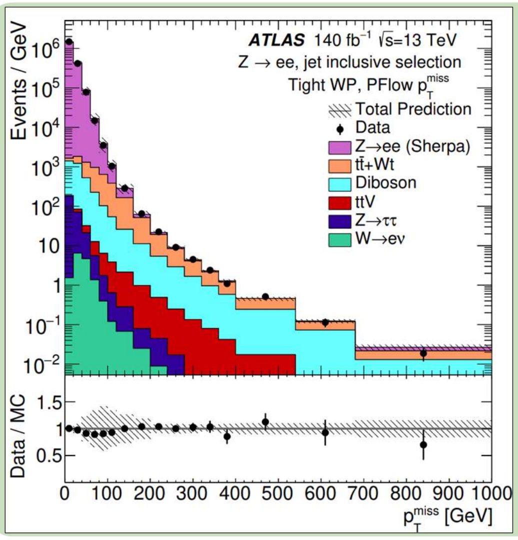
# Missing Transverse Momentum Performance at ATLAS

**Sebastian Rutherford Colmenares** on behalf of ATLAS

[1] arXiv:2402.05858 [2] ATLAS-JETM-2024-01 [3] ATLAS-CONF-2023-028




## $p_T^{miss}$ and TST introduction

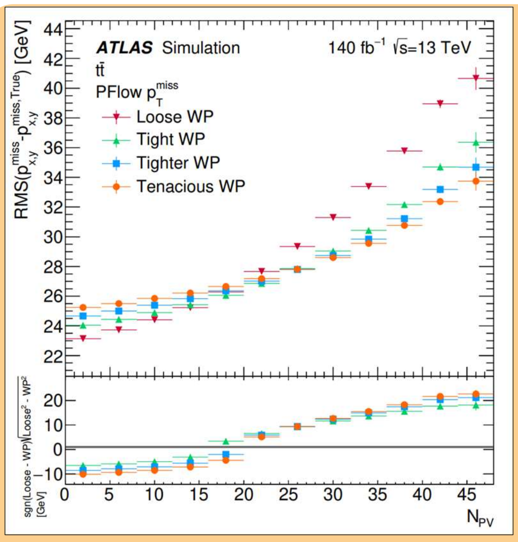
The missing momentum transverse to the proton beam direction ($p_T^{miss}$) infers the existence of undetected particles (e.g. neutrinos, possible dark matter candidates).

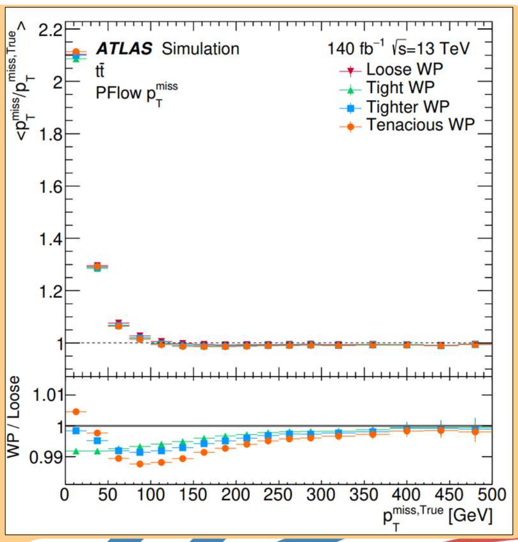
Including $p_T$ from *soft-event* signals not associated to hard reconstructed objects ($p_T^{soft}$) improves $p_T^{miss}$ performance. The track soft term (TST) definition specifically uses the remaining tracks not associated with hard scatter objects and tracks associated with jets with $p_T$ < 20 GeV. The TST misses neutral softs, but is more pile-up resilient.

