SLAC-PUB-2412
October 1979
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AN EVALUATION OF DETECTORS FOR A CERENKOV RING-IMAGING CHAMBER*

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Summary

We report results from an ongoing study of single photon detectors for use in a ring-imaging Cerenkov counter. New results on the operation of parallel plate avalanche gaps is presented.

Introduction

Although almost twenty years have passed since its initial proposal,[1] the Cerenkov ring-imaging counter has not yet been developed into a practical detector. Early efforts[2] involved a crystalline radiator and an image intensifier tube and yielded, as reported in 1963, five detected photons per incident particle. The bulk and expense of the image intensifier and the awkwardness of the recording system, made the device impractical for experiments. The attractiveness of the method for particle discrimination in high energy physics experiments, especially in the large four pi detectors recently brought into vogue at colliding beam machines, has renewed efforts in recent years to construct a device with suitable properties.

Requirements of the Device

The requirements of the device are a radiative medium, a mirror or lens which can produce and focus a high flux of Cerenkov light on a photosensitive detector, which is capable of providing positional read-out of a hundred or so simultaneous photons in the focal plane of the mirror or lens. The radiator must have a suitable index of refraction to produce Cerenkov light over the desired momentum range (in our case 1 to 20 GeV/c) and have high transparency for ultra violet light in the region of the photon detector's sensitivity. The photosensitive detector should have good sensitivity at shorter wavelengths, as Cerenkov light yield is proportional to the inverse of the wavelength. Good spatial resolution in the photosensitive detector is required to make accurate radius measurement and to allow separation of rings from neighboring tracks.

Recent efforts[3-6] have involved the use of a gas or crystalline radiators and various kinds of spark or proportional chambers. Single photoelectrons released in a photo-ionizing gas are amplified in the chambers to produce an optical or electronic signal. However, the overall optical and quantum efficiencies have been low and the number of detected photons per incident particle is still below 10.

Ultra Violet Photon Detectors

We are presently reviewing available techniques for detecting, with good efficiency, the photons from Cerenkov light using proportional or spark chamber techniques system. Several recent efforts have used gas radiators for convenience even though the quantum yield is low. The gas radiator is separated from the photo-ionizing gas by a window with suitable UV transmission properties. Figure 1 shows the relation between the useful wavelength band of several Cerenkov radiators, the transmission cutoffs of window materials, and the photo-ionization thresholds for several useful gases. The typical detector in the recent experiments incorporates an argon radiator with LiF or MgF window, and uses benzene or TEA as the photo-ionizing gas in a proportional chamber. The low yield of detected photons in these experiments has led us to look for a radiator with greater yield of Cerenkov photons and a high quantum efficiency position-sensitive detector. Therefore we are designing a liquid helium radiator[7] in order to produce a high flux of UV quanta in the detector. A 50 cm path length of liquid helium yields on the order of 4×10^3 photons in the band 1200 Å to 2200 Å for an incident particle with high gamma. After accounting for optical, geometric, and detector quantum efficiency, we expect to detect 100 or more photons on a circle from a single incident particle. This will provide an ideal laboratory to study the performance of several position sensitive photon detectors.

Our design for a prototype detector is shown schematically in Fig. 2. The cryogenic design will be described at a later date. Figure 3 shows the calculated radius of rings for this geometry from pions, kaons, and protons up to 15 GeV/c. Radius resolution of one millimeter would allow, if the momentum is measured elsewhere, a separation of pions from kaons up to 10 GeV/c. A detector resolution of one millimeter for each of one hundred photons would provide a radius resolution of about 0.1 mm. Low momentum tracks will scatter in the radiator thereby broadening the distribution of points around the average radius in a way related to the particle momentum. The ring width therefore constitutes a rough measure of the particles momentum. Consequently one device could measure both velocity and momentum.

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* Work supported by the Department of Energy under contract number DE-AC03-76SF00515.
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(Presented at the 1979 Nuclear Science Symposium, San Francisco, California, October 17-19, 1979.)

