The Impact of Inner Detector Misalignments on Selected Physics Processes

The ATLAS Collaboration

Abstract

Many physics analyses at ATLAS depend on the delivery of high quality tracking performance from the Inner Detector. This performance can be substantially degraded by misalignments of the Inner Detector modules which are not corrected for by the alignment procedure. In this note we show results from a number of studies into the impact of misalignments of the Inner Detector on physics and performance. Both random and global systematic misalignments of the Inner Detector are studied. Their impact on $Z \rightarrow \mu\mu$ reconstruction using Inner Detector tracks, $B$-physics observables and Tau identification and rejection performance is investigated.
1 Introduction

The ATLAS detector is a large multi-purpose particle physics detector that is designed to analyse the high energy proton-proton collisions produced by the Large Hadron Collider at CERN. ATLAS comprises of four major subsystems, the Inner Detector (ID) [1, 2], Electromagnetic Calorimeter, Hadronic Calorimeter and Muon Spectrometer. The ID is the innermost detector subsystem of ATLAS, occupying a cylindrical volume 2.1 m in diameter and 6.2 m in length that immediately surrounds the beampipe. This volume is inside a 2 T solenoidal magnetic field with field lines parallel to the beamline. The primary role of the ID is to reconstruct accurately and efficiently the helical trajectories of charged particles in this volume, a component of the overall event reconstruction, which is of crucial importance to many physics analyses at ATLAS. Figure 1 shows a 3-D view of the ATLAS ID. Visible are the three subdetectors; the Pixel detector, Semiconductor Tracker (SCT) detector and Transition Radiation Tracker (TRT). Each subdetector contains two kinds of detector modules, barrel modules which are arranged in cylindrical layers and the endcap modules which are arranged on the disk-like structures of the endcaps.

The accuracy with which the trajectory of a charged particle can be reconstructed from the measurements produced in tracking detector elements is highly dependent on the degree to which one knows the exact positioning and orientation of those detector elements, commonly referred to as their “alignment”. At ATLAS, the ID alignment algorithms [3–5] are used to determine the alignment constants of each of the modules in the ID, and these are then used in the track reconstruction to correct for misalignments. However, residual misalignments can remain due to the statistical precision of the alignment constants and the systematic effects explained below.

In this note, we show studies on the impact on physics and performance of two different types of misalignments:

- Random misalignments of the Inner Detector module positions.
Table 1: Widths of the Gaussian distributions used to smear the module positions for the Day-1 and Day-100 misalignments.

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- Global systematic misalignments of the Inner Detector that could remain after the Inner Detector module positions used in track reconstruction have been corrected by the ID alignment algorithms.

These misalignments are detailed in Sections 2 and 3 that follow. The strategy for investigating the impact of these misalignments is simple. Monte Carlo samples of physics processes are simulated and digitised with a certain ATLAS geometry within which the ID detector elements have a certain position and orientation. However, one can choose which geometry to use in the ATLAS offline event reconstruction of these digitised samples. If one uses exactly the same geometry as the samples were simulated with then the sample will be reconstructed with “ideal” ID alignment. If one reconstructs the same digitised event sample using a misaligned ATLAS geometry, one where the ID module positions/orientations are different to that used in the simulation, one can study the impact of such ID misalignments by comparing to the results obtained using the ideal alignment.

In Section 4, we present studies into the impact of both random and global systematic misalignments on the $Z$ mass reconstructed from ID tracks in a $Z \rightarrow \mu \mu$ simulated Monte Carlo sample. In Section 5, studies into the impact of these misalignments on $B$-physics observables are shown, and in Section 6, the impact of random misalignments on Tau identification and rejection are shown. Finally we summarise and conclude in Section 7.

