SLAC Proposal No. SP-17
September 4, 1973

An Experimental Survey of Positron-Electron Annihilation into Multiparticle Final States in the s Range 27 to 74 GeV^2

Spokesmen: H. L. Lynch, R. F. Schwitters

Experimenters:

SLAC: A. M. Boyarski, M. Breidenbach, F. Bulos, G. Feldman, G. E. Fischer, D. Fryberger, G. Hanson, Rudy Larsen, H. L. Lynch, D. Lyon, C. Morehouse, J. Paterson, M. L. Perl, B. Richter, R. F. Schwitters

LBL: G. S. Abrams, D. Briggs, W. Chinowsky, C. E. Friedberg, G. Goldhaber, R. J. Hollebeek, J. A. Kadyk, A. Litke, G. H. Trilling, M. Sadoff, B. Sadoulet, J. S. Whitaker, J. E. Zipse

SUMMARY OF PROPOSAL

A. Physics - We shall concentrate on the following areas:

1. Measurement of σ_{total} (hadrons)/$\sigma_{\mu\mu}$ as a function of s in small steps for $27 \leq s \leq 74$ GeV^2.
2. Measurement of s dependence of copious exclusive channels in small steps of, s.
3. In large blocks of data at s = 36, 52, and 70 GeV^2 we shall study exclusive spectra and scaling properties of mesons in the deep inelastic region, meson resonances, baryon spectra, and hyperon spectra.
4. Search for jet structure of multihadron production.
5. Search for heavy leptons.

B. Equipment Needed

This experiment would utilize the magnetic detector already successfully used by these groups for SP1/SP2. Some modifications and improvements are planned.

C. Running Time Requested (Shifts)

Checkout	100	
Energy Scan: 2.6 GeV to 4.3 GeV in 0.1-GeV Steps	120	Prime time
Large Blocks: 3.0, 3.6, and 4.2 GeV	285	
Background Measurements	100	

MANY-BODY PRODUCTION - INTRODUCTION

We have become so accustomed to talking about the production of hadrons by electron-positron annihilation, that we sometimes forget how extraordinary a process it is. In all other hadron production reactions we start with at least one hadron and then make more hadrons. But in

$$e^+ + e^- \twoheadrightarrow 2 \text{ or more hadrons} \qquad (1)$$

we start with only a virtual photon and that photon changes into hadrons. Our theoretical understanding of how a single virtual photon changes into hadrons is very weak. The vector-dominance model is more a prescription or framework than it is a basic explanation of the process. For the vector dominance model does not give us any insight into how the virtual photon changes into the vector meson. The simple-quark model does provide some basic insight, but that model faces grave difficulties if the ratio

$$R = \frac{\sigma_{e^+e^- \to \text{hadrons}}}{\sigma_{e^+e^- \to \mu^+\mu^-}} \qquad (2)$$

remains substantially above 1 at high energy. In any case, at SPEAR II energies just about the entire cross section $\sigma(e^+e^- \to \text{hadrons})$ will consist of many-body production; insight into how a virtual photon changes into hadrons must be obtained from many-particle production data.

Another view is provided by noting that the SPEAR II energy range of 2.5 to 4.3 GeV corresponds to

$$25 \lesssim s \lesssim 74 \text{ GeV}^2 . \qquad (3)$$

This corresponds to pion-proton collisions in the range of 13 to 39 GeV/c pion laboratory momentum. Now in this energy range, pion-proton many-body reactions already exhibit many of their high-energy properties. For example, the dependence of the average charged multiplicity $\langle N_{ch} \rangle$ on s is roughly what it is at higher energies. And in this energy range the single-particle, pion, inclusive distributions already exhibit scaling. Therefore, it should be very useful to compare the many-body properties of

$$\gamma^* \rightarrow \text{many hadrons} \tag{4}$$

with

$$\pi + p \rightarrow \text{many hadrons} \tag{5}$$

in the SPEAR II energy range.

