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

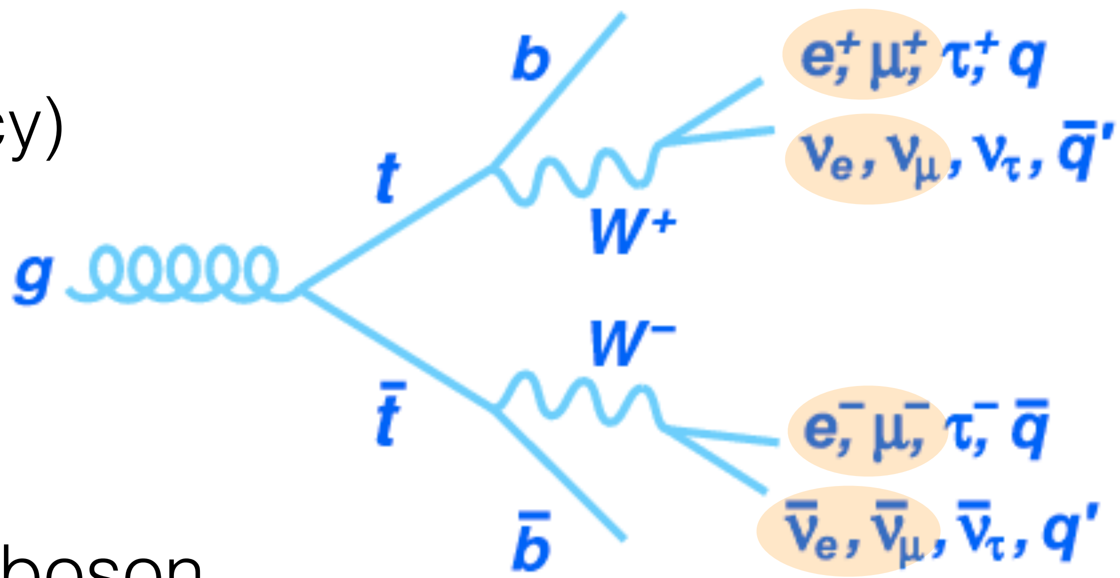
- Cross-section and kinematics of top quarks - important test of SM
- Top is usually a large background for searches for new physics
- Important input for tuning simulations
- First ATLAS measurement in dilepton channel of top p_T

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*

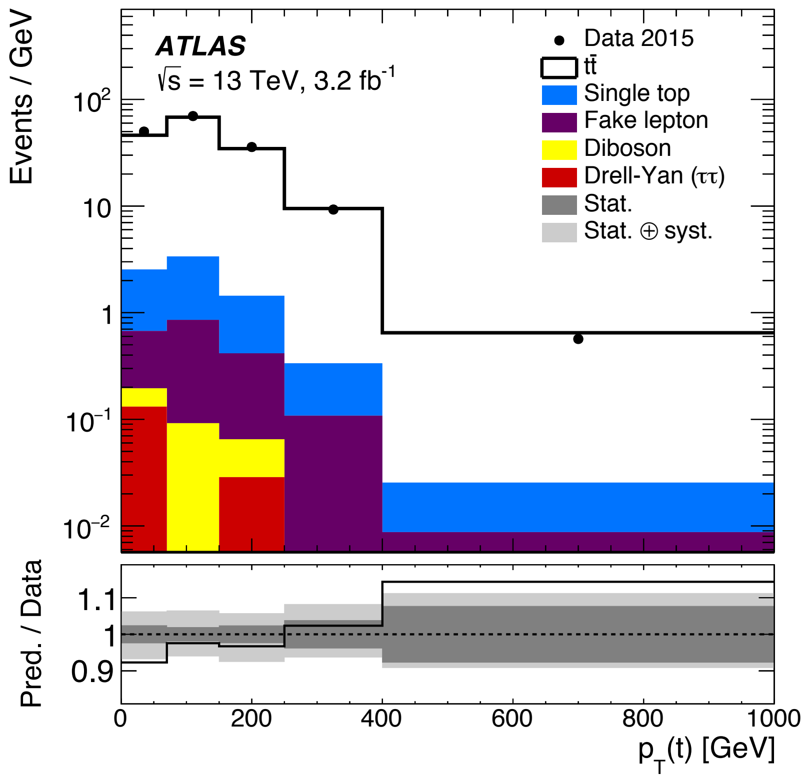
Improving resolution

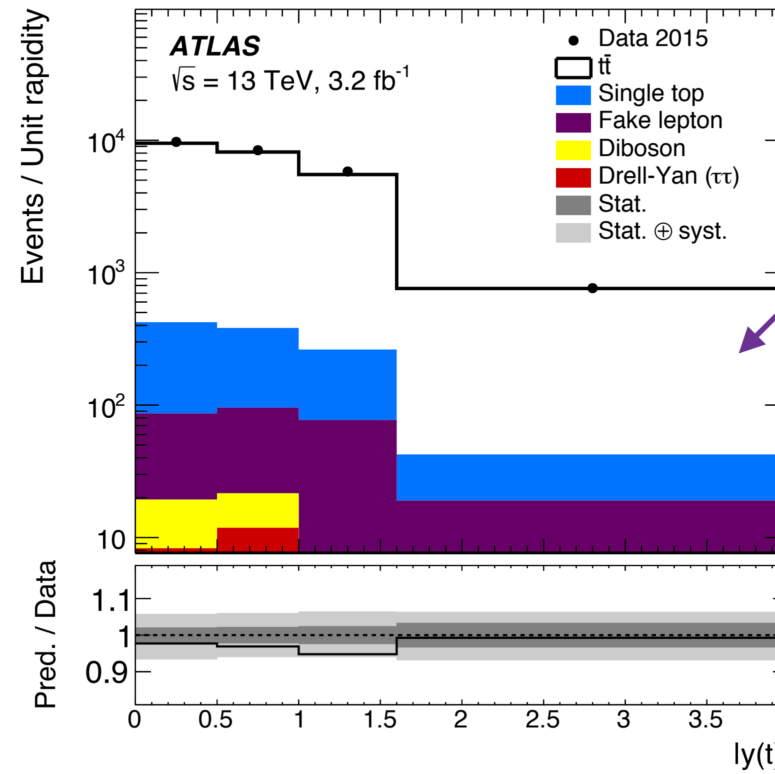
- Smear jet p_T: 10% gaussian, 20 times per jet
- M_t sampling: 1 GeV steps {168, 178}

