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Recent Progress in Photo-injectors

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INTRODUCTION

In photoinjector electron guns, electrons are emitted from a photocathode by a short laser pulse and then accelerated by intense RF fields in a resonant cavity. Photoinjectors are very versatile tools. Normally we think them in terms of the production of high electron density in 6-D phase space, for reasons such as injection to laser accelerators, generation of x-rays by Compton scattering and short wavelength FELs. Another example for the use of photo-injectors is the production of a high charge in a short time, for wake-field acceleration, two-beam accelerators and high-power, long-wavelength FELs. There are other potential uses, such as the generation of polarized electrons, compact accelerators for industrial applications and more.

Photoinjectors are in operation in many electron accelerator facilities and a large number of new guns are under construction. The purpose of this work is to present some trend setting recent results that have been obtained in some of these laboratories. In particular the subjects of high density in 6-D phase space, new diagnostic tools, photocathode advances and high-charge production will be discussed.

SLICE EMITTANCE

Any future improvement in the quality of the electron beam of a photoinjector will require sophisticated diagnostics to study in detail the phase space of the beam and provide guidance for multi-parameter adjustment of the photoinjector. The phase space of a short longitudinal slice of the electron beam is particularly important. The slice-emittance technique [1] is such a diagnostic. In this technique, a short slice is selected out of an energy chirped beam by a slit in a dispersive region. The emittance of this slice is measured downstream of the slit using the quadrupole scan technique (or any other method). The measurement is repeated for different slices and for different beam conditions, like a new value for the current in the emittance compensating solenoid.

In the emittance compensation technique, proposed by Bruce Carlsten [2], the observed emittance growth due to linear components of space charge forces in the photoinjector is compensated by passing the electron beam through a laminar-flow beam-waist. The space charge interaction in this beam waist results in a differential rotation of the slice ellipses to bring them into alignment at some point downstream of this waist. To understand this emittance growth and compensation, one has to look at the slice emittance of a number of slices as they evolve.

Figure 1 shows the schematic layout of the slice-emittance measurement diagnostic at the BNL Accelerator Test Facility. It is important to note that the beam is going through the laminar-flow beam waist while it is accelerated by the linac. Thus it is possible to achieve the perfect compensation and freeze the phase space distribution (space charge forces are practically eliminated by the acceleration) to avoid subsequent deterioration. The measured phase-space ellipses of three slices for three values of the solenoid current are shown in Figure 2. The beam bunch length is 10 ps, and each slice is 1 ps wide.

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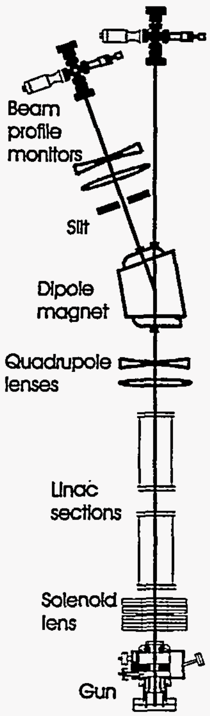

Figure 1. Setup for the measurement of slice emittance at the BNL ATF.

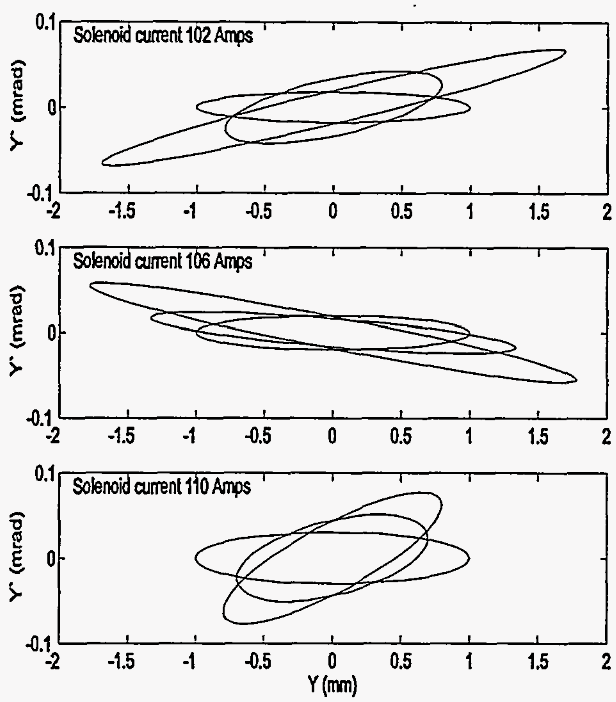

Figure 2. The fitted beam ellipses for the slice emittance measurement. The slice at the end of the beam bunch is taken as a beam waist, showing the relative rotation of the front and middle slices as the solenoid current is increased.

