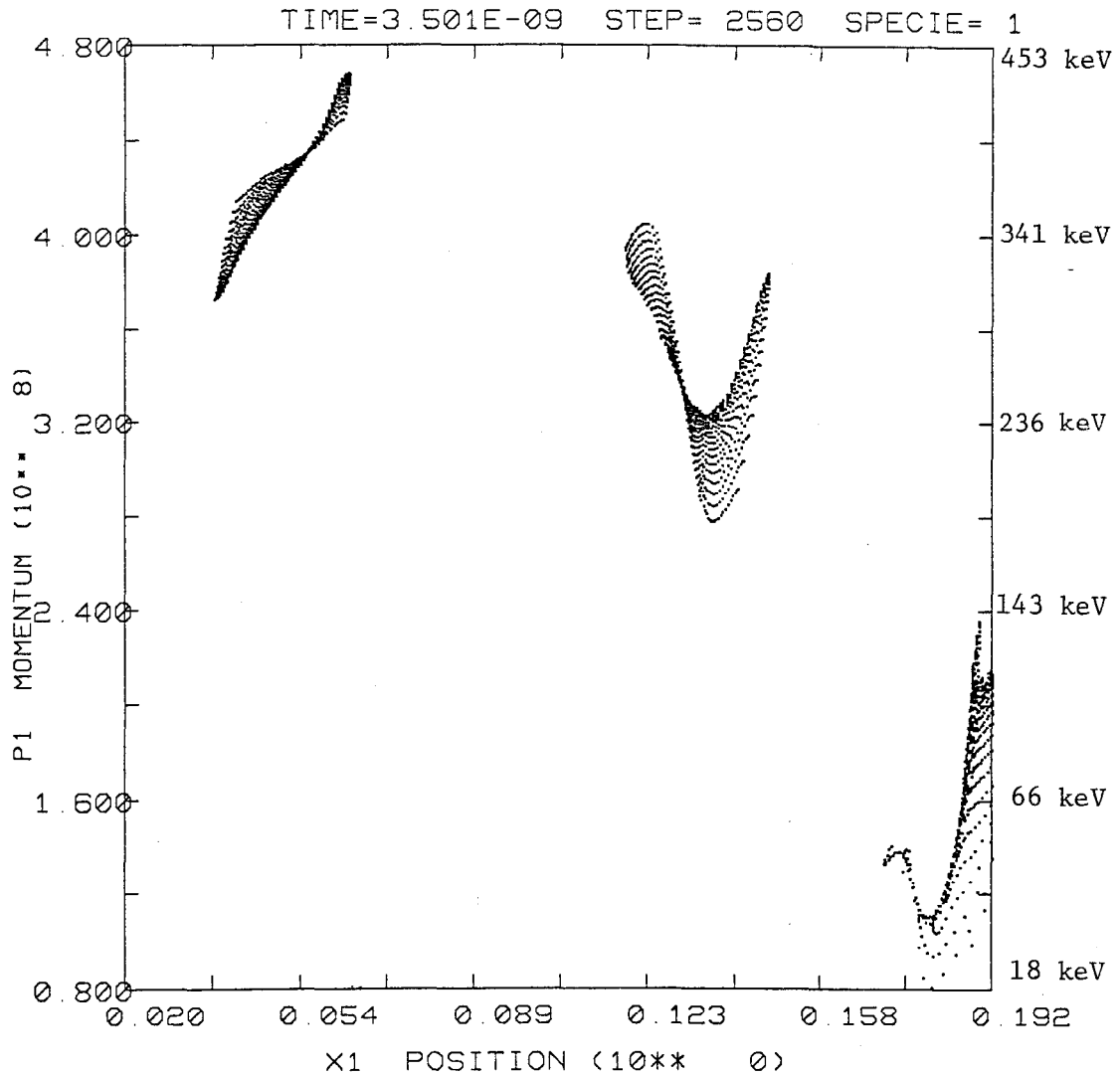


LASERTRON SIMULATION WITH A TWO-GAP OUTPUT CAVITY*

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Abstract: With a two-gap output cavity, it is shown here that



