of $\Lambda$s or neutral $\Sigma$s together with additional neutrals. These events have been used in mass and lifetime determinations, but no further analysis has been made.

Fig. 3 shows the missing mass distribution for the single $\Lambda^0$ or $\bar{\Lambda}^0$ events. The separation of $\Sigma^0\bar{\Sigma}^0$, $\Sigma^0\bar{\Lambda}$ and $\Lambda\bar{\Sigma}^0$ events cannot be done uniquely, but the separation can be done on a statistical basis.

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# A STUDY OF HYPERON-ANTIHYPERON PRODUCTION BY 3, 3.6 AND 4 GeV/c ANTIPROTONS IN HYDROGEN


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*(presented by L. Montanet)*


## I. INTRODUCTION

We present here some results concerning the production of hyperon-antihyperon pairs in the interactions of antiprotons with protons.

The 81 cm Saclay hydrogen bubble chamber was exposed to a separated beam of antiprotons from the CERN proton synchrotron. The beam was taken at 12° from an internal target: the momentum bite was 0.5%.

Approximately 120,000 photographs have been obtained at each of three momenta (3, 3.6 and 4.0 GeV/c): the average number of antiprotons per photograph was 8 to 10, and it has been estimated that the contamination of the beam by $\pi$ and $\mu$ mesons is about 15% at 3 GeV/c and 20% at 3.6, this background being composed of $\pi$ and $\mu$ mesons in the proportions of about 1:6.

From these photographs we have selected for study interactions from which both a hyperon and an antihyperon are observed to decay in the chamber.

Samples of events of different types do not come from equal numbers of photographs. The reasons for this are concerned with the distribution of the film to the various laboratories, and cannot introduce any bias into the results. In particular no work has yet been done on the 4 GeV/c film. The work described here is referred to the number of antiprotons shown in Table I.

TABLE I

| Type of the reaction | 3 GeV/c | 3.6 GeV/c |
|---|---|---|
| 2 prongs with $2V^{\pm}$ | 560.000 | 279.000 |
| 0 prong with $2V^{0}$ | 282.300 | — |
| 2 prongs with $1V^{\pm}$ and $1V^{0}$ | 282.300 | 160.000 |
| $\Xi\,\bar{\Xi}$ | 564.000 | — |

Events can be classed into those in which the pair of hyperons are the only particles emerging from the interaction and those in which there is an additional $\pi$ meson. At the energies used in this work more than one $\pi$ is rarely emitted. The work is therefore confined to two and three body final states.

## II. NEUTRAL HYPERON PAIRS

Among the 2 body states neutral hyperons may be produced in the following reactions:

$$\bar{p}+p\rightarrow \Lambda+\bar{\Lambda} \quad (1a)$$

$$\rightarrow\Sigma^{0}+\bar{\Lambda} \quad (1b)$$

$$\rightarrow\bar{\Sigma}^{0}+\Lambda \quad (1c)$$

$$\rightarrow\Sigma^{0}+\bar{\Sigma}^{0} \quad (1d)$$

In each of these cases the event observed in the bubble chamber is zero-prong vertex accompanied by a pair of neutral $V$ particles.

Selection of events of this type gives a clear separation of events of types 1a, b and c; type 1d however is difficult to distinguish from the process $p+\bar{p}\rightarrow\Lambda^{0}+\bar{\Lambda}^{0}+\pi$. Results for 1$d$ are therefore little more than a guess.

The events have been processed by a computer programme which performs a multivertex least squares fit for each of a series of hypotheses; in the first stage the programme examines the $V^{0}$'s to establish their nature, and then makes a general fit, using all the information given by the measurements, and trying the hypotheses $\Lambda\bar{\Lambda}$, $\Lambda\bar{\Lambda}\gamma$, $\Lambda\bar{\Lambda}\pi^{0}$, $\Lambda K\bar{n}$ and $\bar{\Lambda}Kn$, and then checks that either the $(\Lambda\gamma)$ or $(\bar{\Lambda}\gamma)$ agrees with the decay products of a $\Sigma^{0}$ or $\bar{\Sigma}^{0}$.

The distribution of events is shown in Table II.

