FERMILAB-CONF-86-172-E
LBL-21670

# A SEARCH FOR STABLE QUARKS PRODUCED BY THE TEVATRON

H.S. Matis,* R.W. Bland,† A.A. Hahn,‡ C.L. Hodges,†
M.A. Lindgren,† H.G. Pugh,* M.L. Savage,† G.L. Shaw‡
R. Slansky,§ A.B. Steiner,† and R. Tokarek**

---

This work was supported by in part the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098 and DE 81AC40009.

*Nuclear Science Division, Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720

†Physics and Astronomy Department, San Francisco State University, San Francisco, CA 94132

‡Physics Department, University of California at Irvine, Irvine, CA 92717

§Los Alamos National Laboratory, Los Alamos, NM 87545

**Fermi National Accelerator Laboratory, Batavia, IL 60510

LBL-21670

# A SEARCH FOR STABLE QUARKS PRODUCED BY THE TEVATRON

H.S. Matis,* R.W. Bland,† A.A. Hahn,‡ C.L. Hodges,†
M.A. Lindgren,† H.G. Pugh,* M.L. Savage,† G.L. Shaw‡
R. Slansky,§ A.B. Steiner,† and R. Tokarek**

An experiment has been run at the Tevatron to search for stable fractionally charged particles (i. e. quarks) produced by the 800 GeV/c proton beam. The experiment was performed in two phases. In the first run, 1.0 x $10^{*15}$ protons passed through a series of four mercury targets which were distributed among several lead degraders. The lead degraders were arranged so that fractionally charged particles over a wide range of production angles, masses, and energies would stop in the mercury targets. A small amount of this mercury has been analyzed for fractional charge in an automated Millikan apparatus.

A second run, which had an integrated proton intensity of 4.1 x $10^{13}$, used liquid nitrogen tanks to stop any fractionally charged particles produced when the proton beam interacted in an upstream lead target. In the four tanks, electrically charged gold-plated glass fibers attracted and then trapped any fractional charges which were stopped in the liquid nitrogen. After the exposure, the wires were moved through small beads of mercury in which the gold was dissolved. One of these small beads of mercury also has been analyzed in the same Millikan apparatus.

The results from the first run show that the upper limit for quark production is less than 1 x $10^{-6}$ quarks per proton interaction at 90% confidence limit, the results from the second run show that the upper limit is 9.3 x $10^{-10}$. As the analysis of the mercury is continuing, new results will be available soon.

---

This work was supported in part by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098 and DE 81AC40009.

*Nuclear Science Division, Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720

†Physics and Astronomy Department, San Francisco State University, San Francisco, CA 94132

‡Physics Department, University of California at Irvine, Irvine, CA 92717

§Los Alamos National Laboratory, Los Alamos, NM 87545

**Fermi National Accelerator Laboratory, Batavia, IL 60510

Since the discovery of quantized electric charge by Millikan in 1909, no accelerator experiment has claimed detection of fractional charge(1-2). While there is one experimental group(3) which claims measurement of fractional charge in niobium, there are many other bulk matter(2,4) searches with similar sensitivity and cosmic ray experiments which only have measured integer charged particles.

After Gell-man and Zweig(5) proposed that quarks are the fundamental building blocks of hadrons, it was assumed the measurement of a fractionally charged quark would be necessary to prove their theory. However, with the development of Quantum Chromodynamics (QCD), theorists have postulated the color is an unbroken local gauge symmetry. Thus, quarks are confined and consequently, only integer charged particles can be found in nature. However, there is no proof of confinement in QCD. There exist several models(6,7) which postulate that color symmetry is broken and therefore, free fractionally charged particles could be found.

The signature of a quark produced at an accelerator is very different from that of a typical hadron. De Rujula et al.(6) argued that after a quark is produced it would capture nucleons as it passes through a detector. Therefore, its signature would be a particle with varying electric charge to mass ratio. Such characteristics are very difficult to detect with conventional detectors so many previous experiments would have missed such a signature. In addition, they argued that refined material, which has been used in many bulk matter experiments, might have been depleted of its quark content(8).

