Top quark pair production measurements using the ATLAS detector at the LHC

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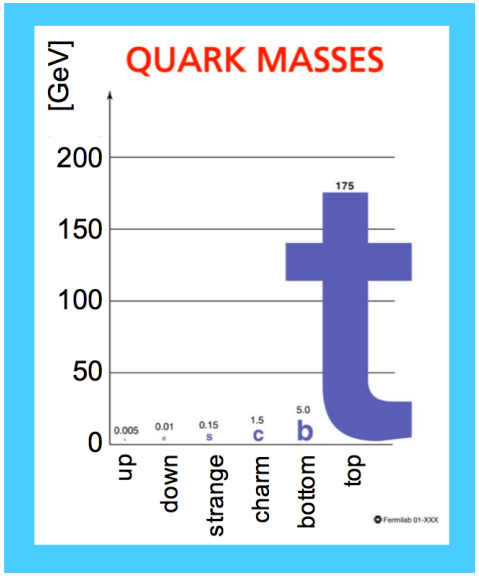
Phenomenology 2015

May 5th, 2015

Top Quark Physics

- Discovered at Tevatron in 1995 PRL 74, 2626 / PRL 74, 2632
- ... with surprisingly large mass
  - $m_{\text{top}} \sim m(\text{gold atom})$
  - m_{top} close to electroweak symmetry breaking scale
  - Largest Yukawa coupling to Higgs: $y_t \approx 1$
- and very short lifetime
  - Decays before hadronizing
  - Allows access of bare quark from decay products

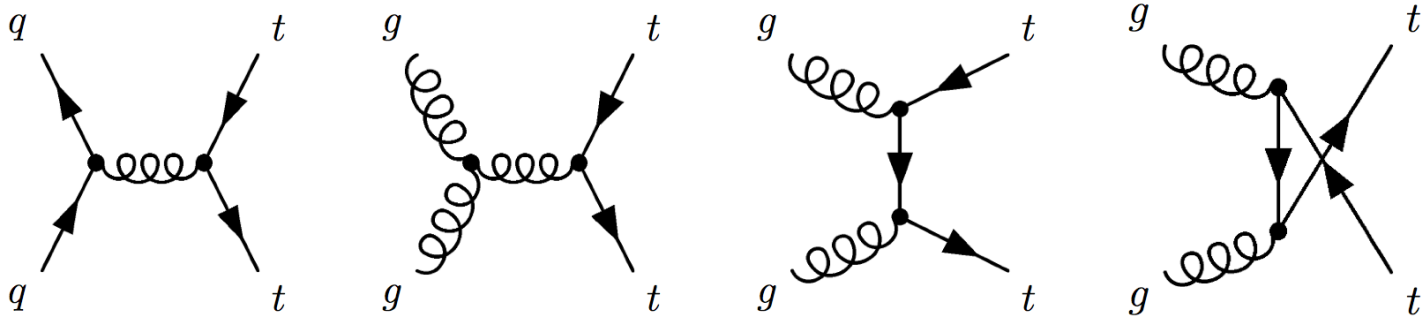


- Production rates and other properties test the Standard Model
  - Background to Higgs production and possibly new physics
  - If new physics is there, possible direct/indirect couplings to tops

A window to new physics

Top quark pair production

- $t\bar{t}$ produced via strong interaction at the LHC, mainly by gluon fusion



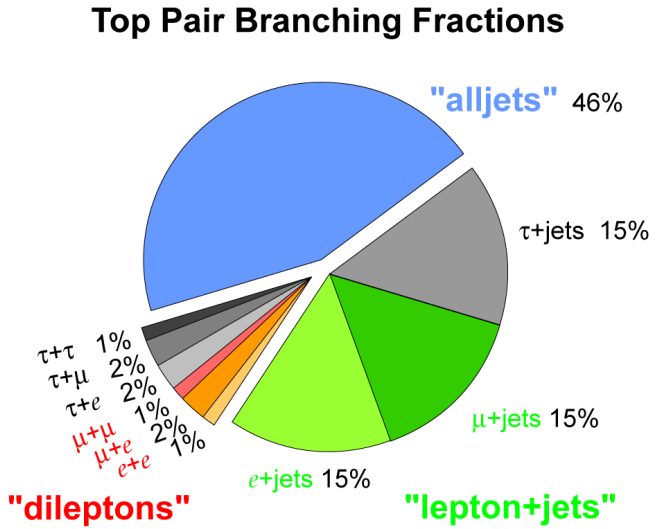
- Theory QCD precision:
  NNLO+NNLL soft gluon resummation

$$\sigma_{pp\to t\bar{t}}(7\ \text{TeV}) = 177^{+10}_{-11}\text{pb}$$
$$\sigma_{pp\to t\bar{t}}(8\ \text{TeV}) = 253^{+13}_{-15}\text{pb}$$

(at m_{top}=172.5 GeV)

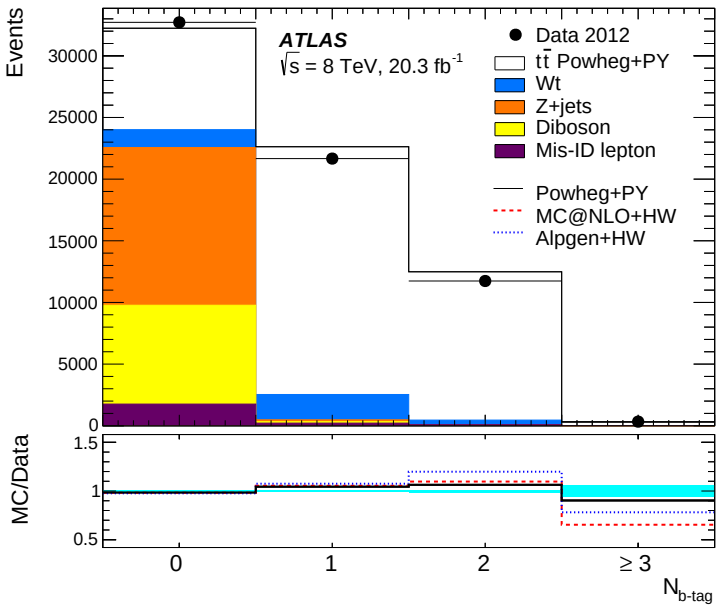
Czakon, Mitov, Fiedler, PRL 110 (2013) 252004

- Decay channels:



