Fermi National Accelerator Laboratory

FERMILAB-Conf-93/215

High Counting Rate Resistive-Plate Chamber

D.F. Anderson, S. Kwan and V. Peskov

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

September 1993

Presented at the *Third London Conference on Position-Sensitive Detectors*,
Brunel University, London, England, September 6-10, 1993

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

FERMILAB-Conf 93/215
August 1993

High Counting Rate Resistive-Plate Chamber

D.F. Anderson, S. Kwan, and V. Peskov
Particle Detector Group
Fermi National Accelerator Laboratory
Batavia, IL 60510, USA

Presented at the Third London Conference on Position-Sensitive Detectors
6-10 September 1993, Brunel University, London
To be published in Nuclear Instruments and Methods

Abstract

Resistive-glass, parallel-plate chambers are studied in both spark and avalanche modes. In the avalanche mode rates of over $10^3 s^{-1} cm^{-2}$ are achievable with a total collected charges per pulse of 10^8 electrons. Operated at low pressure and with secondary-electron emission from a porous CsI surface, a timing resolution of 600 ps has been measured. Future improvements are discussed.

1 Introduction

Parallel-plate avalanche chambers are widely used in physics experiments. They are fast (≈1 ns) and are of simple construction: just two parallel metallic plates or mesh electrodes (see ref. [1] as an example). Depending on the applied voltage, they may work either in spark mode or avalanche mode [2]. The advantage of the spark mode of operation is that there is a large signal amplitude from the chamber. The disadvantage is that there is a large dead time (≈ msec) for the entire chamber after an event. The advantage of the avalanche mode is a high rate capability of $>10^5$ $s^{-1}mm^{-2}$ [3].

A resistive-plate chamber (RPC) is similar to the parallel-plate avalanche chambers in construction with the exception that one, or both, of the electrodes are made from high resistivity ($\geq 10^{10}$ Ω•cm) materials. In practice RPCs are usually used in the spark mode. Because of the high resistivity of the electrodes they are only locally charged by the sparks, reducing the electric field over a small local area, of the order of 10 mm^2, leaving the rest of the detector unaffected. Therefore, the rate capability of such detectors in the spark mode is considerably higher than conventional spark counters. In early designs of RPCs [4, 5] the electrodes were made from resistive-glasses. Among the different glasses tested the best results were obtained with electron-type conductive glasses [6] which obey Ohm's law. Most of the work with such glasses was done with high-pressure, parallel-plate chambers (10 atm) for time-of-flight measurements [6, 7].

One of the drawbacks of resistive glasses was that they were expensive and produced only in small quantities. Thus their application scale has been very limited. This is why recent RPCs used phenolic (Bakelite) and other polymers rather than resistive glasses [8]. Unfortunately these materials do not obey Ohm's law, and the resistivity depends on the applied voltage and time. Nevertheless, at low counting rate (<100 $s^{-1}cm^{-2}$) they are quite stable. At present, the main application of such chambers is muon detection.

Since the earlier days of the RPC, a lot of changes have occurred. Now resistive glasses are commercially available [7], although they are still expensive on a small scale production and used primarily for gas microstrip detectors [9]. In our first work[10] we obtained a 90% efficiency for charged particles at a rate of about 150 $s^{-1}cm^{-2}$ in the spark mode and at a rate of about $10^3 s^{-1}cm^{-2}$ in the avalanche mode. The chamber consisted of an aluminum plate and a plate of resistive glass.

At the same time, Bencivenni et al. [11] independently did a study of RPCs using two resistive glass plates. They measured a 90% efficiency at about 150 $s^{-1}cm^{-2}$ in the spark mode. They also measured a timing resolution of 0.8 ns RMS in the spark mode.

In the work presented here we have investigated resistive-glass RPC in the avalanche mode. This has several advantages: much high-rate capability, low voltage operation, and the ability to work with non-flammable gases. In order to improve the time resolution of the resistive glass RPC, we also investigated the possibility to use secondary-electron emission from a cathode covered by a thick, porous layer of CsI.

2 Experimental Setup

The experimental setup used is shown schematically in fig. 1. In general it consists of an RPC, gas system, well collimated beta source, a thin trigger scintillator with PMT, and associated electronics. Although a variety of gaps between plates were used, most of the measurements presented here were made with a 1.6 mm gap. Signals from the chambers in the spark mode were observed directly on the oscilloscope (50 Ω).

