Recent Developments on the Statistical Treatment of Flavour Tagging Uncertainties in ATLAS

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Flavour tagging calibration & uncertainties in ATLAS

1. b-tagging Scale Factor (SF)

B-tagging is an algorithm to identify b-jets. Its efficiency for b-flavour jets is defined as:

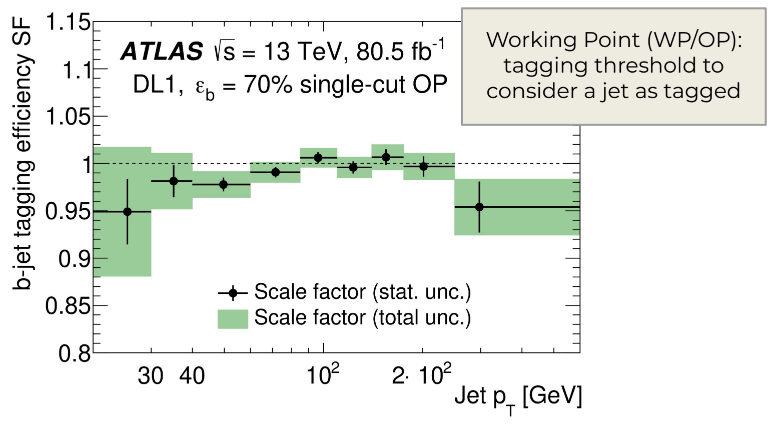
$$\epsilon_f = \frac{\text{\# of jets identified as b-jets}}{\text{Total \# of jets}}$$

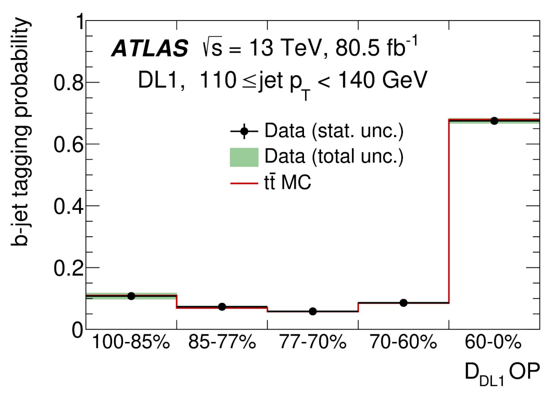
Similar quantities for charm and light jets are referred to as the mis-tag rates.

The efficiency in MC is corrected by the scale factors to match that in data:

$$\mathrm{SF}(p_\mathrm{T}) = \frac{\epsilon_\mathrm{data}}{\epsilon_\mathrm{MC}}(p_\mathrm{T})$$

U corresponds to the uncertainties associated with SF .