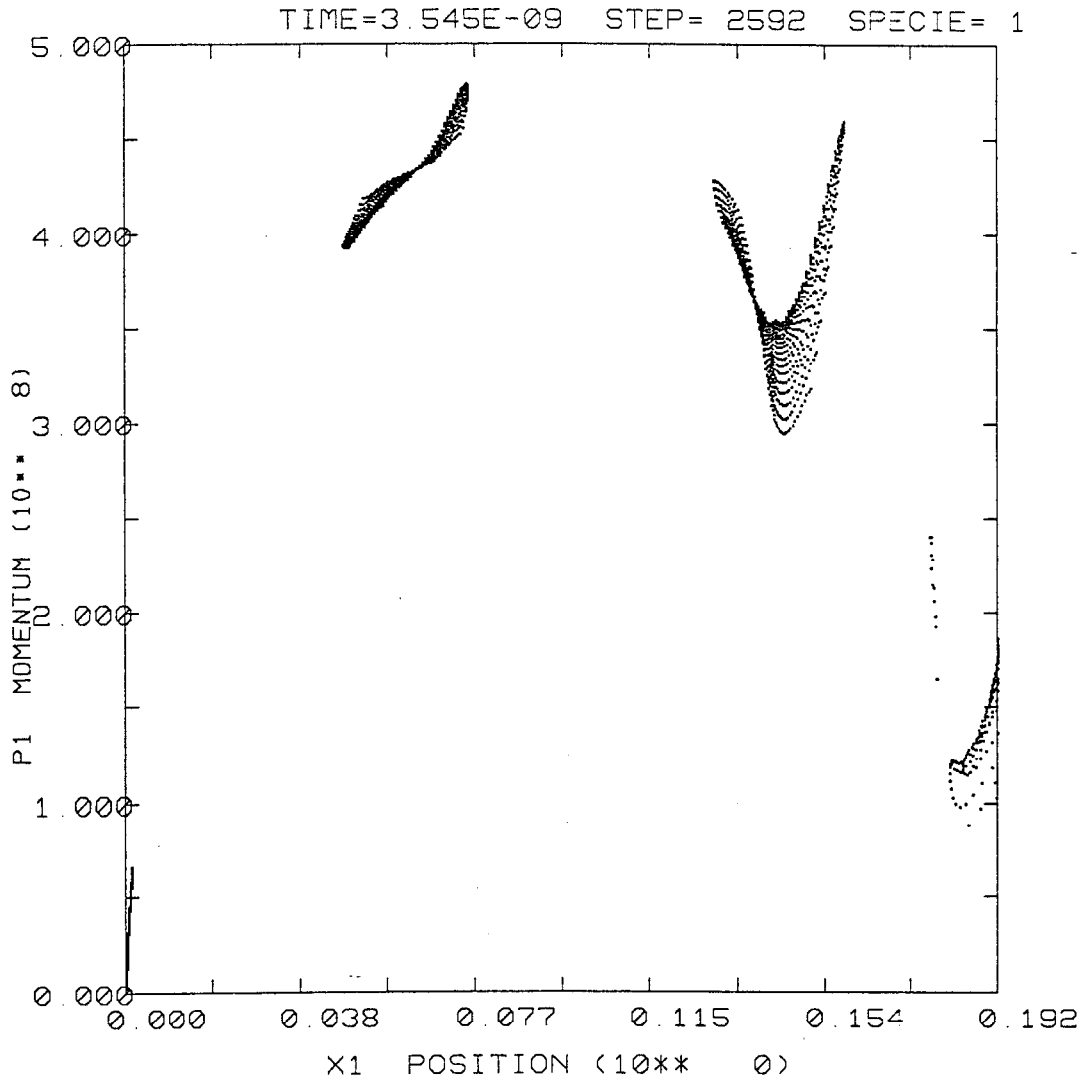
high rf efficiency, up to about 70%, is possible for the parameters planned for the SLAC lasertron experiment: 400 kV, 50 MW, 2856 MHz.

Simulation: To get the reader used to looking at MASK output, I am going to tell the story in pictures. The vertical scale is longitudinal momentum, units of $\beta\gamma c$. The corresponding drift energies are shown on the right side. The horizontal scale is meters; the photo cathode is at 0.0 and the collector is at 0.192 m. There are 256 time steps per rf cycle.

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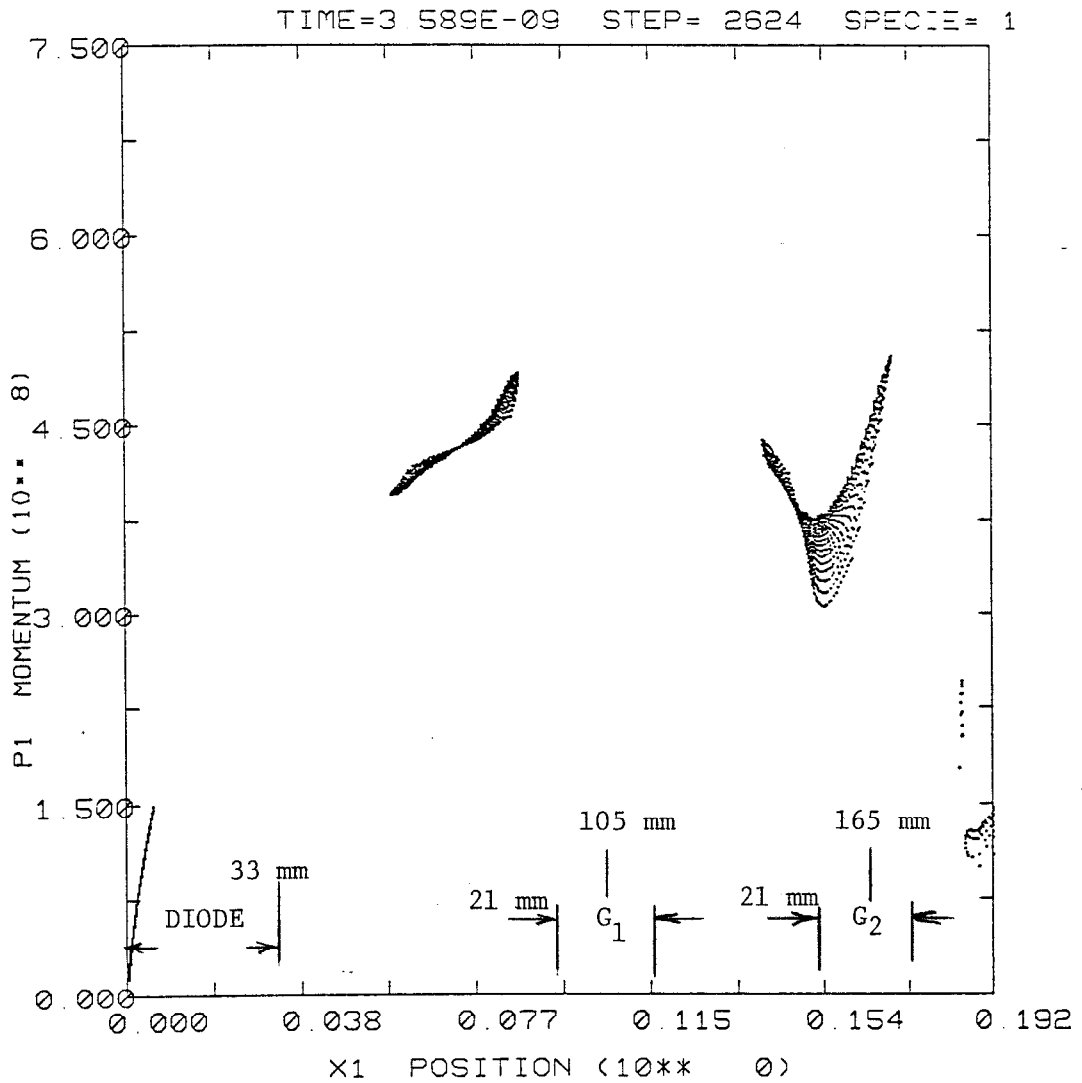
Each picture corresponds to a 45° phase advance. We will show a complete rf cycle in eight steps. When you compare pictures, be warned that the scales will change.

