Differential cross-section measurements of top-quark-pair production in the dilepton final state at 13 TeV with the ATLAS experiment

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on behalf of the ATLAS collaboration

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Overview

Motivation

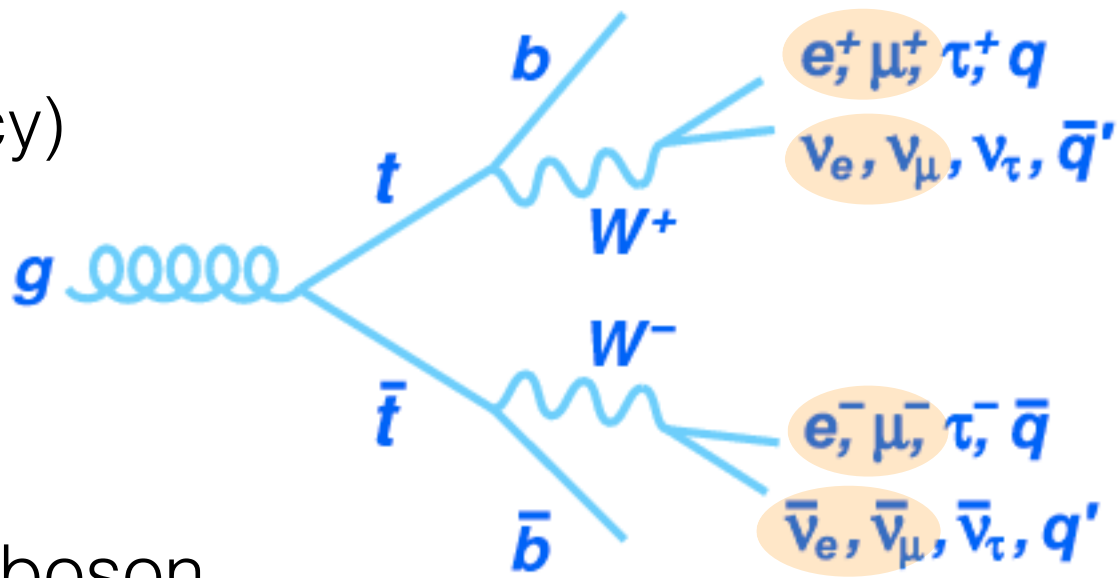
- Cross-section and kinematics of top quarks - important test of SM
- Top is usually a large background for searches for new physics
- Important input for tuning simulations
- First ATLAS measurement in dilepton channel of top p_T

Analysis

- Measurements of top-quark pair differential cross-sections
  using final states with electrons and muons
- Using 3.2 fb^{-1} of data collected by ATLAS in 2015
- Measuring top variables: p_T & $|y|$
  and $t\bar{t}$ variables: p_T, $|y|$ & M

Event selection

- Dileptonic $t\bar{t}$ decay:
    - Look at *eμ* channel - clean signal, low background
- Select exactly two oppositely charged leptons (1 electron, 1 muon) (p_T > 25 GeV)
- At least 2 jets required to reconstruct the $t\bar{t}$ system (p_T > 25 GeV)
- Require at least 1 b-tagged jet (77% efficiency)



Background contributions

- Same final state: *Wt* single top, Z+jets, diboson
- Fake: $t\bar{t}$ (lepton + jets channel), ttV, W + jets, t-channel single top

Reconstruction: Neutrino weighting

- Reconstruct dilepton $t\bar{t}$ system
  → Two unknowns: η of two neutrinos
- Constrain system using values for top mass and W mass
- Test many different assumptions for η for the two neutrinos
- Give each solution a weight based on observed E_T^{miss} in the event
- Select solution with **highest weight**

Kinematic constraints

$$(\ell_{1,2} + \nu_{1,2})^2 = \mathrm{M}_W^2 = 80.2^2$$

$$(\ell_{1,2} + \nu_{1,2} + b_{1,2})^2 = \mathrm{M}_t^2 = 172.5^2$$

Weight function

$$w_i = \exp\left(\frac{-\Delta E_x^2}{2\sigma_x^2}\right) \cdot \exp\left(\frac{-\Delta E_y^2}{2\sigma_y^2}\right)$$

E_T^{miss} resolution:
15 GeV for both *x* and *y*

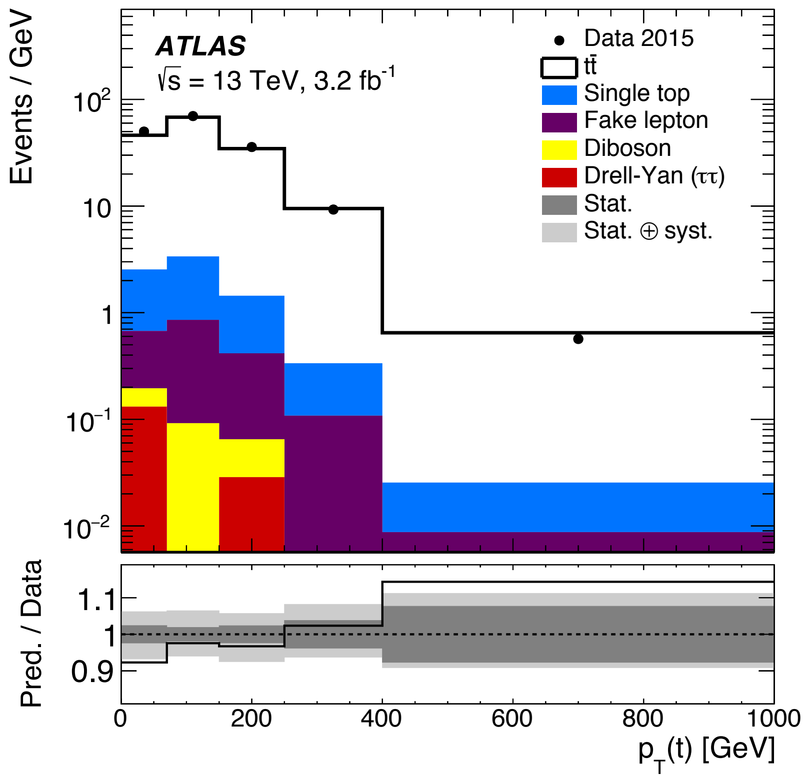
Improving resolution

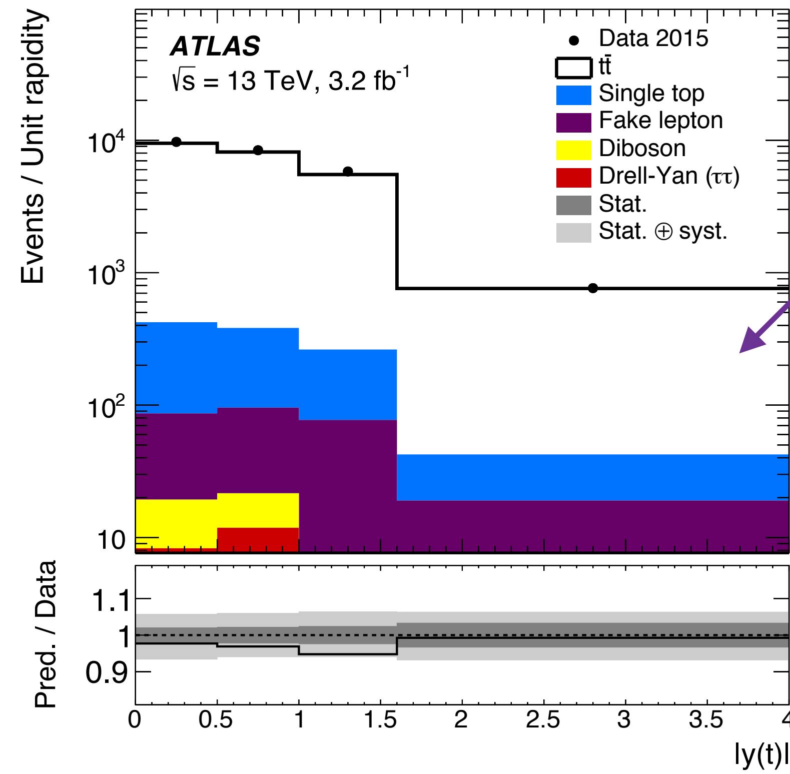
- Smear jet p_T: 10% gaussian, 20 times per jet
- M_t sampling: 1 GeV steps {168, 178}

