Top quark production measurements using the ATLAS detector at the LHC

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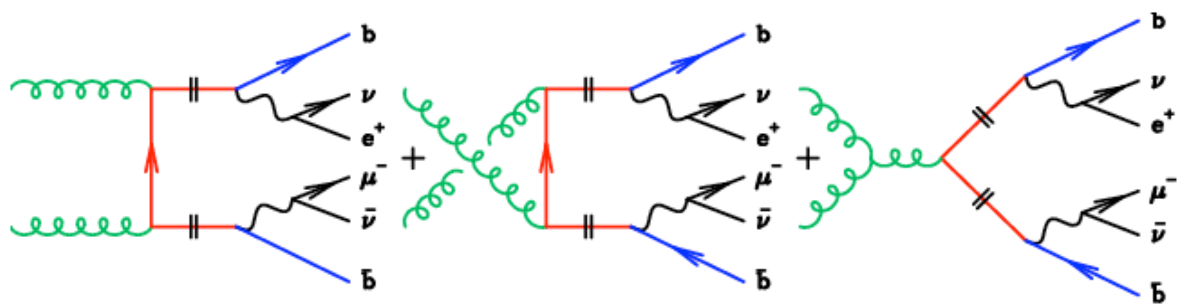
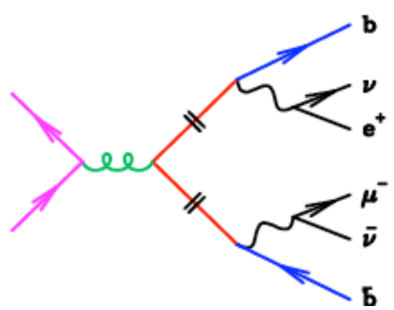
on behalf of the ***ATLAS*** Collaboration

Tests of QCD (and beyond)

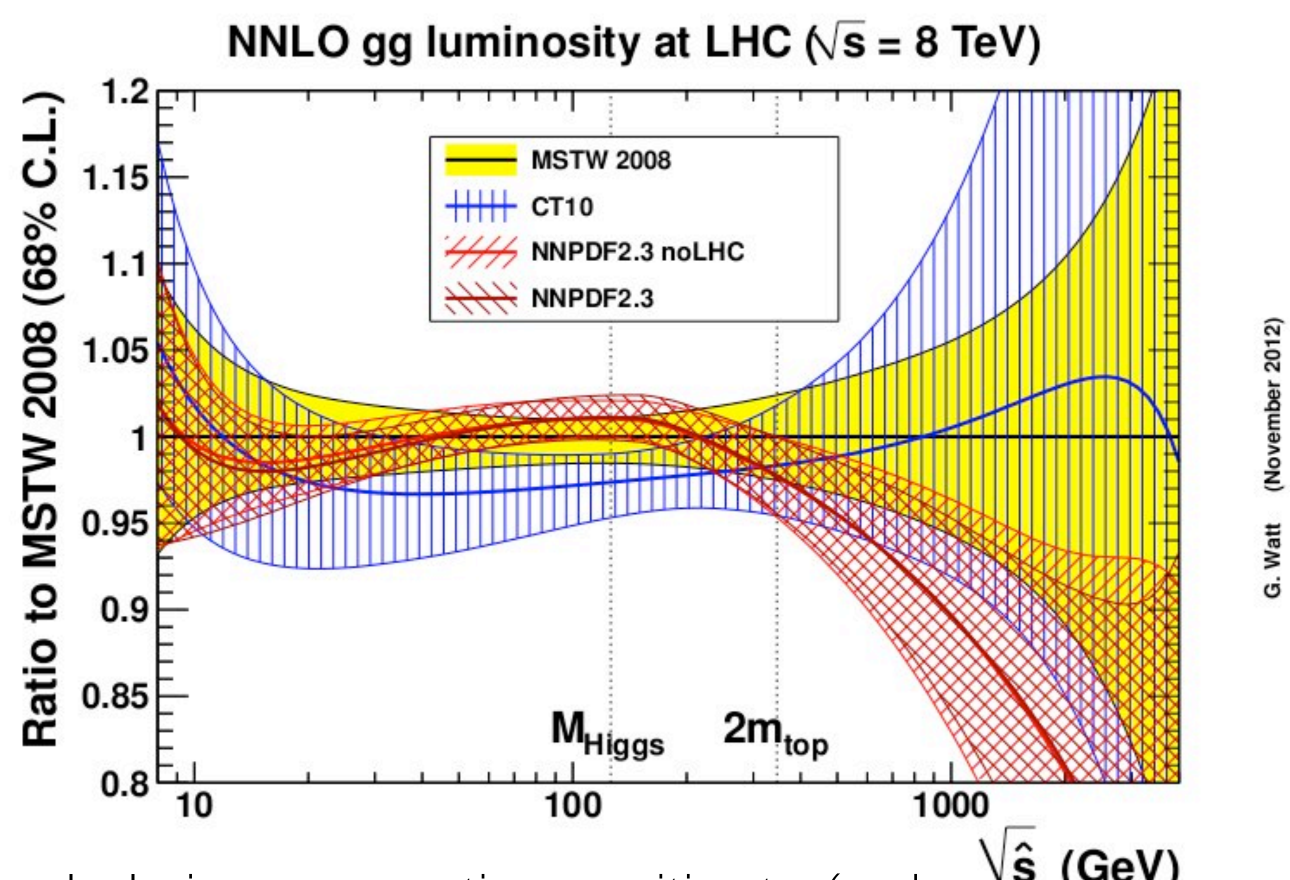


gluon initiated dominant in QCD at LHC E_{cm}



tests perturbative QCD and (gluon) PDF in proton

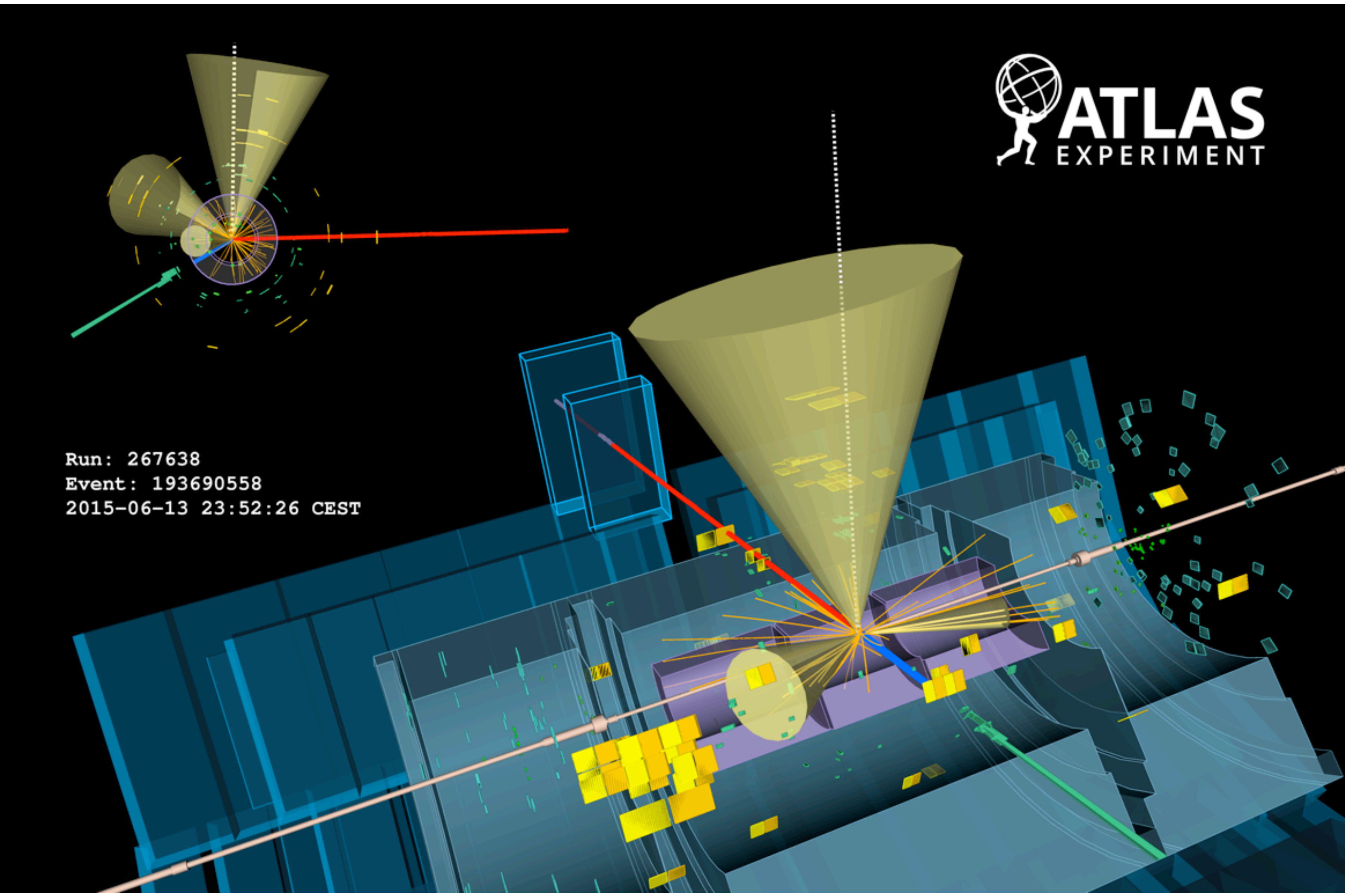
Furthermore, differential cross-sections validate Monte Carlo simulations and could show deviations from predictions



Inclusive cross-section sensitive to (and improves, e.g. arXiv:1303.7215) PDF fits

Integrated x-sec at 13 TeV

- Both di-leptonic and l+jets channels have been used to extract integrated σ_{ttbar}
- L=78-85 pb^{-1} worth of data from last summer
- e+μ *analysis described in the following as an example*



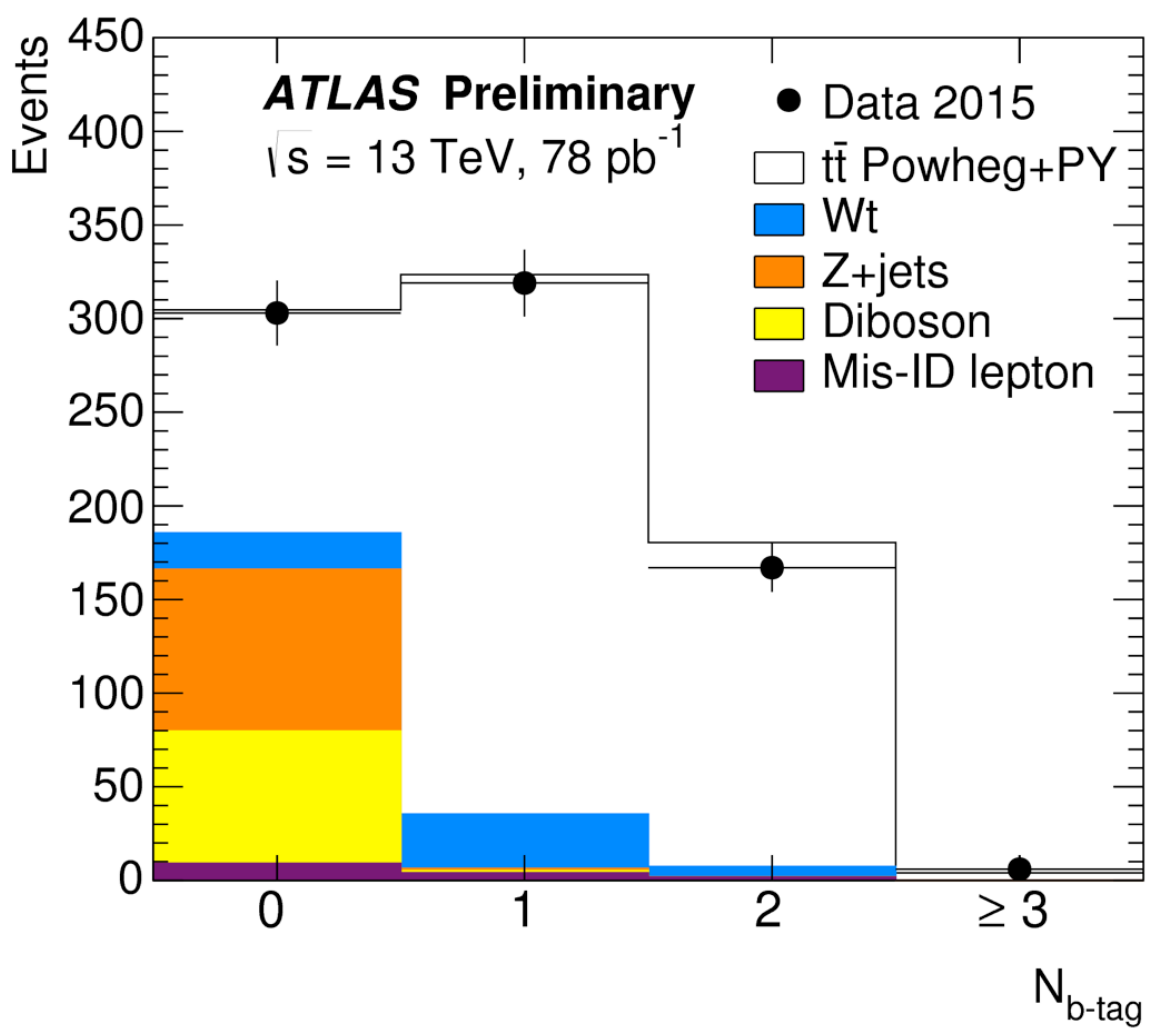
Di-leptonic ttbar candidate event from proton-proton collisions recorded by ATLAS with LHC stable beams at a collision energy of 13 TeV.
2 jets in this event are identified as containing b quarks

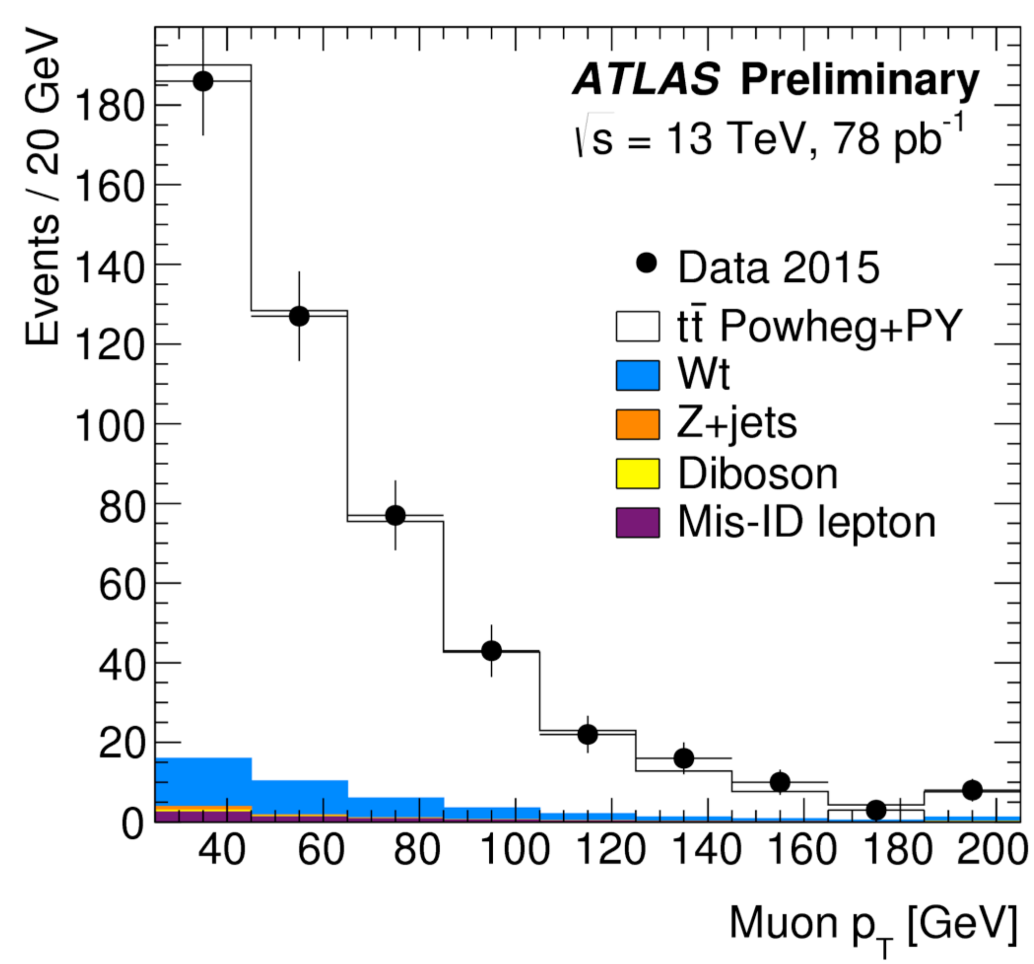
l+j and e+e/μ+μ: ATLAS-CONF-2015-033

e+μ: ATLAS-CONF-2015-049

Particle and event selections

- e: E_T>25 GeV, |η|<2.47, no activity around it in either calorimetry and tracker (e in jets)
- μ: p_T>25 GeV, |η|<2.5, no activity around it in either calorimetry and tracker (μ in jets)
- Jets reconstructed with anti-$K_{T,\,R=0.4}$, p_T>25 GeV, |η|<2.5
- *b* quark identification run on jets, with eff(b)=70% and eff(LF,g) =1/440
- Accepting only $e^{\pm}\mu^{\mp}$ events and 1 or 2 b-tags (ignoring presence of other untagged jets)





e+μ: ATLAS-CONF-2015-049

Backgrounds

Event counts	N_1	N_2
Data	319	167
Wt single top	29.0 ± 3.8	5.6 ± 2.0
Dibosons	1.1 ± 0.2	0.0 ± 0.0
$Z(\to \tau\tau \to e\mu)$+jets	1.3 ± 0.7	0.1 ± 0.1
Misidentified leptons	6.0 ± 3.9	2.8 ± 2.9
Total background	37.3 ± 5.5	8.5 ± 3.5

