Search for resonances decaying to a top quark pair at $\sqrt{s}$ = 13 TeV with the ATLAS detector

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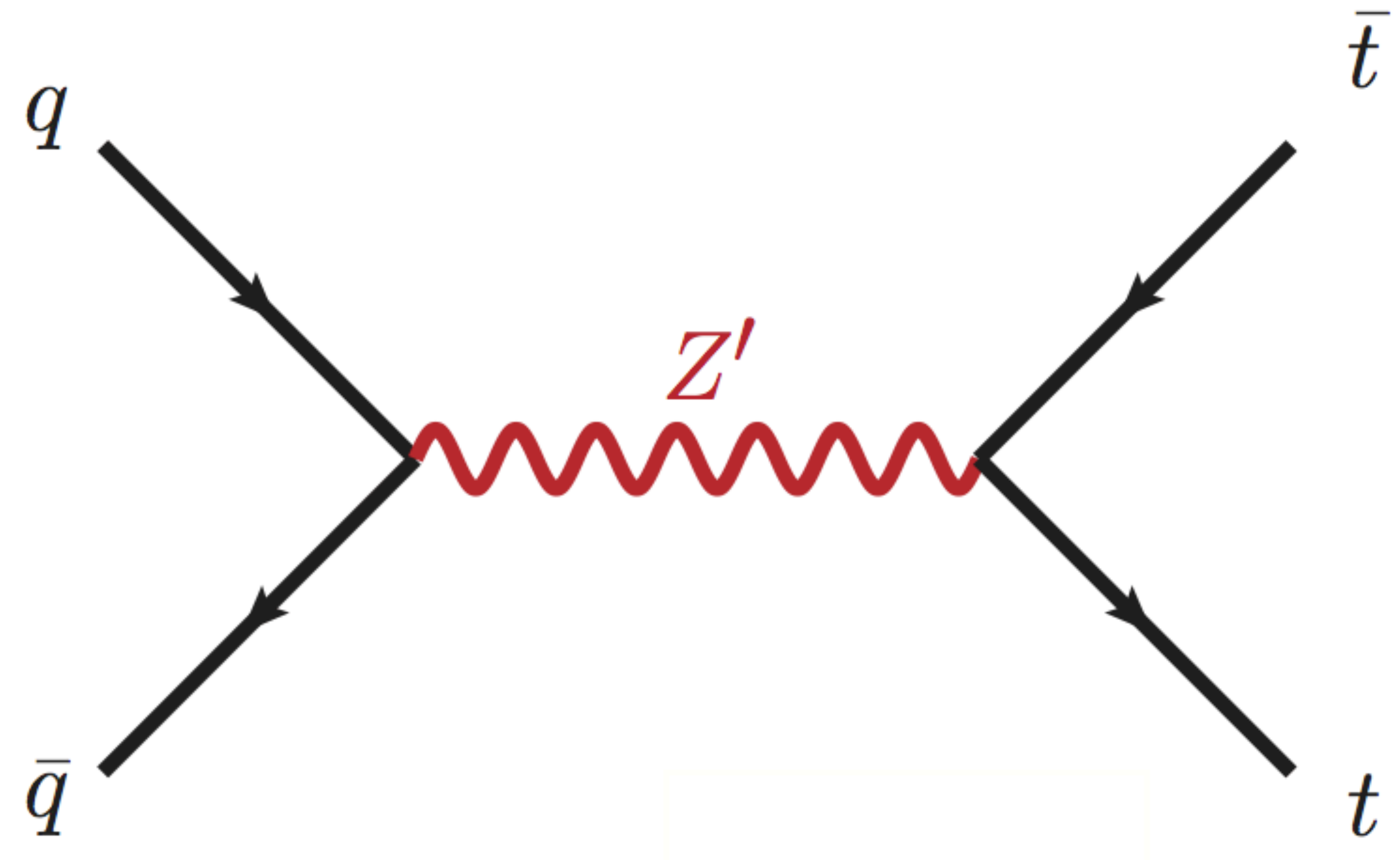
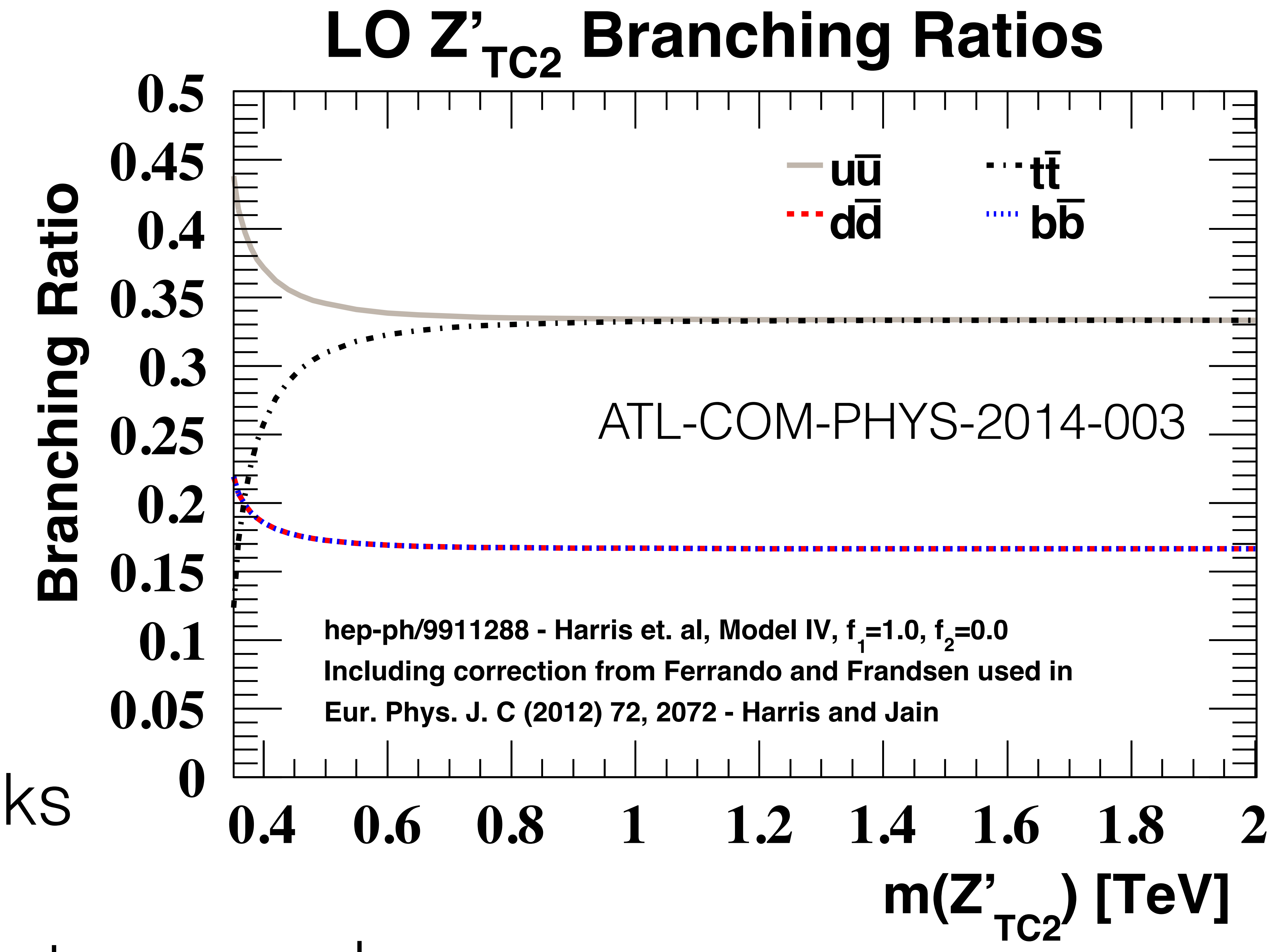
Outline

- Theoretical motivation
- Two search analysis:
    - All-jets final states (arXiv:1902.10077, accepted by PRD)
    - Lepton-plus-jets final states (Eur. Phys. J. C 78 (2018) 565)

4 types of Z'

Top-assisted technicolor





- Only couples to first and third generation quarks
- Couples stronger to up-type quarks than down-type quarks
- Cross-section increases with width
- Harris, R.M. & Jain, S. Eur. Phys. J. C (2012) 72: 2072.

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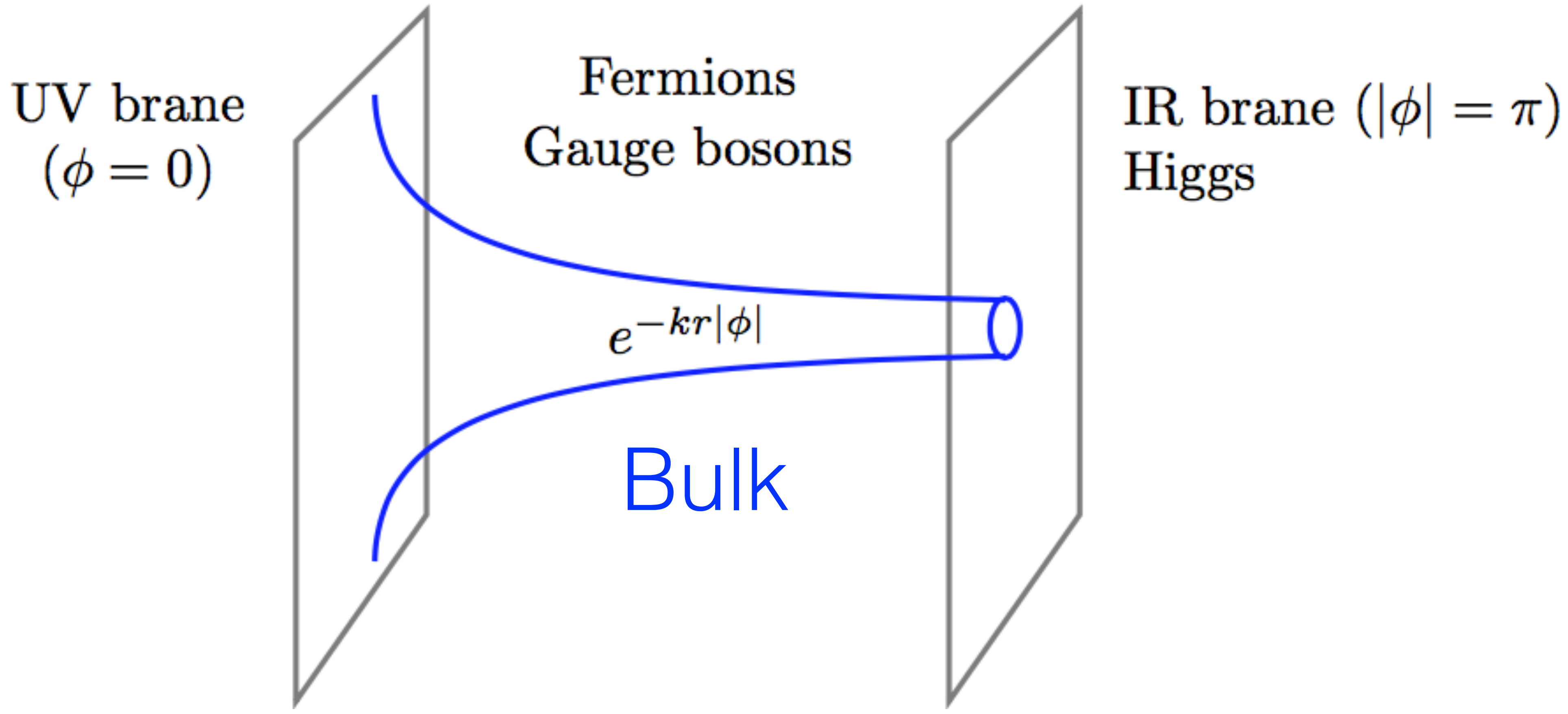
Kaluza Klein boson

ATLAS EXPERIMENT

Kaluza Klein graviton

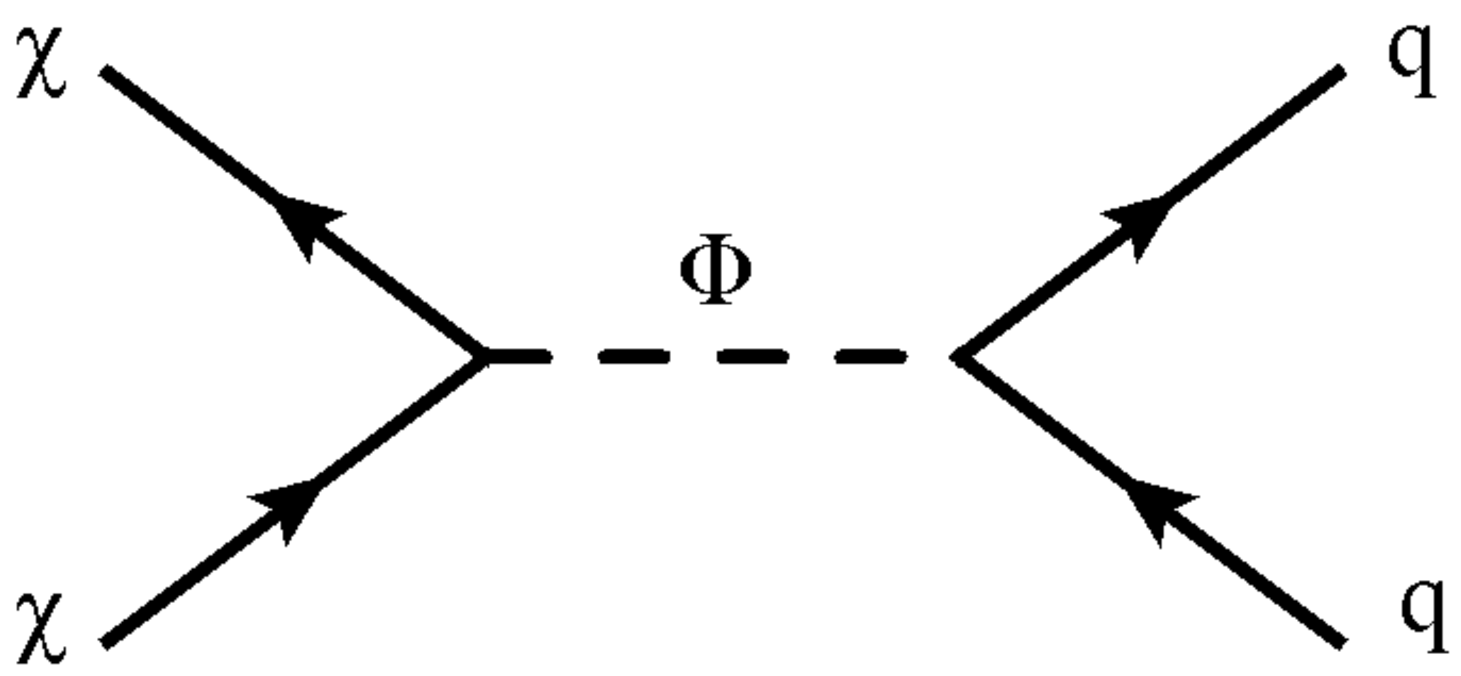
Kaluza Klein gluon



raoulma.github.io/index.html

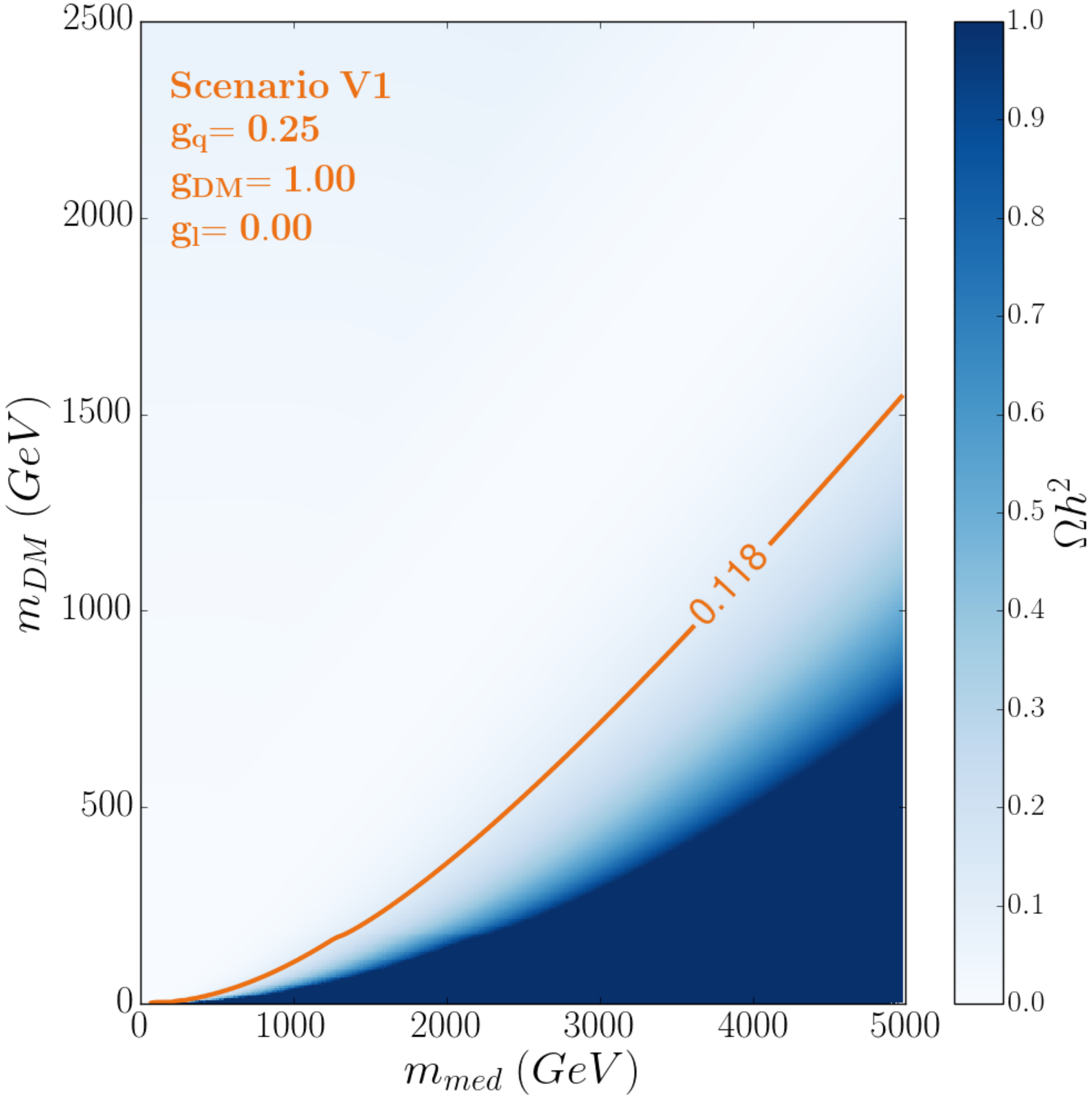
- Randall-Sundrum: warped extra-dimension
- Alleviates hierarchy problem of Higgs mass
- Right handed top quark closer to IR brane to gain large Yukawa coupling with Higgs

Dark matter mediators



- Simplified models allows dark matter to annihilate through a mediator (vector or axial for results shown today) to ordinary matter

- Using measured DM relic density, we can search for the DM mediator through its couplings to quarks to constrain other free parameters in the model



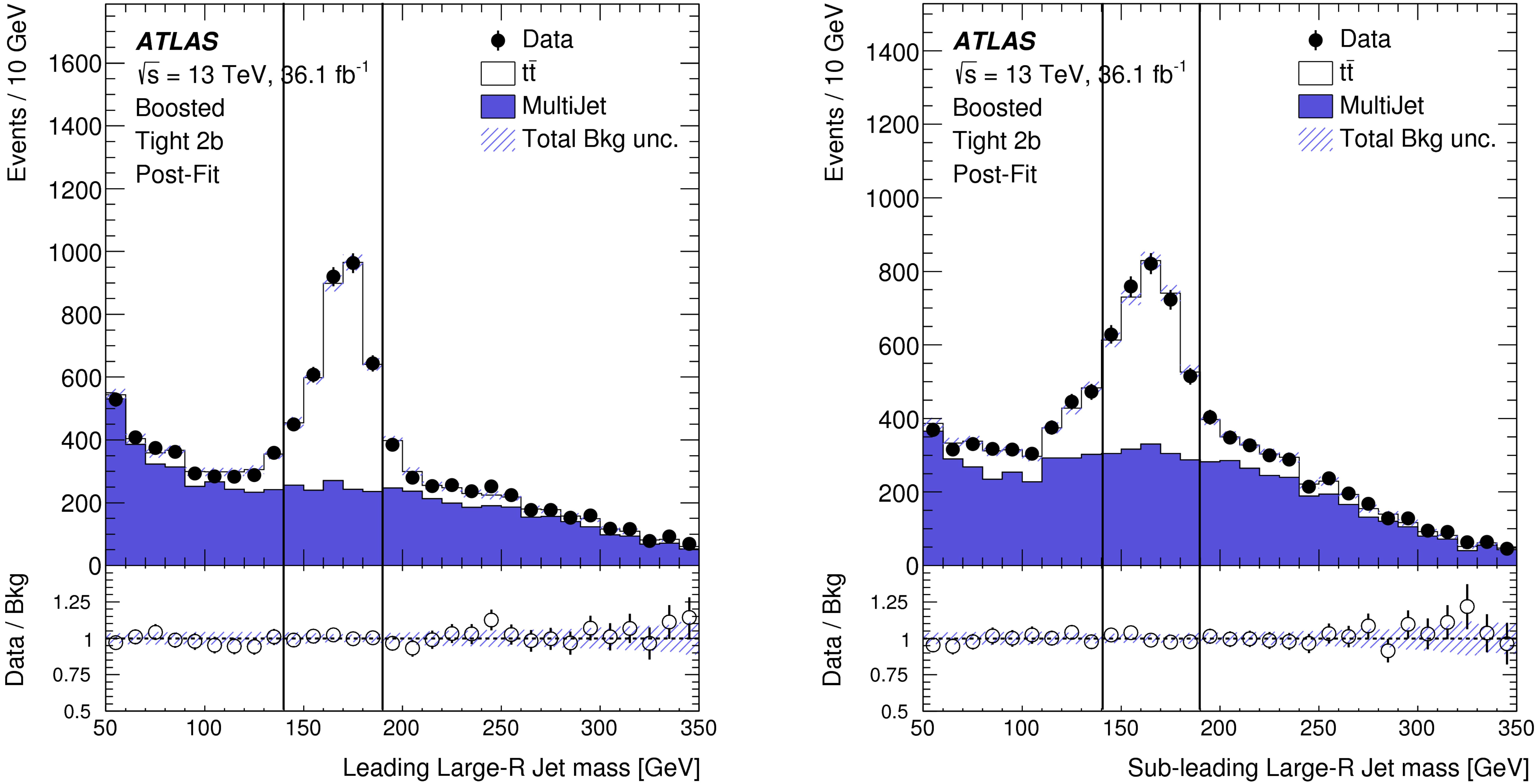
arXiv:1703.05703 [hep-ex]

All-jets final states

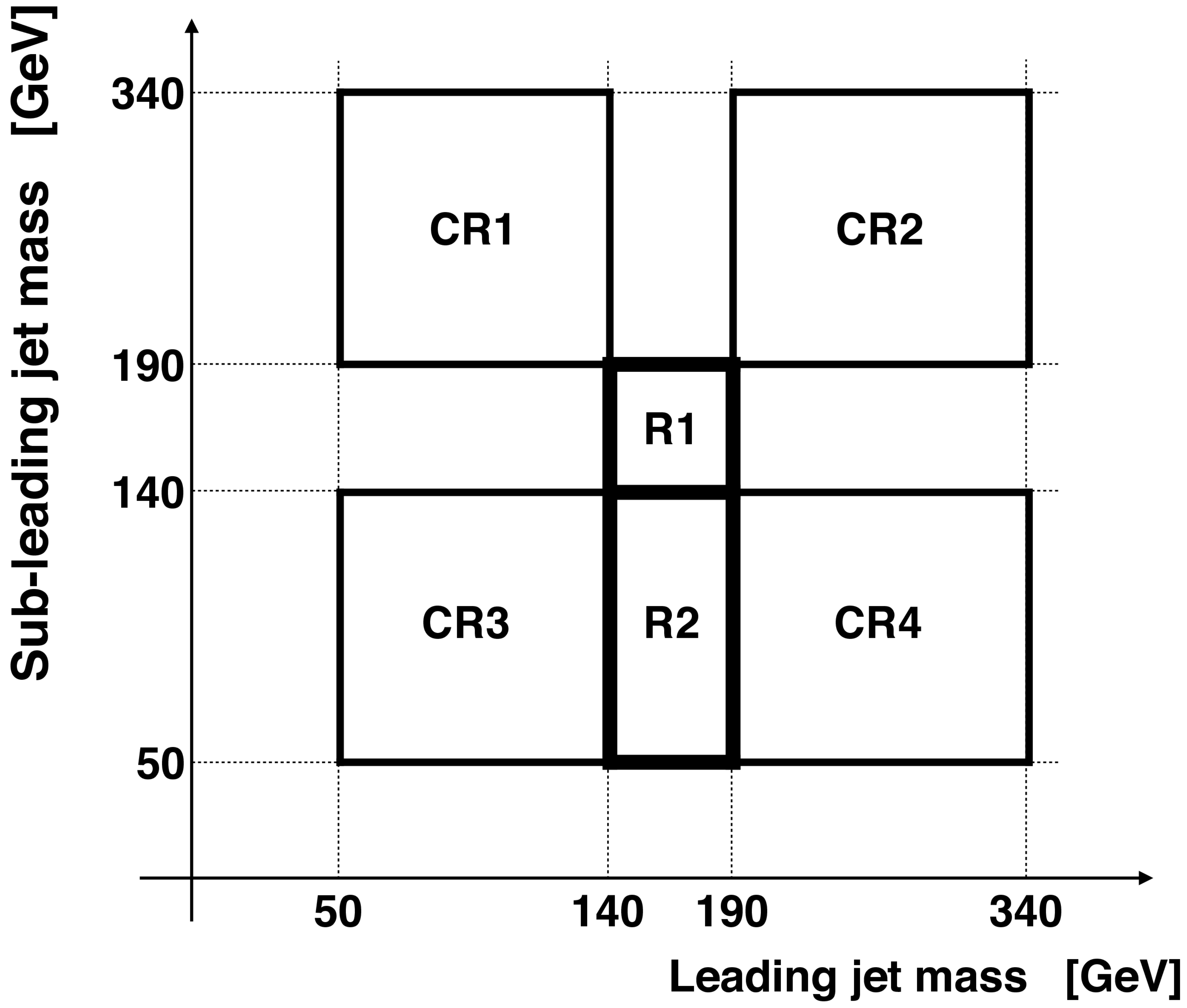
Event selection

- Two **independent** selection optimized for different Z' mass
- Resolved:
  - ≥ 6 calo jets. At least 5 p_T > 75 GeV and two $|\eta|$ < 1.6 plus loosely b-tagged
  - Assign these jets into 2 buckets based on top mass criterion and each bucket has exactly 1 loose b-tagged jet
  - Categorize events based on W mass criterion and tight b-tagging
- Boosted:
  - 1 p_T > 500 GeV & 1 p_T > 400 GeV large-radius jets separated by azimuthal angle > 1.6. Each jet contains ≥ 1 b-tagged track jet
  - Categorize events based on large-radius jet mass, subjettiness τ_{32} of the 2 p_T leading large-radius jet and tight b-tagging

