7. Performance of the Charged Particle Tracking Systems

Charged particle tracking has been studied with large samples of cosmic ray muons, $e^+e^-$, $\mu^+\mu^-$, and $\tau^+\tau^-$ events, as well as multi-hadrons. At this time, these studies are far from complete and the results represent the current status. In particular, many issues related to the intrinsic alignment of the SVT and the DCH, the variation with time of the relative alignment of the SVT and the DCH, and movement of the beam position relative to $\mathbf{B_{Babar}}$ remain under study.

7.1. Track Reconstruction

The reconstruction of charged particle tracks relies on data from both tracking systems, the SVT and the DCH. Charged tracks are defined by five parameters ($d_0, \phi_0, \omega, z_0, \tan \lambda$) and their associated error matrix. These parameters are measured at the point of closest approach to the $z$-axis; $d_0$ and $z_0$ are the distances of this point from the origin of the coordinate system in the $x$-$y$ plane and along the $z$-axis, respectively. The angle $\phi_0$ is the azimuth of the track, $\lambda$ the dip angle relative to the transverse plane, and $\omega = 1/p_t$ is its curvature. $d_0$ and $\omega$ are signed variables; their sign depends on the charge of the track. The track finding and the fitting procedures make use of Kalman filter algorithm [54] that takes into account the detailed distribution of material in the detector and the full map of the magnetic field.

The offline charged particle track reconstruction builds on information available from the L3 trigger and tracking algorithm. It begins with an improvement of the event start time $t_0$, obtained from a fit to the parameters $d_0$, $\phi_0$, and $t_0$ based on the four-hit track segments in the DCH superlayers. Next, tracks are selected by performing helix fits to the hits found by the L3 track finding algorithm. A search for additional hits in the DCH that may belong on these tracks is performed, while $t_0$ is further improved by using only hits associated with tracks. Two more sophisticated tracking procedures are applied which are designed to find tracks that either do not pass through the entire DCH or do not originate from the IP. These algorithms primarily use track segments that have not already been assigned to other tracks, and thus benefit from a progressively cleaner tracking environment with a constantly improving $t_0$. At the end of this process, tracks are again fit using a Kalman filter method.

The resulting tracks are then extrapolated into the SVT, and SVT track segments are added, provided they are consistent with the expected error in the extrapolation through the intervening material and inhomogeneous magnetic field. Among the possible SVT segments, those with the smallest residuals and the largest number of SVT layers are retained and a Kalman fit is performed to the full set of DCH and SVT hits.

Figure 40. The track reconstruction efficiency in the DCH at operating voltages of 1900 V and 1960 V, as a function of a) transverse momentum, and b) polar angle. The efficiency is measured in multi-hadron events as the fraction of all tracks detected in the SVT for which the DCH portion is also reconstructed.
Figure 41. Reconstruction of low momentum tracks: the mass difference, \( \Delta M = M(K^-\pi^+\pi^+) - M(K^-\pi^+) \), both for all detected events (data points) and for events in which the low momentum pion is reconstructed both in the SVT and DCH (histogram). Backgrounds from combinatorics and fake tracks, as well as non-resonant data have been subtracted.

Any remaining SVT hits are then passed to two complementary standalone track finding algorithms. The first reconstructs tracks starting with triplets of space points (matched \( \phi \) and \( z \) hits) in layers 1, 3, and 5 of the SVT, and adding consistent space points from the other layers. A minimum of four space points are required to form a good track. This algorithm is efficient over a wide range of \( d_0 \) and \( z_0 \) values. The second algorithm starts with circle trajectories from \( \phi \) hits and then adds \( z \) hits to form helices. This algorithm is less sensitive to large combinatorics and to missing \( z \) information for some of the SVT modules.

Finally, an attempt is made to combine tracks that are only found by one of the two tracking systems and thus recover tracks scattered in the material of the support tube.

