Searches for new resonant phenomena in final states with two jets using the ATLAS detector

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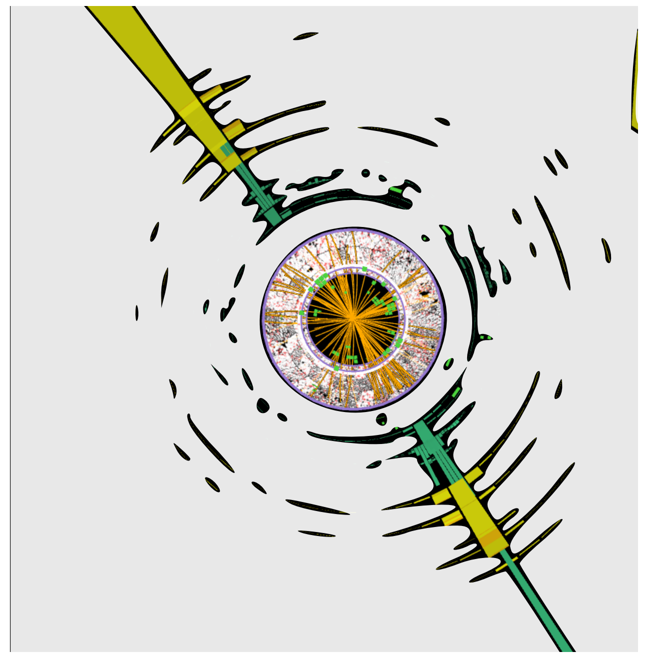
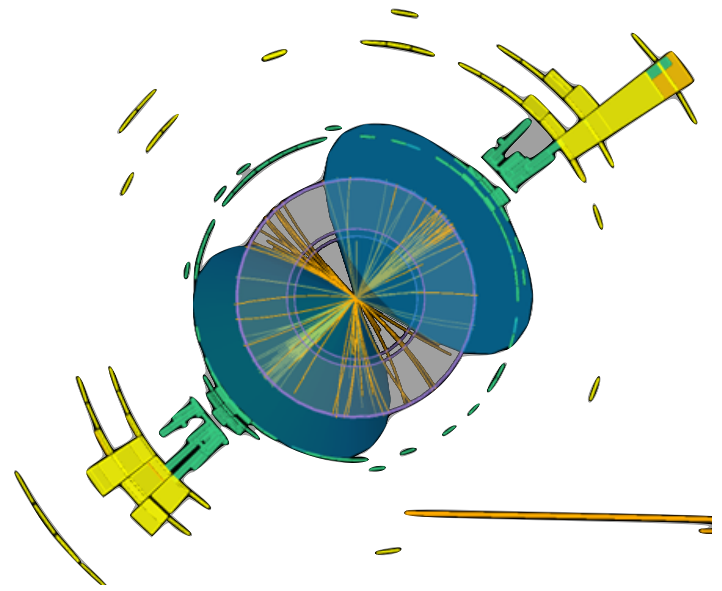
ATLAS EXPERIMENT

Outline



Search for dijet and di-bjet resonances
JHEP 03 (2020) 145



Search for tt resonance in fully hadronic final state
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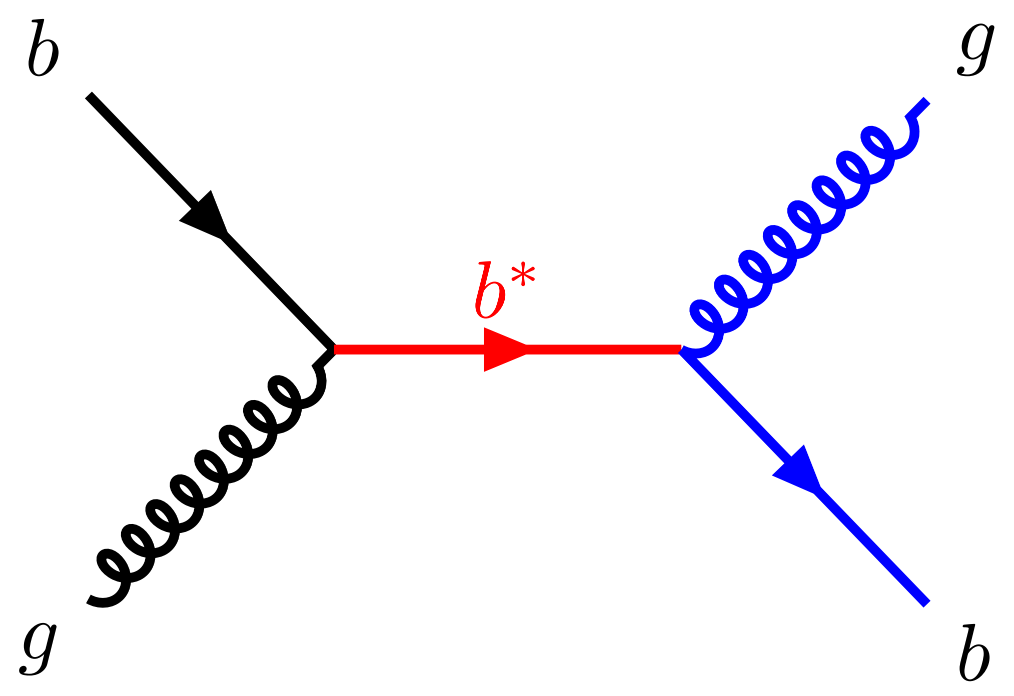
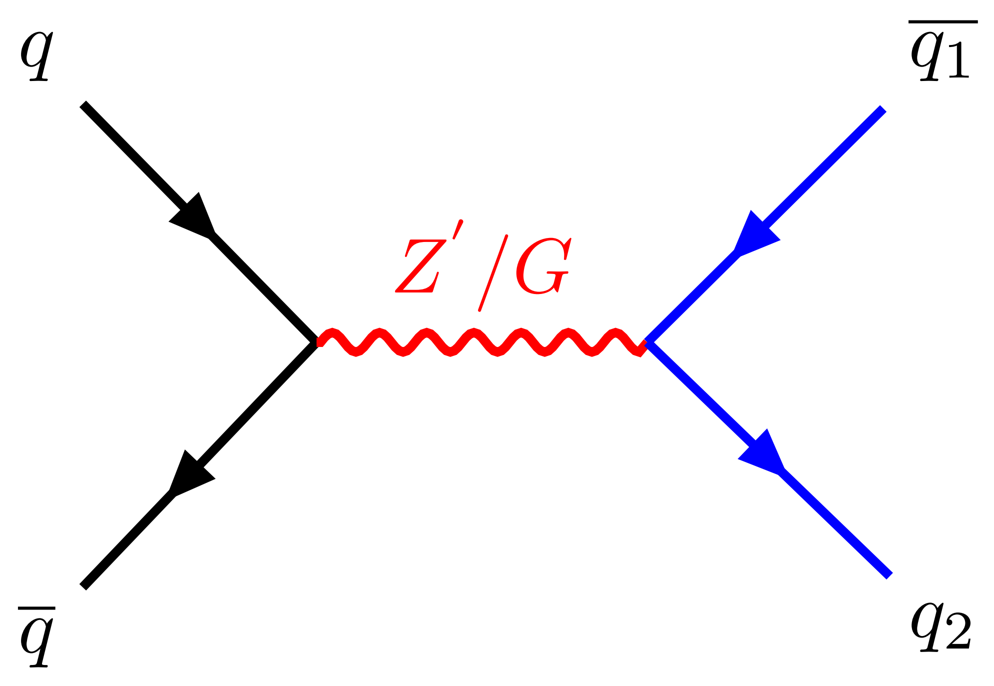
Dijet Resonance





Resonance search in two jet final state

- Simple event topology
- Sensitive to wide range of new physics

- Any such resonance could come from
  - Heavy new particles like Z',W'
  - Excited W-boson (W*)
  - Excited quark (q*)
  - Dark matter particle e.t.c

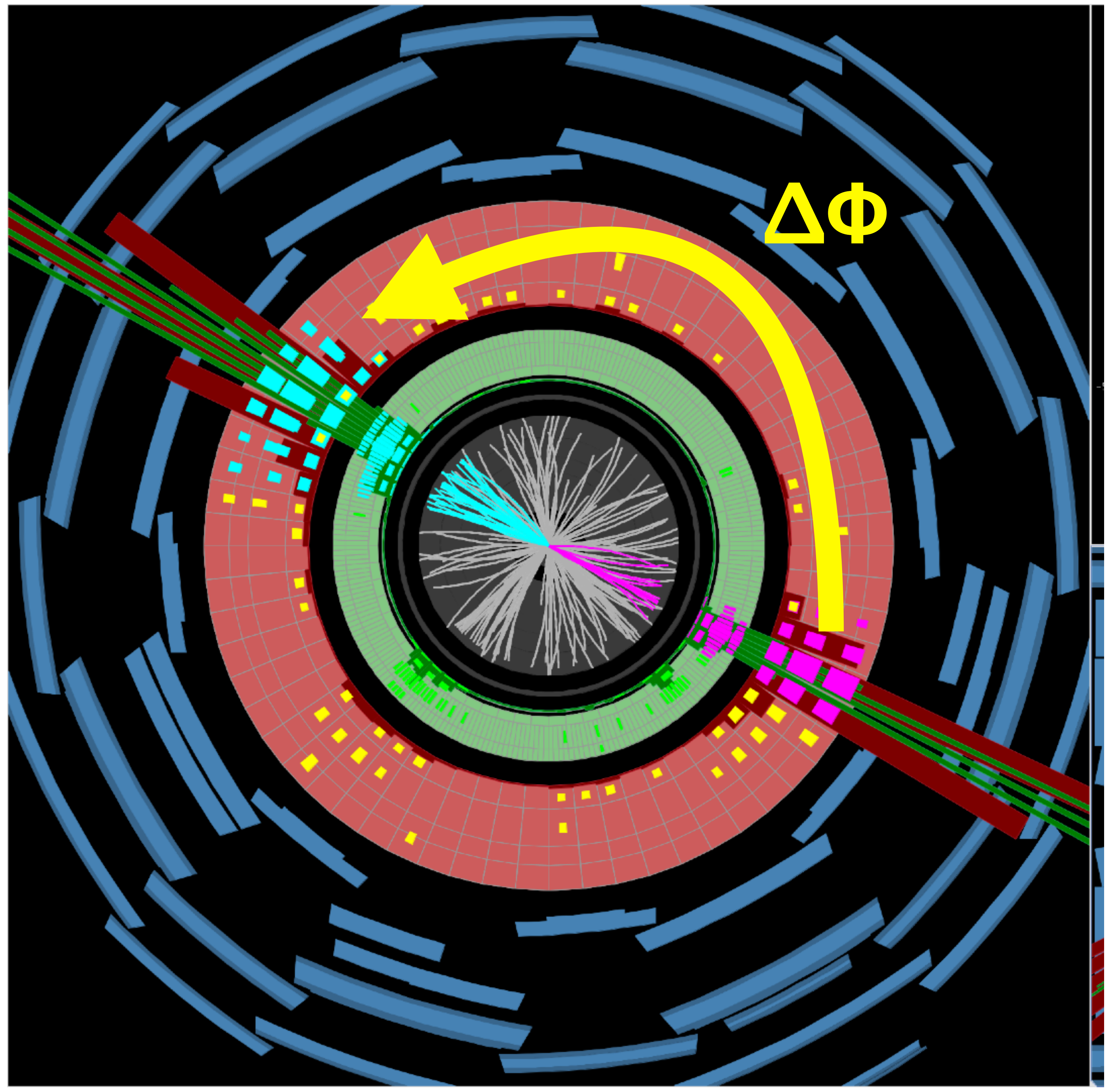
Most commonly used observable

mass of the dijet system

Dijet Search Result

[JHEP 03 (2020) 145]

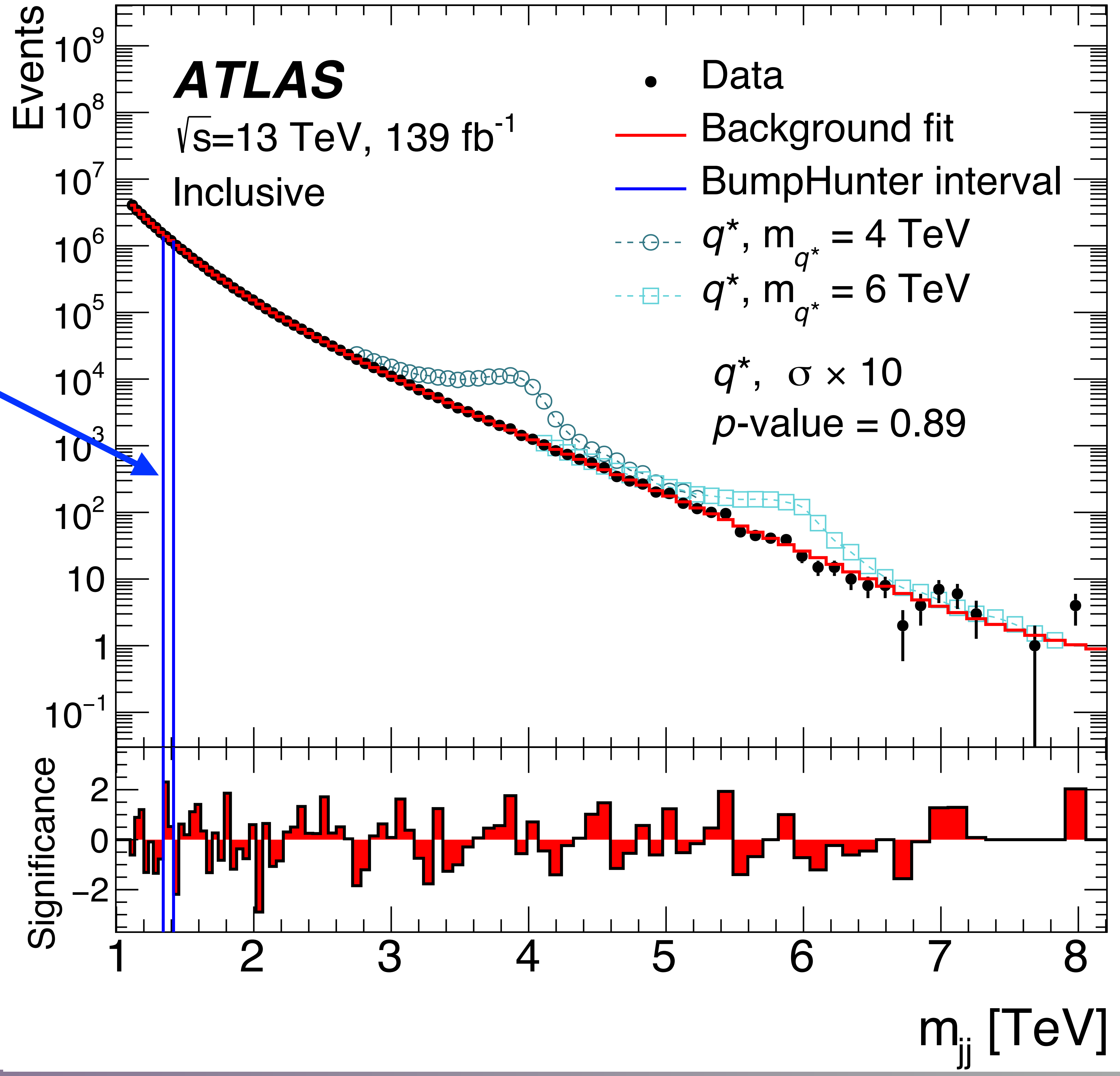
- Single jet trigger with p_T > 420 GeV
- Jets are back-to-back
  - $\Delta\Phi$ (J_1,J_2) > 1.0 (back-to-back)



- **Observable:** invariant mass of the di-jet system (m_{jj})
  - Calculated with R=0.4 jets

Di-jet mass (m_{jj}) > 1.1 TeV

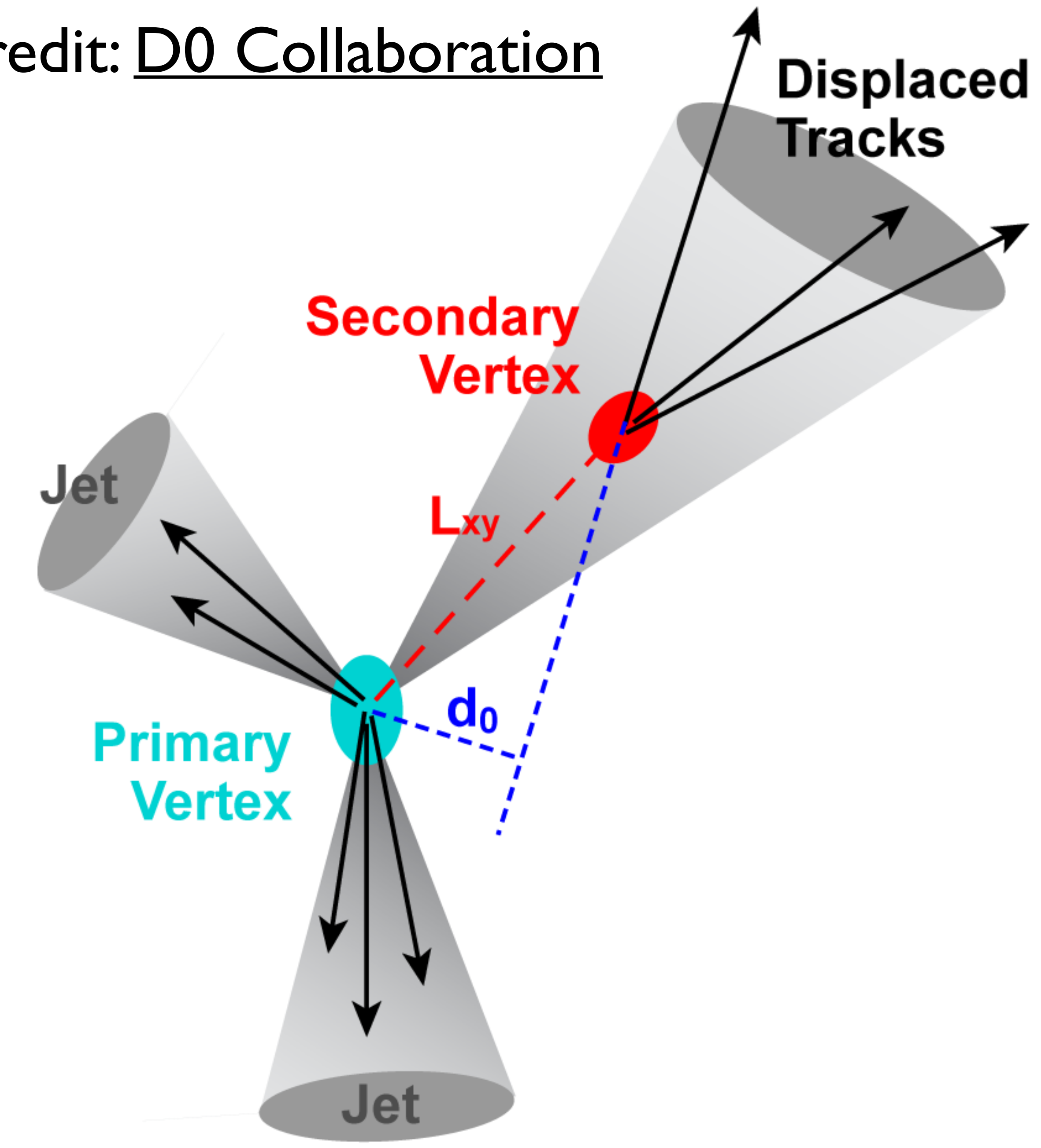
Interval with most significant discrepancy



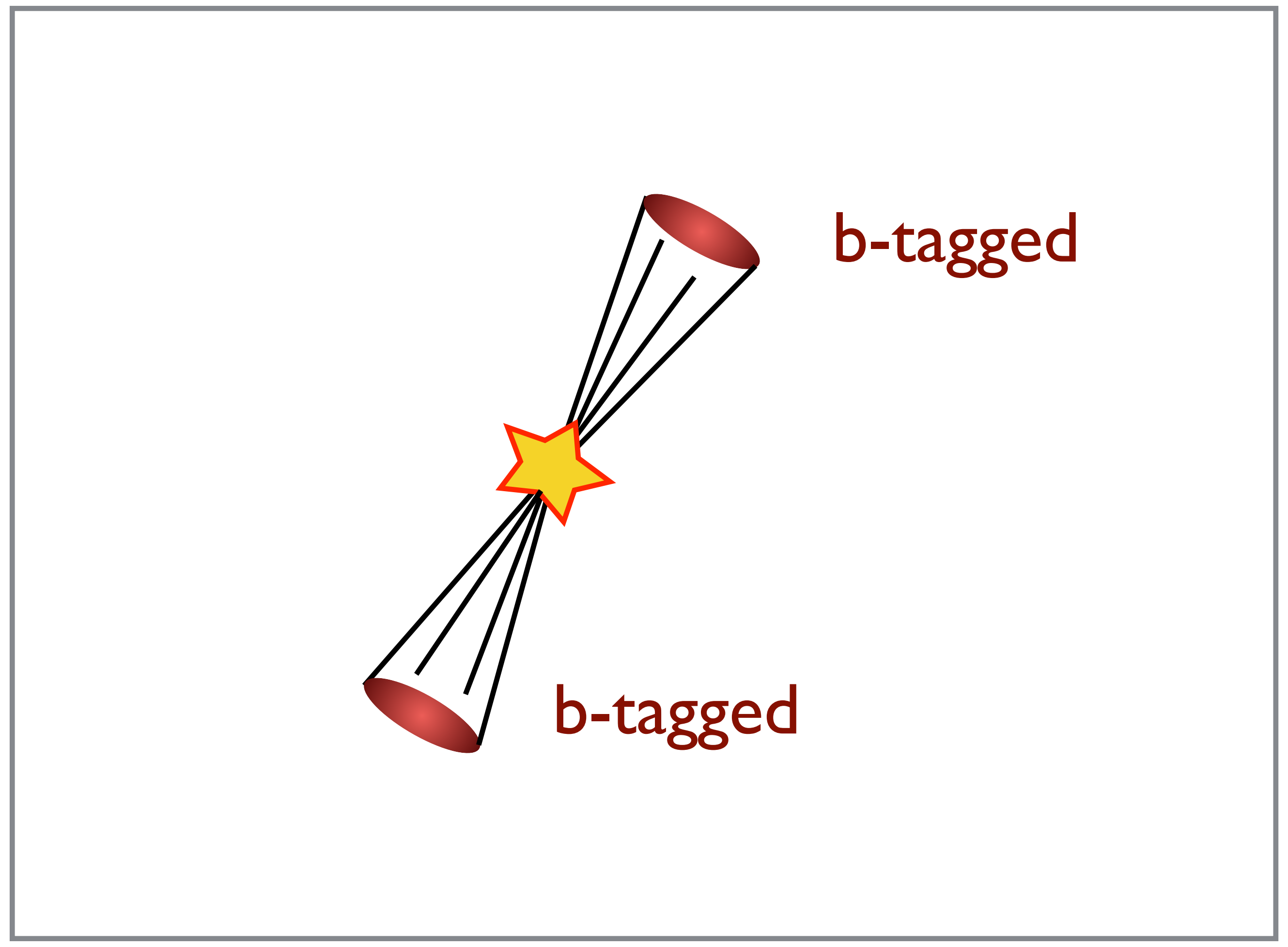
Final states with b-jets

b-hadron decay

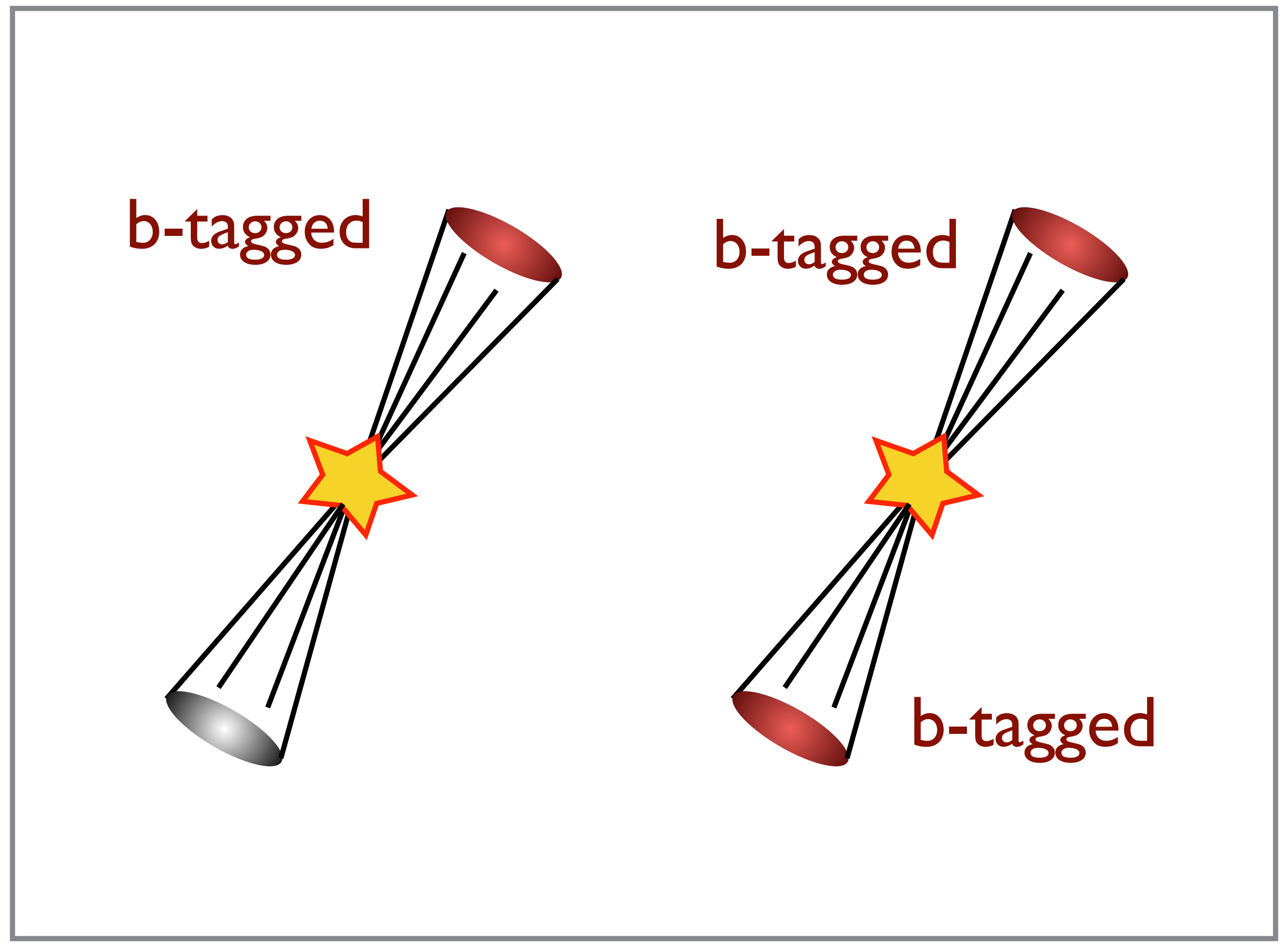
Figure Credit: D0 Collaboration



2 b-tag region
== 2 b-tagged jet



Inclusive 1 b-tag region
>= 1 b-tagged jet



- Displaced secondary vertex
- Deep Neural Network based b-tagging used for the first time in ATLAS

