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SEMINAR LPC

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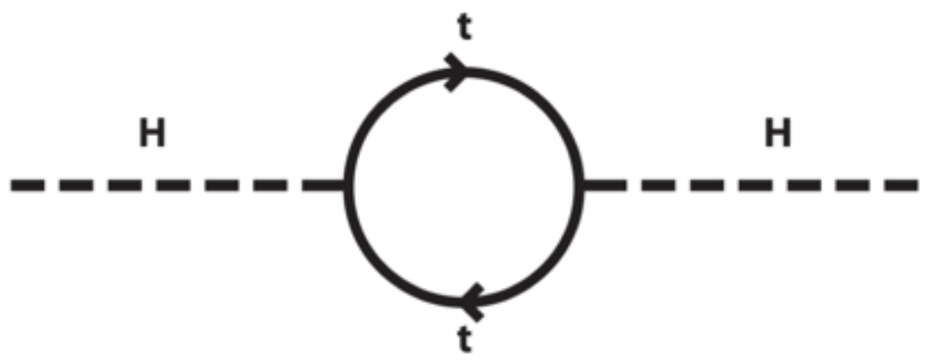
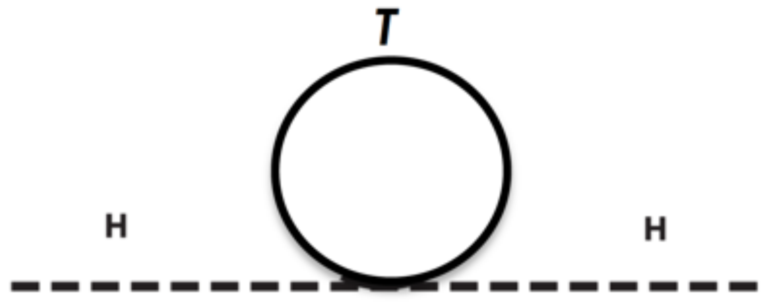
RECENT RESULTS OF SEARCHES FOR NEW PHENOMENA IN FINAL STATES WITH 3RD GENERATION QUARKS USING THE ATLAS DETECTOR

INTRODUCTION

- The large top Yukawa coupling to the Higgs boson motivates searches **for new physics coupling to top or b-quarks**



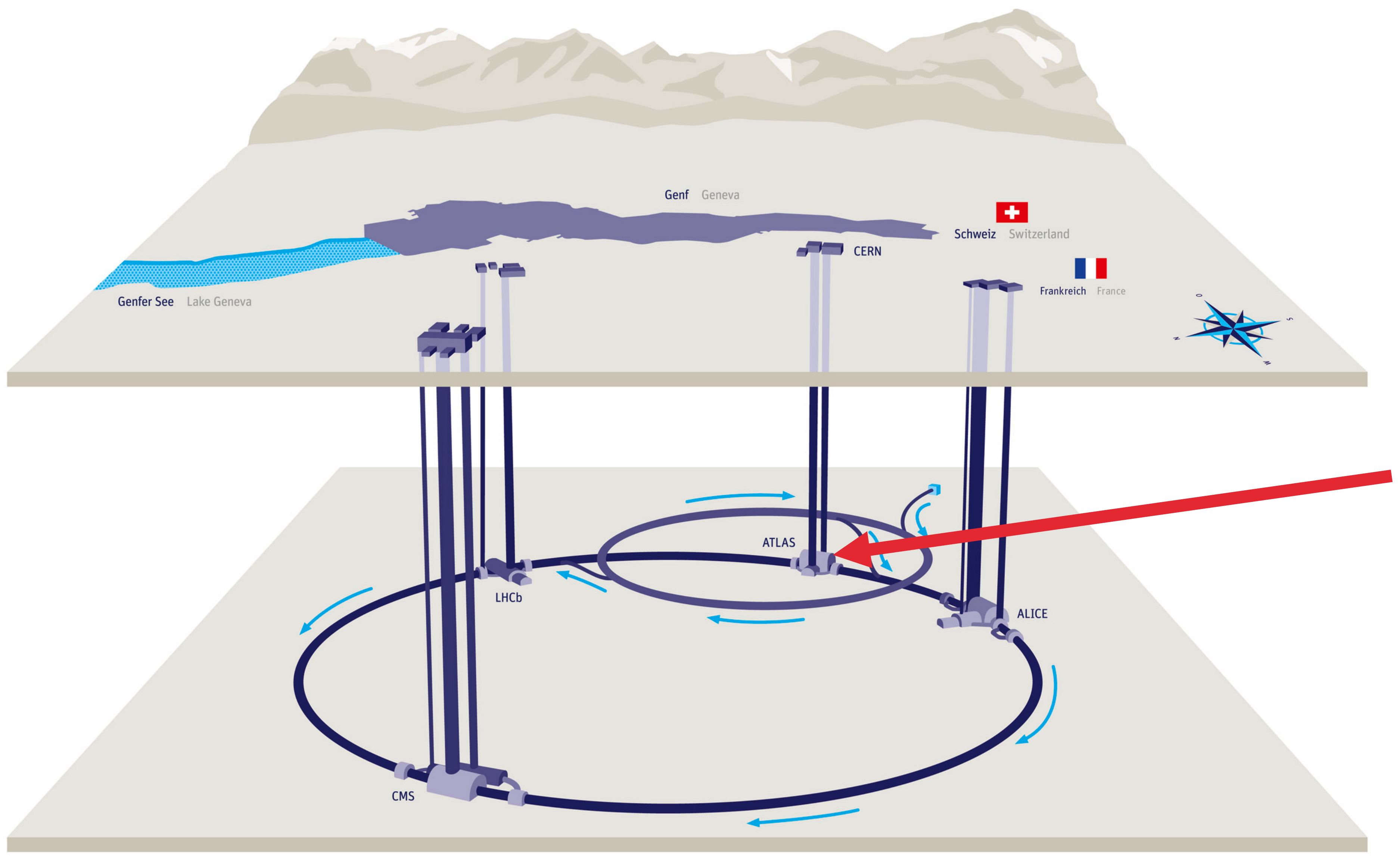
- Radiative corrections from the top quark lead to quadratic divergences to the Higgs boson mass
  - Search for a mechanism to cancel those corrections instead of fine tuning

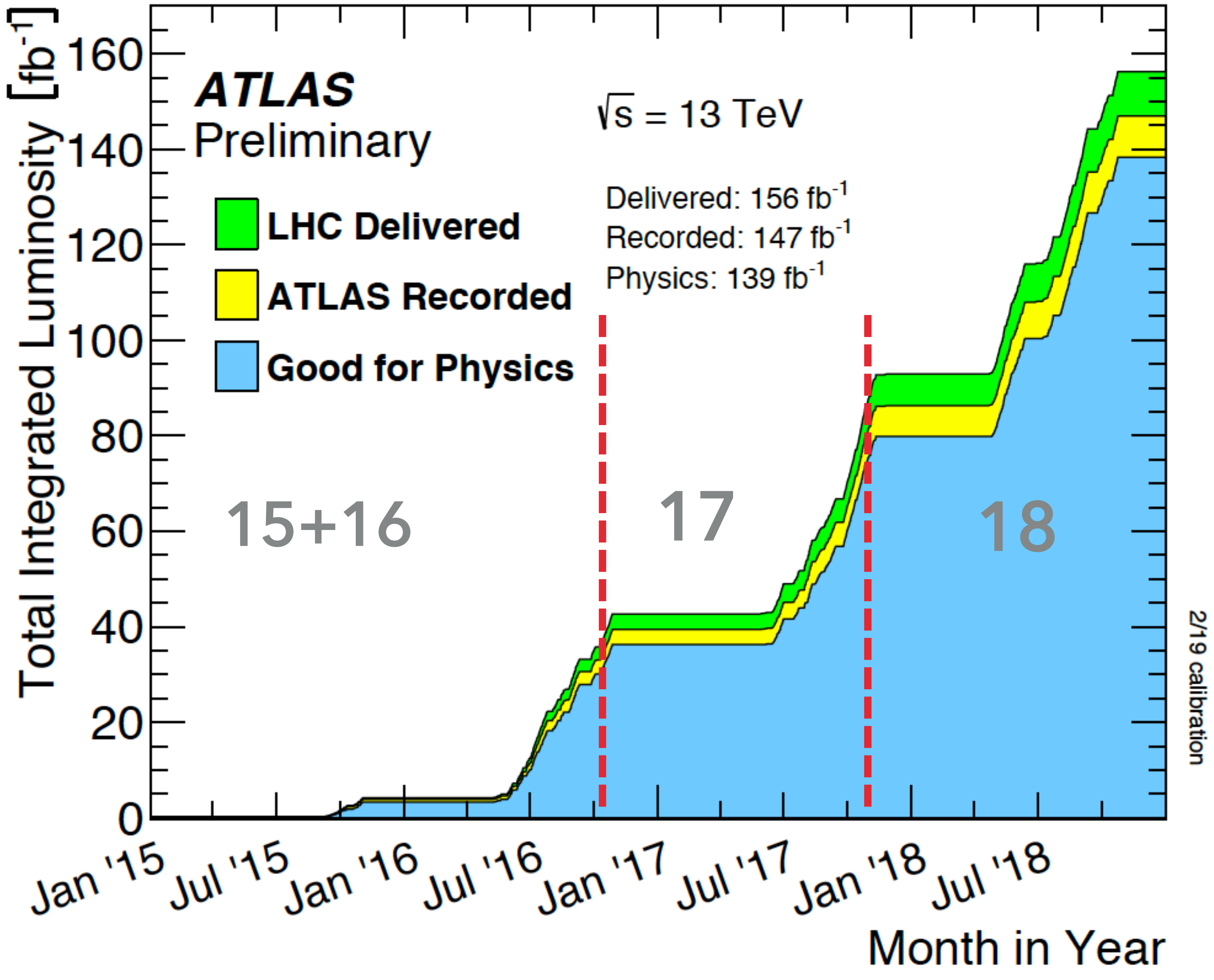


- Many new physics models like Composite Higgs models, extra dimensions etc. predict new particles coupling preferentially to 3rd generation quarks like:
  - Vector-like quarks
  - New heavy gauge bosons like W′ and Z′ as mediators to new vector charged/neutral current interactions
  - New heavy top resonances
- This talk covers results from recent searches for these new physics models using data from proton-proton collisions **recorded by the ATLAS experiment at a center-of-mass energy of 13 TeV collected during the LHC Run 2 (2015-2018)**

THE ATLAS RUN 2 DATASET

- Use ATLAS collision dataset recorded during **Run 2 of the LHC** (2015-2018) @center-of-mass energy √s=13TeV from proton-proton collisions
  - 156 fb-1 pp data delivered
  - **139 fb−1 “good for physics”** (uncertainty 1.7%)
- Thanks for successful operation of the LHC!





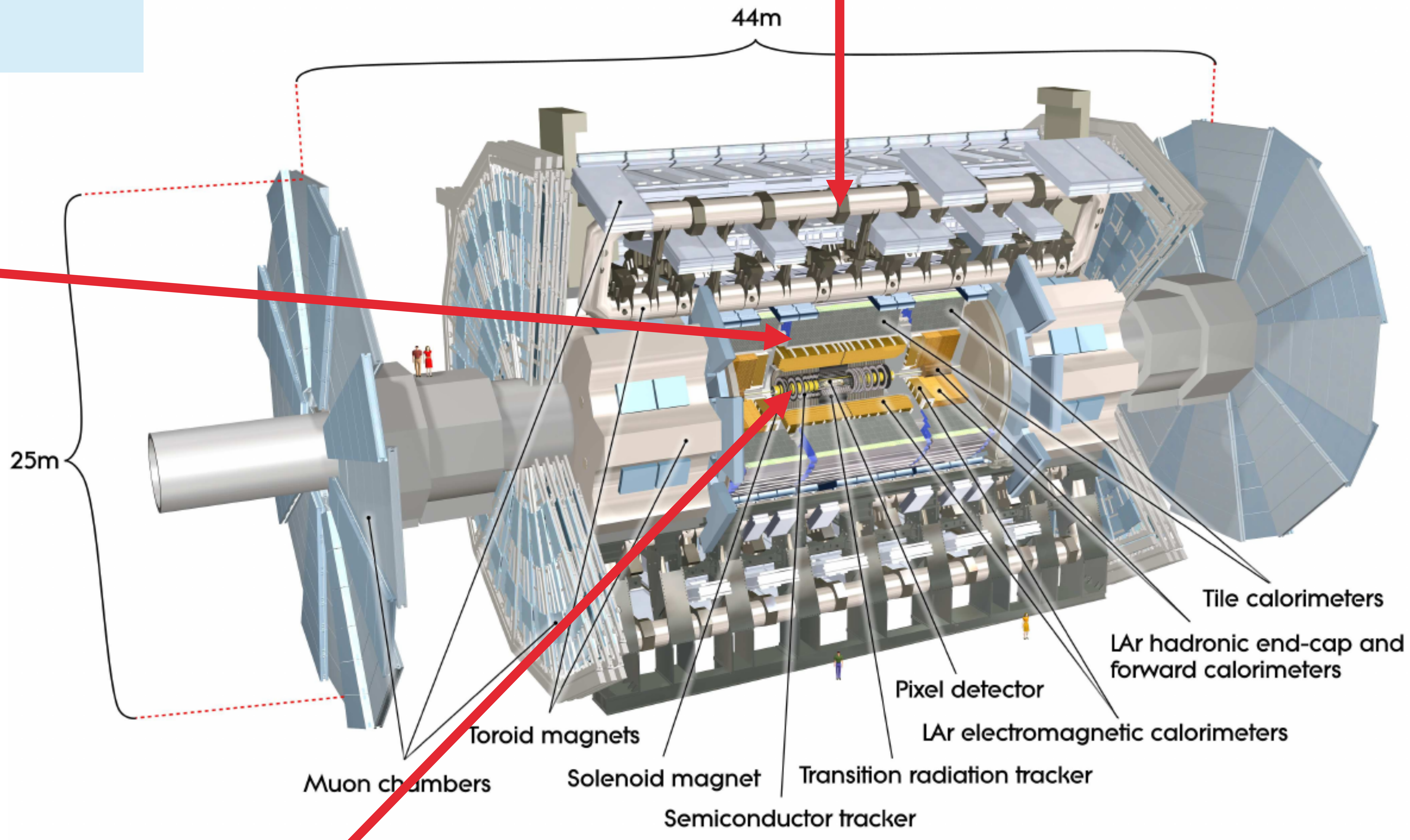
THE ATLAS DETECTOR

- 3 main subsystems
  - All information of the subsystems are combined to reconstruct and identify objects

Calorimeter:

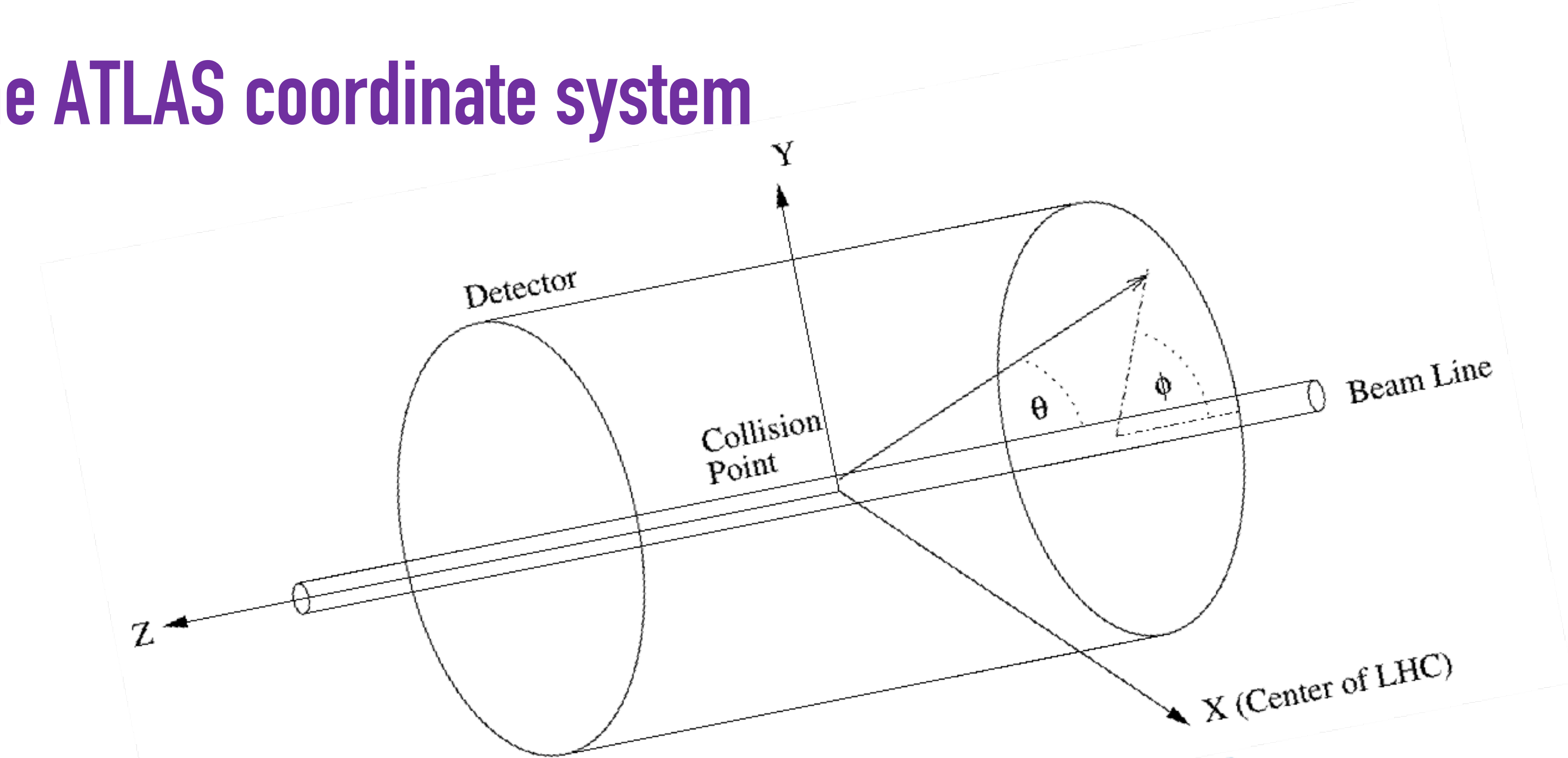
- Electromagnetic calorimeter → **Electrons, photons**
- Hadronic calorimeter →**Hadrons**

Muon chambers in magnetic field of toroid → **muons**



Inner detector tracker in 2T magnetic field by the solenoid → **charged particles**

The ATLAS coordinate system

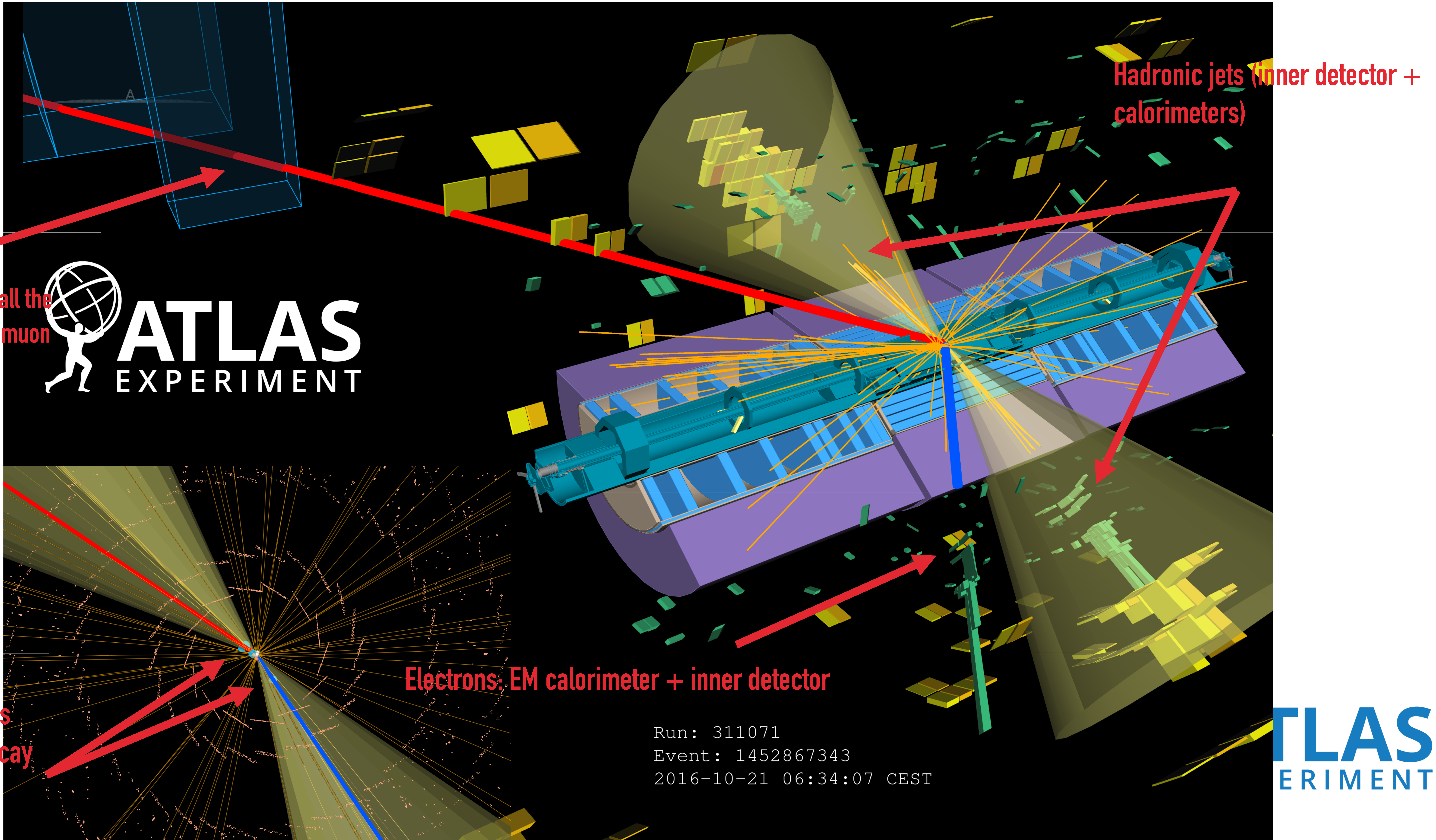


x, y: transverse plane

z: beam direction

η: pseudorapidity, $\eta = -ln(\tan(\frac{\theta}{2}))$

PARTICLE IDENTIFICATION IN ATLAS



Hadronic jets (inner detector + calorimeters)

Muons travel trough all the detector through the muon spectrometer

Electrons: EM calorimeter + inner detector

Secondary vertices from b-hadron decay

HADRONIC JETS IN ATLAS: PARTICLE FLOW JETS

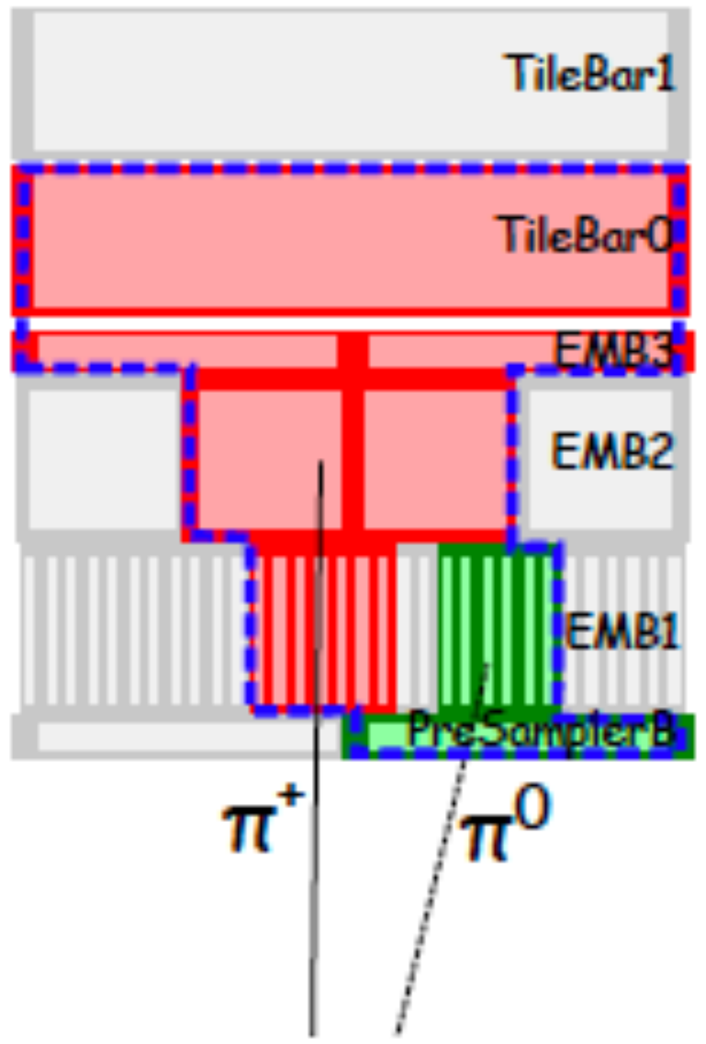
- Jets in ATLAS are reconstructed using the particle flow algorithm
  - Fixed radius R=0.4 (“small-R jets”)
  - For “standard-use” case

TRACKING

- BETTER RESOLUTION FOR LOW PT PARTICLES
- BETTER ANGULAR RESOLUTION
- TRACES PARTICLES TO HARD-SCATTER INTERACTION OR PILE-UP

CALORIMETERS

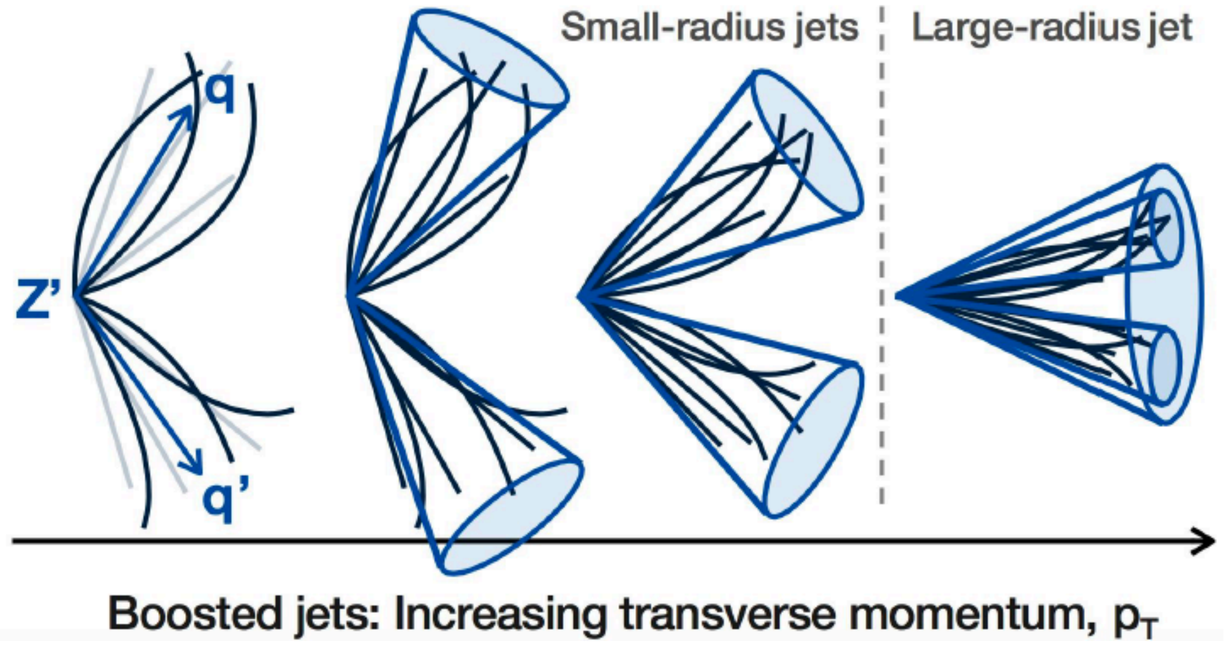
- BETTER RESOLUTION FOR HIGH PT
- CAPTURES NEUTRAL PARTICLES

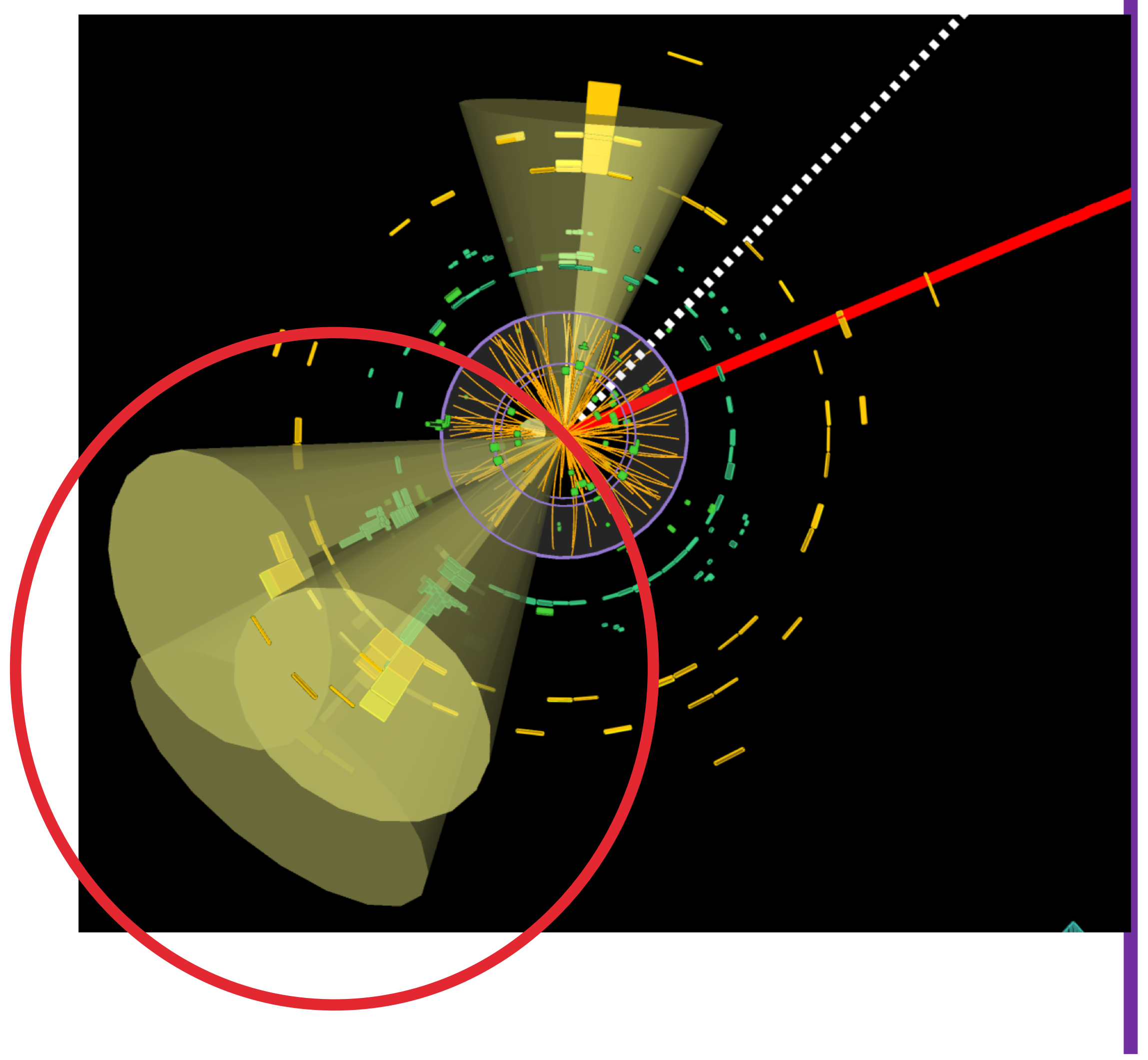


- **Combine** information from Trackers & Calorimeters
  - Tracks are assigned (or not) to signal contributions in the calorimeters, ideally **represent individual particles**
- **Improves energy and angular resolution**

HADRONIC JETS IN ATLAS: JETS OPTIMIZED FOR BOOSTED PARTICLE DECAYS

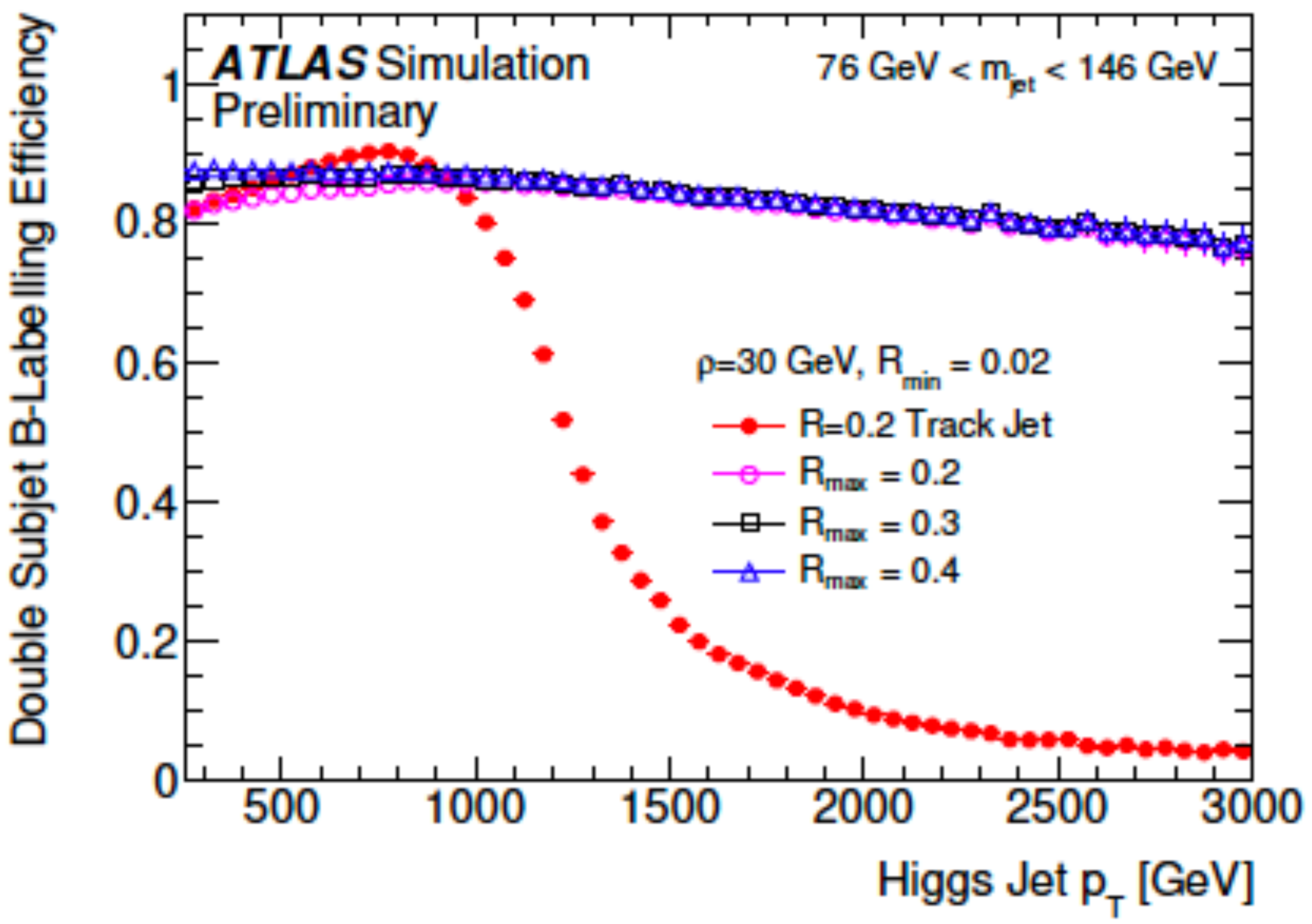
- Decay products from particles with high pT **merged in a single large-radius jet**
  - Reclustering from small-R jets (analysis-custom)
  - Dedicated ATLAS calorimeter jet reconstruction with a **(fixed) radius of R=1.0**



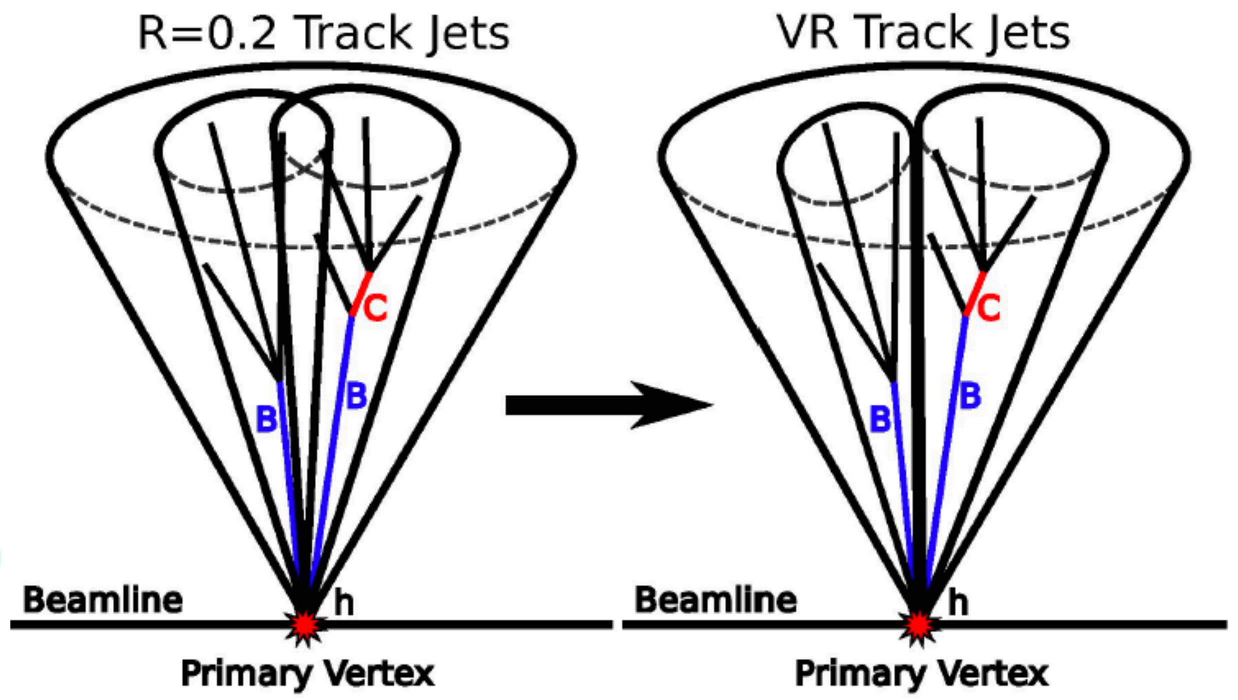


$$\Delta R \approx 2m/p_T$$

- Cannot resolve sub-jets as separate jets with fixed-cone jet algorithm
- Dedicated track jet collection with **variable size : R ~ 1/pT(jet)**
- Defined by **three parameters**: ρ (dimensionless constant), **Rmin=0.02** (minimal size) and **Rmax=0.4** (maximal size)
- Use information from tracker only: **"variable-radius track jets" (VRTrack)**



$$R \longrightarrow R_{\mathrm{eff}}(p_T) = \frac{\rho}{p_T}$$



IDENTIFICATION OF 3RD GENERATION QUARKS

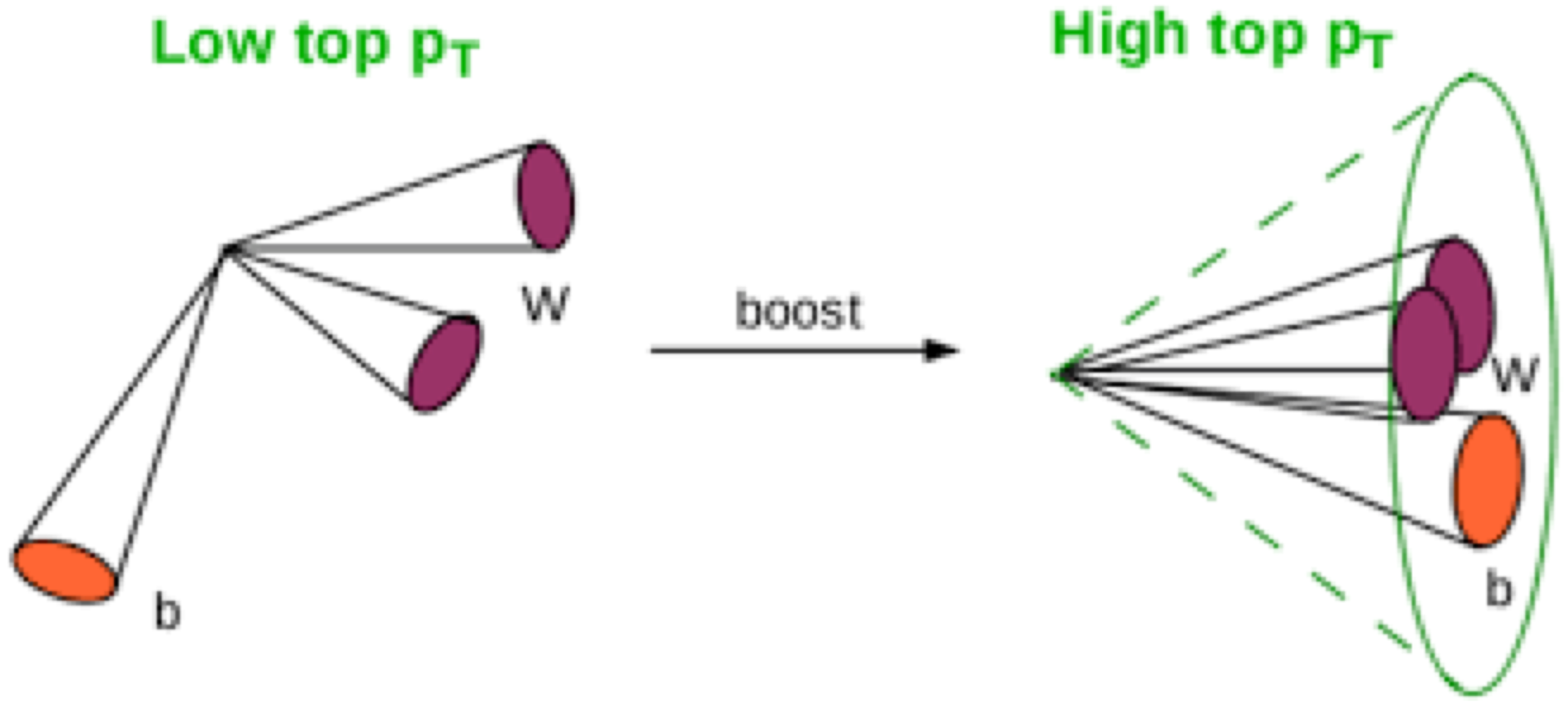
- Many analyses exploit the high branching ratio of the all-hadronic decay
- All searches presented in this talk **rely on the identification of hadronic jets from top or bottom quarks**
  - High identification efficiency
  - Good rejection of non-3rd generation quarks:
    - Bottom quarks <-> charm & light quarks
    - (boosted) Top quarks <-> multijet events

Rejection of (dominant) background from multijet events important, directly related to sensitivity to new physics!

