Run 2 $t\bar{t}$ + Heavy Flavour Jets in ATLAS

tt+heavy flavour measurements with the full run 2 dataset using the ATLAS experiment

ICHEP, 18 – 24 July 2024, Prague

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on behalf of the ATLAS Collaboration

fct Fundação para a Ciência e a Tecnologia

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ATLAS EXPERIMENT

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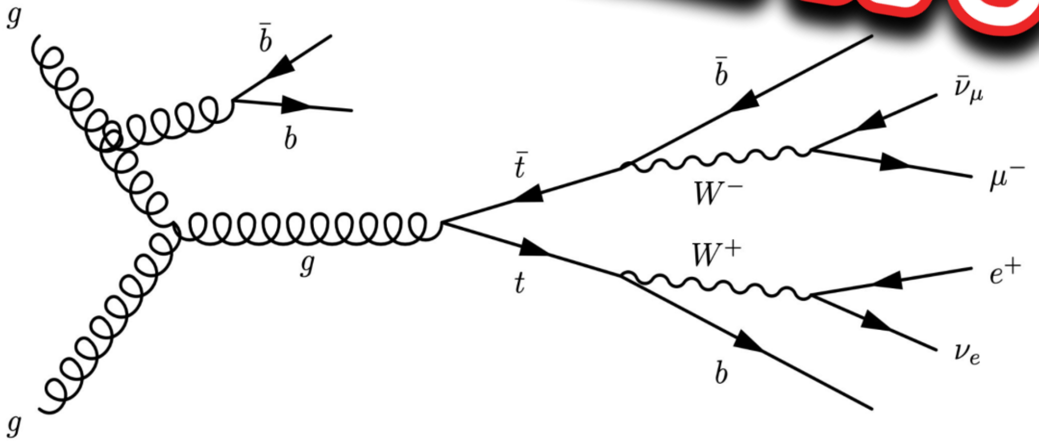
Outlook – top-quark pairs + b-jets

- Motivation
- Analysis description
- Observables and phase spaces
- Event selection and yields
- Backgound estimation
- Unfolding and Results



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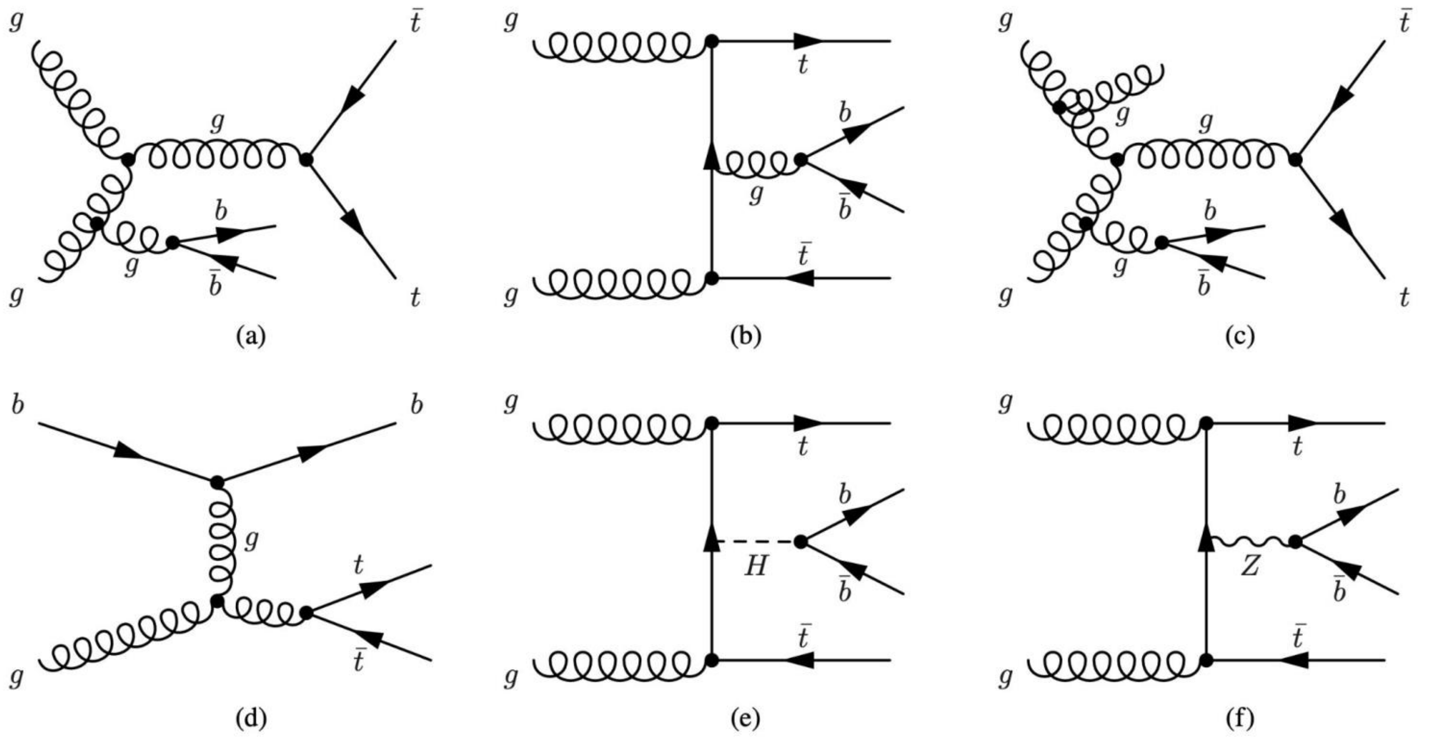
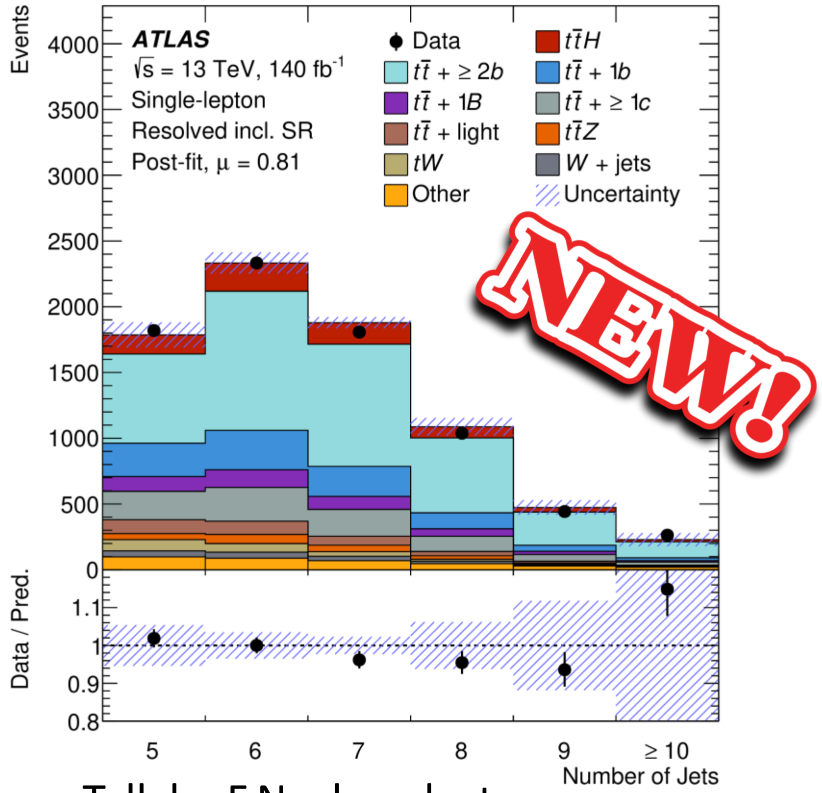
Motivation

