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LARGE t ELASTIC PROTON-PROTON SCATTERING AT $\sqrt{s}$ = 53 GeV

H. de Kerret, E. Nagy[1], M. Regler[2], W. Schmidt-Parzefall,
K.R. Schubert[3], K. Winter

CERN, Geneva, Switzerland

A. Brandt, F.W. Büsser, H. Dibon, G. Flügge[4], F. Niebergall,
P.E. Schumacher

II. Institut für Experimentalphysik
Universität Hamburg, Germany

J.J. Aubert[5], C. Broll[5], G. Coignet[5], J. Favier[5], L. Massonnet[5],
M. Vivargent[5]

Institut de Physique Nucléaire, Orsay, France

W. Bartl, H. Eichinger, Ch. Gottfried and G. Neuhofer

Institut für Hochenergiephysik, Wien, Austria

ABSTRACT

New experimental results are presented on proton-proton elastic scattering in the range of momentum transfer 0.8 GeV^2 < $-t$ < 9 GeV^2 at a centre-of-mass energy of $\sqrt{s}$ = 53 GeV. The data are obtained using the Split-Field-Magnet Detector at the CERN Intersecting Storage Rings. The cross section has the well-known minimum at $-t$ = (1.34±0.02) GeV^2 but no further minimum or change of slope is observed between 2 and 6.5 GeV^2.

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1 Now at Central Research Institute for Physics, Budapest, Hungary.
2 Now at Institut für Hochenergiephysik, Wien, Austria.
3 Now at Institut für Hochenergiephysik, Universität Heidelberg, Germany.
4 Now at DESY, Hamburg, Germany.
5 Now at LAPP, Annecy, France.

Observation of a diffraction-like minimum[1,2] in high energy elastic proton-proton scattering has prompted questions concerning its origin and whether further minima exist at larger values of the momentum transfer. Based on the t-dependence at the first maximum and on the position of the minimum, several authors have predicted a second minimum in the t range of 4 to 6 GeV^2 and an associated flattening in slope, by using optical models[3], constituent models[4] or exchange models[5], whereas others have predicted a smooth behaviour[6].

We are reporting here experimental results in the range of momentum transfer $0.8 < -t < 9$ GeV^2 at a centre-of-mass energy of $\sqrt{s} = 53$ GeV. We observe no further minimum or change of slope of the differential cross section. The measured cross sections are now spanning a range of 10^{10}.

The data have been obtained using the Split-Field-Magnet Detector (SFM) at the CERN Intersecting Storage Rings (ISR). We report here results extending our earlier measurements[2] to $-t = 9$ GeV^2, corresponding to an integrated luminosity of 1.15×10^9/mb.

The SFM detector, its trigger logics, data acquisition and event reconstruction have been described before[2]. The detector contains two forward telescopes, each equipped with 14 multi-wire proportional chambers of 2 mm wire spacing, most of them 1 m high and 2 m wide. Each chamber has a vertical and a horizontal wire plane. The average magnetic field is 1.0 T. Events have been selected by requiring two charged tracks at the trigger level, by a cut on their momenta after geometrical reconstruction and fit, and by a cut on the deviation from collinearity, after having performed a kinematical fit. In terms of χ^2 these cuts correspond to accepting events at the 1% confidence level.

In order to determine absolute differential cross sections, we have to apply t-dependent acceptance corrections and an overall normalisation factor. The acceptance of the detector is calculated using Monte Carlo methods, as described in reference (2). The reliability of the simulation has been checked by comparing distributions in the azimuthal scattering angle of real events and of Monte Carlo events in various bins of t.

The acceptance is found to vary smoothly, from an average value of 50% for the interval 2 $GeV^2 < -t < 6\ GeV^2$ to a value of 20% at 1 GeV^2 and 9 GeV^2.

