

Key Points

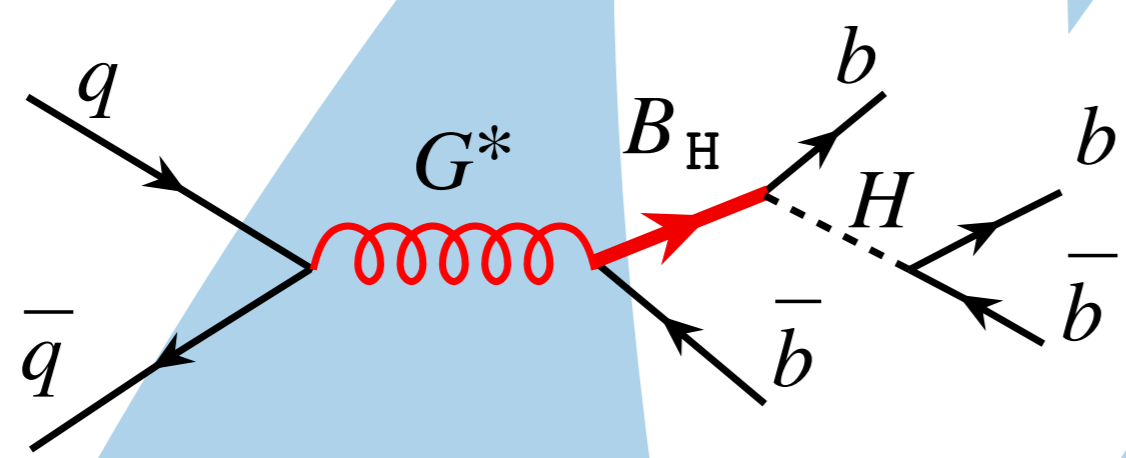
- 1st search for vector-like quarks (VLQs) via heavy gluons G^*
- single production of heavy bottom partners B_H that mix to SM b -quarks via strong interaction
- Lower limit of 2.0 TeV on the G^* mass when $m_{B_H} = m_{G^*}/2$ at 95% C.L.

Motivations

- Benchmark model of M. Chala and J. Santiago (Phys. Rev. D 88, 035010)
- Simplified minimal composite Higgs model with global symmetry

$$SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_Y$$

- Composite sector : heavy gluon G^* , composite Higgs boson and 4 heavy VLQs (elec. charge = $5/3, 2/3, -1/3, -4/3$)
- θ_{bR} : mixing between right-handed SM b -quark and B_H
- θ_s : mixing between elementary and composite gluons
- G^* coupling $\rightarrow g_c = g_s / \cos \theta_s$



Signature

- 4 b -jets in the final state
- Dominant background is QCD multijet (data-driven)
- Monte Carlo for other backgrounds ($t\bar{t}$ /top, W/Z + jets, etc.)
- Lepton veto to reduce $t\bar{t}$ /top and W/Z + jets

Event Selection

- Two different event topologies based on the Higgs boson momentum
 - when the Higgs boson is highly boosted ($p_T \gtrsim 300$ GeV), decay products may be merged into a single large radius parameter (large- R) jet
- Merged**
 - Higgs candidate : one large- R jet matched to a b -tagged small- R jet
- Resolved**
 - Higgs candidate : reconstructed from two small- R jets (one is b -tagged)
- In both scenarios, two extra small- R b -tagged jets are required to reconstruct B_H and G^* candidates
- Category 1 : reconstruct B_H with the leading jet
- Category 2 : reconstruct B_H with the next-to-leading jet
- Signal region (SR) : Higgs mass window [90, 140] GeV with at least three b -tagged jets

	Category 1			Category 2	
	SR1	SR2	SR3	SR4	SR5
Lower cuts on reconstructed (m_{G^*}, m_{B_H}) [TeV]	(1.0, 0.5)	(1.3, 0.5)	(0.8, 0.5)	(1.5, 0.5)	(1.8, 1.0)

- Merged criteria applied first, look for resolved when events fail the merged criteria

Multijet Background (BG) Estimation

- 'ABCD' data-driven method
- Three control regions (CRs) orthogonal to the signal region