→ **Reco efficiency ~ 80%**

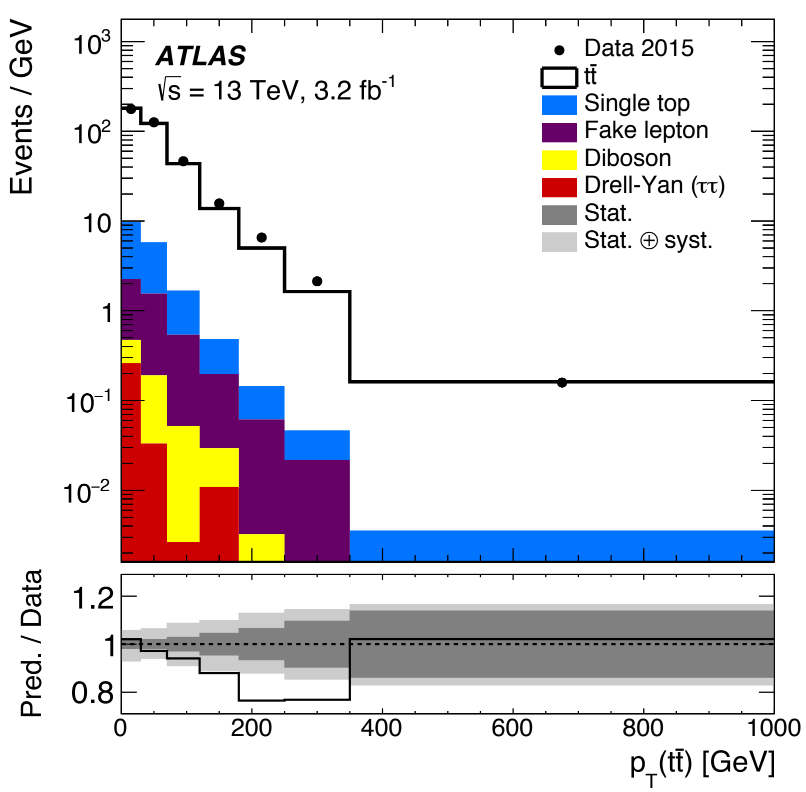
Kinematic distributions of top variables