Remaining background needs to be well modeled

IDENTIFICATION OF 3^{RD} GENERATION QUARKS: TOP QUARKS

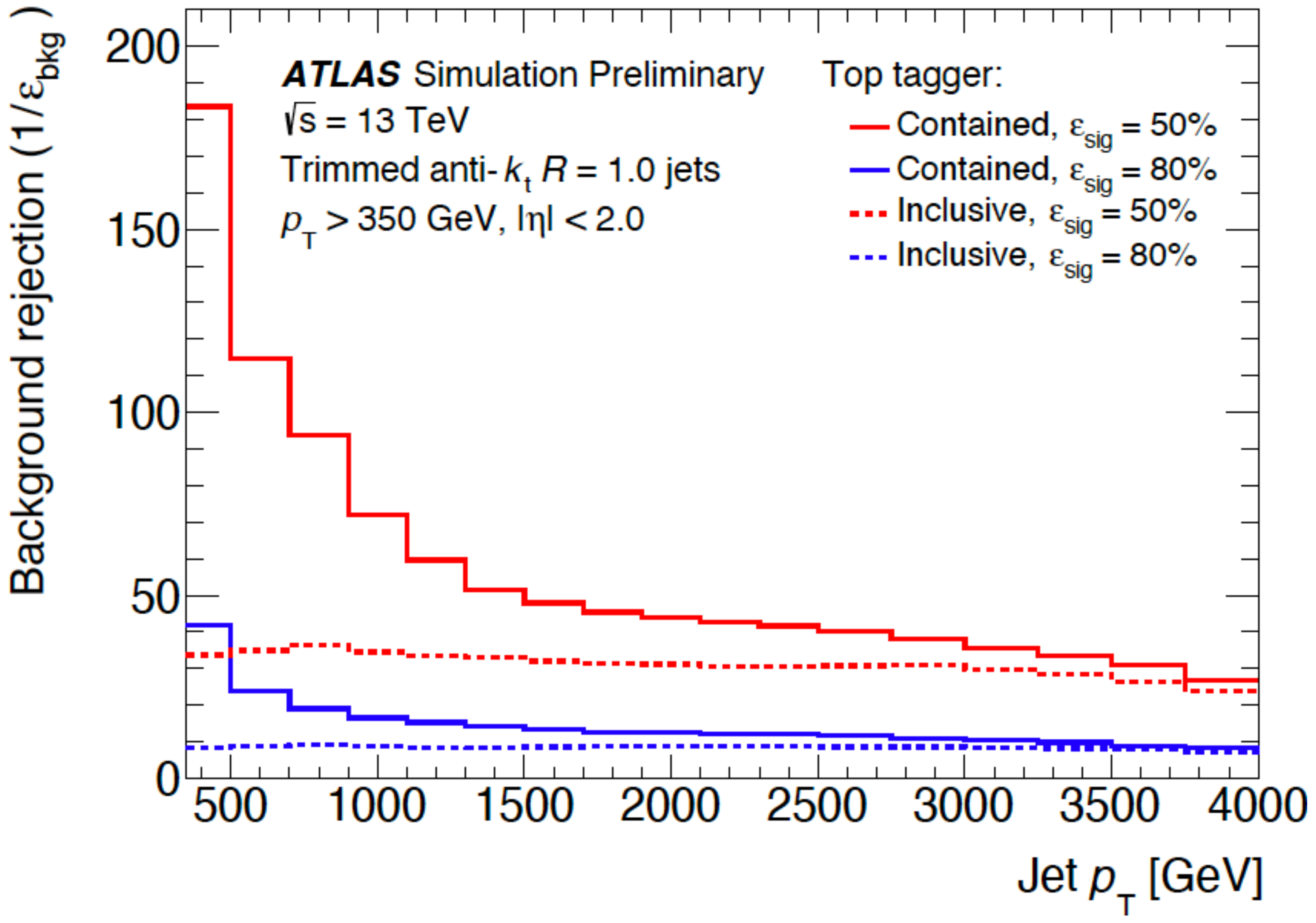
- Top quarks from heavy new physics decay produced with high transverse momentum (p_T) → top decay products **collimated in single large-Radius jet (R=1.0)**
- **Jet substructure techniques** can be exploited to discriminate those top quarks from multijet events
  - **Cut-based approach**: cut on variables like number of large-R jet constituents, mass of the jet, etc.
  - Analysis-custom **multi-variate discriminants**
  - Dedicated **top tagger** by ATLAS

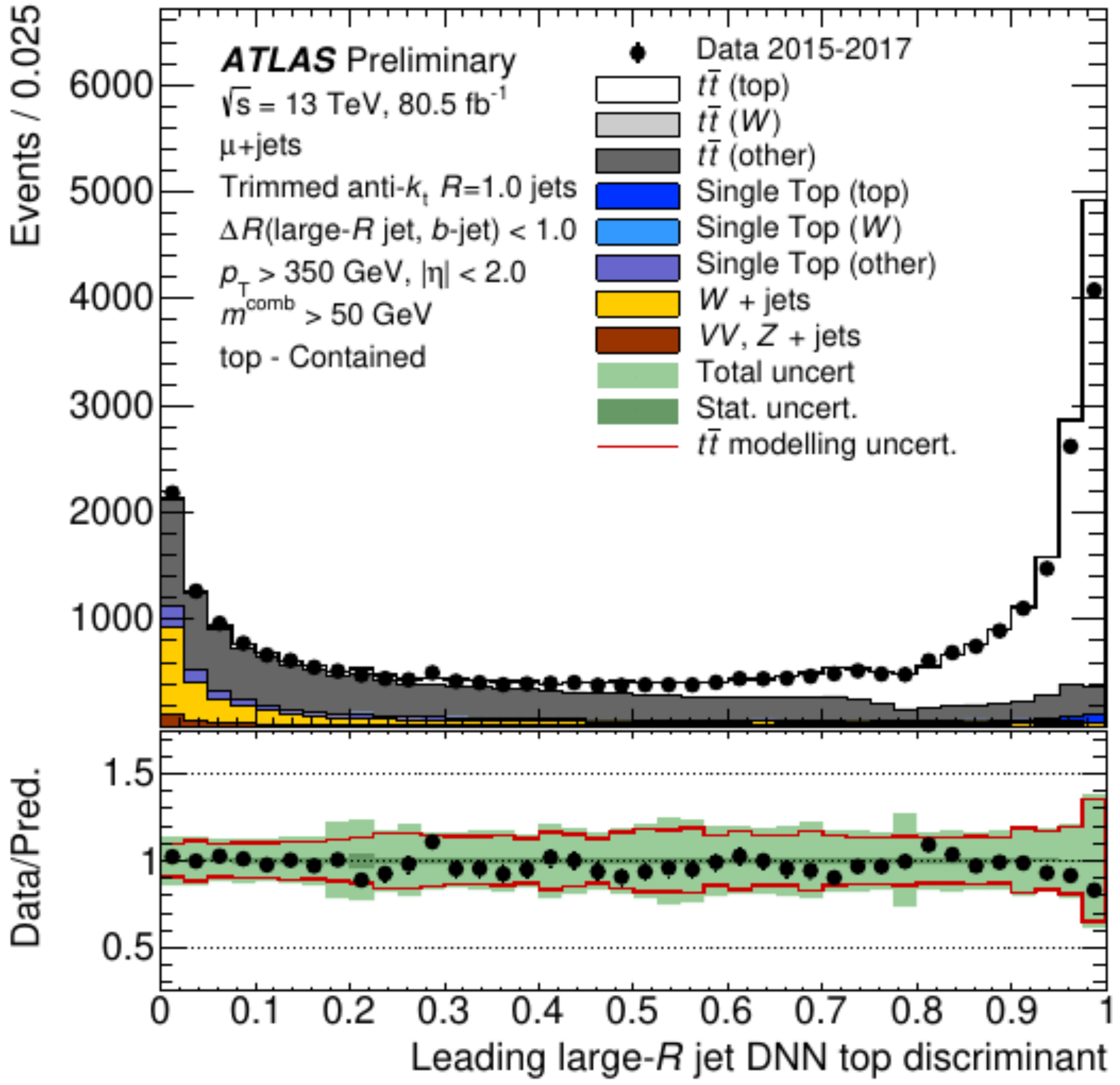


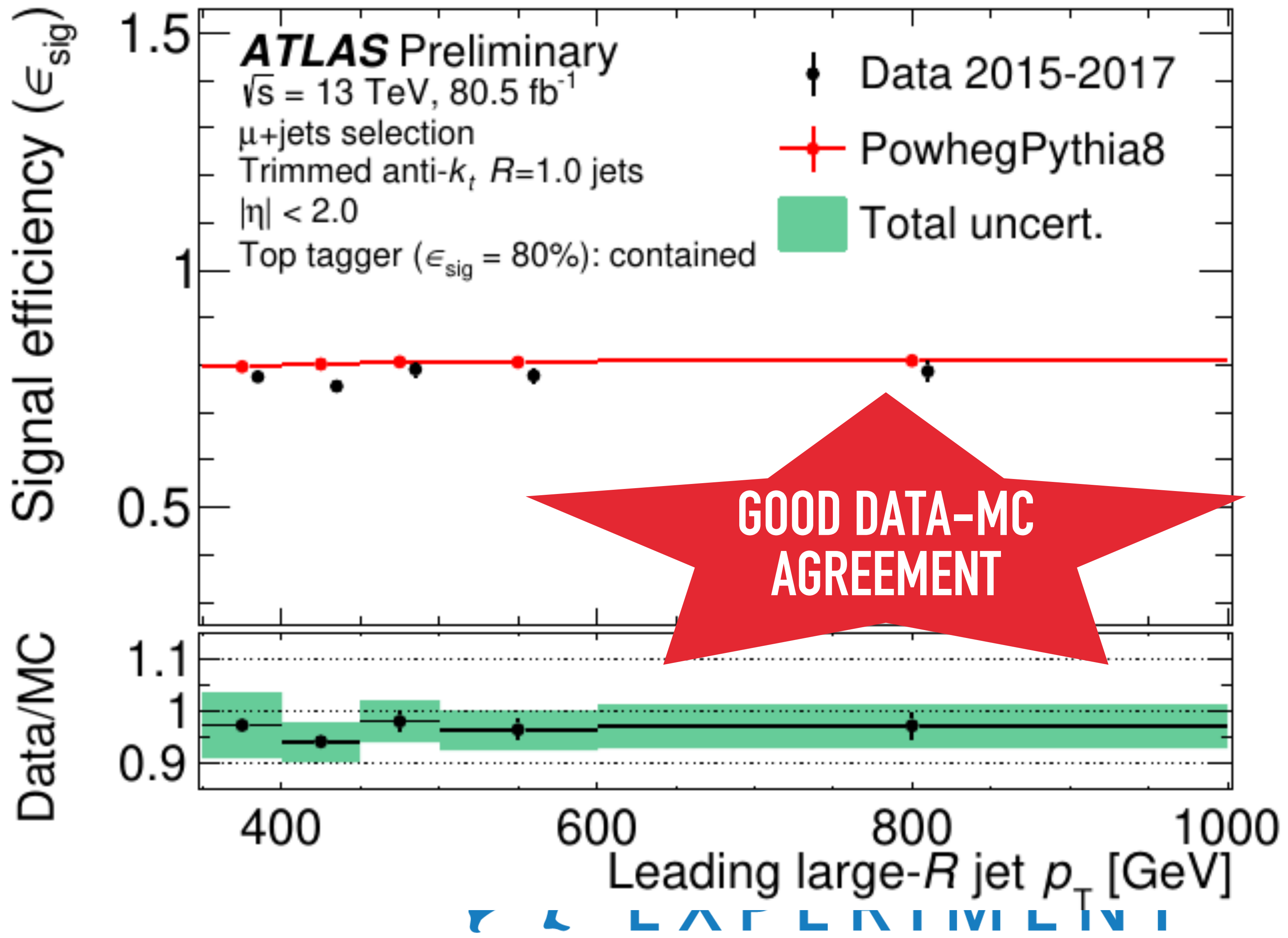
IDENTIFICATION OF 3RD GENERATION QUARKS: THE ATLAS DNN TOP TAGGER

ATL-PHYS-PUB-2020-017

- Training on **Deep Neural Network** (DNN) with large-R jet **substructure moment variables** as input
  - Jet mass, jet pT, energy correlation ratios, N-subjettiness, splitting measures
- **Efficiency working points defined** (50% & 80%) **+ calibrated**
  - Cuts on the DNN output discriminant
- **Calibration:**
  - **Efficiency : ttbar events** (lepton+jets decay)
  - **Mistag: multijet and photon+jets** selection
  - Calibration in the large-R jet pT range [350;1000] GeV using data
  - Extend calibration pT range using MC-based extrapolation





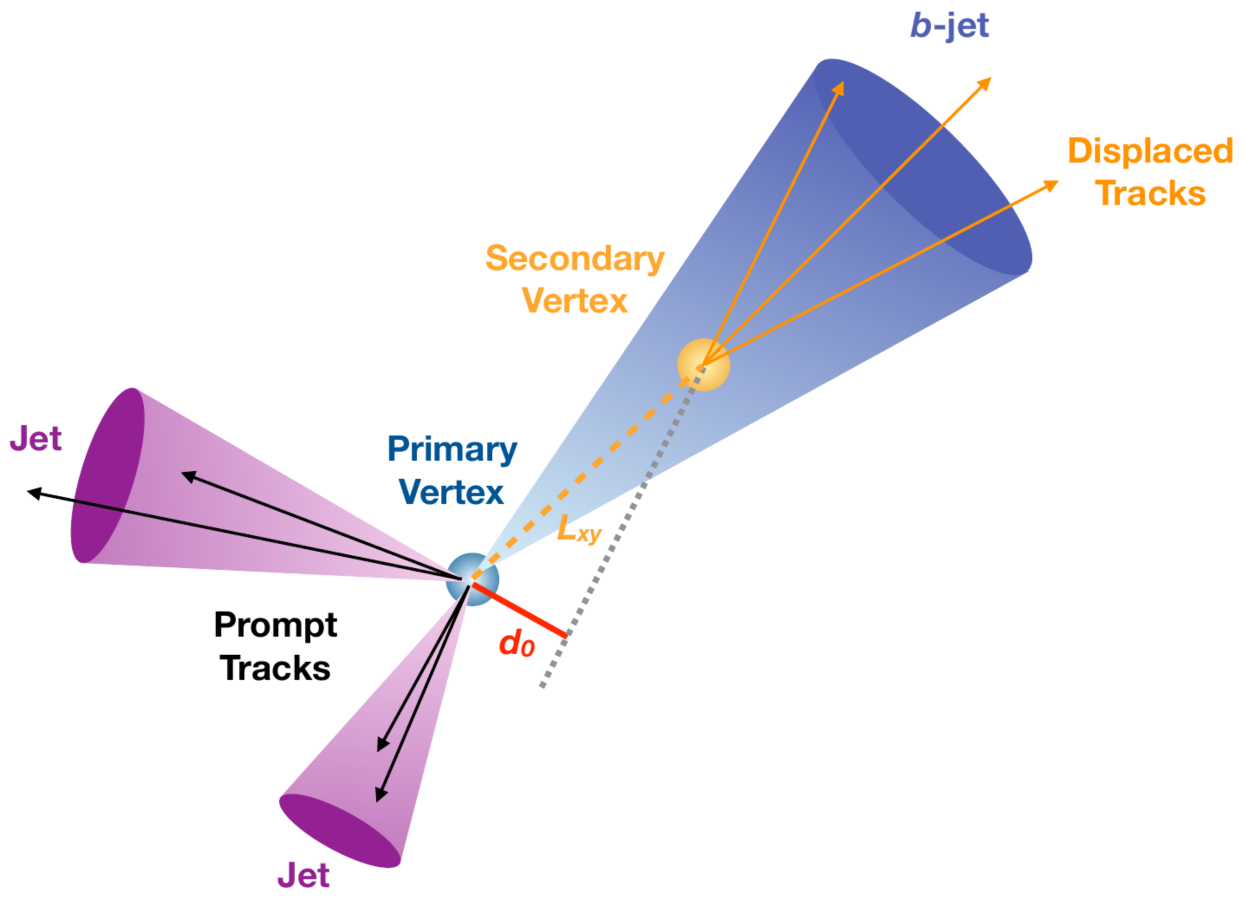


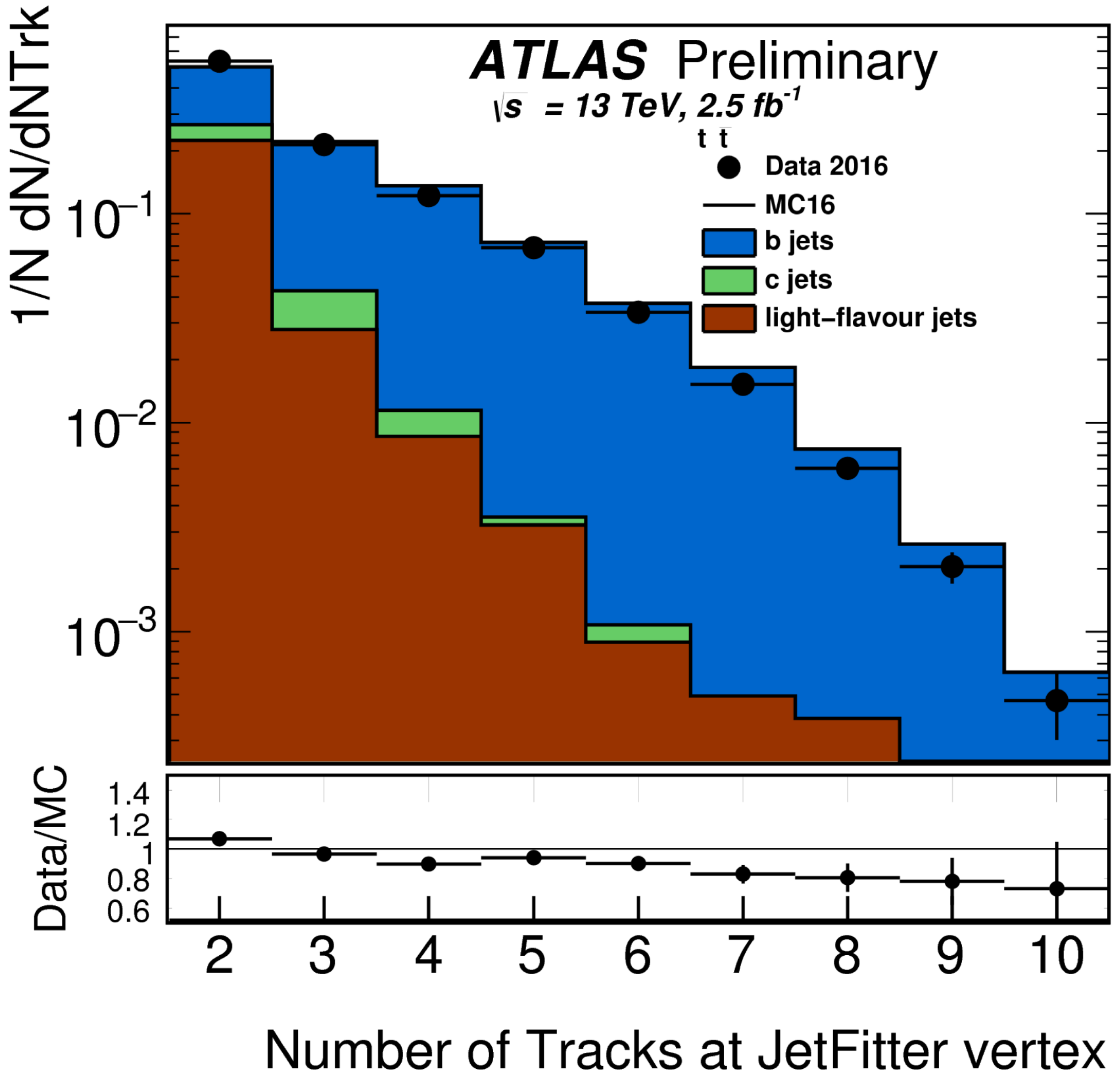
GOOD DATA-MC AGREEMENT

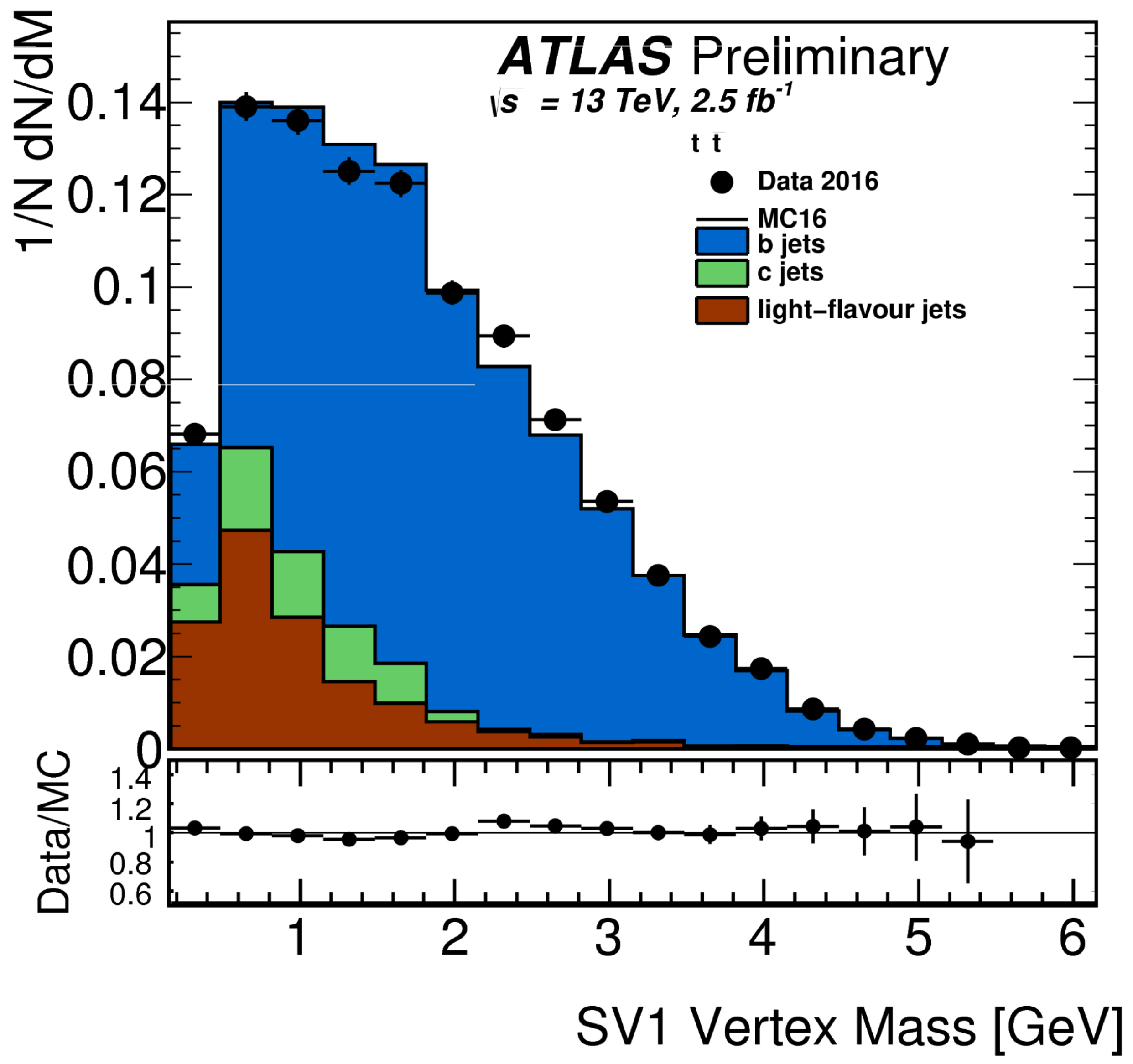
IDENTIFICATION OF 3RD GENERATION QUARKS: B-TAGGING

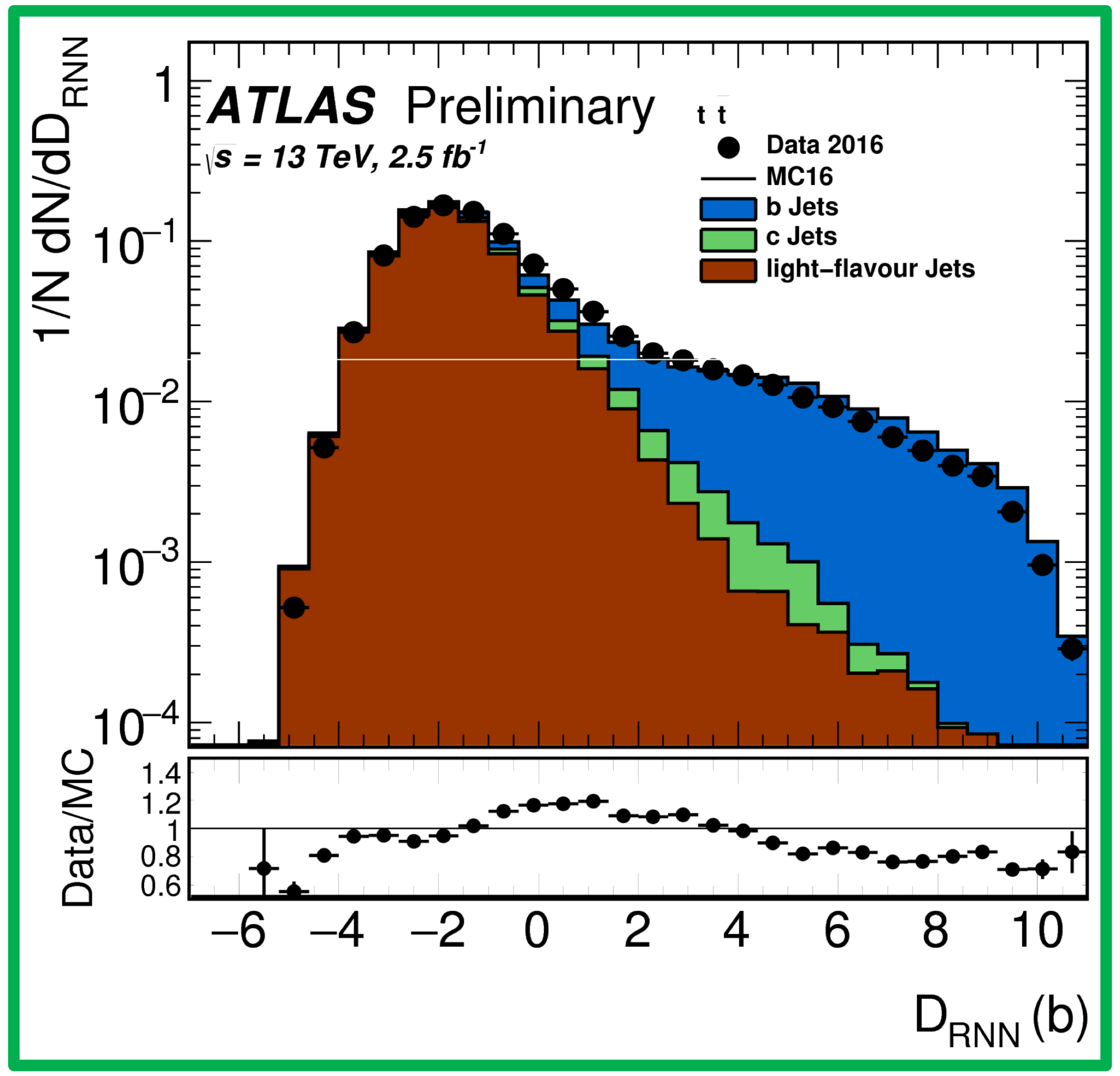
ATL-PHYS-PUB-2017-013

- **Exploit properties of b-hadron decay to construct ATLAS b-taggers**:
  - Long lifetime, displaced secondary decay vertices, high mass, decay multiplicity
- Reconstruct properties of b-hadron: **low-level taggers**
  - **Two approaches** : exploit individual properties of charged particles or reconstruct displaced vertices/decay chain
  - Exploit the **correlation between track impact parameters** in b-hadron decay: output of **recurrent neural network** used in latest ATLAS b-taggers





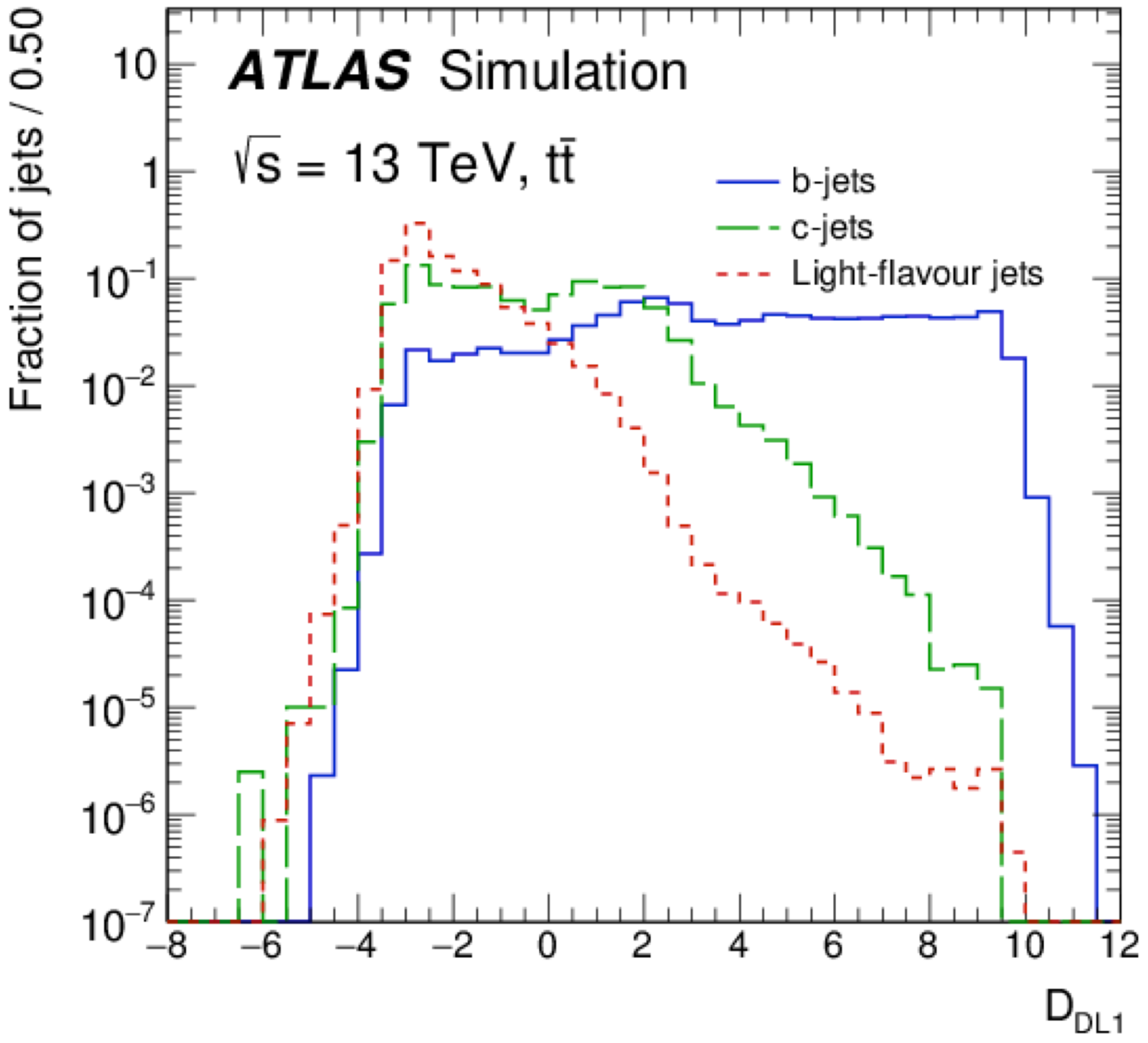


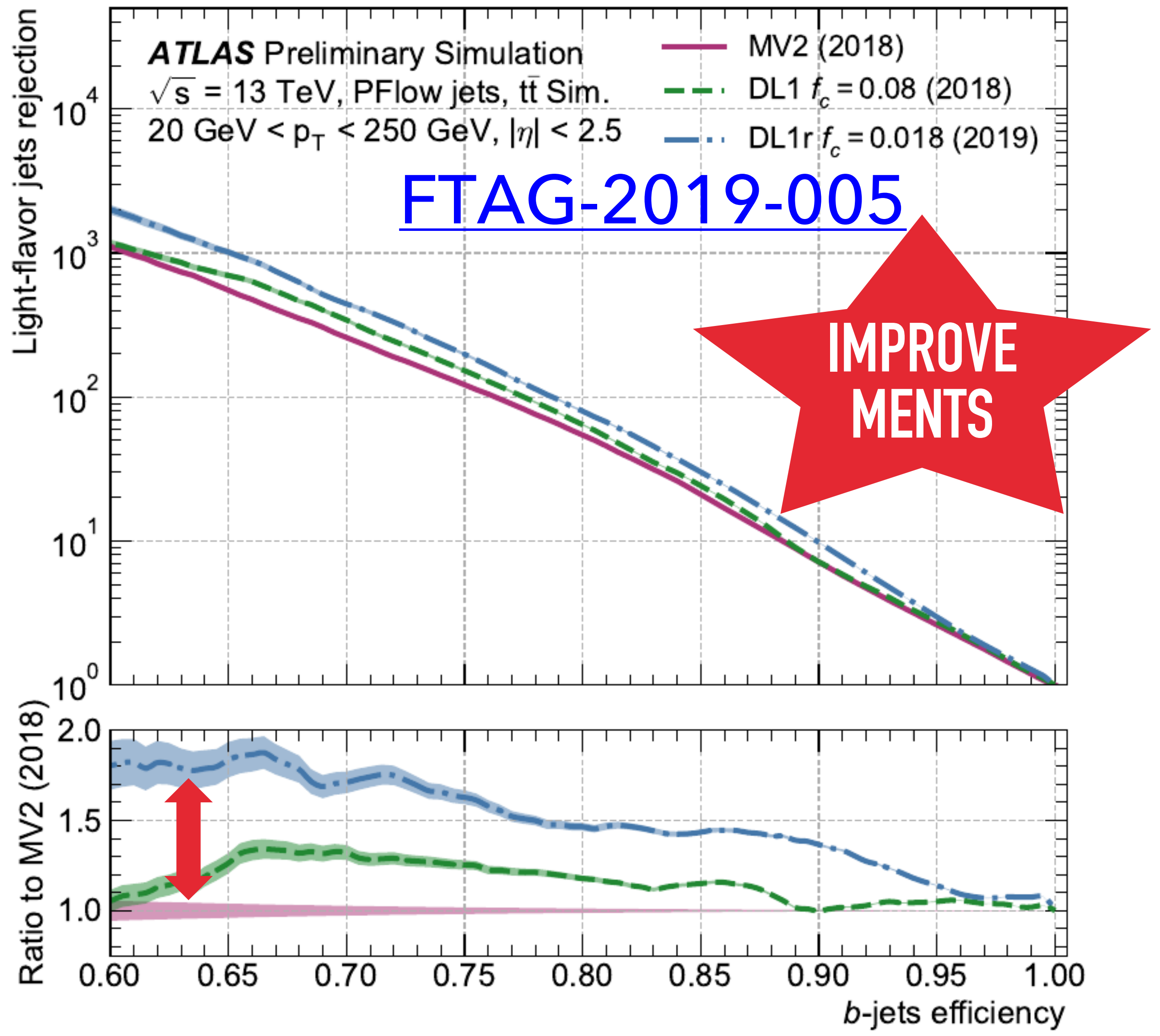


IDENTIFICATION OF 3RD GENERATION QUARKS: B-TAGGING

- Combine output of "low-level" taggers in **Deep Neural Network** (DNN) → **« high-level taggers»**
- Dedicated b-taggers for **particle-flow jets** and **VRTrack jets**

