ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

Лаборатория высоких энергий

Лаборатория теоретической физики

B.P. Bannik, V.G. Grishin, R.N. Fedorova

D – 522

INTERFERENCE OF THE COULOMB AND NUCLEAR SCATTERING AT HIGH ENERGIES

Dubna 1960

B.P. Bannik, V.G. Grishin, R.N. Fedorova

D – 522

INTERFERENCE OF THE COULOMB AND NUCLEAR SCATTERING AT HIGH ENERGIES

The interference of the Coulomb and nuclear scattering has been treated in the quasi-classical approximation. The results of the calculations are given for the scattering of 3.0, 6.0 and 8.7 BeV protons and 2.65 and 6.65 BeV $\pi^{\pm}$ -mesons on light and heavy emulsion nuclei. The problem concerning the magnitude and sign of the real part of the proton-proton scattering is discussed.

1. The amplitude of the elastic scattering of nucleons on nucleons and nuclei in the general case has the form

$$f(\vartheta) = A(\vartheta) + B(\vec{\sigma}_i, \vartheta) \qquad (1)$$

where $A(\vartheta)$ is a certain complex function, $B(\vec{\sigma}_i, \vartheta)$ is a part of the amplitude dependent upon the spins of the interacting particles. At high energies it was usually assumed that the real part of $A(\vartheta)$ and the term $B(\vec{\sigma}_i, \vartheta)$ in expression (1) are equal to zero. Experiments on elastic scattering of 8.7 BeV protons on hydrogen/1/ and emulsion nuclei/2/ are likely to point out that this assumption is not valid. However, the results of these experiments raise essentially the problem of taking into account the real part $A(\vartheta)$ and spin dependence of the nuclear forces, but do not give an answer about their role in the interaction. In the present paper the interference of the nuclear and Coulomb scattering is treated the study of which may give the magnitude and the sign of the real part $A(\vartheta)$.

2. In the quasi-classical approximation for the spinless particles the scattering amplitude is of the form

$$f(\vartheta) = ik\int_0^{\infty}[1 - e^{2i\beta(\rho)}]J_0(k\vartheta\rho)\rho d\rho \qquad (2)$$

where the phase $\beta(\rho)$ is equal to the sum of the Coulomb and nuclear scattering phase shifts. Thus, the Coulomb interference depends upon by the magnitude and the sign of the nuclear phase shifts. The latter ones in the optical approximation, in their turn, are dependent upon the magnitude and the sign of the real part of the forward nucleon-nucleon scattering amplitude $Re\, f_{NN}(0)$.

Therefore, a study of the Coulomb interference on nuclei may give the magnitude and the sign $Re\, f_{NN}(0)$. Formula (2) is approximately correct also for the case of scattering of particles having the spin on the spinless nuclei, e.g., for the proton scattering on light emulsion nuclei (C^{12}, N^{14}, O^{16}). Strictly speaking, in this case the spin-orbital interaction should be taken into account. However, in the range of small angles it does not play an essential role.

Expression (2) was used in the calculations of the interference of the Coulomb and nuclear scattering of 3.0, 6.0 and 8.7 BeV protons and 2.65 and 6.65 BeV $\pi^{\pm}$-mesons (in the lab. system) on the light and heavy (Ag, Br) emulsion nuclei*. The phase shifts of the nuclear scattering have been calculated in a usual manner (see, e.g.,)/2/. The Coulomb phase shifts have been obtained according to the Bethe formula/3/. The magnitudes $\mathrm{Re} f_{NN}(0)$ used in the calculations and the total cross sections $\bar{\sigma}$ for particle scattering on a nucleon of a nucleus, averaged over the number of protons and neutrons in a nucleus, are given in Table 1. The magnitude $\mathrm{Re} f_{NN}(0)$ for the case of 8.7 BeV protons has been taken from/4/. The corresponding effective potential of the nucleon interaction with a nucleus $V \approx 30$ MeV. Under the assumption that the magnitude of the effective potential do not change with energy, the magnitude $\mathrm{Re} f_{NN}(0)$ has been calculated in all the rest cases.

The results are given in Figs. 1 – 5.

