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I. Belotelov, O. Buchmüller, I. González Caballero, P. Martínez, C. Martínez-Rivero, F. Matorras, A. Heister, M. Thomas, T. Lampén, V. Valuev, Simulation of Misalignment Scenarios for CMS Tracking Devices, CMS Note 2006/008, CERN, Geneva, Switzerland, 12pp.,

Available on CMS information server

CMS NOTE 2006/008

The Compact Muon Solenoid Experiment

CMS Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

January 23, 2006

Simulation of Misalignment Scenarios for CMS Tracking Devices

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Abstract

This document describes the simulation of the misalignment scenarios for the CMS tracking devices in the framework of the CMS reconstruction package ORCA. We provide first estimates of the expected alignment uncertainties at different stages of the CMS operation, which can be used to study the impact of misalignment on the tracking performance. A few examples of this impact of misalignment on the tracking performance are presented.

1 Introduction

The limited knowledge about the exact positions and orientations of the silicon sensors in the CMS Tracker is one of the largest potential sources for tracking uncertainties. Similarly, the alignment precision of the Muon system limits the detection of high-momentum muons. In order to study the impact of these so-called alignment uncertainties it is not only necessary to estimate realistic displacements for the individual detector elements but also to setup a software environment allowing to systematically implement these misalignment effects in the track reconstruction.

Rather than to implement the misalignment effects at the level of the detector response simulation in the OSCAR software [1], it has been decided to carry out the displacement of detector modules directly at the reconstruction level in the ORCA software [2]. At ORCA level the hits in the sensitive elements of the detectors are already produced by utilizing the perfect (not misaligned) detector geometry. Thus, a geometrical shift of the detector modules will only shift the hits but cannot, for example, remove a hit which should not be reconstructed because of the misalignment effect. However, given the mechanical placement constraints it is not expected that displacement effects can lead to such drastic results like, for instance, loosing the overlap between modules. Therefore, implementation of displacement shifts at the ORCA level is expected to describe adequately the realistic misalignment effects. The implementation of this software is based on the *Alignment Tools* described in [2] and its purpose is to shift and turn detector modules deliberately to reflect the alignment uncertainty.

In order to assess the impact of misalignment effects on the tracking it is important to develop a consistent set of displacements and rotations for all tracking devices in CMS, which mimic as close as possible the alignment uncertainties expected during the data taking. Care has been taken to ensure that the technical functionality of shifting detector components for all tracking devices – the pixel detector, the Strip Tracker and the Muon chambers (DTs and CSCs) – is warranted. In the following, the combination of this technical functionality and realistic estimates of alignment uncertainties for the individual tracking devices is referred to as the *misalignment scenario*.

Section 2 is devoted to a detailed description of different *misalignment scenarios* and their implementation in the framework of the CMS reconstruction software. Section 3 contains a few illustrations of the impact of misalignment on the tracking performance. We conclude in Section 4.

2 Definition of the misalignment scenarios

In order to study the impact of misalignment on the tracking performance it is not only necessary to provide the technical functionality of displacing the individual detector components in ORCA but also to supply realistic estimates for the expected displacements of the tracking systems with respect to their nominal locations. Given the enormous complexity of the CMS tracking devices, it is obvious that obtaining realistic estimates of uncertainties in the locations of all detector components and their evolution with time is a very challenging task. To follow the expected evolution of the performance of the different alignment procedures, we provide several scenarios. The first scenario is supposed to describe the conditions expected at the initial stage of the data taking (*First Data* scenario), while the second one addresses the alignment uncertainties expected when the full alignment of the detector is done (*Long Term* scenario). In addition, the *Survey Only* scenario is provided for the Muon system, mainly for debugging purposes. All physics studies are intended to be carried out with *First Data* or *Long Term* scenarios.

This section is devoted to the description of these scenarios. However, at this stage we would like to warn the potential user of these scenarios that the proposed alignment uncertainties are only based on the current best estimates, which will be refined (perhaps even significantly) as time evolves and can only be considered as a snapshot of our current understanding of misalignment effects.

2.1 Validity of scenarios

As for the absolute magnitude of the misalignment, the transition from one scenario to another is not clearly defined. However, we propose here a scheme based on the current knowledge. For the Tracker, it is expected that the limiting factor is the amount of integrated luminosity, whereas for the muon system the progress in the alignment depends more on the data taking time than on luminosity since it is more a matter of accumulating experience than accumulating data. The *First Data* situation should be achieved after a short time of data taking (a couple of weeks or a month), progressively reaching the *Long Term* case by the end of the 6-month period of the First Physics run. These values as well as estimates for the corresponding integrated luminosities are presented in Table 1. The expected amount of data after one month of running is about 100 pb^{-1}, and the current estimate for the integrated luminosity reached during the First Physics run is 1 fb^{-1}. This amount of integrated luminosity might turn out to be too small to fully align the Tracker, but it needs to be studied in detail.

