

# Boosting sensitivity in searches for Dark Matter and heavy resonances with ATLAS

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On behalf of ATLAS Collaboration

**BOOST 2021**

August 2-5, 2021



ATLAS



- **Dark matter searches with full Run 2 dataset:**

- ▶ Search for dark matter produced in association with a dark Higgs decaying into  $W^\pm W^\pm$  or  $ZZ$  in fully hadronic final states: **Phys. Rev. Lett. 1126 (2021) 121802** [[arXiv:2010.06548](#)]
  - **Four prompt tagger.**
- ▶ Search for Dark Matter produced in association with a SM Higgs boson decaying to  $b$ -quarks. [[ATLAS-CONF-2021-006](#)]
  - **Identifying boosted  $H \rightarrow b\bar{b}$ .**

- **Heavy resonances searches with full Run 2 dataset:**

- ▶ Search for  $t\bar{t}$  resonances in fully hadronic final states: **JHEP 10 (2020) 61** [[arXiv:2005.05138](#)]
  - **Tagging boosted tops.**
- ▶ Search for pair-production of vector-like quarks with at least one leptonically-decaying  $Z$  boson and a third-generation quark: [[ATLAS-CONF-2021-024](#)]
  - **Multi-class Boosted Object tagger.**
- ▶ Search for a single vector-like  $B$  quark production and decay via  $B \rightarrow bH(b\bar{b})$ : [[ATLAS-CONF-2021-018](#)]
  - **Identifying boosted  $H \rightarrow b\bar{b}$ .**
- ▶ Search for pair production of scalar leptoquarks decaying into first- or second-generation leptons and top quarks: **Eur. Phys. J. C. 81 (2021) 313** [[arXiv:2010.02098](#)]
  - **BDT classifier using jet substructure variables.**
- ▶ Search for high-mass  $W\gamma$  and  $Z\gamma$  resonances: [[ATLAS-CONF-2021-041](#)]
  - **Tagging boosted W/Z bosons.**

# Large- $R$ jet collections

- ▶ Large- $R$  jets used to collect decay products of massive particles.

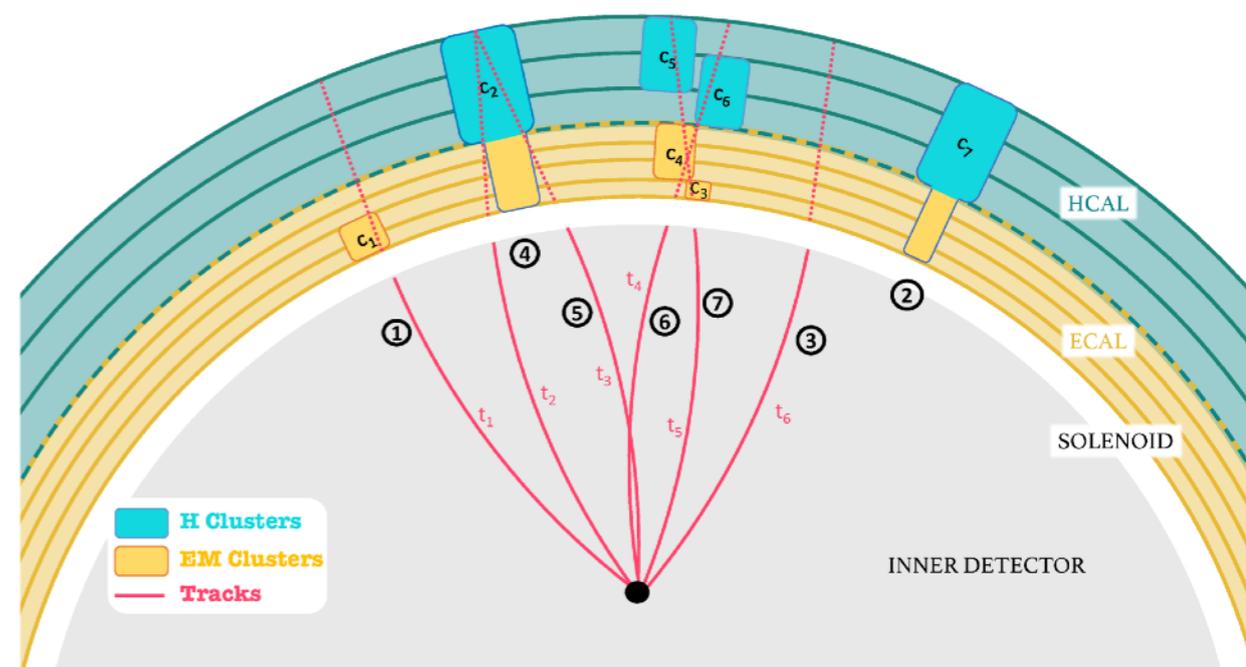
- ▶ **LCTopo Large- $R$  jets:**

- They are built from topological clusters that are calibrated to hadronic energy scale with local cluster weighting (LCW) using anti- $k_t$  jet algorithm with  $R = 1.0$ .
- **Trimming procedure applied to remove contributions from pile-up and soft radiation.**
  - ➔ Constituents from  $R = 0.2$ ,  $k_t$  jets with  $p_T^{R=0.2}/p_T^{R=1.0} < 0.05$  removed.
- $m_J$  **calculated combining calorimeter energy measurement with tracking information:**

