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Measurement of the $t\bar{t}$ production cross section in the lepton+jets channel at $\sqrt{s} = 13$ TeV with the ATLAS experiment

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Bundesministerium
für Bildung
und Forschung

FSP 103 ATLAS

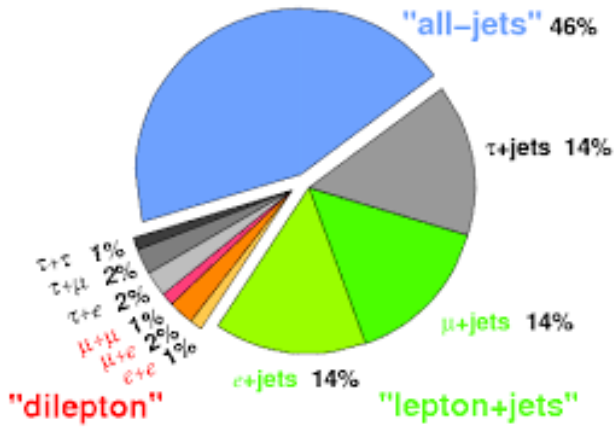
ATLAS EXPERIMENT

Motivation

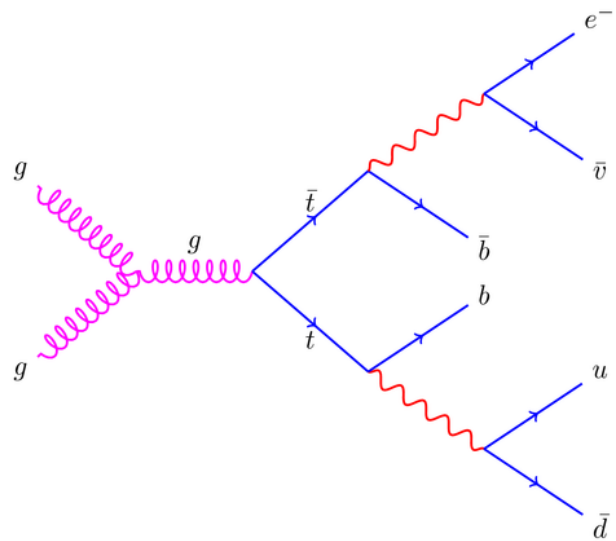
- Test of the SM (strong coupling, $\sqrt{s}$ dependence, PDFs, ...)
- Sensitivity to the mass
- Test of QCD calculation
- Contributions from BSM physics?
- Latest measurements at 13 TeV
  - **ATLAS *l*+jets (85 pb^{-1}, ATLAS-CONF-2015-049): 16.7%**
    $\sigma_{t\bar{t}} = 817 \pm 13$ (stat.) ± 103 (syst.) ± 88 (lumi.) pb
  - **ATLAS $e\mu$ (36.1 fb^{-1}, ATLAS-CONF-2019-041): 2.4%**
    $\sigma_{t\bar{t}} = 826.4 \pm 3.6$ (stat.) ± 11.5 (syst.) ± 15.7 (lumi.) ± 1.9 (beam) pb
- NNLO + NNLL prediction: $831.76^{+19.77}_{-29.20}$ (scale)$^{+35.06}_{-35.06}$ (PDF + α_s) pb

$\rightarrow$ New, more precise ℓ+jets measurement should be done: ATLAS-CONF-2019-044

Introduction



(a) Branching Ratios



(b) lepton+jets channel

- The lepton+jets final state: one W boson originating from the top quark decays leptonically and the other W boson decays hadronically:

$$t\bar{t} \rightarrow W^+W^-b\bar{b} \rightarrow \ell\nu q\bar{q}'b\bar{b} \tag{1}$$

Samples

Signal and Background

Sample	Generator	PDF	Parton Shower
$t\bar{t}$	Powheg-Box + Evtgen	NNPDF3.0	Pythia 8
Single Top	Powheg-Box + Evtgen	NNPDF3.0	Pythia 8
W+jets	Sherpa 2.2.1	NNPDF3.0	
Z+jets	Sherpa 2.2.1	NNPDF3.0	
Diboson	Sherpa 2.2.2	NNPDF3.0	
$t\bar{t}Z$	Madgraph 5_aMC@NLO	NNPDF3.0	Pythia 8
$t\bar{t}W$	Madgraph 5_aMC@NLO	NNPDF3.0	Pythia 8
$t\bar{t}H$	Powheg-Box + Evtgen	NNPDF3.0	Pythia 8
Multijet	Data-driven matrix method		

- Alternative samples ($t\bar{t}$ signal and single-top background) are used to estimate modelling uncertaintites: Powheg-Box +Evtgen showered with Herwig 7.