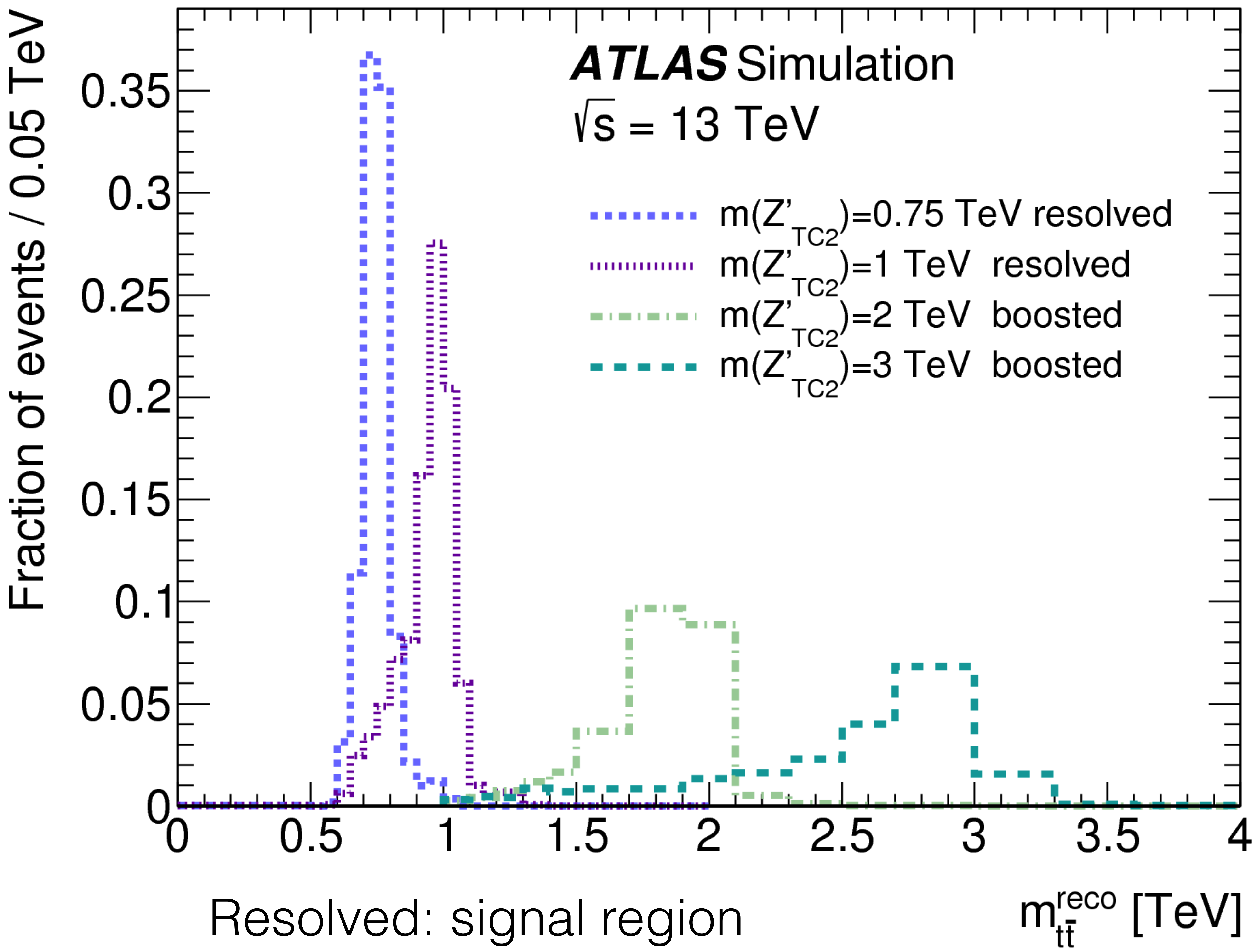
Lower p_T, lower mass



Boosted selection - mass categorization

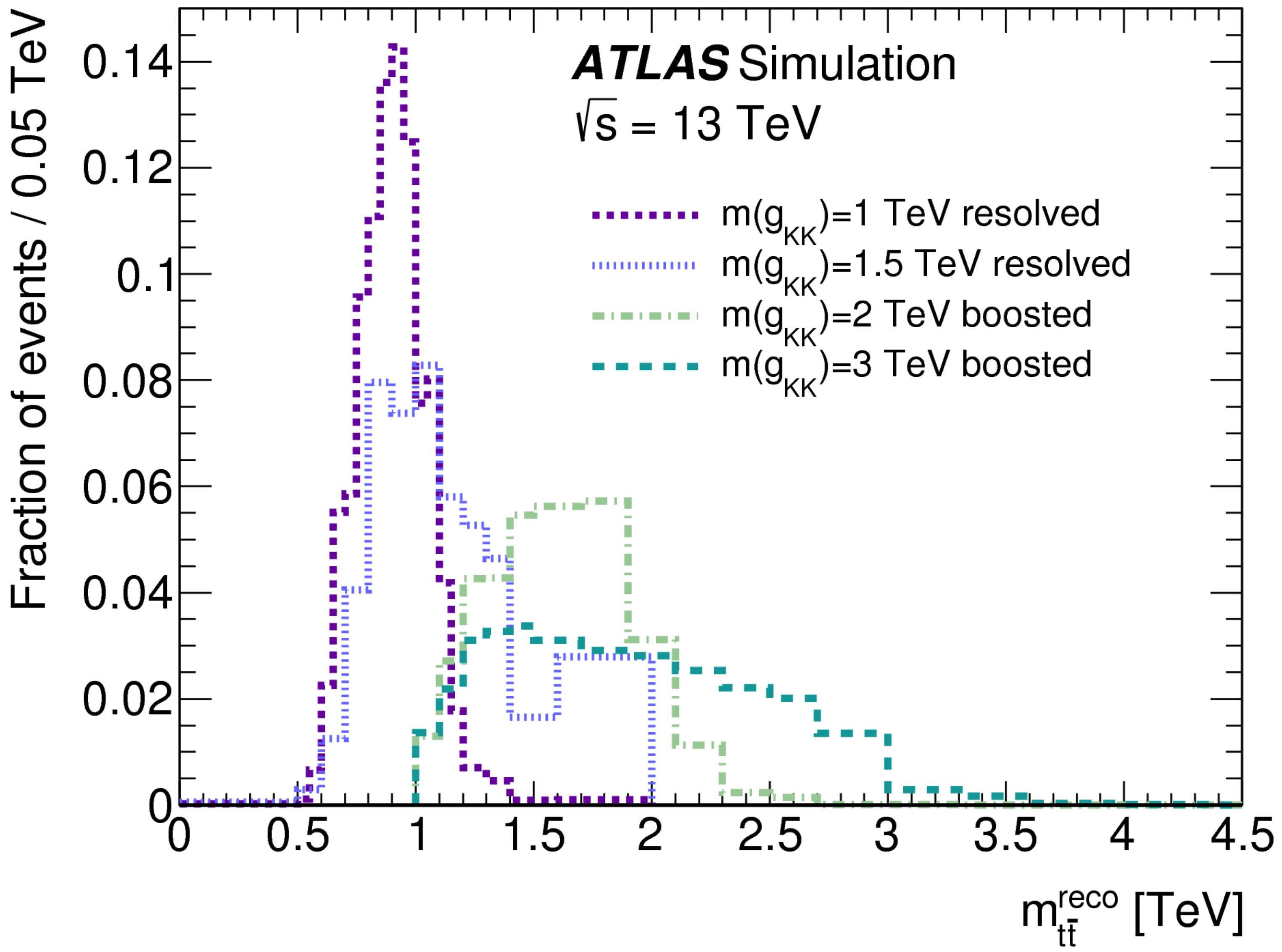


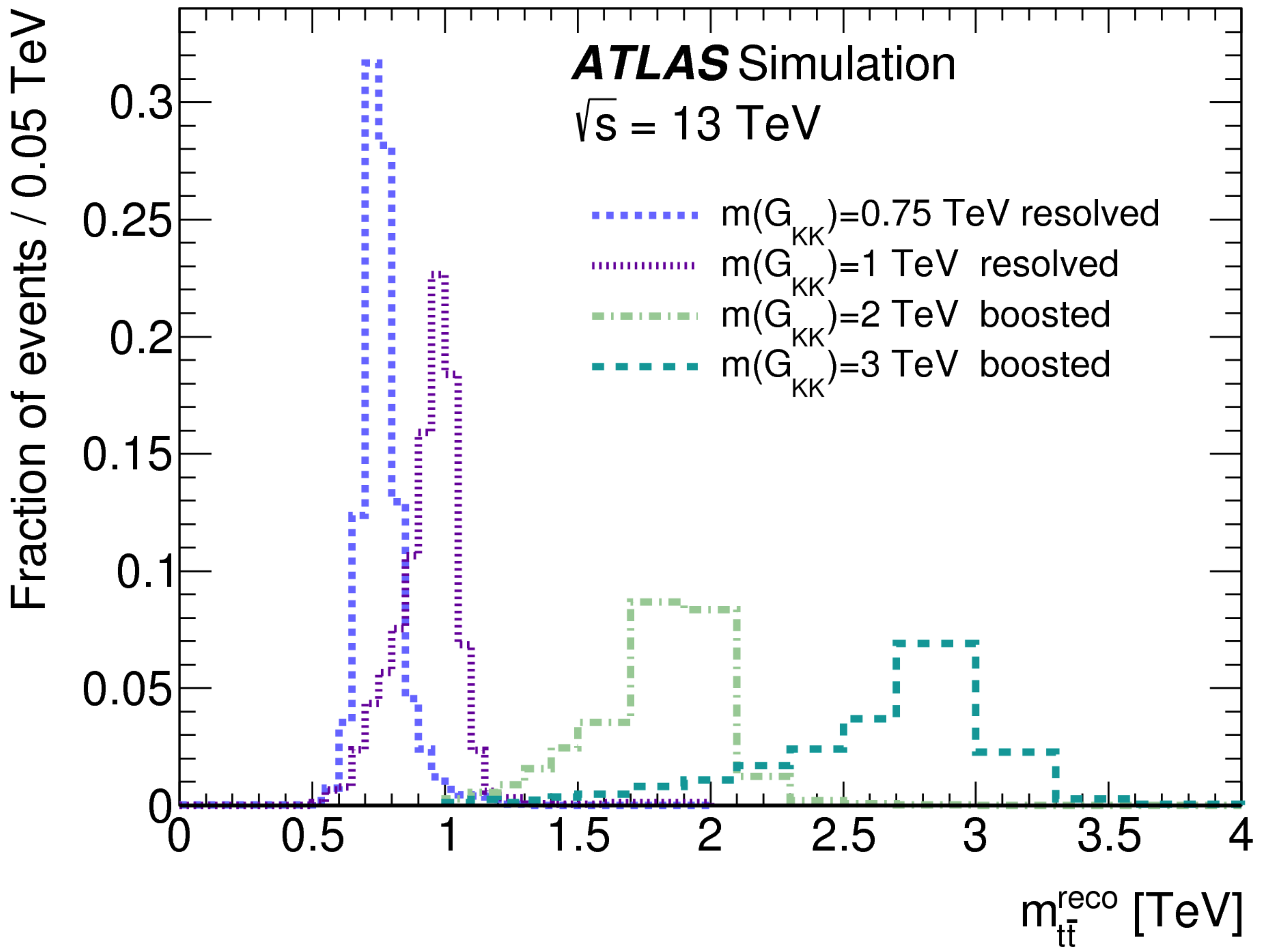
Signal $m_{t\bar{t}}$



Resolved: signal region

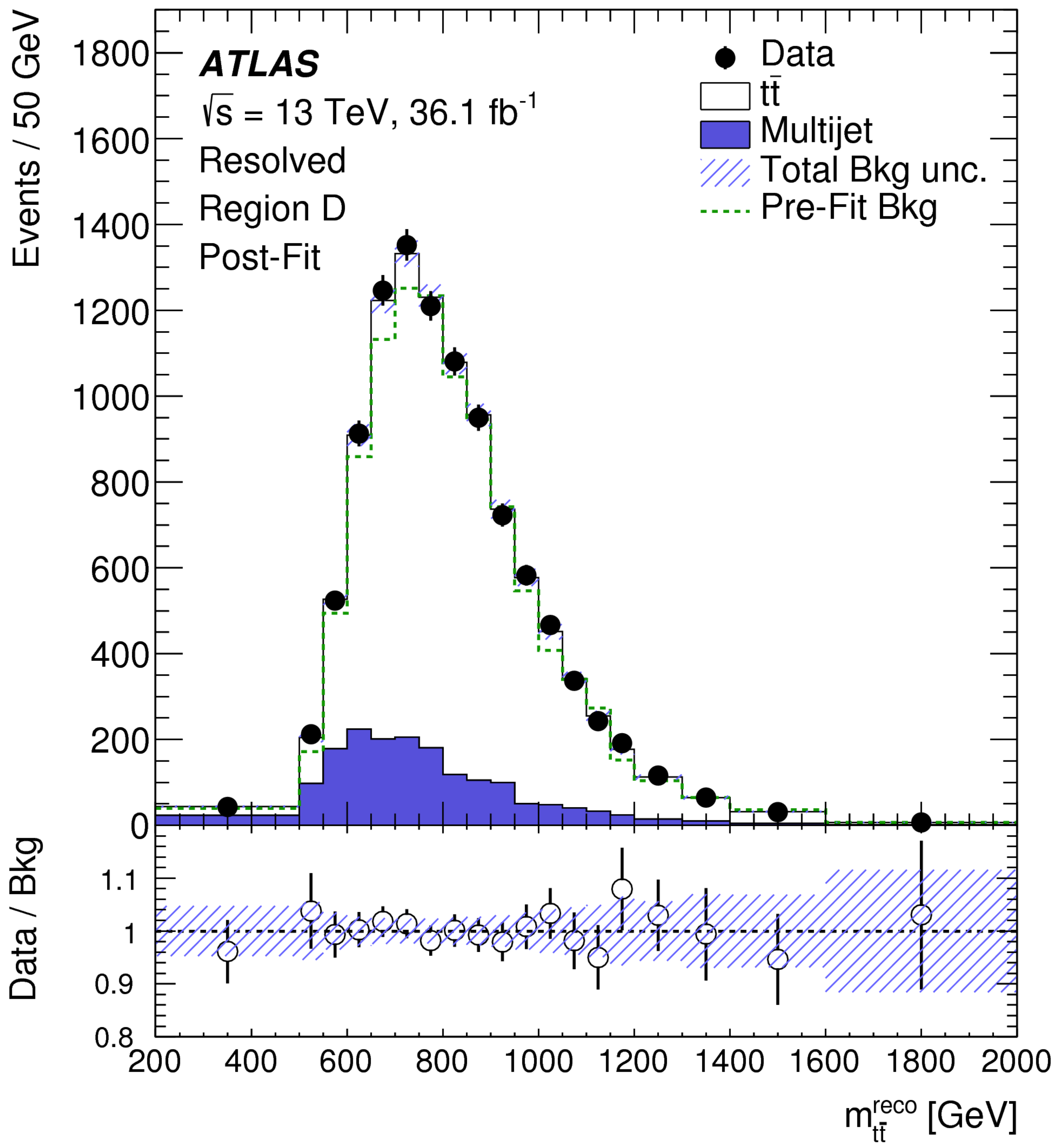
Boosted: R1, tight τ_{32} & 2 b-tag



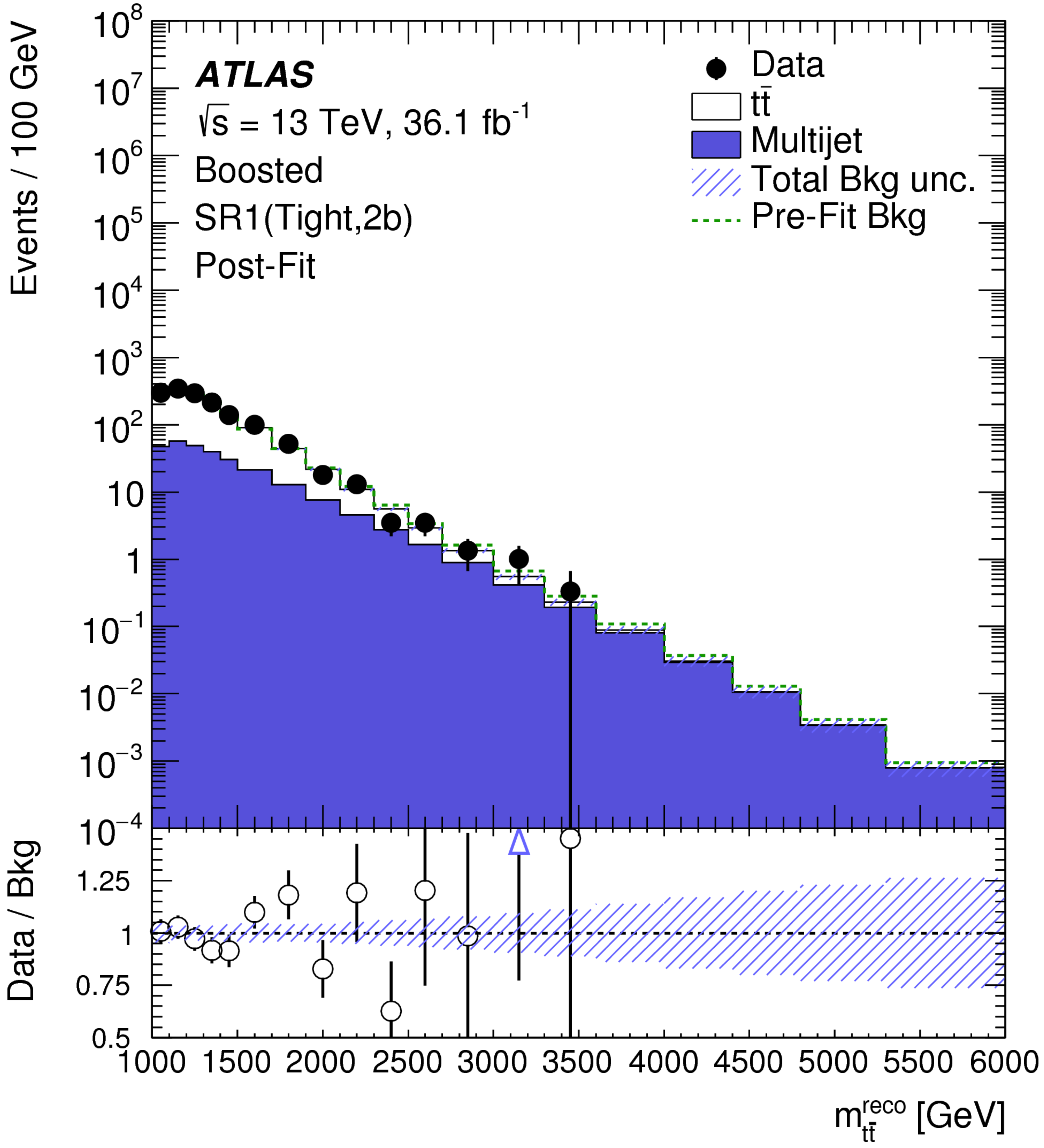


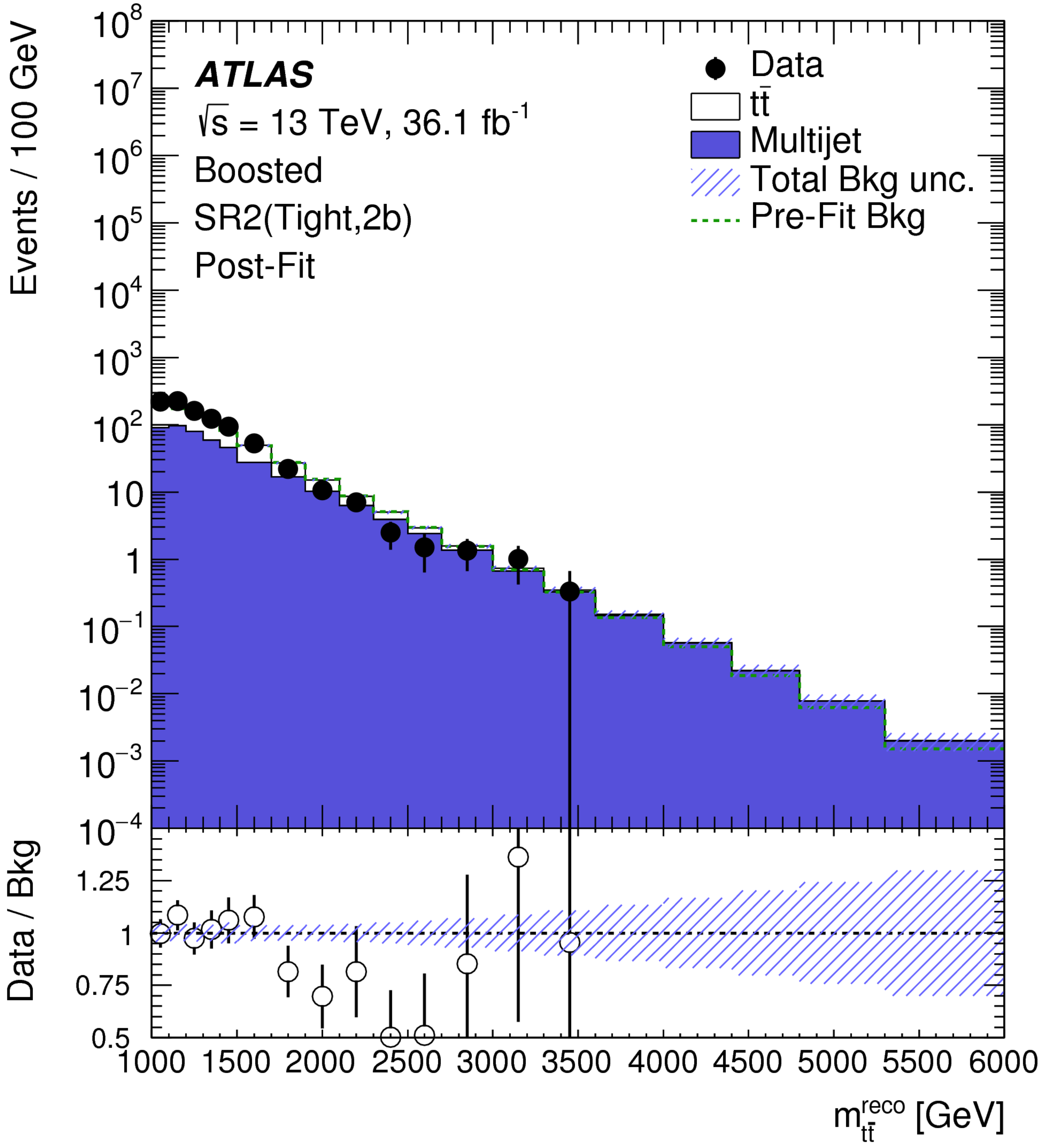
$m_{t\bar{t}}$ spectrum

- $t\bar{t}$ estimated by MC
- Multi-jet estimated by Data
  - 2D sideband (ABCD) method
    - Resolved: mass criteria of buckets vs. number of tight b-tag jets
    - Boosted: large-R jet mass vs. number of tight b-tagged track jets

