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SIMULATIONS OF THE LASER PHOTOCATHODE INJECTOR[†]

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New, fully electromagnetic simulations of the beam optics in a laser-photocathode injector have been made using the PIC Code MASK. The recent studies are for the two-cavity design now undergoing tests by R. Sheffield, LANL. Pulses up to 10 nC are simulated, using cavities operating at 1300 MHz with above 1 MeV energy gain per cavity. The work is guided by previous simulation results which show that to achieve good agreement with the best experimental results, it is necessary to use very high RF fields near the cathode and to maintain small beam cross sections, corresponding to very high emission density.

The laser-photocathode injector has demonstrated the ability to achieve very good emittance from a high peak current injector. Applications requiring such outstanding beam properties include short-wavelength FEL's and other compact synchrotron light sources, and possibly, also, new e^+–e^- colliders. Previous studies [1,2] as well as experiments with a one-cavity model of the laser injector [3] show that it is important to have very high emission density, (> 200 A/cm^2) in order to achieve and maintain good beam properties. To extract pulses of up to 10 nC, laser pulse lengths need to be in the range of 5–25 ps. Finally, in order to accelerate the bunch rapidly to relativistic velocities, very high accelerating fields of around 30 MV/m are needed.

SIMULATIONS

All simulations reported here were made with the particle-in-cell (PIC) program, MASK [5]. Particles were injected with a trapezoidal shaped profile in time, at a fixed pulse length of 23 ps. Different currents were obtained simply by changing the charge weight of each macroparticle.

The magnetic field profile used was suggested by Sheffield at LANL. As will be shown below, the magnetic field was varied in amplitude, but not in shape, in order to accomodate beams of different currents. It can be assumed that an experimenter will perform a similar action simply in order to confine the beam, but that the actual values used may differ significantly from those used here. The criterion used to adjust the field strength was that the beam diameter should be approximately the same as that usually used for emittance measurements at the location of the "pepper pot" screen, which is about 40 cm from the cathode. The usual beam radius at the screen is 0.8 cm.

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The shape of the magnetic field is shown in Figure 1. The longitudinal scale of the drawing of the cross section of the entire system is the same as the scale for the magnetic field profile. The RF fields are established by areas in the side of the simulation space that are given the boundary conditions of "ports" across which an RF voltage is established. The phase and amplitude of the fields in the two cavities can be set independently, as they are at the experimental facility.

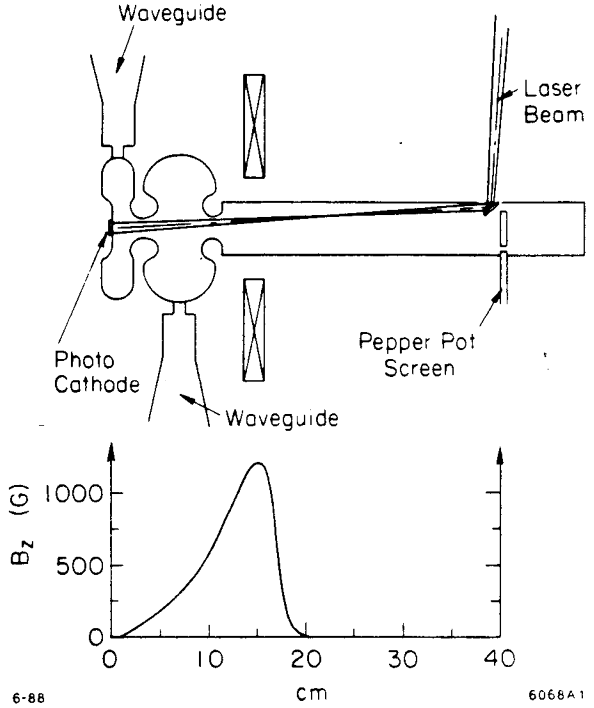

Fig. 1. Diagram of the two-cavity laser photocathode injector with profile of the solenoidal magnetic field at the axis.

Figures 2–4 show plots from the three cases that correspond to the data in the first column of Table I. Except for the charge weight assigned to the macroparticles, each case has the same input conditions, with a laser spot of 0.55 cm radius. The entries for "Coil Current" give the relative strength of the magnetic focusing field compared to the profile of Fig. 1.

Figure 2 shows the transverse and longitudinal phase space, respectively, for the lowest current case with 45 A peak current at the window. In general, the tilt of the transverse phase space ellipse is correlated in time with the position along the length of the bunch. The emittance plots shown are the total accumulation for the entire length of the pulse. If, during subsequent acceleration and beam transport, it is possible to correlate the RF focusing and acceleration with the corresponding part of the bunch, then very low emittance beams could be realized.