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Search results

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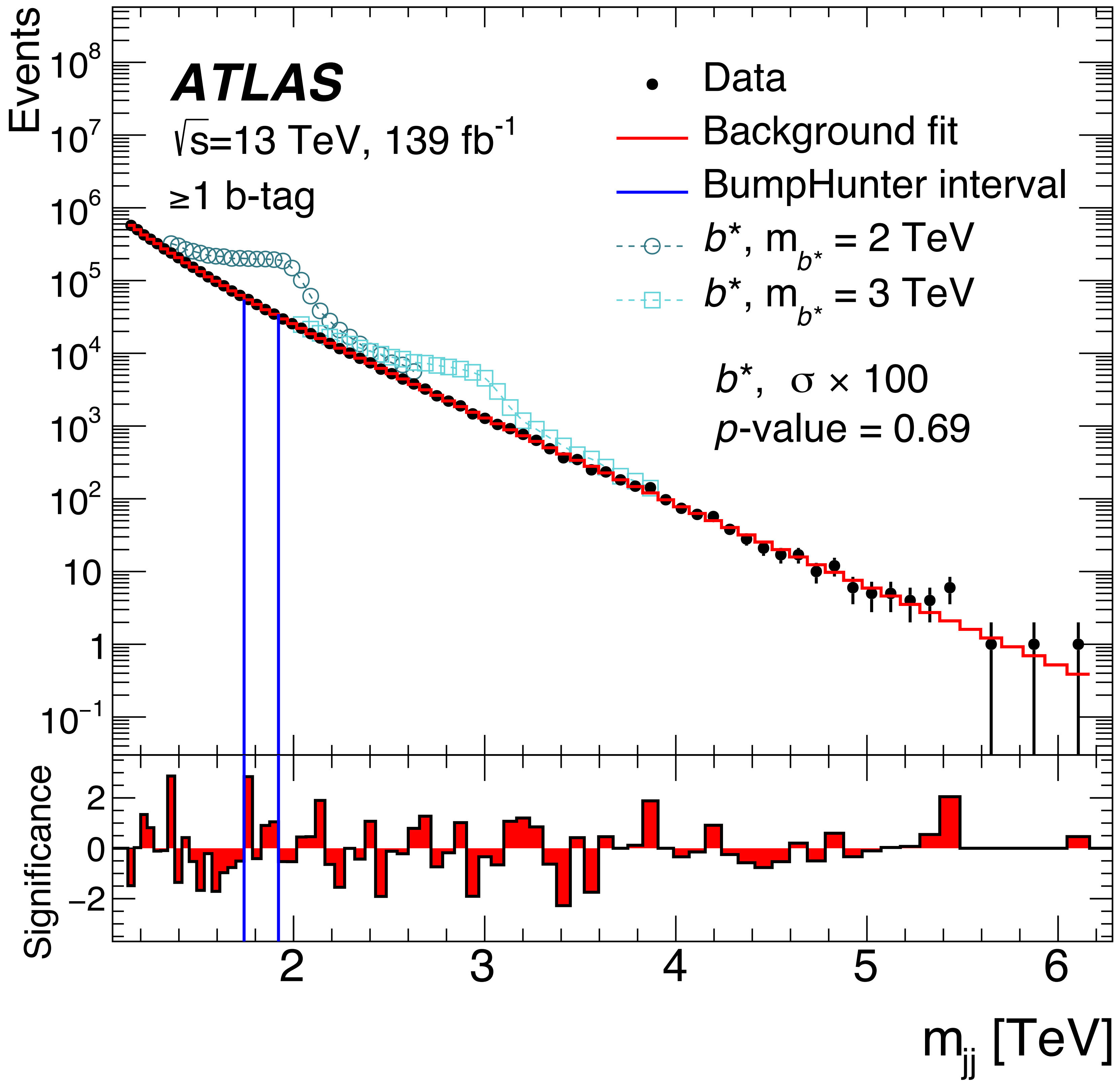
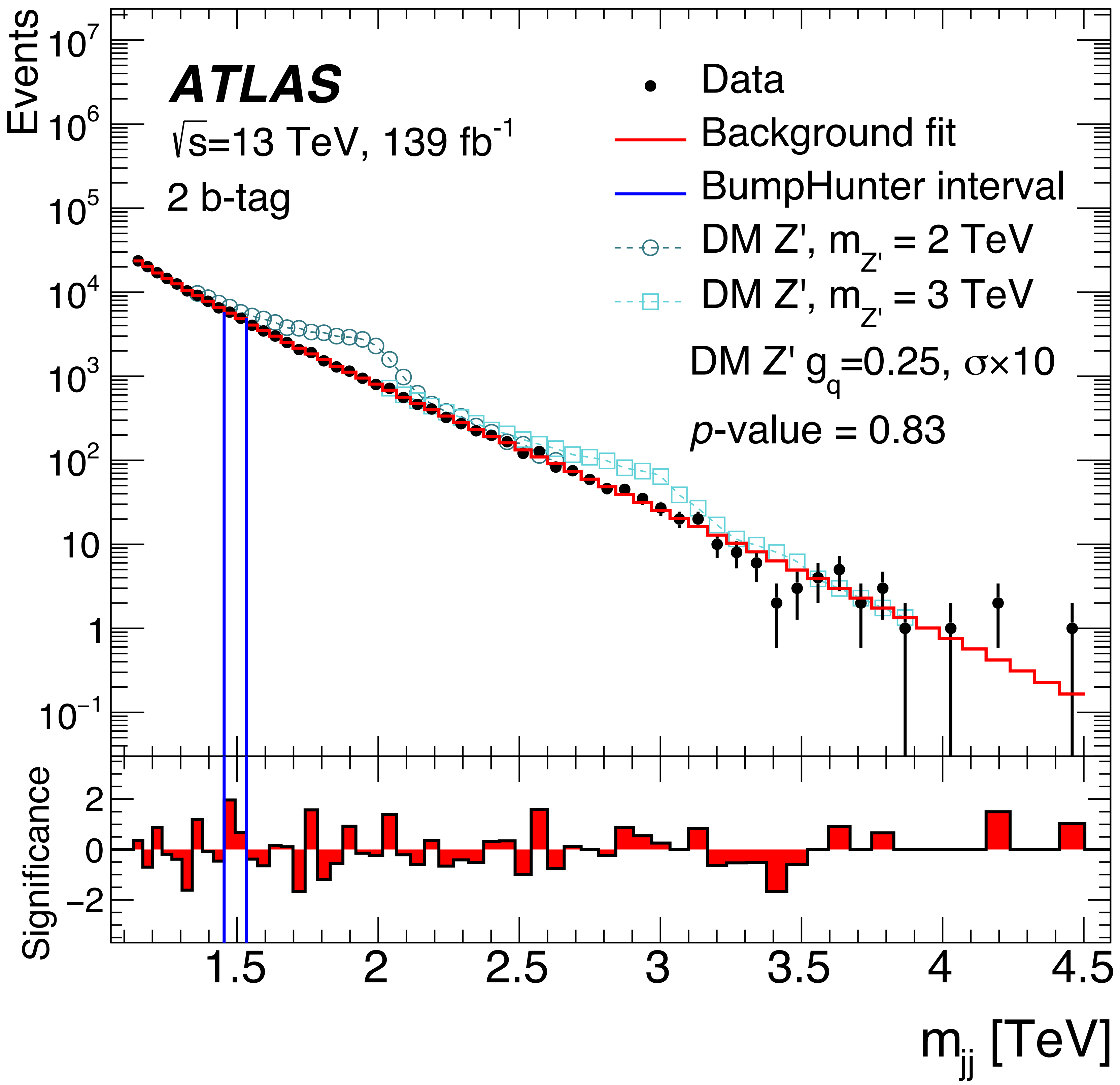
- Variable binning used
- **No evidence of new resonances was observed**
- Global p-values are < 1 sigma

>=1 b-tag Signal Region



2 b-tag Signal Region



Exclusion limit

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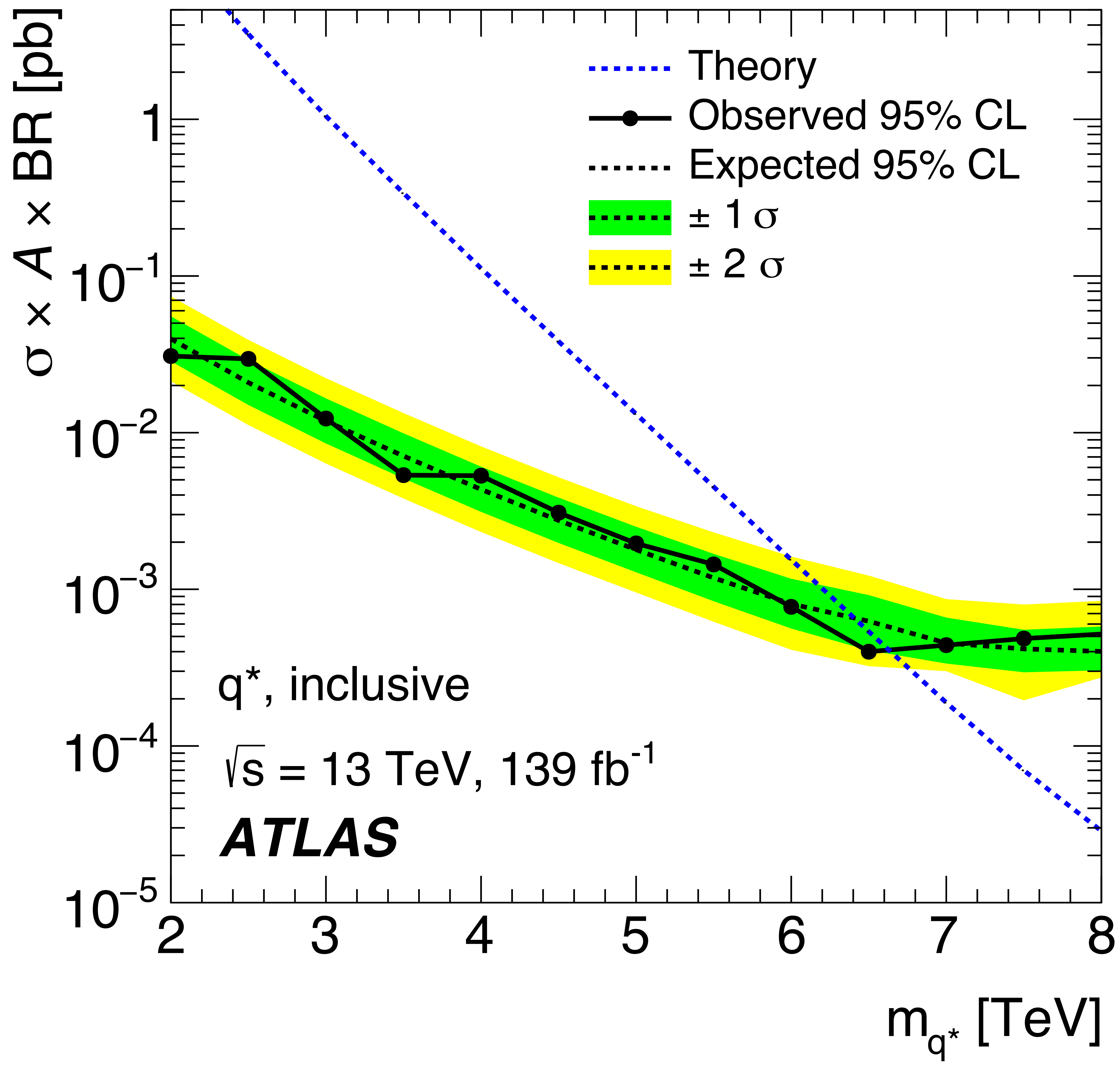
- Upper limits at 95% confidence level on signal cross section

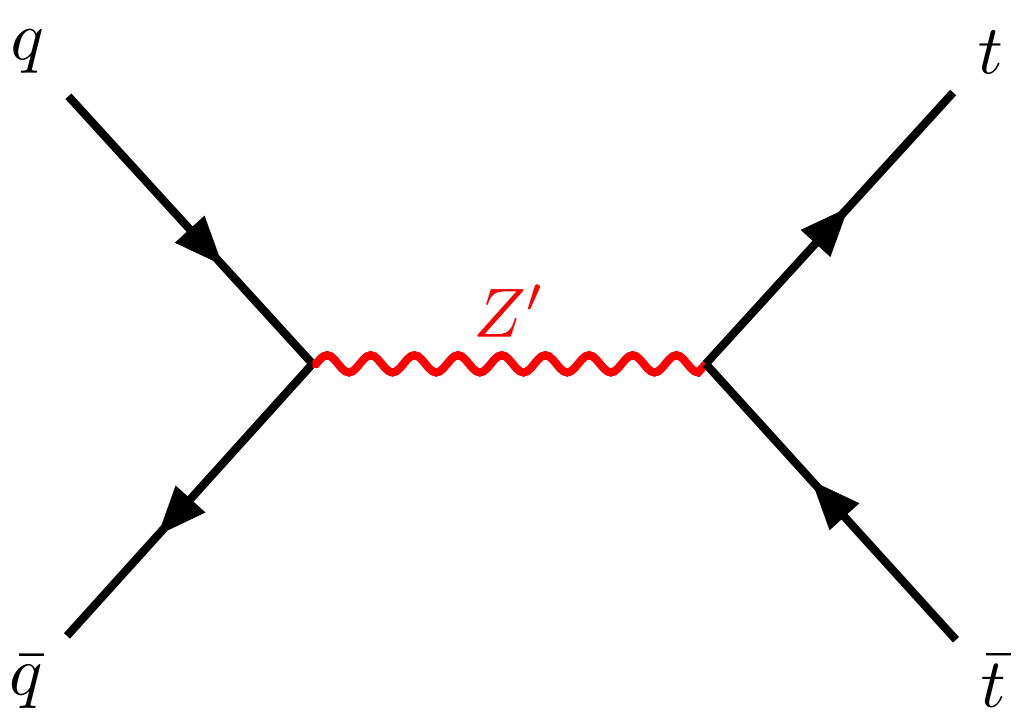
Category	Model	Lower limit on signal mass at 95% CL	
		Observed	Expected
Inclusive	q^*	6.7 TeV	6.4 TeV
	QBH	9.4 TeV	9.4 TeV
	W'	4.0 TeV	4.2 TeV
	W^*	3.9 TeV	4.1 TeV
	DM mediator Z', $g_q = 0.20$	3.8 TeV	3.8 TeV
	DM mediator Z', $g_q = 0.50$	4.6 TeV	4.9 TeV
$1b$	b^*	3.2 TeV	3.1 TeV
$2b$	DM mediator Z' $g_q = 0.20$	2.8 TeV	2.8 TeV
	DM mediator Z', $g_q = 0.25$	2.9 TeV	3.0 TeV
	SSM Z',	2.7 TeV	2.7 TeV
	graviton, $k/\overline{M}_{\rm PL} = 0.2$	2.8 TeV	2.9 TeV



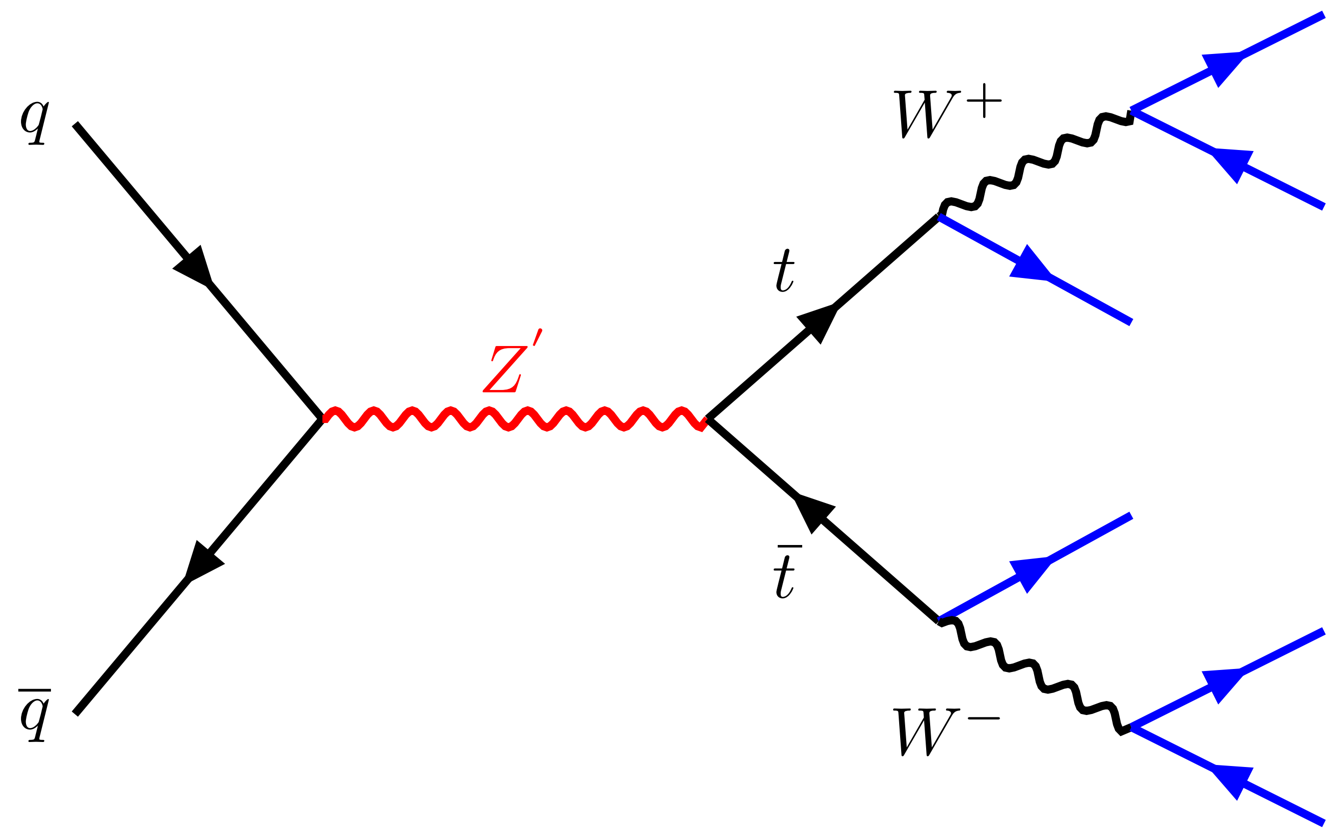
Search for ttbar resonance in boosted all-hadronic final state

Final states with top-jets

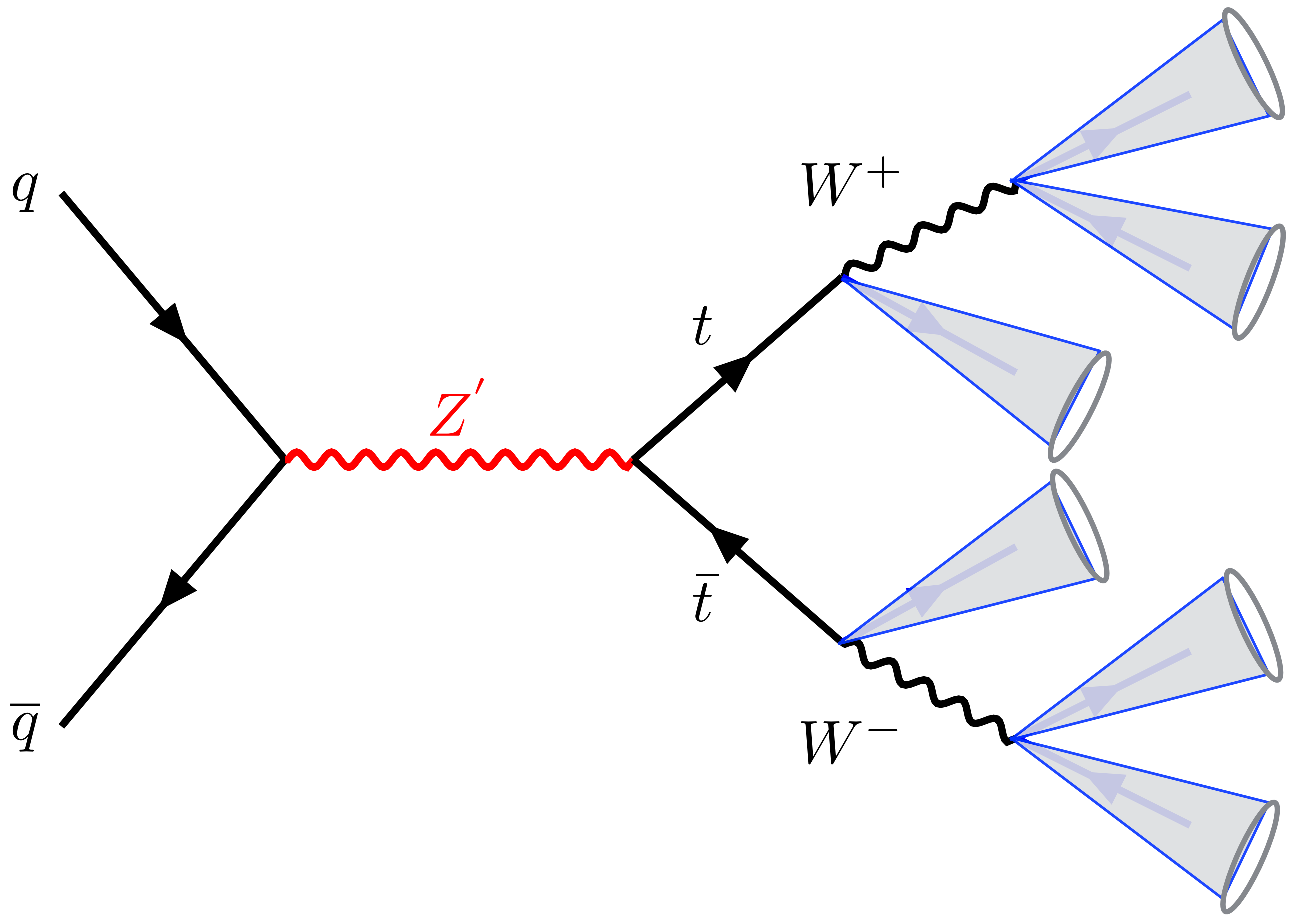
- Final states with two top-quarks are more complicated