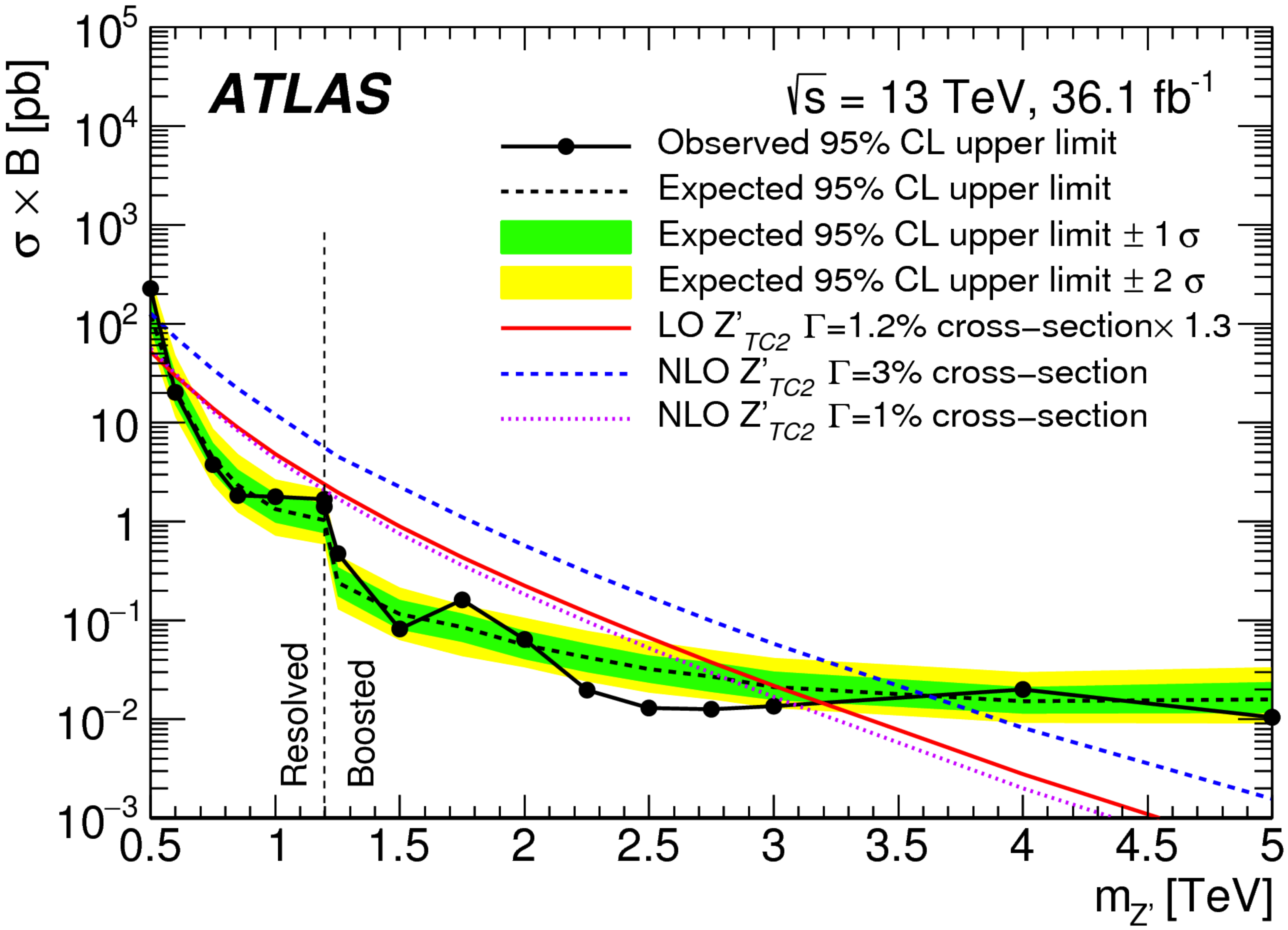


$m_{t\bar{t}}$ spectrum





Top-color Z' exclusion limit



Lepton+jets final states

Event selection

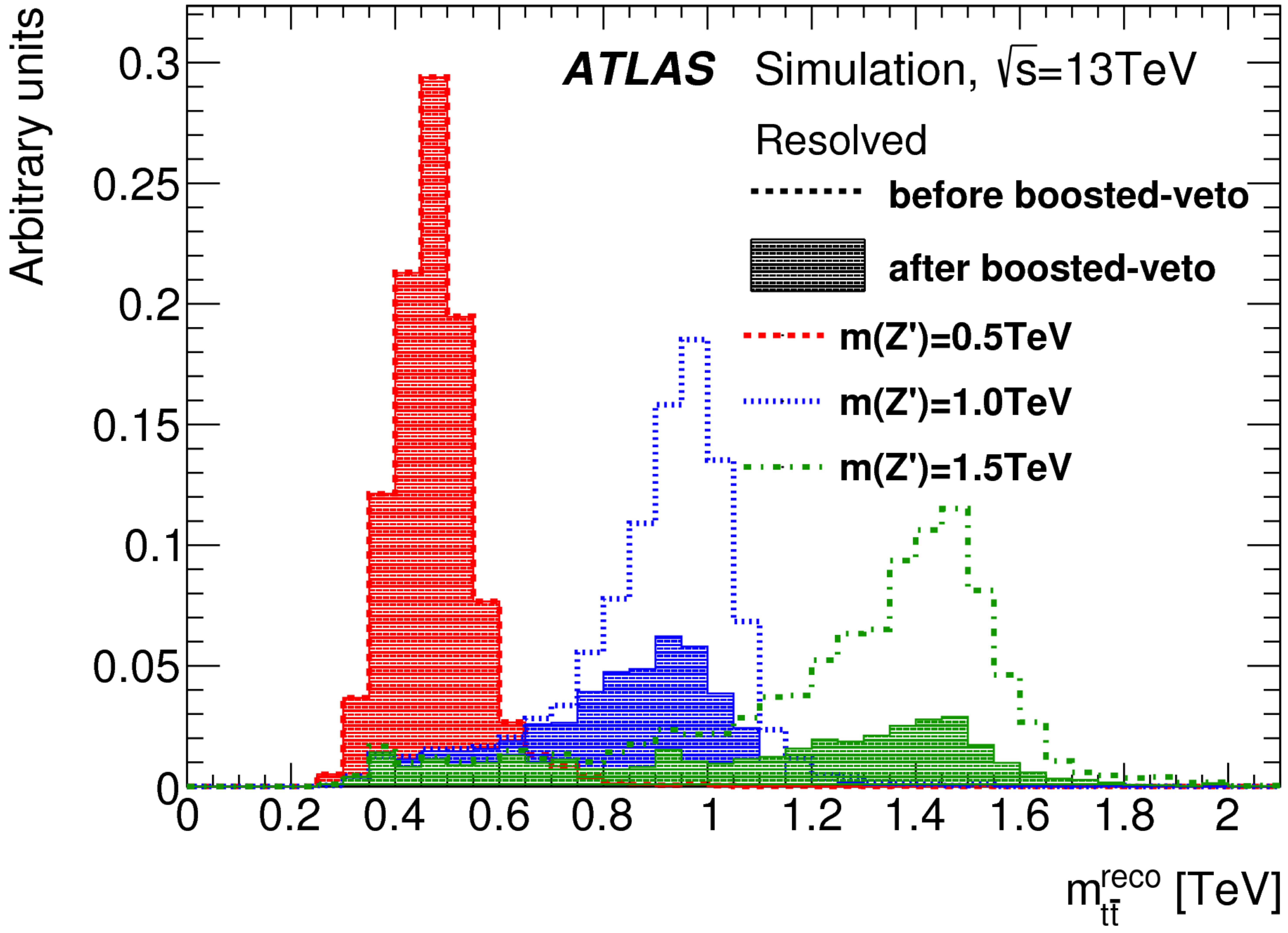
- Exactly one e/μ with p_T > 30 GeV, E_T^{miss} > 20 GeV and $E_T^{miss} + m_T^W$ > 60 GeV. At least one b-tagged track jet with p_T > 10 GeV

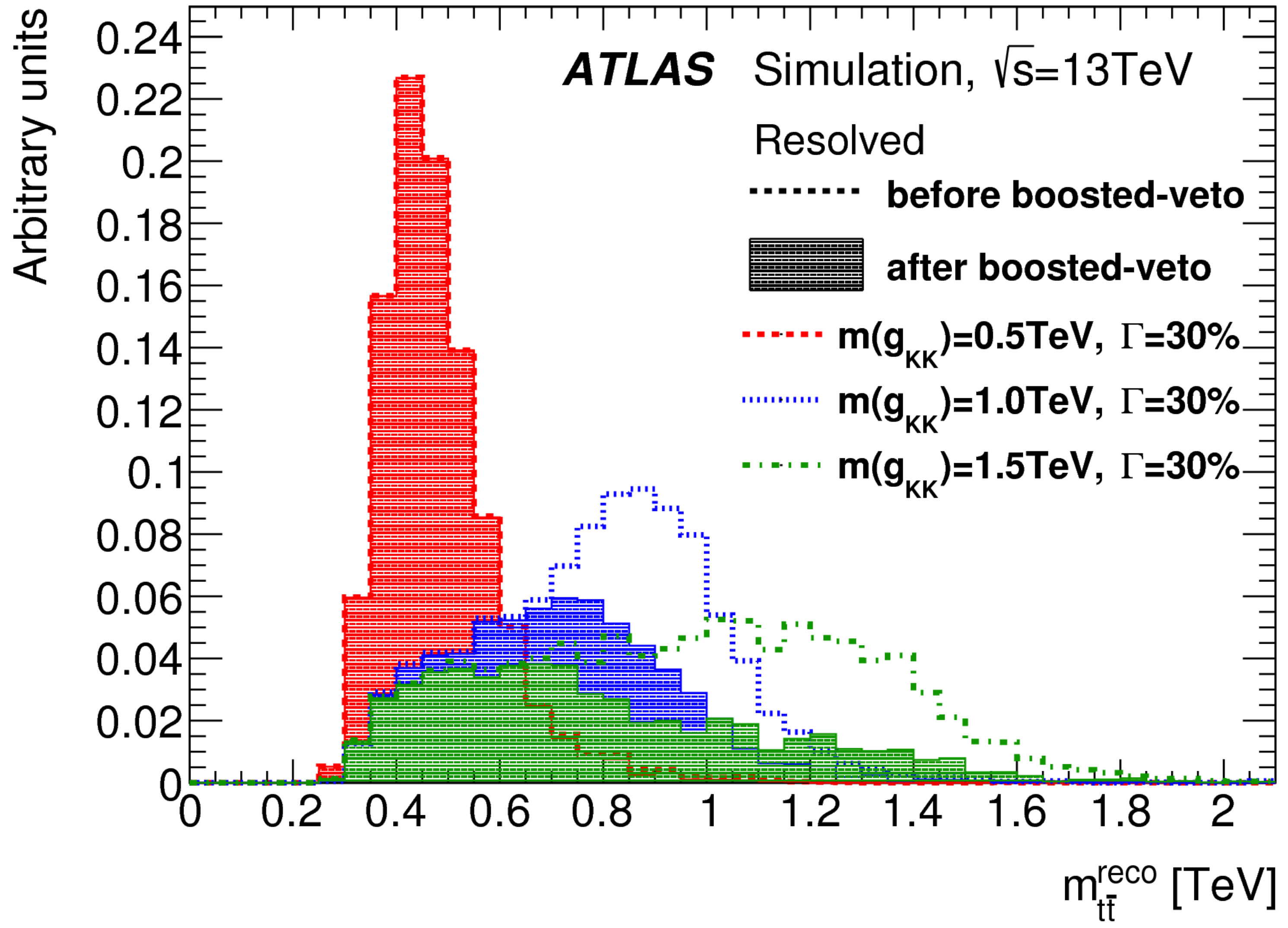
- Boosted:
  - At least one jet with p_T > 25 GeV, ΔR(jet,e/μ) < 1.5 => j_{sel}
  - At least one top tagged large-radius jet with p_T > 300 GeV, $\Delta\phi$(jet,e/μ) > 2.3, ΔR(jet, j_{sel}) > 1.5

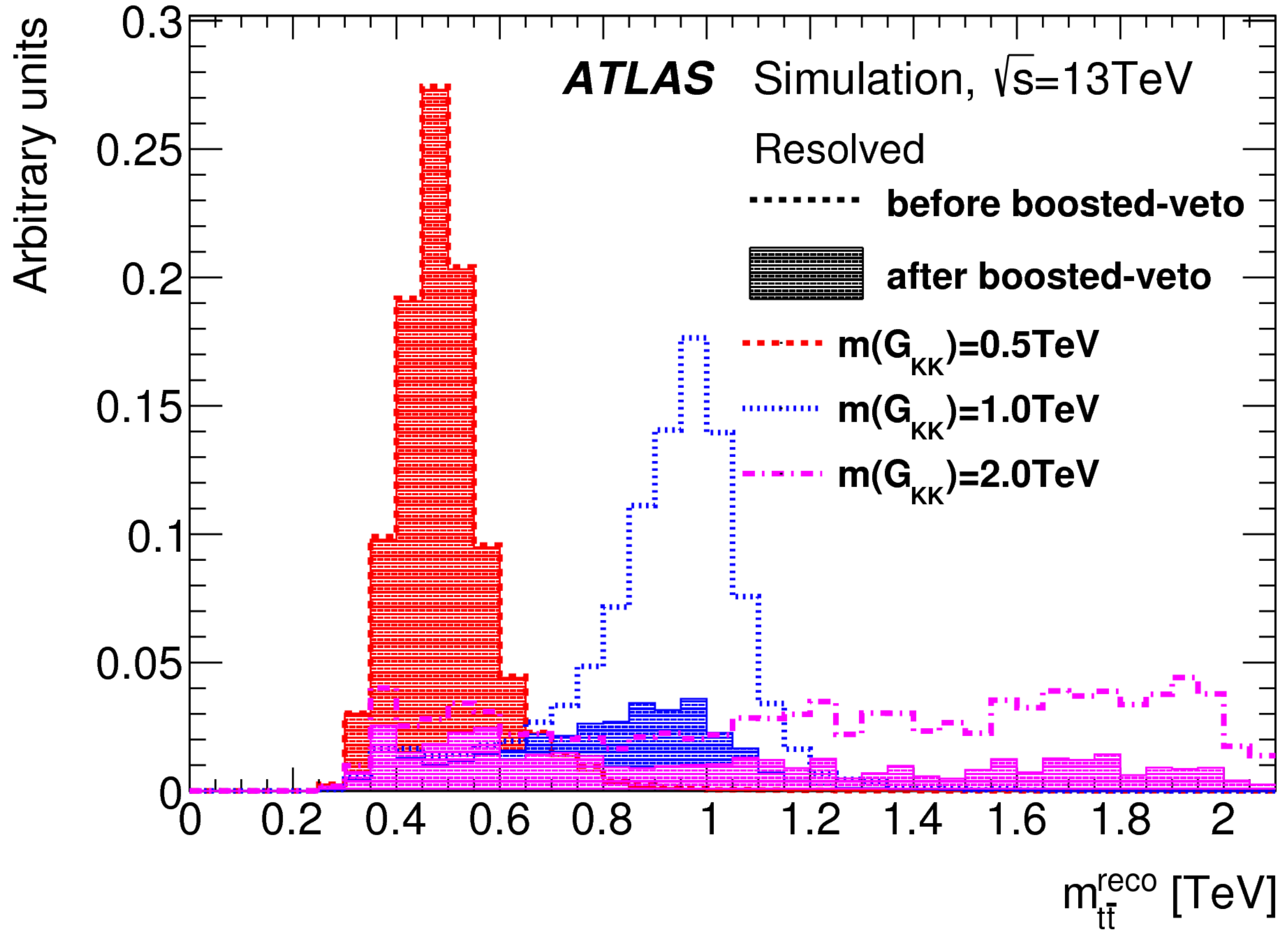
- Resolved (considered if boosted selection fails):
  - At least 4 jets with p_T > 25 GeV
  - Passing kinematic optimization algorithm which assign 3 jets into hadronic top decay and 1 to leptonic top decay

