Missing Transverse Momentum Performance at ATLAS

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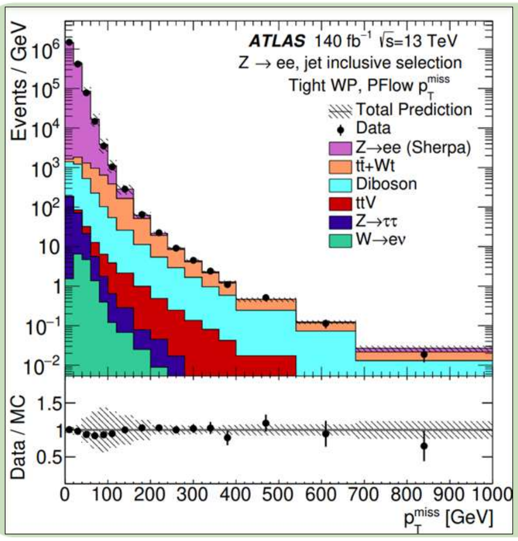
[1] arXiv:2402.05858 [2] ATLAS-JETM-2024-01 [3] ATLAS-CONF-2023-028



p_T^{miss} and TST introduction

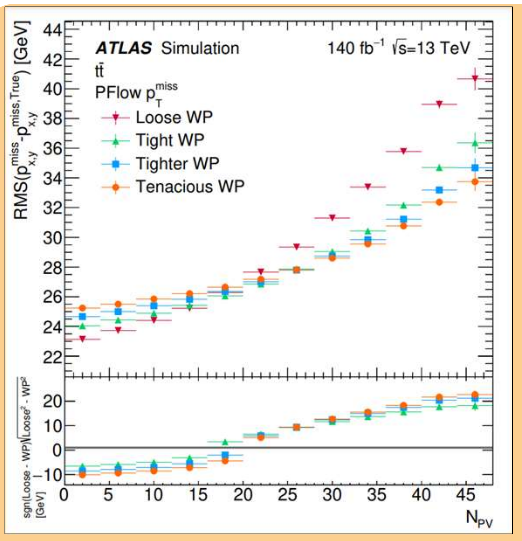
The missing momentum transverse to the proton beam direction (p_T^{miss}) infers the existence of undetected particles (e.g. neutrinos, possible dark matter candidates).

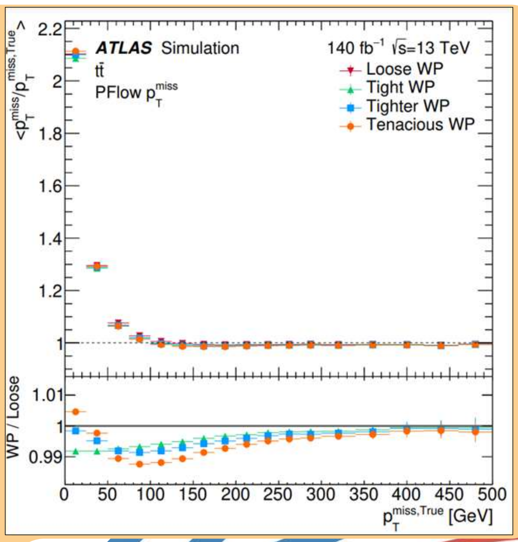
Including p_T from *soft-event* signals not associated to hard reconstructed objects (p_T^{soft}) improves p_T^{miss} performance. The track soft term (TST) definition specifically uses the remaining tracks not associated with hard scatter objects and tracks associated with jets with p_T < 20 GeV. The 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.*



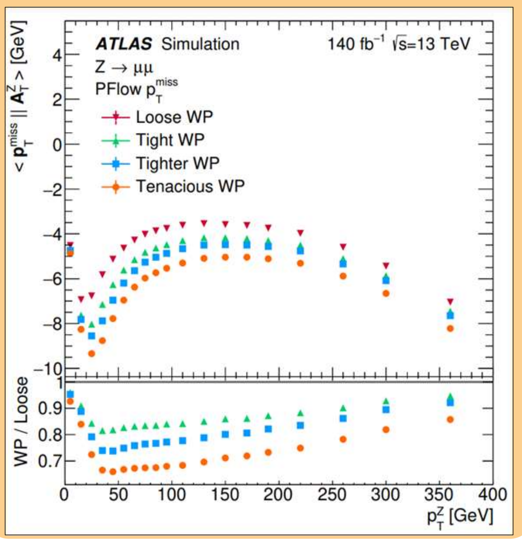


Working points & performance

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 $t\bar{t}$ 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).*

