WORKING GROUP ON PLASMA ACCELERATORS: STATUS REPORT

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I. Introduction

This workshop afforded an opportunity for researchers from the world over to discuss their work in the area of plasma based acceleration and lenses. There has been progress on every idea since the last workshop at Port Jefferson. Table 1 shows the various efforts and their status as reported at this Workshop.

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<thead>
<tr>
<th>Institution</th>
<th>Method</th>
<th>Laser Wavelength</th>
<th>Status at this Workshop</th>
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</thead>
<tbody>
<tr>
<td>AECL, Canada</td>
<td>PBWA*</td>
<td>10.6 (\mu)m</td>
<td>No Report*</td>
</tr>
<tr>
<td>Ecole Polytechnique, France</td>
<td>PBWA</td>
<td>1 (\mu)m</td>
<td>Preliminary Acceleration Results</td>
</tr>
<tr>
<td>KEK, Japan</td>
<td>PWFA*</td>
<td>2 Linac 1 (\mu)m</td>
<td>Transverse Fields Probed Preliminary Acceleration Results</td>
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<tr>
<td>KEK, Japan</td>
<td>LWFA*</td>
<td>1 (\mu)m</td>
<td></td>
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<tr>
<td>Osaka University, Japan</td>
<td>PBWA</td>
<td>10.6 (\mu)m</td>
<td>Self-Trapped Electron Acceleration</td>
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<tr>
<td>UCLA, U.S.A.</td>
<td>PBWA</td>
<td>10.6 (\mu)m</td>
<td>Acceleration of Injected electrons to 30 MeV</td>
</tr>
<tr>
<td>NRL, U.S.A.</td>
<td>Self-modulated LWFA</td>
<td>1 (\mu)m</td>
<td>Planned</td>
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</table>

* A recent preprint from AECL Canada by N. Ebrahim reports successful acceleration of 12.5 MeV electrons to 29 MeV over a plasma length of approximately 1 cm.

*PBWA - Plasma Beat Wave Accelerator

*PWFA - Plasma Wake Field Accelerator

*LWFA - Laser Wake Field Accelerator
In addition there are basic experiments being carried out without the injection of electrons on the LWFA scheme by LLNL-UCLA collaboration at LLNL, UT Austin, U. Michigan and at RAL in U.K. Also experiments on the PWFA are being assembled at UCLA and ANL.

Plasma collective acceleration is a rich field for theorists. Very active theoretical research programs exist at USC, NRL, MIT and UCLA.

II. R & D Goals For the Next 3-5 Years.

PBWA: Current Status: Proof-of-principle experiments have now been done at both 10.6µm and at 1µm and acceleration of externally injected electrons has been shown. UCLA experiments have shown impressive gradients over about 1cm.

Goals: The PBWA program is ready to move to the next step. The goal of such a step should be to show electron acceleration in the 1 GeV range over a distance of about 10cm. Nd: glass laser seems to be the most suitable laser for this. There are two places where such and experiment could be carried out: UCLA and RAL in U.K. Both groups are interested in pursuing such an experiment. The UCLA group wishes to use a photoinjector for injecting a substantial current into the plasma wave. The goal of this experiment is to demonstrate acceleration of at least $10^7$ electrons with a reasonable ($\pm 10\%$) energy spread in the 1 GeV range. This seems to be a reasonable R & D goal for the next 3-5 years.

PWFA: Current Status: There have been no recent experiments in the U.S. since the Wisconsin group carried out the first such experiments at ANL. At KEK, researchers have
carried out detailed experiments, similar to those carried out at ANL, to map out the transverse fields of the wake, using two synchronized linacs. Both ANL and KEK experiments should be treated as proof-of-principle of the PWFA scheme.

Goals: The goal of the PWFA program ought to be to demonstrate a) higher gradients, > 100 MeV/m and b) transformer ratios greater than 2. The first goal requires either very short drive bunches and therefore higher plasma densities or accessing the nonlinear wakefield regime. The second goal requires using shaped drive bunches with risetimes on the order $10\alpha_p^{-1}$ but fall times of about $\omega_p^{-1}$. A third goal might be to try to access the ion-blowout regime. There are two experiments that are upcoming in the U.S. The first is at UCLA using the Saturnus linac. Here a 4ps (FWHM), 1nC beam will be focused down to 70μm in a $10^{14}$ cm$^{-3}$ plasma. Peak accelerating gradients of > 100MV/m are expected. The second experiment is at ANL by a different group from UCLA. They expect to inject an 7 MeV, 10nC, 15ps long beam in a somewhat lower density ($3\times10^{13}$ cm$^{-3}$) plasma that will be 15cm long. A witness beam will be used to diagnose the nonlinear wake formation and energy gain of this witness beam will be measured. Both of these experiments represent an adequate R & D effort on the PWFA scheme in the U.S.

