

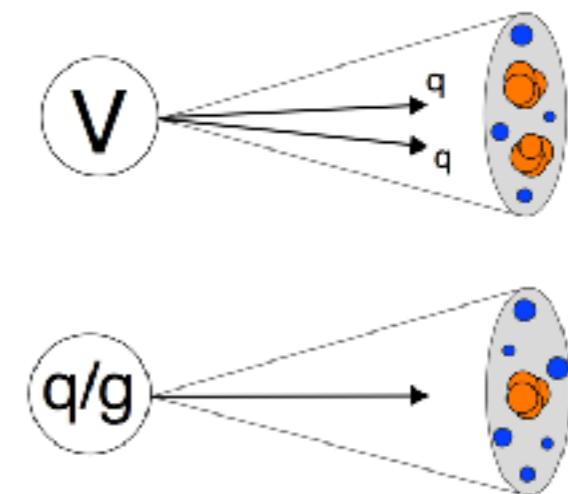
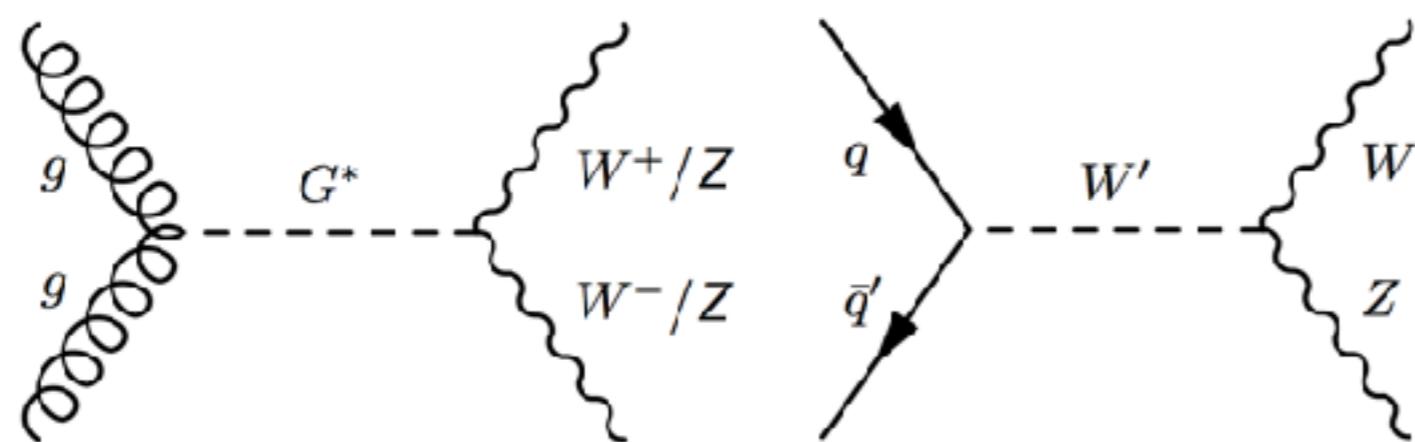
Search for narrow diboson resonances in boosted all-hadronic final states

Yanyan Gao (University of Liverpool)

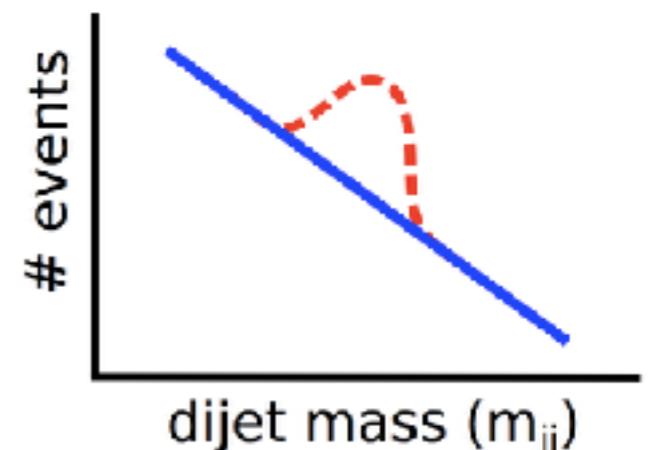
Second China LHC Physics workshop (CLHCP), 18-Dec-2016

Analysis overview

- Search for narrow heavy diboson ($WW/WZ/ZZ$) resonances above 1 TeV
 - Extended symmetry, e.g. spin-1 generic heavy vector triplets (HVT) and scalar from SUSY
 - Modified extra dimensions (spin-2 Randall Sundrum Graviton)

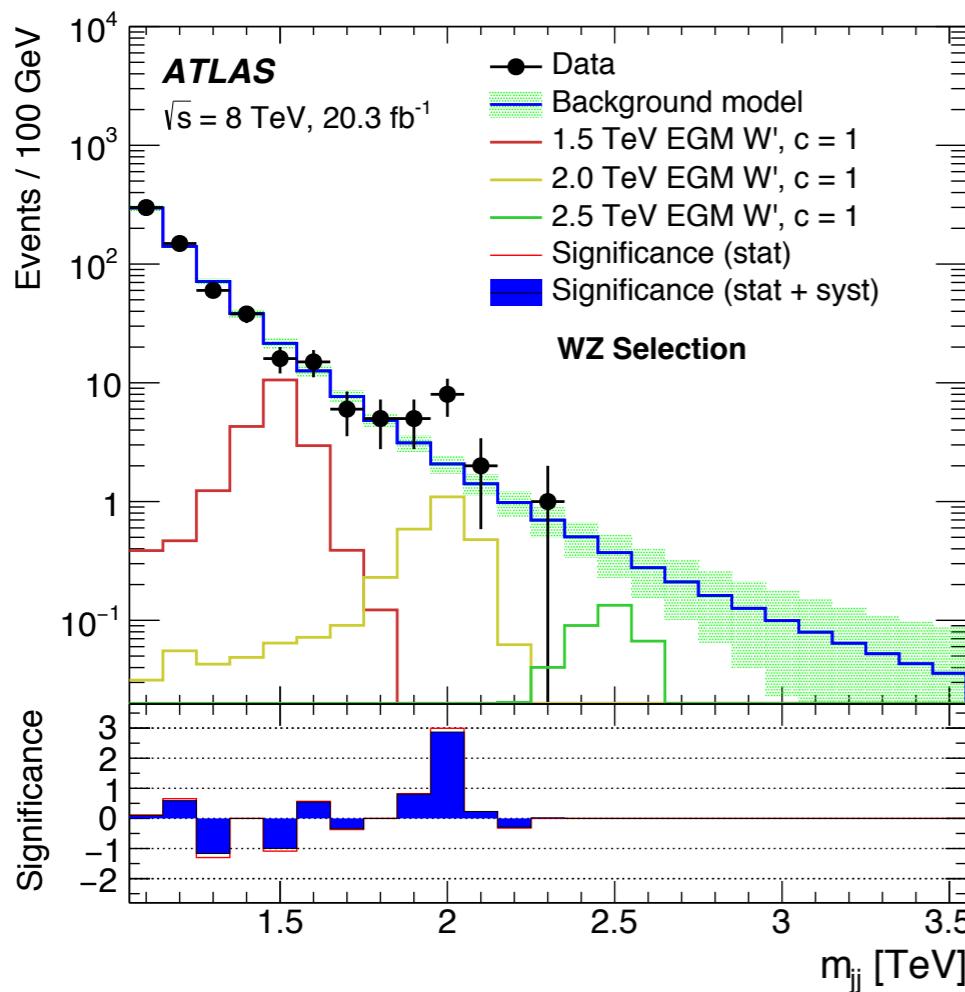


- Focus on the all hadronic final states
 - $BR(W \rightarrow \text{hadronic}) \sim 66\%$, $BR(ZW \rightarrow \text{hadronic}) \sim 70\%$
 - Boosted boson: large- R jet with a two prong substructure
- Main background is QCD
 - Bump hunt for low resonance on top of falling background (analytical parameterisation from data)

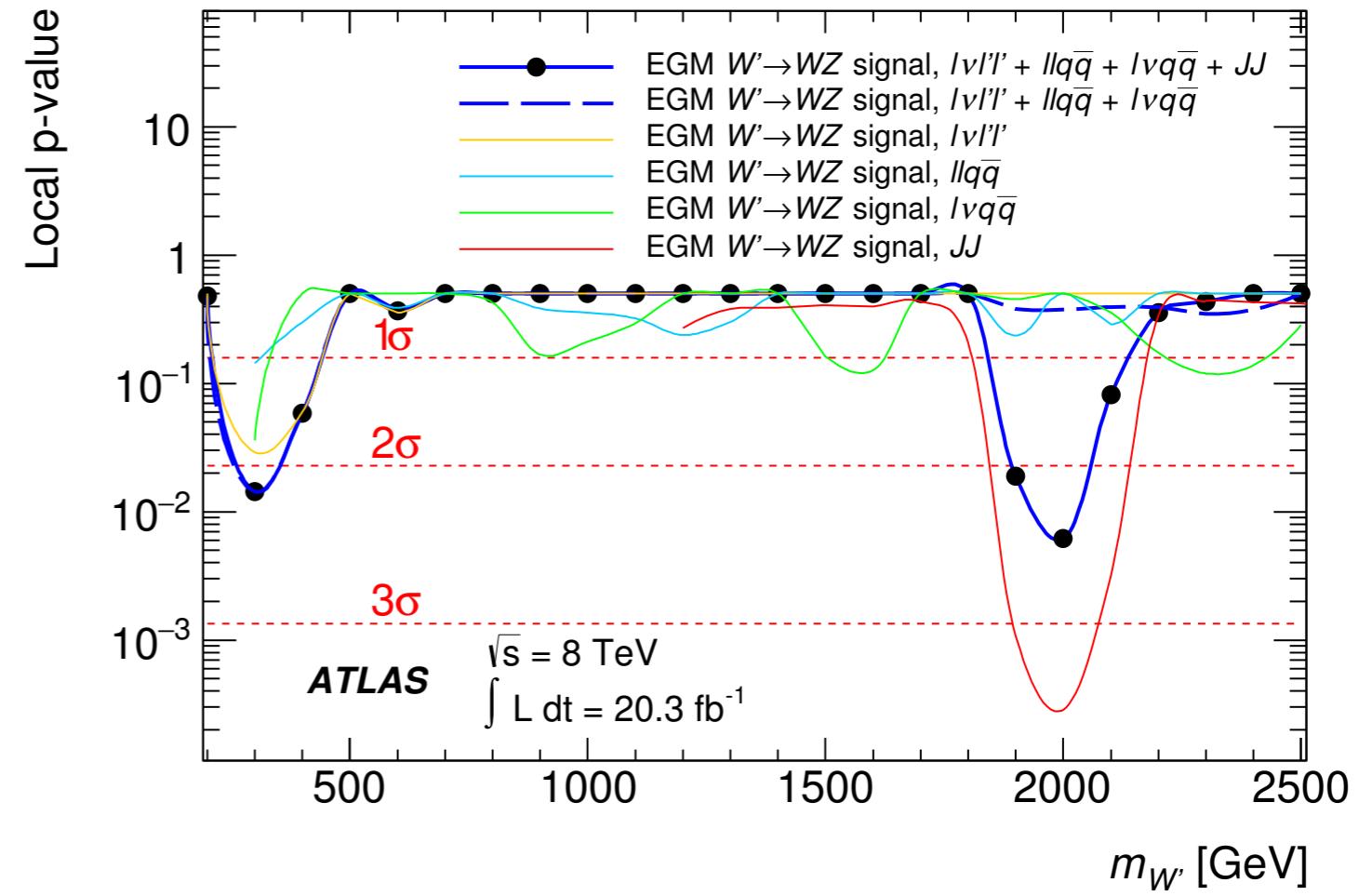


Run-I buzz

- Interesting mild excess observed in Run-I data, particularly at ATLAS
 - CMS has excess on the level of ~ 2 sigma in similar places
 - One of the top priorities to follow up in early Run-2



