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A measurement of $D_s^\pm \to K^{*\pm}K^0$ branching ratio and observation of the corresponding semileptonic B_s decays

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Abstract

The decay $D_s^\pm \to K^{*\pm}K^0$ has been searched for in a sample of 2827165 hadronic events recorded by ALEPH from 1990 to 1994. A signal of 142 events is seen. From this signal a value of $BR(D_s^\pm \to K^{*\pm}K^0) = 4.9 \pm 0.9 \pm 0.9\%$ has been determined. In addition about 10 D_s mesons correlated with a lepton are seen as a sign of the B_s meson decay mode : $B_s \to D_s l\nu$

1 $D_s^{\pm}$ search

There is up to now just one measurement of the decay $D_s^{\pm} \rightarrow K^{*\pm}K^0$, provided by CLEO experiment [1] with relative error of about 20%. Taking into account a branching ratio of the order of 4% and the large number of Z hadronic decays collected in 1990-94 by the ALEPH experiment, we could expect a reasonnable number of $D_s^{\pm}$ events allowing a B_s search.
The present analysis [2] is done via the $K^{*\pm} \rightarrow K^0\pi^{\pm}$ channel favored by the isospin. Consequently there are 2 K_s^0 to detect via $\pi^+\pi^-$ decay. This analysis takes profit of the good ALEPH's efficiency to detect K_s^0. To evaluate the efficiency of this analysis 5400 events $c\bar{c}$ and 5853 $b\bar{b}$ Monte Carlo events have been generated corresponding respectively to 10833 and 12041 D_s decaying in $K^{*\pm}K^0$
Runs "PERF" and "MAYBE" from 1990 to 1994 have been selected, corresponding to 2827165 Z hadronic decays.

1.1 - K_s^0 selection

- K_s^0 are selected amongst the V^0 rebuilt.
- The invariant mass $\pi^+\pi^-$ has to be equal to the K^0 mass $\pm 13 MeV$
- The distance of flight is greater than 1 cm
- K_s^0 momentum has to be greater than 2 GeV (Fig. 1,2,3)

1.2 - $K^{*\pm}$ reconstruction

The selection is done with the following criteria:

- The π momentum has to be greater than 1 GeV,
- The angle between K_s^0 and π is limited by $\cos(K^0, \pi) > 0.7$

The invariant mass (K_s^0, π) spectrum is shown for Monte Carlo and real events (Fig.4) after these cuts. Combination with an invariant mass equal to the $K^{*\pm}$ mass $\pm 60 MeV$ are considered to be $K^{*\pm}$

1.3 $D_s^{\pm}$ selection

Following cuts are applied:

- The K^* momentum has to be greater than 5 GeV (Fig 1),
- $D_s^{\pm}$ decay being in a small cone : $cos(K^0, K^*) > 0.8$

- Since the K^* is a spin 1 particle and the D_s a spin 0, the angular distribution between the 2 K^0 in the K^* frame has to be in $cos^2\theta$. Combinatorial background is flat (Fig 5), consequently $|cos\theta^*| > 0.4$ is required.
- The K^*K^0 combined momentum has to be greater than 10 GeV

The resulting K^*K^0 mass spectrum is shown in Fig 6 for Monte Carlo events and Fig 7 for data. A fit of the data with 2 gaussians and a second order polynomial for the background gives:

$$142.8 \pm 26.1 \text{ events}$$

a mass of: $1966 \pm 2.3 MeV$
and a width of: $\sigma = 13.5 \pm 2.7 MeV$
in agreement with the world value [3].
The second gaussian corresponds to D events.
The efficiencies obtained from the dedicated $c\bar{c}$ and $b\bar{b}$ Monte Carlo events are :

$$\epsilon^{c\bar{c}}_{D_s} = 12.4 \pm 0.4\%$$
$$\epsilon^{b\bar{b}}_{D_s} = 11.9 \pm 0.4\%$$

