Vector Boson Scale Factor Measurement

CAP Congress

Simon Fraser University, Vancouver

Christina Nelson

McGill University

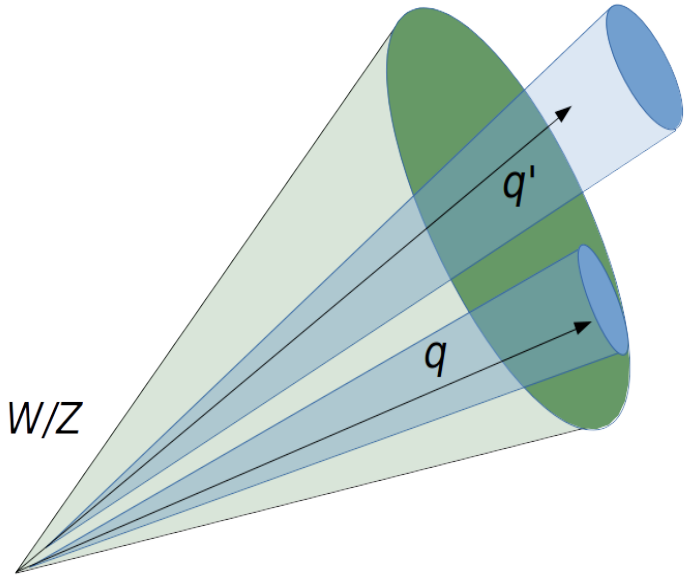
3 June 2019

Introduction

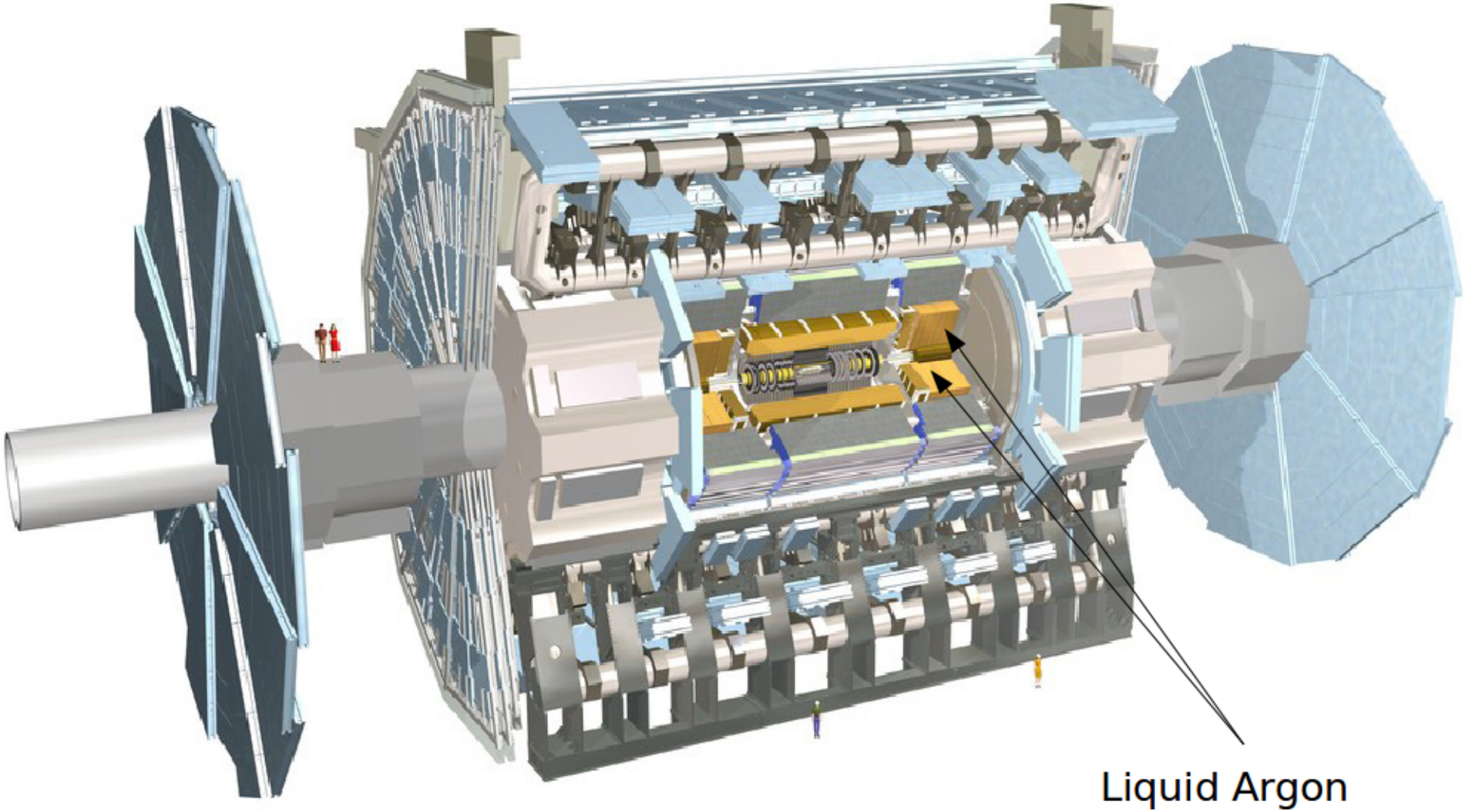
- A scale factor (SF) is simply a ratio of efficiencies in Data to Monte Carlo (MC) for a given process.
- This measurement is done on the purely hadronic decay of a Vector boson (W/Z jet, aka V-jet).