Inclusive $t\bar{t}$ cross section at 7TeV and 8TeV: $e\mu$

Eur.Phys.J. C74 (2014) 3109



- Require: opposite-charge $e\mu$; 4.6fb^{-1}at 7TeV, 20.3fb^{-1}at 8TeV
- Events with one or two b-tagged jets
- Simultaneous determination of $\sigma_{t\bar{t}}$ and b-jet reconstruction efficiency to minimize systematic uncertainties
- Also extracts m_{top}^{pole} and sets limits on direct stop pair production

- The most precise result in ATLAS

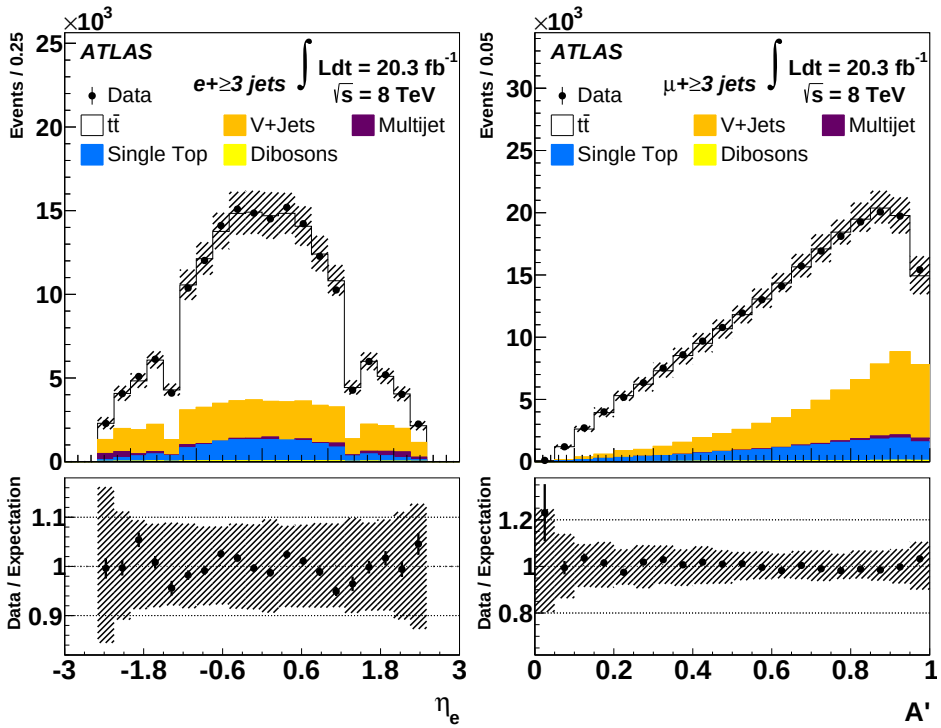
$$\sigma_{t\bar{t}} = 182.9 \pm 3.1(\text{stat}) \pm 4.2(\text{syst}) \pm 3.6(\text{lumi}) \pm 3.3(\text{beam})\text{pb}(\sqrt{s} = 7\ \text{TeV})$$
$$\sigma_{t\bar{t}} = 242.4 \pm 1.7(\text{stat}) \pm 5.5(\text{syst}) \pm 7.5(\text{lumi}) \pm 4.2(\text{beam})\text{pb}(\sqrt{s} = 8\ \text{TeV})$$

Good agreement with QCD NNLO+NNLL calculations

Inclusive $t\bar{t}$ cross section at 8TeV: l+jets, 20.3fb^{-1}

arXiv:1504.04251: Submitted

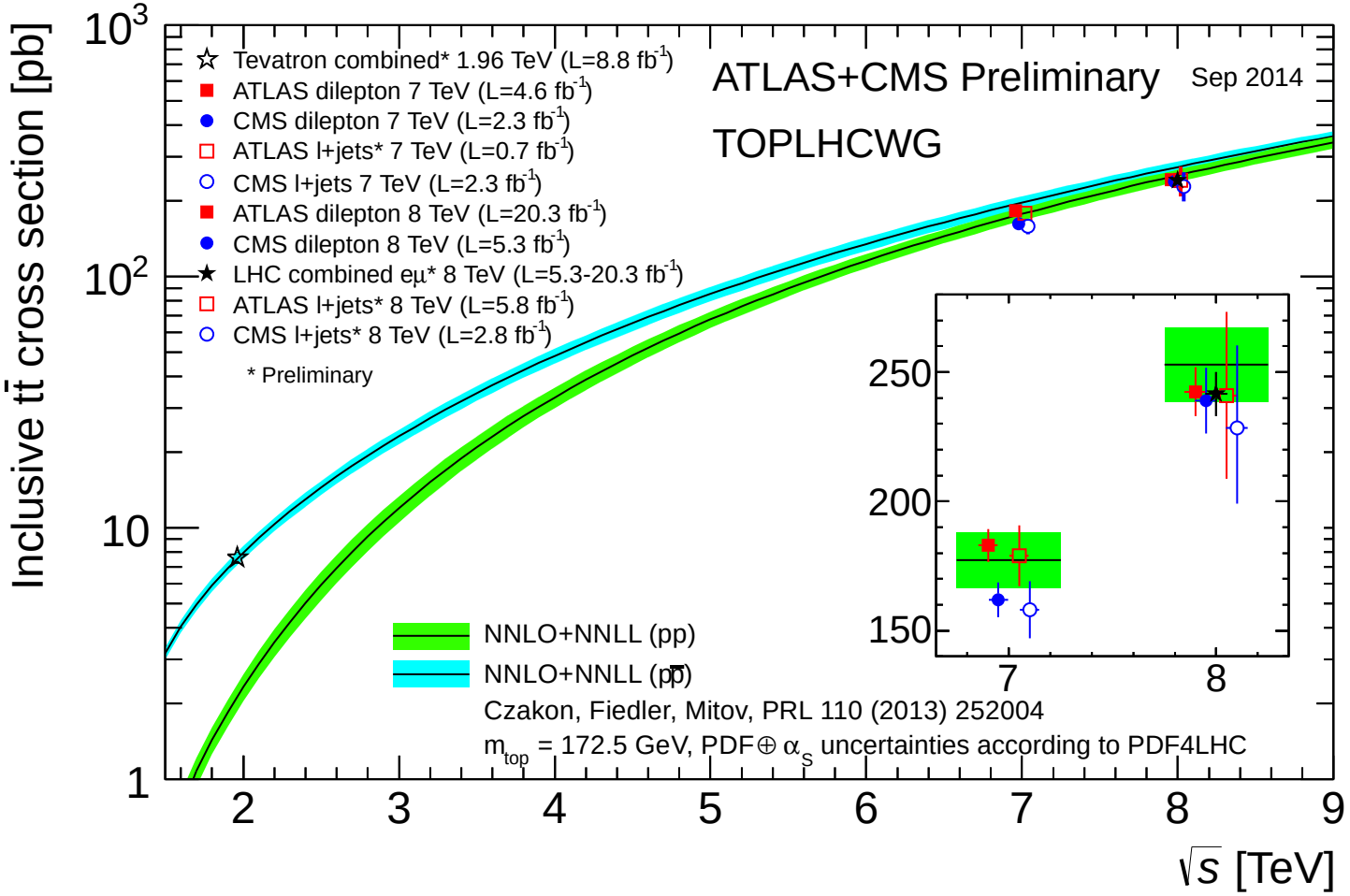
- Require: ℓ+jets, ℓ=e or μ
- Use a likelihood discriminant variable built from lepton η_ℓ and transformed aplanarity $\mathcal{A}'$
- Templates fit to binned likelihood discriminant in data
- Systematics dominated by $t\bar{t}$ MC modeling
- Fiducial $\sigma_{t\bar{t}}^{\text{fid}}$ is also measured