N_1=1 b-tag
N_2=2 b-tags

$$N_1 = L\sigma_{t\bar{t}}\,\epsilon_{e\mu} 2\epsilon_b(1 - C_b\epsilon_b) + N_1^{\mathrm{bkg}}$$
$$N_2 = L\sigma_{t\bar{t}}\,\epsilon_{e\mu} C_b {\epsilon_b}^2 + N_2^{\mathrm{bkg}}$$

From MC simulations, with overall normalization taken from:
W+t: Phys. Rev. D 82 (2010) 054018 (5% unc)
Dibosons: Sherpa (10% unc)
Z+jets: Powheg+Pythia (50/100% in 1/2 b-tags from data validation)

From data:
using same-charged e+μ, highly enriched in fake or secondary leptons from HF decays

➡ Measurements in l+jets and same-flavour di-leptonic final states in Run 1 and Run 2 have used a variety of data-based methods, primarily "Matrix Method" and "ABCD"

Systematic uncertainties

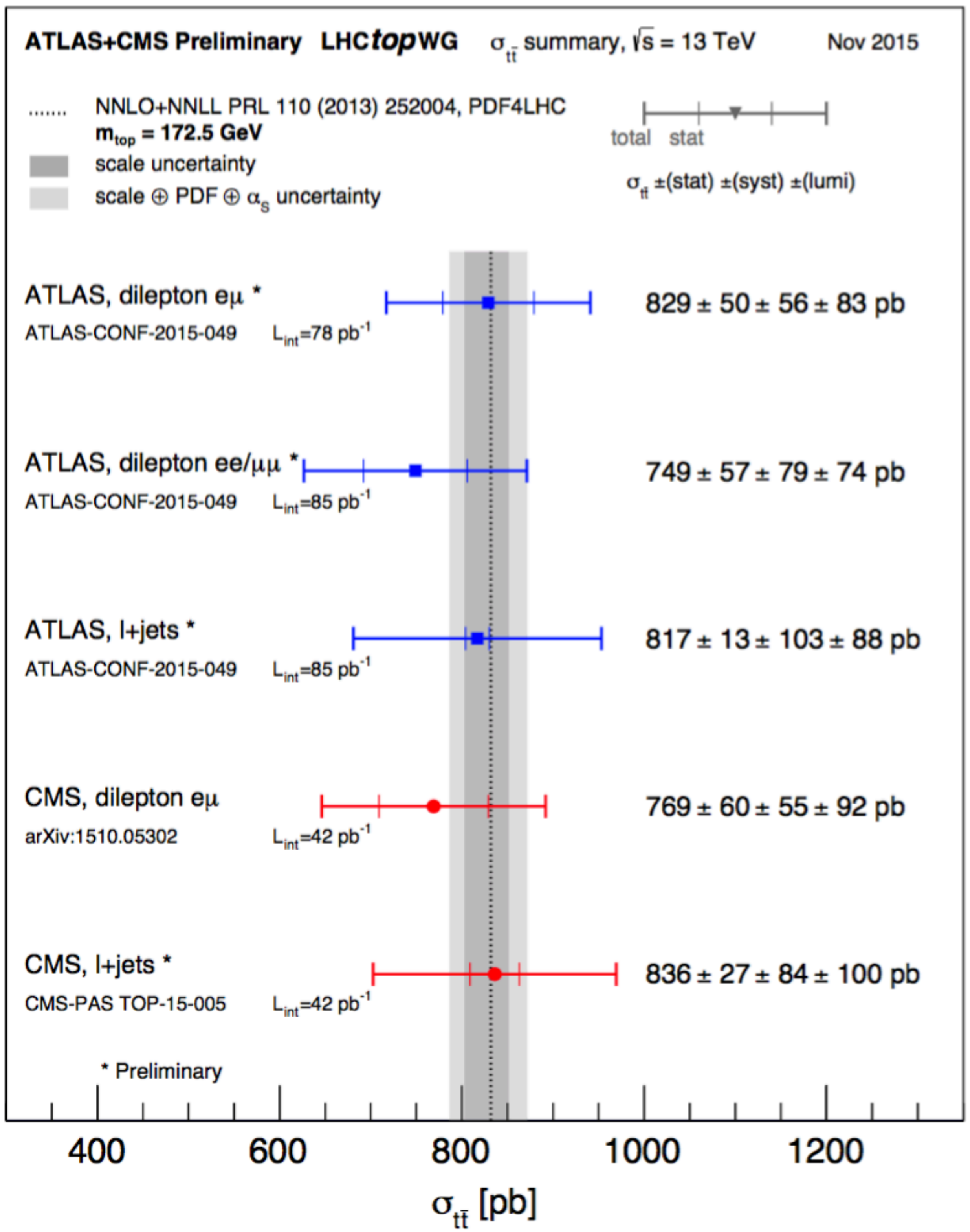
Jul15

Uncertainty	$\Delta\epsilon_{e\mu}/\epsilon_{e\mu}$ (%)	$\Delta C_b/C_b$ (%)	$\Delta\sigma/\sigma$ (%)
Data statistics			6.0
NLO modelling	1.9	-0.3	2.2
hadronisation	-4.0	0.5	4.5
Initial/final state radiation	-1.1	0.1	1.2
Parton distribution functions	1.3	-	1.4
Single-top generator*	-	-	0.5
Single-top/ interference*	-	-	0.1
Single-top Wt cross-section	-	-	0.5
Diboson modelling*	-	-	0.1
Diboson cross-sections	-	-	0.0
Z+jets extrapolation	-	-	0.2
Electron energy scale/resolution	0.2	0.0	0.2
Electron identification	3.6	0.0	4.0
Electron isolation	1.0	-	1.1
Muon momentum scale/resolution	0.0	0.0	0.1
Muon identification	1.1	0.0	1.2
Muon isolation	1.0	-	1.1
Lepton trigger	1.3	0.0	1.3
Jet energy scale	-0.3	0.0	0.3
Jet energy resolution	-0.1	0.0	0.1
b-tagging	-	0.1	0.3
Misidentified leptons	-	-	1.3
Analysis systematics	6.4	0.6	7.3
Integrated luminosity	-	-	10.0
Total uncertainty	6.4	0.6	13.7

- Dominated by unc. on luminosity, now reduced to 5%
- Measurement equally affected by statistical and systematic uncertainties, but it will soon be the latter to dominate
- Relative impact very similar also for 8 TeV di-lep analysis
- Detector syst (i.e. Ele ID) have gone down already with more data

➡ Also l+jets channel exploited, see back-up

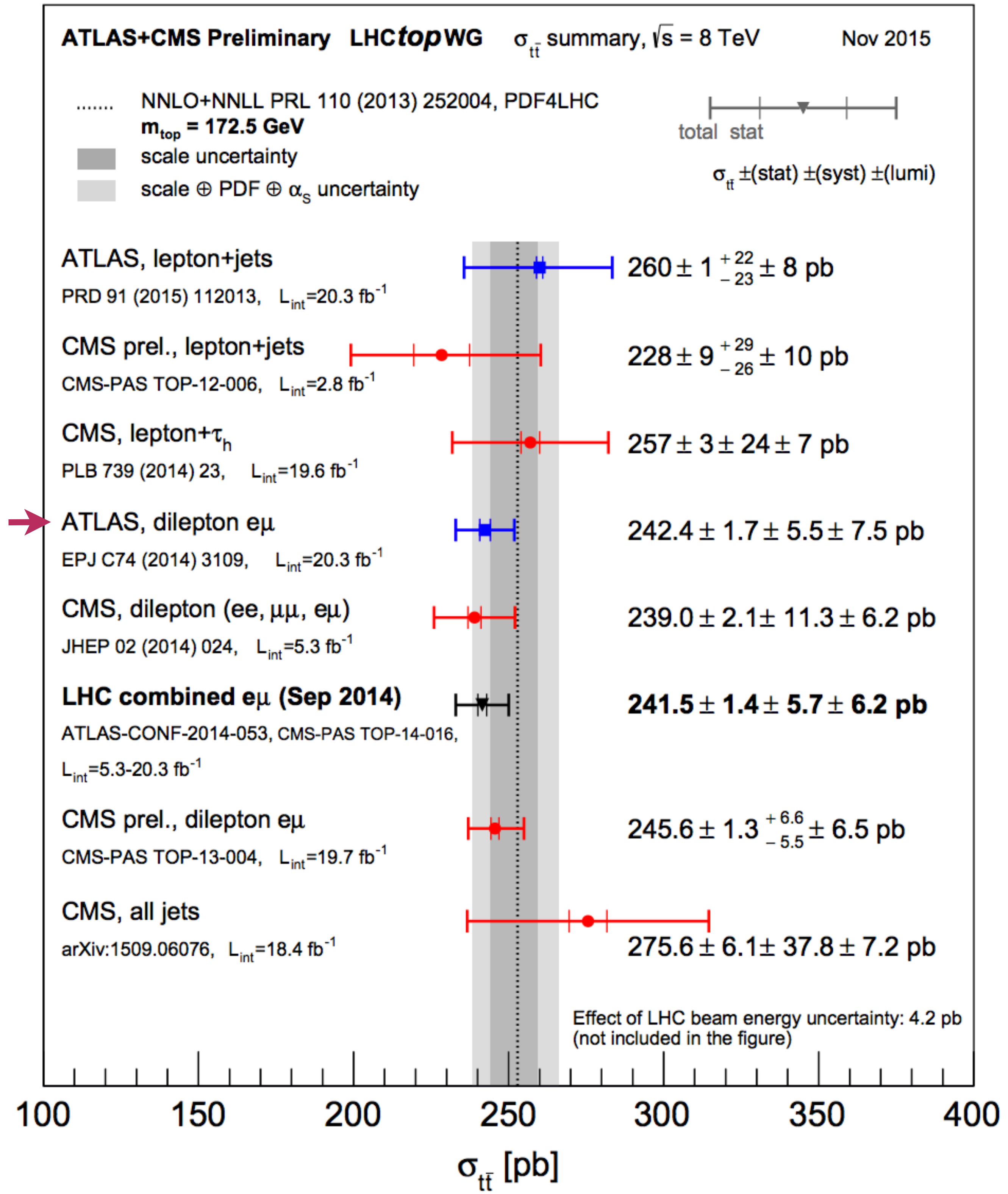
Integrated x-sec at 13 TeV



- Total inclusive cross section for top pair production in Run 2 at 13 TeV
- Tests QCD predictions using all available final states (di-lepton, l+jet and full had)
    - predictions exist at NNLO+ approx NNLL
- Table presents a summary of the **preliminary** ATLAS results
- e+μ channel is most precise one, with ~13.5% total rel unc

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCTopWGSummaryPlots

Integrated x-sec at 7 and 8 TeV

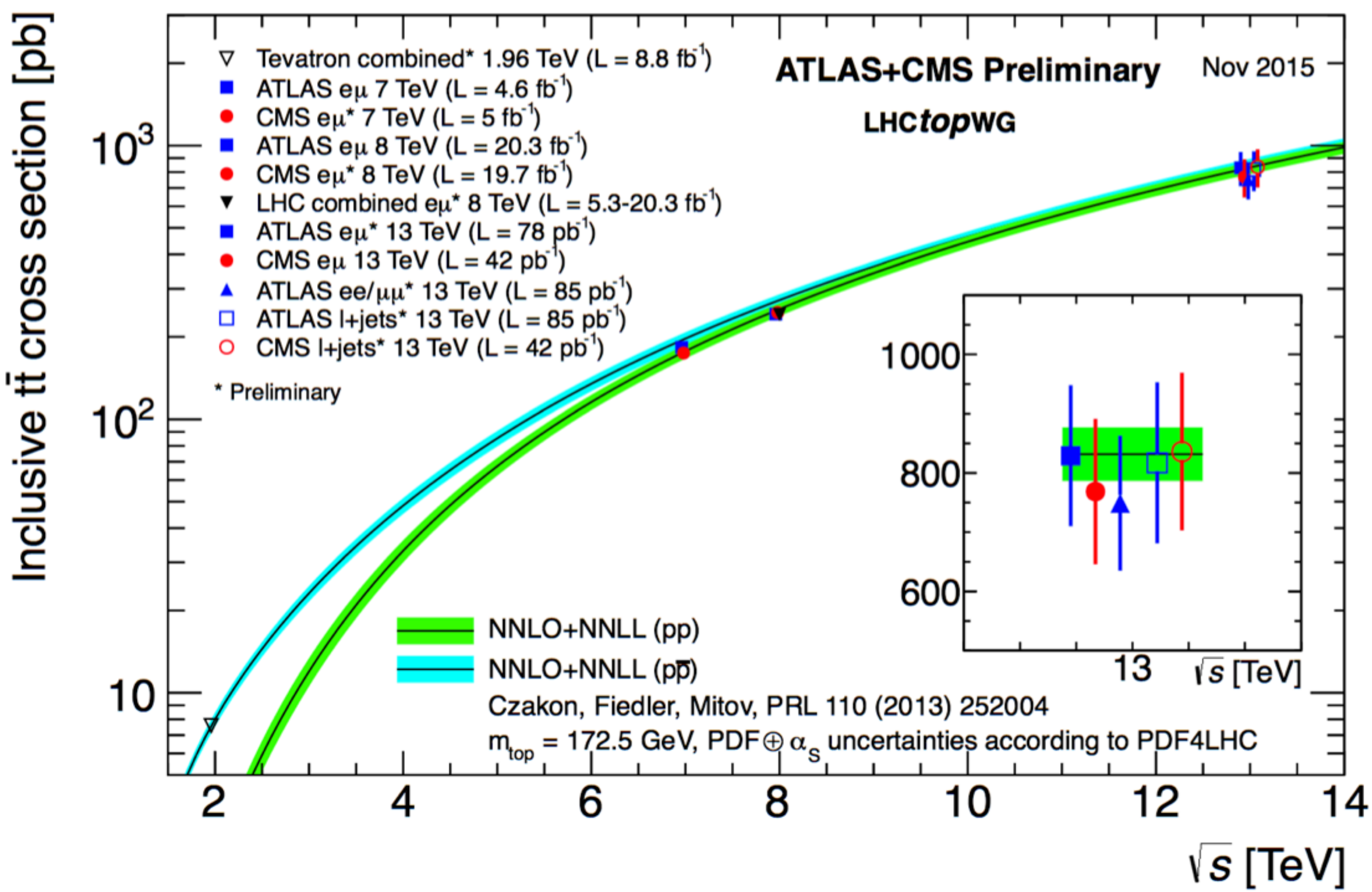


- ATLAS has measured the total inclusive cross section for top pair production in Run-1 with at 7, 8 TeV
- Tests QCD predictions using all available final states (di-lepton, l+jet and full had)
  - predictions exist at NNLO+ approx NNLL
- Table presents a summary of the results at: 8 TeV, Run 1
- Picture at 7 TeV similar to 8 TeV
- Average mainly driven by lepton channels
- Same experimental techniques as Run 2
- World most precise results are in e+μ channel (~3.9% total rel unc)
- Single ATLAS Measurement more precise than theory