For the timing resolution measurements beta particles from a ^{90}Sr source were used. The signal from the trigger scintillator was used as the "start" and the signal from the chamber as the "stop" for the time-to-amplitude converter.

In order to improve the time resolution we also investigated secondary-electron emission from a thick, porous CsI layer. In these measurements the metallic cathode of the resistive-glass RPC was covered by a layer of the CsI. Different technique was used to produce the porous CsI coating: evaporation onto the surface in a few Torr of Ar [12] and sprayed on in air from a solution of the CsI in water and alcohol[13]. Both techniques gave similar results.

3 Results

Many gas mixtures were tried, mostly at 1 atm or below [10]. It was found that in the avalanche mode any good proportional counter mixture would work. In the spark mode, mixtures containing the electronegative gas freon gave the most stable operation, though mixtures without freon gave adequate performance. Two techniques to produce the initial ionization were studied. The first was direct ionization of the gas. The second was secondary-electron emission from a porous CsI surface combined with the low-pressure avalanche mode.

3.1 Gas-ionization spark mode

The advantage of operating an RPC in the spark mode is that the signal is fast and able to be processed without a preamplifier. Fig. 2 shows a typical oscilloscope trace (directly on 50 Ω) for an RPC with a 1.6 mm gap filled with 1 atm of argon-10%

isobutane. The rise time of the signal is about 8 ns and the fall time is on the order of 100 ns. Typical pulse heights are over 1 V.

In most cases this spark pulse is preceded by a precursor pulse, as shown in fig. 3. The interval between the precursor and the spark fluctuates rather strongly (on the order of a few ns), with the precursor giving a better measure of the time of passage of the particle. Thus for optimum timing resolution this precursor should be used. Although we have not measured the timing resolution of the RPC in the spark mode, Bencivenni et al. obtained a resolution of 0.8 ns (rms).

We did measure the detection efficiency as a function of rate for the RPC in the spark mode. The results are shown in fig. 4. The efficiency is 90% at a rate of about 150 $s^{-1}cm^{-2}$, which agrees nicely with those of Bencivenni et al. Fig. 4 also show our best results from an RPC with the resistive glass replaced by a phenolic electrode as well as the results of two other references [14, 15]. The advantages of using resistive glass rather than phenolic is apparent.

3.2 Gas-ionization avalanche mode

The advantages of an RPC operated in the avalanche mode are that there is a much higher rate capability and, although we worked mostly with flammable mixtures, non-flammable gas mixtures can be used. Fig. 5 shows a typical shaped pules from an avalanche in an RPC. Like in the spark mode, the rise time is on the order of 8 ns. As before, the gas filling is 1 atm of argon-10% isobutane. The timing resolution was 1.7 ns (rms) which is consistent with the results reported by others [16].

The detection efficiency for minimum ionizing particle for a resistive-glass RPC is shown in fig. 6 for two different values of total collected charge. At a collected charge of 10^8 electrons the efficiency is about 90% at a rate of $10^3 s^{-1}cm^{-2}$. This is a rate almost ten times higher than when the chamber is operated in the spark mode. At a rate of $4x10^3 s^{-1}cm^{-2}$ the efficiency is still about 80%. At small gains ($<10^5$) rates of up to 10^5 $/s/mm^2$ were achieved for a well collimated beam. Unfortunately, in this measurement we were not able to determine the rate capability with a large area irradiated. It has been shown by Crotty et al. [15] that when a large area is irradiated the limiting rate per unit area is smaller.

3.4 Secondary-electron emission

For a RPC operated in the gas-ionization mode the electrons created in different part of its volume are subjected to different gas multiplication as well as having a different transit time across the chamber. This causes a degradation of the timing resolution. With secondary-electron emission, combined with low pressure, the electrons originate at the surface which reduces the spread in the signal development time. Operating with low gas pressure also improves the resolution and decreases the degradation of the timing due to interaction of the particle with the gas.

