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Investigation of Muon Tracking at the CMS Detector

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Introduction

The Compact Muon Solenoid (CMS) is a detector built on the LHC at CERN. It is designed to detect the products of particle collisions and examine their properties.

A major goal of the CMS is to provide evidence for the existence of the 'Higgs' particle, a significant elementary particle of the Standard Model. Its properties can be inferred by measuring particles which it decays to, such as muons.

Our aim was to simulate possible trajectories of detected muons to investigate the accuracy and precision of the measurements of their properties.

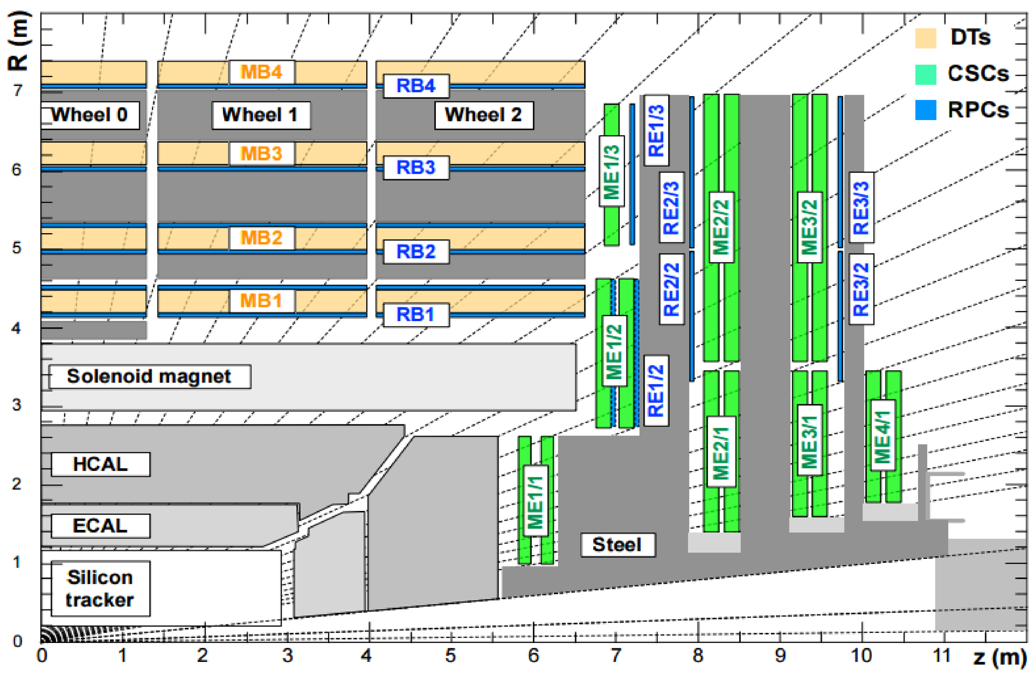

Figure 1. An r-z cross section of a quadrant of the CMS. The origin of the collisions is at the lower left corner. The resulting muon products travel through the silicon tracker, hadronic calorimeter (HCAL), and drift tubes (DTs) and interact with them. Silicon trackers and DTs contain cylindrical detectors that record the position of the muons when they cross them (hit points).

Method

The tracking mechanism relied on the curvature of the muon trajectories in the r-ϕ plane within the uniform magnetic field produced by the solenoid magnet (fig 1). The procedure:

- Simulated a travelling muon and recorded its exact hit points (fig 2).
- Smeared the hit points accounting for detectors' resolution.
- Fitted helical path through smeared hit points hence estimating muon's momentum.
- Iterated procedure over the range of possible momenta hence comparing the effective resolution of the silicon tracker and DTs.
- Also simulated Higgs' decay into four muons ($H \rightarrow ZZ^* \rightarrow \mu^-\mu^+\mu^-\mu^+$) hence estimating Z boson's mass within statistical error.

