Top-quark pole mass from tt+j events (ATLAS side)

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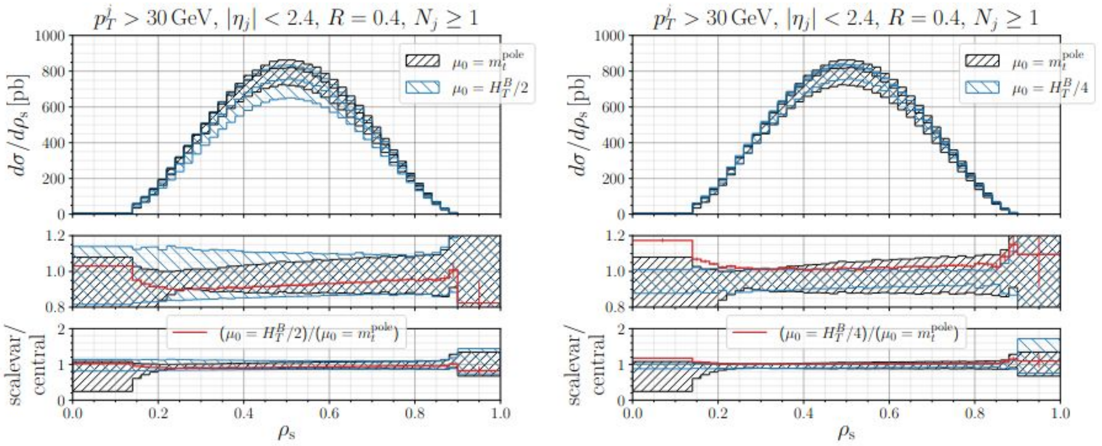
Introduction - the R observable

Advantages of the observable used:

- high sensitivity to top-quark mass
  - most sensitive region is for ϱ_s>0.7
- normalised -> many uncs simplify in ratio
- can be defined similarly in the two fixed-order NLO QCD calculations (being *effectively two different observables*, with different properties):
  - 2->3 process of pp->ttbar+1jet, where top-quarks are "on-shell". Used since the 7 TeV analysis.
  - 2->7 process of pp->*vvllbbj,* where top-quarks are decayed, off-shell effects included. Only di-leptonic final state of ttbar available. First time this is used in a measurement.



https://arxiv.org/pdf/2202.07975

$$\mathcal{R}(m_t^{\mathrm{pole}}, \rho_s) = \frac{1}{\sigma_{t\bar{t}+1\text{-jet}}} \cdot \frac{d\sigma_{t\bar{t}+1\text{-jet}}}{d\rho_s},$$

$$\rho_s = \frac{2m_0}{\sqrt{s_{t\bar{t}+1\text{-jet}}}},$$

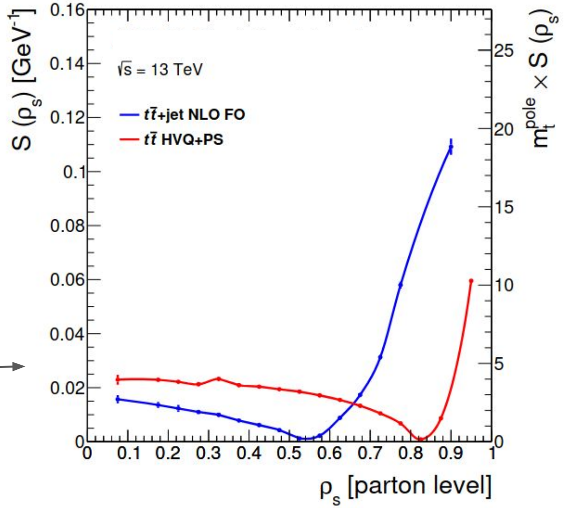
m_0 fixed to 170 GeV

Normalised differential tt+1j xsec

The single 1D distribution which showed best potential to measured mTop is the normalized differential cross-section of tt+1j events

$$\mathcal{R}(m_t^{\text{pole}}, \rho_s) = \frac{1}{\sigma_{t\bar{t}+1\text{-jet}}} \cdot \frac{d\sigma_{t\bar{t}+1\text{-jet}}}{d\rho_s} \qquad \rho_s = \frac{2m_0}{\sqrt{s_{t\bar{t}+1\text{-jet}}}},$$

- extra jet brings increased sensitivity to mTop, wrt a similarly defined ttbar-only observable
- normalization brings reduction of theo uncs



New ATLAS results either follows experimental strategy used for 8TeV publication [1] (with improvements) or follows CMS-style unfolding with profile-likelihood fit:

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

Submitted to: JHEP

Accepted!