7.2. Tracking Efficiency

The efficiency for reconstructing tracks in the DCH has been measured as a function of transverse momentum, polar and azimuthal angles in multi-track events. These measurements rely on specific final states and exploit the fact that the track reconstruction can be performed independently in the SVT and the DCH.

The absolute DCH tracking efficiency is determined as the ratio of the number of reconstructed DCH tracks to the number of tracks detected in the SVT, with the requirement that they fall within the acceptance of the DCH. Such studies have been performed for different samples of multi-hadron events. Figure 40 shows the result of one such study for the two voltage settings. The measurement errors are dominated by the uncertainty in the correction for fake tracks in the SVT. At the design voltage of 1960 V, the efficiency averages 98 ± 1% per track above 200 MeV/c and polar angle \( \theta > 500 \text{mrad} \). The data recorded at 1900 V show a reduction in efficiency by about 5% for tracks at close to normal incidence, indicating that the cells are not fully efficient at this voltage.

The standalone SVT tracking algorithms have a high efficiency for tracks with low transverse momentum, polar and azimuthal angles in multi-track events. These measurements rely on specific final states and exploit the fact that the track reconstruction can be performed independently in the SVT and the DCH.

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The standalone SVT tracking algorithms have a high efficiency for tracks with low transverse momentum, polar and azimuthal angles in multi-track events. These measurements rely on specific final states and exploit the fact that the track reconstruction can be performed independently in the SVT and the DCH.

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The standalone SVT tracking algorithms have a high efficiency for tracks with low transverse momentum, polar and azimuthal angles in multi-track events. These measurements rely on specific final states and exploit the fact that the track reconstruction can be performed independently in the SVT and the DCH.

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The standalone SVT tracking algorithms have a high efficiency for tracks with low transverse
momentum. This feature is important for the detection of $D^*$ decays. To study this efficiency, decays $D^{*+} \rightarrow D^0 \pi^+$ are selected by reconstructing events of the type $B \rightarrow D^{*+} X$ followed by $D^{*+} \rightarrow D^0 \pi^+ \rightarrow K^- \pi^+ \pi^+$. For the majority of these low momentum pions the momentum resolution is limited by multiple scattering, but the production angle can be determined from the signals in innermost layers of the SVT. Figure 41 shows the mass difference $\Delta M = M(K^- \pi^+ \pi^+) - M(K^- \pi^+)$, for the total sample and the subsample of events in which the slow pion has been reconstructed in both the SVT and the DCH. The difference in these two distributions demonstrates the contribution from SVT standalone tracking, both in terms of the gain of signal events and of resolution. The gain in efficiency is mostly at very low momenta, and the resolution is impacted by multiple scattering and limited track length of the slow pions. To derive an estimate of the tracking efficiency for these low momentum tracks, a detailed Monte Carlo simulation was performed. Specifically, the pion spectrum was derived from simulation of the inclusive $D^*$ production in $B \bar{B}$ events, and the Monte Carlo events were selected in the same way as the data. A comparison of the detected slow pion spectrum with the Monte Carlo prediction is presented in Figure 42. Based on this very good agreement, the detection efficiency has been derived from the Monte Carlo simulation. The SVT significantly extends the capability of the charged particle detection down to transverse momenta of $\sim 50 \text{MeV/c}$.

7.3. Track Parameter Resolutions

The resolution in the five track parameters is monitored in OPR using $e^+e^-$ and $\mu^+\mu^-$ pair events. It is further investigated offline for tracks in multi-hadron events and cosmic ray muons. Cosmic rays that are recorded during normal data-taking offer a simple way of studying the track parameter resolution. The upper and lower halves of the cosmic ray tracks traversing the DCH and the SVT are fit as two separate tracks, and the resolution is derived from the difference of the measured parameters for the two track halves. To assure that the tracks pass close to the beam interaction point, cuts are applied on the $d_0$, $z_0$, and $\tan \lambda$. The results of this comparison for the coordinates of the point of closest approach and the angles are shown in Figure 43 for tracks with momenta above $p_t$ of $3 \text{ GeV/c}$. The distributions are symmetric; the non-Gaussian tails are small. The distributions for the differences in $z_0$ and $\tan \lambda$ show a clear offset, attributed to residual problems with the internal alignment of the SVT. Based on the full width at half maximum of these distributions the resolutions for single tracks can be parametrized as

$$
\sigma_{d_0} = 23 \mu m \quad \sigma_{\phi_0} = 0.43 \text{ mrad} \\
\sigma_{z_0} = 29 \mu m \quad \sigma_{\tan \lambda} = 0.53 \times 10^{-3}.
$$

