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T-INVARIANCE CHECK IN 635 MEV ELASTIC PROTON-PROTON SCATTERING

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Проверка T -инвариантности в упругом рассеянии протонов протонами с энергией 635 Мэв

В опытах на поляризованном пучке протонов с энергией 635 Мэв проверялось равенство "поляризация-асимметрия" ($\mathcal{P} = \mathcal{A}$), вытекающее из инвариантности упругого рассеяния относительно обращения времени. С точностью до ошибок опыта (2-4)% обе измеренные величины в интервале углов 34-117° с.ц.м. совпадают между собой, что не противоречит сохранению T - чётности в упругом pp - рассеянии. Получены оценки верхней границы T -члена и фазы λ_2, нарушающих T -чётность $\sin\lambda_2 = -0,11 \pm 0,10$.

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T -Invariance Check in 635 MeV Elastic Proton-Proton Scattering

"Polarization-asymmetry" equality following from interaction T -invariance has been checked in pp -scattering at 635 MeV. No effects of T -invariance violation has been found in the angle region of (34° - 117°) c.m.s., the experimental accuracy being (2-4)%. The T -nonparity scattering amplitude has been estimated. The value of $\sin\lambda_2 = -0.11 \pm 0.10$ has been found for the noninvariance phase λ_2.

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T-INVARIANCE CHECK IN 635 MEV ELASTIC PROTON-PROTON SCATTERING

Interaction invariance with respect to time-inversal results in the well-known "polarization asymmetry" equality ($\mathcal{P} = \mathcal{A}$) for nucleon-nucleon elastic scattering[1, 2]. The experimental check of this conclusion performed earlier at 142-210 MeV[3-5] is also important even at higher energies both due to the. fundamental principles on which the equality under study is based and the feasible dependence of T -invariance violation upon energy. With this purpose the polarization $\mathcal{P}(\theta)$ was measured in the angle region of 34-117° c.m.s. The results were compared with the appropriate values of $\mathcal{A}(\theta)$ obtained in ref.[6]. The polarization $\mathcal{P}(\theta)$ was determined in the triple proton scattering on parallel planes when the first scattering occured inside the accalarator vacuum chamber. The obtained proton beam, having the polarization as large as 0.425±0.013 ref.[7] was scattered for a second time on a hydrogeneous ($CH_2 - C$) target at an angle θ_2. The polarization was analysed by proton scattering on carbon at an angle of $\theta_3 = 8^{\circ} \pm 1^{\circ}30'$. In the case if the planes of all scatterings coincided, the left-right asymmetries e_+ and e_-,which are observed in the analysing scattering and correspond to reciprocally opposite normal directions to the second scattering plane, make it possible to find polarization by the known formula (refs.[1,3])

$$\mathcal{P}(\theta) = \frac{1}{2P_3} \{e_+ (1 + \mathcal{A} P_1) - e_- (1 - \mathcal{A} P_1)\} .$$

Here P_3 is the analysing power in the third scattering: P_1 is the beam polarization after the first scattering; $\mathcal{A}$ is asymmetry, arising in scattering of the totally polarized proton beam on hydrogen.

The angle of the second scattering was taken with the account of the following considerations. One can show that if space parity is conserved, then

$$I_0(\theta_2)[\mathcal{P}(\theta_2) - \mathcal{A}(\theta_2)] = -4 \, \mathrm{Im} \, H^*(\theta_2) \, T(\theta_2) =$$

$$= 4 \, | T | \, \{ \mathrm{Sin} \, \alpha \, \mathrm{Re} \, H(\theta_2) - \mathrm{Im} \, H(\theta_2) \, \mathrm{Cos} \, \alpha \} ,$$

where H and T according to refs.[1,2] are scattering matrix terms which conserve and violate time-parity, respectively; $I_0(\theta_2)$ is the scattering differential cross section, α is a phase of the complex amplitude T. So, one can easily see that θ_2 should be such lest $\mathrm{Re} H(\theta_2)$ and $\mathrm{Im} H(\theta_2)$ vanish to zero, at least, simultaneously. From the results of phase shift analyses (ref.[6]) it follows that in scattering to the forward hemisphere the angle region of $20^\circ < \theta_2 < 65^\circ$ c.m.s. satisfies this condition.

By basing on the requirements in minimum corrections to the measured quantities related to the angular and energy dependence of the scattering cross sections in the above region, the most correct measurements were performed in the angle range from 41° to 90° c.m.s. One may perform measurements in this angle range without the fear that the results will be strongly changed due to the presence of false asymmetries.

Special attention was paid to the determination of the effective zero reference on the angle scale in the third scattering. This was achieved by a method similar to that described in ref.[8]. In our case this allowed to determine the position of the incident beam axis to an accuracy better than $\pm 0^{o}2'$.

The analysing power of P_3 of the scatterers was defined in a special run.