Resonant $t\bar{t}$ production



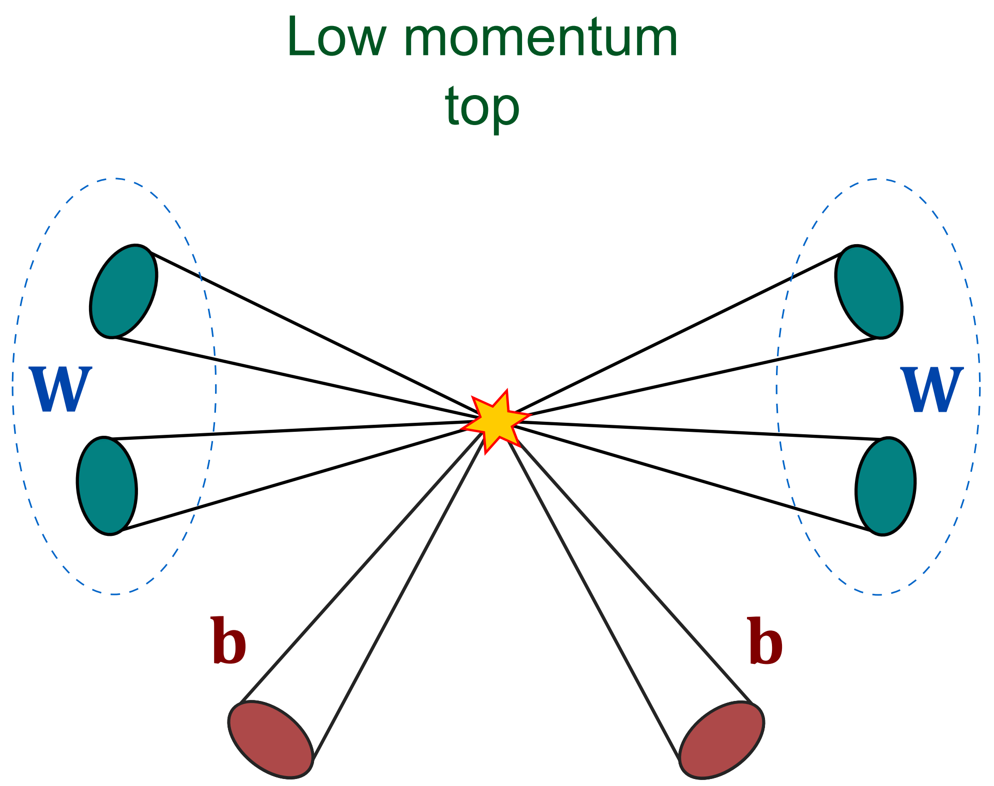
all-hadronic top-decay channel
46% Branching Franction



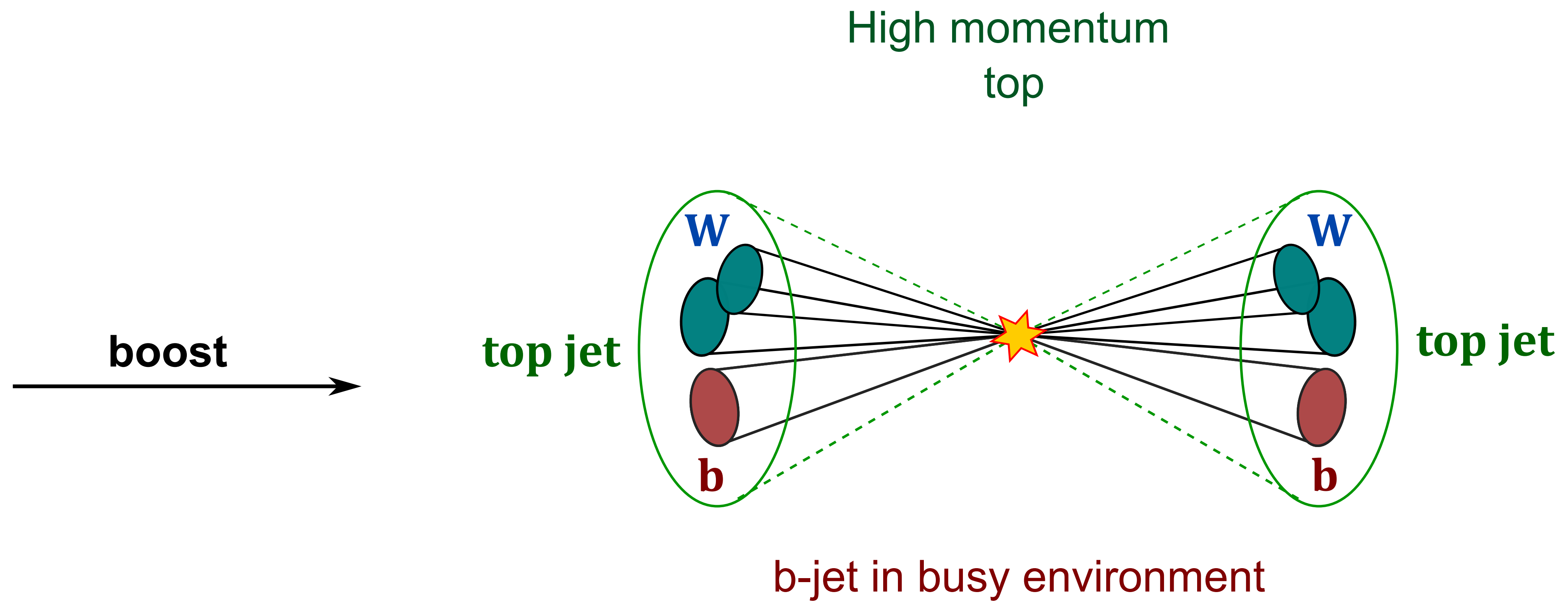
At least 6 jets in the final state

Boosted top-quark decay

- All three jets comming from a high momentum top-quark are close to each other
- Forms a **large radius jet** (R=1)



topology of **resolved** analysis



topology of **boosted** analysis

- ttbar final state becomes easier to study in the boosted regime
- Six jets —> 2 large-R jets (R=1.0)

top-tagging

- Identifies boosted top quark
- Probes the 3-prong structure of the top jets

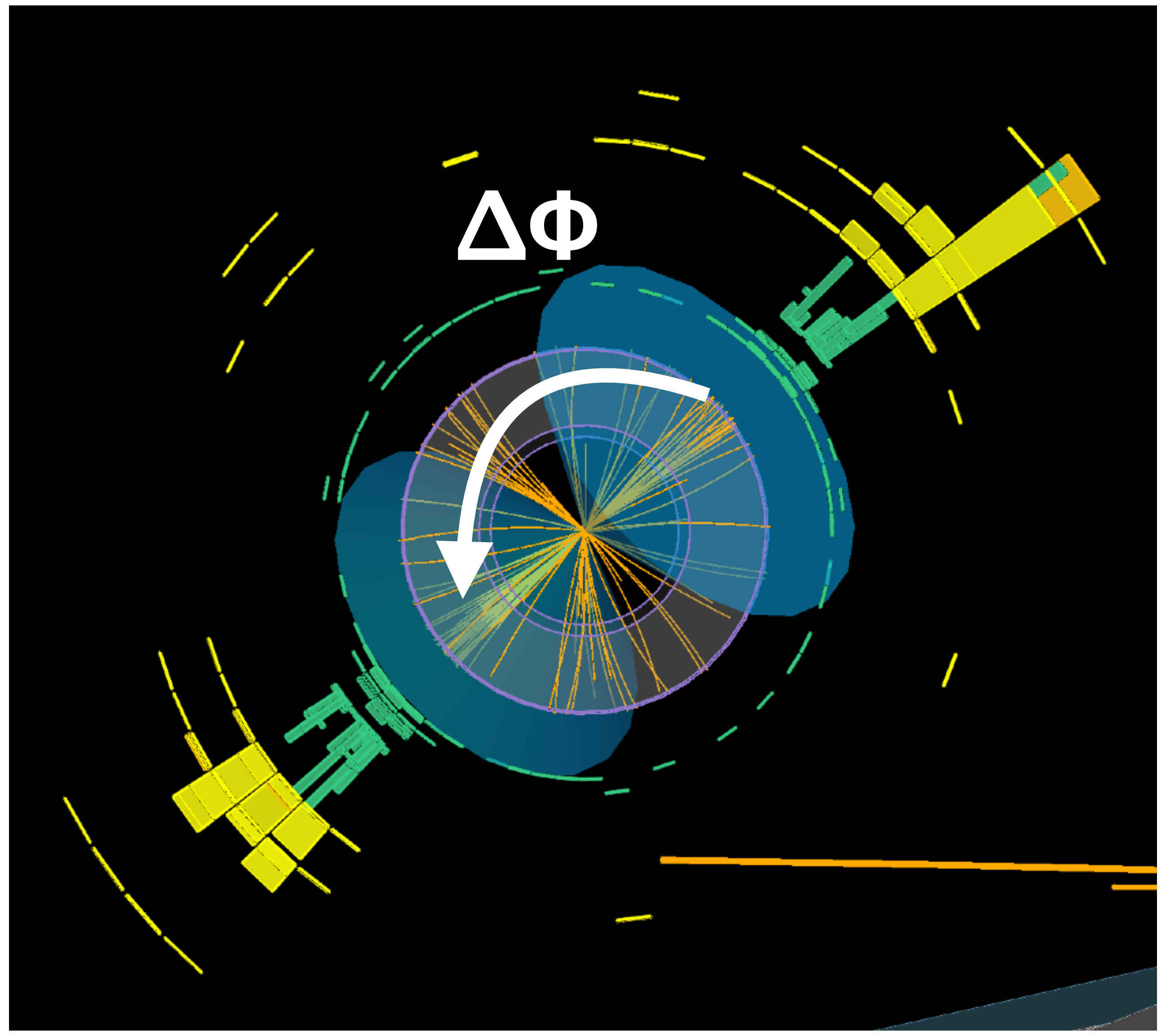
- DNN-based top tagging technique
  - *Factor 2 improvement in bkg rejection*

Phys. Rev. D 99 (2019) 092004

Signal Regions

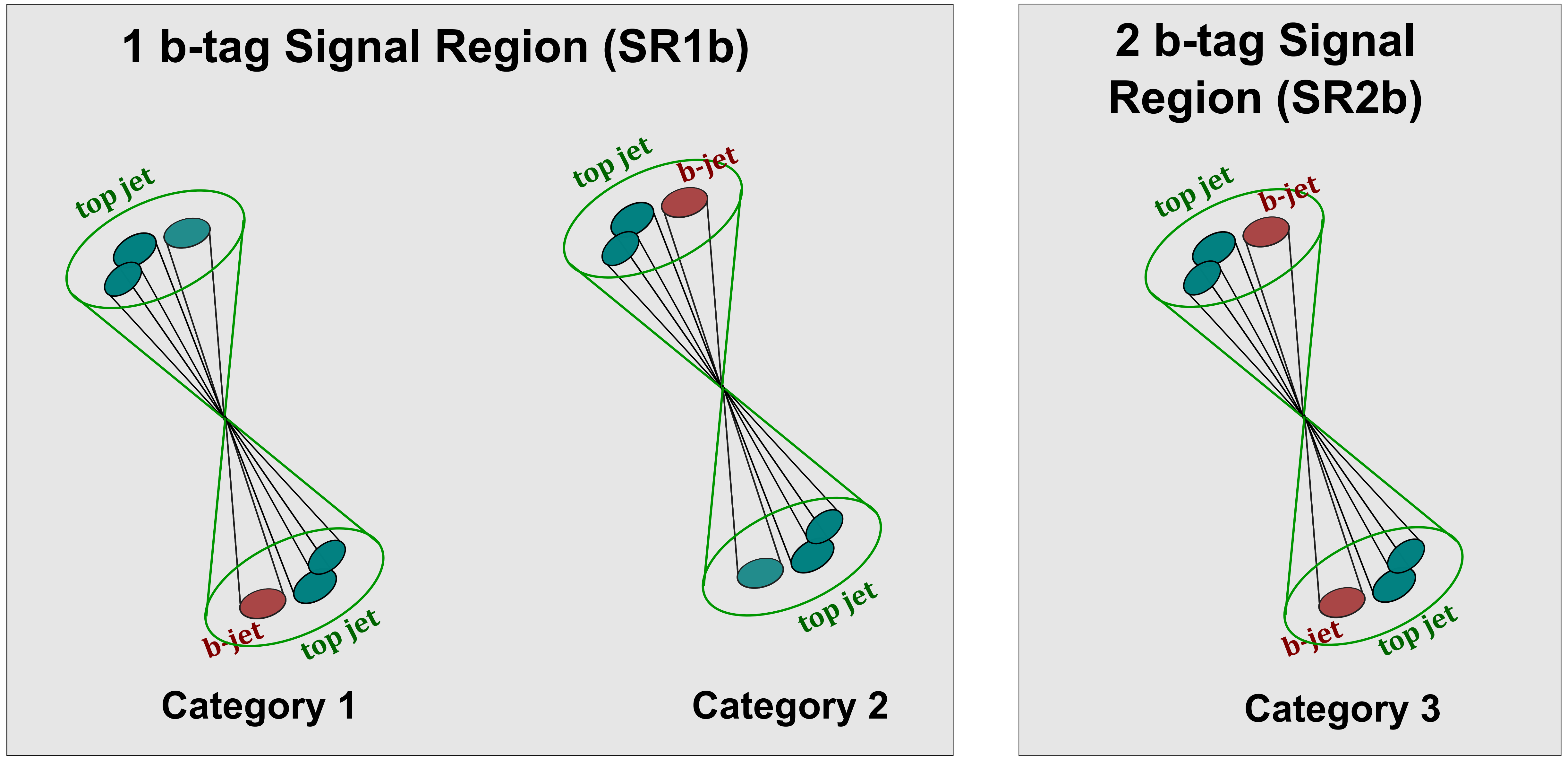
- Two top-tagged large-R jets
- **b-jet:** DL1 77% efficiency Working Point

- **Top-jets** ⟶ **b-jet** association **:** $\Delta R < 1.0$



1 b-jet

2 b-jets



- **Observable:** Mass of the t-tbar system (m_{tt})
  - Calculated from the large-R jets (top-tagged)

- **Interpretations:**
  - Top color assisted technicolor: Z'_{TC2} (1%,1.2% and 3% width)
  - Vector and Axial-vector mediator Dark matter Z'

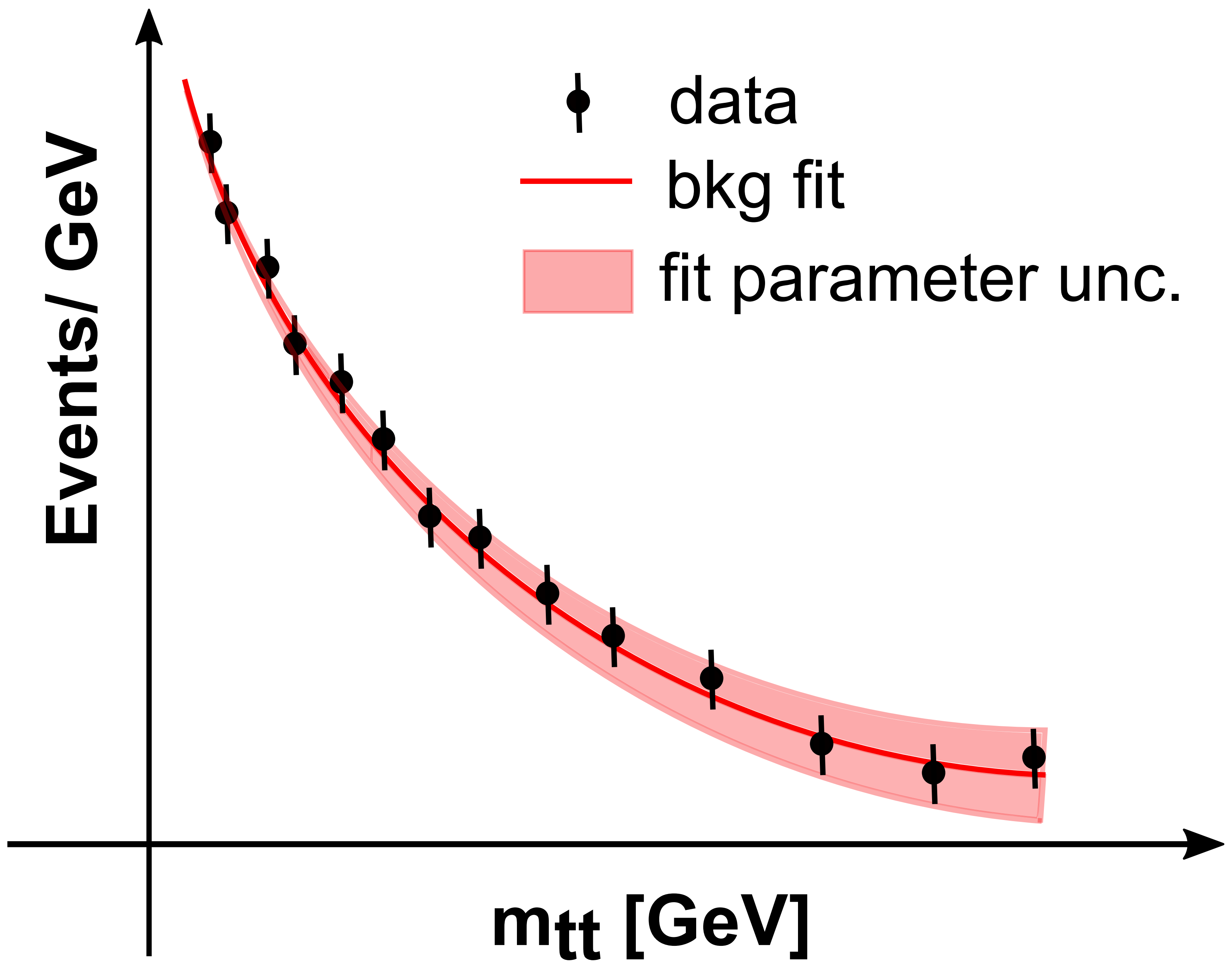
Background estimation

- Dominant backgrounds: **SM ttbar production** and **QCD multi jet processes**
- The total background is estimated from data by a functional fit to data

- **Smoothly falling background function:**

$$f(x) = p_0(1-x)^{p_1} x^{p_2+p_3 \log(x)}$$

- The function form and uncertainties are estimated using simulate ttbar and QCD multijet



m_{tt} distributions

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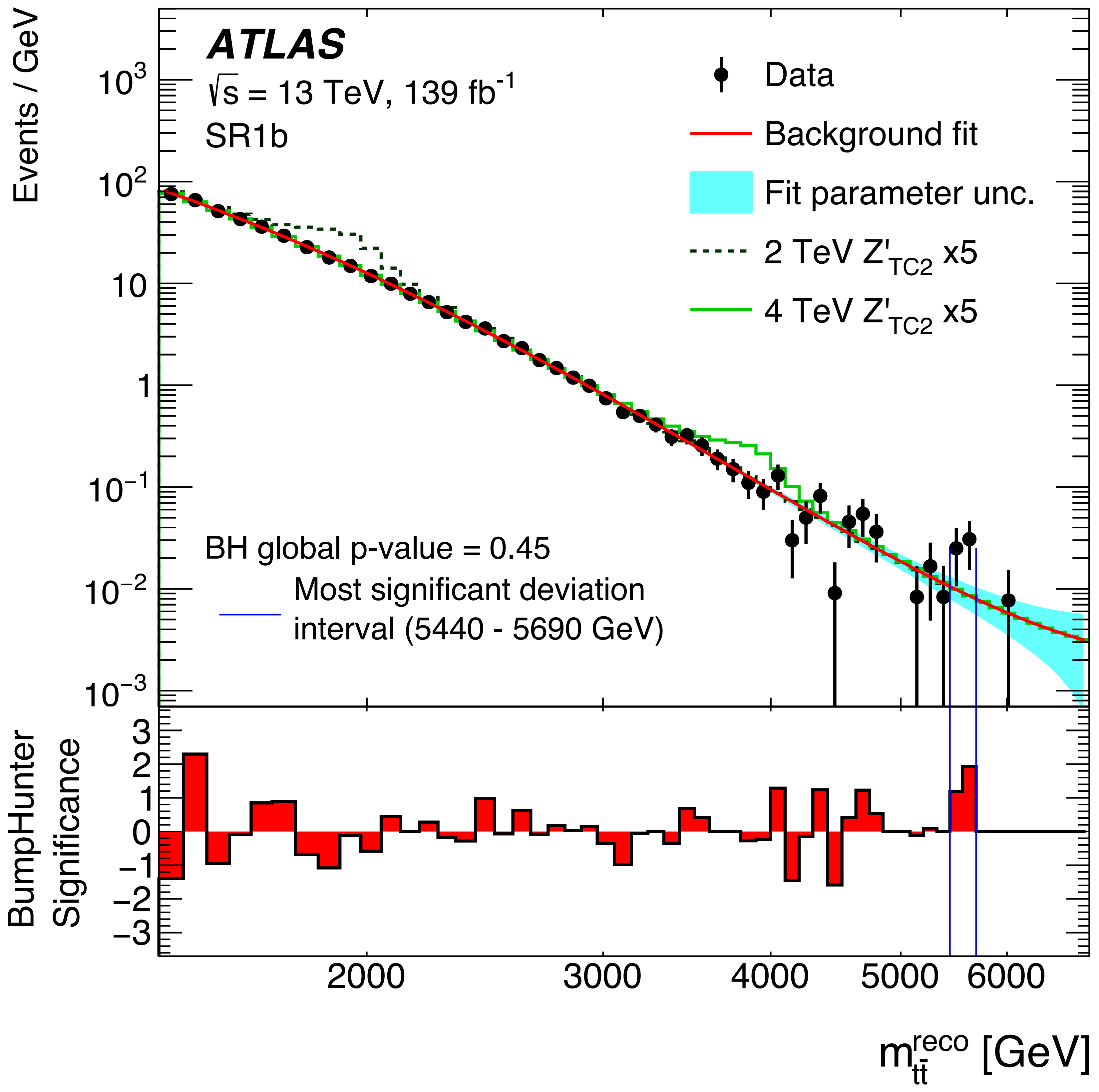
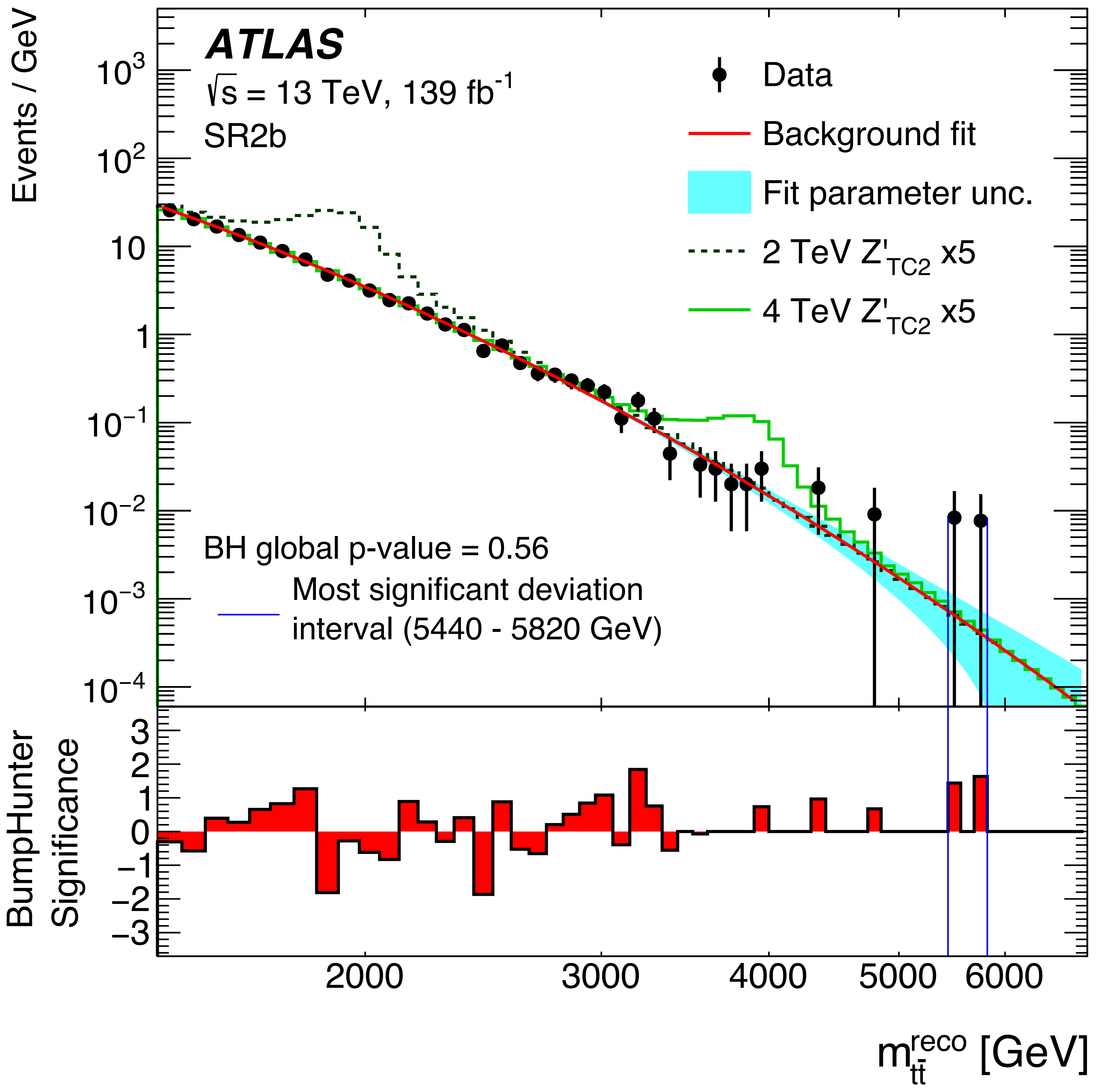
- No significant discrepancy observed in data
- **Global significance:** < 0.2 sigma

