Differential ttbar measurements at ATLAS

Ford Garberson
(Yale University)

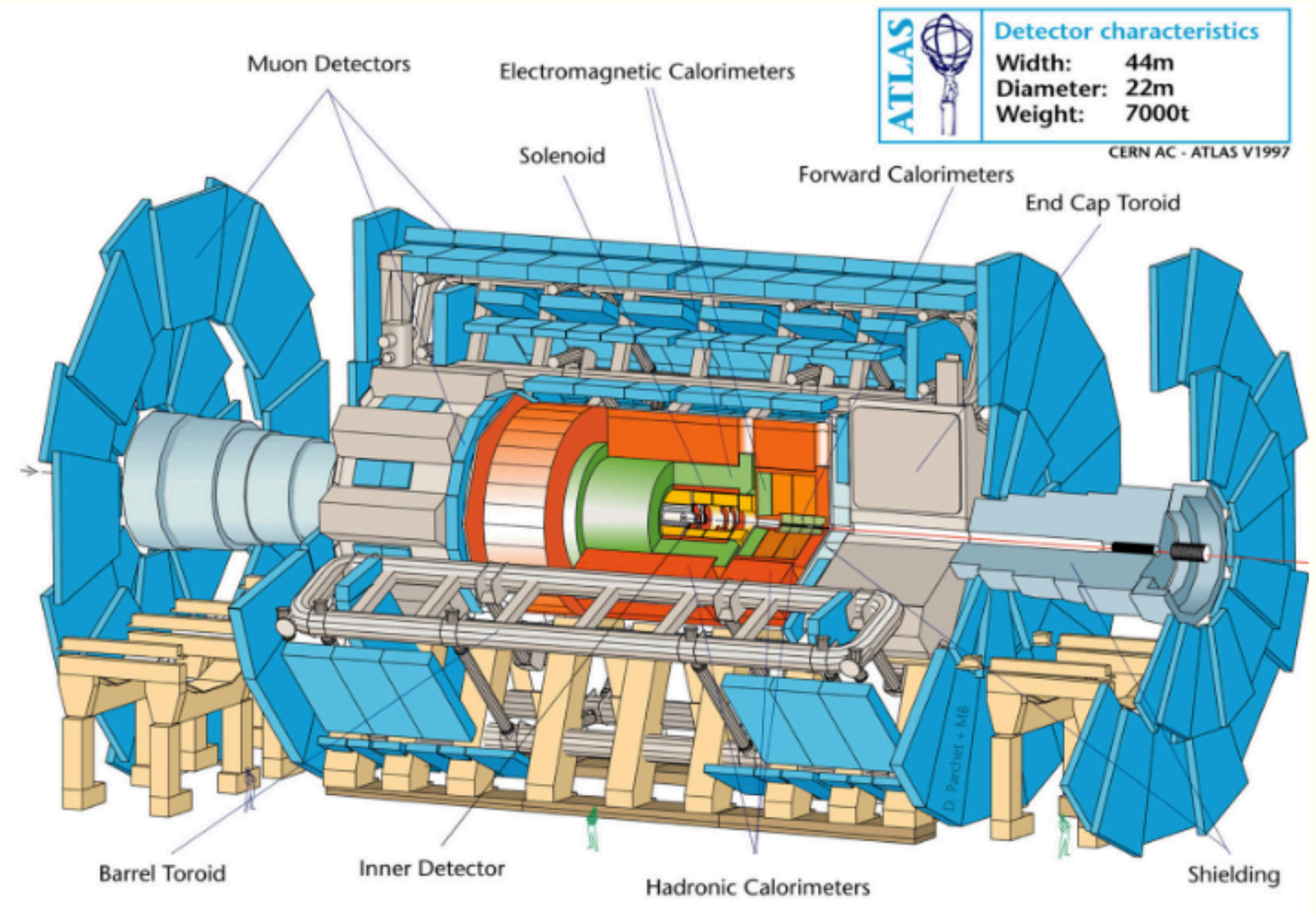
On behalf of the ATLAS collaboration

Introduction

- These slides: discussion of differential tt measurements at ATLAS
  - Inclusive cross-section measurements already covered by Anna Henrichs yesterady
- Will present several differential measurements:
  - Kinematic distributions: can help to constrain various models of top production, PDFs, etc
  - Extra jet multiplicity and flavor measurements: can help to improve radiation modeling
  - Indirect sensitivity to new physics through each of these distributions
    - tt+Higgs, RPV SUSY, etc, can create significant deviations from expectations

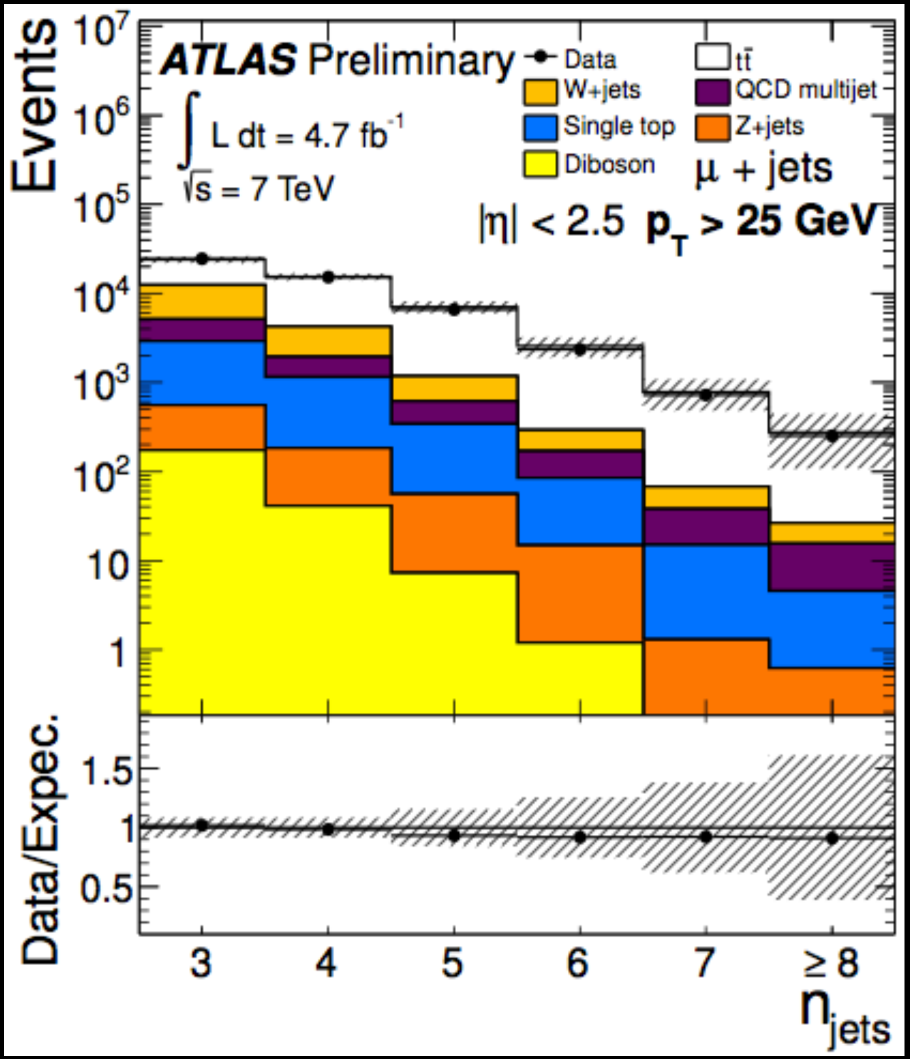
ATLAS Detector

- ATLAS: has everything needed for top physics
  - Sophisticated tracking and muon systems: precise identification of electrons and muons, as well as tagging of *b*-jets
  - Calorimeters provide high resolution measurements of jet energies needed for top reconstruction



tt+jets

- 7 TeV Measurement of multiplicity of extra jets in tt events
  - ATLAS-CONF-2012-155
  - Important to understand tuning of simulation, backgrounds to new physics
- Selection requirements
  - ==1 electron or muon
  - Missing transverse energy (for neutrino)
  - >=3 jets, >=1 tagged as a *b*-jet



Unfolding

- Will unfold to hadron level jets
  - Unfolded events with similar requirements on truth-level leptons, jets, and missing transverse energy

- Procedure to unfold is as follows:

Start with #reconstructed events, subtract background

$$N_{\rm part} = f_{\rm part!reco}\, M_{\rm part}^{\rm reco}\, f_{\rm reco!part}\, f_{\rm accept}\, (N_{\rm reco} - N_{\rm bkg})$$

Unfolding

- Will unfold to hadron level jets
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- Procedure to unfold is as follows:

Correct for acceptance of non-jet cuts

$$N_{\mathrm{part}} = f_{\mathrm{part!reco}}\, M^{\mathrm{reco}}_{\mathrm{part}}\, f_{\mathrm{reco!part}}\, f_{\mathrm{accept}}\, (N_{\mathrm{reco}} - N_{\mathrm{bkg}})$$

Unfolding

- Will unfold to hadron level jets
  - Unfolded events with similar requirements on truth-level leptons, jets, and missing transverse energy

- Procedure to unfold is as follows:

Remove events which pass reconstructed but not truth-level jet cuts

$$N_{\mathrm{part}} = f_{\mathrm{part!reco}}\, M_{\mathrm{part}}^{\mathrm{reco}}\, f_{\mathrm{reco!part}}\, f_{\mathrm{accept}}\, (N_{\mathrm{reco}} - N_{\mathrm{bkg}})$$

Unfolding

- Will unfold to hadron level jets
  - Unfolded events with similar requirements on truth-level leptons, jets, and missing transverse energy

- Procedure to unfold is as follows:

Unfolding matrix to correct for jets being reconstructed in different bin (Iterative Bayesian Unfolding)

$$N_{\mathrm{part}} = f_{\mathrm{part!reco}}\, M^{\mathrm{reco}}_{\mathrm{part}}\, f_{\mathrm{reco!part}}\, f_{\mathrm{accept}}\, (N_{\mathrm{reco}} - N_{\mathrm{bkg}})$$

Unfolding

- Will unfold to hadron level jets
  - Unfolded events with similar requirements on truth-level leptons, jets, and missing transverse energy

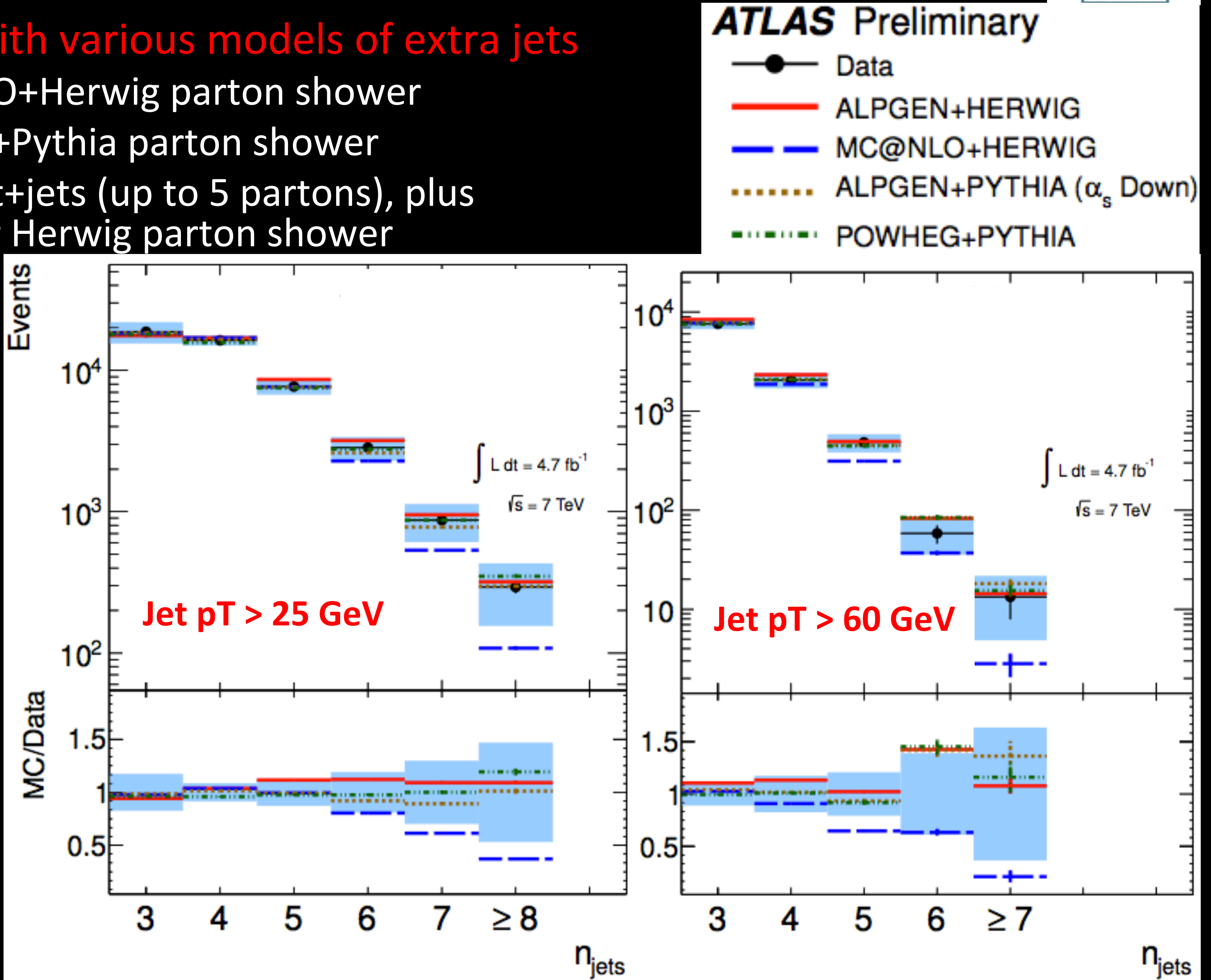
- Procedure to unfold is as follows:

Correct for events that do not pass
Reconstruction cuts but do pass truth cuts

$$N_{\mathrm{part}} = f_{\mathrm{part!reco}}\, M^{\mathrm{reco}}_{\mathrm{part}}\, f_{\mathrm{reco!part}}\, f_{\mathrm{accept}}\, (N_{\mathrm{reco}} - N_{\mathrm{bkg}})$$

