ALEPH 95-115
PHYSIC 95-100
A.Cordier, F.Courault
16.10.1995

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

A.Cordier, F.Courault

Laboratoire de l'Accélérateur Linéaire, IN2P3-CNRS
et Université de Paris Sud-Orsay
F-91405 Orsay Cédex, France

Abstract

The decay $D_s^\pm \to K^0K^\pm$ has been searched for in a sample of 2770735 hadronic events recorded by ALEPH from 1990 to 1994. A signal of 418 events is seen. From this signal a value of $BR(D_s^\pm \to K^0K^\pm) = 3.2 \pm 0.6 \pm 1.0\%$ has been determined.
In addition 34 D_s mesons correlated with a lepton are seen as a sign of the B_s meson. The product

$$BR(b \to B_s) \times BR(B_s \to D_sXl\nu) = 0.029 \pm 0.005_{\text{stat.}}{}^{+0.007}_{-0.009}{}_{\text{syst.}}$$

is deduce from this channel and from the $D_s^\pm \to K^{*\pm}K^0$ decay study.

1 $D_s^{\pm}$ search

Measurements of the $D_s^{\pm} \to K^0 K^{\pm}$ branching ratio have already been published by 3 experiments [1, 2, 3] and studied in ALEPH on a fraction of the statistics [4] . Nevertheless these results are affected by rather large uncertainties and are determined with respect to the $\phi\pi$ channel. This study [5] uses the ALEPH statistics until 1994 and takes into account new intermediate values allowing a absolute measurement of the branching ratio.
To evaluate the efficiency 3000 events $c\bar{c}$ and 3000 $b\bar{b}$ Monte Carlo events containing at least two $D_s^{\pm} \to K^0 K^{\pm}$ per event have been generated. In addition 3000 events $c\bar{c}$ and 3000 $b\bar{b}$ Monte Carlo events containing at least two $D_s^{\pm} \to K^0 \pi^{\pm}$ per event have been generated for study of contamination.
The present analysis use the ALEPH TPC for $K^{\pm}$ identification and the vertex detector.
Runs "PERF" and "MAYBE" from 1990 to 1994 have been selected, corresponding to 2770735 Z hadronic decays.

1.1 K_s^0 selection

The K^0 selection is similar to those done for the $K^* K^0$ analysis [6]:

- 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

1.2 $K^{\pm}$ selection

Charged K are selected with the following criterias:

- Momentum of the charged track has to be greater than 2 GeV,
- $\mathrm{d}E/\mathrm{d}x$ information muss exist and we required: $|\chi_K| < 2$, where:

$$\chi_K = \frac{I_{\text{mes}} - I_{\text{exp}}}{\sigma_I}$$

  and I_{mes} is the measured ionisation in the TPC and σ_I is the measured resolution.

1.3 $D_s^\pm$ selection

The K^0K invariant mass is calculated for Monte Carlo events (Fig.1) and data (Fig. 2), with Kaons satisfying the following cuts:

- The K_s^0 and $K^\pm$ momentum have to be greater than 2 GeV ,
- $D_s^\pm$ decay being in a small cone : $cos(K^0, K) > 0.7$
- The K^0K combined momentum has to be greater than 10 GeV.

A gaussian fit and a second order polynomial for the background lead to a mass of $1961 \pm 3\ \ MeV$, 7 MeV lower than the world value [7].
This effect can be explain by a $D^\pm$ contamination.

1.4 Contamination study

The large number of $D^\pm$ decaying into $K^0\pi^\pm$ leads to a contamination of the $K^0K^\pm$ channel when the π is misidentified like a K. We have compared the efficiencies for $D^\pm$ and D_s events:$\epsilon_{D_s}^{c\bar{c}}$, $\epsilon_{D_s}^{b\bar{b}}$, $\epsilon_D^{c\bar{c}}$ and $\epsilon_D^{b\bar{b}}$, with different cuts. Efficiencies $\epsilon_D^{c\bar{c}}$ and $\epsilon_D^{b\bar{b}}$ are calculated by counting the number of true $D^\pm$ with a K^0K invariant mass closer than 2 σ from the D_s mass.
Different cuts have been tested. Best results are obtained with the cut:

$$-2 < \chi_K < 0$$

leading to the following efficiencies:

$$\begin{array}{rclrcl} \epsilon_{D_s}^{c\bar{c}} & = & 13.5 \pm 0.7\% & \epsilon_{D_s}^{b\bar{b}} & = & 11.9 \pm 0.6\% \\ \epsilon_D^{c\bar{c}} & = & 0.7 \pm 0.2\% & \epsilon_D^{b\bar{b}} & = & 0.5 \pm 0.1\% \end{array}$$

With this last cut we obtain the $K^0K^\pm$ invariant mass spectrum of the Figure 3.

