BNL-104570-2014-TECH
AGS/AD/Tech Note No. 141;BNL-104570-2014-IR

TESTS OF AN ELECTROSTATIC WIRE SEPTUM MODEL IN THE AGS

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December 1977

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Brookhaven National Laboratory

U.S. Department of Energy
USDOE Office of Science (SC)

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AGS DIVISION TECHNICAL NOTE

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December 14, 1977

SUMMARY

An electrostatic wire septum model, made from parts furnished by FNAL, was operated in the H20 straight section as part of the slow extraction channel. No untoward effects on AGS intensity were seen. The septum survived without breaking wires. Data on beam loss vs. septum skew showed significantly larger beam divergence than expected.

It is planned to improve the AGS extraction efficiency by means of an electrostatic septum. An analysis[1] of the costs and benefits of various ways to deploy the extraction equipment and simultaneously upgrade the switchyard, has led to the decision to install a 230 cm long wire septum operating at 80 kV/cm at the H20 straight section, followed 24 wavelengths downstream by the existing copper septum magnets at F5 and F10. Calculations and measurements have shown that a foil septum will suffer from wrinkling induced by beam heating at typical AGS intensities, and therefore it is necessary to use a septum made from an array of wires.

To get experience as quickly as possible with a wire septum in the AGS, a 60 cm long model was made and installed at H20, and tested during the period June 16-21. The purposes of the test were: (1) To see if there were any unexpected effects on the beam intensity from leakage electric fields, x-rays produced at the cathode, or other phenomena;

(2) To study possible wire breaking; and (3) To study beam loss on the septum and beam divergence effects.

Septum Design

The construction of the proposed septum is based on experience with such devices at FNAL.[2] One major difference at the AGS is the larger vertical beam size at injection. At FNAL the circulating beam fits inside the septum frame and the cathode is external (Fig. 1a); for the AGS design the circulating beam is external to the frame (Fig. 1b). It would have been in advisable simply to scale-up the vertical aperture of the frame because unsupported wire length is a critical parameter in septum design for a given gradient, wire diameter and allowable wire bowing.

A cross section of the model septum is given in Fig. 2a. The model uses short lengths of standard FNAL cathode and frame, which were kindly given to us by the FNAL Switchyard Group. This septum is much shorter than the proposed final design (Fig. 2b) and hence has much less bending power. In addition, the cathode is supported by a plastic insulator and so the design voltage across the 1 cm gap is only 40 kV, compared to 80 kV for the final model. Also, the test septum field uniformity is poor because of its geometry, but this is of no consequence for tests.

Effect on Beam Intensity

To keep the leakage electrostatic field small, the wire septum extends 2.5 gap spacings upstream and downstream of the cathode. Also the baffle (H in Fig. 2b) shields the beam from the field of the high voltage feedthru. Then, provided that no wires are broken, it is easy to calculate that the electrostatic field that leaks through the wires or elsewhere is much too small to have a significant effect on the beam at injection. However, since the wire septum is transparent to plasma and x-rays, one might imagine more subtle influences of the wire septum on beam intensity.

A test was run to search for effects on the low-energy beam. The test was made with a high field orbit bump at H20 and with the septum in position to shadow the F5 copper septum, as for "normal" H20 extraction. When the septum was energized to 40 kV/cm, no effect on the horizontal orbit was seen on the radial pickup electrodes (sensitivity $\sim$ 1 mm). The accelerated beam intensity fell, however, by about 10%. No attempt was made to change injection tuning to compensate. The effect on intensity was a non-linear function of gradient, with most of the change occurring at only 5 kV/cm. A correlated effect was seen in the current flowing between the cathode and the wires, which was 40 μA at injection time with low gradient and 10 μA with $\geq$ 5 kV/cm. The electrostatic septum was undoubtedly acting as a clearing electrode for the residual gas ionization associated with the beam.

It was found that the intensity effect could be eliminated by energizing an inward low field orbit bump. A backleg winding current of 2 A, corresponding to a deflection of 6 mm inward at H20, was used.