In Figs. 1 – 2 the interference of the Coulomb and nuclear scattering of $\pi^{\pm}$–mesons on emulsion nuclei is shown. The signs (+), (–), (o) indicate the curves corresponding to $+\mathrm{Re} f_{NN}(0)$, $-\mathrm{Re} f_{NN}(0)$, $\mathrm{Re} f_{NN}(0)=0$ for π^- mesons and $-\mathrm{Re} f_{NN}(0)$, $+\mathrm{Re} f_{NN}(0)$, $\mathrm{Re} f_{NN}(0)=0$ for π^+ mesons. In Figs. 3 – 5 are presented the results for protons. The signs (+), (–) and (o) indicate the curves corresponding to $+\mathrm{Re} f_{NN}(0)$, $-\mathrm{Re} f_{NN}(0)$ and $\mathrm{Re} f_{NN}(0) = 0$.

The Figs. a) are reffered to light nuclei, the Figs b) – to the heavy emulsion nuclei. To obtain the differential cross section for the mixture of the emulsion nuclei, the cross sections for light with the weight (0.58) and heavy with the weight (0.42) nuclei should be added together.

3. The differential cross section for the 8.7 BeV protons has been also calculated by the approximate formula of Bethe./3/

$$\frac{d\sigma}{d\Omega} = \left| g_n(0) - \frac{2n}{k\vartheta^2} \exp 2i\eta \right|^2 F^2(k\vartheta a) \qquad (3)$$

where $g_n(0)$ is the amplitude of the forward nuclear scattering, $\eta = n(0.058 - \ln ka - \ln\vartheta)$, a is the root-mean-square radius multiplied by $\sqrt{5/3}$. The form-factor has been taken as $F = e^{-\frac{1}{4}(k\vartheta a)^2}$. At the same time it has been borne in mind to clear up the limit of applicability of this approximate formula in view of the critical remarks made in/5/.

As a result of calculations it has been turned out that the difference between the cross sections obtained by the approximate formula and in the quasi-classical consideration does not exceed some per cents.

---

* The spins of heavy nuclei which do not play an appreciable role in the process of scattering are neglected here. This is connected with the fact that the ratio of the spin of a heavy nucleus to its mass number is small.

4. In the case of proton proton scattering at 8.7 BeV it was assumed that the effect of their spins may be neglected.* The differential cross section has been calculated by formula (3). The form-factor like that for nuclei has been calculated with $a = 0.86 \cdot 10^{-13}$cm [6]. The results of the calculations (in the c.m.s.) are shown in Fig. 6. It is seen from this figure that the chosen magnitude of the real part ($13.5 \cdot 10^{-13}$cm in the lab. syst.) does not contradict to the experiment if its sign is positive. However, this assertion cannot be regarded as a final one, since the errors presented in the histogram are great, while the above assumptions are based upon the insufficiently accurate experimental data.

The authors are grateful to I.I. Levintov, M.I. Podgoretsky and J.A. Smorodinsky for useful discussions.

References

1. В.Б.Любимов, П.К.Марков, Э.Н.Цыганов, Чжен Пу-ин, М.Г.Шафранова. ЖЭТФ, 37, 910 (1959).

2. Б.П.Банник, В.Г.Гришин, М.Я.Даныш, В.Б.Любимов, М.И.Подгорецкий. ЖЭТФ, 37, 1575 (1959).

3. H. Bethe, Ann. of Phys., 3, 190–240 (1958);

   Г.Бете, ПСФ, № 6, стр. 21 (1958).

4. П.К.Марков, Э.Н.Цыганов, М.Г.Шафранова, Б.А, Шахбазян, доклад В.И.Векслера на 1X Международной конференции по физике высоких энергий, Киев, 1959 г.

