Novel Transformations for Very High Multiplicity Events

H. Drevermann — *CERN, Geneva, Switzerland*
D. Kuhn[1] — *Leopold-Franzens-Universität, Innsbruck, Austria*
B.S. Nilsson — *Niels Bohr Institute, Copenhagen, Denmark*

Abstract

A method to visually detect tracks from hits in high density events based on compressing and skewing of a ρ/ϕ presentation is described.

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1 Introduction

The LHC experiments will have to deal with very many outgoing particles per beam crossing. They stem from many simultaneous proton-proton interactions. This leads to an extremely high density of recorded hits in the inner tracking chambers.

From these hits tracks are reconstructed by a pattern recognition program. When using Monte Carlo data the track finding performance can be optimized by comparing the reconstructed tracks to the Monte Carlo input. However, in order to check the pattern recognition software and to understand its limits, visual inspection has proven to be an indispensable complementary tool. It is the only feasable one when dealing with real data.

For visual inspection it is necessary to recognize the relevant track pattern from the recorded data only. However, this is very difficult for high track densities and becomes even more difficult as in most of the new detectors hits are effectively recorded in two dimensions (u,v) only. The third dimension (w) is defined only very roughly, e.g. by the length of the subdetector or the length of the recording wire, so that it can only be used to divide the total data into different sets to be analysed separately. In this way the apparent hit density can be reduced.

Visual pattern recognition is simplified by the fact that only particles originating from the small central interaction region and leaving the inner detectors are of interest. The cylindrical inner detectors lie in a homogeneous field parallel to the cylinder axis (z). This means that only low curvature tracks passing through the center need to be recognized.

In the case of three dimensional hits, the V-Plot representation [1] allows us to identify such tracks. However, this technique cannot be applied to two-dimensional hits. Therefore it is of special interest to find methods to recognize tracks of particles of sufficiently high momentum through visualisation of two-dimensional hits. In the following, we propose a solution to this problem.

2 Method

The problem was studied by simulating the high track density by superimposing many real events of the ALEPH TPC to form one data set. The reduction to two dimensions was realized by

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ignoring the z-coordinate of the hits. Similar to the inner detectors of the LHC experiments, ATLAS and CMS, the ALEPH TPC lies in a homogeneous solenoidal magnetic field in the z direction, so that particles run along helices, which reduce to circles, if the z-coordinate is ignored.

3 ϕ expansion and ρ compression

In order to resolve close radial tracks from each other, their representation needs to be expanded perpendicular to the track direction i.e. in ϕ. This means that, depending on the track density, only a sufficiently small azimuthal segment can be visualized on a normal display or picture at a given moment.