2 $D_s^\pm$ branching ratio

$D_s^\pm$ branching ratio is usually determined with respect to the $\phi\pi$ channel, nevertheless, recent results from ALEPH [4, 5] allow a absolute determination using the following formula and table 1

$$\begin{aligned} N(D_s^\pm \to K^{*\pm}K^0) = 2\ N_{q\bar{q}} \ & \times BR(D_s^\pm \to K^{*\pm}K^0) \times BR(K^{*\pm} \to K^0\pi^\pm) \\ & \times BR(K^0 \to K_s^0)^2 \times BR(K_s^0 \to \pi^+\pi^-)^2 \\ & \times \{\epsilon^{c\bar{c}}_{D_s} \times P(q \to c) \times f_s^c + \\ & \epsilon^{b\bar{b}}_{D_s} \times P(q \to b) \times [f_s^b \times P_{B_s \to D_s} + P(b \to B) \times P_{B \to D_s}]\} \end{aligned}$$

where:
$N(D_s^\pm \to K^{*\pm}K^0)$ is the number of observed events
$N_{q\bar{q}}$ is the number of hadronic events analyzed
$BR(D_s^\pm \to K^{*\pm}K^0)$ is the branching ratio we are looking for
$P(q \to b) = \frac{\Gamma(Z^0 \to b\bar{b})}{\Gamma(Z^0 \to \text{hadrons})}$
f_s^c is the probability for the primary quark $c(\bar{c})$ to hadronize with a quark $\bar{s}(s)$, creating a D_s: $BR(c \to D_s)$.
f_s^b is the probability for the primary quark $b(\bar{b})$ to hadronize with a quark $\bar{s}(s)$, creating a B_s: $BR(b \to B_s)$.
Values have been determined by ALEPH [5] :

$$P(q \to b) = 0.2202 \pm 0.0020$$
$$f_s^c = 0.127 \pm 0.025$$
$$f_s^b \times P_{B_s \to D_s} = 0.086 \pm 0.031$$

One gets the following branching ratio:

$$\boxed{BR(D_s^\pm \to K^{*\pm}K^0) = 4.9 \pm 0.9 \pm 1.0\%}$$

The systematic errors are due to the limited statistics of the Monte Carlo, the uncertainties on efficiencies and mainly on the parameters of the table 1.
This branching ratio can also be obtained via the relative width with respect to the $\phi\pi$ decay. We use an analysis done by ALEPH for this channnel [6].
To limit the systematic errors we apply the same cuts on D_s than for the $\phi\pi$ channel:

$$X(D_s) > 0.4, \text{ where } X(D_s) = \frac{P(D_s)}{E_{\text{beam}}}.$$

It reduces the number of events to $N_{D_s \to K^*K^0} = 62 \pm 12$ and the selection efficiencies to:

$$\epsilon_{c\bar{c}}^{K^*K^0} = 8.6 \pm 0.3\%, \quad \epsilon_{b\bar{b}}^{K^*K^0} = 4.8 \pm 0.2\%$$

The corresponding values for the $D_s^\pm \to \phi\pi^\pm$ channel are : $N_{D_s \to \phi\pi} = 492 \pm 39$ and

$$\epsilon_{c\bar{c}}^{\phi\pi} = 15.0 \pm 0.5\%, \quad \epsilon_{b\bar{b}}^{\phi\pi} = 7.7 \pm 0.4\%$$

if we assume that:

$$\alpha_c = \frac{\epsilon_{c\bar{c}}^{K^*K^0}}{\epsilon_{c\bar{c}}^{\phi\pi}} \approx \quad \alpha_b = \frac{\epsilon_{b\bar{b}}^{K^*K^0}}{\epsilon_{b\bar{b}}^{\phi\pi}} \approx .60 \pm 0.04$$

we deduce:

$$\frac{\Gamma(D_s^\pm \to K^{*\pm}K^0)}{\Gamma(D_s^\pm \to \phi\pi^\pm)} = 1.32 \pm 0.25_{\text{stat.}} \pm 0.14_{\text{syst.}}$$

