

# Search for $b^*$ decaying to $tW$ in the $l+jets$ final state

Alexander Fröhlich,  
Johannes Haller, Roman Kogler

Universität Hamburg  
Institut für Experimentalphysik

Terrascale Annual Meeting 2018



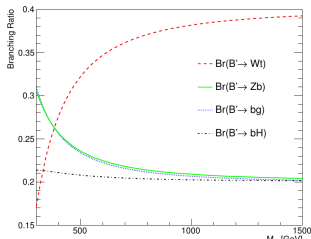
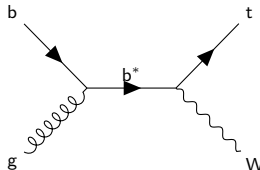
GEFÖRDERT VOM



Bundesministerium  
für Bildung  
und Forschung

## Excited bottom quarks

- Predicted by various theories beyond the standard model (e.g. warped extra dimensions, composite Higgs)
- Single production in  $pp$  collisions by gluon and bottom quark interaction
- Left-handed, right-handed and vector-like couplings to  $W$  are possible



J.Nutter, R. Schwienhorst et al.: 1207.5179

## $b^*$ decay

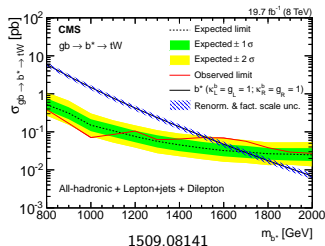
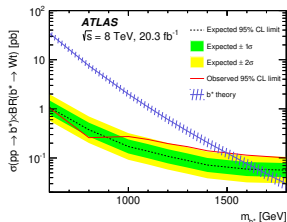
- Modes:  $gb$ ,  $bZ$ ,  $bH$  and  $tW$
- $tW$  branching ratio is dominant at high  $b^*$  masses
- Interesting signature of  $tW$  decay mode

## Run 1 Analyses

- ATLAS<sup>1</sup> at 7 TeV
- ATLAS<sup>2</sup> at 8 TeV
- CMS<sup>3</sup> at 8 TeV
  - CMS and ATLAS searches with comparable results
  - Limits set for left-/right-handed and vector-like benchmark scenarios

Limits [GeV]

left h.	right h.	vector-like
1390	1430	1530

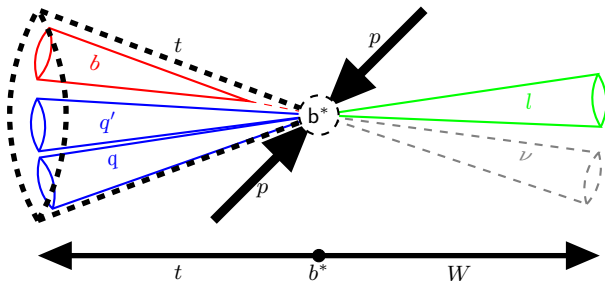


<sup>1</sup>ATLAS: 1301.1583

<sup>2</sup>ATLAS: 1510.02664

<sup>3</sup>CMS: 1509.08141

## In this talk: focus on muon channel

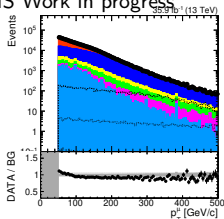


## Event Kinematics

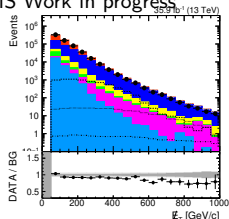
- Top and  $W$  are back to back due to high  $M_{b^*}$
- Boost of top quark and  $W$  boson dependent on  $M_{b^*}$
- Reconstruct top quark using top tagging with HOTVR
  - one algorithm for all  $b^*$  masses
- Reconstruct  $W$  boson from muon and  $\cancel{E}_T$

