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Kink Search with Improved TPC Coordinates

Georg Stimpfl-Abele
MPI Munich

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Abstract

The kink search algorithm of JULIA was studied with 10 GeV muons and pions generated with GALEPH. A new parametrization of the TPC coordinate errors and a method to determine the z coordinate from the wire data are presented. The kink search algorithm is discribed and its efficiencies are given for 10 GeV $\pi \Rightarrow \mu + \bar{\nu}$ inside ITC and TPC with dip angles of $5^\circ, 25^\circ$ and 50°.

1 Errors on TPC pad coordinates

In order to test the quality of the TPC coordinates three samples of 10 GeV muons where generated with GALEPH 2.30 and TPCSIM 2.07 with dip angles $\lambda = 5^\circ, 25^\circ$ and 50° and those selected which did not generate secondary particles inside the tracking detectors. Since there are still some problems in the TPC wire reconstruction in JULIA with tracks which go straight up a minimal dip angle of 5° was choosen. The errors on the TPC pad coordinates given by JULIA were checked by fitting a helix without multiple scattering correction (which should be negligible at 10 GeV) only inside the TPC. The results show a rather peaked probability distribution for the χ^2 values of the fits (Figure 4) which decreases the performance of the kink searches algorithms. Currently the errors are estimated as a function of the cluster width only and the parameters were determined by fitting Lund events without taking multiple scattering into account.

1.1 r-ϕ plane

A check of the r-ϕ residuals shows that the parametrization of the errors works quite well in JULIA but gives too high values (the lower cutoff for $\sigma_{r\phi}$ is 190 μm and the mean value for the tracks studied was about 225 μm). This can be understood in terms of a wrong multiple scattering contribution at high momenta coming from a global fit over all Lund tracks. It was found that a reduction of $\sigma_{r\phi}$ by

$$40\mu m/cos\lambda$$

gives the right resolution in r-ϕ.

1.2 r-z plane

The r-z errors given by JULIA do not agree with the fit residuals. The difference can not be explained by a wrong multiple scattering treatment since the resolution of the TPC is much worse in r-z than in r-ϕ. It was found that the z resolution depends strongly on the maximal pulse charge (PC_{max}) of the cluster and on the dip angle. Therefore the r-z errors were fitted as a function of PC_{max} and λ. The results are summarized in Table 1 and Figure 1. Figure 2 contains the frequency distribution of PC_{max}. The pulse charge saturates at 255 ADC counts.

PC_{max}	$\lambda = 5°$	$\lambda = 25°$	$\lambda = 50°$
0 - 50	0.081	0.100	0.130
50 - 100	0.076	0.106	0.150
100 - 150	0.070	0.114	0.180
150 - 200	0.090	0.190	0.320
200 - 250	0.110	0.245	0.420
250 - 255	0.250	0.270	0.420

Table 1

σ_z [cm] as function of maximal pulse charge PC_{max} and dip angle λ

σ_z changes slowly and almost linearly with PC_{max} for fixed λ and $PC_{max} < 150$. But the resolution worsens rapidly for $PC_{max} > 150$.

The dependence of the z resolution on the drift length is negligible. The pad crossing angle was not taken into account because it is small for the samples choosen.

2 Z coordinates deduced from the wires

The time information of the wires in the TPC allows the determination of the z coordinate with a resolution of about 0.2 cm which is on average worse than that of the pads. But a track crosses about 15 times more wires than pad rows and the resolution of the pads does not change in the same way with the dip angle as the wire resolution. This should at least for large dip angles result in a better total z resolution of wires than pads.

The resolution of the wires was parametrized as a function of drift length and dip angle. The wire crossing angle was not taken into account. A linear dependence of the resolution on the driftlength agrees well with the fit residuals. The results are shown in Figure 3.

The z coordinates of the wires around a pad row are used to fit an improved z 'pad' coordinate. This is done by a linear fit in r-z. Since the distances are short and the curvatures of the tracks are large it is not necessary to do this fit in s-z.

