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Tau lepton decays into neutral kaons

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Abstract

Using $Z^0 \to \tau^+\tau^-$ candidates collected with the ALEPH detector at LEP during 1991-1994, we have measured the inclusive branching ratio of the tau lepton to K^0_S to be $(0.88 \pm 0.05 \pm 0.05)\%$.

We have also measured the exclusive branching ratios $\tau^- \to K^0_S h^- \nu_\tau = (0.43 \pm 0.04 \pm 0.03)\%$, $\tau^- \to K^0_S h^- \nu_\tau \pi^0 = (0.30 \pm 0.04 \pm 0.02)\%$.

Evidence is presented for the first time of the decay: $\tau^- \to K^0_S K^0_L h^- \nu_\tau$.

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1 Introduction

The decays of the τ lepton in final states with one or more kaons are a powerful probe of the strange sector of the weak charged current. Many issues can be tested such as Cabibbo suppression, SU(3) symmetry breaking [1], [2] . However all the theoretical results are rather sensitive to the details of the parameterizations used in the calculations; therefore firm experimental results are needed.

In this paper we present results on the decays of the τ into states containing neutral kaons, using data collected by the ALEPH detector at LEP in the years 1991-1994, corresponding to an integrated luminosity of about 120 pb^{-1} at a center of mass energy around the Z^0 peak.

Neutral kaons are searched in τ events via the $K^0_S \to \pi^+\pi^-$ signature. Events with a K^0_S and a K^0_L are selected by looking also for an excess of hadronic energy in the calorimeters.

2 Detector and Data Sample

A complete description of the ALEPH detector can be found in [3]. Charged particles momenta are measured by a magnetic spectrometer consisting of a precision silicon vertex detector (VDET), a cylindrical inner drift chamber (ITC), and a large time projection chamber (TPC), operating in a solenoidal magnetic field of 1.5 T. The transverse momentum resolution is $\sigma_p/p = 6 \text{ x } 10^{-4} p(GeV/c)$. Photons are detected by the electromagnetic calorimeter (ECAL), with an energy resolution of $\sigma_E/E = 0.18/\sqrt{E(GeV)}$. The 1.2 m thick iron return yoke is interleaved with 23 layers of streamer tubes and acts as a hadronic calorimeter (HCAL); its energy resolution is $\sigma_E/E = 0.9/\sqrt{E(GeV)}$. Finally, two double layers of streamer tubes outside the HCAL act as muon detector.

The selection of τ pair events is the same used in reference [4]; 117247 events were selected in the four data taking periods with an efficiency of (78.16 $\pm$ 0.23) % and an estimated background from non-τ events of 1.6 %.

A dedicated Monte Carlo, consisting of 13551 events in which the τ decays into $K^*\nu$ or $K^0\overline{K^0}\pi$ only, was used to study the selection efficiency. Moreover, 196631 τ pair Monte Carlo events, generated with KORALZ [5], were used to study the contamination to our signal from other τ decay channels. The contamination from non-τ pair events was studied using more than two millions Monte Carlo $q\bar{q}$ and 100000 bhabha events.

3 Selection Criteria

Neutral vertices are reconstructed by pairing two opposite charged particles in the same hemisphere; the two tracks are requested to have at least four TPC coordinates and a measured momentum exceeding 300 MeV/c. A 3 dimensional vertex fit is performed without kinematical costraints, using an approximate vertex position as a starting point of the fit. The parameters of the fit are the coordinates of the secondary vertex and the track momenta at this point; the chisquared of the fit for Data and Monte Carlo is shown in fig. 1; it is required to be less than 15.

At LEP, the kaons produced in τ decays have a quite hard spectrum, the mean value of the momentum being about 15 GeV/c: therefore in ALEPH K^0_S vertices are located anywhere in the tracking volume, and about 10 % of them are expected to reach the calorimeters. We require that good K^0_S's must have a 2D decay length larger than 11 cm and shorter than 150 cm, and a reconstructed momentum exceeding 5 GeV/c; the lower limit on the decay path corresponds to the external radius of the VDET, while the upper one is choosen to let the tracks have a minimum of four TPC coordinates geometrically allowed. These cuts remove most of the combinatorial background coming mainly from $\tau \rightarrow 3\pi$ decays.

In order to remove further this background, the two tracks forming the vertex must have no associated point in the VDET and the impact parameter of the K^0_S candidate must be ≤ 2 cm.

Events with hadronic interactions on the TPC-ITC wall are removed by looking at the track multiplicity of the emisphere: we require that $N_{res} \leq 5$, where N_{res} is the number of tracks left after having removed the two forming the neutral vertex.

