BaBar VDET Alignment Requirements

David Brown, LBL

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Abstract

The job of precisely determining the position of the vertex detector silicon wafers is planned to be performed using tracks from collision data. Previous e^+e^- experiments with similar silicon vertex detectors have achieved an alignment precision which does not substantially degrade the VDET point resolution using this technique [1]. The track-based alignment procedure requires special algorithms, dedicated software, and a certain amount of reasonable quality collision data. In this note the proposed alignment procedure is briefly outlined, and the amount of data necessary for good alignment of the current BaBar VDET design is estimated.

1 Track-based alignment

Because the vertex detector point resolution is much more precise than the drift chamber, the VDET alignment must rely primarily on self-consistency constraints. The most powerful such constraint comes from the overlap between wafers adjacent in ϕ. Another important constraint comes from muon-pair events. In these events knowledge of the mass, boost, and common origin of the 2-track system allows constraints to be made between hits on opposite sides of the VDET. Constraints using the redundancy of the VDET layers are also useful.

The drift chamber still plays an important role in the VDET alignment. The DC is needed both for identifying good events with which to perform the alignment, and for identifying useful tracks in those events. Drift chamber tracks will be needed to perform simple VDET pattern recognition during alignment, and to provide initial track parameters in the VDET alignment. Thus, a functioning and reasonably-aligned DC is a precondition to performing the VDET alignment.

Precise calibration and alignment of the drift chamber will require information from the aligned VDET [1]. Feedback from the VDET on the DC alignment and calibration is also necessary to insure consistency between the two devices, an essential requirement for VDET pattern recognition using DC tracks. These cross-connections between the VDET and the DC imply that the VDET and DC alignments will have to be performed iteratively.

Implicit in this paper is the assumption that the VDET alignment is static in time. Given that the VDET layers are not mounted to the same support as the DC, it is not obvious that motion between the two will not occur. Relative VDET/DC motion over the time-scale needed to accumulate the alignment events could seriously compromise the resulting alignment, and should therefore be carefully monitored. One possible monitoring system would be laser spots flashed onto the VDET wafers from fibers mounted directly on the DC. This solution would be problematic to engineer for the inner layers of the VDET.

2 VDET alignment parameterization

The VDET alignment is proposed to be parameterized as a pair of nested transformations. The first (global) will describe the position and orientation of each detector layer considered as a rigid body, relative to the DC. The second (local) will describe the position and orientation of each silicon wafer relative to its nominal position in the layer. This parameterization is slightly redundant, but convenient, as explained below.

Additional parameters are also needed to define positions from VDET hits, namely the $\vec{E} \times \vec{B}$ shift and the effective charge deposition depth. The $\vec{E} \times \vec{B}$ shift drops out in the local alignment, but is still nice to know for Monte Carlo purposes. The effective charge depth also drops out of the local alignment if it is the same for both readout directions. ALEPH has shown that, on average, the two depths are compatible [1]. Even so, there is no physical principle which constrains the two depths to be equal, and we should be prepared to introduce an additional (7th) local alignment parameter to the parameterization giving the difference in the effective charge depth of the two views should this prove necessary. A direct determination of both the $\vec{E} \times \vec{B}$ shift and the effective charge depths using a test-beam is desirable.

3 VDET global alignment

The VDET global alignment is more a matter of convenience than necessity, as its degrees of freedom are redundant with those of the local alignment. Previous experiments have shown however that a good global alignment helps speed the convergence of the local alignment, and allows a simple, low-statistics check of time-dependent effects such as detector motion. Global alignment must assume some local alignment, which can be the nominal wafer positions, or the current (measured) local alignment. The procedure depends completely on the DC tracking, simply requiring consistency between VDET hits and the extrapolated DC track positions. Systematic effects limit the accuracy of the global alignment to $\sim 50\mu$m. Assuming an accuracy of $\sim 2mm$ for the DC track extrapolation in the Z direction, this implies that a global alignment can be performed with $\sim$ 2000 tracks. Further assuming 2 useful (high momentum) tracks per event, we find that 1000 hadronic events will suffice to perform a global alignment.

4 VDET local alignment

As mentioned above, the local alignment of the VDET gets most of its statistical precision from the active area overlap between ϕ-adjacent wafers. The overlap directly constrains 3 of the 6 geometric degrees of freedom of each wafer, namely those that define its position in the nominal wafer plane. A further strong constraint on the wafer translation in the out-of-plane direction comes from combining the overlap information for all wafers in a given layer. This is essentially a circumference constraint, using the fact that the size of the wafers is precisely known. The overlaps also provide weaker constraints on the 2 out-of-plane rotations.

Overlaps do not however constrain the relative positions of the different layers, nor the relative positions of the different *annuli* which comprise the layer. An annulus is here defined as the set of wafers in a layer all having the same Z position. The relative positions of these sets of wafers is best obtained using $e^+e^- \rightarrow \mu^+\mu^-$ events. Because the energy and boost of the system are known a-priori, as well as the fact that both tracks come from a common origin, only 3 parameters are necessary to describe both tracks in the event. These 3 parameters can be determined using VDET hits in any 2 layers, and the resulting track can be extrapolated and compared with the hits observed in the other layers. By carefully choosing which of all possible combinations of constraints and comparisons to make, the relative positions of all the layers and annuli can be determined using the muon pair events. Combining the overlap and the muon-pair event constraints, the *average* difference in the effective charge depths of the two views can also be determined.

