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THRESHOLD MEASUREMENT OF THE REACTION $\bar{p}p \to \bar{\Lambda}\Lambda$ AT LEAR

The PS185 Collaboration:

P.D. Barnes[1], P. Birien[3], B.E. Bonner[6], W.H. Breunlich[8], G. Diebold[1], W. Dutty[3], R.A. Eisenstein[4], G. Ericsson[7], W. Eyrich[2], R. von Frankenberg[2], G. Franklin[1], J. Franz[3], N. Hamann[3], D. Hertzog[4], A. Hofmann[2], T. Johansson[7], K. Kilian[5], C. Maher[1], M. Meyerhofer[2], N. Nägele[8], W. Oelert[5], S. Ohlsson[7], P. Pawlek[8], B. Quinn[1], E. Rössle[3], H. Schledermann[3], H. Schmitt[3], G. Sehl[5], J. Seydoux[1], F. Stinzing[2] and J. Szymanski[1]

Presented by R. von Frankenberg

ABSTRACT

We report on new results of experiment PS185 at LEAR. In particular, the threshold measurement of the reaction $\bar{p}p \to \bar{\Lambda}\Lambda$ will be discussed. From the shapes of the excitation function and of the angular distributions, we conclude that there are p-wave contributions even at energies down to threshold.

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1) Carnegie-Mellon University, Pittsburgh, USA.
2) Universität Erlangen-Nürnberg, Erlangen, Fed. Rep. Germany.
3) Universität Freiburg, Freiburg, Fed. Rep. Germany.
4) University of Illinois, Urbana, USA.
5) Institut für Kernphysik der KFA Jülich, Jülich, Fed. Rep. Germany.
6) Rice University, Houston, USA.
7) University of Uppsala, Uppsala, Sweden.
8) Institut für Mittelenergiephysik der ÖAW, Vienna, Austria.

The study of the reaction $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ near threshold offers an opportunity to examine the dynamics of strangeness exchange. From both the energy dependence of the total cross-section and the shape of the differential one, as well as from the polarization, possible mechanisms for the production process can be extracted. Close to threshold only the first few partial waves contribute. The total cross-section appears as a function of the excess energy ϵ: $\sigma_{tot} \propto \epsilon^{\ell+1/2}$, where ℓ is the final-state orbital angular momentum. The partial-wave behaviour of the production process can also be seen in isotropic ($\ell = 0$) or non-isotropic ($\ell \geq 1$) shapes of the angular distributions. The Λ and $\bar{\Lambda}$ polarizations and their spin correlations can be directly related to the $\bar{s}s$ loop in the additive quark model [1]. In this model a hadronic reaction is assumed to be determined by the annihilation and creation of two 'active' quarks, while all other quarks behave as spectators. Since the Λ and s quark both have isospin zero, the u and d quarks must couple to spin $J = 0$. This implies that the spins of the Λ and $\bar{\Lambda}$ are identical to the spins of their s and $\bar{s}$ quarks, making the polarization measurement interesting. Interesting effects can be expected very close to threshold. Final-state interactions may cause a leakage of the $\bar{\Lambda}\Lambda$ strength into other channels, predominantly into annihilations [2].

To detect Λ's we restrict ourselves to the charged decay mode $\bar{p}p \rightarrow \bar{\Lambda}\Lambda \rightarrow \bar{p}\pi^+p\pi^-$. The $\bar{\Lambda}\Lambda$ production in the LEAR momentum range is confined to angles below 31°. Also the decay baryons are only permitted within a small forward cone around the hyperon direction. Therefore, the maximum angle of decay baryons in the laboratory frame varies between ~ 9° (at $\bar{\Lambda}\Lambda$ threshold) and ~ 42° ($\bar{\Lambda}\Lambda$ at 2.0 GeV/c). The detector consists of a trigger-active target (performing a neutral event trigger), a track-imaging part (multiwire proportional chamber and drift-chamber stacks), a scintillator trigger hodoscope, and a solenoid to determine the sign of the charge of the particles. The trigger hodoscope covers a solid angle of $\leq$ 45° for the decay baryons and reflects therefore a centre-of-mass acceptance of 100%. A more detailed description of the apparatus is given elsewhere [3]. The target is divided into five modules, each having a thickness of 2.5 mm. Four target cells are built of polyethylene CH_2 (high proton density). This structure allows fine momentum scans in 800 keV/c bins. In order to control the carbon background of the other modules, one cell consists of pure ^{12}C.