$$m_J = \frac{\sigma_{\text{calo}}^{-2}}{\sigma_{\text{calo}}^{-2} + \sigma_{\text{TA}}^{-2}} \times m^{\text{calo}} + \frac{\sigma_{\text{TA}}^{-2}}{\sigma_{\text{calo}}^{-2} + \sigma_{\text{TA}}^{-2}} \times m^{\text{TA}}$$

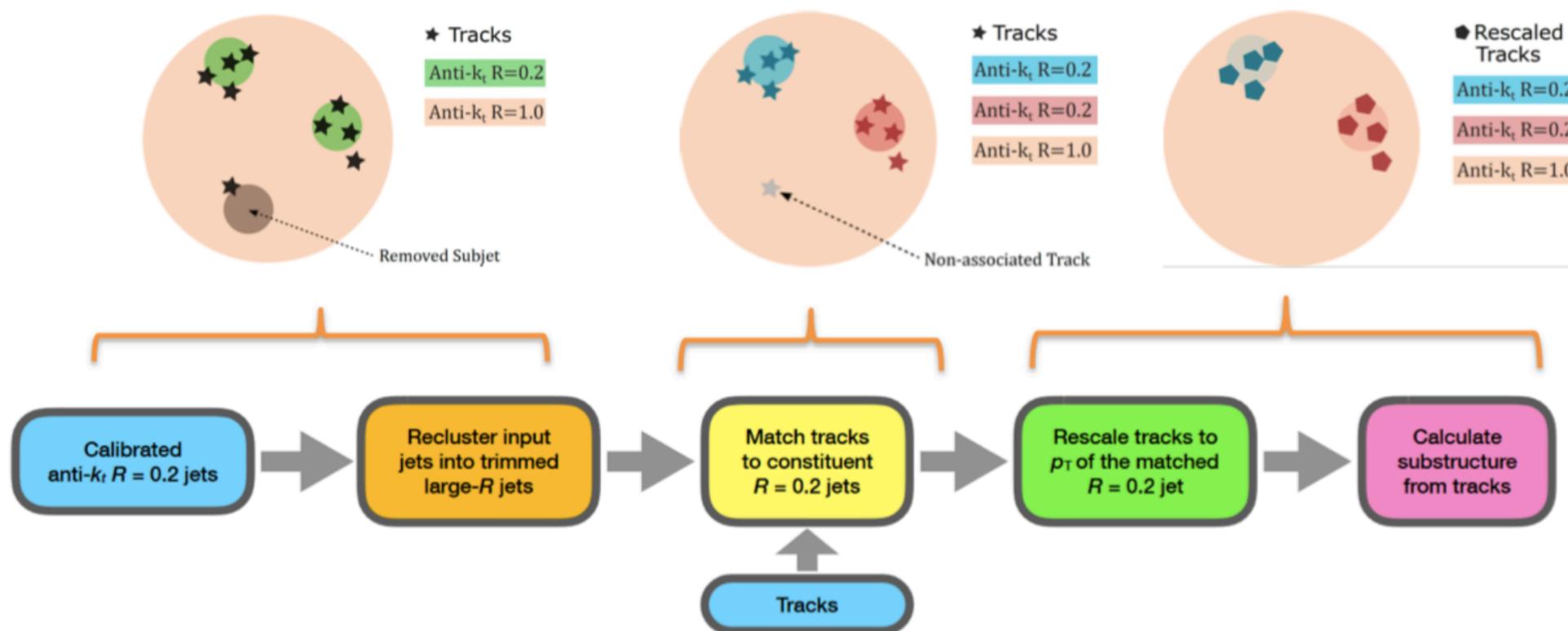
- ▶ **TCC Large- $R$  jets:**

- Jets built from track-calorimeter clusters (TCCs) which **combines** information from the calorimeter and ID.
- **Very good reconstruction performance found for jet-substructure variables at high- $p_T$ .**
- **Trimming procedure applied to remove contributions from pile-up and soft radiation.**
  - ➔ Constituents from  $R = 0.2$ ,  $k_t$  jets with  $p_T^{R=0.2}/p_T^{R=1.0} < 0.05$  removed.



