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Study of the $D_s \to \bar{K}^0 K^+$ and $D^+ \to \bar{K}^0 \pi^+$ Decay modes

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Abstract

From a sample of 1.14 million Z^0 hadronic decays recorded in 1990,1991 and 1992 by the ALEPH detector, the decay modes $D_s^+ \to \bar{K}^0 K^+$ and $D^+ \to \bar{K}^0 \pi^+$ are studied. The level of reflexion of one mode on the other is determined using the dE/dx information. The performance of this separation is monitored from the data using $D^* \to \pi D^0 \to \pi K \pi$ events. The measured production rates are:

$$\frac{\Gamma(Z \to D_s^{\pm} X)}{\Gamma(Z \to \text{hadrons})} \cdot B(D_s^+ \to \bar{K}^0 K^+) = (2.40 \pm 0.73)10^{-3}$$

and

$$\frac{\Gamma(Z \to D^{\pm} X)}{\Gamma(Z \to \text{hadrons})} \cdot B(D^+ \to \bar{K}^0 \pi^+) = (4.59 \pm 1.09)10^{-3}$$

1 Selection of the $D_s^+ \to \bar{K}^0 K^+$ and $D^+ \to \bar{K}^0 \pi^+$ signals

The analysis has been carried out on 1.14 million events collected by the ALEPH detector at LEP in 1990, 1991 and 1992 and available in the nano-DST form(version 111). The Monte Carlo sample consists of 1.62 million $q\bar{q}$ events. A very similar analysis of the $D_s^+ \to \bar{K}^0 K^+$ signal has already been presented by J. Boucrot et al. [Aleph 93-47] and has shown the problem of the reflexion of the $D^+ \to \bar{K}^0 \pi^+$ which is kinematically unseparable. They use the dE/dx information to estimate the D^+ events. In this note, we are going to use the dE/dx information to determine, in addition the number of D^+ events.

1. K_S^0 are reconstructed using tbe YRMIST package.
   The K_S^0 were identified by means of their $\pi^+\pi^-$ decay products. The analysis has been performed using the informations of the YRFT bank written by the YRMIST package at the nano-DST creation. To reduce the background the following selection cuts have been applied to the K_S^0 candidates:
   - a cut on the invariant mass M was applied requiring $|M - M_{K^0}|$ to be less than 40 MeV/c^2;
   - a rough agreement with the mass hypothesis was set by requiring that the pull on the the mass $|M - M_{K^0}|/\sigma(M_0)$ to be less than 5;
   - the angle θ^* between the decay particles and the K_S^0 direction in the K^0 center of mass system had to satisfy $|cos(\theta^*)| < 0.95$;
   - the decay length had to be larger than 5 cm;
   - if a track pair gave two candidates of the same mass hypothesis but at different vertex position, the candidate with the larger χ^2 was rejected. If two candidates shared a track, the candidate with the smallest χ^2 was kept;
   - when there was a kinematic ambiguity of the K_S^0 candidate with $\Lambda, \bar{\Lambda}, \gamma$, the K_S^0 candidate was rejected;
   - the momentum of the K_S^0 had to be greater than 1 GeV/c.
2. K^+ from D_s^+ or π^+ from D^+
   For each K_S^0 we associate a charged track. Its momentum is required to be greater than 1.5 GeV/c. The dE/dx information is used (with at least 50 samples) to compute the K and π estimators:

$$E_K = \frac{R^I_{mes} - R^I_{exp}}{\sigma(K)}$$

$$E_\pi = \frac{R^I_{mes} - R^I_{exp}}{\sigma(\pi)}$$

We have two possibilities for setting the mass of this charged track. If we take the K mass (resp. π) we shall have the optimal resolution on $D_s^+ \to \bar{K}^0 K^+$ events (resp. $D^+ \to \bar{K}^0 \pi^+$). In each of these two choices, we require:

- $X_E(D_s)(resp. X_E(D^+))$ had to be greater than 0.33;
- the angle θ^* between the charged kaon (resp. pion) and the D_s direction (resp. D^+) in the D_s (resp. D^+) centre of mass had to satisfy $cos(\theta^*) < 0.85$.