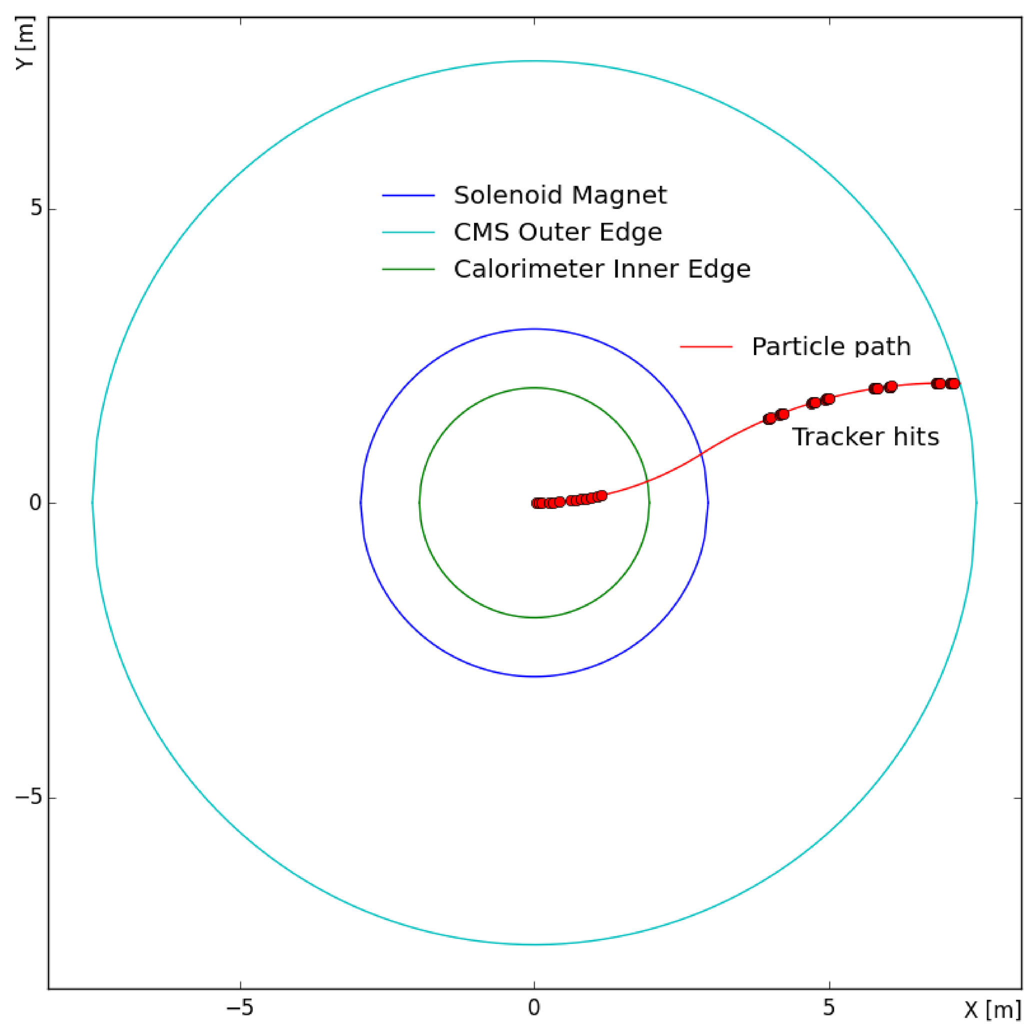

Figure 2. An r-ϕ cross section of a simulated muon's exact helical path through the CMS. Beyond the solenoid magnet the magnetic field is reversed, and thus the curvature is flipped. The muon interacts with the HCAL and deposits energy, slightly shifting its trajectory.

