CERN/TC/PHYSICS 63-6

A DETERMINATION OF THE RELATIVE $\Sigma - \Lambda$ PARITY *

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*Work at University of Maryland supported in part by U.S. Atomic Energy Commission.

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A Determination of the Relative $\Sigma - \Lambda$ Parity.

To determine the relative $\Sigma - \Lambda$ parity, we have measured the invariant mass spectrum of Dalitz pairs from the decay of unpolarized Σ^0 - hyperons, $\Sigma^0 \to \Lambda^0 + e^+ + e^-$. This method has been suggested by Feinberg [1], Feldman and Fulton [2], and by Dalitz [3]. The problem is to establish the decay as an electric (odd $\Sigma - \Lambda$ parity) or a magnetic (even parity) dipole transition. Under the even parity hypothesis the radiative matrix element is proportional to the momentum of the Dalitz pair, whereas with odd parity the matrix element is independent of the pair momentum. This has the consequence that for odd parity, more Dalitz pairs exhibiting large invariant mass would be expected to occur than for even parity. Our data favor even $\Sigma - \Lambda$ parity.[8]

We will first analyze our data neglecting terms proportional to the electric form factor, the effect of which will be considered later. Under this assumption, the differential invariant mass distribution of the Dalitz pairs has the approximate form [4),5)].

$$\frac{1}{C(x)} \frac{dw}{dx} = 1 - x \qquad \text{for even parity} \qquad (1)$$

$$\frac{1}{C(x)} \frac{dw}{dx} = 1 + \tfrac{1}{2}x \qquad \text{for odd parity} \qquad (2)$$

where $x = \left[(E_+ + E_-)^2 - (\vec{p}_+ + \vec{p}_-)^2 \right] \Big/ \Delta^2$

is the square of the invariant mass in units of Δ^2, and

$$\Delta = (M_\Sigma - M_\Lambda) = 76.1 \text{ MeV}.$$

The quantities $E_\pm$ and $P_\pm$ are the electron energy and momentum, and

$$C(x) \approx \frac{1}{x}(1-x)^{\frac{1}{2}}\left(1-\frac{x_o}{x}\right)^{\frac{1}{2}} \tag{3}$$

with

$$x_o = \frac{4m_e^2}{\Delta^2} = 1.83 \cdot 10^{-4} .$$

In our experiment, Σ^o-hyperons were produced by K^--mesons at rest in hydrogen. The 81-cm Saclay hydrogen bubble chamber was exposed to a K^--meson beam at the CERN PS. About 10^6 K^--mesons were stopped in the chamber, producing 3×10^5 Σ^o-hyperons via the reaction $K^- + p \rightarrow \Sigma^o + \pi^o$. About 1,000 of these undergo Dalitz decay. The decays produced in this manner are recognized in scanning by the presence of an electron pair originating at the stopping point of an incident K^--meson together with a Λ^o-hyperon decay in the proximity of the K^--stopping point. There are three reactions of stopped K^--mesons capable of producing such events:

a) $K^- + p \rightarrow \Sigma^o + \pi^o$
$\qquad\qquad\quad \hookrightarrow \Lambda^o + e^+ + e^-$

b) $K^- + p \rightarrow \Sigma^o + \pi^o$
$\qquad\qquad\quad \hookrightarrow \Lambda^o + \gamma \qquad \hookrightarrow \gamma + e^+ + e^-$

c) $K^- + p \rightarrow \Lambda^o + \pi^o$
$\qquad\qquad\qquad\qquad \hookrightarrow \gamma + e^+ + e^-$

The theoretical branching ratios for π^o and Σ^o Dalitz decays are 1/80 and 1/180, respectively. The experimental production rates for (Σ^o, π^o) and (Λ^o, π^o) from (K^-, p) at rest[7] are 0.28 and 0.064, respectively. This implies that, of 3.6 events with a Λ^o and Dalitz pair, one corresponds to reaction (a).

To date we have obtained 353 events which, after measurement and analysis, have proved to be examples of type (a). These events came from a sample of 1430 measured and analyzed events. The remaining events in the present sample have been identified as being either types (b) and (c) or events in flight. Events of type (a) were accepted in the sample if their χ^2-probability exceeded 5% for a five constraint fit. Events of type (b) and (c) were also identified by kinematic fitting and events in flight rejected on the basis of the Λ^o or Σ^o momentum in the decay-fit. There is a small region of overlap between the allowed configuration of reaction (b) and reaction (a).

