STUDY OF RARE HYPERON DECAYS

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Introduction

Experimental study of hyperons received a powerful incitement in the beginning of the 80s due to construction of intensive high energy hyperon beams at the proton accelerators at CERN and FNAL. The relative intensity of hyperons produced in the proton interaction with nuclei is growing with the energy of bombarding protons. And more, due to the Lorentz augmentation of the observable hyperon lifetime, the momentum of the charged hyperons and their decay products can be measured with ordinary magnetic spectrometers. An essential advantage of the FNAL hyperon beams is their considerable polarization with controllable orientation. This enables precision determination of the asymmetry in the hyperon decays and also measurements of the polarization and magnetic moments of the hyperons with minimum systematic errors.

The beginning of the PNPI–FNAL collaboration goes back to the year 1981. The basis of the collaboration was the PNPI suggestion of an experiment for studying the Σ^- hyperon β-decay in view of a strange situation in investigation of this process. The existing at that time experimental information on the asymmetry in the decay of polarized Σ^- hyperons was in contradiction with the Cabibbo model prediction while the β-decays of the other baryon octet members were well described by this model. The most difficult task in the study of the reaction $\Sigma^- \to ne\tilde{\nu}_e$ was its separation from the 1000 times more intense reaction $\Sigma^- \to n\pi^-$. To overcome this difficulty, the PNPI group proposed to use a Transition Radiation Detector sensitive to electrons and less sensitive to π mesons. This proposal was not a trivial one because such detectors were practically not used in similar experiments before. Nevertheless, the proposal was accepted. The experiment got the official name: "Experiment E715, precision measurement of polarized Σ^- beta-decay". The beginning of the experiment was planned with the start up of SAVER – the world's first superconducting high energy proton accelerator.

The start up of SAVER was scheduled on October 1, 1983. At that time there was a lot of skepticism in the world about the viability of such accelerator. Also, numerous difficulties (mostly political) arose in the process of preparation of our experiment. The last one (the Korean aircraft shot on September 1, 1983) hardly has not ruined the experiment. Only the firm position of the President of the Academy of Sciences A.P.Aleksandrov and the Director of FNAL L.Lederman saved the situation. The experiment was prepared exactly in time. And also exactly in time SAVER began to accelerate protons. In a month, we already had a reasonable quality beam and started the measurements. The experiment was completed successfully. Besides the main program (study of the Σ^--hyperon β-decay), also a very delicate measurement of the Σ^--hyperon magnetic moment has been performed.

In the course of the E715 experiment, a strong collaboration (FNAL–PNPI–Universities of USA) was grown up. Following the PNPI initiative, this collaboration presented in 1986 a new proposal – an attempt to solve another problem in the hyperon physics. Existing at that time experimental data revealed a strong asymmetry in the radiative decay $\Sigma^+ \to p\gamma$, and none of the numerous theories succeeded in explanation of this fact. But the experimental data were based on very small statistics (about 300 events in total), and there were serious doubts about the correctness of these results because of possible admixture of the much more intense background reaction $\Sigma^+ \to p\pi^0 \to p2\gamma$. In our new experiment (experiment E761) it was suggested both a multiple increase of the statistics and, what is most important, a reliable elimination of the reaction $\Sigma^+ \to p\pi^0$ using a specially developed for these purposes Transition Radiation Detector. The measurements were carried out in 1990, and they proved to be a success. Not only the reaction $\Sigma^+ \to p\gamma$ was reliably studied but many other interesting results were obtained. This article gives a short survey of the experiments E715 and E761.

Measurement of the asymmetry parameter in the polarized Σ^--hyperon beta-decay and determination of the decay amplitude form factors. Experiment E715

Baryon semileptonic decays are commonly described by the Cabibbo model [N.Cabibbo, Phys.Rev.Lett., 10, 531 (1963)] which considers only the left-handed leptonic current and assumes that the hadronic vector and axial-vector currents belong to the SU(3) octets. For the $\Sigma^- \to ne^-\widetilde{\nu}_e$ decay this model predicted the following axial-vector to vector form factors ratio: $g_1/f_1 = -0.28 \pm 0.02$, that corresponded to a large negative electron asymmetry $\alpha_e = -0.51 \pm 0.04$.

The absolute value of this ratio was determined in several experiments with non-polarized Σ^- hyperons on a statistical level of about 10,000 events: $|g_1/f_1| = 0.36 \pm 0.04$. This value agrees satisfactorily with the Cabibbo model prediction. Four experiments were carried out measuring the electron asymmetry in the polarized Σ^- hyperon decay. The results of these experiments were in strong contradiction with the prediction of the Cabibbo model: $\alpha_e^{exp} = 0.26 \pm 0.19$. Even the sign of the asymmetry appeared to be opposite to the expected one. But the total statistics in these experiments reached only 352 events that did not allow the reliable control of the systematic errors.

