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ACE*

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- AMY CDC Fast Track Finder -

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Abstract

The central drift chamber (CDC) of the AMY detector at the TRISTAN e^+e^- collider features its fine granuarity and multi-band structure. The tracking software named ACE which makes the most of these features shows an excellent performance for reconstruction of high multiplicity events with highly collimated jets. The obtained reconstruction efficiency is 97% for the particles coming from within 5 cm of the primary vertex with $p_t \geq 500$ MeV/c in the simulated hadronic events. The processing time is on average less than 300 ms per hadronic event (simulated or real) on a FACOM M-382 computer.

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1. Introduction

Hadronic events observed at the TRISTAN e^+e^- collider tend to have narrow jets of many charged particles. Reconstruction of the particle trajectories under such circumstances is not an easy task and requires some special considerations for both hardware and software of the tracking device.

The central drift chamber (CDC) of the AMY detector features its fine granuarity and multi-band structure to aid efficient and fast tracking. The chamber configuration of CDC is indicated in Fig. 1. It consists of 6 bands; the innermost band has 5 axial cylinders of wires; each of the outer 5 bands has 4 axial and 3 stereo cylinders of wires. The cell configuration of an outer band is shown in Fig. 2. The band structure enables a fast resolution of left-right ambiguities and also allows for the determination of independent track vectors at each band.

I present here a tracking software named ACE (AMY CDC Event Tracker), which makes the most of these good features of CDC and demonstrate that it is fast and efficient even for high multiplicity events with narrow jets.

2. Track Finding in r-ϕ Plane

The hit axial wires are first searched to reconstruct tracks in the r-ϕ plane, the plane perpendicular to the beam axis.

Shown in the Fig. 2 is an example of the response of a CDC band to charged tracks which come from the primary vertex, i.e., our co-ordinate origin. High momentum tracks (i.e. $p_t > 1\mathrm{GeV/c}$) are always close to the radial direction and the resolution of the left-right ambiguities is quite straight-forward. For lower momentum tracks which traverse outer bands with angles the mirror image of the correct left-right choice may yield a "ghost" track vector.

For each hit wire on the innermost layer (or next to the innermost) of a band, hit wires are searched for in the neighboring wires in the other layers of the band. This search for hit wires is done within the pattern of the wires indicated in Fig. 3. It allows us to find track vectors with p_t as low as 250 MeV/c for the middle bands. At least 3 hits (each hit in a different layer) are required to make a vector. This allows for one missed hit in a band, giving a cure to the problems of the chamber inefficiency and two close tracks traversing the same wire cell. Note that by reconstructing vectors we can efficiently reject noise hits caused by background synchrotron radiation etc.

All the vector candidates are then fitted to straight lines; they can be reasonably approximated as straight lines of the form, $\psi_i - \phi = \xi(r_i - r_1)$, where i =1,2,3,4. Here r_i refers to the radius of the i^{th} layer of the band, and ψ_i the azimuthal angle of the corresponding hit. ϕ and ξ are obtained from the fit. Only the vectors with reasonable χ^2 are accepted. The "ghost vectors," usually giving good χ^2, will be also accepted.

On a reasonable assumption that the track comes from the origin and describes a circle, the track parameters C and ϕ_0 are calculated from ϕ and ξ for each track vector, where C is the curvature of the track circle (defined as an inverse of the radius) and ϕ_0 the tangential angle at the origin (see Fig. 4):[1]

$$\phi_0 = \phi - \beta, \quad C = -\frac{2\sin\beta}{r_1},$$

where $\beta = \arctan(r_1\xi)$. All the track vectors which are part of the same track should have the same values of C and ϕ_0. Comparing these values for vectors in differnt bands, therefore, enables us to find complete tracks very quickly. Shown in Fig. 5 is a ϕ_0-C scatter plot of the vectors in a sample event shown in Fig. 7. Clusters of points which correspond to tracks are clearly seen.

As can be seen from Fig. 5, the vectors tend to cluster along lines with similar gradients, because errors in calculating C and those in calculating ϕ_0 are closely correlated. It is easily shown from the eqs. above that $dC/d\phi_0 \simeq -2/r_1$ for tracks with $r_1C/2 \ll 1$, i.e., p_t >400 MeV/c. The average value of $2/r_1$ is about 0.045 cm^{-1} for our CDC, which agrees with the global slope of Fig. 5.

Since clusters tend to be separate along the axis perpendicular to the global slope, a parallelogram-shaped window as shown in Fig. 5 is used to search for clusters. The search starts from the outermost vector and goes inward. The found cluster is stored only if it contains vectors from different bands. The size of the window is rather large, typically three times the expected spread of the cluster, to avoid dividing a cluster into two.

