ at CMS - 8 TeV

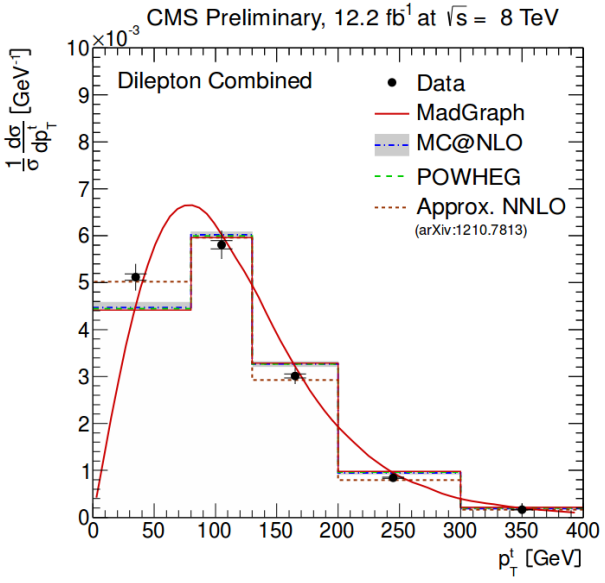
Measurement of inclusive parton-level cross sections

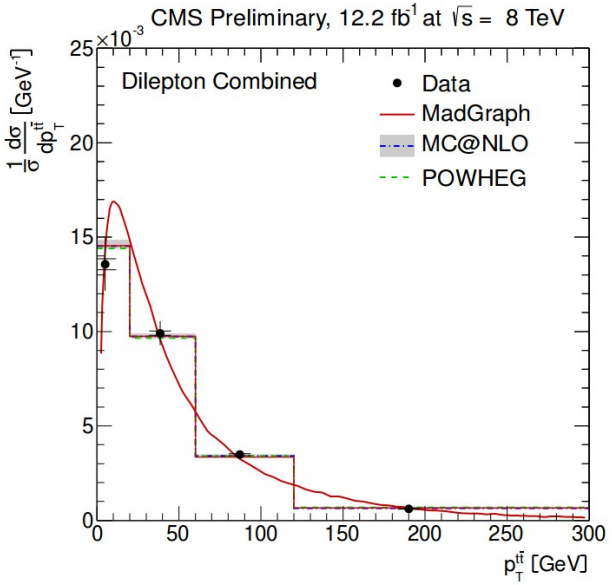
CMS-PAS-TOP-12-027
CMS-PAS-TOP-12-028

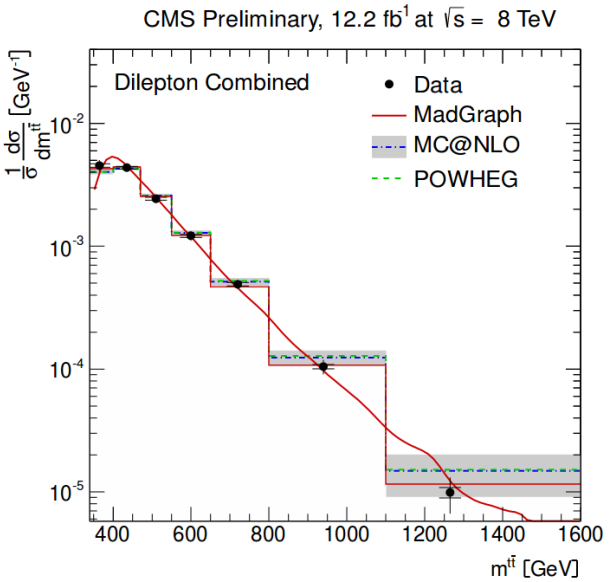








