EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/EP 81-142
5 November 1981

EXPERIMENTAL RESULTS ON pp FORWARD ELASTIC SCATTERING AND THE POSSIBILITY OF UNIVERSAL SHRINKAGE OF THE HADRONIC DIFFRACTION CONE

J.P. Burq[*], M. Chemarin[*], M. Chevallier[*], A.S. Denisov[*], T. Ekelöf[***,+], F. Fay[*], P. Grafström[***,+], L. Gustafsson[+], E. Hagberg[+], B. Ille[*], A.P. Kashchuk[**], A.V. Kulikov[**], M. Lambert[*], J.P. Martin[***,*], S. Maury[***,++], M. Querrou[++] V.A. Schegelsky[**], I.I. Tkach[**], M. Verbeken[++] and A.A. Vorobyov[**]

ABSTRACT

The differential cross-section of pp scattering has been measured in the energy region 100-300 GeV and in the t-range $.002 < |t| < .04$ $(GeV/c)^2$. The results on the real part of the scattering amplitude agrees with dispersion relation calculations. We also report on our determination of the slope parameter b together with an analysis of the world data of b for different hadrons and different t-values. It is shown that the data are consistent with the hypothesis of a universal shrinkage of the hadronic diffraction cone at high energies.

Submitted to Physics Letters B

---

*) Institut de Physique Nucléaire, IN2P3, Université de Lyon-Villeurbanne, France.

**) Leningrad Nulcear Physics Institute, Gatchina, USSR.

***) At present, CERN, Geneva, Switzerland.

+) The Gustaf Werner Institute, University of Uppsala, Sweden.

++) Laboratoire de Physique Corpusculaire, IN2P3, Universitè de Clermont-Ferrand, Aubière, France.

0007P/PG/jr

A small angle elastic scattering experiment has recently been performed at the CERN SPS. The main aim of the experiment was to study high energy $\pi^- p$ elastic scattering in the Coulomb interference region. The results of this part of the study are presented elsewhere [1].

In the experiment the differential cross-sections for pp elastic scattering were also measured at incident momenta of 100, 150, 250 and 300 GeV/c. Here we report on the results of these measurements and on the results of our analysis of the world data on the slope parameters of the diffraction cone. It will be shown that the data are consistent with the hypothesis of universal shrinkage of the hadronic diffraction cones at high energies.

The differential cross-sections were measured in the t-range $.002 \leq |t| \leq .04$ $(GeV/c)^2$. The absolute normalization of the cross-sections has been measured with a precision of ±1%. The absolute t-scale was known with a precision of better than .5% in the measured t-interval. The corrections for the background and for the inefficiency of the detector system were determined experimentally with errors of less than 1. %. The details of the experimental technique used for these measurements can be found in Refs [1-4].

The measured cross-sections were fitted with the Coulomb-nuclear interference formula in the same manner as described in Ref. [1]. Two parameters were left free in the fits: the ratio of the real to imaginary part of the forward scattering amplitude ρ_{pp} and the exponential slope parameter b_{pp}. The values of $\sigma_{tot}(pp)$ used in the fit were taken from the measurements of Carroll et al. [5]. In the fits σ_{tot} and K, the normalization parameter of the differential cross-section, were constrained within the limits of the error bars ($\Delta\sigma_{tot}$ is given in Ref. [5] and $\Delta K/K = \pm 1\%$). The results of the fits are presented in Table 1. The errors for b_{pp} and ρ_{pp} shown in the table include statistical errors, the errors in the normalization and the errors in σ_{tot}. The correlation between b_{pp} and ρ_{pp} is very small: $d\rho/db = -.003$ $(GeV/c)^2$. Furthermore, a change in σ_{tot} by +.1 mb gives $\Delta\rho = +.004$.

