Search for heavy resonances decaying to tW

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DESY Hamburg

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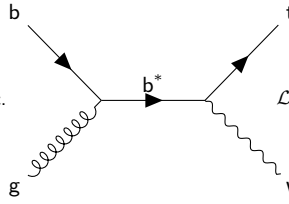
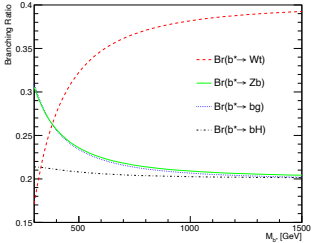
Benchmark Model: Excited b Quarks

$$\mathcal{L}_1 = \frac{g_s}{2\Lambda} G_{\mu\nu} \bar{b} \sigma^{\mu\nu} \left(\kappa_L^b P_L + \kappa_R^b P_R \right) b^* + \text{h.c.}$$



$$\mathcal{L}_2 = \frac{g_2}{\sqrt{2}} W_\mu^+ \bar{t} \gamma^\mu \left(g_L P_L + g_R P_R \right) b^* + \text{h.c.}$$

- single production in pp collisions via strong force
- decay to tW dominant at high b* masses (> 400 GeV)
- three benchmark models considered:
  - left-handed ($\kappa_L^b = g_L = 1$, $\kappa_R^b = g_R = 0$)
  - right-handed ($\kappa_L^b = g_L = 0$, $\kappa_R^b = g_R = 1$)
  - vector-like ($\kappa_L^b = g_L = 1$, $\kappa_R^b = g_R = 1$)



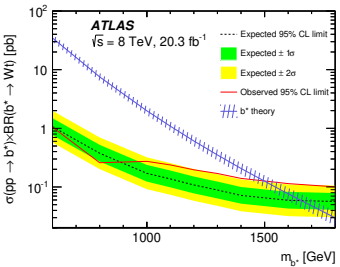
J.Nutter, R. Schwienhorst et al. Phys.Rev.D 86, 094006

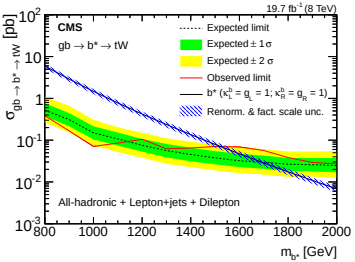
Searches for b^* decaying to tW

- ATLAS[a] at 8 TeV
- CMS [b] at 8 TeV
- new: CMS (all-hadronic final state)[c] at 13 TeV
- new: CMS (ℓ+jets final state)[d] at 13 TeV
  - combination of all-hadronic and ℓ+jets search
  - most stringent limits:

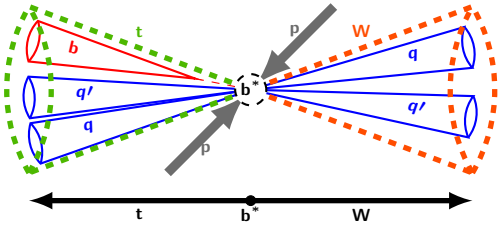
Limits [TeV]		
LH	RH	VL
3.0	3.0	3.2

[a] JHEP 02 (2016) 110
[b] JHEP 01 (2016) 166
[c] arXiv: 2104.12853; submitted to JHEP
[d] arXiv: 2111.10216; submitted to JHEP

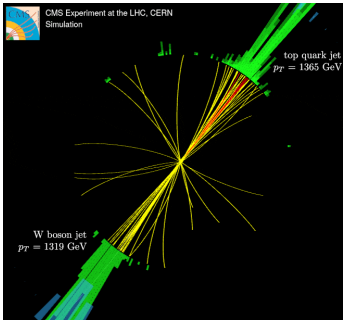




Analysis Strategy of all-hadronic channel



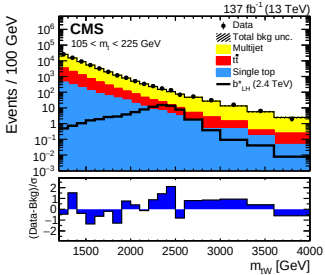
- top quark and W boson boosted due to high m_{b^*}
- focus on final state merged top jet and merged W jet
- reconstruct top quark and W boson as AK8 jets
- search for resonance in two dimensional $(m_{\mathrm{t}}, m_{\mathrm{tW}})$ plane