In 1985 measurements were performed in the threshold region of the reaction $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ at incident $\bar{p}$ momenta of 1449.1 MeV/c and 1440.7 MeV/c. A further point was measured at 1550.0 MeV/c giving a momentum $p_{\bar{p}}$ = 1546.2 MeV/c at the centre of the target. For this latter momentum, the event-reconstruction analysis results in 4063 $\bar{\Lambda}\Lambda$ events kinematically fitted with $\chi^2 \leq 5$ [4]. The total cross-section is determined to be (44.6 ± 1.5) μb. The differential cross-section and polarization are displayed in Fig. 1. The angular distribution shows a 'flat' region at backward angles and a strong forward rise. The ratio of $d\sigma/d\Omega$, where the distribution shows a rather flat structure, and of $d\sigma/d\Omega$ around $\Theta^*_{\bar{\Lambda}} = 0°$ gives a qualitative measure of the non-isotropic behaviour. This ratio will be denoted as ϑ. For the data at 1546.2 MeV/c, this ratio yields $\vartheta \approx 5.5$. The angular distribution of the polarization shows positive values in the range of the reduced four-momentum transfer $-t' = [0.0, 0.2]$ $(GeV/c)^2$ and negative values for $-t'$ above 0.2 $(GeV/c)^2$. In fact, a large negative polarization was found for $-t' \geq 0.25$ $(GeV/c)^2$ in previous $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ experiments [5] and in other reactions where an $\bar{s}s$ pair is created [6].

First results are also available for an incident $\bar{p}$ momentum of 1695 MeV/c. The maximum flux on target was 1.9×10^6 $\bar{p}$ /s. The threshold of the reaction $\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0$ + c.c. is at 1653 MeV/c. First evaluations show a sufficiently good separation of $\bar{\Lambda}\Sigma^0$ from $\bar{\Lambda}\Lambda$ events. A rough estimate of the cross-section ratio of these two reactions results in $\sigma(\bar{\Lambda}\Lambda)/\sigma(\bar{\Lambda}\Sigma^0) \approx 8$.

From the kinematical reconstruction of $\bar{\Lambda}\Lambda$ events it was proved that the momentum spread of the extracted beam is $\Delta p/p < 2 \times 10^{-4}$. Averaging over events from a single target cell, the momentum resolution yields $\Delta p_{\bar{p}} = 430$ keV/c and, averaged over all four CH_2 targets, $\Delta p_{\bar{p}} = 1.6$ MeV/c.

Table 1 shows the values obtained from a reconstruction fit for the extracted and event-producing beam momenta, the excess-energy range, the number of reconstructed events, and the resulting total cross-sections for the three threshold beam settings. The differential cross-section and polarization distributions are plotted in Fig. 2. The given errors are statistical, only. The differential cross-sections are the results of summing events in all target cells in the corresponding momentum setting. At threshold the statistical significance in angular distributions is too poor to obtain relevant results in single target cells. From the anisotropy of the differential cross-sections one can conclude that even in the range of $\leq$ 600 keV excess energy there are still $\ell > 0$ contributions [the qualitative 'anisotropy' ratio ϑ results in: ϑ (1435.9 MeV/c) $\approx$ 2, ϑ (1436.9 MeV/c) $\approx$ 2, and ϑ (1445.3 MeV/c) $\approx$ 3.5].

The given polarizations are averaged over $\bar{\Lambda}$ and Λ. In the energy region of [0.2, 1.0] MeV, the statistics are sufficiently high to see positive polarization. An indication of the previously stated 'zero-polarization' crossing can be seen at ϵ = 3.6 MeV. Up to $-t' < 0.15$ $(\mathrm{GeV/c})^2$ the polarization stays positive. This behaviour of the polarization seen before in high-energy data holds also for the regions very close to threshold and seems to be characteristic for this reaction.

Using the modular structure of the target, total cross-sections are obtained for 16 data points in the region of 0.5 MeV below and 4 MeV above reaction threshold. Figure 3 displays the excitation function. The errors are statistical, only. Systematic errors can be estimated by Monte Carlo studies to be less than 5%.