The experimental resolution in t has been investigated using simulated events. The distribution of $|t_{true} - t_{measured}|$ is found to have an rms width of $\sigma_t = \pm 0.020\ GeV^2$ at the position of the first minimum and to increase linearly with $|t|$ to a value $\sigma_t = \pm 0.10\ GeV^2$ at $t = -10\ GeV^2$.

Absolute cross-sections are obtained by collecting monitor counts simultaneously with data taking. A scintillation counter monitor has been calibrated using the Van der Meer method[7]; we estimate the systematic accuracy of this monitor to be ±5%.

A study of the collinearity distribution as a function of the momentum transfer has shown that in the range of the results reported here, and after applying the selection criteria described before, there is less than 3% background contamination[8] at all t values. This residual background has therefore not been subtracted.

The results* are shown in figure 1. The dominant property of the differential cross section is the narrow minimum near $t = -1.3\ GeV^2$ and the smooth behaviour beyond the second maximum at $t = -1.8\ GeV^2$. Indeed, in the interval $2.0 < -t < 8.5\ GeV^2$ the cross section is well described over four orders of magnitude by a single exponential

$$\frac{d\sigma}{dt} = A\ e^{bt}$$

with $b = (1.81 \pm 0.02)\ GeV^{-2}$ and $\chi^2 = 17.7$ for 28 degrees of freedom. To our best knowledge none of the models put forward to describe elastic scattering at large t values has predicted a single exponential of such small slope over this wide range in t. In particular, due to the large statistics, the occurrence of a second minimum and of an associated change in slope can be excluded for $|t| < 6.5\ GeV^2$.

* Tables of the differential cross sections are available from the authors.

We now summarize some values of the differential cross section and discuss their energy dependence. The cross section at the second maximum is $(5.9\pm0.4)\times10^{-5}$ mb/GeV^2, consistent with the energy dependence which we have observed[2] between $\sqrt{s}$ = 23 GeV and 62 GeV. The position and the depth of the minimum have been determined by describing the data with an expression of the form

$$\frac{d\sigma}{dt} = \left| \sqrt{A}\, e^{\frac{Bt}{2}} + \sqrt{C}\, e^{\frac{Dt}{2} + i\psi} \right|^2$$

folded with the experimental resolution in t. The best fit gives a minimum at

$$t_{min} = -(1.34\pm0.02)\ \mathrm{GeV}^2;$$

the error is contributed equally by the one-standard-deviation of the fit and an estimated systematical uncertainty in the t-scale. This value is consistent with the previously reported energy dependence[2] as expected from diffraction on an object of increasing radius. The differential cross section at the minimum is found to be

$$\left.\frac{d\sigma}{dt}\right|_{t_{min}} = (1.9\pm0.2)\times10^{-5}\ \mathrm{mb/GeV}^2;$$

the resolution in t is affecting this value within its error only. We note that the cross section at t_{min}[1,2,9] has a strong energy dependence, with a minimum value around $\sqrt{s} \approx 20$ GeV. If we assume that the minimum is due to a vanishing imaginary part of the scattering amplitude, and that spin-flip contributions are negligible, we can use the cross section at t_{min} as a direct measurement of the real part of the scattering amplitude. It will be interesting to compare the energy dependence of the real part at $t = 0$ and $t = t_{min}$; we are presently analysing more data to improve the statistical accuracy at the other ISR energies.

We gratefully acknowledge the excellent support of the SFM detector and software groups. We thank W. Wilmsen for his further development of the trigger electronics and A. King for his technical assistance. A large fraction of the analysis work was performed at the computer centers of DESY Hamburg and of Vienna University; we wish to thank these institutions for their support. The group from the University of Hamburg wishes to acknowledge financial support from the Bundesministerium für Forschung und Technologie.

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FIGURE CAPTION

Figure 1 - Differential cross sections as a function of t. The error bars represent statistical errors and bin-to-bin systematical errors. An overall scale uncertainty of ±5% has to be added.