The mass of the antiparticles $\bar{\Lambda}$ have been determined: $m_{\bar{\Lambda}} = 1.11552\pm0.00055$ (for comparison, from a similar sample: $m_{\Lambda} = 1.11504\pm0.00041$).

Fig. 1 gives the angular distribution of the hyperons in the centre-of-mass system. The antihyperons are emitted forwards. The histogram shows our uncorrected observations: corrections for the probability that a fast antihyperon may leave the chamber unobserved may modify the form of the distribution, but not substantially.

TABLE II

| | $\Lambda\bar{\Lambda}$ | $\Lambda\bar{\Sigma}$ | $\Sigma\bar{\Lambda}$ | $\bar{\Lambda}Kn$ | $\Lambda Kn$ | $\Lambda\bar{\Lambda}\pi^{0}$ | $\Sigma\bar{\Sigma}$ | $Y\bar{Y}(\pi^{0})$ |
|---|---|---|---|---|---|---|---|---|
| Number: | 12 | 6 | 7 | 3 | 1 | 6 | $\approx 3$ | $\approx 4$ |
| Cross-section ($\mu$b): | 78.5±23 | 91±25 | | 26±13 | | | | |

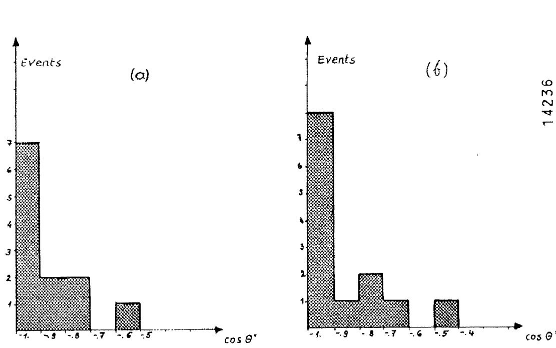


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**Fig. 1** (a) $\cos\theta^{*}_{(\Lambda,\bar{p})}$ for $\bar{p}+p\rightarrow\Lambda+\bar{\Lambda}$ (3.0 GeV/c) $\overline{\cos\theta^{*}} = 0.887\pm0.003$;

(b) $\cos\theta^{*}_{(\text{baryon},\bar{p})}$ for $\bar{p}+p\rightarrow\Lambda+\bar{\Sigma}^{0}$ and $\rightarrow\Sigma^{0}+\bar{\Lambda}$ (3 GeV/c) $\overline{\cos\theta^{*}} = 0.783\pm0.010$.

## III. EVENTS OF THE TYPE $Y^{\pm}\overline{Y^{\pm}}$

a) There are three types of 2-body reaction with charged hyperons. These are

$$p+\bar{p}\rightarrow\Sigma^{+}+\overline{\Sigma^{+}} \tag{2}$$

$$\rightarrow\Sigma^{-}+\overline{\Sigma^{-}} \tag{3}$$

$$\rightarrow\Xi^{-}+\overline{\Xi^{-}} \tag{4}$$

Reaction 4) is easily distinguished from 2) and 3) by the kinematics. Types 2) and 3) cannot be separated by the kinematics of the production vertex.

In Table III we list the decay possibilities for $\Sigma$ and $\bar{\Sigma}$ for events of type 2) and 3). The third column gives a classification of these decay types.

TABLE III

| | Nature of the positive decay product | Nature of negative decay product | Class of decay | Number observed 3 and 3.6 GeV/c |
|---|---|---|---|---|
| $\Sigma^{+}+\overline{\Sigma^{+}}$ | $p$ | $\bar{p}$ | $A$ | 12 |
| | $p$ | $\pi^{-}$ | | 17 |
| | $\pi^{+}$ | $\bar{p}$ | | 14 |
| $\overline{\Sigma^{-}}+\Sigma^{-}$ | $\pi^{+}$ | $\pi^{-}$ | $B$ | 28 |
| | $\pi^{+}$ | $\pi^{-}$ | | |

Events of type A have at least one nucleon decay product. Since a proton can be uniquely distinguished from a pion by the kinematics, or sometimes from the ionization density, events of type A and B are immediately separable. In addition, from the sign of the nucleon, the antiparticle is identified in events of type A. In class B events no such separation is possible.

