Searches for Resonances Decaying to Quarks using the ATLAS Detector

DIS 2019, Torino, 10.04.2019

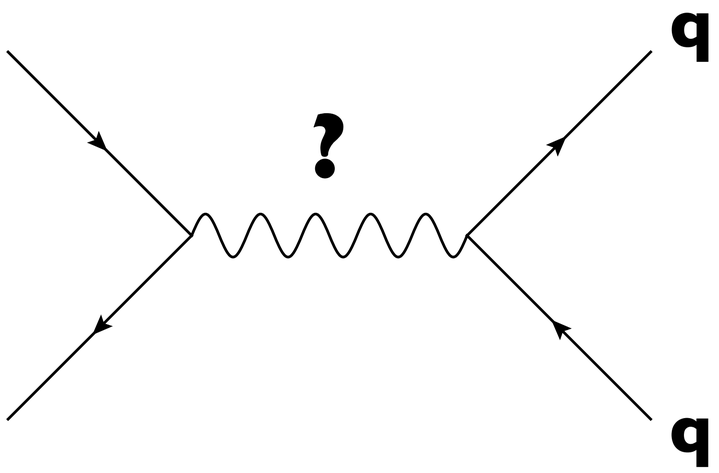
Johannes Erdmann
TU Dortmund University

on behalf of the ATLAS Collaboration

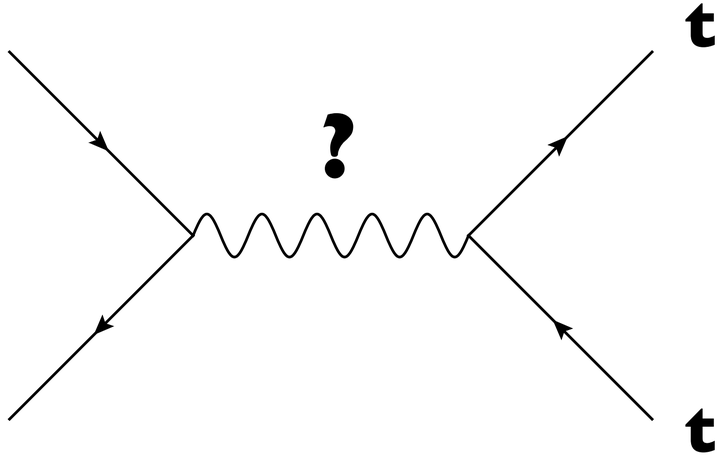
GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung
FSP 103 ATLAS
ATLAS EXPERIMENT

Outline of this talk

Dijet

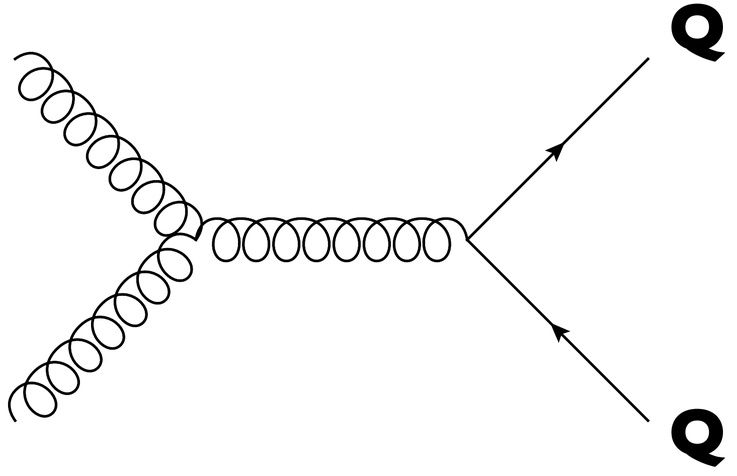


Top-antitop



$t \rightarrow qq'b$

Vector-like quarks



$Q \rightarrow Zq$

$Q \rightarrow Hq$

$Q \rightarrow Wq'$

What is the …

- … solution to the naturalness problem?
- … origin of dark matter?
- … origin of the fermion mass hierarchy?
- …

Outline of this talk

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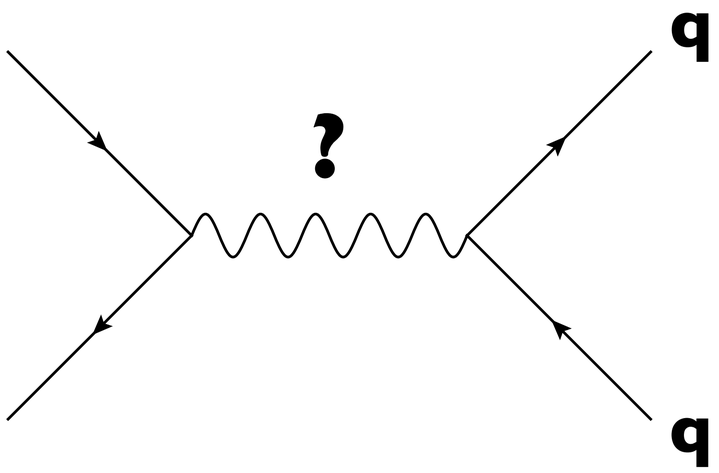

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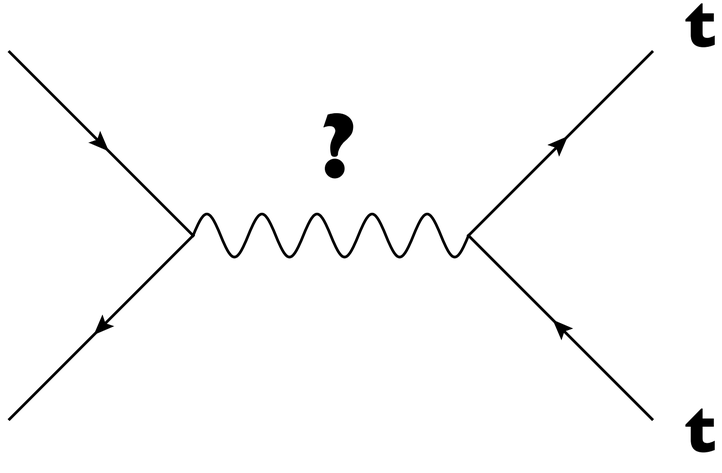

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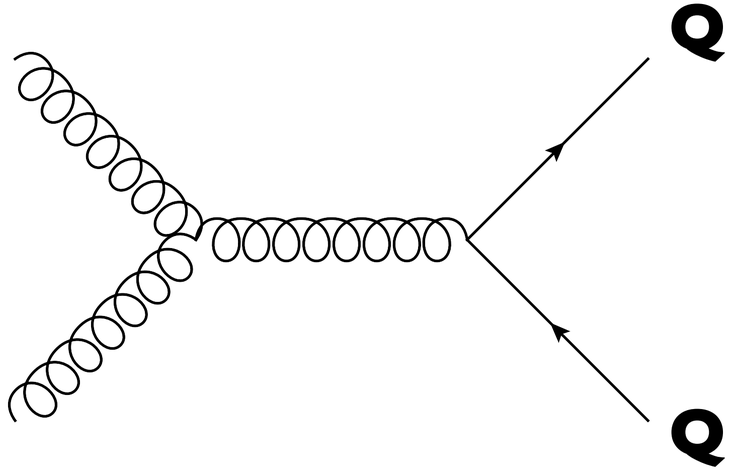

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- Warped extra dimensions
- Simplified DM models
- Composite Higgs models
- …

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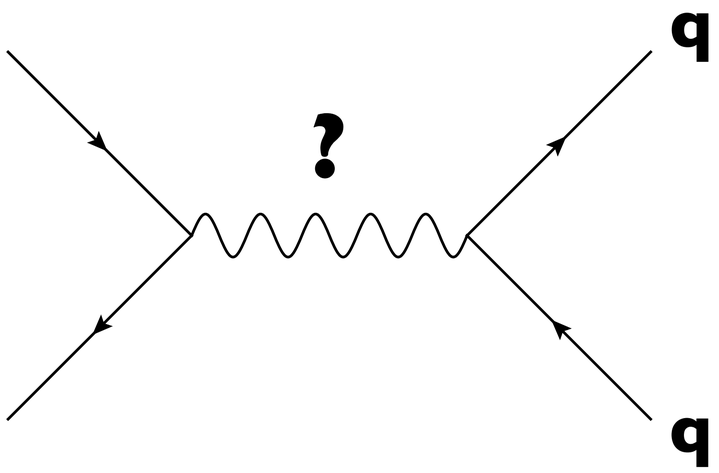

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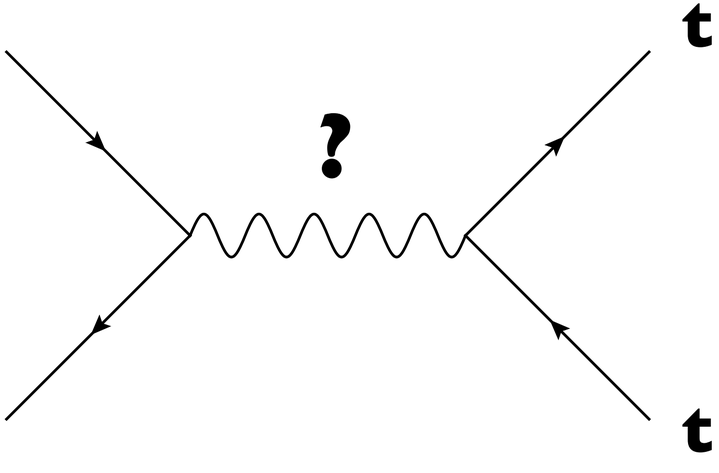

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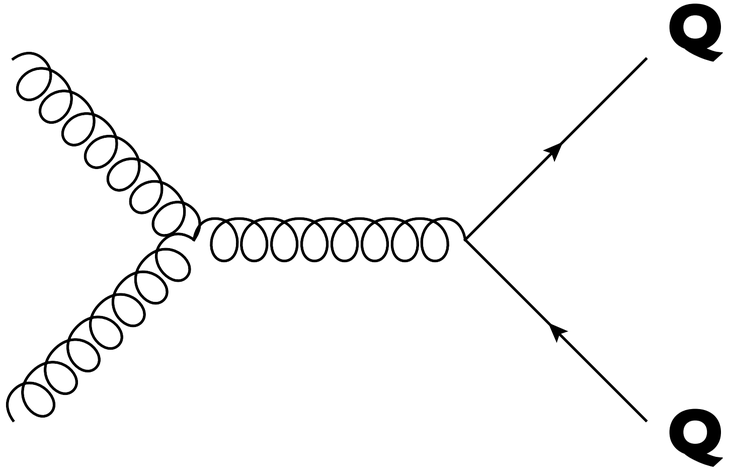
Vector-like quarks



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- Simplified DM models
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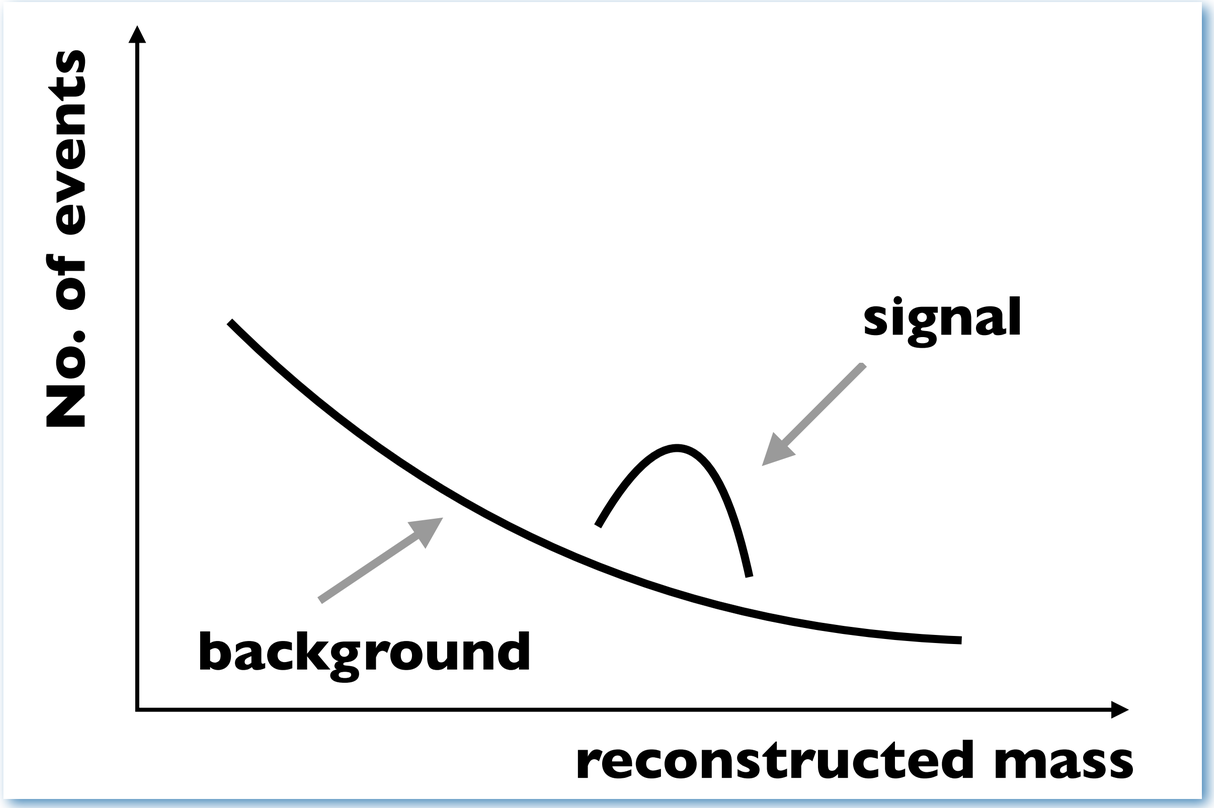
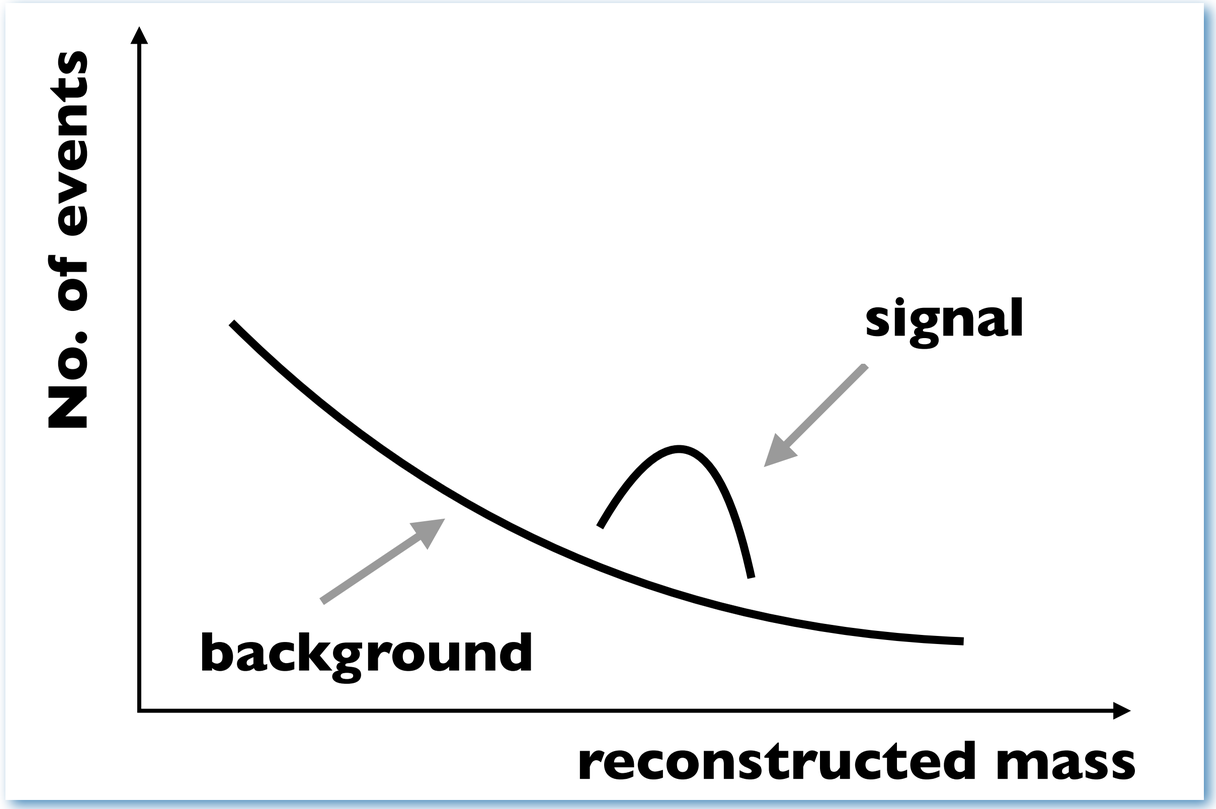
- …

- Dijet
- Top-antitop
- Vector-like quarks

Background-estimate strategies



Background-estimate strategies

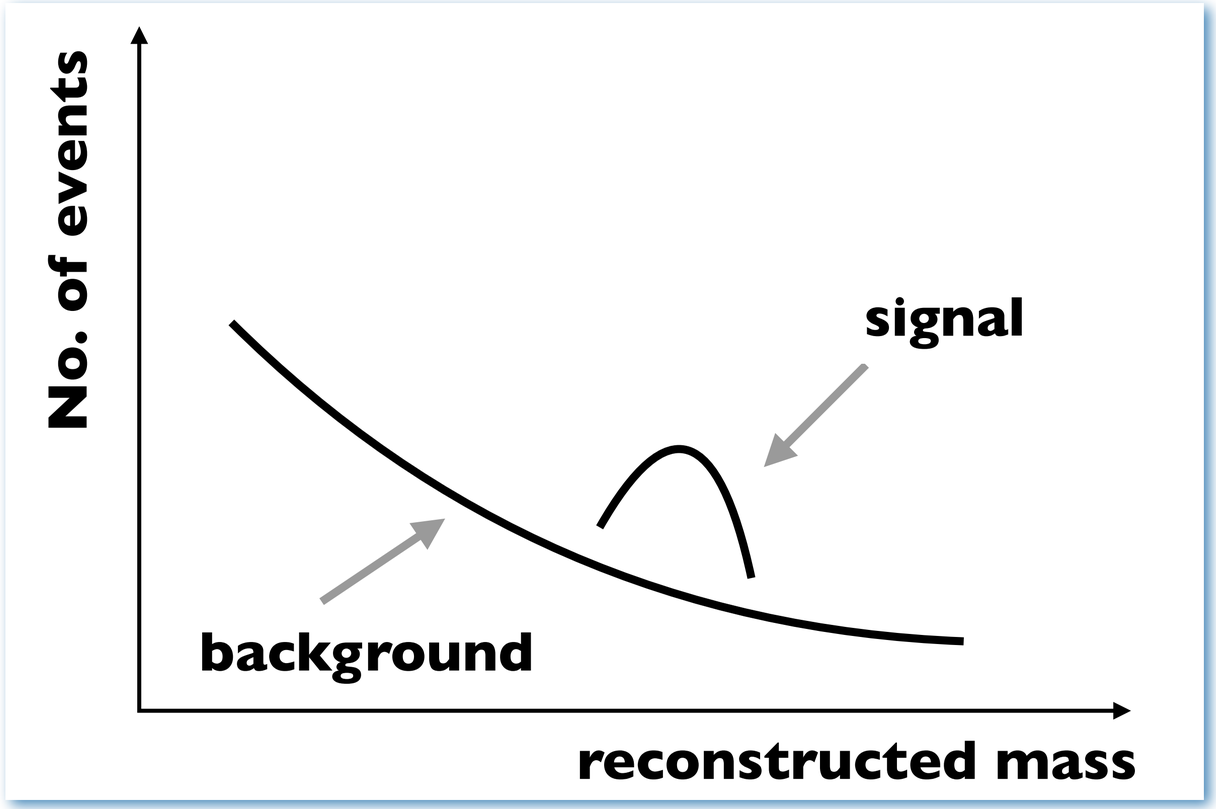


$t\bar{t}$ / EW

↓

MC

Background-estimate strategies



$t\bar{t}$ / EW

MC

Multijet production

Strong suppression?