Calorimeter, tracker, and muon spectrometer signals combine the $p_T$ of fully calibrated hard objects ($p_T^{hard}$) with $p_T^{soft}$ via a vector sum, with signal ambiguities solved through complex *overlap removal* with object priority as ordered below [1].

$$\mathbf{p}_T^{miss} = -\left(\sum \mathbf{p}_T^{e} + \sum \mathbf{p}_T^{\gamma} + \sum \mathbf{p}_T^{\tau} + \sum \mathbf{p}_T^{\mu} + \sum \mathbf{p}_T^{jet} + \sum \mathbf{p}_T^{soft}\right)$$

◄ *Modelling check: $p_T^{miss}$ in Sherpa MC simulation and data. Events pass Z→ee selection; error band includes MC statistical, luminosity, and detector uncertainties. Very good agreement within uncertainties.*



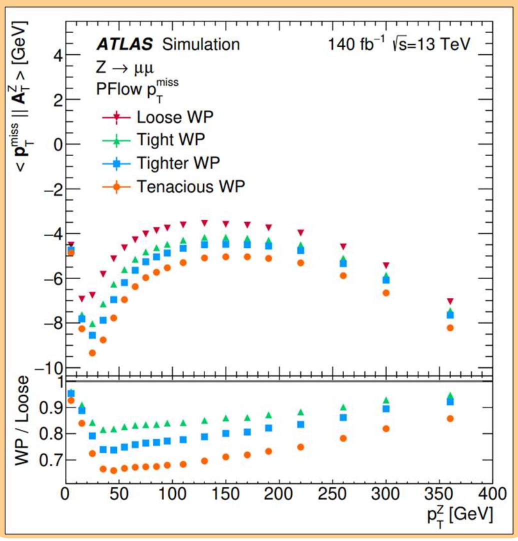




## Working points & performance

Additional proton-proton interactions (pile-up) contribute to 'fake' $p_T^{miss}$. Working points (WPs) set different selections on jets entering the $p_T^{miss}$ calculation and mainly differ in the forward jet $p_T$ cut. WP choice based on trade-offs between reducing pile-up contamination and missing real jets, based on event topology.

▲ *Performance check: Tighter WPs better at higher pile-up tt̄ events, but cut too much real hadronic activity at low pile-up (left). Tight has smaller bias at low $p_T^{miss}$ due to removing pile-up while not removing too many hard scatter jets (right).*

