PARAMETER OPTIMIZATIONS FOR VACUUM LASER ACCELERATION AT ATF/BNL[*]

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Abstract

The major difficulty in using laser fields in the vacuum to accelerate the electrons is that its phase velocity of the electric field for accelerated electrons is faster than the speed of light when the electrons travel over long distance larger than 3 times the laser Rayleigh length. Its acceleration length can be defined with simple optics. In order to get the higher energy gain at ATF/BNL, the laser parameters and related electron beam are analytically investigated. The experiment specifics require an extremely small electron beam size. Achieving and measuring such small beams present a real challenge. The vacuum laser acceleration experiment will be conducted at the Brookhaven Accelerator Test Facility (ATF), using its high-power CO2 laser and tiny focused electron beam. An energy gain of the order of 0.5 MeV is expected.

1 INTRODUCTION

The acceleration of the electron beams with the laser was successfully demonstrated at ATF in inverse Cherenkov as well as inverse FEL acceleration principals. CO2 laser was utilized in both experiments at ATF. We plan to use the upgraded CO2 laser that will produce shorter pulses, for experimental test of laser acceleration in the vacuum. The advantage of using a CO2 compare to solid-state laser for acceleration is the fact that all dimensions of the components scaled linearly with wavelength. The difficulty of the aliment of the "invisible" laser is well compensated by the 10 times less rigid requirements for the CO2 laser as well as an extended experience with the CO2 laser at ATF.

We work in three directions in order to prepare for the experiment:

1. Electron beam emittance and focusing improvement to produce a small enough beam.
2. Current CO2 laser upgrade to produce 30 ps and 1 ps CO2 pulses later. Gain experience in synchronization of the short CO2 and electron beams.
3. A computer simulation of the experiment to simulate the acceleration process

Our current progress in each of those directions will be described below.

2 ACCELERATION SCHEME

The optical scheme that we are going to form a right laser beam for the vacuum accelerator consists of

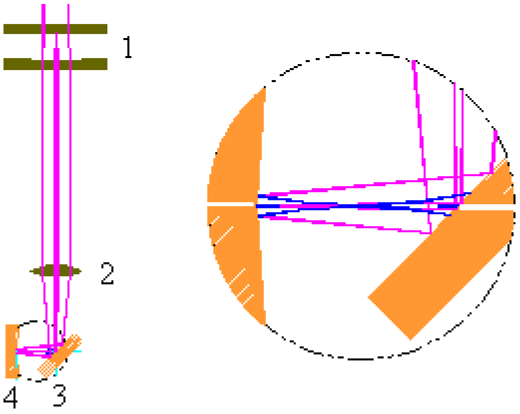

Figure 1 Vacuum acceleration scheem.

1. axicon telescope to form an annual beam.
2. spherical lens to increase diversions.
3. turning mirror with 100 μm diameter hall in the middle to path the electron beam
4. 65 mrad focusing axicon with 100 μm diameter hall in the middle to path the electron beam

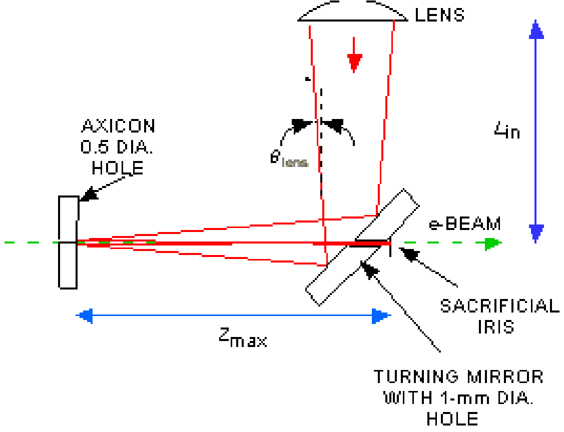

Figure 2 Modified scheme with "sacrificial" iris

We plan to use a radially polarized CO2 beam. The disadvantage of this scheme is the high divergence of the CO2 beam. This is necessary to overcame any optic damage on the axicon and the turning mirror surface for the current length of the CO2 pulse. Further improvements of the CO2 laser will directly address this problem.

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The modification of this scheme was suggested to overcome this problem with the use of sacrificial iris to terminate CO2 beam. CO2 pulse divergence can be optimised for acceleration without constrain of the large laser beam at the axicon locaion.