Systematic errors are coming from the Monte Carlo statistics, number of $D_s^\pm \to \phi\pi^\pm$, K_s^0 and ϕ branching ratios.
Using the world value for $BR(D_s^\pm \to \phi\pi^\pm) = 3.5 \pm 0.4\%$ [3], we obtain :

$$\boxed{BR(D_s^\pm \to K^{*\pm}K^0) = 4.6 \pm 1.1\%}$$

in agreement with the direct determination. These values agree also with the CLEO results : $BR(D_s^\pm \to K^{*\pm}K^0) = 4.2 \pm 1.0\%$

3 D_s-lepton correlations

One can try to correlate the D_s meson with a lepton in order to observe the presence of a B_s meson decaying in the semi leptonic mode $B_s \to D_s l\nu$

- Electrons are identified by dE/dx if available and following cuts on estimators: $R2 > -1.6, \quad -1.8 < R3 < 3, \quad \chi_e > -2.5$

- Muons are identified by :
  - at least 40% of the expected and 5 amongst the last 10 HCAL plans fired,
  - at least 1 associated hit in muon chambers

- Lepton momentum has to be greater than 3 GeV
- D_s momentum has to be greater than 10 GeV
- D_s and lepton have to be in a cone: $\cos(D_s, \text{lepton}) > 0.7$
- Background being important at low mass and momentum we required: $m(D_s^{\pm}, \text{lepton}) > 3$ GeV, and $p(D_s^{\pm} - \text{lepton}) > 20$ GeV

For background evaluation, combinations of D_s with a lepton of same sign are also selected.
For efficiency determination 1245 B_s decaying via $D_s \to K^*K^0$ are generated by Monte Carlo.
With the previous cuts, the efficiency is

$$\epsilon_{B_s}^{K^*K^0} = 6.9 \pm 0.8\%$$

The K^*K^0 invariant mass spectrum obtain with this criteria, adding electrons and muons, is shown Fig.8, indicating a signal of B_s of 10 ± 4 events.
From this number and the following formula:

$$\begin{aligned} N_{B_s \to D_s \to K^*K^0} = 2\ N_{q\bar{q}} & \times BR(B_s \to D_s X l\nu) \times BR(D_s \to K^*K^0) \\ & \times BR(K^* \to K^0\pi) \times BR(K^0 \to K_s^0)^2 \\ & \times BR(K_s^0 \to \pi^+\pi^-)^2 \times \epsilon_{B_s}^{K^*K^0} \times P(q \to b) \times f_s^b \end{aligned}$$

we can deduce the branching ratio product:

$$f_s^b \times BR(B_s \to D_s X l\nu) \times BR(D_s \to K^*K^0) = (1.48 \pm 0.59_{\text{stat.}} {}^{+0.17}_{-0.21}{}_{\text{syst.}}) \times 10^{-3}$$

using the branching ratio $BR(D_s \to K^*K^0)$ determined above, we deduce:

$$\boxed{BR(b \to B_s) \times BR(B_s \to D_s X l\nu) = 0.032 \pm 0.013_{\text{stat.}} {}^{+0.009}_{-0.010}{}_{\text{syst.}}}$$

Systematic errors are due to uncertainties on $BR(K_s^0 \to \pi^+\pi^-)$, $(P(q \to b))$, Monte Carlo statistics and non symetric background coming from $B \to D_s$"D"X, "D" $\to X l\nu$ and $B \to D_s$"K"W^*, $W^* \to l\nu$
This value is in good agreement with previous measurement from ALEPH [7], (after updating of $BR(D_s^{\pm} \to \phi\pi^{\pm})$) and recent ALEPH results on B_s^0 lifetime [8]

Conclusion

A signal of 142 events $D_s^{\pm} \to K^{*\pm}K^0$ has been extracted from the 1990 to 1994 ALEPH data, allowing a determination of the branching ratio

$$BR(D_s^{\pm} \to K^{*\pm}K^0) = 4.9 \pm 0.9 \pm 0.9\%$$

A comparable value has been obtained by comparison to the $\phi\pi$ channel.
This result is in good agreement with the unique previous value coming from CLEO.
Measurement of 10 D_s mesons correlated with a lepton is a sign of the B_s meson.
It allowed to determine the product:

$$BR(b \to B_s) \times BR(B_s \to D_s X l\nu) = 0.032 \pm 0.013_{\mathrm{stat.}}{}^{+0.009}_{-0.010}{}_{\mathrm{syst.}}$$