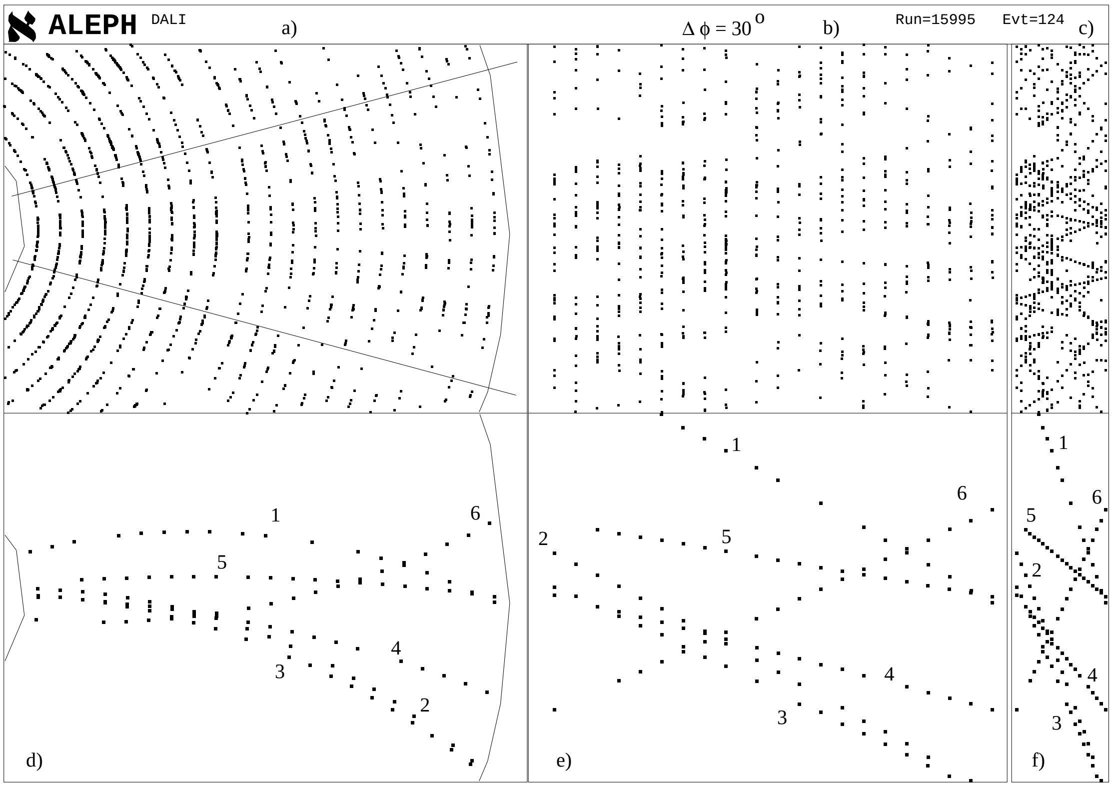

Figure 1: a,d: section of a Y/X projection. b,e: section of ϕ/ρ corresponding to the $30°$ angular section drawn in a. c,f: the same angular section as in b,e compressed. a,b,c: 6000 hits from real ALEPH events, which gives about 500 hits in the $30°$ section. d,e,f: 6 numbered selected tracks from the sample above.

An azimuthal segment of $30°$ is shown in a Y versus X projection (Y/X) in figure 1a. The same hits are shown in figure 1b in a ϕ versus ρ projection (ϕ/ρ), which roughly preserves the spacing of the hits as compared to Y/X. As was shown in ref. [1], circle segments through the origin in Y/X are transformed into straight lines in ϕ/ρ with a gradient proportional to their curvature, i.e. inversely proportional to the transverse momentum p_t of the particle. When compressing the picture in the ρ direction (see figure 1c) some few tracks become visible. These are tracks with a small gradient produced by high p_t particles. Tracks of low p_t particles remain unnoticed.

In order to understand better how ϕ expansion and ρ compression acts on tracks of low p_t particles a set of few tracks which are contained in the set of many tracks, were selected and displayed in figures 1d,e,f in identical representations. It is seen that for these tracks the ϕ expansion yields straight lines with a fairly large angle to the horizontal axis. Therefore the improvement in visibility by the ρ compression is not as striking as for high p_t tracks and even deteriorates visibility for some tracks (compare figure 1e and 1f).

In these cases one has to compress in other directions than the horizontal (i.e. ρ) direction, which corresponds to a "compression angle" 0. Then they can be examined by changing slowly the compression angle through animation or by displaying the data in several slots side by side with different compression angles. Each of the slots is sensitive to the charge of the particle and a momentum range around a given transverse momentum value p_t . Such a set of slots will be called "Skewplot" in the following. Figure 2 shows such a Skewplot for the data of figure 1, where the relevant p_t range is indicated by the value given at the bottom of each slot.

