Observation of the Reaction $\bar{p}+d \rightarrow \Lambda+\Sigma^-+\bar{\Xi}^+$ *

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A $\bar{p}d$ interaction involving all three nucleons in the production of the hyperons $\Lambda+\Sigma^-+\bar{\Xi}^+$ has been observed in a deuterium-filled bubble chamber. All the subsequent strangeness-changing decays, and the final $\bar{p}n$ annihilation, appeared in the chamber.

In the study of the interactions of a separated beam of 2.8-BeV/c antiprotons with deuterium contained in the BNL 20-in. bubble chamber, an event of the type

$$\bar{p}+d \rightarrow \Sigma^-+\bar{\Xi}^+ +\Lambda \qquad (1)$$

has been observed. Previous observations of the rarely seen antiparticle of Ξ^-, $\bar{\Xi}^+$, have been reported in the literature[1,2]; in the present example production took place on the deuteron and all the subsequent strangeness-changing decays appeared in the chamber. In addition, the $\bar{p}$ from the decay chain of the $\bar{\Xi}^+$ annihilated with a neutron to produce a star of five identified pions.

A photograph and a sketch of the event are shown in Fig. 1, together with the proposed assignments of the particles. Measurement was carried out with a digitized projection machine, and the event was analyzed on the BNL IBM-7094 computer with programs TRED and KICK. Four views of the event were available and it was measured twice on different view pairs; the two results are in excellent agreement. The measured and fitted quantities are given in Table I. Where sufficient length of track was available, gap-length distributions were measured to confirm particle identification. The bubble densities derived from these distributions, and the bubble densities expected from the $1/\beta^2$ predictions for the assigned masses, are listed in Table I.

Table II lists the goodness of fit to the assigned hypotheses; the $\bar{\Xi}^+$ mass was taken to be 1321.0 MeV from the work of Bertanza *et al.*[3] on the mass of the Ξ^-. Using the fitted momentum of the $\bar{\Lambda}$ and assuming the other decay product of particle 3 to be a π^+, we obtained a mass of 1325±2 MeV for the particle which produced track 3. The total energy available in the center of mass of the $\bar{p}$–d system was 3.92 BeV; the threshold for reaction (1) is 3.63 BeV. Other possible reactions with the same topology and with thresholds

TABLE I. Momenta and bubble densities.

Track	Assignment	Measured momentum (MeV/c)	Fitted momentum (MeV/c)	Expected bubble density	Observed bubble density
1	$\bar{p}$	2799±36[a]	2775±10	1.12	···
2	Σ^-	···	618±11	4.80	···
3	$\bar{\Xi}^+$	···	1810±12	1.55	···
4	π^-	262± 10	273± 2	1.26	0.93±0.12
5	π^+	251± 6	241± 1	1.31	1.23±0.12
6	π^-	63± 7	65± 1	2.20	2.70±0.28
7	p	488± 15	500±10	4.55	4.85±0.40
8	$\bar{p}$	1449±180	1438±15	1.42	1.57±0.15
9	π^+	201± 4	203± 3	1.47	1.32±0.11
10	Λ	···	485± 8	···	···
11	$\bar{\Lambda}$	···	1612±14	···	···

[a] In fitting the event, the momentum assigned to the $\bar{p}$ was obtained by the measurement of 91 beam tracks in the chamber, obtained from the same roll of film.

TABLE II. Kinematic fits.

Reaction	Number of constraints	χ^2	Probability
$\Lambda \rightarrow p+\pi^-$	3	2.7	0.44
$\bar{\Lambda} \rightarrow \bar{p}+\pi^+$	3	0.7	0.88
$\bar{\Xi}^+ \rightarrow \pi^+ +\bar{\Lambda}$	3	4.2	0.24
$\bar{p}+d \rightarrow \bar{\Xi}^+ +\Sigma^- +\Lambda$	4	1.7	0.79
$\Sigma^- \rightarrow \pi^- +n$	1	1.1[a]	0.29

[a] The 4C fit to the interaction $\bar{p}+d \rightarrow \bar{\Xi}^+ +\Sigma^- +\Lambda$ was carried out using values for the Σ^- from a 0C fit to that decay; the Σ^- was subsequently refitted with 1C using the Σ^- momentum calculated for the production vertex, in the standard BNL KICK fashion.

TABLE III. Configuration of the event.

	Lab angle degrees	c.m. angle degrees	c.m. Momentum (MeV/c)	Flight time in rest system of decaying particle (10^{-10} sec)
$\bar{p}$	0.0	0.0	1327	···
$\bar{\Xi}^+$	7.7	21.7	659	0.8
Σ^-	29.8	134.0	428	1.9
Λ	23.2	148.7	368	2.2
$\bar{\Lambda}$	···	···	···	2.3

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[1] H. N. Brown, B. B. Culwick, W. B. Fowler, M. Gailloud, T. E. Kalogeropoulos *et al.*, Phys. Rev. Letters 8, 255 (1962).

[2] CERN, Ecole Polytechnique, and Centre d'Etudes Nucléaires, Phys. Rev. Letters 8, 257 (1962).

[3] L. Bertanza, V. Brisson, P. L. Connolly, E. L. Hart, I. S. Mittra *et al.*, Phys. Rev. Letters 9, 229 (1962).