# Large- $R$ jet collections

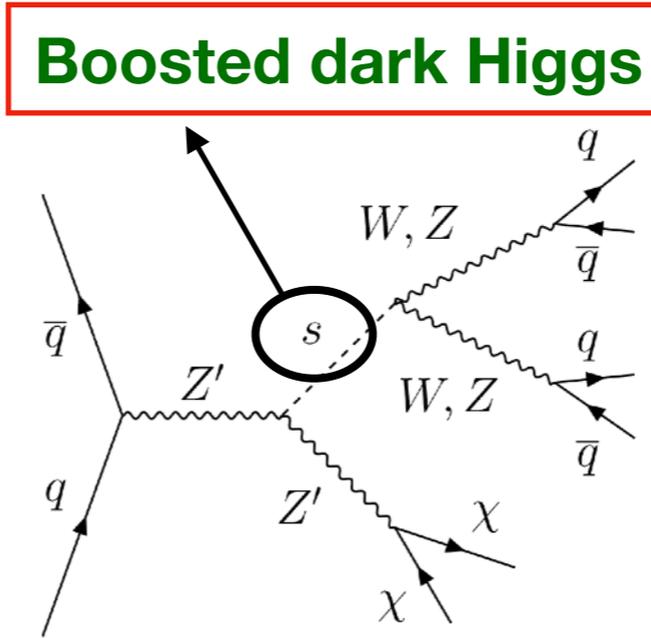
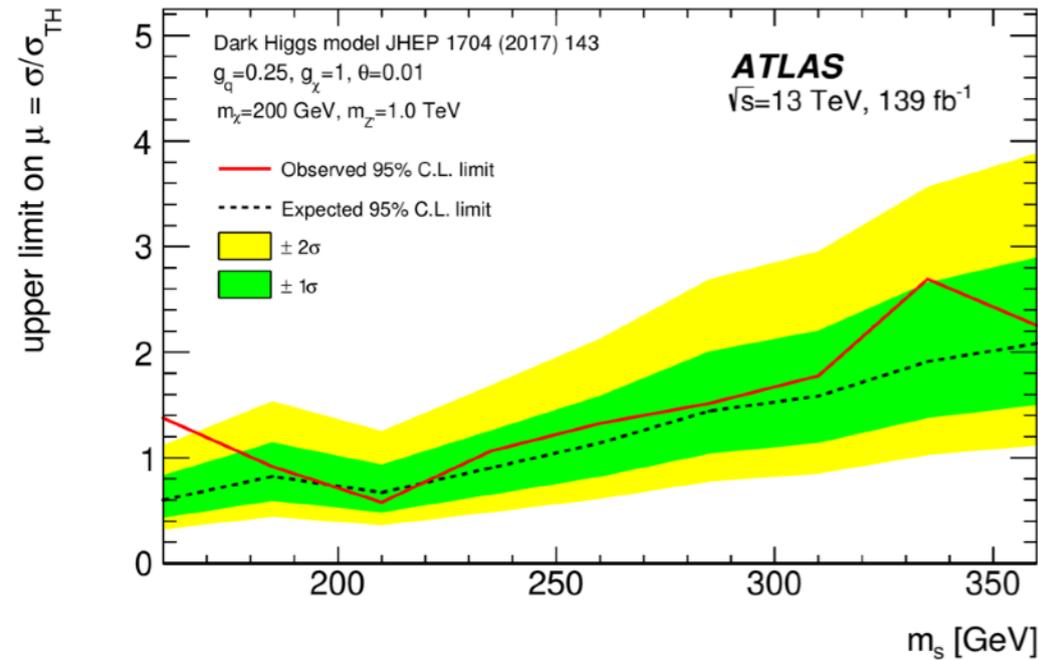
- Certain Large- $R$  jet collections allow for a “**bottom-up approach**” to propagate uncertainties:
  - Systematic uncertainties from jets constituents propagated to substructure variables.
- ▶ **Track-assisted reclustered (TAR) jets used:** based on reclustering well calibrated small- $R$  (0.4) jets with  $R = 0.8$  (or 1.0) anti- $k_T$  jet clustering.
  - Using **associated tracks to construct mass and substructure variables: tracks rescaled** using  $R = 0.4$  jets information **to account for contributions from neutral particles.**



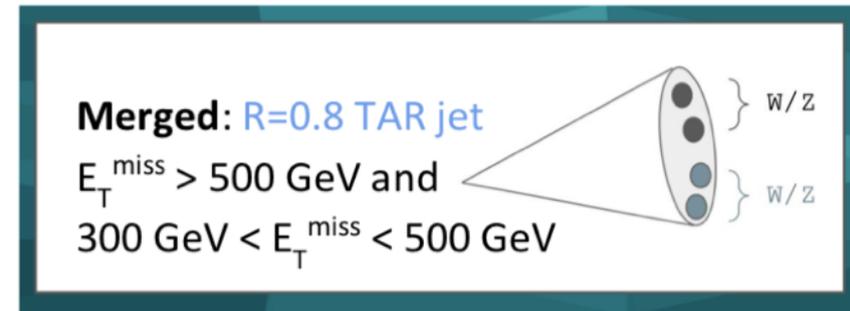
- ▶ **Large- $R$  reclustered (RC) jets:**
  - ▶ **Small- $R$  jet inputs for an anti- $k_T$  large- $R$  jet clustering.**

