Analytic Amplitudes for Hadronic Forward Scattering : COMPETE update

B. Nicolescu[a], J. R. Cudell[b], V. V. Ezhela[c], P. Gauron[a], K. Kang[d], Yu. V. Kuyanov[c], S. B. Lugovsky[c], E. Martynov[e], E. A. Razuvaev[c], N. P. Tkachenko[c]

[a]LPNHE (Unité de Recherche des Universités Paris 6 et Paris 7, Associée au CNRS), Université Pierre et Marie Curie, Tour 12 E3, 4 Place Jussieu, 75252 Paris Cedex 05, France

[b]Institut de Physique, Bât. B5, Université de Liège, Sart Tilman, B4000 Liège, Belgium

[c]COMPAS group, IHEP, Protvino, Russia

[d]Physics Department, Brown University, Providence, RI, U.S.A.

[e]Bogolyubov Institute for Theoretical Physics, 03143 Kiev, Ukraine

We consider several classes of analytic parametrizations of hadronic scattering amplitudes, and compare their predictions to all available forward data ($pp, \bar{p}p, \pi p, Kp, \gamma p, \gamma\gamma, \Sigma p$). Although these parametrizations are very close for $\sqrt{s} \geq 9$ GeV, it turns out that they differ markedly at low energy, where a universal Pomeron term $\sim \ln^2 s$ enables one to extend the fit down to $\sqrt{s} = 4$ GeV. We present predictions on the total cross sections and on the ratio of the real part to the imaginary part of the elastic amplitude (ρ parameter) for present and future pp and $\bar{p}p$ colliders, and on total cross sections for $\gamma p \rightarrow$ hadrons at cosmic-ray energies and for $\gamma\gamma \rightarrow$ hadrons up to $\sqrt{s} = 1$ TeV.

Analytic parametrizations of forward ($t = 0$) hadron scattering amplitudes is a well-established domain in strong interactions.

However, in the past, the phenomenology of forward scattering hadquite a high degree of arbitrariness : i) Excessive attention was paid to pp and $\bar{p}p$ scattering ; ii) Important physical constraints were often mixed with less general or even ad-hoc properties ; iii) The cut-off in energy, defining the region of applicability of the high-energy models, differed from one author to the other ; iv) The set of data considered by different authors was often different ; v) No rigorous connection was made between the number of parameters and the number of data points ; vi) No attention was paid to the necessity of the stability of parameter values ; vii) The experiments were performed in the past in quite a chaotic way : huge gaps are sometimes present between low-energy and high-energy domains or inside the high-energy domain itself.

The COMPETE (COmputerized Models and Parameter Evaluation for Theory and Experiment) collaboration has cured as much as possible the above discussed arbitrariness.

The χ^2/dof criterium is not able, by itself, to cure the above difficulties : new indicators have to be defined. Once these indicators are defined[1], it is possible to estimate the overall performance of each model, and to establish a ranking : the highest the numerical value of the rank the better the model under consideration.

The final aim of the COMPETE project is to provide our community with a periodic cross assessments of data and models via computer-readable files on the Web [2].

We consider the following exemplar cases of the imaginary part of the scattering amplitudes :

$$ImF^{ab} = s\sigma_{ab} = P_1^{ab} + P_2^{ab} + R_+^{ab} \pm R_-^{ab} \qquad (1)$$

where :
- the $\pm$ sign in formula (1) corresponds to antipar-

ticle (resp. particle) - particle scattering amplitudes.
- $R_\pm$ signify the effective secondary-Reggeon $((f, a_2),\ (\rho, \omega))$ contributions to the even (odd)-under-crossing amplitude

$$R_\pm(s) = Y_\pm \left(\frac{s}{s_1}\right)^{\alpha_\pm}, \quad (2)$$

where Y is a constant residue, α - the reggeon intercept and s_1 - a scale factor fixed at 1 GeV^2 ;
- $P_1(s)$ is the contribution of the Pomeron Regge pole

$$P_1^{ab}(s) = C_1^{ab} \left(\frac{s}{s_1}\right)^{\alpha_{P_1}}, \quad (3)$$

α_{P_1} is the Pomeron intercept $\alpha_{P_1} = 1$, and C^{ab} are constant residues.
- $P_2^{ab}(s)$ is the second component of the Pomeron corresponding to three different J-plane singularities :

a) a Regge simple - pole contribution

$$P_2^{ab}(s) = C_2^{ab} \left(\frac{s}{s_1}\right)^{\alpha_{P_2}}, \quad (4)$$

with $\alpha_{P_2} = 1 + \epsilon,\ \epsilon > 0$, and C_2^{ab} constant ;

b) a Regge double-pole contribution

$$P_2^{ab}(s) = s \left[A^{ab} + B^{ab} \ln\left(\frac{s}{s_1}\right)\right], \quad (5)$$

with A^{ab} and B^{ab} constant ;

c) a Regge triple-pole contribution

$$P_2^{ab}(s) = s \left[A^{ab} + B^{ab} \ln^2\left(\frac{s}{s_0}\right)\right], \quad (6)$$

where A^{ab} and B^{ab} are constants and s_0 is an arbitrary scale factor.

We consider all the existing forward data for $pp, \bar{p}p, \pi p, Kp, \gamma\gamma$ and Σp scatterings. The number of data points is : 904, 742, 648, 569, 498, 453, 397, 329 when the cut-off in energy is 3, 4, 5, 6, 7, 8, 9, 10 GeV respectively. A large number of variants were studied. All definitions and numerical details can be found in Ref. 1.

