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Comprehensive Set of Misalignment Scenarios for the CMS Tracker

T. Lampén, N. de Filippis, F.-P. Schilling, A. Schmidt, M. Weber

Abstract

New misalignment scenarios are implemented for the CMS Tracker as a set of working hypotheses for simulation studies. Educated guesses of random misalignments are applied to various geometrical structures. χ^2-invariant deformations are not simulated. The new scenarios are called as SurveyLASOnly, SurveyLASCosmics, $10\,\mathrm{pb}^{-1}$, $100\,\mathrm{pb}^{-1}$ and $1000\,\mathrm{pb}^{-1}$ scenarios, and they correspond approximately to the respective situation. Details of the scenarios and a list of possible future improvements are discussed. The impact on track reconstruction performance and Z mass reconstruction are also discussed.

1 Introduction

The limited knowledge about the exact position and orientation of silicon sensors in the CMS tracker (illustrated in Fig. 1) is one of the largest sources for tracking uncertainties. To take this into account in the physics analyses, a new set of misalignment scenarios has been implemented for the CMS Tracker. These scenarios serve as a tool to estimate systematic errors and resolution degradations caused by misalignment. Although this set is constructed with the best available estimates of the position uncertainties, it is a set of working hypotheses, which might turn out to be different from the real situation.

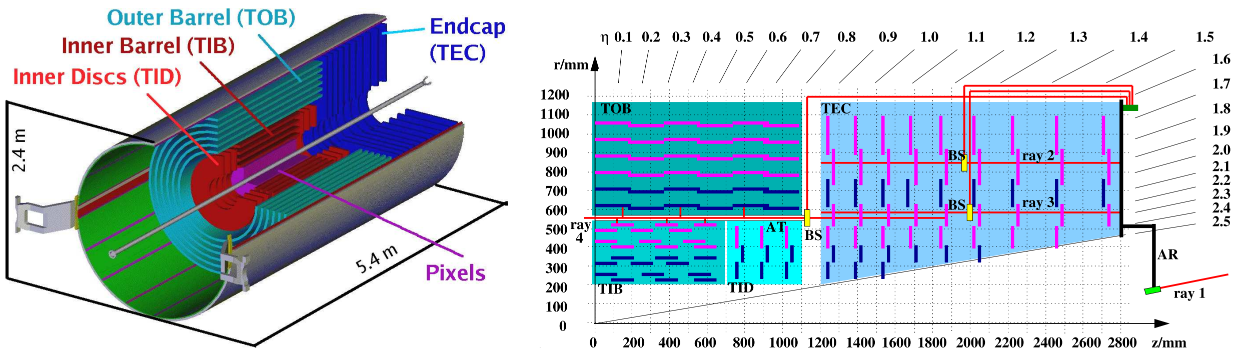

Figure 1: Left: Illustration of the CMS tracker. The beam line, colored in gray, is shown in the middle. Right: Cross-section of one quarter of the CMS tracker. Double-sided modules are colored in dark blue, and single-sided modules in magenta. Rays of the Laser Alignment System are also shown as well as the Laser beam splitters (BS). The CMS coordinate system is such that the origin is in the nominal interaction point, y is vertically upward, x is radially toward to center of the LHC ring, and thus z coincides with the beam line and points towards the Jura mountains. The azimuthal angle ϕ is measured from the x-axis in the x-y plane, and the azimuthal coordinate is marked as r-ϕ. The polar angle θ is measured from the z-axis [3]. The pseudorapidity $\eta = -\log\tan\theta/2$ is also shown.

In 2005, two predefined easy-to-use misalignment scenarios (*First Data* and *Long Term* scenarios) were developed in the reconstruction software framework ORCA [1] on the basis of the software package *Alignment Tools*. This package allowed to move and rotate detector modules and larger support structures and made possible to introduce artificial misalignment to the CMS geometry. These two misalignment scenarios are described in Ref. [2].

In 2006, with the change from ORCA to the new CMSSW framework [3], the alignment tools as well as the scenarios were ported. In early 2007, when the CMS tracker assembly was finished and a period of intensive testing started, new results that allowed to estimate better alignment uncertainties became available. These included results from tests performed during integration, survey measurements taken at different stages during tracker assembly, and Monte Carlo studies on track based alignment. Most of these results were rendering the line of argumentation behind the old scenarios obsolete.

New up-to-date scenarios were needed for start-up LHC physics studies to get the feel of improvements in alignment with increasing integrated luminosity. Therefore, scenarios corresponding to approximately 10, 100 and 1000 pb^{-1} of collected data were implemented. Then, two additional scenarios, the *SurveyLASOnly* and *SurveyLASCosmics* scenarios, were developed to estimate alignment status before proton collisions. These scenarios were needed for the early performance studies of CMS, and also for the Computing, Software and Analysis Challenge of 2007 (CSA07).

In section 2, the positional uncertainties after assembly and survey measurements are presented. Results from Laser Alignment System (LAS) are given in section 3, and results from track based alignment studies in section 4. The new scenarios are presented in section 5. In section 6 the impact on physics performance is illustrated, and in section 7 a list of possible future improvements is given.

It should be noted that although these scenarios are based on better knowledge than those from 2005, they remain educated guesses because many systematic studies of alignment precision have either not yet been finalized or even not yet started. In the end of this note, a list of ideas for further development of the scenarios is given, which also gives insight to the approximations used. The user should especially note that new scenarios do not simulate the χ^2-invariant deformations, which will be an important part of residual misalignments after track based alignment.

2 Assembly precision and survey data

During CMS Tracker construction, the accuracy of assembly has been verified with help of precise measurements, e. g. with

- coordinate measuring machines with a typical accuracy of few $\mu\mathrm{m}$ up to few tens of $\mu\mathrm{m}$, depending on the size of the object,
- photogrammetry, which gives a precision of 80–150 $\mu\mathrm{m}$, and
- theodolites, with which one can achieve a precision of about 300 $\mu\mathrm{m}$.

Survey measurements can be used in two ways to improve alignment; firstly, they can be used to correct the initial geometry, and secondly, they can be used as track-like measurements in track based alignment algorithms.

Corrections to the initial geometry with survey data improve the track reconstruction, and provide starting point with all available information for track based alignment algorithms.

Survey data can be used as track-like measurements in alignment algorithms, if the covariance matrix of the survey measurements is known (at least the diagonal elements). This improves convergence of the alignment algorithms, especially if only a small number of tracks is available for the object under consideration, and the statistical weight of survey dominates the weight of tracks.

Precaution has to be taken with survey measurements, since they naturally have been obtained when the surveyed objects were accessible. Later stages of Tracker assembly may thus have affected alignment and introduced some bias, which also needs to be estimated. In addition, survey measurements haven't been carried out for all levels of hierarchy (the hierarchical structure of tracker as implemented in *Alignment Tools* [1)] is illustrated in Fig. 2).

When using survey measurements in the alignment procedure, time-dependent effects need also to be taken into account, which can move modules from their surveyed position. This can be taken into account by modifying the survey error appropriately, which needs careful evaluation.

In the following two sections, accuracy of assembly and survey measurements is discussed for the Pixel and Strip Tracker.

2.1 Pixel detector

Since the pixel detector is not measured by the Laser Alignment System (LAS) [4], survey measurements are the only measurements available before track-based alignment, and therefore their resolution is taken as the RMS for the initial misalignments.

Survey measurements have been carried out for the Tracker Pixel Endcap (TPE). Their results can be used to correct the ideal geometry, and their precision can be used as an estimate for the remaining uncertainties. These estimates are presented in Table 1 (from Ref. [5]). Definitions of the six alignment parameters for a rigid object are illustrated in Fig. 3.

Survey measurements are also being carried out for the Tracker Pixel Barrel (TPB). The precision of these measurements is of the order of $10\,\mu\mathrm{m}$ in 2D [6]. Preliminary estimates suggest that the remaining uncertainties on individual sensor positions is $20\,\mu\mathrm{m}$ (RMS of a Gaussian distribution) instead of the previous estimate of $60\,\mu\mathrm{m}$, but for the higher-level structures there are no significant differences. An update of this value should be considered once the survey measurements are completed and analyzed. In the current scenarios, misalignments are based on the more conservative estimates used already in the previous scenarios (Table 4 of Ref. [2]).

2.2 Strip detector

Table 2 lists the estimated or measured assembly precision of components of each subdetector of the Silicon Strip Tracker (from [7]). Assembly precision is expressed with respect to the next level in the tracker hierarchy.

Values of Table 2 represent the RMS of the distribution of the difference between the nominal value, as obtained from the engineering drawings, and the (possibly) measured value, hence representing the measured and estimated

[1)] Here the updated tracker hierarchy and naming convention of CMSSW_1_7_0 is used. Unless otherwise stated, this naming convention is also used elsewhere in the note.