The cluster thus found usually contains ghost vectors in addition to real ones. Furthermore, it may consist of two close tracks. Here we utilized a modified "Link-and-Tree" method[2] to find good track candidates in the cluster. Two vectors in neighboring bands are linked if the distance between them in the ϕ_0-C plane is smaller than a certain value. By linking all possible combinations of vectors in the cluster, we make "trees" of vectors. Then the longest chain in a tree is chosen as the best track candidate. (The length of the chain is defined as the number of vectors in it.)

The track candidate is finally fitted to a circle. Note that only reasonably good track candidates can survive for fitting; the time-consuming circle-fit is thus avoided as much as possible. Only tracks giving good χ^2 of the fit are finally accepted. We also throw out a track whose closest approach to the origin is more than a certain value (typically 5 cm), reflecting our earlier assumption made to calculate C and ϕ_0. For the accepted tracks, the hits located far from the fitted track are rejected while new hits sitting within an acceptable distance from the track are accepted. This process of fitting and refining the hits is repeated until no hit gets rejected or newly accepted.

3. Z-Reconstruction and Final Fitting

For each r-ϕ track thus found, z coordinates are reconstructed by selecting an appropriate combination of the stereo hits. (We call it a z-track.) For each r-ϕ track all the hit stereo wires which cross it are collected. The z-coordinate and the arc length, s, defined in Fig. 4 are then calculated for each stereo hit. It is easy to see that z and s are in proportion to each other for the hits which compose a track. As an example, shown in Fig. 6 is the s-z scatter plot of the stereo hits collected for one of the r-ϕ tracks in Fig. 7. The correct z-track appears as a straight line in the plot. So the z-track reconstruction is just equivalent to reconstructing a straight line in the s-z plot. We adopted an algorithm very similar to that used for the r-ϕ track finding: firstly track vectors are reconstructed in each band; then using a modified "Link-and-Tree" method the vectors are linked and the z-track candidates are sorted out; finally a straight-line fit is applied and the best track which passes the final criteria is stored. It is important to note that the z-track finding has no bias on tracks coming from the primary vertex unlike the r-ϕ tracking.

Since we have only 3 layers of stereo wires in each band, we decided to accept vectors with only two hits. This choice leaves us many fake vectors; with left-right ambiguities two hits yield 4 vectors in total. This increases the number of the z-track candidates. But it does not significantly increase the CPU time, because the straight-line fit is much faster than the circle fit.

Now we have tracks reconstructed in three dimensional space, the final chamber corrections are carried out, and then they are fitted again. Its momentum vector is calculated from the track parameters. Because of the non-uniformity of the magnetic field inside CDC (7-8% at maximum), we use an empirical formula to get the momentum, $p_t = f(\theta, C)/C$, where f is determined from the simulation. Errors of this simple formula are found to be smaller than the current momenutum resolution of CDC, $\sigma_{p_t}/p_t \simeq 0.9\%\ p_t(\mathrm{GeV/c})$, if $p_t \geq 500$ MeV/c.

Currently we are working on a 3-dimensional fitting routine which takes the non-uniformity of the field into consideration. Since this routine corrects the particle's trajectory itself, the correct direction of the particle at any spacial point can be obtained.

5. Results of Tracking

We have been running ACE with our real and simulated events of all kinds on the FACOM M-382 system at the KEK computer center. What have been known about the results of the ACE tracking follow here.

ACE is very fast: it takes less than 300 msec per hadronic event, whether it is simulated or real, on a FACOM M-382 computer. It is also quite efficient: roughly 97 % of the particles coming from within 5 cm of the primary vertex with $p_t \geq 500$ MeV in the simulated hadronic events are reconstructed with the quality expected from the assumed spacial resolution.

There are also a few drawbacks to ACE. First, it fails to find tracks that do not pass nearby the origin, so some secondary particles which are created at a distance from the primary vertex may not be reconstructed. But since the track vectors of those secondary particles are properly reconstructed by ACE, it would not be difficult to extend the current algorithm so they can be linked to yield tracks. Secondly, ACE is not very efficient for low momentum tracks, i.e., the tracks with $p_t < 400$MeV/c, because at least two fairly radial vectors are required for reconstruction. This problem can be solved by expanding the search pattern for the vectors after finding high momentum tracks.