Results

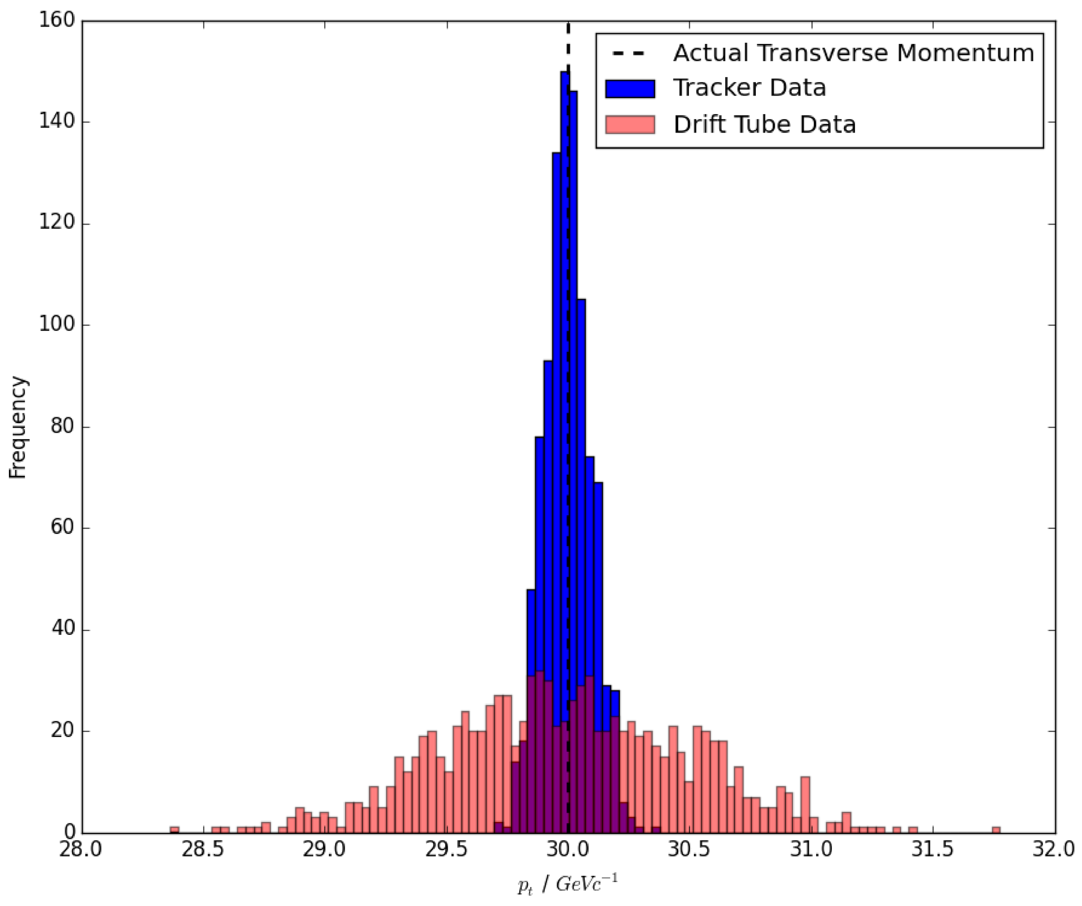

Figure 3. A histogram of the momentum distribution for a low energy muon. Both the silicon tracker and the DTs produce normally distributed measurements centred around approximately 30 GeV/c. The inner tracker distribution exhibits a lower standard error than the DT distribution. The reason lies in the random nature of the energy deposited by the muons to the calorimeter. Since the muon is at low energy, the energy loss has the most significant impact on the resolution.