Table 1: Validity of scenarios in time from the beginning of operation as well as in estimated integrated luminosity.

	Time	Integrated luminosity
Survey Only	0 - 1 month	0 - 100 pb^{-1}
First Data	1 month - 6 months	100 pb^{-1} - 1 fb^{-1}
Long Term	6 months - ∞	1 fb^{-1} - ∞

2.2 Survey Only scenario

The *Survey Only* scenario describes the knowledge of detector positions before any alignment information is included. Therefore, it is intended to be used mainly for the debugging of the misalignment software and other technical tasks, and not for physics studies. It is directly provided only for the muon system. For the tracker, a corresponding situation can be obtained by making some minor changes to the default configuration of the *First Data* scenario.

The initial knowledge of the geometry of the muon system will be provided by a combination of different sets of information:

- Mechanical constraints on the mounting tolerances of the chambers.
- Chamber construction information, including tolerances and quality control measurements.
- Survey measurements of chambers and of the mechanical structures on which muon chambers are mounted, performed prior to the activation of the magnetic field.
- Finite Element Analysis of the expected deformations when the field is powered on [3].

Once the magnetic field is activated, the locations of the muon chambers change because of the displacements of the iron rings and discs on which the chambers are mounted. Displacements along the Z axis of the detector, for example, are expected to be negligible for the central barrel wheel, ± 5 mm for the outer barrel wheels and ± 15 mm for the endcaps (positive shifts are for structures located at $Z < 0$; negative shifts for structures at $Z > 0$) [3]. Such movements and distortions of the discs and wheels are expected to further increase uncertainties in the location of the chambers. Table 2 gives the values of 1-sigma uncertainties in the position and orientation of the various elements of the muon system expected at this stage. These numbers include contributions expected from the displacements in X and Y, as well as the uncertainty in the Z shifts caused by the magnetic field.

Table 2: Uncertainties in the position and orientation of support structures (such as barrel wheels and endcap discs) and individual chambers after the application of the magnetic field. These numbers are used to simulate the *Survey Only* scenario for the muon system.

	Barrel		Endcap	
	Position [mm]	Orientation [mrad]	Position [mm]	Orientation [mrad]
Structures	2.5	0.25	2.5	0.25
Chambers	1	0.5	1	0.5

These uncertainties are used to simulate the misalignment of chambers in the *Survey Only* scenario. First, all chambers mounted on a given element of the support structure (i.e., the YE1 endcap disc) are shifted in X, Y and Z directions and rotated around the Z axis of the detector. The values of these displacements and rotations are sampled randomly according to the Gaussian distribution with the mean given by the average movement expected once the magnetic field is applied (non-zero only for displacements in Z) and with the RMS given in the first row of Table 2. Note that at this stage all ME2 and ME3 chambers in each endcap are displaced by the same amount since they are mounted on the same iron disc, and that displacements of ME1/1 chambers are in general different from displacements of ME1/2 and ME1/3 chambers. Next, each barrel and endcap chamber is shifted in all three directions and rotated around all three axes in the local (chamber) reference frame; the magnitudes of the displacements and rotations are chosen individually for every chamber from a Gaussian centered at zero and with a sigma given in the second row of Table 2.

2.3 First Data scenario

This scenario describes the conditions expected during the first data taking in CMS. Since it is unclear if full track-based alignment will deliver accurate and reliable information for all tracking devices at such an early stage of CMS operation, the hardware alignment system as well as the mechanical placement uncertainties will play an important role in defining the alignment uncertainties at this stage.

It is planned to align first the higher level structures (e.g., to align barrel layers as concentric cylinders). Further alignment studies are however needed to know how much integrated luminosity is needed for this purpose.

2.3.1 Tracker

Before the first data taking the alignment constraints of the Tracker are defined by the mechanical placement constraints and the information of the Laser Alignment System (LAS) [4]. The combination of these two sources typically leads to alignment uncertainties of O(100 μm) for layers, discs, or equivalent large support structures. This level of uncertainty does not jeopardize an effective execution of pattern recognition and, thus, ensures track reconstruction. While it seems clear that a few hundred pb^{-1} of data are not sufficient to fully align the strip detector with its approximately 15000 individual modules, they could be adequate to achieve a reasonable alignment of the Pixel detector. Unfortunately, a fully functioning track-based alignment algorithm which could be used to quantitatively evaluate the expected alignment uncertainties after track-based alignment is not yet implemented in ORCA. Therefore, we rely on an educated guess for the potential improvement that we can get with a few hundred pb^{-1} and a properly functioning track-based alignment. Experience from other experiments has shown that track-based alignment typically improves the mechanical placement constraints by an order of magnitude.

Therefore, whenever it is expected that there is sufficient statistics to allow a proper execution of the track based alignment we assume that this leads to an improvement of an order of magnitude, i.e., of a factor of 10, with respect to the mechanical constraints. This estimate will be updated when track based alignment becomes fully operational in ORCA.