- Categorize events based on number of b-tagged track jets with angular matching

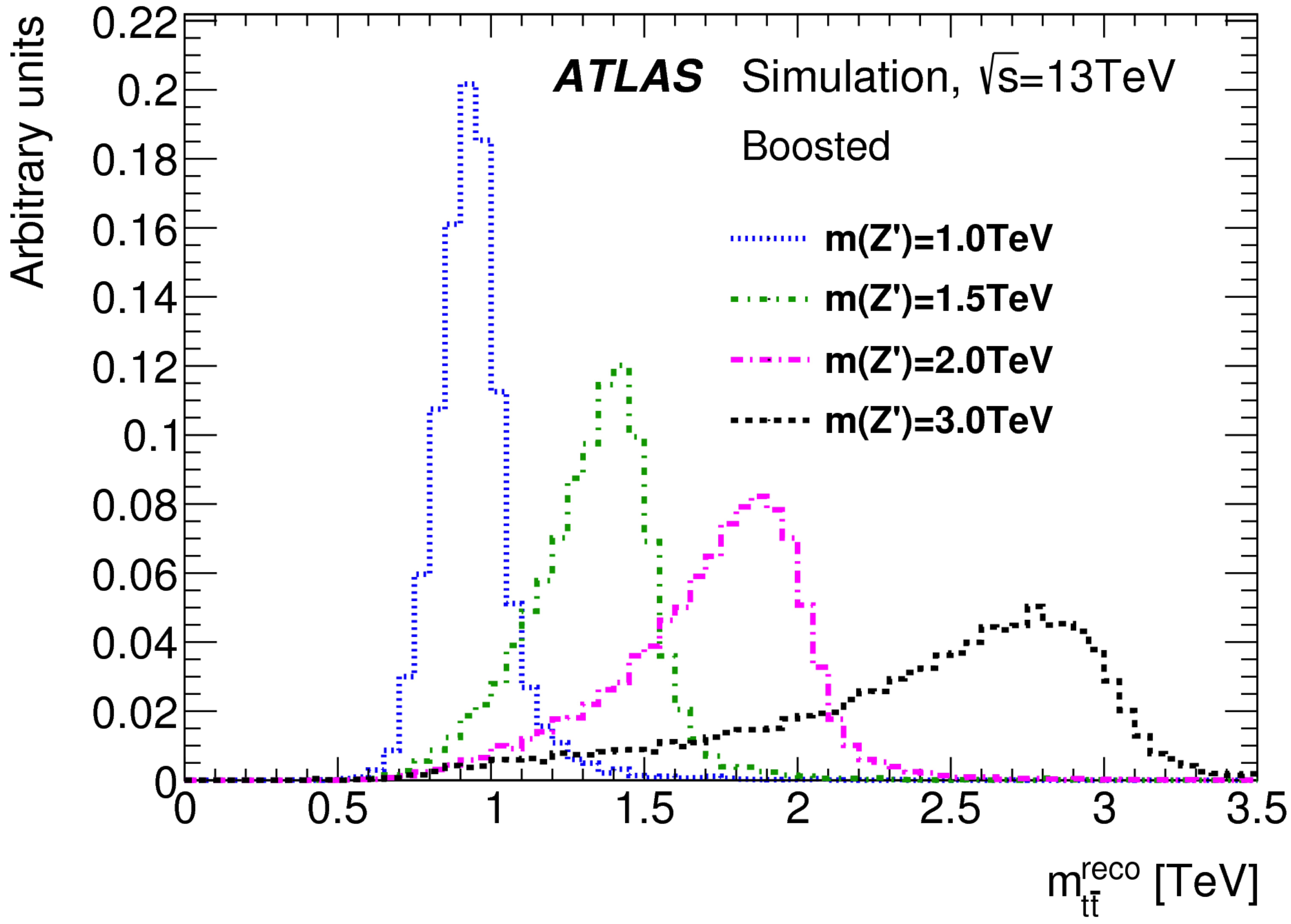
Resolved signal $m_{t\bar{t}}$

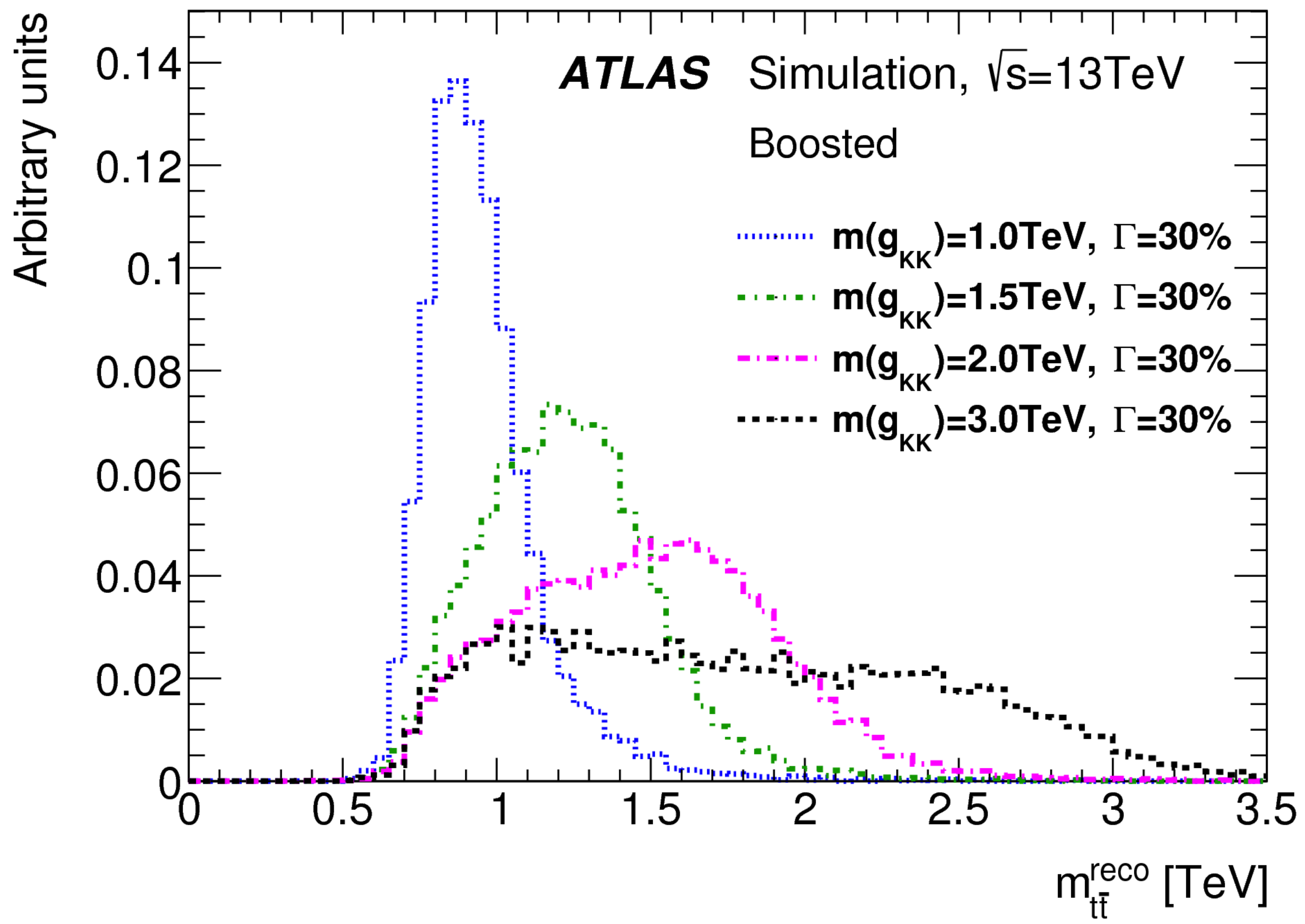


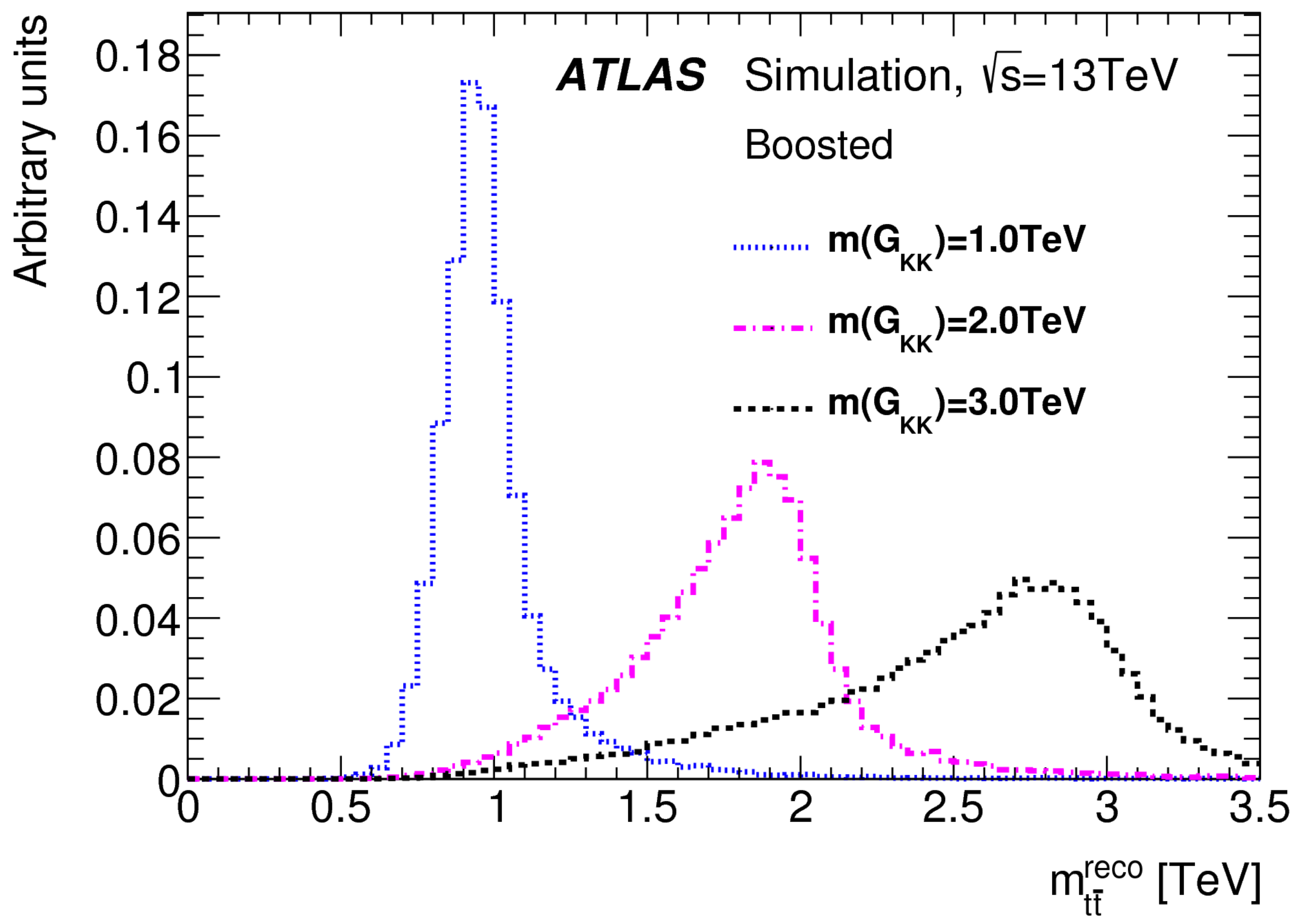




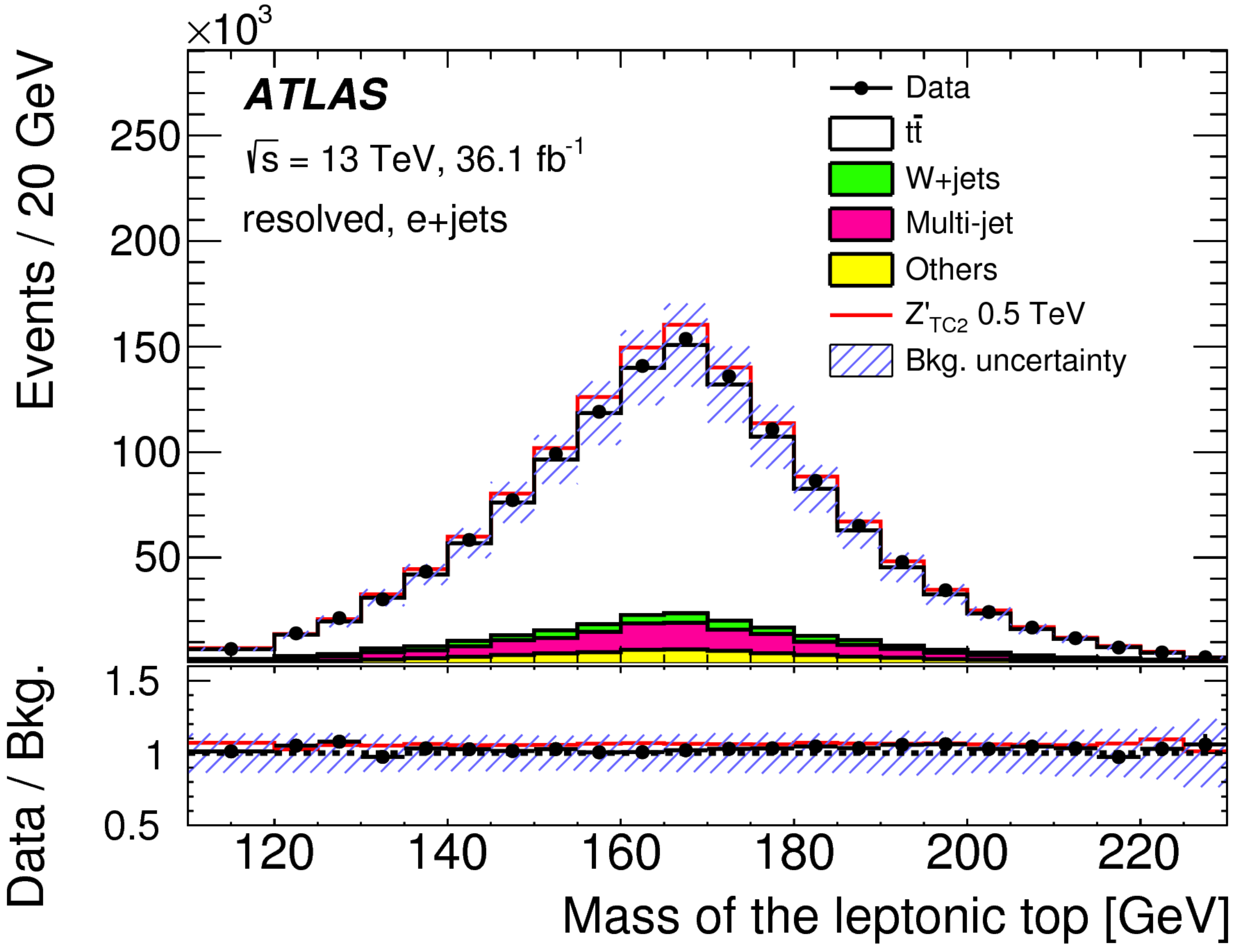
Boosted signal $m_{t\bar{t}}$

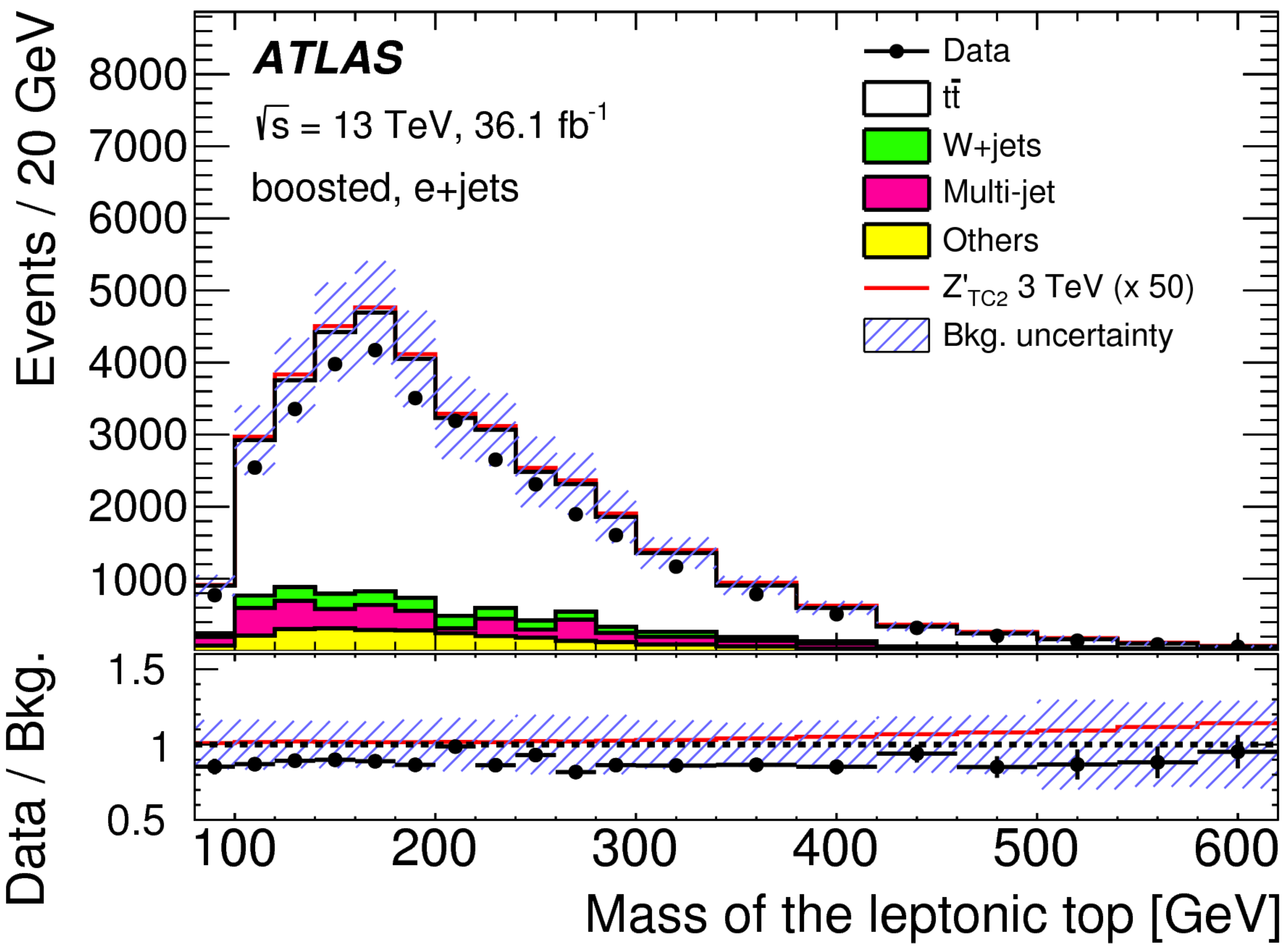




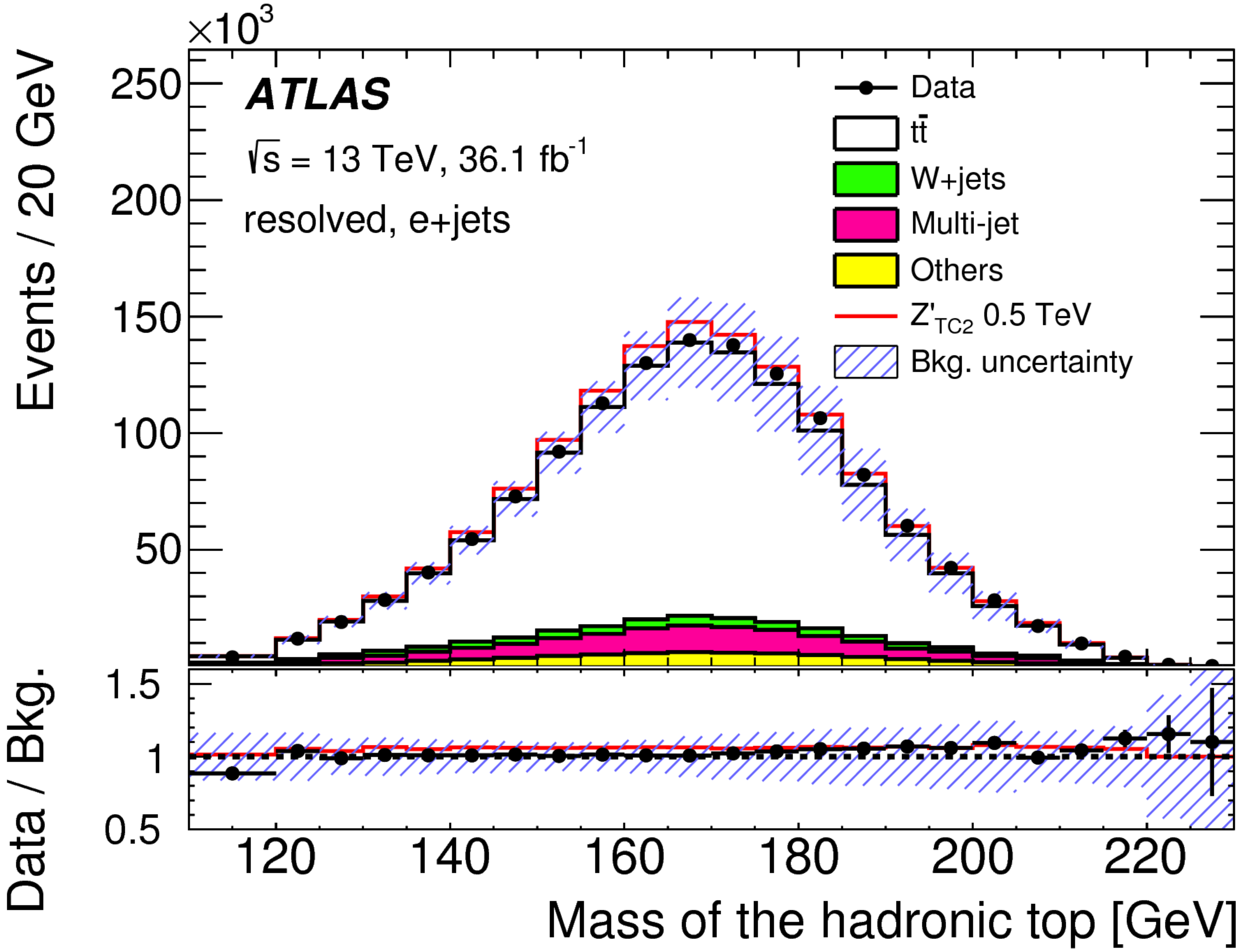


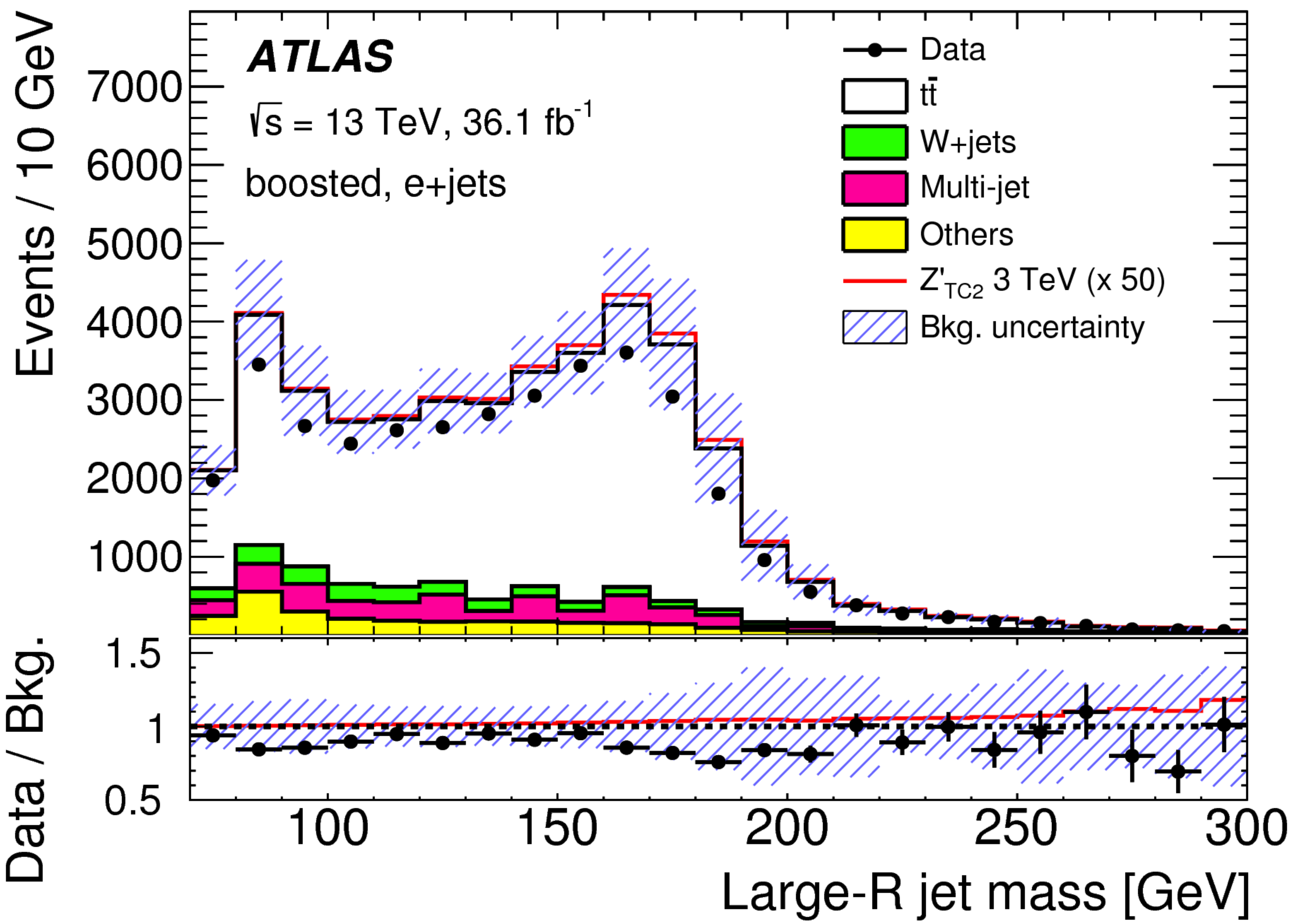
Leptonic top mass





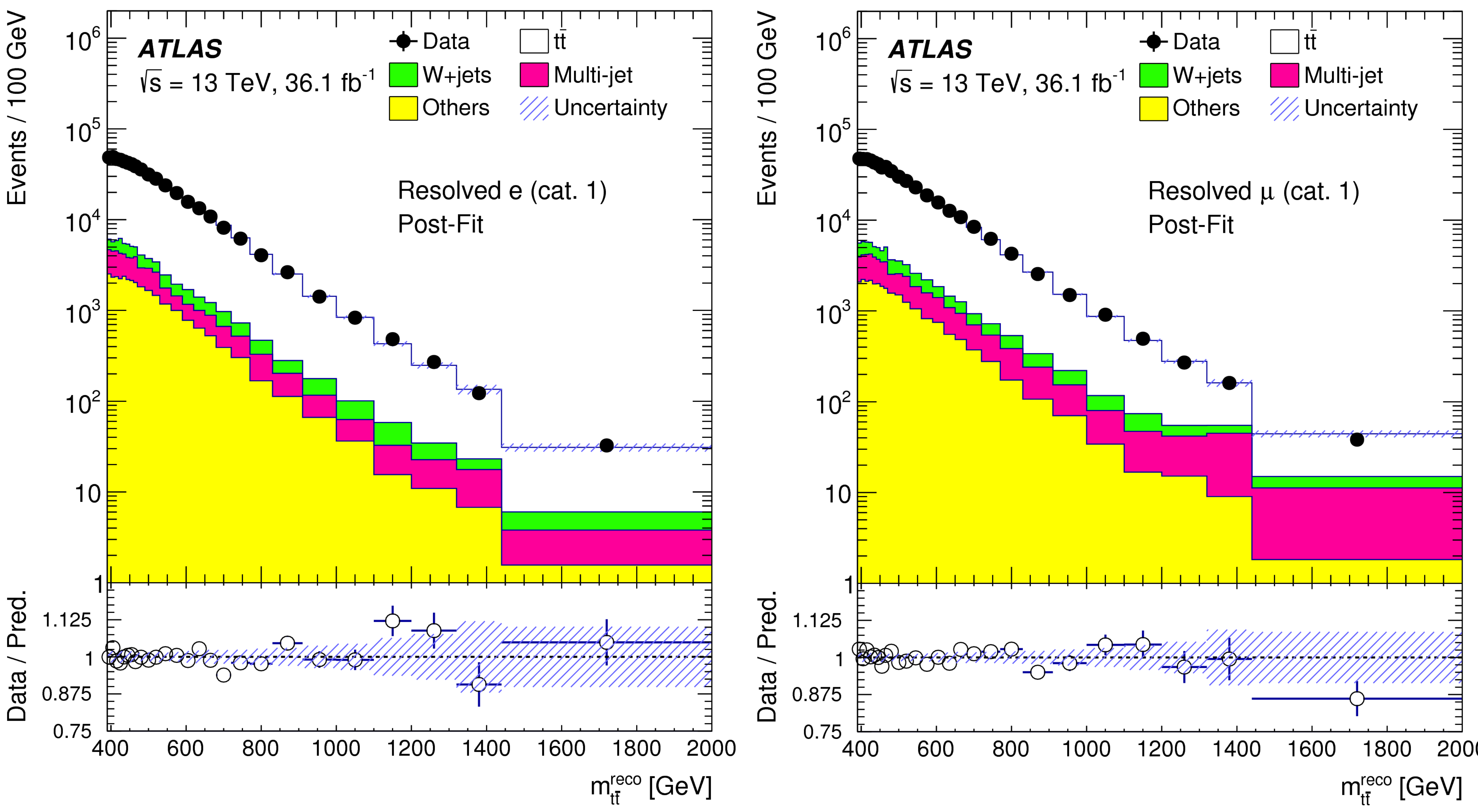
Hadronic top mass



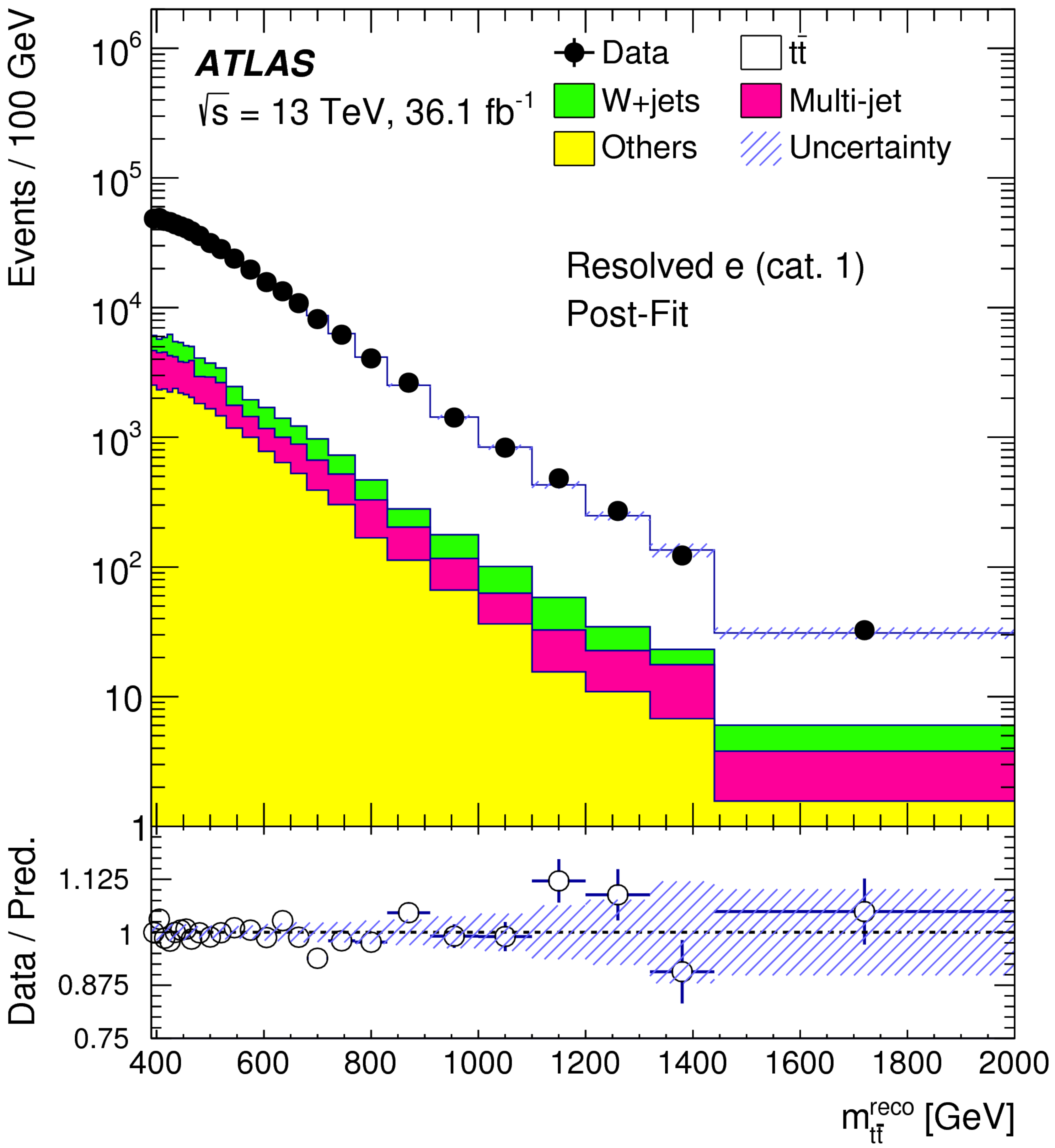


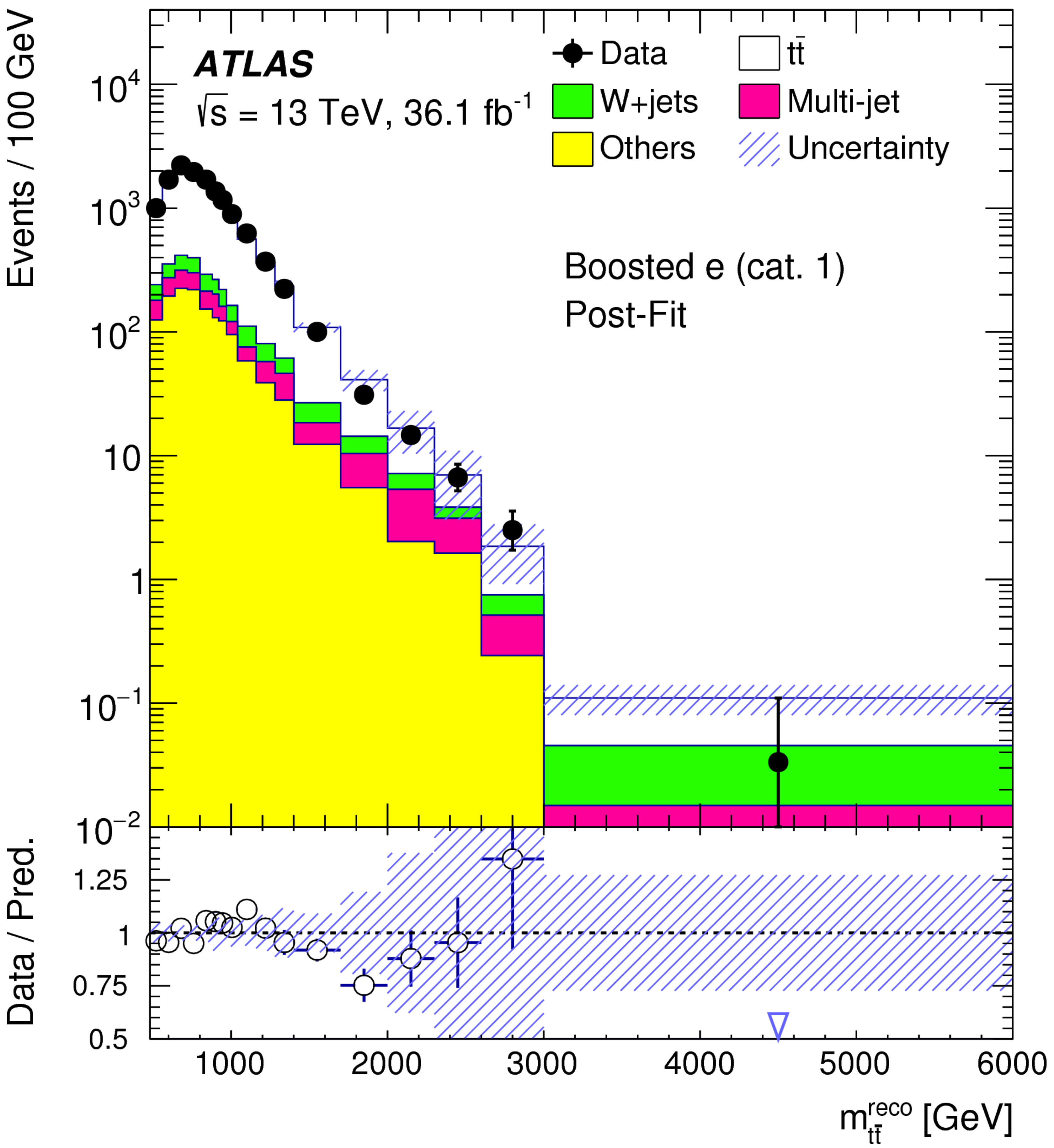
$m_{t\bar{t}}$ spectrum (resolved, e vs. μ)

- $t\bar{t}$ estimated by MC
- Multi-jets estimated by matrix method from data
  - Loose e/μ region
  - Control region by inverting cuts on E_T^{miss} and $E_T^{miss} + m_T^W$
- W+jets estimated by
  - Shape: Sherpa MC
  - Corrections in total yields and flavor components: charge asymmetry data