According to Monte Carlo, the invariant mass distribution of the true K^0_S's is given by a gaussian of about 7 MeV $/c^2$ width plus a tail given mainly by vertices with badly reconstructed tracks; we cut at $M_{V0} = M_{K^0} \pm 30 MeV/c^2$. Fig. 2 shows the invariant mass spectrum of the K^0_S candidates before the invariant mass cut is applied; it also shows Monte Carlo expectation for signal and background.

After applying all these selection criteria, we estimate an overall efficiency of 21.9 % (35.2 % in the fiducial volume) with a τ background of 7.5 %. The non-τ background comes only from $q\bar{q}$ events and, with the present statistics, is estimated to be 13 events.

To measure exclusive branching ratios of decay channels such as $\tau^- \rightarrow K^0_S h^- \nu$ and $\tau^- \rightarrow K^0_S h^- \nu \pi^0 's$ we look also for π^0 candidates; π^0's selection is described in detail in [6].

In the case of the first decay channel we require the absence of any fully reconstructed π^0 or of any photon not compatible with being emitted as initial/final state radiation in the Z decay. In the second case only fully reconstructed π^0's are accepted. Moreover, for both decay channels, it is requested the presence of only one good charged track besides the two K^0 decay products. The number of photons and of reconstructed π^0's for Data and Monte Carlo is shown in fig. 3.

The efficiency and contamination for the first (second) decay channel are 19.2 % (27 %) and 13.8 % (21 %), respectively.

4 Determination of the Branching Fractions

In the four years of data taking we collected 435 inclusive K^0_S events, 230 $\tau^- \rightarrow K^0_S h^- \nu$ candidates, and 106 $\tau^- \rightarrow K^0_S h^- \nu \pi^0$'s candidates.

The following branching ratios are computed:

$$Br(\tau^- \rightarrow K^0_S + anyth.) = (0.88 \pm 0.05 \pm 0.05)\% \quad (1)$$

$$Br(\tau^- \rightarrow K^0_S h^- \nu) = (0.43 \pm 0.04 \pm 0.03)\% \quad (2)$$

Variable	*Variation*	Δ*(B.R.) (%)*
L_{2D}	$\pm$ 2 cm	$\pm$ 1
P_K	$\pm$ 1 GeV/c	$\pm$ 2
d_0	$\pm$ 1 cm	$\pm$ 1
M_{inv}	$\pm$ 10 MeV/c^2	$\pm$ 2

Table 1: Contributions to the systematic error

$$Br(\tau^- \rightarrow K^0_S h^- \nu \pi^0) = (0.30 \pm 0.04 \pm 0.02)\% \quad (3)$$

The reconstructed π^0 multiplicity is compatible, within the statistical error, with the production of only one π^0 per event.

The systematic error is evaluated as a convolution of several different contributions.

The effect of the cuts (except the χ^2 one, which is considered later) is determined by the difference in the branching ratios recomputed after varying each cut separately by the amounts shown in table 1, and recalculating the background and the efficiencies accordingly. This gives Δ(B.R.) = 3 %$\times$ B.R..

To evaluate the systematic effects of the tracking-vertexing algorithms we studied the $B.R.$'s variation as a function of the polar angle of the K^0_S candidate, of the number of ITC+TPC points of the tracks and of the χ^2 of the vertex fit. The maximum variation amounts to 3 %, and is assumed as a fair evaluation of this part of the systematic error.

The K^0_S reconstruction efficiency is, in fact, a function of the K^0_S momentum. Dividing the events in five momentum bins, and computing the efficiencies and background for each bin separately, we observe a maximum variation of the computed branching ratios of 4 %. This is considered as an additional contribution to the systematics.

We consider systematics also the errors due to Monte Carlo statistics ($\pm$ 2 %) and to the uncertainty in the hadronic background evaluation ($\pm$ 1 %).

In the exclusive branching ratios determination also a 2 % error is considered, due to π^0 reconstruction; it is determined by the variation in the branching ratios computed using the two different definitions of π^0, (see also [6]).

5 The $\tau^- \rightarrow K^0_S K^0_L h^- \nu$ decay

The theoretical description of the τ decay in two neutral kaons is subject to the presence of several unknown parameters [1]; in order to shade light on this complex dynamics it is interesting to separate the different components ($K_S K_S$, $K_L K_L$, $K_S K_L$) of the decay. In the following, a measurement of the $\tau^- \rightarrow K^0_S K^0_L h^- \nu$ branching ratio is described.