The method and the developed apparatus were preliminary tested in the scattering experiment at an angle of 90^{o} c.m.s. The Pauli principle and P -parity requirements result in the fact that $\mathcal{P}(90^0)$ should be zero for pp -systems. The results of the test experiment and those of measuring $\mathcal{P}(\theta_2)$ are summarized in Table 1. As follows from Table 1, $\mathcal{P}(90^0) = 0.004 \pm 0.020$, which does not contradict the equality $\mathcal{P}(90^0) = 0$. This result can be considered as an experimental proof of the absence of essential systematic errors in the measurements.

Table 1

θ_2 c.m.s.	$\mathcal{P} \pm \Delta\mathcal{P}$	$\mathcal{A} \pm \Delta\mathcal{A}$	$\mathcal{P} - \mathcal{A}$	$ReT/\sqrt{I_0}$; %
34.5	0.558±0.039	0.496±0.024	0.062±0.046	-4.0±3.0
41	0.563±0.041	0.518±0.014	0.045±0.044	-2.6±2.5
48	0.473±0.020	0.485±0.009	-0.012±0.022 x)	0.8±1.6
61	0.378±0.020	0.395±0.014	-0.017±0.024	-1.5±2.1
72	0.274±0.034	0.296±0.014	-0.022±0.037	-3.2±5.4
90	0.004±0.020	0.012±0.009	-0.008±0.022 x)	3.5±9.7
106	-0.358±0.028	-0.268±0.015	-0.090±0.037	13.2±4.9
117	-0.338±0.039	-0.400±0.020	0.062±0.044	8.2±5.8

x/ Preliminary results have been published in ref.[9]

xx/ In our calculations it was assumed that $\sin a = \cos a$.

The values of $\mathcal{P}(\theta)$ are given without the account of corrections due to the existence of correlation, angle-energy, in the third scattering. These corrections are about $+0.004\pm0.002$ and 0.002 ± 0.002 in the angle region of 106° and 41° c.m.s., respectively. Errors of Table 1 are complete and, , in contrast to the results of other authoes (refs./3,4,5,10/), they include the errors of primary beam polarization measurements and the target analysing powers.

By taking into consideration the obtained values of $\mathcal{P}-\mathcal{Q}$ the contribution of the matrix term T of elastic pp -scattering (see, Table 1) as well as the noninvariance phase λ_2 /2/ were evaluated. For the former it was suggested that $\mathrm{Re}\,T = \mathrm{Im}\,T$, and for the latter $\lambda_4 = 0$.

Table 2

142 MeV/3/		176–179 MeV/4/		220 MeV/5/		635 MeV	
θ° l.s.	$\mathcal{P}-\mathcal{Q}$, %	θ° c.m.s.	$\mathcal{P}-\mathcal{Q}$, %	θ° c.m.s.	$\mathcal{P}-\mathcal{Q}$, %	θ° c.m.s.	$\mathcal{P}-\mathcal{Q}$, %
10	1.4±3.0	-	-	-	-	34.5	6.2±4.6
15	-4.3±2.5	30.9	0.7±2.3	30	-1.9±1.8	41	4.5±4.4
20	-2.3±2.8	-	-	-	-	48	-1.2±2.2
25	-6.3±2.4	50	1.1±2.2	-	-	61	-1.7±2.4
30	1.0±2.3	-	-	-	-	72	-2.3±3.7
35	0.2±4.8	-	-	-	-	90	-0.8±2.2
40	-8.3±6.6	-	-	-	-	106	-9.0±3.7
-	-	-	-	-	-	117	6.2±4.4

By averaging over all the angles we have

$$\sin\lambda_2\ (635\ \text{MeV}) = -0.11 \pm 0.10$$

assuming $\lambda_4 = 0$;

$$\frac{\mathrm{Re}\,T}{\sqrt{I_0}} = \frac{\mathrm{Im}\,T}{\sqrt{I_0}} = -(0.8 \pm 1.1)\cdot 10^{-2}.$$

If one assumes that the results of Wright et al.[10] obtained for 435 MeV are valid also for 635 MeV, their treatment together with our experimental data allow one to find the real and imaginary part of the T_a. The calculations have shown that in our case

$$\mathrm{Re}\,T = (-0.008 \pm 0.021)\sqrt{10^{-27}\ \text{cm}}$$

$$\mathrm{Im}\,T = (0.015 \pm 0.022)\sqrt{10^{-27}\ \text{cm}}$$

$$|T| = (0.017 \pm 0.030)\sqrt{10^{-27}\ \text{cm}}$$

$$\sqrt{I(30^0\ \text{c.m.})} \approx 2\sqrt{10^{-27}\ \text{cm}}.$$

For the sake of comparison Table 3 presents the values of sin λ_2 at 140-430 MeV available in the literature.

Table 3

Energy	142 MeV[3]	180 Mev[4]	220 MeV[5]	430 MeV[10]	635 MeV present paper
SIN λ_2	-0.05±0.033	0.022±0.038	-0.100±0.060	≤0.1	-0.11±0.10

Thus, as it seen from Tables 2 and 3, even if there is any effect of T -invariance violation in the angle and energy regions, it should occur at the level not higher than $(2-3)\times 10^{-2}$ of the total amplitude of elastic pp -scattering.

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