ATLAS JHEP 12 (2015) 55



<http://arxiv.org/abs/1512.05099>

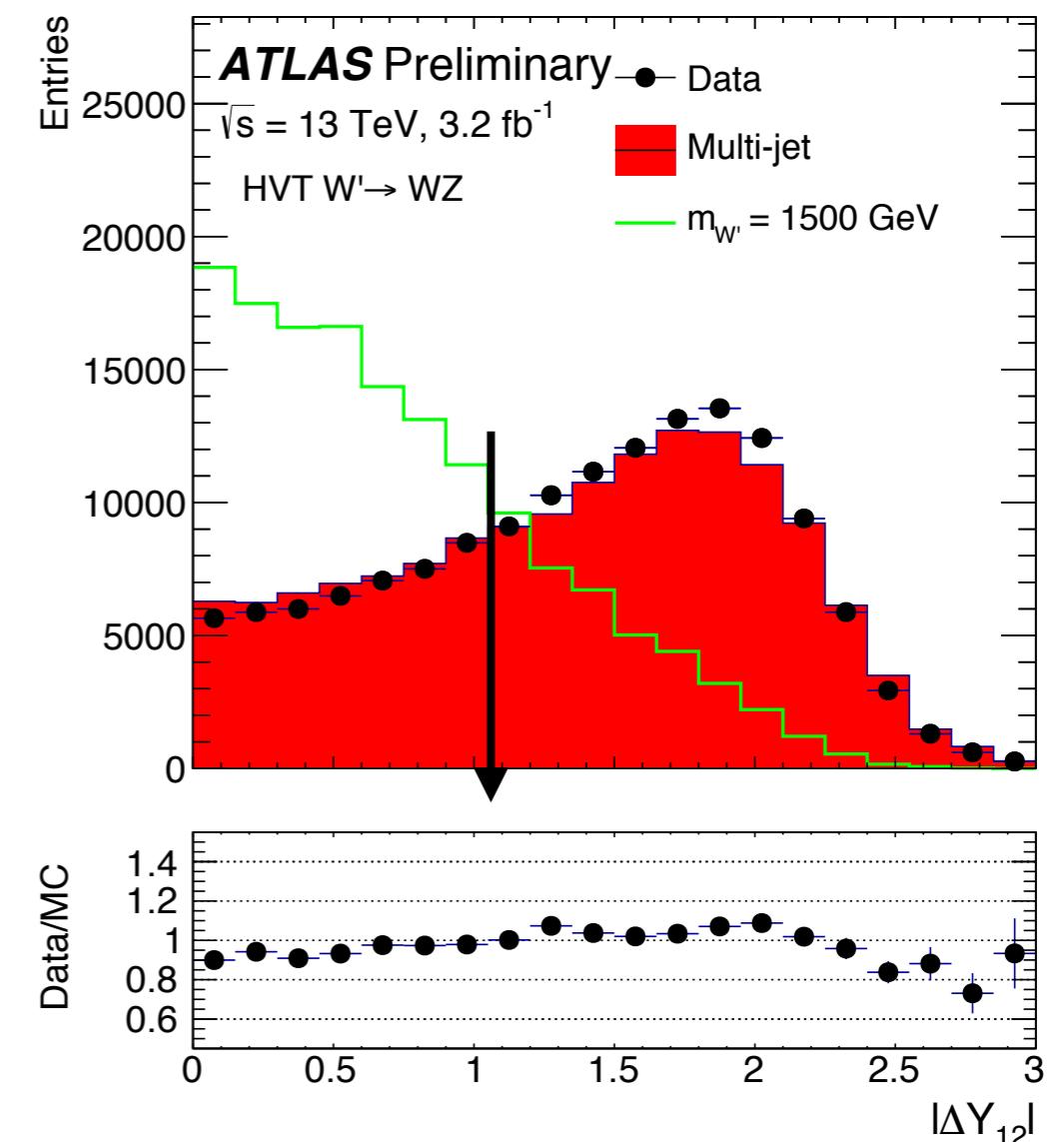
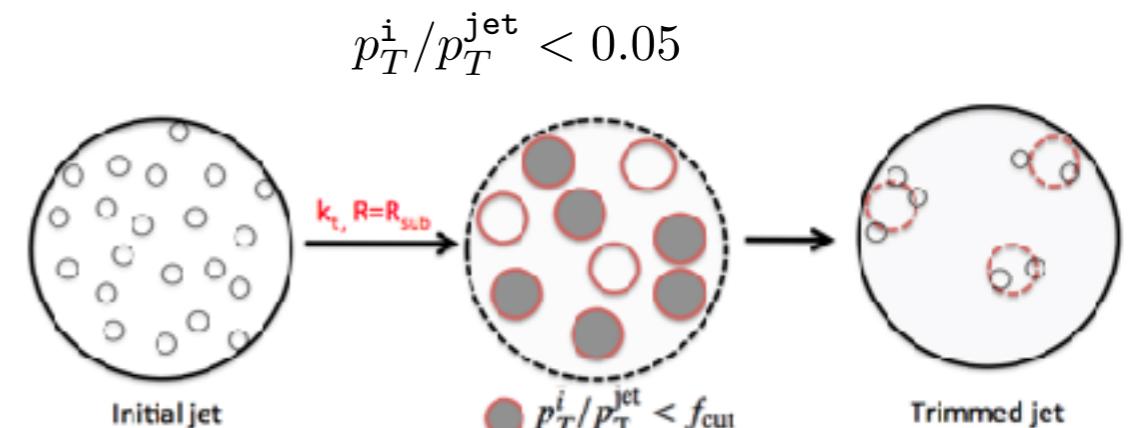
Analysis selection

- Two large-R ($R=1.0$) jets anti-Kt
 - $p_T > (450, 200)$ GeV
 - $|\eta| < 2, M > 50$ GeV
- Topological cuts to enhance s-channel signal

$$(p_T^{\text{jet}1} - p_T^{\text{jet}2}) / (p_T^{\text{jet}1} + p_T^{\text{jet}2}) < 0.15$$

$$\Delta y_{12} < 1.2$$
- Overlapping WW/WZ/ZZ boson tag
 - Jet mass window ~ 30 GeV around m_W
 - p_T -dependent substructure cut
 - **# tracks with the ungroomed jet < 30**
 - bkg rejection: 70%, sig efficiency $\sim 90\%$
 - **Weakly correlated with groomed jet kinematics and di-jet mass**

Trimming removes soft stuff from PU/ISR/MPI



Boosted boson tagging: mass and substructure

$$E_{CF0}(\beta) = 1,$$

$$E_{CF1}(\beta) = \sum_{i \in J} p_{T_i},$$

$$E_{CF2}(\beta) = \sum_{i < j \in J} p_{T_i} p_{T_j} (\Delta R_{ij})^\beta,$$

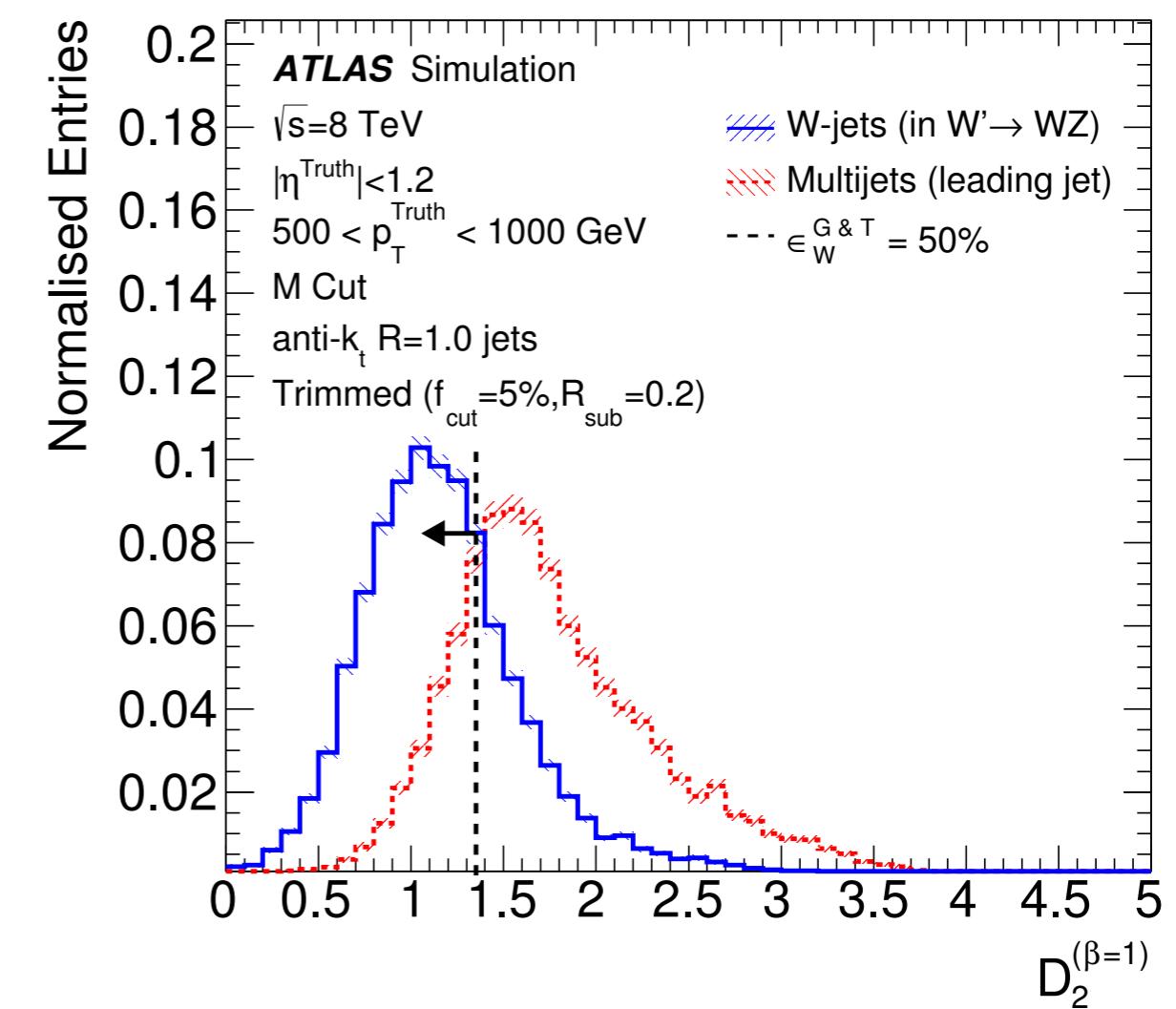
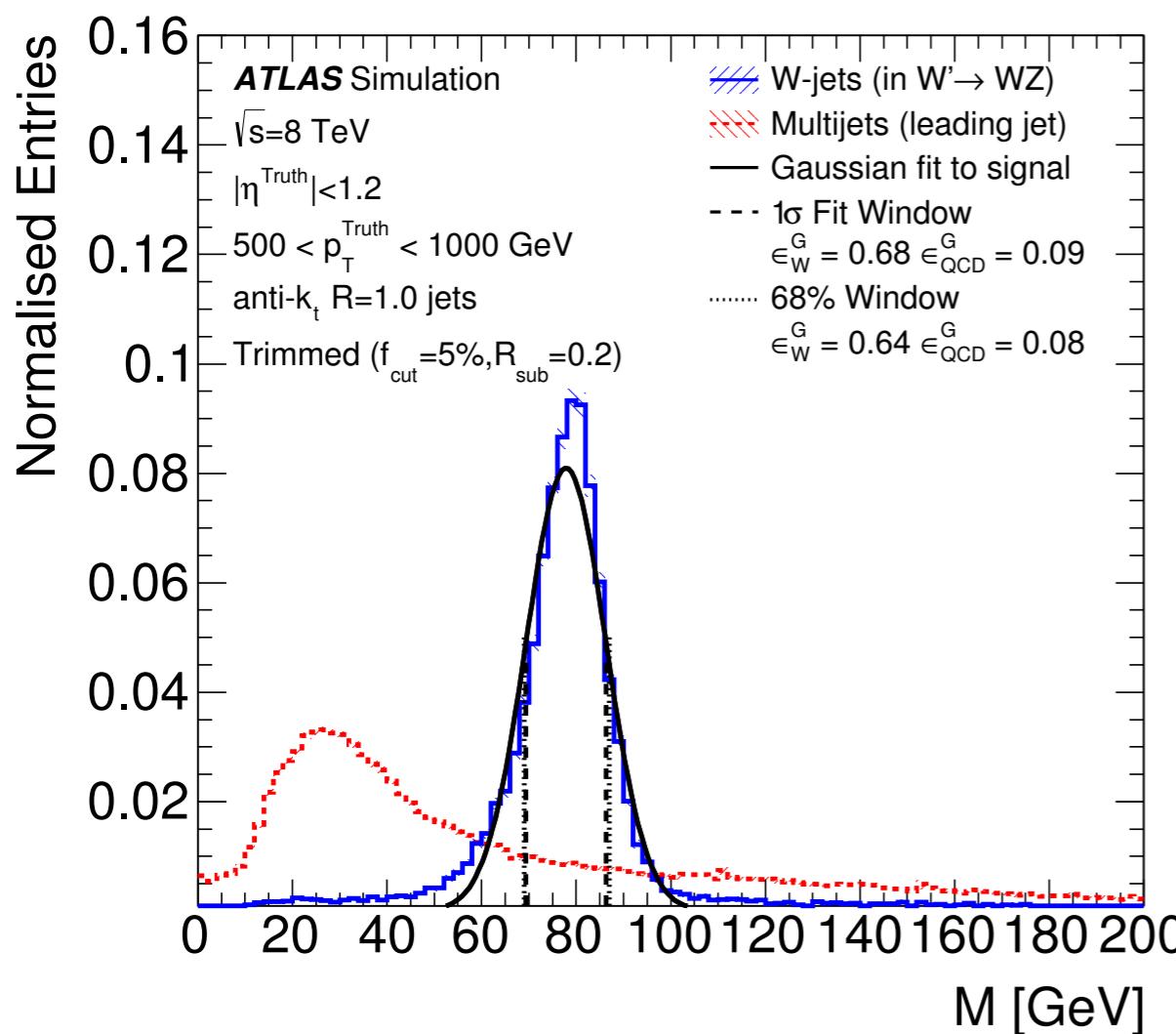
$$E_{CF3}(\beta) = \sum_{i < j < k \in J} p_{T_i} p_{T_j} p_{T_k} (\Delta R_{ij} \Delta R_{ik} \Delta R_{jk})^\beta$$



