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PRELIMINARY RESULTS ON THE RELATIVE $\Sigma^{o} - \Lambda^{o}$ PARITY AND ON Σ - LEPTONIC DECAYS FROM THE CERN K^- MESON STOPPING EXPERIMENT

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PRELIMINARY RESULTS ON THE RELATIVE $\Sigma^o - \Lambda^o$ PARITY AND ON Σ - LEPTONIC DECAYS FROM THE CERN K^- MESON STOPPING EXPERIMENT

Last December an experimental exposure was completed at the CERN proton synchrotron in which about one million K^- mesons were stopped in the Saclay 80 cm hydrogen bubble chamber. The aims of this experiment were:

1) To produce 1000 examples of Dalitz decay of the Σ^o - hyperon ($\Sigma^o \longrightarrow \Lambda^o + e^+ + e^-$) and to determine the relative parity of the Σ^o and Λ^o by studying the invariant mass spectrum of these Dalitz pairs.
2) To measure the branching ratios for leptonic decays of the charged Σ- hyperons.

The present status of the experiment is the following:

Σ - Λ parity

The method we have used to determine the relative parity from the decay of unpolarized Σ^o - hyperons has been suggested by Feinberg[1], and Feldman and Fulton[2]. The essential feature is that if the relative Σ parity were odd the transition matrix element for the process $\Sigma^o \longrightarrow \Lambda^o + e^+ + e^-$ would be independent on the momentum of the Dalitz pair whereas if the relative Σ parity were even this matrix element would be proportional to the Dalitz pair momentum. This has the consequence that if the relative parity were odd more Dalitz pairs exhibiting large invariant mass (hence large opening angle between the pair) would be expected to occur than if the relative parity were even.

The differential mass distribution has the following form:

$$W = \frac{dw}{d\chi} = \left(1 + \frac{\chi^2}{2\Delta^2}\right) C(\chi) \quad \text{for odd parity, e.g. I}$$

$$W = \frac{dw}{d\chi} = \left(1 - \frac{\chi^2}{\Delta^2}\right) C(\chi) \quad \text{for even parity, e.g. II}$$

where

$$C(\chi) = \frac{1}{\chi} \left(1 - \frac{\chi^2}{\Delta^2}\right)^{1/2} \left(1 - \frac{4m_e^2}{\chi^2}\right)^{1/2} \left(1 + \frac{2m_e^2}{\chi^2}\right)$$

$\Delta = M_{\Sigma^o} - M_{\Lambda^o}$ and $\chi^2 = (E_+ + E_-)^2 - (p_+ + p_-)^2$ the mass of the Dalitz pair.

m_e is the electron mass.

1) G. Feinberg, Phys. Rev. 109, 1019 (1958)
2) G. Feldman and T. Fulton, Nuclear Physics 8, 106, (1958)

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In our experiment Σ^0 hyperons are produced by K^- mesons at rest in the hydrogen of the bubble chamber according to the reaction

$$K^- + p \longrightarrow \Sigma^0 + \pi^0$$

The Dalitz decay events of Σ^0 hyperons produced in this manner are recognized in scanning by both a) the presence of an electron pair originating at the stopping point of an incident K^- - meson.

b) The presence of a Λ^0 - hyperon decay in the proximity of the K^- stopping point.

Fig. 1 shows a typical case of Σ^0 Dalitz decay. We have obtained 154 such events which after measurement and analysis have proved to be examples of this decay process.*) An additional 450 events measured and analyzed have proved not to be examples of Σ^0 Dalitz decay. The three reactions capable of producing Dalitz pairs in the presence of Λ^0 - hyperon from stopped K^- - mesons in hydrogen are:

a) $K^- + p \longrightarrow \Sigma^0 + \pi^0$, $\quad \Sigma^0 \longrightarrow \Lambda^0 + e^+ + e^-$

b) $K^- + p \longrightarrow \Sigma^0 + \pi^0$, $\quad \pi^0 \longrightarrow e^+ + e^- + \gamma$, $\quad \Sigma^0 \longrightarrow \Lambda^0 + \gamma$

c) $K^- + p \longrightarrow \Lambda^0 + \pi^0$, $\quad \pi^0 \longrightarrow e^+ + e^- + \gamma$

The expected yield of events of type a) is 1/3.6 which agrees very well with our sample. We estimate that about 20 - 30 additional events will eventually be included in this partial sample from the events now slated from remeasurement.