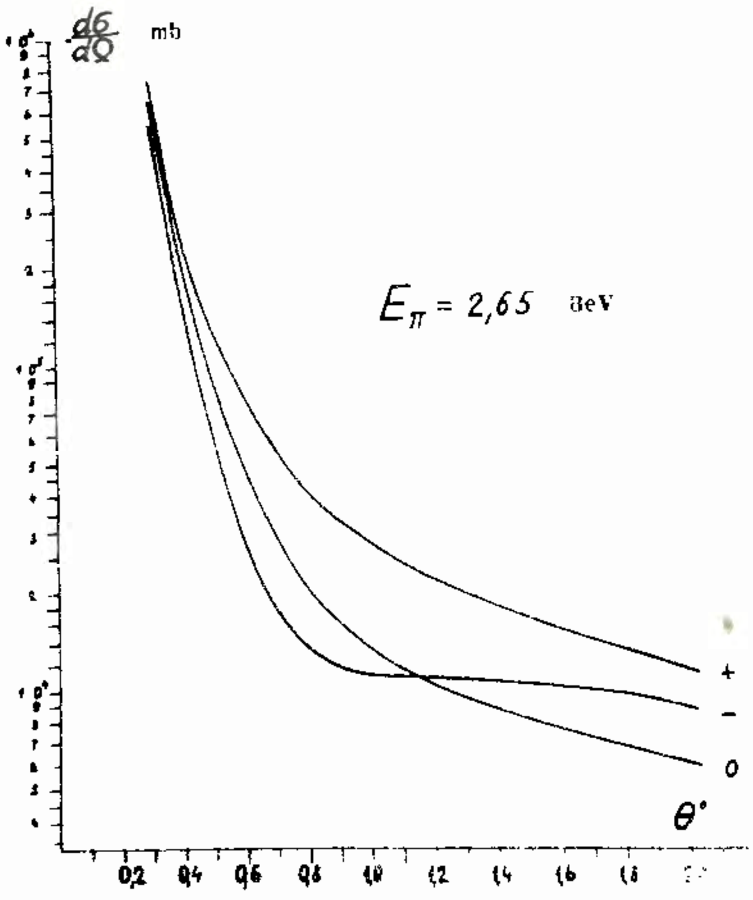
5. C.J. Batty, Proc. Phys. Soc., 73, N 470, 185 (1959).

6. W.M. Preston , доклад В.И.Векслера на 1X Международной конференции по физике высоких энергий, Киев, 1959 г.

Table 1.

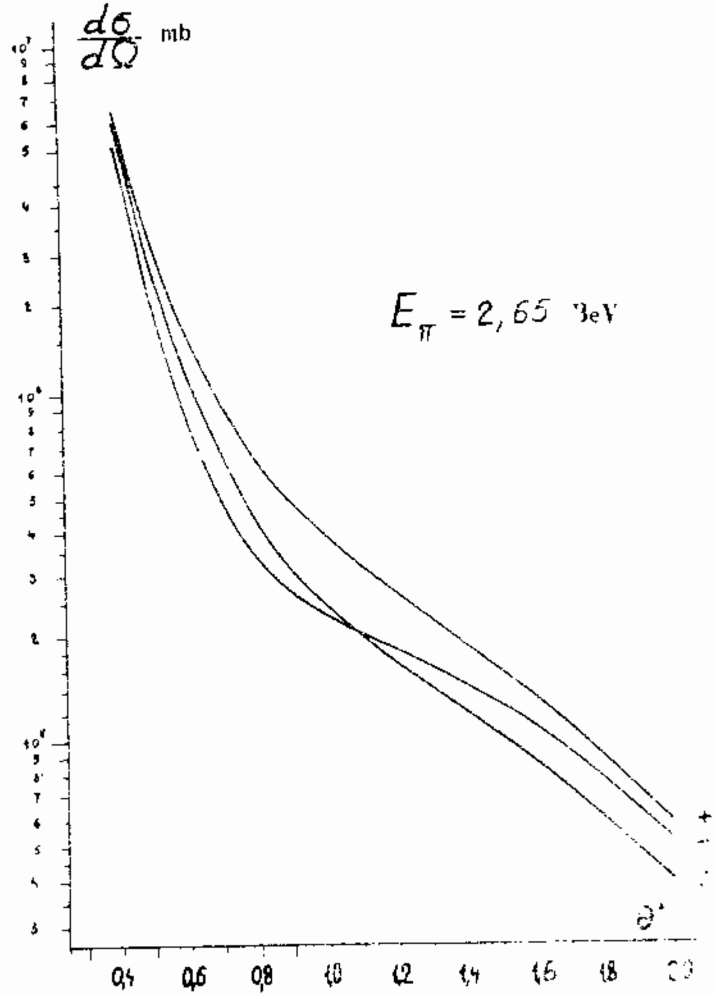
Type of particle	Kinetic energy in BeV	$Re\, f_{NN}^{(0)} \cdot 10^{13}$	$\bar{\sigma}$ mb
$\pi^{\pm}$	2.65	2.8	28
$\pi^{\pm}$	6.65	6.9	30
P	3.0	4.0	40
P	6.0	6.9	34
P	8.7	14.4	34