2 Random Misalignments of the Inner Detector

In this note, we present results using misaligned ID geometries where random misalignments have been applied at the module level. These misalignments have been produced by applying random translations in the plane of the module to the module positions. The translations are generated using Gaussian distributions centred on zero. In the case of the TRT, entire TRT modules in the barrel and disks in the endcap have their positions smeared in this way. No module rotations are introduced, and no systematic global misalignments of the ID are introduced. Two different randomly misaligned geometries which use different Gaussian widths in the module position smearing have been produced, referred to as the Day-1 and Day-100 misalignments. The widths used in each case for each detector element is given in Table 1.

The Gaussian widths used to produce the Day-1 misalignments were motivated by the observed widths of tracking residual distributions in cosmic ray data, when this data was reconstructed using ID module positions that have been corrected by the ID alignment algorithms. By comparing these residual widths in the data to those of simulated cosmic ray Monte Carlo events that have been reconstructed with an ideal geometry one can estimate how large random misalignments would have to be to produce the broadening observed in the data (assuming that misalignments are the only cause). Thus the Day-1 misalignments are so-called because they represent an estimate of the alignment accuracy that will be
encountered on the first day of collision data taking, when the alignment constants derived from the cosmic ray data will be used\(^1\).

The Gaussian widths used to produce the Day-100 misalignments are reduced since this misaligned geometry is intended to represent the expected alignment accuracy after one hundred days of collision data taking, where the collisions data accumulated to this point will have been used to improve the ID alignment. However, there is considerable uncertainty as to what will actually be achieved after 100 days of running. The degree of module position smearing in the Day-100 misalignments are approaching the required alignment tolerances as defined by the initial performance requirements of the ATLAS experiment [1].

3 Global Systematic Misalignments of the Inner Detector

Unlike random module-to-module misalignments, global systematic misalignments of large scale structures, such as rotations/translations of entire barrel layers or endcap disks, have the potential to introduce systematic biases in the track reconstruction. Clearly there are many such global systematic misalignments that could potentially be present in the ATLAS Inner Detector structure. The vast majority of these will produce biases in the tracking residuals and can thus be removed by the ID alignment algorithms.

However, there exist a number of global systematic misalignments which, for tracks originating at a common interaction point, leave the tracking residuals unbiased (within the measurement accuracy). With certain initial conditions it is thus possible that alignment approaches which rely on the minimisation of tracking residuals could converge on such a misalignment, known as a “weak mode” misalignment. In this situation one would not know from an examination of tracking residuals that the detector was in fact misaligned. Several approaches to tackle weak mode misalignments are being investigated, such as running the alignment algorithms using a track sample with a different topology (cosmic ray, beam gas or beam halo tracks), or using additional constraints in the alignment algorithms: calorimetry measurements, the reconstructed primary vertex or track pairs from \(J/\psi\) and \(Z\) decays.

Unfortunately we cannot know a priori to which weak mode misalignments we may be susceptible or how large these misalignments could be. However, in order to facilitate an understanding of which weak modes may have the greatest impact on ID tracking, and how we might remove them, we have attempted to create several weak mode misalignments of the ATLAS Inner Detector “by hand”. Global systematic misalignments produced via transformations of module global \(R\) (radius), \(\phi\) or \(z\) coordinates \((\Delta R, \Delta \phi, \Delta z)\) as a function of module \(R\), \(\phi\) or \(z\), have the property of retaining approximate helical trajectories for particles originating at the interaction point [6]. Thus far the following misalignments produced in this way have been considered:

- The Curl misalignment \(\Delta \phi = c_1 R + c_2 / R\): A transformation of module global \(\phi\) coordinates with magnitude dependent on the module radius.
- The Twist misalignment \(\Delta \phi = cz\): A transformation of module global \(\phi\) coordinates with magnitude dependent on the module global \(z\) coordinate \(^2\).
- The Telescope misalignment \(\Delta z = cR\): A transformation of module global \(z\) coordinates with magnitude dependent on the module radius.

\(^1\)In fact, it is known that the actual alignment precision achieved in the barrel using the cosmic ray data depends significantly on the module \(\phi\), but this dependency is not reproduced in the Day-1 misalignments.