2 Monitoring of the dE/dx: K/π Identification

Three sets of dE/dx cuts have been considered:

1. $E_K < 0$
2. $E_K > 0$ and $E_\pi < 0$
3. $E_\pi > 0$

The scatter plot E_K versus E_π is displayed in fig.1. If the dE/dx is well centered and gaussian one expects that in $E_K < 0$ one should get 50% of all the kaons and 2.3% of all the pions if the two distributions are separated by 2σ. Symmetrically, for the pions with $E_\pi > 0$ one would get 50% of all the pions and 2.3% of the kaons.To measure the purity in π and K of the above three dE/dx samples, we use $D^{*+} \to \pi_s^+ D^0 \to \pi_s^+ K^- \pi^+$ events (and charge reverse). For such events the kaon and pion are known without ambiguity from the charges. Indeed, in this case the charge of the kaon must be opposite to that of the soft pion. Among the two others, the fast track is a pion. By requiring $X_E(D^0) > 0.33$, the kaon and fast pion tracks have a kinematic very comparable to the charged K and π tracks originating from the decays $D_s^+ \to \bar{K}^0 K^+, D^+ \to \bar{K}^0 \pi^+$. The dE/dx identification properties are therefore very close.
For a three-track combination satisfying a cut on the two body mass $(1.835 \leq M(K\pi) \leq 1.895)$, we histogram the mass difference $M(K\pi\pi_s) - M(K\pi)$ and count the number of D* events. On fig. 2, we display the three ΔM distributions for the kaon belonging to one of the three dE/dx samples. In the cases of low D^* statistics (kaon sample 3 and pion sample 1) the signal and background shapes have been fixed to the result of a fit performed on all D^* events. The corresponding ΔM distributions for the pion are shown on fig.3. We therefore measure the probability f_i^K (resp.f_i^π) for real kaons (resp. pions) to have a dE/dx measurement in each of the three samples $(1 \leq i \leq 3)$. The relative populations deduced from these fits are given in table 1 for years 1990, 1991 and 1992. The combined 1990, 1991 and 1992 result is shown in table 2. Assuming that the estimators have gaussian distributions one expects for the kaon track

50% of the kaons for $E_K < 0$ and for the pion track 50% of the pions for $E_\pi > 0$. The deviations from these numbers provide an estimate of the shift of the central value of the dE/dx estimator from 0 respectively for K and π. The results are given at the bottom of each table. At the level of a tenth of its error, the dE/dx calibration appears to be good. While pions are well centered in 1991 and 1992, a small shift is observed for the kaons. The 1991 and 1992 results are compatible while 90 differs a little.

Table 1: Kaon and pion fractions in the three dE/dx samples for the three years of data taking

track	**90**	**91**	**92**
Kaon $E_K < 0$	$(58.7 \pm 3.7)\%$	$(56.4 \pm 2.8)\%$	$(55.4 \pm 1.8)\%$
$E_K > 0$ **and** $E_\pi < 0$	$(39.2 \pm 1.1)\%$	$(39.1 \pm 2.7)\%$	$(43.0 \pm 1.8)\%$
$E_\pi > 0$	$(2.1 \pm 1.1)\%$	$(4.5 \pm 1.2)\%$	$(1.6 \pm 0.4)\%$
Pion $E_K < 0$	$(7.0 \pm 1.9)\%$	$(3.5 \pm 1.0)\%$	$(4.6 \pm 0.7)\%$
$E_K > 0$ and E_π	$(54.3 \pm 3.7)\%$	$(45.0 \pm 2.7)\%$	$(45.9 \pm 1.8)\%$
$E_\pi > 0$	$(38.7 \pm 3.6)\%$	$(51.5 \pm 2.7)\%$	$(49.4 \pm 1.8)\%$
shift **K**	-0.15 ± 0.07	-0.13 ± 0.05	-0.10 ± 0.03
π	-0.20 ± 0.06	$+0.03 \pm 0.05$	-0.01 ± 0.03

Table 2: Combined result from 1990+1991+1992

track	**Kaon**	**Pion**
$E_K < 0$	$(56.1 \pm 1.4)\%$	$(4.7 \pm 0.6)\%$
$E_K > 0$ **and** $E_\pi < 0$	$(41.5 \pm 1.4)\%$	$(46.9 \pm 1.4)\%$
$E_\pi > 0$	$(2.4 \pm 0.4)\%$	$(48.5 \pm 1.4)\%$
shift	-0.11 ± 0.02	$-.03 \pm 0.02$