→ **Reco efficiency ~ 80%**

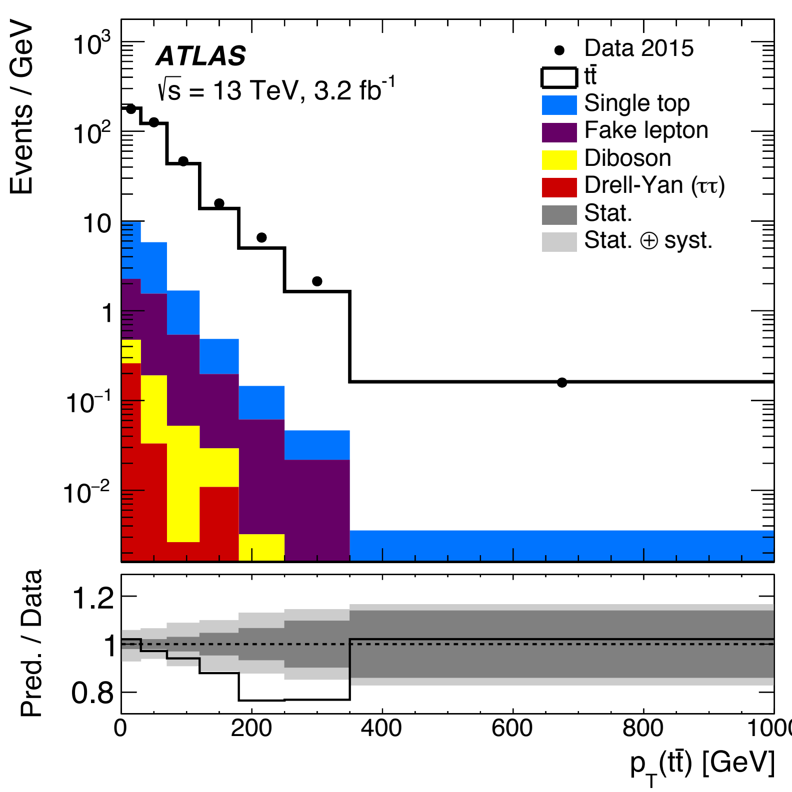
Kinematic distributions of top variables

