Misura del momento trasverso mancante in ATLAS nel Run 2 di LHC a 13 TeV

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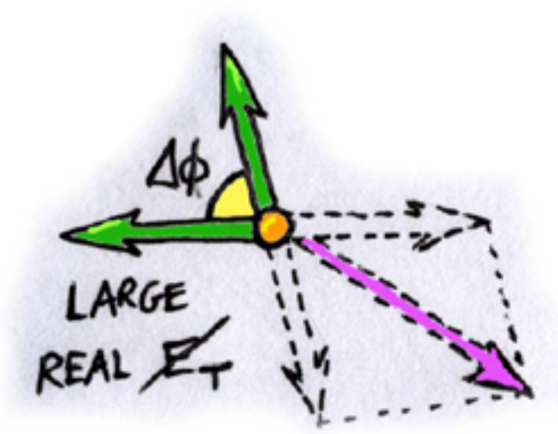
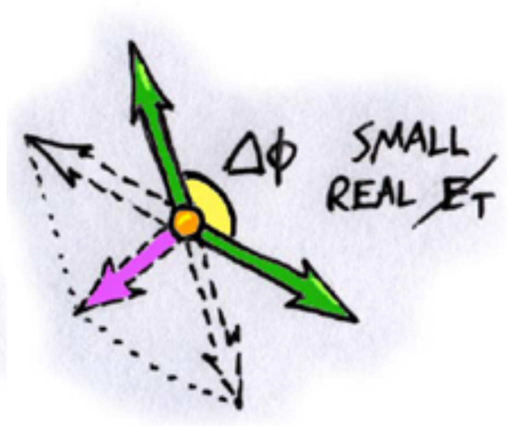
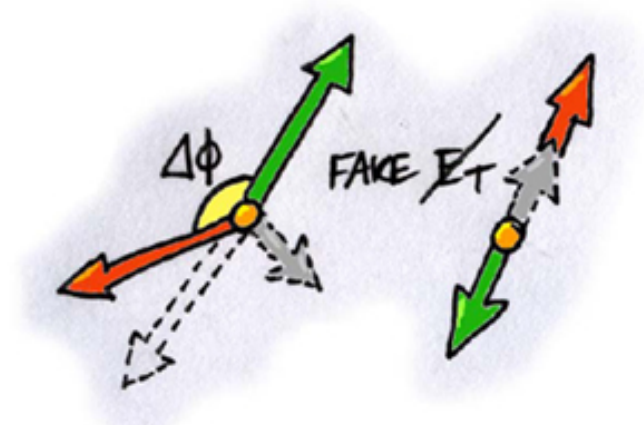
E_T^{miss} = Missing Transverse Momentum

- Negative ***vector*** sum of the ***transverse*** momenta of ***all*** detected particles
- Global quantity of the event
- The handle for the invisible part of the event







Real E_T^{miss}:

- New particles
- Neutrinos

E_T^{miss} is the discriminating variable for many searches for new physics

Fake E_T^{miss}:

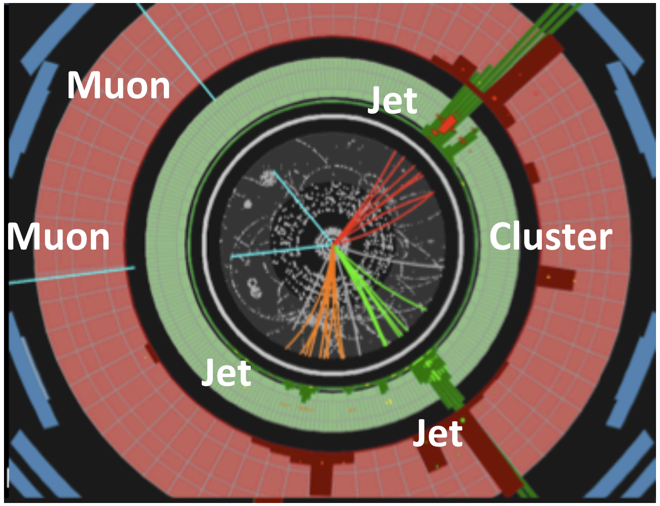
- Miscalibrations
- Mismeasurements
- Limited detector acceptance
- Detector Noise

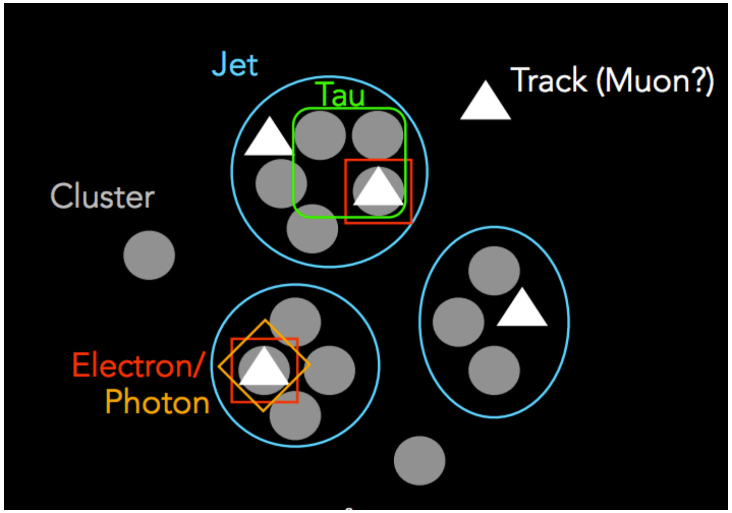
Outline

In this talk:

- ✧ How we ***reconstruct*** the E_T^{miss} in Run 2
  - Reconstruction algorithm
  - E_T^{miss} variants
- ✧ How we ***measure*** its ***performance*** in 2015 data and MC
  - Data/MC comparisons
  - Resolution
  - Scale and Linearity

E_T^{miss} Reconstruction: *Ingredients*





- Reconstructed and calibrated ***"physics objects"***:
  - electrons, photons, taus, muons
    - Identified and selected as recommended from the various CP groups
    - analyses can optimize the object quality and selections for their needs
  - ***Jets***:
    - Fully calibrated EM+JES Anti-kt4 (i.e. with R=0.4) with p_T > 20 GeV and JVT cut, jet selection being optimized
    - Anti-kt4 with p_T > 7 GeV for handling the overlap between physics object, as every physics object (except muons) is reconstructed as a jet
- ***Signal objects:***
  - ***tracks*** and ***clusters***

E_T^{miss} Reconstruction: *Term by Term*

$$E_{x(y)}^{miss} = E_{x(y)}^{miss,\,e} + E_{x(y)}^{miss,\,\gamma} + E_{x(y)}^{miss,\,\tau} + E_{x(y)}^{miss,\,jets} + E_{x(y)}^{miss,\,\mu} + E_{x(y)}^{miss,\,Soft}$$

$$E_{x(y)}^{miss,\,k} = -\Sigma_k\, p_T^{\,k}$$

- Reconstructed and calibrated ***"physics objects"***:
  - electrons, photons, taus, muons
    - Identified and selected with fairly general criteria
    - Coherent choice between event selection and E_T^{miss} selection is possible
  - ***Jets***:
    - Anti-kt4 with $p_T > 20$ GeV