3 $D_s \to \bar{K}^0 K^+ and D^+ \to \bar{K}^0 \pi^+$ Signals

Table 2 shows that sample 1 retains 56.1% of K and 4.7% of π. It keeps mainly $D_s^+ \to \bar{K}^0 K^+$ events. The corresponding $K_S^0 K$ invariant mass distribution is displayed in fig.4. A peak of 82.6 ± 20.7 events is seen at a mass of 1.970 GeV with a width of 0.015 GeV compatible with the D_s mass and resolution. Sample 3 which keeps 48.5% of π and 2.4% of K, contains mainly $D^+ \to K_S^0 \pi^+$ events. Fig.5 displays for this sample the $K_S^0 \pi$ invariant mass distribution. We observe a peak of 119.7 ± 26.7 events at a mass of 1.863 GeV with a width of 0.012 GeV compatible with the D^+ mass and resolution.
Using the notation given above for the K and π fractions contained in the dE/dx samples 1 and 3, we can calculate N_S and N_D the original numbers of D_s^+ and D^+ events before the dE/dx selection:

$$82.6 = \epsilon_{NS}^K \cdot f_1^K \cdot N_S + \epsilon_{NS}^\pi \cdot f_1^\pi \cdot N_D$$

$$119.7 = \epsilon_{NS}^K \cdot f_3^K \cdot N_S + \epsilon_{NS}^\pi \cdot f_3^\pi \cdot N_D$$

where ϵ_{NS}^K and ϵ_{NS}^π are the efficiencies for requiring 50 samples respectively for the kaon and pion track. They are measured from the D* sample to be 0.80 ± 0.01 and 0.83 ± 0.01. Solving the above equations with the numbers of table 2, we get:N_S=158.6 ± 47.4 and N_D=289.6 ± 67.3 events. Therefore, we deduce that in the D_s signal we have 71.2 ± 21.3 kaons and 11.3 ± 7.2 pions and in the D^+ signal, there is 116.7 ± 27.3 pions and 3.0 ± 1.0 kaons.
For the dE/dx sample 2 (cut $E_K < 0$ and $E_\pi > 0$),we expect almost equal composition of kaons and pions. D_s^+ and D^+ events are mixed. We have the two solutions for the charged particle mass and can build the $K_S^0 K$ or the $K_S^0 \pi$ invariant mass. This is shown on fig.6. We observed 144 ± 30 events for the "D_s" hypothesis and 233 ± 37 events for the "D^+" hypothesis while from N_D and N_S values given above and table 2, 165 ± 33 events are expected. This independant sample is compatible with the two "pure" samples.

4 Production rates

From $q\bar{q}$ Monte Carlo events the total efficiency is $(17.4 \pm 0.9)\%$ for the $D_s \to K_S^0 K$ events and $(16.6 \pm 0.7)\%$ for the $D^+ \to K_S^0 \pi$ events. These efficiencies average the efficiencies for D originating from $c\bar{c}$ events ($24.7 \pm 1.7\%$ for D_s and $24.4 \pm 1.3\%$ for D^+) and from $b\bar{b}$ events ($13.0 \pm 1.1\%$ for D_S and $11.2 \pm 0.8\%$ for D^+). Taking into account these efficiencies, the class 16 efficiency and the K^0 branching ratios, we deduce from N_D and N_S number of events the following productions rates:

$$\frac{\Gamma(Z \to D_s^{\pm} X)}{\Gamma(Z \to \text{hadrons})} \cdot B(D_s^+ \to \bar{K}^0 K^+) = (2.40 \pm 0.73) 10^{-3}$$

and

$$\frac{\Gamma(Z \to D^{\pm} X}{\Gamma(Z \to \text{hadrons})} \cdot B(D^+ \to \bar{K}^0 \pi^+) = (4.59 \pm 1.09) 10^{-3}$$

From the charm paper , we know that:

$$\frac{\Gamma(Z \to D^{\pm} X)}{\Gamma(Z \to \text{hadrons})} \cdot B(D^+ \to K^- \pi^+ \pi^+) = (2.01 \pm 0.21) 10^{-2}$$

therefore, we can deduce the ratio of branching ratios:

$$\frac{B(D^+ \to \bar{K}^0 \pi^+)}{B(D^+ \to K^- \pi^+ \pi^+)} = (0.23 \pm 0.06)$$

which can be compared to the PDG value of 0.324 ± 0.034.

5 Acknowledgements

The authors like to thank P. Colas for his contribution.

