EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

NEW MEASUREMENTS OF PROTON-PROTON TOTAL CROSS-SECTION AT THE CERN INTERSECTING STORAGE RINGS

CERN*)-Pisa**)-Rome†)-Stony Brook††) Collaboration

ABSTRACT

New measurements of the proton-proton total cross-section have been made with increased precision (±0.6%) over the ISR energy range $\sqrt{s}$ = 23.5-62.7 GeV. Two different experimental methods gave consistent results, showing that the total cross-section increases 10% over the ISR range and in addition that the absolute value of the ISR luminosity can be measured to ±0.9%.

Geneva - April 1976

*) CERN (Geneva, Switzerland): U. Amaldi, G. Cocconi, A.N. Diddens, Z. Dimcovski, R.W. Dobinson, J. Dorenbosch, P. Duinker, G. Matthiae, A.M. Thorndike (on leave from Brookhaven National Laboratory, Upton, New York) A.M. Wetherell.

**) Pisa (Istituto di Fisica dell'Università and Istituto Nazionale di Fisica Nucleare, Pisa, Italy): G. Bellettini (present address: Laboratori Nazionali CNEN, Frascati, Italy) P.L. Braccini, R. Castaldi (CERN fellow), V. Cavasinni (also at Scuola Normale Superiore), F. Cervelli, T. Del Prete, P. Laurelli, M.M. Massai, M. Morganti, G. Sanguinetti, M. Valdata-Nappi.

†) Roma (Istituto Superiore di Sanità and Istituto Nazionale di Fisica Nucleare, Roma, Italy): A. Baroncelli, C. Bosio.

††) Stony Brook (State University of New York, Stony Brook, USA): G. Abshire, J. Crouch, G. Finocchiaro, P. Grannis, H. Jöstlein, R. Kephart, D. Lloyd-Owen, R. Thun (present address: Dept. of Physics, Univ. of Michigan, Ann Arbor, USA).

In this paper the results of new measurements of σ, the proton-proton total cross-section at ISR energies, are presented. This work is the joint effort of the CERN-Rome (CR) and of the Pisa-Stony Brook (PSB) groups which, three years ago, performed separate measurements of σ at the ISR, using two different methods [1,2].

The motivation of the present experiment is the following. Both previous measurements made use of the ISR luminosity L measured by the Van der Meer (VDM) method [3] in order to derive the cross-section. Since the cross-section scale depends on $\sqrt{L}$ in one method (CR) and on L in the other one (PSB), the good agreement between the results of the two experiments indicated that the VDM method was not subject to large systematic errors. However, direct measurements of L [4] could not determine this quantity to better than ±2%. Thus it was felt desirable to perform measurements of σ in a way independent of L. This is possible if the two measurements, which depend differently on L, are performed under conditions guaranteeing that L is the same for both. In practice, the only way to satisfy this condition is to perform the two measurements at the same time in the same intersection. An additional motivation for repeating the experiments was that, since the machine operation has improved continuously, the VDM method should now be reliable to ±0.5%, and consequently the separate determinations of σ should reach better precisions.

THE STANDARD MEASUREMENT OF ISR LUMINOSITY. Proton-proton collisions with cross-section σ_J (cm^2) occur in an ISR intersection at a rate

$$R_J = \sigma_J \, L \ (\mathrm{sec}^{-1}) \ . \tag{1}$$

This expression defines the luminosity L (cm^{-2} sec^{-1}) of the colliding beams at that intersection. The value of L depends only on the currents, I_1, I_2, of the two beams and on their vertical (z-axis) overlap, because in the ISR the beams cross, at a fixed angle α, in the horizontal plane. If z is the distance from the centroid of each beam, and

$$I_{1,2} = \int_{-\infty}^{+\infty} i_{1,2}(z)\, dz \ , \tag{2}$$

then

$$L(\delta) = \frac{1}{K} \int_{-\infty}^{\infty} i_1(z)\, i_2(z+\delta)\, dz \ , \tag{3}$$

where

$$K = \beta c e^2 \frac{\sin \alpha/2}{(1-\beta^2 \sin^2 \alpha/2)^{1/2}} \simeq \beta c e^2 \, \mathrm{tg}\, \frac{\alpha}{2} = \beta \ 0.9972 \times 10^{-28} \ (\mathrm{A}^2 \ \mathrm{cm\ sec}) \ ,$$

and $\delta = z_1 - z_2$ is the vertical displacement between the centroids z_1 and z_2 of the two beams. In the ISR, $\alpha = 14.77°$.