Event Selection

Selection Criteria

- Lepton trigger, 1 lepton (e,μ) with $p_T >$ (25, 27, 28, 28) GeV for 2015-2018
- ≥ 4 jets with $p_T > 25$ GeV
- ≥ 1 b-tag (60% WP), pseudo-continuous b-tagging
- e+jets: $E_T^{\text{miss}}, M_W^T > 30$ GeV μ+jets: $E_T^{\text{miss}} + M_W^T > 60$ GeV

Define signal regions according to jet- and b-tag multiplicity (60% WP)

	n_{jet}	$n_{b\text{-tag}}$	Features
SR1	≥ 4	1	largest background
SR2	4	2	expected signature (for LO $t\bar{t}$)
SR3	≥ 5	2	jet radiation (ISR, FSR)

- Usage of full Run 2 data set (139 fb^{-1})

Fiducial Region

Defined with particle-level objects

- Leptons: Electrons, muons, neutrinos from W and Z decays
- Jets: anti-k_t with $R = 0.4$
- b-jet identification via ghost-matching

Selection

- Exactly one electron or muon, $p_T > 25$ GeV, $|\eta| < 2.5$
- At least four jets, $p_T > 25$ GeV, $|\eta| < 2.5$
- One or two ghost-tags

Strategy

Variable Selection

- Separation power for signal vs. background
- Good modelling
- Good data/prediction agreement

Variable	Region	
Aplanarity	SR1	Defined by smallest eigenvalue of the sphericity tensor
m_{lj}^{min}	SR2	Minimal lepton-jet mass
$\Delta R_{bjj,\text{max } p_T}^{\text{avg}}$	SR3	Average distance in subset of a b-jet and two other jets with max. p_T

Profile Likelihood Fit

- Simultaneous fit of three regions
- Include systematic uncertainties as nuisance parameters
- Constrain uncertainties and extract the cross section

Systematic uncertainties

Detector modelling

- Jet reconstruction (JES, JER, ...), Flavour-tagging
- Electrons, muons, E_T^{miss}, pile-up
- Luminosity

$t\bar{t}$ modelling

- Top p_T NNLO reweighting
- PDF: 30 PDF4LHC15 variations
- ISR: three variations (μ_R, μ_F, Var3c)
- FSR: up/down variation $\mu_R^{\text{FSR}} \times (2, 0.5)$
- Parton showering: Comparison to Powheg+Herwig7, split in components
  - Shape-only uncertainties (decorrelated between regions)
  - Migration of events between three regions
  - Acceptance-only uncertainty

Backgrounds

- Single top: normalisation, ISR and FSR (as for $t\bar{t}$), parton shower, DR vs DS
- Multijet: normalisation and shape uncertainties (decorrelated between leptons and regions)
- W+jets: QSF, CKKW and μ_R, μ_F variations (shape-only)