Experiment E715 enabled investigation of the Σ^- hyperon β-decay on a qualitatively new level. The scheme of the experiment is given in Fig. 1. The 400 GeV proton beam hits the target T at the entrance of the M1 magnet which selects the secondary particles with the momentum of 250 GeV/c. The incident angle of the proton beam could be varied so that the vector of the secondary particle's polarization is oriented up, down, to the left, or to the right. The momentum of the beam particles was measured with proportional chambers PWC1–PWC4 determining deflection of the particles in the magnet M1. Their decay products were registered by the magnetic spectrometer including the bending magnet M2 and six drift chambers DC1–DC6. The transition radiation detector TRD was positioned between the magnetic spectrometer and the scintillator monitors SM1–SM4. The electromagnetic calorimeter LG containing the lead glass blocks was used in combination with the TRD for electron identification. The neutron calorimeter NC measured the energy and the coordinates of the neutron. The simultaneous utilization of TRD and LG provided registration of the reaction $\Sigma^- \to ne\widetilde{\nu_e}$ with 94% efficiency, suppression factor for the reaction $\Sigma^- \to n\pi^-$ being more than 5×10^4. The momenta of all the particles were measured $(\vec{P}_{\Sigma^-}, \vec{P}_n, \vec{P}_{e^-})$ thus enabling full reconstruction of the β-decay kinematics. This was for the first time when determination of all the asymmetry parameters $(\alpha_e, \alpha_n, \alpha_{\widetilde{\nu}})$, as well as analysis of the electron and neutron energy spectra, proved to be possible in one experiment. About 50,000 Σ^--hyperon β-decay events were unambiguously reconstructed. Simultaneously, the hadron decay $\Sigma^- \to n\pi^-$ (more than 10^6 events) was registered. The detailed description of the apparatus and the data analysis is given in Refs. [1,2].

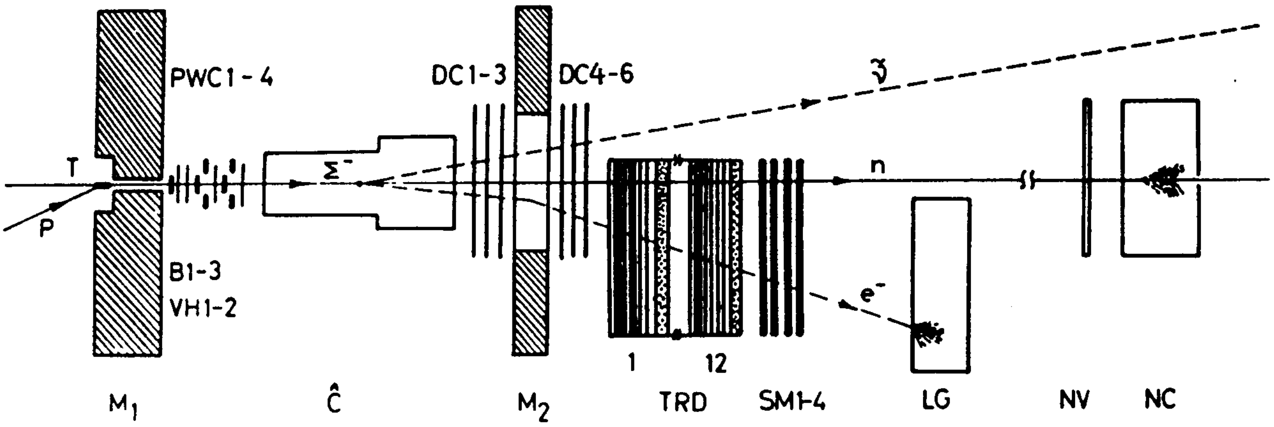

Fig. 1. Plan view of the E761 setup in the FNAL hyperon beam line.

Fig. 2 shows the angular distributions of π^- mesons from the $\Sigma^- \to n\pi^-$ decay and the distributions of electrons, neutrons, and antineutrinos from the $\Sigma^- \to ne^-\widetilde{\nu_e}$ decay. These distributions determine directly the coefficients $A_i = \alpha_i P_\Sigma$, where P_Σ is the hyperon beam polarization. Considering the α_π value as known from other experiments ($\alpha_\pi = +0.068 \pm 0.008$) and using the measured value of A_π, it was possible to determine the polarization $P_\Sigma = +0.236 \pm 0.043$. With this P_Σ value, the asymmetry coefficients in the Σ^- hyperon β-decay were found: $\alpha_e = -0.519 \pm 0.104$; $\alpha_n = +0.509 \pm 0.102$; $\alpha_{\widetilde{\nu}_e} = -0.230 \pm 0.061$. The measured electron asymmetry proved to be in good agreement with the Cabibbo model prediction ($\alpha_e = -0.51 \pm 0.04$). So, the long time contradiction between experiment and theory was settled in favour of the Cabibbo model.

