see that the dependence of the slope difference on energy is in remarkable similarity with that of the cross sections difference, parameters α and q being practically equal: $q = 0.52 \pm 0.02$, $\alpha = 0.55 \pm 0.02$ in the case of $p^{\pm}p$ scattering; $q = 0.56 \pm 0.03$, $\alpha = 0.56 \pm 0.03$ in the case of $K^{-}p$ scattering.

As we have already mentioned, the equation (1) describing momentum dependence of the total cross sections difference for particles and antiparticles follows from the Regge poles model. But the equality of the parameters α and q is very difficult for explanation. Probably, this will require a fundamental revision of the Regge poles theory. On the other hand, this fact is quite natural for the usual diffraction picture.

Conclusion

The recent studies resulted in observation of remarkable regularities in the high energy hadrons interaction. The most significant are the universal rise of the total cross sections and the universal shrinkage of the diffraction cone with the energy increase. The common character and the simplicity of the found regularities holds out a hope of elaboration of the theoretical approaches for their description. The obtained experimental data confirm the conclusions of the general theorems formulated on the basis of the local quantum theory axioms, so these axioms remain valid in the studied high energy region.

A further stage in studies of the strong interaction will begin when new accelerators – colliders of protons and antiprotons – will be put into operation. The steep progressing into the region of super high energies provided with these accelerators might give many important and unexpected results.

References

[1] *A.A.Vorobyov, Yu.S.Grigoriev, A.S.Denisov, Yu.K.Zalite, G.A.Korolev, V.A.Korolev, G.G.Kovshevnyi, N.K.Lastochkin, Ye.M.Maev, V.I.Medvedev, G.L.Sokolov, G.Ye.Solyakin, E.M.Spiridenkov, I.I.Tkatch, V.A.Schegelski.* Preprint LNPI–429, Leningrad, 1972, 47 c.; *A.A.Vorobyov, G.A.Korolev, V.A.Schegelsky, G.Ye.Solyakin, G.L.Sokolov, Yu.K.Zalite.* // Nucl. Instr. Meth., 1974. V.119. P.509.

[2] *A.A.Vorobyov, A.S.Denisov, Yu.K.Zalite, G.A.Korolev, V.A.Korolev, G.G.Kovshevnyi, Ye.M.Maev, V.I.Medvedev, G.L.Sokolov, G.Ye.Solyakin, E.M.Spiridenkov, I.I.Tkatch, V.A.Schegelski.* Preprint LNPI–430, L., 1976, 34 p.; // Phys. Lett., 1972. V.B41. P.639.

[3] *V.G.Ableev, V.D.Apokin, A.A.Vorobyov, G.N.Velichko, Yu.K.Zalite, G.A.Korolev, Ye.M.Maev, Yu.A.Matulenko, S.B.Nurushev, N.M.Piskunov, V.S.Seleznev, V.V.Siksin, I.M.Sitnik, V.L.Solovyanov, Ye.A.Strokovski, L.N.Strunov, N.K.Terentyev, V.I.Sharov, V.A.Schegelski, A.V.Khanzadeev.* // Yad. Fiz., 1978. V.28. P.1529.

[4] *J.P.Burq, M.Chemarin, M.Chevallier, A.S.Denisov, C.Doré, T.Ekelöf, J.Fay, P.Grafström, L.Gustafsson, E.Hagberg, B.Ille, A.P.Kashchuk, G.A.Korolev, A.V.Kulikov, S.Kullander, M.Lambert, J.P.Martin, S.Maury, M.Querrou, V.A.Schegelsky, E.M.Spiridenkov, I.I.Tkach, M.Verbeken, A.A.Vorobyov.* // Nucl. Phys., 1983. V.B217. P.285.

[5] A.A.Vorobyov. // Vestnik Akademii Nauk SSSR, 1983. No 4. P.67.

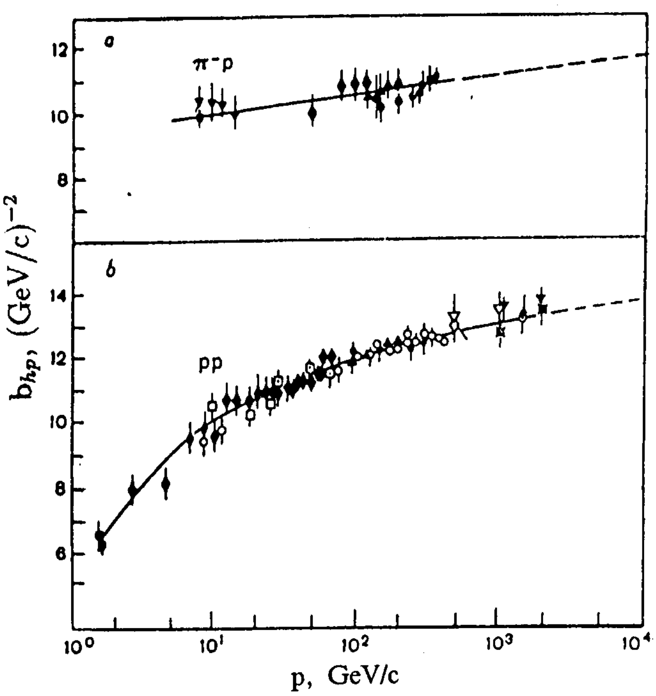

Fig.6. Slope parameters of the diffraction cone in the region of small transfer momenta. All experimental data are interpolated to the value $-t = 0.02$ (GeV/c)^2; solid lines – the result of the best fit with formula (7).
a) $b_2 = 0.29 \pm 0.08$ (GeV/c)$^{-2}$,
b) $b_2 = 0.30 \pm 0.04$ (GeV/c)$^{-2}$.