Hard Terms

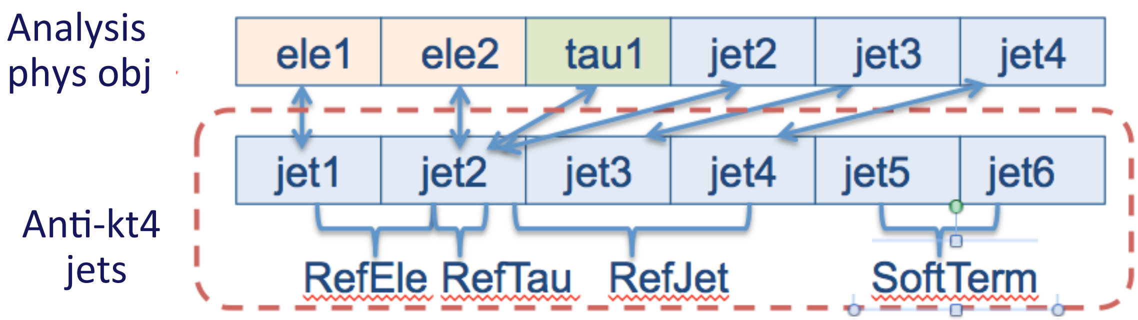
- Unmatched ***tracks*** and ***clusters*** (= Core Soft Term)

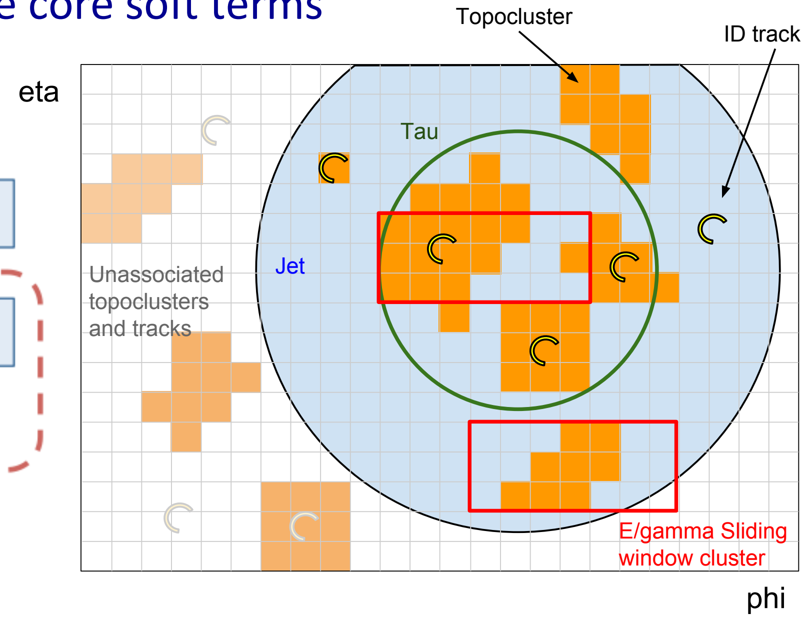
  \+ ***soft jets*** with ***7 GeV < p_T < 20 GeV***

Soft Terms

⇒ There must be a mechanism to keep track of the overlaps between physics/signal objects:

- ✧ Run 1 ***Composition Map***:
  - Contains links between each E_T^{miss} term and the physics objects / signals contributing to it with weights reflecting their kinematic contribution
  - Could be used to recalculate MET at analysis level if all topo-clusters and tracks and their links to physics objects are saved ➔ resource heavy
- ✧ Run 2 ***Association Map***:
  - Contains the spatial association of each physics object to anti-kt4 jets
  - Within each jet, object overlaps are identified
  - Unassociated tracks/clusters go into the core soft terms





E_T^{miss} Reconstruction: *Soft Terms*

Two E_T^{miss} variants depending on the Soft Term:

- Track Soft Term => ***TST E_T^{miss}***
  - Fully calibrated physics objects
  - Core tracks coming from the primary vertex unassociated to physics objects
  - Tracks from primary vertex not associated to hard objects
    - ⇒ **Pile-up suppressed**
    - ⇒ **Neutrals in Soft Term are lost**
    - ⇒ **Limited Tracker acceptance**
- Calorimeter Soft Term => ***CST E_T^{miss}***
  - Fully calibrated physics objects
  - Core clusters
  - Clusters belonging to jets between 7 and 20 GeV, no JVT cut
    - ⇒ **Non Pile-up suppressed**
    - ⇒ **Neutrals in Soft Term are kept**
    - ⇒ **Full calorimeter acceptance**

Track E_T^{miss}

One variant using only tracking information for both hard and soft terms:

- ***Track E_T^{miss}***
  - Fully calibrated electrons and muons, jets only from tracks
  - TST Soft Term
    - ⇒ **Very pile-up suppressed**
    - ⇒ **Neutrals are lost**
    - ⇒ **Limited Tracker acceptance**

E_T^{miss} Performance: *Topologies*

E_T^{miss} magnitude and direction are very topology-dependent:

- **Z → *ll***
  - with expected small or null E_T^{miss}, used as standard candles
- **W → *lν***
  - with expected significant E_T^{miss} coming from the hard scatter
- **ttbar**
  - busier events with expected significant E_T^{miss}
- Further categorization in jet multiplicities is an important discriminant

