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FISIST/7-95/CENTRA

UNIVERSALITY TESTS FOR TOTAL CROSS SECTIONS

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Abstract

Starting directly from data we test the universality of the decomposition of total cross-sections in an asymptotically dominant term, the Pomeron, and a non dominant one, the Reggeon. Without assuming Regge pole model behaviour or additive quark model relations we show that data are compatible with both models. Support is not found for models predicting asymptotical equality of total cross-sections.

The understanding of the high energy behaviour of hadron-hadron collisions remains an open theoretical question of QCD. As the long distance behaviour is necessarily present, a pure perturbative treatment, starting from the asymptotic freedom limit, is most certainly not sufficient and nonperturbative QCD may have to be included in an essential way. In any case, some universality features, due to the colour structure of the theory, must be present in the data.

We do not intend to adress here the important and general problem of QCD in soft high energy physics (see Ref.[1] for a recent review) but simply to ask, looking directly at data, what conclusions can be drawn concerning universality in high energy elastic scattering data, namely, in total cross-sections.

Two very simple models will be taken as reference: the Regge Pole Model (RPM), in the version of Donnachie and Landshoff [2], and the Generalized Additive Quark Model (GAQM), in the version developed in [3]. Both models propose an asymptotically dominating term, the Pomeron, σ^P , and another term decreasing with energy, the Reggeon, σ^R .

In the RPM the emphasis is on the Regge pole behaviour of the two components,

$$\sigma^P \sim s^{\alpha_P-1} \quad , \quad \sigma^R \sim s^{\alpha_R-1} \quad , \quad (1)$$

α_P and α_R being the intercepts of the Pomeron and Reggeon trajectories, respectively. In the GAQM the emphasis is on relations between total cross-sections, for instance [4,3],

$$\sigma_{\pi p}^P / \sigma_{pp}^P = 6/9 = 2/3 \quad (2)$$

and

$$(\sigma_{\bar{p}p} - \sigma_{pp}) = 5 (\sigma_{\pi^- p} - \sigma_{\pi^+ p}) = \frac{5}{2} (\sigma_{k^- p} - \sigma_{k^+ p}) = \frac{5}{4} (\sigma_{\bar{p}n} - \sigma_{pn}) \quad . \quad (3)$$

It should be stressed that both models, RPM and GAQM, are at most reasonable approximations as, for instance, multiple scattering absorptive corrections are not included.

We shall write the total cross-section $\sigma(s)$ for a process ab in the form

$$\sigma_{ab}(s) = P_{ab}\sigma^P(s) + R_{ab}\sigma^R(s) \quad , \quad (4)$$

where $\sigma^P(s)$ and $\sigma^R(s)$ are, possibly universal, cross-sections and the normalization is such that for $\bar{p}p$ we have

$$\sigma_{\bar{p}p}(s) = 9\sigma^P(s) + 5\sigma^R(s) \quad . \quad (5)$$

The numbers 9 and 5 in (5) are suggested by the GAQM (9 combinations of quark pairs in $\bar{p}p$ and pp , 5 possibilities for quark-antiquark annihilation in $\bar{p}p$).

From the analysis of experimental data made in [2], using (1), the resulting values for P_{ab} and R_{ab} are the ones presented in Table 1. The values of P_{ab} and R_{ab} of GAQM are

also presented in Table 1. Flavour breaking factors in P_{ab} were not included. A parameter u , not fixed by the model, measures the ratio of the forward imaginary parts of the $\bar{q}q$ annihilation amplitudes in the channels u and s , respectively. In general one expects

$$u < 1 \ , \quad (6)$$

the limit $u = 0$ corresponding to strong exchange degeneracy [5]. It should be mentioned that the relations (3) are independent of u . Finally, in both models, RPM and GAQM, it is supposed that $P_{ab} = P_{a\bar{b}}$ (Pomeranshuk theorem).

Our strategy here is to go beyond RPM and GAQM and directly test the structure of (4), with universality of $\sigma^{\mathbf{P}}(s)$ and $\sigma^R(s)$, by looking at data without making use neither of assumption (1) nor assumptions (2) and (3).