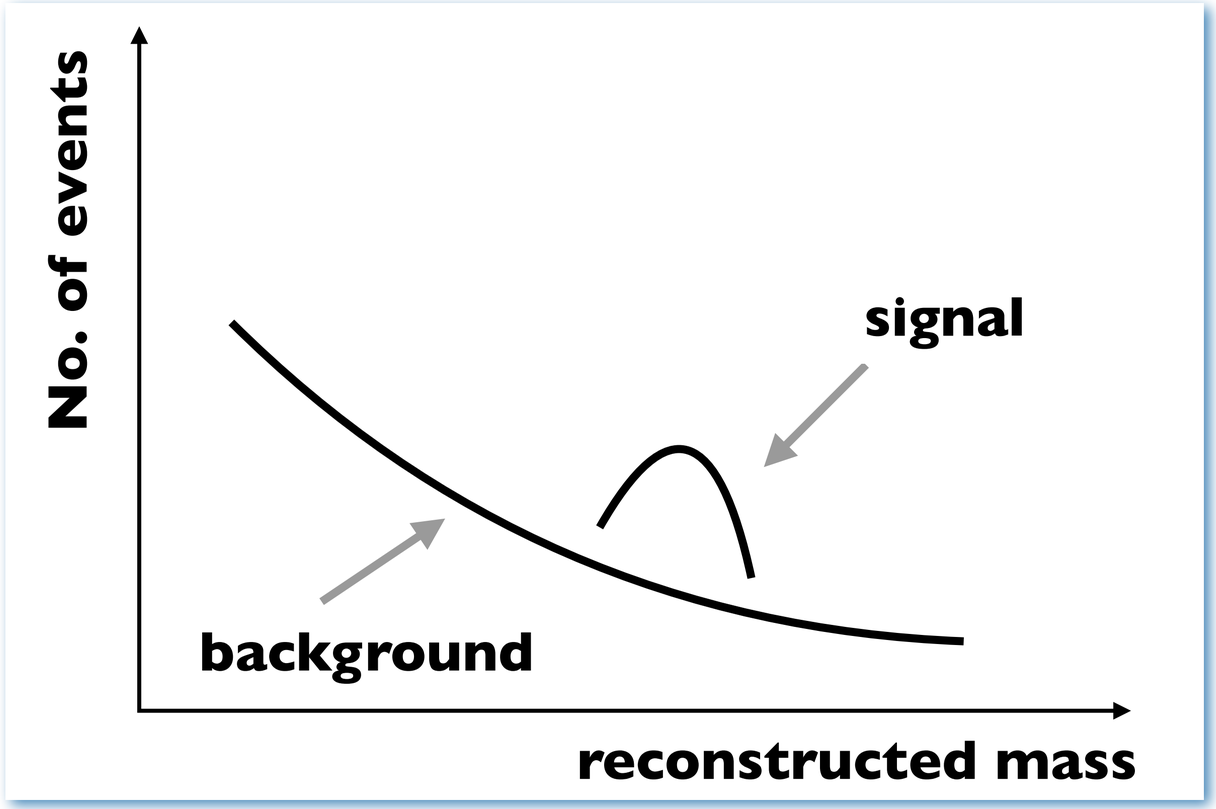
yes

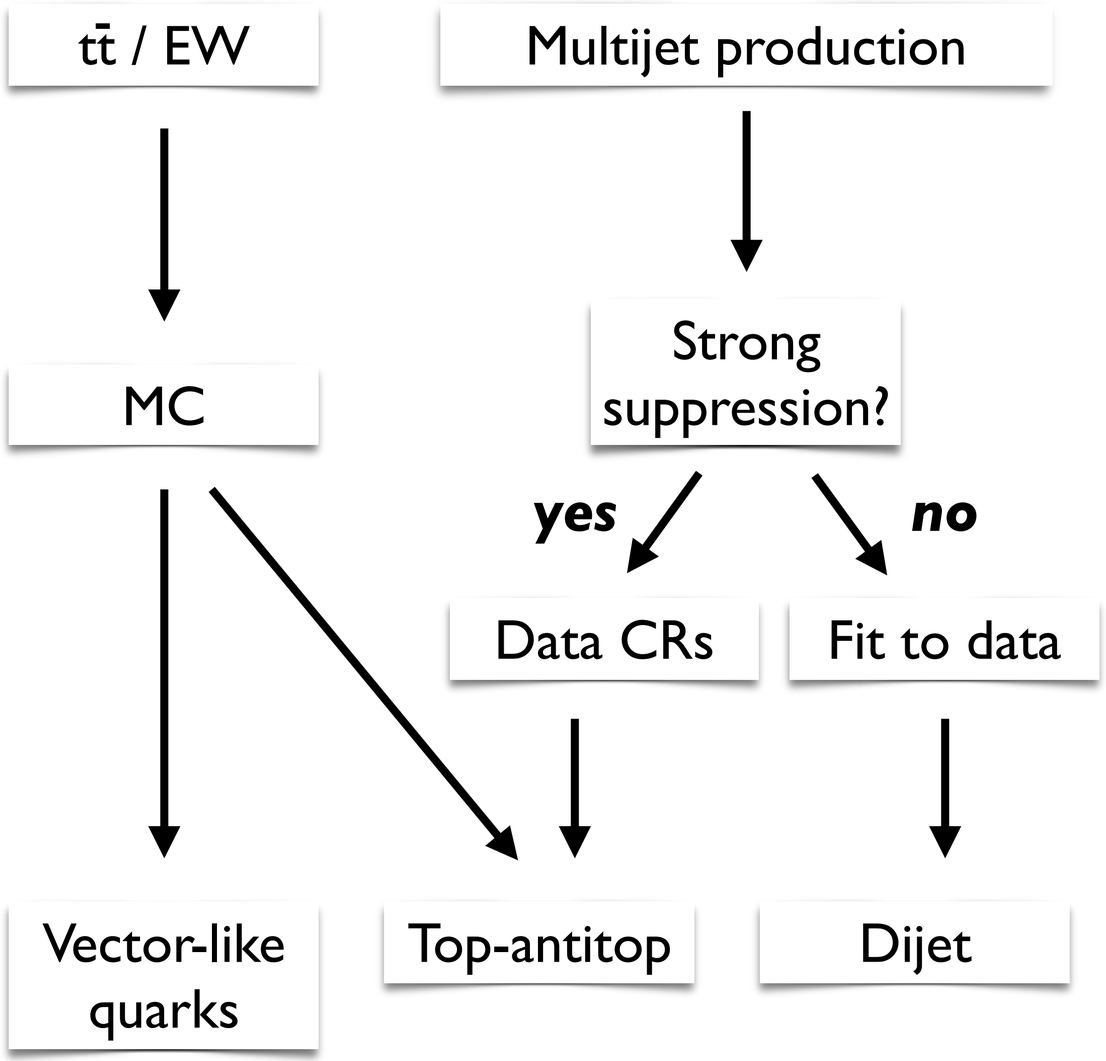
no

Data CRs

Fit to data

Background-estimate strategies





Trigger strategies

Excerpt from 2017 trigger menu

Trigger	**Typical offline selection**	**Trigger Selection**		**Level-1 Peak Rate (kHz)**	**HLT Peak Rate (Hz)**
		Level-1 (GeV)	HLT (GeV)	$L = 1.7 \times 10^{34}$ cm^{-2}s^{-1}	
Single leptons	Single isolated μ, $p_{\mathrm{T}} > 27$ GeV	20	26 (i)	16	187
	Single isolated tight e, $p_{\mathrm{T}} > 27$ GeV	22 (i)	26 (i)	26	178
	Single μ, $p_{\mathrm{T}} > 52$ GeV	20	50	16	65
	Single e, $p_{\mathrm{T}} > 61$ GeV	22 (i)	60	26	17
	Single τ, $p_{\mathrm{T}} > 170$ GeV	100	160	1.2	49
Two leptons	Two μ's, each $p_{\mathrm{T}} > 15$ GeV	2×10	2×14	2.0	30
	Two μ's, $p_{\mathrm{T}} > 23, 9$ GeV	20	22, 8	16	42
	Two very loose e's, each $p_{\mathrm{T}} > 18$ GeV	2×15 (i)	2×17	1.6	11
	One e & one μ, $p_{\mathrm{T}} > 8, 25$ GeV	20 (μ)	7, 24	16	5
	One e & one μ, $p_{\mathrm{T}} > 18, 15$ GeV	15, 10	17, 14	2.0	4
	One e & one μ, $p_{\mathrm{T}} > 27, 9$ GeV	22 (e, i)	26, 8	26	2
	Two τ's, $p_{\mathrm{T}} > 40, 30$ GeV	20 (i), 12 (i) (+jets, topo)	35, 25	5.1	59
	One τ & one isolated μ, $p_{\mathrm{T}} > 30, 15$ GeV	12 (i), 10 (+jets)	25, 14 (i)	2.1	9
	One τ & one isolated e, $p_{\mathrm{T}} > 30, 18$ GeV	12 (i), 15 (i) (+jets)	25, 17 (i)	3.9	16
Three leptons	Three loose e's, $p_{\mathrm{T}} > 25, 13, 13$ GeV	20, 2×10	24, 2×12	1.2	< 0.1
	Three μ's, each $p_{\mathrm{T}} > 7$ GeV	3×6	3×6	0.2	8
	Three μ's, $p_{\mathrm{T}} > 21, 2 \times 5$ GeV	20	20, 2×4	16	8
	Two μ's & one loose e, $p_{\mathrm{T}} > 2 \times 11, 13$ GeV	2×10 (μ's)	$2 \times 10, 12$	2.0	0.3
	Two loose e's & one μ, $p_{\mathrm{T}} > 2 \times 13, 11$ GeV	$2 \times 8, 10$	$2 \times 12, 10$	1.6	0.2
One photon	One loose γ, $p_{\mathrm{T}} > 145$ GeV	22 (i)	140	26	46
Two photons	Two loose γ's, $p_{\mathrm{T}} > 55, 55$ GeV	2×20	50, 50	2.4	6
	Two medium γ's, $p_{\mathrm{T}} > 40, 30$ GeV	2×20	35, 25	2.4	18
	Two tight γ's, $p_{\mathrm{T}} > 25, 25$ GeV	2×15 (i)	2×20 (i)	2.4	15
Single jet	Jet ($R = 0.4$), $p_{\mathrm{T}} > 435$ GeV	100	420	3.4	33
	Jet ($R = 1.0$), $p_{\mathrm{T}} > 480$ GeV	100	460	3.4	24
$E_{\mathrm{T}}^{\mathrm{miss}}$	$E_{\mathrm{T}}^{\mathrm{miss}} > 200$ GeV	50	110	4.4	100
Multi-jets	Four jets, each $p_{\mathrm{T}} > 125$ GeV	3×50	4×115	0.5	16
	Five jets, each $p_{\mathrm{T}} > 95$ GeV	4×15	5×85	4.9	10
	Six jets, each $p_{\mathrm{T}} > 80$ GeV	4×15	6×70	4.9	4
	Six jets, each $p_{\mathrm{T}} > 60$ GeV, $\lvert\eta\rvert < 2.0$	4×15	6×55, $\lvert\eta\rvert < 2.4$	4.9	15
b−jets	One b ($\epsilon = 40\%$), $p_{\mathrm{T}} > 235$ GeV	100	225	3.4	15
	Two b's ($\epsilon = 60\%$), $p_{\mathrm{T}} > 185, 70$ GeV	100	175, 60	3.4	12
	One b ($\epsilon = 40\%$) & three jets, each $p_{\mathrm{T}} > 85$ GeV	4×15	4×75	4.9	15
	Two b's ($\epsilon = 70\%$) & one jet, $p_{\mathrm{T}} > 65, 65, 160$ GeV	$2 \times 30, 85$	$2 \times 55, 150$	2.7	15
	Two b's ($\epsilon = 60\%$) & two jets, each $p_{\mathrm{T}} > 45$ GeV	4×15	4×35	4.9	13
B-Physics	Two μ's, $p_{\mathrm{T}} > 11, 6$ GeV	11, 6	11, 6 (di-μ)	3.1	50
	Two μ's, $p_{\mathrm{T}} > 6, 6$ GeV, $2.5 < \mathrm{m}(\mu, \mu) < 4.0$ GeV	2×6 (J/ψ, topo)	2×6 (J/ψ)	1.8	59
	Two μ's, $p_{\mathrm{T}} > 6, 6$ GeV, $4.7 < \mathrm{m}(\mu, \mu) < 5.9$ GeV	2×6 (B, topo)	2×6 (B)	1.8	7
	Two μ's, $p_{\mathrm{T}} > 6, 6$ GeV, $7 < \mathrm{m}(\mu, \mu) < 12$ GeV	2×6 (Υ, topo)	2×6 (Υ)	1.5	10
Total Rate				85	1550

twiki.cern.ch/twiki/bin/view/AtlasPublic/TriggerPublicResults

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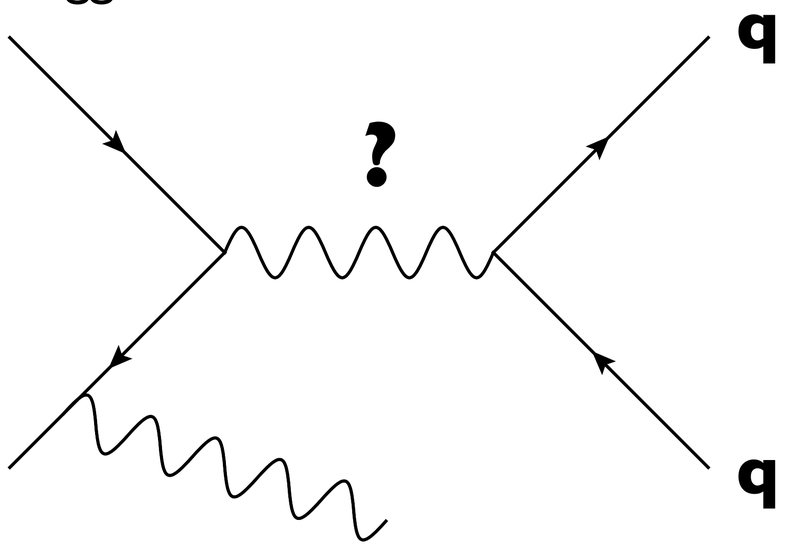
- Low-mass resonances:
  - "Trigger-level analysis" or
  - Trigger on ISR:



