第28卷 第7期 高能物理与核物理 Vol. 28, No. 7
2004年7月 HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS Jul., 2004

Track Finding of Cosmic Multi-muon Events in the L3 + C Muon Detector *

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Abstract We describe a track finding method based on the Combinatorial Hough Transform (CHT) in the large drift chambers of the L3 + C experiment at CERN. With the feature of near parallelism of muons in cosmic multi-muon events, the dominant direction can be estimated from the histogram of directions of segments. Then the CHT in finding the whole track can be greatly optimized. The cross octant reconstruction program can efficiently reconstruct cosmic muon events with multiplicity up to 50.

Key words pattern recognition, Hough transform, cosmic rays, drift chamber

1 The L3 + C Detector

L3 + C[1] is a shallow depth underground cosmic ray muon experiment. The detector system mainly combines the high precision muon drift chambers of the L3 spectrometer[2] with T_0 scintillator detector covering the outside of the three top faces of the magnet as shown in Fig. 1. The muon drift chamber system (MUCH), with an octant shape in the plane perpendicular to the beam (11m in width and 11m in height) and a square shape in the plane along the beam (11m in length), installed in a $1000m^3$ magnetic field of 0.5 T was used to record cosmic ray muons and to measure their momenta.

In the L3 coordinate system, the plane perpendicular to the beam is defined as the x-y plane, while the z axis is parallel to the beam. Position information of the charged particles is observed in the x-y and the y-z plane separately. The momentum measuring, or "P" chambers, consist of signal wires parallel to the magnetic field, while the z chambers measure the coordinates of tracks in the y-z plane.

The L3 spectrometer is originally designed for L3, which is a collider experiment. So the system is symmetrical with respect to the beam line. The symmetry is realized not only geometrically, but also in the software aspect. This feature fits the data from LEP well, but does not bring benefit when measuring the particles from cosmic rays, which arrive downward without fix vertices (Fig. 2). Muons in the collider events only pass single octant. So Track finding can be proceeded in each octant locally. But most cos-

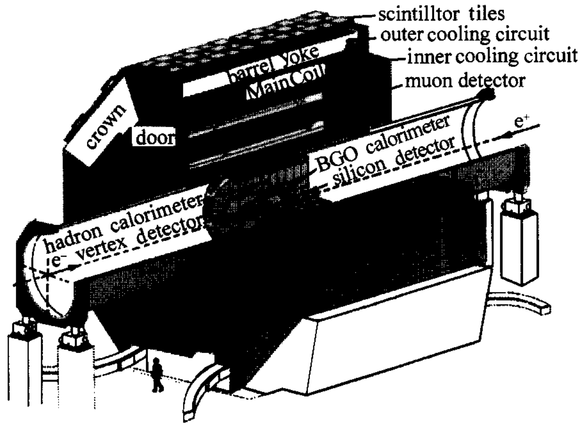

Fig. 1 The L3 spectrometer.
Only the muon detectors, the magnet and the scintillator tiles were used in this experiment.

Received 16 December 2003, Revised 12 February 2004
* Supported by National Natural Science Foundation of China (19999500)
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mic muons cross octants. A more general track finding algorithm is required.

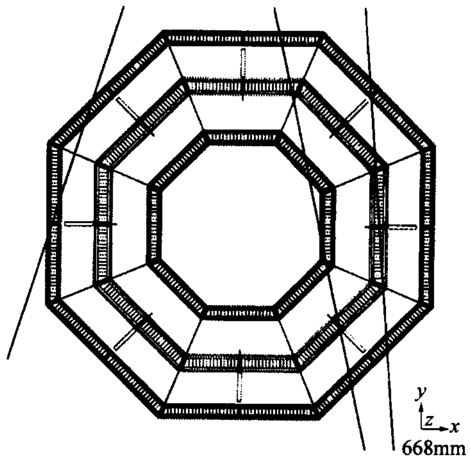

Fig.2 Typical cross octant tracks.

2 Methods of Track Finding

Methods of track finding can be classified as global and local[3]. The method is called global if all objects (hits or points) enter the algorithm in the same way. The Hough transform (HT)[4] is a typical method in this catalog. PHENIX[5], Atlas and D0 use the HT in the track finding program. On the contrary, the local method is one that selects one track candidate at a time by starting with a few points only. The Kalman filter [6] is an example of the local method.