It is known that some emitters, like porous CsI, can give 3-5 electrons per passing charge particle [12, 17]. We have also found that we can achieve a similar efficiency for a thick CsI photocathode produced by our liquid spray technique [13]. A parallel-plate avalanche chamber was constructed with two aluminum electrodes with a 2 mm gap. One electrode had a thick, sprayed-on CsI layer on it. The gas filling was typically 10 Torr of isobutane. Beta particles entered the chamber through the plate with the CsI. With the chamber biased such that the CsI was the cathode, secondary electrons from the CsI were detected. With the bias reversed, the bare aluminum plate becomes the secondary-electrons emitter. Fig. 7 shows the pulse-height spectrum of this chamber with the CsI and with the aluminum as the cathode. The two curves have the same number of triggers. The efficiency was estimated to be 80-85% implying an average of about 2 secondary electrons per beta particle.

Similar results were obtained with a resistive-glass RPC with a sprayed-on CsI layer on the aluminum plate. The count rate for the signal from the CsI layer with a gas filling of 20 Torr of isobutane was compared with the chamber with the CsI removed and filled with 1 atm of argon-10% isobutane. The efficiency was approximately 85% for the secondary-electron emission and the pulse-height spectra were very similar to those of fig. 7.

Operating with the porous CsI layer and a gas filling of 20 Torr of isobutane a timing resolution of 0.9 ns was measured, as can be seen in fig. 8. The timing resolution of the thin trigger counter was measured against a fast, thick scintillator and found to be 0.73 ns. This implies that the resolution of the RPC with secondary-electron emission is on the order of 0.6 ns. If the gas pressure is increased to 40 Torr the timing spectra became skewed to the left because of interaction of the beta particles with the gas. With better electronics and a with a test beam rather than a beta source, we hope to see an improvement on this timing resolution.

The count rate capability of a secondary-electron RPC has not been measured. It should be at least as good as an RPC operated at 1 atm in the avalanche mode.

4 Discussion

The results obtained show that the resistive-glass RPC has a much better rate capability then one with phenolic having ionic conductivity. In the spark mode the pulse amplitude is a factor of two larger than a normal RPC. An important point is that the recovery time is stable and is independent of the applied voltage or the intensity of the initial ionization. The recovery time is just equal to the RC time constant, in good agreement with earlier measurements and calculations of W.B. Atwood [7]. The quality of the glass surface is extremely good so the mechanical tolerance is much better than with phenolic, and no spurious pulses were seen when no spacers were used. The concept of the design of a large parallel-plate avalanche chambers without spacers has been developed by other authors [18].

In the avalanche mode of operation the RPC has an excellent counting rate capability. A total charge of 10^8 electrons per pulse can be achieved with a slight dependence on the gas mixture but with little dependence on the amount of primary charge (see fig. 7 from ref. [2]). For a large initial charge, any RPC goes into spark mode which may be a problem in a hadron environment where there is a substantial flux of neutrons. In the phenolic RPC sparks can interrupt the normal operation for 20-30 min. In the resistive-glass RPC sparks do not strongly affect the normal operation and therefore working in the avalanche mode with the occasional sparks is acceptable, especially if the anode is made from the moderate-size, resistive-glass pads. Operation in this marginal regime (with occasional sparks) is practical with resistive-glass electrodes.

It should be emphasized that the difference between a resistive-glass RPC and an avalanche counter [18] is their sensitivity to occasional sparks. At high rates there is always a statistical probability that two event will overlap in space causing a spark [2]. In an avalanche counter the spark deposits a great deal of energy and affects the entire counter. In a resistive-glass RPC the spark does no damage and only about 10 mm^2 is affected.

In the early work with high-pressure, resistive-glass RPCs for time-of-flight measurements, "Pestov-gas" mixture (Ar, butane, ethylene, plus 1, 3 butadiene) was used [17] which is very quenching and has strong absorption of the photons with wavelength less than 220 nm. This gas mixture is essential for operation in the spark mode because the propagation of the discharge give a long recovery time. A highly quenching gas mixture is much less essential in the case of the resistive-glass RPC operated in the avalanche mode. Almost any good proportional-counter gas, including non-flammable mixtures, will work well.

At the SSC/LHC hadron colliders, RPCs can be used to provide the fast trigger necessary to identify the beam bunch crossing associated with a particular physics event as well as the muon momentum trigger for identifying muons of sufficient momentum. There are several requirements of the RPC to be useful in a muon system in a high rate environment. The material must be stable; phenolic becomes damaged and deformed in a high rate environment. The RPC must have a uniform gap; glass is an excellent material that can be made very flat and smooth. The RPC must be able to handle a particle flux of 100 $s^{-1}cm^{-2}$ in the barrel region and up to $10^4 s^{-1}cm^{-2}$ in the forward region. Finally the timing resolution should be better than 5 ns. The resistive-glass RPC fulfills all of these requirements.

