Measurement of the top quark mass with the ATLAS detector using $t\bar{t}$ events with a high transverse momentum top quark

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On behalf of the ATLAS Collaboration

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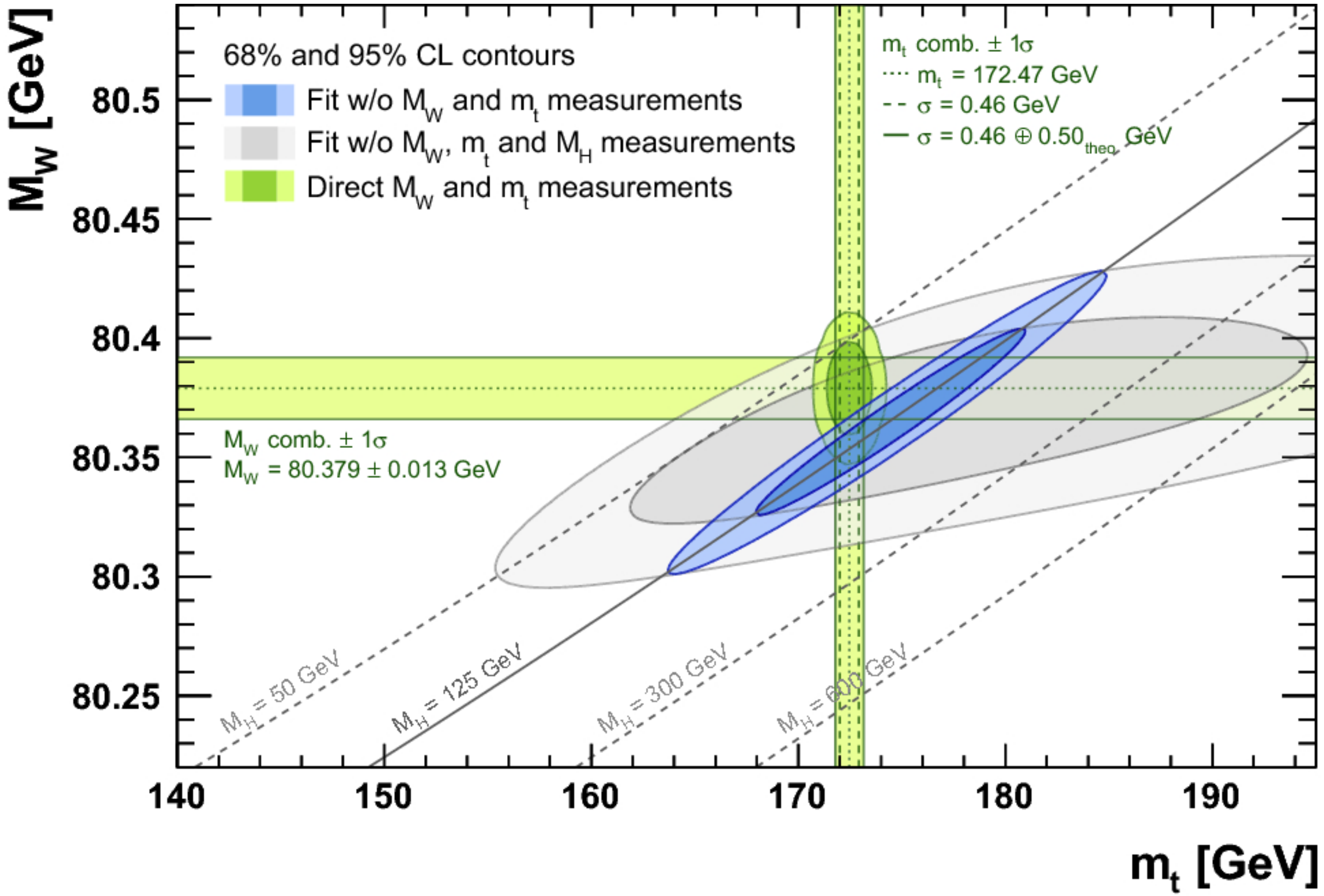
Why measure the top quark mass

Standard Model

- The top quark mass, m_t, is a very important parameter of the Standard Model.
- m_t affects the dynamics of elementary particles via loop diagrams.
- Precision measurements of m_t provide information for global fits of electroweak parameters.

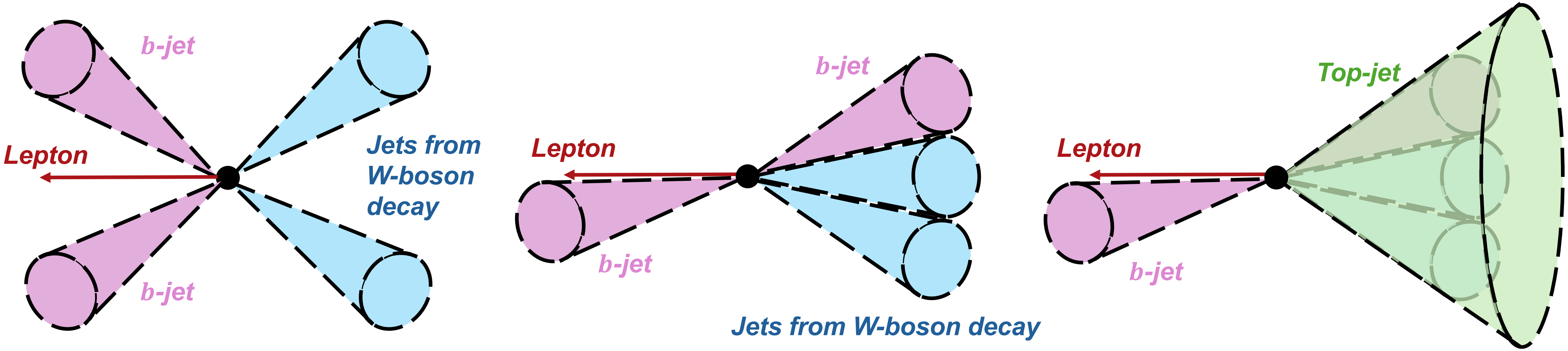
→ Can assess consistency of SM and probe its extensions.

Taken from: Eur. Phys. J. C78, 675 (2018)



Why use the boosted regime?

$$t\bar{t} \to W^+W^-b\bar{b} \to \ell\nu q\bar{q}'b\bar{b}$$



Resolved scenario

Boosted scenario

Jet reclustering

Advantage

Simplifies the reconstruction of hadronically decaying top quarks compared to the inclusive phase space.

→ Potentially reduces the systematic uncertainties on m_t.

Disadvantage

Lower available statistics
(but still systematically limited at the LHC)

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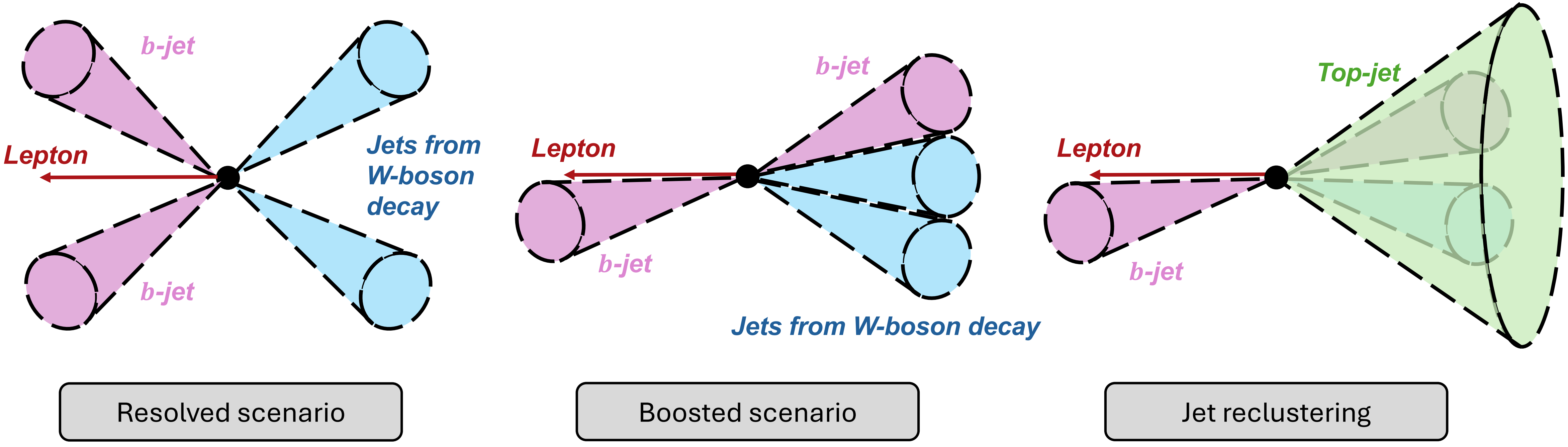

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→ Potentially reduces the systematic uncertainties on m_t.

Disadvantage

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(but still systematically limited at the LHC)

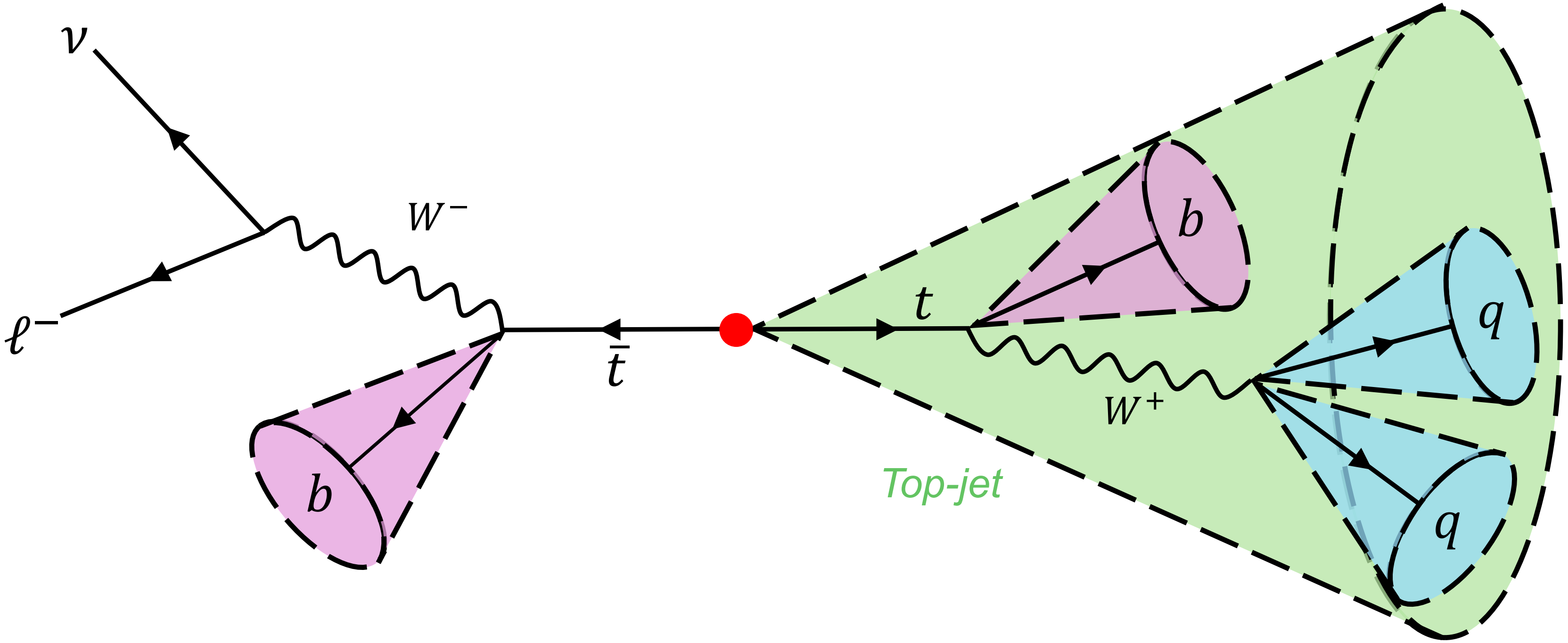
Dataset and event selection

Dataset

Full Run-2 ATLAS dataset corresponding to an integrated luminosity of $140\ \mathrm{fb}^{-1}$.

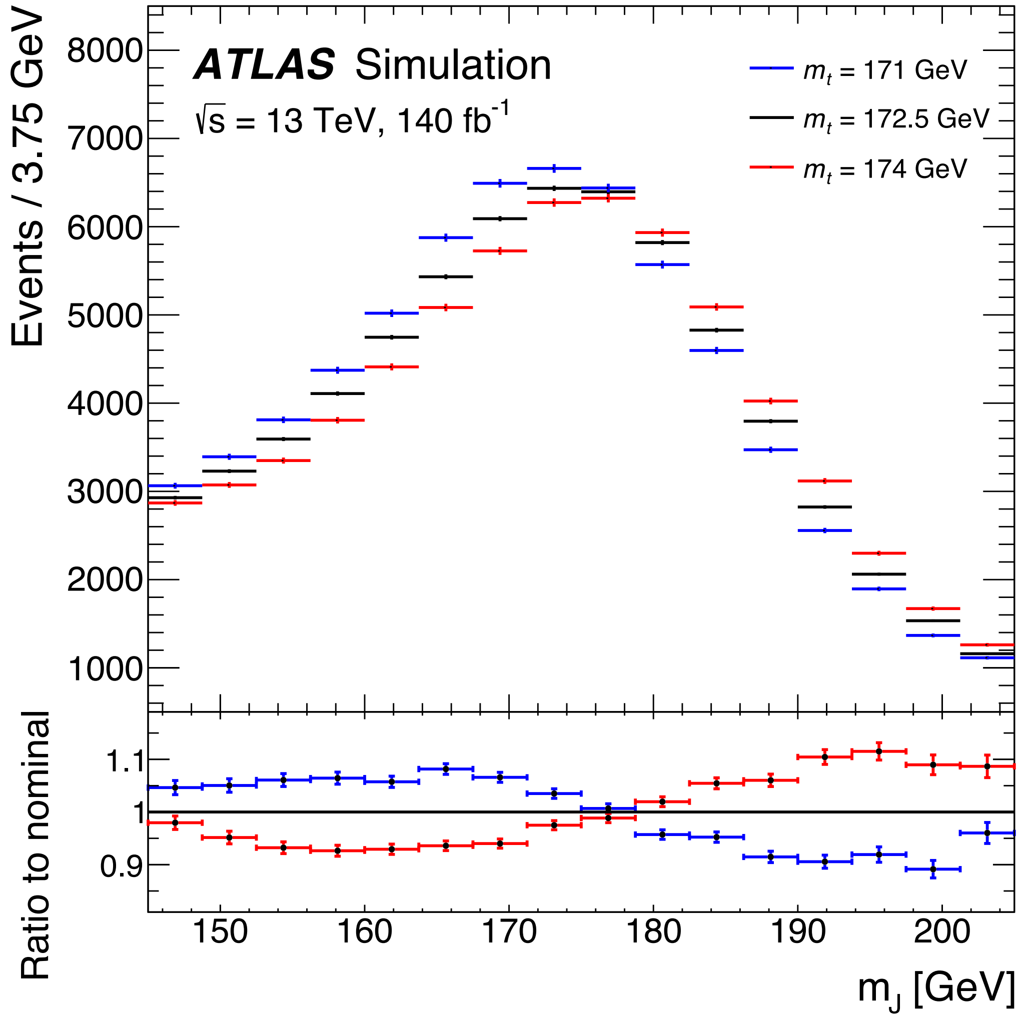
Selection

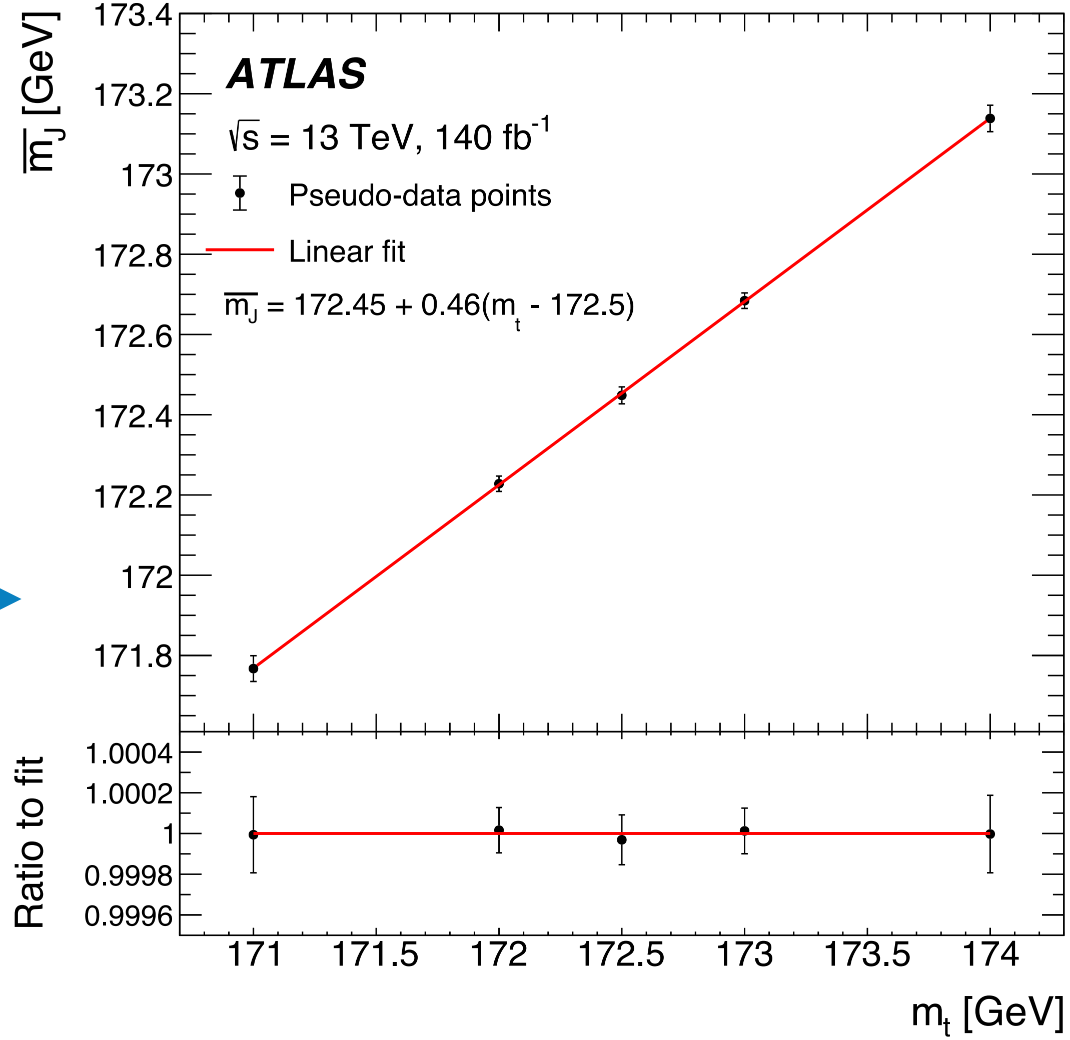
- Every event has at least one "top-jet" with:
  - $p_T > 355$ GeV.
  - 120 GeV < m_J < 220 GeV.
  - ≥ 2 small-radius jet constituents, where ≥ 1 is b-tagged.
- Need a second b-tagged jet.
- Exactly one lepton (electron or muon).
- $E_T^{\mathrm{miss}} > 20\ \mathrm{GeV}$ and $E_T^{\mathrm{miss}} + m_T^W > 60\ \mathrm{GeV}$.