1 b-tag Signal Region



2 b-tag Signal Region



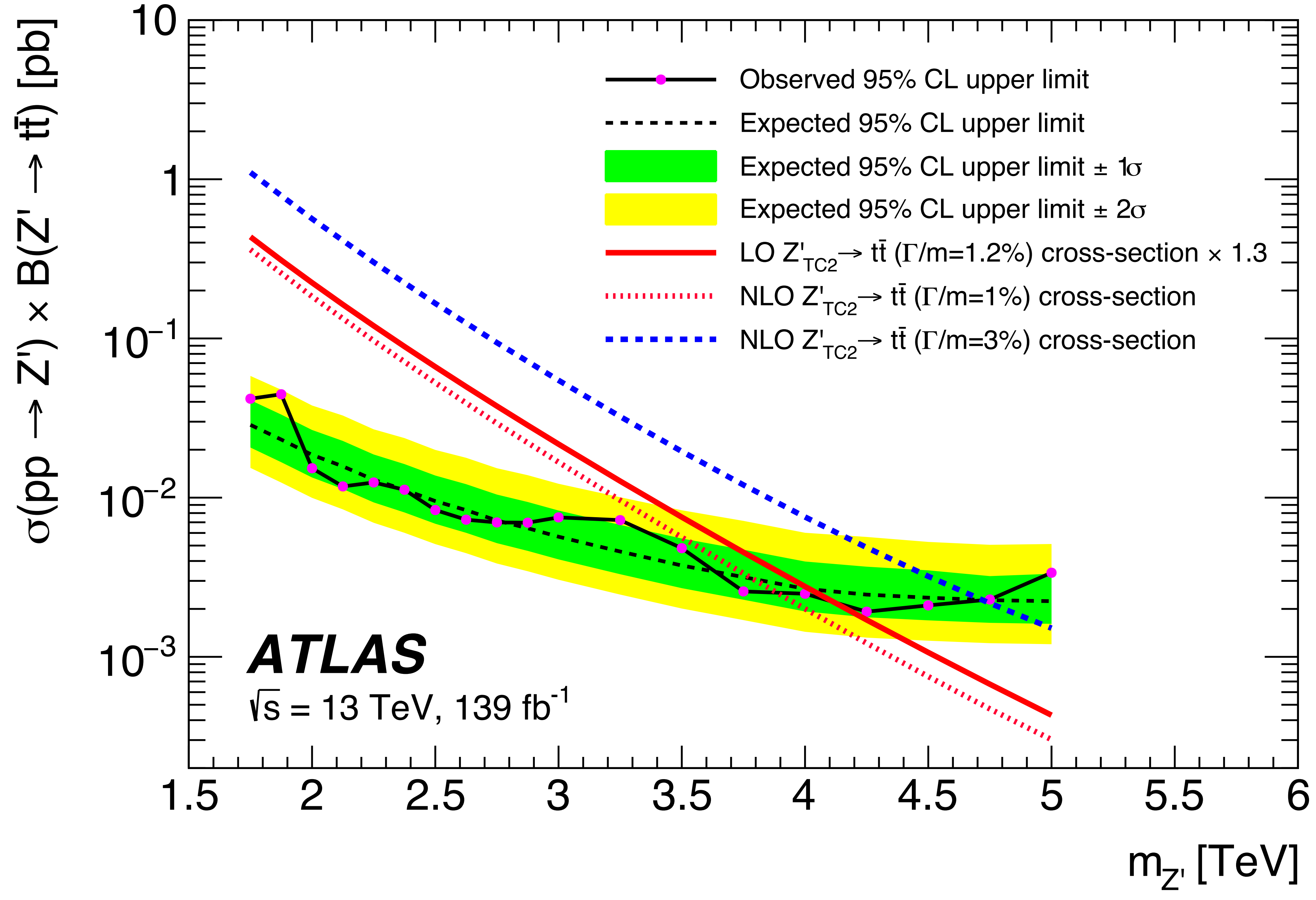
Exclusion limit

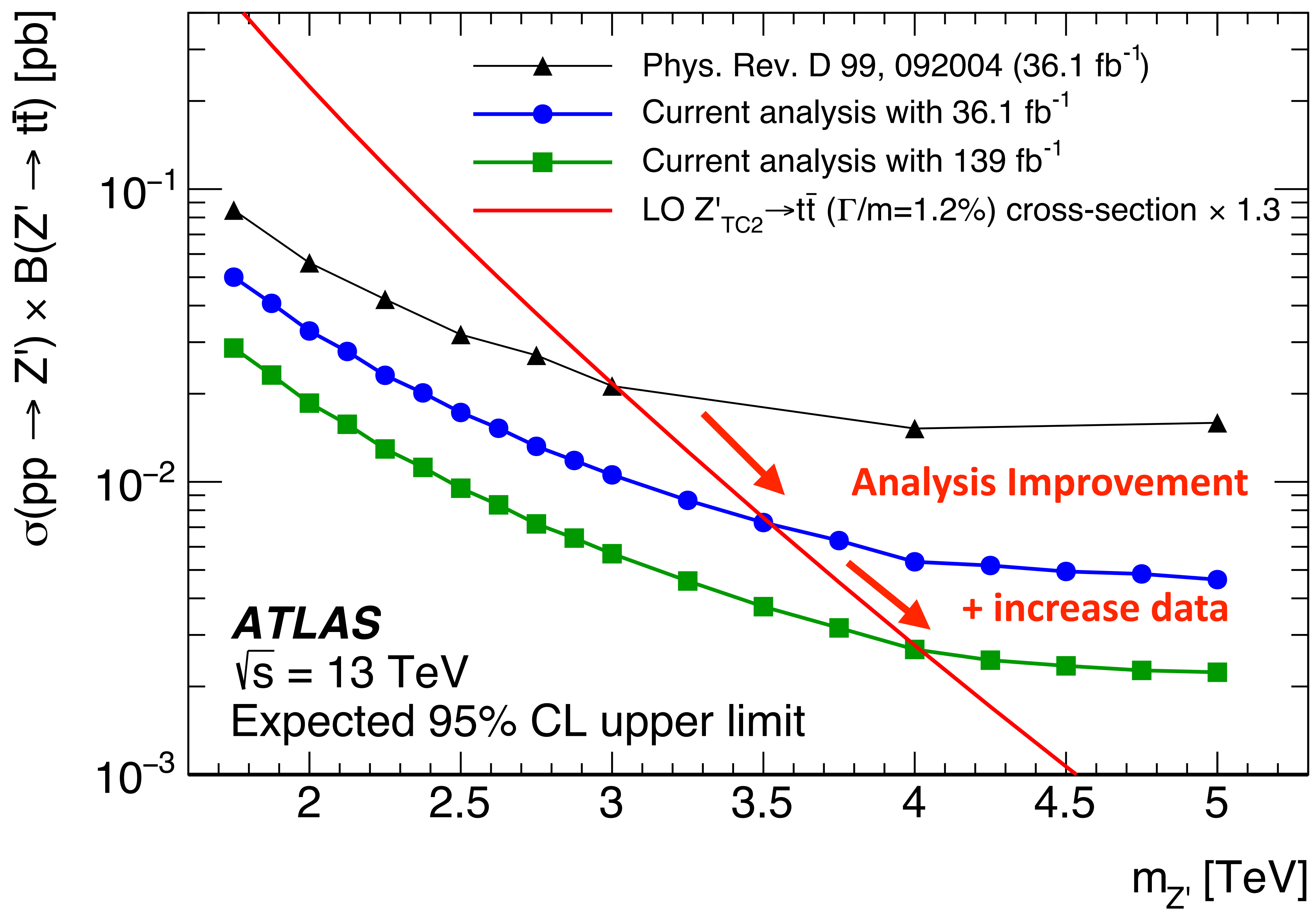
[JHEP 10 (2020) 061]

Z'_{TC2} mass excluded up to 3.9 and 4.7 TeV
for 1% and 3% widths

- **New analysis techniques**
  ➡ *Improved the cross section limit by 2 times*

- **Almost 4 times increase in data**
  ➡ *Improved cross section limit by another factor of 2*



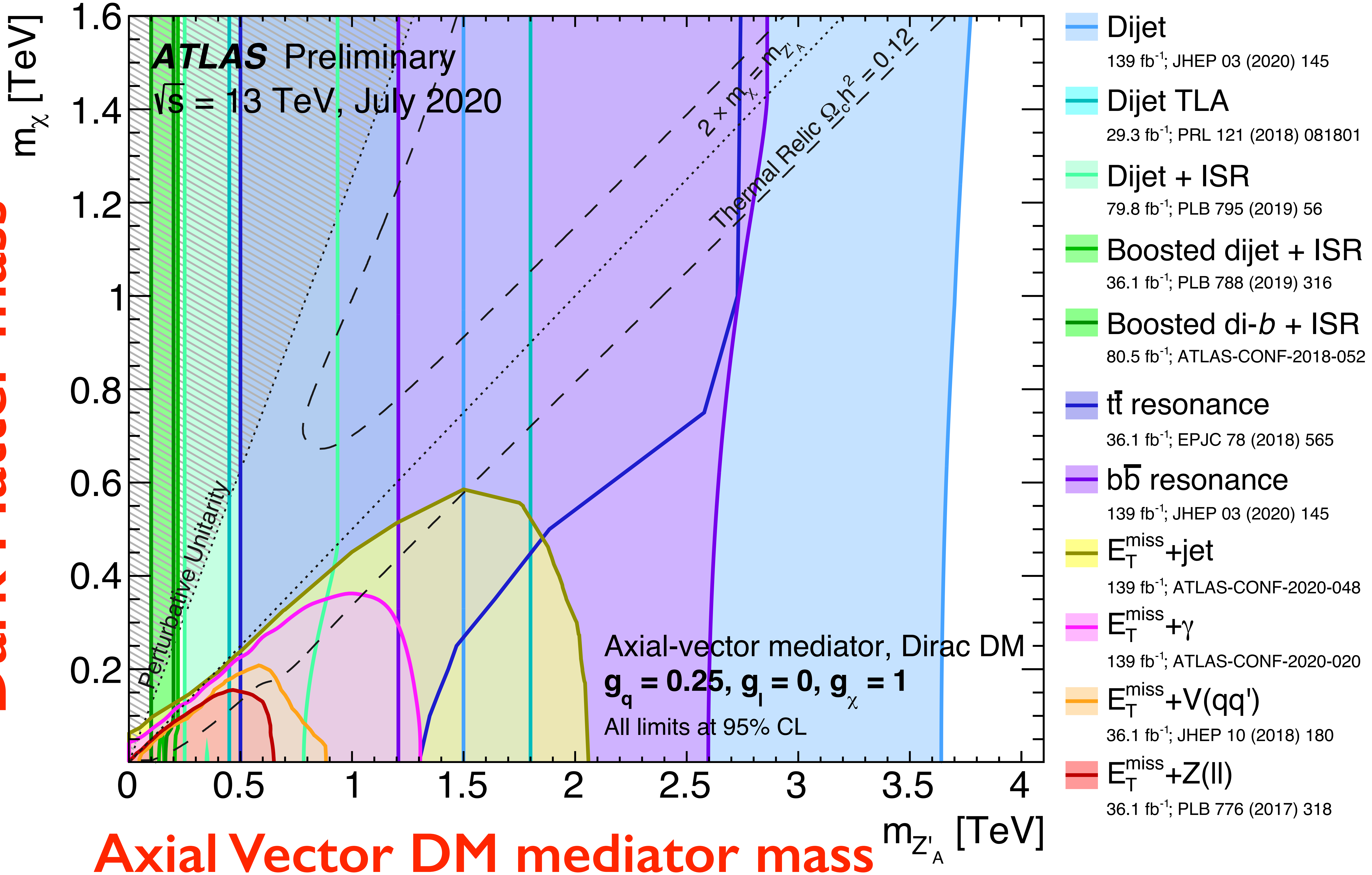


	Expected [TeV]	Observed [TeV]
Old Analysis	3.0	3.2
New analysis at 36 fb^{-1}	3.5	-
New analysis	4.0	4.1

DM interpretation

ATL-PHYS-PUB-2020-021

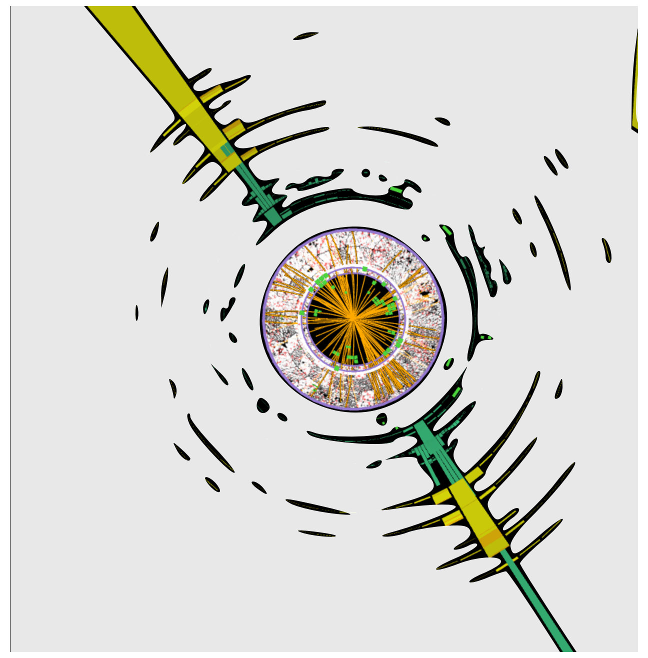
- Assuming no coupling to leptons
- Full Run-II ttbar resonance results are not added yet

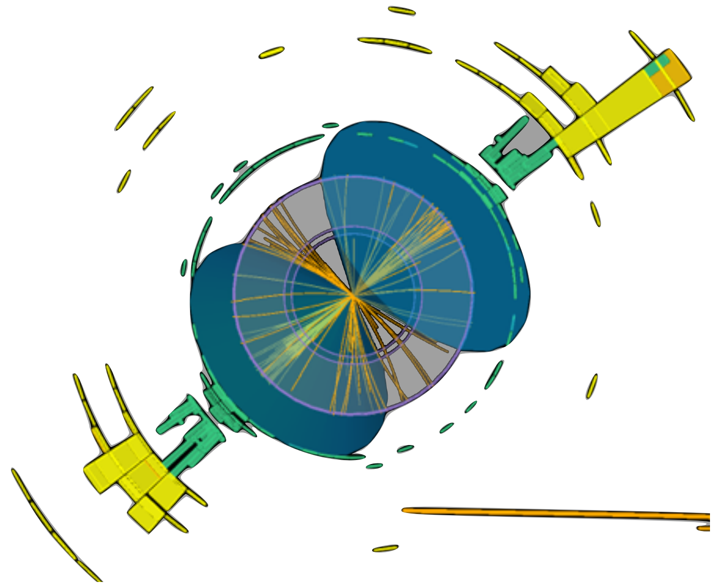


Dark Matter mass

Axial Vector DM mediator mass

Summary





Search for dijet and di-bjet resonances

- Cross section limit improves by a factor within 1.2 and 3.5
  - Maximum improvement at 4 TeV
- The b-tagged analysis benefits from the DNN-based b-tagger

Search for tt resonances in fully hadronic final state

- New top-tagging, b-tagging and background estimation method provide large improvements
- 65% improvement in the expected cross-section limit at 4 TeV!
- 1 TeV improvement in mass limit for 1.2% Z' (TC2 model)

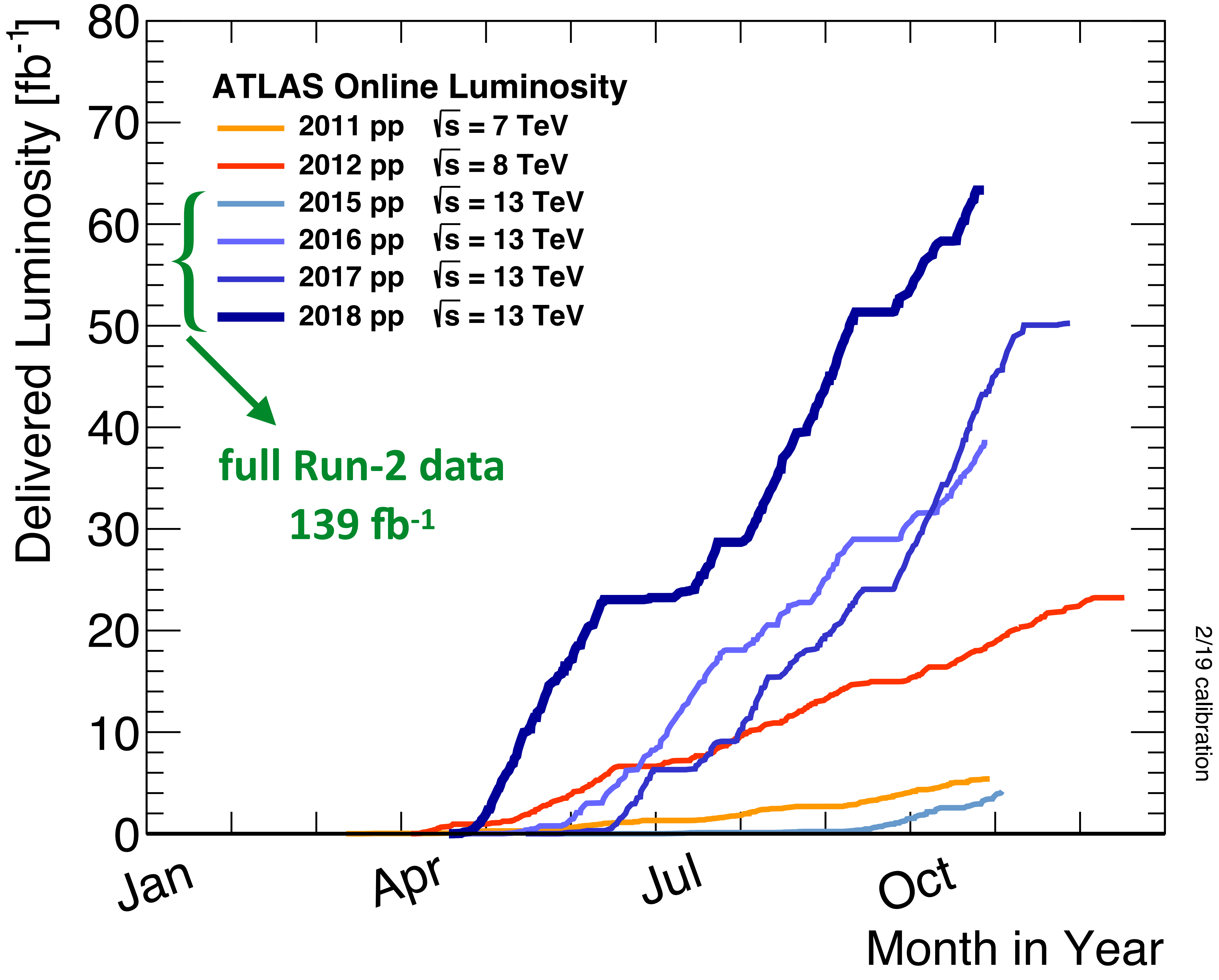
More results with full Run-II LHC data is coming soon. Stay tuned!