To determine the value of L, a monitor, consisting of two telescopes of scintillation counters placed symmetrically downstream from the intersection is employed. If the distance of the telescopes from the crossing point is large enough, a left-right coincidence between the telescopes detects only events produced in pp colliding beam interactions; the monitor coincidence rate is then, from eqs. (1) and (3),

$$R_M(\delta) = \frac{\sigma_M}{K} \int_{-\infty}^{+\infty} i_1(z) i_2(z+\delta)\, dz \ , \tag{4}$$

where σ_M denotes the inclusive cross-section for all events triggering the monitor.

If now δ is varied in small, precise steps (by steering the ISR beams vertically), the following integral can be measured, as suggested by Van der Meer [3]:

$$\int_{-\infty}^{+\infty} R_M(\delta)\, d\delta = \frac{\sigma_M}{K} \iint i_1(z) i_2(z+\delta)\, dz\, d\delta = \frac{\sigma_M}{K} I_1 I_2 \ . \tag{5}$$

The beam currents are measured to better than 0.1%, so that this relation leads to the determination of σ_M, and finally of the luminosity from eq. (1),

$$L = R_M/\sigma_M \ . \tag{6}$$

During the experiment, this procedure was repeated at each ISR energy many times in different beam conditions using simultaneously several independent monitors with σ_M ranging from $\sim$ 0.3 to $\sim$ 25 mb (σ_M cannot be larger than $\sigma \approx 40$ mb). From the internal consistency of these measurements it was concluded that at each ISR energy L can be measured with a relative (point-to-point) precision $\Delta L/L \approx 0.5\%$. The absolute value of L depends linearly on the absolute value of δ. Since δ is varied by about 1 cm and the positioning error estimated [5] over that distance is about 50 μm, it is expected that also the absolute value of L, which determines the scale of the cross-section, be known within $\Delta L/L \approx 0.5\%$. The measurements of σ performed in this experiment have shown that indeed the errors of L are of this order of magnitude.

σ MEASURED WITH THE PSB METHOD. Equation (1) defining the luminosity can be written

$$\Delta\sigma = R/L \ . \tag{7}$$

If now R_{tot} is the rate of the events recorded by an apparatus that surrounds so well the beam-beam intersecting region that "all" the interactions produced by pp collisions are recorded, then

$$\Delta\sigma \equiv \sigma = \frac{R_{tot}}{L} . \tag{8}$$

The PSB detector (described in more detail in ref. 2), came very close to realizing this condition. It consisted (see fig. 1) of two telescopes of circular counter hodoscopes covering cones of about 30° aperture downstream of each beam and of a central box composed of two layers of planar counter hodoscopes covering angles larger than about 40°. Each telescope consisted of two sets of counters, about one metre apart from each other, in coincidence. The trigger required a left-right or a side-centre coincidence [2]. In each telescope additional hodoscopes, finely split into bins of polar angle, detected the multiplicity and the angular distribution of the charged secondaries.

When a trigger occurred, all information pertinent to the event was transferred to an on-line computer via a CAMAC data acquisition system. This information comprised the timings of the signals from all trigger hodoscopes, which were used in an off-line analysis to reject the residual background due to single-beam interactions [2].

The slightly incomplete coverage of the entire solid angle makes the rates measured in this detector, R_{obs}, smaller than R_{tot}, and corrections had to be introduced to compensate for the losses. Most of the lost solid angle was due to the coronas between $\theta \cong 30°$ and $\theta \cong 40°$ (θ is the angle to the proton beams). However, the most serious losses were those due to small angle processes escaping through the two small holes ($\Delta\omega = 1.7 \times 10^{-4}$ sr) at $\theta \leq 5$ mrad, which accomodated the ISR vacuum pipes.

Different methods were used to evaluate the losses in the cases of elastic and inelastic collisions.

The loss of elastic events in the beam pipe holes, $\Delta\sigma_{el}$ (see fourth column of table 1) was calculated using the differential elastic scattering cross-sections previously measured at the ISR [6]. $\Delta\sigma_{el}$ is strongly energy-dependent, because $\langle\theta_{scatt}\rangle \propto 1/\sqrt{s}$. The errors quoted in table 1 include the uncertainties in the values of all input data, and were evaluated by simulating the production of elastic events over the beam-beam overlap region in a Monte Carlo calculation.

