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[11] A. W. Chao and C. N. Yang, Phys. Rev. D 9, 2505 (1974).

Translated by Julian B. Barbour

Physics research program using high-energy polarized proton beams

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Fiz. Elem. Chastits At. Yadra **14**, 620–647 (May–June 1983)

The polarization program proposed for the Fermilab Tevatron using polarized proton beams is reviewed. The physics motivation of the scientific program is explained, the proposals are outlined, and the experimental facilities are described. The status of the polarization program at summer 1982 is summarized.

PACS numbers: 13.85.Qk, 29.75. + x, 29.20.Lq

INTRODUCTION

The ever increasing interest in polarization investigations in high-energy physics is due, on the one hand, to the discovery in experiments of large spin effects in some reactions (the polarization of inclusively produced hyperons, asymmetry in π^0-meson production, etc.) and, on the other, to the appearance of quantum chromodynamics (QCD), which predicts a number of spin effects. They can be tested in the coming years with the large accelerators. Following the approval of a plan at Fermilab to develop a channel of polarized proton and antiproton beams by physicists from the United States, Europe, and Japan, a program of polarization investigations using such a beam has been proposed. The following scientific-research institutes and laboratories are participating in the preparation and realization of this program: *United States of America*: Fermilab, Batavia (FNAL); Argonne National Laboratory, Argonne (ANL); Lawrence Berkeley Laboratory, Berkeley (LBL), Northwestern University, Evanston (NWU), Rice University, Houston, University of Wisconsin, Madison, Lehigh University, Bethlehem, University of Philadelphia, Pennsylvania; *Japan*: University of Kyoto; *France*: Laboratory of Particle Physics at Annecy, the Department of Elementary Particle Physics at Saclay; *Italy*: National Institute of Nuclear Physics at Trieste; *Soviet Union*: Institute of High Energy Physics, Serpukhov. In June 1981 there were eight proposals for consideration by the Scientific Committee of Fermilab, these forming the first stage of the investigations. The status of these proposals at the middle of 1982 will be discussed in the conclusions. Below, we give brief information about the polarized beam and then discuss all the eight proposals. A preliminary report on this question was given by A. Penzo in September 1980 at Lausanne and by one of the authors of the present review (A. Y.) in November 1981 at Dubna.[1]

1. THE POLARIZED BEAM OF THE FERMILAB TEVATRON

The possibility of using the decay $\Lambda \to p + \pi^-$ ($\bar{\Lambda} \to \bar{p} + \pi^+$) as a source of polarized protons was considered for the first time in Ref. 2, and schemes of actual realization were proposed in Refs. 3–5. For the 400-GeV and 1-TeV accelerators at Fermilab calculations were made in Ref. 4, the results of which we give briefly below.

Polarized protons and antiprotons arise from the parity-violating decay of the $(\Lambda, \bar{\Lambda})$ particles. By means of special magnets or collimators, one can, moreover, change the direction of the polarization vector from cycle to cycle. The beam optics is adjusted to reduce to a minimum the beam depolarization on the attainment of the geometrical dimensions needed in the experiment. At the end of the channel, a system of eight magnets is established to achieve rapid polarization reversal in the necessary direction.

The expected intensity of the polarized proton beam as a function of its energy for the tevatron (continuous curve) and the operating 400-GeV accelerator (broken curve) is shown in Fig. 1. A beam polarization of order 45% is expected. The realization of such a beam opens up a wide perspective of polarization investigations in the TeV energy range.

2. EXPERIMENT TO MEASURE THE DIFFERENCE $\Delta\sigma_L^{tot}$ BETWEEN THE TOTAL CROSS SECTIONS OF pp AND $p\bar{p}$ INTERACTIONS IN THE INTERVAL 100–500 GeV (ANL–KYOTO–ANNECY–LBL–NWU–RICE–SACLAY–SERPUKHOV–TRIESTE COLLABORATION: P-676)

It is well known that the total cross sections of pp and $p\bar{p}$ interactions increase with the energy, and the part played by spin effects in this rise remains as yet unanswered. One of the possible ways of solving this prob-

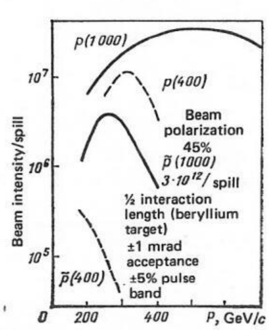

FIG. 1. Dependence of the intensity of polarized beams on their momenta. The initial beam energy (GeV) is given in brackets.

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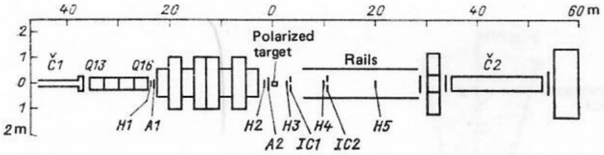

FIG. 2. Schematic arrangement for measuring the total cross sections $\Delta\sigma_L^{tot}$.

lem is to measure the total cross sections for the interaction of protons with different directions of the helicities as a function of the initial energy,[6] and this is what is proposed in the present experiment.

The arrangement of the experiment, in which the total cross section is measured on the basis of the beam attenuation, is shown in Fig. 2. The incident particles of the beam are detected by two hodoscopes H1 and H2 with scintillator widths of 1.5 and 1 mm, respectively, the total number of scintillators in each hodoscope being 40. The light from the scintillators is collected by a fiberglass light tube on both sides to photomultipliers. The beam interacts with a polarized target of organic material of length 10 cm and diameter 2.5 cm. After passing through the target, the particles are detected by the hodoscopes H3–H5. A special matrix logic makes it possible to discriminate events by means of the scattering angle. Additional apparatus in the form of the anticoincidence counters A1 and A2 or IC1 and IC2 ensures the suppression of background events. This is also the purpose of the threshold Cherenkov counters Č1 and Č2, which are adjusted to detect pions in the incident beam as well as after the target.

The trigger is determined by the following conditions: T_0, when neither the incident nor the transmitted particle is a pion; T_1, when there is one and only one particle in each plane X and Y; T_2, when the track of the incident particle must pass through the target and satisfy the angular divergence of the beam; T_3, when one of the particles emerging from the target must be detected in H4 and H5; T_4, when a track emerging from the target must match one entering it with allowance for the spatial resolution of the hodoscopes.

The high intensity of the beam (3×10^7 polarized protons per cycle, cycle duration 20 sec) imposes certain requirements on the resolution time of the apparatus, which must be of order 15 nsec.

The number N_i of particles that pass through the target and enter the solid angle Ω_i is determined by the expression

$$N_i^{\pm} = N_0^{\pm} \exp\left[-\alpha_i - \frac{1}{A}\left(\sigma_i \pm P_B P_T \frac{\Delta\sigma_{L,\,i}}{2}\right)\right], \tag{1}$$

where ± denote parallel or antiparallel orientation of the polarization of the beam and the target, $N_0^{\pm}$ is the number of incident particles, α_i is the coefficient of beam attenuation for the material of a target not containing hydrogen, σ_i is the partial total cross section for the i-th solid angle, $A = (N_A \rho_F L)^{-1} = 2320$ mb is a constant for a hydrogen target, N_A is Avogadro's number, $\rho_F = 0.0714$ g/cm^3 is the density of free hydrogen, $L = 10$ cm is the length of the target, and $P_B = 0.5$ and $P_T = 0.8$ are the polarizations of the beam and the target, respectively.

The partial cross section $\Delta\sigma_{L,\,i}$ is determined from the experiment as follows:

$$\tanh[\Delta\sigma_{L,\,i} P_B P_T/2A] = (N_i^-/N_0^- - N_i^+/N_0^+)/(N_i^-/N_0^- + N_i^+/N_0^+). \tag{2}$$

Note that in this expression the contributions from the main terms containing α_i and σ_i/A cancel, and also that the influence of the efficiency of the apparatus and its drift in time can be eliminated by frequent reversal of the beam polarization.

The statistical accuracy in the determination of the cross section is given by

$$\Delta(\Delta\sigma_L) = \frac{2A}{P_B P_T}\left(\frac{1-T}{T}\right)^{1/2} \frac{1}{\sqrt{N_0}}, \tag{3}$$

where T is the fraction of the particles that pass through the target: $T = 0.85$. Then

$$\Delta(\Delta\sigma_L) = 4800\ \text{mb}/\sqrt{N_0}. \tag{4}$$

To achieve a level of accuracy of ±10 μb, it is necessary to pass 2×10^{11} protons through the target, which is equivalent to accumulating statistics for 100 h. It is planned to make measurements at five points between 100 and 500 GeV for protons and at one (optimal) point for antiprotons. With allowance for about 200 h for adjusting the apparatus and control measurements, the proposed program requires 800 h operating time of the accelerator.