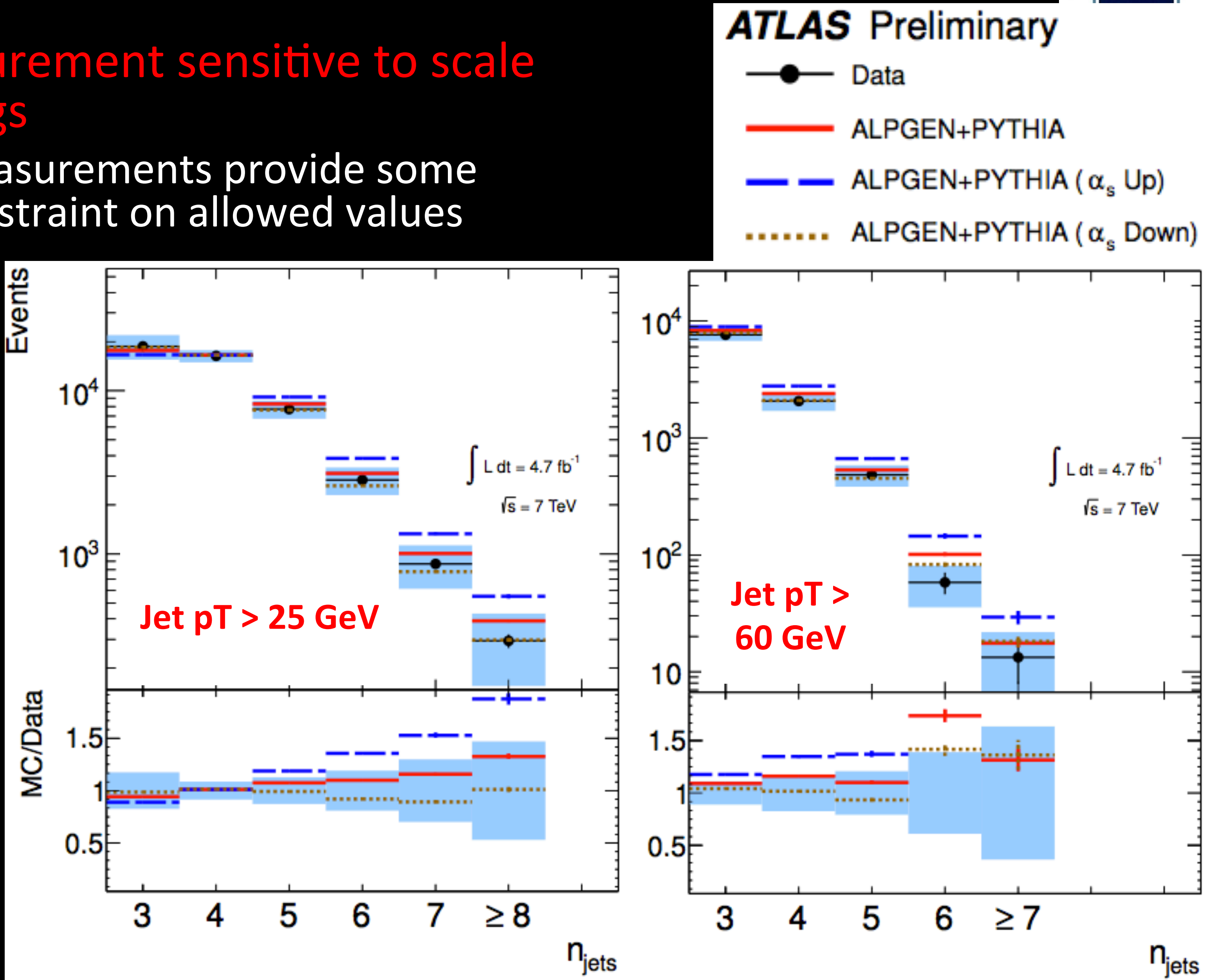
tt+jets results

- Compare with various models of extra jets
  - MC@NLO+Herwig parton shower
  - PowHeg+Pythia parton shower
  - Alpgen tt+jets (up to 5 partons), plus Pythia or Herwig parton shower



Scale uncertainties are important

- Measurement sensitive to scale settings
  - Measurements provide some constraint on allowed values



tt+heavy flavor

- 7 TeV Measurement of fraction of extra jets in association with tt that are *c* or *b*
  - Important for MC tuning, new physics searches and tt +Higgs background model
  - arXiv 1304.6386
- Perform measurement in 2-lepton channel
  - Avoids challenging contamination from W => charm decays
  - Require 2 jets tagged as *b*-jets, study properties of extra tagged jets to determine heavy-flavor fraction

tt+HF analysis method

- Heavy-flavor fraction is defined as the ratio of cross-sections:

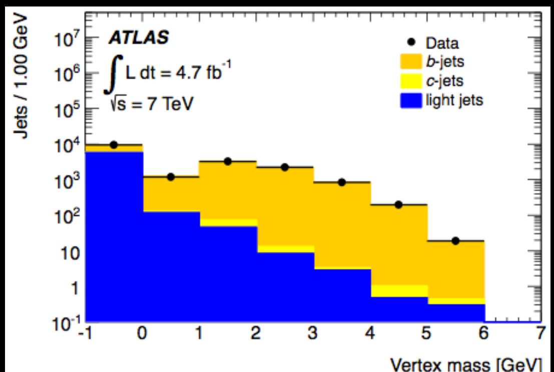
$$R_{\mathrm{HF}} = \frac{\sigma(\mathrm{tt}+b,c)}{\sigma(\mathrm{tt{+}jet})}, \sigma = \frac{N}{\int \mathcal{L}\,\epsilon}$$

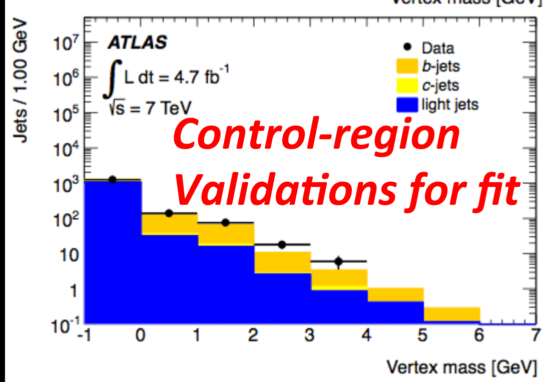
- Measurement of denominator:
  - Determine number of events with two *b*-tags, subtract backgrounds, unfold to number of events with tt pair and additional truth-level particle jet

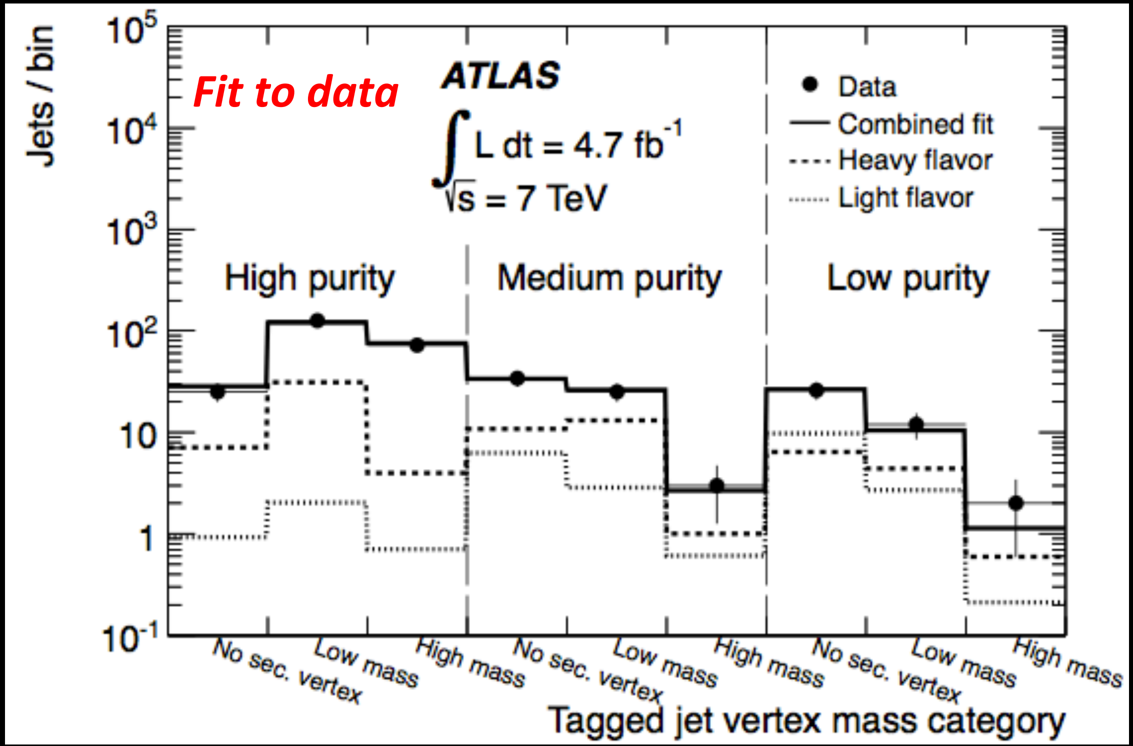
- Measurement of the numerator requires fitting based upon jet properties to determine *N*

Fit to determine extra HF

- Most *b*-tags at ATLAS have a reconstructed secondary vertex from heavy-hadron decay within the jet
  - Fit invariant mass of vertex to determine fraction of jets from heavy-flavor
  - Separate fits in bins of expected *b*-purity based upon tightness of *b*-tagging algorithm







tt+HF unfolding and results

- Challenge with the unfolding:
  - Not enough stats at 7 TeV to know *b*-fraction and *c*-fraction separately with high precision, so determining simultaneously
  - *b*-tagging efficiency depends strongly on whether extra jet is a *b* or a *c*