For the *First Data* scenario we assume that the positions of strip detectors are given only by mechanical constraints and the LAS, while the Pixel detector is expected to be already aligned.

It should be noted that for this scenario we also assume that the Pixel detector is already installed. The currently preferred startup scenario without the Pixel detector cannot currently be studied because the current version of the track reconstruction in ORCA relies on the information from the Pixel. It would be desirable to include this functionality in the track reconstruction algorithms but this goes beyond the scope of this note.

The Laser Alignment System will provide accurate information about the misalignment of the Tracker Inner Barrel (TIB), the Outer Barrel (TOB) and the Tracker Endcap (TEC). It can be used to align the TEC discs with respect to each other and to align TIB and TOB as whole objects with respect to TEC. To take this information into account, we used the TIB, TOB and TEC placement uncertainties shown in Table 3 together with the formulas presented in [4] to calculate the expected accuracy of the Laser Alignment System. The Tracker Inner Discs (TID), the Pixel Barrel (TPB) and the Pixel Endcap (TPE) are out of reach of the LAS; their placement uncertainties are shown in Table 4.

Table 5 shows the mounting precisions, based on the placement uncertainties in Table 3 and 4, used for the random shifts of the modules and of their lowest-level support structure (ladders, rods, rings and petals) for various tracker parts in the *First Data* scenario. Table 6 lists the expected RMS values for Δx, Δy, Δz and R_z, which are used as input to the random number generator to produce a fixed shift or rotation of the layers and discs of the Tracker. As explained above, the numbers for the Pixel detector are best estimates, based on the assumption that a track-based alignment will reduce the alignment uncertainties given by the placement constraints (see Table 4) by an order of magnitude. The uncertainties obtained from any measurement (laser- or track-based alignment) are supposed to follow Gaussian distribution; those given only by placement constraints are assumed to follow a uniform distribution in the range of values specified.

Table 3: Placement uncertainties for laser-alignable Tracker parts before the LAS is used. The highlighted number corresponds to the more probable value.

TOB	Δ [μm]
Sensor vs. Module	$\pm$ 10
Module vs. Rod	$\pm$ 100
Rod vs. Cylinder	$\pm$ **100** - 500
Cylinder vs. Cylinder	$\pm$ 100 - **500**
TIB	
Sensor vs. Module	$\pm$ 10
Module vs. Rod	$\pm$ 200
Rod vs. Cylinder	$\pm$ 200
Cylinder vs. Cylinder	$\pm$ 100 - **500**
TEC	
Sensor vs. Module	$\pm$ 10
Module vs. Petal	$\pm$ **50** - 100
Petal vs. Disc	$\pm$ **100** - 200
Disc vs. Disc	$\pm$ 100 - **500**

Table 4: Placement uncertainties for Tracker parts for which LAS is not available. Uncertainties in 2D refer to uncertainties in the local plane, and 3D indicates that uncertainties are equal along the three axes. Errors are assumed to have a uniform distribution in the specified dimensions. Coordinates X and Y correspond to horizontal and vertical directions perpendicular to the beam, and Z is along the beam direction.

TPB	Δ [μm]
sensor within barrel module	$\pm$ 30 in 2D
module within ladder	$\pm$ 100 in 3D
ladder within one half-layer	$\pm$ 50 in 3D
half-layer within half-barrel	$\pm$ 100 in 3D
half-barrel within TPB	$\pm$ 300 in 3D
TPB within SiTK	$\pm$ 250 in X and Y $\pm$ 500 in Z
TPE	
sensor within disc blade	$\pm$ 25 in 2D
disc blade within half-disc	$\pm$ 50 in 3D
sensor within half-disc (after optical survey)	$\pm$ 25 in 3D
half-disc within discs-half-service-cylinder	$\pm$ 50 in 3D
discs-half-service-cylinder within TPE	$\pm$ 300 in 3D
TPE within SiTK	$\pm$ 500 in 3D
TID	
Sensor within TID module	$\pm$ 5 in 2D
module within ring	$\pm$ 100 in 2D $\pm$ 250 in third dimension
ring within disc	$\pm$ 300 in 3D
disc within the TID	$\pm$ 400 in 3D
TID within TIB	$\pm$ 500 in 3D

Table 5: Mounting precisions used for the *First Data* scenario (TPB and TPE already aligned with tracks).

	TPB [μm]	TIB [μm]	TOB [μm]	TPE [μm]	TID [μm]	TEC [μm]
Modules	13	200	100	2.5	105	50
Ladders/Strings/Rods/Blades/Rings/Petals	5	200	100	5	300	100

Table 6: Expected RMS values for Δx, Δy, Δz and R_z (rotation around the local axis corresponding to the beam direction) for layer/disc level structures (after Laser Alignment, if available). For the TID the range of the uniform distribution is given. Used as input for the random number generator to generate the fixed shifts and rotations in the *First Data* scenario.