Yields & Pre-Fit Plots

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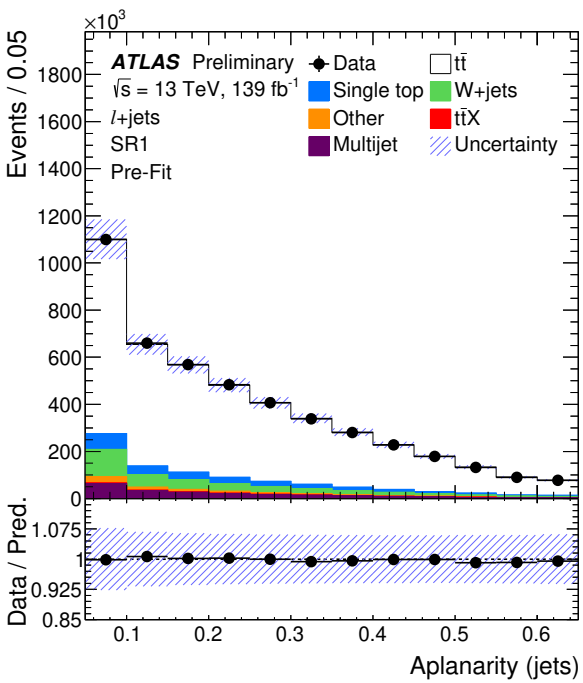
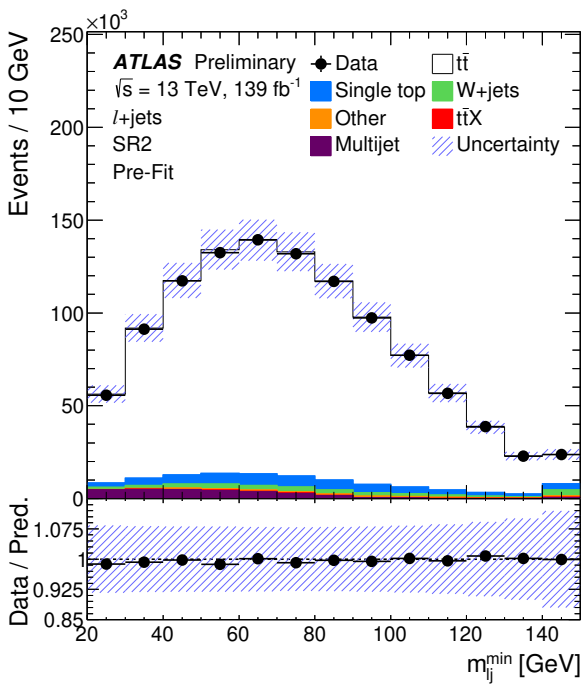
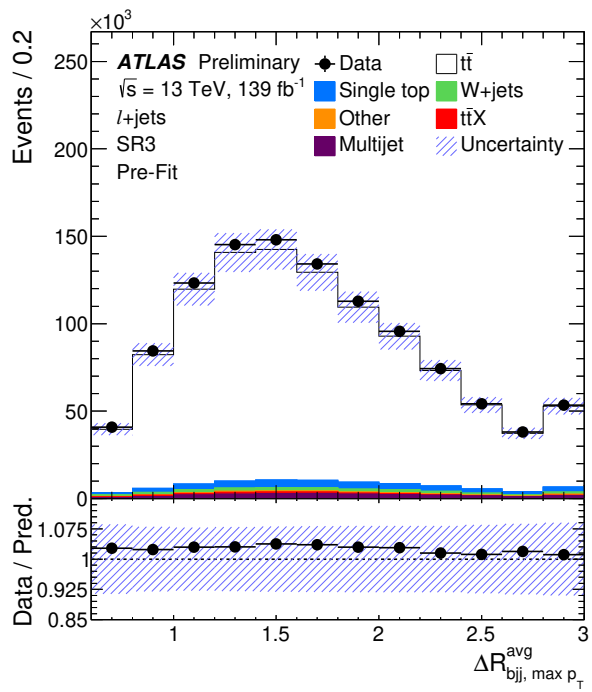
	SR1	SR2	SR3
$t\bar{t}$	3 630 000±180 000	990 000±90 000	980 000±80 000
W+jets	350 000±160 000	24 000±10 000	17 000± 9 000
Single top	255 000± 31 000	52 000± 7 000	37 000± 8 000
Other	80 000± 40 000	8 000± 4 000	5 800± 3 000
$t\bar{t}X$	15 600± 2 100	2 110± 290	7 200± 1 000
Multijet	210 000± 80 000	28 000±10 000	22 000± 8 000
Total prediction	4 540 000±290 000	1 110 000±90 000	1 070 000±80 000
Data	4 540 886	1 100 558	1 103 317



(c) SR1



(d) SR2



(e) SR3

Cross section extraction

- For the inclusive measurement, all $t\bar{t}$ distributions are scaled to the same inclusive cross section
- For the fiducial measurement, all distributions are scaled to the same **fiducial acceptance**