- Challenging QCD calculation due to different scales: from m_t down to soft radiation
- Important and poorly constrained background to other measurements: ttH, tttt, …

arXiv:2407.10904



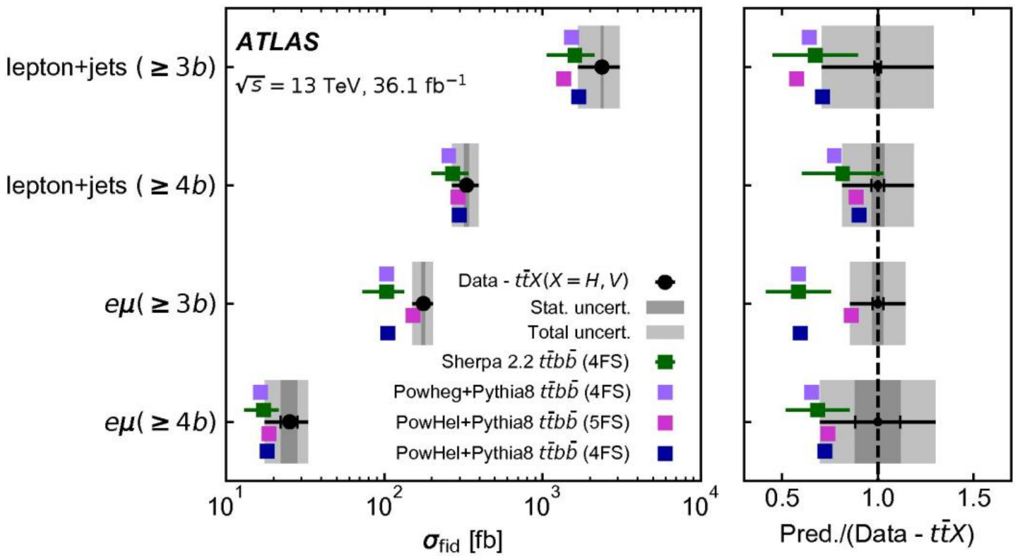


Talk by F.Nechansky tomorrow

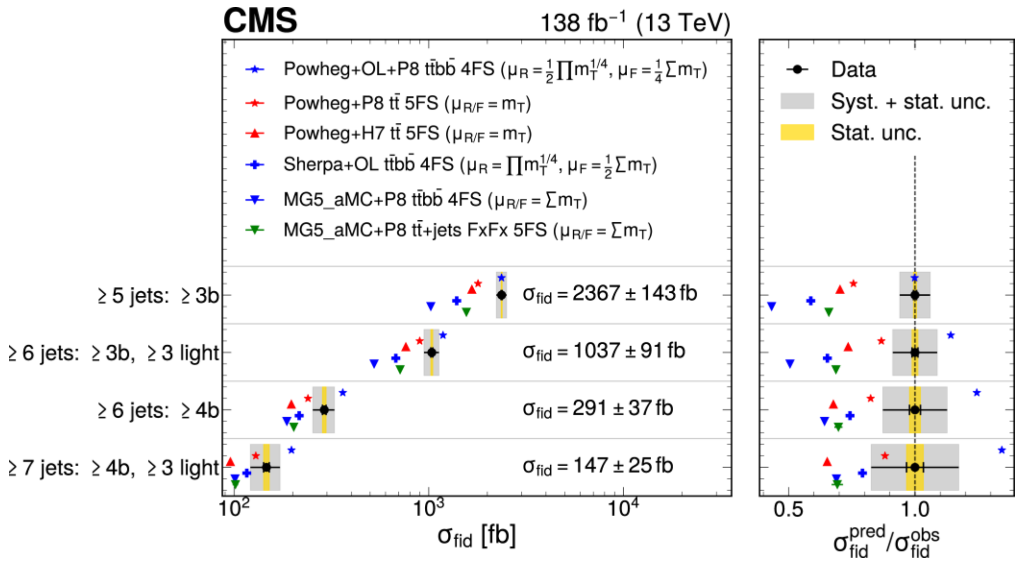
Analysis Description

- Measure **tt + ⩾1 b** jet **fiducial cross sections** at **particle level** in **eμ** top decays
    - Compare with state of the art generators
- In **phase-space regions** of different **b-jet multiplicity**
    - ≥3b; ≥4b ; ≥3b + ≥1 light jets; ≥4b+≥1 light jets
    - **Inclusive** cross sections in each region
    - **Normalised differential** cross sections
- Backgrounds partially determined from data:
    - Fake leptons (small)
    - Mistagged tt+light jets and tt+charm
- Aim to improve upon previous measurements:
    - ATLAS 13 TeV, 36 fb^{-1}: JHEP 04 (2019) 046
    - CMS 13 TeV, 36 fb^{-1}: JHEP 07 (2020) 125
    - CMS 13 TeV, 138 fb^{-1}: JHEP 05 (2024) 042

JHEP 04 (2019) 046



JHEP 05 (2024) 042



Observables

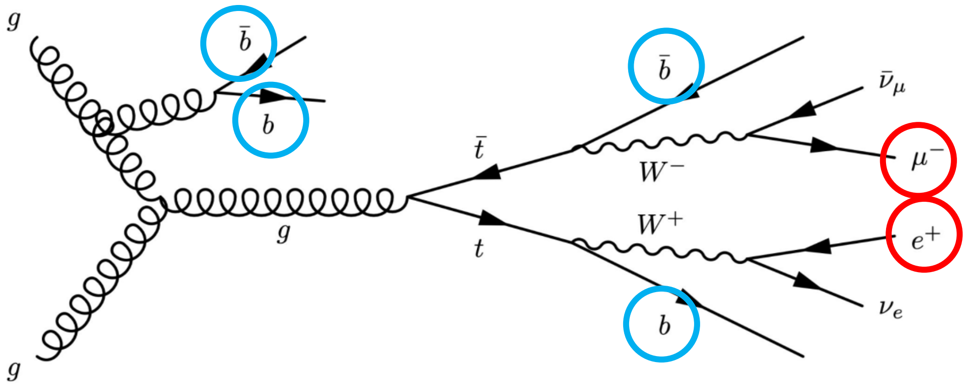
- Phase space regions:
  - ≥ 2 b-jets inclusive
  - ≥ 3(4) b-jets inclusive
  - ≥ 3(4) b-jets + ≥1 light jets
- Two categories of observables:
  - p_T ordered b-jets
  - b-jets from top decay vs QCD radiation
- Cross sections with respect to observables sensitive to complementary aspects:
  - Matrix element and parton shower modelling
  - Additional QCD radiation
  - Kinematics of top quarks (b_1, b_2) and extra jets
  - Top quark decays and possible new physics
  - Modelling of additional b-jet activity
  - Recoil modelling
  - In second category identify b-jets from top decays or QCD radiation
- Observables at particle- and detector-level