	Δx [μm]	Δy [μm]	Δz [μm]	R_z [μrad]	LAS available
TPB	10	10	10	10	no
TIB	105	105	500	90	yes
TOB	67	67	500	59	yes
TPE	5	5	5	5	no
TID	±400	±400	±400	±100	no
TEC	57	57	500	46	yes

2.3.2 Muon System

The Muon Hardware Alignment System (MHAS) [5] can improve significantly the knowledge of the chamber locations with respect to that in the *Survey Only* scenario, even before the data taking starts, once the detector is closed and the structures are stabilized. However, the MHAS is not expected to reach its optimal precision from the very beginning, since this requires the full understanding of systematic errors and measurement correlations. Therefore, it is expected that for some time (see discussion in Section 2.1) the MHAS will be fully-functional (i.e., providing both local alignment of barrel and endcap detectors, and a link to relate the muon and Tracker alignment systems), but its performance will not yet reach the design level, and will be significantly worse than the nominal. The expected precision in this intermediate situation is estimated from real scale calibration tests projected to the early data taking situation and is implemented in the *First Data* scenario. Table 7 shows the expected alignment precision. The numbers in the first row ("muon to tracker") give estimates of uncertainties in the position and orientation of the muon system as a whole (given by the Link system). They are used to generate random displacements (three independent random shifts along each of the three directions) and rotations (three independent random rotations around each of the three axes). The numbers in the second row ("chambers") correspond to the alignment of individual chambers and are used to simulate additional independent displacements and rotations of every chamber, similarly to the *Survey Only* scenario.

Table 7: Uncertainties in the position and orientation of the muon system relative to the Tracker ("muon to tracker") and of individual chambers after gaining the first experience with the Muon Hardware Alignment System. These numbers are used to simulate the *First Data* scenario for the muon system.

	Barrel		Endcap	
	Position [mm]	Orientation [mrad]	Position [mm]	Orientation [mrad]
Muon to tracker	1	0.2	1	0.2
Chambers	1	0.25	1	0.5

2.4 Long Term scenario

This scenario is supposed to be utilized in order to study the impact of the expected final alignment uncertainties on the tracking performance. Both laser and track based alignment are supposed to reach their best possible accuracy in this scenario.

2.4.1 Tracker

According to the assumptions discussed in subsection 2.3.1, the uncertainties given by the mechanical constraints are decreased by an order of magnitude (divided by 10) in an attempt to describe the expected improvement obtained by track based alignment. Since measurements (reconstructed tracks) are used for the improvement, the improved uncertainties are supposed to follow Gaussian distribution. The RMS values which are used as input to this scenario are shown in Tables 8 and 9. Once a track based alignment is fully functioning in ORCA we will replace these ad hoc estimates with more refined numbers.

Table 8: Mounting precisions used for the *Long Term* scenario (track-based alignment assumed for all Tracker parts). Pixel parts are supposed to be already aligned in the *First Data* scenario.

	TPB $[\mu m]$	TIB $[\mu m]$	TOB $[\mu m]$	TPE $[\mu m]$	TID $[\mu m]$	TEC $[\mu m]$
Modules	13	20	10	2.5	10.5	5
Ladders/Strings/Rods/Blades/Rings/Petals	5	20	10	5	30	10

Table 9: Expected RMS values for Δx, Δy, Δz and R_z (rotation around the local axis corresponding to the beam direction) for layers (Barrel) and discs (Endcaps) for the *Long Term* scenario. Used as input for the Gaussian random number generator to generate the fixed shifts and rotations. Pixel parts are supposed to be already aligned in the *First Data* scenario.

	Δx $[\mu m]$	Δy $[\mu m]$	Δz $[\mu m]$	R_z $[\mu rad]$
TPB	10	10	10	10
TIB	10.5	10.5	50	9
TOB	6.7	6.7	50	5.9
TPE	5	5	5	5
TID	40	40	40	10
TEC	5.7	5.7	50	4.6

2.4.2 Muon System

Better understanding of the MHAS and the inclusion of alignment with muon tracks is expected to improve the alignment to asymptotically reach the nominal precision, approximately five times better than in the *First Data* scenario [5]. These residual uncertainties are shown in Table 10 and constitute the input to the *Long Term* scenario. As in the case of the *First Data* scenario, we simulate two types of movements: of the muon system as a whole relative to the Tracker, and of every chamber with respect to the muon system.

Table 10: Uncertainties in the position and orientation of the muon system relative to the Tracker ("muon to tracker") and of individual chambers ("chambers") expected to be reached after full alignment. Used to simulate the *Long Term* scenario for the muon system.

	Barrel		Endcap	
	Position [mm]	Orientation [mrad]	Position [mm]	Orientation [mrad]
Muon to tracker	0.2	0.04	0.2	0.04
Chambers	0.2	0.05	0.2 in X and Y, 0.4 in Z	0.1

2.5 Correlated misalignments

Correlated movements of individual detector modules are implemented in the scenarios as random movements of rod/ladder-level structures, and as random movements and rotations of the barrel/layer-level structures around the beam axis. This kind of misalignments can be caused by the initial placement uncertainties. Other correlated misalignments due to e.g., temperature variation, gravitation, humidity etc. are also possible. This kind of effects are difficult to predict, and they are not taken into account in the misalignment scenarios.