The analysis of the neutron and electron energy spectra gave also the form factors of the Σ^- hyperon β-decay amplitude. With the ordinary assumptions (g_2=0, dipole q^2-dependence of the form factors), it was obtained:

$$g_1(0)/f_1(0) = -0.328 \pm 0.019,$$
$$f_2(0)/f_1(0) = -0.96 \pm 0.15.$$

Here f_2 and g_2 are the weak magnetic and electric form factors, respectively. The analysis of the existing data in the framework of the Cabibbo model with unbroken SU(3)-symmetry predicts for the Σ^- hyperon β-decay:

$$(g_1(0)/f_1(0))^{theor} = -0.28 \pm 0.02,$$
$$(f_2(0)/f_1(0))^{theor} = -1.30.$$

With breaking the SU(3)-symmetry in the first order of $\Delta = (m_\Sigma - m_n)/m_\Sigma$, the form factors g_1 and f_1 remain unchanged, while the f_2 value is changing in the following way: $(f_2(0)/f_1(0))^{theor} = -0.910 \pm 0.034$. Comparison shows that the E715 data agree with the expected SU(3)-symmetry breaking effect.

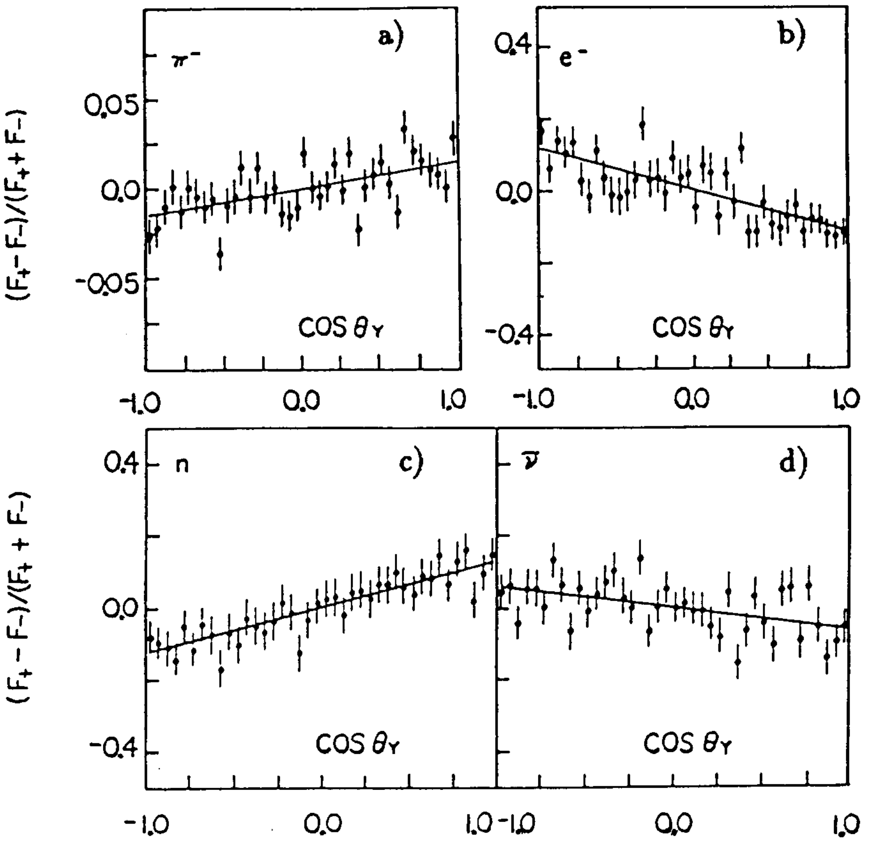

Fig. 2. Angular distributions in the Σ^--hyperon reference system:
a) pions from the $\Sigma^- \to n\pi^-$ decay, b), c), d) electrons, neutrons, and antineutrinos from the $\Sigma^- \to ne^-\tilde{\nu}_e$ decay.
$F_+(F_-)$ – part of the events with given cos Θ_y where Θ_y is the angle between the particle momentum and the Y-axis in the Σ^--hyperon reference system. The sign $+(-)$ corresponds to the data obtained with the orientation of the Σ^- beam polarization vector in the direction of the Y-axis (in the opposite direction). The Y-axis is directed vertically upwards. The straight lines – the result of fitting the distributions with the formula $(F_+ - F_-)/(F_+ + F_-) = A_i \cos\Theta_y$.