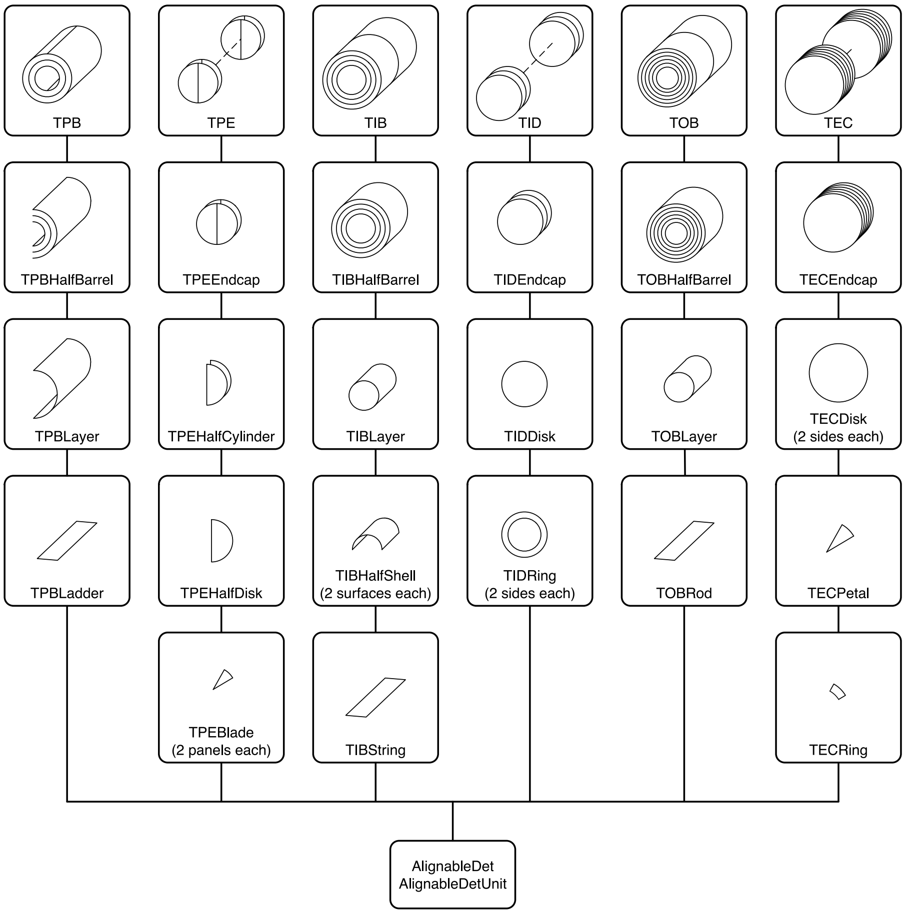

Figure 2: Illustration of the hierarchical structure of Tracker as implemented in the alignment software. Some of the implemented structures have no corresponding mechanical structure (for instance *TOBLayers*, *TIBStrings* and *TECRings*).

Table 1: Precision of TPE survey measurements as from Ref. [5] for translations (u, v and w) and rotations (α, β and γ). A Gaussian distribution (1D) with the stated standard deviation is applied for all three coordinates.

TPE structure	translation [μm]	rotation in γ [μrad]
Sensor	5	100
Panel	10	200
Blade	10	200
Halfdisc	50	1000
Halfcylinder	50	1000

assembly precisions of different components. Those values thus state how precisely the Tracker has been built compared to the specification.

Additional alignment precision can be obtained from survey measurements. However, survey measurements have not yet been fully assessed, and as a consequence we will use values of Table 2 as a basis for the misalignment scenarios.

3 Estimated Accuracy of Laser Alignment System

Some of the rays and beam splitters of the Laser Alignment System (LAS) can be seen in Fig. 1. LAS measures precisely the r-ϕ position of the subdetectors Tracker Inner Barrel (TIB), Tracker Outer Barrel (TOB), and Tracker Endcap (TEC) with respect to each other, and the relative orientation of their symmetry axes. Additionally, due to the high redundancy of measurements within the TECs, the LAS can determine the position of TEC disks in the

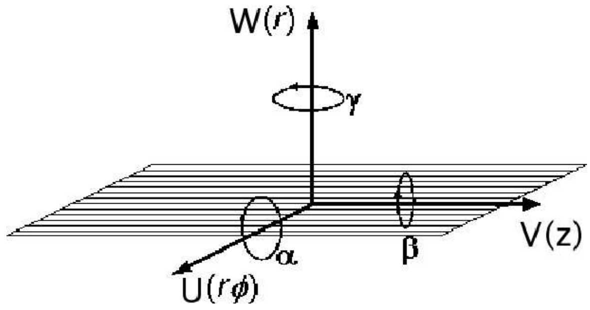

Figure 3: Schematic illustration of the alignment parameters: translations u, v and w and the rotation around the respective axes α, β and γ. The same local coordinate system is also applied for pixel modules. For barrel modules, u corresponds to the r-ϕ direction and v corresponds to z (the direction of the beam line). For endcap modules, u corresponds to r-ϕ and v approximately to r.

Table 2: Measured and estimated assembly precision (RMS, in $\mu\mathrm{m}$) of tracker components (from Ref. [7]). Values are given with respect to the next hierarchy, e. g. the position accuracy of sensors in modules is 10 $\mu\mathrm{m}$.

TIB		TID		TOB		TEC	
Sensor		Sensor		Sensor		Sensor	
	10		10		10		10
Module		Module		Module		Module	
	180		54		30		20
Shell		Ring		Rod		Petal	
	450		185		100		70
Cylinder		Disc		Wheel		Disc	
	750		350		140 ($r\phi$), 500 (z)		150
Tube		Cylinder		Tube		TEC	
			450		1000		600
		Tube		CMS		Tube	

global r-ϕ plane. Neither the pixel detector nor the Tracker Inner Detector (TID) are measured with the LAS. The LAS also cannot determine the position along the laser beam direction, i. e. it is not sensitive along the global CMS z coordinate (direction of the LHC beam). [4]

A muon-tracker link, consisting of six laser beams equally distributed in ϕ and originating at the outside of each Tracker Endcap, pointing to position sensitive devices in the muon system, allows to establish the relative position of tracker and muon system, defining the overall CMS coordinate system used in reconstruction [8, 9]. The accuracy of this link has been estimated in simulation studies and static laboratory tests to be about $200\,\mu\mathrm{m}$ and about 40 μrad [10].

The performance of the LAS has been evaluated during the integration of one half of the TEC. For the internal TEC alignment, results from the LAS, cosmic measurements and metrology agree within $60\,\mu\mathrm{m}$ for translations and 80 μrad for rotations. These values can be taken as upper limits for the LAS precision [11]. For the relative alignment of TIB, TOB and TEC with the LAS, even slightly better precision can be expected thanks to a larger number of LAS measurements.

Given the precision achievable with the LAS, we expect that the uncertainties on the placements of some components can be decreased with respect to the ones shown in Table 2, only for the TIB, TOB and TEC, as follows:

- for TIB, survey of cylinders was done with respect to the tube, and no position of the TIB half-barrels was extracted. LAS observes the position of 48 outermost modules in TIB layer four with respect to TEC and TOB. Due to the difficulty of a technical implementation of increased knowledge of just one layer, the conservative approach was chosen to have the TIB half-barrel positions known perfectly and to use the survey measurement precision as relative precision of cylinders. To incorporate LAS measurements, the rotational uncertainty of TIB is set to $80\,\mu$rad around ϕ as surveyed by LAS.
- for TOB, the value "Wheel-Tube" is improved in r-ϕ from $140\,\mu\mathrm{m}$ to $60\,\mu\mathrm{m}$, and the rotational uncertainty is set by the LAS to $80\,\mu$rad around ϕ. The value "Tube-CMS" is improved in r-ϕ from $1000\,\mu\mathrm{m}$ to $200\,\mu\mathrm{m}$ and set in ϕ to $40\,\mu$rad thanks to the muon link.
- for TEC, values of "Disc-TEC" and "TEC-Tube" are improved from $600\,\mu\mathrm{m}$ to $60\,\mu\mathrm{m}$ in r-ϕ. The rotational

uncertainty is set to $80\,\mu$rad.

4 Estimated Accuracy of Track Based Alignment

In contrast to the situation described in the previous note [2], preliminary results from alignment studies have been obtained in the meantime. The studies have been performed with either Monte Carlo or cosmic muon data. Since the obtained results do not contain a full systematic evaluation, they can only be taken as an estimate of the final achievable alignment precision. The presented Monte Carlo studies are optimistic in the sense that they include only alignment but otherwise completely rely on an idealized detector (perfect calibration, perfect magnetic field, no time-dependent effects, planar strip sensors, ...). Therefore when estimating the truly achievable precision, the RMS needs to be increased by a guessed factor to take into account those systematic effects.

Of course, future improvements in the alignment algorithms and refurbishment in the analysis can lead to more precise alignment, but estimating this development is out of the scope of this note.

4.1 Measurement with cosmic muons in the TEC

Tracks of cosmic muons have been measured with one horizontally placed half of the TEC during its integration. With about 1500 hits per petal, an alignment precision better than $80\,\mu\mathrm{m}$ could be reached in r-ϕ.

The initial assembly precision of TEC petals is $70\,\mu\mathrm{m}$, already better than reached by track based alignment during TEC integration. In addition, the TEC will be installed in CMS in a vertical position underground, which makes alignment with cosmic muons more challenging. Therefore we do not assume that the alignment of endcaps can be improved with cosmic muons.

4.2 Measurement with cosmic muons in the TOB Cosmic Rack

A special setup dubbed “TOB Cosmic Rack” [12] has been conceived to test alignment in a horizontal TOB-like setup. First, preliminary results indicate that by using about 2500 hits per module, a precision of 10–50 $\mu\mathrm{m}$ in the precise r-ϕ coordinate can be obtained [13]. The $10\,\mu\mathrm{m}$ precision corresponds to the situation when only the most sensitive parameter in r-ϕ is aligned. In addition, a study on aligning the TOB rods has been performed. By using 15000 hits per rod, a precision of $5\,\mu\mathrm{m}$ in r-ϕ can be reached. In the r coordinate, a precision of $70\,\mu\mathrm{m}$ has been measured. The two angles α and β have a precision of roughly 30 μrad, which corresponds to a maximum tilt of $33\,\mu\mathrm{m}$ over the length of approximately 1.1 m of a TOB rod.