Events are pre-selected in the same way as $\tau \rightarrow K^0_S h \nu$ events. The total energy deposition in the calorimeters for this events can be estimated by their momentum measured by the TPC; it is expected to fluctuate approximately as $\sqrt{P_{Ch}}$. The hadronc energy excess is then defined as

$$\sigma_{E_{had}} = (E_{HCAL} + k \times E_{ECAL} - \Sigma_i P^i_{Ch})/(\sqrt{\Sigma_i P^i_{Ch}\sqrt{GeV}}) \quad (4)$$

where $\Sigma_i P^i_{Ch}$ is the hadronic energy expected using the measured charged particle's momenta, and $k = 1.3$ is determined by test beam data. $\sigma_{E_{had}} > 0$ can be the result of HCAL energy fluctuations or of the presence of a real neutral hadron. Its distribution for data and Monte Carlo pre-selected events is shown in fig. 4. A cut is imposed at $\sigma_{E_{had}} > 4$. Events are also required to have HCAL energy exceeding 5 GeV.

With these cuts an overall signal efficiency of 4% is obtained by Monte Carlo, with an expected background of 3 ± 2 events, coming from $\tau \to K^0_S h\nu$ events in which HCAL energy is overfluctuating.

To monitor systematic effects due to possible differences in the Monte Carlo behaviour of the variable $\sigma_{E_{had}}$ respect to Data, we used $\tau \to 3\pi$ decays. There is good agreement between Data and the Monte Carlo prediction, as shown in fig. 5. Using the Data/MC difference in the populations of the region $\sigma_{E_{had}} > 4$ for these decays, we estimate an error in the evaluation of the background to our signal of 1 ± 1 event.

After selection we remain with 14 candidates obtaining therefore a branching ratio

$$Br(\tau^- \to K^0_S K^0_L h^- \nu) = (0.13 \pm 0.04 \pm 0.02)\% \tag{5}$$

in fair agreement with the prediction of [1].

References

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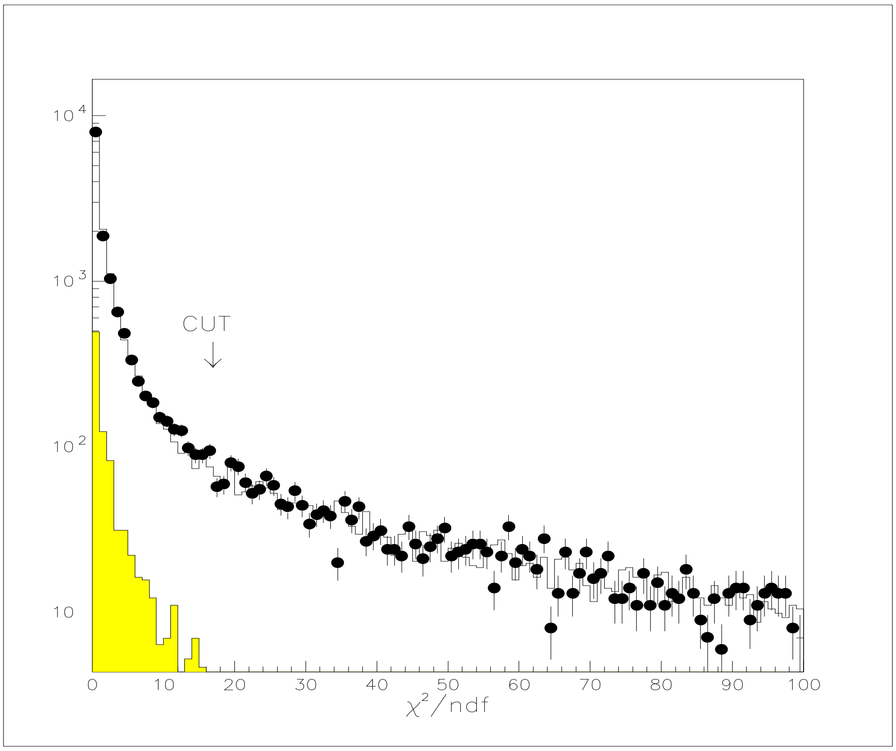

Figure 1: Chisquare distribution of the vertex fit. Data (black points) and MonteCarlo (solid line); the shaded area is the expected K_s^o signal