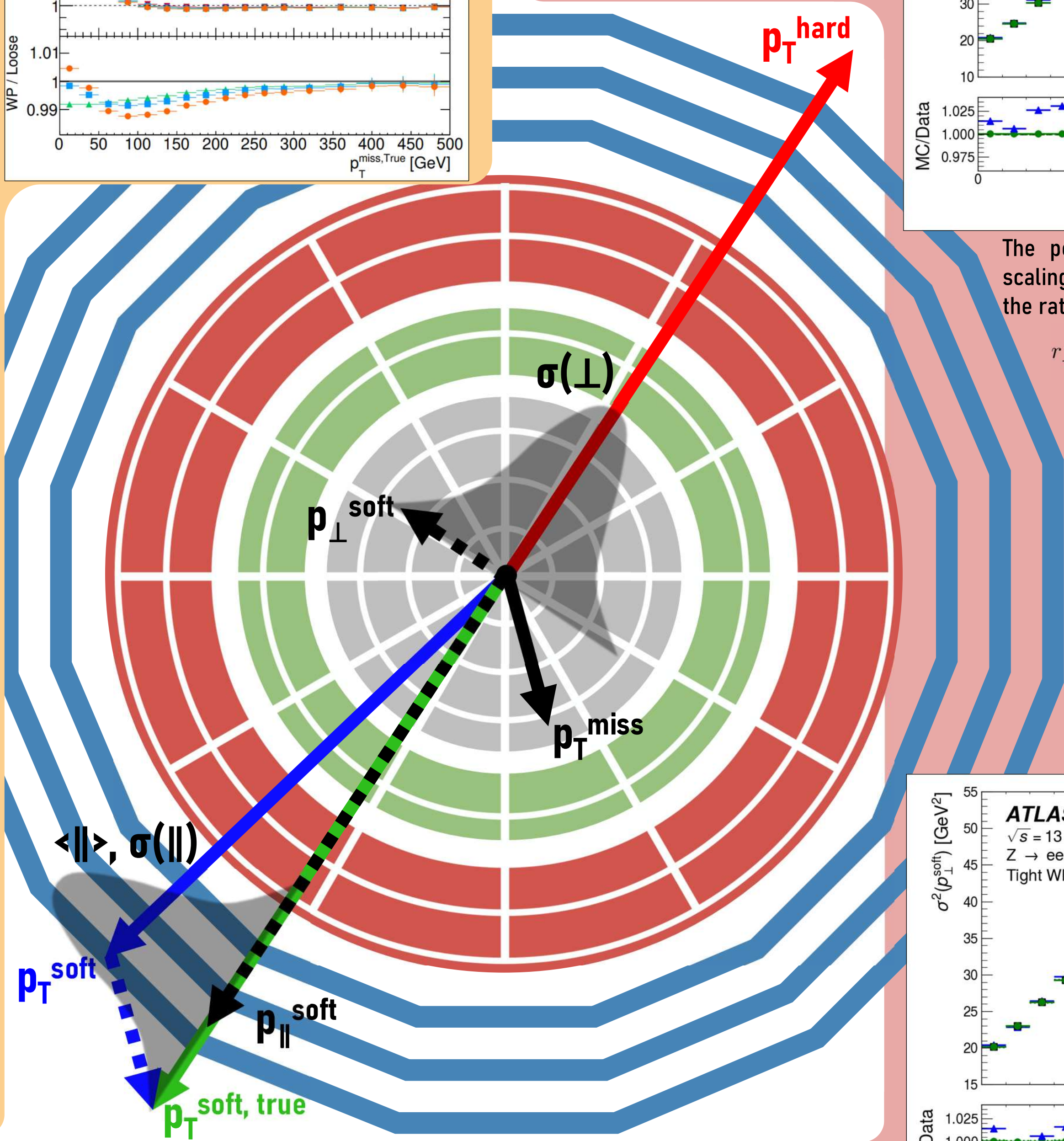
▼ *Performance check: The average projection of $p_T^{miss}$ on to the Z boson axis as a function of the Z boson's $p_T$. Negative values show an underestimation of the hadronic balance with the Z boson. Tightening the WP misses more of the hadronic activity.*



