THE NEPTUNE FACILITY FOR 2nd GENERATION ADVANCED ACCELERATOR EXPERIMENTS

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ABSTRACT

The NEPTUNE Laboratory, under construction at UCLA, will be a user facility for exploring concepts useful for advanced accelerators. [1] The programmatic goal for the laboratory is to inject extremely high quality electron bunches into a laser-driven plasma beat wave accelerator (PBWA) [2] and explore ideas for extracting a high quality $\Delta E/E < 0.1$, $\varepsilon_n < 10\ \pi$ mm-mrad), high energy (100 MeV) beam from a plasma structure operating at about 1 THz and about 3 GeV/m. The lab will combine an upgraded MARS CO_2 laser and the state-of-the-art SATURNUS RF gun and linac. [3] The new MARS laser will be about 1 TW (100 J, 100 ps), up from 0.2 TW (70 J, 350 ps). This allows for doubling the spot size at the IP and quadrupling the interaction length while still driving gradients of 3 GeV/m. The SATURNUS gun will be upgraded to the Brookhaven 1.6 cell design. [4] A novel, multi-cell Plane-Wave Transformer (PWT) RF gun is also under development. [5] A sync-pumped, sub-ps dye laser is available to directly produce ultrashort electron pulses (1/5 of an accelerating bucket). Part of the research program will be devoted to studying pulse compression [6] and phase-locking techniques at these ultrahigh frequencies and diagnosing microbunches generated by such structures. [7] Finally, shaped electron pulses will be studied for the electron driven Plasma Wakefield Accelerator (PWFA) concept.

1 INTRODUCTION

In the previous 10 years, many experiments have demonstrated the “proof-of-principle” of high-gradient laser- or electron-beam-driven plasma accelerators. [1] In fact, accelerating gradients as high as hundreds of GeV/m have been inferred in the high-density laser/plasma experiments. [9] But for applications to high energy physics (HEP), the main question regarding plasma accelerators is no longer will if they work in principle but rather, what can plasma accelerators deliver in terms of beam quality and numbers of electrons per bunch. We refer to experiments of this type as “second generation” plasma accelerator experiments which begin to deal with the structural aspects of the plasma accelerator and its control. These experiments will take place in the new NEPTUNE Laboratory currently being outfitted with electron and laser beam apparatus. The new lab is essentially the combination of two separate state-of-the-art facilities at UCLA: namely the MARS Laser Laboratory where the 0.2 TW CO_2 MARS Laser has been used for a series of PBWA experiments and the SATURNUS Accelerator Laboratory where an extremely high brightness RF gun and PWT linac has been used in plasma lens [10] and FEL experiments [11]. The contents of these two labs are being upgraded and combined.

In this paper we will briefly describe the changes being made to the MARS Laser and to the SATURNUS beamline to improve their respective performance levels.

2 MARS LASER UPGRADE

The purpose of this upgrade is two-fold. First, a means of synchronizing the CO_2 pulse, and hence the accelerating structure, to the electrons from the photocathode is required Secondly,. more laser power is needed to drive plasma waves over a longer interaction length. The former is accomplished through a new “front-end” to the laser while the second latter is primarily accomplished using a new preamplifier prior to the large-aperture final amplifier.

2.1 The Front End

In the prior configuration of the MARS laser, a technique called Optical Free Induction Decay (OFID) was used to generate sub-100 psec pulses to inject into the amplifier chain. This passive, experimentally simple technique was adequate since the electron source was a pulsed X-band magnetron driven linac. There was no control over the startup phase of the magnetron so no attempt was made to phase-lock the micropulses from the linac to the peak of the PBWA as it grew in time. The 107 psec separation of the micropulses was short enough to ensure that some electrons would interact with the PBWA on most shots, [2] although the probability of hitting the peak amplitude of the PBWA in time was < 1 in 10 shots.

