Angular dependence of the spin-correlation parameter A_{00nn} and of the asymmetry A_{000n} in pp scattering at 950 MeV

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The angular dependences of the spin-correlation parameter A_{00nn} and of the asymmetry A_{000n} in pp scattering at 950 MeV have been measured in an experiment using a polarized beam and a polarized proton target. The results of the measurements were used to determine the phase shifts at 1 GeV more accurately.

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A phase analysis of pp scattering, which was performed after measuring the Wolfenstein parameters D, A, and R in the region of 1 GeV,[1] showed that the ambiguous predictions of the observed values can be eliminated by very accurate measurements over a broad range of scattering angles. One such value is the spin-correlation parameter A_{00nn}, whose sufficiently accurate measurements at the time of the start of our experiment were available only for two values of the scattering angle.[2]

The differential cross section for elastic scattering of a beam of polarized protons by a polarized proton target is given by the expression

$$\sigma(\theta) = \sigma_0(\theta)\,[1 + (\mathbf{P}_B\mathbf{n} + \mathbf{P}_T\mathbf{n})A_{000n}(\theta) + \mathbf{P}_B\mathbf{P}_T A_{00nn}(\theta)]$$

if the beam polarization $\mathbf{P}_B$ and the target polarization $\mathbf{P}_T$ are directed along the normal $\mathbf{n}$ to the scattering plane. Here $\sigma_0(\theta)$ is the cross section for scattering of unpolarized protons by an unpolarized proton target, A_{000n} is the scattering asymmetry of an unpolarized beam by a polarized target, and A_{000n} is the spin-correlation parameter. Counting the number of pp coincidences as a function of the direction of the beam and target polarizations relative to the normal to the scattering plane, we can

TABLE I. Angular dependence of the parameter A_{oonn} and of the Asymmetry A_{ooon}

θ	A_{oonn}	A_{ooon}
35	0.420 ±0.014	0.413 ±0.008
40	0.485 ±0.014	0.418 ±0.008
45	0.526 ±0.019	0.407 ±0.009
50	0.578 ±0.016	0.405 ±0.008
55	0.558 ±0.025	—
60	0.587 ±0.019	0.356 ±0.010
65	0.550 ±0.037	—
70	0.533 ±0.023	0.275 ±0.011
82	0.517 ±0.029	0.115 ±0.012
85	0.604 ±0.027	0.082 ±0.012
90	0.588 ±0.025	0.019 ±0.012
98	0.565 ±0.030	−0.137 ±0.013

determine the spin-correlation parameter and the scattering asymmetry

$$A_{oonn} = [(\sigma_{++} + \sigma_{--}) - (\sigma_{-+} + \sigma_{+-})]/P_B P_T (\Sigma \sigma_{ij}),$$

$$A_{ooon} = [(\sigma_{++} + \sigma_{-+}) - (\sigma_{+-} + \sigma_{--})]/P_T (\Sigma \sigma_{ij}).$$

Here $\Sigma\sigma_{ij} = \sigma_{++} + \sigma_{+-} + \sigma_{-+} + \sigma_{--}$; the first subscript refers to the beam polarization direction and the second subscript refers to the target polarization direction.

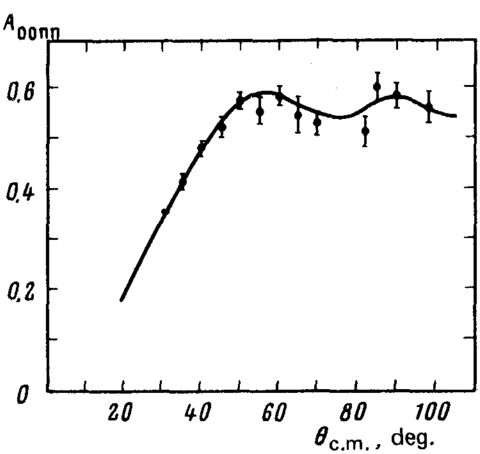

FIG. 1. This solution is close to that obtained by Hoshizaki in his study of the energy dependence of the phase shifts in the energy region of 0.5 to 2.2 GeV (Ref. 5), but, in contrast with Hoshizaki's solution, it is in agreement with the value of A_{oonn} (90°).