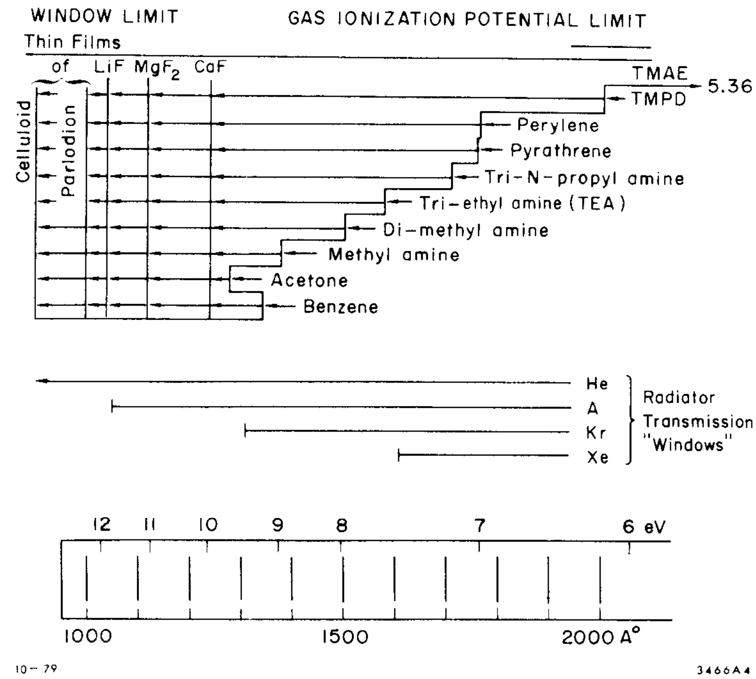

Fig. 1. Relationship between radiators, window materials, and ionization potentials of several useful gases.

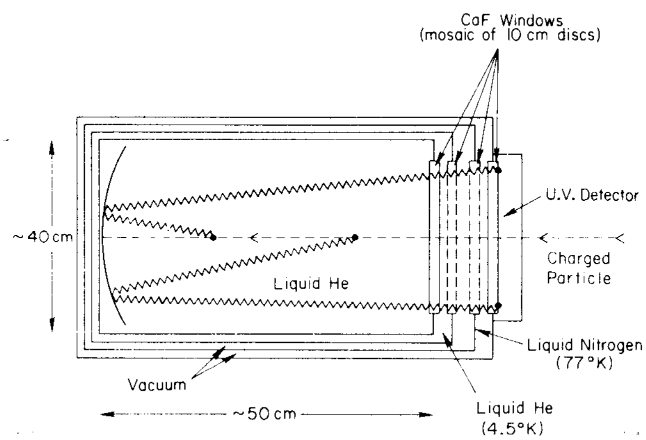

Fig. 2. Schematic of a prototype Cerenkov detector.

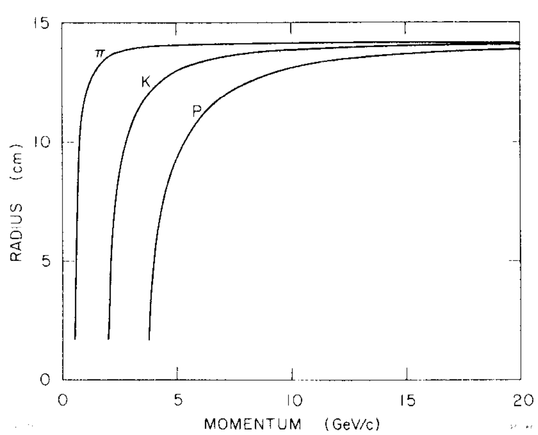

Fig. 3. Radius of the Cerenkov ring at the focal plane for pions, kaons, and protons.

Single Photoelectron Amplification

We have started a systematic study of photoelectron amplification with parallel wire meshes with particular attention paid to electrode geometry, electric field, amplifying gases, and two dimensional charge collection methods. This element has been described previously[3,8] as a preamplifier in front of a spark chamber (hybrid chamber) or in front of a PWC, with transparent screen cathodes. While the preamplified spark chamber, with a camera readout, is a fairly straightforward technique to obtain a two dimensional readout of many simultaneous photons with high spatial resolution, it is desirable to have a direct electronic readout capable of reasonable spatial and good time resolution. Others have been developing the needle chamber for this application. While some degree of success has been achieved, the chamber construction has become rather complicated (i.e., needles need to be spherically shaped at the point and focusing grids are required to obtain uniform efficiency). This led us to try to use two preamplification (also called parallel plate gaps or avalanche gaps) gaps to obtain gains high enough to readout the resultant electron cloud directly with an anode pad.