Measurement strategy

Top-quark mass sensitivity: Use average top-jet mass, $\overline{m_J}$, as the m_t sensitive variable.





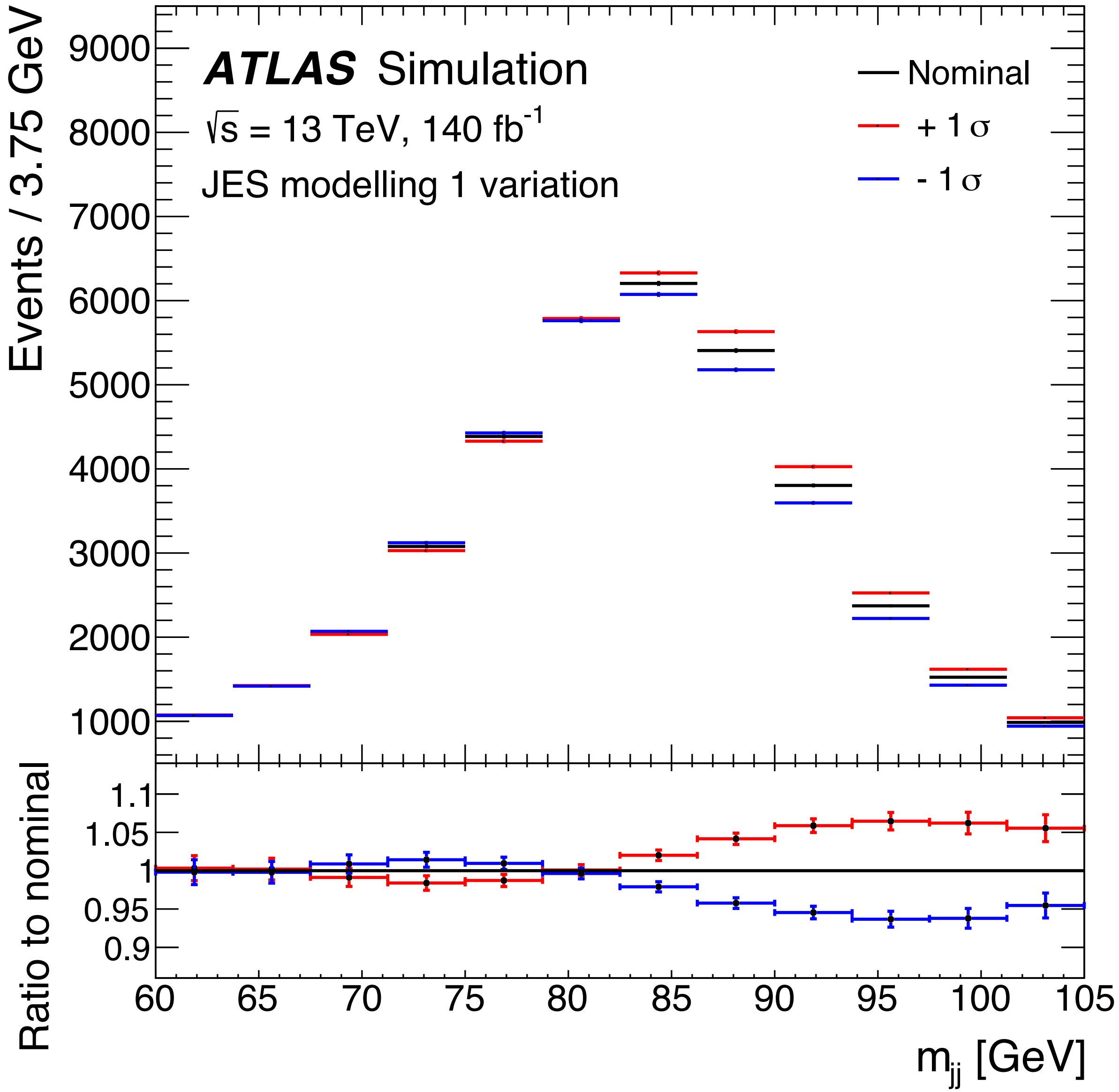
Reducing uncertainties: Jet energy scale

- Measurement is highly sensitive to uncertainties in the calibration of the energy of the jets.

  → Known as jet energy scale (JES) uncertainties.

- Introduce an observable that is sensitive to variations in the JES, but not m_t.

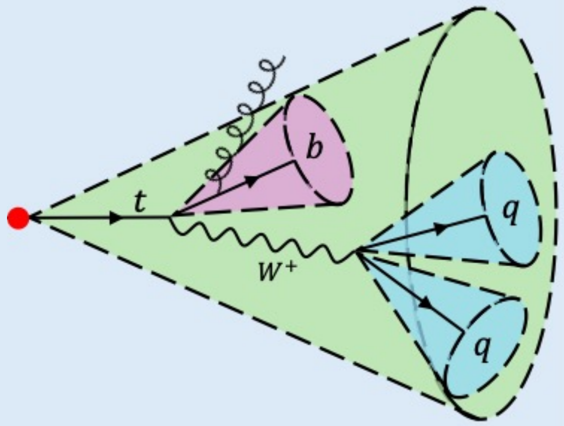
- Reconstructed W boson mass, m_{jj}, built from two non-b-tagged jets inside the top-jet.
  - The observable is independent of m_t.



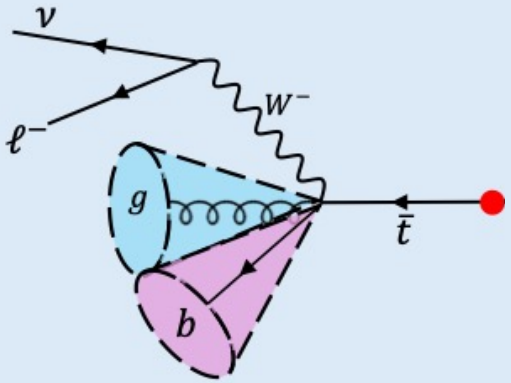
Reducing uncertainties: Recoil

When parton shower creates gluons from the b-quark in the top decay, there is ambiguity in choice of recoiling particle: b-quark or top quark.

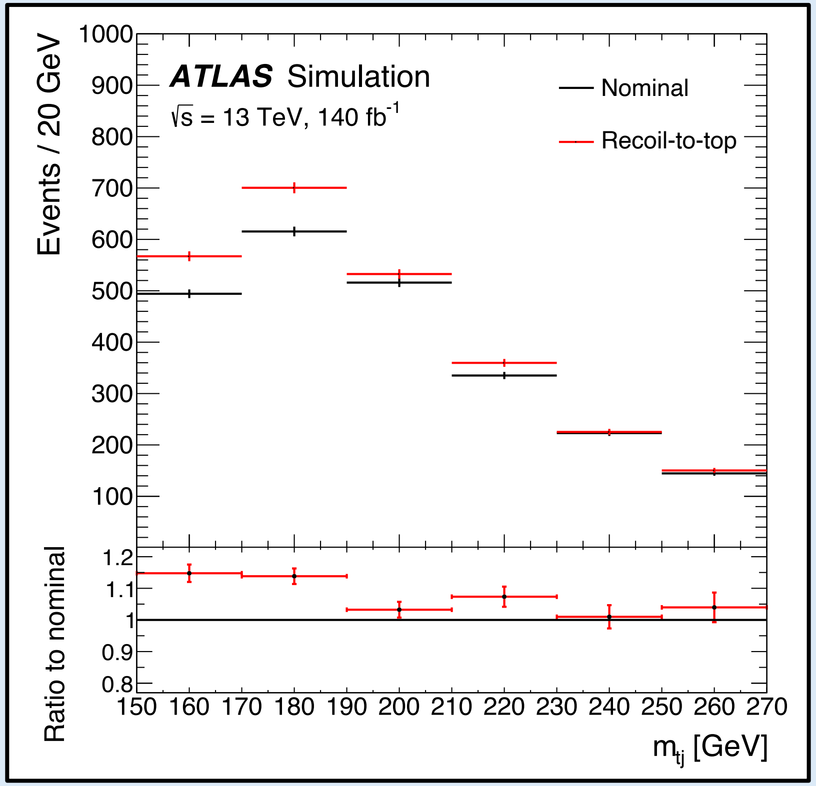
Choices change the amount of wide-angle radiation off the b-quark, which changes m_J and the measured m_t.



Additionally, changes the number of events where b-quark is reconstructed as two separate jets.



Introduce another observable to constrain uncertainty: the invariant mass of the semi-leptonically decaying top and the closest additional jet, m_{tj}.



Profile likelihood fit

$$L\left(\overline{m_J}^d, \boldsymbol{n}_{\boldsymbol{m}_{jj}}, \boldsymbol{n}_{\boldsymbol{m}_{tj}} \middle| m_t, \mu, \boldsymbol{\theta}\right) = \overbrace{G\left[\overline{m_J}^d \middle| \overline{m_J}(m_t, \mu, \boldsymbol{\theta}), \sigma_{\overline{m_J}}\right]}^{\overline{m_J}} \times \overbrace{\prod_s G(\beta_s|\theta_s, 1)}^{\text{Gaussian NP terms}} \times \overbrace{\prod_j P\left(n_{m_{jj},i}|\nu_i(\mu, \boldsymbol{\theta})\right)}^{m_{jj}} \times \overbrace{\prod_k P\left(n_{m_{tj},i}|\rho_{\mathrm{k}}(\mu, \boldsymbol{\theta})\right)}^{m_{tj}}$$

$$\mu = \frac{\sigma}{\sigma_{SM}}$$

As $\overline{m_J}$ is a single value and the only part of the fit with m_t dependence → NP fit values entirely determined by fitting m_{jj} and m_{tj}

Profile likelihood fit

1D fit

$$\boxed{L\left(\overline{m_J}^{d}, \boldsymbol{n}_{\boldsymbol{m_{jj}}}, \boldsymbol{n}_{\boldsymbol{m_{tj}}} \middle| m_t, \mu, \boldsymbol{\theta}\right) = \overbrace{G\left[\overline{m_J}^{d} \middle| \overline{m_J}(m_t, \mu, \boldsymbol{\theta}), \sigma_{\overline{m_J}}\right]}^{\overline{m_J}} \times \overbrace{\prod_{s} G(\beta_s|\theta_s, 1)}^{\text{Gaussian NP terms}}} \times \overbrace{\prod_{j} P\left(n_{m_{jj},i} \middle| \nu_i(\mu, \boldsymbol{\theta})\right)}^{m_{jj}} \times \overbrace{\prod_{k} P\left(n_{m_{tj},i} \middle| \rho_{\mathrm{k}}(\mu, \boldsymbol{\theta})\right)}^{m_{tj}}$$

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Expected uncertainty change using **Asimov** data

Source	Uncertainty [GeV]		
	1D fit	2D fit	3D fit
JES	± 1.41	± 0.30	± 0.26
Radiation (ISR and FSR)	± 0.82	± 0.08	± 0.14
Recoil	± 0.10	± 0.36	± 0.08
Total statistical	± 0.11	± 0.27	± 0.25
Total systematic	± 1.66	± 0.57	± 0.44
Total	± 1.66	± 0.63	± 0.51

Significant reductions!

~70% improvement to precision!

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Profile likelihood fit

2D fit

$$L\left(\overline{m_J}^d, \boldsymbol{n}_{m_{jj}}, \boldsymbol{n}_{m_{tj}} \middle| m_t, \mu, \boldsymbol{\theta}\right) = \overbrace{G\left[\overline{m_J}^d \middle| \overline{m_J}(m_t,\mu,\boldsymbol{\theta}), \sigma_{\overline{m_J}}\right]}^{\overline{m_J}} \times \overbrace{\prod_s G(\beta_s|\theta_s,1)}^{\text{Gaussian NP terms}} \times \overbrace{\prod_j P\left(n_{m_{jj},i} \middle| \nu_i(\mu,\boldsymbol{\theta})\right)}^{m_{jj}} \times \overbrace{\prod_k P\left(n_{m_{tj},i} \middle| \rho_\mathrm{k}(\mu,\boldsymbol{\theta})\right)}^{m_{tj}}$$

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Profile likelihood fit

3D fit

$$L\left(\overline{m_J}^{d}, \boldsymbol{n}_{\boldsymbol{m}_{jj}}, \boldsymbol{n}_{\boldsymbol{m}_{tj}} \middle| m_t, \mu, \boldsymbol{\theta}\right) = \overbrace{G\left[\overline{m_J}^{d} \middle| \overline{m_J}(m_t, \mu, \boldsymbol{\theta}), \sigma_{\overline{m_J}}\right]}^{\overline{m_J}} \times \overbrace{\prod_{s} G(\beta_s|\theta_s, 1)}^{\text{Gaussian NP terms}} \times \overbrace{\prod_{j} P\left(n_{m_{jj},i}|\nu_i(\mu, \boldsymbol{\theta})\right)}^{m_{jj}} \times \overbrace{\prod_{k} P\left(n_{m_{tj},i}|\rho_{\mathrm{k}}(\mu, \boldsymbol{\theta})\right)}^{m_{tj}}$$