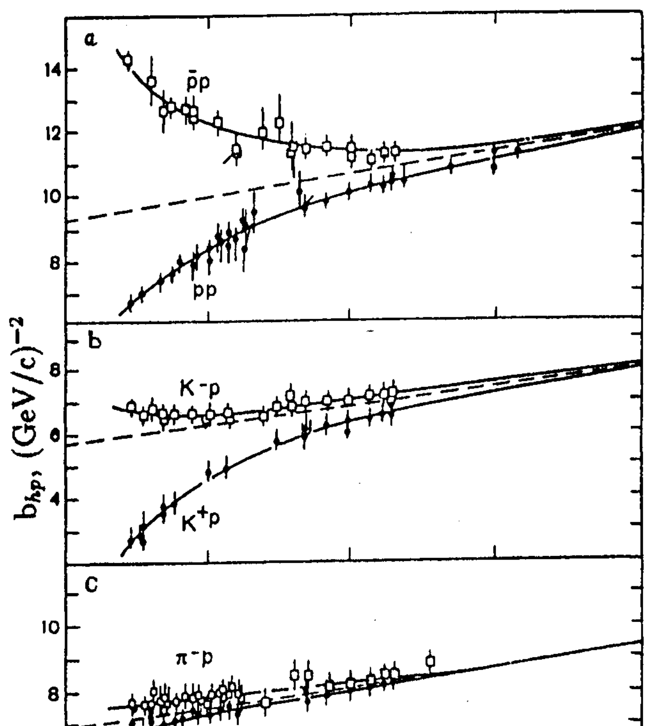

Fig.7. Slope parameters of the diffraction cone at $-t = 0.2$ (GeV/c)^2. Solid lines – the result of the best fits of experimental data with formula (7).
a) $b_2(\bar{p}p) = 0.28 \pm 0.05$ (GeV/c)$^{-2}$,
b) $b_2(k^{\pm}p) = 0.24 \pm 0.08$ (GeV/c)$^{-2}$,
c) $b_2(\pi^{\pm}p) = 0.27 \pm 0.05$ (GeV/c)$^{-2}$.

Using the pomeron exchange model, V.N.Gribov predicted in 1961 a logarithmic growth of the hadrons interaction radius with the energy increase – the shrinkage of the diffraction cone:

$$b_{hp}(p, t \simeq 0) \propto 2\alpha'_P \ln p. \tag{6}$$

Here α'_P is some constant called the slope of the pomeron trajectory. It is related to the pomeron mass: $\alpha'_P \propto 1/(m_P)^2$, but the absolute value of this constant is not given by the theory. The diffraction cone shrinkage is also predicted by the critical and the overcritical pomeron models. Perhaps, the most characteristic feature of the predicted phenomena is its universality: the rate of shrinkage determined by α'_P must depend neither on the type of the interacting hadrons nor on the transfer momentum in the region of small negative t-values.

Until recently, it seemed that the experimental data did not confirm the hypothesis of the universal cone shrinkage. The maximum shrinkage of the diffraction cone was observed in pp scattering, in πp scattering it was very small and in $\bar{p}p$ scattering, on the contrary, the slope parameter decreased with the energy increase. Such a situation created a skeptical attitude of many physicists to the possibility of using the Regge poles model in high energy physics. Thus, M.Perl wrote in 1974 in his book "Physics of high energy hadrons": "The diffraction cone in elastic scattering ... stimulated the application of the Regge theory to description of the strong interaction. The irony today is in our doubts whether the Regge theory has any relation to the diffraction scattering at all". More prudent opinion was that in the studied energy region there are still significant contributions from various processes masking the pomeron related shrinkage of the diffraction cone. Nevertheless, some investigators believed that in pp scattering there happened an accidental cancellation of the contributions from the nonpomeron processes, and thus the observed increase of the slope parameter $b_{pp}(t \simeq 0)$ with the energy was related to the slope of the pomeron trajectory. In 1973, the FNAL–Dubna group analyzing the data on pp scattering found $2\alpha'_P = 0.56 \pm 0.05$ (GeV/c)$^{-2}$, and this value was widely used in theoretical works.

