Precision measurements in $t\bar{t}$ final states from ATLAS

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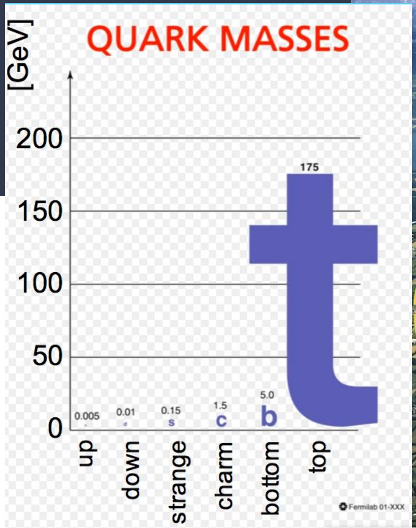
ATLAS EXPERIMENT

Top quark

Unique particle in SM:

- Quark with the largest mass
- Large coupling to Higgs boson (λ~1)
- Extremely small lifetime
  τ ~ 10^{-25} s
  => Decays before hadronization
  => Possibility to study "bare"-quark properties directly from top decay products
- Almost exclusively decays to W and b quark



LHC = top-quark factory

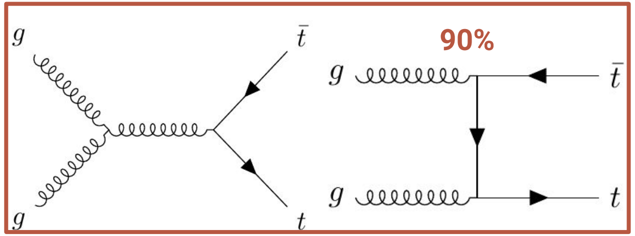
- ~ 120 M top quarks produced at LHC during Run2 in ATLAS experiment

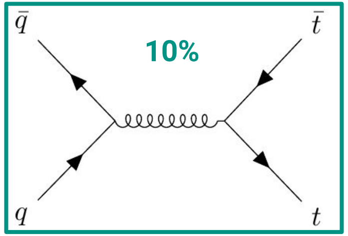
  => Allows very precise measurements

  => Probe QCD production of massive particles

  => **Potential to improve modelling for better understanding and control of uncertainties!**

In pp @ 13TeV:





Differential cross-section of dilepton $t\bar{t}$ production

arXiv.2303.15340

- **b-tag counting method** used:
  - σ_{tt} and **combined jet selection and *b*-tagging efficiency** ε^i_b fitted simultaneously
  - N_1^i, N_2^i = number of data events with either 1 or 2 b-tagged jets in each bin i

$$N_1^i = \mathcal{L}\sigma^i_{t\bar{t}} G^i_{e\mu} 2\epsilon^i_b (1 - \epsilon^i_b C^i_b) + N^i_{1,\mathrm{bkg}}$$

$$N_2^i = \mathcal{L}\sigma^i_{t\bar{t}} G^i_{e\mu} (\epsilon^i_b)^2 C^i_b + N^i_{2,\mathrm{bkg}}$$

- Single/double-differential distributions of lepton kinematic variables from decays of $t\bar{t}$ pairs:

  p_T^{ℓ}, $|\eta^{\ell}|$, $m^{e\mu}$, $p_T^{e\mu}$, $|y^{e\mu}|$, $E^e + E^{\mu}$, $p_T^{e} + p_T^{\mu}$, $|\Delta\phi^{e\mu}|$

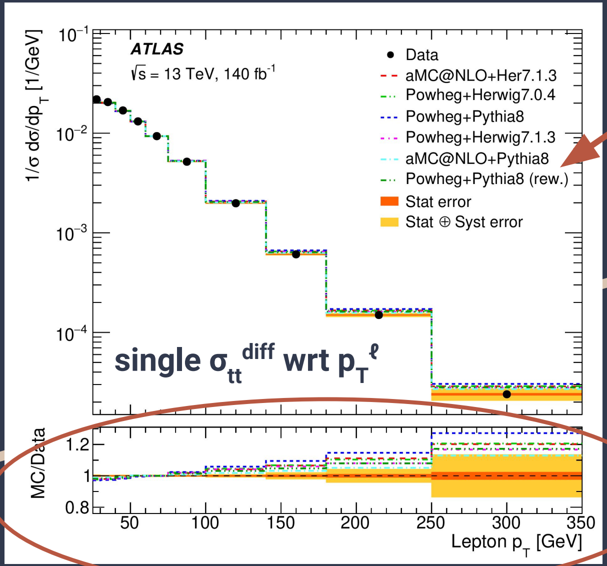
- Full Run2 dataset @ 13 TeV (140/fb), $e\mu$ channel
- Absolute and normalized σ_{tt}^{diff} in fiducial phase space ($p_T^{\ell 1(\ell 2)} > 27$ (25) GeV, $|\eta^{\ell}| < 2.5$)
- Uncertainties:
  - lumi (dominant for absolute σ_{tt})
  - $t\bar{t}$ modelling
  - reconstruction of leptons
  - bkg modelling: **interference of $t\bar{t}$ and tW amplitude** (dominant for normalized σ_{tt}, in high energy/mass bins)

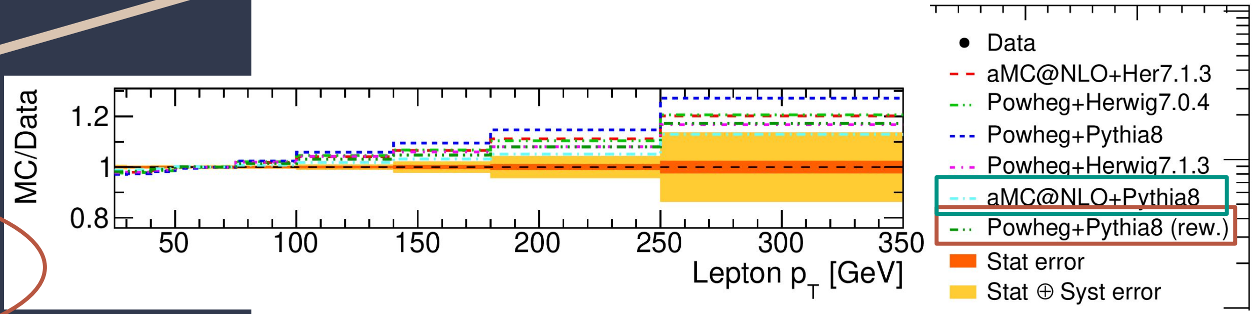
Improved luminosity determination
-> lumi uncertainty on Xsection measurement only 0.93%!

Differential cross-section of dilepton $t\bar{t}$ production

arXiv.2303.15340

- **No MC prediction consistent with all distributions**
- Better agreement with reweighted Powheg+Pythia8 based on NNLO corrections to top-quark p_T
- Almost all generators predict harder spectra for p_T^{ℓ}, $E^e + E^\mu$, $p_T^e + p_T^\mu$
- **Poorest** agreement given by **Powheg+Pythia 8 (nominal)**
- **Acceptable match** for normalized distrib. given by **MadGraph5_aMC@NLO+Pythia 8.230**