TST E_T^{miss} Performance: *Data/MC*

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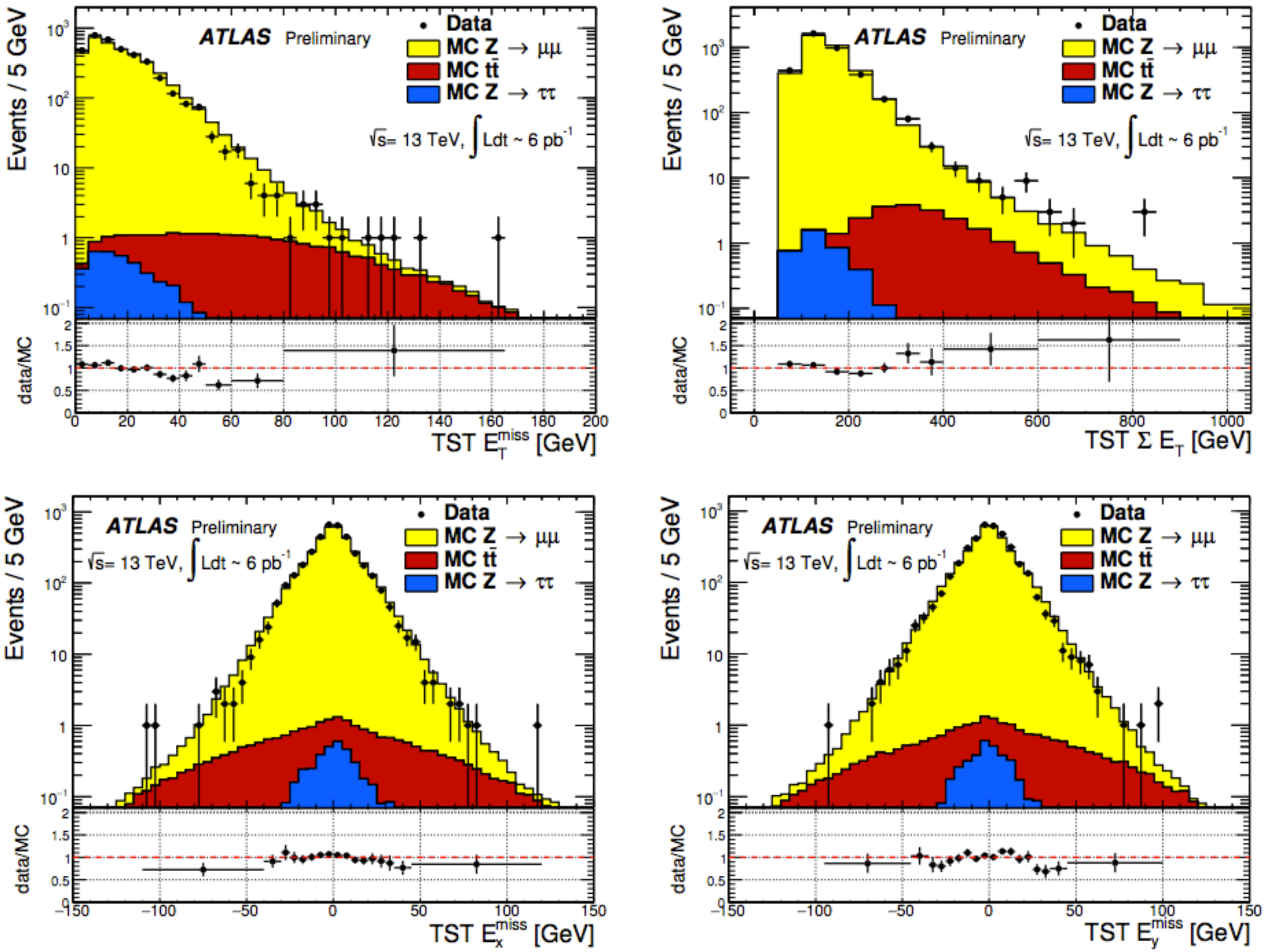

✧ Agreement between data and MC with very first data, Z ➔ $\mu\mu$ events

E_T^{miss} Performance: *Resolution*

- Width of the $E_{x,y}^{miss}$ is a sensitive quantity to pile-up effects
- Measured as a function of pile-up correlated quantities:
  - number of primary vertices, N_{PV}, (left)
  - $\Sigma E_T = \Sigma_k \, p_T^k$ reconstructed ***scalar*** sum of all particles p_T

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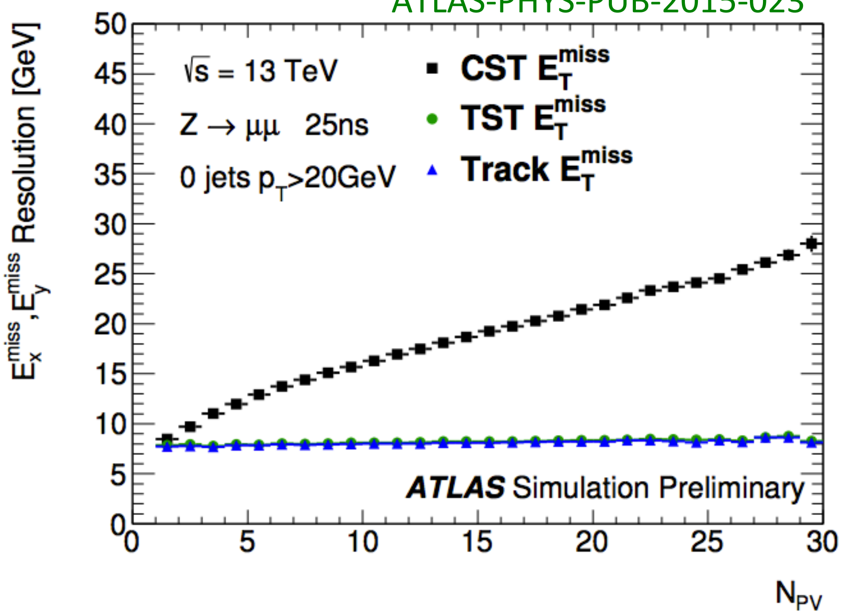

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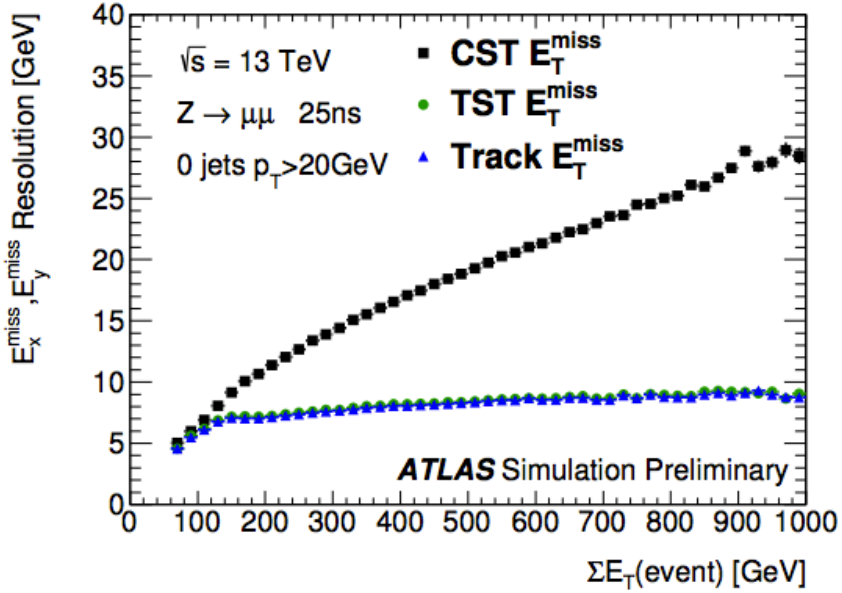

- In 0-jet events TST and Track E_T^{miss} perform very similar, insensitive to pile-up
- Same behaviour as a function of N_{PV} or TST ΣE_T
- Very similar behaviour between Z and W topologies

E_T^{miss} Performance: *Resolution*

- W ➔ $\mu\nu$ inclusive jets (left), ttbar inclusive jets (right)