Eur. Phys. J. C 79 (2019) 970



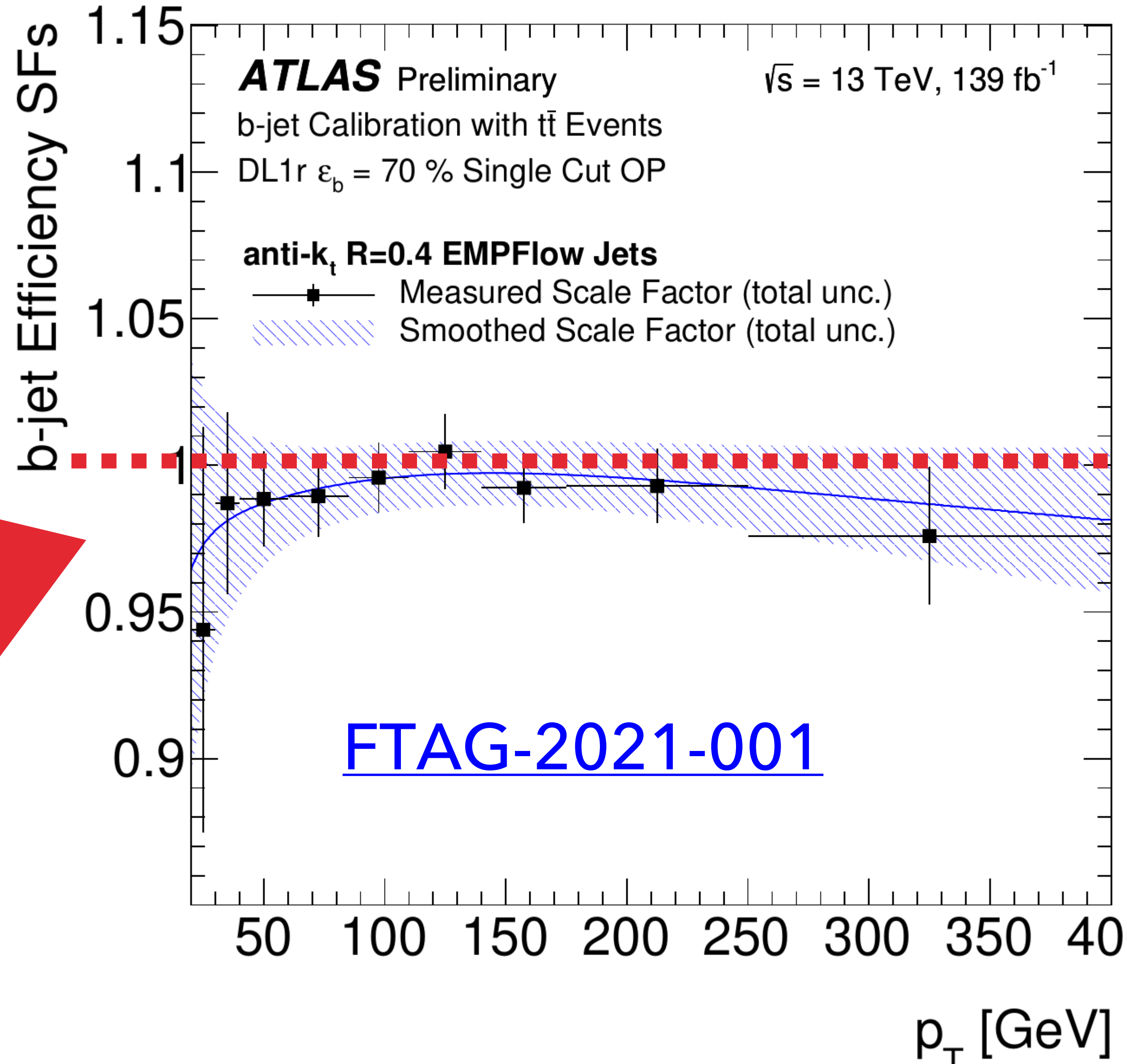


FTAG-2019-005

IMPROVE MENTS

- **Calibration:**
  - **b-jet efficiency & charm mistag rate (data):** ttbar selection
  - **Light mistag rate (data):** Z+jets selection
  - Up to pT(jet) = 400 GeV (PFlow) and 250GeV (VRTrack) for b-jet efficiency calibration
  - MC-based extrapolation up to pT(jet) = 3 TeV for b-jets

GOOD DATA-MC AGREEME NT



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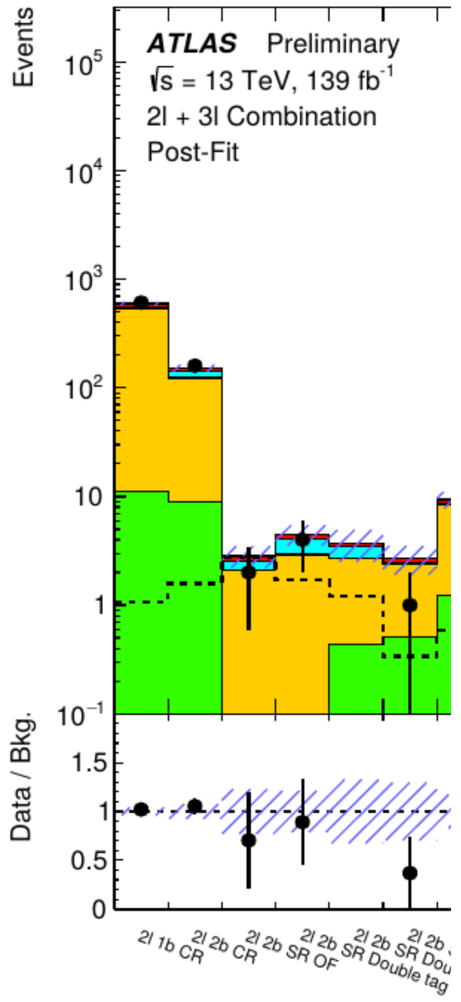
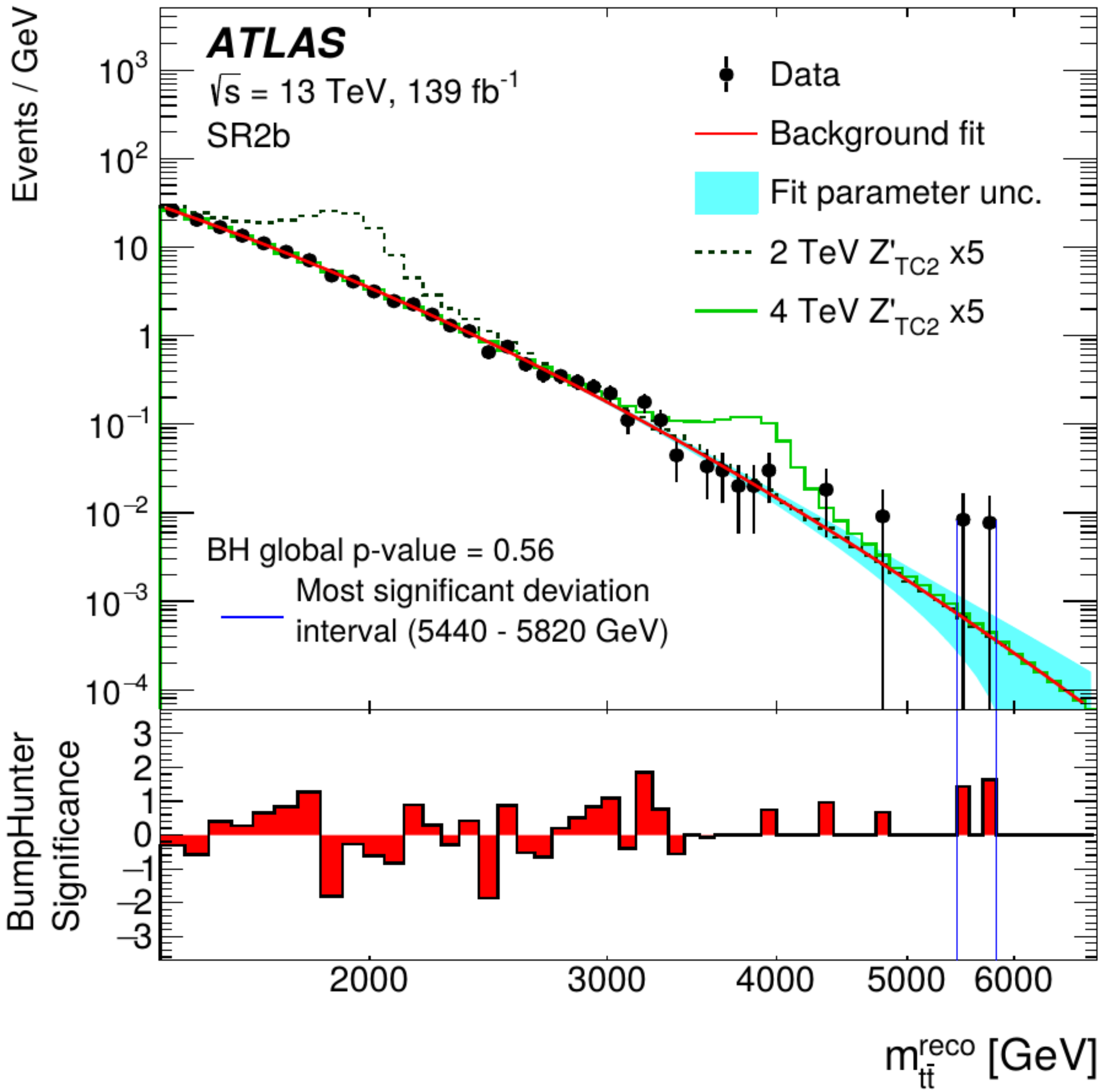
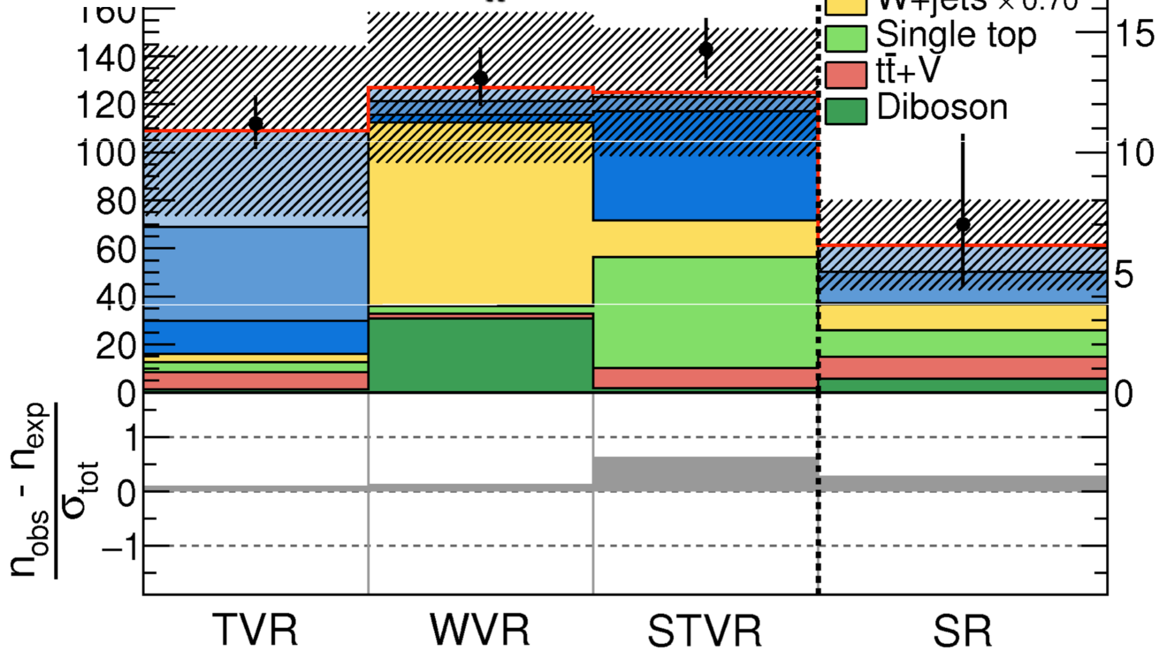
TYPICAL ANALYSES STRATEGIES FOR THESE SEARCHES

- **1) Search for excess over background**
  - Condition: possible to reconstruct new physics particle as resonance
  - Bump in invariant mass spectrum
- **2) "Divide and conquer"**
  - Maximize sensitivity to several possible signal topologies
  - Construct several signal and control regions, perform combined fit in all regions
- **3) Cut-and-count analysis or construction of multivariate discriminant**
  - Count events: expected background and data events in signal region
  - Fit to DNN/BDT-based discriminant







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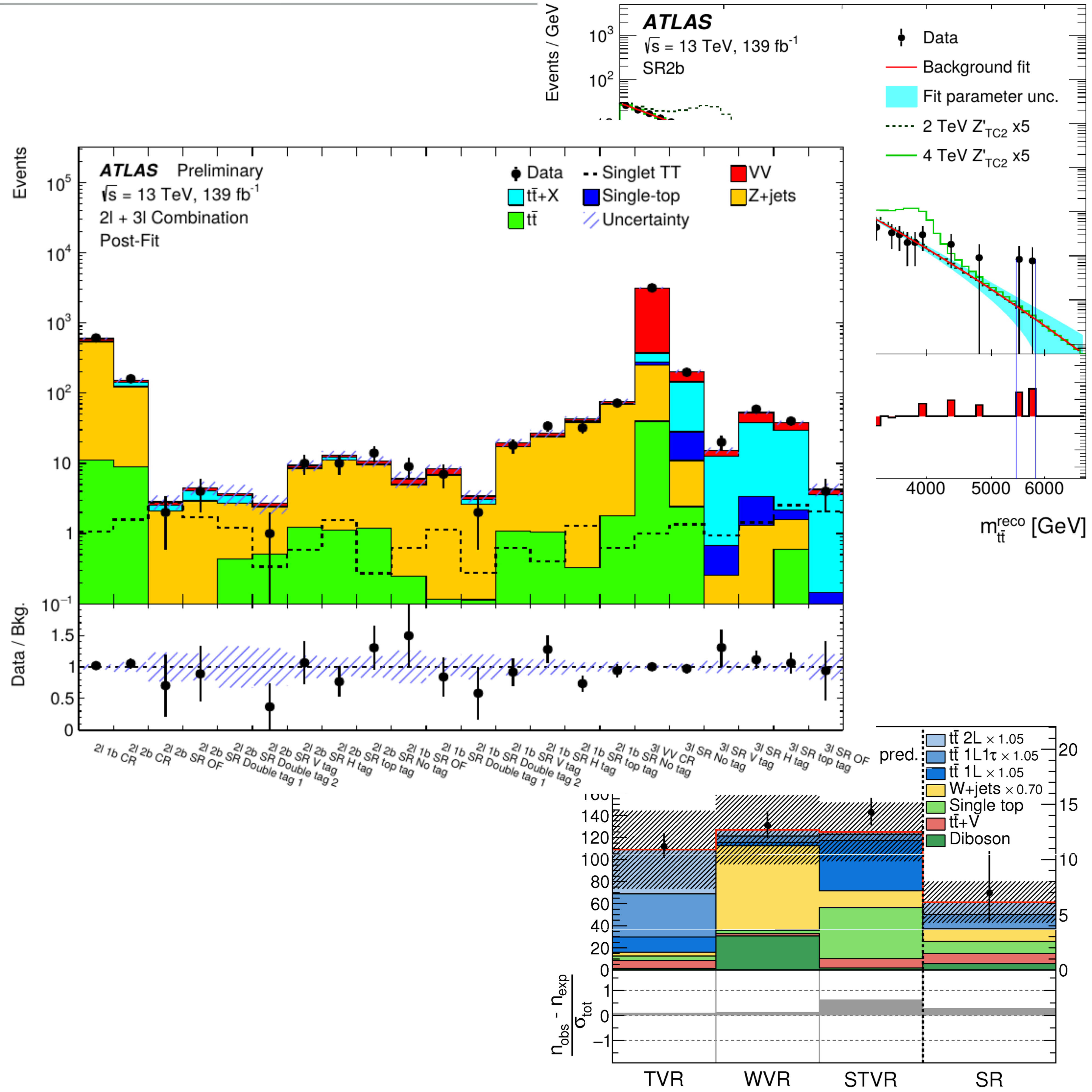

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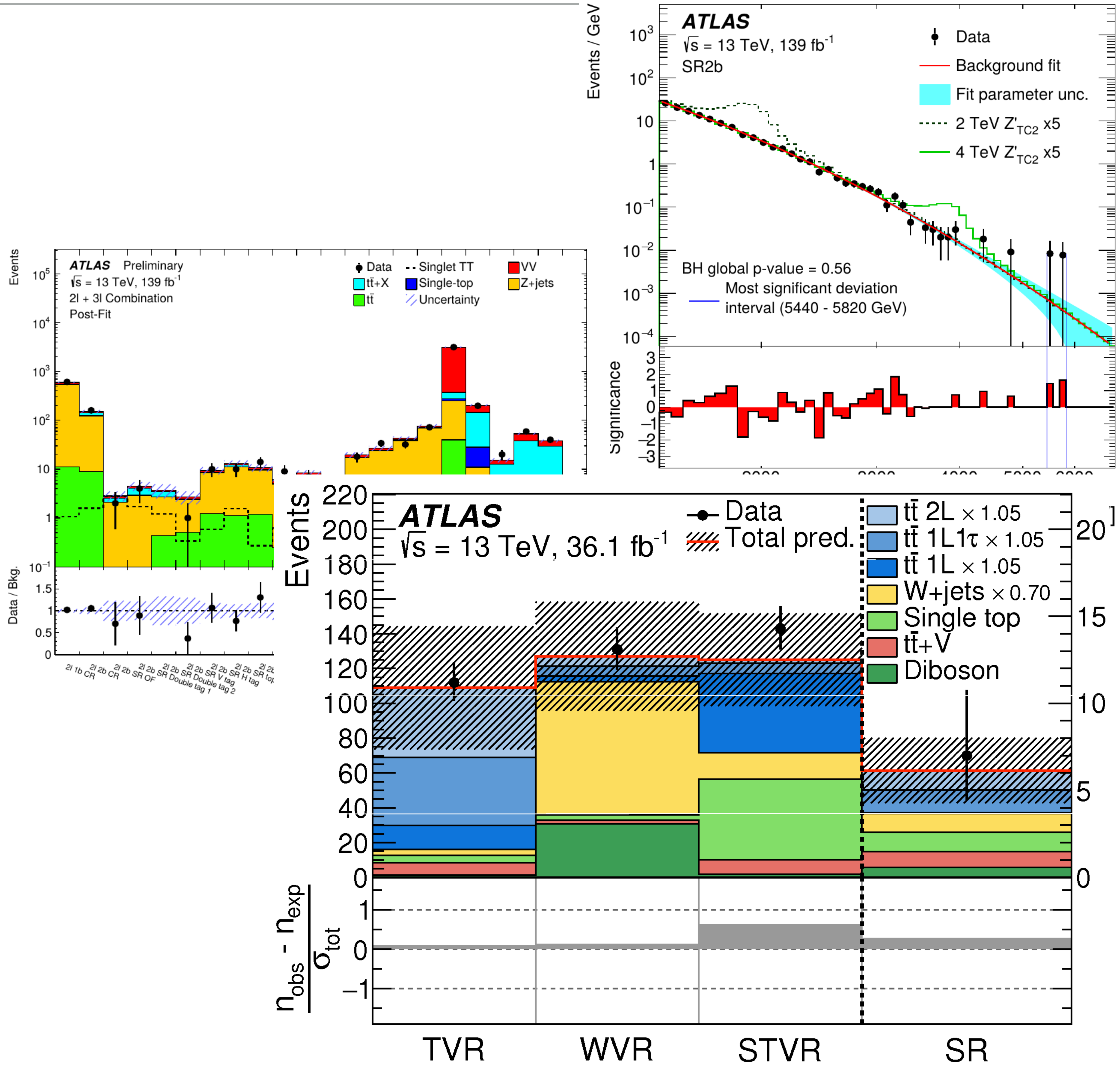
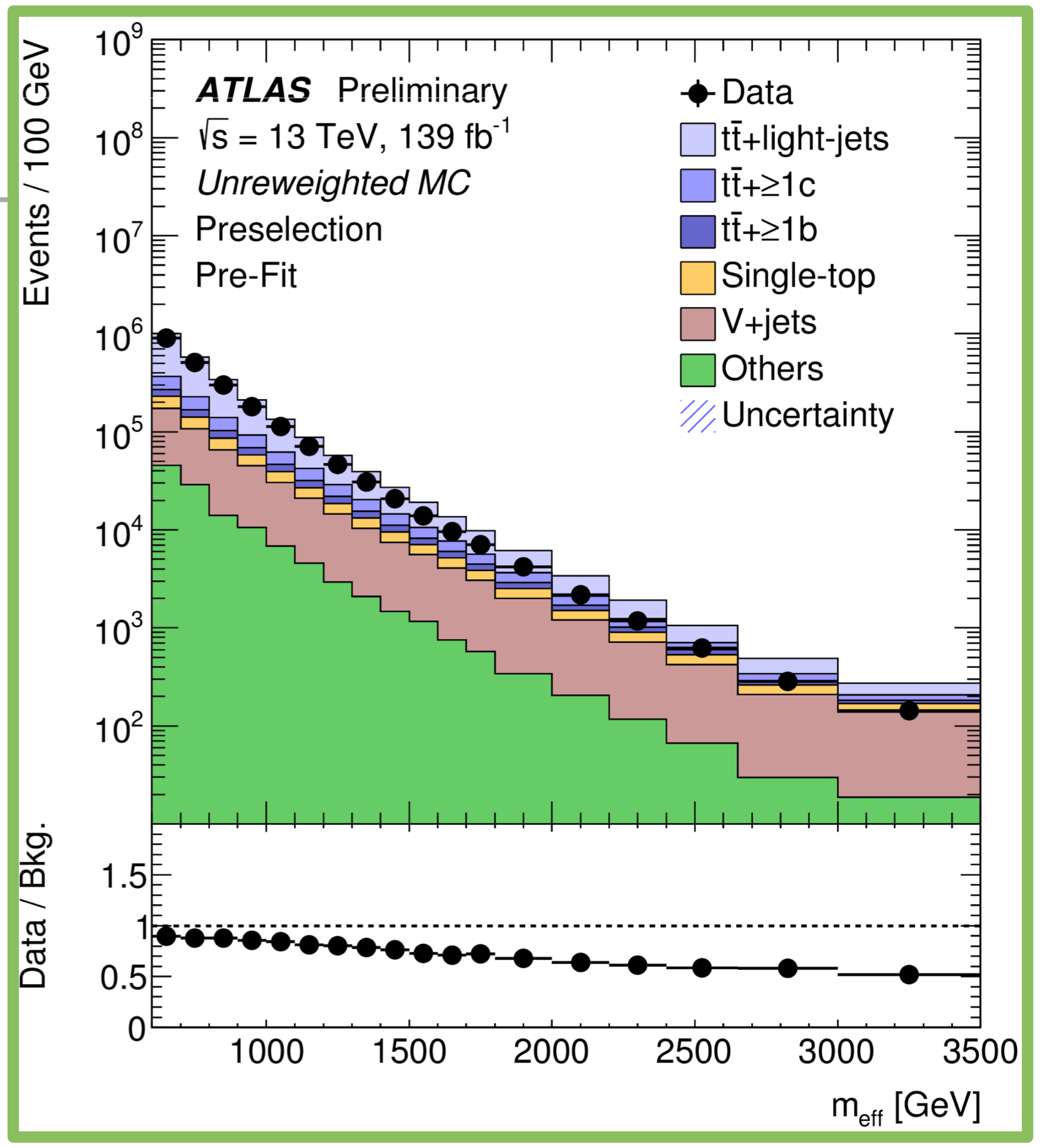
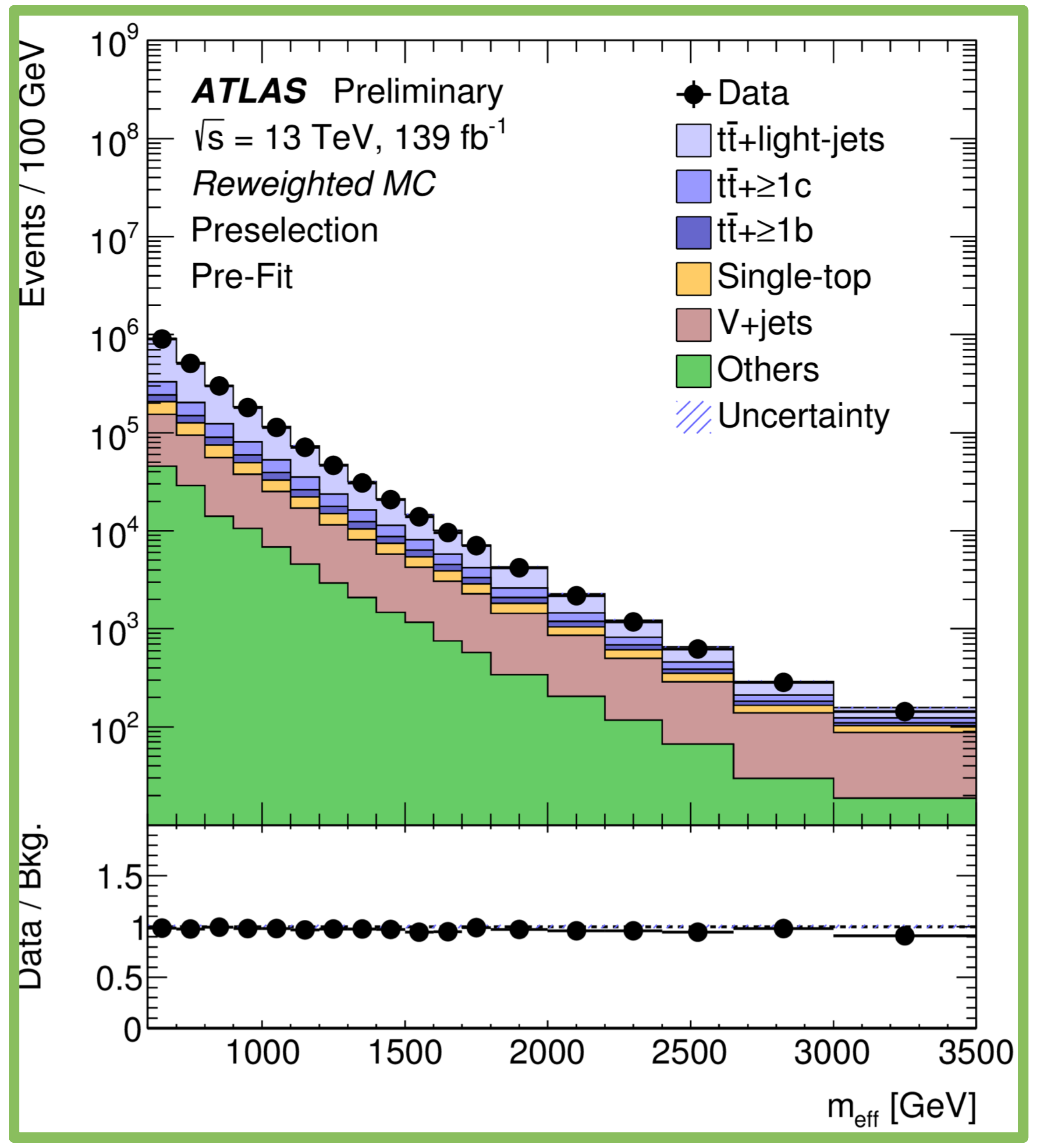
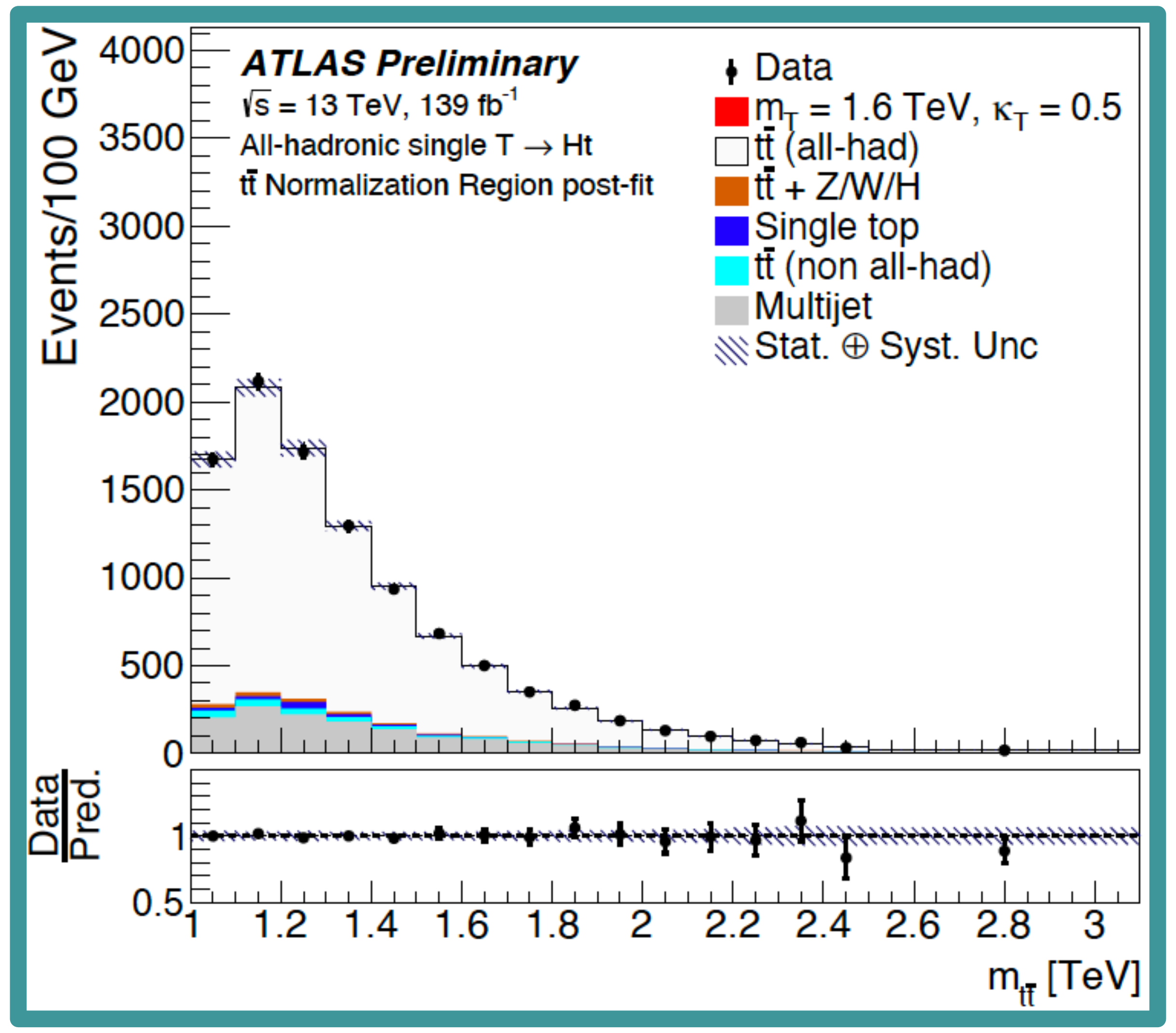


BACKGROUND ESTIMATION STRATEGIES

- **Use MC simulation**
  - Requirement: good description of data by simulation
- **MC-based with data-driven corrections**
  - Derive correction in control region (normalization, reweighting factor)
  - Derive normalization in final fit
  - Example: some processes well modeled in "bulk" region but not in distribution tails/high pT



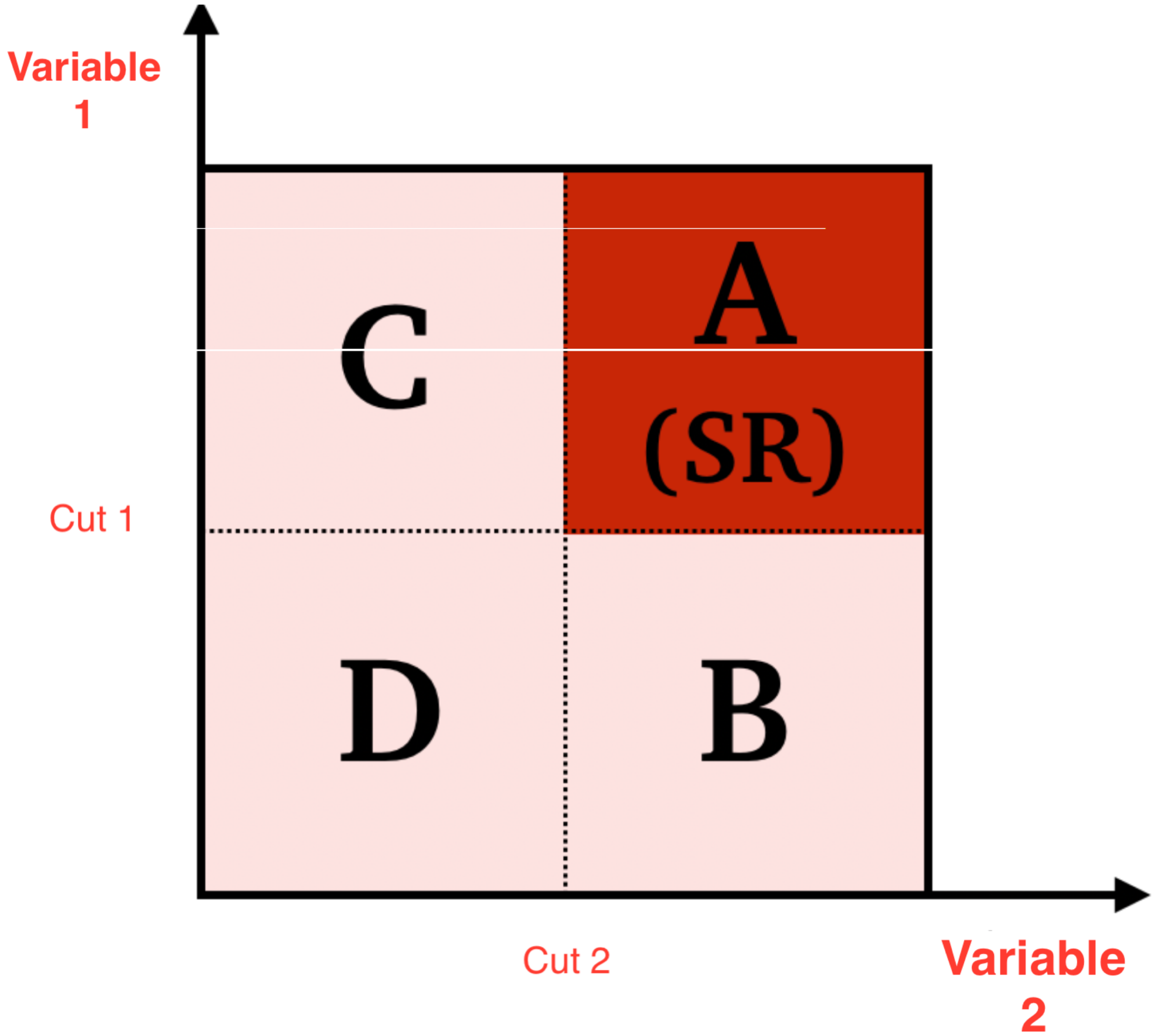




Fit of ttbar MC normalization in dedicated Control region

BACKGROUND ESTIMATION STRATEGIES

- **Data-driven estimation strategies**
  - Bad modeling of process by simulation
  - Multijet background
  - Example: ABCD method
    - Derive extrapolation factor in regions C and D
    - Extrapolate yields/shape from region B to region A
    - Assume variable 1 and 2 uncorrelated, apply additional corrections
- **Description with analytic function**
  - Derive/validate analytic function in control region



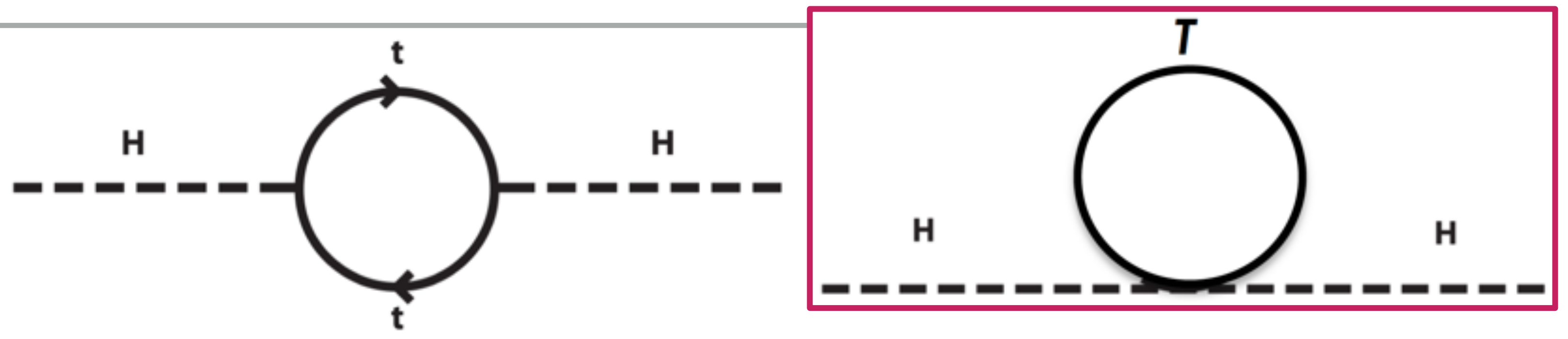
$$N_A = N_B \times \frac{N_C}{N_D}$$

ATLAS EXPERIMENT

SEARCHES FOR VECTOR-LIKE QUARKS

Searches for vector-like quarks

THEORETICAL MOTIVATION– VECTOR-LIKE QUARKS (VLQ)

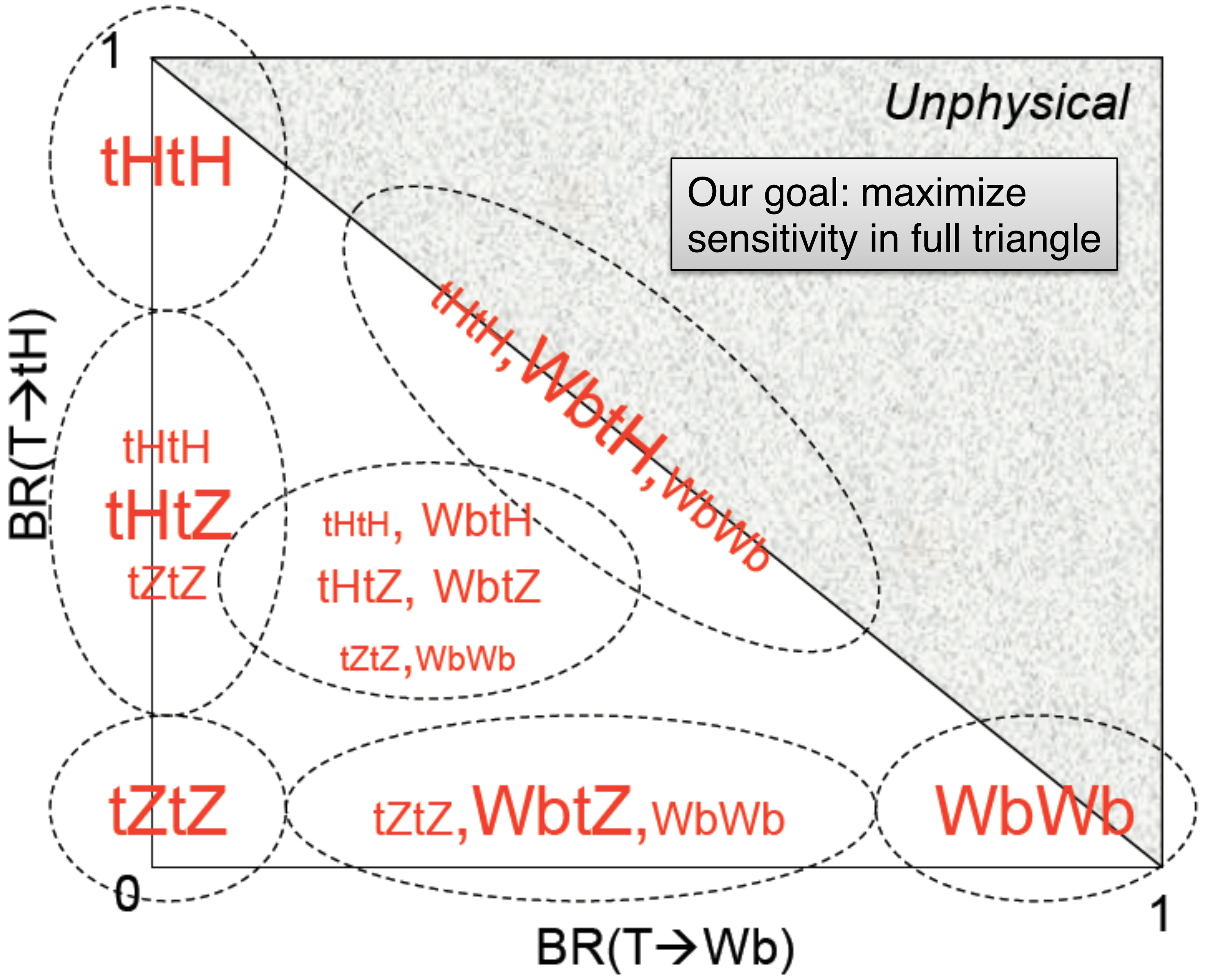


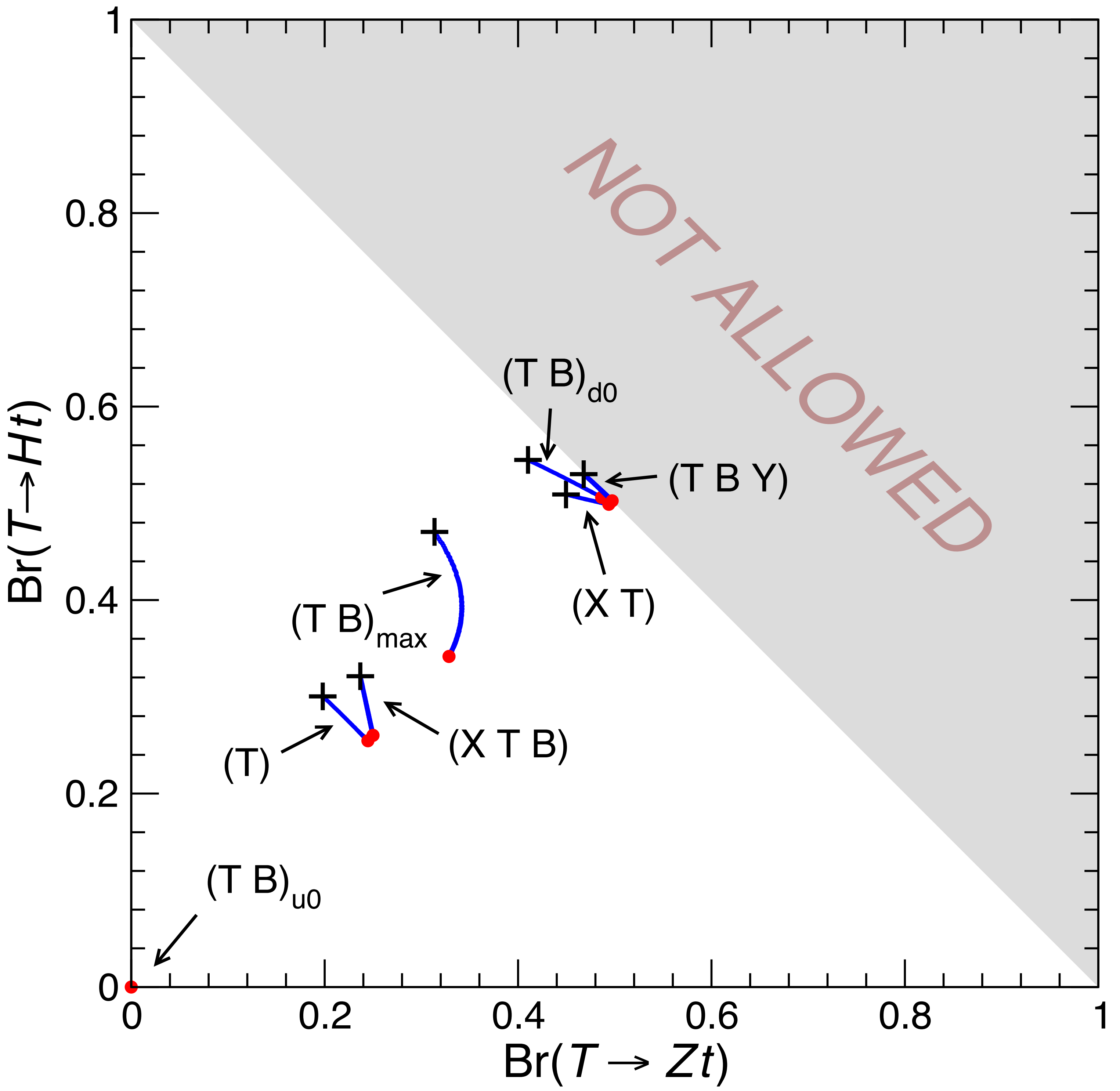
- Heavy VLQs predicted in many models, especially those aimed at solving the hierarchy problem
  - SUSY: Scalar top partners ⇔ VLQ: fermionic top partners
- Both chiralities transform the same under SM gauge groups ➔ **vector-like**
- Expected to **decay to bosons and to top or bottom quarks**
  - **Singlet, doublet and triplet representations** of T, B, and exotic-charged X & Y → define relative couplings to V,H

SM V-A current	VLQ current
$(\bar{q}\gamma^\mu(1-\gamma^5)q')$	$(\bar{Q}\gamma^\mu Q')$

TEST ALL POSSIBILITIES!