3 CO2 LASER BEAM

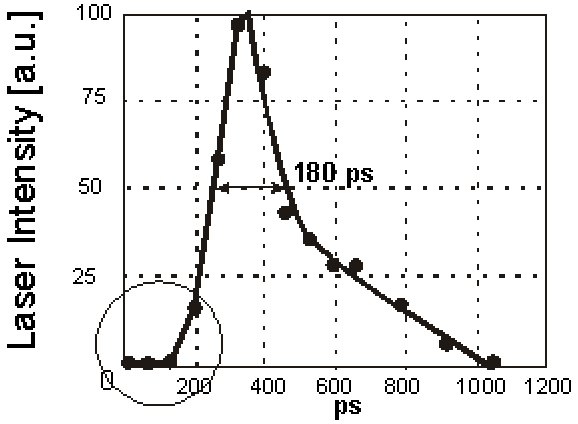

Figure 3 Measured time profile of the CO2 beam after preamplifier.

Recently upgraded with a high-pressure, big-aperture booster amplifier, the ATF CO2 laser system delivers up to 6 J in 180 ps (FWHM) pulse (see Fig. 3). The system has a potential for considerable pulse shortening that will allow delivering to the IP stronger laser intensity without damage of the accelerating structure. As the first step in this direction, we will explore a possibility of amplification of the 30 ps pulse sliced before the booster amplifier with a plasma shutter (see Fig.4).

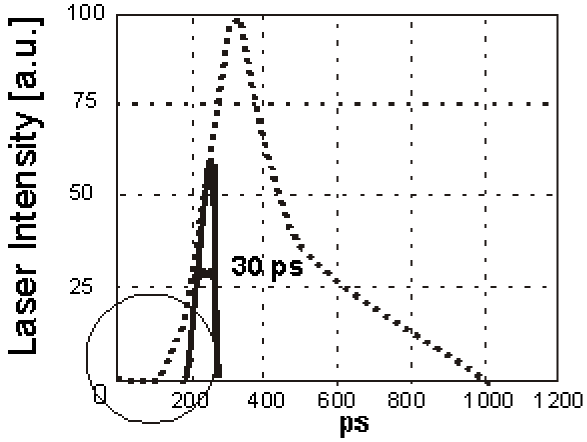

Figure 4 Expected laser profile after plasma shutter and saturable absorber.

After replacing the presently operated low-bandwidth laser preamplifier with a high-pressure laser, the output will reach subterawatt level in the 15 ps pulse. Future plan calls for replacement of the presently operated 14 ps Nd:YAG laser with a subpicosecond laser. This opens a prospect for slicing and direct amplification of 1 ps CO2 laser pulses to the 10 TW level.

4 ULTRA SMALL β-FUNCTION FOCUS

The experiment was done on ATF beam line 1. Produced by photoinjector electron beam, get accelerated by linac to 50 MeV and transported through straight focusing channel after that, deflected into despertion line and finally into experimental beam line 1. Dispersion compensated before beam line but energy and energy spread continuously monitored in the nonzero dispersion region.

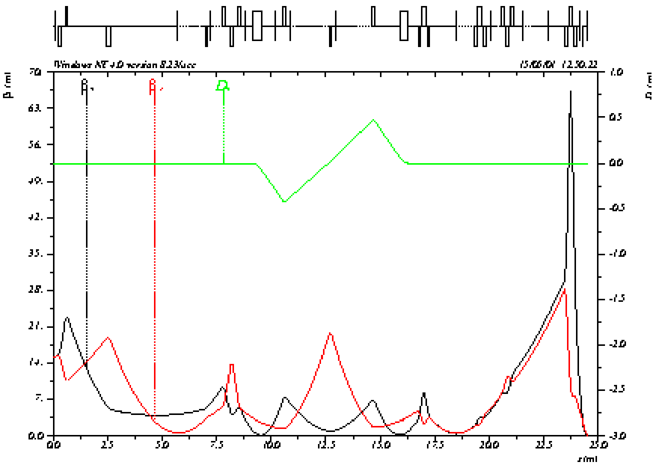

Figure 5. Transport optics from linac exit till beam profile monitor.

Initial tuning of beam line was done by measuring beam size on multiple beam transport line and fitting with calculations.

First triplet beam line 1 forms waist on the next beam profile monitor. Well-controlled and reproducible starting point for the rest of the transport line was obtained this way.

