Performance of MET reconstruction and pileup mitigation techniques in CMS

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On the behalf of the CMS Collaboration

Introduction

Most stable particles produced in pp collisions at the LHC can be detected by the CMS detector, notable exceptions being neutrinos and other hypothetical neutral weakly interacting particles. Their presence can be inferred from the momentum imbalance in the plane perpendicular to the beam, known as missing transverse momentum ($\vec{\not{E}}_T$). Its magnitude called missing transverse energy or MET.

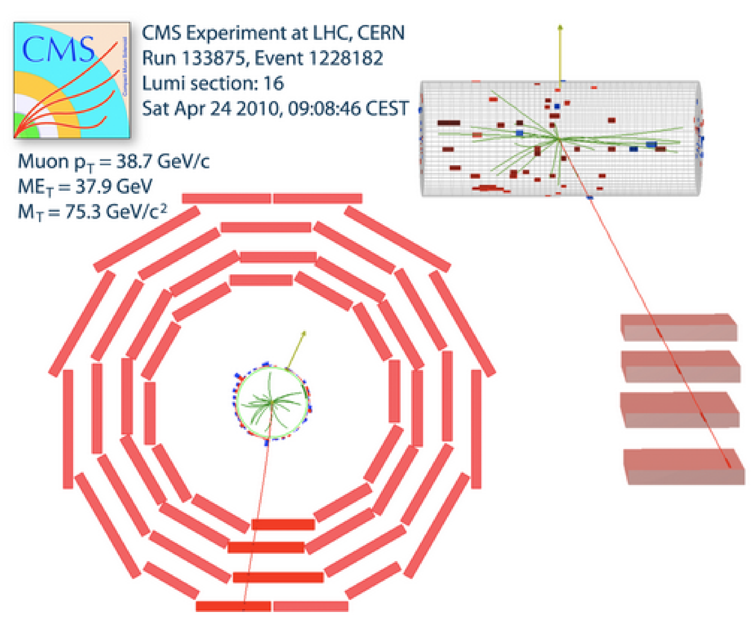

Figure: $W \to \mu\nu$ candidate event at CMS. The yellow arrow represents the $\vec{\not{E}}_T$ in the event, presumably due to a neutrino.

$\vec{\not{E}}_T$ is a key variable for:

- standard model physics measurements involving W bosons and top quarks
- studies contributing to discovery of a new boson at a mass of around 125 GeV, in channels with WW and $\tau\tau$ final states
- searches for BSM physics , such as supersymmetry, extra dimensions etc.

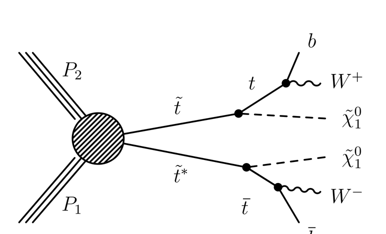

Figure: Diagram for top squark pair production for the $\tilde{t} \to t\tilde{\chi}^0$. Signature for supersymmetry with $\not{E}_T$ in final state.

$\vec{\not{E}}_T$ is highly sensitive to detector malfunctions, reconstruction effects, calibration and effects of pileup interactions.

Reconstruction of MET in CMS

$\vec{\not{E}}_T$ is defined as the imbalance in the transverse momentum of all visible particles detected by the CMS detector.

$$\vec{\not{E}}_T = -\Sigma \vec{E}_{T_i}$$

Particle Flow (PF) $\vec{\not{E}}_T$, based on the PF algorithm (which consists of reconstructing and identifying each particle with an optimized combination of all sub-detector information), is most widely used in CMS.