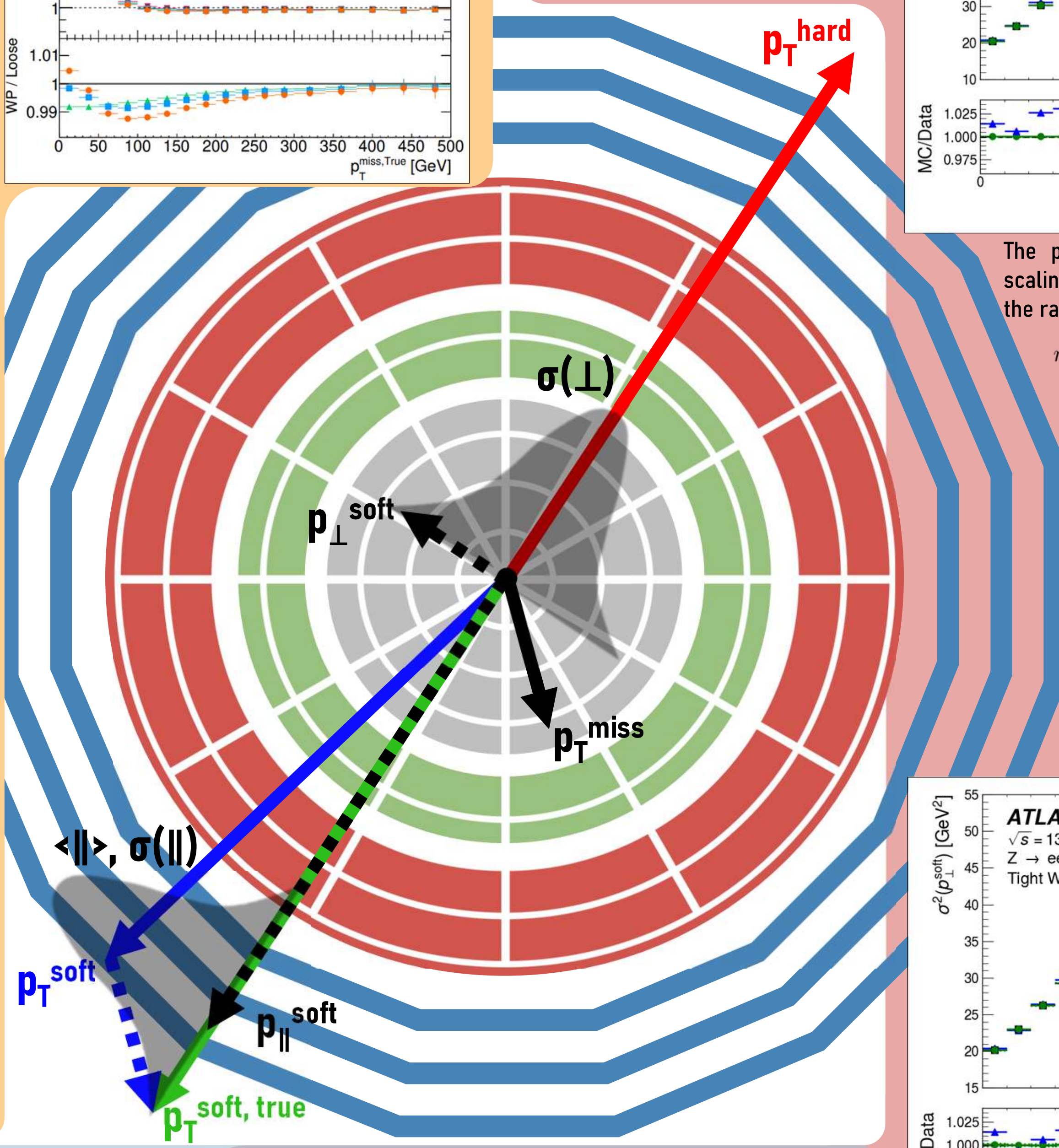
▼ *Performance check: The average projection of p_T^{miss} on to the Z boson axis as a function of the Z boson's p_T. Negative values show an underestimation of the hadronic balance with the Z boson. Tightening the WP misses more of the hadronic activity.*