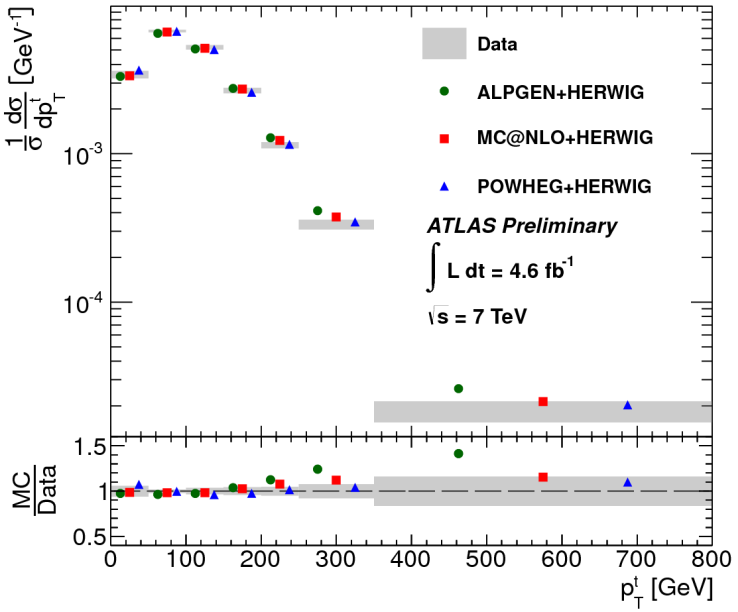


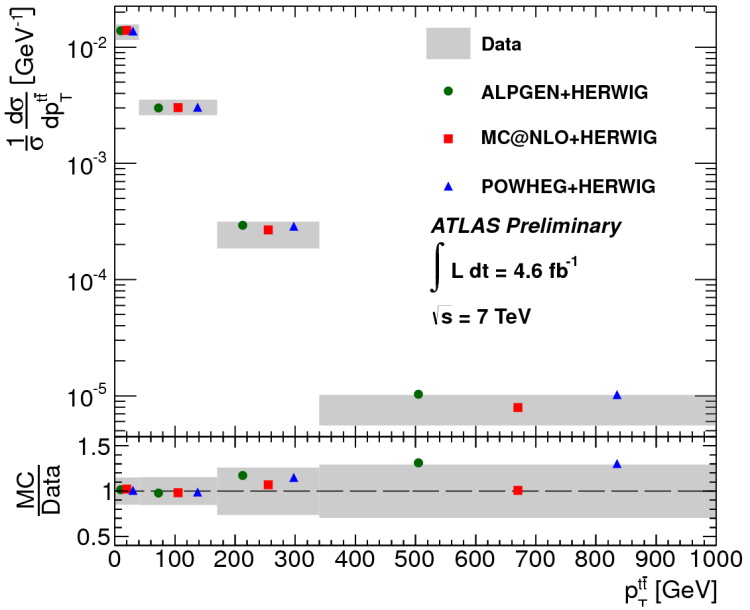


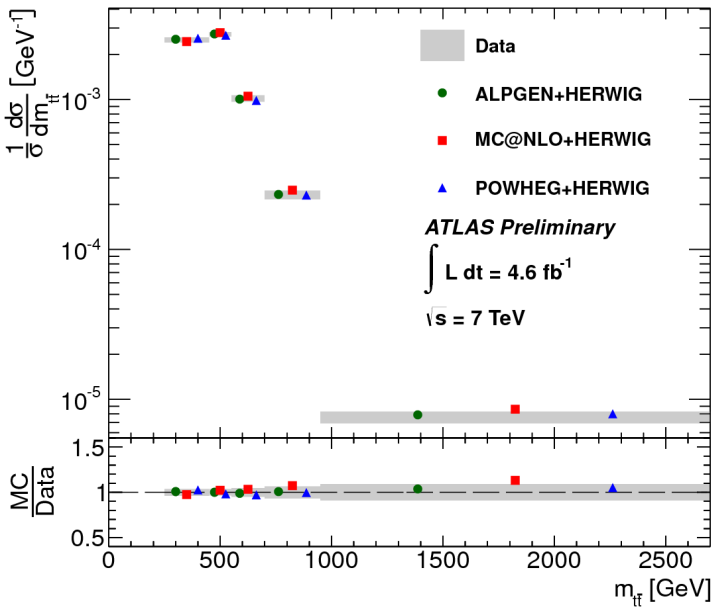
$1/\sigma\, d\sigma/dX$ at ATLAS - 7 TeV

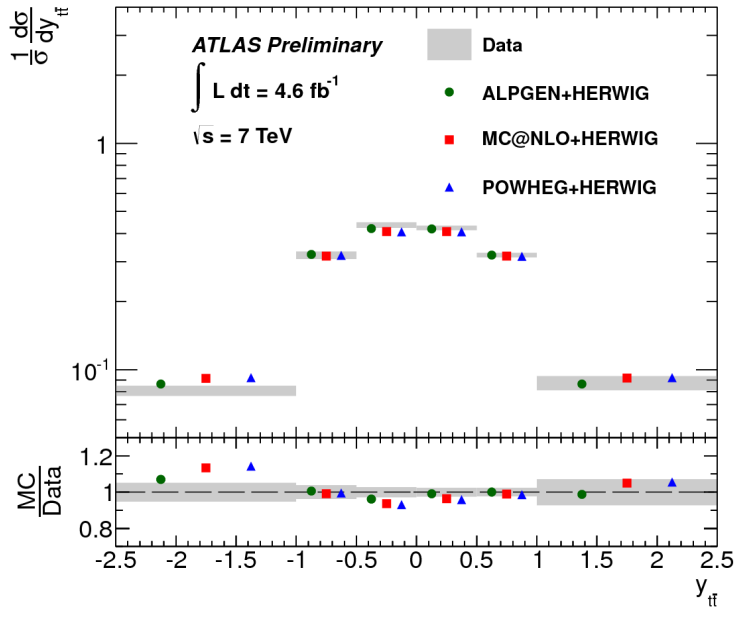
Measurement of inclusive parton-level cross sections