3. PROPOSAL TO STUDY SPIN EFFECTS IN THE INCLUSIVE PRODUCTION OF π^0 AND DIRECT PHOTONS AT LARGE $p_\perp$ WITH A POLARIZED PROTON BEAM AT FERMILAB (ANL–KYOTO–ANNECY–LBL–NWU–RICE–SACLAY–SERPUKHOV–TRIESTE COLLABORATION: P-678)

Recently performed experiments on deep inelastic scattering of polarized electrons by polarized protons have shown[7,8] that, with appreciable probability, quarks with large x remember and transmit information about the spin orientation of the parent particle. It can be expected that such effects can also be studied in hadronic interactions. In addition, hadronic interactions are effectively the only source for investigating the possibilities of transmitting spin information by gluons through the quantum-chromodynamic Compton effect (gluon + quark → photon + quark), which is important for testing the predictions of QCD at large $p_\perp$. In particular, QCD predicts zero values of the single-spin asymmetry A_N for inclusively produced hadrons and photons. At the same time, there are experimental data which show the presence of appreciable asymmetry A_N in the inclusive production of π^0 mesons[9] or Λ^0 particles.[10] To reconcile these data with QCD, it is necessary to assume that either the initial energy in the first case, or $p_\perp$ in both cases, are insufficiently large to test QCD. Therefore, it is extremely desirable to make such measurements at high energies (>100 GeV) and large $p_\perp$ (≥3 GeV/c).

Models based on QCD and perturbation theory give very interesting predictions for the two-spin asymme-

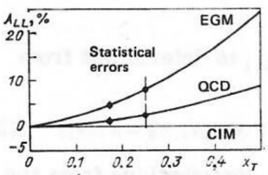

FIG. 3. Dependence of theoretical predictions of the asymmetry A_{LL} for $x_F = 0$ and $\sqrt{s} = 20$ GeV on x_T for the reaction $p(\to) + p(\to) \to \pi^0 + X$.

try A_{LL} when the spins of both initial particles are directed along the momentum. In Fig. 3, we show the dependence of A_{LL} on the variable $x_\perp = 2p_\perp/\sqrt{s}$ as calculated in accordance with three models: 1) the hard-collision model on the basis of QCD and perturbation theory (QCD)[11]; 2) the effective gluon model (EGM)[12]; and 3) the constituent-interchange model (CIM). In the final case, a zero value of A_{LL} is predicted at all $x_\perp$, whereas in the effective gluon model $A_{LL} \approx 10\%$ at $x_\perp \approx 0.25$. Thus, measurements of A_{LL} with accuracy at the percent level at, for example, $x_\perp \approx 0.25$ permit a choice between these extreme predictions.

An experimental arrangement intended for the measurements listed above is shown in Fig. 4. For the measurement of the single-spin asymmetry A_N in the inclusive production of π^0 mesons, the beam has polarization directed along the normal to the scattering plane, and the target is liquid hydrogen (LHT). For the measurement of the two-spin asymmetry A_{LL}, a longitudinally polarized beam is formed and a target with longitudinal polarization (LPT) is used. The beam polarization is reversed from cycle to cycle by means of "serpent" magnets. The angle of incidence of the beam particles is determined by two hodoscopes H1 and H2 with 1.5-mm resolution in both planes. The photons emitted by the target are detected by two blocks G1 and G2 of total-absorption Cherenkov counters based on lead glass designed at the Institute of High Energy Physics, Serpukhov.[13,14] At initial momentum 300 GeV/c, the detectors are placed 12 m from the target at an angle of 80 mrad, which corresponds to 90° in the center-of-mass system ($x_F = 0$). Each block covers an azimuthal angle ±22.5° (see Fig. 4). In front of the gamma detectors there are the scintillation hodoscopes H3 and H4 with three planes X, Y, and U and cells measuring 4 cm. They are intended to detect the charged particles that accompany the photons. To separate the direct photons from the photons produced by the decay of the secondary hadrons, the large-cell gamma counters G1′

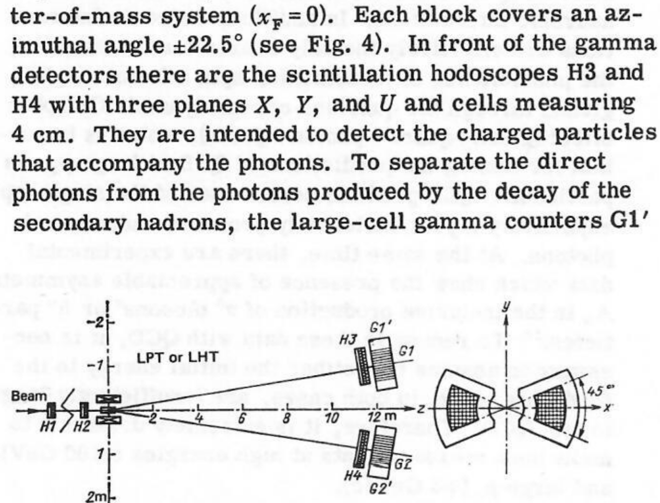

FIG. 4. Arrangement of experiment for measurement of the asymmetry in the inclusive production of π^0 and direct photons using the Fermilab Tevatron.

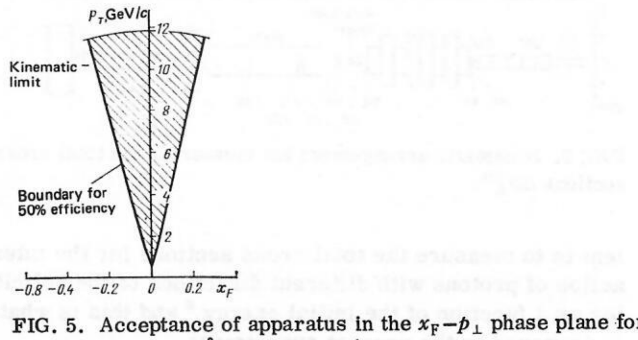

FIG. 5. Acceptance of apparatus in the $x_F - p_\perp$ phase plane for the reaction $pp \to \pi^0 X$ at 300 GeV/c.

and G2′ are placed around the blocks G1 and G2.

The useful region in the $x_F - p_\perp$ plane detected by the apparatus is shown by the hatching in Fig. 5. The geometrical efficiency of the apparatus, calculated by the Monte Carlo method, is shown in Fig. 6. As can be seen from the figure, the probability that both particles hit the same cell is almost negligibly small up to momentum transfers $p_\perp \approx 7$ GeV/c. Even when both photons hit one cell, they can still be disentangled to a considerable extent if the distance between them is greater than 2.5 cm.

To ensure that the dead time is sufficiently short, the pulse from each counter is digitized by its own ADC. The subtraction of the pedestal and the energy normalization are done automatically by a fast processor. The relative amplification of the photomultiplier + ADC circuit is controlled between cycles by means of a microprocessor and light-emitting diodes, which makes it possible to achieve a long-term stability better than 1%. The energy resolution, measured by means of electron beams with pulses in the interval 1–40 GeV/c, can be

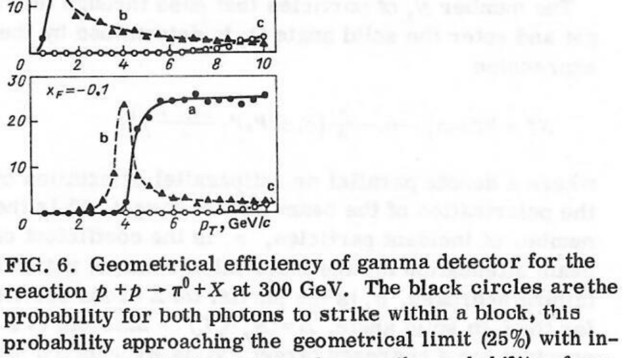

FIG. 6. Geometrical efficiency of gamma detector for the reaction $p + p \to \pi^0 + X$ at 300 GeV. The black circles are the probability for both photons to strike within a block, this probability approaching the geometrical limit (25%) with increasing $p_\perp$. The black triangles are the probability of one photon striking within a detector. The open circles are the probability for both photons to strike within one cell measuring 38 × 38 mm.

represented in the form

$$\Delta E/E = 0.025 + 0.13/\sqrt{E\,(\text{GeV})}, \tag{5}$$

where ΔE is the width at half-maximum. In the indicated interval of momenta, the deviation from linearity of the pulse height from the counters did not exceed 1%.