\(^2\)The implementation of the Twist misalignment in the TRT barrel has to be modified since the modules span the entire length of the barrel. Instead the TRT modules are rotated about an axis that points radially out from the interaction point through the centre of the module.
The Elliptical misalignment $\Delta R = c_2 \cos(2\phi) R$: A transformation of module global $R$ coordinates with magnitude dependent on the module global $\phi$. The effect of this parameterisation is to radially expand the top and bottom half of the ID whilst radially contracting the sides.

The simple parameterisations of the misalignments described above should result in weak mode misalignments, but only if each measurement on a track can be freely translated and rotated in the global frame. We know that in reality this is not possible. Each measurement is necessarily constrained to be on a detector element, and it is only the detector element that can be transformed and rotated, not the measurement itself. For example, a perfect Curl misalignment should have each measurement rotated in global $\phi$ by an amount proportional to the radial distance from the beampipe. However, this radial distance is clearly not the same for each measurement on an endcap detector element, and even in the barrel a small difference in the radial distance across the detector elements exists. Thus misalignments generated using these simple parameterisations are likely only to approximate weak modes.

Two magnitudes of misalignment are studied for each of the above types, labelled “Large” and “Small”. The constants of proportionality for the Curl-Large and Twist-Large misalignments are chosen such that modules in the outermost SCT layer are translated in the azimuthal plane by $\sim 300 \, \mu\text{m}$. The $1/R$ term in the Curl parameterisation produces a $\sim 50 \, \mu\text{m}$ shift of modules in the innermost pixel layer. The Telescope-Large and Telescope-Small misalignments produce $\Delta z$ translations of the outermost SCT layer of $\sim 3000 \, \mu\text{m}$ and $\sim 300 \, \mu\text{m}$ respectively, and the Elliptical-Large and Elliptical-Small misalignments correspond to radial shifts of $\sim 1000 \, \mu\text{m}$ and $\sim 250 \, \mu\text{m}$ respectively. No random module-to-module misalignments are introduced in any of the parameterised global deformations. It should be noted that the choice for the magnitude of these misalignments is somewhat arbitrary, and motivated by the desire for misalignments large enough to have some visible impact on track reconstruction. Currently we have only a limited understanding of the size of weak mode misalignments that we could encounter in the real detector. Thus any impact on physics and performance that is observed using these misalignments should be interpreted as being indicative of possible effects. The Curl-Small and Twist-Small misalignments are produced by running the Global $\chi^2$ alignment algorithm [3] on an ID geometry that has been misaligned using the Curl-Large and Twist-Large misalignments respectively.

In Fig. 2, we show the $\chi^2/\text{DOF}$ distribution of tracks in a $Z \rightarrow \mu\mu$ simulated Monte Carlo event sample when the sample is reconstructed using each of the global systematic misalignments described above, compared with reconstruction using ideal alignment. One can see that for all of the misalignments, with the exception of the Elliptical-Large, the $\chi^2/\text{DOF}$ distribution is very similar to that of the ideal alignment case. This indicates that by using these parameterisations we have created misalignments that approximate weak modes. This is further evidenced by a detailed examination of the tracking residual distributions produced by these misalignments; the residuals are observed to be unbiased at the level of $\sim 2 \, \mu\text{m}$ in the barrel region. The degradation of the quality of the track fits for the Elliptical-Large misalignment is an indication that at this magnitude the Elliptical parameterisation does not well approximate a weak mode misalignment.

In all the studies in this note that follow, we only show results using the Curl-Large and Curl-Small misalignments. The Telescope misalignments have not been found to produce any significant impact on track reconstruction (only introducing a very small $\eta$ bias). The impact of the Elliptical and Twist misalignments on track reconstruction requires further study.

3) Here the Global $\chi^2$ algorithm was run using a sample of 1 million simulated muon tracks with $2 < p_T < 50 \, \text{GeV}$ and a common interaction point.