This measurement can be used under conditions in which the linear compensation technique of Carlsten is not adequate. These conditions are expected to occur with higher beam peak currents. It has been analysed by Gallardo and Palmer [3] that there is a large degree of correlation, including non-linear terms in the radial and londitudinal phase-spaces. They suggested that nonlinear emittance compensation techniques can be applied in such cases to produce higher electron beam brightness. The application of non-linear corrections schemes requires the adjustment of more than one parameter. The slice emittance measurement demonstrated here provides the diagnostic tool to observe and control a non-linear emittance correction scheme. We plan to carry out such an experiment, using the longitudinal power distribution of the laser pulse to control the currents of individual slices. The method that has been suggested by Gallardo [4] is control of the laser intensity in 3-D to produce an improved electron beam distribution. Gallardo's discussion did not include the Carlsten laminar beam waist linear correction. If one uses the laminar beam waist technique together with a programmed longitudinal and transverse modulation of the laser's intensity, a much better correction is to be expected with convenient and precisely controlled variables.

MEASUREMENT OF EMITTANCE COMPENSATED BEAMS

A systematic program of measuring the emittance of compensated beams is in progress, using the new BNL/SLAC/UCLA collaboration photoinjector (see gun in Figure 3 and detailed later on). Emittance measurement, in particular that of a very small emittance, is difficult. One problem is the handling of beam halo. In a parametric measurement of emittance compensated beams, one may encounter a difficulty due a limited dynamic range of the frame grabber.

As an example, consider the quad scan measurement of the total emittance as a function of solenoid current. As seen in Figure 4, the emittance initially decreases as expected as a result of emittance compensation. However, the increase in emittance is not as rapid as one would expect. This is the result of a cross over (non-laminar) of some part of the beam. Cross over results a large divergence and the creation of a low intensity beam halo that is not registered by a low dynamic range camera and frame-grabber system. The loss of the halo electrons due to the dynamic range results in a better emittance than should be observed otherwise.

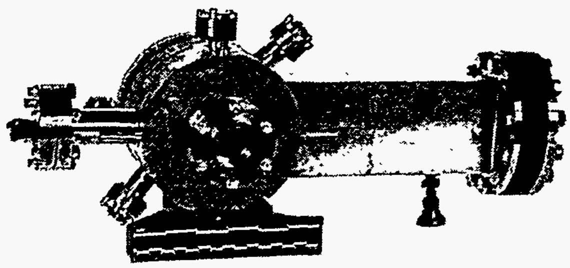

Figure 3. The BNL/SLAC/UCLA s-band photoinjector. The waveguide is at 3 O'clock, symmetrizer and vacuum port at 9 O'clock, laser ports at 1 and 7 O'clock, rf pickup at 12 O'clock.

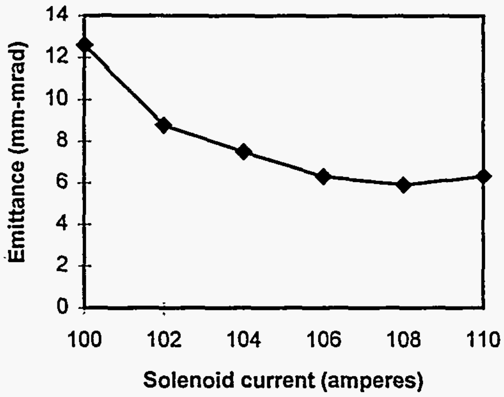

Figure 4. Normalized total vertical rms emittance as a function of solenoid current.

The reason for the cross-over on some low current slices at a large solenoid field and the resultant beam halo can be shown by integrating the envelope equation of the beam in the linac. The relativistic envelope equation of a beam with space charge and emittance is given by:

$$R''+R'\frac{\gamma'}{\gamma}=\frac{2I}{\gamma^3 I_A}\frac{1}{R}+\frac{\varepsilon_n^{\,2}}{\gamma^2}\frac{1}{R^3}$$

R is the local envelope, γ is the energy, I_A is the van Alfven current, I is the local current and ε_n is the normalized local emittance.

The Carlsten emittance correction relies on a laminar flow beam waist, which is described by the envelope equation without the emittance term. We can define a critical beam waist envelope size, R_c by equating the two terms on the right hand side, resulting in:

$$R_c=\sqrt{\frac{\gamma\varepsilon_n^{\,2} I_A}{2I}}$$

A beam waist that is larger (smaller) than the critical size, R_c, is dominated by space charge (emittance). The emittance dominated beam waist leads to a cross over of electrons at that particular slice. Since R_c is a function of the current, the low current slices will cross over while high current ones will maintain a laminar flow.

