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

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What is $E_T^{\text{miss}}$?

$E_T^{\text{miss}} = \text{Missing Transverse Momentum}$

✧ 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 $E_T^{\text{miss}}$:
* New particles
* Neutrinos

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

Fake $E_T^{\text{miss}}$:
* Miscalibrations
* Mismeasurements
* Limited detector acceptance
* Detector Noise
Outline

In this talk:

✧ How we **reconstruct** the $E_T^{\text{miss}}$ in Run 2
  * Reconstruction algorithm
  * $E_T^{\text{miss}}$ variants

✧ How we **measure** its **performance** in 2015 data and MC
  * Data/MC comparisons
  * Resolution
  * Scale and Linearity
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
$E_{T}^{\text{miss}}$ Reconstruction: *Term by Term*

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

\[ E_{x(y)}^{\text{miss, k}} = -\sum_{k} p_{T}^{k} \]

✧ **Reconstructed and calibrated “physics objects”:**

- electrons, photons, taus, muons
  - Identified and selected with fairly general criteria
  - Coherent choice between event selection and $E_{T}^{\text{miss}}$ selection is possible
- **Jets:**
  - Anti-kt4 with $p_{T} > 20$ GeV

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

+ *soft jets* with $7 \text{ GeV} < p_{T} < 20 \text{ GeV}
There must be a mechanism to keep track of the overlaps between physics/signal objects:

Run 1 *Composition Map*:
- Contains links between each $E_T^{\text{miss}}$ 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.
Two $E_T^{\text{miss}}$ variants depending on the Soft Term:

✧ Track Soft Term => $TST \ E_T^{\text{miss}}$
  • 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 => $CST \ E_T^{\text{miss}}$
  • 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
One variant using only tracking information for both hard and soft terms:

- **Track $E_T^{\text{miss}}$**
  - Fully calibrated electrons and muons, jets only from tracks
  - TST Soft Term
    - Very pile-up suppressed
    - Neutrals are lost
    - Limited Tracker acceptance
$E_T^{\text{miss}}$ magnitude and direction are very topology-dependent:

- **$Z \rightarrow ll$**
  - with expected small or null $E_T^{\text{miss}}$, used as standard candles

- **$W \rightarrow l\nu$**
  - with expected significant $E_T^{\text{miss}}$ coming from the hard scatter

- **ttbar**
  - busier events with expected significant $E_T^{\text{miss}}$

- Further categorization in jet multiplicities is an important discriminant
TST $E_T^{\text{miss}}$ Performance: \textit{Data/MC}

\begin{itemize}
  \item Agreement between data and MC with very first data, $Z \rightarrow \mu\mu$ events
\end{itemize}
\( E_T^{\text{miss}} \) Performance: \textit{Resolution}

✧ Width of the \( E_{x,y}^{\text{miss}} \) 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 \textit{scalar} sum of all particles \( p_T \)

✧ In 0-jet events TST and Track \( E_T^{\text{miss}} \) perform very similar, insensitive to pile-up
✧ Same behaviour as a function of \( N_{PV} \) or TST \( \Sigma E_T \)
✧ Very similar behaviour between Z and W topologies
$E_T^{\text{miss}}$ Performance: Resolution

- $W \rightarrow \mu\nu$ inclusive jets (left), $t\bar{t}$bar inclusive jets (right)

- 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
**$E_T^{\text{miss}}$ Performance: Scale in $Z \rightarrow ll$**

✧ Well calibrated $E_T^{\text{miss}}$ in $Z \rightarrow ll$ events projected along any axis should be zero:

✧ Projection of the $E_T^{\text{miss}}$ onto the Z axis is sensitive to the imbalance between Hard and Soft part of the event

✧ Bias is bigger in 0-jet events indicating underestimation of the soft term

✧ In events with jets, TST $E_T^{\text{miss}}$ performs best
**$E_T^{\text{miss}}$ Performance: Scale in $W \rightarrow l\nu$**