Overlaps plus muon pair events in principle constrain all the degrees of freedom for the local alignment. A valuable consistency check comes from over-constraining the system, using tracks in hadronic events. These are best used by comparing the track angle measured in different pairs of layers. The self-consistency of the over-constrained system provides a valuable estimate of the systematic error in the final alignment.

Optimal use of the alignment information provided by overlaps, muon pair events and multi-layer hadronic tracks is made by applying their constraints simultaneously. In principle, this implies minimizing a single chi-squared for a huge ($6 \times N_{wafers}$) number of degrees of freedom. In practice, the problem can be partially diagonalized and solved iteratively. The experience of ALEPH was that a sensibly designed iterative alignment procedure converges rapidly (within a few hours), and gives a result close enough to the true chi-squared minimum that the difference contributes negligibly to the total alignment error.

5 Local alignment event needs

The number of events needed to perform the local VDET alignment can be roughly estimated using the overlap and muon pair constraints. Given that virtually every high-momentum hadronic track can be used to make the multi-layer angle constraint, these place no additional requirements on the number of events needed to perform the alignment.

In the following arguments, we assume that each wafer is aligned separately for 6 (geometric) degrees of freedom. It is possible that construction-time measurements of relative wafer positions on a ladder might reduce the total number of degrees of freedom. It is also possible that non-geometric effects (unequal effective charge depths for the 2 views, wafer bowing) might increase the number.

We start by assuming that the alignment should not contribute significantly ($< 5\%$) to the VDET point resolution. This implies that each wafer position must be known to better than 30% of its average point resolution. The average resolution of the the overlap and muon pair *residuals* can be simply calculated. We assume the accuracy of the alignment scales according to the square root of the number of constraints, and from that compute the number of tracks needed. Basic assumptions about acceptance and efficiency then give us the number of events needed.

For the overlaps, the extrapolation distance between wafers is small, so that multiple scattering is negligible for medium momentum ($> 500 MeV$) tracks. Thus, the statistical power of each overlap is ~ 1.4 times the point resolution. Taking into account the rotational degrees of freedom adds another factor of ~ 1.4. For the inner 3 layers, the tracks traverse the overlap at a substantial angle, worsening the resolution relative to the average wafer resolution by an additional factor of ~ 1.4. The number of tracks needed per wafer is given by the square of the available resolution divided by the desired accuracy. Putting together the above numbers then implies that each inner (outer) layer wafer needs a total of 80 (40) tracks through its active overlap in order to be well aligned.

To translate this into numbers of events, we use the current proposed VDET geometry [2]. We assume 4 usable (medium-momentum) tracks per event, based on plots produced by BBSIM. The overlap solid angle and number of wafers are different for each layer, and are given in table 5. Multiplying these out gives the number of events needed by layer, which is also listed in table 5. Layer 5 is seen to set the limit, needing $\sim$ 75K hadronic events to be precisely aligned. This is mainly because

Layer	Overlap Ω	# wafers	# Tracks/wafer	# hadronic events
1	$\sim 2.4\%$	24	80	$\sim$ 20K
2	$\sim 1.8\%$	24	80	$\sim$ 27K
3	$\sim 1.8\%$	36	80	$\sim$ 40K
4	$\sim 4.0\%$ (4.8%)	112	40	$\sim$ 28K (24K)
5	$\sim 2.0\%$ (1.9%)	144	40	$\sim$ 74K (77K)

Table 1: Properties of the different VDET layers, and the number of hadronic events these imply for an accurate alignment. The values in parentheses for layers 4 and 5 correspond to the wedge modules.

Layer	Track σ	Hit σ	# annuli	# muon pair events
1	25 μm	10 μm	4	$\sim$ 225
2	30 μm	10 μm	4	$\sim$ 325
3	50 μm	10 μm	6	$\sim$ 1300
4	80 μm	30 μm	7	$\sim$ 4000
5	100 μm	30 μm	8	$\sim$ 7000

Table 2: Properties of the different VDET layers, and the number of muon-pair events these imply for an accurate alignment.

of the large number of wafers in this layer.

The effect of the muon pairs on the alignment is less direct, and our calculation of the number of events needed is somewhat arbitrary. We assume that the 3 parameters defining the muon trajectory have been measured with essentially no error on one side of the VDET, and this trajectory is compared to hits on the opposite side. The tracks are presumed to have 2.5 GeV momentum, and the material of each layer is presumed to be 0.5% of a radiation length on average. This gives the resolution of the track extrapolation due to multiple scattering as presented in table 5, which is seen to dominate the total (extrapolation $\oplus$ intrinsic) resolution. We again require an alignment precision of 30% of the intrinsic resolution for each annulus of a given layer (the wafers within an annulus are assumed to be aligned using overlaps), giving the number of muon pair events needed per annulus. Multiplying by the number of annuli gives the total number of events needed. Layer 5 is again seen to require the most events, needing 7K muon pair events to be accurately aligned. Using the PDG value of $R \simeq 3.8$ at the upsilon 4S, this implies an equivalent of 27K hadronic events. Thus the overlaps set the overall minimum number of events needed to align.

6 Conclusion

Previous experiments have shown that a silicon VDET is best aligned using track data self-consistency constraints. Applying established techniques to the proposed BaBar geometry implies that a minimum of $\sim$ 75K events (hadronic equivalent) are needed for a precise VDET alignment. The VDET position relative to the DC during this time must either remain constant, or be carefully monitored, for the alignment procedure to function correctly.

References

[1] D. Brown, ALEPH Internal Note 92-10, 1992.

[2] Drawings presented at the December 1994 collaboration meeting.