ATLAS Searches for Resonances Decaying to Boson Pairs

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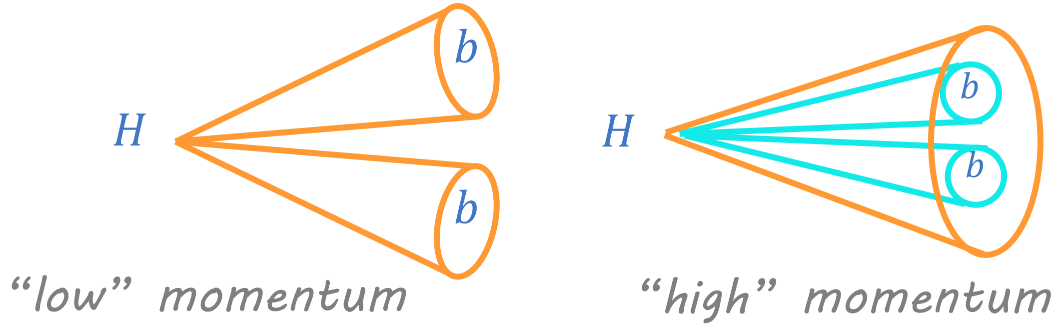
VIRTUAL EDITION

Introduction

- ATLAS has a vast di-boson search program
- Often target heavy resonances
  - Boosted performance vital to these searches
- Jet performance and jet substructure crucial for many di-boson searches
  - High mass resonances require excellent tagging in boosted topologies
- Summarise few of the latest techniques and search results

Jet Substructure for Boosted Topologies

- At high momentum ≥ 2 prong decays gives "merged" jets

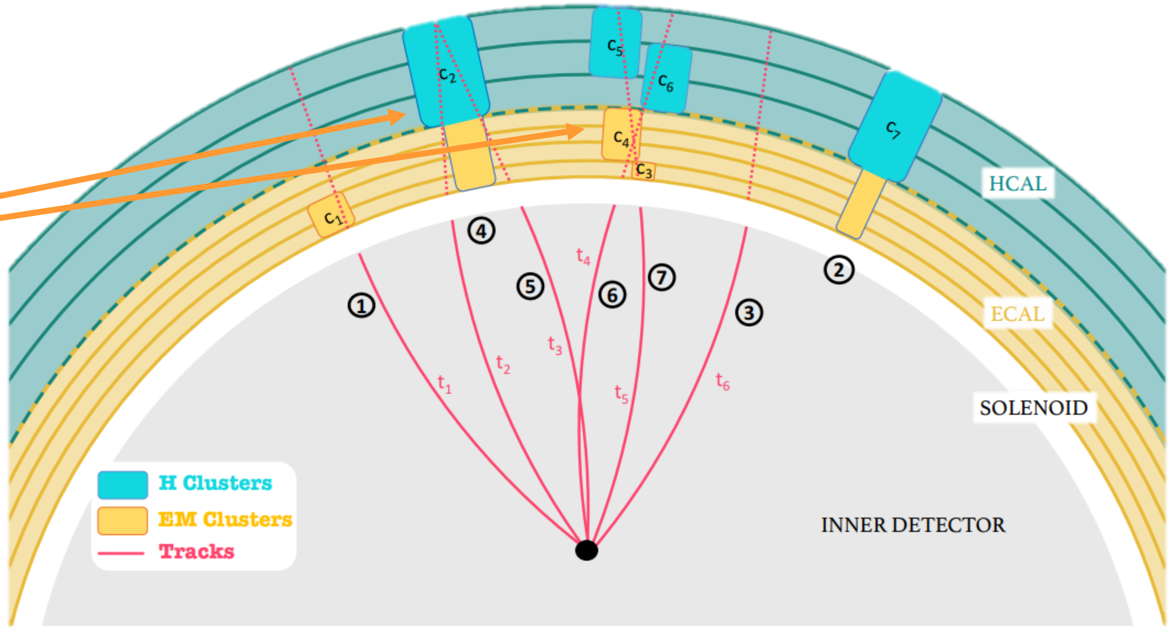


- "Standard" large radius (large-R) jets reconstructed only from **calorimeter (calo) information**
- **Discuss three methods** by ATLAS to help improve the jet performance for these types of decays

ATL-PHYS-PUB-2017-015

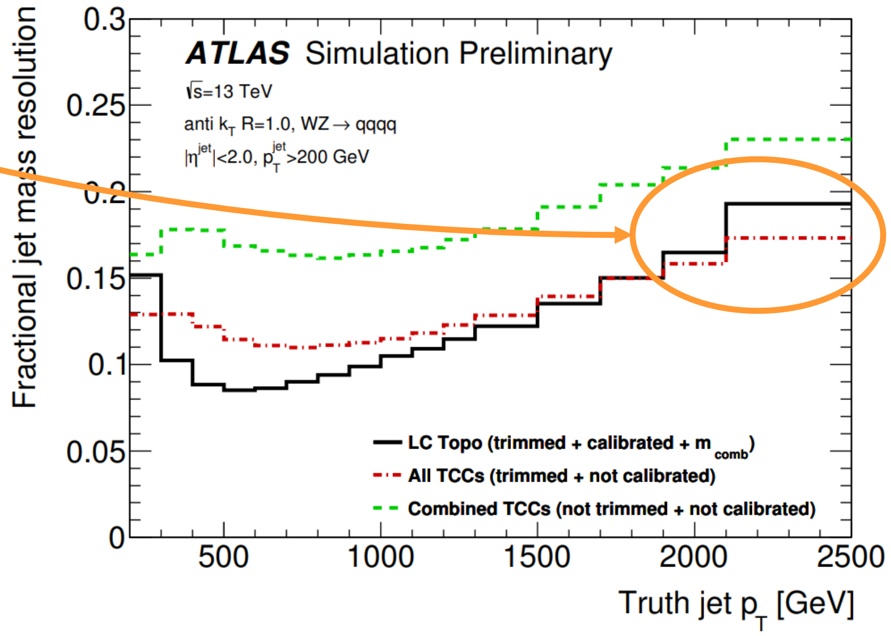
Track-Calo-Clusters (TCC)