The shape of the total cross-section indicates a strong contribution of the p-wave in the production of $\bar{p}p \to \bar{\Lambda}\Lambda$ at and just above reaction threshold. The data point at 1434.35 MeV/c containing a non-zero cross-section of (0.071 $\pm$ 0.057) μb needs some comment. The beam momentum resolution is $\pm$430 keV/c. Thus the momentum range for this point is between 1433.9 MeV/c and 1434.8 MeV/c. Therefore it is possible, comparing the horizontal error bars of the upper two neighbouring data points, that the reaction threshold lies just within the valid momentum range around the upper value at 1434.9 MeV/c. This is consistent with the assumption that the events are produced at the front end of the target cell where there are small energy losses for the $\bar{p}$'s. The following lower data point at 1434.25 MeV/c shows a zero cross-section, which confirms the statements given above. From these assumptions one can determine the reaction threshold to be at $p_{\bar{p}}$ = (1434.75 $\pm$ 0.43) MeV/c. The corresponding value given by the Particle Data Group is (1434.88 $\pm$ 0.30) MeV/c [7]. This value can be used for a consistency check of the calculation of the Λ hyperon mass. We obtain m_Λ = (1115.54 $\pm$ 0.07) MeV in excellent agreement with the value given by the Particle Data Group: $\langle m_\Lambda \rangle$ = (1115.566 $\pm$ 0.056) MeV.

Figure 4 shows the present situation of the experimental data for the reactions $\bar{p}p \to \bar{\Lambda}\Lambda$, $\bar{p}p \to \bar{\Lambda}\Sigma^0$ + c.c., $\bar{p}p \to \bar{\Sigma}^+\Sigma^+$, and $\bar{p}p \to \bar{\Sigma}^-\Sigma^-$. For the last reaction, no data are available yet below 2.6 GeV/c. In view of possible cusp effects, it will be of great interest to measure $\bar{\Lambda}\Lambda$ across the thresholds of the $\bar{\Sigma}\Sigma$ channels at 1853 MeV/c ($\bar{\Sigma}^+\Sigma^+$), 1871 MeV/c ($\bar{\Sigma}^0\Sigma^0$), and 1898 MeV/c ($\bar{\Sigma}^-\Sigma^-$). Also the direct measurements of the reactions $\bar{p}p \to \bar{\Sigma}^+\Sigma^+$, and $\bar{p}p \to \bar{\Sigma}^-\Sigma^-$ are particularly interesting. A comparison with the $\bar{\Lambda}\Lambda$ results might allow to extract the behaviour of $\bar{s}$ and s quarks in different hadronic surroundings. Furthermore, in the case of $\bar{\Sigma}^-\Sigma^-$, we could see in a clean way a two-boson exchange reaction.

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Table 1

Beam momentum settings and total cross-sections

Extracted $p_{\bar{p}}$ (MeV/c)	Effective $p_{\bar{p}}$ (MeV/c)	Excess energy range (MeV)	Number of events	Total cross-section (μb)
1440.7 ± 0.4	1435.9 ± 1.6[a)]	≤ 0.60	214	0.84 ± 0.20
1440.7 ± 0.4	1436.9 ± 1.6	0.24–1.08	374	1.44 ± 0.32
1449.1 ± 0.4	1445.3 ± 1.6	3.20–4.04	848	4.86 ± 0.42
1550.0 ± 0.4	1546.2 ± 1.6	38.8–39.6	4063	44.6 ± 1.5

a) Obtained by using a degrader.