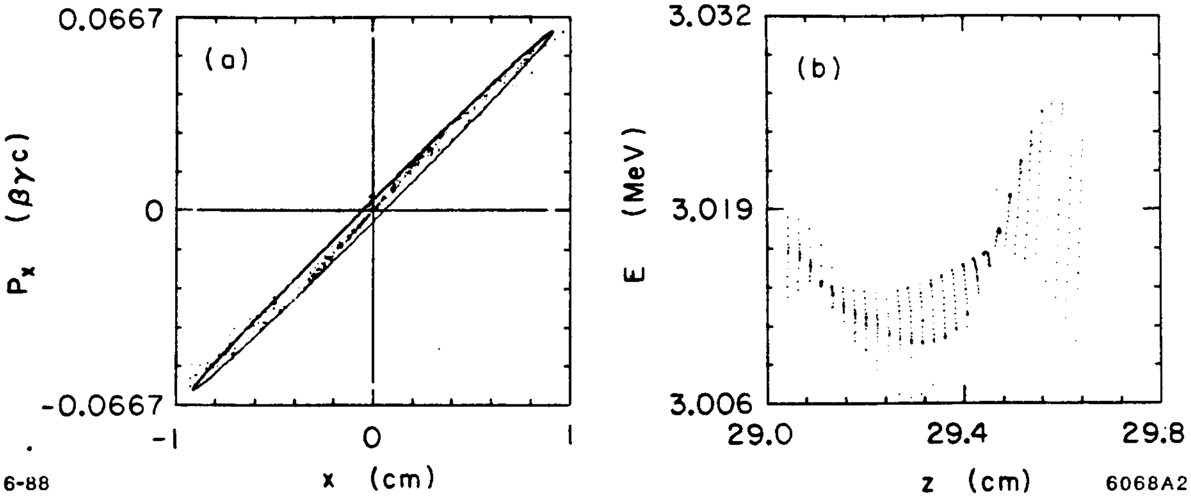

Fig. 2. Transverse and longitudinal phase space for 45 A Peak Current at 30 cm from the cathode.

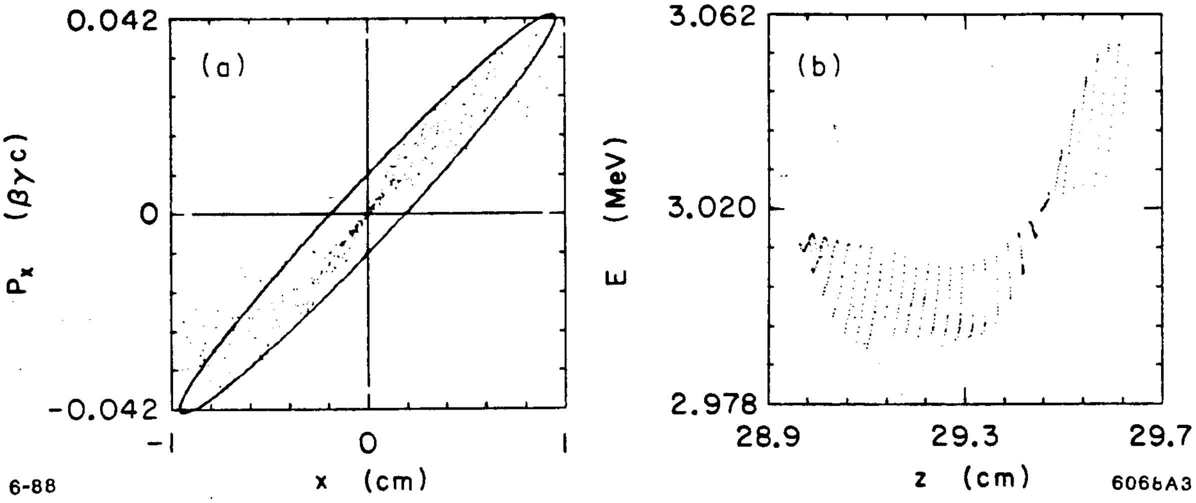

Fig. 3. Phase space calculations for the 160 A Peak Current case.