$$\sigma = \frac{N}{\int \mathcal{L}\,\epsilon}$$

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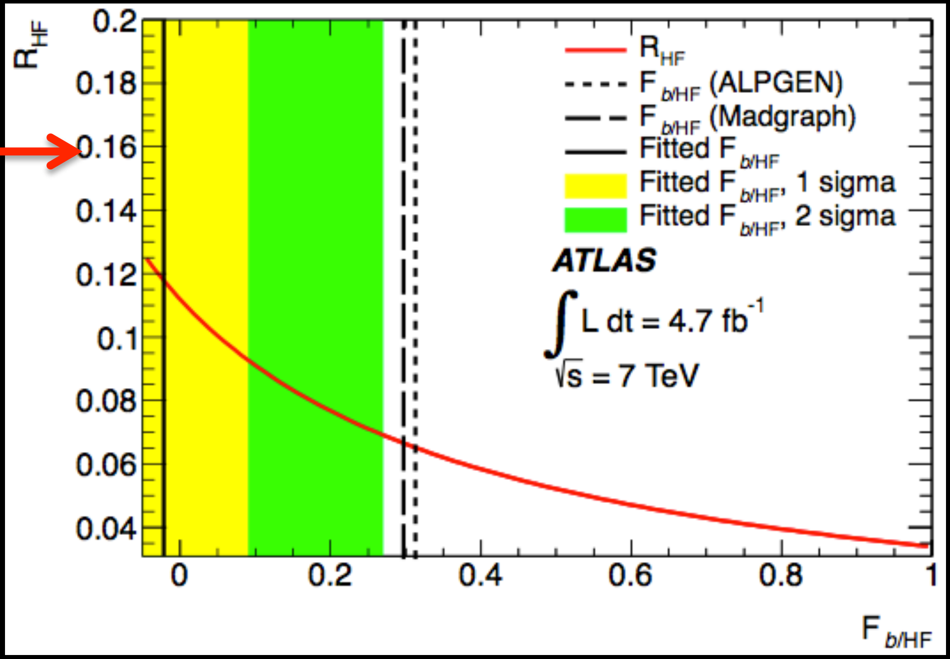
y-axis: result of measurement
x-axis: input ratio of Fb = Nb / (Nb + Nc)



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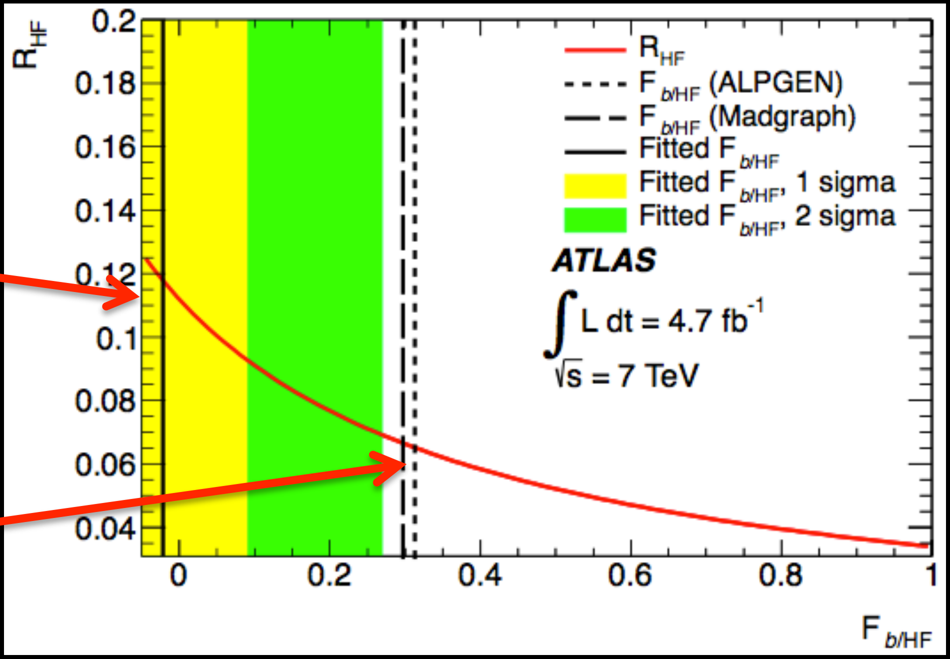
Measurement in data, with 1- and 2-sigma Statistical errors

Truth-level predictions of two tt generators : Some tension with the data



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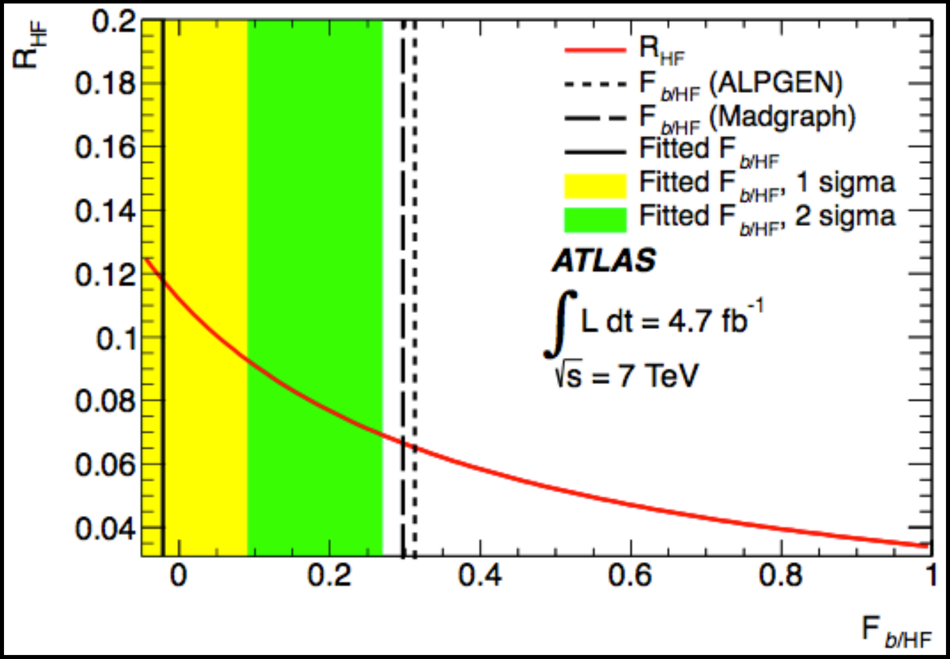
Measured value of Fb in data is unphysical (negative)

Use Alpgen's prediction of Fb for central value of measurement

Take asymmetric systematic that covers measurement in data. Conservative enough to cover all reasonable possibilities.

This is the largest uncertainty in the measurement



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$$\sigma = \frac{N}{\int \mathcal{L}\,\epsilon}$$

Final measurement result:

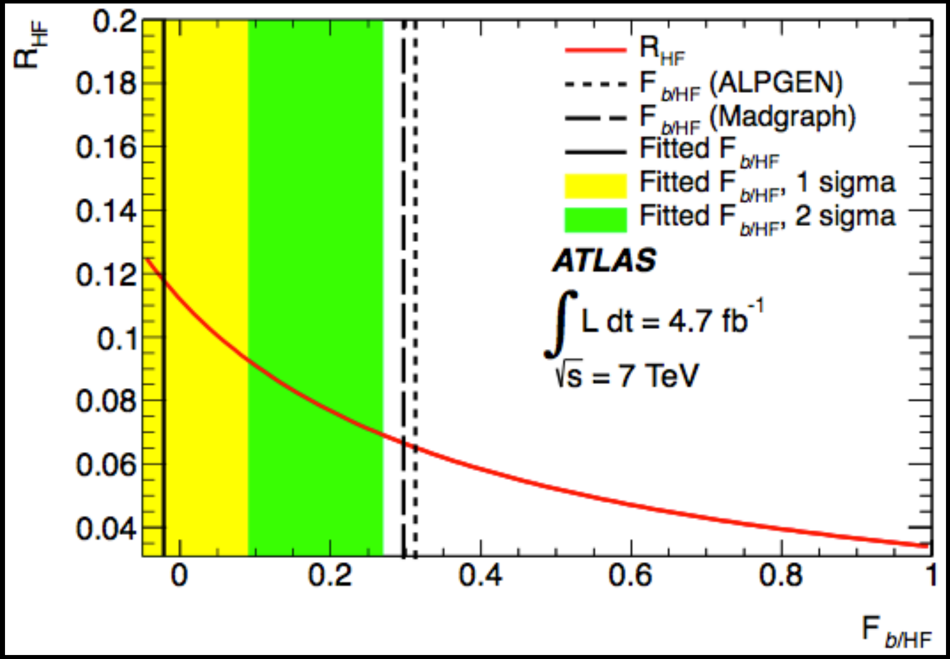
$$R_{\mathrm{HF}} = 7.1 \pm 1.3(\mathrm{stat.})^{+5.3}_{-2.0}(\mathrm{syst.})\%$$

LO Prediction from Alpgen+Herwig:

$$R_{\mathrm{HF}} = 3.4 \pm 1.1(\mathrm{syst.})\%$$

Prediction from PowHeg+Herwig:

$$R_{\mathrm{HF}} = 5.2 \pm 1.7(\mathrm{syst.})\%$$



7 TeV Differential cross-section

- Differential distributions published with 2.05 fb-1
  - Eur. Phys. J. C (2013) 73: 2261