To avoid confusion we call the data belonging to a wire 'single wire' data and the results of fits over the wires 'wire' data. Furthermore we call the coordinates obtained only from the pads 'pad' coordinates and those where the z information is derived from the wire data 'wire' coordinates (although the r-ϕ coordinates still come from the pads of course).

The z resolution of the wire coordinates is about 4 times better than that of the single wire coordinates. This factor corresponds roughly to the square root of the number of wires used to fit the coordinates. Table 2 gives the mean value of the z resolution for the pad, the single wire and the wire coordinates.

λ	σ_z^p	σ_z^{sw}	σ_z^w
5°	0.079	0.245	0.065
25°	0.107	0.215	0.057
50°	0.153	0.148	0.045

Table 2

Mean z resolution [cm] for pad, single wire and wire coordinates
as function of the dip angle λ

At small dip angles the z resolutions of pads and wires are almost the same and a factor 4-5 worse than the r-ϕ resolution (150-200 μm). Therefore the track fits can not be improved using the wires. The situation is different in the forward direction, where the resolution of a single wire is already better than that of a pad and only 2-3 times worse than the r-ϕ resolution.

3 The kink search algorithm in JULIA

One method to find kinks [1] consists in fitting first one helix to the coordinates (non-kink fit), then several times two helices with different kink positions (kink fits) and cutting on the difference between the χ^2 of the non-kink fit and the minimal χ^2 of the kink fits. This method works nicely if the coordinate errors are well estimated but needs careful tuning of the cut depending on the resolution and the number of coordinates. Furthermore it is not easy to quantify the results of this test by probabilities.

Therefore another algorithm was developped and implemented in JULIA which is more stable against incorrect errors, gives directly the probability for the hypothesis that the track did not decay and has the same efficiency. It has the only disadvantage that it does not give the decay vertex, which is not of big interest anyway because 'visible' decays are reconstructed as two separate tracks and should get the vertex from the secondary vertex fit code.

The new method is called parameter test and consists in breaking the full track into two halves, fitting each half separately, and comparing the helix parameters of the two fits. The χ^2 value for the hypothesis that the two parameter sets (par_1, par_2) are the same within the statistical errors is given by

$$\chi^2 = \Delta par^T E \, \Delta par$$

with

- $\Delta par = par_1 - par_2$ difference of the 5 helix parameters
- $E = (E_1^{-1} + E_2^{-1})^{-1}$ combined 5x5 error matrix

This χ^2 gives the probability that the two halves belong to the same physical track, which is called non-kink probability and stored in the particle identification bank FRID. This probability has a flat distribution between 0 and 1 for tracks which do not decay and peaks at 0 for decaying tracks. The flatness in the first case depends of course still crucially on the quality of the coordinate errors. Too large errors lower the number of found kinks, too small errors lead to spurious kinks of good tracks. If there are enough measurements the multiple scattering angle between ITC and TPC in the r-ϕ plane is included in the fit.

4 Track selection and fits

In order to test the kink search routines implemented in JULIA and the new coordinate algorithms three samples of 10 GeV muons and three otherones of 10 GeV pions were generated with $\lambda = 5°, 25°$ and $50°$ in the following way

- single pion and single muon events with momenta of 10 GeV were simulated with GALEPH 2.30 and the pions were forced to decay inside TPC and ITC
- the GALEPH output was filtered to have clean decaying and non-decaying samples
- the TPC was simulated in full detail with TPCSIM 2.07
- the events were reconstructed with JULIA 2.24 and the banks which are necessary for the test were written on special POT files, one for each sample.

An analysis program reads the events from these POT files and does the following track selection, coordinate updates and fits

- if there is more than one track in the fit bank FRFT then the tracks are merged to be independend from changes in the track reconstruction algorithms
- because the z resolution of the pads is worse for very small and for high values of the maximal pulse charge (PC_{max}) in the cluster only coordinates with $25 < PC_{max} < 150$ are accepted (Figure 1). The number of eliminated coordinates is of the order of 10% (Figure 2)

- in order to fit the z coordinate from the wires all coordinates with less than 5 wire hits around the pad row are eliminated
- all tracks with less then 10 remaining coordinates are discarded
- the TPC coordinate errors are changed as explained in section 1
- the parameter test described in section 3 and a normal χ^2 test (i.e. χ^2 of an helix fit) are made on the TPC tracks alone and on the full ITC-TPC tracks
- the z pad coordinates are replaced by the wire coordinates (see section 2) and the tests are repeated.