Introduction

- A scale factor (SF) is simply a ratio of efficiencies in Data to Monte Carlo (MC) for a given process.
- This measurement is done on the purely hadronic decay of a Vector boson (W/Z jet, aka V-jet).
- The hadronic decay of a V-jet is characterized by its two-prong structure using ATLAS's fine-grained calorimeter.



The ATLAS Detector



Liquid Argon
hadronic end-cap
and forward
calorimeters

Motivation

- Motivation for Scale Factors
  - A way to compare Data to MC efficiencies
  - Estimation of uncertainties: particularly useful when one has many correlated uncertainties

Motivation

- Motivation for Scale Factors
  - A way to compare Data to MC efficiencies
  - Estimation of uncertainties: particularly useful when one has many correlated uncertainties
- Motivation for V-jets
  - Background estimation for heavy resonance searches, eg. diboson searches
  - Refinement of methods to distinguish hadronic decays of W/Z from other processes

SF Measurement Procedure

Outline

- Tagging and selecting jets
- Jet mass distributions
- MC signal and background fits
- Scale Factor results

Defining a jet

At high transverse momenta (p_T), jets from the hadronic decay of a vector boson become highly collimated. The angular distance between the hadronic decays goes as $\sim 2m/P_T$

- Anti-k_t clustering algorithm $R = 1.0$ reconstructed fat jet
- Subjets: $R = 0.2$, $f_{cut} = 0.05$

Defining a jet

At high transverse momenta (p_T), jets from the hadronic decay of a vector boson become highly collimated. The angular distance between the hadronic decays goes as $\sim 2m/P_T$

- Anti-k_t clustering algorithm $R = 1.0$ reconstructed fat jet
- Subjets: $R = 0.2$, $f_{cut} = 0.05$

Tagging a W/Z jet

- D_2 variable uses energy and pair-wise angles of particles within a jet
- Cut on jet p_T
- n_{Trk} variable enhances quark like content

Jet Selection Conditions

- Kinematic requirements
  - $|y| < 2.0$ (y is rapidity)
  - Leading jet $p_T > 600$ GeV
  - both jets have $m_j > 50$ GeV
- Identified lepton events are vetoed
- Selected jet must pass the D_2 selection independently
- Each W/Z signal mass distribution is modelled by a double Gaussian

Track Calorimeter Cluster (TCC) jets

- A type of particle flow object
- Combines energy measurement from the calorimeter with the excellent spatial resolution provided by the track segments from the inner detector