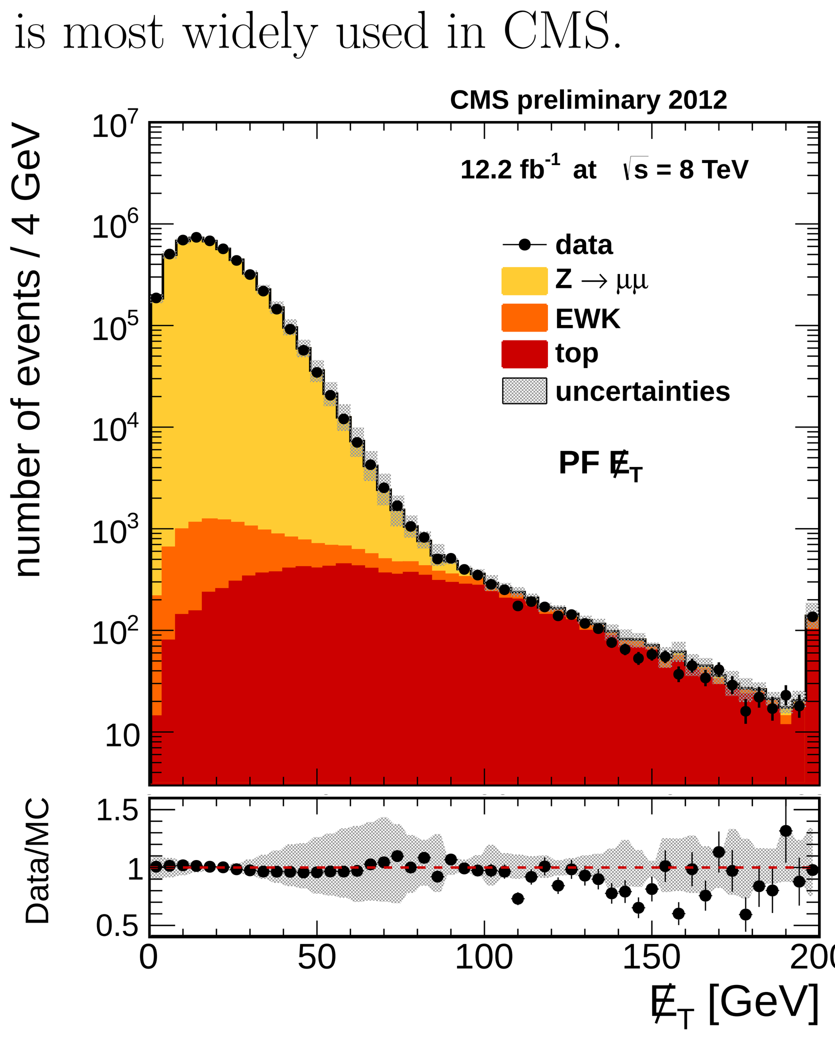

Figure: PF $\not{E}_T$ distribution for $Z \to \mu^+\mu^-$ candidate events.

Corrections are applied to PF $\vec{\not{E}}_T$ for:

- Jet energy scale
- Difference between charged and neutral particles from pileup
- ϕ-asymmetry of $\vec{\not{E}}_T$

Performance of MET

Studies of performance of $\vec{\not{E}}_T$ are done using $Z \to \mu^+\mu^-$, $Z \to e^+e^-$ and γ events. The quantities used to study the performance of $\not{E}_T$ are the vector boson momentum in the transverse plane ($\vec{q_T}$) and transverse momentum of the hadronic recoil ($\vec{u_T}$).

$$\vec{q_T} + \vec{u_T} + \vec{\not{E}}_T = 0$$

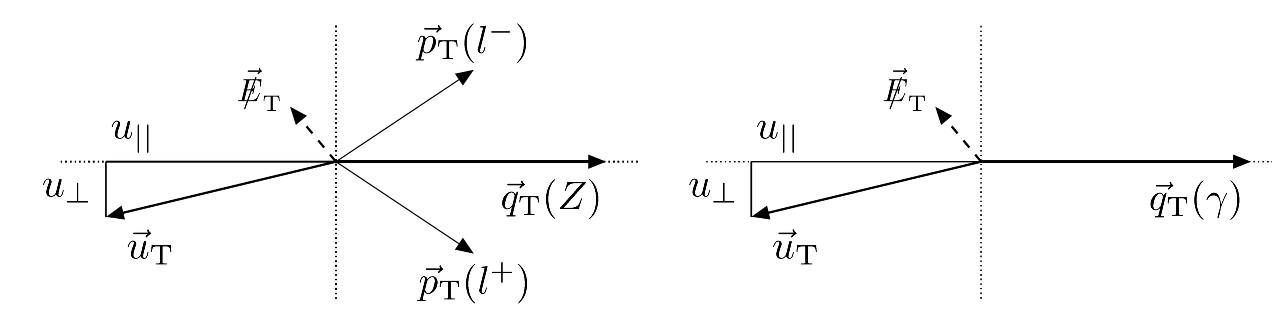

Figure: Illustration of event kinematics in the transverse plane for $Z \to l^+l^-$ (left) and γ (right) events. The recoil vector $\vec{u_T}$ denotes the vectorial sum of all particles reconstructed in the event except for the two leptons from the Z decay (left) or the photon (right).