Most of these events are events rejected by the geometry program due either to poor measurements on slow electrons of about 2 MeV/c or to poorly located Λ^0 decay vertices in the case of large opening angles. It is very unlikely that the inclusion of these events in our sample will change the nature of the conclusions which we draw at present.

Fig. 2 shows the measured distribution of the invariant mass quantity. It also shows the shapes of the mass distributions calculated using equations I and II.

In order to distinguish between the two hypotheses we have performed the following tests:

Dividing the theoretical spectra into two regions consisting of 20 o/o (high mass end) and 80 o/o (low mass end) of the total area we have performed a

*) We have now 280 $\Sigma^0 \longrightarrow \Lambda\, e^+e^-$ decays. The distributions of these events are shown in Fig. 2 and Fig. 3.

χ^2 test with one degree of freedom. The results for the two hypotheses are:

even: $\chi^2 = \frac{0.05}{1}$ giving $\approx$ 85 o/o probability

odd: $\chi^2 = \frac{8}{1}$ giving $\approx$ 0.3 o/o probability

We have calculated the likelihood ratio

$$\text{Log } R = \sum_i \log \frac{W \text{ even } (\chi_i)}{W \text{ odd } (\chi_i)}$$

Under the two hypotheses and for our sample, we would expect this quantity to have the values

$$\log R \text{ even} = 2.4 \pm 1.0 \qquad 1)$$
$$\log R \text{ odd} = -2.1 \pm 1.2$$

We find

$$\text{Log } R \text{ this experiment} = 2.4$$

We have also calculated the average value of the invariant mass quantity. The expected values for this average are

$$\bar{\chi} = 13.42 \text{ MeV even parity} \qquad 2)$$
$$\bar{\chi} = 17.61 \text{ MeV odd parity}$$

We find

$$\bar{\chi} \text{ this experiment} = 12.2 \text{ MeV} \pm 1.2 \text{ MeV}$$

Fig. 3 shows a 2-dimensional plot calculated by Willis. Here the energy of the low energy member of the electron pair is plotted against its invariant mass quantity for each of our events. Contours of constant density as well as the relative density values are drawn for the two hypotheses. From the contour lines, it is seen that for odd parity an accumulation of points is expected in the upper right hand region of this plot whereas for even parity a paucity of events is expected in this region. The preference for even parity is obvious.

Σ Leptonic Decays

A rapid scan of about 170,000 pictures containing about 2 x 10^5 Σ^- hyperon production events has been performed.

Leptonic Decays with $\Delta S = 0$

We have found one example of the decay

$$\Sigma^- \longrightarrow e^- + \nu + \Lambda^0$$

1,2) The quantities for the sample of 280 events are

$\log R$ even = + 4,5 $\pm$ 1.4, $\log R$ odd = - 3.9 $\pm$ 1.6

$\log R$ this experiment = + 7.

$\bar{\chi}$ this experiment = 13.2 $\pm$ .7 MeV.

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This is shown in Fig. 4. No corresponding decays of Σ^+ have been found.*) Since the maximum electron momentum in the above decay is 80 MeV/c we expect our efficiency for detecting this type of event to be about 70 o/o. The branching ratio for those events in our sample, then is

$$R = (1 \times 3/2 \times 1/0.7)/_{2 \times 10^5} \approx 10^{-5}$$

If we assume that Universal Fermi Interaction to apply, we would expect a value of

$$R = \frac{\Sigma^- \longrightarrow \Lambda^0}{\text{all } \Sigma^-} \approx 2 \times 10^{-4} \text{ (Ref. 3)}$$

Even though based on very poor statistics it would appear that the rate for this decay is substantially lower.

Leptonic Decays with $\Delta S = 0$

For the decay

$$\Sigma^- \longrightarrow e^- + \nu + n$$

we have found 8 events with $P_e \leqslant 50$ MeV/c, and 3 events with $P_e > 50$ MeV/c. In the type of rapid scanning which we have performed only decays with electrons of $\leqslant 50$ MeV/c can be efficiently detected. This energy range corresponds to only 1/20 of the whole spectrum.

Using only the 8 low-momentum events, we obtain

$$R = \frac{\Sigma^- \longrightarrow e^- + \nu + n}{\text{all } \Sigma^-} \approx 10^{-3}$$

where the uncertainties in scanning efficiency correspond to a factor of 2.

Two examples of the decay

$$\Sigma^- \longrightarrow \mu^- + \nu + n$$

have been found. This decay mode has not been previously observed.