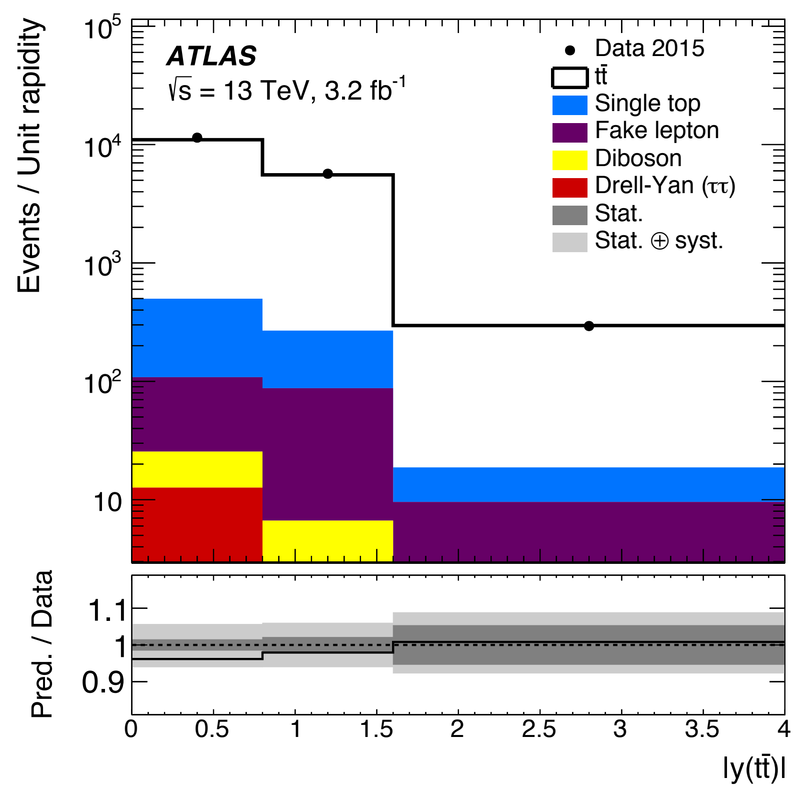
arXiv:1612.05220

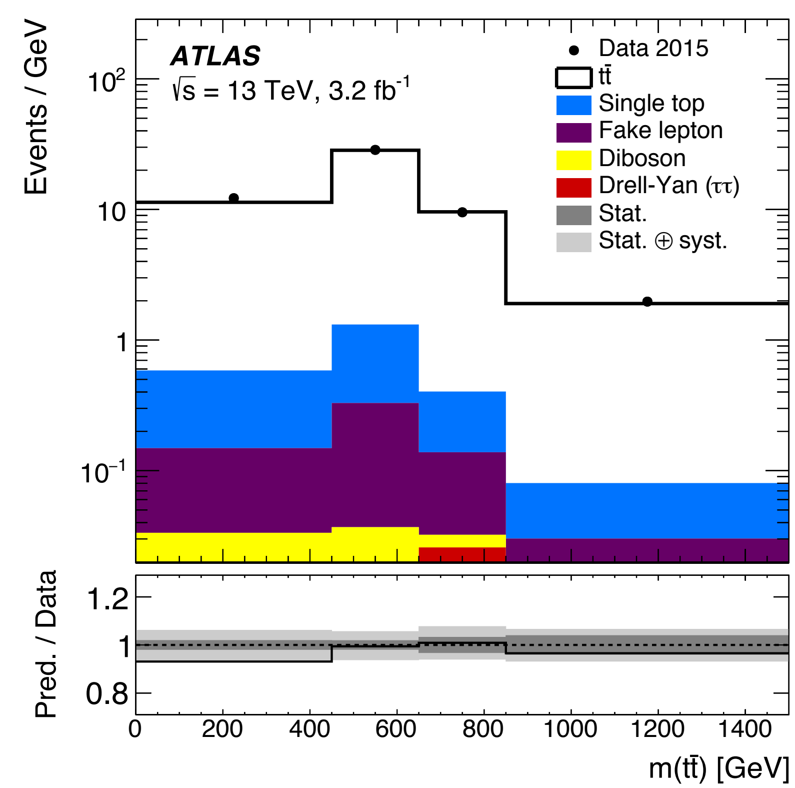




Mostly $t\bar{t}$ events







Unfolding

Data

↓ Subtract backgrounds estimated using MC from data

Data - Background

↓ Bayesian iterative unfolding with 6 iterations

Unfolded data

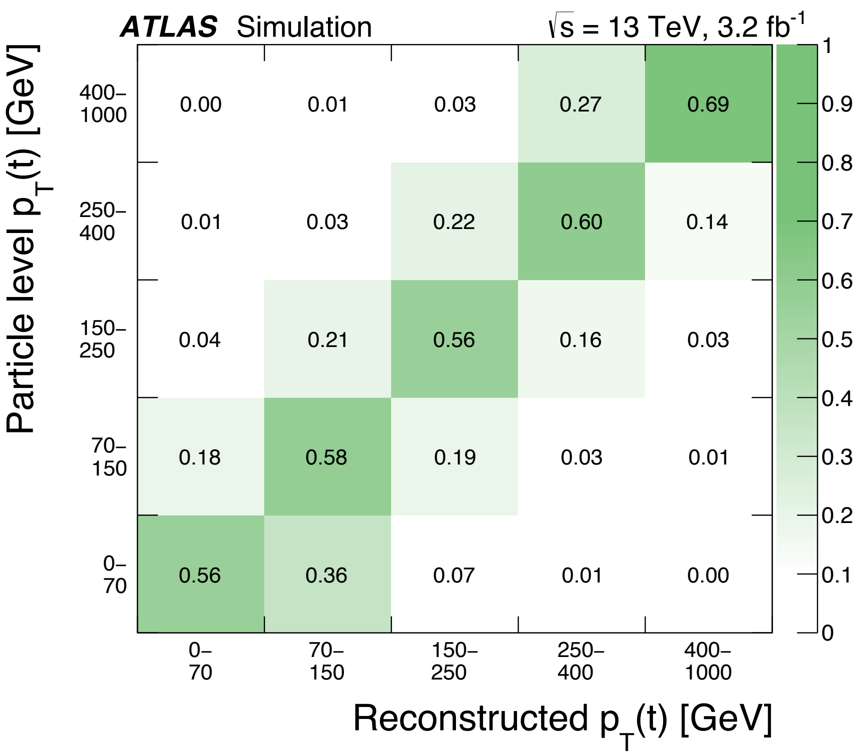
↓ Correct for fiducial phase-space acceptance