# Boosting sensitivity in searches for DM and heavy resonances

## 1) Search for DM produced in association with a dark Higgs: **Large- $R$ TAR jets**

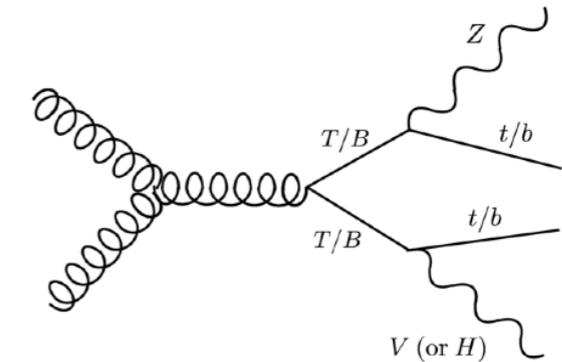


For  $m_{Z'} \gg m_s$ , 4-prong  
 Large- $R$  jets expected for signal.



- Background jets reduced by requiring:  
 $0.0 < \tau_4/\tau_2 < 0.3$  and  $0.0 < \tau_4/\tau_3 < 0.6$ .

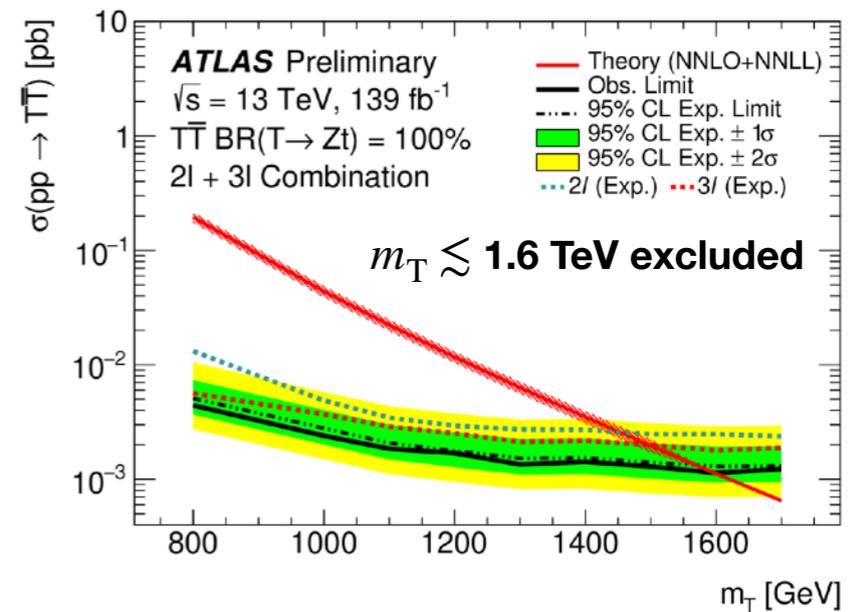
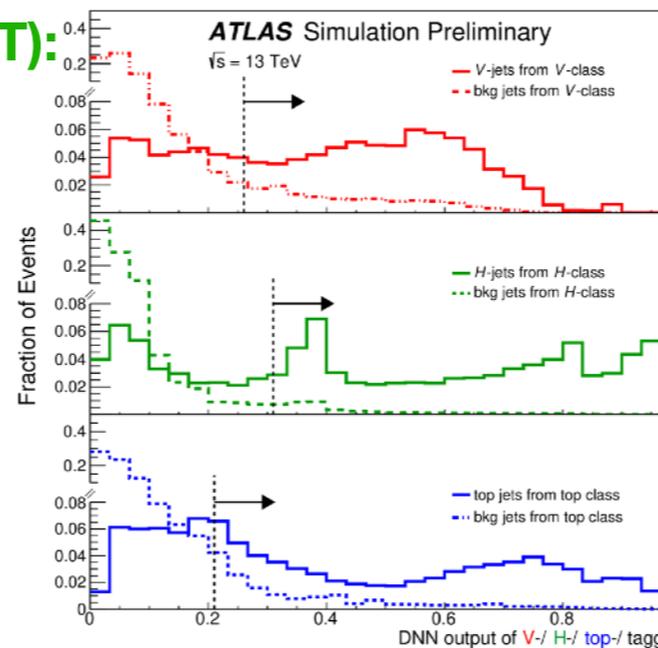
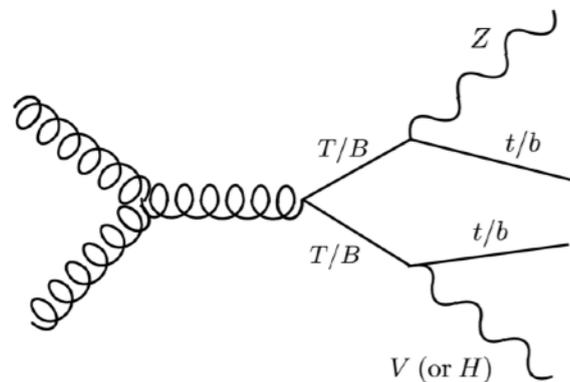
**VLQ pair production**