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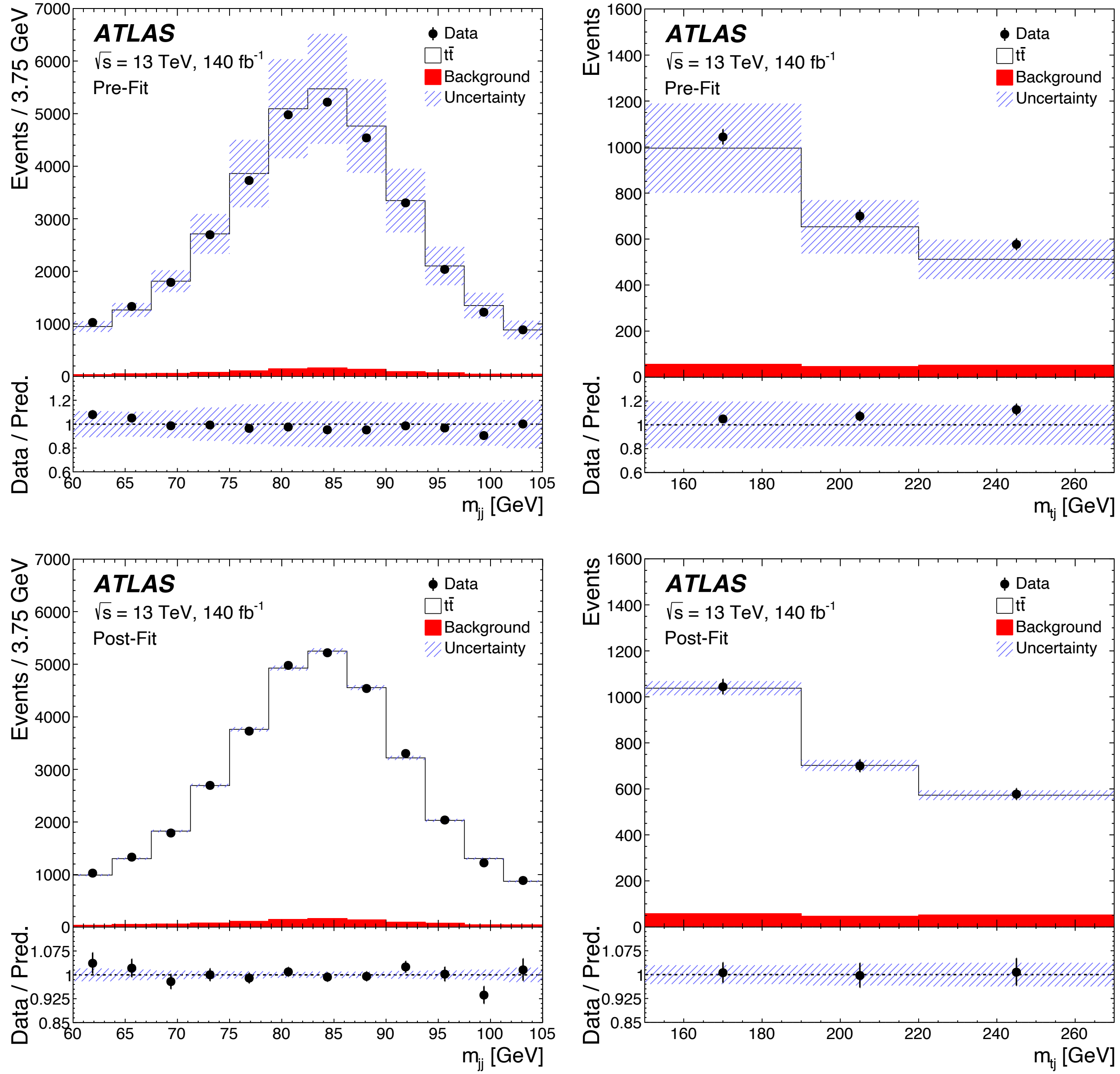
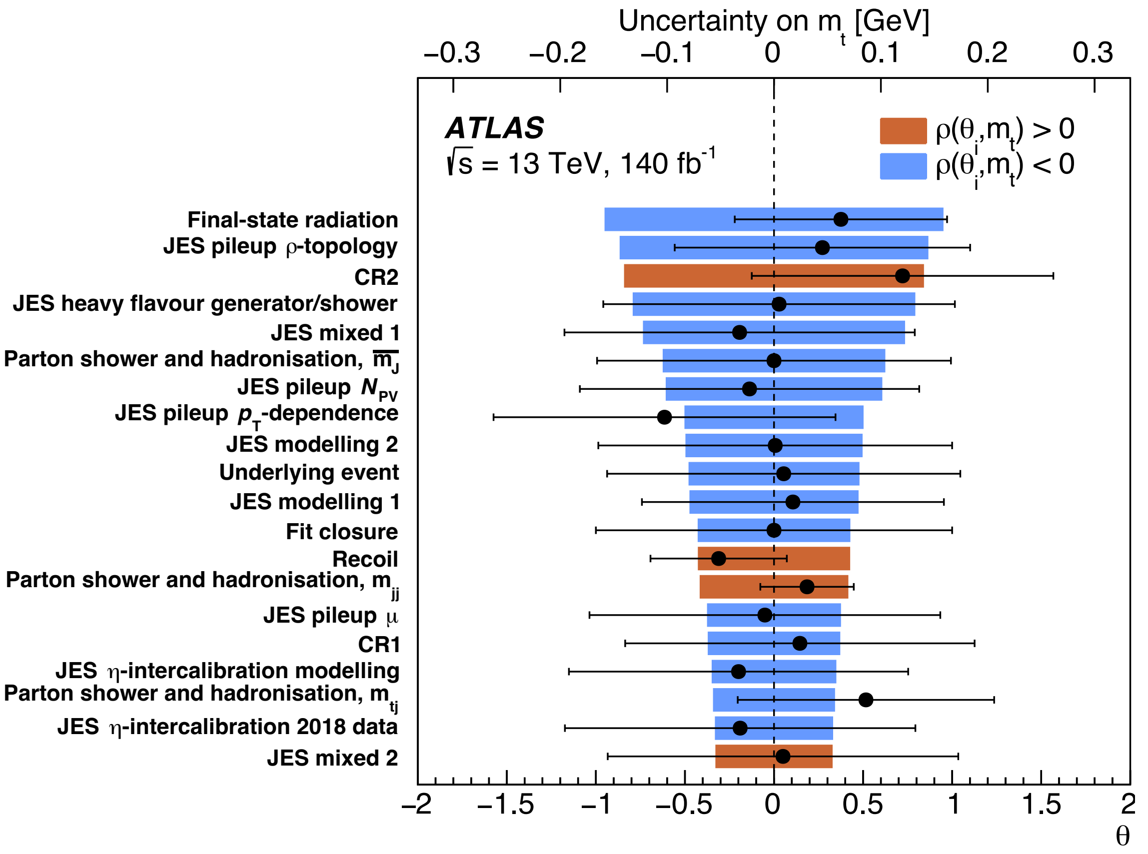
Constrained model

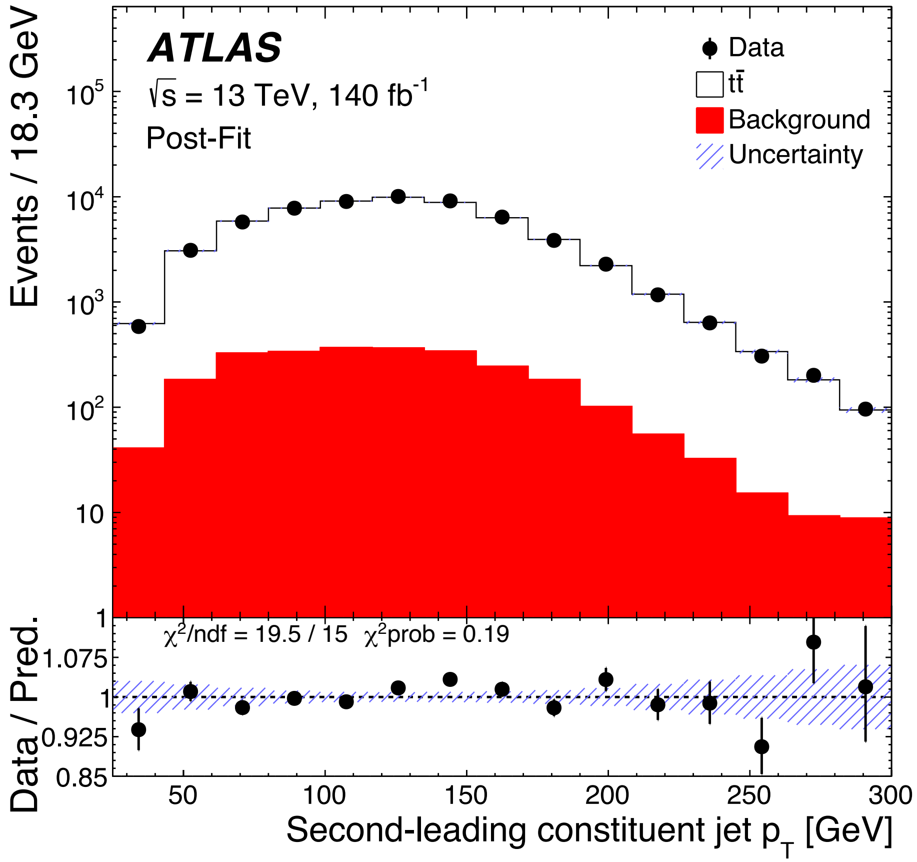


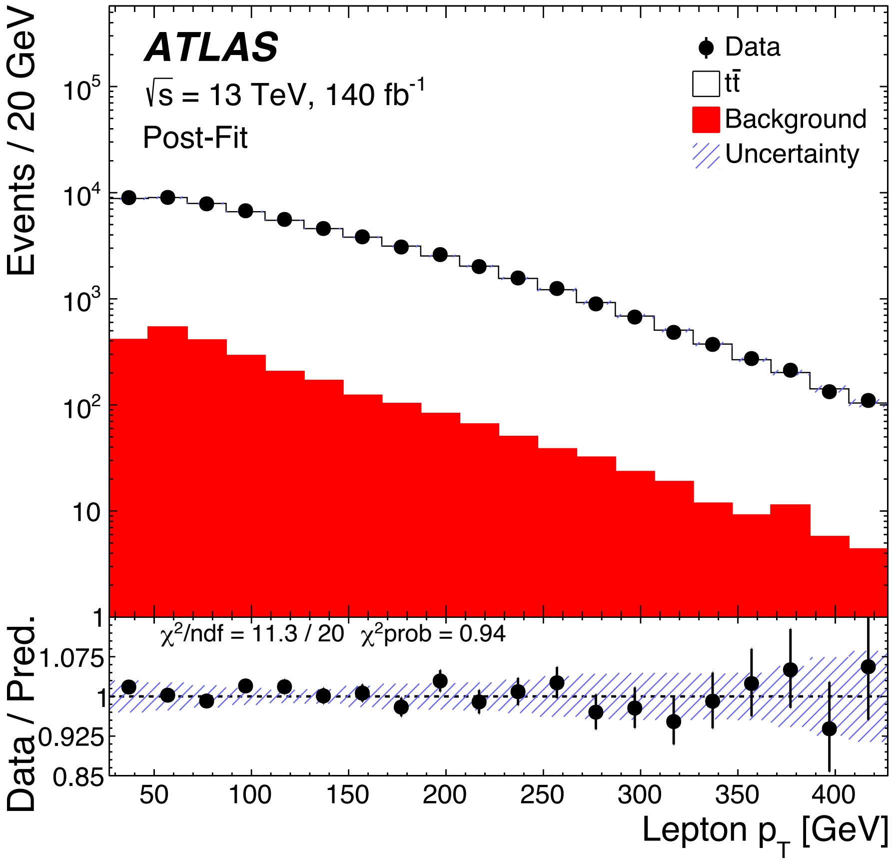


Validation

To validate the constrained model, apply it to other observables in the sample.

Can also do reliable χ^2 test when the correlations with m_{jj} and m_{tj} are low.



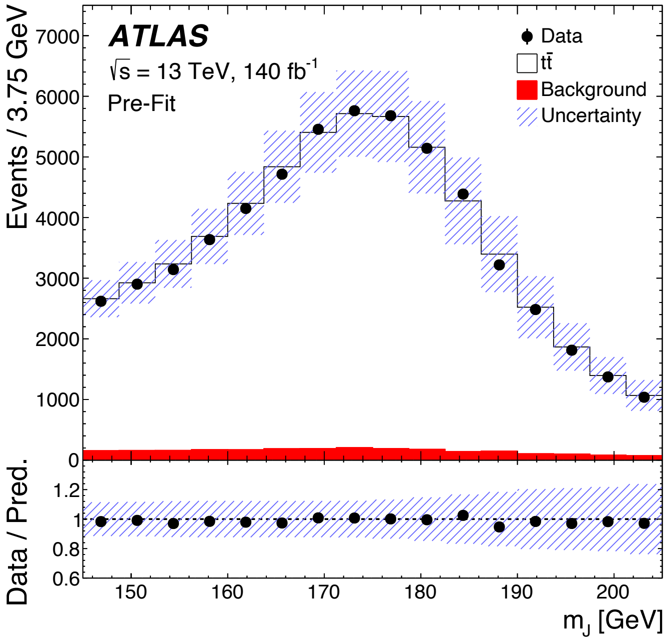


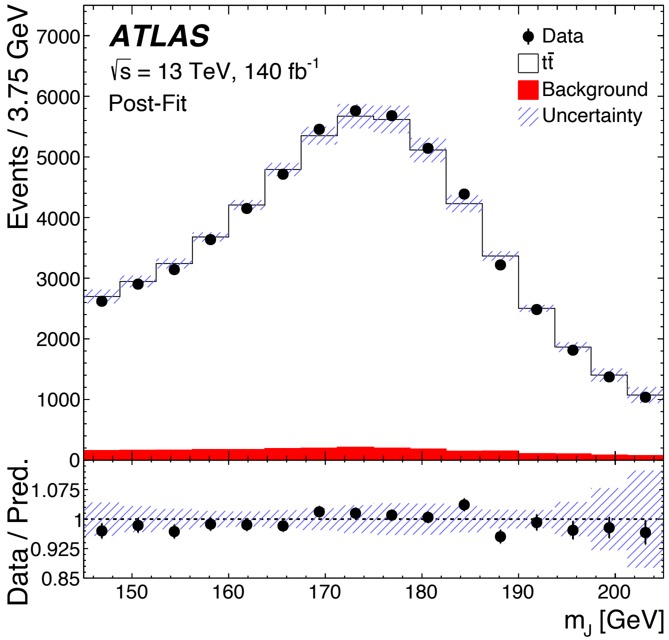
Checked that m_t result is independent of lepton flavour, data-taking period, number of constituent jets.

Result

$$m_t = 172.95 \pm 0.53\ \text{GeV}$$

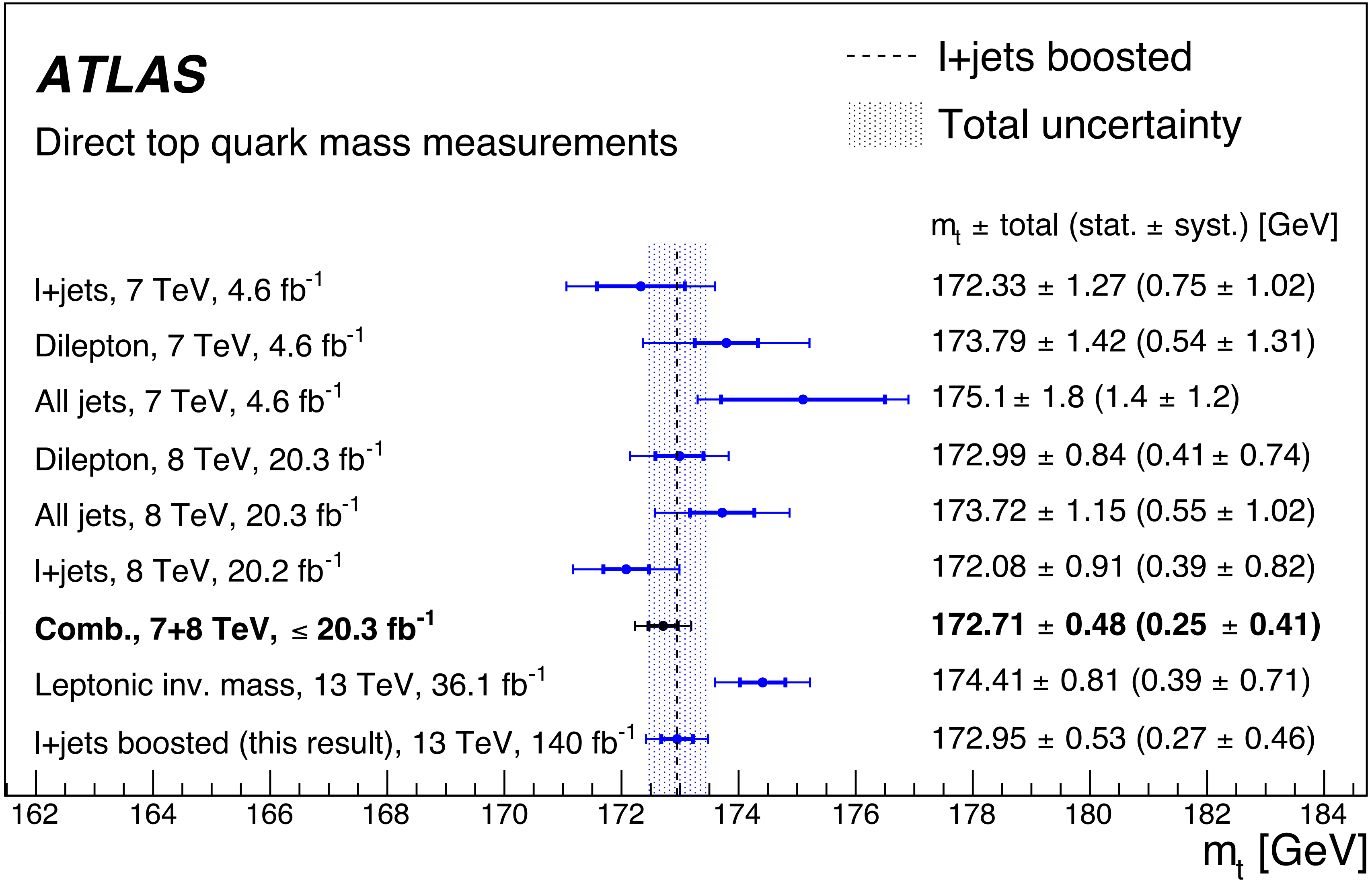
The most precise m_t measurement from ATLAS in a single channel!