Acknowledgements

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$N_{q\bar{q}}$	2827165
$BR(K^{*\pm} \to K^0\pi^\pm$	2/3
$BR(K^0 \to K^0_s)$	0.5
$BR(K^0_s \to \pi^+\pi^-)$	68.61±0.21%
$P(q \to c)$	15.83±0.98%
f^c_s	12.7±2.5%
$P(q \to b)$	22.02±0.20%
$f^b_s \times P_{B_s \to D_s}$	8.6±3.1%
$P(b \to B)$	77±5%
$P_{B \to D_s}$	8.9±1.1%

Table 1: Values used for the $BR(D^\pm_s \to K^{*\pm}K^0)$calculation

References

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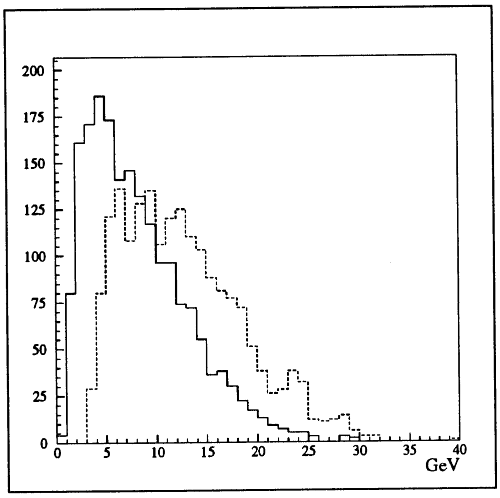

Figure 1: K^0 momentum (full line) and K^* momentum (dotted line) for $c\bar{c}$ events

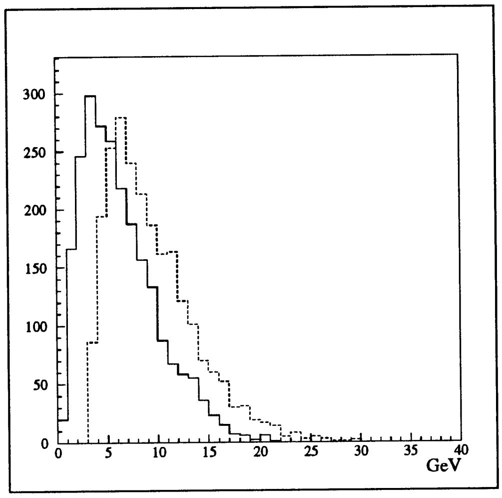

Figure 2: K^0 momentum (full line) and K^* momentum (dotted line) for $b\bar{b}$ events

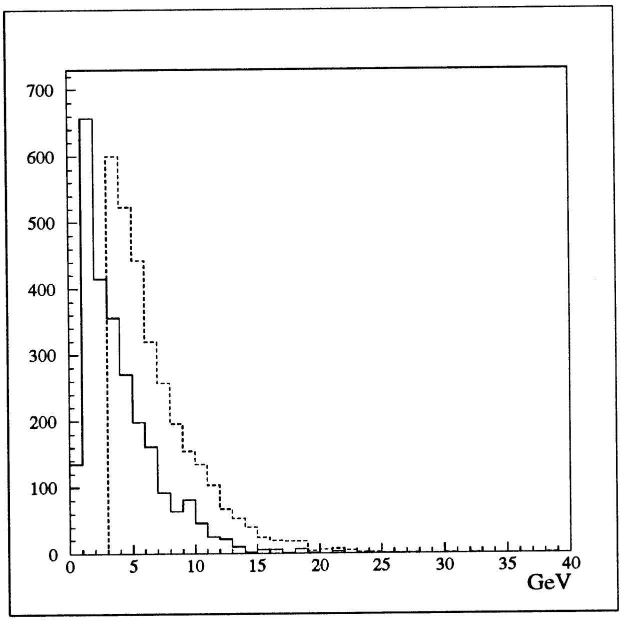

Figure 3: K^0 momentum (full line) and K^* momentum (dotted line) for background events