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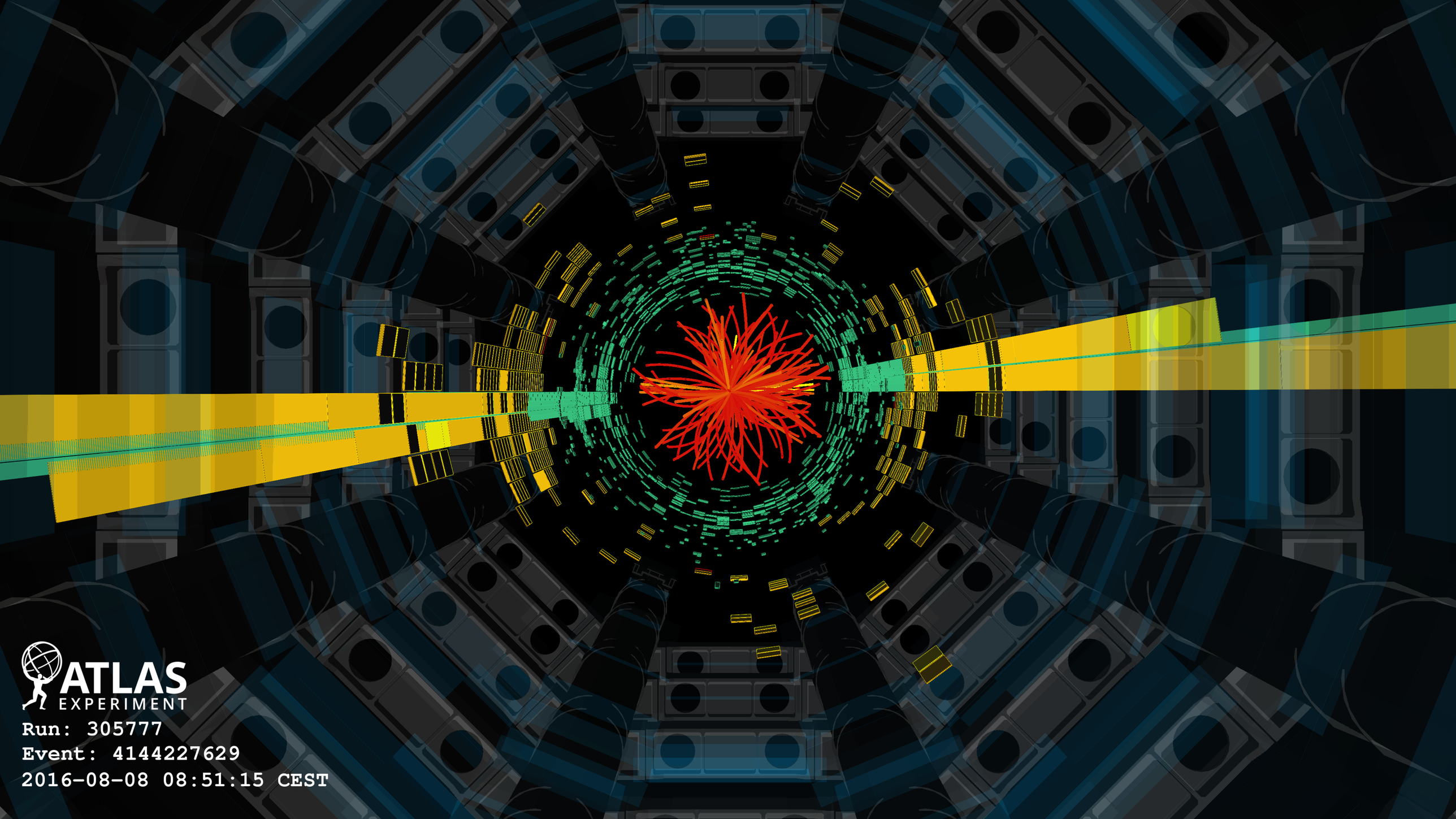
ATLAS
EXPERIMENT
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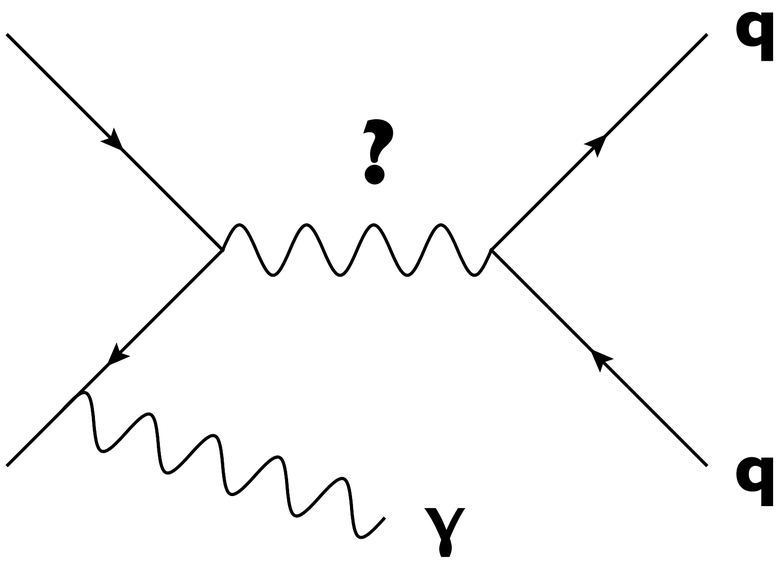
Event: 4144227629
2016-08-08 08:51:15 CEST

Dijet resonances at low mass

arXiv:1901.10917

January '19



Single-γ or γ+jet trigger

- better at high mass

  (lower γ-p_T^{min})
- worse for low mass

  (higher jet-p_T^{min})

Dijet resonances at low mass

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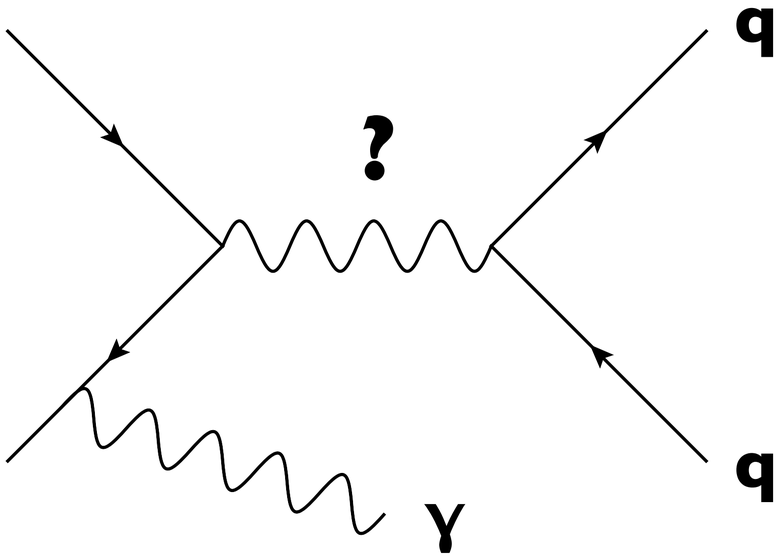
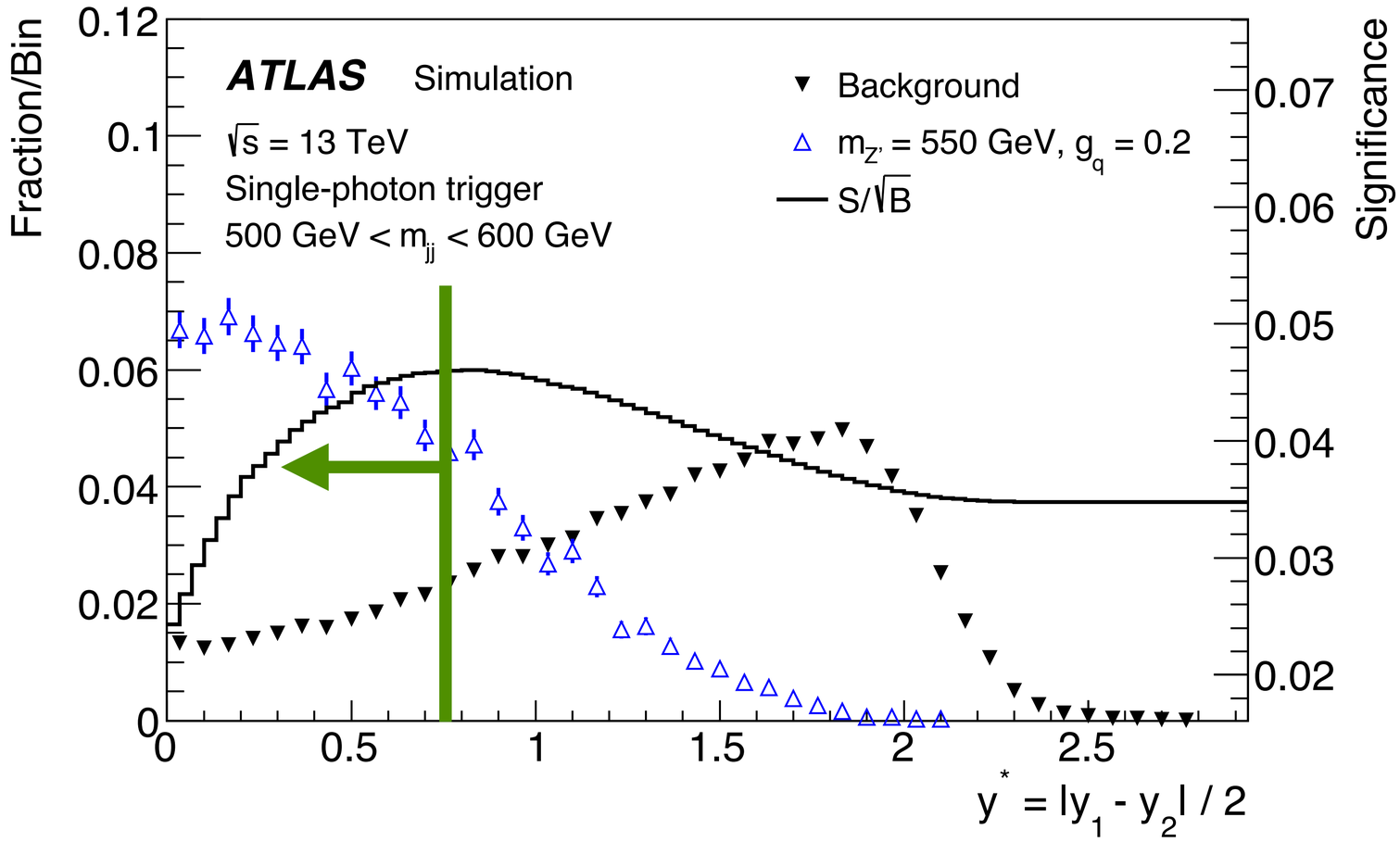


- Flavor-inclusive and 2-b-tag selections
- SM dijet (t-channel) suppressed by y* < 0.75



Single-γ or γ+jet trigger

- better at high mass (lower γ-p_T^{min})
- worse for low mass (higher jet-p_T^{min})

Dijet resonances at low mass

arXiv:1901.10917
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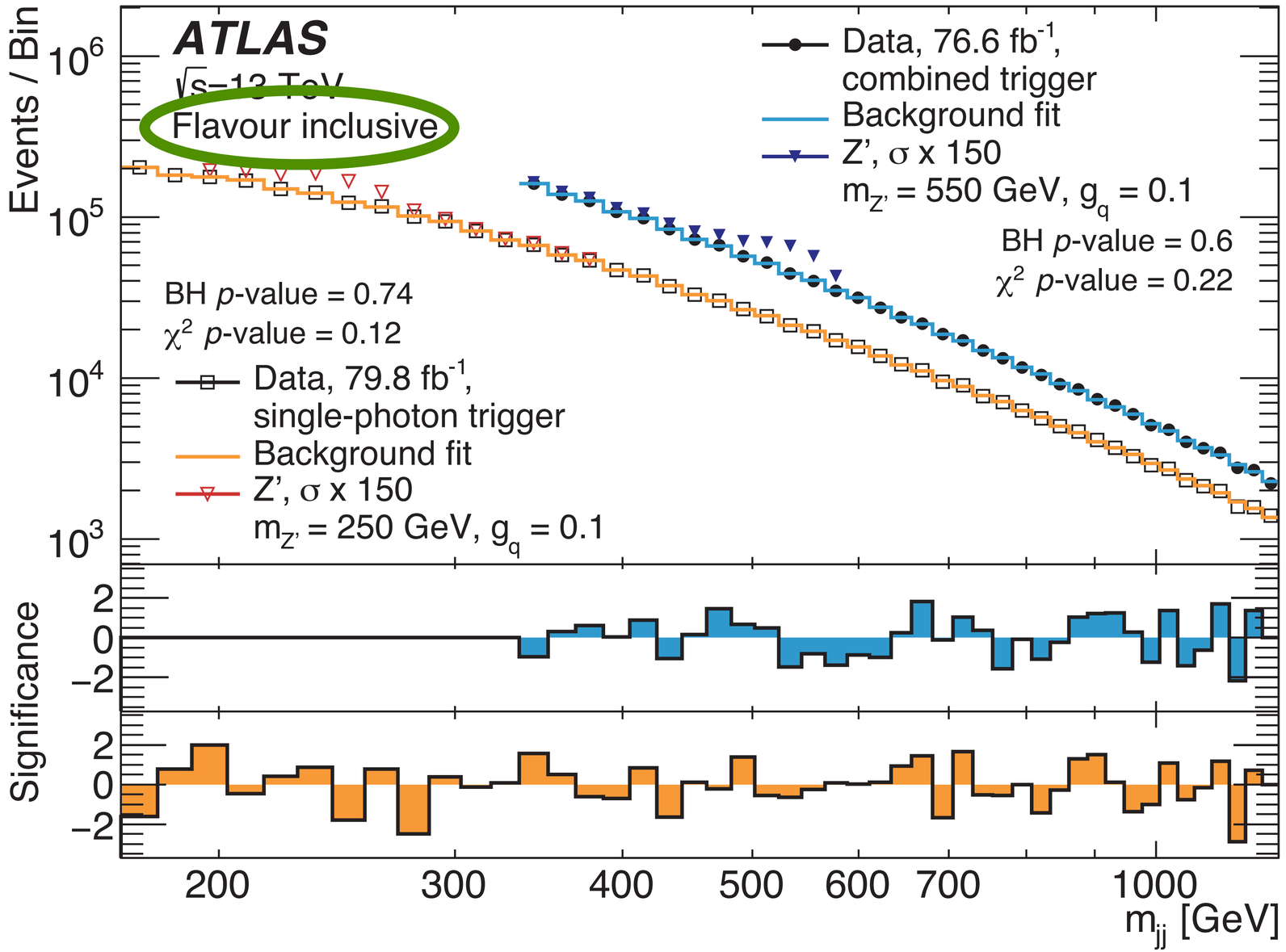
Sliding windows estimate

- Select a bin
- Choose a function
- Use largest possible range with:
  - p-value > 0.05
- Fit function to data in range
- Repeat for each bin

- Choose function with largest p-value (3 - 5 parameters)
- Function with lowest p-value as systematic variation



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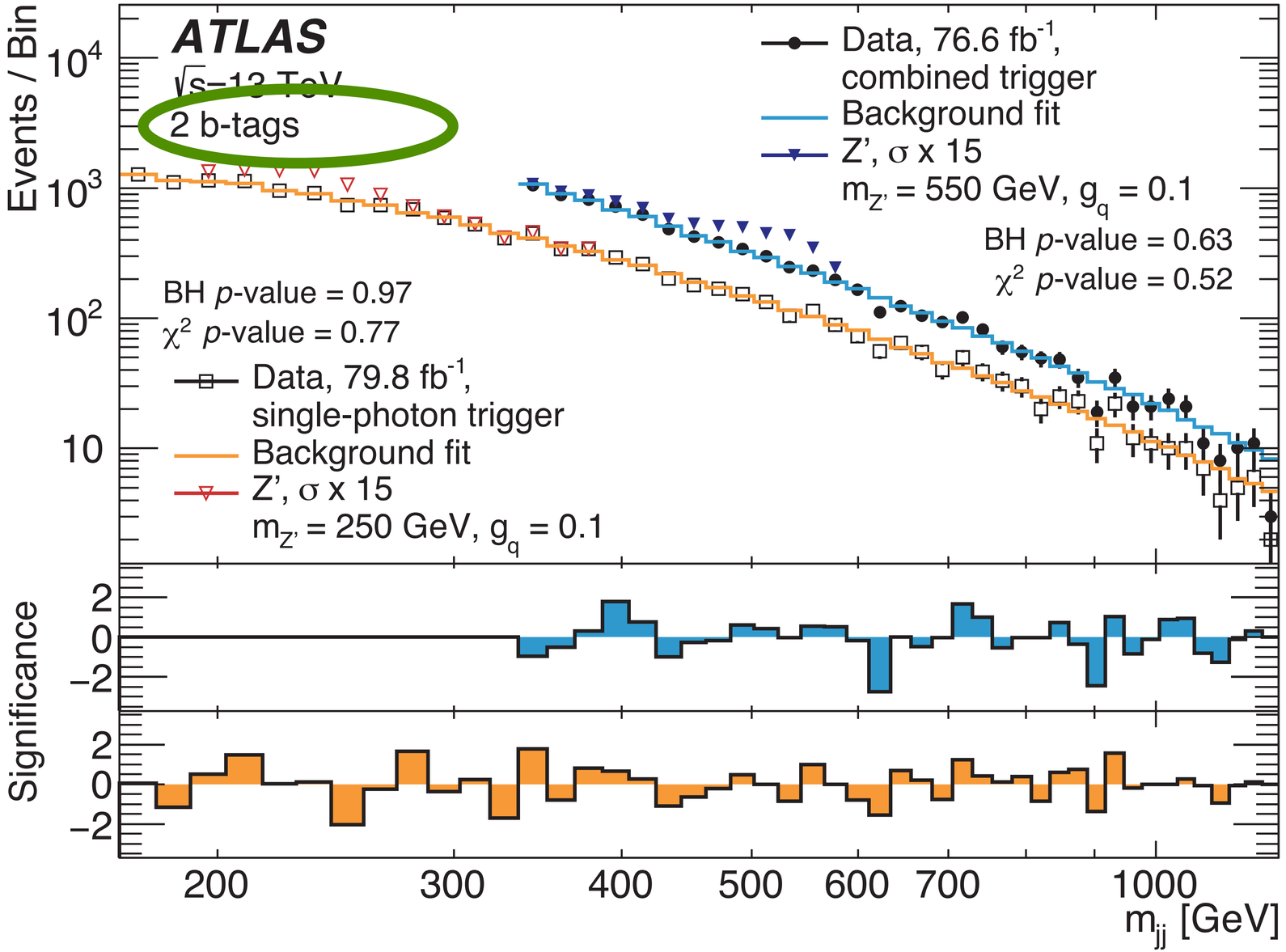