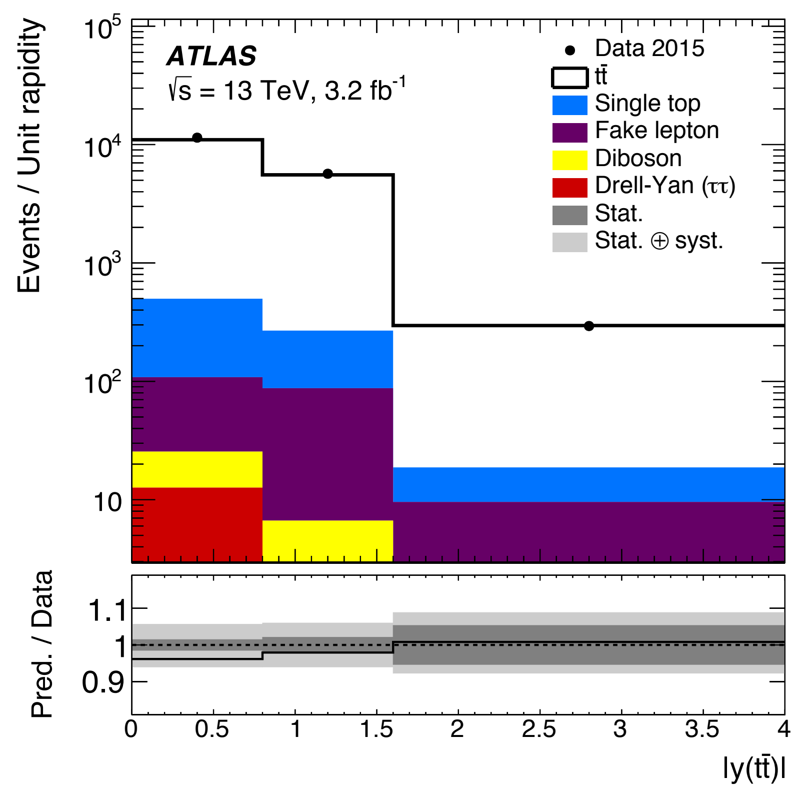
arXiv:1612.05220

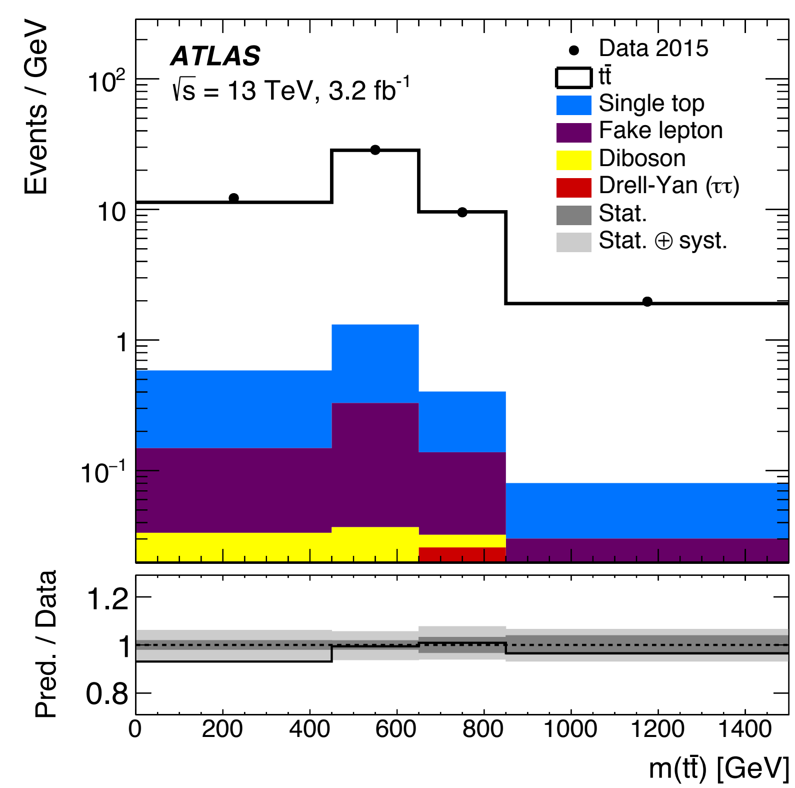




Mostly $t\bar{t}$ events







Unfolding

Data

↓ Subtract backgrounds estimated using MC from data

Data - Background

↓ Bayesian iterative unfolding with 6 iterations

Unfolded data

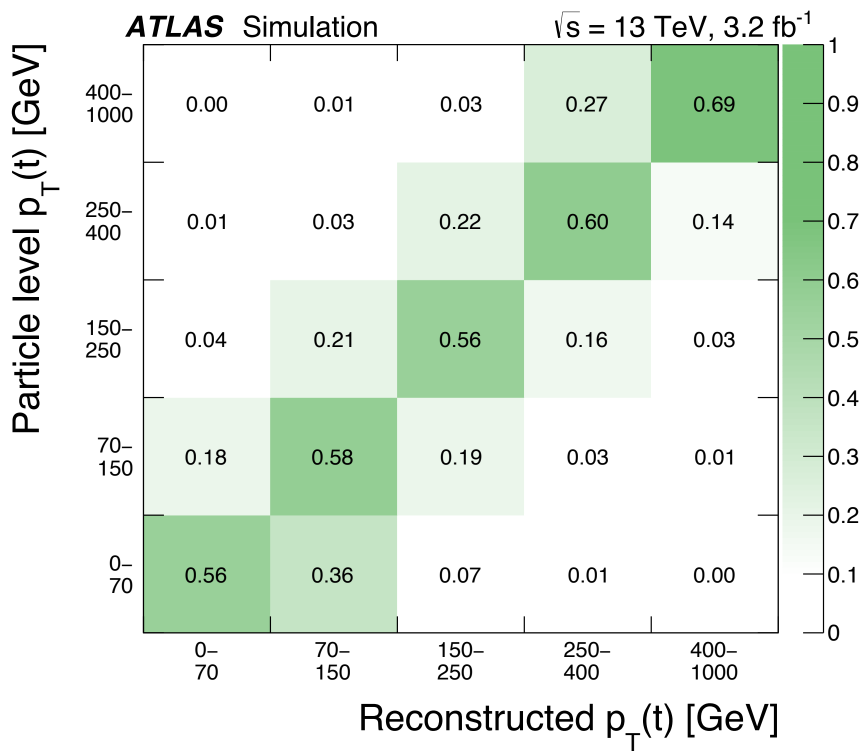
↓ Correct for fiducial phase-space acceptance