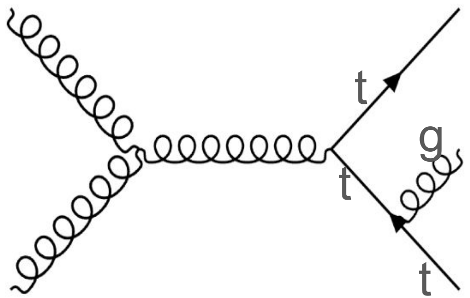
CERN-EP-2025-135
4th July 2025

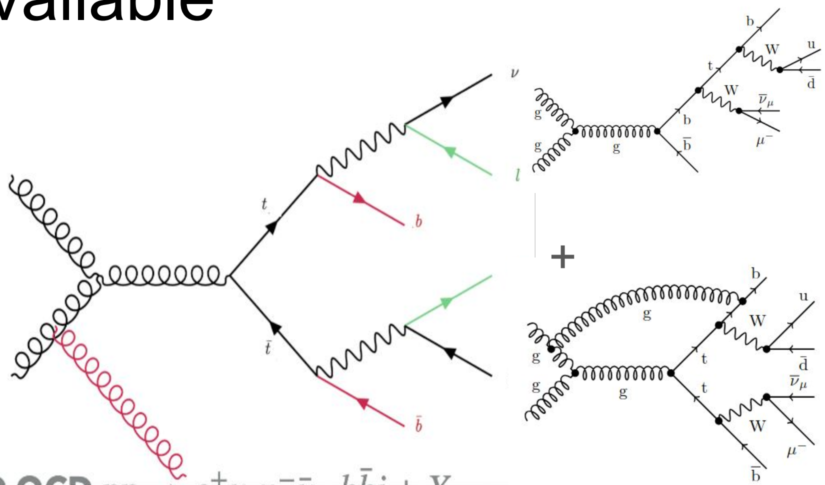
Measurement of the top-quark pole mass in dileptonic $t\bar{t}$ + 1-jet events at $\sqrt{s}$ = 13 TeV with the ATLAS experiment

The ATLAS Collaboration

Introduction - theory predictions available

tt+1jet NLO QCD calculations employed





- **Fixed-Order NLO QCD** $t\bar{t}$ + 1-jet
  - provided by "ttbarj" in Powheg-Box-v2 [1110.5251]
  - 2->3 process, top-quarks are "stable"
  - scale choices and other parameters studied (for 13 TeV) in [2202.07975]

$$\frac{E_T}{2}: E_T = \sum_{i=1}^{3} \sqrt{p_{T,i}^2 + m_i^2}$$

- **FO NLO QCD** $pp \to e^+\nu_e\mu^-\bar{\nu}_\mu b\bar{b}j + X$
  - provided by authors of [1509.09242]
  - scale choices suggested