If we assume that $\Sigma^{+}$ decays in the mode $p+\pi^{0}$ in 50% of the cases, and that the $\overline{\Sigma^{+}}$ decays in the same proportion to $\bar{p}+\pi^{0}$, which assumptions agree with our observations, then we should expect class A to represent 3/4 of all the $\Sigma+\Sigma^{+}$. With these assumptions we find for the cross-sections at 3 GeV/c and at 3.6 GeV/c.

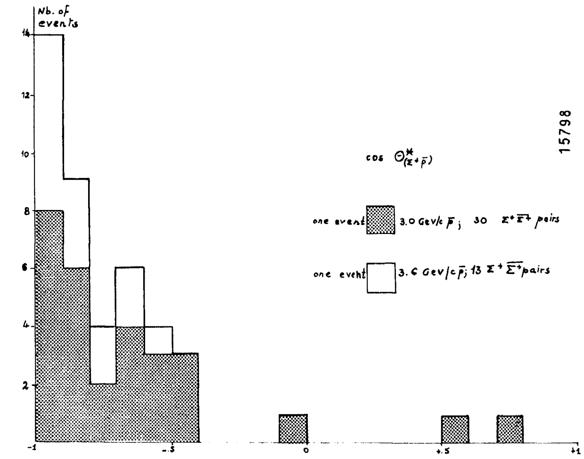


**Fig. 2** Angular distribution of the class " A " events.

$$\sigma(\Sigma^{+}+\overline{\Sigma^{+}}) = 38\pm7\mu\text{b at 3 GeV/c}$$
$$= 45\pm12\mu\text{b at 3.6 GeV/c}$$

Fig. 2 gives the differential cross-section of the events of class A. Since the decay mode should not be influenced by the production angle, this distribution should be representative of the whole sample. Again we observe that the majorities of the antihyperons are emitted forwards.

b) The study of $\Sigma^{-}\overline{\Sigma^{-}}$.

In class B there is a mixture of $\Sigma^{+}\overline{\Sigma^{+}}$ and $\Sigma^{-}\overline{\Sigma^{-}}$. With the same assumptions as before we expect the angular distribution of the events of the first group to reproduce that of the events of type A, with 1/3 the magnitude. We can therefore obtain, by subtraction, the distribution for the remainder. Fig. 3 gives the distribution for all events of class B, while Fig. 4

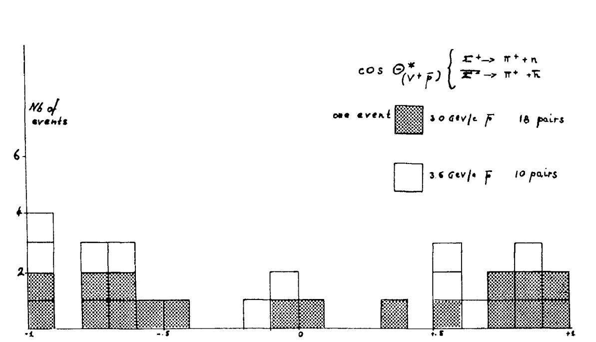


**Fig. 3** Angular distribution of the class " B " events.

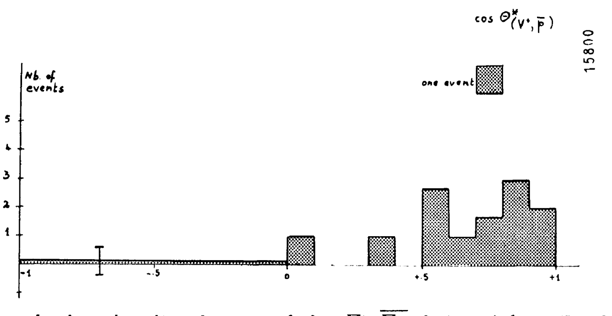


**Fig. 4** Angular distribution of the $\Sigma^-\overline{\Sigma^-}$ deduced from Fig. 2 and 3.

gives the result of the subtraction. We again observe a tendency for the $\overline{\Sigma^-}$ to be emitted forwards in the *C*-system.