New experimental data obtained in 1981 by the CERN–PNPI group enabled to suggest another interpretation of the observed picture. It was shown that all available data on $p^{\pm}p$, $K^{\pm}p$ and $\pi^{\pm}p$ scattering at $-t \leq 0.2$ (GeV/c)^2 could be well described with the universal dependence:

$$b_{h^{\pm}p}(p, t) = b_h(t) \mp b'_{h^{\pm}p}(t)/p^q + b_2(\ln p), \tag{7}$$

where $q \simeq 1/2$ takes into account the non-logarithmic dependence of the slope parameter at low energies. Most essential, the b_2 parameter proved to be independent neither on the particle type nor on the transfer momentum (Figs. 6,7): $b_2 \equiv 2\alpha'_P = 0.28 \pm 0.03$ (GeV/c)$^{-2}$, that is factor of two less than the value accepted before. It is interesting to note that in this interpretation the most close to the asymptotic is the behaviour of $\pi^{\pm}p$ scattering. On the contrary, the considerable growth of $b_{pp}(p, t \simeq 0)$ observed at $p \leq 10^2$ GeV/c is associated mainly not with the pomeron trajectory but with the disappearance of the contributions from other processes.

So, one may state that the existing experimental data agree well with the hypothesis of universal shrinkage of the diffraction cone in the high energy region. From formula (6) an expression follows for the difference between the slopes of the differential cross sections of particles and antiparticles scattering on proton:

$$b_{h^-p}(p) - b_{h^+p}(p) = \text{const}/p^q. \tag{8}$$

First, one can see that this difference goes to zero at $p \to \infty$ in an agreement with the theorem of the asymptotic equality of the differential cross sections. Further, comparing (7) and (1) one can be quite well approximated with the following universal expression:

$$\sigma^{tot}_{h^{\pm}p}(p) = \sigma_h \mp \sigma'_h(p/p_0)^{-\alpha} + \sigma''_h(p/p_0)^{-\beta} + \sigma'''_h[\ln(p/p_0)]^{\gamma}, \qquad (4)$$

where p_0 is the dimension parameter ($p_0 = 1$ GeV/c) and $\sigma_h, \sigma'_h, \sigma''_h, \sigma'''_h, \alpha, \beta, \gamma$ are some positive in value constants found from the best fit to the experimental data on $\sigma^{tot}_{hp}(p)$ and $\rho_{hp}(p, t = 0)$.

In the high energy region, the second and the third terms in (4) disappear and the cross sections of particles and antiparticles interaction with protons become equal and logarithmically growing with the energy increase. It is interesting that the index γ in (4) is practically equal to the utmost Froissart value $\gamma= 2$. In other words, the rapidity of the total cross sections rise proved to be maximum possible within the limits accepted by the Froissart theorem. But it is still early to speak about the saturation of the Froissart limit because of the limited energy interval explored and the ambiguity in the choice of the parameter p_0.

One can see in Figs. 4,5 that in the high energy region the total cross sections grow by approximately 7% with ln$p$ increasing by 1. Note that explanation of such an intense total cross sections rise with the energy is not an easy task for the Regge poles model. In its first version, it was supposed that in the region of asymptotically high energies the scattering amplitude will be determined entirely by a single exchange of some particle called "pomeron". The pomeron was assigned (rather arbitrary) the characteristics providing the constancy of the total cross sections at $p \to \infty$. The model assumed a small and slow rise of $\sigma^{tot}_{hp}(p)$ in the preasymptotic region before the cross sections approach the constant value. The recent experimental data on total cross sections evidently do not confirm these predictions and force, to our regrets, to deny this so simple scheme of strong interaction in the high energy region.

During last years, some other versions of the pomeron model leading to the rise of the total cross sections were elaborated. One of them is the "critical pomeron" model (V.N.Gribov, A.A.Migdal, 1968; A.A.Migdal, A.M.Polyakov, K.A.Ter-Martirosyan, 1976) which takes into consideration the interaction between pomerons during the exchange process. The model predicts the total cross sections to be proportional to ln$p$ up to the energies of $\sim 10^9$ GeV and proportional to $\ln^{1/6}p$ at $p \to \infty$. Another version is the model of "overcritical pomeron" (H.Cheng, T.Wu, 1970; J.Cardy, 1974) where the pomeron properties are changed in such a way that the cross sections rise first as p^{Δ} (where $\Delta \simeq 0.07$) and then as $\ln^2 p$ at $p \to \infty$. Both models may describe well enough the existing data on $\sigma^{tot}_{hp}(p)$ in the region of accelerators energies.

Universal shrinkage of diffraction cones

As we have already mentioned, the total cross sections rise may mean either decrease of the colliding objects transparency or increase of their dimensions. To clear up the nature of the phenomena, it is very useful to consider the data on the slope parameters of the elastic scattering differential cross sections in the region of small transfer momenta, $b_{hp}(p, t)$. The slope parameter is defined as the derivative of the logarithm of the elastic scattering differential cross section. This value is directly related to the radii of the interacting particles. Approximately

$$b_{hp}(p, t = 0) \propto R^2_h + R^2_p, \qquad (5)$$

where R_h and R_p are the root-mean-square radii of the bombarding hadron and the target proton, correspondingly.