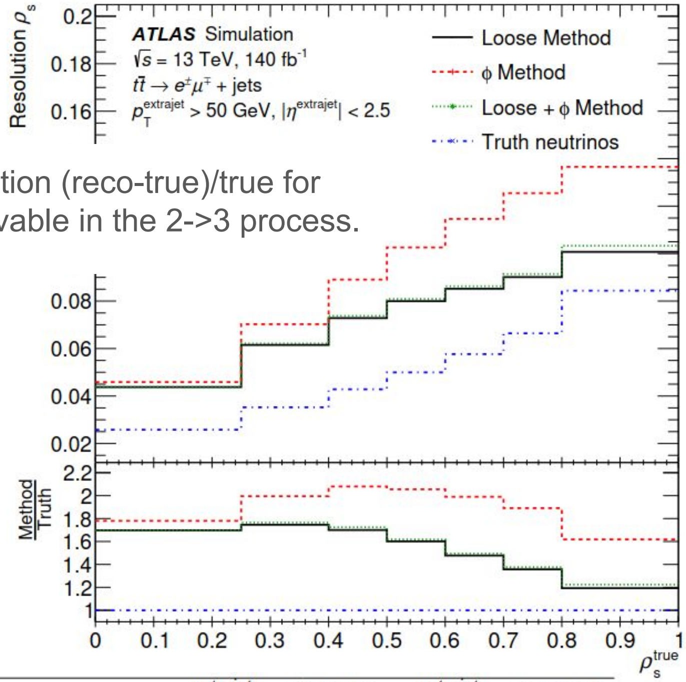
$$\text{Scale } \frac{H_T}{2}: \quad H_T = p_{T,e^+} + p_{T,\mu^-} + p_{T,b_1} + p_{T,b_2} + p_{T,j} + p_T^{miss}$$

  - 2->7 process, diagrams with no tops, single-top, off-shell top-quarks included. Full off-shell and top-quark width effects also included.

Event selection

Select dilepton+jets final states with opposite charge leptons:

- single lepton trigger, emu opposite charge
- significant MET (>30GeV)
- ==2 b-jets >30GeV, lead light jet pT>50/60GeV
- m(lb) <200 GeV region only
- Combination of two tt-system reco methods, gives 98% efficiency, 95% ttbar purity:
    - Loose method:
        - not reconstructing individual tops
        - unphysical solutions for ~25% events phi-weighting method ():
    - ϕ method:
        - used for events failing loose method reco
        - throw random values to neutrino phi and minimize reconstructed top/antitop mass differences



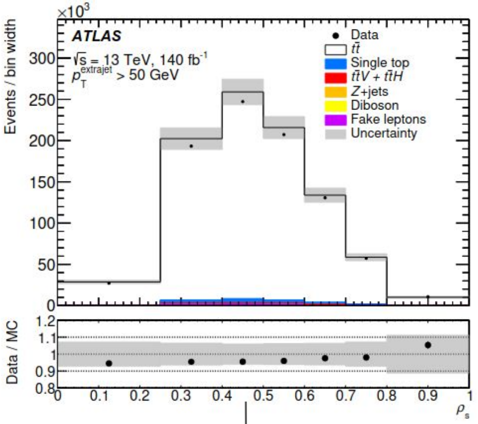
resolution (reco-true)/true for observable in the 2->3 process.

	$p_T^{extrajet}$ > 50 GeV	$p_T^{extrajet}$ > 60 GeV
$t\bar{t}$	103000 ± 7000	86000 ± 6000
Single top	1840 ± 100	1470 ± 80
Diboson	53 ± 27	48 ± 23
Z+jets	55 ± 28	48 ± 24
$t\bar{t}V + t\bar{t}H$	590 ± 80	530 ± 70
Fake leptons	750 ± 380	640 ± 320
Total MC	106000 ± 7000	89000 ± 6000
Data	102215	85366
Data/MC	0.96	0.96

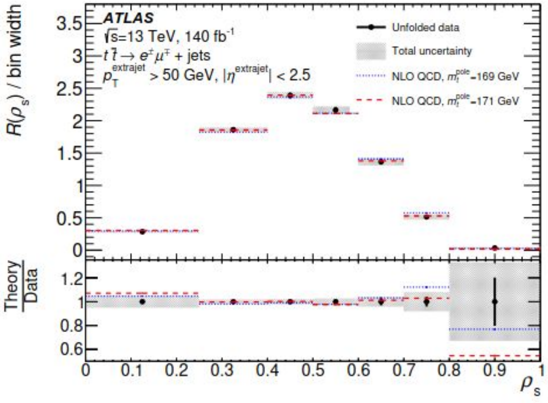
Unfolding

Reco-to-truth correction using Iterative Bayesian Unfolding (IBU)