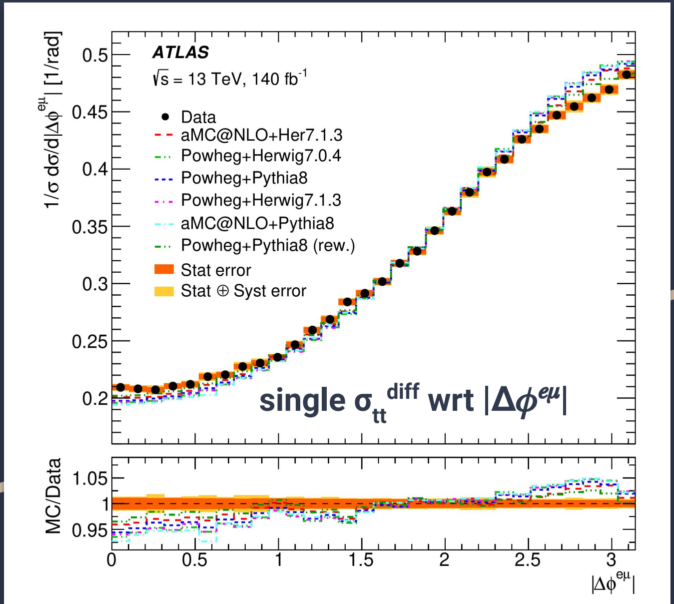


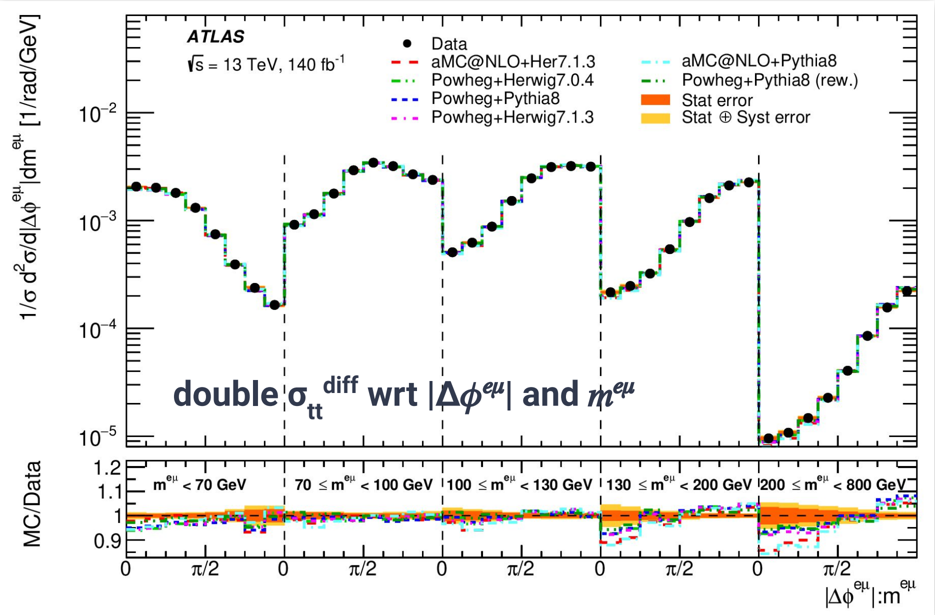


[arXiv.2303.15340](https://arxiv.org/abs/2303.15340)

Differential cross-section of dilepton $t\bar{t}$ production

- Variable pairs useful for testing and tuning of MC generators
- **No MC prediction consistent with all distributions**
- No MC model describes data trend in $|\Delta\phi^{e\mu}|$:
  - MC under(over)-estimates data at low(high) bins





arXiv.2303.15340

Differential cross-section of dilepton $t\bar{t}$ production

Modelling of Wt background:

- **Interference between $t\bar{t}$ and Wt** evaluated by comparing effects of DR and DS scheme
- Modelling uncertainties in Wt considered correlated between $t\bar{t}$ and Wt

Uncertainties related to $t\bar{t}$ modelling:

- Calculated **with alternative $t\bar{t}$ samples** or by **reweighting nominal sample**
- $t\bar{t}$+heavy flavor quarks underestimated in MC
  => uncertainty estimated by increasing the fraction of events with at least 3 b-jets by 30%
- Powheg+Pythia 8.230 gives poor description of p_T^{ℓ} = due to top-quark p_T mismodelling
  => difference wrt reweighted sample based on NNLO top p_T prediction

$p_T^{e\mu}$ bins [GeV]	$1/\sigma\, d\sigma/dp_T^{e\mu}$ $\times 10^{-3}$ [1/GeV]	Data stat. [%]	MC stat. [%]	$t\bar{t}$ mod. [%]	Lep. [%]	Jets/ b-tag. [%]	Bkg. [%]	Lumi + E_{beam} [%]	Total unc. [%]
0.0–20.0	3.08	0.64	0.20	0.47	0.29	0.12	0.47	0.01	0.99
20.0–30.0	6.55	0.61	0.16	0.77	0.27	0.17	0.42	0.01	1.13
30.0–45.0	8.29	0.42	0.10	0.47	0.25	0.09	0.47	0.01	0.84
45.0–60.0	10.53	0.37	0.09	0.55	0.17	0.06	0.42	0.01	0.81
60.0–75.0	11.48	0.35	0.08	0.23	0.13	0.03	0.40	0.01	0.60
75.0–100.0	8.84	0.29	0.07	0.24	0.05	0.04	0.19	0.00	0.43
100.0–125.0	4.60	0.43	0.09	0.66	0.30	0.12	0.37	0.00	0.94
125.0–150.0	1.87	0.67	0.16	0.53	0.73	0.21	1.46	0.03	1.86
150.0–200.0	0.54	0.93	0.22	0.73	1.20	0.28	3.13	0.08	3.57
200.0–300.0	0.08	1.78	0.48	3.71	2.24	0.33	11.38	0.22	12.32

interference of $t\bar{t}$ and tW amplitude
-> dominant in high energy/mass bins

Inclusive cross-section of dilepton $t\bar{t}$ production

arXiv.2303.15340

- Fiducial space σ_{tt} and full phase-space σ_{tt}
- B-tag counting method
- Dominant uncertainty is luminosity unc., tW Xsection, electron isolation, top p_T reweighting)
- **Excellent agreement with prediction**
- **Total uncertainty < 2% (1.8%)!**

$$\sigma_{t\bar{t}} = 829 \pm 1\ \text{(stat)} \pm 13\ \text{(syst)} \pm 8\ \text{(lumi)} \pm 2\ \text{(beam) pb}$$

NNLO+NNLL calculation:

$$\sigma_{t\bar{t},\text{pred}} = 832^{+20}_{-29}\ \text{(scale)}^{+23}_{-23}\ (m_t)^{+35}_{-35}\ (\text{PDF}+\alpha_s)\ \text{pb}$$

Most precise inclusive $t\bar{t}$ cross-section measurement up to date!

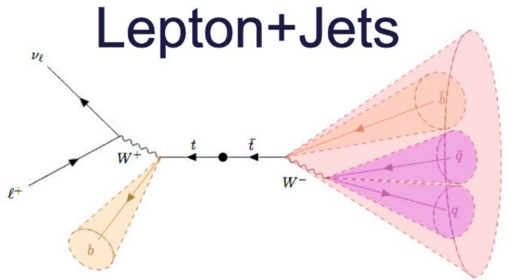
Source of uncertainty	$\Delta\sigma^{\text{fid}}_{t\bar{t}}/\sigma^{\text{fid}}_{t\bar{t}}$ [%]	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ [%]
Data statistics	0.15	0.15
MC statistics	0.04	0.04
Matrix element	0.12	0.16
h_{damp} variation	0.01	0.01
Parton shower	0.08	0.22
$t\bar{t}$ + heavy flavour	0.34	0.34
Top p_T reweighting	0.19	0.58
Parton distribution functions	0.04	0.43
Initial-state radiation	0.11	0.37
Final-state radiation	0.29	0.35
Electron energy scale	0.10	0.10
Electron efficiency	0.37	0.37
Electron isolation (in situ)	0.51	0.51
Muon momentum scale	0.13	0.13
Muon reconstruction efficiency	0.35	0.35
Muon isolation (in situ)	0.33	0.33
Lepton trigger efficiency	0.05	0.05
Vertex association efficiency	0.03	0.03
Jet energy scale & resolution	0.10	0.10
b-tagging efficiency	0.07	0.07
$t\bar{t}/Wt$ interference	0.37	0.37
Wt cross-section	0.52	0.52
Diboson background	0.34	0.34
$t\bar{t}V$ and $t\bar{t}H$	0.03	0.03
Z+jets background	0.05	0.05
Misidentified leptons	0.32	0.32
Beam energy	0.23	0.23
Luminosity	0.93	0.93
Total uncertainty	1.6	1.8