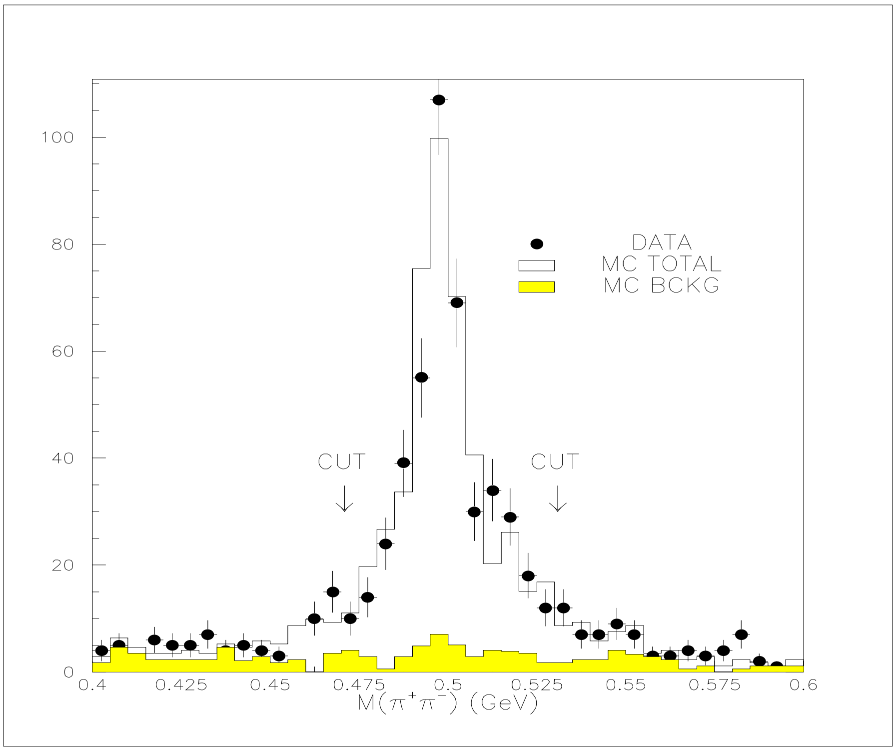

Figure 2: Recontructed mass distribution of the K_s^o candidates. Data (black points) and MonteCarlo (solid line); the shaded area is the expected background.

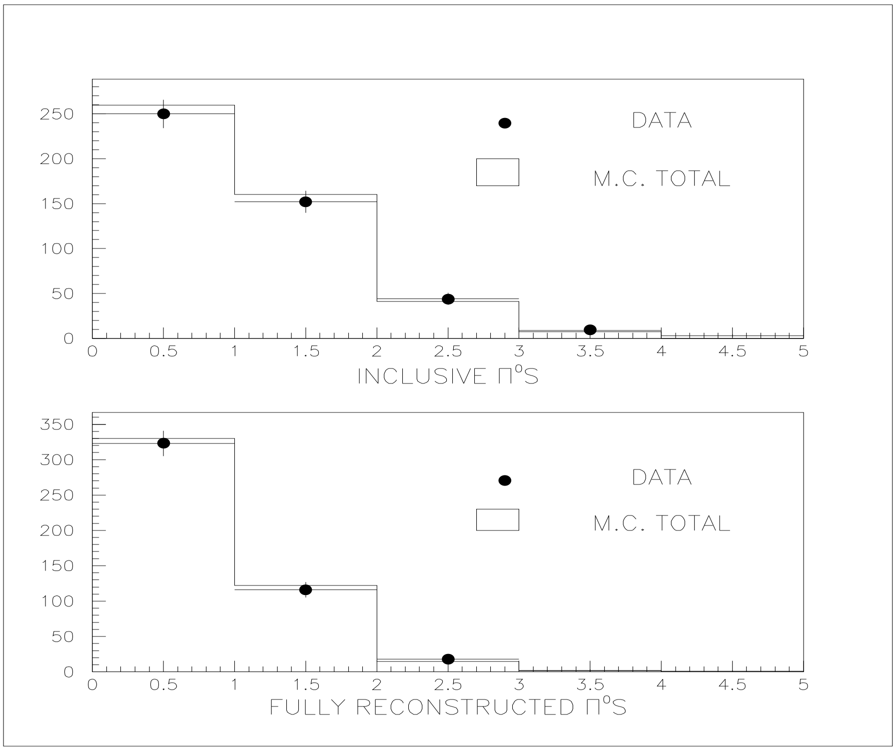

Figure 3: Number of photons (upper) and reconstructed π^0's (lower) for Data (black points) and MonteCarlo (solid line).