ATLAS-CONF-2013-099









The effect of PDFs

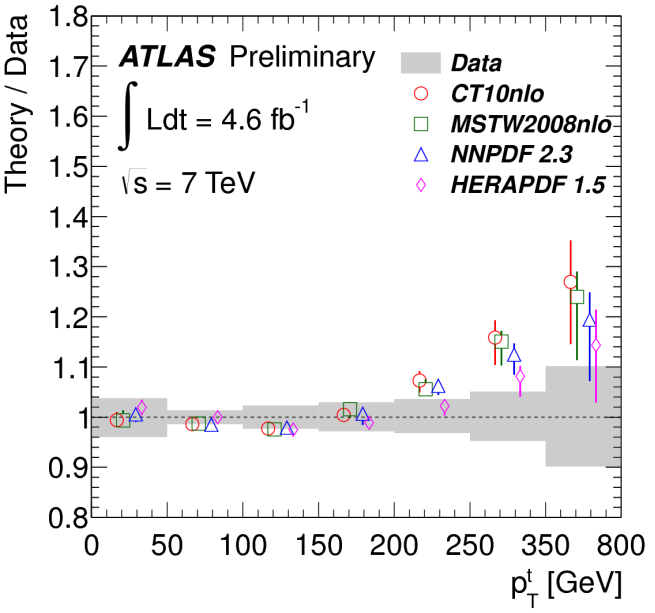
ATLAS-CONF-2013-099

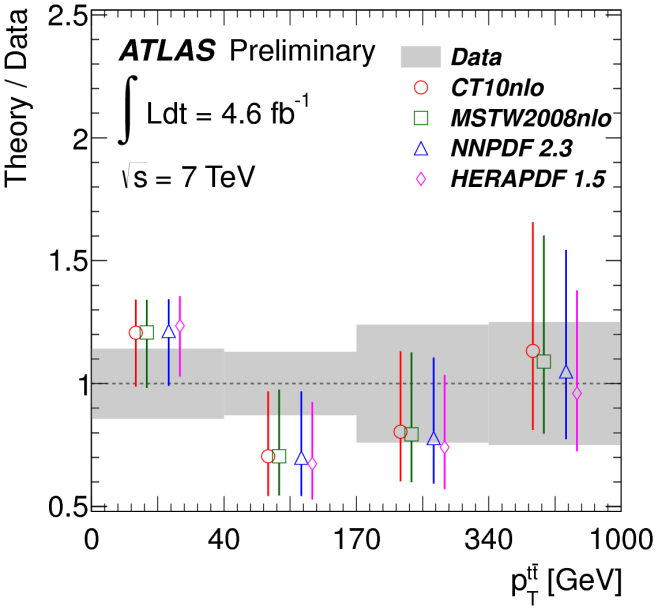
NLO predictions (MCFM) interfaced with different PDF sets

Uncertainty on PDF and factorization and renormalization scales included in each point

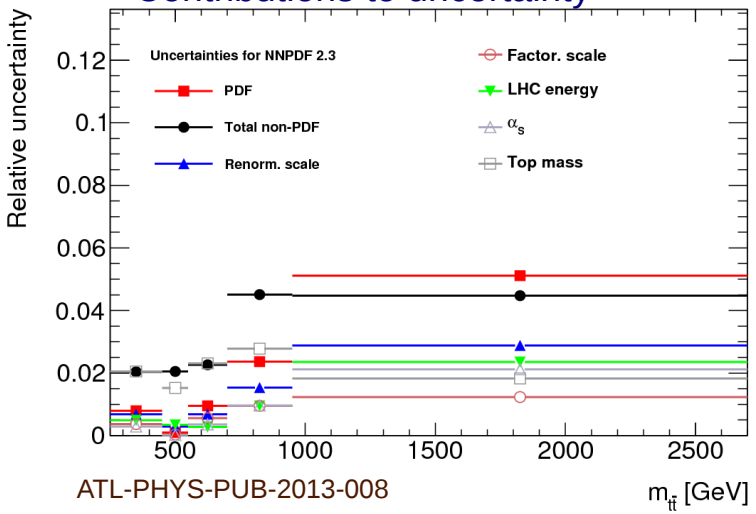
Generally good agreement for different PDF sets