Now we numerically integrate the envelope equation through the linac. We integrate the equation both with and without the emittance term. For comparison we also plot the critical envelope R_c. We can show that at a low solenoid field the beam waist is larger than R_c even for a small slice current, but at a larger solenoid field low current slices will cross over while high current slices will not (that is will have an envelope size larger than R_c.) The typical values for which we integrate the equation are: Local (slice) normalized emittance: $\varepsilon_n=2\times10^{-6}$ meter radians, initial energy at the entrance to the linac, $\gamma=9$, initial beam envelope at the entrance to the linac $R_0=2.5\times10^{-3}$ meters, accelerating gradient in the linac $\gamma'=14$ meter $^{-1}$.

In the Figure 5 we use an initial beam envelope derivative of $R'_0=3.7\times10^{-3}$ radians (corresponding to a large solenoid field) and a slice current of I=30 amperes. Under these conditions we get a cross over, since the envelope gets smaller than the critical size (at about z=2 meters). Note the large divergence of the beam at the linac exit. Figure 6 shows that with the same R_0' (solenoid field), a higher current of 50 amperes does not cross over, and the divergence of the beam at the end of the linac is markedly smaller. Also the effect of the emittance term is much smaller, as expected for a laminar flow beam waist.

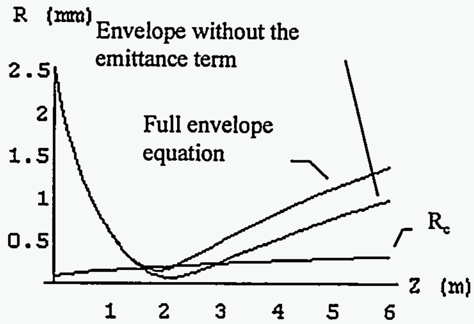

Figure 5. Beam envelope as a function of position for a large solenoid current and a small slice current.

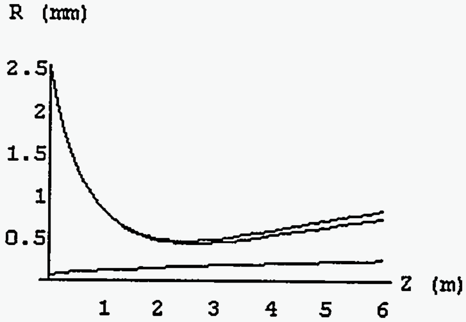

Figure 6. Beam envelope as a function of position for a large solenoid current and a large slice current.

In Figures 7 and 8 have the same beam slice currents, but a weaker solenoid field (initial divergence 2.8 mrad). Figure 7 is for a slice at 30 amps, and Fig. 8 is for 50 amps at the same solenoid setting. Both cases are characterized by a laminar flow beam waist and a small divergence of the beam.

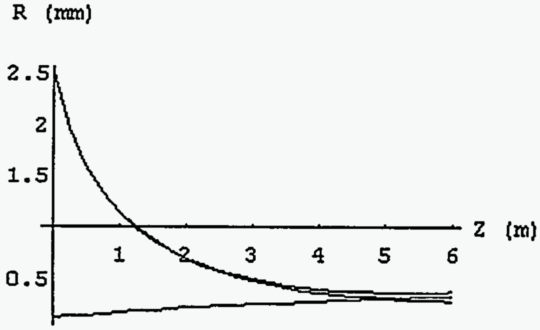

Figure 7. The beam envelope as a function of position for a small solenoid current and a small slice current.

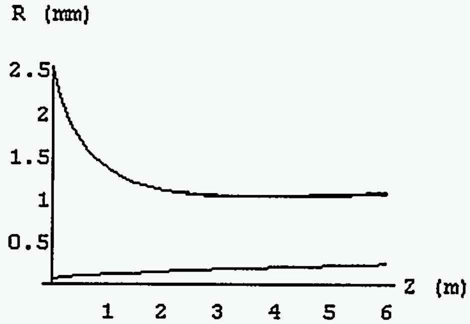

Figure 8. The beam envelope as a function of position for a small solenoid current and a large slice current.

TOMOGRAPHY

By discussing beam ellipses or by making a-priory assumptions concerning the distribution of the beam in phase space in order to fit a quadrupole scan data (or other measurement techniques) to some beam parameters we are loosing a lot of information. As has been shown by McKee, O'Shea and Madey [5], one can apply tomographic techniques to a quadrupole scan and derive the full phase space distribution. This is a powerful technique that, together with the slice emittance measurement technique will provide a greater understanding of the beams of photoinjectors and help improve the performance.

Tomography is being applied at the BNL ATF to gain an understanding of the transverse phase space of the photoinjector. As an example [6], in Figure 9 below we have the recovered x-x' phase space at the end of the ATF linac for a 7ps (full width) electron bunch with a charge of 350 pC.