- In $W \rightarrow l\nu$ events “genuine” $E_T^{\text{miss}}$ is expected
- Scale is measured with the linearity as a function of the $E_T^{\text{miss, True}}$
- Linearity = 0 is expected if the reco scale is equal to the true scale

\[
\text{linearity} = \left( \frac{E_T^{\text{miss, reco}} - E_T^{\text{miss, True}}}{E_T^{\text{miss, True}}} \right)
\]

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

✧ $E_T^{\text{miss}}$ 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
[1] Performance of missing transverse momentum reconstruction for the ATLAS detector in the first proton-proton collisions at $\sqrt{s} = 13$ 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 $\sqrt{s} = 13$ TeV
ATLAS Collaboration, ATLAS-PHYS-PUB-2015-023
Agreement between data and MC with very first data, $Z \rightarrow \mu\mu$ events
Agreement between data and MC with very first data, $W \rightarrow e\nu$ events
$E_T^{\text{miss}}$ Performance: *Scale in ttbar*

- In ttbar events “genuine” $E_T^{\text{miss}}$ is expected
- Scale is measured with the linearity as a function of the $E_T^{\text{miss, True}}$
- Linearity = 0 is expected if the reco scale is equal to the true scale

\[
\text{linearity} = \left( \frac{E_T^{\text{miss}} - E_T^{\text{miss, True}}}{E_T^{\text{miss, True}}} \right)
\]

- At low $E_T^{\text{miss, True}}$ a positive bias is expected
- At high $E_T^{\text{miss}}$ TST and CST similar, Track $E_T^{\text{miss}}$ worse due to loss of neutrals
Soft term systematics: *Soft Term Projections*

- Mean of longitudinal component
  - $\Rightarrow$ scale uncertainty
- RMS of transverse and longitudinal components
  - $\Rightarrow$ resolution uncertainty
Soft term systematics: *Soft Term Projections*

**ATLAS Simulation Preliminary**

\[ \sqrt{s} = 13 \text{ TeV} \]

**Z \rightarrow \mu \mu + 0\text{-jet}**

- **Powheg+Pythia**
- **Herwig**
- **Sherpa**

<table>
<thead>
<tr>
<th>Events</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal</td>
<td>1.0</td>
</tr>
<tr>
<td>Up</td>
<td>1.05</td>
</tr>
<tr>
<td>Down</td>
<td>0.95</td>
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<tr>
<td>Statistical uncertainty</td>
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</table>

**Ratio**

\[ \langle E_{T,soft} \rangle \parallel p_T^{\text{hard}} [\text{GeV}] \]

**Effect on total** \[ E_T^{\text{miss}} \]

**Mean of** \[ E_{T,soft} \parallel p_T^{\text{hard}} [\text{GeV}] \]
Track $E_T^{\text{miss}}$ systematics

✧ One additional component of uncertainty considered for Track $E_T^{\text{miss}}$
✧ 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 $\eta$ and $p_T$ of the jet

\[ R = \frac{\sum p_{\text{trk}}^T}{p_{\text{jet}}^T} \]

\[
\begin{align*}
\text{Variation of } R & \quad \text{Jet } p_T[\text{GeV}] \\
\text{Effect on total Track } E_T^{\text{miss}} & \quad p_{\text{miss}}^{\text{trk}}[\text{GeV}]
\end{align*}
\]

ATLAS Simulation Preliminary

$\sqrt{s} = 13 \text{TeV}$

Dijet

\[
\text{Events/GeV}
\]

\[
\text{Ratio}
\]

Nominal
Up
Down
$E_T^{\text{miss}}$ Performance: Useful quantities

$E_T^{\text{miss}} = \text{reconstructed } E_T^{\text{miss}}$

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

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

$\Sigma E_T = \Sigma_k p_T^k \text{ reconstructed scalar sum of all particles } p_T$

$\text{pile-up correlated quantity}$