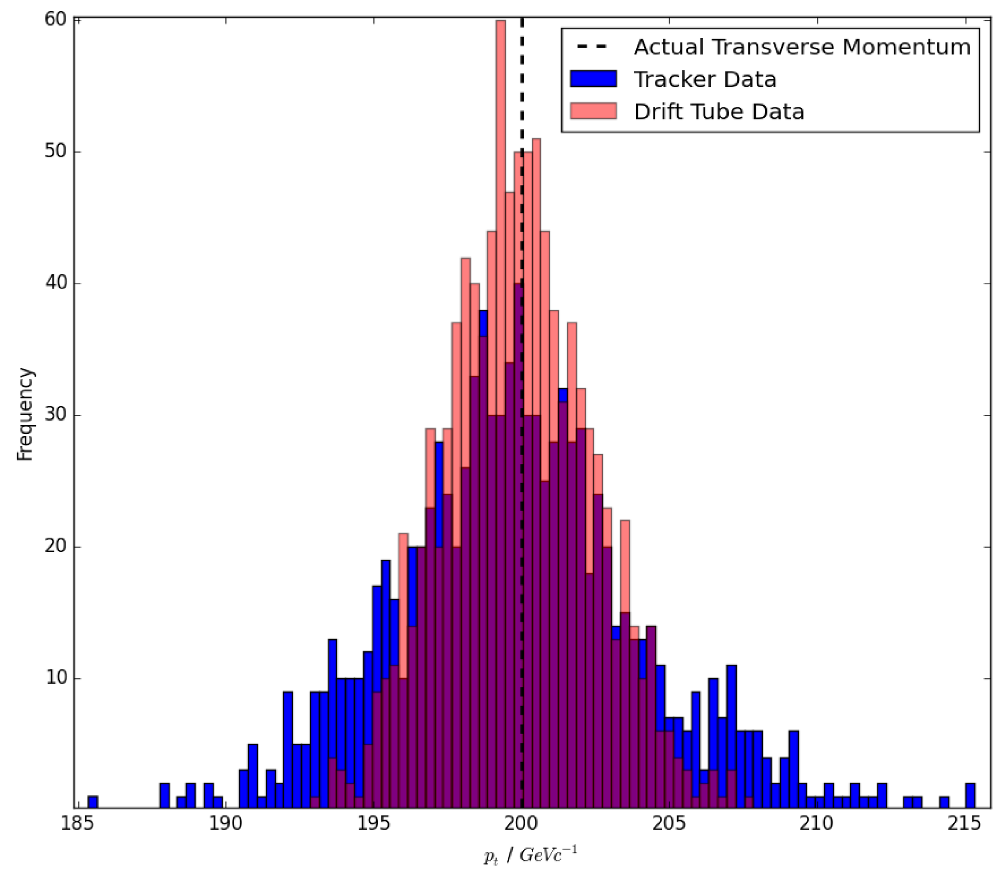

Figure 4. A histogram of the momentum distribution for an approximately 'critical' energy muon. Both the silicon tracker and the DTs produce normally distributed measurements centred around approximately 200 GeV/c. At these energy levels, the effect of the energy loss due to the calorimeter is almost exactly offset by the better effective resolution of the DTs. The DT detectors are more spread out, thus allowing for more precise measurements of muon trajectories.