Jet substructure in boosted $t\bar{t}$ pairs

- **Study the substructure of top-quark jets** arising from it's decay products (light-/b-quarks, gluons)
- **1- and 2-dimensional σ_{tt}^{diff}** of 8 jet substructure variables defined using only charged components of jets

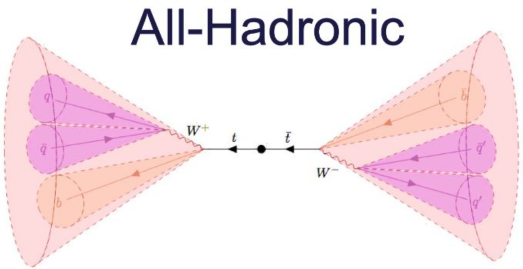
Motivation:

- **Poor modelling of jet substructure**
- **High sensitivity to some MC parameters**
- **Analytic description challenging**
- Possibility to spot BSM effects



Single-lepton channel:

- Hadronic top reconstructed as **re-clustered (RC) large-R jet (R=1.0)**



All-hadronic channel:

- **2 large-R jets (R=1.0)**
- (sub)Leading jet p_T > (350) 500 GeV
- DNN top-tag on the non-probe large-R jet

- Full Run2 dataset @ 13 TeV (140/fb)
- **Boosted events**: top-quark jet **p_T > 350 GeV**, decay products collimated into single large jet

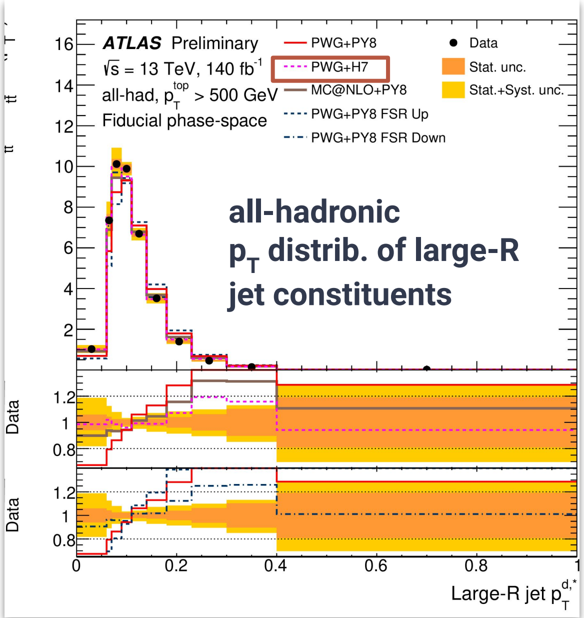
- Distributions unfolded by IBU to particle level

ATLAS-CONF-2023-027

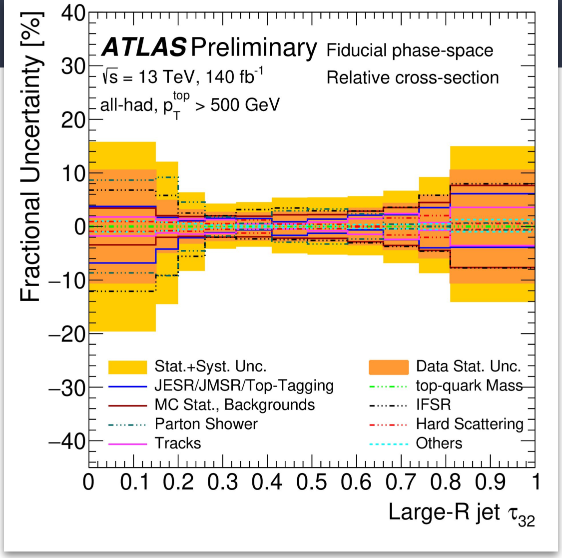
Jet substructure in boosted $t\bar{t}$ pairs: single σ_{tt}^{diff}

8 jet substructure variables sensitive to e.g.:

- Modeling of 3-body (**τ_{32}, C_3**) or 2-body (**D_2, τ_{21}**) substructure of jets
- Distribution of the momentum of the constituents inside the jet (**$p_T^{d,*}$**)



- **Good description by Powheg+Pythia 8 (FSR Down)** => data favors a reduction of FSR scale = **increase of α_s^{FSR}** value
- **Herwig 7** preferred by data over Pythia 8



- Measurement sensitive to **modelling of parton-shower, hadronization process, and FSR**

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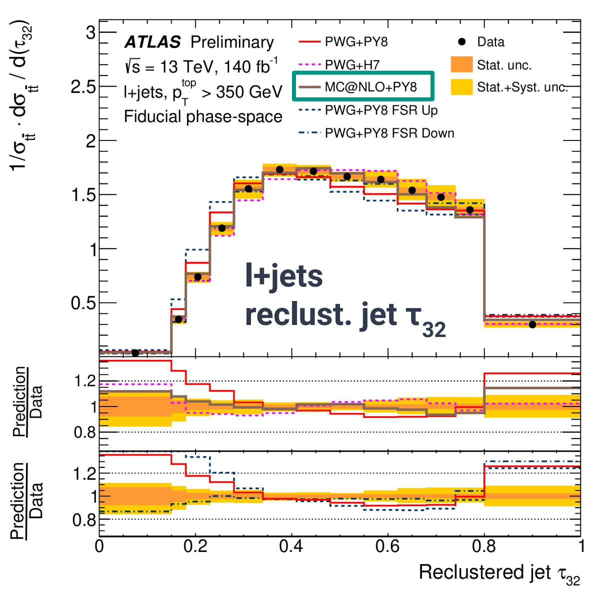
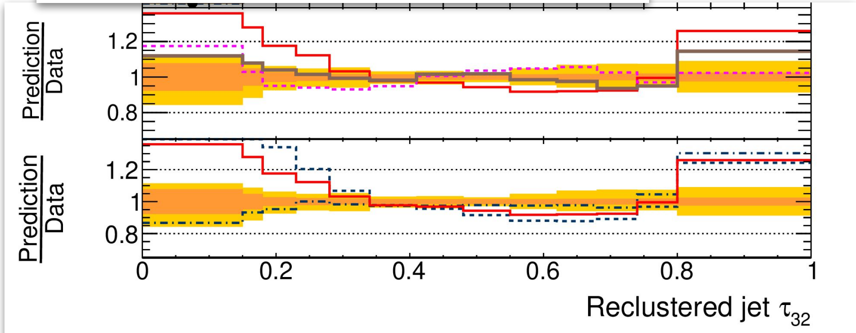
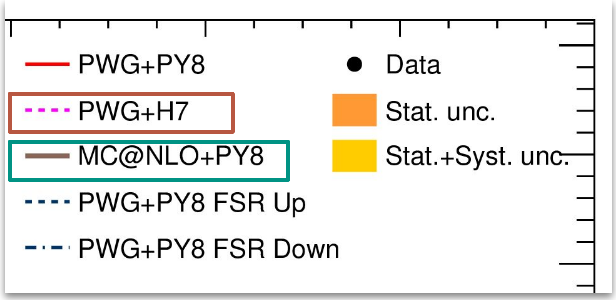
Jet substructure in boosted $t\bar{t}$ pairs: single σ_{tt}^{diff}

