AC

MODEL-INDEPENDENT DETERMINATION
OF THE HADRON ELASTIC SCATTERING
AT HIGH ENERGY AND SMALL MOMENTUM TRANSFER

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ABSTRACT — It is shown that the measurement of the polarization together with the hadron elastic dN/dt distribution in the Coulomb-nuclear interference region allows to extract directly from the data both the real and imaginary parts of the spin non-flip nuclear amplitude, independently from each other and without any arbitrary theoretical assumption. The crucial parameter $\rho = ReF/ImF$ will be therefore known as a function of t at fixed s and will allow us to detect new phenomena in hadron physics.

The elucidation of the structure of the high energy elastic hadron-hadron scattering amplitude at small angles is a problem of topical and great interest. Such quantities as total cross section and the phase of the scattering amplitude are relevant for the fundamental understanding of the strong interaction theory. However, they can not be yet calculated in the framework of Quantum Chromodynamics and therefore realistic models have to be used.

Numerous recent discussions of the value of the ratio of the real to imaginary part of the forward spin non-flip amplitude $\rho = ReF^{nf}/ImF^{nf}$ measured by the UA4 [1] and UA4/2 [2] Collaborations at $\sqrt{s} = 541$ GeV have revealed the ambiguity in the definition of this parameter [3], and, as a result, it has been shown that one has some trouble in extracting from experiment the total cross sections and the value of the real parts of the scattering amplitudes [4, 5]. Moreover, we have no rigorous information about the form of the real part of the hadron amplitude as a function of the momentum transfer. In most cases one supposes that the real part of the scattering amplitude has the same behaviour with the momentum transfer as the imaginary part. But it is just a rather arbitrary supposition. Other assumptions [6] lead to the increase of the real part with increasing transfer momenta. In fact, the problem is that we have at our disposal only one observable $d\sigma/dt$ for two unknowns $ReF^{nf}(s, t)$ and $ImF^{nf}(s, t)$. So we need some additional experimental information which would allow us to determine independently the real and the imaginary parts of the non-flip hadron elastic scattering amplitude.

In this paper, we show that such information can be obtained from precise measurements of the spin correlation parameter A_N at very small transfer momenta. In this domain the analyzing power A_N is determined by the Coulomb-hadron interference effects. As the Coulomb amplitude is known from the theory, we can obtain some information about the hadron non-flip amplitude from this quantity A_N .

Such studies are even more relevant taking into account that the spin correlation parameters in the Coulomb-nuclear region of elastic proton-proton scattering will be measured in the near future at RHIC and LHC. It could also possibly be measured at

the Tevatron.

From now on, all our formulae will be written for the pp case. We will use the five helicity amplitudes $F_i(s, t)$ as defined in ref. [7]. The differential cross-section and spin correlation parameter A_N are

$$\frac{d\sigma}{dt} = 2\pi[|F_1|^2 + |F_2|^2 + |F_3|^2 + |F_4|^2 + 4|F_5|^2] \quad (1)$$

and

$$A_N \frac{d\sigma}{dt} = -4\pi \operatorname{Im}[(F_1 + F_2 + F_3 - F_4)F_5^*] . \quad (2)$$

The total helicity amplitudes can be written as a sum of nuclear $F_i^h(s, t)$ and Coulomb $F_i^c(s, t)$ amplitudes :

$$F_i(s, t) = F_i^h(s, t) + e^{i\alpha\phi} F_i^c(s, t) . \quad (3)$$

where $F_i^c(s, t)$ are the leading-terms at high energy of the one-photon amplitudes as defined by eq. 34-36 in ref. [7] and the common phase ϕ , computed by Cahn [8], is

$$\phi = -[\gamma + \log(B(s, t)|t|/2) + \nu_1 + \nu_2] \quad (4)$$

where $B(s, t)$ is the slope of the nuclear amplitude and ν_1 and ν_2 are small correcting terms in our case, which therefore will not be taken into account.