A fit of the data with 2 gaussians and a second order polynomial for the background gives:

$$N_{D_s^\pm \to K^0K^\pm} = 418.6 \pm 79.3 \text{ events},$$

a mass of:

$$m = 1968.6 \pm 3.4 \ \ \text{MeV},$$

in agreement with the world value [7]
and a width of

$$\sigma = 13.2 \pm 3.5 \ \ \text{MeV},$$

The second gaussian corresponds to $D^\pm \to K^0K^\pm$ events.

2 $D_s^{\pm}$ branching ratio

As for the K^*K^0 channel [6], $D_s^{\pm}$ branching ratio is usually determined with respect to the $\phi\pi$ channel, nevertheless, recent results from ALEPH [9, 10] allow a absolute determination using the following formula and table 1

$$\begin{aligned} N(D_s^{\pm} \to K^0K^{\pm}) = 2\ N_{q\bar{q}} \ & \times BR(D_s^{\pm} \to K^0K^{\pm}) \times BR(K^0 \to K_s^0) \\ & \times BR(K_s^0 \to \pi^+\pi^-) \\ & \times \left\{\epsilon_{D_s}^{c\bar{c}} \times P(q \to c) \times f_s^c + \right. \\ \epsilon_{D_s}^{b\bar{b}} \times P(q \to b) \times [f_s^b \times P_{B_s \to D_s} & + P(b \to B) \times P_{B \to D_s}]\} \end{aligned} \tag{1}$$

where:

$N(D_s^{\pm} \to K^0K^{\pm})$ is the number of observed events,
$N_{q\bar{q}}$ is the number of hadronic events analyzed,
$BR(D_s^{\pm} \to K^0K^{\pm})$ 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: $BR(b \to B_s)$.
Nevertheless the $D^{\pm}$ contamination has to be considered. The number of $D^{\pm}$ decaying into $K^0\pi^{\pm}$ is given by:

$$\begin{aligned} N(D^{\pm} \to K^0\pi^{\pm}) = N_{q\bar{q}} \ & \times \mathcal{F} \times \mathcal{R}_{\text{ PDG}} \times BR(K^0 \to K_s^0) \times BR(K_s^0 \to \pi^+\pi^-) \\ & \times \left[\epsilon_D^{c\bar{c}} \times P(q \to c) + \epsilon_D^{b\bar{b}} \times P(q \to b)\right] \end{aligned}$$

where:

$N(D^{\pm} \to K^0\pi^{\pm})$ is the number of $D^{\pm}$ selected as D_s

the factor $\mathcal{F} = \dfrac{\Gamma(Z \to D^{\pm}X)}{\Gamma(Z \to \text{hadron s})} \times BR(D^{\pm} \to K^{\mp}\pi^{\pm}\pi^{\pm})$ measured by ALEPH [11]

determine the production of $D^{\pm}$: $\mathcal{F} = 2.01 \pm 0.21\%$

$$\mathcal{R}_{\text{PDG}} = \frac{\Gamma(D^{\pm} \to K^0\pi^{\pm})}{\Gamma(D^{\pm} \to K^{\mp}\pi^{\pm}\pi^{\pm})} = 0.302 \pm 0.031 \ [2,\ 7]$$

Then we deduce the number of contaminating D :

$$N(D^{\pm} \to K^0\pi^{\pm}) = 12.7 \pm 4.1$$

The corrected number of D_s is then :

$$N(D_s^{\pm} \to K^0K^{\pm}) = 405.9 \pm 79.3$$

With the numerical values of the Table 1, we deduce the branching ratio :

$N_{q\bar{q}}$	2770735
$BR(K^0 \to K_s^0)$	0.5
$BR(K_s^0 \to \pi^+\pi^-)$	68.61±0.21%
$P(q \to c)$	15.83±0.98%
f_s^c	12.7±2.5%
$P(q \to b)$	22.02±0.20%
$f_s^b \times P_{B_s \to D_s}$	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 $BR(D_s^\pm \to K^0K^\pm)$calculation

$$\boxed{BR(D_s^\pm \to K^0K^\pm) = 3.2 \pm 0.6 \pm 1.0\%}$$

The systematic errors are due to the limited statistics of the Monte Carlo, the uncertainties on efficiencies, the uncertainties on the $\mathrm{d}E/\mathrm{d}x$ cut for $K^\pm$ selection and precision on the parameters of the Table 1.

