We present results on the observation of the $\Omega_c^+$ hadronic weak decays by the WA89 experiment using 330 GeV/c momentum $\Sigma^+$ beam at the CERN West Hall. With the data sample of about 160 million events from 1993 beam time, signals of non-leptonic $\Omega_c^+$ decays have been reconstructed in seven decay modes with $A$, $\Xi^-$ or $\Omega^-$ in the final states. These decay channels are: $\Omega^-\pi^+$, $\Omega^-\pi^+\pi^-\pi^+$, $\Xi^-K^-\pi^+\pi^+$, $\Xi^-K^-\pi^+\pi^+$, $\Xi^-K^-\pi^+\pi^+$, $A\bar{K}^0\pi^0\pi^0$, $A\bar{K}^0\pi^0\pi^0$, and $A\bar{K}^0\pi^0\pi^0$. The mass of the $\Omega_c^+$ is determined to be $2708.3 \pm 1.0$ (stat.) $\pm 1.6$ (syst.) MeV/c$^2$.

The relative branching ratios among the first six decay modes mentioned above have been determined. The measured relative branching ratios are discussed within the frame of the current models. In particular, the data seem to be well explained by the statistical model.
1 Introduction

The \( \Omega_c^0 \) (ssc) is the JP = 1/2⁺ doubly-strange charmed baryon which was first observed in 1985 by WA62 experiment at CERN. Ten years later, it remains the least-known weakly-decaying single-charmed baryon (see Fig. 1).

Why the \( \Omega_c^0 \) is interesting? First of all, it has been predicted within the framework of the Quark Model long before its experimental discovery, and there have been theoretical predictions on its mass and weak decay mechanism. Experimental observation and precise measurement of its mass are therefore important for the quark model description of the ground state baryon. Secondly, the weak decay process of a free charm quark \( c \rightarrow s'(ud') \) is well understood and analogous to the weak decay of \( \mu^+ \rightarrow e^+\nu\bar{\nu} \), due to the universality of the weak interaction. This would result in a unique lifetime for all charmed hadrons. The experimentally measured lifetimes of the charmed baryons, however, differ by a large factor. For example, the lifetime of the \( \Xi^+_c \) and \( \Xi^0 \) are respectively 0.35±0.07 ps and 0.098±0.018 ps. The large difference in the lifetimes of the charmed baryons are due to: i) Strong interaction between quarks in the baryon before and after the weak decay of the charm quark; ii) Non spectator weak processes such as the W-exchange (cd→(su) and (cs)--(su)). By measuring the lifetime of the \( \Omega_c^0 \), one can gain valuable information on its internal structure and decay process. Finally, the primordial state of five quarks (sss'(ud')) after the decay of the charm quark will hadronize into various final states. For Cabibbo favoured decays, these final states each have a total strangeness of −3. The hadronization process is however non-perturbative and is not calculable within the framework of perturbative QCD. Measuring the branching-ratios into different decay final states will give us valuable information on the baryon wave-function.

The \( \Omega_c^0 \) decay is of particular interest. It proceeds dominantly via the direct quark decay. In the final state, however, three identical quarks are present (\( \Omega_c^0 \rightarrow ssu \)). If the two strange quarks of the \( \Omega_c^0 \) are only spectators, the \( \Omega_c^0 \) lifetime will be comparable to the \( \Xi^0 \) lifetime. If, however, the three strange quarks overlap in phase space in the final state, the decay will be accelerated because there are three ways to reach the same final state, and the \( \Omega_c^0 \) lifetime will be very short. In addition the Cabibbo suppressed W-exchange with an s-quark (cs→su) may contribute [4].

The WA62 evidence for the \( \Omega_c^0 \) was a cluster of 3 events in the decay channel of \( \Omega_c^0 \rightarrow \Xi^-K^+\pi^+\pi^- \) at a mass of 2740 ± 20 MeV/c². They used a \( \Sigma^- \) beam of momentum of 135 GeV/c impinging onto a fixed beryllium target. The ARGUS collaboration presented signals for the \( \Omega_c^0 \) in the channels of \( \Omega_c^0 \rightarrow \Xi^0\pi^-\pi^- \) with 6.5±3.2 events at 2713.0 ± 5.1 MeV/c² and \( \Xi^0\pi^-\pi^- \) with 12.2±4.5 events at 2719.0 ± 7.0 ± 2.5 MeV/c². The photo-production experiment E687 in Fermilab has published their observation of \( \Omega_c^0 \) in the channels \( \Omega^-\pi^+\pi^- \) with 10.3±3.9 events at 2705.9 ± 3.3 ± 2.0 MeV/c² and \( \Sigma^+K^-\pi^+ \) with 42.5±8.8 events at 2699.9 ± 1.5 ± 2.5 MeV/c². The strongest signal of \( \Omega_c^0 \) decays mentioned above is the E687 observation in \( \Sigma^+K^-\pi^+ \) decay channel.