TOTAL CROSS SECTION

Quark or parton models have been actively pursued recently as the result of measurements of deep inelastic electron scattering and e^+e^- annihilation into hadrons. Largely because of its simplicity, the total cross section for $e^+e^- \rightarrow$ hadrons has received much attention within these models. The parameter $R = \sigma_{total}/\sigma_{point}$, the ratio of the total cross section to the cross section for producing a pair of point-like Dirac particles is one of the most important numbers to be studied. The most naive models assume that any quarks/partons produced are produced to the fullest extent consistent with being point-like particles, and that no threshold or dynamical effects destroy the simplicity of their result, viz., $R = \sum_i Q_i^2$, where Q_i are the charges of the constituents and R is thus some universal number. Many different such numbers have been proposed in efforts to solve various problems: The first value of R = 2/3 is the result of the original quark model; such a value is in clear conflict with existing storage-ring experiments. Adding "color" to quarks not only patched up the quark statistics but also brought R up to a more "reasonable" value of 2. Figure 1 shows a collection of the world's data on σ_{tot} ($e^+e^- \rightarrow$ hadrons), including the most recent datum from CEA at $s = 25$ GeV^2. While R = 2 is not incompatible with the lower-energy Frascati results, it is in poor agreement with the CEA data. Other models are possible yielding still higher values of R (e.g. charmed quarks, Ham Nambu + charm...)

Fundamentally, however, these various models all predict some asymptotic constant. If one takes the data of Fig. 1 at face value, there is no evidence of having reached a constant value of σ_{tot} as a function of s, never mind get the "right answer" in any of these models. It should also be pointed out that the cross section is far from structureless; indeed the total cross section at $s \sim 3$ GeV^2 is dominated by the $\pi^+\pi^-\pi^+\pi^-$ and $\pi^+\pi^-\pi^0\pi^0$ channels, which contribute in roughly equal amounts. The former channel is the channel used for the announcement of the existence of the ρ' vector meson by Frascati workers. The second channel has not been studied in these terms but the ρ' is expected to have a large branching fraction into this channel. If one takes claims of the ρ' seriously, then we must admit that the Frascati data are more nearly the domain of spectroscopy than asymptotic quark models. Experiments now in progress at SPEAR (SP2) will provide the first accurate, detailed s dependence of σ_{total} in the range $9 < s < 27$ GeV^2. These data should provide a good link to Frascati data and extend knowledge of σ_{tot}. With SPEAR II a similar experiment would extend the range of s up to 73 GeV^2.

Recognizing that existing experiments, or experiments in the near future, may not reach the asymptotic region, models have been studied of how the limit might be approached. For example, Appelquist and Georgi[1] suggest that the limit would be reached from above but the approach is only logarithmic in s.

$$R = \left[1 + c/\log(s/m^2)\right] \sum Q_i^2$$

A model by Gatto and Preparata[2] would have

$$R = (1 + \lambda/\sqrt{s}\,) \sum Q_i^2$$

where

$$\lambda \gtrsim 5 \text{ GeV}.$$

A more complex result of Renard[3] would also approach the limit from above.

All of these models in one way or another share the common basis of Bjorken scaling. An intriguing possibility suggested by Chanowitz and Drell[4] is that we shall see a breakdown of scaling. Their prediction is that R increases with s:

$$R \propto (1 + 2\, s/M_G^2) \text{ for } s \ll M_G^2 .$$

Estimates of M_G^2 are ~50-100 GeV^2. These estimates of M_G^2 come from deviations from the dipole fit to the nucleon form factor and from the deviation from scaling in inelastic electron scattering. To be sure, both of these results are subject to other interpretation, but a SPEAR II experiment at $s \sim 70$ GeV^2 would make a clear test of this hypothesis.