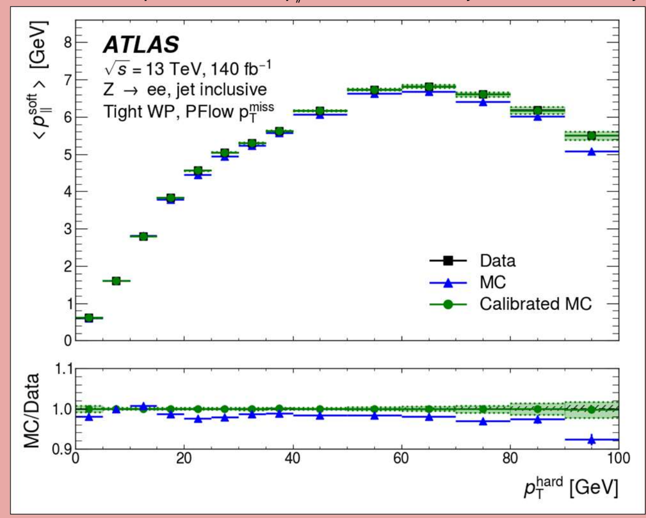

## New TST Calibration

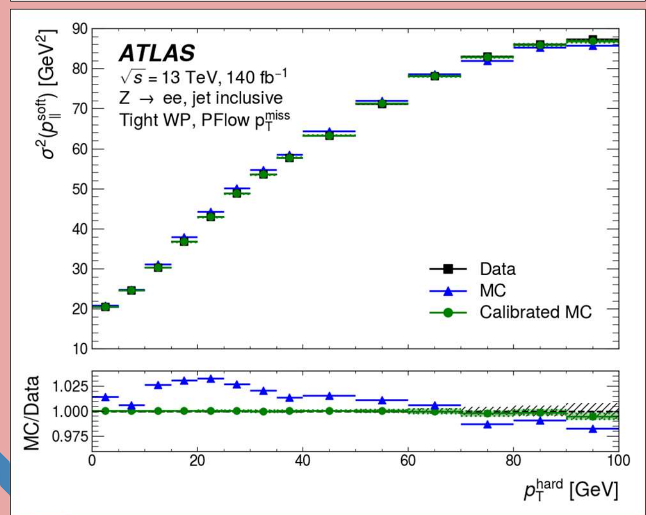
In progress: reduced TST systematics via generator-specific calibration in *three variables on the $p_T^{hard}$ axis [2]:

1. **the parallel scale $\langle p_\parallel^{soft}\rangle$**
2. **the parallel resolution $\sigma(p_\parallel^{soft})$**
3. **the perpendicular resolution $\sigma(p_\perp^{soft})$**




▼ *Full $p_\parallel^{soft}$ calibration. The calibrated MC $\langle p_\parallel^{soft}\rangle$ (top) is shifted to match the data with the additional terms in ratio method. Green bands show statistical uncertainties from the calibration procedure. Agreement post-calibration is excellent, except for final bin of $\sigma(p_\parallel^{soft})$ (bottom) covered by statistical uncertainty*




The perpendicular component is calibrated by scaling the observed value of each MC event by the ratio of the data and MC resolutions [3]:

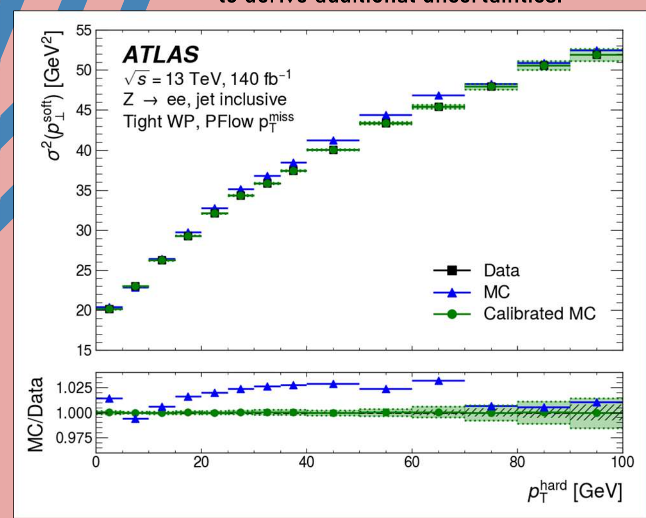
$$r_\perp = \frac{\sigma(u_\perp)^{data}}{\sigma(u_\perp)^{MC}} \qquad u_\perp^{MC,corr} = u_\perp^{MC} \cdot r_\perp$$

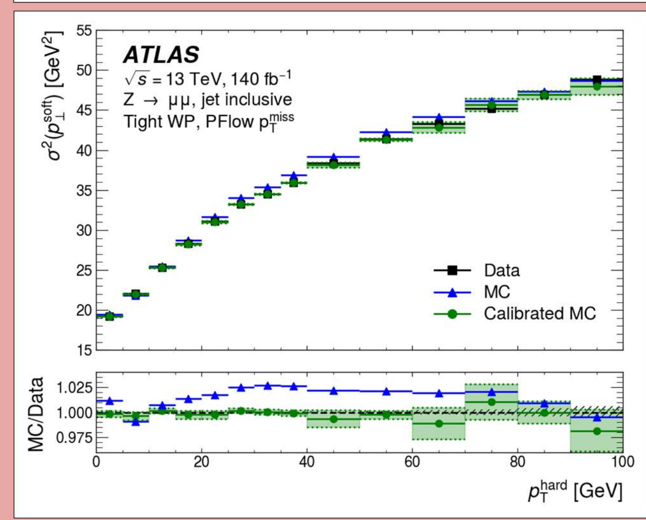
The parallel scale tends to oppose $p_T^{hard}$, so the parallel component is calibrated by using the resolution ratio, and data and MC distribution averages to correct the scale and resolution concurrently:

$$r_\parallel = \frac{\sigma(u_\parallel)^{data}}{\sigma(u_\parallel)^{MC}}$$

$$u_\parallel^{MC,corr} = u_\parallel^{MC} \cdot r_\parallel + \langle u_\parallel^{data}\rangle - \langle u_\parallel^{MC}\rangle \cdot r_\parallel$$