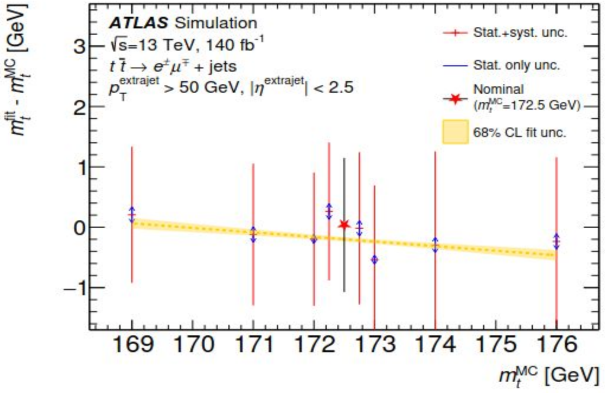
- updated approach for systematics
  - now implemented in covariance matrix
- IBU internal parameter (number of iterations) set to lowest value which minimize bias on the MC used to define the correction
  - dependence on the assumed mTop value in the MC minimized
  - residual mMC dependence included in systematic covariance matrix



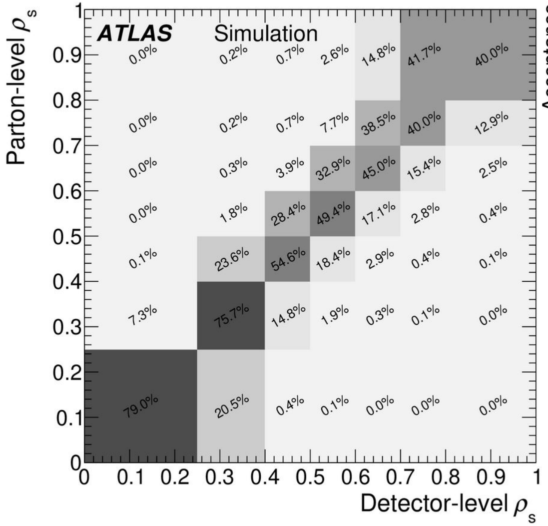
IBU

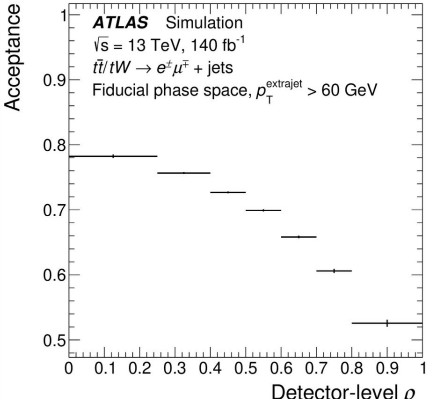


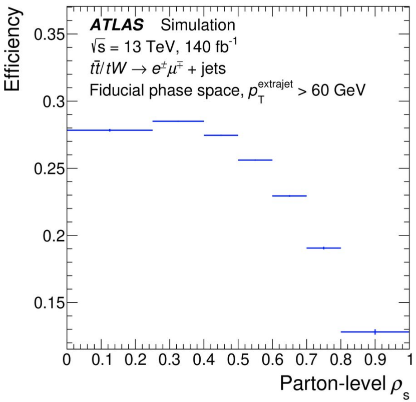
Observed deviation from linearity tests is covered by residual mMC syst uncertainty

