EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/79-93
20 August 1979

A MEASUREMENT OF THE Ω^- LIFETIME

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ABSTRACT

In an experiment at the CERN-SPS charged-hyperon beam, a sample of 2500 $\Omega^- \to \Lambda K^-$ decays has been collected at Ω^- momenta of 98.5 and 115 GeV/c. The Ω^- lifetime is found to be

$$\tau_\Omega = (0.822 \pm 0.028) \times 10^{-10} \text{ s} .$$

Geneva - 3 August 1979

(Submitted to Physics Letters)

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1. INTRODUCTION

In 1977, the first operation of the CERN-SPS charged-hyperon beam established [1] that it provided a significant flux of Ω^-. With an intensity of 10^6 particles per burst in the beam, the rate of Ω^- selected by the DISC Čerenkov counter at the exit of the magnetic channel was 0.2 per burst at 98.5 GeV/c beam momentum and 0.6 per burst at 115 GeV/c. This article presents a measurement of the Ω^- lifetime, based on 2500 $\Omega^- \to \Lambda K^-$, $\Lambda \to p\pi^-$ decays, which were recorded in a 25-day period in 1978. The lifetime analysis has been restricted to this particular decay mode, since the detection of the decay particles is much simpler than for the $\Omega^- \to \Xi\pi$ modes and the decay configuration is the same as that of the well-known $\Xi^- \to \Lambda\pi^-$ decay. Furthermore, the $\Omega^- \to \Lambda K^-$ decay channel is the most abundant one, with a branching ratio of about two thirds.

A preliminary result, based on two thirds of the data, has already been reported [2]. Measurements of the Ω^- decay branching ratios and asymmetry parameters will be reported in subsequent publications.

2. APPARATUS AND TRIGGER REQUIREMENT

A detailed description of the hyperon beam and of the magnetic spectrometer is given elsewhere [3], so we shall briefly mention here only those parts which were important for the lifetime measurement. A schematic view of the apparatus is shown in fig. 1.

The momentum of the primary proton beam was 210 GeV/c. Data were taken at two hyperon momenta, 98.5 and 115 GeV/c. The mean production angle of the hyperons was about 2 mrad. At the exit of the hyperon beam, a DISC-type Čerenkov counter was used to trigger on Ω^- particles. The momentum acceptance of the beam and the DISC was $\Delta p/p$ = 7% FWHM. High resolution multiwire proportional chambers (MWPC) were placed upstream and downstream of the DISC.

The charged decay particles were analysed in a magnetic spectrometer equipped with drift chambers. The momentum resolution was $\Delta p = \pm 1.5$ GeV/c at 100 GeV/c. The solid angle subtended by the magnet and the drift chambers accepted all charged decay particles from $\Omega^- \to \Lambda K^-$ originating from the decay region upstream of the first drift chamber.

To trigger on Ω^- decays, we required a coincidence between the signals delivered by the following counters:

a) The DISC counter. To obtain a high trigger efficiency, we used a profiled diaphragm [3] and required 7 out of the 8 phototubes of the DISC to give a signal. The efficiency thus obtained was 95% for Ω^- passing through the DISC.

b) A multiplicity counter downstream of the first drift chamber, which required more than one charged decay particle.

c) A proton counter, which was located downstream of the spectrometer magnet and intercepted all protons from $\Lambda \rightarrow p\pi^-$ decays, but could not be reached by negative decay particles or beam particles.

On account of (b) and (c) we required that a $\Lambda \rightarrow p\pi^-$ decay occurred before the first drift chamber. This condition was fulfilled by 55% of all those Ω^- which triggered the DISC and decayed in the $\Omega^- \rightarrow \Lambda K^-$ mode.

The number of triggers was about 9 (15) at 98.5 (115) GeV/c for 10^6 beam particles, which corresponded to one beam spill under typical running conditions. A microprocessor [4] reduced this rate to 2.5 (6.5) by rejecting high track-multiplicity events using information from the chambers. Even so, the trigger rate was more than one order of magnitude greater than the genuine Ω^- counting rate. The background triggers were mainly due to multiparticle events or to $\Xi^- \rightarrow \Lambda\pi^-$, $\Lambda \rightarrow p\pi^-$ decay cascades, which occurred before or inside the DISC and managed to fire seven of the eight DISC phototubes and also fulfilled the multiplicity and proton requirements [(b) and (c)].