One of the most important cases which can be expected is the twist of the TOB. The TOB is supported by four separate discs, two of them in the ends and two in the middle. If these discs have different rotations with respect to the beam axis, all the corresponding TOB rods are rotated in their plane accordingly. It is estimated that the size of this effect can be as large as ± 0.2 mm at the outer radius of the TOB wheel, which corresponds to an angle of $\phi = \pm 0.17$ mrad. This effect is not taken into account in the default scenarios, but it can be simulated by enabling the appropriate options in the *.orcarc* file containing the configuration of the ORCA job.

Similar twist is possible also for the Pixel Barrel. It is expected to be in the range of $50 - 300\,\mu\mathrm{m}$ at the radius of the outermost layer (110 mm) on the whole length of the barrel (from $Z = -260$ mm to $Z = +260$ mm). This corresponds to an angle of $0.5 - 2.7$ mrad.

Even though there exist *.orcarc* cards to simulate twist-like correlated movements for the TIB, its support structure is such that it does not suffer from twist-like correlated movements.

Additional specific situations, such as local misalignment of a set of subdetectors, can be simulated with the help of various configuration parameters. The description of these options would however go beyond the scope of this note. Technical documentation of the misalignment scenarios is provided in a CMS Analysis Note, which has been made available to the CMS Community.

2.6 Alignment Position Errors

An important feature of the misalignment scenarios is the possibility to set the so-called Alignment Position Error (APE). This is a variable introduced within the `TkAlignment` and `MuonAlignment` tools for each detector module [2]. The APE characterizes the measurement uncertainty of a given detector due to misalignment. The APE is combined with the spatial resolution of the device giving the total error on the position of hits belonging to these detector modules.

The APE can be set by the user. Its value has a direct impact on the performance of the track reconstruction [6]:

- Efficiency: The bigger the APE is, the higher the probability to associate misaligned hits to a given track seed or to match hits in two misaligned subdetectors to one track. With the APE large enough one should almost always get the maximal track reconstruction efficiency.
- Fake rate: Setting the APE to a large value makes it more likely that a track is built out of uncorrelated hits, thus dramatically increasing the rate of fake tracks and, as a side effect, also increasing the amount of required computing time for the reconstruction.
- Momentum resolution: The p_{T} resolution is affected by the APE in three ways:
  1. The probability of including uncorrelated hits into a track is increased with higher APE settings. This leads to p_{T} bias.
  2. Even when a track includes only correctly associated hits, their relative weight in the fit can be distorted by the misalignment, assigning larger weight than it should. The inclusion of an appropriate APE reduces this bias, by a more realistic weight assignment, having as a consequence a global improvement in the momentum resolution.
  3. It can also alter the fit iteration, through the artificial decrease of the χ^2, stopping the procedure before the real minimum is reached.

  Therefore for the exact determination of the track parameters, an APE as close as possible to the RMS of the misalignment is preferred.

The optimal value for the APE should therefore be as high as needed to ensure sufficient reconstruction efficiency, but as low as possible to get the smallest fake rate and best momentum resolution. This optimal value can be found by optimizing efficiency versus resolution and fake rate, but this has not been done yet. Therefore at the moment we set the APE to be approximately equal to the width of the combined deformation distribution applied to a given detector module, which seems to be reasonable because, as we show below, efficiency gets recovered in the Tracker and p_{T} resolution improves in the Muon System.

The user can easily change this by using the scaling factor for the APE. Except for cases when the user has studied in detail the impact of the APE, we suggest to use the default setting provided by a given scenario. It is supposed to resemble the alignment uncertainties expected during the corresponding data taking period and, thus, should compensate on average the impact of misalignment on the tracking efficiency.