$$e_2^{(\beta)} = \frac{E_{CF2}(\beta)}{E_{CF1}(\beta)^2}$$

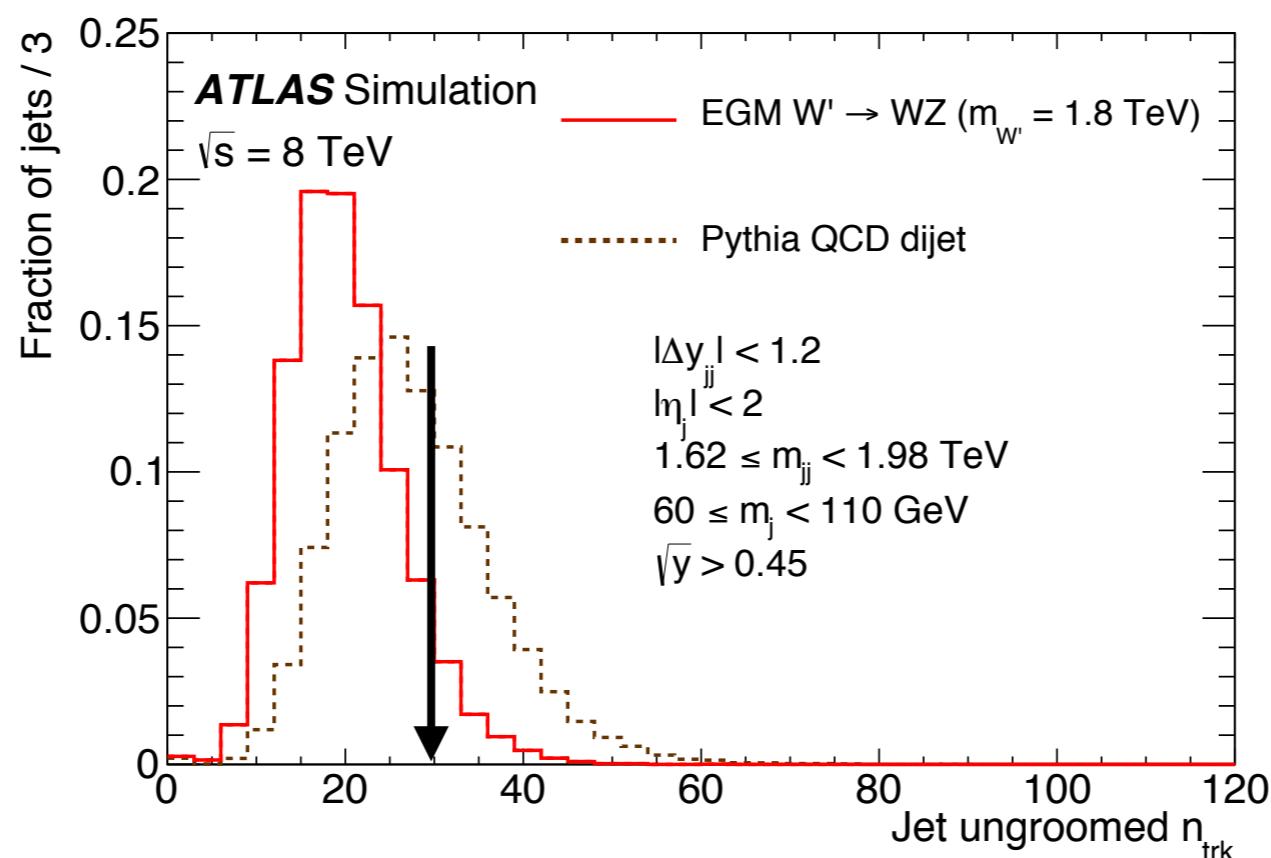
$$e_3^{(\beta)} = \frac{E_{CF3}(\beta)}{E_{CF1}(\beta)^3}$$