We can estimate the number of Σ^+ leptonic decays which should have been observed if $\Delta S = - \Delta Q$ transitions were allowed. To eliminate scanning biases, this number is best derived from the rate of observed $\Delta Q = + \Delta S$ decays which were 13.

We would expect then

$$\text{No. } \Sigma^+ \longrightarrow \begin{pmatrix} e^+ \\ \mu^+ \end{pmatrix} + \ldots = \frac{13}{2 \times 2.2} = 3$$

The factor 2.2 corresponds to the number of produced $\Sigma^+ = \frac{1}{2.2}$ No. Σ^- and the factor 2 takes into account that the non leptonic decay rate of the Σ^+ is twice the rate of the Σ^-. No Σ^+ leptonic decays have been observed.

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*) We have now 3 $\Sigma^- \longrightarrow \Lambda\, e^- \nu$ and 2 $\Sigma^+ \longrightarrow \Lambda\, e^+ \nu$ from about 350.000 Σ^- and 175.000 Σ^+ hyperons.

Fig. 1 Example of $K^- + p \longrightarrow \Sigma^o + \pi^o$
$\hookrightarrow \Lambda^o + e^+ + e^-$

Fig. 2 (Caption is on the Fig.)

Fig. 3 Two dimensional plot of $\Sigma^o \longrightarrow \Lambda^o + e^+ + e^-$ decay distribution. The energy ($T_{e^\pm}$ small) of the low energy member of the electron pair is plotted against its invarient mass

$$\chi = \left\{ (E_+ + E_-)^2 - (\vec{P}_+ + \vec{P}_-)^2 \right\}^{1/2} \approx \left\{ (M_{\Sigma^o} - M_{\Lambda^o})^2 - (\vec{P}_+ + \vec{P}_-)^2 \right\}^{1/2}$$

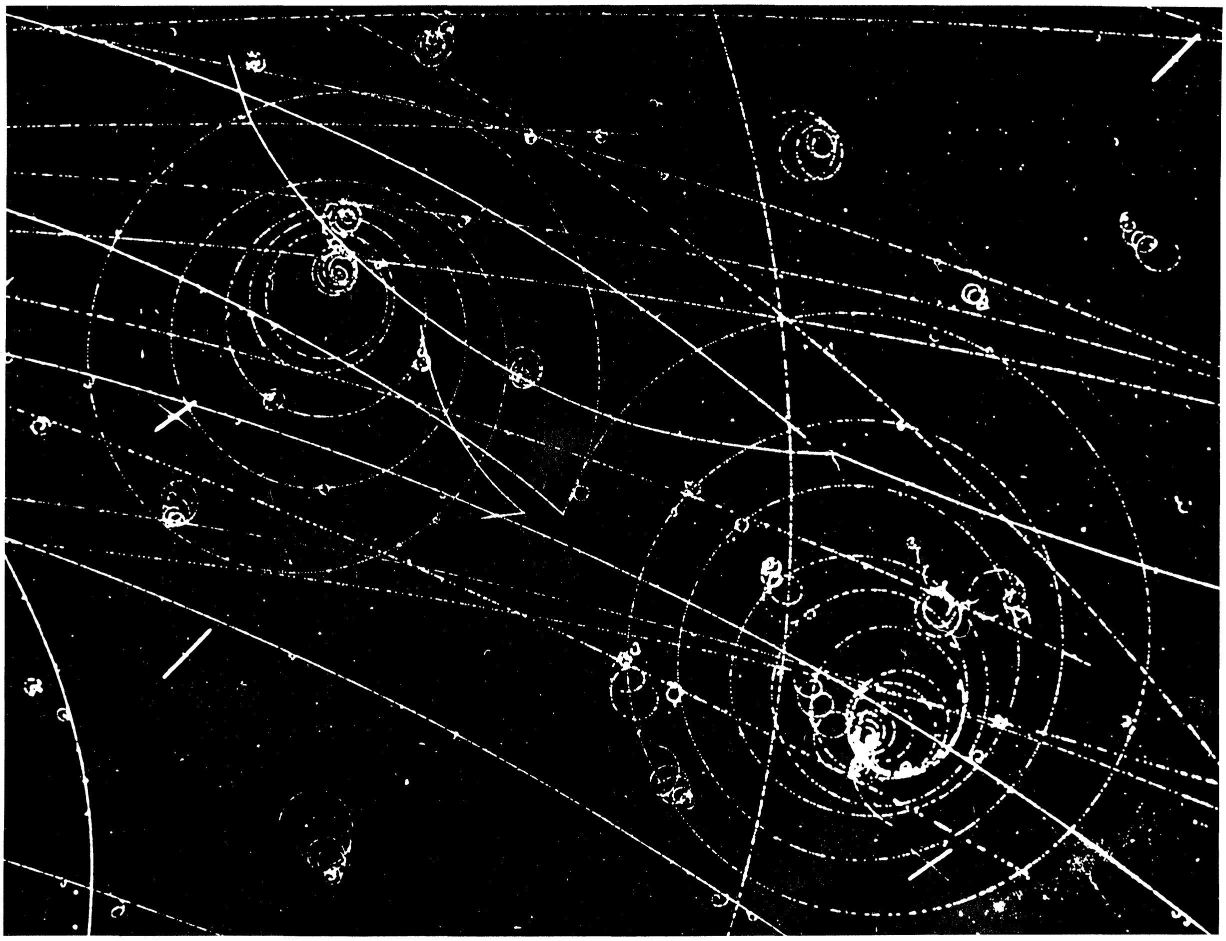
Contours of constant density as well as the relative density values are drawn for the two hypotheses.