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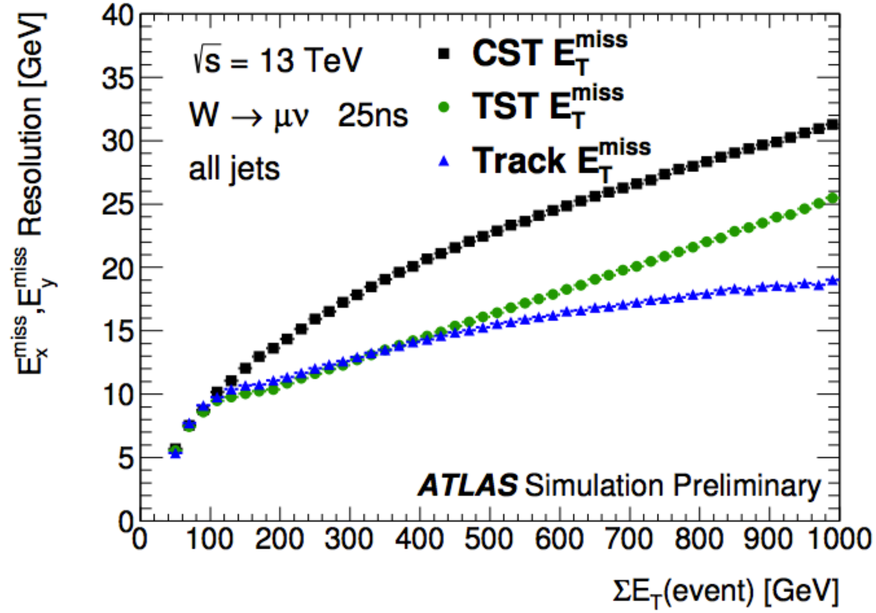

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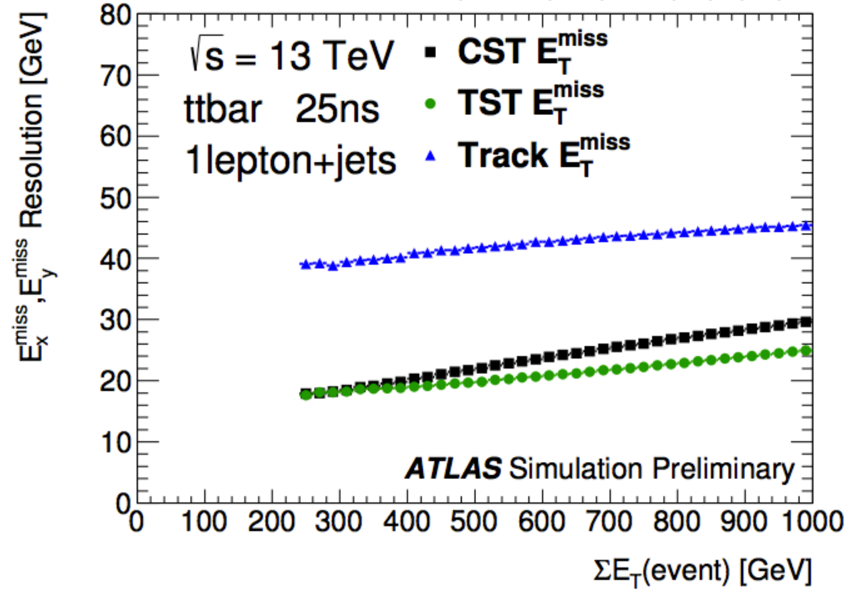
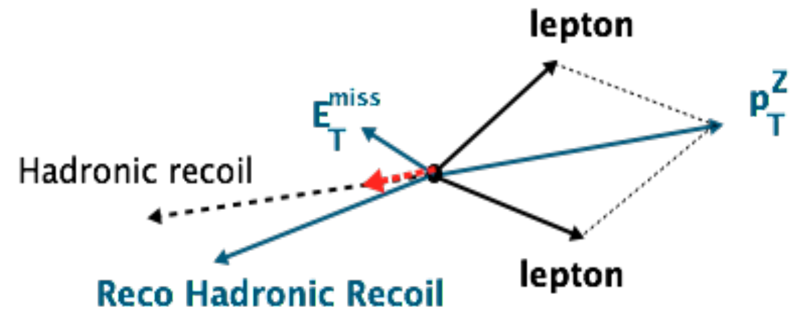


- In inclusive jet events, all variants suffer by the increased event activity in higher pile-up regions
- TST and CST show similar values of the resolution among various topologies, while Track resolution suffers in high-jet multiplicity events

E_T^{miss} Performance: *Scale in Z → ll*

- Well calibrated E_T^{miss} in Z→*ll* events projected along any axis should be zero:
- Projection of the E_T^{miss} onto the Z axis is sensitive to the imbalance between Hard and Soft part of the event



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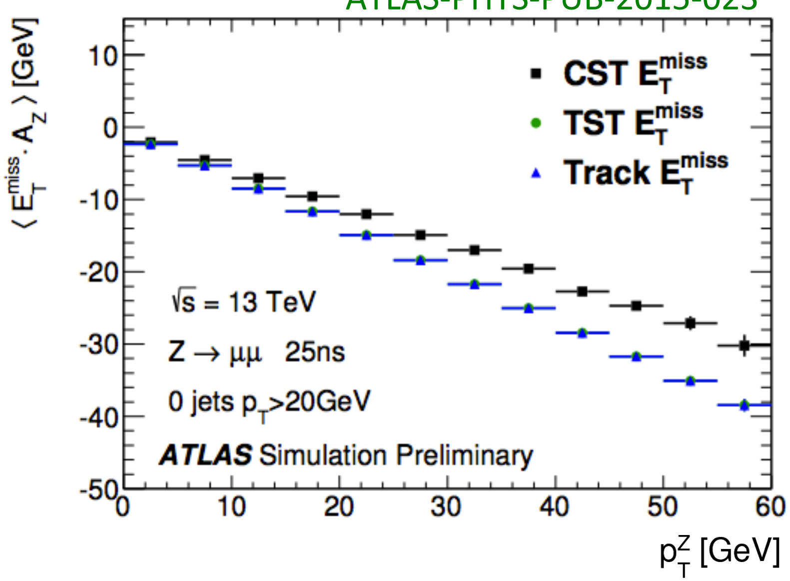

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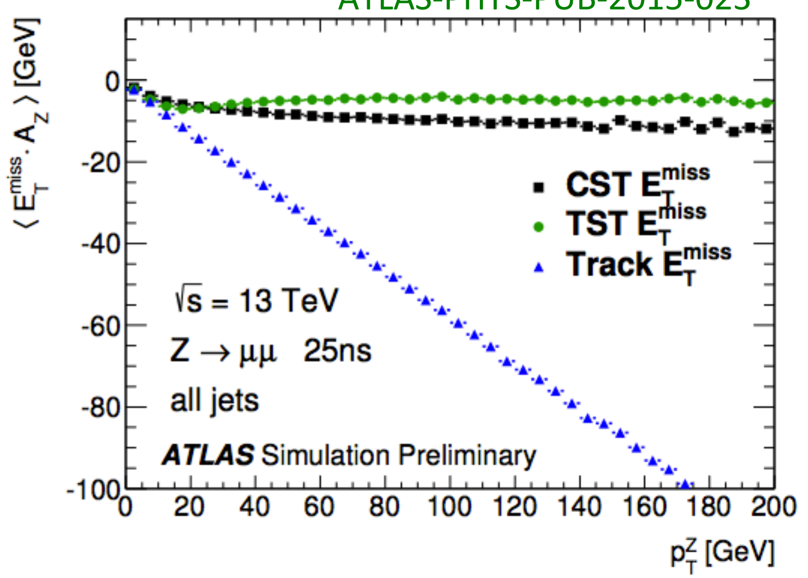

