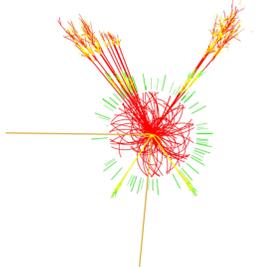# MEASUREMENT OF MISSING TRANSVERSE MOMENTUM WITH THE ATLAS DETECTOR AT THE LHC RUN-I AND BEYOND

The ATLAS Collaboration
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INTRODUCTION

A precise measurement of the missing transverse momentum E_T^{miss} is essential for many physics studies at LHC. It is particularly crucial for Higgs boson, supersysmmetry or extra dimensions searches where a very good precision on E_T^{miss} is required in order to achieve the necessary background rejection and signal indentification. This poster presents the missing transverse momentum as measured with the ATLAS Detector as well as pileup suppression methods developed for RUN-I. Developments of a new E_T^{miss} for high luminosity in RUN-II are also presented.

BASIC METHOD

Calorimeter-based missing transverse momentum

Calorimeter-based missing transverse momentum measurement (E_T^{miss}) is calculated from all identified and fully calibrated high-p_T physics objects (e, γ, μ, τ, jets) as well as the remaining calorimeter energy clusters. These non associated calorimeter clusters constitute the "SoftTerm" of E_T^{miss} .

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

Track-based missing transverse momentum

Track-based missing transverse momentum measurement (p_T^{miss}) is calculated from high quality tracks reconstructed with the ATLAS Inner Detector (ID) originating from the primary vertex where the hard interaction has occurred.

$$p_{x(y)}^{miss} = -\sum p_{x(y)}^{track}$$
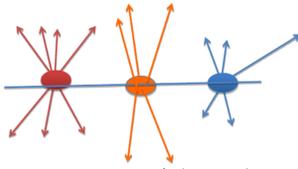
The p_T^{miss} provides a pileup independent measurement of the scale and the direction of the missing transverse momentum, although its performance is affected by the limited ID geometry coverage ($|\eta| < 2.5$) and its inability to measure the momentum of neutral particles.
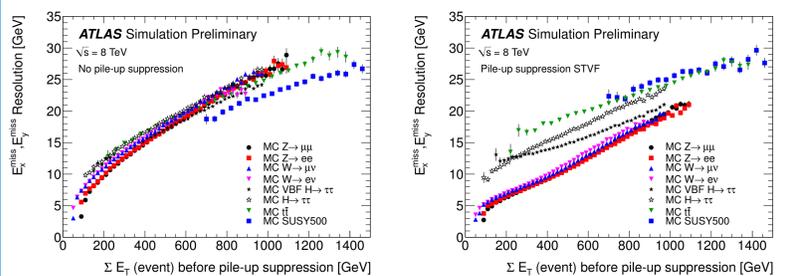
PERFORMANCE PLOTS

The E_T^{miss} performance has been studied using different kinds of events.
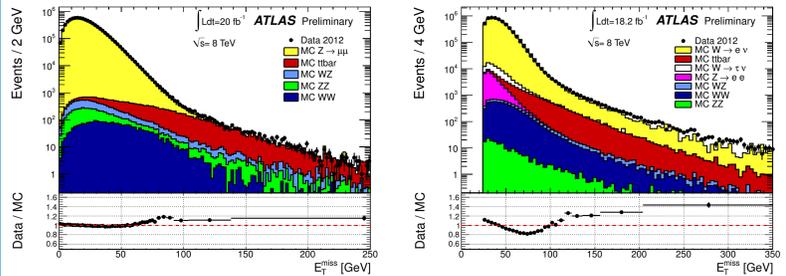
The E_T^{miss} distribution for $Z \to \mu\mu$ and $W \to e\nu$ events before applying pileup suppression.
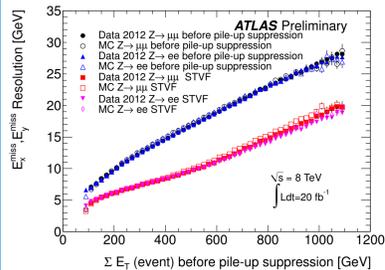
The E_T^{miss} resolution as function of $\sum E_T$ without and with pileup suppression: Data and MC show very good agreement and better performance after applying STVF pileup suppression.