The ρ_{pp} data are shown in Fig. 1 together with results from other experiments. At the ISR ρ_{pp} has been measured up to $p_{lab} \approx 2000$ GeV/c [6]. Using dispersion relations, the authors were able to predict a continuous rise in $\sigma_{tot}(pp)$ up to at least $p_{lab} \approx 40{,}000$ GeV/c. However, recent measurements at Fermilab [7] showed deviations from dispersion relation calculations in the range 100-200 GeV/c. The authors also reanalysed old data from a jet target experiment [8] in the momentum region 200-400 GeV/c by introducing bigger values of b_{pp}. As a result, the ρ-values calculated from the jet target data were shifted by $\Delta\rho \approx .04$ and then also disagree with dispersion relations. As can be seen from Fig. 1, our data in the range 100-300 GeV/c do not confirm these deviations. Moreover, using values of b_{pp} that we derived from fits to all existing data on b_{pp} (see below) we obtain a shift of the jet target data of not more than $\Delta\rho \approx .02$. Furthermore, it may be noted that if one disregards the points with $|t| \leq .002$ (GeV/c)^2 in the jet target differential cross-sections ρ is shifted by $\Delta\rho \equiv -.01$ and thus the overall shift becomes insignificant.

We thus conclude that the results from our experiment, like those from Ref. [8], support the validity of the dispersion relation calculations and also the validity of the conclusion of the ISR group [6] about rising total cross-sections.

Classical Pomeron theory predicted a logarithmic shrinkage of the diffraction cone at large energies:

$$b(p) = b_0 + 2\alpha'_p \ln p$$

where α'_p is the slope of the Pomeron trajectory and p the momentum of the incident particle. According to the theory the shrinkage should be similar for all kinds of incident hadrons and it should have no strong t-dependence. Our recent data on πp scattering together with other data available at other t-values led us to the conclusion [1] that the shrinkage of the πp diffraction cone at $|t| = .02$ (GeV/c)^2 does not differ from that at $|t| = .2$ (GeV/c)^2 or $|t| = .4$ (GeV/c)^2 (Fig. 2).

The situation for the pp-system has so far been thought to be different. High energy pp data at $|t| = .2$ (GeV/c)^2 showed considerably less shrinkage than at $|t| = .05$ (GeV/c)^2, where a value of $2\alpha'_p \approx .6$ (GeV/c)$^{-2}$ was found [9,10]. One of the interests in the present experiment was therefore to investigate the shrinkage at small t-values in pp scattering.

Our data are plotted in Fig. 2 together with other small angle data, corrected if necessary for t-dependence to correspond to the same t-value, i.e. $|t| = .02$ (GeV/c)^2. Note the good agreement of our points with those of a recent Fermilab experiment [7]. On the other hand, our data disagree in the absolute scale with the jet target data of Ref. [9]. The disagreement is of the order of $\Delta b = +.4$ (Gev/c)$^{-2}$ after the correction for t-dependence has already been applied.

The data at $|t| = .02$ (GeV/c)^2 have been fitted with the following simple parametrization compatible with the Regge pole model:

$$b(p) = b_0 + \frac{b_1}{p^\beta} + b_2 \cdot \ln p \qquad (1)$$

where the b_1/p^β term with $\beta = 1/2$ originates from the interference between the Pomeron and secondary trajectories. In this fit the absolute scale of the data of Ref. [9] was left free.

The results are given in Table 2. It is seen from the table that the shrinkage parameter $b_2 = 2\alpha'_p$ is close to the value found in the πp case and not equal to the much higher value $\sim .6$ (GeV/c)$^{-2}$ found previously. The origin of this is twofold. Firstly, our data together with the recent data from Fermilab certainly decrease the value of $2\alpha'_p$. Secondly, the big value quoted was obtained not using the term b_1/p^β in the parametrization (1). Table 2 shows that this term is important in the pp case.

The similarity of the value of the shrinkage parameter for πp and pp scattering at $|t| = .02$ (GeV/c)^2 has led us to perform a similar analysis of existing data on $p^\pm p$, $K^\pm p$ and $\pi^\pm p$. This was done at $|t| = .2$ (GeV/c)^2 where data are most abundant. Figure 3 shows our compilation of the world data. The data were analyzed with the simple parametrization (1). The

details of this analysis and the tables with the experimental values will be published elsewhere. The particle-antiparticle data were fitted simultaneously with four free parameters (b_1 was allowed to be different for particles and antiparticles). The results are presented in Table 2. Note the remarkably good values for χ^2/N which is somewhat unexpected, taking into account the simple form of the parametrization and the big p-range used in the fits. The shrinkage parameters were found to have nearly the same value for all particles:

$$2\alpha'_p = .26 \pm .05 \ (\text{GeV/c})^{-2}$$

The results have been checked for stability. For example, if we take away all p-p points below 10 GeV we obtain

$$b_2(pp) = .26 \pm .08 \ (\text{GeV/c})^{-2}$$

We have also performed fits with the parameter β free and as can be seen from Table 2 the shrinkage parameter did not change much.

