the Fermi motions of the nucleons in the copper target, the limit on the quark mass can be appreciably increased, appropriately increasing, of course, the cross-section limit. Calculations by Gottfried,[3] assuming a Gaussian momentum distribution in the nucleus, indicate that there is an 18% probability for a nucleon in the nucleus to have a momentum greater than 1.5 times the Fermi momentum of 250 MeV/c and a 0.5% probability for 2.5 times. Assuming instead a hard-sphere gas, the probabilities are 15% and 4% for 375 and 625 MeV/c, respectively. From a study of inelastic electron-nucleus reactions, Ericson[4] has estimated that there is a probability of about 0.5% for a nucleon to have a momentum of greater than 600 MeV/c.

The head-on collision of the incoming proton with nucleons of 375 and 625 MeV/c may lead to the production of quarks with mass up to 3.4 GeV and 4.0 GeV, respectively. Therefore, using the above probabilities and considering our acceptance angle, our experiments would set an upper limit of $\approx 10^{-33}$ cm^2 and of $\approx 10^{-32}$ cm^2 for these two masses.

Previous searches for fractionally charged particles, all unsuccessful, have been reported by Morrison,[5] Bingham et al.,[6] and Leipuner et al.[7] The first two experiments involved the scanning of existing bubble chamber film, for which there was no record of the time of arrival of the particles. The third work was a counter experiment which gave a total cross-section limit of 10^{-34} cm^2 for quarks with mass up to 2 GeV.

We wish to thank Professor G. Cocconi, Professor B. Gregory, Professor P. Kabir, and Professor Ch. Peyrou for many helpful discussions. We are deeply indebted to the operating crews of the CERN proton synchrotron and of the Saclay 81-cm hydrogen bubble chamber.

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NEUTRAL STRANGE-PARTICLE PRODUCTION AND Y_1*(1385) FORMATION IN p-p COLLISION AT 5.5 GeV/c†

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This note presents results on the production of neutral strange particles, and the formation of the Y_1*(1385) resonance in p-p collisions at 5.52 GeV/c.[1] The study is based on 30 000 pictures taken with the Saclay 81-cm hydrogen bubble chamber exposed to a secondary 5.5-GeV/c proton beam at CERN. Measurements on a sample of long beam tracks (larger than 50 cm) gave an average beam momentum of 5.52 ± 0.01 GeV/c. A total contamination of 3.9% was found, of which about 1.5% was due to K^+ and 2.4% to π^+, μ^+, and e^+ together. 25 725 p-p events were found in an inscribed fiducial volume corresponding to a total path length of 1.67×10^7 cm and a total p-p cross section[2] of 42.1 ± 1.3 mb.[3]

A sample of 83 p-p events associated with either Λ^0 or K_1^0 decays was found in the inscribed fiducial volume. Using the CERN programs THRESH and GRIND, the sample was subject to

Table I. p-p events with neutral strange particles.

Reaction	Observed[a] events	Corrected[b] number	Cross section (μb)
$\Lambda^0 k^+ p$	8.5	17.7 ± 6.0	78 ± 21
$\Sigma^0 k^+ p$	5	14.8 ± 6.6	
$\Lambda^0 k^+ p\pi^0$	10*	21.1 ± 7.0	208 ± 32
$\Lambda^0 k^0 p\pi^+$	17.5*	22.3 ± 5.5	
$\Lambda^0 k^+ n\pi^+$	13*	27.3 ± 7.5	
$\Sigma^0 k^0 p\pi^+$	4	12.6 ± 6.8	
$\Sigma^+ k^0 n\pi^+$	1	3.3 ± 3.3	
$ppk^0\bar{k}^0$	2	2.5 ± 1.8	28 ± 13
$pnk^+\bar{k}^0$	3	9.1 ± 5.4	
$\Lambda^0 k^+ p\pi^+\pi^-$	6.7	15.9 ± 6.1	72 ± 24
$\Lambda^0 k^0 n\pi^+\pi^+$	0.5	~2.8	
$\Lambda^0 k^0 p\pi^+\pi^0$	1.5	10.9 ± 9.0	
$\Sigma^0 k^+ p\pi^+\pi^-$	0.3	~0.5	
$\Lambda^0 k^+ p\pi^+\pi^-\pi^0$	0.5	~0.93	~5 ± 5
$\Lambda^0 k^0 p^+\pi^+ p^+\pi^-$	0.5	~1.33	
Events without fit	9	28.0 ± 9.3	67 ± 22
Total	83	191.0	458 ± 52

[a]The asterisk denotes what may be Σ^0 events.