Like for the K^*K^0 [6], 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 channel [12]. To limit the systematic errors we apply the same cuts on D_s than on the $\phi\pi$ chanel:

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

It corresponds to an increase of the D_s momentum cut from 10 GeV to about 18 GeV, reducing strongly the statistics to $N_{D_s \to K^0K} = 203 \pm 34$, and the selection efficiencies to:

$$\epsilon_{c\bar{c}}^{K^0K} = 9.7 \pm 0.6\%, \quad \epsilon_{b\bar{b}}^{K^0K} = 4.6 \pm 0.3\%$$

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:

$$\alpha_c = \frac{\epsilon_{c\bar{c}}^{K^0K}}{\epsilon_{c\bar{c}}^{\phi\pi}} \approx \quad \alpha_b = \frac{\epsilon_{b\bar{b}}^{K^0K}}{\epsilon_{b\bar{b}}^{\phi\pi}} \approx .62 \pm 0.07$$

we deduce:

$$\frac{\Gamma(D_s^\pm \to K^0K^\pm)}{\Gamma(D_s^\pm \to \phi\pi^\pm)} = 0.97 \pm 0.16_{\text{stat.}} \pm 0.13_{\text{syst.}}$$

Systematic errors are coming from the Monte Carlo statistics, number of $D_s^\pm \to \phi\pi^\pm$, uncertainties on the $\mathrm{d}E/\mathrm{d}x$ cut for $K^\pm$ selection,and K_s^0 and ϕ branching ratios.

This value is in good agreement with the previous measurements:

$1.15 \pm 0.31_{\text{stat.}} \pm 0.19_{\text{syst.}}$	for E691
$0.92 \pm 0.32_{\text{stat.}} \pm 0.20_{\text{syst.}}$	for MARK III
$0.99 \pm 0.17_{\text{stat.}} \pm 0.10_{\text{syst.}}$	for CLEO

Using the world value for $BR(D_s^\pm \to \phi\pi^\pm) = 3.5 \pm 0.4\%$ [7], we obtain :

$$\boxed{BR(D_s^\pm \to K^0K^\pm) = 3.5 \pm 0.6 \pm 1.0\%}$$

Statistics and systematic errors being added quadratically.
The values determined by these two ways agree with the other experiments:

	$BR(D_s^\pm \to K^0K^\pm)$
This experiment, absolute measurement	$3.2 \pm 1.0\%$
This experiment,measurement / $\phi\pi^\pm$	$3.4 \pm 0.8\%$
World value [7] (E691, MARK III, CLEO)	$3.5 \pm 0.7\%$
Mean value with this experiment	$3.5 \pm 0.6\%$

Table 2:. Comparison of the $BR(D_s^\pm \to K^0K^\pm)$ experimental measurements

3 Comparison to theoretical predictions

There are essentially two theorical models available: M.Bauer,B.Stech and M.Wirbel [13], using factorisation and B.Y.Blok and M.A.Shifman [14] based on sum rules. These models give, in particular, predictions for 4 of the D_s decays:$\phi\pi^\pm$, $K^0K^\pm$,$K^{*\pm}K^0$, $K^\pm K^{*0}$. We can compare experimental results obtained by ALEPH on $K^0K^\pm$, this analysis,and $K^{*\pm}K^0$, [5, 6], with the theoretical predictions,Table 3.

Values on $\phi\pi^\pm$ and $K^\pm K^{*0}$ are the world values [7].

We can see that, if predictions and results are compatible for $\phi\pi^\pm$, there is a rather large disagreement for other decays. In more the ratio $K^{*\pm}K^0$/ $K^\pm K^{*0}$ is reversed. These differencies could be due to interactions in the final state, underestimated in the theoretical models.