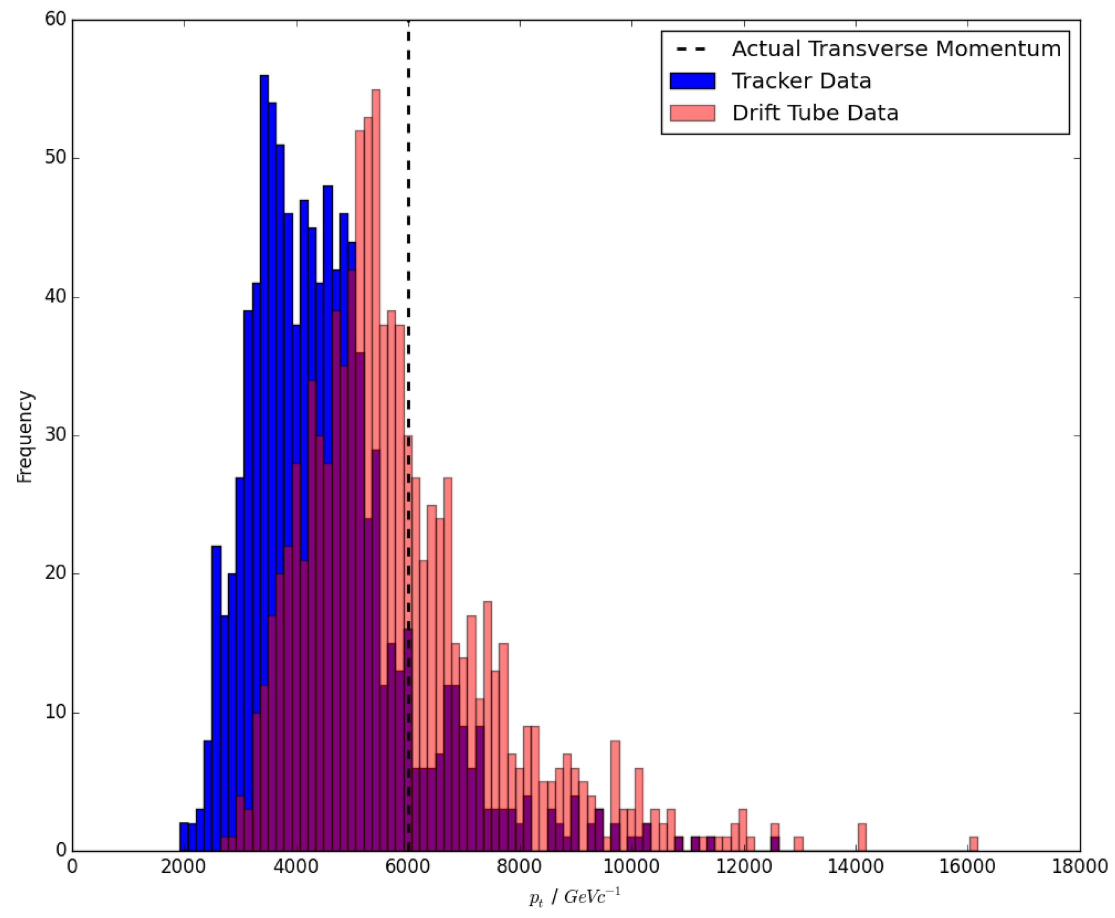

Figure 5. A histogram of the momentum distribution for a very high energy muon (6000 GeV). At these energy levels, both momentum distributions are skewed to the right and their peaks are shifted left of the simulated muon's momentum value. The path of muons approximate straight lines at high momenta and therefore fitting a helical path involves a very high random error as seen in the figure.

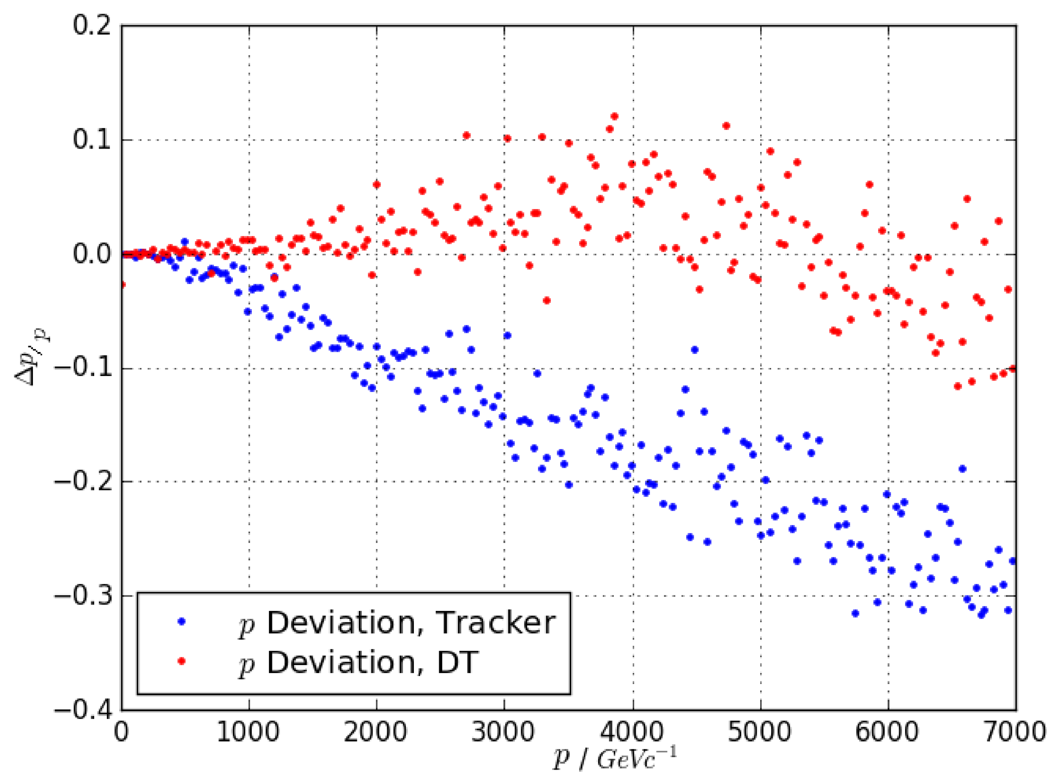

Figure 6. A plot of the fractional deviation of the measured momentum against the actual momentum of the muon. Beyond the low energy spectrum, the tracker quickly and steadily becomes highly inaccurate (reaching 30% deviation). The DT system also loses accuracy, but remains accurate to within 10% of the actual momentum in our range of interest (< 7 TeV).