The energy and coordinate of a shower are determined in the real time of the measurements using the method of moments. This makes it possible to carry out a preliminary selection of events from a record on tape. Estimates show that with allowance for all the relevant dead times a rate of accumulation of statistics of 500 events/sec even for enents with high multiplicity can be expected.

The π^0 reconstruction is based on the already developed methods of the experiment NA12 at CERN.[15] More complicated is the method for separating the direct photons, for which the main background sources are the following:

1. Decays of π^0 and η^0 into two photons, one of these either missing a detector or being converted somewhere in flight, or having its energy below the detection threshold.

2. Neutral hadrons of the type $n, \bar{n}, K^0, \Lambda, \bar{\Lambda}$, whose interaction with the lead glass imitates the formation of an isolated shower.

To increase the geometrical acceptance of the photon detector, it is proposed to surround the blocks G1 and G2 with additional protective counters G1′ and G2′. If these have transverse dimensions of 30 cm, it is possible to detect 97% of the photons that do not enter the working aperture and whose sources are π^0 mesons with $x_F = 0$ and $p_\perp = 5$ GeV/c. The fraction of π^0 mesons for which the two photons "stick together" is small, about 0.3%, and for ratio $\gamma/\pi^0 = 0.1$ the background from such π^0 mesons in the yields of direct photons is not more than 3%. The correction for conversion from photons in the material of the target, counters, etc., can be correctly calculated on the basis of the reconstructed π^0 mesons. The background from the interaction of neutral hadrons can be determined by placing lead converters (about $10X_0$) between the hodoscopes H3 and H4 and the detectors G1 and G2, following Ref. 16. The measurements of the yields of π^0 mesons and direct photons can be made simultaneously.

To estimate the counting rate, the following conditions were assumed: beam momentum $p_0 = 300$ GeV/c, beam intensity $I_0 = 3\times 10^7$ protons per cycle (one cycle per minute), beam polarization $P_B = 50\%$, target polarization $P_T = 80\%$, length of the polarized target 15 cm, liquid-hydrogen target 100 cm long, and geometrical efficiency of the detectors 25%. The invariant cross section was parametrized in accordance with Ref. 17:

$$f = Ed^3\sigma/dp^3 = Cp_\perp^{-n}\exp(-bx_T), \tag{6}$$

where $C = 1.42\times 10^{-26}$ cm^2/GeV^2, $n = 8.6$, and $b = 12.9$.

The error in the single-spin asymmetry A_N was estimated by means of the expression

$$\Delta A_N = \Delta\varepsilon\chi/P_B, \tag{7}$$

TABLE I. Estimates of the accuracy of measurements of the asymmetries A_N and A_{LL} in the inclusive reaction $p + p \to \pi^0 + X$.

$p_\perp$, GeV/c	$x_\perp$	Δx_F	$\Delta p_\perp$, GeV/c	N_N	ΔA_N, %	N_{LL}	α	ΔA_{LL}, %
2	0.17	0.10	0.5	—	—	$4.4\cdot 10^6$	10	0.4
3	0.25	0.125	1.0	$7.8\cdot 10^5$	0.22	$1.2\cdot 10^5$	13	3.0
4	0.34	0.15	1.0	$2.8\cdot 10^4$	1.3	$4.1\cdot 10^3$	17	17
5	0.42	0.20	1.0	$1.9\cdot 10^3$	4.8	$2.8\cdot 10^2$	20	69
6	0.51	0.30	1.0	$2.1\cdot 10^2$	14.0	$3.1\cdot 10^1$	—	—

where $\chi = N_T/(N_R + N_L)$; $\Delta\varepsilon = 1/\sqrt{N_T}$; N_R and N_L are the counts corresponding to the effect in the case of scattering to the right or to the left, respectively; $N_T = N_R + N_L + 2N_B$ is the total count, including the background contributions N_B. For the two-spin asymmetry A_{LL} the accuracy of the measurement is determined by

$$\Delta A_{LL} = \chi\alpha\Delta\varepsilon/P_BP_\perp, \tag{8}$$

where α takes into account the presence of "ballast" material (carbon and oxygen mainly) in the polarized target. This quantity depends on the kinematic parameters, in particular $p_\perp$.

In view of the absence of experimental data it was assumed as an estimate that α varies from 10 to 20 as p varies from 2 to 5 GeV/c. For $\chi = 1.1$ in the case of A_N and $\chi = 1.5$ in the case of A_{LL} and 1000 h of operation of the accelerator, the expected statistical accuracies are given in Table I and are shown in Fig. 3 (black circles).

Similar estimates were made for the accuracy of the single-spin asymmetry in the production of direct photons under the assumption that the ratio γ/π^0 varies from 0.08 at $p_\perp = 3$ GeV/c to 0.15 at $p_\perp = 5$ GeV/c (Ref. 16) and $\chi = 1.1$. The results of the estimate are given in Table II.

The estimates obtained for A_N are given in Fig. 7 and plotted on the theoretical prediction in accordance with QCD. In the proposal of the experiment the systematic errors and possible ways of taking them into account or suppressing them are analyzed. A total of 2600 h of operation of the accelerator is planned for the complete program. At the same time, it is noted that this experiment can be combined with some other proposed experiments .

4. ASYMMETRY IN THE INCLUSIVE PRODUCTION OF PIONS AND KAONS AT LARGE x USING A POLARIZED BEAM (ANL–KYOTO–TRIESTE–ANNECY–LBL–NWU–RICE COLLABORATION: P-674)

In this experiment, it is posposed to measure the asymmetry in the inclusive reactions

TABLE II. Estimates of the accuracy of measurement of the asymmetry A_N for direct production of photons in the reaction $p_\uparrow + p \to \gamma + X$.

$p_\perp$, GeV/c	$x_\perp$	Δx_F	$\Delta p_\perp$, GeV/c	γ/π^0	N	ΔA_N, %
3	0.25	0.125	1.0	0.08	$6.3\cdot 10^4$	1.0
4	0.34	0.15	1.0	0.12	$3.3\cdot 10^3$	4.4
5	0.42	0.20	1.0	0.15	$2.9\cdot 10^2$	14.5
6	0.51	0.30	1.0	0.19	$3.9\cdot 10^1$	39.0

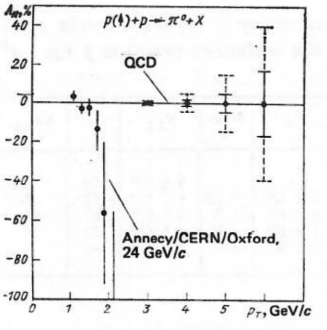

FIG. 7. Dependence of the single-spin asymmetry at 300 GeV/c on $p_\perp$. The expected statistical errors: continuous bar for π^0 and broken bar for direct photons.

$$\left.\begin{array}{l} p_\uparrow + p \to \pi^\pm + X(\text{a}); \\ p_\uparrow + p \to K^+ + X(\text{b}), \end{array}\right\} \quad (9)$$

with a transversely polarized proton beam using a liquid-hydrogen target, and a multipurpose magnetic spectrometer with proportional chambers and gas threshold Cherenkov counters. The measured kinematic region lies within the limits $p_\perp \leqslant 1.5$ GeV/c and $x = p_L^*/p_{\max} = 0.5-0.9$. If appreciable asymmetry at small $p_\perp$ is detected, the apparatus of this experiment can be used as a polarimeter in other experiments. Some of the apparatus can be used as a polarimeter for measurements in the region of Coulomb–nuclear interference.