4) Here we have only considered track topologies produced in simulated beam collisions, thus this does not demonstrate that these misalignments approximate weak modes to other track topologies such as cosmic rays or beam halo events. It is possible that these misalignments could be reduced by running the alignment algorithms with such events.
A Curl misalignment is expected to produce a systematic bias in the track curvature. In Fig. 3, we show the track curvature biases that are produced by the Curl-Large and Curl-Small ID misalignments. One can see that the Curl-Large misalignment produces a bias in the curvature of \( \Delta Q / p_T \sim -0.002 \; \text{GeV}^{-1} \). Positively charged tracks will have their curvature reduced by approximately this amount, and negatively charged tracks their curvature increased. The Curl-Small misalignment produces a much smaller curvature bias of \( \Delta Q / p_T \sim -0.0004 \; \text{GeV}^{-1} \). This demonstrates that the alignment algorithm has been able to correct for the misalignments introduced by the simple Curl-Large parameterisation to a significant extent, a result that is not entirely surprising given that these misalignments only approximate weak modes. With greater statistics it is expected that there would be further reductions in the size of the residual misalignment.

A systematic track curvature bias results in a bias in the measured transverse momenta, which is dependent on both the track \( p_T \) and charge, as shown in Fig. 4. In the Curl-Large case, the reconstructed track \( p_T \) is increased by \( \sim 14\% \) for positively charged tracks and decreased by \( \sim 11\% \) for negatively charged tracks at \( p_T = 50 \; \text{GeV} \). The bias is larger for positively charged tracks because of the non-linear effect on the measured transverse momentum produced by a variation in track curvature.

\[ \text{To further illustrate why the bias is larger for positively charged tracks, consider a Curl misalignment which produces a curvature bias of } \Delta Q / p_T = -0.02. \text{ A track of true } p_T = 50 \; \text{GeV} \text{ will be reconstructed with infinite momenta if it is positively charged, but reconstructed with } p_T = 25 \; \text{GeV} \text{ if it is negatively charged.} \]
Figure 2: The $\chi^2$/DOF distributions of Inner Detector tracks when reconstructed with each of the Curl, Twist, Elliptical and Telescope weak mode ID misalignments compared to the ideal ID alignment case. A $Z \rightarrow \mu\mu$ Monte Carlo sample is used, and all tracks with reconstructed $p_T > 2$ GeV are shown.
Figure 3: The difference between the reconstructed Inner Detector track $Q/p_T$ and the associated truth particle $Q/p_T$, $\Delta Q/p_T$ (Reco – Truth), when tracks are reconstructed with the Curl-Large and Curl-Small ID misalignments compared to the ideal ID alignment case. A $Z \rightarrow \mu\mu$ Monte Carlo sample is used, and all tracks with reconstructed $p_T > 2$ GeV are shown. The different plots cover different track $\eta$ regions.
Figure 4: Ratio of the reconstructed Inner Detector track $p_T$ to the associated truth particle $p_T$, $p_{T\text{reco}}/p_{T\text{truth}}$, as a function of the truth particle $Q*p_T$ for track $|\eta| < 1.0$. Tracks from a $Z \rightarrow \mu\mu$ Monte Carlo sample are reconstructed with the Curl-Large and Curl-Small ID misalignments and the ideal alignment case. Each point represents the mean of the $p_{T\text{reco}}/p_{T\text{truth}}$ distribution in that bin, with the error bars representing the error on the mean.

(a) Positive track $p_T$ bias for Curl misalignment (track $|\eta| < 1.0$).