Under these conditions, we collected 360,000 triggers at 98.5 GeV/c and 160,000 triggers at 115 GeV/c.

At regular intervals, the DISC pressure was set to detect Ξ^- and triggers were taken in otherwise unchanged conditions. The $\Xi^- \rightarrow \Lambda\pi^-$ events, which have a decay topology similar to $\Omega^- \rightarrow \Lambda K^-$ decays, were used to monitor the performance of the apparatus.

The correct pressure setting for the Ω^- trigger was deduced from the relative positions of the Ξ^-, Σ^-, and π^- peaks in the pressure curve. The positions of these peaks were checked regularly during data taking.

3. SELECTION OF $\Omega^- \to \Lambda K^-$ DECAYS

The first step in the off-line event selection, which was common to Ω^- and Ξ^- decays, was to search for $\Lambda \to p\pi^-$ decays (i.e. a positive and a negative track with an intersection situated between z = 2 m and z = 13.5 m, fig. 1) having an invariant (p, π^-) mass $m_{p\pi}$ within ±10 MeV/c^2 of the Λ mass. The width of the $m_{p\pi}$ distribution was 2 MeV/c^2 (r.m.s.).

The second step was to require an additional track, which, if interpreted as a K^- track, gave an invariant mass $m_{\Lambda K}$ within ±50 MeV/c^2 of the Ω^- mass. The difference $\Delta\vec{p}$ between the sum of the Λ and K^- momenta, as measured with the spectrometer, and the mean beam momentum $\vec{p}_b$ was required to have components $|\Delta p_L| < 10$ GeV/c and $|\Delta p_T| < 0.14$ GeV/c. The widths of these quantities for Ξ^- decays were $\delta p_L = 0.035\ p_b$ (r.m.s.) and $\delta p_T = 0.04$ GeV/c (r.m.s.). Furthermore, the intersection of the K^- track and the reconstructed Λ track had to be, within reconstruction errors, upstream of the Λ decay point and downstream of z = 2 m.

The sample still contained more $\Xi^- \to \Lambda\pi^-$ decays than $\Omega^- \to \Lambda K^-$ decays. The Ξ^- decays were rejected by requiring $m_{\Lambda\pi} > 1.35$ GeV/c^2, where $m_{\Lambda\pi}$ is the invariant mass obtained by interpreting the event as a $\Xi^- \to \Lambda\pi^-$ decay. In the case of events giving more than one possible decay track combination, that value of $m_{\Lambda K}$ ($m_{\Lambda\pi}$) was used which gave the closest approximation to the constraints $m_{p\pi} = m_\Lambda$, $\Delta p_L = 0$ and $m_{\Lambda K} = m_{\Omega^-}$ ($m_{\Lambda\pi} = m_{\Xi^-}$). This cut rejected practically all Ξ^-, but also 14% of the genuine $\Omega^- \to \Lambda K^-$ events. The distribution of $m_{\Lambda K}$ after this cut is shown in fig. 2. The observed width is 3 MeV/c^2 (r.m.s.). Within ±10 MeV/c^2 of the Ω^- mass, the sample contains 1532 (905) events at 98.5 (115) GeV/c, with an estimated background of 30 (20) events. This background consists of about equal parts of $\Xi^- \to \Lambda\pi^-$ and $\Omega^- \to \Xi^0\pi^-$ decays.

The monitor sample of $\Xi^- \to \Lambda\pi^-$ events was selected with the same cuts on $\Delta m_{\pi p}$, Δp_L, Δp_T, $m_{\Lambda\pi}$ and on the vertices. Throughout the analysis, Ξ^- events were treated in exactly the same way as the Ω^- events.

4. Ω^- AND Ξ^- LIFETIME MEASUREMENT

The Ω^- decay point was reconstructed from the K^- track and the reconstructed Λ track without using the MWPC in the DISC region. Thus we avoided a possible systematic error for the reconstruction of Ω^- decays in the DISC region, because it is often difficult to decide whether an observed track point in a MPWC belongs to the Ω^- or to the K^- from its decay. The reconstruction error along the beam direction was $\Delta z = 0.25$ m (r.m.s.), which is about 1/6 of the mean Ω^- decay length. The resulting decay-point distributions along the beam direction are shown in figs. 3a and 3b for Ω^- at 98.5 and 115 GeV/c, and in figs. 3c and 3d for Ξ^-. There are 1532 (905) Ω^- and 34000 (7400) Ξ^- events at 98.5 GeV/c (115 GeV/c).

