[2]S. L. Glashow, J. Iliopoulos, and L. Maiani, Phys. Rev. D 2, 1285 (1970).

[3]C. Bouchiat, J. Iliopoulos, and Ph. Meyer, Phys. Lett. 38B, 519 (1972).

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[7]S. Weinberg, Phys. Rev. D 8, 605 (1973), and Phys. Rev. Lett. 31, 494 (1973).

[8]O. W. Greenberg, Phys. Rev. Lett. 13, 598 (1964).

[9]H. D. Politzer, Phys. Rev. Lett. 30, 1346 (1973); D. J. Gross and F. Wilczek, Phys. Rev. Lett. 30, 1343 (1973); T. Appelquist and H. Georgi, Phys. Rev. D 8, 4000 (1973); A. Zee, Phys. Rev. D (to be published); H. Georgi and H. D. Politzer, Phys. Rev. D (to be published); D. J. Gross and F. Wilczek, Phys. Rev. D 8, 3633 (1973), and Phys. Rev. D (to be published).

[10]In a general gauge theory, the Lie algebra of the gauge group is a direct sum of a semisimple and an Abelian Lie algebra. Only if the Abelian term is absent—as in a unified theory—is the gauge group necessarily compact, and charge necessarily quantized. Assume that electric charge Q were not quantized in such a theory, i.e., that its eigenvalues were not commensurate. The topological closure of the one-parameter subgroup $\{\exp(i\alpha Q)\}$ would be a compact Abelian Lie group with at least two parameters. Let its Lie algebra A be spanned by $Q, Q_1, \ldots, Q_n$, where $n>0$. Because the gauge group is compact, its Lie algebra contains A and the Q_i are associated with gauge fields other than the photon. Because $\exp(i\alpha Q)$ is an unbroken local symmetry, the Q_i generate unbroken local symmetries and their associated gauge fields are massless. Since there is only one massless gauge field, we conclude that Q is quantized.

[11]S. Weinberg, Phys. Rev. D 5, 1962 (1972); H. Georgi and S. L. Glashow, Phys. Rev. D 7, 2457 (1973).

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[13]See the second paper in Ref. 7 and the sixth paper in Ref. 9.

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[16]A naive calculation indicates that the vector boson mass must be greater than 10^{15} GeV $\simeq 10^{-9}$ g! Let the reader who finds this hard to swallow double the number of fermion states and put quarks and leptons in different (but equivalent) thirty-dimensional representations. He must introduce both weakly interacting quarks and strongly interacting leptons. Now quark number is conserved modulo two and the proton is stable. The deuteron decays via the exchange of four superweak vector bosons, but this is not a serious problem.

Measurement of the p-p Total Cross Section at 200 and 300 GeV/c*

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We have measured total cross sections for p-p scattering with the results $\sigma_T = 40.42 \pm 0.27$ mb at 200 GeV/c and 40.40 ± 0.28 mb at 300 GeV/c. Our 300-GeV/c result is significantly higher than published data from the CERN intersecting storage rings. Our data, taken together with the Serpukhov data, indicate that the cross section rises ≈ 2 mb between 60 and 250 GeV. The variation of the cross section with energy may be more complicated than the $a + b \ln^\alpha s$ behavior commonly assumed for $E_{\rm lab} \gtrsim 50$ GeV.

We have carried out a measurement of proton-proton total cross sections at 200 and 300 GeV/c with a proton beam at the National Accelerator Laboratory (NAL). The standard good-geometry transmission technique was used with a liquid-hydrogen target and scintillation counters.

The experimental arrangement is shown schematically in Fig. 1. The proton beam was made by slightly modifying an existing neutral beam by the addition of two small bends, each about 0.7 mrad. The beam was taken off at an angle of 1 mrad from a beryllium target in an external pro-

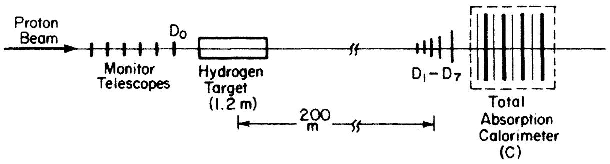

FIG. 1. Schematic of the experiment.

ton beam. The beam line had a nominal momentum spread of $\pm 7\%$. However, diffractively scattered protons completely dominated the spectrum, so that the actual momentum spread was less than 1%, and the uncertainty in the momentum was $\ll 1\%$. Pulse-height spectra from the total-abosrption calorimeter[1] showed no evidence for low-energy particles in the beam. The beam size at the hydrogen target was about 2 mm in diameter as defined by a collimator about 15 m upstream of the target. The beam at counters D_1–D_7 was approximately 0.6 cm in radius. The beam intensity was generally kept below 10^4 protons/pulse so that accidentals were $\ll 1\%$.