Predictions tend to be harder than data





Contributions to uncertainty



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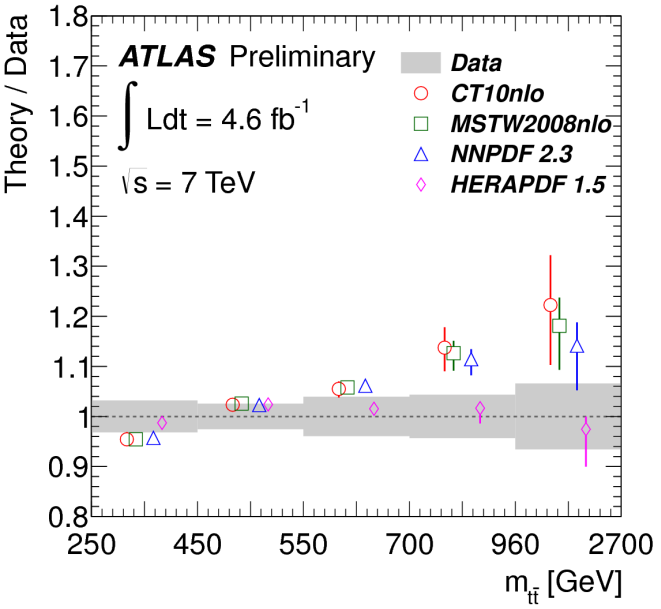
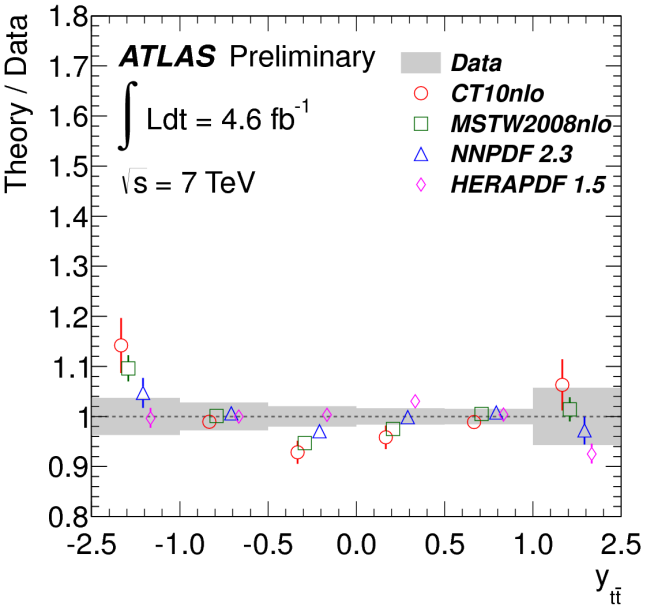