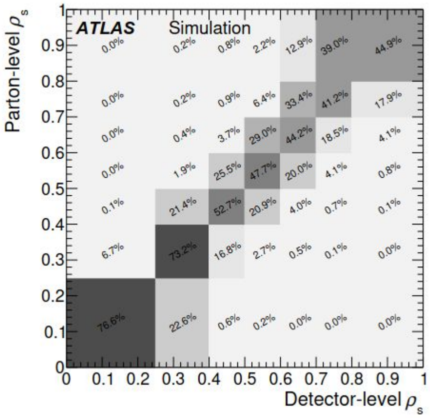


Mpole from ttj: Unfolding factors

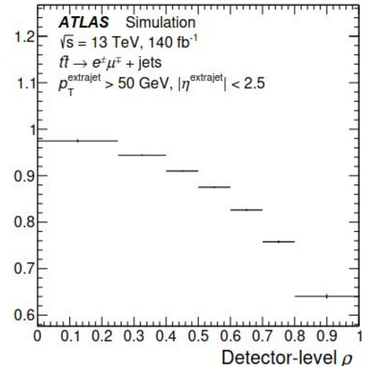


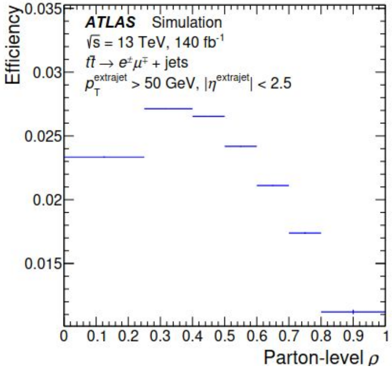




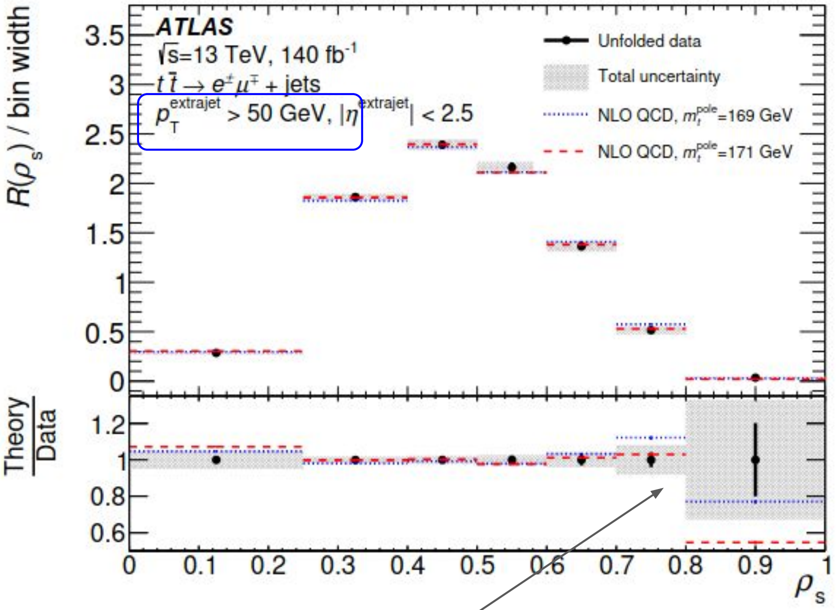


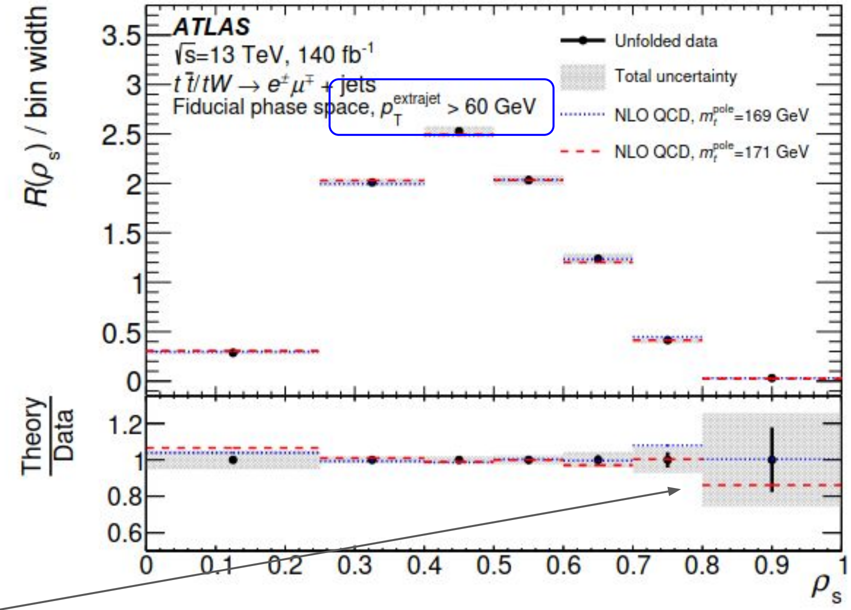
(a)