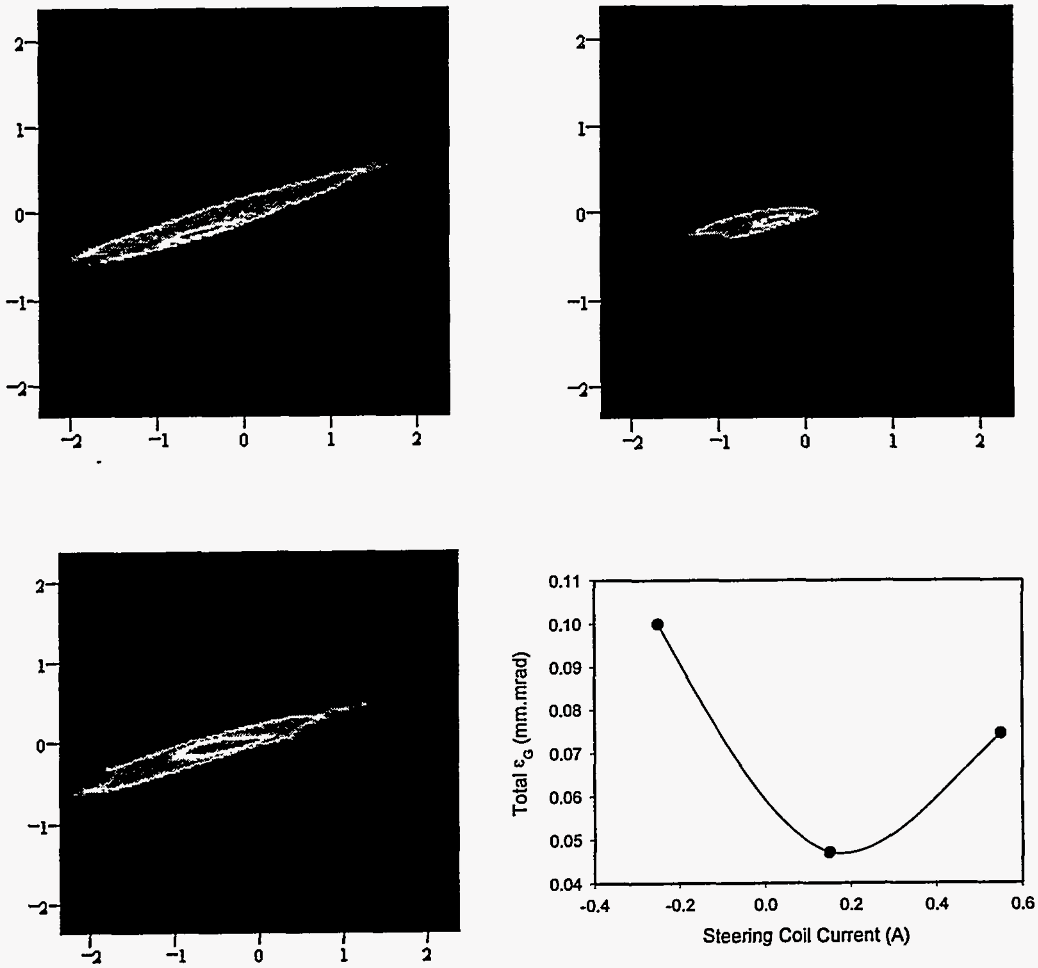

Figure 9. Tomographic measurement of the transverse phase space and a conventional emittance scan for three values of the steering coil in the linac's entrance. In the tomographic phase space plots, electron density is color coded, the vertical axis is divergence in mrad and the horizontal axis is in mm.

MICROBUNCHING

Femtosecond electron bunches that contain a large number of electrons and have small dimensions in the six-dimensional phase space have emerged as a powerful tool for the investigation of transient effects. Extremely short, low emittance electron pulses are of interest to a number of disciplines. Femtosecond pulses of X-ray can be produced by a head-on Thomson scattering geometry of laser light from a femtosecond electron bunch. Such radiation is the most effective probe of structural dynamics of materials on the time scale of the motion of atoms. The best coherence and intensity of the produced X-rays requires electrons with a high density in six-dimensional phase space. Other uses are injection into future linear colliders or laser accelerators and the generation of powerful broad band radiation in the millimeter to Far-Infrared (FIR) wavelength as well as industrial uses, such as lithography.