Different events combined plots for the E_T^{miss} resolution as function of $\sum E_T$ without (left) and with (right) pileup suppression.
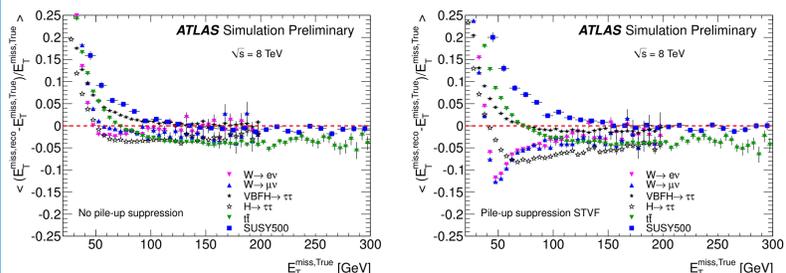
Different events combined plots for the mean of $(E_T^{miss,reco} - E_T^{miss,true})/E_T^{miss,true}$ as function of $E_T^{miss,true}$ without (left) and with (right) pileup suppression.
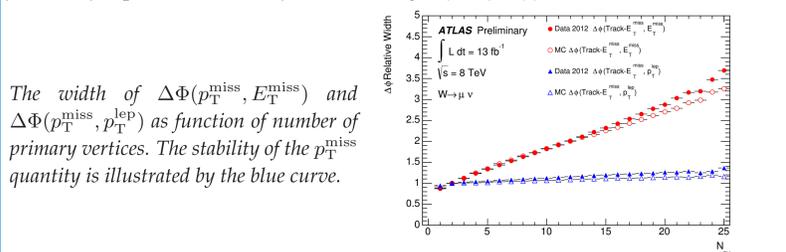
The width of $\Delta\Phi(p_T^{miss}, E_T^{miss})$ and $\Delta\Phi(p_T^{miss}, p_T^{lep})$ as function of number of primary vertices. The stability of the p_T^{miss} quantity is illustrated by the blue curve.
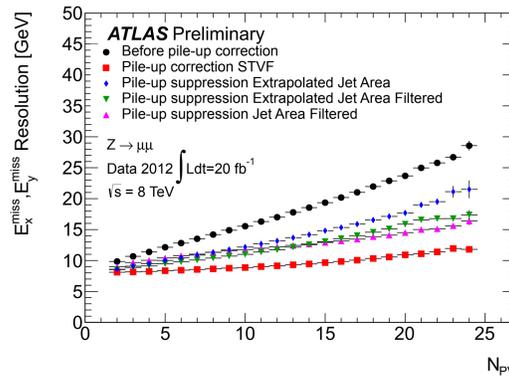
PILEUP SUPPRESSION

Pileup suppression in E_T^{miss}

Pileup suppression is already applied for physics-object reconstruction but not for the E_T^{miss} SofTerm as it includes only the non-associated calorimeter energy clusters. Two methods have been developed to suppress pileup effects on $E_T^{miss,SoftTerm}$ and improve the overall E_T^{miss} performance.

STVF (Soft Term Vertex Fraction):

Uses charged-particle tracks which are not associated with physics objects. After identifying the tracks originating from the hard scattering vertex (HS), pileup suppression is obtained by scaling $E_T^{miss,SoftTerm}$ with the STVF factor defined as:

$$STVF = \frac{\sum_{i=1}^{N_{trk}(V_{HS})} p_{T,i}^{trk}(V_{HS})}{\sum_{k=1}^{N_{PV}} \sum_{i=1}^{N_{trk}(V_k)} p_{T,i}^{trk}(V_k)}$$

$$E_{x(y),corr}^{miss,SoftTerm} = STVF \times E_{x(y)}^{miss,SoftTerm}$$

Jet Area Based Pileup Suppression:

The pileup correction is obtained by replacing $E_{x(y)}^{miss,SoftTerm}$ with filter-jets which are built from the soft-event tracks and calorimeter energy clusters with the k_T algorithm. The $p_{T,i}^{jet}$ of jets follow the filter:

$$p_{T,i}^{jet} = \begin{cases} 0 \\ p_{T,i}^{filter-jet} - \rho_{evt}^{med}(\eta_i^{filter-jet}) \cdot A_i^{filter-jet} \end{cases}$$

for two cases $p_{T,i}^{filter-jet} < \rho_{evt}^{med}(\eta_i^{filter-jet}) \cdot A_i^{filter-jet}$ and $p_{T,i}^{filter-jet} \geq \rho_{evt}^{med}(\eta_i^{filter-jet}) \cdot A_i^{filter-jet}$ respectively. The median transverse momentum density $\rho_{evt}^{med}(\eta)$ is determined from ρ-jets which are also built by same algorithm and inputs. There are three different jet area based pileup suppression configurations: *Extrapolated Jet Area (EJA)*, *Extrapolated Jet Area Filtered (EJAF)*, *Jet Area Filtered (JAF)*.
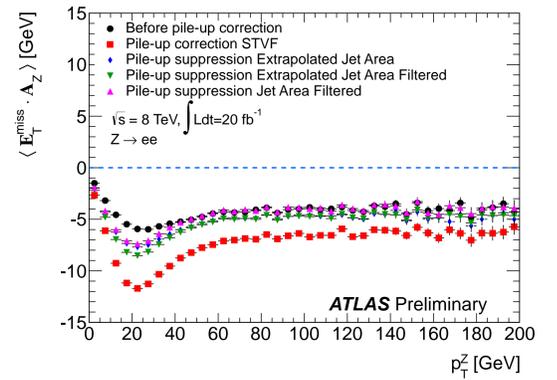
The missing transverse momentum resolution for the inclusive $Z \to \mu\mu$ data sample. The projection of E_T^{miss} on the direction of the Z transverse momentum vector $\mathbf{A}_Z$, for the inclusive $Z \to ee$ data sample.