We conclude that the present experimental data are consistent with the hypothesis of universal shrinkage of the hadron diffraction cone independent of incident particle and independent of t-values for $|t| < .4 \ (\text{GeV/c})^2$. This conclusion depends of course on the parametrization used, but the good quality of the fits shows that it cannot be changed on the basis of statistical criteria only.

Table 1

Values of ρ and b in pp scattering as obtained in the fits to the data. N is the number of degrees of freedom in the fits.

Energy (GeV)	No. of events	$\sigma_{tot} \pm \Delta\sigma$ from Ref.[5] (mb)	$\rho \pm \Delta\rho$	$b \pm \Delta b$ $(GeV/c)^{-2}$	χ^2/N
100	85,000	38.46 ± .04	-.092 ± .014	12.01 ± .29	81/69
150	130,000	38.69 ± .04	-.040 ± .014	12.09 ± .28	73/64
250	120,000	39.29 ± .04	-.041 ± .014	12.17 ± .29	44/60
300	80,000	39.53 ± .06	-.028 ± .016	12.40 ± .32	63/56

Table 2

Values of the constants b_{c0}, b_{11} and b_{22} obtained by fitting the existing data on the slope parameter b with the formula $b = b_{c0} + b_{11}\frac{ll}{|p^{\beta}|} + b_{22}\ln|p|$. b_{11} was allowed to be different for particle and antiparticle, respectively. b_{11}^{+} stands for the value found for positively charged particles and b_{11}^{-} for negatively charged particles. NDF is the number of degrees of freedom in the fits.

$\|t\|$ ((GeV/c))^2	particle	b_{c0} ((GeV/c))$^{-2}$	b_{11}^{+} ((GeV/c))$^{-3/2}$	b_{11}^{-} ((GeV/c))$^{-3/2}$	b_{22} ((GeV/c))$^{-2}$	β	χ^2/NDF
0.02	p	11.1 ± 0.2	−6.2 ± 0.5	—	0.30 ± 0.04	0.5 (fixed)	82/69
0.02	π^-	9.1 ± 0.7	—	0.65 (fixed)	0.29 ± 0.08	0.5 (fixed)	17/22
0.2	p/$\bar{p}$	9.2 ± 0.2	−4.9 ± 0.2	7.2 ± 0.9	0.28 ± 0.05	0.5 (fixed)	32/59
0.2	K^+/K^-	6.7 ± 0.3	−5.7 ± 0.1	11.0 ± 0.4	0.24 ± 0.06	0.5 (fixed)	41/44
0.2	π^+/π^-	6.9 ± 0.2	− 0.7 ± 0.4	0.65 ± 0.45	0.27 ± 0.05	0.5 (fixed)	53/60
0.2	p/$\bar{p}$	9.2 ± 0.2	−5.0 ± 0.5	7.4 ± 0.7	0.28 ± 0.05	0.52 ± 0.02	31/59
0.2	K^+/K^-	6.5 ± 0.3	−5.9 ± 0.5	11.6 ± 0.5	0.27 ± 0.06	0.56 ± 0.03	37/44
0.2	π^+/π^-	6.8 ± 0.4	− 0.4 ± 0.6	0.59 ± 0.62	0.29 ± 0.07	0.33 ± 0.08	49/60
0.4	p	9.6 ± 0.4	−7.5 ± 0.8	—	0.10 ± 0.08	0.5 (fixed)	41/29
0.4	π^-	6.1 ± 0.1	—	0.65 (fixed)	0.25 ± 0.07	0.5	33/24

REFERENCES

[1] J.P. Burq et al., submitted to Physics Letters.

[2] J.P. Burq et al., Nucl. Phys. B187 (1981) 205.