2016 dataset

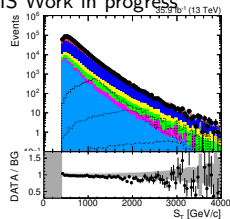
CMS Work in progress



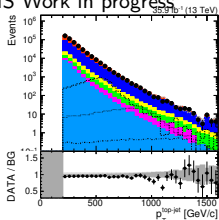
CMS Work in progress



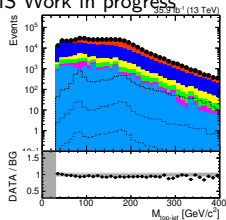
CMS Work in progress



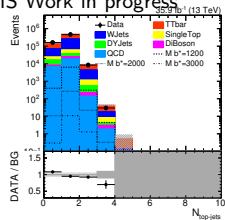
CMS Work in progress



CMS Work in progress

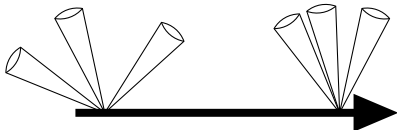
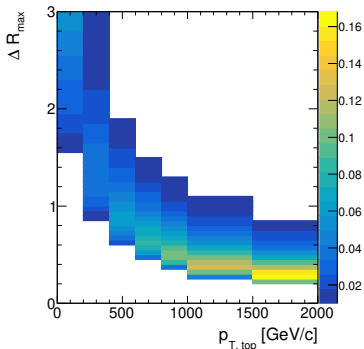


CMS Work in progress



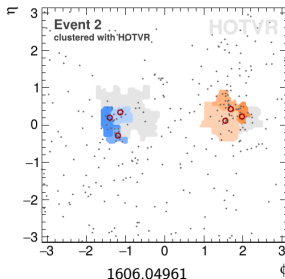
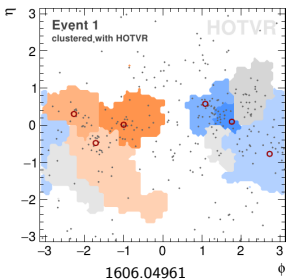
- Top tagging over wide kinematic range is challenging
  - Top quark decay is more collimated with higher  $p_T$
  - Fixed cone size jets are only sensitive to certain  $p_T$  region
- ⇒ Adaptable jet size to cover large kinematic region

CMS Work in progress



## Heavy Object Tagger with Variable R

- Stable performance in wide  $p_T$  range
- 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



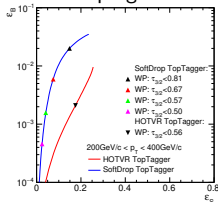
<sup>4</sup>T. Lapsien et al.: 1606.04961

### Efficiency

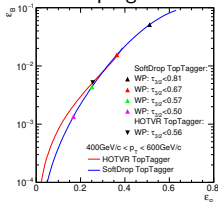
$$\varepsilon = \frac{N_{\text{tagged}}}{N_{\text{total}}}$$

- signal efficiency  $\varepsilon_S$  measured in  $b^*$  samples
  - HOTVR jet matched to generator level top
- misstag rate  $\varepsilon_B$  measured in QCD samples
  - HOTVR jet matched to generator level jet

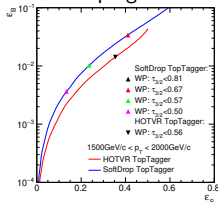
CMS Work in progress



CMS Work in progress



CMS Work in progress

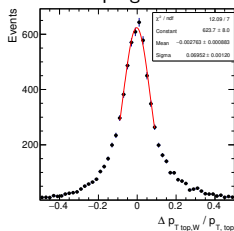




## Reconstruction Hypotheses

- Top hypothesis from HOTVR jet
- W hypotheses from muon and  $\cancel{E}_T$

## CMS Work in progress



## Reconstruction Discriminator

$$\chi^2 = \left( \frac{\Delta\phi_{t,W}^{\text{reco}} - \Delta\phi_{t,W}^{\text{mean}}}{\sigma_{\Delta\phi_{t,W}}} \right)^2 + \left( \frac{\Delta p_{T,\text{rel}}^{\text{reco}} - \Delta p_{T,\text{rel}}^{\text{mean}}}{\sigma_{\Delta p_{T,\text{rel}}}} \right)^2 \quad \Delta p_{T,\text{rel}} = \frac{p_{T,t} - p_{T,W}}{p_{T,t}}$$

- Mean values and widths from matched distributions in MC

$\Delta\phi_{t,W}^{\text{mean}}$	$\sigma_{\Delta\phi_{t,W}}$	$\Delta p_{T,\text{rel}}^{\text{mean}}$	$\sigma_{\Delta p_{T,\text{rel}}}$
$\pi$	0.055	0	0.069

