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Effect of CSC Misalignment on Single Muon p_t Reconstruction

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Abstract

A modified version of ORCA v5_3_1 has been used to study of the impact of CSC chamber misalignment on p_t resolution in the CMS Muon Endcap System by supplying a random or constant shift to the location of the CSC chambers in the CMS RPhi plane immediately prior to the reconstruction of single muon events. The effect of CSC 'misalignment' on ORCA L2 and L3 Muon Reconstructors is evaluated for single muons between 10 GeV $\leq p_t \leq$ 1000 GeV for both random and systematic shifts of CSCs from their nominal locations.

1. Introduction

A modified version of ORCA v5_3_1 [1] was used to study of the impact of CSC chamber misalignment on p_t resolution in the CMS Endcap Muon System by supplying a random or constant shift to the location of the CSC chambers in the CMS global RPhi plane prior to the reconstruction of simulated events. P_t^{-1} resolution is described in a manner analogous to the CMS Muon Technical Design Report [2] as the σ_{rms} is the p_t^{-1} residual distribution with:

$$p_t^{-1} \text{ residual} = \frac{\Delta p_t^{-1}}{p_t^{-1}} = \frac{p_t^{-1}{}_{\mathrm{Re}constructed} - p_t^{-1}{}_{Generated}}{p_t^{-1}{}_{Generated}} \qquad \text{Equation 1}$$

The results presented in this paper are a subset of the studies done in Reference [3].

2. Simulation of the Ideal System

Figure 1 and 2 illustrate the typical Muon System performance, in terms of the p_t^{-1} residual distributions, of the ORCA Level 2 and Level 3 Muon Reconstruction as a function of $|\eta|$ for three magnitudes of p_t. The plots were constructed from single muon samples at fixed values of $|\eta|$ and unrestricted values of phi. Error bars on the plot indicate the quality of the fit used to determine the value of σ plotted.

The standalone Muon System with the vertex constraint imposed (ORCA L2 Reconstruction) can be seen to remain relatively constant in performance between $1.3 \leq |\eta| \leq 1.7$. Beyond $|\eta| = 1.7$, the resolution begins to degrade or, in the case of muons with $p_t \approx$ 1 TeV, the residual becomes considerably less well defined (i.e. larger error bars). Both the residual p_t^{-1} distribution and p_t^{-1} distribution becomes very difficult to fit for large values of p_t at high $|\eta|$. The addition of the Inner Tracker to the Muon System fit (L3 Reconstruction, Figure 2) significantly improves the p_t resolutions with the exception of very high p_t muons in high $|\eta|$ regions.