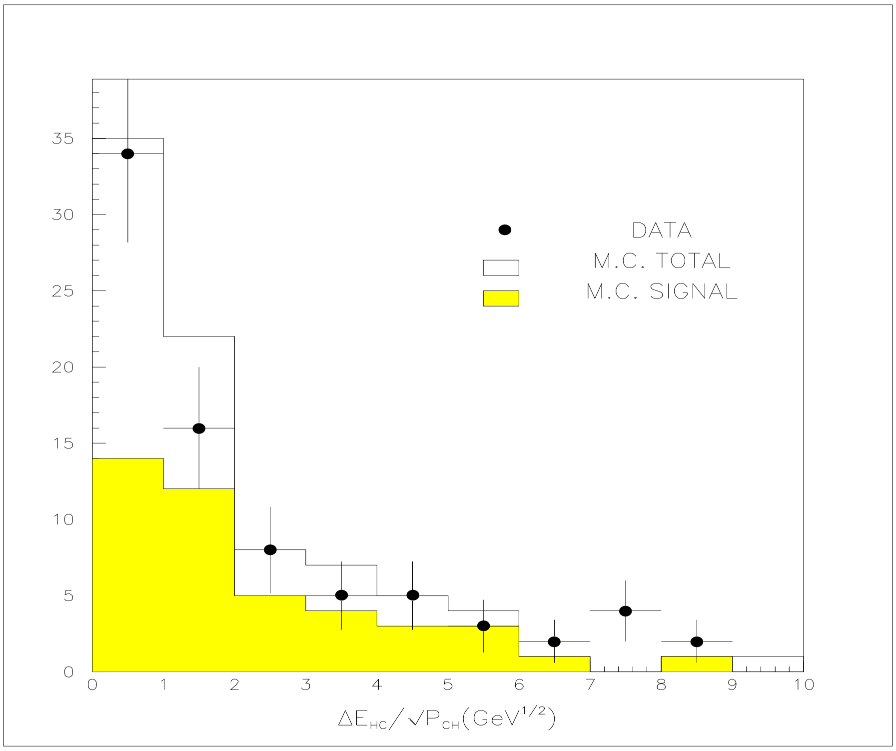

Figure 4: Hadronic energy excess for one K_S^0 + one prong events. Data (black points) and MonteCarlo (solid line); the shaded area is the expected K_S^0, K_L^0 signal

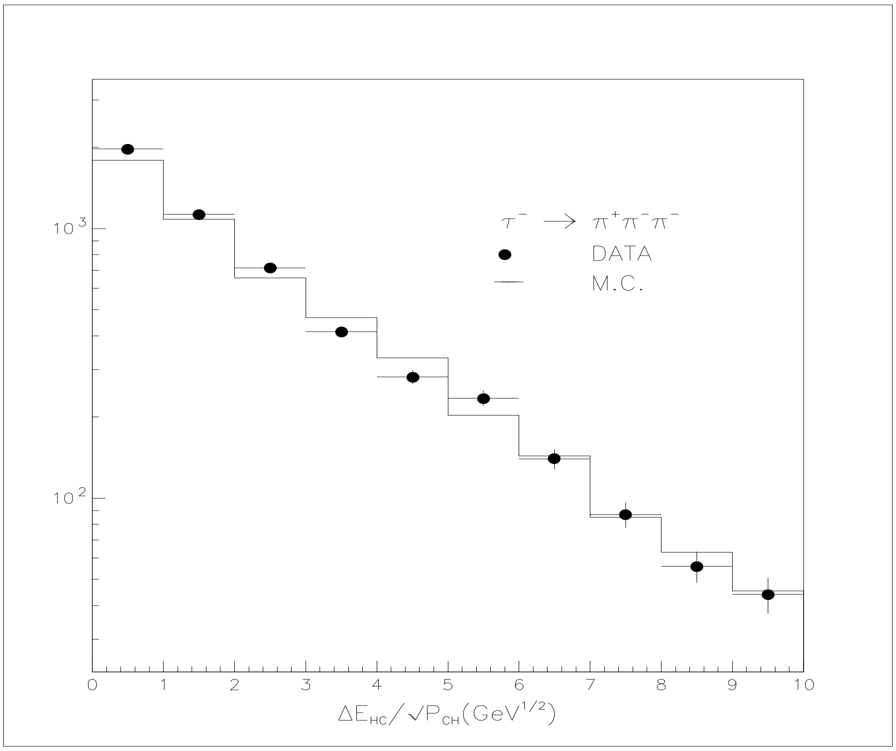

Figure 5: Hadronic energy excess for $\tau \rightarrow 3\pi$ events. Data (black points) and MonteCarlo (solid line)