## Two Signal Regions

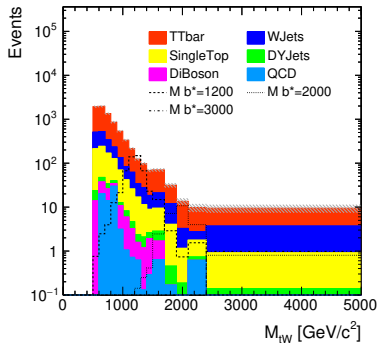
main region:

- 1 b-tagged anti- $k_T$  jet
- 1 top-tagged HOTVR jet
  - $\Delta\phi_{t,\mu} > \pi/2$
  - after reconstruction:  $\chi^2 < 20$

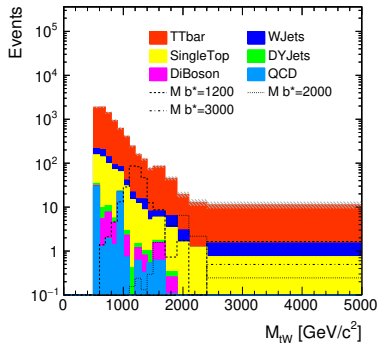
$t\bar{t}$  enriched region:

- 2+ b-tagged anti- $k_T$  jet
- 1 top-tag HOTVR jet

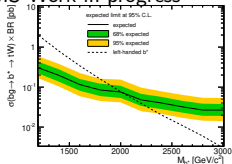
CMS Work in progress



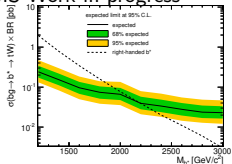
CMS Work in progress



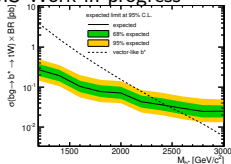
CMS Work in progress



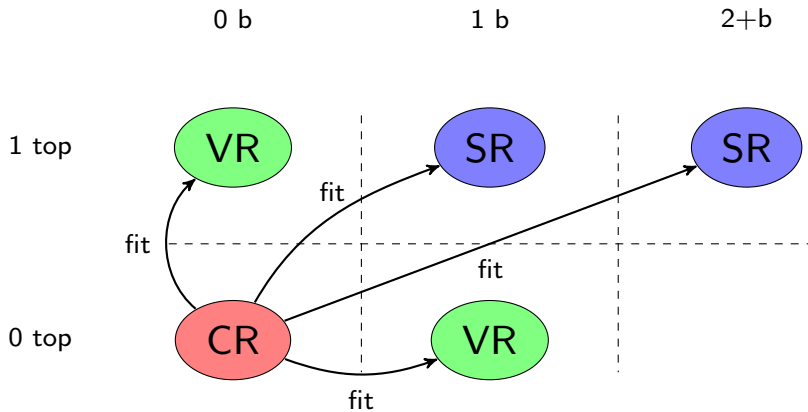
CMS Work in progress



CMS Work in progress



- expected limits calculated in *main* signal region
- only stat. and MC scale uncertainties right now
- good sensitivity over wide mass range
- *bump* around 2 TeV from uncertainties on non-top backgrounds
  - more reliable background estimation needed



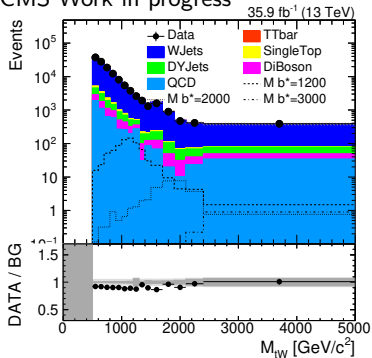
## Non-top control region

- veto b-tag
- veto HOTVR top-tag

## Strategy

- obtain extrapolation function from fit to non-top MC ratio
$$\alpha(M_{tW}) = \frac{N_{SR}(M_{tW})}{N_{CR}(M_{tW})}$$
- subtract top backgrounds ( $t\bar{t}$  and single  $t$ ) from data and extrapolate