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCTopWGSummaryPlots

The big picture

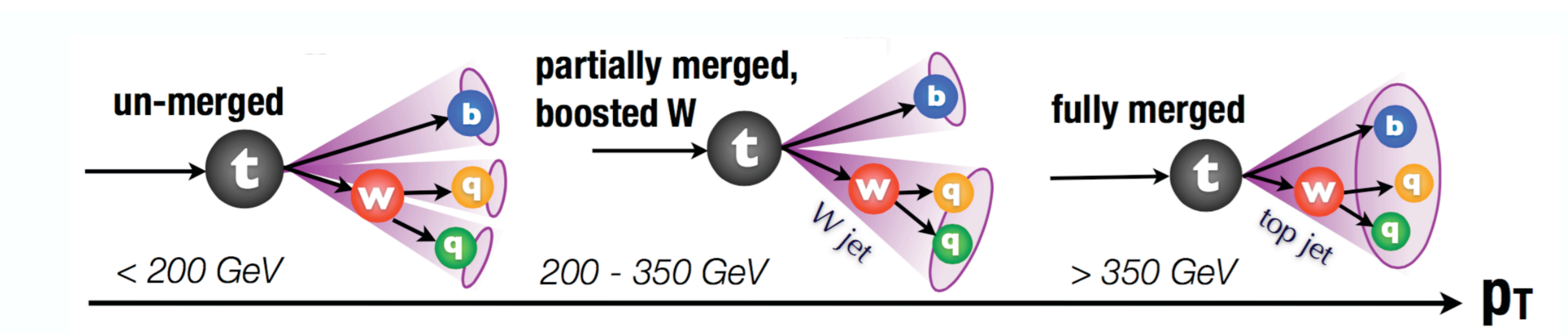
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCTopWGSummaryPlots



Rather remarkable agreement with theory

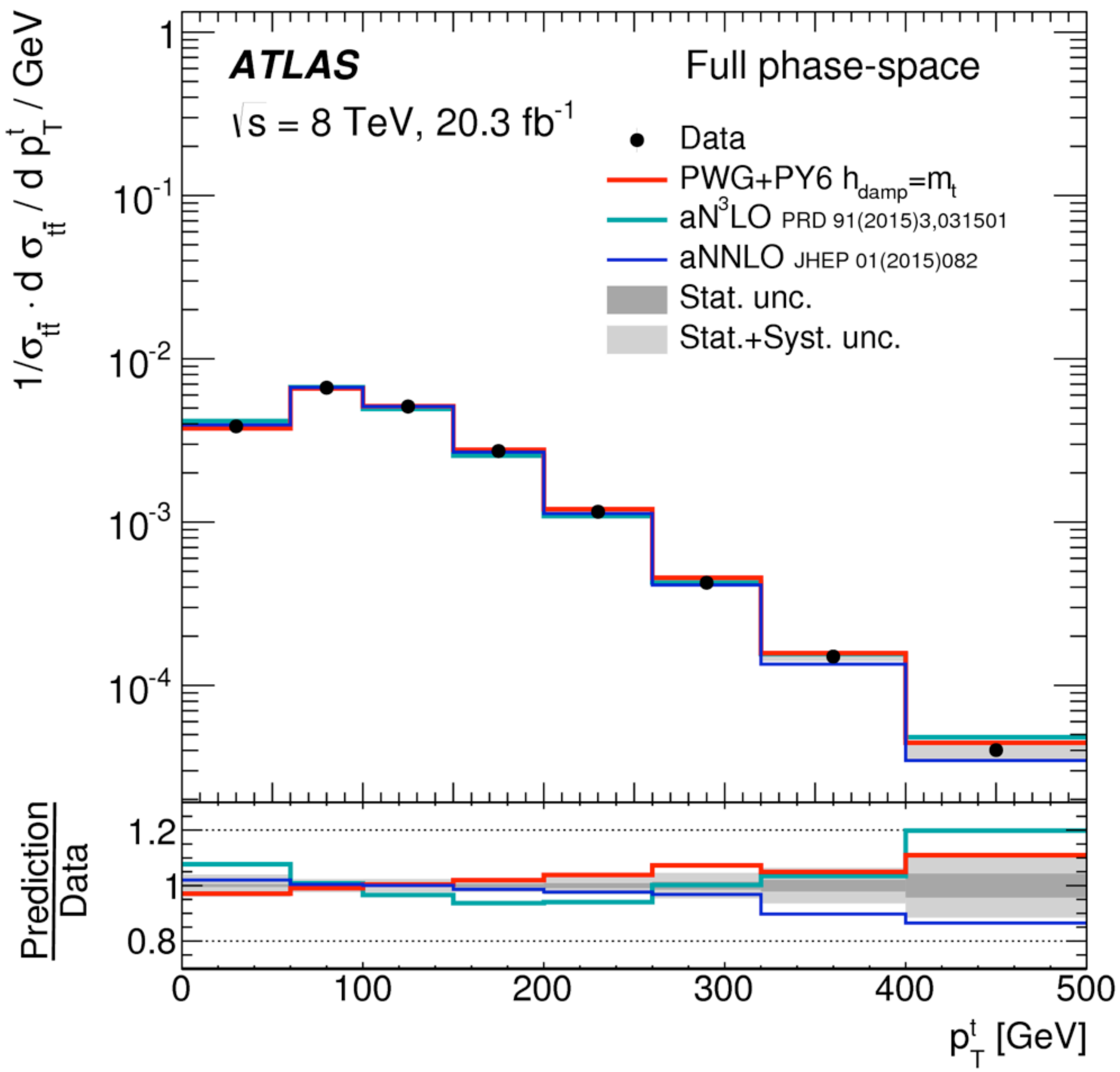
Differential measurements

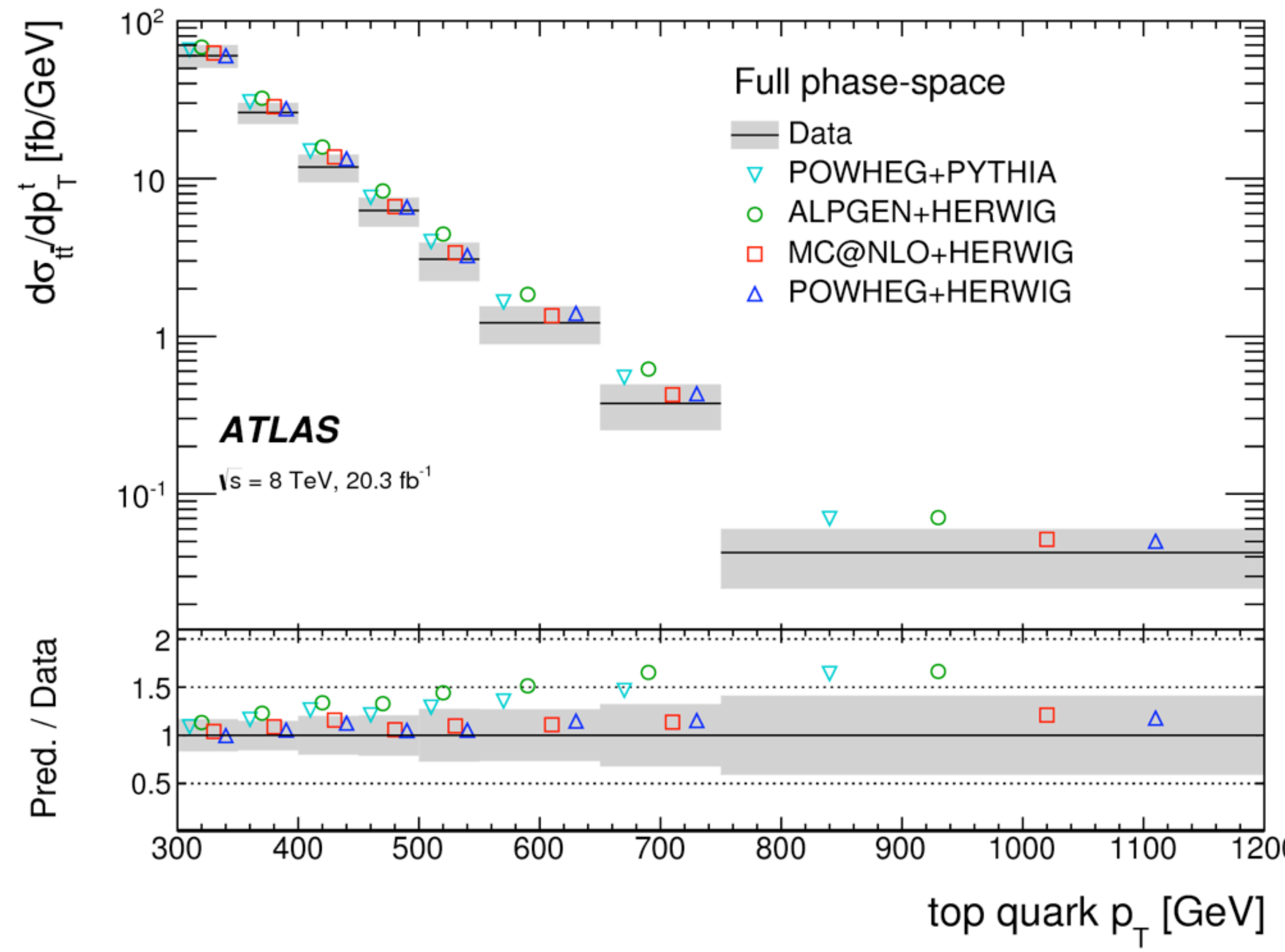
- To probe our understanding of the pdf, kinematics and parton shower evolution
- Measure σ as a function of $p_T(t)$, $y(t)$, M_{ttbar}; and look at N(jets) in the event
- Both in the
    - "Resolved" regime: top quark produced almost at rest - isolated leptons, not overlapping jet cones
    - "boosted regime: form "big fat" jets + W leptons immersed in them appear non-isolated → brand new issues and, hence, optimizations



Nov15

$d\sigma/dp_T(t)$, 8 TeV, l+jets





- Measurement unfolded to <u>parton</u> level and extrapolated to full phase space using Powheg+PYTHIA
- <u>Resolved</u> topology
- hints of harder spectrum in MC than data....

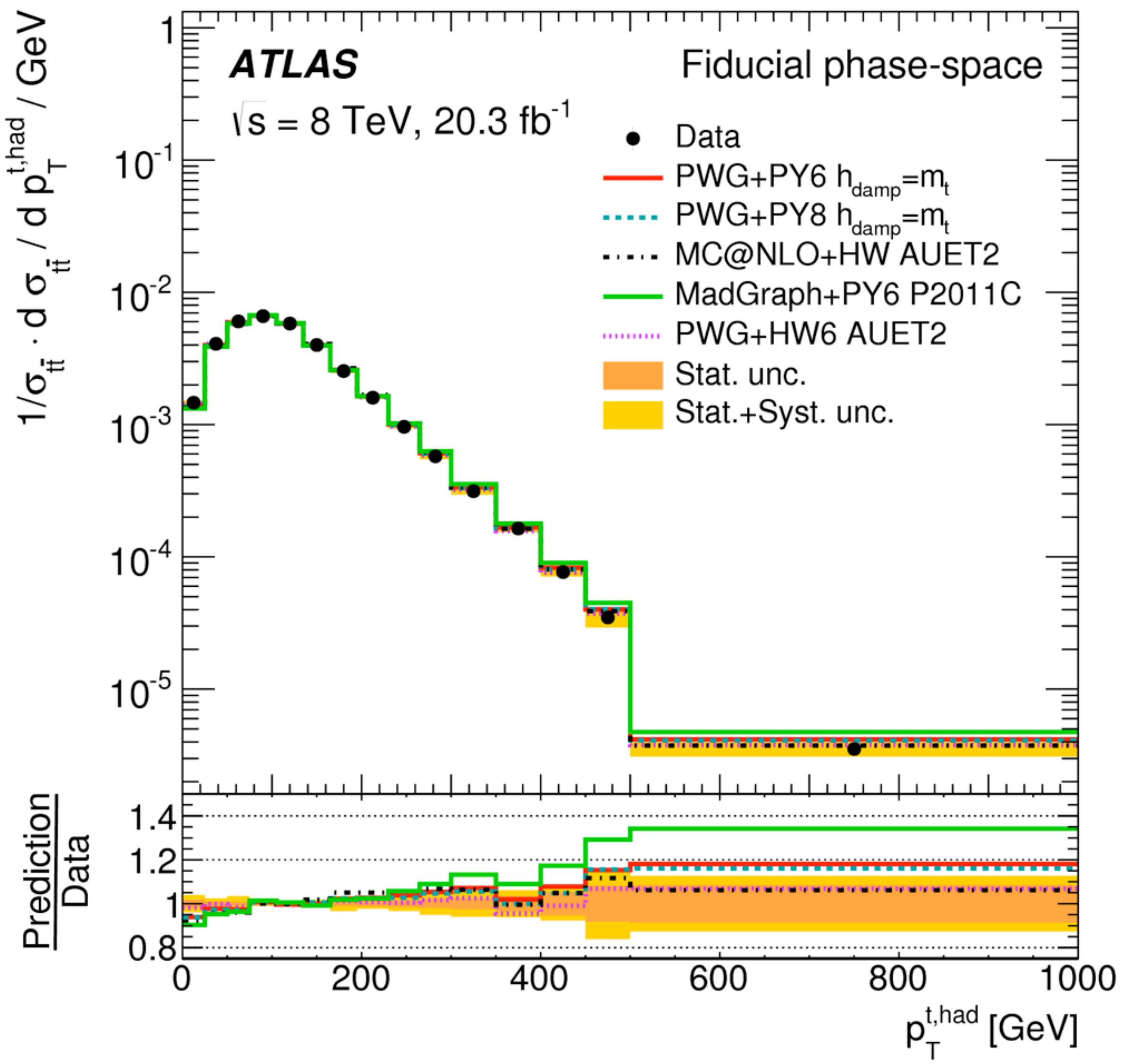
- Measurement unfolded to <u>parton</u> level using MC
- ....confirmed at very high top quark p_T using <u>boosted</u> topology