Wire Breaking

Like the FNAL septa, the AGS septa will be provided with retractor springs and baffles so that the occasional breaking of a single wire (for example from sparking) will not be a problem. However, wire breaking by beam could be serious.

Calculation shows that the low energy beam cannot break wires. This theory was tested when the control system inadvertently drove the septum radially inward to its limit stops. At this position, about 5×10^{12} ppp were "scraped" by the septum. Despite several minutes of operation this way, no wires broke.

Calculation also shows that the 30 GeV non-resonant beam, if steered onto the septum, would heat the wires near their melting point in about 1 msec. No test was made, however, to see if the 30 GeV beam would break wires. A beam abort, triggered by excess H20 loss monitor signal, is planned to protect against inadvertent wire breaking.

Beam Loss and Beam Divergence Effects

Using the H20 radiation loss monitor, beam loss on the test septum was studied. Protons that strike the septum undergo multiple coulumb scattering and emerge after traversing $\sim$ 8 cm ($\sim$ 64 wires).[3] The loss monitor responds to the small ($\sim$ 6%) fraction of the protons that interact strongly before scattering out. Therefore, the loss monitor response is to a very good approximation proportional to the average path length traversed by the beam particles, neglecting strong interactions. Since multiple coulumb scattering in tungsten is well understood, this average path length can be calculated accurately. The only unknown in the calculation is the angular distribution of the beam. The other parameters in the calculation are the radiation length in tungsten, the wire diameter and spacing, and the septum length and skew angle, all of which are known.

The measured results are compared in Fig. 3 with calculations for various assumed beam divergences. Note that the calculated width of the distribution is essentially independent of assumed beam divergence and agrees with observation, lending credibility to the calculation.

The angular distribution of the resonantly extracted beam at the H20 septum was assumed in the calculation to be that corresponding to a non-resonant beam that has uniform density in phase space within an ellipse of area ϵ_H. For a "reasonable" non-resonant beam emittance of $\pi\beta\gamma\epsilon_H = 75\ \pi$ mm-mrad we expect the full width of the divergence of the resonantly extracted beam to be $\Delta = 0.35$ mrad. However, to fit the data we need $\Delta \approx 0.8$ mrad. Of course the non-resonant beam may not be uniformly distributed in phase space, but then the discrepancy is even greater.

After the septum was removed from the ring, its straightness was measured mechanically. The dial indicator measurements showed a departure from straightness of 0.0009 cm peak to peak. This departure will have a negligible effect on the skew curves in Fig. 3.

The effective thickness of the septum, and therefore the extraction efficiency, is a sensitive function of the beam divergence Δ (it varies as Δ^2). If the present (admittedly rather indirect) measurement of Δ is correct, then a considerable improvement will have to be made if the full benefit of the electrostatic septum is to be obtained. Particular areas that will be investigated are magnet ripple and rebunching effects, and the possible existence of a non-resonant component of the extracted beam.

Acknowledgments

Helen Edwards and Jim Walton of FNAL gave us the septum and cathode. Lou Repeta, Dick Lingg, Fred Schneider, Bob Horton, Ron Lankshear and Bill Cahill did the design and installation.