Initial measurements were made with a preamplifier gap in front of a drift gap through which the electron cloud drifted toward a conventional multiwire proportional chamber (20 micron wires, 2 mm wire spacing, 8 mm between cathodes, one cathode is a transparent mesh). It was confirmed that a preamplification gain of about a thousand may be achieved in such a geometry with 2% acetone in argon and with electric field of 5000 v/cm. Attempts to obtain gains significantly above 1000 resulted in breakdown of the preamplification gap. These results correspond to those of Refs. 8c and 8d.

Test Results for a High Gain Pad Readout Chamber

The PWC was then replaced by the anode pad readout plane shown in Fig. 4. The test chamber illustrated schematically in Fig. 5 was constructed. One to three gaps can be used to amplify the 6 keV photons from an

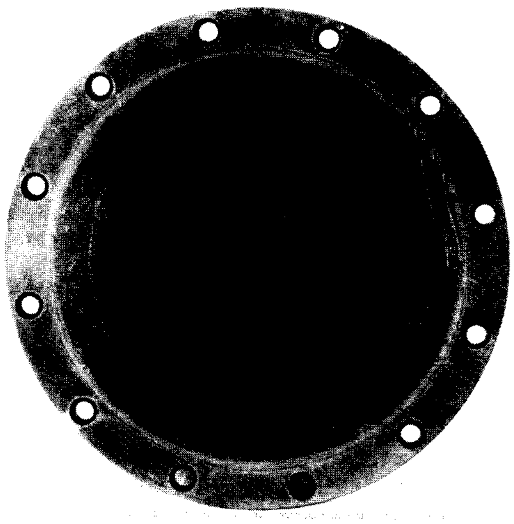

Fig. 4. Anode pad plane used in the test chamber.

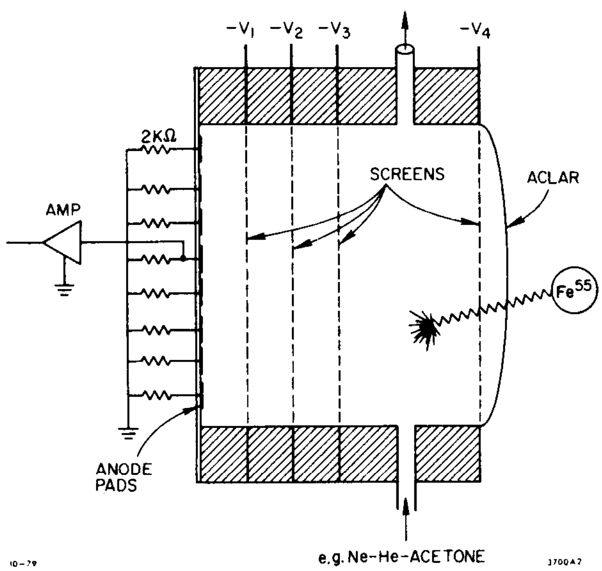

Fig. 5. Cross section of the test chamber.

Fe-55 source in order to study the gain capabilities of one gap, or two gaps in combination. The test chamber contained a 2.54 cm conversion gap operated at 0.4 kV/cm to sweep primary ionization from the Fe-55 source to the amplifying gaps. Three 4 mm gaps were operated as drift or amplification gaps. The pad readout plane was etched with 6 mm pads on 7 mm centers using conventional printed circuit board material.

Operation of two gaps in the amplification region (7 kV/cm) (with 1.5% acetone in argon) produced proportional pulses with energy resolution similar to that obtained in a PWC (20% FWHM, see Fig. 6). This indicates that the electron cloud is considerably smaller than the 6 mm square readout pads. Smaller pads will be studied in the future.