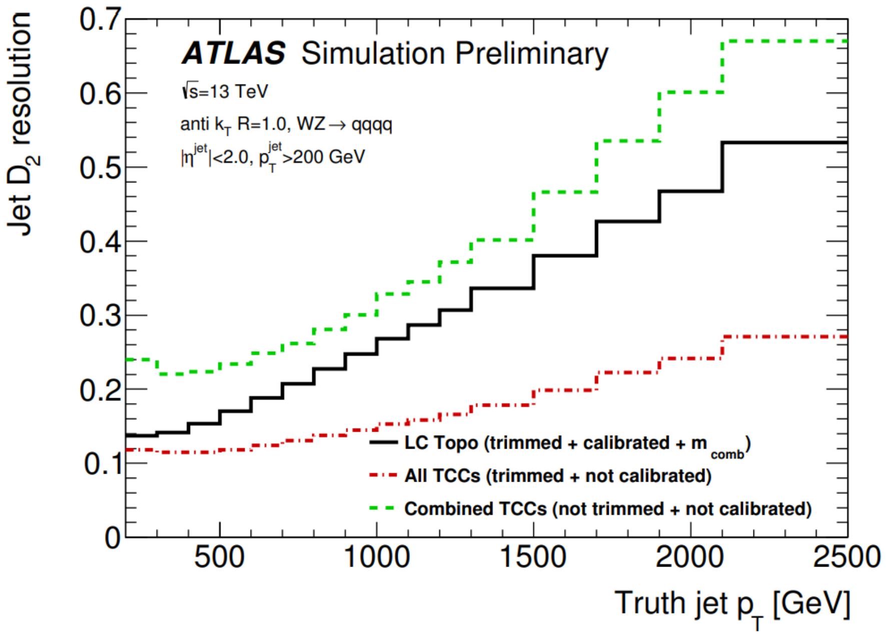
- Take advantage of the tracking detector in jet reconstruction
- **Tracks** got **superior spatial resolution** at high momentum
- Construct jets by calo-energy and track η, φ
  - Matched calo clusters and tracks
  - Account for "sharing" between clusters and tracks in four-momentum calculation



Track-Calo-Clusters (TCC)

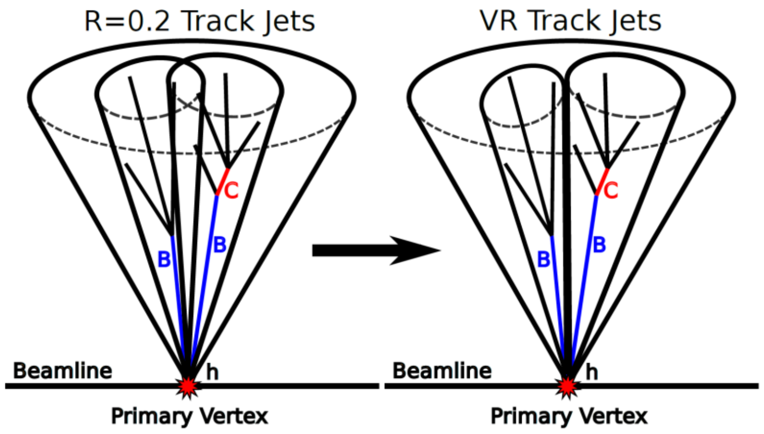
- **Improves mass resolution** at high momentum
  - Excellent D_2 performance
    - Offers significant separation between two-body decays and QCD jets



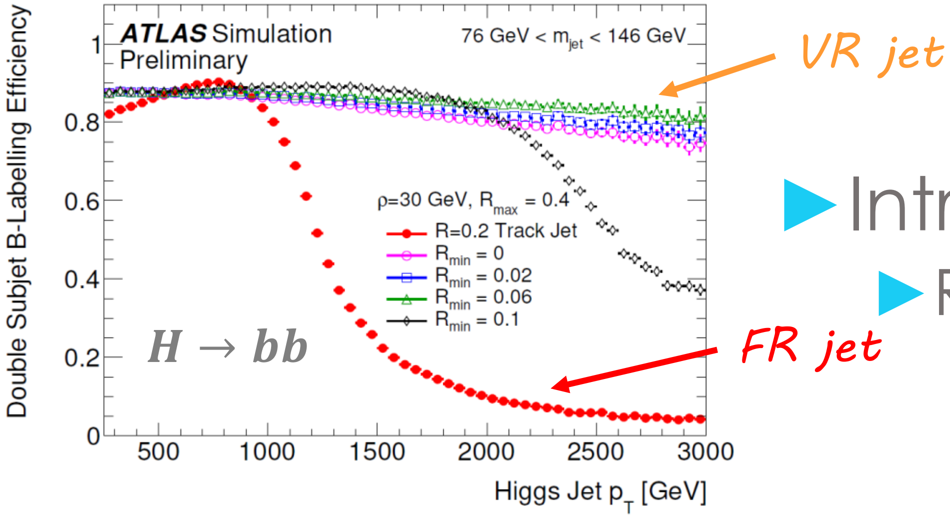


ATL-PHYS-PUB-2020-010

Variable Radius Track Jets



- Fixed radius (FR) track-jets works well until the **decay products** starts to **overlap** due to high momentum of the decaying particle
  - Two-prong flavour-tagging more difficult in boosted environments