Fig. 4 The decay of $\Sigma^- \longrightarrow \Lambda^o + e^- + \bar{\nu}$ the Σ^- is produced in the reaction

$$(K^- + p)_{rest} \longrightarrow \Sigma^- + \pi^+$$

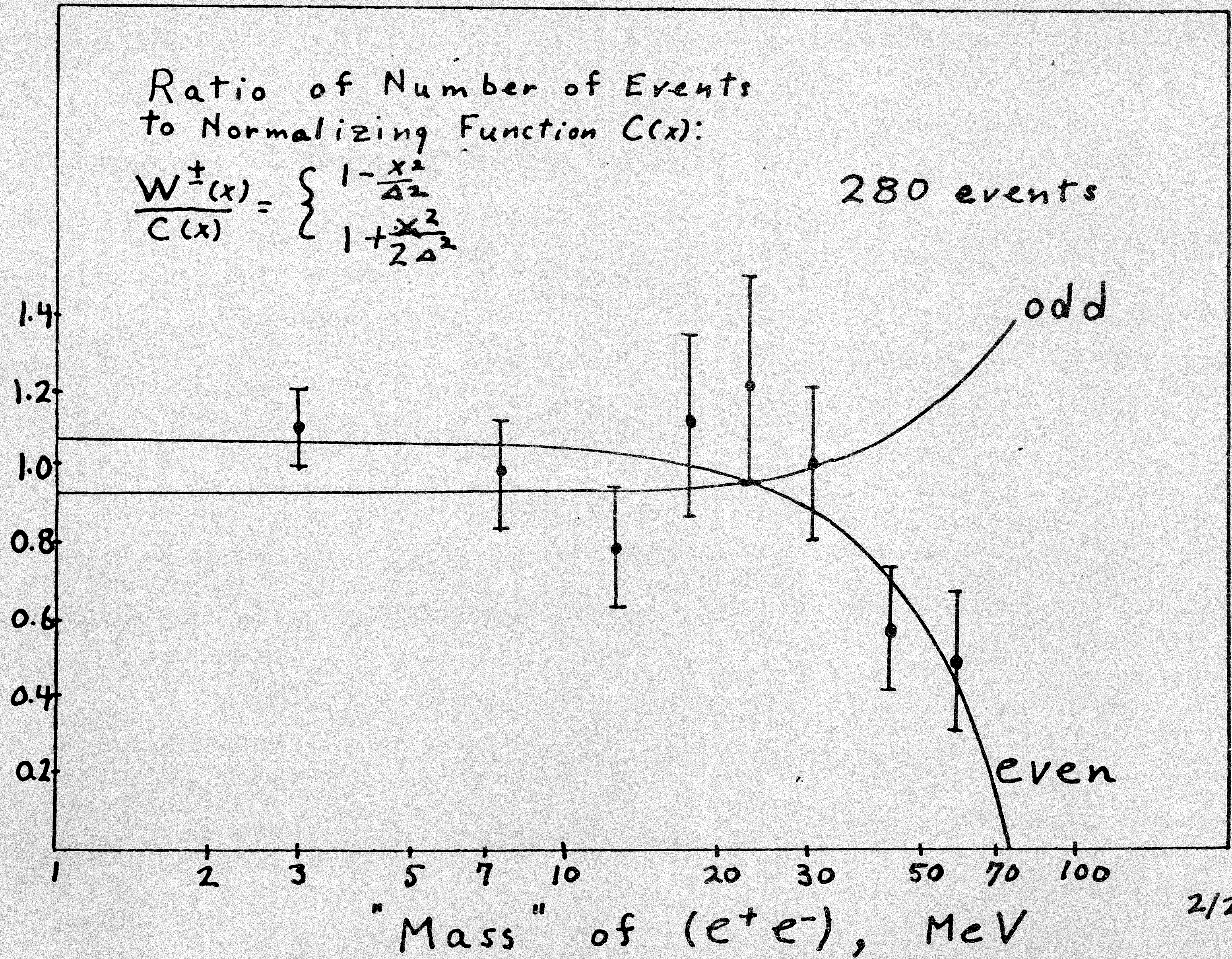
Fig. 5 The decay of $\Sigma^- \longrightarrow n + \mu + \bar{\nu}$