Making a detailed measurement of the s dependence of R into the range $s \lesssim 70$ GeV^2 would be valuable for testing these various models. We should hope to gain information for these questions: Is there an asymptotic region where scaling holds? Where does such a region begin? How does R approach the asymptotic region? The answers to these questions lie not only in the measurement of R but also in looking at specific channels. If, for example, one finds that some exclusive channel scales, then the correspondence arguments of Bjorken and Kogut[5] will be in difficulty. Likewise, one wishes to know if σ_{tot} is made up of a number of channels which scale, or whether it is made up of many channels which open, peak, and fall away again. In order to study such questions one must collect a much larger set of data, at various values of s, than would be required for a measurement only of σ_{tot}. One of the by-products of an accurate measurement of the s dependence of R is a search for heavy leptons which, due to some branching ratio into hadrons, would be manifested as a step in R. More detailed information on this search are given in a separate section.

MULTIPLICITIES

The large solid-angle detector used for SP2 is not only ideally suited to measurements of σ_{tot} but also to measurement of the multiplicity of the final state. The trigger counters cover 70% of 4π and the spark chambers an even larger fraction. Thus convincing measurements of the charged multiplicity can be done with rather little model dependence of detection efficiency. The shower counters will provide some information on the π^0 multiplicity.

Numerous different models have been made of the multiplicity expected for high energy e^+e^- annihilation. The statistical model predicts $<n> \sim \sqrt{s}$; other models predict $< n >$ to grow logarithmically with s or even to reach a constant. The latter alternative would pose grave difficulties for the correspondence arguments of Bjorken and Kogut,[5] where $< n > \rightarrow$ const. would mean that some specific channel would scale instead of behaving like an elastic channel (e.g., $e^+e^- \rightarrow \pi^+\pi^-$). Sanda,[6] using a constituent model, related possible growth rates of the total cross section to the average multiplicity; viz., if R increases like log s, then $< n >$ must increase like s/log s.

The angular distribution of the final products of σ_{tot} is also of interest. One model which has been suggested to describe the production of multihadronic events in e^+e^- collisions is the "jet" model. In this model the electron and positron annihilate to form a heavy virtual photon which decays into a pair of virtual partons which subsequently decay into hadrons (mainly pions). The "jet" model predicts that the average hadron multiplicity $< n >$ increases with a log s dependence. On the other hand, in a statistical model for multihadronic production, $< n >$ increases as $\sqrt{s}$.

The average multiplicity of charged hadrons $< n_c >$ in multihadronic events has been measured at Frascati and CEA for $s \leq 25$ GeV^2. Using these data one cannot distinguish between s-dependences of the form $< n_c > = a + b \log s$ and $< n_c > = a + b\sqrt{s}$ (see Fig. 2). We shall measure the s-dependence of $< n_c >$ over the range 25 GeV$^2 \leq s \leq 74$ GeV^2. This will extend the results of SP2, which will cover $9 \leq s \leq 25$ GeV^2.

In the jet model the average transverse momentum of the hadrons $< p_\perp >$ with respect to the jet axis for each event is ~360 MeV/c, whereas the average longitudinal momentum can be much larger. At s = 16 GeV^2 and 25 GeV^2 (CEA), $< |\vec{p}| > \sim 700$ GeV/c. In order to measure $< p_\perp >$, one must determine the jet axis for each event. We are now investigating methods for calculating the jet axis, for example, by determining the eigenvalues and eigenvectors of the tensor

$$T_{\alpha\beta} = \sum_i \left(\frac{3}{2} p^i_\alpha \cdot p^i_\beta - \frac{1}{2} \delta_{\alpha b}\, p_i^2 \right) / \sum_i p_i^2$$

(suggested by Bjorken and Brodsky,[7]). The distribution of the angle between the jet axis and the beam direction will be used to determine the properties of the jets, if they are produced.

INCLUSIVE SPECTRA

The study of inclusive spectra is closely related to measurements of σ_{total}: in particular, models based on scaling relate to both types of measurements. The complete analog of inelastic electron scattering from protons is the process $e^+e^- \rightarrow \bar{p}$ + hadrons. With the apparatus used for SP2 we should be able to identify protons having a momentum less than 1.5 GeV by time-of-flight. Calculations by Bjorken and Kogut[5] indicate that 30-40% of all proton events would be accepted by this cut. In addition they estimate that $\gtrsim 4\%$ of σ_{total} consists of events having a proton in the final state at s ~ 70. Preliminary results from the UCLA group[8] at SPEAR suggest that the estimate of Bjorken and Kogut[5] is conservative. On the basis of one observed event at s = 27 they estimate the cross section for $e^+e^- \to \bar{p}$ + anything of 0.2 nb. Such a cross section would represent ~1.5% of σ_{tot}. The fraction is expected to rise rapidly with s.