In order to test the universality of $\sigma^R(s)$ it is enough to consider the positive differences

$$\Delta\sigma_{ab} \equiv \sigma_{\bar{a}b} - \sigma_{ab} > 0 \ . \quad (7)$$

By comparing hadron hp and $\bar{h}p$ processes to pp and $\bar{p}p$ we obtain

$$\Delta\sigma_{pp} = A_h \Delta\sigma_{hp} \quad (8)$$

with

$$A_h \equiv \frac{R_{\bar{p}p} - R_{pp}}{R_{\bar{h}p} - R_{hp}} \ , \quad (9)$$

A_h being a constant and $A_p = 1$. The parametrization (4) thus requires the linear relation (8). Plots of $\Delta\sigma_{pp}$ vs. $\Delta\sigma_{\pi p}$, $\Delta\sigma_{kp}$, $\Delta\sigma_{np}$ are presented in Figs. 1a), 2a) and 3a). The experimental values of A_h and the values from the models RPM and GAQM are given in Table 2.

In order to extract the Pomeron component we shall write

$$\sigma_{hp}^{\mathbf{P}} = \alpha_h \sigma_{hp} - (\alpha_h - 1) \sigma_{\bar{h}p} = \sigma_{\bar{h}p} - \alpha_h \Delta\sigma_{hp} \quad (10)$$

with

$$\sigma_{hp}^{\mathbf{P}} = P_{hp} \sigma^{\mathbf{P}} \quad (11)$$

and

$$\alpha_h \equiv \frac{R_{\bar{h}p}}{R_{\bar{h}p} - R_{hp}} \geq 1 \ . \quad (12)$$

By comparing (10) with the equivalent equation for $\sigma_{pp}^{\mathbf{P}}$ and introducing the parameter γ_h ,

$$\gamma_h \equiv \sigma_{hp}^{\mathbf{P}} / \sigma_{pp}^{\mathbf{P}} \equiv P_{hp} / P_{pp} = \text{const.} \ , \quad (13)$$

with $\gamma_p \equiv 1$, one obtains

$$\Delta\sigma_{pp} = \frac{1}{\alpha_p \gamma_h} [\alpha_h \Delta\sigma_{hp} + (\gamma_h \sigma_{\bar{p}p} - \sigma_{\bar{h}p})] . \quad (14)$$

Consistency of (14) with (8) requires

$$\gamma_h \sigma_{\bar{p}p} - \sigma_{\bar{h}p} = B_h \Delta\sigma_{hp} . \quad (15)$$

In other words, $\gamma_h \sigma_{\bar{p}p} - \sigma_{\bar{h}p}$ must depend linearly on $\Delta\sigma_{hp}$, with

$$B_h = \frac{\gamma_h R_{\bar{p}p} - R_{\bar{h}p}}{R_{\bar{h}p} - R_{hp}} = \text{const.} , \quad (16)$$

and $B_p = 0$.

In the test of (15) for various reactions the parameter γ_h was varied and adjusted to reproduce, as best as possible, a linear relation, going through the origin, between $\gamma_h \sigma_{\bar{p}p} - \sigma_{\bar{h}p}$ and $\Delta\sigma_{hp}$. In Fig. 1b), 2b) and 3b) we present the fits using (15) and in Table 3 the values of γ_h and B_h experimentally obtained and the ones of RPM and GAQM.

One may ask if the tests (8) and (15) or the knowledge of A_h , γ_h and B_h for different reactions, are enough to construct the true “experimental” Pomeron, $\sigma^{\mathbf{P}}(s)$, and Reggeon, $\sigma^R(s)$. The answer is no.

In fact, from (14), (15) and (8), we obtain

$$\alpha_h = (A_h \gamma_h) \alpha_p - B_h . \quad (17)$$

Eq. (17) tells us that α_p and α_h are not determined by the knowledge of A_h , γ_h and B_h . The constraints (8) and (15) are *not enough* to fix $\sigma^{\mathbf{P}}(s)$ and $\sigma^R(s)$. This can be easily seen in a different way. If one makes the transformation

$$\begin{aligned} \sigma^{\mathbf{P}} &\rightarrow \sigma'^{\mathbf{P}} \equiv \sigma^{\mathbf{P}} + k \sigma^R \\ \sigma^R &\rightarrow \sigma'^R \equiv (1 - k) \sigma^R \end{aligned} \quad (18)$$

σ_{hp} becomes:

$$\sigma_{hp} = P_{hp} \sigma^{\mathbf{P}} + R_{hp} \sigma^R = P'_{hp} \sigma'^{\mathbf{P}} + R'_{hp} \sigma'^R \quad (19)$$

with

$$\begin{aligned} P'_{hp} &= P_{hp} \\ R'_{hp} &= \frac{R_{hp} - k P_{hp}}{1 - k} . \end{aligned} \quad (20)$$

It is straightforward to see that the transformation (18), with (19) and (20), leaves A_h , γ_h and B_h invariant. For this reason it is not possible to extract unambiguously from data the normalization and the energy dependence of $\sigma^{\mathbf{P}}(s)$ and $\sigma^R(s)$. Eq.(1) is just a possibility.