Generator Setup	A_{fid} [%]	$\frac{A_{\text{fid}}^{\text{alt}} - A_{\text{fid}}^{\text{nom}}}{A_{\text{fid}}^{\text{nom}}}$ [%]
Powheg+Pythia	13.50	0.00
Top NNLO Rew.	13.40	−0.75
$\mu_R^{\text{FSR}} \times 2$	13.58	1.29
$\mu_R^{\text{FSR}} \times 0.5$	13.02	−2.86
$\mu_R \times 2$	13.37	−0.25
$\mu_R \times 0.5$	13.45	0.38
$\mu_F \times 2$	13.38	−0.15
$\mu_F \times 0.5$	13.43	0.17
`Var3cUp`	13.46	0.41
`Var3cDown`	13.35	−0.38
Powheg+Herwig	13.44	0.31
`PDF4LHC15` Variations	13.38 (central)	0.47 (combined)
Powheg+Pythia total	13.50	$^{+1.5}_{-3.0}$

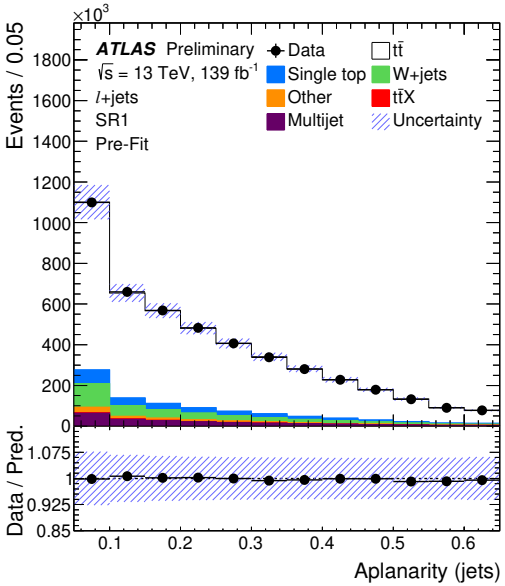
Table: Baseline-fiducial acceptances for different $t\bar{t}$ models when applying the particle level event selection.

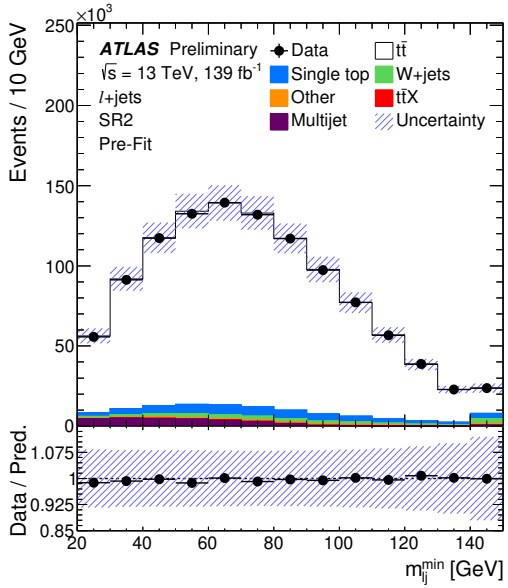
Pre/Post-fit (fiducial fit)