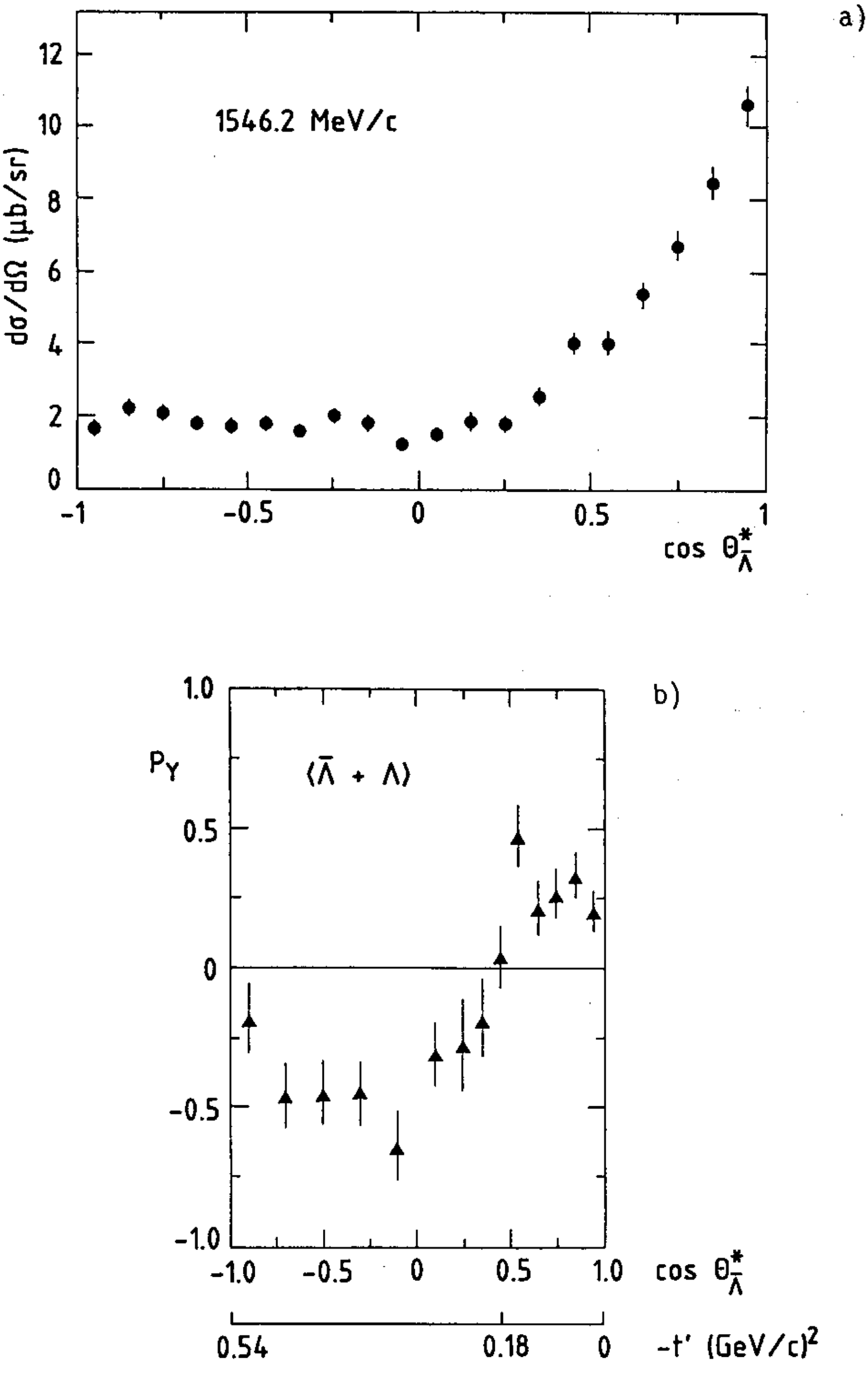

Fig. 1 a) Differential cross-section at 1546.2 MeV/c; b) Differential polarization at 1546.2 MeV/c.