(b) Negative track $p_T$ bias for Curl misalignment (track $|\eta| < 1.0$).
4 Impact of ID Misalignments on $Z \rightarrow \mu \mu$ Reconstruction using ID Tracks

In this section, we examine the impact of the Day-1 and Day-100 random misalignments and the Curl misalignments on the $Z$ mass reconstruction in a simulated $Z \rightarrow \mu \mu$ Monte Carlo sample, where the muon tracks are reconstructed in the ID only. Since we use a pure $Z \rightarrow \mu \mu$ event sample without any background processes present, this can be tested with very simple $Z$ boson identification criteria. The ID reconstructed $Z$ mass is the invariant mass formed from the two highest $p_T$ Inner Detector tracks, with both tracks satisfying $p_T > 15$ GeV and having opposite charge. In Fig. 5, we show this $Z$ mass distribution where the $Z \rightarrow \mu \mu$ Monte Carlo sample has been reconstructed using the Day-1 and Day-100 ID misalignments and the ideal ID alignment. One can see that the random smearing of module positions in the Day-1 and Day-100 alignment constants clearly impact the $Z$ mass resolution. The exact size of this impact on the resolution is better seen in Fig. 6. Here we show the event-by-event difference between the ID reconstructed $Z$ mass and the truth $Z$ mass, where the truth $Z$ mass is the invariant mass of the two truth particles that can be associated to the ID tracks used in the $Z$ reconstruction. A Gaussian is fitted to this distribution in the range $[\mu - \text{RMS}, \mu + \text{RMS}]$, and the mean and width of this Gaussian is stated in the plot. The random module position smearing of the Day-1 misalignments produces a $Z$ mass resolution degraded by $\sim 50\%$ when compared to the ideal alignment case. The Day-100 geometry uses a reduced random smearing of the module positions (see Table 1) and consequently the impact on the $Z$ mass resolution is smaller, a $\sim 13\%$ degradation (for the full $\eta$ range).

In Fig. 7 and Fig. 8, we show the equivalent plots where the same $Z \rightarrow \mu \mu$ Monte Carlo sample has been reconstructed using the Curl-Small and Curl-Large misalignments. The degradation in the mass resolution is $\sim 30\% (\sim 20\%)$ in the Curl-Large (Curl-Small) cases (for the full $\eta$ range). The improvement in using the Curl-Small compared with the Curl-Large geometry is a consequence of the alignment procedure being able to correct the $p_T$ bias of the Curl-Large misalignment to a large extent (see Fig. 4). However, even though the $p_T$ bias is reduced from $\sim 14\%$ to $\sim 2\%$ at $p_T = 50$ GeV, we are still left with a $20\%$ degradation in the $Z$ mass resolution. The reason for this is that, due to limited statistics, the alignment algorithm produces residual random misalignments in the TRT barrel and SCT endcap detector modules which subsequently degrade the tracking resolutions. It is estimated that a sample of 1 million tracks suitable for alignment could be collected within 24 hours of reliable collisions data taking, and thus in reality such statistical uncertainties will be rapidly reduced.

The Curl-Large misalignment also introduces a $\sim 400$ MeV bias into the reconstruction of the $Z$ mass. Although the biases in the track momenta largely cancel in the invariant mass, the positive $p_T$ bias for positively charged tracks is slightly larger than the negative $p_T$ bias for negatively charged tracks (see Fig. 4), and thus a bias in the mass is produced.
Figure 5: The ID reconstructed Z mass distribution for a $Z \rightarrow \mu \mu$ Monte Carlo sample reconstructed using the Day-1 and Day-100 ID misalignments and the ideal ID alignment.

Figure 6: The difference between the ID reconstructed Z mass and the truth Z mass, $\Delta M_{\mu\mu}(\text{Reco} - \text{Truth})$, for a $Z \rightarrow \mu \mu$ Monte Carlo sample reconstructed using the Day-1 and Day-100 ID misalignments and the ideal ID alignment. The two plots differ in the $\eta$ restrictions applied to the tracks used to reconstruct the Z boson. A Gaussian is fitted in the range [$\mu - \text{RMS}, \mu + \text{RMS}$], and the mean and width of this Gaussian is stated in the plot.
Figure 7: The ID reconstructed $Z$ mass distribution for a $Z \rightarrow \mu\mu$ Monte Carlo sample reconstructed using the Curl misalignments, compared with the perfect ID alignment. The ID reconstructed $Z$ mass is the invariant mass formed from the two highest $p_T$ Inner Detector tracks, with both tracks satisfying $p_T > 15$ GeV and having opposite charge. An impact on the $Z$ mass resolution is clearly produced by the Curl misalignment. The magnitude of this impact is better seen in Fig. 8.
Figure 8: The difference between the ID reconstructed Z mass and the truth Z mass, $\Delta M_{\mu\mu}$ (Reco – Truth), for a $Z \rightarrow \mu\mu$ Monte Carlo sample reconstructed using the Curl-Large and Curl-Small ID misalignments and the perfect ID alignment. The two plots differ in the $\eta$ restrictions applied to the tracks used to reconstruct the Z boson. A Gaussian is fitted in the range $[\mu - \text{RMS}, \mu + \text{RMS}]$, and the mean and width of this Gaussian stated in the plot.
5 Impact of ID Misalignments on Reconstructed $J/\psi$ and $B$-meson Masses