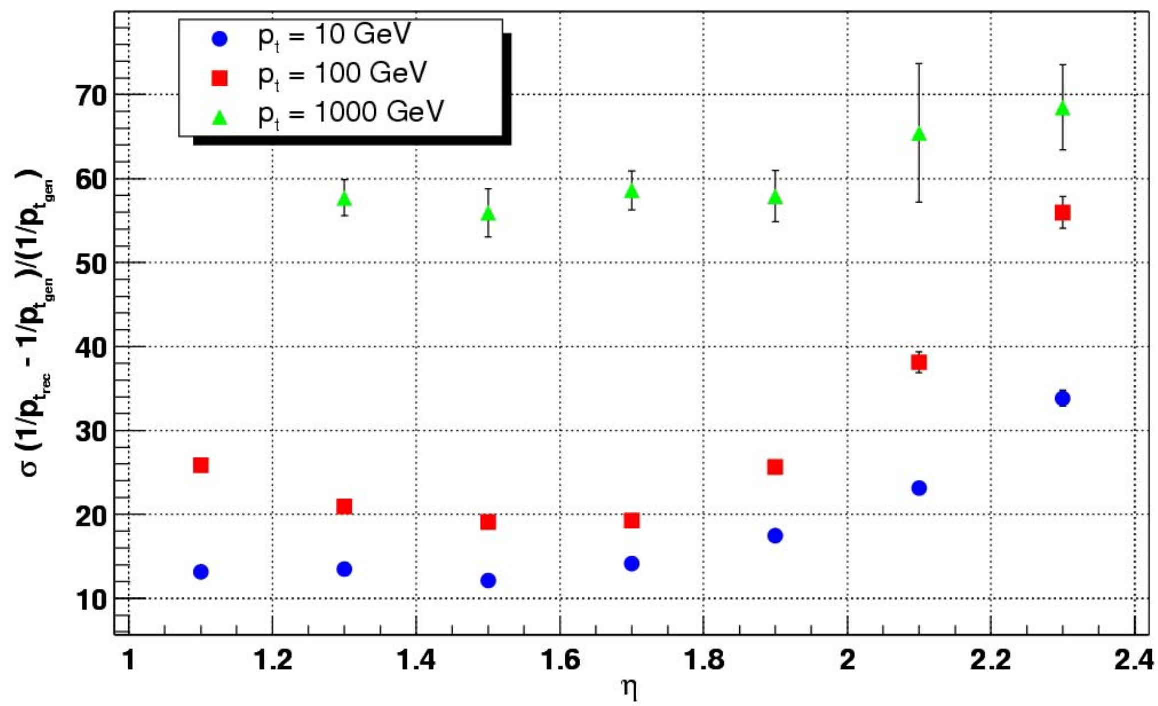

Figure 1: The Muon System Standalone + Vertex Constraint p_t Resolution as a Function of $|\eta|$.

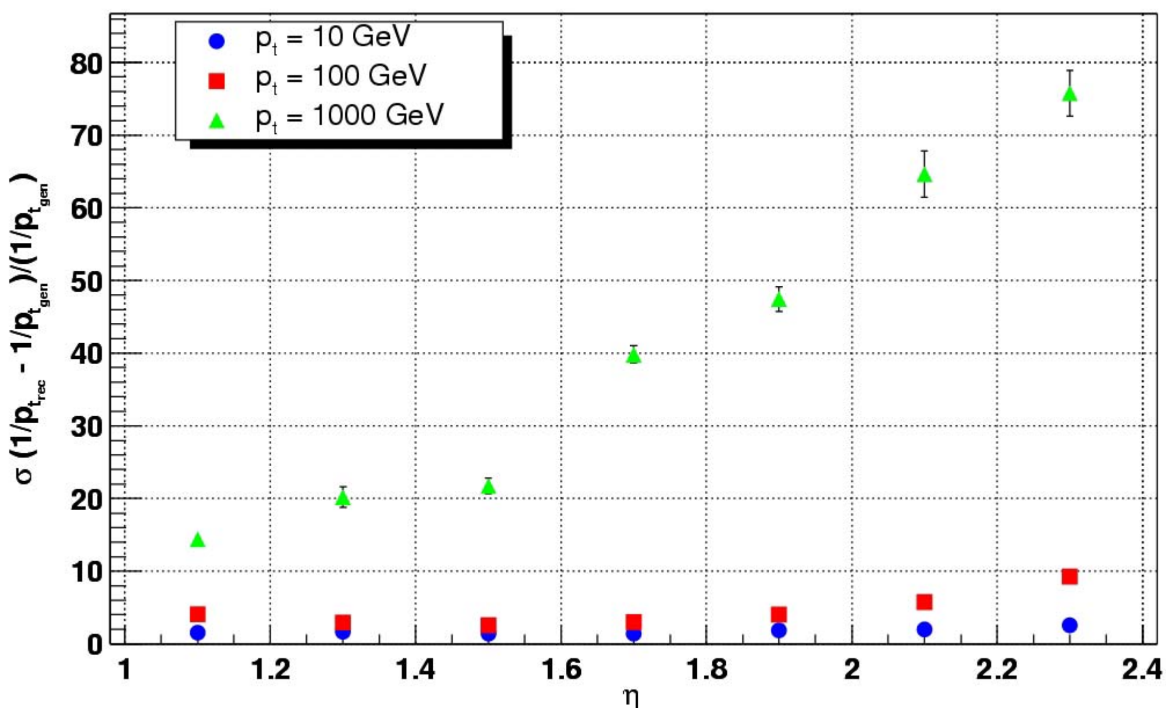

Figure 2: The Muon System + Inner Tracker p_t Resolution as a Function of $|\eta|$.