References

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2. J. Walton, R. Andrews, H. Edwards and M. Palmer, IEEE Transactions on Nuclear Sciences NS-22, pg. 1091.
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Distr: Dept. Admin.
Accel. Dept. S&P
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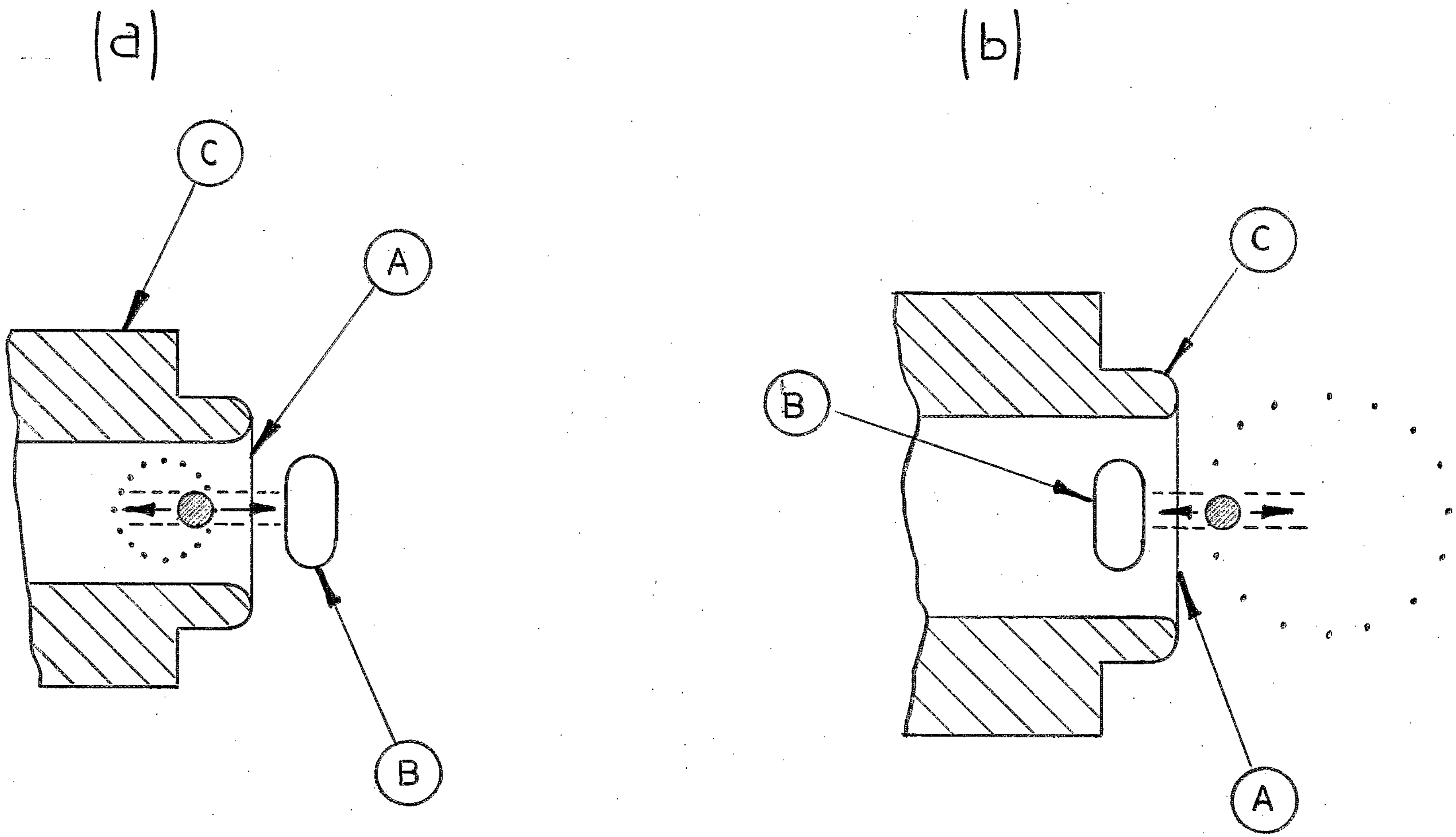
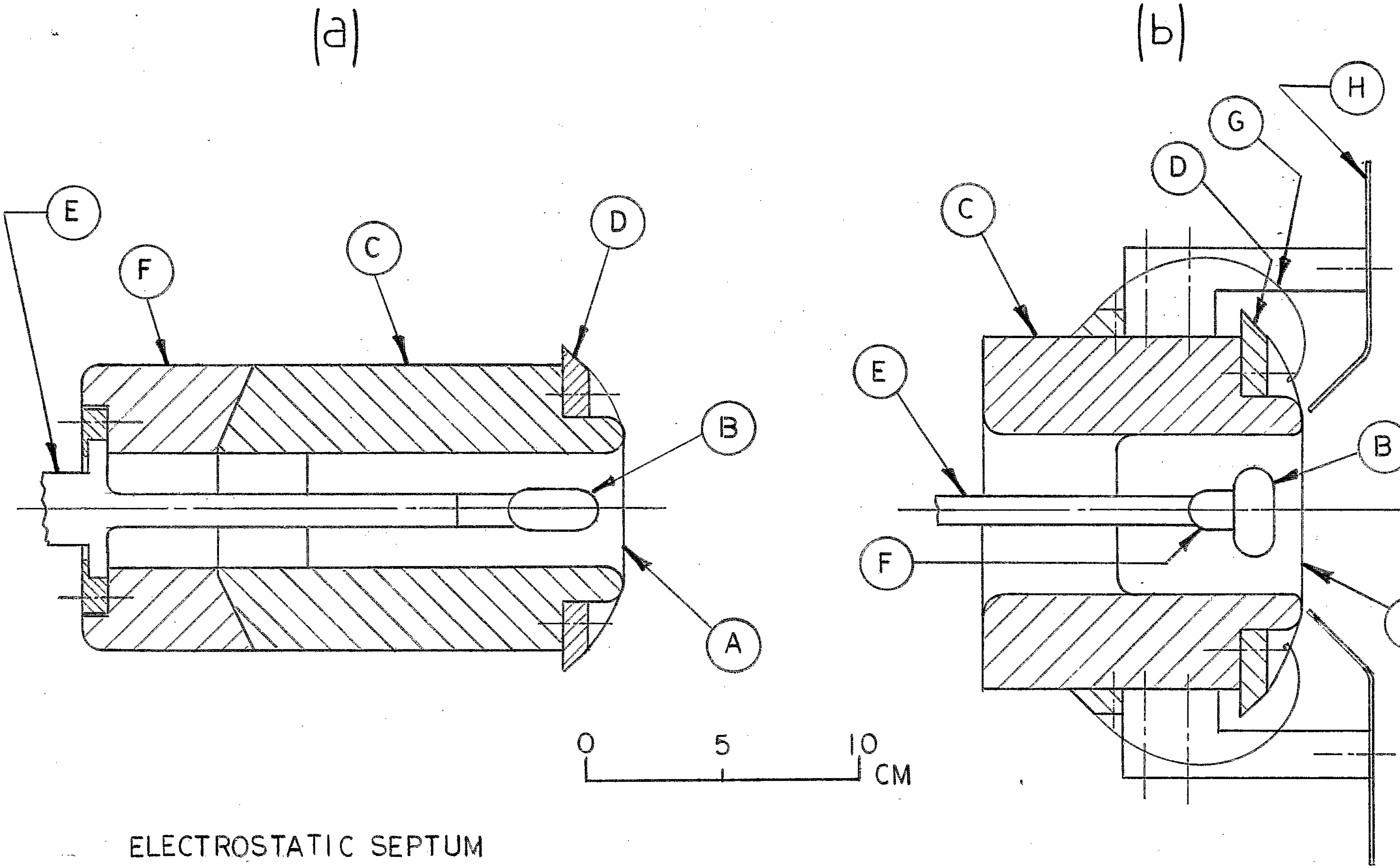