Inelastic events were missed whenever all the ionizing secondaries produced in one hemisphere fell on insensitive regions. A typical case was that in which only one ionizing secondary was present in one hemisphere and fell within the small angle subtended by the vacuum pipe. The amount of these losses was obtained by extrapolating the angular distribution of the inelastic events in one hemisphere [2]. At all energies these losses were less than 1.5%, and in all cases it was found that the loss due to the coronas between $\theta \sim 30°$ and $\theta \sim 40°$ was negligible.

Elastic or inelastic events could also be missed by the trigger if all particles emitted in one hemisphere passed through the small dead-space between adjacent counters. This effect was studied in special runs in which the double coincidences between the layers of counters in the trigger were replaced by OR-ed signals. In this way, the rate of events normally lost because of dead-space could be monitored and was found not to exceed 1.5% at all energies.

In the data reduction, all systematic effects larger than 0.1% which one could think of were computed and corrected for. Finally, the total cross-section was obtained as

$$\sigma(\mathrm{PSB}) = \frac{R(\mathrm{PSB})(1+\varepsilon)}{L} + \Delta\sigma_{el} \;. \tag{9}$$

Here R(PSB) is the rate of beam-beam events corrected for randoms and dead-time measured by the PSB detector and ε is the correction factor, accounting for the trigger losses, which is listed in column five of table 1. L is the ISR luminosity measured by large acceptance luminosity monitors, which were calibrated with the Van der Meer method at the beginning of each run.

The number of events collected at each energy was such that the final errors for σ_{obs} are not due to statistics, but essentially to the uncertainties in the evaluation of L quoted in the previous section.

The values finally obtained for σ are given in column six of table 1. A point-to-point error of $\sim \pm 0.5\%$ on L was assumed in evaluating the over-all error.

σ MEASURED WITH THE CR METHOD. The differential elastic cross-section at zero scattering angle due to hadronic interactions,

$$\left(\frac{d\sigma}{dt}\right)_0 = \frac{\pi}{p^2}\left(\frac{d\sigma}{d\omega}\right)_0 \left[\frac{1}{1+(1-\beta^2)\,\mathrm{tg}^2\,\alpha/2}\right]^{1/2} , \tag{10}$$

can be related to the total hadronic cross-section by the optical theorem (neglecting spin effects):

$$\sigma(\mathrm{CR}) = \sqrt{\frac{16\pi}{1+\rho^2}\left(\frac{d\sigma}{dt}\right)_0} \;, \tag{11}$$

where

$$\rho = \frac{\text{Real part of the forward scattering amplitude}}{\text{Imaginary part of the forward scattering amplitude}} \;.$$

At ISR energies, ρ is positive and of the order of a few per cent [7].

At each energy the rate R_{el} of elastic events into a detector covering a solid angle $\Delta\omega$ at a small angle θ with respect to the unscattered proton beam was measured. Then

$$\left(\frac{d\sigma}{d\omega}\right)_\theta = \frac{1}{\Delta\omega}\frac{R_{el}}{L} . \tag{12}$$

The forward elastic cross-section, which appears in the optical theorem, is obtained by extrapolating to $\theta = 0$, and by correcting for electromagnetic effects (see ref. 7).

$$\left(\frac{d\sigma}{d\omega}\right)_0 = \left(\frac{d\sigma}{d\omega}\right)_\theta \left[1 - \varepsilon_{Coul}\right] e^{b|t|} , \tag{13}$$

where

$$\varepsilon_{Coul} = \frac{(2\alpha/t)^2 - (\rho + \alpha\phi)(\alpha\sigma/\pi|t|)}{(\sigma/4\pi)^2(1 + \rho^2)} ,$$

$$\alpha = \frac{1}{137.04} \qquad \text{and} \qquad \phi = \ln\frac{0.08\ \text{GeV}^2}{|t|} - 0.577 .$$

The exponential $e^{b|t|}$ compensates for the dependence of the cross-section on the four-momentum transfer. At small angles the value of b depends only on the proton energy [6]. Finally, by making use of Eqs. (10), (12), and (13), formula (11) can be written in the following way:

$$\sigma(\text{CR}) = \sqrt{\frac{16\pi}{1 + \rho^2}\frac{\pi}{p^2}(1 - \varepsilon_{Coul})\, e^{b|t|}\frac{1}{\Delta\omega}\frac{R_{el}}{L}} = \sqrt{\frac{F(\text{CR})}{L}} . \tag{14}$$

In the CR experiment, the elastic events were detected by means of the two symmetric sets of hodoscopes A and B, one of which is sketched in fig. 1.

