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WHAT CAN BE LEARNT FROM THE NEW UA4/2 DATA

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The elastic hadron-hadron scattering plays an important role in the investigation of strong interactions. For the description of the interaction at small distances we have the exact theory, QCD, but for the interaction at large distances, that is the basis for the elastic scattering at small angles, the calculation in the framework of QCD is impossible at present. These two domains are tightly connected and the experimental determination of the parameters of elastic scattering is very important for the development of the modern strong interaction theory [1].

The potential of interaction of charged hadrons is a sum of coulomb and nuclear interactions. After the eikonal summation the terms with the coulomb and nuclear interactions appear. As a result, the total interaction amplitude has a complicated structure and depends on the spin parameters. However, currently, at sufficiently high energies and small scattering angles the contribution of spin-flip amplitudes can usually be neglected [2].

A surprisingly high value of the ratio ρ of the real to imaginary part of the forward elastic scattering amplitude obtained by the UA4 Collaboration [3] gave rise to various theoretical interpretations [4]. A new experiment was made by the UA4/2 Collaboration [5] to confirm or to specify this value of ρ. This experiment gives unique experimental data: a very small value of $|t|$ was reached for a large enough energy and the differential cross section was obtained with sufficiently small errors. In a preliminary publication the authors gave the calculated value $\rho = 0.135 \pm .015$. This value of ρ refutes the previous UA4 data and is close to many odderon models. But is it really so?

In paper [6] the existence of four possibilities is noticed for understanding the large value of ρ. In this work, we carry out a careful analysis of the new experimental UA4/2 data trying to take into account only these experimental data. This analysis shows, from our viewpoint, that the value of ρ is sufficiently large and is not in contradiction with the UA4 experimental data. Moreover, these data, maybe, show for the first time a real possibility for the existence of the spin-flip amplitude at superhigh energies in the range of small $|t|$.

The differential cross sections measured in the experiment are described by the square of the scattering amplitude

$$d\sigma/dt = \pi \ (F_C^2(t) + (1+\rho(s,t)) \ ImF_N^2(s,t) \mp 2(\rho(s,t) + \alpha\varphi)) \ ImF_N F_C), \quad (1)$$

where $F_c = \mp 2\alpha G^2/|t|$ is the coulomb amplitude; α is the fine-structure constant and $G(t)$ is the proton electromagnetic form factor squared; $\rho(s,t) = Re\ F(s,t)/Im\ F(s,t)$.

Just this formula is used for the fit of experimental data determining the coulomb and hadron amplitudes and the coulomb- hadron phase to obtain the value of $\rho(s,t)$. Solving (1) for the imaginary part of the hadron amplitude, we get

$$Im\ F_N(s,t) = -\frac{\rho+\alpha\varphi}{1+\rho^2}F_C + [\frac{(\rho+\alpha\varphi)^2}{(1+\rho^2)^2}F_C^2 + \frac{1}{(1+\rho^2)}(\frac{1}{\pi}\frac{d\sigma(s,t)}{dt} - F_C^2)]^{1/2}. \quad (2)$$

Here, the one-to-one correspondence of the imaginary part of the hadron amplitude and $\rho(s,t)$ is seen. At each point of the transfer momentum, using $\rho(s,t)$ we can obtain $ImF(s,t)$ from the experimental data on the differential cross sections. The phase of the coulomb-hadron interaction has been calculated and discussed by many authors [7] and has the form [8]

$$\begin{aligned}\varphi(s,t) &= \mp[\gamma + \ln(B|t|/2) + \ln(1+8/(B\Lambda^2)) + \\ & (4|t|/\Lambda^2)\ \ln(4|t|/\Lambda^2) + 2|t|/\Lambda^2], \end{aligned} \quad (3)$$

where Λ is a constant entering into the dipole form factor. The pure hadron amplitude is represented in the exponential form in the range of the diffraction peak and a small interval of t:

$$F(s,t) = A\ (i+\rho)\ \exp(-B(s,t)/2\ |t|), \quad (4)$$

where A is the interaction effective constant. In the experiment the coefficient $\rho(s,t)$ is obtained from the analysis of the differential cross sections in the region of the coulomb-hadron interference where the coulomb and hadron amplitudes are nearly equal to one another and their interference term has the maximum relative contribution. The imaginary part of the amplitude of elastic scattering is connected with the total cross section

$$\sigma_{tot}(s) = 4\pi Im\ T(s,t=0).$$

In work [5], the value of ρ was obtained by using formula (1), but the value of A in (4) was determined from another experiment [9]. This experiment gives $\sigma_{tot}\cdot(1+\rho^2) = 63.3mb$, and for $\rho = .15$ one obtains $\sigma_{tot} = 61.9mb$. It is just the value used in work [5] to compute ρ. Therefore the formula for the imaginary part of the scattering amplitude is represented as follows:

$$ImT(s,t) = A_\sigma \cdot exp(-B\cdot|t|); \quad (5)$$

$$A_\sigma = (\sigma^1_{tot}\cdot(1+\rho_1^2) = 63.3)/(1+\rho_2^2)/(4\pi\cdot 0.38937966).$$

The constant A_σ is in fact dependent on σ^1_{tot} and ρ_1 defined from another experiment. Note that the error of σ^1_{tot} is not included in the final error of ρ_2.

As is noted in previous paper [10], the procedure of extrapolation of the imaginary part of scattering amplitude is very significant for determining σ_{tot}. The importance of the extrapolated contribution is seen from paper [11] where the contribution to σ_{tot} of σ_{obs}, the directly measured value, and of $\Delta\sigma_{el}$ and $\Delta\sigma_{inel}$, the extrapolated contributions of the elastic and inelastic cross sections, are shown at energies $\sqrt{s}$ = 30.6 GeV, 52.8 GeV and 62.7 GeV. One can see that the growth of the total cross sections is due to $\Delta\sigma_{el}$ by 50% for pp and nearly by 100% for $p\bar{p}$ scattering.

If we can determine the value of ρ using (2), then we obtain almost the same value (see Table, variant 1) $\rho = 0.137 \pm .007$, the error is only statistical. Insignificant difference from the result [5] may consist in more precise numerical calculations. Let us take the value $A_\sigma \to A$ as a free parameter. In this case we obtain $\rho = 0.148 \pm 0.018$ (see var. 2 in Table).

In these two variants we suppose that the amplitude has a constant slope in this range of transfer momenta. Let us examine this supposition as this unique experiment allows us to do it. We will reduce the number of the considered experimental points from 99,95,90,85 ... to 50 and therefore the interval of transfer momenta from $|t| = 120.\cdot 10^{-3}GeV^2$ to $|t| = 18\cdot 10^{-3}GeV^2$, and will obtain a new value of ρ_i and B_i. We show that the value of ρ_i grows and the value of B_i decreases (see figs. 1 and 2). Therefore our method of determination of ρ depends on the investigated interval of $|t|$.

Let us examine another form of the scattering amplitude which is $|t|$ -dependent in form (see var. 3,4 and 5,6 in Table). For variants 3,4 we also take the constant A_σ as in work [5] and obtain some decrease of χ^2 and growth of ρ. The values of the constant C are 0.86 ± 0.48 and -0.15 ± 0.08 respectively. In variants 5,6 we change again A_σ *to* A as a free parameter. The χ^2 continues to decrease and ρ grows. In these variants the values of the constant C are 1.80 ± 0.56 and -0.27 ± 0.097 respectively. We obtain the decrease of χ^2 almost by 8% and large growth of ρ. But which form of the scattering amplitude will be obtained in these cases? As the value of the coefficient C is positive in variants 3,5 and negative in variants 4,6, we obtain a decrease of the slope of the scattering amplitude in these cases when $t \to 0$. It is to be recalled that the slope of differential cross sections grows in the range of $|t|$ near $0.05 - 0.4GeV^2$ and now we see that it decreases when $|t| \to 0$. This is very unusual and imposes strong restrictions both on the ordinary pomeron and the odderon models. This behavior of the scattering amplitude is, maybe, due to its some oscillations [12] or can be obtained by taking into account the next rescattering term of the amplitude. In the latter case we also obtain a large value of ρ (see var. 7,8 in Table).
This requires one or two additional free parameters and raises problems with the sum-