When applying to CMS the results based on studies with the cosmic rack, one has to keep in mind that for the barrel, cosmic muons will only be useful mainly for the top and bottom parts, and therefore the average precision achievable with cosmic muons will be smaller.

4.3 Alignment study with cosmic and high $p_\mathrm{T}$muons corresponding to 500 pb^{-1}

The CMS Tracker has been aligned in a Monte Carlo study, using simulated data that corresponds to 500 pb^{-1} [14]. This data consists of single muons from 1.5 million $Z \to \mu^+\mu^-$ events (to mimic W events), 500 000 mass- and vertex-constrained $Z \to \mu^+\mu^-$ events and 25 000 cosmic muons. For cosmic muons a constraint of $p > 50\,$GeV is applied. The initial misalignments in this study correspond to the *First Data* scenario from Ref. [2]. The alignment was performed in the u, w and γ coordinates for strip modules that only measure one direction, additionally v for modules measuring two dimensions. In the latter case, “module” refers to the entity of two precisely back-to-back mounted single-sided strip detectors with a stereo angle of $100\,$mrad. Table 3 lists the achieved precision on the global[2)] module coordinates. Since no misalignment in α and β was applied, the results present a lower limit for a more realistic alignment study with misalignment in all three angles.

4.4 Alignment study with cosmic and high $p_\mathrm{T}$muons corresponding to 100 pb^{-1}

A study similar to that mentioned in the previous section has been performed, but for data that can be expected after 100 pb^{-1} of integrated luminosity [15]. This includes 500k single muons (without vertex or mass constraint)

[2)] “Global” in this sense means that the RMS of the absolute difference of module positions in the global CMS frame is computed. Therefore this includes the remaining misalignment in the higher levels of the hierarchy.

Table 3: RMS values of global module positions for the different subdetectors and coordinates in a study corresponding to 500 pb^{-1}.

	r-ϕ [μm]	r [μm]	z [μm]
Pixel Barrel	1.2	2.8	4.0
Pixel Endcap	2.5	4.9	5.4
TIB	5.9	39.5	23.4
TID	17.5	32.0	60.2
TOB	12.5	41.7	29.6
TEC	26.2	32.9	35.9

Table 4: RMS values of global module positions for the different subdetectors and coordinates in a study corresponding to 100 pb^{-1}.

	r-ϕ [μm]	r [μm]	z [μm]
Pixel Barrel	7.2	38	45
Pixel Endcap	23.8	40	55
TIB	19.3	63	57
TID	37.5	32	77
TOB	27.3	55	48
TEC	40.0	55	71

and 25k cosmic muons with $p > 50$ GeV. Again, the *First Data* scenario has been used as an estimate for the misalignments, but in order to mimic startup conditions, an initial large misalignment of the pixel detector has been applied in addition. Table 4 lists the precision that has been reached in this study.

5 Misalignment scenarios

5.1 Installation uncertainties

All installation uncertainties are enumerated in Table 5, together with the corresponding values implemented in the *SurveyLASOnly* scenario. Historically, the naming of the hierarchy levels is different in the software from the survey experts' notation. Also, the software implementation of the tracker substructure hierarchy contains for the TOB one additional level, that is physically not existing (the *TOBLayers*). On the left-hand side of Table 5, the survey naming scheme is being used, on the right-hand side the naming in the software.

Unless otherwise stated, misalignments are isotropic. The Gaussian 1D-distributions are applied separately for all three dimensions x, y and z, and the result is a 3D-Gaussian in (x, y, z). [3)]

5.2 New misalignment scenarios

Different misalignment scenarios were implemented by using as basis the values from Table 5. Due to the fact that only preliminary results were presented in sections 3 and 4, the numbers which enter the different scenarios from these sections still have large inherent uncertainties. Many of the necessary systematic alignment studies are still to be done.

Idea of the scenarios is to reflect the residual misalignments in the following situations (the order of magnitude of the integrated luminosity is given, not the exact amount):

- assembly, survey ans LAS (the *SurveyLASOnly* scenario)
- alignment studies with cosmic muons (the *SurveyLASCosmics* scenario)
- track based alignment with collision events with high cross section: minimum bias events, low mass resonances etc. (the *10 pb^{-1}* scenario)

3) The resulting 3D-Gaussian appears a bit wider than individual 1D-distributions. If all three Gaussian 1D-distributions have a standard deviation σ_{1D}, the distance $r = \sqrt{x^2 + y^2 + z^2}$ corresponding to the 68% confidence interval of the 3D-Gaussian is $\sim 1.88\ \sigma_{1D}$.

- track based alignment with a limited sample of most useful collision events: high-mass resonance from Z and W (the *100 pb^{-1}* scenario) , and
- track based alignment with plenty of useful collision events (the *1000 pb^{-1}* scenario).

In the scenarios, misalignments are applied to modules in global x, y and z coordinates. Since the most sensitive coordinate is the r-ϕ-coordinate and therefore cannot be set in global coordinates, values for the r-ϕ-coordinate have been used as an estimate for all three spatial coordinates x, y, z, in order not to compromise the precision of the most sensitive coordinate. The different alignment sensitivity in r-ϕ, r and z as can be seen from Tables 3 and 4 therefore could not be used.

All three angles for all structures are now misaligned. If the rotational misalignments were not known (and not stated in Table 5), the following procedure was used to estimate the effect: The effect of the angle is assumed to increase the given RMS of the residual distribution by 10 %. This value is then converted by using the length of the structure into an angle, which is used in the scenario.

An important feature of the misalignment scenarios is the possibility to set the so-called Alignment Position Error (APE), discussed in detail in Ref. [2]. This is a variable introduced for each detector module characterizing 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. By default, the scenarios use the APE corresponding exactly to the standard deviation of the applied random variable.

The scenarios are built in a way that with additional measurements and accumulated integrated luminosity the precision of the alignment estimate increases. The applied misalignments in the new scenarios are given in Table 6. Also the values used in the previous *First Data* and *Long Term* scenarios are given for comparison. Details of the scenarios are discussed in the following subsections.

The *SurveyLASCosmics* scenario is based on *SurveyLASOnly* and *10 pb^{-1}* scenario, and therefore these two are presented first in the following sections.

5.2.1 *SurveyLASOnly* Scenario

The *SurveyLASOnly* scenario describes the alignment knowledge of the CMS Tracker once assembly precision, survey measurements, and information provided by the laser alignment system (LAS) have been taken into account. The LAS improves the relative precision of TIB, TOB and the two TECs. Taking the TECs as the reference system, the estimated relative LAS precision in r-ϕ was only applied to TIB and TOB half-barrels, corresponding to a relative measurement of its position with respect to the TECs. The full list of estimates of the initial uncertainties is given on the left side of Table 5.

The misalignments actually used in the *SurveyLASOnly* scenario are given on the right side of Table 5. The following modifications to the initial installation uncertainties were required to comply to the hierarchy of the alignment tools:

- For TPB there was no specific software class implemented in *Alignment Tools* corresponding to half-layers, half-barrels or the whole TPB when the scenarios were implemented. These objects could not be misaligned directly. Instead, misalignments of half-barrels and the whole TPB were summed quadratically, and applied to *TPBLayers* (previously called as *PixelHalfBarrelLayers*). Misalignments of sensors and modules were summed quadratically (RMS values), and assigned to module-level objects. A software class corresponding to pixel ladders did exist, and those misalignment were be applied directly.
- For TPE, TID and TIB, initial misalignments of Table 5 are applied as such (except for the negligible sensor-level misalignments). For TOB, misalignments of sensors and modules are summed quadratically and applied to *Dets*; otherwise for TOB values of the table are used as such. The effect of the accuracy of the LAS muon link to the TOB is difficult to estimate, and therefore not taken into account.
- For TEC, misalignments of sensors and modules are summed quadratically and applied to *Dets*. The mounting precision of the TEC in the support tube is not used, since it can not be measured from data. Instead the disk positions are known from survey (z) and r-ϕ (LAS) already with good precision.

Table 5: Installation uncertainties as from [2] (TPB), [5] (TPE) and Table 2 (TIB, TOB, TEC and TID) and their translation to the existing hierarchy of alignment tools in the *SurveyLASOnly* scenario. Survey measurements are taken into account for TPE. Rotational misalignments are taken into account, if the information was available. Improvement by LAS is taken into use for marked values. Gaussian distributions are expressed as plain number (the σ). Uniform distributions are stated as Uxx with range $\pm$xx μm. The corresponding RMS is also presented for uniform distributions of installation uncertainties.