2 The WA89 experiment setup

WA89[8] is a fixed-target experiment at CERN. It uses protons of 450 GeV/c momentum from the SPS accelerator to bombard a beryllium target. A dipole magnet channel is installed to select the \( \Sigma^- \) (\( \approx 2 \times 10^9 \Sigma^- \) spill) with a momentum of about 330 GeV/c and guide them onto the experimental targets. A beam TRD (Transition Radiation Detector) is employed to do the on-line \( \Sigma^-/\pi^- \)
discrimination. The main goal of the experiment is to study the production, spectroscopy, and weak decay of charmed hadrons. The use of the hyperon beam is believed to favour the charmed-strange hadron production\cite{9}.

The setup of the experiment, a forward tracking spectrometer located at the SPS Omega facility, is shown in fig. 2. The experimental target is longitudinally segmented along the beam and includes a 4 mm thick copper disk and three 2.2 mm thick carbon disks. The target slabs at an equal spacing of 2 cm are placed in a closed box flushed with helium gas. The beam track is reconstructed within a silicon micro-strip detector of 8 planes with 50 µm pitch. The silicon vertex detector consisting of 29 micro-strip planes with 25 µm and 50 µm pitch is employed to reconstruct the charm decay vertices. Following this area is a 10 m long decay zone, equipped with drift chambers and MWPC's to track the secondary particles or their decay products. The momenta of the charged particles are measured in the Omega spectrometer with an accuracy of $\Delta p/p = 10^{-4}$. A RICH detector allows the identification of $p$, $\bar{p}$, $K^\pm$ and $\pi^\pm$ in a wide momentum range. A lead glass calorimeter to search for radiative decays and a "spaghetti" type hadron calorimeter for detection of neutrons form the most downstream detectors.

The $\Omega_c^-$ is reconstructed using a "candidate driven approach". Correct track combinations are first formed to look for a potential secondary vertex and the remaining tracks in the event are then used to reconstruct the primary vertex. The main selection criteria include : i) Particle identifications, either by kinematic reconstruction (e.g. for $\Lambda$, $\Xi$, $\Omega$, $K^\pm$) or with the help of the RICH detector (for $p$, $\bar{p}$, $K^\pm$). ii) Various vertex criteria are applied, the most powerful being the cut on the vertex separation $L$ in terms of either real distance or its significance $L/\sigma_L$. Other cuts, such as kinematic cuts, are used to optimise signal-to-background ratios.

3 The $\Omega_c^-$ mass

Using 160 million events recorded in a beam period in 1993, we have reconstructed $\Omega_c^-$ signals in 7 decay modes. For details of the event selection and reconstruction see ref. \cite{10}. The invariant mass spectra are shown in Fig. 3. The signals for the final states $\Xi^-$ $K^-\pi^+$, $\Xi^- K^-\pi^+\pi^-$, $\Lambda K^-K^-\pi^+$ and $\Lambda K^- K^-\pi^+\pi^-$ constitute the first observation of the corresponding $\Omega_c^-$ decay modes.

With signals from the 7 decay modes, the $\Omega_c^-$ mass is determined to be $2708.3 \pm 1.0\text{(stat.)} \pm 1.6\text{(syst.)}\text{ MeV/}c^2$. This is a preliminary result and the systematic error on the mass is being further studied.
4 The $\Omega_c^0$ lifetime

With three independent $\Omega_c^0$ data samples, the lifetime of $\Omega_c^0$ has been determined to be $\tau_{\Omega_c^0} = 55^{+11}_{-18} \text{ (stat)}^{+11}_{-43} \text{ (syst)}$ fs using a continuous maximum likelihood method. This makes the $\Omega_c^0$ the shortest living weakly decaying particle observed so far. The short value of the lifetime confirms the predicted pattern of the charmed baryon lifetimes (i.e., $\tau_{\Omega_c^0} < \tau_{\Xi_c^0} < \tau_{\Xi_{cc}^0}$) and demonstrates that the strong interaction plays a vital role in decays of charmed hadrons.