The dots are macro particles that are being followed from photo cathode to collector. Here we see four pulses. In the lower left corner, a new pulse is just being emitted. The previous pulse, at the top, has just left the accelerating region of the diode. The pulse in the upper right corner is between rf gaps.



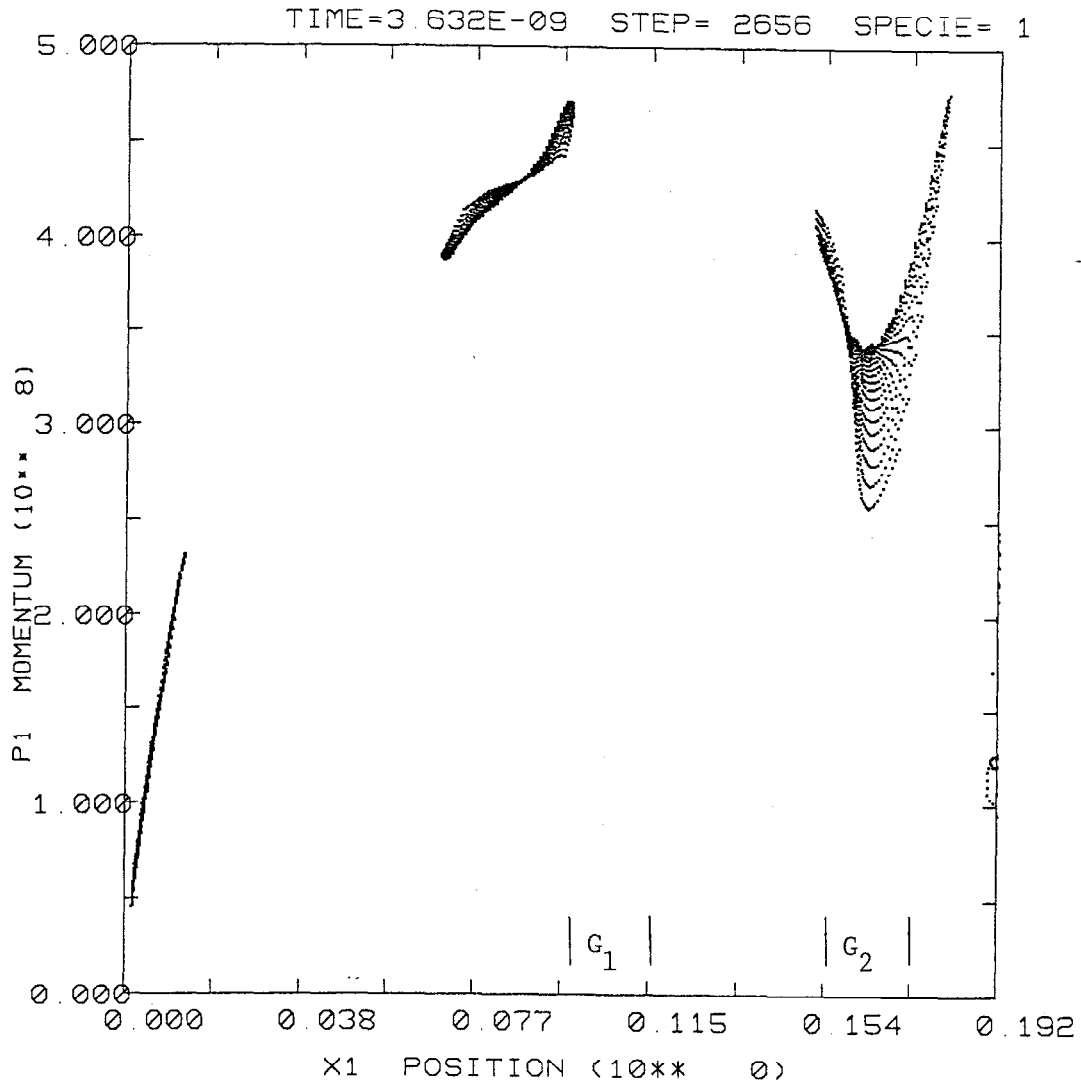
In the lower right corner, the last remnants of the fourth pulse is just going into the collector.

Field Inputs: On this figure we have located the position of the diode gap, from 0.0 to 33 mm, and the two rf gaps, each 21 mm wide, centered at 10.5 cm and 16.5 cm, respectively, from