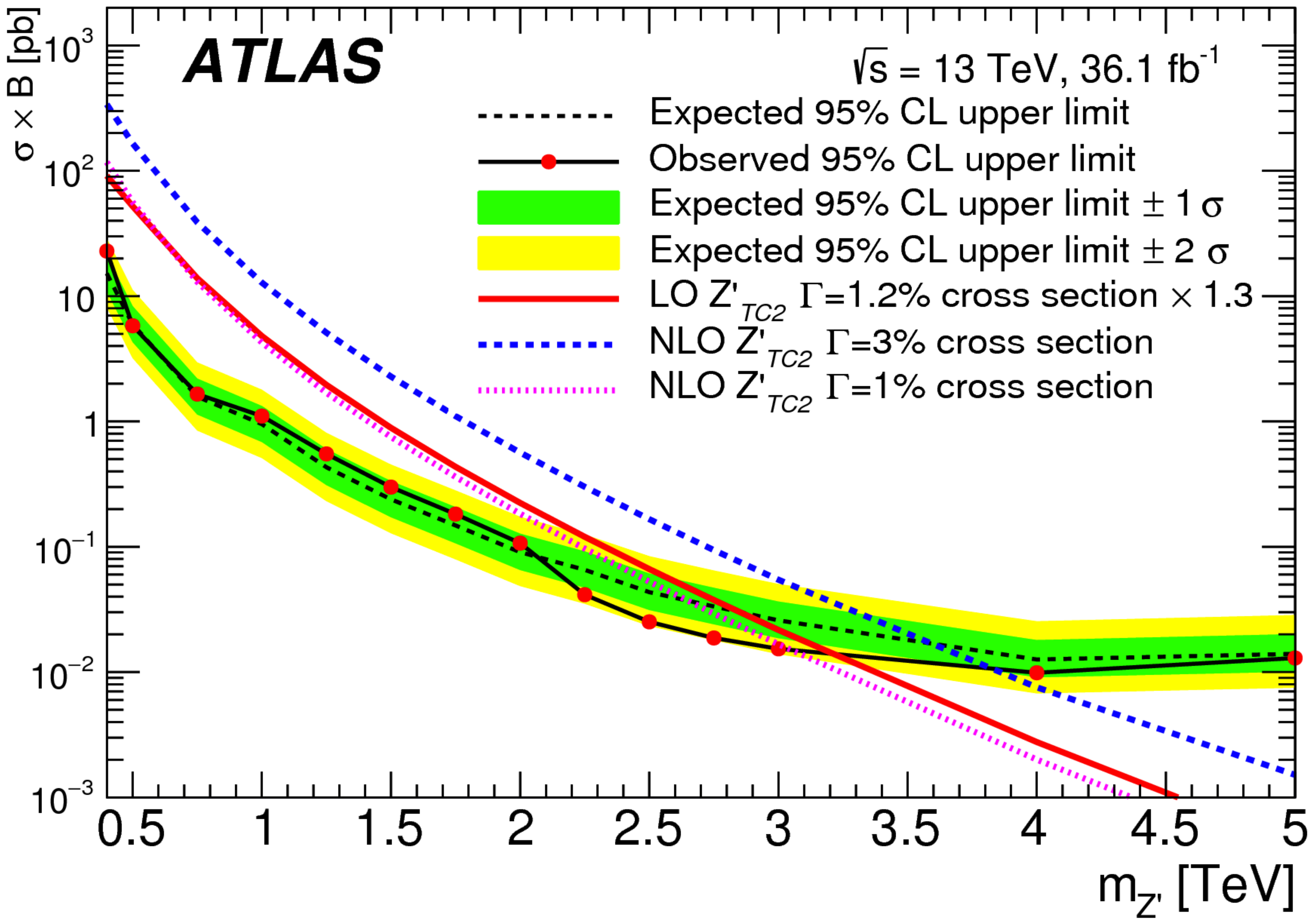


$m_{t\bar{t}}$ spectrum (e, resolved vs. boosted)





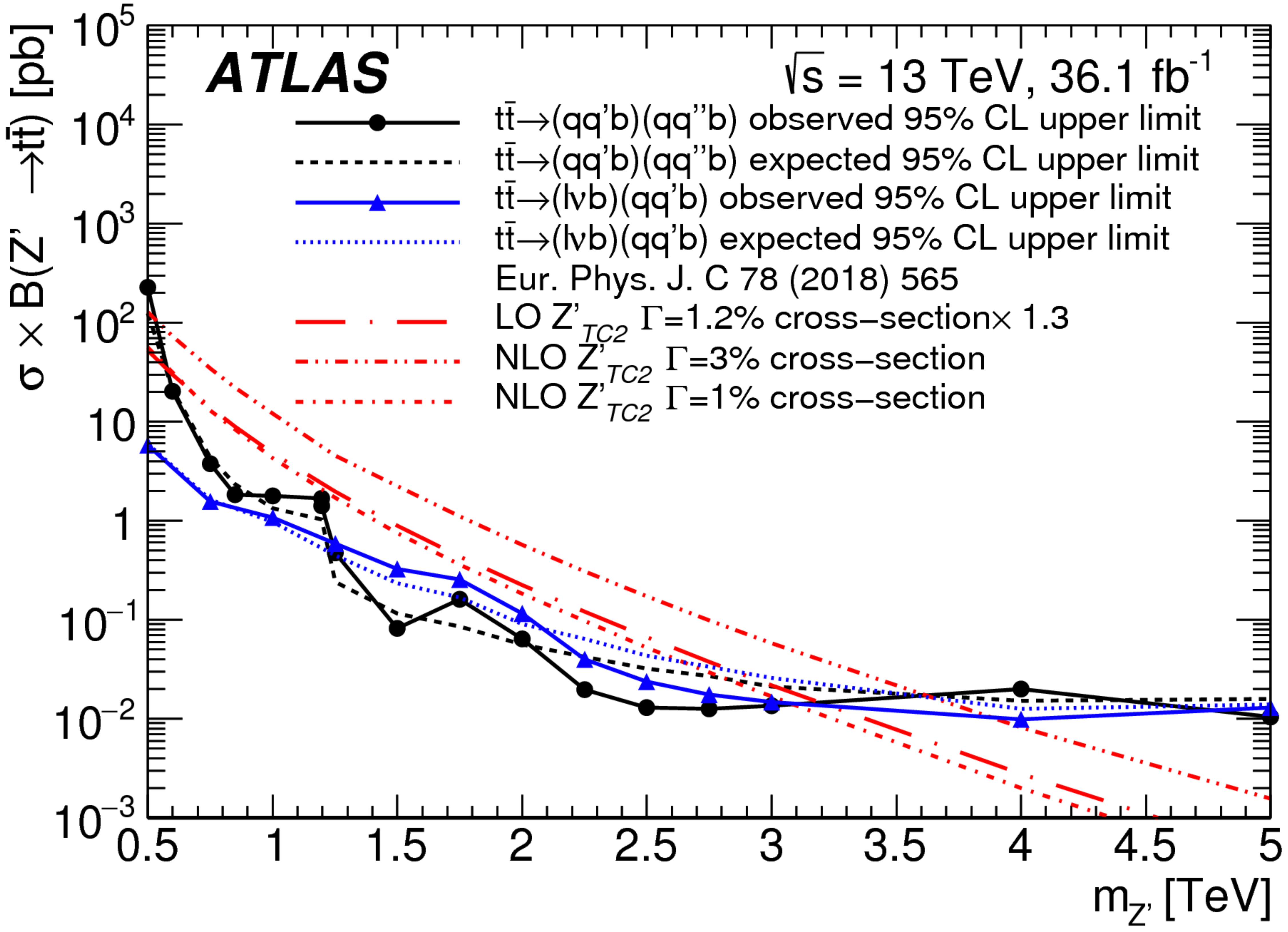
Top-color Z' exclusion limit



Summary

- Top color Z’, Kaluza Klein gluon & graviton, and vector & axial DM mediators searched by all-jets & lepton+jets final states at 13 TeV

- Both searches have similar signal sensitivity but lepton+jets performed slightly better at low mass



Back-up

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Topcolor assisted technicolor

ATLAS EXPERIMENT

arXiv:hep-ph/9911288v1

- Has its root in top-color models
  - QCD SU(3) comes from the symmetry breaking of $SU(3)_1 \times SU(3)_2$
  - Coupling of $SU(3)_1$ << $SU(3)_2$. The later couples to third generation quarks
  - $t\bar{t}$ condensate to generate large top quark mass and EWSB
- Topcolor assisted technicolor introduces $U(1)_1 \times U(1)_2$
  - Coupling $U(1)_1$ << $U(1)_2$. The later couples to third generation quarks
  - $U(1)_2$ gives attractive force between $t\bar{t}$ but repulsive force between $b\bar{b}$
  - The $t\bar{t}+b\bar{b}$ condensate gives top quark larger mass than bottom quark

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Summary of mass limits

ATLAS EXPERIMENT

All-jets

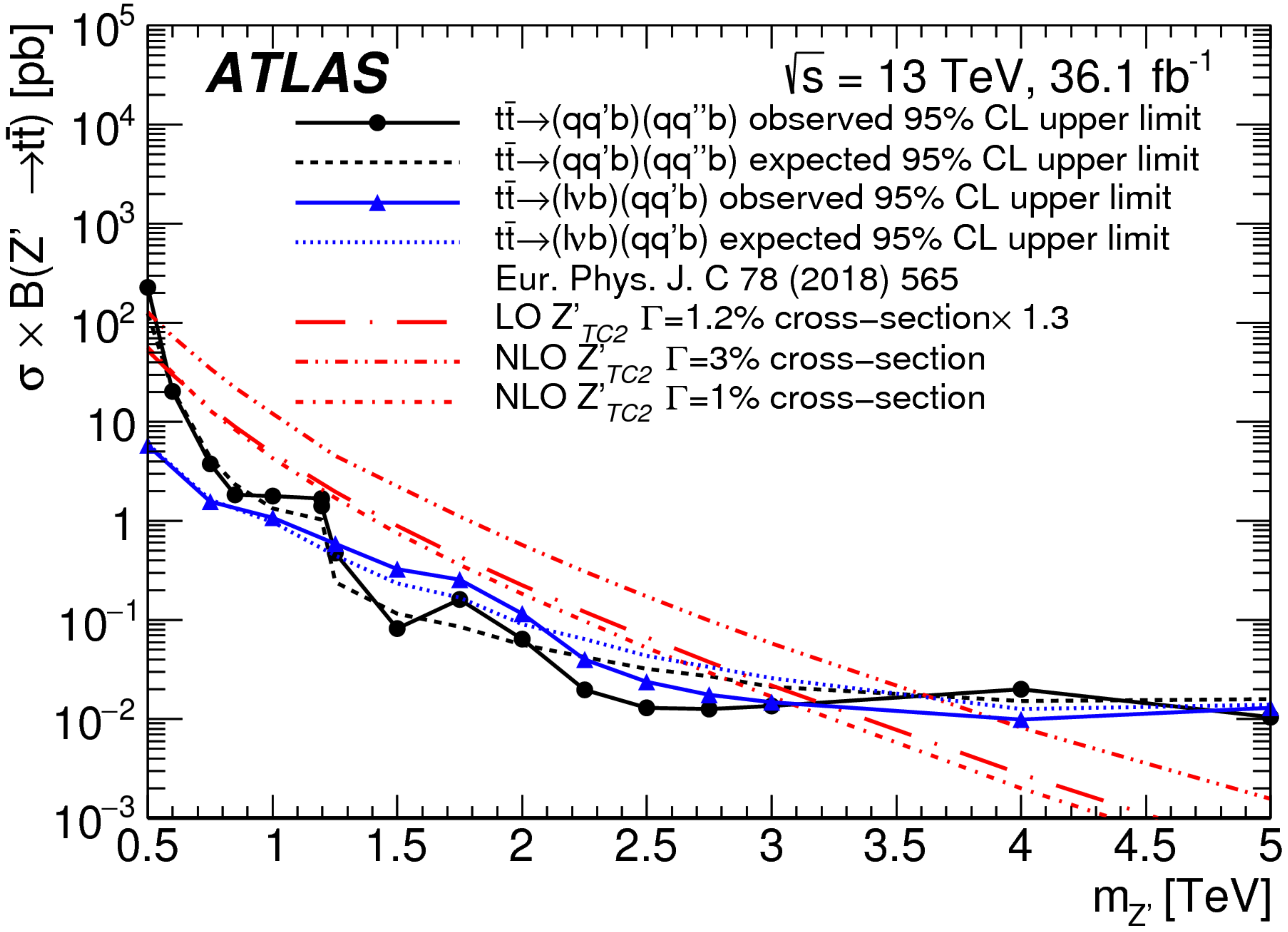
Signal		Expected excluded mass [TeV]	Observed excluded mass [TeV]
Z'_{TC2}	$(\Gamma = 1\%)$	$[0.57, 2.8]$	$[0.58, 3.1]$
	$(\Gamma = 3\%)$	$[0.51, 3.6]$	$[0.53, 3.6]$
Z'_{med}	(vector)	$[0.75, 1.07] \cup [2.0, 2.1]$	$[0.74, 0.97] \cup [2.0, 2.2]$
	(axial-vector)	$[1.99, 2.04]$	$[0.80, 0.92] \cup [2.0, 2.2]$
g_{KK}	$(\Gamma = 10\%)$	< 3.5	< 3.4
	$(\Gamma = 20\%)$	< 3.4	< 3.4
	$(\Gamma = 30\%)$	< 3.3	< 3.4
	$(\Gamma = 40\%)$	< 3.2	< 3.4

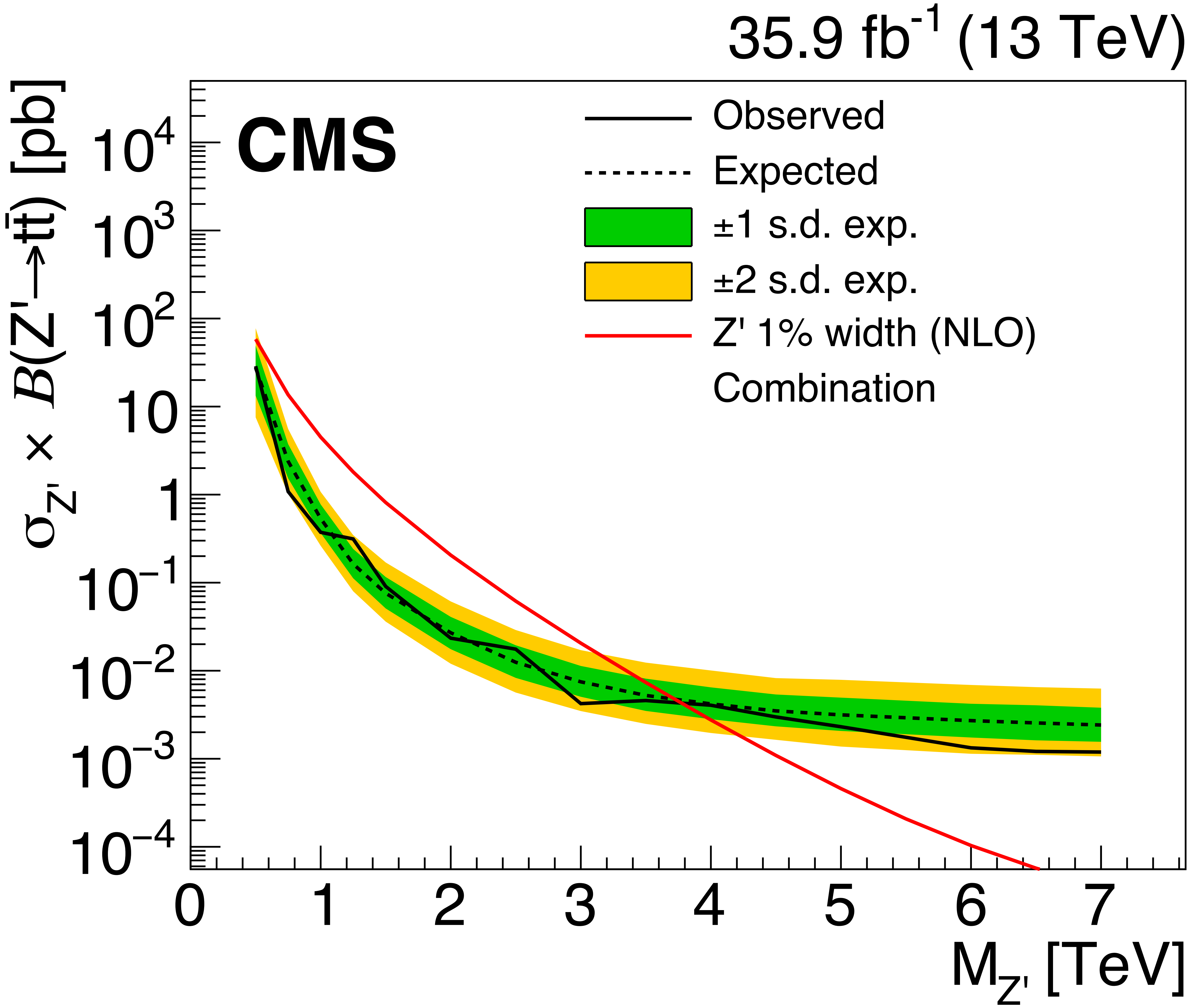
Lepton+jets

Summary of 95 % Confidence Level mass exclusion ranges on benchmark models

Model	Observed excluded mass [TeV]	Expected excluded mass [TeV]
Z'_{TC2} (1% width)	< 3.0	< 2.6
$Z'_{\mathrm{DM,ax}}$	< 1.2	< 1.4
$Z'_{\mathrm{DM,vec}}$	< 1.4	< 1.6
G_{KK}	$[0.45,\ 0.65]$	$[0.45,\ 0.65]$
g_{KK} (15% width)	< 3.8	< 3.5
g_{KK} (30% width)	< 3.7	< 3.2