Assuming the dispersion relations to be valid up to the momenta of 10^4–10^5 GeV/c, a simultaneous analysis of the data on $\sigma_{hp}^{tot}(p)$ and $\rho_{hp}(p, t=0)$ was carried out. For pp scattering this was done by the CERN-Rome group in 1977 and for πp scattering – by the CERN-Gatchina collaboration in 1981. The analyses showed that the total cross sections rise found at the accelerator energies will continue at higher energies. In particular, the cross section $\sigma_{\pi p}^{tot}(p)$ will be rising up to, at least, $p = 2000$ GeV/c (Fig. 4) and $\sigma_{pp}^{tot}(p)$ – up to, at least, $p = 40000$ GeV/c (Fig. 5). As it turned out, the energy dependence of the cross sections can

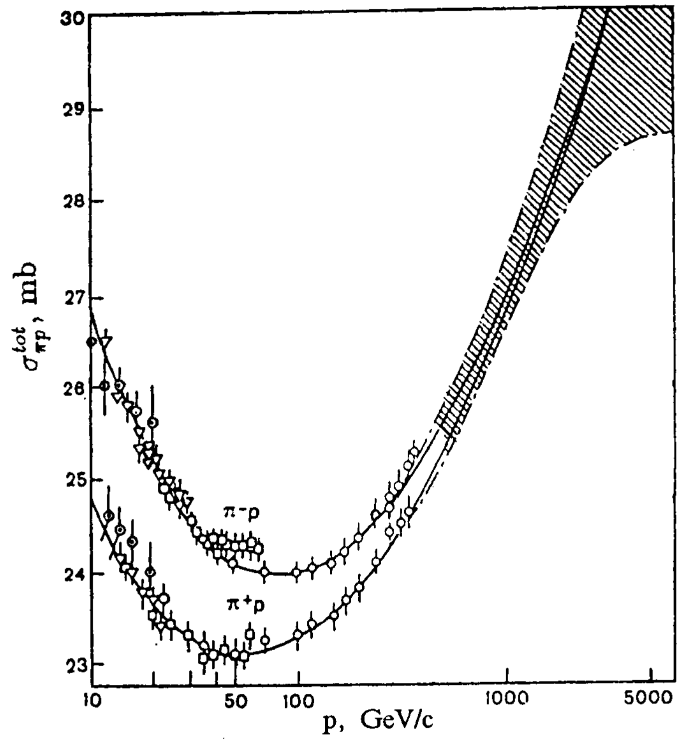

Fig. 4. Extrapolation of the total cross sections of πp interaction beyond the accelerator energies by combined analysis of $\sigma_{\pi^\pm p}^{tot}$ and $\rho_{\pi^- p}(p, t=0)$ data with the dispersion relations.
The solid lines – the best fit of the data with formula (4), the dashed area corresponds to the extrapolation uncertainty.

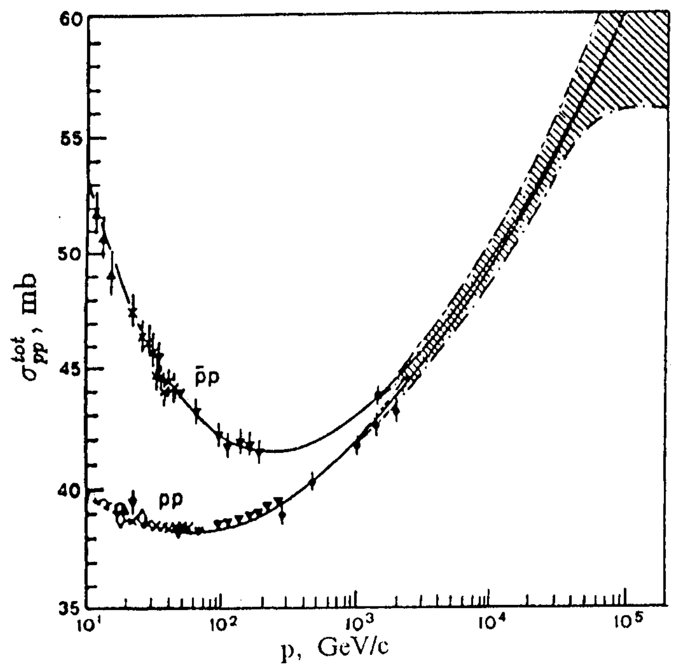

Fig. 5. Extrapolation of the total cross sections of $p^\pm p$ interaction beyond the accelerator energies by combined analysis of $\sigma_{p^\pm p}^{tot}$ and $\rho_{pp}(p, t=0)$ data with the dispersion relations.
The solid lines – the best fit of the data with formula (4), the dashed area corresponds to the extrapolation uncertainty.