2->3 vs 2->7 unfolded results



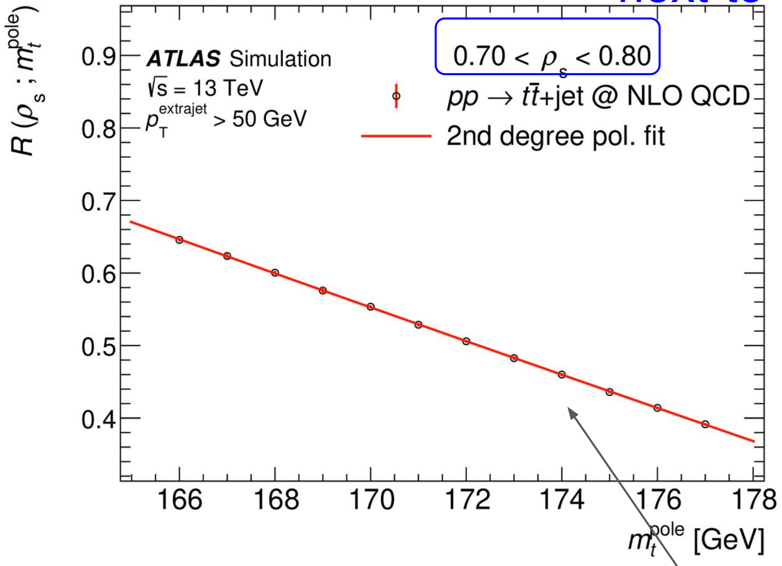


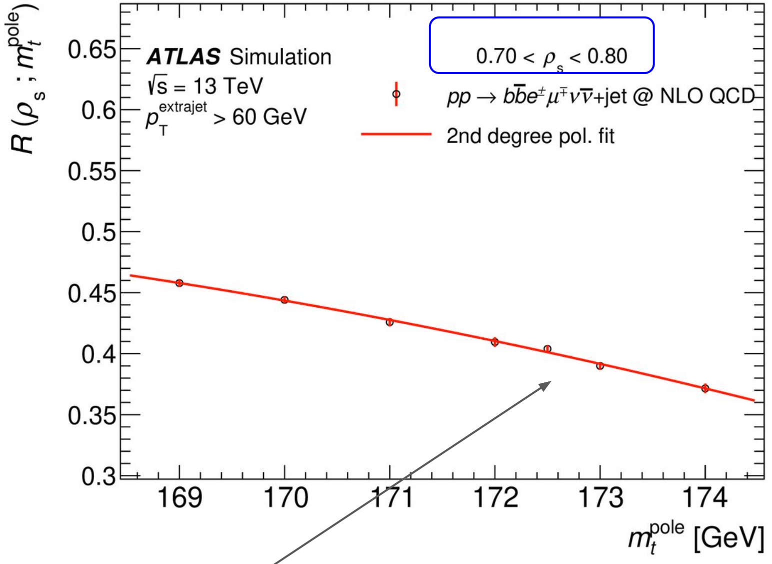
Slightly different pT cut choice, but in general two balancing effects:

- 2->3 has larger experimental uncertainties (due to “more” unfolding/correction)

2->3 vs 2->7 theoretical templates

next-to-most sensitive bin





Slightly different pT cut choice, but in general two balancing effects:

- 2->3 has larger experimental uncertainties (due to “more” unfolding/correction)
- 2->7 theo has reduced sensitivity to mTpole (feature of theo calculation)

Which effect is the most important?

Top pole mass extraction

For 2->3 measurement (PDF4LHC21)

$$m_t^{\text{pole}} = 170.73 \pm 0.33\ (\text{stat.}) \pm 1.36\ (\text{syst.})\ ^{+0.34}_{-0.28}\ (\text{scale}) \pm 0.24\ (\text{PDF} \oplus \alpha_s)\ \text{GeV}.$$

For 2->7 measurement (PDF4LHC21)

$$m_t^{\text{pole}} = 171.69 \pm 0.41\ (\text{stat.}) \pm 1.68 (\text{syst.})\ ^{+0.66}_{-1.34}\ (\text{scale})\ ^{+0.49}_{-0.46}\ (\text{PDF} \oplus \alpha_s)\ \text{GeV}.$$