Observable	Description	Phase spaces ≥ 2b	≥ 3b	≥ 3b ≥ 1l/c	≥ 4b	≥ 4b ≥ 1l/c
p_T-ordered b-jets						
σ^{fid}	Fiducial total cross-section		✓	✓	✓	✓
$N_{b\text{-jets}}$	Number of b-jets	✓	✓			
$N_{l/c\text{-jets}}$	Number of light- or c-jets		✓		✓	
H_T^{had}	Scalar sum of p_T of all jets		✓		✓	
H_T^{all}	Scalar sum of p_T of charged leptons, jet and missing E_T		✓		✓	
$\Delta R_{\text{avg}}^{bb}$	Average angular distance in ΔR of b-jet pairs		✓		✓	
$\Delta\eta_{\text{max}}^{jj}$	Maximum absolute difference in η between any pair of jets		✓		✓	
$p_T(b_1)$	p_T of the hardest b-jet		✓		✓	
$p_T(b_2)$	p_T of second-hardest b-jet		✓		✓	
$p_T(b_3)$	p_T of third-hardest b-jet		✓		✓	
$p_T(b_4)$	p_T of fourth-hardest b-jet				✓	
$\eta(b_1)$	η of hardest b-jet		✓		✓	
$\eta(b_2)$	η of second-hardest b-jet		✓		✓	
$\eta(b_3)$	η of third-hardest b-jet		✓		✓	
$\eta(b_4)$	η of fourth-hardest b-jet				✓	
$p_T(l/c\text{-jet}_1)$	p_T of the hardest light- or c-jet			✓		✓
$\eta(l/c\text{-jet}_1)$	η of the hardest light- or c-jet			✓		✓
$m(b_1b_2)$	Invariant mass of two hardest b-jets in p_T		✓		✓	
$\Delta R(b_1, b_2)$	ΔR between two hardest b-jets		✓		✓	
$p_T(b_1b_2)$	p_T of two hardest b-jets		✓		✓	
$m(bb^{\min\Delta R})$	Invariant mass of two closest b-jets in ΔR				✓	
$p_T(bb^{\min\Delta R})$	p_T of the closest b-jets pair				✓	
$\min\Delta R(bb)$	Closest angular distance in ΔR among b-jets				✓	
$m(e\mu b_1b_2)$	Invariant mass of electron, muon and two hardest b-jets		✓		✓	
top-decay vs extra b-jets						
$p_T(b_1^{\text{top}})$	p_T of the hardest b-jet assigned to top quark		✓		✓	
$p_T(b_2^{\text{top}})$	p_T of the second-hardest b-jet assigned to top quark		✓		✓	
$p_T(b_1^{\text{add}})$	p_T of the hardest additional b-jet		✓		✓	
$p_T(b_2^{\text{add}})$	p_T of the second-hardest additional b-jet				✓	
$\eta(b_1^{\text{top}})$	η of the hardest b-jet assigned to top quark		✓		✓	
$\eta(b_2^{\text{top}})$	η of the second-hardest b-jet assigned to top quark		✓		✓	
$\eta(b_1^{\text{add}})$	η of the hardest additional b-jet		✓		✓	
$\eta(b_2^{\text{add}})$	η of the second-hardest additional b-jet				✓	
$m(bb^{\text{top}})$	Invariant mass of a pair of b-jets assigned to top quarks		✓		✓	
$p_T(bb^{\text{top}})$	p_T of a pair of b-jets assigned to top quarks		✓		✓	
$m(bb^{\text{add}})$	Invariant mass of a pair of additional b-jets				✓	
$p_T(bb^{\text{add}})$	p_T of a pair of additional b-jets				✓	
$m(e\mu bb^{\text{top}})$	Invariant mass of $e\mu$ and the b-jets pair assigned to top quarks		✓		✓	
$\Delta R(e\mu bb^{\text{top}}, b_1^{\text{add}})$	ΔR between the direction of the system of $e\mu$ and b-jet pair assigned to top and the direction of the hardest additional b-jet		✓		✓	
$\Delta R(e\mu bb^{\text{top}}, l/c\text{-jet}_1)$	ΔR between the direction of the system of $e\mu$ and b-jet pair assigned to top and the direction of the hardest light- or c-jet			✓		✓
$p_T(l/c\text{-jet}_1) - p_T(b_1^{\text{add}})$	Difference in p_T between the hardest l/c-jet and the additional b-jet			✓		✓

Event Selection

At **detector level**:

- Single-lepton triggers:
  - p_T > 24 (26) GeV for 2015 (2016-2018)
- Exactly one electron and one muon:
  - Opposite sign, isolated leptons
  - $m_{e\mu}$ > 15 GeV to reject low-mass di-τ
- At least 2 jets:
  - Anti-kt (R=0.4) on Particle flow constituents
- At least 2 b-tagged jets:
  - DL1r b-tagging algorithm (deep NN)
  - Baseline **working point with 77% efficiency**
  - Mis-tagging: 140 ± 12-19% (light); 5 ± 18-31% (c-jets)
- Similar **particle-level** selection criteria to define **fiducial** phase space



	$t\bar{t}$ +b-jets		
	$t\bar{t} +\geq 0b$	$t\bar{t} +\geq 1b$	$t\bar{t} +\geq 2b$
Electron	p_T > 28 GeV $\lvert\eta\rvert$ < 2.5		
Muon	p_T > 28 GeV $\lvert\eta\rvert$ < 2.5		
jets/b-jets	p_T > 25 GeV $\lvert\eta\rvert$ < 2.5		
Number of electron (N_e)	1		
Number of muon (N_μ)	1		
Number of b-jets (N_b)	≥ 2	≥ 3	≥ 4
charge $Q_e + Q_\mu$	0		
ΔR(lepton, jet)	> 0.4		
e/μ from τ lepton decay	included		

Data & Monte Carlo Expected Yields

- Selected sample quite rich in top pair production
  - Non-top backgrounds determined and subtracted
- Backgrounds with true prompt leptons: ttH, ttV, single top, Z+jets, dibosons, etc
  - Estimated from Monte Carlo
- Background from Non-prompt and fake leptons
  - Estimated from Same Sign lepton sample, scaled using Monte Carlo derived factor
- Dominant background from mis-tagged tt+light jets / tt+charm
  - Normalized from **template fit to data**

Process	$\geq 2j, 2b@77\%$	$\geq 3j, 3b@77\%$	$\geq 4j, \geq 4b@77\%$
$t\bar{t}$ +b-jets	4100 ± 790	3550 ± 650	474 ± 99
$t\bar{t}c$	11600 ± 2200	2190 ± 430	57 ± 15
$t\bar{t}l$	263000 ± 33000	2080 ± 440	25 ± 15
Wt	9100 ± 1800	227 ± 94	14 ± 11
$t\bar{t}V$	740 ± 230	94 ± 30	16.3 ± 5.1
$t\bar{t}H$	180 ± 22	108 ± 13	37.2 ± 5.3
Non-prompt lepton	340 ± 210	37 ± 20	10.9 ± 6.1
Z/γ^*+jets	96 ± 38	3.4 ± 1.4	0.15 ± 0.09
Diboson	85 ± 43	3.0 ± 1.5	0.11 ± 0.07
Others	41 ± 20	16.4 ± 8.2	6.4 ± 2.9
Total predicted	290000 ± 35000	8300 ± 1300	640 ± 120
Observed	281213	10235	798