The standard Hough transform (SHT) is an algorithm popular in image processing and computer vision. It has received much attention as a powerful method of track finding in particle detectors. The algorithm is a transformation between the image space and the parameter space. For instance, a straight line can be parameterized by slope and intercept, which will form a 2-dimensional parameter space. Every point in the image space is transformed into a line in the parameter space and vice versa. If n points are collinear, the line parameters in the image space correspond to a peak in the parameter space, produced by the intersection of n lines.

A variation on the SHT for general image-processing about ten years ago has been proven to be much better suited to the drift chamber tracking. In this "combinatorial Hough transform" (CHT)[7] the image points (drift chamber hits) are mapped pair-wise into the parameter space. In the SHT the nominal peak height is equal to the number of points n on the track; in the CHT, on the other hand, the peak height is $n(n-1)/2$.

3 Track Finding in Cross Octant Reconstruction

In each octant of MUCH, there are 3 layers of P chambers separated widely in space. The distance of two adjacent P chambers is ~1.4m, while the thickness of a P chamber is ~30 cm or 45 cm. So a track is only sampled within small parts of the octant. The momentum of a muon cannot be measured precisely within a single layer. Consequently the track finding in P chambers is composed of two steps: Firstly, the short track elements, the so-called P segments, are locally recognized among hits within each fired P chamber. Then the P segments are combined into P tracks. Here all the combinations of P segments within the whole detector are considered. So the cosmic muons, many of which cross octants (Fig.2) can be recognized. A P track is made up of 2 to 6 P segments. After that, the P tracks are matched with Z segments in the other projection to form 3-dimensional tracks. There are much fewer sense wires in Z chambers, so the tracks are mainly recognized in P chambers.

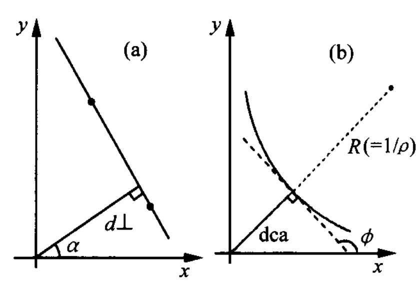

Fig.3 The parameters of CHT in the recognition of (a) P segment; (b) P track.

CHT is used in both steps of the track finding in P chambers. Within the thickness of a P chamber and the magnetic field of 0.5 T, a P segment induced by a muon with momentum in the range we are interested in (>0.5 GeV) can be well parameterized by a straight line. The two parameters used are $d_{\perp}$ and α. They are defined as Fig. 3 (a) $d_{\perp}$ and α form a 2-dimensional parameter space. Hits in a typical P segment is transformed by CHT into the parameter space as Fig. 4 (a). The two peaks reflect the ambiguity nature of signals in the drift chamber. This ambiguity will be resolved in the P track recognition phase. Omitting the multiple scattering and energy loss, a track with a length at the order of several meters can be described by an arc with 3 parameters: curvature (ρ), the distance of closest approach (d_{ca}) to the origin and the direction of propagation (ϕ) at the point of closest approach as shown in Fig. 3 (b). A fast method for circular trajectory fitting [8] is used upon such parameterization. A sample of double muon event is recognized as Fig.4 (b) in the plane of ρ and dca. Only those combinations with enough small χ^2 are considered as valid entries and plotted.

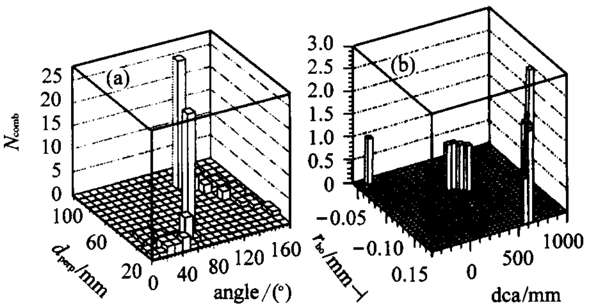

Fig. 4　The parameter space in CHT.
(a) The parameter space in the recognition of P segment;
(b) The parameter space in the recognition of P track.

4　Optimization of the Hough Transform

The number of combinations and then the possibility of chance matching, increase with the number of elements to the power 2. Multi-muon events, with much more P/Z segments than single muon events, will bear more errors and lower reconstruction efficiency. For the events with a multiplicity greater than 10, special consideration is implemented based on the feature of near parallelism of cosmic muons. The following procedure is taken before CHT is used to search for P tracks.