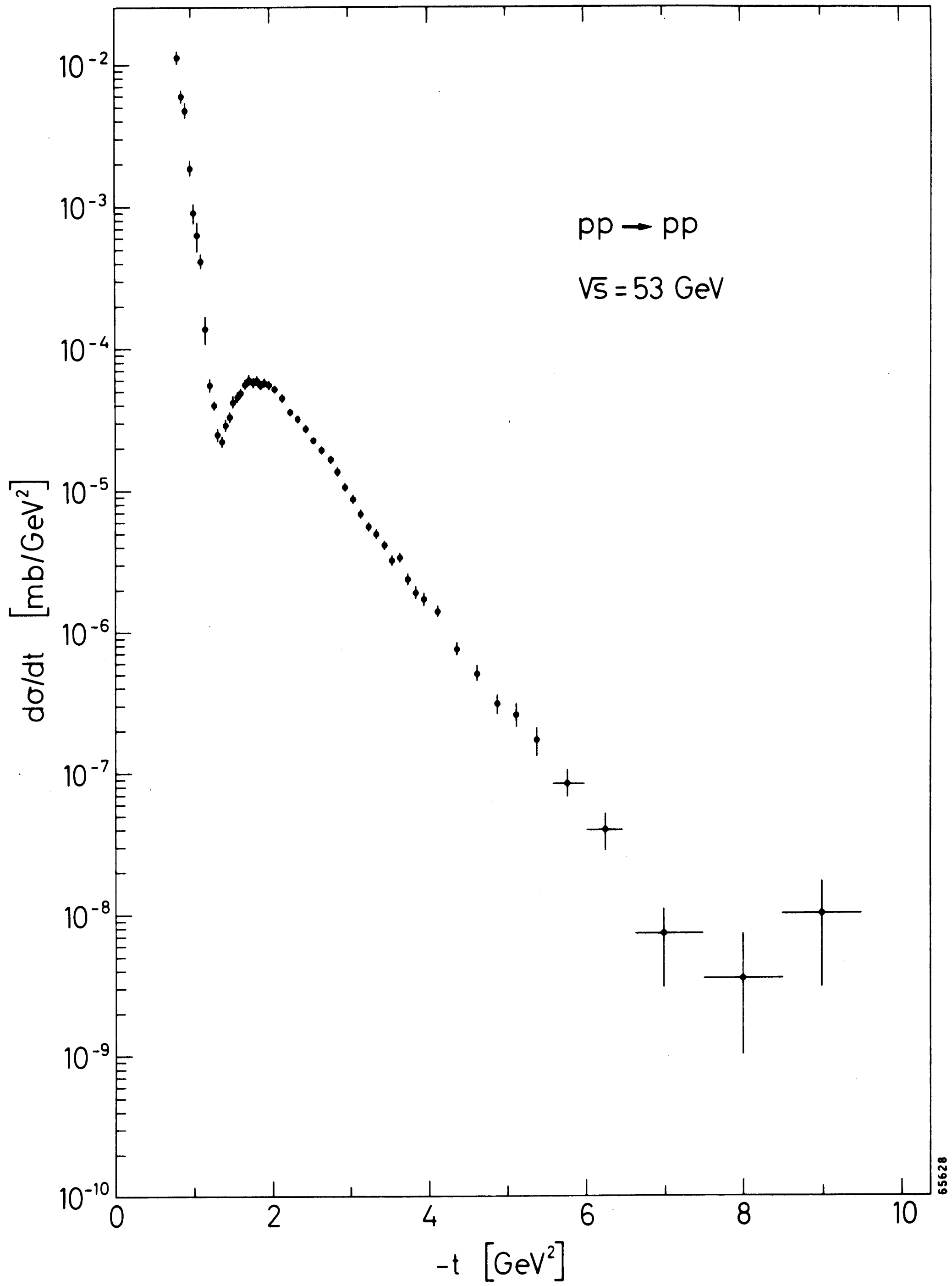
pp → pp
√s = 53 GeV
dσ/dt [mb/GeV²]
-t [GeV²]
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
0
2
4
6
8
10
65628

Fig. 1