## 2) Search for a pair-production of vector like quarks: **Large- $R$ reclustered (RC) jets**

### ► **Multi-Class Boosted Object Tagger (MCBOT):**

- DNN trained with 18 input variables to identify jet origin.
- Simultaneous identification of V/H/top jets



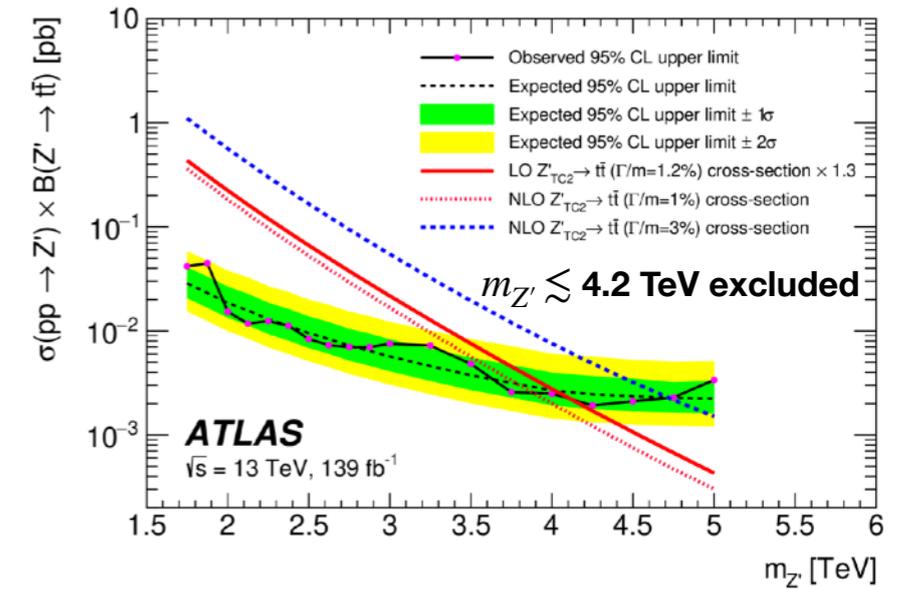
# Boosting sensitivity in searches for DM and heavy resonances

## 3) Search for $t\bar{t}$ resonances in fully hadronic final states

### ► DNN-based top tagger applied to suppress multijet background:

- Trained with several substructure variables:  
 $p_T, m_J, e_3, C_2, D_2, \tau_{21}, \tau_{32}, \sqrt{d_{12}}, \sqrt{d_{23}}, Q_W \dots$
- Top tagger performance corrected by means of SFs estimated by comparing data and MC in  $t\bar{t}$  events:

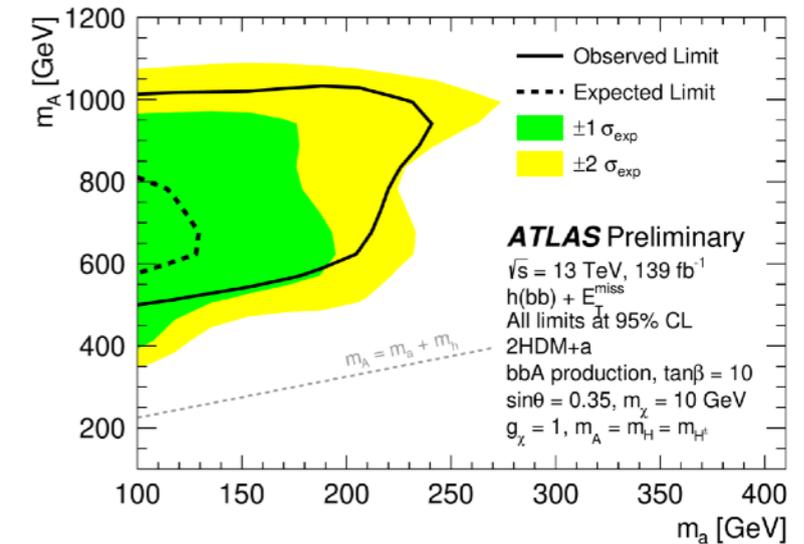
$$SF(p_T) = \epsilon_D / \epsilon_{MC}$$



