Measurement of the polarization parameter $M_{s'okn}$ in pp scattering at 950 MeV

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Measurements of the proton polarization after the elastic scattering of a longitudinally polarized proton beam by a polarized proton target have yielded the parameter $M_{s'okn}$ and the Wolfenstein parameters A and K_{noon} at angles of 70°, 90°, and 110° in the c.m. frame.

Many parameters of pp scattering near the energy of 1 GeV have been measured in recent years : the total cross sections σ_{tot}, σ_{tot}^{in}, $\Delta\sigma_L$, and $\Delta\sigma_T$, the differential cross section for elastic scattering, $d\sigma/d\Omega$; and the polarization parameters of the elastic scattering, i.e., the polarization P, the Wolfenstein parameters D, A, and R, and the polarization correlations A_{oonn}, A_{ookk}, and A_{oosk}. This experimental information, however, does not eliminate the ambiguity in the reconstruction of the amplitude for elastic pp scattering at an energy of 1 GeV, since the results found by phase-shift analysis by various investigators[1-5] differ significantly. A study[6] of the number of solutions of phase-shift analysis has led to the conclusion that under the assumptions of phase-shift analysis there are only two solutions, which are equally likely on the basis of their statistical criteria and which lead to only slight differences in terms of observables which depend on the components of the first- and second-rank polarization tensors (e.g., P_{oono}, D_{iojo}, and A_{ooij}). On the other hand, the predictions of these solutions are substantially different in terms of the angular dependence of the components of the third-rank tensors.

In an effort to select one of the solutions, we have measured the parameter $M_{s'okn}$ at a proton energy of 950 MeV at angles $\theta = 70°$, 90°, and 110° in the c.m. frame. The parameters $M_{s'okn}$ and $M_{k'okn}$ characterize the change in the longitudinal component of the polarization in scattering by protons which are polarized normal to the scattering plane. In the scattering of longitudinally polarized protons with a polarization P_B by vertically polarized protons with a polarization P_T, the final polarization $\langle\vec{\sigma}\rangle$ is

$$\langle\vec{\sigma}\rangle = \{(P + K_{noon}P_T)\mathbf{n} + (D_{s'oko} + M_{s'okn}P_T)P_B\,\mathbf{s}' + (D_{k'oko} + M_{k'okn}P_T)P_B\,\mathbf{K}'\}\,/\,(1 + PP_T), \quad (1)$$

where $\mathbf{n}$, $\mathbf{s}'$, $\mathbf{k}'$ is the orthonormal basis for the scattering in the laboratory frame of reference; $\mathbf{n} = [\mathbf{k}\times\mathbf{k}]$; $\mathbf{s}' = [\mathbf{n}\times\mathbf{k}']$; $\mathbf{k}$ and $\mathbf{k}'$ are unit vectors along the momenta of the incident and scattered protons; $\mathbf{P} = \mathbf{n}P$ is the polarization in the scattering of unpolarized protons; $K_{noon} = K_{nn'}$, $D_{s'oko} = A$ and $D_{k'oko} = A'$ are Wolfenstein parameters; and $M_{s'okn}$ and $M_{k'okn}$ are components of the third-rank tensor.

The measurements were carried out in a longitudinally polarized proton beam with an energy of 950 MeV at the synchrocyclotron of the Leningrad Institute of Nuclear Physics.[7] Longitudinally polarized protons were produced through scattering in the vertical plane of protons extracted from the accelerator; the scattered protons were then turned through a total angle of 24.6°. As a result of precession, the proton spins which were originally directed perpendicular to the momentum turned out to be directed along the momentum at the position of the target. The polarization of the beam was $P_B = 0.30 \pm 0.01$ and was directed either parallel or antiparallel to the momentum of the incident protons. The beam intensity in the target plane was 5×10^6 s^{-1}.

As the target we used a "frozen" polarized proton target[8]; the working medium was propanediol ($C_3H_8O_2$). The weight of the bombarded sample was about 10 g. To reduce the spin precession of the scattered protons, we reduced the field at the polarized target to 1.2 T. The maximum polarization was $P_T = 0.84 \pm 0.02$ and the polarization relaxation time was about 700 h. The polarization was measured at the beginning and end of a cycle of measurements with a given P_T direction; a cycle lasted no more than 40 h.