* A certain ground for such an assumption is that the comparison of the 8.7 BeV proton scattering on hydrogen [1,4] and on the emulsion nuclei [2] does not show a noticeable influence of the spin-dependent interaction.



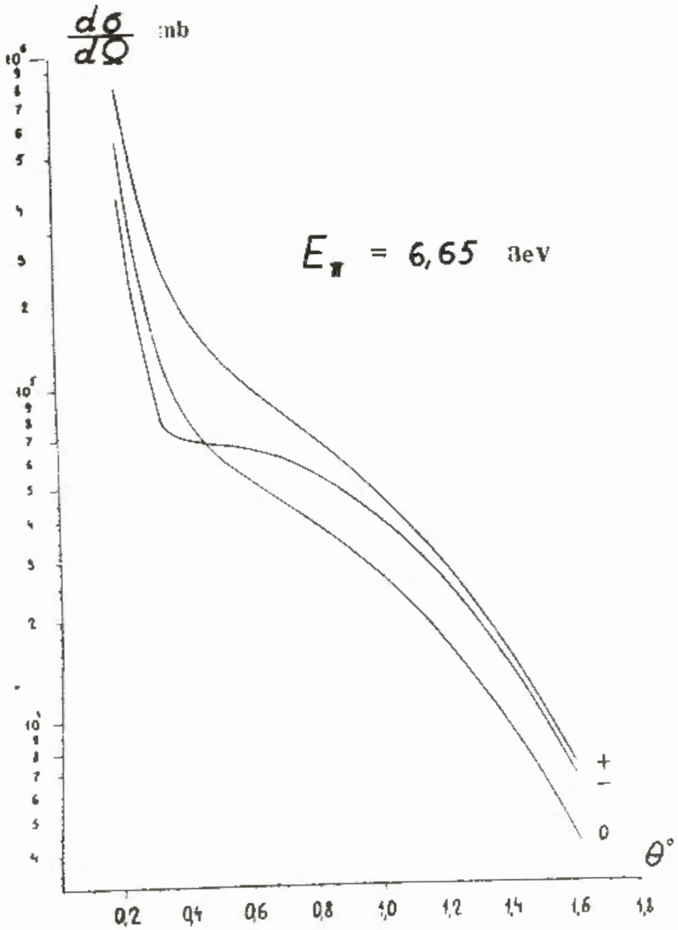
$\frac{d\sigma}{d\Omega}$ mb
$E_\pi = 2,65$ BeV
+
−
0
$\theta°$
0,2
0,4
0,6
0,8
1,0
1,2
1,4
1,6
1,8

Fig. 1 a)