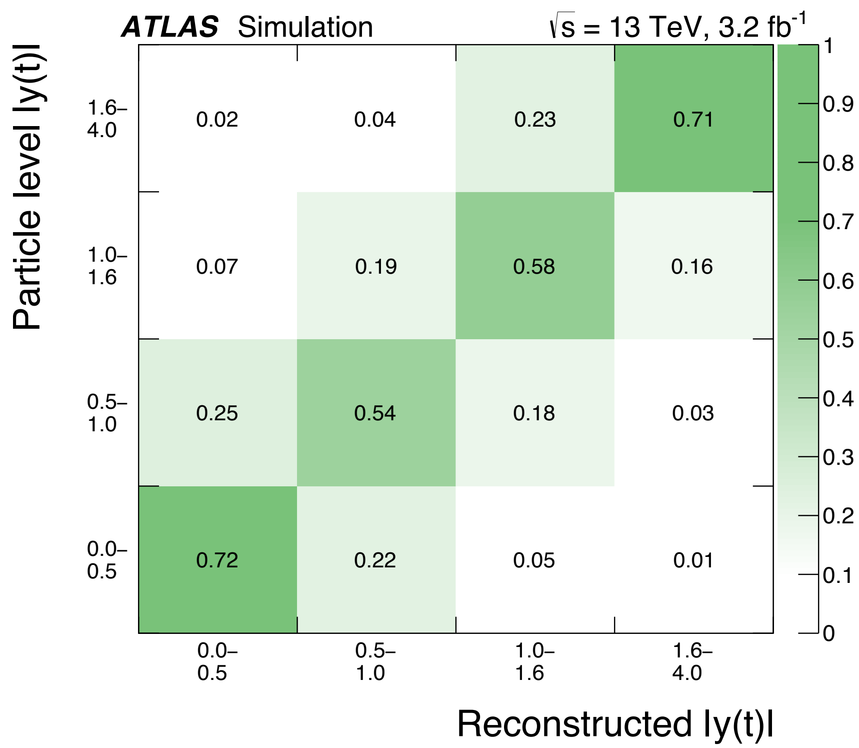
Fiducial data

↓ Determine cross-section, absolute or normalised

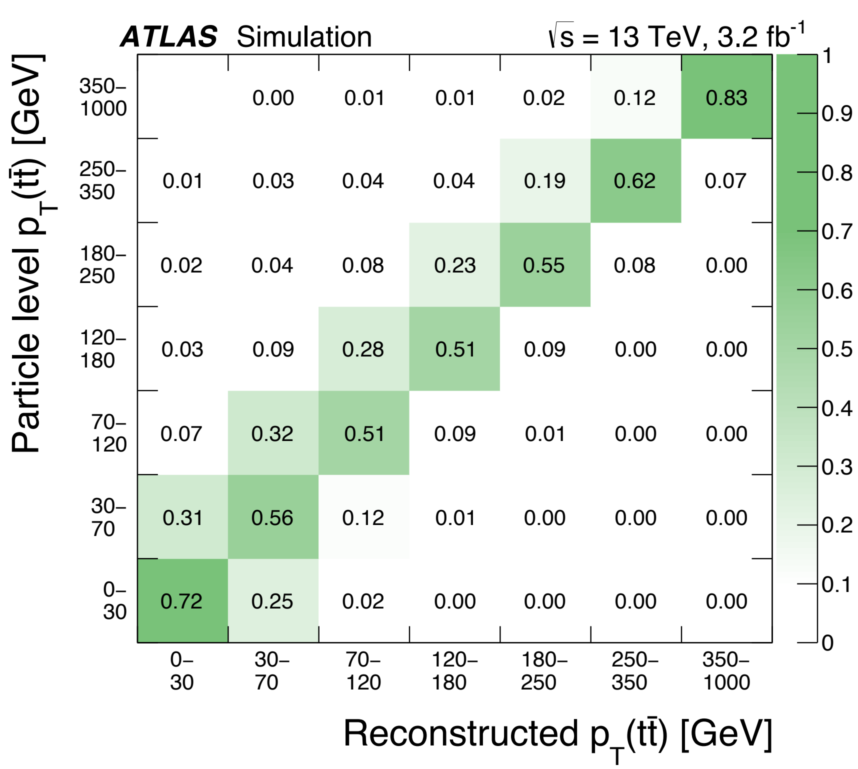
Result

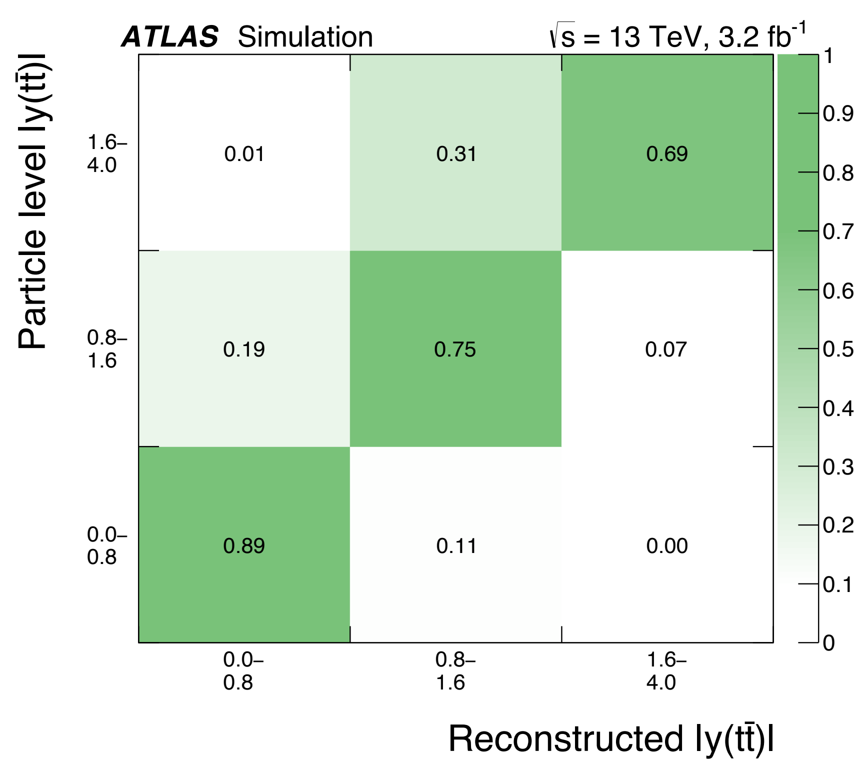
Unfolding: migration matrices

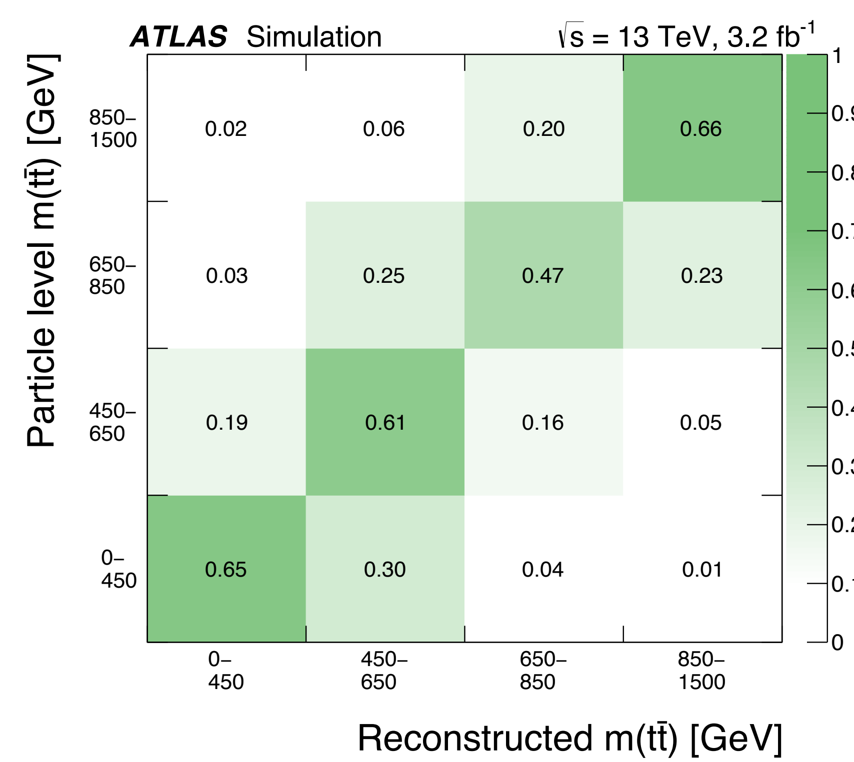




- Binning is chosen to have at least 50% on diagonal
- Also consider resolution, statistics and unfolding stability







Systematic uncertainties

General method:

unfold shifted sample with nominal response matrix, compare to nominal sample

Largest uncertainties

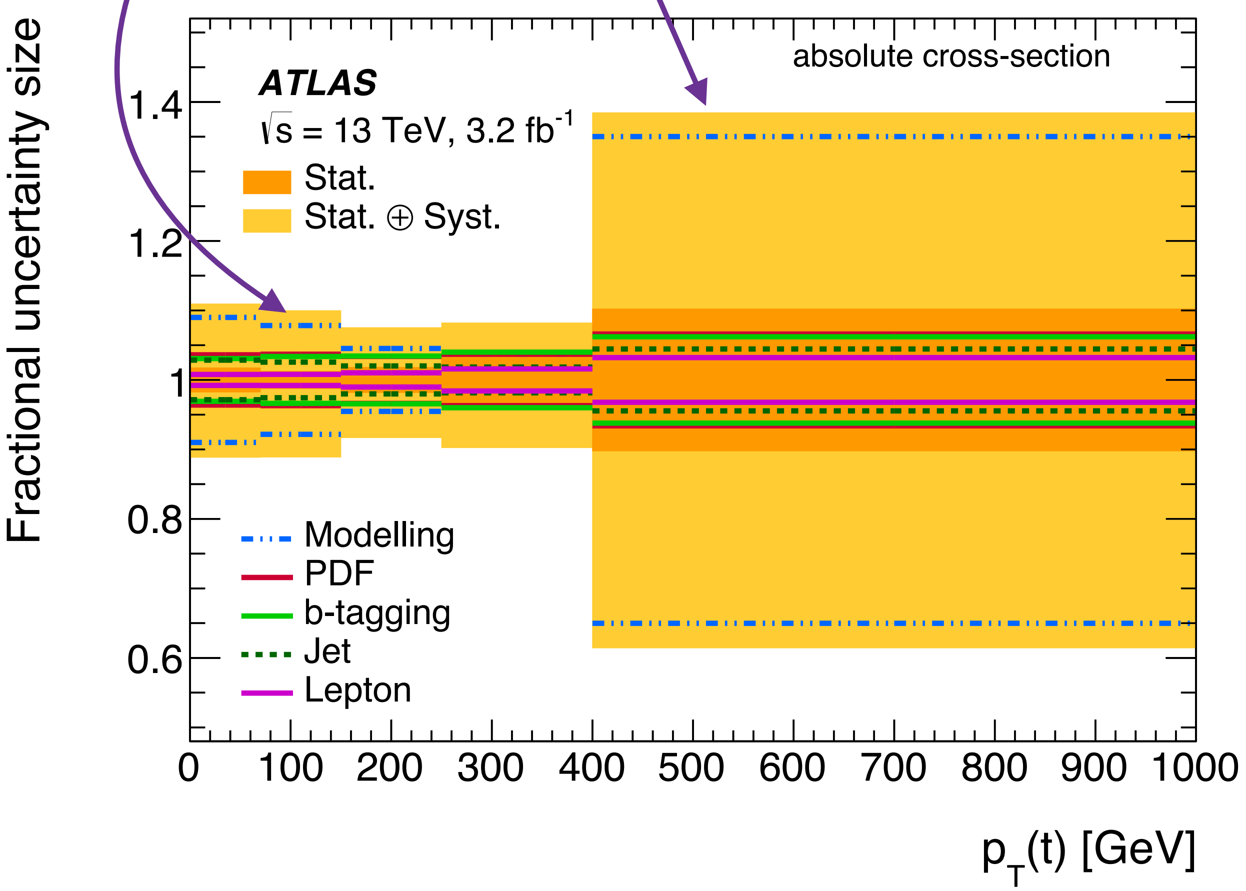
- Jet related: significant uncertainties in both absolute and normalised
- Luminosity: large for absolute cross-sections (~2%)
- PDFs: use PDF4LHC15 prescription, with extrapolation of CT10 → CT14
- Modelling uncertainties:
  - ★ ISR/FSR: Powheg+Pythia6 with high and low radiation settings
  - ★ NLO generator: Powheg+Herwig++ vs aMC@NLO+Herwig++
  - ★ Parton shower: aMC@NLO+Herwig++ vs aMC@NLO+Pythia8