[3] J.P. Burq et al., Nucl. Instr. Meth. 177 (1980) 353.

[4] J.P. Burq et al., Phys. Lett. 77B (1978) 438.

[5] A.S. Carroll et al., Phys. Lett. 80B (1979) 423.

[6] U. Amaldi et al., Phys. Lett. 66B (1977) 390.

[7] L.A. Fajardo et al., Phys. Rev. D24 (1981) 46.

[8] D. Gross et al., Phys. Rev. Lett. 41 (1978) 217.

[9] V.D. Bartenev et al., Phys. Rev. Lett. 31 (1973) 1088.

[10] G. Giacomelli, Phys. Reports 23C (1976) 123.

[11] J.S. Russ et al., Phys. Rev. D15 (1977) 3139.

[12] K.J. Foley et al., Phys. Rev. 181 (1969) 1775.

[13] G. Barbiellini et al., Phys. Lett. 39B (1972) 663.

[14] L. Baksay et al., Nucl. Phys. B141 (1978) 1.

[15] G.G. Beznogikh et al., Phys. Lett. 43B (1973) 85.

[16] K.M. Chernev et al., Phys. Lett. 36B (1971) 266.

[17] G Belletini et al., Phys. Lett. 14 (1965) 164.

[18] I. Velichko et al., Preprint LINP N 656 (1981).

[19] G.G. Beznogikh et al., Phys. Lett. 39B (1979) 411.

[20] K.J. Foley et al., Phys. Rev. Lett. 19 (1967) 857.

[21] P. Jenni et al., Nucl. Phys. B129 (1977) 232.

[22] A.A. Vorobyov et al., Phys. Lett. 41B (1972) 639.

[23] W. Grein et al., Nucl. Phys. B131 (1978) 1975.

FIGURE CAPTIONS

Fig. 1 : Experimental data on ρ for pp scattering. The dashed line is taken from a dispersion relation calculation by Amaldi et al. [6] and the full line from a calculation by Grein [23]. The dashed area corresponds to the uncertainty estimated by Grein.

Fig. 2 : The slope parameter b at different t-values as a function of incident energy for $\pi^- p$ and pp scattering. The points at $|t| = .2$ (GeV/c)^2 and at $|t| = .4$ (GeV/c)^2 represent our compilation of the world data.

Fig. 3 : Our compilation of the slope parameter b as a function of energy at $|t| = .2$ (GeV/c)^2 for $\bar{p}p$, pp, $K^- p$, $K^+ p$, $\pi^- p$ and $\pi^+ p$ scattering.