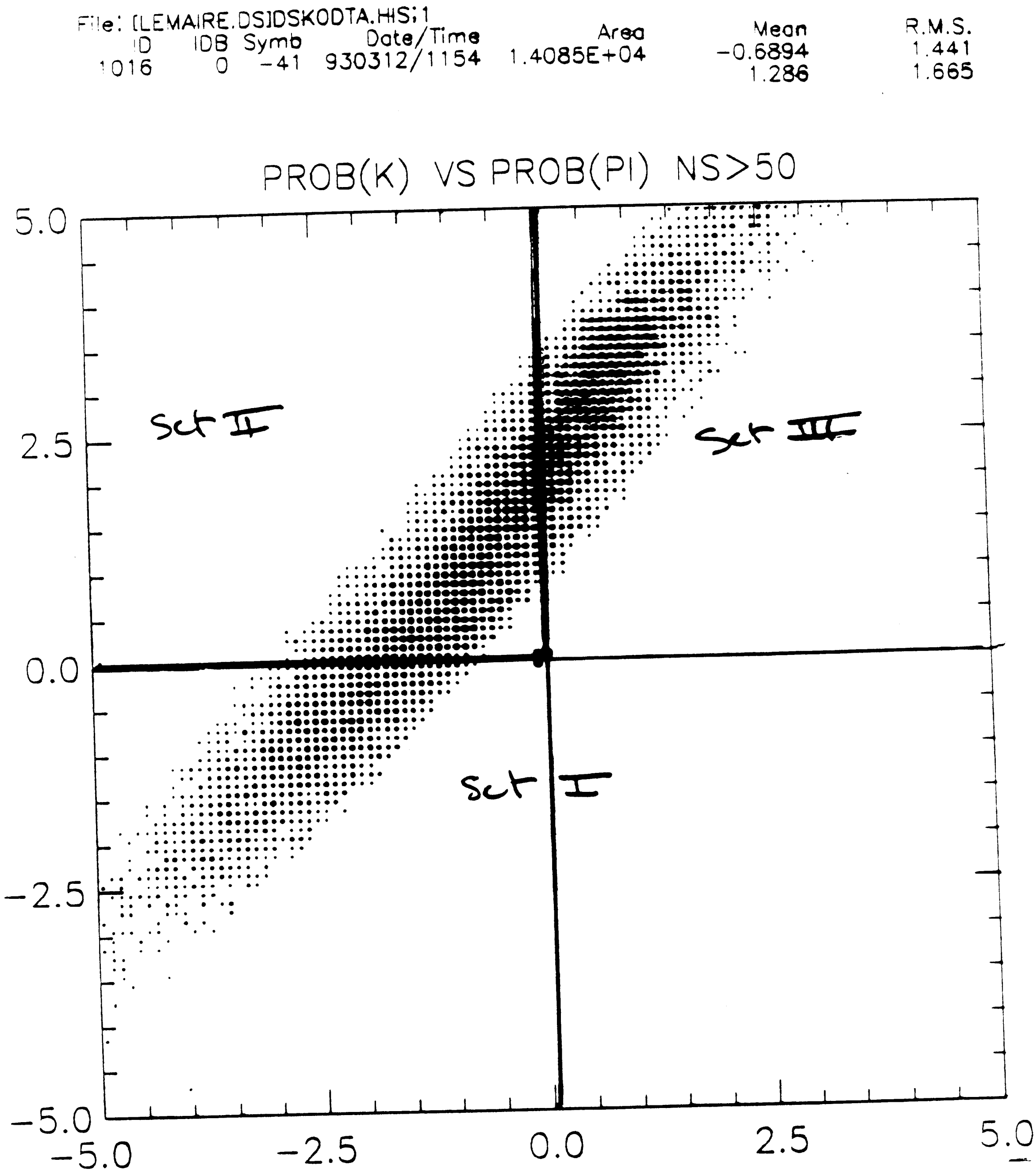

Figure 1: Scatter plot of the estimator E_K versus the estimator E_π

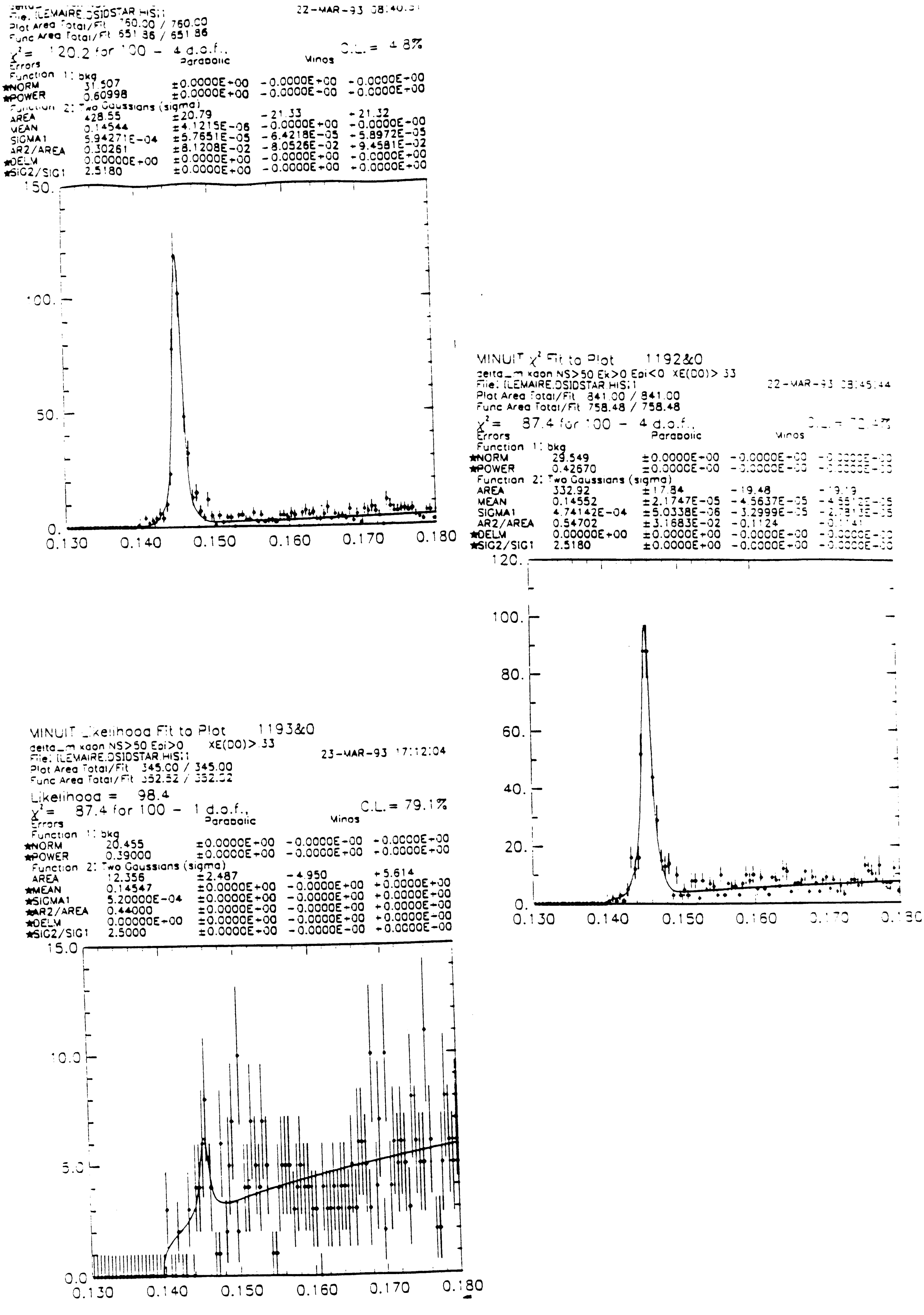

Figure 2: The ΔM mass difference distributions for the three sets of dE/dx cuts discussed in section 2 applied to the kaon track