Taking the $\vec{q_T}$ as the axis, the recoil $\vec{u_T}$ is projected into two signed components, parallel ($u_{\parallel} \equiv \vec{u_T} \cdot \hat{q_T}$) and perpendicular ($u_\perp$).

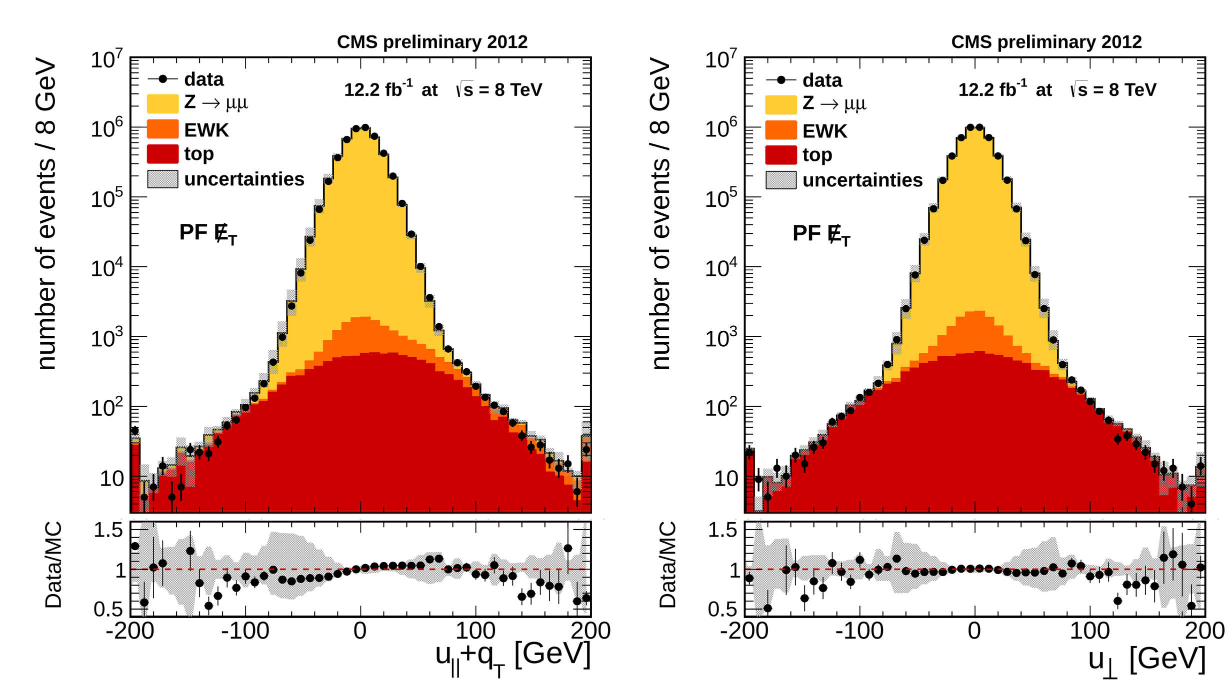

Figure: $u_\parallel + q_T$ distribution (left) and $u_\perp$ distribution (right) for PF $\vec{\not{E}}_T$ for $Z \to \mu^+\mu^-$ candidate events.

The response $(-u_\parallel/q_T)$ and the resolution are studied as a function of q_T.