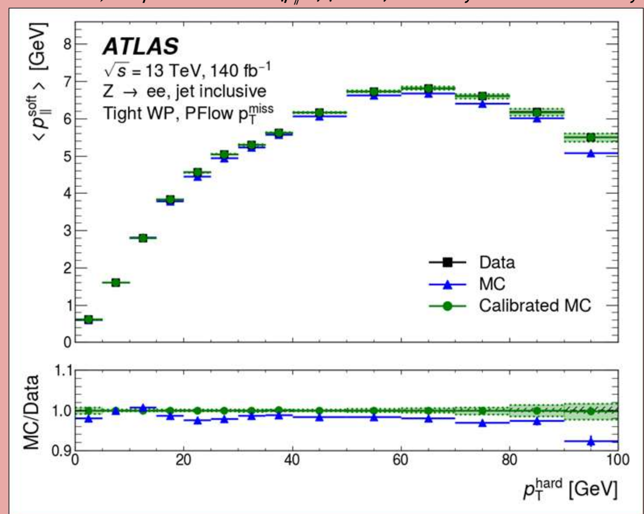
New TST Calibration

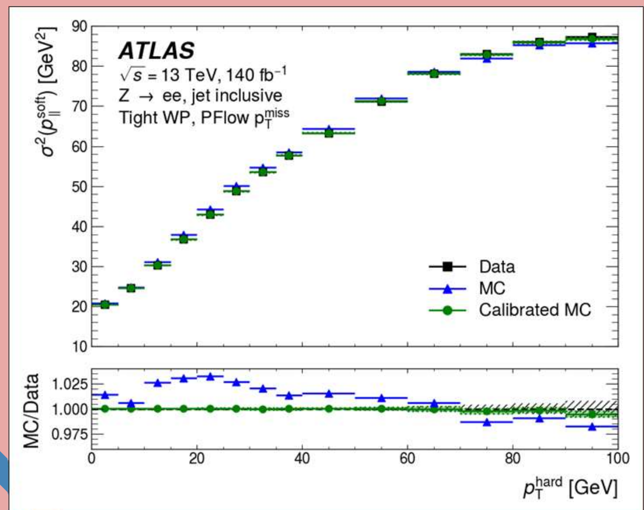
In progress: reduced TST systematics via generator-specific calibration in ***three variables** on the p_T^{hard} axis [2]:

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]:

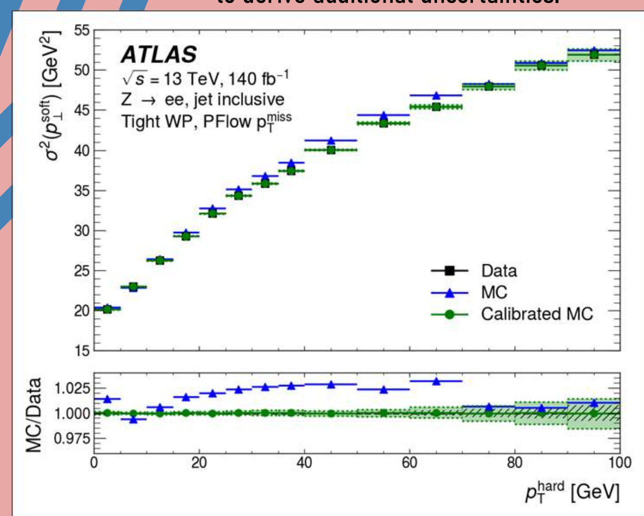
$$r_\perp = \frac{\sigma(u_\perp)^{\text{data}}}{\sigma(u_\perp)^{\text{MC}}} \qquad u_\perp^{\text{MC,corr}} = u_\perp^{\text{MC}} \cdot r_\perp$$