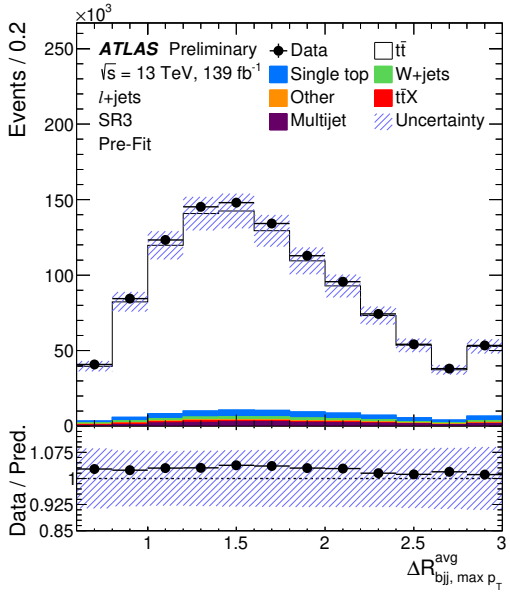
Fit variables

SR1 SR2 SR3

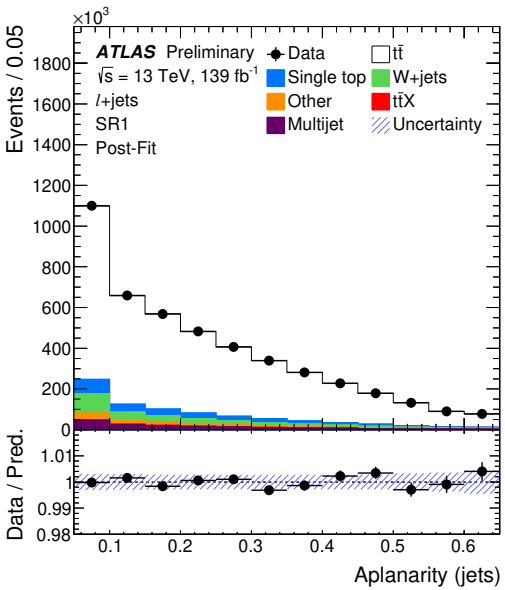
Pre-fit

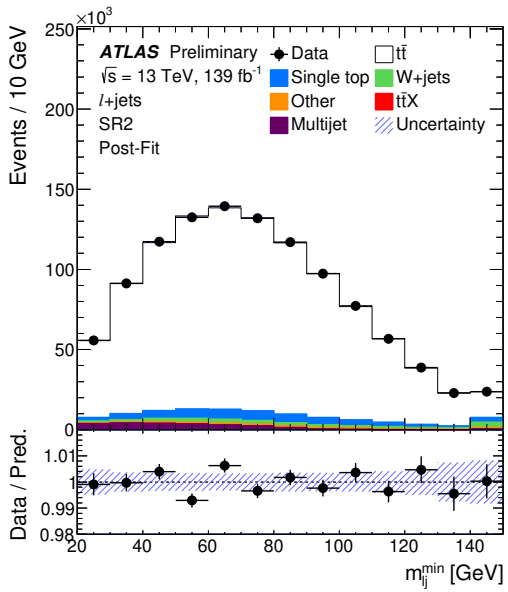


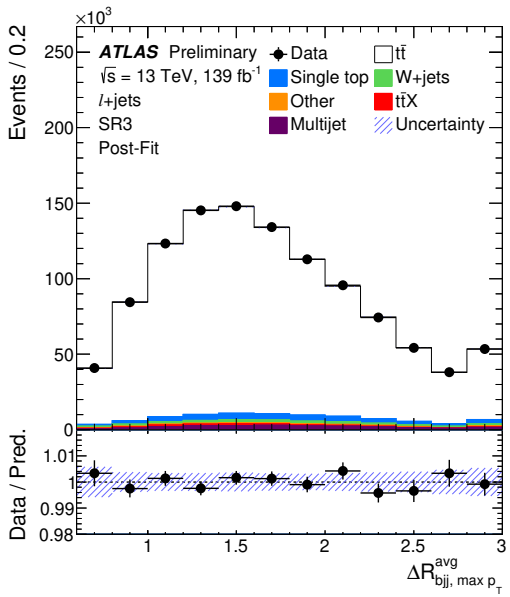




Post-fit







NOTE: Different ratio scales in pre/post-fit

Results I

Fiducial cross section:

$$\sigma_{\text{fid}} = 110.78 \pm 0.05\ (\text{stat.})\ ^{+4.59}_{-4.38}\ (\text{syst.})\ \text{pb} = 110.8^{+4.3}_{-4.2}\ (\text{tot.})\ \text{pb}$$

Inclusive cross section:

$$\sigma_{\text{inc}} = 830.4 \pm 0.4\ (\text{stat.})\ ^{+38.2}_{-37.0}\ (\text{syst.})\ \text{pb} = 830^{+38}_{-37}\ (\text{tot.})\ \text{pb}$$

