[8]For a more detailed analysis of the charged-prong multiplicity distributions in the 50–300-GeV/c region of incident momentum, see P. Slattery, University of Rochester Report No. UT-409, 1972 (to be published). This paper also includes a discussion of the impact of this observation on the Mueller-Regge viewpoint.

pp Interactions at 303 GeV/c: Multiplicity and Total Cross Section

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In an exposure of the 30-in. hydrogen bubble chamber to a 303-GeV/c proton beam, 2245 interactions have been observed. The measured total cross section is 39.0 ± 1.0 mb and the average charged particle multiplicity $\langle n_{ch}\rangle = 8.86 \pm 0.16$.

We present data on the charged-particle multiplicity produced in 303-GeV/c proton-proton collisions. The shape of this distribution as well as the energy dependence of its moments are of fundamental importance to strong interaction theory.

The primary proton beam was extracted from the National Accelerator Laboratory proton synchrotron and the 30-in. hydrogen bubble-chamber beam line and was tuned using these protons. The intensity of the beam was then suitably attenuated by closing collimators and defocusing magnets, and by insertion of an aluminum target approximately 1 km upstream of the bubble chamber which was viewed at 1.5 mrad. Measurements indicated that the beam-momentum spread was less than 0.5%. The primary proton beam entered the bubble chamber with a very small angular spread, and we believe that within this angular region the fraction of contaminating particles is small.

For this run we used the following bubble-chamber parameters: $B = 27$ kG, 35-mm film, four views, bubble size on film ~15 μm, and a bubble density for minimum-ionizing particles 10–12/cm. The entrance window is ~18 cm high by ~5.5 cm wide.

In the scanning the chamber was imaged at 90% of its true size, and all the film was scanned twice, once by a physicist and once by a professional scanner. In the first scan a decision was made as to whether a picture was acceptable based on two criteria: (1) All hadron tracks entering the chamber had to be parallel to the beam to $\lesssim 1$ mrad. (2) The number of beam tracks entering through the window as projected in view 2 had to be ≤ 15. Frames were also rejected because of chamber malfunction. With these criteria 6201 frames were accepted out of ~16 000 frames taken. The scanners were instructed to record the number of entering beam tracks, all events, any secondary interactions, neutron stars, V's, kinks, Dalitz pairs, and stopping protons as well as any unusual features in the picture. The average number of tracks per accepted framed was 4.9. The beam intensity was adjusted to optimize the product of acceptable pictures and tracks.

The rescan consisted of only the 6201 accepted frames. In a third, or conflict scan, every event was carefully re-examined by one or two physicists, if necessary using magnification a factor of ~9× chamber size.

Scanning was done with no fiducial cut and 2750 events were found. A fiducial volume cut reduced this to our final sample of 2245 events. From the first two scans the scanning efficiency was computed to be (99.2 ± 0.2)% for two-pronged events; for other topologies it was even higher. For the 1674 events with the number of charged secondaries $n_{ch} \geq 4$ found in both scans, and assuming the conflict scan topological decision to be correct, 78.2% of the events were correctly identified in both scans, 16.6% of the events were wrongly identified in one scan, and 5.2% were wrongly identified in both scans.

The following corrections were applied to the data:

(I) *Low-t two-prongs.*—The recoil proton has been measured for all two-prong events with a stopping proton. The detection efficiency is >99% for the t range $0.02 \leq -t \leq 0.12$ $(\text{GeV}/c)^2$. For smaller t the scanning efficiency drops.

The extrapolation to $t=0$ using the functional form $d\sigma/dt \propto ke^{bt}$ yields 52 ± 8 undetectable or undetected two-prongs in the experiment.