Each hodoscope covered an area of $54 \times 88\ \text{mm}^2$ and consisted of two separate arrays of horizontal and vertical scintillators. The horizontal scintillators θ_i ($i = 1, \ldots, 12$) were 4.5 mm high and 90 mm long, while the vertical scintillators ϕ_j ($j = 1, \ldots, 11$) were 8 mm wide and 80 mm long. The two arrays were placed between two trigger counters (A′A″ and B′B″) of dimensions just sufficient to cover the hodoscope scintillators.

A and B were held fixed behind indentations in the ISR vacuum chambers that permitted the protons scattered in the vertical plane to reach the hodoscopes after crossing a stainless steel wall 1 mm thick. The centre of each hodoscope was 55 mm away from the circulating proton beams, corresponding to a scattering angle $\langle\theta\rangle \approx 6$ mrad.

The fourfold coincidence A′A″B′B″ was used to gate pattern units which registered the signals from the hodoscope counters. These signals, together with the time-of-flight between conjugate trigger counters and the pulse heights of all counters, were recorded for each event and sent through the CAMAC system to the small on-line computer.

In order that the intersecting region should be small with respect to the size of the hodoscope, the data were taken with the ISR working in the Terwilliger mode [8]. In this scheme, which uses special quadrupoles in the machine lattice, the distribution of the interaction points is approximately Gaussian, with r.m.s. values of $\sim$ 3 mm in the transverse direction and $\sim$ 1.5 mm in the vertical direction. Thus for the elastic events, when one of the protons was detected in the central region of one hodoscope, the coincident proton was nearly always detected by the other hodoscope.

A particularly delicate problem was presented by the cases where more than one ionizing particle were detected in a hodoscope. In normal operating conditions the cases with only one θ counter and one ϕ counter triggered in each hodoscope (the "one-particle" triggers) were 52% of the total. One cause of multiple triggers was inelastic pp collisions in which two or more ionizing secondaries reached the hodoscopes. Another cause, particularly important in these miniature scintillators, was the presence of δ-rays, created in the hodoscope itself, which fired other counters in the neighbourhood of the main track and created ambiguities about the location of the scattered proton. A number of criteria to overcome this difficulty were tried and found to give equivalent results. In the final analysis such situations were handled by selecting in each hodoscope the one θ and the one ϕ counter that gave a pulse with amplitude nearest to the average amplitude observed in "one-particle" triggers. From the widths of the peaks thus obtained it was concluded that, after scattering, the two protons observed were collinear within ±0.5 mrad. The background due to multiple events spread smoothly over the other coincidence combinations, in no case amounting to more than 2% of the events observed under the elastic peaks.

The final results are given in table 2, together with the values assumed for the quantities appearing in eqs. (11) and (13). For each entry the estimated uncertainty is also given. A point-to-point error of $\sim$ ±0.5% on the luminosity was assumed.

DETERMINATION OF σ INDEPENDENT OF THE LUMINOSITY. The PSB and CR experiments can be run independently of each other and at different times. In each experiment a different event rate is measured, and in principle a separate luminosity measurement can be performed. As a matter of fact, it was found convenient to rely on the most stable monitor for luminosity measurement, which was used to derive both

PSB and CR results quoted in tables 1 and 2. However, if both the elastic and the total rate are measured at the same time in the same intersection, the luminosity is bound to be identically the same, and the ratio of R(CR) to R(PSB) determines σ without the need for any luminosity measurement. Formally, this corresponds to eliminating L from eqs. (9) and (14), obtaining

$$\sigma(\text{L-ind}) = \frac{1}{2}\,\frac{1}{1+\varepsilon}\,\frac{F(CR)}{R(PSB)}\left[1 + \sqrt{1 - 4\Delta\sigma_{el}(1+\varepsilon)\,\frac{R(PSB)}{F(CR)}}\right] . \qquad (15)$$

The values obtained for σ(L-ind) using eq. (15), together with those already given in tables 1 and 2 for σ(PSB) and σ(CR), are found in columns 2, 3, and 4 of table 3.