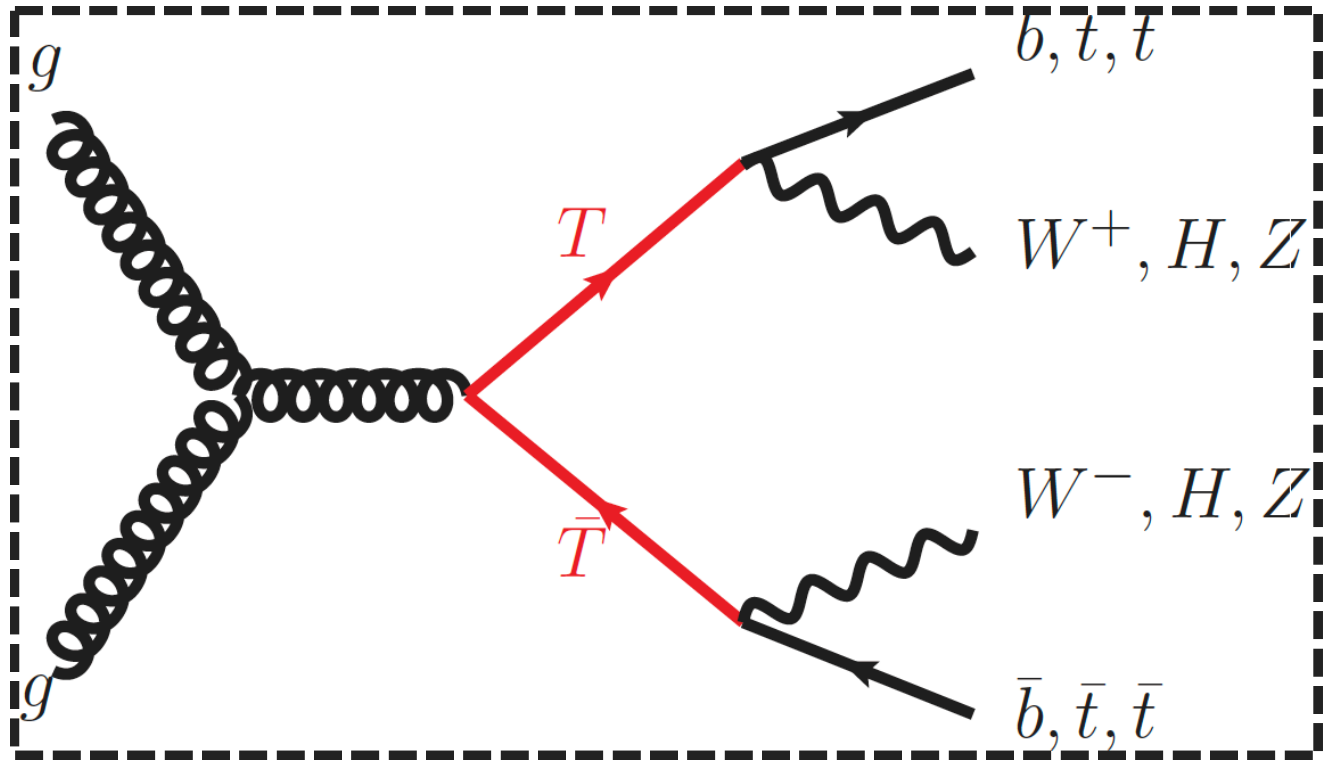
Q[e]	VLQs						
	singlets		doublets			triplets	
5/3			X			X	
2/3	(T)		T	T		T	T
−1/3		(B)		B	B	B	B
−4/3					Y		Y





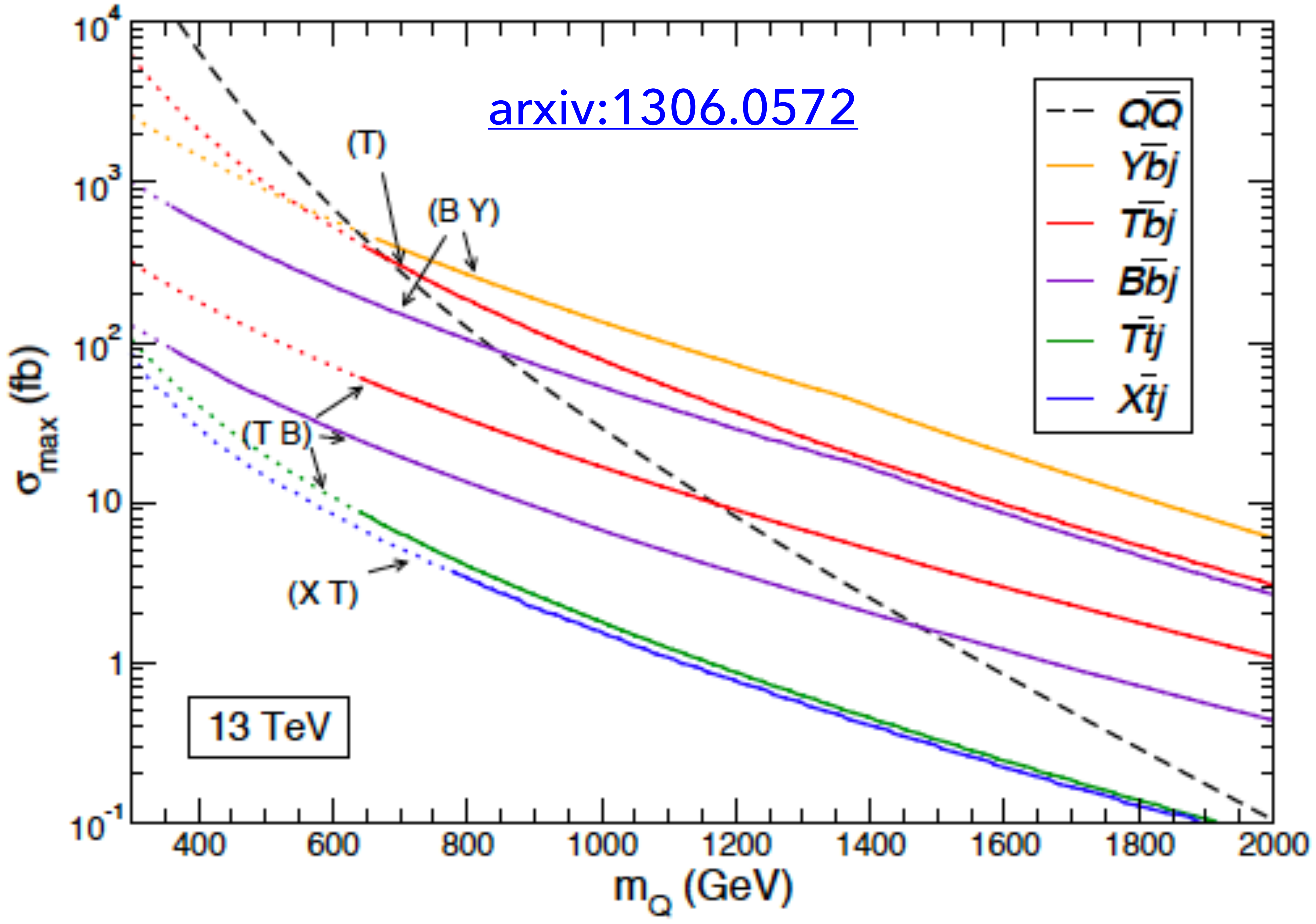
THEORETICAL MOTIVATION- VECTOR-LIKE QUARKS (VLQ)

Pair-production via the strong force



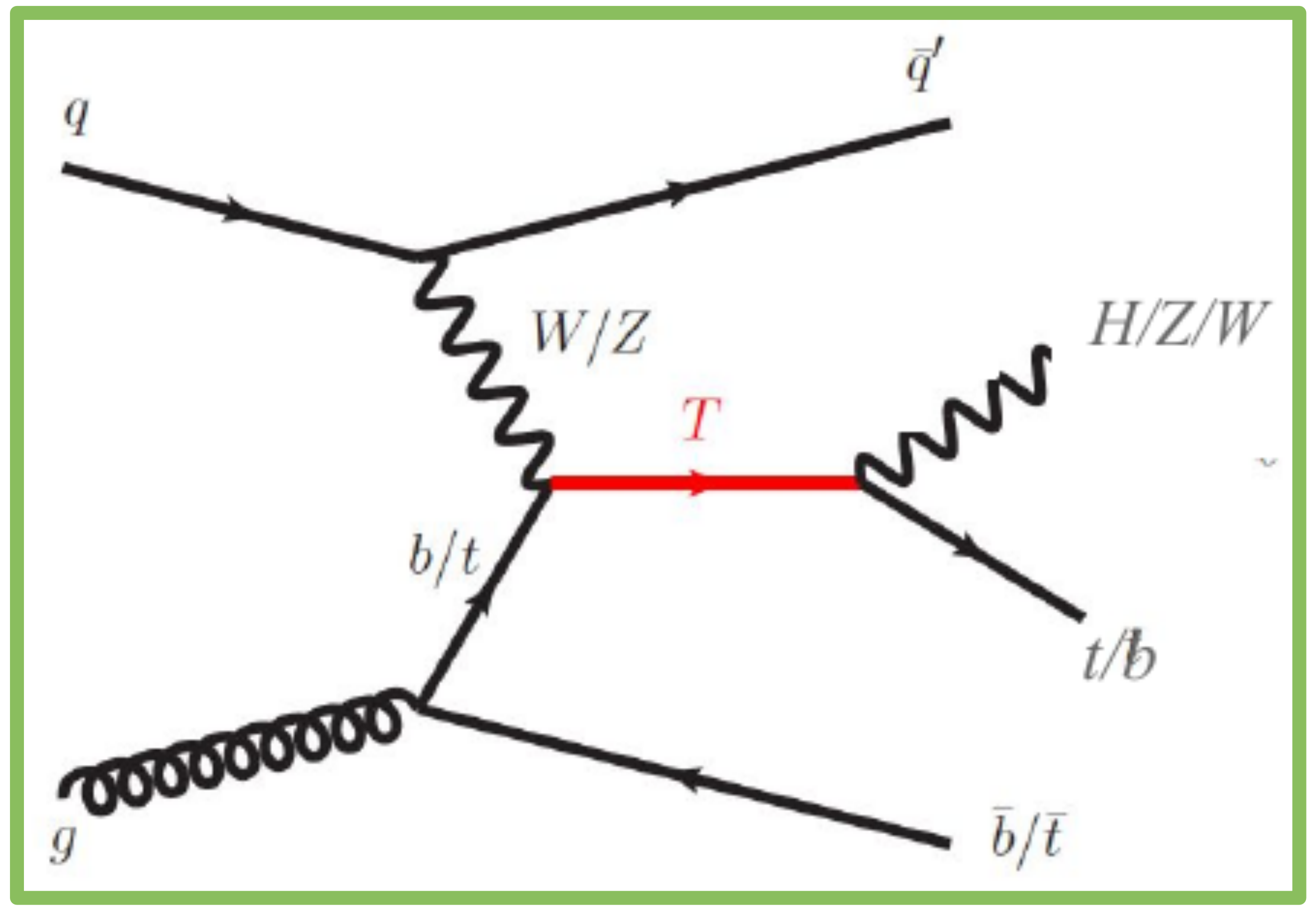
Pair-production **cross-section only dependent on VLQ mass**

Single production could dominate for VLQ masses > 1 TeV



arxiv:1306.0572

Single production via the weak interaction

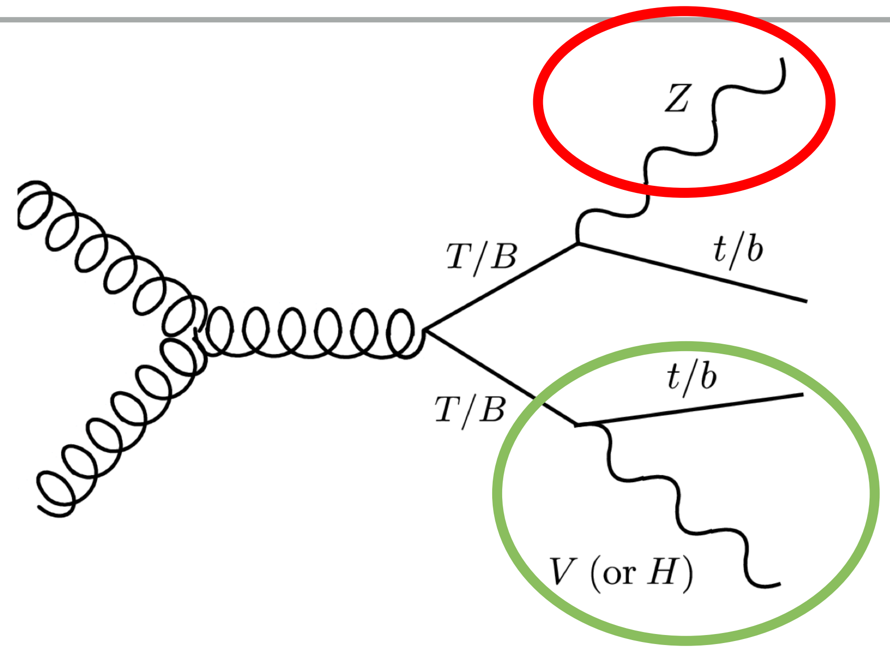


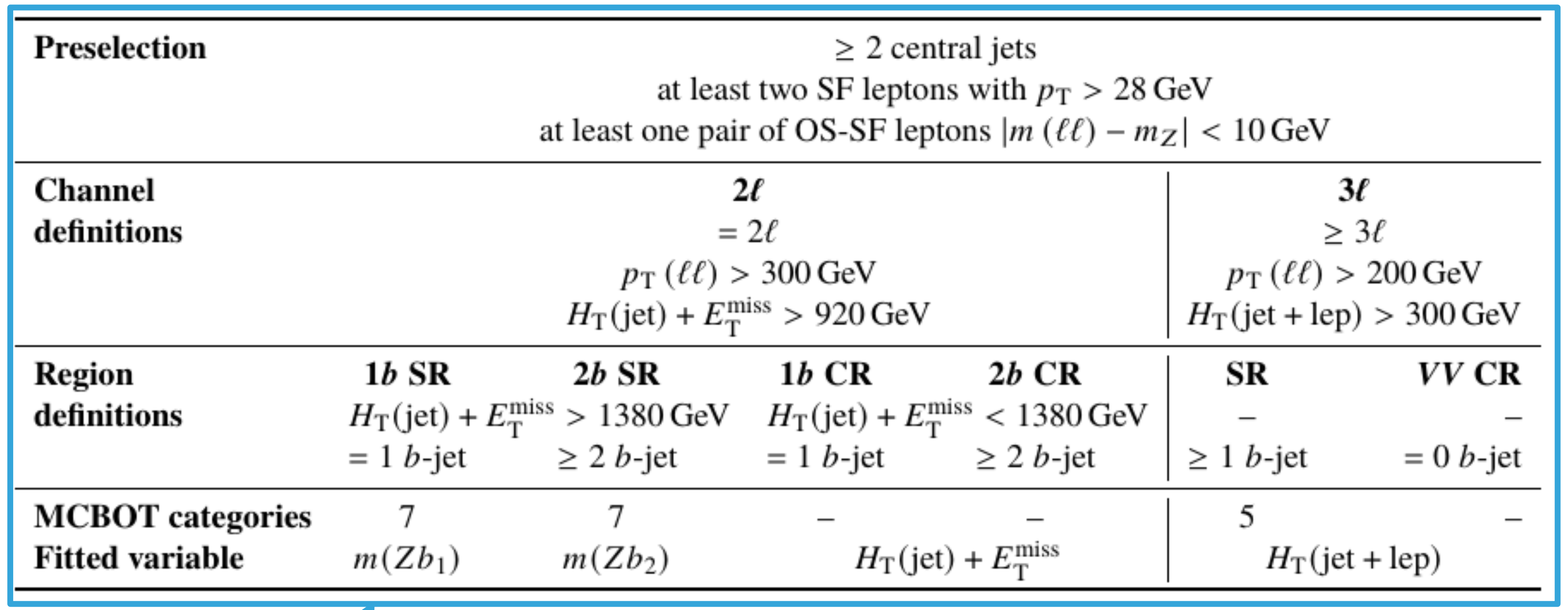
Single-production cross-section also dependent on **coupling (κ) to Standard Model particles**

SEARCH FOR PAIR-PRODUCTION OF VECTOR-LIKE QUARKS WITH AT LEAST ONE LEPTONICALLY DECAYING Z-BOSON – ANALYSIS STRATEGY

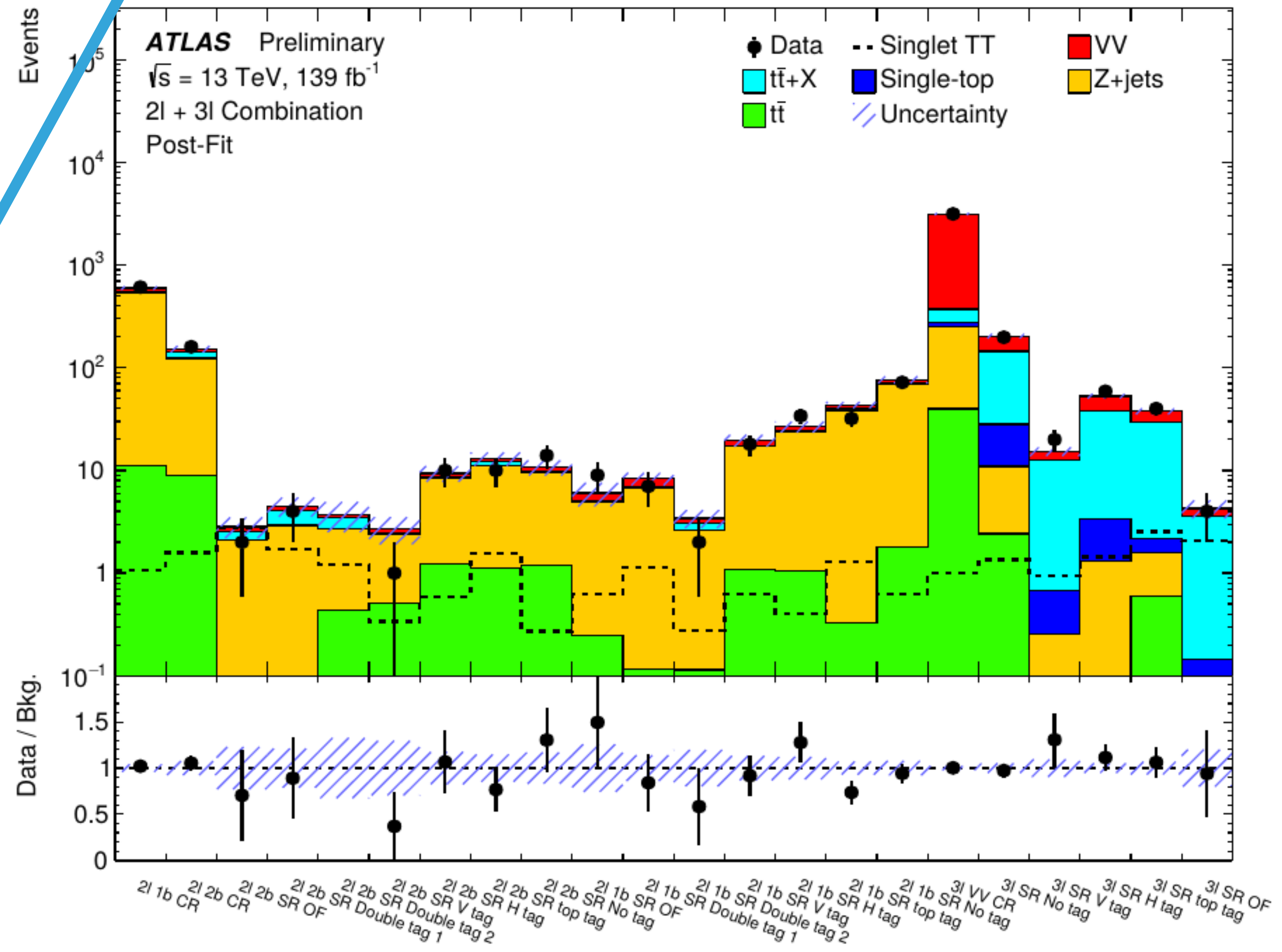
ATLAS-CONF-2021-024

- Optimized for **TT → Zt+X**
  - Z → ee or Z → mumu
  - 2 or 3-leptons in the final state
  - Train **multi-class DNN** on reclustered large-R jets ("MCBOT") to optimize selection for 2nd hadronically decaying VLQ to **top, V (Z,W) or H**
- Define exclusive event categories based on **kinematic properties, b-tag and MCBOT decision** for signal-sensitive regions, control and validation regions
- **Combined fit performed in all regions to discriminating variable to extract signal and constrain background estimated by Monte-Carlo**





Preselection	≥ 2 central jets at least two SF leptons with $p_{\mathrm{T}} > 28$ GeV at least one pair of OS-SF leptons $\lvert m\,(\ell\ell) - m_Z \rvert < 10$ GeV					
Channel definitions	**2ℓ** $= 2\ell$ $p_{\mathrm{T}}\,(\ell\ell) > 300$ GeV $H_{\mathrm{T}}(\mathrm{jet}) + E_{\mathrm{T}}^{\mathrm{miss}} > 920$ GeV				**3ℓ** $\geq 3\ell$ $p_{\mathrm{T}}\,(\ell\ell) > 200$ GeV $H_{\mathrm{T}}(\mathrm{jet+lep}) > 300$ GeV	
Region definitions	**1b SR**	**2b SR**	**1b CR**	**2b CR**	**SR**	**VV CR**
	$H_{\mathrm{T}}(\mathrm{jet}) + E_{\mathrm{T}}^{\mathrm{miss}} > 1380$ GeV		$H_{\mathrm{T}}(\mathrm{jet}) + E_{\mathrm{T}}^{\mathrm{miss}} < 1380$ GeV		–	–
	$= 1$ b-jet	≥ 2 b-jet	$= 1$ b-jet	≥ 2 b-jet	≥ 1 b-jet	$= 0$ b-jet
MCBOT categories	7	7	–	–	5	–
Fitted variable	$m(Zb_1)$	$m(Zb_2)$	$H_{\mathrm{T}}(\mathrm{jet}) + E_{\mathrm{T}}^{\mathrm{miss}}$		$H_{\mathrm{T}}(\mathrm{jet+lep})$	

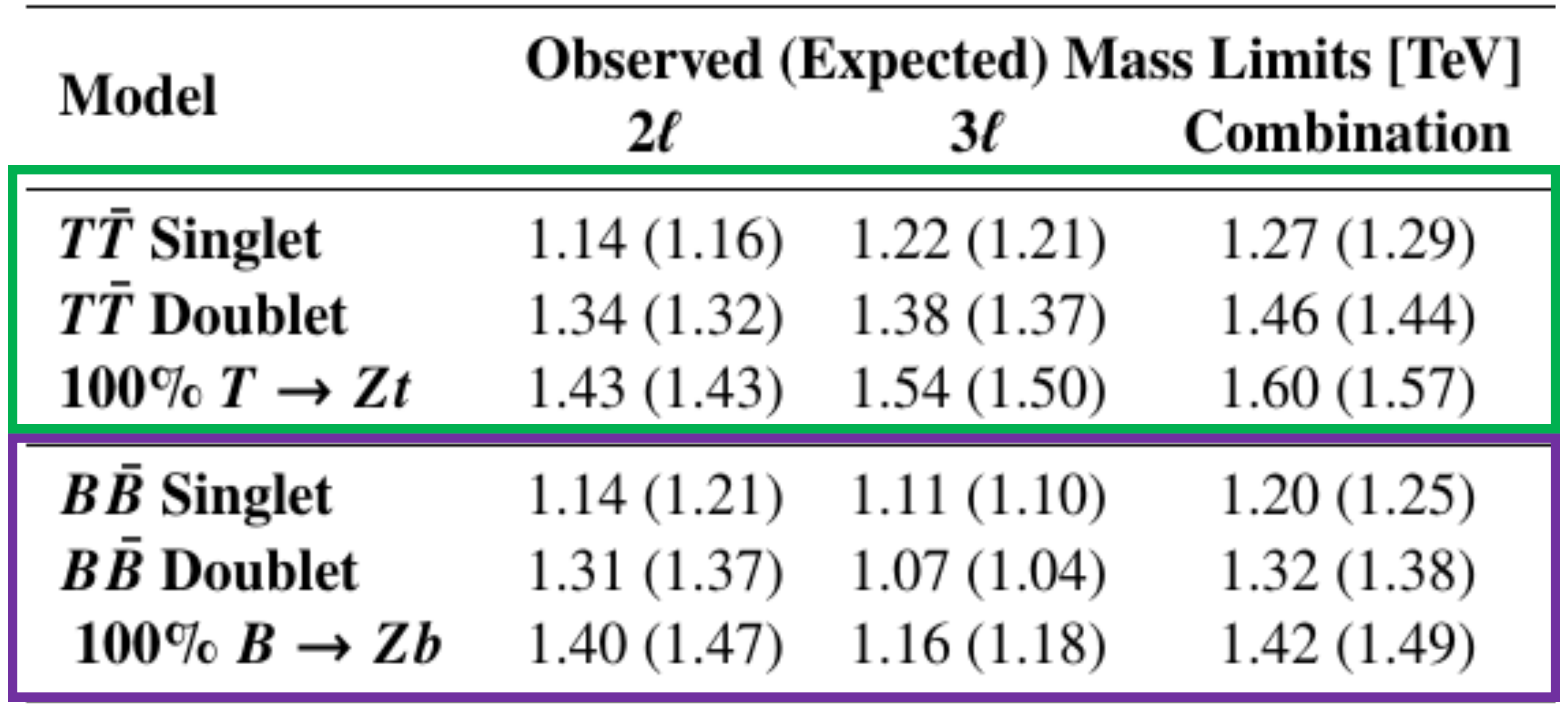


SEARCH FOR PAIR-PRODUCTION OF VECTOR-LIKE QUARKS WITH AT LEAST ONE LEPTONICALLY DECAYING Z-BOSON – RESULTS

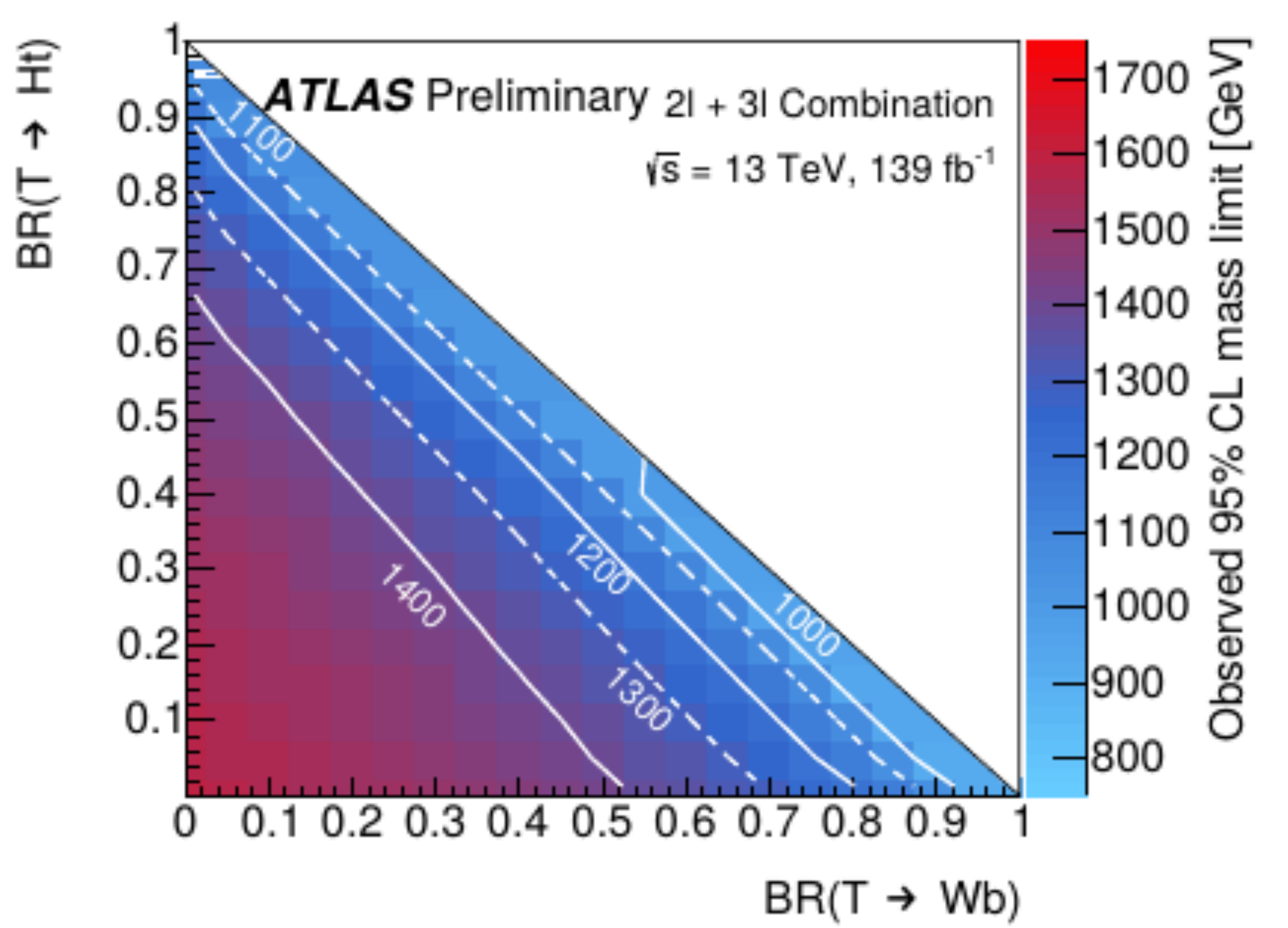
ATLAS-CONF-2021-024

- Use ATLAS data of the full Run 2 of the LHC at a center-of-mass energy of 13 TeV (139fb^{-1})
- No deviations from the background-only model observed
    - Sensitivity limited by statistical uncertainties
- Higher sensitivity to **VLB in 2-lepton final state** and to **VLT in 3-lepton final state**
- Set limits in singlet and doublet model and as function of the VLT(B) branching ratio to SM bosons

Extend the excluded B & T mass limits by more than 200 GeV compared to previous analysis using 2015+16 data (36fb^{-1})



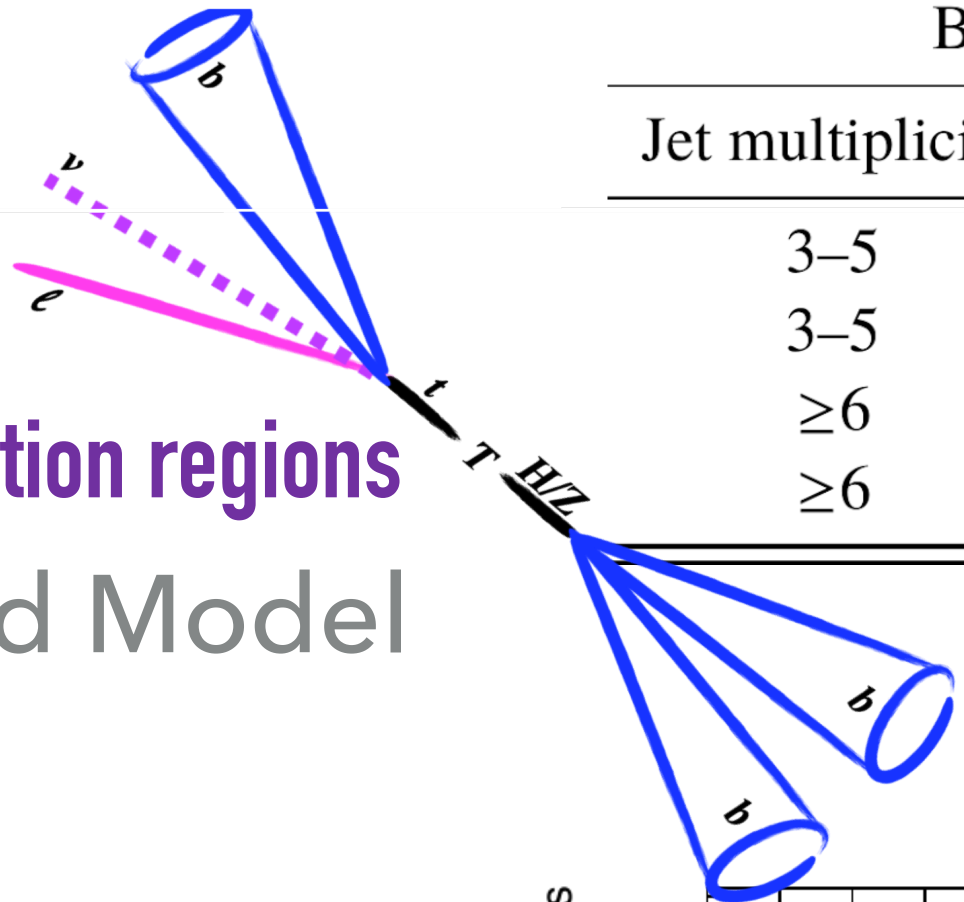
Model	Observed (Expected) Mass Limits [TeV] 2ℓ	 3ℓ	 Combination
$T\bar{T}$ Singlet	1.14 (1.16)	1.22 (1.21)	1.27 (1.29)
$T\bar{T}$ Doublet	1.34 (1.32)	1.38 (1.37)	1.46 (1.44)
100% $T \to Zt$	1.43 (1.43)	1.54 (1.50)	1.60 (1.57)
$B\bar{B}$ Singlet	1.14 (1.21)	1.11 (1.10)	1.20 (1.25)
$B\bar{B}$ Doublet	1.31 (1.37)	1.07 (1.04)	1.32 (1.38)
100% $B \to Zb$	1.40 (1.47)	1.16 (1.18)	1.42 (1.49)