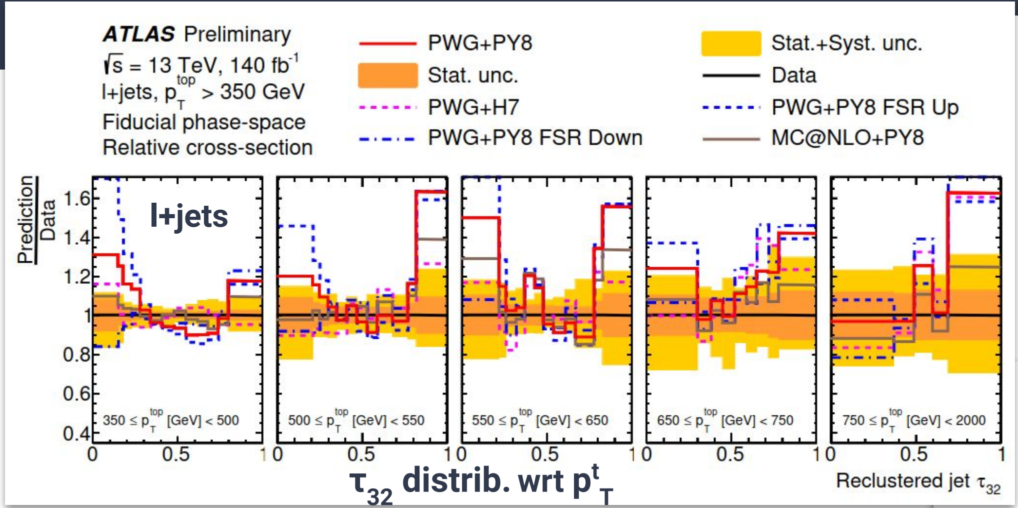


- **Poor modelling of 3-body substructure of jets** by nominal or nominal+FSR up prediction
- Variables sensitive to 2-body jet substructure well modelled
- **Powheg+Pythia 8 (FSR Down) = good description of all observables, except τ_{32} in l+jets**
- **τ_{32}/τ_3** = poorly modelled, only **MC@NLO+Pythia8** gives reasonable agreement with data





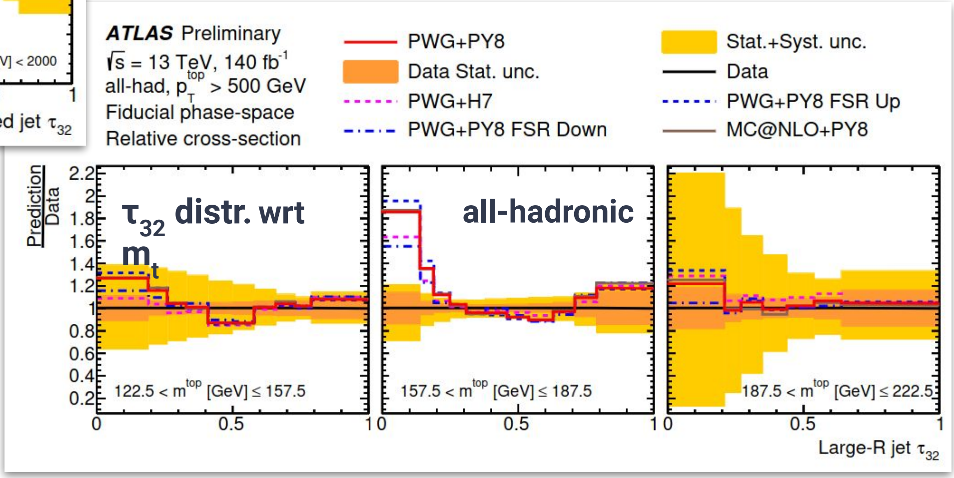
Jet substructure in boosted $t\bar{t}$ pairs: double σ_{tt}^{diff}



- τ_{32} and D_2 distinguish jets with 3/2-body substructure from simpler jets (taggers)

  => **correlations with m_t and p^t_T important**

- Correlations of τ_{32}/D_2 with m_t and p^t_T poorly modelled
  (low m_t and higher p^t_T regions problematic)



- Predictions give more 3-body like substructure than data
- **Powheg+Pythia 8 gives poor description**
- Other MC more promising, **best Powheg+Pythia 8 (FSR down)**

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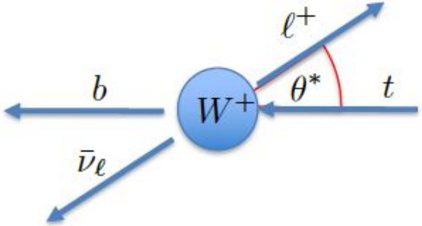
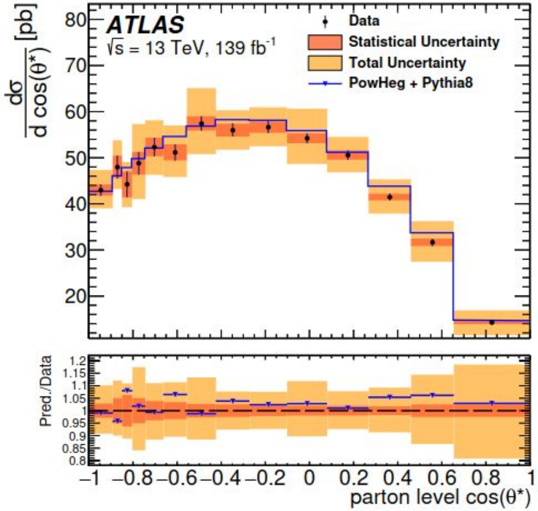
W-boson polarization in $t\bar{t}$ production

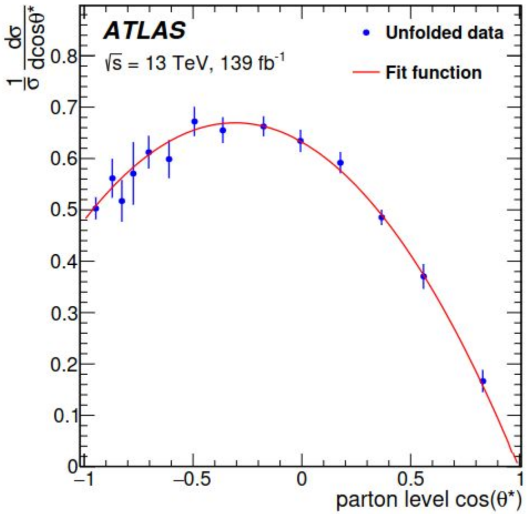
- W-boson polarization states governed by *Wtb* vertex and quark masses (only left-handed f_L and longitudinal f_0 , right f_R polarization ~ 0 in SM = V-A structure of SM)
- Probe new physics processes which modify the structure of *Wtb* vertex
- Dilepton $t\bar{t}$ decay channel @13 TeV (139/fb)

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} = \frac{3}{4}(1-\cos^2\theta^*)f_0 + \frac{3}{8}(1-\cos\theta^*)^2 f_L + \frac{3}{8}(1+\cos\theta^*)^2 f_R$$

- Helicity fractions extracted by fit to normalised differential cos θ* distribution unfolded to parton level by IBU







W-boson polarization in $t\bar{t}$ production

- MC at parton level fails to model cos θ* distribution correctly
- Distribution distorted by simulation of parton shower at ~ 0.1% level