Theoretical uncertainties estimated fitting different theoretical truth distributions with nominal template (diagonal covariance matrix)

- scale uncertainties for 2->7 result are larger than 2->3 approach
  - kind of expected as more finale state objects and cuts
  - also reduced R(mTop) sensitivity enhances this effect

Different PDFs for 2->3 result

Compared result obtained with different PDFs

$$m_t^{\text{pole}}(\text{CT18 [95]}) = 170.94 \pm 0.33\,(\text{stat.}) \pm 1.36\,(\text{syst.})\,^{+0.37}_{-0.28}\,(\text{scale}) \pm 0.28\,(\text{PDF} \oplus \alpha_s)\ \text{GeV},$$

$$m_t^{\text{pole}}(\text{MSHT20 [97]}) = 171.03 \pm 0.33\,(\text{stat.}) \pm 1.36\,(\text{syst.})\,^{+0.33}_{-0.31}\,(\text{scale})\,^{+0.26}_{-0.13}\,(\text{PDF} \oplus \alpha_s)\ \text{GeV},$$

$$m_t^{\text{pole}}(\text{NNPDF30 [43]}) = 170.70 \pm 0.33\,(\text{stat.}) \pm 1.36\,(\text{syst.})\,^{+0.34}_{-0.28}\,(\text{scale}) \pm 0.22\,(\text{PDF} \oplus \alpha_s)\ \text{GeV},$$

$$m_t^{\text{pole}}(\text{ABMP16 [96]}) = 172.76 \pm 0.33\,(\text{stat.}) \pm 1.36\,(\text{syst.})\,^{+0.33}_{-0.28}\,(\text{scale}) \pm 0.24\,(\text{PDF} \oplus \alpha_s)\ \text{GeV}.$$

known fact that the ABMP PDF fits have different gluon PDF

Nominal result given with PDF4LHC21 values

Stability of result against extrajet pTcut, year also tested and confirmed.

Cross-checked validity of tt+singletop MC stack against bb4l in 2->7 approach

Uncertainty breakdown

ttbar modeling, jet energy and b-tagging are the largest systematic uncertainties:

- "new" (wrt 8TeV) top radiation recoil and top mass shape systematics

Theoretical uncertainties contribute to around 0.4/0.5 GeV

Uncertainty source	Δm_t^{pole} [GeV]	MC stat. unc. [GeV]
Data statistics	0.33	-
Detector unc.		
b-tagging and mistag	0.44	0.06
Jets	0.65	0.06
Leptons	0.25	0.06
Others	0.18	0.06
Modeling unc.		
MC statistical uncertainty	0.08	-
Backgrounds normalization	0.02	-
Single-top modeling	0.03	0.06
m_t^{MC} dependence	0.10	0.09
PS Recoil model	0.68	0.06
Parton shower	0.43	0.14
Underlying event	0.39	0.12
Color reconnection	0.13	0.08
ME+PS matching: p_T^{hard}	0.09	0.06
ME+PS matching: h_{damp}	0.26	0.06
ME+PS matching: line shape	0.38	0.12
3D NNLO reweight	0.21	0.06
PDF	0.26	0.06
Initial-state radiation	0.24	0.06
Final-state radiation	0.04	0.16
Factorization scales	0.09	0.06
Renormalization scales	0.03	0.06
Theory unc.		
Scale variations	+0.34 -0.28	+0.05 -0.06
PDF $\oplus$ α_S	0.24	+0.06 -0.06
Total	+1.47 -1.44	-

Effects on the mpole extraction common to analyses

- threshold corrections
- top-quark width

Threshold effects in tt+1jet - auxmat

No calculation of Coulomb correction exists for tt+1jet 2->3 calculation:

- under discussion by theorists
- enhancement of xsec **up to 20%** in the 340<Mttbar/Gev<355 region, **for ttbar**
- presence of **extrajet dilute** the effect

Impact on measurement evaluated by enhancing ttbar threshold region contribution by 10 & 20%.

Impact on mTop extraction ~200MeV.