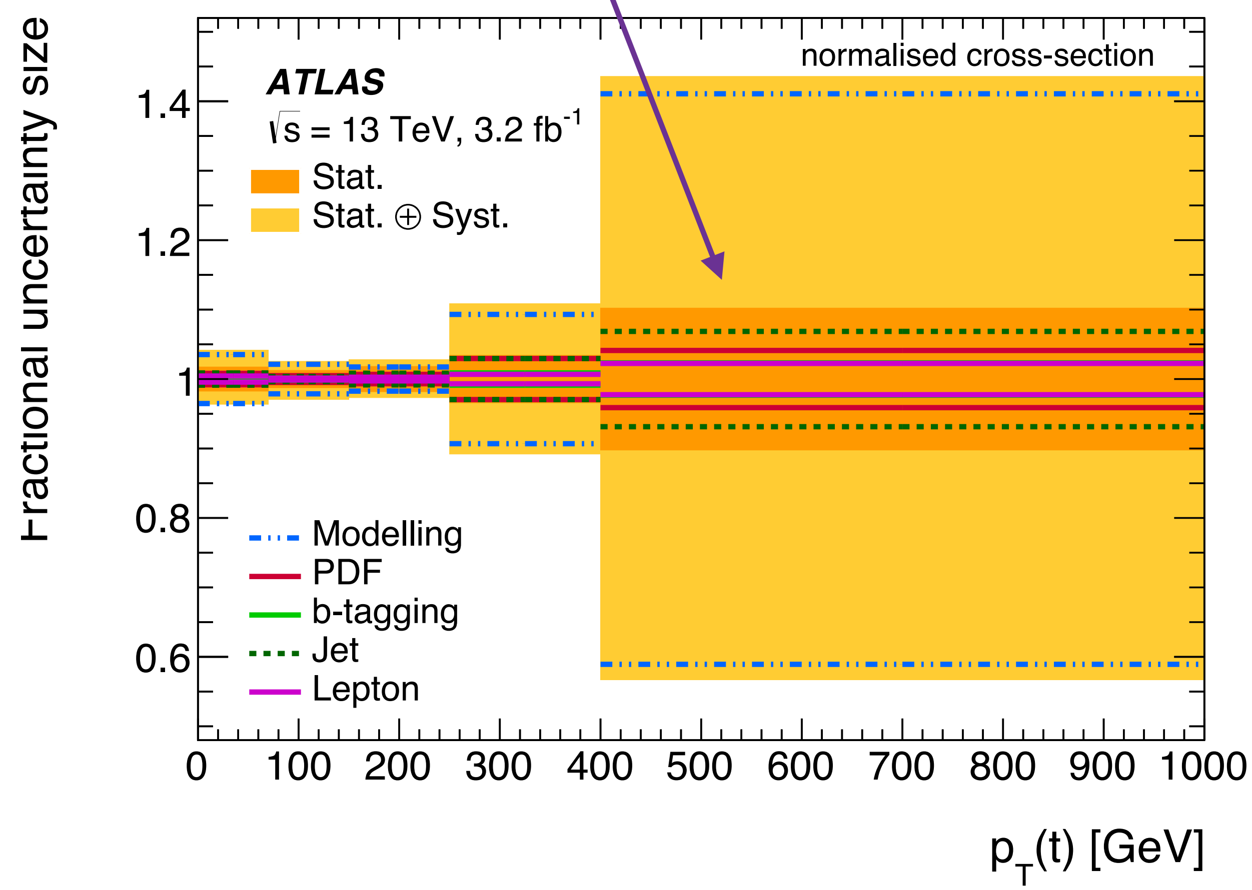
baseline sample unfolded using alternative sample