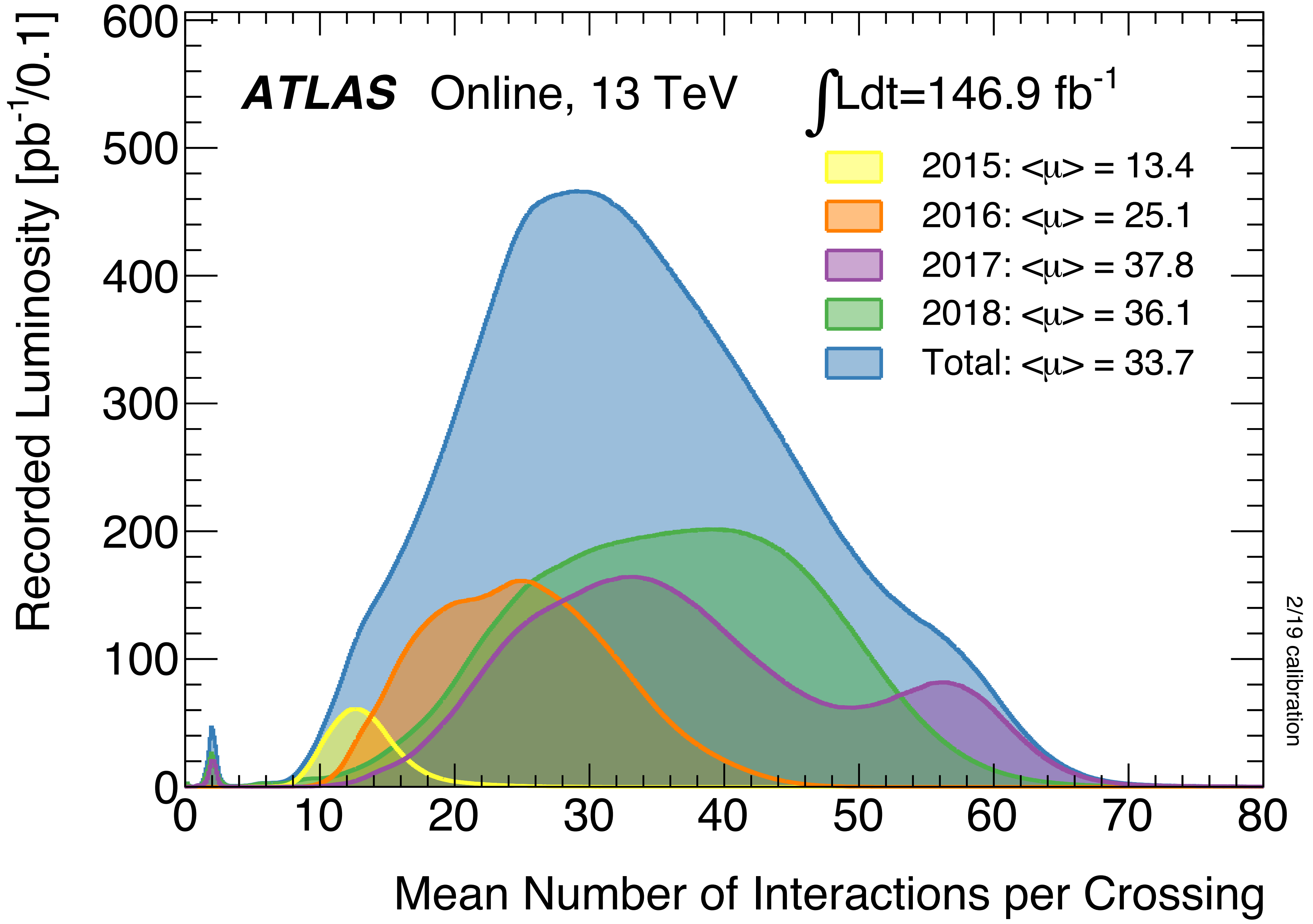
Thank you for your attention

Extra slides

Full Run-2 data (2015-2018)

- LHC Run-II started in mid 2015
- ATLAS collected 147 fb^{-1} data during Run-2
- **139 fb^{-1}** data used for physics analysis
  - **95% data is usable for physics!**





LuminosityPublicResultsRun2

Dijet/di-bjet selection table

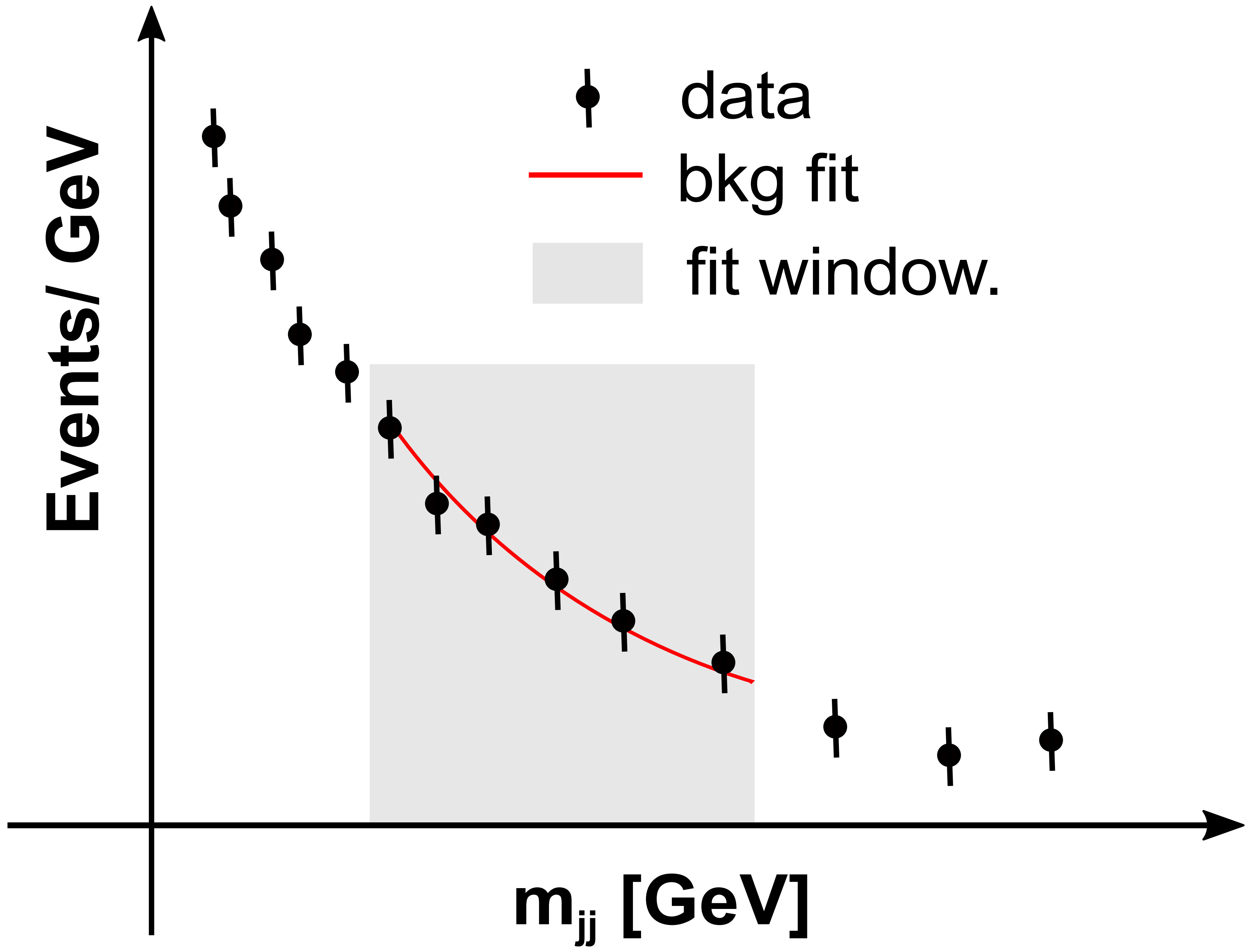
Category	Inclusive		$1b$	$2b$
Jet p_{T}	> 150 GeV			
Jet ϕ	$\lvert\Delta\phi(jj)\rvert > 1.0$			
Jet $\lvert\eta\rvert$	-		< 2.0	
$\lvert y^*\rvert$	< 0.6	< 1.2	< 0.8	
m_{jj}	> 1100 GeV	> 1717 GeV	> 1133 GeV	
b-tagging	no requirement		$\geqslant 1$ b-tagged jet	2 b-tagged jets
Signal	DM mediator Z' W' q^* QBH Generic Gaussian	W^*	b^* Generic Gaussian	DM mediator Z' $(b\bar{b})$ SSM Z' $(b\bar{b})$ graviton $(b\bar{b})$ Generic Gaussian

Background estimation

- **Smoothly falling background function:**

$$f(x) = p_0(1-x)^{p_1} x^{p_2 + p_3 \log(x)}$$

- Data is fitted in small widow using *sliding window fit* method
- The function is validated in **S**ignal **R**egions (SR) using **background-only template**



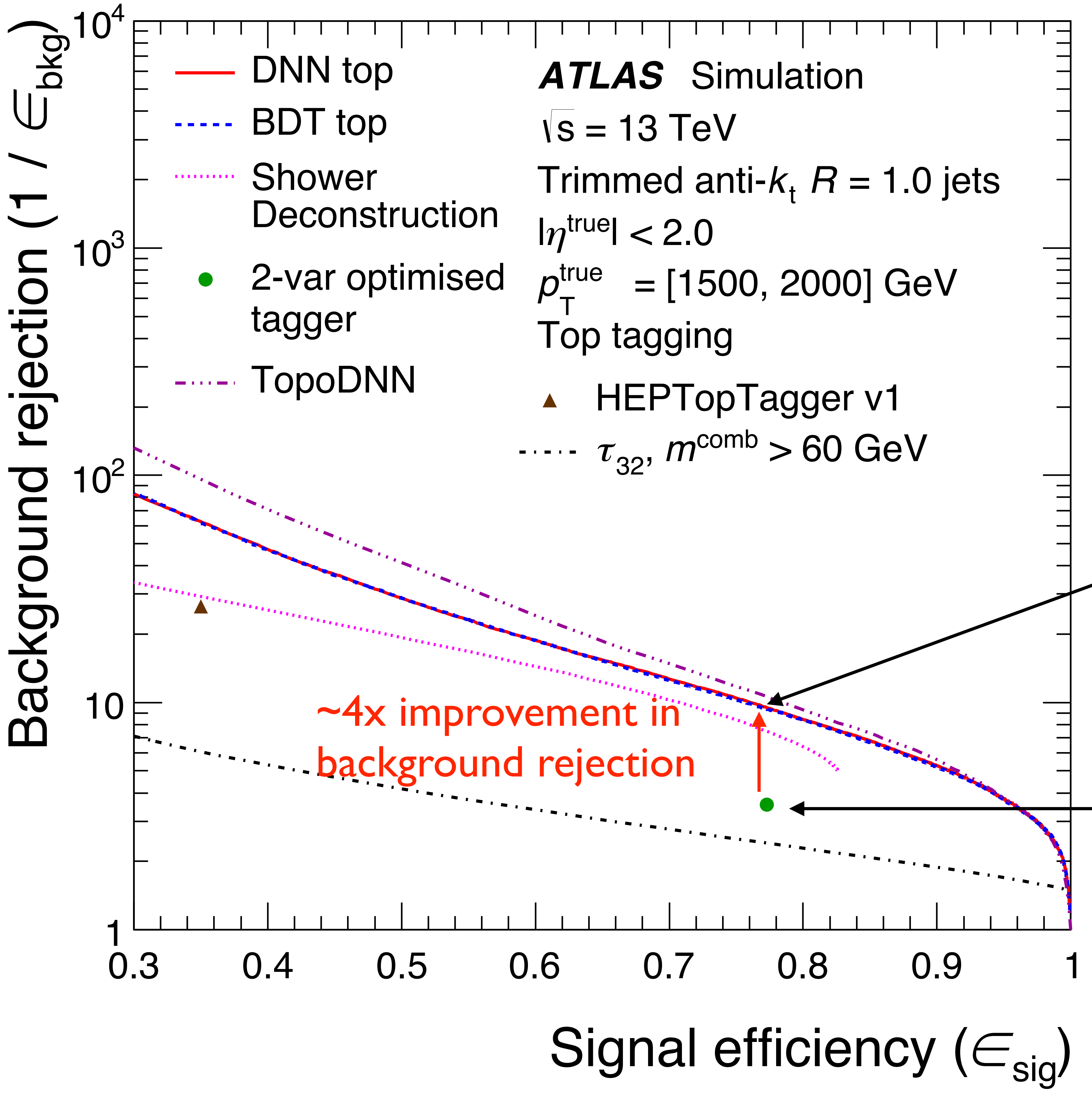
The quality of the fit to the data:

- Global Chi-square p-value > 0.05
- BumpHunter p-value > 0.01

Improvements in top-tagging

Eur. Phys. J. C 79 (2019) 375

- First analysis using the new high level DNN top-tagger in ATLAS
- Around 4x improvement in background rejection at very high p_T region
  - Improves background rejection at high ttbar mass



DNN top tagger

Uses several variables with high discriminating power between a top-jet and other jets

Old tagger (tau$_{32}$, mass)

Used in the partial Run-2 analysis ($36.1\ fb^{-1}$)

Phys. Rev. D 99 (2019) 092004

Variables used in the DNN top-tagger

Table 1: Summary of jet moments studied along with an indication of the tagger topology to which the observable is applicable. In the case of the energy correlation observables, the angular exponent β is set to 1.0 and for the N-subjettiness observables, the winner-take-all [55] configuration is used. A concise description of each jet moment can be found in Ref. [8].

Observable	Variable	Used for	References
Calibrated jet kinematics	p_T, m^{comb}	top,W	[46]
Energy correlation ratios	e_3,C_2,D_2	top,W	[52, 56]
N-subjettiness	τ_1,τ_2,τ_{21}	top, W	[57, 58]
	τ_3,τ_{32}	top	
Fox–Wolfram moment	R_2^{FW}	W	[59, 60]
Splitting measures	z_{cut}	W	[61, 62]
	$\sqrt{d_{12}}$	top, W	
	$\sqrt{d_{23}}$	top	
Planar flow	$\mathcal{P}$	W	[63]
Angularity	a_3	W	[64]
Aplanarity	A	W	[60]
KtDR	$KtDR$	W	[65]
Qw	Q_w	top	[61]

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Inclusive Signal Regions

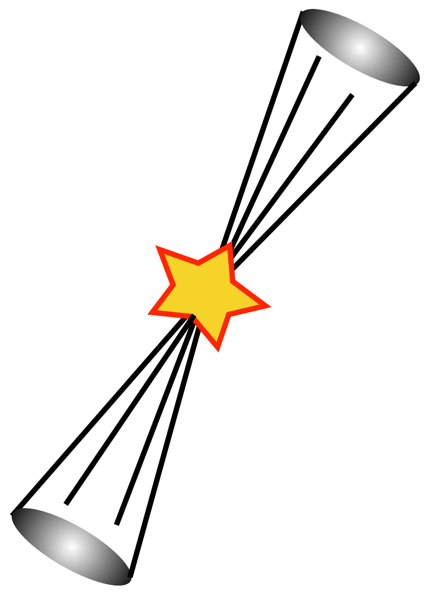
Inclusive Signal Regions
no b-jet requirement

$y^* = (y_1 - y_2)/2$

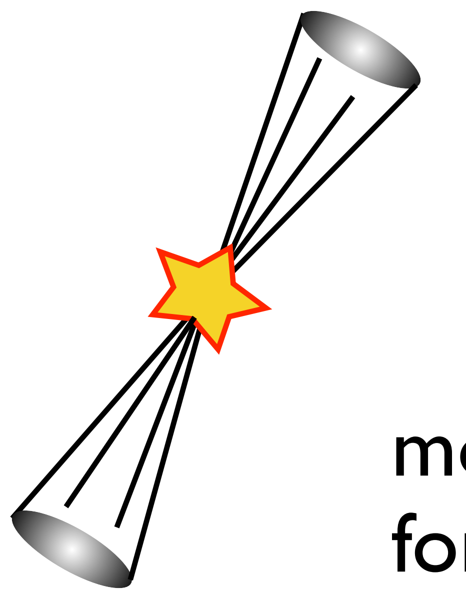
y_1 = rapidity of leading jet

y_2 = rapidity of sub-leading jet

Inclusive dijet signal region
$|y^*| < 0.6$



W* signal region
$|y^*| < 1.2$



more
forward jets

Search result: No b-jet requirement

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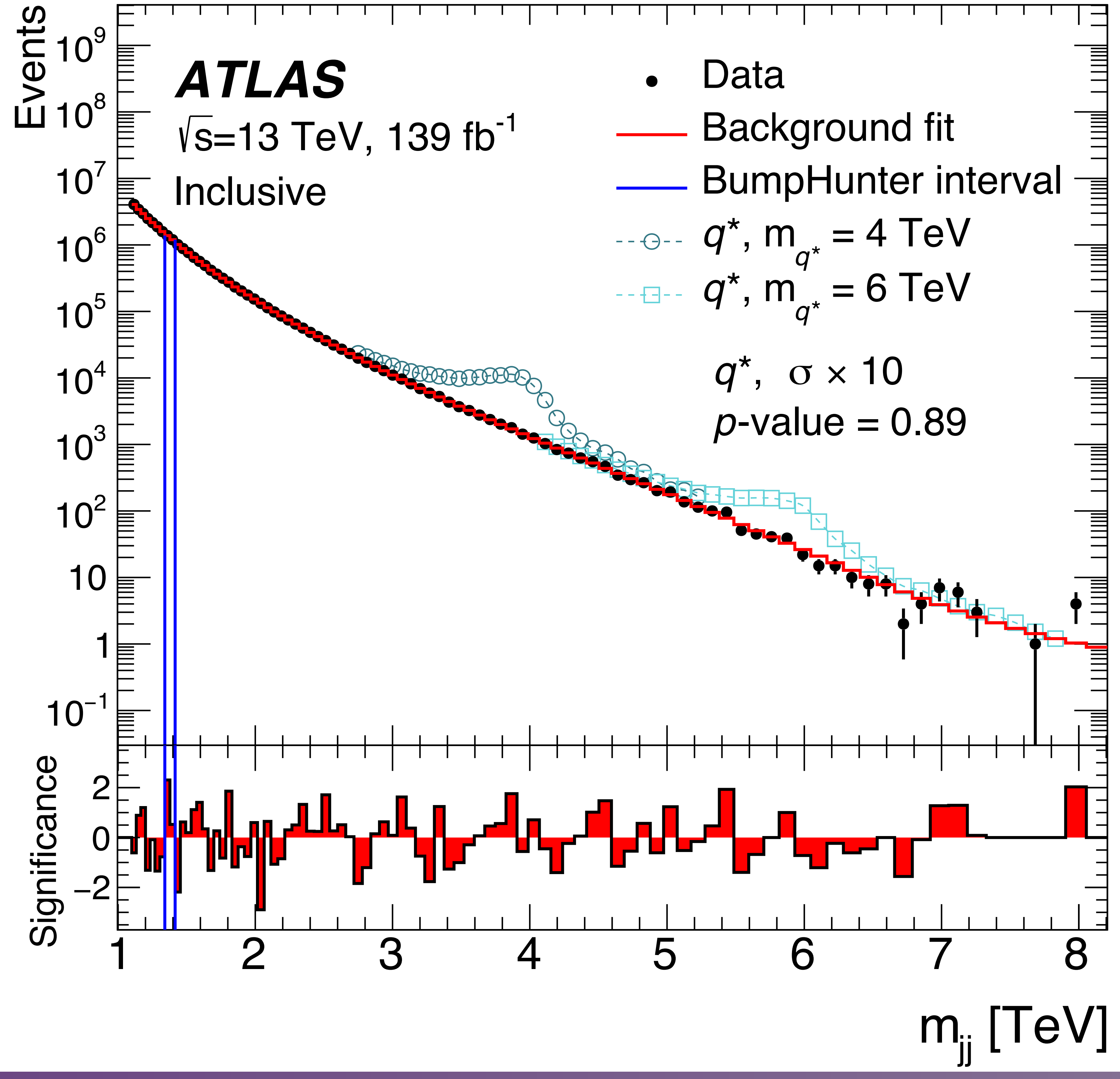
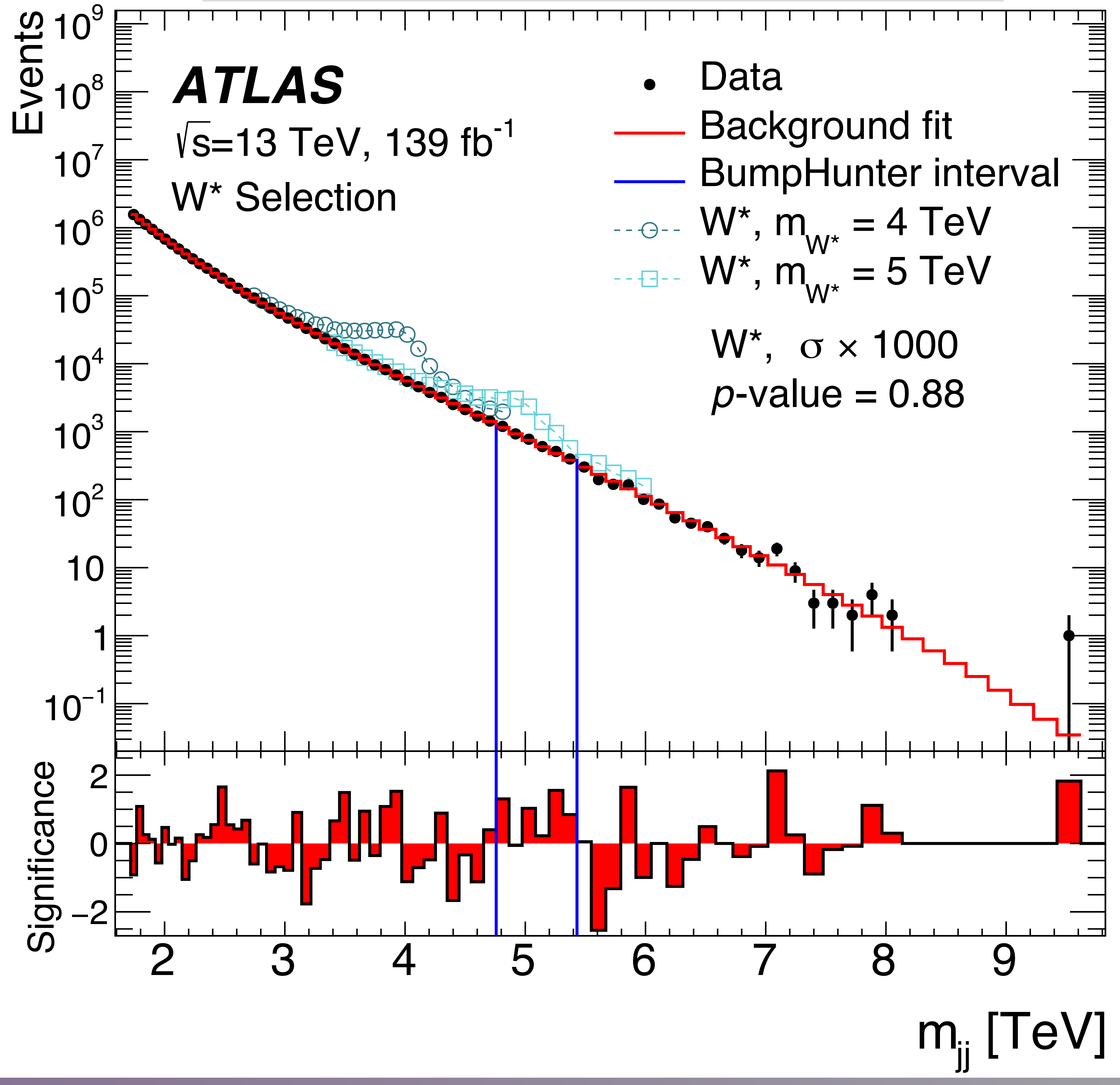
- Use BUMPHUNTER for signal search
- **BUMPHUNTER p-value:** probability of random fluctuations to create at least as much excess as observed in the data
- Variable binning used
- **No evidence of new resonances was observed**