	Installation uncertainties (+LAS corrections)			Implementation in *SurveyLASOnly*		
	Translation [μm]	RMS	Rotation [μrad]		Translation [μm]	Rotation [μrad]
TPB						
Sensor	U30 (2D)	17	-			
Module	U100	57	-	DetUnits	60	270
Ladders	U50	29	-	Ladders	U50	U20
Half-Layer	U100	58	-	Layers	225(xy),337(z)	10
Half-Barrel	U300	173	-			
TPB	U250(xy) / U500(z)	144 / 289	10			
TPE						
Sensors	5		100	DetUnits	5	100
Panels	10		200	Panels	10	200
Blades	10		200	Blades	10	200
Halfdiscs	50		1000	HalfDisks	50	1000
Halfcylinder	50		1000	HalfCylinders	50	1000
TIB						
Sensor	10		-			
Module	180		-	Dets/DetUnits	180	412
Shell	450		-	Strings	450	293
Cylinder	750		80	Layers	750	488
TOB						
Sensor	10		-			
Module	30		-	Dets/DetUnits	32	75
Rod	100		-	Rods	100	40
Wheel	60(rϕ, LAS),500(z)		80	HalfBarrel	60(xy),500(z)	10
Tube	200(LAS muon link)		40			
TEC						
Sensor	10		-			
Module	20		-	Dets/DetUnits	22	50
Petal	70		-	Petals	70	30
Disc	60(xy,LAS),150(z)		80	Disks	60(xy),150(z)	15
TEC-tube	60 (xy,LAS),600(z)		80			
TID						
Sensor	10		-			
Module	54		-	Dets/DetUnits	54	250
Ring	185		-	Rings	185	850
Disc	350		-	Disks	350	532
Cylinder-Tube	450		-	Endcaps	450	649

5.2.2 Scenario corresponding to approximately *10 pb*$^{-1}$

Before recording collision data, the CMS Tracker will be used to record tracks of cosmic muons. The expected rate of cosmic muons with $p > 5\,\mathrm{GeV}$ is approximately 9 Hz for the barrel of the Strip Tracker and approximately 2.5 Hz for the strip tracker endcaps. For the pixel detector, we expect tracks with a rate of 0.1 Hz. Assuming 50 % DAQ efficiency and one month operation, we expect 35 000 cosmic muon tracks in the pixel detector and roughly 10 million of tracks in the Strip Tracker.

In addition to cosmic muons, there are lots of minimum bias events available in the *10 pb*$^{-1}$ scenario, and also other tracks from collisions (QCD tracks with high p_{T}, low-mass resonances like J/ψ and Υ). There is no study on the usefulness of minimum bias or low-mass resonances, so an estimate is needed.

We assume therefore that we can align the tracker by using cosmic muon data and a sample of collision tracks. For the pixel detector, we assume a knowledge of the disk/layer level of roughly $10\mu\mathrm{m}$ (RMS), which corresponds to an improvement of a factor 5 compared to the assembly uncertainty. We also assume an alignment of the rod/blade level of the same order in absolute value, i.e. an improvement of a factor 3 compared to the assembly uncertainty for the pixel barrel and no improvement for the pixel endcap (due to the precise survey measurements). We do not assume any alignment on the module level but take the survey precision instead.

The studies presented in section 4 show that the strip detector can be aligned with cosmic muons to a precision of better than $100\,\mu\mathrm{m}$ on the rod/layer/petal/string level. However, not all modules are crossed by sufficiently many tracks to obtain this precision, This concerns modules in the endcaps TID and TEC as well as those modules in TIB and TOB close to $|y| = 0$. For reasons of simplicity, we assume that we can align the strip subdetector position, the layer level and the rod/petal/string/ring level with an accuracy of $100\,\mu\mathrm{m}$. We attribute $100\,\mu\mathrm{m}$ to the rod/petal/string/ring level and the same to the layer level, and if either LAS or survey is able to provide better precision we choose the best value.

This scenario, detailed in Table 6, contains the largest uncertainty on the given numbers, since no reliable studies are available.

5.2.3 Scenario corresponding to approximately *SurveyLASCosmics*

For the *SurveyLASCosmics* scenario, we expect to benefit from the cosmic muons in a similar way as in the *10 pb*$^{-1}$ scenario. We expect that large structures like whole subdetectors can be aligned with this amount of cosmic muons.

However, alignment in the *SurveyLASCosmics* scenario cannot rely on any tracks arriving from the vertex region (minimum bias events, low mass resonances), which would complement the sample of cosmic tracks. Track-based alignment with this kind of uniform sample of tracks suffers from global distortions. To account for these difficulties, we assume not to reach the value taken for the *10 pb*$^{-1}$ scenario. Instead, the following approach was chosen: for those parts of the CMS Tracker which we know to benefit from cosmic muons, RMS of misalignments is assumed to be the arithmetic average of the RMS used in the *SurveyLASOnly* and *10 pb*$^{-1}$ scenarios. Gaussian distributions are used for the resulting misalignments.

The barrel-like detectors (TPB, TIB and TOB) are expected to benefit from cosmic muons. For the TPE, we don't expect to benefit from cosmic muons, since the survey measurements provide already a very good starting point. For the TEC, we don't expect an improvement with alignment with cosmic muons, since TEC is measured by LAS and as a vertically placed detector, cannot measure cosmic muons very accurately. The TID, however, is not surveyed by LAS, and therefore it is expected that its largest misalignment can be improved with alignment with cosmic muons, even though it is a vertically placed detector. The applied misalignments are shown in Table 6.

5.2.4 Scenario corresponding approximately to *100 pb*$^{-1}$

For *100 pb*$^{-1}$ collected data, high-mass resonance decays from Z and W are available in addition to the previously mentioned data. Here the results of Table 4 (r-ϕ) are being used as estimates of the achievable precision, multiplied by a factor of two to account for the simplifications that were mentioned beforehand. The achieved RMS is split equally (factor of $\sqrt{2}/2$ each) to the module and to next higher level object (rod, petal, panel, ring), and half of the latter value ($\sqrt{2}/4$) is attributed to the other higher-level objects (disks, layers).

Again, if either survey data or the Laser Alignment System allow for a better precision, the most precise value is chosen as an estimate. Table 6 shows the values as used in the scenario.

5.2.5 Scenario corresponding approximately to *1000 pb*$^{-1}$

The same procedure is applied as in the previous section 5.2.4, but with the values from Table 3. Additionally, a cutoff is applied to simulate systematic time-dependent effects that cannot be recovered from alignment monitoring. This cutoff is set to $5\,\mu\mathrm{m}$ for the Pixel and $10\,\mu\mathrm{m}$ for the Strip Tracker. The values which are used in the *1000 pb*$^{-1}$ scenario are detailed in Table 6.

5.3 Most important differences to previous scenarios

The end user is now supposed to use the *10 pb*$^{-1}$, *100 pb*$^{-1}$ or *1000 pb*$^{-1}$ scenarios for physics analysis. Since a large number of previous studies (especially those in Refs. [3, 16]) have been done with the previous *First Data* and *Long Term* scenarios, we give here a short comparison of the major differences between these two sets of scenarios:

- New scenarios do not directly correspond to any of the previous scenarios (for instance, the *1000 pb*$^{-1}$ scenario is not identical to *Long Term*).
- Initial uncertainties follow now rather Gaussian distribution than uniform distributions
- TIBLayers (previously called as BarrelLayers) have large ($750\,\mu\mathrm{m}$) initial misalignment in 3D, whereas in previous scenarios only the z-component was large ($500\,\mu\mathrm{m}$)
- All angles for all structures are now miscalibrated, whereas in the old scenarios only layer/disk level structures were rotated around the beam line.
- The *100 pb*$^{-1}$ and *1000 pb*$^{-1}$ scenarios are based on MC studies of the achievable alignment precision rather than improvement factors of the initial survey uncertainties.

6 Impact on Physics Performance

The impact of tracker misalignment on physics is evaluated first in terms of effects on track reconstruction efficiency and track parameters resolution. Then the impact on the $Z \rightarrow \mu^+\mu^-$ mass reconstruction is studied. Furthermore, the impact on the b-tagging performance has been assessed.

6.1 Track reconstruction performance

Tracks are reconstructed using the default CMS Combinatorial Track Finder algorithm [1]. The track reconstruction efficiency and fake rate are defined as in Ref. [17] by using the same cuts on simulated and reconstructed tracks to allow for the comparison with previous results. Simulated and reconstructed tracks are associated using the track associator by hits algorithm [17] which requires a reconstructed track to share at least half of its hits with the corresponding simulated track. The resolution of a track parameter is defined as the RMS of a Gaussian function fitted to the distribution of the difference between the reconstructed and the simulated values (i.e. the distribution of residuals). During track reconstruction, the alignment position error is accounted for in the search for compatible hits and in the track fitting, by adding it in quadrature to the error matrix of the measured hit position.

Muons with $p_{\mathrm{T}} = 100\,\mathrm{GeV/c}$ are used as a benchmark, and the effect of misalignment on the track reconstruction efficiency is observed to be strongly dependent on the value of the alignment position error that is combined with the hit resolution during track finding and fitting. If the alignment position error corresponds to the size of the applied misalignment, full track finding efficiency is recovered in all the investigated misalignment scenarios, as shown in Figure 4 (left). The dependence of the efficiency loss on η, in case the APE is not applied, is a reflection of the various degrees of misalignment used in the different tracker subdetectors. The efficiency is recovered at large η because of the large search window used due to the large extrapolation distances in the endcap region.

However, recovering the efficiency by increasing the alignment position error causes an increase of the fake rate (Figure 4 right) up to 17 % for the *10 pb*$^{-1}$ scenario in the same η region where the efficiency is recovered (with respect to a mean of 3 % derived if the alignment uncertainties are not taken into account) because more compatible hits are found along tracks; a conservative estimate of the fake rate was obtained by using a sample of $t\bar{t}$ events with a track multiplicity between 50 and 100 tracks per event. For larger misalignments, the alignment position error has to be increased, resulting in an increase in the fake rate.

Table 6: Values used in the misalignment scenarios. Installation uncertainties and applied misalignments are given as well as misalignments used in previous scenarios. For the misalignment scenarios, RMS values are given together with scaling factors (comparison to initial uncertainties). Uniform distribution is denoted as Uxx, where xx signifies the range $\pm\mathrm{xx}\,\mu\mathrm{m}$. Gaussian distribution is denoted as Gxx, where $\sigma = \mathrm{xx}$. If not mentioned, the distribution is Gaussian. Angular misalignment $\phi = \alpha, \beta, \gamma$ is expressed in μrad.