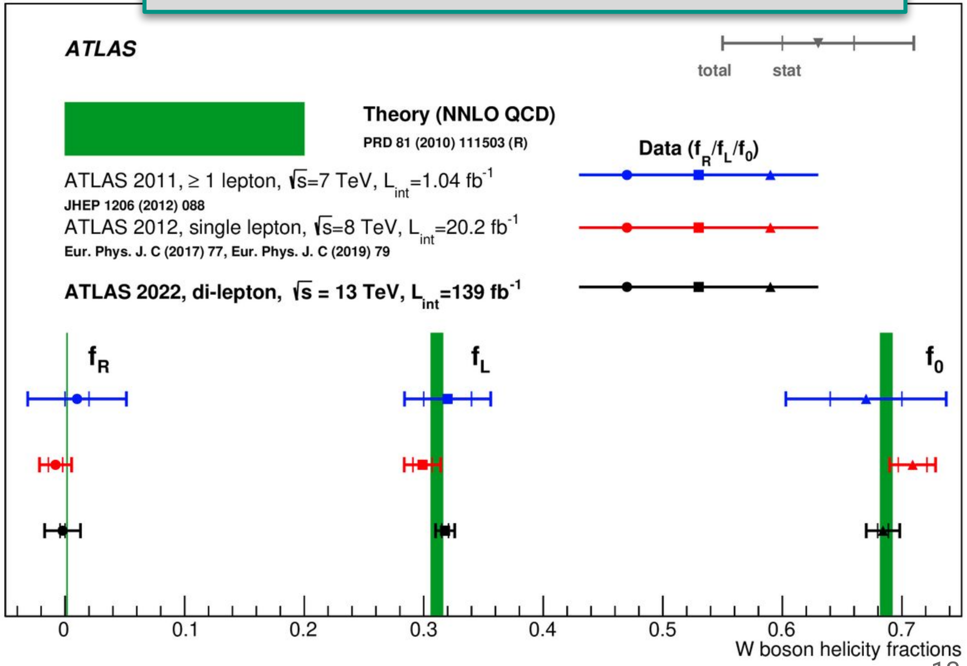
=> **MC** has to be **reweighted** to match **quadratic function of cos θ***

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} = \frac{3}{4}(1-\cos^2\theta^*)f_0 + \frac{3}{8}(1-\cos\theta^*)^2 f_L + \frac{3}{8}(1+\cos\theta^*)^2 f_R$$

- Systematic uncertainty dominant

$$f_0 = 0.684 \pm 0.005\,(\text{stat.}) \pm 0.014\,(\text{syst.})$$
$$f_L = 0.318 \pm 0.003\,(\text{stat.}) \pm 0.008\,(\text{syst.})$$
$$f_R = -0.002 \pm 0.002\,(\text{stat.}) \pm 0.014\,(\text{syst.})$$

Results **consistent with SM prediction**



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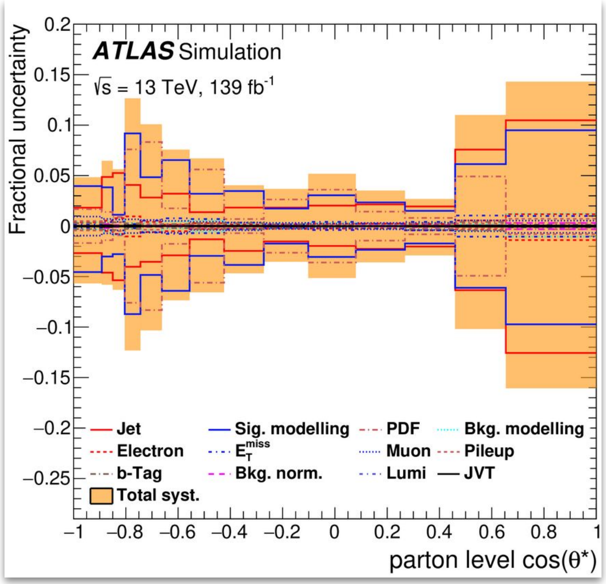
W-boson polarization in $t\bar{t}$ production

- Largest systematics: **modelling of $t\bar{t}$ production**, dominated by **choice of matrix-element generator**
- Other significant uncertainties: jet energy scale and resolution, electron and muon reconstruction

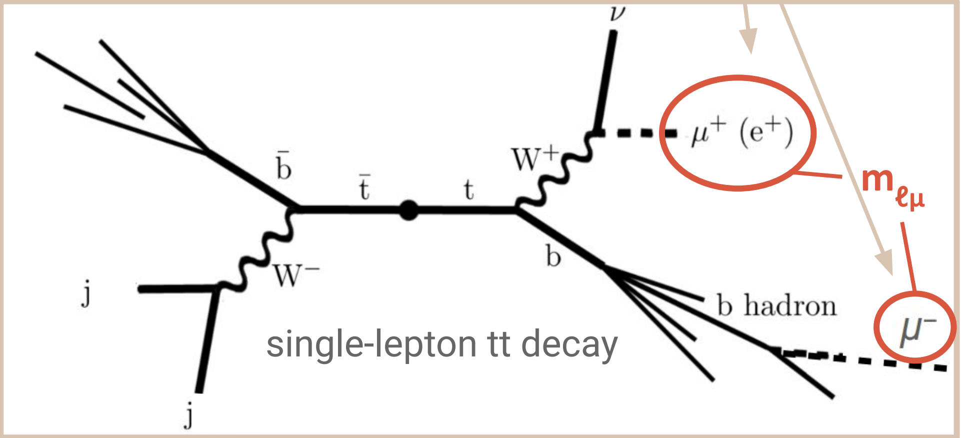
Category	σ_{f_0}	σ_{f_L}	σ_{f_R}
Detector modelling			
Jet reconstruction	0.008	0.004	0.010
Flavour tagging	0.003	0.001	0.001
Electron reconstruction	0.003	0.002	0.002
Muon reconstruction	0.003	0.003	$< 10^{-3}$
E_T^{miss} (soft term)	$< 10^{-3}$	0.002	$< 10^{-3}$
Pile-up	0.002	0.002	$< 10^{-3}$
Luminosity	0.001	0.001	$< 10^{-3}$
Signal and background modelling			
$t\bar{t}$ production	0.011	0.005	0.010
PDF	0.002	0.001	$< 10^{-3}$
Single top production	$< 10^{-3}$	0.002	$< 10^{-3}$
Other background	0.002	0.001	$< 10^{-3}$
Total systematic uncertainty	0.014	0.008	0.014
Data statistical uncertainty	0.005	0.003	0.002
Total uncertainty	0.015	0.008	0.014



Soft muon tag top-quark mass

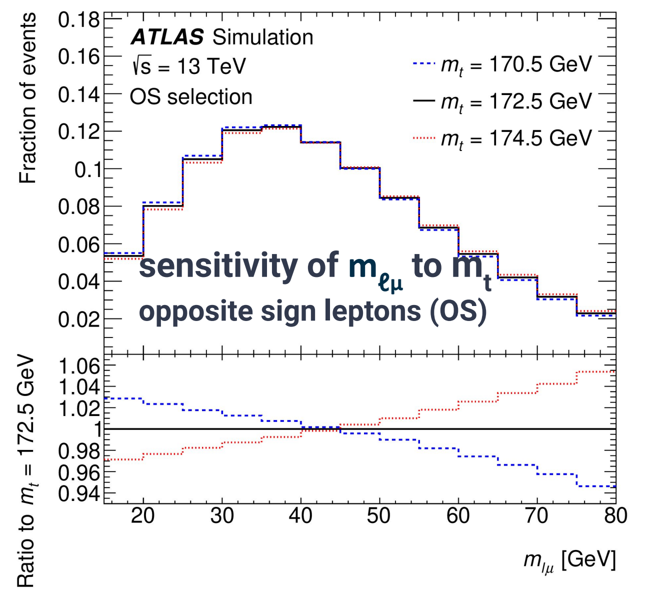
JHEP 06 (2023) 019

Different method of direct top-quark mass measurement => invariant mass of lepton from W (ℓ) and soft muon (μ) $\mathbf{m_{\ell\mu}}$ used



- Single-lepton $t\bar{t}$ channel, 36/fb @ 13 TeV

- **Proxy for m_t constructed only from leptons** = invariant mass $\mathbf{m_{\ell\mu}}$:
  - Less sensitive to jet related uncertainties
  - More direct impact from b⟶B fragmentation modelling