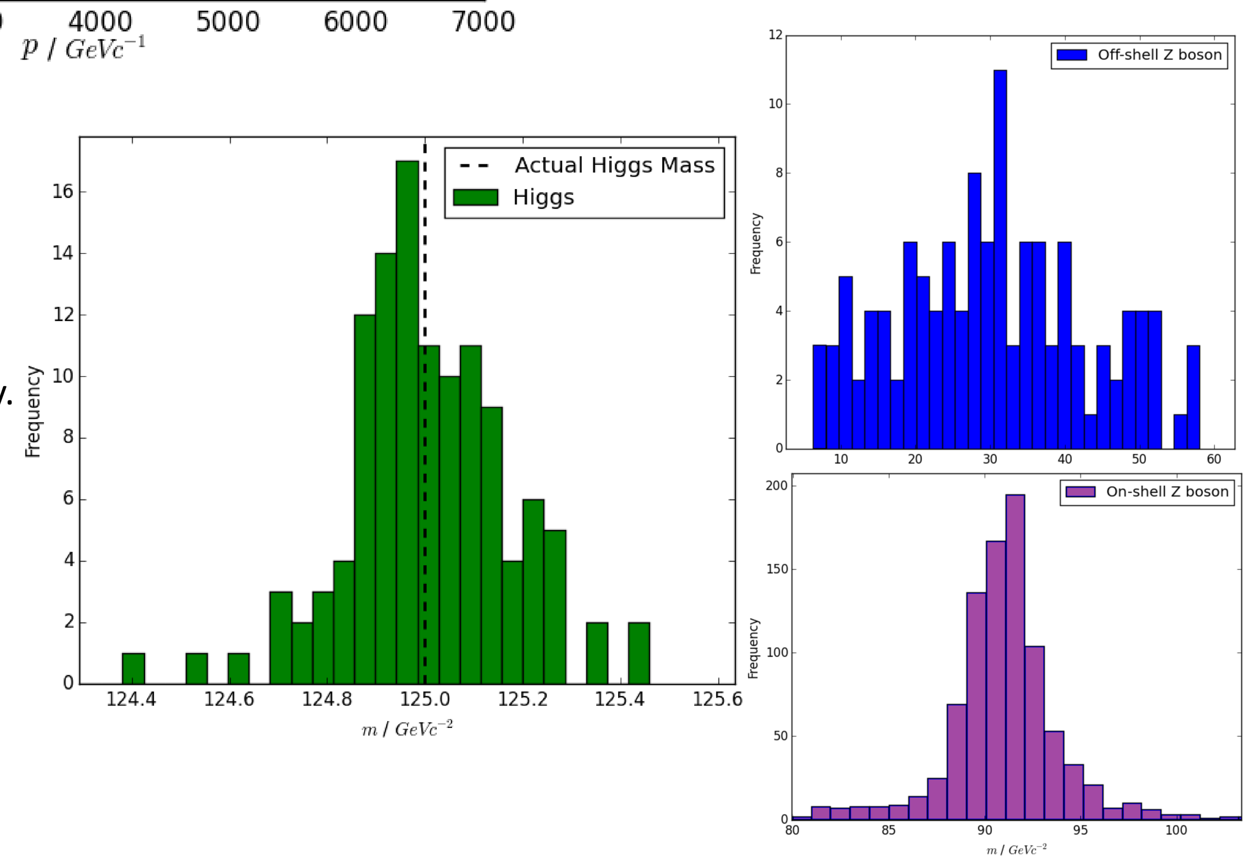

Figure 7. Histograms of the mass distributions of an off-shell and an on-shell Z boson, and the Higgs. The measurements were taken by simulating a Higgs decay. Investigation of the muon products led to this Gaussian distribution of the Higgs' mass with a mean value of (124.98 ± 0.02) GeV/c^2.

Conclusion

The best effective resolution lies in lower energy levels. There exists a 'critical' interval after which the DT system of detectors overtakes the silicon tracker in precision. For very high energy levels (i.e. > 400 GeV) both systems are relatively unreliable (imprecise and inaccurate), but the DTs remain within a sensible range of error.

Muon measurements can also provide reliable and precise predictions of boson decay events, and can be used to indirectly measure properties of these extremely short-lived particles.

References & Acknowledgements

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