Unfortunately the price of the resistive glasses is still higher than phenolic polymers. On the other hand this price is comparable to plastic scintillators (plus the PMT) and this makes it attractive as a trigger for muons. The resistive-glass RPC also has the advantage over scintillators with PMT readout in that they work well in magnetic fields. With little effort a low-pressure RPC with secondary-electron emission can obtain an efficiency of 85% and a timing resolution of about 0.6 ns. With more work and better electronics, it is likely that this could be substantially improved. More research is still needed to demonstrate that resistive-glass RPCs are competitive with phenolic in a large-scale detector.

Acknowledgments

This work was inspired by motivated with Dr. W.B. Atwood (SLAC) who worked with high pressure resistive-glass RPC for time-of-flight measurements. We are indebted to him for his advice and generous gift of materials.

References

1. K. Kleinknecht, Detectors for Particle Radiation (Cambridge University Press, New York, 1985) vol. .
2. P. Fonte, et al., Nucl. Instr. and Meth. A305 (1991) 409.
3. A. Peisert, Nucl. Instr. and Meth. 217 (1983) 409.
4. M. V. Babykin, et al., Sov. J. of Atomic Energy 4 (1956) 487.
5. V. V. Parhomchuk, et al., Nucl. Instr. and Meth. 93 (1971) 269.
6. Y. Pestov, preprint NIP 90-83.
7. W. B. Atwood, preprint SLAC-PUB-2620, 1980.
8. R. Santonico, et al., Nucl. Instr. and Meth. 187 (1981) 377.
9. R. Bouclier, et al., Nucl. Instr. and Meth. A323 (1992) 240.
10. V. Peskov, D. F. Anderson, and S. Kwan, Fermilab TM-1838, 1993.

