Finding the Decay Vertex of a Charged Track with Neural Networks

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Several neural network methods to determine the position of a track decay are studied using feed-forward nets with error back-propagation. The results are checked for robustness and are compared with a conventional approach based on the Kalman filter technique.

1 Introduction

Decays of tracks with very small decay angles pose two hard pattern recognition problems in High Energy Physics. The first one is to recognize the kink in the track. It has be shown that neural network (NN) techniques are very efficient for this task [1, 2]. The second problem, which will be addressed here, is to find the position of the kink. Although it is often sufficient to know whether a track decayed or not the knowledge of the decay vertex allows to make a kink fit.

Since both tasks need different mappings between the input and the output units a modular approach is taken. First a NN is used to recognize kinks in well reconstructed tracks. The inputs to this classification network are the residuals and the curvature obtained by a one-track fit [2]. If a kink has been found the same inputs are fed into a second neural network which gives the radial position of the decay vertex.

The data used and the NN layouts are described in the following two sections. The results for fully-measured tracks and for tracks with missing coordinates are presented in section 4 together with a comparison with a Kalman filter method.

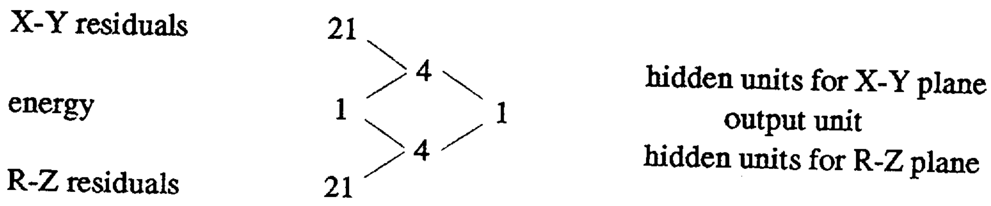
2 Tracks

For this study simulated data of the Aleph TPC [3] at LEP are used. The training and test samples consist of $\pi^\pm \rightarrow \mu^\pm + \nu$ with pion energies E_π = 3, 5 and 10 GeV. Such single-track events are simulated with the Aleph Monte Carlo program GALEPH and the pions are forced to decay well inside the TPC (at least 15 cm away from the edges of the TPC, which insures that each of the two tracks has at least three coordinates). The direction (polar angle) of the tracks is chosen such that the tracks cross the whole TPC in radial direction. The simulated data are reconstructed with the Aleph reconstruction program JULIA.

In order to study the influence of the data quality two different sets of data are generated: one set using a rather fast and somewhat idealistic simulation (FSIM = Fast SIMulation), the otherone using a detailed simulation (DSIM).

3 Network layout

The kinked tracks are selected using a specially tailored NN [2]. The inputs to this classification network are the residuals and the curvature obtained by a one-track fit. One can treat the information of the X-Y plane and of the R-Z plane separately in the hidden layer. The best performance is obtained with the following 'half-connected' network



The same inputs are fed into the position finder. This NN is like the classification net (kink / non-kink) a feed-forward network with error back-propagation. In order to achieve the best performance a fully-connected network with 21 hidden units (i.e. a 43-21-1 layout) has to be used now. Since the tasks to classify a track into kink and non-kink and to determine the position of the kink are rather different it is not surprising that different NN layouts are needed to achieve the best mapping although the inputs are the same.

4 Results

4.1 Fully measured tracks

Several ways to determine the kink position with NNs are investigated. The NN can be trained to answer the radial position (R) directly or to give the interval (I) between the last coordinate of the primary track and the first coordinate of the secondary track. Since the problem is linear (the same accuracy is wanted for all vertex positions) a linear output unit (L) can be used instead of a sigmoid one (S). These four methods (R-L, R-S, I-L, and I-S) are tested on fully-measured tracks. The resolution (standard deviation of the differences between the found and the true kink position) obtained for the six different data sets is given in table I. The results agree very well, the differences of a few mm have to be compared to the radial distance between two coordinates of about 6.5 cm. The method I-L (interval finding with linear output unit) is chosen for further tests (the other methods give equivalent results).

E_π/GeV	3	5	10	3	5	10
I-L	13.4	14.4	15.8	15.6	16.5	18.4
I-S	13.0	14.1	15.8	15.6	16.6	18.6
R-L	13.3	14.3	15.7	15.7	16.4	18.4
R-S	13.9	14.4	15.8	15.1	16.2	18.6

Table I: Resolution [cm] for FSIM data (left) and DSIM data (right).