$$D_2^{(\beta)} = \frac{e_3^{(\beta)}}{(e_2^{(\beta)})^3}$$



Boson tagging: track multiplicity cut

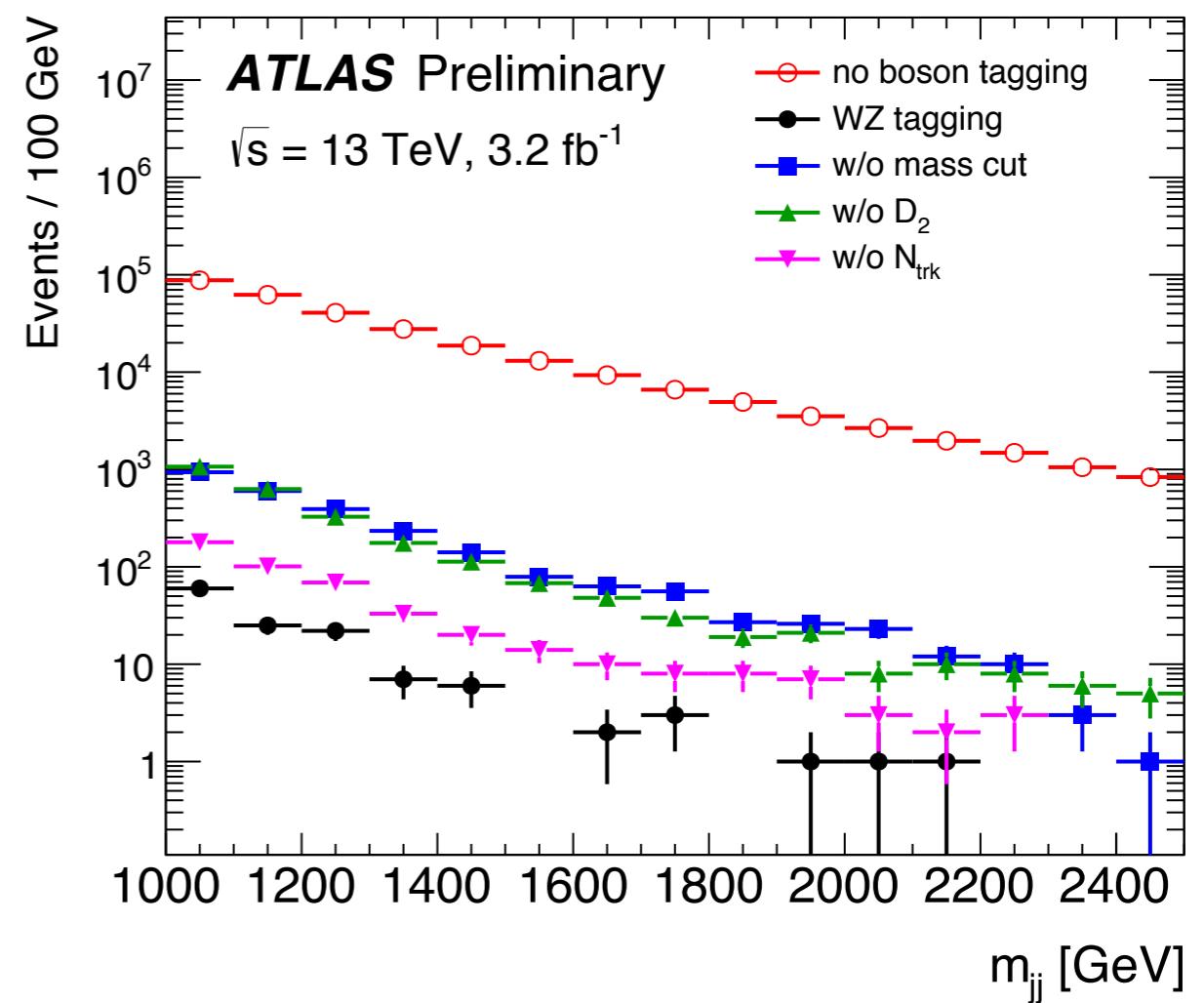
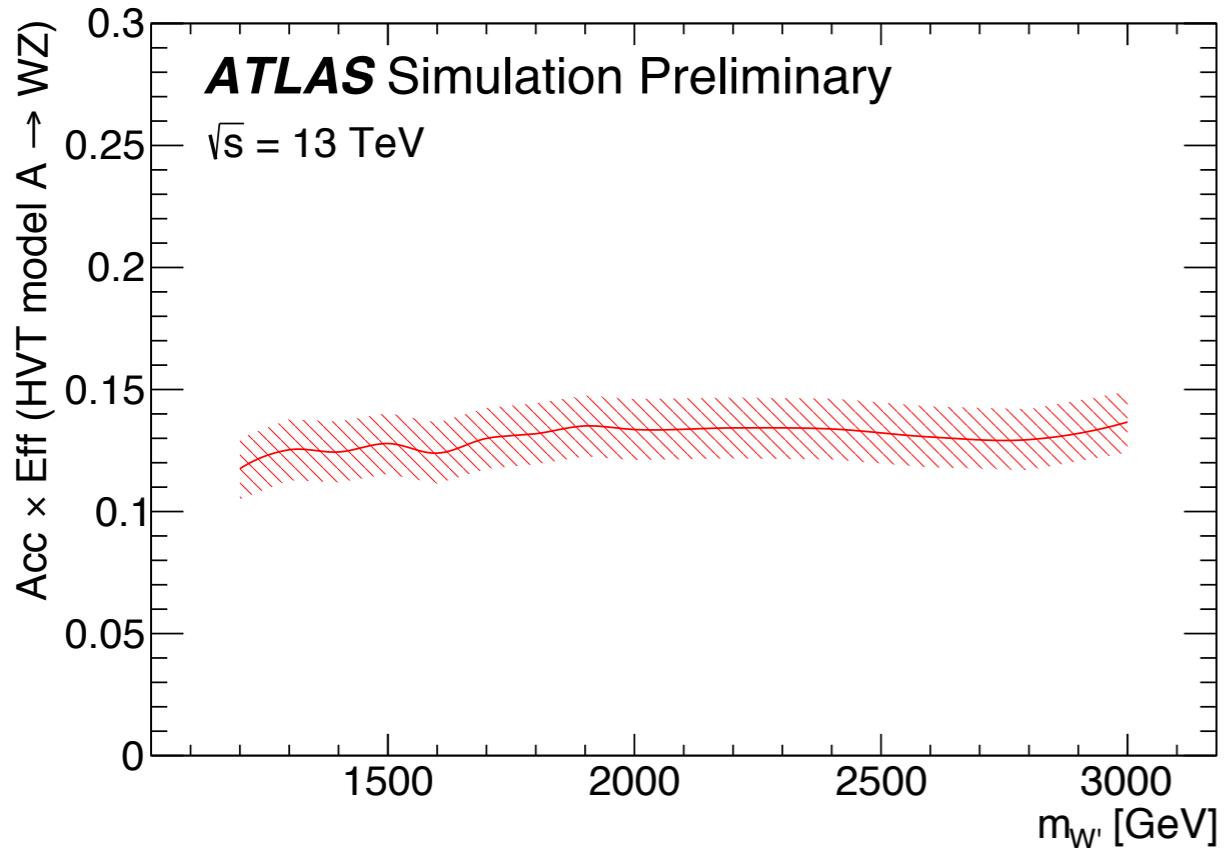
- QCD jets have larger track multiplicity
 - Jet fragmentation scales of the V-boson and QCD jets are vastly different
 - V-boson: m_V , QCD jet: $pT(\text{jet})$
 - Significant gluon contribution in the QCD jets further increases the track multiplicity



- Improves the expected significance by $\sim 30\%$
- Efficiency of this cut and the associated systematic uncertainties studied in $V + \text{jets}$ data

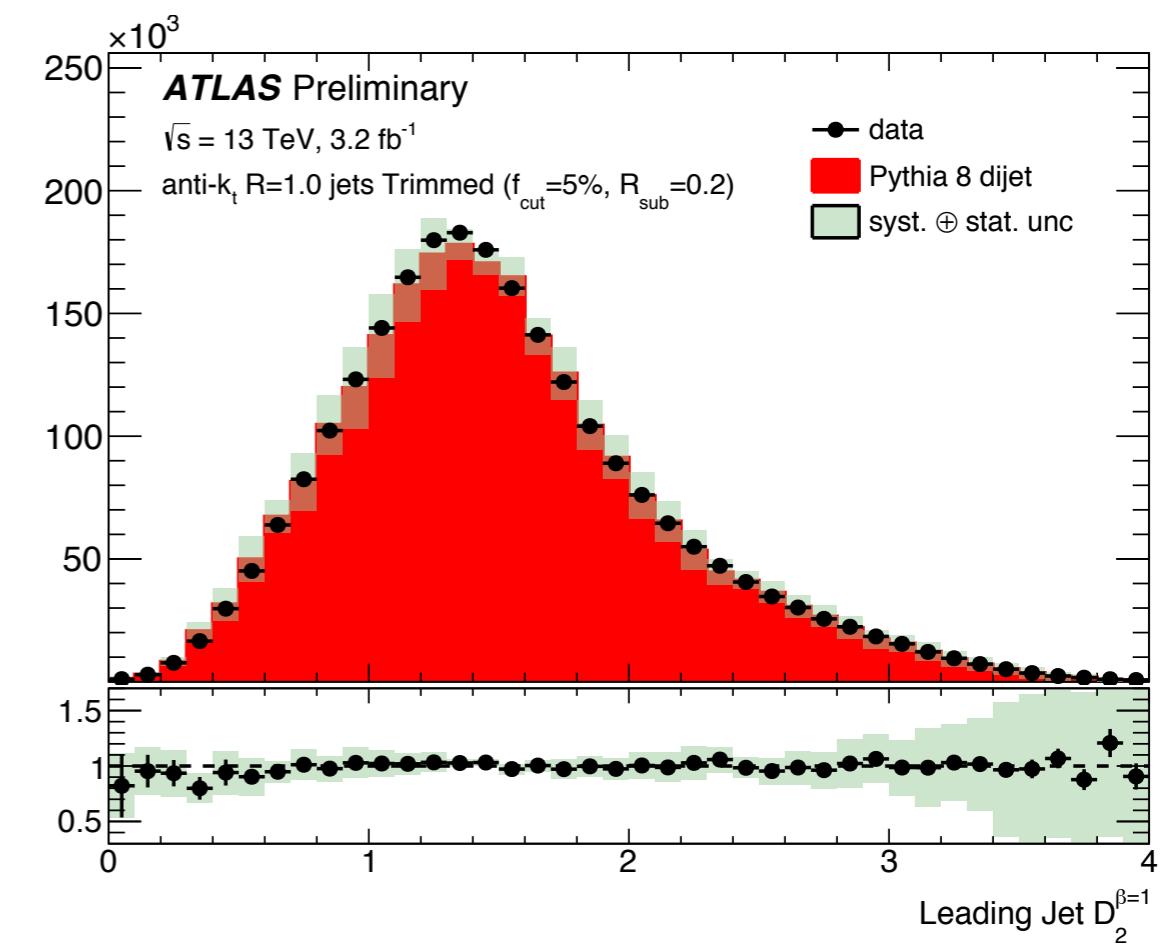
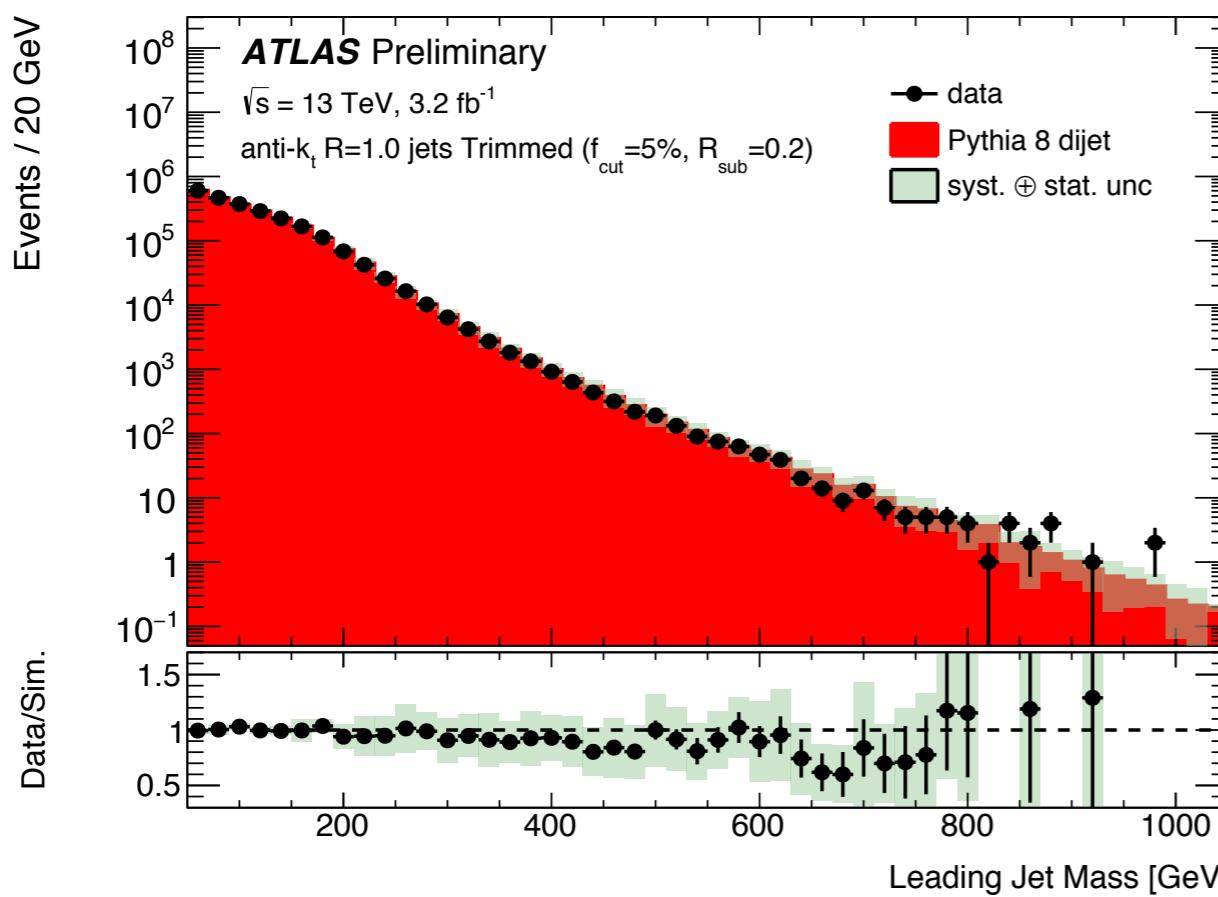
Selection efficiencies

- Relatively flat signal selection efficiency (m_{VV})
 - ~50% signal tagging (mass and D2) efficiency (on top of acceptance etc) per jet
 - ~A factor of 50 background rejection per jet