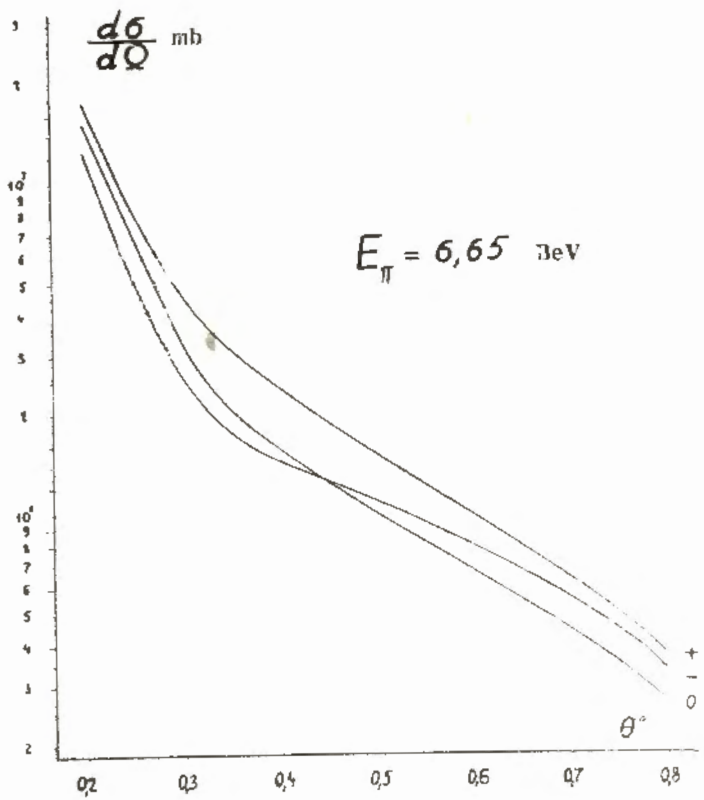
$\frac{d\sigma}{d\Omega}$ mb
$E_\pi = 2,65$ BeV
+
0,4
0,6
0,8
1,0
1,2
1,4
1,6
1,8

Fig. 1 b)



dσ/dΩ mb
E_π = 6,65 BeV
+
−
0
θ°
0,2
0,4
0,6
0,8
1,0
1,2
1,4
1,6
1,8

Fig. 2 a)



dσ/dΩ mb
E_π = 6,65 BeV
+
−
0
θ°
0,2
0,3
0,4
0,5
0,6
0,7
0,8

Fig. 2 b)

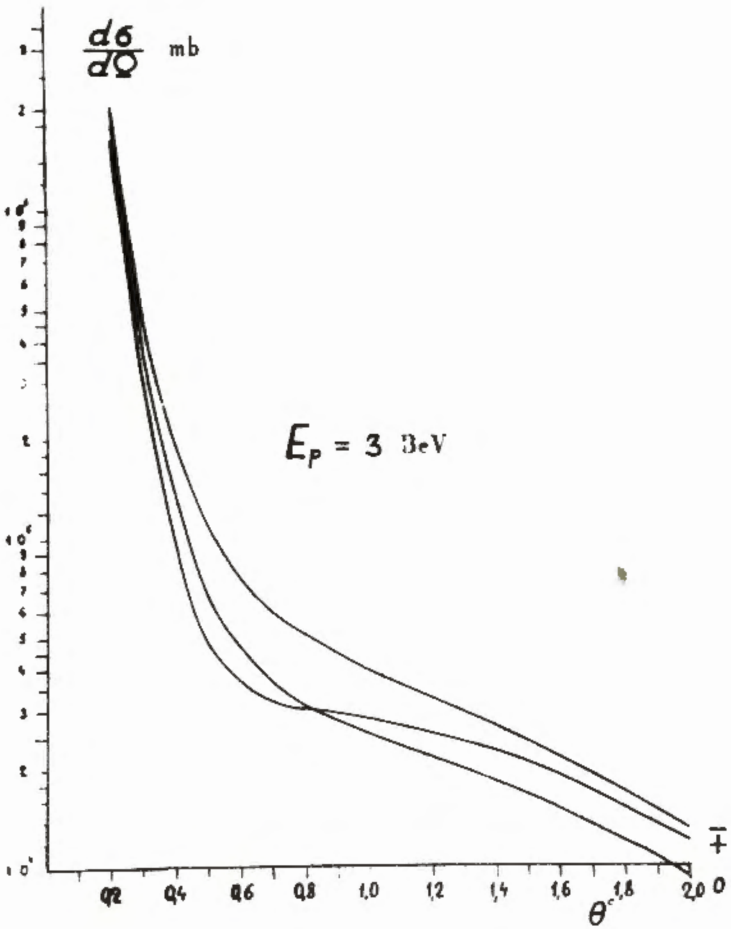


Fig. 3 a)