Predicted event yields before corrections

Unfolding

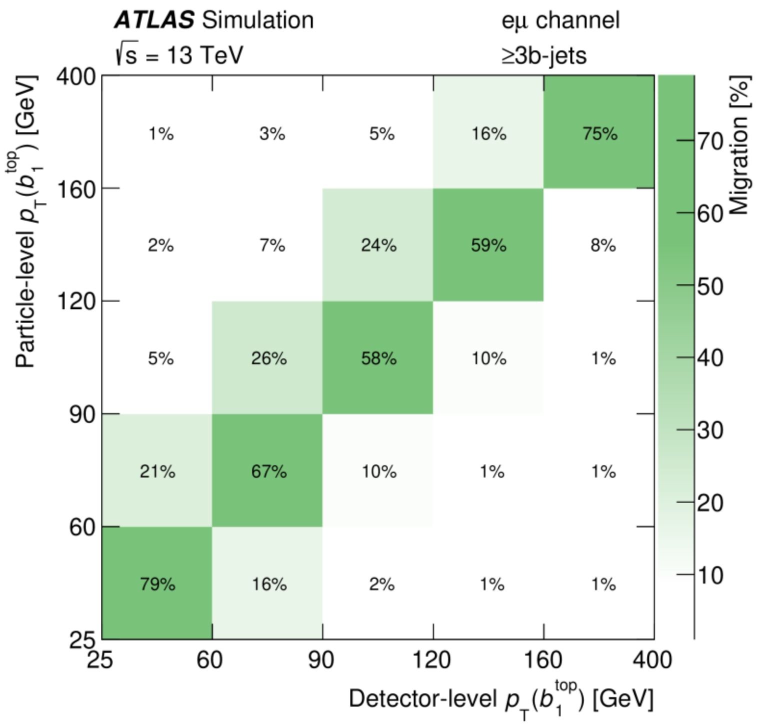
- Detector-level distributions unfolded to particle-level with iterative Bayesian method
- Non-tt backgrounds subtracted from data distribution at detector level – leaves ttb(b), ttc, ttl
- For an observable ***X*** in particle-level bin ***i***:

$$N^i_{\text{unfold}} = \frac{1}{f^i_{\text{eff}}} \sum_k \mathcal{M}^{-1}_{ik}\, f^k_{\text{accept}}\, f^k_{t\bar{t}b}\, (N^k_{\text{data}} - N^k_{\text{bkg}})$$

- Where:

$$f^k_{t\bar{t}b} = \frac{\mathcal{S}^k_{t\bar{t}b,\text{reco}}}{\mathcal{S}^k_{t\bar{t}b,\text{reco}} + \mathcal{B}^k_{t\bar{t}b,\text{reco}}} \quad f^k_{\text{accept},t\bar{t}b} = \frac{\mathcal{S}^k_{t\bar{t}b,\text{reco}\wedge\text{part}}}{\mathcal{S}^k_{t\bar{t}b,\text{reco}}} \quad f^i_{\text{eff},t\bar{t}b} = \frac{\mathcal{S}^i_{t\bar{t}b,\text{part}\wedge\text{reco}}}{\mathcal{S}^i_{t\bar{t}b,\text{part}}}$$

  - $S^k_{ttb,reco}$: number of detector-level events belonging to the ttb category after scale factors applied
  - $B^k_{ttb,reco}$: number of detector-level ttc and ttl events after scale factors
  - $S^k_{ttb,reco\wedge part}$: number of detector-level ttb events in bin **k** which are also in particle-level bin **k**
  - $S^i_{ttb,part}$: number of particle-level ttb events in bin *i*
  - $S^i_{ttb,part\wedge reco}$: number of particle-level ttb events in bin *i* that pass the fiducial selection in the same bin



Migration matrix for observable $p_T(b_1^{top})$ in fiducial region with ≥3 b-jets

Inclusive Fiducial Cross Sections

- Inclusive fiducial cross sections determined for each phase space region
  - Compared to several generators and modelling options
- Dominant uncertainties are systematic:
  - b-tagging, jet energy scale, and tt modelling

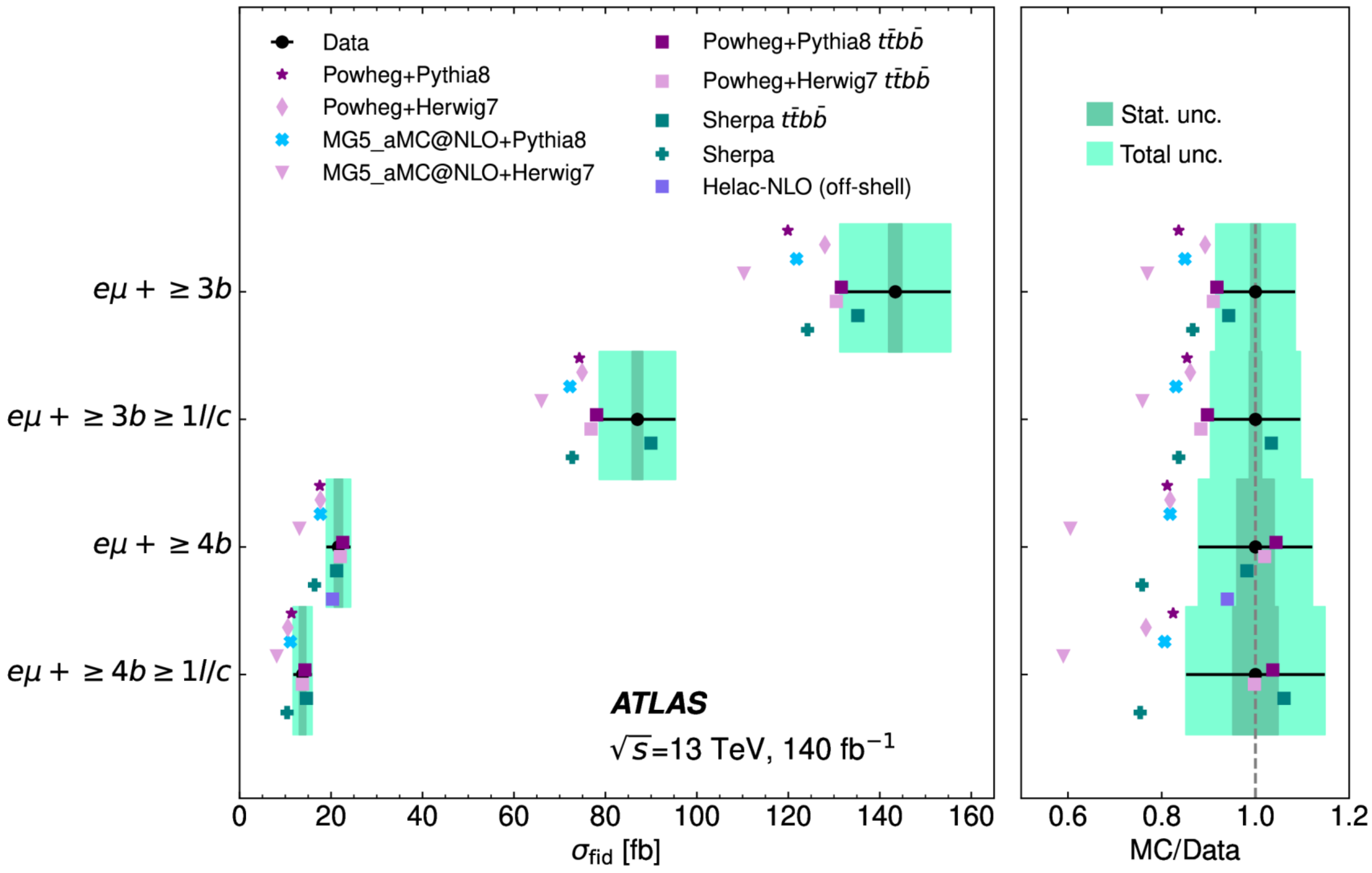
$$\sigma_i^{fid} = \frac{N_{unfold}^i}{\mathcal{L}}$$