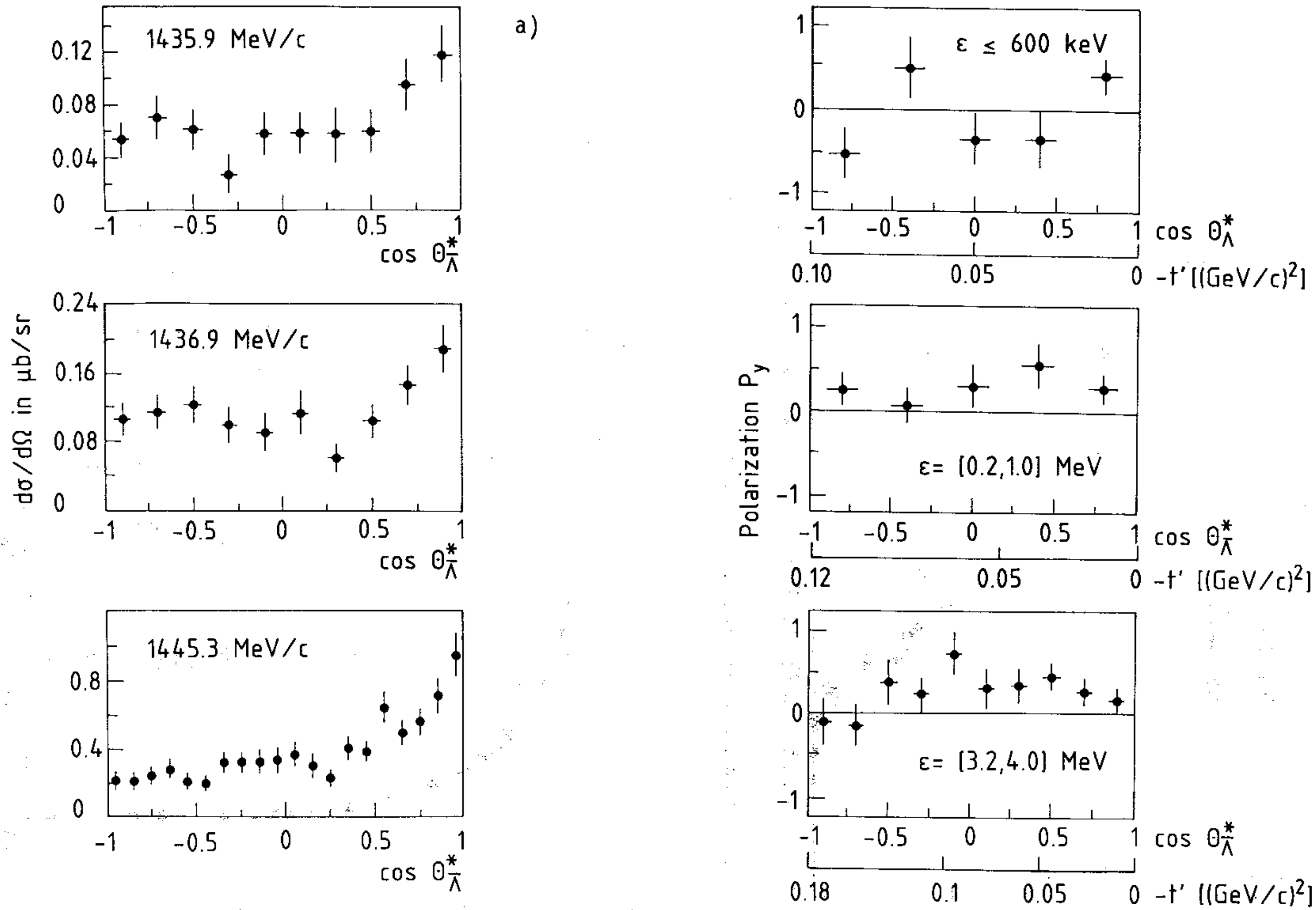

Fig. 2 a) Differential cross-sections at 1435.9 MeV/c, 1436.9 MeV/c, and 1445.3 MeV/c;
b) Differential polarizations at 1435.6 MeV/c, 1436.9 MeV/c, and 1445.3 MeV/c.