Precision $B$-physics measurements at ATLAS rely heavily on high quality charged particle track reconstruction in the Inner Detector. In this section, we examine the impact of the Day-1 and Day-100 random ID misalignments and the Curl misalignments on two key $B$-physics observables: the $J/\psi$ mass and the $B^0_d$ mass. A simulated $B^0_d \rightarrow J/\psi K^{0*}$ Monte Carlo event sample is used for these studies. The $J/\psi$ candidates are selected by looking for opposite charged track pairs which originate from a common vertex and have a mass within $3\sigma$ of the nominal $J/\psi$ mass. The reconstruction of the $B^0_d$ mass proceeds via the identification of a quadruplet of tracks which are consistent with a decay $B^0_d \rightarrow J/\psi K^{0*}$ where $J/\psi \rightarrow \mu\mu$ and $K^{0*} \rightarrow \pi^{\pm} K^{\mp}$. Full details of the $J/\psi$ and $B^0_d$ mass reconstruction are given in [7], pages 1124-1126.

In Fig. 9(a), we show the results of a Gaussian fit to the $J/\psi$ mass distribution where the event sample has been reconstructed with Day-1 and Day-100 ID alignment constants and ideal ID alignment. In Fig 9(b), we show the same results for a Gaussian fit to the $B^0_d$ mass distribution. Using ideal ID alignment the $J/\psi$ and $B^0_d$ mass resolutions are $\sim 48$ MeV and $\sim 77$ MeV respectively, dominated by the effects of material interactions. One can see that the impact of the random ID misalignments on the $J/\psi$ and $B^0_d$ mass resolutions is not significant. This is further evidenced by the distributions in Fig. 10. Figure 10(a) shows the event-by-event difference in $J/\psi$ mass when reconstructed with the ideal ID alignment, to the $J/\psi$ mass when the exact same event is reconstructed using the Day-1 or Day-100 ID random misalignments. Since all other elements of the event simulation are the same, this shows directly the impact of the misalignments. The Day-1 and Day-100 misalignments degrade the $J/\psi$ mass resolution relative to the ideal alignment case by only $\sim 23$ MeV and $\sim 12$ MeV respectively. This effect is not significant when added in quadrature to the ideal $J/\psi$ resolution. Figure 10(b) shows the equivalent distribution for the $B^0_d$ mass. Similarly the Day-1 and Day-100 misalignments degrade the $B^0_d$ mass resolution relative to the ideal alignment case by only $\sim 32$ MeV and $\sim 16$ MeV respectively.

In Fig. 11, the distributions of the event-by-event differences in the reconstructed masses produced when reconstructing using the Curl-Large and Curl-Small misalignments are shown. Again we observe that the impact of the ID misalignments are not significant. The Curl-Large and Curl-Small misalignments degrade the $J/\psi$ mass resolution relative to the ideal alignment case by only $\sim 26$ MeV and $\sim 9$ MeV respectively, and the $B^0_d$ mass resolution by only $\sim 36$ MeV and $\sim 12$ MeV respectively.
Figure 9: The results of Gaussian fits to the $J/\psi$ mass distribution and $B^0_d$ mass distribution for events in a $B^0_d \to J/\psi K^0_s$ Monte Carlo sample that have been reconstructed with Day-1 and Day-100 ID alignment constants and ideal ID alignment.