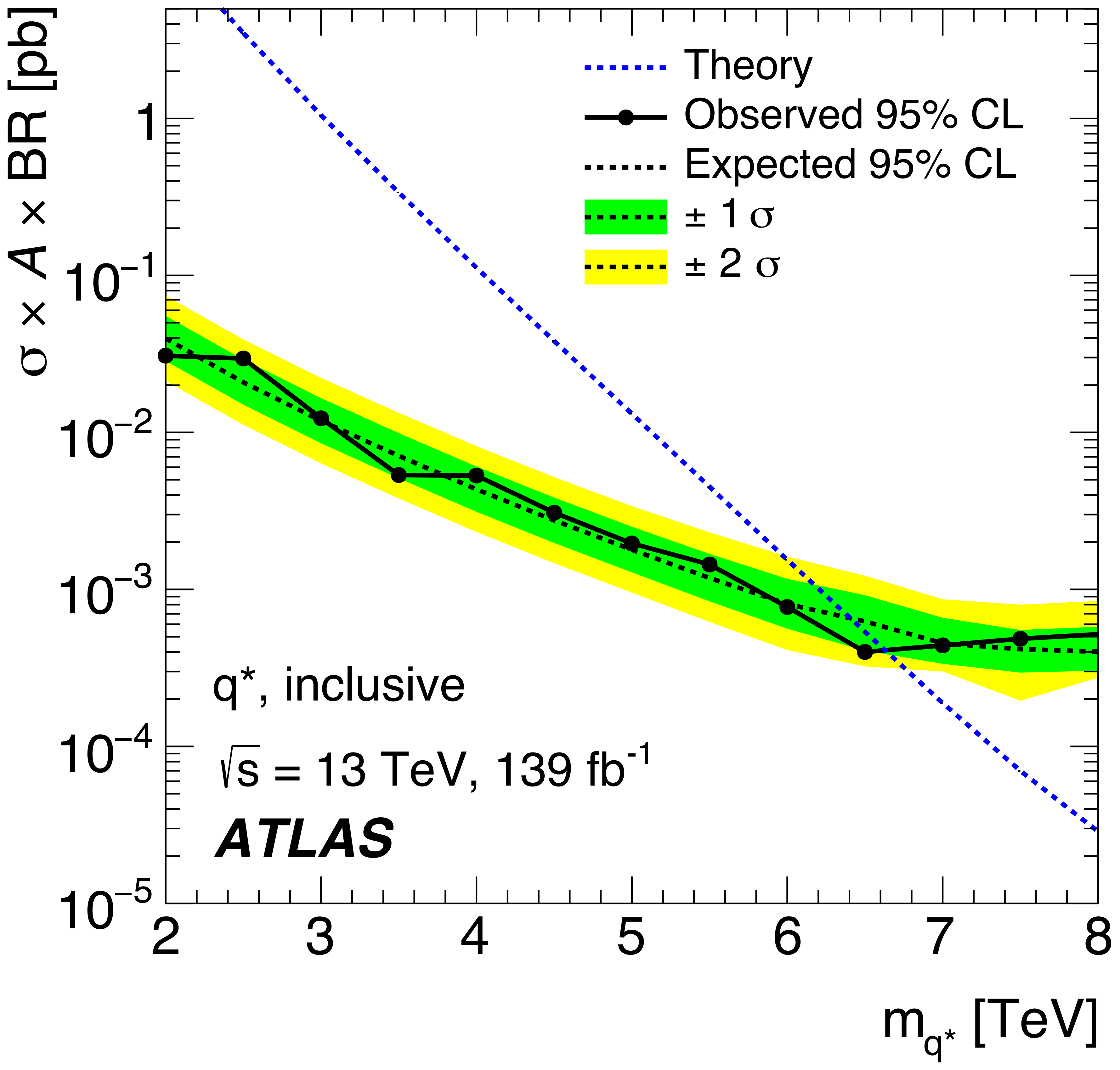
Inclusive Signal Region

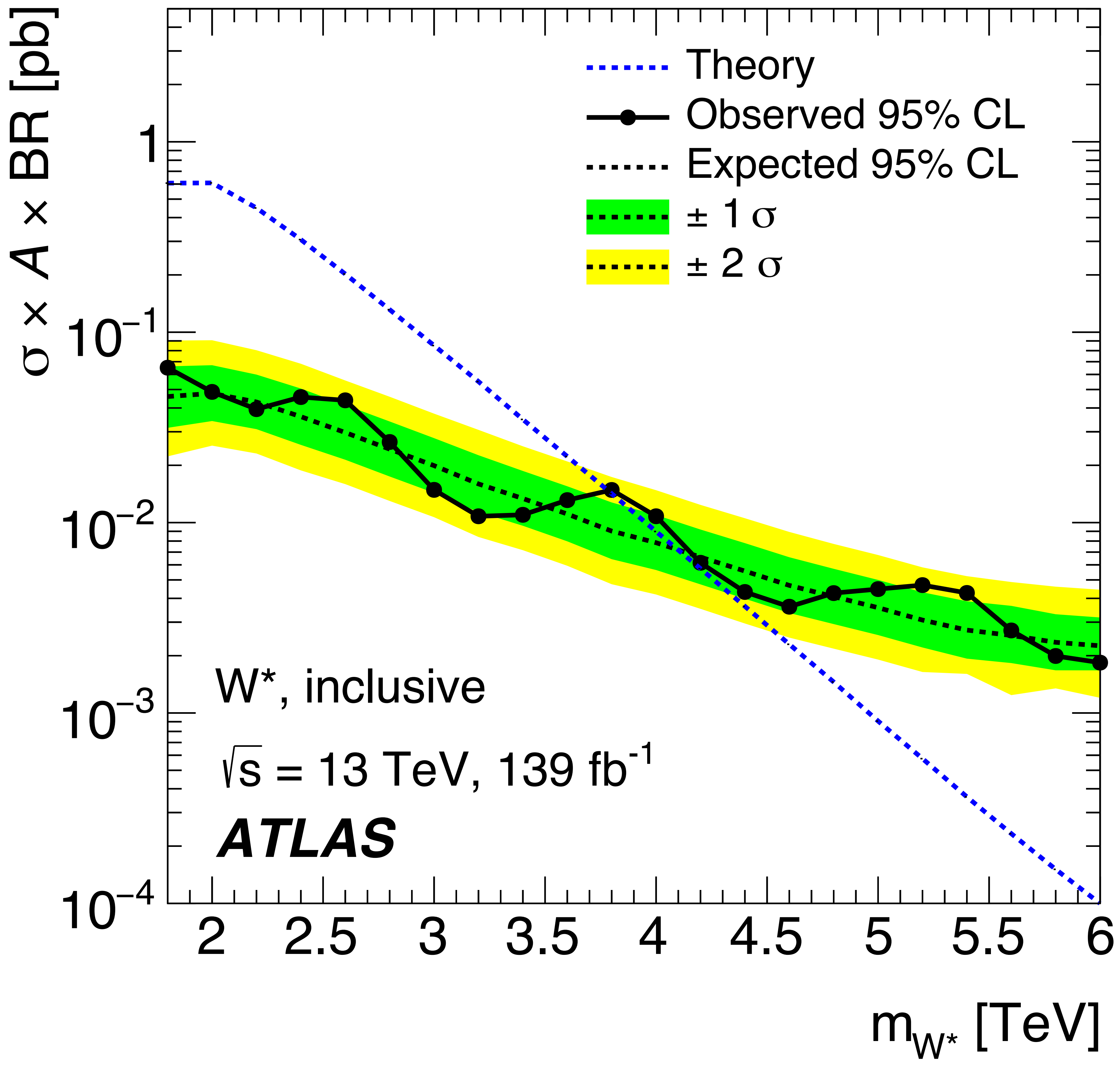


W* Signal Region



Exclusion limit: Inclusive selection

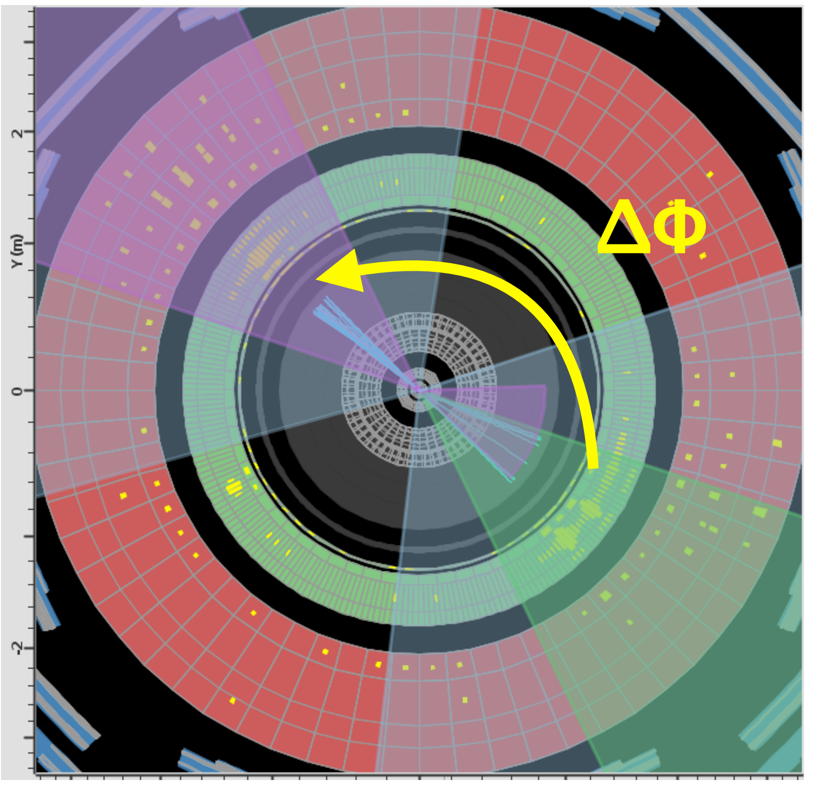


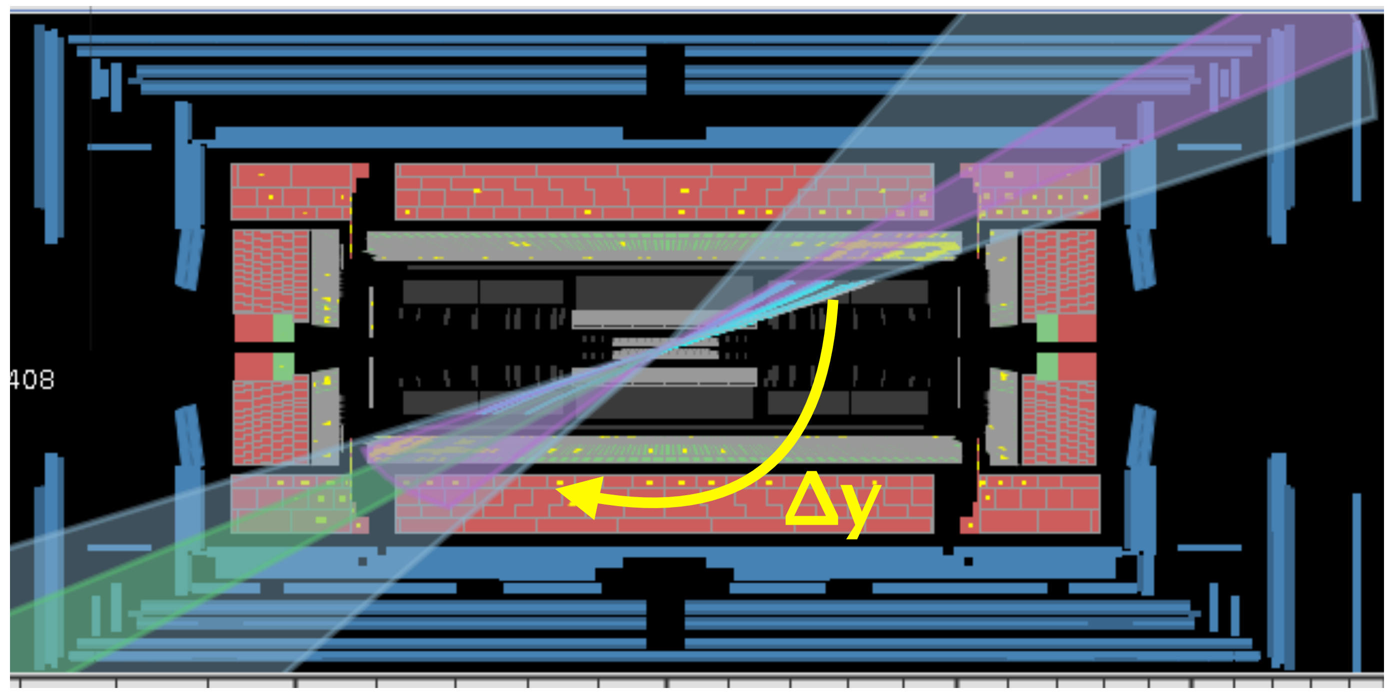


Event selection

- **Large-R jet trigger** p_T > 360-460 GeV depending on data period
- **Lepton veto:** Required exactly 0 lepton (el/mu) in the event

- >= 2 large radius jets with:
  - $p_{T,J1}$ > 500 GeV and $p_{T,J2}$ > 350 GeV
  - $\Delta\Phi$ (J_1,J_2) > 1.6 (back-to-back)
  - Δy(J_1,J_2) < 1.8 (remove t-channel SM ttbar production)





y = rapidity

- Leading and sub-leading large-R jets are top-tagged (DNN top tagger)
- m_{tt} > 1.4 TeV

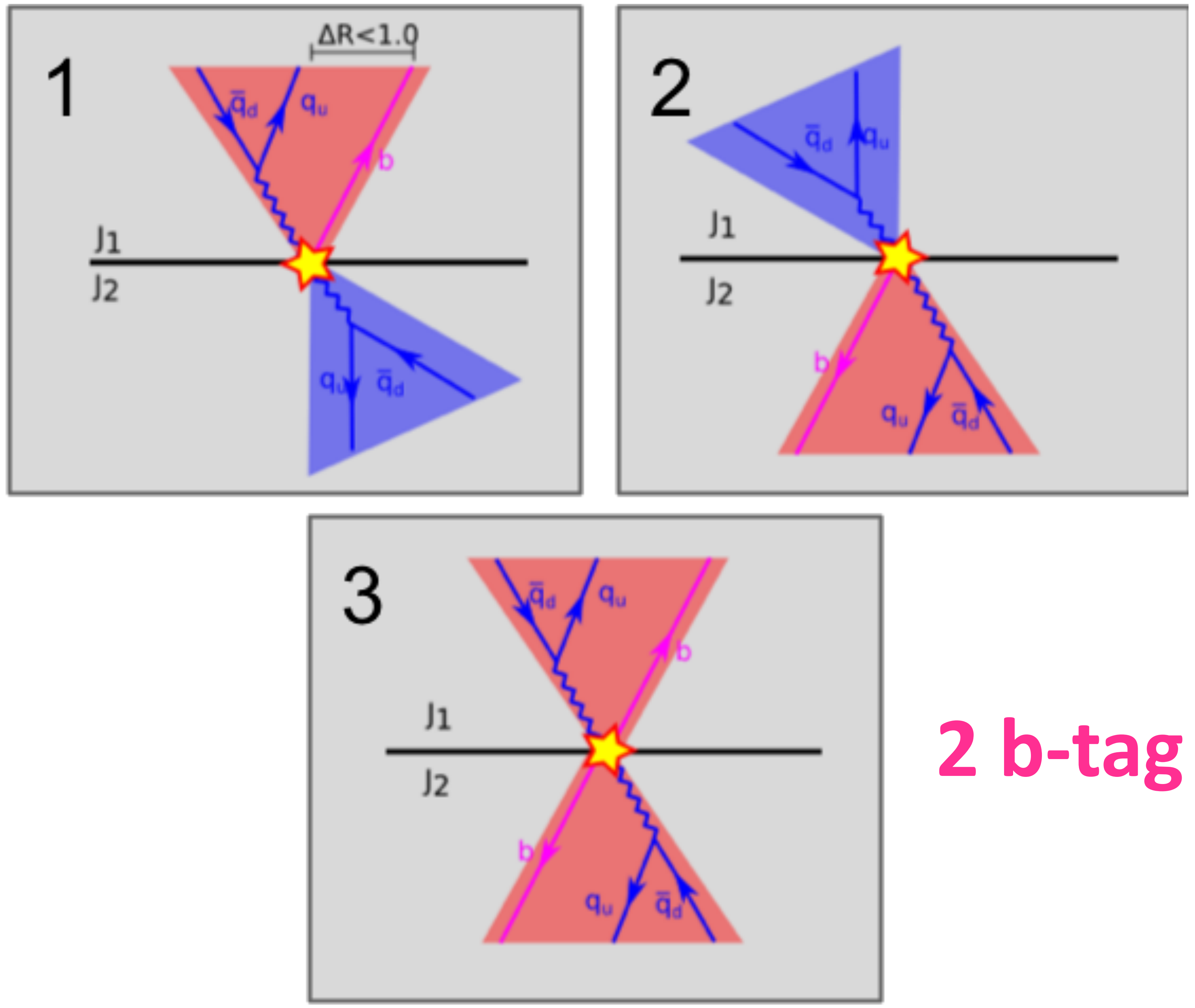
ATLAS-PHOTO-2018-002

Control and Signal Regions

- Top-jets are matched with b-tagged track jets (DL1 efficiency 77% WP) in the SR

0 b-tag Control Region: No b-jet close (dR < 1.0) to the top jets

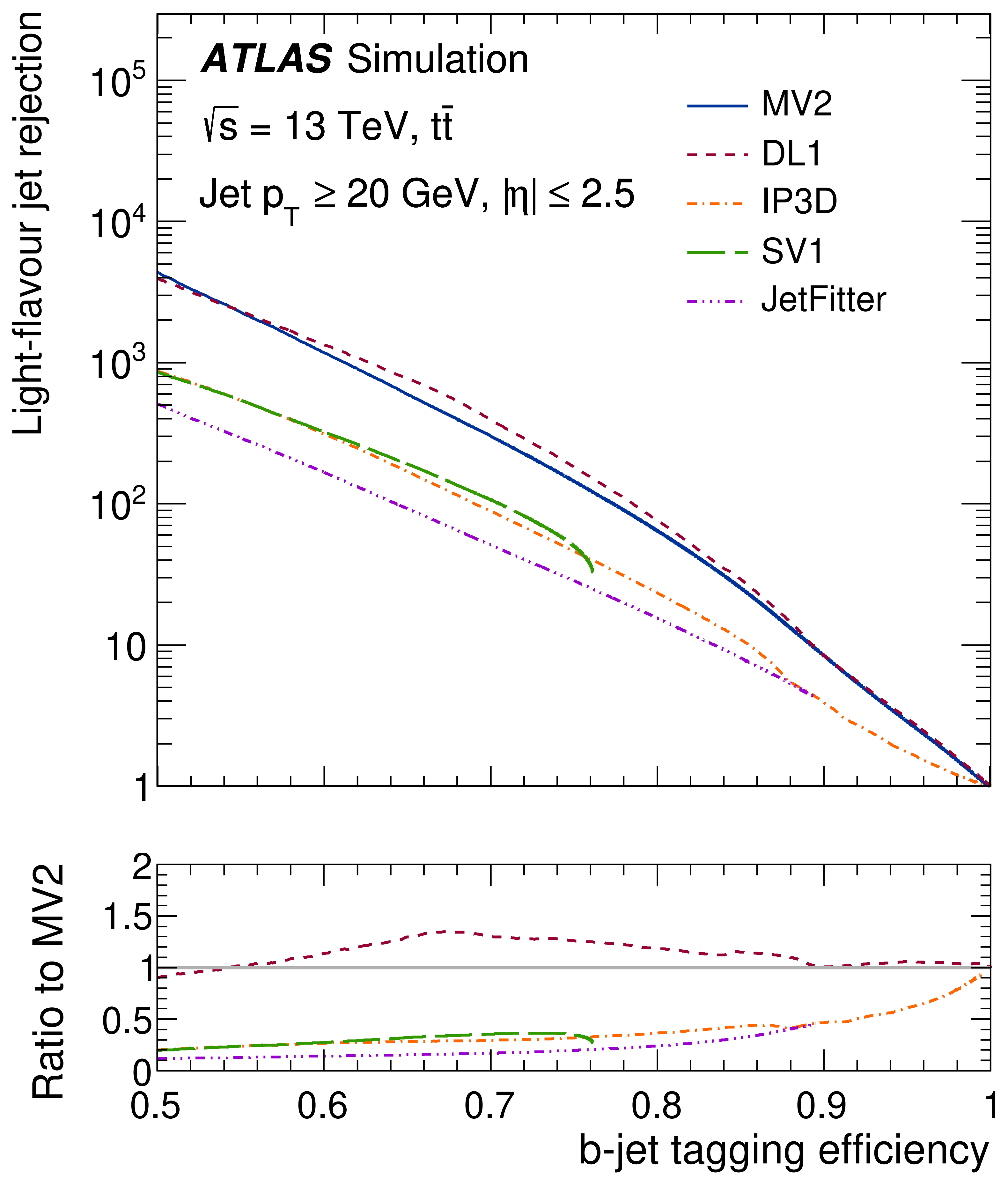
1 b-tag Signal Region: One b-jet close to one of the top jets
2 b-tag Signal Region: Each top jet is associated with a b-jet

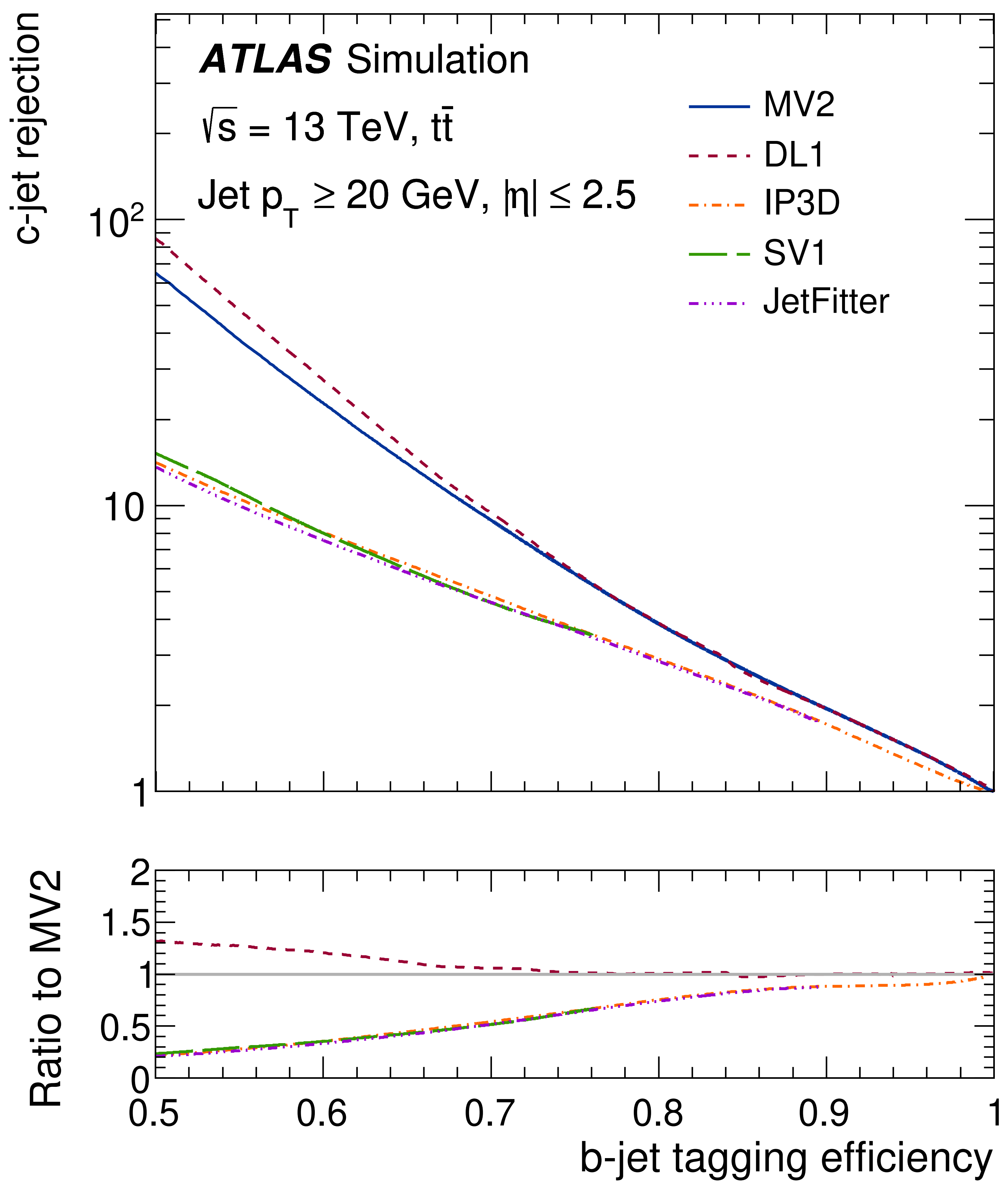


1 b-tag Signal Region (SR1b)

2 b-tag Signal Region (SR2b)