11. G. Bencivenni, et al., Nucl. Instr. and Methods A332 (1993) 368.

12. G. Charpak, et al., CERN 78-05, 1978.

13. D. F. Anderson, S. Kwan, and V. Peskov, Nucl. Instr. and Meth. A326 (1993) 611.

14. M. Bertino, et al., Nucl. Instr. and Meth. A283 (1989) 645.

15. I. Crotty, et al., Nucl. Instr. and Meth. A329 (1993) 133.

16. O. Gardes, et al., preprint Orsay IPNO-RC-81-05, 1981.

17. W. Braunschweig, Phys. Scripta 23 (1981) 384.

18. Y. Galaktionov, et al., Nucl. Instr. and Meth. A317 (1992) 116.

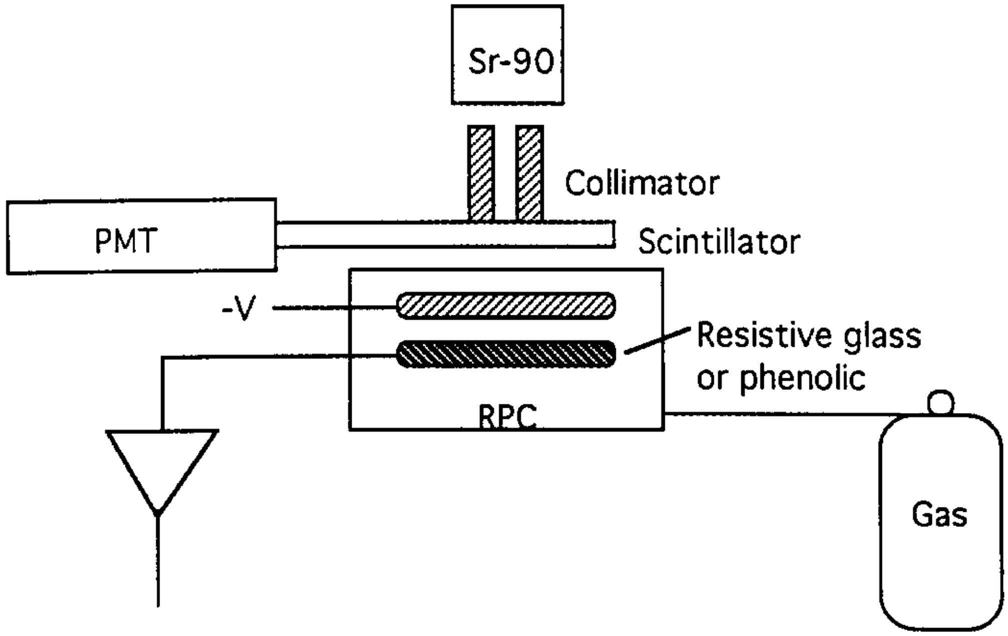

Fig.1 Experimental set-up

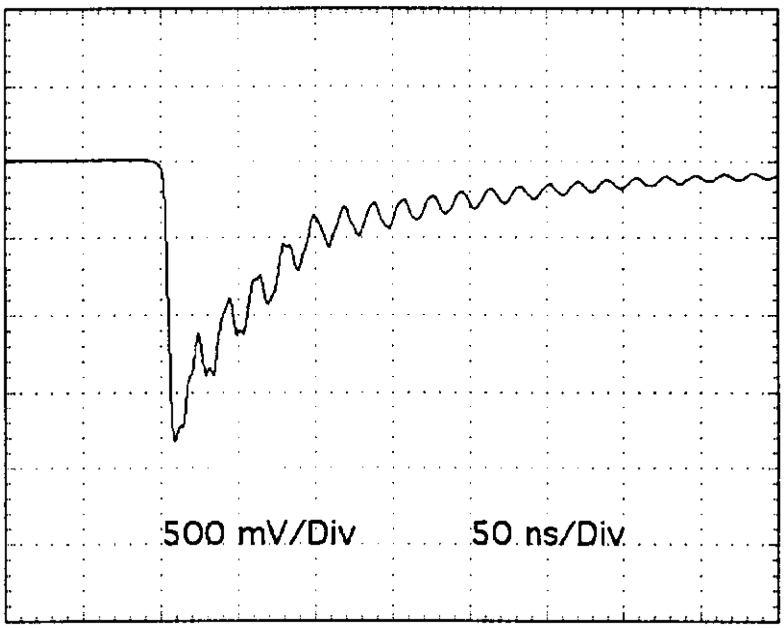

Figure 2 Oscilloscope trace, directly onto 50 Ω, of a resistive-glass RPC operated in the spark mode.

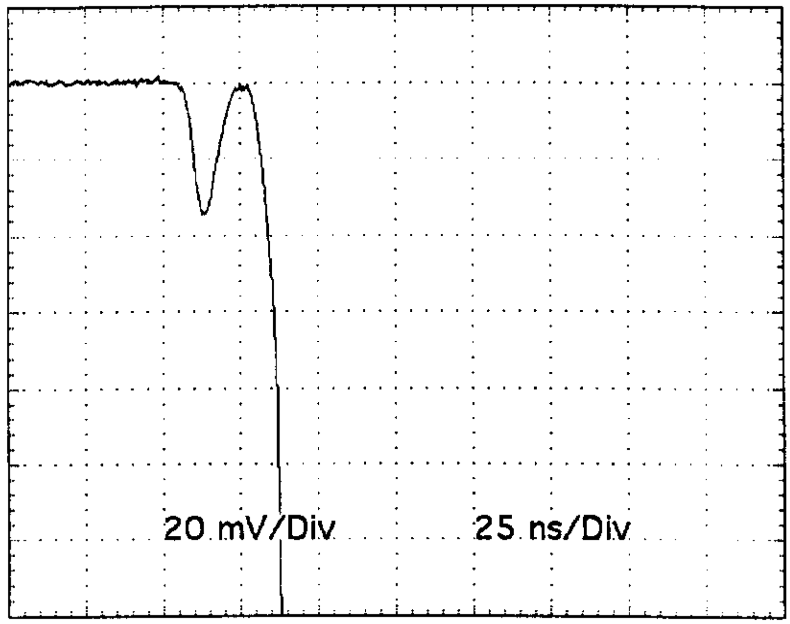

Figure 3 Precursor to the spark pulse.