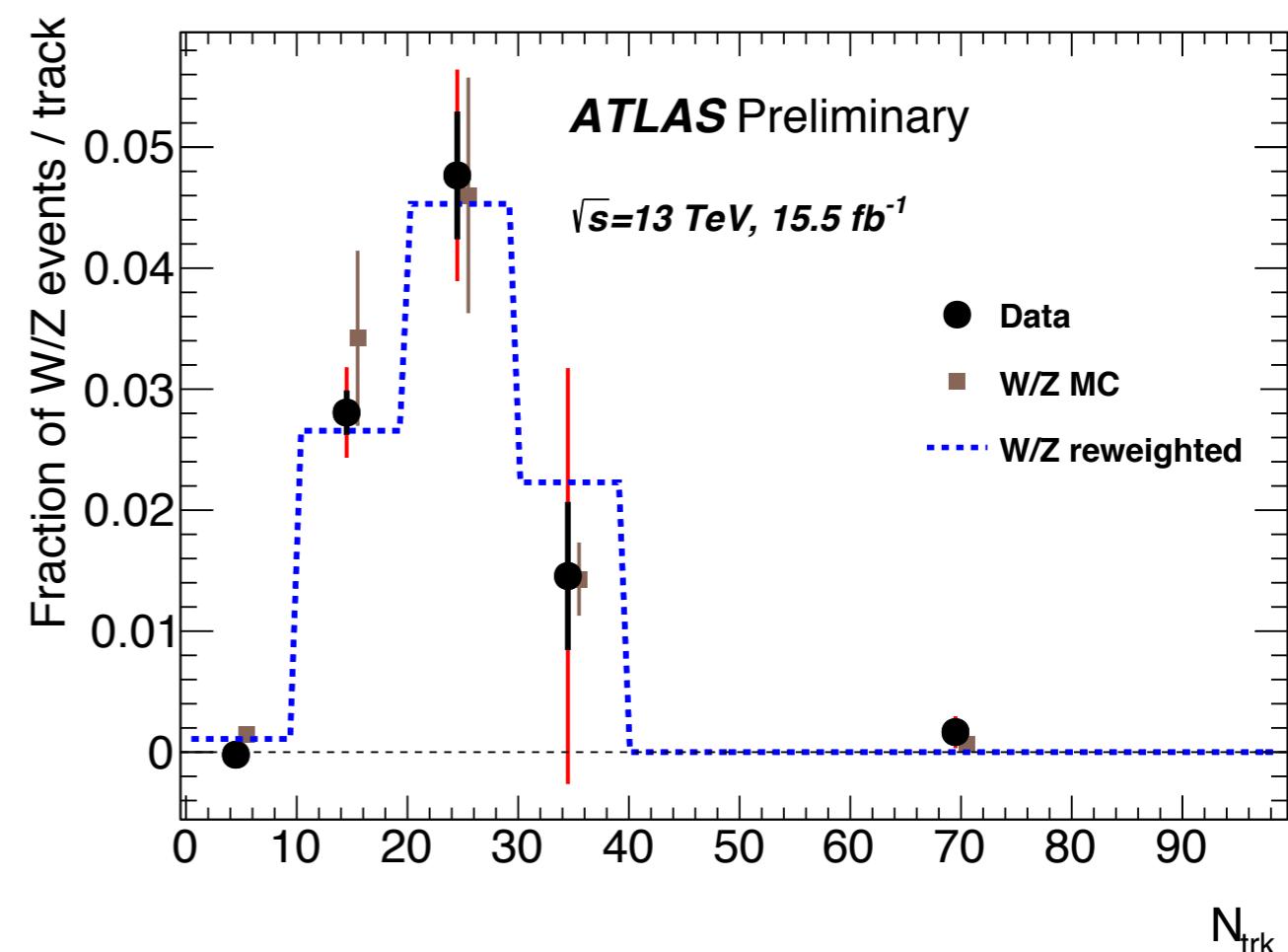
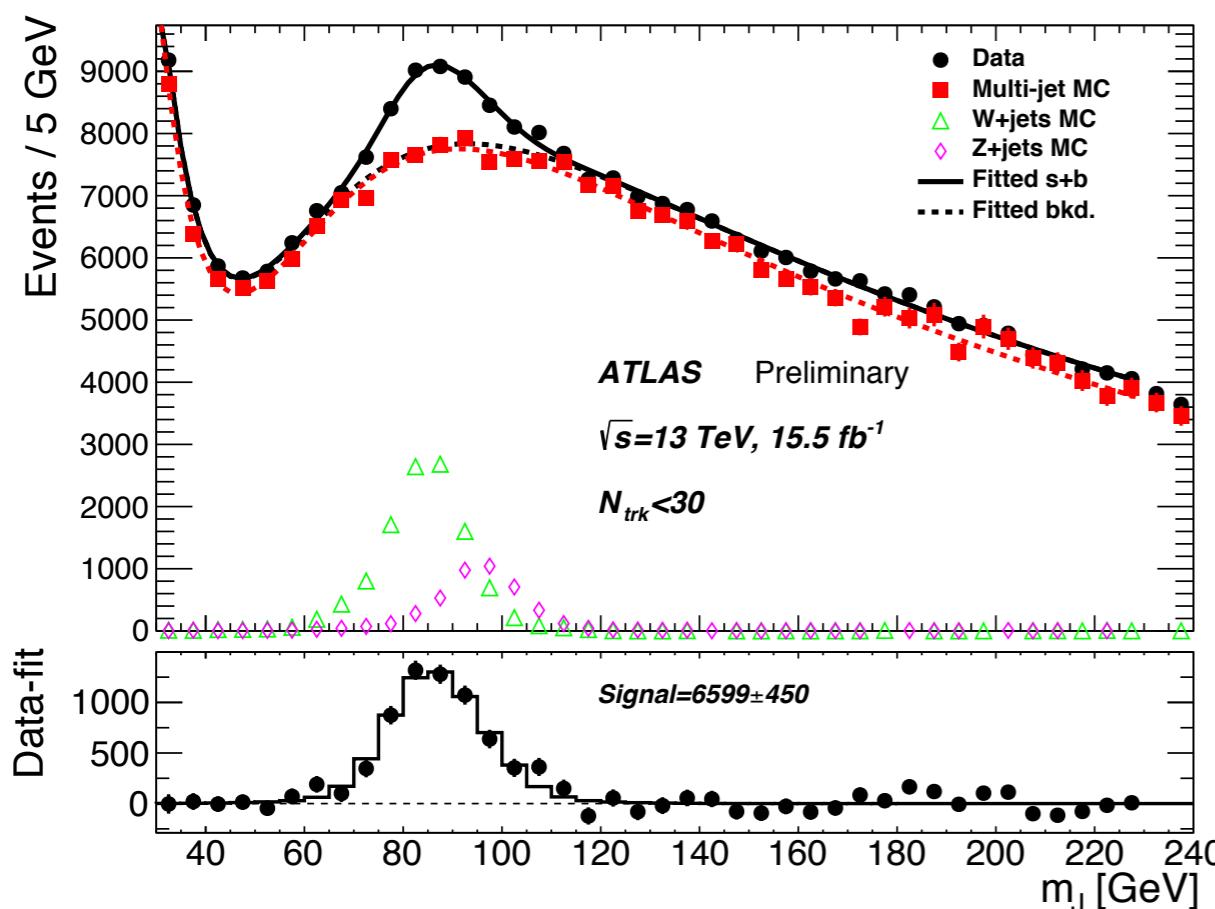
Jet mass and substructure in QCD enriched data

- No boson tagging is applied
 - Shapes are well modelled in the QCD events in data at 13 TeV



Jet mass and substructure in W/Z-enriched data

- Select only one W/Z-tagged region for “in-situ” studies of the jet kinematics

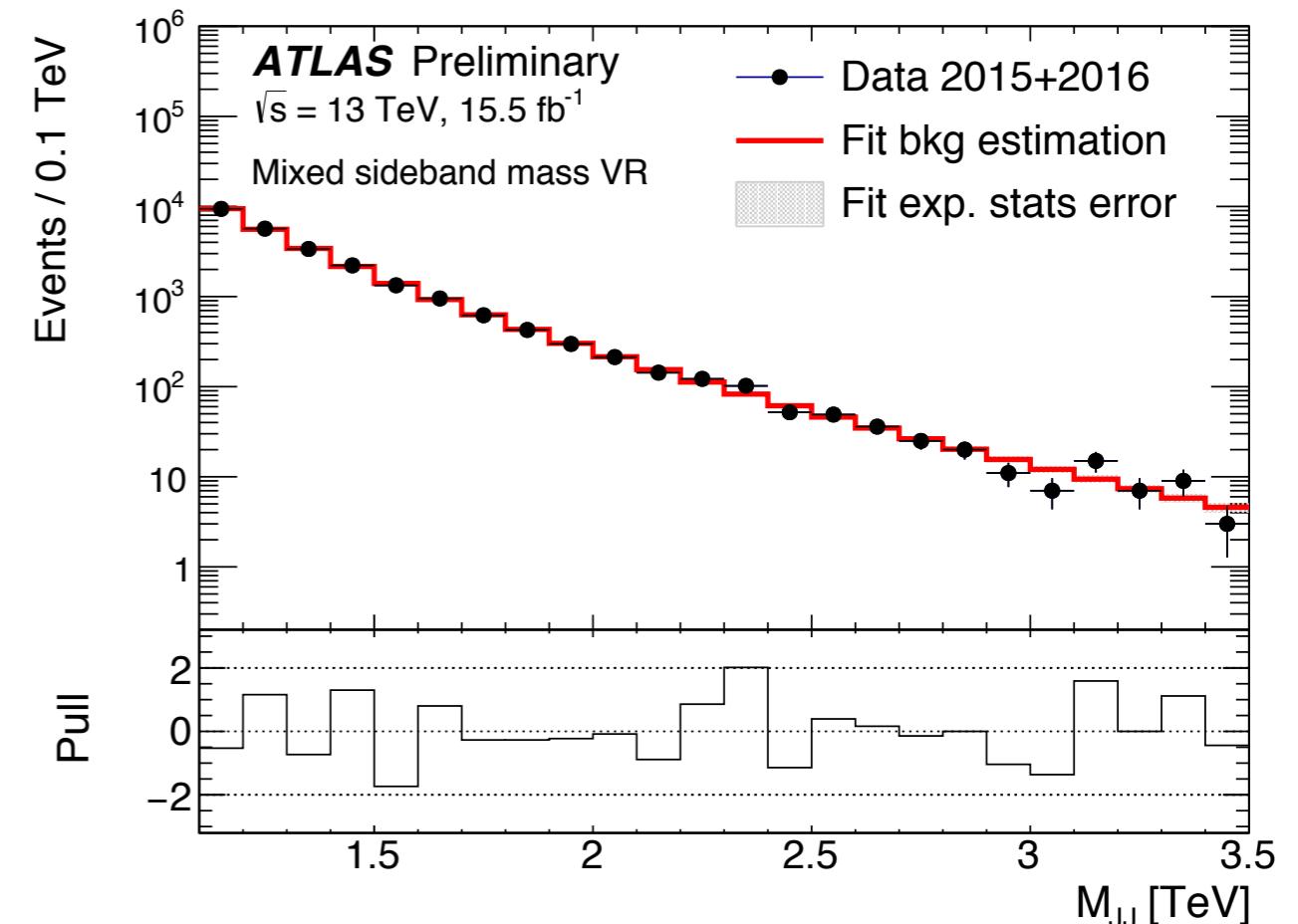
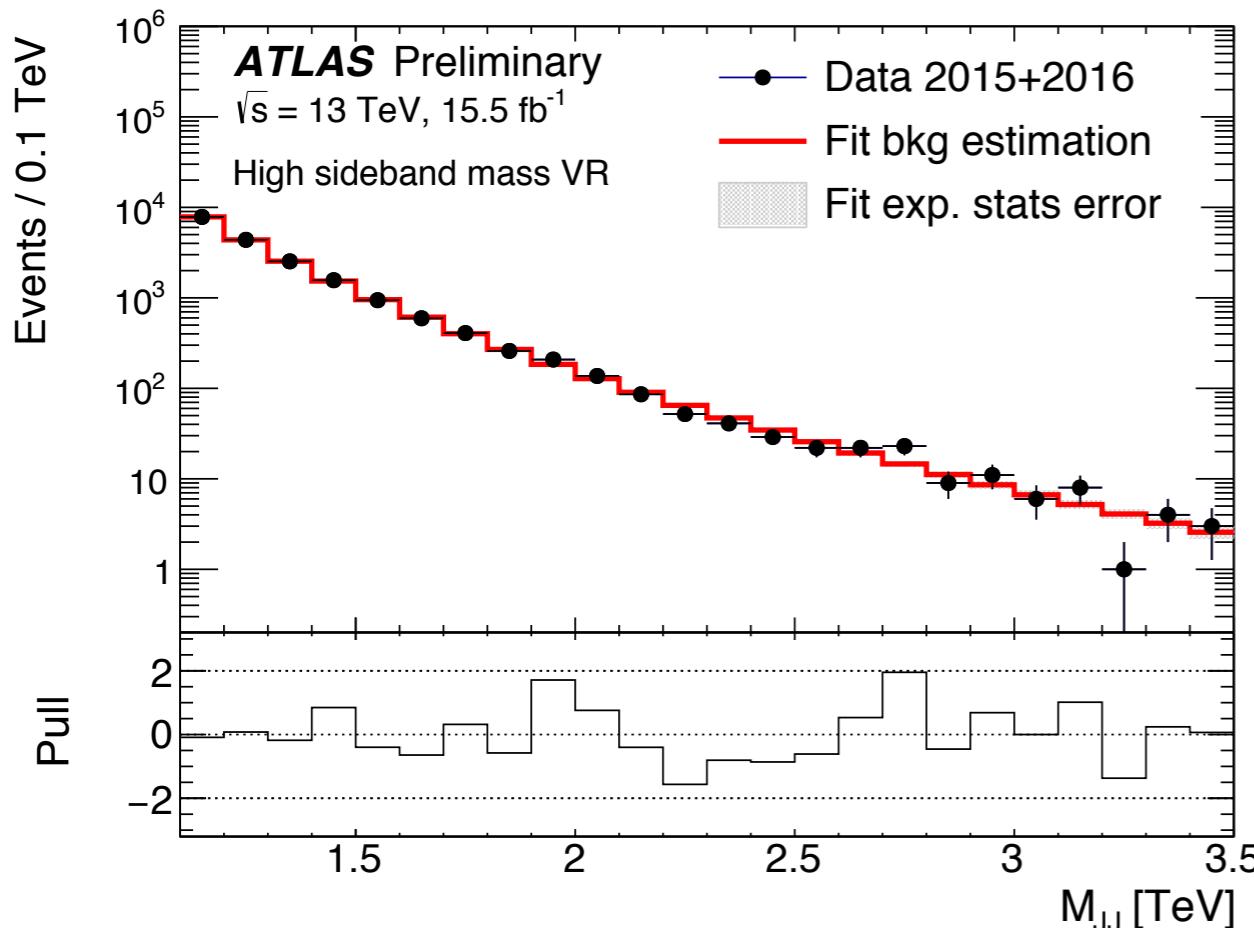