Fiducial phase space	$\geq 3b$	$\geq 3b \geq 1l/c$	$\geq 4b$	$\geq 4b \geq 1l/c$
	Fiducial cross-sections [fb]			
Measured	143 ±1 (stat) ±12 (syst)	87 ±1 (stat) ±8 (syst)	22 ±1 (stat) ±3 (syst)	14 ±1 (stat) ±2 (syst)
POWHEG+PYTHIA 8 $t\bar{t}b\bar{b}$ (4FS)	132	78	23	14
POWHEG+PYTHIA 8 $t\bar{t}b\bar{b}$ h_{bzd} (4FS)	129	74	21	13
POWHEG+PYTHIA 8 $t\bar{t}b\bar{b}$ dipole (4FS)	128	71	22	13
POWHEG+PYTHIA 8 $t\bar{t}b\bar{b}$ $p_{\mathrm{T}}^{\mathrm{hard}}$ (4FS)	129	68	21	12
POWHEG+HERWIG 7 $t\bar{t}b\bar{b}$ (4FS)	130	77	22	14
SHERPA $t\bar{t}b\bar{b}$ (4FS)	135	90	21	15
HELAC-NLO (off-shell) $e\mu + 4b$	–	–	20	–
POWHEG+PYTHIA 8 $t\bar{t}$ (5FS)	120	74	18	11
POWHEG+HERWIG 7 $t\bar{t}$ (5FS)	128	75	18	11
MG5_aMC@NLO+PYTHIA8 $t\bar{t}$ (5FS)	122	72	18	11
MADGRAPH5_aMC@NLO+HERWIG 7 $t\bar{t}$ (5FS)	110	66	13	8
SHERPA 2.2.12 $t\bar{t}$ (5FS)	124	73	16	10

Source	Fiducial cross-section phase space			
	$\geq 3b$ Unc. [%]	$\geq 3b \geq 1l/c$ Unc. [%]	$\geq 4b$ Unc. [%]	$\geq 4b \geq 1l/c$ Unc. [%]
Data statistical uncertainty	1.0	1.2	3.9	4.8
Luminosity	0.8	0.8	0.8	0.8
Jet	3.4	5.2	6.6	8.5
b-tagging	5.1	4.9	6.5	6.4
Lepton and trigger	1.4	1.4	1.2	1.2
Pile-up	0.9	0.7	0.6	0.3
$t\bar{t}c/t\bar{t}l$ fit variation	1.7	1.7	0.8	0.8
$t\bar{t}c/t\bar{t}l$ shape variation	0.2	0.5	0.3	1.6
$t\bar{t}H/t\bar{t}V$ and non-$t\bar{t}$ background	1.1	1.1	2.2	2.4
Detector+background total syst.	6.7	7.6	9.7	11.2
Parton shower and hadronisation	2.9	3.5	1.5	3.6
μ_{R} and μ_{F} scale variations	0.7	0.6	0.2	0.3
Matrix element matching ($p_{\mathrm{T}}^{\mathrm{hard}}$)	1.3	1.1	4.8	7.0
h_{damp}	1.8	1.5	2.9	3.2
ISR	0.1	0.4	0.2	0.3
FSR	3.1	3.6	3.3	3.1
RecoilToTop	1.8	1.9	2.4	3.4
PDF	0.2	0.2	0.1	0.1
NNLO reweighting	0.6	0.5	0.5	0.5
MC statistical uncertainty	0.2	0.2	0.5	0.6
$t\bar{t}$ modelling total syst.	5.2	5.7	7.2	9.7
Total syst.	8.5	9.6	12.1	14.8
Total	8.5	9.6	12.7	15.5

Inclusive Fiducial Cross Sections

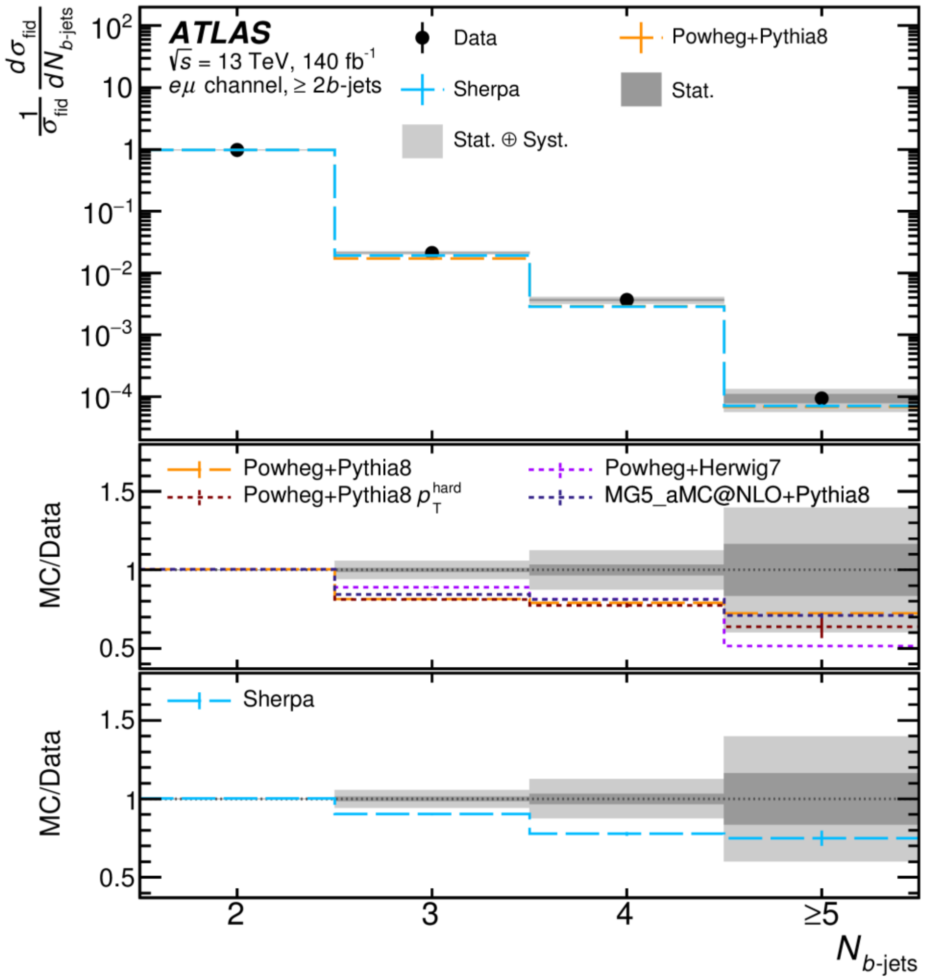
- ttbar (5FS) NLO ME+PS slightly under predicts additional b-jets production
- Sherpa with one parton at NLO (5FS) under predicts events with ≥3 and ≥4 b-jets
- Powheg ttbb predictions in 4FS describe data well in the ≥4 b-jets region
- Sherpa ttbb remains consistent with data in all four phase spaces