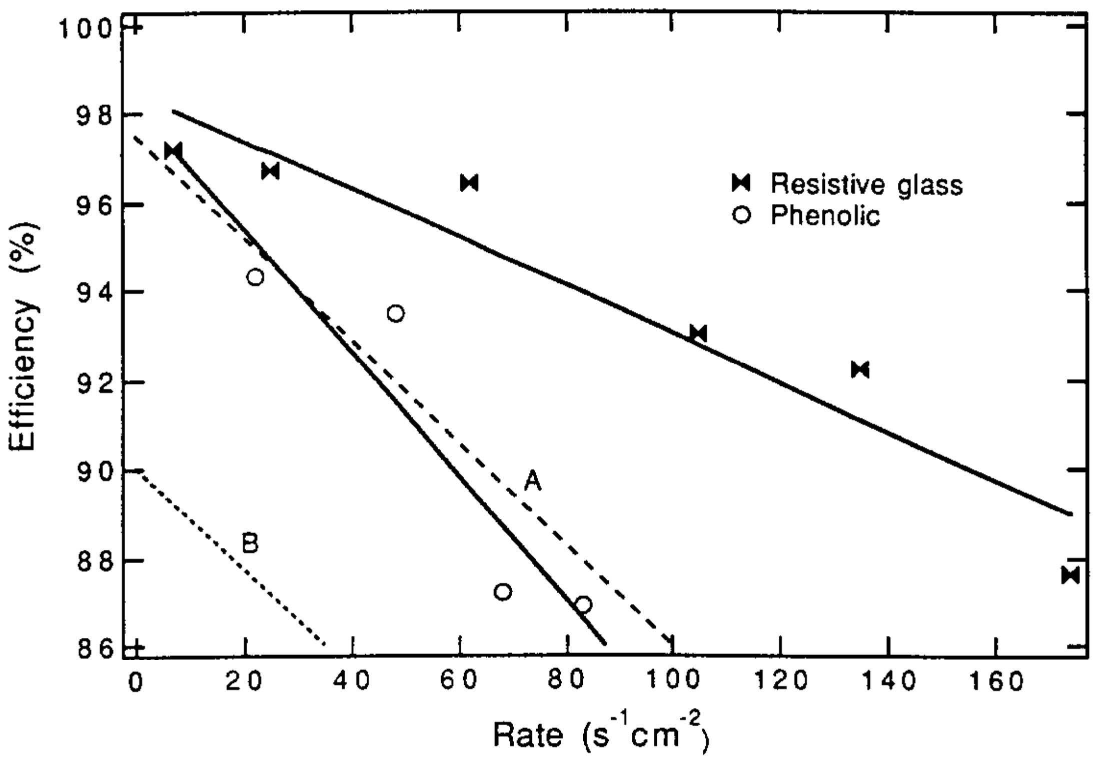

Figure 4 Efficiency as a function of rate of glass and phenolic RPCs operated in the spark mode. For a comparison data from other authors using phenolic are presented: A, ref. [14];B, ref [15].

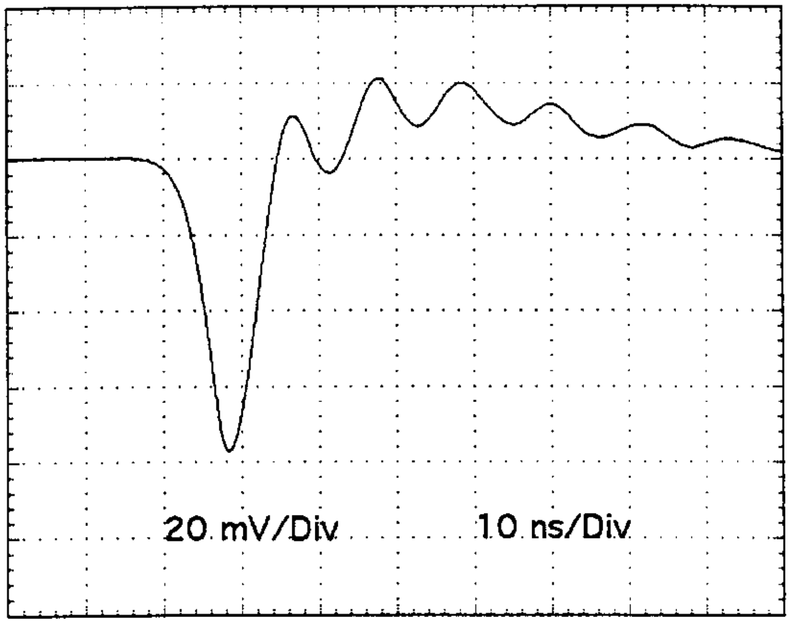

Figure 5 Oscilloscope trace of a resistive-glass RPC operated in the avalanche mode.