In addition to a proton inclusive spectrum, more complex baryon inclusive spectra may be studied; e.g., Λ or Δ. These states appear as two particles in the magnetic detector. Because of this, the particles may be identified over a wider kinematic range than protons; the yields should be of a magnitude similar to the proton yields.

States such as K_s and K^* may be identified and studied. Other less specific inclusive spectra may also be studied with the magnetic detector; any charged hadron will be accepted. However, it will only be possible to distinguish between π's and K's for momenta less than 800 MeV/c. Nonetheless, the kinematics are the same (or very nearly the same), and tests of scaling are possible. In addition, the application of scaling and the Callen-Gross relation predicts a simple angular dependence of $1 + \cos^2\theta$, which is characteristic of the production of point-like fermions at high energies.

THE SEARCH FOR HEAVY CHARGED LEPTONS

A. Introduction

So much has recently been written about the possible existence and the hypothetical properties of heavy leptons (see, for example, M. L. Perl, SLAC-PUB-1062, now being revised) that there is no need to discuss those questions here. We merely summarize the latest results.

There are two main classes of hypothetical heavy charged leptons (called ℓ in this proposal):

Type I — Lepton number is that of e or μ. The dominant decay mode is

$$\ell \to e \text{ or } \mu + \gamma \quad (1)$$

Type II — Lepton number is different from that of e and μ.

The decay modes are

$$\ell \to e + \nu_\ell + \bar{\nu}_e \qquad (2a)$$

$$\ell \to \mu + \nu_\ell + \bar{\nu}_\mu \qquad (2b)$$

$$\ell \to \nu_\ell + \text{hadrons} \; . \qquad (2c)$$

For type I heavy leptons the present lower limit on mass is 2 to 5 GeV. For an ℓ with electron lepton number the limit comes from an e^+e^- colliding beam search[9] for the reaction

$$e^+ + e^- \to e^{\pm} + \ell^{\mp} \to e^+ + e^- + \gamma, \qquad (3a)$$

and from colliding beam studies of[10]

$$e^+e^- \to \gamma\gamma. \qquad (3b)$$

For an ℓ with muon lepton number the limit comes from preliminary high-energy neutrino experiments[11] using the reaction

$$\nu_\mu + \text{nucleon} \to \ell^+ + \text{hadrons}. \qquad (4)$$

For type II heavy leptons, the present lower limit of 1.0 ~~GeV~~ comes from an e^+e^- colliding beam search.[12] This search method consisted of looking for $e^{\pm}\,\mu^{\mp}$ pairs from

$$e^+ + e^- \to \ell^+ + \ell^- \qquad (5)$$

with the decay modes in Eqs. 2a and 2b.

B. Search Method

Since charged leptons with masses greater than 1 GeV are expected to have lifetimes shorter than 10^{-11} second, the detection of these leptons depends completely upon the nature of the decay modes. The decay rate λ into the modes of Eqs. 2a and 2b can be calculated from first-order weak interaction theory if the hypothetical lepton ℓ has the normal weak interaction coupling. Ignoring the μ-e mass difference

$$\lambda_{\ell \to \nu_\ell \mu \bar{\nu}_\mu} = \lambda_{\ell \to \nu_\ell e \bar{\nu}_e} \; . \qquad (6)$$