Figure 10: The distribution of the event-by-event difference between the $J/\psi$ and $B^0_d$ masses when reconstructed with the ideal ID alignment, to the masses when the same event is reconstructed using the Day-1 or Day-100 ID random misalignments. The mean and width of a Gaussian fit made to the core of the distribution is reported in the plot.
Figure 11: The distribution of the event-by-event difference between the $J/\psi$ and $B_d^0$ masses when reconstructed with the ideal ID alignment, to the masses when the same event is reconstructed using the Curl-Large or Curl-Small ID misalignments. The mean and width of a Gaussian fit made to the core of the distribution is reported in the plot.
6 Impact of ID Misalignments on Tau Performance

The identification of jets from hadronic $\tau$ decays at ATLAS is a complex task that relies on making the best use of calorimeter- and tracking-based quantities in order to achieve efficient identification whilst controlling the number of fakes from QCD multi-jet production. In this section, we investigate the impact of the Day-1 and Day-100 random ID misalignments on $\tau$ reconstruction.

Figure 12 shows the efficiency to reconstruct ID tracks from $\pi^{\pm}$ resulting from $\tau$ decays in a $Z \rightarrow \tau \tau$ simulated Monte Carlo sample (requiring $|\eta^{\tau}| < 1.5$). This sample has been reconstructed using ideal ID alignment and the Day-1 and Day-100 ID misalignments, and the resulting efficiencies compared. In Fig. 12(a) the standard ID track selection criteria is used [2]. In Fig. 12(b) the track selection criteria used to define the leading track in a $\tau$ lepton multi-track candidate is used, which makes more stringent requirements on the impact parameter, $z_0$, and the number of pixel hits on track. One can see that there is an up to 2% loss of efficiency when using the tight selection with the Day-1 ID misalignments, due to the impact of these random misalignments on the impact parameter resolution. This effect is insignificant using the Day-100 misalignments. However, one should note that here the leading track selection has been applied to all $\pi^{\pm}$ resulting from $\tau$ decays, whereas in the actual algorithm only one of the charged pion tracks from a $\tau$ decay are required to pass the selection. Thus the impact observed in Fig. 12(b) will not manifest in a reduction of $\tau$ reconstruction efficiency so long as it is only the non-leading pions that are failing the cuts.

Figure 13 shows the impact of the Day-1 and Day-100 misalignments on tracking variables used in the identification of track-seeded $\tau$ candidates in the same $Z \rightarrow \tau \tau$ Monte Carlo sample. The $\tau$ candidates are required to match a $\tau$ from $Z \rightarrow \tau \tau$ that undergoes 1-prong or 3-prong hadronic decay. The variables are constructed from ID measured track quantities. Calorimeter energy measurements are also used in the case of the visible mass variable. A full description of each of these variables is given in [7], pages 230-259. No significant impact of the random ID misalignments on any of these variables are observed.