The Ξ^- and Ω^- lifetimes were deduced from the experimental distributions by comparison with distributions from a Monte Carlo calculation which took into account the following:

a) The momentum and spatial distributions of the beam particles.

b) The reduction of the DISC efficiency for Ω^- which decay within the sensitive volume of the DISC.

c) The track measurement errors and multiple scattering.

d) An inefficiency of the drift chambers in the beam region, which was determined using a beam particle trigger.

e) K^- decays within the apparatus. Of all $\Omega^- \to \Lambda K^-$ decays fulfilling the trigger conditions outlined in Section 2, 9.5% (8%) at 98.5 (115) GeV/c had a K^- decay occurring upstream of the last drift chambers (z = 29 m, fig. 1). Neglecting the effect of the K^- decays would have increased our estimate of the Ω^- lifetime by 0.005×10^{-10} s.

The number of Monte Carlo events used for the comparison was 34,000 for $\Xi^- \to \Lambda\pi^-$ at 98.5 GeV/c, 10,000 for $\Xi^- \to \Lambda\pi^-$ at 115 GeV/c, 10,000 for $\Omega^- \to \Lambda K^-$ at 98 GeV/c and 10,000 for $\Omega^- \to \Lambda K^-$ at 115 GeV/c.

The validity of this simulation was checked by comparing various distributions of the Monte Carlo events with the corresponding experimental distributions. In particular, the Λ lifetime was determined from the distributions of the Λ decay path ℓ_Λ. At 98.5 GeV/c and for 1 m < ℓ_Λ < 10 m, we obtained $\tau_\Lambda = (2.64 \pm 0.06) \times 10^{-10}$ s with $\chi^2/DF = 42/37$ from Ξ^- decays and $\tau_\Lambda = (2.91 \pm 0.19) \times 10^{-10}$ s with $\chi^2/DF = 38.2/37$ from Ω^- decays. The errors quoted are the statistical errors of the fits. (We did not try to estimate the systematic errors.) These results are in agreement with the average value $\tau_\Lambda = (2.63 \pm 0.02) \times 10^{-10}$ s [5-8].

For the Ω^- and Ξ^- lifetime fits we used the value $\tau_\Lambda = 2.63 \times 10^{-10}$ s. The data at 98.5 GeV/c and 115 GeV/c were treated separately. The cuts on z, the position of the Ω^- (Ξ^-) decay point along the beam, were chosen as z_{min} = 2 m and z_{max} = 10 m. The fit results are summarized in table 1.

The results for Ξ^-, $\tau_\Xi = (1.675 \pm 0.025) \times 10^{-10}$ s at 98.5 GeV/c and $\tau_\Xi = (1.615 \pm 0.055) \times 10^{-10}$ s at 115 GeV/c agree with each other and with the average value $\tau_\Xi = (1.635 \pm 0.022) \times 10^{-10}$ s [9-12]. For Ω^- decays, the results $\tau_\Omega = (0.835 \pm 0.027) \times 10^{-10}$ s at 98.5 GeV/c and $\tau_\Omega = (0.795 \pm 0.040) \times 10^{-10}$ s at 115 GeV/c also agree well with each other. All errors quoted are statistical. The Monte Carlo distributions corresponding to the quoted lifetime values are shown together with the experimental data in fig. 3. There is good agreement between the data and the Monte Carlo distributions, as demonstrated also by the χ^2 values given in table 1. The variation of χ^2 with the assumed values for τ is shown in fig. 4.

Combining the results from the two momenta, we obtain $\tau_\Xi = (1.665 \pm 0.023) \times \times 10^{-10}$ s and $\tau_\Omega = (0.822 \pm 0.022) \times 10^{-10}$ s.