Figure 1 shows a sample of events from reactions (a) and (b). The ordinate and abscissa are the sum of the momenta and the invariant mass, respectively, of the constrained Λ^o and the measured e^+ and e^-. Good Σ^o events cluster about a value of momentum, 182.2 Mev/c, and invariant mass, 1191.5 Mev, characteristic of Σ^o's produced by K^- interacting at rest. It is evident from Figure 1 and the inset that the density of points in a region about the expected Σ^o momentum and mass is much larger than the general density. Therefore, the fraction of events from reaction (b) contained in the sample of "good" $\Sigma^o \rightarrow \Lambda^o + e^- + e^+$ events is a few percent only. Moreover, reaction (b) gives an invariant mass spectrum very similar to the function C(x), Equation (3). Thus, we conclude that background effects are negligible.

Figure 2 shows the measured distribution of the invariant mass divided by $C(x)$. It also shows the mass distributions calculated using equations (1) and (2). The measurements agree well with the even parity spectrum.

The agreement can be expressed in terms of the average value of the invariant mass. We find experimentally:

$$\langle x^{\frac{1}{2}} \rangle = 0.161 \pm 0.009$$

The values expected from the equations of Evans[4] are:

$$\text{for even } \langle x^{\frac{1}{2}} \rangle = 0.167,$$

$$\text{for odd } \langle x^{\frac{1}{2}} \rangle = 0.221.$$

Figure 3 shows a two-dimensional plot of our data. The energy of the low-energy member of the electron pair is plotted against the invariant mass for each of our events. Contours of constant density are drawn for the two hypotheses, using an approximate form of Evans' equation and neglecting terms proportional to the electric form factor. 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 seen. The figure shows a loss of low energy electron events, which is explained by the difficulty of scanning for and measuring such events. It can be shown that the effect of this on the spectrum is small, and correcting for this would make our conclusion in favour of even parity slightly stronger. We have also checked our results for possible biases in the scanning and analysis of the Λ^{0}'s, and have found none.

The full expression for the invariant mass spectrum, given by Evans [4], shows a dependence on the electric and magnetic form factors, $f_1(x)$ and $f_2(x)$, of the $\Sigma - \Lambda$ electromagnetic transition. In obtaining the expressions (1) and (2), we have assumed that $f_2(x) = f_2(0)$ and that $|f_1| \lesssim |f_2|$.

The variation of $f_2(x)$ in the range $0 \leq x \leq 1$ is expected to be smaller than two per cent. This has been discussed by many authors [1,2,3,4]. Neglecting $f_1(x)$, a large variation in $f_2(x)$ of the order of 100 per cent would be required to make the odd spectrum fit our results.

Finally, we have considered the possibility of $|f_1| \gg |f_2|$, although one expects that $|f_1|$ will be small, as is the case for the neutron. In figure 4, we show the theorectical average invariant mass of the Dalitz pairs as a function of f_1/f_2, for real values of the ratio. Unless $f_1/f_2 \sim +10$, it is seen that our result clearly favors even parity. A perturbation theory estimate [2] of f_1/f_2 gives $\sim 1/4$.

We would like to thank, for their invaluable help and support, Prof. R. Adair, Dr. R. Armenteros, Dr. R. Florent, Dr. C. Germain, Prof. B. Gregory, Dr. E. Malamud, Prof. Ch. Peyrou, H. Schneider, Prof. A. Schlüter, and R. Tinguely.

We acknowledge very gratefully the efforts of the CERN PS machine group, the Saclay hydrogen bubble chamber group, the CERN data analysis group, the CERN track chamber division, and the data analysis groups at Maryland, and NRL.