SYSTEMATIC UNCERTAINTIES

Systematic uncertainties on reconstructed physics objects are evaluated independently and propagated to E_T^{miss} . The remaining sources of uncertainties affecting $E_T^{miss,SoftTerm}$ have to be estimated accordingly. Two methods have been developed to evaluate variations in $E_T^{miss,SoftTerm}$ measurement:

- Using data/MC ratio to estimate the uncertainty in the events without jets:
- Using the balance of soft term and hard objects to estimate the uncertainty for the events with jets:

| $E_T^{miss,SoftTerm}$ uncertainty	data/MC method		balance method		
	scale	resolution	scale		resolution
	(%)	(%)	([GeV])	(%)	(%)
Default	3.6	2.3	< 1 GeV	<13	2.0
STVF	7.9	4.8	< 1 GeV	<12	4.5
Extrapolated Jet Area Filtered	4.7	2.0	< 1 GeV	< 18	3.0
Jet Area Filtered	5.8	2.5	< 1 GeV	< 16	2.0
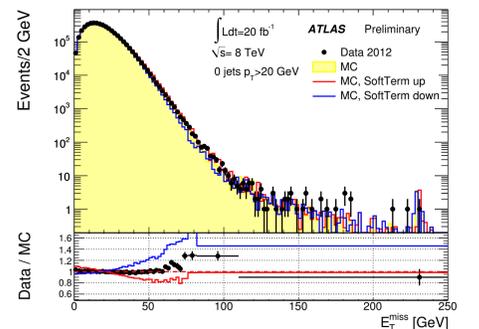
Distribution of E_T^{miss} before pileup suppression. Data are compared with the nominal $Z \to \mu\mu$ MC simulation and with MC simulation calculated after scaling and smearing the $E_T^{miss,SoftTerm}$ using data/mc ratio method

RUN-II AND BEYOND

The performance of E_T^{miss} in high pileup conditions has been studied using full simulation MC samples. Its behavior is consistent among different pileup conditions.

The LHC RUN-II expected high luminosity requires more powerful pileup suppression in order to keep E_T^{miss} performance at the level needed in high precision physics analyses and searches. The optimal procedure being developed in ATLAS consists on taking into account only tracks from the HS vertex, and not associated to any physics objects, to evaluate the E_T^{miss} soft term. The new track-based soft term ($E_T^{miss,TST}$), built using the same tracks and vertex quality selections as in p_T^{miss} , has the main advantage of keeping both E_T^{miss} resolution and scale optimal and unaffected in high pileup conditions.
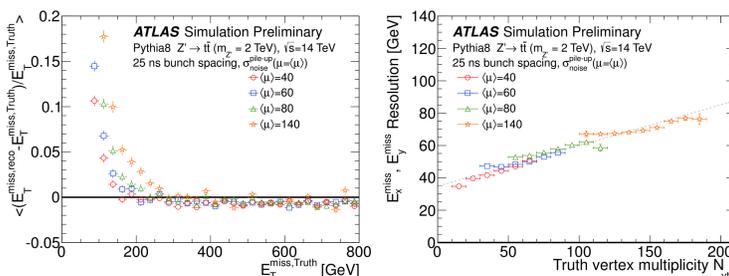
Performance plots of E_T^{miss} with high pileup conditions using $Z' \to t\bar{t}$ events: E_T^{miss} linearity (left) and resolution (right).

SUMMARY

The performance of E_T^{miss} has been studied using the events recorded by the ATLAS detector. In order to improve the performance, several pileup suppression methods have been introduced. Good performance results are shown both before and after pileup suppression. The performance of p_T^{miss} has also been studied and shows stable results with respect to pileup.

A new E_T^{miss} which combines the E_T^{miss} and p_T^{miss} has been developed and will be used for RUN-II missing transverse momentum reconstruction.

REFERENCES

- ATLAS-CONF-2013-082
- ATLAS-CONF-2014-019