At Los Alamos, bunch compression has achieved sub-picosecond pulses with charges in the range from 0.1 to 1 nC at 8 Mev [7]. The compression has been done with a chicane magnet. A compression in excess of 40 and peak currents greater than 1 kA has been measured. The method of measurement of the short bunch lengths was spot size increase due to a transversely deflecting rf cavity. The typical normalized rms emittance of the Los Alamos photoinjector is 2.5 mm mrad (however a measurement of emittance under the compression conditions was not reported.). One expects that the low emittance of the photoinjector will be, if not actually preserved, not degraded too much. The measured bunch length as a function of the phase for the Los Alamos result is shown in Figure 10.

Figure 11 shows the measured longitudinal peak current distribution as a function of longitudinal position in picoseconds (which is nearly in degrees of 2856 MHz) for a number of initial laser to rf phases at the BNL ATF gun. The salient feature of this demonstration is that the bunching was done without magnetic compression (no chicane or alpha magnet). For this reason the emittance can be very good even after compression, leading to a high bunch density. In a recent measurement [8], a short, high brightness electron bunch with a 40 pC charge (2.5·108 electrons), has been produced. For this measurement, the laser spot size on the cathode was reduced to 0.4 mm diameter. For the layout of the system one may consult Figure 1. The calculated β function was set to 3 m at the momentum slit. The slit opening was set to the equivalent of 500 fs. With this setting, better than 95% of the charge, or 40 pC, passed through the slit. An emittance measurement was done for this bunch yielding 0.5 π mm mrad normalized rms and the intrinsic energy spread of the beam was $\Delta\gamma_i / \gamma$=0.15% full width. The emittance contribution to the beam size can be shown to be negligible, but the intrinsic energy spread contributes nearly half of the beam size on the momentum slit. Therefore the estimated bunch length (95% charge) is 370 femtosecond. The corresponding peak current is 170 amperes. This is a record 6-D phase-space density.

The 6-D phase space density can be improved by operating the photoinjector in a linear regime of the energy vs. Phase curve. The length of the first cell, (normally the half cell in the BNL gun) has an effect on the linearity of the longitudinal phase space [9], thus the 1.6 cell (and later on the 3.6 cell) design has been adopted by the Grumman-BNL collaboration for its photoinjector (termed Gun II at BNL). In this work it was established that the increased length does not affect the emittance and, incidentally, it leads to a reduction of the peak surface field in the gun so that the highest electric field is attained on the cathode rather on the iris. Therefore this type of gun can be operated at a higher field before breakdown occurs.

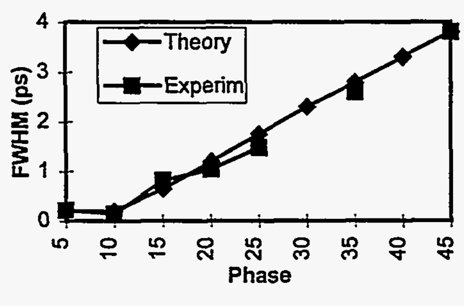

Figure 10. Electron bunch length as a function of the laser to rf phase for the Los Alamos gun.

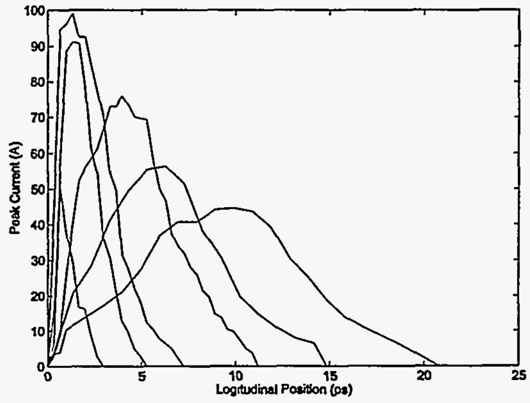

Figure 11. Measured electron bunch current distribution as a function of time for a few laser to rf phases in the Brookhaven gun.

HIGH CHARGE PRODUCTION

A high surface field on the cathode and the high yield of electrons possible by photo emission, permit a very large current density, J ~ 10^4 to 10^5 A/cm^2 [10]. This is much larger than thermionic emission (about 10 A/cm^2). To achieve this it is necessary to have a good quantum efficiency and a large damage threshold for the cathode material. The progress that has been made recently in cesium telluride in various laboratories is very impressive, and this is the material of choice for very large charge production. This material is reasonably stable and provides quantum efficiencies of 2-3% in a routine manner. Good reviews on this subject are given by Guy Suberlucq and by Paolo Michelato [11]. However, this is not necessarily the case for single bunch production.