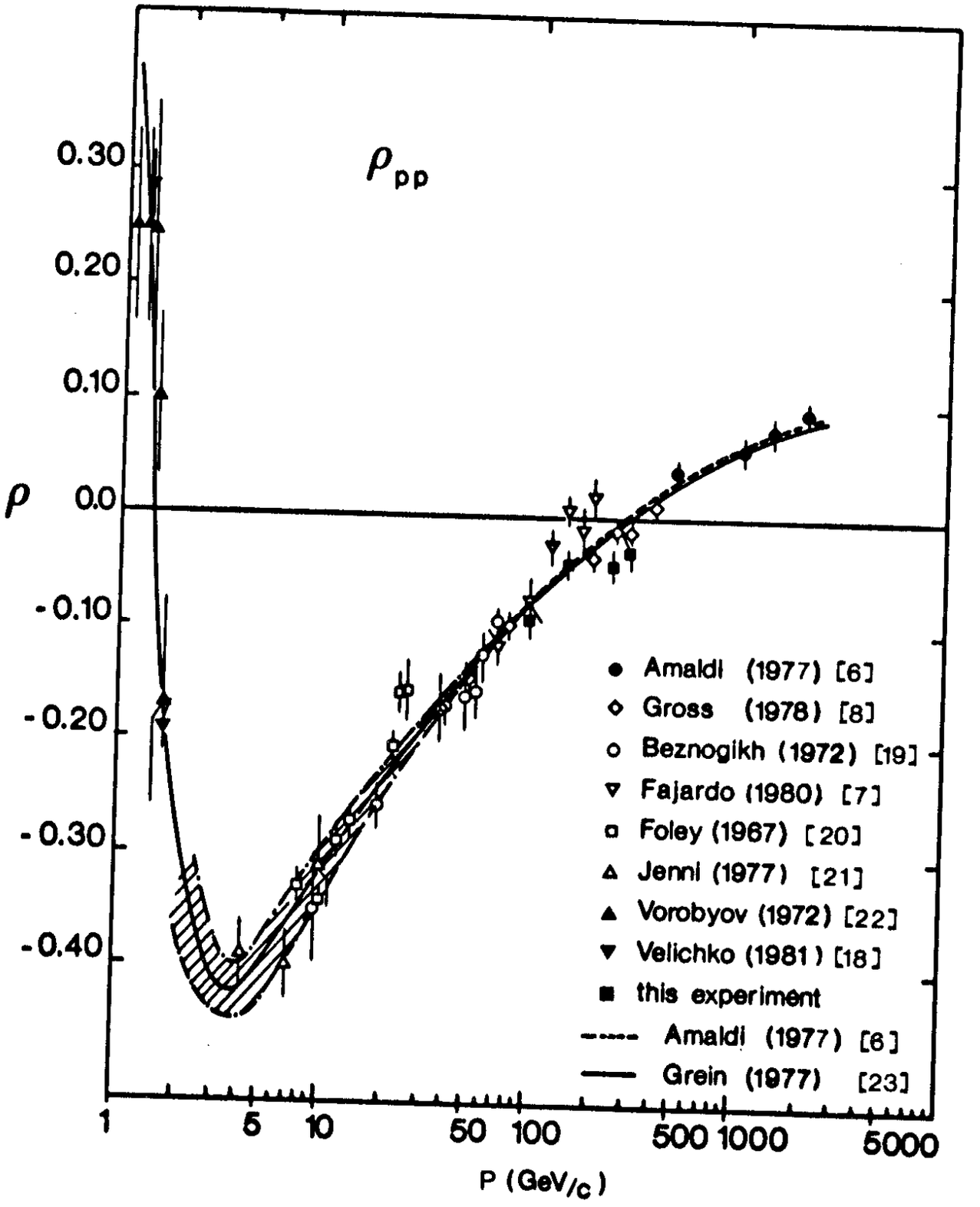
ρ_{pp}
0.30
0.20
0.10
0.0
-0.10
-0.20
-0.30
-0.40
ρ
1
5
10
50
100
500
1000
5000
P (GeV/c)
Amaldi (1977) [6]
Gross (1978) [8]
Beznogikh (1972) [19]
Fajardo (1980) [7]
Foley (1967) [20]
Jenni (1977) [21]
Vorobyov (1972) [22]
Velichko (1981) [18]
this experiment
Amaldi (1977) [6]
Grein (1977) [23]