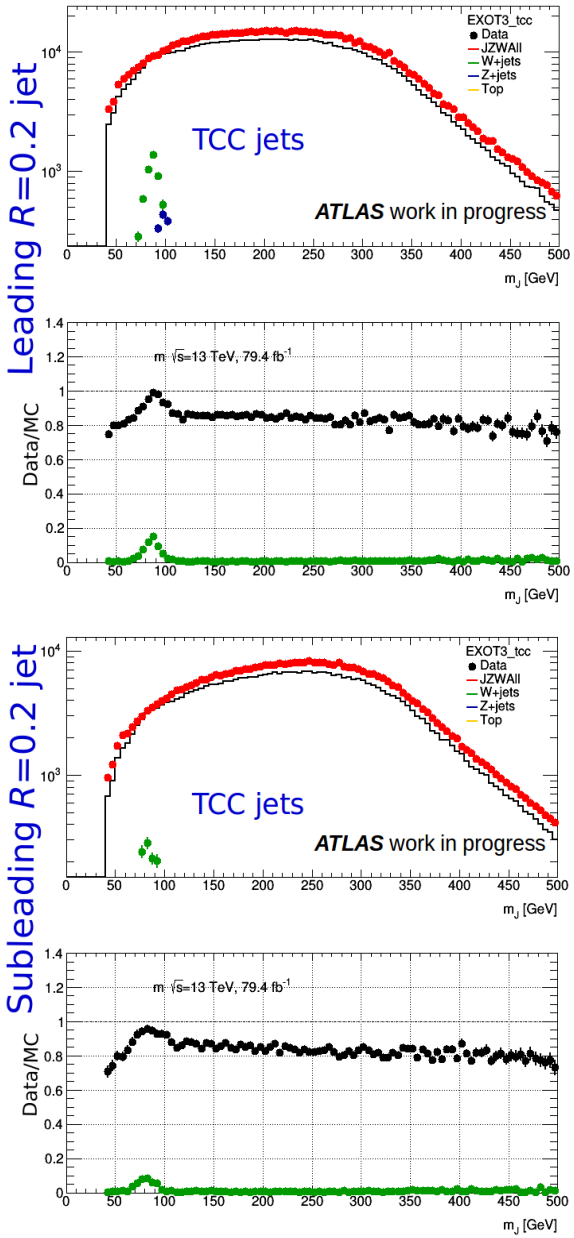
Track Calorimeter Cluster (TCC) jets

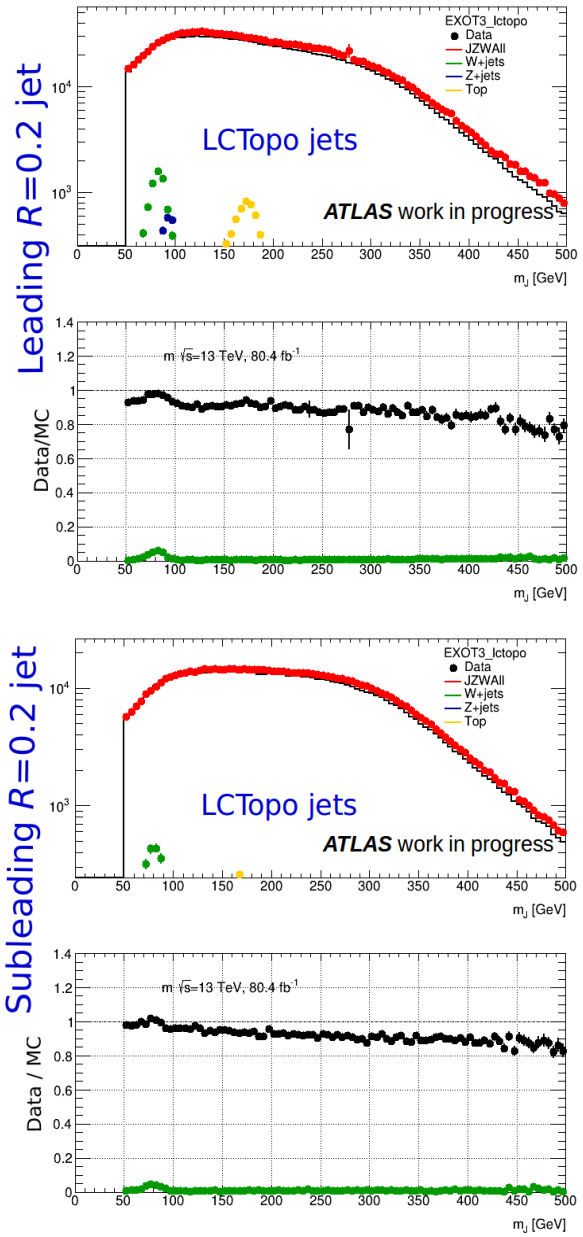
- A type of particle flow object
- Combines energy measurement from the calorimeter with the excellent spatial resolution provided by the track segments from the inner detector

Local Calibrated Topological Cluster (LCTopo) jets

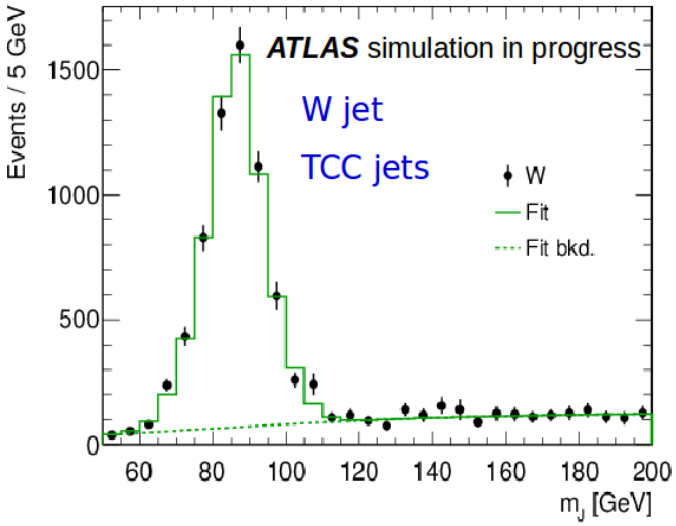
- Clusters of calorimeter cells after local cluster weighting
- Relies on the granularity of the calorimeter