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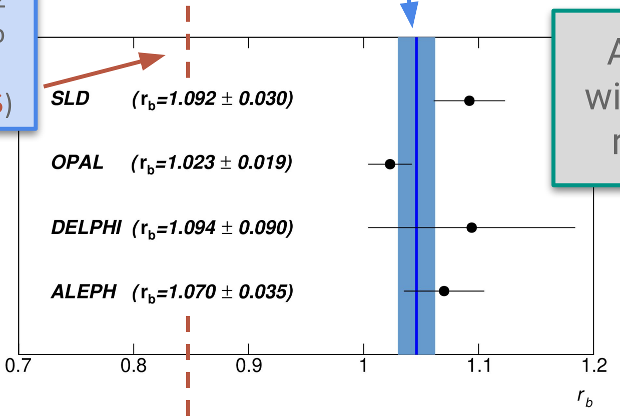
Soft muon tag top-quark mass

- **Modelling of momentum transfer between b-quark and b-hadron important**
- **LEP data exploited to constrain b-fragmentation for $t\bar{t}$ events**
- A14 tune in Pythia improved by fitting r_b parameter (corresp. to b-quark fragmentation) = new **A14-r_b tune**

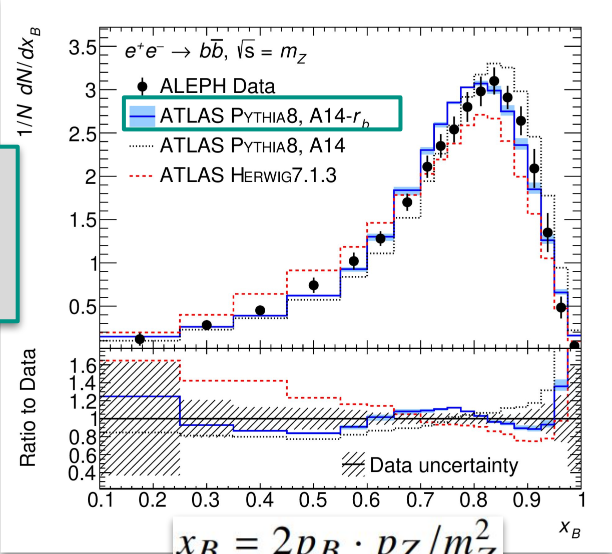
Lund-Bowler *b*-quark fragmentation function in Pythia8:

$$f(z) = \frac{1}{z^{1+b r_b m_b^2}} (1-z)^a \exp(-b m_T^2 / z)$$

A14-r_b = 1.05 ± 0.02 from combined fit to LEP+SLD data (previously r_b = 0.855)

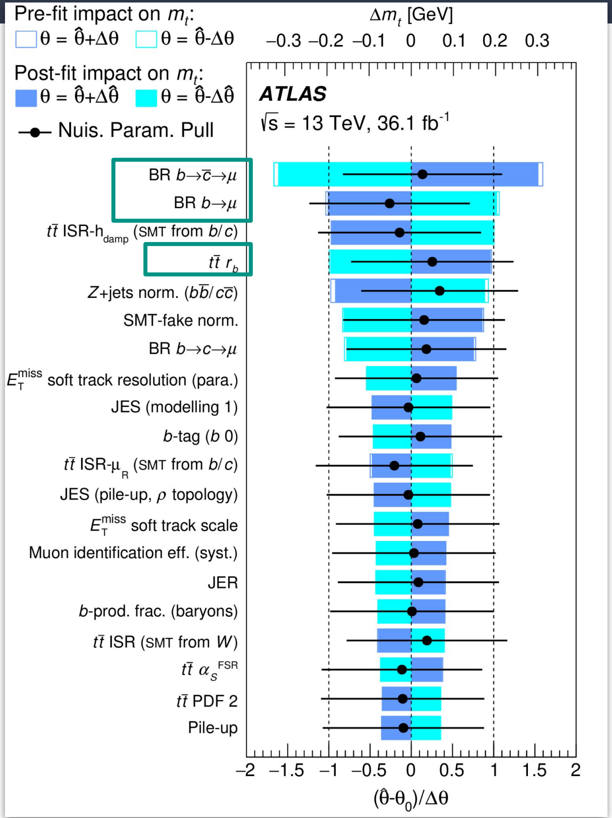


Agreement with LEP data recovered!



$$x_B = 2 p_B \cdot p_Z / m_Z^2$$

Soft muon tag top-quark mass



- Binned-template profile likelihood fit is performed to extract m_t
  - **Region of $m_{\ell\mu}$** between 15 and 80 GeV used in fit (most sensitive to m_t)

$$m_t = 174.41 \pm 0.39\,(\text{stat.}) \pm 0.66\,(\text{syst.}) \pm 0.25\,(\text{recoil})\ \text{GeV}$$

- Events divided into same-sign/opposite sign regions (**$q_{softmu} * q_{W\text{-}lepton}$ > 0 and < 0**)
  - Better isolation of same top events with direct b->μX decays, which have better sensitivity to top mass wrt different top and/or b->cX->μX' decays
- Dominant uncertainty comes from **modelling of** direct/sequential **b-hadron decays and b-quark fragmentation**

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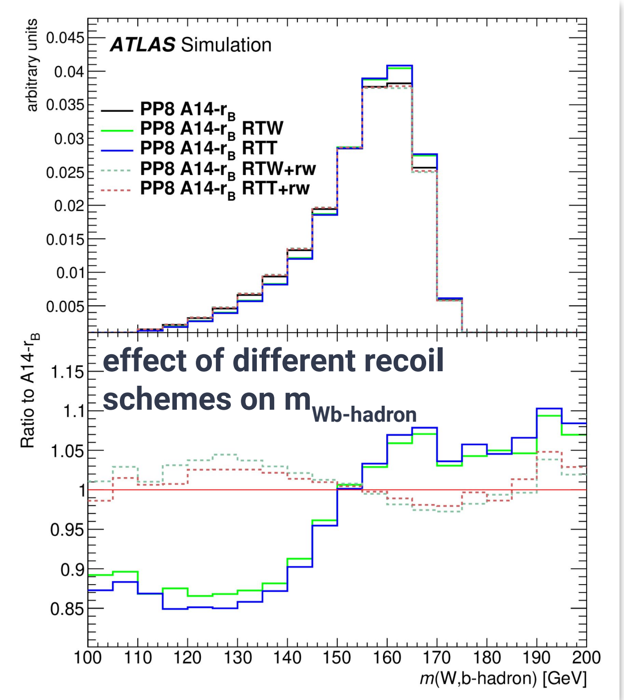
Soft muon tag top-quark mass



$$m_t = 174.41 \pm 0.39\ (\text{stat.}) \pm 0.66\ (\text{syst.}) \pm 0.25\ (\text{recoil})\ \text{GeV}$$

For the first time used **uncertainty on gluon emission** in t→Wb

Change in parton shower gluon-recoil scheme:

- **Nominal**: gluons recoil against b-quark
- **Alternative**: recoil against W-boson (RTW) or top-quark (RTT)
  - Changes energy distribution within jet, jet p_T due to out-of-cone radiation, hardens b-hadron momentum, lowers gluon-energy emission

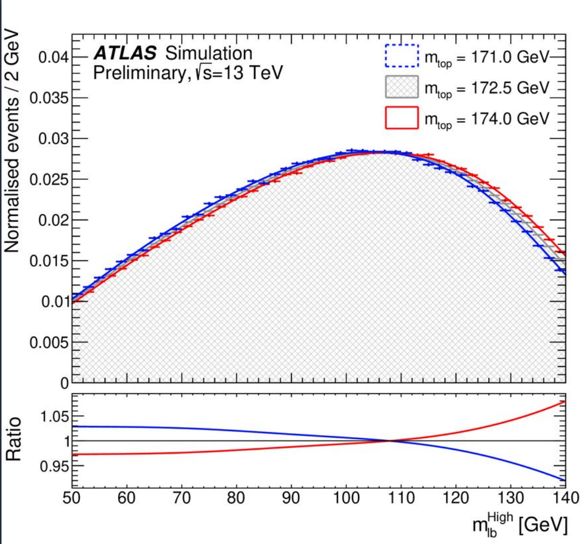
  => b-fragmentation function altered as a side effect