Fig. 6 The decay of $\Sigma^- \longrightarrow n + e^- + \bar{\nu}$



Example of $K^- p \rightarrow \Sigma^\circ \pi^\circ$

$\hookrightarrow \Lambda^\circ e^+ e^-$



Ratio of Number of Events
to Normalizing Function C(x):
$\frac{W^{\pm}(x)}{C(x)} = \begin{cases} 1-\frac{x^2}{\Delta^2} \\ 1+\frac{x^2}{2\Delta^2} \end{cases}$
280 events
odd
even
$\frac{W}{C}$
1.4
1.2
1.0
0.8
0.6
0.4
0.2
1
2
3
5
7
10
20
30
50
70
100
"Mass" of (e^+e^-), MeV

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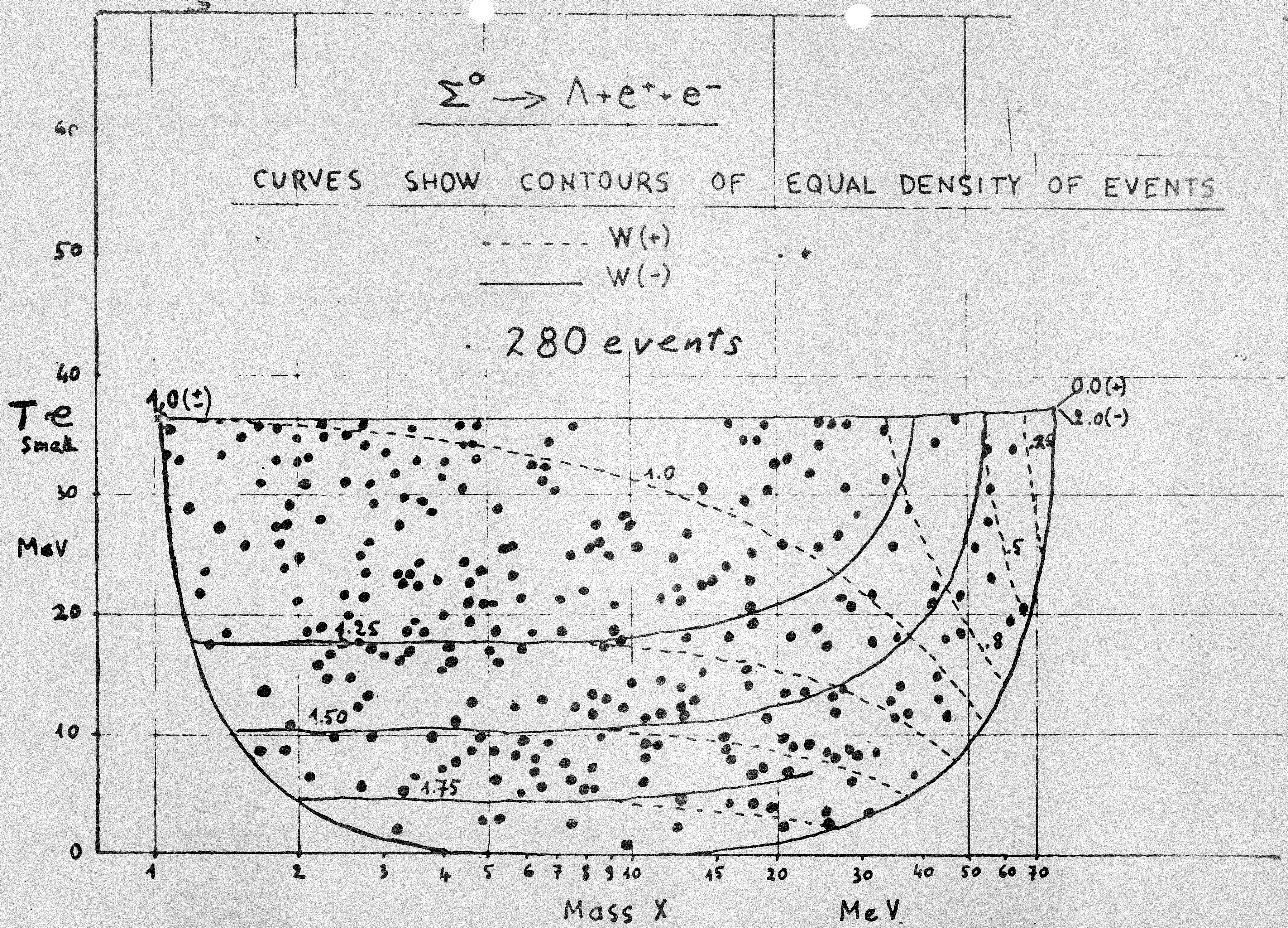
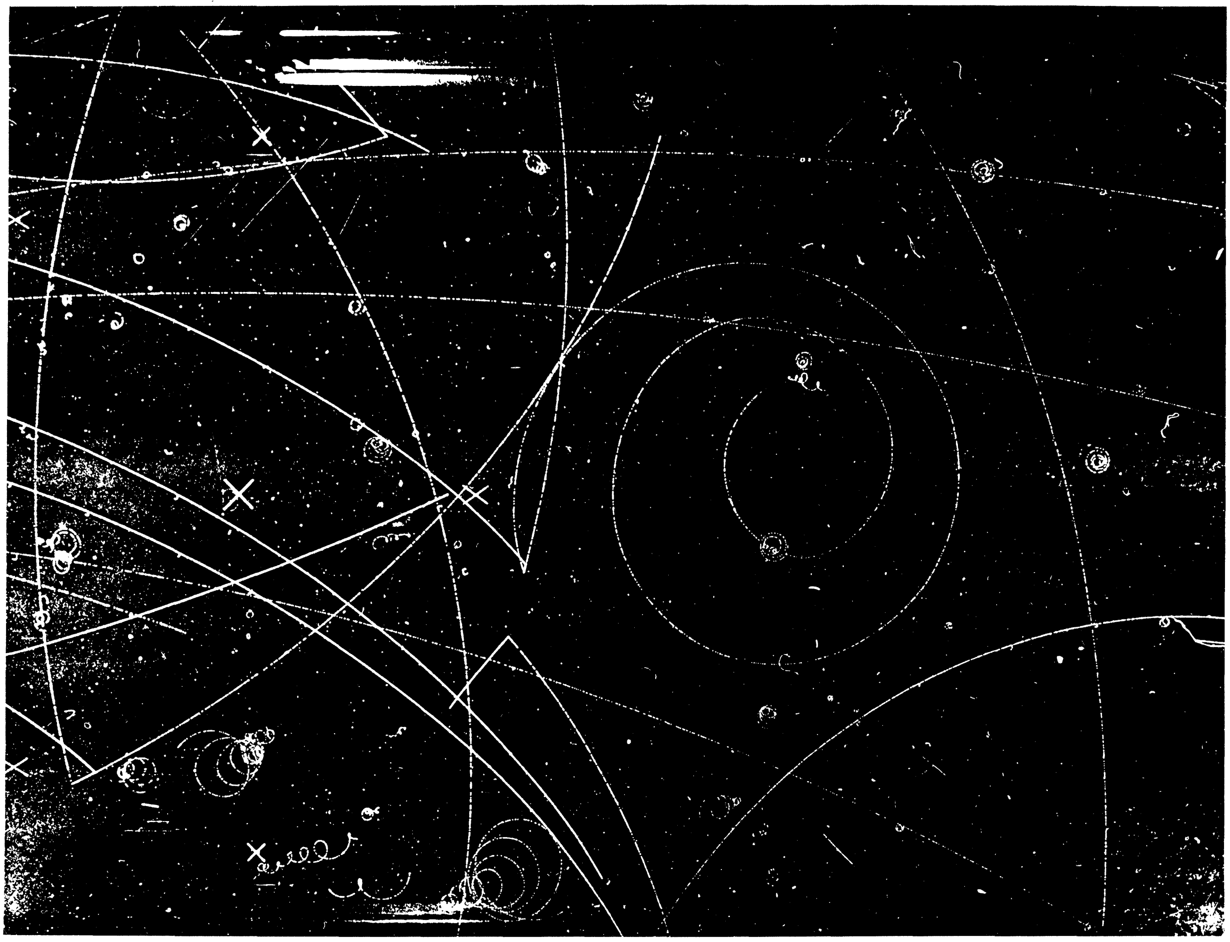
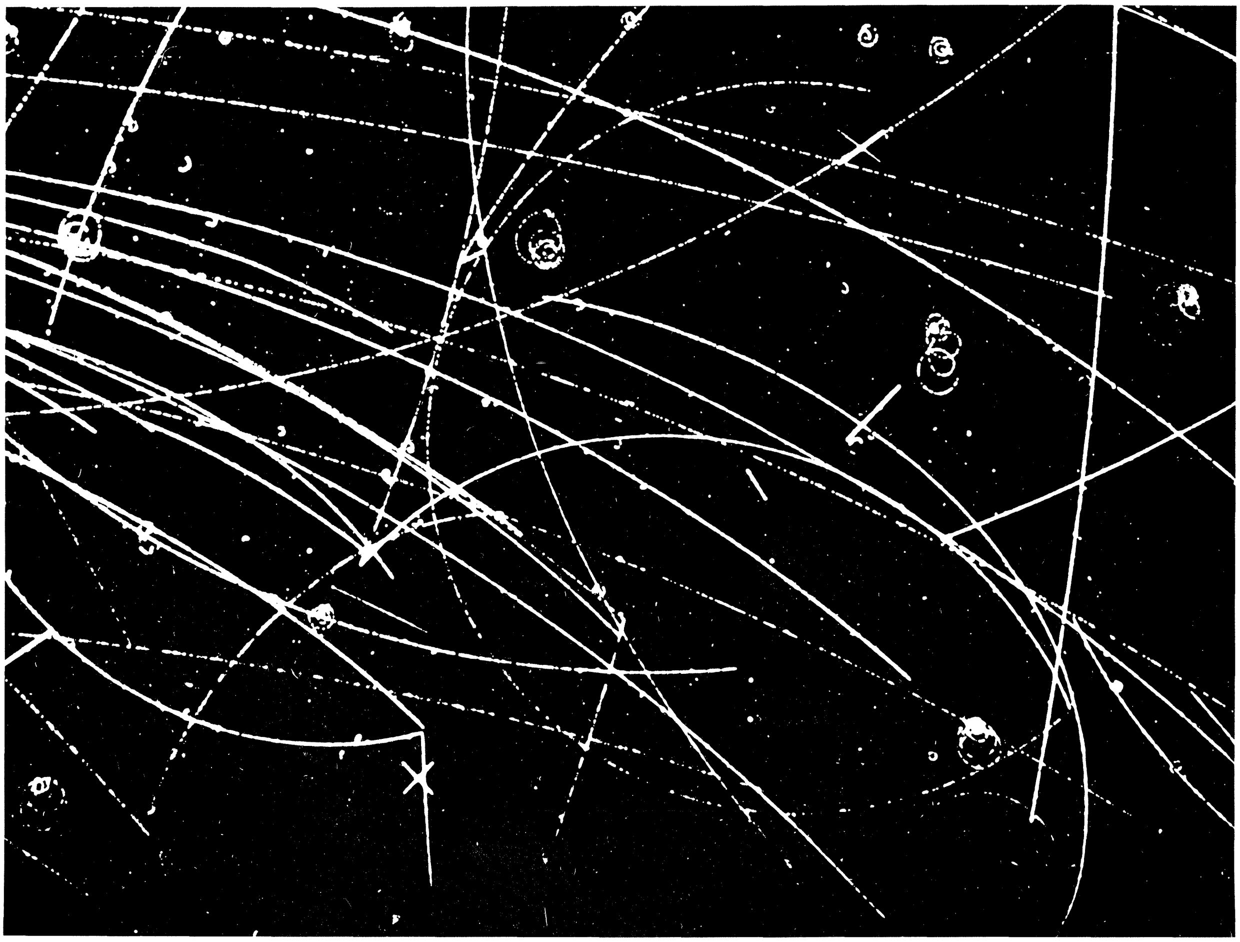