Jet multiplicity in $t\bar{t}$ events

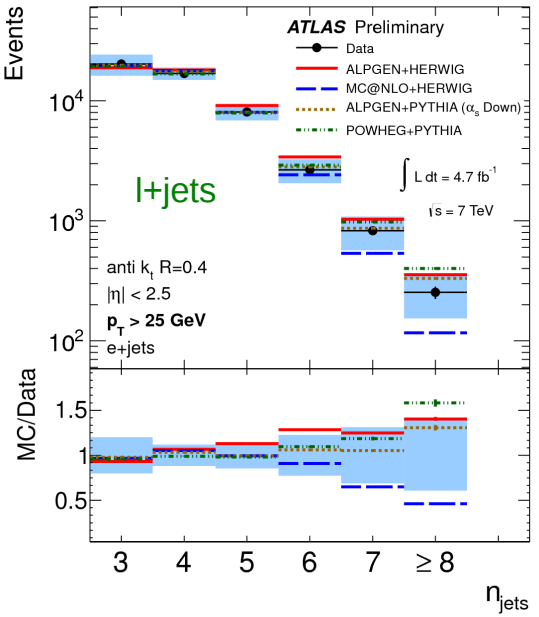
Inclusive $t\bar{t}$ production

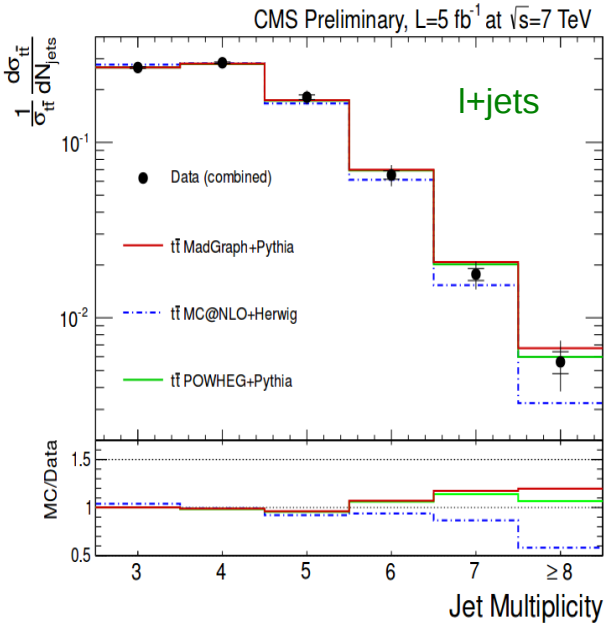
The number of additional jets (as a function of p_T) provide constraints to initial/final state radiation models and test perturbative QCD at the LHC

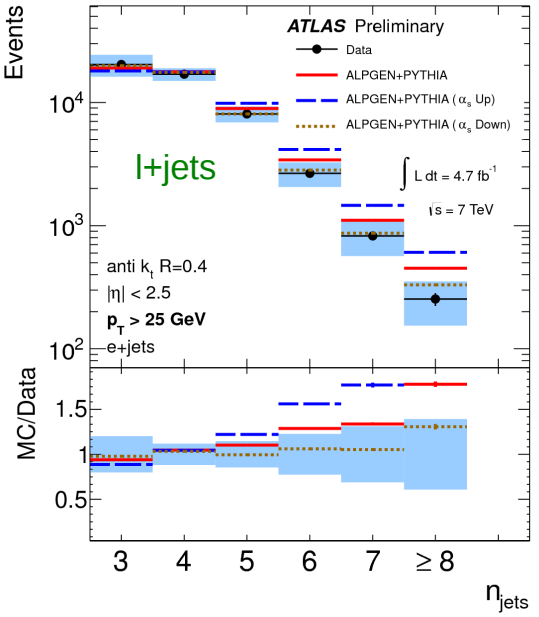
Efficiency and acceptance correction applied for comparison with model predictions
All results presented in a fiducial volume

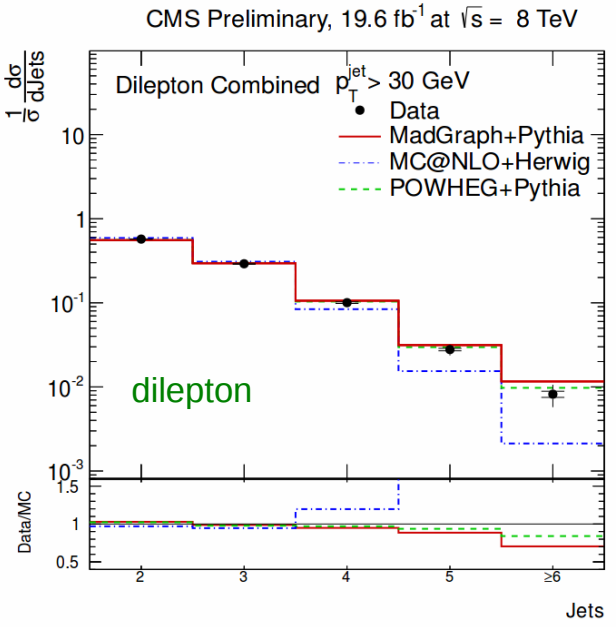
Generally good agreement between data and models

MC@NLO + HERWIG underestimates the multiplicity









ATLAS-CONF-2012-155
CMS-PAS-TOP-12-018
CMS-PAS-TOP-12-023

$t\bar{t}$+heavy flavour production

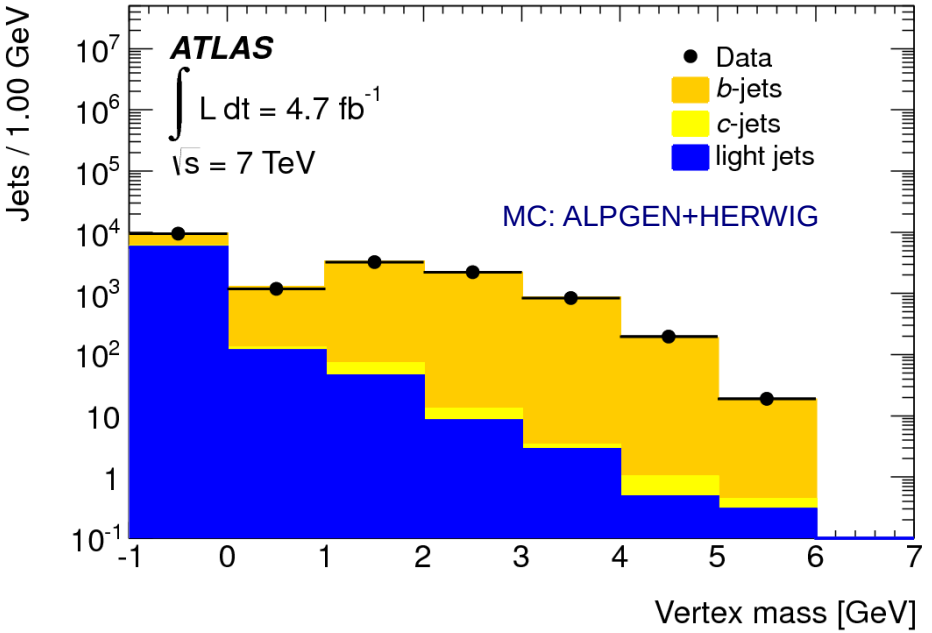
Irreducible background for $t\bar{t}H$ with $H \to b\bar{b}$ - SM predictions consistent with the observations