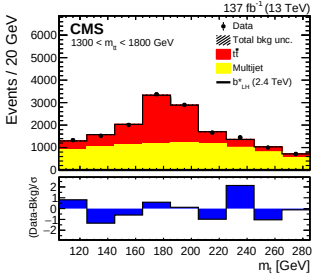


simulated b* event

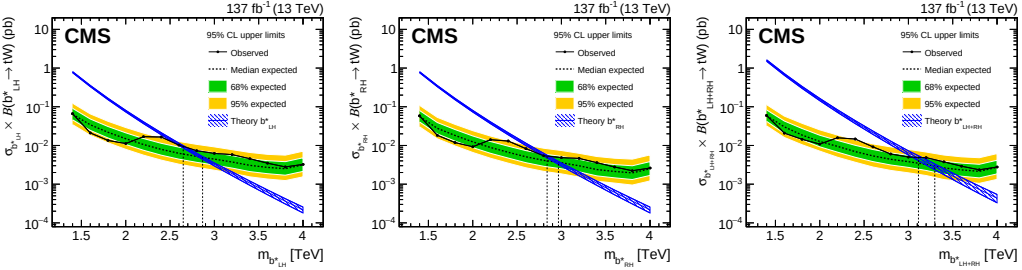
Analysis Method

- select events with 2 AK8 jets ($p_{\mathrm{T}} > 400\,\mathrm{GeV}$)
  - one W-tagged AK8 jet $\rightarrow$ W candidate
  - opposite AK8 jet $\rightarrow$ top candidate
- 2D likelihood fit of $(m_{\mathrm{t}}, m_{\mathrm{tW}})$ plane within $[65, 285]\mathrm{GeV}$ and $[1200, 4000]\mathrm{GeV}$
- sensitive to b^* at $M_{\mathrm{b}^*} \geq 1.4\,\mathrm{TeV}$
- smoothly falling non-resonant background
  - multijet scattering, W+jets
  - estimated from data
- resonant background
  - $\mathrm{t\bar{t}}$ and single t
  - estimated from MC templates
  - constrained in control region





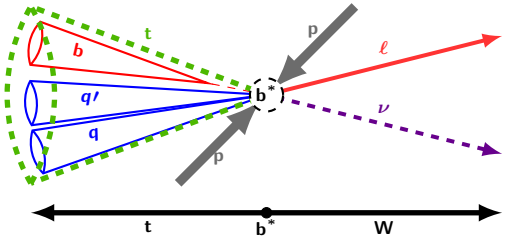
Results

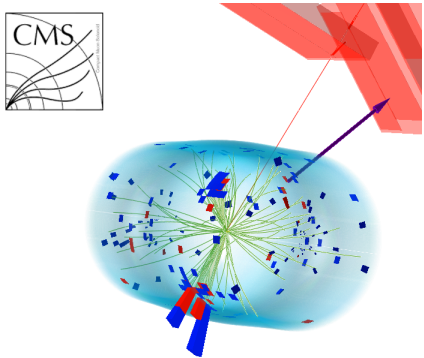


- limits on m_{b^*}:
  - 2.6 (LH), 2.8 (RH), and 3.1 (VL)

$\rightarrow$ combination with ℓ+jets channel for best sensitivity

$\rightarrow$ extend range down to m_{b^*} because of lower trigger thresholds

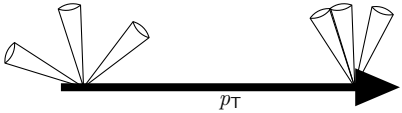


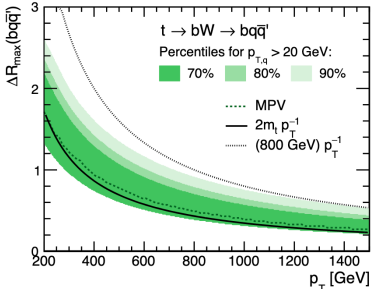


simulated b* event

- top quark and W boson boosted due to high m_{b^*}
- focus on final state with lepton, $\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}$ and merged top jet
- reconstruct top quark using top tagged HOTVR jet
- reconstruct W boson from lepton and $\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}$
- search for heavy resonance in m_{tW} spectrum

- top quark decay products more collimated with higher p_T
- at large enough Lorentz boost:
  - reconstruction as single jet possible
  - identification of top jet via substructure





R. Kogler: Springer Tracts Mod.Phys. 284 (2021)

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  - reconstruction as single jet possible
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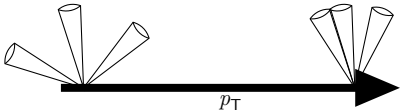
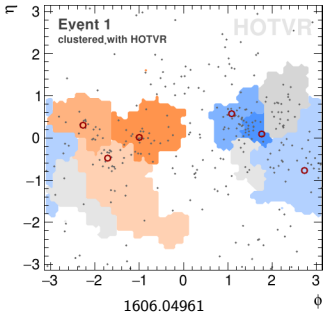
Heavy Object Tagger with Variable R [1]