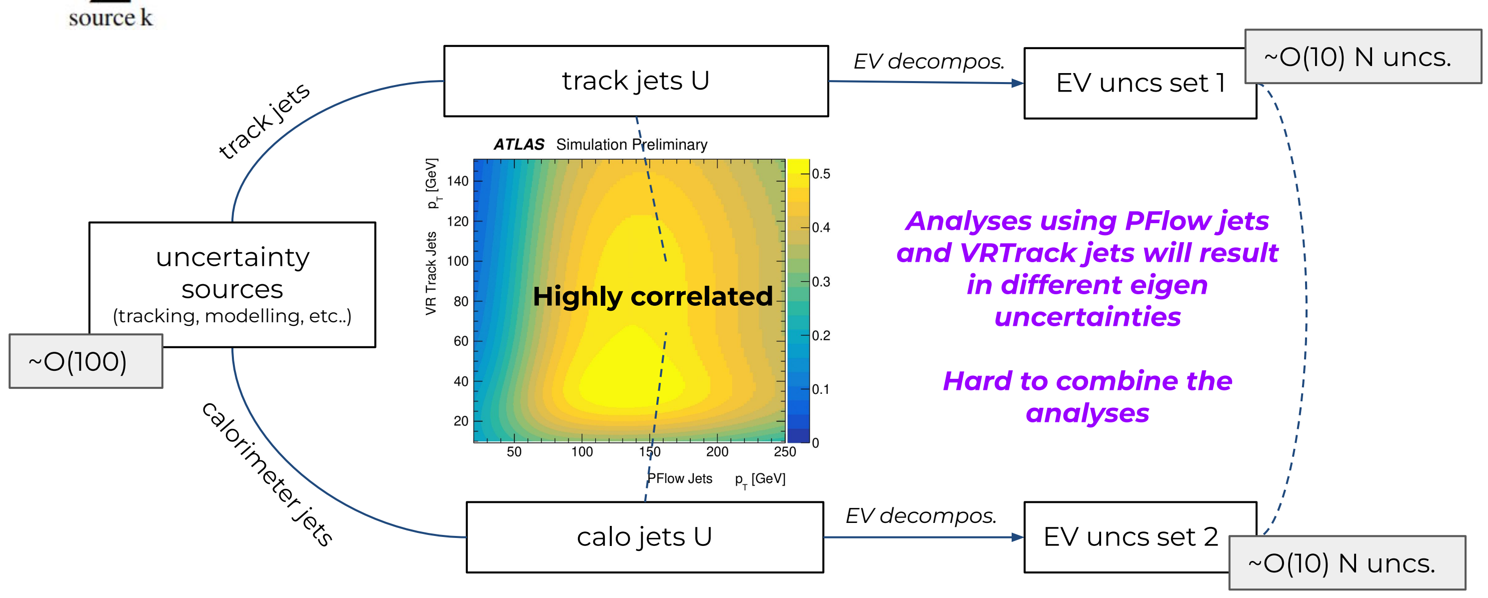


Pseudo-continuous WP, classify jets into 5 categories according to their score.

2. Eigenvector Decomposition

- A Method to reduce the number of b-tagging uncertainties in physics analyses.
- Eigenvector decomposition applied to the covariance matrix V built from the systematic variations U.
- The resulting eigenvector (EV) uncertainties preserve correlations among uncertainties.

$$V_{ij} = \sum_{\text{source k}} U_{\text{pt bin i, source k}} U_{\text{pt bin j, source k}} \rightarrow V = U^T U \xrightarrow{\text{Eigenvector decomposition}} \text{Eigenvector uncertainties}$$



Eigenvector recomposition

- Need lower # of b-tagging uncs. & original b-tagging uncertainties ⇒ Eigenvector recomposition
- Eigenvector recomposition (EVR): Recovering the original SF uncs. in the analysis likelihood, starting from the eigenvector uncertainties.
- In practice: **eigenvector nuisance parameters** θ can be expressed as a combination of **original nuisance parameters** η in physics analysis likelihood⇒ the b-tagging uncertainties can thus be correlated among physics analyses. ⇒ helpful in downstream **combination analyses**.

Recomposition matrix

$$\vec{\theta} = \vec{\eta} \cdot \boxed{U \cdot \tilde{U}^{-1}_{\text{right}}}$$

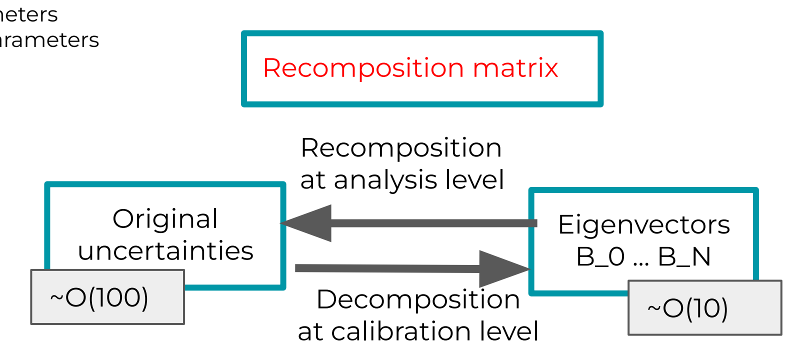
Θ = EV nuisance parameters
η= original nuisance parameters

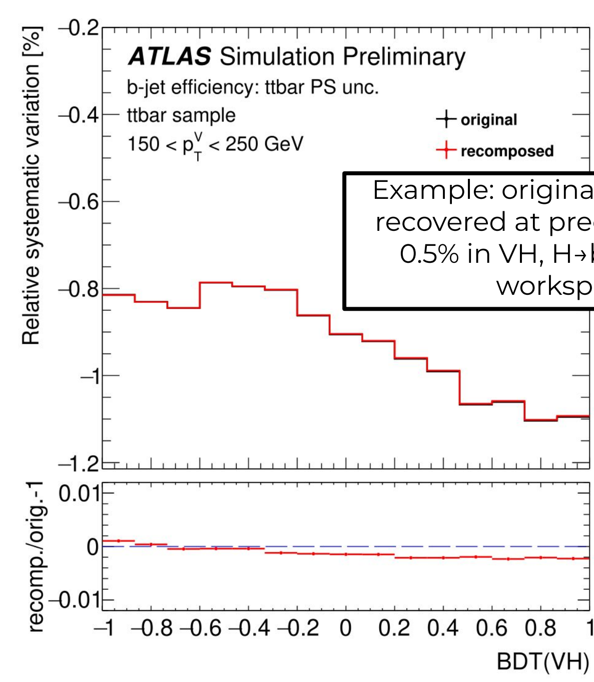
Where $\tilde{U}^{-1}_{\text{right}}$ is derived from covariance matrix V.