Higgs sideband	D	B
Higgs mass window	C	SR

- Number of events in SR $\rightarrow N_{SR}^{MJ} = N_B/N_D \times N_C$
- N_X is the number of events in CR X after removing MC backgrounds
- Validation of the method using 15 GeV sideband validation regions (VRs) outside the Higgs mass window
- compare the expected and observed number of events in the VR

	Merged				
	VR1	VR2	VR3	VR4	VR5
Expected	563 \pm 16	213 \pm 10	1680 \pm 29	135 \pm 8	45 \pm 4
Observed	558	184	1666	137	35

	Resolved				
	VR1	VR2	VR3	VR4	VR5
Expected	1065 \pm 21	337 \pm 11	3758 \pm 50	242 \pm 10	63 \pm 5
Observed	1073	324	3906	238	56

Systematic Uncertainties

- Merged analysis

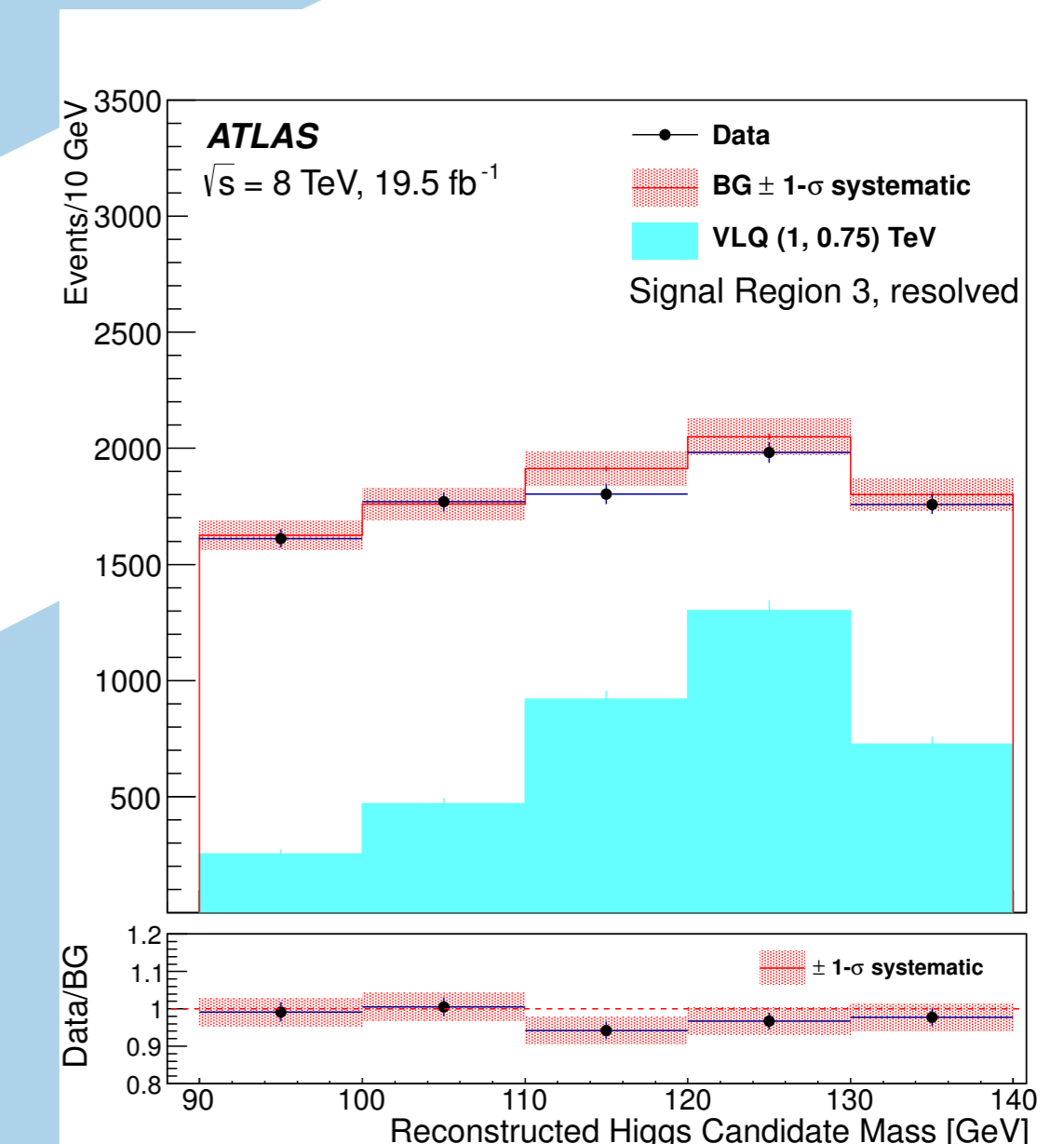
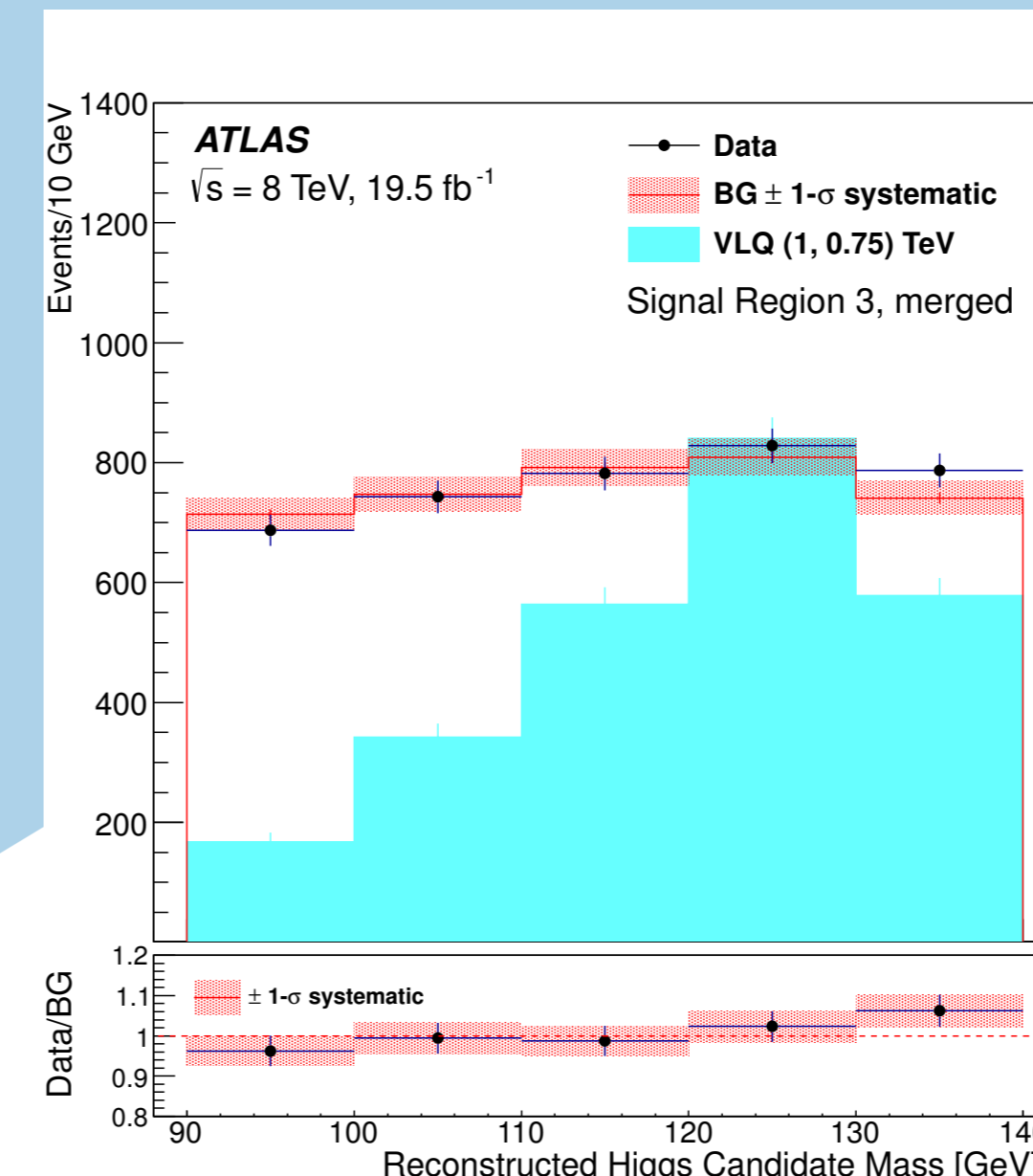
Systematic uncertainties	Uncertainties [%]				
	SR1	SR2	SR3	SR4	SR5
Background estimation	± 5	± 15	± 2.8	± 10	± 27
$t\bar{t}$ cross section	+1.0 -1.1	+0.8 -0.9	+1.2 -1.4	+0.8 -0.9	+0.6 -0.7
JER small- R	+0.29	+0.15	+0.01	-0.32	+0.20
JES small- R	+0.9 -0.8	+1.6 -0.7	+1.0 -1.0	+0.9 -1.0	+1.5 -1.0
JES/JMS large- R	+0.31 -1.5	+1.3 -1.5	+0.13 -1.9	+0.9 -0.8	+1.6 -0.20
b -tagging	+0.18 -0.18	+0.23 -0.33	+0.24 -0.18	< 0.01	+1.6 < 0.01
Luminosity	± 0.3	± 0.3	± 0.3	± 0.2	± 0.2
Data/MC stat. (CR)	± 2.2	± 4	± 1.3	± 4	± 8
Total (stat.)	± 2.7	± 5	± 1.5	± 6	± 10
Total (syst.)	± 6	± 15	± 4	± 11	± 28