The fix is to use active optical switching of the CO_2 oscillator pulse, using the same 1 μm wavelength, 70 psec pulse from Nd:YAG laser to both switch out a 100 psec CO_2 pulse and, after pulse compression down to 3 psec and frequency converting into the UV, to liberate the electrons from the photocathode. The 1 μm pulse can act as a switch for the 10 μm CO_2 pulse by forming a

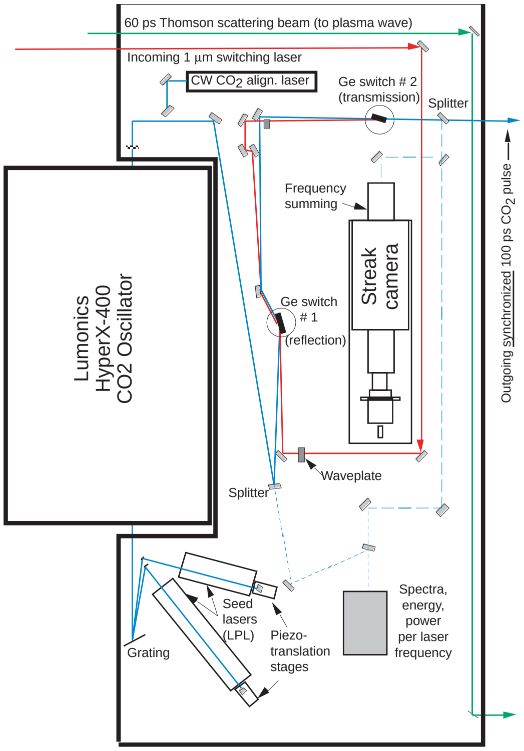

Figure 1: Schematic of the front end of the upgraded MARS laser.

transient solid-state plasma on two pieces of germanium set at Brewster's angle for the CO_2. This technique, know as semiconductor switching, is currently used at the ATF at Brookhaven. Now, by simply translating an optical delay line, one can ensure that the few psec electron bunch from the photocathode will always interact with the peak fields of the PBWA, approximately 60 psec after the CO_2 beam reaches the interaction point.

Another dramatic improvement, already tested and ready for implementation, is to uses a 3-mirror oscillator cavity for generating the required 2-frequency pulse for the beat wave. Essentially, each frequency will have its own cavity by using a grating to send the two frequencies to two separate rear mirrors as shown in Fig. 1. The two cavities share the same energy-storage gain section (a TEA laser) but have individual low-pressure (seeding) lasers (LPL). This eliminates gain competition since each cavity is separately seeded with the appropriate laser frequency and both can extract energy from the TEA laser. This will stabilize the shot-to-shot ratio of the two frequencies.

2.2 CO_2 Preamplifier

The old MARS laser used a one atmosphere, double-passed preamp followed by a 2.5 ATM, triple-passed power amplifier. Most of the pulse stretching (3 ×) of the original sup-100 ps OFDI pulse occurred in this preamp. The new laser will use a 10 ATM preamp run in the "regenerative amplifier" mode. Now, pressure-broadening will support the short pulse. In this mode, the pulse is electrooptically switched into an optical cavity containing the gain medium and after about 10 round trips, the pulse is switched out with no degradation of the pulse shape and duration. Also, due to the large number of passes of the preamp, the power is high enough that the final, now 3 ATM, large aperture amplifier need only be double-passed to achieve the 1 TW goal. Making fewer passes on the 3 ATM section will ensure that the pulse will remain short.

3 SATURNUS BEAMLINE

The Saturnus photoinjector has recently been decommissioned following successful running for SASE FEL[11] and high brightness beam dynamics[12,13] experimentation. Most of the Saturnus beamline, rf and control hardware has been transferred from its previous location in the Physics Dept. to the Neptune Laboratory. In order to bring the injector on line as expeditiously as possible, we have made a few important improvements in its design, and developed needed new facilities and diagnostics.

3.1 The photoinjector and LINAC

The injector itself presently consists of 1.5 cell BNL rf gun, with a plane wave transformer[3] (PWT) linac, run in an emittance compensation mode. Before recommissioning, we will incorporate a new rf photocathode gun, the next-generation 1.625 cell BNL/SLAC/UCLA gun[4], which, with additional improvements we have made on our emittance compensation solenoids, should yield state-of-the-art emittance performance at Neptune when run at over 100 MV/m peak on-axis field. The PWT linac, which is a very high *Q* device, is being accommodated at Neptune by the development of a longer pulse rf system (5 μsec, vs. the present 3 μsec rf flat-top) in order to completely fill the linac and, along with the improved gun extend the energy range of the injector from 14.5 to 17 MeV.

3.2 The beamline

The beamline itself will be augmented by the introduction of a chicane compressor[6], as shown in Fig. 2, which can be employed to create ultra-short beams for injection into the PBWA experiment, and ultra-high current beams for driving high gradient plasma wake-field acceleration (PWFA) experiments in the blow-out regime[14]. As a PBWA injector, the photoinjector/chicane complex has the desirable effect of suppressing the timing jitter (caused by the injection laser jitter) between the electron emission and the rf wave. The properties of the beam predicted by PARMELA simulations in the various modes of operation discussed are shown in Table 1.