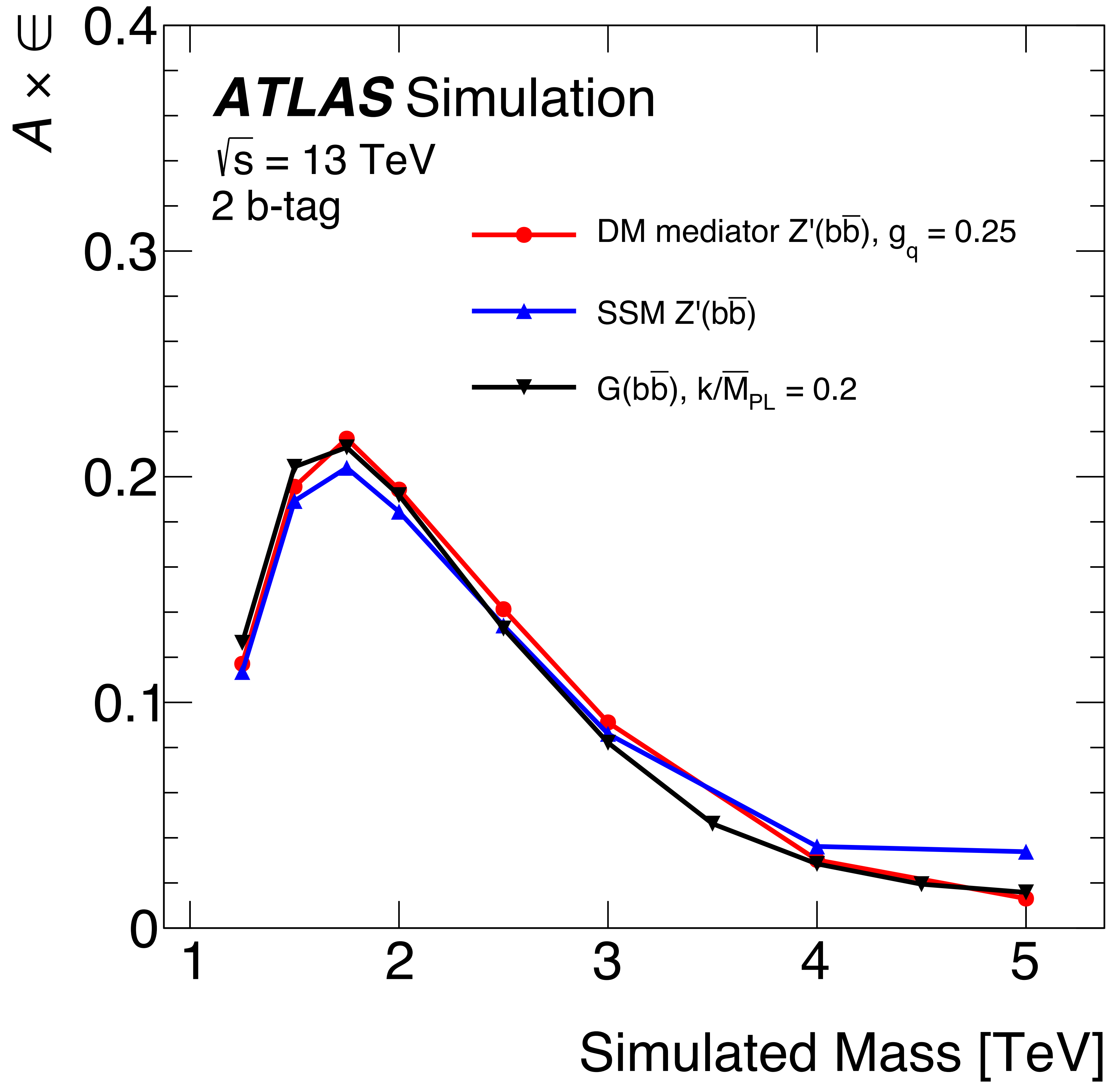
b-tagging performance

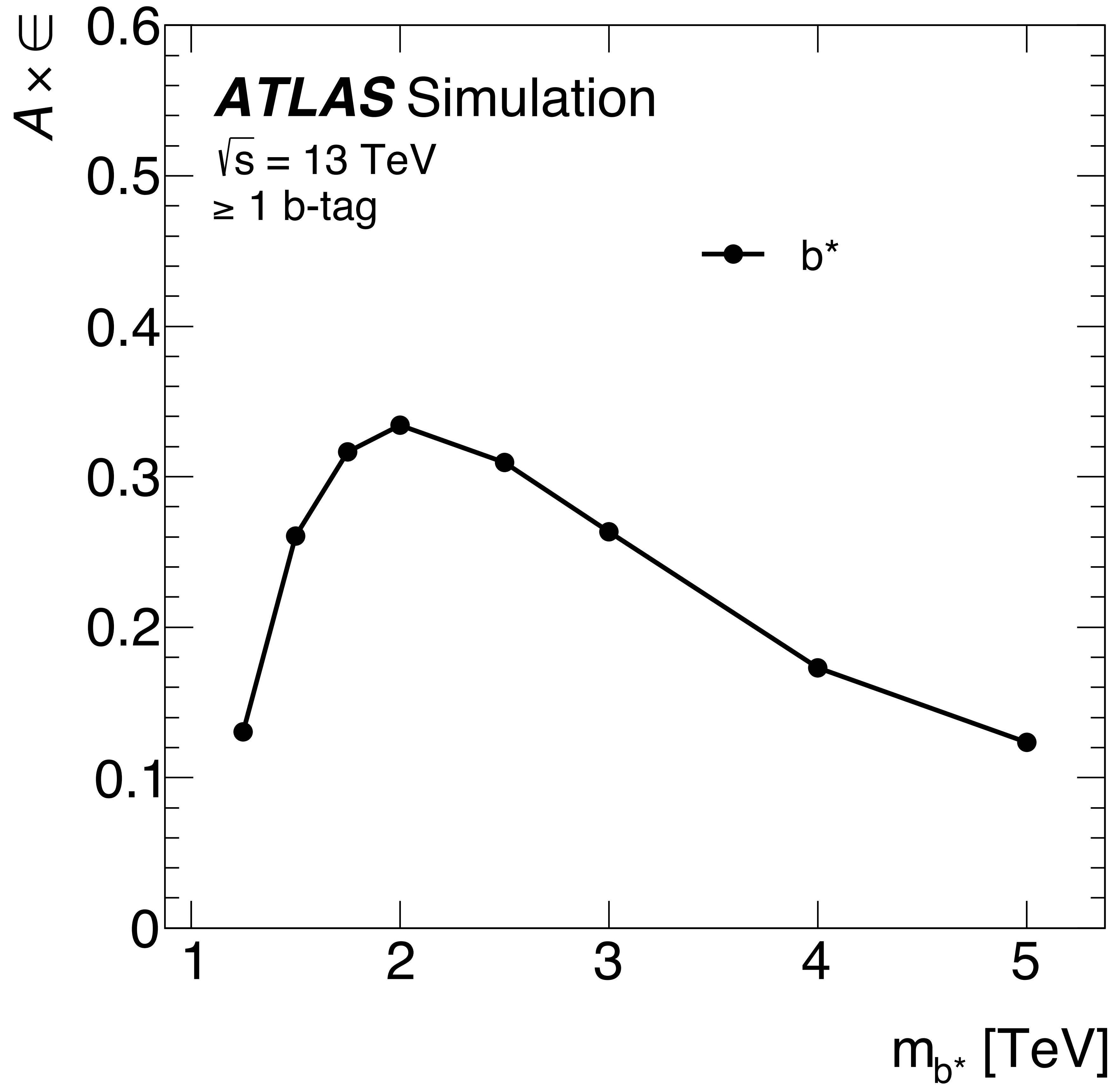




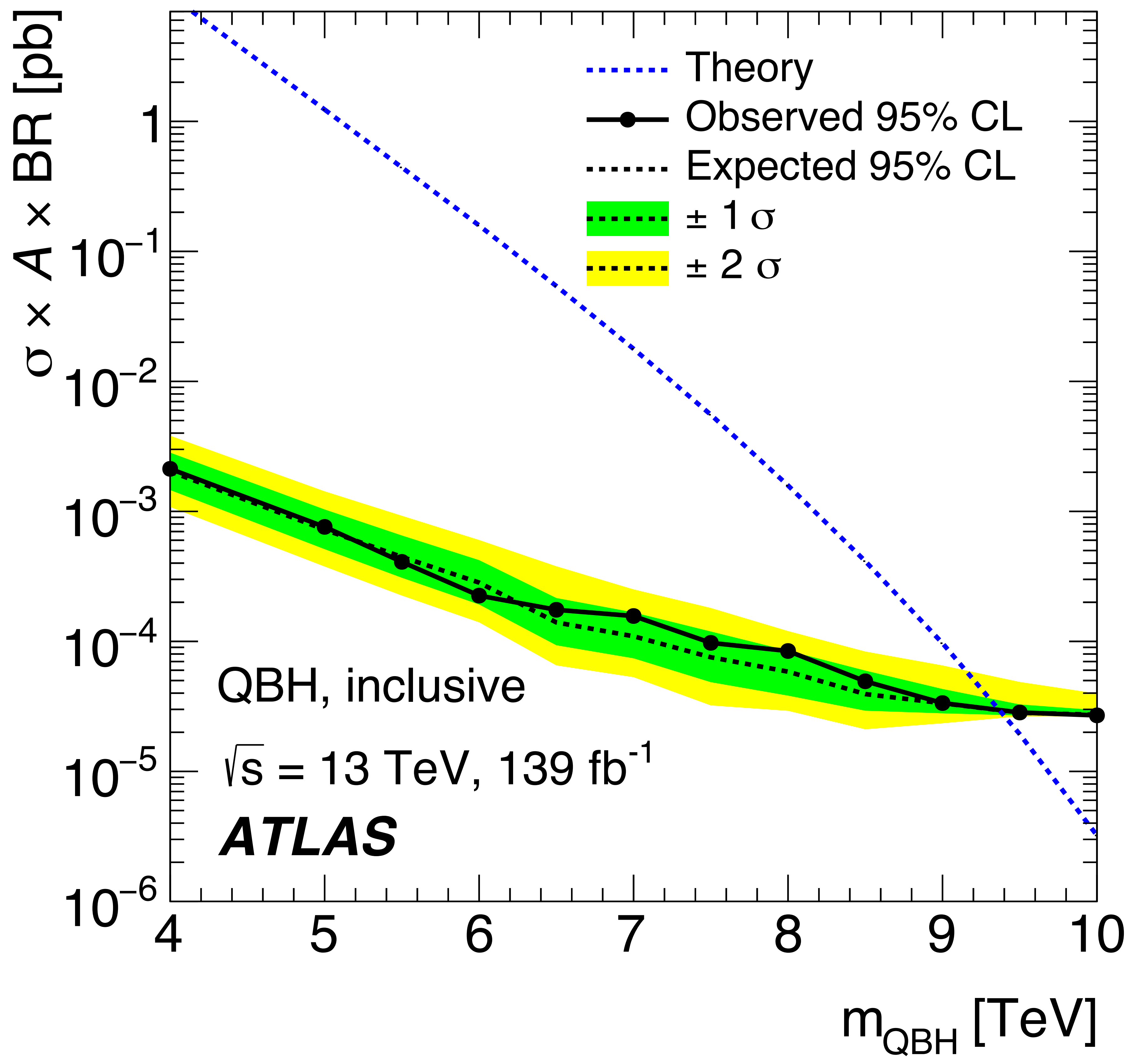
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/FTAG-2018-01/

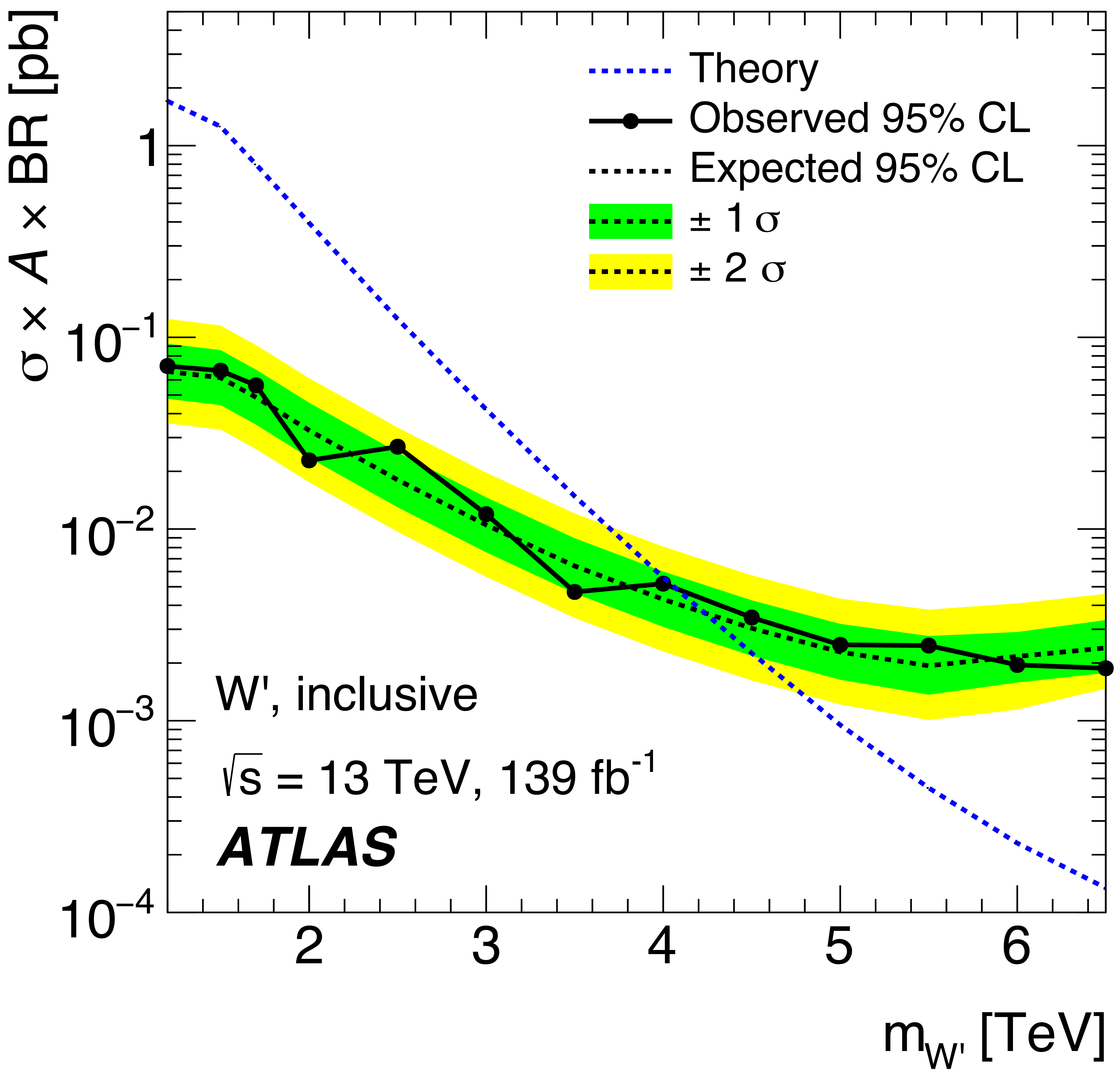
Signal acceptance X efficiency



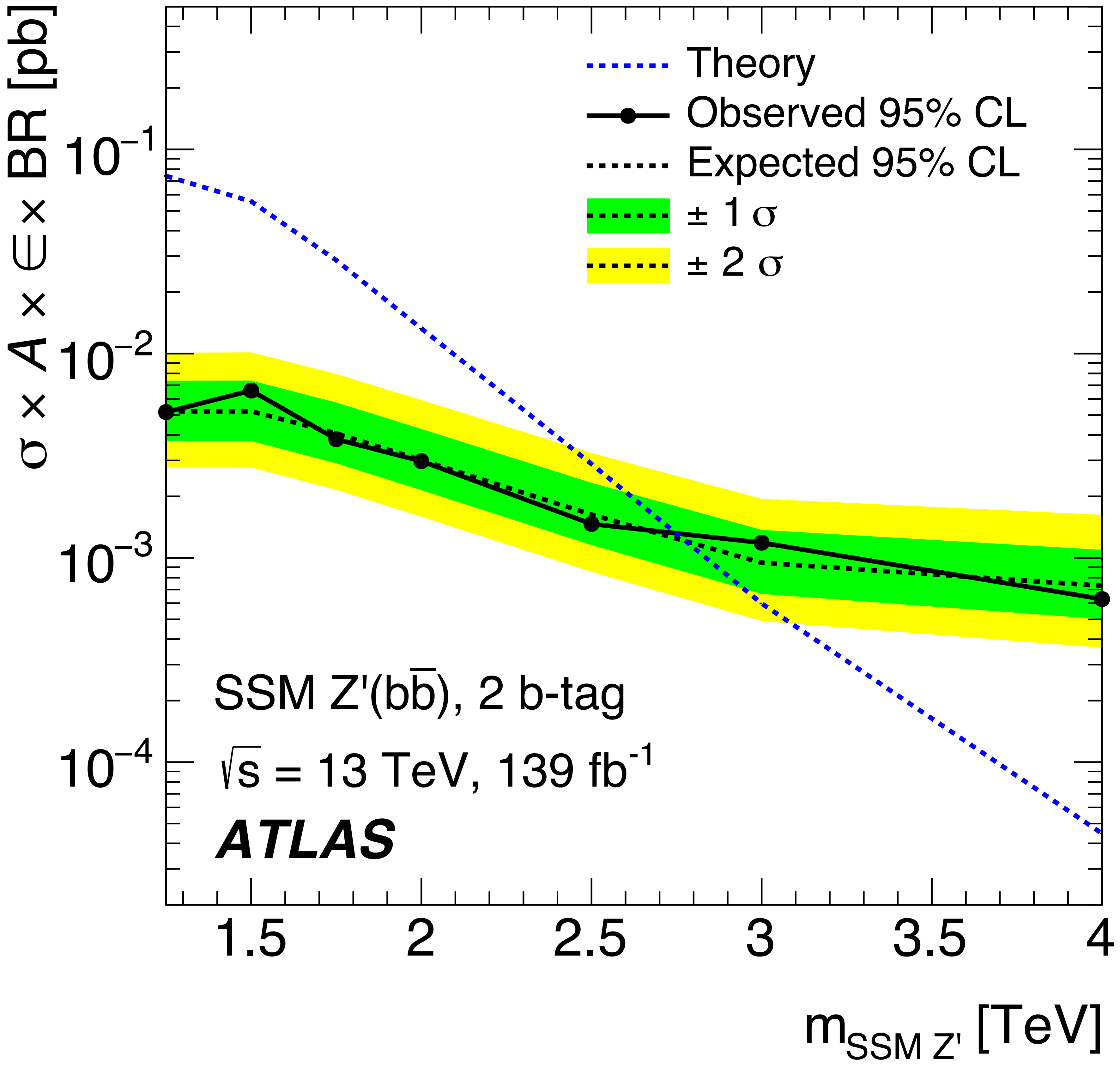


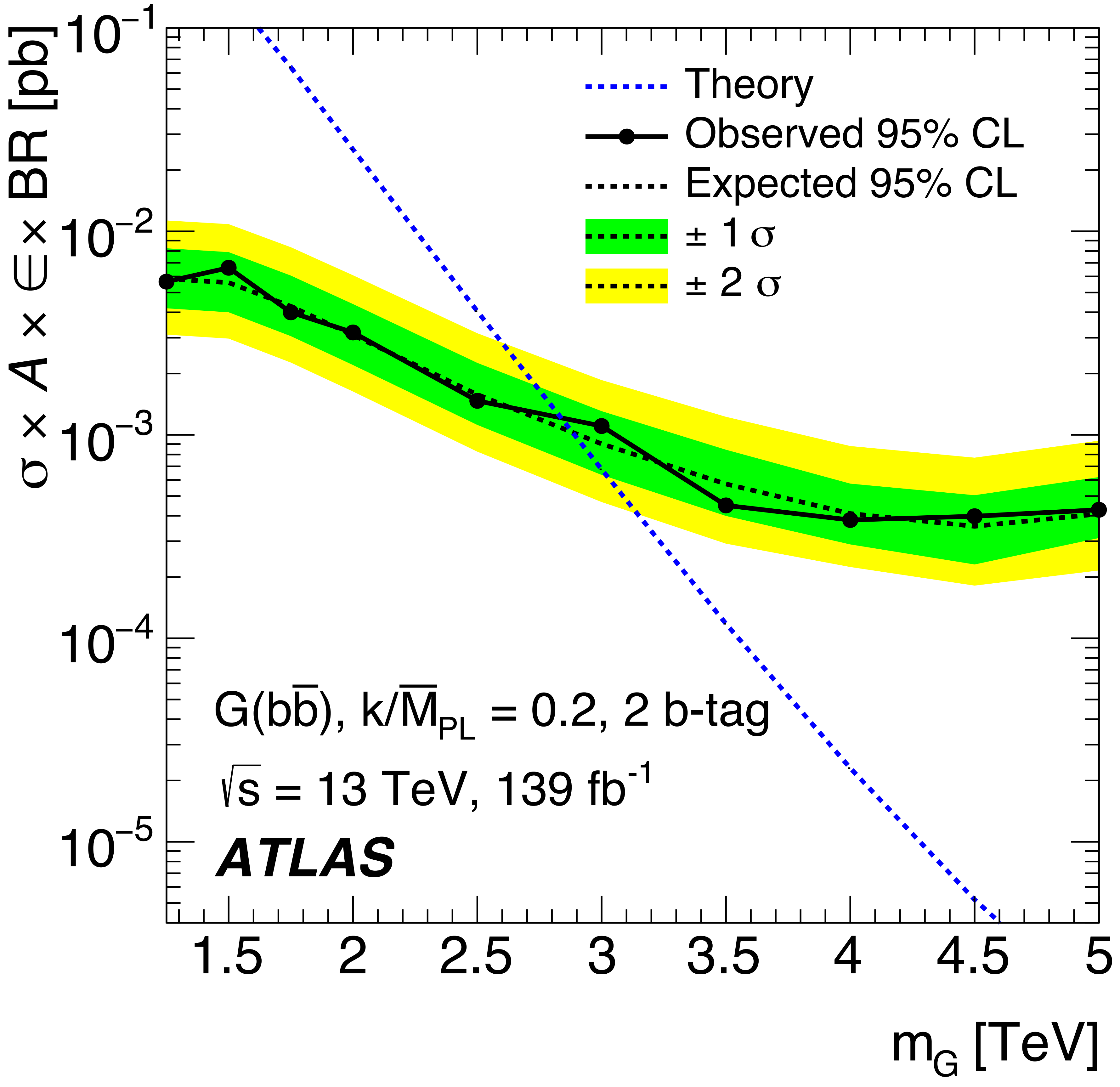
Dijet/di-bjet Limit: inclusive



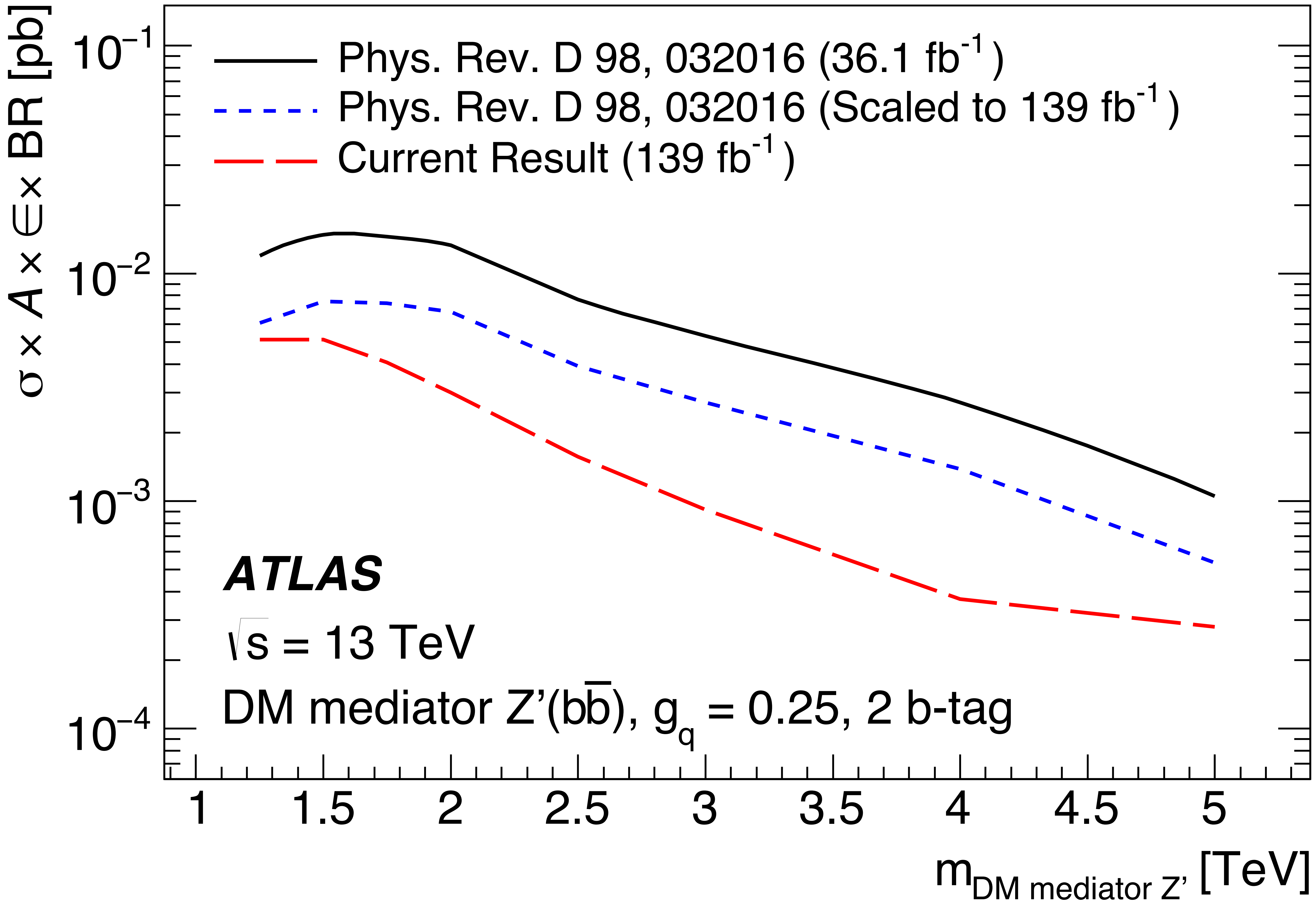


Dijet/di-bjet Limit: 2 b-tag region



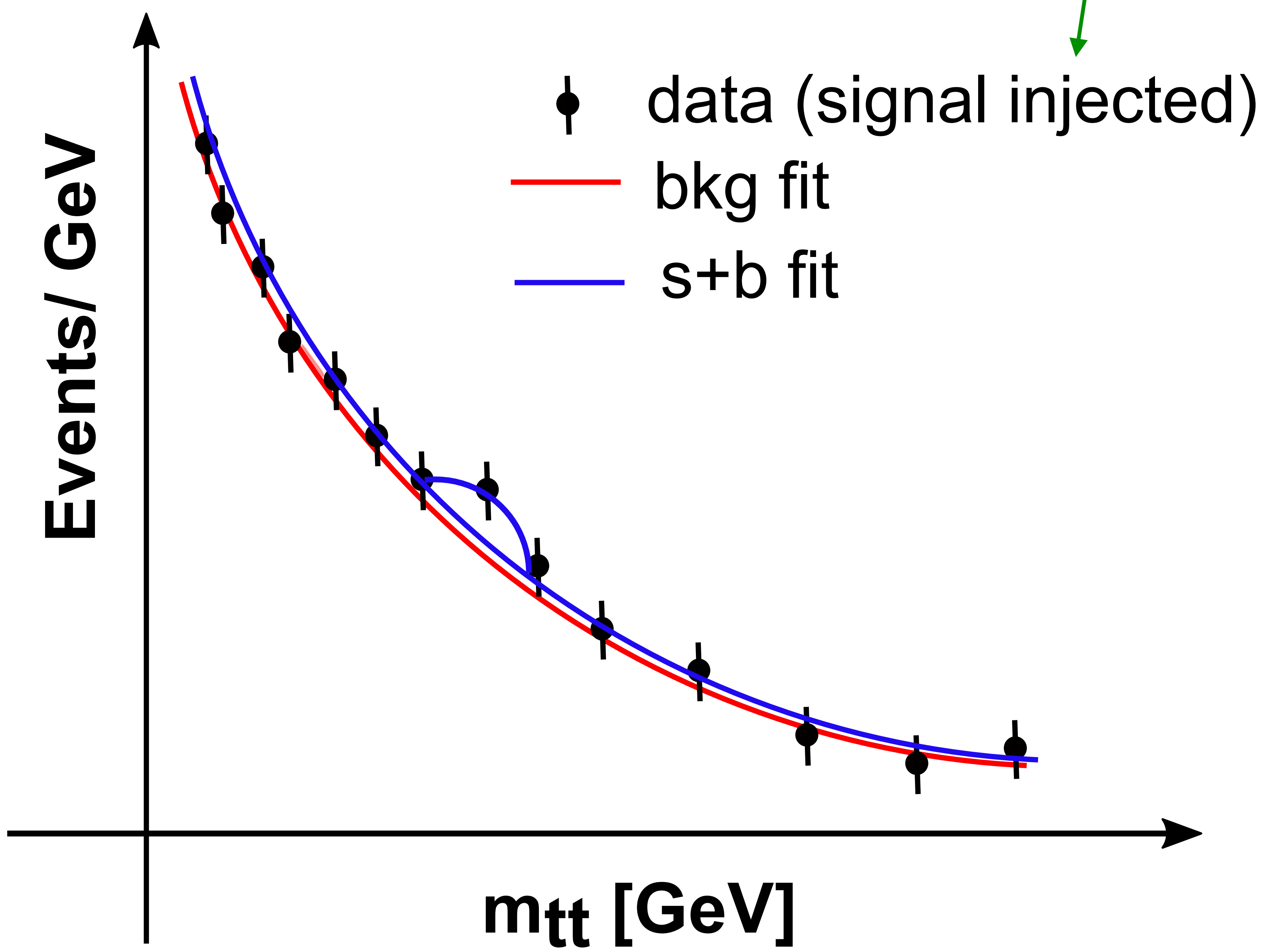


Dijet Analysis: cross section improvement



Signal Injection Test

- Ability of extracting signal was tested by **injecting known signal**
- Do a s+b fit
  - **Signal function:** Gaussian + Crystal Ball
- Extracted vs injected strength: **linear trend**