- Selection requirements:
  - >=1 electron or muon
  - >=4 jets, >= *b*-jet
  - Identification of neutrino through missing transverse energy

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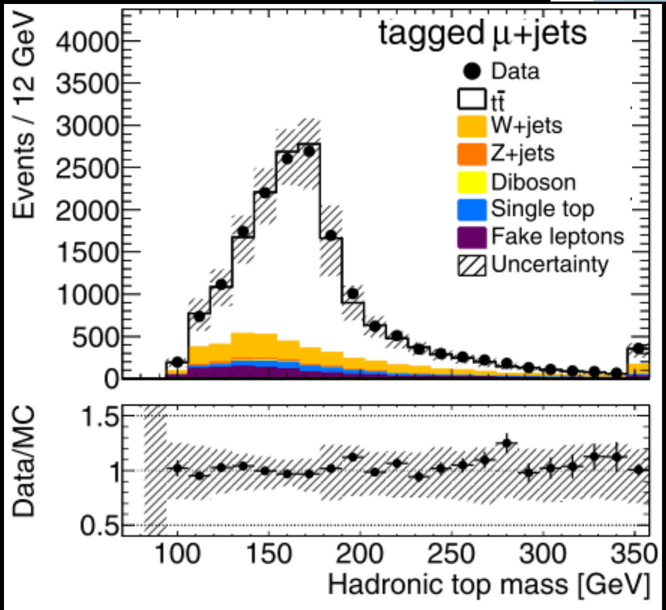
- tt reconstruction
  - Likelihood fit to all reconstructed particles from tops
  - Based upon top and W-masses



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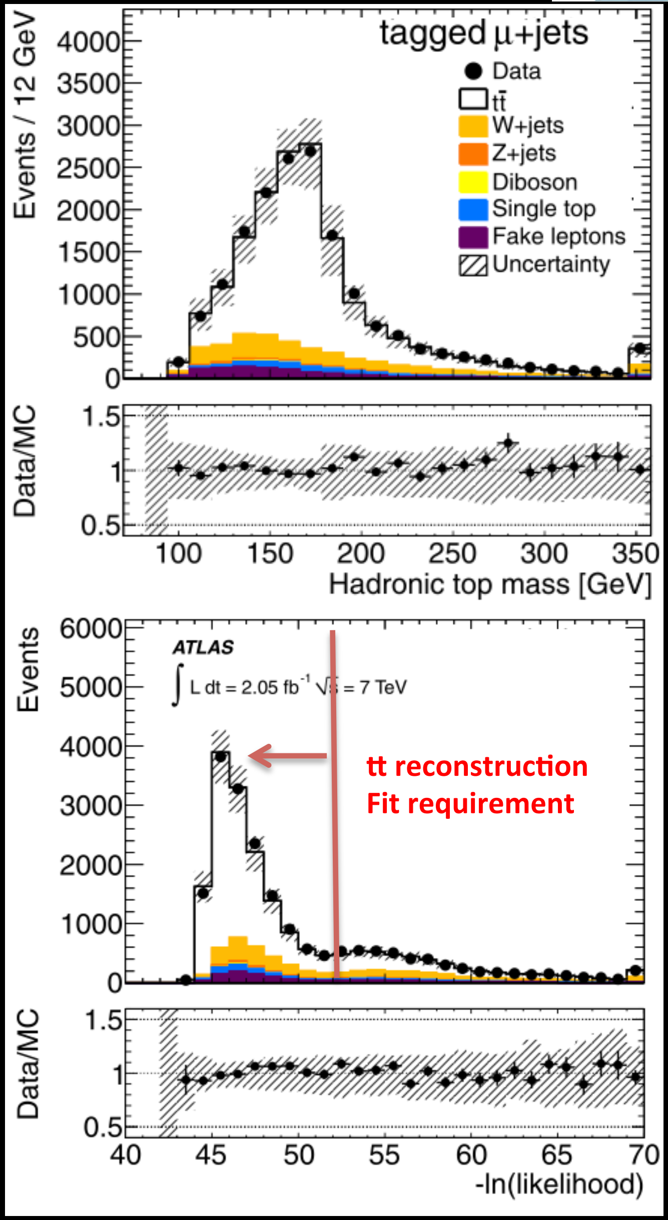
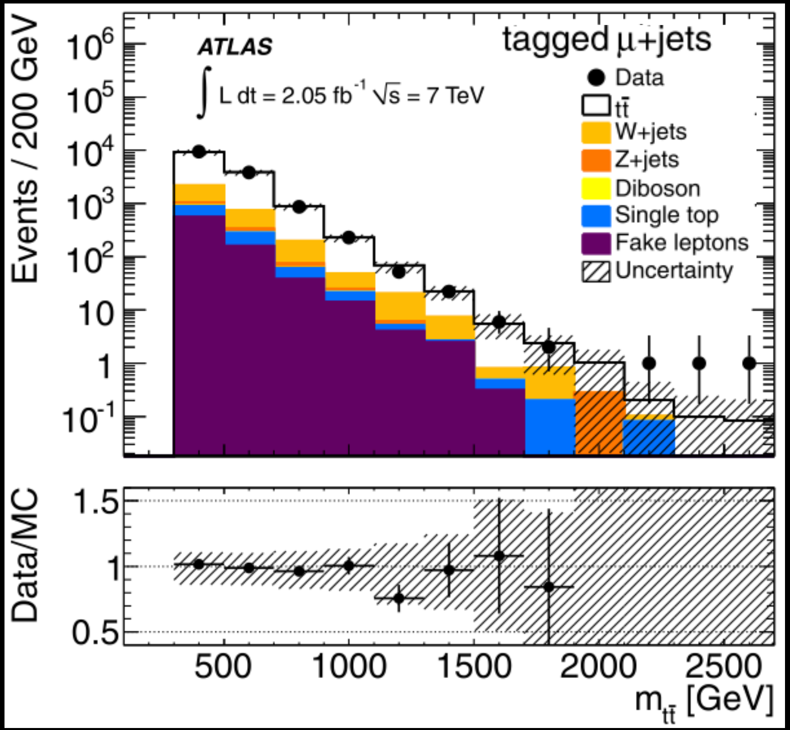
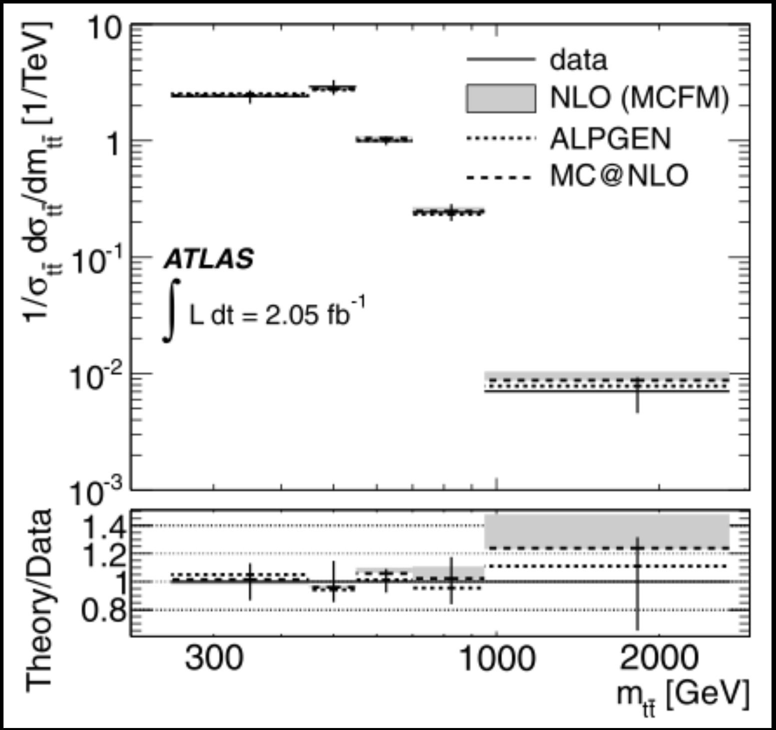
  - Identification of neutrino through missing transverse energy
- tt reconstruction
  - Likelihood fit to all reconstructed particles from tops
  - Based upon top and W-masses
  - Loose cut to remove poorly-reconstructed events