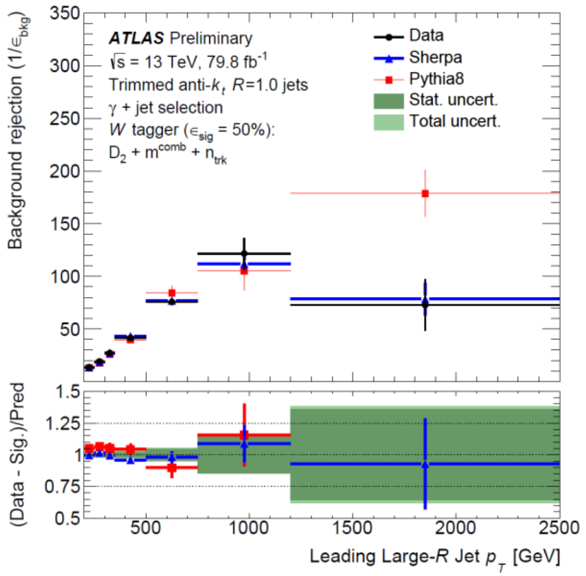
- Introduce **variable radius (VR)** jets
  - Radius dependent on the jet momentum

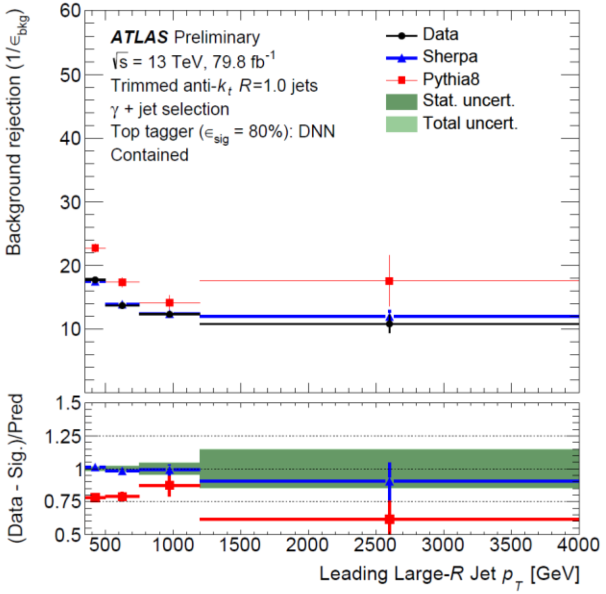
$$R \longrightarrow R_{\text{eff}}(p_{\text{T}}) = \frac{\rho}{p_{\text{T}}}$$

ATL-PHYS-PUB-2020-017

WZ and top taggers

- Probe substructure of large-R jets from W, Z and top quarks
- Cut based WZ tagger – "simple" topology
  - Jet mass window requirement, cuts on energy correlation functions, and associated tracks
- Deep neural network (DNN) top taggers
  - Either for jets containing top and inclusive tops
  - 13 jet moments as input to both
- Excellent **signal efficiency** and **background rejection** for both taggers
  - Taggers are calibrated on data!