Study of hyperon radiative decays. Experiment E761

The situation with the hyperon radiative decays at the end of 80s was very exciting due to the $\Sigma^+ \to p\gamma$ decay riddle. The Hara theorem [Y.Hara, Phys.Rev.Lett., 12, 378 (1964)] states that, under assumption of the CP-invariance and dominance of the weak interaction left-handed currents, the asymmetry coefficients in the radiative decays $\Sigma^+ \to p\gamma$ and $\Xi^- \to \Sigma^-\gamma$ are equal to zero in the limit of exact SU(3)-symmetry. Existed at that time results of three experiments, on the contrary, provided some evidence of a large negative asymmetry in the $\Sigma^+ \to p\gamma$ decay. The difficulties in measuring this reaction arise from the competition with the 400 times more intense hadron decay channel $\Sigma^+ \to p\pi^0$ with the kinematics similar to that of the decay under study and with the same particles in the final state. Moreover, the asymmetry coefficient in the background decay $\Sigma^+ \to p\pi^0$ is just large and negative: $\alpha_\pi = -0.980 \pm 0.016$, that may imitate the observed asymmetry in the $\Sigma^+ \to p\gamma$ decay. The statistics of the three previous experiments was rather limited (about 300 events in total), and this prevented to estimate the contribution of the systematic errors.

Another parameter of the $\Sigma^+ \to p\gamma$ radiative decay, the branching ratio, has been measured in several experiments and, unexpectedly, appeared to have a large magnitude $B(\Sigma^+ \to p\gamma) = (1.25 \pm 0.07) \times 10^{-3}$. These facts were and still remain the object of theoretical investigations. Unfortunately, neither of the studied models can give a mutually consistent description of all observed hyperon radiative decays including the large negative asymmetry and the large probability of the $\Sigma^+ \to p\gamma$ decay.

The main task of the E761 experiment was to measure the $\Sigma^+ \to p\gamma$ decay parameters with a good statistical accuracy and a small systematic error. The experimental setup is shown in Fig. 3. The 800 GeV proton beam was focused on the copper target at the entrance of the M1 hyperon magnet. The incident angle was variable relatively to the hyperon beam direction within ±5 mrad in the horizontal and vertical planes. The 375 GeV secondary beam was selected by the narrow channel of the hyperon magnet. The intensity of the Σ^+ component in the beam was about 2000 s^{-1}, or 1.3% of the total beam intensity (the rest of the particles were protons and π^+ mesons). The measurements were carried out with two vertical directions of the polarization vector of Σ^+ hyperons (spin up and spin down). This favored the mutual compensation of the false asymmetry. The absolute value of the Σ^+ polarization was 12%.

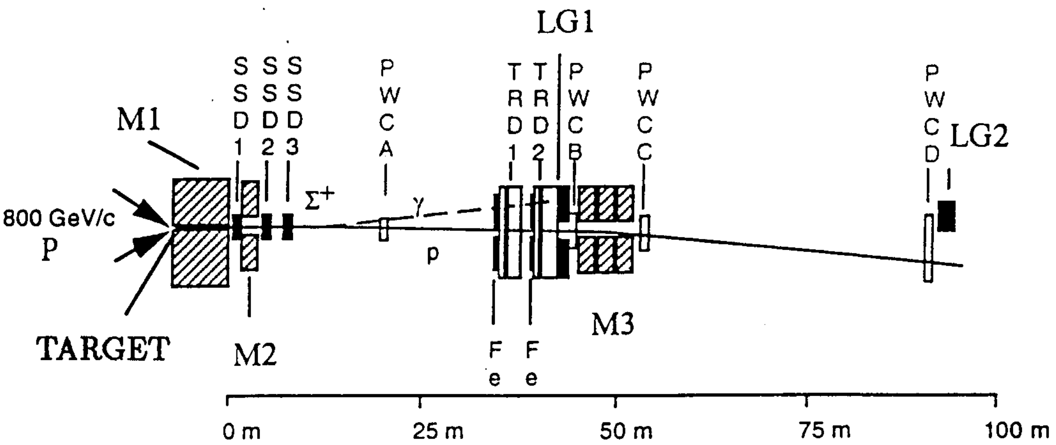

Fig. 3. Scheme of the E761 experiment:
M1,2,3 – magnets, SSD1,2,3 – Si-microstrip detectors, PWCA,B,C,D – proportional chambers, LG1,2 – electromagnetic calorimeters, TRD1,2 – modules of TRD, Fe – steel convertors.

The momentum of the Σ^+ hyperon and that of the proton from the hyperon decay were measured by two magnetic spectrometers which, besides the magnets M2 and M3, included the micro-strip silicon detectors SSD1,2,3 and the proportional chambers PWCA,B,C,D. They provided high resolution in squared mass of the missing neutral particle (Fig. 4). The energy of the photons was measured in the lead glass calorimeters LG1 and LG2. The coordinates of the