Background fit model

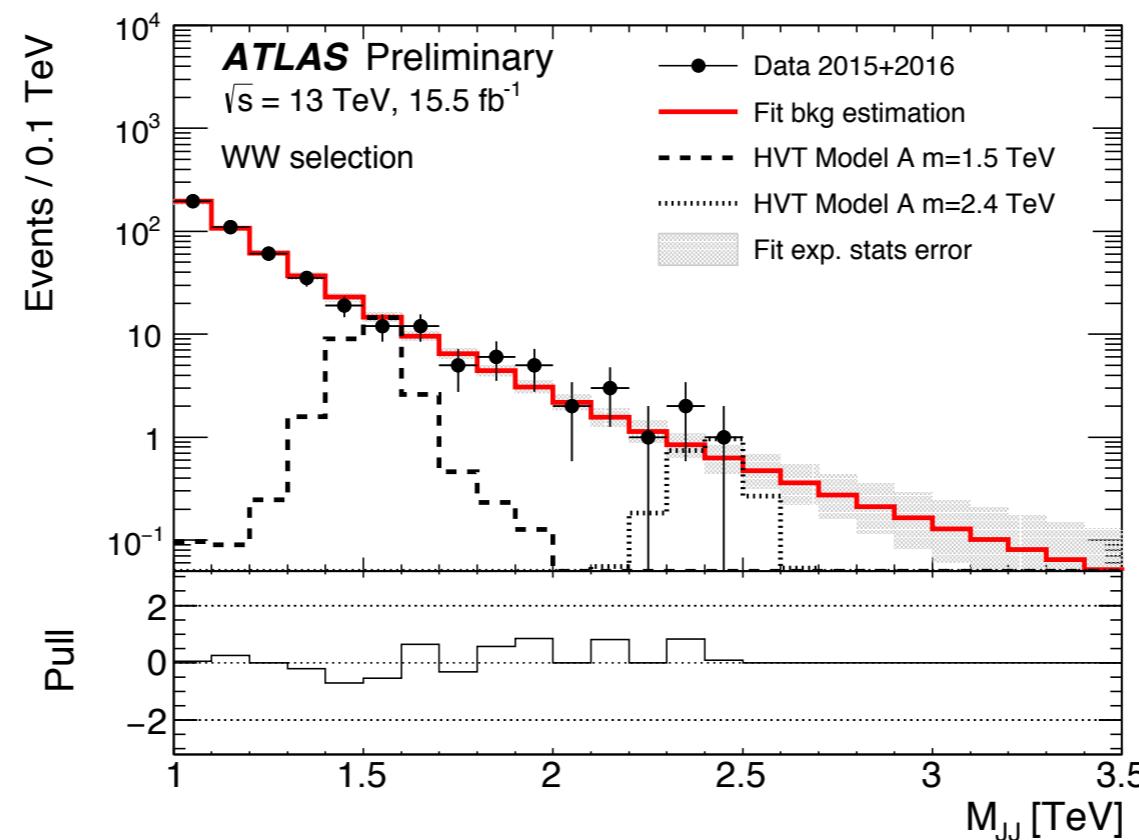
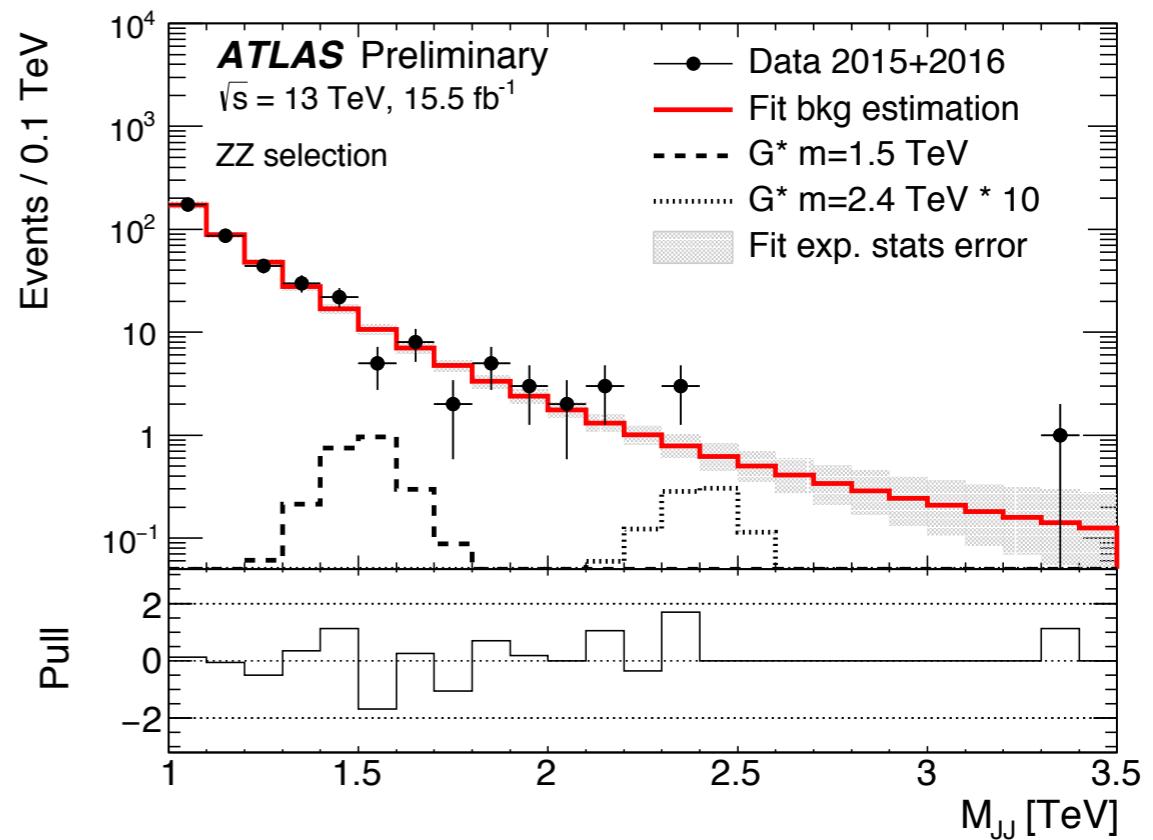
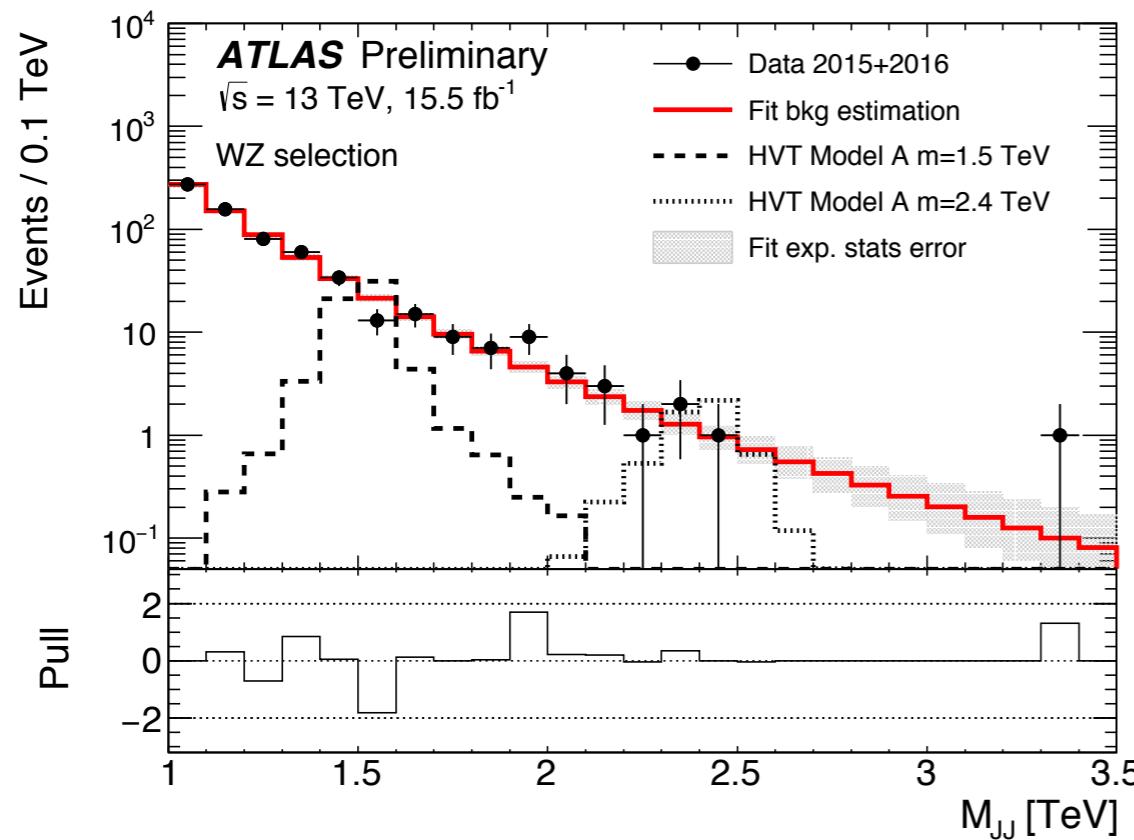
- Background fit model