Systematic uncertainties

modelling uncertainties dominate

jet uncertainties large at high pT

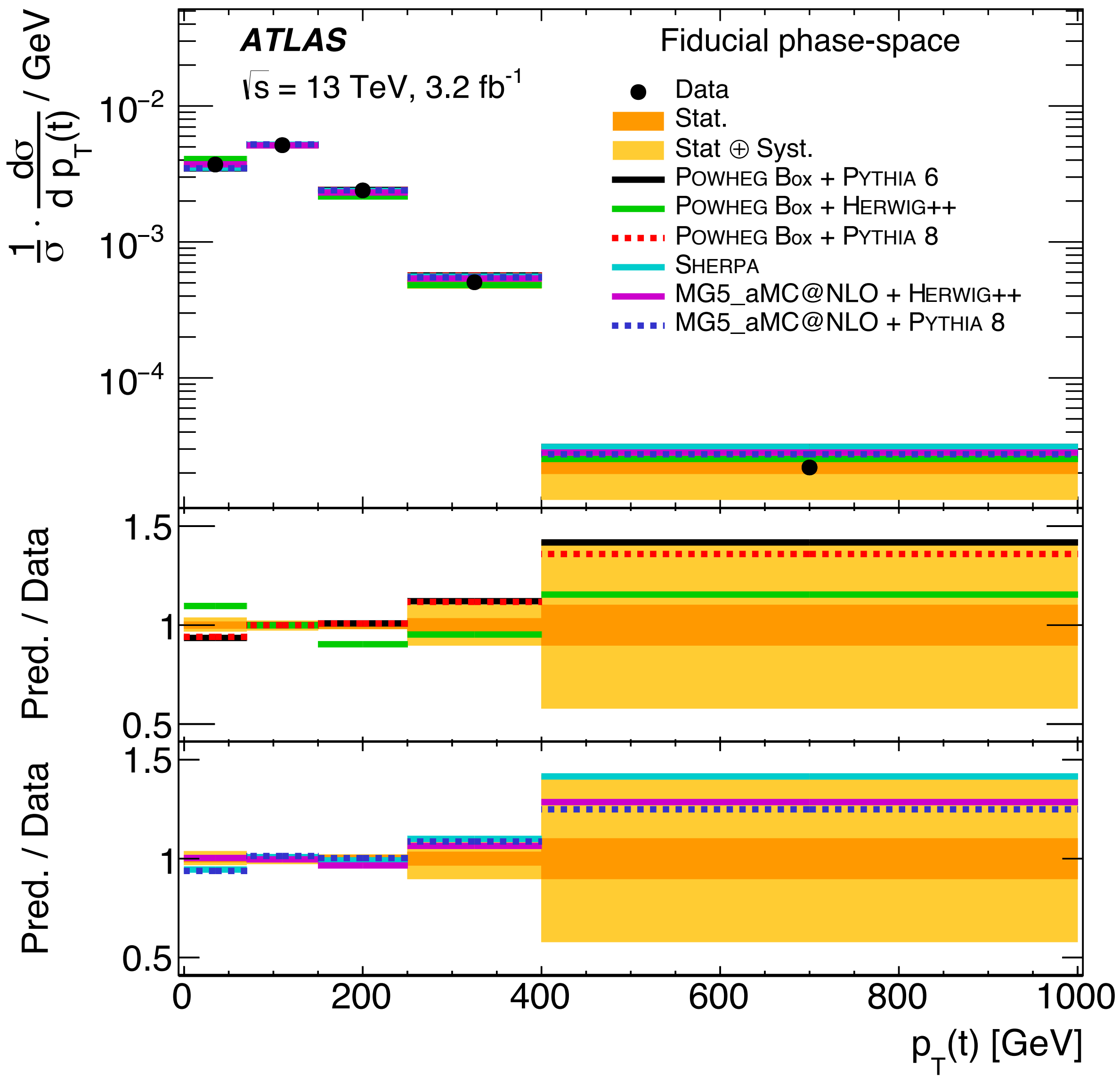


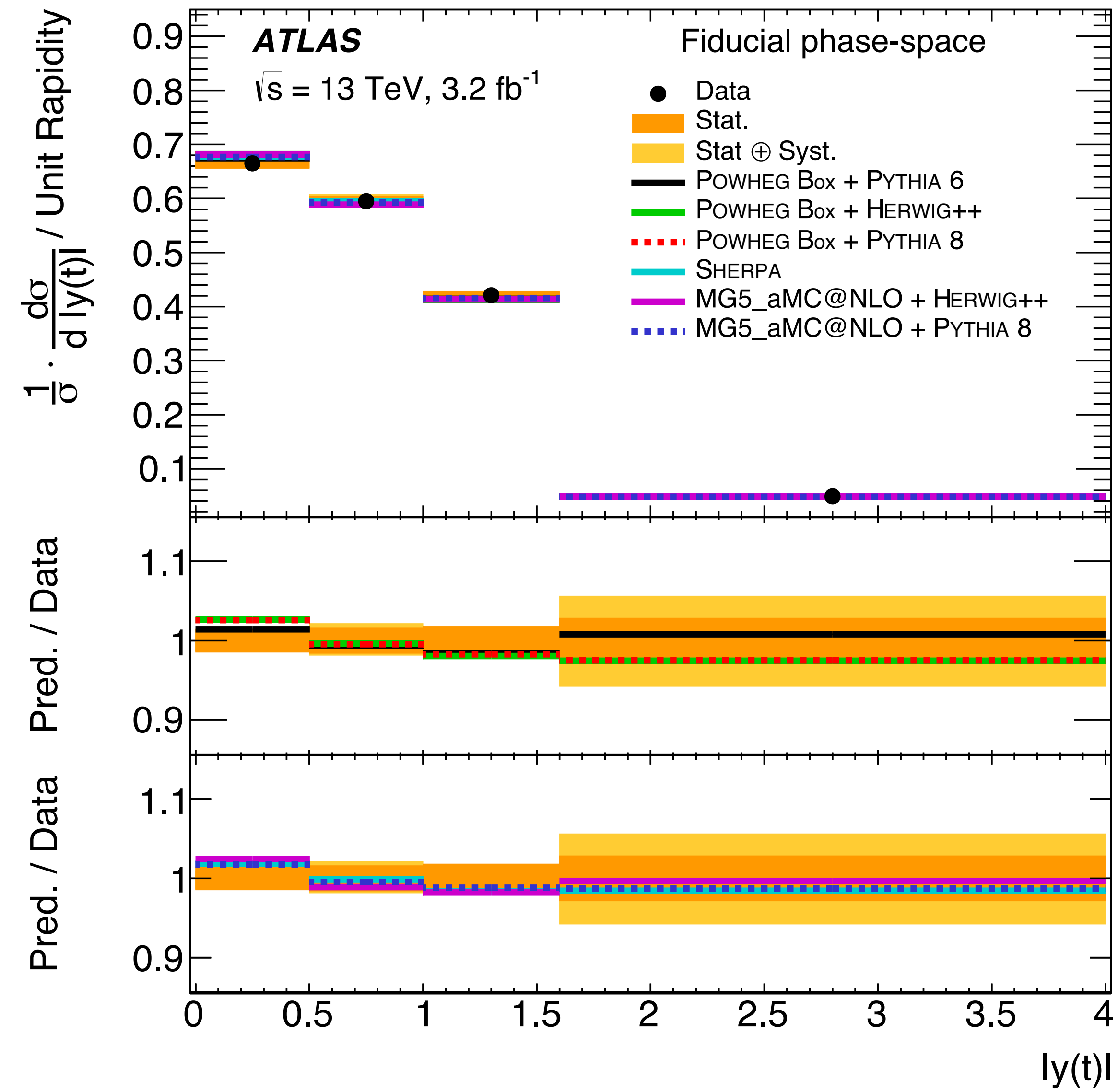


Fractional sizes of uncertainties grouped by type

—— symmetric - - - asymmetric

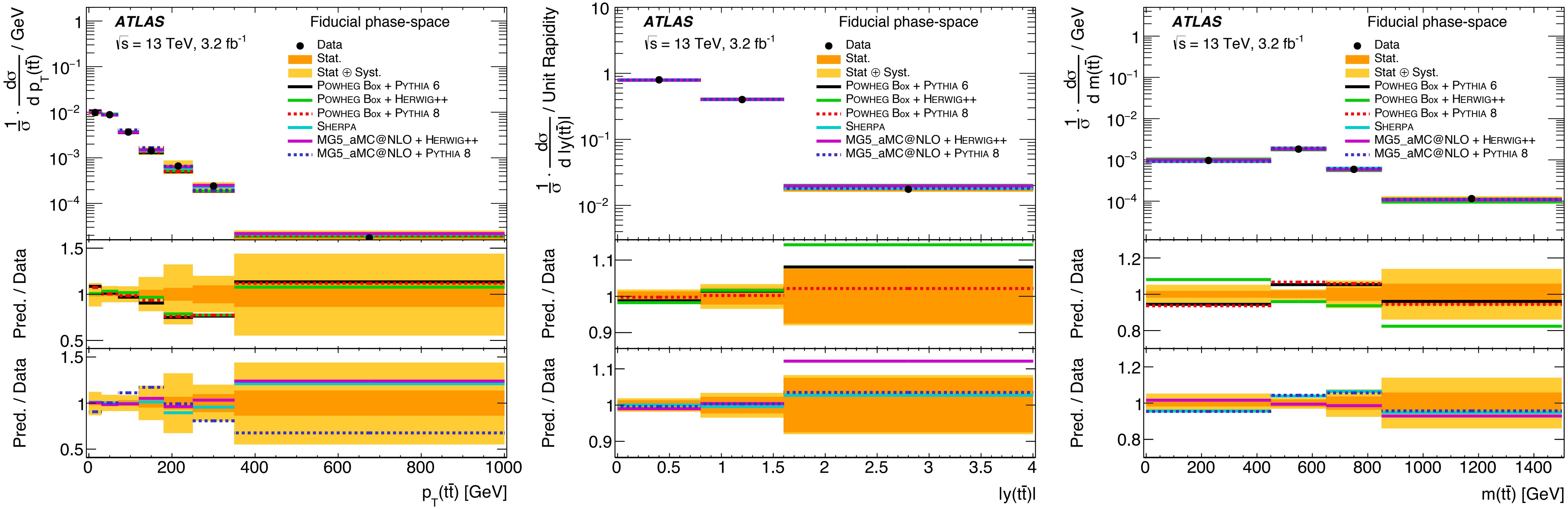
Results: normalised differential cross-sections





Powheg+Pythia6 | Sherpa
Powheg+Herwig++ | aMC@NLO+Herwig++
Powheg+Pythia8 | aMC@NLO+Pythia8

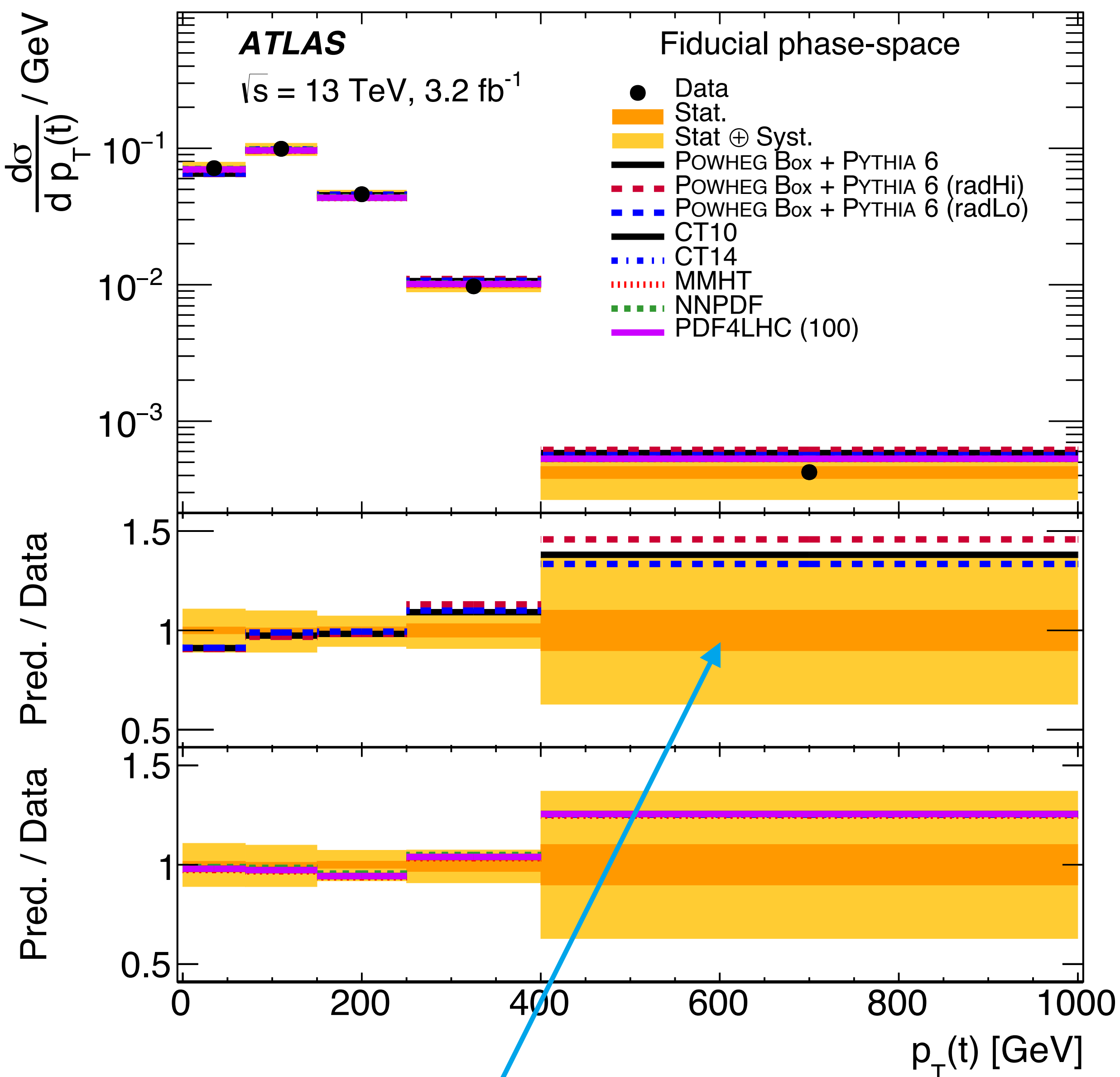
Results: normalised differential cross-sections