(II) *Disposition of odd-prong events, close-secondary interactions, and low-t recoils.*—There are 25 odd-prong events. These may be due to an undetectable low-t proton or an unresolvable secondary interaction close to the primary vertex. The latter mostly affect high-multiplicity events. There are 528 secondary interactions produced from events in the fiducial volume. A plot of their distance from the primary vertex reveals that ~16 secondary interactions were possibly missed within 2.2 cm of the primary. All stopping-proton events in the film have been measured. A study of the t distribution plot for $n_{\text{ch}} \geq 4$ shows a depletion of ~12 events for $|t| \leq 0.02$ $(\text{GeV}/c)^2$. If the odd-prong events are due to close secondaries, they should be shifted to a *lower* multiplicity bin. If they are due to unseen low-t recoils, they should be shifted to the next *higher* multiplicity bin. In preparing the table of topological cross sections these odd-prong events have been split evenly between adjacent even-topology bins; the effect on $\langle n_{\text{ch}} \rangle$ of shifting them all up or all down is less than 0.2 standard deviations (σ).

(III) *Close V's.*—There are 514 V's produced by interactions in the fiducial volume. Of these ~100 are obvious electron pairs. A plot of the distance between the primary vertex and secondary vertex shows that ~25 V's were missed within 2.2 cm of the primary vertex. Correcting for these V's would lower the multiplicity. This correction is small compared to the present level of statistical accuracy so is not applied to the topological cross sections. However, its effect on $\langle n_{\text{ch}} \rangle$ is less than 0.2σ.

(IV) *Dalitz pairs.*—It is assumed that the average number of π^0's is one half the average num-

TABLE I. Topological cross sections at 303 GeV/c.

n_{ch}	Events Found	Corrected Number[a]		Cross Section[b]
1		529 ± 23	el. 424 ± 24	7.2 ± 0.4 mb
2	475		inel. 105 ± 33	1.78 ± 0.56
3	1			
4	278	285 ± 17		4.84 ± 0.30
5	2			
6	329	336 ± 19		5.71 ± 0.34
7	6			
8	311	318 ± 19		5.40 ± 0.33
9	5			
10	274	278 ± 18		4.72 ± 0.32
11	2			
12	245	247 ± 17		4.19 ± 0.30
13	2			
14	127	128 ± 12		2.17 ± 0.21
15	4			
16	83	82 ± 10		1.39 ± 0.17
17	1			
18	52	51 ± 8		0.87 ± 0.14
19	1			
20	31	30 ± 6		0.51 ± 0.11
21	0			
22	5	4 ± 3		0.07 ± 0.06
23	1			
24	6	6 ± 3		0.10 ± 0.05
25	0			
26	4	3 ± 2		0.05 ± 0.03
Total	2245	2297		39.0 ± 1.0

[a]Corrected for low-t two prongs and Dalitz pairs; odd-prong events distributed as discussed in text.

[b]These errors contain an additional uncertainty contributed by hydrogen density and track-length errors.

TABLE II. Moments of the multiplicity distribution.

	All Prongs	Negative Only
$\langle n\rangle$	8.86 ± 0.16	3.428 ± 0.079
$\langle n^2\rangle$	97.6 ± 2.9	16.55 ± 0.57
$\langle n^3\rangle$	$(1.261 \pm 0.054)\cdot 10^3$	96.7 ± 4.9
$\langle n^4\rangle$	$(1.84 \pm 0.11)\cdot 10^4$	649 ± 46
$\langle n^5\rangle$	$(2.96 \pm 0.24)\cdot 10^5$	$(4.84 \pm 0.47)\cdot 10^3$
$\langle n\rangle(\langle n^2\rangle - \langle n\rangle^2)^{-\frac{1}{2}}$	2.022 ± 0.062	1.568 ± 0.054
g_2 [a]	88.8 ± 2.7	13.12 ± 0.50
g_3	987 ± 46	54.0 ± 3.4
g_4	$(1.186 \pm 0.081)\cdot 10^4$	230 ± 23
f_2 [a]	10.31 ± 0.92	1.36 ± 0.25
f_3	17.1 ± 6.1	-0.40 ± 0.74
f_4	-88 ± 48	-4.59 ± 2.25

[a]See Ref. 2. Note: $n = n_{ch}$.

ber of charged π's, that the average number of $K^\pm$ is 10% of the $\pi^\pm$, and that the average number of protons is 1.4. Thus, $\langle n_{\pi^0}\rangle \simeq 3.4$ and 2245 events will contain ~88 Dalitz pairs. The 24 observed Dalitz pairs have been used to make the correction to the topological cross sections. The corrected number, 88, is distributed among topologies in the same way as the observed 24.