  Nominal in better agreement with NLO+NLL resummations → fragmentation variable x_B reweighted to match that of the nominal sample (RTW+rw/RTT+rw)
  - **Crude adjustment, requires dedicated tune**

Recoil uncertainty = comparison of nominal scheme and recoil against top-quark + reweighting of x_B

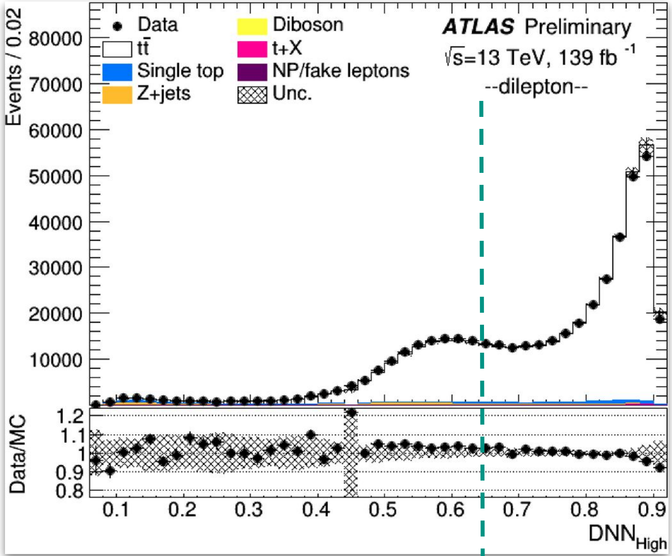
Top mass template method in dilepton $t\bar{t}$ channel

- m_t extracted using template fit functions, $m_{\ell b}$ in (50, 140) GeV used = $m_{\ell b}^{High}$



- Dilepton $t\bar{t}$ decay channel @13 TeV (139/fb)
- **Proxy for m_t constructed from decay products of top**: lepton ℓ and b-jet => $\mathbf{m_{\ell b}}$
- Optimized selection:
  - DNN used for ℓ−b-jet pairing: events with DNN score > 0.65 selected
  - $p_T^{\ell b}$ > 160 GeV
  - ℓ-b with highest $p_T^{\ell b}$ selected → helps reduce signal modelling and jet-related uncertainties

better precision!



ATLAS-CONF-2022-058

Top mass template method in dilepton $t\bar{t}$ channel

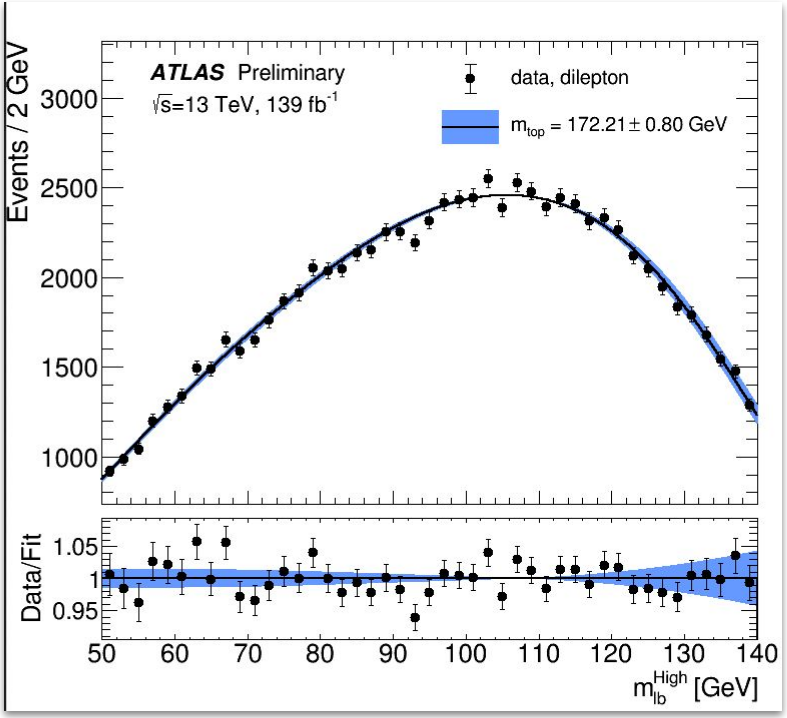
- Unbinned maximum-likelihood fit to data
- Fitted m_t = mass parameter in ATLAS signal generator setup

Recoil scheme in parton shower:

- Nominal = 2nd gluon emission (and subsequent), recoils against b-quark
  - Narrower m_t spectrum, more collinear radiation
- Alternative = recoil against top-quark
  - More out-of-cone radiation, but likely overestimates these effects (**no dedicated tune**)

- **Additional** source of **uncertainty** = choice of **gluon-recoil scheme**

$$m_{top}^{dilepton} = 172.21 \pm 0.20\,(\text{stat}) \pm 0.67\,(\text{syst}) \pm 0.39\,(\text{recoil})\ \text{GeV}$$



ATLAS-CONF-2022-058

Top mass template method in dilepton $t\bar{t}$ channel

- **Signal-modelling uncertainties significant**
  - Evaluated by comparing pairs of theory models
  - Largest: modelling of **matrix-element to parton-shower matching** in $t\bar{t}$
- Precision limited also by uncertainties in **jet energy determination**
- Description **recoil in the Pythia parton shower** sizable impact on m_t
  -> quote a conservative estimate

	m_{top} [GeV]
Result	172.21
Statistics	0.20
Method	0.05 ± 0.04
Matrix-element matching	0.40 ± 0.06
Parton shower and hadronisation	0.05 ± 0.05
Initial- and final-state QCD radiation	0.17 ± 0.02
Underlying event	0.02 ± 0.10
Colour reconnection	0.27 ± 0.07
Parton distribution function	0.03 ± 0.00
Single top modelling	0.01 ± 0.01
Background normalisation	0.03 ± 0.02
Jet energy scale	0.37 ± 0.02
b-jet energy scale	0.12 ± 0.02
Jet energy resolution	0.13 ± 0.02
Jet vertex tagging	0.01 ± 0.01
b-tagging	0.04 ± 0.01
Leptons	0.11 ± 0.02
Pile-up	0.06 ± 0.01
Recoil effect	0.39 ± 0.09
Total systematic uncertainty (without recoil)	0.67 ± 0.05
Total systematic uncertainty (with recoil)	0.77 ± 0.06
Total uncertainty (without recoil)	0.70 ± 0.05
Total uncertainty (with recoil)	0.80 ± 0.06

Summary

- Presented some top-related precision measurements: **Xsection, jet substructure, W polarization and top mass measurements**
- More results: **ATLAS Top Results page**

- Modelling uncertainties have sizable impact on some measurements
  => despite **impressive precision achieved!**
  => the most precise measurement of **inclusive $t\bar{t}$ cross section!**

- Nominal pair of generators (Powheg+Pythia8) has drawbacks -> improvement needed!
  - recoil of gluons in color resonance decay (t->Wb)
  - parton shower (shown some preference of Herwig7 over Pythia8)
  - interference of $t\bar{t}$ and tW
  - α_S^{FSR} values in modelling of final state radiation
  - top-quark p_T mismodelling -> distortions in p_T^{ℓ} spectrum

- More studies needed for better understanding
- Development of specific dedicated tunes (recoil, color reconnection) also needed

