The BSW Impact Picture 30 Years After[1]

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Abstract

Thirty years ago Bourrely-Soffer-Wu (BSW) investigated an impact picture description of $p-p$ and $\bar{p}-p$ elastic scattering with success. For this anniversary, a short review of the main features of this picture will be presented with its evolution over the years. The future experiments at the LHC collider will provide decisive tests for the impact picture at high energy.

In the year 1978, BSW proposed an impact parameter description of the high energy behavior of elastic $p-p$ and $\bar{p}-p$ scattering [1]. A main feature was the peculiar form of the energy dependence of the pomeron, based on the results of Cheng and Wu [2, 3] derived from the high-energy behavior of quantum field theory. Later, in 1984, with the advent of $\bar{p}-p$ experiments, a more complete analysis was performed [4, 5]. I will present a recent update of the results which are focused on the LHC energy domain. An extension to the elastic processes $\pi-p$ and $K-p$ can be found in [6]. Moreover, we have also shown that under certain assumptions $\gamma-p$ and $\gamma-\gamma$ total cross sections can be predicted [7].

In the impact-picture representation, the spin-independent scattering amplitude[2], for pp and $\bar{p}p$ elastic scattering, reads as

$$a(s,t) = \frac{is}{2\pi}\int e^{-i\mathbf{q}\cdot\mathbf{b}}(1-e^{-\Omega_0(s,\mathbf{b})})d\mathbf{b} \ , \tag{1}$$

where $\mathbf{q}$ is the momentum transfer ($t=-\mathbf{q}^2$) and $\Omega_0(s,\mathbf{b})$ is defined to be the opaqueness at impact parameter $\mathbf{b}$ and at a given energy s. We take

$$\Omega_0(s,\mathbf{b}) = S_0(s)F(\mathbf{b}^2) + R_0(s,\mathbf{b}) \ , \tag{2}$$

the first term is associated with the pomeron exchange, which generates the diffractive component of the scattering and the second term is the Regge background. The Pomeron energy dependence is given by the crossing symmetric expression [2, 3]

$$S_0(s) = \frac{s^c}{(\ln s)^{c'}} + \frac{u^c}{(\ln u)^{c'}} \ , \tag{3}$$

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[2] Here we neglect the spin-dependent amplitude which was considered in Refs. [1, 8] for the description of polarizations and spin correlation parameters.

where u is the third Mandelstam variable. The choice one makes for $F(\mathbf{b}^2)$ is crucial and we take the Bessel transform of

$$\tilde{F}(t) = f[G(t)]^2 \frac{a^2+t}{a^2-t} \ , \tag{4}$$

where $G(t)$ stands for the proton "nuclear form factor", parametrized like the electromagnetic form factor, as a two poles,

$$G(t) = \frac{1}{(1-t/m_1^2)(1-t/m_2^2)} \ . \tag{5}$$

The slowly varying function occuring in Eq.(4), reflects the approximate proportionality between the charge density and the hadronic matter distribution inside a proton. So the pomeron part of the amplitude depends on only *six* parameters c, c', m_1, m_2, f, and a. The asymptotic energy regime of hadronic interactions are controlled by c and c', which will be kept, for all elastic reactions, at the values obtained in 1984 [4], namely

$$c = 0.1675 \quad c' = 0.7479 \quad m_1 = 0.5763\text{GeV}^2 \quad m_2 = 0.5763\text{GeV}^2$$
$$f = 6.9968 \quad a = 1.9354\text{GeV}^2. \tag{6}$$

The remaing four parameters are related, more specifically to the reaction pp ($\bar{p}p$) and they will be slightly re-adjusted from the use of a new set of data.

We now turn to the Regge background. A generic Regge exchange amplitude has an expression of the form

$$\tilde{R}_i(s,t) = C_i e^{b_i t}\left[1 \pm e^{-i\pi\alpha_i(t)}\right](\frac{s}{s_0})^{\alpha_i(t)} \ , \tag{7}$$

where $C_i e^{b_i t}$ is the Regge residue, $\pm$ is the signature factor, $\alpha_i(t) = \alpha_{0i} + \alpha_i^{'} t$ is an effective linear Regge trajectory and $s_0 = 1\text{GeV}^2$. If we consider the sum over all the allowed Regge trajectories $\tilde{R}_0(s,t) = \sum_i \tilde{R}_i(s,t)$, the Regge background $R_0(s,\mathbf{b})$ in Eq. (2) is the Bessel transform of $\tilde{R}_0(s,t)$. In pp ($\bar{p}p$) elastic scattering, the allowed Regge exchanges are A_2, ρ, ω, so the Regge background involves several additional parameters which are described in [6].

For completeness, in order to describe the very small t-region, one should add to the hadronic amplitude considered above, the Coulomb amplitude whose expression is $a^C(s,t) = 2\alpha[s/|t|]G_{em}^2(t)exp[\pm i\alpha\phi(t)]$, where α is the fine structure constant, $G_{em}(t)$ is the electromagnetic form factor, $\phi(t)$ is the West-Yennie phase [9] and the $\pm$ sign corresponds to pp and $\bar{p}p$. With the present parameters we obtained a χ^2/pt=1840/431, in comparison with the same data and the 1978 parameters χ^2=4275. In Fig. 1, the variation of the total cross section and the ratio $\rho = \text{Re } a(s,0)/\text{Im } a(s,0)$ is shown as a function of the energy. In Fig. 2, the ratio σ_{el}/σ_{tot} is an increasing function of the energy, the differential cross section as a function of the momentum transfer is plotted for different bins of energy in the LHC energy domain. In particular, at the LHC nominal energy, $\sqrt{s} = 14\text{TeV}$, we predict $\sigma_{tot} = 103.6 \pm 1.1\text{mb}$, $\rho = 0.122 \pm 0.003$ and $\sigma_{el}/\sigma_{tot} = 0.274 \pm 0.008$. A significant departure from the previous ρ value would imply a violation of dispersion relations due to an unexpected behavior of the scattering amplitude as discussed in [11].