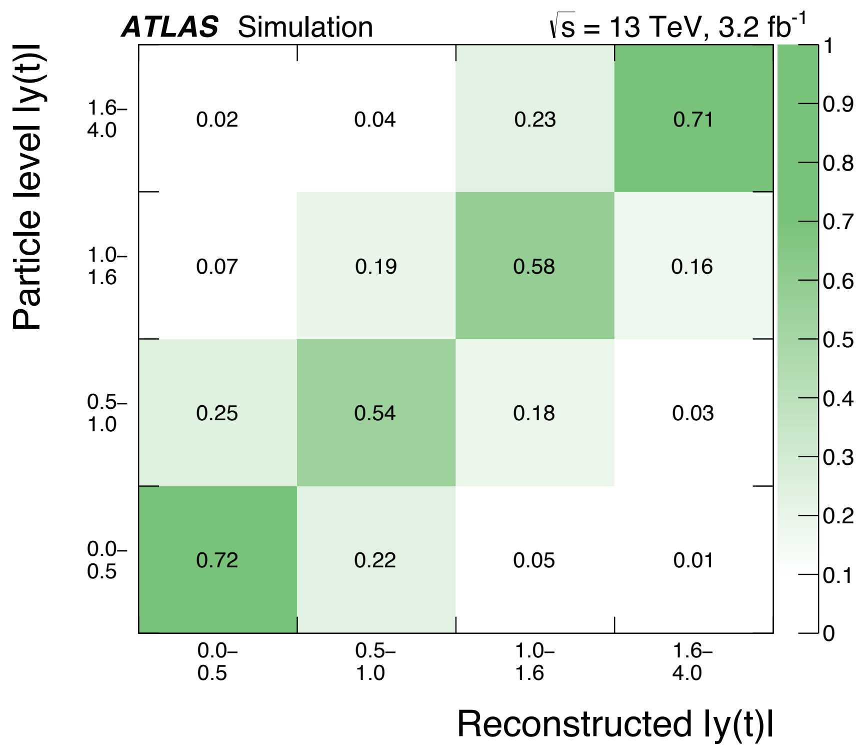
Fiducial data

↓ Determine cross-section, absolute or normalised

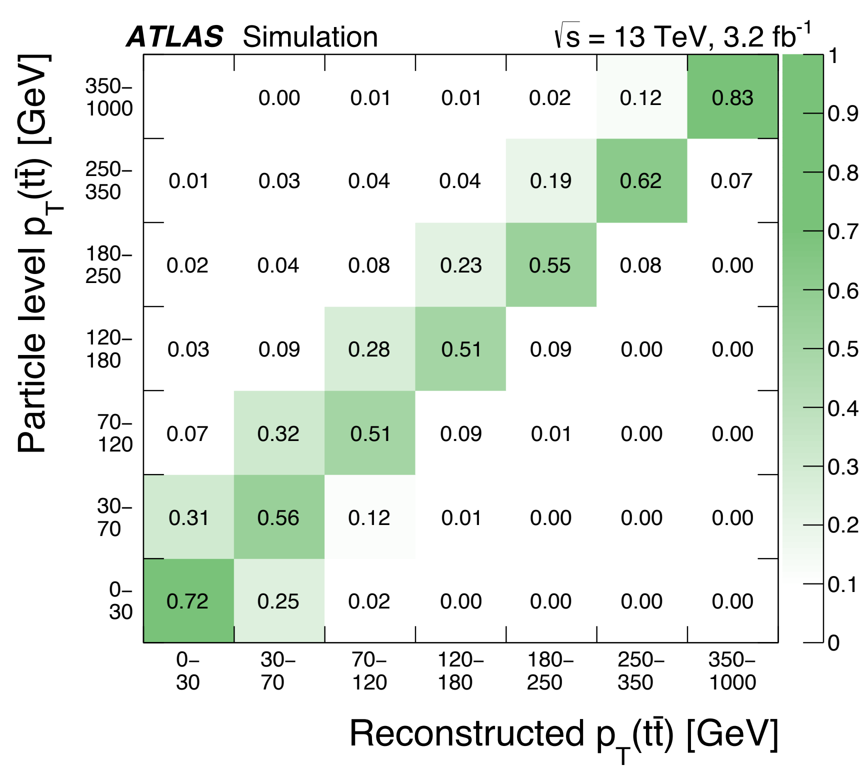
Result

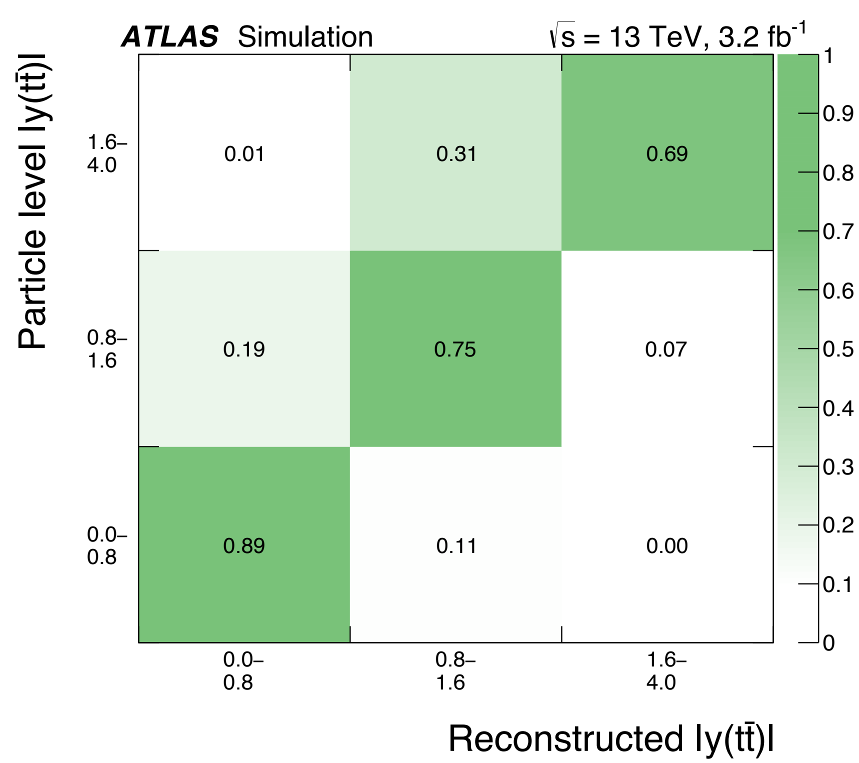
Unfolding: migration matrices

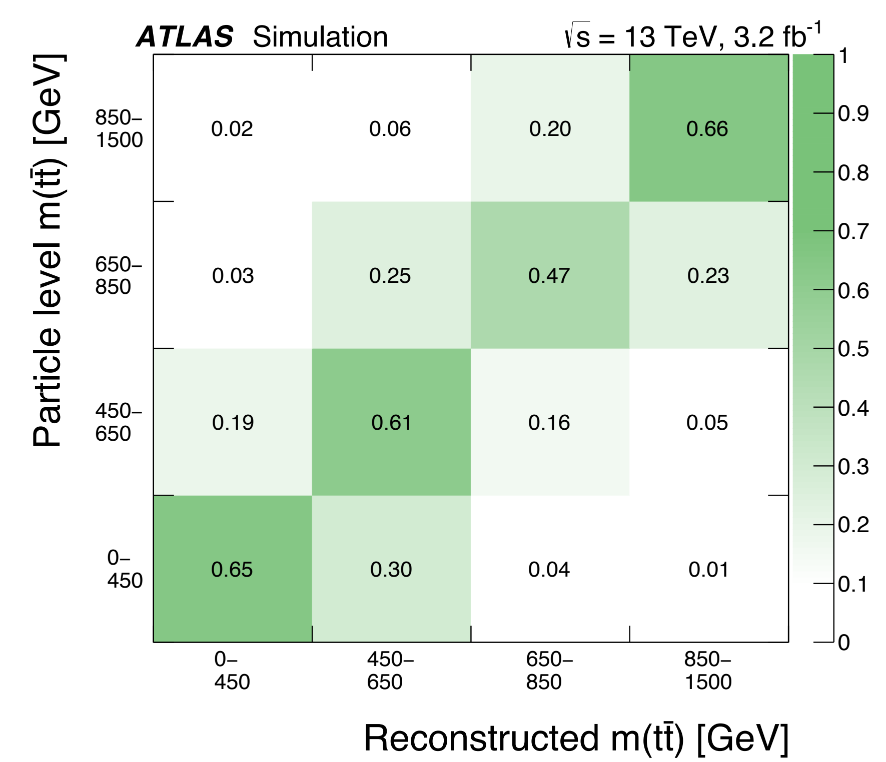




- Binning is chosen to have at least 50% on diagonal
- Also consider resolution, statistics and unfolding stability







Systematic uncertainties

General method:

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

Largest uncertainties

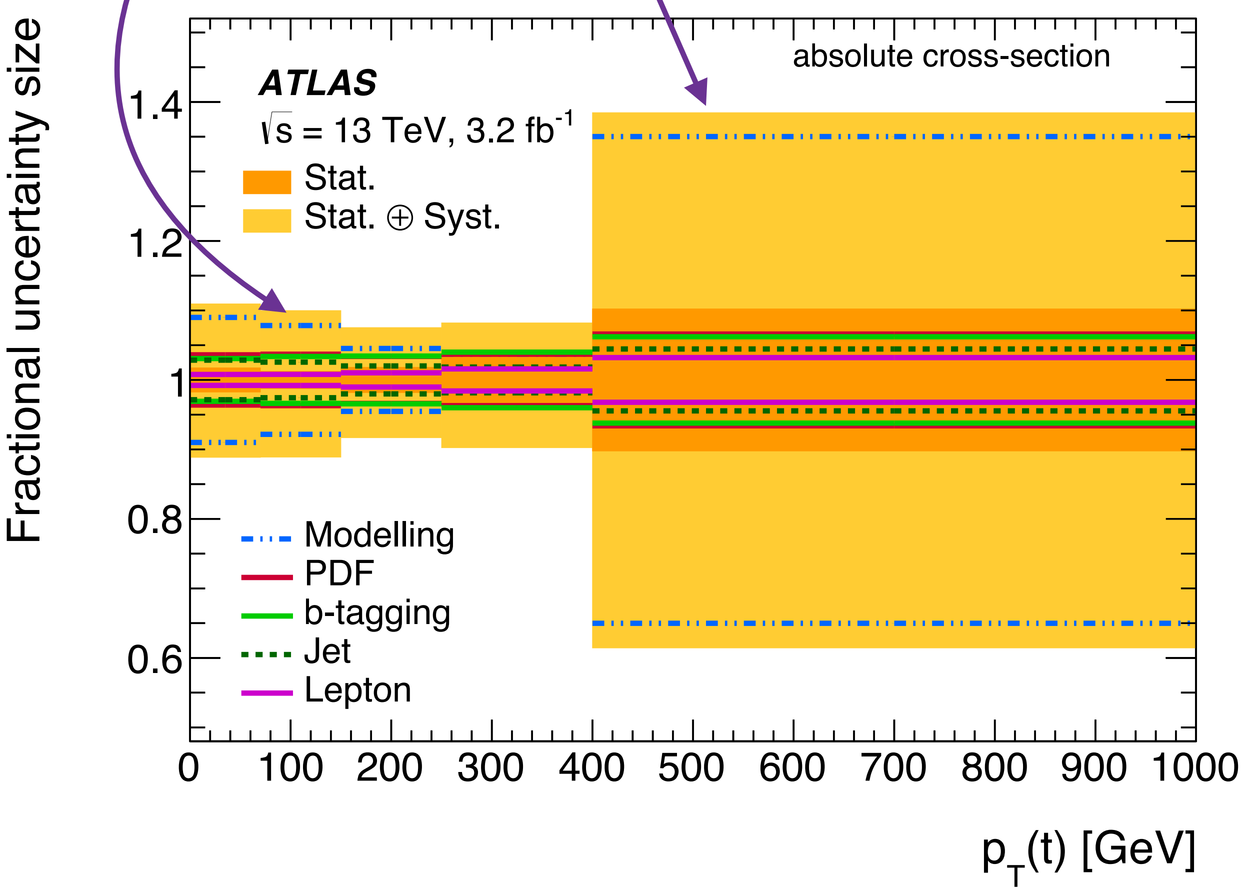
- Jet related: significant uncertainties in both absolute and normalised
- Luminosity: large for absolute cross-sections (~2%)
- PDFs: use PDF4LHC15 prescription, with extrapolation of CT10 → CT14
- Modelling uncertainties:
  - ★ ISR/FSR: Powheg+Pythia6 with high and low radiation settings
  - ★ NLO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

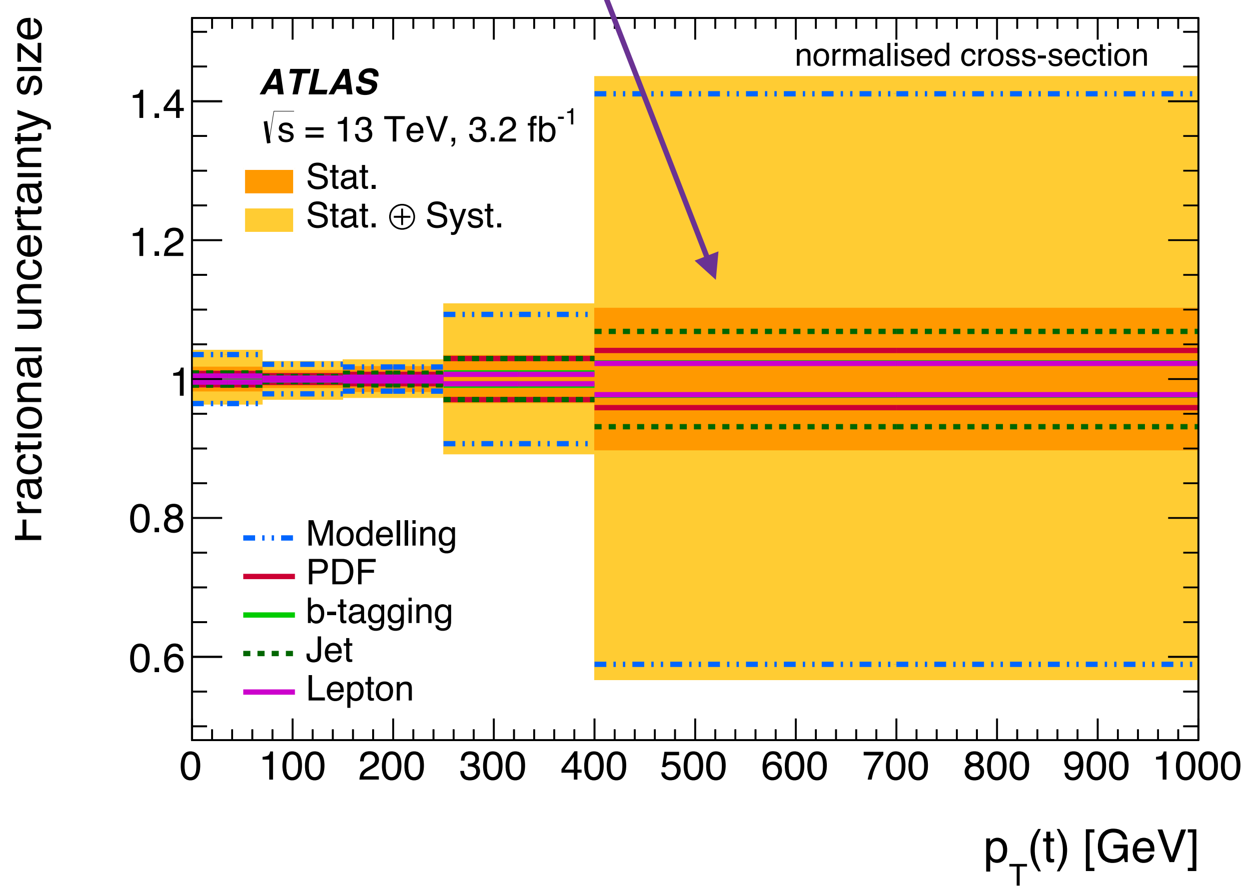
baseline sample unfolded using alternative sample