Source	Uncertainty [GeV]
Jets	± 0.33
$t\bar{t}$ modelling	± 0.29
Other experimental sources	± 0.12
Background modelling	± 0.05
Total statistical	± 0.27
Total systematic	± 0.46
Total	± 0.53

Result



Run-1

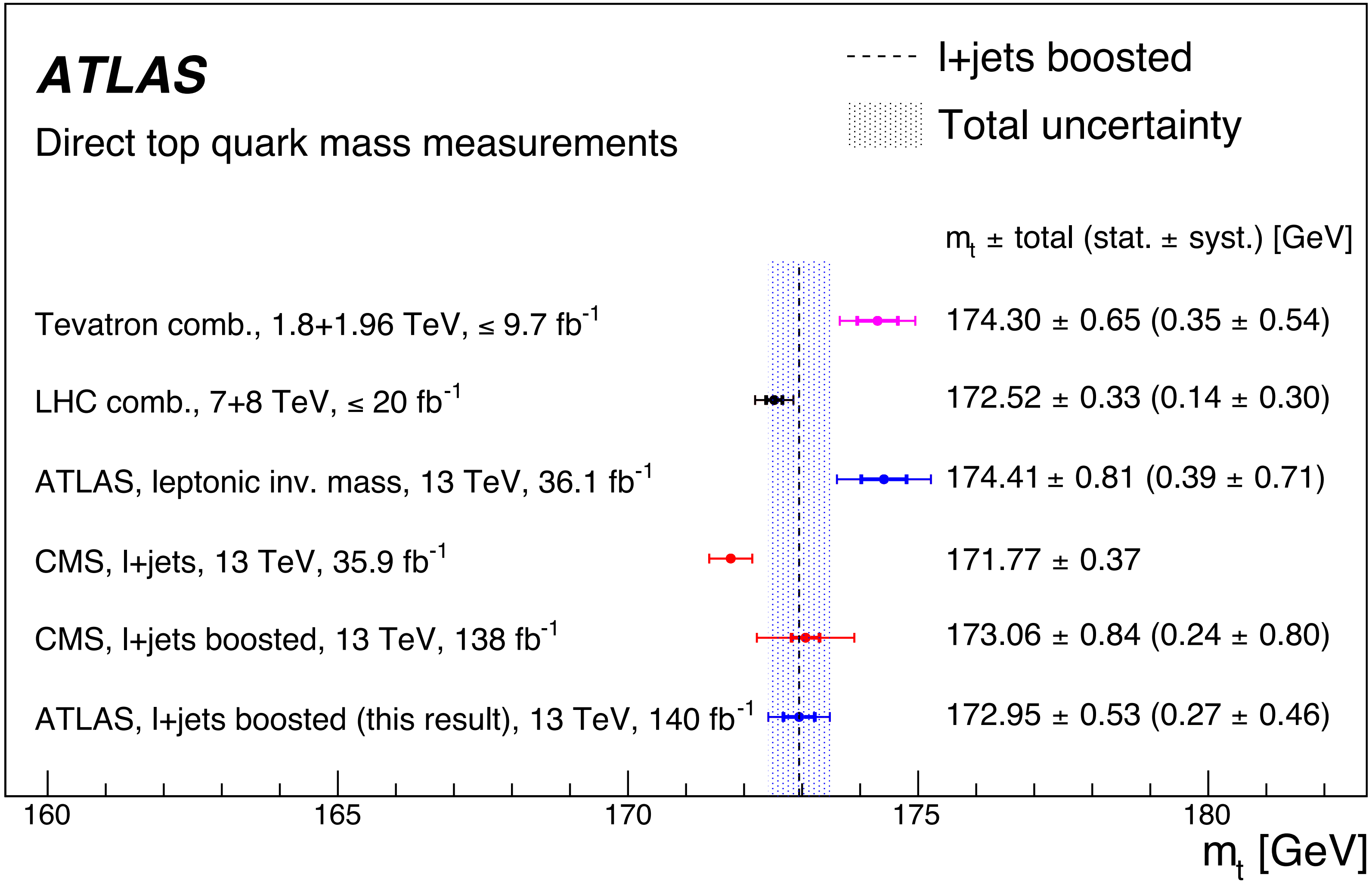
Run-1 combination

This result

Measurement is in very good agreement and almost as precise as ATLAS Run 1 combination.

Result

This result {



- Measurement is more precise than the Tevatron combination.
- Measurement is more precise than boosted measurement from CMS.

Summary

$$m_t = 172.95 \pm 0.53\ \text{GeV}$$

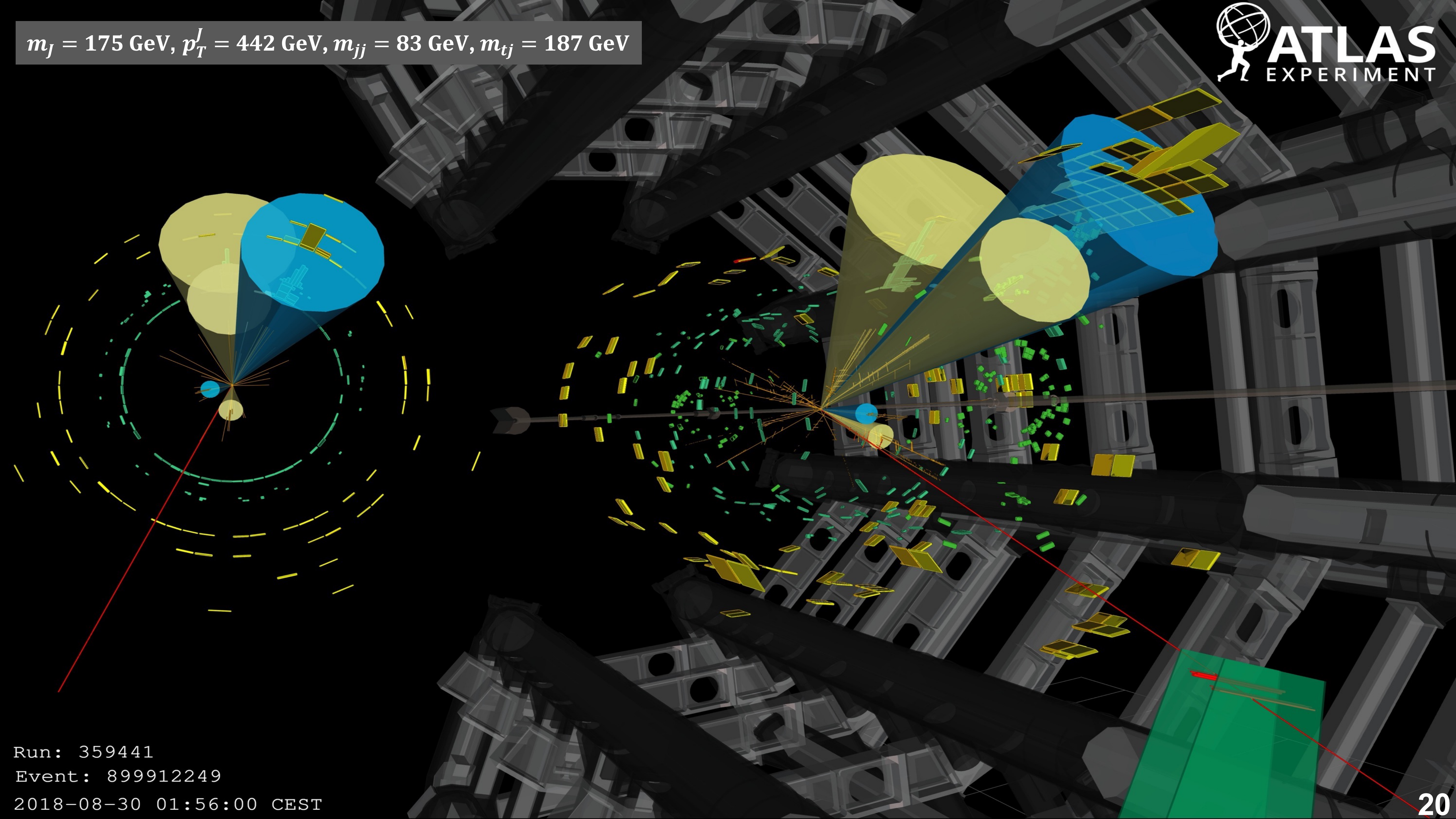
The most precise m_t measurement from ATLAS in a single channel!

- Achieved goal of making precise m_t measurement.
- This is thanks to a combination of aspects including the boosted selection and profile likelihood fit strategy.
- Uncertainty includes a $0.27\ \text{GeV}$ statistical component…

  → Potential for improvement given Run-3 data and the expected output of HL-LHC.

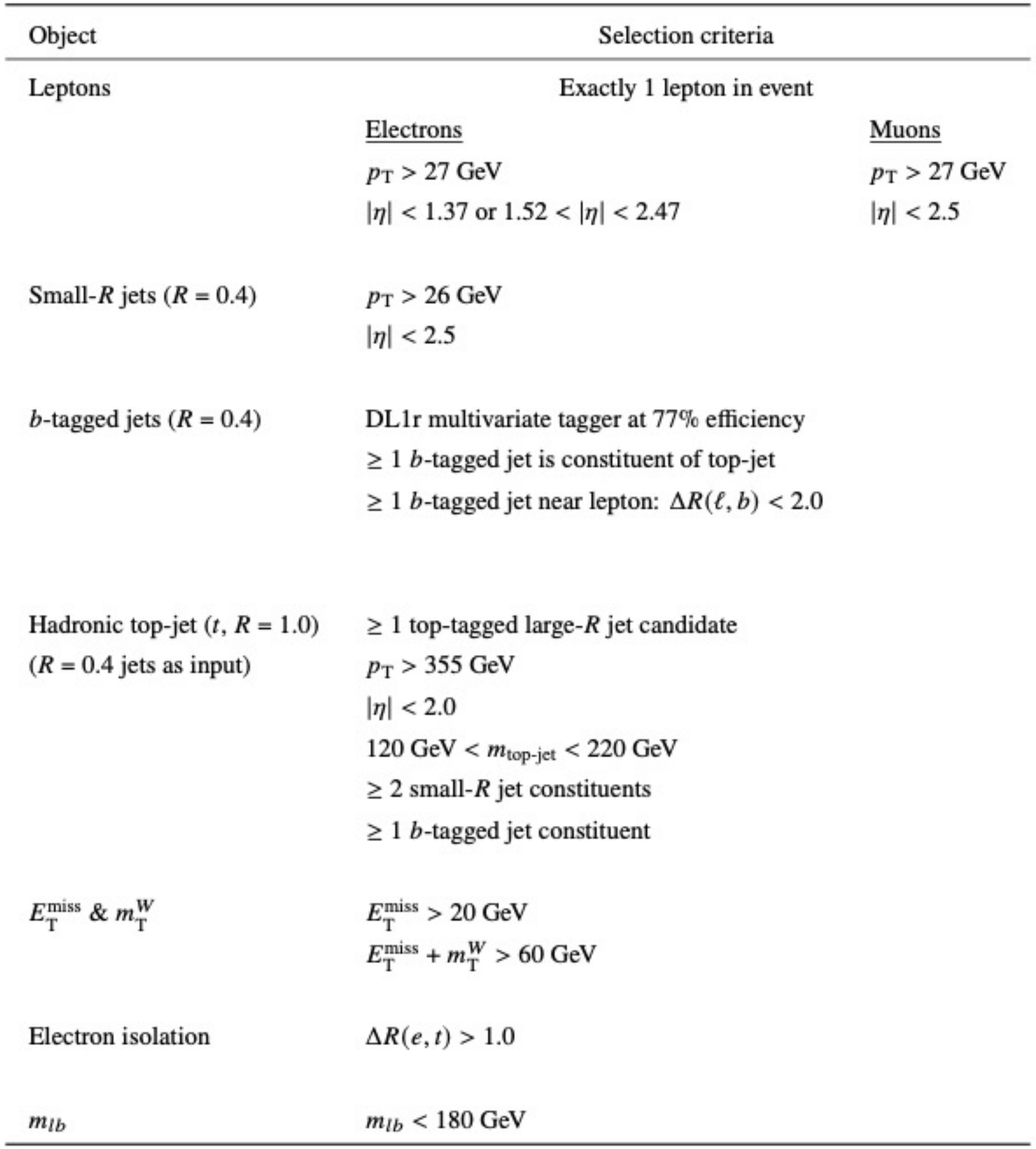
Backup

$m_J = 175$ GeV, $p_T^J = 442$ GeV, $m_{jj} = 83$ GeV, $m_{tj} = 187$ GeV



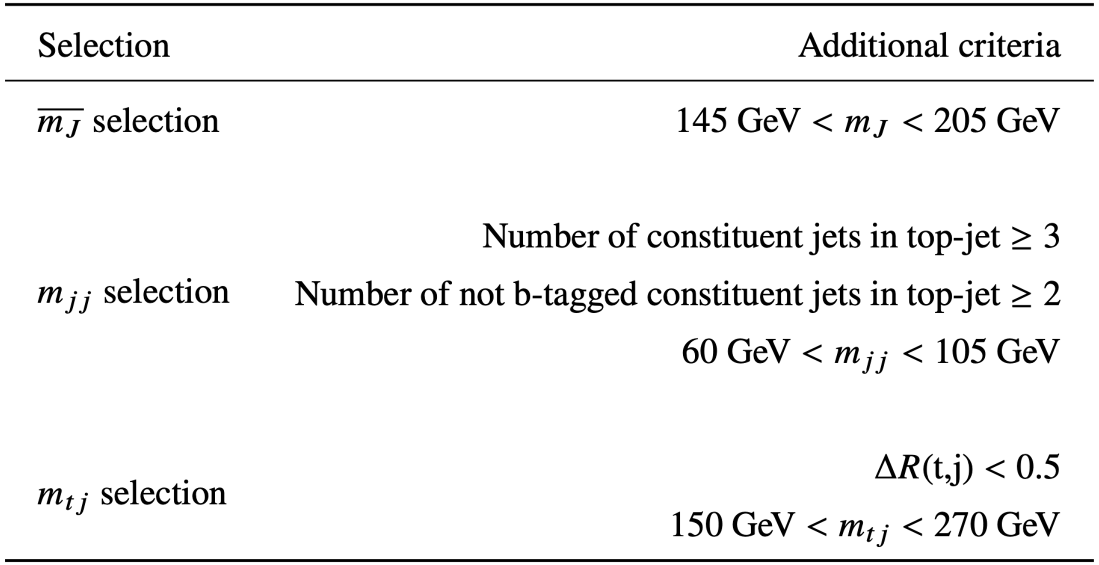
Run: 359441
Event: 899912249
2018-08-30 01:56:00 CEST

Event selection



Object	Selection criteria	
Leptons	Exactly 1 lepton in event	
	Electrons	Muons
	$p_{\mathrm{T}} > 27$ GeV	$p_{\mathrm{T}} > 27$ GeV
	$\lvert\eta\rvert < 1.37$ or $1.52 < \lvert\eta\rvert < 2.47$	$\lvert\eta\rvert < 2.5$
Small-R jets ($R = 0.4$)	$p_{\mathrm{T}} > 26$ GeV $\lvert\eta\rvert < 2.5$	
b-tagged jets ($R = 0.4$)	DL1r multivariate tagger at 77% efficiency ≥ 1 b-tagged jet is constituent of top-jet ≥ 1 b-tagged jet near lepton: $\Delta R(\ell, b) < 2.0$	
Hadronic top-jet (t, $R = 1.0$) ($R = 0.4$ jets as input)	≥ 1 top-tagged large-R jet candidate $p_{\mathrm{T}} > 355$ GeV $\lvert\eta\rvert < 2.0$ 120 GeV $< m_{\text{top-jet}} <$ 220 GeV ≥ 2 small-R jet constituents ≥ 1 b-tagged jet constituent	
$E_{\mathrm{T}}^{\text{miss}}$ & m_{T}^{W}	$E_{\mathrm{T}}^{\text{miss}} > 20$ GeV $E_{\mathrm{T}}^{\text{miss}} + m_{\mathrm{T}}^{W} > 60$ GeV	
Electron isolation	$\Delta R(e, t) > 1.0$	
m_{lb}	$m_{lb} < 180$ GeV	

Additional used to build fit observables



Selection	Additional criteria
$\overline{m_J}$ selection	145 GeV $< m_J <$ 205 GeV
m_{jj} selection	Number of constituent jets in top-jet ≥ 3 Number of not b-tagged constituent jets in top-jet ≥ 2 60 GeV $< m_{jj} <$ 105 GeV
m_{tj} selection	ΔR(t,j) < 0.5 150 GeV $< m_{tj} <$ 270 GeV