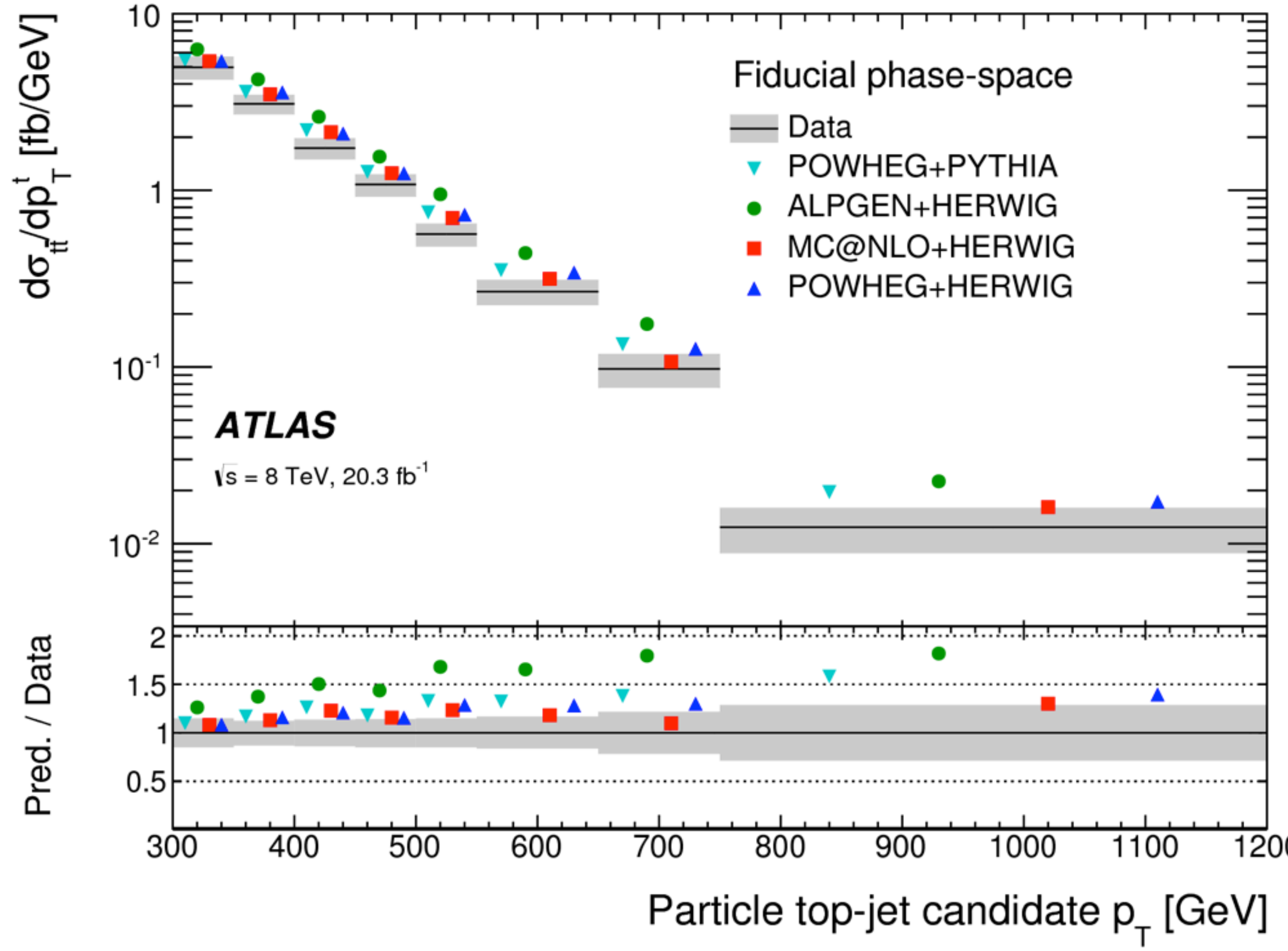
arXiv:1511.04716, submitted to EPJC

arXiv:1510.03818, submitted to PRD

Nov15

$d\sigma/dp_T(t)$, 8 TeV, l+jets

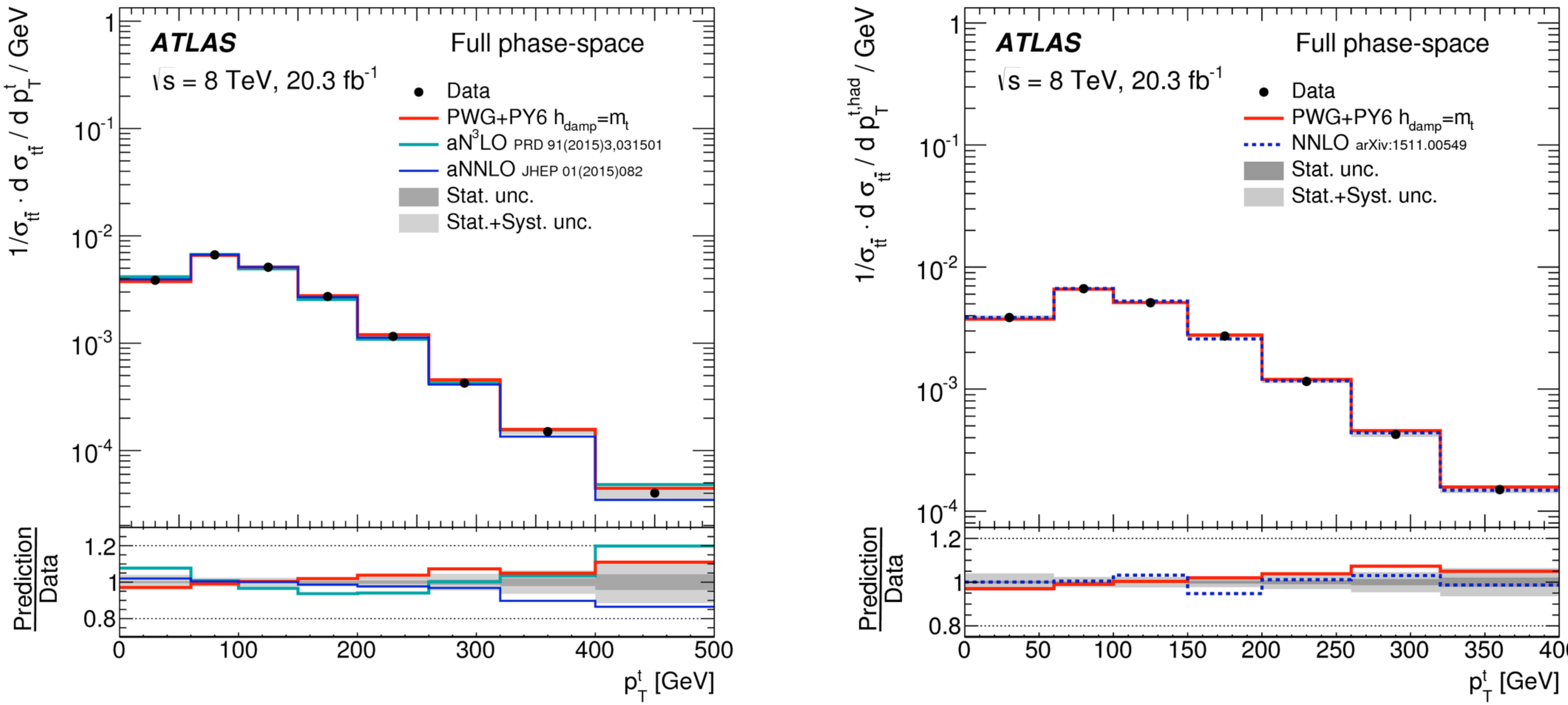




- Resolved topology
- boosted topology

- Visible also at jet-particle level, i.e. with jets built of stable truth-level particles
  - i.e. "meet you half way"
  - ➡ reduced extrapolation uncertainties

dσ/dp$_T$(t), 8 TeV, l+jets



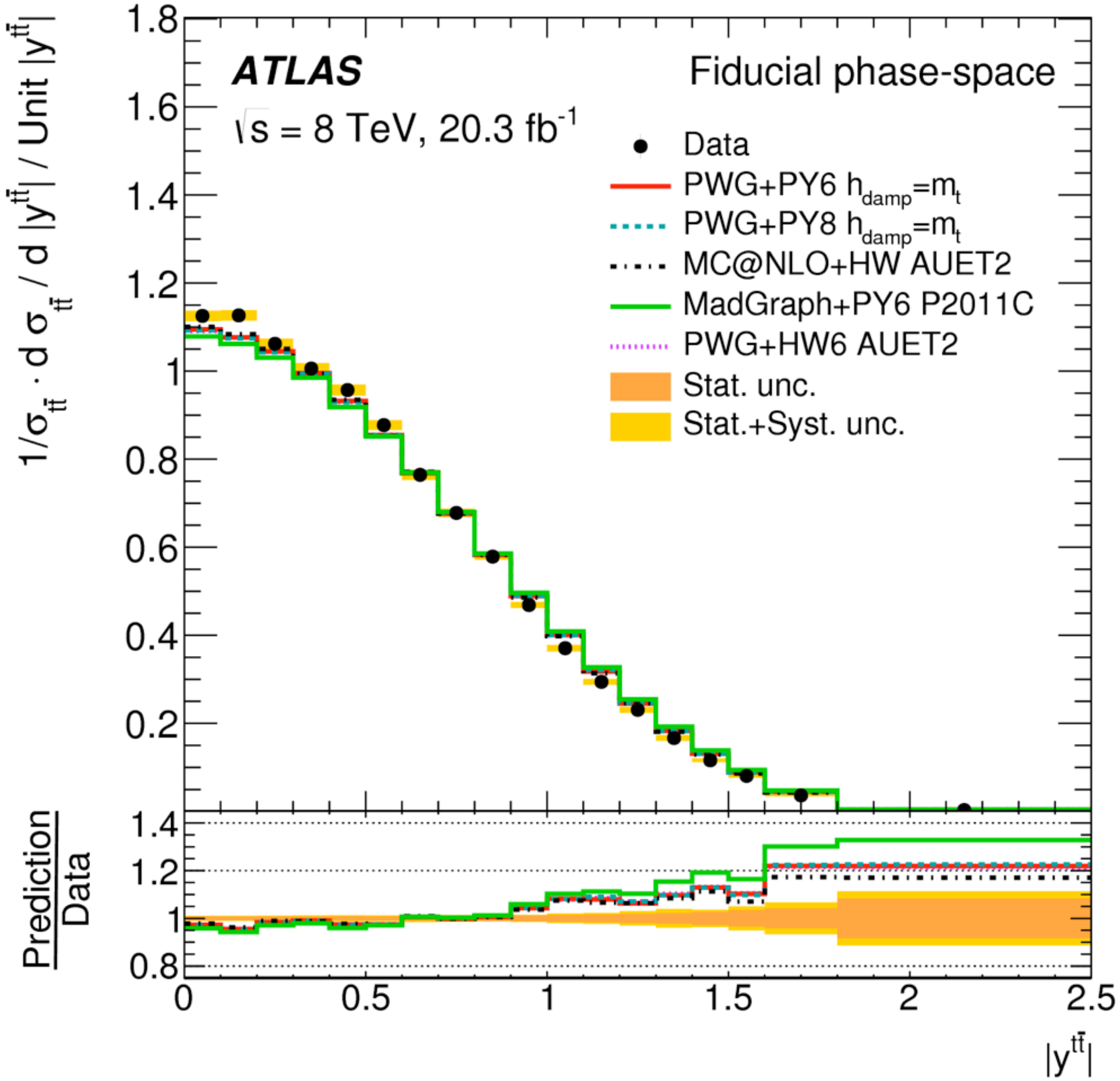
- Unfolded to parton level and extrapolated to full phase space using Powheg+PYTHIA
- Resolved topology

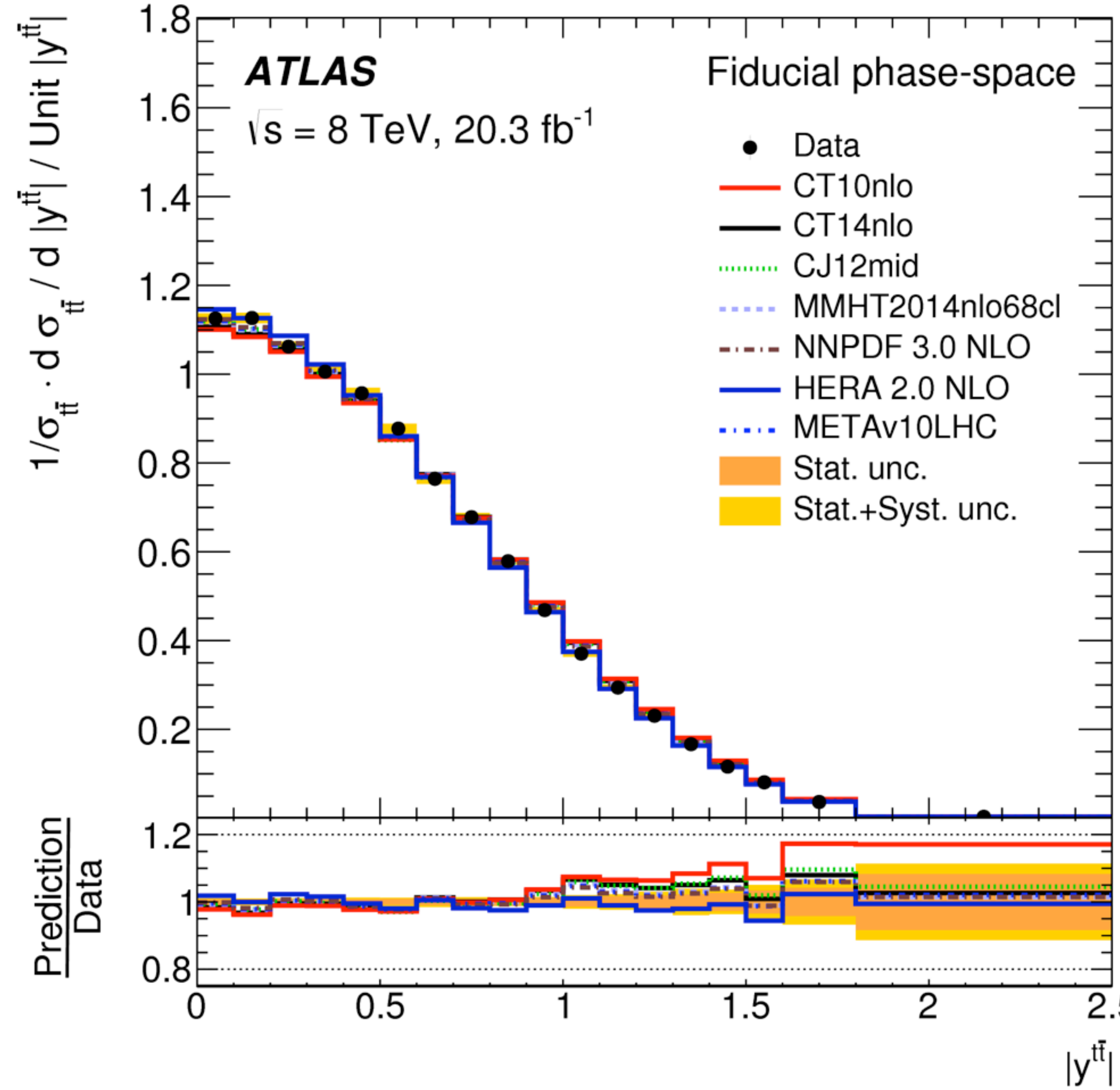
✓ Improved agreement when compared to full NNLO prediction (using the MSTW2008nnlo PDF)

arXiv:1511.04716, submitted to EPJC

dσ/dy(ttbar)

Nov15





- Measurement unfolded to parton level using Powheg+PYTHIA
- Resolved topology

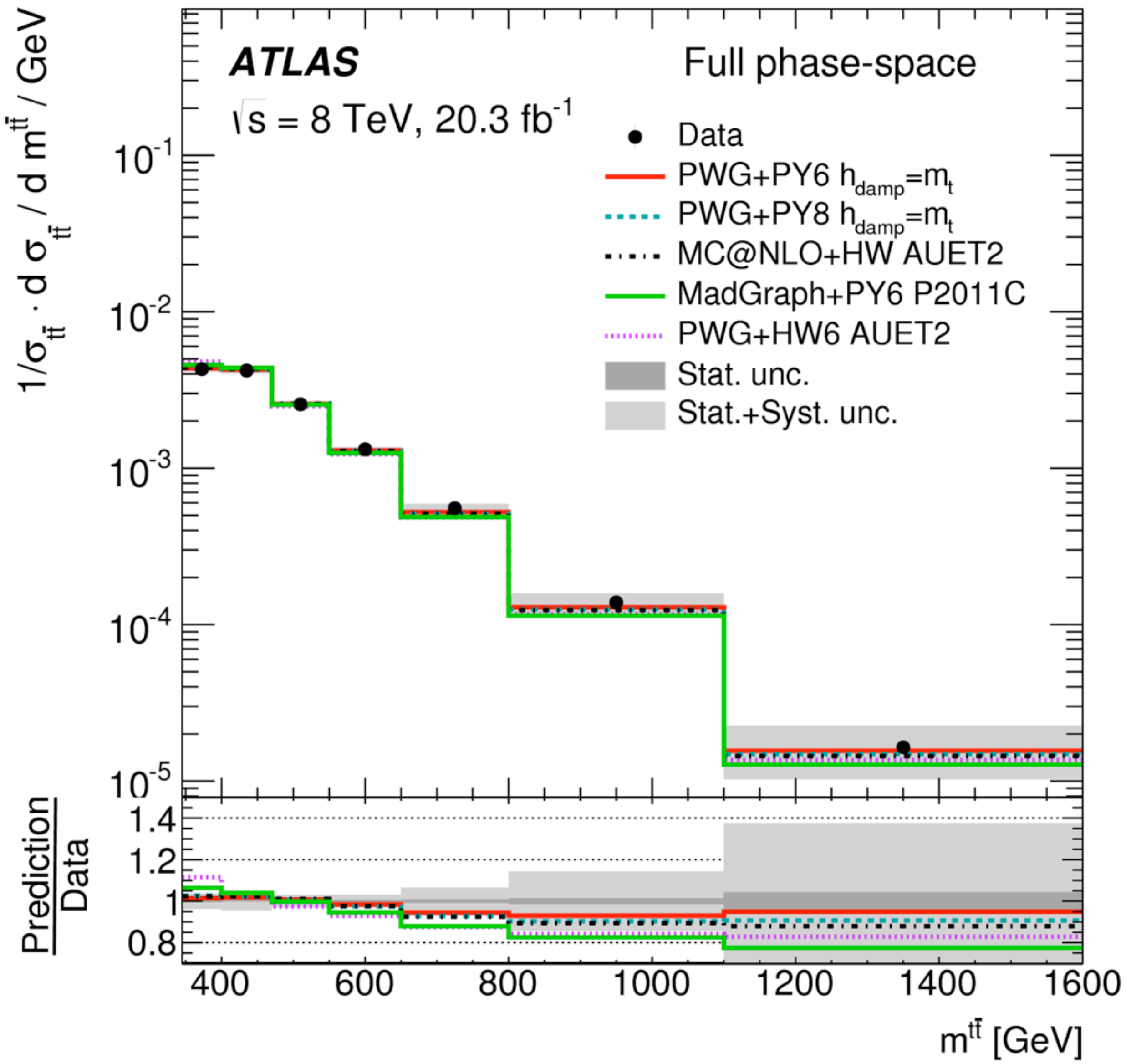
- Measurement unfolded to parton level using Powheg+PYTHIA
- Resolved topology