$\Sigma^0 \to \Lambda + e^+ + e^-$
CURVES SHOW CONTOURS OF EQUAL DENSITY OF EVENTS
W(+)
W(-)
280 events
1.0(±)
0.0(+)
2.0(-)
1.0
1.25
1.50
1.75
.25
.5
.8
T_e Small
MeV
0
10
20
30
40
50
1
2
3
4
5
6
7
8
9
10
15
20
30
40
50
60
70
Mass X
MeV



The decay of $\Sigma^- \rightarrow \Lambda^o e^- \bar{\nu}$



The decay of $\Sigma^- \rightarrow n\ \mu^- \bar{\nu}$

$\qquad\qquad\qquad\qquad \hookrightarrow e^- \nu \bar{\nu}$

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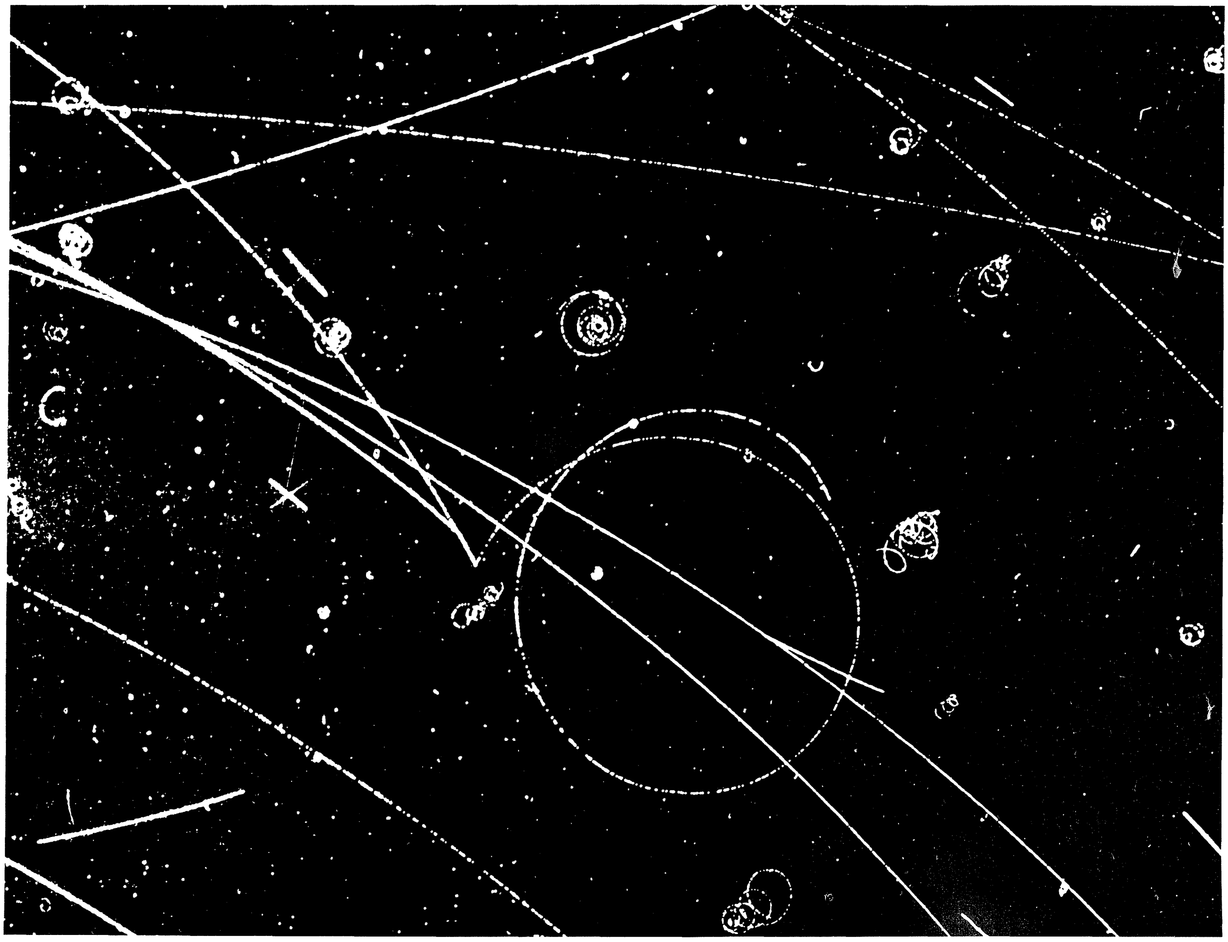

The decay of $\Sigma^- \rightarrow n\ e^-\ \bar{\nu}$