A very high-charge photoinjector is the Argonne Advanced Wake Accelerator [12], where charges in a single pulse of up to 100 nC have been achieved using magnesium cathodes. The Schottky effect can enhance the quantum efficiency tremendously if the cathode is operated at a high electric field. A high field operation is a must in order to avoid space charge limits. The Child-Langmuir Law, (in an approximate expression for two infinite plane parallel electrodes and a short pulse) relates the charge density q/A in nC per cm^2 to the electric field E in MV/m by $q/A=0.885E$. Therefore it is natural to design a high field photoinjector for high charge operation. Indeed the ANL gun operates at 100 MV/m even though it is an L-band gun. The emittance of this gun is quite good for this high charge. Figure 12 shows that at 70 nC charge the pulse length is under 50 ps (more than 1.4 kA current!). The measured emittance at this charge is 20 mm mrad.

The CLIC photoinjector has a somewhat different objective than the ANL device, that is to generate high frequency rf (transferring energy in a resonant structure). For this purpose a high charge in a bunch train is required. The 1 ½ cell S-band CLIC photoinjector together with a four cell booster have successfully accelerated a bunch train of 48 bunches containing 450 nC (!) to a beam momentum of 9.5 MeV/c [13]. The maximum charge for a single bunch was 35 nC with a bunch length of 16 ps, more than 2 kA! With an intense bunch train beam loading can lead to a bunch-timing error as a result of the change in field before the electrons become relativistic. The CLIC team is designing a special multi-mode gun that will minimize the this timing error.

An novel system, based on a pulse transformer, is in operation at BNL. This table-top device has demonstrated electric fields of up to 1000 MV/m over a gap of 1 mm with a flat top of the order of 1 ns (see scope trace in Figure 13) and very little dark current. This is a unique ultra high electric field test bed. In addition it holds the promise of ultra-high charge extraction and a good emittance (no rf effects). Photoemission of 3 nC has already been demonstrated [14] at a reduced gradient of 150 MV/m, and the synchronization of the high voltage pulse with the laser is already better than 0.5 ns. The rather compact device is shown in Figure 14.

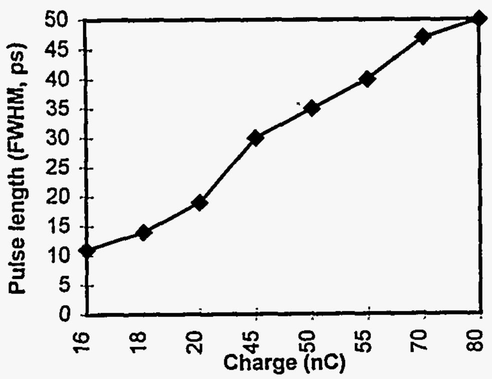

Figure 12. Pulse length as a function of charge for the Argonne gun.

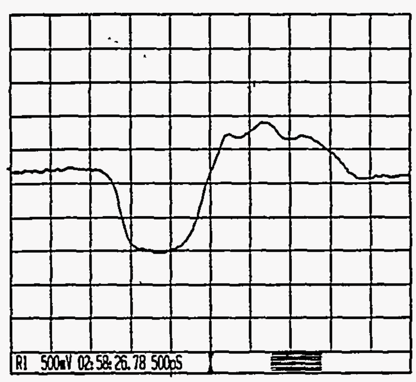

Figure 13. A 1 MV over 1 mm gap pulse, 1 ns flat top, 150 ps rise time for the BNL pulsed gun.

THE BNL/SLAC/UCLA COLLABORATION PHOTOINJECTOR

Using expertise and resources of a number of laboratories can facilitate the development of a new photoinjector at low cost and improved performance. Such a collaboration was started a few years ago [15] and led to the construction and testing of one prototype, with three production guns nearing completion. The salient features of this gun (shown in Figure 3) are 1.6 cell, 2.856 GHz, high degree of symmetry, replaceable cathode with the joint at the low electric field rim of the fractional cell, increased aperture, simplified machining and precision mount. The solenoid has been also extensively modified as compared to previous BNL guns. It is a single, iron enclosed solenoid with a careful conductor design, includes fields straightners, has a high degree of symmetry and made to exacting tolerances.

The design and handling of the gun have been successful in obtaining a very high electric field on the cathode with a relatively short conditioning. The gun has been operated stably as high as 150 MV/m peak field on the cathode and operation at fields of 120 to 130 MV/m is routine.

Following the gun production a User's Experiment was started at the ATF to characterize the gun in great detail and compare its performance various many parameters to numerical simulations. Initial results of this program are reported in this workshop [16]. One of the systematic measurements is the emittance as a function of charge shown in Figure 15. This curve was taken at a constant solenoid current of 106 amperes (the solenoid was not optimized for each charge), phase of 45 degrees, gun field of 120 MV/m, laser spot size of 2 mm diameter, laser pulse length of 10 ps and at a final linac energy of 40 MeV. The charge could not be taken above 450 pC at the time due to a laser power limitation. The emittance is in agreement with what is expected from simulations given that the longitudinal intensity of the laser is Gaussian and not uniform. With a flat-top laser distribution one would expect an emittance of 1 mm mrad at 1 nC charge.