The interest in the reaction (9a) is due to the fact that in this reaction appreciable asymmetry has been found at momenta 6 and 12 GeV/c (see Fig. 8).[18,19] Its value reaches 30–40% for $x \geqslant 0.7$, increases with increasing x and p_T, and, evidently, does not depend on the initial energy. As yet, there is no theoretical understanding of such a large effect, although there have been attempts to associate it with backward pion–nucleon elastic scattering.[19,20]

One can put forward qualitative arguments suggesting that these large asymmetry effects could arise at the level of the interaction of constituents. The SLAC experiments on deep inelastic ep scattering showed[7] that the leading quark preserves the longitudinal polarization of the proton with a high probability at large x. One may assume that it also transmits well the transverse spin component of the proton. On the other hand, study of the polarization of inclusively produced Λ particles shows[21] that, in all probability, a pair of quarks

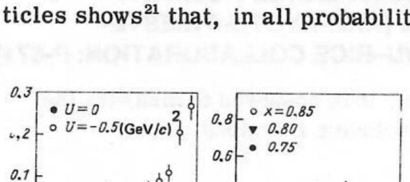

FIG. 8. Dependence of asymmetry in the inclusive production of π^- in pp collisions on x (a) and u (b). Initial momentum 12 GeV/c.

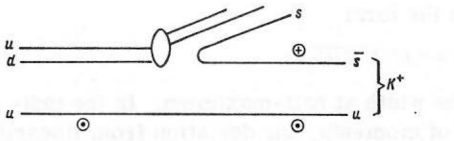

FIG. 9. Scheme of inclusive production of K^+.

produced in strong interactions is also polarized. In such a case, the scheme given below readily shows that pions and kaons with large x must lead to a large left-right asymmetry. In the reaction (9b), shown in the scheme in Fig. 9, the leading u quark transmits information about the transverse spin component of the proton. To form a K^+, it must capture an $\bar{s}$ quark with opposite orientation of the spin (spin $K^+=0$). Exactly the same mechanism leads to the production of Λ particles, i.e., the asymmetry in the inclusive production of K^+ is proportional to the polarization in the inclusive production of Λ, multiplied by the probability for transmission of the transverse component of the polarization in the kinematic region in which we are interested. Using an analogous scheme, one can show that the presence of asymmetry for the inclusive production of $\pi^\pm$ mesons will indicate the capability of u and d quarks to preserve a memory of the proton spin.

The arrangement of the proposed experimental apparatus is shown in Fig. 10. The hodoscopes H1 and H2, with spatial resolution 1.5 mm, determine the angle of incidence of the beam particle on the liquid-hydrogen target LHT. The hodoscopes H3–H5, with the same resolution, are used as a trigger in the detection of the secondary particles. The momentum of the secondaries is determined from the deflection angle in the magnet BM109, the angle being measured by the proportional chambers PC1–PC10. The determination of the sign of the charge, in particular of the π^- mesons, is made easier by the sign of the curvature of their trajectory, which is opposite to the sign of the curvature of the proton-beam trajectory. The scintillation counter C_{π^-} ensures a sufficiently clean trigger for the π^-. An additional improvement in the π^- selection can be achieved by the two threshold Cherenkov counters Č1 and Č2.

It is somewhat harder to organize the π^+ trigger. For this purpose, the counters Č1 and Č2 in coincidence are used; each of them must give a suppression factor of order 10^{-2}. An additional suppression of the proton background ($p/\pi^+ = 10^3$ for $x = 0.9$) is ensured by the Cherenkov-radiation detector C.I.D. Identification of K^+ mesons with momenta 300 GeV/c by the traditional

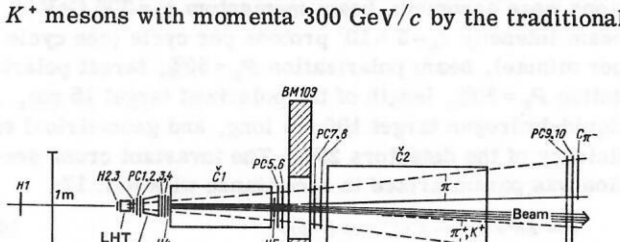

FIG. 10. Schematic arrangement of apparatus 39 for measuring the asymmetry in the inclusive production of pions and kaons at large x.

TABLE III. Estimate of measurement times.

Reaction	Region of simultaneous measurements		Beam intensity, I_0 (polarized protons per cycle)	ΔA (10 bins with respect to p_T for $x = 0.05$)	Beam time required (60 cycles per hour), h	
	p_T, GeV/c	x				
$p_\uparrow + p \to \pi^+ + X$	0.1–1.0	0.5–0.85	10^7	$0.01/P_B$	120	Simultaneous measurements
$\to \pi^- + X$	0.1–1.0	0.5–0.9	10^7	$0.015/P_B$	300	
$\to K^+ + X$	0.1–1.0	0.5–0.8	10^7	$0.02/P_B$	300	
$p_\uparrow + p \to \pi^+ + X$	1.0–1.5	0.5–0.85	$3 \cdot 10^7$	$0.01/P_B$	400	Simultaneous measurements
$\to \pi^- + X$	1.0–1.5	0.5–0.9	$3 \cdot 10^7$	$0.02/P_B$	400	
$\to K^+ + X$	1.0–1.5	0.5–0.8	$3 \cdot 10^7$	$0.03/P_B$	400	

methods is harder. Here, it is possible to use the C.I.D. or some other technique that may appear in three or four years' time.

The results of calculations of the counting rate and the required accelerator time for the initial stage of the experiment are given in Table III. In these calculations, the parametrization of the inclusive cross sections employed in Ref. 22 was used. In addition to the 700 h given in Table III, a further 200 h is needed to adjust the apparatus. If appreciable asymmetry is detected (~0.2–0.3), this spectrometer can provide the basis of a polarimeter ensuring measurement of the beam polarization with accuracy $\Delta P_B/P_B = 0.05$ over 20′.[23]

5. PROPOSAL TO STUDY THE SPIN DEPENDENCE IN THE INCLUSIVE PRODUCTION OF Λ PARTICLES USING A POLARIZED BEAM AT FERMILAB (ANL-KYOTO-ANNECY-LBL-NWU-RICE-SACLAY-SERPUKHOV-TRIESTE COLLABORATION: P-677)

A cycle of measurements of the polarization of inclusively produced Λ particles showed[21] that the polarization increases with increasing $p_\perp$ and is almost independent of the material of the target and the initial energy. This fact has not found quantitative explanation, though there are a number of theoretical studies that pretend to a qualitative interpretation of it.[24,25] It is therefore very important to continue investigations using polarized beams, and also polarized targets, and from these experiments it is possible to find such important characteristics as the spin distribution of the gluons in nucleons, the polarization of the sea quarks, the spin correlations in quark–quark and quark–antiquark interactions, and so forth.

If a transversely polarized beam and a liquid-hydrogen target are used in one experiment on Λ production, is is possible to determine simultaneously the values of A_N and D_{NN} by means of the expressions

$$\sigma(x, p_\perp^2, \varphi) = \frac{1}{2\pi}\sigma_0(x, p_\perp^2)\,[1 + A_N(x, p_\perp^2)\,\mathbf{P}_B \cdot \mathbf{n}]; \quad (10)$$

$$(\mathbf{P}_\Lambda \cdot \mathbf{n})\,\sigma(x, p_\perp^2, \varphi) = \frac{1}{2\pi}\sigma_0(x, p_\perp^2)\,[P_0(x, p_\perp^2) + D_{NN}(x, p_\perp^2)\,\mathbf{P}_B \cdot \mathbf{n}], \quad (11)$$

where n is the normal to the reaction plane, $\mathbf{P}_B$ is the beam polarization, $P_0(x, p_\perp^2)$ is the polarization of a Λ hyperon from initially unpolarized particles, $\mathbf{P}_\Lambda$ is the resulting polarization of the Λ particles, $\sigma_0(x, p_\perp^2)$ is the spin-averaged cross section, and D_{NN} is the fraction of the polarization transmitted from the beam to the Λ particle. For a longitudinally polarized beam, one defines the parameter D_{LL}, which has the same meaning as D_{NN}. Simultaneously, one can obtain information

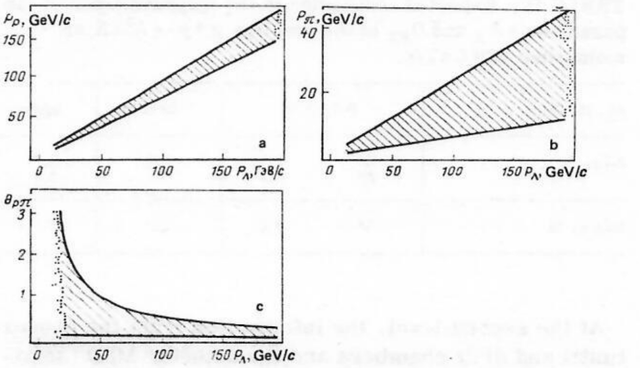

FIG. 11. Dependence of the kinematic variables of the pion and proton in the laboratory system from Λ decay in the reaction $pp \to \Lambda^0 + X \to (p\pi^-) + X$ at 200 GeV/c on the momentum of the Λ^0 particle.

about the single-spin asymmetry A_N in the inclusive production of K^0.