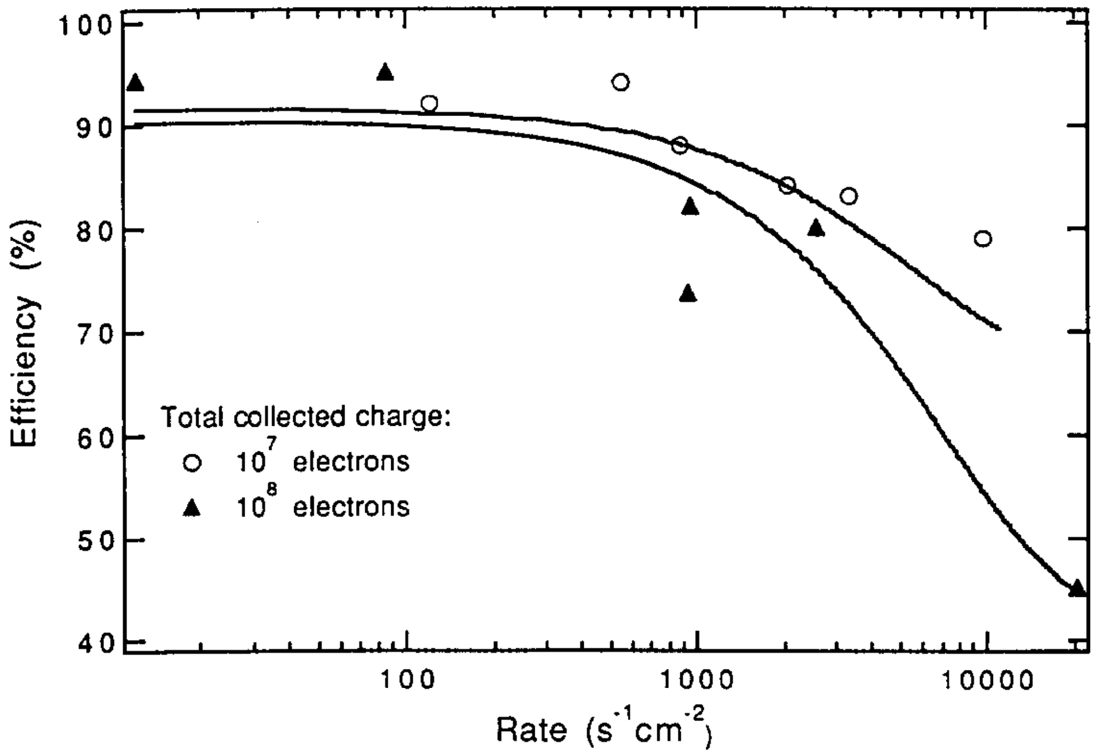

Figure 6 Efficiency as a function of rate of a resistive-glass RPCs operated in the avalanche mode at two values of total collected charge.