Footnotes

1) G. Feinberg, Phys. Rev. 109, 1019 (1958)

2) G. Feldman and T. Fulton, Nucl. Physic 8, 106 (1958)

3) R. H. Dalitz, Proceedings of the Aix-en-Provence International Conference in Elementary Particles 1961, page 158

4) L. E. Evans, Nuovo Cimento 25, 580 (1962) and University of Wisconsin Preprint (Unpublished). The complete formula (not included in Evans' published paper) is:

$$\frac{dw}{dxdy} = \frac{\alpha^2}{\pi} \frac{q}{2} \frac{\Lambda}{M_\Sigma^2 \Delta^2 x^2} Q^{\pm}(x,y)$$

$$\frac{Q^{\pm}}{M_\Sigma} = |f_1|^2 \left(\frac{\Delta}{M}\right)^4 x^2 \left[M_\Sigma q^2 (1+y^2) + \Delta^2 x \left(1+\frac{x_o}{2x}\right)(q_o \mp M_\Lambda)\right]$$

$$- 2 \,\mathrm{Re}\, f_1^* f_2 \left(\frac{\Delta}{M}\right)^2 \frac{\Delta^2 x^2}{M} \left(1 + \frac{x_o}{2x}\right) \left[(M_\Sigma - q_o)(M_\Sigma \mp M_\Lambda) - \Delta^2 X\right]$$

$$+ |f_2|^2 \left[\left(\frac{\Delta}{M}\right)^2 x \left(M_\Sigma q^2 (1+y^2) + \Delta^2 x (q_o \mp M_\Lambda)\right) + \right.$$

$$\left. + \frac{x_o}{2} \frac{\Delta^2}{M^2} \left(2M_\Sigma q^2 + \Delta^2 x (q \mp M_\Lambda)\right)\right]$$

where q and q_o are the Λ^o momentum and energy, and $y = (E_+ - E_-)/q$.

5) Throughout this paper we set $c = 1$ and therefore energy, momentum, and mass are all given in units of MeV.

6) R. Aubert, H. Courant, H. Filthuth, A. Segar and W. Willis, Nuclear Instrumentation Conference Geneva, 1962.

7) W. E. Humphrey and R. R. Ross, Phys. Rev. 127, 1305 (1962).

8) Our conclusion in favor of even Σ-Λ parity supports the conclusion given by Tripp, Ferro-Luzzi and Watson (reference9) that the $K\Sigma$ parity is odd, since it has been shown that the $K\Lambda$ parity is very probably odd (see reference 10).

9) R. Tripp, M. Ferro-Luzzi and M. Watson, Phys. Rev. Letters 8, 175 (1962).

10) M. M. Block, F. Anderson, A. Pevsner, E. M. Harth, J. Leitner and H. Cohn, Phys. Rev. Letters 3, 291 (1959). Also M. Block, L. Lendinara and L. Monari Proceedings of the 1962 International Conference on High Energy Physics at CERN, (page 371).

Figure 1

The momentum and invariant mass of the constrained Λ^{o} and the measured e^{+} and e^{-} for a sample of events from reactions (a) and (b). Crosses have passed and dots have failed the selection criterion for good events. The inset is an enlargement of the shaded region.

Figure 2

The ratio of the number of events to the function C (x) plotted against x, the square of the invariant mass. The theoretical predictions for odd and even parity are shown, assuming $|f_1| \lesssim |f_2|$ and $f_2 (x) = f_2 (0)$. Spectra are normalized for the same number of events.

Figure 3

The energy ($T_e^{\pm}$ small) of the low-energy member of the electron pair is plotted against x, the square of the invariant mass. Contours of constant density are drawn for the two hypotheses.

Figure 4

The theoretical average invariant mass of Σ^{o} Dalitz pairs as a function of the ratio of factors f_1/f_2. The shaded area is the experimental value.