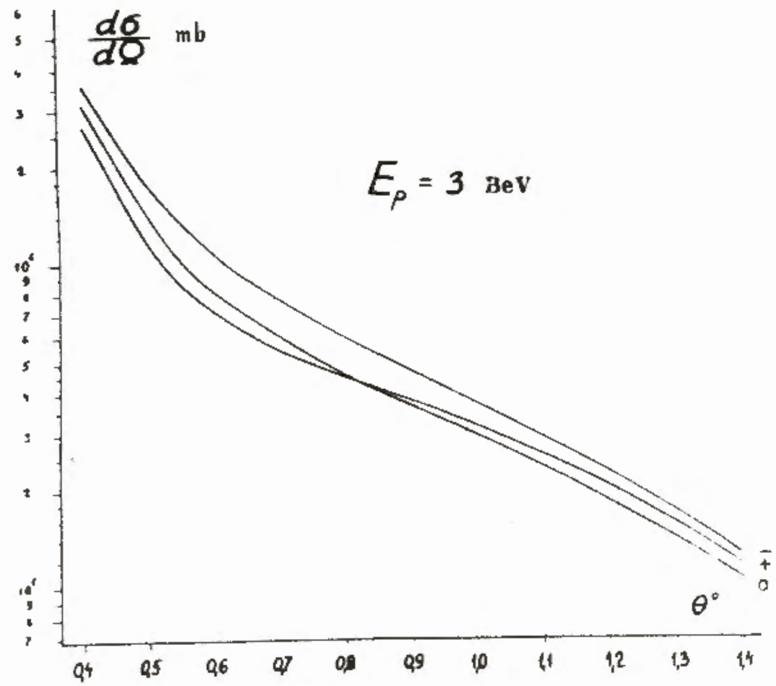


Fig. 3 b)

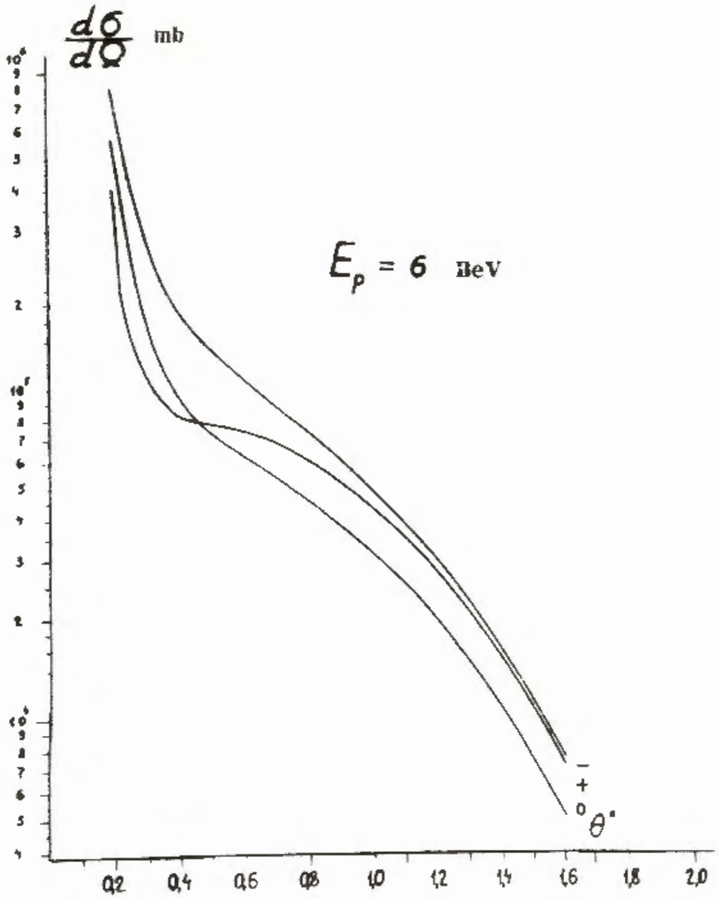

dσ/dΩ mb
E_p = 6 BeV
−
+
0
θ°
0,2
0,4
0,6
0,8
1,0
1,2
1,4
1,6
1,8
2,0

Fig. 4 a)