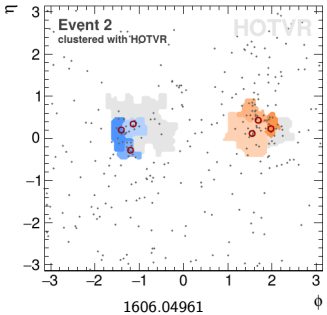
- adapts jet size to $p_{T,\text{jet}}$ using $R_{\text{eff}}(p_T) = \frac{\rho}{p_T}$
- mass jump veto to suppress clustering of soft radiation and resolve substructure



low-p_T $t\bar{t}$ event

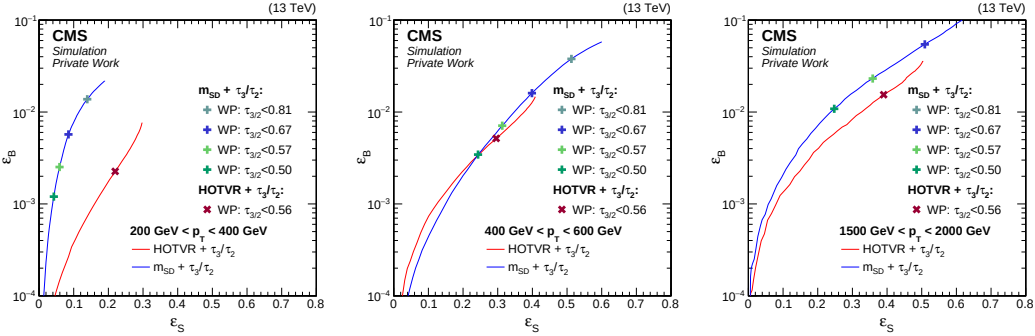


high-p_T $t\bar{t}$ event



[1] T. Lapsien et al.: Eur. Phys. J. C 76, 600 (2016), arXiv: 1606.04961

Top Tagging Efficiency

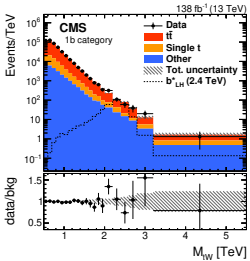


- scan over N-Subjettines ratio τ_3/τ_2
- HOTVR covers wider range in p_{T} giving stable performance for low and high b* masses

- signal efficiency ε_S:
  - measured in b* signal MC
- background efficiency ε_B:
  - measured in QCD multi-jet MC

Analysis Method

- select events with isolated e/μ, $p_{\mathrm{T}}^{\mathrm{miss}}$ and t-tagged HOTVR jet
- extend signal sensitivity down to $m_{\mathrm{b}^*} \geq 0.7\,\mathrm{TeV}$
- three categories based on number of b-tagged AK4 jets (0b, 1b, 2b)
- background with t quarks
  - $\mathrm{t\bar{t}}$ and single t
  - estimated from MC templates
  - constrained in 2b category
- subdominant background with misidentified t jets
  - W/Z+jets, diboson
  - estimated from data in 0b category
- simultaneous binned likelihood fit 1b, 2b categories and all-hadronic channel

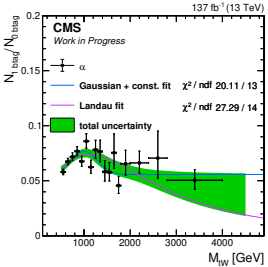


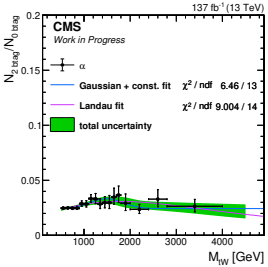
- subdominant background with misidentified top jets estimated from 0b control region
- calculate α ratio for non-top backgrounds

$$\alpha_i = \frac{N_{\mathrm{SR},i}}{N_{\mathrm{CR},i}}$$

transfer functions

- obtained from fit to α ratio
- different parametrizations considered
- systematic uncertainty estimated as difference between functions $\oplus$ statistical uncertainty