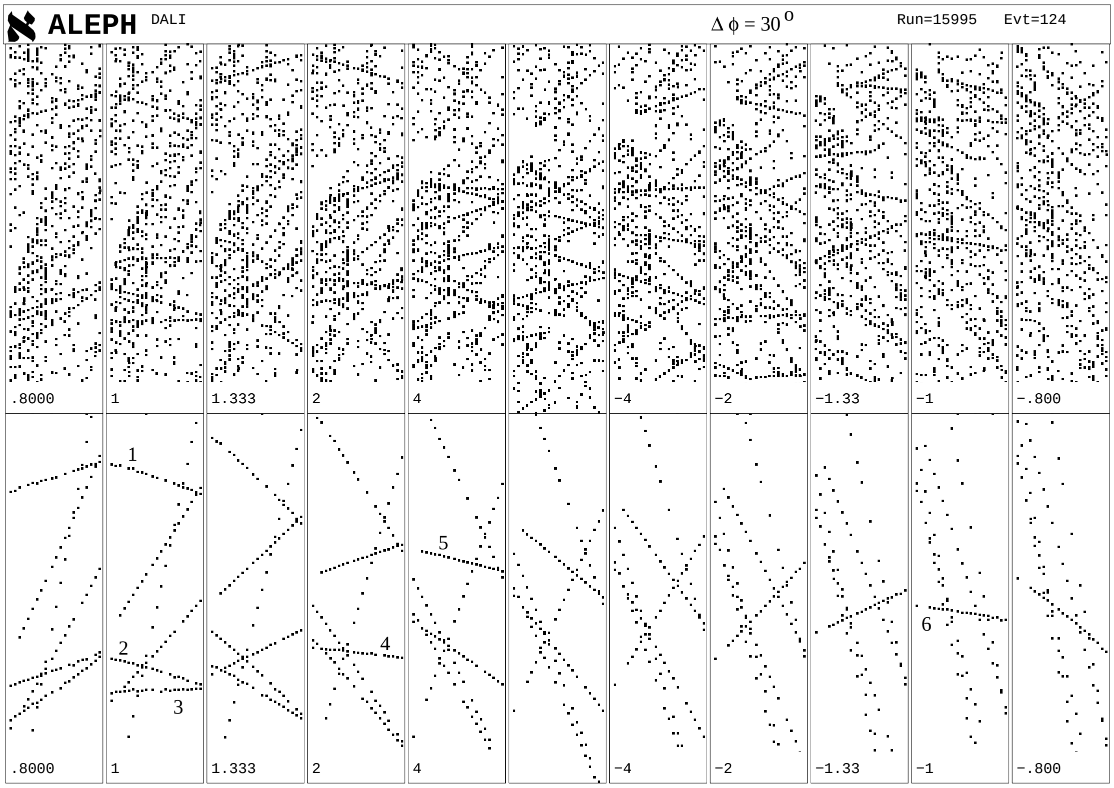

Figure 2: Skewplots containing 11 slots covering the same angular region as in fig. 1c,f. The slots in the center are identical to figure 1c,f, respectively, the other slots are sensitive to different momentum ranges around the value (in GeV/c) given below each slot. The upper skewplot contains approx. 500 hits per slot, the lower skewplot contains the same selected tracks with identical track numbers as figs. 1d,e,f.

A compression for a given angle is obtained by compressing the horizontal variable ρ and choosing as vertical variable V the following expression:

$$V = \phi - \operatorname{asin}\{\rho / (2cp_t)\} + \operatorname{asin}\{\rho_1 / (2cp_t)\} \qquad (1)$$

where p_t, which varies over the slots, and ρ_1, which is the same for all slots, are predefined parameters. When choosing V in this way, a circle corresponding to a particle with transverse momentum p_t leaving the center in the direction ϕ_0, described in polar coordinates by: $\rho = 2cp_t \cdot \sin(\phi - \phi_0)$ (2)

transforms into a horizontal, straight line at the vertical position:

$$V = \phi_1 = \operatorname{asin}\{\rho_1 / (2cp_t)\} + \phi_0 \quad (3)$$

When varying the parameter p_t, the approximately linear track pictures therefore rotate around the point ϕ_1, ρ_1, where ϕ_1 is given by equation 3. For $p_t = \infty$ one gets back the normal ϕ/ρ projection.

For horizontal lines the mean hit distance is much more reduced by a ρ compression, than for inclined lines representing tracks of opposite charge or sufficiently different p_t. Hence tracks with a transverse momentum close to the p_t value of the slot are resolved easily from the background by the human visual system, which connects close hits to tracks. Accordingly, in different slots of the Skewplot, which are characterized by different p_t values, different sets of tracks become visible.

The power of the method is revealed by comparing figures 2a,b,c to figures 2d,e,f, which shows that all selected tracks can be identified even if very many other tracks are superimposed.

When approximating $\operatorname{asin}\{\rho / (2cp_t)\}$ by $\rho / (2cp_t)$, which gives a linear skew, the visible track images in the low p_t slots get slightly curved.

With higher hit density the ϕ expansion must be increased, which in turn reduces the p_t range of tracks becoming visible in a single slot, so that for the same total p_t range the number of slots in the Skewplot must be increased accordingly, and vice versa.

4 Application to the Y/X projection

If the track density is sufficiently low a radial compression applied to the Y/X projection yields a picture where high momentum tracks can be identified, see figure 3a,b. A skew in phi may also be applied here to recognize tracks of the same charge around a given p_t value (see figure 3c). The picture was obtained in the following way:

$$\rho = \sqrt{(X^2 + Y^2)} \quad , \qquad \phi = \operatorname{asin}(Y/X) \quad ,$$

$$\rho' = k \cdot \rho + (1-k) \cdot \rho_{max} \qquad \text{with } k \le 1 \quad (4)$$

$$\phi' = \phi - \operatorname{asin}\{\rho / (2cp_t)\} + \operatorname{asin}\{\rho_1 / (2cp_t)\} \quad (5)$$

where ρ_{max} is the maximum value of ρ.

With

$X' = \rho' \cdot \cos\phi'$ and $Y' = \rho' \cdot \sin\phi'$

one can generate the pictures in figure 3b for $p_t = \infty$ and in figure 3c for $p_t = 1GeV$.