	WBS	BS	Experiment
$BR(D_s^\pm \to \phi\pi^\pm)$	3.7%	2.0%	$3.5 \pm 0.4\%$
$BR(D_s^\pm \to K^0K^\pm)$	1.8%	0.9%	$\mathbf{3.4 \pm 0.8\%}$
$BR(D_s^\pm \to K^{*\pm}K^0)$	0.8%	0.2%	$\mathbf{4.6 \pm 1.1\%}$
$BR(D_s^\pm \to K^\pm K^{*0})$	2.1%	1.5%	$3.3 \pm 0.5\%$

Table 3: Comparison of experimental D_s branching ratios measurements with theoretical predictions

4 D_s-lepton correlations

The significant number of D_s allows to try to correlate the D_s meson with a lepton in order to observe the presence of a B_s meson decaying in the semileptonic mode $B_s \to D_s l\nu$.
We require the same criterias than for the $K^{*\pm}K^0$ analysis [6]

- 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 6003 B_s decaying via $D_s \to K^0K$ are generated by Monte Carlo.
With the previous cuts, the efficiency is:

$$\epsilon_{B_s}^{K^0K} = 8.5 \pm 0.4\%$$

The K^0K invariant mass spectrum obtain with this criteria is shown Fig.4, indicating a signal of B_s but also a excess of events around 2100 MeV. This excess is due to the reflexion of a Λ_b baryon decaying into Λ_c-lepton, the Λ_c going into pK^0 where the

proton is misidentified like a K. A cut at $\pm 25 MeV$ on the invariant mass calculated assuming a K^0 associated to a proton suppresses this reflexion.
Final $K^0K^{\pm}$ invariant mass spectrum is shown Fig.5, indicating a signal of

$$N_{B_s \rightarrow D_s \rightarrow K^0 K} = 34 \pm 7 \text{events}$$

From this number and the following formula we can deduce the branching ratio produce:

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

where:

$N_{B_s \rightarrow D_s \rightarrow K^0 K}$ is the number of observed events
$\epsilon_{B_s}^{K^0 K}$ is the efficiency.
We obtained:

$$f_s^b \times BR(B_s \rightarrow D_s X l \nu) \times BR(D_s \rightarrow K^0 K) = (9.55 \pm 1.97_{\text{stat.}} {}^{+0.46}_{-0.69}{}_{\text{syst.}}) \times 10^{-4}$$

Then using the branching ratio $BR(D_s \rightarrow K^0 K)$ determined above:

$$f_s^b \times BR(B_s \rightarrow D_s X l \nu) = 0.028 \pm 0.006_{\text{stat.}} {}^{+0.006}_{-0.007}{}_{\text{syst.}}$$

Systematic errors are due to uncertainties on $BR(K^0_s \rightarrow \pi^+\pi^-)$, $(P(q \rightarrow b))$, Monte Carlo statistics, evaluation of the $D^{\pm} \rightarrow K^0\pi^{\pm}$ reflexion and non symetric background coming from $B \rightarrow D_s$"D"X, "D" $\rightarrow X l \nu$ and $B \rightarrow D_s$"K"W^*, $W^* \rightarrow l\nu$

Results of this analysis and of the $D_s \rightarrow K^{*\pm} K^0$ [5, 6] can be added. Then we obtain the invariant mass spectrum of the Fig. 6, corresponding to 44±8 events and to the product:

$$\boxed{BR(b \rightarrow B_s) \times BR(B_s \rightarrow D_s X l \nu) = 0.029 \pm 0.005^{+0.007}_{-0.009}}$$

Conclusion

A signal of 418 events $D_s^\pm \to K^0 K^\pm$ has been extracted from the 1990 to 1994 ALEPH data, allowing a determination of the branching ratio

$$BR(D_s^\pm \to K^0 K^\pm) = 3.2 \pm 0.6 \pm 1.0\%$$

A comparable value has been obtain by comparison to the $\phi\pi$ channel.
Results are in good agreement with previous measurement but disagree strongly from the theoretical predictions.
Measurement of 34 D_s mesons correlated with a lepton is a sign of the B_s meson. The product

$$BR(b \to B_s) \times BR(B_s \to D_s X l \nu) = 0.029 \pm 0.005_{\mathrm{stat.}}{}^{+0.007}_{-0.009}{}_{\mathrm{syst.}}$$

is determined from this channel and from the $D_s^\pm \to K^{*\pm} K^0$ decay studies.

Acknowledgements

We thank the ALEPH-Heavy flavor group from Orsay for discussions and particulary J.Boucrot for his contribution at different steps of this analysis.