$$\sigma_{t\bar{t}} = 260 \pm 1(\text{stat})^{+20}_{-21}(\text{syst}) \pm 8(\text{lumi}) \pm 4.0(\text{beam})\text{pb}$$

Summary of inclusive $t\bar{t}$ cross sections

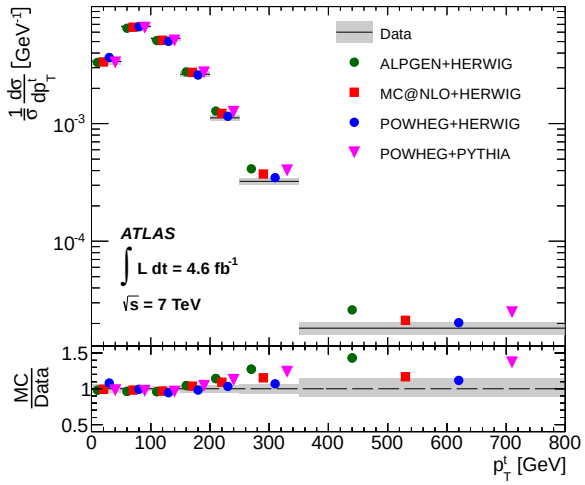
All $\sigma_{t\bar{t}}$ measurements agree well with theory predictions

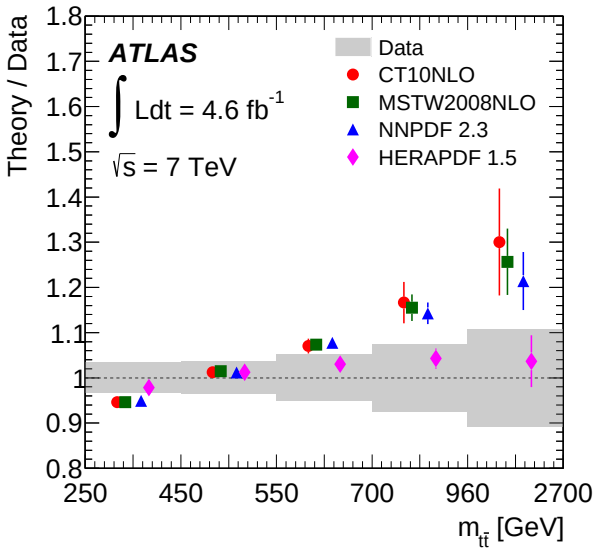


Differential measurements at 7TeV: resolved tops (ℓ+jets)

Phys. Rev. D 90, 072004

- Normalized $t\bar{t}$ differential cross section measurement
  - as a function of p_{T}^{t} and $m_{t\bar{t}}$, $p_{\mathrm{T}}^{t\bar{t}}$ and $|y_{t\bar{t}}|$
  - unfolded to top parton, full phase space
- LO and NLO MCs generally harder than data, increasing with p_{T}
- Data is softer than both QCD NLO and NLO+NNLL calculations in high p_{T}^{t} and high $m_{t\bar{t}}$
- Data also compared to various NLO PDFs using MCFM (LO)
  - HERAPDF1.5 best describes data in high p_{T}^{t} and $m_{t\bar{t}}$
- Main systematics:
  - JES, JER, I/FSR, PS, MC modeling

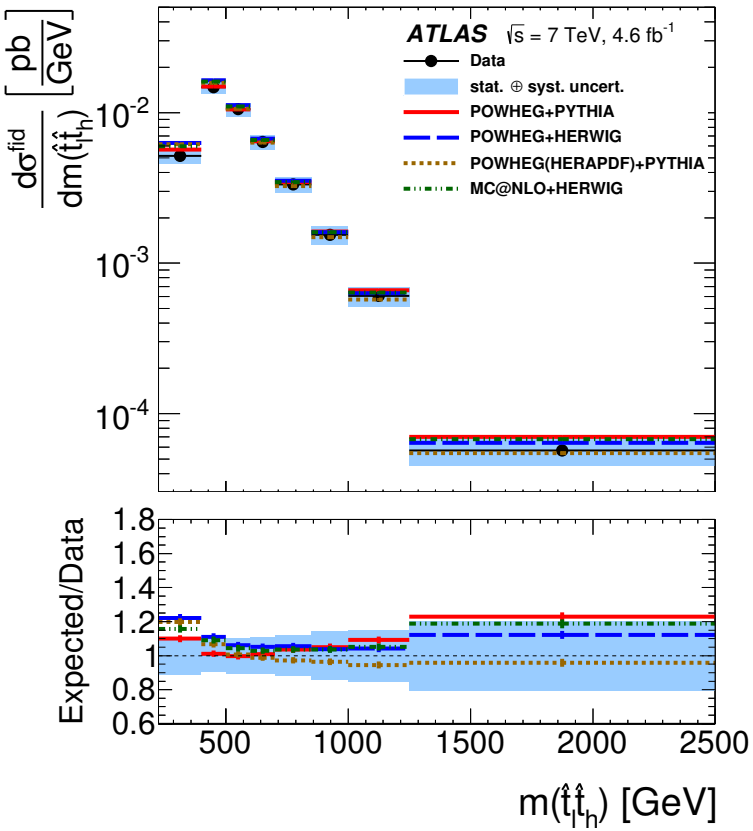




Differential measurements at 7TeV: pseudo tops (ℓ+jets)