The decay rate into the hadronic modes can only be estimated, particularly for the higher masses where the decay will usually be into (ν_ℓ + 2 or more hadrons). As discussed in SLAC-PUB-1062 there is a connection between

$$r = \frac{\lambda_{\ell \rightarrow \nu_\ell \mathrm{hadrons}}}{\lambda_{\ell \rightarrow \nu_\ell e \bar{\nu}_e}} \tag{7}$$

and

$$R = \frac{\sigma_{e^+e^- \rightarrow \mathrm{hadrons}}}{\sigma_{e^+e^- \rightarrow \mu^+\mu^-}} . \tag{8}$$

Using recent data on R, we estimate r in Eq. 7 to be about 3. Therefore we assume

$$\lambda_{\ell \rightarrow \nu_\ell \mathrm{hadrons}} : \lambda_{\ell \rightarrow \nu_\ell \mu \bar{\nu}_\mu} : \lambda_{\ell \rightarrow \nu_\ell e \bar{\nu}_e} = 3:1:1 \tag{9}$$

We propose to use two search methods:

1. Earlier in this proposal we described a measurement of the total cross section in 0.1-GeV energy increments. The total cross section for

$$e^+ + e^- \rightarrow \ell^+ + \ell^- \tag{10}$$

is

$$\sigma_{e^+e^- \rightarrow \ell^+\ell^-} = \sigma_{\mu\mu}\beta \left[1 + \frac{1}{2}(1 - \beta^2)\right] , \tag{11}$$

where β is the velocity of $\ell^\pm$. Therefore if there is a heavy charged lepton of mass M_ℓ, once $E_{\mathrm{beam}} > M_\ell$ and β approaches 1, we should see

$$\sigma_{e^+e^- \rightarrow \ell^+\ell^-} \sim \sigma_{e^+e^- \rightarrow \mathrm{hadrons}}/R, \tag{12}$$

where R is defined in Eq. 8. Of course we do not know R but we guess it will be about 5. Then the existence of a heavy charged lepton of mass M_ℓ will produce a shoulder in the observed total hadronic cross section of magnitude

$$\frac{3}{5} \; \frac{1}{R} \; \sigma_{e^+e^- \rightarrow \mathrm{hadrons}} \sim 0.12 \, \sigma_{e^+e^- \rightarrow \mathrm{hadrons}} . \tag{13}$$

by collecting several thousand hadronic events at 0.1-GeV-energy intervals, we ought to be able to find such a heavy lepton.

2. The second search method involves a search for the special decay-mode combination of an $e^{\pm}\mu^{\mp}$ pair produced by the sequence

$$\begin{aligned} & e^+ + e^- \rightarrow \ell^+ + \ell^- \\ & \ell \rightarrow \nu_\ell + \mu + \bar{\nu}_\mu \\ & \ell \rightarrow \nu_\ell + e + \bar{\nu}_e \end{aligned} \qquad (14)$$

This search would use the data acquired in the large statistics runs at 3.0, 3.6, 4.3 GeV, which were proposed earlier in this proposal, in order to study many-body production.

OTHER SUNDRY INFORMATION

As residual information obtained naturally during normal data-taking, we point out that a test of μ-e universality may be made. At the energies of SPEAR II the only two-body cross sections expected to survive are the e^+e^- and $\mu^+\mu^-$ final states. Electrons will be clearly identified in the shower counters and in addition the μ spark chambers give additional information on penetrating particles. Such a test will be entirely limited by systematic errors of the apparatus; we estimate these to be ~5 to 10%.

R. F. Schwitters[13] has studied depolarization mechanisms for storage rings and found that there should exist operating points relatively free of such effects, and the calculations of Sokolov and Ternov[14] should be applicable. Our apparatus may be profitably used for detecting effects of beam polarization by observing azimuthal non-uniformities of the angular distribution of μ pairs.

RUNNING TIME REQUESTED

This experiment divides naturally into two distinct parts: One part calls for modest data-taking at many different machine energies. This "Energy Scan" is useful for determining the detailed s dependence of the total cross section and searching for a heavy lepton. The scan is useful also for studying the behavior of copious exclusive channels. For studying less copious exclusive or inclusive channels we shall also need three "Large Blocks" of data to collect sufficient data on any one channel to study its scaling behavior, angular distribution, etc.