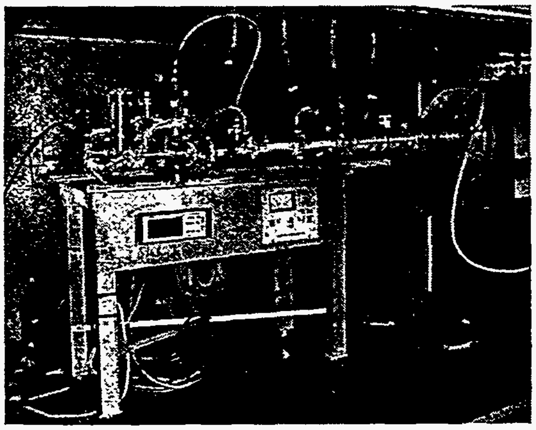

Figure 14. A photograph of the compact GV/m pulsed photoinjector at BNL.

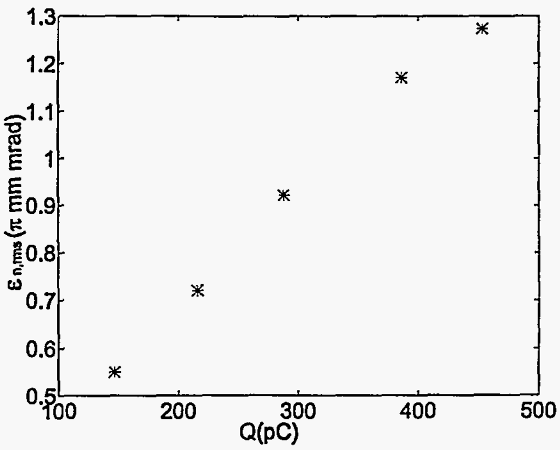

Figure 15. Normalized rms emittance as a function of the bunch charge for the BNL/SLAC/UCLA gun.

FUTURE DIRECTIONS

Where should we go from here? A list (not prioritized) of needed developments can be easily made:

- Non-linear emittance correction, with the objective of maximizing the transverse brightness.
- Compression studies, with the objective of maximizing the longitudinal brightness.
- Systematic parametric measurement of photo-injectors and comparison to simulations.
- Measurement of the thermal emittance for various emitters to establish the lower limit of emittance.
- Tomographic analysis of the six dimensional phase space of the electron bunch.
- Research of the emission properties of the photocathode.
- Development of superconducting photo-injectors.
- Development of polarized electron photoinjectors.
- Multiple RF frequency photo-injectors for improved brightness.
- Improved lasers for photo-injectors with the objective of further improvement in stability.

We need an exhaustive set of measurements exposing the dependence of emittance on the relevant gun and laser parameters such as phase, electric fields, laser spot size, laser pulse length, solenoid setting, and charge. These measurements should be carried out for both integrated and slice emittance to gain a complete understanding of the photoinjector. Experimental work aimed at this goal is now in progress as a user experiment at the BNL ATF. [16] Such a parametric study would not be complete or even completely meaningful unless the complete six dimensional phase space of the gun is measured (four dimensions if one can assure cylindrical symmetry) using tomographic techniques. This would be the only way to gain true understanding of the various emittance growth mechanisms and possible trade-off among parameters.

Non-linear emittance compensation would be most rewarding research in terms of potential improvement of the beam brightness. This direction has been made possible by the advent of the slice-emittance diagnostic technique. Non-linear compensation can be done longitudinally by shaping the longitudinal power distribution of the photocathode laser. Transverse compensation can be done by shaping the transverse distribution of the laser power. Ultimately both longitudinal and transverse correction must be made simultaneously.

Bunch compression in and immediately following the photoinjector has been achieved recently. Partial compression of the electron bunch at his early stage can be important for the following reasons: Simulations show that the optimal bunch length under emittance compensation conditions is relatively long - enough so that energy spread due to the curvature of the linac RF wave-form and transverse wake-field emittance growth may be a problem. A reduction of the bunch length immediately following the gun will help. It is very desirable to avoid magnetic compression at the low energy of the photoinjector. Emittance compensation under such compression has to be studied.

The emission properties of the photocathode covers many areas requiring extensive R&D. The thermal emittance of photocathodes has to be measured and its dependence on the photocathode material studied. We must continue the study various photocathodes to improve the quantum efficiency and robustness. A better understanding of the Schottky effect, the field enhancement coefficient, the work function and quantum efficiency for the common cathode material such as copper, magnesium, cesium telluride is necessary. It is possible that materials that combine a better combination of high quantum efficiency and robustness than what we have now will be discovered.