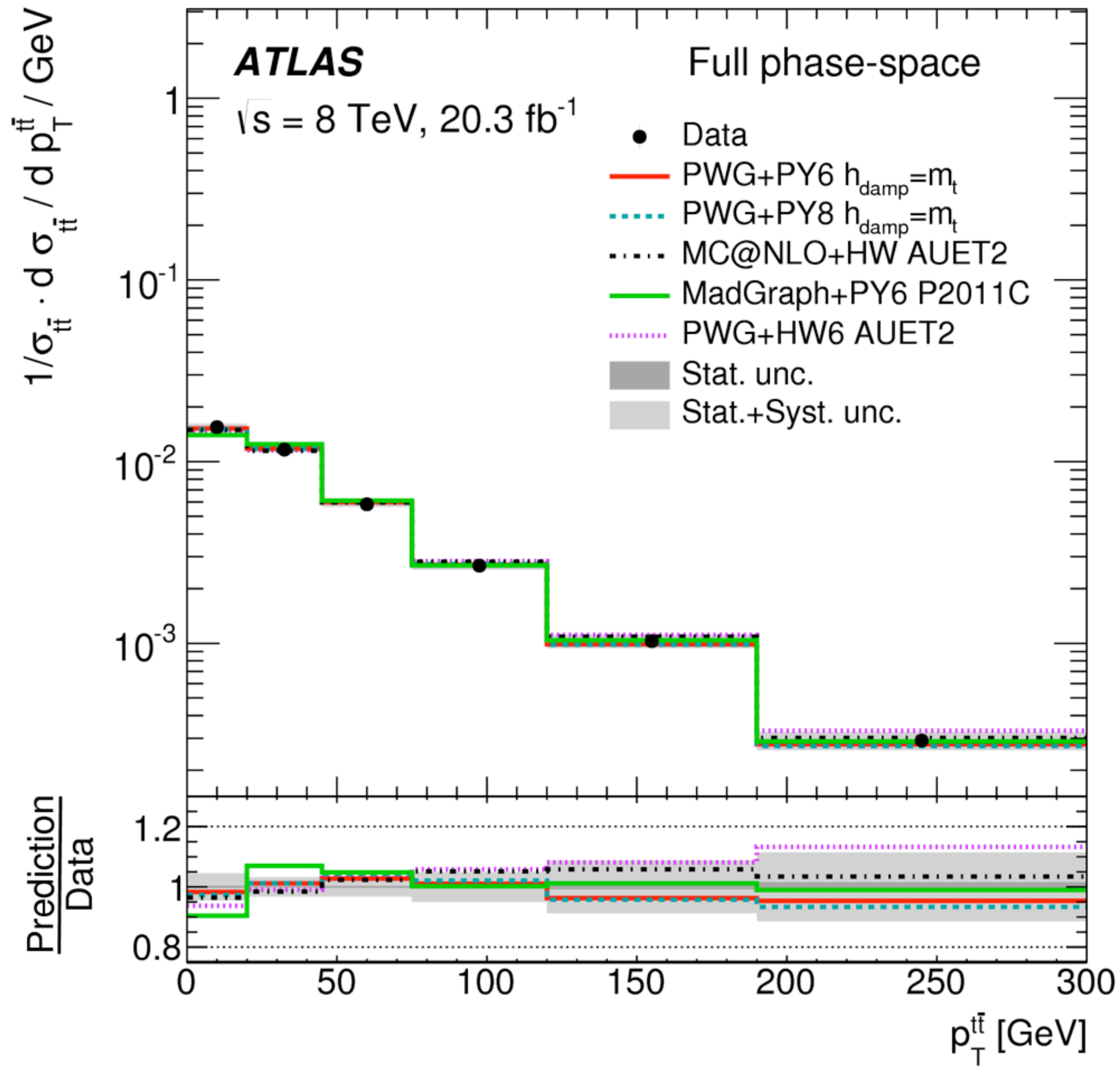
- Sensitive to (gluon) PDF, especially in forward region
- direct comparison among PDF sets for same generator (POWHEG+PY6)
- Most recent PDF sets do a better job that CT10nlo

arXiv:1511.04716, submitted to EPJC

$d\sigma/dM_{ttbar}$ and $d\sigma/dp_T(ttbar)$

Nov15





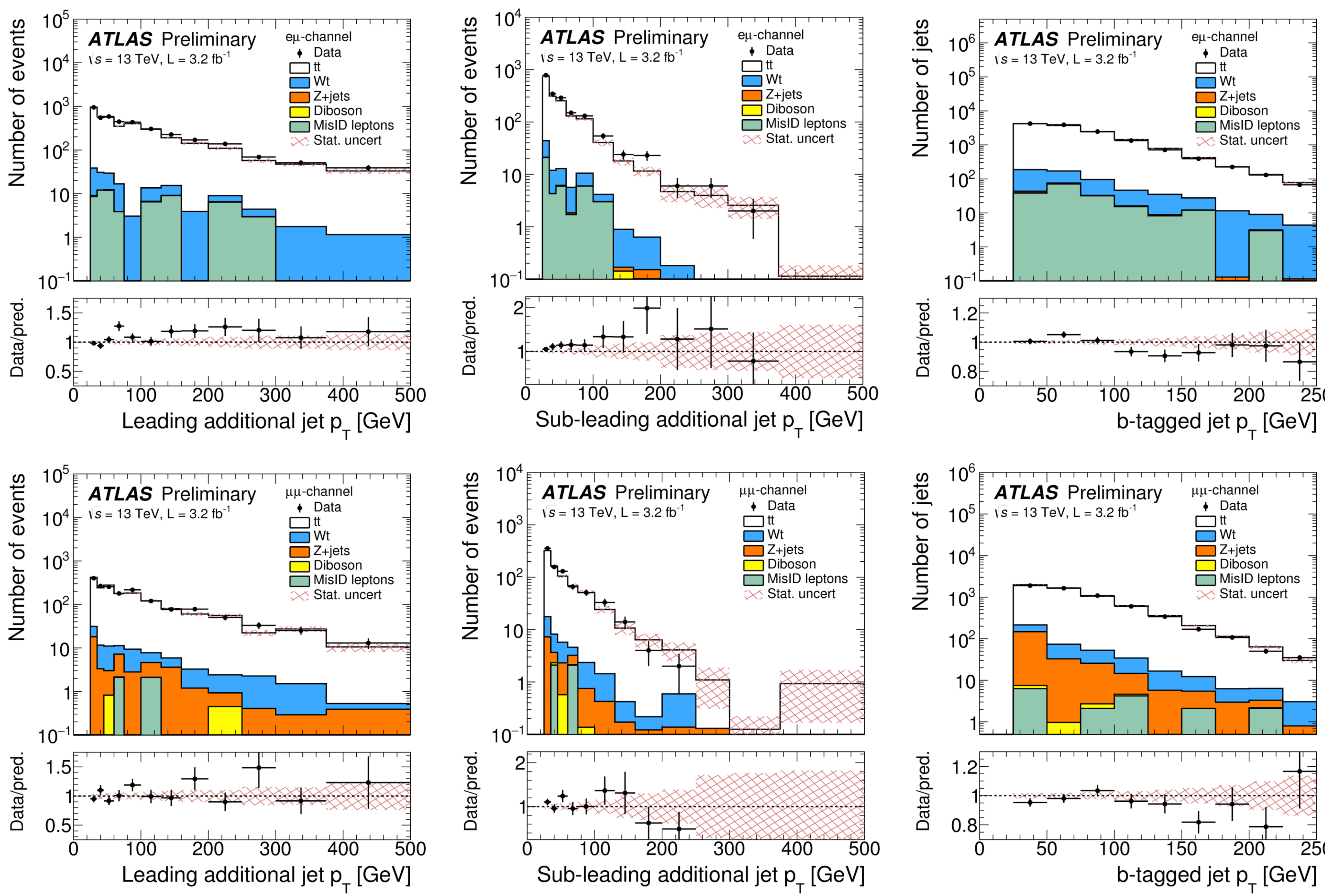
- Parton level, full phase space after unfolding of detector effects
- Resolved topology
- Important to tune MC well
- Sensitive to new, large width, particles decaying to ttbar

arXiv:1511.04716, submitted to EPJC

$d\sigma/dN_{jets}$, 13 TeV, *di-lepton*

Dec15

- *New* result measuring the differential cross-section as a function of number of accompanying jets: *tests theoretical predictions of QCD radiation*
- Di-leptonic events, ≥ 2 b-tagged jets, Z mass veto
- *Unfolded to particle-level, fiducial region*

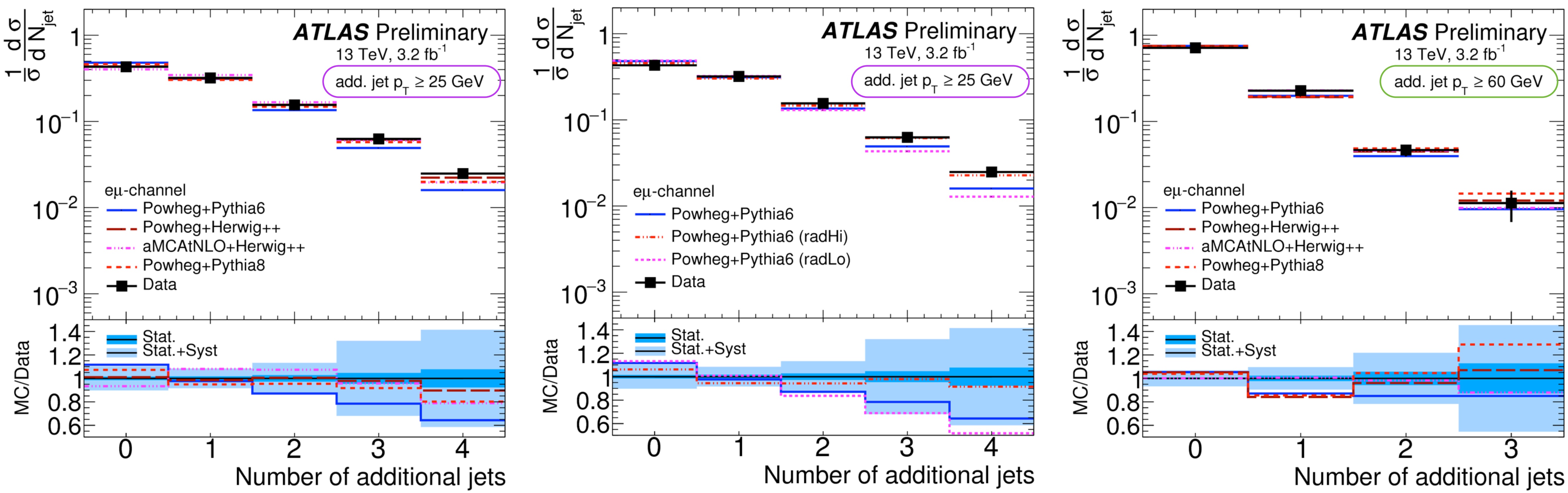


Full 2015 dataset

$d\sigma/dN_{jets}$, 13 TeV, *di-lepton*

Dec15

unfolded with Powheg+Py6

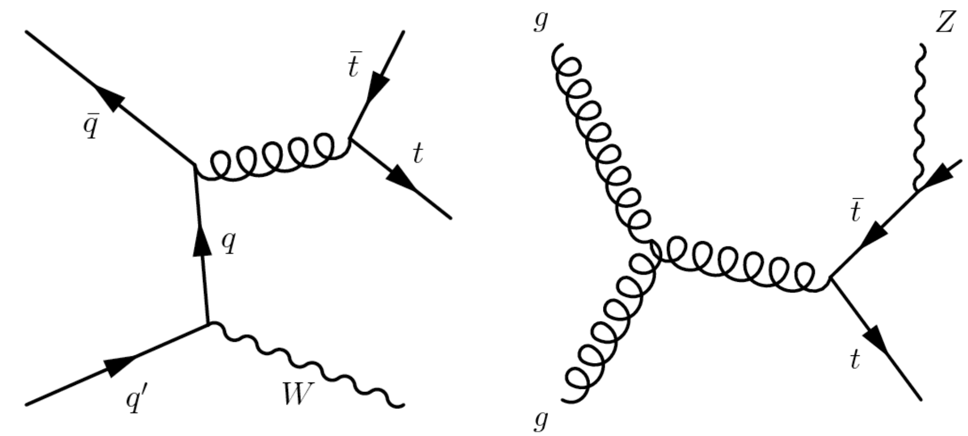


- Measure with different p_T thresholds to test momentum dependence of hard-gluon emission
- All set-ups compatible with data set used
- Most recent PS programmes compatible with data, differ from each other by 15% at most
- (Powheg+)Pythia 6, tuned on 7 and 8 TeV results, systematically lower at 13 TeV from 2 jets on
  - 13 TeV seem to prefer more radiation than nominally considered, but data can't constrain yet (at high N(jets))
  - "radHi"=hdamp set to 2mt, the renormalisation and factorisation scale set to half the nominal value and using the Perugia 2012 radHi UE tune

ATLAS-CONF-2015-065

ttbar+V

- top-Z coupling probed at tree level and would be affected by NP
- W emitted in initial state: different process
- important to measure per se (e.g. enhancement by NP like strongly coupled Higgs) and as main bkgs to e.g. ttH



at 8 TeV

σ(ttZ) = 215 ± 30 fb (aMC@NLO)

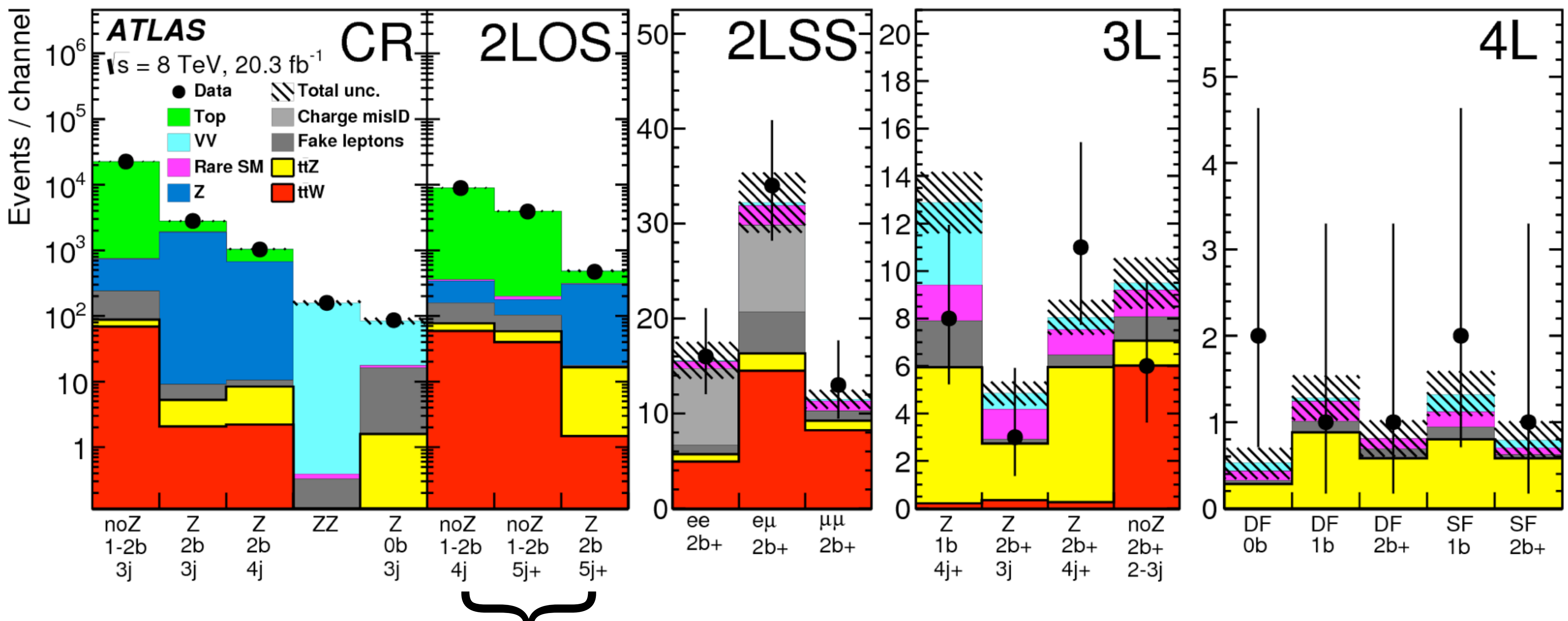
σ(ttW) = 232 ± 32 fb (aMC@NLO)

Process	$t\bar{t}$ decay	Boson decay	Channel	$Z \to \ell^+\ell^-$
$t\bar{t}W^\pm$	$(\ell^\pm\nu b)(q\bar{q}b)$	$\ell^\mp\nu$	OS dilepton	no
	$(\ell^\pm\nu b)(\ell^\mp\nu b)$	$q\bar{q}$	OS dilepton	no
	$(\ell^\pm\nu b)(q\bar{q}b)$	$\ell^\pm\nu$	SS dilepton	no
	$(\ell^\pm\nu b)(\ell^\mp\nu b)$	$\ell^\pm\nu$	Trilepton	no
$t\bar{t}Z$	$(\ell^\pm\nu b)(\ell^\mp\nu b)$	$q\bar{q}$	OS dilepton	no
	$(q\bar{q}b)(q\bar{q}b)$	$\ell^+\ell^-$	OS dilepton	yes
	$(\ell^\pm\nu b)(q\bar{q}b)$	$\ell^+\ell^-$	Trilepton	yes
	$(\ell^\pm\nu b)(\ell^\mp\nu b)$	$\ell^+\ell^-$	Tetralepton	yes