- Resolved analysis

Systematic uncertainties	Uncertainties [%]				
	SR1	SR2	SR3	SR4	SR5
Background estimation	± 3.5	± 6	± 4	± 8	± 16
$t\bar{t}$ cross section	+0.24 -0.27	+0.20 -0.23	+0.31 -0.4	+0.23 -0.26	+0.17 -0.20
JER small- R	+0.17	+0.32	+0.18	-0.37	-0.5
JES small- R	+0.8 -0.6	+0.7 -0.6	+0.6 -0.7	+0.8 -0.7	+1.0 -0.8
b -tagging	+0.5 -0.4	+0.5 -0.30	+0.5 -0.4	+0.4 -0.4	+0.7 -0.7
Luminosity	± 0.13	± 0.13	± 0.15	± 0.15	± 0.11
Data/MC stat. (CR)	± 1.6	± 2.7	± 1.0	± 3.3	± 6
Total (stat.)	± 2.1	± 4	± 1.0	± 4	± 8
Total (syst.)	± 4	± 7	± 4	± 8	± 17

Results

- Observed and expected distributions of the reconstructed Higgs boson candidate mass in SR3



- Observed data and background yields in the SRs for the merged and resolved analyses

	Merged				
	SR1	SR2	SR3	SR4	SR5
Background					
Multijet	1104 \pm 27	398 \pm 16	3372 \pm 49	259 \pm 12	85 \pm 7
$t\bar{t}$ /top	107 \pm 4	30.0 \pm 2.3	398 \pm 8	18.3 \pm 1.9	4.2 \pm 1.0
W/Z + jets	10.5 \pm 1.3	4.4 \pm 0.9	30.1 \pm 1.9	2.6 \pm 0.8	0.8 \pm 0.5
Total BG	1222 \pm 33 \pm 70	432 \pm 20 \pm 60	3800 \pm 60 \pm 150	280 \pm 16 \pm 30	90 \pm 9 \pm 25
Data	1310	456	3827	287	89

	Resolved				
	SR1	SR2	SR3	SR4	SR5
Background					
Multijet	1985 \pm 34	639 \pm 18	8580 \pm 90	523 \pm 18	141 \pm 9
$t\bar{t}$ /top	64.2 \pm 3.2	17.7 \pm 1.8	353 \pm 8	15.4 \pm 1.6	3.3 \pm 0.7
W/Z + jets	35.0 \pm 3.3	12.7 \pm 1.8	142 \pm 6	12.8 \pm 2.2	2.6 \pm 0.4
Total BG	2080 \pm 40 \pm 80	669 \pm 25 \pm 50	9080 \pm 90 \pm 340	551 \pm 23 \pm 50	147 \pm 12 \pm 25
Data	2106	706	8927	568	122

Combined Limits

- Limits extracted by combining results from the merged and resolved analyses
- Potential contamination of the control regions by signal
 - Signal contamination estimated and removed from each control region, assuming a signal corresponding to the limit calculated
- Limits are evaluated until convergence