5 Results of the kink searches

The kink algorithm returns the probability that the track has no kink (non-kink probability P_{nok}). P_{nok} is based on the χ^2 value obtained in the parameter test with 5 degrees of freedom or in the normal χ^2 test, where the number of degrees of freedom is twice the number of coordinates minus 5 (the number of the helix parameters). If one studies non-decaying tracks and if the coordinate errors are well understood then P_{nok} is flatly distributed between 0 and 1 and e.g. $P_{nok} = 0.2$ means that on average 20 % of the tracks have a χ^2 in the test which is bigger as or equal to the χ^2 of this track. Tracks with kinks have on average a higher χ^2 value and therefore a smaller value of P_{nok}. If one selects tracks with $P_{nok} < 1\%$ one gets 1% of the non-decaying tracks and a substantial fraction of the kinked tracks. In practice it is impossible to understand the coordinate errors completely and therefore one does not get exactly 1 % of the non-decaying tracks.

The results of the analysis are summarized in Tables where the percentages of tracks with $P_{nok} < 1\%$ are listed as a function of the dip angle for the 4 tests

- parameter test on pad coordinates (par pad)
- χ^2 test on pad coordinates (χ^2 pad)
- parameter test on wire coordinates (par wire)
- χ^2 test on wire coordinates (χ^2 wire)

and the 3 cases

- TPC only without coordinate corrections
- TPC only with improved coordinates
- TPC and ITC with improved TPC coordinates

for the primary muon and the $\pi \Rightarrow \mu + \tilde{\nu}$ samples.

5.1 Non-decaying tracks

The percentage of primary muons which are wrongly identified as decaying tracks is given in the 3 Tables below. The results using the TPC coordinates and errors provided by JULIA (in the TPCO bank) without including ITC points are listed in Table 3. The values for the parameter test given in this table look fine but the distributions peak at high probabilities. Figures 4 and 5 show typical P_{nok} distributions for the χ^2 test before and after the improvement of the TPC coordinates. The effect of the new error estimation is obvious.

λ	par pad	χ^2 pad
5°	0.4%	2.5%
25°	1.7%	6.0%
50°	1.4%	7.5%

Table 3

Percentage of non-decaying tracks with $P_{nok} < 1\%$ in TPC without error correction

λ	par pad	χ^2 pad	par wire	χ^2 wire
5°	2.5%	3.7%	1.5%	1.9%
25°	3.2%	3.2%	3.8%	3.3%
50°	3.2%	3.4%	6.2%	3.1%

Table 4

Percentage of non-decaying tracks with $P_{nok} < 1\%$ in TPC

λ	par pad	χ^2 pad	par wire	χ^2 wire
5°	2.1%	3.8%	2.4%	2.2%
25°	1.8%	3.3%	2.9%	3.2%
50°	1.4%	2.5%	2.7%	2.8%

Table 5

Percentage of non-decaying tracks with $P_{nok} < 1\%$ in TPC and ITC

Tables 4 and 5 and Figure 5 show that the probability distributions for the fits of non-decaying tracks are rather flat which means that the errors are understood quite well. Only the case where the parameter test is applied on wire coordinates without ITC at $\lambda = 50°$ has a substantially higher value (6.2%) than the ideal one of 1.0 %. Adding ITC coordinates to the fit cures this (2.7%).

5.2 Decaying tracks

Tables 6, 7 and 8 give the efficiencies to detect kinks in the $\pi \Rightarrow \mu + \bar{\nu}$ samples (a typical P_{nok} distribution with improved TPC coordinates is shown in Figure 6).