Calibration factors derived in Z→ee. Calibration validated in various final states (e.g. Z→μμ, tt̄, W→μν, Z→ττ, Z via VBF, γ+jets). Any non-closure used to derive additional uncertainties.



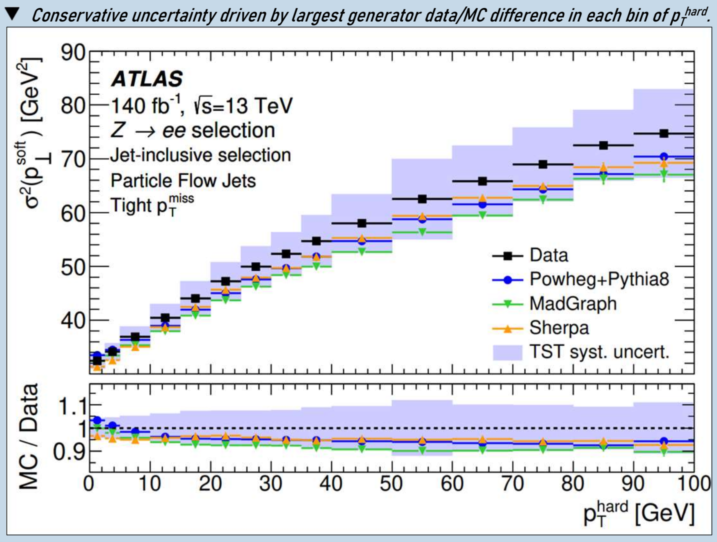




▲ *The calibration ratio factor for $\sigma(p_\perp^{soft})$ is derived in Z→ee (top). Closure is excellent and uncertainty bands correspond to statistical uncertainties from the calibration procedure. Calibration validated in Z→μμ (bottom). Closure is very good but uncertainty band includes additional non-closure contribution.*

## Current TST systematics

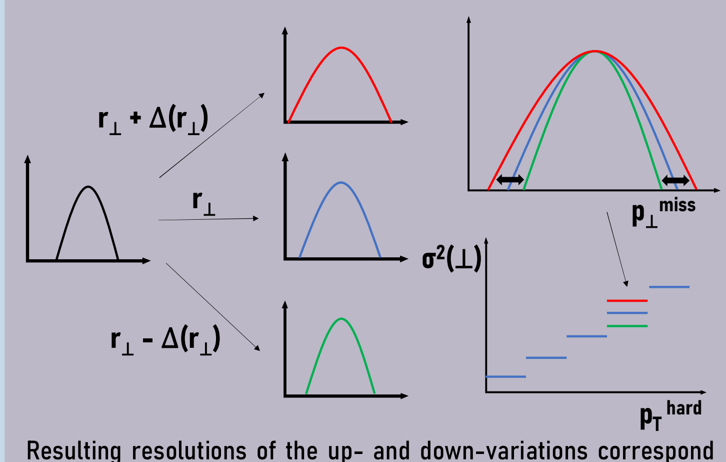
TST systematics calculated in the ***three variables** by quantifying the hard/soft term balance in events with no real $p_T^{miss}$. Envelope set as maximal data/MC difference for different generators in $p_T^{hard}$ bins.

▼ *Conservative uncertainty driven by largest generator data/MC difference in each bin of $p_T^{hard}$.*




## New TST calibration systematics

New reduced systematics from calibration procedure. Uncertainty on the calibration ratio factor derived and applied three times, with the nominal, up-variation, and down-variation:




Resulting resolutions of the up- and down-variations correspond to uncertainties of the TST post-calibration (presented as the green error bars in the calibration plots).