$$\frac{dn}{d\textcolor{blue}{x}} = \textcolor{red}{p_1}(1 - \textcolor{blue}{x})^{\textcolor{red}{p}_2 + \xi p_3} \textcolor{blue}{x}^{\textcolor{red}{p}_3}, x = \frac{m_{jj}}{13\text{TeV}}$$

- Uncertainties on the fit parameter are the dominant systematic uncertainties in the results
- Validity of this model has been tested in various side-band data and QCD MC

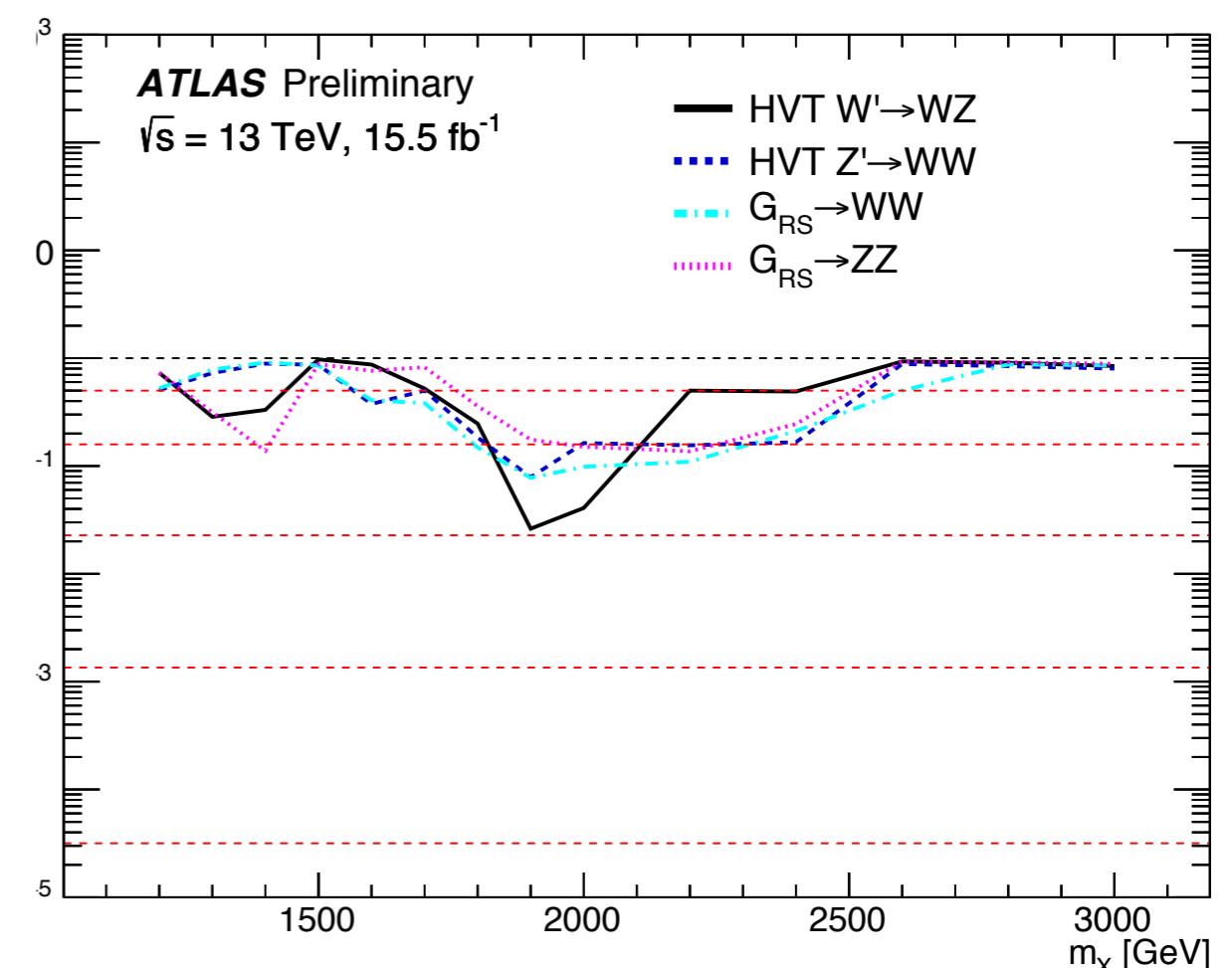
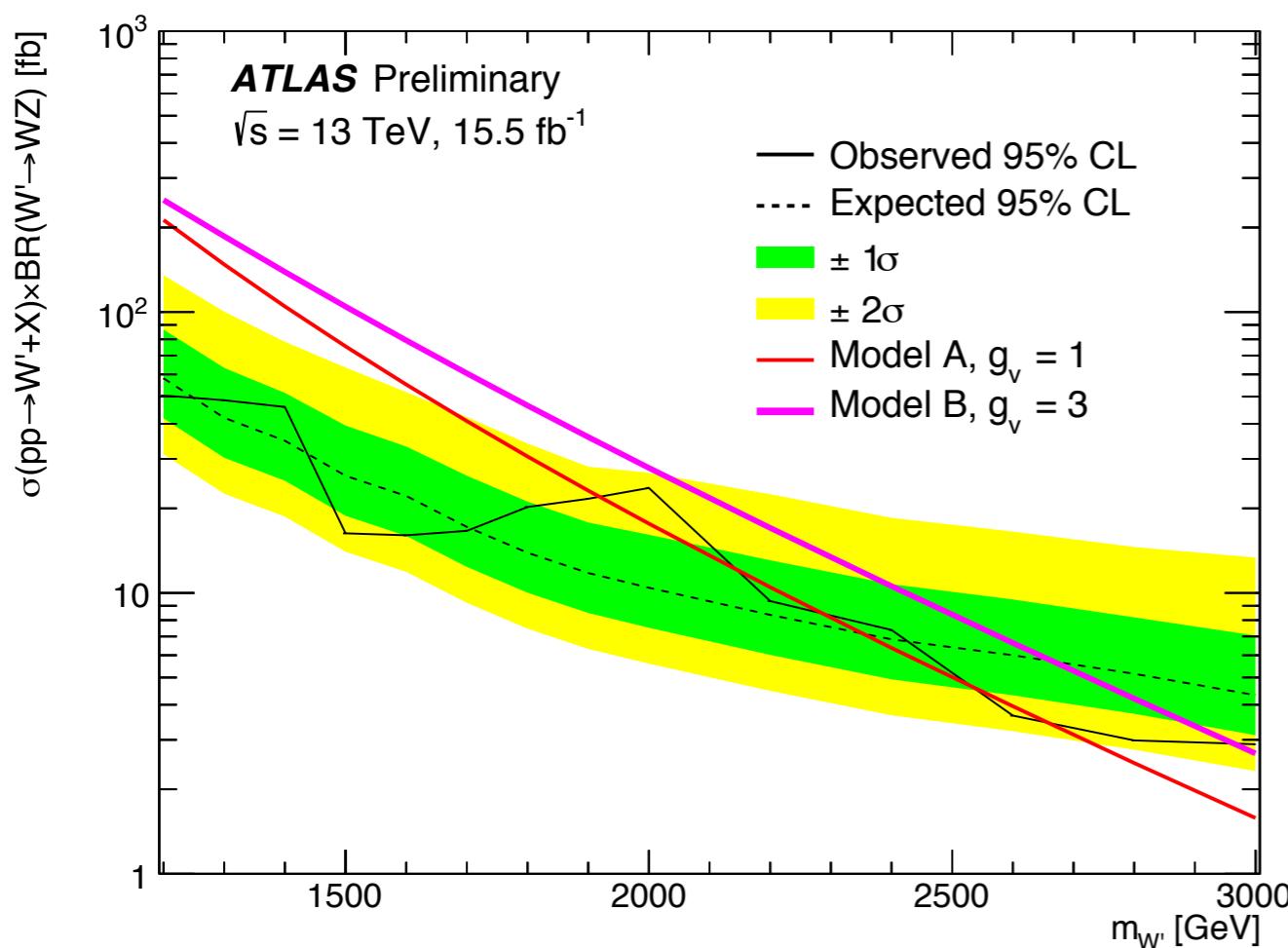