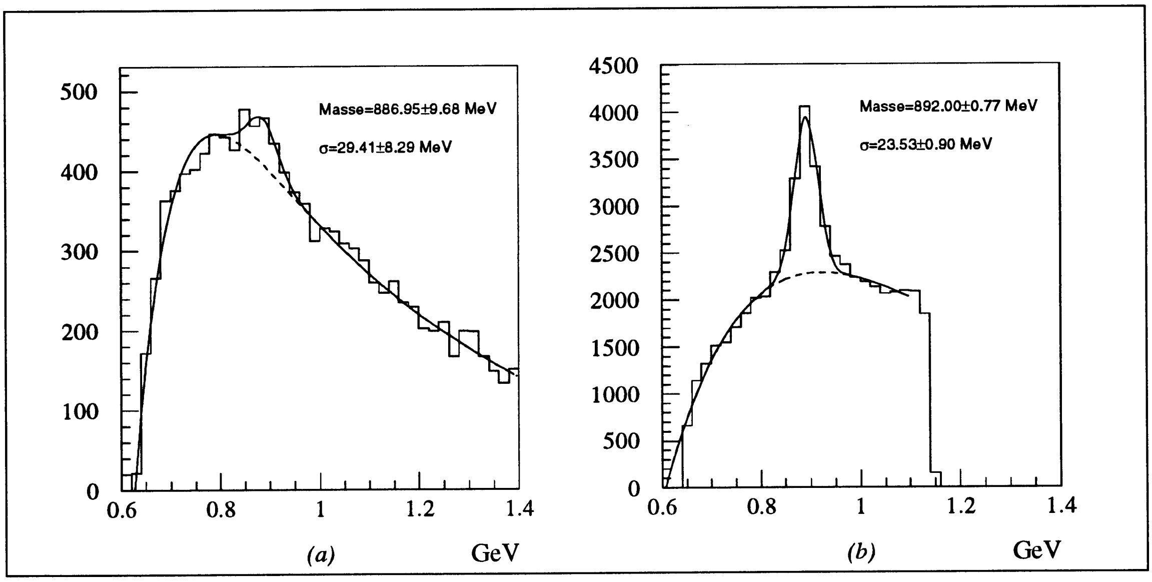

Figure 4: $K^0\pi$ invariant mass for data (a) and for Monte-Carlo events (b). Background is fitted by a 3rd degree polynomial times a exponential