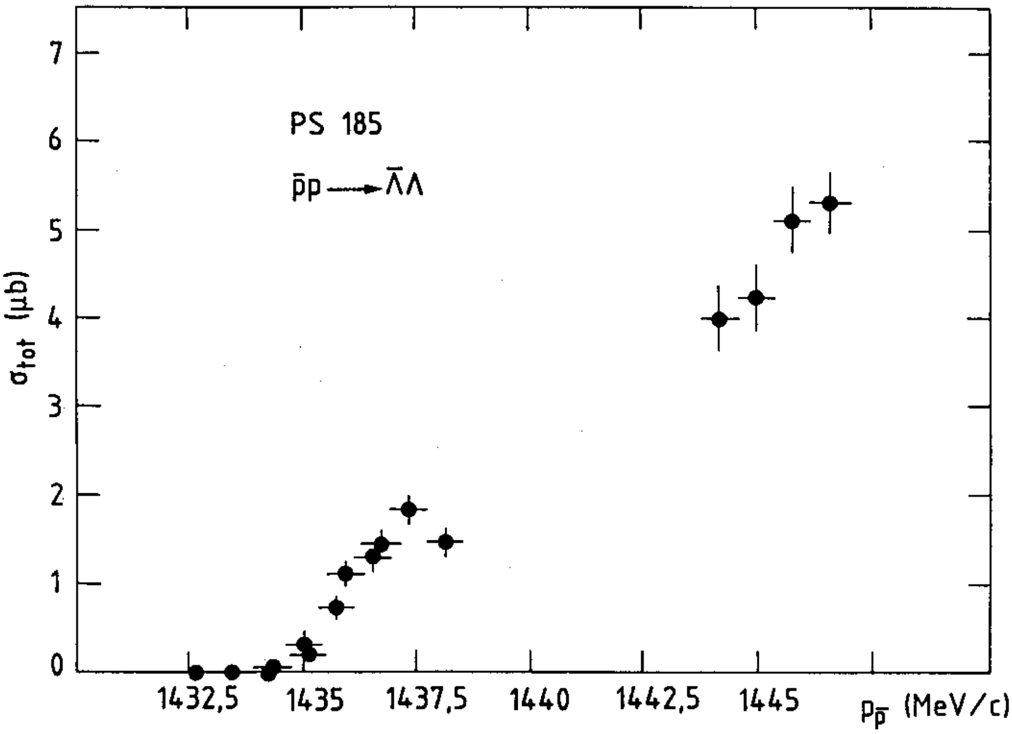

Fig. 3 Total cross-sections of the reaction $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ in the threshold region.

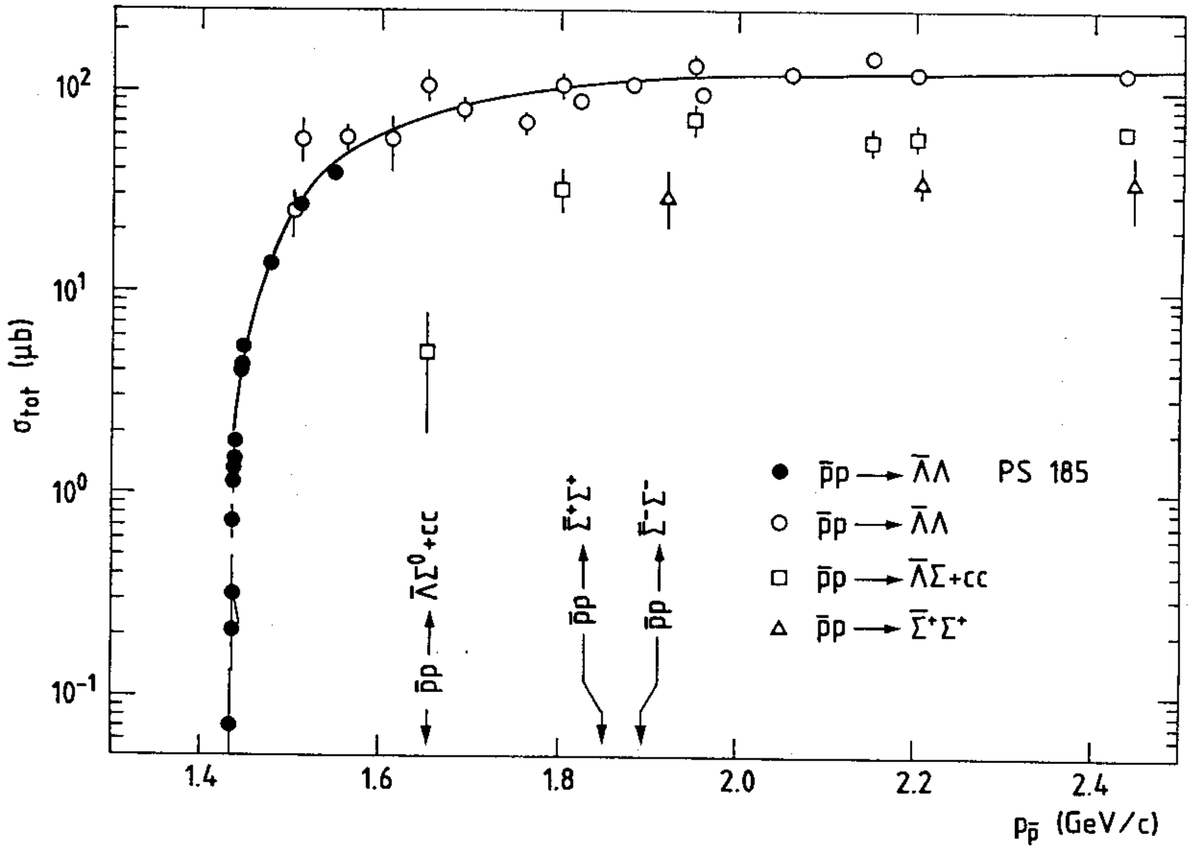

Fig. 4 Present situation of existing hyperon data [8].