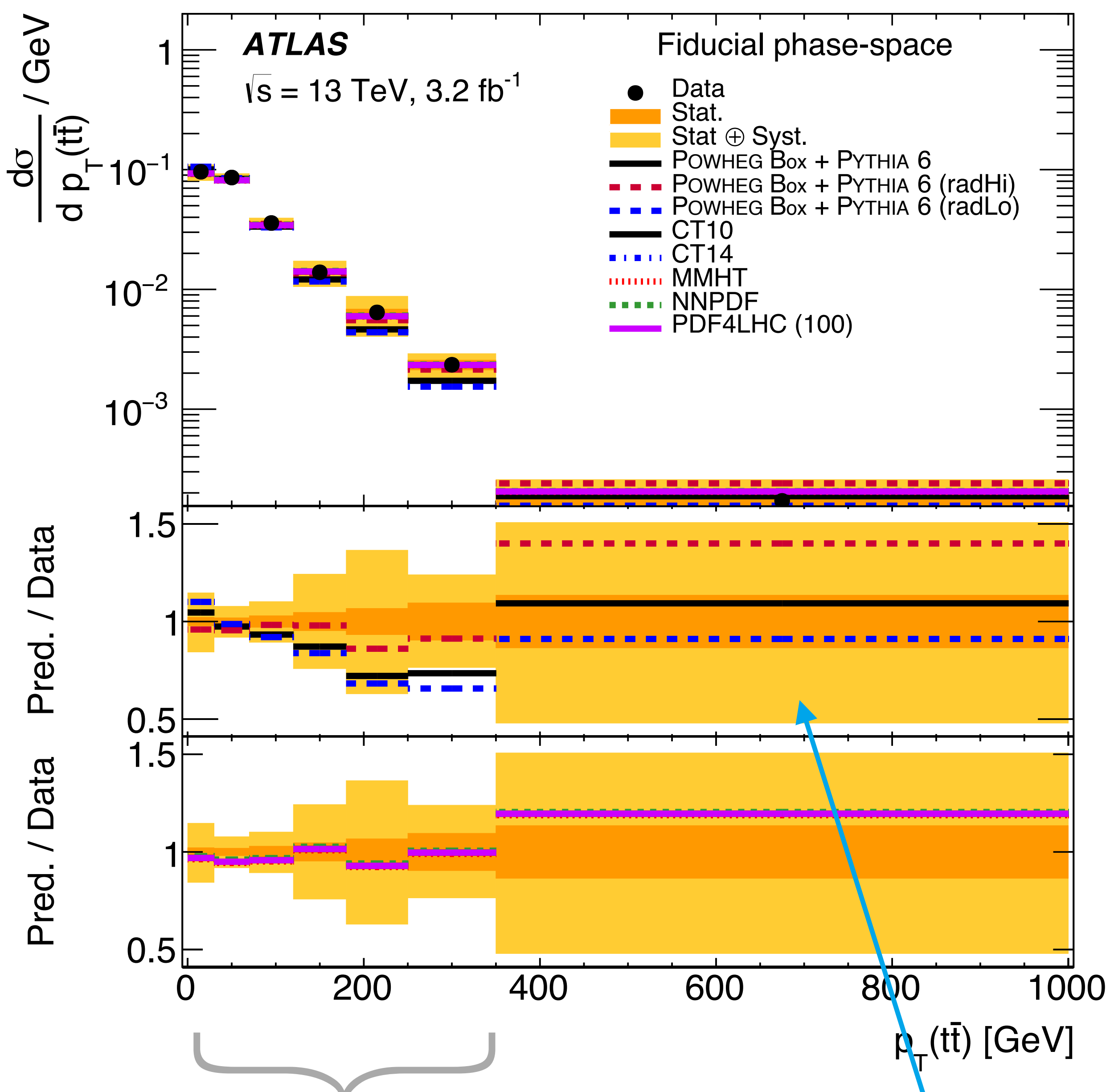


Powheg+Pythia6	Sherpa
Powheg+Herwig++	aMC@NLO+Herwig++
Powheg+Pythia8	aMC@NLO+Pythia8

Results: absolute differential cross-sections

Compare high and low radiation settings in Powheg





Data prefers low radiation at high p_T

High radiation preferred at low p_T

low radiation preferred at high p_T

Comparison of generators

- Calculate χ^2 and determine *p*-values using NDF for normalised cross-sections

$$\chi^2 = S^{\mathrm{T}}_{(N-1)} \cdot \boxed{\mathrm{Cov}^{-1}_{(N-1)}} \cdot \boxed{S_{(N-1)}}$$

number of bins

full bin-to-bin covariance matrix

difference between unfolded data and prediction

- Most generators agree within experimental uncertainties
- Powheg+Herwig++ differs significantly in both $p_T(t)$ and $m(tt)$

Results

- Most generators agree with the data
- Nothing conclusive across all variables

Predictions	$p_T(t)$		$\|y(t)\|$		$p_T(t\bar{t})$		$\|y(t\bar{t})\|$		$m(t\bar{t})$	
	χ^2/NDF	p-value	χ^2/NDF	p-value	χ^2/NDF	p-value	χ^2/NDF	p-value	χ^2/NDF	p-value
Powheg+Pythia6	5.2/4	0.27	0.5/3	0.92	5.5/6	0.48	0.6/2	0.74	3.9/4	0.42
Powheg+Pythia8	4.6/4	0.33	1.3/3	0.73	5.1/6	0.53	0.0/2	1.00	5.7/4	0.22
Powheg+Herwig++	14.6/4	0.01	1.4/3	0.71	4.1/6	0.66	1.0/2	0.61	12.0/4	0.02
aMC@NLO+Herwig++	2.0/4	0.74	1.3/3	0.73	0.6/6	1.00	0.2/2	0.90	0.9/4	0.92
aMC@NLO+Pythia8	3.6/4	0.46	0.6/3	0.90	10.7/6	0.10	0.1/2	0.95	2.7/4	0.61
Sherpa	3.8/4	0.43	0.8/3	0.85	0.7/6	0.99	0.0/2	1.00	2.3/4	0.68
Powheg+Pythia6 High Rad	7.8/4	0.10	0.6/3	0.90	0.9/6	0.99	0.4/2	0.82	3.8/4	0.43
Powheg+Pythia6 Low Rad	5.5/4	0.24	0.8/3	0.85	9.6/6	0.14	0.8/2	0.67	4.5/4	0.34

