pp and $p\bar{p}$ Elastic Scattering at $\sqrt{s} = 0.55$ to 40 TeV

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The recent data at $\sqrt{s} = 0.546$ TeV from the CERN $p\bar{p}$ collider confirm once more the predictions of the impact picture, which is based on quantum field theory. These predictions on pp and $p\bar{p}$ total and elastic differential cross sections are extended to higher energies up to $\sqrt{s} = 40$ TeV. They are of direct interest for future experiments at CERN, Fermilab, and the superconducting super collider.

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Some time ago, it was found theoretically on the basis of gauge theory that all total cross sections must increase at extremely high energies.[1] Shortly thereafter, a phenomenology referred to as the impact picture[2] was worked out incorporating this limiting behavior, even before there was any experimental confirmation. This phenomenology was subsequently improved[3–5] in a number of ways when data became available.[6,7]

Recently, data on $p\bar{p}$ elastic scattering were obtained from the CERN $p\bar{p}$ collider[8–10] at a center-of-mass energy of $\sqrt{s} = 0.546$ TeV. This is the highest energy that has so far been obtained in a laboratory. The data once again confirm the predictions of the impact picture.[11] In particular, the ratio σ_{el}/σ_{tot} has been measured at the CERN $p\bar{p}$ collider energy by Battiston *et al.*[8] and Bozzo *et al.*,[8] and it was found to be 0.215 ± 0.005, in agreement with theoretical prediction[11] (see Fig. 1). This is to be compared with 0.174 ± 0.005[12] at the highest intersecting storage rings energy of 0.063 TeV. In this paper we give in some detail these theoretical predictions for higher energies soon to be available at the CERN $p\bar{p}$ collider and the Fermilab Tevatron collider, and also for the energies expected at the planned large hadron collider (LHC) in the CERN large electron-position tunnel and at the superconducting super collider (SSC).

We use the version of the impact picture given in Ref. 5, but with spin effects not included. The pp and $p\bar{p}$ elastic scattering amplitude is given by

$$a_0(s,t) = is\int_0^\infty J_0(b\sqrt{-t})(1 - e^{-\Omega_0(s,b)})\,b\,db,$$

where

$$\Omega_0(s,b) = S_0(s)F(b^2) + R_0(s,b),$$

with $R_0(s,b)$ being the Regge background[5] which is negligible at the energies under consideration,

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

u being the third Mandelstam variable,[13] and the Fourier transform of $F(b^2)$ being given by

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

with

$$G(t) = \{[1 - (t/m_1^2)][1 - (t/m_2^2)]\}^{-1}.$$

There are here six real parameters. Their numerical values are[5,11]

$$c = 0.167, \quad c' = 0.748, \quad a = 1.953,$$

$$m_1 = 0.586, \quad m_2 = 1.704, \quad f = 7.115,$$

in units of gigaelectronvolts.

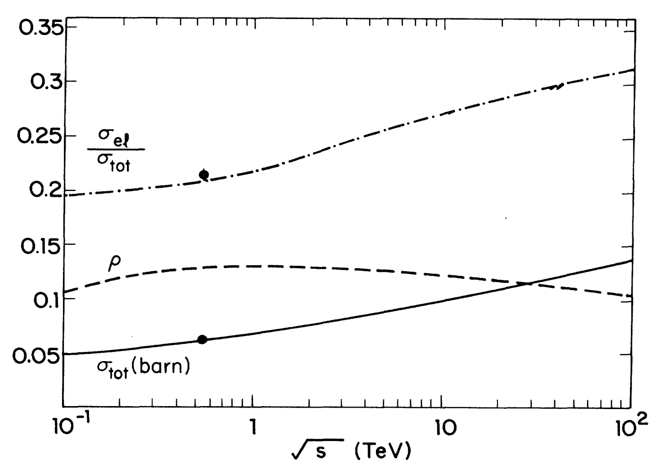

FIG. 1. The total cross section σ_{tot} in barns, the ratio σ_{el}/σ_{tot} of the integrated elastic cross section to the total cross section, and the ratio ρ of the real to imaginary parts of the forward scattering amplitude for pp and $p\bar{p}$ scattering as functions of the center-of-mass energy $\sqrt{s}$. Note that both σ_{tot} and σ_{el}/σ_{tot} increase significantly in this energy range of 0.1 to 100 TeV, while ρ decreases slightly. The data points are from Battiston *et al.* (Ref. 8).