Dijet resonances at low mass

arXiv:1901.10917
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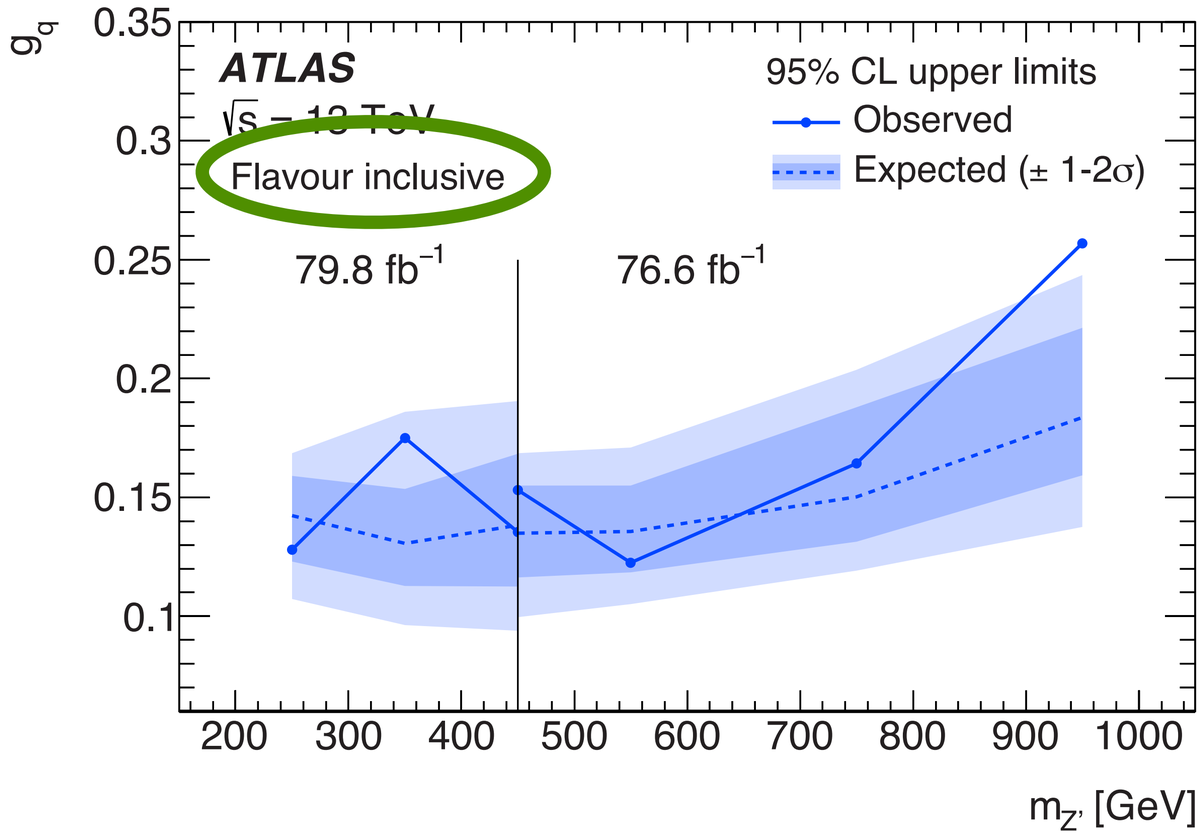
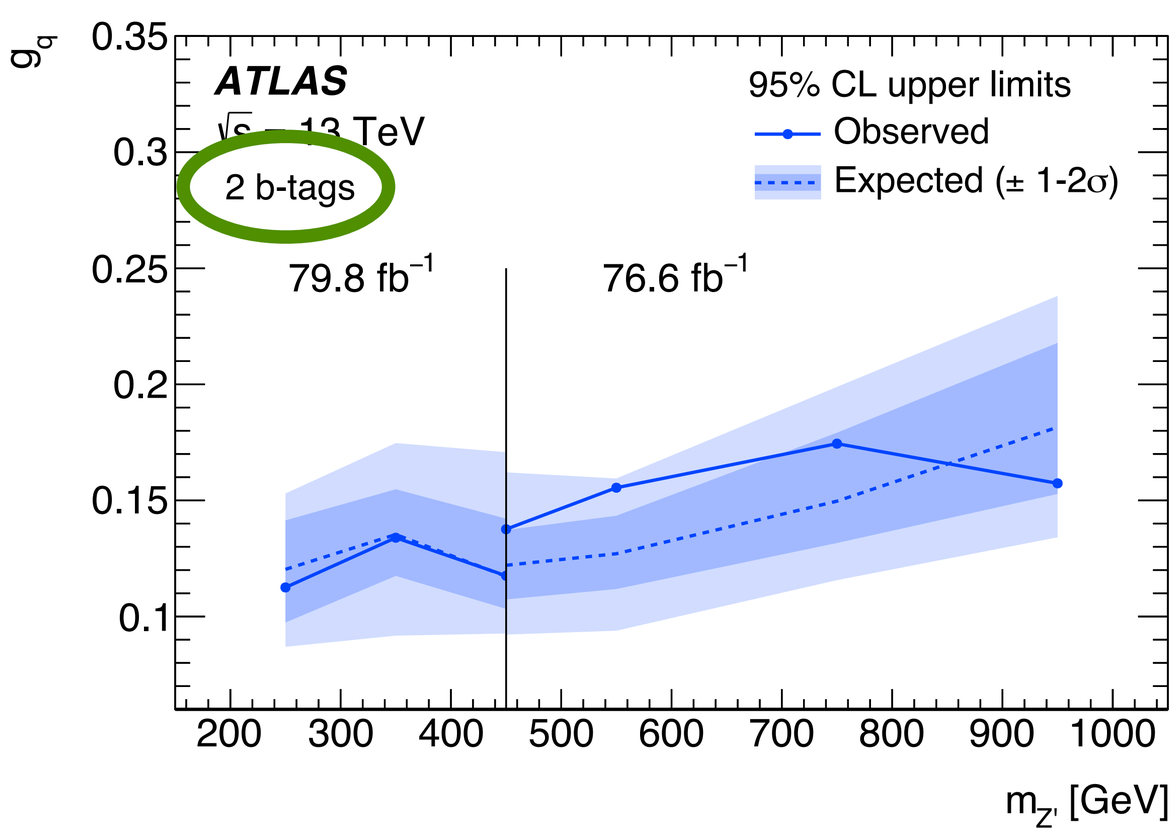
- 2-b-tag selection sensitive to models with enhanced couplings to b-quarks
- 2-b-tag sensitivity to flavour-inclusive couplings even slightly better than flavour-inclusive selection



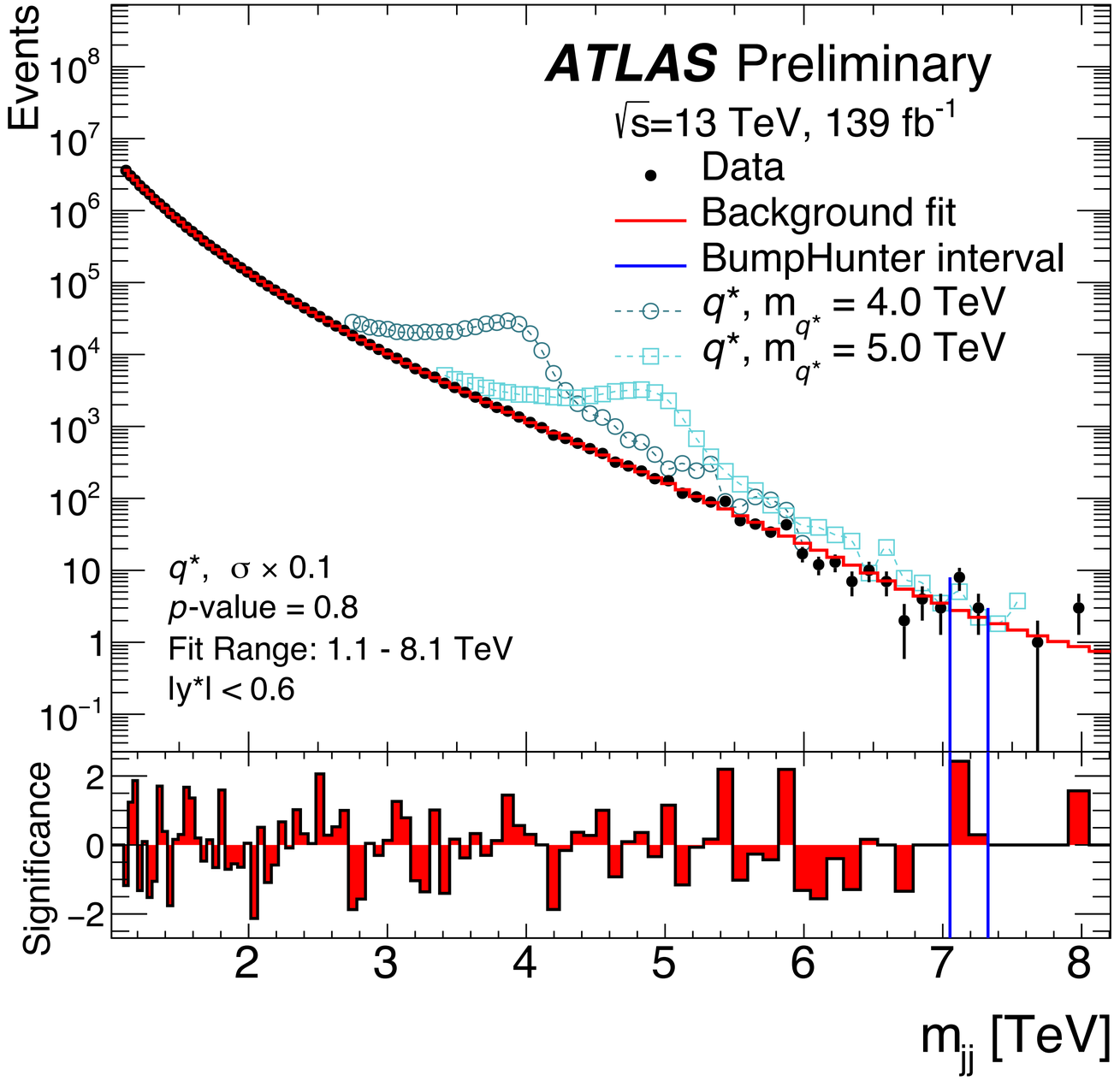


Dijet resonances at high mass

ATLAS-CONF-2019-007
February '19

- Trigger p_T threshold: 420 GeV
- $y^* < 0.6$
- Variable binning to reflect varying resolution

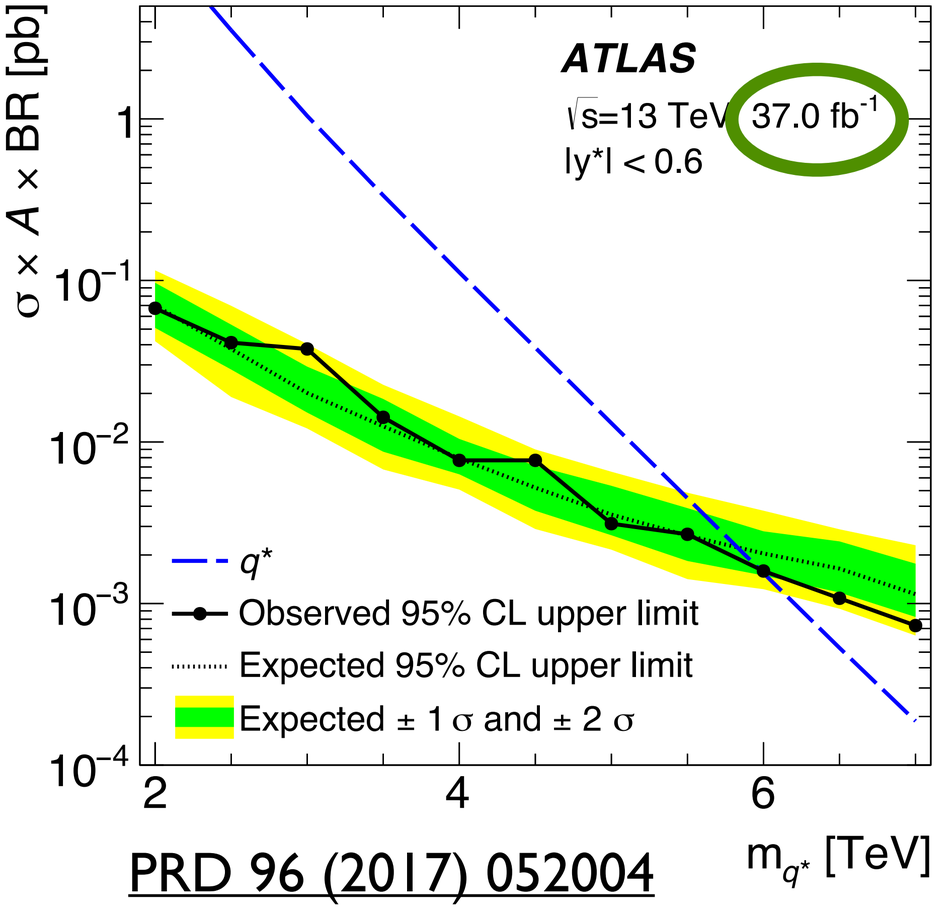
- Background estimate with sliding windows
- Chose function with 4 parameters
  - 5 parameters as systematic variation



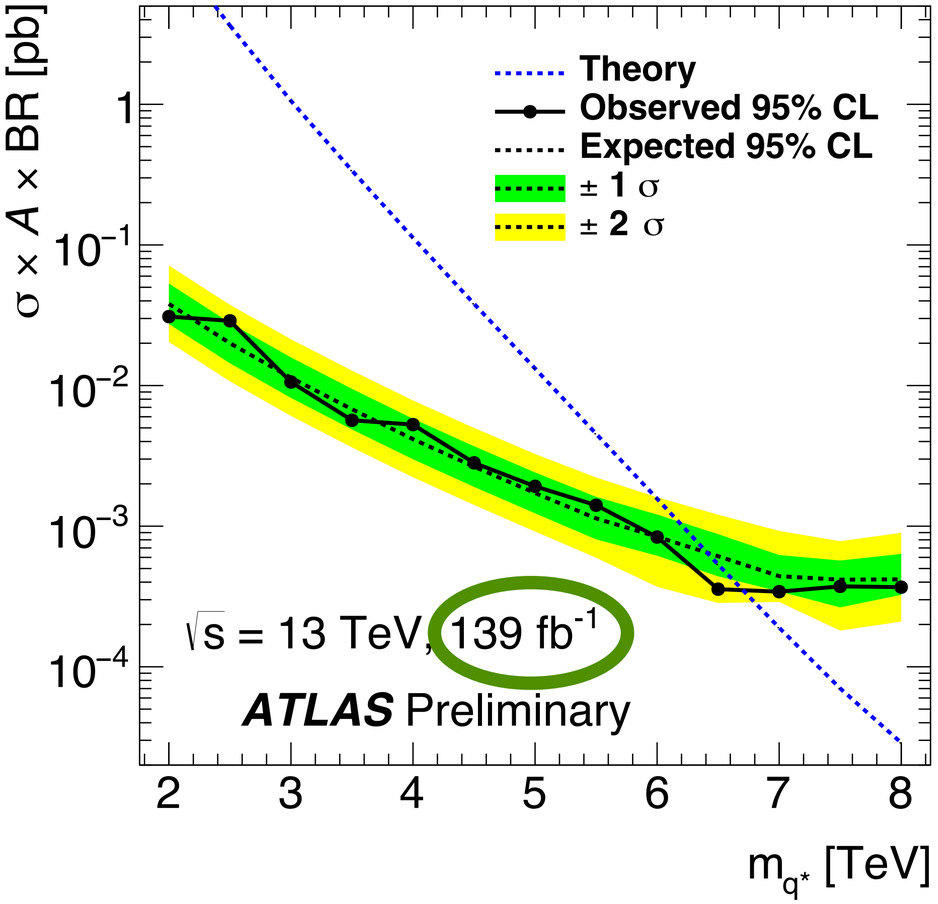
Dijet resonances at high mass

ATLAS-CONF-2019-007
February '19

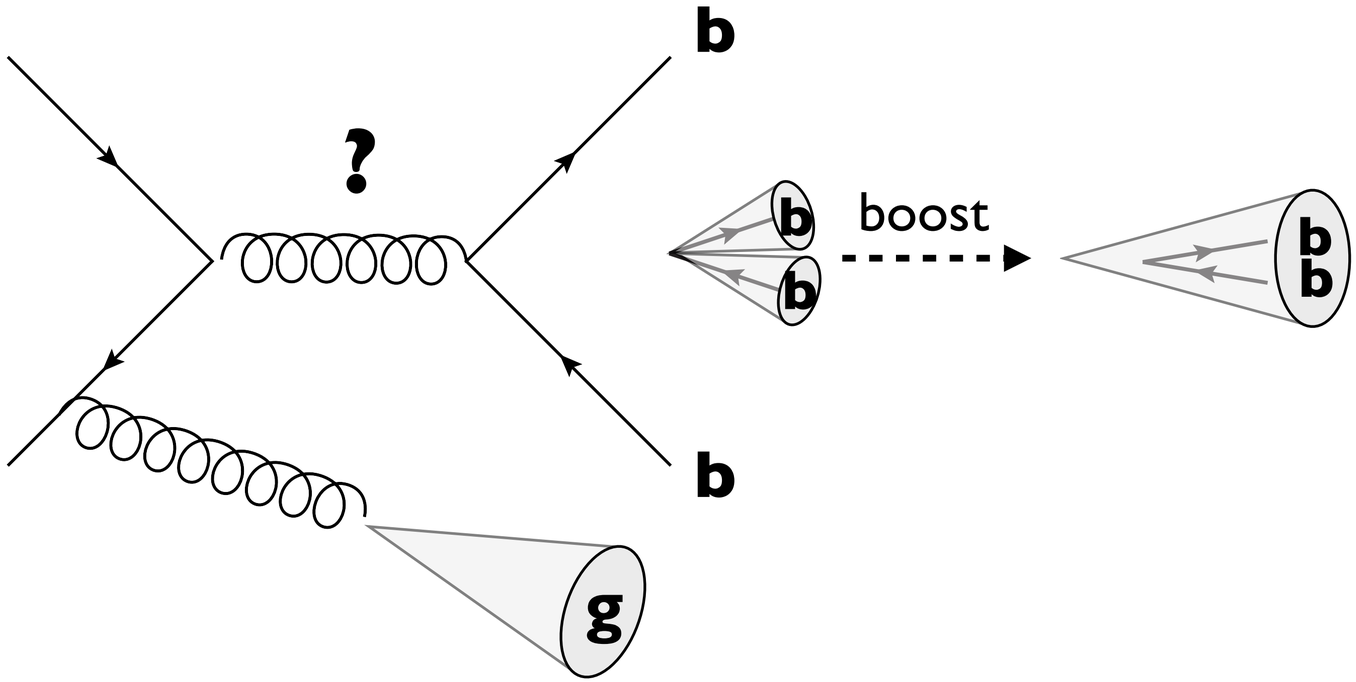
- Improved sensitivity compared to result with 2015/16 data
- Benchmark: q* model
  - But constraining many more models



