Alignment with Kalman filter fitted tracks and reconstruction of B0/s → J/ψφ decays

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2011

Summary

The LHC at CERN provides a new testing ground for the Standard Model of elementary particles as well an opportunity to further explore the mysteries and expand our knowledge of Nature. The Standard Model is a theory based on experimental observations of particle interactions at collider experiments and at cosmic ray experiments. Despite the successes of the Standard Model it does not provide a complete picture of the beautiful intricately woven tapestry called Nature. To further explore the finest threads of this tapestry and to validate or exclude the Standard Model or extensions thereof, so-called New Physics Models, particle physicists at the LHC have built precision instruments to measure fundamental parameters, which may reveal New Physics, with the highest possible precision.

A case in point is the weak mixing phase ϕ_s, a key measurement of the LHCb experiment, which can be accessed via $B_s^0 \to J/\psi\phi$ decays. According to the Standard Model this phase is expected to small, approximately $\phi_s = -0.04\,\mathrm{mrad}$. However, New Physics contributions may augment this phase, yielding a larger value. To be able to attribute the observed magnitude of the phase to New Physics, the LHCb experiment has been designed to measure ϕ_s with a precision of $0.024\,\mathrm{mrad}$ after one nominal year of data taking. To achieve this sensitivity on ϕ_s requires high precision tracking detectors. Furthermore, to determine charged particle trajectories and observables with a high precision, the positions of the tracking detectors need to be known well within their respective hit resolutions.

To determine the positions of the detectors well within their hit resolutions, a generic track based alignment framework for the LHCb detector has been developed. The novelty of this framework is that it uses a Kalman filter track model and fit in the so-called *global method of alignment* procedure. In this procedure alignment offsets are determined through a global least squares method, in which not only the hits themselves are considered but also the correlations between the hits. This has the advantage that only a few iterations are required to determine the alignment offsets. Furthermore, the framework uses the same track model and fit as the standard LHCb reconstruction and physics analyses procedures. The obtained alignment offsets are therefore expected to be consistent with the track model and fit used in these procedures. An additional advantage of this alignment framework is the possibility to align all of the LHCb sub-detectors simultaneously or each sub-detector individually at any granularity.

This thesis presents the implementation and validation of the LHCb alignment framework. In a Monte Carlo validation study the effects of multiple scattering on the alignment procedure are studied. It is shown that it is possible to align two sub-detectors of different detection technology and with different hit resolutions simultaneously without requiring high momentum tracks ($> 10\,\mathrm{GeV}$) to eliminate multiple scattering effects. Furthermore, at most eight iterations are required for the procedure to converge and the obtained alignment offsets are consistent with the input mis-alignments. The obtained offsets also allowed to recover the nominal performance of

the LHCb detector with respect to the reconstruction of $J/\psi \to \mu^+\mu^-$ decays.

Using cosmic ray data from September 2008, various alignment procedures are explored to determine the positions of the OT C-frames and modules. It is shown that the determined alignment offsets are compatible with the OT survey offsets. Furthermore, systematic studies show that the statistical error in Δx is around $54\,\mu\mathrm{m}$ and that the systematic uncertainty is approximately $131\,\mu\mathrm{m}$. In comparison, an OT straw tube has a typical drift distance resolution of $200\,\mu\mathrm{m}$.

In another Monte Carlo study the effects of mis-alignments in the VELO and T-stations, respectively, on the reconstruction of $B_s^0 \to J/\psi\phi$ decays as well is their implications on the sensitivity to ϕ_s are investigated. It is shown that mis-alignments in the VELO and T-stations lead to a degradation in the $\mu^+\mu^-K^+K^-$ invariant mass resolution. This leads to an increase of the observed background and consequently to a dilution of the purity of the signal, which in turn leads to a worse measurement of ϕ_s. Though the effect of this is limited in the case of the analysis of $B_s^0 \to J/\psi\phi$ decays, it can be large in analyses of B decays with either a poor sensitivity, such as $B_s^0 \to \mu^+\mu^-$, or in which different decays with identical topologically states need to be kinematically separated, *e.g.* $\overline{B_d^0} \to K^-\pi^+$ versus $B_s^0 \to K^-\pi^+$. Furthermore, it is shown that the $\mu^+\mu^-K^+K^-$ invariant mass resolution can be improved by applying a J/ψ mass constraint in the vertex reconstruction procedure, even in the presence of mis-alignments in the VELO and T-stations, respectively.

Of importance in the analysis of $B_s^0 \to J/\psi\phi$ decays is the reconstructed B_s^0 proper time resolution, which directly affects the sensitivity to ϕ_s. It is shown that the reconstructed proper time resolution is predominantly affected by mis-alignments in the VELO. This is a consequence of the fact that for short living particles the proper time resolution is practically constant and proportional to the hit resolution of the VELO. Mis-alignments in the T-stations, which have an effect on the momentum resolution of the reconstructed particles, start having an effect on the reconstructed proper time resolution when the reconstructed proper time is approximately seven times the B_s^0 lifetime.

Finally, it is also shown, an initial mis-aligned detector can be recovered using the LHCb alignment framework and that the nominal performance of the LHCb detector with respect to the reconstruction of $B_s^0 \to J/\psi\phi$ decays is fully restored.