In conclusion, after 30 years of existence the BSW impact picture remains reliable to describe high energy hadron-hadron elastic scattering. The structure of the pomeron amplitude we proposed has an energy dependence deduced from the high energy behavior of tower diagrams in QFT. Over the years, with the advent of new experimental data, in particular, at Tevtron and SPS, we have obtained a more precise determination of the parameters which leads to an improvement of the predictive power. A crucial test of the high energy behavior of the impact picture will be provided by ATLAS and TOTEM experiments at LHC[3].

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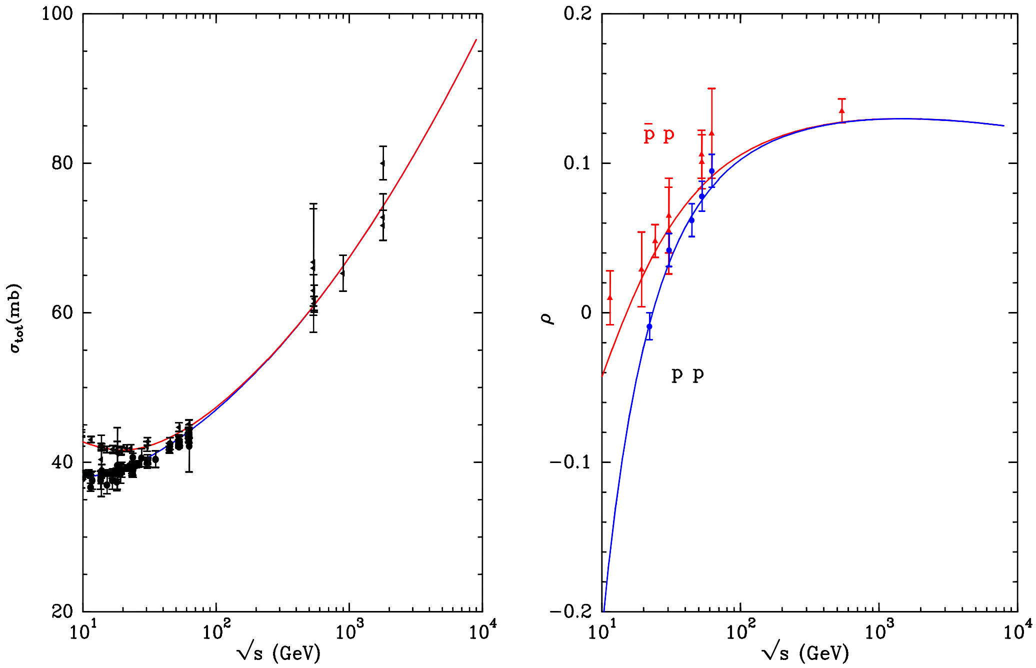

Figure 1: pp and $\bar{p}p$ elastic scattering, σ_{tot} (left), ρ (right) as a function of the energy.

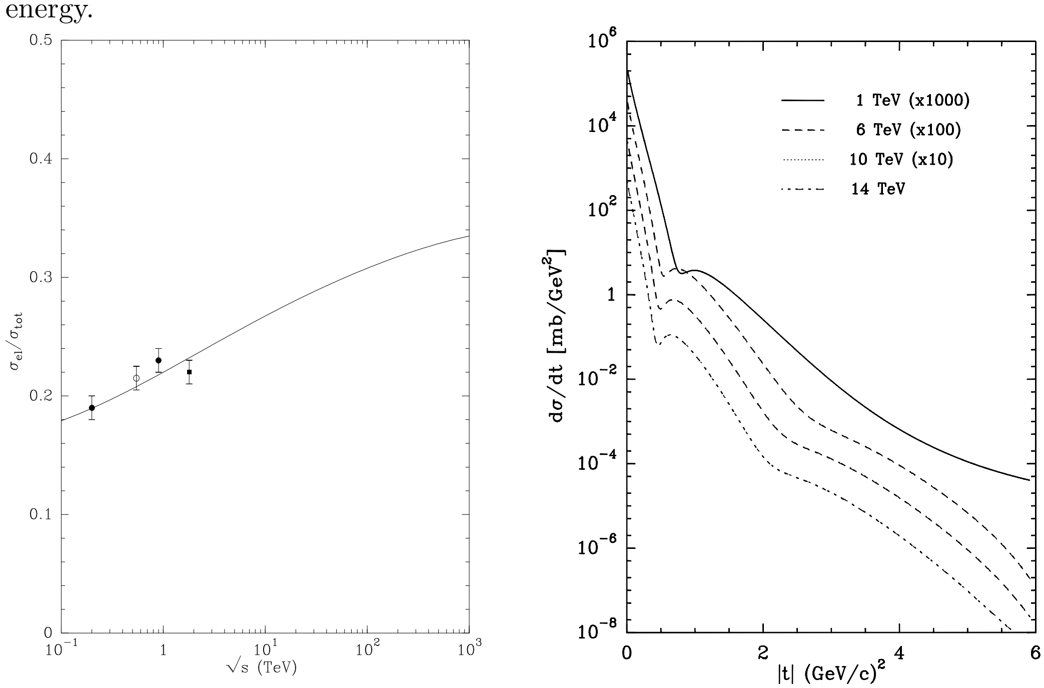

Figure 2: The ratio σ_{el}/σ_{tot} as function of $\sqrt{s}$ (left) data from [10], the differential cross section for different energy bins as a function of the momentum transfer (right).