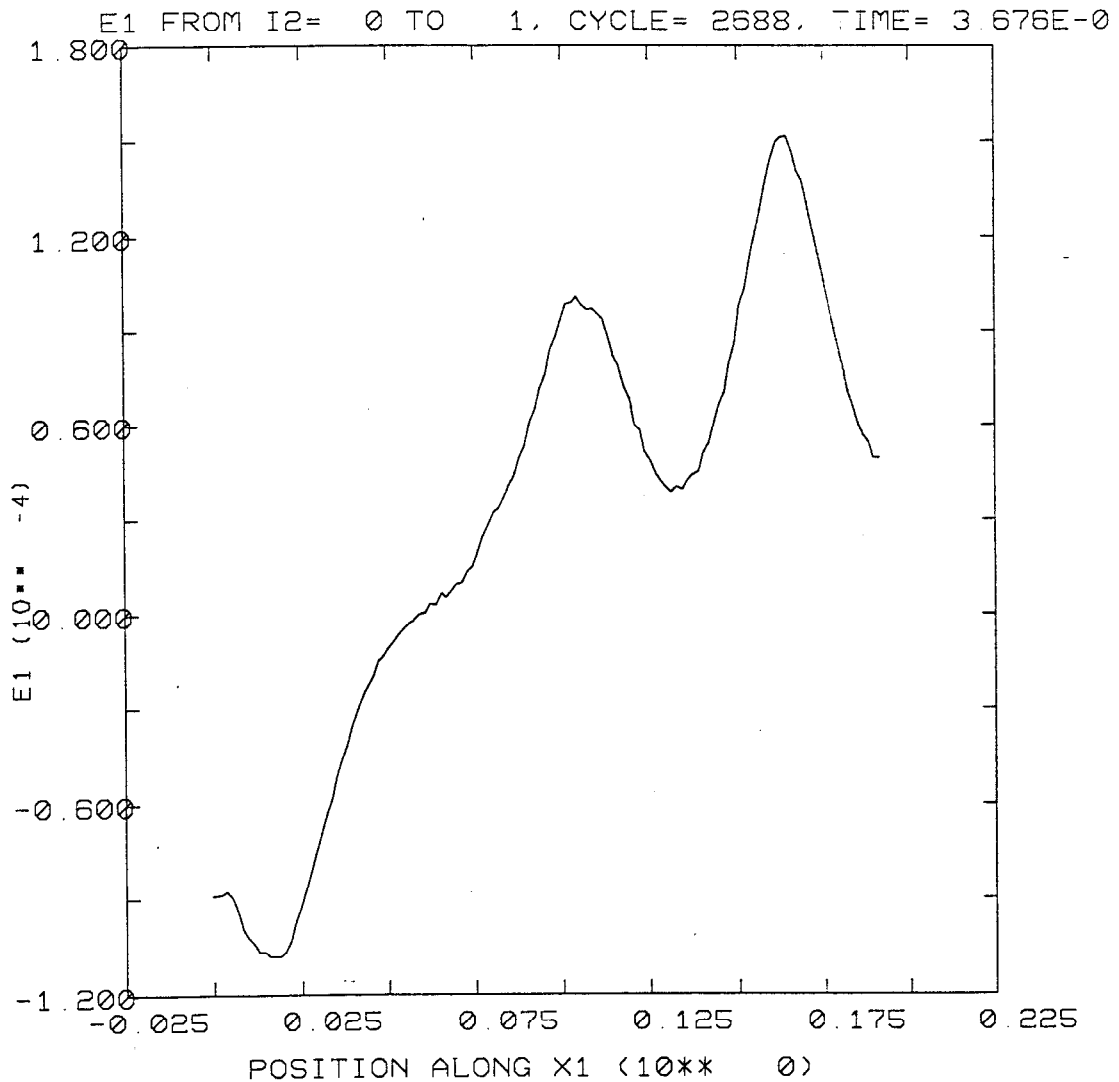
the cathode. The voltage over the diode is 400 kV. In this simulation, the rf voltages are 300 kV and 400 kV over G_1 and G_2 respectively. The model for the two gap cavity is essentially the same as was used for the 150 MW klystron built at SLAC as part of the Japanese collaboration. (1) The double gap cavity operates in the 2π mode, i.e., the rf phases are the same in both gaps.

Particle Dynamics: Here the new pulse has left the cathode, i.e., the laser is turned off. The preceding pulse is just entering the region of gap G_1 . The next pulse is right over G_2 . Note that particles from the pulse that was in the collector region on the first figure, are still being collected. In fact, we will see that we are collecting particles during each of the eight 45° intervals. In effect, we have converted



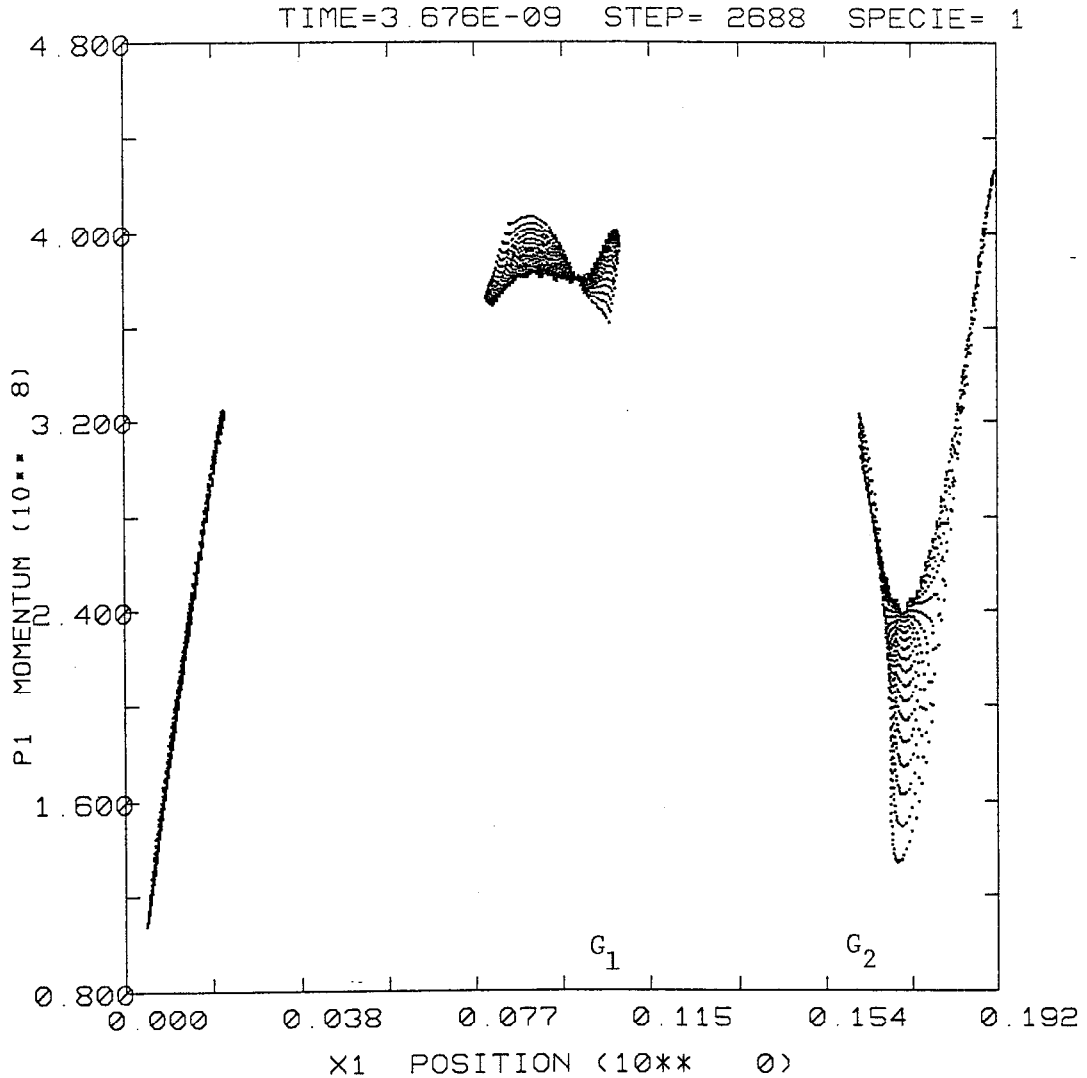
the pulsed beam to dc. Obviously, if we extracted all of the rf modulation from the beam, we would have removed all of the possible rf energy. By adding up the energy that is collected during an rf cycle, and dividing by the rf period, we have a measurement of the lost beam power. The difference between the input power and the collected power is the rf power.