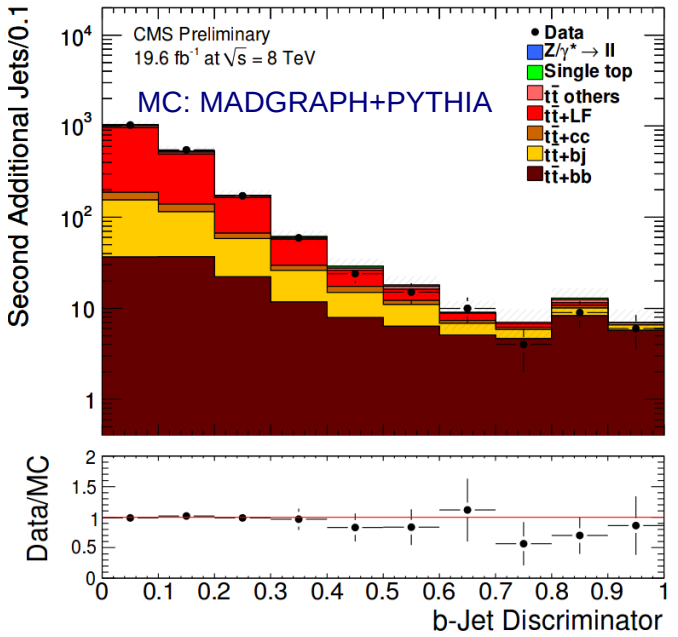
Analysis strategy:

- Measure ratio with $t\bar{t}$+jets
- Use dilepton $t\bar{t}$ events
- Fit different b-jet purity regions to extract b/c/light components
- Main systematic uncertainties: HF tagging efficiency and fragmentation modeling

CMS-PAS-TOP-12-024 (7 TeV)
CMS-PAS-TOP-13-010 (8 TeV)

arXiv:1304.6386





$$\frac{\sigma_{fid}(t\bar{t}+HF)}{\sigma_{fid}(t\bar{t}+jets)} = (6.2 \pm 1.1(stat) \pm 1.8(syst))\% \quad (7\ \text{TeV})$$

$$\frac{\sigma_{fid}(t\bar{t}\,b\bar{b})}{\sigma_{fid}(t\bar{t}\,jj)} = (3.6 \pm 1.1(stat) \pm 0.9(syst))\% \quad (7\ \text{TeV})$$

$$\frac{\sigma_{fid}(t\bar{t}\,b\bar{b})}{\sigma_{fid}(t\bar{t}\,jj)} = (2.3 \pm 0.3(stat) \pm 0.5(syst))\% \quad (8\ \text{TeV})$$