5 Relative branching ratios of the $\Omega_c^0$

Preliminary relative branching ratios among the observed $\Omega_c^0$ decay modes are determined. For this purpose, the reconstruction efficiency for each of the decay channels has been estimated by using a Monte Carlo simulation with the measured lifetime of the $\Omega_c^0$ as input. The results are listed in Table 1 together with the $x_F$ ranges used. The differences in the ranges chosen reflect differences in the $x_F$ dependence of the efficiency for the decay channels involved. Two important checks are done: i) The obtained relative branching ratios do not depend much on the lifetime of the $\Omega_c^0$. This has been done by altering the lifetime of the MC events from 0.032 ps to 0.1 ps which roughly correspond to the error range of the measured lifetime. ii) The obtained relative branching ratios do not depend much on the choice of the $x_F$ range. The systematic errors are preliminary and are being investigated in more detail.

No evident resonant subsystems have been observed in the multi-body final states. Two body decay modes seem to be less important than in the $D$ or the $\Lambda_c^+$ decays. A strong branching fraction of the $\Omega_c^0$ decaying into $\Lambda^+$ mesons has been observed in the data. It seems that the three strange quarks in the primordial state tend to go into different hadrons with a breakup of the two spectator s quarks.

6 Discussion of the results

There is very little theoretical work on $\Omega_c^0$ hadronic decays. In general, two methods can be applied to $\Omega_c^0$ decays. The first involves direct calculation using Feynman diagrams, this has so far only proven to be practical for two body or quasi two body decays. The second is the statistical approach.
The quasi two body approach \cite{12} assumes that the four quarks and the one anti-quark, after the decay of the charm quark in the $\Omega^0_c$, decay into two hadrons which have large wave function overlap with the primordial state. Higher multiplicity decays are then simply the consequence of subsequent decays of the two resonant hadrons. The strong decay branches of $AK^+K^-\pi^+$ and $AK^-K^+\pi^+$ of $\Omega^0_c$ cannot easily be explained by the quasi two body approach since their Q values are already small and the decays through higher resonant states are very unlikely or even energetically forbidden.

Another approach to hadronic decay of the charmed baryons is the idea of string fragmentation. The current standard version of Lund model, however, assumes that the daughter baryon is made of the stable spectator diquark and decays of the charm quark. The final baryon thus always contains this diquark which greatly distorts the distribution of possible final states. Therefore very strong branching ratios to final states of the $\Omega^0_c$ decay with a $A$ are not expected in this model, contrary to the experimental observation.

The very short lifetime of the $\Omega^0_c$ decay seems to suggest that a large phase space overlap should exist for the direct $c$-quark decay products $c \rightarrow s ud$ and both strange quarks in the $\Omega^0_c$. The intermediate state of 5 quarks in $\Omega^0_c$ after $c \rightarrow s ud$ could be well defined as a homogeneous fluid state during the hadronization process. This has motivated us to use the Fermi statistical model \cite{13} for hadronic decays of the $\Omega^0_c$.

The statistical model assumes that the energy from $c \rightarrow s ud$ decay quickly turns the primordial state into a thermodynamic equilibrium, which also assumes that the square of the effective matrix element is merely proportional to probability that all particles are contained at the same time inside a space volume $w$, within which the strong interaction (hadronization) occurs. As long as the relativistic Lorentz contraction is neglected, the volume $\Omega$ should be expected to have a radius of $\hbar/(m_c c)$, which is 1.4 fm, the Compton wavelength of the pion. Beyond the distance of 1.4 fm the strong interaction between hadrons turns off.

The use of the model has to be supplemented by additional statistical factors, which take into account that the initial state has three identical particles (strange quarks). There is only one possibility to make a $\Omega^-$ out of three strange quarks, but three possibilities to make $\Xi K$ or $AK K$ states. The last two cases will have a relative statistical factor of 3 with respect to the $\Omega^-$ channel. For further details see ref. \cite{10}.

The model shows a Poisson distribution and takes into account only the phase space. The results are summarized in Figure 4 together with the experimental values.

Taking into account the uncertainties of our data and the crude assumption of the model, the agreement seems to be rather good. The large variety of hadronic final states for the $\Omega^0_c$ decay is fully consistent with the measured very short lifetime.

With more statistics soon from 1994 data, the error on the relative branching ratios is expected
Figure 4: The comparison of the relative branching ratios between the data (triangle with error bar) and the statistical model predictions (black full dot).

to be reduced.

References