Table

N	$F(s,t)^{++}$	$\sum_{i=1}^{99}\chi_i^2$	$B\ (GeV^{-2})$	ρ	$\sigma_{tot}\ (mb)$
1	$A_\sigma \cdot exp(-B/2 \cdot \|t\|)$	106.52	15.52 ± 0.06	$.137 \pm .007$	62.13
2	$A \cdot exp(-B/2 \cdot \|t\|)$	106.06	15.50 ± 0.07	$.148 \pm .018$	62.79
3	$A_\sigma \cdot exp(-B/2 \cdot \|t\| - C * t^2)$	103.24	15.16 ± 0.20	$.147 \pm .009$	61.96
4	$A_\sigma \cdot exp(-B/2 \cdot \|t\| - C \cdot \sqrt{\|t\|})$	102.90	16.21 ± 0.36	$.168 \pm .018$	61.56
5	$A \cdot exp(-B/2 \cdot \|t\| - C \cdot t^2)$	100.20	14.91 ± 0.25	$.188 \pm .027$	63.74
6	$A \cdot exp(-B/2 \cdot \|t\| - C \cdot \sqrt{\|t\|})$	98.44	16.66 ± 0.43	$.2437 \pm .045$	63.4
7	$A_1 \cdot exp(-B/2 \cdot \|t\|)$ $-A_2 \cdot exp(-B \cdot \|t\|)$	99.42	16.76 ± 0.43	$.197 \pm .029$	63.89
8	$A_1 \cdot exp(-B_1/2 \cdot \|t\|)$ $-A_2 \cdot exp(-B_2/2 \cdot \|t\|)$	98.0	15.74 ± 0.26	$.236 \pm .061$	64.26
9	$A \cdot exp(-B/2 \cdot \|t\|)$ and $F^{+-} = \sqrt{\|t\|} \cdot A \cdot exp(-B \cdot \|t\|)$	98.62	15.67 ± 0.065	$.233 \pm .022$	62.79
10	$A_\sigma \cdot exp(-B/2 \cdot \|t\|)$ and $F^{+-} = \sqrt{\|t\|} \cdot A_s \cdot exp(-B \cdot \|t\|)$	102.90	15.63 ± 0.08	$.152 \pm .011$	61.87
11	$A_{\sigma 2} \cdot exp(-B/2 \cdot \|t\|)$ and $F^{+-} = \sqrt{\|t\|} \cdot A_s \cdot exp(-B \cdot \|t\|)$	99.8	15.64 ± 0.08	$.178 \pm .011$	62.82

mation of non-leading terms of the scattering amplitude. This leads us to the range of theoretical models whereas we wish to stay only in the framework of this experiment.

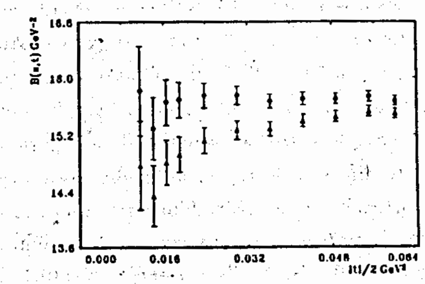

Fig.1. The dependence of the slope, B, on the examined interval of $|t|$;
Φ- for variant 2 ,
ϕ -for variant 9 (see Table)

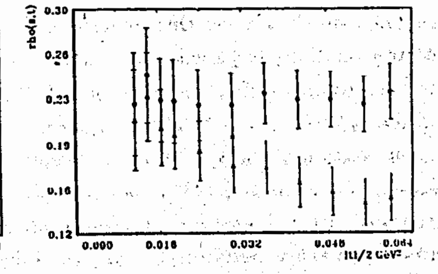

Fig.2. The dependence of ρ on the examined interval of $|t|$;
Φ- for variant 2 ,
ϕ -for variant 9 (see Table)