The cross-sections for this process are

$$\sigma(\Sigma^-\overline{\Sigma^-}) = 8 \pm 3 \mu\text{b at 3 GeV/c}$$
$$= 7 \pm 3.5 \mu\text{b at 3.6 GeV/c}$$

c) $\Xi\overline{\Xi}$ production.

We have observed 3 cases of the production of cascade particles. This corresponds to a cross-section

$$\sigma(\Xi^-\overline{\Xi^-}) = 4 \pm 2.5 \mu\text{b at 3 GeV/c}$$

The angles of emission of the anti $\Xi$ in the *C*-system are 18°, 90°, and 135° so no conclusion can be drawn about the angular distribution.

## IV. 3-BODY REACTIONS

The cross-sections observed in these cases are

$$\sigma(\Lambda\bar{\Lambda}\pi^0) = 41 \pm 17 \mu\text{b (3 GeV/c)}$$
$$\sigma(\overline{\Sigma^\pm}\Sigma^\pm\pi^0) = 3.5 \pm 2 \mu\text{b (3 GeV/c)}$$
$$= 9.8 \pm 5 \mu\text{b(3.6 GeV/c)}$$

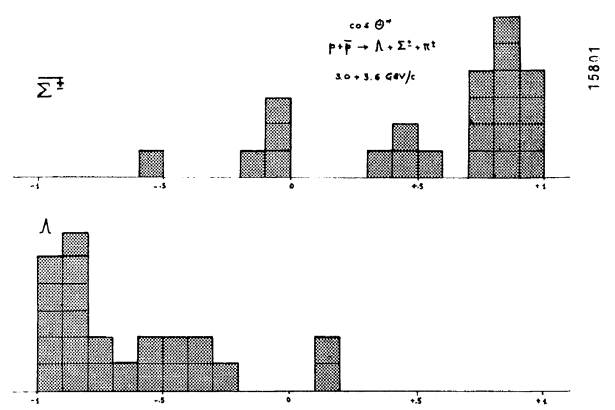


**Fig. 5** Angular distribution of the hyperons ($\Lambda^0$) and the anti-hyperons ($\overline{\Sigma^\pm}$).

It is worth noting that of the eight events observed in the class ($\Sigma^\pm\overline{\Sigma^\pm}\pi^0$) 6 belong to class B.

$$\sigma(\Lambda\overline{\Sigma^-}\pi^- + \bar{\Lambda}\Sigma^-\pi^+) = 24.3 \pm 6 \mu\text{b}$$
$$\sigma(\Lambda\overline{\Sigma^+}\pi^+ + \bar{\Lambda}\Sigma^+\pi^-) = 43 \pm 10 \mu\text{b}$$

We note that the second of these is approximately twice the first. The angular distribution given in Fig. 5 is again asymmetric, though this effect is less pronounced than in the 2-body cases.

## V. CONCLUSIONS

a) The fact that the angular distribution $p + \bar{p} \to Y + \bar{Y}$ are strongly asymmetric suggests that the main channel for this type of event may be peripheral.

It should be noted that the final states $\Sigma^-\overline{\Sigma^-}$ and $\Xi^-\overline{\Xi^-}$ have much smaller cross-sections than the processes $\Sigma^+\overline{\Sigma^+}$ and $Y^0\,\overline{Y^0}$. This is a qualitative feature to be expected in a peripheral collision, since in the first cases two units of charge must be exchanged; and in the case of the $\Xi$ particles 2 units of hypercharge also.

b) If, however, one tries to make a quantitative estimate of a *K*-meson exchange, and one assumes that the *KY* parity is odd, one finds the well-known difficulty: the cross-section should rise with increasing momentum transfer, which is not the case in our experiments (see Fig. 6). It seems rather that the cross-section is independent of the momentum transfer below 800 MeV/c and decreases rapidly above 1 GeV/c, which corresponds to a range of interaction roughly equal to the Compton wavelength of the nucleon.