Pre-fit yields

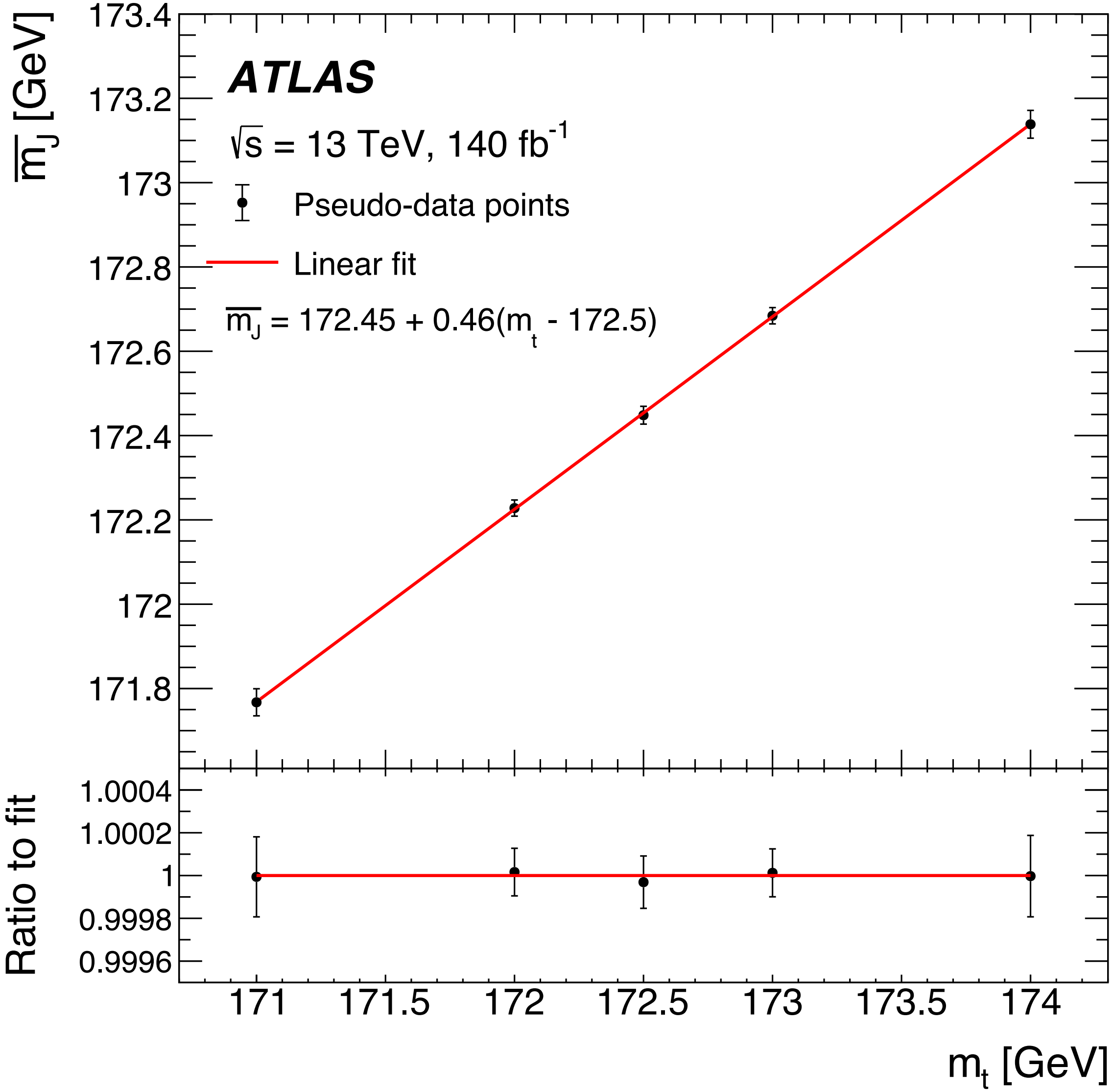
Process	$145 < m_J < 205$ GeV	$60 < m_{jj} < 105$ GeV	$150 < m_{tj} < 270$ GeV
$t\bar{t}$	65000 ± 9500	38100 ± 5800	2340 ± 430
Single-top	1000 ± 170	400 ± 130	50 ± 9
$t\bar{t}X$	700 ± 130	360 ± 67	54 ± 10
Multijet	400 ± 260	170 ± 110	23 ± 15
W+jets	250 ± 100	59 ± 22	21 ± 9
Z+jets	49 ± 24	10 ± 5	5 ± 3
Diboson	22 ± 11	5 ± 3	2 ± 1
Total prediction	67400 ± 9500	39100 ± 5800	2500 ± 430
Data	57459	32722	2312

- Uncertainties include impact of all systematics.
- Offset between data and total prediction is expected from previous measurement of $t\bar{t}$ differential cross-section using similar events (JHEP 06 (2022) 063).

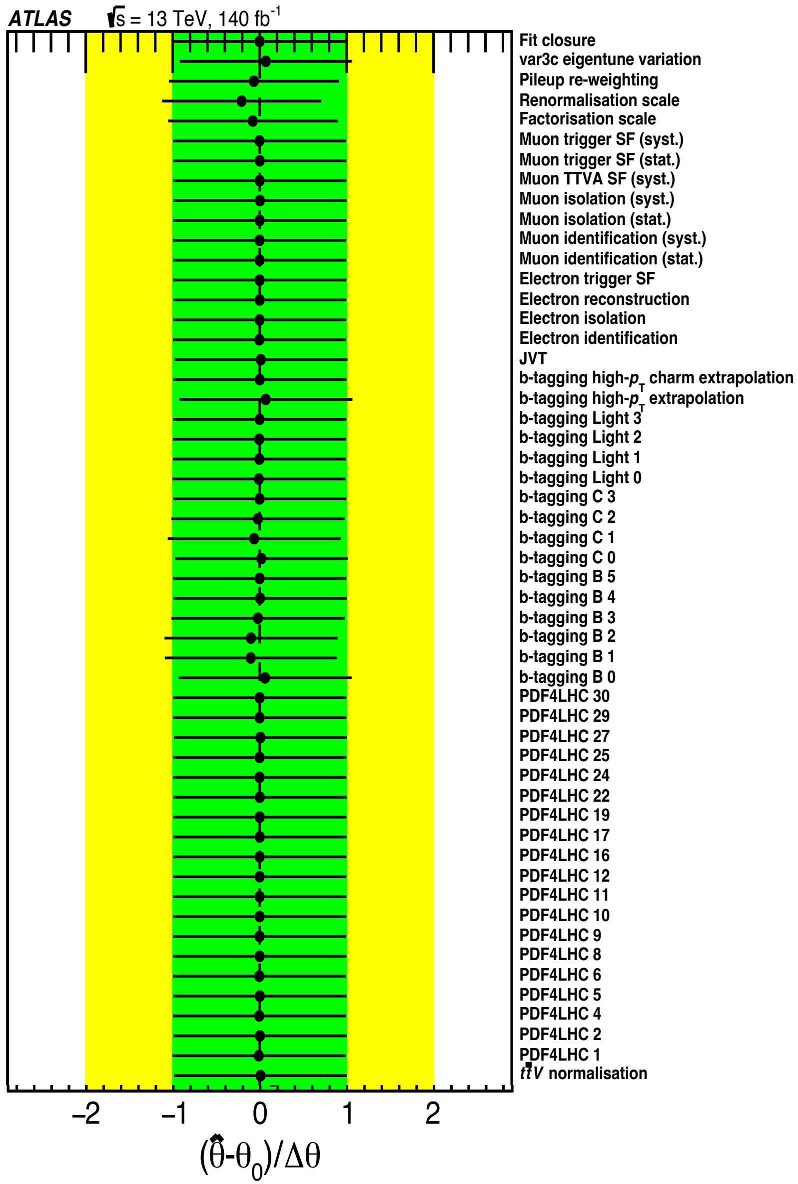
Linear relationship

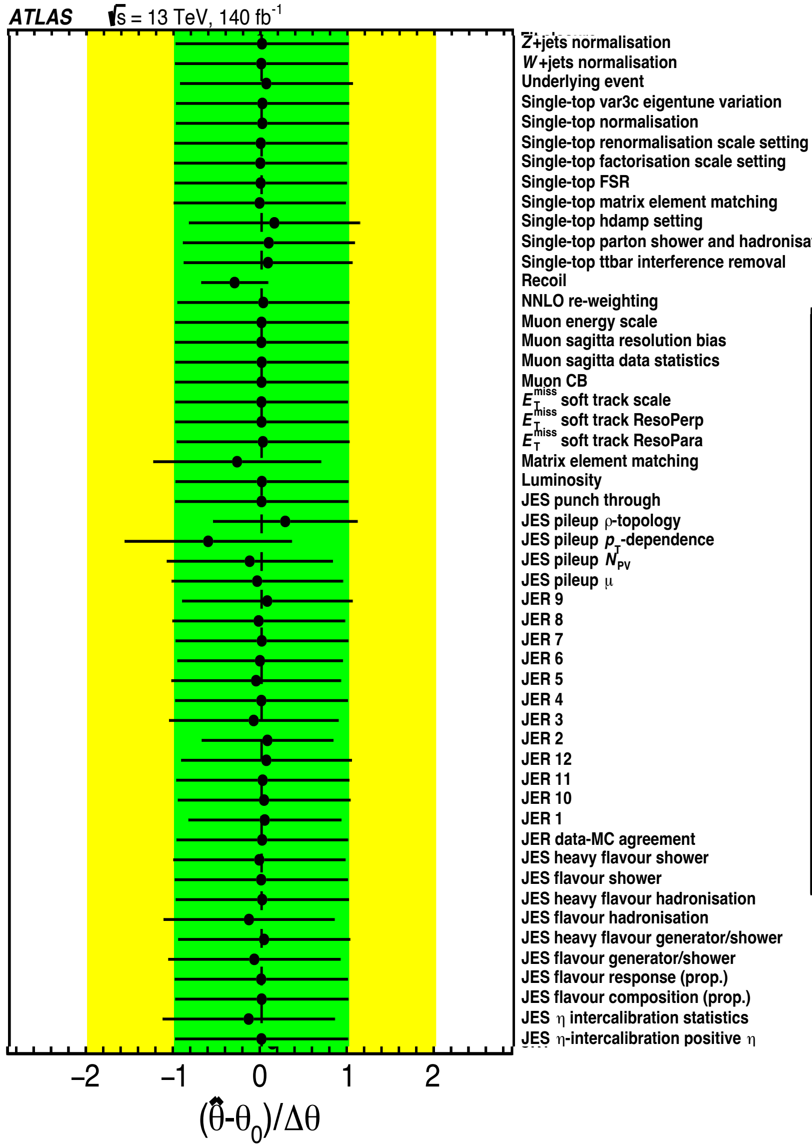
$$\overline{m_J}(m_t,\mu,\boldsymbol{\theta}) = A + B(m_t - 172.5) + C(\mu - 1) + \sum_s \theta_s\Delta_s$$

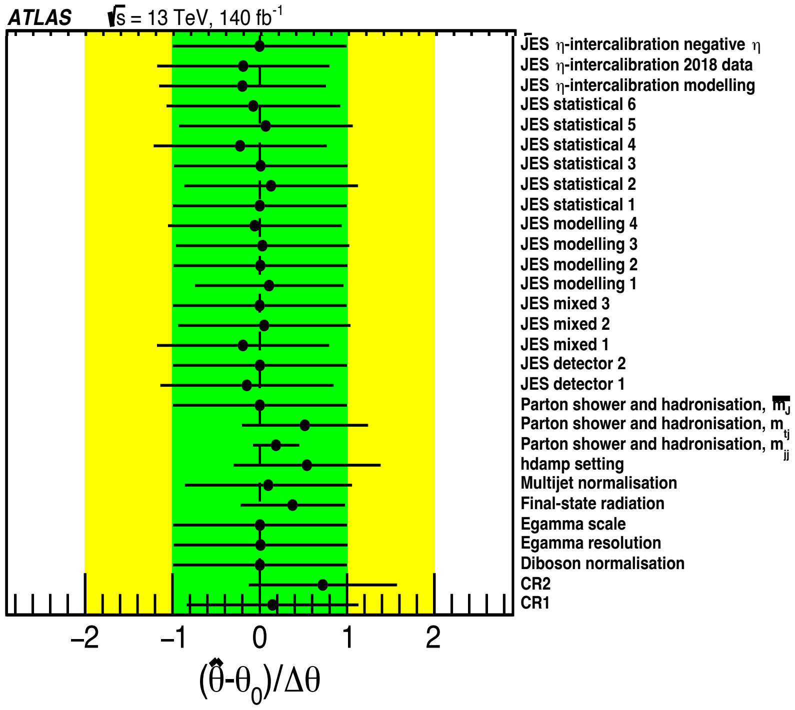
- $\mu = \frac{\sigma}{\sigma_{SM}}$,
- $\boldsymbol{\theta}$ is the set of NPs,
- Δ_s is the impact of a 1σ change in NP s on $\overline{m_\mathrm{J}}$,
- A, B, and C, are constants found from the simulation,
- Note that $C = 0$ for zero background.
- We find:
  - $A = (172.45 \pm 0.01)\ \mathrm{GeV}$,
  - $B = (0.46 \pm 0.02)\ \mathrm{GeV}^{-1}$,
  - $C = 0.02\ \mathrm{GeV}$.



Nuisance parameter fitted values

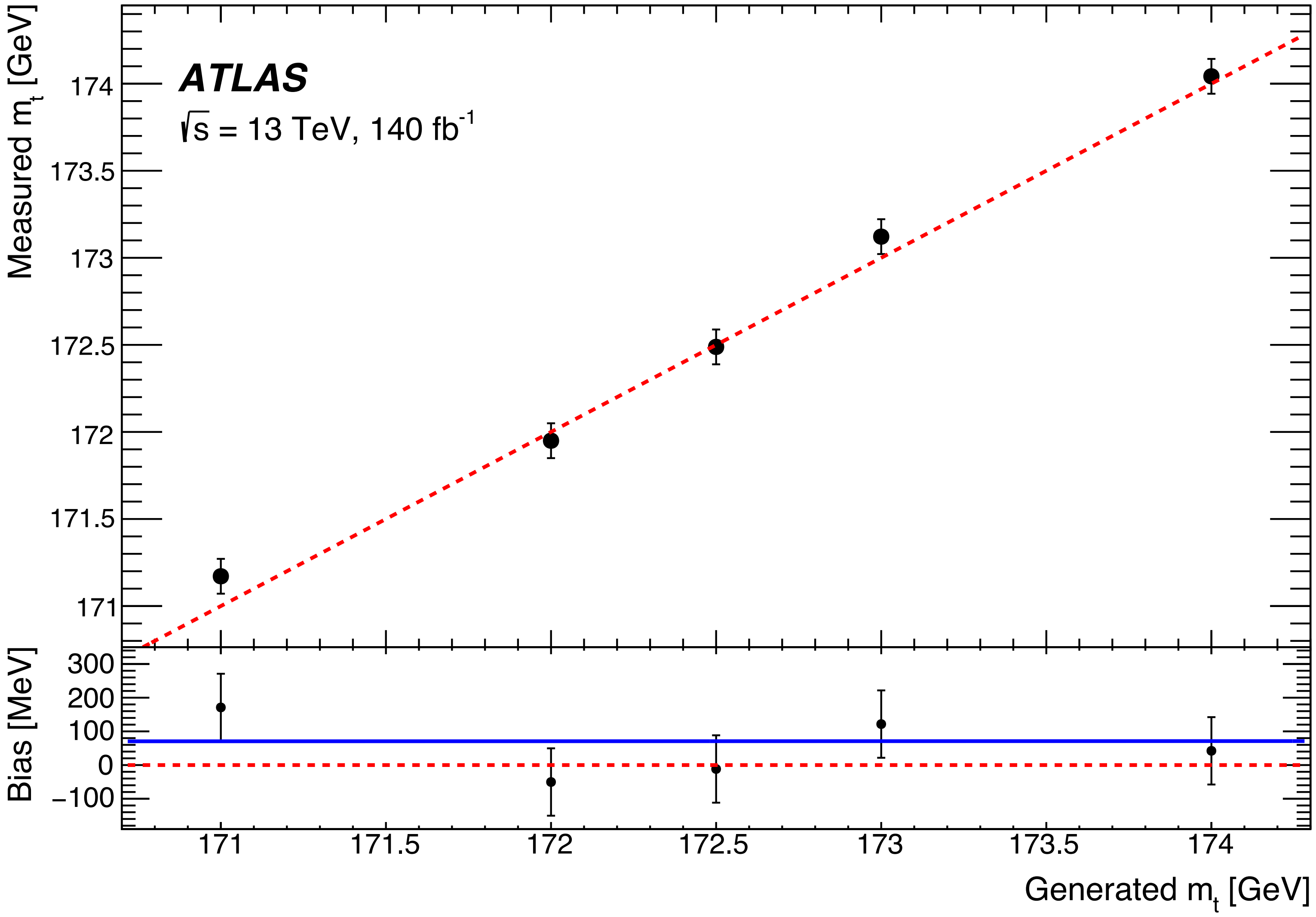






Closure test

- The uncertainty bars on each point show the uncertainty from MC statistics.
- The dashed red line shows perfect linearity.
- The lower panel shows the bias (measured m_t minus true m_t) and the blue line shows a linear fit to the points (excluding $m_t = 172.5\ \mathrm{GeV}$).
- The linearity test is performed by injecting pseudo-data into the fit.
- Each pseudo-data sample is treated as data and the fit is performed.



Uncertainty breakdowns

- Systematic uncertainties evaluated by extracting the correlation between each nuisance parameter and the m_t using the profile likelihood fit's covariance matrix.

- Categories of uncertainties are built by summing in quadrature the effect of all nuisance parameters in the category.