- Bias is bigger in 0-jet events indicating underestimation of the soft term
- In events with jets, TST E_T^{miss} performs best

E_T^{miss} Performance: *Scale in W→ lν*

- In W → *lν* events "genuine" E_T^{miss} is expected
- Scale is measured with the linearity as a function of the $E_T^{miss,\,True}$

$$\text{linearity} = \left\langle \frac{E_T^{miss} - E_T^{miss,True}}{E_T^{miss,True}} \right\rangle$$

- Linearity = 0 is expected if the reco scale is equal to the true scale

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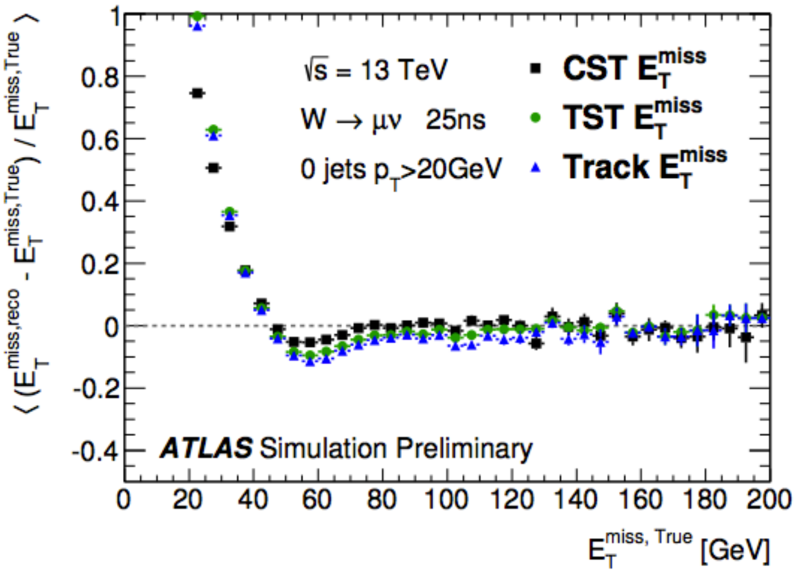

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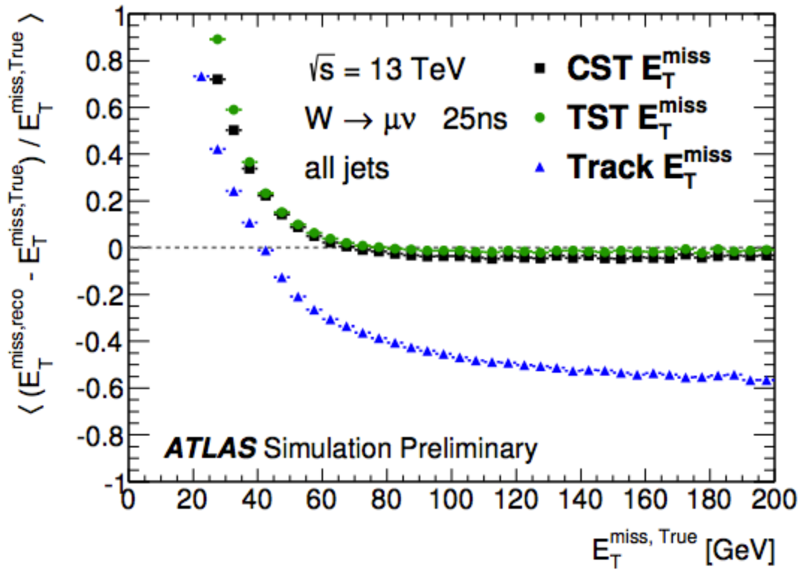

- At low $E_T^{miss,\,True}$ a positive bias is expected
- At high E_T^{miss} TST and CST similar, Track E_T^{miss} worse due to loss of neutrals

Conclusions

- E_T^{miss} reconstruction well tested in Run 2
- Most promising calculation based on fully calibrated physics objects + tracks for the soft part
- Well understood performance at 13 TeV in MC simulations
- First data/MC comparisons show very good agreement
- MC-based systematic uncertainties already calculated, data-based expected with higher statistics

BACK-UP

References

[1] *Performance of missing transverse momentum reconstruction for the ATLAS detector in the first proton-proton collisions at √s = 13 TeV*
ATLAS Collaboration, ATLAS-PHYS-PUB-2015-027

[2] *Expected Performance of missing transverse momentum reconstruction for the ATLAS detector in the first proton-proton collisions at √s = 13 TeV*
ATLAS Collaboration, ATLAS-PHYS-PUB-2015-023

TST E_T^{miss} : *Resolution and Scale in 2015 data and MC*

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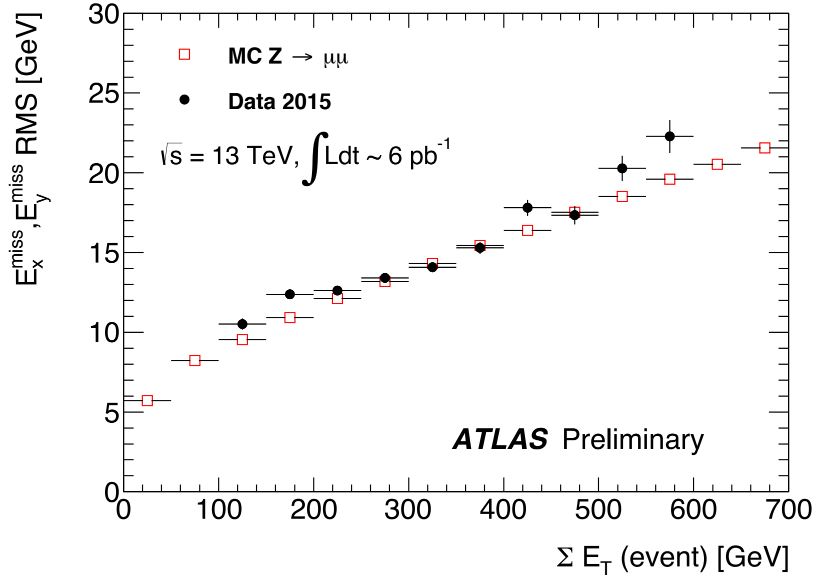