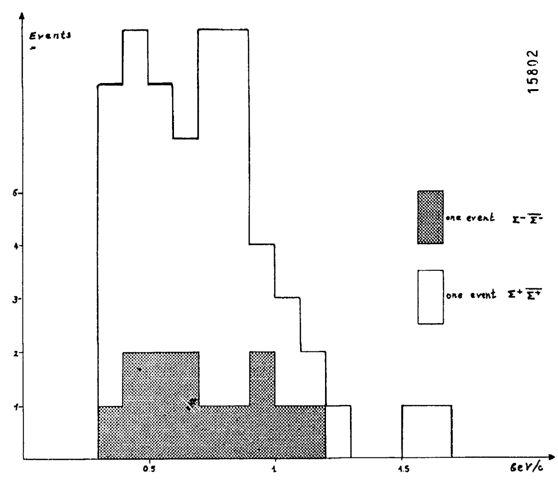


**Fig. 6** Momentum transfer distribution for $\Sigma^\pm$, $\overline{\Sigma^\pm}$.

## DISCUSSION

SANDWEISS: The comment is that in the events $\Sigma^+\overline{\Sigma}^+$ that we observed there were 12 identified, and in 11 of those the antiparticle went forward and the particle went backward in agreement with these results.

COOL: May I ask if there is an appreciable amount of production of $\overline{\Xi}^-$ with additional mesons?

MONTANET: At 3 GeV/c we cannot produce a $\pi$ in addition to the $\Xi\overline{\Xi}$ pair. At 3.6 and 4 GeV/c, the results are far from complete, but the preliminary results tell us that there is certainly not an appreciable amount of such $\pi$ production.

SANDWEISS: In answer to Dr. Cool's question: In the charged $\Sigma$ events we seem to find about 15% charged $\Sigma$ pairs with an extra $\pi^0$, but again, in agreement with the others no cascades with extra $\pi$'s at 3.3 GeV.

GREGORY: As Montanet mentioned all the data are not analysed but we have started the scanning on the 4 GeV and there is one $\overline{\Xi}^-\pi^-\Xi^0$ event.

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# STRANGE PARTICLE CORRELATIONS IN HIGH ENERGY PION-NUCLEON COLLISIONS

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*(presented by A. Lagarrigue)*

## I. INTRODUCTION

We report here results based on 127 selected $V^0$ pairs produced by $\pi^-$ of 6, 11 and 18 GeV/c in hydrogen-like (or free neutron-like) collisions in the Ecole Polytechnique 1 m heavy liquid bubble chamber [1] filled with a mixture 86% propane—14% Fréon $CF_3Br$ (by volume). Due to the large size (300 litres) of our BC our efficiency to detect both $V^0$'s of a pair is greater than that obtained in previous [2] studies made using the CERN 32 cm HBC and the Dubna 24 litre propane BC. Choosing events in which both neutral strange particles are visible enables us to study the correlations of the two strange particles produced in a given interaction and to study separately the behaviour of the $K_1^0$'s from the reactions:

$$\pi^- + \text{nucleon} \to K^0 + \overline{K^0} + n\pi + \text{nucleon} \quad (\text{hereafter "} K\overline{K} \text{"})$$

and $\pi^- + \text{nucleon} \to K^0 + Y^0 + n\pi$ (hereafter "$YK$")

## II. BUBBLE CHAMBER AND BEAM

Characteristics of the bubble chamber and the $\pi$-beams are summarized in Table I. The BC was about 100 m from the fast flip aluminium target in the CERN PS. The beam momentum was defined by the PS field, two bending magnets, and associated collimators.

TABLE I

| E.P.B.C. | $\pi^-$BEAM | | | |
|---|---|---|---|---|
| Useful volume: $100 \times 52 \times 48$ cm³. | Momenta GeV/c | $\Delta p/P$ | Contamination $\mu + e$ | Number of useful pictures |
| Magnetic field: 17,5 $k$ gauss. (uniform to 10%) Stereoscopic angle: 27° | 6.1 | ±4% | ~5% | 28,000 |
| Liquid composition: $C_3H_8$ 86%, $CF_3Br$ 14% by volume. | 11.6 | ±2% | ~4% | 7,000 |
| Density: 0.55. Radiation length: 52 cm. | 18.1 | ±2% | ~4% | 20,000 |