The "Energy Scan" is expected to require about 120 shifts to cover the 18 steps of machine energy. This will provide ~2000 multihadron events at each energy. To this an extra 25% should be added for background studies (separated beams, single beams, etc.). The "Large Blocks" are estimated to require 75 shifts at 3.0 GeV, 50 at 3.6 GeV, and 160 at 4.2 GeV in order to obtain about 500 proton events at each energy. To these amounts another 25% should be added for background studies. This channel was selected as an interesting but not a copious reaction for study. In addition, looking for scaling behavior of exclusive channels will require much data.

Naturally, the detector having been off for an extended period, for upgrading SPEAR and for some equipment improvements to the detector itself, some checkout time will be required to bring all equipment into working order. Time will also be needed to learn about possible unexpected backgrounds associated with SPEAR II. For these purposes we estimate 100 shifts of checkout time.

Summary of Running Time

	(shifts)	
Checkout	100	
Energy Scan	120	Prime time
Large Blocks	285	
Background Measurements	100	

EQUIPMENT NEEDED

This experiment is based upon use of the solenoidal detector designed and built for SP1/SP2 by some of the authors of this proposal. Generally speaking, the detector would be used as it has been successfully used during the running of SP1/SP2. There will, however, be some refinements: Because of the shorter rf structure of SPEAR II compared to SPEAR I, the time-of-flight will be improved somewhat. This improvement is desirable because of the increase in energy. Because of the increased energy, momentum measurements are more difficult with SPEAR II, and therefore we shall undertake to build an additional track chamber inside the existing chambers to increase the sagitta of the tracks and to improve identification of K_s and Λ decays. We are presently in the testing stage for some additional spark chambers not described in the SP1 proposal. These so-called "endcap" chambers extend the solid-angle coverage of the detector to 95% of 4π. Various changes have been made and are being planned for improvements to the SPEAR vacuum system to decrease the background rates.