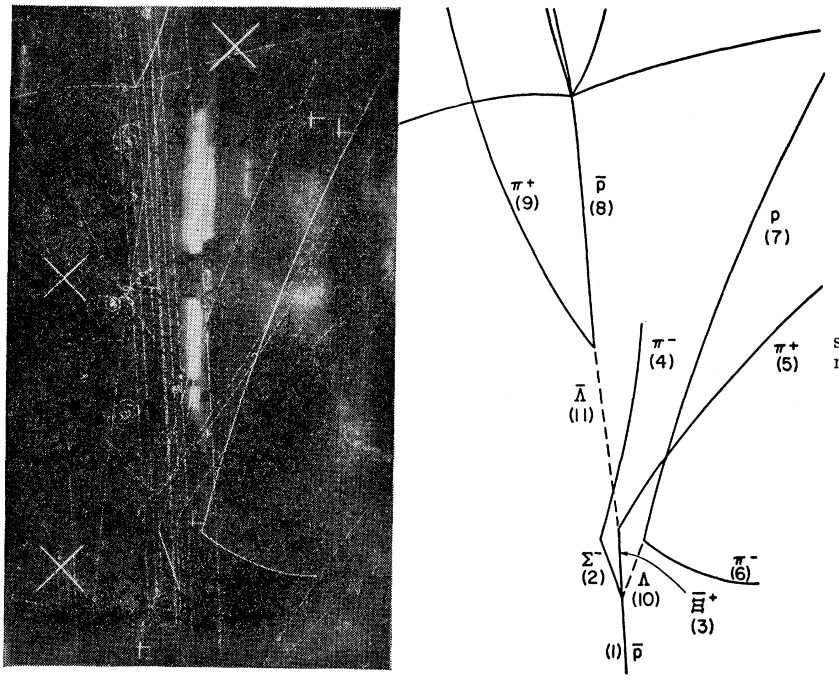


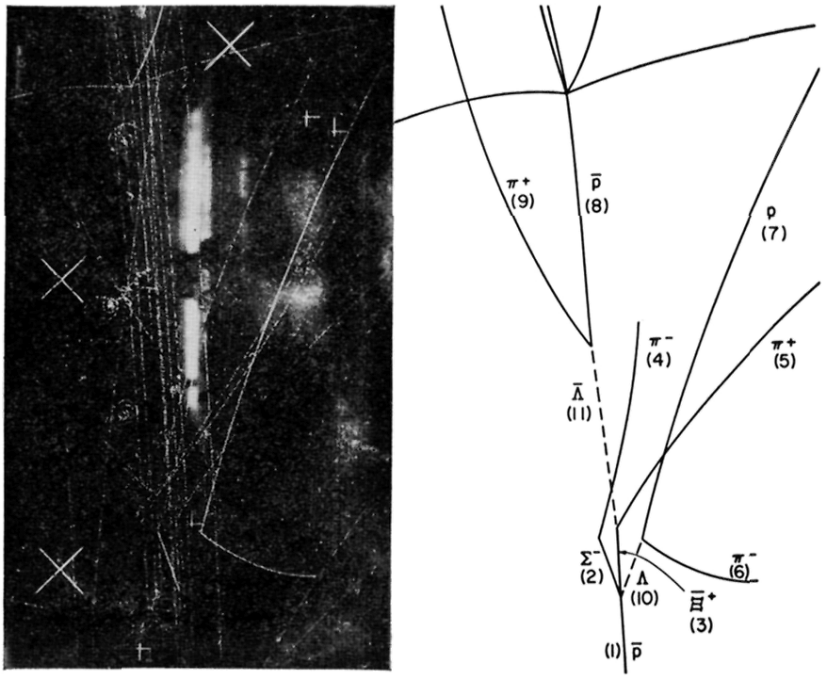
FIG. 1. Bubble chamber photograph and sketch of the event. The proposed assignments of the tracks are indicated.

below the available c.m. energy ($\Xi^-K^+K^0$, $\Sigma^+K^-K^0K^0$, $\Sigma^-K^+K^0\bar{K}^0$, $K^+K^-\Lambda K^0$, $\Xi^-\bar{\Xi}^+n$, $K^-K^+K^0\bar{K}^0n$) were completely rejected in the kinematic analysis. The hypothesis that either of the observed neutral V's came from any other star in the picture is ruled out on kinematic grounds.

The cross section for production of a $\bar{\Xi}^+$ in an event of this topology, based on one event seen in 70 000 scanned photographs, is about one microbarn.

Formation of $\bar{\Xi}^+$ from $\bar{p}$ requires a change of $+2$ units in both strangeness and charge. This requirement is satisfied for the observed event by a simple two-step process in which a hyperon-antihyperon pair is produced by K (or by K^*) exchange in a $\bar{p}$-nucleon interaction, and the third hyperon is produced by K (or K^*) exchange in the interaction of the antihyperon with the remaining nucleon of the deuteron. It is also satisfied by mechanisms involving virtual $\bar{p}$-nucleon annihilation instead of meson exchange.

We wish to thank the BNL bubble chamber crew, the members of the AGS staff, and our scanning team for their invaluable services.



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