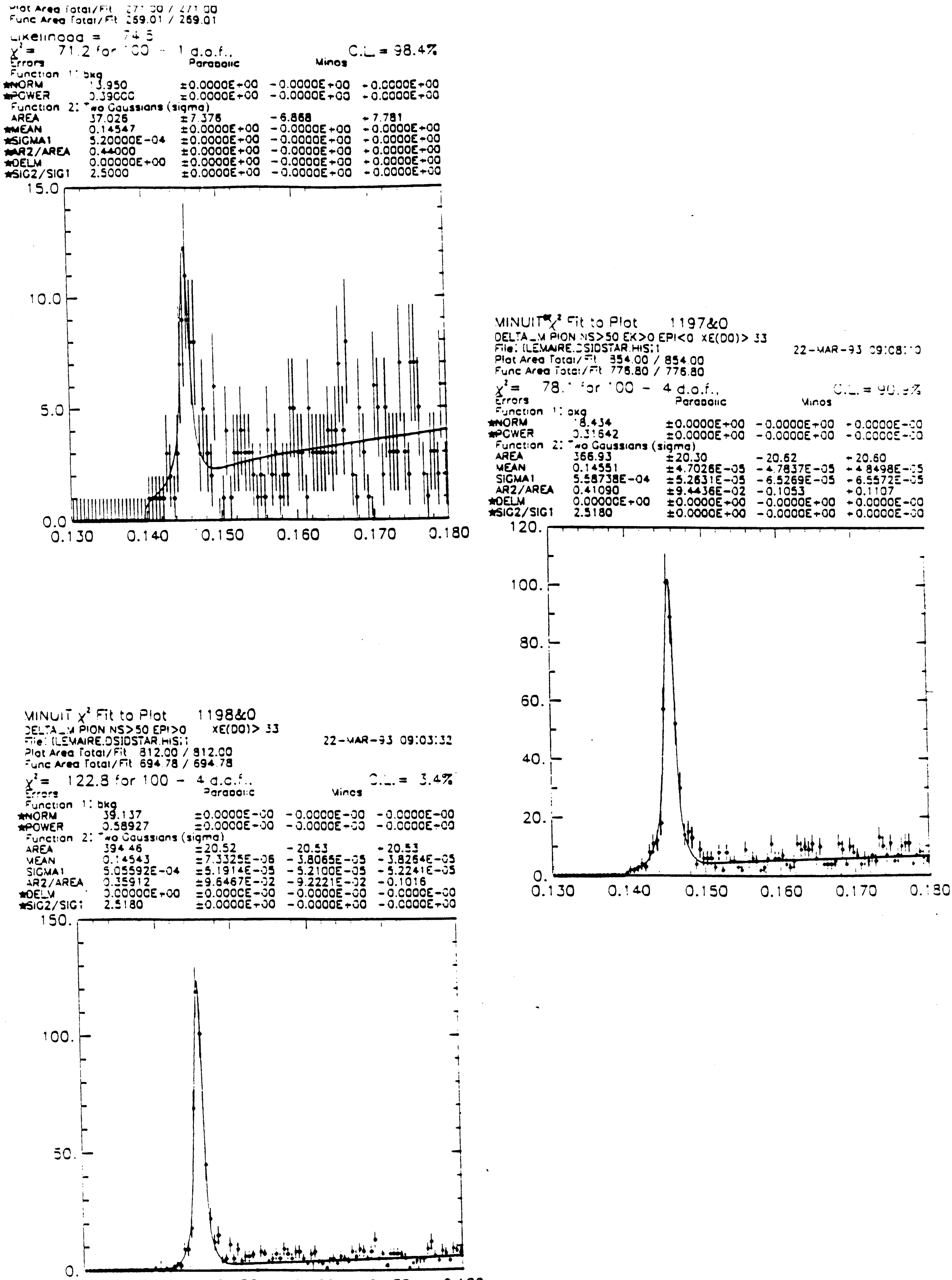

Figure 3: The ΔM mass difference distributions for the three sets of dE/dx cuts discussed in section 2 applied to the pion track