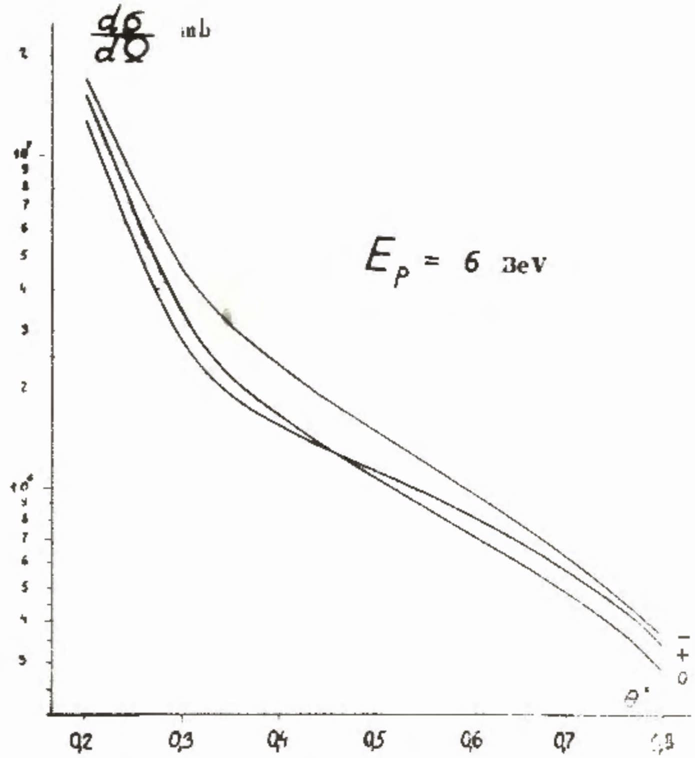
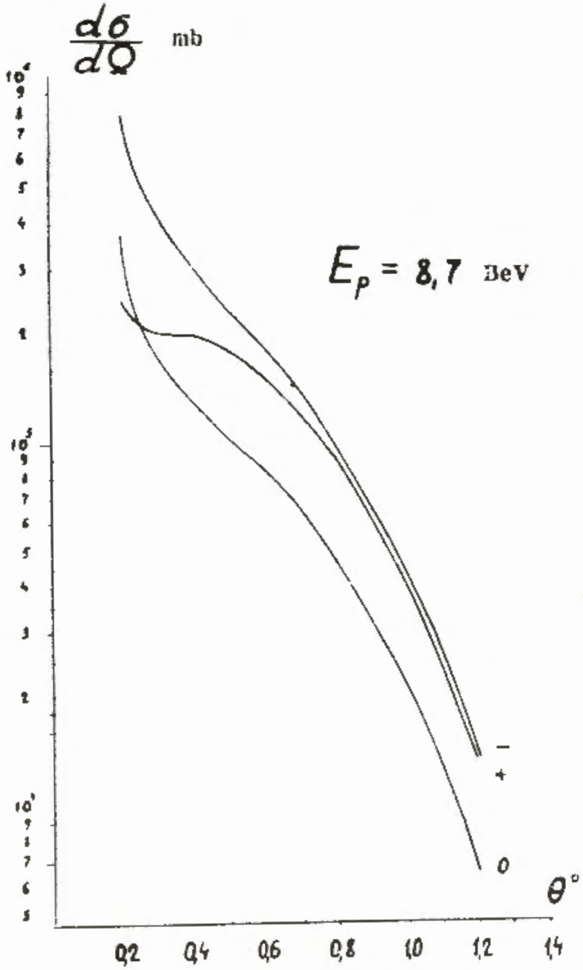
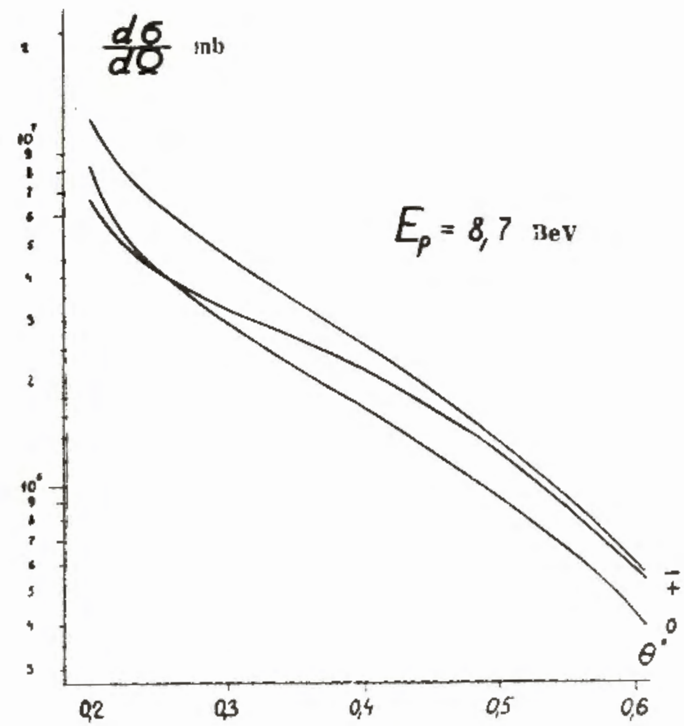