Channels considered in the ATLAS analysis

Signal extraction

- ttW and ttZ rates extracted simultaneously by means of binned max LL fit
- syst uncertainties constrained in fit adjusting input rates to data



Control normalization of backgrounds, reducing final uncertainty

NN to separate ttV from bkgs

Channel	$t\bar{t}W$ significance Expected	$t\bar{t}W$ significance Observed	$t\bar{t}Z$ significance Expected	$t\bar{t}Z$ significance Observed
2ℓOS	0.4	0.1	1.4	1.1
2ℓSS	2.8	5.0	—	—
3ℓ	1.4	1.0	3.7	3.3
4ℓ	—	—	2.0	2.4
Combined	3.2	5.0	4.5	4.2

All channels contribute to final measurement

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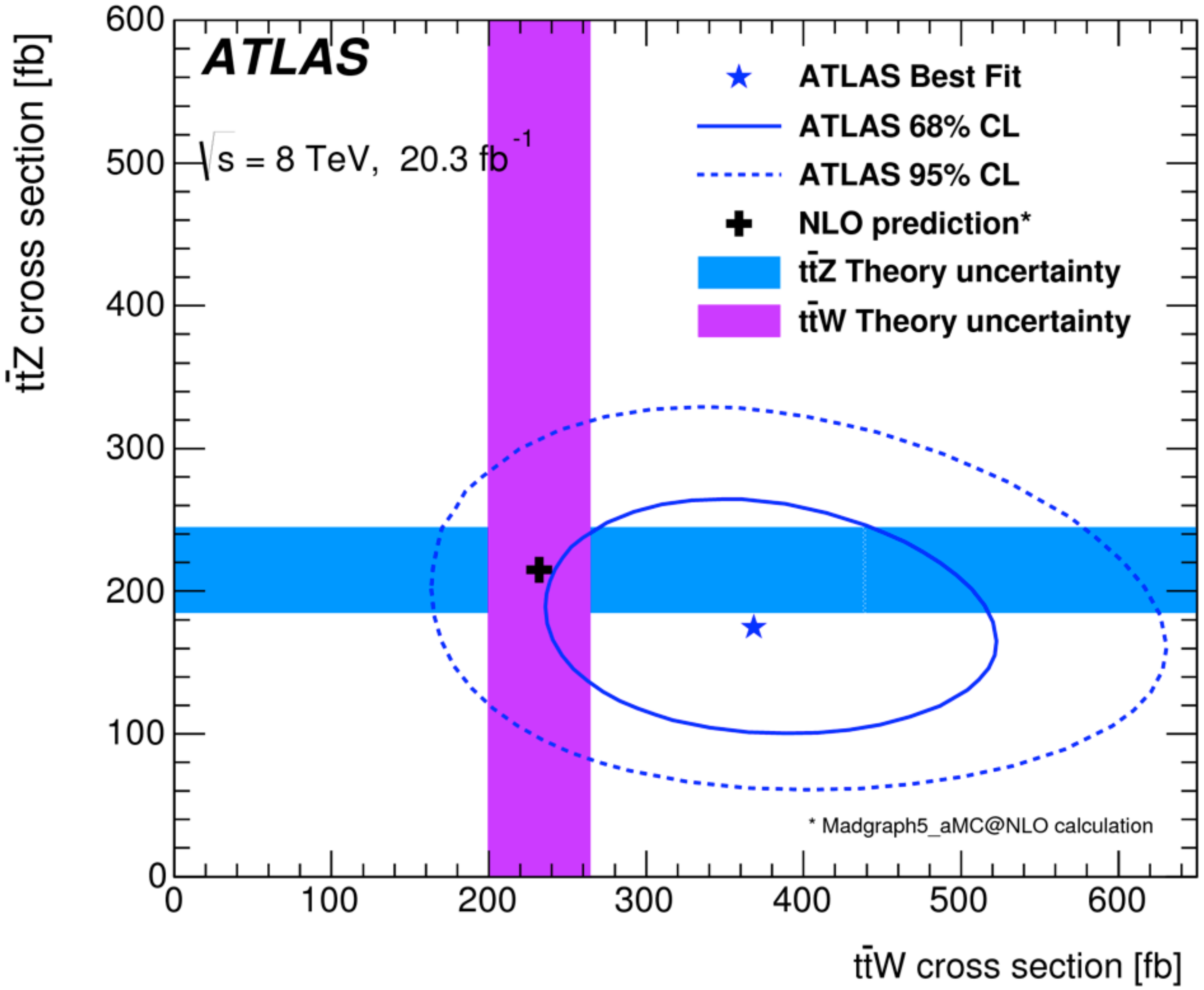
ttV: Results



Uncertainty	$\sigma_{t\bar{t}W}$	$\sigma_{t\bar{t}Z}$
Luminosity	3.2%	4.6%
Reconstructed objects	3.7%	7.4%
Backgrounds from simulation	5.8%	8.0%
Fake leptons and charge misID	7.5%	3.0%
Signal modelling	1.8%	4.5%
Total systematic	12%	13%
Statistical	+24% / −21%	+30% / −27%
Total	+27% / −24%	+33% / −29%

at 8 TeV

σ(ttZ) = 215 ± 30 fb (aMC@NLO)

σ(ttW) = 232 ± 32 fb (aMC@NLO)

The result of the combined simultaneous fit to the two parameters of interest is

$$\sigma_{t\bar{t}W} = 369^{+86}_{-79}\,(\text{stat.}) \pm 44\,(\text{syst.})\,\text{fb} = 369^{+100}_{-91}\,\text{fb} \qquad (7.1)$$

and

$$\sigma_{t\bar{t}Z} = 176^{+52}_{-48}\,(\text{stat.}) \pm 24\,(\text{syst.})\,\text{fb} = 176^{+58}_{-52}\,\text{fb}. \qquad (7.2)$$

Figure 11 provides a comparison of these measurements with NLO QCD theoretical calculations using MADGRAPH5_aMC@NLO.

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Conclusions

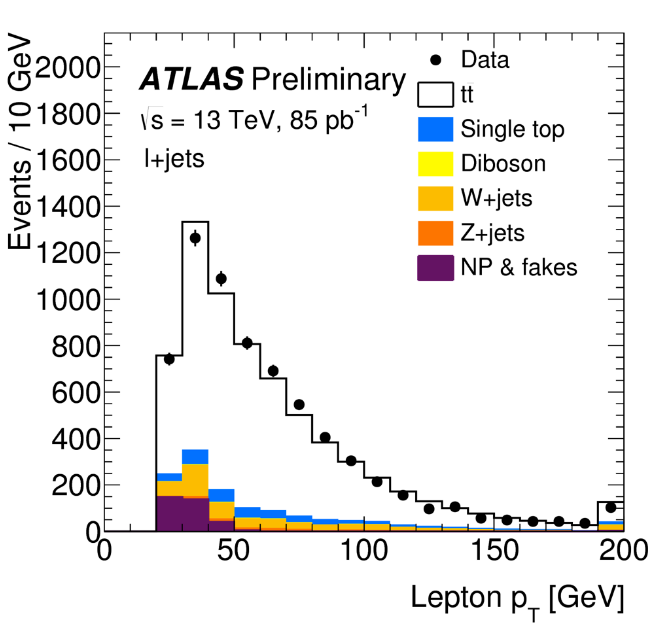
- Several measurements in top quark sector, both with Run I and Run 2 data (fast duty cycle)
- Inclusive cross-section measurements reach below 5% precision, testing NNLO+NNLL predictions
- Differential cross-section measurements probe SM predictions over wide range of kinematic phase space
  - full NNLO might be needed
  - newest PDF sets improve description of data
- Evidence/observation of ttV
- So far SM holds...

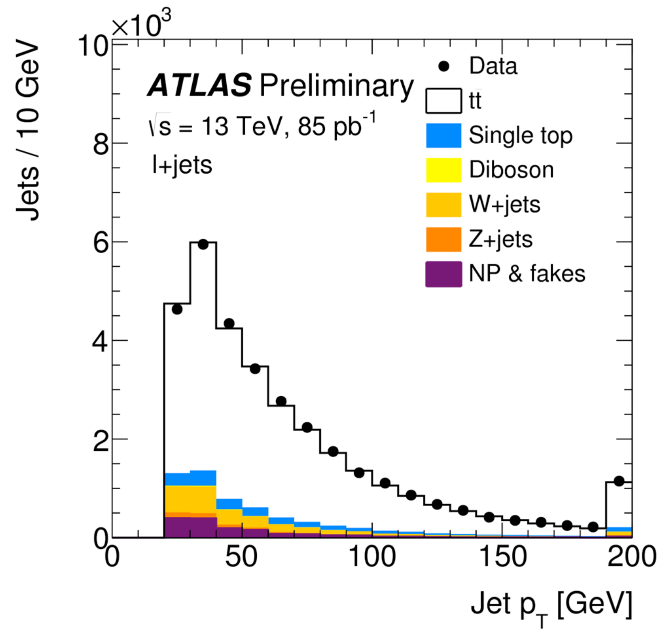
Back-up material

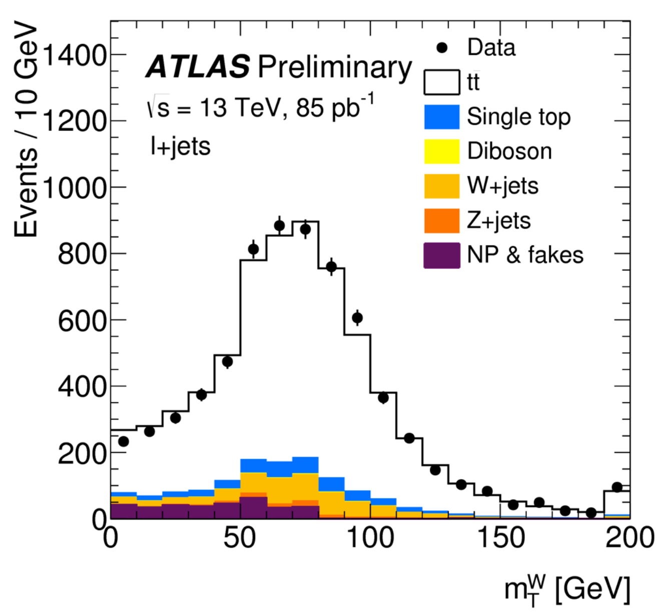
l+j and e+e/μ+μ: ATLAS-CONF-2015-033

l+jets channel

- Counting experiment
- main background (W+jets) from data using the W^+/W^- asymmetry (see back-up)
- Result dominated by unc. on luminosity, data sample size and hadronisation modelling







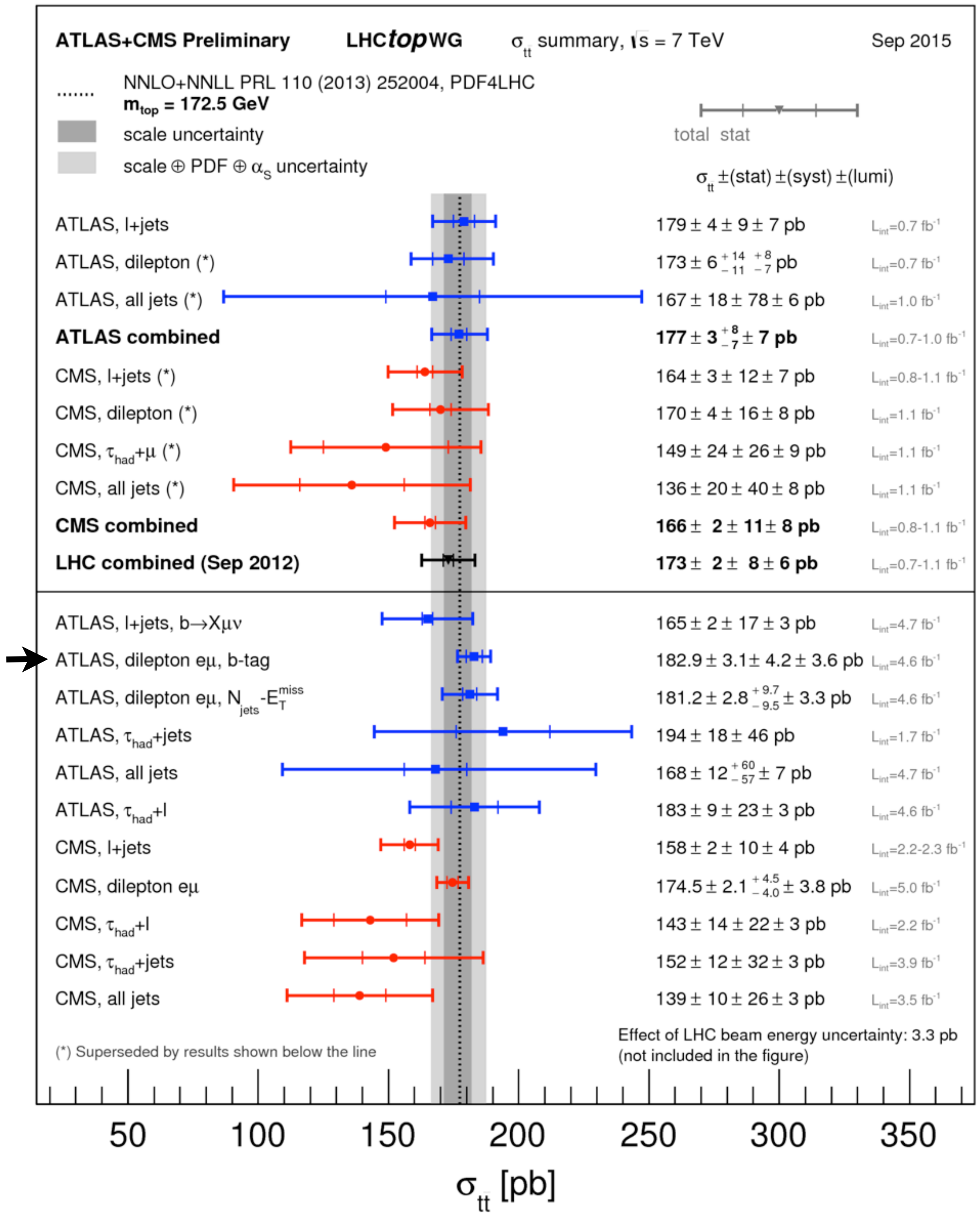
Yields

Sample	e + jets	μ + jets
$t\bar{t}$	2800 ± 400	2620 ± 340
W+jets	340 ± 100	230 ± 60
Single top	192 ± 34	180 ± 30
Z+jets	71 ± 35	45 ± 22
Dibosons	10 ± 5	10 ± 5
Fakes	200 ± 70	130 ± 60
Total background	820 ± 130	600 ± 100
Total expected	3600 ± 500	3220 ± 350
Observed	3439	3314

Uncertainties

Uncertainty	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Data statistics	7.6
$t\bar{t}$ NLO modelling	2.6
$t\bar{t}$ hadronisation	7.9
Initial/final state radiation	1.5
PDF	3.7
Analysis systematics	11
Integrated luminosity	10
Total uncertainty	16

Integrated x-sec at 7 and 8 TeV



- ATLAS has measured the total inclusive cross section for top pair production in Run-1 at 7, 8 TeV
- QCD predictions using all available final states (di-lepton, l+jet and full had)
  - predictions exist at NNLO+ approx NNLL
- Table presents a summary of the results at: 7 TeV, Run 1
- Average mainly driven by di-lepton channels
- Same experimental techniques as Run 2
- With a large enough data sample, world most precise results are in e+μ channel (~3.5% total rel unc)
- Single ATLAS Measurement more precise than theory

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCTopWGSummaryPlots

Event yields in 7 and 8 TeV integrated σ_{ttbar}

Table 1 Observed numbers of opposite-sign $e\mu$ events with one and two b-tagged jets (N_1 and N_2) for each data sample, together with the estimates of backgrounds and associated total uncertainties described in Sect. 6

Event counts	$\sqrt{s} = 7$ TeV		$\sqrt{s} = 8$ TeV	
	N_1	N_2	N_1	N_2
Data	3527	2073	21666	11739
Wt single top	326 ± 36	53 ± 14	2050 ± 210	360 ± 120
Dibosons	19 ± 5	0.5 ± 0.1	120 ± 30	3 ± 1
$Z(\to \tau\tau \to e\mu)$+jets	28 ± 2	1.8 ± 0.5	210 ± 5	7 ± 1
Misidentified leptons	27 ± 13	15 ± 8	210 ± 66	95 ± 29
Total background	400 ± 40	70 ± 16	2590 ± 230	460 ± 130