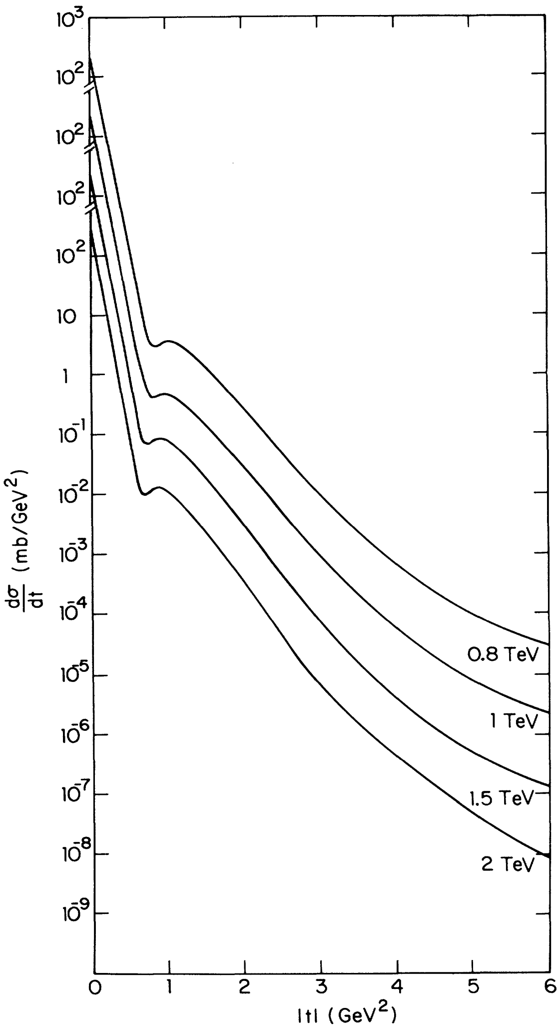

FIG. 2. The pp and $p\bar{p}$ elastic differential cross section as a function of $|t|$, the square of the momentum transfer for energies in the ranges of the CERN and Fermilab $p\bar{p}$ colliders.

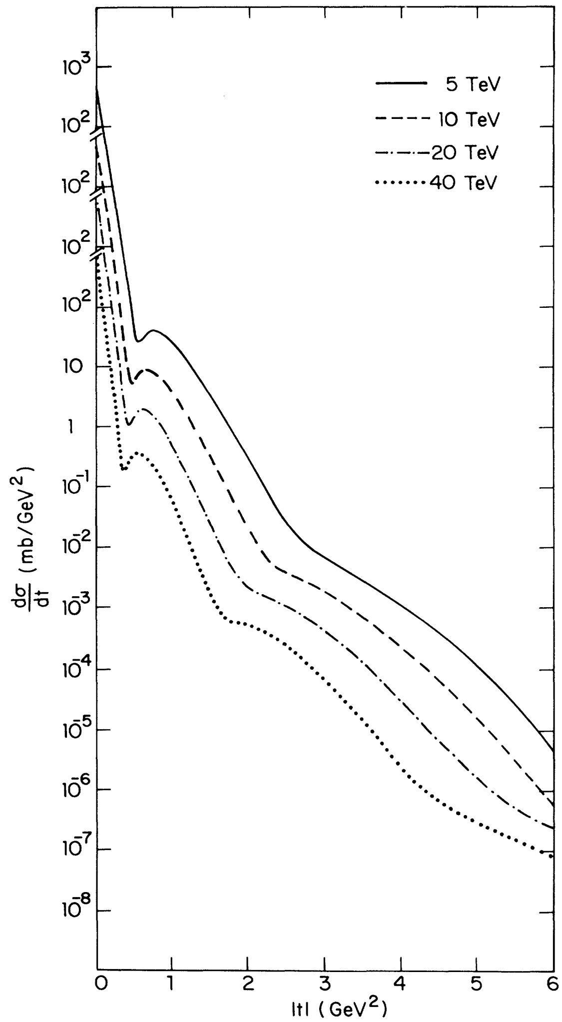

FIG. 3. The same as in Fig. 2 for energies in the ranges of the SSC and the CERN LHC.

On the basis of these parameters, theoretical results on pp and $p\bar{p}$ scattering at center-of-mass energies from 0.55 to 40 TeV have been calculated for the total cross section σ_{tot}, the integrated elastic cross section σ_{el}, the ratio ρ of the real and imaginary parts of the forward scattering amplitude, and the differential cross section $d\sigma/dt$ for various values of $-t$, the square of the momentum transfer. It is found that the predicted total cross section at 40 TeV (121.2 mb) is almost twice that measured at the CERN $p\bar{p}$ collider, and that the integrated elastic cross section increases even faster. On the other hand, the value of ρ decreases rather slowly. Figure 1 shows these three quantities in the form σ_{tot}, σ_{el}/σ_{tot}, and ρ for $\sqrt{s}$ between 0.1 and 100 TeV. In this figure, the total cross section is given in units of barns. Experimental results[8] from CERN are also shown for comparison. The ratio σ_{el}/σ_{tot} is expected to reach 0.3 at $\sqrt{s} \sim 40$ TeV, and thereafter increases slowly to the asymptotic value of 0.5.[1]

Differential cross sections are shown in Figs. 2 and 3. Figure 2 contains a set of cross sections as functions of $|t|$, for $\sqrt{s} = 0.8$, 1, 1.5, and 2 TeV which are or will be available soon at CERN and Fermilab, and Fig. 3 shows another set for $\sqrt{s} = 5$, 10, 20, and 40 TeV which will be reached in the next decade by the SSC and the CERN LHC. It is seen from both figures that the increases in the differential cross sections are more drastic for the higher energies. The first dip moves to smaller values[1] of $|t|$ as the energy increases, which leads to a more pronounced structure because of the smallness of ρ as shown in Fig. 1. In the meantime, the second dip structure is gradually restored. Another consequence of the movement of the dip is that the ratio of differential cross sections $d\sigma/dt$

in the nearly forward direction to that at the first shoulder between the first and second dips decreases with increasing energy. At 40 TeV this ratio is predicted to be only 3.5 orders of magnitude, to be compared with the 5 orders of magnitude at the CERN $p\bar{p}$ collider.[8] A number of other features are also evident from Figs. 2 and 3.

If this multiteraelectronvolt region is referred to as asymptopia, at least so far as pp and $p\bar{p}$ elastic scattering is concerned, then asymptopia is full of interesting structures and physics. Both theoretically and experimentally, there are also many issues that deserve to be clarified. Perhaps the most obvious one concerns the possible characterization of the rapidly increasing inelastic cross section. Presumably both diffractive and pionization processes are involved, and a more refined analysis can be expected to lead to a deeper understanding.

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