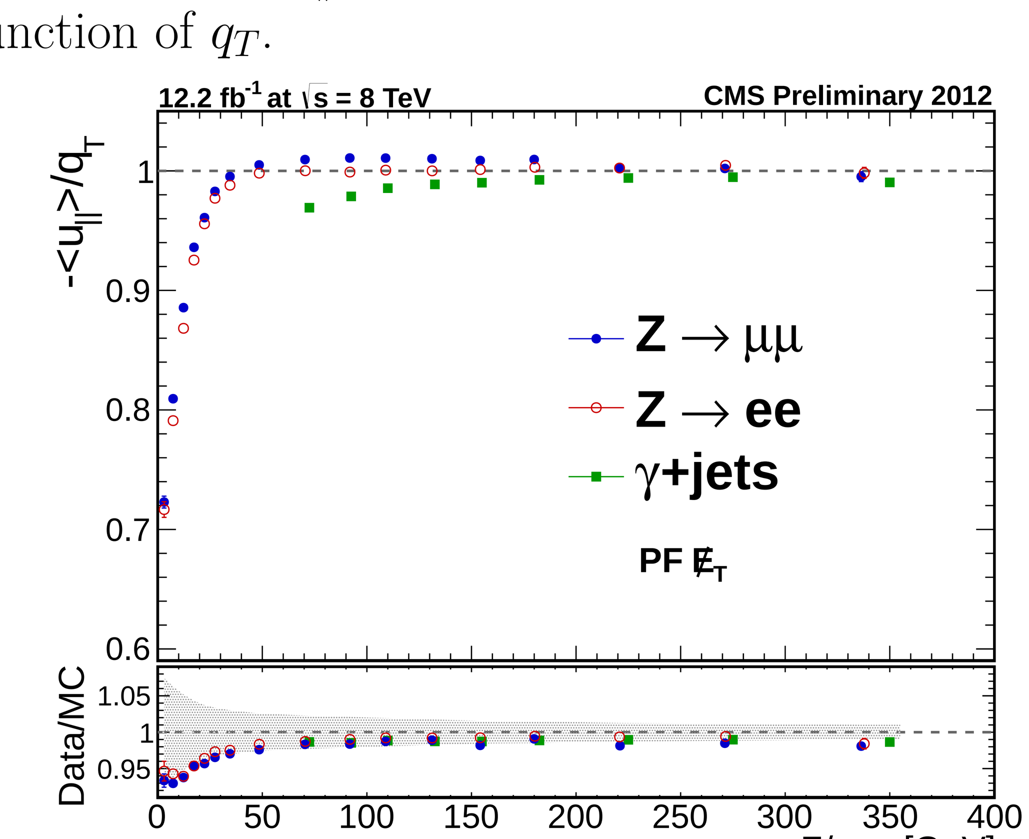

Figure: Response for PF $\vec{\not{E}}_T$ vs q_T for $Z \to \mu^+\mu^-$, $Z \to e^+e^-$ and γ events in data (on top), with the ratio of data to simulation (shown below).

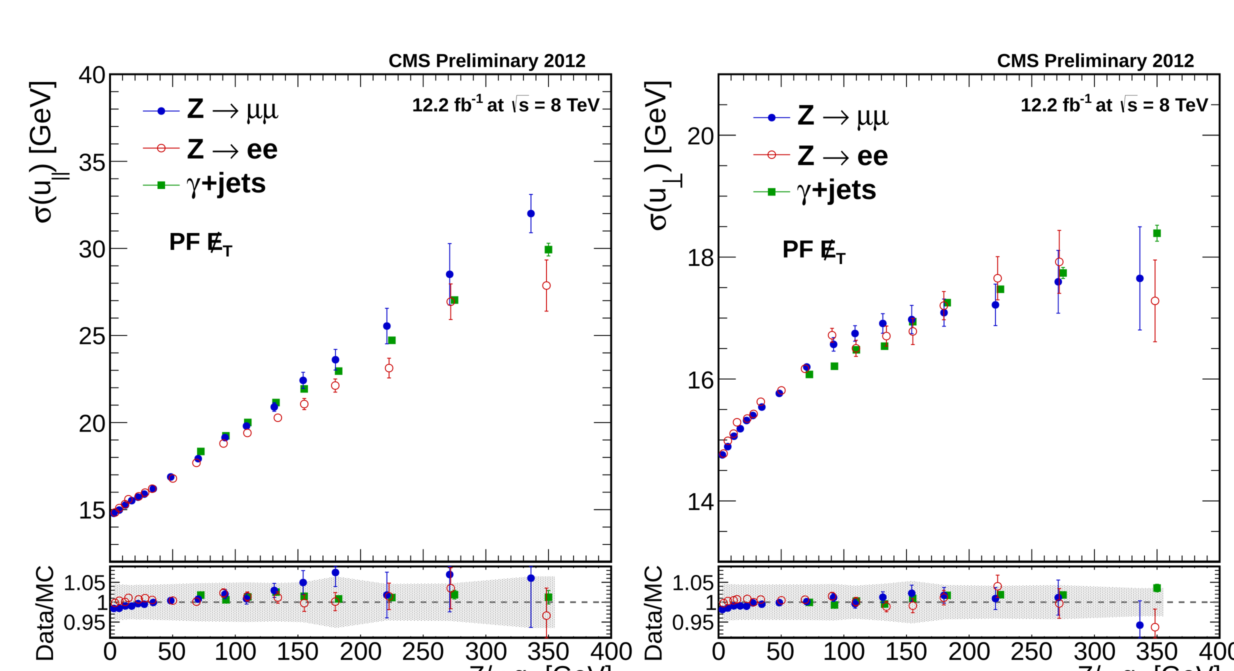

Figure: Resolution of parallel recoil component (left) and perpendicular recoil component (right) for PF $\vec{\not{E}}_T$ vs q_T in data (on top), with the ratio of data to simulation (shown below).