$t\bar{t}$+V production

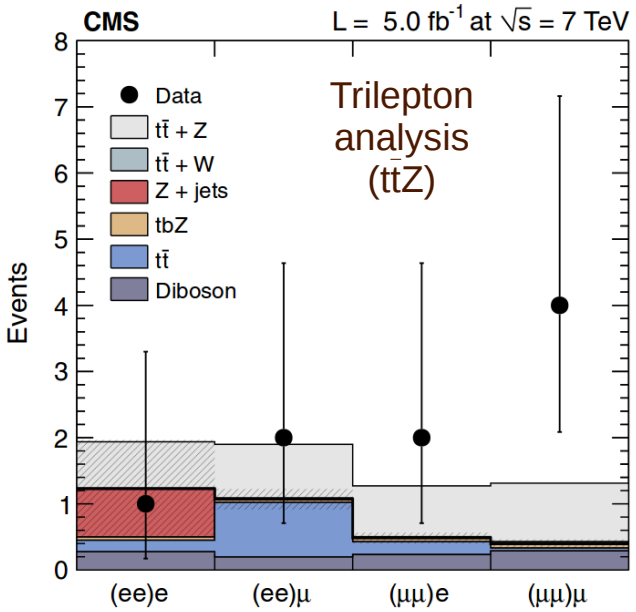
Trilepton: $t\bar{t}Z$

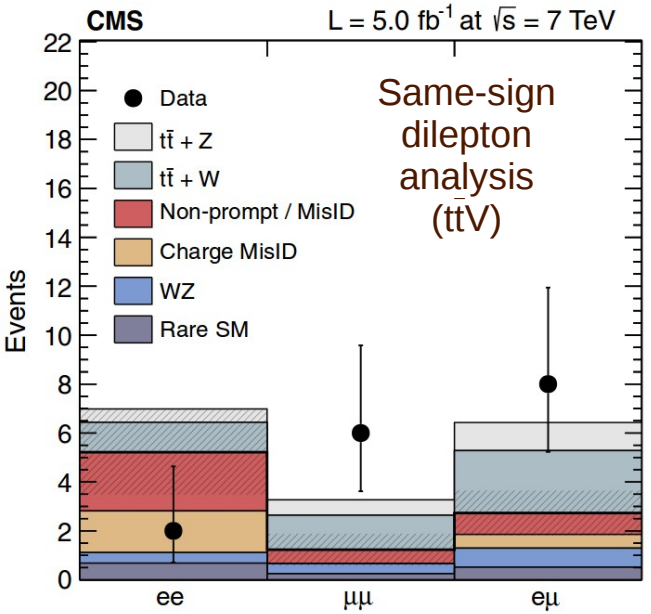
- 3 leptons, two consistent with Z decay
- ≥3 (CMS) or 4 (ATLAS) jets
- b-tagging

Same-sign leptons: $t\bar{t}V$ (V=W,Z)

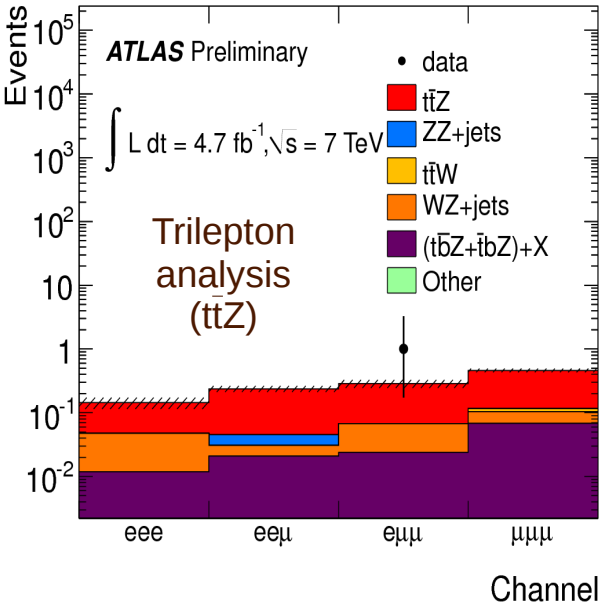
- 2 same-sign leptons
- ≥3 jets
- b-tagging

Phys. Rev. Lett. 110, 172002 (2013)





ATLAS-CONF-2012-126



$$\sigma_{t\bar{t}Z} = 0.28^{+0.14+0.06}_{-0.11-0.03}\ pb$$

$$\sigma_{t\bar{t}V} = 0.43^{+0.17+0.09}_{-0.15-0.07}\ pb$$

$$\sigma_{t\bar{t}Z} < 0.71\ pb \quad (95\%\ C.L.)$$

Test top coupling to SM particles (W/Z)
Very low yields, SM expectations in good agreement

Theoretical predictions (NLO QCD)

$$\sigma^{SM}_{t\bar{t}Z} = 0.137^{+0.012}_{-0.016}\ pb$$

$$\sigma^{SM}_{t\bar{t}Z} = 0.306^{+0.031}_{-0.053}\ pb$$

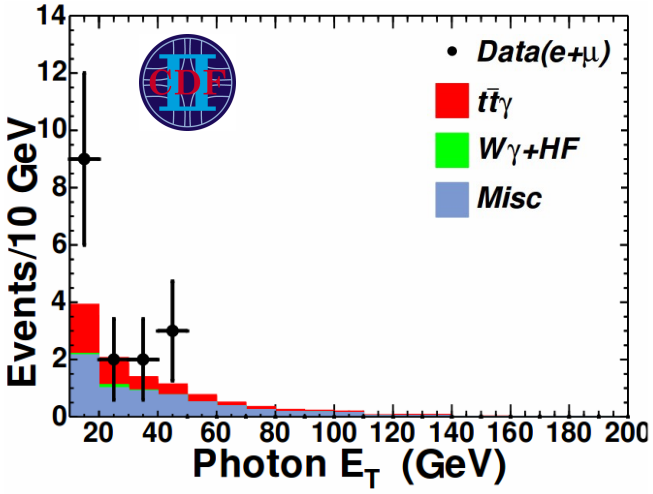
JHEP 07, 052 (2012) - JHEP 11, 056 (2012)