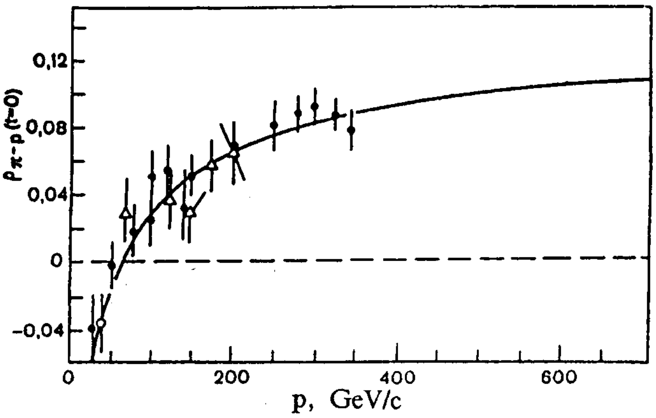

Fig. 2. Experimental data on $\rho_{\pi^- p}(p, t = 0)$. The solid line is the result of calculations with the dispersion relations method; the calculations used the $\sigma^{tot}_{\pi^\pm p}$ values approximated by the solid lines in Fig. 4.
• – CERN–Gatchina, ∘ – Serpukhov–Gatchina, △ – FNAL.

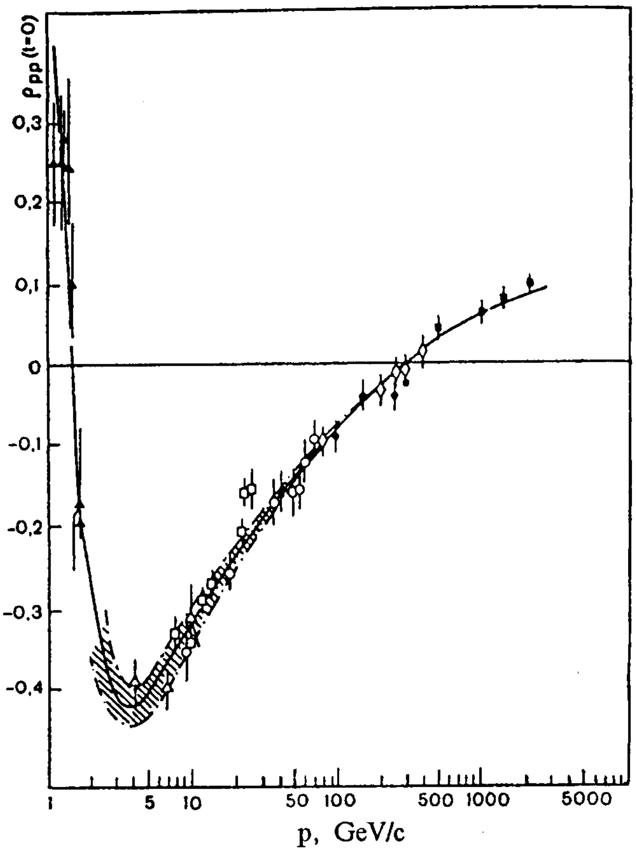

Fig. 3. Experimental data on $\rho_{pp}(p, t = 0)$. The solid line is the result of calculations with the dispersion relations method; the calculations used the $\sigma^{tot}_{p^\pm p}(p)$ values approximated with the solid lines in Fig. 5; the dashed area corresponds to the uncertainty of the calculations.
■ – CERN, ◇ – FNAL-Dubna, ∘ – Serpukhov, □ – Brookhaven, △ – CERN, △ – Gatchina, • - CERN–Gatchina.

A check of the dispersion relations may be carried out by comparing the experimental values of $\rho_{hp}(p, t = 0)$ with the calculated ones via the dispersion relations using the experimental data on σ^{tot}_{hp}. The momentum region of $10 \le p \le 100$ GeV/c is preferable for πp scattering and the region of $40 \le p \le 400$ GeV/c – for pp scattering, as the dispersion calculation results must be most reliable in these regions and less sensitive to the total cross sections behaviour beyond the accelerator energies.

Such a comparison is shown in Figs. 2,3 demonstrating a good agreement of the calculations with the experimental data. So, one may conclude with certainty that the dispersion relations are valid, at least, up to the momentum of 100 GeV/c for πp scattering and up to 400 GeV/c – for pp scattering.

Determination of the total cross sections beyond the accelerator energies

The dispersion relations have a remarkable property – they allow to estimate the behaviour of the total cross sections beyond the energies reached at today's accelerators. The point is that the dispersion relations bind in an integral way the total cross sections $\sigma^{tot}_{h^{\pm}p}(p)$ of particle and antiparticle interactions with protons with another experimentally measurable parameter $\rho_{hp}(p, t = 0)$ which is the real to imaginary part ratio of the hp elastic scattering amplitude. This value is measured at very small transfer momenta $t \to 0$, that is in the region of very small scattering angles. Strictly speaking, the dispersion relations enable to calculate $\rho_{hp}(p, t = 0)$ at some given momentum p of the incoming particle only in the case when the total cross sections $\sigma^{tot}_{h^{\pm}p}(p)$ are known in the whole momentum range from $p = 0$ to $p \to \infty$. That is why the $\rho_{hp}(p, t = 0)$ value measured in the region of the accelerator energies is sensitive to the total cross sections behaviour outside this region. Calculations show that $\rho_{hp}(p, t = 0)$ measured in some momentum interval up to p_{max} with the error $\Delta\rho \leq \pm 0.01$ gives a possibility to predict $\sigma^{tot}_{hp}(p)$ behaviour up to the momenta 10 times higher than p_{max}.