RF Phases: If you have been counting carefully you will note that we are now at the fourth step, that is, we are at 180° of the rf phase. We arbitrarily chose to start counting at 0° , and since the rf fields follow a cosine law, 0° and 180° are the points of maximum field: 180° is the maximum decelerating field in the rf gaps. The two humps correspond to the middle of the gaps. Recall that the rf voltages are 300 kV and 400 kV, respectively. The vertical scale labelled E_1 , is actually D_1 .



If you divide by 8.854×10^{-12} , you will have the electric fields, E_z , but note that the effects of local space charge is included. The plot is the field on the axis of symmetry.

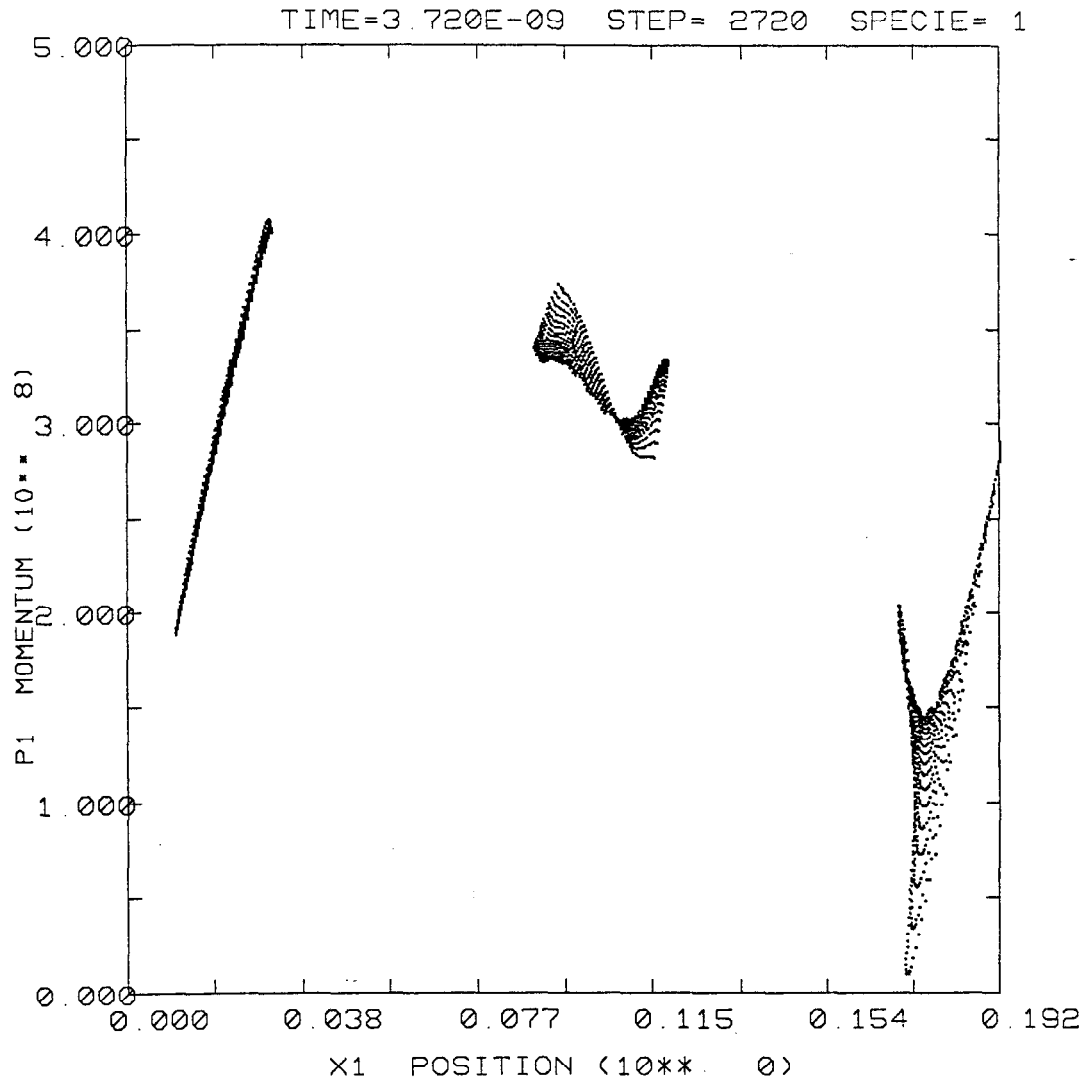
Momentum Control: The ideal klystron pulse is monochromatic at the output gap. By phasing the field at G_1 a little bit early, we will in fact result in tipping the momentum plot from the slope that is caused by space charge in the diode to one in which the trailing part of the pulse has higher momentum. We are also extracting some energy so that lower fields are possible at the rf gaps. As the pulse drifts from



G_1 to G_2 , the self forces will act to redistribute the momentum within the bunch. The results do not depend critically on the choice of rf phase and amplitude. For example, the same efficiency results if the voltage at G_2 is only 300 kV, or if the phases are changed by a few degrees.