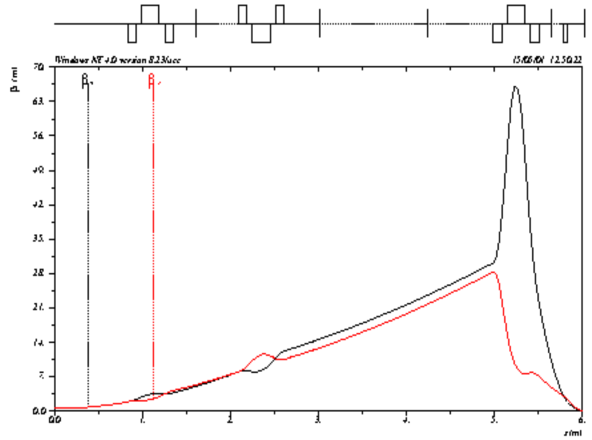

Figure 6. Last 6 m of the beam transport line.

Figure 2 shows the rest beam line 1. It forms telescopic demagnification with 5:1 ratio. Less then 2 cm β-function in both planes produced at the end. Betatron phase advance was optimised to be exactly 180 degrees in both horizontal and vertical planes. That simplifies fine-tuning this portion of transport by measuring response matrix. Last quadrupole before final target is permanent magnet in-vacuum design. This allowed having it 20 cm from the target and therefore dramatically decreased chromaticity of the final focus. The strength of the last two quadrupoles was noticeably adjusted compare to simulation to achieve smallest possible size. That can be explain by strong space charge effect.

Linac phase jitter was producing small increase in the energy spread and immediately was increasing beam size on the final target. We did not see beam size change on the rest of beam line 1 monitors. This confirms fact that dispersion was well compensated but the variation of beam size with energy-spread change confirms simulation prediction that chromatic effects were comparable for ultra small β-function case. We did not have any sextupoles in the nonzero dispersion region to compensate chromaticity of the final focus focusing.

5 NUMERICAL SIMULATIONS

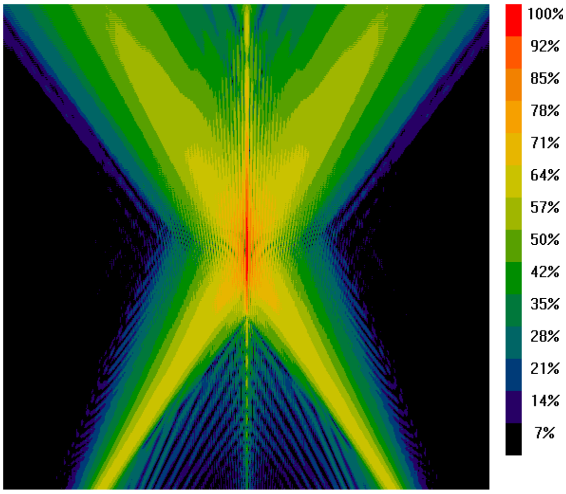

Figure 7 Intensity Plot Shows Axicon Focal Region (5 decade log scale)

The simulation of the laser propagation is performed with the physical optics code General Laser Analysis And Design (**GLAD**) version 4.6 from Applied Optics Research. The diffraction of the optical field is calculated in the paraxial approximation by a scalar theory. Each field is represented by a 2D array with phase and intensity components. Using FFT to convert the beam array to the frequency domain, a simple propagation operator can be used to calculate the beam distribution at any given distance from the initial input. The inverse FFT then converts back to the intensity domain. Optical elements can be represented by phase and intensity modifiers and used in arbitrary combination with the diffraction operator.

An input file representing the optical elements of the vacuum accelerator experiment is used to generate the plot of beam intensity in the interaction region shown above. The horizontal axis is a transverse slice through the beam, and the vertical axis is the distance between the two mirrors. The beam propagates from top to bottom, and the crossing at the interaction point clearly shows a region of high intensity. The corresponding plot showing the phase has a very large variation through the interaction region of about 10 waves. To minimize this phase variation, an additional spherical lens and slight variation in the second lens of the axicon angle in the telescope was used. Although the reduction of the phase variation may improve the acceleration, it is necessary to calculate the longitudinal electric field component. This will require extension of the simulation code to provide true 3D propagation. Different approaches to achieve this are under consideration.

6 CONCLUSION

Electron beam parameters measured and optimised for the laser acceleration experiment. The laser beam focusing scheem is optimised for vacuum laser acceleration based on the current CO2 performance. Optical simulation with standard optical code will include longitudinal field integration. Its real beam experiment is to be tested at ATF very soon.

7 REFERENCES

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