PRD 96 (2017) 052004



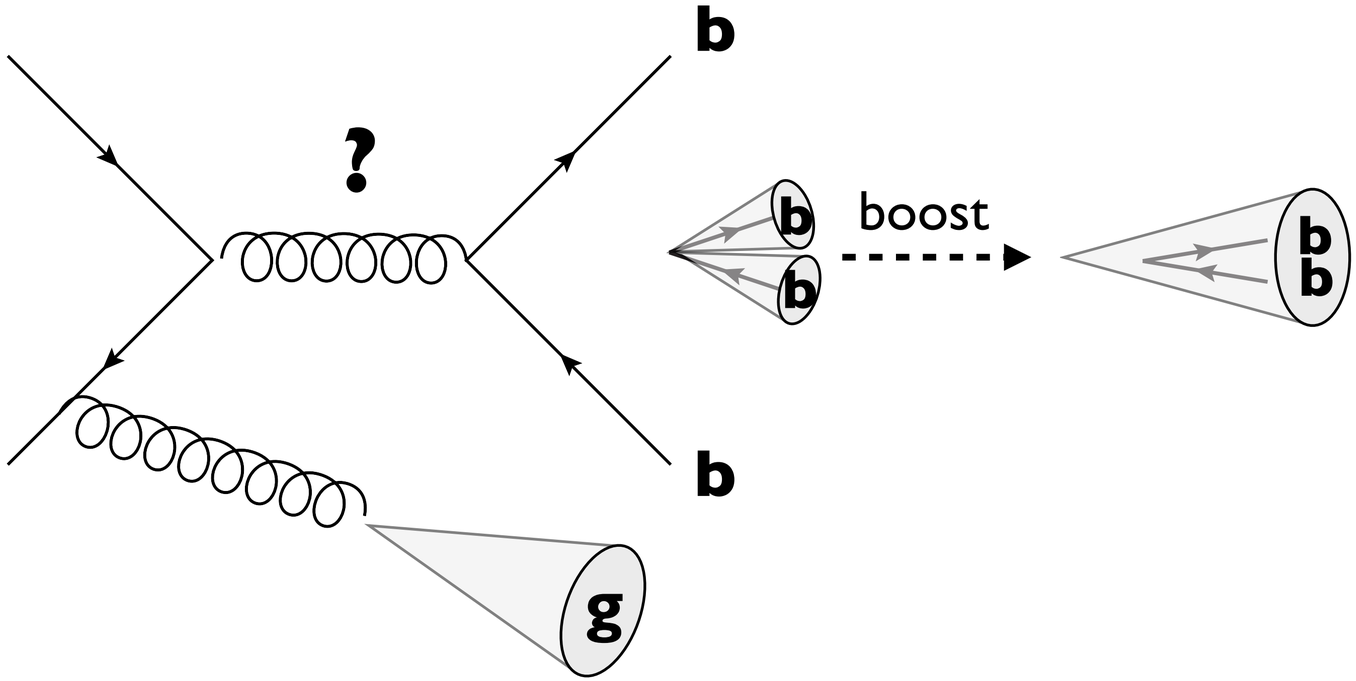
b-anti-b resonances



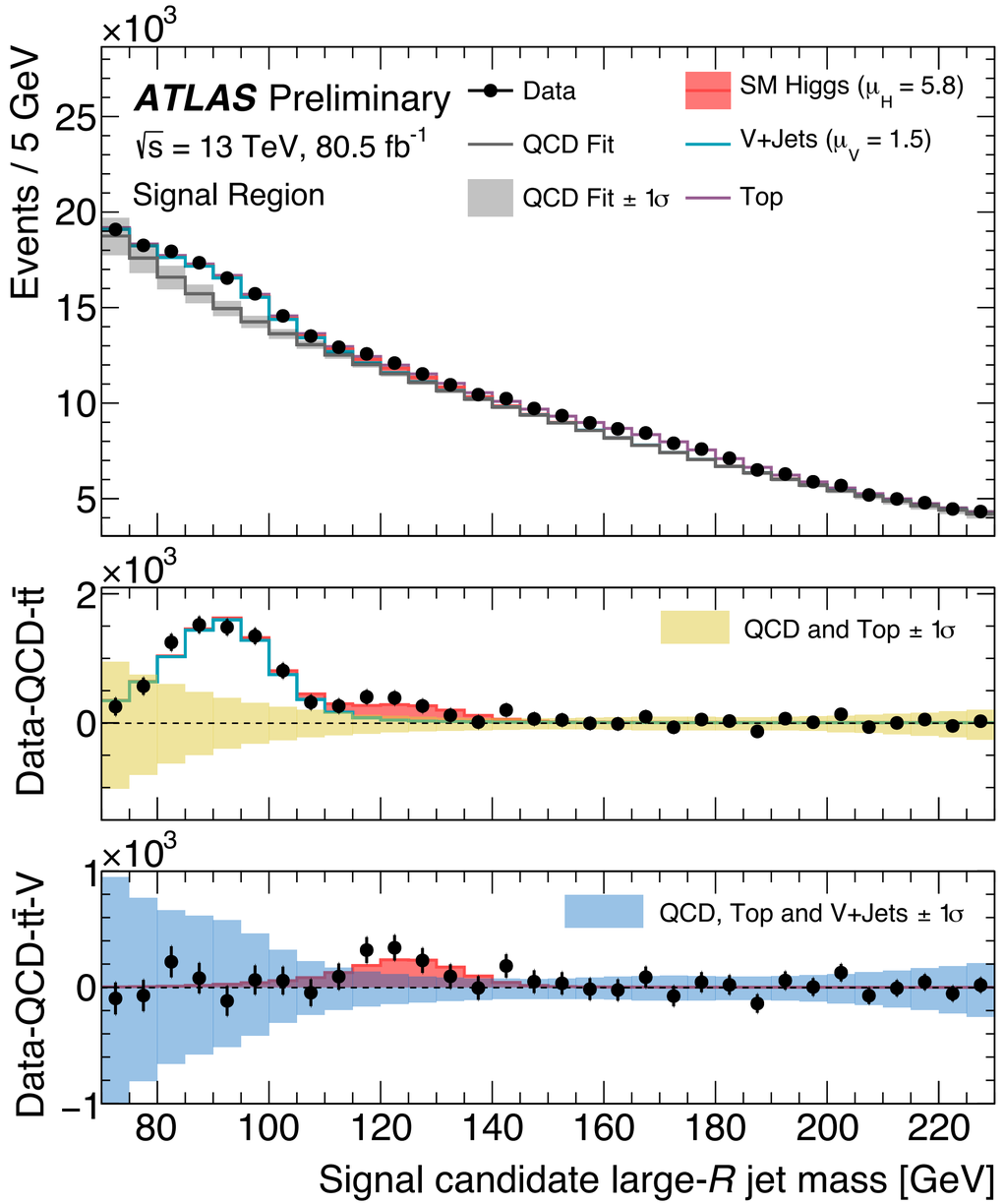
- Candidate jet:
  - p_T > 480 GeV
  - 70 GeV < m < 230 GeV
  - 2m / p_T < 1
  - 2 b-tagged track jets

b-anti-b resonances

ATLAS-CONF-2018-052
November '18



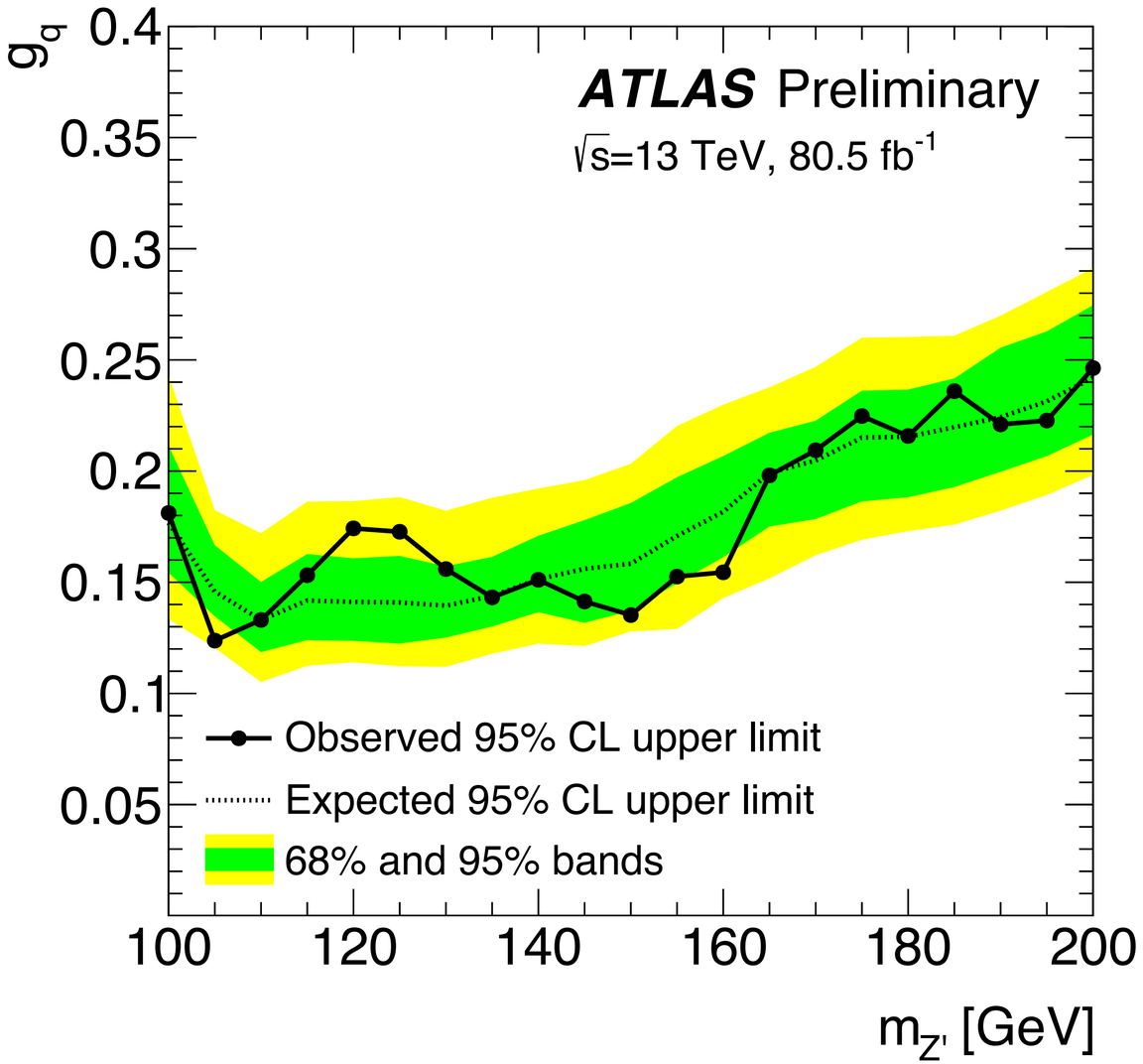
- Candidate jet:
  - p_T > 480 GeV
  - 70 GeV < m < 230 GeV
  - 2m / p_T < 1
  - 2 b-tagged track jets
- Multijet estimate:
  - Fit to data
  - Choose function in 0-b CR: slice with data ~ SR
- Rest from MC (+ $t\bar{t}$ CR)