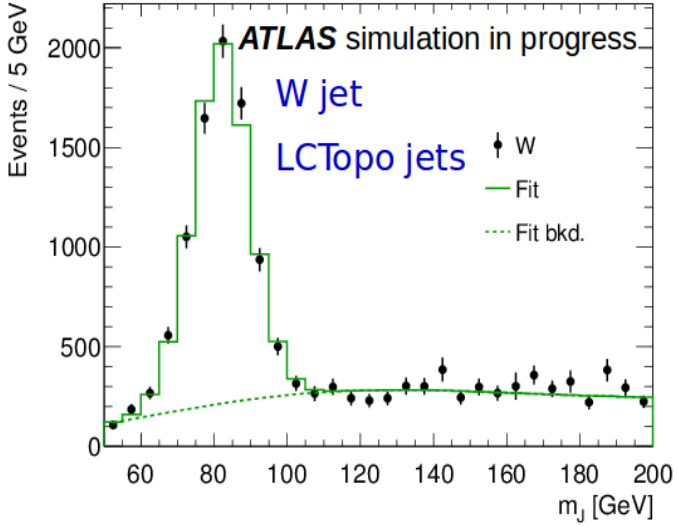
Jet Mass Distributions

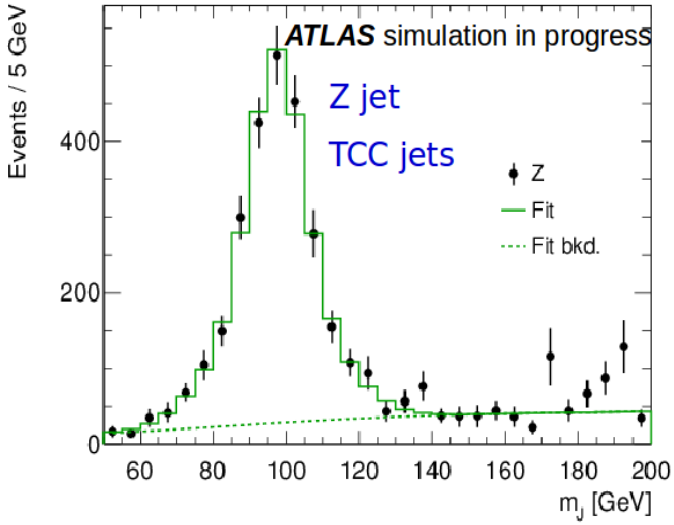


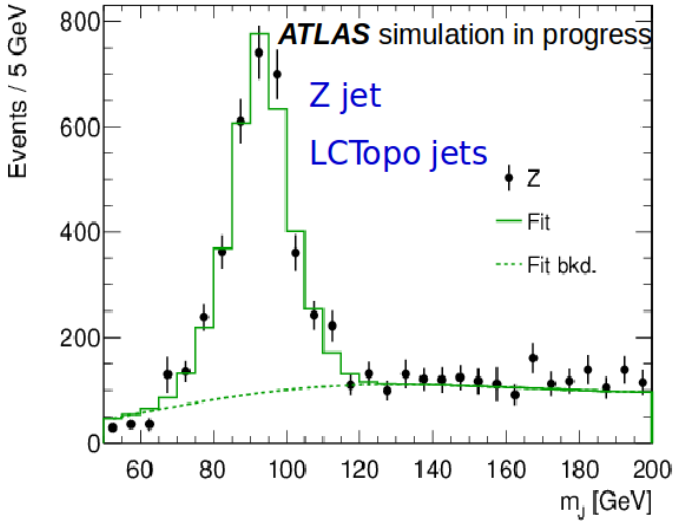


MC Template fit for W/Z+jets

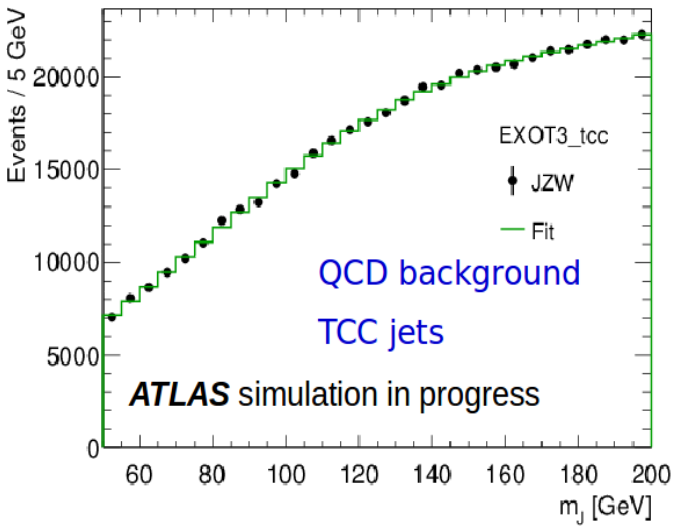


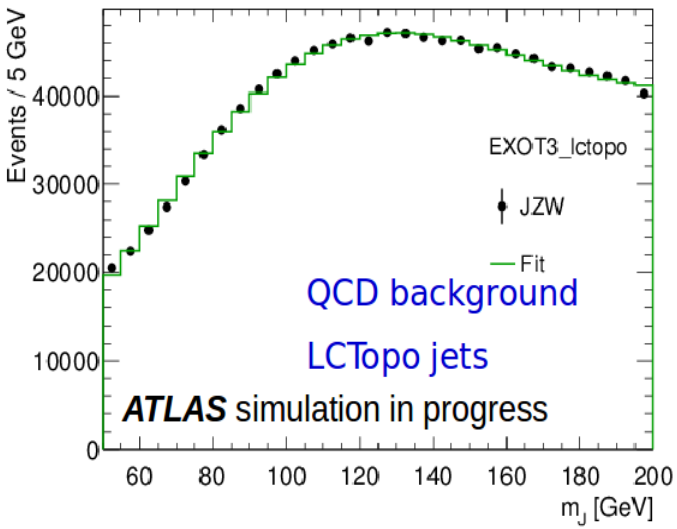






QCD Background Modelling





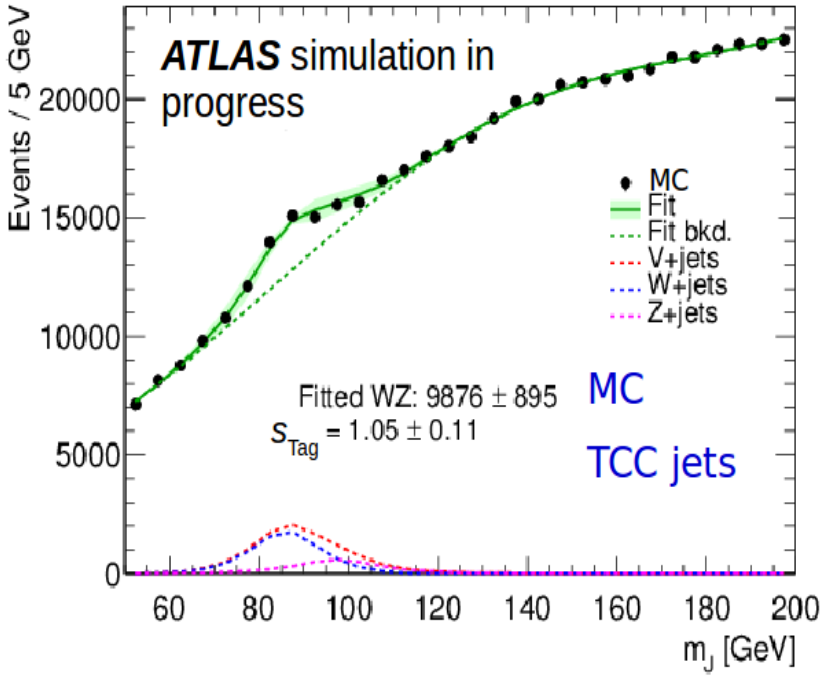
- Background fit function:

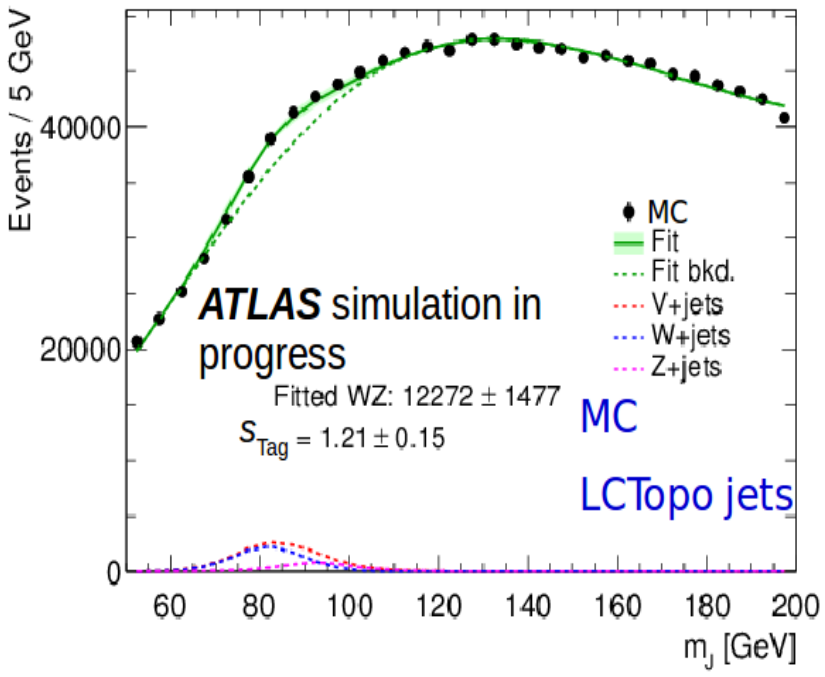
$$y = a_0 e^{a_1 M + a_2 M^2 + a_3 M^3 + a_4 M^4}$$

where $M = m_j - 100$ GeV

- Function is fitted to QCD jet simulation first, then fit parameters are fixed and only scale allowed to float when fitting on data