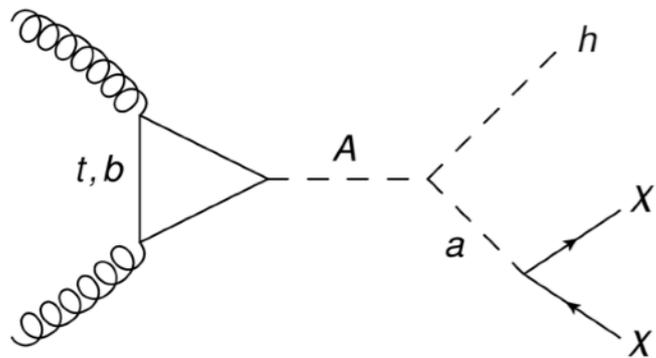
## Variable-radius track jets to identify boosted Higgs boson:

- $H \rightarrow b\bar{b}$  decay mode used: high BR + adequate S/B ratio thanks to  $b$ -tagging.
- $b$ -tagged VR track jets ghost-associated to large- $R$  jet Higgs candidate.
- VR track jets allow to reconstruct subjets ( $> 1$ ) for highly boosted Higgs bosons:

$$R_{\text{eff}}(p_T) = 30 \text{ GeV}/p_T \text{ with } 0.02 < R_{\text{eff}}(p_T) < 0.4$$

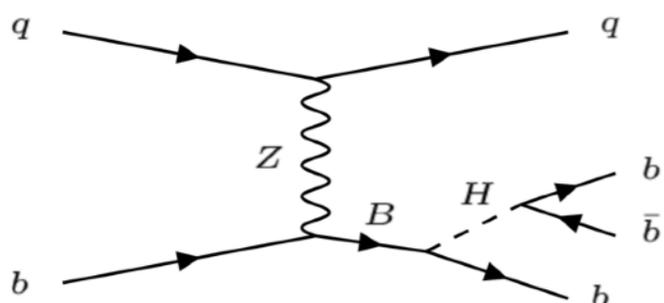


## 4) Search for DM produced in association with a SM Higgs



- Boosted Higgs boson for  $m_A \gg m_a$ .
- VR track jets allow to extend limits:  
► up to  $m_A \approx 1 \text{ TeV}$  for  $m_a = 100 \text{ GeV}$ .

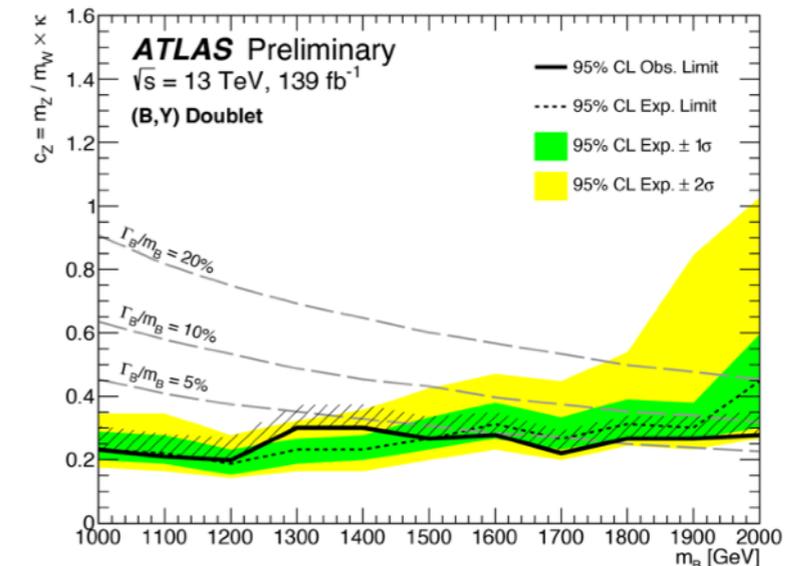
## 5) Search for a single vector-like $B$ quark



- Boosted Higgs boson for  $m_B \gg m_H$ .