SEARCH FOR SINGLE PRODUCTION OF VECTOR-LIKE T QUARKS DECAYING TO Ht OR Zt – ANALYSIS STRATEGY

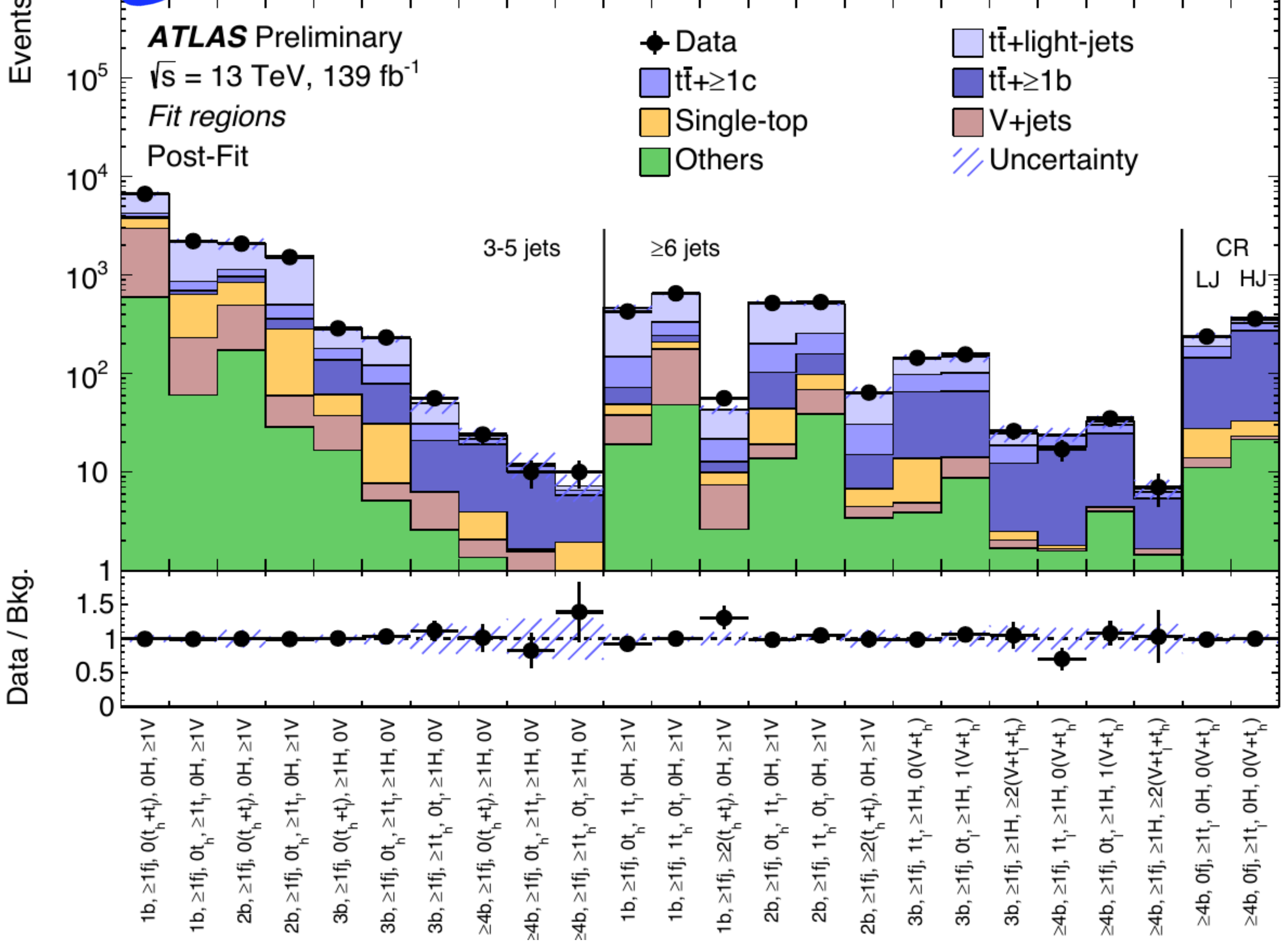
ATLAS-CONF-2021-040

- Optimize sensitivity to **T ⟶ Ht/Zt**
  - 1 lepton in final state from top quark decay
- Categorization in **exclusive signal-sensitive, control and validation regions** to constrain different signal models and Standard Model backgrounds
- **Properties of reclustered large-R jets** to divide into sensitive regions for **final state containing boosted Higgs, vector bosons or top quarks**
  - Cuts on large-R jet mass, p_T and number of constituents
- **Data-driven corrections** to dominant MC estimated background using a 2-D reweighting technique
- **Combined fit in all regions to discriminating variable to extract the signal and improve background description**



Baseline selections on jet and *b*-tag multiplicity

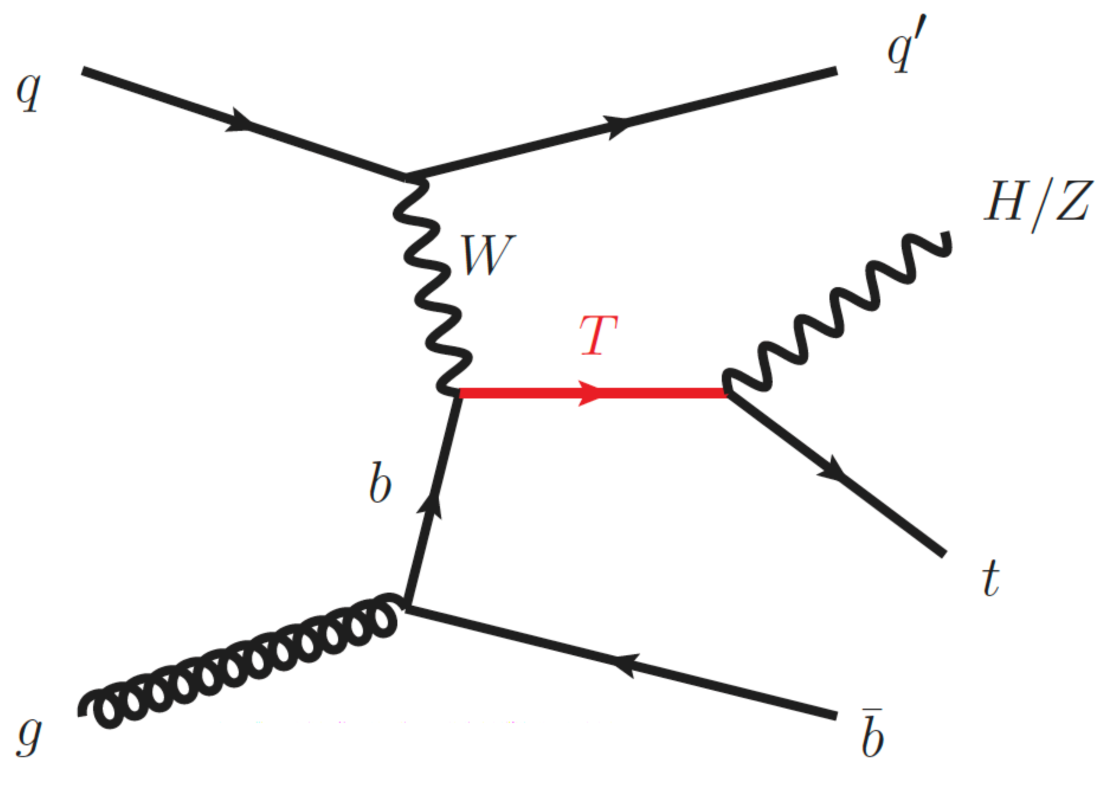
Jet multiplicity	*b*-tag multiplicity	Channel name	Targeted signal
3–5	1–2	LJ, 1-2b	$T \rightarrow Zt$
3–5	≥ 3	LJ, $\geq$3b	$T \rightarrow Ht$
≥ 6	1–2	HJ, 1-2b	$T \rightarrow Zt$
≥ 6	≥ 3	HJ, $\geq$3b	$T \rightarrow Ht$

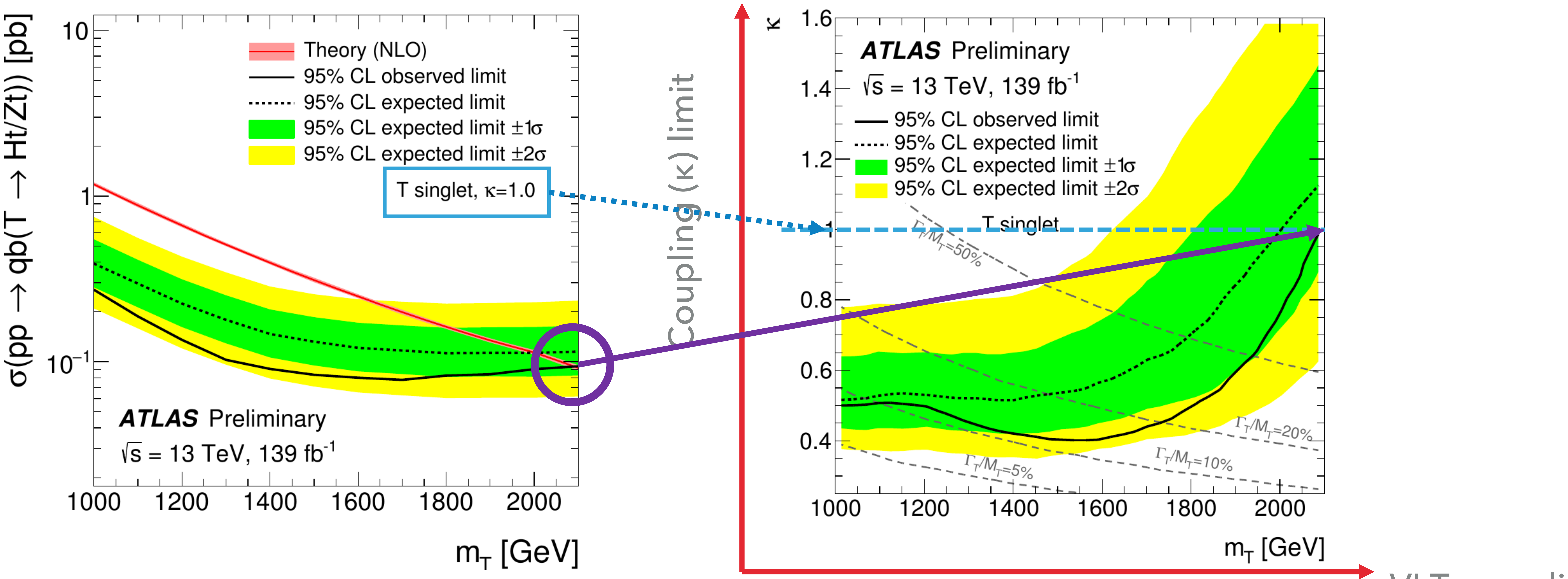


SEARCH FOR SINGLE PRODUCTION OF VECTOR-LIKE T QUARKS DECAYING TO Ht OR Zt – RESULTS

ATLAS-CONF-2021-040

- Use ATLAS full Run 2 data set
- **No deviation from the background only hypothesis**
- Interpretation in terms of the **universal coupling constant (κ)** , which determines the production cross section and total decay width for a given mass
- Sensitivity limited by ttbar and single top modeling



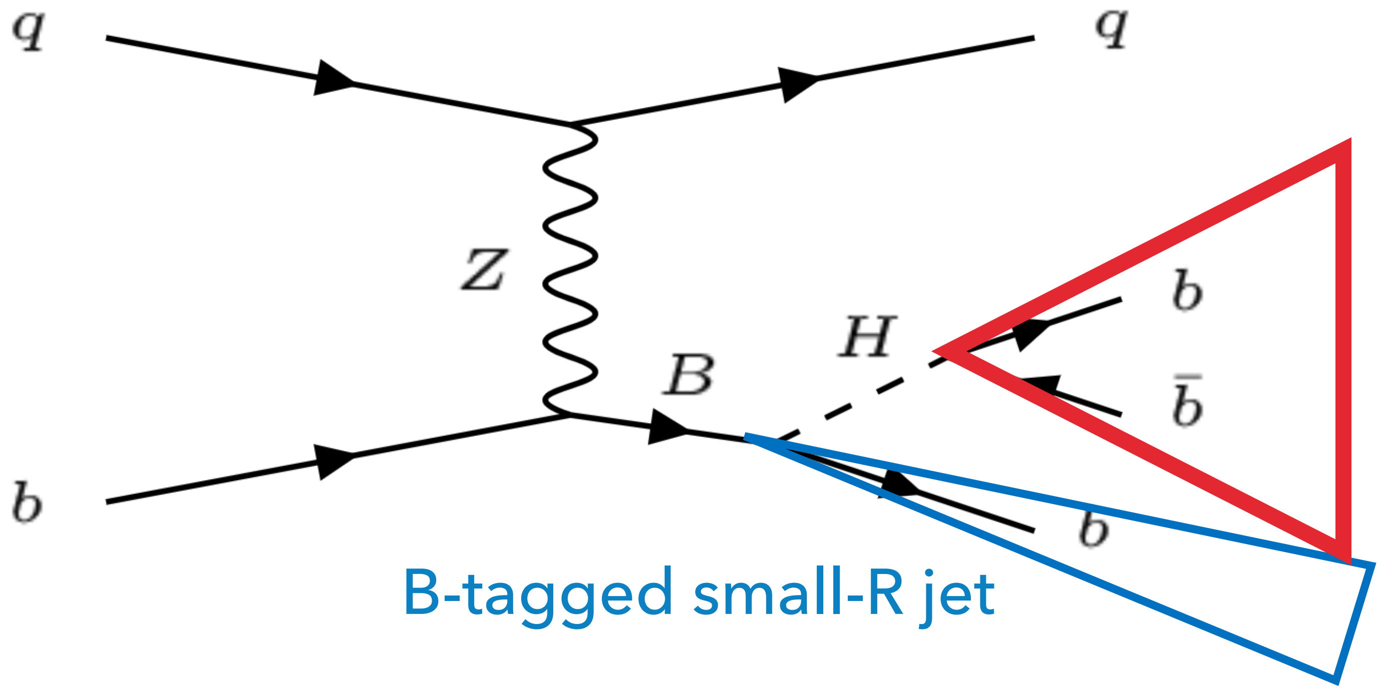


VLT mass limit

SEARCH FOR SINGLE VECTOR-LIKE B QUARK PRODUCTION AND DECAY VIA B ⟶ bH(bb)

ATLAS-CONF-2021-018

- Identification of **3 b-jets important for dominant (90%) multijet background suppression**
- **Identify boosted Higgs boson** using the jet mass, 2-pronged jet structure and associated b-tagged variable-radius track jets
- Purely data-driven background estimate using the **ABCD method**
- **Binned maximum-likelihood fit to reconstructed VLB mass**
- Limits on VLB production set in different coupling scenarios for (B,Y) doublet and as a function of the VLB mass using the ATLAS Full Run 2 dataset

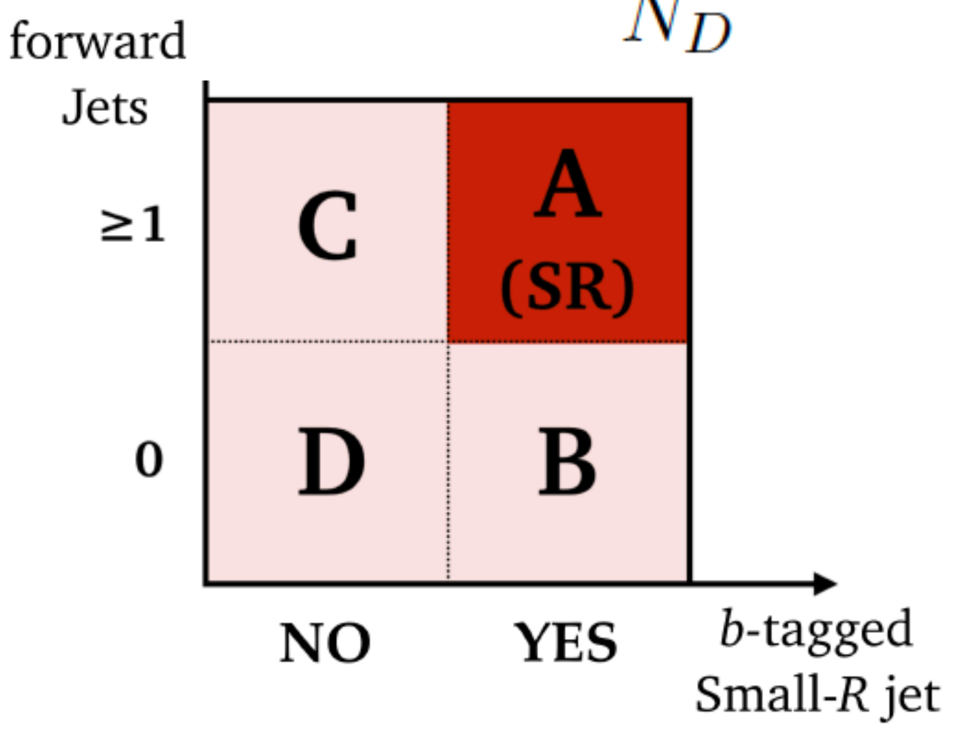


Reclustered large-R jet with two matched b-tagged variable radius track jets

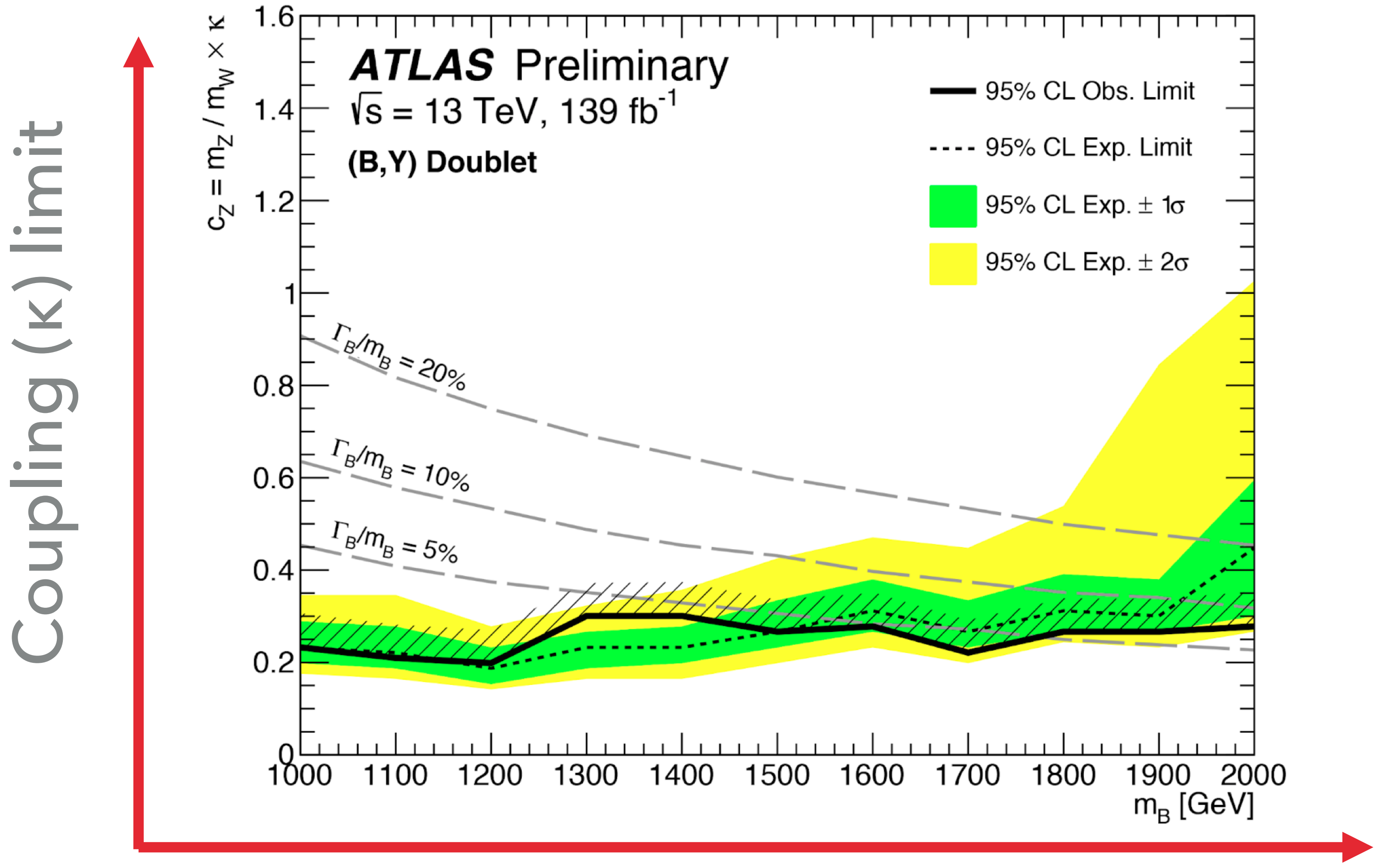
B-tagged small-R jet

Expand substantially the region of the VLB parameter space probed (previous limits: for (B,Y) doublet scenario @1.2TeV)

$$N_A = N_B \times \frac{N_C}{N_D}$$

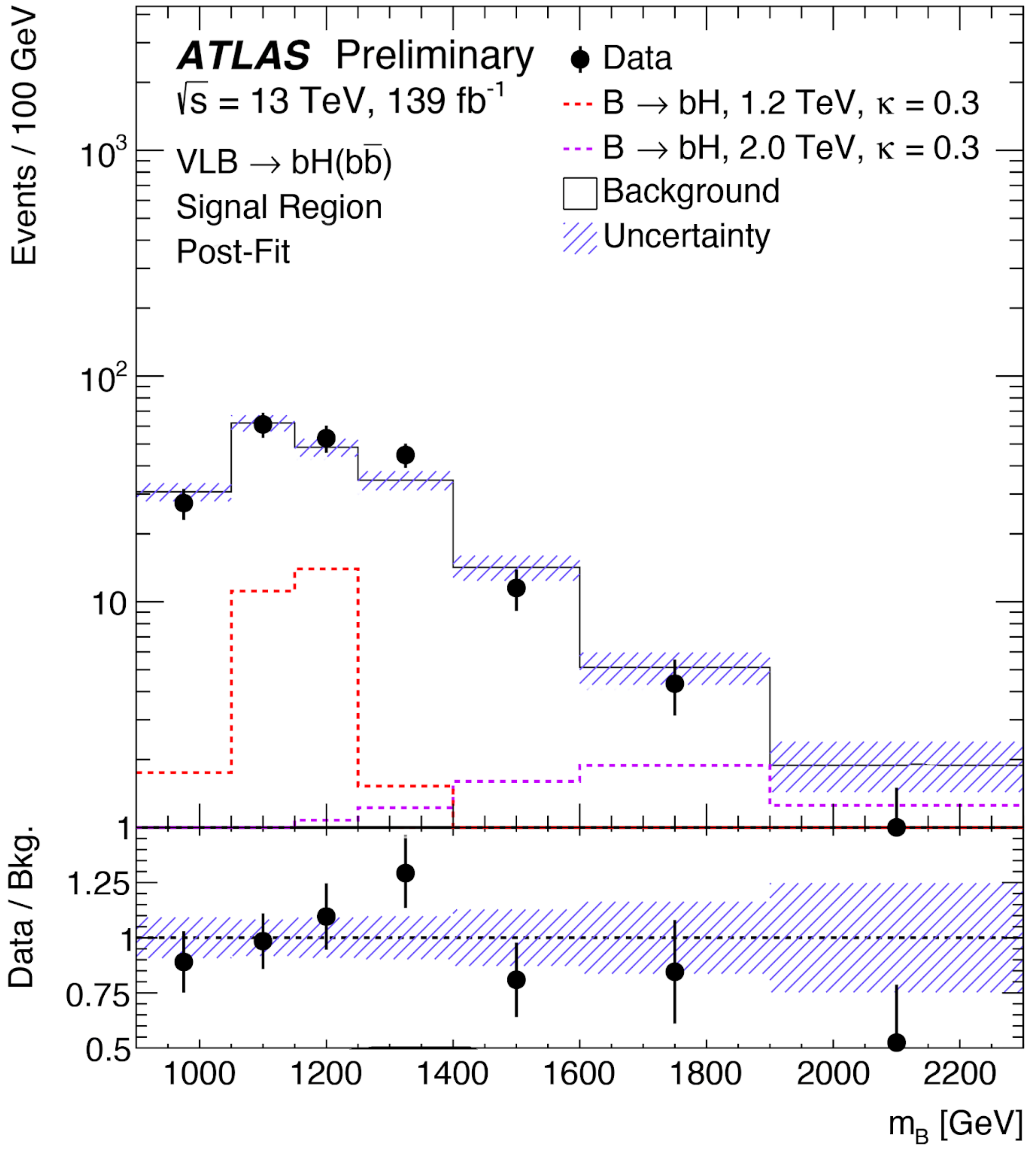


“ABCD method”



Coupling (κ) limit

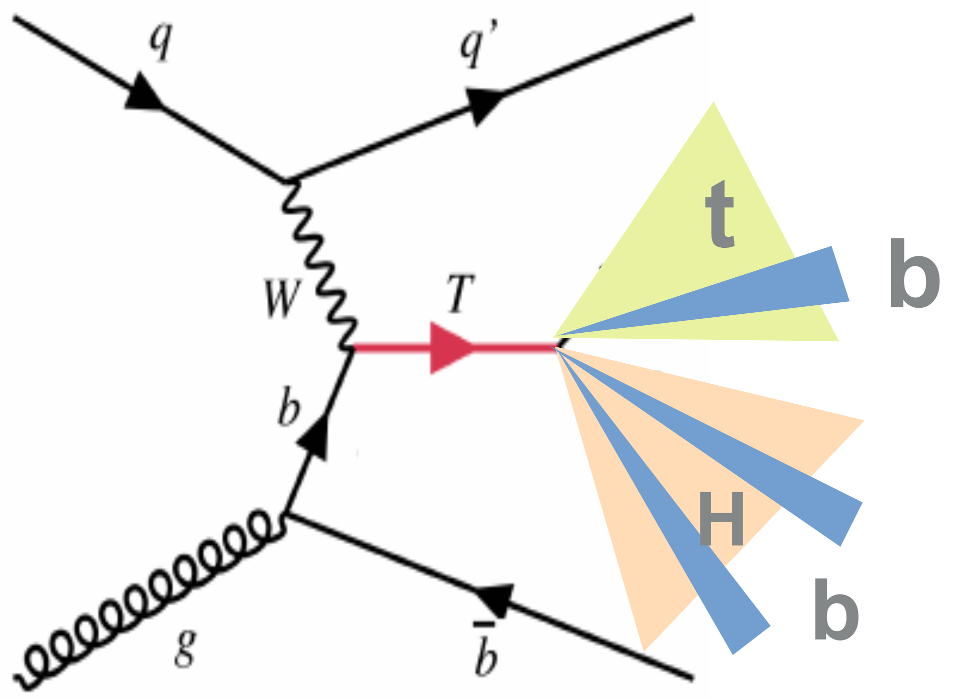
VLB mass limit



SEARCH FOR SINGLE PRODUCTION OF A VECTOR-LIKE T QUARK DECAYING INTO A HIGGS BOSON AND A TOP QUARK WITH FULLY-HADRONIC FINAL STATES

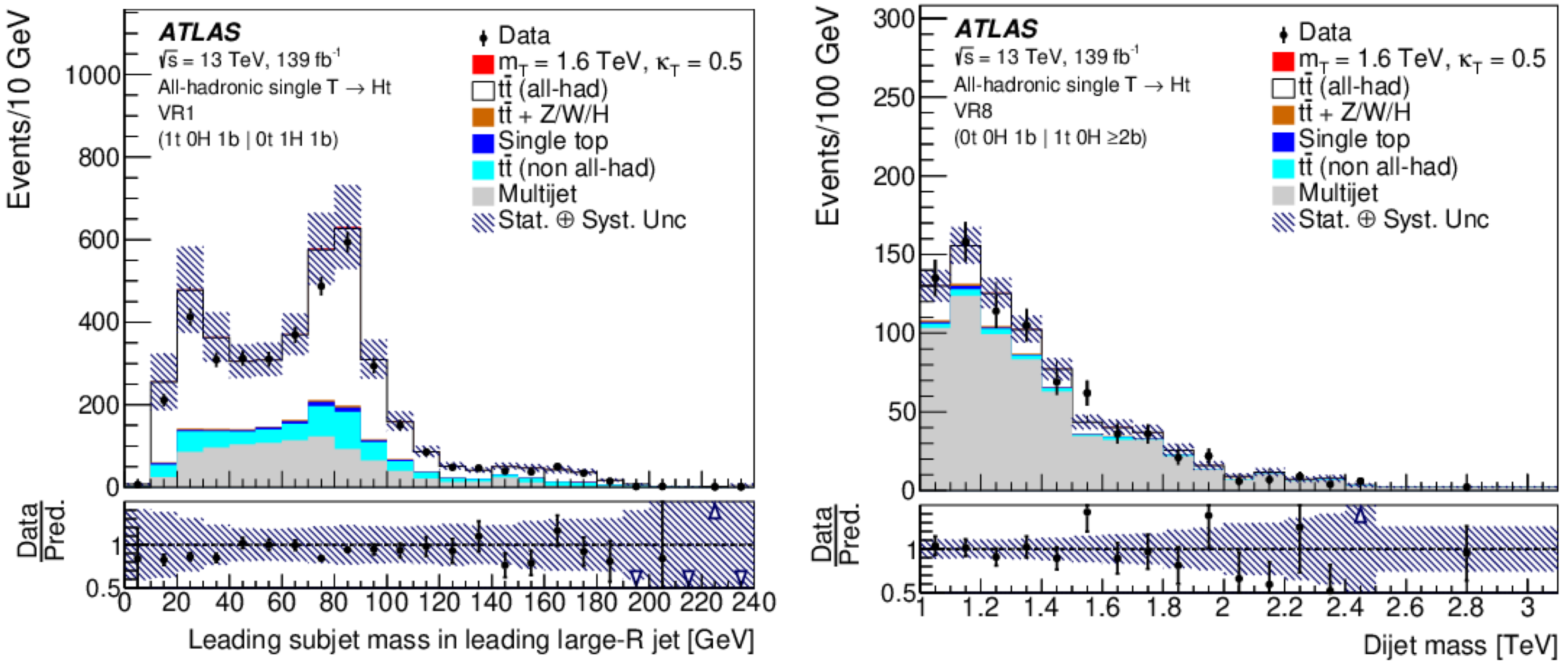
EXOT-2019-07

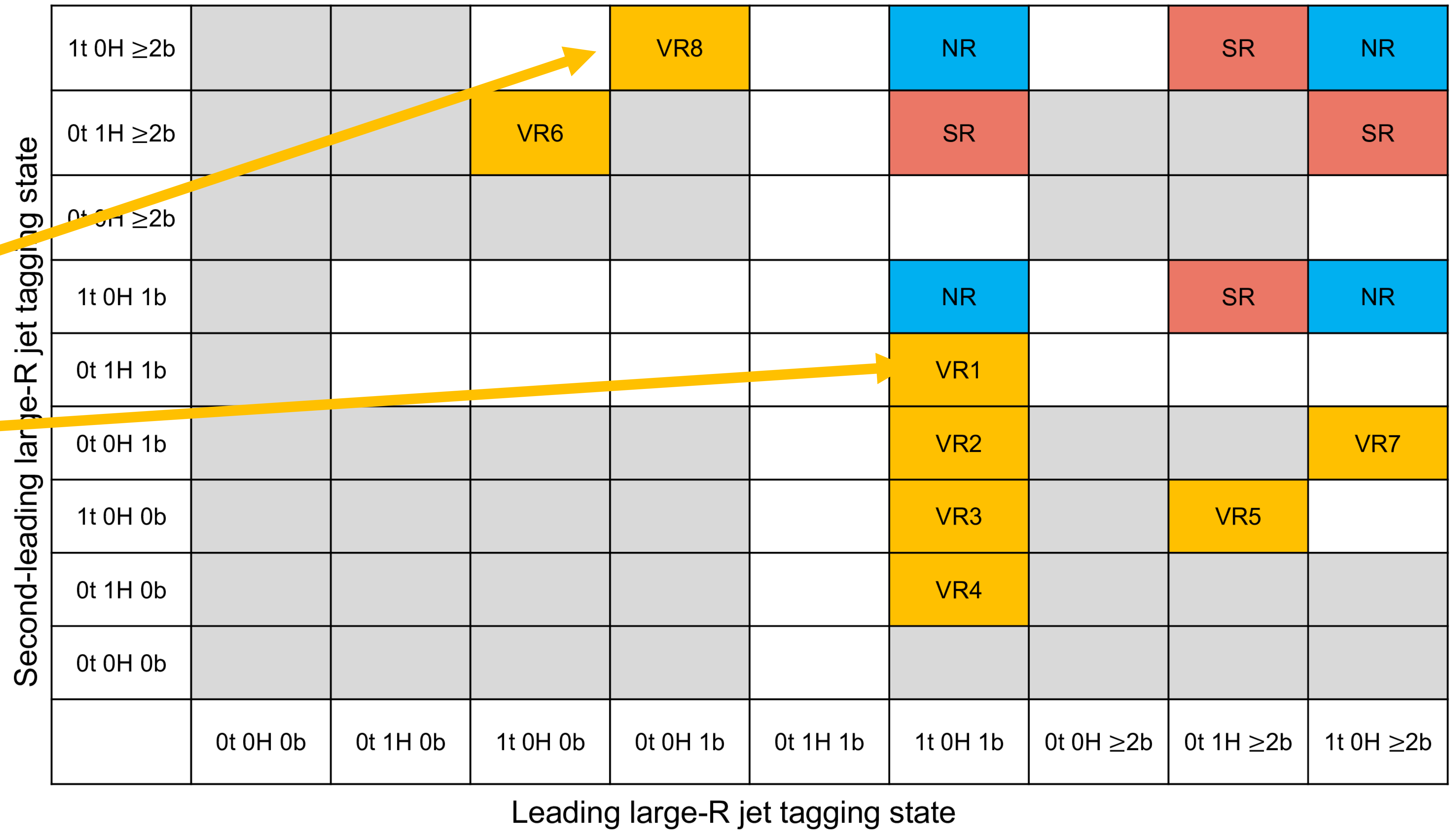
- Search targets **T → H(→ bb)t** decay
- Top and Higgs reconstructed using **leading and subleading large-R jet**, identification using the **jet mass** and
  - ATLAS **DNN top tagger** (top)
  - Cuts on **jet substructure variables** (H)
- **Classify events** according to the number of
  - **Higgs and top tags**
  - **b-tagged VRTrack jets associated with large-R jet**



2D-grid of signal regions (SR), ttbar normalization regions (NR), control and validation regions

- **Dominant multijet background** calculated using the **data-driven ABCD method**





Second-leading large-R jet tagging state

1t 0H ≥2b				VR8		NR		SR	NR
0t 1H ≥2b			VR6			SR			SR
0t 0H ≥2b									
1t 0H 1b						NR		SR	NR
0t 1H 1b						VR1			
0t 0H 1b						VR2			VR7
1t 0H 0b						VR3		VR5	
0t 1H 0b						VR4			
0t 0H 0b									
	0t 0H 0b	0t 1H 0b	1t 0H 0b	0t 0H 1b	0t 1H 1b	1t 0H 1b	0t 0H ≥2b	0t 1H ≥2b	1t 0H ≥2b

Leading large-R jet tagging state

SEARCH FOR SINGLE PRODUCTION OF A VECTOR-LIKE T QUARK DECAYING INTO A HIGGS BOSON AND A TOP QUARK WITH FULLY-HADRONIC FINAL STATES

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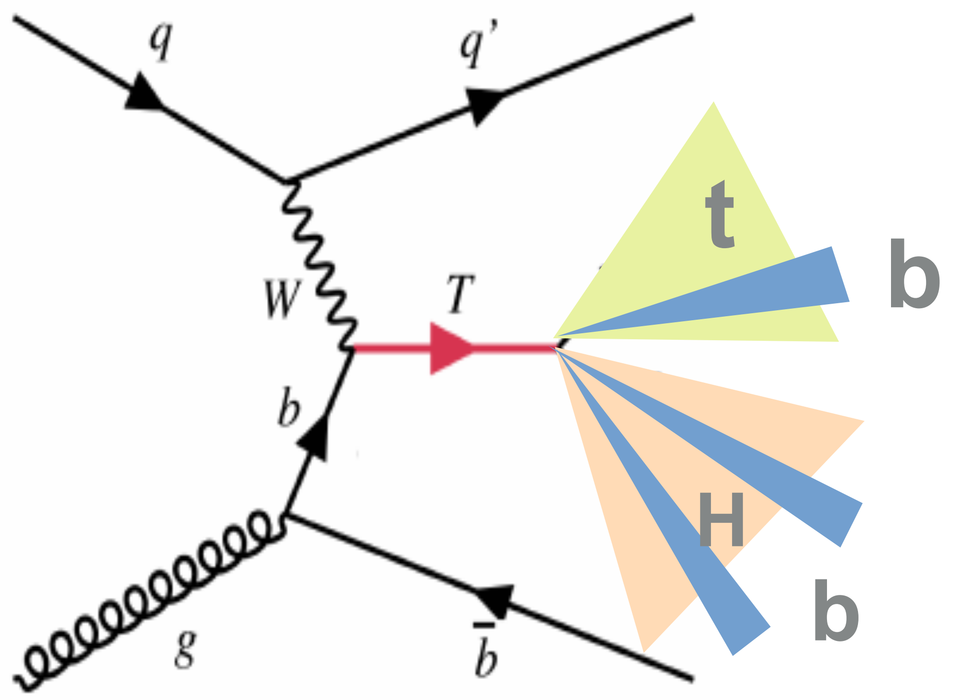

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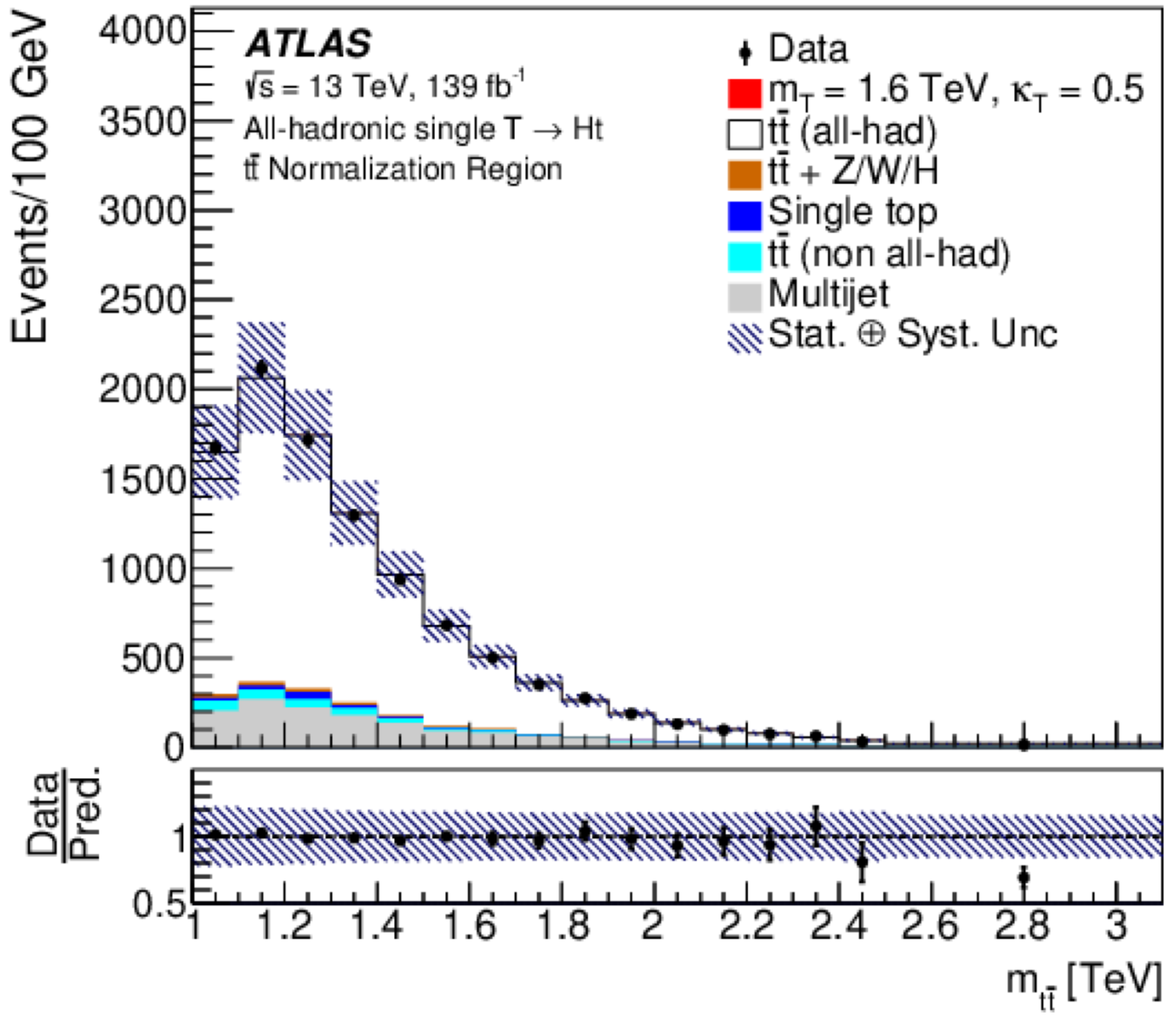