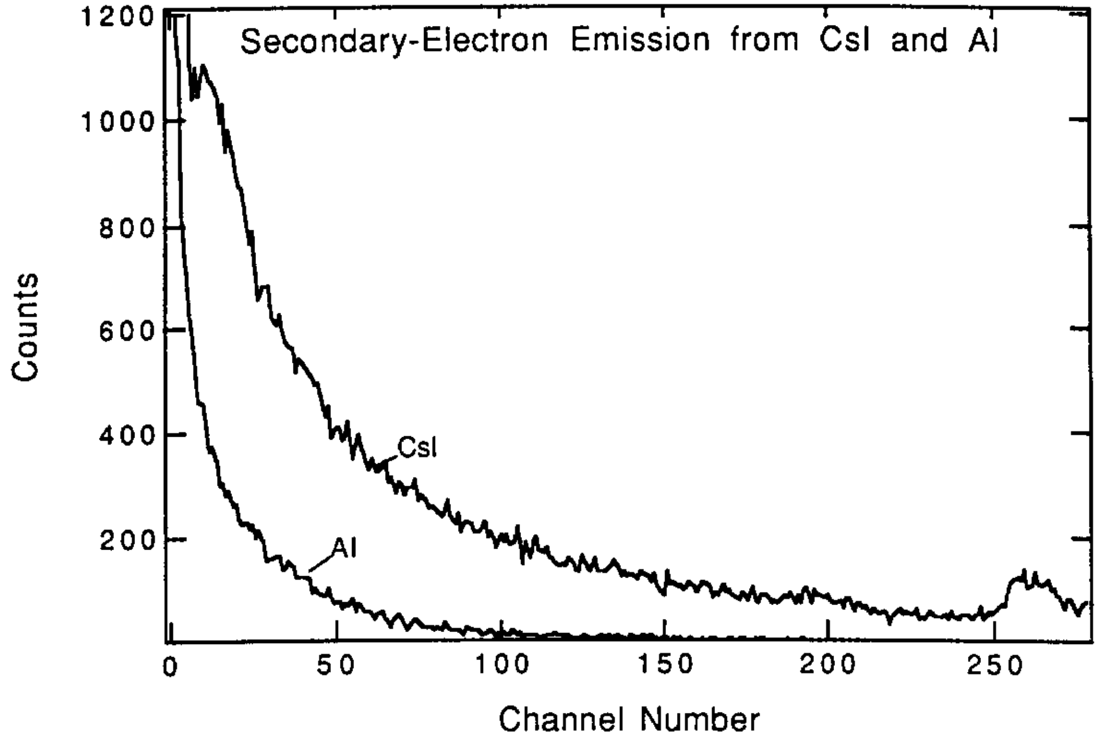

Figure 7 Pulse-height spectrum of secondary-electron from a thick, sprayed-on CsI surface and from an aluminum surface.

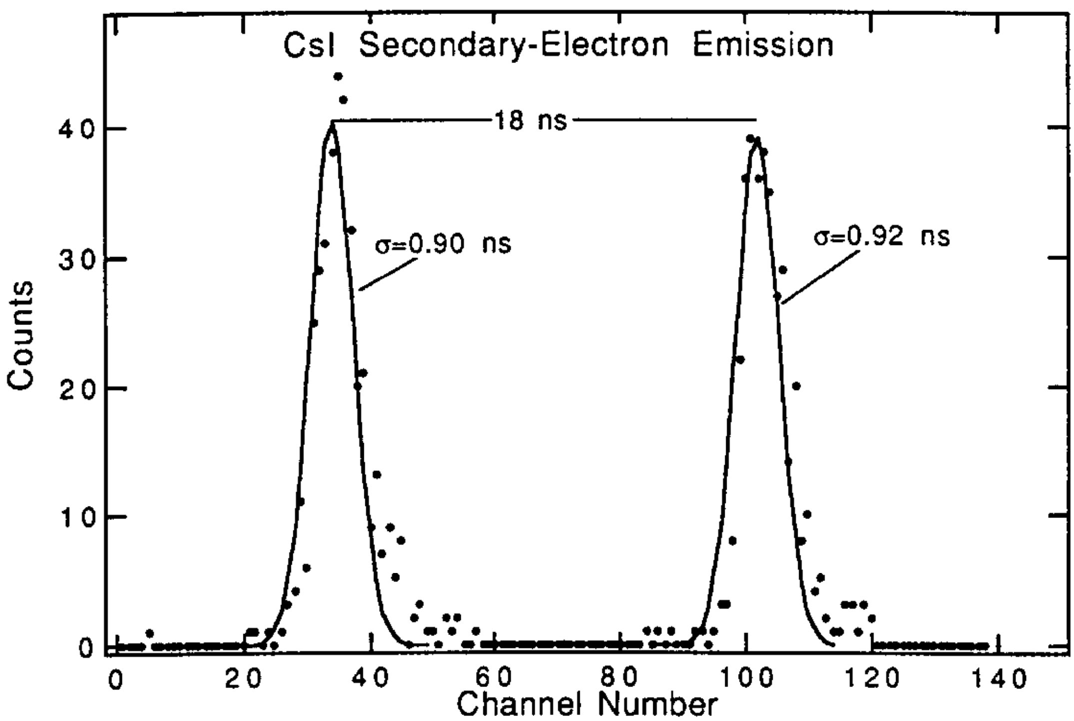

Figure 8 Timing spectra of secondary electrons from a thick, sprayed-on CsI surface in a low pressure resistive-glass RPC.