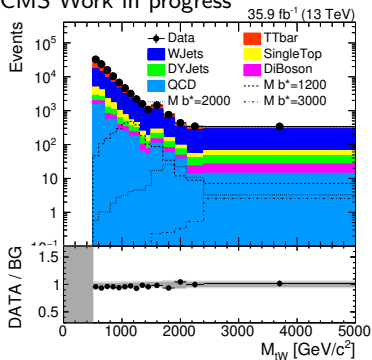
## CMS Work in progress



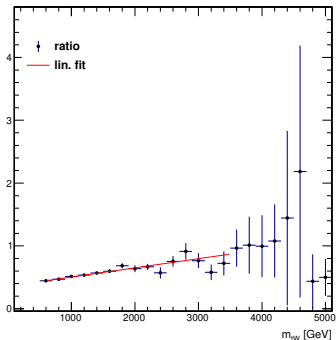
### Validation region

- 1 b-tag
- veto HOTVR top-tag
- fitting linear function

### CMS Work in progress



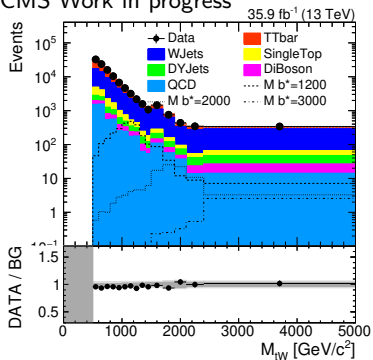
### CMS Work in progress



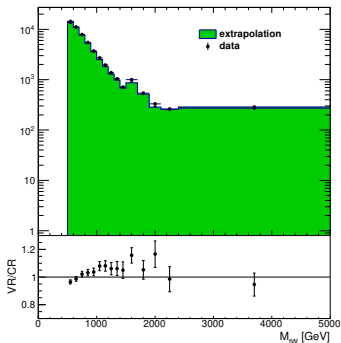
### Validation region

- 1 b-tag
- veto HOTVR top-tag
- fitting linear function

### CMS Work in progress



### CMS Work in progress



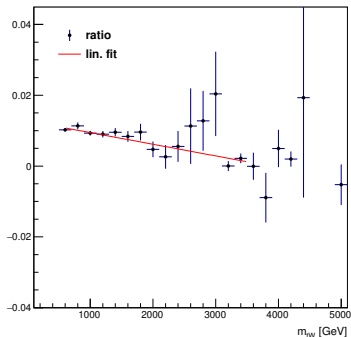
### main signal region

- 1 b-tag
- 1 HOTVR top-tag

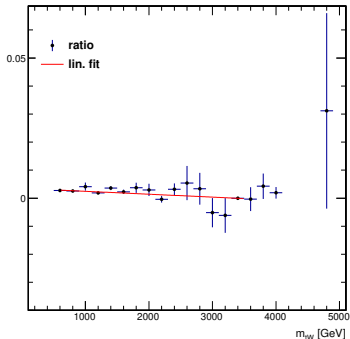
### $t\bar{t}$ enriched signal region

- 2+ b-tag
- 1 HOTVR top-tag

CMS Work in progress



CMS Work in progress





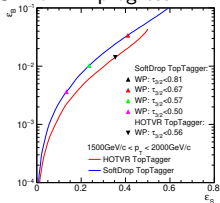
## Conclusion

- First search for  $b^* \rightarrow tW$  in  $pp$  collisions at 13 TeV
- Top tagging with HOTVR-PUPPI very promising
- First look at expected limits in muon channel
- Taken first steps towards datadriven background estimation

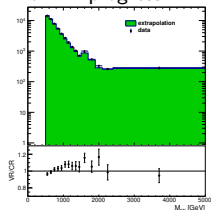
## Outlook

- Include electron channel and full systematics
- Full Run2 analysis

## CMS Work in progress

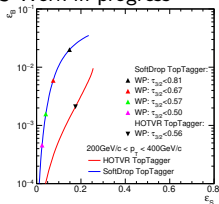


## CMS Work in progress

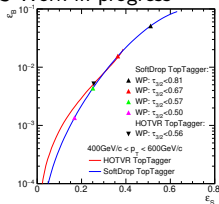


BACKUP

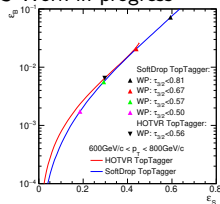
CMS Work in progress



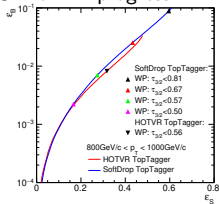
CMS Work in progress



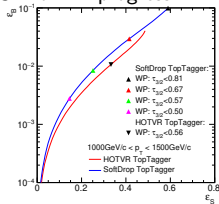
CMS Work in progress



CMS Work in progress



CMS Work in progress



CMS Work in progress