Effect of Pileup on MET

During the LHC runs in 2012, the average number of pileup interactions during pp collisions was 20. Pileup is found to degrade $\vec{\not{E}}_T$ resolution by 3.3-3.7 GeV in quadrature per additional pileup interaction.

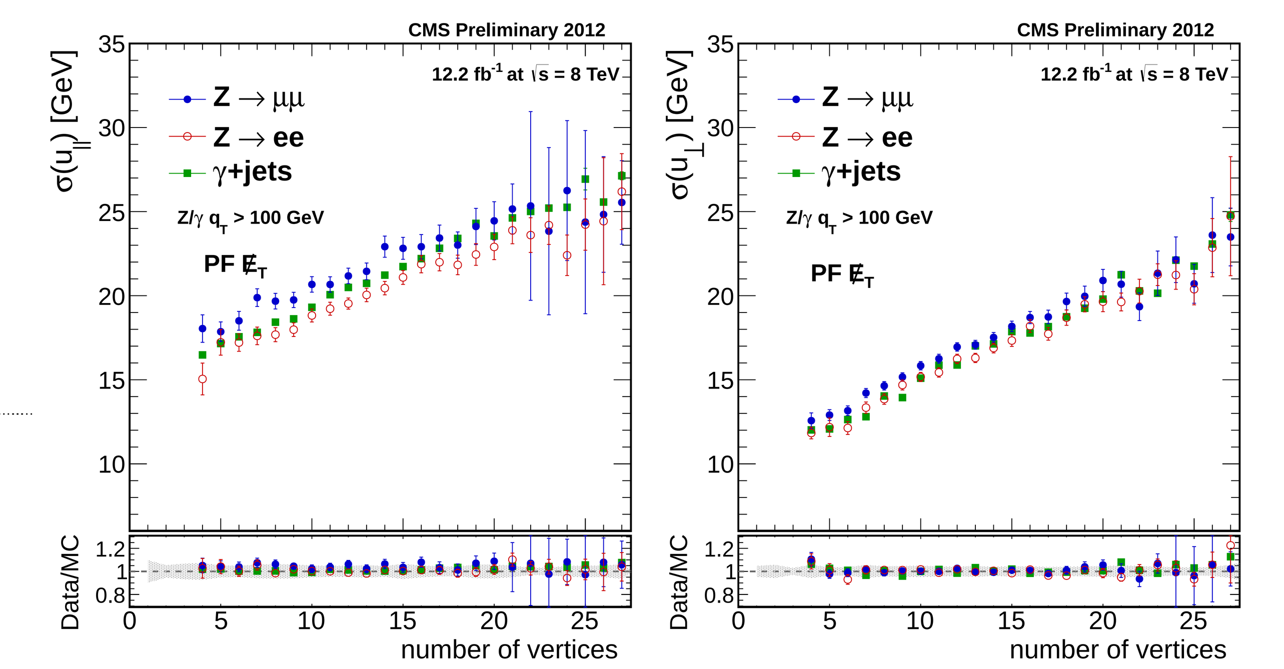

Figure: Resolution of parallel recoil component (left) and perpendicular recoil component (right) for PF $\vec{\not{E}}_T$ vs the number of vertices in an event.

Pileup mitigated MET

Two algorithms, No-PU PF $\vec{\not{E}}_T$ and MVA PF $\vec{\not{E}}_T$, were developed to reduce the effect of pileup interactions on $\vec{\not{E}}_T$.

- Attempt to distinguish particles from hard-scatter (HS) vertex to those from pileup (PU).
- MVA-based pileup jet identification discriminator separates jets from HS and jets from PU.
- **No-PU PF $\vec{\not{E}}_T$** separates particles into those from HS (leptons, HS jets, charged hadrons from HS) and those from PU (charged hadrons from PU, PU jets, neutrals not in jets) and re-weights the contribution of particles to $\vec{\not{E}}_T$ accordingly.
- **MVA PF $\vec{\not{E}}_T$** algorithm is based on a set of multivariate regressions that correct the recoil $\vec{u_T}$ for magnitude and azimuthal angle. PF particles, that have been separated into different categories corresponding to HS and PU particles, are used to reconstruct correct $\vec{u_T}$ using BDT regressions that are trained on $Z \to \mu^+\mu^-$ MC sample. $\vec{u_T}$ and $\vec{q_T}$ are used to compute $\vec{\not{E}}_T$.