Back-up

Jet substructure in boosted $t\bar{t}$ pairs

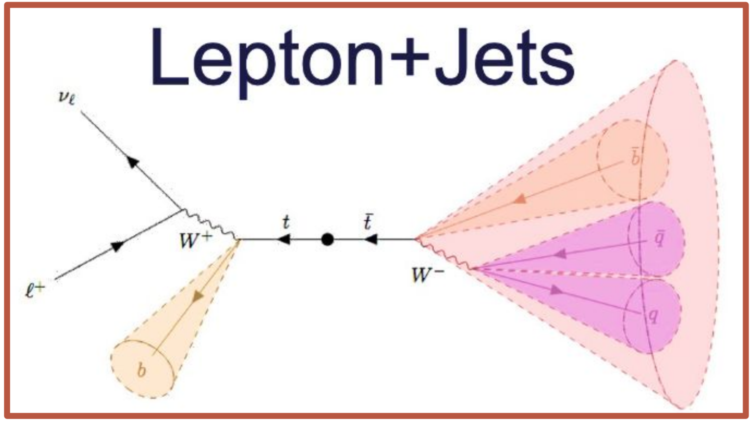
ATLAS-CONF-2023-027

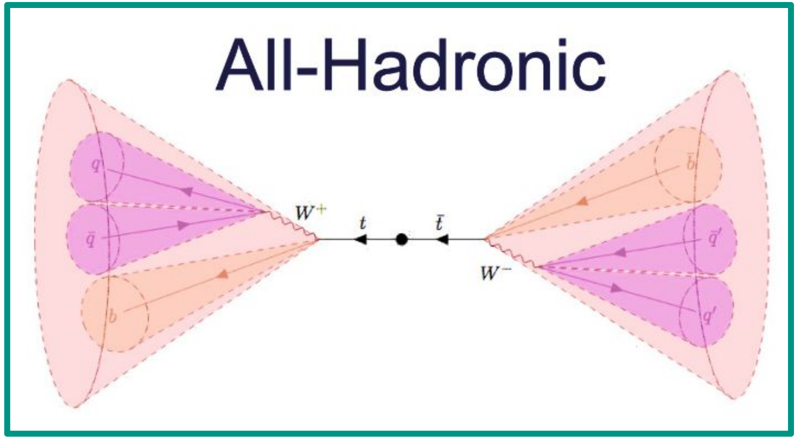
Single-lepton channel:

- Electron or Muon
- m_T^W > 20 GeV, E_T^{miss} > 15 GeV and m_T^W+ E_T^{miss} > 60 GeV to suppress fake leptons
- Hadronically-decaying top reconstructed as **re-clustered (RC) large-R jet (R=1.0)**
- No required b-matching on the measured jets

All-hadronic channel:

- No leptons
- Hadronically-decaying top reconstructed as large-R jet => **2 large-R jets (R=1.0)**
- (sub)Leading jet p_T > (350) 500 GeV
- Required b-matching on the measured jets to suppress multijet bkg.
- DNN top-tag on the non-probe large-R jet





Jet substructure in boosted tt pairs

8 jet substructure variables:

- Observables sensitive to modeling of three-prong (**τ_{32}, C_3**) or two-prong (**D_2, τ_{21}**) objects
  - N-subjettiness variables **τ_3** and ratios $\tau_{32} \equiv \tau_3/\tau_2$ and $\tau_{21} \equiv \tau_2/\tau_1$
  - C_3 and D_2 defined as ratios of energy-correlation functions
  - (τ_{32}, C_3) /(D_2, τ_{21}) close to 0/1 for three/two-pronged substructure of jet
- Normalized energy-correlation function **ECF2**
- Modeling of Les Houches angularity **LHA** = describes broadness of a jet
- **Scaled p_T dispersion $p_T^{d,*}$** = sensitive to distribution of momentum of the constituents inside the jet

arXiv.2303.15340

Differential cross-section of dilepton $t\bar{t}$ production

Modelling of Wt background:

- **Interference between $t\bar{t}$ and Wt** evaluated by comparing effects of DR and DS scheme

Uncertainties related to $t\bar{t}$ modelling:

- Calculated **with alternative $t\bar{t}$ samples** or by **reweighting nominal sample**
- $t\bar{t}$+heavy flavor quarks underestimated in MC => uncertainty estimated by increasing the fraction of events with at least 3 b-jets by 30%
- Powheg+Pythia 8.230 gives poor description of p_T^{ℓ} = due to top-quark p_T mismodelling => difference wrt reweighted sample based on NNLO top p_T prediction

absolute cross section

$p_T^{e\mu}$ bins [GeV]	$d\sigma/dp_T^{e\mu}$ [fb/GeV]	Data stat. [%]	MC stat. [%]	$t\bar{t}$ mod. [%]	Lep. [%]	Jets/ b-tag. [%]	Bkg. [%]	Lumi + E_{beam} [%]	Total unc. [%]
0.0–20.0	32.51	0.66	0.21	0.87	0.79	0.19	0.67	0.92	1.79
20.0–30.0	69.08	0.64	0.17	0.87	0.78	0.22	0.68	0.92	1.78
30.0–45.0	87.41	0.46	0.11	0.90	0.78	0.18	0.66	0.92	1.72
45.0–60.0	111.0	0.41	0.09	0.71	0.79	0.15	0.64	0.92	1.61
60.0–75.0	121.0	0.38	0.09	0.66	0.79	0.14	0.63	0.92	1.57
75.0–100.0	93.20	0.33	0.07	0.70	0.78	0.12	0.66	0.92	1.59
100.0–125.0	48.51	0.45	0.10	0.97	0.89	0.15	0.99	0.93	1.96
125.0–150.0	19.74	0.70	0.17	0.38	1.20	0.21	1.98	0.95	2.64
150.0–200.0	5.73	0.95	0.23	0.55	1.62	0.28	3.65	1.00	4.28
200.0–300.0	0.86	1.78	0.49	3.39	2.64	0.35	11.88	1.14	12.82

interference of $t\bar{t}$ and tW amplitude
-> dominant in high energy/mass bins

arXiv.2303.15340

Differential cross-section of dilepton $t\bar{t}$ production

b-tagging correlation coef.

reconstruction efficiency

Systematic uncertainty name	$\Delta C_b/C_b$ [%]	$\Delta G_{e\mu}/G_{e\mu}$ [%]
Matrix element	−0.10 ± 0.22	0.25 ± 0.11
h_{damp}	−0.06 ± 0.08	−0.05 ± 0.04
Parton shower and hadronisation	0.16 ± 0.08	−0.26 ± 0.04
Top p_T reweighting	0.03 ± 0.08	0.22 ± 0.04
$t\bar{t}$ + heavy flavour	−0.33 ± 0.08	0.01 ± 0.04
ISR (high)	−0.01 ± 0.08	0.06 ± 0.04
ISR (low)	0.04 ± 0.08	−0.13 ± 0.04
FSR (high)	0.05 ± 0.09	−0.07 ± 0.04
FSR (low)	−0.09 ± 0.15	0.10 ± 0.07
PDF	0.02 ± 0.08	0.04 ± 0.04

All uncertainties shown are due to the limited MC sample size

Uncertainties related to $t\bar{t}$ modelling:

- Calculated **with alternative $t\bar{t}$ samples** or by **reweighting nominal sample**
- Contribution of $t\bar{t}$+heavy flavor quarks underestimated in MC
  => uncertainty estimated by increasing the fraction of events with at least 3 b-jets by 30%
- Powheg+Pythia 8.230 does not give good description of p_T^{ℓ} = due to top-quark p_T mismodelling
- => uncertainty derived as difference wrt sample with top p_T reweighted to NNLO

Modelling of Wt background:

- **Interference between $t\bar{t}$ and Wt** evaluated by comparing effects of DR and DS scheme on result
- Modelling uncertainties in Wt considered correlated between $t\bar{t}$ and Wt