Figure 14 shows the Tau identification efficiency vs QCD jet rejection calculated using Monte Carlo event samples reconstructed with ideal ID alignment and the Day-1 and Day-100 ID misalignments. A requirement on the generator level visible transverse energy of the $\tau$ candidates is made $10 < E_{T}^{vis} < 30$ GeV. The efficiency is defined as the fraction of 3-prong hadronically decaying $\tau$’s in a $Z \rightarrow \tau \tau$ sample that are positively identified by either the calorimetry- or track-seeded $\tau$ algorithms (using the same criteria as detailed in [7], pages 230-259). The rejection factor is determined from QCD di-jet samples in the same way. One can see that there is no significant impact from the random misalignments on the efficiency or rejection factors.
Figure 12: The efficiency to reconstruct ID tracks from $\pi^{\pm}$ resulting from $\tau$ decays in a $Z \to \tau\tau$ simulated Monte Carlo sample (requiring $|\eta^{\pi}| < 1.5$). This sample has been reconstructed using ideal ID alignment and the Day-1 and Day-100 ID misalignments, and the resulting efficiencies are compared.
Figure 13: Distributions of variables used in $\tau$ identification by the track-seeded $\tau$ reconstruction algorithm when a $Z \rightarrow \tau\tau$ simulated Monte Carlo sample is reconstructed using ideal ID alignment and the Day-1 and Day-100 ID misalignments. The $\tau$ candidates are required to match a $\tau$ from $Z \rightarrow \tau\tau$ that undergoes 1-prong or 3-prong hadronic decay.
Figure 14: Tau identification efficiency vs QCD jet rejection calculated using Monte Carlo event samples reconstructed with ideal ID alignment and the Day-1 and Day-100 ID misalignments.
7 Summary and Conclusion

The impact of random and global systematic misalignments of the ATLAS Inner Detector on $Z \to \mu\mu$ reconstruction, $J/\psi$ and $B^0_d$ mass reconstruction and Tau identification and rejection has been investigated. Random misalignments corresponding to the expected alignment precision on the first day (Day-1) and the hundredth day (Day-100) of collisions data taking have been used. Several types of global systematic misalignments have been produced via simple parameterisations of individual module shifts, and their compatibility with weak mode misalignments has been demonstrated.

The Day-1 and Day-100 random misalignments have been shown to produce a degradation in the $Z \to \mu\mu$ mass resolution when constructing the mass from the muon tracks in the ID. Even when using the smaller Day-100 misalignments, the $Z$ mass resolution is degraded by 13% relative to the ideal alignment case. However, studies on a $B^0_d \to J/\psi K^{0*}$ sample indicate that the impact of these random misalignments on $J/\psi$ and $B^0_d$ mass reconstruction is not significant. Using the larger Day-1 random misalignments the $J/\psi$ mass resolution is increased by only $\sim 10\%$ ($\sim 23$ MeV added in quadrature to the ideal alignment resolution of $\sim 48$ MeV), with a similar impact observed in the $B^0_d$ mass resolution ($\sim 32$ MeV added in quadrature to the ideal alignment resolution of $\sim 77$ MeV). No significant impact of the random misalignments on Tau identification performance has been observed.

The Curl global systematic misalignment has been observed to produce a charge dependent curvature bias on ID reconstructed tracks, which translates into a bias on the reconstructed track momenta. Two different magnitudes of Curl misalignment were investigated, labelled Curl-Large and Curl-Small, which produce $p_T$ biases of $\sim 14\%$ and $\sim 2\%$ respectively. The Curl-Small misalignment was produced by running the Global $\chi^2$ alignment algorithm on a Curl-Large misaligned geometry, and thus this demonstrates the success of this algorithm in correcting the misalignment to some extent. With greater collision data statistics and the use of additional event types (cosmic rays, beam gas, beam halo) it is expected that the Curl misalignment would be further reduced.

The $p_T$ biases of the Curl misalignments result in a significant degradation of the $Z \to \mu\mu$ mass resolution, by $\sim 30\%$ and $\sim 20\%$ in the Curl-Large and Curl-Small cases respectively. However, the impact of the misalignments is much less significant for $J/\psi$ and $B^0_d$ reconstruction. The Curl-Large misalignment increases the $J/\psi$ mass resolution by only $\sim 14\%$ ($\sim 26$ MeV added in quadrature to the ideal alignment resolution of $\sim 48$ MeV), with a similar impact observed in the $B^0_d$ mass resolution. The Curl-Small misalignment has a greatly reduced effect on these observables.

Overall these results show that, due to the intrinsically low $p_T$ of the decay products, the $J/\psi$ and $B^0_d$ mass resolutions are dominated by material interactions rather than misalignments. Misalignments have a more significant impact in $Z$ mass reconstruction, where the $p_T$ of the decay products is typically much larger.

References