3. CSC 'Misalignments' Introduced Into ORCA Simulation

CSC chambers are expected to be surveyed after installation on the YE iron disks, but prior to the final positioning of the disks themselves. Although photogrammetric surveys similar to those used during the 2000 EMU Alignment ISR Tests [4] can yield resolutions of approximately 250μm when multiple views of the same object are available, it is expected that the reduced number of viewpoints available for the survey of the CSC chambers during installation will effectively limit the resolution of some chamber positions to approximately ±1mm [5]. Once the disks are positioned in the detector, uncertainties are likely to increase beyond 1mm and further survey will be impossible. As the magnetic field is applied in the solenoid, the iron disks are expected to move by as much as ±3mm in the CMS XY plane. Distortions in the disks themselves are expected to further shift the location of the CSC chambers. There are no plans to survey or otherwise determine the initial location of the ME disks once the magnetic field is activated.

The misalignments performed for this study include a random displacement of each CSC chamber in the CMS RPhi plane and, separately, a constant shift of the YE iron disks holding the CSC chambers. Applying a random shift to the location of CSC chambers is intended to mimic the uncertainty associated with the placement of individual chambers on a ME disk either before or after the application of the magnetic field. The application of random shifts was done in a manner which assures that the total distribution of all displacements applied to every individual chamber in the CMS RΦ plane matches a Gaussian distribution with a specified value of σ = 200, 500, 1000, and 2000μm. The direction of the random displacements in the CMS RΦ plane was chosen randomly from a flat distribution in Φ. The application of constant shifts to the YE Iron was done in a manner which moves neighboring YE disks in opposing directions (i.e. the worst case scenario). In this case, ME ±1 and ±4 were moved along the CMS +X axis and ME ±2 and ±3 were moved along the CMS –X axis. The magnitudes of the ME Layer shifts were restricted to ±1, ±2, and ±3 mm.

4. Study Results

The manner in which p_t^{-1} resolutions degraded in response to the induced misalignment is summarized as the relative shift in the p_t^{-1} residual resolution from the simulation performed with perfect CSC chamber alignment. A more detailed examination of p_t^{-1} resolution and the dispersion of p_t^{-1} distributions can be found in Reference 3.

4.1 Effect on ORCA L3 Reconstruction (Muon System + Inner Tracker)

The ORCA Level 3 (L3) Muon Reconstruction in ORCA incorporates the Inner Tracker into the final determination of muon p_t. The dominance of the Inner Tracker in the determination of L3 resolution reduces the sensitivity of the reconstructed L3 p_t^{-1} resolutions to random CSC misalignment for low p_t muons ($p_t \leq 100$ GeV). Shifts in the p_t^{-1} resolutions for generated muons between 10-100 GeV are evident, though the net effect of these shifts, even for random misalignments up to 2mm, generally reduces the net resolution of the final L3 resolutions by ≤ 1%. Deviations in L3 resolutions are much more significant for single muons approaching $p_t = 1$ TeV. Figure 3 and 4 show single muon p_t^{-1} resolutions of high p_t muons (1 TeV) degrade substantially for random CSC motion and YE Iron Disk misalignment.