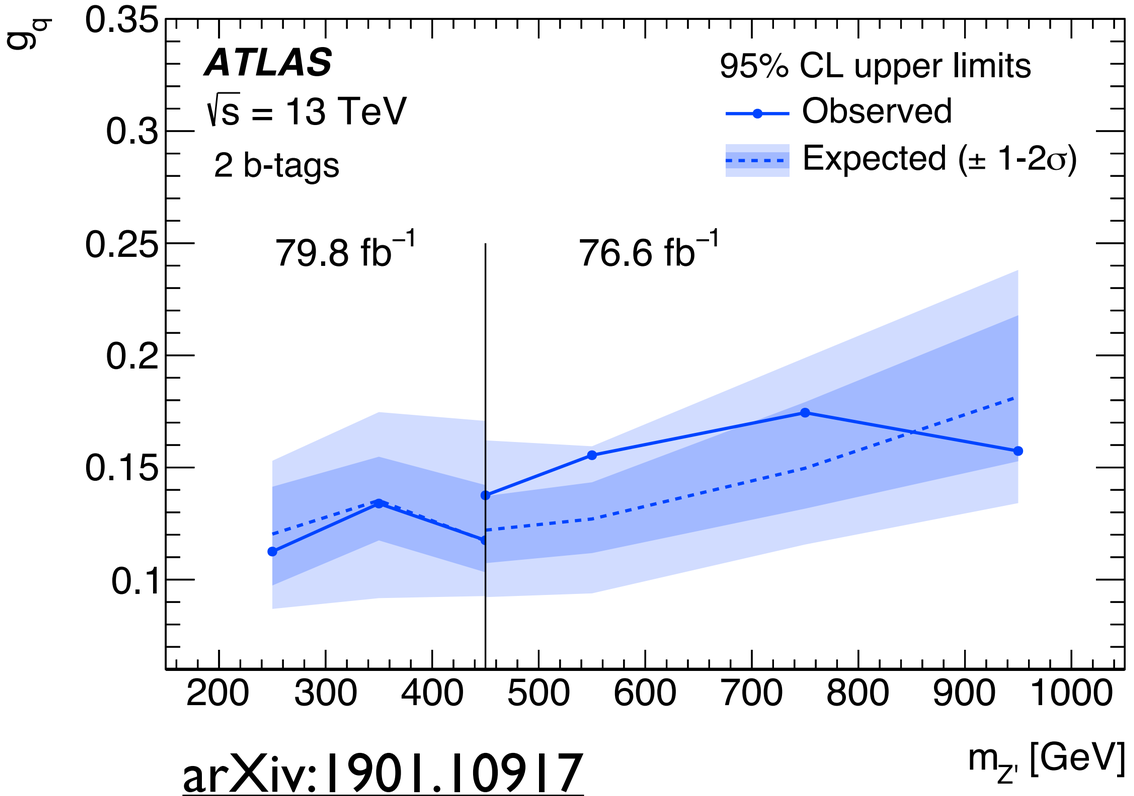
b-anti-b resonances

ATLAS-CONF-2018-052

November '18



- Complementary to dijet+γ search with 2-b-tag selection



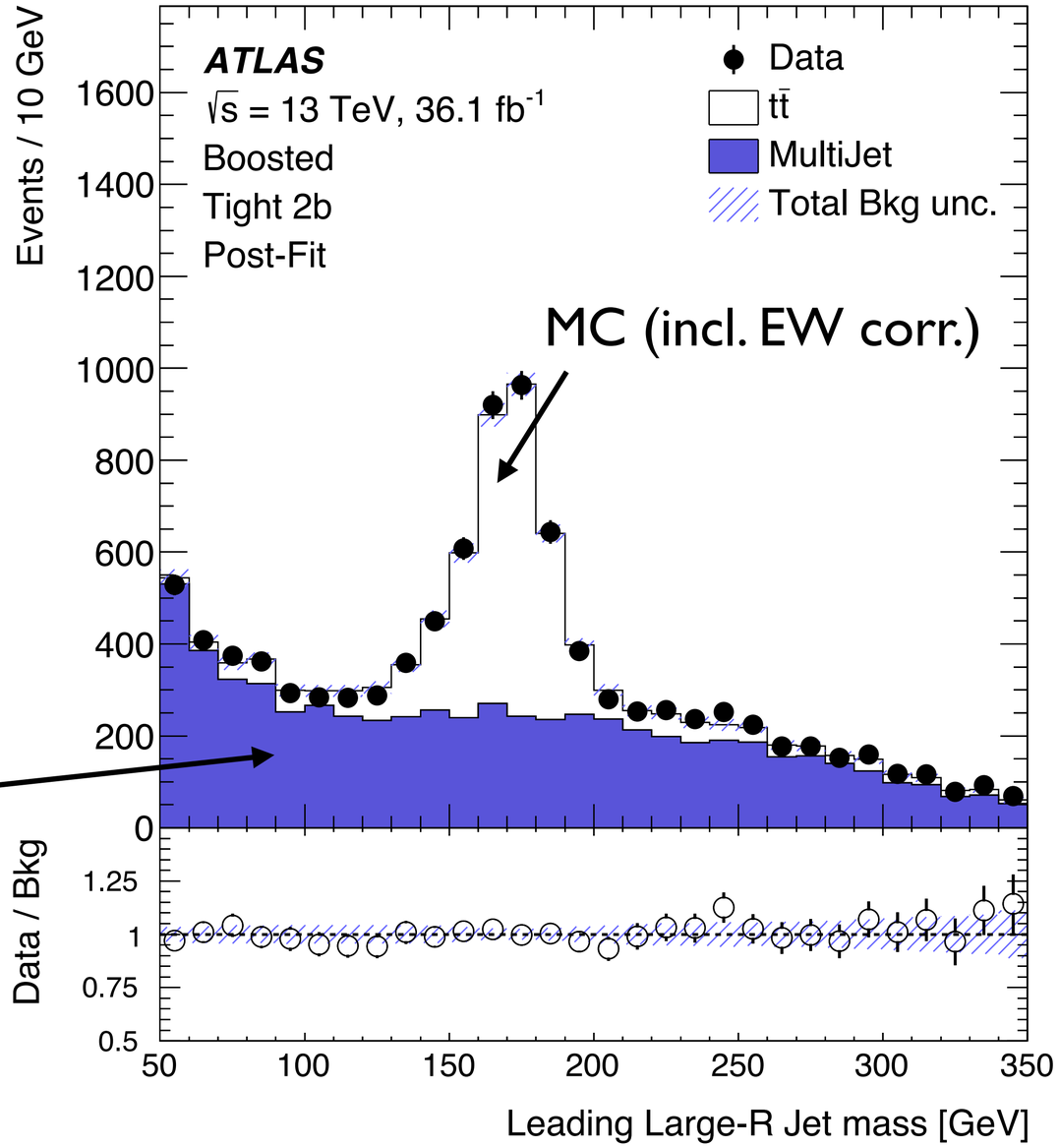
arXiv:1901.10917


top quark
antitop quark

Top-antitop resonances

arXiv:1902.10077
February '19

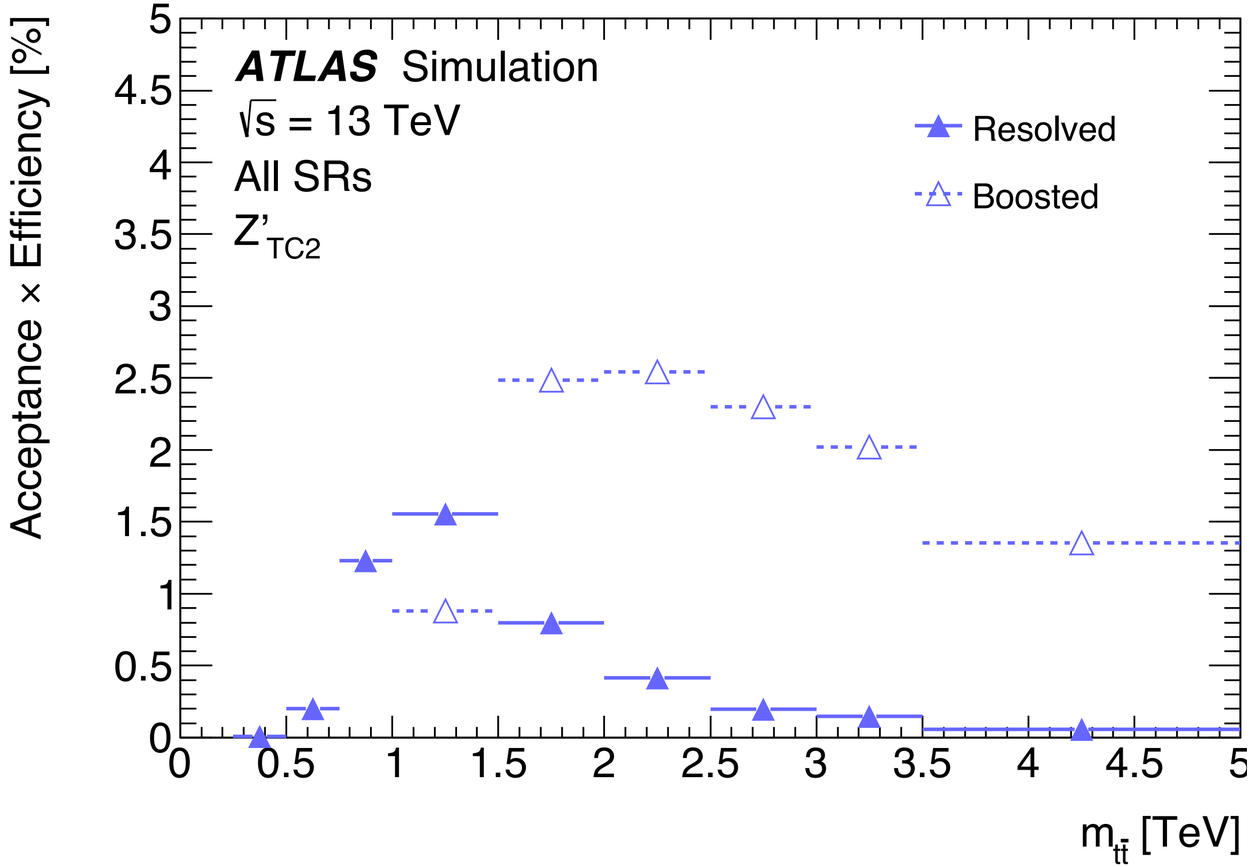
- Allhadronic analysis
  - Low mass: multijet final state ("resolved")
  - High mass: two large-R jets ("boosted")
- Suppression of multijet-background
  - b-tagging and top-quark reconstruction
    - Resolved: "buckets of tops" based on m_{top} and m_W
    - Boosted: top-tagging based on m_{top} and pronginess
- Multijet estimate from data
  - Using background-rich regions
    - Resolved: invert b-tag & top-reco quality
    - Boosted: invert b-tag & jet mass

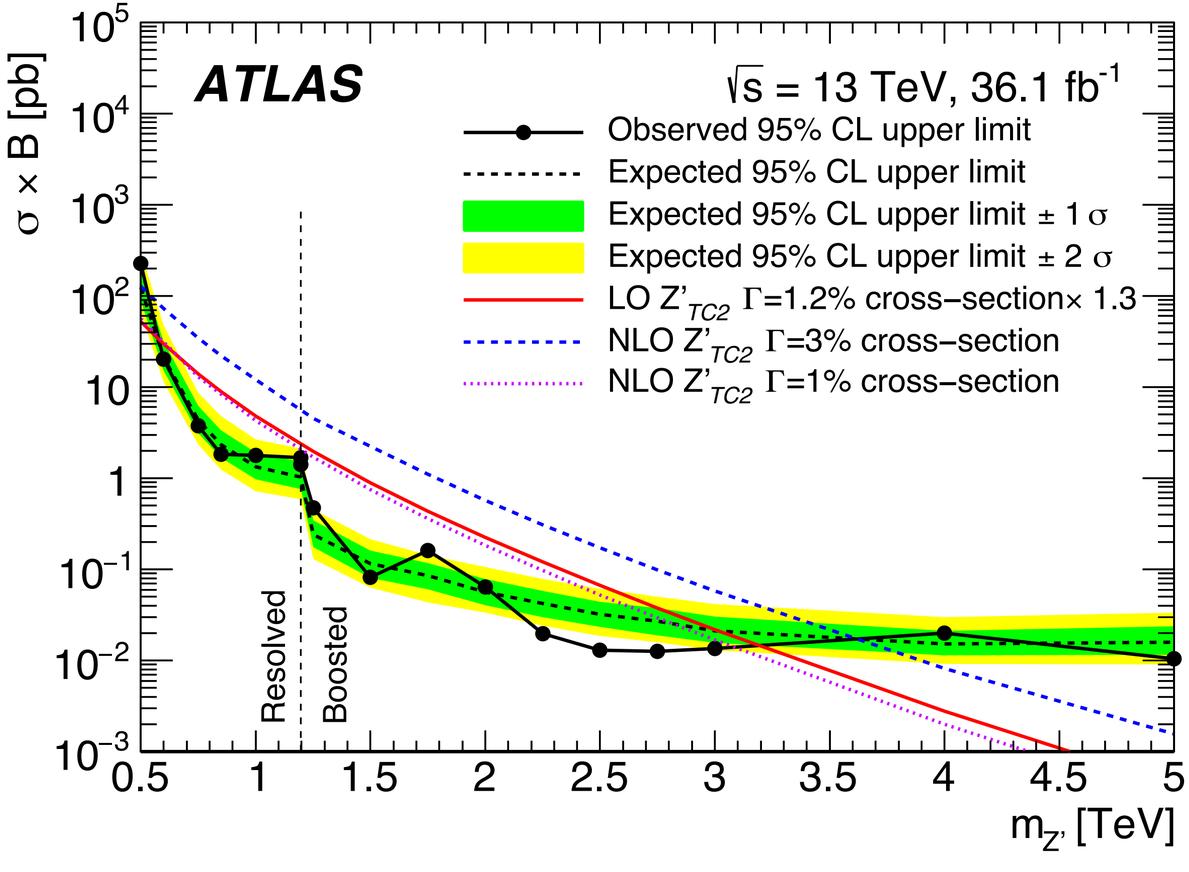


Top-antitop resonances

arXiv:1902.10077
February '19

- One fit per analysis:
  - 3 CRs + 1 SR (resolved)
  - 8 SRs (boosted) based on b-tag, jet mass and τ_{32} likelihood ratio
- Sensitivity comparable to ℓ+jets analysis (EPJC 78 (2018) 565)





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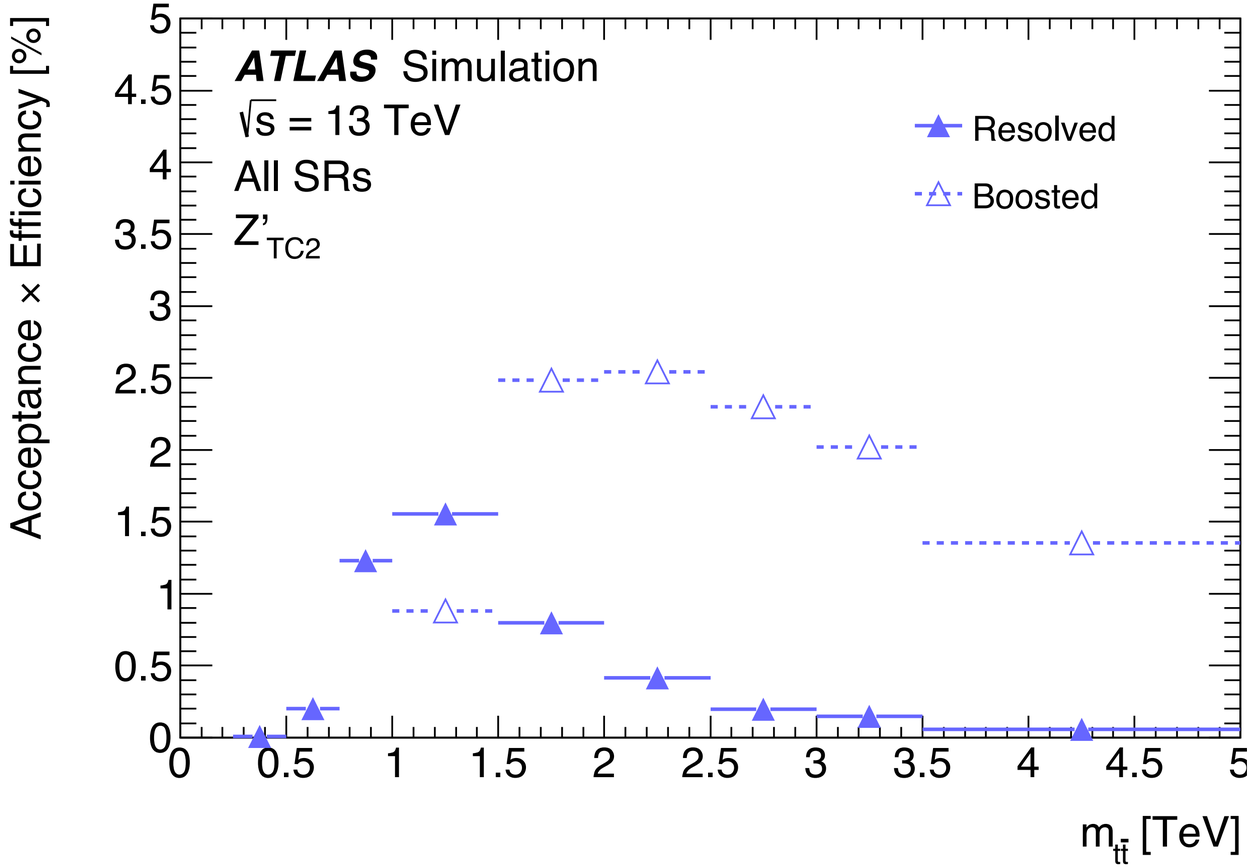
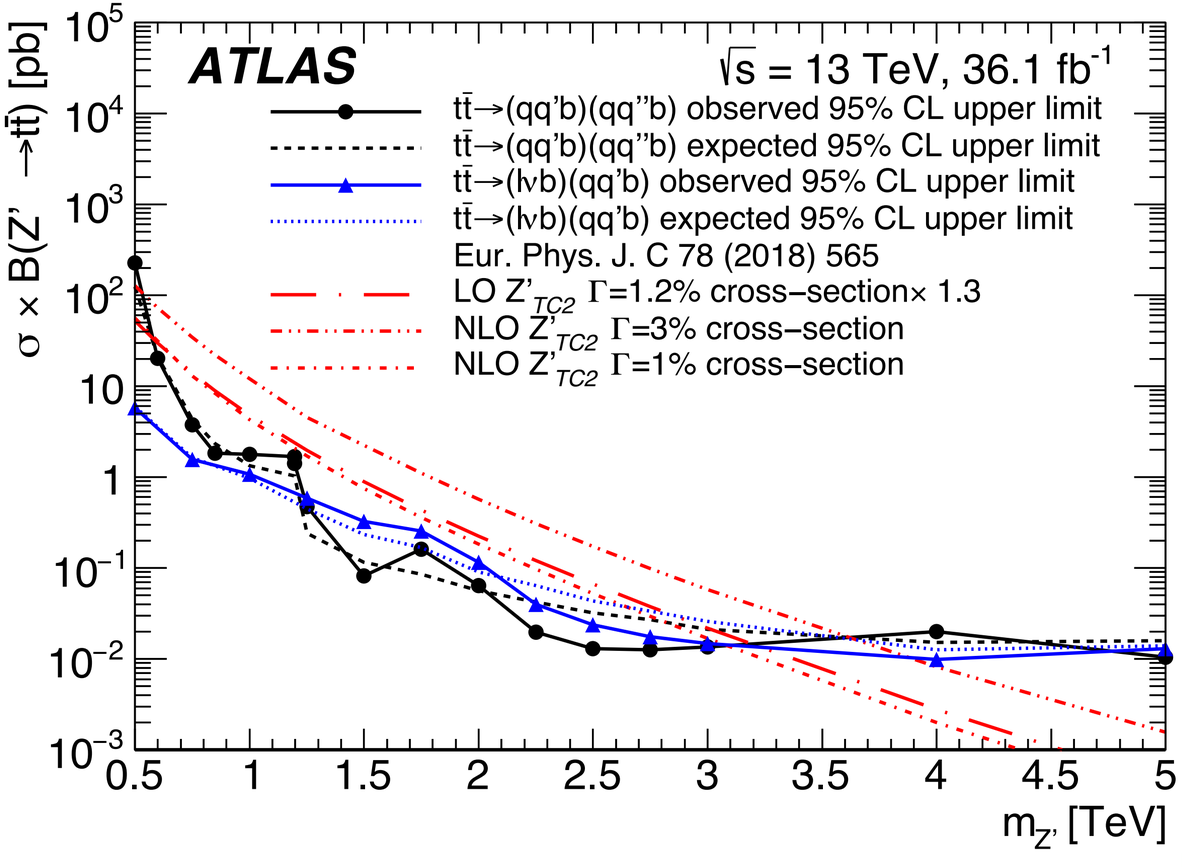
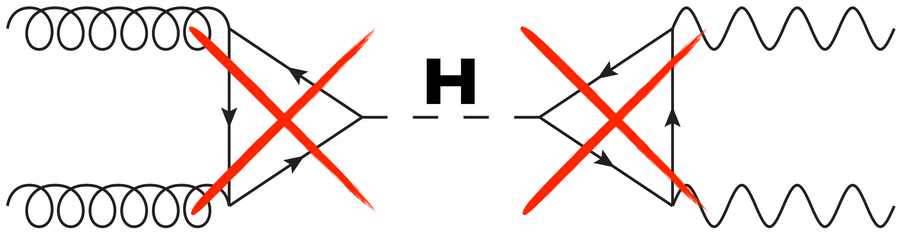




Vector-like quarks

Chiral 4th quark generation

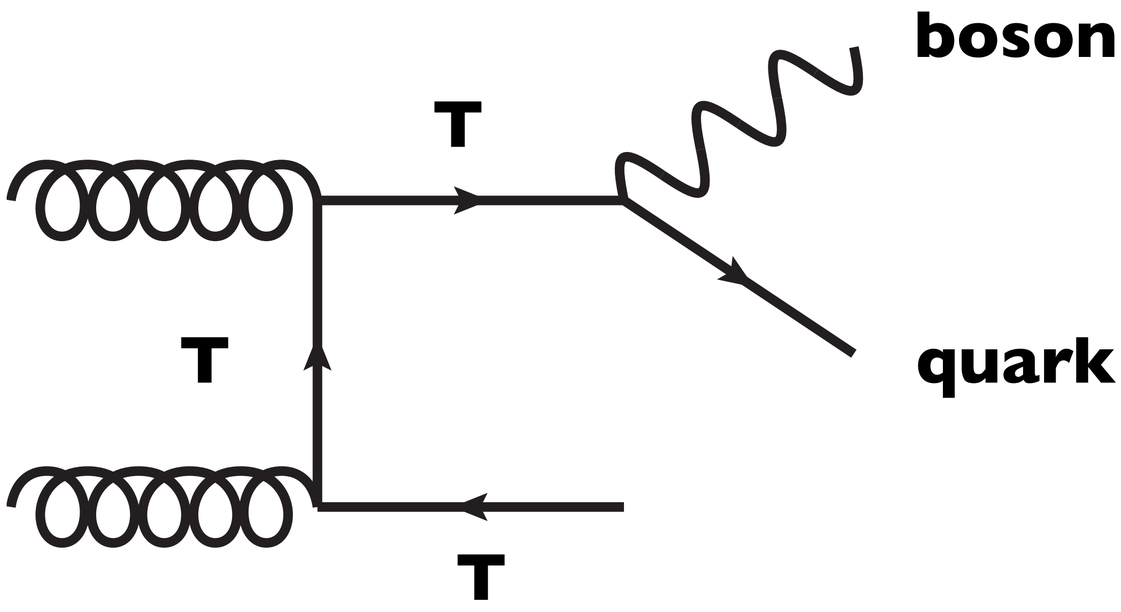
- excluded by Higgs measurements

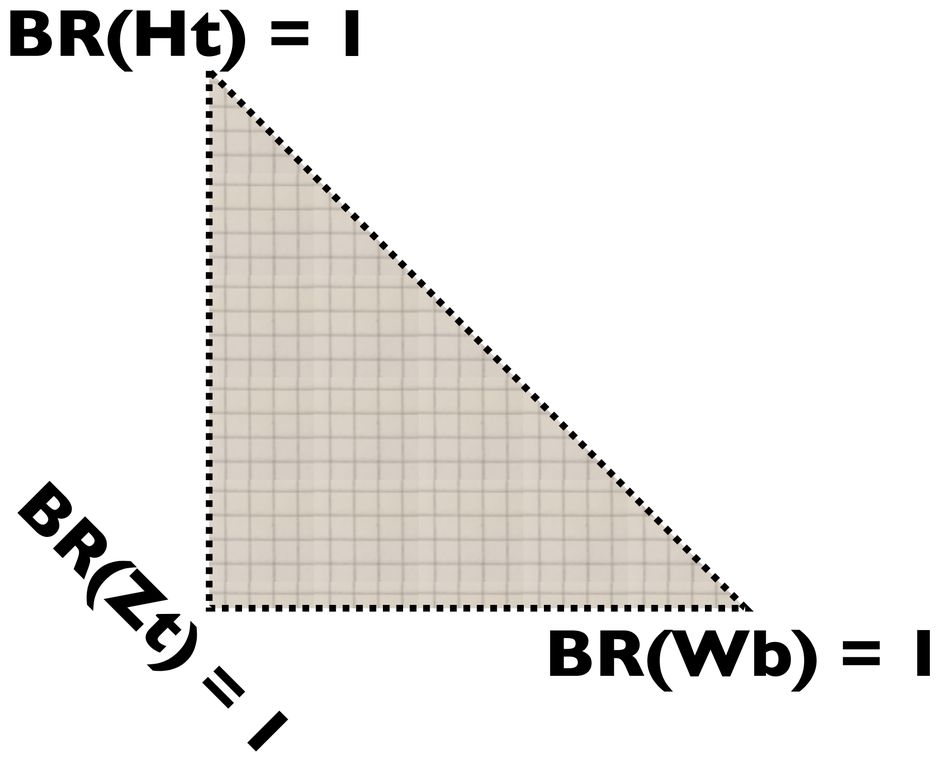


Vector-like Quarks (VLQ)