CONCLUSIONS. For each energy, the comparison between the values of σ given in table 3 is instructive in a number of ways. In particular, the scale error of the luminosity is monitored by the ratio λ between σ(L-ind) and σ(PSB) which depends linearly on L. If a scale error affected the luminosity measurements, such as to influence the σ values in a significant manner, then λ would deviate significantly from unity. Assuming zero scale error and averaging over all energies,

$$\langle\lambda\rangle = \left\langle\frac{\sigma(\text{L-ind})}{\sigma(\text{PSB})}\right\rangle = 0.9944 \pm 0.0077 \, . \qquad (16)$$

This result implies the reliability up to about 0.9% of the Van der Meer method for measuring the absolute value of the ISR luminosity. From a different point of view, the above result indicates an over-all consistency of the various methods for measuring σ and can be considered as a proof that the optical theorem holds true to ±0.5% for proton-proton collisions at ISR energies.

In column 5 of table 3 are also given the weighted averages of the PSB and CR results, which we take at present as the best values of σ. These are the values plotted in fig. 2 together with previous ISR and FNAL results (refs. [1], [2], [9], [10], and [11]). At each energy, the agreement between old and new values is as good as could be expected from the quoted errors.

The new values can be fitted with the following equation

$$\frac{\sigma}{\text{mb}}\,(23.5 \leq \sqrt{s} \leq 62.7 \text{ GeV}) = 25.4 + 4.29 \ln\frac{\sqrt{s}}{\text{GeV}} \, . \qquad (17)$$

However, this dependence of σ on $\sqrt{s}$ is not unique. For instance, good fits can still be obtained with either a $(\ln\sqrt{s})^{1/2}$ or a $(\ln\sqrt{s})^2$ dependence.

As a conclusion, these new measurements have confirmed that the proton-proton total cross-section continues to increase as a power in $\ln\sqrt{s}$ up to the maximum energy reached by the ISR. The data also show that the optical theorem is well satisfied. The Van der Meer method, which is currently used at the ISR for the luminosity measurements, has been proved to be valid to about ±0.9%. Although the precision of ∿ 0.6% which has been reached on the values of σ, should be considered very good for this type of experiment, it is not sufficient to discriminate between a number of different weak energy dependences of σ suggested by various models [12].

We are indebted to the personnel of the ISR Department, and especially to K. Potter, for their many contributions to this experiment and for the excellent operation of the machine. We are grateful to G. Kantardjian for his coordination of technical services and to J. Renaud and M. Wensveen for their supervision during the installation of the apparatus. We are also grateful to M. Busi for much effort in the data reduction, to J. Meyer for helpful discussion and to J.V. Allaby, W. Duinker, G. Paternoster and M. Romano for help in various phases of the experiment. We thank A. Bechini, R. Donnet and M. Ferrat for their excellent technical support. Thanks are also due to M. Del Colletto and P. Marchi for their skilful mechanical work.

REFERENCES

[1] U. Amaldi et al., Phys. Letters 44B (1973) 112.

[2] S.R. Amendolia et al., Phys. Letters 44B (1973) 119.
S.R. Amendolia et al., Nuovo Cimento 17A (1973) 735.

[3] S. Van der Meer, CERN Internal Report ISR-PO/68-31 (1968).

[4] S.R. Amendolia et al., Internat. Conf. on Instrumentation for High-Energy Physics, Frascati, 1973 (Lab. Naz. del CNEN, Frascati, 1973) p. 397.

[5] K. Potter, ISR Internal Report (1975).

[6] U. Amaldi et al., Phys. Letters 36B (1971) 504.
V. Bartenev et al., Phys. Rev. Letters 31 (1973) 1088.
G. Barbiellini et al., Phys. Letters 39B (1972) 663.
The value of b at 31 + 31 GeV comes from a recent measurement of the CERN-Rome group (to be published).

[7] U. Amaldi et al., Phys. Letters 43B (1973) 231.
V. Bartenev et al., Phys. Rev. Letters 31 (1973) 1367.

[8] K.M. Terwilliger, Proc. Internat. Conf. on High-Energy Accelerators, CERN, Geneva, 1959 (CERN, Geneva, 1959) p. 53.