We have investigated the following sources of systematic errors:

a) For hyperons decaying inside the active volume of the DISC counter, the loss of efficiency compared to hyperons decaying downstream of the DISC depends on the DISC photoelectron statistics. The resulting uncertainties on the lifetimes are $\Delta\tau_\Xi = 0.028 \times 10^{-10}$ s and $\Delta\tau_\Omega = 0.014 \times 10^{-10}$ s.

b) Uncertainties in the relative positions of the DISC counter, the beam trigger counter T, and the veto counter A surrounding T introduce uncertainties $\Delta\tau_\Xi = 0.005 \times 10^{-10}$ s and $\Delta\tau_\Omega = 0.004 \times 10^{-10}$ s.

c) Another uncertainty results from the drift-chamber inefficiency in the beam region (see above). From the comparison of different efficiency calibration runs, we estimate these uncertainties to be $\Delta\tau_{\Xi} = 0.047 \times 10^{-10}$ s and $\Delta\tau_{\Omega} = 0.003 \times 10^{-10}$ s.

d) Changing the value of τ_{Λ} in the Monte Carlo calculation by five times the error of the world average, i.e. by $\Delta\tau_{\Lambda} = 0.10 \times 10^{-10}$ s, shifts the Ξ^- and Ω^- lifetime results by $\Delta\tau_{\Xi} = 0.019 \times 10^{-10}$ s and $\Delta\tau_{\Omega} = 0.002 \times 10^{-10}$ s.

All the above uncertainties have been calculated for 98.5 GeV/c. They are not significantly different at 115 GeV/c.

e) The absolute momentum calibration of the spectrometer is known to 1%, resulting in uncertainties $\Delta\tau_{\Xi} = 0.016 \times 10^{-10}$ s and $\Delta\tau_{\Omega} = 0.008 \times 10^{-10}$ s.

f) A possible bias due to the estimated 2% background in the $\Omega^- \to \Lambda K^-$ sample has been investigated by considering the decay point distribution of the 112 events at 98.5 GeV/c which lie in the tails of the $m_{\Lambda K}$ peak, i.e. in the intervals 1.622 GeV/c^2 < $m_{\Lambda K}$ < 1.657 GeV/c^2 and 1.687 GeV/c^2 < $m_{\Lambda K}$ < < 1.722 GeV/c^2 (fig. 2). This distribution agrees well with the distribution of the 1532 selected $\Omega^- \to \Lambda K^-$ events; thus no correction is necessary for background effects.

We conclude that our total systematic uncertainties are $\Delta\tau_{\Xi} = 0.060 \times 10^{-10}$ s and $\Delta\tau_{\Omega} = 0.017 \times 10^{-10}$ s. Since the vertex distribution extends to larger z for Ξ^- than for Ω^-, some of the systematic effects are more important for Ξ^- than for Ω^-.

To study the effects of systematic errors connected with decays at small z or large z, we have evaluated the lifetimes for a reduced decay region, $z_{min} = 3$ m and $z_{max} = 8$ m where the variation of acceptances is small. The results are also listed in table 1. The differences between these results and the results obtained for the larger decay region $z_{min} = 2$ m and $z_{max} = 10$ m, are within our estimated systematic errors.

5. CONCLUSION

Including the systematic errors, we finally obtain the result

$$\tau_\Omega = (0.822 \pm 0.028) \times 10^{-10}\ \mathrm{s}\ .$$

There exist three other measurements of the Ω^- lifetime from bubble chambers exposed to K^- beams of 4-16 GeV/c:

$$\tau_\Omega = \left(1.41 \begin{smallmatrix} +\ 0.15 \\ -\ 0.24 \end{smallmatrix}\right) \times 10^{-10}\ \mathrm{s} \qquad \text{(ref. [13], 101 events)}$$

$$\tau_\Omega = \left(0.75 \begin{smallmatrix} +\ 0.14 \\ -\ 0.11 \end{smallmatrix}\right) \times 10^{-10}\ \mathrm{s} \qquad \text{(ref. [14], 40 events)}$$

$$\tau_\Omega = \left(0.80 \begin{smallmatrix} +\ 0.16 \\ -\ 0.12 \end{smallmatrix}\right) \times 10^{-10}\ \mathrm{s} \qquad \text{(ref. [15], 41 events)}\ .$$

Two of these results are in agreement with our result.

For the Ξ^- lifetime we obtain

$$\tau_\Xi = (1.665 \pm 0.065) \times 10^{-10}\ \mathrm{s}\ ,$$

in agreement with the value $\tau_\Xi = (1.635 \pm 0.022) \times 10^{-10}$ s from previous experiments [9-12].