As Fermilab recently entered a new fixed target energy regime with its 800 GeV/c Tevatron program, we decided to perform a quark search experiment using a method that has been used in a previous accelerator experiment(4) and that has also been used in several bulk matter searches(2). This paper reports on a preliminary analysis of that experiment.

In order to avoid problems that previous quark search experiments have had, we have used bulk matter to capture any produced quark from the Tevatron beam. Since quarks are stable because of charge conservation, the analysis of the stopping material can be done later in a laboratory. A nuclear target, which maximizes the quark density that can be achieved, was used because in some models(7) free fractional charges are produced only when conditions similar to production of the quark-gluon plasma occur. In addition, the target material was designed to be examined because quarks can be detected even if they were absorbed shortly after production.

In the first run, four steel cylinders filled with mercury were centered in a primary proton beam line which ran at 800 GeV/c. Each cylinder contained about 1.5 liters of mercury. In order to sample different depths of the hadronic shower, 10 cm of lead were interspersed between the mercury targets to slow any produced quarks. A sample of mercury was extracted from the second tank and processed in the San Francisco State Millikan apparatus which measures the residual charge of the drop.

The Millikan apparatus(4), shown in Fig. 1, consists of a electrically biased mercury dropper which produces small drops of mercury which fall between two electrically charged plates. The polarity of the electric field is switched two times while the drop passes through the plate. Measurements are made of the time that the drops passes the slits. Using these measurements, calculation of the terminal velocity and thus the net charge can be made. Consistency checks which include charge changing during the measurement, drop radius and multiple drops are made for each measurement of charge.

Fig. 2 shows a fitted velocity curve that was measured from a typical drop. The velocity is fitted in the three different regions shown on that curve. The curve shows the difference between the fitted and the measured velocity. In the first region, the drop falls and reaches terminal velocity. The first arrow shows when the sign of the electric field is reversed. After a short time, the drop again reaches its terminal velocity. At the second arrow the field is once again reversed. After passing a few more slits, it reaches its terminal velocity. For this particular drop the measured charge was 19e where e is the electric charge of an electron, its radius was 3.86 microns, and its velocity in the three regions were respectively 18.35, 29.84, and 18.30 mm/s. The net charge resolution for the apparatus was measured to be about 0.02e.

From the mercury tested for the first run, a total of 9200 drops (23.8 micrograms) passed all tests. The measured electric charge for all events is consistent with all drops only consisting of integer charged particles. Consequently, an upper limit at 90% confidence level for quark production can be set at 1 x $10^{-6}$ quarks per incident proton interaction.

In order to analyze the rest of the mercury from that run, a distillation apparatus is necessary. Since a quarked mercury atom is attracted to its neighbors by its image charge(8), these atoms will not evaporate when the mercury is heated. When the mercury is gently heated, the residue should contain the quarked atoms. A distillation factor of 3.9 x $10^{5}$ has already been achieved. Using this process, an improved sensitivity of a factor of at least $10^{5}$ can be done. Distillation of the irradiated mercury is underway and results will be available soon.

A second technique was used in the second run of this experiment in the PW5 beam line at Fermilab. In this run, the 800 GeV/c proton beam struck a 10 cm thick lead target. The scattered fragments were stopped in four liquid nitrogen tanks. A quark, produced in the interaction, could stop in one of the tanks. Once it stopped, then it would be attracted to one of two electrically charged gold plated glass fibers which were in each tank. After the exposure, the gold was carefully dissolved in a small bead of mercury. As the radioactivity of the bead was sufficiently higher than the surrounding material, the ability to attract charged particles was demonstrated. Folding in the field configuration, the efficiency of this process to capture charged particles can be estimated to be about 50%.