References

[1] CLEO coll., *Measurement of D_s decay modes*, Phys. Lett. **B226** (1989) 192

[2] E691 coll., *Study of the decays $D \to \bar{K}^0\pi^+$ and $D \to \bar{K}^0K^+$*, Phys. Rev. **D41** (1990) 2705

[3] MARK III coll., *Observation of $D_s^+ \to \bar{K}^0K^+$ and $D_s^+ \to \bar{K}^{*0}K^+$ and an Upper Limit on $D_s^+ \to K^0\pi^+$*, Phys. Rev. Lett. **63** (1989) 1211

[4] J.Boucrot, D.E.Jaffe, M-H.Schune, ALEPH Note 93-47

[5] F.Courault, These de Doctorat(1995), LAL report 95-12

[6] A.Cordier, F.Courault, ALEPH note 95-114

[7] Review of Particle Properties, *Phys. Rev.* **D50** (1994) 1173.

[8] CLEO Coll., *Phys. Lett.* **B226** (1989) 192

[9] LEP coll., *Combined Preliminary Data on Z Parameters from the LEP Experiments and Constraints on the Standard Model*, CERN/PPE/94-187 (25 novembre 1994)

[10] ALEPH coll., *Measurement of the B_s^0 lifetime and D_s^+ meson production in Z^0 decays*, CERN/PPE/95-092

[11] ALEPH Coll., *Production of charmed mesons in Z decays*, Z. Phys. **C 62** (1994) 1

[12] J. Boucrot, G. Musolino, M.-H. Schune et D.E. Jaffe, private communication

[13] M. Bauer, B. Stech et M. Wirbel, *Exclusive Non-Leptonic Decays of D^-, D_s^- and B^-Mesons*, Z. Phys. **C34** (1987) 103

[14] B. Y. Blok et M. A. Shifman *Toward a theory of weak hadronic decays of charmed mesons*, Sov. J. Nucl. Phys. **45** (1987) 135,*Weak nonleptonic decays of charmed mesons in QCD sum rules*, Sov. J. Nucl. Phys. **45** (1987) 301,*Weak nonleptonic decays of charmed mesons. Comparing theory with experiment*, Sov. J. Nucl. Phys. **45** (1987) 522 ,*Weak nonleptonic decays of charmed mesons*, Sov. J. Nucl. Phys. **46** (1987) 767

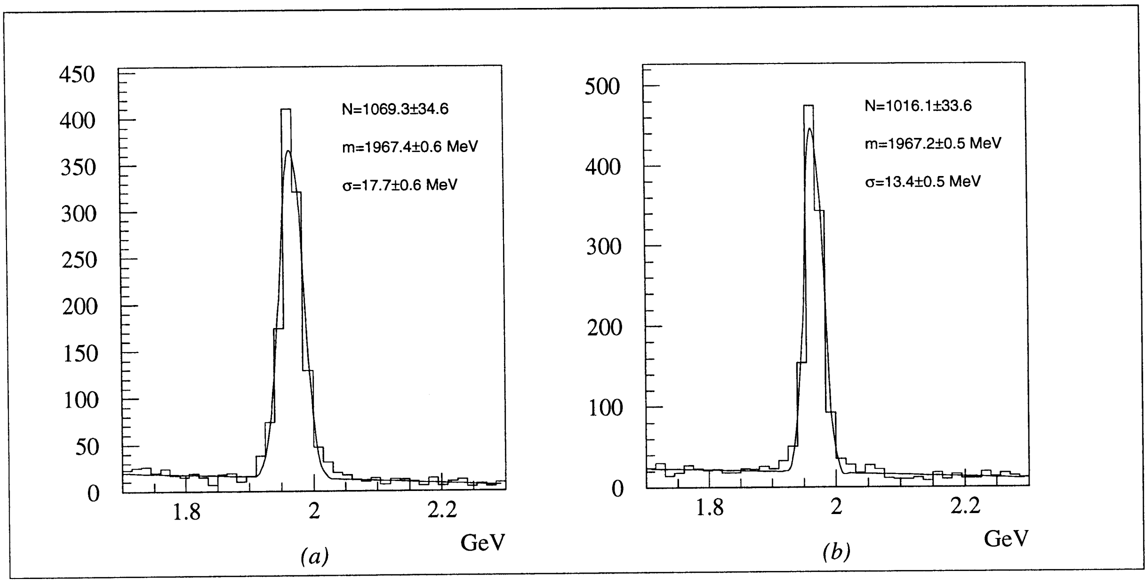

Figure 1: K^0K invariant mass spectrum for Monte Carlo $c\bar{c}$ (a) et $b\bar{b}$ (b)events. Background is fitted by a second order polynomial