At very small t and fixed s , these Coulomb amplitudes are such that

$$F_1^c(s, t) = F_3^c(s, t) \sim \alpha/t , \quad (5)$$

$$F_2^c(s, t) = -F_4^c(s, t) \sim \alpha \cdot \text{const.} , \quad (6)$$

$$F_5^c(s, t) \sim -\alpha/\sqrt{|t|} , \quad (7)$$

and hence $F_{i=2,4,5}^c(s, t)$ can be neglected when directly compared to $F_{1,3}^c(s, t)$, but they will be, of course, kept in the interference terms. Moreover in the interference region ($|t| \simeq 10^{-3} \text{ GeV}^2$) we can safely approximate the nuclear amplitudes by their values at $t = 0$,

$$F_i^h(s, t) \simeq F_i^h(s, 0) , \quad (8)$$

and the Coulomb form factors by their values at $t = 0$,

$$G^2(t) \simeq G^2(0) = 1. \quad (9)$$

Also in this interference region $\alpha\phi \sim .03$ and hence we will neglect from now on the imaginary parts of $e^{i\alpha\phi}F_1^c(s, t)$ in eq. (4) when compared to the corresponding real parts. Finally, $\rho(s, t)$ is expected to be $\rho \sim 0.1 - 0.2$ and ρ^2 is negligible when compared to 1.

In the standard theory the spin-flip hadronic amplitudes are expected to fall as $1/\sqrt{s}$ as $s \rightarrow \infty$ and they give negligible contributions at the present high energies. Only the spin-non-flip hadronic amplitudes

$$F_1^h(s, t) \simeq F_3^h(s, t) \quad (10)$$

survive at these energies. The approximate equality (10) is commonly used in the literature [9]. One theoretical justification of eq. (10) is given by the fact that, in the Regge pole model, the difference $F_1^h - F_3^h$ is controlled by unnatural-parity low-lying trajectories (intercepts near or below 0) and therefore is negligible at high s and small t [10]. So, the spin effects to be studied in this paper arise mostly from the interference between the non-flip hadron amplitudes with the spin-flip Coulomb amplitudes.

With these approximations eq. (1) reads

$$\frac{1}{4\pi} \frac{d\sigma}{dt} = |F_1^h + e^{i\alpha\phi}F_1^c|^2 = Im^2 F_1^h(1 + \rho^2) + 2ImF_1^h \cdot F_1^c(\rho + \alpha\phi) + (F_1^c)^2. \quad (11)$$

In the same way, the analyzing power given by eq. (2) can be rewritten as

$$A_N \simeq -2 \frac{F_5^c/ImF_1^h}{1 + (F_1^c/ImF_1^h)^2 + 2(\rho + \alpha\phi)F_1^c/ImF_1^h}. \quad (12)$$

It is clear that the position $(t_{\max})_1$ of the maximum of A_N will depend only on the total cross sections

$$\sigma_{tot}(s) = 8\pi ImF_1^h(s, t = 0) \quad (13)$$

at very small t .

Of course, in the general case $(t_{\max})_1$ depends on ϕ , ρ and B . One can find these parameters by fit. But such a fit is not needed here. We can cancel almost completely the influence of the correction terms if we define the new quantity $\langle A_N \rangle$ which is homogeneous in F_1 and F_5 :

$$\langle A_N \rangle \equiv (A_N)^2 \frac{d\sigma}{dt} = 16\pi \frac{[Im(F_1 F_5^*)]^2}{|F_1|^2 + 2|F_5|^2} . \quad (14)$$

$\langle A_N \rangle$ being expressed in terms of the experimental quantities A_N and $d\sigma/dt$.