ATLAS-CONF-2021-041

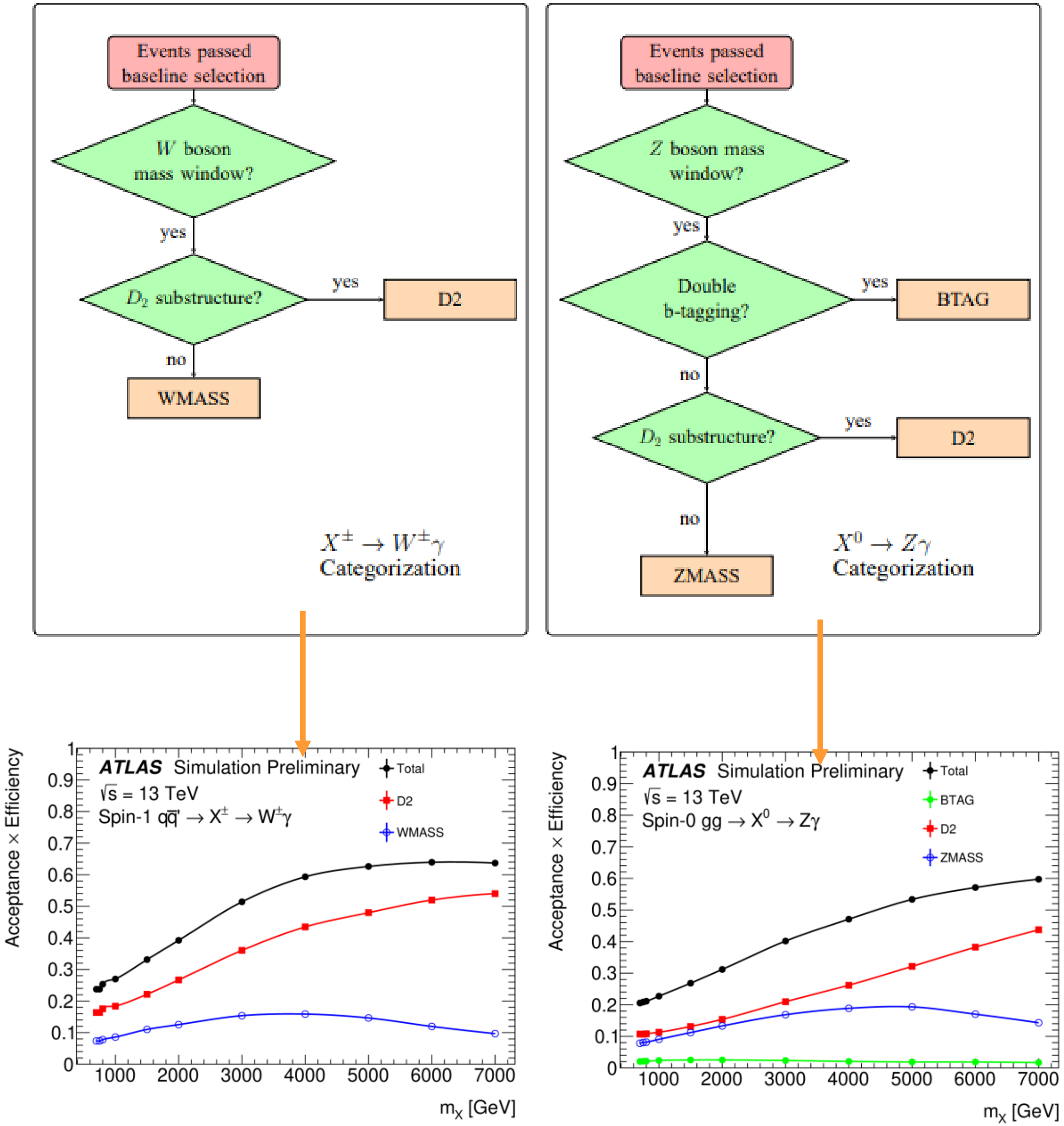
Search for Wγ and Z γ resonances

- **Many Beyond the Standard Model (BSM) models** predicts new charged $X^{\pm}$ and neutral X^{0} bosons that couple to the SM W, Z, and γ
  - Analysis targets high mass resonances, decaying via $X^{\pm} \rightarrow W^{\pm}\gamma$ and $X^{0} \rightarrow Z^{0}\gamma$ (W/Z decay hadronically)
    - Gluon-gluon fusion and quark-antiquark annihilation
  - Studying boson masses ranging from 1-6.8 TeV

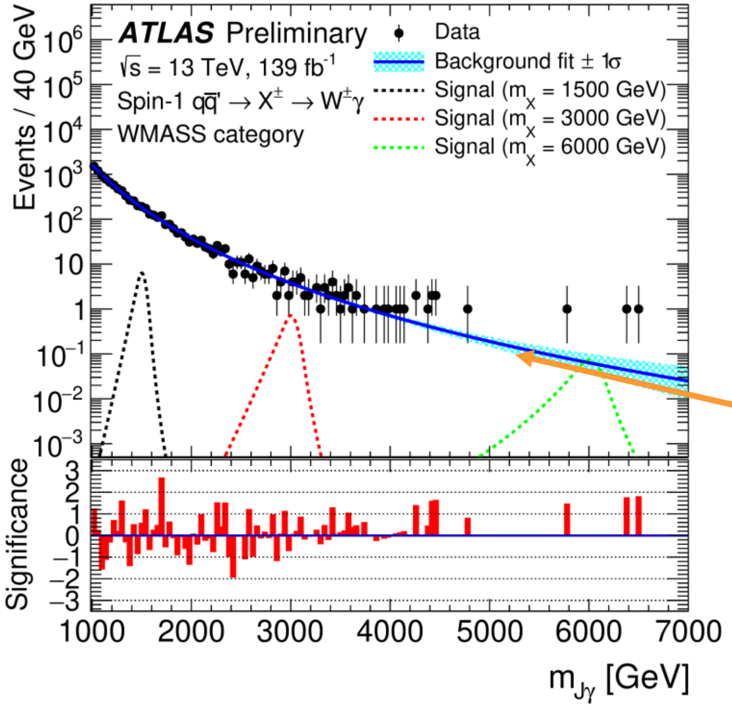
- The $V\gamma$ final states gives **clear signatures** in the detector
  - The presence of photons gives high signal efficiency and good background rejection

Search for Wγ and Z γ resonances

- Single photon trigger with transverse energy (E_T^γ) > 140 GeV
- **Identifying two-prong substructure** from W/Z in boosted jets
  - Add E_T^γ variant cut dependent on the mass
- Fit data to the SM background
  - Parameterised functions for both signal and background