Fig. 1

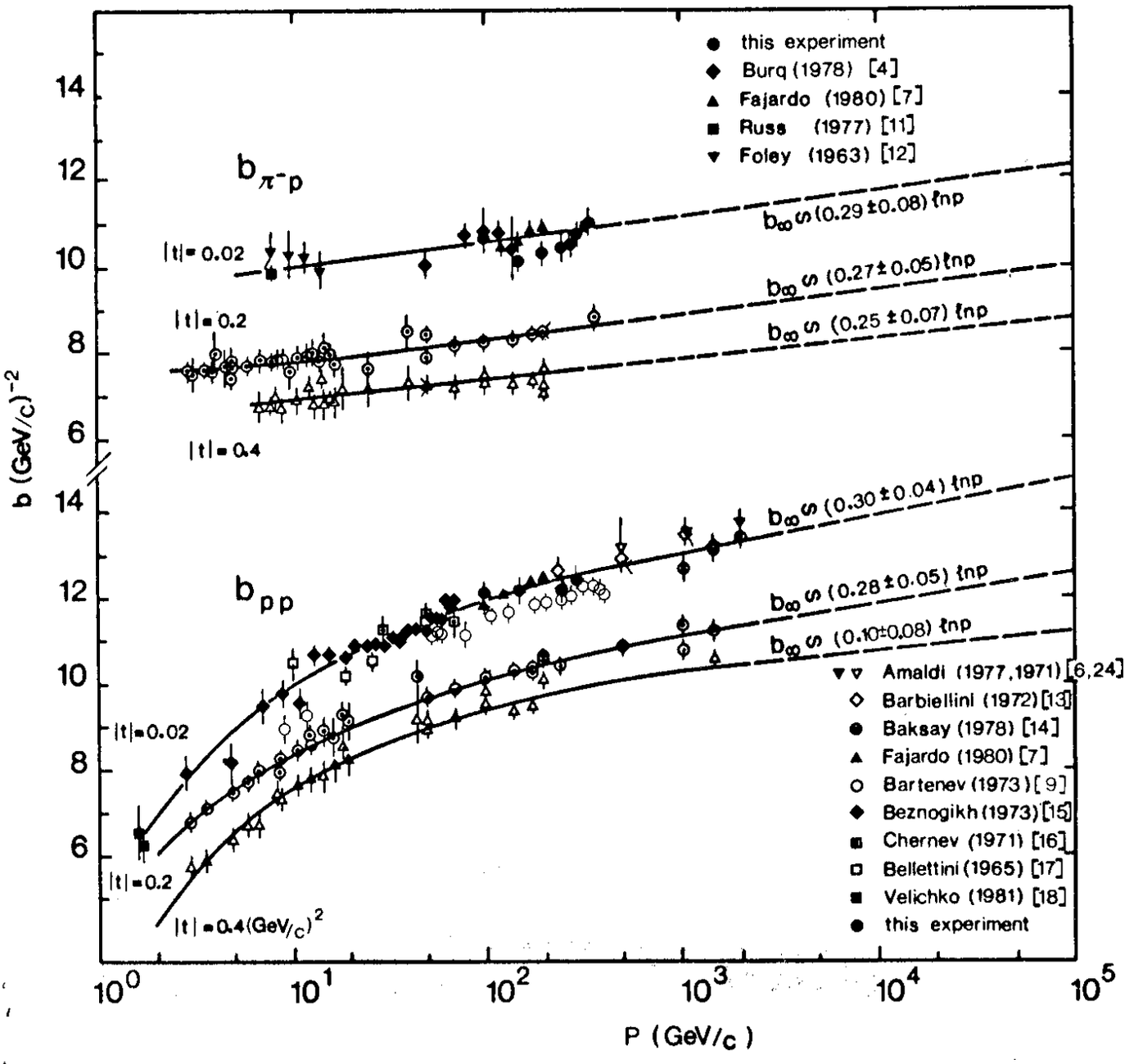
this experiment
Burq (1978) [4]
Fajardo (1980) [7]
Russ (1977) [11]
Foley (1963) [12]
$b_{\pi^- p}$
$b_\infty s^{(0.29\pm0.08)\ln p}$
$b_\infty s^{(0.27\pm0.05)\ln p}$
$b_\infty s^{(0.25\pm0.07)\ln p}$
|t|= 0.02
|t|= 0.2
|t|= 0.4
b_{pp}
$b_\infty s^{(0.30\pm0.04)\ln p}$
$b_\infty s^{(0.28\pm0.05)\ln p}$
$b_\infty s^{(0.10\pm0.08)\ln p}$
Amaldi (1977,1971) [6,24]
Barbiellini (1972) [13]
Baksay (1978) [14]
Fajardo (1980) [7]
Bartenev (1973) [9]
Beznogikh (1973) [15]
Chernev (1971) [16]
Bellettini (1965) [17]
Velichko (1981) [18]
this experiment
|t|=0.02
|t|=0.2
$|t| = 0.4 (GeV/c)^2$
b $(GeV/c)^{-2}$
P (GeV/c)