Fig. 1 Electrostatic septum geometry (a) FNAL; (b) AGS. Large dotted circle: beam at injection; shaded circle: beam at high energy, displaced toward septum by local orbit bump; arrows and dashed lines: resonantly extracted beam; A: wire septum; B: cathode; C: septum frame.



ELECTROSTATIC SEPTUM
2 FT MODEL

PROPOSED H20
ELECTROSTATIC SEPTUM

Fig. 2 (a) Section through 60 cm long test septum. A: 0.050 mm tungsten rhenium wires, 1.25 mm spacing; B: 0.75 mm wall titanium tubing cathode; C: aluminum frame; D: aluminum support strip with wires swaged on; E: stainless steel cathode support; F: plastic insulator. (b) Section through proposed 230 cm long extraction septum. A,B,C,D: same as above; E: titanium rod cathode support; F: 0.75 mm wall titanium tubing stiffener for cathode; G: retractor spring for broken wires; H: baffle and electrostatic shield.

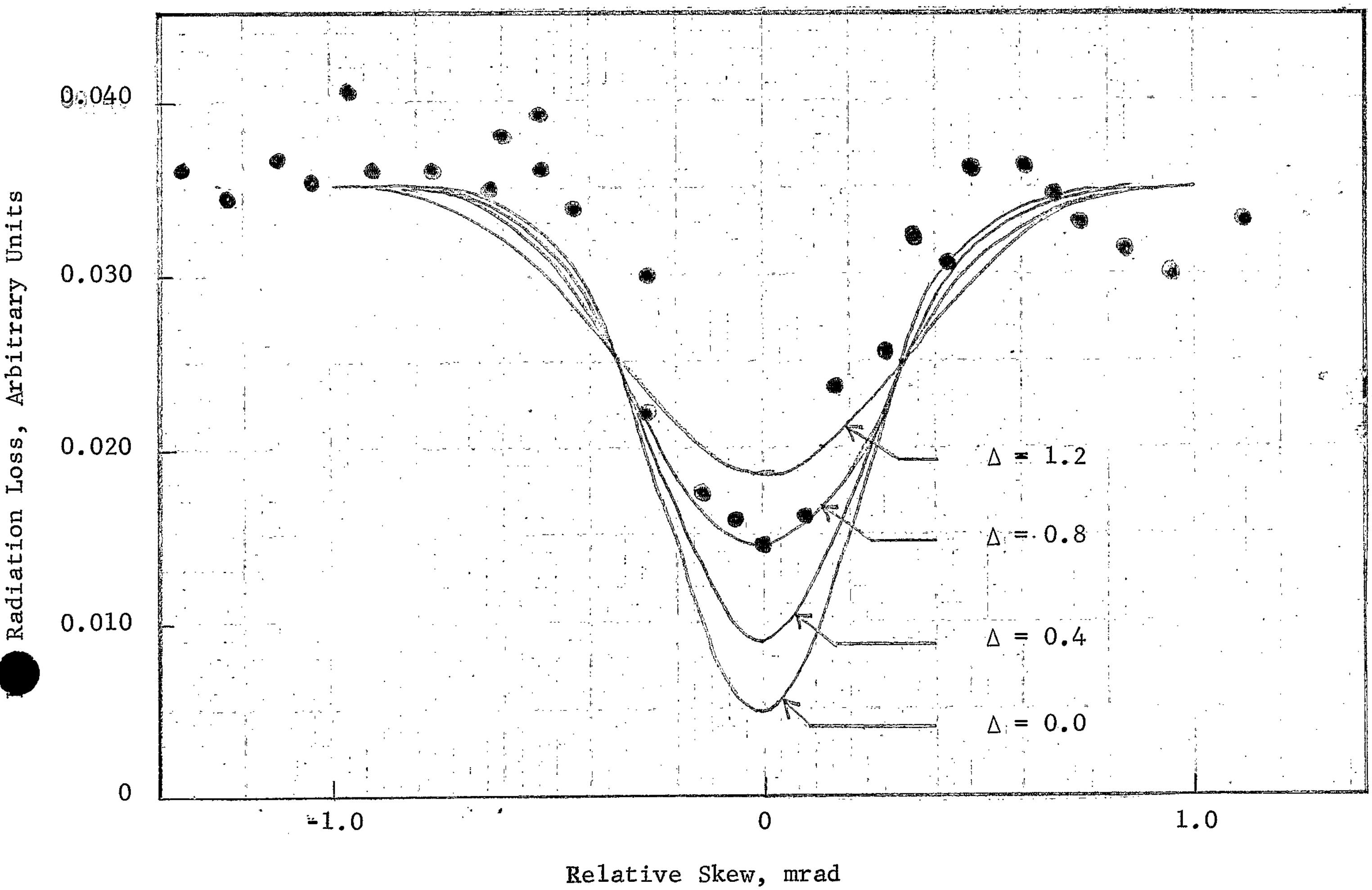


Fig. 3 Loss monitor signal vs. septum skew angle. The points are measured values (background subtracted). The curves are predictions of a Monte Carlo calculation for various assumed beam divergences Δ in milliradians.