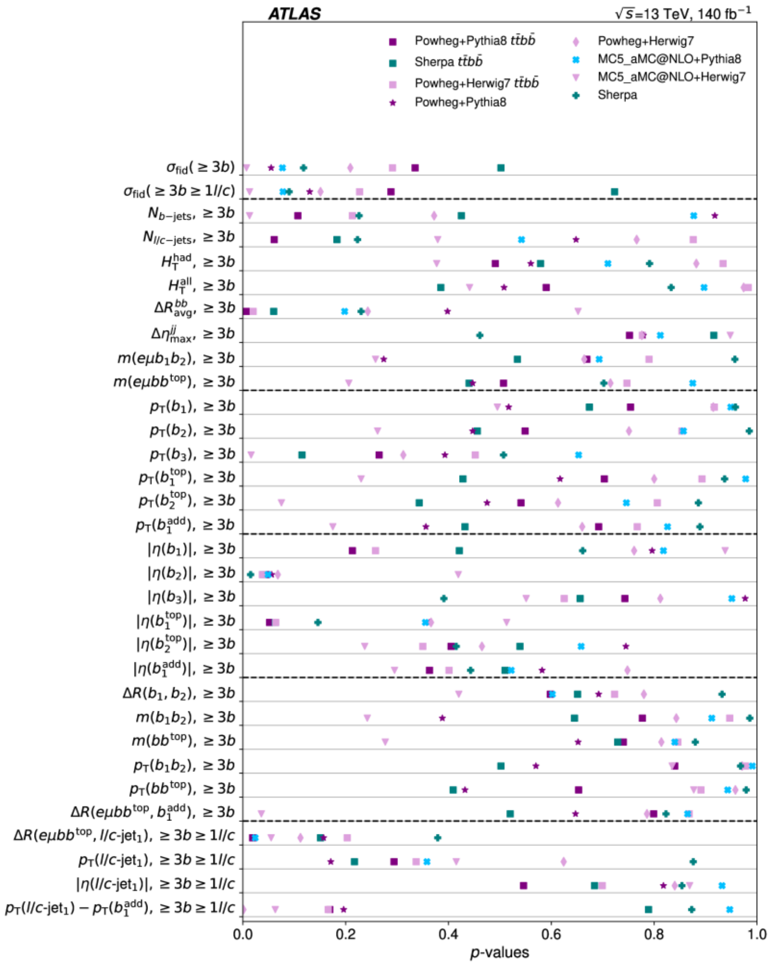


Differential Normalized Fiducial Cross Sections

- Differential cross sections
  - Determined in each phase space region
  - And each observable
- Good general agreement with predictions
  - See distribution of p-values

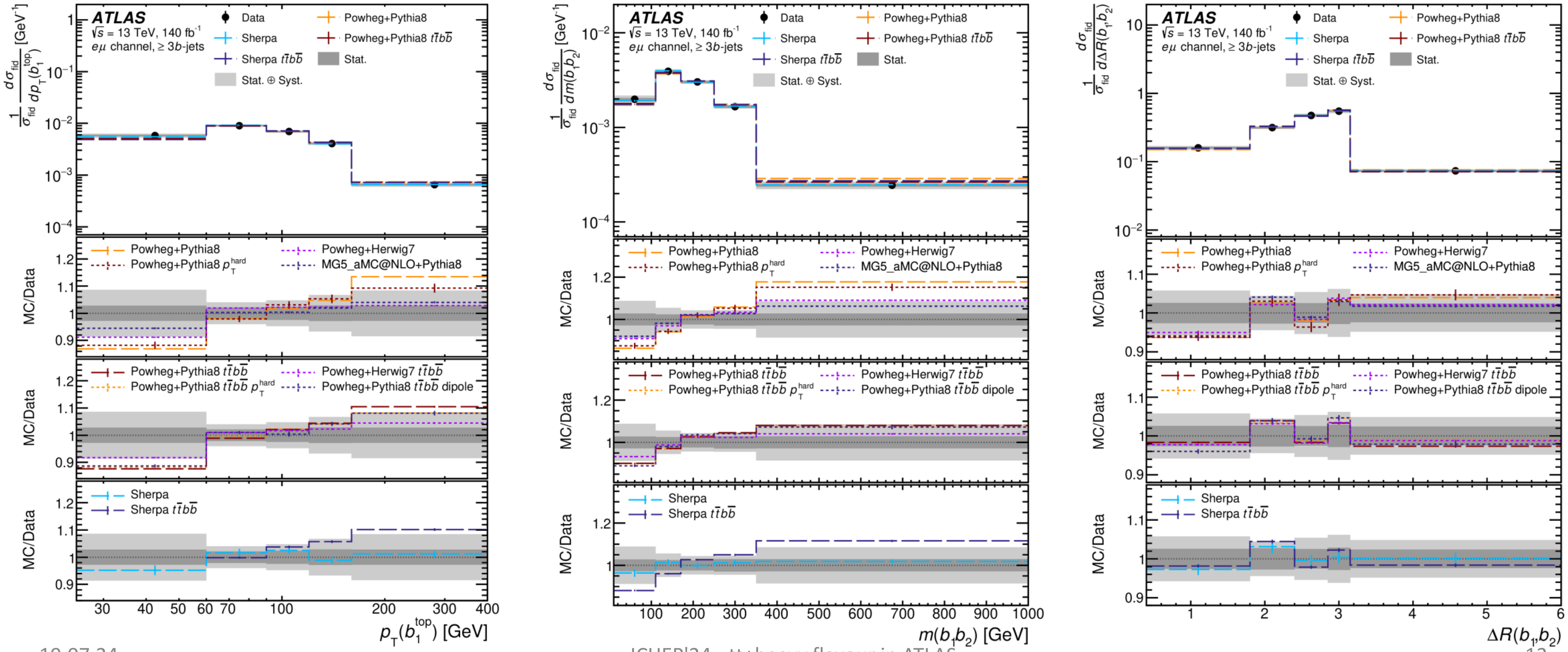
$$\frac{1}{\sigma^{\mathrm{fid}}}\cdot\frac{\mathrm{d}\sigma^{\mathrm{fid}}}{\mathrm{d}X^{i}} = \frac{N^{i}_{\mathrm{unfold}}}{\Delta X^{i}\sum_{i} N^{i}_{\mathrm{unfold}}}$$





Examples of Unfolded Distributions

- Fiducial region: lepton p_T > 28 GeV, jet p_T > 25 GeV, ≥ 3 b-jets
- From left to right: leading b-jet p_T; invariant mass of 2 leading b-jets; **Δ**R between 2 leading b-jets