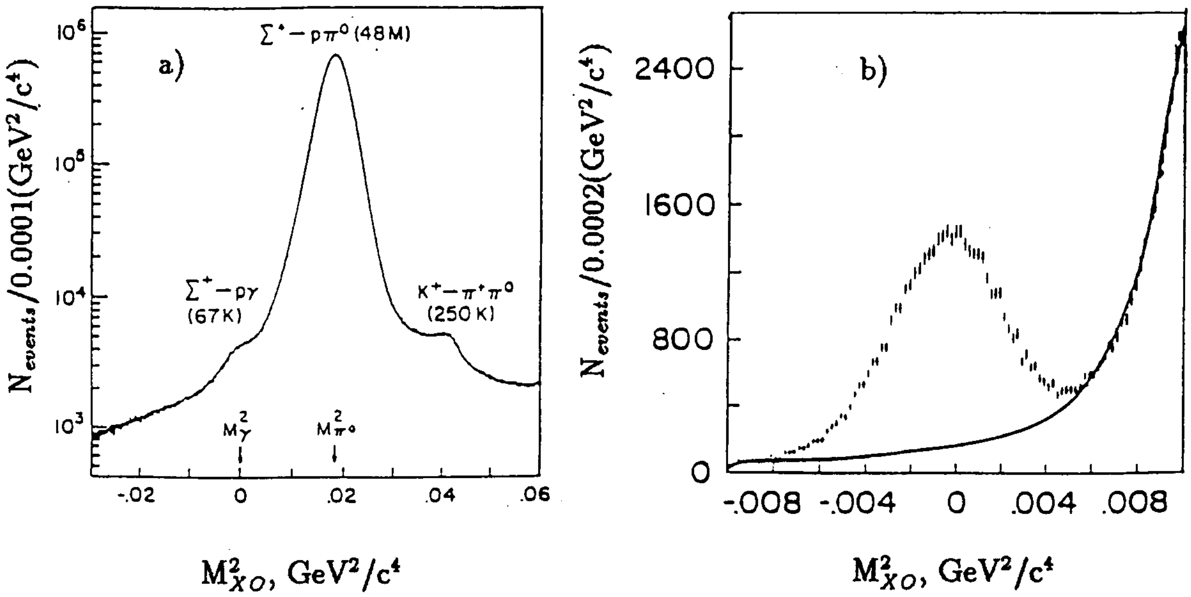

Fig. 4. Mass squared distribution of the missing neutral particle $M^2_{x^0}$ for the hypothesis $\Sigma^+ \to pX^0$:
a) without selection of the photon energy and coordinate,
b) with selection of the photon energy and coordinate measured with calorimeters LG1, LG2 and with TRD.

photons were measured with the transition radiation detectors TRD1 and TRD2 operating in a special mode. The TRDs were supplemented with steel convertors of photons and registered the X- and Y-coordinates of the most energetic charged component of the electromagnetic shower which is oriented mostly in direction of the incident photon. These coordinates can be predicted using the point of the Σ^+-hyperon decay and the momenta of the Σ^+ and the proton, which are determined in the experiment. One should expect coincidence of the predicted coordinates and the measured ones for the radiative decay event $\Sigma^+ \to p\gamma$. In the case of the background decay $\Sigma^+ \to p\pi^0$, the photons from the π^0-decay are distributed in a wider cone along the predicted direction. This fact was used as the criterion for the events selection. The detailed description of the installation and the data analysis are given in Ref. [3]. Fig. 4 illustrates how the combination of the magnetic spectrometer, the calorimeter, and TRD favored reliable selection of the $\Sigma^+ \to p\gamma$ radiative decay from the background reaction $\Sigma^+ \to p\pi^0$.

The analysis of about 35,000 radiative decays $\Sigma^+ \to p\gamma$ provided the decay asymmetry parameter: $\alpha_\gamma = -0.720 \pm 0.086(\mathrm{stat}) \pm 0.045(\mathrm{syst})$, and the analysis of about 32,000 events – the decay rate $B(\Sigma^+ \to p\gamma) = (1.20 \pm 0.08) \times 10^{-3}$ (total error is given). The E761 data demonstrated that the asymmetry in the Σ^+ hyperon radiative decay was indeed large and negative, the observed decay rate being in an agreement with the world data.

In parallel with this work, the PNPI theorists developed a model reproducing the experimental observables of the radiative decay $\Sigma^+ \to p\gamma$ on base of the QCD sum rules [4]. But it is still unclear how solid is this description. Till now the comparison is carried out only in the case of $\Sigma^+ \to p\gamma$ decay. It should be important to extend this comparison on the other radiative decays as well.

In the same experiment new data on radiative decays $\Xi^- \rightarrow \Sigma^-\gamma$ [5] and $\Omega^- \rightarrow \Xi^-\gamma$ [6] were collected. The only previous measurement of the $\Xi^- \rightarrow \Sigma^-\gamma$ decay rate (just 11 events) gave the value of $B(\Xi^- \rightarrow \Sigma^- + \gamma)=(0.23\pm0.10)\times10^{-3}$. That was considerably higher than the one-quark exchange model prediction and exceeded by two orders of magnitude the estimates taking into consideration the contribution of the so-called penguin diagrams. Note that the two-quark transition, dominating in the other radiative decays, is forbidden in the Ξ^- and Ω^- radiative decays due to absence of the valence u quark in the initial state.