- Total statistical uncertainty is found via:

$$\sigma_{\text{stat}}^2 = \sigma_{\text{total}}^2 - \sum_i \sigma_{\text{syst},i}^2$$

- For more details, see EPJC 84 (2024) 6, 593

Expected uncertainties

- Table refers to the expected uncertainties obtained using Asimov fit with $m_t = 172.5\ \text{GeV}$ and $\mu = 1$.
- 1D fit = fit to $\overline{m_J}$
- 2D fit = fit to $\overline{m_J} + m_{jj}$
- 3D fit = fit to $\overline{m_J} + m_{jj} + m_{tj}$
- The size of the uncertainty reflects both the post-fit uncertainty on the NP and the correlation between the NP and m_t, and these correlations change between the different fit setups.

Source	Uncertainty [GeV]		
	1D fit	2D fit	3D fit
JES	± 1.41	± 0.30	± 0.26
Colour reconnection (CR1 and CR2)	± 0.05	± 0.18	± 0.15
Radiation (ISR and FSR)	± 0.82	± 0.08	± 0.14
JES heavy flavour	± 0.08	± 0.15	± 0.14
Parton shower and hadronisation model	± 0.10	± 0.10	± 0.13
JER	± 0.14	± 0.09	± 0.10
MC statistics	< 0.01	± 0.09	± 0.09
Underlying event	± 0.07	± 0.07	± 0.08
Recoil	± 0.10	± 0.36	± 0.08
Fit closure	< 0.01	± 0.07	± 0.07
Background modelling	± 0.05	± 0.05	± 0.05
Matrix element matching ($p_{\mathrm{T}}^{\mathrm{hard}} = 1$)	± 0.05	± 0.02	± 0.05
b-tagging	± 0.02	± 0.04	± 0.04
$E_{\mathrm{T}}^{\mathrm{miss}}$	± 0.01	± 0.01	± 0.02
Higher-order corrections	± 0.02	± 0.03	± 0.01
Pileup	± 0.15	± 0.02	± 0.01
JVT	± 0.01	± 0.01	± 0.01
PDF	± 0.01	± 0.01	± 0.01
Luminosity	< 0.01	< 0.01	< 0.01
Leptons	< 0.01	< 0.01	± 0.01
Total statistical	± 0.11	± 0.27	± 0.25
Total systematic	± 1.66	± 0.57	± 0.44
Total	± 1.66	± 0.63	± 0.51

Uncertainty breakdown

Source	Uncertainty [GeV]
JES	± 0.29
Radiation (ISR and FSR)	± 0.17
Colour reconnection (CR1 and CR2)	± 0.15
JES heavy flavour	± 0.14
Parton shower and hadronisation model	± 0.14
JER	± 0.10
MC statistics	± 0.08
Underlying event	± 0.08
Recoil	± 0.07
Fit closure	± 0.07
Background modelling	± 0.05
Matrix element matching ($p_{\mathrm{T}}^{\mathrm{hard}} = 1$)	± 0.04
b-tagging	± 0.04
Higher-order corrections	± 0.02
$E_{\mathrm{T}}^{\mathrm{miss}}$	± 0.02
Pileup	± 0.01
JVT	± 0.01
PDF	± 0.01
Leptons	± 0.01
Luminosity	< 0.01
Total statistical	± 0.27
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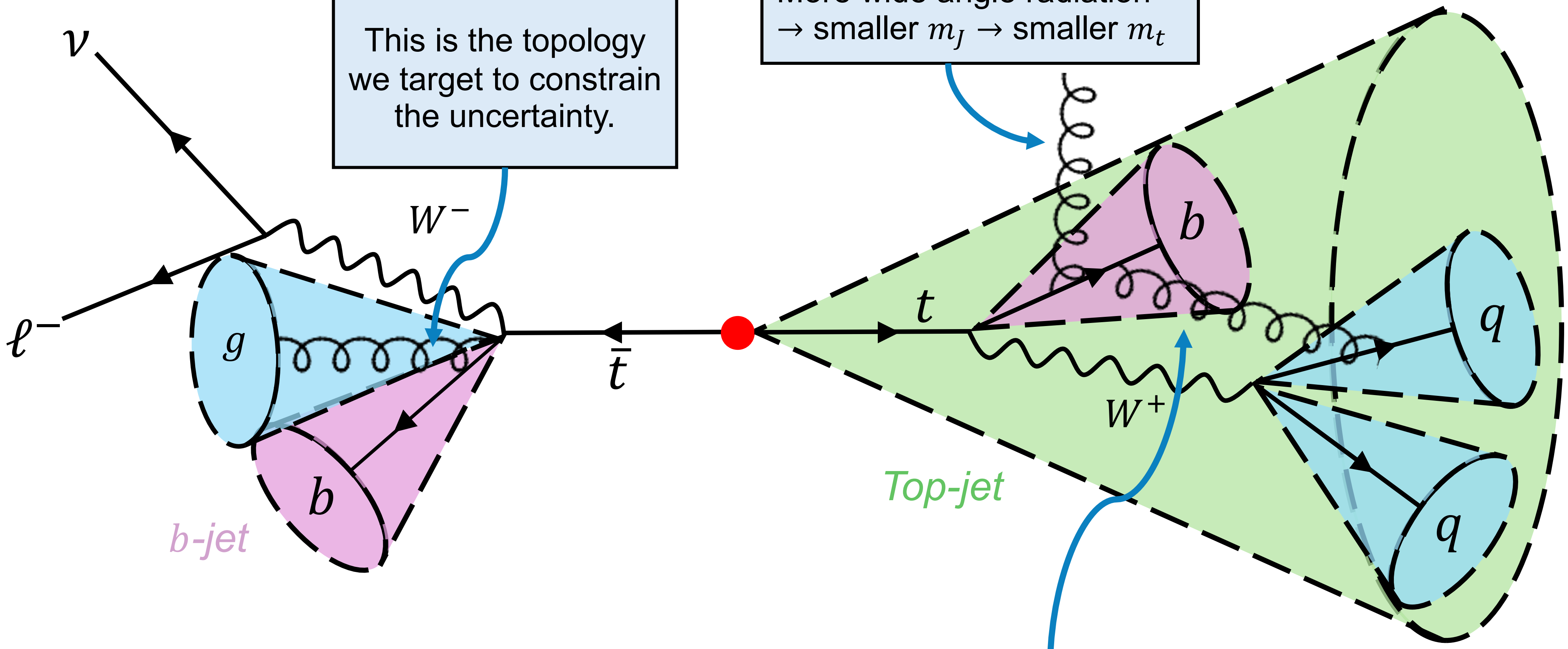
Why does recoil uncertainty increase for 2D fit?



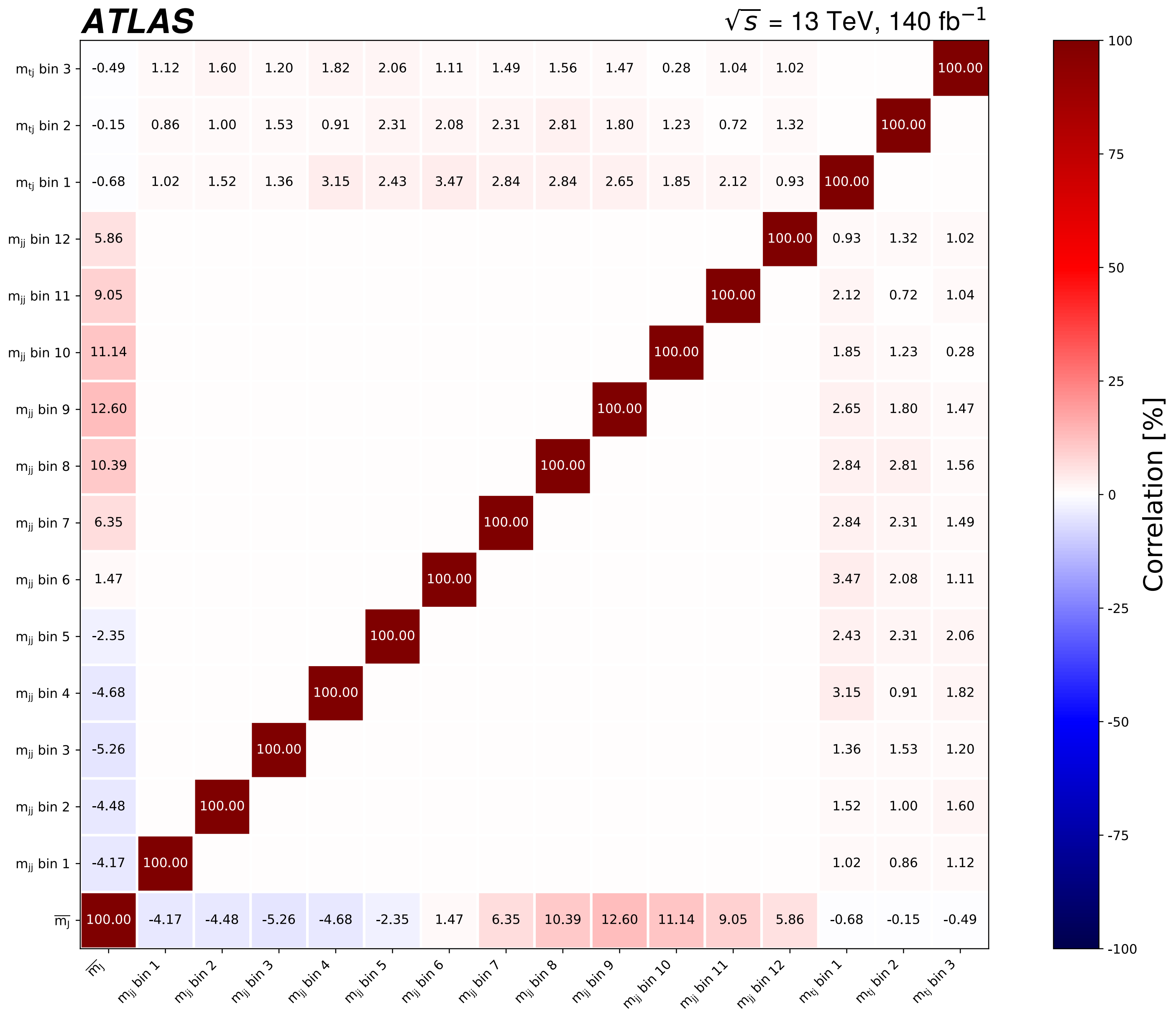
This is the topology we target to constrain the uncertainty.

More wide angle radiation → smaller m_J → smaller m_t

- More wide angle radiation → more cases where radiation enters other jets → larger m_{jj}.
- Recoil change leads to larger m_{jj} for same effect that lowers m_J.
- This is opposite to the expected impact of the JES (larger m_{jj} and m_J).

Statistical correlations

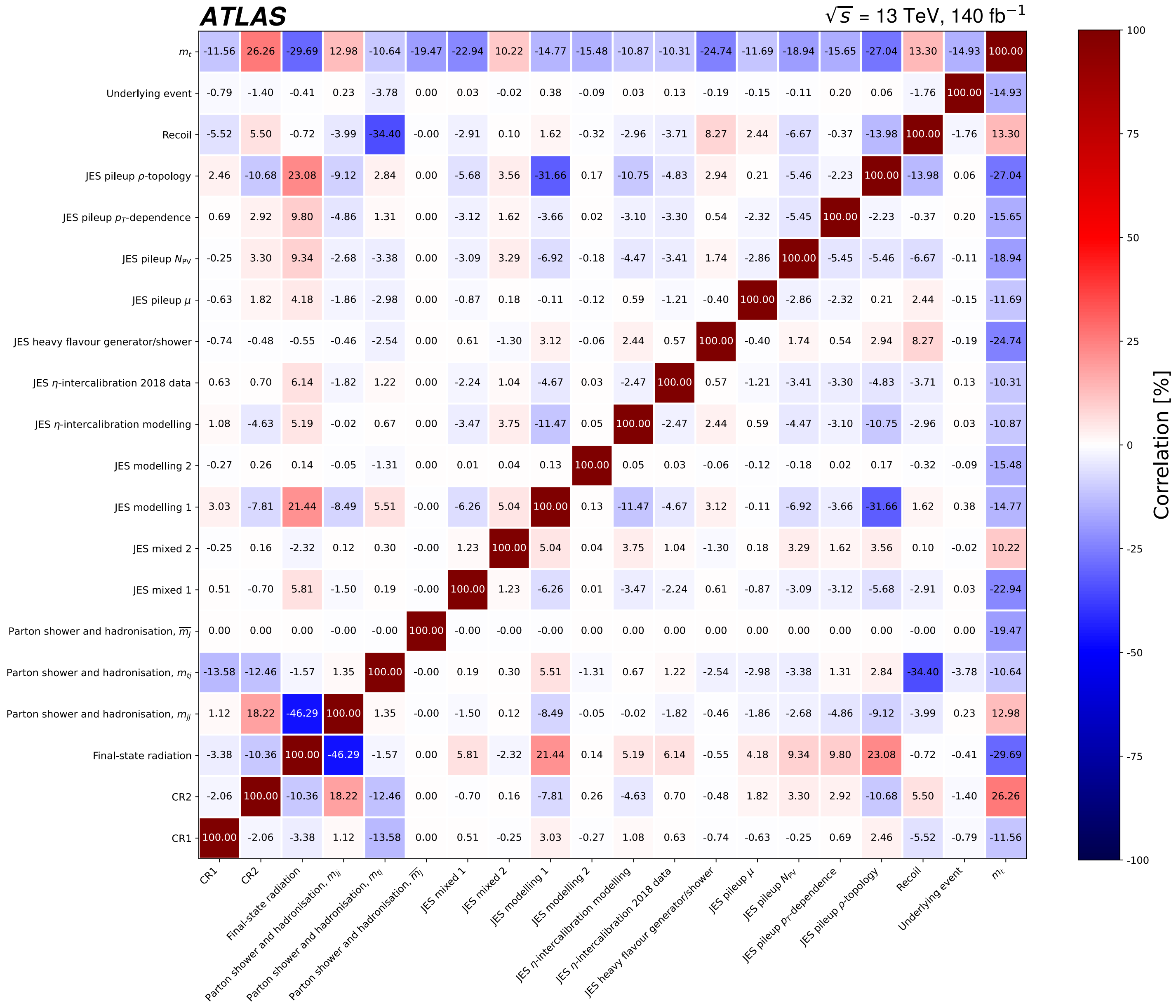
- Statistical correlations between the observables used in the profile likelihood fit.
- The correlations were estimated using pseudo-experiments from the expected signal and background distributions.
- Bins with no entry are bins where the correlation is zero by definition.



	$\overline{m_j}$	m_{jj} bin 1	m_{jj} bin 2	m_{jj} bin 3	m_{jj} bin 4	m_{jj} bin 5	m_{jj} bin 6	m_{jj} bin 7	m_{jj} bin 8	m_{jj} bin 9	m_{jj} bin 10	m_{jj} bin 11	m_{jj} bin 12	m_{tj} bin 1	m_{tj} bin 2	m_{tj} bin 3
m_{tj} bin 3	-0.49	1.12	1.60	1.20	1.82	2.06	1.11	1.49	1.56	1.47	0.28	1.04	1.02			100.00
m_{tj} bin 2	-0.15	0.86	1.00	1.53	0.91	2.31	2.08	2.31	2.81	1.80	1.23	0.72	1.32		100.00	
m_{tj} bin 1	-0.68	1.02	1.52	1.36	3.15	2.43	3.47	2.84	2.84	2.65	1.85	2.12	0.93	100.00		
m_{jj} bin 12	5.86												100.00	0.93	1.32	1.02
m_{jj} bin 11	9.05											100.00		2.12	0.72	1.04
m_{jj} bin 10	11.14										100.00			1.85	1.23	0.28
m_{jj} bin 9	12.60									100.00				2.65	1.80	1.47
m_{jj} bin 8	10.39								100.00					2.84	2.81	1.56
m_{jj} bin 7	6.35							100.00						2.84	2.31	1.49
m_{jj} bin 6	1.47						100.00							3.47	2.08	1.11
m_{jj} bin 5	-2.35					100.00								2.43	2.31	2.06
m_{jj} bin 4	-4.68				100.00									3.15	0.91	1.82
m_{jj} bin 3	-5.26			100.00										1.36	1.53	1.20
m_{jj} bin 2	-4.48		100.00											1.52	1.00	1.60
m_{jj} bin 1	-4.17	100.00												1.02	0.86	1.12
$\overline{m_j}$	100.00	-4.17	-4.48	-5.26	-4.68	-2.35	1.47	6.35	10.39	12.60	11.14	9.05	5.86	-0.68	-0.15	-0.49

Fit parameter correlations

- Post-fit correlation matrix for nuisance parameters with absolute correlations with m_t of at least 10%.
- The first row and last column display the correlation of each nuisance parameter with m_t.