At this point we tried other gas mixtures and found that the use of Ne-He (90-10 spark chamber gas) instead of argon produced very high gains (up to 10^6) with a single 4 mm gap. Gains were measured by recording the

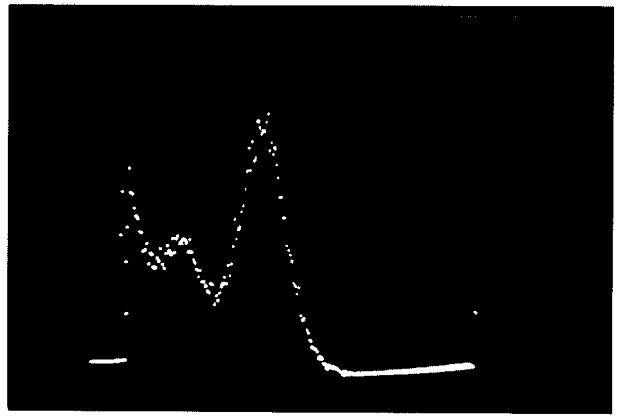

Fig. 6. Iron-55 spectrum obtained with a double gap chamber operated with 1.5% acetone in argon.

amplitude of the 6 keV peak of Fe-55 on a scope. One gap was operated in the amplification mode to obtain a small signal on the anode pad. The field on the gap under study was then increased from zero up to 5 kV/cm. Initially the amplitude increases linearly with the field as charge is being transfered and drifted across the gap (see Fig. 7). Above 1 kV/cm the amplitude remains more or less constant until the multiplication process begins. Eventually the electron cloud in the final gap exceeds some maximum size (approximately 10^7 e^-) and breakdown occurs in this gap. At this point the gain of the first (non-studied) gap is reduced a calibrated amount while maintaining the electric field on the gap under study. The resultant broken amplitude curve (an example is shown in Fig. 7) was corrected to give an overall gain curve for the gap, where gain was defined relative to the flat drift region.

While preamplification has been previously reported in argon mixed with acetone, alcohol, or TEA, we have found higher gains in Ne-He mixed with low percentages of acetone, alcohol, TEA, isobutane, CO2, and methane. Gain curves for several concentrations of acetone in Ne-He and several other gases are shown in Fig. 8.

The gain characteristics have been measured with Fe-55, which deposits about 200 primary electrons in the conversion region. The gain for single photoelectrons has not been measured, however, the chamber operated at the highest gains produces pulses on the pads when the chamber's metallic screens are exposed to a mercury lamp (2537 Å). Studies of quantum efficiency will be made with a photo-ionizing gas such as TEA and a photocathode formed by evaporating CsI on the cathode screen of the parallel plate gap.

Screen Materials

The parallel "plate" gaps tested here are actually parallel mesh gaps, so the influence of the mesh structure on the gain needs to be evaluated. Furthermore, since the present application involves the passage of an electron cloud through the mesh, it is important to understand the dependence of the transfer efficiency on the geometry of the mesh.

We have measured gains for several types of mesh materials — stainless screens woven with 25 and 50 micron wire (one shown in Fig. 9), 85 to 90% optical transparency, electroformed nickel mesh 90% transparency by 5 microns thick, parallel 100 micron wire grids. The finer, thinner meshes gave somewhat higher gains than coarser ones. Parallel 100 micron wires with 2 mm spacing gave very poor results. Mesh materials will