Uncertainties in 8 TeV integrated σ_{ttbar}

$\sqrt{s}$	7 TeV			8 TeV		
Uncertainty (inclusive $\sigma_{t\bar{t}}$)	$\Delta\epsilon_{e\mu}/\epsilon_{e\mu}$ (%)	$\Delta C_b/C_b$ (%)	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)	$\Delta\epsilon_{e\mu}/\epsilon_{e\mu}$ (%)	$\Delta C_b/C_b$ (%)	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Data statistics			1.69			0.71
$t\bar{t}$ modelling	0.71	−0.72	1.43	0.65	−0.57	1.22
Parton distribution functions	1.03	–	1.04	1.12	–	1.13
QCD scale choice	0.30	–	0.30	0.30	–	0.30
Single-top modelling	–	–	0.34	–	–	0.42
Single-top/$t\bar{t}$ interference	–	–	0.22	–	–	0.15
Single-top Wt cross-section	–	–	0.72	–	–	0.69
Diboson modelling	–	–	0.12	–	–	0.13
Diboson cross-sections	–	–	0.03	–	–	0.03
Z+jets extrapolation	–	–	0.05	–	–	0.02
Electron energy scale/resolution	0.19	−0.00	0.22	0.46	0.02	0.51
Electron identification	0.12	0.00	0.13	0.36	0.00	0.41
Muon momentum scale/resolution	0.12	0.00	0.14	0.01	0.01	0.02
Muon identification	0.27	0.00	0.30	0.38	0.00	0.42
Lepton isolation	0.74	–	0.74	0.37	–	0.37
Lepton trigger	0.15	−0.02	0.19	0.15	0.00	0.16
Jet energy scale	0.22	0.06	0.27	0.47	0.07	0.52
Jet energy resolution	−0.16	0.08	0.30	−0.36	0.05	0.51
Jet reconstruction/vertex fraction	0.00	0.00	0.06	0.01	0.01	0.03
b-tagging	–	0.18	0.41	–	0.14	0.40
Misidentified leptons	–	–	0.41	–	–	0.34
Analysis systematics ($\sigma_{t\bar{t}}$)	1.56	0.75	2.27	1.66	0.59	2.26
Integrated luminosity	–	–	1.98	–	–	3.10
LHC beam energy	–	–	1.79	–	–	1.72
Total uncertainty ($\sigma_{t\bar{t}}$)	1.56	0.75	3.89	1.66	0.59	4.27
Uncertainty (fiducial $\sigma_{t\bar{t}}^{\text{fid}}$)	$\Delta\epsilon_{e\mu}/\epsilon_{e\mu}$ (%)	$\Delta C_b/C_b$ (%)	$\Delta\sigma_{t\bar{t}}^{\text{fid}}/\sigma_{t\bar{t}}^{\text{fid}}$ (%)	$\Delta\epsilon_{e\mu}/\epsilon_{e\mu}$ (%)	$\Delta C_b/C_b$ (%)	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
$t\bar{t}$ modelling	0.84	−0.72	1.56	0.74	−0.57	1.31
Parton distribution functions	0.35	–	0.38	0.23	–	0.28
QCD scale choice	0.00	–	0.00	0.00	–	0.00
Other uncertainties (as above)	0.88	0.21	1.40	1.00	0.17	1.50
Analysis systematics ($\sigma_{t\bar{t}}^{\text{fid}}$)	1.27	0.75	2.13	1.27	0.59	2.01
Total uncertainty ($\sigma_{t\bar{t}}^{\text{fid}}$)	1.27	0.75	3.81	1.27	0.59	4.14

Fiducial volume in 7 TeV ttbar+jets

$E_T^{miss} > 30$ GeV & $m_T(W) > 35$ GeV
One or more b-jets
Three or more jets with p_T >25 GeV & $\lvert\eta\rvert < 2.5$
e (μ) with $p_T > 25$ GeV & $\lvert\eta\rvert < 2.5$
No additional e (μ) with $p_T > 15$ GeV & $\lvert\eta\rvert < 2.5$
No μ (e) with $p_T > 15$ GeV & $\lvert\eta\rvert < 2.5$
No jet-jet pair with $\Delta R < 0.5$
No jet-electron or jet-muon pair with $\Delta R < 0.4$

Table 3. Fiducial-volume definition for the electron (muon) channel of the $t\bar{t}$+jets cross-section measurement with the jet p_T threshold of 25 GeV. These conditions were applied on reconstruction-level and particle-level objects, with the exception of the electron where a veto on the η-region corresponding to the barrel-endcap transition region was applied on the reconstruction level (as described in section 3.1), but not included in the fiducial-volume definition. The jet p_T threshold in the jet multiplicity distributions was increased to 40, 60 and 80 GeV, for the corresponding cross-section measurements.

Leading jet with $p_T > 50$ GeV & $\lvert\eta\rvert < 2.5$
2^{nd} leading jet with $p_T > 35$ GeV & $\lvert\eta\rvert < 2.5$

Table 4. Additional fiducial-volume requirements implemented for the $t\bar{t}$ cross-section with respect to the jet p_T. These requirements were made in addition to those given in table 3 and were applied to the electron and the muon channel.

Fiducial volume in 13 TeV ttbar+jets

The fiducial volume for the cross-section was defined using events with exactly two opposite sign leptons (ee, $\mu\mu$ or $e\mu$) and at least two b-jets, all with $p_T > 25$ GeV and $|\eta| < 2.5$. If more than 2 b-jets are present the ones with the highest p_T are taken for the event selection. For the same lepton flavour channels (ee, $\mu\mu$), $|m_{ll} - m_Z| > 10$ GeV and $m_{ll} \geq 40$ GeV where m_{ll} refers to the mass reconstructed from the two leptons, are additionally required.

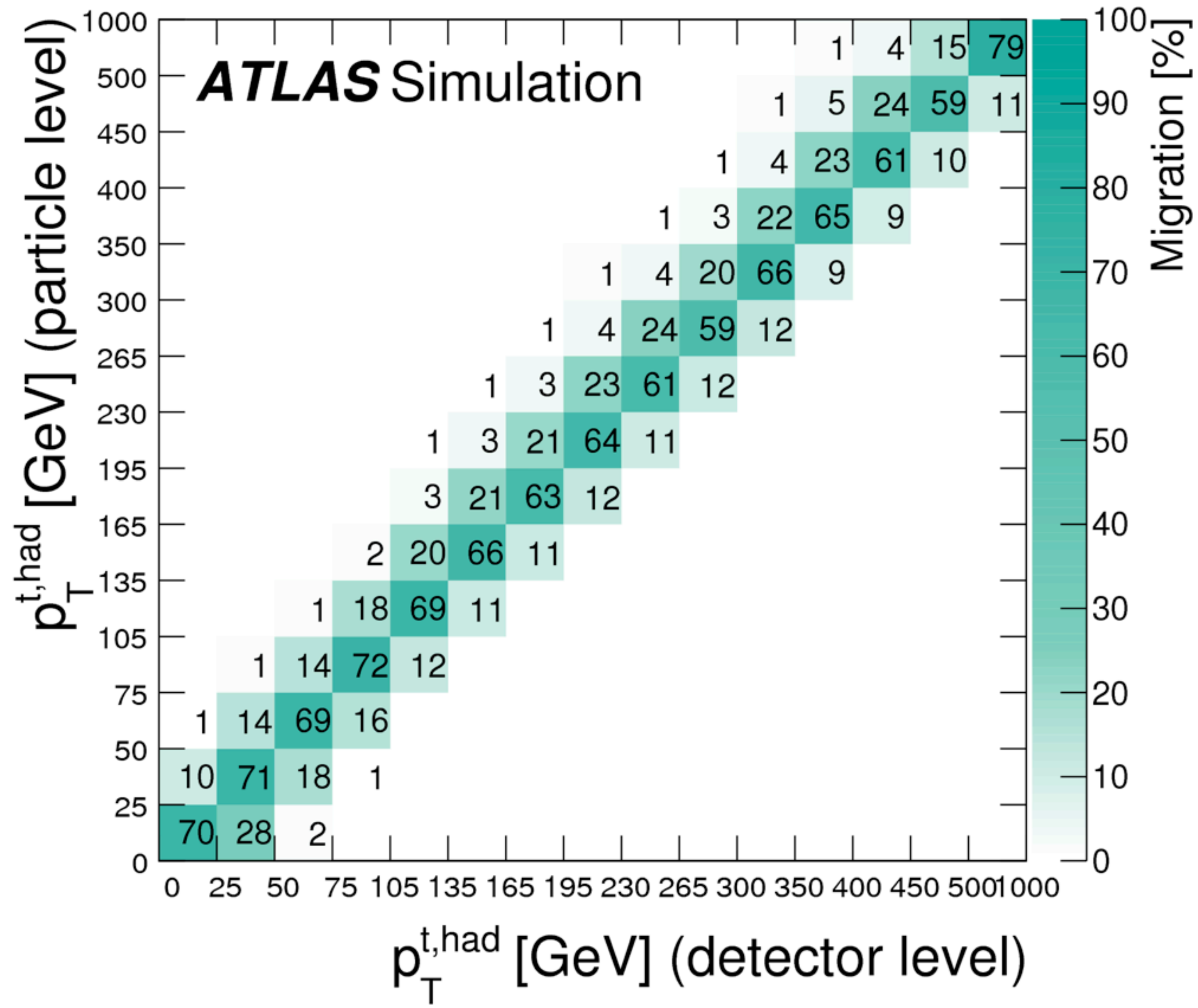
Additional jets, defined as all jets excluding the two highest momentum b-jets, are considered with p_T thresholds of 25, 40, 60 and 80 GeV and $|\eta| < 2.5$, independent of their flavour. Following the reconstructed object selection, events with jet-electron pairs or jet-muon pairs with $\Delta R < 0.4$ are excluded.

Syst. unc. in 13 TeV ttbar+jets

Sources	0 additional jets [%]	1 additional jet [%]	2 additional jets [%]	3 additional jets [%]	4 additional jets [%]
***ee* channel**					
Statistics	2.6	3.1	4.8	8.0	13.8
Signal modelling	5.9	7.2	7.0	17.6	41.0
Jets	6.0	4.5	8.4	19.1	30.4
Other	1.6	2.8	5.1	6.6	14.4
Total	**9.0**	**9.4**	**12.8**	**27.9**	**54.8**
$\mu\mu$ channel					
Statistics	2.2	2.8	4.2	7.0	11.4
Signal modelling	6.5	6.8	7.2	22.8	30.3
Jets	7.4	5.1	10.9	28.3	34.8
Other	1.0	3.5	4.2	4.8	11.0
Total	**10.1**	**9.6**	**14.4**	**37.3**	**48.8**
$e\mu$ channel					
Statistics	1.5	1.8	2.8	4.6	7.7
Signal modelling	6.3	7.3	5.1	22.0	32.8
Jets	6.7	3.9	11.3	22.2	21.5
Other	0.3	1.4	1.3	3.3	9.5
Total	**9.3**	**8.6**	**12.7**	**31.8**	**41.1**

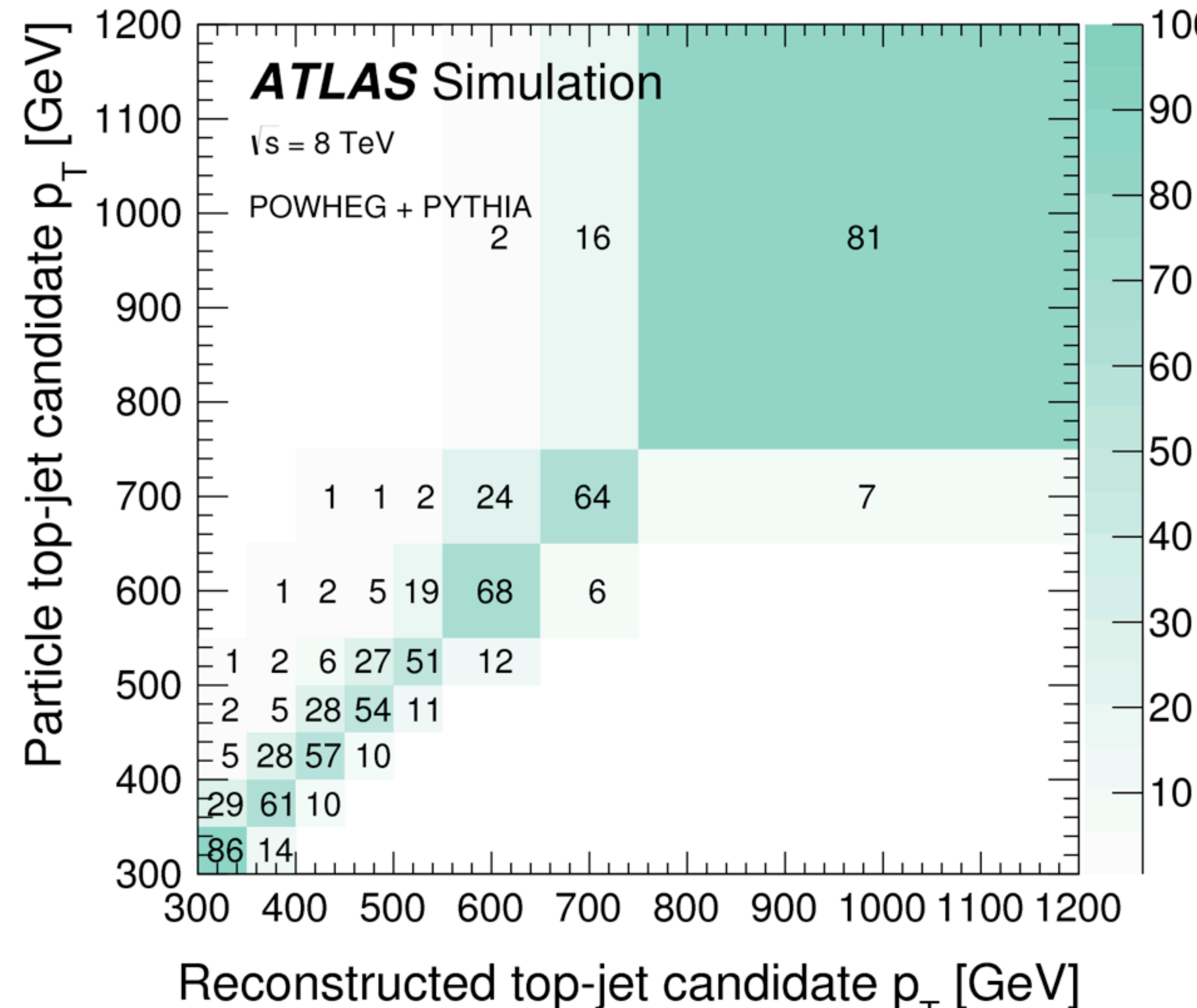
Table 2: Summary of measurement uncertainties in ee (top), $\mu\mu$ (middle) and $e\mu$ (bottom) channel for the jet p_T threshold of 25 GeV.