arXiv:1502.05923: Submitted

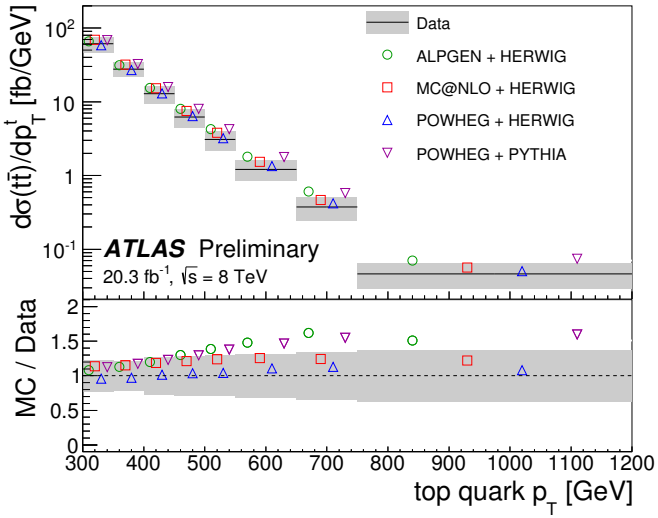
- Novel $t\bar{t}$ differential cross section measurement using pseudo-top $\hat{t}$
  - $\hat{t}$: top-proxy reconstructed from detector-level or particle-level objects
  - fiducial measurement minimizes modeling dependence
  - as a function of $p_{\mathrm{T}}^{\hat{t}}$ and $|y_{\hat{t}}|$ of leptonic and hadronic pseudo-top; $p_{\mathrm{T}}^{\hat{t}\bar{\hat{t}}}$, $|y_{\hat{t}\bar{\hat{t}}}|$ and $m_{\hat{t}\bar{\hat{t}}}$ of pseudo-top pair system
- Similar conclusions to parton level distributions, with lower total uncertainties
- Main systematics: b-tagging, JES, I/FSR, PS, MC modeling

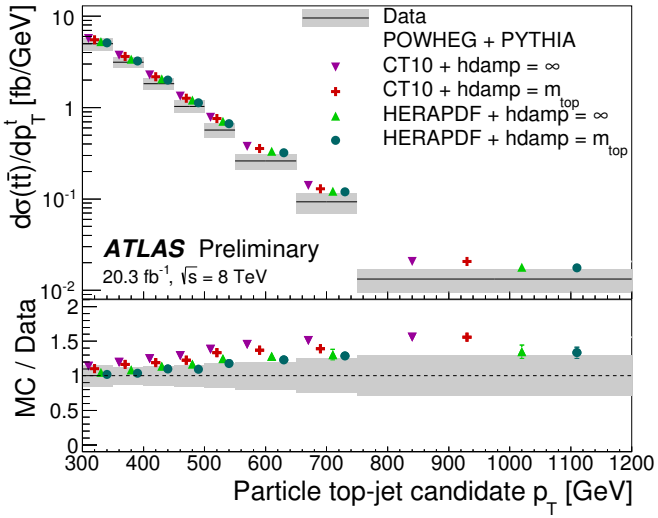


Differential measurements at 8TeV: boosted tops (ℓ+jets)

ATLAS-CONF-2014-057

- First boosted top pair differential cross section measurement
  - as a function of hadronic top p_{T}, with $p_{\mathrm{T}} > 300$ GeV
  - *Jet substructure techniques* using anti-k_t jet with R=1.0
  - Measured at fiducial particle level and full phase-space parton level
- LO and NLO MCs generally harder than data, increasing with p_{T}
  - HERAPDF with limited hard radiations (h_{damp}) best describes data
- Precision gained in particle level distributions



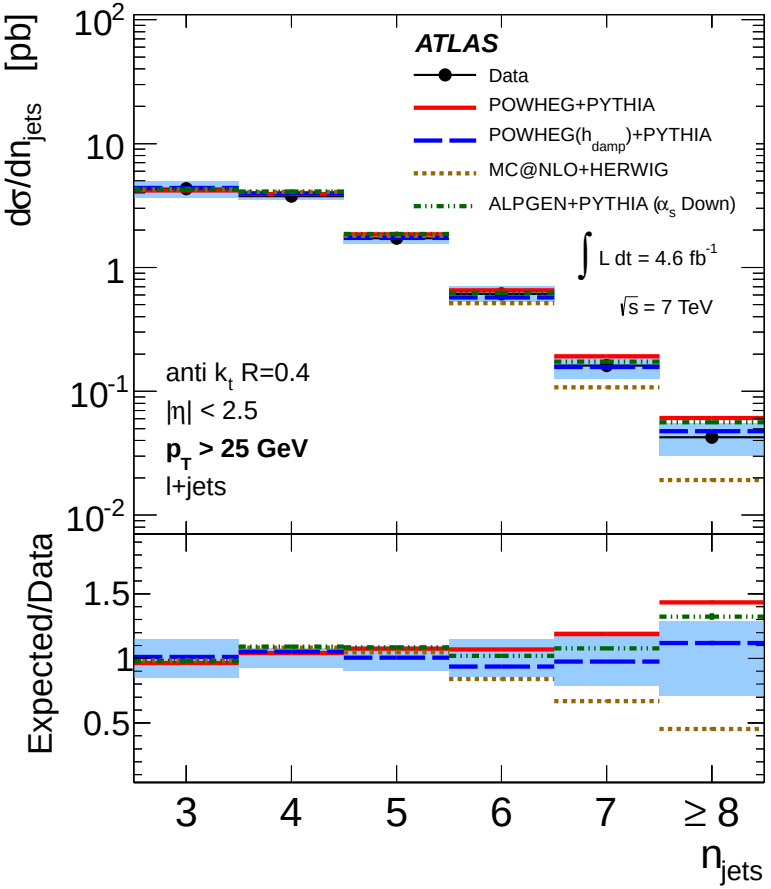


- Main systematics: large-R JES, signal modeling (at parton-level)

$t\bar{t}$+jets measurement at 7TeV (ℓ+jets, 4.6fb^{-1})

JHEP01(2015)020

- $t\bar{t}$ differential cross section as a function of jet multiplicity and jet p_{T}
  - Several jet p_{T} thresholds
- Sensitivity to PS modeling at high jet multiplicities
- Compared to LO and NLO MCs
  - POWHEG+PYTHIA with limited hard radiations (h_{damp}): MC best describes data
  - MC@NLO+HERWIG: predicts too few events at high jet multiplicities
- Main systematics:
  - JES, b-tagging, I/FSR