Collected Energy: The energy collected during each of the 45° intervals is tabulated below, (in units of 10⁻⁴ joules):

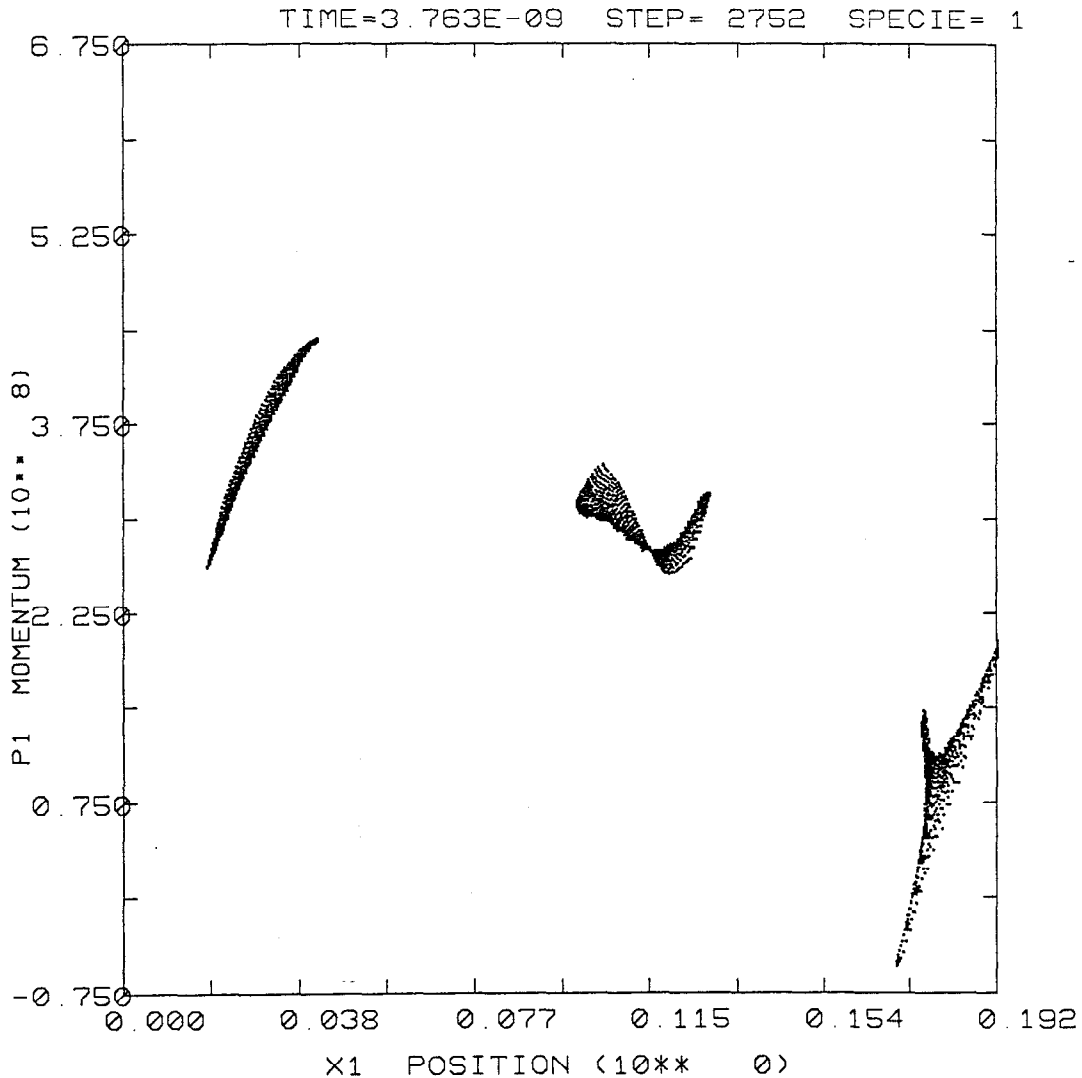
Interval:	1	2	3	4	5	6	7	8
End Wall:	16.64	8.35	3.88	3.78	5.96	5.57	3.22	4.13
Side Wall:	4.42							.59



The total collected energy is 0.005659 joules. Multiply by 2856 MHz and the collected power is 16.15 MW. The input power is 50 MW, so the collected "efficiency" is about 32% and the rf efficiency is about 68%. The simulation is remarkably stable; subsequent cycles yield the same efficiency \pm 0.5%.

Double Gaps: As we watch the rest of the rf cycle go past, we can contemplate (briefly) the virtues of double gaps:

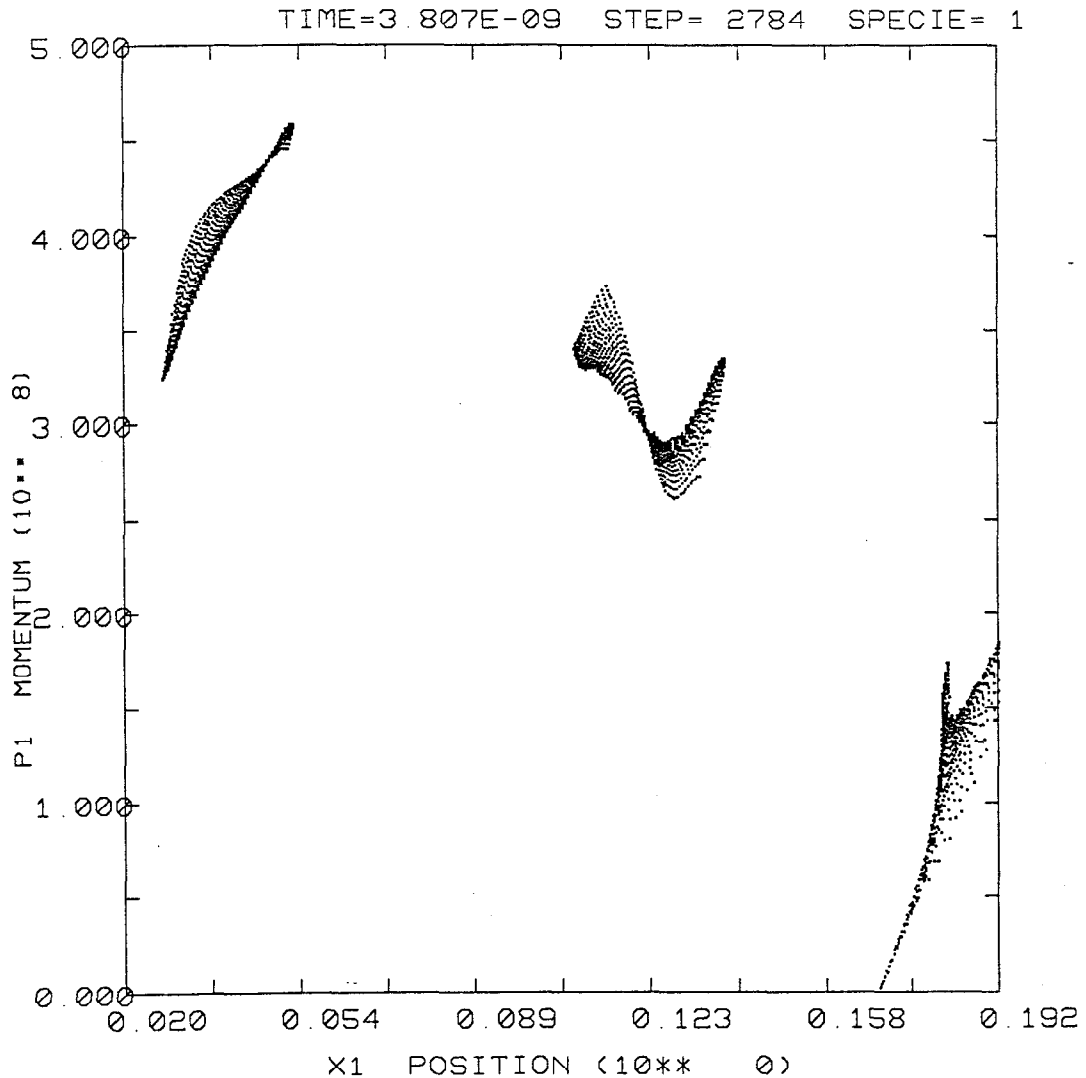
- 1) Efficiency... The best efficiency that we were able to get under these conditions with a single gap was about 50%.
- 2) Peak fields... Especially if the lasertron goes to higher voltage beams, the peak rf fields would become



excessive unless multiple output gaps are used.

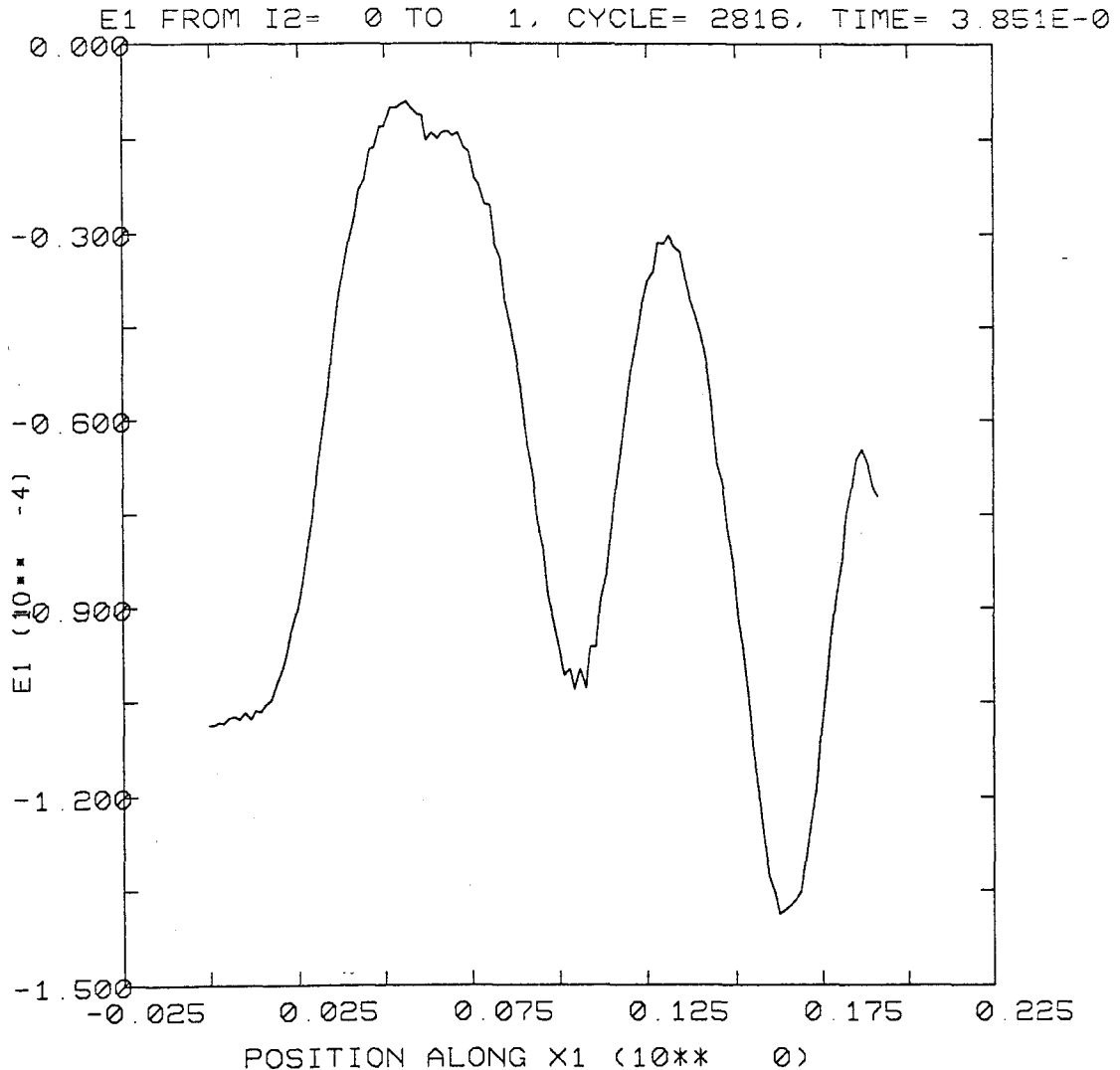
- 3) Control... Because the rf fields are lower, the beam is much more manageable. Although some beam was collected on the wall in this run, the same efficiency was obtained with lower fields and no beam was lost on the wall. This is important for photo cathode lifetime.