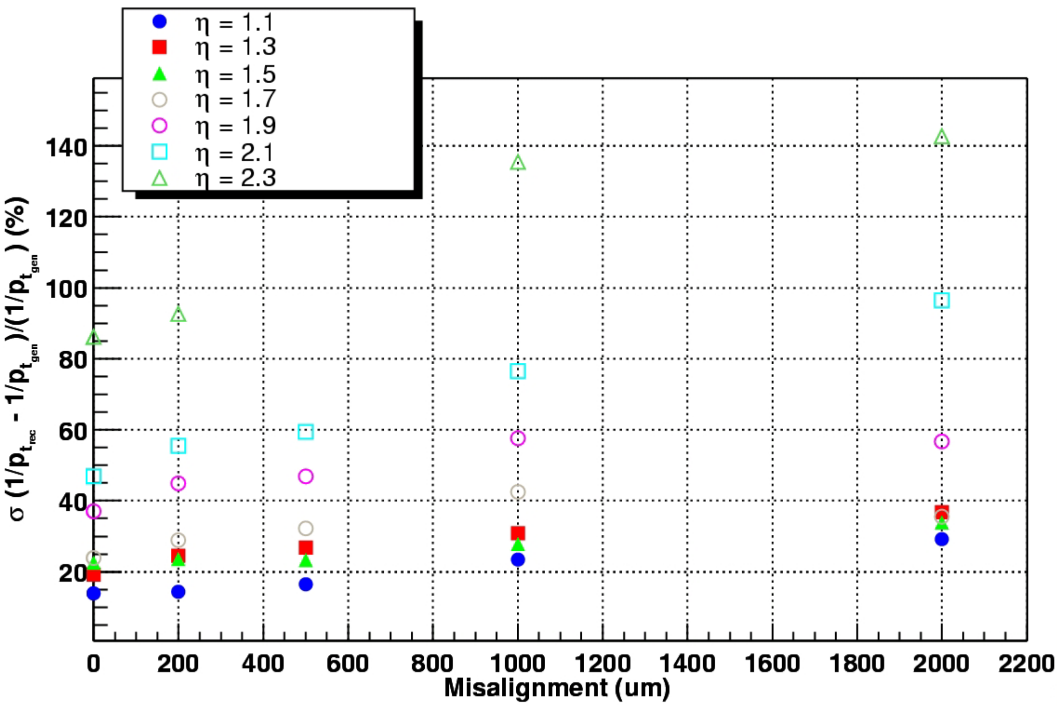

Figure 3: Muon System + Inner Tracker (ORCA L3) Resolution for the Reconstruction of $p_t = 1000$ GeV Muons vs. Random CSC Misalignment.