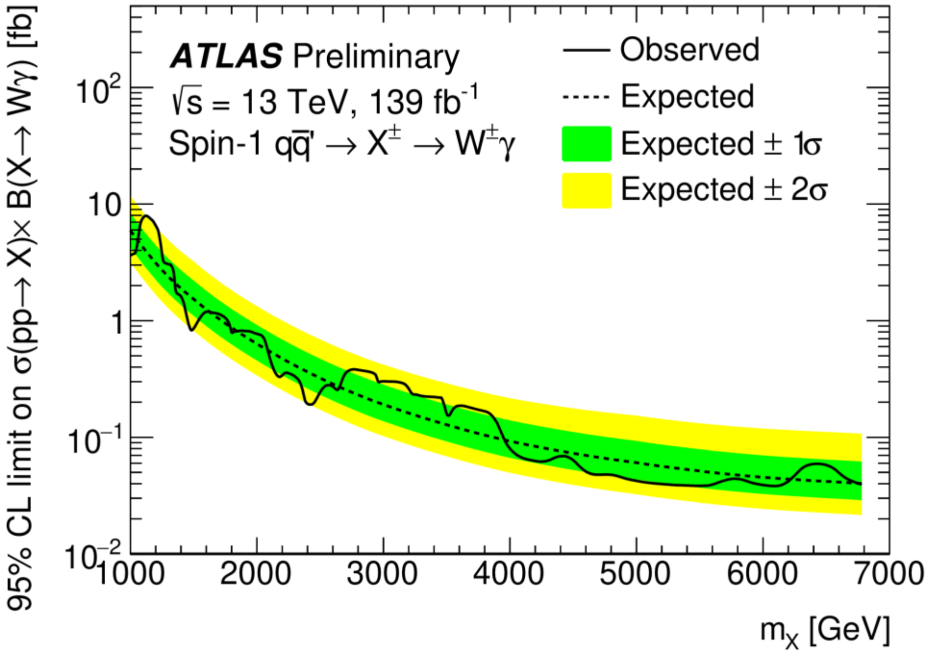


Search for Wγ and Z γ resonances



- Unbinned likelihood fit over a smooth falling background spectrum
  - Background fit models the data well

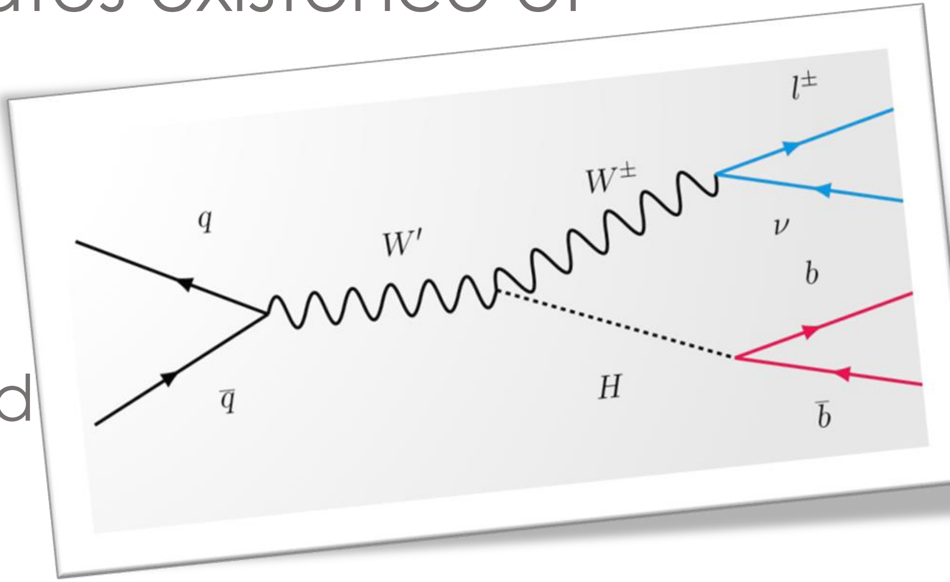
- No significant excess found
  - **Limits are set** on the production cross-section times the branching fraction (BF)
  - Results interpreted with spin-0/1/2 hypothes
  - **10 to 0.05 fb** are excluded depending on the resonance mass



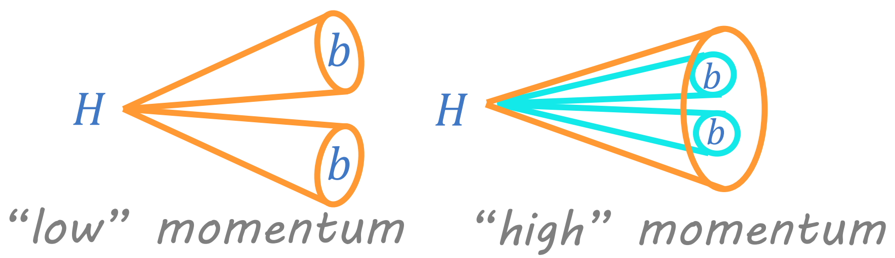
ATLAS-CONF-2021-026

Search for a heavy resonance decaying to WH

- Heavy Vector Triplet (HVT) model postulates existence of new heavy bosons
  - Provide limited number of new couplings to SM particles
  - **Model A:** BF equal to fermions and bosons
  - **Model B:** Fermionic couplings are suppressed