$t\bar{t}+\gamma$ and $t\bar{t}$+V, V=W or Z measurements

Phys Rev D 91 072007 (2015)

- 7TeV: photon $E_{\mathrm{T}} > 20$ GeV, ℓ+jets; 4.59fb^{-1}
- Observed number of events and fiducial cross section measurement

Observation of $t\bar{t}\gamma$: 5.3σ

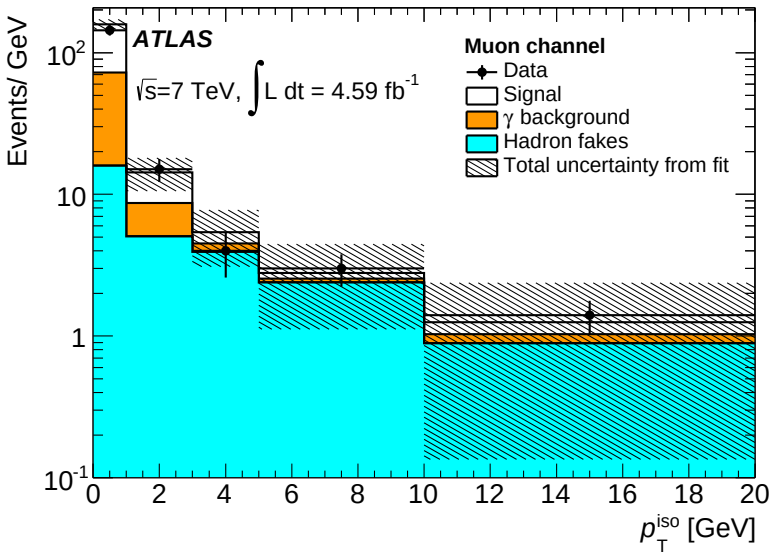
$\sigma^{\mathrm{fid}}_{t\bar{t}\gamma}$xBR in agreement with NLO predictions

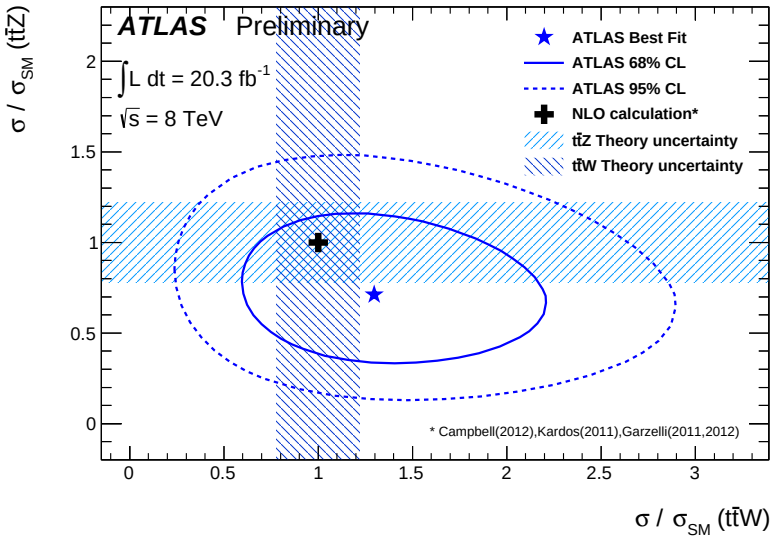
ATLAS-CONF-2014-038

- 8TeV: $2l$ (SS), $2l$ (OS), $3l$; 20.3fb^{-1}
- Measured signal strengths of $t\bar{t}Z$ and $t\bar{t}W$

Evidence of $t\bar{t}Z$ and $t\bar{t}W$: 4.9σ

$\mu_{t\bar{t}W,Z}$ consistent with NLO QCD calculations





Conclusions

- Top quark pair production measurements in ATLAS have reached precision levels that put the SM to test. The most precise measurement in inclusive $t\bar{t}$ cross section is more precise than theoretical precision.
- Differential measurements of $t\bar{t}$ production in top p_{T} and other kinematics provide constraints to improve MC modeling and parameter tuning in $t\bar{t}$ production.
- Measurements of $t\bar{t}$ production in association with gauge bosons are consistent with the SM.
- With new techniques for selecting high-p_{T} top pairs, ATLAS is ready for more top physics in the TeV regime.

Extra slides

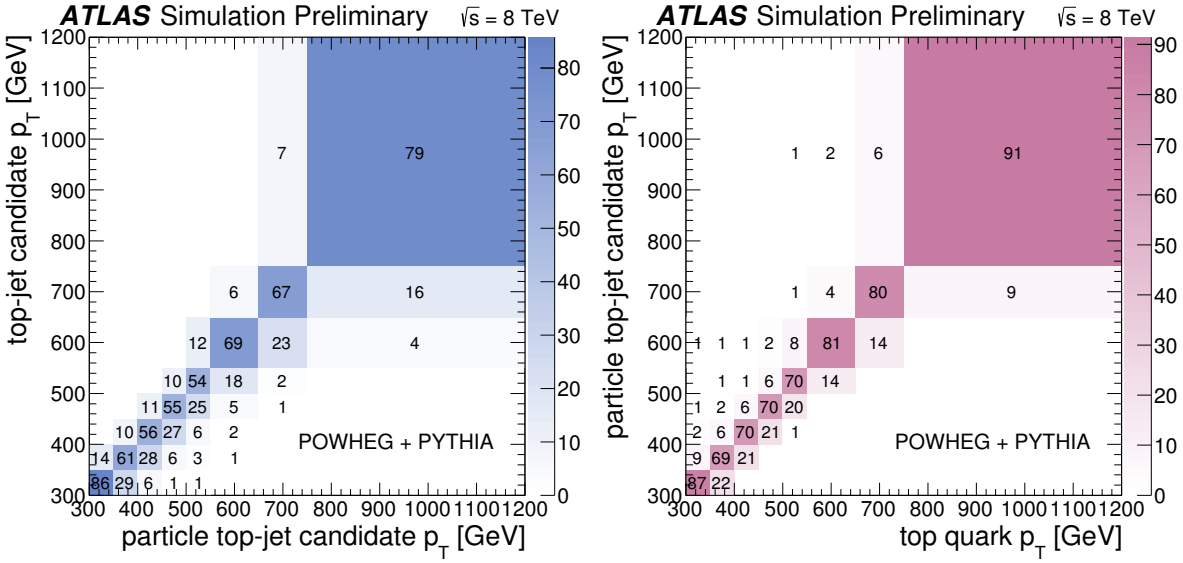
ATLAS Top public results

All results shown can be found in the following page:

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults

Differential $t\bar{t}$ cross section measurements

- Boosted tops (8TeV) and resolved tops (7TeV)
- Unfolding to particle level (in fiducial region) and parton level (extrapolated to full phase space)
- As a function of kinematic properties of t and $t\bar{t}$
- Compared to LO and NLO MC generators
- Compared to NLO QCD calculations

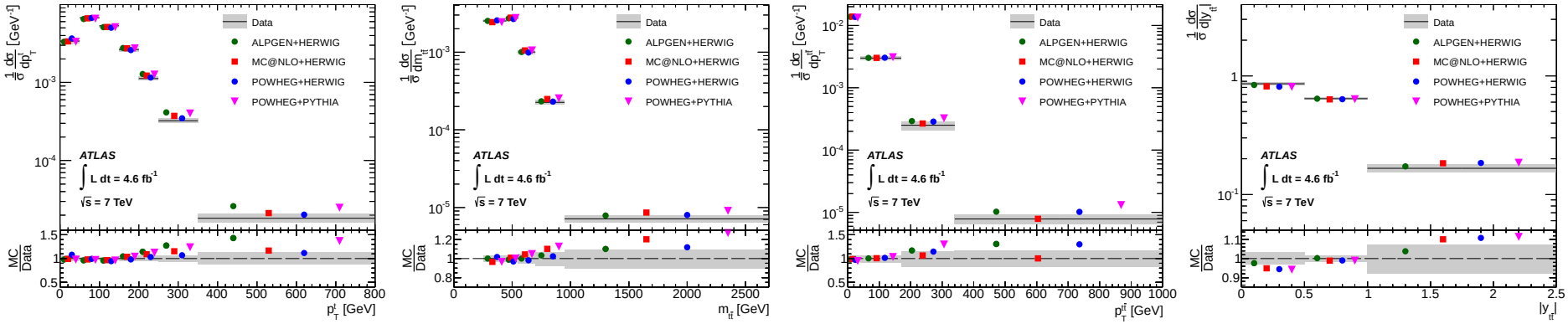


ATLAS-CONF-2014-057

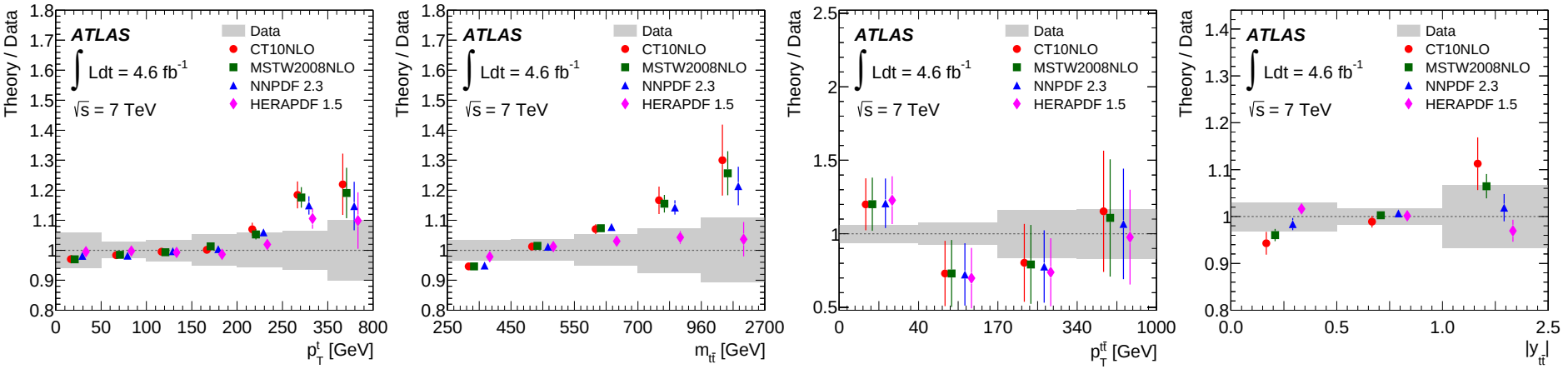
Comparison to MCs and PDFs

Phys. Rev. D 90, 072004

MCs:

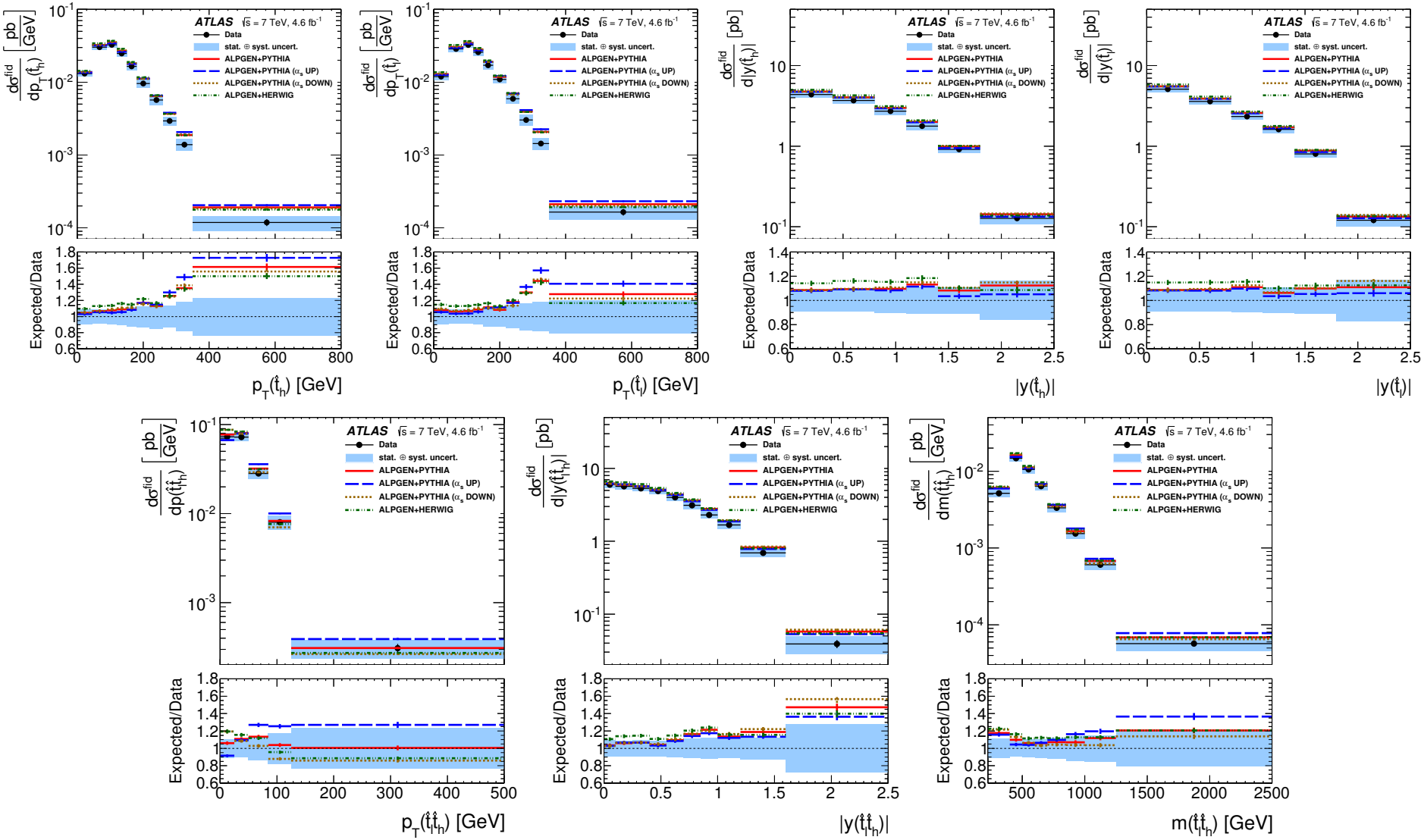


PDFs:



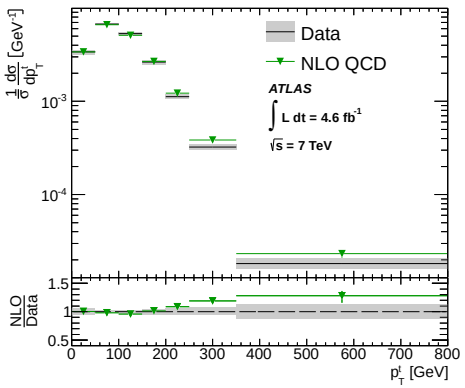
Comparison to MC LO

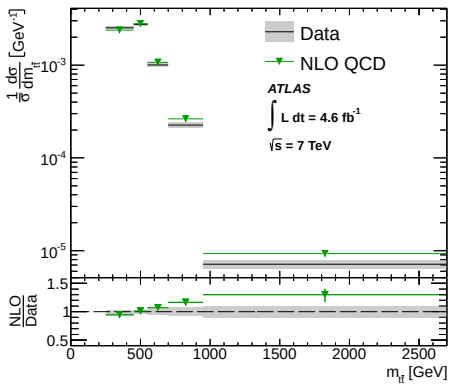
arXiv:1502.05923: Submitted

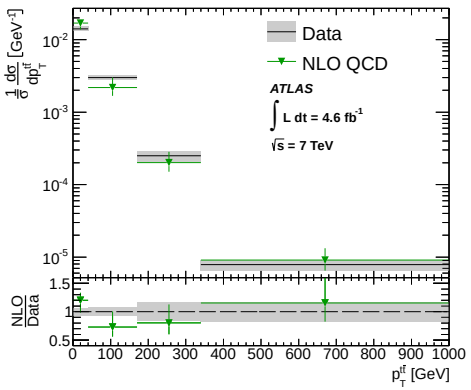


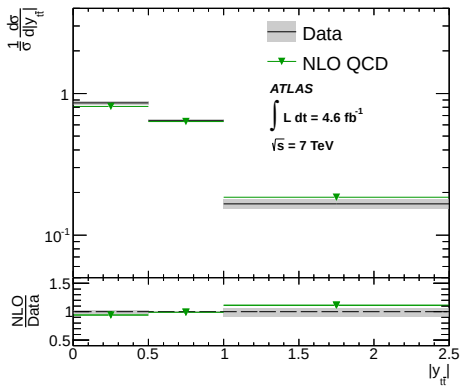
Comparison to NLO QCD calculations

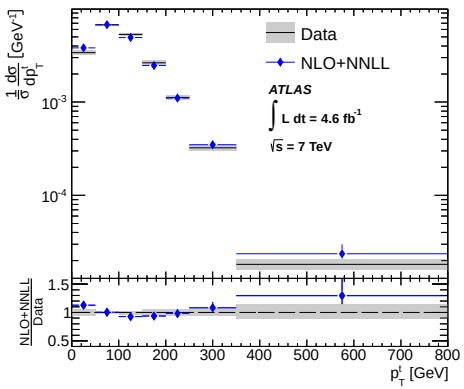
Phys. Rev. D 90, 072004, ATLAS-CONF-2014-057