Fig. 2

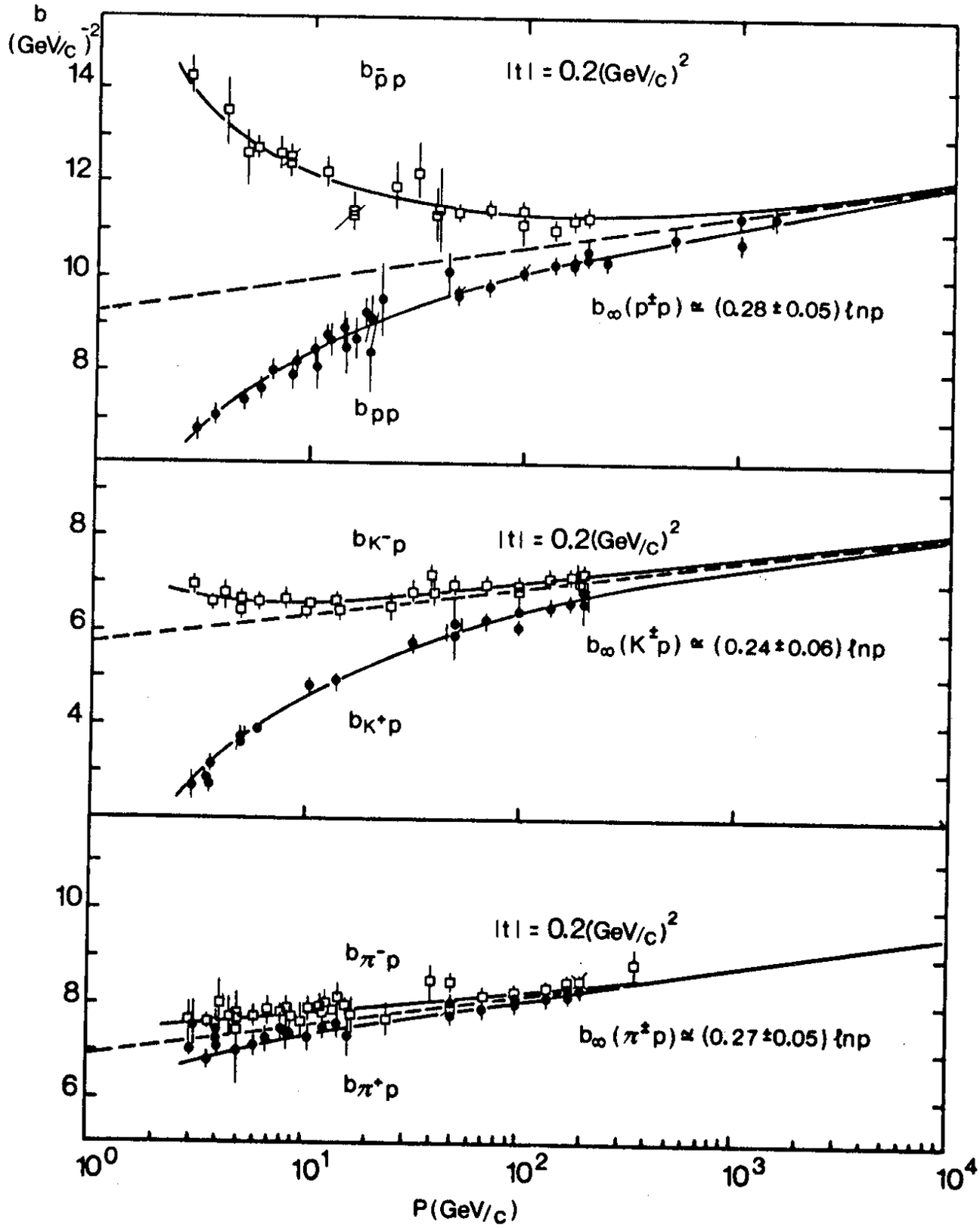
b
(GeV/c)^-2
14
12
10
8
$b_{\bar{p}p}$
|t| = 0.2(GeV/c)^2
$b_\infty(p^\pm p) \propto (0.28 \pm 0.05) \ell np$
b_{pp}
8
6
4
b_{K^-p}
|t| = 0.2(GeV/c)^2
$b_\infty(K^\pm p) \propto (0.24 \pm 0.06) \ell np$
b_{K^+p}
10
8
6
|t| = 0.2(GeV/c)^2
b_{π^-p}
$b_\infty(\pi^\pm p) \propto (0.27 \pm 0.05) \ell np$
b_{π^+p}
10^0
10^1
10^2
10^3
10^4
P(GeV/c)

Fig. 3