dσ/dΩ mb
E_p = 6 BeV
−
+
0
θ°
0,2
0,3
0,4
0,5
0,6
0,7

Fig. 4 b)



dσ/dΩ mb
E_p = 8,7 BeV
−
+
0
θ°
0,2
0,4
0,6
0,8
1,0
1,2
1,4

Fig. 5 a)



dσ/dΩ mb
E_p = 8,7 BeV
−
+
0
θ°
0,2
0,3
0,4
0,5
0,6

Fig. 5 b)

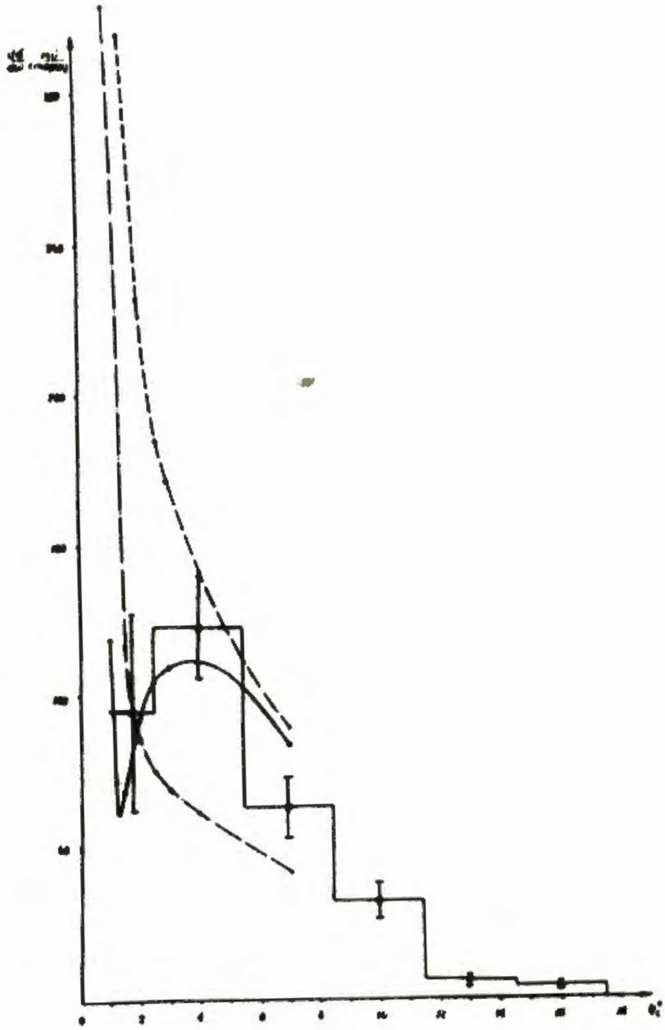


Fig. 6 Interference on hydrogen
Solid, dashed and dash- dot curves correspond
to $+\mathrm{Ref}_{NN}(0)$, $-\mathrm{Ref}_{NN}(0)$ and $\mathrm{Ref}_{NN}(0) = 0$.
The histogram shown the results of the experiment/4/