# *Muon Reconstruction*

**Piotr Traczyk**

## 1 High energy muons

The CMS detector is a muon spectrometer, with the muon transverse momentum ($p_T$) measured by the inner silicon Tracker and the outer Muon System. For muon momenta below ∼200 GeV the measurement provided by the Tracker dominates, whereas for higher $p_T$ muons the additional lever arm of the Muon System becomes necessary to reach optimal performance. At these energies, however, muons have an increasing probability of catastrophic energy loss in the iron of the CMS magnet return yoke and in the calorimeters. Such processes result in showers of secondary particles that contaminate the muon detectors and in consequence deteriorate the trajectory measurement.

Since 2007 I am the coordinator of high-$p_T$ muon reconstruction in CMS. I have developed the now-standard CMS algorithm for high energy muon reconstruction, known as the muon "cocktail" or "Tune P". The approach is based on running several versions of the muon trajectory fit (including the "Picky" refit that I designed in 2004) and choosing the appropriate one for every muon candidate based on global goodness-of-fit variables. I have shown this algorithm to provide optimal results in the past with Monte Carlo simulations [7], and since 2009 it is being also studied with cosmic-ray muon data [5]. The current performance is shown in Fig. 1 [1]. This algorithm is the one officially recommended for all analyses involving high-$p_T$ muons and has been used in a number of analyses publishing resutls based on the 2010 LHC run [2, 3].

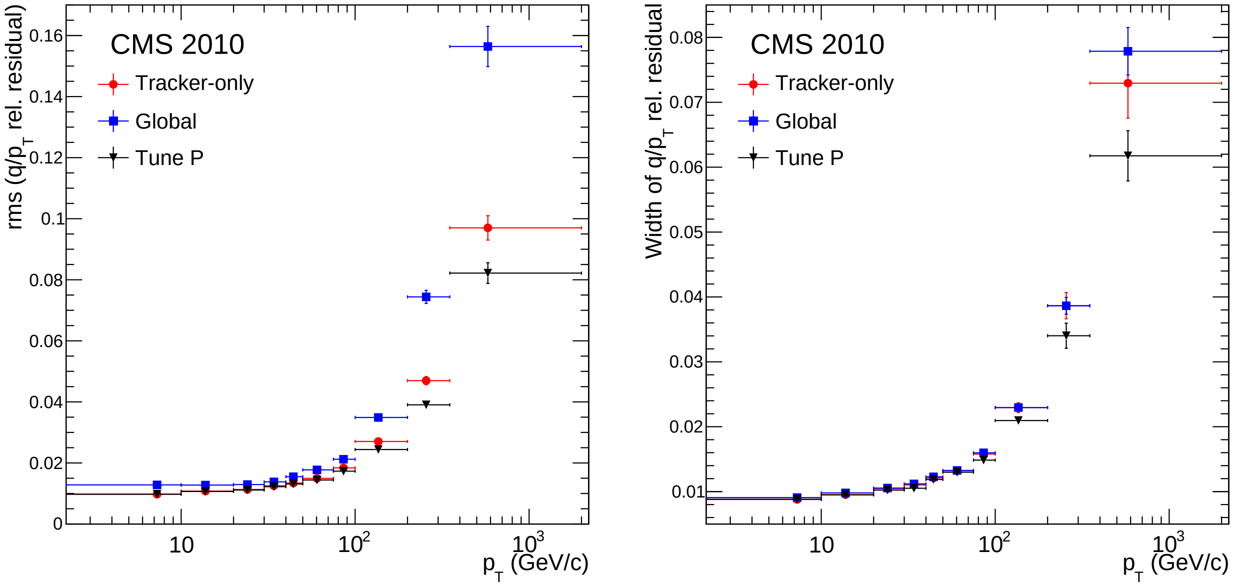

Figure 1: Left plot shows truncated sample RMS's of the distributions of the muon $q/p_T$ relative residuals for the tracker-only and global fits, and for the output of the "Tune P" algorithm, as a function of the $p_T$ of the muon. Right plot shows the widths of Gaussian fits to the same distributions.

I am currently involved in work on both development and performance studies of high-$p_T$ muon reconstruction, a topic which is becoming more mainstream in CMS in 2011. My plans for 2011 include coordinating and involvement in the development of new algorithms and retuning the existing ones, including the possible impact of switching from using single detector hits to using track segments in the trajectory fit, and a possible dedicated tracker fit. I'm also involved in data-driven studies of high energy muon resolution and efficiency performed using cosmic-ray muon data, specifically dealing with the subtleties induced by the fact that cosmic rays are out-of-time.