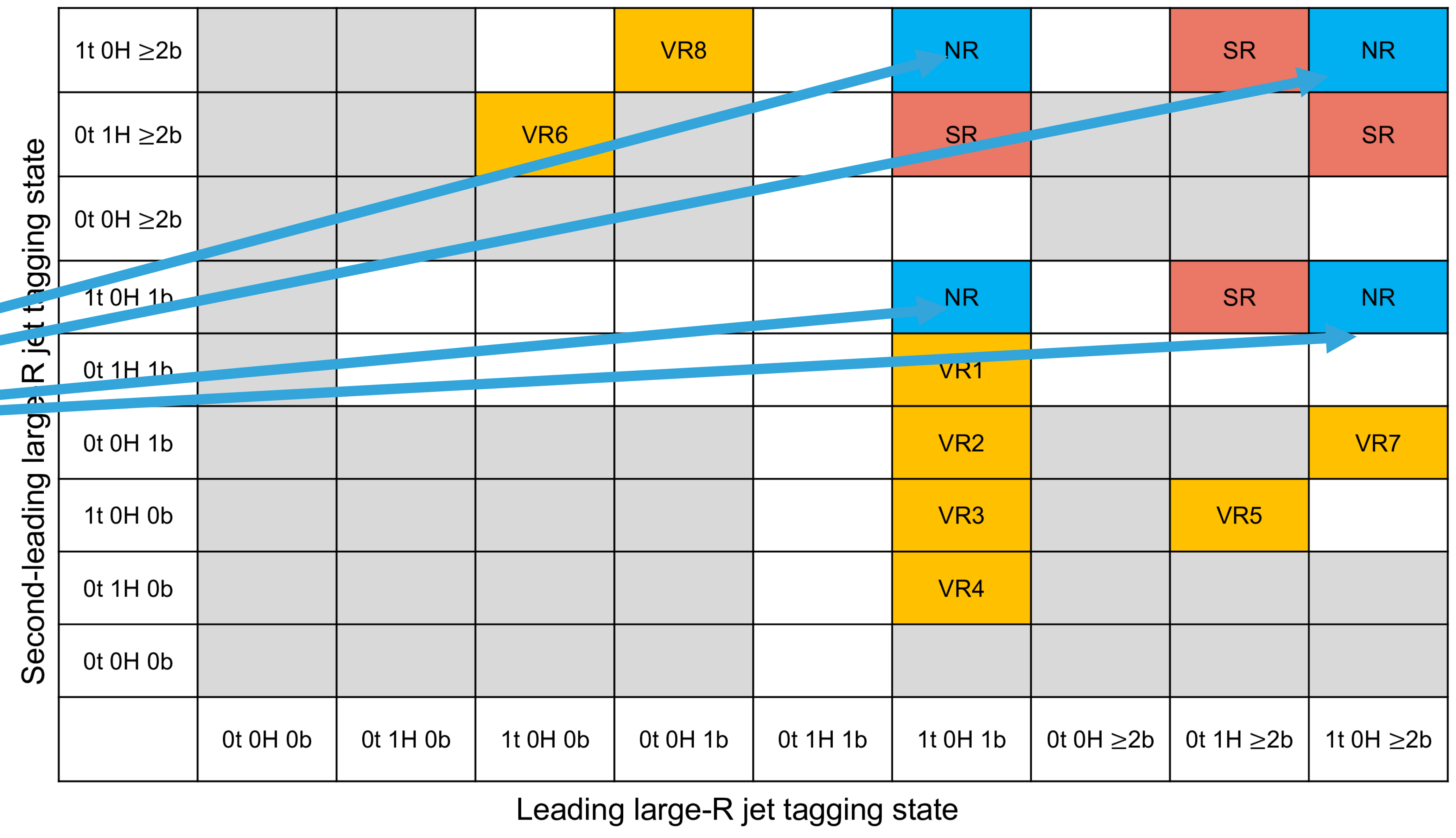

1t 0H ≥2b				VR8		NR		SR	NR
0t 1H ≥2b			VR6			SR			SR
0t 0H ≥2b									
1t 0H 1b						NR		SR	NR
0t 1H 1b						VR1			
0t 0H 1b						VR2			VR7
1t 0H 0b						VR3		VR5	
0t 1H 0b						VR4			
0t 0H 0b									
	0t 0H 0b	0t 1H 0b	1t 0H 0b	0t 0H 1b	0t 1H 1b	1t 0H 1b	0t 0H ≥2b	0t 1H ≥2b	1t 0H ≥2b

SEARCH FOR SINGLE PRODUCTION OF A VECTOR-LIKE T QUARK DECAYING INTO A HIGGS BOSON AND A TOP QUARK WITH FULLY-HADRONIC FINAL STATES

EXOT-2019-07

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- Top and Higgs reconstructed using **leading and subleading large-R jet**, identification using the **jet mass** and
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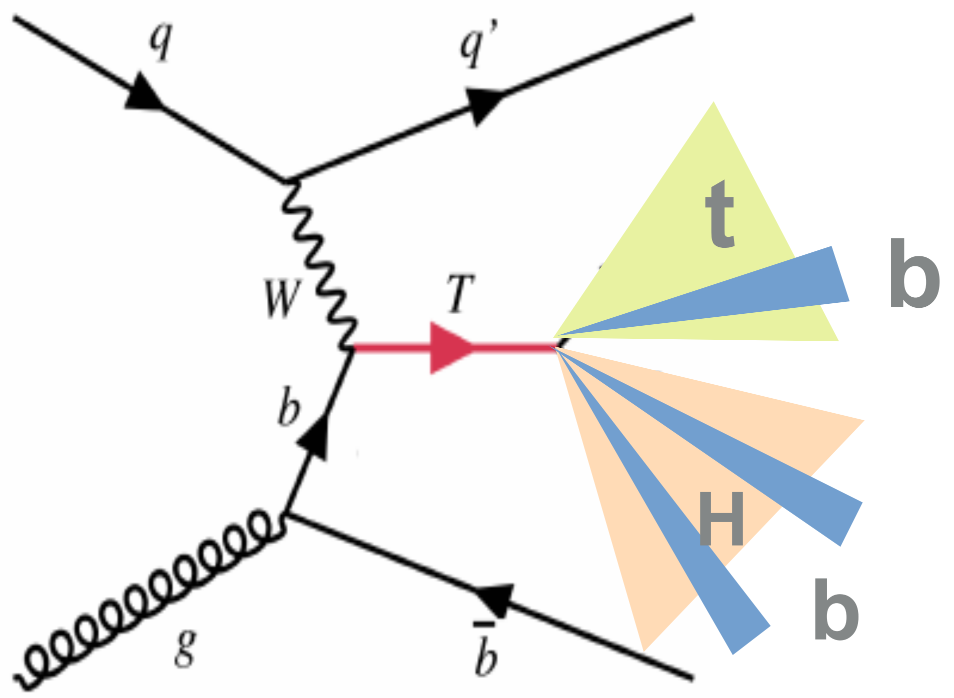
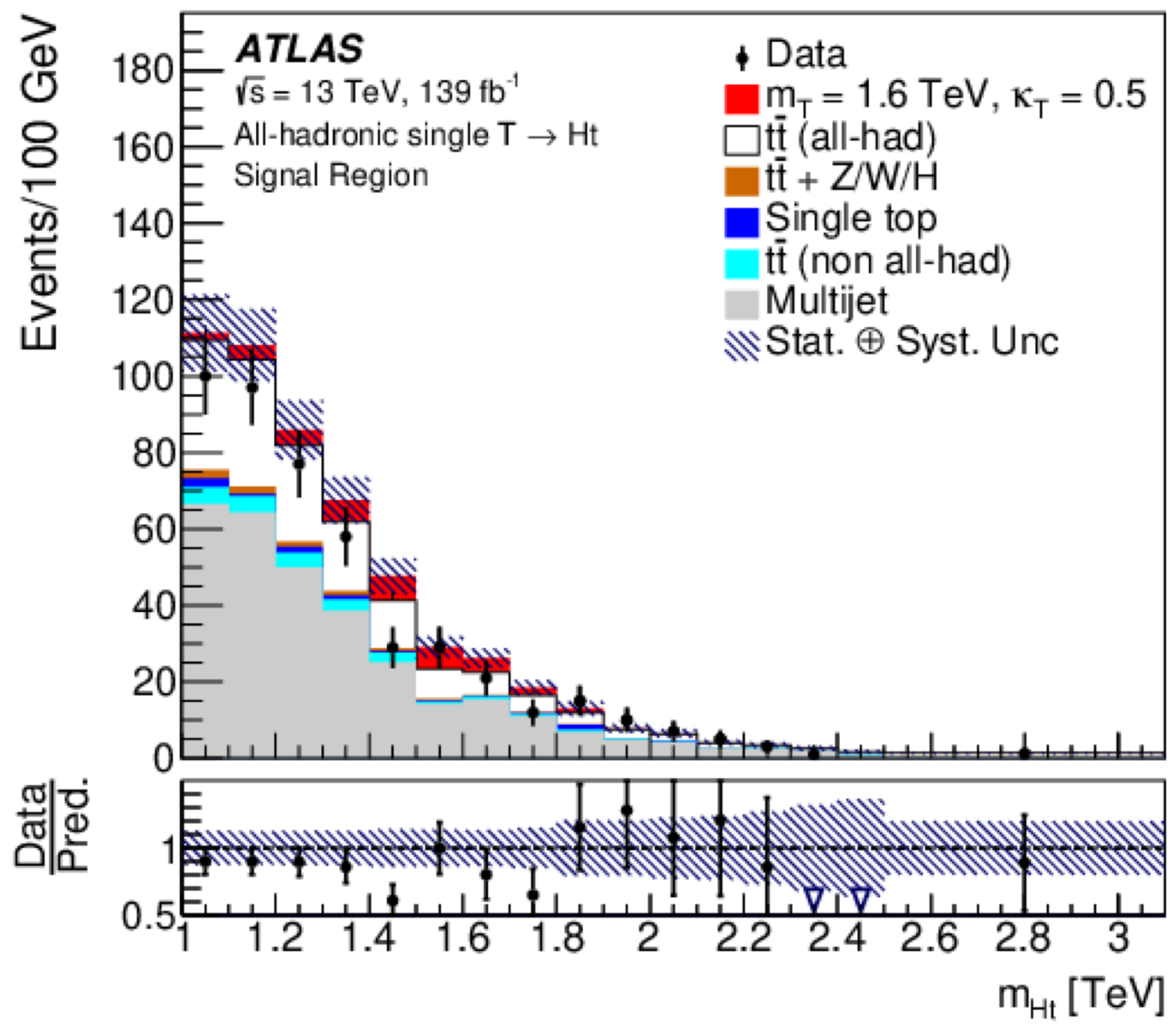
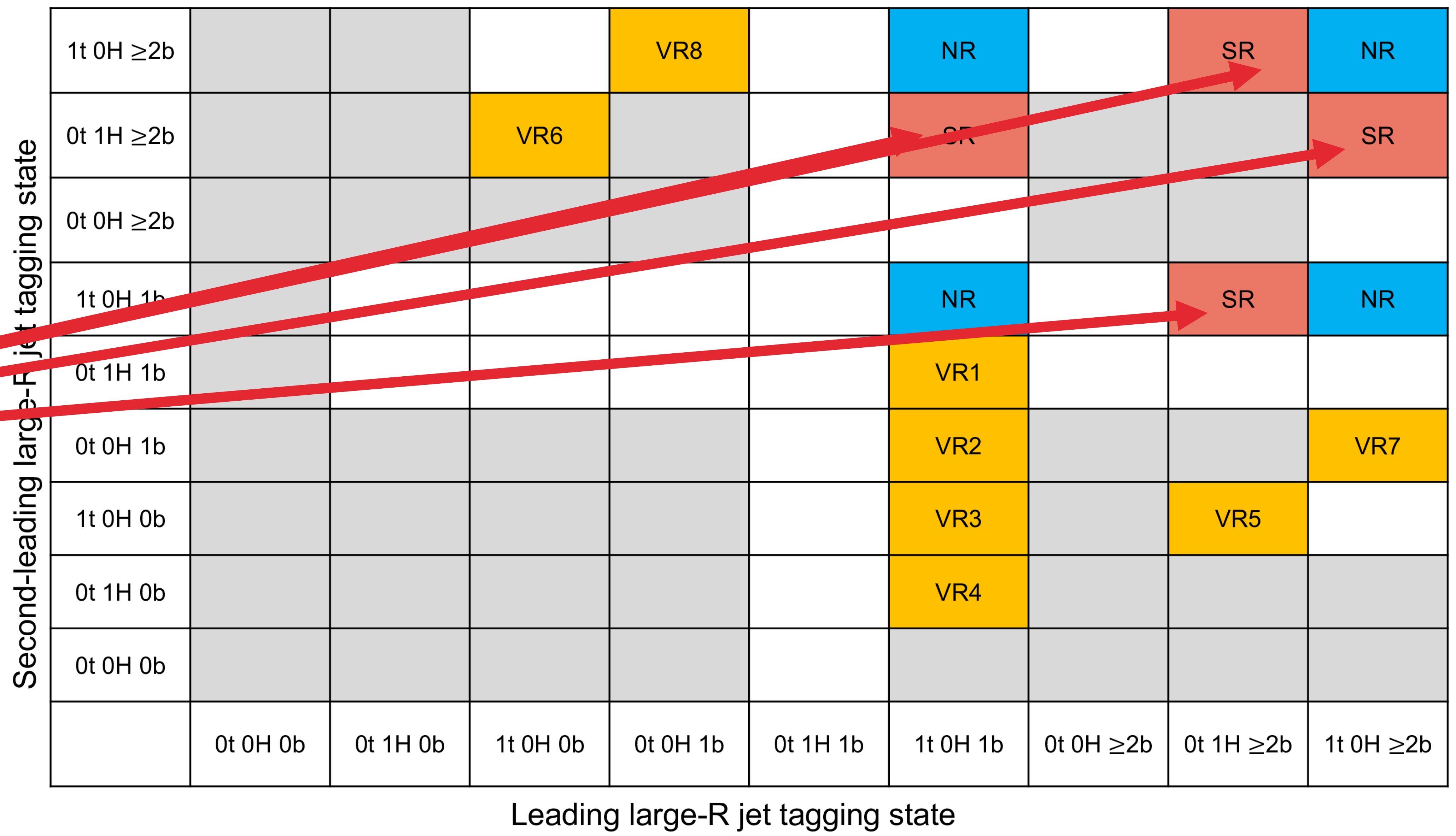
- **Classify events** according to the number of
  - **Higgs and top tags**
  - **b-tagged VRTrack jets associated with large-R jet**



2D-grid of signal regions (SR), ttbar normalization regions (NR), control and validation regions

- **Dominant multijet background** calculated using the **data-driven ABCD method**





	0t 0H 0b	0t 1H 0b	1t 0H 0b	0t 0H 1b	0t 1H 1b	1t 0H 1b	0t 0H ≥2b	0t 1H ≥2b	1t 0H ≥2b
1t 0H ≥2b				VR8		NR		SR	NR
0t 1H ≥2b			VR6			SR			SR
0t 0H ≥2b									
1t 0H 1b						NR		SR	NR
0t 1H 1b						VR1			
0t 0H 1b						VR2			VR7
1t 0H 0b						VR3		VR5	
0t 1H 0b						VR4			
0t 0H 0b									

Second-leading large-R jet tagging state

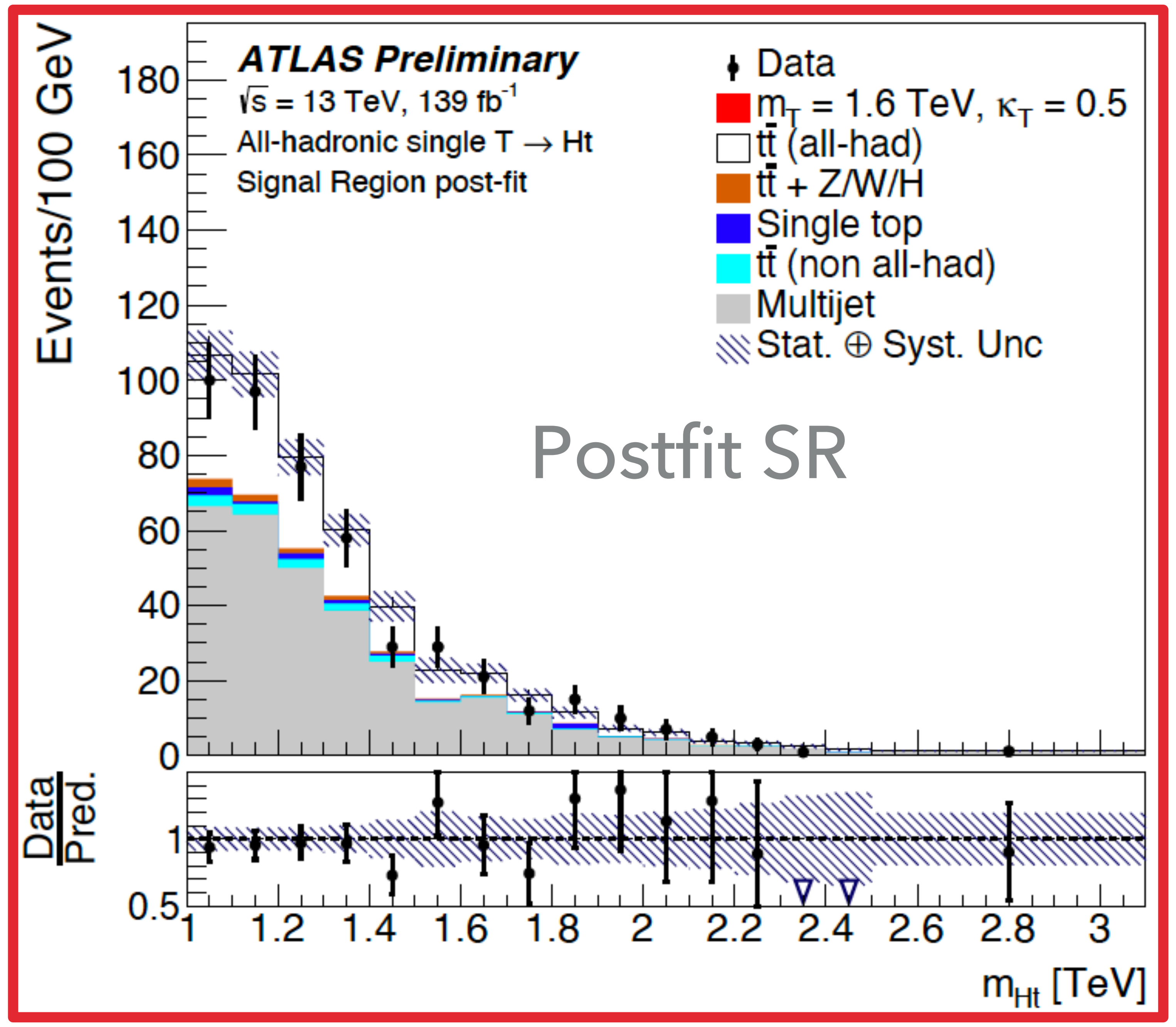
Leading large-R jet tagging state

SEARCH FOR SINGLE PRODUCTION OF A VECTOR-LIKE T QUARK DECAYING INTO A HIGGS BOSON AND A TOP QUARK WITH FULLY-HADRONIC FINAL STATES

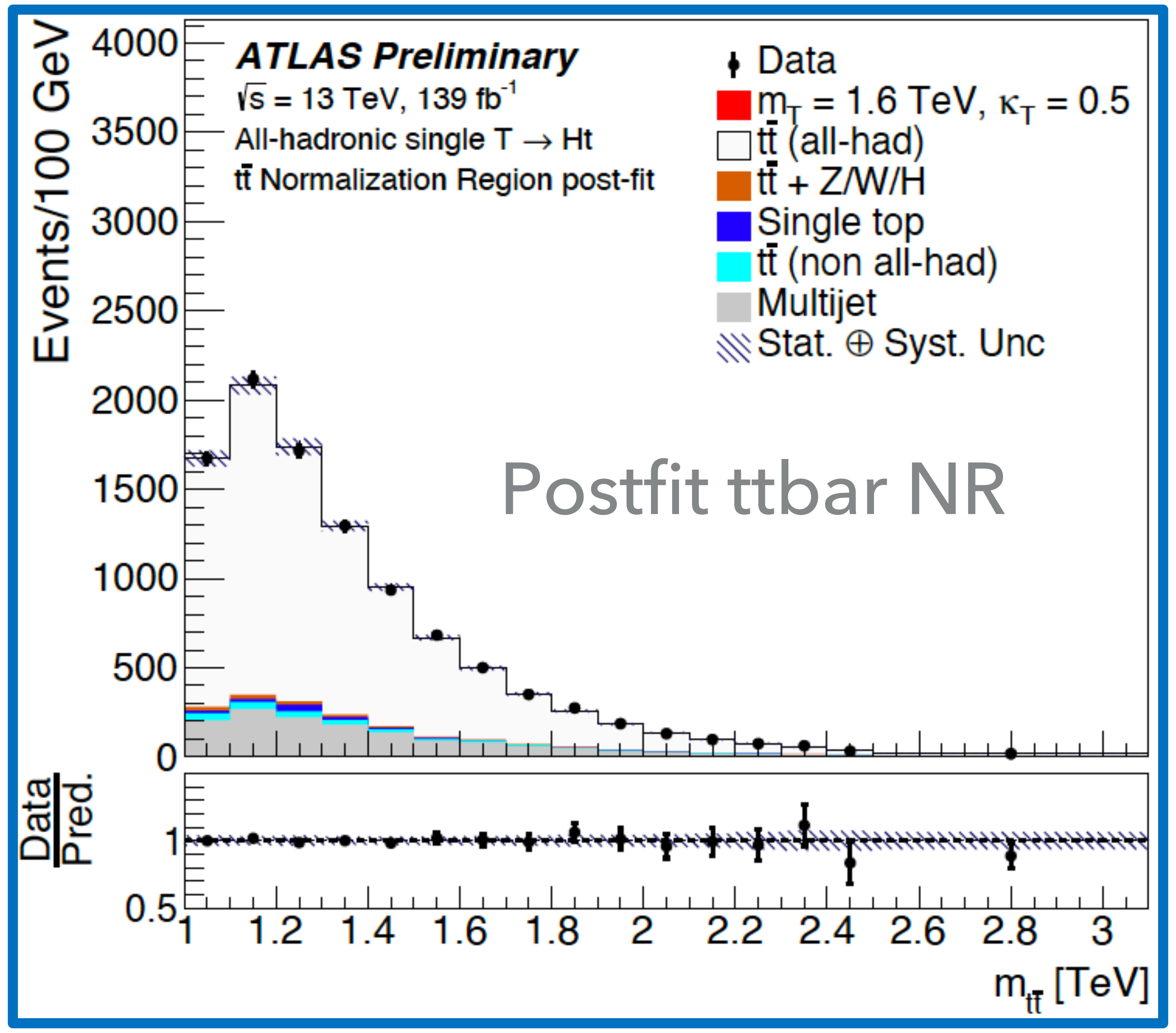
EXOT-2019-07

- Binned likelihood fit to **dijet invariant mass distribution** simultaneously in Signal region and ttbar normalization region
  - Fit of signal cross section and normalization of MC-based ttbar estimation
- Limit set as a function of the **VLQ mass and coupling**
- **VLQ masses up to m(VLQ)=2.3TeV excluded dependent on the coupling κ in the singlet scenario**

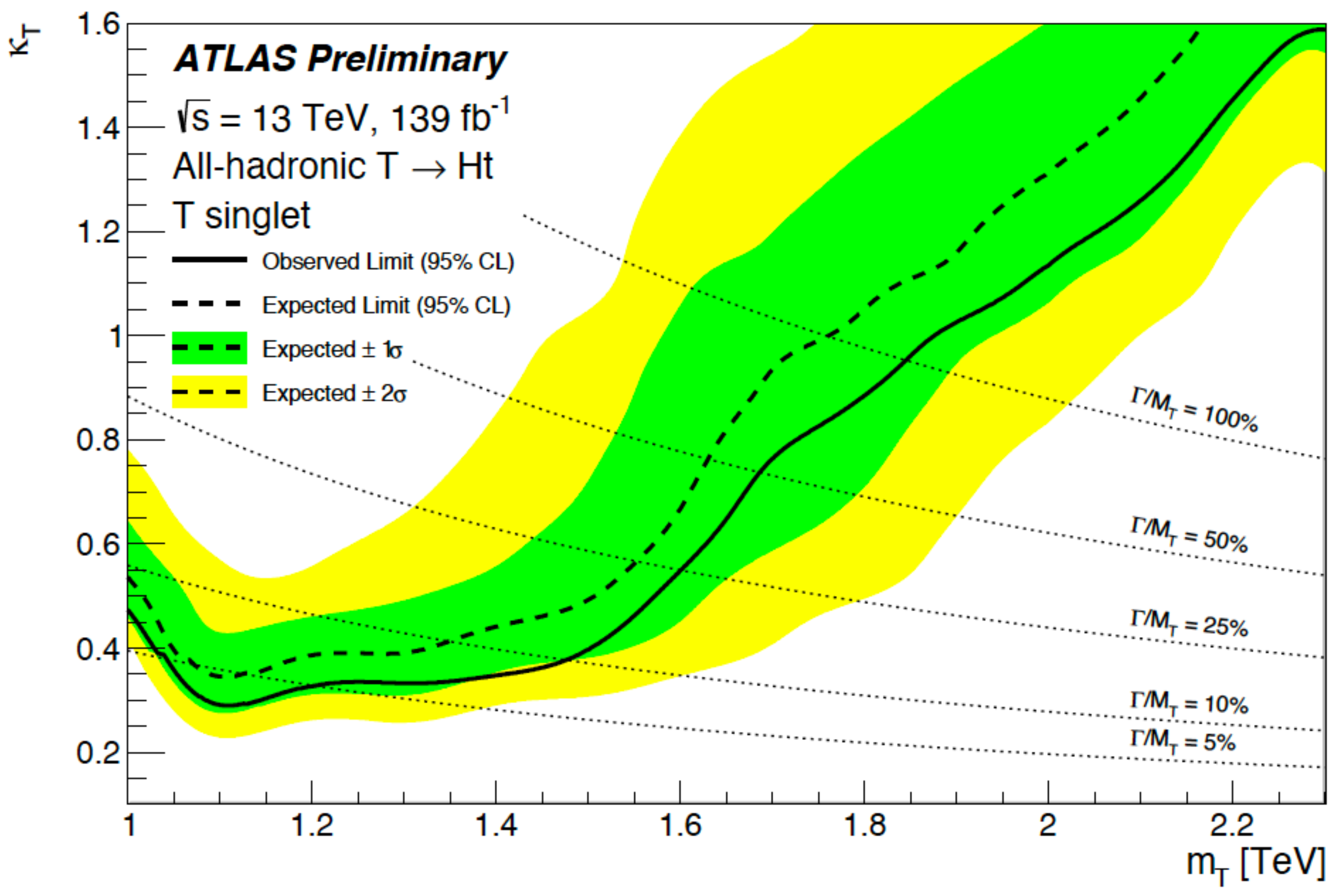
Improvements in sensitivity beyond what is expected by integrated luminosity increase due to exploitation of boosted topologies, multijet estimation technique, jet tagging



Postfit SR



Postfit ttbar NR



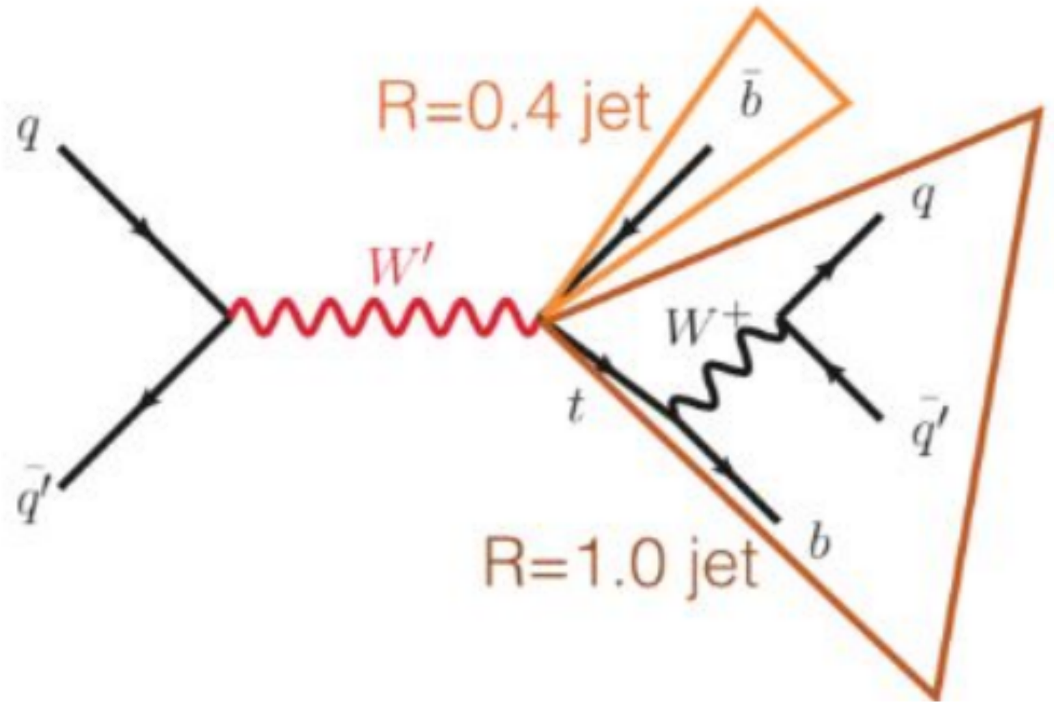
SEARCHES FOR HEAVY GAUGE BOSONS & TOP RESONANCES

Searches for heavy gauge bosons & top resonances

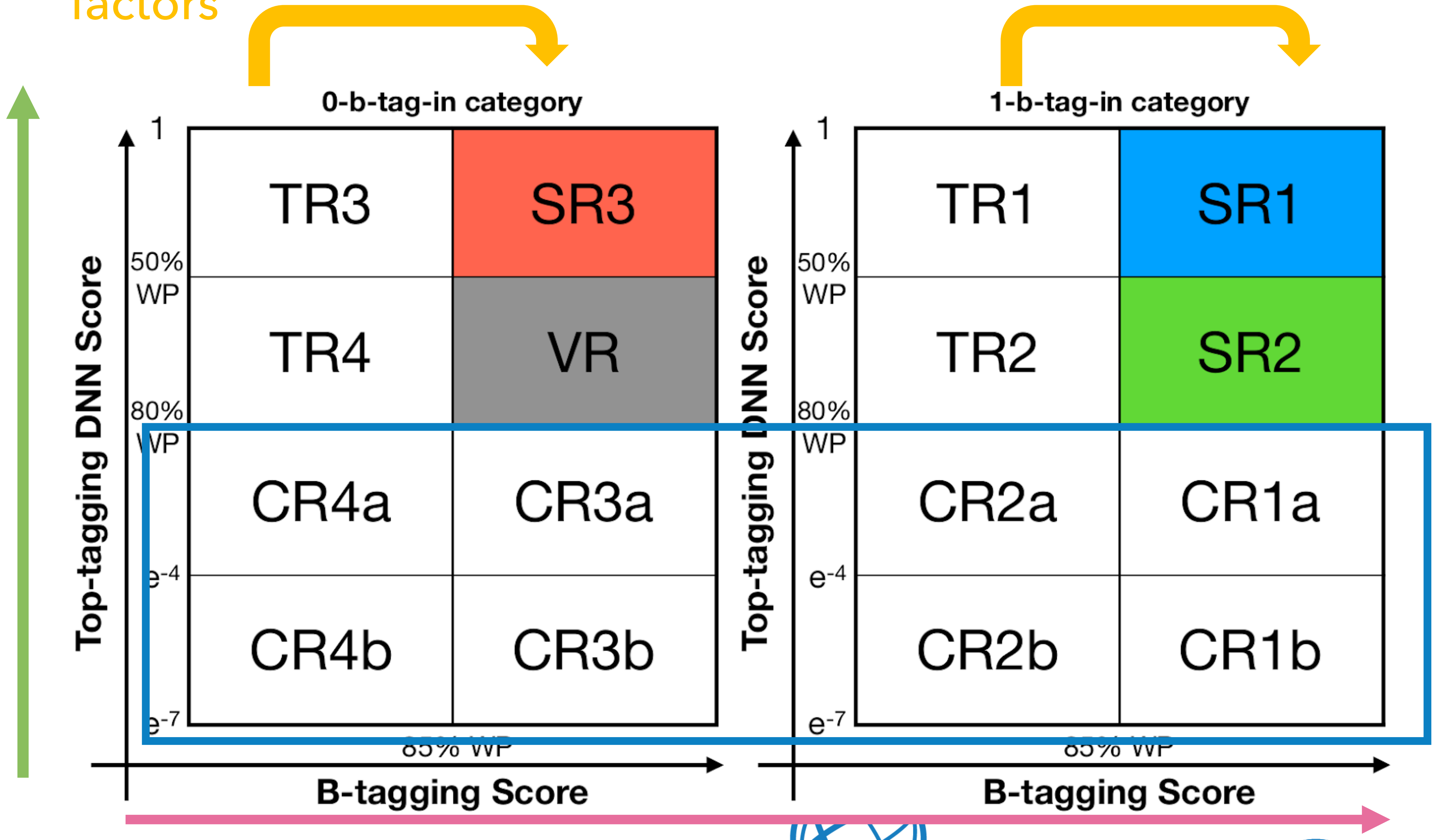
SEARCH FOR VECTOR BOSON RESONANCES DECAYING TO A TOP QUARK AND A BOTTOM QUARK IN HADRONIC FINAL STATES – STRATEGY

ATLAS-CONF-2021-043

- Search for new heavy W′ gauge bosons decaying to a **(boosted) top quark and a b-quark**
- Analysis profits from **improved top and b-quark identification and improved multijet estimate**
- Analysis regions classified according to
  - DNN top tag category
  - b-tag from W′ decay
  - b-tagged jet in large-R jet
- Multijet background estimated with data-driven ABCD method



extrapolation using transfer factors



TR3	SR3
TR4	VR
CR4a	CR3a
CR4b	CR3b

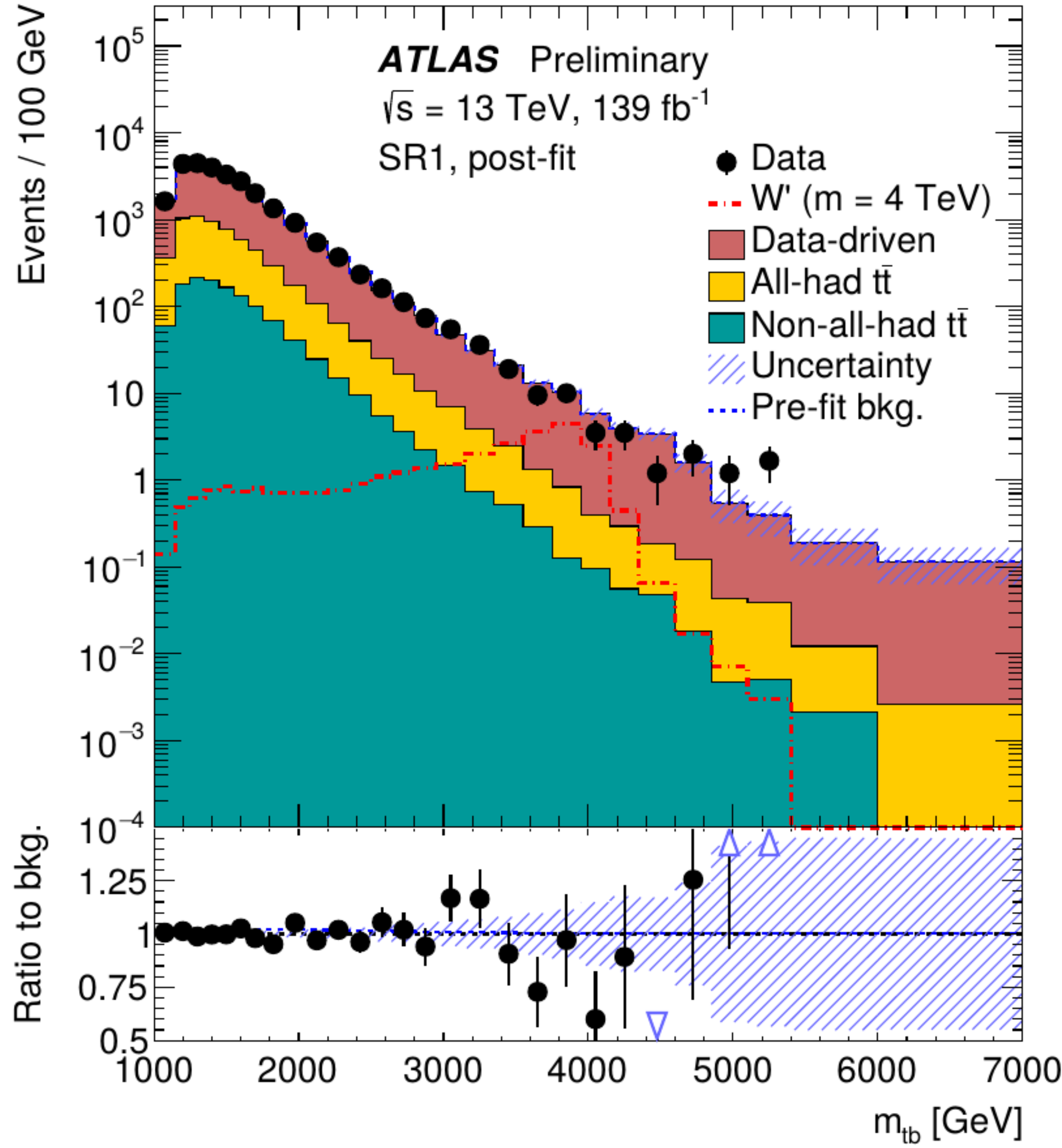
TR1	SR1
TR2	SR2
CR2a	CR1a
CR2b	CR1b

calculation of transfer factors & uncertainties

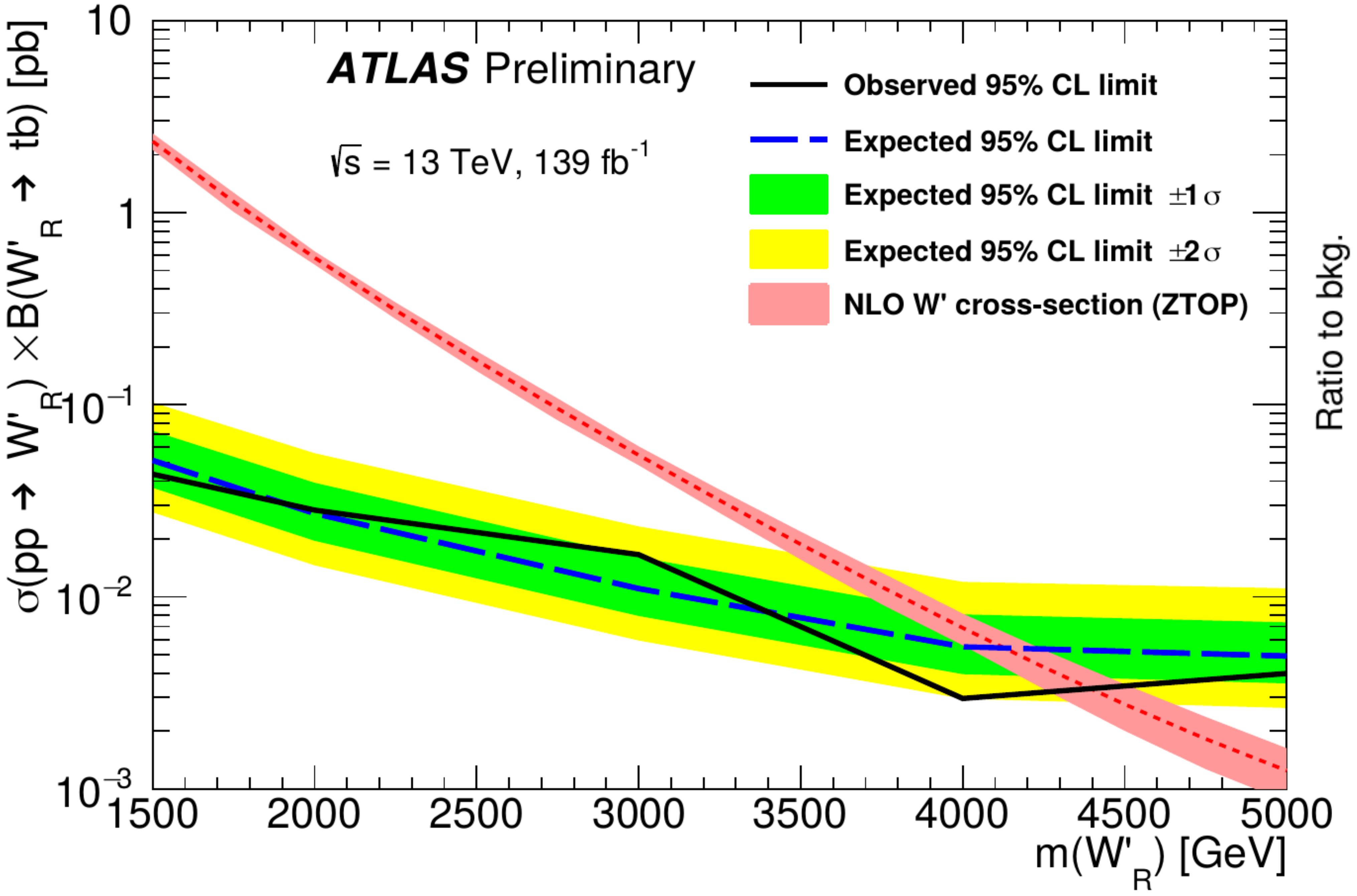
SEARCH FOR VECTOR BOSON RESONANCES DECAYING TO A TOP QUARK AND A BOTTOM QUARK IN HADRONIC FINAL STATES – RESULT