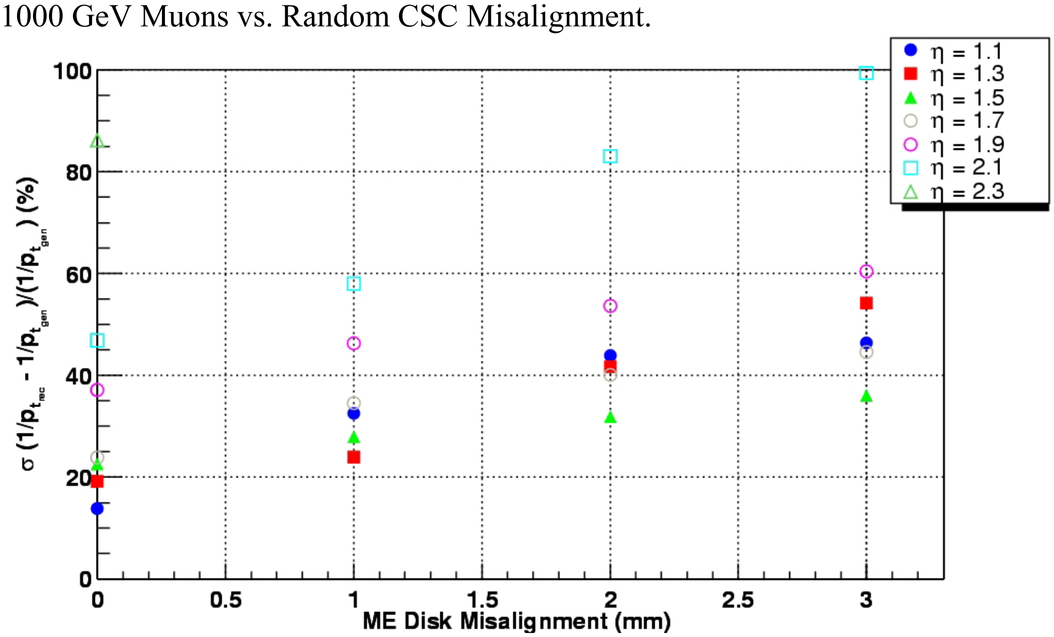

Figure 4: Muon System + Inner Tracker (ORCA L3) Reconstruction Resolution for $p_t = 1000$ GeV Muons as a Function of ME Station Misalignment.

4.2 Effect on ORCA L2 Reconstruction (Muon System Standalone + Vertex Constraint)

The resolutions obtained from the Muon Standalone + Vertex Constraint fit (ORCA L2 Reconstructor) of the single muon samples depend strongly on the particular value of $|\eta|$ being examined. The ORCA L2 Reconstruction of single muons with generated $p_t \geq 100$ GeV quickly degraded with any random CSC or constant ME Layer misalignment. However, loss of ORCA L2 resolution for high muon p_t is not a primary concern in CMS, as the final determination of muon p_t will incorporate the Inner Tracker. More important is the ORCA L2 resolution for low muon p_t, which directly impacts CMS Level 1 Global Muon Trigger Rates. Table 1 summarizes the sensitivity of the Muon Standalone + Vertex (ORCA L2) p_t^{-1} resolutions for low p_t muons ($p_t \leq 50$ GeV) to the random CSC misalignments introduced as defined.

Table 1 shows the sensitivity of the reconstructed p_t^{-1} resolutions increases in regions of high $|\eta|$ and for high muon p_t. The one exception to this trend appears at $|\eta| = 1.5$, where neighboring regions of $|\eta|$ show less sensitivity to random misalignments. It is not clear why p_t resolutions should exhibit an increased sensitivity to misalignment in this region, though it lies in an area where muon trajectories just miss measurement by ME 1/1 and exit the central detector at the end of the solenoid.

Single Muon pt	Measurement Range	Random CSC Misalignment				
		0um	200um	500um	1mm	2mm
pt = 10 GeV	$1.3 < \eta < 1.7$	12.8%	12.8%	12.9%	13.0%	13.8%
	$1.7 < \eta < 2.3$	21.9%	21.6%	21.9%	23.8%	29.2%
pt = 20 GeV	$1.3 < \eta < 1.7$	14.8%	15.0%	15.3%	16.6%	19.7%
	$1.7 < \eta < 2.3$	23.7%	25.6%	27.0%	28.7%	37.0%
pt = 50 GeV	$1.3 < \eta < 1.7$	16.9%	18.0%	20.3%	26.6%	42.3%
	$1.7 < \eta < 2.3$	27.6%	29.2%	35.0%	46.6%	87.2%
CSC Average	$1.3 < \eta < 1.7$	14.9%	15.3%	16.2%	18.7%	25.3%
	$1.7 < \eta < 2.3$	24.4%	25.5%	28.0%	33.0%	51.1%
Endcap Average	$1.3 < \eta < 2.3$	21.2%	22.1%	24.0%	28.2%	42.5%

Table 1 : Averaged Standalone Muon System + Vertex Constraint (ORCA L2) Single Muon p_t Resolution for Random CSC Misalignment for Low p_t Muons. The measurement ranges are grouped and averaged in a manner to approximate measurements made with ME ±1/1 + ME ±234/2 ($1.3 \leq |\eta| \leq 1.7$) and ME ±1/1 + ±ME234/2 ($1.7 \leq |\eta| \leq 2.3$) for the range in momentum likely to be important in determining Trigger Performance.