Observed spectra

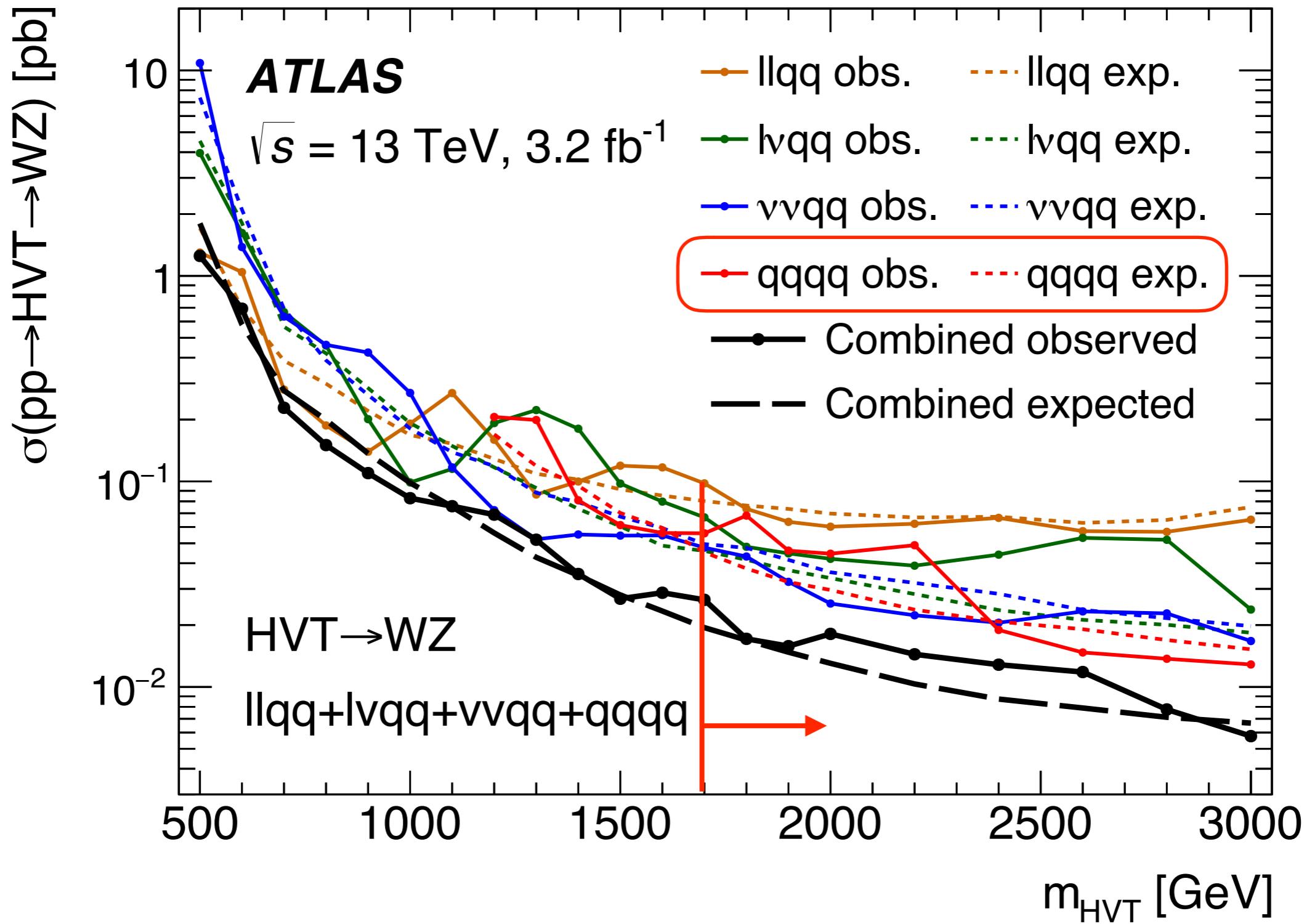


Recall selections are
largely overlapping!

Interpretation of results



Contribution to the grand combination



Conclusion

- Searches for heavy resonances in diboson final states have kept us on toes constantly
 - The run-I 2 TeV excess in the all-hadronic channel didn't reappear with equal strength in Run-2
- Plans towards the future
 - Keep probing higher mass range
 - Provide more stringent limit → nail down theory models
 - Dig in corners (such as VBF topology)

Backup slides

Energy correlation variables

- Energy correlation variables

$$E_{CF0}(\beta) = 1,$$

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$$E_{CF3}(\beta) = \sum_{i < j < k \in J} p_{T_i} p_{T_j} p_{T_k} (\Delta R_{ij} \Delta R_{ik} \Delta R_{jk})^\beta$$



$$e_2^{(\beta)} = \frac{E_{CF2}(\beta)}{E_{CF1}(\beta)^2}$$

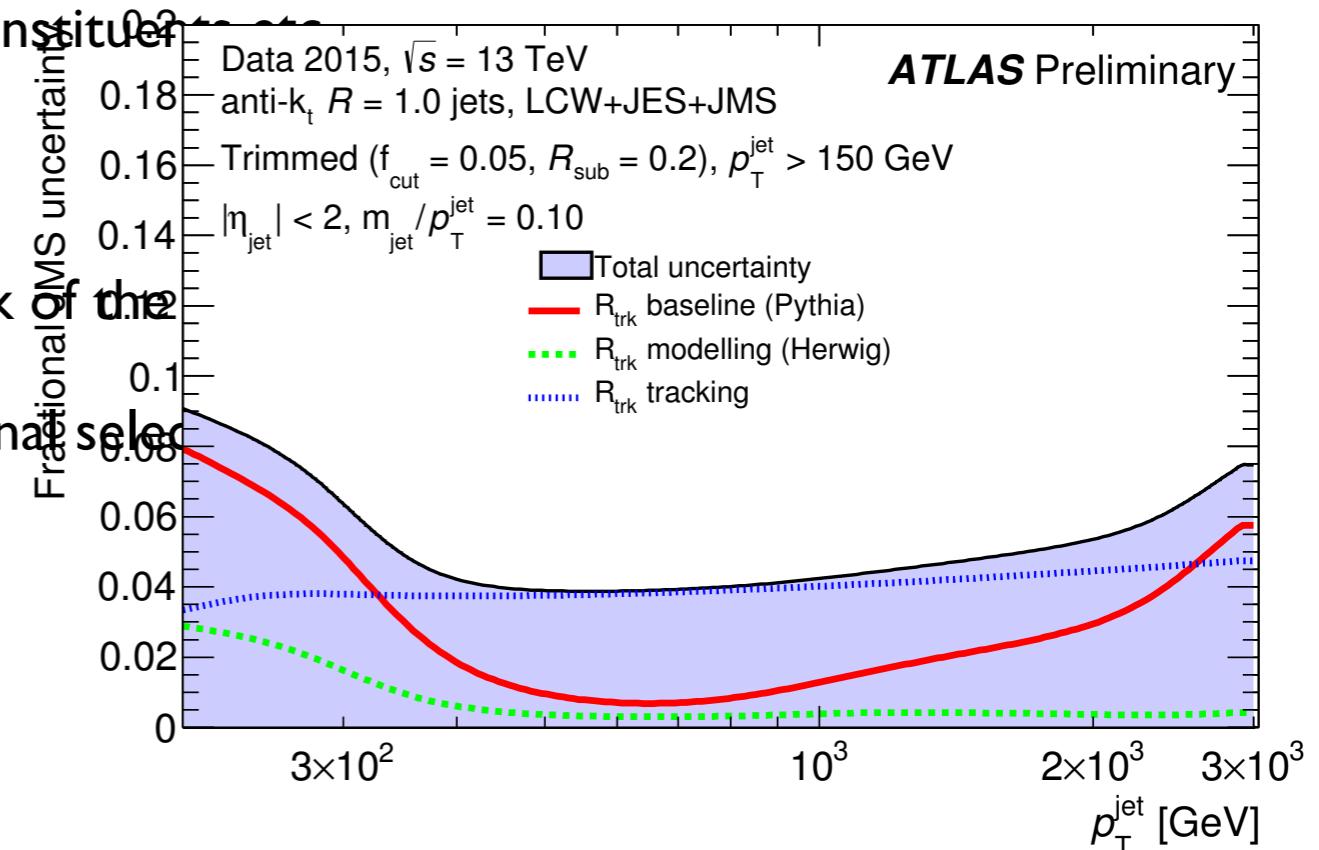
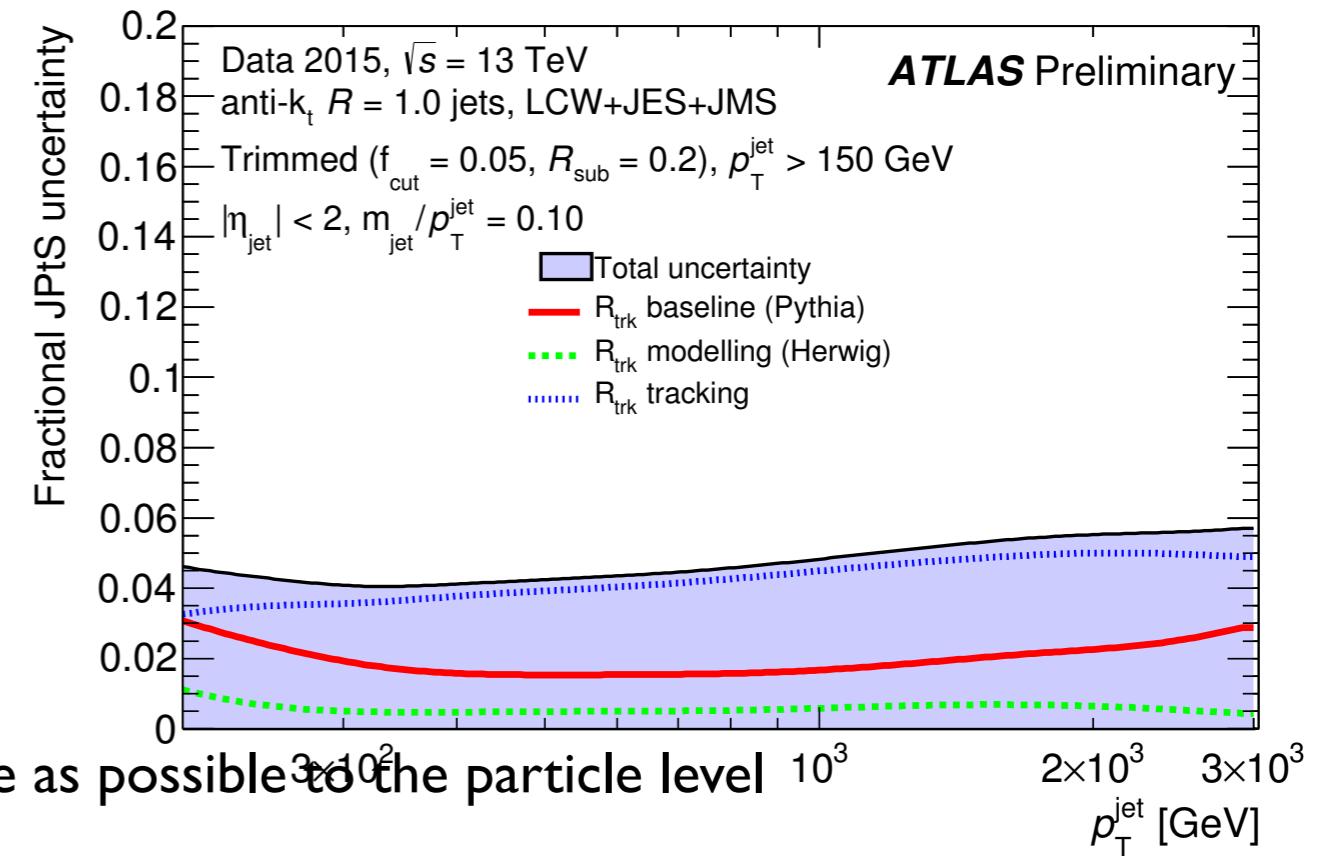
$$e_3^{(\beta)} = \frac{E_{CF3}(\beta)}{E_{CF1}(\beta)^3}$$



$$D_2^{(\beta)} = \frac{e_3^{(\beta)}}{(e_2^{(\beta)})^3}$$

W-jet tagging performance and calibrations

- **Boson tagging working point**
 - 50% signal efficiency
 - ~30-60 times QCD rejection
- **Energy and mass calibrations**
 - To scale the reconstructed quantity as close as possible to the particle level
 - Pileup, noise, angular distributions of the constituents
- **Systematics**
 - Jet energy scale uncertainty affects the peak of the signal selection
 - Jet mass scale uncertainty affects mainly signal selection
 - Jet energy and mass resolutions



Track multiplicity cut

- QCD jets have larger track multiplicity
 - Jet fragmentation scales of the V-boson and QC
 - V-boson: m_V
 - QCD jet: $pT(\text{jet})$
 - Significant gluon contribution in the QCD jets fur
- Efficiency of this cut can be studied using V+jet varying the value
- QCD enriched data is also studied to verify thi
- Improves the expected significance by ~30%