$$c_Z \gtrsim 0.3 \text{ excluded}$$

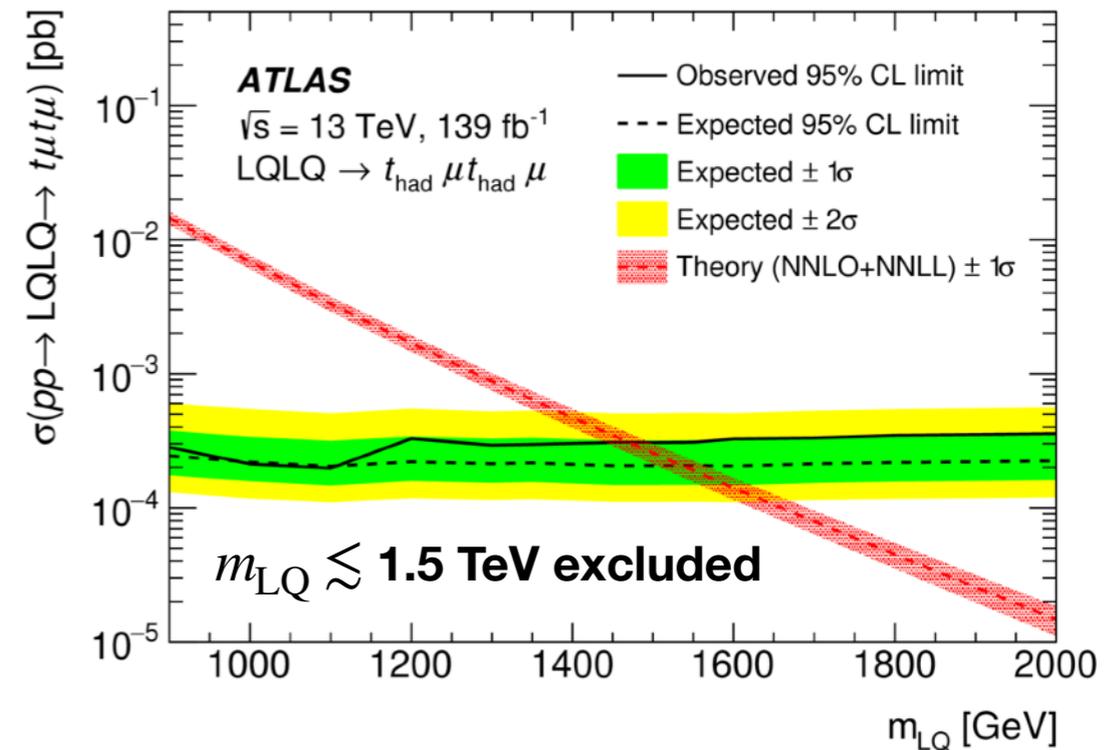
$$\text{for } 1 \text{ TeV} < m_B < 2.0 \text{ TeV}$$