More than 200 radiative decay events $\Xi^- \rightarrow \Sigma^-\gamma$ were identified in the E761 experiment. Fig. 5 presents the mass squared distribution of the missing neutral particle $M^2_{x^0}$ for the hypothesis $\Xi^- \rightarrow \Sigma^- + X^0$. The background was mainly due by the anti-hyperon decay $\bar{\Sigma}^- \rightarrow \bar{p}\pi^0$. The obtained radiative decay rate was $B(\Xi^- \rightarrow \Sigma^-\gamma) = (0.122\pm0.023(\text{stat})\pm0.006(\text{syst}))\times10^{-3}$ that is very close to the theoretical unitary limit $B_{unit}(\Xi^- \rightarrow \Sigma^-\gamma) = = 0.1\times10^{-3}$.

The study of the radiative decay $\Omega^- \rightarrow \Xi^-\gamma$ is very difficult both for the experiment and for the theory. The Ω^- hyperons are the least intensive part of the hyperon beam compared to the other hyperons. Also, the theory predicts a smaller probability of their radiative decay: $B(\Omega^- \rightarrow \Xi^-\gamma) \simeq 10^{-5}$. Theoretical description is complicated because among the radiative hyperon decays the decay $\Omega^- \rightarrow \Xi^-\gamma$ is the only transition from the SU(3) spin 3/2 decouplet into the octet. The experimental upper limit for the branching ratio was $B(\Omega^- \rightarrow \Xi^-\gamma) < 2.2\times10^{-3}$. In this experiment, a new upper limit is obtained: $B(\Omega^- \rightarrow \Xi^-\gamma) < 4.6\times10^{-4}$.

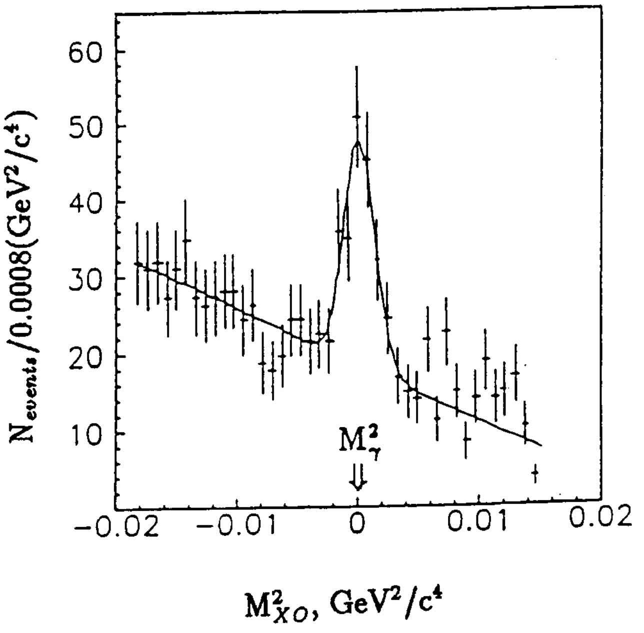

Fig. 5. Mass squared distribution of the missing neutral particle $M^2_{X^0}$ for the hypothesis $\Xi^- \rightarrow \Sigma^- X^0$.

Polarization of hyperons

Polarization of hyperons produced in the interaction of high energy protons with nuclei has been observed in the FNAL hyperon beam already about 20 years ago. Polarization of Λ^0 hyperons was about 20% for the proton energy of 400 GeV and the transverse momentum $P_t \approx 1$ GeV/c. On the other hand, $\bar{\Lambda}^0$ hyperons were non-polarized in the same kinematics region. The Λ^0 hyperon polarization was qualitatively explained by the "leading particle" effect when a valent quark of the incoming proton picks up a strange sea quark and forms a polarized hyperon. In such a scheme the hyperon polarization should decrease with increasing the number of quarks picked up from the sea. This scheme seemed to be confirmed by further measurements of polarization of the $\Sigma^{\pm}$, Ξ^-, Ξ^0, Ω^-, and $\bar{\Lambda}^0$ hyperons. In particular, the fact of the $\bar{\Lambda}^0$ and Ω^- hyperons being practically non-polarized was explained as these hyperons do not contain any quark from the incident proton.

But the results of the recent $\bar{\Xi}^+$ polarization measurements at FNAL cast serious doubts on this scheme. Both particles, hyperon Ξ^- and anti-hyperon $\bar{\Xi}^+$, proved to be polarized, the value and the sign of the polarization being the same for the particle and anti-particle. Such a behaviour essentially differed from the polarization picture in the $\Lambda^0/\bar{\Lambda}^0$ system and raised a question about polarization in the $\Sigma^+/\bar{\Sigma}^-$–system.