Migration matrices



Resolved

Boosted

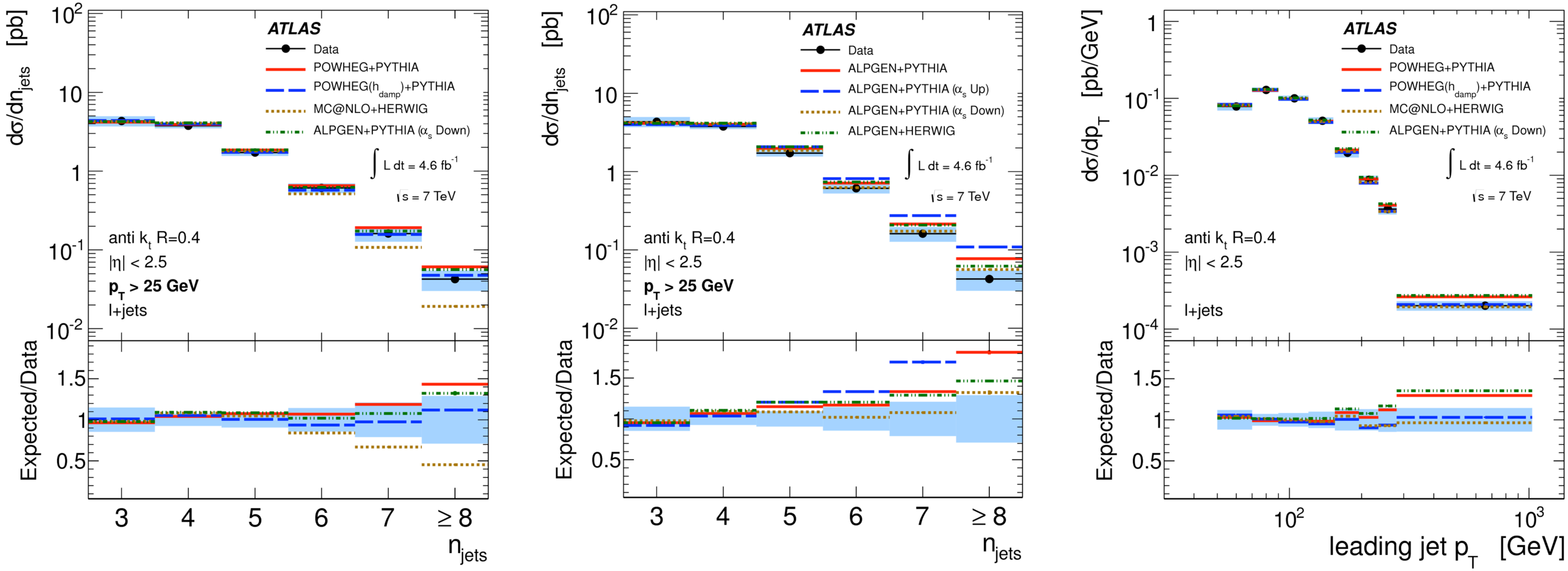


Event yields in 8 TeV ttbar+V

Region	$t+X$	Bosons	Fake leptons charge misID	Total expected background	$t\bar{t}W$	$t\bar{t}Z$	Data
2ℓ-noZ-3j*	20800 ± 2600	600 ± 200	160 ± 80	21600 ± 2700	42.0 ± 2.8	23.2 ± 1.5	22585
2ℓ-noZ-4j	8200 ± 1400	240 ± 90	80 ± 40	8600 ± 1400	36.6 ± 1.8	22.4 ± 1.1	8909
2ℓ-noZ-5j	3700 ± 850	100 ± 40	47 ± 23	3810 ± 870	24.9 ± 2.2	22.4 ± 2.0	3901
2ℓ-Z-3j*	800 ± 140	1960 ± 880	4.1 ± 2.1	2760 ± 890	1.24 ± 0.13	3.71 ± 0.38	2806
2ℓ-Z-4j*	330 ± 70	740 ± 390	2.2 ± 1.1	1100 ± 400	1.31 ± 0.11	7.21 ± 0.58	1031
2ℓ-Z-5j	170 ± 40	340 ± 200	1.4 ± 0.7	510 ± 210	0.89 ± 0.07	17.7 ± 1.4	471
$2e$-SS	0.66 ± 0.13	0.17 ± 0.10	8.9 ± 2.4	9.8 ± 2.6	2.97 ± 0.30	0.93 ± 0.23	16
$e\mu$-SS	1.9 ± 0.35	0.39 ± 0.28	14.1 ± 4.5	16.4 ± 5.1	8.67 ± 0.76	2.16 ± 0.51	34
2μ-SS	0.94 ± 0.17	0.25 ± 0.14	0.93 ± 0.55	2.12 ± 0.86	4.79 ± 0.40	1.12 ± 0.27	13
3ℓ-Z-0b3j*	1.11 ± 0.32	67 ± 16	15.2 ± 6.0	83 ± 15	0.05 ± 0.03	1.86 ± 0.47	86
3ℓ-Z-1b4j	1.58 ± 0.42	3.8 ± 1.3	2.4 ± 1.1	7.8 ± 1.6	0.14 ± 0.05	7.1 ± 1.6	8
3ℓ-Z-2b3j	1.29 ± 0.34	0.68 ± 0.33	0.19 ± 0.13	2.16 ± 0.42	0.21 ± 0.07	2.76 ± 0.69	3
3ℓ-Z-2b4j	1.00 ± 0.29	0.48 ± 0.24	0.42 ± 0.37	1.93 ± 0.49	0.14 ± 0.07	6.6 ± 1.6	11
3ℓ-noZ-2b	1.06 ± 0.25	0.27 ± 0.17	1.31 ± 0.90	2.7 ± 0.9	3.7 ± 0.9	1.23 ± 0.32	6
4ℓ-DF-0b	0.06 ± 0.01	0.11 ± 0.04	0.03 ± 0.17	0.21 ± 0.22	—	0.28 ± 0.01	2
4ℓ-DF-1b	0.22 ± 0.03	0.05 ± 0.03	0.13 ± 0.22	0.39 ± 0.27	—	1.05 ± 0.03	1
4ℓ-DF-2b	0.11 ± 0.02	< 0.01	0.11 ± 0.19	0.22 ± 0.21	—	0.64 ± 0.02	1
4ℓ-ZZ*	0.01 ± 0.00	134.2 ± 1.2	0.27 ± 0.18	134.5 ± 1.3	—	0.07 ± 0.01	158
4ℓ-SF-1b	0.16 ± 0.02	0.29 ± 0.06	0.14 ± 0.19	0.61 ± 0.27	—	0.91 ± 0.02	2
4ℓ-SF-2b	0.08 ± 0.01	0.09 ± 0.03	0.04 ± 0.18	0.21 ± 0.23	—	0.64 ± 0.02	1

$d\sigma/dN_{jets}$, 7 TeV, *l+jets*

unfolded with Powheg+Py6



- 1 lep (p_T>25 GeV) + jets, veto on 2nd lep, >2 jets, matched with MC particles
- Within fiducial volume (see back-up) and corrected for detector and acceptance effects back to particle jet level
- Rules out MC@NLO+Herwig at high N(jets)
- Leading jet p_T measurement complementary to $d\sigma/dp_T$(ttbar) measurements at high p_T
- Large sensitivity of data to additional QCD radiation demonstrated with ALPGEN variations
  - "α_S DOWN (UP)"= ALPGEN renormalisation scale associated with α_S up (down) at each local vertex in the matrix element relative to the original scale. A factor of 2.0 (0.5) was applied, resulting in lower (higher) α_S values, respectively.

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Cross-section determination

- σ_{ttbar} determined from events with 1 and 2 b-tags

N_1=1 b-tag
N_2=2 b-tags

$$\begin{aligned} N_1 &= L\sigma_{t\bar{t}}\,\epsilon_{e\mu}2\epsilon_b(1-C_b\epsilon_b)+N_1^{\mathrm{bkg}} \\ N_2 &= L\sigma_{t\bar{t}}\,\epsilon_{e\mu}C_b{\epsilon_b}^2+N_2^{\mathrm{bkg}} \end{aligned}$$

- $\epsilon_{e\mu}$ = efficiency for signal to pass di-lepton opposite charge, different flavour selection (obtained from MC)
- ϵ_b = combined probability for a b quark from a top decay to:
  - fall within ATLAS detector acceptance
  - be reconstructed as a jet and pass jet pre-selections of previous page
  - be identified as b-jet
- ${\epsilon_b}^2 \simeq \epsilon_{bb}$ (with correction factor C_b, obtained from MC)

$$C_b = 4N_{e\mu}^{t\bar{t}}N_2^{t\bar{t}}/(N_1^{t\bar{t}}+2N_2^{t\bar{t}})^2$$

W+jets in l+jets, 13 TeV

$$N_{\geq 1b}^{W,\mathrm{DD}} = \frac{N_{0b}^{W,\mathrm{DD}}}{N_{0b}^{W,\mathrm{MC}}} \cdot N_{\geq 1b}^{W,\mathrm{MC}} \tag{3}$$

where $N_{0b}^{W,\mathrm{MC}}$ and $N_{\geq 1b}^{W,\mathrm{MC}}$ are the number of W+jets events with zero and at least one b-tagged jet predicted by simulation, and

$$N_{0b}^{W,\mathrm{DD}} = \frac{\left(N_{\mathrm{data}}^{+} - N_{\mathrm{bkg}}^{+}\right) - \left(N_{\mathrm{data}}^{-} - N_{\mathrm{bkg}}^{-}\right)}{A_W}, \tag{4}$$

where $N_{\mathrm{data}}^{\pm}$ are the number of selected events with positive and negative charge, $N_{\mathrm{bkg}}^{\pm}$ are the number of events expected from single top processes (which are not charge symmetric) and A_W is the asymmetry predicted in the W+jets simulation,

$$A_W = \frac{N_{\mathrm{MC}}^{+} - N_{\mathrm{MC}}^{-}}{N_{\mathrm{MC}}^{+} + N_{\mathrm{MC}}^{-}}\,. \tag{5}$$

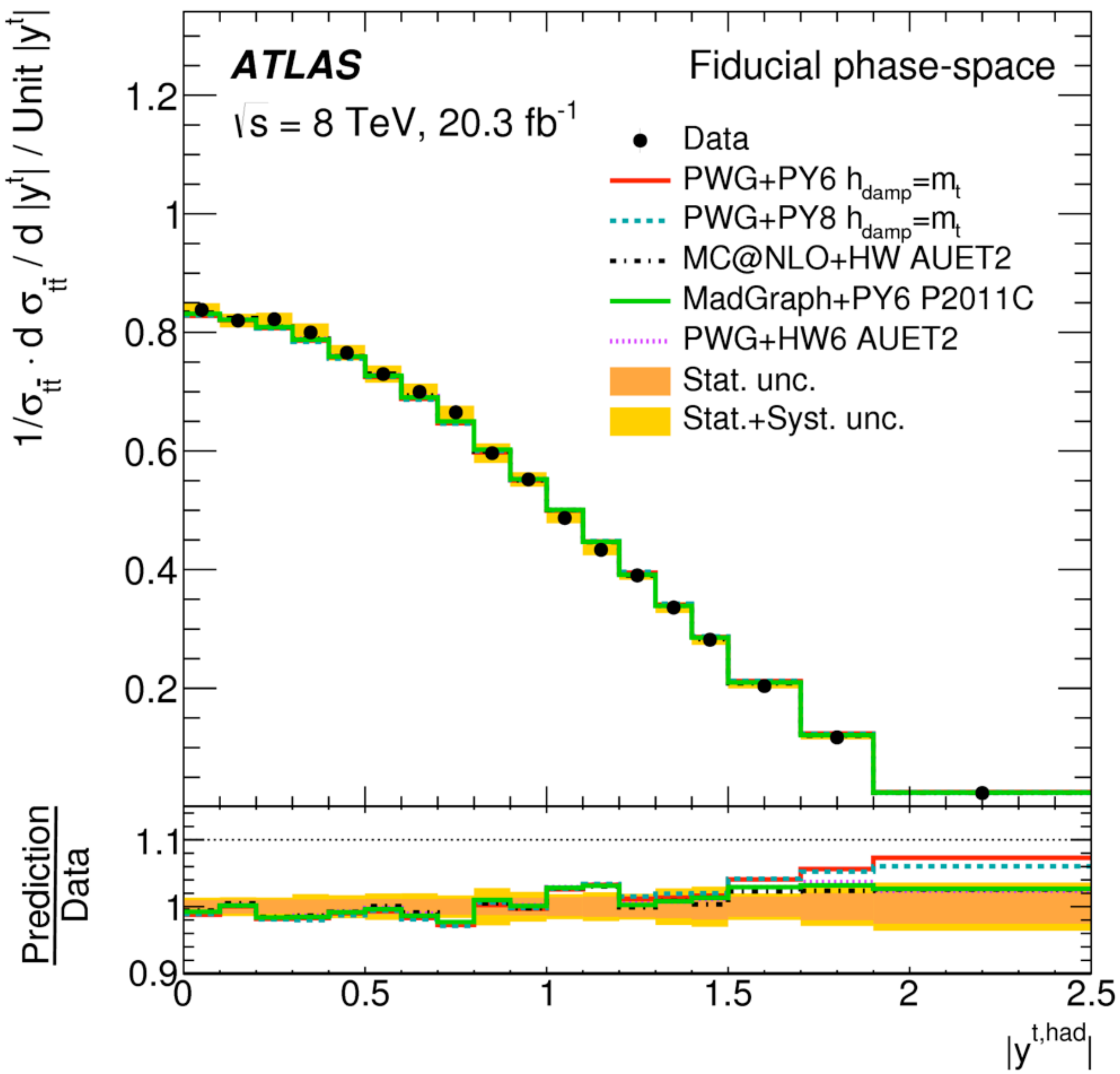
PDF for data in fwd region

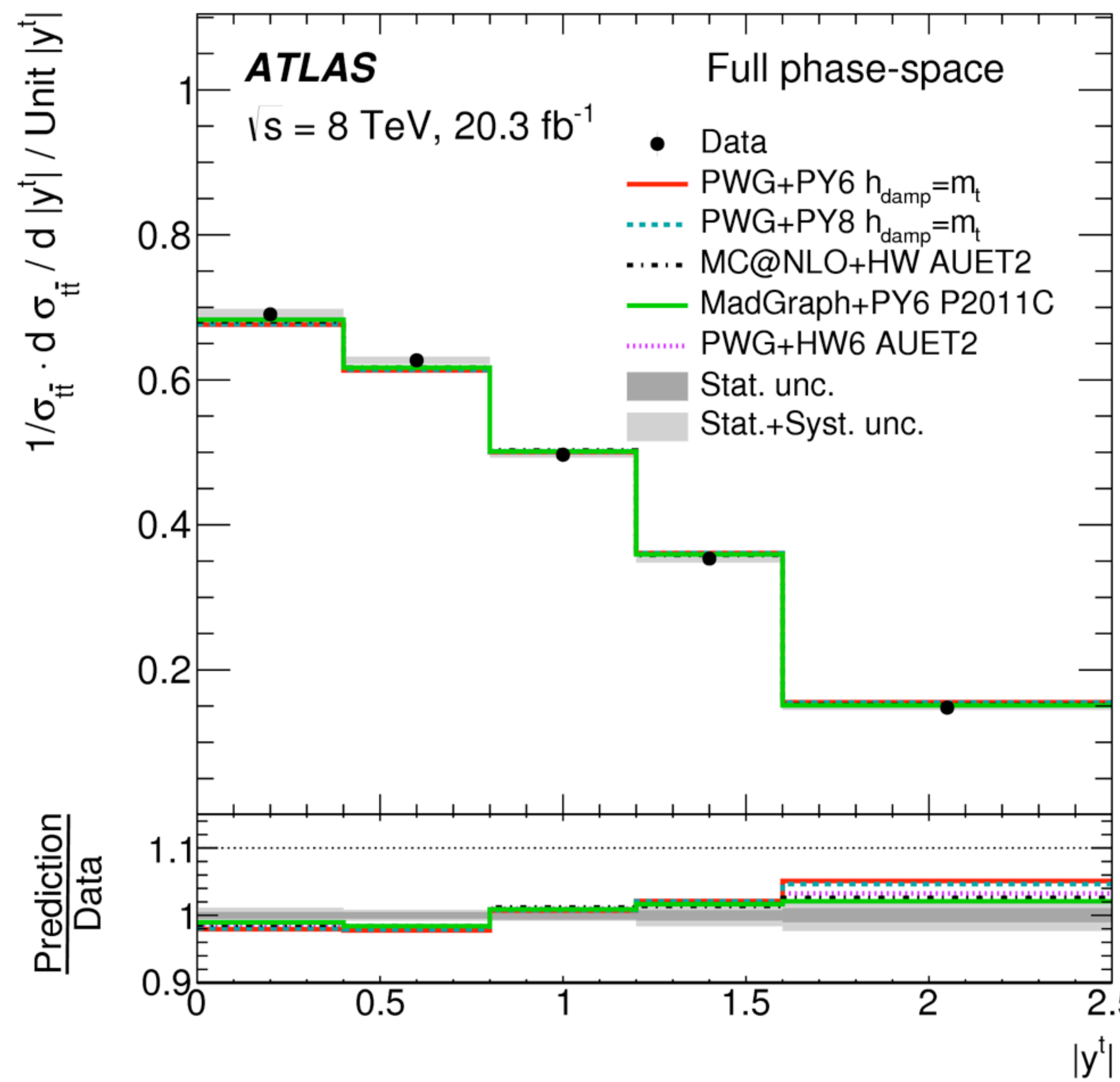
The difficulty in correctly predicting the data in the forward region was further investigated by studying the dependence of the predictions from different PDF sets. The study was performed for the rapidity observables $\left|y^{t,\mathrm{had}}\right|$, $\left|y^{t\bar{t}}\right|$ and $y^{t\bar{t}}_{\mathrm{boost}}$, shown in Figure 10 and comparing the data with the predictions of MC@NLO+HERWIG for more recent sets of parton distribution functions. The results exhibit a general improvement in the description of the forward region for the most recent PDF sets (CT14nlo [74], CJ12mid [75], MMHT2014nlo [76], NNPDF 3.0 NLO [77], METAv10LHC [78], HERAPDF 2.0 NLO [79]). The improvement with respect to CT10nlo is also clearly shown in Table 5 which lists the χ^2 and corresponding p-values for the different sets. The only exception is represented by the $\left|y^{t,\mathrm{had}}\right|$ distribution using HERAPDF 2.0 NLO, for which a large disagreement in the forward region is observed.

arXiv:1511.04716, submitted to EPJC

dσ/dy(t)

Nov15





- Measurement unfolded to parton level using Powheg+PYTHIA
- Resolved topology

- Measurement unfolded to parton level + extrapolated to full phase space using Powheg+PYTHIA
- Resolved topology

- Sensitive to PDF set used with various generators
- Event more evident in d**σ**/dy(ttbar)...