[b]Equal production rate for K_1^0 and K_2^0 have been assumed. The errors on the cross section are the statistical errors.

kinematical fit and ionization analysis with the following results: For 74 events good fits were found both at the decay and production vertices, out of which 48 cases fitted a single hypothesis and 26 cases two or more hypotheses. The remaining nine events had good fits only at the decay vertex: three with Λ hypothesis, three with K_1^0 hypothesis, and three with either Λ or K_1^0 hypotheses. Most of the nine events that failed to fit any hypothesis at the production vertex are associated with large missing mass, which suggests more than one missing particle at production.

A correction weight was assigned to each accepted event to account for p-p events with neutral strange particles, produced in the inscribed volume, but which were not detected or accepted in this experiment. The weight of events that fitted two or more hypotheses was properly shared between them. Every p-p event in the inscribed volume contributes 2.40 μb to the total cross section.

The observed and corrected number of p-p events with neutral strange particles, classified according to their final-state configuration, are summarized in Table I. Events with a Σ^0 and another neutral particle like $\Sigma^0 K^+ p\pi^0$ or with a Λ and two neutral particles like $\Lambda K^+ n\pi^+\pi^0$ could not be detected in this experiment. Now, because of the small mass difference between Σ^0 and Λ, some of the cases that were accepted as Λ events may in fact be Σ^0 events (marked with an * in Table I).[4]

The results of Table I can be compared with similar ones at 3.7 GeV/c (or 2.85-GeV kinetic energy),[1] and with the predictions of the one-particle exchange model.[5] The total cross section for neutral strange particle production increases from 0.12 ± 0.02 mb at 3.7 GeV/c to 0.46 ± 0.05 mb at 5.52 GeV/c. This rise in the total cross section is due to the increasing contribution of some of the channels, like $pp \to YNK\pi$ and $pp \to YNK\pi\pi$ at 5.52 GeV/c. The dominant channel at 3.7 GeV/c is $pp \to YNK$, while at 5.52 GeV/c it is $pp \to YNK\pi$. The same behavior exists in the $pp \to ppK^0\bar{K}^0$ and $pp \to pnK^+\bar{K}^0$ cross section, which is ~0.002 mb at 3.7 GeV/c and increases to 0.028 ± 0.013 mb at 5.52 GeV/c.

Calculations of Robinson[5] for the reactions $pp \to \Lambda K^+ p$ and $pp \to \Sigma^0 K^+ p$, according to the one-pion exchange (OPE) and one-kaon exchange (OKE) models, are compared in Table II. It appears that at both momenta the OKE results are much too high (more than a factor of 20), while the OPE results are twice the experimental values.

The formation of baryonic and mesonic resonance states, associated with strange particles in p-p collisions, was examined for various final-state configurations. The Dalitz plot of M_{NK}^2 and $M_{\Lambda K}^2$ (or $M_{\Sigma K}^2$) for the reaction $pp \to \Lambda(\Sigma^0)NK$ is given in Fig. 1. Some accumulation of points can be seen along the $N_{1/2}^*(1688)$

Table II. Comparison with the OPE and OKE models.[a]

Momentum	Cross sections (μb) 3.7 GeV/c			5.52 GeV/c		
Reaction	OPE	OKE	Reference 1	OPE	OKE	This experiment
$pp \to \Lambda^0 k^+ p$	68 ± 14	971 ± 200	38 ± 9	101 ± 15	2480 ± 500	42.5 ± 14.4
$pp \to \Sigma^0 k^+ p$	···	208 ± 40	12 ± 7	···	730 ± 145	35.3 ± 15.8

[a]See reference 4.

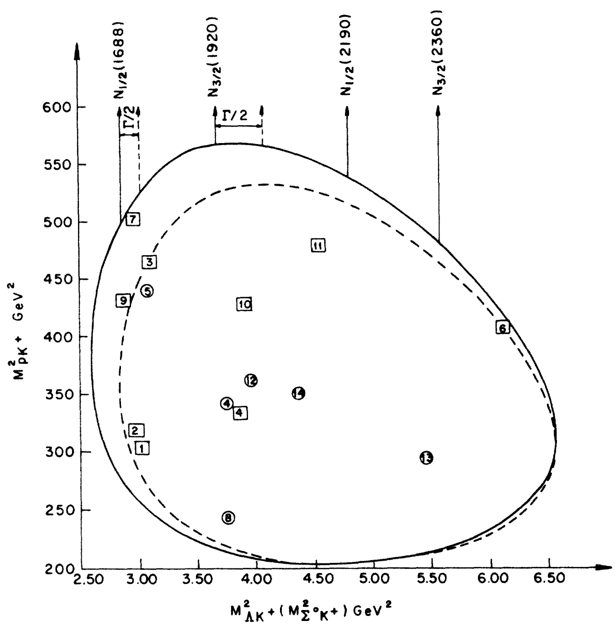

FIG. 1. Dalitz plot for $pp \to \Lambda pK$ (solid line and squares) and for $pp \to \Sigma^0 pK^+$ (dashed line and circles). Event No. 4 is represented by two kinematical solutions on this plot.