One half of a bead of mercury, which was taken from the first two positively charged wires, was dissolved in triple distilled mercury. The dilution was done to facilitate the transfer to the quark measuring apparatus. So far, approximately, 145 micrograms of material have been processed from the total drop of 11.1 milligrams. The charge on all the 43,672 measured drops is consistent with the drops containing only integer charges. Using the flux for 4.1 x $10^{13}$ protons and the assumed stopping efficiency in the first two liquid nitrogen tanks of 0.02, the upper limit for quark production is 9.3 x $10^{-10}$ quarks per proton interaction at the 90% confidence level.

The other beads of dissolved gold will also will be processed in the next few months. Using the combined results from these two data sets will enable a significant increase in the upper limit for quark production or else may even produce a positive signal for fractional charge.

A similar experiment will be run during the heavy ion program at CERN(9) and at the AGS(10) by our collaboration. Both experiments are scheduled to run within the next year. These experiments will be able to detect quarks if they are produced by the creation of a quark-gluon plasma at either machine at a level of about $10^{-10}$ quarks per nucleus interaction.

In summary upper limits using two different methods of trapping fractional charge have been found. Analyzing an irradiated target of mercury yields a limit of $1 \times 10^{-6}$ quarks per proton interaction at 90% confidence limit; while a method using electrostatic attraction of quarks to a gold plated wire results in an upper limit of $9.3 \times 10^{-10}$.

Many people have contributed to the performance of this experiment and we would like to thank them. We especially would like to thank the operations crew at Fermilab who provided very valuable support. In addition, we would like to thank J. Haley from LBL for advice on the distillation process and J. Bucher from LBL for his helpful comments and for use of his laboratory. This work was supported in part by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098 and DE 81AC40009.

## References

1) M. Banner et al., Phys. Lett. **156B**, 129 (1985).

2) L. Lyons, Phys. Rept. **129**, 225 (1985).

3) G. LaRue, J. D. Phillips and W. D. Fairbank, Phys. Rev. Lett. **46**, 967 (1981).

4) M. L. Savage et al., Phys. Lett. **167B**, 481 (1986).

5) M. Gell-man, Phys. Lett. **8**, 214 (1964); G. Zweig, CERN Rep. TH-401 (1964); CERN Rep. TH-412 (1964).

6) A. De Rujula, R. C. Giles and R. L. Jaffe, Phys. Rev. **D17**, 285 (1978).

7) R. Slansky, T. Goldman and G. L. Shaw, Phys. Rev. Lett. **47**, 887 (1981); G. L. Shaw and R. Slansky, Phys. Rev. Lett. **50**, 1967 (1983).

8) G. Zweig, Science **201**, 973 (1978).

9) CERN proposal NA39, G. Shaw spokesman (1986).

10) BNL AGS proposal 801, R. Bland spokesman (1985).

Figure Captions

Fig. 1. This figure shows a schematic of the Millikan apparatus. In the upper left corner is the mercury dropper. When the dropper is pulsed, a small drop of mercury falls between the two charged plates. The image of the falling drop is projected on a grid. The intensity of the light signal is detected by a photomultiplier and recorded by a computer on magnetic tape.

Fig. 2. The measured velocity minus the fitted velocity is shown for a typical drop. The arrows indicate the location of the drop when the field was reversed. The fitted velocity was fitted independently in each of the three regions.

Fig. 3. This figure shows a histogram of residual charge for drops which passed all acceptance tests. The two arrows show the expected position for residual charge for any drop which contains a net fractional charge.