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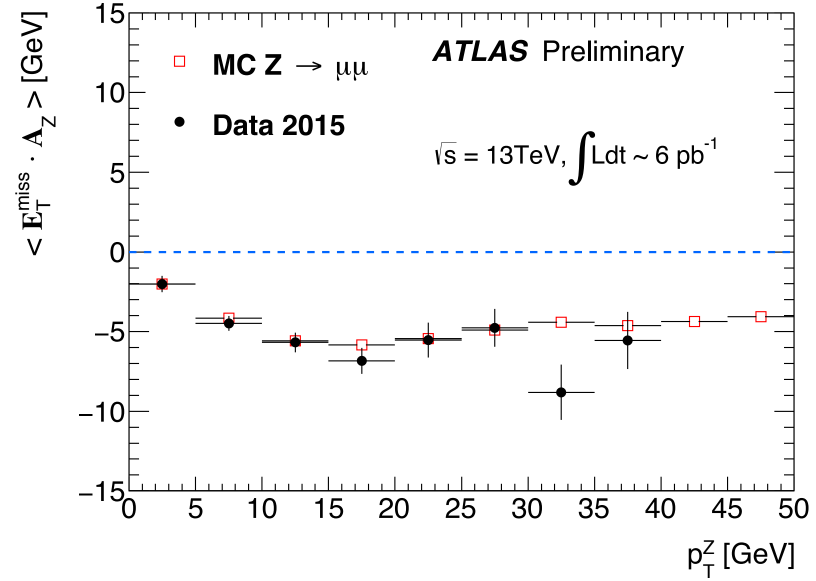

- Agreement between data and MC with very first data, Z ➔ *μμ* events

TST E_T^{miss} Performance: *Data/MC*

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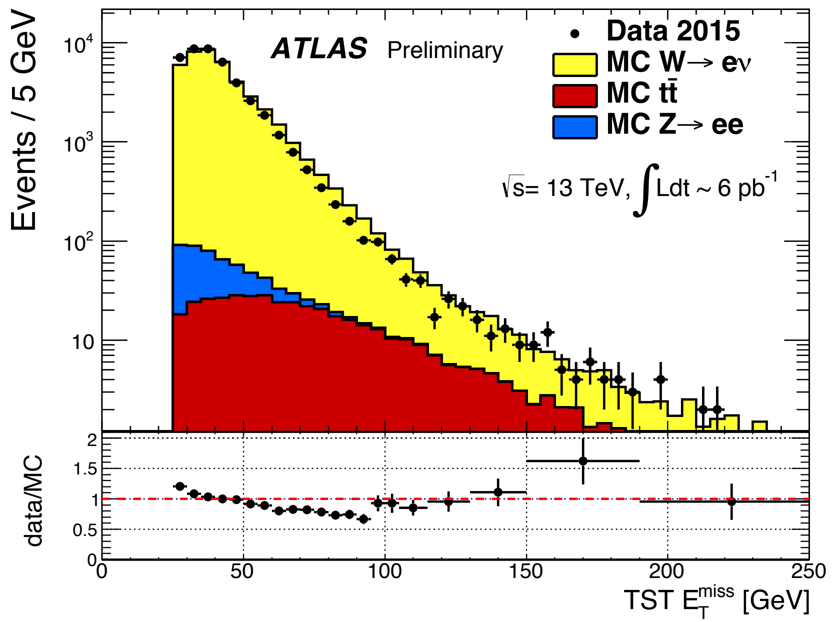

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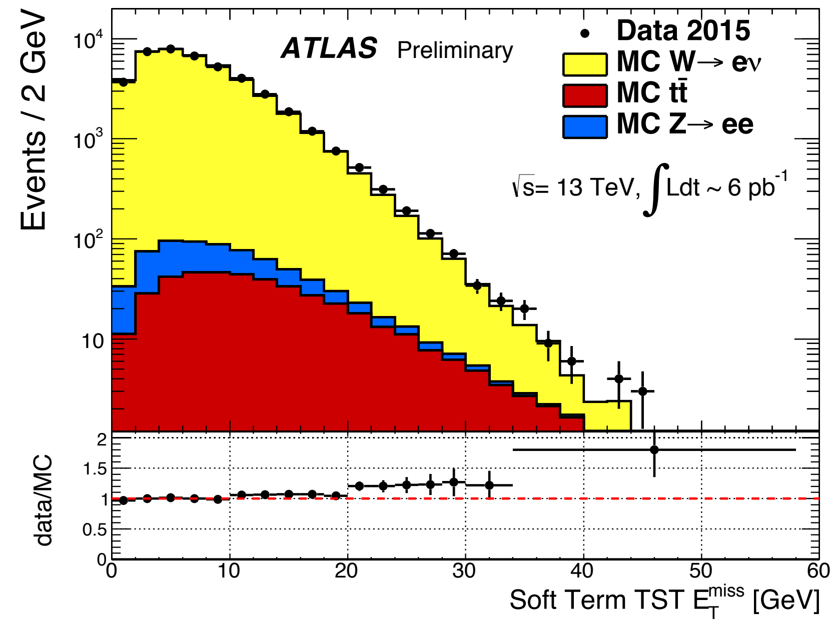

- Agreement between data and MC with very first data, W ➔ *eν* events

E_T^{miss} Performance: *Scale in ttbar*

- In ttbar events "genuine" E_T^{miss} is expected
- Scale is measured with the linearity as a function of the $E_T^{miss,\,True}$

$$\text{linearity} = \left\langle \frac{E_T^{miss} - E_T^{miss,True}}{E_T^{miss,True}} \right\rangle$$

- Linearity = 0 is expected if the reco scale is equal to the true scale

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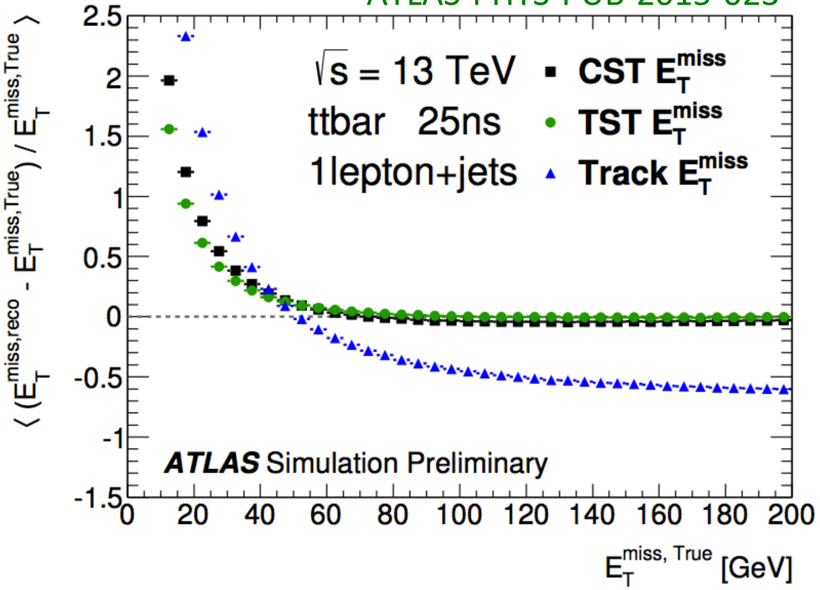