and $N_{3/2}{}^*(1920)$ mass lines.

In Fig. 2 the Λ-π and N-π effective mass distributions for the $pp \to \Lambda NK\pi$ events are shown. The shaded part of the histogram is related to events which fit a single hypothesis. The dashed line is the phase-space distribution normalized to the total number of events. The Λ-π effective mass distribution shows a clear evidence for the formation of the $Y_1{}^*(1385)$ resonance. It is remarkable that for the events with a unique fit (shaded area) nearly all Λ events are associated with $Y_1{}^*(1385)$ formation.

The N-π effective mass histograms are plotted (a) for all $pp \to \Lambda NK\pi$ events, and (b) for all events not associated with $Y_1{}^*(1385)$ formation (i.e., for events with $M_{\Lambda\pi} > 1425$ MeV or $M_{\Lambda\pi} < 1350$ MeV). Four N-π pairs from $pp \to \Sigma NK\pi$ events were added to histogram (b). In both histograms, and in particular in (b), there is evidence for the formation of the $N_{3/2}{}^*(1235)$ resonance.

Angular distributions in the c.m. system for the baryons N, Λ, and $Y_1{}^*$ produced in the reaction $pp \to \Lambda NK\pi$ were examined. All three distri-

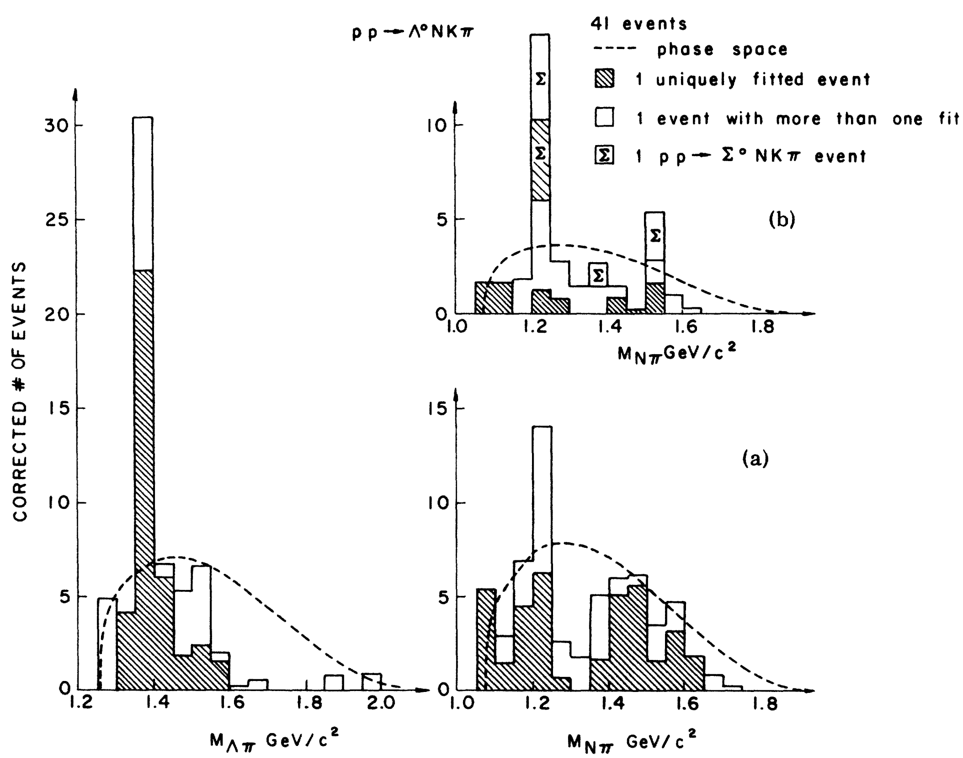

FIG. 2. Effective mass distribution for the pairs of particles Λ-π and N-π produced in the reaction $pp \to \Lambda NK\pi$. (a) All the events; (b) events outside the $Y_1{}^*(1385)$ region.

butions are anisotropic, and in particular that of the nucleons is strongly peaked in the forward-backward directions. Similar angular distributions are found for the baryons in the three-body reactions $pp \to YNK$.