ATLAS vs CMS Z' limits

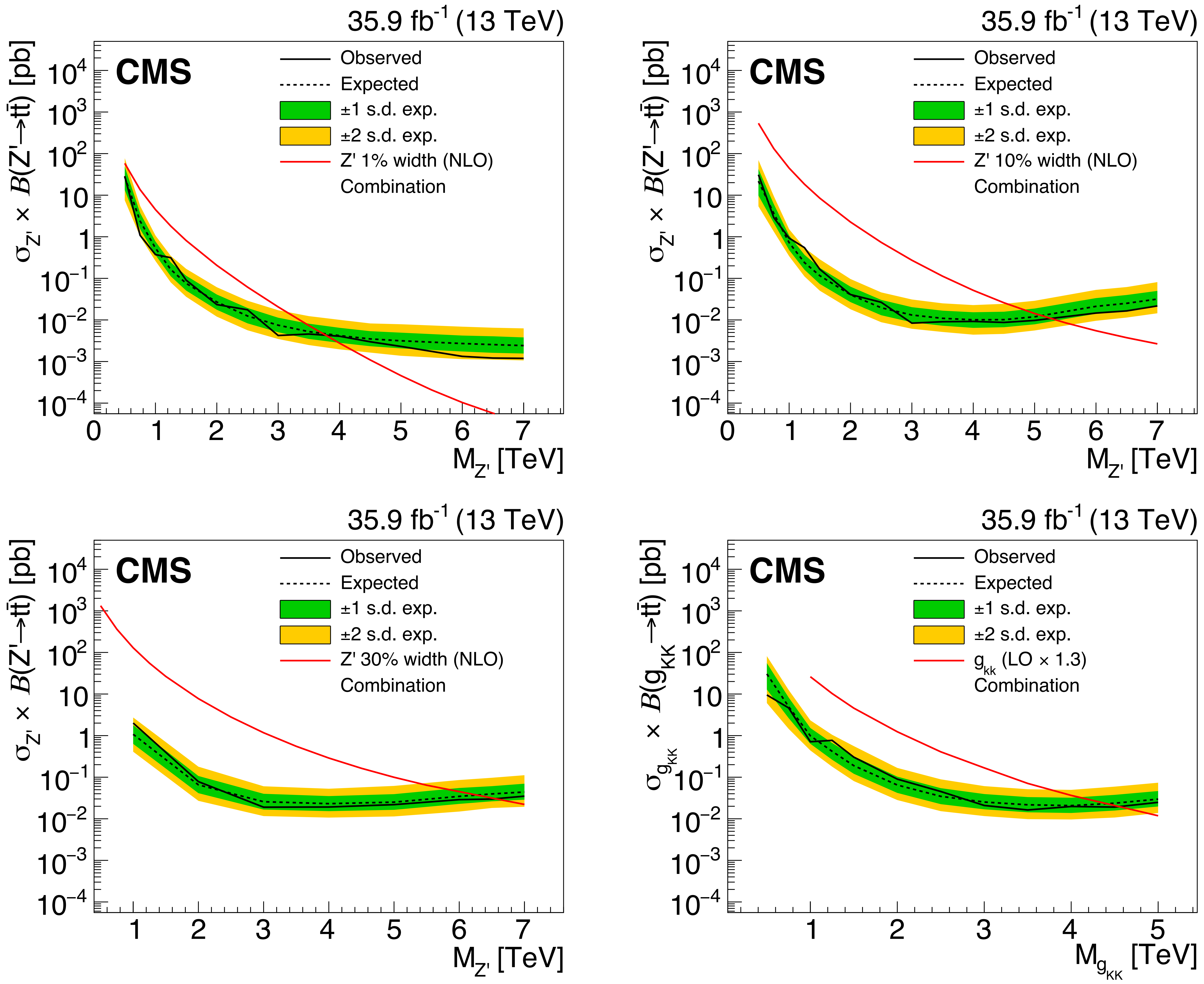




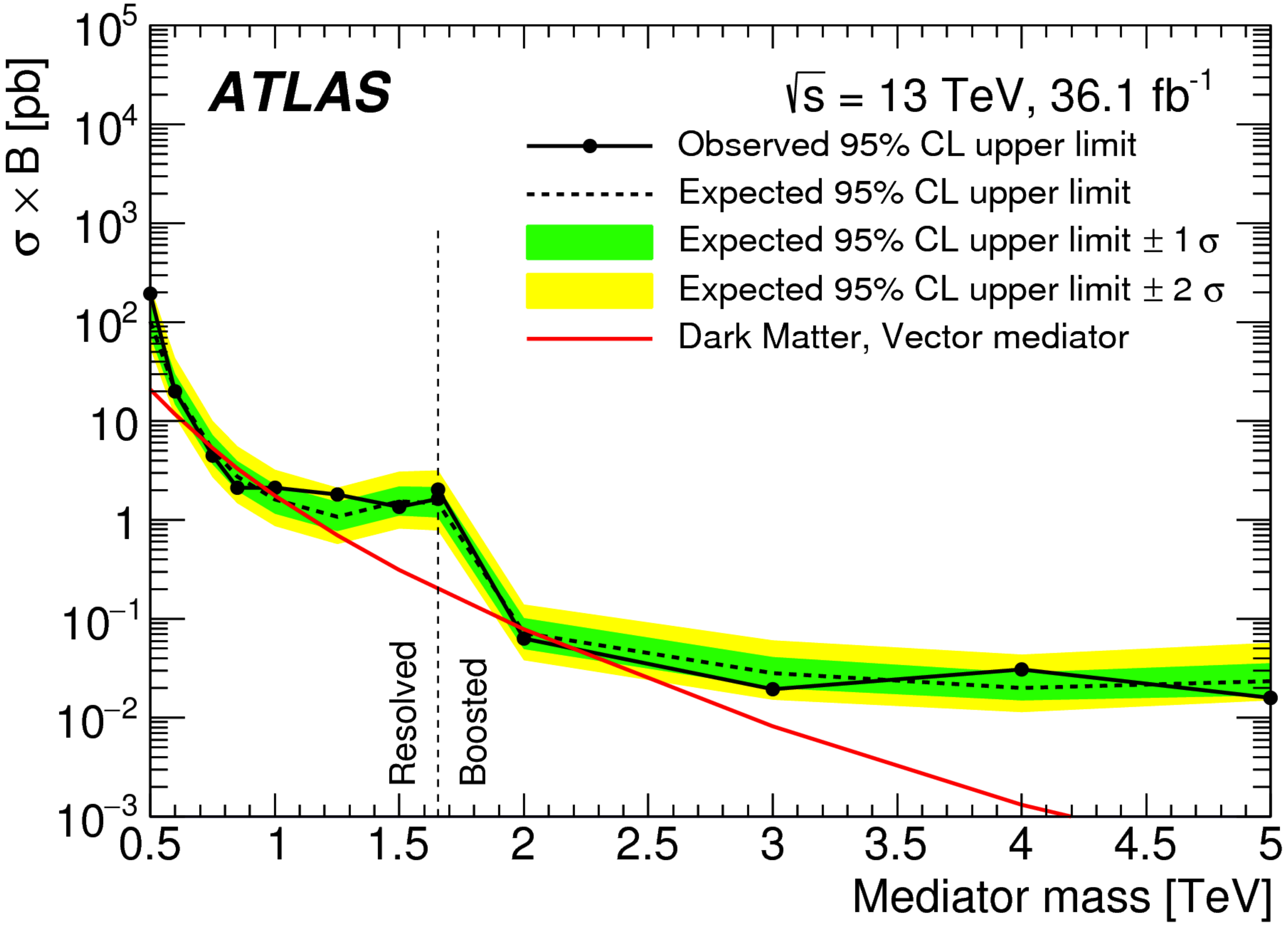
JHEP 04 (2019) 031

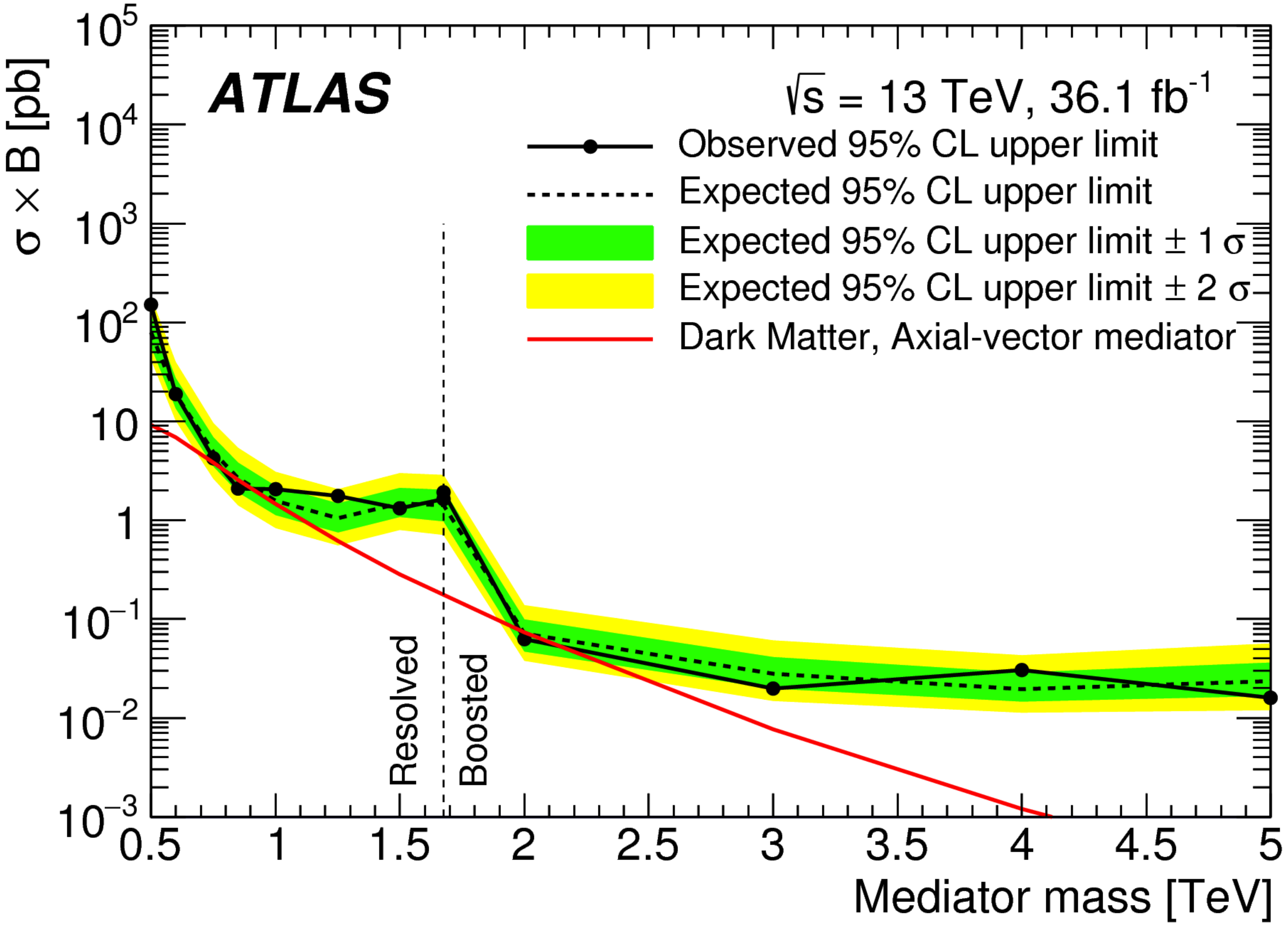
CMS results

JHEP 04 (2019) 031



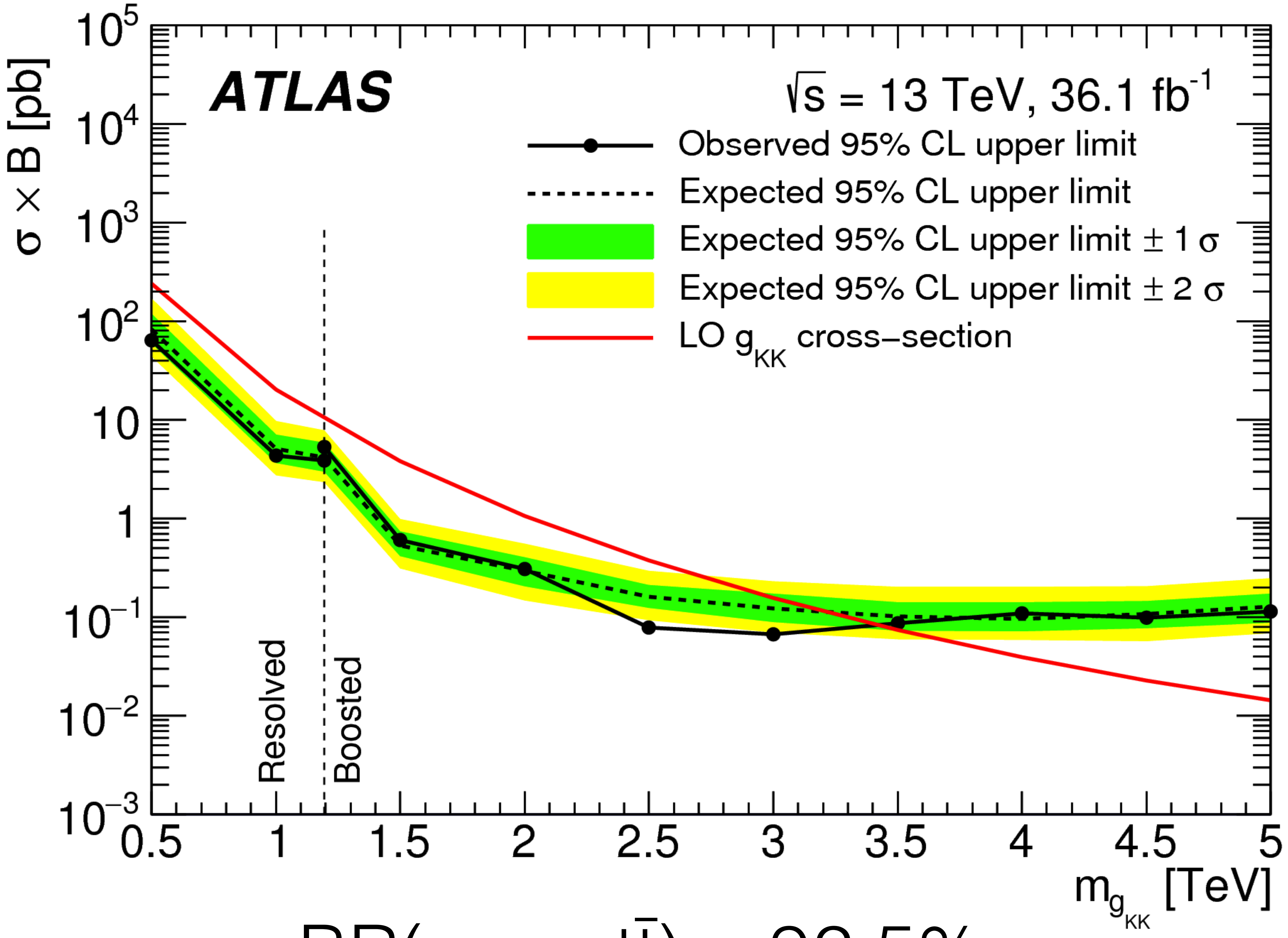
All-jets: exclusion limits





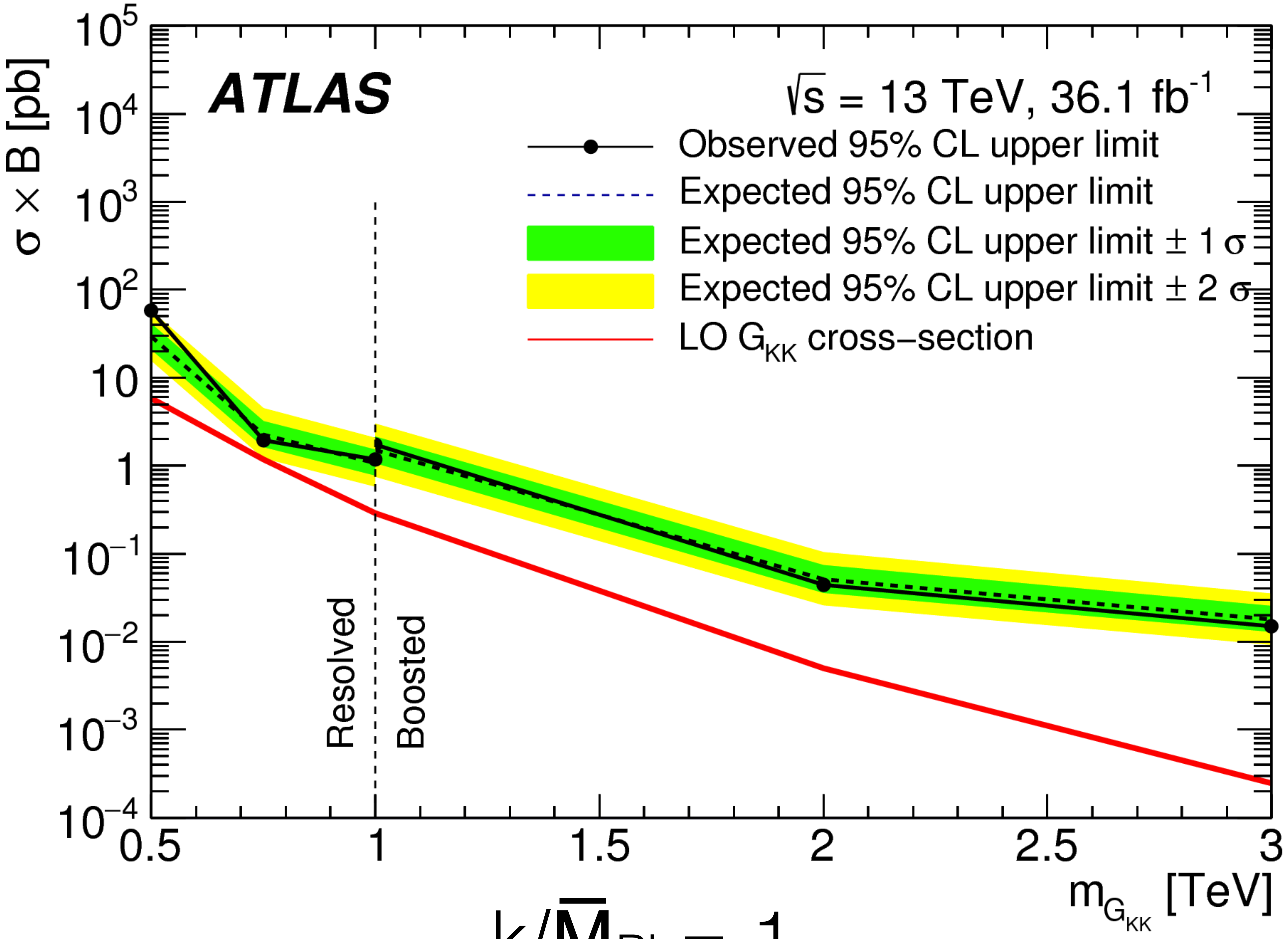
Width ≃ 5.6% mass

All-jets: exclusion limits



$BR(g_{KK} \to t\bar{t}) \simeq 92.5\%$

Width = 30% mass

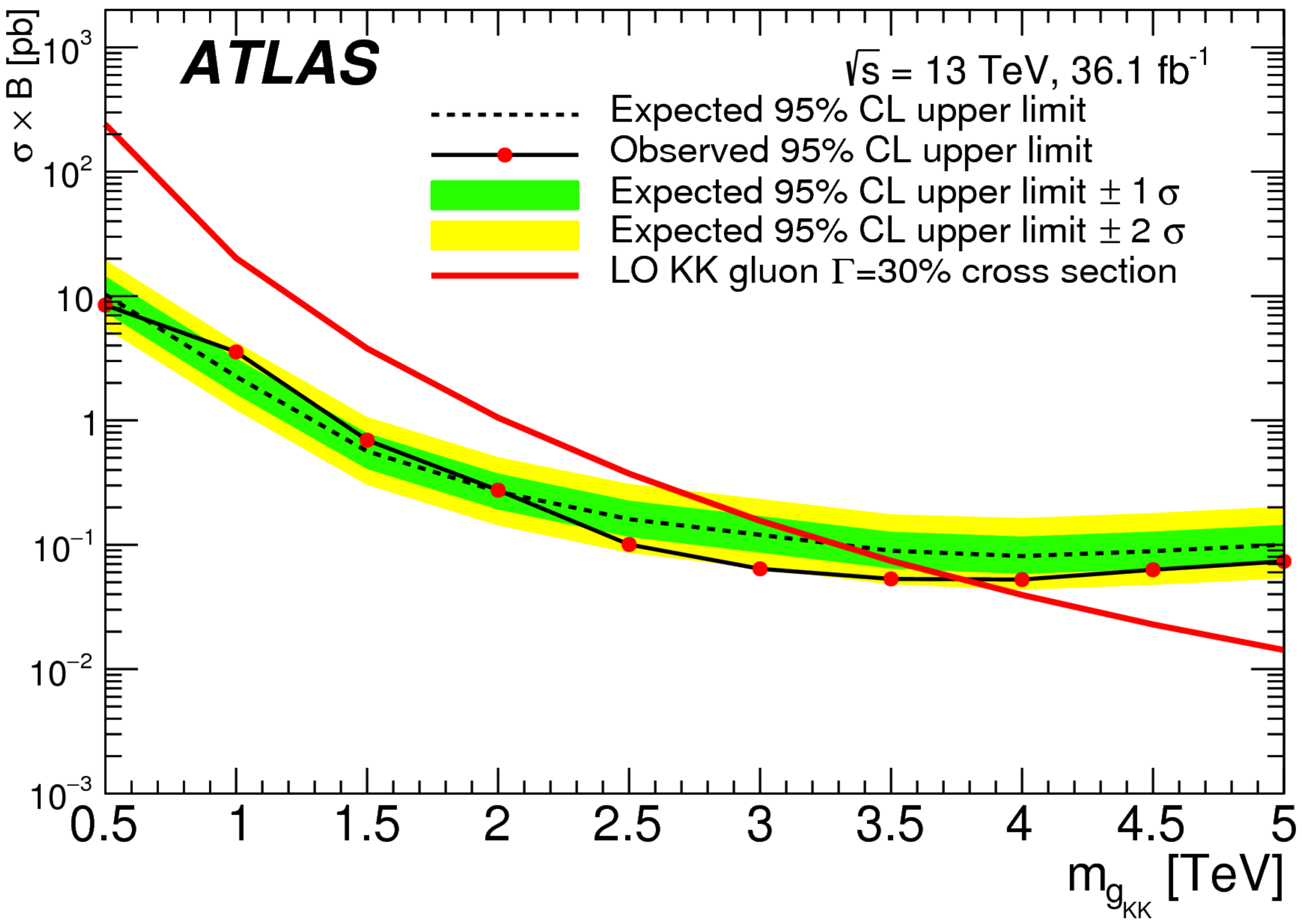


$k/\overline{M}_{Pl} = 1$

$BR(g_{KK} \to t\bar{t})$ varies from 18% to 68%

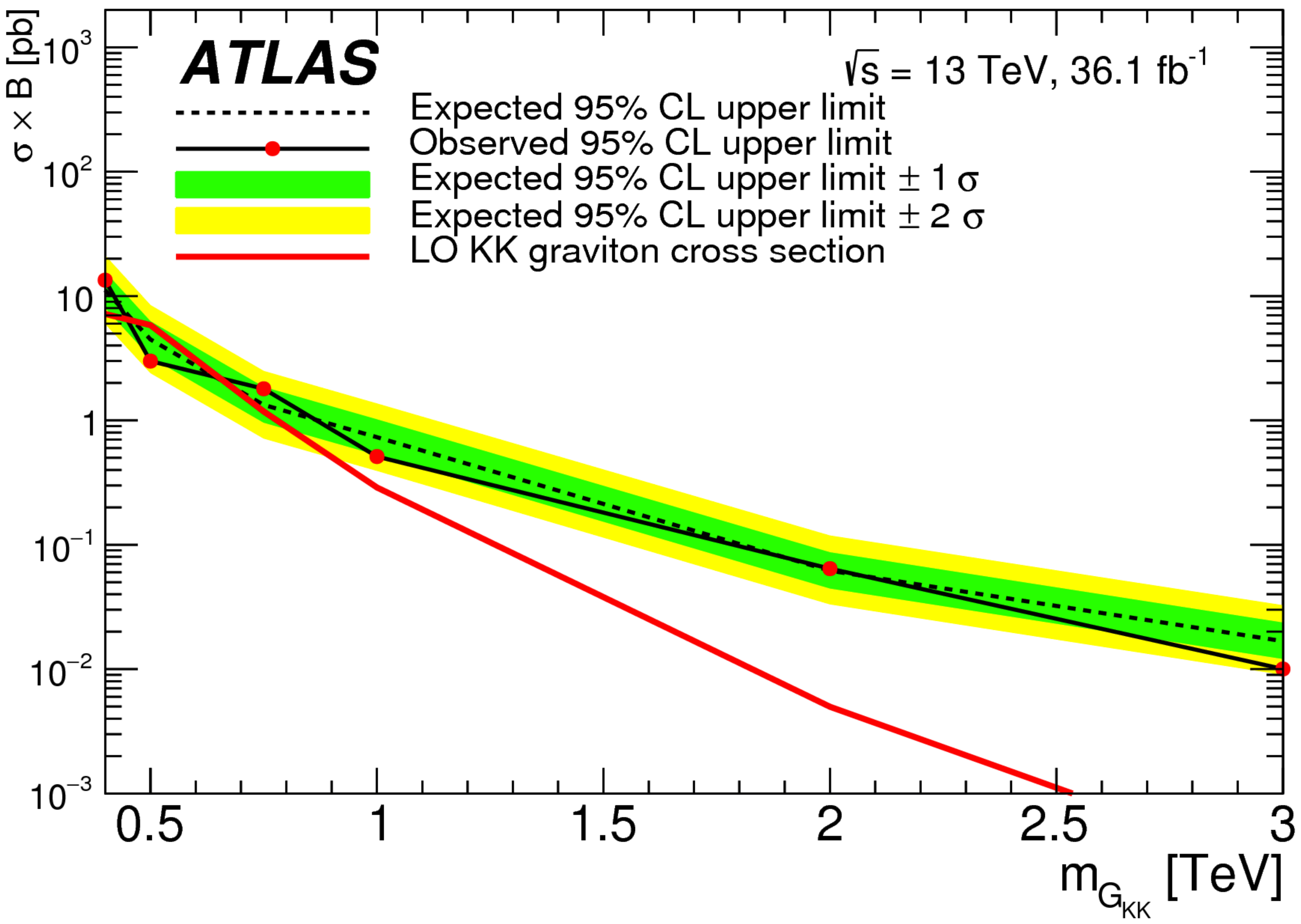
Width = 3% ~ 6% mass

Lepton+jets: exclusion limits



BR($g_{KK}\to t\bar{t}$) ≃ 92.5%

Width = 30% mass



$k/\mathbf{M}_{Pl}$ = 1

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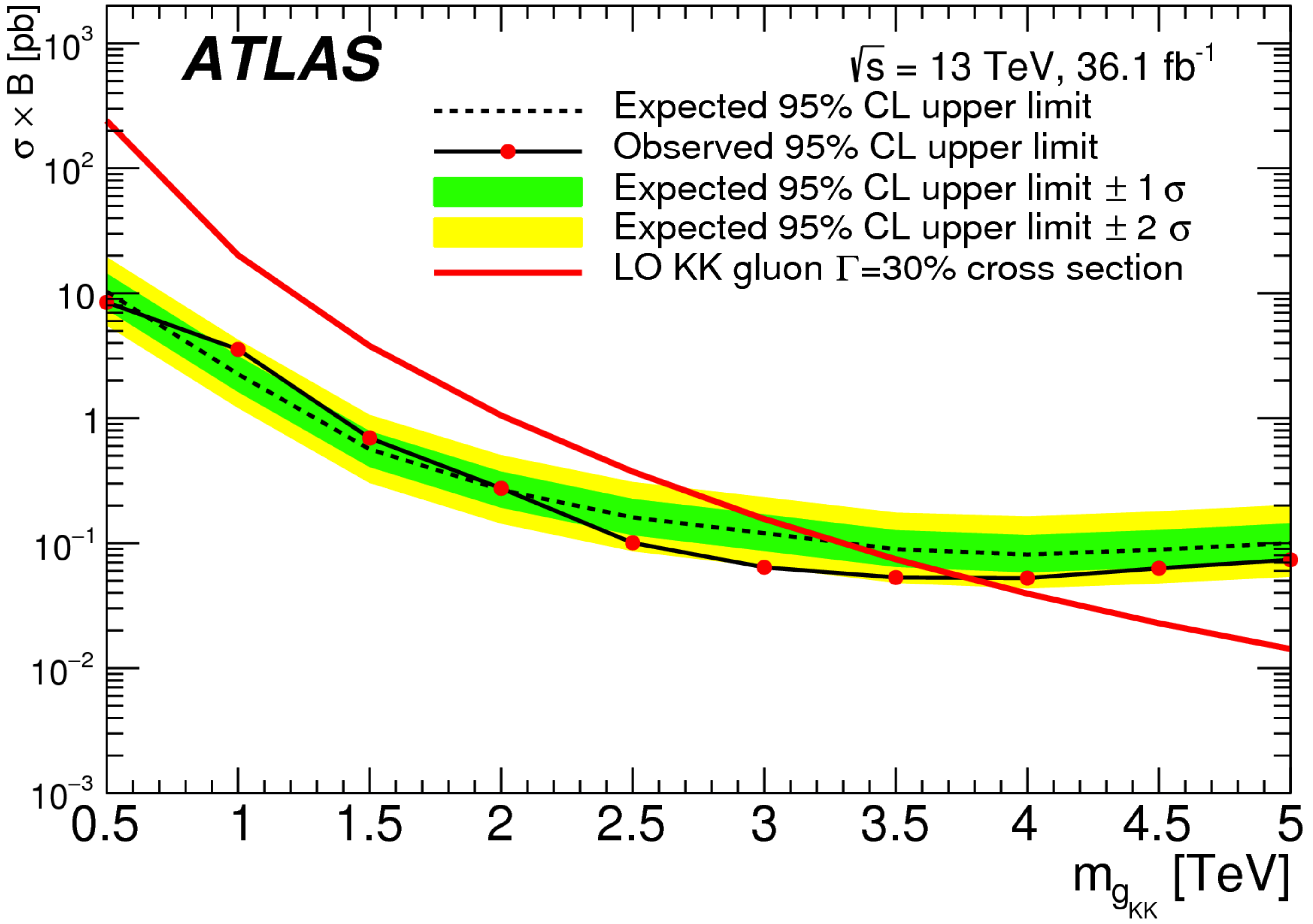
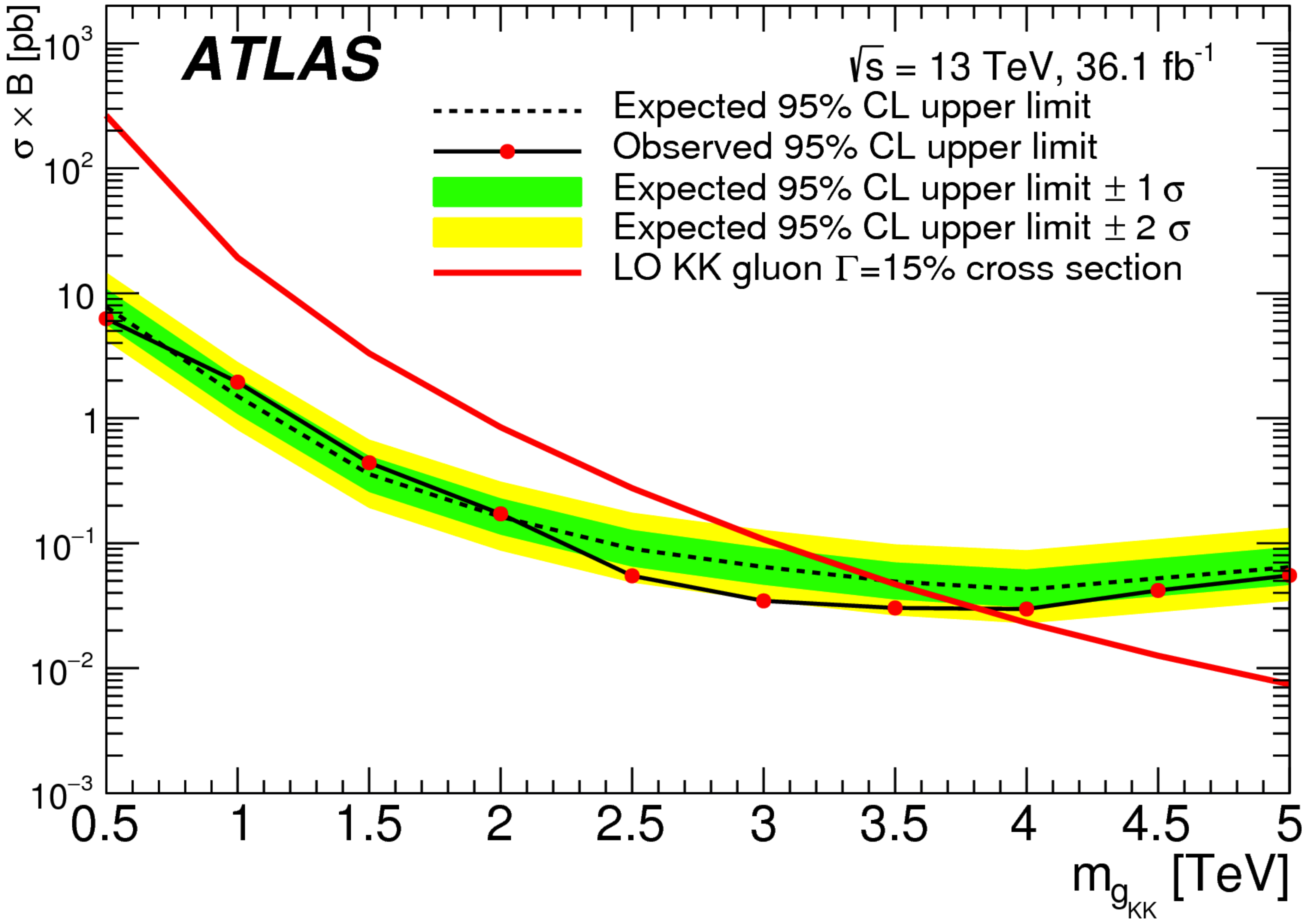
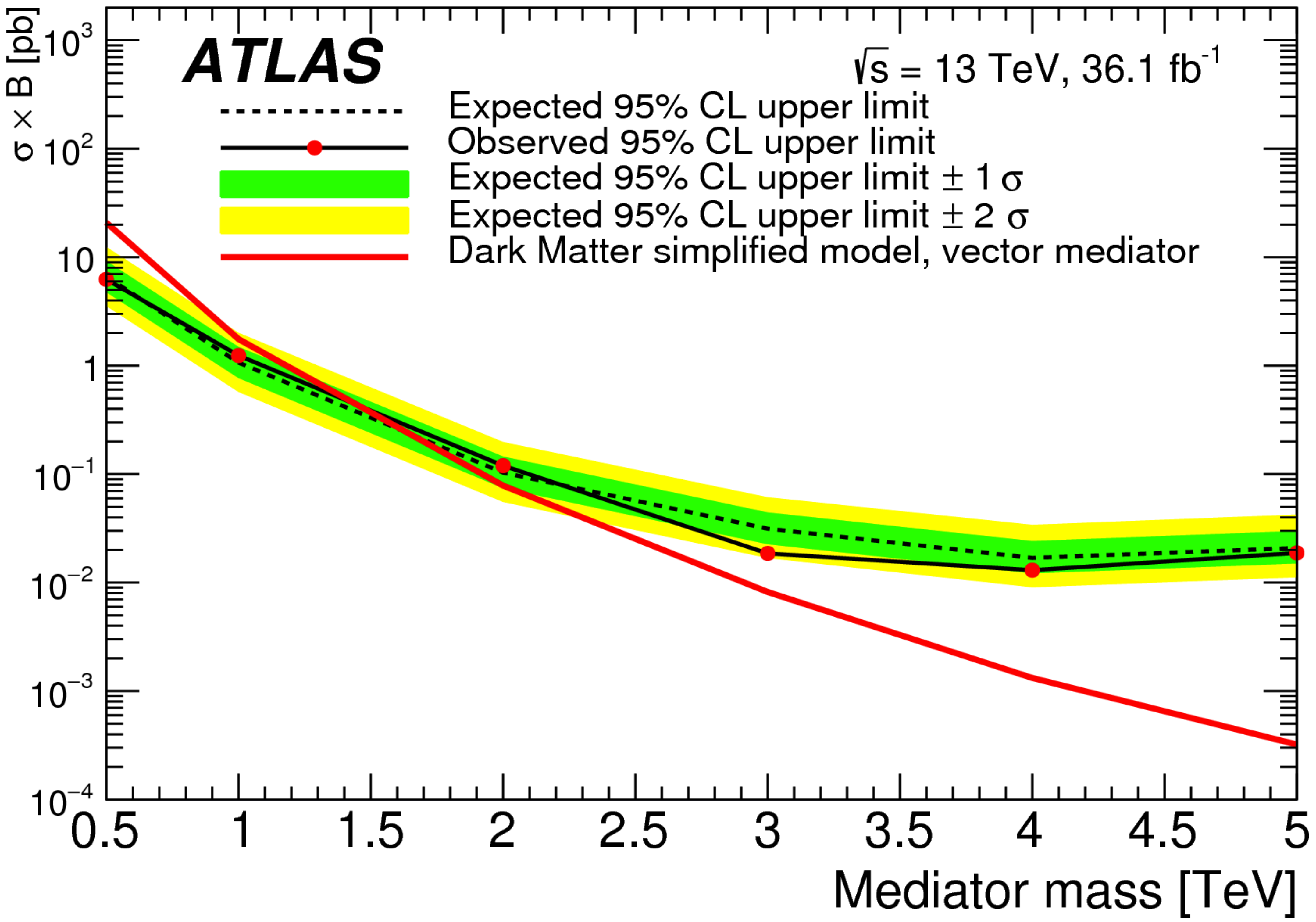
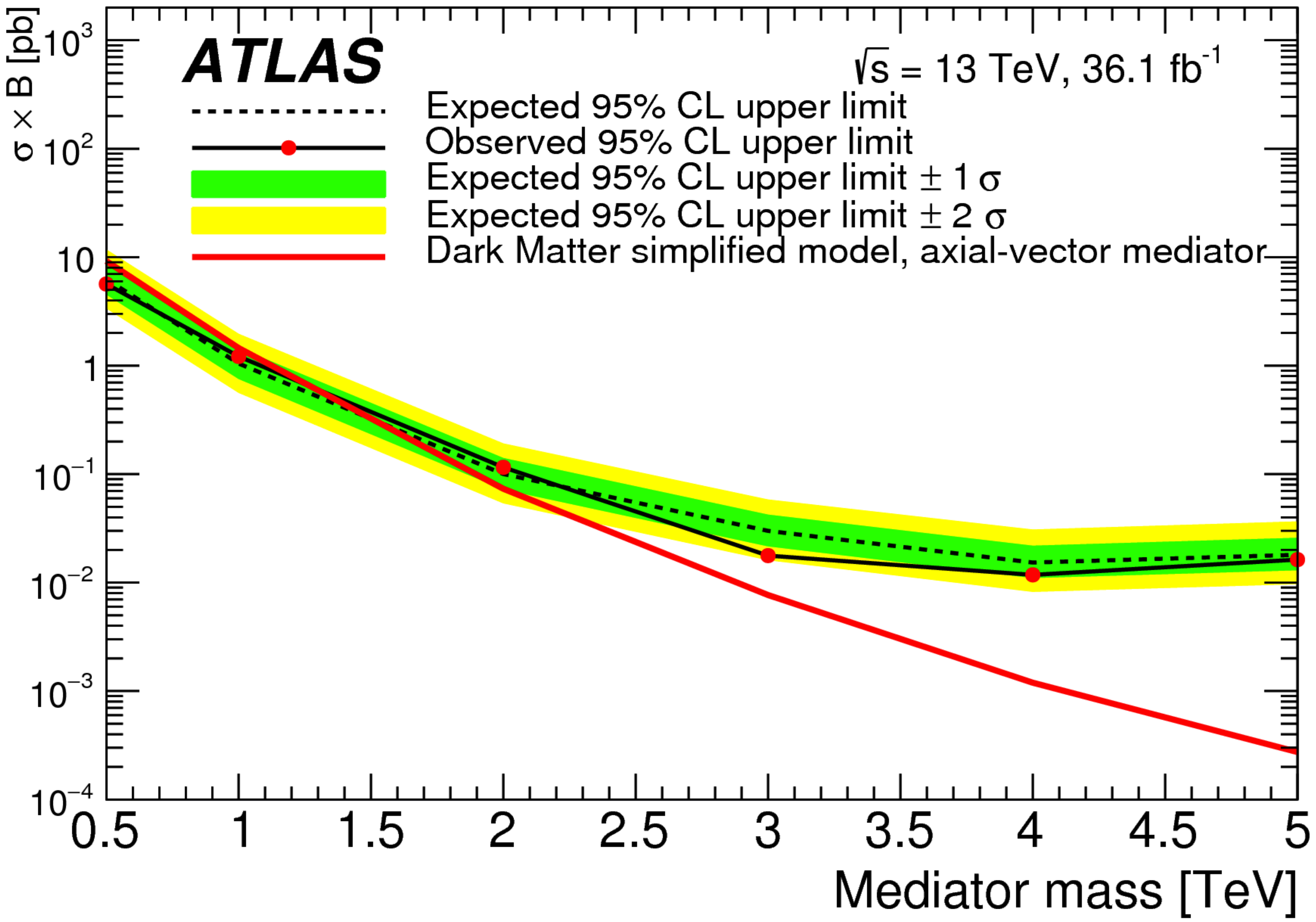
Lepton+jets: exclusion limits