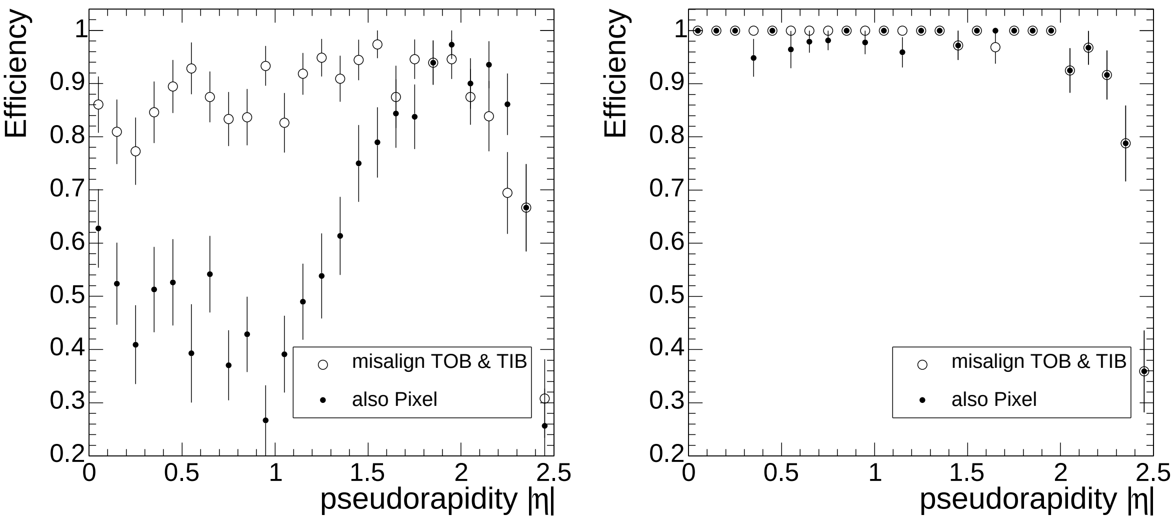

Figure 1: Track-finding efficiency as a function of the pseudorapidity η, for misaligned TOB and TIB (open circles), and for misaligned TOB, TIB and the Pixel detector (dark circles). Left: the APE is not taken into account; Right: the APE is taken into account.

Figure 1 shows the track-finding efficiency of the tracker as a function of the pseudorapidity, first when only TOB and TIB are misaligned (open circles), and then in case in which Pixel ladders are misaligned in addition to TOB and TIB (dark circles). All misaligned detectors are moved randomly with an RMS of 10 μm, and single muons are used. The Alignment Position Error is not set in the reconstruction algorithm used for the left plot. As a result, the track-finding efficiency is low even with the ideally-aligned Pixel detector, when only TIB and TOB are misaligned, and drops considerably if the Pixel detector is also misaligned. In the right plot the Alignment Position Error is taken correctly into account. In this case full efficiency is recovered, since the hit search window is broadened enough.

Figure 2 shows the impact of the muon APEs on the efficiency and p_{T} resolution for the full (the Tracker and Muon detectors) reconstruction of the muons. Here we are in a situation different from that in the Tracker: muon APEs hardly affect the efficiency, but significantly improve the muon momentum resolution.

More detailed discussion of the Alignment Position Errors can be found in the PhD Thesis by S. König [6].

3 Physics examples

The simulation of the Tracker and muon misalignment described in the previous sections was studied with a number of different simulated datasets. Variables like reconstruction efficiency, number of associated hits, momentum and angular resolutions were used to check that the implemented Tracker and Muon system misalignment scenarios work as expected and to illustrate possible effects of misalignment on track reconstruction. We show here a few examples obtained with the samples of single muons generated with the transverse momenta, p_{T}, of 100 GeV and 1 TeV and at different values of pseudorapidity, η. Figures 3, 4 and 5 show η dependence of the $1/p_{\mathrm{T}}$ resolution obtained by the full track reconstruction (including the Tracker and the Muon System) for three cases: with the nominal detector geometry, with the detector misaligned according to the *First Data* scenario, and with the detector misaligned according to the *Long Term* scenario. In Fig. 3, only the Tracker was misaligned (the nominal geometry of the muon system was used in all three cases); Fig. 4 shows the effect of misaligning the muon system alone (the nominal geometry of the Tracker was used); finally, the effect of misaligning both the Tracker and the muon system is illustrated in Fig. 5. As expected, misalignment of the muon system plays an important role only for high-p_{T} muons. We expect p_{T} resolution to be rather poor at the beginning of the data taking (*First Data* scenario) and improve substantially with time (*Long Term* scenario).

Other examples of first studies of the impact of misalignment on the physics results can be found in [7] and [8].