- LH & RH parts transform the same
- Mass not by Higgs mechanism
- If couple preferentially to 3rd generation

  $\Longrightarrow$ "top partners" (T, B, X, Y)





VLQ pair-production combination

PRL 121 (2018) 211801

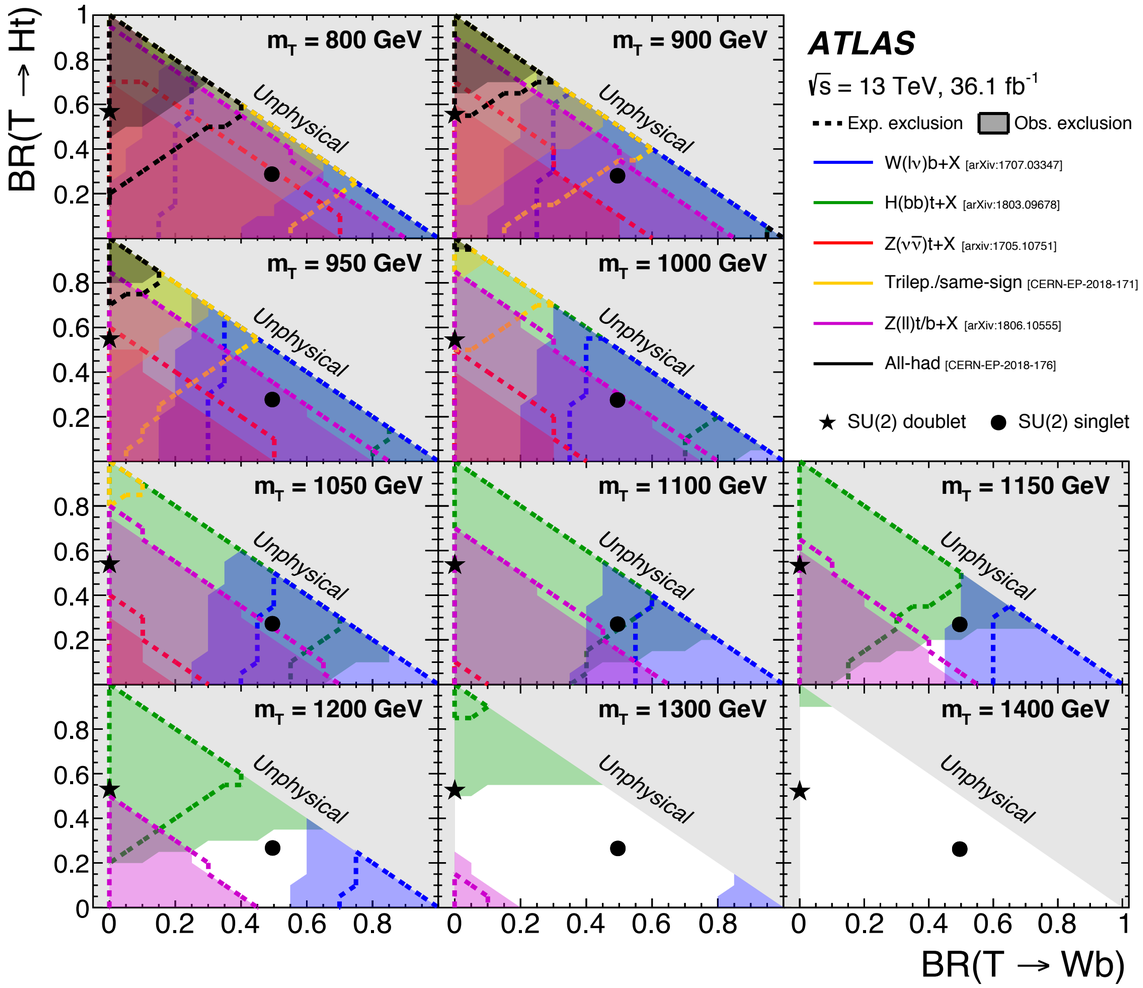
August '18

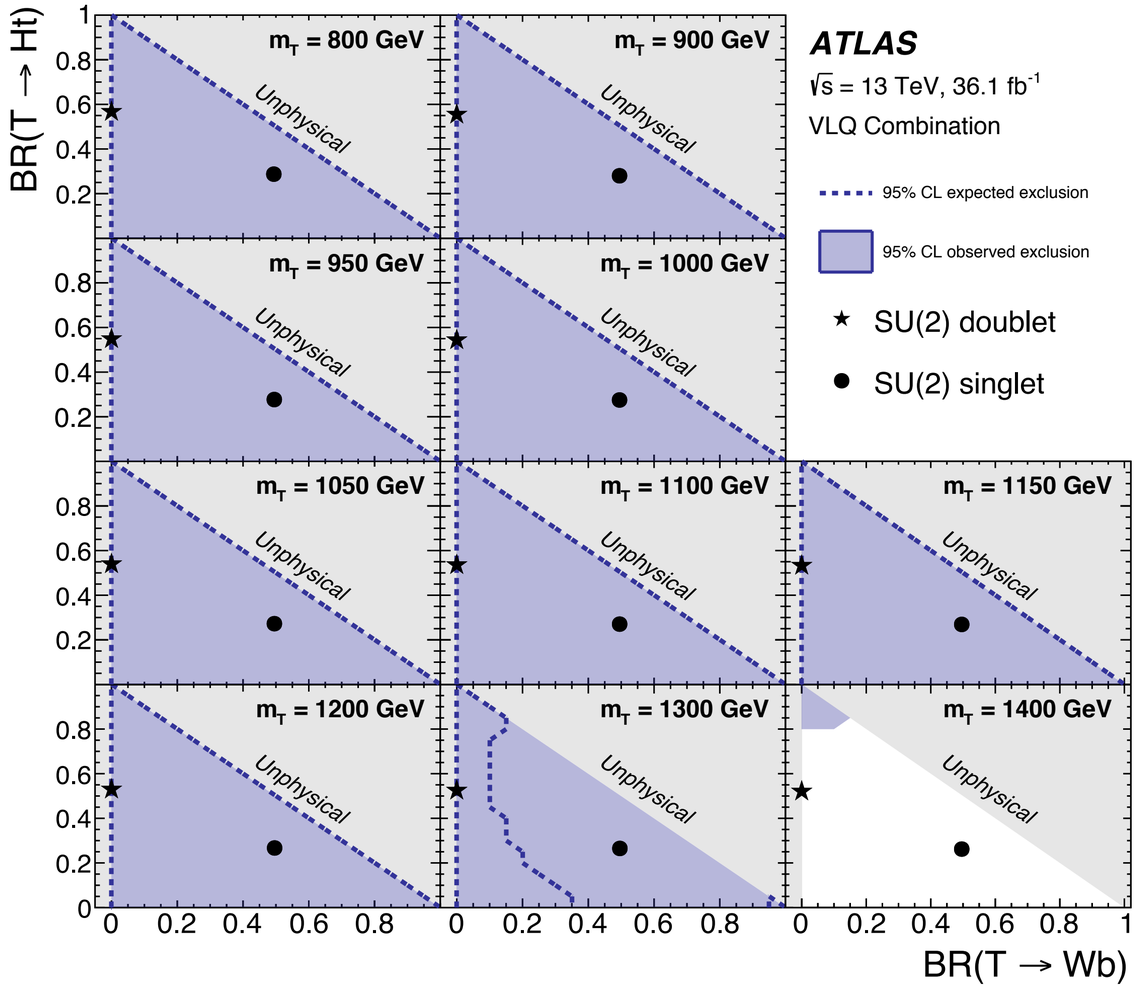
Combination of

- 6 published analyses for vector-like T
- 4 published analyses for vector-like B

m_T > 1.31 TeV for all possible BRs

(if only decays to SM particles)





VLQ pair-production combination

PRL 121 (2018) 211801

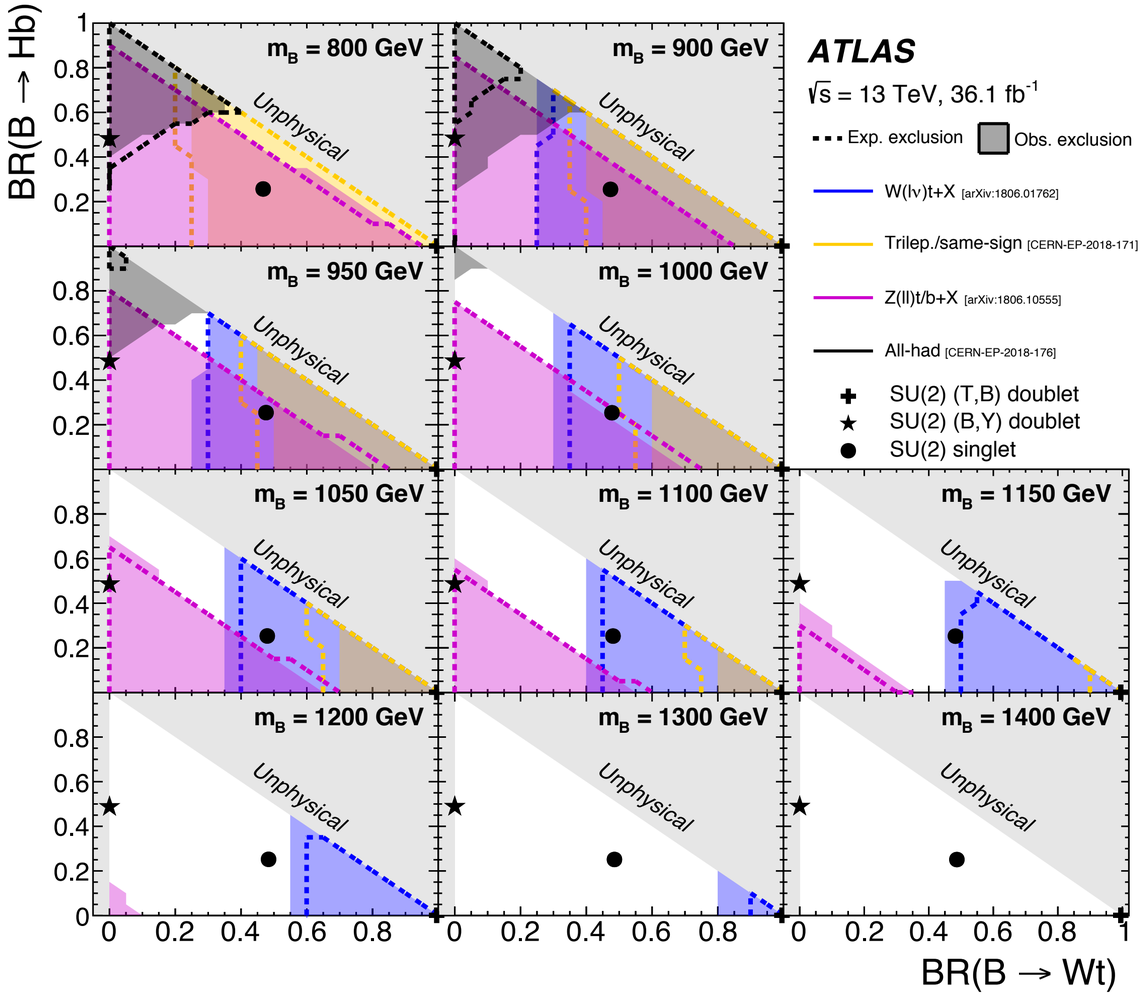
August '18

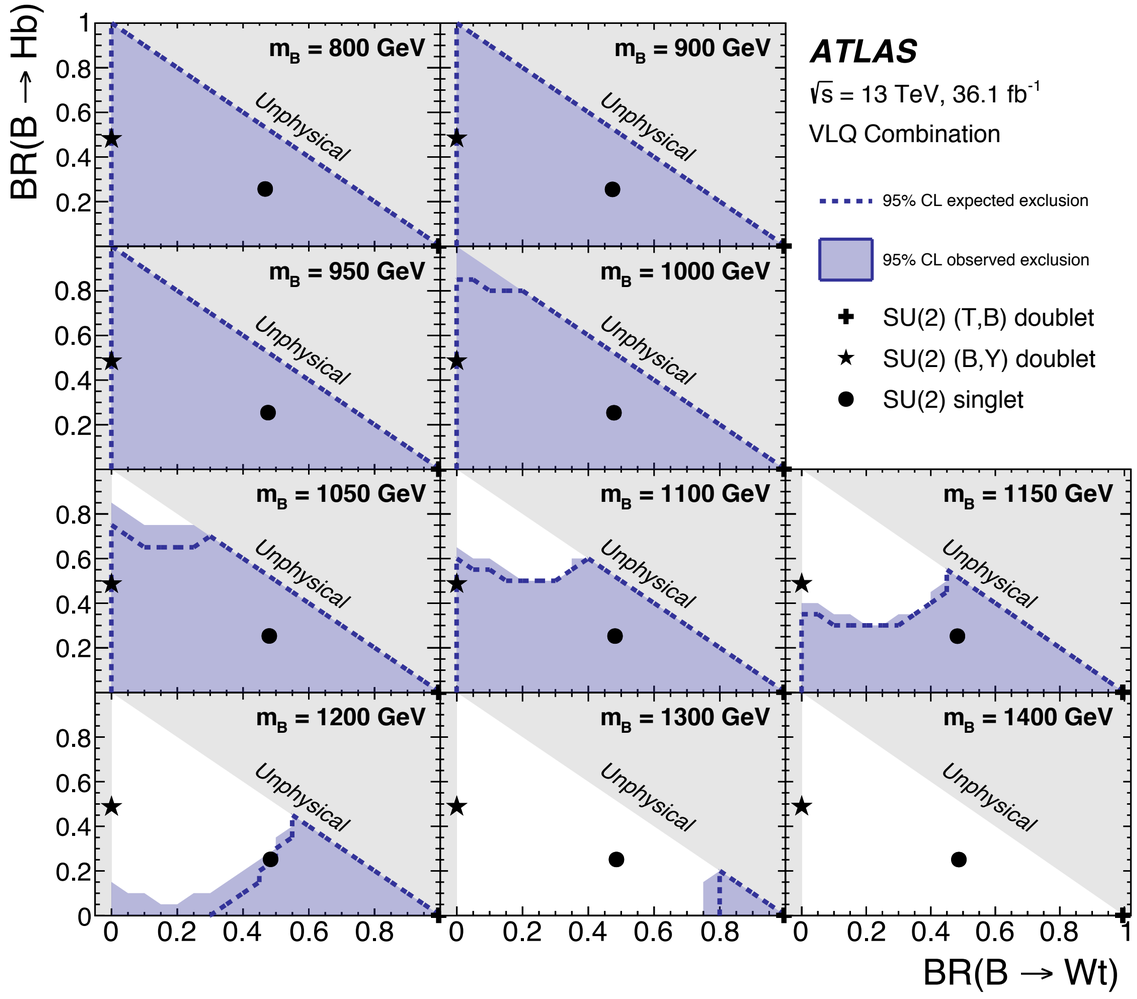
Combination of

- 6 published analyses for vector-like T
- 4 published analyses for vector-like B

m_B > 1.03 TeV for all possible BRs

(if only decays to SM particles)