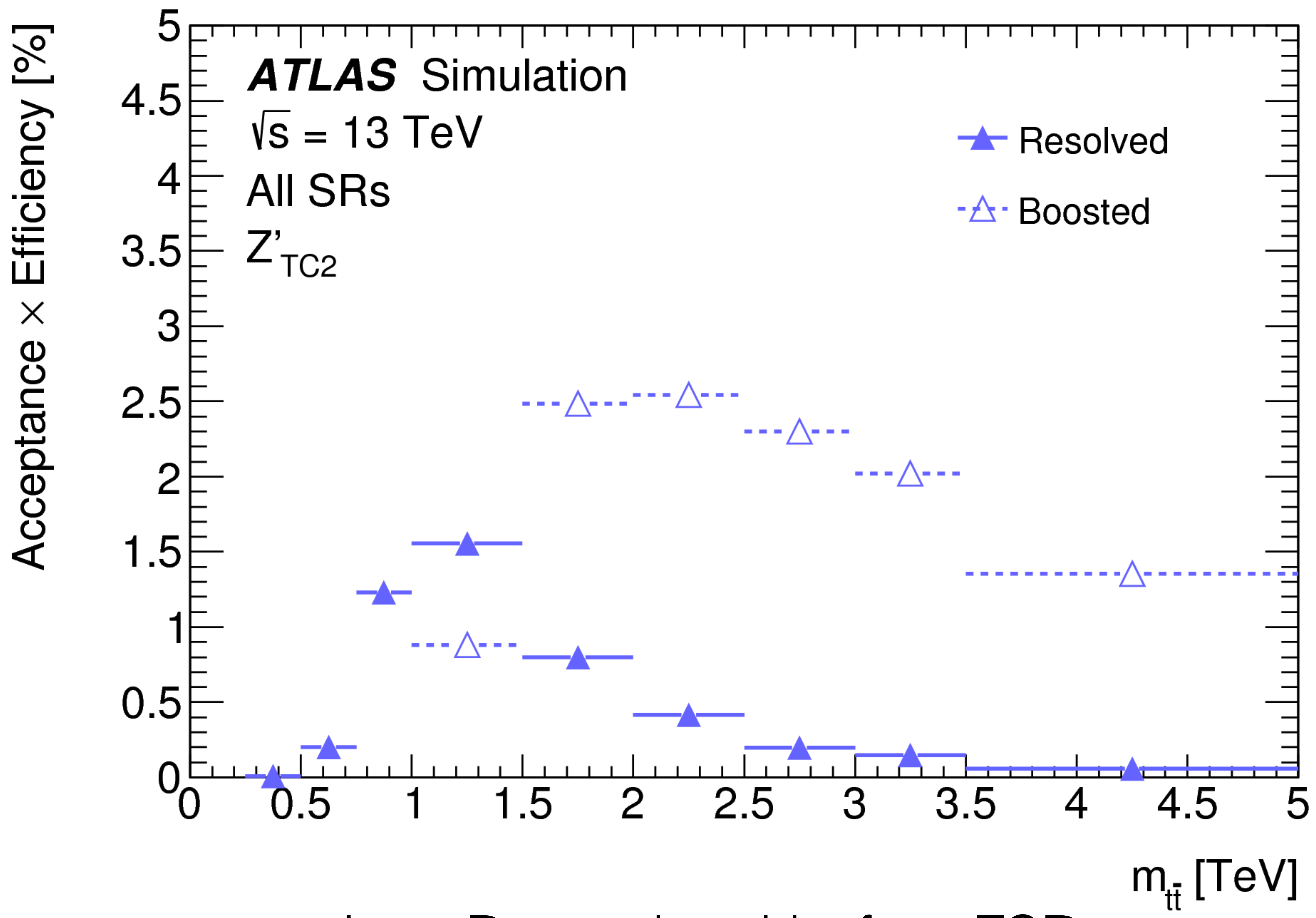
Lepton+jets: exclusion limits



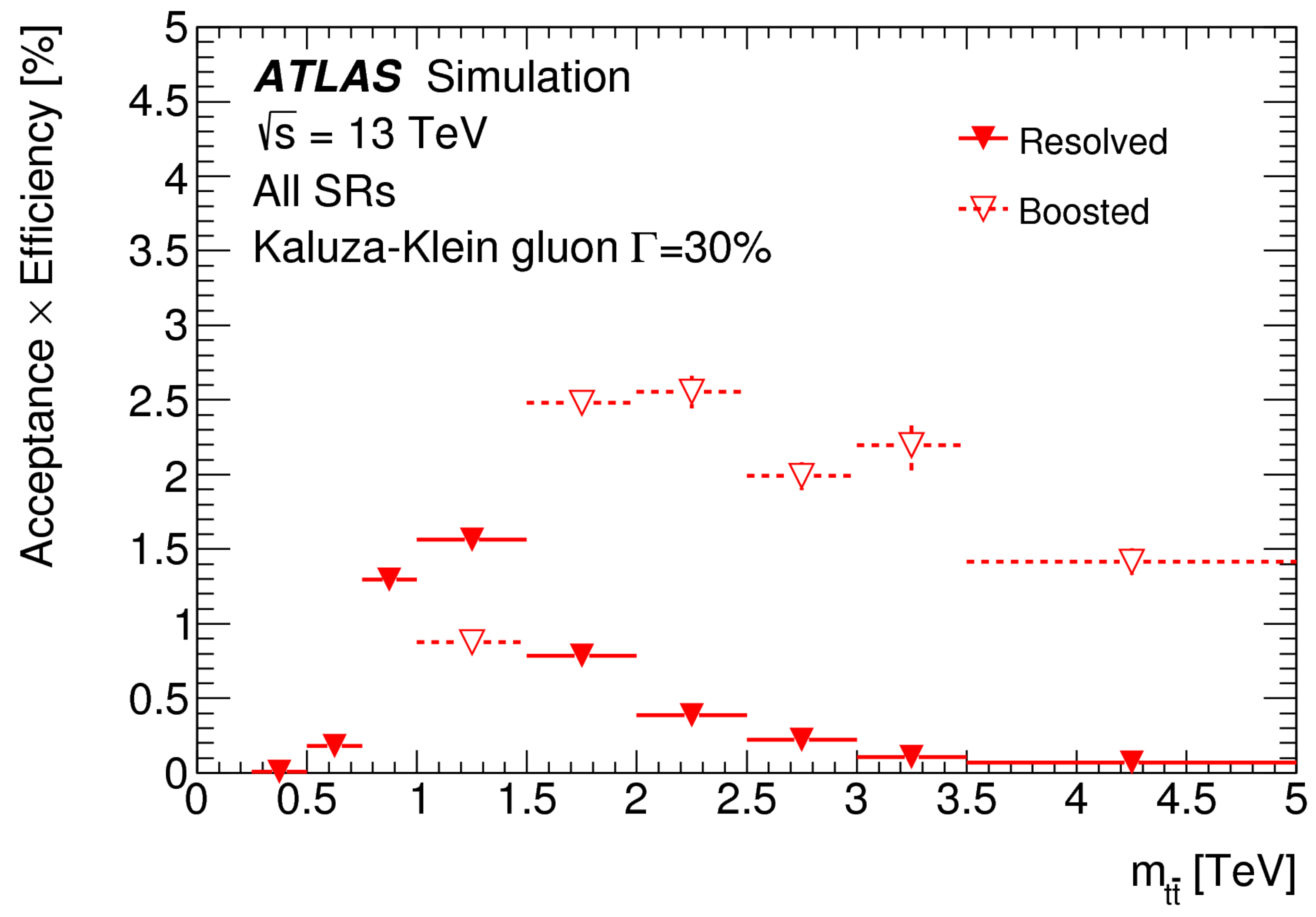


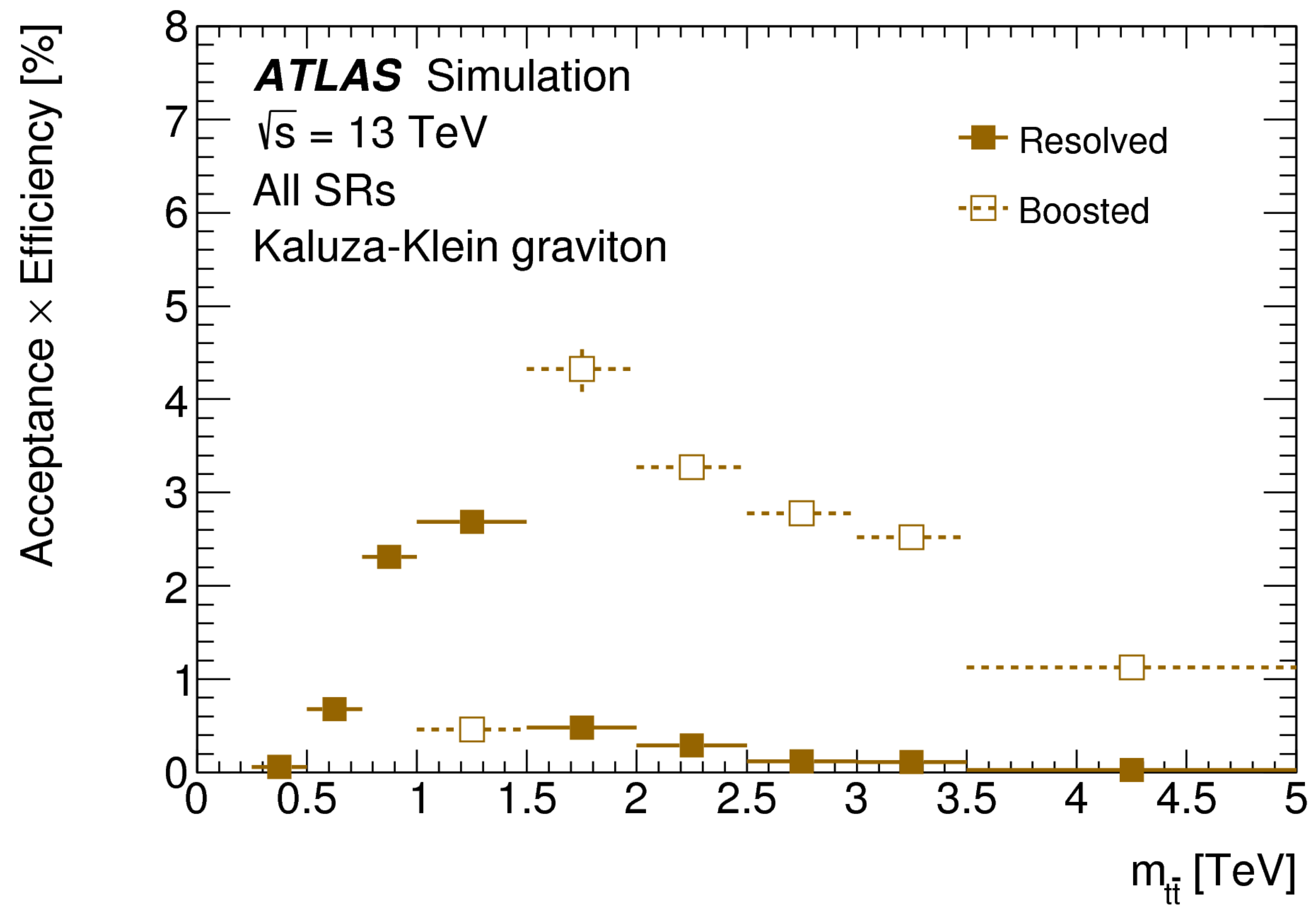
Width ≃ 5.6% mass

All-jets: selection efficiency times acceptance

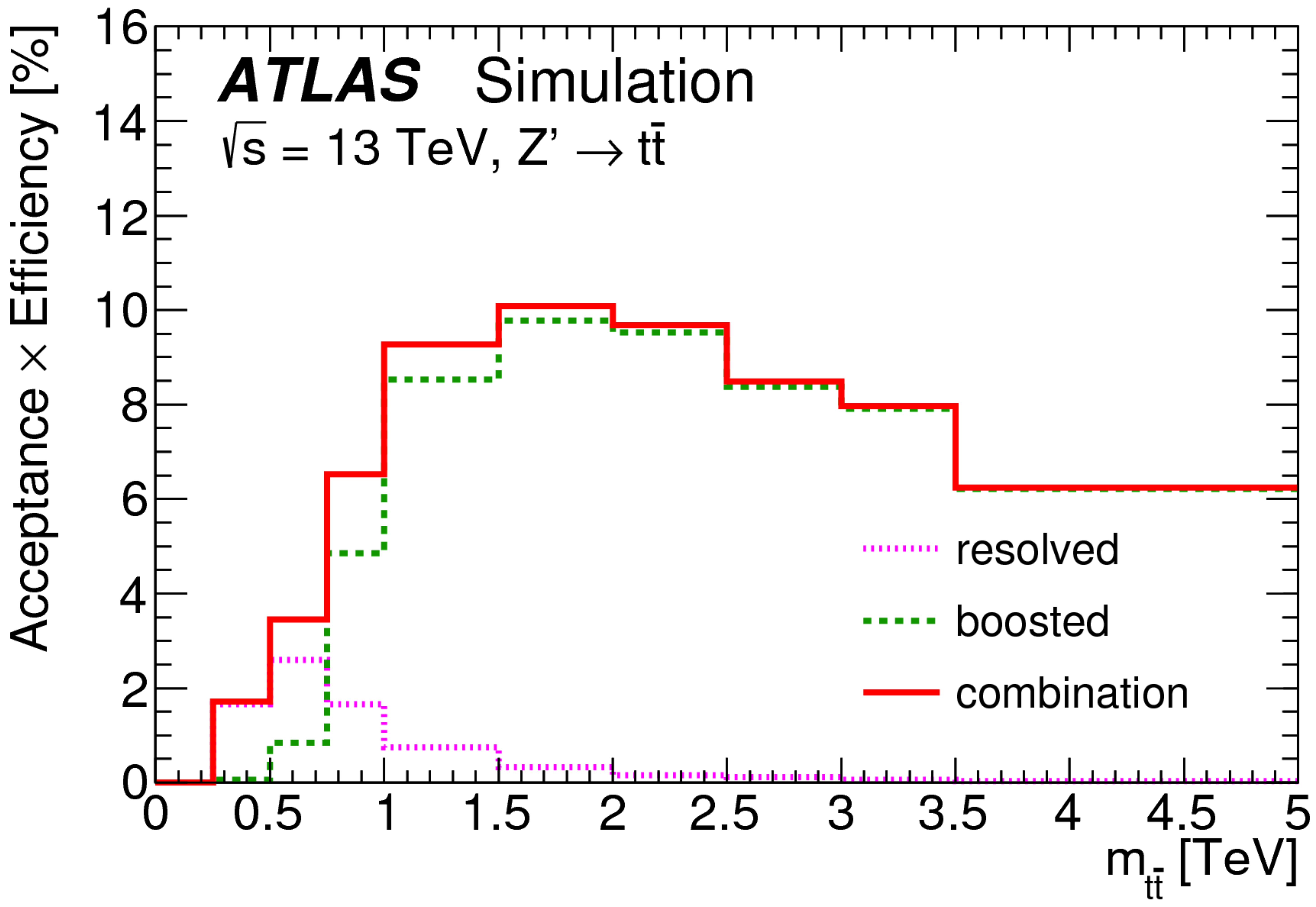


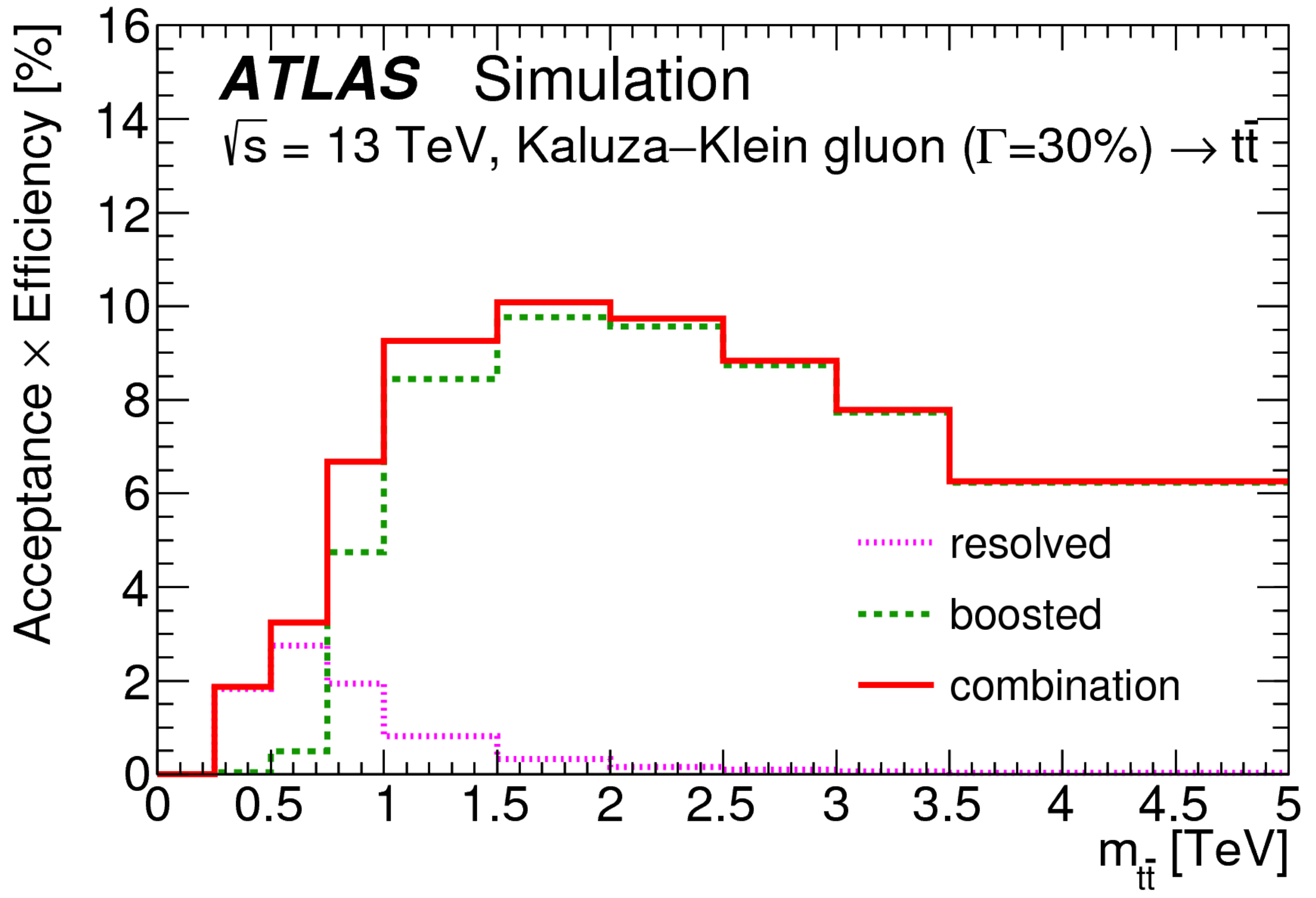
$m_{t\bar{t}}$ is at Parton level before FSR