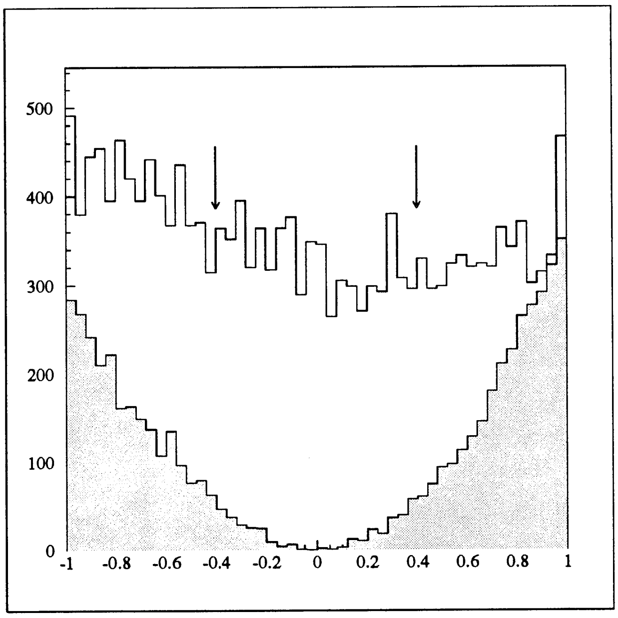

Figure 5: $cos\theta^*$ distribution for signal (hatched) and background events

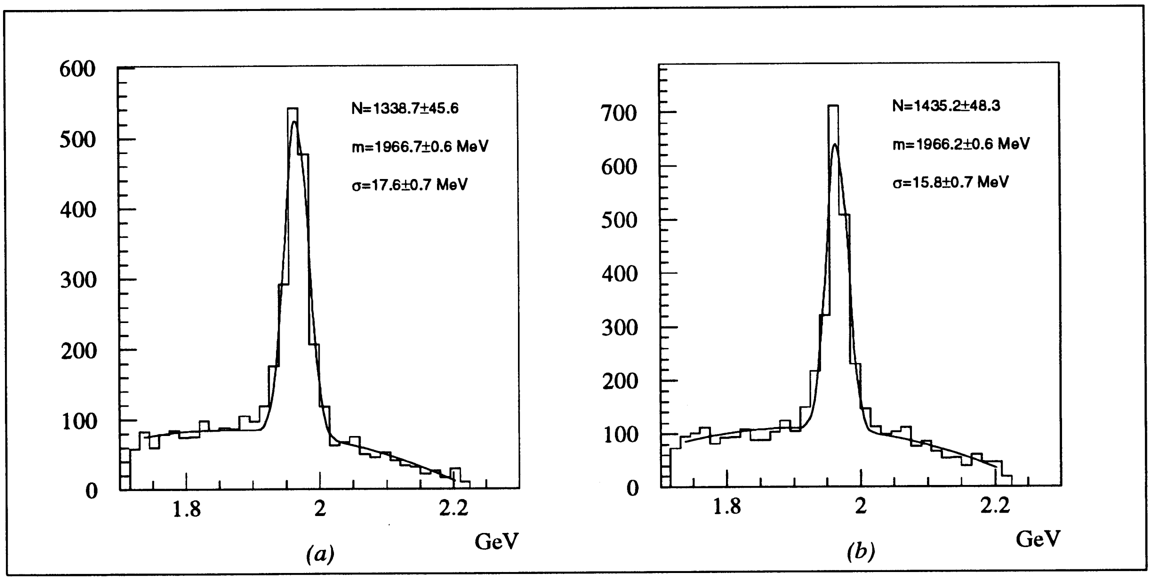

Figure 6: K^*K^0 invariant mass spectrum for $c\bar{c}$ (a) and $b\bar{b}$ (b)Monte Carlo events. Background is fitted with a second degree polynomial