The dependence of the resolution in $d_0$ and $z_0$ on the transverse momentum $p_t$ is presented in
The measurement is based on tracks in multi-hadron events. The resolution is determined from the width of the distribution of the difference between the measured parameters, $d_0$ and $z_0$, and the coordinates of the vertex reconstructed from the remaining tracks in the event. These distributions peak at zero, but have a tail for positive values due to the effect of particle decays. Consequently, only the negative part of the distributions reflects the measurement error and is used to extract the resolution. Event shape cuts and a cut on the $\chi^2$ of the vertex fit are applied to reduce the effect of weak decays on this measurement. The contribution from the vertex errors are removed from the measured resolutions in quadrature. The $d_0$ and $z_0$ resolutions so measured are about 25 $\mu$m and 40 $\mu$m respectively at $p_t = 3$ GeV/c. These values agree well with expectations, and are also in reasonable agreement with the results obtained from cosmic rays.

Figure 44. Resolution in the parameters $d_0$ and $z_0$ for tracks in multi-hadron events as a function of the transverse momentum. The data are corrected for the effects of particle decays and vertexing errors.

Figure 45 shows the estimated error in the measurement of the difference along the $z$-axis between the vertices of the two neutral $B$ mesons, one of them is fully reconstructed, the other serves as a flavor tag. The rms width of 190 $\mu$m is dominated by the reconstruction of the tagging $B$ vertex, the rms resolution for the fully reconstructed $B$ meson is 70 $\mu$m. The data meet the design expectation [2].

While the position and angle measurements near the IP are dominated by the SVT measurements, the DCH contributes primarily to the $p_t$ measurement. Figure 46 shows the resolution in the transverse momentum derived from cosmic muons. The data are well represented by a linear function,

$$p_t = p_t^0 + (0.45 \pm 0.03)\% p_t + (0.45 \pm 0.03)\%,$$

where the transverse momentum $p_t$ is measured in GeV/c. These values for the resolution parameters are very close to the initial estimates and can be reproduced by Monte Carlo simulations. More sophisticated treatment of the DCH time-to-distance relations and overall resolution function are presently under study.

Figure 47 shows the mass resolution for $J/\psi$ mesons reconstructed in the $\mu^+\mu^-$ final state, averaged over all data currently available. The reconstructed peak is centered 0.05% below the expected value, this difference is attributed to the remaining inaccuracies in the SVT and DCH alignment and in the magnetic field parameterization. The observed mass resolution differs by 15%
Figure 46. Resolution in the transverse momentum $p_t$ determined from cosmic ray muons traversing the DCH and SVT.

Figure 47. Reconstruction of the decay $J/\psi \rightarrow \mu^+\mu^-$ in selected $B\overline{B}$ events.

for data recorded at the two DCH HV settings, it is $13.0 \pm 0.3$ MeV/c$^2$ and $11.4 \pm 0.3$ MeV/c$^2$ at 1900 V and 1960 V, respectively.

7.4. Summary
The two tracking devices, the SVT and DCH, have been performing close to design expectations from the start of operations. Studies of track resolution at lower momenta and as a function of polar and azimuthal angles are still under way. Likewise, the position and angular resolution at the entrance to the DIRC or EMC are still being studied. Such measurements are very sensitive to internal alignment of the SVT and relative placement of the SVT and the DCH. A better understanding will not only reduce the mass resolution for the reconstruction of exclusive states, it will also be important for improvement of the performance of the DIRC.