λ	par pad	χ^2 pad
5°	22.7%	12.3%
25°	28.4%	23.0%
50°	27.1%	25.3%

Table 6

Percentage of decaying tracks with $P_{nok} < 1\%$ in TPC without error correction

λ	par pad	χ^2 pad	par wire	χ^2 wire
5°	31.6%	27.9%	28.7%	23.3%
25°	35.4%	30.7%	34.8%	29.2%
50°	33.4%	32.7%	43.0%	35.0%

Table 7

Percentage of decaying tracks with $P_{nok} < 1\%$ in TPC

λ	par pad	χ^2 pad	par wire	χ^2 wire
5°	44.2%	39.5%	41.4%	36.4%
25°	48.9%	46.3%	49.5%	44.3%
50°	56.1%	51.9%	59.4%	52.9%

Table 8

Percentage of decaying tracks with $P_{nok} < 1\%$ in TPC and ITC

One can see that

- the new TPC error estimates improve the kink search efficiency by 6% – 16%

- the efficiency increases with the dip angle because the measured helices become longer
- the parameter test is about 5 % more efficient than the χ^2 test
- adding ITC coordinates to the test increases the efficiency substantially
- the wire z coordinates improve the kink search only at large dip angles.

The 'ITC effect' comes partly from a too idealistic simulation in GALEPH. The fact that the benefit of the wire coordinates depends on the dip angle can already be seen from the resolutions given in Table 2.

6 Conclusions

The parametrization of the resolution of TPC coordinates of fast tracks (i.e. tracks with small pad crossing angles) can be improved in an easy way to give reasonable probability and pull distributions. This has to be done in JULIA because one needs information about the TPC clusters which is not written to the POT. For fast tracks the errors in the TPC coordinate bank TPCO could be updated after pattern recognition and before the final fit inside the TPC.

The use of TPC wire coordinates improves the kink finding efficiencies for large dip angles by about 3% but does not help for small dip angles where the z resolution of the pads is quite good. Work is going on to understand some inconsistencies in the results which might come from differences between inner and outer sectors (in the parameter test on TPC tracks the first track half almost lies in an inner sector and the second one in an outer sector). This and a more sophisticated parametrization of the single wire resolution could increase the benefit of using wire coordinates.

About 50 % of the decays of 10 GeV $\pi \Rightarrow \mu + \bar{\nu}$ (maximal decay angle = 4 mrad) are recognised. This means that kinks of about 1 mrad are detected if the tracks decay well inside the tracking detectors. The helix parameter test implemented in JULIA finds about 5 % more decays than the normal χ^2 test.

Reference

[1] G. Stimpfl, Kink Search for Muon Candidates in the TPC, ALEPH 86-48

Figure Captions

Fig. 1 ... σ_z [cm] for pads as function of PC_{max} and λ

Fig. 2 ... PC_{max} distribution (in ADC counts) at $\lambda = 25°$

Fig. 3 ... σ_z [cm] for single wires as function of the drift length and λ

Fig. 4 ... Typical P_{nok} distribution (TPC only) for non-decaying tracks before coordinate improvement

Fig. 5 ... Typical P_{nok} distribution (TPC only) for non-decaying tracks after coordinate improvement

Fig. 6 ... Typical P_{nok} distribution (TPC only) for decaying tracks after coordinate improvement