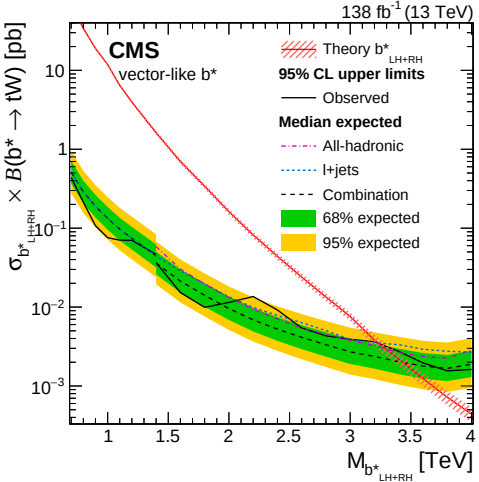




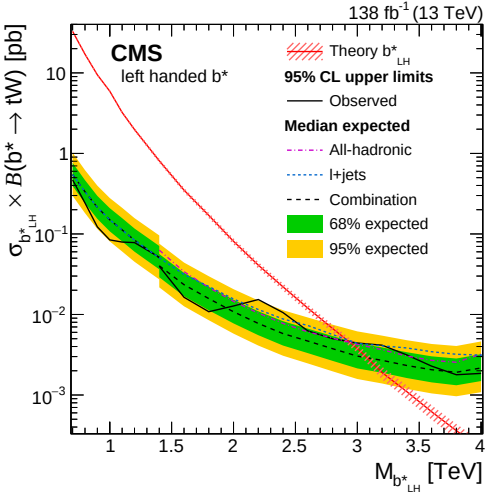
- simultaneous fit of all-hadronic and ℓ+jets distributions
- expected and observed upper cross section limits from combination
- unique limits in m_{tW} range [700,1400] GeV from ℓ+jets analysis
- comparable sensitivity above 1400 GeV
- mass exclusion limits:

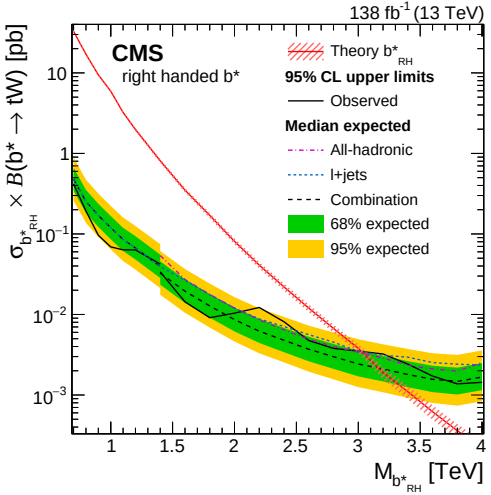
Mass limits [TeV]

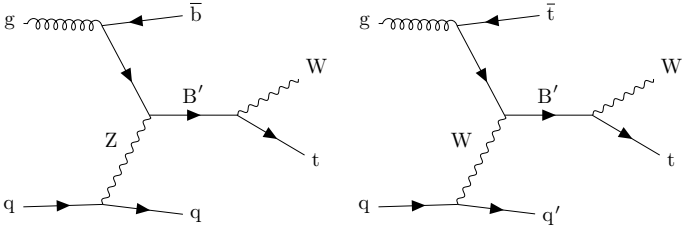
	Median expected		Observed	
Chirality	ℓ+jets	all-hadronic	combination	
LH	2.95	2.95	3.09	2.95
RH	3.02	3.02	3.17	3.03
VL	3.22	3.28	3.43	3.22



Results of Combination

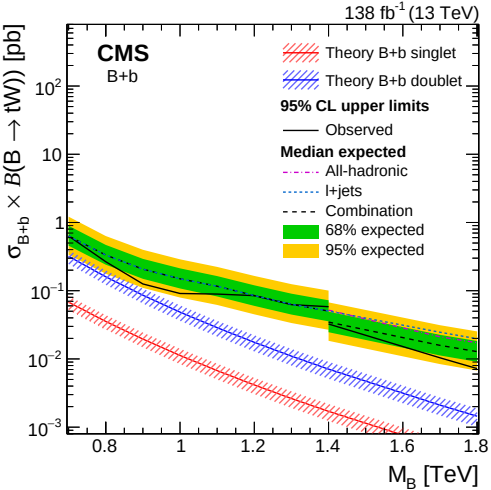


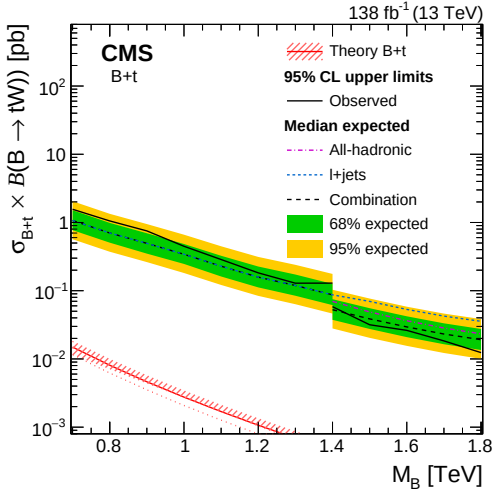




- production of heavy resonance via weak interaction
- production modes in association with b or t quark
- addition forward jet in final state

Reinterpretation: Vector-like B′ Quark





Summary

- search for a heavy resonance decaying to tW
- statistical combination of all-hadronic and ℓ+jets channels
- no deviation from SM observed
- strongest limits on b* to date
- reinterpretation in the context of VLQ B
- just submitted to JHEP