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Table 1

Results of Ω^- and Ξ^- lifetime fits for different cuts on z, the position of the Ω^- (Ξ^-) decay point

Particle	Momentum (GeV/c)	z_{min} (m)	z_{max} (m)	τ (10^{-10} s)	χ^2	DF
Ω^-	98.5	2	10	0.835 ± 0.027	16.7	20
		3	8	0.850 ± 0.045	11.3	14
	115	2	10	0.795 ± 0.040	23.2	20
		3	8	0.785 ± 0.060	10.1	14
Ξ^-	98.5	2	10	1.675 ± 0.025	31.2	30
		3	8	1.715 ± 0.045	17.7	18
	115	2	10	1.615 ± 0.055	31.4	30
		3	8	1.620 ± 0.080	25.2	18

Figure captions

Fig. 1 : Plan view of the apparatus: T: beam counter, A: beam halo veto counter, He: helium bag, Li: lithium radiators, Xe: xenon proportional chambers, DC: drift chambers.

Fig. 2 : $m_{\Lambda K}$ distribution at 98.5 GeV/c with cut $m_{\Lambda\pi} > 1.35$ GeV/c^2 applied.

Fig. 3 : Decay point distributions:

a) $\Omega^- \to \Lambda K^-$ at 98.5 GeV/c;

b) $\Omega^- \to \Lambda K^-$ at 115 GeV/c;

c) $\Xi^- \to \Lambda\pi^-$ at 98.5 GeV/c;

d) $\Xi^- \to \Lambda\pi^-$ at 115 GeV/c .

The Monte Carlo distributions for the best lifetime fits (smooth curves) are superimposed on the data, the cuts on z used for the fit are indicated by arrows.

Fig. 4 : Variation of χ^2 with the lifetime for $\Omega^- \to \Lambda K^-$ and $\Xi^- \to \Lambda\pi^-$ at 98.5 GeV/c (full curves) and 115 GeV/c (dashed curves).