The total cross section measured in this experiment is 39.0 ± 1.0 mb based on 2245 observed events. Besides the statistical error we have included a 1% uncertainty in the density of liquid hydrogen used, 0.0625 g/cm^3, and a 1% uncertainty in the average potential path of 53.05 cm. The contribution to the uncertainty arising from the correction for events lost at low t is negligible.

The slope parameters determined by Barbiellini *et al.*[1] and our measured total cross section give an elastic-scattering cross section of 7.2 $\pm$ 0.4 mb computed using the optical theorem.

The topological cross sections are given in Table I.

An attempt was made to fit the topological distribution with a Poisson distribution normalized to $\langle n_{ch}^-\rangle$, the average number of negative secondaries. The fit is totally unacceptable. Table II displays some of the moments of the multiplicity distribution.[3]

In Fig. 1(a) $\langle n_{ch}\rangle$ is shown. The five bubble-chamber experiments spanning 50–300 GeV/c do not appear to follow a simple $\ln p_{\rm lab}$ ($\sim \ln s$) dependence; $\langle n_{ch}(n_{ch}-1)\rangle$ is shown in Fig. 1(b). Berger[11] fits the momentum dependence of this quantity for two general models and extrapolates

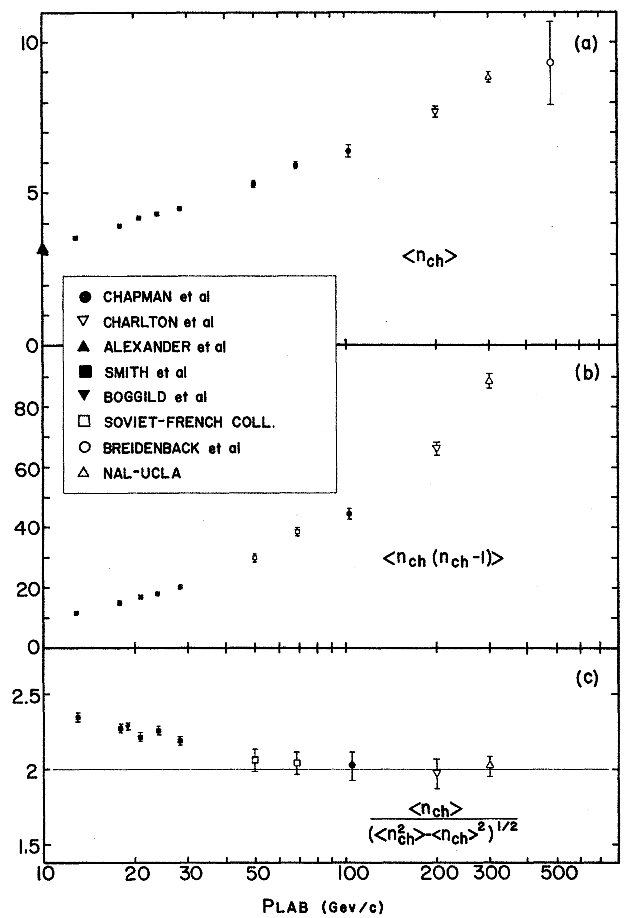

FIG. 1. Momentum dependence of $\langle n_{ch}\rangle$, $\langle n_{ch}(n_{ch}-1)\rangle$, and $\langle n_{ch}\rangle(\langle n_{ch}^2\rangle - \langle n_{ch}\rangle^2)^{-1/2}$. The data are from Chapman *et al.*, Ref. 4; Carlton *et al.*, Ref. 5; Alexander *et al.*, Ref. 6; Smith *et al.*, Ref. 7; Boggild *et al.*, Ref. 8; the Mirabelle Collaboration, Ref. 9; Briedenback *et al.*, Ref. 10; and the present experiment.