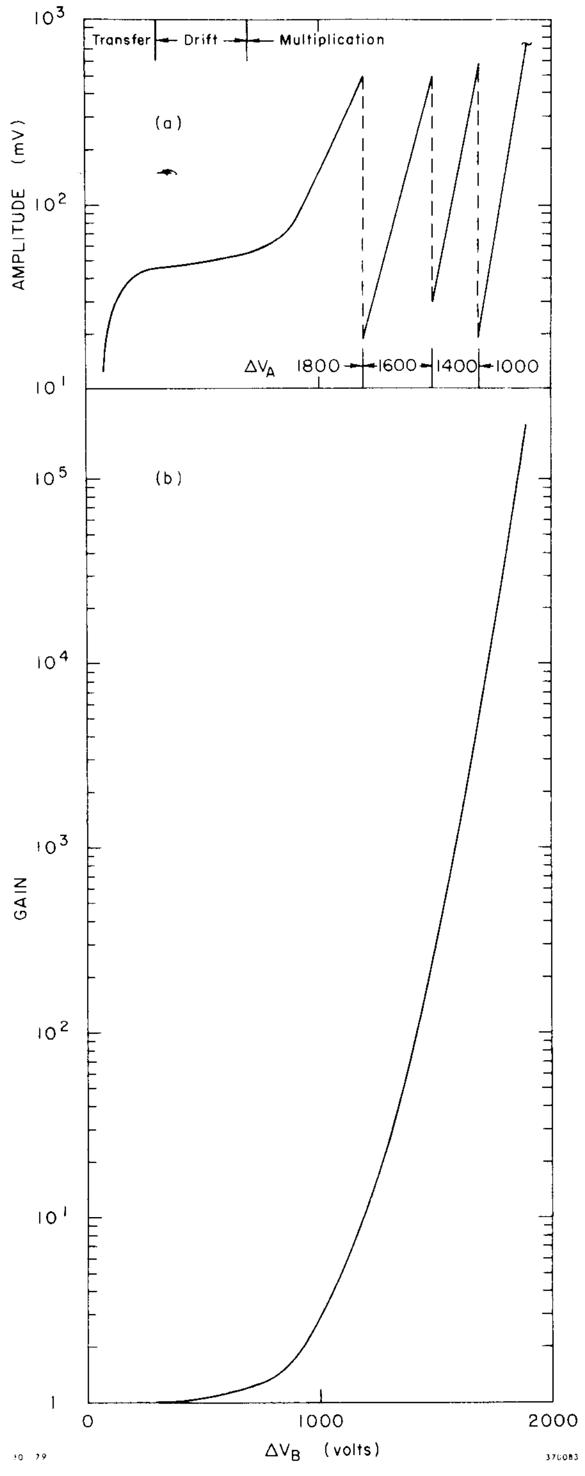

Fig. 7. (a) Amplitude versus voltage measurement made in the test chamber with 2% CO2 in Ne-He. (b) Gain curve obtained from (a). A 4 mm gap was used.

continued to be studied, but at this point it can be stated that high optical transparency is less important than close wire spacing (better than 2 per mm).

In an effort to understand the effect of the mesh on the transfer of charge, we inserted a 90% transparent mesh midway in a 8 mm gap. The gain was reduced by 50% rather than the expected 10%. The transfer of an electron cloud through the mesh is apparently not just simple geometry. Quantative studies are in progress.

Further Studies

The parallel plate anode pad readout chambers may provide a simple and effective readout for high fluxes of photons from a Cerenkov radiator. Further studies of efficiency, time and spatial resolution are being undertaken to demonstrate its usefulness. A single gap chamber operated with Ne-He and TEA should provide good quantum efficiency for photons in a region where Cerenkov light yield is high. Recent work by one of us indicates that coating the upper screen with CsI can provide an efficient photocathode and may permit a wider variety of amplifying gases to be used. Our plans are to complete a study of the parallel plate element and then evaluate its use in a photosensitive detector using the above photocathode materials.

The high gain gas mixtures in the parallel plate geometry suggests that a new breed of wire-less proportional chamber can be built for the detection of minimum ionizing particles. A test chamber is being designed with parallel 8 mm anode strips and a solid cathode to study efficiency, spatial and time resolution for high energy charged particles. This type of chamber could provide a simple yet rugged detector with good spatial and time resolution.

Amplification Mechanism

The higher gains obtained with Ne-He can be understood in terms of a classic curve (found in any text on gaseous electronics) which shows the first Townsend coefficient for the noble gases. The coefficient for neon and helium for low electric fields (here 6 kV/cm (mm Hg)) is almost two orders of magnitude higher than argon. But at very high electric fields (as found near the anode wire of a PWC) argon is about an order of magnitude higher than neon. Of course admixtures of gases alter dramatically the Townsend coefficient, however pure neon (or helium) have a strong advantage over argon at the lower electric fields used in the parallel plate chambers.

The mechanism for gain in a parallel plate preamplifier gap has been attributed a new photon mediated mechanism. The demonstration of gain in mixtures of Ne-He with several standard quenching gases (alcohol, acetone, methane, isobutane, CO2) which, have low ionization potentials, suggests to us that an alternative explanation of the mechanism is the classical Penning effect (de-excitation of metastable states of the noble gas by collision with the easily ionizable quenching gas). While secondary photon emission in argon at 1350 Å has been observed around a PWC wire,[9] the case of Ne-He and either CO2 or methane, both having an ionization potential of 14.4, would require short wavelength 800 Å photons. Unfortunately secondary emission would be difficult to observe because of the opacity of all known windows at this wavelength; so the issue cannot be easily resolved experimentally. All considered, while it remains possible that secondary emission photons from metastable states of neon or argon mediate the multiplication process in these gas mixtures, the Penning effect also offers an explanation.