We used a liquid-hydrogen target 121.41 ± 0.05 cm long. The target pressure was monitored continuously during the running and was ~1 atm. The liquid hydrogen was essentially in equilibrium with hydrogen vapor, so that knowledge of the pressure was sufficient to determine the temperature, and consequently the density. Sufficient time elapsed between filling the target and taking data to ensure that the orthohydrogen-to-parahydrogen transition was complete. The hydrogen vessel was interchanged with an evacuated dummy target of similar construction about once a minute during data taking. The uncertainty in the final cross sections due to uncertainties in the target length and density are estimated to be $< 0.2\%$.

The beam transmitted by the hydrogen target was measured by the transmission counters D_1–D_7 and the calorimeter C. The transmission counters were circular scintillator disks, concentric with the beam, and ranged from 1.9 to 10.2 cm in radius. A total of 64 coincidences of various kinds were recorded. Most of these were of the type $D_0 D_j D_{j+1} C_i$, where C_i represents a pulse from one of seven discriminators which were set to trigger only if the pulse height from the calorimeter exceeded some minimum δ_i. The δ_i corresponded to energies deposided in the calorimeter of approximately 40, 80, 130, 180, 215, 240, and 270 GeV. Thus, in effect, we were able to measure the apparent cross section versus energy deposited in the calorimeter. This served as a useful check against beam contamination and also greatly facilitated the extrapolation to zero solid angle as discussed below.

The other scaler channels recorded the monitors, accidental coincidences of various kinds, singles rates, proton beam intensity, etc. The scaler counts were recorded on magnetic tape after every beam pulse. This allowed later editing of occasional bad beam pulses.

The apparent cross section for any channel (corresponding to a calorimeter pulse-height cut δ_i and a solid angle $\Delta\Omega_j$) is given by the usual expression

$$\sigma_{ij} = \frac{1}{nx} \ln\left[\frac{(C_{ij}/M)_{\text{empty}}}{(C_{ij}/M)_{\text{full}}}\right],$$

where C_{ij}/M is the ratio of counts in that channel to monitor counts with the target full or empty and nx is the target constant. As is well known, the cross sections are independent of the counter efficiencies provided they are the same for target empty and full.

The measured cross sections were corrected for Coulomb scattering. Corrections for multiple scattering were calculated following the technique of Sternheimer.[2] Only data points for which these corrections were *negligible* were used to obtain the final total cross sections. Corrections for single Coulomb scattering were also made.[3] These corrections were usually < 0.2 mb. As a sensitive check on the Coulomb corrections, data taken when the beam spot was displaced 0.7 cm from the center of the transmission counters were compared to data taken with the beam centered properly. For counters for which the calculated multiple Coulomb corrections were negligible, no change was seen in the cross sections, even though large changes occurred for the smaller counters.

The corrected cross sections were extrapolated to zero solid angle in the usual way. It was found that the slope of the extrapolation increased significantly for the lower calorimeter pulse-height channels as a result of detection of inelastic events with low-energy secondaries. As might be expected, the slope of the extrapolation approached $(d\sigma/d\Omega)_{\text{elastic}}$ when the pulse-height cut was just below the incident proton energy. It was also found that the extrapolated total cross sections were essentially independent of the pulse-height cut. Typically, the extrapolation increased the cross section about 1% above the cross sections measured with the smaller counters. The error in the extrapolated cross section due to the uncertainty in the extrapolation was about 0.35%.

In the final data sample, only runs with accidental rates $\lesssim 0.4\%$ were used. At 200 GeV/c, a group of runs with an average accidental rate of 3% yielded a cross section differing by $+0.4 \pm 0.3$ mb from that of the lower-rate data retained in the final sample. For each run the ratios C_{ij}/M were also plotted versus rate for each beam pulse. Typically, the beam rate per pulse varied over an order of magnitude during each run, but no sign of any variation of the C_{ij}/M with rate was found. The pulse-to-pulse variations of these ratios were also studied and compared with variations expected as a result of statistical fluctuations. For most runs the variations were consistent with statistics. For a few, slightly larger variations were found and the statistical errors in the cross sections were increased proportionately.

For the 300-GeV/c data there were ten runs in the final sample. These gave a $\chi^2 = 7.6$, relative to their weighted average, for nine degrees of freedom (56% confidence level). For the 200-GeV/c data there were six runs with a χ^2 of 2.0, corresponding to a confidence level of 83%.

Our result for the total cross section at 300 GeV/c is 40.40 ± 0.28 mb. The error corresponds to adding in quadrature the statistical error (± 0.22 mb), the error in the extrapolation to zero solid angle (± 0.15 mb), the error due to possible uncertainties in Coulomb scattering corrections (± 0.06 mb), and the uncertainty in the target constant (± 0.08 mb). Our result at 200 GeV/c is 40.42 ± 0.27 mb, with very similar contributions to the error.