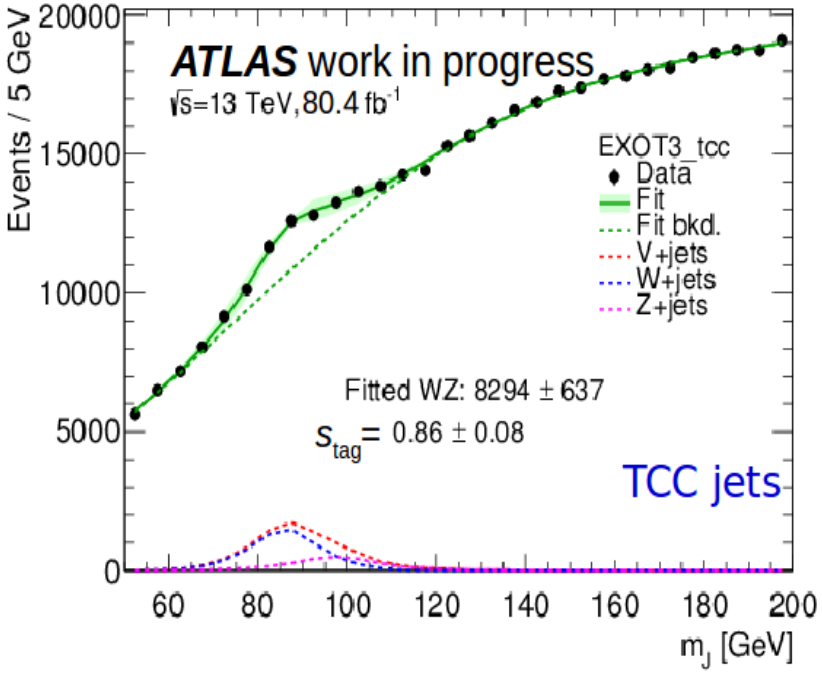
Closure Test

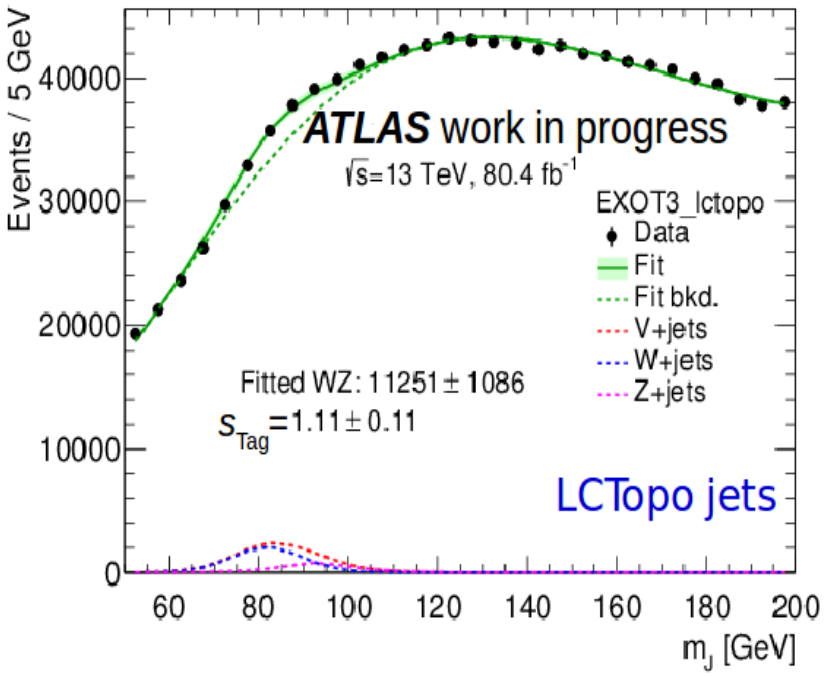




- Scale Factor $= S_{Tag}$
- A SF equal to 1 is "injected" into fake data
- The analysis is redone to see if the known value is retrieved
- TCC jets appear to perform slightly better than LCTopo jets

2015-2017 Results

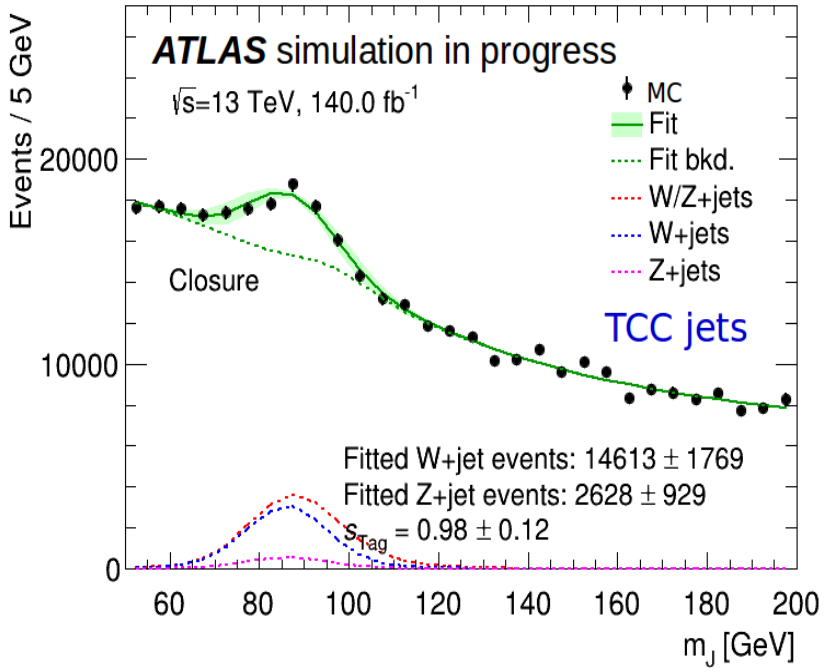


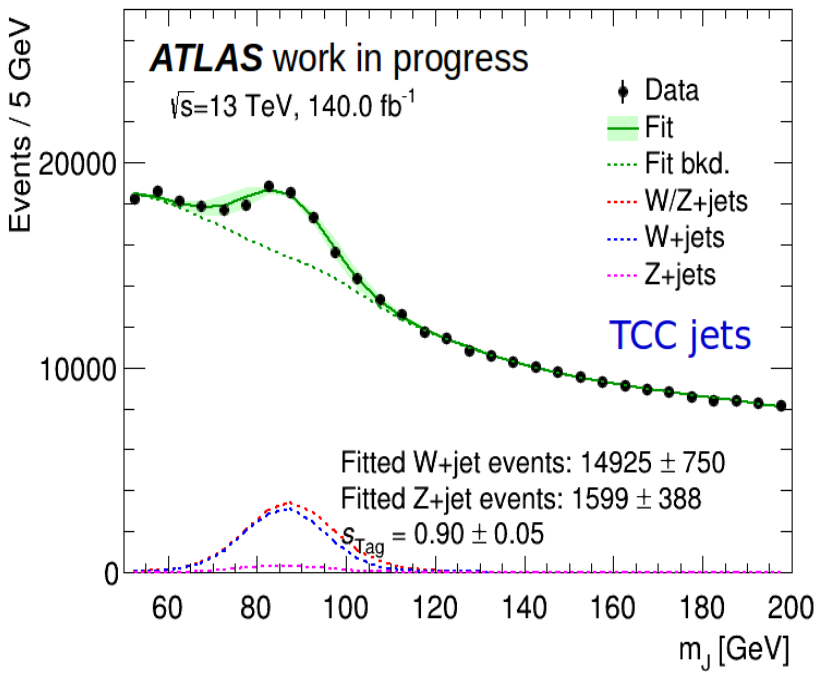


The measured SF for V+jets tagging:

- TCC jets: $S_{Tag} = 0.86 \pm 0.08$
- LCTopo jets: $S_{Tag} = 1.11 \pm 0.11$

2015-2018 Results





The measured SF for V+jets tagging:

- TCC jets: $S_{Tag} = 0.90 \pm 0.05$

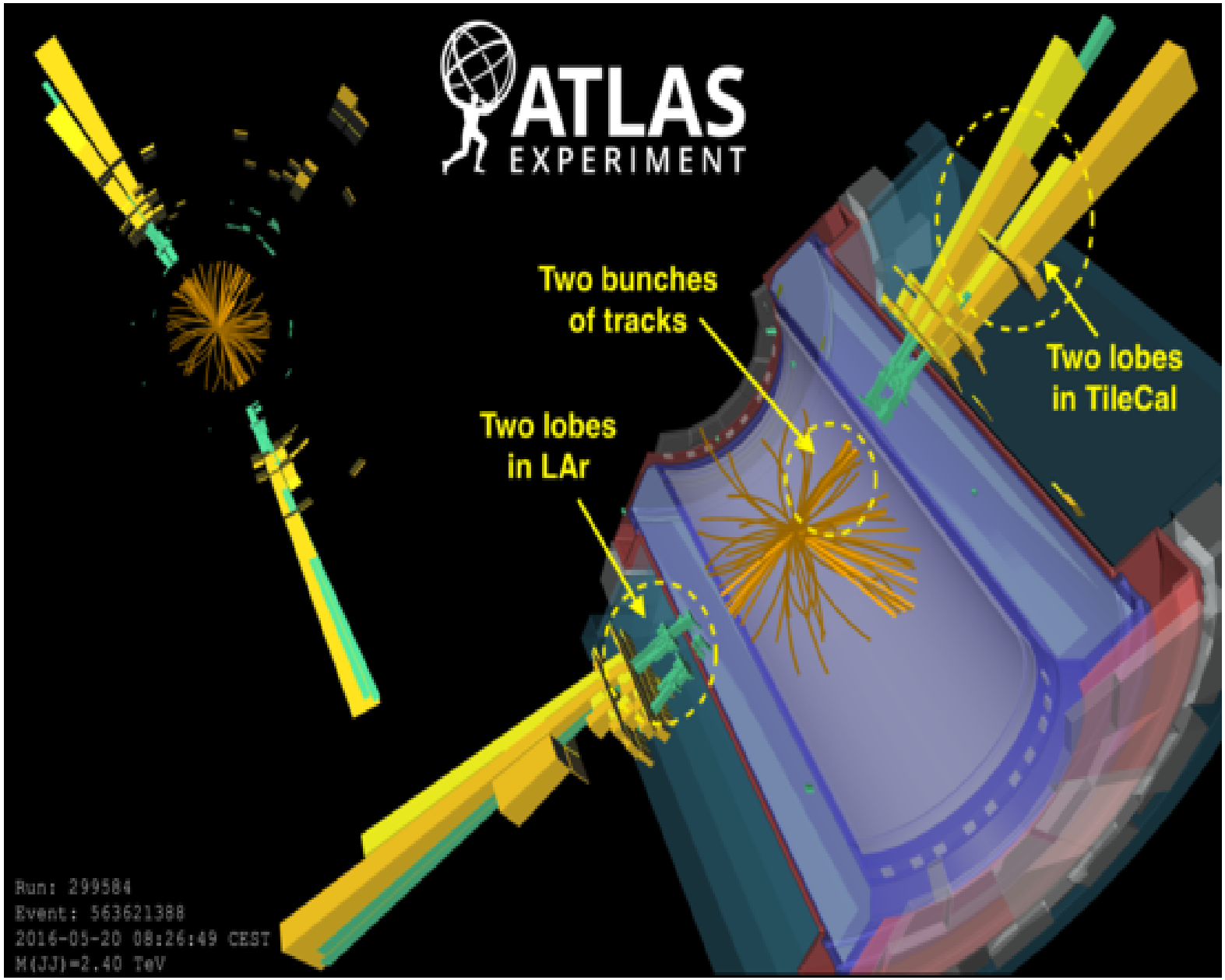
Conclusion

- Application of some of the newest advances in particle identification with jet substructure, TCC and LCTopo jets
- ATLAS work in progress results have been shown for data 2015-2018 at 13 TeV
- Scale factors measured and observed good closure, this will be provided to physics analyses across ATLAS

- Thank You
- Special thanks to Professor Francois Corriveau, Chris Malena Delitzsch, Bill Murray, and Roland Jansky

Backup

ATLAS-CONF-2016-055



Anti-Kt algorithm

The following distance measures are used:

- The distance between particles
  $d_{ij} = \min(k_{ti}^{2p}, k_{tj}^{2p})\frac{\Delta_{ij}^2}{R^2}$
  - $\Delta_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$
  - k_{ti} = transverse momentum
  - y_i = rapidity of particle i
  - ϕ_i = azimuth of particle i
- The distance between a particle and the beam
  $d_{iB} = k_{ti}^{2p}$
- Clustering takes place by finding the smallest distance. If it is dij, particles i and j and clustered together and process repeats. Else if it is d_{iB}, i is declared a jet and removed from the list of particle entries.