Category	$\frac{\Delta\sigma_{\text{fid}}}{\sigma_{\text{fid}}}$ [%]		$\frac{\Delta\sigma_{\text{inc}}}{\sigma_{\text{inc}}}$ [%]	
Signal modelling				
$t\bar{t}$ shower/hadronisation	+2.1	−1.9	+2.7	−2.7
$t\bar{t}$ scale variations	+2.0	−1.8	+2.5	−2.6
Background modelling				
MC background modelling	+1.8	−1.7	+1.6	−1.8
Multijet background	+0.5	−0.6	+0.6	−0.7
Detector modelling				
Jet reconstruction	+2.4	−2.3	+2.5	−2.3
Luminosity	+1.8	−1.7	+1.8	−1.6
Flavour tagging	+1.4	−1.4	+1.5	−1.4
E_T^{miss} + pile-up	+0.3	−0.2	+0.5	−0.5
Muon reconstruction	+0.4	−0.6	+0.4	−0.5
Electron reconstruction	+0.4	−0.2	+0.2	−0.4
Simulation stat. uncertainty	+0.7	−0.6	+0.9	−0.9
Total systematic uncertainty	+4.1	−3.9	+4.6	−4.5
Data stat. uncertainty	+0.05	−0.05	+0.05	−0.05
Total uncertainty	+4.1	−3.9	+4.6	−4.5

Results II
Ranking

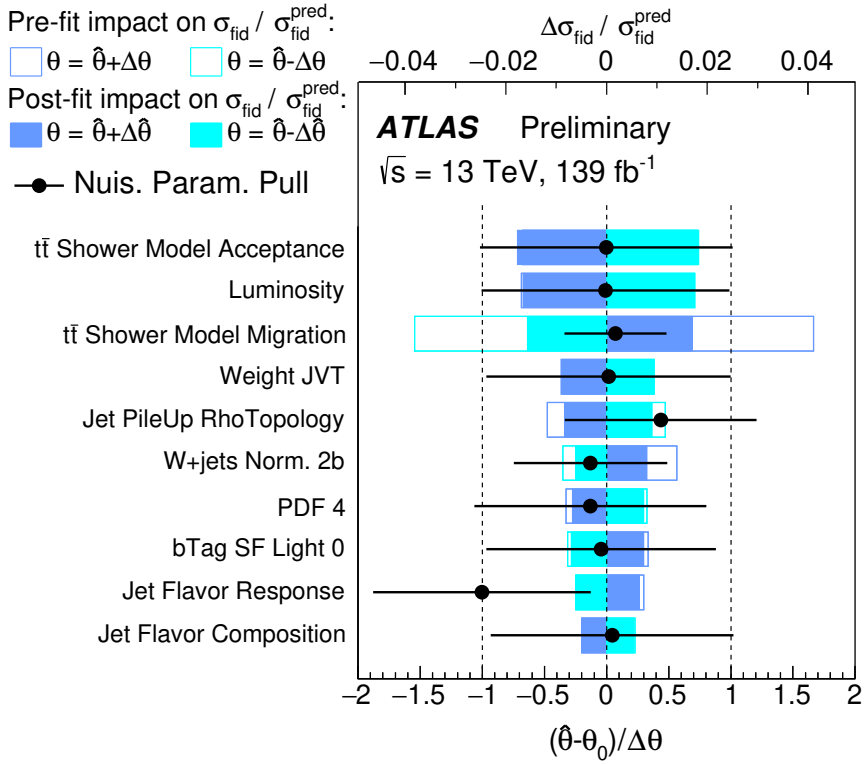


Figure: Fiducial ranking

- In the fit, uncertainty is dominated by parton shower uncertainties on the overall and relative normalisations

Conclusion

- Inclusive and fiducial $t\bar{t}$ production cross-section has been measured in ℓ+jets channel
- Measurement uses full Run 2 dataset corresponding to 139 fb^{-1}
- Profile likelihood fit has been used for fitting three SR simultaneously
- Constrained uncertainties significantly
- Used three well modelled variables to decrease impact of modelling uncertainty
- Measured cross-section [`https://cds.cern.ch/record/2690717`]

$$\sigma_{\text{fid}} = 110.78 \pm 0.05\ (\text{stat.})\ ^{+4.59}_{-4.38}\ (\text{syst.})\ \text{pb} = 110.8^{+4.3}_{-4.2}\ (\text{tot.})\ \text{pb}$$

$$\sigma_{\text{inc}} = 830.4 \pm 0.4\ (\text{stat.})\ ^{+38.2}_{-37.0}\ (\text{syst.})\ \text{pb} = 830^{+38}_{-37}\ (\text{tot.})\ \text{pb}$$

- Corresponding to relative uncertainties of 4.1% (fid) and 4.6% (inc)
- Limited by $t\bar{t}$ (shower/hadronisation) modelling

Backup