Multiple gap output cavities and other extended interaction area systems have been used before (1,2). The experimental 150 MW tube achieved 43% efficiency with a single gap and 51% with the double gap. The increase in output power was almost 19%.



The design parameters for the output cavities, (frequency, Q and R/Q) can be determined from these MASK results using the klystron simulation version of MASK that Simon Yu developed (3).

If you read with the speed of light, then we have been together now for 350 picoseconds. You can tell how the fields changed if you compare this sheet with the field, 180° back.



If two gaps are good, are even more gaps better? Not in this case because there isn't much rf left in the beam, but perhaps for a higher power beam more gaps would help. Would double gaps improve the efficiency for conventional klystrons? We will look at using multiple gap output cavities for the SLAC 50 MW klystron as part of our on-going simulation work.

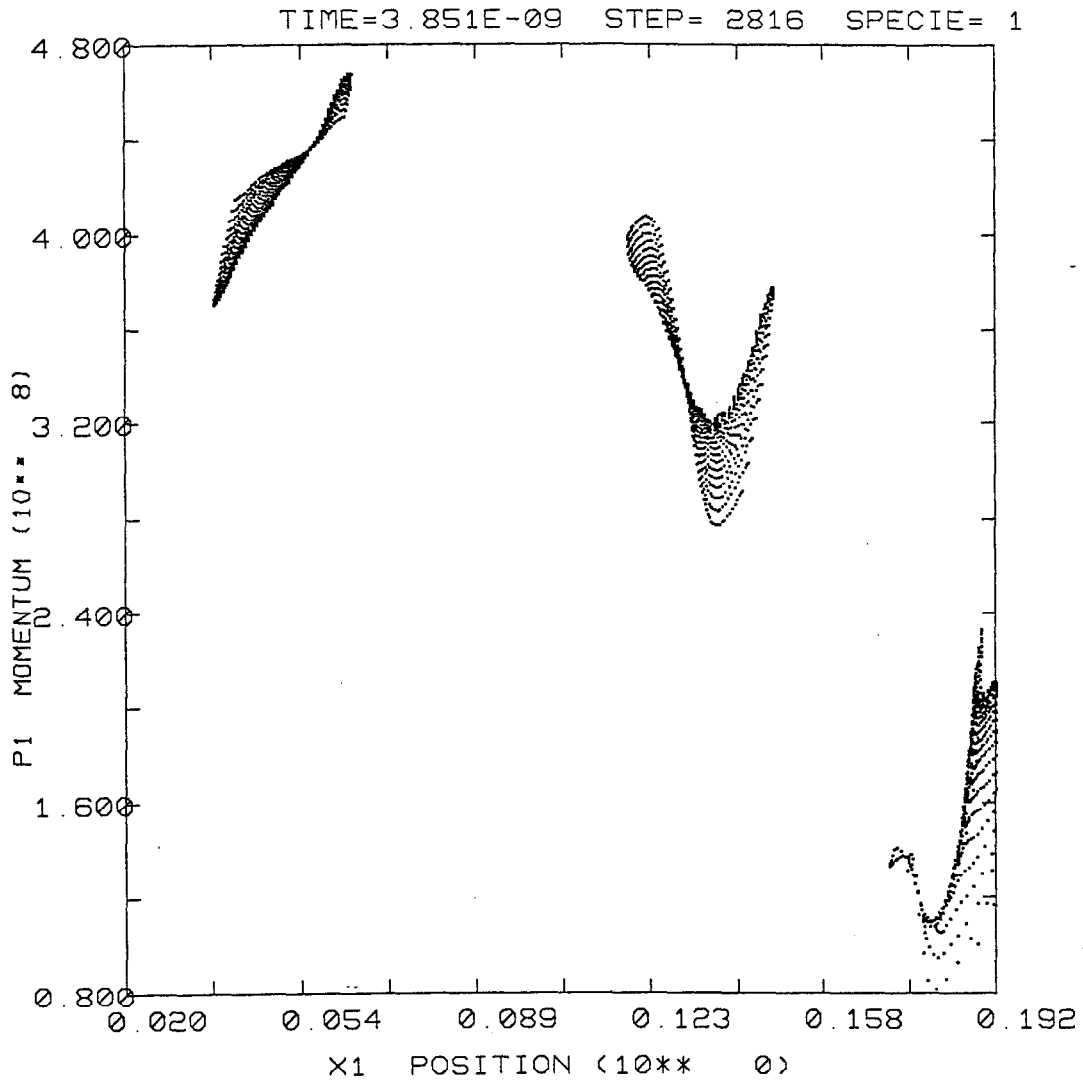
It is interesting to compare the picture on this page with the plot on page 1, 360° back in time.

Acknowledgment:

Thanks to Terry Lee and Marvin Chodorow for helpful discussions.

References:

- 1) Lee, Konrad, Okazaki, Watonabe and Yonezawa, The 150 MW Klystron Experiment, to be published in IEE Transactions Plasma Science on High Power Microwave Generation.



- 2) M. A. Allen, Coupling of Multiple-Cavity Systems, Microwave Laboratory Report 584, Stanford University, April 1959.
- 3) S. Yu, Particle-in-Cell Simulation of High Power Klystrons, SLAC/AP-34, September 1984.