	Updated initial uncertainties	Scenarios															Previous scenarios			
		SurveyLASOnly			*SurveyLASCosmics*			*10 pb^{-1}*			*100 pb^{-1}*			*1000 pb^{-1}*			*First Data*		*Long Term*	
		x, y, z	Scale	ϕ	x, y, z	Scale	ϕ	x, y, z	Scale	ϕ	x, y, z	Scale	ϕ	x, y, z	Scale	ϕ	x, y, z	ϕ	x, y, z	ϕ
TPB																				
Dets/DetUnits	G60	60	1	270	60	1	270	60	1.00	270	10	0.17	45	5	0.08	22	G13	—	G13	—
Ladders	U50	U50	1	U20	20	0.69	9	10	0.35	7	10	0.35	7	5	0.17	3	G5	—	G5	—
Layers	U100	225,225,337	3.9/5.84	10	118,118,174	2.05/3.02	9	10	0.17	7	5	0.08	3	5	0.08	3	G10	G10	G10	G10
TPE																				
DetUnits	G5, ϕ:G100	5	1	100	5	1	100	5	1.00	100	5	1.00	11	5	1.00	11	Dets G5	—	G5	—
Panels	G10, ϕ:G200	10	1	200	10	1	200	10	1.00	200	10	1.00	22	5	0.50	11	—	—	—	—
Blades	G10, ϕ:G200	10	1	200	10	1	200	10	1.00	15	10	1.00	15	5	0.50	7	Petals G2.5	—	G2.5	—
HalfDisks	G50, ϕ:G1000	50	1	1000	50	1	1000	10	0.20	15	10	0.20	15	5	0.10	7	EndcapLayers G5	G5	G5	G5
HalfCylinders	G50, ϕ:G1000	50	1	1000	50	1	1000													
TIB																		—		—
Dets/DetUnits	G180	180	1	412	180	1	412	180	1.00	412	30	0.17	70	10	0.06	20	U200	—	G20	—
Strings	G450	450	1	293	275	0.61	179	100	0.22	65	30	0.07	20	10	0.02	5	U200	—	G20	—
Layers	G750	750	1	488	425	0.57	277	100	0.13	65	15	0.02	10	10	0.01	5	G105/G500	G90	G10.5/G50	G9
TOB																				
Dets/DetUnits	G32	32	1	75	32	1	75	32	1.00	75	32	1.00	70	18	0.56	40	U100	—	G10	—
Rods	G100	100	1	40	100	1	40	100	1.00	40	40	0.40	15	18	0.18	7	U100	—	G10	—
Layers																	G67/G500	G59	G6.7/G50	G5.9
HalfBarrels	$r\phi$: G60, z: G500	60,60,500	1	10	60,60,300	1/0.6	10	60/100	1/0.2	10	20	.33/.04	5	10	.17/.1	2				
TEC																				
Dets/DetUnits	G22	22	1	50	22	1	50	22	1.00	50	22	1.00	50	22	1.00	50	U50		G5	
Petals	G70	70	1	30	70	1	30	70	1.00	30	55	0.79	20	40	0.57	15	U100		G10	
Disks	$r\phi$: G60 z: G150	60,60,150	1	15	60,60,150	1	15	60/150		15	30		5	20		5	G57/G500	G46	G5.7/G50	G4.6
TID																				
Dets/DetUnits	G54	54	1	250	54	1	250	54	1.00	250	50	0.93	230	25	0.46	110	U105		G10.5	
Rings	G185	185	1	850	185	1	850	185	1.00	850	50	0.27	230	25	0.14	110	U300		G30	
Disks	G350	350	1	532	350	1	532	250	0.71	380	25	0.07	40	12	0.03	20	U400	U100	G40	G10
Endcaps	G450	450	1	649	225	0.5	325													

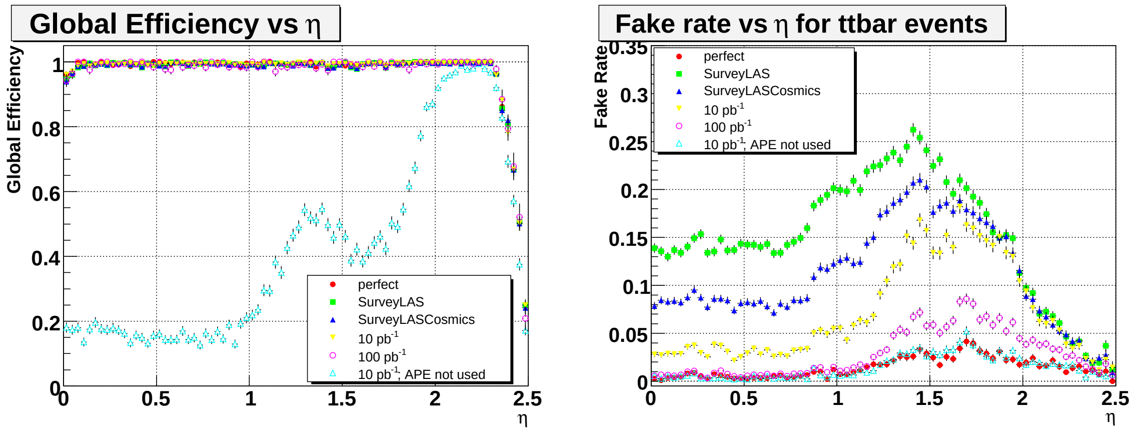

Figure 4: Track reconstruction efficiency (left) for single muons with $p_{\mathrm{T}} = 100\,\mathrm{GeV/c}$ in different misalignment scenarios. At right is reported the fake rate obtained with $t\bar{t}$ events for all the scenarios. The effect of not taking into account the alignment uncertainties is also shown for the $10\,pb^{-1}$ scenario.

The main effect from misalignments is found to be a degradation of the resolution of the five track parameters, p_{T}, ϕ, $\cot\theta$, d_0 and z_0, the latter two being defined at the point of closest approach of the track to the beam axis (this point is called the impact point). The transverse and longitudinal impact parameters d_0 and z_0 are the coordinates of the impact point in the transverse and longitudinal plane ($d_0 = x_0 \sin\phi - y_0 \cos\phi$, where x_0 and y_0 are the transverse coordinates of the impact point). The angle ϕ is the azimuthal angle of the momentum vector of the track at the impact point, and θ is the polar angle.

The distribution of the p_{T} residual and the dependence of the p_{T} resolution on the pseudo-rapidity are shown in Figure 5 for perfect alignment as well as for the *SurveyLASOnly*, *SurveyLASCosmics*, *10* pb^{-1} and the *100* pb^{-1} scenarios when the alignment position error is taken into account; muons are distributed uniformly in $|\eta| < 2.5$. In the case of perfect alignment, the resolution is in $1.5 - 2\,\%$ in the barrel region, in agreement with previous studies [18]. In the *SurveyLASCosmics* scenario, the resolution in the barrel deteriorates to $6 - 10\,\%$, and in the *10* pb^{-1} scenario to $5.5 - 8\,\%$. Resolution values degrade further in the endcap region for increasing values of $|\eta|$, because of the reduced lever arm of the measurement.

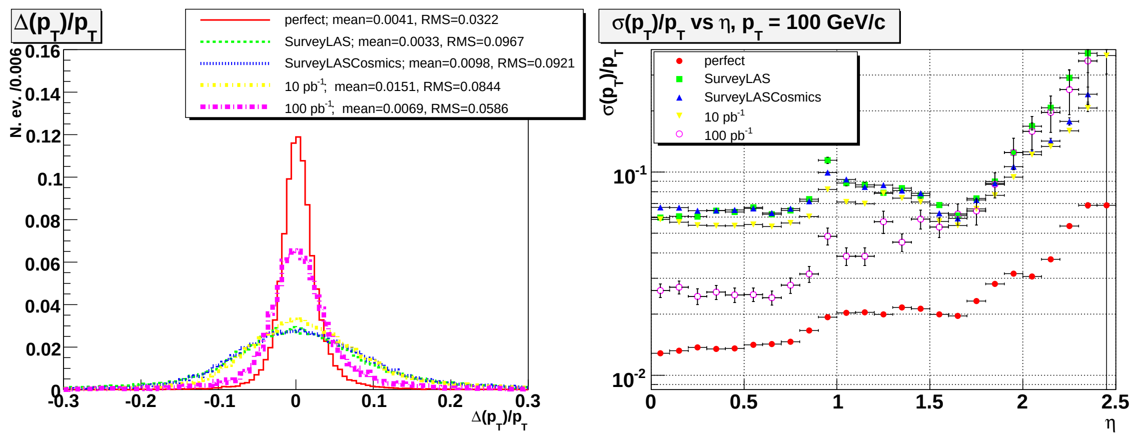

Figure 5: Muon p_{T} residual distribution (left) and p_{T} resolution (right) as a function of η for the ideal alignment and for all the scenarios investigated for $p_{\mathrm{T}} = 100\,\mathrm{GeV/c}$.

The degradation of track reconstruction performance because of tracker misalignment is also observed in the distribution of transverse and longitudinal impact parameters and the resolution as a function of pseudorapidity, as shown in Figure 6. The d_0 and z_0 displacements reflect misalignments of *TPBLayers* that is assumed to be misaligned in the *SurveyLASOnly* and *SurveyLASCosmics* scenarios, but not in the *10* pb^{-1} scenario, as explained in section 5.2. It should be noted that for each of the TPBLayers, a single random value is taken according to a Gaussian with RMS 118 $\mu\mathrm{m}$ in x and y and width 174 $\mu\mathrm{m}$ in z. The observed mean value of the z_0 distribution is smaller than 100 $\mu\mathrm{m}$, consistent with expectation. At high momentum the d_0 resolution is fairly constant and is dominated by the hit resolution of the first hit in the pixel detector. The larger pixel detector misalignment in *SurveyLASOnly* and *SurveyLASCosmics* scenarios causes a degradation of the resolution of about a factor of ten over all the η range. For the *1000 pb*$^{-1}$, *100 pb*$^{-1}$ and *10 pb*$^{-1}$ scenarios, degradation from the ideal value of $10\,\mu m$ is smaller: ~ 12, ~ 20 and $\sim 50\,\mu\text{m}$, respectively. The longitudinal impact parameter resolution $\sigma(z_0)$ is less strongly affected by the *1000 pb*$^{-1}$, *100 pb*$^{-1}$ and *10 pb*$^{-1}$ scenarios. The distributions of the ϕ and $\cot\theta$ residuals are shown in Figure 7.