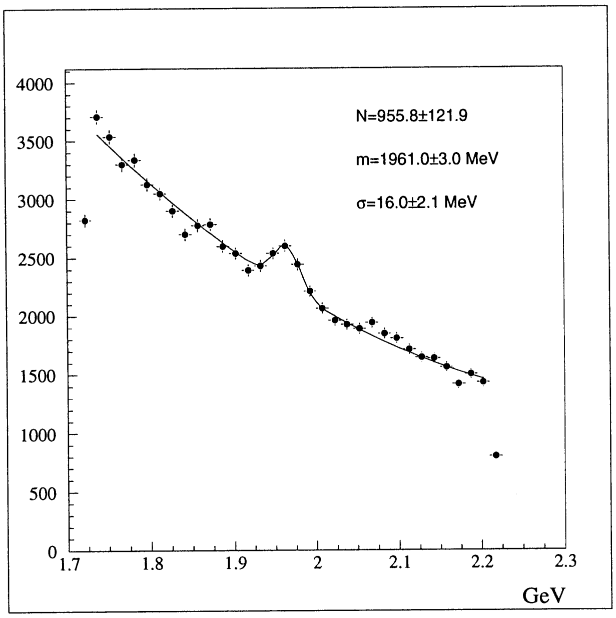

Figure 2: K^0K invariant mass spectrum for data. Background is fitted by a second order polynomial