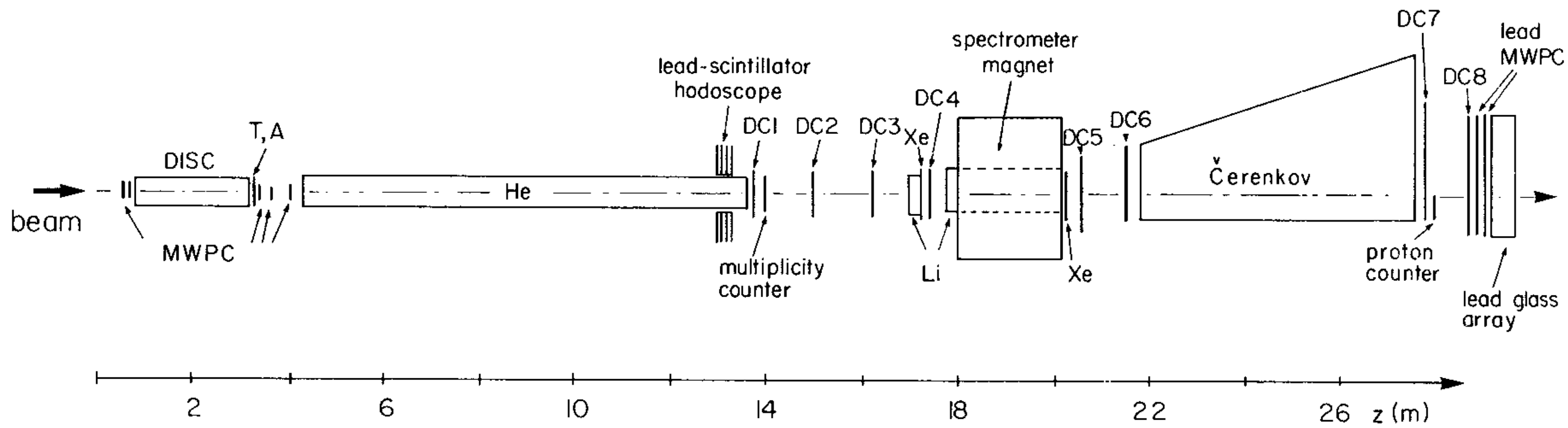
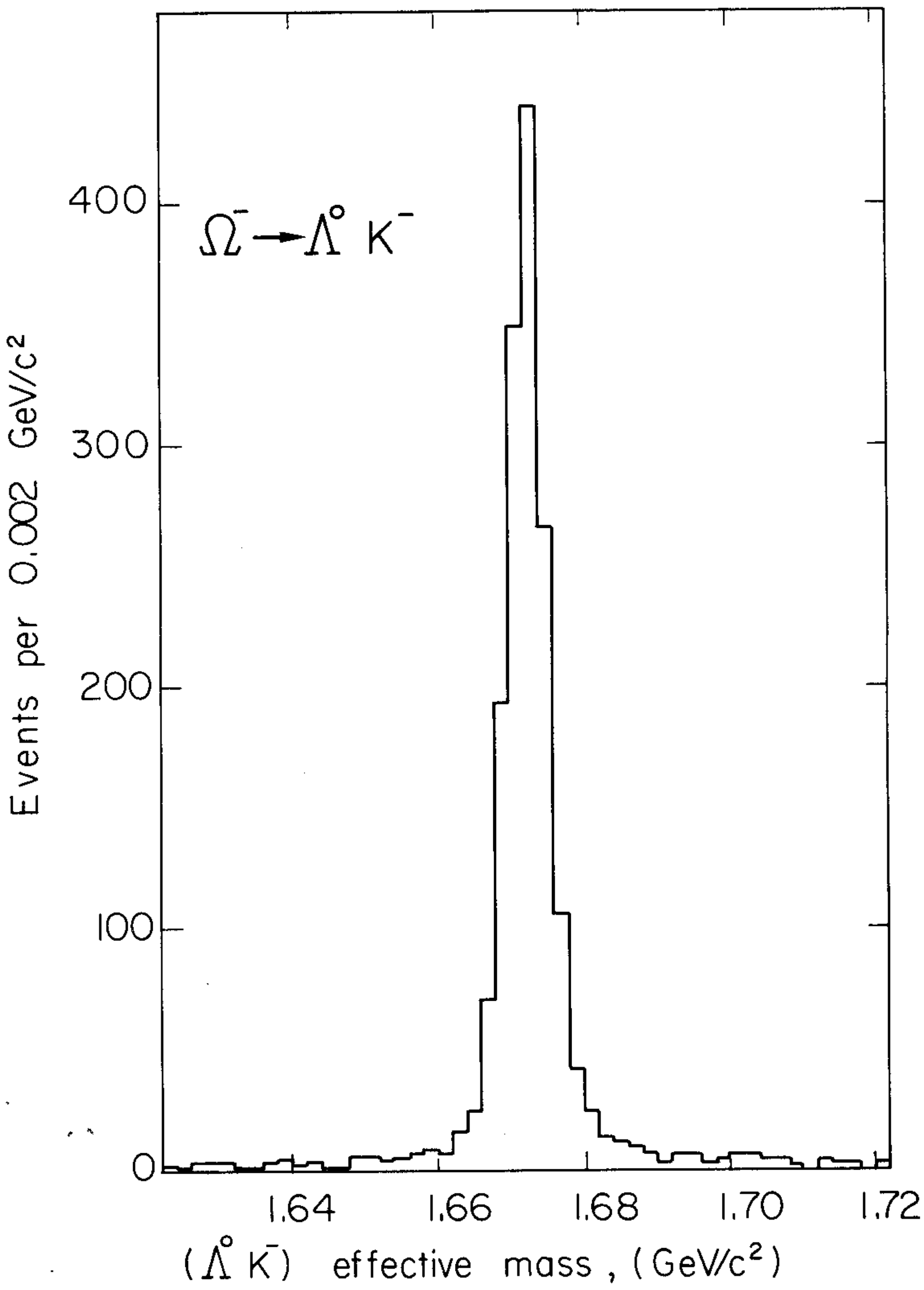

beam
MWPC
DISC
T,A
He
lead-scintillator
hodoscope
DCI
DC2
DC3
multiplicity
counter
Xe
DC4
Li
spectrometer
magnet
DC5
Xe
DC6
Čerenkov
DC7
proton
counter
DC8
lead
MWPC
lead glass
array
2
6
10
14
18
22
26
z (m)

Fig. 1



400
300
200
100
0
Events per 0.002 GeV/c²
Ω⁻ → Λ° K⁻
1.64
1.66
1.68
1.70
1.72
(Λ° K⁻) effective mass, (GeV/c²)