The resolution of the $1/p_{\mathrm{T}}$, d_0 and z_0 was studied as function of p_{T} using muons from $Z \to \mu\mu$ decay and is shown in in Figures 8 and 9. The effect of tracker misalignment on p_{T} resolution is less in the low-p_{T} range than in the high-p_{T} range due to the increasing multiple scattering contribution for low momenta. The behaviour of d_0 and z_0 as a function of p_{T} is quite the same for all the scenarios. Nearly an order of magnitude degradation is found in the *SurveyLASCosmics* scenario with respect to the perfect alignment case.

6.2 Z mass reconstruction performance

The impact of tracker misalignment on the Z mass reconstruction is investigated reconstructing the Z from di-muon events and comparing the invariant mass with the simulated one in the all investigated scenarios.

The di-muon invariant mass and the Z mass residual obtained comparing the di-muons reconstructed invariant mass with the simulated one are reported in Figure 10. The effect of misalignment is to enlarge the Z peak by 12 % in the the *SurveyLASCosmics* scenario with respect to the ideal case. This enlargement is 10 % in the *10 pb*$^{-1}$ scenario, and 3.6 % in the *100 pb*$^{-1}$ scenario. The Z mass resolution, which has been estimated to be the sigma of a Gaussian fit to the Z mass residual distribution, is worsened by 90 % in the *SurveyLASCosmics* scenario with respect to the ideal case. This worsening is 84 % in the *10 pb*$^{-1}$ scenarios, and 37 % in the *100 pb*$^{-1}$ scenario.

6.3 b-tagging performance

The quality of the track reconstruction is also a crucial input for the performance of b-tagging algorithms. In particular, the measurement of the signed impact parameter significance is of high importance because it is used as discriminating variable in almost all b-tagging algorithms [19, 20]. The impact parameter is defined as the

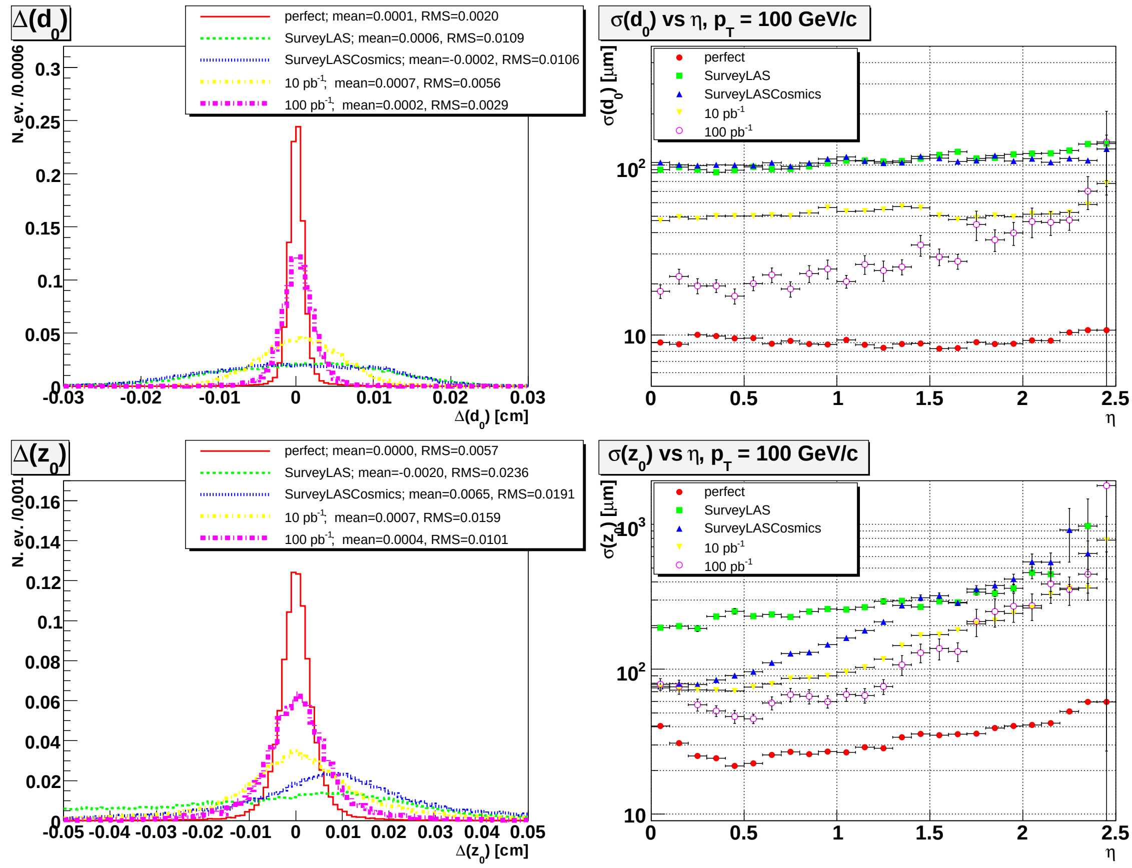

Figure 6: Distribution of d_0 and z_0 residuals and resolutions vs η for single muons with $p_{\mathrm{T}} = 100\,\mathrm{GeV/c}$ in case of perfect alignment and *SurveyLASOnly*, *SurveyLASCosmics*, *10 pb*$^{-1}$ and *100 pb*$^{-1}$ scenarios.

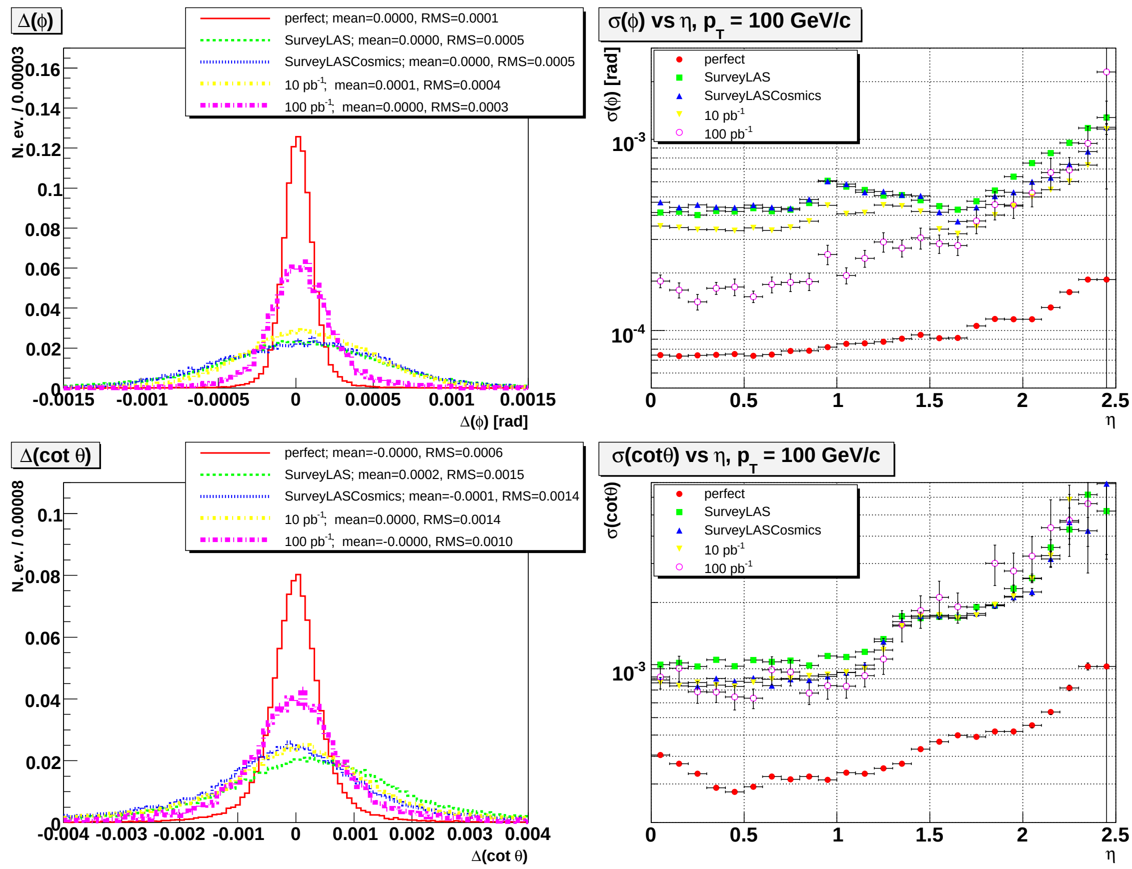

Figure 7: Distribution of ϕ and $\cot\theta$ residuals and resolutions vs η for single muons with $p_T = 100\,\mathrm{GeV}/c$ in case of perfect alignment and *SurveyLASOnly*, *SurveyLASCosmics*, *10 pb*$^{-1}$ and *100 pb*$^{-1}$ scenarios.