Differential distributions and unfolding

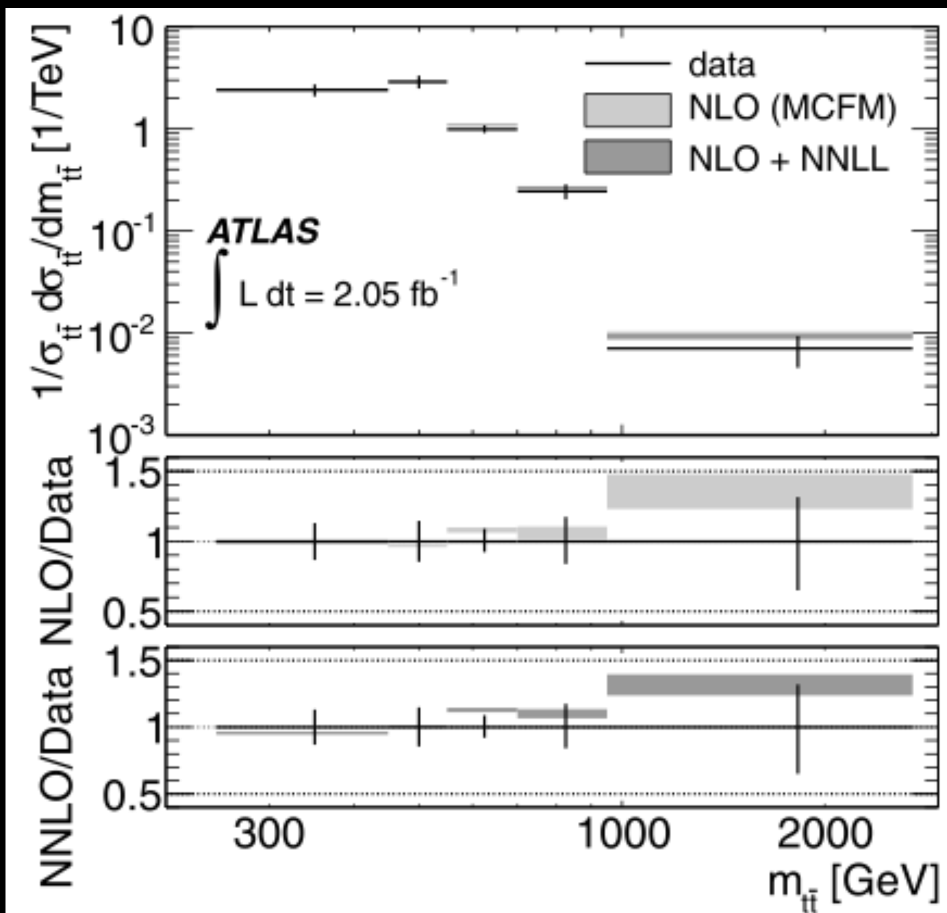
- Kinematic distributions of tt invariant mass, rapidity, pT
  - With respect to truth top quarks after radiation
- Unfolding
  - Bin width optimized to minimize systematics from unfolding
  - Unfolding procedure chosen to be robust if the Standard Model predictions are biased or new physics processes are present

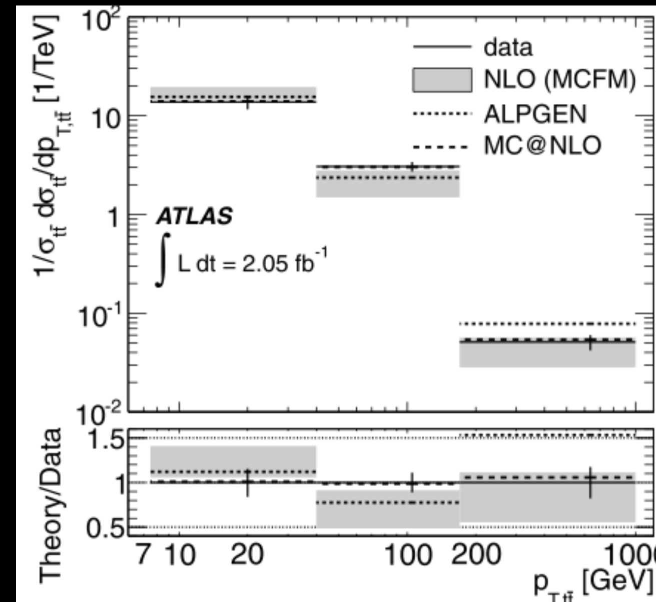


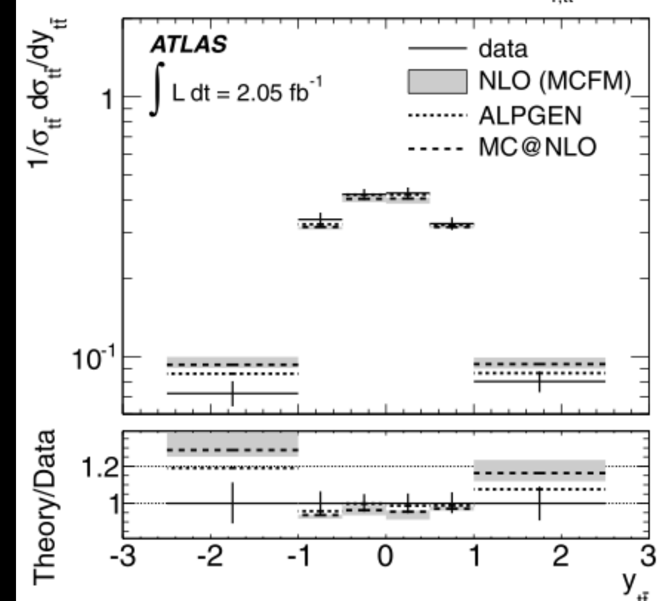


Results

- Comparisons with respect to various ATLAS simulations and MCFM NLO QCD
  - For m_tt also compare with NLO+NLL
    - V. Ahrens et all
  - Theory uncertainties from spread of three PDFs, alpha_S, and renormalization+factorization scales