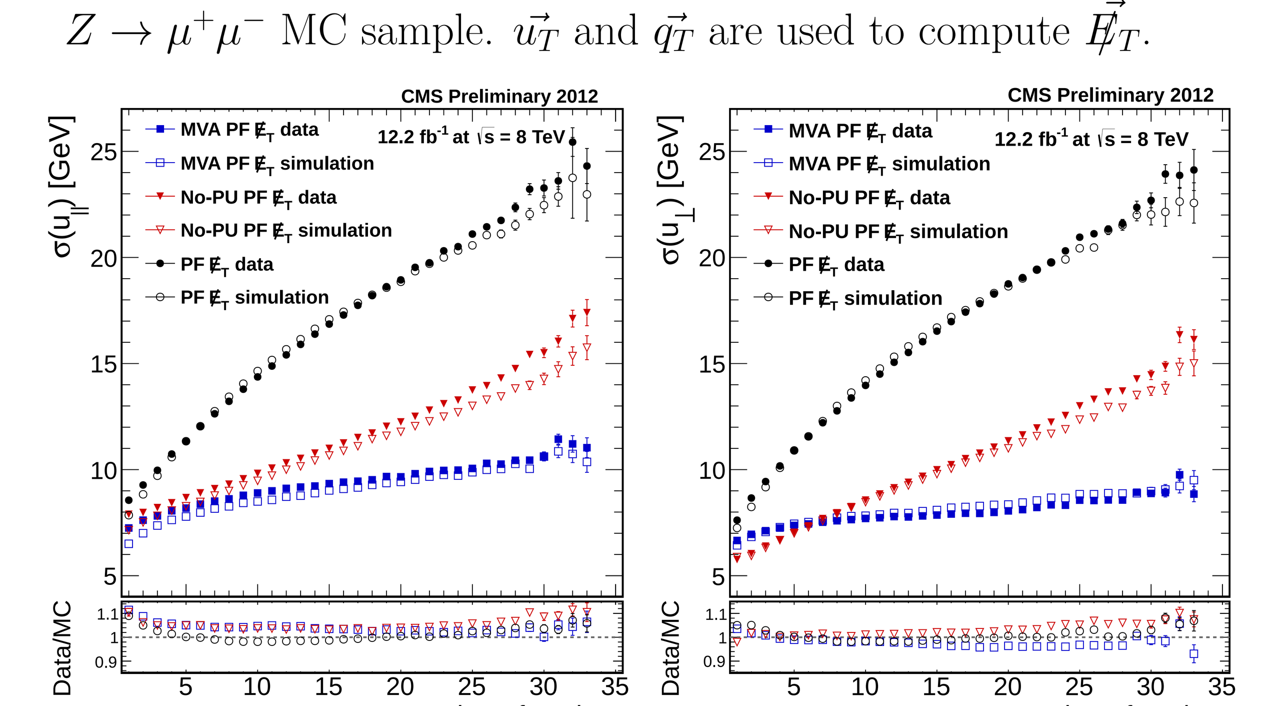

Figure: Parallel (left) and perpendicular (right) resolution as a function of the number of reconstructed vertices for PF $\vec{\not{E}}_T$, No-PU PF $\vec{\not{E}}_T$, and MVA PF $\vec{\not{E}}_T$ for $Z \to \mu^+\mu^-$ events.

Conclusion

The performance of $\vec{\not{E}}_T$ reconstruction algorithms has been studied using data corresponding to an integrated luminosity up to $12.2 \pm 0.5 fb^{-1}$ collected in 8 TeV pp collisions with the CMS detector at the LHC.

The response and resolution of PF $\vec{\not{E}}_T$ and the effect of pileup interactions on PF $\vec{\not{E}}_T$ have been measured.The distributions in data and simulation agree well.

Studies of two new $\vec{\not{E}}_T$ algorithms, No-PU PF $\vec{\not{E}}_T$ and MVA PF $\vec{\not{E}}_T$, show a significantly reduced dependence of the $\vec{\not{E}}_T$ resolution on pileup interactions.

References

[1] CMS Collaboration, CMS PAS JME-12-002