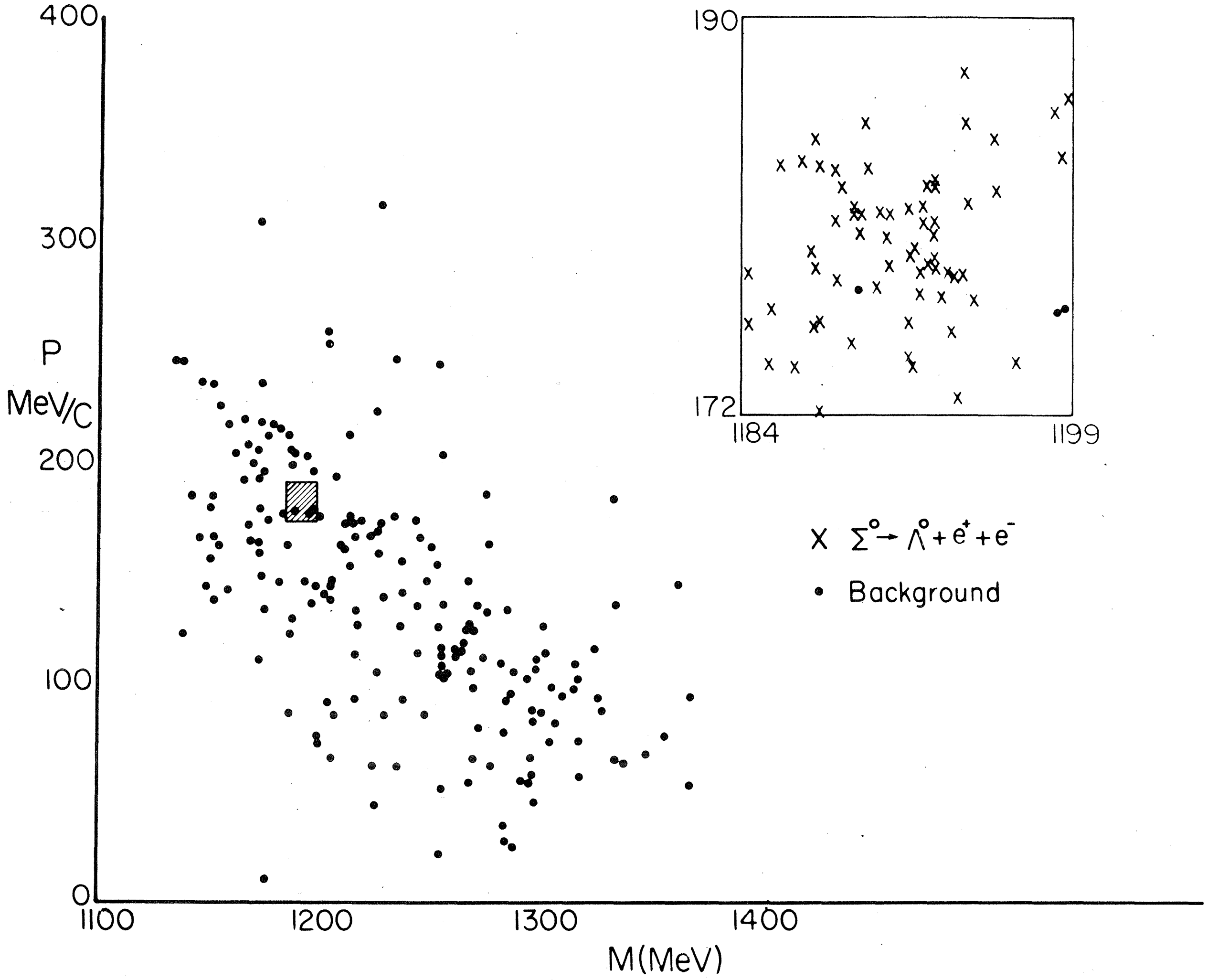
400
300
200
100
0
P
MeV/C
1100
1200
1300
1400
M(MeV)
190
172
1184
1199
X $\Sigma^0 \rightarrow \Lambda^0 + e^+ + e^-$
• Background

Fig. 1.