The 2-component Pomeron classes of models are RRPE, RRPL and RRPL2, where by RR we denote the two effective secondary-reggeon contributions, by P - the contribution of the Pomeron Regge-pole located at $J = 1$, by E - the contribution of the Pomeron Regge-pole located at $J = 1 + \epsilon$, by L - the contribution of the component of the Pomeron, located at $J = 1$ (double pole), and by L2 - the contribution of the component of the Pomeron located at $J = 1$ (triple pole). We also studied the 1-component Pomeron classes of models RRE, RRL and RRL2.

The highest rank are get by the RRPL2$_u$ models (see Table 1), corresponding to the $\ln^2 s$ behaviour of total cross sections first proposed by Heisenberg 50 years ago [3]. The u index denotes

Table 1
Ranking of the the 21 models having nonzero area of applicability. The number between paranthesis, in the Model Code column, denotes the number of free parameters.

Model Code	Rank
RRPL2$_u$(19)	230
RRP$_{nf}$L2$_u$(21)	222
RRL$_{nf}$(19)	222
(RR$_c$)^d PL2$_u$(15)	204
(RR)^d P$_{nf}$L2$_u$(19)	194
[R^{qc} L^{qc}]R$_c$(12)	184
(RR$_c$)^{d}P^{qc}L2$_u$(14)	181
(RR)^{d}P^{qc}L2$_u$(16)	180
RR$_c$ L2^{qc}(15)	180
(RR)^d P$_{nf}$L2(20)	178
(RR)^d PL2$_u$(17)	174
RRPL(21)	173
RR$_c$ L^{qc}(15)	172
RRL2^{qc}(17)	170
[R^{qc} L2^{qc}]R$_c$(12)	170
RRL^{qc}(17)	162
RRPE$_u$(19)	158
[R^{qc}L^{qc}]R(14)	155
RRL2(18)	152
RR$_c$PL(19)	142
RRL(18)	133

Table 2
Predictions for σ_{tot} and ρ, for $\bar{p}p$ (at $\sqrt{s} = 1960$ GeV) and for pp (all other energies). The central values and statistical errors correspond to the preferred model RRPL2$_u$.

$\sqrt{s}$ (GeV)	σ (mb)	ρ
100	46.37 ± 0.06	0.1058 ± 0.0012
200	51.76 ± 0.12	0.1275 ± 0.0015
300	55.50 ± 0.17	0.1352 ± 0.0016
400	58.41 ± 0.21	0.1391 ± 0.0017
500	60.82 ± 0.25	0.1413 ± 0.0017
600	62.87 ± 0.28	0.1416 ± 0.0018
1960	78.27 ± 0.55	0.1450 ± 0.0018
10000	105.1 ± 1.1	0.1382 ± 0.0016
12000	108.5 ± 1.2	0.1371 ± 0.0015
14000	111.5 ± 1.2	0.1361 ± 0.0015

Table 3
Predictions for σ_{tot} for $\gamma p \rightarrow hadrons$ for cosmic-ray photons. The central values and the statistical errors are as in Table 2.

p^{γ}_{lab} (GeV)	σ (mb)
$0.5 \cdot 10^6$	0.243 ± 0.009
$1.0 \cdot 10^6$	0.262 ± 0.010
$0.5 \cdot 10^7$	0.311 ± 0.014
$1.0 \cdot 10^7$	0.333 ± 0.016
$1.0 \cdot 10^8$	0.418 ± 0.022
$1.0 \cdot 10^9$	0.516 ± 0.029

the *universality property* : the coupling B of the $\ln^2 s$ term is the same in all hadron-hadron scatterings and s_0 is the same in all reactions.

We note that the familiar RRE Donnachie-Landshoff model is *rejected* at the 98% C.L. when models which achieve a χ^2/dof less than 1 for $\sqrt{s} \geq 5$ GeV are considered.

The predictions of the best RRPL2$_u$ model, adjusted for $\sqrt{s} \geq 5$ GeV, are given in Tables 2-4.

The uncertainties on total cross sections, including the systematic errors due to contradictory data points from FNAL (the CDF and E710/E811 experiments, respectively), can reach 1.9% at RHIC, 3.1% at the Tevatron, and 4.8% at the LHC, whereas those on the ρ parameter are respectively 5.4%, 5.2%, and 5.4%. The global picture emerging from fits to all data on forward observables supports the CDF data and disfavors the E710/E811 data at $\sqrt{s} = 1.8$ TeV.

Any significant deviation from the predictions based on model RRPL2$_u$ will lead to a re-evaluation of the hierarchy of models and presumably change the preferred parametrisation to another one. A deviation from the "allowed region" would be an indication that strong interactions demand a generalization of the analytic models discussed so far, *e.g.* by adding Odderon terms, or new Pomeron terms, as suggested by QCD.

Table 4
Predictions for σ_{tot} for $\gamma\gamma \rightarrow hadrons$. The central values and the statistical errors are as in Table 2.

$\sqrt{s}$ (GeV)	σ (μ b)
200	0.546 ± 0.027
300	0.610 ± 0.035
400	0.659 ± 0.042
500	0.700 ± 0.047
1000	0.840 ± 0.067

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