Conclusion

Recent progress in studies of the use of photoionizing gases and solid photocathodes, and high gain single photoelectron amplification schemes, may now allow the design of a practical Cerenkov detector for high energy physics experiments. We have demonstrated that high gains (up to 10^6) can be achieved with a variety of Penning mixtures of Ne-He with a trace of

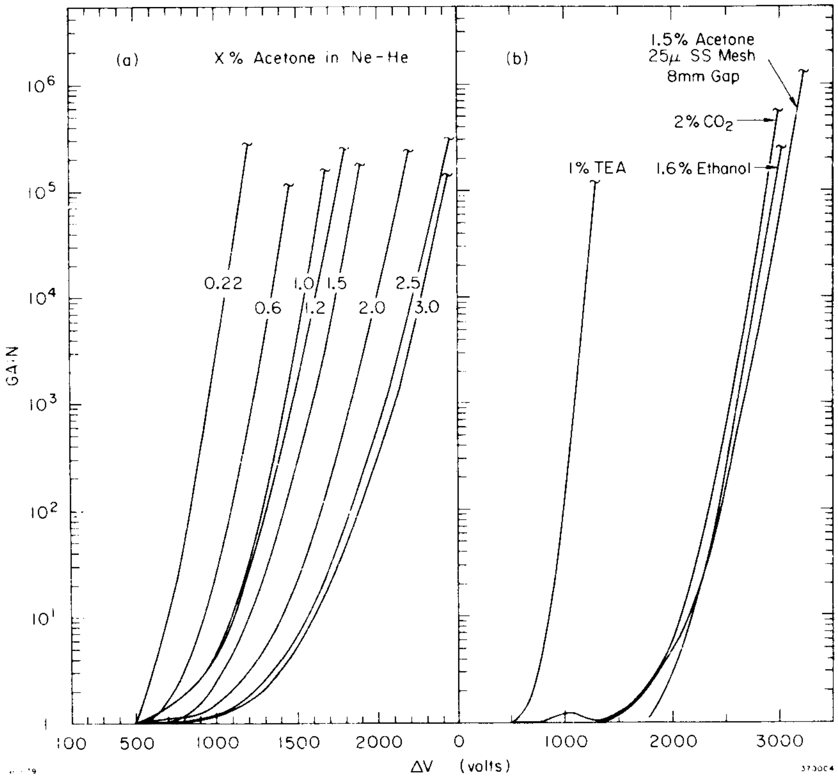

Fig. 8. (a) Gain curves for several concentrations of acetone in Ne-He. (b) Gain curves for several other gases mixed with Ne-He. (4 mm gap except where noted.)

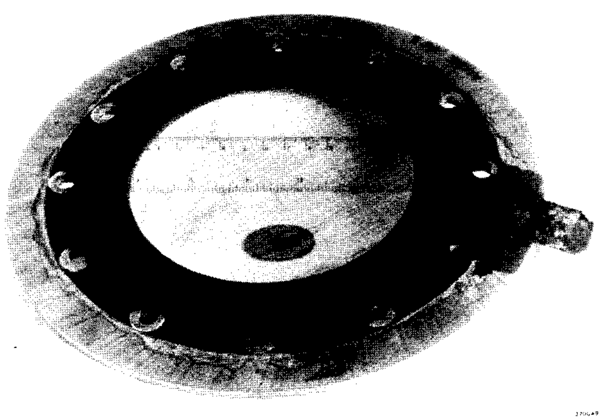

Fig. 9. One of the transparent meshes used in the test chamber.

organic gases, in a parallel plate gap and that the gains are sufficient to readout the charge directly on anode pads. This technique can be especially useful for Cerenkov ring-imaging detectors where high fluxes of simultaneous photons are incident on the detector. Additional applications of this technique may be found in detecting minimum ionizing particles in a parallel plate wire-less hodoscope.

The authors are indebted to A. Kilert for his careful search for suitable screen materials and the design of a flexible test chamber facility. We also thank W. Walsh for his execution of this design.

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