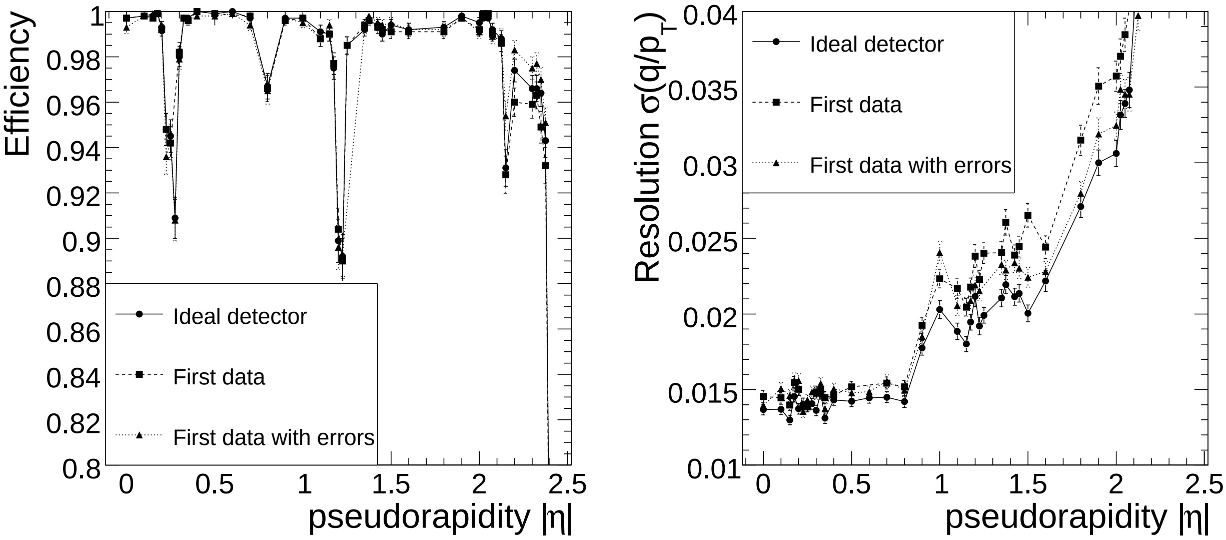

Figure 2: Muon reconstruction efficiency (left) and $1/p_{\mathrm{T}}$ resolution (right) as a function of the pseudorapidity η for muons with the generated p_{T} of 100 GeV, for the ideal alignment and for the *First Data* scenario with and without the muon APE. The nominal geometry of the tracker is used in all three cases.

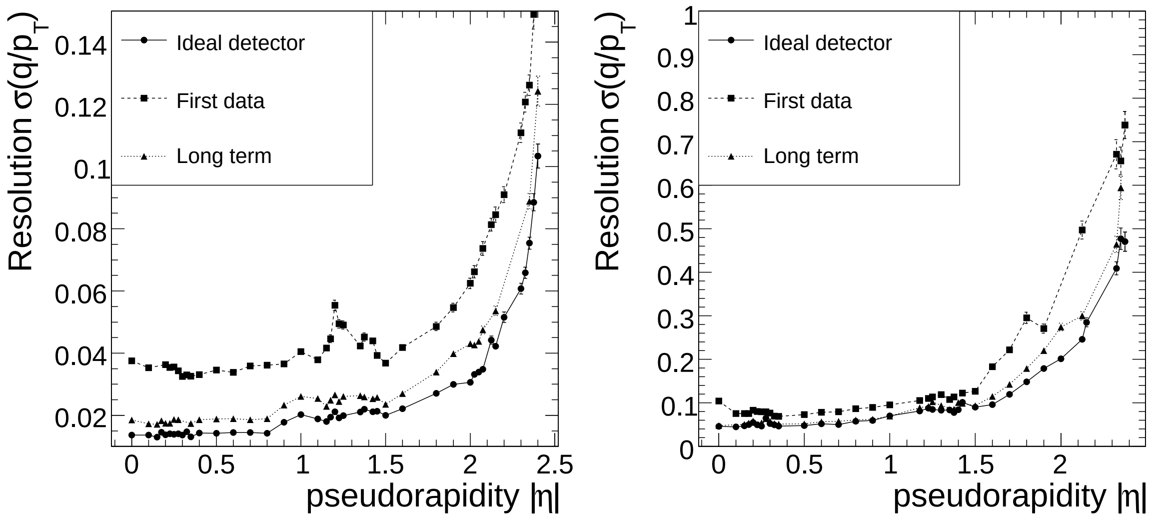

Figure 3: Muon $1/p_{\mathrm{T}}$ resolution (sigma of a Gaussian fit) as a function of η for the ideal alignment and for the *First Data* and *Long Term* Tracker misalignment scenarios, for $p_{\mathrm{T}}^{\mathrm{gen}} = 100$ GeV (left) and $p_{\mathrm{T}}^{\mathrm{gen}} = 1$ TeV (right).

4 Summary

The first realistic misalignment scenarios have been developed. These scenarios introduce misalignments for the tracking devices of the CMS (the Tracker and the Muon system). Misalignment is carried out at the reconstruction level (in the ORCA software). This makes possible to use the existing data samples for various misalignment studies.

The *First Data* scenario corresponds to the situation when the Pixel detector can already be aligned with tracks and when the first optical information is available for the muon system. The *Long Term* scenario corresponds to the situation of an established running. Details of the misalignment can be easily adjusted, if necessary.

Misalignment scenarios utilize the mounting precisions of various parts of the CMS as well as the estimated accuracies after the use of optical alignment systems and track based alignment. These numbers are so far rough estimates and will be updated once better estimates become available from alignment studies.