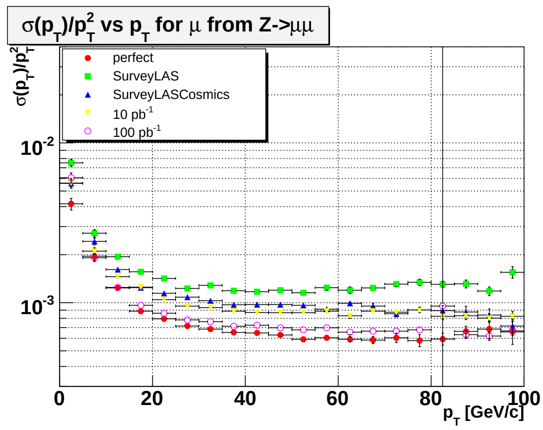

Figure 8: $1/p_T$ resolution vs. p_T in case of perfect alignment and *SurveyLASOnly*, *SurveyLASCosmics*, *10 pb*$^{-1}$ and *100 pb*$^{-1}$ scenarios.

minimal distance of the reconstructed track to the primary vertex. The sign is positive (negative) if the b-hadron decay appears to occur upstream (downstream) with respect to the jet axis [19]. Especially the long non-Gaussian tails in this variable are relevant since these are the cause of mistags. The significance is defined as the value of the measurement divided by its error. This means that also the correct determination of the measurement error is of equal importance. Since this error is directly correlated to the assumptions for the Alignment Position Error (APE), which is a priori unknown, these results have to be considered to be somewhat idealized. The impact of a wrong assumption of the APE is studied in [21].

Figure 11 shows the distribution of the signed transverse impact parameter significance for light, charm and beauty quarks for perfect alignment as well as for *SurveyLASOnly*, *SurveyLASCosmics*, *10 pb*$^{-1}$ and *100 pb*$^{-1}$ scenarios.

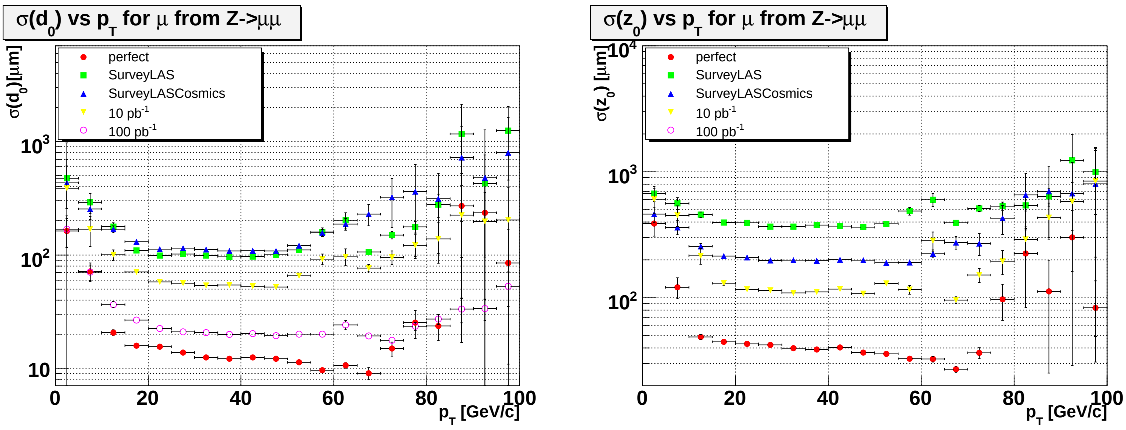

Figure 9: d_0 and z_0 resolution vs p_{T} in case of perfect alignment and *SurveyLASOnly*, *SurveyLASCosmics*, *10 pb*$^{-1}$ and *100 pb*$^{-1}$ scenarios.

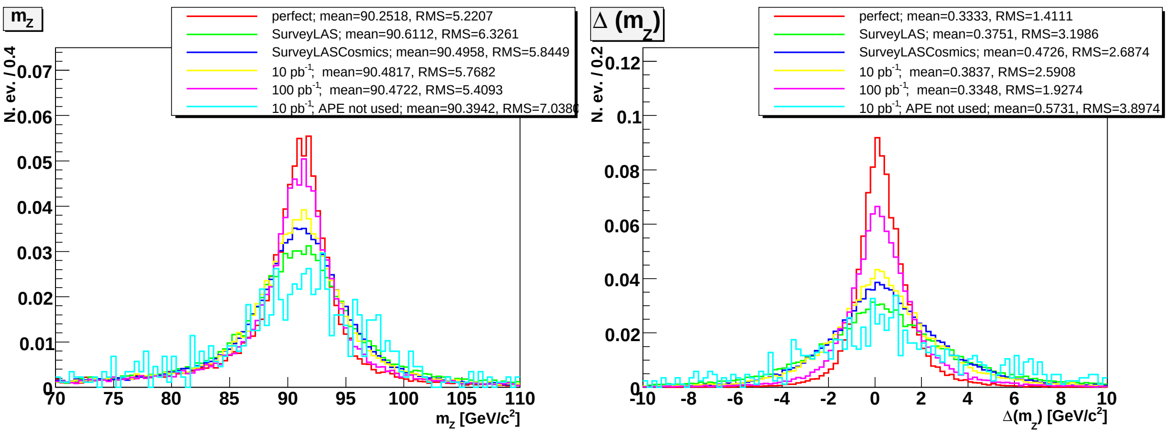

Figure 10: Di-muons invariant mass (left) and Z mass residual (right) for perfect alignment and *SurveyLASOnly*, *SurveyLASCosmics*, *10 pb*$^{-1}$ and *100 pb*$^{-1}$ scenarios. Also the *10 pb*$^{-1}$ scenario without use of APE is shown.

For the *100 pb*$^{-1}$ scenario the distributions are only mildly affected since the pixel detector is assumed to be aligned to the level of $\sim 10\,\mu\mathrm{m}$ already. The same applies also to the *1000 pb*$^{-1}$ scenario, omitted in Figure 11. As significant pixel detector misalignment is applied in the *10 pb*$^{-1}$ scenario ($60\,\mu\mathrm{m}$), also discrimination between light and heavy quarks is degraded. This degradation increases further in the *SurveyLASCosmics* scenario, as expected. The main effect is that the impact parameter significance for heavy quarks is reduced, mainly caused by the increased measurement error. Several effects are responsible for this behavior:

- the efficiency of reconstructing tracks in a misaligned detector decreases.
- the rate of fake tracks increases.
- the rate of wrongly assigned hits increases. In case only one hit in the first pixel layer is wrongly assigned, the track is not called fake track, but the impact parameter might still be severely mismeasured. It turns out that this occurs in about 3% to 4% of the tracks within jets in $\mathrm{t\bar{t}}$ events.

More details about these observations can be found in [21].

Figure 12 presents the light flavour and charm quark mistagging rates as a function of b-tagging efficiency for the *track counting* algorithm [19]. For ideal geometry, the mistagging rates are ~ 0.02 and ~ 0.15 for light and charm quark jets, respectively, for a b-tagging efficiency of 0.6. The b-tagging performance is only mildly affected by the *100 pb*$^{-1}$ and *1000 pb*$^{-1}$ (omitted in Figure 12) scenarios. However, for the *10 pb*$^{-1}$ scenario the mistagging rates at constant b-efficiency are significantly increased, and this effect increases further in the *SurveyLASCosmics* scenario.

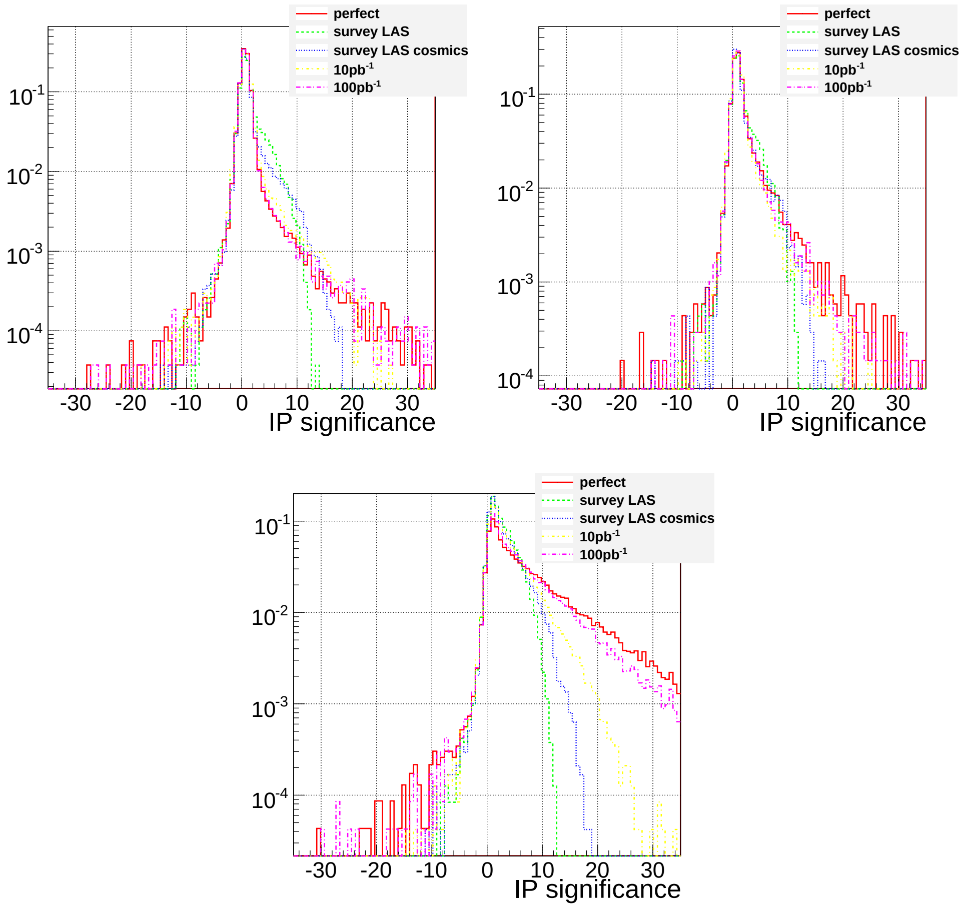

Figure 11: Transverse impact parameter significance as used in most b-tagging algorithms. Light quarks (top left), charm quarks (top right) and b-quarks (bottom) are displayed, using ideal alignment (solid) as well as the *100* pb^{-1} (dot-dashed), *10* pb^{-1} (dotted) and *SurveyLASCosmics* (fine dotted) scenarios.