The likelihood function based on b-tagging EV uncs can be modified to depend on η

$$\mathcal{L} = L(\vec{\mu}, \theta_1, \theta_2, ..., \theta_L)P(\theta_1)P(\theta_2)...P(\theta_L)$$

$$\mathcal{L} = L(\vec{\mu}, \eta_1, \eta_2, ..., \eta_M)P(\eta_1)P(\eta_2)...P(\eta_M),$$





Example: original uncertainty recovered at precision within 0.5% in VH, H→bb analysis workspace

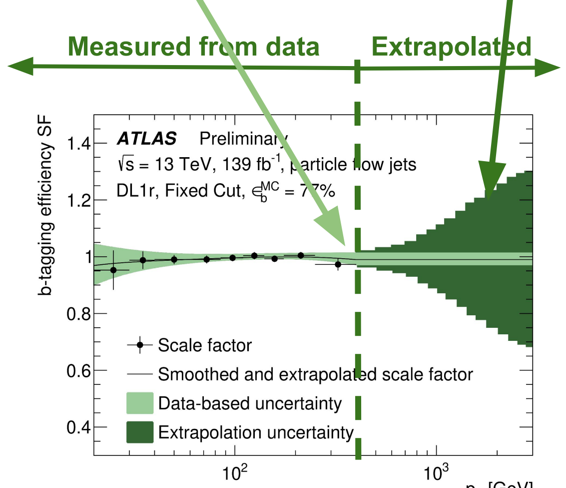
high-pt extrapolation for the pseudo-continuous b-tagging calibration

For TeV scale jets, the data-based calibration uncertainties are complemented by MC-based extrapolation uncertainties:

SF uncertainty in the highest pT bin in data based calibration (reference point)

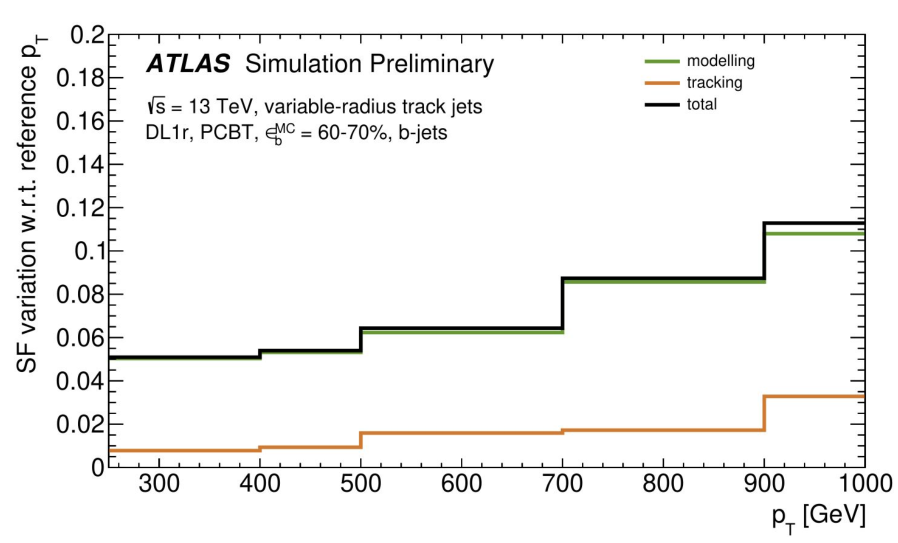
MC-based extrapolation term

$$\sigma^2_{\text{rel}}(\mathrm{SF}_b(p_T)) = \boxed{\sigma^2_{\text{rel}}(\mathrm{SF}_b(p_{T,\text{ref}}))} + \boxed{\sum_{s\in S} \max_{<p_T} \left[\delta\epsilon^{\text{MC}}_{b,s}(p_T) - \delta\epsilon^{\text{MC}}_{b,s}(p_{T,\text{ref}})\right]^2}$$



This method has been refined for the pseudo-continuous calibration to: :

$$\Delta_{rel}(SF_{p_T}) = \boxed{\Delta_{rel}(SF_{p_{T,ref}})} + \boxed{\Delta_{rel}(\epsilon_{MC,p_T}) - \Delta_{rel}(\epsilon_{MC,p_{T,ref}})}$$



Extrapolation terms for the b-jet calibrations. black: total contribution

In this new approach the sign of the single uncertainties preserved, to ensure:

$$\sum_{i=1}^{5} \epsilon^i_{p_T} SF^i_{p_T} = 1$$

The new uncertainties are implemented as a set of NPs and the eigenvector decomposition is used to reduce their number in the analysis.

References:
1. ATLAS Collaboration, ATLAS b-jet identification performance and efficiency measurement with $t\bar{t}$ events in pp collisions at √s = 13 TeV, (2019), arXiv: 1907.05120 [hep-ex]
2. ATLAS Collaboration,The eigenvector recomposition: a new method to correlate flavor-tagging systematic uncertainties across analyses, CERN, 2021, url: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/FTAG-2022-001/
3. ATLAS Collaboration, Simulation-based extrapolation of b-tagging calibrations towards high transverse momenta in the ATLAS experiment, CERN 2021, url: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2021-003/