## 2 Muon timing

The information about muon arrival time can be extracted from the muon detector signals in addition to the position measurement. In 2005 I implemented a method using the CMS Drift Tube (DT) system in the CMS offline reconstruction framework, motivated by a physics search for Heavy Stable Charged Particles (HSCP) which can be identified as out-of-time particles in the muon system. While working on this, I developed an alternative algorithm for local track segment building in the DT system, since the default one performs poorly for out-of-time particles. Since 2007 the algorithm is included in standard CMS software, while muon timing measurement is part of the standard muon reconstruction chain since 2008. This measurement now includes timing information provided by the calorimeters and the endcap Cathode Strip Chambers.

Currently two main uses of muon timing in CMS are in HSCP searches and in cosmic-ray muon identification. I am actively working on both topics, optimizing the timing measurement and studying it's performance on data. I have performed studies of cosmic-ray muon backgrounds for searches of a new heavy resonance decaying to muon pairs [2] and I'm the editor of the section on cosmic-ray and beam-halo muon identification in the paper describing muon reconstruction performance on 2010 CMS data [1]. An illustration of the reconstructed timing of collision and cosmic muons is shown in Fig. 2, with single muon timing shown on the left plot, and the difference in time between the upper and lower parts of the cosmic muon track shown on the right, where a clean separation between collision and cosmic-ray muons can be seen. Depending on whether a cosmic-ray muon has been reconstructed as a single muon or a pair of muons, these two handles can be used to establish the non-collision origin of the muon candidate.

My current work and plans are to perform detailed studies of the performance of my alternative DT pattern recognition algorithm and continued work on providing optimal timing measurement for HSCP searches.

## References

[1] The CMS Collaboration, *Performance of muon identification in 2010 data*, CMS MUO-10-004, In preparation

[2] The CMS Collaboration, *Search for Resonances in the Dilepton Mass Distribution in pp Collisions at* $\sqrt{(s)} = 7\ TeV$, CMS-EXO-10-013, arXiv:1103.0981 [hep-ex]. submitted to JHEP

[3] The CMS Collaboration, *Search for a W' boson decaying to a muon and a neutrino in pp collisions at* $\sqrt{(s)} = 7\ TeV$, CMS-EXO-10-015, arXiv:1103.0030 [hep-ex]. submitted to JHEP

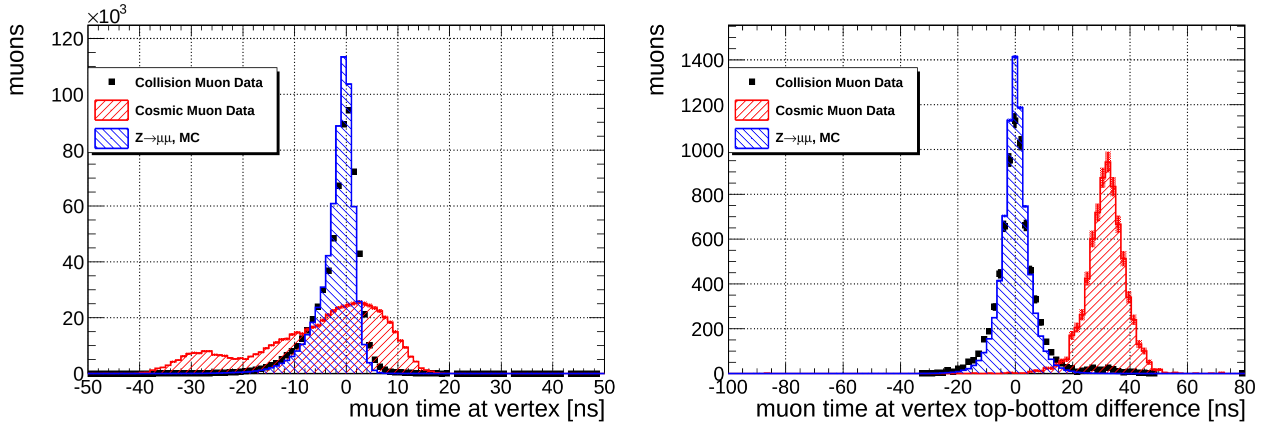

Figure 2: Distributions of muon timing variables for collision and cosmic ray data samples. Left plot shows single muon timing, right plot shows difference between muons reconstructed in the upper and lower hemispheres. Plot taken from [1].

[4] Traczyk, P., *Collision and Cosmic Muon Timing Measurement*, CMS IN-2010/013

[5] The CMS Collaboration, "Performance of CMS muon reconstruction in cosmic-ray events", 2010 *J. Inst.* **5** T03022

[6] Abbiendi, G.; et al., *Muon Reconstruction in the CMS Detector*, CMS AN-2008/097