The Λ^0 particles are identified by means of the decay $\Lambda^0 \to p\pi^-$, which has characteristic distributions (Fig. 11); namely, the momenta of the secondary particles and their angles of emission relative to the direction of the parent particle lie in the ranges

$$\text{for protons } 0.72p_\Lambda \leqslant p_p \leqslant 0.90p_\Lambda;\ 0 \leqslant \theta_p \leqslant 124/p_\Lambda \text{ (mrad)} \quad (12)$$

$$\text{for pions } 0.06p_\Lambda \leqslant p_\pi \leqslant 0.23p;\ 0 \leqslant \theta_\pi \leqslant 679/p_\Lambda \text{ (mrad).} \quad (13)$$

Therefore, a preliminary separation of a $p\pi^-$ pair can be made in the wide-aperture magnet SCM105 (Fig. 12), and a more accurate measurement of the angular and momentum characteristics of the proton can be made by the small-aperture magnetic spectrometer BM109 with high resolution, which leads to an appreciable suppression of the background from accompanying particles.

The trigger is organized successively by two levels: 1) using counters and fast "sewing" electronics; 2) with event selection on line by means of microprogram processors. At the first level, the following conditions must be satisfied: the presence of signals in the beam hodoscopes HB1 and HB2; the number of signals in H2 must be twice the number in H1 (nominally, decay of a neutral particle into two charged particles); correlation in time and space between the counters of the hodoscopes H3 and H4; the absence of pulses in the counters A1, A2, and A3 to suppress beam particles that have not interacted; pulses from the Cherenkov counters Č1 and Č2 indicating the particle species.

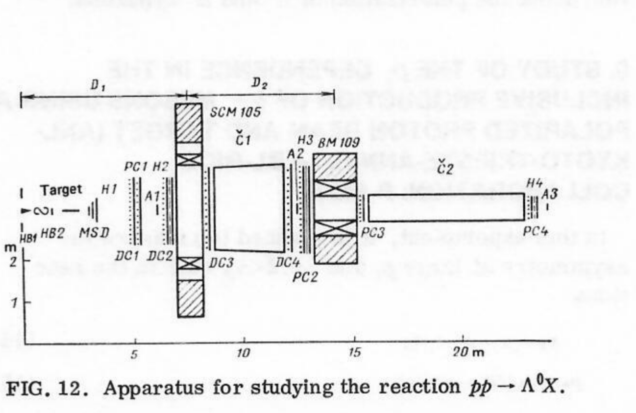

FIG. 12. Apparatus for studying the reaction $pp \to \Lambda^0 X$.

TABLE IV. Expected accuracies in the measurements of the parameters A_N and D_{NN} in the reaction $p + p \rightarrow \Lambda^0 + X$ at momentum 200 GeV/c.

$p_\perp^2$, (GeV/c)^2		0.3±0.06	2.2±0.44	5±1
ΔA_N, %	Λ^0 K^0	0.1 0.3	0.5 2.5	3.7 2.9
ΔD_{NN}, %	Λ^0	0.2	1.0	8

At the second level, the information from the proportional and drift chambers and the detector MSD (semiconductor silicon detectors), which determine the multiplicity, is read out by a signal from the first-level trigger. A fast microprogram processor[26] uses this information to check whether the multiplicity in the proportional chamber PC1 is two times greater than in the detector MSD. Thereafter, it can determine the decay vertex and make a preliminary selection of the necessary events.

Monte Carlo measurements show that the Λ^0 decays can be masked in 10% of the cases by the decay $K^0 \rightarrow \pi^+\pi^-$ in the distribution with respect to the invariant mass.

Using an empirical parametrization of the differential cross section of the $pp \rightarrow \Lambda^0 X$ reaction,[27] calculations were made of the expected accuracy of the measurements of the parameters A_N and D_{NN} for an intensity 10^7 of the polarized protons per cycle (cycle duration 20 sec, 1 cycle per minute frequency) and a liquid-hydrogen target of length 50 cm. The beam polarization was taken to be 45% and the background-to-signal ratio to be 1:2. The expected accuracies of the measurements are given in Table IV. The program of the experiment foresees several stages. For the first stage of operation with a polarized beam (transversely and longitudinally polarized) a total of 1600 h are needed, these being distributed as follows:

Adjustment of apparatus and calibration . . . .160 h

Measurements of A_N and D_{NN}. . . . . .720 h

Measurements of D_{LL}. . . . . .720 h

In the second stage, it is intended to work with a polarized antiproton beam, and in the third with a polarized target with higher hydrogen content than the currently used organic materials. If in addition a gamma detector is used, it will also be possible to obtain information about the polarization of Σ^0 and Ξ^0 hyperons.

6. STUDY OF THE $p_\perp$ DEPENDENCE IN THE INCLUSIVE PRODUCTION OF $\pi^\pm$ MESONS USING A POLARIZED PROTON BEAM AND TARGET (ANL-KYOTO-TRIESTE-ANNECY-LBL-RICE COLLABORATION: P-682)

In this experiment, it is planned to measure the asymmetry at large $p_\perp$ and $-0.2 < x_F < 0.2$ in the reactions

$$p_\uparrow + p \rightarrow \pi^\pm + X; \quad (14)$$

$$p_\uparrow + p_\uparrow (d_\uparrow) \rightarrow \pi^\pm + X. \quad (15)$$

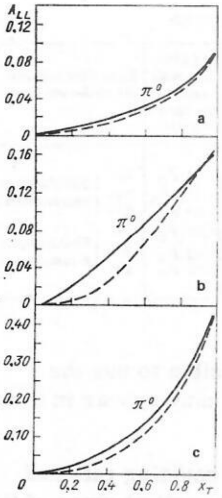

FIG. 13. Dependence of the asymmetry A_{LL} for the reaction $p + p \rightarrow (\pi^0$ or jet$) + X$ on x_T for different distributions of quarks in the hadron: a) conservative distribution; b) diquark distribution; c) the distribution of Carlitz and Kaur; the continuous curve is for π^0, the broken curve for a jet.

At large $p_\perp$, QCD predicts zero single-spin asymmetry A_N in the reaction (14) and appreciable effects for the two-spin asymmetry A_{LL} in reactions of the type (15) (Fig. 13).[28] The scheme is shown in Fig. 14 and involves a two-arm spectrometer based on the magnets BM105, proportional and drift chambers, and scintillation hodoscopes. Multichannel threshold Cherenkov counters are used to identify the secondary particles. The trigger is determined by pulses from the hodoscopes H1 (16 counters 2-cm wide) and H2 (two overlapping layers of scintillators 12.5-cm wide) with the aim of determining a minimal $p_\perp$ momentum transfer as a lower threshold. This threshold can change. For this experiment, the quality of the polarized target is praticularly important, and the authors, after a detailed discussion, favor a ^{6}LiD target, which has effective polarization of 30%.[29] In veiw of the strong dependence of the cross sections of the reactions (14) and (15) on $p_\perp$, there is a detailed disussion of various sources of spurious asymmetry (unwanted components of the polarization and nonuniformity of the beam profile, the accuracy in the measurement of $p_\perp$, nonuniformity of the target density, etc.).

The results of Ref. 30 were used to estimate the counting rate. The errors given in Table V are the statistical errors. Systematic inaccuracies are expected at the 0.3% level.

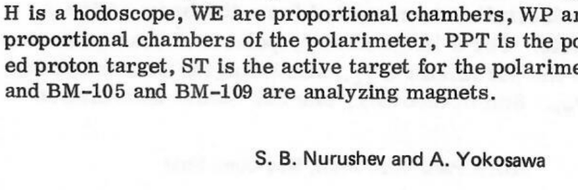

FIG. 14. Two-arm spectrometer for studying the $p_\perp$ dependence of the $\pi^\pm$ asymmetry with polarized beam and target. H is a hodoscope, WE are proportional chambers, WP are proportional chambers of the polarimeter, PPT is the polarized proton target, ST is the active target for the polarimeter, and BM-105 and BM-109 are analyzing magnets.

TABLE V. Counting rate and statistical errors.