Elastic *pp* scattering was identified on the basis of the coincidence of signals from two scintillation telescopes, which detected the scattered particle and the recoil particle. The polarization of the scattered protons was analyzed by polarimeters consisting of proportional chambers and a carbon analyzer target positioned along the axes of the telescopes. The azimuthal distribution of the protons scattered by the analzyer target of the polarimeter is characterized by the left-right asymmetry ϵ and the up-down asymmetry δ:

$$N(\varphi) = N_0(1 + \epsilon\cos\varphi + \delta\sin\varphi), \tag{2}$$

where φ is the angle between the pp and pC scattering planes. The asymmetries ϵ and δ depend on the parameters of the pp scattering:

$$\epsilon = \frac{P(1+\alpha) + K_{nn}P_T}{1 + PP_T + \alpha} A_{pC}, \tag{3}$$

$$\delta = \frac{A(1+\alpha) + M_{s'okn}P_T}{1 + PP_T + \alpha} P_B A_{pC}, \tag{4}$$

where A_{pC} is the analyzing power of the carbon and α is the ratio of the contributions of protons which have been scattered by the hydrogen-free part of the frozen polarized proton target and of the protons which have been scattered by the protons of this target.

For a fixed c.m. scattering angle θ, we accumulated proton angular distributions $N(\varphi)$ for various combinations of the signs of the polarizations P_B and P_T. To reduce the effect of instabilities of the apparatus, we repeated the measurements two or three times with each combination of P_B and P_T directions. The angular interval of the analyzing pC scattering was $\theta_{pC}\in[5°,17°]$ for $\theta = 70°$, 90° and $\theta_{pC}\in[6°,17°]$ for $\theta = 110°$. At these angles, the effect of multiple Coulomb scattering on the analyzer target was essentially eliminated. From the resulting $N(\varphi)$ distributions we found the pp-scattering parameters P, K_{nn}, A, and $M_{s'okn}$ by minimizing the χ^2 functional, in which the unknown quantities were adjustable parameters. The parameter α in Eqs. (3) and (4) was found from measurements of the intensities of the "conjugate" coinci-

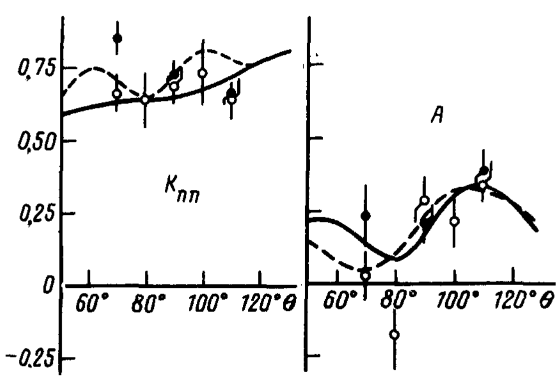

FIG. 1. Values of the parameters $K_{nn} = K_{noon}$ and A. ●—Present study; ○—results of Refs. 1 and 9. Solid line) The first solution from phase-shift analysis[1]; dashed line) the second solution from phase-shift analysis.[1]

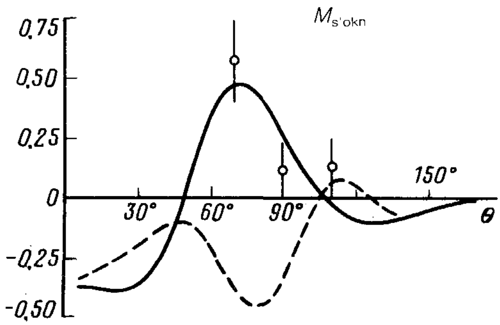

FIG. 2. Angular dependence of the parameter $M_{s'okn}$ (the notation is the same as in Fig. 1).

dences from the frozen polarized proton target and from its hydrogen-free equivalent.

Figures 1 and 2 show the values found for the parameters K_{nn}, A, and $M_{s'okn}$, along with their statistical errors. The systematic errors in the parameter values stem from the uncertainty in the scattering angle, $\Delta\theta \leqslant 5°$ c.m., and the uncertainties in the values of the polarizations P_B and $P_{T'}$ and the analyzing power. This uncertainty does not exceed $\Delta A_{pC}/A_{pC} = 0.05$. An additional error arises in the determination of A and $M_{s'okn}$ for the angles $\theta = 70°$ and $110°$ because of the precession of the proton spins in the magnetic field of the frozen polarized proton target; this error is about 5°. Under these conditions, the contribution of the longitudinal components of A' and $M_{k'okn}$ in (1) to the unknown parameters A and $M_{s'okn}$ does not exceed 0.03, according to estimates based on a phase-shift analysis. The values of the parameter A agree with those from earlier measurements.[1] The difference between the value found for K_{nn} at $\theta = 70°$ in the present study and the result of Ref. 9 does not exceed three standard deviations. The satisfactory agreement of the values found for the parameters K_{nn} and A, on the one hand, with the values found previously, on the other, is evidence that the measurement procedure is valid. The values predicted for the parameter $M_{s'okn}$ by the first phase-shift solution[1] for angles $\theta = 70°$ and $90°$ differ from those predicted by the second phase-shift solution by more than three standard deviations. It can therefore be suggested that the first solution is more likely.

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