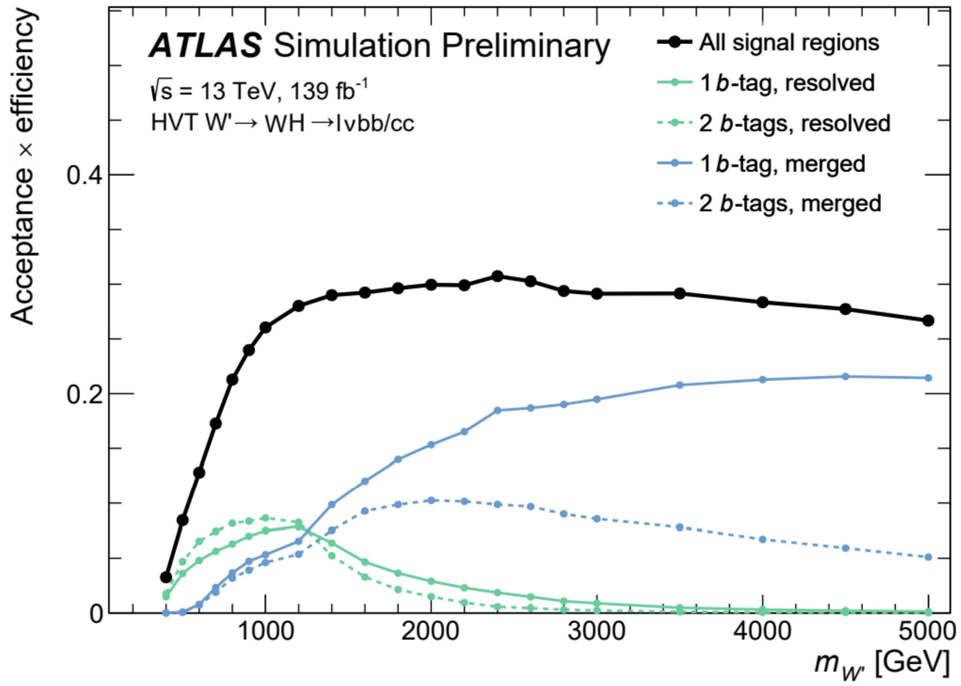


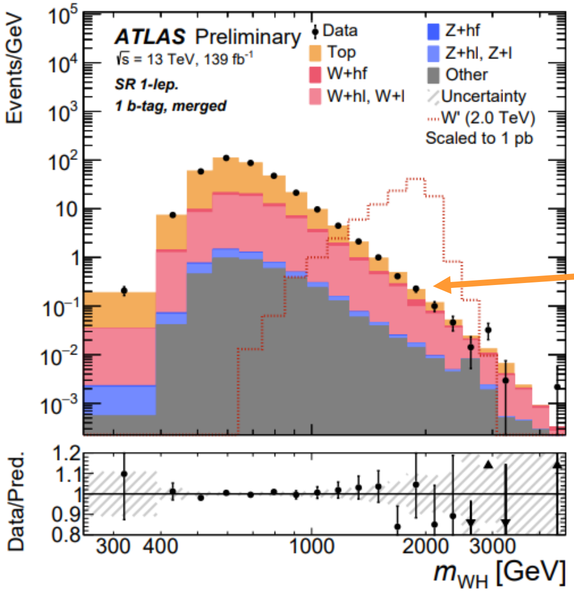
- New diboson search from ATLAS
  - Search for W' $(W' \rightarrow WH \rightarrow l\nu bb)$

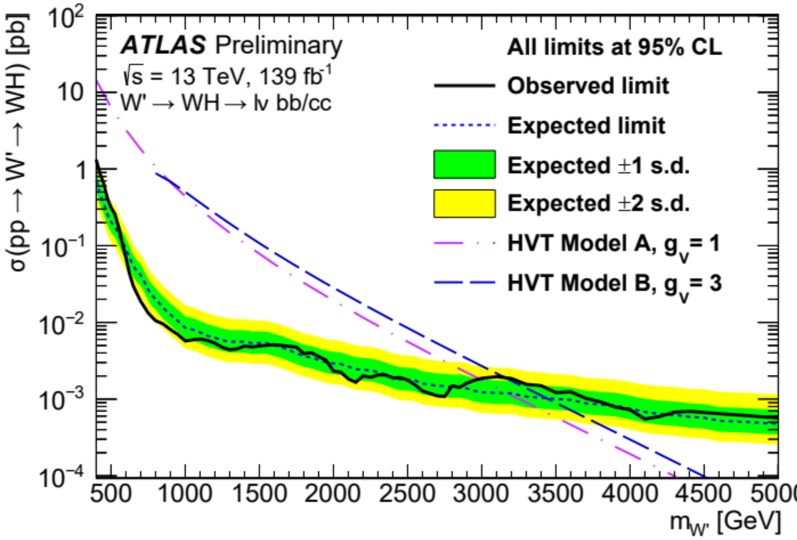


Analysis Strategy

- ▶ Targets both low and highly boosted decays
  - ▶ Rely on **TCC large-R jets and VR track-jets** to improve the performance in the boosted regime
- ▶ Require the event to have **one lepton** and **missing momentum**
  - ▶ Single electron triggers (e-channel) and missing transverse momentum (MET) triggers (μ-channel)
- ▶ Probe events with 1 or 2 b-hadron jets
- ▶ Reconstruct the invariant mass of the W' candidate from W and H
- ▶ **Binned likelihood fit** to the m_{WH} distribution