We can rewrite (14) within our approximations in the form

$$\langle A_N \rangle = 16\pi \frac{-t(\tilde{F}_5^c)^2}{t^2 + (\alpha/ImF_1^h)^2 + 2t(\rho + \alpha\phi)\alpha/ImF_1^h} . \quad (15)$$

where

$$\tilde{F}_5^c \equiv \sqrt{|t|} F_5^c . \quad (16)$$

$\langle A_N \rangle$ given by eq. (15) has a maximum at the point $(t_{\max})_2$ which depends, of course, on s . From (15) we easily obtain the value of $\sigma_{tot}(s)$ as a function of $(t_{\max})_2$:

$$\sigma_{tot}(s) = \frac{8\pi\alpha}{|(t_{\max})_2(s)|} . \quad (17)$$

The remarkable relation (17) tells us that we can obtain the value of the total cross section directly from the value $(t_{\max})_2$, without the need of knowing the luminosity. Moreover, the energy-dependence of σ_{tot} is linked to the energy dependence of $(t_{\max})_2$. This new way of extracting σ_{tot} from high-precision A_N measurements is interesting and should be performed at present and future accelerators.

For a numerical test of our approximations let us take two models [11] and [12] which give a good quantitative description of the experimental data at and below ISR energies. These two models involve very different detailed dynamics but they satisfy the general requirements leading to eq. (17). They give two independent estimates of

the magnitude of corrections to eq. (17). For example, if we take the model [11] for the amplitude F_1^h we can calculate separately $\sigma_{tot}^{mod}(s)$ from the model and $\langle A_N \rangle(s)$. Then, define $(t_{max})_2$ and calculate $\sigma_{tot}(s)$ again from eq. (17), denoted as $\sigma_{tot}^A(s)$ and compare our results. We obtain, for $\sqrt{s} = 50$ GeV and $\sqrt{s} = 500$ GeV :

$$\sigma_{tot}^{mod}(\sqrt{s} = 50) = 42.6 \text{ mb}, \quad \sigma_{tot}^{mod}(\sqrt{s} = 500) = 59.3 \text{ mb} \quad (18)$$

$$(t_{max})_2(\sqrt{s} = 50) = 1.65 \cdot 10^{-3} \text{ GeV}^2, \quad (t_{max})_2(\sqrt{s} = 500) = 1.19 \cdot 10^{-3} \text{ GeV}^2 \quad (19)$$

$$\sigma_{tot}^A(\sqrt{s} = 50) = 43.2 \text{ mb}, \quad \sigma_{tot}^A(\sqrt{s} = 500) = 59.9 \text{ mb} . \quad (20)$$

In the same way, we get in the case of the GLN model [12] :

$$\sigma_{tot}^{mod}(\sqrt{s} = 52.8) = 42.7 \text{ mb}, \quad \sigma_{tot}^{mod}(\sqrt{s} = 541) = 64.7 \text{ mb} \quad (21)$$

$$(t_{max})_2(\sqrt{s} = 52.8) = 1.66 \cdot 10^{-3} \text{ GeV}^2, \quad (t_{max})_2(\sqrt{s} = 541) = 1.09 \cdot 10^{-3} \text{ GeV}^2 \quad (22)$$

$$\sigma_{tot}^A(\sqrt{s} = 52.8) = 43.0 \text{ mb}, \quad \sigma_{tot}^A(\sqrt{s} = 541) = 65.5 \text{ mb} . \quad (23)$$

It is seen from eqs. (18) - (23) that the values of the total cross sections computed from the analytical formula (17) are in a agreement with the model calculations in both cases. This simply checks the *internal consistency* of our calculations and not the validity itself of the respective model*.