ATLAS-CONF-2021-043

- **Combined fit to all three signal-sensitive regions of ttbar and multijet estimate and signal model in W'(t+b) invariant mass distribution**
- Search uses 139fb^{-1} of Full Run 2 data from the ATLAS experiment
- **W' with right-handed coupling excluded below a mass of 4.4TeV**
  - Sensitivity limited by statistical uncertainties



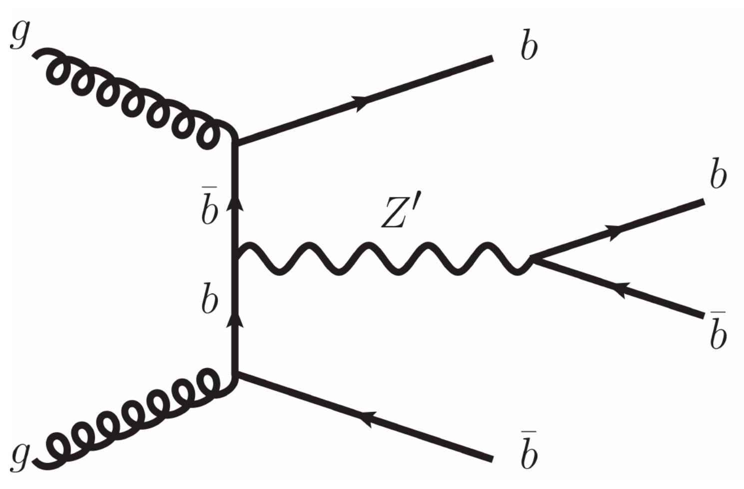
Improvement of the mass limit by 1TeV w.r.t previous result using 2015+2016 data (36fb^{-1})



SEARCH FOR HEAVY PARTICLES IN THE b-TAGGED DIJET MASS DISTRIBUTION WITH ADDITIONAL b-JETS

arXiv:2108.09059

- New W' and Z′ could explain the lepton-flavour universality deviations from LHCb & Belle recent results
- The two jets leading in p_T (from Z′ → bb decay) and either 3rd or 4th jet in p_T are b-tagged to **reduce multijet background**
  - **Previous searches did not include additional b-jets**

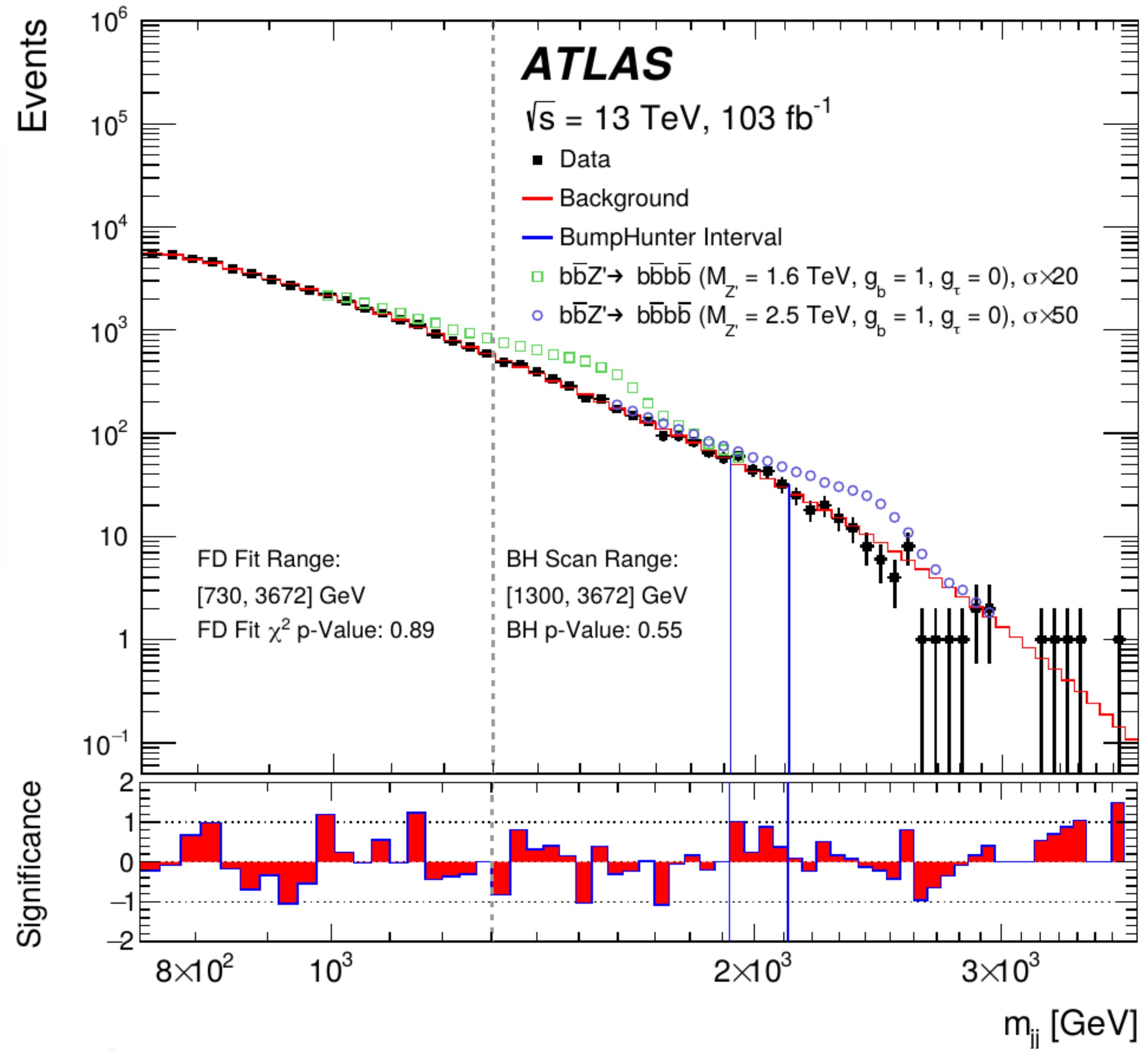


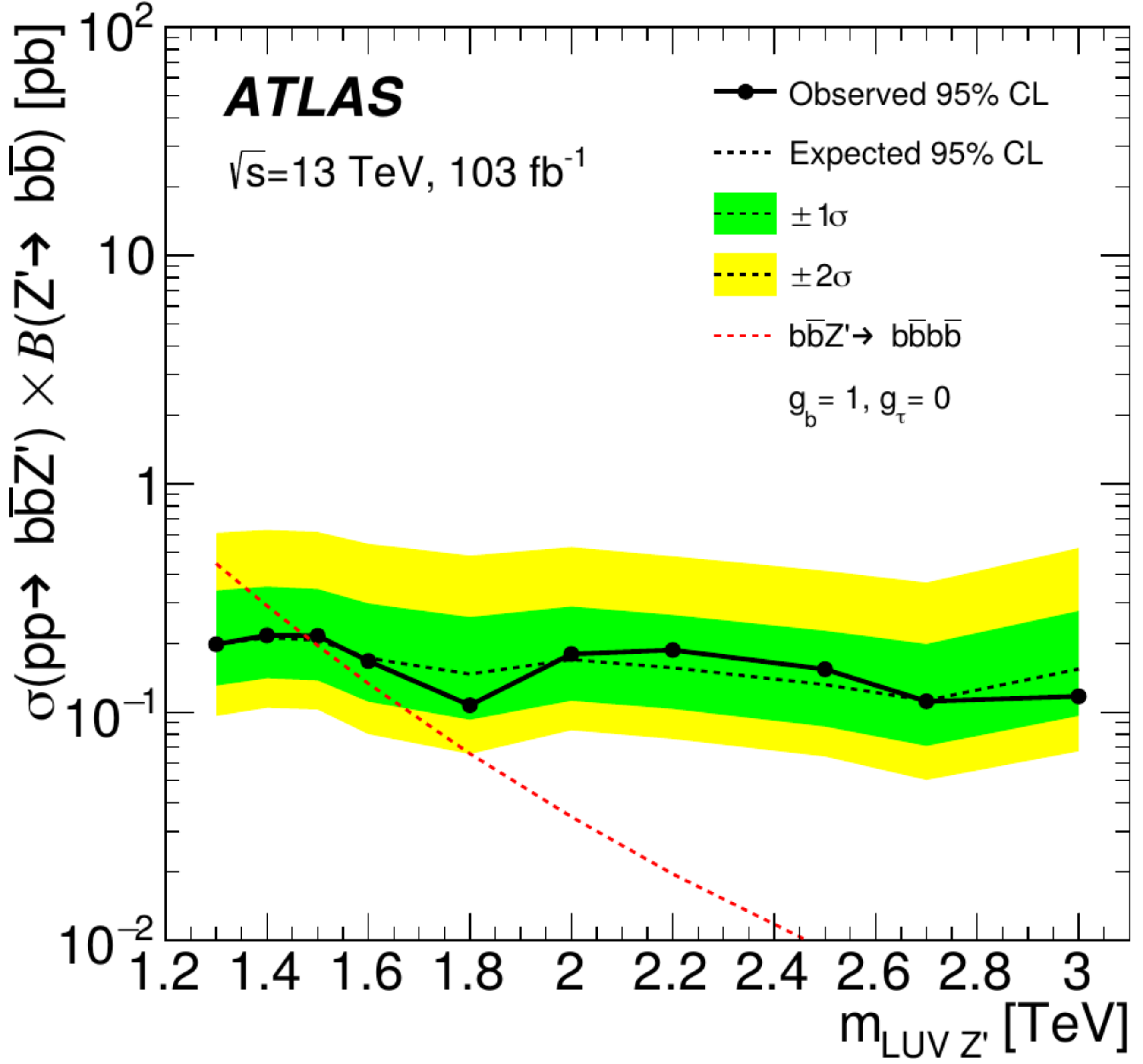
- Use **new trijet trigger with asymmetric p_T thresholds**, introduced in 2017 → use 103fb^{-1} of 2017 & 2018 ATLAS data
- Dominant background from multijet events: fully data-driven estimate
  - **Functional decomposition (FD) method :** truncated series of a sum of orthonormal basis exponential functions describe background spectrum

$$\Omega(z) = \sum_{n=1}^{N} c_n E_n(z)$$

- **Scan of reconstructed Z′(→ bb) invariant mass spectrum using Bump-Hunter**

Additional b-jets increase the sensitivity by 20-50% at a mass scale of 1.3-3 TeV



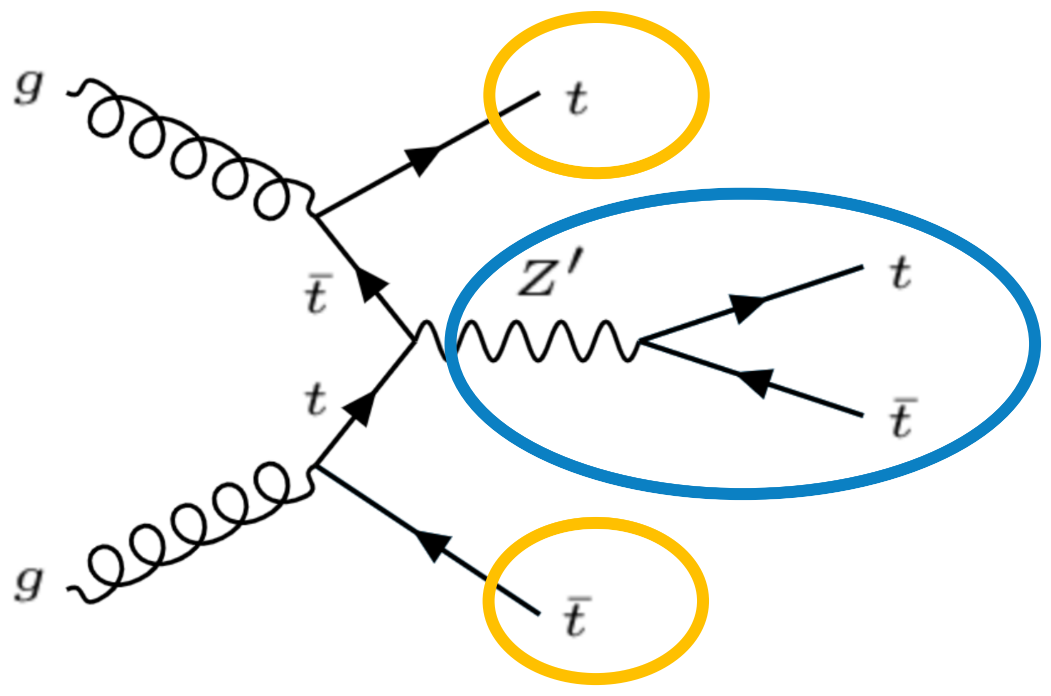


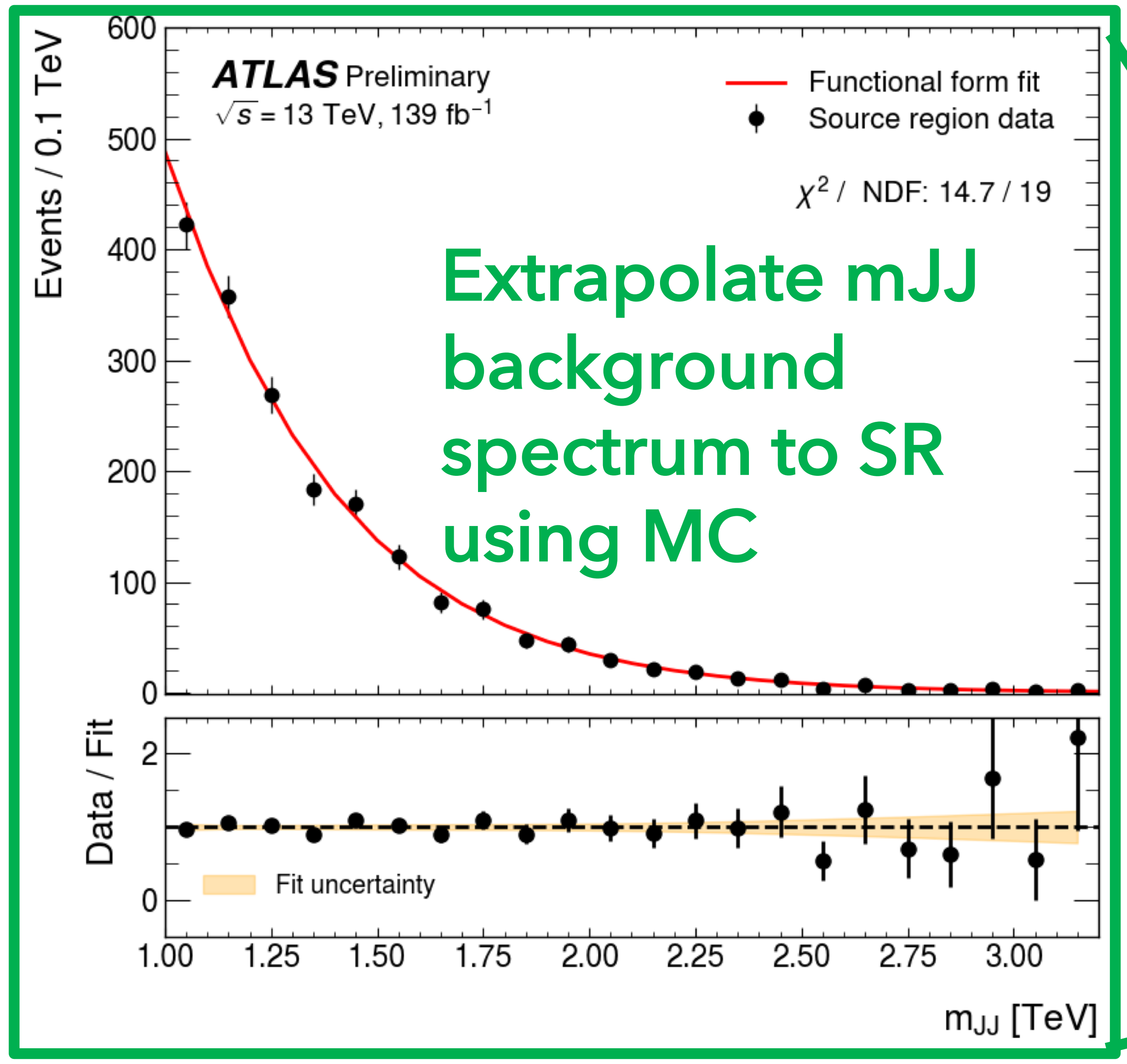
SEARCH FOR HEAVY RESONANCES IN FOUR-TOP-QUARK FINAL STATES

ATLAS-CONF-2021-048

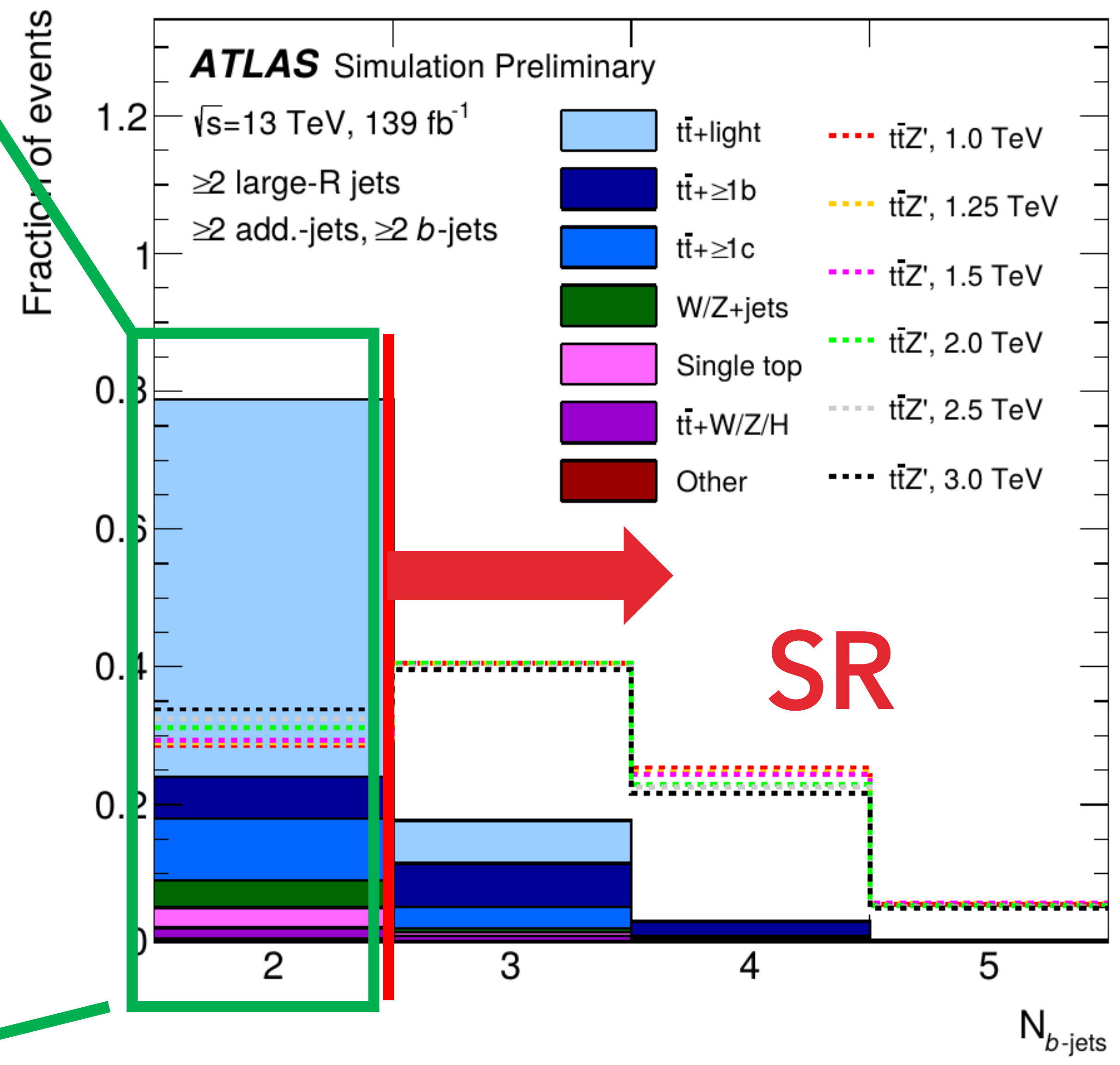
- Search for **new top-philic resonances** using the full Run 2 dataset
- Final state with **1 lepton to suppress multijet background**
- Z′ resonance reconstructed from two large-R jets from boosted top quarks
  - Cuts on p_T, mass and number of constituents to identify as top quark
- Define signal and control regions according to multiplicity of additional jets and b-jets
- **Estimate background (ttbar + jets)** by extrapolating from control regions with 2 additional jets and 2 b-jets to signal regions using MC-derived extrapolation factors

If coupling to top quark dominant, Z′ can only be produced in association with ttbar





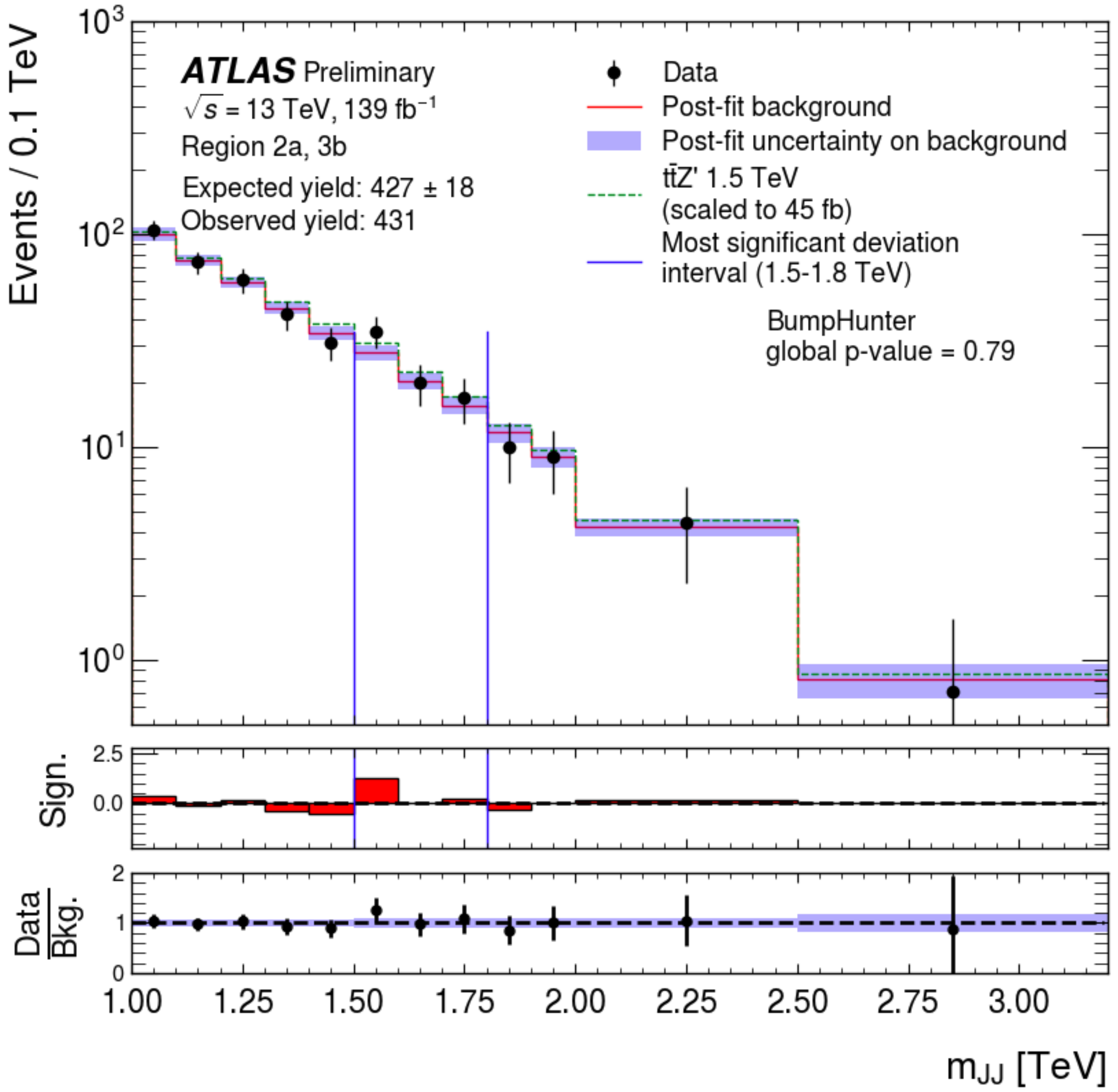
Extrapolate mJJ background spectrum to SR using MC

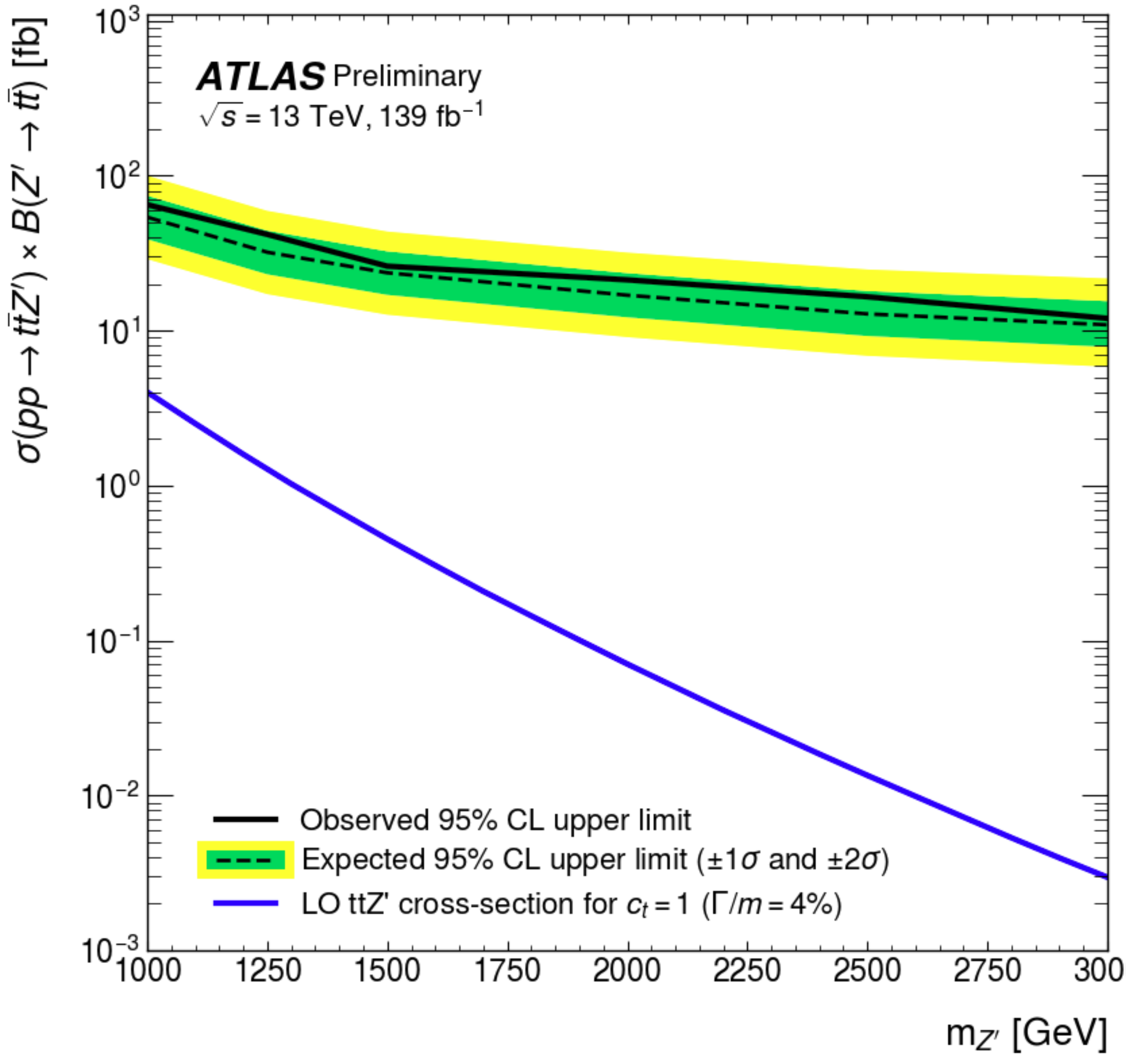


SEARCH FOR HEAVY RESONANCES IN FOUR-TOP-QUARK FINAL STATES

ATLAS-CONF-2021-048

- Profile-likelihood fit to further constrain the background
- **Scan m(tt) spectrum using Bump-Hunter and use also a model-dependent search for color-singlet top-philic Z′**
- Dominant uncertainty on ttbar background prediction at low Z′ masses, statistical uncertainties at higher mass points





SUMMARY

- Many recent searches published with **final states containing 3rd generation quarks** using all (or most) of the **ATLAS data collected during Run 2** of the LHC
- Models predicting **vector-like quarks, top resonances and heavy gauge bosons** are probed
- Improved top and b-quark identification techniques help to reject background from multijet events and to increase the sensitivity to new physics
- Nevertheless, the data is compatible with the Standard Model and no deviation has been found
- **Exclusion limits were set, good improvements have been observed w.r.t previous analyses using 2015+2016 data only**

Eagerly anticipating Run 3 data to probe further into the O(TeV) regime!

BACKUP

LIST OF PRESENTED ANALYSES

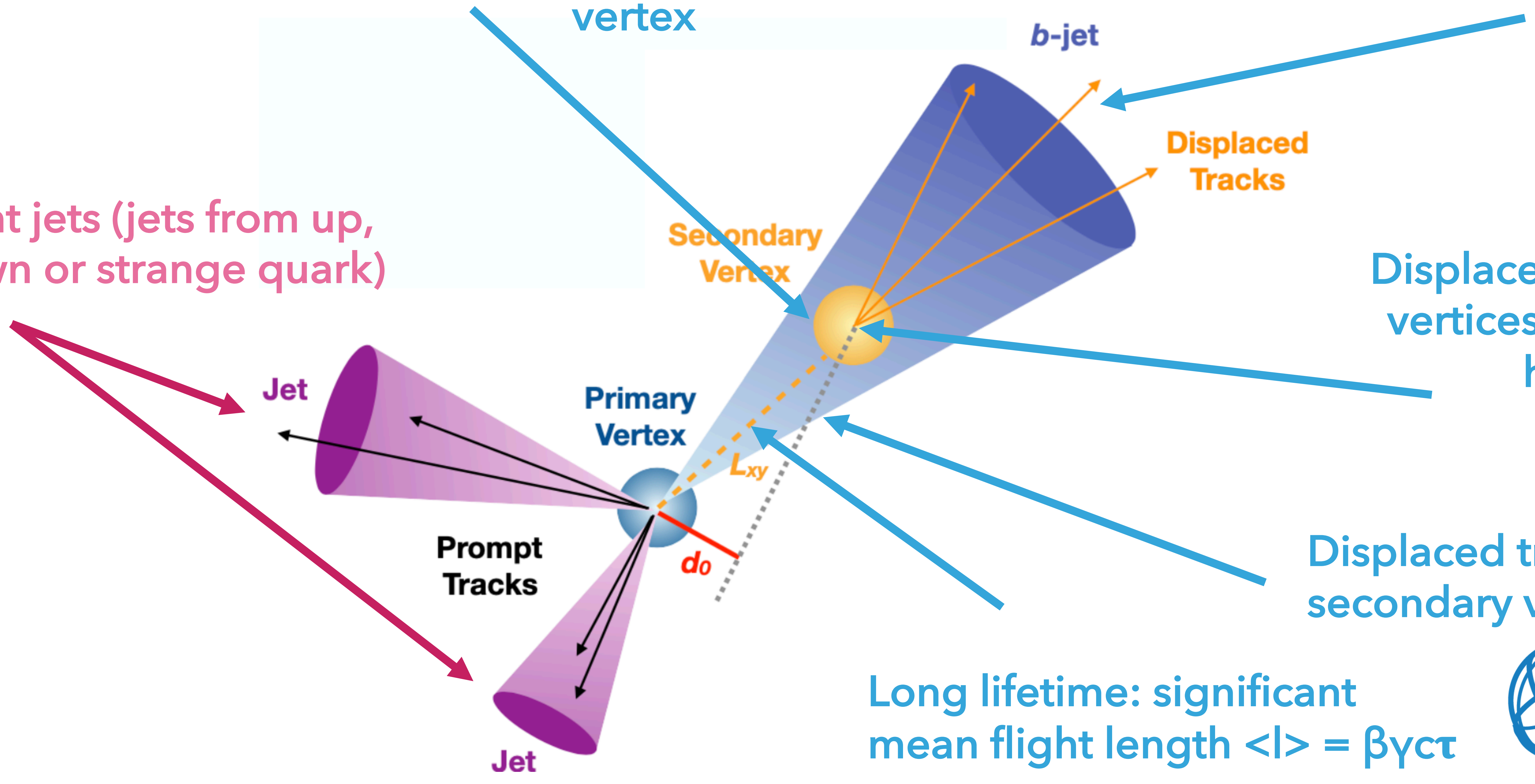
- Search for pair-production of vector-like quarks in *pp* collision events at $\sqrt{s}$ =13 TeV with at least one leptonically-decaying *Z* boson and a third-generation quark with the ATLAS detector (ATLAS-CONF-2021-024)
- Search for single production of vector-like *T* quarks decaying to *Ht* or *Zt* in *pp* collisions at $\sqrt{s}$ =13 TeV with the ATLAS detector (ATLAS-CONF-2021-040)
- Search for single Vector-Like *B* -quark production and decay via $B \rightarrow bH(bb)$ in pp collisions at $\sqrt{s}$ =13 TeV with the ATLAS detector (ATLAS-CONF-2021-018)
- Search for tt resonances in fully hadronic final states in *pp* collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector (JHEP 10 (2020) 61)
- Search for vector boson resonances decaying to a top quark and a bottom quark in hadronic final states using *pp* collisions at $\sqrt{s}$ =13 TeV with the ATLAS detector (ATLAS-CONF-2021-043)
- Search for heavy resonances in four-top-quark final states in *pp* collisions at $\sqrt{s}$=13 TeV with the ATLAS detector (ATLAS-CONF-2021-048)
- Search for heavy particles in the *b*-tagged dijet mass distribution with additional *b*-tagged jets in proton-proton collisions at $\sqrt{s}$=13 TeV with the ATLAS experiment (arXiv:2108.09059)
- Search for a vector-like quark produced in 13 TeV proton-proton collisions and decaying into a Higgs boson and top quark with a fully-hadronic final state at ATLAS (EXOT-2019-07)

DECAY OF B-HADRONS

- The distinct signature of a b-hadron decay can be used to identify jets containing b-hadrons in ATLAS
- C-hadrons also have a slightly longer lifetime and a larger mass w.r.t light jets, lower track multiplicity, lifetime and mass w.r.t b-jets

Truth flavour definition
(definition of a b-jet in simulation):

- Search for b-hadrons with pT>5GeV within ΔR<0.3 within the jet
- If no b-hadron found, search for c-hadron, then tau-lepton
- Else: classify jet as light jet



High mass of B-hadron/secondary vertex

High track multiplicity

Light jets (jets from up, down or strange quark)

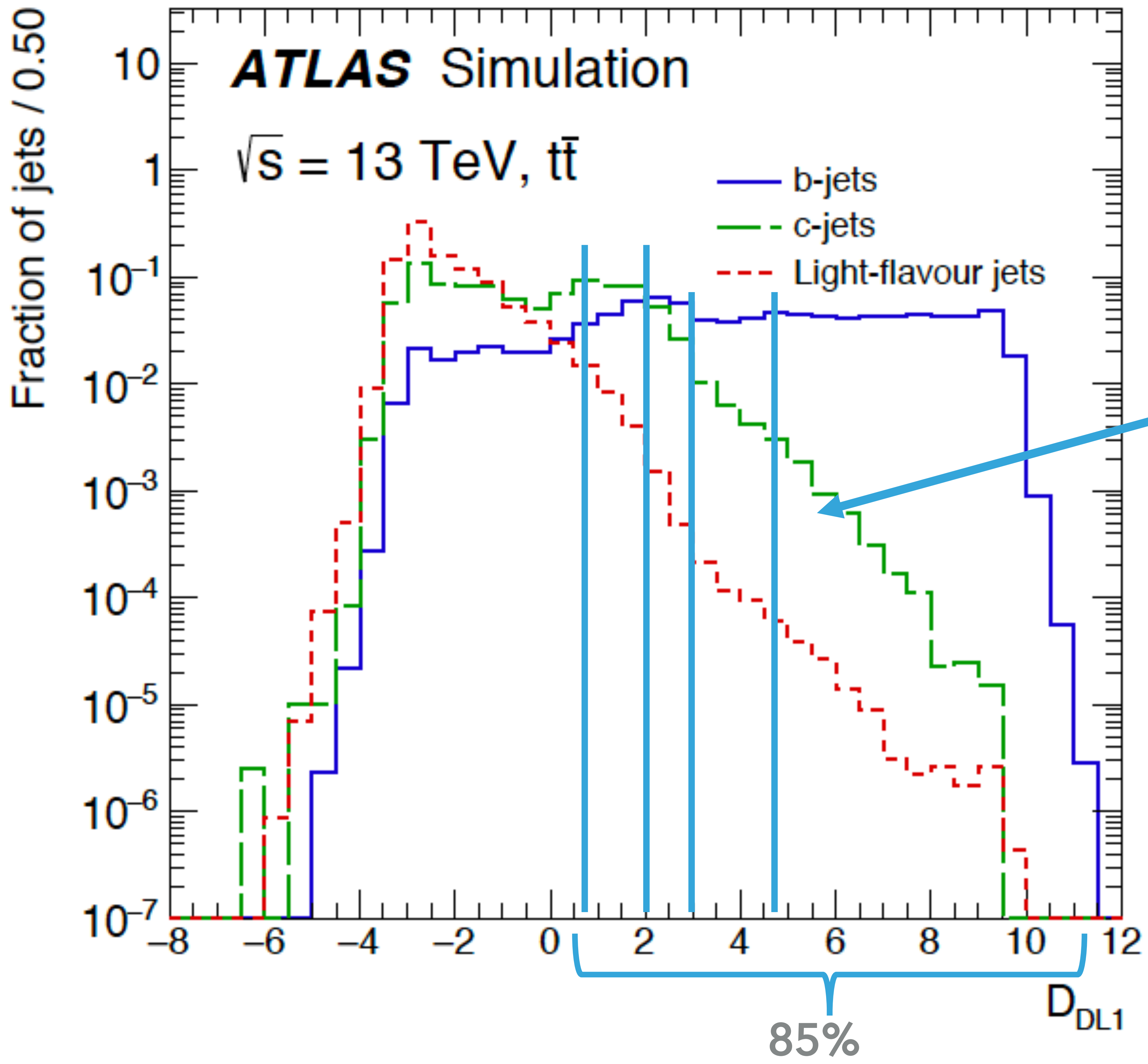
Displaced/secondary/tertiary vertices (>=1) from B (or c)-hadron decay