Time, h	Number of cycles	Total intensity, particles/cycle	Beam polarization	Fraction of interactions in target	Target	Number of events	Physical asymmetry, %	Cross sections for triggering interaction, nb	Max. $p_\perp$, GeV/c	Width of $p_\perp$ bins, GeV/c	Width of x bins
					Measurements of A_N						
700	$4\cdot10^4$	10^{12}	0.45	0.1	H_2	$5\cdot10^4$	1	20	2.9	0.05	0.1
						$6\cdot10^3$	3	2.5	3.2	—	—
						$5\cdot10^2$	10	0.2	4.0	—	—
						$5\cdot10^2$	10	0.2	4.9	0.1	0.2
					Measurements of A_{LL}						
700	$4\cdot10^4$	10^{12}	0.45	0.3	(^{6}LiD)	$5\cdot10^6$	1	66	2.5	0.05	0.1
						$6\cdot10^4$	3	8	3.1	—	—
						$5\cdot10^3$	10	0.7	3.7	—	—
						$5\cdot10^3$	10	0.7	4.1	0.1	0.2

It is proposed to perform the experiment in two stages:

1) With a polarized beam and a liquid-hydrogen target. The single-spin asymmetry A_N is measured. According to the estimates, 200 h will be needed for adjustment work and 700 h for the measurements:

2) With a polarized beam and a polarized target. It is planned to use 100 h for the adjustment work and 700 h to measure the two-spin asymmetry A_{LL}.

7. DEPENDENCE OF THE SINGLE-SPIN ASYMMETRY ON THE SIZE OF THE NUCLEUS IN THE PRODUCTION OF HADRONS WITH LARGE $p_\perp$ (ANL-RICE COLLABORATION: P-688)

The aim of the experiment is to measure the A dependence of the single-spin asymmetry A_N in the production of individual hadrons and in the production of jets at large momentum transfers. The interest in such measurements is due to the fact that the determination of the A dependence of the cross sections of inclusively produced hadrons[31] or pairs,[32] and also jets,[33] has revealed a dependence of the type $A\alpha(p_\perp)$, where $\alpha>1$ at large $p_\perp$. There are various models that claim to describe this effect, but it is clear that without further accumulation of experimental facts it is impossible to make an unambiguous choice between them. Qualitative arguments can be put forward as to why the single-spin asymmetry should have an A dependence. Suppose that processes with large $p_\perp$ are determined primarily by one-gluon exchange and small contributions of the diagrams of higher order. One-gluon exchange conserves the quark helicity, whereas the exchange of two

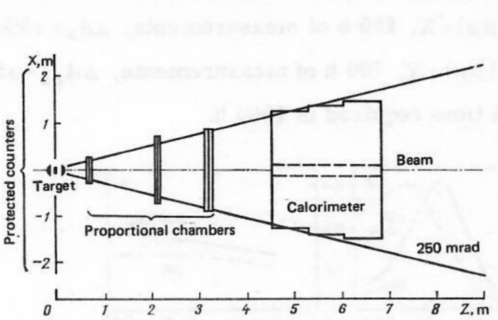

FIG. 15. Arrangement of calorimeter for use on polarized beam to study the dependence of the asymmetry on the size of the nucleus in the production of hadrons with large $p_\perp$.

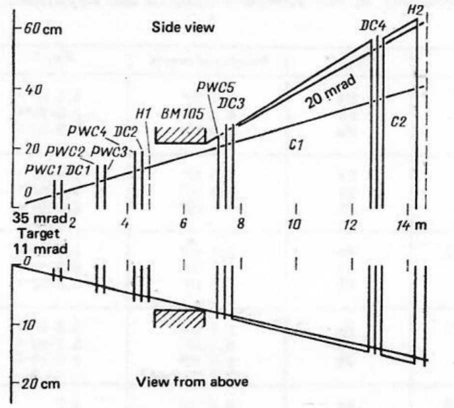

FIG. 16. Schematic arrangement of one of the arms of the two-arm spectrometer. Each arm is at an angle of 70 mrad to the beam. There must be coincidence between definite counters of the hodoscopes H1 and H2, which makes it possible to restrict the minimal selected momentum to the range from 25 to 50 GeV/c.

or more gluons does not. The single-spin asymmetry arises as a result of the interference of these two amplitudes. It is easy to see that the amplitude corresponding to one-gluon exchange has an $A^{1/2}$ dependence, whereas the exchange of two gluons leads to a dependence of the amplitude proportional to A. Taking the interference of the two amplitudes and dividing by the cross section, we obtain an A dependence of the single-spin asymmetry proportional to $A^{1/2}$.

There are two modifications of the experiment in accordance with its tasks: 1) for the measurement of jets, it is planned to use the calorimeter from the experiment P-699 (Fig. 15); 2) to measure the inclusive asymmetry, it is intended to use the apparatus from experiment P-682 (Fig. 16). In both cases, it is planned to reduce the systematic errors by placing in the beam simultaneously three targets (Be, Fe, and Pb) one after the other with thicknesses of 0.1 nuclear lengths, the statistics being accumulated in parallel. This is possible if the interaction vertex can be established with good accuracy. Drift of the apparatus is eliminated by frequent reversal of the beam polarization.

The successive arrangement of the targets can lead to two undesirable effects: attenuation of the beam by the preceding target and variation of the acceptance with z. To avoid these consequences, it is intended to

TABLE VI. Accuracy in the measurements of the assymmetry of single pions.

$p_\perp$, GeV/c	Target	Number of events	ΔA_N, %
2.9	Be	$3.4\cdot10^4$	1.1
	Fe	$6.0\cdot10^4$	0.9
	Pb	$9.9\cdot10^4$	0.7
3.2	Be	$4.1\cdot10^3$	3.3
	Fe	$7.1\cdot10^3$	2.6
	Pb	$1.2\cdot10^4$	1.9
4.0	Be	795	7.5
	Fe	1390	5.7
	Pb	2320	4.4

TABLE VII. Accuracy in the measurement of the asymmetry of jets.

p_1, GeV/c	α	Target	Number of events	A_N, %
3	1.3	Be	$2.4\cdot10^{9}$	$4.4\cdot10^{-3}$
		Fe	$4.2\cdot10^{9}$	$3.6\cdot10^{-3}$
		Pb	$6.2\cdot10^{9}$	$2.9\cdot10^{-3}$
4	1.5	Be	$2.6\cdot10^{7}$	$4.4\cdot10^{-2}$
		Fe	$6.5\cdot10^{7}$	$2.7\cdot10^{-2}$
		Pb	$1.2\cdot10^{8}$	$2.0\cdot10^{-2}$
5	1.62	Be	$2.1\cdot10^{6}$	$1.5\cdot10^{-1}$
		Fe	$6.5\cdot10^{6}$	$8.7\cdot10^{-2}$
		Pb	$1.5\cdot10^{7}$	$5.8\cdot10^{-2}$
6	1.75	Be	$1.7\cdot10^{5}$	$5.3\cdot10^{-1}$
		Fe	$6.7\cdot10^{5}$	$2.7\cdot10^{-1}$
		Pb	$1.8\cdot10^{6}$	$1.7\cdot10^{-1}$
7	1.75	Be	$9.7\cdot10^{3}$	2.2
		Fe	$3.8\cdot10^{4}$	1.1
		Pb	$1.0\cdot10^{5}$	0.69

change the positions of the targets periodically.

Estimates of the expected statistics and the accuracy of the measurements of the asymmetry in the inclusive production of hadrons ($\alpha=1.1$, $P_B=50\%$, $X=0.1$ nuclear lengths, $T=300$ h of measurements or 4.3×10^{11} protons) and jets ($T=100$ h) are given in Tables VI and VII.

Assuming that the apparatus will have been adjusted in the previous experiments, the complete program requires 400 h of beam time.

8. MEASUREMENTS OF THE ASYMMETRY IN THE PRODUCTION OF DIMUONS IN THE MASS REGION OF THE J/ψ PARTICLES (ANL–KYOTO–ANNECY–LBL–NWU–RICE–TRIESTE COLLABORATION: P-675)

The aim of this project is to measure the single- and two-spin asymmetry in the decay into two muons of J/ψ particles produced by polarized protons and antiprotons on polarized targets, and also different nuclei.