Thus these problems will be overcome by the slight improvements of ACE, which is forth-coming. But currently, in order to cure these problems, we have adopted to use a second-stage tracking program, DUET,[3] to back up ACE's tracking. DUET takes the tracks found by ACE, refines them, and tries to reconstruct unfound tracks. This program uses a rather conventional but unbiased search method. But it is essential that most of the tracks have been already found by ACE, since DUET easily consumes a considerable amount of CPU time. From the CPU time considerations, therefore, the forth-coming upgrading of ACE would be greatly beneficial.

6. Conclusion

Here I have presented a new track finding program designed to take its advantage of the band structure of AMY CDC. This program, ACE, has been successfully used as a fast event tracker to select from a large sample of data taken by our collaboration. Furthermore, supported by a more conventional tracking program, it also serves the purpose of final intensive tracking.

It is demonstrated that the tracking device which allows to reconstract track segments locally and unambiguously is very powerful in analyzing the complex events with narrow jets and high multiplicity if a proper tracking software is accompanied.

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2) D.G. Cassel and H. Kowalski, Nucl. Inst. Methods **185**, 235 (1981).

3) D.G. Cassel and M. Ogg, "DUET - a Track-Finding Program for Cylindrical Geometries", CLEO Internal Report, December 1983 (unpublished)

Figure 1 : Central Drift Chamber

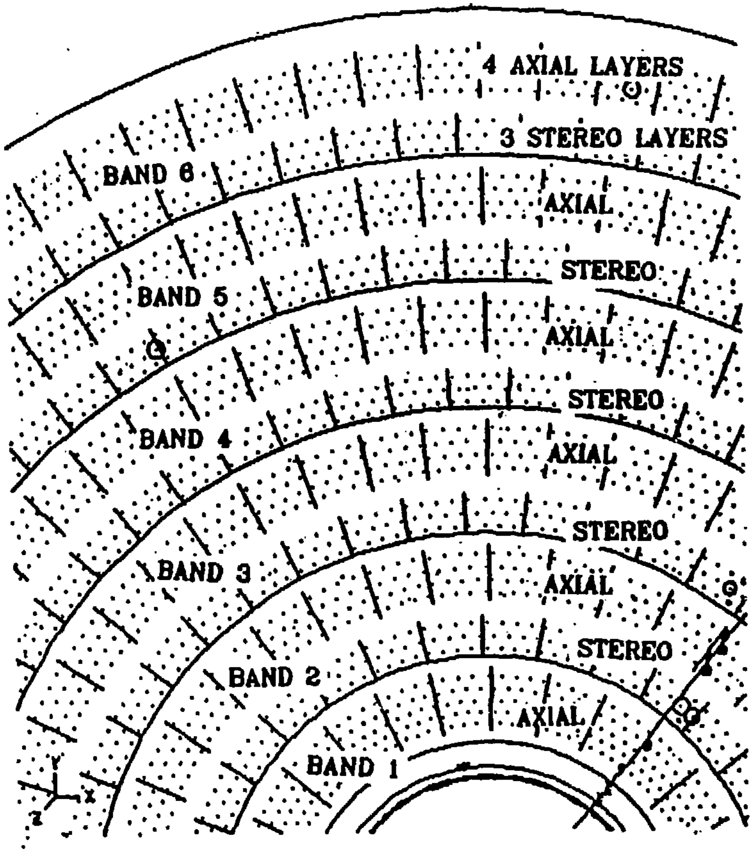


Figure 2 : Cell Configuration of CDC

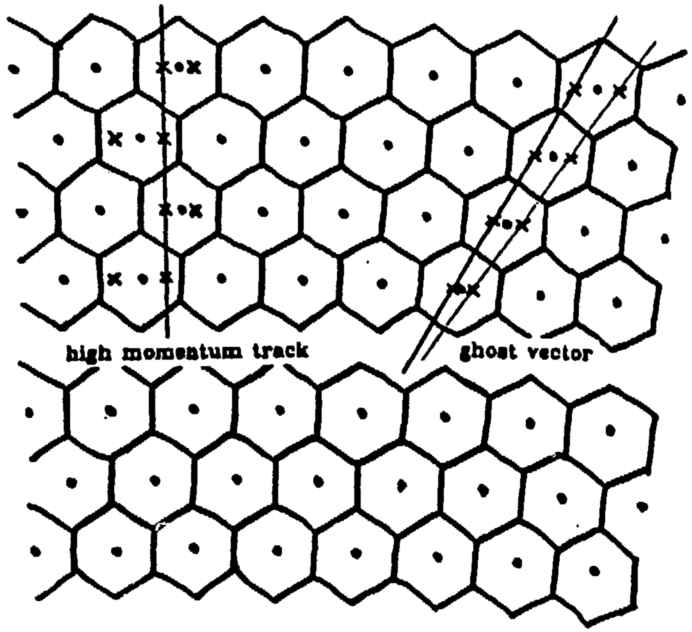
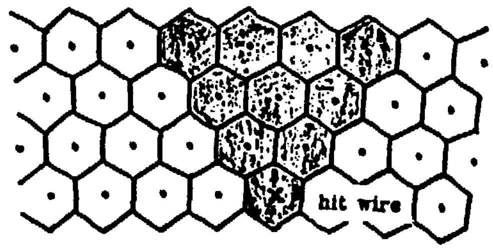