Fig. 2

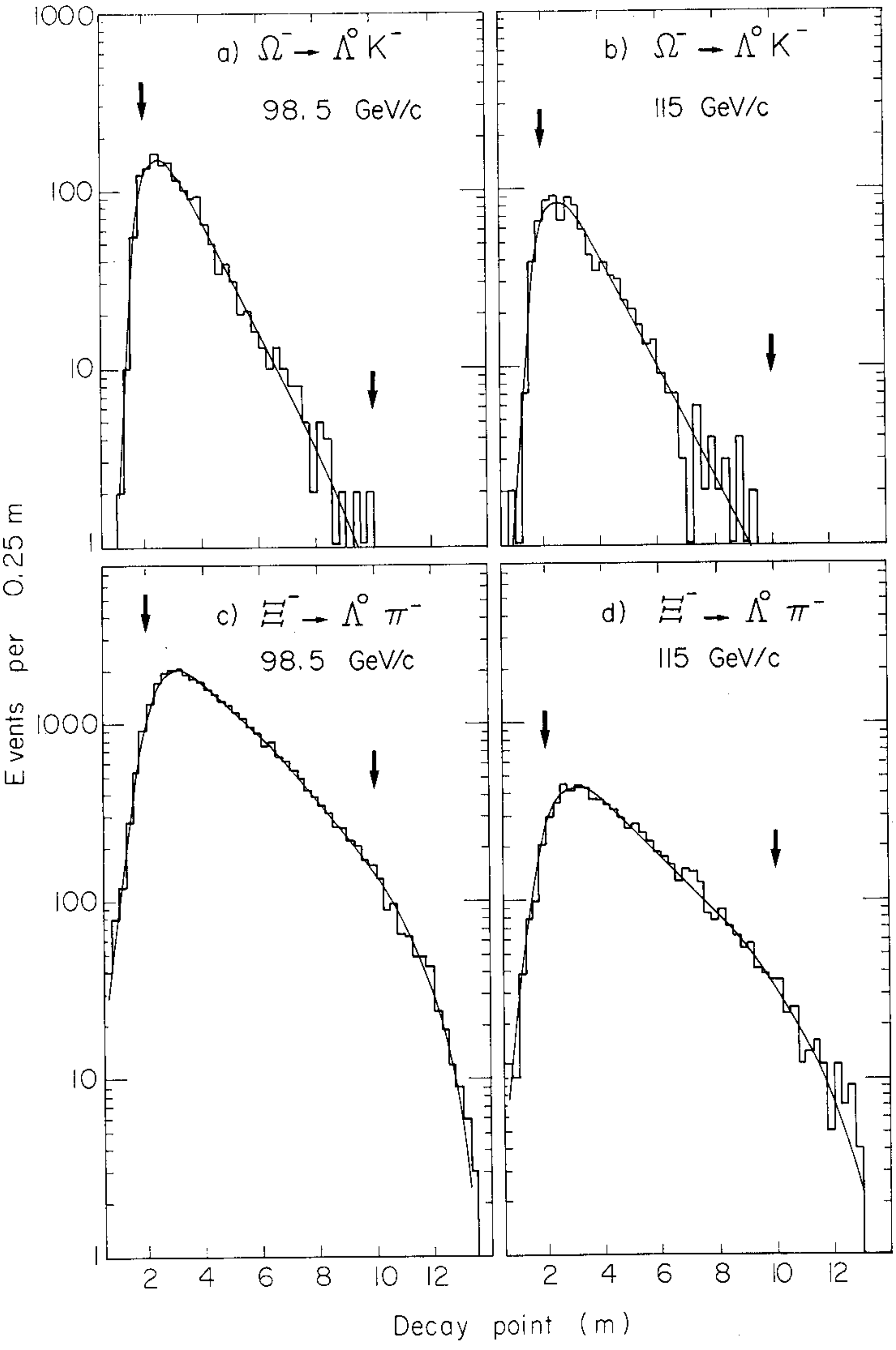
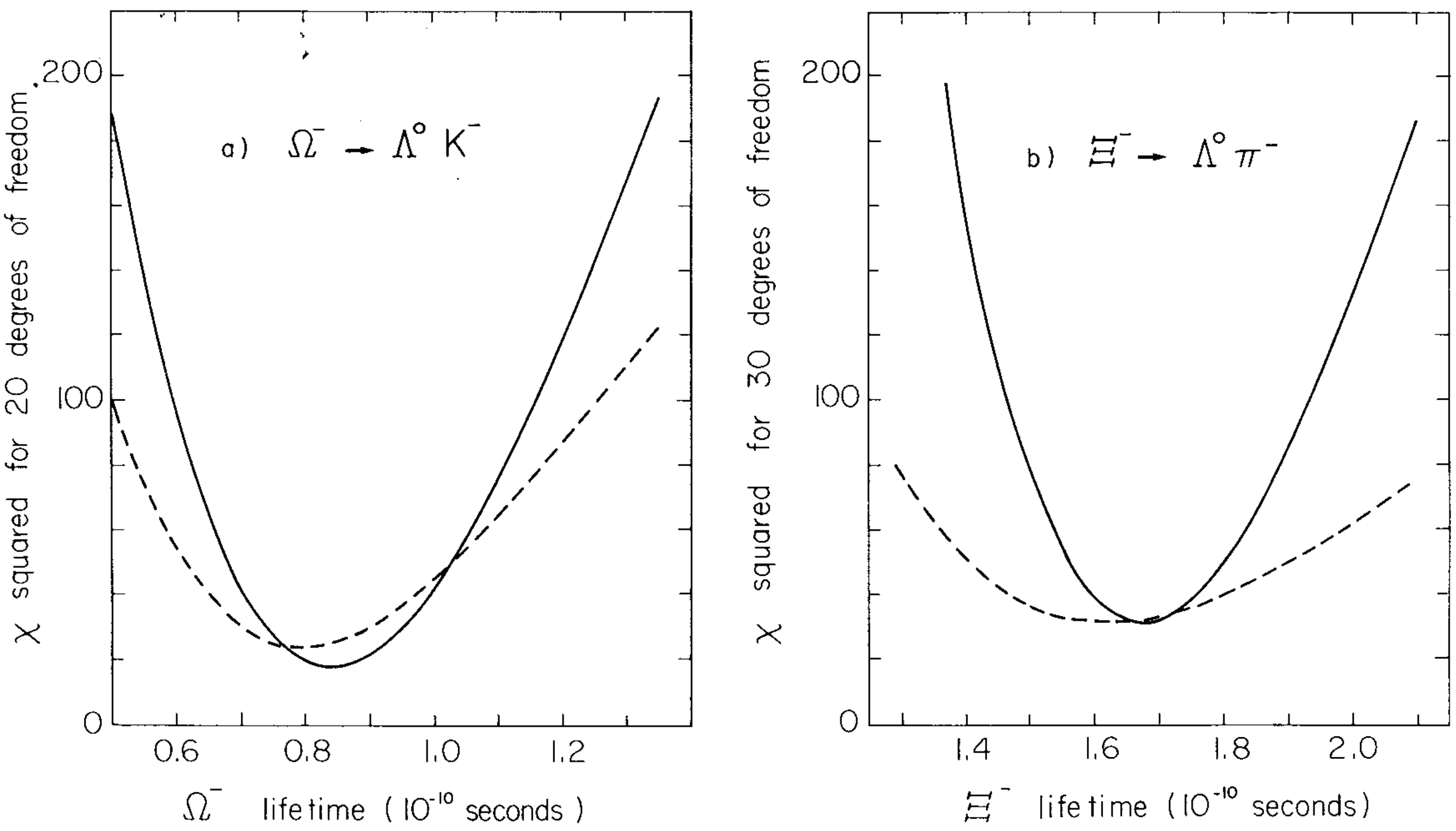

a) $\Omega^- \rightarrow \Lambda^\circ K^-$
98.5 GeV/c
b) $\Omega^- \rightarrow \Lambda^\circ K^-$
115 GeV/c
c) $\Xi^- \rightarrow \Lambda^\circ \pi^-$
98.5 GeV/c
d) $\Xi^- \rightarrow \Lambda^\circ \pi^-$
115 GeV/c
Events per 0.25 m
Decay point (m)
1000
100
10
1
2
4
6
8
10
12

Fig. 3



a) $\Omega^- \rightarrow \Lambda^\circ K^-$
χ squared for 20 degrees of freedom
200
100
0
0.6
0.8
1.0
1.2
Ω^- lifetime (10^{-10} seconds)
b) $\Xi^- \rightarrow \Lambda^\circ \pi^-$
χ squared for 30 degrees of freedom
200
100
0
1.4
1.6
1.8
2.0
Ξ^- lifetime (10^{-10} seconds)

Fig. 4