# Boosting sensitivity in searches for DM and heavy resonances

## 6) Search for pair production of scalar leptoquarks:

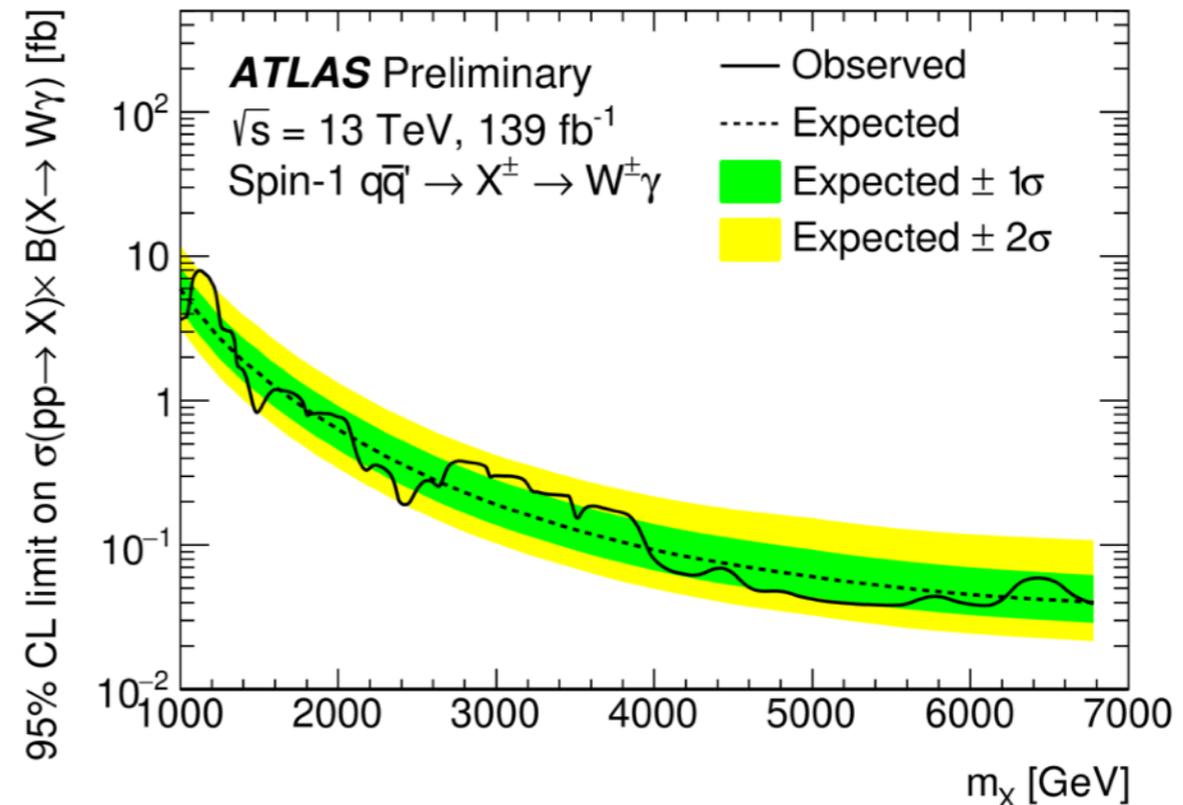
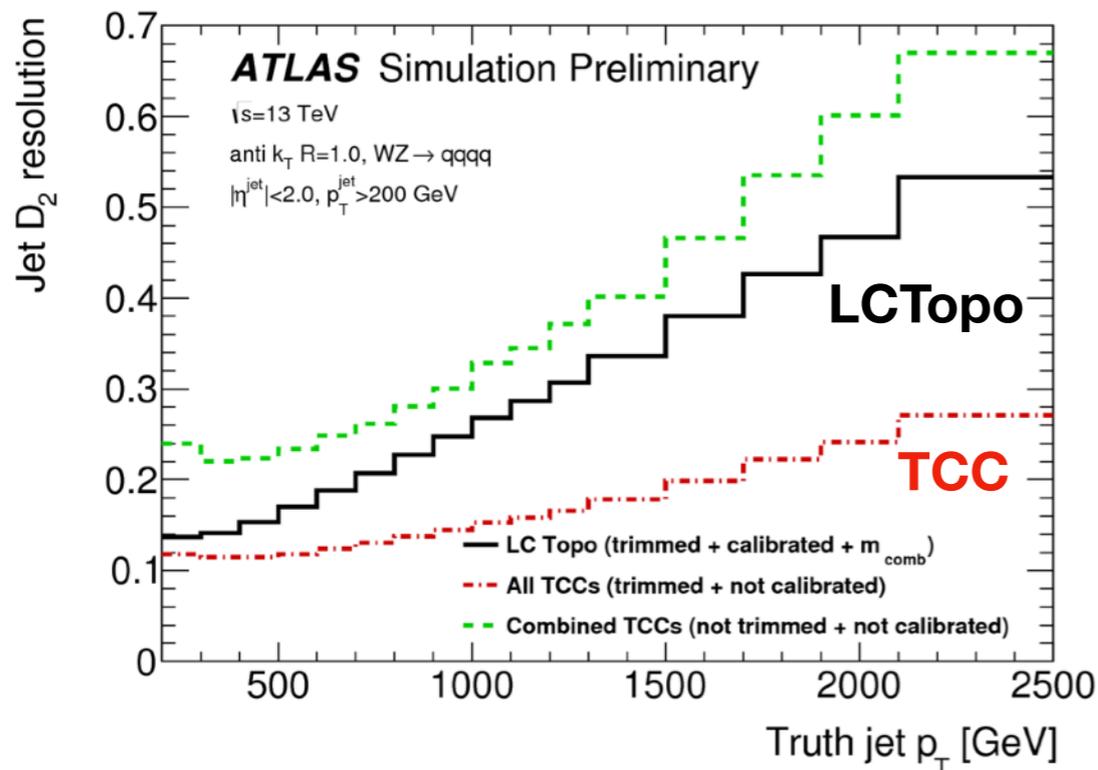
- ▶ This search targets LQ pair production focused on:
  - **LQ  $\rightarrow e/\mu t$ , where top quark decays hadronically.**
  - Final state signature described by pair leptons and a pair of LCTopo large- $R$  jets.
- ▶ **BDT approach based on kinematic variables and jet substructure variables** applied to classify events as originating from the signal or background.
  - Best discriminating variables:  $m_{l_1 l_2}$ ,  $p_{T, l_1} + p_{T, l_2}$ ,  $m_{J_1}$ ,  $m_{J_2}$ ,  $m_{l_1 l_2 J_1 J_2}$ .
  - Parametrize BDT to maximize sensitivity in a wide  $m_{LQ}$  range.



## 7) Search for high-mass $W\gamma$ and $Z\gamma$ resonances

### Large- $R$ TCC jets

- $D_2$  variable used to identify 2-prong structure expected from  $W^\pm/Z$  decays.



# Conclusions

- ▶ Several searches for DM particles and heavy resonances have been presented.
- ▶ Boosting techniques allows to improve sensitivity to signal models where boosted heavy particles are expected in the final state.
  - Mainly in models where resonances in TeV mass range decay to  $O(EW)$ -massive particles, such as, Higgs, W/Z and tops.
  - They allow to extend sensitivity of searches to very massive particles.
  - Improving the performance of boosted top/W/Z and Higgs taggers has allowed to increase sensitivity to smaller signal cross-sections.

➔ More improvements will come  
In the future!