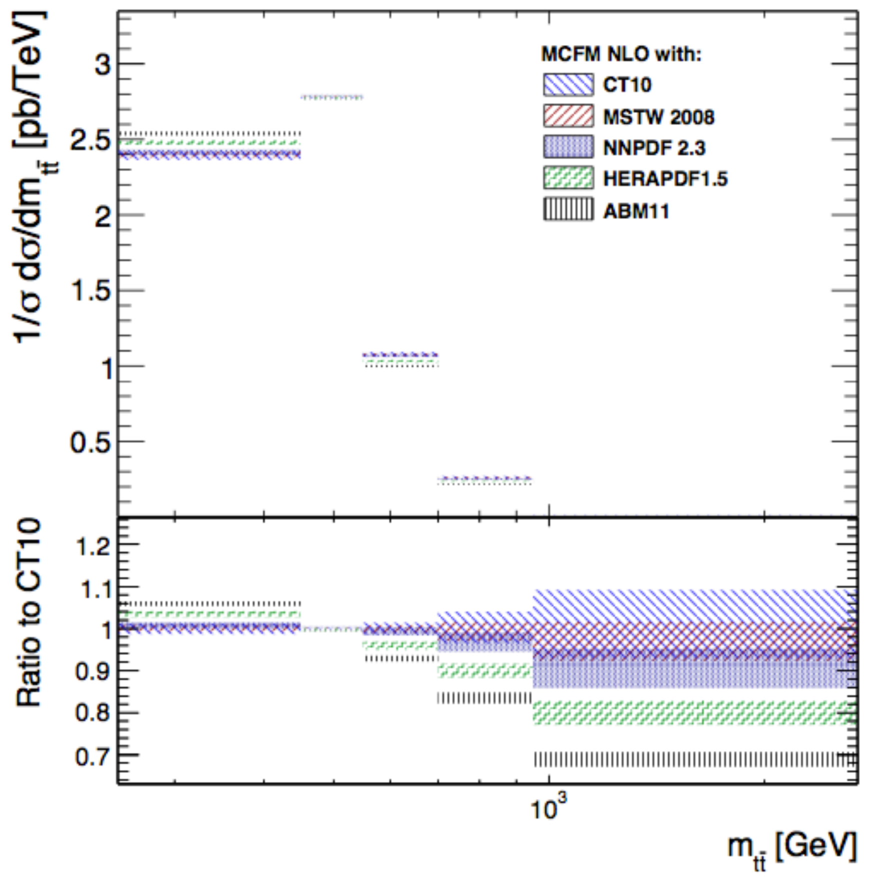


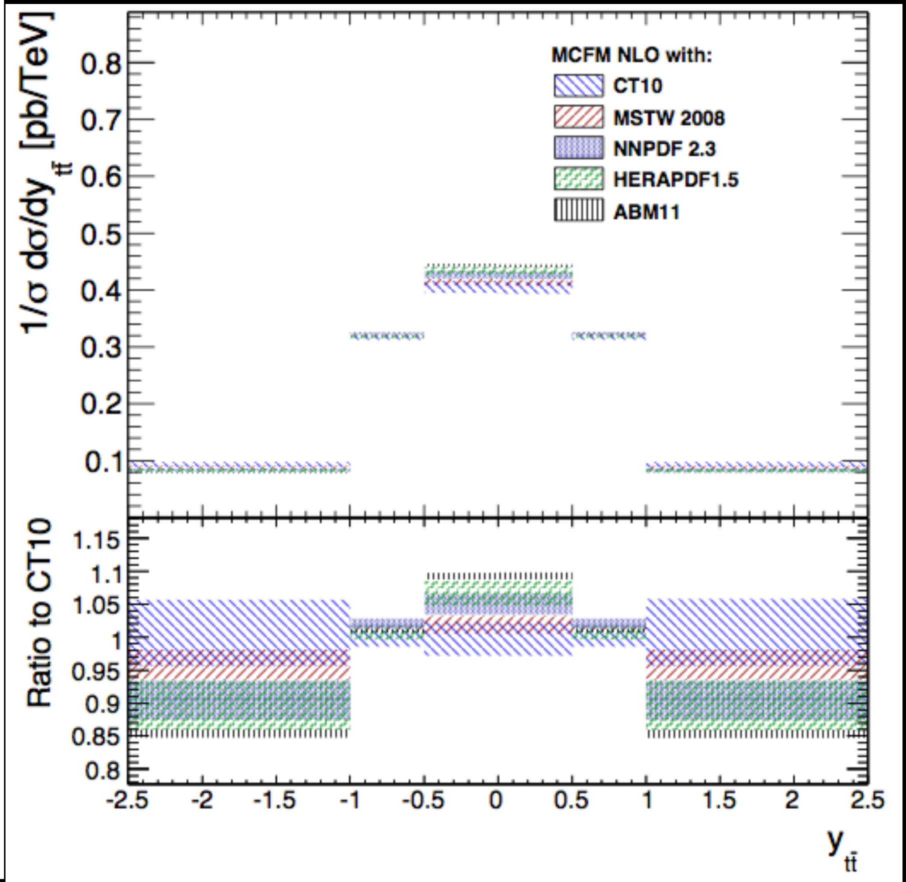




Implications for PDFs

- Compare NLO PDFs using NLO MCFM for these distributions
  - PDF uncertainties evaluated according to prescriptions of each PDF collaboration, accounting for asymmetries
  - Significant spread in predictions of each PDF set. Can we constrain these PDFs?

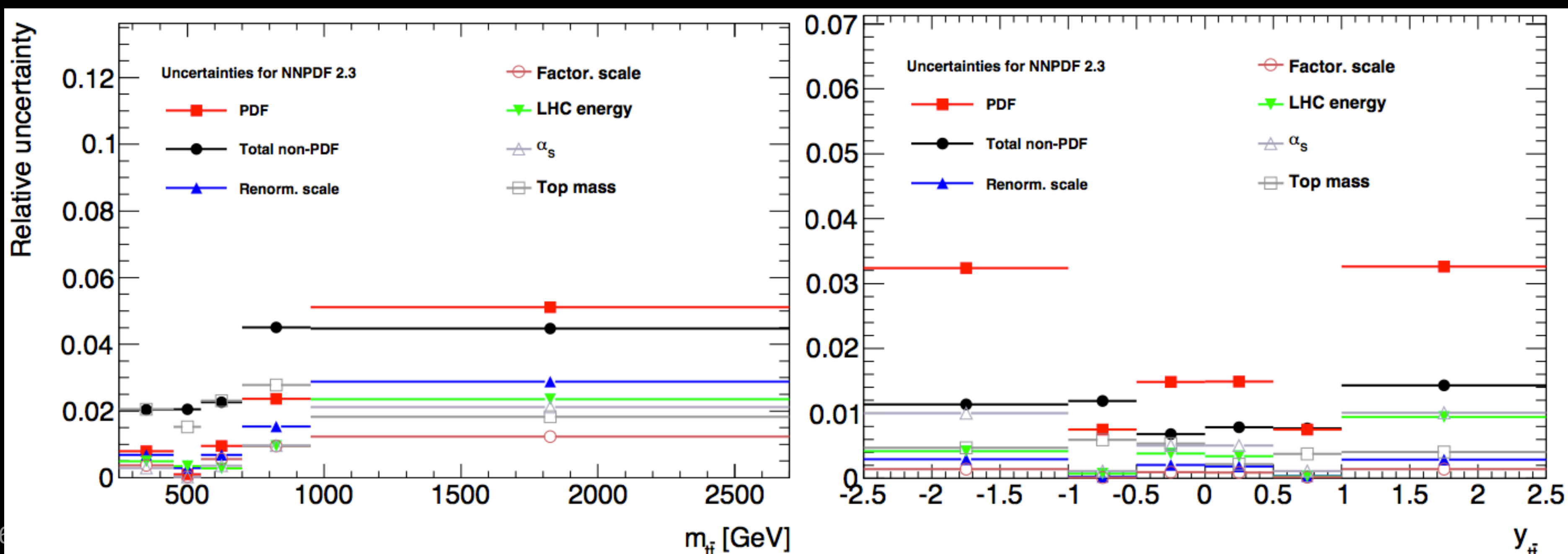




Other modeling uncertainties matter too!

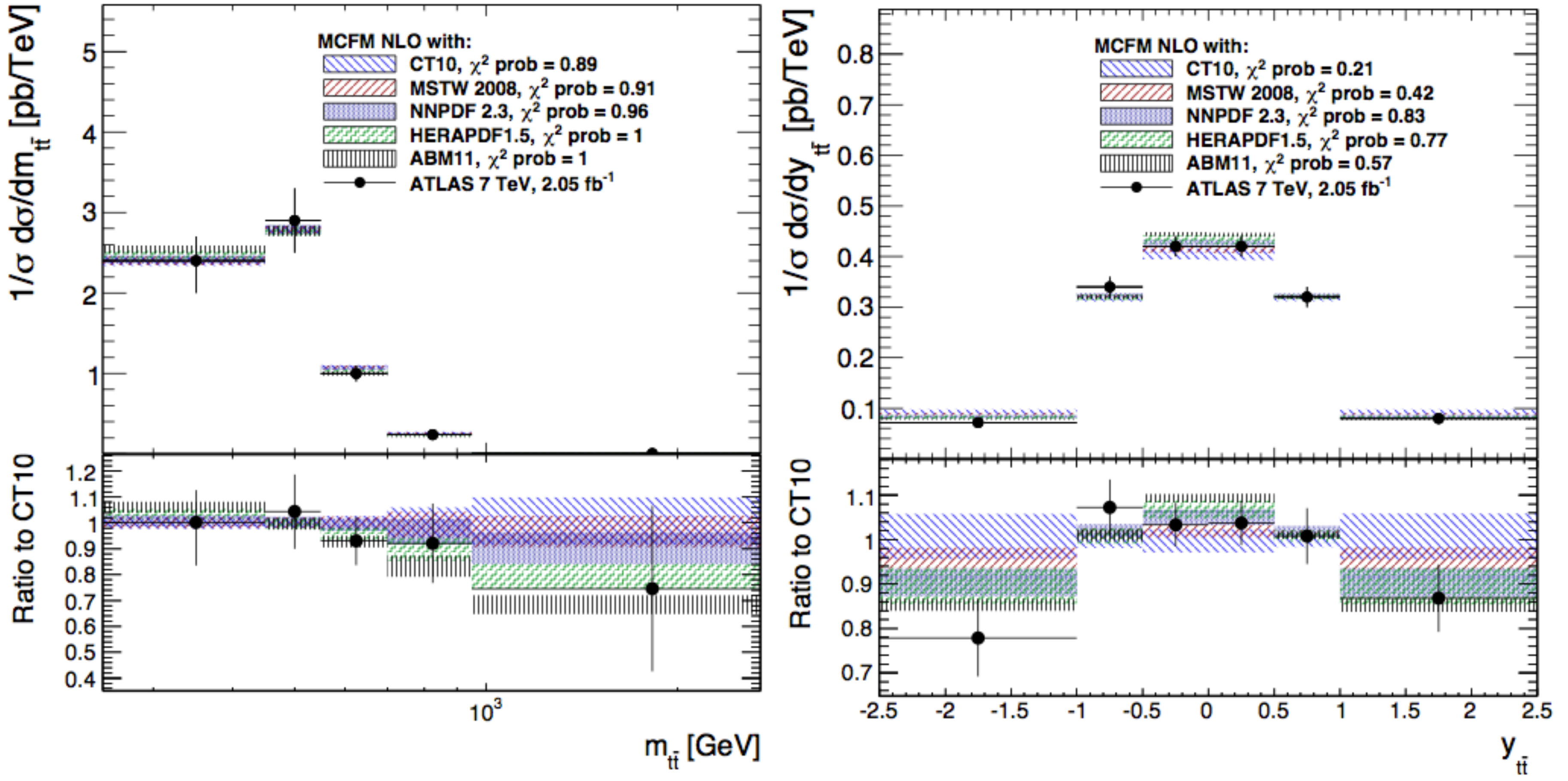
- Can't just compare with PDFs in isolation, other modeling uncertainties matter
  - Vary factorization and renormalizations scales by x2
  - Vary top mass by 1%
  - Vary LHC beam energy by 1% according to recommendations
  - Vary alpha_S by 1-sigma
  - These other modeling uncertainties are not negligible