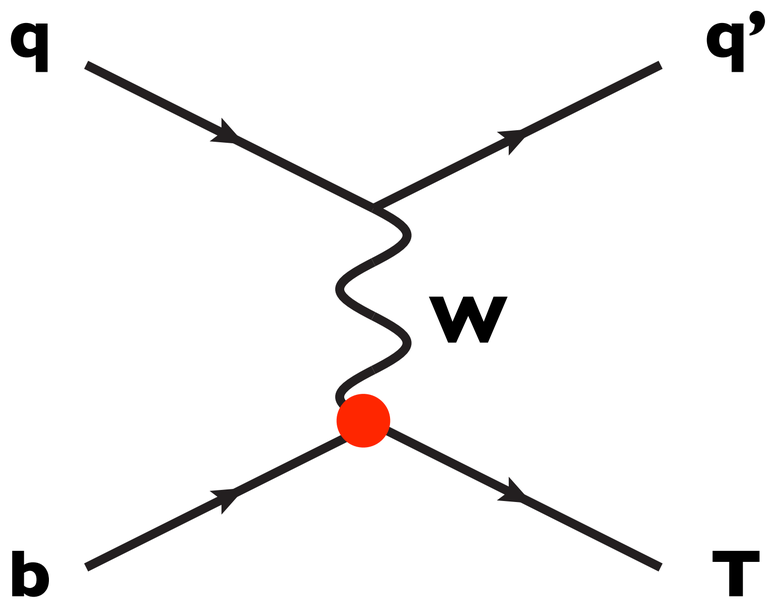




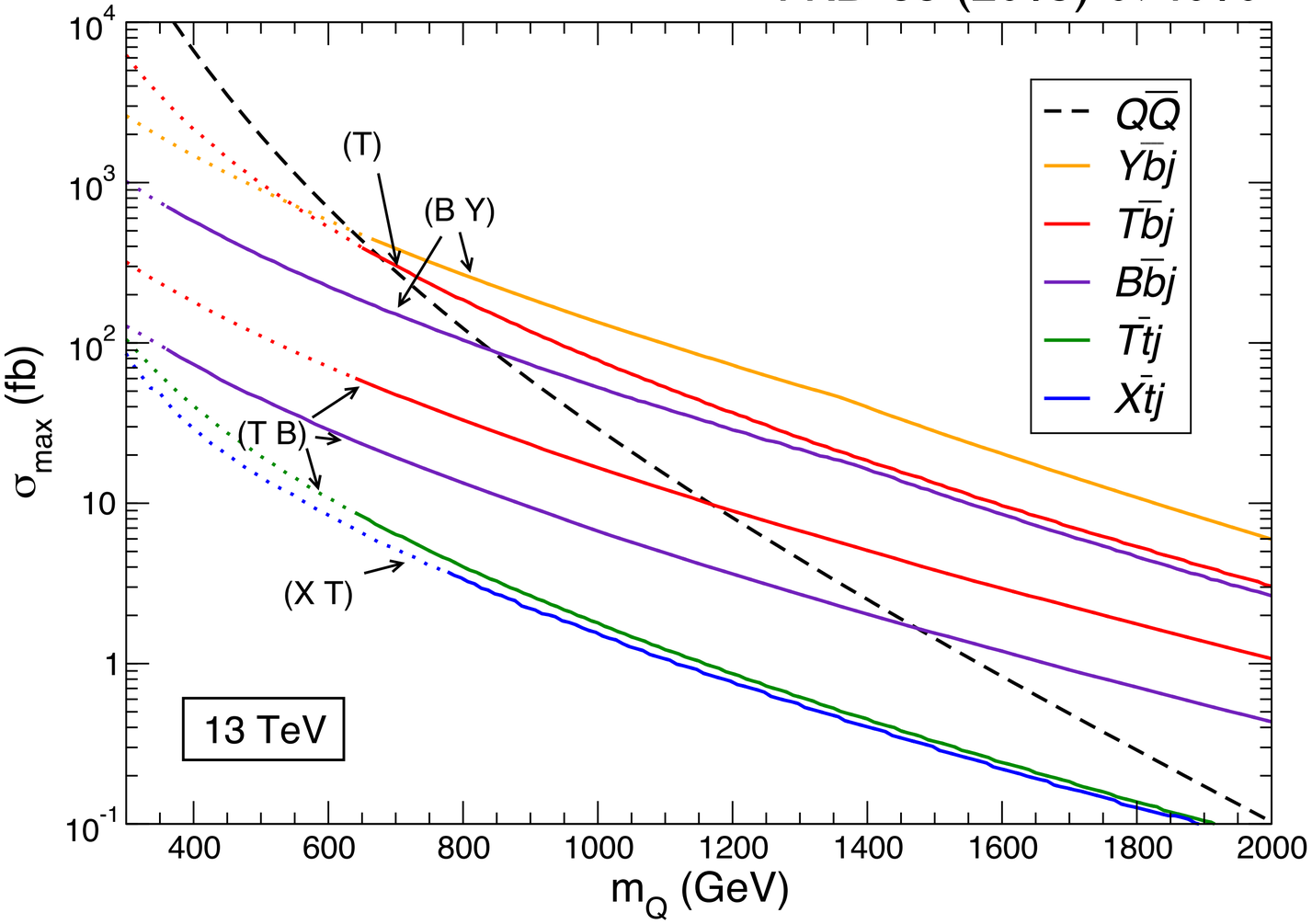
Single-VLQ production

For large masses

- Single-production cross section may be larger than pair-production cross section
- Depends on electroweak coupling



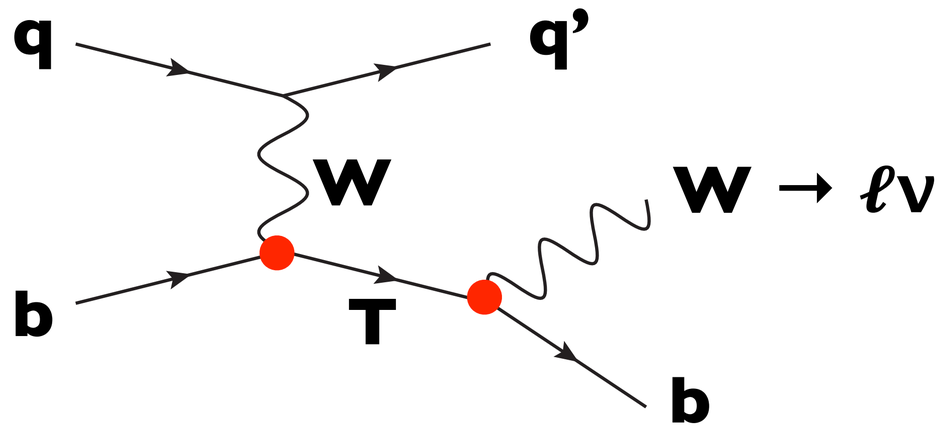
PRD 88 (2013) 094010

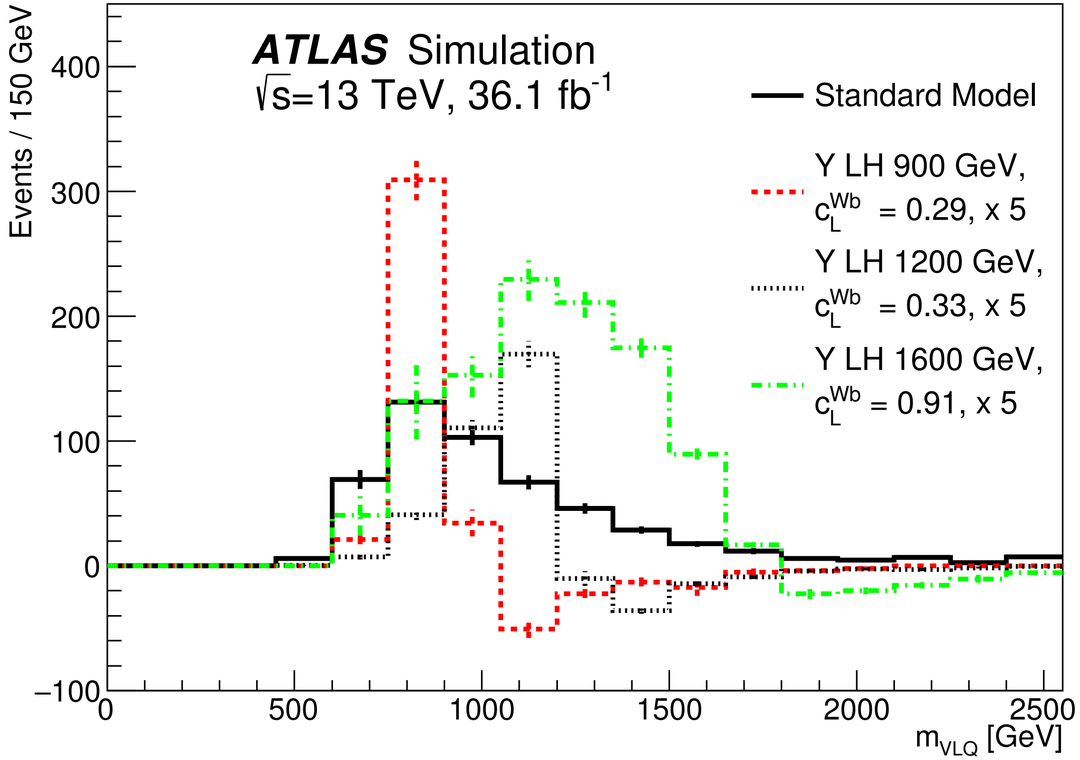


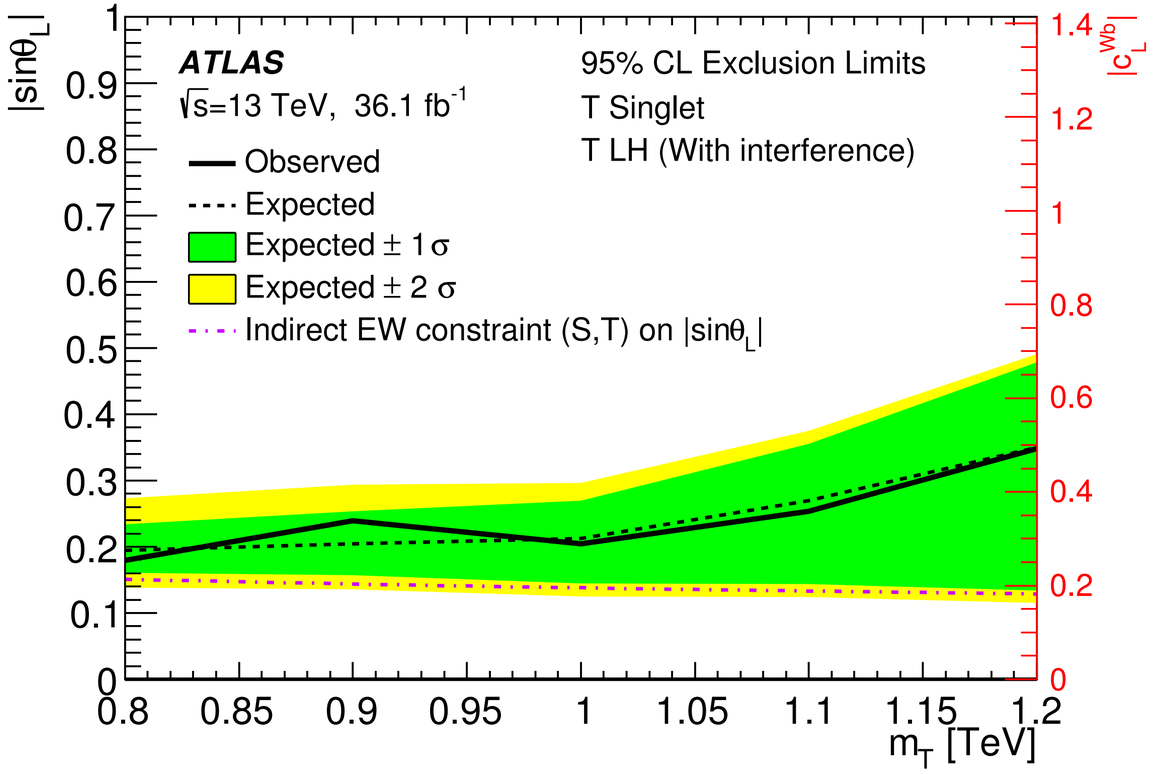
Single-VLQ → Wb

arXiv:1812.07343
December '18

- one e or μ & E_T^{miss} & one b-jet & one forward jet
- Main backgrounds: W+jets and single top
  - Interfere with signal
  - Depends on signal width and hence coupling





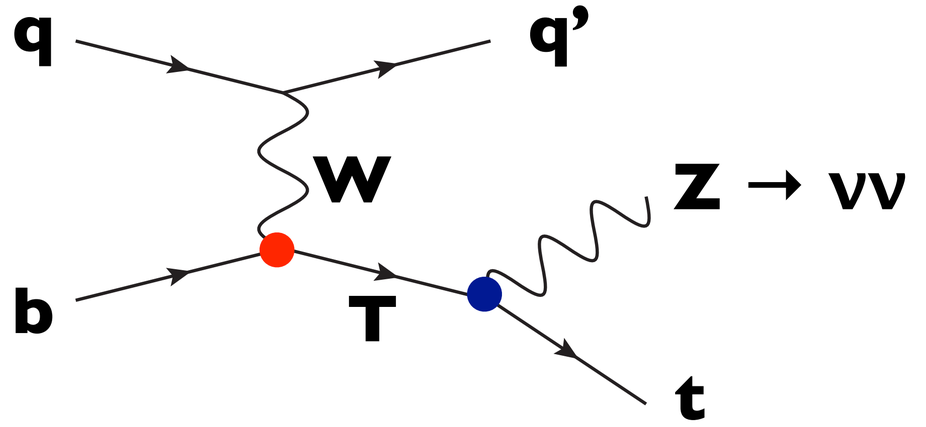


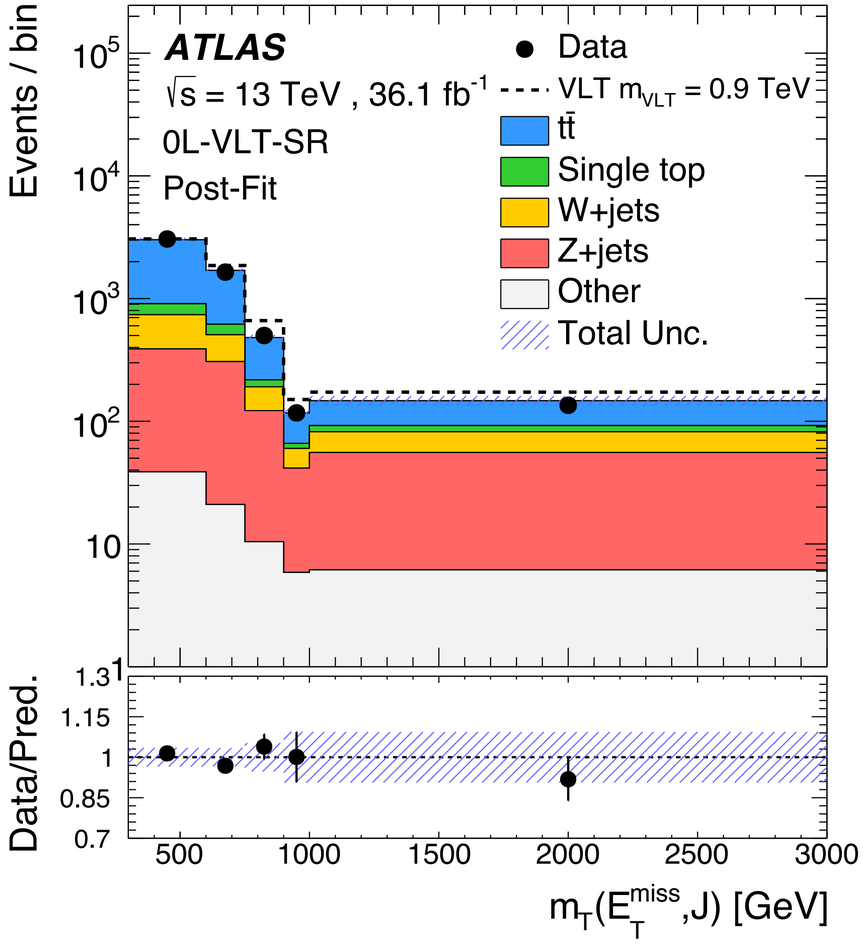
Single-VLQ → Zt

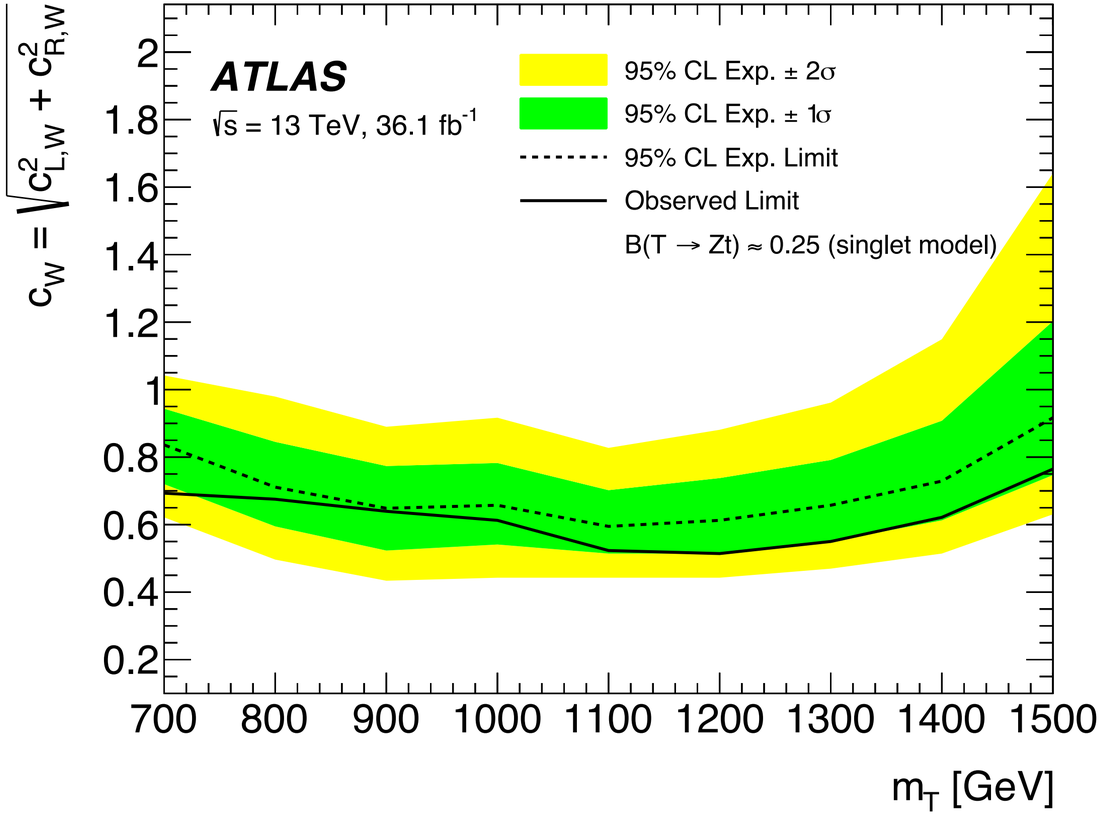
arXiv:1812.09743
December '18

"Monotop" signature

- 1 top + E_T^{miss}
- Boosted hadronic top ⟹ top-tagged large-R jet







Summary

- Significant improvements due to
  - Increased dataset

Dijet analyses at 13 TeV

Luminosity	3.6 fb^{-1}	37 fb^{-1}	139 fb^{-1}
q* limit	5.2 TeV	6.0 TeV	6.7 TeV

  - New analysis strategies
- Many analyses with full Run-2 data still to come