Displaced tracks from secondary vertices

Long lifetime: significant mean flight length <l> = βγcτ

THE OUTPUT DISCRIMINANTS

- Low-level tagger outputs are feed into Deep Fast neural network
- DNN creates output probabilities p_b, p_c, p_u
- Calculate output discriminant value: DL1 and DL1r (DL1r includes RNNIP)

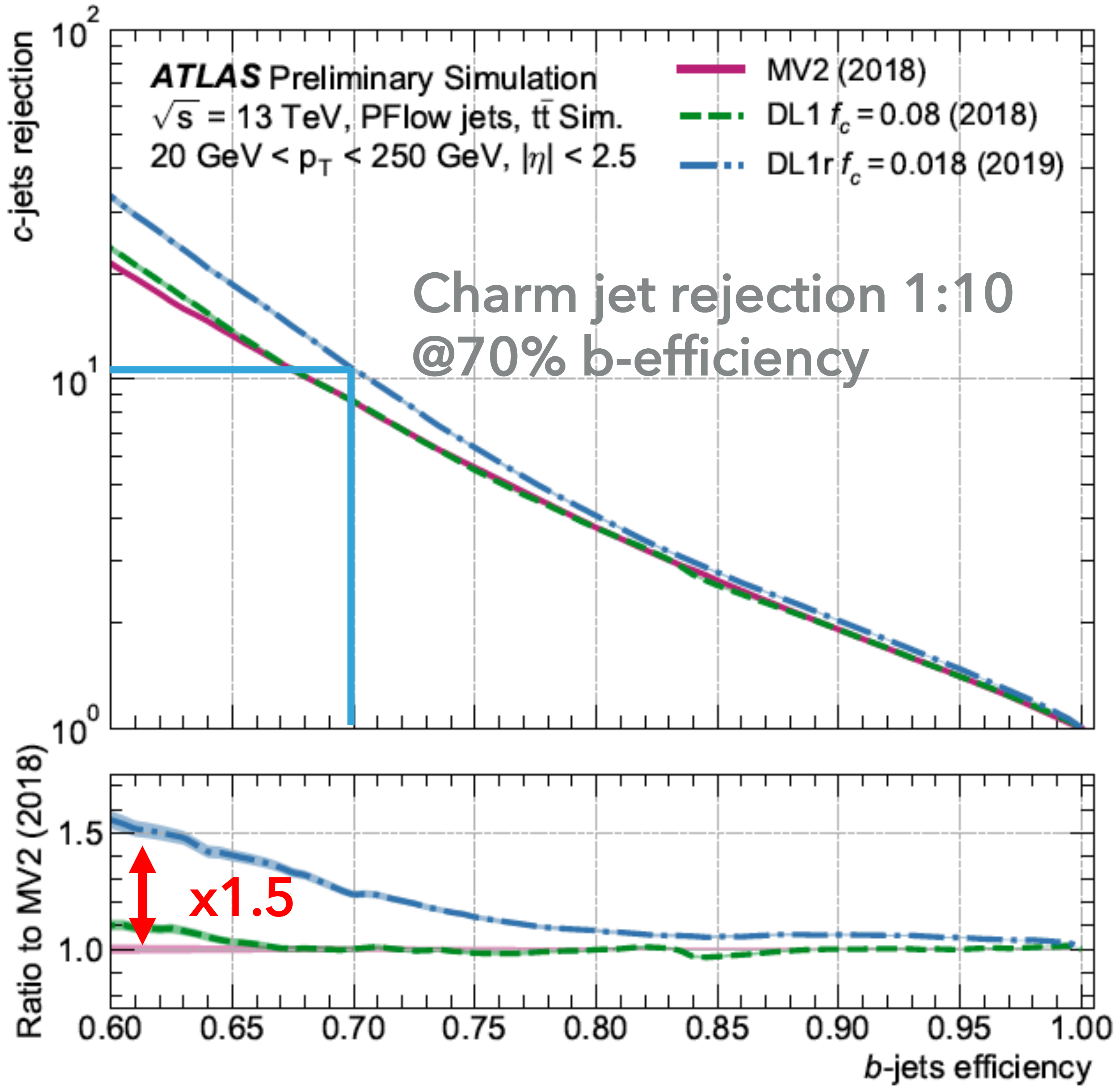


Define **single-cut operating points** corresponding to an average b-tagging efficiency (in ttbar MC)

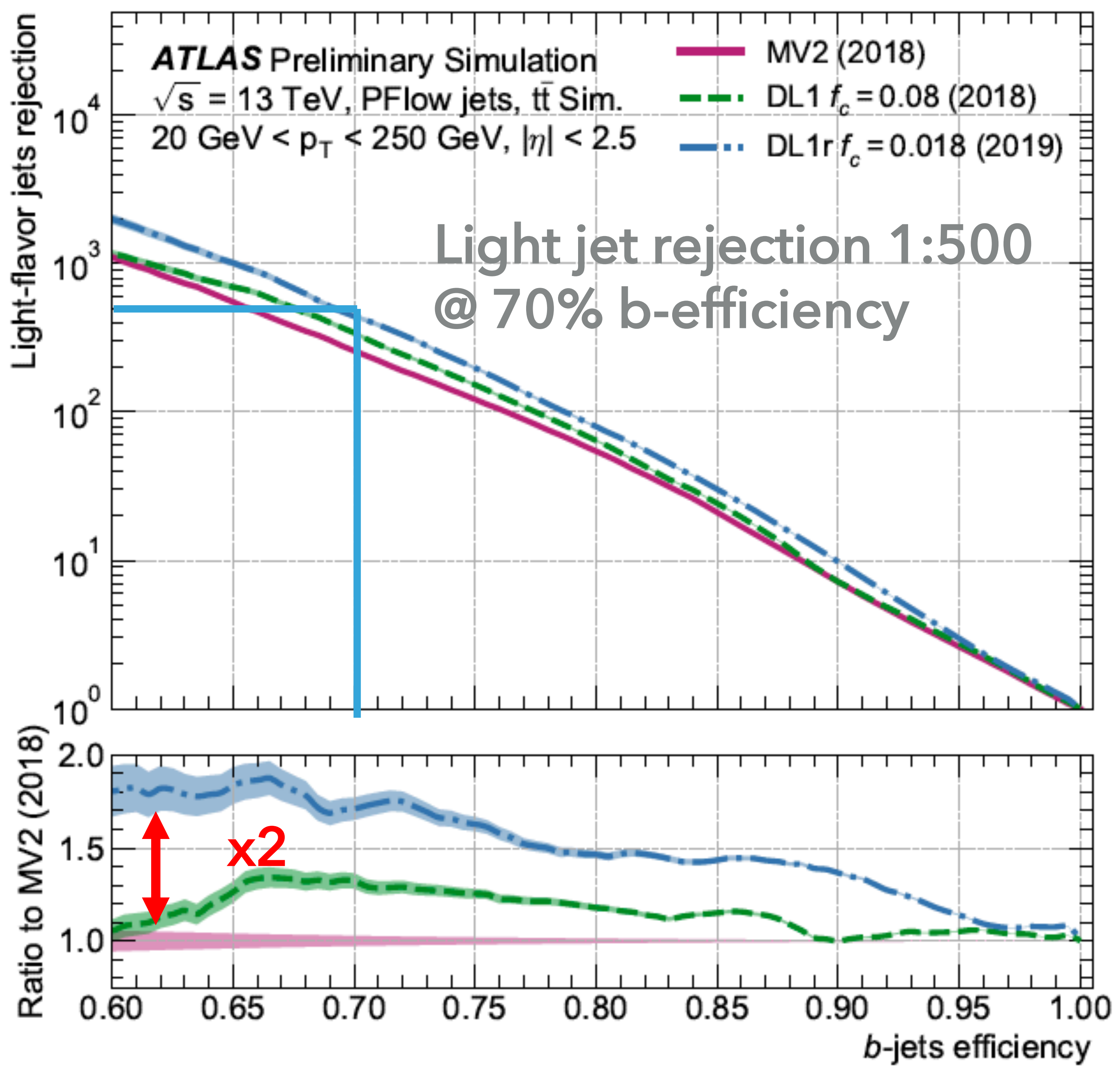
- 85%, 77%, 70%, 60%

$$\boxed{D_{\mathrm{DL1(r)}} = \ln\left(\frac{p_b}{f_c \cdot p_c + (1 - f_c) \cdot p_{\mathrm{light}}}\right)}$$

TAGGER PERFORMANCE: PFLOW JETS

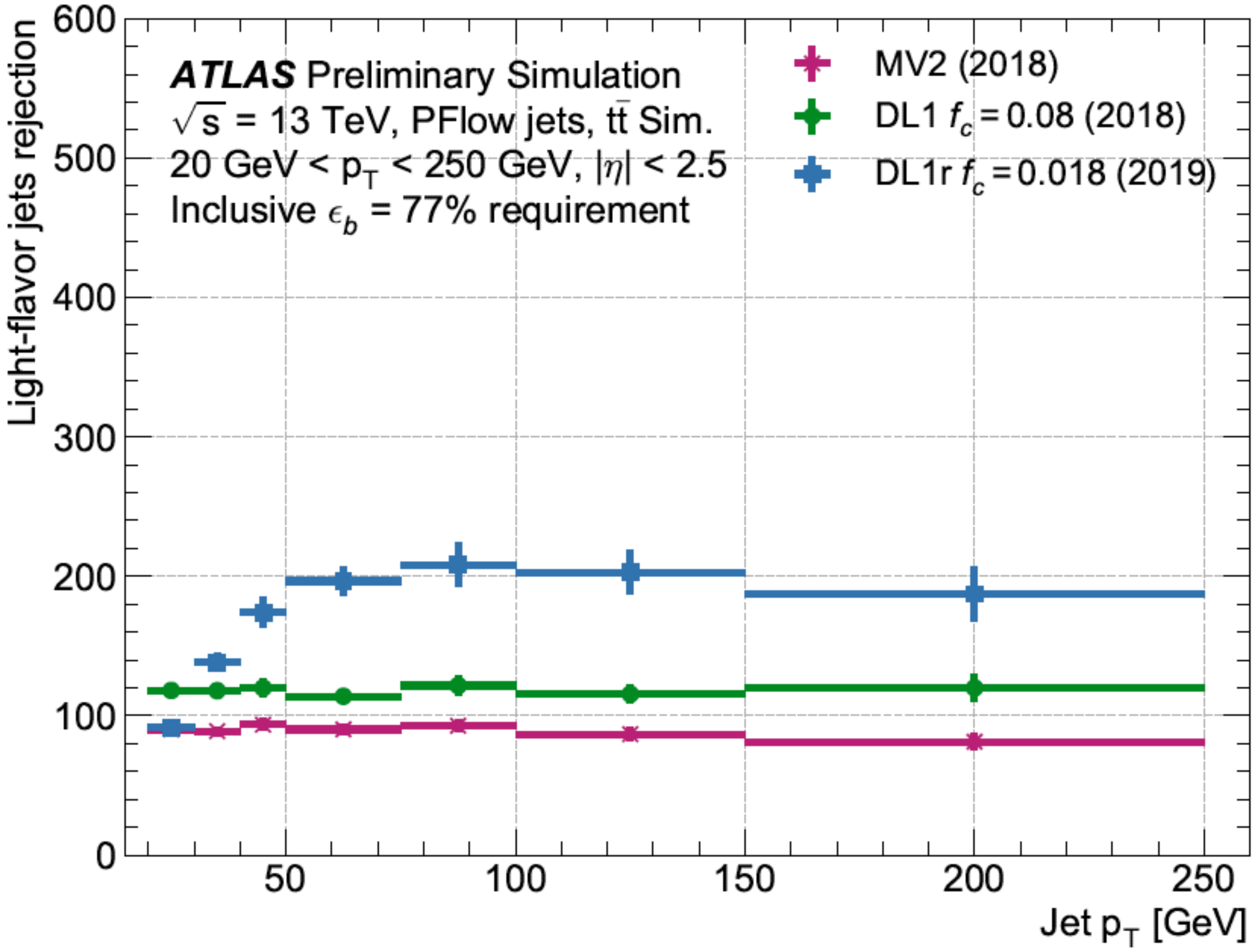


Charm jet rejection 1:10 @70% b-efficiency



Light jet rejection 1:500 @ 70% b-efficiency

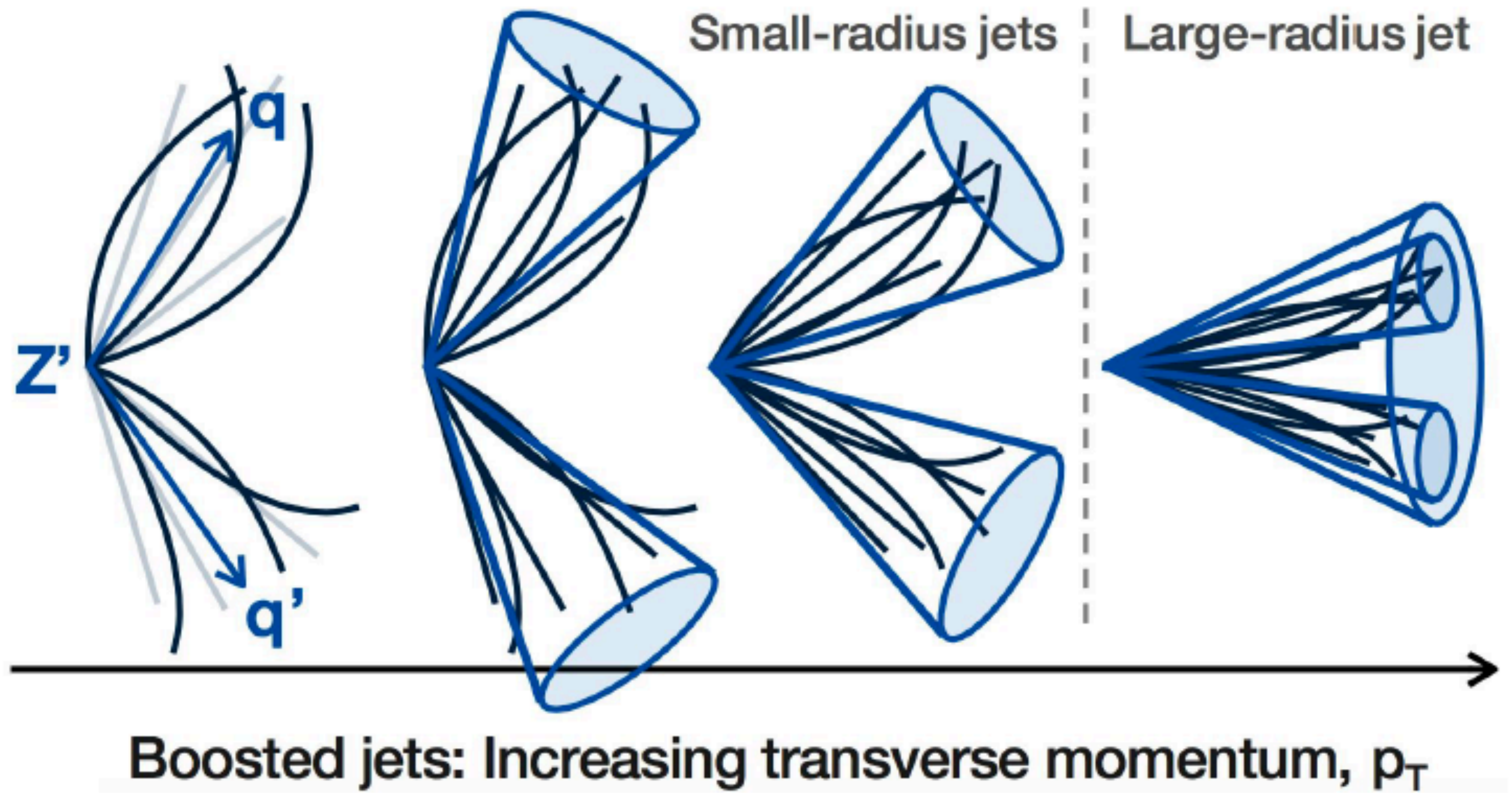
Light jet rejection for fixed-cut b-efficiency of 77%



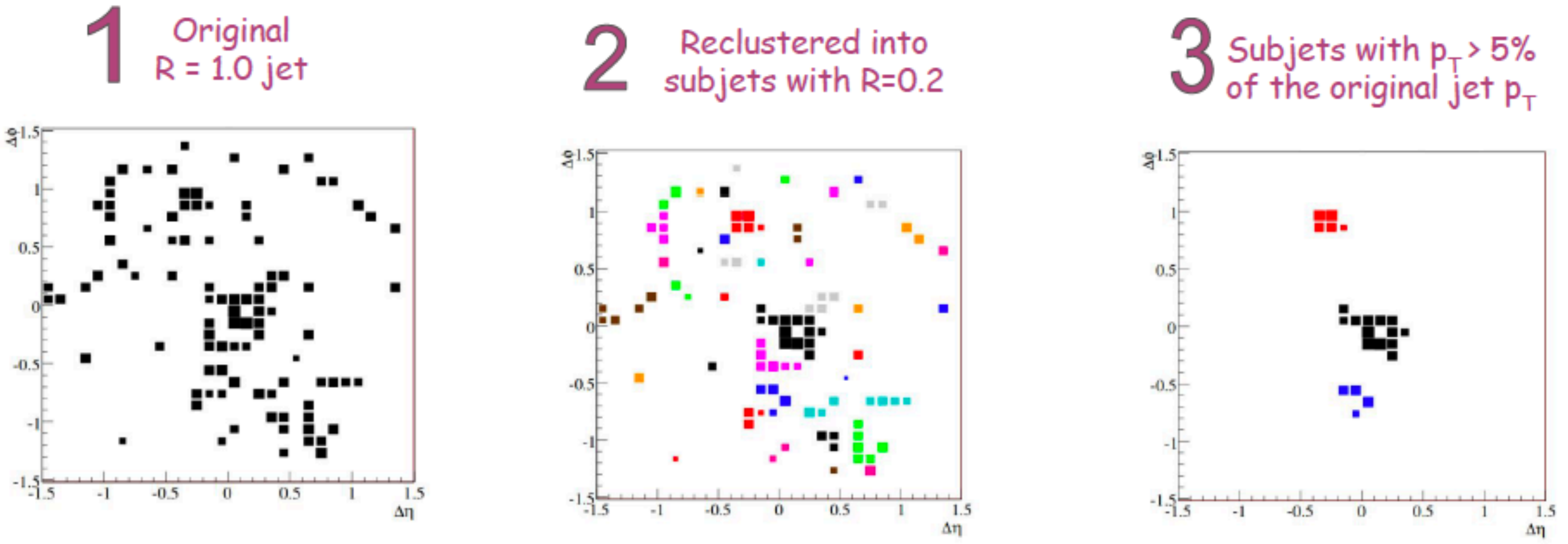
- Improvements by up to a factor of 2 with recent improvements: inclusion of RNNIP and use of Deep Neural network instead of boosted decision trees (MV2)
- B-tagging efficiency and light and charm rejection pT-dependent

JET RECONSTRUCTION: LARGE-RADIUS ("LARGE-R") JETS

- For a two-body decay, distance ΔR between the decay production is given by: $\Delta R \approx 2m/p_{\mathrm{T}}$
- Decay products from particles with high pT are expected to be merged in a single large-radius jet
- Reconstruct jets with a (fixed) radius of R=1.0
- Apply "grooming" for pile-up mitigation



Boosted jets: Increasing transverse momentum, p_T



1 Original R = 1.0 jet

2 Reclustered into subjets with R=0.2

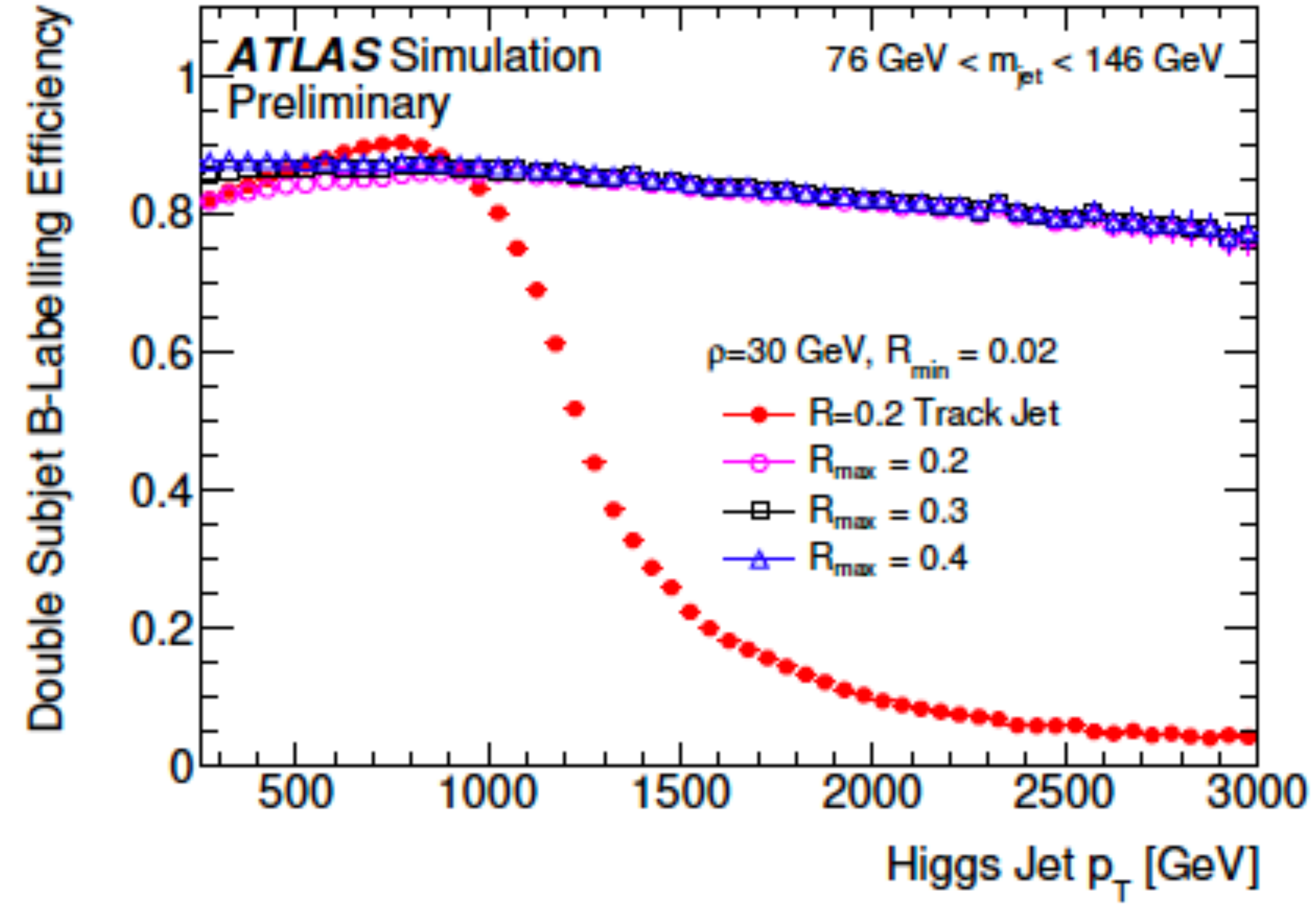
3 Subjets with p_T > 5% of the original jet p_T

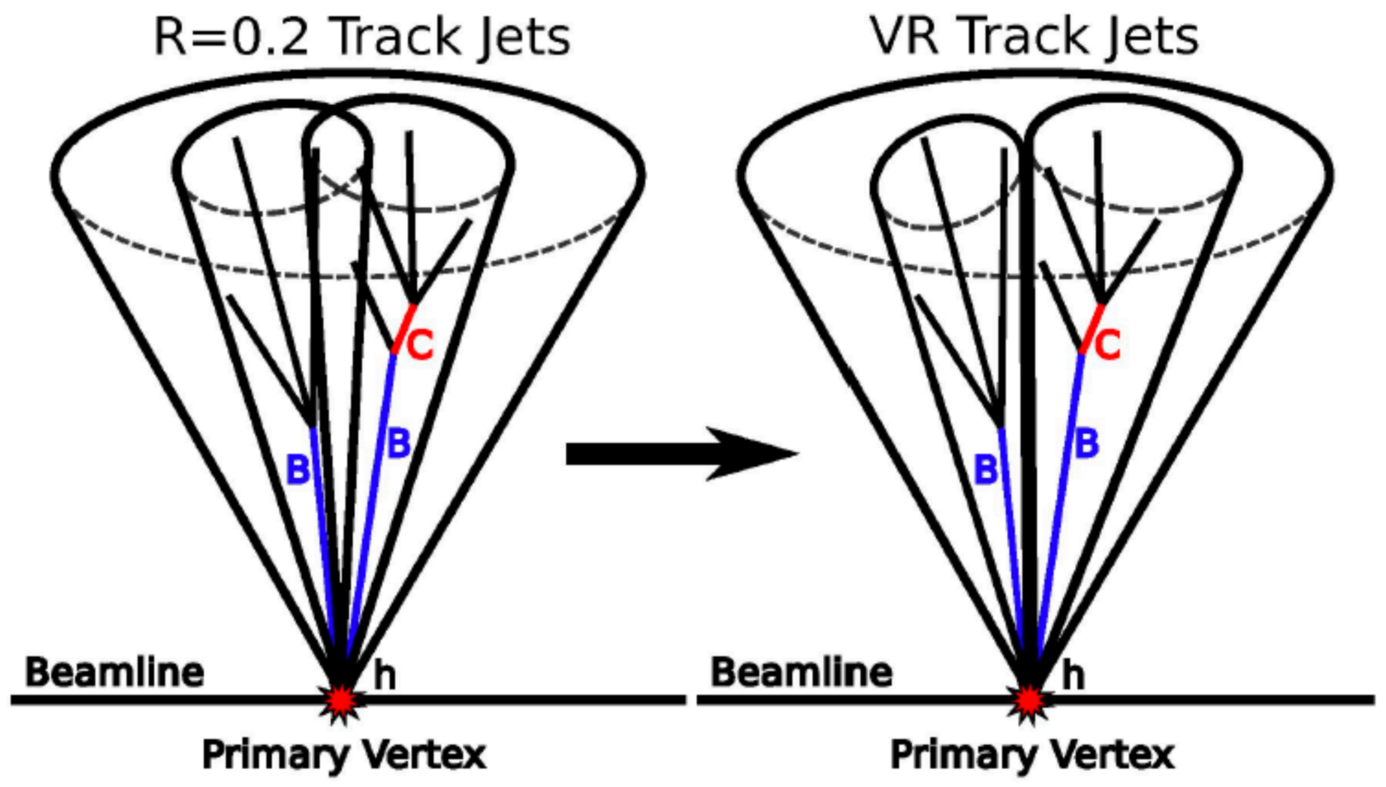
- Calibration: Simulation based jet pT, eta and jet mass correction, and data-driven in-situ correction using reference objects

JET RECONSTRUCTION: VARIABLE RADIUS JETS (VRTRACK)

- At high pT, (sub)jets are collimated → cannot be resolved any more as separate jets with fixed-cone jet algorithm
- New jet collection in ATLAS to resolve the decay products of H->bb decay
  - Identify them as b-jets via b-tagging algorithm
- Jets have variable size which goes with R ~ 1/pT(jet)
  - Defined by three parameters: ρ (dimensionless constant), R_{min}=0.02 (minimal size) and R_{max}=0.4 (maximal size)
    - Optimized to resolve b-hadrons in H->bb decay
- Use only tracks for reconstruction, good angular and momentum resolution
- Note: b-tagging algorithm with dedicated training for VRTrack jets available

$$R \longrightarrow R_{\mathrm{eff}}(p_{\mathrm{T}}) = \frac{\rho}{p_{\mathrm{T}}}$$



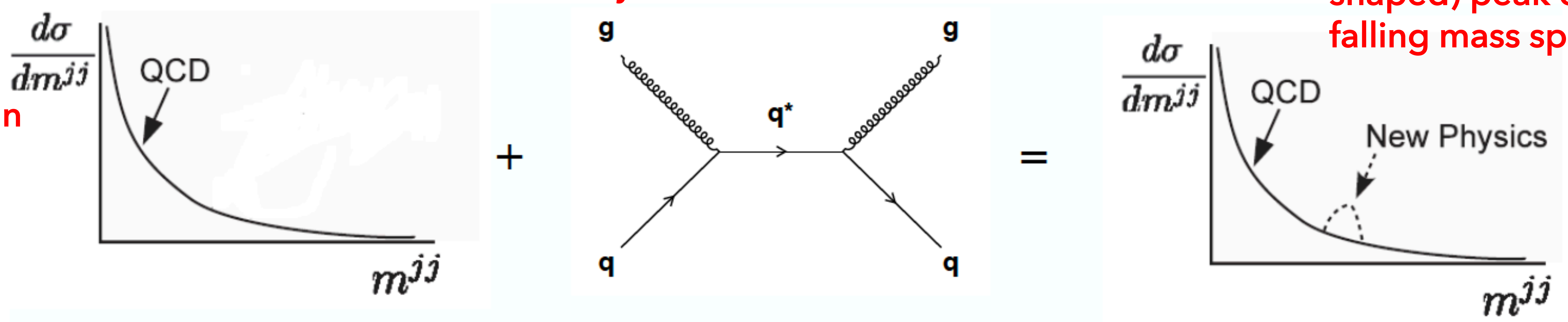


DIJET RESONANCE SEARCH (ARXIV:1910.08447)

- Search for high-mass resonance coupling to quark and/or gluons
  - Heavy gauge bosons (Z′ ->bb), Kaluza-Klein Graviton G->bb, excited quarks b*(->qb)
  - Decay to two high-energetic hadronic jets

New heavy resonance with mass M

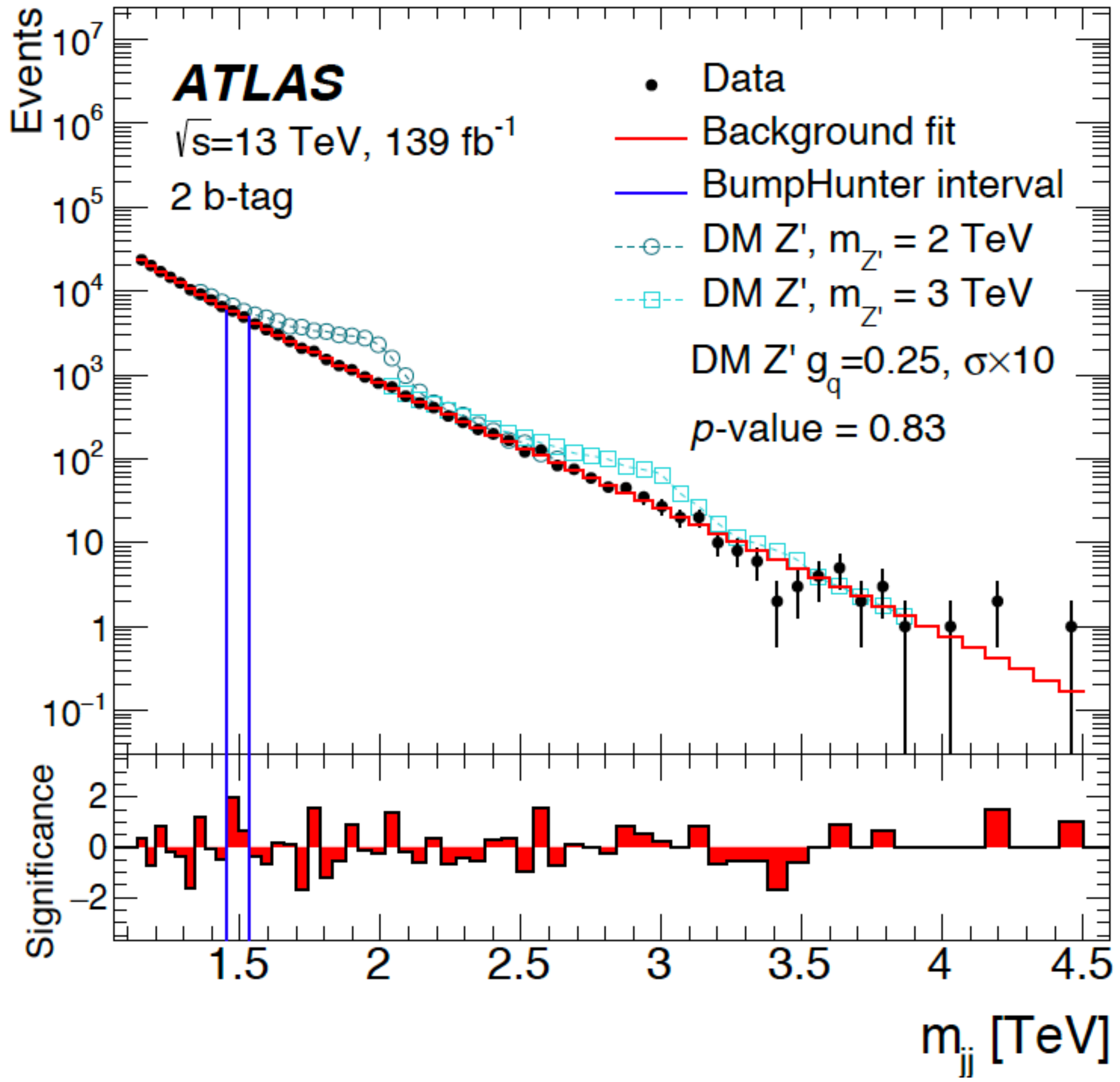
Invariant di-jet mass spectrum produced in QCD processes: smoothly falling with m(jj)

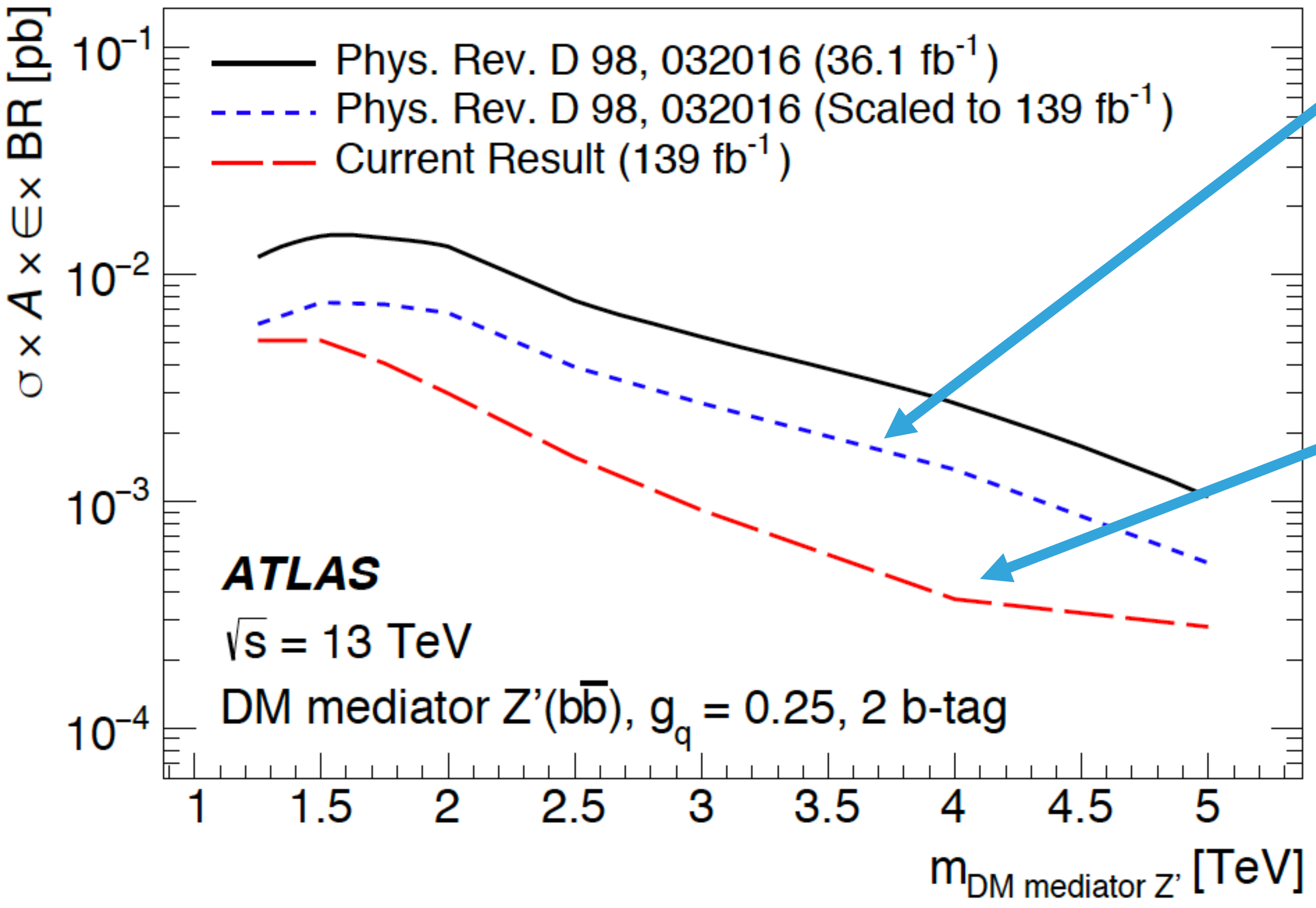


New physics as (Gaussian-shaped) peak on smoothly falling mass spectrum

- Inclusive search and with >=1 or ==2 b-tagged jets
- Search performed on full Run2 ATLAS data
- First ATLAS analysis using new DL1r tagger
- **Flagship measurement for high-pT jet b-tagging**

DIJET RESONANCE SEARCH: RESULTS





Previous analysis (data15+16) scaled to 139fb-1 luminosity

New limits with improved calibration & new DL1r b-tagger

- Scan curve in continuous mass interval using a sliding-window fit
- No significant deviation from the Standard Model background
- Better limits observed in 2b-category w.r.t previous analysis
  - Increased high-pT efficiency for new DL1r tagger (due to dedicated high-pT training)
  - Lower systematic uncertainties of high-pT calibration (extrapolated calibration)

SEARCH FOR TTBAR RESONANCES IN THE FULLY HADRONIC FINAL STATE

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- Resonant ttbar production predicted by many models
  - Topcolor-assisted-technicolor model (TC2) is used as a benchmark model
  - Model-independent search using Bump-Hunter to search for a localized excess in the m(tt) spectrum
- Selection of **two high-p_T large-R jets**, kinematic cuts ensure multijet event suppression and back-to-back topology
- Analysis regions for **signal extraction and derivation of background functional representation** classified according to:
  - DNN Top-tag of leading and sub-leading large-R jet
  - b-tagged VRTrack jet assigned to 0/1/2 large-R jets
  - **2 top-tags and 1 or 2 associated b-tags characterize signal region**
- Parameterize smoothly falling background spectrum using an analytic function

Improvements on cross section limit w.r.t analysis on 2015+2016 data by 65% at 4 TeV