D2 jet substructure variable

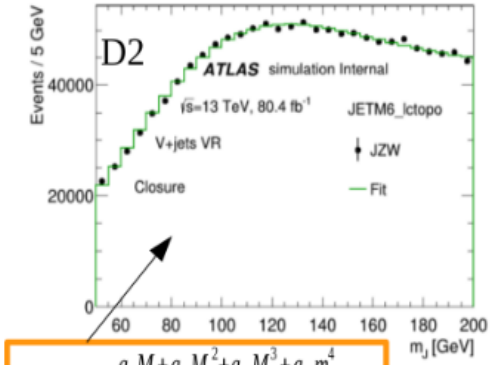
Correlation functions are based on the energies and pair-wise angles of particles within a jet, with (N+1)-point correlators sensitive to N-prong substructure. The 1-point, 2-point and 3 -point energy correlation functions are given by:

- $E_{CF}0(\beta) = 1$
- $E_{CF}1(\beta) = \sum_{i \in J} p_T$
- $E_{CF}2(\beta) = \sum_{i<j \in J} p_{T_i} p_{T_j} (\Delta R_{ij})^\beta$
- $E_{CF}3(\beta) = \sum_{i<j<k \in J} p_{T_i} p_{T_j} p_{T_k} (\Delta R_{ij} \Delta R_{ik} \Delta R_{jk})^\beta$

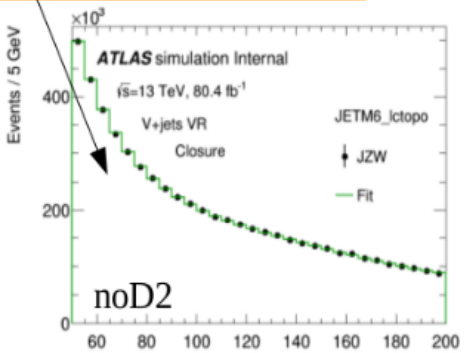
Where β is used to give weight to the angular separation of the jet constituents. We have taken $\beta = 1$.

V+jets Method: Fit functions & parameters

- Functions modeling signal and background; parameters fixed from fit on MC only

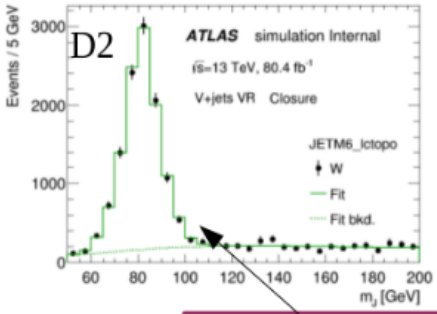


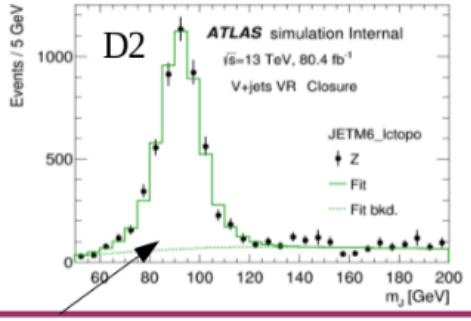
$$y = a_0 e^{a_1 M + a_2 M^2 + a_3 M^3 + a_4 m^4}$$



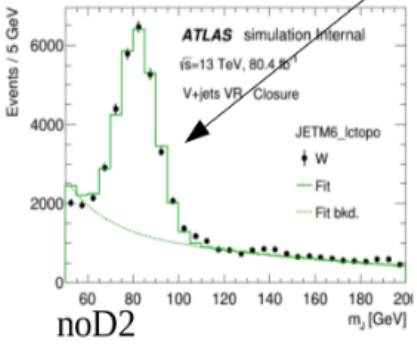
(1) Parameters fit on MC dijet background, then fixed.

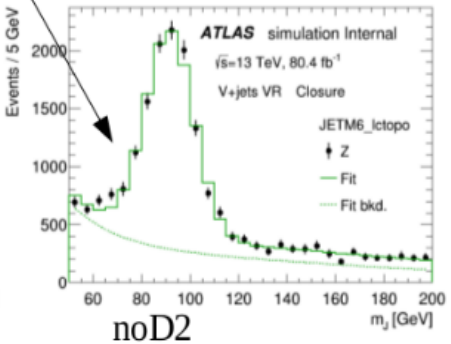
(2) MC signal modelled by double Gaussian plus background function. Only scale is allowed to vary in background function.





$$\sigma_{WZ} = \sigma_f (1 - f_Z)\left(e^{-\frac{1}{2}\frac{(m - m_W - O_W)^2}{\sigma_W^2}} + R_W e^{-\frac{1}{2}\frac{(m - m_W - O_W)^2}{(S_W \sigma_W)^2}}\right)$$
$$f_Z\left(e^{-\frac{1}{2}\frac{(m - m_Z - O_W - O'_Z)^2}{\sigma_Z^2}} + R_Z e^{-\frac{1}{2}\frac{(m - m_Z - O_W - O'_Z)^2}{(S_Z \sigma_Z)^2}}\right)$$





(3) W/Z parameters obtained from fit on MC signal, and then fixed.

(4) Finally, when fitting on data, fitting function is double Gaussian plus background function, where only scale is allowed to vary.

Closure Test

MC fake data is scaled by a range of values. Then the SF procedure is done on the fake data and the extracted SF is compared to known value.