Comments and Addenda

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Possible existence of a second minimum in elastic *pp* scattering

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Comparing new elastic *pp* data at 200 and 1500 GeV, it is suggested that at higher energies $d\sigma/dt$ "caves in" at an intermediate t value. Comparison with predictions of a geometrical picture leads to the speculation of the existence of a second minimum and a third maximum in the elastic differential cross section.

Recently there have been published[1,2] new data for high-$|t|$, high-energy (1500 and 200 GeV) elastic *pp* scattering. These data are sketched in Fig. 1 together with older data[3,4] for lower $|t|$ values at similar energies (1500 and 280 GeV). The average slope parameter $b=(d/dt)\ln(d\sigma/dt)$ in the lower- and higher-$|t|$ regions is tabulated in Table I. It has been observed[1,2] that the slope parameter is smaller at higher $|t|$ values. An additional characteristic that we now want to emphasize is that the slope parameter *increases* (from a high value) with increasing energy for the lower-$|t|$ region, and *decreases* (from a low value) with increasing energy for the higher-$|t|$ region. If this trend continues into higher energies, the $\ln(d\sigma/dt)$ vs $|t|$ curve must "cave in" in the $|t|\approx 4$ to 6 GeV^2 region (portions a and b of the dashed curve in Fig. 1). Now it is rather difficult to imagine that at these higher energies the slope parameter remains <0.8 GeV^2 for $|t|$ larger than 10 GeV^2 (cf., the experimental curve in this region for 200 GeV). Hence we suggest the schematic shape of the portion c of the dashed curve of Fig. 1. Putting the three pieces of the dashed curve together, we suggest the development of a shoulder, or even a (second) minimum and a (third) maximum in the region $|t|\approx 4$ to 7 GeV^2 at energies higher than 1500 GeV.

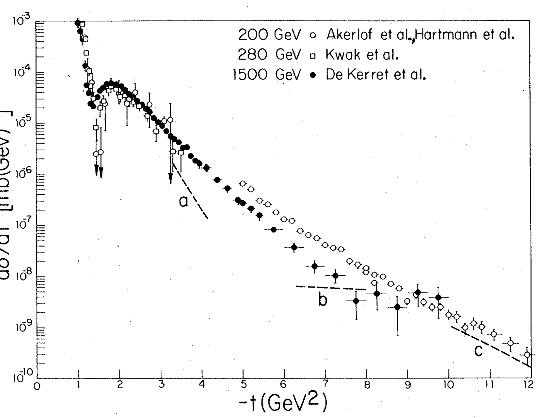

FIG. 1. *pp* elastic differential cross section at 200, 280, and 1500 GeV equivalent laboratory energies. Low-$|t|$ data are taken from Refs. 3, 4, and 12, and high-$|t|$ data from Refs. 1 and 2. The dashed curve indicates the conjectured (schematic) shape for *pp* differential cross section at ultrahigh energies much above the ISR range. Error bars that are small are omitted.

The suggestion above is based purely on the trend of change of the experimental slope parameter with energy. It is interesting to compare this suggestion with the calculations based on a very simple geometrical picture[5] of hadron collisions. The calculation involves no adjustable parameters; the input is the experimental total cross section σ_T and the form factor G_M for the proton. Before discussing the calculation it is perhaps appropri-

TABLE I. Average slope parameter $b=(d/dt)\ln(d\sigma/dt)$ (in GeV^{-2}) in the low-$|t|$ and high-$|t|$ regions for 200-280-GeV and 1500-GeV elastic *pp* scattering.

p_L (GeV/c)	$3<\|t\|<6$ GeV^2	$7<\|t\|<10$ GeV^2
200–280	1.4	1.05
1500	1.8	0.8

ate to point out that this geometrical picture has had impressive success: (i) It produced excellent agreement[6] with the high-energy *pp* differential cross section, down to details in the $|t| < 1.2$ GeV^2 region. (ii) It predicted[7,8] the existence of a (first) minimum and a (second) maximum at higher $|t|$ values, which were later found in CERN ISR experiments. The agreement of the calculation[6] with experimental data around the first minimum and the second maximum is very good. (iii) Since σ_T increases with increasing energy, the calculation predicts[9] a shift of the position of the first minimum with energy and a concurrent rise of the second maximum. These characteristics were later found to be in agreement with experiments.[4] However, the picture also predicts[7,8] a second minimum and a third maximum which have[10] so far not been experimentally verified.

We have redone the computation for the *pp* differential cross section, using the same parametrization for form factor G_M as in Fig. 1 of Ref. 7, but using a total cross section of $\sigma_T = 42.5$ mb. The result is exhibited as curve A in Fig. 2. Also exhibited, as curve B, is the same calculation, but with a dipole form factor $G_M/\mu = (1 + |t|/0.71)^{-2}$ and with $\sigma_T = 42.5$ mb. Both curves exhibit a second minimum and a third maximum, qualitatively in agreement with the calculations[7,8] of 1968, as they should be, since in the input only the total cross section has been changed.

Comparing curves A and B with the dashed speculative curve of Fig. 1 we wonder whether at superhigh energies the $d\sigma/dt$ curve may indeed exhibit a second minimum and a third maximum. The four curves, (a) 200 GeV data, (b) 1500 GeV data, (c) dashed curve of Fig. 1, and (d) the curve A (or B), seem to represent a possible trend of development of the $d\sigma/dt$ curve as the energy increases. Whether this is true is of course best tested with future accelerators such as Isabelle. We suggest a preliminary test in measuring the energy dependence of $d\sigma/dt$ at fixed t, for $|t| = 4$ to 9 GeV^2, within the ISR energy range of 280 to 2000 GeV. A comparison of these dependences at different t may indicate whether there is the beginning of the "cave-in" phenomenon referred to earlier.

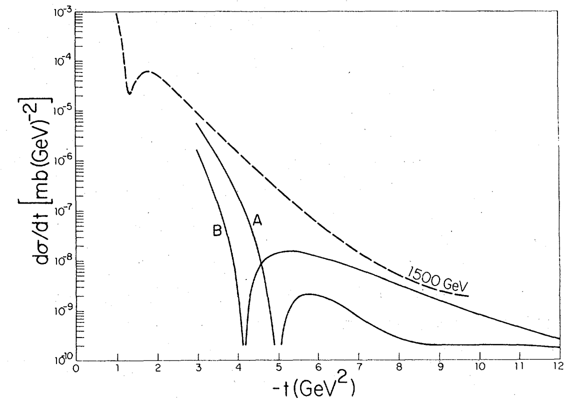

FIG. 2. Experimental *pp* differential cross section curve at 1500 GeV equivalent laboratory energy. Curves A and B are results of calculations described in the text.

If the $d\sigma/dt$ curve at superhigh energies does exhibit qualitative features like those of curves A and B, it would be easy to understand why, in the $7 < |t| < 10$ GeV^2 region, the differential cross sections of existing data do not[11] smoothly decrease with increasing energy: As is the case with the second maximum, the high-$|t|$ side of the third maximum, i.e., the region $7 < |t| < 10$ GeV^2, is approached by the $d\sigma/dt$ curve at a lower energy than the region near the preceding minimum, $|t| = 4-5$ GeV^2 (cf. the 100 GeV curve in Ref. 12). Thus it is quite natural that the $d\sigma/dt$ settles down to a "limiting" value quite rapidly in the $7 < |t| < 10$ GeV^2 region.

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