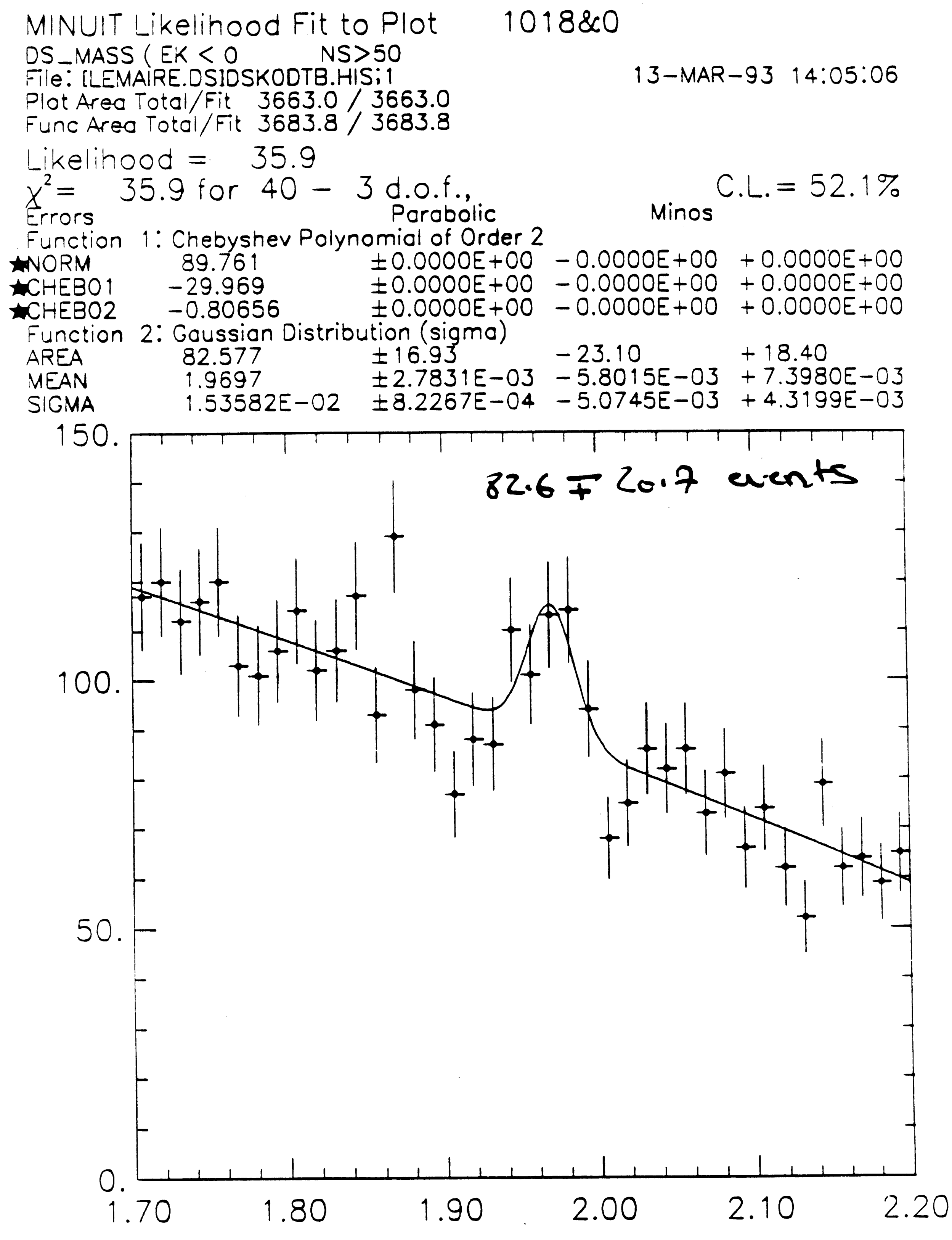

Figure 4: The $D_s^+ \to \bar{K}^0 K^+$ signal

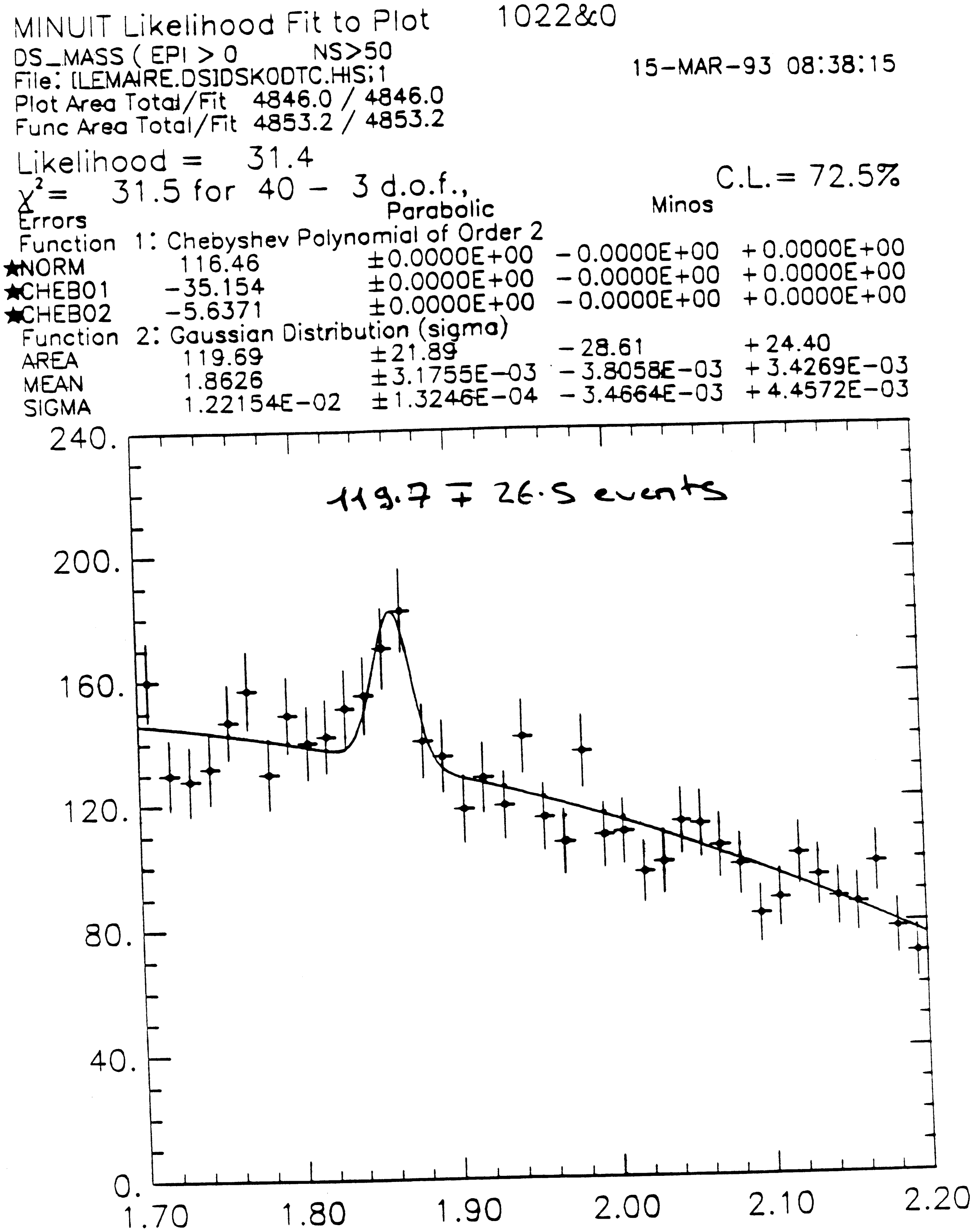

Figure 5: The $D^+ \to \bar{K}^0\pi^+$ signal