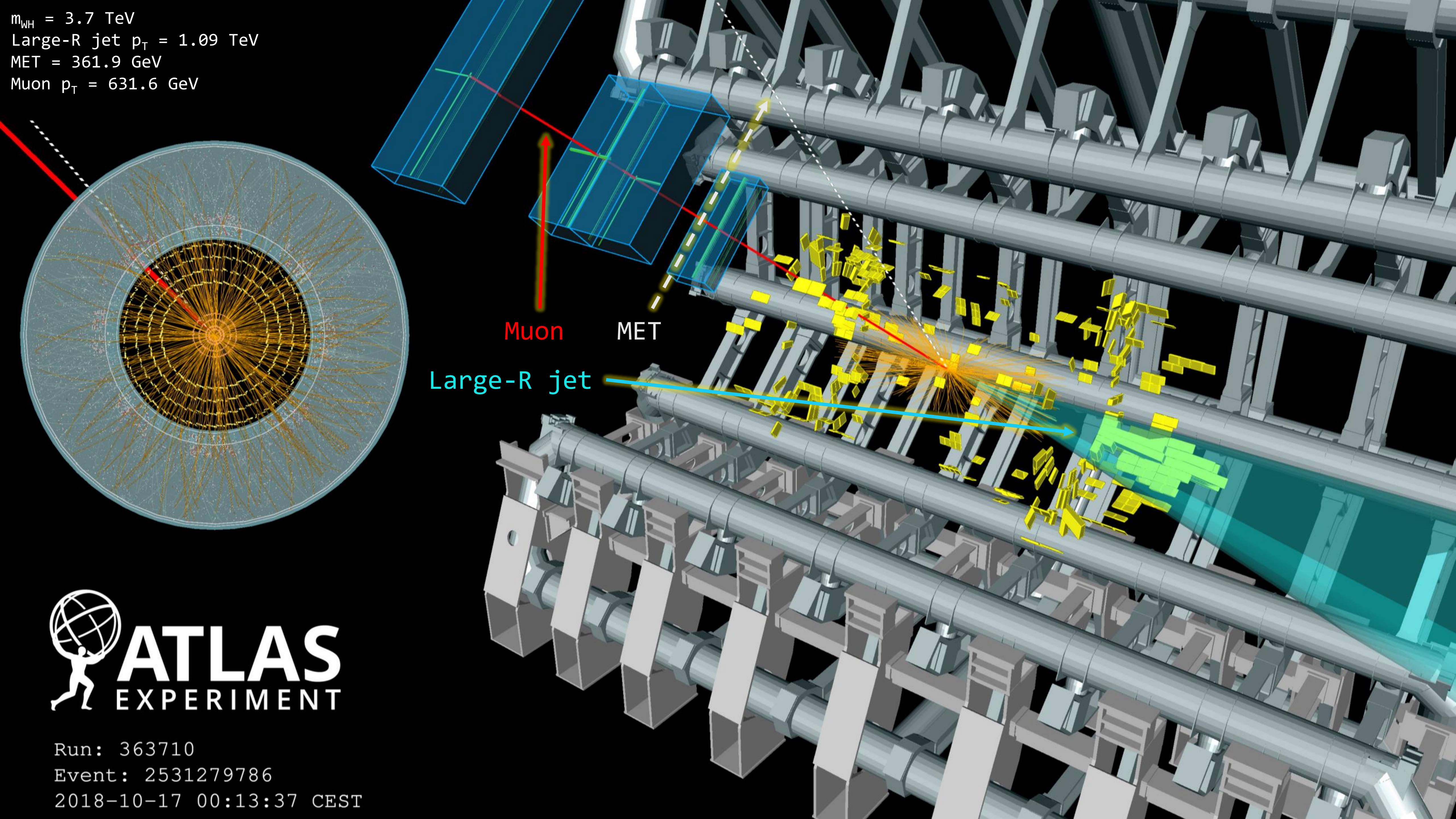






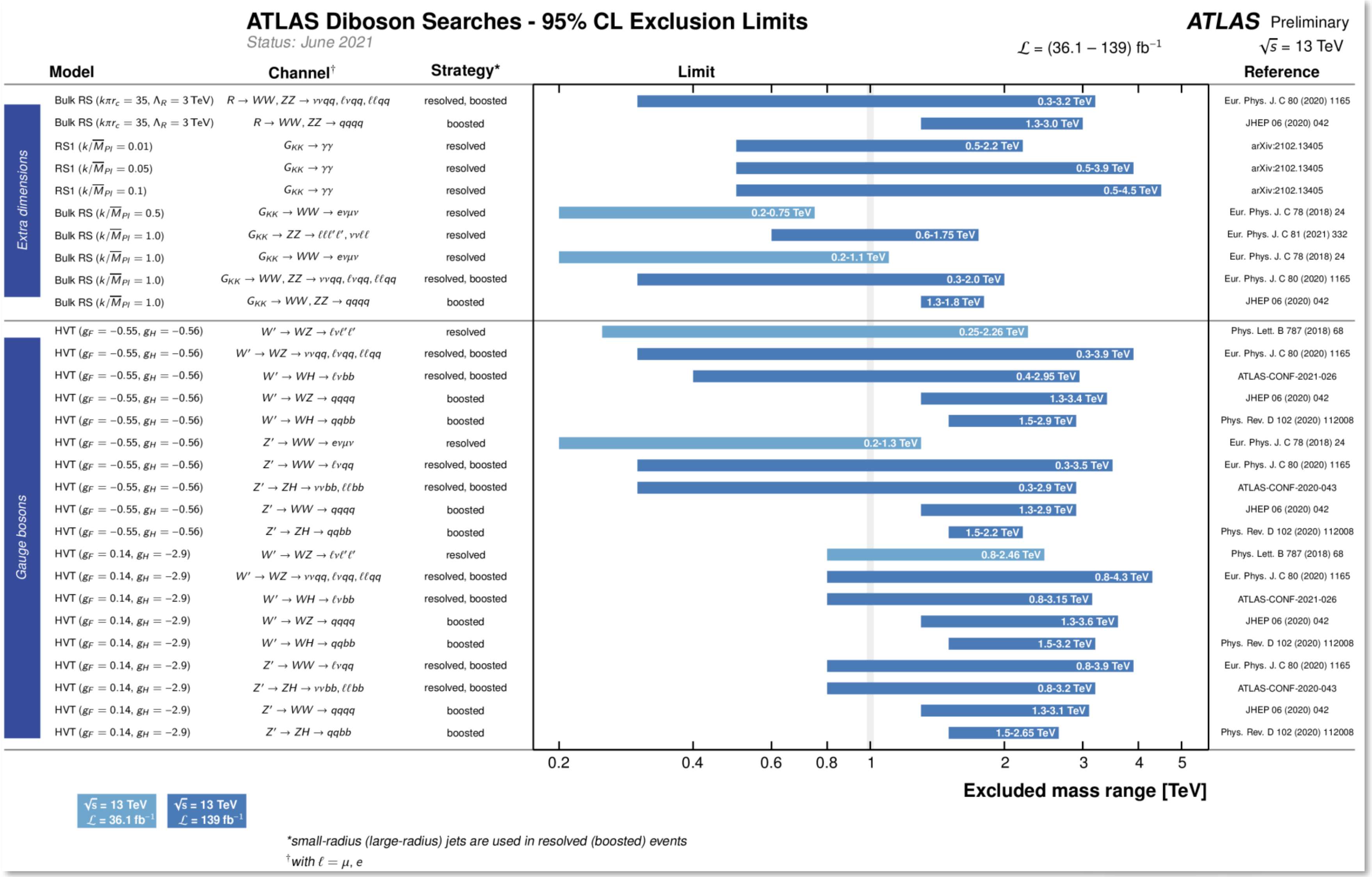
New Resonances… ?