The up-to-date measurements of the real part of the forward elastic scattering amplitude are based on the interference between the Coulomb and nuclear interactions. The experimental task is precision measuring of the elastic scattering differential cross section in the region of very small transfer momenta where the interference effect is maximum. The data analysis is performed using the known Bethe interference formula. Despite the approximate nature of the formula, it allows to determine $\rho_{hp}(p, t = 0)$ with the error $\Delta\rho \leq \pm 0.01$.

The required precision in measurements of $\rho_{hp}(p, t = 0)$ has been achieved due to development of new experimental methods. An effective method of pp scattering studies has been elaborated at JINR by V.A.Nikitin et al. It consists in measuring the energy and the emission angle of the recoil proton from the hydrogen gas jet target inside the accelerator beam pipe. At PNPI, the author of this article with collaborators suggested a method which enabled to study not only pp but also πp scattering in a wide energy region. In this case a hydrogen-filled ionization chamber served both as a target and as a detector of the recoil protons. Finally, at CERN U.Amaldi et al. worked out a precision technique for registration of two scattered protons in colliding beams. One should add that all these methods enable also to measure the diffraction cone slope parameter at small transfer momenta.

Up to now, the most investigated are pp and πp scattering. The principal experiments are carried out at the accelerators at PNPI (Gatchina), IHEP (Serpukhov), FNAL, and CERN. The results of the $\rho_{hp}(p, t = 0)$ measurements are shown in Figs. 2,3. One can see that the real part of the forward amplitude, being negative in the energy region of $\sim$10 GeV, diminishes in its absolute value with the energy growth, then changes the sign and increases again. Such a behaviour corresponds to the rise of the total cross sections. One can draw a more definite conclusion on the cross sections behaviour having done the analysis of the experimental data using the dispersion relations.

Here, however, a question arises on the dispersion relations validity in the high energy region. For example, if the causality principle is not conserved at small distances (order of l_0) than, as several authors noted, this leads to a noticeable violation of the dispersion relations at the energies $E \geq 1/l_0$. And on the contrary, if the dispersion relations are experimentally proved, say, up to the energies of about 100 GeV, this would mean the validity of the causality principle up to distances of the order, at least, of 10^{-16} cm (R.Oehme, 1955).

cross sections for particles h^+ and antiparticles h^- diminishes with the energy increase according to a remarkably simple law:

$$\sigma^{tot}_{h^-p}(p) - \sigma^{tot}_{h^+p}(p) = \text{const}/p^{\alpha}, \quad (1)$$

where p is the momentum of the bombarding particle and $\alpha \simeq 1/2$. At present, the direct measurements defined this law only in the region $5 \le p \le 400$ GeV/c but it seems to remain valid also at higher energies. Just recently, CERN published a new result of measurement of the total cross sections in colliding proton-antiproton beams with the equivalent laboratory momentum $p = 1500$ GeV/c: $\sigma^{tot}_{\bar{p}p} = 43.8 \pm 0.4$ μb. This result is in a good agreement with the value obtained by formula (1). This formula shows that the interaction cross sections for particles and antiparticles become practically undistinguishable at the energies $\geq 10^4$ GeV that corresponds to the Pomeranchuk theorem prediction. The power law of decreasing of the difference between the particle and antiparticle cross-sections is well explained by the Regge poles model, and the parameter value $\alpha \simeq 1/2$ is predicted by this model through the independent analysis of the sequence of masses of the known meson resonances.

Fig. 1 shows that the total cross sections depend significantly on the type of the interacting hadrons that is natural due to different quark composition of the hadrons. And what is remarkable, the cross sections follow some relations based on the simplest independent quarks model of the hadrons (E.M.Levin, L.L.Frankfurt, 1965; H.Lipkin, F.Scheck, 1966), for example:

$$\sigma^{tot}_{pp} / \sigma^{tot}_{\pi p} = 3/2 \quad (2)$$

or

$$\sigma^{tot}_{\pi p} - \sigma^{tot}_{Kp} = \sigma^{tot}_{pp} - \sigma^{tot}_{\Sigma p} = \sigma^{tot}_{\Sigma p} - \sigma^{tot}_{\Xi p} = \sigma^{tot}_{\Xi p} - \sigma^{tot}_{\Omega p}. \quad (3)$$

Unfortunately, the independent quarks model has no strict substantiation in the framework of QCD yet.

The rise of the total cross sections with the energy increase is of special interest. The rise of $\sigma^{tot}_{k^+p}$ was first observed by Yu.D.Prokoshkin et al. in 1971 in Serpukhov. Later similar behaviour was found for other cross sections. In terms of diffraction, the cross section growth means either decreasing of the colliding objects transparency or increasing of their dimensions. The infinite rise of the cross sections must be accompanied with the increase of the interaction radius.