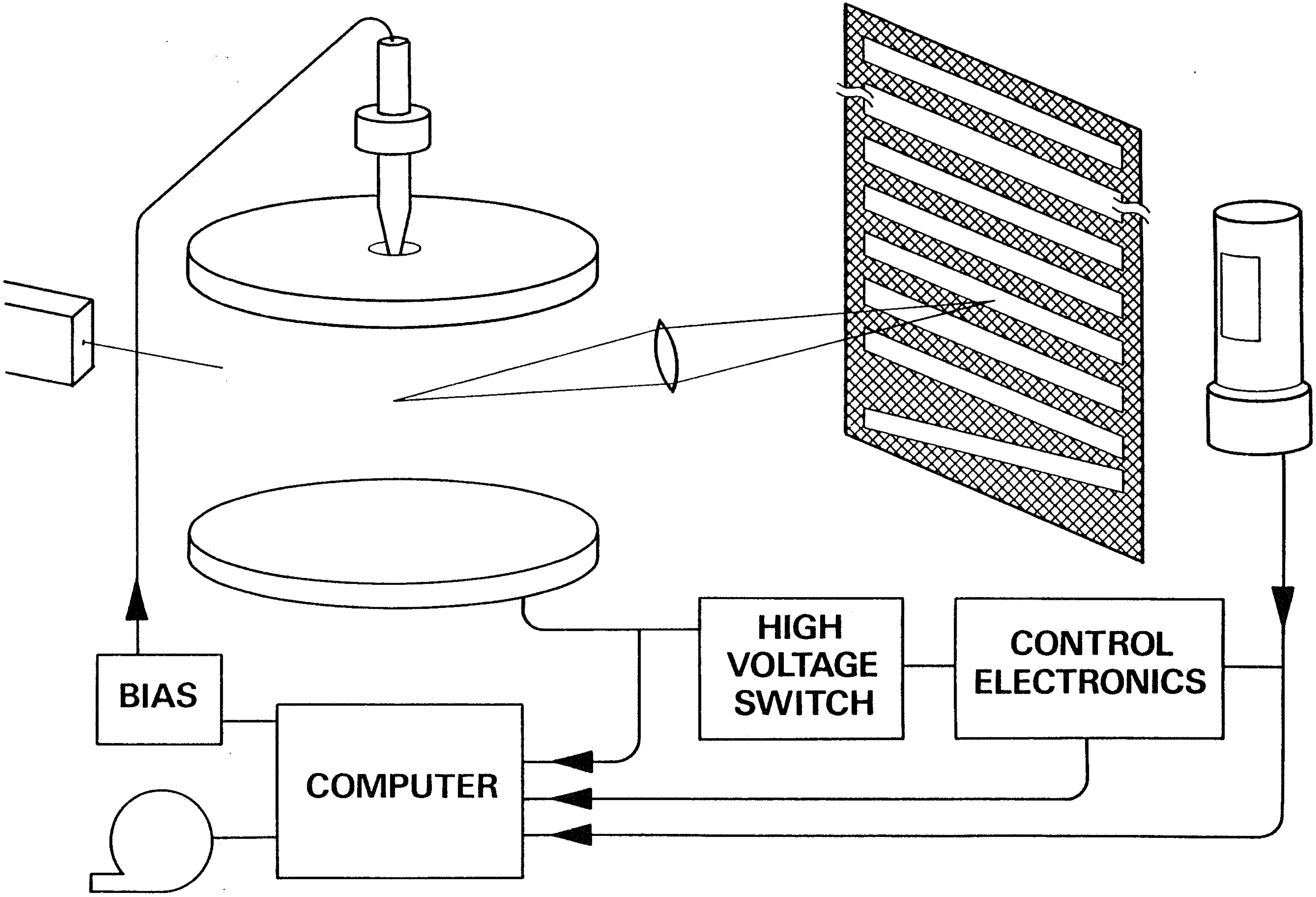


Figure 1

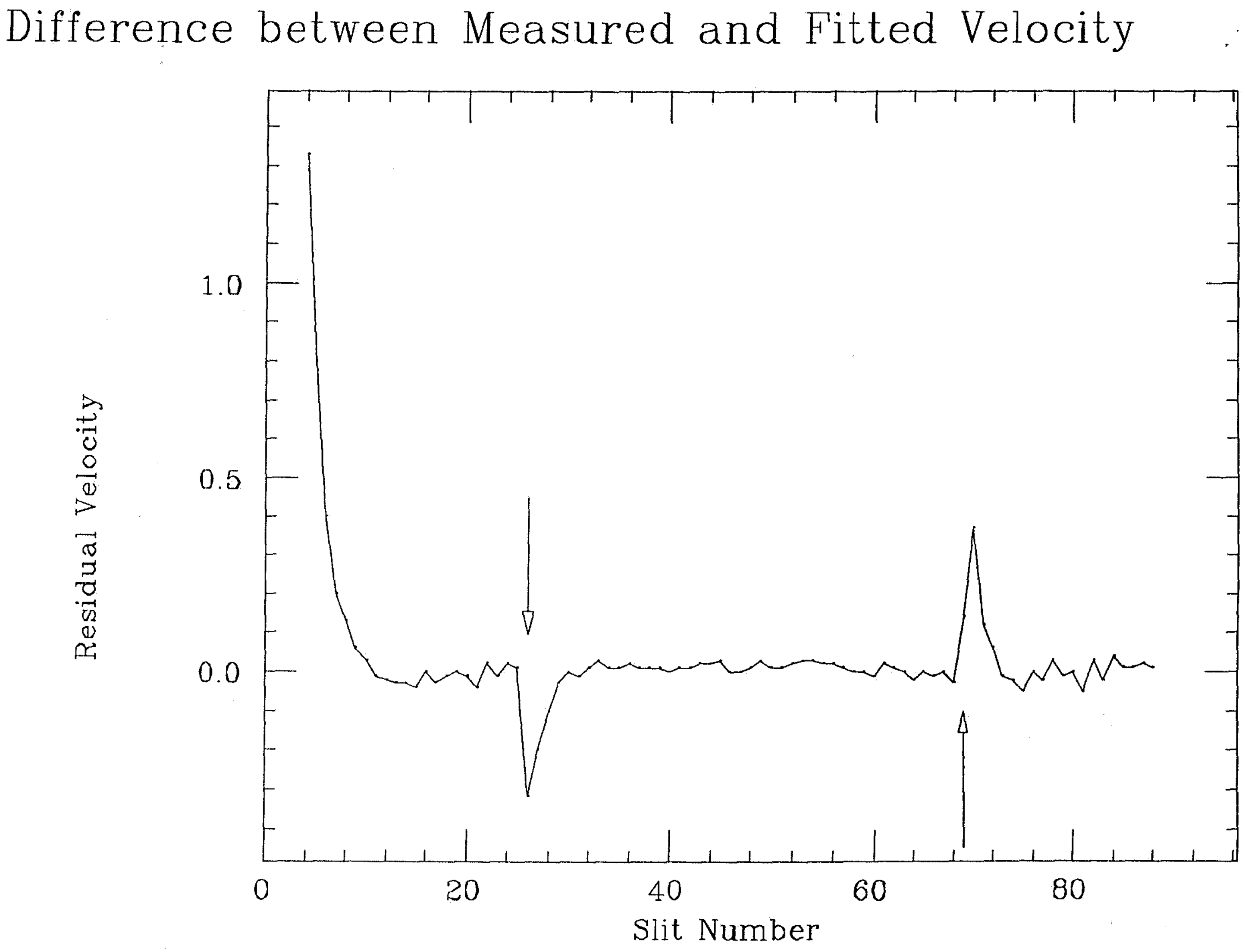
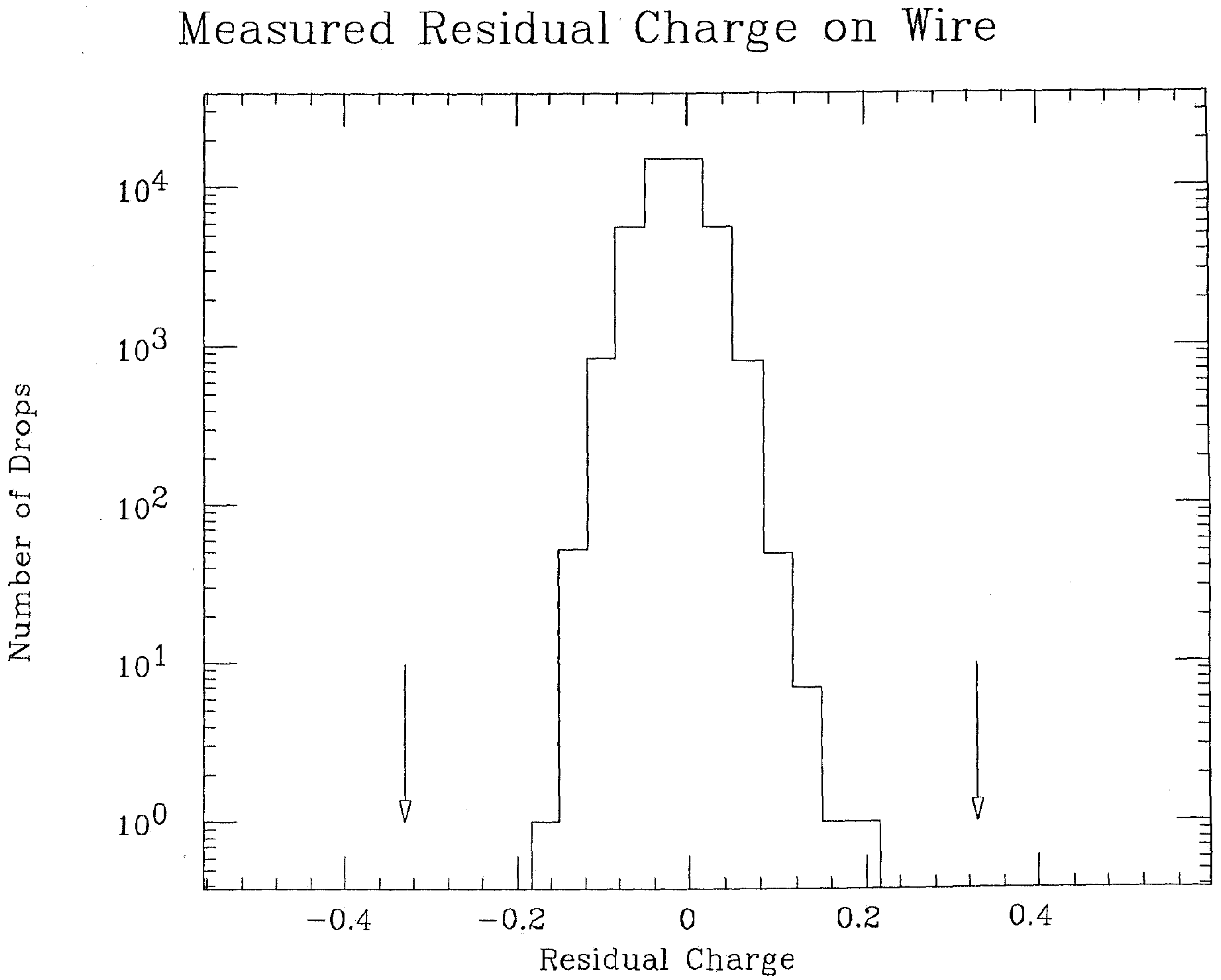

Difference between Measured and Fitted Velocity
Residual Velocity
1.0
0.5
0.0
0
20
40
60
80
Slit Number

Figure 2



Measured Residual Charge on Wire
Number of Drops
$10^4$
$10^3$
$10^2$
$10^1$
$10^0$
−0.4
−0.2
0
0.2
0.4
Residual Charge

Figure 3