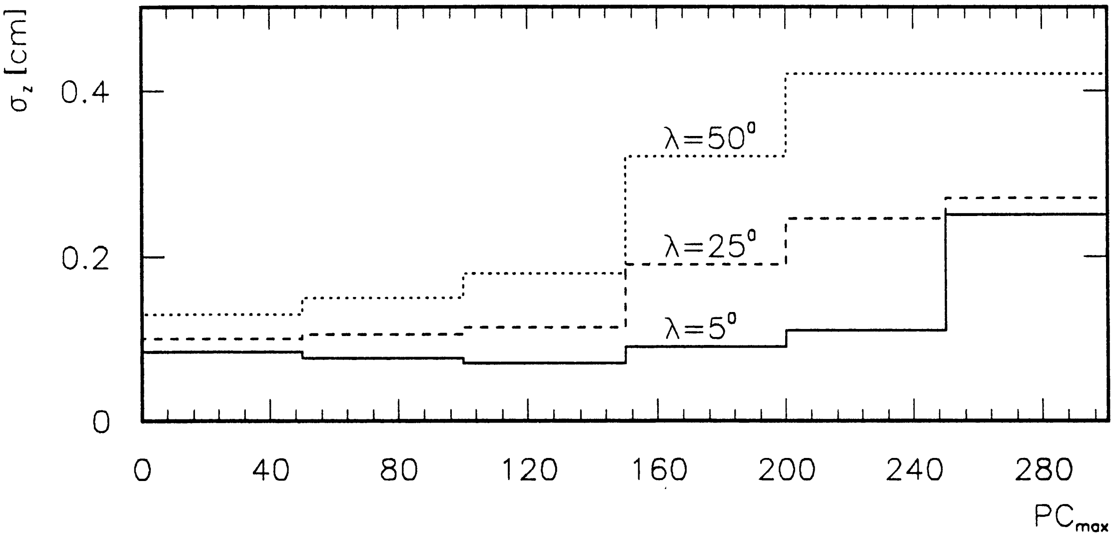

Figure 1: σ_z [cm] for pads as function of PC_{max} and λ

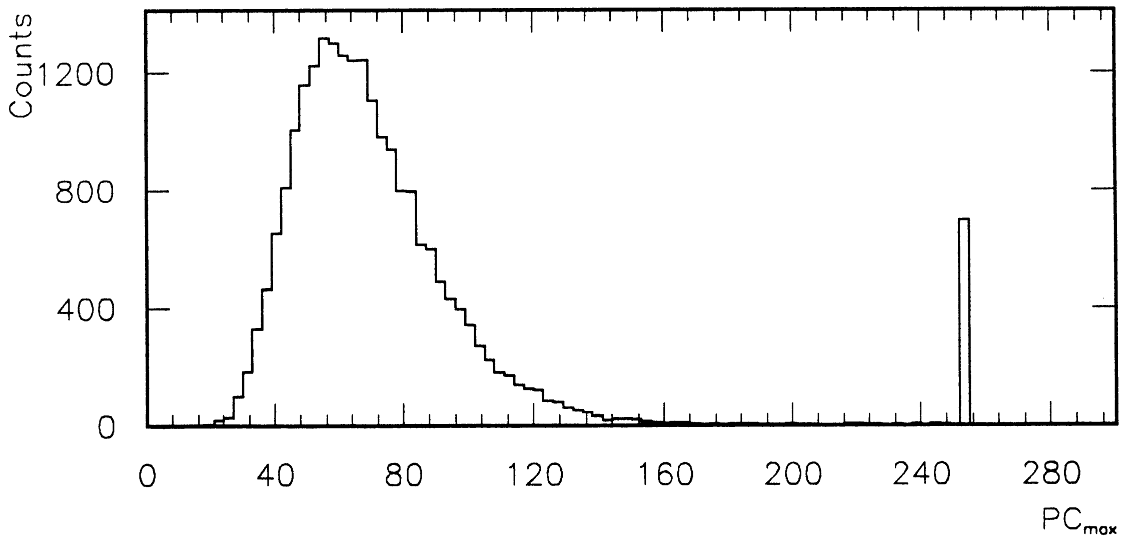

Figure 2: PC_{max} distribution (in ADC counts) at $\lambda = 25°$

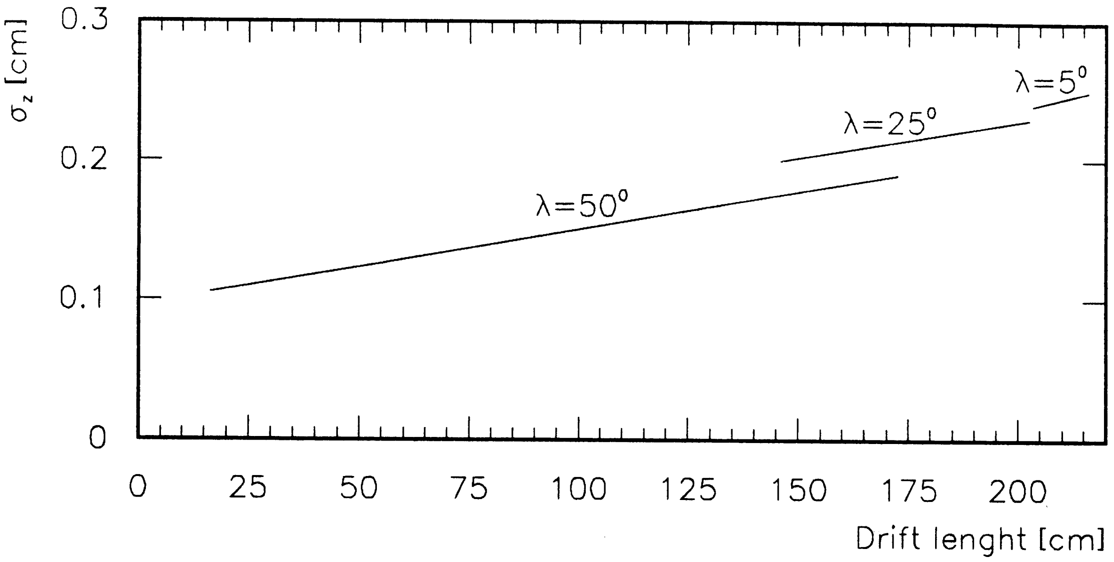