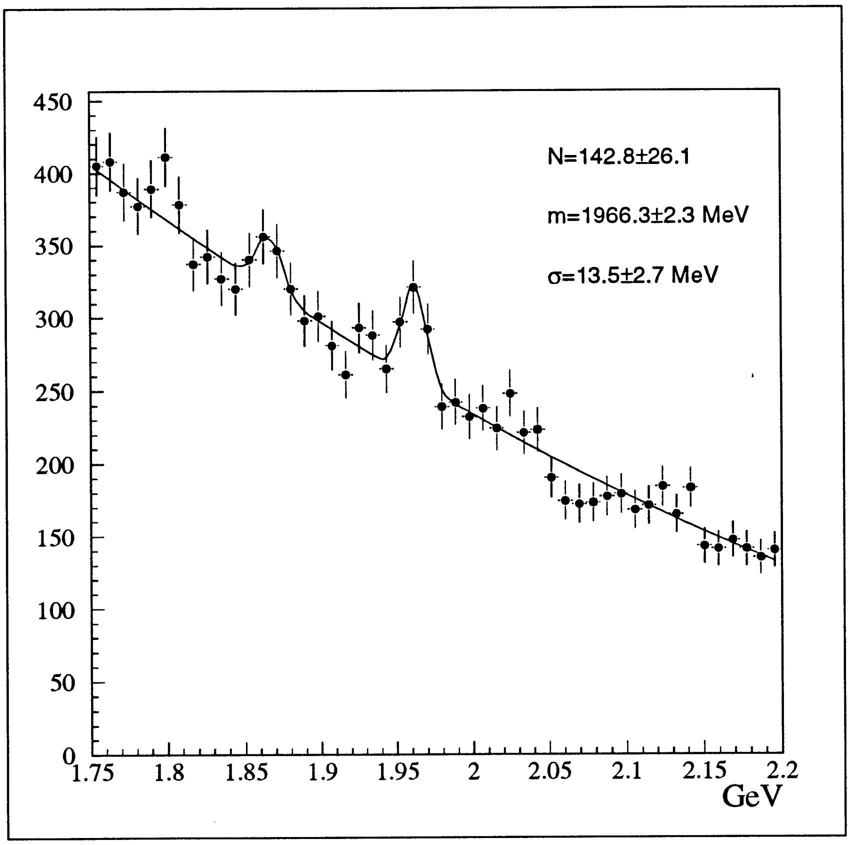

Figure 7: K^*K^0 invariant mass spectrum for the data

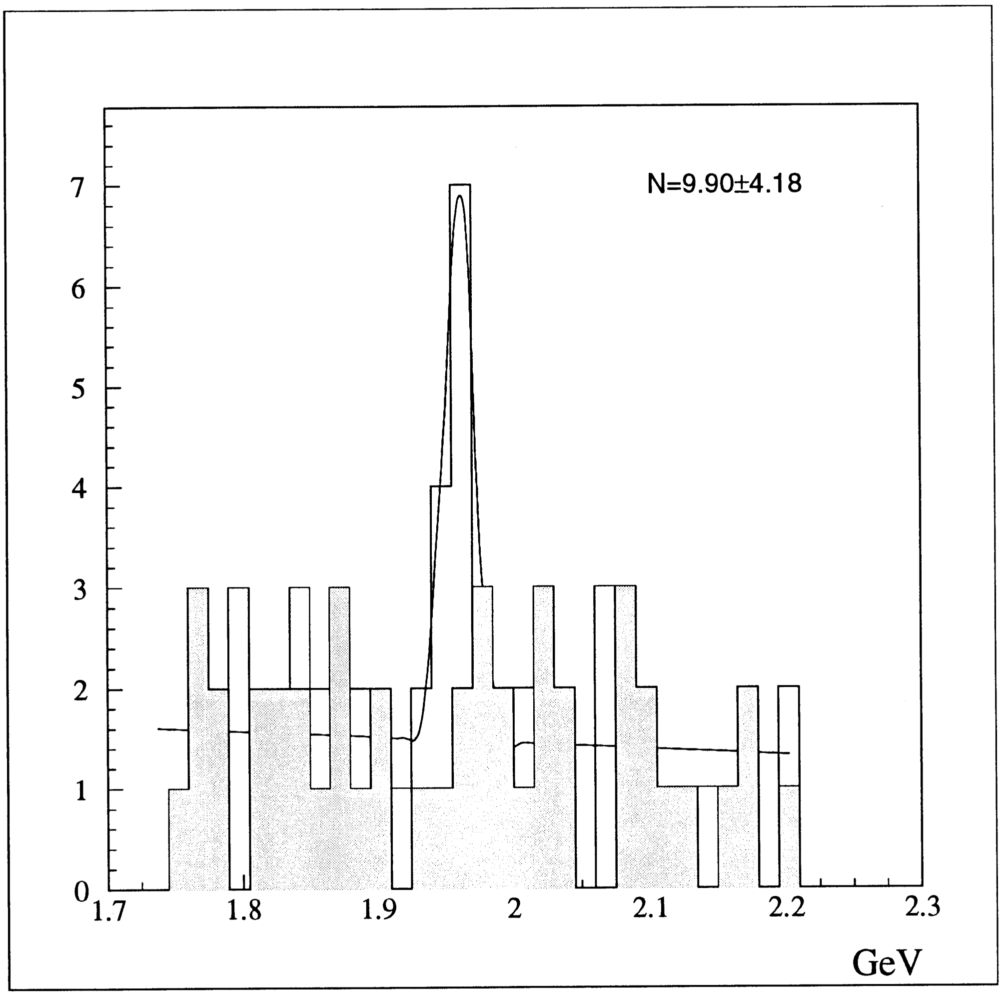

Figure 8: $K^{*\pm}K^0$ invariant mass. Unshaded for opposite-sign, hatched for same-sign $D_s - l$ pairs