Systematic uncertainties

modelling uncertainties dominate

jet uncertainties large at high pT

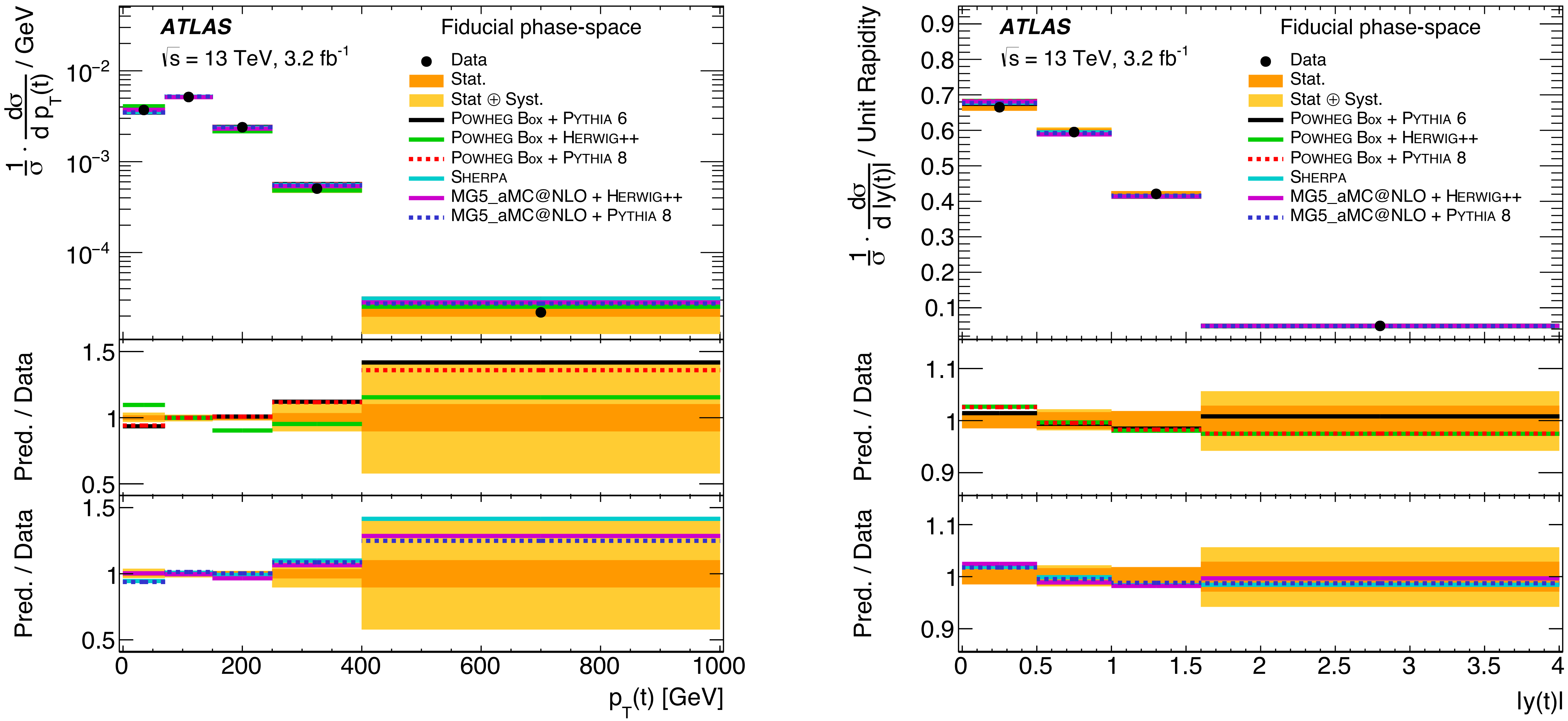




Fractional sizes of uncertainties grouped by type

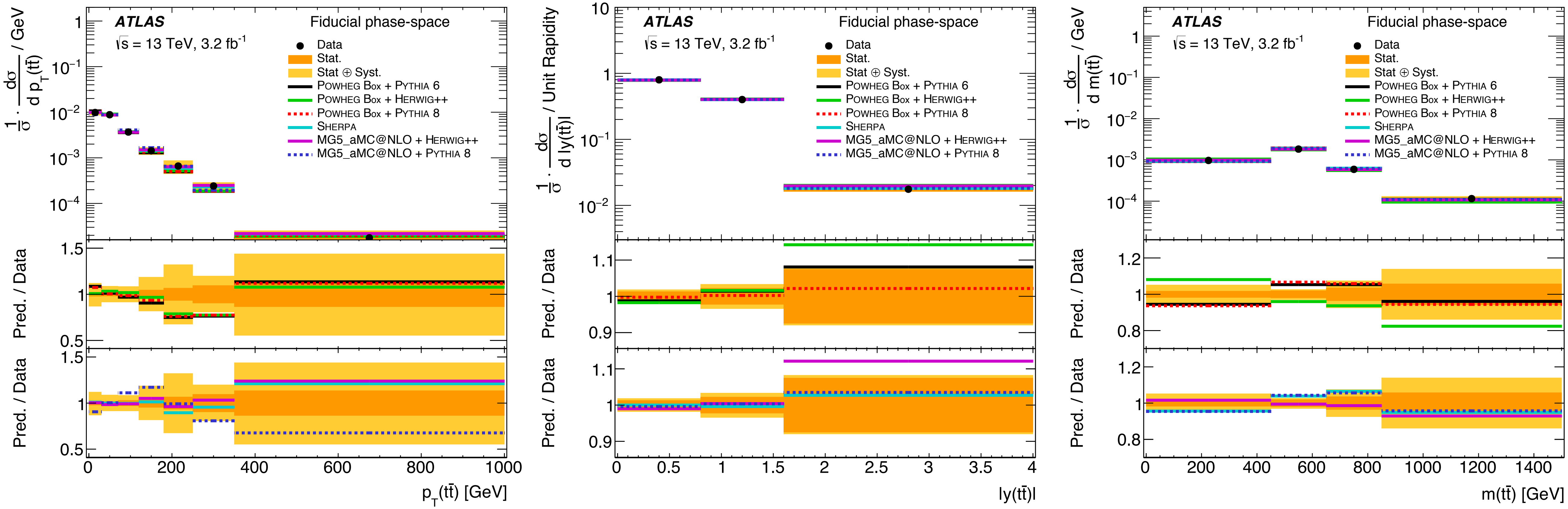
—— symmetric - - - asymmetric

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

Powheg+Herwig++

Powheg+Pythia8

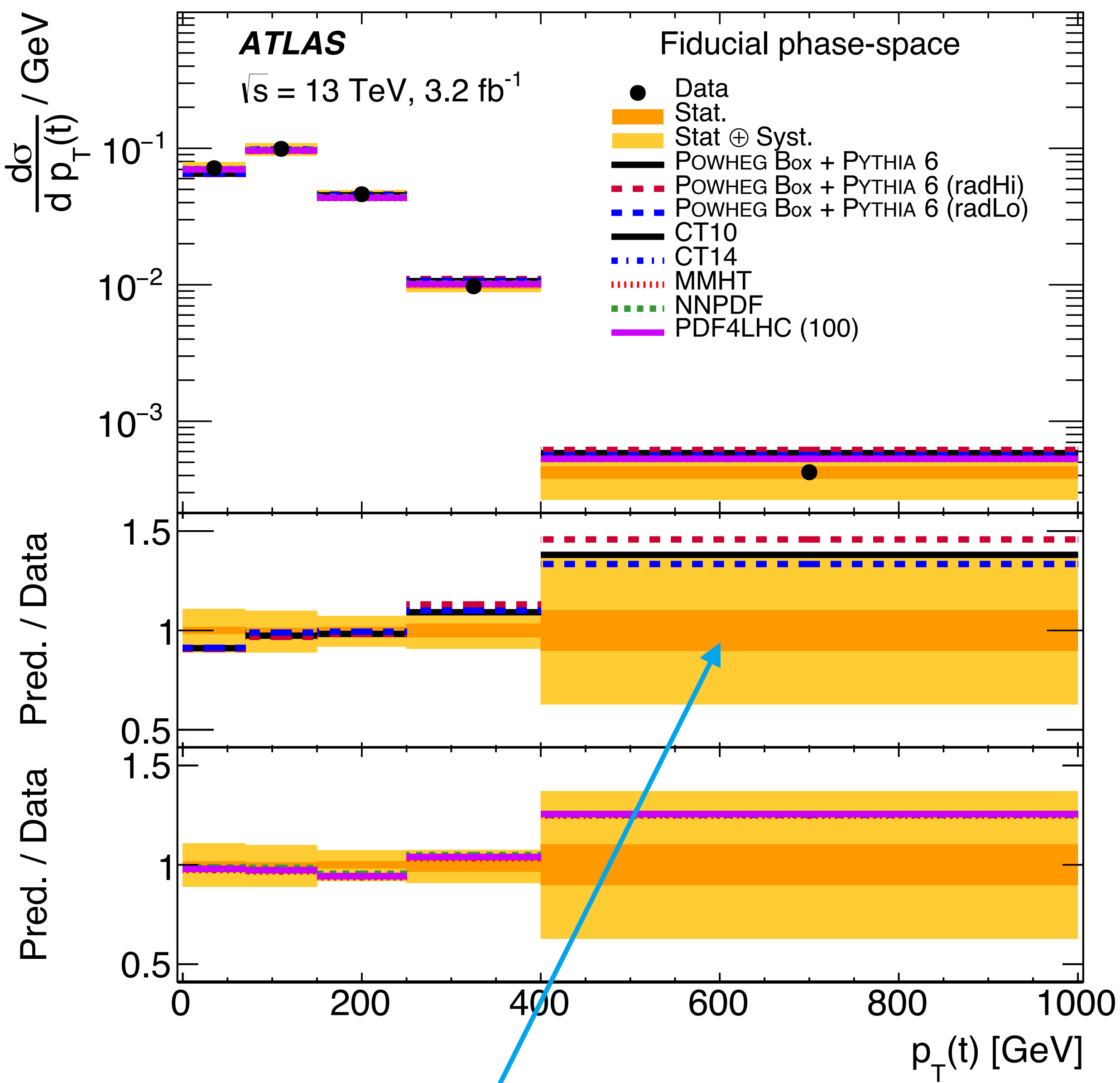
Sherpa

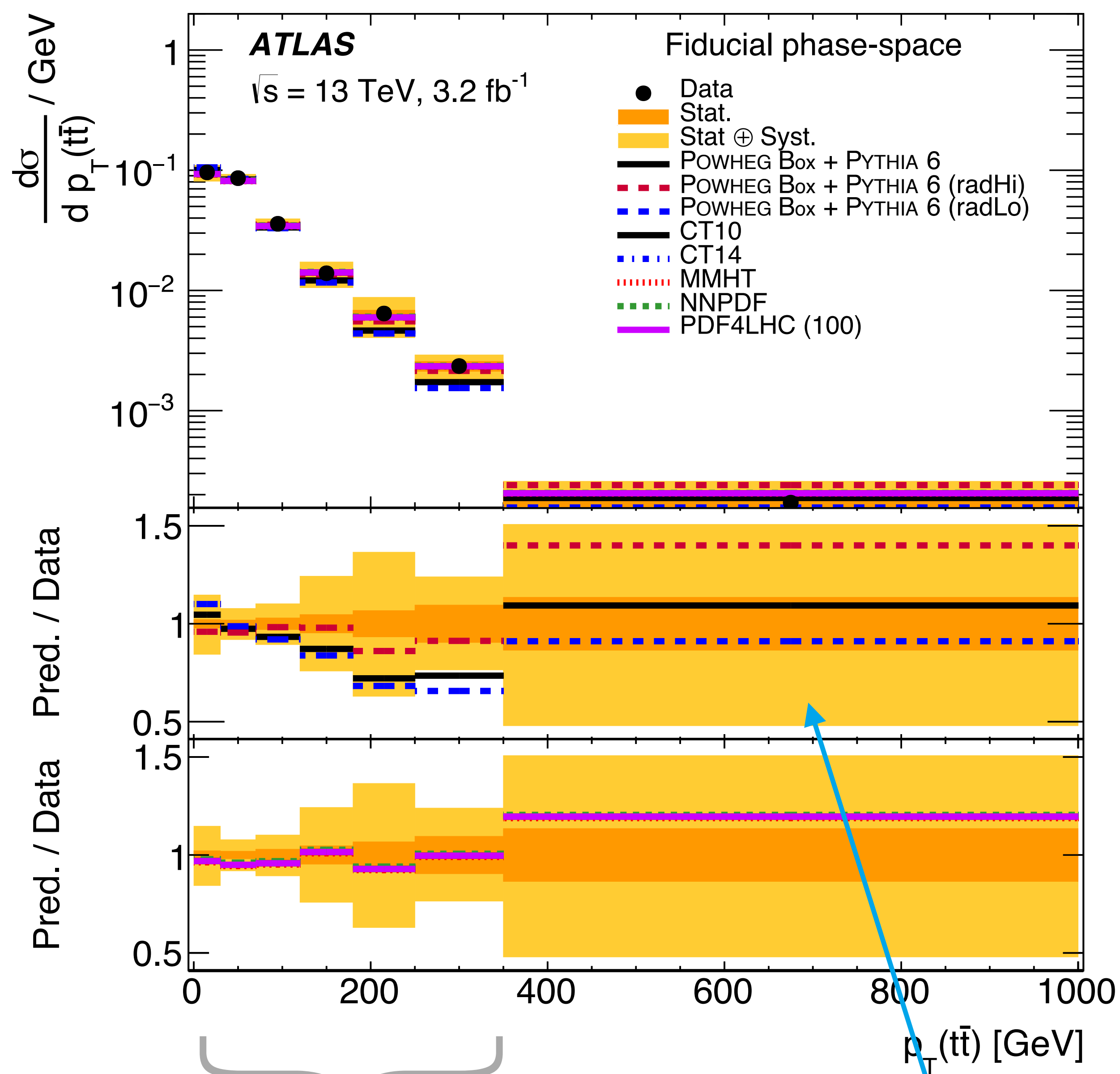
aMC@NLO+Herwig++

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

Results

Comparison of generators