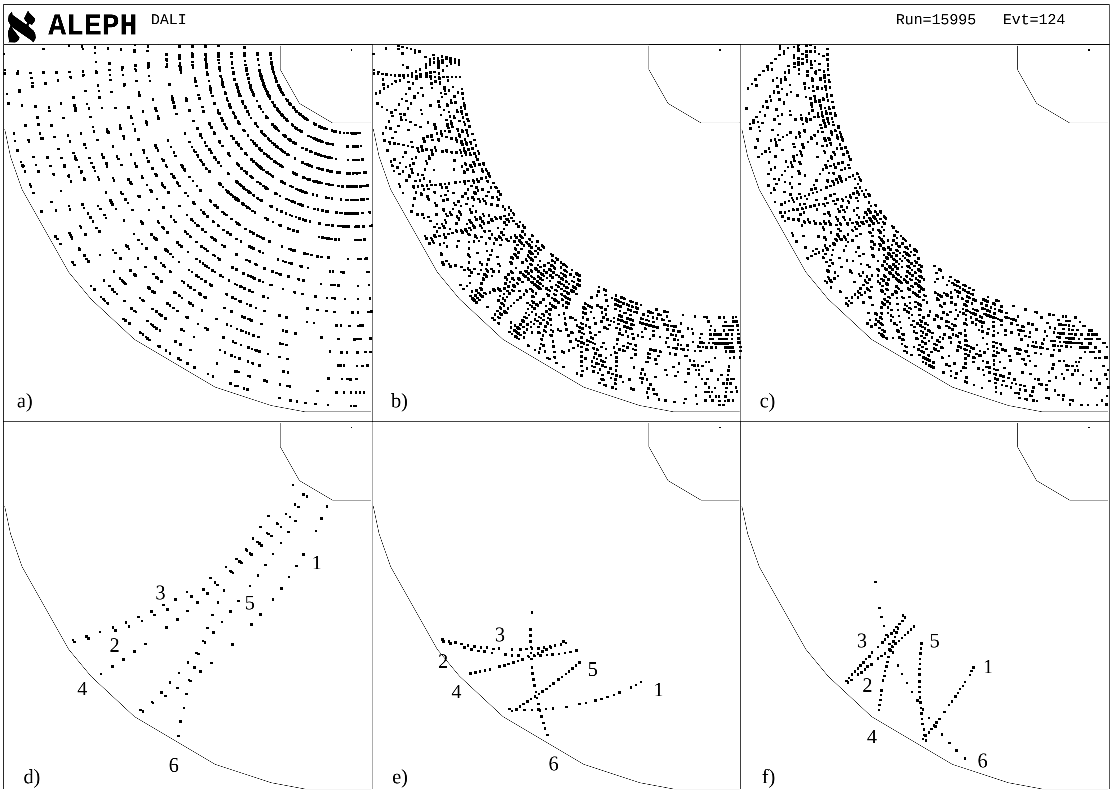

Figure 3: a,b,c: 6000 hits from several superimposed real ALEPH $q\bar{q}$ events, i.e. about 1500 hits per quadrant. a: quadrant of a Y/X projection. b: the same quadrant of Y/X compressed in radial direction. c: the same quadrant of Y/X compressed in a direction sensitive to 1 GeV/c. d,e,f: 6 numbered selected tracks from the sample above in the same representations as in a,b,c.

The figures 3d,e,f show the same representations for the six selected tracks. Track 5 can be identified in figure 3b and the tracks 1,2,3 in figure 3c, even in the crowded environment, but not as well as in the Skew-Plot of figure 2, as the apparent ϕ expansion is reduced by a factor of two in figure 3 compared to figure 2.

For these radial compressions, animation will be the best tool to vary continuously the sensitive p_t range, as it will be difficult to represent pictures of all required p_t ranges side by side.

5 Track finding algorithm

The method used for the Skewplot is also suited for use in track finding programs. By adjusting the ϕ expansion and number of slots, so that each track gets sufficiently horizontal in one slot and by histogramming the different slots, tracks should be detectable as narrow peaks in the histograms. If this track finding method is used, the Skewplot is a natural way to visualize and check the algorithm.

6 Conclusion

The task to visually identify tracks from high density, two-dimensional hits can be achieved for a given momentum range by appropriate skews of ϕ/ρ followed by an appropriate ϕ expansion and ρ compression. The transverse momentum range may be changed by animation or by displaying pictures sensitive to different transverse momentum ranges side by side (Skewplot). This representation is especially suited for analysis but not for presentation to non-experts.

If the track density is not too high, a similar method can be applied to the Y/X projection yielding a picture where again tracks in a given range of transverse momentum can be recognized. Representations of this kind may be shown to non-experts and may be a basis for further developments.

7 Acknowledgements

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8 References

1 H. Drevermann, D.Kuhn and B.Nilsson, Event Display: ‘Can We See What We Want to See?’ Proc. of CERN School of Computing, Arles, France, CERN Yellow Report 95-05 and CERN/ECP 95-25[2] and references therein.

2 http://www.cern.ch/CERN/Divisions/ECP/IPT/Papers/CSC95/EDisplay/