An example of the cross section infinitely growing with the energy due to the increase of the interaction radius is the cross section of atomic ionization by the relativistic charged particles described by the well-known Bethe-Bloch formula. Though it should be mentioned that in a real medium the electromagnetic interaction radius is limited by the polarization of the medium. As a result, the ionization cross section becomes constant with the energy increase (Fermi plateau) after some rise. Similar phenomena may occur in the case of hadron interactions as well, with the physical vacuum as the medium. But it is clear that the experimental data represented in Fig. 1 do not allow to determine the character of the cross sections asymptotic behaviour. For that it is necessary to move into the region of considerably higher energies.

with the target (M.Gell-Mann et al., 1954; M.Goldberger, 1955; N.N.Bogolyubov, 1956). Of the other important theorems, we note the Pomeranchuk theorem on equality of the total cross-sections of the particle and antiparticle interaction with the target (I.Y.Pomeranchuk, 1958), the theorem on asymptotic equality of the elastic scattering differential cross sections for particles and antiparticles (A.A.Logunov et al., 1963; L.Van Hove, 1963), and also the Froissart theorem introducing an upper limit on the possible rate of the total cross sections rise with the energy increase (M.Froissart, 1961; M.Martin, 1963).

The study of the diffraction processes led at one time to formulation of several phenomenological models of strong interaction. The most popular was the Regge poles model. The theory of complex angular momenta developed first by T.Regge (1959) for description of low energy particles scattering was later extended for interactions of high energy particles (G.Chew, S.Frautschi, 1961; V.N.Gribov, 1962; R.Blankenbecler and M.Goldberger, 1962). The up-to-date versions of this model describe correctly many phenomena observed in the high energy hadron interactions. So, the recent trials to establish a quantitative relation between the Regge poles model and the QCD are of interest.

Direct measurement of the total cross sections

A very high precision (0.3%) in measurements of the total hadron(h)-proton(p) cross sections, σ_{hp}^{tot}, was reached using external accelerator beams (fixed-target experiments). The precision of experiments with the colliding beams is at present somewhat lower, but in the best experiments it was as high as ~1%. The main experimental data on the total hadron-proton cross sections are shown in Fig. 1.

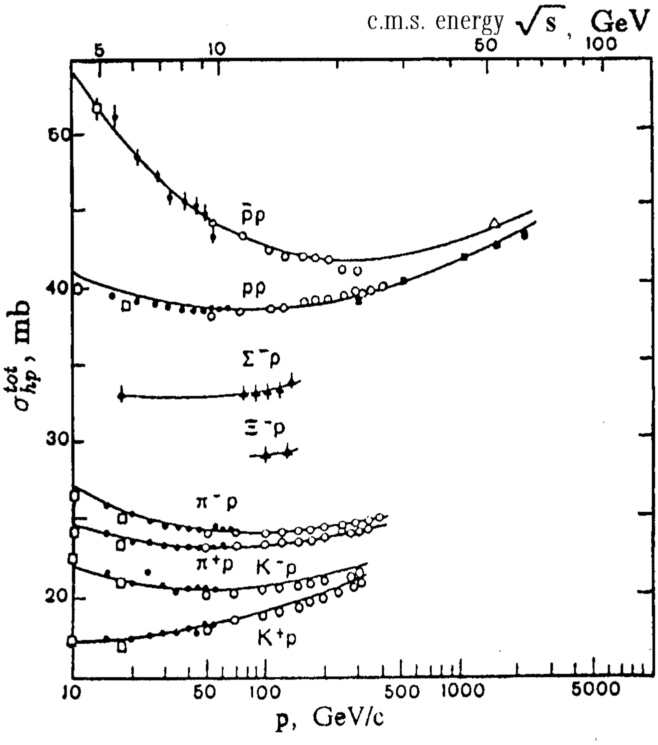

Fig. 1. Results of direct measurements of the total hadron-proton cross sections. The data for $p > 400$ GeV/c are obtained with colliding proton-proton and proton-antiproton beams at CERN.
□ – Brookhaven (1965), • – Serpukhov (1971), ∘ – FNAL (1976,1978), ■ – CERN (1976), △ – CERN (1980), △ – CERN (1982).

One can find some regularities in the dependence of the total cross sections on the energy and on the type of interacting particles. In particular, one can see that the difference in the

INTERACTION OF HADRONS AT HIGH ENERGIES

Vestnik Akademii Nauk SSSR, 4 (1983) 67.

A joint experiment on elastic hadron scattering at the proton accelerator SPS of the European Centre of Nuclear Research (CERN, Switzerland) was successfully completed in 1981. The base of the experiment was a new recoil detector worked out at the Leningrad Nuclear Physics Institute. Physicists from French Universities of Lyon and Clermont-Ferrand and from Swedish Gustaf Werner Institute (Uppsala) participated in the experiment. Such combination of efforts, experiences and potentialities of different laboratories allowed to carry out in a short time a large scale program. In fact, it proved to be a closing experiment in the series of studies of total cross sections and parameters of the diffraction scattering of strongly interacting particles, which were carried out by different world laboratories in the region of today's maximum accelerator energies.