7 Ideas for Further Development of Misalignment Scenarios

For possible updates of the misalignment scenarios, we list in the following some ideas for further development.

- When the optical survey of the TPB is complete and analyzed, an update of the scenarios should be considered. As explained in section 2.1, an improvement for individual sensors is expected, and this can significantly improve physics results in the startup scenarios.

- χ^2 invariant deformations should be considered. In the present scenarios, they have not been implemented. Their effect to physics results will be more important in the longer term scenarios, in which most of the residual misalignment will consist of this kind of deformations. However, their implementation with the existing alignment tools is quite difficult. Also, it is not yet studied how large these deformations can be (especially since running an alignment algorithm might even introduce this kind of deformations). One possible approach to solving this problem is given in the last paragraph of this section.

- Alignment achievable by using cosmic muons is only carried out as estimates on the average level (not taking into account the ϕ-dependence, which would have to be determined from dedicated studies).

- In these scenarios, the following structures were not misaligned: TPB half-layers, TPB half-barrels, TPB, TIB and TEC halves. The reason is that when the scenarios were created, the software classes corresponding to these physical structures were not implemented in the *Alignment Tools*.

  The necessity of misaligning also these parts of has to be considered. Also, the *10* pb^{-1} , *100* pb^{-1} and *1000* pb^{-1} scenarios were created before TPE HalfCylinders and TID Endcaps were implemented, and therefore these misalignments are not used in these scenarios. A revision of the hierarchy of alignment tools might turn out necessary. One thing to keep in mind is that the TOBLayer is a structure which does not correspond to the physical structures.

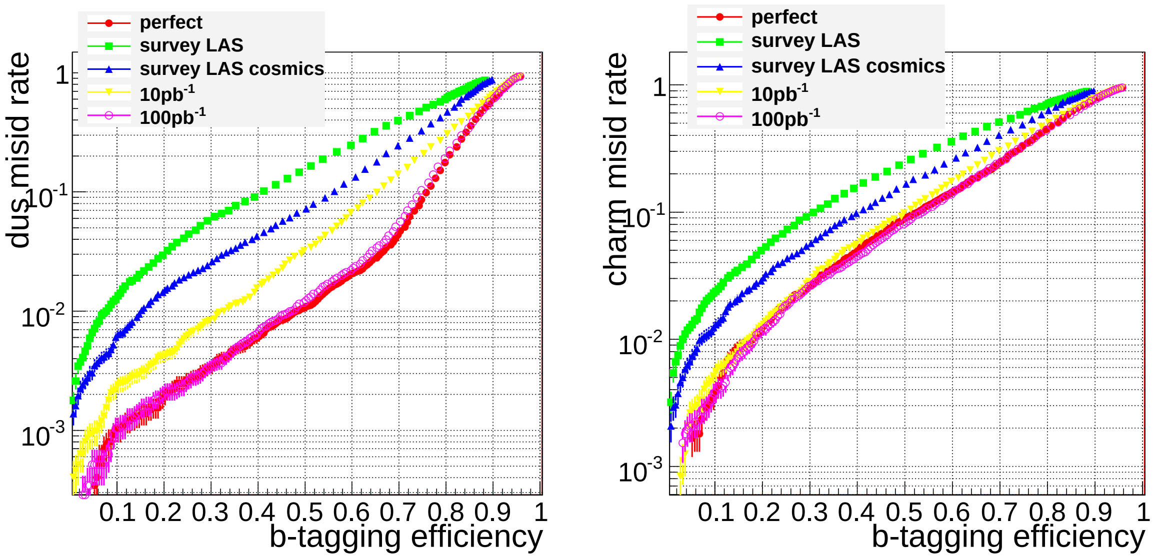

Figure 12: Light flavour (left) and charm quark (right) mistagging probability as a function of b-tag efficiency for the track counting b-tagging algorithm, obtained using $t\bar{t}$ events, presented for ideal alignment (circles), as well as for the *100 pb*$^{-1}$ (open circles), *10 pb*$^{-1}$ (down triangles) and *SurveyLASCosmics* (up triangles) scenarios.

- Results from studies of alignment performance with minimum bias, J/ψ, Υ and beam halo events should be included. This information is also significant for the early detector performance. Also the use of jets and single muons could further improve the *10 pb*$^{-1}$ scenario.
- Systematic effects due to temperature variations, miscalibration, stability of the detector etc. need to be estimated more precisely, if possible. These effects are now estimated with the cut-off values of 5 μm for the pixel, and 10 μm for the strip detector.
- As results from more detailed alignment studies become available, misalignments of different size should be applied in r-ϕ, r and z. In a similar way, α, β and γ should be treated separately.
- In realistic studies, one should take into account that the APE cannot be correctly set. In these scenarios, the APE is set to correspond exactly to the applied misalignments. In reality, we can only estimate the accuracy of alignment, and set the APE accordingly. Use of incorrect value for APE affects efficiency, fake rate and momentum resolution as described in section 2.6 of Ref. [2].

In the future, we foresee to use only the *SurveyLASOnly* scenario together with database objects created with track based alignment algorithms. The alignment performance for a given luminosity is exercised with a Monte-Carlo simulation of all available data for the given time. Track based alignment algorithm is run, and the resulting alignment parameters and errors are stored to the Database. This object can then be used as an estimate of the remaining misalignment. This approach take also properly into account χ^2-invariant deformations that the given data are not sensitive to. Of course also in this approach extensive knowledge of the initial uncertainties is needed.

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References

[1] A. Khanov, M. Lenzi, T. Todorov, T. Speer, P. Vanlaer, and M. Winkler, *Tracking in CMS: software framework and tracker performance*, Nuclear Instruments and Methods A. 478:460–464 (2002).

[2] I. Belotelov, O. Buchmüller, I. González Caballero, P. Martínez, C. Martínez-Rivero, F. Matorras, A. Heister, M. Thomas, T. Lampén, and V. Valuev, *Simulation of Misalignment Scenarios for CMS Tracking Devices*, CMS Note 2006/008 (2006).

[3] CMS Collaboration, *Physics Technical Design Report Vol. I, Detector Performance and Software*, CERN/LHCC 2006-001 (2006).

[4] A. Ostapchouk et al., *The Alignment System of the CMS Tracker*, CMS Note 2001/053 (2001).

[5] A. Gritsan, Pixel survey analysis and application to alignment, Presentation in CMS Tracker Alignment Workshop in Hamburg, May 2007.

[6] H.-C. Kaestli, private communication, February 2008.

[7] CMS Collaboration, *The CMS experiment at the CERN LHC*, JINST 3 S08004 (2008).

[8] CMS Collaboration, *The CMS Muon TDR*, CERN/LHCC 97-32 (1997).

[9] P. Arce, E. Calvo, C. F. Figueroa, N. García, T. Rodrigo, I. Vila, A. L. Virto, J. M. Barcala, M. G. Fernández, A. Ferrando, M. I. Josa, A. Molinero, and J. C. Oller, *Performance test of the CMS link alignment system*, Nuclear Instruments and Methods A. 492:365–375 (2003).

[10] T. Rodrigo, private communication, June 2007.

[11] B. Wittmer et al., *The Laser Alignment System for the CMS Silicon Microstrip Tracker*, to be published in Nuclear Instruments & Methods in Physics Research, Section A (NIM A) (2007).

[12] C. Bloch, "Commissioning of the CMS Tracker Outer Barrel", in *proceedings of 9th ICATPP*, Como, (2005).

[13] C. Bloch, Studies for the Commissioning of the CERN CMS Silicon Strip Tracker, PhD. Thesis [CERN-THESIS-2008-004], (2008).

[14] G. Flucke, P. Schleper, G. Steinbrück, and M. Stoye, *A Study of Full Scale CMS Tracker Alignment using High Momentum Muons and Cosmics*, CMS NOTE-2008/008 (2008).

[15] M. Stoye, private communication, June 2007.

[16] CMS Collaboration, *Physics Technical Design Report Vol. II, Physics Performance*, CERN/LHCC 2006-021 (2006).

[17] W. Adam, Th. Speer, B. Mangano, and T. Todorov, *Track reconstruction in the CMS Tracker*, CMS Note 2006/041 (2006).

[18] P. Vanlaer et al., *Impact of CMS Silicon Tracker Misalignment on Track and Vertex Reconstruction*, CMS Note 2006/029 (2006).

[19] A. Rizzi, F. Palla, and G. Segneri, *Track impact parameter based b-tagging algorithm in CMS*, CMS Note 2006/019 (2006).

[20] Christian Weiser, *A Combined Secondary Vertex Based B-Tagging Algorithm in CMS*, CMS Note 2006/014 (2006).

[21] CMS Collaboration, *Impact of Tracker Misalignment on the CMS b-Tagging Performance*, CMS PAS BTV_07_003 (2008).