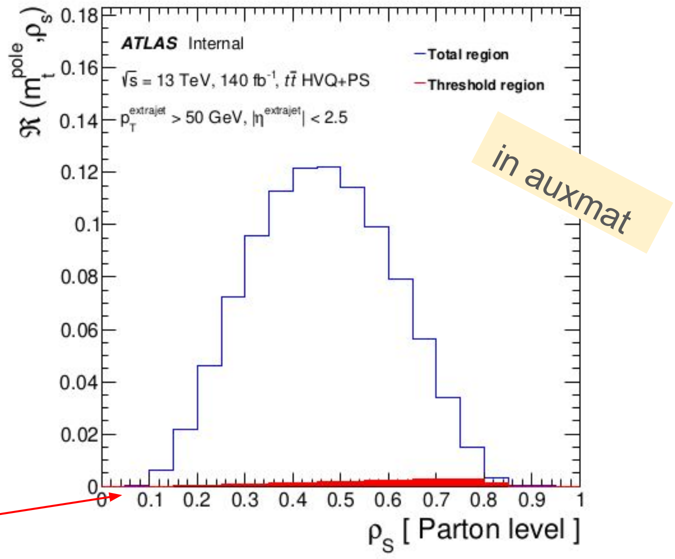
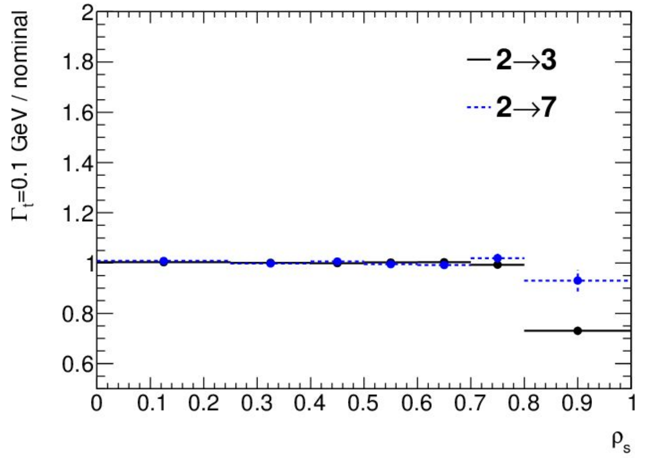


Figure 28: The normalized differential cross section $\mathcal{R}(m_t^{\text{pole}}, \rho_s)$ from the nominal MC sample at the parton level. All events passing the $p_T^{\text{extrajet}} > 50$ GeV selection are shown in blue while the contribution of events with parton-level top quark pair invariant mass satisfying 340 GeV $< M_{t\bar{t}} <$ 355 GeV is shown in red.

No dedicated systematic uncertainty assigned, as no consensus on the theory side on Coulomb corrections in tt+1jet (when theory will be available, re-fit of data possible with HEPdata info). Added plot as auxiliary material

Top width corrections (from MC) to FO



Corrected theoretical predictions by factor estimated from comparison of MC sample with 0.1GeV top width [as a proxy for ~0 width/stable top].

Impact on individual bins and to global fit (stat+syst test)

```
 MASS BIN BY BIN!!
0  378.5 +- 3.8132
1  384.2 +- 1.9015
2  383.55 +- 3.8857
3  nan +- nan
4  384.89 +- 3.2125
5  384.68 +- 1.6891
6  380.27 +- 2.6767
FIT RESULT: 383.68 +- 1.4005  GeV
fit details (chi2Min, 4.3078
```

<u>this was for the public ATLAS 13TeV binning.</u>
In semilep only one bin (last) is sensitive.
Significant impact expected!
(can provide a MC-based correction, but more a topic for ttj theorists: need width corrections)

→

```
 MASS BIN BY BIN!!
0  378.5 +- 3.8143
1  384.2 +- 1.9014
2  383.55 +- 3.8859
3  nan +- nan
4  384.89 +- 3.2123
5  384.9 +- 1.6732
6  382.32 +- 2.3281
FIT RESULT: 383.87 +- 1.2951  Ge
fit details (chi2Min, 2.2199 rDe
```

2GeV in last bin and 200MeV in all-bins result. Chi2@min improved