Our results are plotted in Fig. 2 along with previous data from Serpukhov,[4] the NAL bubble chamber,[5] and the CERN intersecting storage rings (ISR).[6,7] Our result at 300 GeV is significantly higher than the published ISR data[6,7a] and the NAL bubble-chamber result.[5b] However, it does agree well with ISR data from the Pisa-Stony Brook group taken with lead converters in front of their counters[7b] (the dashed-line points in Fig. 2). Our data, together with the Serpukhov data, indicate a rise of approximately 2 mb in σ_T between 60 and 250 GeV/c.[8] Pumplin, Henyey, and Kane have recently pointed out that a rise of several millibarns would be expected between ~30 and 500 GeV/c due to the effects of pion exchange.[9] With our results included, it is difficult to fit the data with the smooth $a + b \ln^\alpha s$ energy dependence commonly assumed at high energies.[10] However, a smooth rise starting just above $P_{\rm lab} = 60$ GeV/c and continuing beyond 1500 GeV/c is not excluded.

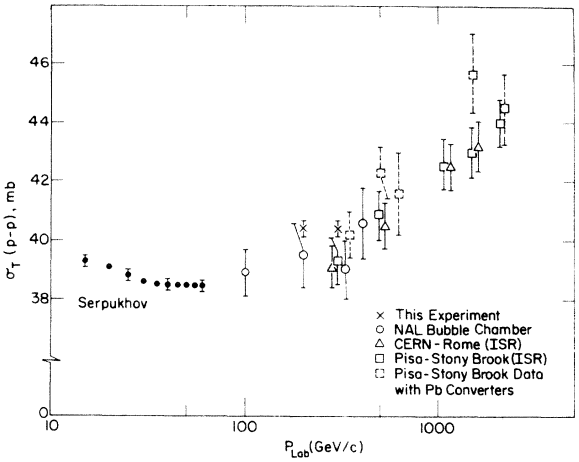

FIG. 2. Total-cross-section data for p-p scattering.

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[1]For a complete discussion of the total absorption calorimeter see L. W. Jones *et al.*, University of Michigan Report No. UMHE 73-3-24, 1973 (unpublished).

[2]R. M. Sternheimer, Rev. Sci. Instrum. 25, 1070 (1954). Sternheimer assumes a Gaussian distribution for multiple Coulomb scattering. For a thin, low-Z target such as ours, the actual distribution deviates significantly from a Gaussian. The Snyder-Scott distribution includes single and "plural" scattering and gives a more accurate description. We have used a technique like that used by Sternheimer in his treatment of single scattering (Sect. III) to estimate how sensitive the Coulomb corrections are to the distribution function. We find that the error in σ_T due to the neglect of plural scattering is $\lesssim 0.05$ mb.

[3]The Coulomb-nuclear interference term was included, but was found to be negligible.

[4]S. P. Denisov *et al.*, Phys. Lett. 36B, 415 (1971).

[5a]G. Charlton *et al.*, Phys. Rev. Lett. 29, 515 (1972).

[5b]F. T. Dao *et al.*, Phys. Rev. Lett. 29, 1627 (1972).

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[7a]S. R. Amendolia *et al.*, Phys. Lett. 44B, 119 (1973).

[7b]G. Bellettini, in *High Energy Collisions—1973,* AIP Conference Proceedings No. 15, edited by C. Quigg (American Institute of Physics, New York, 1974).

[8]If the increase in σ_T is interpreted as a result of an increase in the effective radius of the nucleon, it should be accompanied by a proportionate increase in the slope of the forward peak, b. It is interesting to note that the data of V. Bartenev *et al.* [Phys. Rev. Lett. 31, 1088 (1973)] indicate that b increases from 10.84 ± 0.20 at 78 GeV/c to 11.56 ± 0.12 at 199 GeV/c.

[9]J. Pumplin, F. Henyey, and G. Kane, to be published. This rise in σ_T is on top of a "background" which is assumed to be slowly varying with energy. The "background" could include a logarithmic rise at high energy.

[10]See, for example, V. Bartenev *et al.*, Phys. Rev. Lett. 31, 1367 (1973).

ERRATA

SPECTRAL AND INTENSITY-DEPENDENT MEASUREMENTS OF THE TWO-PHOTON PHOTOCONDUCTIVITY IN ZnS CRYSTALS. G. Koren and Y. Yacoby [Phys. Rev. Lett. 30, 920 (1973)].

The units of the ordinates of Figs. 2 and 3 should be mho/cm instead of $\sec^{-1}$.

DEPENDENCE OF THE LINEAR POLARIZATION OF γ RADIATION ON THE HYPERFINE INTERACTION. R. Heusinger, W. Kreische, W. Lampert, K. Reuter, K. H. Roth, and K. Thomas [Phys. Rev. Lett. 31, 899 (1973)].

The expression for ΔW_e in Eq. (6) must be

$$\Delta W_e = g_e B \mu_N.$$