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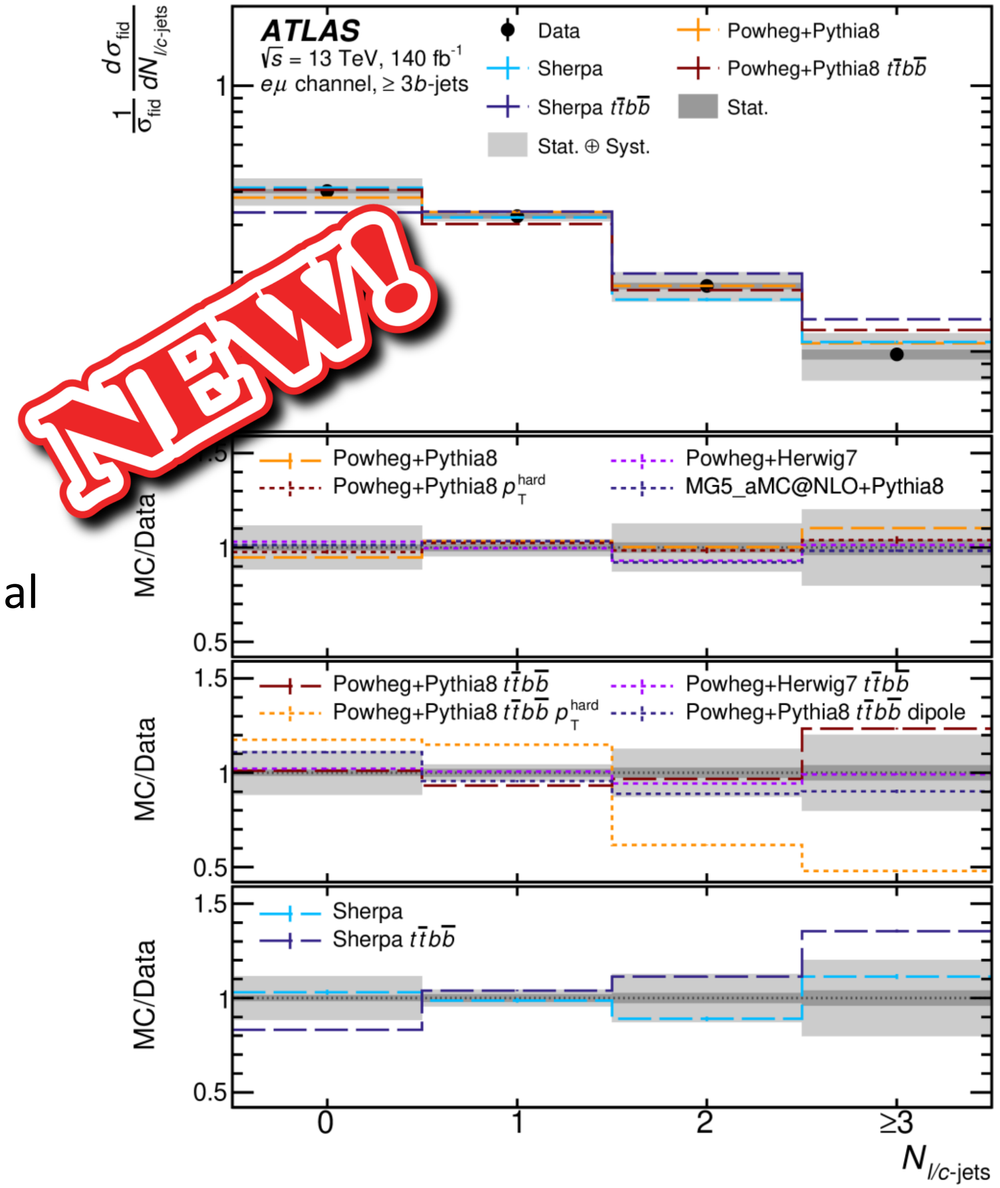
Summary and Outlook

- Fiducial cross sections of top-quark + b-jets production were measured with 140 fb^{-1} of data at 13 TeV
- The measured integrated fiducial cross-sections are consistent with some predictions from various NLO calculations
  - But several generators under-predict production of additional b-jets
- A great wealth of measurements available!
  - No MC generators simultaneously describe all differential observables
  - Differences between any two predictions are smaller than the measurement uncertainties for most observables

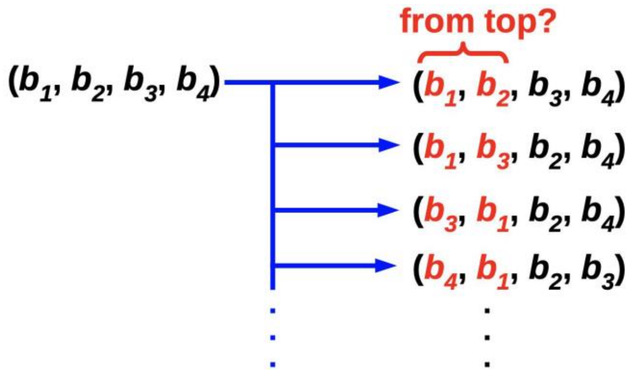


Backup Slides

b-jet Classification

- b-hadrons associated with closest b-quark and ghost-associated with particle-level jet
- If b-quark from top decay then b-jet identified as coming from top decays

$$w = \begin{cases} e^{-\left(\Delta R_{\ell 1 b1} - \Delta R^{\min}_{\ell 1 b}\right)^2} \times e^{-\left(\Delta R_{\ell 2 b2} - \Delta R^{\min}_{\ell 2 b}\right)^2} \times e^{-\left(\max(\Delta R_{b1b3}, \Delta R_{b2b3}) - \Delta R^{\max}_{bb}\right)^2} & \text{if } N_{b\text{-jets}} = 3, \\ e^{-\left(\Delta R_{\ell 1 b1} - \Delta R^{\min}_{\ell 1 b}\right)^2} \times e^{-\left(\Delta R_{\ell 2 b2} - \Delta R^{\min}_{\ell 2 b}\right)^2} \times e^{-\left(\Delta R_{b3b4} - \Delta R^{\min}_{bb}\right)^2} & \text{if } N_{b\text{-jets}} \geq 4, \end{cases}$$



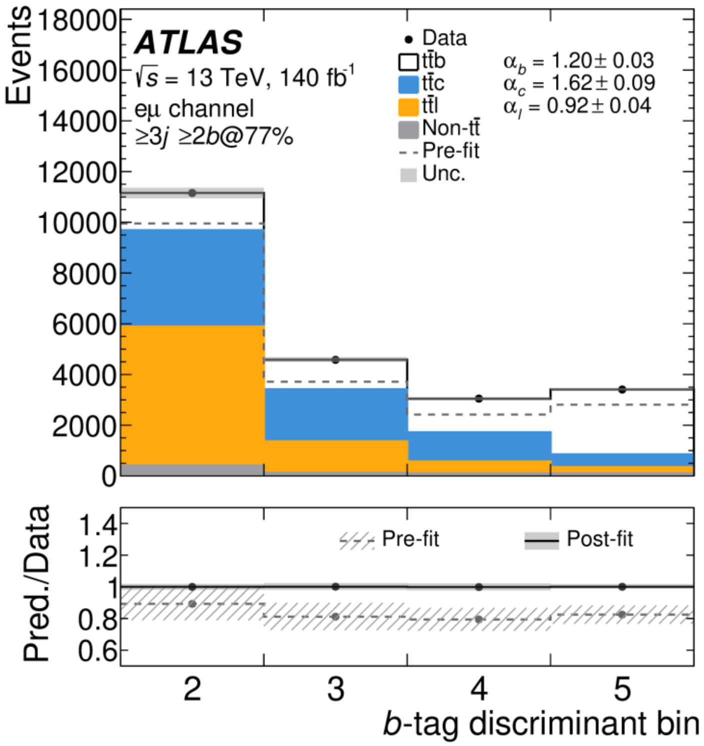
- Use angular distances to calculate classifier *w* for each b-jet permutati
  - b_1 and b_2 from top, rest from QCD radiation
- Purity of classification:
  - In 53% (56%) of particle-level events, 2 b-jets correctly assigned to tops
  - In 53% (56%) of reconstructed, 2 b-jets correctly assigned to tops
  - Association fails in < 10% events with ⩾ 3 b-jets as one is out of detetctor acceptance
  - Purity much better than both random association and pT-based association