Figure 3: σ_z [cm] for single wires as function of the drift length and λ

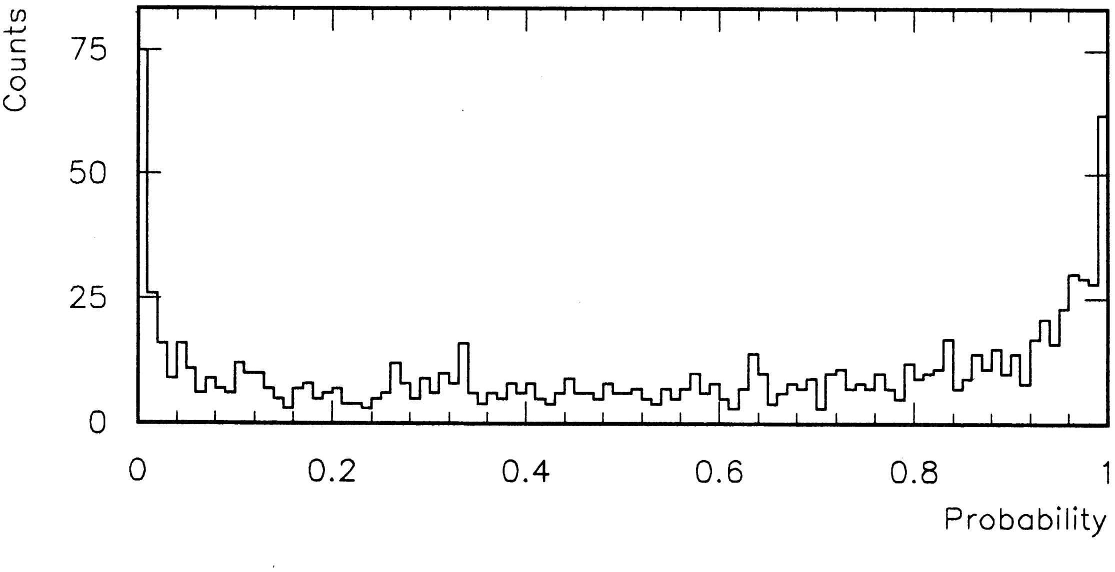

Figure 4: Typical P_{nok} distribution (TPC only) for non-decaying tracks before coordinate improvement