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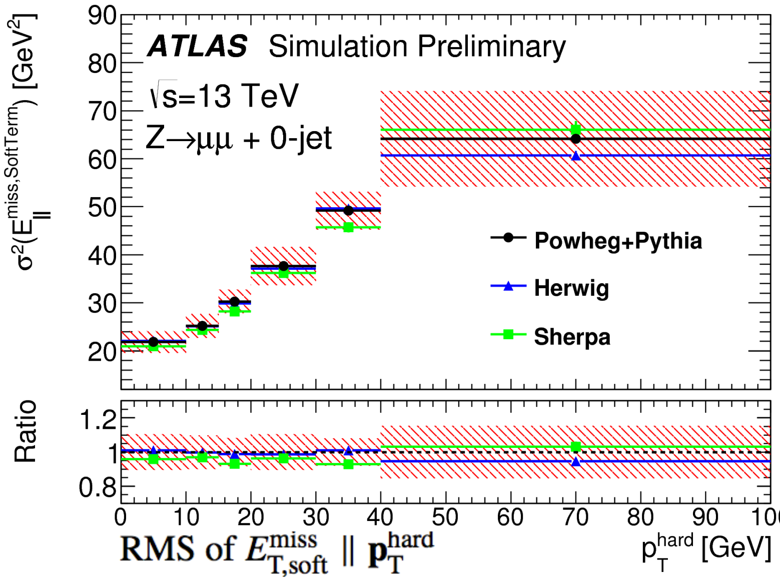
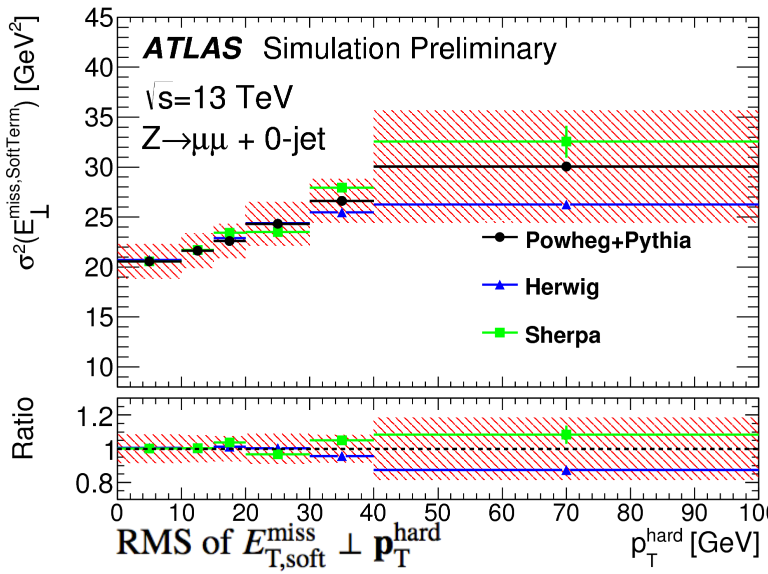
- At high E_T^{miss} TST and CST similar, Track E_T^{miss} worse due to loss of neutrals

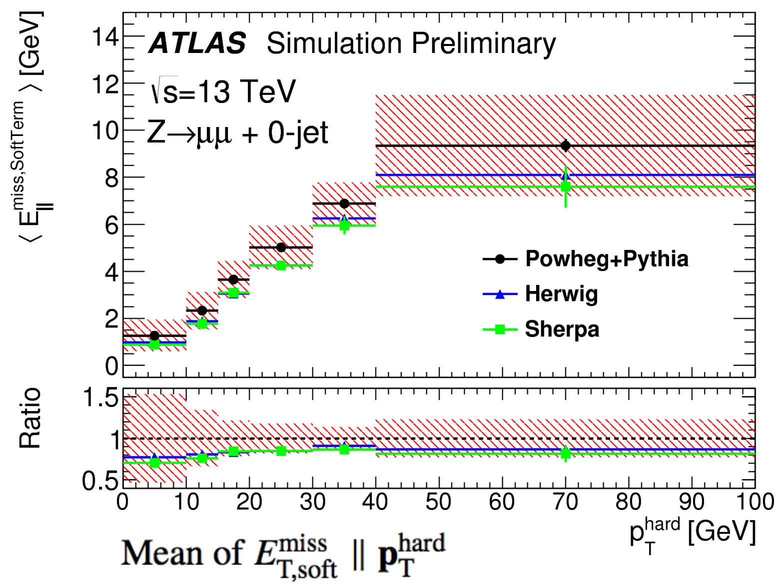
Soft term systematics: *Soft Term Projections*



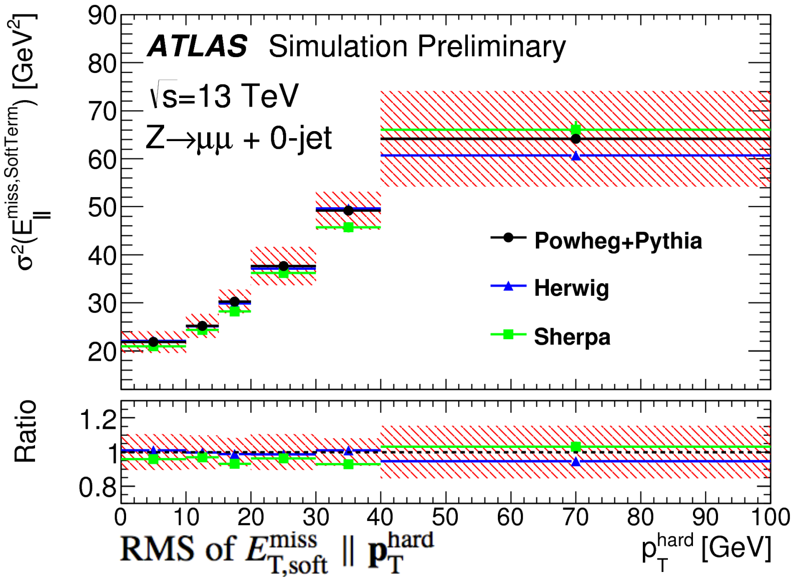


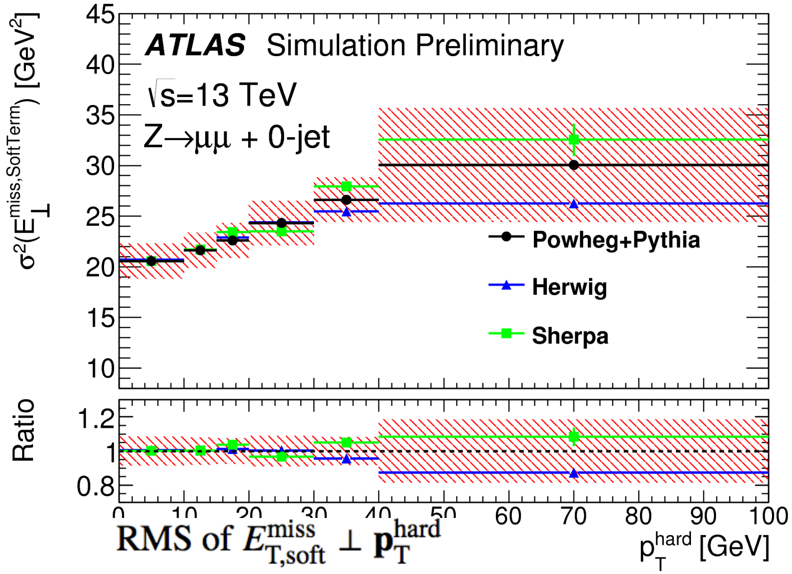
Soft Term projections onto p_T^{hard}:

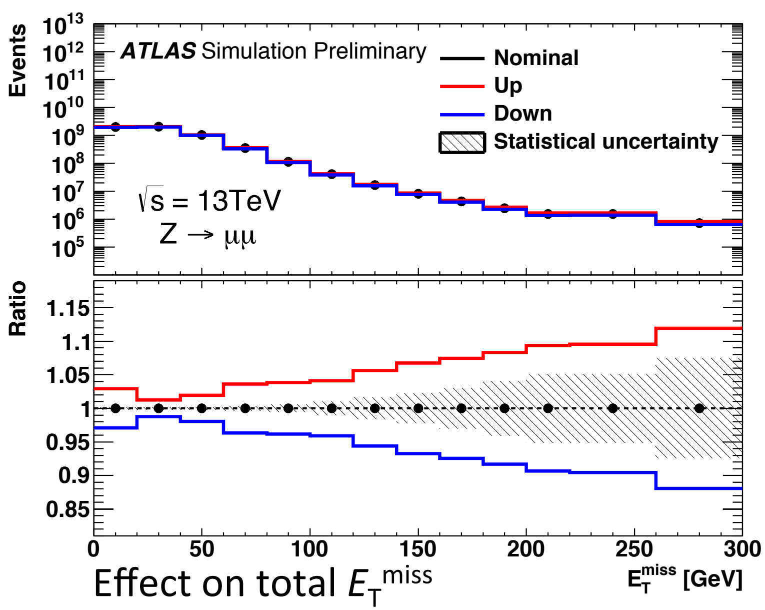
- Mean of longitudinal component
  => scale uncertainty
- RMS of transverse and longitudinal components
  => resolution uncertainty

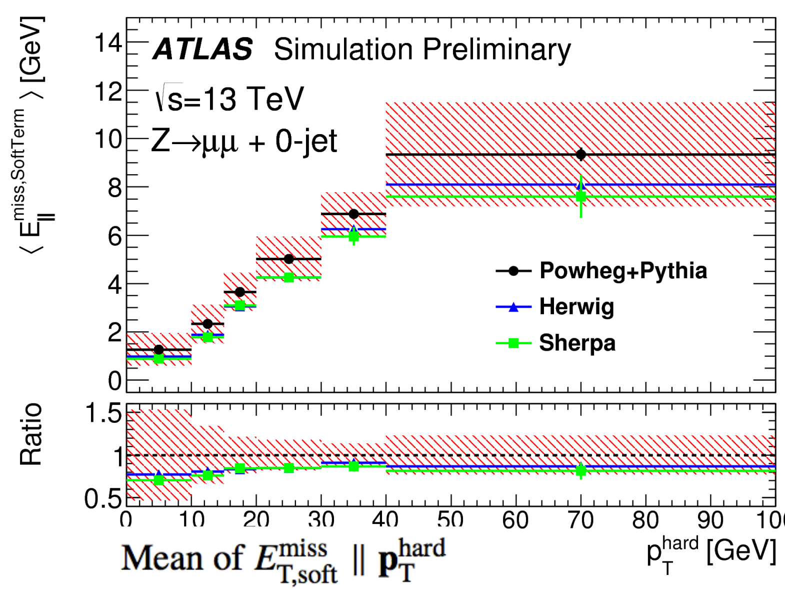


Soft term systematics: *Soft Term Projections*





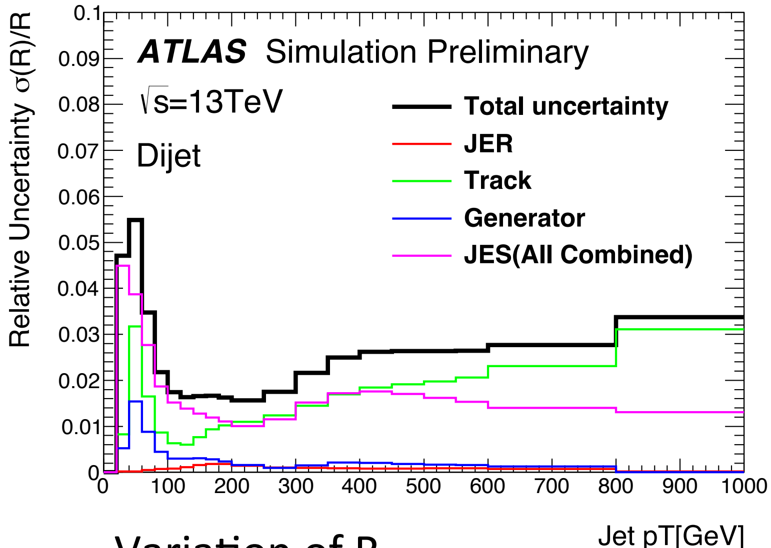




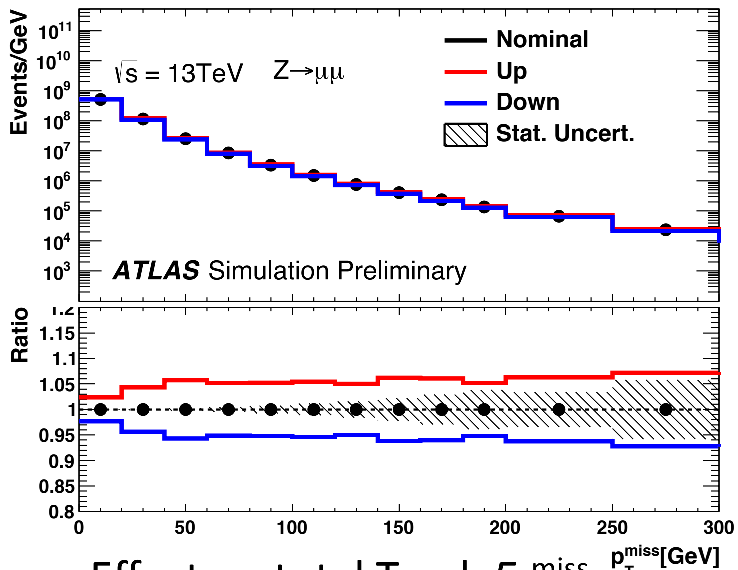
Track E_T^{miss} systematics

- One additional component of uncertainty considered for Track E_T^{miss}
- Tracks associated to calorimeter jets, not entering Soft Term
- Considered effects:
  - MC generator modelling
  - Effects of material modelling
  - JES/JER
- Relative variation of R, defined for each jet, is used as observable to describe the systematic variations, as a function of η and p_T of the jet

$$R = \frac{\sum p_T^{trk}}{p_T^{jet}}$$



Variation of R



Effect on total Track E_T^{miss}

E_T^{miss} Performance: *Useful quantities*

E_T^{miss} = reconstructed E_T^{miss}

$E_{x,y}^{miss}$ = components

$E_T^{miss,True}$ = the missing transverse momentum at true level, including all non-interacting particles

$\Sigma E_T = \Sigma_k\, p_T^k$ reconstructed ***scalar*** sum of all particles p_T
pile-up correlated quantity