Single Muon pt	Measurement Range	ME Station Misalignment 0um	1mm	2mm	3mm
pt = 10 GeV	$1.3 < \eta < 1.7$	12.8%	13.0%	13.5%	14.3%
	$1.7 < \eta < 2.3$	21.9%	26.1%	35.9%	46.5%
pt = 20 GeV	$1.3 < \eta < 1.7$	14.8%	15.8%	17.0%	19.9%
	$1.7 < \eta < 2.3$	23.7%	24.9%	39.7%	52.5%
pt = 50 GeV	$1.3 < \eta < 1.7$	16.9%	33.1%	64.5%	103.5%
	$1.7 < \eta < 2.3$	27.6%	98.8%	139.4%	147.7%
CSC Average	$1.3 < \eta < 1.7$	14.9%	20.6%	31.7%	45.9%
	$1.7 < \eta < 2.3$	24.4%	49.9%	71.7%	82.2%
Endcap Average	$1.3 < \eta < 2.3$	21.2%	37.7%	75.2%	103.8%

Table 2 : Averaged Standalone Muon System + Vertex Constraint (ORCA L2) Single Muon p_t Resolution for ME Station Misalignment for Low p_t Muons. The measurement ranges are grouped and averaged in a manner to approximate measurements made with ME 1/1 + ME234/2 ($1.3 \le |\eta| \le 1.7$) and ME 1/1 + ME234/2 ($1.7 \le |\eta| \le 2.3$) for the range in momentum likely to be important in determining Trigger Performance.

A complete study of the trigger rates and threshold in the Endcap Muon System should ultimately be made with additional ORCA simulations of minimum bias events and special trigger simulation software. Such studies require large amounts of computing time and data storage and go beyond the scope of this study. However, the 'Endcap Average' CSC resolutions in Table 1 and 2 are comparable to previous work with CMSIM which characterized the Endcap Muon Trigger Rate as a function of CSC resolution, where the performance of the Standalone Muon System was described as having an average resolution across the entire Endcap. The results of these studies [5] are shown in Figure 3 with the single muon p_t threshold which must be imposed to meet the proposed 3kHz Trigger Rate budget for the Endcap Muon System overlaid. Figure 3 indicates that degrading the average CSC chamber single muon p_t resolution from 30% to 40% will force the inclusive muon trigger p_t threshold from 22 GeV to 105 GeV in order to maintain the 3 kHz Trigger Rate. Restricting the single muon p_t resolution to less than 30% implies that the location of individual CSC chambers must be known within ±1mm and that ME Station motions must be monitored to better than ±1mm . Simulations of the proposed EMU alignment scheme indicate that the knowledge of the ME disks and CSC chambers along monitoring lines can be made to approximately 200μm.