Figure 3 : Search Pattern for Vectors



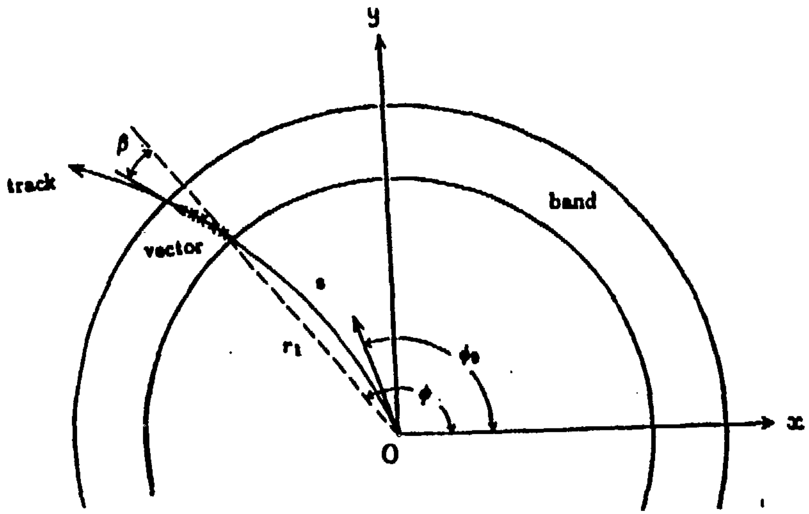
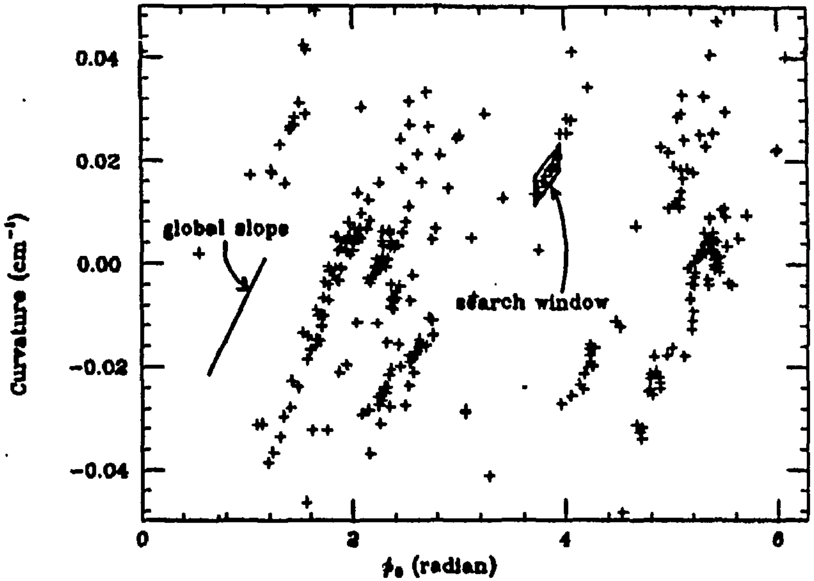


Figure 4 : Geometry of a Circular Track

Figure 5



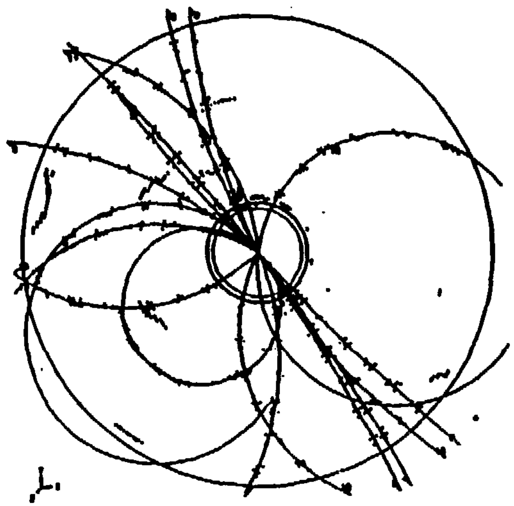


Figure 7 : A Real Hadronic Event Reconstructed by ACE

Figure 6