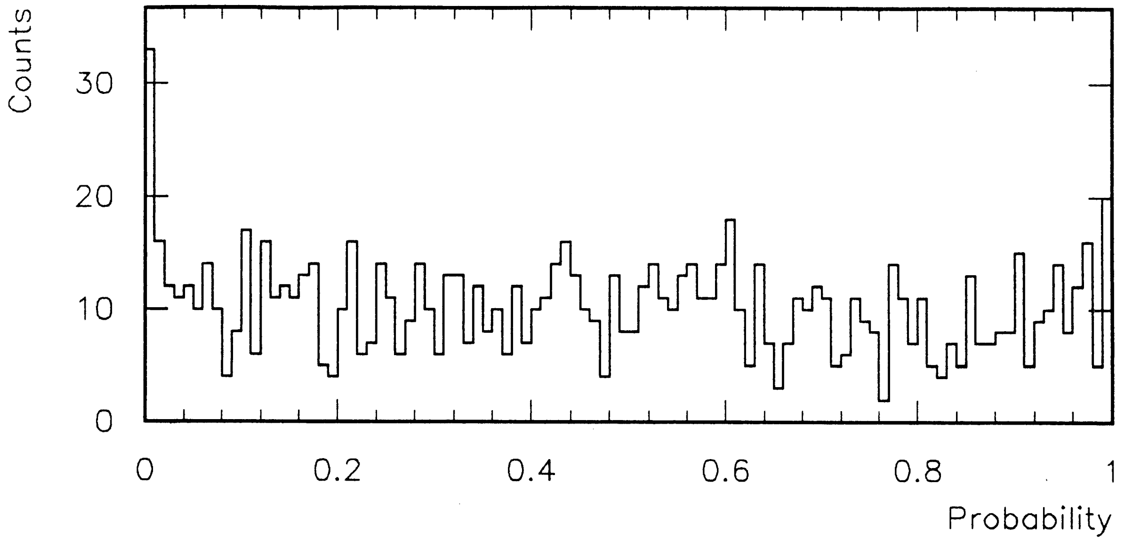

Figure 5: Typical P_{nok} distribution (TPC only) for non-decaying tracks after coordinate improvement

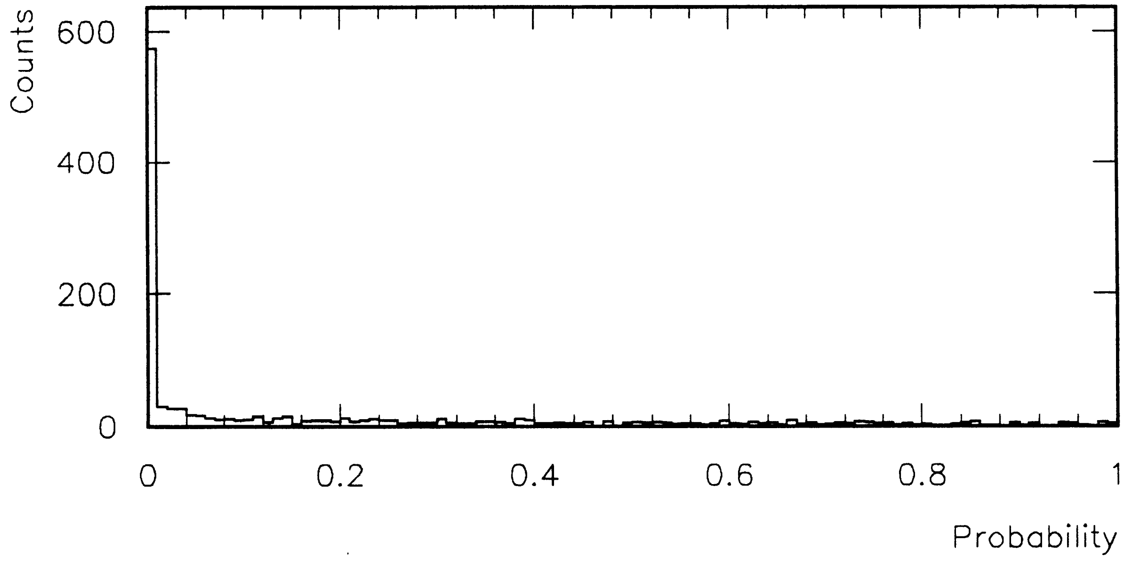

Figure 6: Typical P_{nok} distribution (TPC only) for decaying tracks after coordinate improvement