- Data is consistent with the background-only hypothesis
- **No excess** found but new improved limits are set
  - Set upper limit on $\sigma(pp \to W' \to WH)$ to be **1.3 pb** for a mass of 400 GeV down to **0.56 fb** for masses of 5 TeV
  - 2-3x improvement w.r.t previous iteration (36 fb^{-1})
- Excluding masses below **2.95 (3.15) TeV** for Model A and B
- TCC large-R and VR track-jets significantly improved the performance at high resonance masses
  - Ranging from **20% up to 250%** from 1.8 to 5 TeV


m_WH = 3.7 TeV
Large-R jet p_T = 1.09 TeV
MET = 361.9 GeV
Muon p_T = 631.6 GeV
Muon
MET
Large-R jet
ATLAS
EXPERIMENT
Run: 363710
Event: 2531279786
2018-10-17 00:13:37 CEST

Summary …

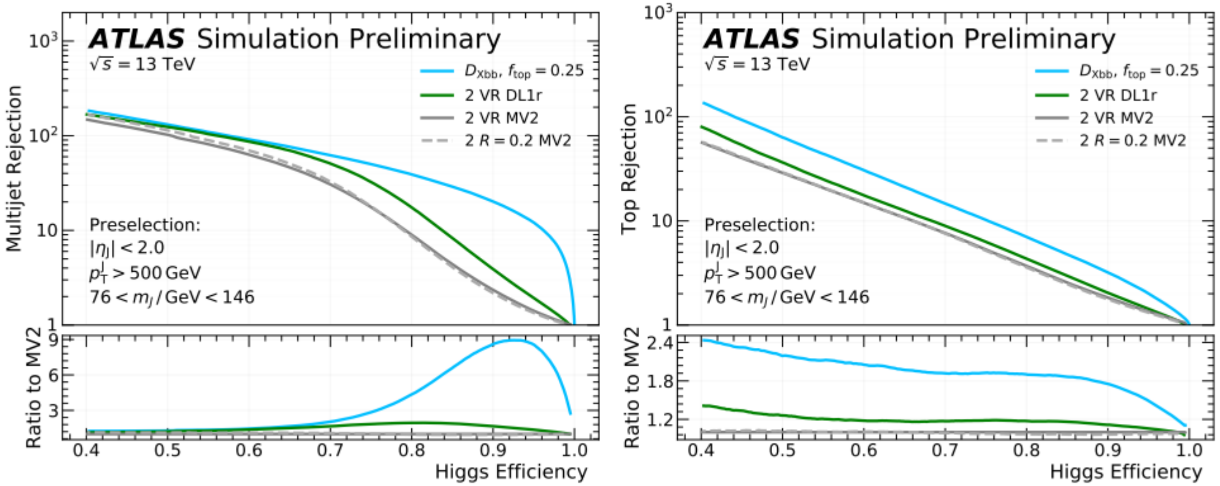
- Only shown two analyses..
- But ATLAS have a **vast search program** for final states including **dibosons**



Back-up

VR in NN based H→bb taggers

- New tagger developed: feed-forward neural network (NN)
  - Using flavour tagging information of the **VR track-jet as input**
    - Training on simulated $H \rightarrow bb$ events
  - Provide distinguishable variable for Higgs / multijet / top
- **Significant improvements** over previous tagging strategy of individually tagging the jets with MV2 or DL1r
  - Multijet (top) rejection at 60% eff is increased by 1.4 (2.0) compared to MV2



Search for Wγ and Z γ resonances

- Signal Parameterisation:

$$\mathcal{S}(m_{J\gamma}; N, \mu, \sigma, \alpha_1, n_1, \alpha_2, n_2) = N \cdot \begin{cases} \left(\frac{n_1}{|\alpha_1|}\right)^{n_1} \exp\left(-\frac{|\alpha_1|^2}{2}\right)\left(\frac{n_1}{|\alpha_1|} - |\alpha_1| - \frac{m_{J\gamma}-\mu}{\sigma}\right)^{-n_1} & \frac{m_{J\gamma}-\mu}{\sigma} \leq -\alpha_1 \\ \exp\left(-\frac{(m_{J\gamma}-\mu)^2}{2\sigma^2}\right) & -\alpha_1 < \frac{m_{J\gamma}-\mu}{\sigma} \leq \alpha_2 \\ \left(\frac{n_2}{|\alpha_2|}\right)^{n_2} \exp\left(-\frac{|\alpha_2|^2}{2}\right)\left(\frac{n_2}{|\alpha_2|} - |\alpha_2| + \frac{m_{J\gamma}-\mu}{\sigma}\right)^{-n_2} & \alpha_2 < \frac{m_{J\gamma}-\mu}{\sigma}. \end{cases}$$

- Background Parameterisation:

$$\mathcal{B}(m_{J\gamma}; \boldsymbol{p}) = (1-x)^{p_1} x^{p_2 + p_3 \log(x) + p_4 \log^2(x) + p_5 \log^3(x)}$$