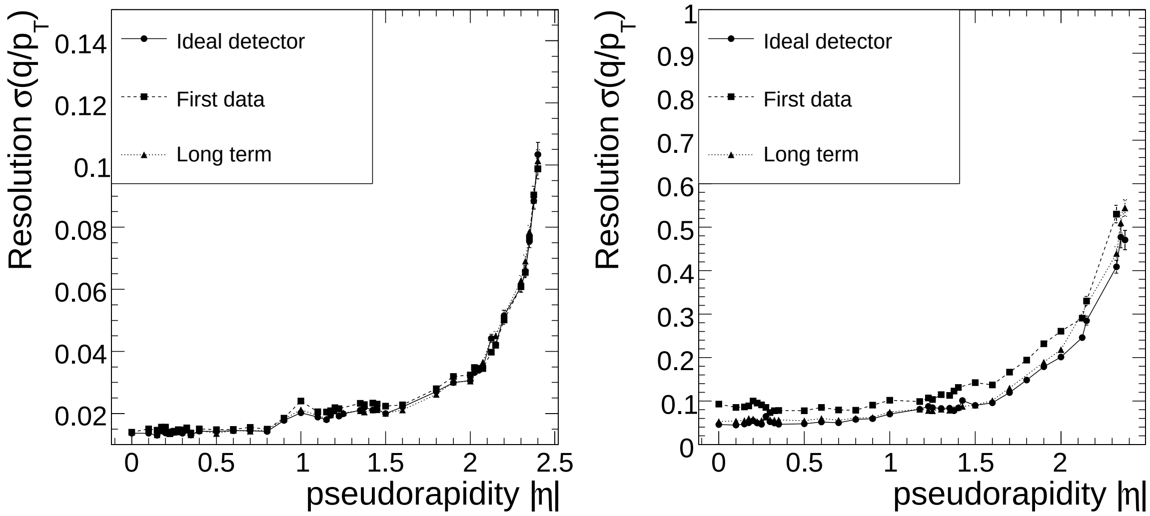

Figure 4: Muon $1/p_{\mathrm{T}}$ resolution (sigma of a Gaussian fit) as a function of η for the ideal alignment and for the *First Data* and *Long Term* muon misalignment scenarios, for $p_{\mathrm{T}}^{\mathrm{gen}} = 100$ GeV (left) and $p_{\mathrm{T}}^{\mathrm{gen}} = 1$ TeV (right).

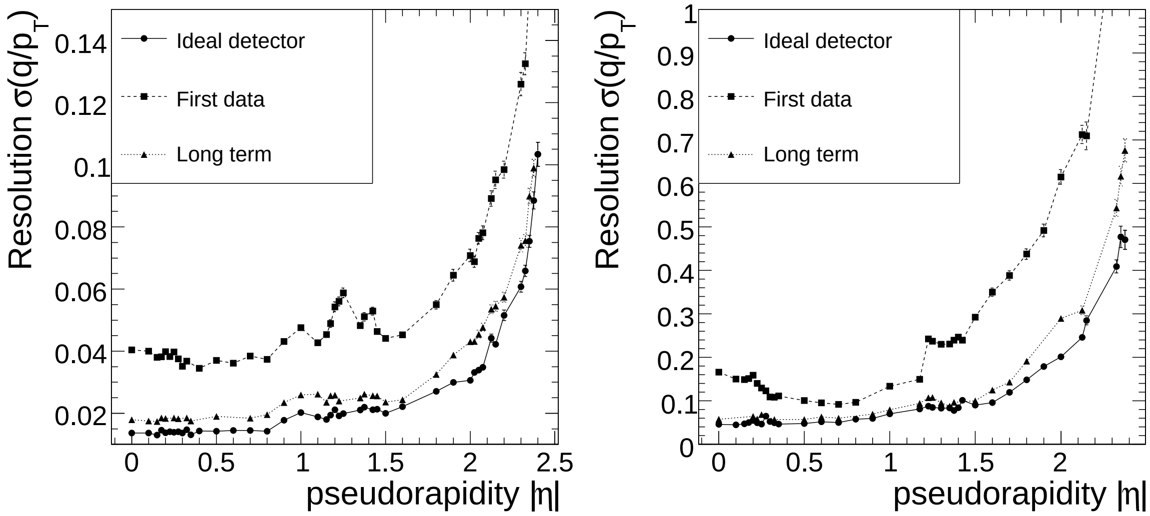

Figure 5: Muon $1/p_{\mathrm{T}}$ resolution (sigma of a Gaussian fit) as a function of η for the ideal alignment and for the *First Data* and *Long Term* scenarios applied simultaneously to the Tracker and to the muon detector, for $p_{\mathrm{T}}^{\mathrm{gen}} = 100$ GeV (left) and $p_{\mathrm{T}}^{\mathrm{gen}} = 1$ TeV (right).

Acknowledgements

We thank Helge Voss and Britta Schwering for implementing the original `TkAlignment` tools, Wolfgang Adam, Tim Cox and Teddy Todorov for their help in various ORCA-related issues, as well as Filippo Bosi, Kurt Gabathuler, Bruno Gobbi, Roland Horisberger, Danek Kotlinski, Maurizio Massa, Antti Onnela and Albert de Roeck for illuminating discussions.

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