It is clear that the tests (8) and (15) are fairly well satisfied by the data, as can be seen by the quality of our linear fits. So far, we find no indication of deviations from the ansatz (4). In addition, the quark model relations (2) and (3) are approximately satisfied. On the other hand, the results of [2] satisfy reasonably well the universality tests, agreeing with the quark model for relations (2) and (3) and giving reasonable values for B_h (the GAQM with $u \sim 0.4$ is also acceptable). Better data — and more data, in particular at higher energy for πp and Kp — are needed in order to have more definite conclusions. However, the fact that the linear fits with (8) and (15) work is in itself highly nontrivial and brings strong support to the universal ansatz (4).

Another conclusion of this work is that models that propose equality of total cross-sections asymptotically, $\sigma_{ab}(s) \rightarrow \sigma_{pp}(s)$, [6,7] do not seem to be favoured by data.

An extended version of this work including a discussion on the near forward direction elastic scattering data and on the validity of geometrical models is under preparation.

Acknowledgements

We would like to thank FAPESP and CNPq from Brazil and JNICT from Portugal for financial support.

Table 1

	RPM		GAQM	
Process	P_{ab}	R_{ab}	P_{ab}	R_{ab}
$\bar{p}p$	9	5	9	5
pp	9	2.85	9	$5u$
$\pi^- p$	5.65	1.83	6	$2 + u$
$\pi^+ p$	5.65	1.40	6	$1 + 2u$
$K^- p$	4.90	1.34	6	2
$K^+ p$	4.90	0.41	6	$2u$
$\bar{p}n$	9	4.71	9	4
pn	9	2.78	9	$4u$

Table 2

A_h	EXP.	RPM	GAQM
A_π	6.04 ± 0.24	5.00	5
A_K	2.52 ± 0.05	2.31	2.5
A_n	1.32 ± 0.05	1.11	1.25

Table 3

	EXP		RPM		GAQM	
hp	γ_h	B_h	γ_h	B_h	γ_h	B_h
πp	0.62 ± 0.15	3.27 ± 0.15	0.63	3.04	$2/3$	$\frac{4/3-u}{1-u}$
kp	0.53 ± 0.08	1.28 ± 0.03	0.54	1.49	$2/3$	$\frac{2/3}{1-u}$
np	1.02 ± 0.38	0.38 ± 0.04	1	0.15	1	$\frac{1/4}{1-u}$

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Figure Captions

Fig. 1 Universality relations for πp vs. pp

- a) Test of (8): $\Delta\sigma_{pp} = A_\pi \Delta\sigma_{\pi p}$
- b) Test of (15): $\gamma_\pi \sigma_{\bar{p}p} - \sigma_{\pi^- p} = B_\pi \Delta\sigma_{\pi p}$

The experimental and theoretical values of the parameters, A_π , γ_π and B_π , are given in Tables 2 and 3. For experimental data see Ref. [8].

Fig. 2 Universality relations for Kp vs. pp

- a) Test of (8): $\Delta\sigma_{pp} = A_K \Delta\sigma_{Kp}$
- b) Test of (15): $\gamma_K \sigma_{\bar{p}p} - \sigma_{K^- p} = B_K \Delta\sigma_{Kp}$

The experimental and theoretical values of the parameters, A_K , γ_K and B_K , are given in Tables 2 and 3. For experimental data see Ref. [8].

Fig. 3 Universality relations for p_n vs. pp

- a) Test of (8): $\Delta\sigma_{pp} = A_n \Delta\sigma_{np}$
- b) Test of (15): $\gamma_n \sigma_{\bar{p}p} - \sigma_{\bar{n}p} = B_n \Delta\sigma_{np}$

The experimental and theoretical values of the parameters, A_n , γ_n and B_n , are given in Tables 2 and 3. For experimental data see Ref. [8].

Fig. 1

Fig. 2

Fig. 3