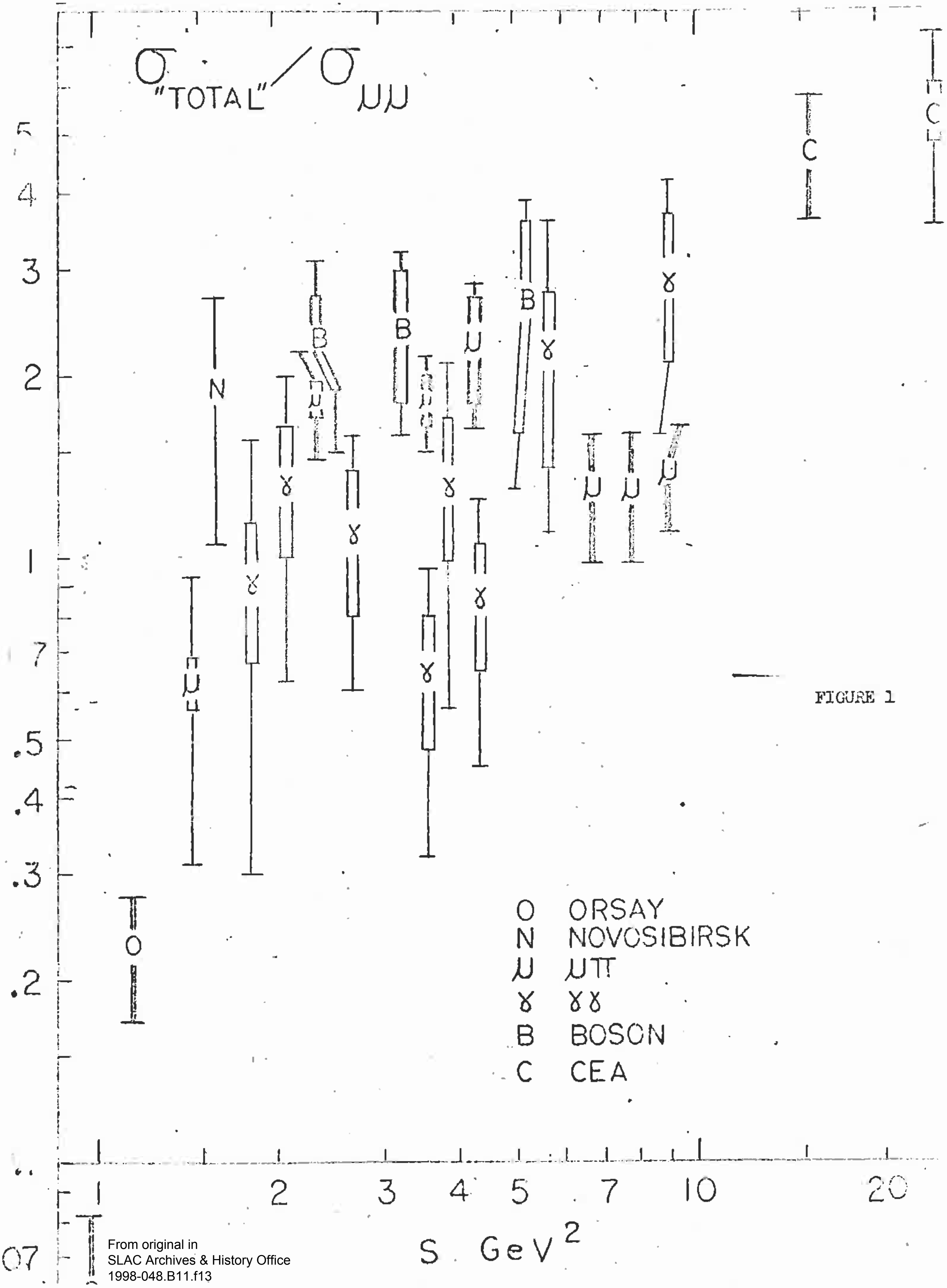

FIGURE 1

From original in
SLAC Archives & History Office
1998-048.B11.f13

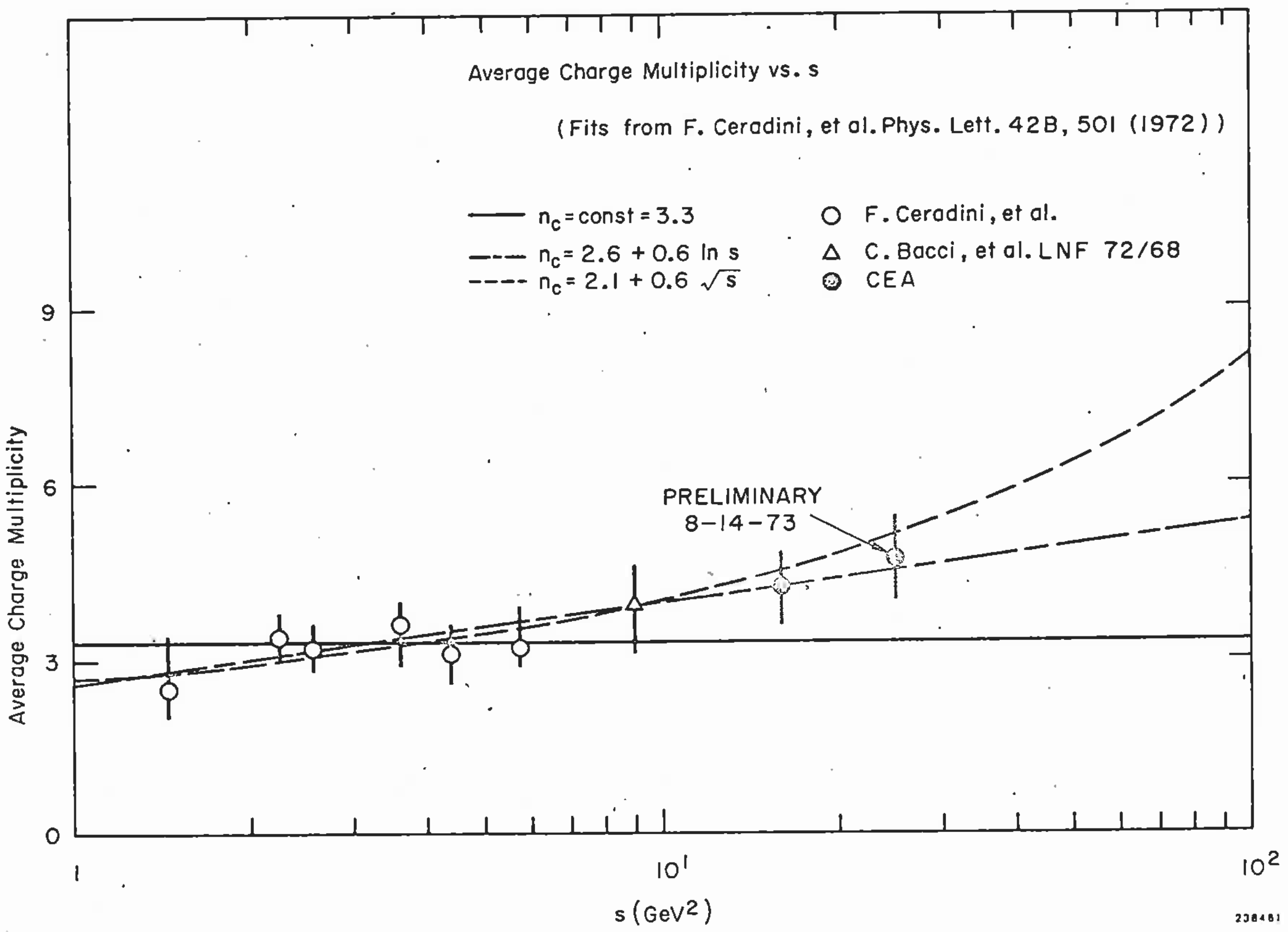
Average Charge Multiplicity vs. s
(Fits from F. Ceradini, et al. Phys. Lett. 42B, 501 (1972))
n_c = const = 3.3
n_c = 2.6 + 0.6 ln s
n_c = 2.1 + 0.6 $\sqrt{s}$
○ F. Ceradini, et al.
△ C. Bacci, et al. LNF 72/68
◎ CEA
PRELIMINARY
8-14-73
Average Charge Multiplicity
9
6
3
0
1
10^1
10^2
s (GeV^2)
238461

FIGURE 2

REFERENCES

1. Thomas Appelquist and Howard Georgi, Harvard preprint, June 1973.
2. R. Gatto and G. Preparata, Frascati preprint, July 1973.
3. F. M. Renard, Nucl. Phys. B50, 44 (1972).
4. Michael S. Chanowitz and Sidney D. Drell, Phys. Rev. Letters 30, 807 (1973).
5. J. D. Bjorken and J. Kogut, SLAC-PUB-1213.
6. A. I. Sanda, SLAC-PUB-1279.
7. J. D. Bjorken and S. Brodsky, Phys. Rev. D1, 1416 (1970).
8. C. Buchanan *et al.*, submitted to Berkeley APS Meeting, August 1973.
9. C. Bacci *et al.*, Phys. Letters 44B, 531 (1973).
10. G. Hanson *et al.*, Lett. al Nuovo Cimento 7, 587 (1973).
11. B. C. Barish *et al.*, Phys. Rev. Letters 31, 410 (1973). A lower limit of 5 GeV was given by D. Buchholz at the Berkeley APS Meeting, August 1973.
12. M. Bernardini *et al.*, preprint submitted to 6th International Symposium on Electron and Photon Physics at Bonn, 1973.
13. R. F. Schwitters, SPEAR Report.
14. A. A. Sokolov and I. M. Ternov, Soviet Physics Doklady 8, 1203 (1964).

FIGURE CAPTIONS

1. Existing data on σ_{tot} ($e^+e^- \to$ hadrons) as a function of s

2 Average charged multiplicity as a function of s