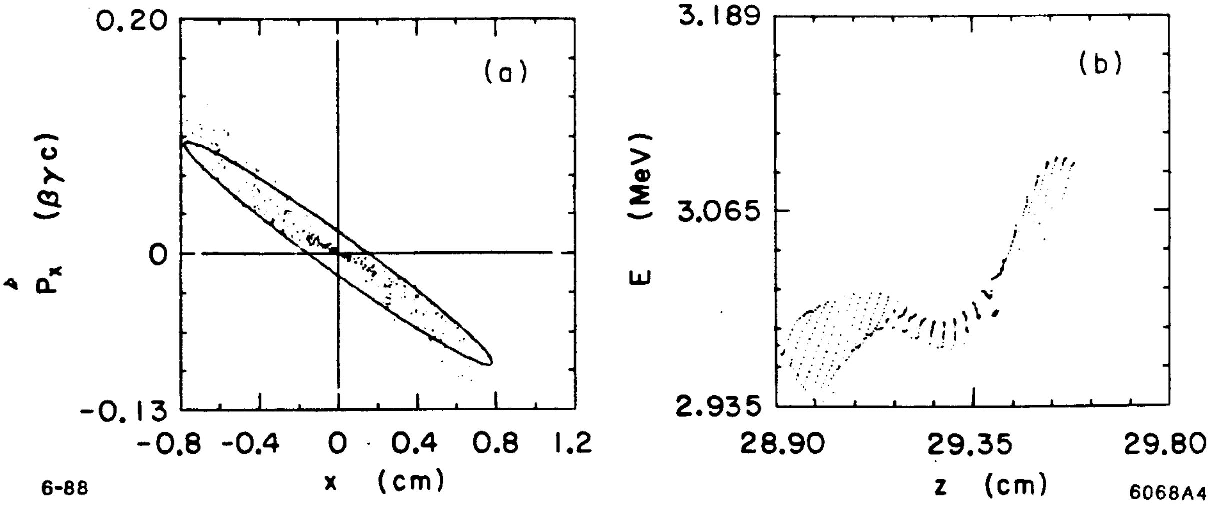

Fig. 4. Phase space calculations for the 340 A Peak Current case.

Figure 3 shows the phase space plots for the middle current case, 160 A peak current at the window, while Fig. 4 is for the highest current case of 340 A.

Table I

Laser Spot Size	R = .55 cm	.41 cm	.27 cm
Coil Current × 1.5			
Peak Current (A)	45	42	44
Charge (nC)	.59	.59	.59
Emittance ($\beta\gamma$ mm-mrad)	33.5	23.6	24.6
Coil Currents × 1.7			
Peak Current (A)	160	155	145
Charge (nC)	2.5	2.5	2.5
Emittance ($\beta\gamma$ mm-mrad)	80.8	67.3	59.3
Coil Currents × 2.2			
Peak Current (A)	340	305	250
Charge (nC)	5.9	5.9	5.9
Emittance ($\beta\gamma$ mm-mrad)	148.2	126.3	123.9

INTERPRETATION

Table I shows the dependence of the calculations on laser spot size. For differing emitted current, the focus coil strength was adjusted as indicated to make approximately the same beam spot size at the pepper pot location, about 40 cm from the photocathode. The emittance calculations and peak current calculations are at an emittance "window" 30 cm from the cathode. The indicated changes in peak current are due to space charge forces that dynamically affect pulse shape, although laser pulse lengths are all 23 ps.

At the higher current levels, the emittance has a weak but consistant dependence on laser beam spot size. This apparently results primarily from the lower emittance that results from a smaller spot size, even though the current density at injection is much higher with the small spot. The effect appears to be saturating as the spot diameter is decreased for the highest current level.

At the lowest current levels, the beam is made fairly small through most of the beam path by the focusing system, since space charge is not a significant force.

CONCLUSIONS

The very good results reported for the photocathode injector are due largely to the presence of over 30 MV/m of RF field on the cathode. If it is desired to achieve equivalent results at a lower frequency, it is important to maintain the highest possible fields. If the fields are reduced a factor of three, then the stored energy per unit volume near the cathode is reduced an order of magnitude, and space charge affects can be expected to become severe. There is still the option of running the injector at a harmonic of the accelerator frequency, if this can result in higher local fields.

To preserve the intrinsic high brightness of a laser photocathode source, it is essential to avoid, insofar as possible, the radial RF fields that affect particles oppositely depending on their position relative to the crest of the RF wave. This can be done by:

1) keeping the beam diameter as small as possible relative to the diameter of the RF structure, and
2) making the pulse length as short as possible.

Both of the above points require very high current density at the photocathode.

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