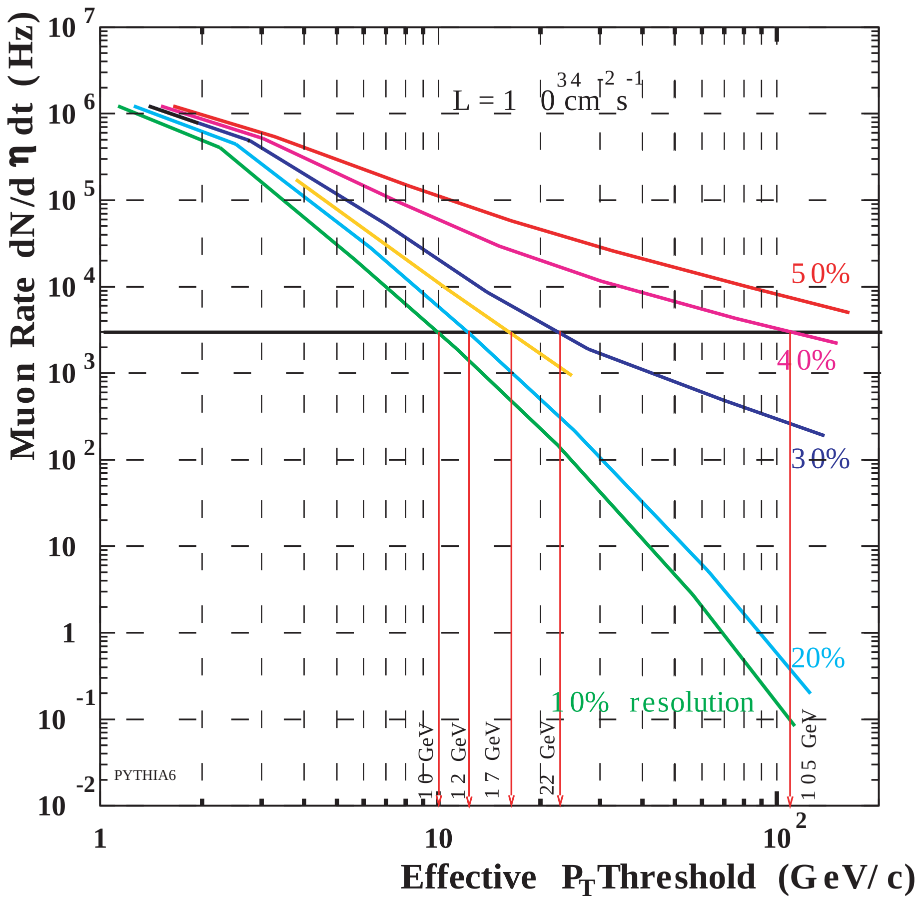

Figure 5: Inclusive Endcap Muon Trigger Rates For CSC Chambers with Various Resolutions as a Function of Threshold p_t. The red arrows indicate the intersection of each curve with the budgeted 3kHz Trigger Rate in the Endcap and is labeled with the required p_t threshold required to meet it [7].

5. Discussion of Results

The physics simulations conducted in ORCA suggest that the knowledge of CSC chamber locations in the CMS RΦ plane within ±1mm is adequate for the p_t reconstruction and inclusive trigger of single muon events in the Endcap Muon System. The uncertainty in CSC chamber locations along the EMU Alignment System SLM lines in CMS RΦ has been estimated as ≤ 200-250μm on ME ±234 and < 150μm for ME ±1/2 CSC chambers [3,8]. The alignment of ME ±1/1 chambers along LINK laser lines is estimated as ≈150μm. The simulations suggest that the estimations of off-SLM CSC chambers must be made on the order of ±1 mm to accommodate the desired Level 1 Inclusive Single Muon Trigger Rate of 3kHz. Regardless of the uncertainties in off-SLM chamber positions, 200-250μm definition of ME Station positions along the CMS X/Y axes by the EMU Alignment System has been shown to restrict potentially serious gross uncertainties in ME Station positioning (i.e. shifts in the YE Iron Disks) which, in the extreme case, could seriously impede the determination of muon p_t and trigger selection.

ORCA simulation studies incorporating the misalignment of CSC chambers did not consider the effects of minimum bias or pile-up events in p_t reconstruction nor the impact of misalignment on the reconstruction of di-muon topologies. Additional studies on the impact of misalignment on Global Muon Trigger Rates using ORCA are recommended, as CSC chamber misalignments had the largest impact on the Standalone Muon System performance, which uses a reconstruction method similar to that employed by the CMS Level 1 Triggering Scheme.

References

[1] ORCA CMS OO Reconstruction, http://cmsdoc.cern.ch/orca/

[2] CMS collaboration. The Muon Project Technical Design Report, CERN/LHCC 97-32, 1997

[3] R. Lee. Simulation and Study of the CMS Endcap Alignment Scheme. PhD Thesis, Purdue University, 2002.

[4] http://home.fnal.gov/~maeshima/alignment/outline/outline.html

[5] D. Eartly, R. Lee, K. Maeshima. ISR 2000 EMU Alignment Test Results Summary. CMS IN-2002/004.

[6] Private conversation with Sergei Lusin, David Eartly, April 2002.

[7] Figure adapted from plot supplied by D. Acosta, April 2002.

[8] D. Eartly, R. Lee, K. Maeshima. COCOA Simulation of the EMU Alignment System. Presently under review for publication as a CMS Internal Note.