the fit to our momentum. His extrapolated prediction yields a value of 77 for a multiperipheral model and 84 for a fragmentation model. Our value of 89 ± 3 is in closer agreement with the latter. Finally, in Fig. 1(c) $\langle n_{ch}\rangle(\langle n_{ch}^2\rangle - \langle n_{ch}\rangle^2)^{-1/2}$ is shown. The apparent constancy of this expression has been noted by a number of authors[12] and in particular Koba, Nielsen, and Olesen point out that it follows from one of their scaling laws.

Significant scientific contributions to this work have been made by many physicists other than the authors. They have built and operated the National Accelerator Laboratory, its extraction system, and the hadron beam line to the bubble chamber. It has been a privilege for us to work with them during the course of this experiment, and we thank them for their enthusiastic participation. We gratefully acknowledge the dedicated support of the operation staffs of the accelerator, the Neutrino Laboratory, the 30-in. Bubble Chamber, and Film Analysis Facility.

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

[2]Definitions of f_n and g_n are as follows: $g_1 = \langle n\rangle$, $g_2 = \langle n(n-1)\rangle$, $g_3 = \langle n(n-1)(n-2)\rangle$, $g_4 = \langle n(n-1)(n-2)(n-3)\rangle$, $f_2 = g_2 - g_1^2$, $f_3 = g_3 - 3g_2g_1 + 2g_1^3$, $f_4 = g_4 - 4g_1g_3 + 12g_1^2g_2 - 3g_2^2 - 6g_1^4$.

[3]We would like to thank E. Berger for pointing out an overestimation of our errors in an earlier version.

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[6]G. Alexander *et al.*, Phys. Rev. 154, 1284 (1967).

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[8]H. Boggild *et al.*, Nucl. Phys. 27B, 285 (1971).

[9]Soviet-French Mirabelle Collaboration, submitted to the Proceedings of the Sixteenth International Conference on High Energy Physics, National Accelerator Laboratory, Batavia, Illinois, September 1972 (to be published).

[10]M. Briedenback *et al.*, Phys. Lett. 39B, 654 (1972).

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Measurement of the Ξ^- Magnetic Moment*

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A measurement of the magnetic moment of the Ξ^- hyperon yielded the value $\mu_\Xi = (-2.2 \pm 0.8)\mu_N$. The Ξ^- polarization averaged over the acceptance angle and the four-momenta at which data were taken was $\bar{P} = 0.30 \pm 0.05$.

We report a measurement of the magnetic moment of the Ξ^- hyperon made at the Brookhaven alternating gradient synchrotron using a method similar to that of our earlier measurement of the Λ hyperon.[1] Transversely polarized Ξ^- were produced and subsequently decayed through the reactions

$$\begin{aligned} &K^- + p \to \Xi^- + K^+ \\ &\qquad\quad \llcorner\!\!\to \Lambda + \pi^- \\ &\qquad\qquad\quad \llcorner\!\!\to p + \pi^-. \end{aligned} \tag{1}$$

We selected for analysis those Ξ^- which passed through a strong longitudinal magnetic field and subsequently decayed through the chain (1).

Since parity is not conserved in the Ξ^- and Λ decays, the angle through which the polarization vector has precessed about the magnetic field can be obtained by measuring the angular distribution of the two decay processes with respect to the plane of production. In the Ξ^- rest frame, the equation of motion of the polarization vector $\hat{\sigma}_\Xi$ in a magnetic field $\vec{H}$ is

$$d\hat{\sigma}_\Xi/dt = (\mu_\Xi/s_\Xi\hbar)\hat{\sigma}_\Xi \times \vec{H}, \tag{2}$$

where μ_Ξ and $s_\Xi\hbar$ are, respectively, the magnetic moment and spin angular momentum of the Ξ^-. In our apparatus, a Ξ^- with a magnetic moment of $1\mu_N$ would precess through an angle of about 20°.