The answer to this question was obtained in the E761 experiment [7,8], where polarization of Σ^+ and $\bar{\Sigma}^-$ hyperons was measured. The incident angle of the 800 GeV proton beam on the copper target was varied within ±5 mrad both in the horizontal and vertical planes. The hyperon polarization vector was, correspondingly, parallel or perpendicular to the vertical direction of the magnetic field in the hyperon magnet M1. The momentum of the hyperons was 375 GeV/c. The sign of the hyperons was chosen by changing the current direction in the magnets. The decay modes $\Sigma^+ \to p\pi^0$ and $\bar{\Sigma}^- \to \bar{p}\pi^0$ with large asymmetry parameter $\alpha_\pi = -0.980 \pm 0.016$ were used for measurement of the polarization.

The dependence of the measured polarization on P_t is presented in Fig. 6. One can see that both Σ^+ and $\bar{\Sigma}^-$ hyperons are produced polarized. For the same P_t their polarizations have the same sign but somewhat differ in magnitudes. Together with the data on polarization of the $\Xi^-/\bar{\Xi}^+$, the results of the E761 experiment tell us that the anti-hyperon polarization is a general phenomenon. The question is now why the $\bar{\Lambda}^0$ hyperons are produced non-polarized?

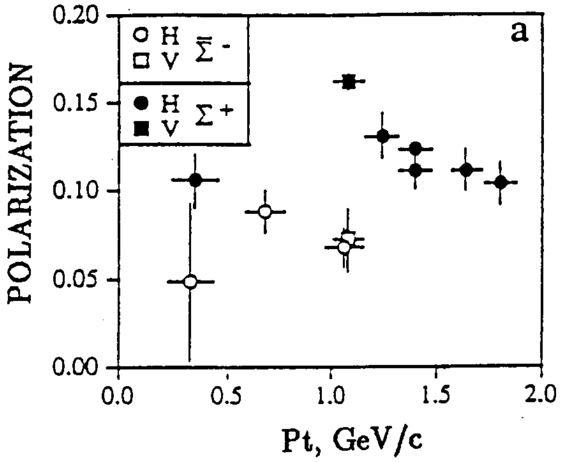

Fig. 6. Dependence of Σ^+ and $\bar{\Sigma}^-$ polarization on transverse momentum P_t.

In view of these observations, we must state that the hyperon polarization in hadron collisions has no even a qualitative explanation today. Here we summarize some of the observed features, characterizing the complexity of the polarization process:

- Sign of polarization.
  Polarization of Σ^-, Σ^+, $\bar{\Sigma}^-$ hyperons is positive, polarization of Λ^0, Ξ^-, $\bar{\Xi}^+$ hyperons is negative, polarization of $\bar{\Lambda}^0$ hyperons is zero.

- Energy dependence.
  With the increase of the proton beam energy, the polarization of Σ^+ hyperons decreases,

the polarization of Ξ^- hyperons increases, the polarization of Λ^0 hyperons remains constant.

- Dependence on Feynman variable X_f.
  With the increase of X_f at fixed P_t, the polarization of Σ^+ and Λ^0 hyperons increases and the polarization of Ξ^- hyperons is constant.

- P_t dependence.
  With the increase of P_t, the polarization increases reaching maximum at $P_t \simeq 1$ GeV/c. Then the polarization of Σ^- and Λ^0 hyperons reaches a plateau traced up to $P_t \simeq 2$ GeV/c. The polarization of Σ^+ hyperons decreases at $P_t >1$ GeV/c.

Of course, explanation of these experimental facts is not an easy task for the theory.

Magnetic moments of hyperons

High-intensity beams of polarized hyperons of the FNAL Tevatron present a unique opportunity for precise measurements of the hyperon and anti-hyperon magnetic moments by the spin precession method. In addition to the main program of the E715 and E761 experiments, there were also measurements of the magnetic moments of Σ^-, Σ^+, $\bar{\Sigma}^+$, and Ξ^- hyperons.

The apparatus configuration was the same as in the main measurements. The incidence angle of the proton beam on the target was fixed within ±5 mrad in the vertical plane, so the hyperon polarization vector was in the horizontal plane providing maximum spin precession in the vertically directed magnetic field. The horizontal components (A_x and A_z) of the decay asymmetries were analyzed for determination of the spin rotation angle and evaluation of the magnetic moments. The following decay channels were used:

$$\begin{array}{lll}
\Sigma^- \to n\pi^- & \alpha = +0.07 & B{=}99.8\% \\
\Sigma^- \to ne^-\tilde{\nu}_e & \alpha_e = -0.51 & B{=}10^{-3} \\
\Sigma^+ \to p\pi^0 & \alpha = -0.98 & B{=}51\% \\
\bar{\Sigma}^- \to \bar{p}\pi^0 & \alpha = -0.98 & B{=}51\% \\
\Xi^- \to \Lambda^0\pi^- & \alpha = -0.46 & B{=}99.9\%.
\end{array}$$