With start up of new accelerators the energy range of the accelerated particles is constantly extended. In 1966 the maximum accelerator energy was 30 GeV, while nowadays the energy region up to 400 GeV is well explored. Experimentalists have at their disposal not only proton beams but also quite intensive beams of antiprotons, mesons, hyperons. Development of the colliding beams technique enabled to study *pp* interactions up to the centre-of-mass energy of 62 GeV. To reach such an energy with a standard accelerator, it would be necessary to accelerate protons up to 2000 GeV. In the nearest future we will witness the further progress of the accelerator technique. At CERN the experiments have already started with the proton-antiproton beams at the collision energy of 540 GeV. Later on this energy will be extended to 2000 GeV at the accelerator at the Fermi National Accelerator Laboratory (FNAL, USA).

During last years, scientific programs at high energy proton accelerators were concentrated mostly on the studies of the internal structure of elementary particles. These studies resulted in formulation of the strong interaction theory – the quantum chromodynamics (QCD). The QCD turned out to be able to describe correctly practically all observed in the experiment "hard processes" – i.e. the processes occurring at the distances essentially smaller than the nucleon radius. But many important questions are still left unsolved. One of them is the problem of quarks and gluons confinement in the nucleon. The quantitative description of the diffraction processes occurring at relatively large distances (comparable to the confinement radius) is tightly bound to the problem of confinement. The solution of these problems could give the answer to the question whether the QCD is able to describe all the basic phenomena in the world of the strongly interacting particles or the area of the practical application of this theory will be restricted only by the deep inelastic processes.

The total cross sections together with the parameters of the diffraction scattering are among the main characteristics of the strong interaction. Theorists succeeded in formulation of several theorems relating to each other different parameters of the diffraction scattering. These theorems are based only on general axioms of the relativistic local quantum field theory including, in particular, the assumption of the causality conservation in the processes occurring in the micro-space at the distances much smaller than the proton radius. The experimental test of these theorems is of principal importance.

Among the general theorems of the axiomatic field theory a special place belongs to the so-called dispersion relations binding in an integral way the real part of the elastic forward scattering amplitude with the total cross sections of the particle and antiparticle interactions

DIFFRACTION SCATTERING OF HIGH ENERGY HADRONS

A.A.Vorobyov, G.A.Korolev, V.A.Schegelsky

Introduction

At the end of 60s, the study of the global characteristics of the hadron interactions was of common interest. How will the total cross sections of the hadron interactions behave with the energy increase? Will one observe a shrinkage of the diffraction cone (and associated increasing of the elementary particles dimensions) with the energy increase? The popular at that time Regge poles theory predicted a constancy of the total cross sections in the asymptotic region of high energies accompanied by the logarithmic shrinkage of the diffraction cone. Also, it was a question whether the dispersion relations between the real part of the forward scattering amplitude and the total cross section remain valid. The violation of these fundamental relations would mean the breakdown of the causality principle at small distances. These questions were a permanent point of discussion at all high energy conferences. In particular, there were intriguing publications of L.Dutton et al. (1967) and, also, S.J.Lindenbaum et al. (1969) who reported significant discrepancies between the measured real parts of the forward scattering amplitudes and the predictions from the dispersion relations in pp and πp scattering at 0.6 GeV and 30 GeV, respectively.

In 1969, a new experimental method was suggested and worked out at PNPI for studies of the small angle scattering of high energy hadrons. A hydrogen-filled high pressure ionization chamber used as a recoil detector (this detector was later called IKAR) was the base of the method [1]. The new method appeared to be extremely fruitful. It provided precise measurements of differential cross sections for small angle scattering of various hadrons with the absolute normalization at the 1% precision level. It is also important that this method had no limitations with increasing the energy of scattering particles.

First experiments using the new method were carried out at PNPI (Gatchina) in 1972. The pp scattering in the energy interval from 600 to 1000 MeV was investigated. In these experiments, the "puzzle of Dutton" was solved and validity of the dispersion relations in pp scattering at this energy was restored [2]. Soon after, the preparations were started of an experiment at the SPS accelerator at CERN, which was to be put into operation in 1976. The main goal of the experiment was to study πp scattering in the energy region up to 400 GeV. A preliminary experiment with 40 GeV π mesons was carried out at IHEP (Serpukhov) [3]. The CERN experiment had two stages. First, the maximum beam energy was 140 GeV (WA9 experiment, 1978), and later it was increased up to 400 GeV (NA8 experiment, 1981). These experiments yielded important results [4] which together with the results of other experiments enabled to recreate a general picture of the hadron interactions at available at that time energies. A short description of this picture was given in an article published in 1983 [5]. Below this article is presented with small reductions.