The main conclusions from this experiment are: The dominant process of Λ production is associated with $Y_1^*(1385)$ formation, i.e., Λ is mainly produced by the reaction $pp \to Y_1^*NK \to \Lambda\pi NK$. Other possible modes of Λ production like direct production or as a decay product from nucleonic resonances $N^* \to YK$ are small or unimportant in $pp \to YNK\pi$ at 5.52 GeV/c.

In the present work it is difficult to detect the formation of $Y_0^*(1405)$ resonance via the neutral (i.e., $\Sigma^0\pi^0$) decay mode. The only type of events identified as Σ^0 events are those in which there are no invisible neutral particles. The number of Σ^0 events thus identified is small and in agreement with a minor contribution of Σ^0 production through nonresonating states.

It seems that in events of the type $pp \to \Sigma^0(\Lambda)NK$, where either the Σ^0 or the Λ does not belong to a Y_1^*, the N-π pair is associated with the formation of the $N_{3/2}^*(1235)$ resonance.

The lack of direct evidence for the K^* resonance formation and the small cross section for K-$\bar{K}$ production show that the formation of mesonic resonances in the pp reaction at 5.52 GeV/c is unimportant.

We would like to express our gratitude to CERN and to the hydrogen bubble chamber crew for enabling us to have the p-p exposure, and to the CERN programming group for help in the adaptation of CERN programs to our computer.

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[2]For the evaluation of the total cross section and beam contamination, see B. Haber, M.S. thesis, The Weizmann Institute of Science, Rehovoth, Israel, 1964 (unpublished).

[3]This is in good agreement with the value of 41.6 ±0.6 mb at 5.83 GeV/c by A. N. Didden et al., Phys. Rev. Letters 9, 32 (1964).

[4]However, the large amount of $Y_1^*(1385)$ formation (see further in the text) supports the identification of the Λ^0 events in the experiment.

[5]C. Robinson, M.S. thesis, The Weizmann Institute of Science, Rehovoth, Israel, 1964 (unpublished); and private communication. The calculations follow E. Ferrari [Phys. Rev. 120, 988 (1960)] and E. Ferrari and F. Selleri [Nuovo Cimento, Suppl. 24, 453 (1962)], extended to 5.5 GeV/c, and using recent data on πN and KN interactions.

POSSIBILITY OF CP VIOLATION IN $\Delta I=\frac{3}{2}$ DECAY OF THE K^0 MESON*

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The existence of the decay mode $K_2^0 \to \pi^+ + \pi^-$ has recently been reported by Christenson, Cronin, Fitch, and Turlay.[1] This establishes the violation of CP invariance. The branching ratio of $K_2^0 \to \pi^+ + \pi^-$ relative to $K_1^0 \to \pi^+ + \pi^-$ is 2.6 $\times 10^{-6}$. In view of this small branching ratio Sachs[2] proposes that this small effect may be an indirect consequence of the maximum violation of CP in the leptonic decay of the K^0 meson. Interesting consequences of this assumption can be readily checked by experiments as discussed by Sachs.

In this note we take a somewhat different viewpoint. We assume that in the (strangeness-changing) decay of the K meson which obeys the $\Delta I = \frac{1}{2}$ rule, CP is conserved, while in the decay which violates this rule CP is violated. Our motivation is inspired by the fact that there is evidently a connection between the strength of interactions and their symmetry property. The presence of the $\Delta I = \frac{3}{2}$ amplitude, as evidenced by the decay of $K^+ \to \pi^+ + \pi^0$, is at least one order of magnitude smaller than that which obeys the $\Delta I = \frac{1}{2}$ rule.[3] Admittedly, our assumption is quite speculative; however, if checked experimentally it might provide some insight to the weak decay mechanism. We have implicitly assumed that the existence of the decay mode $K^+ \to \pi^+ + \pi^0$ is not a consequence of electromagnetic violation of a strict $\Delta I = \frac{1}{2}$ weak interaction. Schwinger[4] has recently constructed a model for the decay of $K^+ \to \pi^+ + \pi^0$ without invoking electromagnetic effect, and pointed out the difficulty in a model with strict $\Delta I = \frac{1}{2}$ rule. The recent experiment on $K^+ \to \pi^+ + \pi^0 + \gamma$ by Cline and Fry[5] indicates that the rate and charged-pion spectrum are quite