tt+jets Background Estimation

- Templates use b-tagging weight of 3rd highest b-tagging discriminant in each event
  - Proxy for 3rd jet after b-jets from top decay
  - Templates include **top-pair, ttH, ttV**
- **Global** fit to inclusive region to determine overall scaling factors
  - **Kinematic-dependent** fit to evaluate systematic uncertainty
- Binned max-likelihood fit of **[ttbb + ttb + ttc + ttl]** to **[data – non-tt]**
- In each bin ***k***, number of events $\boldsymbol{\nu_k}$ given by:

$$\nu_k(\alpha_b^s, \alpha_c^s, \alpha_l^s) = \alpha_b^s N_{t\bar{t}b}^{k,s} + \alpha_c^s N_{t\bar{t}c}^{k,s} + \alpha_l^s N_{t\bar{t}l}^{k,s} + N_{\text{non-}t\bar{t}}^{k,s}$$

	Inclusive region *Global* approach (nominal)	Regions in terms of jet multiplicity and third highest-p_T jet-p_T bins *Kinematic-dependent* approach (systematic)					
Category	$\geq 3j \geq 2b$@77%	$3j \geq 2b$@77%			$\geq 4j \geq 2b$@77%		
	$\geq$ 25 GeV	25-35 GeV	35-50 GeV	$\geq$ 50 GeV	25-50 GeV	50-75 GeV	$\geq$ 75 GeV
$t\bar{t}b$	≥3 *b*-jets	≥3 *b*-jets			–		
$t\bar{t}b_{ex}$	–	–			exactly 3 *b*-jets		
$t\bar{t}b\bar{b}$	–	–			≥4 *b*-jets		
$t\bar{t}c$	< 3 *b*-jets and ≥ 1 *c*-jet	< 3 *b*-jets and ≥ 1 *c*-jet			< 3 *b*-jets and ≥ 1 *c*-jet		
$t\bar{t}l$	events that do not meet above criteria	events that do not meet above criteria			events that do not meet above criteria		



Data and Monte Carlo

- Data: **140 fb^{-1}** of √s = 13 TeV p-p collisions from LHC Run 2 (2015-2018)
- Monte Carlo simulations differ in:
  - Treatment of **b-quark mass**
  - **Extra b quarks** from matrix element or parton shower
  - Angular ordering of **parton shower** jets
  - **Matching** of parton shower and matrix element
  - Kinematics of extra b-jets
  - **Flavour scheme** in PDFs
- Comparing data with multiple MC generators at particle level

	MC sample	Generator	Process	Parton shower	Matching/ Parton shower settings	Tune	Use
Nominal	Powheg+Pythia8	Powheg Box v2	$t\bar{t}$ NLO	Pythia 8.230	Powheg h_{damp} =1.5m_{top} $p_{\text{T}}^{\text{hard}}$ = 0 `globalRecoil` `recoilToColoured=ON`	A14	nom.
Systematic uncertainty estimation	Powheg+Pythia8 h_{damp}	Powheg Box v2	$t\bar{t}$ NLO	Pythia 8.230	Powheg h_{damp} =3m_{top}	A14	syst.
	Powheg+Pythia8 $p_{\text{T}}^{\text{hard}}$	Powheg Box v2	$t\bar{t}$ NLO	Pythia 8.230	Powheg $p_{\text{T}}^{\text{hard}}$ = 1	A14	syst.
	Powheg+Pythia8 RecoilToTop	Powheg Box v2	$t\bar{t}$ NLO	Pythia 8.230	Powheg `recoilToTop`	A14	syst.
	Powheg+Herwig 7	Powheg Box v2	$t\bar{t}$ NLO	Herwig 7.1.3	Powheg	H7.1-Default	syst.
Comparison with data	Powheg+Pythia8 dipole	Powheg Box v2	$t\bar{t}$ NLO	Pythia 8.230	Powheg `dipoleRecoil` on	A14	comp.
	MadGraph5_aMC@NLO+Pythia 8	MadGraph5_aMC@NLO v2.6.0	$t\bar{t}$ NLO	Pythia 8.230	MC@NLO	A14	comp.
	MadGraph5_aMC@NLO+Herwig 7	MadGraph5_aMC@NLO v2.6.0	$t\bar{t}$ NLO	Herwig 7.1.3	MC@NLO	H7.1-Default	comp.
	Sherpa	Sherpa 2.2.12	$t\bar{t}$ +0,1 parton at NLO +2,3,4 parton at LO	Sherpa	MePs@Nlo	Author's tune	comp.
	Powheg+Pythia8 $t\bar{t}b\bar{b}$	Powheg Box Res	$t\bar{t}b\bar{b}$ NLO	Pythia 8.230	Powheg Box Res h_{bzd}=5 $p_{\text{T}}^{\text{hard}}$ = 0 `globalRecoil`	A14	comp.
	Powheg+Pythia8 $t\bar{t}b\bar{b}$ $p_{\text{T}}^{\text{hard}}$	Powheg Box Res	$t\bar{t}b\bar{b}$ NLO	Pythia 8.230	Powheg Box Res $p_{\text{T}}^{\text{hard}}$ = 1	A14	comp.
	Powheg+Pythia8 $t\bar{t}b\bar{b}$ h_{bzd}	Powheg Box Res	$t\bar{t}b\bar{b}$ NLO	Pythia 8.230	Powheg Box Res h_{bzd}=2	A14	comp.
	Powheg+Pythia8 $t\bar{t}b\bar{b}$ dipole	Powheg Box Res	$t\bar{t}b\bar{b}$ NLO	Pythia 8.230	Powheg Box Res h_{bzd}=2 `dipoleRecoil` on	A14	comp.
	Powheg+Herwig 7 $t\bar{t}b\bar{b}$	Powheg Box Res	$t\bar{t}b\bar{b}$ NLO	Herwig 7.1.6	Powheg Box Res	H7.1-Default	comp.
	Sherpa $t\bar{t}b\bar{b}$	Sherpa 2.2.10	$t\bar{t}b\bar{b}$ NLO	Sherpa	MePs@Nlo	Author's tune	comp.
	Helac-NLO (off-shell)	Helac-NLO	$e\mu$ + 4b NLO	–	–	–	comp.