1. The direction of each P segment in the x-y plane is calculated. The histogramming method is used to find the dominant direction of the event. For a typical multi-muon event, Fig. 5 shows the distribution of the phi angle of the P segments passing a χ^2 cut of 20. Although there are some small peaks caused by ambiguities, the real P segments form the major cluster at the direction of the event.

2. Due to the ambiguity of P segments, about half of them are fake. So before the combination is made, a certain ratio of P segments are filtered out by their deviation to the dominant direction. In the example of Fig. 5, most part of the small peak centered at 70°, which is the furthest from the dominant direction of 10°, are got rid of.

3. For each combination, the rough direction is calculated with the master points of the P segments. The combinations outside a window centered at the dominant direction are canceled.

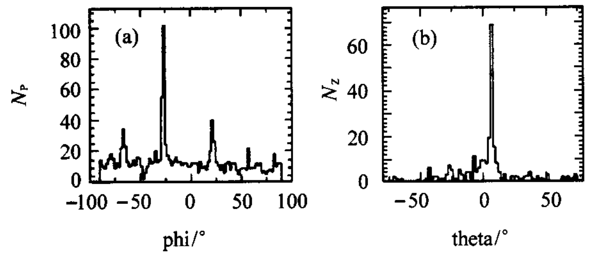

Fig. 5　Calculation of the dominant direction in the x-y plane and the y-z plane of a sample event with the multiplicity of 40.
(a) The distribution of phi (angle with respect to y axis in the x-y plane) of P segments with good quality; (b) The distribution of theta (angle with respect to y axis in the y-z plane) of Z segments with good quality.

After the dominant direction (the major peak at the left plot in Fig.5) in the x-y plane is obtained, a similar procedure is taken at the y-z plane. For each Z segment passing a χ^2 cut, the global theta angle is calculated. As shown in Fig. 5, the dominant direction at the projection in the y-z plane is also distinct. Those Z segments far away from the direction are filtered out.

This preprocessing greatly improves the reconstruction efficiency and reduces the execution time of reconstructing high multiplicity muon events.

5　Implementation and Performance

The tracking algorithm described above has been implemented in the L3 + C reconstruction package based on the L3 reconstruction software[9]. Compared with the original program, the reconstruction ratio on L3 + C raw-data of new algorithm is increased by about 40%. Track finding efficiencies for the algorithm were determined with the help of Monte Carlo simulations that include realistic detector response and position resolution. For the sample of single muon events generated within a $4m^2$ square above the T_0 detector with a zenith angle below 20°, the reconstruction efficiency is greater than 97%. The effieiency keeps constant for high momenta and drops precipitously at about $P_T = 5$GeV due to the multiple scattering and energy loss. For multi-muon events, the reconstruction efficiency keeps constant up to the multiplicity of 50.

6 Discussion

The detector structure influences the effect of track finding greatly. Each cell of the L3 + C P chamber consists of 16 (MI, MO) or 24 (MM) sense wires. Most P segments consist of 10 or more hits. In the CHT, the cluster is distinct and the possibility of chance matching is marginal. But the number of P segments in a P track ranges from 2 to 6. Most P tracks only have 2 to 3 P segments. The distance of P segments is relatively far. The chance matching appears more frequently especially for multi-muon events, in which there may be thousands of P segments. The influence of noises and the hits caused by very low momentum tracks cannot be omitted. To increase the ratio of correct track finding in events with a very high multiplicity, further improvement is needed.

We would like to thank Albert Van Mill, Bert Peterson, Henric Wilkens, Michael Unger, Volker Schmitt and Shu Zhang for their contribution to this collaborative work and productive discussions.

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L3+C μ子探测器中宇宙线多μ事例的径迹寻找*

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摘要 描述了在L3+C实验的大型漂移室中基于组合Hough变换(CHT)的径迹寻找方法. 针对宇宙线事例中μ子方向近似平行的特点,从径迹段的方向的直方图可估算出事例的主方向,从而大大优化寻找完整径迹的Hough变换. 跨卦重建程序可高效率的重建多重度在50以下的宇宙线多μ事例.

关键词 模式识别 Hough变换 宇宙线 漂移室

2003-12-16收稿,2004-02-12收修改稿

* 国家自然科学基金(19999500)资助

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