Conclusions

Differential cross-sections

- Measurements of top-quark pair differential cross-sections using eμ events
- Measured differential cross-sections compared to predictions of NLO generators matched to parton showers
- Results consistent with all models within uncertainties
- Largest uncertainties arise from signal modelling and jet uncertainties


back up

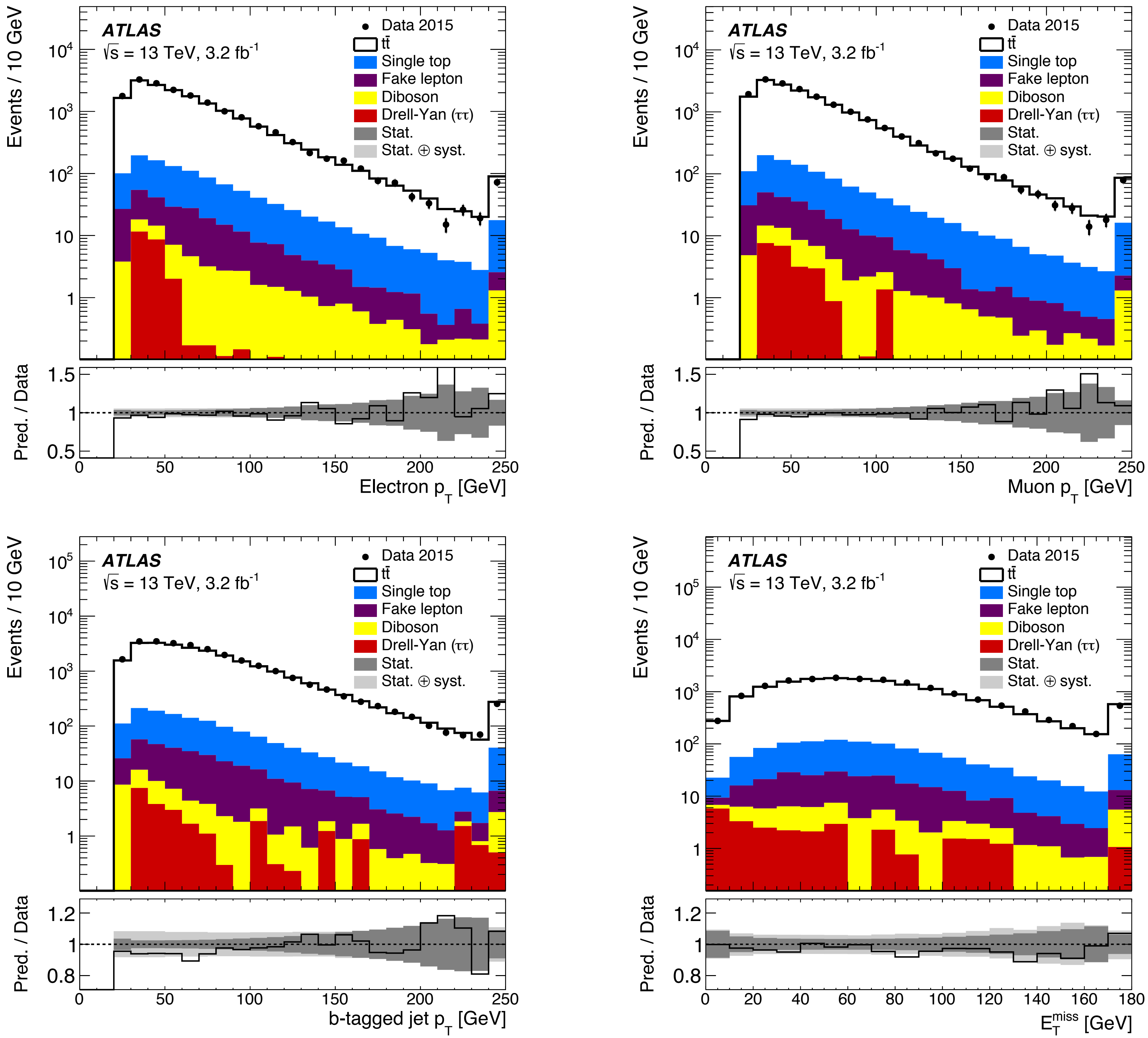
Event yields

- Requiring $t\bar{t}$ system reconstruction increases percentage of $t\bar{t}$ events —> preferentially selects $t\bar{t}$ events over background

- Data/MC agreement is within total uncertainties

Process	Signal region		Signal region + NW	
$Z/\gamma^* \rightarrow \tau^+\tau^-$	22	± 9	10	± 8
Diboson	44	± 4	17	± 2
Fake lepton	200	± 60	150	± 50
Wt	860	± 60	480	± 40
$t\bar{t}$	15 800	± 900	13 300	± 800
Expected	17 000	± 900	13 900	± 800
Observed	17 501		14 387	

Kinematic distributions



Cross-section measurement

correct for events
passing fid but not reco

response matrix

integrated luminosity

$$\frac{d\sigma_{t\bar{t}}}{dX^{i}_{t\bar{t}}} = \frac{1}{\mathcal{L}\cdot\mathcal{B}\cdot\Delta X_i\cdot\epsilon_i}\cdot\sum_j \boxed{R^{-1}_{ij}}\cdot\boxed{\epsilon^{\mathrm{fid}}_j}\cdot\left(\boxed{N^{j}_{\mathrm{obs}}}-\boxed{N^{j}_{\mathrm{bkg}}}\right)$$

number of
observed events

branching ratio

number of
background
events

observable

bin width

correct for events
passing reco but not fid

i = bin number

Results

X	$\frac{d\sigma_{t\bar{t}}}{dX}$ [$\frac{pb}{GeV}$]	$\frac{1}{\sigma_{t\bar{t}}}\frac{d\sigma_{t\bar{t}}}{dX}$ [$\frac{1}{GeV}$]	Stat. (abs.)	Stat. (norm.)	Syst. (abs.)	Syst. (norm.)
$p_T(t)$ [GeV]			[%]	[%]	[%]	[%]
0 – 70	7.1	0.371	± 1.8	± 1.7	+11 -11	+4 -3.2
70 – 150	9.9	0.515	± 1.3	± 1.2	+10 -11	+2.3 -2.7
150 – 250	4.61	0.239	± 1.8	± 1.7	+7 -8	+2.1 -2.0
250 – 400	0.97	0.051	± 3.4	± 3.3	+7 -9	+10 -11
400 – 1000	0.042	0.0022	± 10	± 9	+40 -40	+40 -40
$p_T(t\bar{t})$ [GeV]						
0 – 30	9.6	0.99	± 2.2	± 2.0	+15 -16	+12 -13
30 – 70	8.6	0.88	± 1.9	± 1.7	+8 -8	+9 -9
70 – 120	3.6	0.368	± 3.0	± 2.7	+10 -11	+8 -9
120 – 180	0.139	0.143	± 5	± 5	+24 -24	+19 -18
180 – 250	0.064	0.066	± 7	± 6	+40 -40	+32 -32
250 – 350	0.023	0.024	± 10	± 9	+24 -24	+30 -19
350 – 1000	0.0017	0.0018	± 14	± 13	+50 -50	+40 -40
$m(t\bar{t})$ [GeV]						
0 – 450	0.94	0.097	± 1.8	± 1.6	+12 -13	+5 -5
450 – 650	1.76	0.183	± 2.0	± 1.9	+8 -9	+2.8 -3.0
650 – 850	0.57	0.059	± 4	± 3.3	+10 -12	+8 -8
850 – 1500	0.111	0.0115	± 6	± 5	+11 -11	+14 -14
X	$\frac{d\sigma_{t\bar{t}}}{dX}$ [pb]	$\frac{1}{\sigma_{t\bar{t}}}\frac{d\sigma_{t\bar{t}}}{dX}$	Stat. (abs.)	Stat. (norm.)	Syst. (abs.)	Syst. (norm.)
$\lvert y(t\bar{t})\rvert$			[%]	[%]	[%]	[%]
0.0 – 0.8	7.7	0.797	± 1.3	± 1.1	+8 -9	+1.8 -1.8
0.8 – 1.6	3.9	0.400	± 2.2	± 2.0	+9 -10	+3.4 -3.4
1.6 – 4.0	0.170	0.0176	± 7	± 7	+13 -13	+8 -8
$\lvert y(t)\rvert$						
0.0 – 0.5	12.9	0.665	± 1.5	± 1.4	+8 -10	+1.0 -1.3
0.5 – 1.0	11.5	0.595	± 1.6	± 1.5	+10 -10	+2.2 -1.9
1.0 – 1.6	8.1	0.421	± 1.8	± 1.7	+8 -9	+1.4 -1.2
1.6 – 4.0	0.95	0.0489	± 2.9	± 2.7	+8 -9	+6 -6