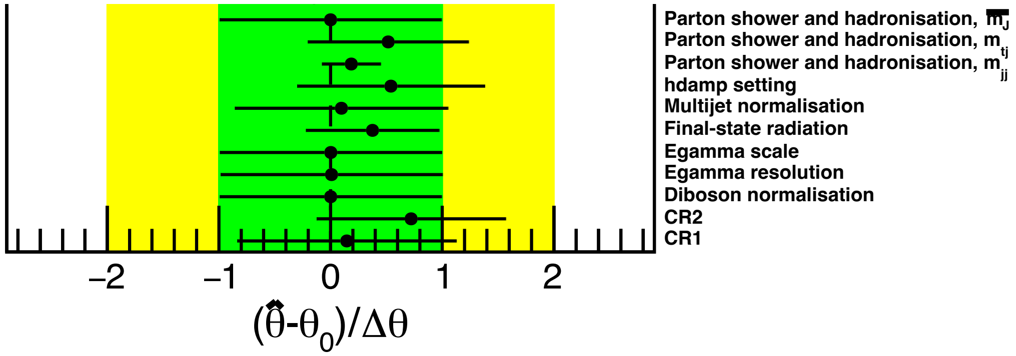
	CR1	CR2	Final-state radiation	Parton shower and hadronisation, m_{jj}	Parton shower and hadronisation, m_{tj}	Parton shower and hadronisation, $\overline{m_J}$	JES mixed 1	JES mixed 2	JES modelling 1	JES modelling 2	JES η-intercalibration modelling	JES η-intercalibration 2018 data	JES heavy flavour generator/shower	JES pileup μ	JES pileup N_{PV}	JES pileup p_T-dependence	JES pileup ρ-topology	Recoil	Underlying event	m_t
m_t	-11.56	26.26	-29.69	12.98	-10.64	-19.47	-22.94	10.22	-14.77	-15.48	-10.87	-10.31	-24.74	-11.69	-18.94	-15.65	-27.04	13.30	-14.93	100.00
Underlying event	-0.79	-1.40	-0.41	0.23	-3.78	0.00	0.03	-0.02	0.38	-0.09	0.03	0.13	-0.19	-0.15	-0.11	0.20	0.06	-1.76	100.00	-14.93
Recoil	-5.52	5.50	-0.72	-3.99	-34.40	-0.00	-2.91	0.10	1.62	-0.32	-2.96	-3.71	8.27	2.44	-6.67	-0.37	-13.98	100.00	-1.76	13.30
JES pileup ρ-topology	2.46	-10.68	23.08	-9.12	2.84	0.00	-5.68	3.56	-31.66	0.17	-10.75	-4.83	2.94	0.21	-5.46	-2.23	100.00	-13.98	0.06	-27.04
JES pileup p_T-dependence	0.69	2.92	9.80	-4.86	1.31	0.00	-3.12	1.62	-3.66	0.02	-3.10	-3.30	0.54	-2.32	-5.45	100.00	-2.23	-0.37	0.20	-15.65
JES pileup N_{PV}	-0.25	3.30	9.34	-2.68	-3.38	0.00	-3.09	3.29	-6.92	-0.18	-4.47	-3.41	1.74	-2.86	100.00	-5.45	-5.46	-6.67	-0.11	-18.94
JES pileup μ	-0.63	1.82	4.18	-1.86	-2.98	0.00	-0.87	0.18	-0.11	-0.12	0.59	-1.21	-0.40	100.00	-2.86	-2.32	0.21	2.44	-0.15	-11.69
JES heavy flavour generator/shower	-0.74	-0.48	-0.55	-0.46	-2.54	0.00	0.61	-1.30	3.12	-0.06	2.44	0.57	100.00	-0.40	1.74	0.54	2.94	8.27	-0.19	-24.74
JES η-intercalibration 2018 data	0.63	0.70	6.14	-1.82	1.22	0.00	-2.24	1.04	-4.67	0.03	-2.47	100.00	0.57	-1.21	-3.41	-3.30	-4.83	-3.71	0.13	-10.31
JES η-intercalibration modelling	1.08	-4.63	5.19	-0.02	0.67	0.00	-3.47	3.75	-11.47	0.05	100.00	-2.47	2.44	0.59	-4.47	-3.10	-10.75	-2.96	0.03	-10.87
JES modelling 2	-0.27	0.26	0.14	-0.05	-1.31	0.00	0.01	0.04	0.13	100.00	0.05	0.03	-0.06	-0.12	-0.18	0.02	0.17	-0.32	-0.09	-15.48
JES modelling 1	3.03	-7.81	21.44	-8.49	5.51	-0.00	-6.26	5.04	100.00	0.13	-11.47	-4.67	3.12	-0.11	-6.92	-3.66	-31.66	1.62	0.38	-14.77
JES mixed 2	-0.25	0.16	-2.32	0.12	0.30	-0.00	1.23	100.00	5.04	0.04	3.75	1.04	-1.30	0.18	3.29	1.62	3.56	0.10	-0.02	10.22
JES mixed 1	0.51	-0.70	5.81	-1.50	0.19	-0.00	100.00	1.23	-6.26	0.01	-3.47	-2.24	0.61	-0.87	-3.09	-3.12	-5.68	-2.91	0.03	-22.94
Parton shower and hadronisation, $\overline{m_J}$	0.00	0.00	0.00	-0.00	-0.00	100.00	-0.00	-0.00	-0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.00	0.00	-19.47
Parton shower and hadronisation, m_{tj}	-13.58	-12.46	-1.57	1.35	100.00	-0.00	0.19	0.30	5.51	-1.31	0.67	1.22	-2.54	-2.98	-3.38	1.31	2.84	-34.40	-3.78	-10.64
Parton shower and hadronisation, m_{jj}	1.12	18.22	-46.29	100.00	1.35	-0.00	-1.50	0.12	-8.49	-0.05	-0.02	-1.82	-0.46	-1.86	-2.68	-4.86	-9.12	-3.99	0.23	12.98
Final-state radiation	-3.38	-10.36	100.00	-46.29	-1.57	0.00	5.81	-2.32	21.44	0.14	5.19	6.14	-0.55	4.18	9.34	9.80	23.08	-0.72	-0.41	-29.69
CR2	-2.06	100.00	-10.36	18.22	-12.46	0.00	-0.70	0.16	-7.81	0.26	-4.63	0.70	-0.48	1.82	3.30	2.92	-10.68	5.50	-1.40	26.26
CR1	100.00	-2.06	-3.38	1.12	-13.58	0.00	0.51	-0.25	3.03	-0.27	1.08	0.63	-0.74	-0.63	-0.25	0.69	2.46	-5.52	-0.79	-11.56

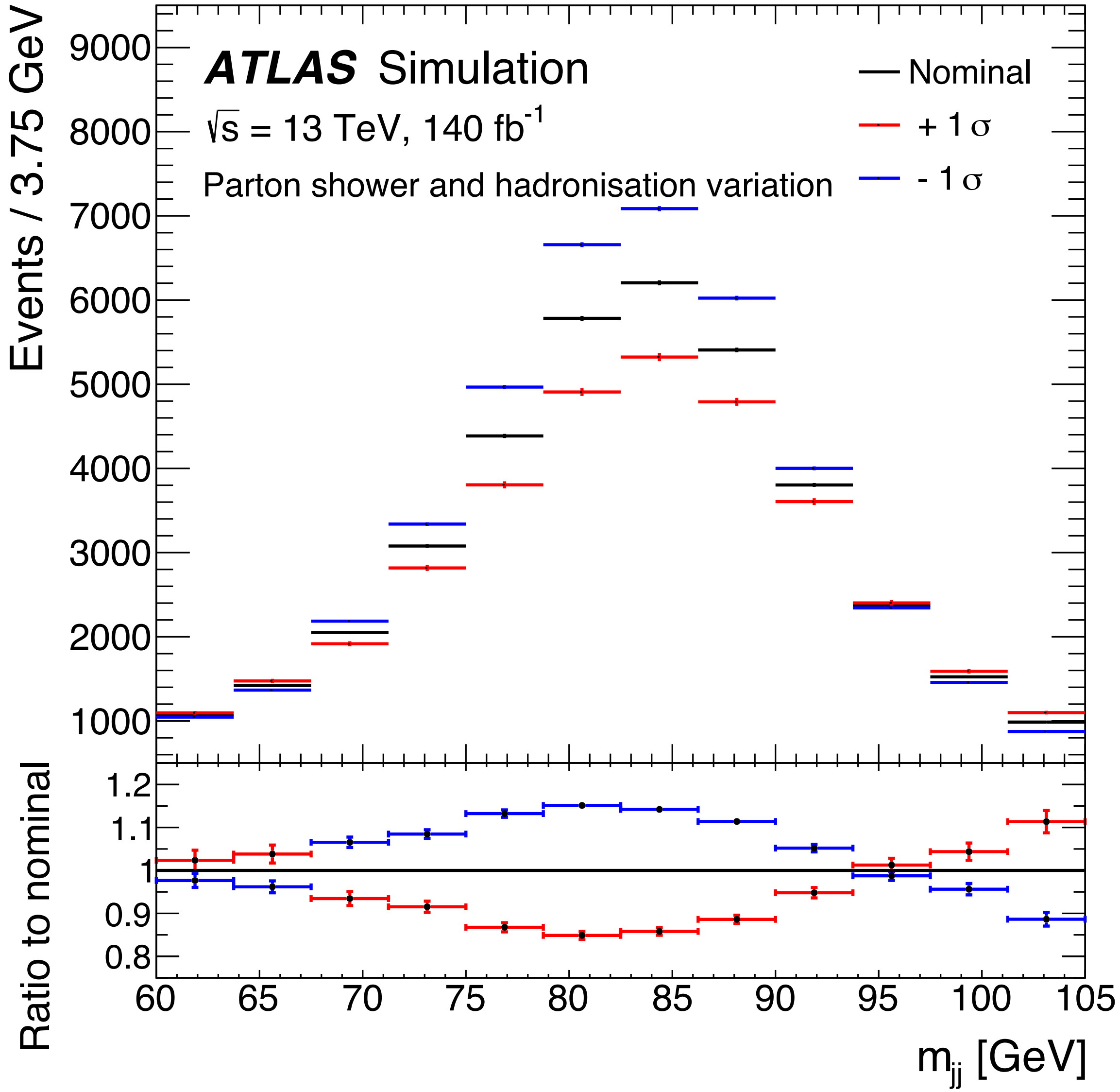
Decorrelating parton shower and hadronisation uncertainty

- Parton shower and hadronisation uncertainty assessed by Powheg+Pythia8 vs Powheg+Herwig7.

  → Covers many physics effects in the simulation.

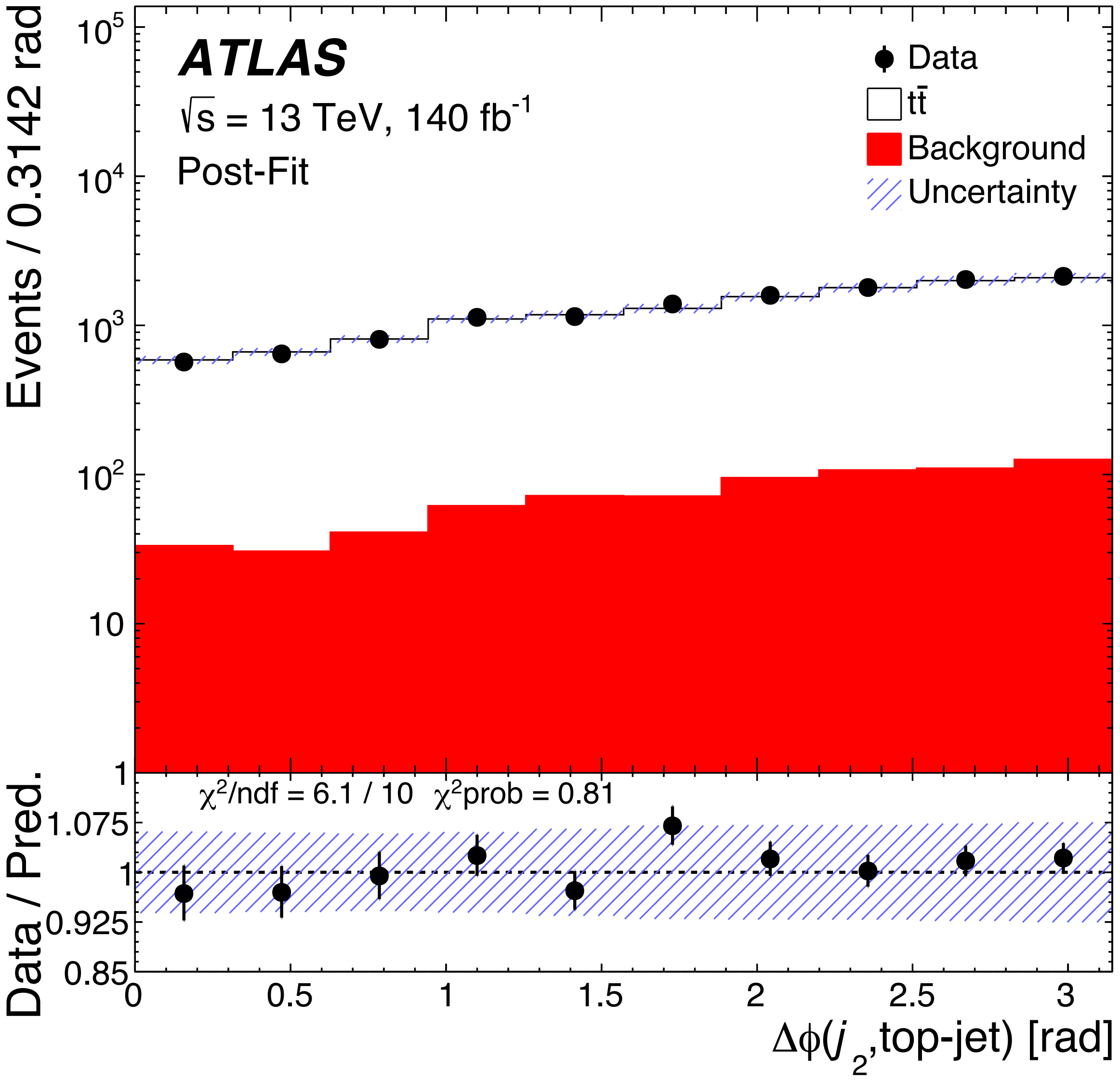
- Get a large constraint from our m_{jj} distribution.
- Decided it was not safe to propagate constraint from m_{jj} to m_{tj} and $\overline{m_J}$.
- This uncertainty is now decorrelated between all observables (larger final m_t uncertainty).
- Central value shifts by $0.06\ \mathrm{GeV}$ if NP are correlated.



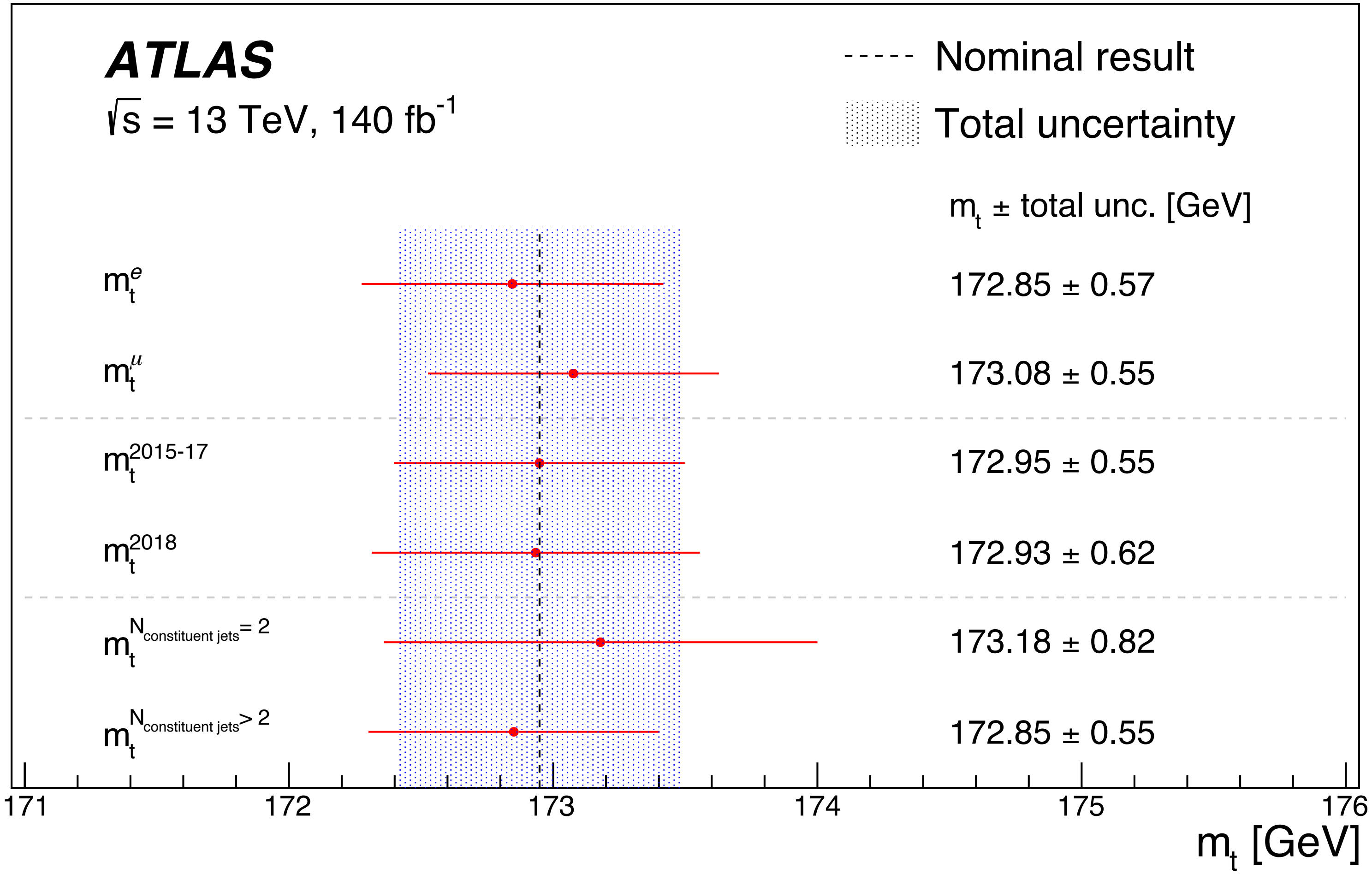


Additional observable sensitive to parton shower

- To validate the constrained model, apply it to other observables in the sample.
- Can also do reliable χ^2 test when the correlations with m_{jj} and m_{tj} are low.
- This observable is sensitive to parton shower effects.