A collaboration between SLAC and CERN has started to develop galium arsenide photoinjectors [17]. The motivation is to make a high brightness source of polarized electrons for future linear colliders The status of this work is that a cesiated GaAs crystal was mounted and tested in a CLIC S-band photoinjector and taken up to an electric field of 50 MV/m. The gun conditioned very rapidly to 50 MV/m with surprisingly little dark current and some photo-emission was observed. This is a very promising direction for photoinjector R&D.

REFERENCES

[1] X. Qiu, K. Batchelor, I. Ben-Zvi and X.J. Wang, Demonstration of emittance compensation through the measurement of the slice emittance of a 10 picosecond electron bunch, Phys. Rev. Let. 76 No. 20, 3723, (1996) BNL 62386

[2] B.E. Carlsten, New Photoelectric Injector Design for the LANL XUV FEL Accelerator, Nucl. Instr. And Meth. In Phys. Res. **A285**, 313 (1989)

[3] J.C.Gallardo and R.B.Palmer. Preliminary Study of Gun Emittance Correction. IEEE Journal **QE-26** 1328-1331 (1990)

[4] J.C.Gallardo, Control of non-linear space-charge emittance growth, Brookhaven National Laboratory Report BNL-522246, BNL Center for Accelerator Physics Report CAP 58 -90R

[5] C.B. McKee, P.G. O'Shea and J.M.J. Madey, Phase Space Tomography of Relativistic Electron beams, Nucl. Inst. And Meth. In Phys. Res. **A358**, 264 (1995)

[6] X. Qiu, private communication.

[7] Bruce E. Carlsten and Steven E. Russell, Phys. Rev. **E53**, Rapid Communication, R2072,(1996)

[8] X.J. Wang, X. Qiu and I. Ben-Zvi, Experimental Observation of High-Brightness Micro-Bunching in a Photocathode RF Gun To be published in Phys. Rev. E Rapid Communications

[9] I.S. Lehrman, I.A. Birnbaum, S.Z. Fixler, R.L. Heuer, S. Siddiqi, I. Ben-Zvi, K. Batchelor, J.C. Gallardo, H.G. Kirk, T. Srinivasan-Rao, Design of a High Brightness, High Duty Factor Photocathode RF Gun, Nuclear Instruments & Methods in Physics Research A318,247 (1992)

[10] T. Srinivasan-Rao, J. Fischer and T. Tsang, Journal Appl. Phys. **69**, 3291 (1991).

[11] G. Suberlucq, Development and Production of Photocathodes for the CLIC Test Facility.
P. Michelato, Photocathodes for RF Photoinjectors. Both papers presented in the 1996 International FEL Conference, Rome August 26-31, 1996. To be published in Nucl. Instr. And Meth. In Phys. Res. **A.**

[12] W. Gai, M. Conde, G. Cox, R. Konecny, J. Power, P. Schoessow, J. Simpson and N. Barov, Performance of the Argonne Wakefield Accelerator Facility and Initial Experimental Results, presented in the 1996 International Linac Conference, Geneva August 26-31, 1996.

[13] R. Bossart, H. Braun, M. Dehler and J.-C. Godot, A 3 GHz Photoelectron Gun for High Beam Intensity, CLIC Note 29, PS/RF Note 95-25, CERN, Switzerland.

[14] T. Srinivasan-Rao and J. Smedley, Tabletop, Pulsed Relativistic Electron Gun with GV/m Gradient, these proceedings.

[15] The collaboration was initialized between I. Ben-Zvi, (BNL), C. Pellegrini, (UCLA) and H. Winick, (SLAC). X.-J. Wang (BNL) is leading the gun development and measurements. The production and measurement of the gun are part of the Ph.D. thesis of D. Palmer advised by R. Miller (SLAC). The engineering at BNL was done by J. Sheehan K. Batchelor (microwave) M. Woodle (gun-mechanical) and J. Skaritka (solenoid and instrumentation). K. Halbach's help in the solenoid magnetic design is gratefully acknowledged.

[16] D.T. Palmer, X.-J. Wang, R.H. Miller, I. Ben-Zvi, C. Pellegrini, J. Sheehan, J. Skaritka, H. Winick, M. Woodle and V. Yakimenko, Commissioning Results of the Next Generation Photoinjector, these proceedings.

[17] K. Aulenbacher, R. Bossart, H. Braun, J. Clendenin, J.P. Delahaye, J. Madsen, G. Mulhollan, J. Sheppard, G. Suberlucq and H. Tang, CLIC Note 303 , CERN, Switzerland, and NLC Note 20, SLAC-Stanford, CA, May 1, 1996.