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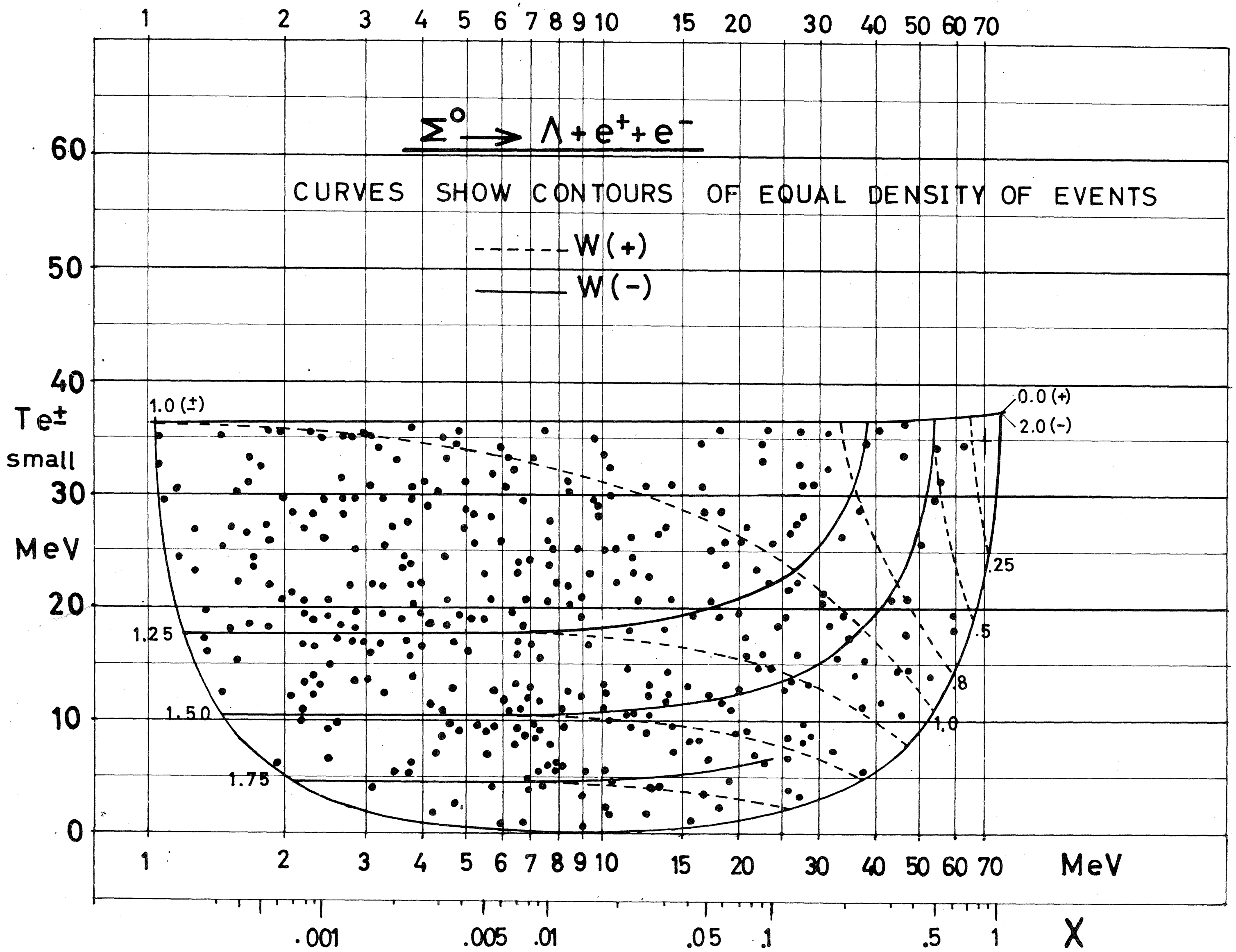