Of outmost importance is the fact that *the measurement of the analyzing power A_N allows us to extract directly from experimental data and independently one from the other the real and imaginary parts of the hadron scattering amplitude $F_1^h(s, t)$* . Namely, from eq. (2) we get the imaginary part of the hadron amplitudes

$$\text{Im} F_1^h(s, t) = n \cdot \tilde{A}_N \frac{d\sigma^{exp}}{dt} , \quad (24)$$

where

$$\tilde{A}_N \equiv -A_N^{exp}(s, t)/(8\pi \cdot F_5^c) , \quad (25)$$

* The values of σ_{tot} and t_{max} from the models [11] and [12], while practically identical in both cases at ISR energies (where the data are fitted), differ by $\simeq 10$ % in the TeV region of energy (where the pp data are not yet available). Such a difference is normal for models having a different dynamical content leading to a different energy dependence of σ_{tot} and t_{max} .

and $d\sigma^{exp}/dt$ is the experimentally measured differential cross-sections, A_N^{exp} is the experimentally measured analysing power and n is the normalisation factor for $d\sigma^{exp}/dt$.

From eqs. (1) and (24), we get the real part of the hadron amplitude

$$ReF_1^h(s, t) = -F_1^c + \left[\frac{n}{4\pi} \frac{d\sigma^{exp}}{dt} - (\alpha\phi F_1^c + n\tilde{A}_N \frac{d\sigma^{exp}}{dt})^2 \right]^{1/2}, \quad (26)$$

again expressed in terms of the experimental quantities $d\sigma^{exp}/dt$ and A_N^{exp} , the normalisation factor n and also in terms of the theoretically known Coulomb amplitude F_1^c .

Eqs. (24) and (26) completely specify the hadron amplitude $F_1^h(s, t)$ at small t without any theoretical assumptions concerning their form in t at given s . Of course the same is true for $\rho(s, t)$:

$$\rho(s, t) = \frac{ReF_1^h(s, t)}{ImF_1^h(s, t)}. \quad (27)$$

The extrapolation at $t = 0$ of the quantity $\rho(s, t)$ directly computed from the experimental data on $d\sigma/dt$ and A_N will give us the value of the familiar parameter $\rho(s, t = 0)$ without any theoretical assumptions concerning the hadron amplitude $F_1^h(s, t)$, though of course it will remain dependent on the way of extrapolating from very small t towards $t = 0$.

The precise experimental measurements of dN/dt and A_N at future accelerators, as well as, if possible, at the Tevatron, will therefore give us unvaluable information on the hadron elastic scattering at small t . New phenomena at high energies could be therefore detected without going through the usual arbitrary assumptions (such as the exponential form) concerning the hadron elastic scattering amplitudes.

REFERENCES

- [1] UA4 Collaboration, D. Bernard et al., Phys. Lett. **B198** (1987) 583.
- [2] UA4/2 Coll., C. Augier et al., Phys. Lett. **B316** (1993) 448.
- [3] O.V. Selyugin, Phys. Lett. **B33** (1994) 245.
- [4] B. Nicolescu, In Proceedings of the International Conference on Elastic and Diffractive Scattering *Frontiers in Strong Interactions* (VIth Blois Workshop). Editions Frontières, in press ; preprint Orsay IPNO/TH 95-62.
- [5] P. Gauron, In Proceedings of the International Conference on Elastic and Diffractive Scattering *Frontiers in Strong Interactions* (VIth Blois Workshop). Editions Frontières, in press ; preprint Orsay IPNO/TH 95-63.
- [6] V. Kundrat, M. Lokajicek, Z. Phys. **C63** (1994) 619.
- [7] N.H. Buttmore, E. Gotsman, E. Leader, Phys. Rev. **D18** (1978) 694.
- [8] R. Cahn, Z. Phys. **C15** (1982) 253.
- [9] See, for example, M. Anselmino and S. Forte, Phys. Rev. Lett. **71** (1993) 223 ; N. Akchurin, N.H. Buttmore and A. Penzo, Phys. Rev. **D51** (1995) 3944.
- [10] E.L. Berger, A.C. Irving and C. Sorensen, Phys. Rev. **D17** (1978) 2971.
- [11] S.V. Goloskokov, S.P. Kuleshov, O.V. Selyugin, Z. Phys. **C50** (1991) 455.
- [12] P. Gauron, E. Leader, B. Nicolescu, Phys. Lett. **B238** (1990) 406.