[9] G. Bellettini, 5th Internat. Conf. on High-Energy Collisions, Stony Brook, 1973 (ed. C. Quigg) (Amer. Inst. Phys., NY, 1973) AIP Conf. Proc. No. 15; Particles and Fields subseries, No. 7; AEC CONF 730841, p. 9. (The new measurements of the ISR displacement scale indicate that the 1.7% correction adopted in this paper should not be applied.)

[10] K. Eggert et al., Nuclear Phys. B98 (1975) 93.

[11] A.S. Carroll et al., Phys. Letters 61B (1976) 137.

[12] See, for example, V. Barger, Proc. 17th Internat. Conf. on High-Energy Physics, London, 1974 (Rutherford Lab., Chilton, Didcot, 1974), p. I-193.

Table 1

Summary of the results obtained with the Pisa-Stony Brook method. The symbols heading columns 3 to 6 are the same as those used in eq. (9).

ISR energies (GeV)	$\sqrt{s}$ (GeV)	σ observed (mb)	$\Delta\sigma_{el}$ (mb)	ε (%)	σ(PSB) (mb)
11.8 + 11.8	23.5	37.89 ± 0.23	0.24 ± 0.03	1.77 ± 0.21	38.80 ± 0.25
15.4 + 15.4	30.6	38.86 ± 0.21	0.52 ± 0.04	1.80 ± 0.22	40.08 ± 0.24
22.5 + 22.5	44.7	39.82 ± 0.21	1.24 ± 0.09	2.16 ± 0.22	41.92 ± 0.25
26.6 + 26.6	52.8	40.16 ± 0.31	1.66 ± 0.12	2.27 ± 0.22	42.73 ± 0.34
31.6 + 31.6	62.7	39.81 ± 0.33	2.22 ± 0.17	2.49 ± 0.32	43.02 ± 0.40

Table 2

Summary of the results obtained with the CERN-Rome method. The symbols heading columns 2 to 7 are the same as those used in eqs. (11 and 13).

ISR energies (GeV)	$\langle\lvert t\rvert\rangle$ (GeV^2)	ρ	ε_{Coul}	b (GeV^{-2})	$e^{b\lvert t\rvert}$	σ(CR) (mb)
11.8 + 11.8	0.0065	0.0 ±0.02	+0.0574 ±0.0010	11.8 ± 0.3	1.080 ±0.002	39.01 ± 0.29
15.4 + 15.4	0.0097	0.03 ±0.03	+0.0141 ±0.0005	12.3 ± 0.3	1.127 ±0.004	40.35 ± 0.34
22.5 + 22.5	0.0184	0.06 ±0.04	-0.004	12.8 ± 0.3	1.266 ±0.008	41.45 ± 0.26
26.6 + 26.6	0.0218	0.07 ±0.05	-0.006	13.1 ± 0.3	1.331 ±0.010	42.38 ± 0.29
31.6 + 31.6	0.0292	0.08 ±0.06	-0.007	13.3 ± 0.3	1.475 ±0.013	43.05 ± 0.33

Table 3

Total proton-proton cross-sections as a function of the total c.m. energy, $\sqrt{s}$. The weighted averages of the last column are plotted in Fig. 2.

$\sqrt{s}$ (GeV)	σ(PSB) (mb)	σ(CR) (mb)	σ(L-ind) (mb)	σ(Weighted average) (mb)
23.5	38.80 ± 0.25	39.01 ± 0.29	39.22 ± 0.54	38.88 ± 0.21
30.6	40.08 ± 0.24	40.35 ± 0.34	40.58 ± 0.68	40.16 ± 0.22
44.7	41.92 ± 0.25	41.45 ± 0.26	41.01 ± 0.50	41.70 ± 0.21
52.8	42.73 ± 0.34	42.38 ± 0.29	41.99 ± 0.54	42.50 ± 0.27
62.7	43.02 ± 0.40	43.05 ± 0.33	43.13 ± 0.65	43.04 ± 0.31
Scale error	± 0.36	± 0.22	± 0.25	± 0.28

Figure captions

Fig. 1 : ISR intersection I-8. General layout of the Pisa-Stony Brook large solid-angle, secondary-particle detector, and of the CERN-Rome hodoscopes measuring elastic scattering in the vertical plane.

Fig. 2 : The proton-proton total cross-sections obtained in the present work are plotted together with those from FNAL (Carroll et al. [11]). The broken lines represent in both cases the estimated scale errors. In the upper left corner, on a reduced scale, the results of all previous measurements of σ obtained at the ISR are also shown. The line corresponds to Eq. (17), and the scale error is also indicated.