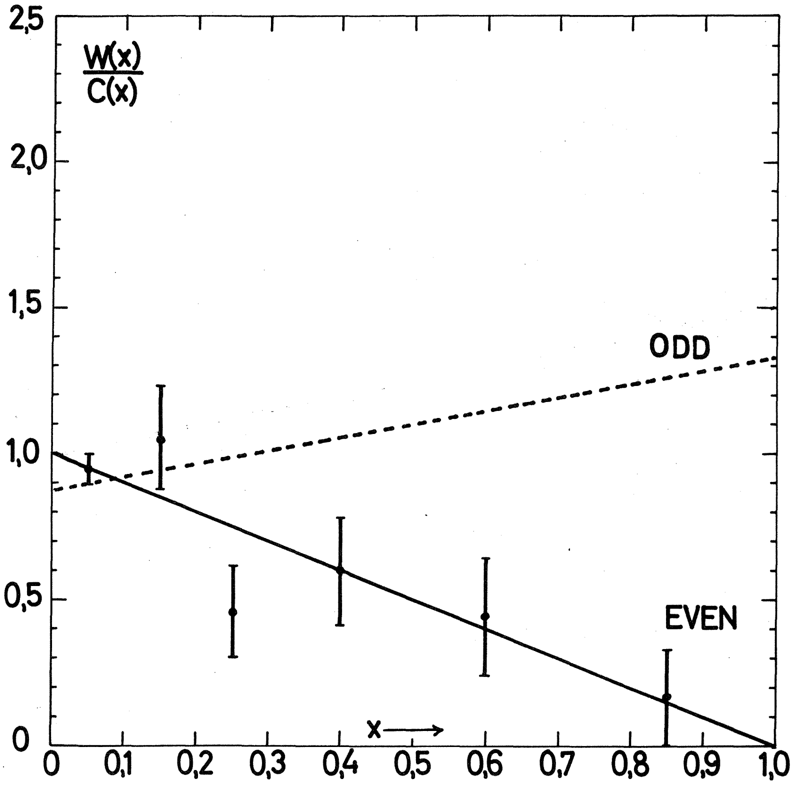
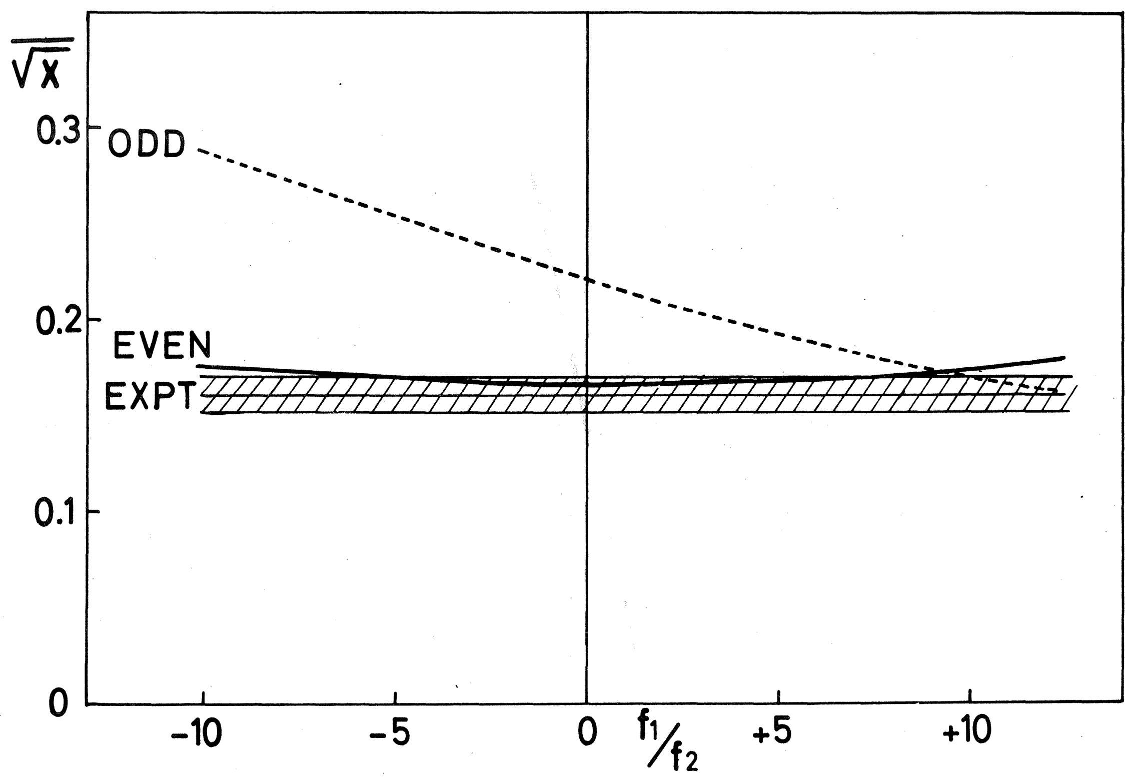