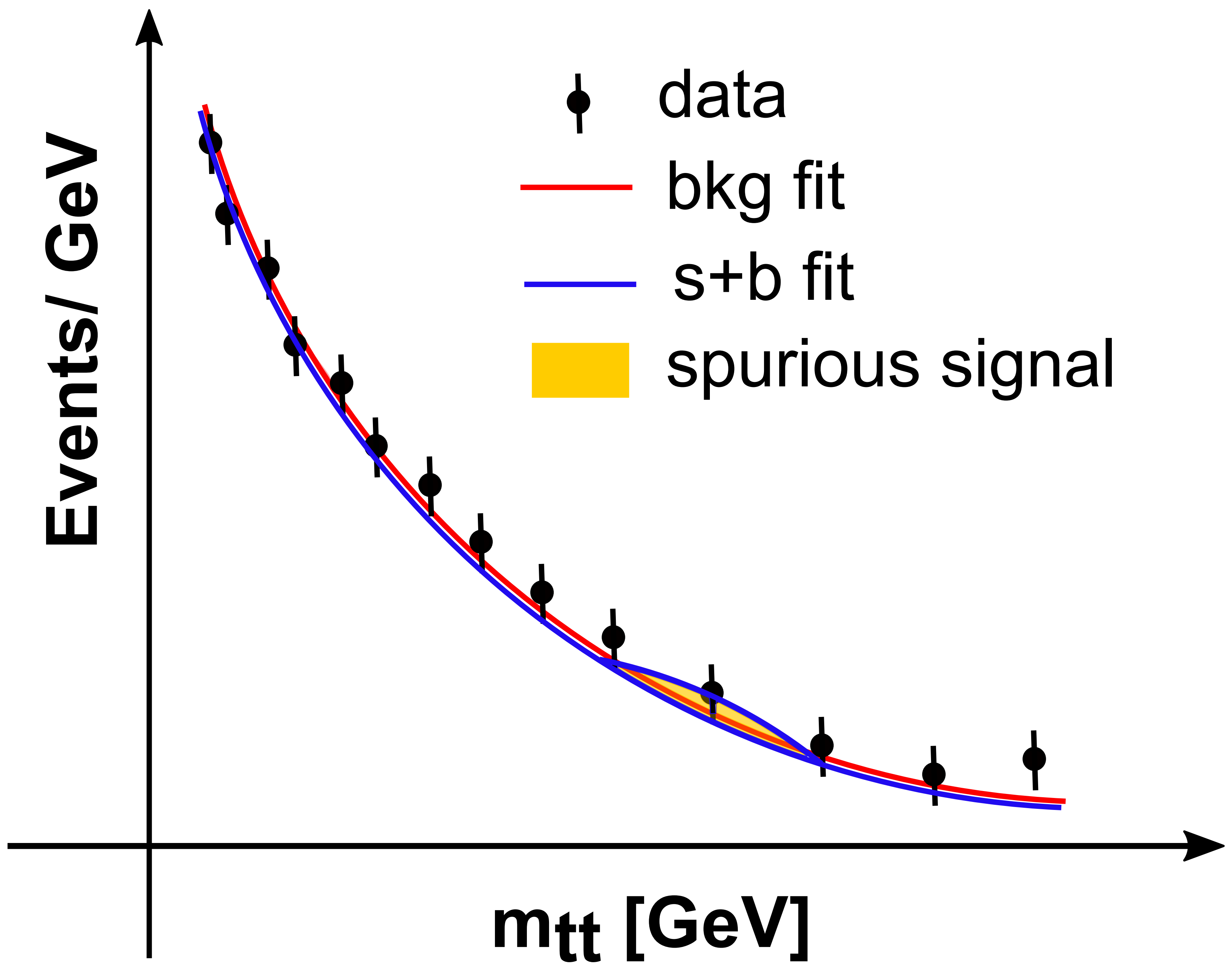


Spurious Signal Test

Number of fit parameters optimized based on the following:

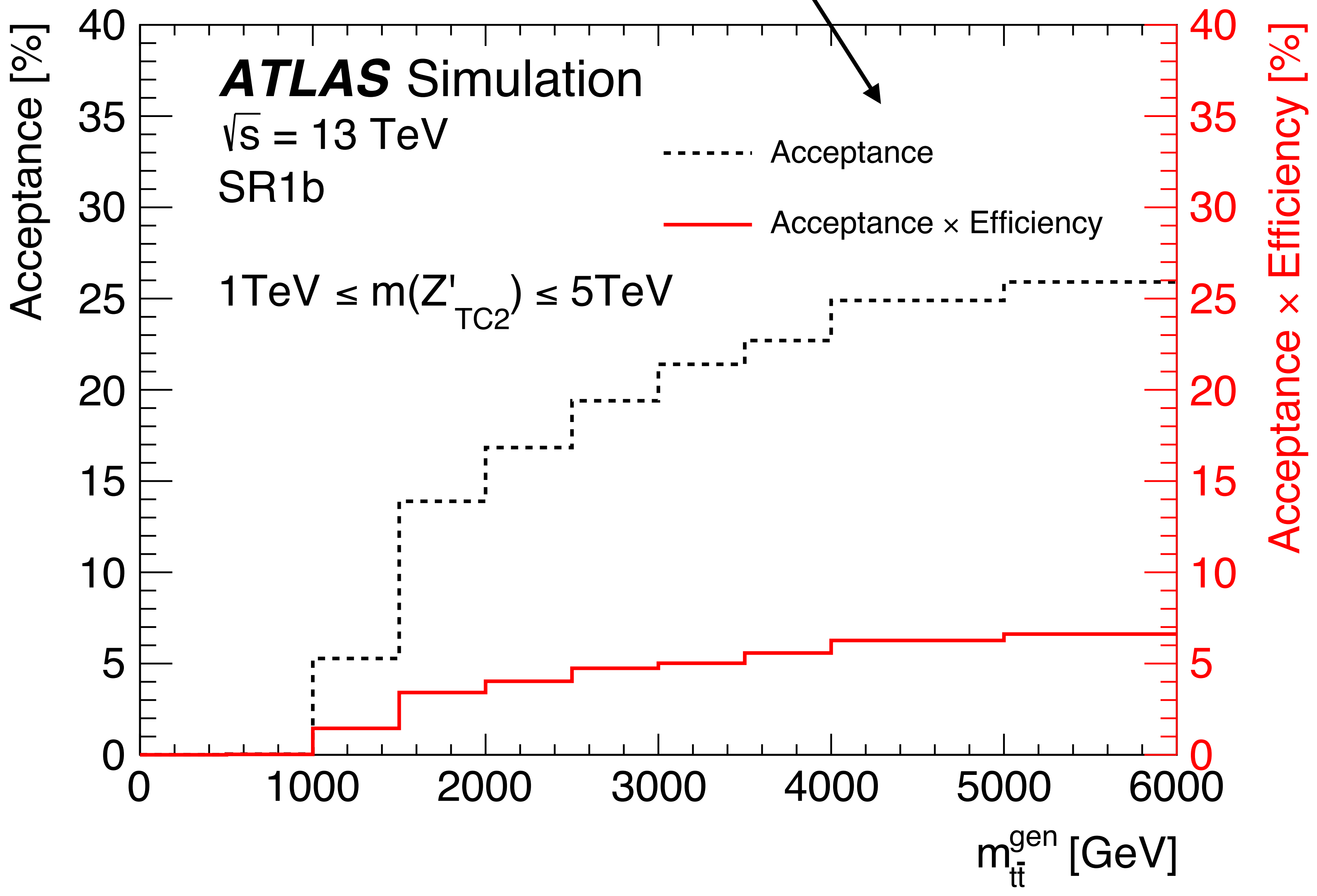
1. lowest chiSq
2. Wilk's test
3. Minimize the spurious signal yield obtained by s+b fit to this b-only template

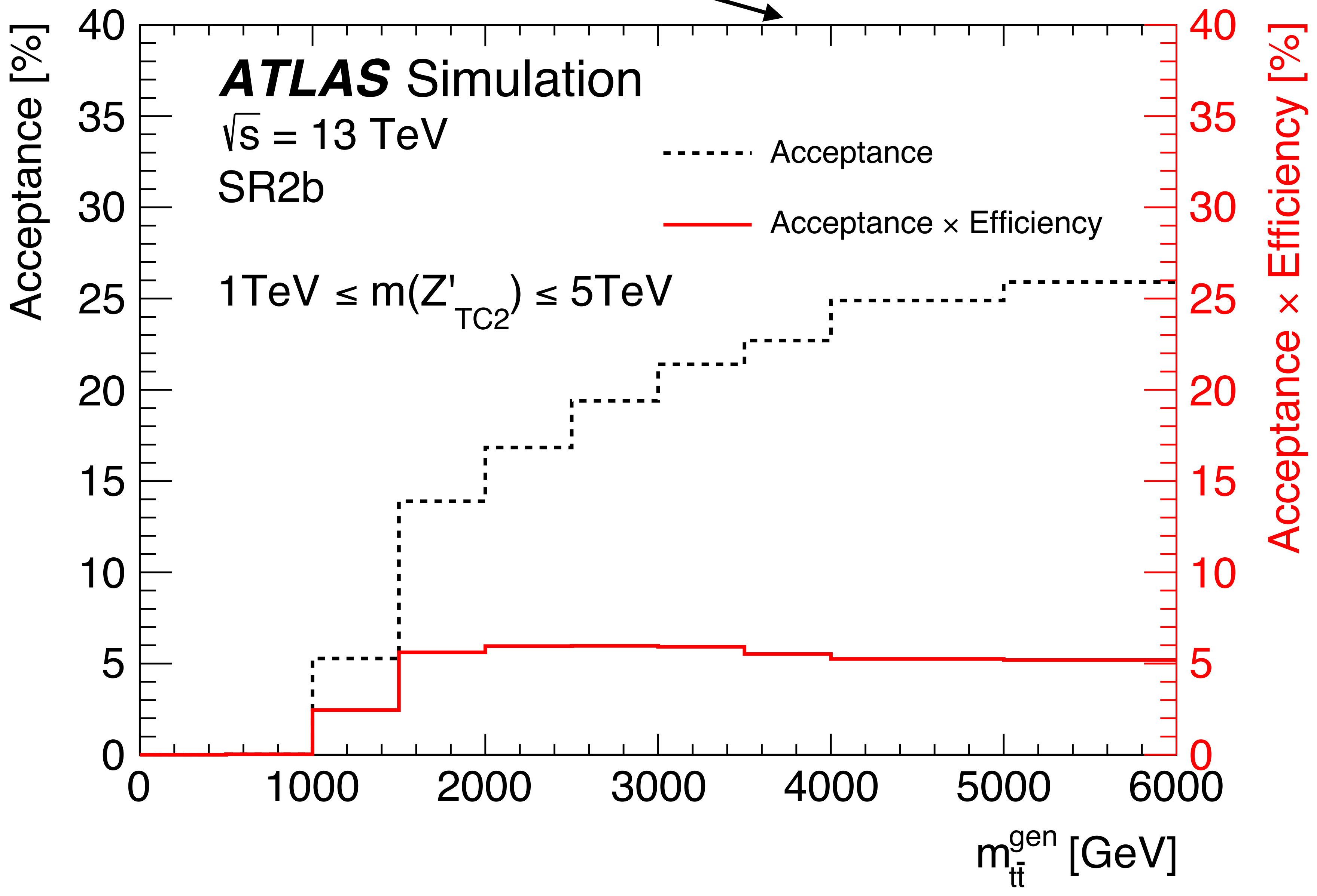
- Signal shape dependent "localized" uncertainty is assigned as spurious signal unc.



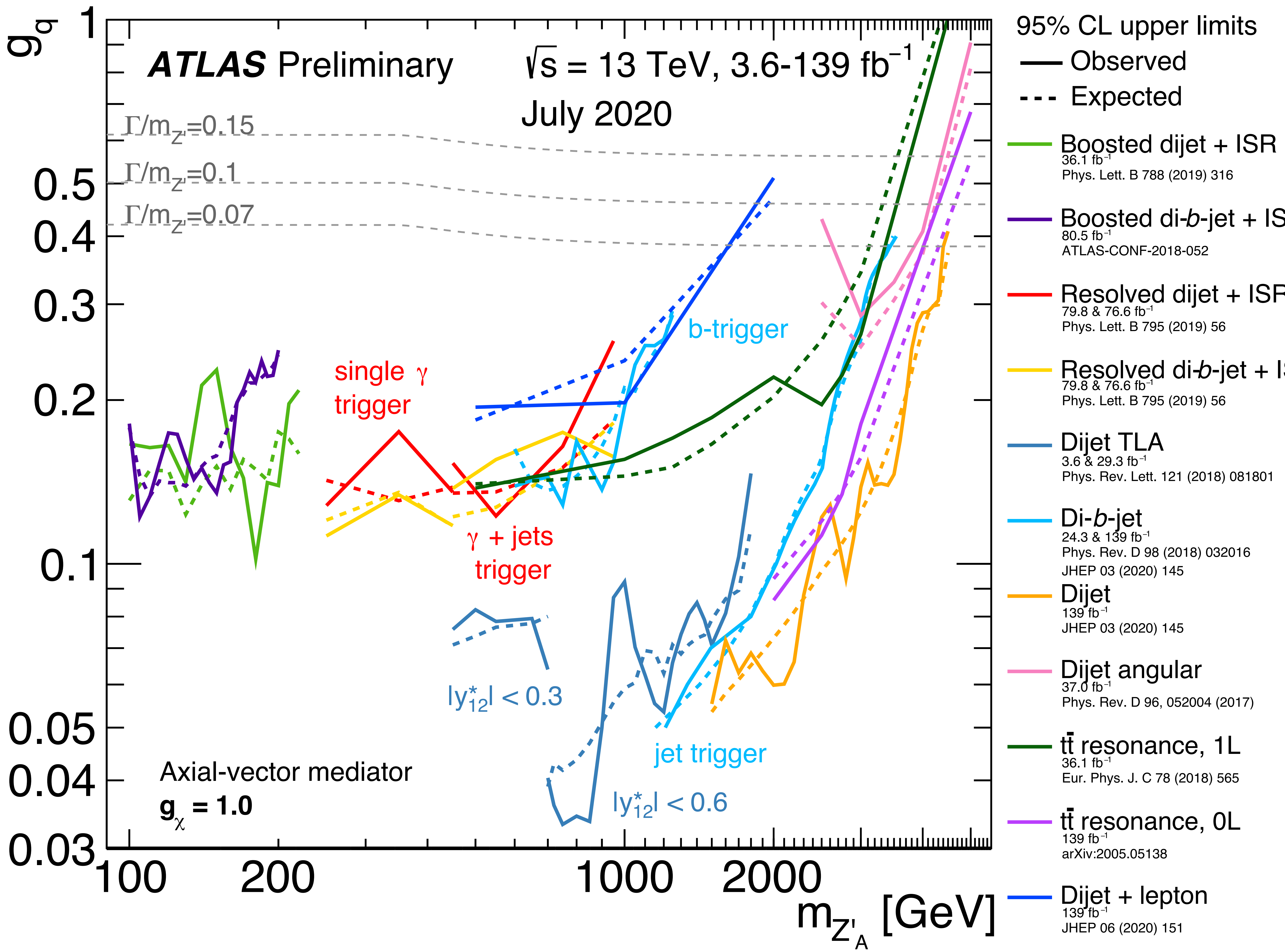
Selection Efficiency

- **Acceptance** times **efficiency** as a function of the invariant mass of a top-quark pair at the generator level
- Acc x eff is around 7% (1bSR) and 5 % (2bSR)





DM interpretation: coupling Vs mediator mass



[ATL-PHYS-PUB-2020-021]

The ATLAS Experiment

General purpose detector

Toroidal Magnet: 0.5 T

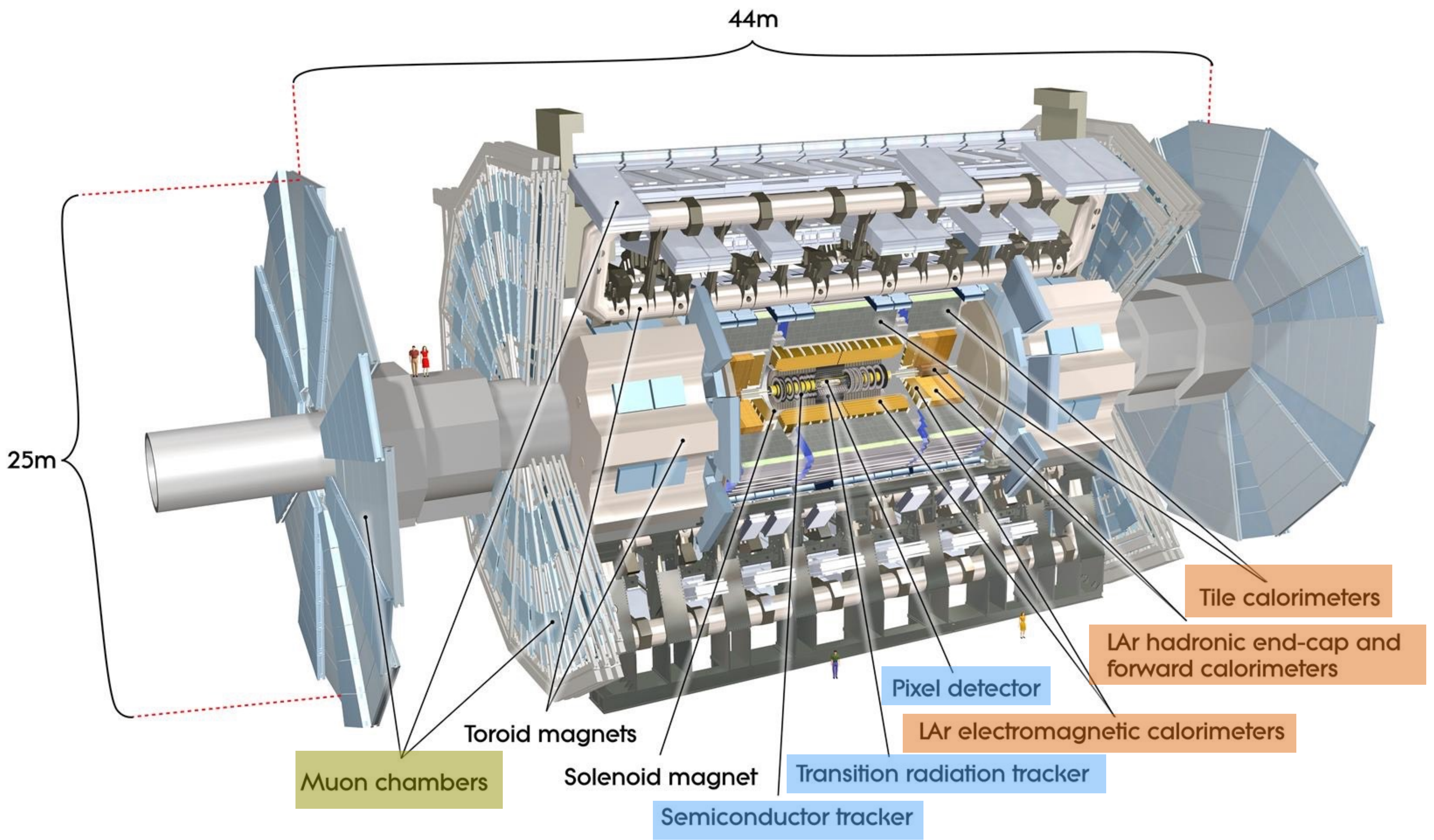
Muon Spectrometer: four different detector technology

Calorimeter: Electromagnetic (Liquid Argon), Hadronic (Liquid Argon (endcap) & Tile (barrel))

Solenoid Magnet: 2.0 T

Inner Detector:
three different detector technology

1. Silicon Pixel
2. Silicon Strip
3. Straw Tubes: Transition Radiati
Tracker (TRT)



Background composition: tt res all-had

Table 11: Event yields in the $|\Delta y(J, J)| < 1.8$ 0, 1 and 2 b-tag regions in 2015+2016+2017+2018 data.

Type	btag cat.0	btag cat.1	btag cat.2
$t\bar{t}$ (all-had)	2842.1 ± 1191.3 (2.5%)	5967.1 ± 43.2 (21.1%)	6195.7 ± 38.4 (75.9%)
$t\bar{t}$ (non-all-had)	261.8 ± 99.1 (0.2%)	500.7 ± 9.9 (1.8%)	229.2 ± 5.2 (2.8%)
Multijet	110 536.6 ± 1329.2 (97.3%)	21 794.8 ± 104.5 (77.1%)	1734.5 ± 11.8 (21.3%)
Total	113 640.5 ± 350.3	28 262.7 ± 113.4	8159.4 ± 40.4
Data	113 612 ± 337.1	26 964 ± 164.2	8160 ± 90.3

Systematic Uncertainties: tt res all-had

Major contribution comes from JES uncertainty (all combined shown here)

Source	**2 TeV Z' [%]**		**4 TeV Z' [%]**	
	SR1b	SR2b	SR1b	SR2b
JES	35	34	47	44
JMS	5.0	4.3	9.5	7.9
JER	0.1	0.1	0.1	< 0.1
JMR	3.9	4.0	8.0	8.0
b-tagging	14	5.0	23	5.3
Top-tagging	9.0	9.3	10	10