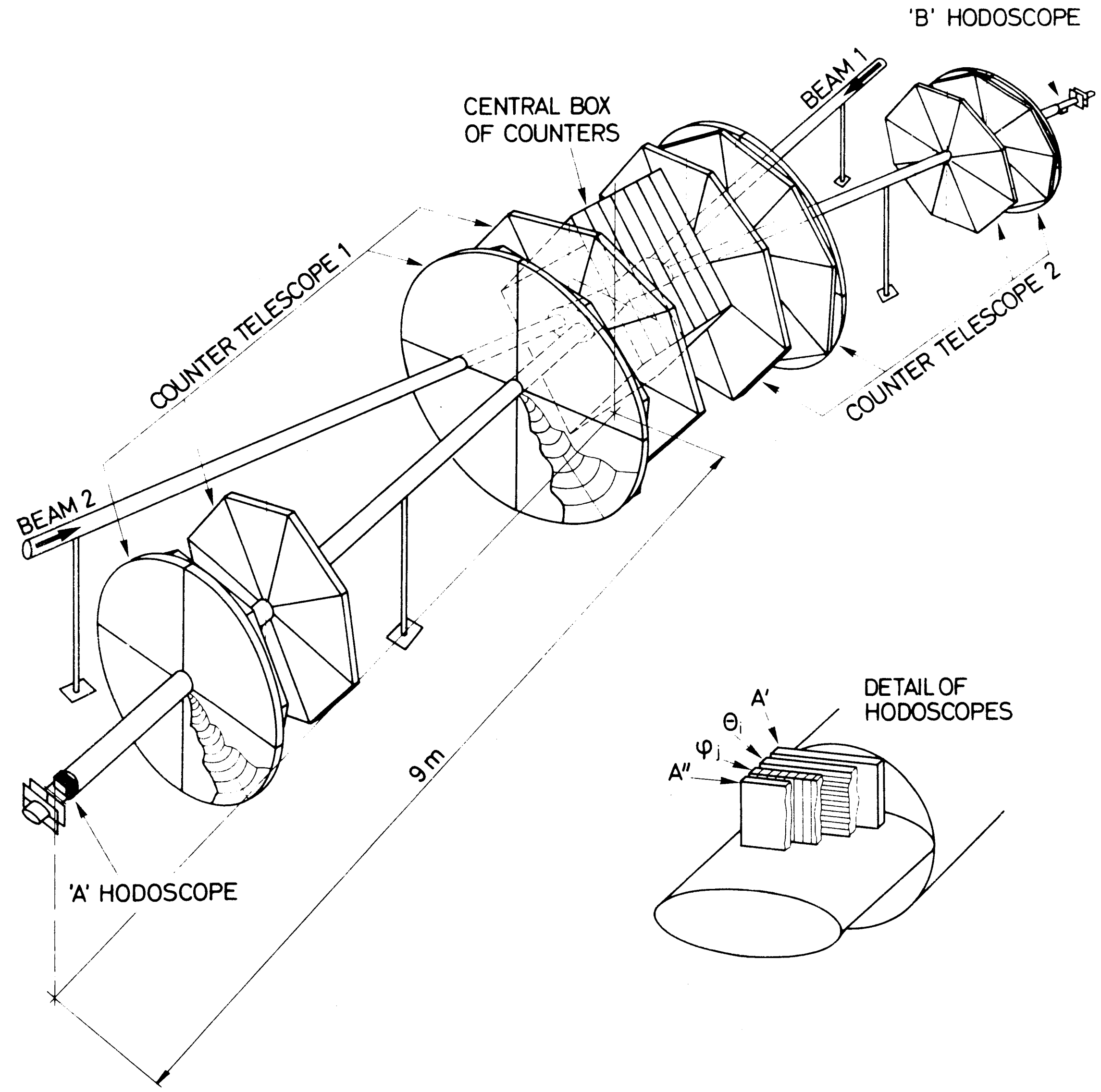
'B' HODOSCOPE
BEAM 1
CENTRAL BOX
OF COUNTERS
COUNTER TELESCOPE 1
COUNTER TELESCOPE 2
BEAM 2
9 m
'A' HODOSCOPE
DETAIL OF
HODOSCOPES
A'
Θ_i
φ_j
A''