Fig. 3.



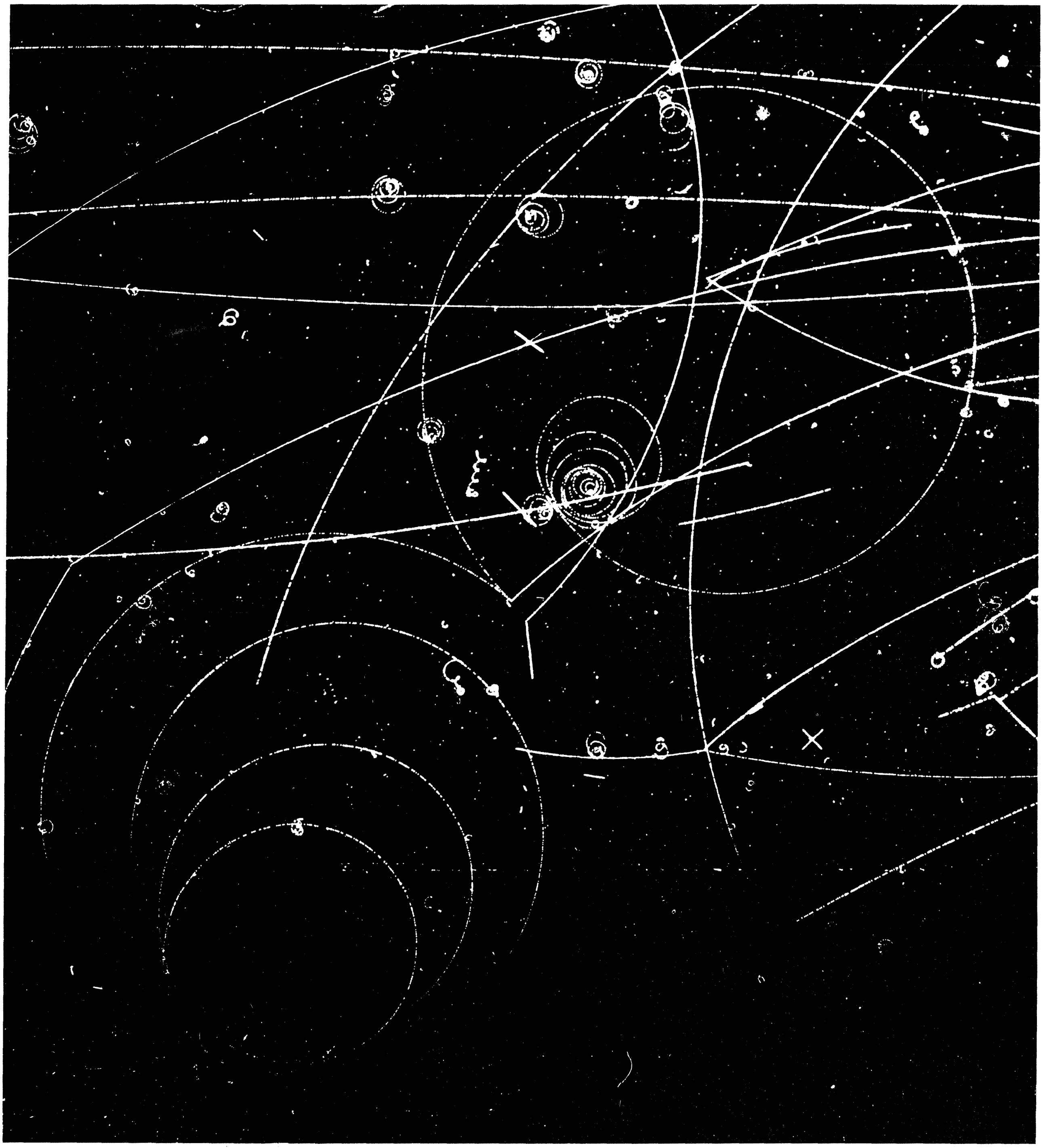
2,5
W(x)
C(x)
2,0
1,5
ODD
1,0
0,5
EVEN
0
x
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1,0

Fig. 2.



$\overline{\sqrt{X}}$
0.3
ODD
0.2
EVEN
EXPT
0.1
0
-10
-5
0
f_1/f_2
+5
+10

Fig. 4.



$$K^- p \rightarrow \Sigma^0 \pi^0$$
$$\Sigma^0 \rightarrow \Lambda^0 e^+ e^-$$
$$\Lambda^0 \rightarrow p \pi^-$$

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