However, maybe, the matter is simpler. Let us consider the possibility of the contribution of the spin-flip amplitude to the differential cross sections. The simplest form of this amplitude that gives a sufficiently large contribution in the range of small $|t|$ and does not change the form of the differential cross sections at large $|t|$ is, for example, as follows:

$$F^{+-}(s,t) = \sqrt{|t|} \cdot A \cdot exp(-B \cdot |t|). \qquad (6)$$

In this case we don't introduce additional free parameters. As we can see from variant 9 of Table , we obtain the same minimum of χ^2 without additional parameters for the slope. Let us examine again the behavior of our parameters as a function of the considered interval of transfer momenta. We obtain that in this variant.the values of the slope and ρ do not change with decreasing intervals of $|t|$ (see figs. 1 and 2).

This shows that the possibility of the existence of the spin-flip amplitude and its manifestation in this experiment is sufficiently large. However, we obtain a very large value of $\sigma_{tot} \cdot (1 + \rho^2)$, different from $63.3 \pm 1.5mb$ by three errors. The degree of the increase of σ_{tot} is examined [13]. It is clear that such a large value of σ_{tot} requires special explanation. If we use the fixed value of A_σ and make A_{spin} free parameter, then we obtain variant 10. The increase by one error for σ_{tot} leads to $A_{\sigma 2}$ in variant 11. Evidently, there is a direct relationship between the values of ρ and A_σ .

Thus, we can make the following conclusion. The new UA4/2 experimental data measured with very small errors and in a sufficiently small interval of transfer momenta allow us to calculate the normalization coefficient, determine the values of ρ and the slope (B) based only on this experiment. The analysis of these experimental data gives an essentially large value of ρ, most likely, $\rho = 0.19 \pm 0.03$ (only statistical error). This contradicts neither the value $\rho = 0.168 \pm 0.018$, when we lean upon the earlier obtained σ_{tot}, nor $\rho = 0.24 \pm .045$, when we take σ_{tot} as a free parameter. The question of manifestation of the spin-flip amplitude in the diffraction scattering is exceptionally interesting. We show that this possibility is sufficiently probable. This is tightly connected with the value of σ_{tot}. It would be very important to have some experimental points in the range before $|t|_{max}$ at which the relative maximum of interference of the coulomb nucleon amplitudes occurs. In this case the normalization will be entirely determined by the coulomb amplitude. It sharply decreases the errors of the obtained σ_{tot}, ρ and B. The manifestation of spin-flip amplitude requires polarization experiments in the diffraction range. Some models predict sufficiently large effects in this energy range (see [14, 15]) especially in the range of the diffraction minimum for the polarization and in the range of $|t| = 1 \div 3 GeV^2$ for A_{NN}.

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Селюгин О.В. E2-93-454

Что можно узнать

из новых данных коллаборации UA4/2

Тщательный анализ новых данных коллаборации UA4/2 показывает, что эти данные дают существенно большую величину $\rho = ReT(s, t)/Im(s, t)$, не противоречащую предыдущим данным коллаборации UA4. Имеются определенные основания полагать, что этот эксперимент впервые обнаруживает возможное существование амплитуды с переворотом спина при сверхвысоких энергиях и в области малых передач импульса.

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What Can Be Learnt from the New UA4/2 Data

A careful analysis of the new data of the UA4/2 collaboration reveals that these data give an essentially large value of $\rho = ReT(s, t)/Im(s, t)$ that does not contradict the early UA4 experiment. There are grounds for thinking that this experiment reveals for the first time a real possibility of the existence of the spin-flip amplitude at superhigh energies in the range of small transfer momenta.

The investigation has been performed at the Bogoliubov Laboratory of Theoretical Physics, JINR.

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