Fig. 1

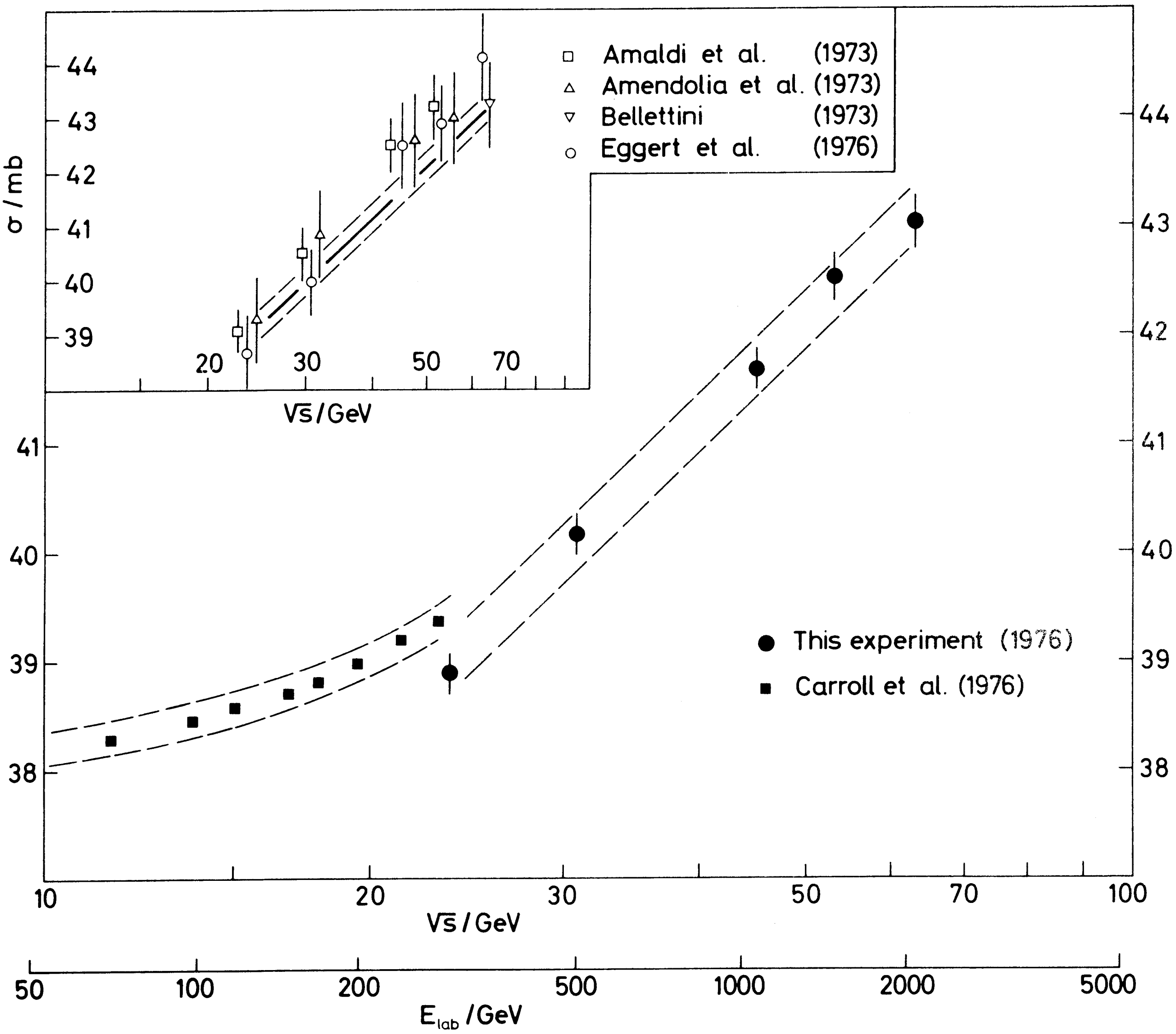
Amaldi et al. (1973)
Amendolia et al. (1973)
Bellettini (1973)
Eggert et al. (1976)
σ / mb
44
43
42
41
40
39
20
30
50
70
√s / GeV
This experiment (1976)
Carroll et al. (1976)
38
10
100
E_lab / GeV
50
200
500
1000
2000
5000

Fig. 2