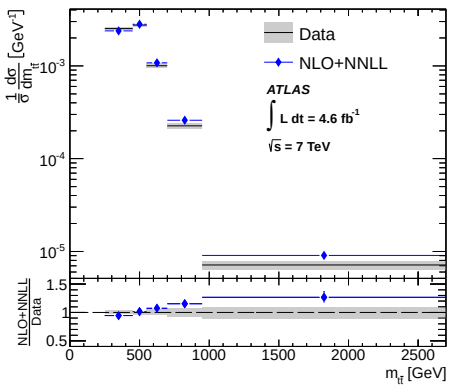


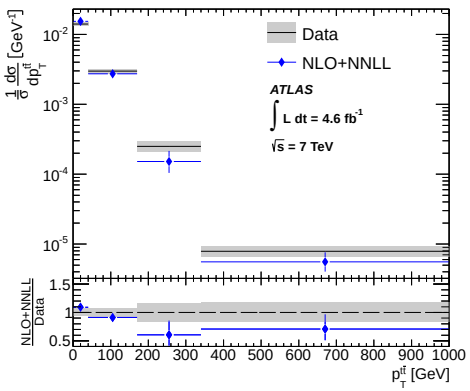


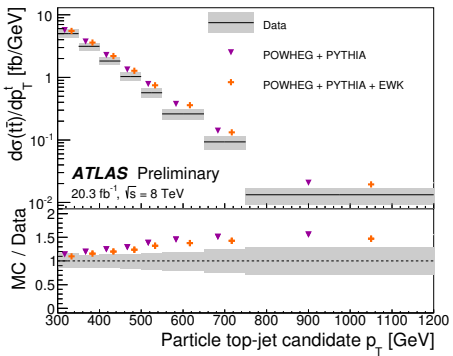


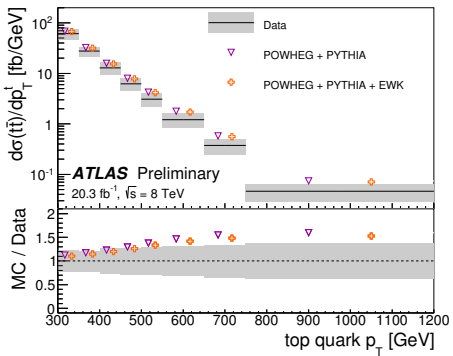


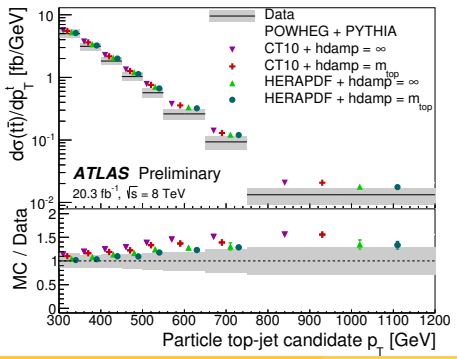


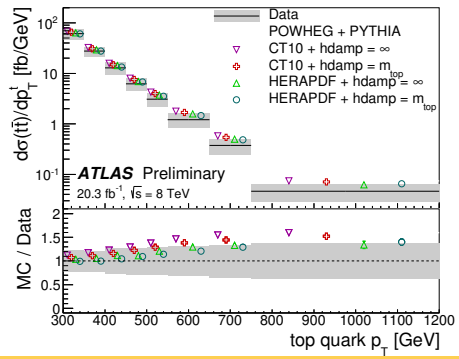










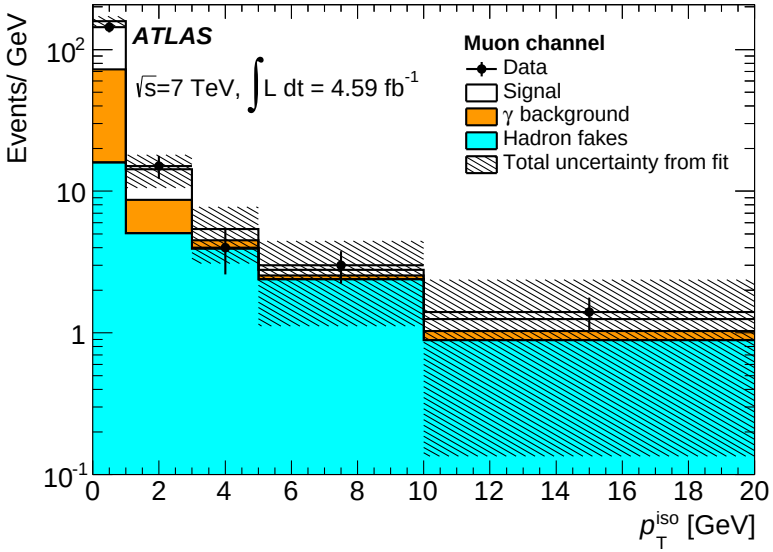


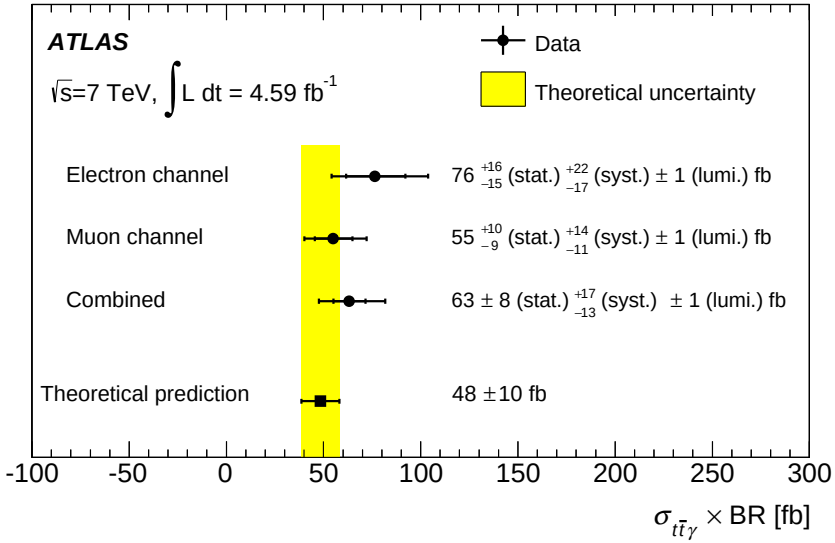
$t\bar{t}+\gamma$ measurement at 7TeV: ℓ+jets

Phys Rev D 91 072007 (2015)

- Require: photon with $E_{\mathrm{T}} > 20$ GeV, ℓ+jets; 4.59fb^{-1}
- Observation + fiducial cross section measurement
- Extract fiducial cross section by template fit to the photon track isolation distribution p_{T}^{iso}

Observation of $t\bar{t}\gamma$: 5.3σ ($\sigma^{\mathrm{fid}}_{t\bar{t}\gamma}$xBR=63$\pm$8(stat.)$^{+17}_{-13}$(syst.)$\pm$1(lumi.)fb)
Measurement in agreement with NLO predictions





$t\bar{t}$+V, V=W or Z measurement at 8TeV

ATLAS-CONF-2014-038

- Search in 3 channels: $2l$ (SS), $2l$ (OS), $3l$; 20.3fb^{-1}
- First evidence of $t\bar{t}Z$, $t\bar{t}W$: $t\bar{t}V$, 4.9σ excess over bkg, $\mu_{t\bar{t}V} = 0.89^{+0.23}_{-0.22}$
- Simultaneous measurement of $t\bar{t}Z$ and $t\bar{t}W$ signal strengths: $\mu_{t\bar{t}Z} = 0.71^{+0.28}_{-0.26}$, $\mu_{t\bar{t}W} = 1.30^{+0.59}_{-0.48}$, overall significance: 3.1σ for both $t\bar{t}Z$ and $t\bar{t}W$

Measurement consistent with NLO QCD calculations