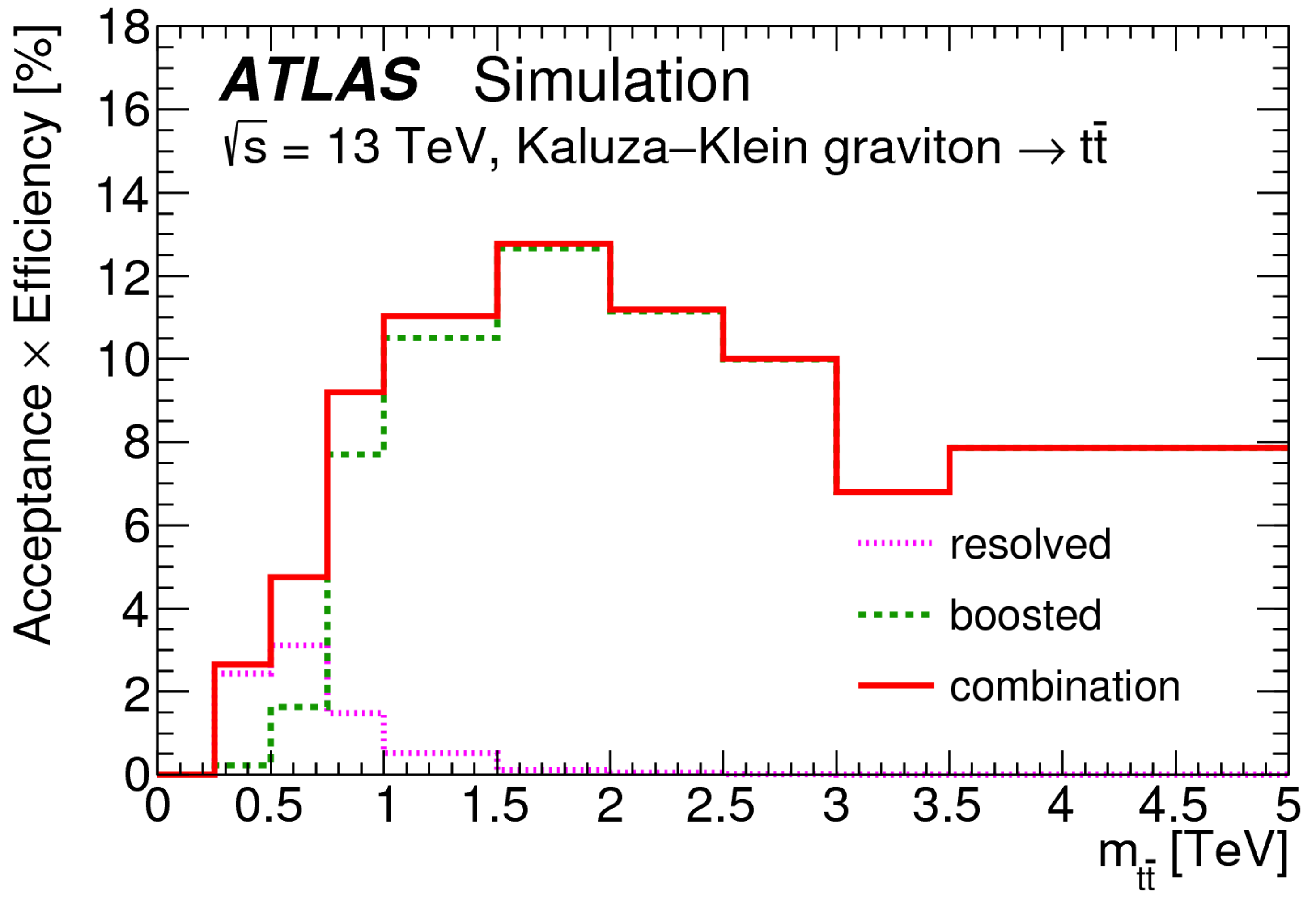




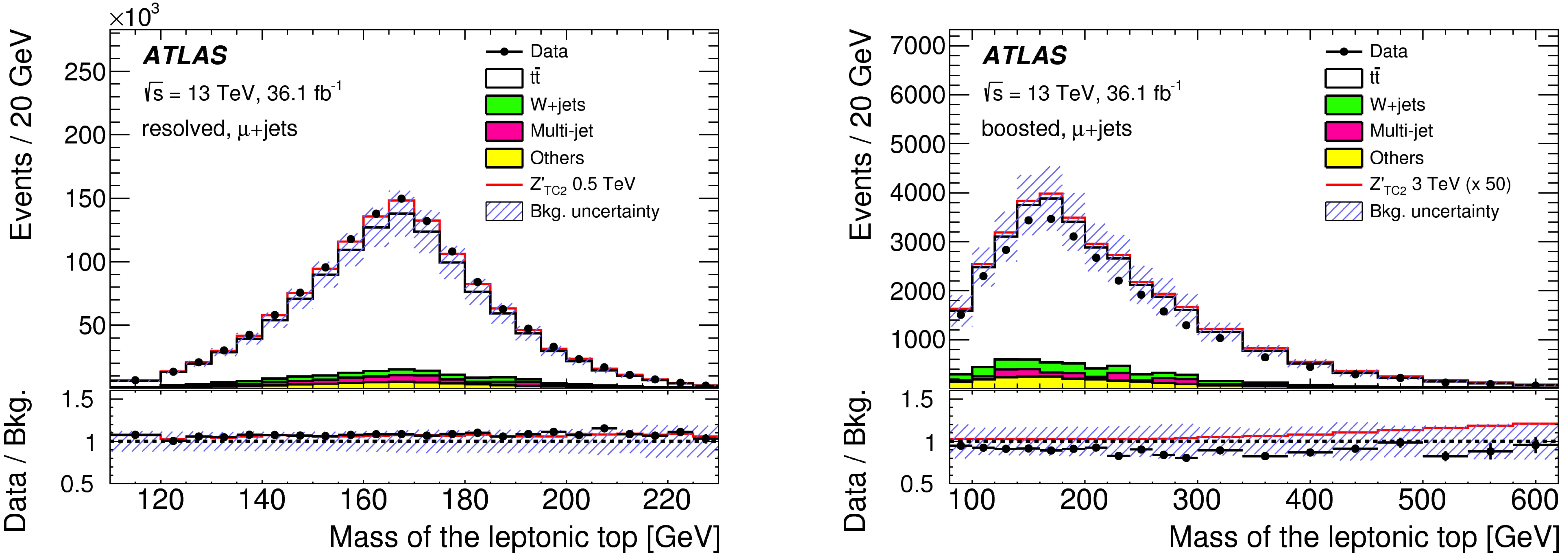
Lepton+jets: selection efficiency times acceptance



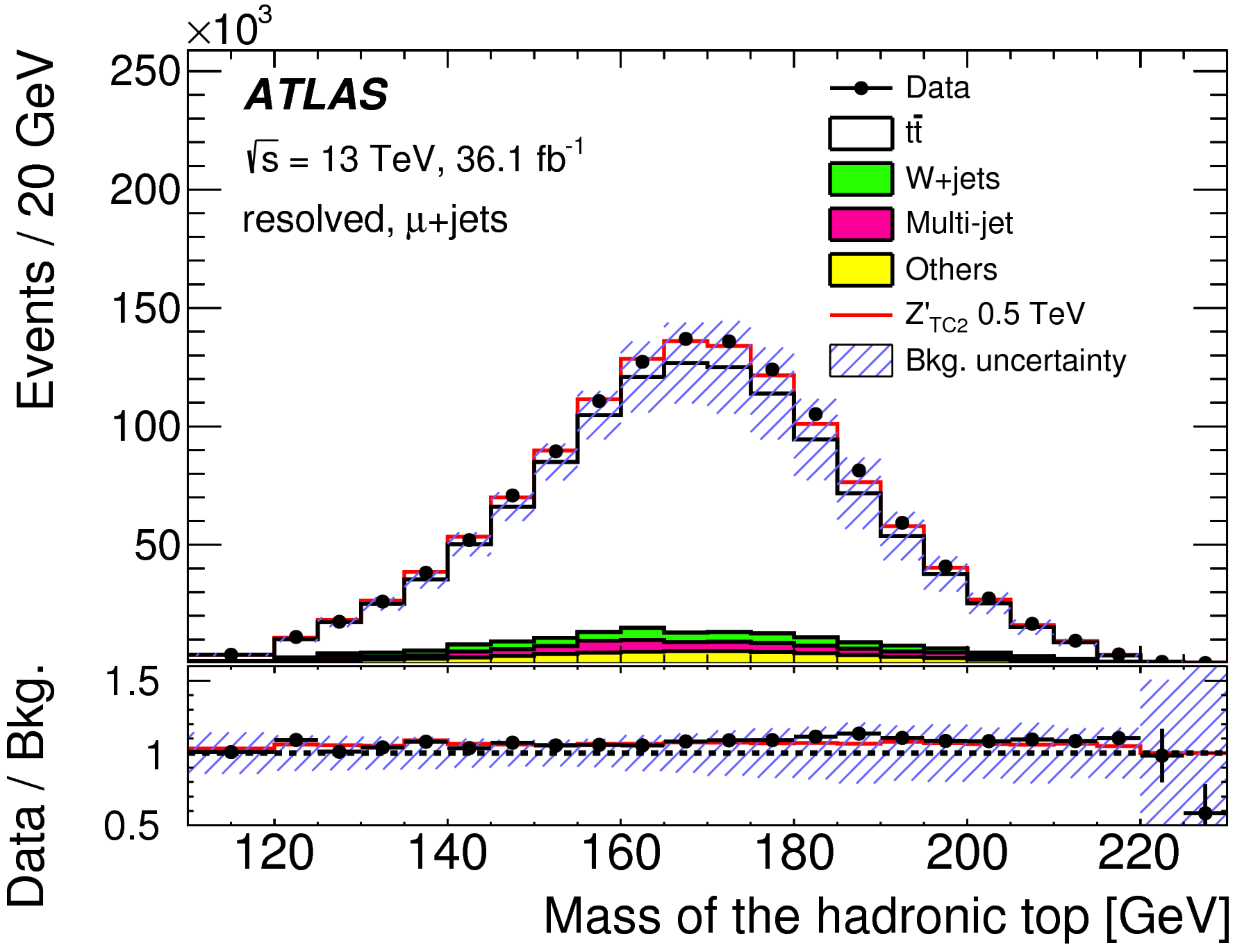


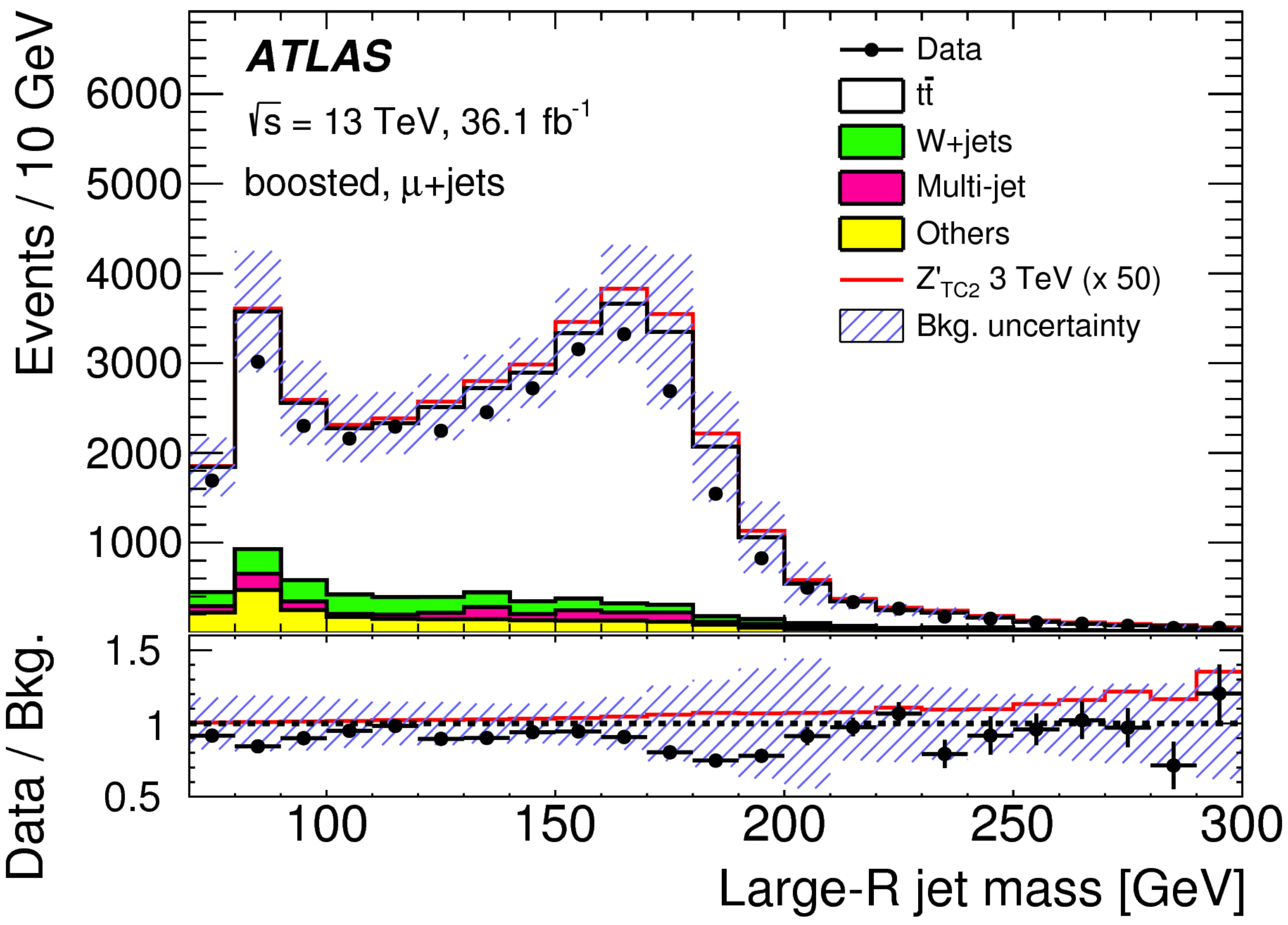


Leptonic top mass (muon)

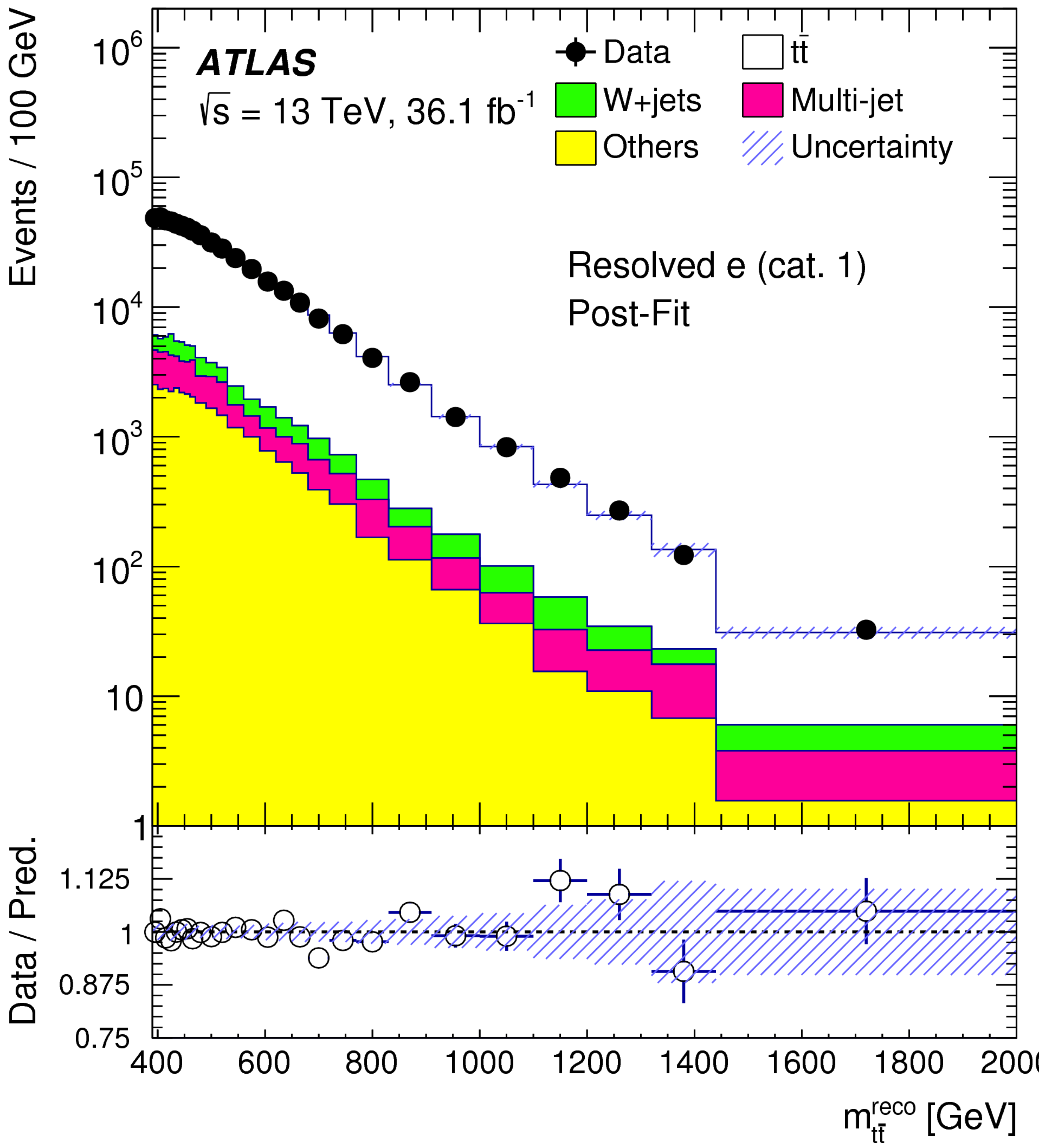


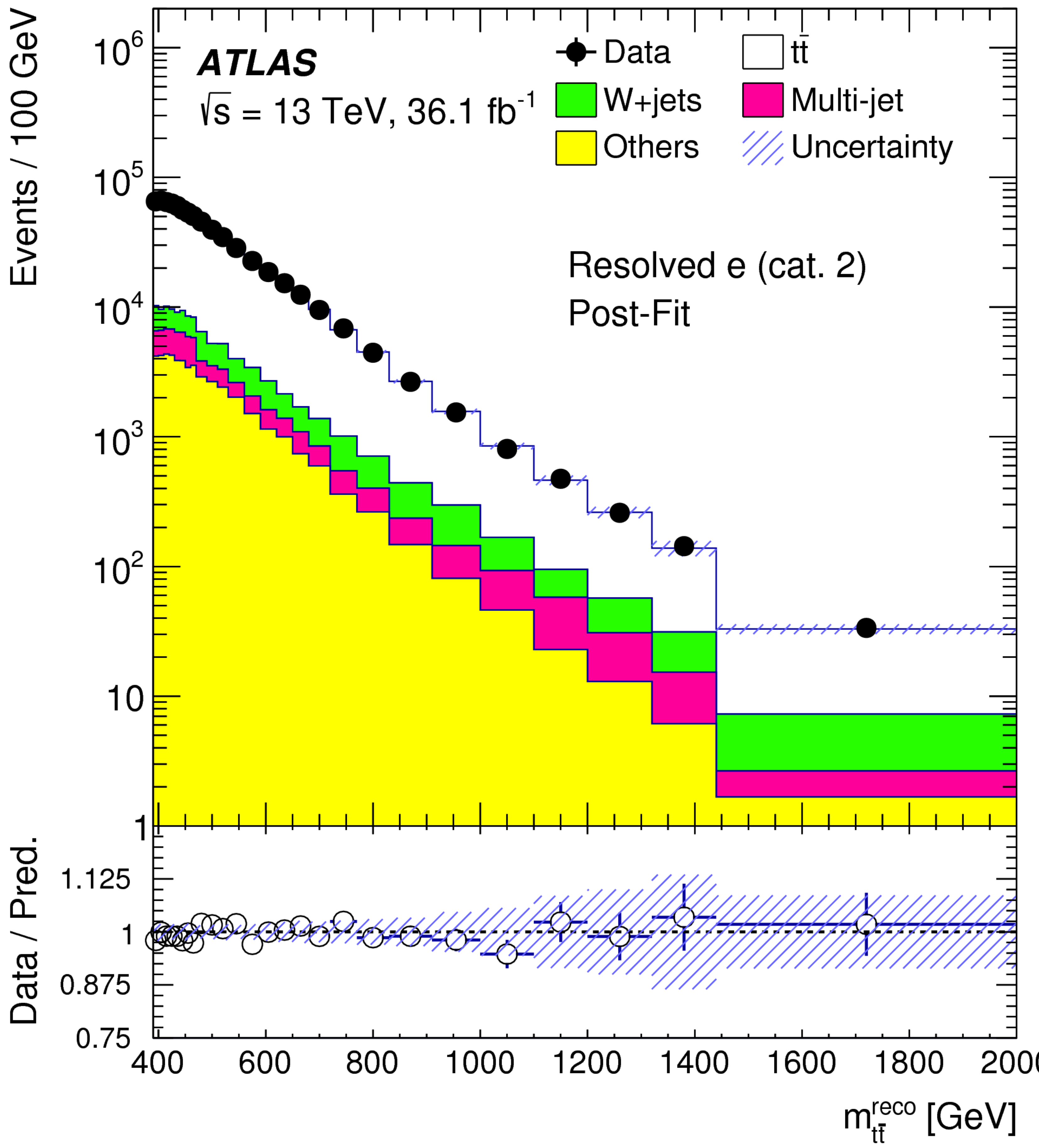
Hadronic top mass (muon)

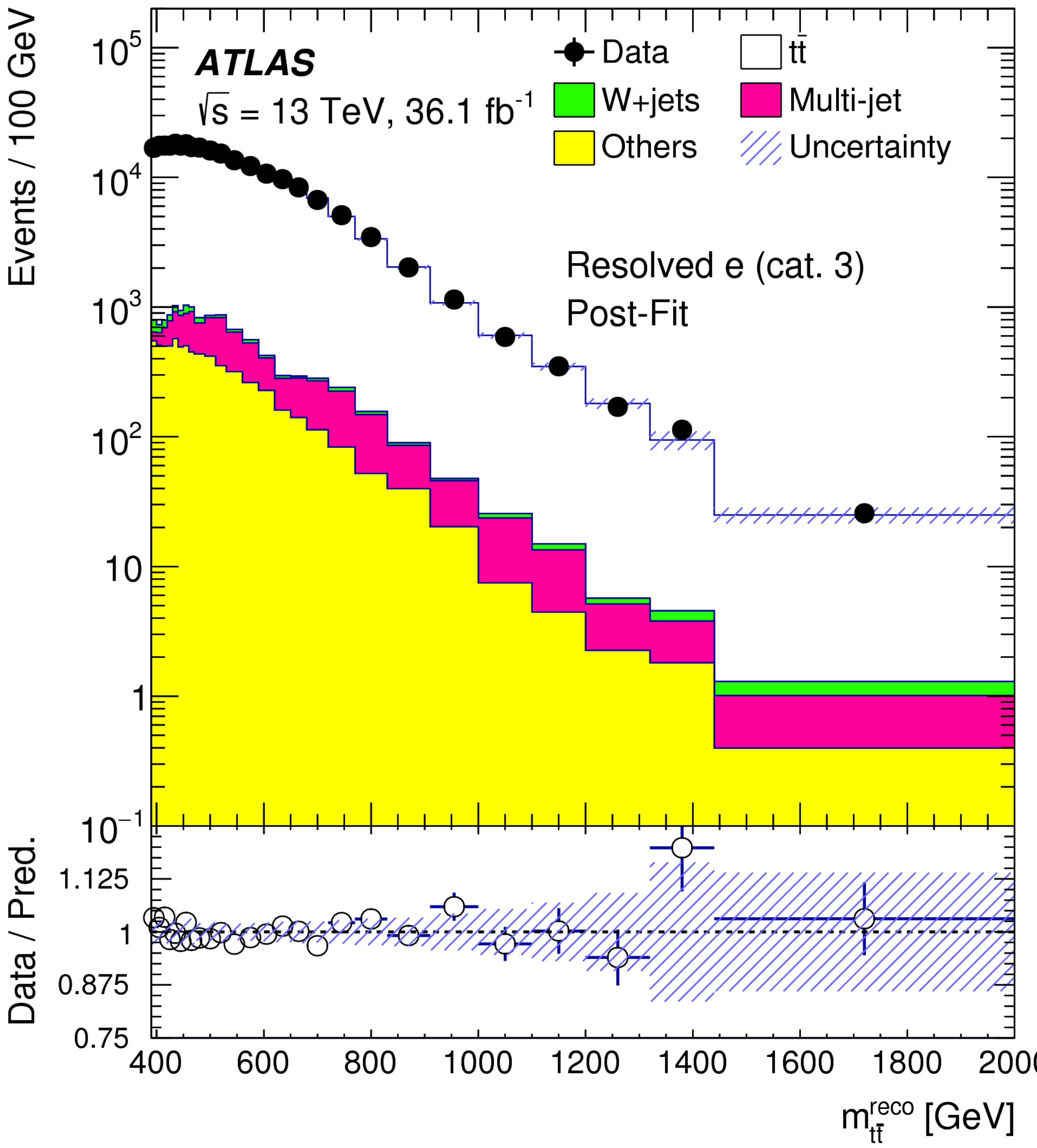




$m_{t\bar{t}}$ spectrum (resolved, e)







Which top matched to b-tagged jet(s)?

Leptonic top | Hadronic top | Both top

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$m_{t\bar{t}}$ spectrum (resolved, μ)

ATLAS EXPERIMENT

$m_{t\bar{t}}$ spectrum (boosted, e)

$m_{t\bar{t}}$ spectrum (boosted, μ)

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All-jets: Systematic uncertainties

ATLAS EXPERIMENT

	Resolved (Z'_{TC2} $m = 0.75$ TeV)	Boosted (Z'_{TC2} $m = 3$ TeV)
Source of uncertainty	Relative impact on μ	Relative impact on μ
Luminosity	< 0.01	$+0.03/-0.03$
b-tagging efficiency	$+0.05/-0.04$	$+0.07/-0.07$
Small- and large-R JES and JER	$+0.20/-0.24$	$+0.21/-0.09$
$t\bar{t}$ modeling	$+0.34/-0.33$	$+0.10/-0.09$
Multijet estimation	$+0.25/-0.27$	$+0.16/-0.13$
Extrapolation	–	$+0.34/-0.33$
PDF	$+0.07/-0.08$	$+0.10/-0.10$
Pileup reweighting	$+0.07/-0.05$	< 0.01
Simulation statistical uncertainty	± 0.41	–
Total systematic uncertainty	± 0.92	± 0.67
Data statistical uncertainty	± 0.39	± 0.74

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Lepton+jets: systematic uncertainties

ATLAS EXPERIMENT

Systematic Uncertainty	Background [%]		Z'_{TC2}, 2 TeV [%]		Z'_{TC2}, 3 TeV [%]	
	resolved	boosted	resolved	boosted	resolved	boosted
$t\bar{t}$ extra QCD radiation	4.0	2.4	–	–	–	–
$t\bar{t}$ QCD NNLO	0.8	7.4	–	–	–	–
$t\bar{t}$ cross-section	5.2	–	–	–	–	–
$t\bar{t}$ generator	1.7	3.8	–	–	–	–
$t\bar{t}$ parton shower	0.6	3.2	–	–	–	–
Multi-jet	2.6	2.7	–	–	–	–
Anti-k_t $R = 0.4$ JER	1.1	0.2	3.2	0.2	1.2	0.2
Anti-k_t $R = 0.4$ JES	5.8	0.9	7.0	0.7	3.6	0.6
Anti-k_t $R = 1.0$ JER	0.1	4.0	5.3	3.7	2.0	4.2
Anti-k_t $R = 1.0$ JES	0.3	6.0	3.7	4.7	2.8	6.0
b-tagging efficiency	3.2	1.8	1.8	1.9	2.3	2.7
b-tagging extrapolation	2.4	2.3	2.0	0.6	1.2	1.8
Luminosity	1.9	1.9	2.1	2.1	2.1	2.1
Pile-up	4.4	0.5	4.4	0.8	3.9	0.5
Total	11.6	12.8	11.7	7.1	7.6	8.7

More plots & tables

- All-jets final states: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2016-24/
- Lepton+jets final states: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2015-04/