The importance of such experiments is justified both by qualitative arguments and by the results of quantitative calculations. The qualitative argument is that since the J/ψ particle has spin 1 and is produced basically by the gluon–gluon interaction, not all intermediate states are involved. For example, the states with projection $J_z=2$ of the total angular momentum are not; only those with $J_z=0$ are. In this case, the two-spin asymmetry $\hat{A}_{LL}$ for the constituents is equal to 100%, and the measured asymmetry is $A_{LL}=(P_g)^2\hat{A}_{LL}$, where P_g is essentially the initial polarization of the gluons. If it is assumed that the gluons transmit completely the polarization of the quarks, and the latter are polarized to 30% (as found from deep inelastic ep scattering), then $A_{LL}\approx10\%$. Thus, from the experimental data it is possible to recover the distribution of the gluons from the polarization states in the nucleons.

The quantitative estimates made in Ref. 34 using perturbation theory in QCD show that at 200 GeV/c the expected asymmetry A_{LL} is near zero in pp interactions and is of order 10–20% in $\bar{p}p$ interactions.

The yield of dimuons will be measured by the apparatus shown in Fig. 17. The momenta p_1 and p_2 of both

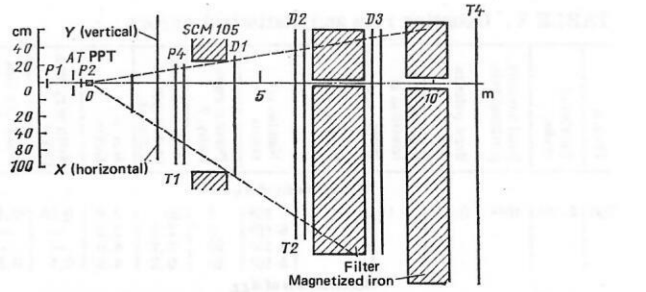

FIG. 17. Variant of experiment to measure asymmetry in the production of dimuons in the region of masses of the J/ψ particles. P1–P4 are proportional chambers, D1–D3 are drift chambers, T1–T4 are scintillation hodoscopes, AT is a protected counter, PPT is the polarized proton target, and SCM105 is an analyzing magnet.

the muons passing through the absorber and the angle θ between them are measured. Then the dimuon mass can be recovered from the relation

$$M^2_{\mu\mu}\approx2p_1p_2(1-\cos\theta). \qquad (16)$$

Figure 18 shows the acceptance, which for J/ψ events is 35%, while the mass resolution is 2.5% at the momentum 400 GeV/c.

Monte Carlo calculations show (Fig. 19) that the background from random imitation of dimuon pairs by decays of π and K mesons is 0.2 events per cycle in the region of the J/ψ masses, whereas the effect is expected to be at the level 2.4 events per cycle. However, the background increases sharply with decreasing mass of the muon pair, increasing the load on the apparatus. In this case, a different arrangement of the apparatus is foreseen (Fig. 20), aimed at suppressing the background and decreasing the load on the proportional and drift chambers. However, a shortcoming of this apparatus is the worse mass resolution and poor resolution in the reconstruction of the vertex.

The program of measurements foresees the following stages:

I. At 400 GeV/c

$p_\uparrow+p\to(\mu\mu)+X$, 100 h of measurements, $\Delta A_N=\pm2\%$;

$p_\uparrow+p_\uparrow\to(\mu\mu)+X$, 800 h of measurements, $\Delta A_{LL}=\pm2\%$;

at 200 GeV/c

$p_\uparrow+p_\uparrow\to(\mu\mu)+X$, 150 h of measurements, $\Delta A_{LL}=\pm5\%$.

II. At 200 GeV/c with the antiproton beam

$\bar{p}_\uparrow+p\to(\mu\mu)+X$, 150 h of measurements, $\Delta A_N=\pm5\%$;

$\bar{p}_\uparrow+p_\uparrow\to(\mu\mu)+X$, 700 h of measurements, $\Delta A_{LL}=\pm5\%$.

The total time required is 1900 h.

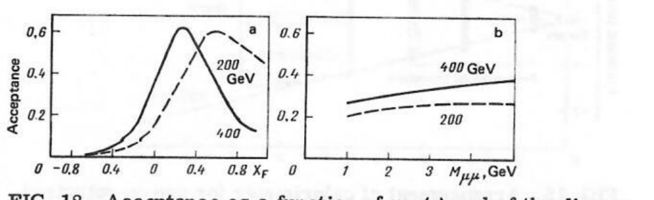

FIG. 18. Acceptance as a function of x_F (a) and of the dimuon mass (b).

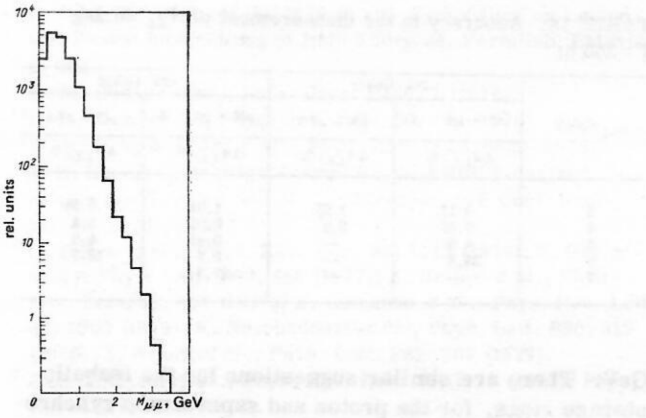

FIG. 19. Dependence of the random background of muon pairs on their mass.

9. MEASUREMENT OF THE ASYMMETRY IN PROCESSES WITH LARGE $p_\perp$ THAT ARE IDENTIFIED BY A CALORIMETER AND USE A POLARIZED BEAM AND POLARIZED TARGET (ANL–KYOTO–ANNECY–LBL–LEHIGH–PHILADELPHIA–RICE–SACLAY–TRIESTE–MADISON: P-699)

The intension is to measure the single-spin asymmetry A_N and the two-spin asymmetry A_{LL} in the case of individual hadron production and also in jet-like events with large $p_\perp$. Measurements with a polarized proton beam are planned at momentum 400 GeV/c, and with proton and antiproton beams at momentum 200 GeV/c.

The development of perturbation theory in QCD has led to the establishment of a connection between the experimentally observed asymmetries and the distributions of the constituents with respect to the polarization states within the hadrons. In particular, investigation of the asymmetry in jet production gives information about the spin distribution of the gluons, which cannot be obtained in deep inelastic ep scattering. In addition, by varying the region of $p_\perp$ and the beam (p and $\bar{p}$), one can attempt to determine the part played by individual fundamental processes of the type $qG\to qG, \bar{q}q\to GG, GG\to GG$, etc.

In contrast to single jets, in which processes of the type $qG\to qG$ are predominant, in two-jet events $qq\to qq$ processes play an important part at large x. The expected values of the two-spin asymmetry for the reactions $pp\to\pi^{\pm}X$, $pp\to(\pi^0$ or jet$)+X$, and $\bar{p}p\to(\pi^0$ or jet$)$

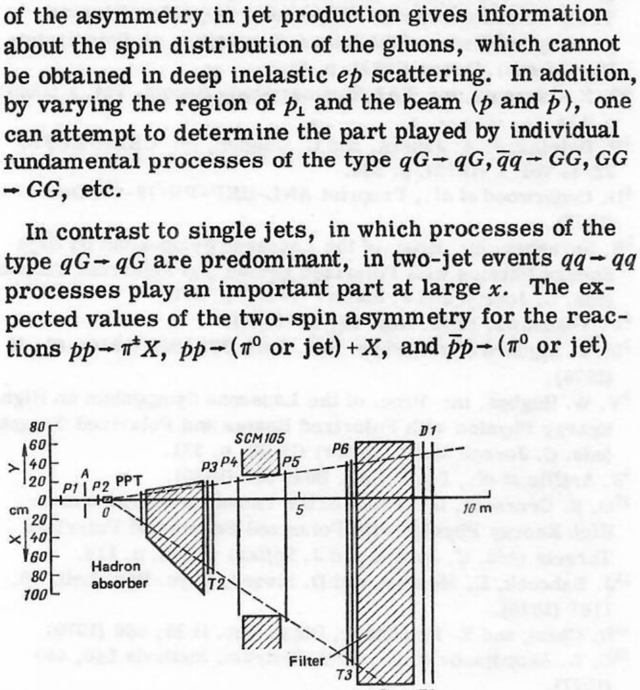

FIG. 20. Variant of experiment for measuring the asymmetry in the production of dimuons using a hadron absorber.