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

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

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	$p_T(t)$ χ^2/NDF	$p_T(t)$ p-value	$\lvert y(t)\rvert$ χ^2/NDF	$\lvert y(t)\rvert$ p-value	$p_T(t\bar{t})$ χ^2/NDF	$p_T(t\bar{t})$ p-value	$\lvert y(t\bar{t})\rvert$ χ^2/NDF	$\lvert y(t\bar{t})\rvert$ p-value	$m(t\bar{t})$ χ^2/NDF	$m(t\bar{t})$ 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

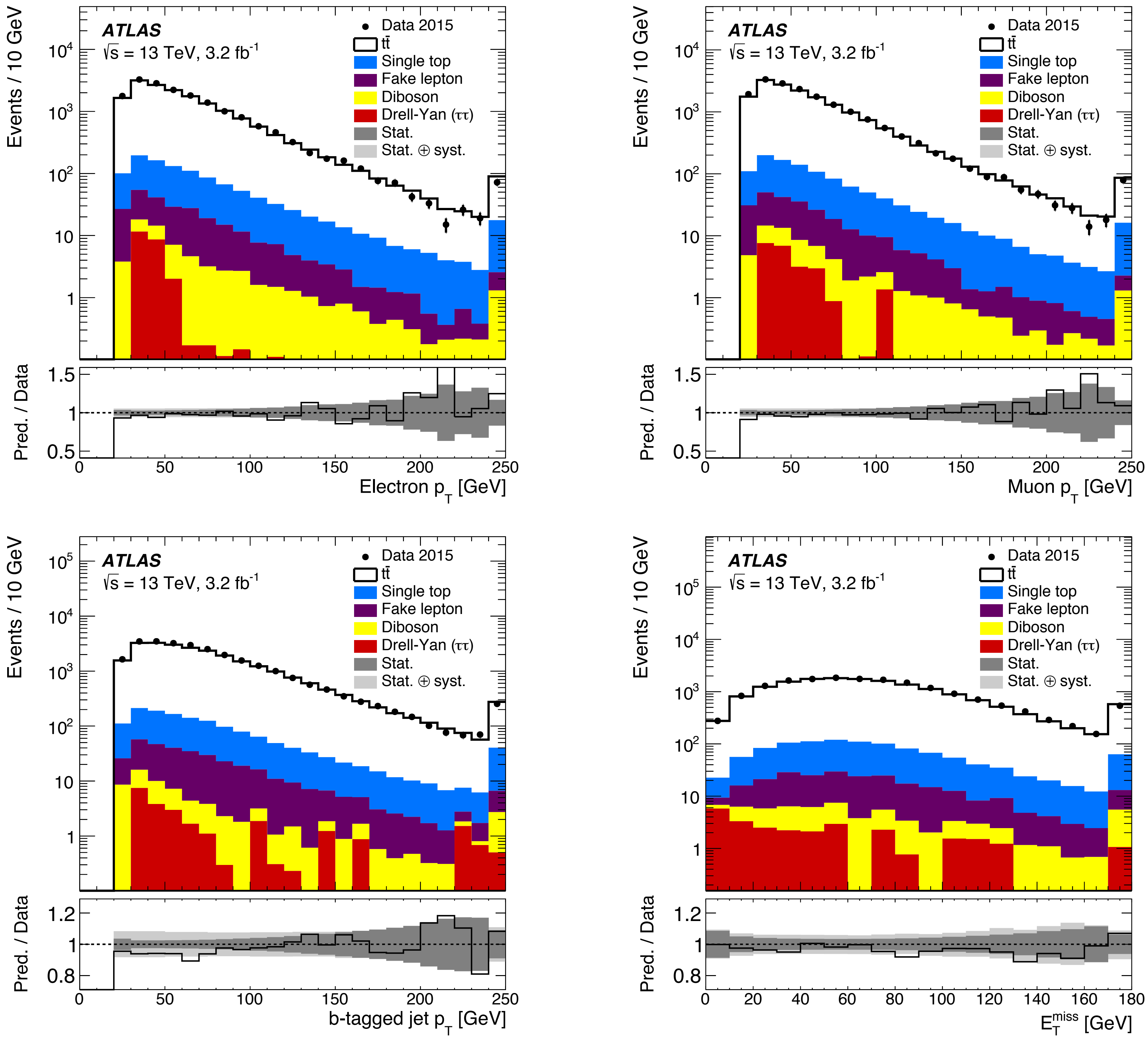
Event yields

- 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
$Z/\gamma^* \to \tau^+\tau^-$	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

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

integrated luminosity

response matrix

correct for events passing fid but not reco

observable

branching ratio

bin width

correct for events passing reco but not fid

number of observed events

number of background events

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.)
$\|y(t\bar{t})\|$			[%]	[%]	[%]	[%]
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
$\|y(t)\|$						
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