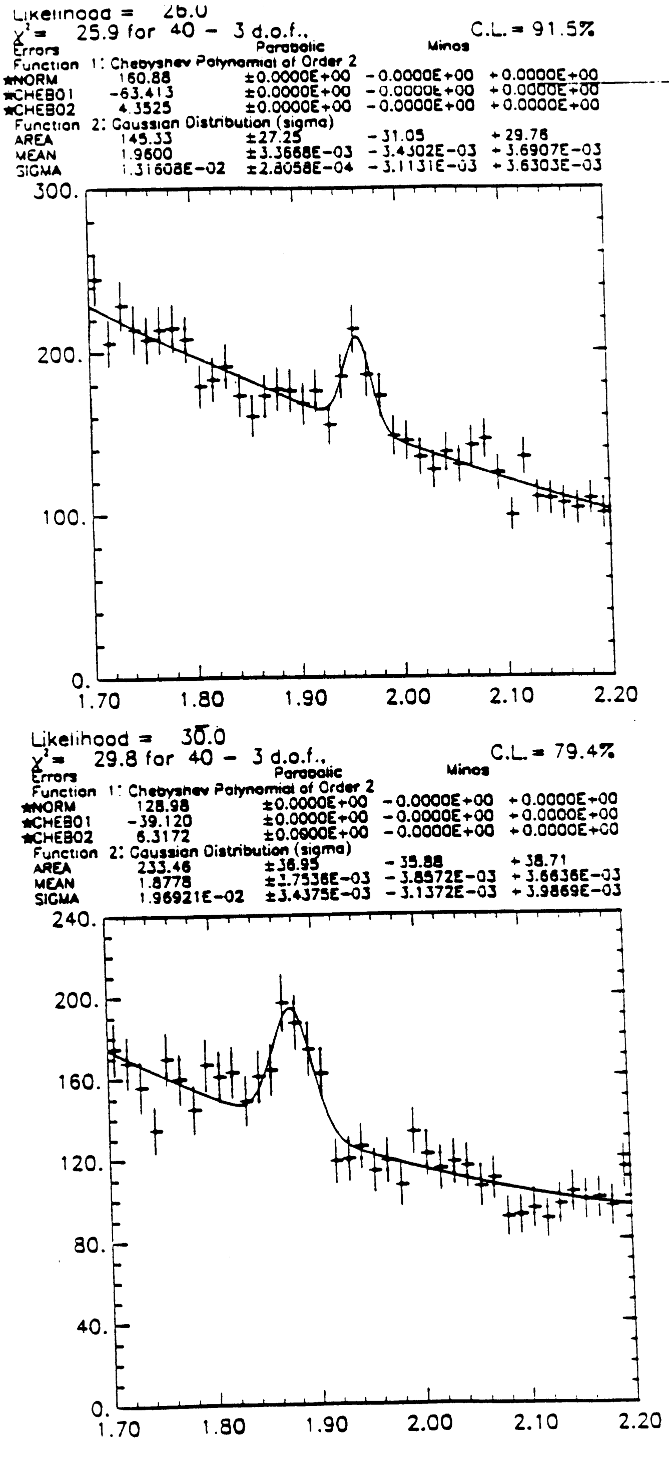

Figure 6: The$D_s \rightarrow K^{0\prime} K^{\prime}$ signal (top) and $D^+ \rightarrow K^{0\prime} \pi^{\prime}$ signal (bottom) for the dE/dx cut $E_K > 0$ and $E_\pi < 0$