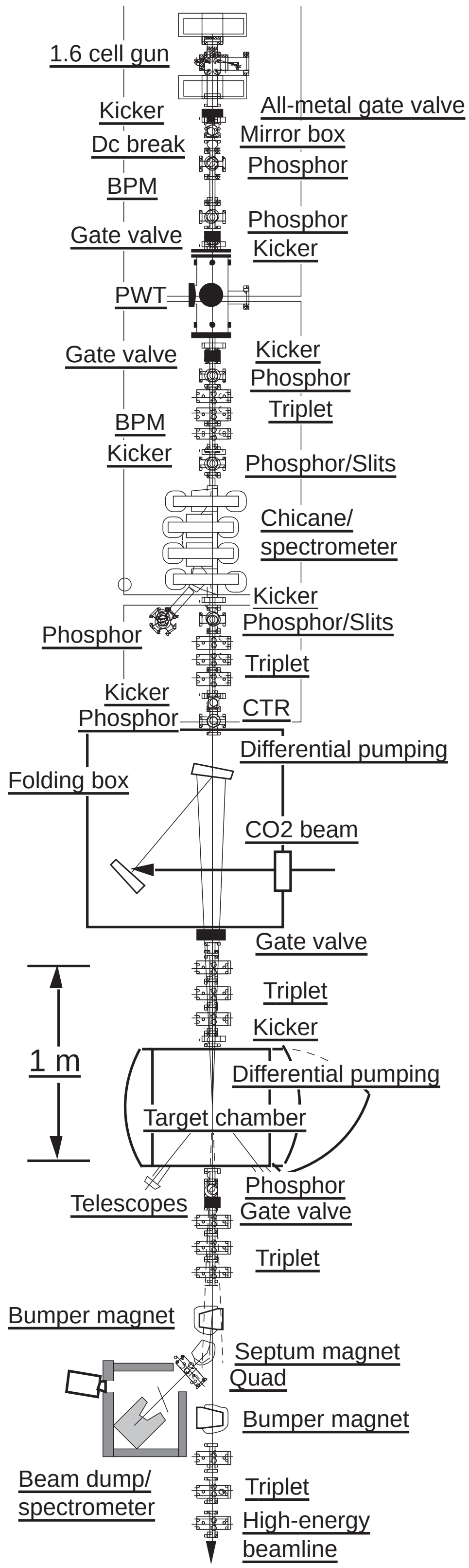

Figure 2: Schematic of the new beamline and PBWA experimental area. The “Folding box” contains a mirror with a small hole to facilitate bringing the electrons collinear with the two-frequency laser.

Mode	High Q	Low Q	High Q (compr.)	Low Q (compr.)
Q	1 nC	015 pC	8 nC	15 pC
σ_z	1 mm	300 µm	130 µm	42 µm
ε_n	**1 mm-mrad**	**.06 mm-mrad**	**50 mm-mrad**	**0.2 mm-mrad**

Table 1. Predicted performance of the Saturnus photoinjector at Neptune for various modes of operation.

The beam diagnostics for the photoinjector yield on-line information on beam energy (spectrometer, kicker scans), emittance (pepper pot/slit system), charge (integrating current transformer - ICT - Faraday cups, BPM sum signal), beam profile and position (phosphor and transition radiation screens, BPM difference signals) and bunch length (coherent transition radiation - CTR - and streak camera). The longitudinal diagnostics are the most challenging, in that we must diagnose beam structure well below 1 psec at Neptune. This is to be accomplished by CTR, for both macrobunch[c] and microbunch[h] structure, by autocorrelation, and spectral measurements, respectively. All diagnostics and beamline processes are controlled by a Power Macintosh running LabVIEW 4 which directs a GPIB local network (CAMAC crates/modules, digital oscilloscopes, etc.).

3.3 PWT LINAC

A new injector for Neptune, which is an integrated gun/linac of 11.5 cells based on the PWT structure, is now under construction by a UCLA/Duly Research collaboration[5]. This device will produce 20 MeV emittance compensated electron beams with the potential to create 50 µm long bunches without pulse compression. It is planned to perform SASE free-electron laser experiments using short beams created by both this injector and using the compressor in a 2 m long 100 period, 6 kG undulator. These experiments will clarify the role of slice emittance and emittance growth in bends as they apply to the FEL gain process.

4 ACKNOWLEDGMENTS

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