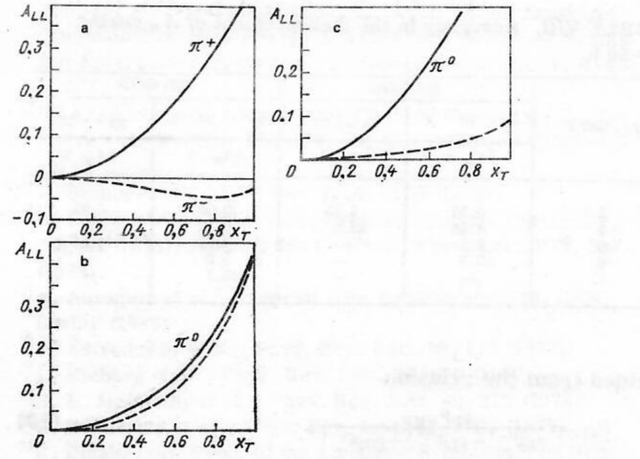

FIG. 21. Dependence of two-spin asymmetry A_{LL} in the reactions $p+p\to\pi^{\pm}+X$ (a), $p+p\to\pi^0$+jet (b), and $\bar{p}+p\to\pi^0$+jet (c) on x_T.

$+X$, which can attain appreciable values, are given in Fig. 21. The experiment intended for such measurements is shown schematically in Fig. 22. The calorimeter covers the complete azimuthal angle and detects events in the interval $30\leq\theta_{cms}\leq 110°$ with rapidity resolution $\Delta y = 0.4$. The solid angle around the jet axis varies in the interval 1–2 sr with the aim of a more accurate determination of $p_\perp$ ($\pm$0.3 GeV/c). It is known from the experiment E-609 that the uniformity of the calorimeter is $\pm$4%. The same fluctuation in the amplification of the calorimeter is observed with time constant 24 h. To reduce the influence of this factor on the final results, frequent reversal of the beam polarization is proposed (every cycle, for example). Similar, to reduce the systematic errors the polarization of the target will be reversed every few hours.

For the measurements of A_N, a liquid-hydrogen target of length 100 cm will be used, and to measure A_{LL} a polarized ^{6}LiD target of length 20 cm (0.25 of the nuclear interaction length).

Preliminary investigations of an analogous calorimeter in the experiment E-395 showed that its resolution is

$$\text{for hadrons}\quad \Delta E/E = 0.75/\sqrt{E}; \tag{17}$$

$$\text{for electrons}\quad \Delta E/E = 0.14/\sqrt{E}. \tag{18}$$

The effective polarization of the ^{6}LiD target is deter-

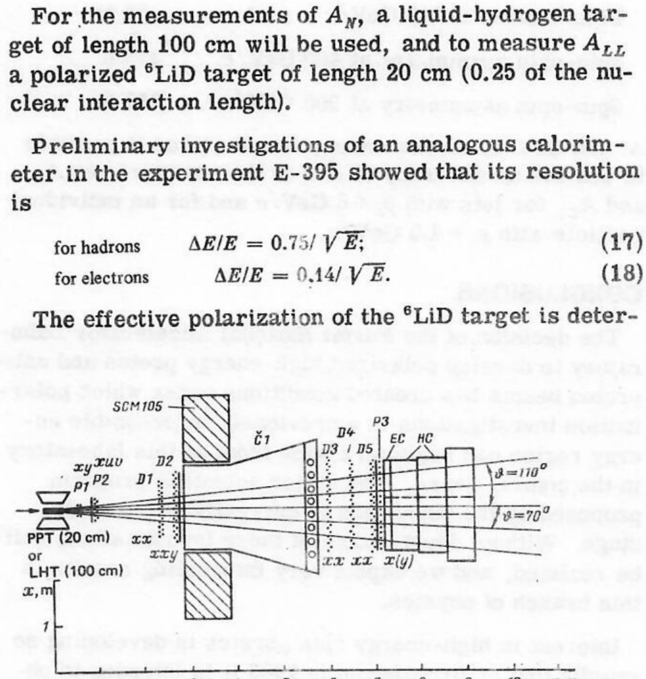

FIG. 22. General arrangement of experiment for detecting events with large $p_\perp$.

TABLE VIII. Accuracy in the measurement of A_N during $T = 50$ h.

$p_\perp$, GeV/c	200 GeV/c		400 GeV/c	
	$\bar{p}p \to$ jet X	$\bar{p}p \to \pi^\pm X$	$pp \to$ jet X	$pp \to \pi^\pm X$
	ΔA_N, %	ΔA_N, %	ΔA_N, %	ΔA_N, %
3	0.34	4.85	0.03	0.85
4	1.46	23.8	0.12	3.4
5	6.5	—	0.62	11.5
6	29.5	—	3.2	—
7	—	—	16.7	—

TABLE IX. Accuracy in the measurement of A_{LL} during $T = 350$ h.

$p_\perp$, GeV/c	200 GeV/c		400 GeV/c	
	$\bar{p}N \to$ jet X	$\bar{p}N \to \pi^\pm X$	$pN \to$ jet X	$pN \to \pi^\pm X$
	ΔA_{LL}, %	ΔA_{LL}, %	ΔA_{LL}, %	ΔA_{LL}, %
3	0.17	1.95	1.01	0.34
4	0.86	9.5	0.07	1.4
5	4.5	—	0.43	4.6
6	24.8	—	2.7	13.7
7	—	—	17.8	—

mined from the relation

$$P_{eFF} = \frac{\rho_D P_{NMR}}{\rho_D 2^{\alpha-1} + \rho_{Li} 6^{\alpha-1} + \rho_{He} 4^{\alpha-1}}, \quad (19)$$

where ρ_i is the density of the materials of the target, $1 < \alpha < 2$, and $P_{NMR} = 75\%$. Then

$$Pe_{FF} = [0.33 - (\alpha - 1)/4]. \quad (20)$$

Here, for a jet $\alpha = 1 + p_\perp/8$. The cross sections for jet production at 400 GeV/c were parametrized by

$$E\frac{d^3\sigma}{dp^3} = 10^{-28} \cdot 10^{-1.5(p_\perp - 3)} \text{mb/GeV}^2, \quad (21)$$

and for individual hadrons ($\pi^\pm$) by

$$E\frac{d^3\sigma}{dp^3} = \frac{15}{(1+p_\perp^2)^4} \exp(-13x_T) \text{mb/GeV}^2. \quad (22)$$

The expected accuracies of the measurements of A_N and A_{LL} are given in Tables VIII and IX.

For the fulfillment of the program, 1000 h are requested for the following measurements:

Adjustment and calibration. . . . . 150 h (parasitic time)

Polarization at 400 GeV/c . . . . 50 h

Polarization at 200 GeV/c . . . . 50 h

Spin-spin asymmetry at 400 GeV/c. . . .375 h

Spin-spin asymmetry at 200 GeV/c. . . .375 h

At 400 GeV/c, such a measurement makes it possible to achieve an accuracy of ±3% in the asymmetries A_N and A_{LL} for jets with $p_\perp \leq 6$ GeV/c and for an individual particle with $p_\perp \leq 4.5$ GeV/c.

CONCLUSIONS

The decision of the Fermi National Accelerator Laboratory to develop polarized high-energy proton and antiproton beams has created conditions under which polarization investigations in a previously inaccessible energy region can begin on a wide front at this laboratory in the coming years. The major scientific program proposed by the physicists is currently at the study stage. Without doubt, some of these investigations will be realized, and we expect very interesting results in this branch of physics.

Interest in high-energy spin physics is developing so rapidly that at Brookhaven in 1983 it is intended to obtain an accelerated polarized proton beam with an energy of about 30 GeV in the AGS, while at Dubna polarized deuterons have already been accelerated to 10 GeV. There are similar suggestions for the Isabelle storage rings, for the proton and superproton synchrotrons at CERN, at KEK in Japan, and at Fermilab. It is evident that the time is coming when this branch of physics will require coordinated plans on an international scale.

In June 1981, the Scientific Committee of Fermilab recommended the combining of the three experiments P-674, P-676, and P-678. In view of the important physics program, it was proposed that there should also be an examination of the possibility of including proposal P-677 in the first stage of the physics program. Such a combined physics program was presented at the beginning of December 1981. We were informed by Professor L. Lederman, the director of Fermilab, that this program has been approved as the polarization experiment E-704. At the time of completion of the present review (June, 1982) work on the preparation of the first stage of the polarization program is developing on a wide front (polarization experiment E-704).

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Translated by Julian B. Barbour