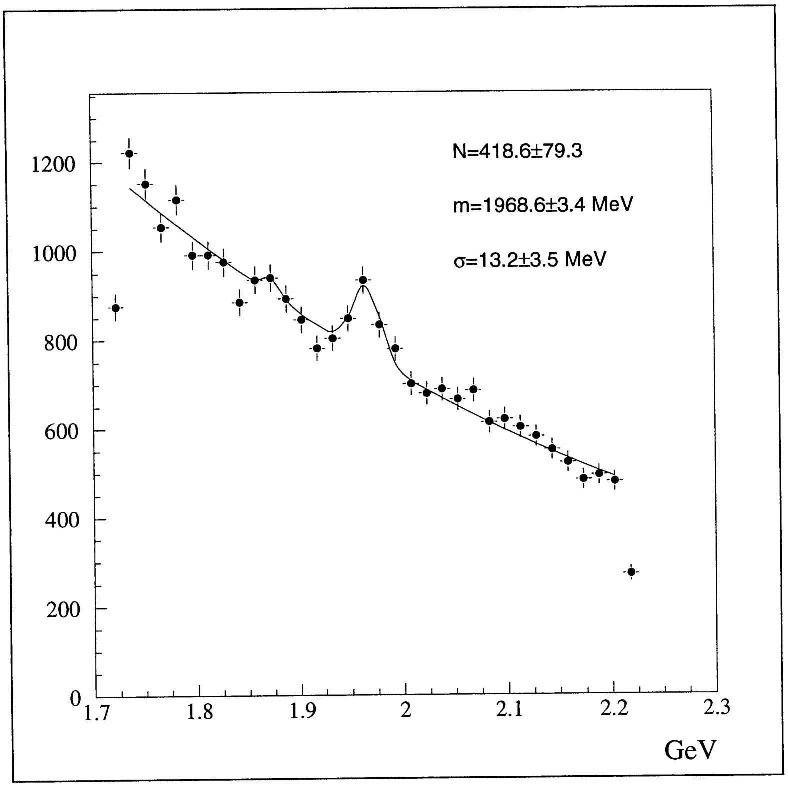

Figure 3: Final K^0K invariant mass spectrum for data

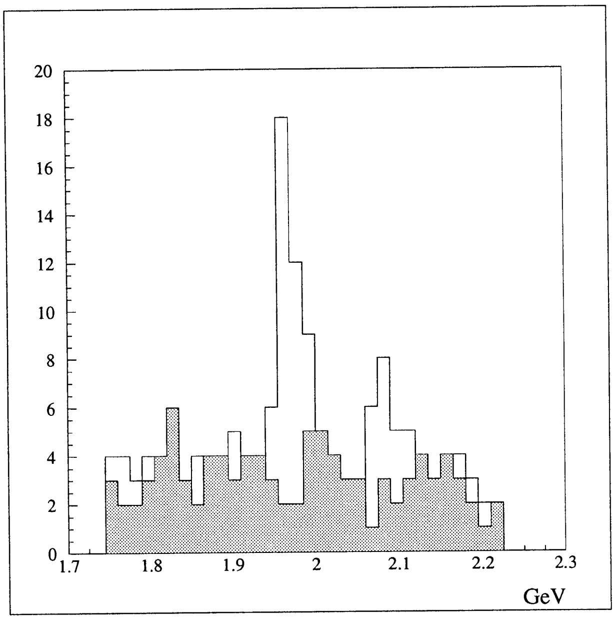

Figure 4: $K^{\pm}K^0$ invariant mass spectrum.Unshaded for opposite-si gn, hatched for same-sign $D_s - l$ pairs

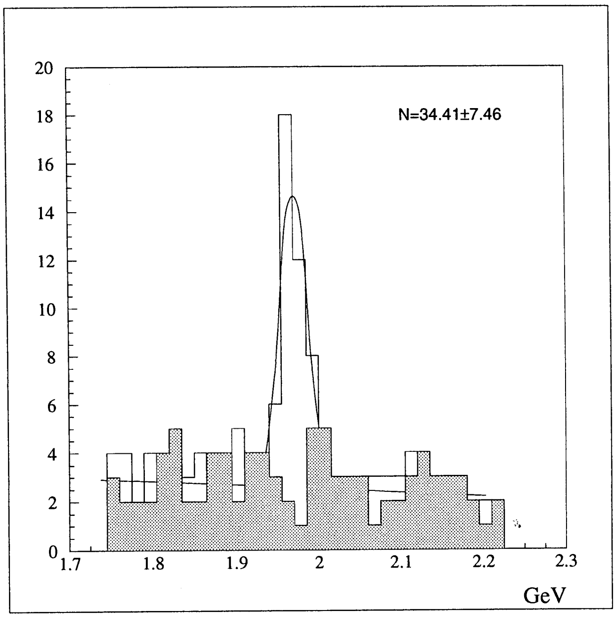

Figure 5: $K^{\pm}K^{0}$ invariant mass spectrum after the cut on Λ_c mass.Unshaded for opposite-sign, hatched for same-sign $D_s - l$ pairs

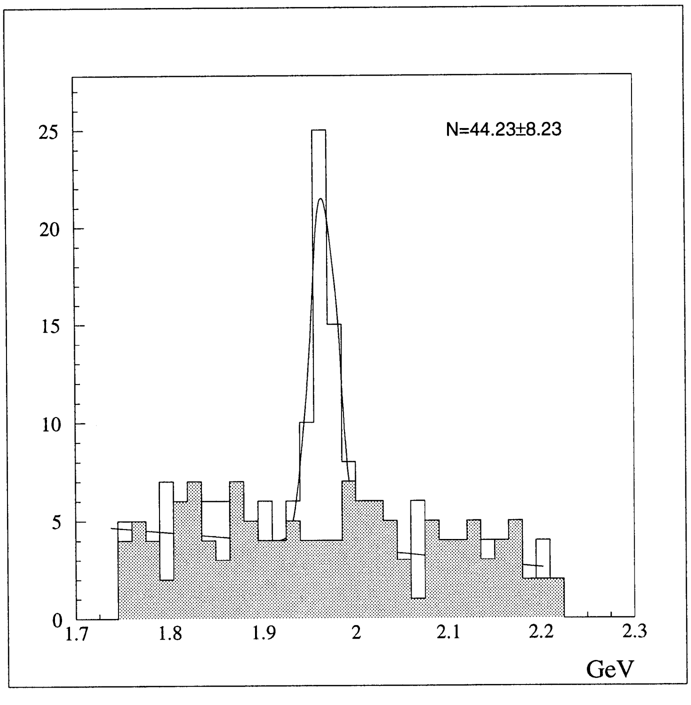

Figure 6: $K^{\pm}K^{0}$ invariant mass spectrum with $K^{*}K^{0}$ and $K^{0}K$ channels.Unshaded for opposite-sign, hatched for same-sign $D_s - l$ pairs