4.2 Missing coordinates

Missing coordinates are treated in the same way as in the kink classification [1] by setting the residuals to 0. In order to show the robustness of the NN against missing coordinates three tests are made with 5 missing coordinates in the inner half of the TPC (coordinate 6-10), in the centre (coordinate 9-13) and in the outer half (coordinate 12-16), respectively. The results for these three cases are quite similar, the resolution increases by a few cm. The biggest difference is observed for FSIM data at 3 GeV (about 4 cm) and the smallest for DSIM data at 3 GeV (about 1 cm).

The following figure shows some distributions for DSIM data at 3 GeV : the differences between the found and the true decay radius for fully-measured tracks (left) and the decay radii found for fully-measured tracks (centre) and for tracks with 5 missing coordinates in the centre (right)

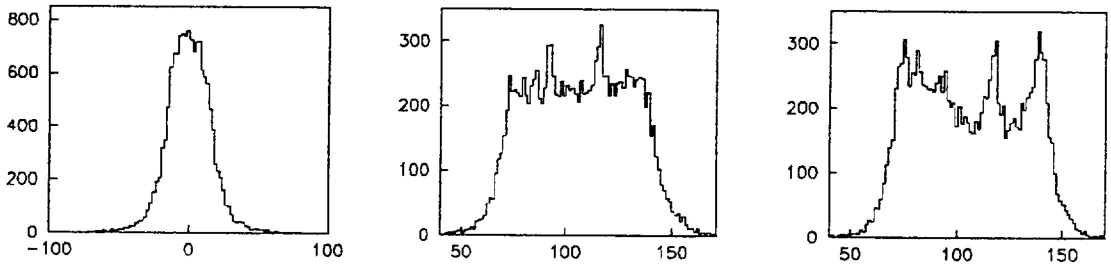


Figure 1: Resolution and radius distributions for DSIM data at 3 GeV.

The resolution curve is nicely centered and does not show long tails. The effect of missing coordinates is rather small.

4.3 Comparison with a conventional method

In order to evaluate the quality of the NN results a conventional method is applied based on the Kalman filter technique. The Kalman filter routine used for track fits in Aleph is modified to allow for a kink at a given radius. The algorithm consists in fitting a kink at different positions and comparing the χ^2 values obtained. The fit with the best χ^2 value gives the kink position. To avoid edge effects only decays are taken where the primary and the secondary track has at least 5 coordinates. 12 fits per track are done with a kink in the middle between two adjacent coordinates starting from the coordinates 5 and 6 until the coordinates 16 and 17. The resolution of the NN and the Kalman filter (KF) method is given in table II for decaying tracks recognized by the classification NN.

	E_π/GeV	3	5	10	3	5	10
Full TPC	NN	11.7	12.9	15.3	14.1	15.7	17.6
	KF	11.7	14.8	18.8	15.1	17.9	22.1
Centre	NN	11.8	12.1	13.2	11.9	12.3	13.4
	KF	9.3	12.1	16.0	12.2	14.4	18.2
Edges	NN	11.6	13.5	17.2	15.6	18.2	21.2
	KF	13.4	16.9	21.2	17.1	20.6	25.7

Table II: Resolution [cm] for FSIM data (left) and DSIM data (right).

In order to check whether a 'neural' bias was introduced through the kink selection also the decays not recognized by the classification NN are used now. The results are listed in table III for several groups: all tracks, tracks decaying in the central region (at a radius between 85 and 125 cm) or outside, and tracks with 'small' or 'big' decay angles (using a cut at 7, 5 and 3 mrad for 3, 5 and 10 GeV, respectively).

E_π / GeV	test	all	center	edge	small	big	all	center	edge	small	big
3	NN	14.2	12.1	15.4	16.4	13.9	16.3	12.3	18.5	17.8	16.1
	KF	15.0	9.8	17.7	17.7	15.1	18.0	12.7	20.8	22.4	17.3
5	NN	16.8	12.8	19.1	21.4	15.2	19.6	12.7	23.0	22.1	18.8
	KF	20.2	13.0	23.9	24.5	18.7	23.3	15.3	27.4	26.8	22.2
10	NN	21.1	14.0	24.9	23.4	19.6	22.9	14.4	27.3	24.8	21.8
	KF	25.8	17.4	30.3	28.4	24.0	28.5	20.0	33.1	30.3	27.3

Table III: Resolution [cm] using all tracks for FSIM data (left) and DSIM data (right).

A comparison with table II shows a degradation of the resolutions due to the fact that all difficult decays are included now. No bias effect can be observed.

5 Conclusions

Several methods to determine the position of a track decay were tested and have shown very similar behaviour. The results are quite stable against noise and missing coordinates. Very good performance is found in comparison to a conventional method using Kalman filtering. The NN methods are especially suited for the difficult cases like noisy data (DSIM data compared to FSIM data) and decays outside the central region.

In addition the NNs are much faster than the Kalman filter (several orders of magnitude on a digital computer). Since the networks are quite small the learning effort is rather modest.

Acknowledgement

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References

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