$t\bar{t}+\gamma$ production

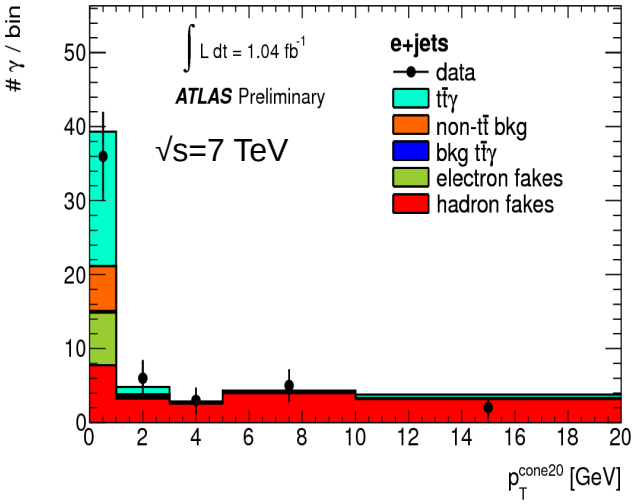
$t\bar{t}$ event selection + isolated photon with cut on E_γ

Photon isolation used as discriminating variable at the LHC
(sum of energy or p_T of particles within a cone of fixed ΔR around the photon candidate)

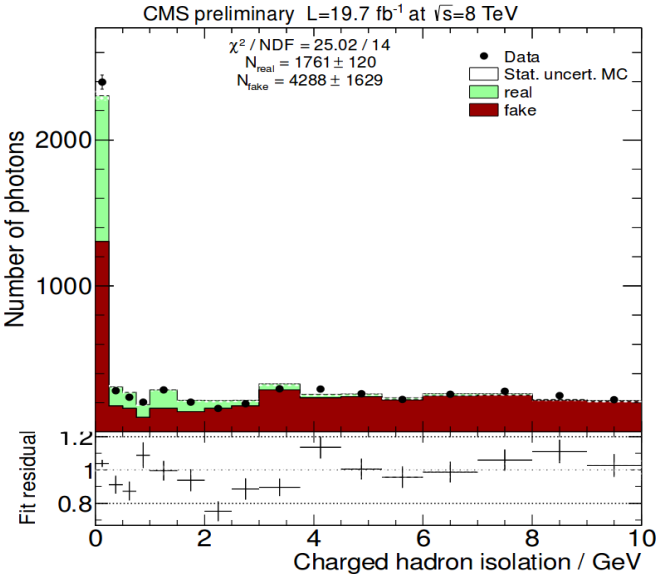
Phys. Rev. D 80, 011102 (2009)



ATLAS-CONF-2011-153



CMS-PAS-TOP-13-011



$$\sigma_{t\bar{t}\gamma} = 0.15 \pm 0.08\ pb$$

$$\sigma^{SM}_{t\bar{t}\gamma} = 0.080 \pm 0.011\ pb$$

$$\sigma_{t\bar{t}\gamma} = 2.0 \pm 0.5 \pm 0.7\ pb$$

$$\sigma^{SM}_{t\bar{t}\gamma} = 2.1 \pm 0.4\ pb$$

$$\sigma_{t\bar{t}\gamma} = 2.4 \pm 0.2 \pm 0.6\ pb$$

$$\sigma^{SM}_{t\bar{t}\gamma} = 1.8 \pm 0.5\ pb$$

SM expectations in agreement with all measurements
(LO MC with k-factor NLO corrections)

Summary

- Top physics at the Tevatron and LHC provides precision SM tests
  - Most measurements already limited by systematic uncertainties
  - $\sigma_{t\bar{t}}$ measured at few % level at Tevatron and LHC
  - Measurements in agreement with SM predictions available at NNLO ($\sigma_{t\bar{t}}$) or NLO ($d\sigma_{t\bar{t}}/dX$) with comparable uncertainties
  - Large statistics samples of LHC Run2 will allow to improve measurements in the tails of the differential distributions or for associated production ($\sigma_{t\bar{t}+X}$)
  - Total and differential cross sections already sensitive to PDFs
- So far good agreement with SM expectations