- Not considered yet: Electroweak corrections, which are not negligible either



Compare results with data

- Add all uncertainties in quadrature and compare with data
  - Mtt: data uncertainties too large to say much yet
  - Ytt: some significant tension with CT10



Conclusion

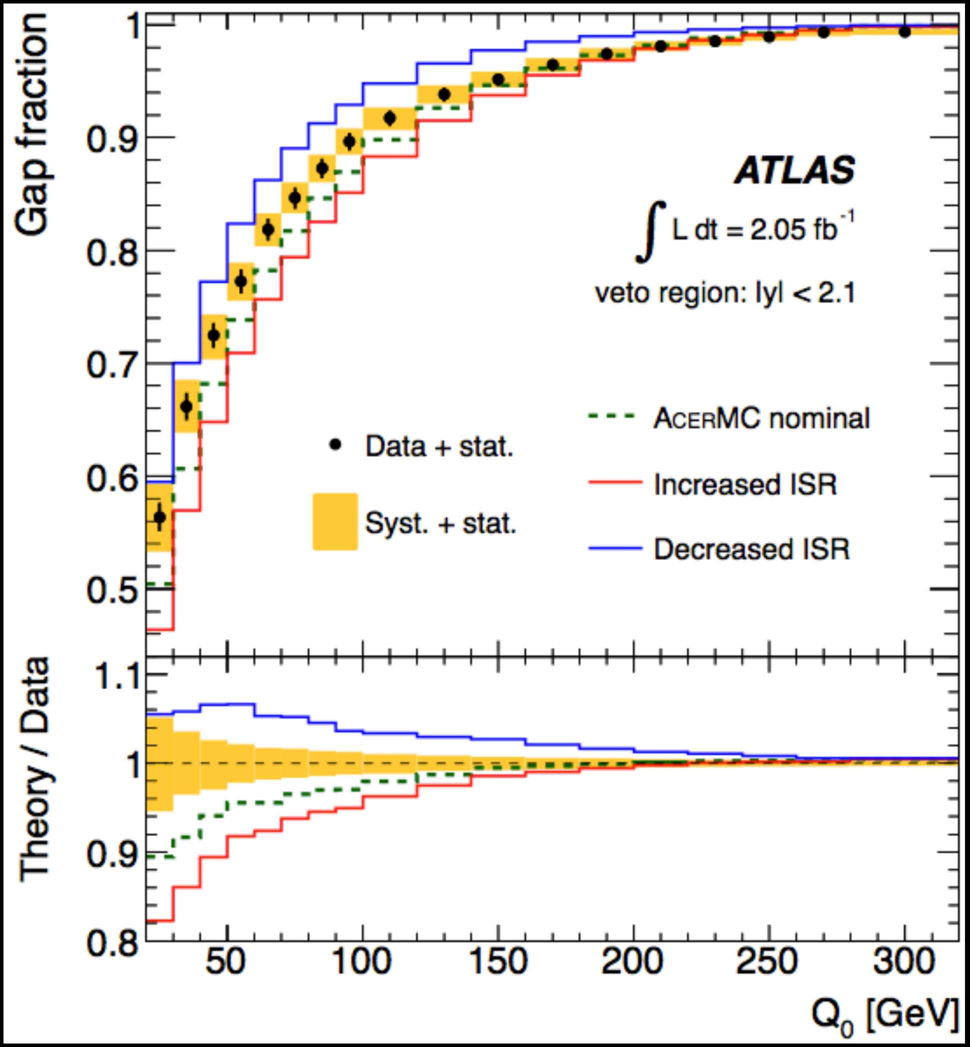
- Results of various 7 TeV differential tt measurements at ATLAS have been presented
  - Largely consistent with expectations
- Results are useful for constraining modeling
  - tt+jets measurements have been used to constrain scale/radiation-related uncertainties
  - Differential kinematic measurements already show tension with some PDF sets
    - Future measurements with smaller uncertainties should allow improvements in PDF fits
    - But further work is needed to understand what the proper predictions are (e.g. effects of Electroweak corrections)

Backup

"Gap fraction" measurement

[Eur.Phys.J. C72 (2012) 2043]

- Early 7 TeV measurement to constrain showering:
  - Select dilepton tt events, and tag two *b*-jets
  - Plot the fraction of events without an extra jet above a certain pT
    - This is the "gap fraction"
  - Measurement allowed us to reduce radiation uncertainties by ~50%



The fraction of events without an extra jet above a pT cut of Q_0

tt mass and rapidity errors

$1/\sigma\ d\sigma/dm_{tt}$	m_{tt} bins [GeV]				
Uncertainty [%]	250 – 450	450 – 550	550 – 700	700 – 950	950 – 2700
Total	14 / -14	15 / -15	10 / -10	18 / -16	37 / -43
Stat only	2 / -2	4 / -4	5 / -5	8 / -8	18 / -19
Syst. only	14 / -14	14 / -15	8 / -8	16 / -14	32 / -37
Luminosity	1 / -1	2 / -2	2 / -1	1 / -1	1 / -2
Jets	11 / -10	10 / -11	6 / -6	13 / -11	20 / -24
Leptons	1 / -1	1 / -1	1 / -2	2 / -2	9 / -6
$E_{\mathrm{T}}^{\mathrm{miss}}$ energy scale	1 / -1	1 / -1	1 / -2	2 / -1	9 / -5
Fake-lepton and W backgrounds	5 / -7	10 / -7	5 / -4	5 / -6	10 / -15
Monte Carlo gen., theory, ISR/FSR, and PDF	6 /-7	7/-7	4/-4	8/-7	14/-18

$1/\sigma\ d\sigma/dy_{tt}$	y_{tt} bins					
Uncertainty [%]	-2.5 – -1	-1 – -0.5	-0.5 – 0	0 – 0.5	0.5 – 1	1 – 2.5
Total	11 / -10	7 / -7	5 / -5	5 / -5	6 / -5	9 / -9
Stat. only	5 / -5	4 / -4	3 / -3	3 / -4	4 / -4	5 / -5
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Luminosity	1 / -2	1 / -1	1 / -1	1 / -1	1 / -1	1 / -1
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tt+b,c systematic uncertainties

Source	% (full calculation)	% (A x ε_{HF})
Lepton reconstruction	0.2	0.2
Jet reconstruction and calibration	11.2	5.4
$E_{\mathrm{T}}^{\mathrm{miss}}$ reconstruction	0.9	0.6
Fake lepton estimate	3.4	0.0
Tagging efficiency for *b*-jets	3.1	2.4
Tagging efficiency for *c*-jets	21.2	5.9
Tagging efficiency for light jets	8.4	0.2
Fragmentation modeling	1.2	7.3
Generator variation	4.2	3.4
Initial- and final state radition	2.5	2.2
PDF uncertainties	2.8	1.0
Additional fit uncertainties	6.6	–
Fiducial flavor composition	$^{+69.0}_{-0.0}$	$^{+69.0}_{-0.0}$
Total systematic	$^{+74.2}_{-27.4}$	$^{+69.9}_{-11.9}$