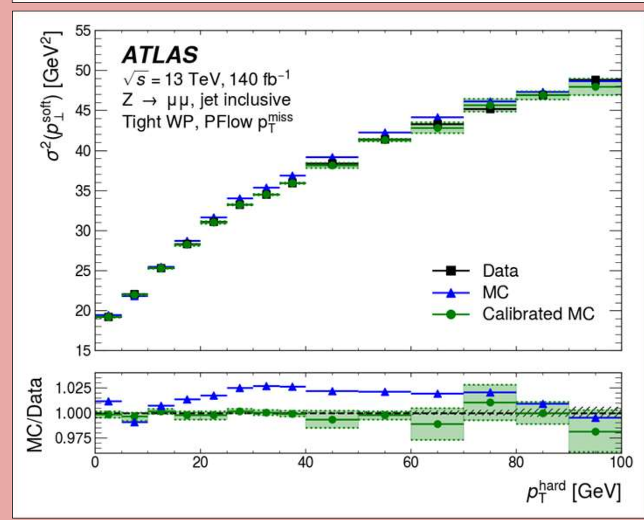
The parallel scale tends to oppose p_T^{hard}, so the parallel component is calibrated by using the resolution ratio, and data and MC distribution averages to correct the scale and resolution concurrently:

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

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

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



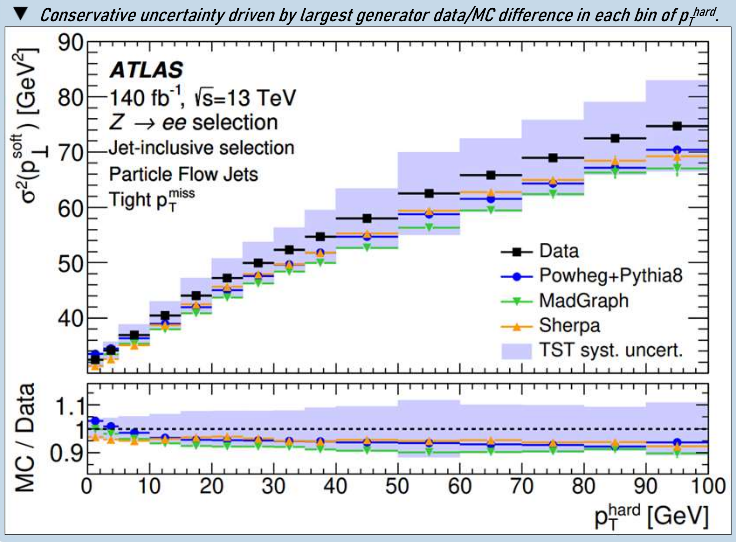


▲ *The calibration ratio factor for $\sigma(p_\perp^{soft})$ is derived in Z→ee (top). Closure is excellent and uncertainty bands correspond to statistical uncertainties from the calibration procedure. Calibration validated in Z→μμ (bottom). Closure is very good but uncertainty band includes additional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

Current TST systematics

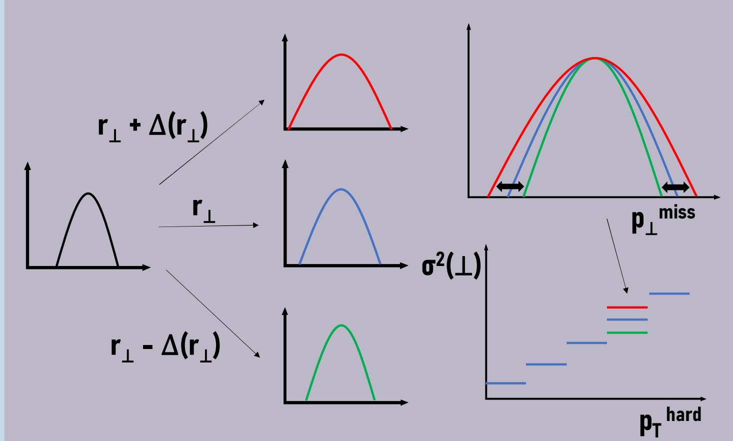
TST systematics calculated in the ***three variables** by quantifying the hard/soft term balance in events with no real p_T^{miss}. Envelope set as maximal data/MC difference for different generators in p_T^{hard} bins.

▼ *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).