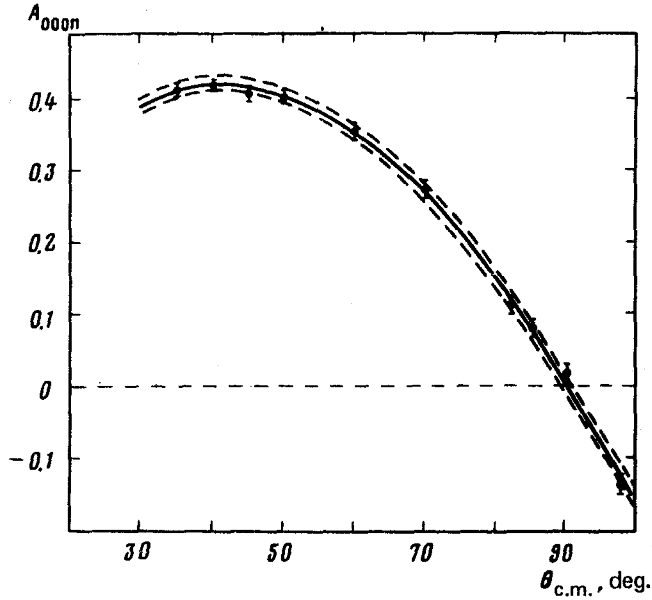

FIG. 2. Angular dependence of the asymmetry A_{000n}. ⫯ represents the results of the measurements and the solid and dashed curves denote the average values of the polarization[4] with an error margin.

The measurements were conducted using a polarized proton beam with a momentum $p = 1.64$ GeV/c. The beam polarization, which was measured by using a double-arm pp polarimeter, was $P_B = 0.305 \pm 0.010$. The absolute polarization remained the same within the limits of statistical measurement accuracy after changing

TABLE II. Phase shifts and mixing parameters in degrees.

Parameter	Re	Im	Parameter	Re	Im
$\delta(^1S_0)$	-27.9 ± 2.8	2.7 ± 4.3	ϵ_4	-2.7 ± 0.7	Fixed
$\delta(^3P_0)$	-63.1 ± 5.3	13.0 ± 4.6	$\delta(^3H_4)$	-0.7 ± 1.0	"
$\delta(^3P_1)$	-57.7 ± 3.2	3.1 ± 1.2	$\delta(^3H_5)$	-3.9 ± 1.0	"
$\delta(^3P_2)$	17.4 ± 5.4	42.8 ± 10.2	$\delta(^3H_6)$	2.8 ± 0.4	"
$\delta(^1D_2)$	6.7 ± 3.7	19.5 ± 1.9	$\delta(^1I_6)$	0.4 ± 0.4	"
ϵ_2	-7.4 ± 3.0	Fixed	ϵ_6	-0.6 ± 0.4	"
$\delta(^3F_2)$	-2.7 ± 1.7	1.1 ± 1.8	$\delta(^3I_6)$	1.2 ± 0.3	"
$\delta(^3F_3)$	-10.3 ± 1.5	9.3 ± 1.1	$\delta(^3I_7)$	-0.7 ± 0.7	"
$\delta(^3F_4)$	5.7 ± 0.9	2.6 ± 0.8	$\delta(^3I_8)$	1.2 ± 0.2	"
$\delta(^1G_4)$	3.7 ± 0.9	3.7 ± 0.5	—	—	

the direction of the polarization vector. The 90-98% polarization of the "frozen-type" proton target, in which propanediol was used as the working material, was measured to within 3% accuracy.[3] The results of the measurement of the polarization parameters A_{00nn} and A_{000n} are given in Table I and in Figs. 1 and 2. The errors in the experimental values of A_{00nn} are statistical. The relative error of A_{00nn} is $\leqslant 5\%$ because of the uncertainty in the measurements of the beam and target polarizations. The errors of A_{000n} in Table I include statistical errors and errors associated with the uncertainty in the location of the proton beam. The other measurement errors and errors in determining the constants amount to less than 4%. The asymmetry values of A_{000n} are in good agreement with the averaging of all the polarization and asymmetry measurements in the *pp* scattering reported in Ref. 4; these average values are represented in Fig. 2 by the solid curve with an averaging error margin.

The results of measurement of the A_{00nn} parameter were included in the phase analysis of *pp* scattering. Four sets of phase shifts obtained in Ref. 1 were used as the initial values. The introduction of new data changed some of the phase shifts slightly (within the limits of two statistical errors). The most probable and stable solution is the one in Table II. The behavior of A_{00nn} predicted by this solution is represented by the solid curve in Fig. 1. This solution is close to that obtained by Hoshizaki in his study of the energy dependence of the phase shifts in the energy region of 0.5 to 2.2 GeV (Ref. 5), but, in contrast with Hoshizaki's solution, it is in agreement with the value of A_{00nn} (90°).

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