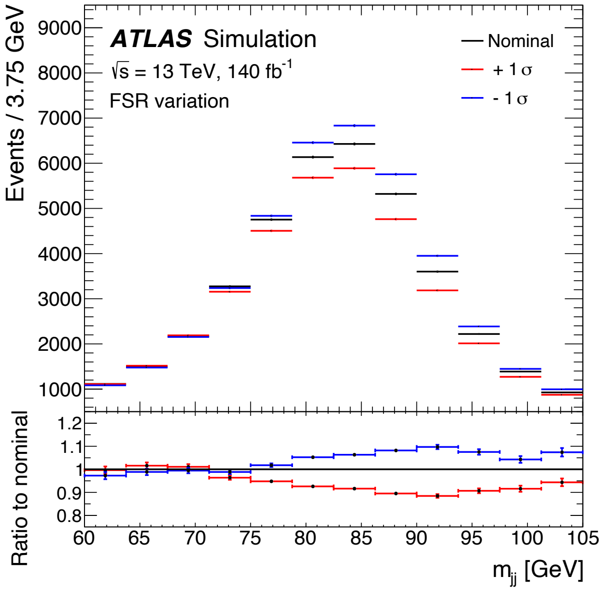
Fit robustness

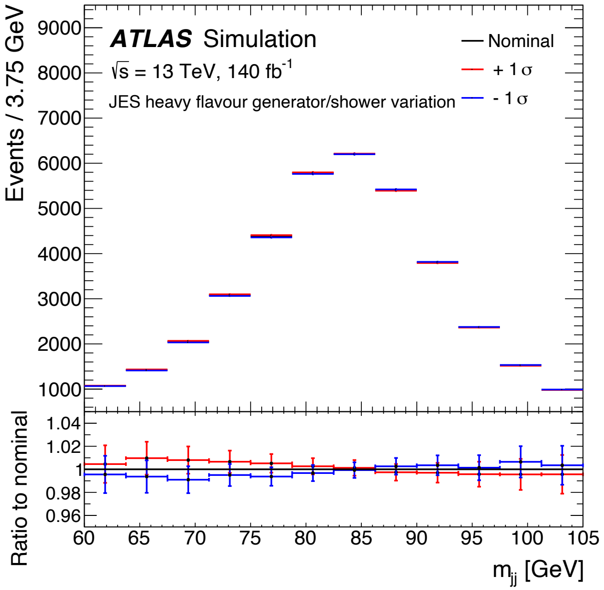


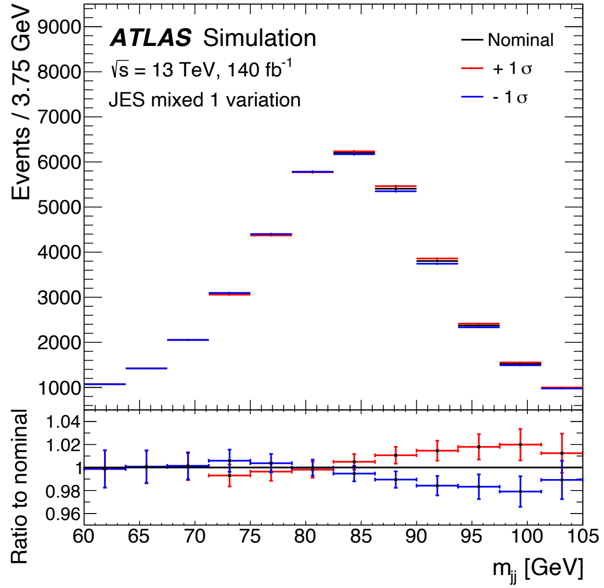
- In each of the fits, there is one free parameter for the top quark mass for each section of the dataset.
- The correlation between the top-quark mass parameters are: 0.73 for lepton flavour splitting, 0.64 for data-taking period splitting, 0.30 for number of constituent jets splitting.

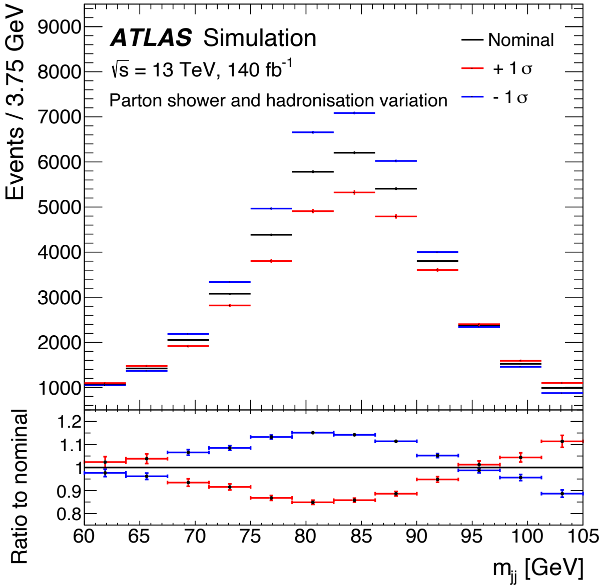
Some systematic impacts on m_{jj}

- The comparison between the m_{jj} distribution expected for the nominal $t\bar{t}$ simulation and the $t\bar{t}$ simulation where specific uncertainties are varied to $\pm 1\sigma$.
- The error bars show the statistical uncertainty in the MC samples.





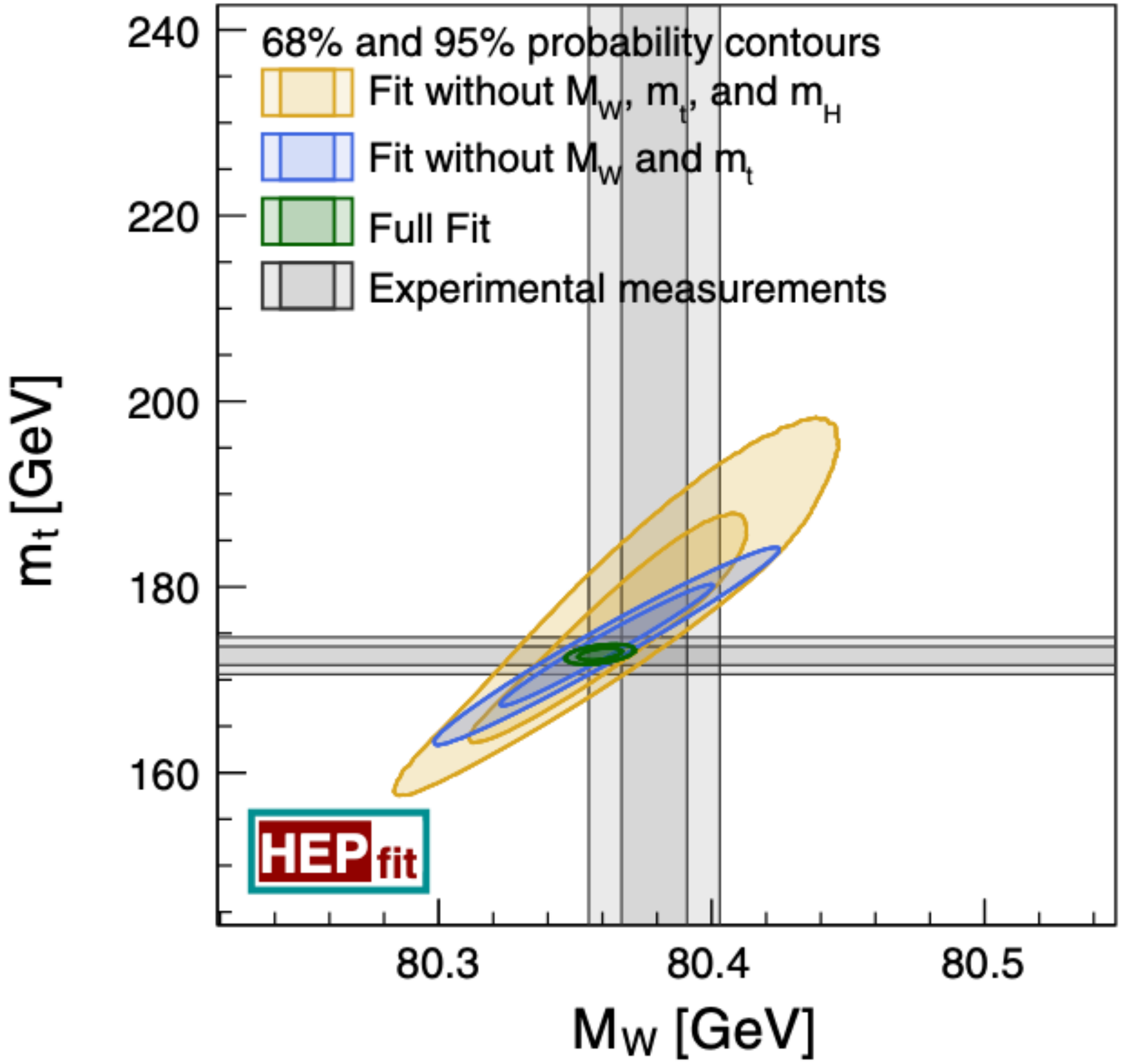




A more recent global fit

- $m_t = 172.58 \pm 0.45$ GeV
- $m_W = 80.379 \pm 0.012$ GeV

Taken from: *Phys.Rev.D* 106 (2022) 3, 033003

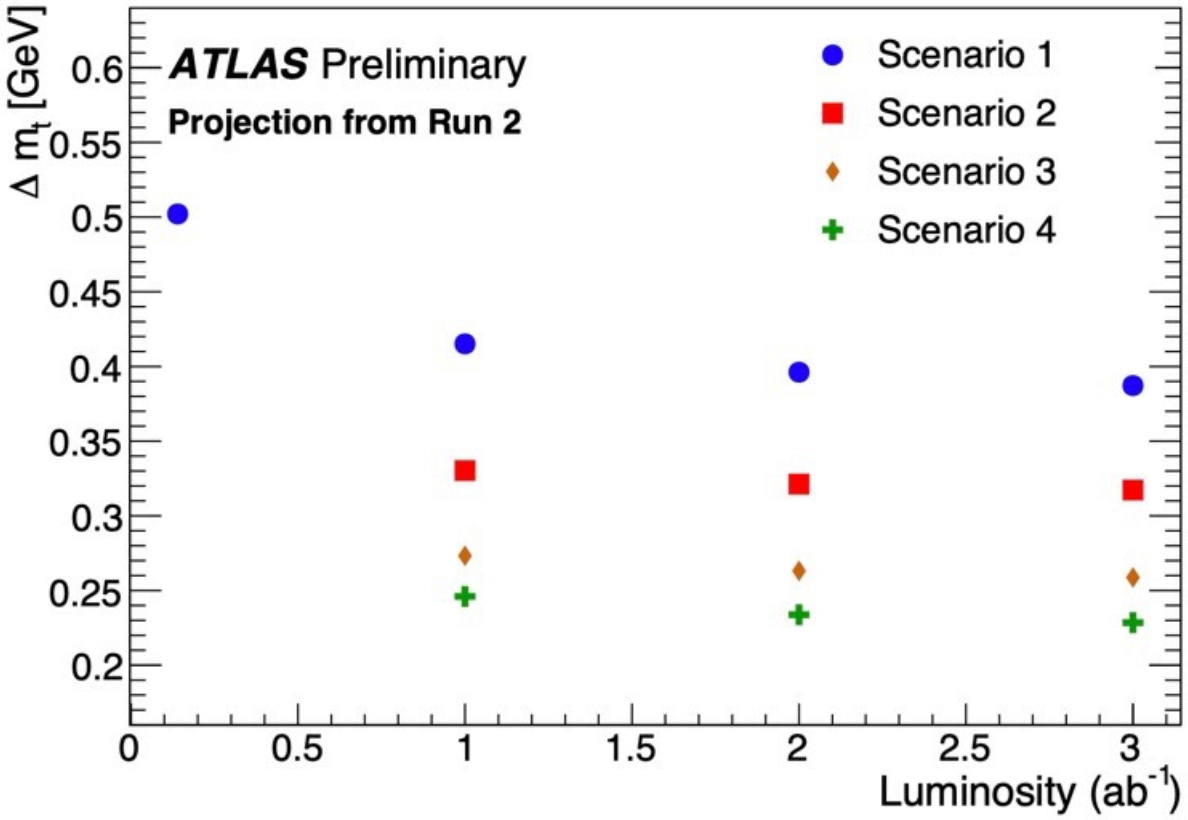


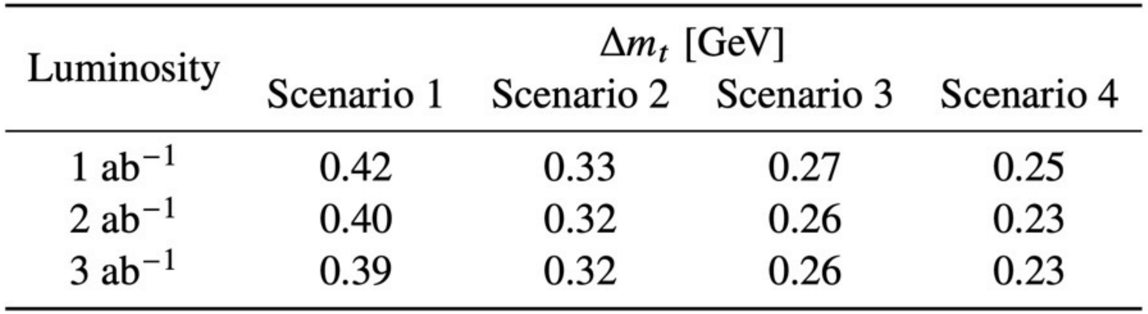
HL-LHC projection

- Given European strategy update, we looked at the precision at HL-LHC.
- Improvements in the JES can also be expected in future:
  - Techniques to reduce pileup uncertainties in EPJC 83 (2023) 761.
  - Improved JES uncertainty from single-particle measurements in arXiv:2407.15627.

- **Scenario 1**: Only improvement from data and simulation statistics.
- **Scenario 2**: Scenario 1 + improvements in JES uncertainties apart from JES flavour.
- **Scenario 3**: Scenario 2 + reduction in $t\bar{t}$ modelling uncertainties by factor of two.
- **Scenario 4**: Scenario 3 + reduction in JES flavour uncertainties by factor of two.

Taken from ATL-PHYS-PUB-2025-009





Luminosity	Δm_t [GeV]			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
1 ab^{-1}	0.42	0.33	0.27	0.25
2 ab^{-1}	0.40	0.32	0.26	0.23
3 ab^{-1}	0.39	0.32	0.26	0.23

Top quark mass interpretation

Interpretation problem

- The top quark mass is a renormalisation-scheme-dependent parameter in perturbative QFT [1].
- The MC generators in measurement use has the mass defined in the pole scheme.

  → Top quark mass is defined as position of the pole in the top quark propagator.
- However, parton shower and hadronisation models use approximations, requiring free parameters to be fixed by tuning MCs to data.

  → Can achieve good data description but physical meaning of top quark mass becomes uncontrolled, $m_t^{\mathrm{MC}} {\sim} m_t^{\mathrm{pole}}$ within $0.5\ \mathrm{GeV}$ precision.

Studies

Precise identification of m_t used in MC simulations within a field-theoretic mass scheme is still an on-going study:

- For a coherent branching parton shower algorithm, the evolution for massive quarks implies that the generator quark mass corresponds to a cutoff-dependent short-distance mass scheme and is therefore ***not*** the pole mass [2].
- Boosted regime could (in future) offer possibility to connect to hadron-level calculations where the top quark mass is unambiguously defined [3].

[1] A. H. Hoang, *What is the top quark mass?*, Ann. Rev. Nucl. Part. Sci. **70** (2020) 225

[2] ATLAS Collaboration, “Towards a precise interpretation for the top quark mass parameter in ATLAS Monte Carlo samples”, ATL-PHYS-PUB-2021-034, 2021

[3] B. Dehnadi, A. H. Hoang, O. L. Jin and V. Mateu, *Top quark mass calibration for Monte Carlo event generators—an update*, JHEP **12** (2023) 065