Special attention was paid to the precise measurement of the integral of the magnetic field in which the particle spin precession occurs. It was measured with 0.1% precision. Finally, the following values of the hyperon magnetic moments were obtained:

$$\begin{array}{lll}
\mu_{\Sigma^-} & = -1.166 \pm 0.014 \pm 0.010\ \mu_N & [9] \\
\mu_{\Sigma^+} & = +2.4613 \pm 0.0034 \pm 0.0040\ \mu_N & [10] \\
\mu_{\bar{\Sigma}^-} & = -2.428 \pm 0.036 \pm 0.007\ \mu_N & [10] \\
\mu_{\Xi^-} & = -0.661 \pm 0.036 \pm 0.036\ \mu_N & [11].
\end{array}$$

Here μ_N is the nuclear magneton.

The measurement of the magnetic moment of $\bar{\Sigma}^-$ hyperon was carried out for the first time. The other results are exceeding the existed before data in accuracy. Fig. 7 demonstrates the comparison of the experimental hyperon magnetic moments with the calculations based on the compound quark model. In this model the baryon magnetic moment is determined by the sum of magnetic moments of the valent quarks described with the SU(6)-wave functions. The magnetic moments of Λ^0 hyperon, proton and neutron are used for normalization. Evidently, there is a significant discrepancy of the theory and experiment. The further progress in this area requires development of some more precise theory of magnetic moments.

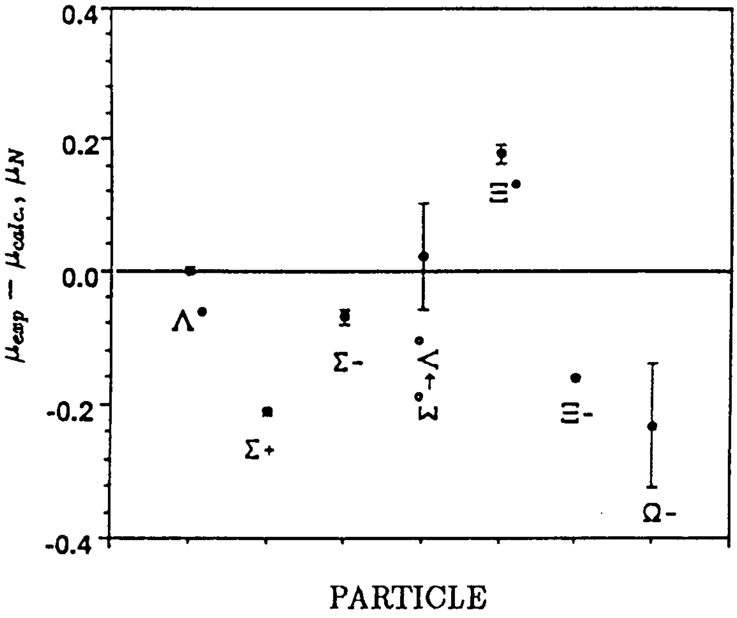

Fig. 7. Comparison of experimental magnetic moments with calculations in frames of the compound quark model.

Further cooperation

The success of the joint experiments E715 and E761 stimulated further cooperation of PNPI with FNAL. A new (E781) experiment on C-baryon study has been started and will be continued till 1999. In addition, PNPI became a member of the D0 collaboration preparing a new generation of experiments at the FNAL $p\bar{p}$–collider. This experiment will be started in 1999 after the reconstruction of the collider and the detectors is completed.

E715 collaboration

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References

[1] *V.A.Andreev, A.A.Vorobyov, G.E.Gavrilov, V.T.Grachev, P.Grafström, A.S.Denisov, A.G.Krivshich, P.Cooper, J.Lach, D.M.Seliverstov, N.N.Smirnov, N.K.Terentyev, I.I.Tkach, V.A.Schegelsky.* Preprint LNPI–1186, Gatchina, 1986. 42 p.

[2] *E715 collaboration.* // Phys. Rev., 1988. V.D38. P.2056.

[3] *E761 collaboration.* // Phys. Rev., 1995. V.D51. P.4638.

[4] *I.I.Balitsky, V.M.Braun, A.V.Kolesnichenko.* // Nucl. Phys., 1989. V.B312. P.509.

[5] *E761 collaboration.* // Phys. Rev. Lett., 1994. V.72. P.808.

[6] *E761 collaboration.* // Phys. Rev., 1994. V.D50. P18.

[7] *E761 collaboration.* // Phys. Rev. Lett. 1993. V.71. P.2172.

[8] *E761 collaboration.* // Phys. Rev., 1995. V.D52. P.3777.

[9] *E715 collaboration.* // Phys. Rev. Lett., 1986. V.57. P.1526.

[10] *E761 collaboration.* // Phys. Rev. Lett., 1993. V.71. P.3417.

[11] *E715 collaboration.* // Phys. Rev., 1989. V.D40. P.1703.