LWFA: Current Status: Although LWFA was the earliest of the collective laser-plasma acceleration scheme it's experimental demonstration has proven to be elusive. This has been mainly because of two reasons. First extremely short laser pulses of sufficient intensity were until recently not routinely available. Second, there was no experience with forming and diagnosing plasmas with such short pulses. This is now changing because many groups around the world have access to the so-called T$^3$ lasers. Most notably the groups at LLNL and at Rutherford lab are making very good progress on the formation and diagnosis of plasmas produced by such short pulses. At this workshop a group from KEK reported on experiments carried out at Osaka University on both LWFA and self modulated
LWFA. They apparently observed significant acceleration of electrons when 0.5 MeV electrons from a solid target plasma were injected either in a low density plasma or in a high density gas-jet plasma. The results were explained in terms of LWFA at low densities and self-modulated laser wake field excitation at high densities. Unfortunately there was no other evidence for the excitation of the plasma wake field. Thus, although the results are tantalizing, much more work remains to be done before one can definitively claim that a proof-of-principle LWFA experiment has been done.

Goals: LWFA at Low Densities: There are many groups who are attempting to diagnose a plasma wake excited by a short laser pulse. Among these, are notable efforts at LLNL, U. Texas at Austin and U. Michigan. The NRL group would like to pursue a more ambitious experiment with a photoinjector as an electron source for injection. However their laser is currently at about 1.5 TW. They expect to upgrade it to 10 TW range in the near future. The U. Texas at Austin group wants to uses frequency upshifting of another short laser pulse as a diagnostic for the wake. They have developed a five pass system with independent plasmas for accumulating the frequency upshift, U. Michigan group is also developing careful diagnostics for the wake.

Self-modulated LWFA: The best experiment is probably at LLNL using a gas jet target and with back and forward scattered cascade as diagnostics. LLNL does not have an electron beam for injection however, 2D PIC simulation indicate that it may not be necessary to inject electrons in this regime. Once the laser goes unstable to modulational instability / Raman forward scatter, the resulting plasma wave grows rapidly, self traps background electrons and accelerates them. The acceleration gradients are truly fantastic, > 100 GeV/m. In the next 3 years, there is an excellent chance that this regime of laser-plasma interactions will be shown to work as advertised. There are four groups where it could be done, LLNL, NRL, RAL, KEK. In addition the French group at Ecole -
Polytechnique wants to upgrade their laser to do this experiment. Whichever group succeeds will also probably be the same group that conclusively demonstrates relativistic self-focusing in plasmas since the two effects are closely related to one another.

PLASMA LENS: Although many different types of plasma lenses have been proposed over the years, this Group concerned itself with a thin plasma lens for relativistic electrons and positron beams. Some evidence for focusing of such beams was obtained indirectly in a PWFA experiment at ANL. The KEK group did the first thin plasma lens experiment and demonstrated a 20% reduction in the spot size. At this Workshop G. Hairapetian of UCLA reported the first significant, thin but overdense plasma lens experiment which agreed very well with theory. Furthermore, the time dependent focusing properties of the plasma lens were well demonstrated in this experiment.

Goals: Although an overdense (beam density much less than the plasma density) plasma lens experiment has been done, an underdense plasma lens experiment has not. It is perhaps the more important experiment to do because the focusing force is linear in \( r \). The UCLA group intends to do such an experiment. Also both underdense and overdense experiments are planned at the Beam Test Facility at LBL. The LBL group may also do an adiabatic plasma lens experiment where the two orders of magnitude variation in plasma density over a few centimeters will be obtained by using the \( I^2 \) dependence of 2 photon ionization. If these experiments are successful as the overdense experiment was, then a plasma lens experiment at the FFTB at SLAL makes sense. An international collaboration involving many groups has indeed proposed a plasma lens experiment at the FFTB.

III. Other Ideas:
Resonantly Driven Laser-Plasma Accelerator: Don Umstadler of U. Michigan, put forth the idea of using a series of short pulses of varying durations and each placed precisely at the zero of the wave potential for obtaining an enhancement of the plasma wave amplitude. At U. Michigan, his group is planning a test of this idea using pulse crafting techniques in the Fourier plane of the first grating pair in a CPA laser. J.L. Bobin and Amatuni also elaborated on this idea.

Bunchers for Plasma Acceleration. C. Pellegrini proposed an IFEL accelerator as a buncher for plasma accelerator applications. An IFEL has many advantages over an FEL for bunching, the principal one being the bunched electrons are also accelerated and therefore space charge effects are reduced for the electrons in the micro bunches.

A. Boguez of FNAL suggested the use of a crystal buncher where a sound wave propagating through a crystal (Si) is used to periodically modulate its refractive index at $\lambda = 2000\lambda A$. When electrons are sent through such a structure they are wiggled and bunched. The bunching is efficient if an em wave at $\lambda_{en} = 2\lambda$ (ie 4000\lambda A) is sent together with the electrons. The bunching process is basically IFEL.

Laser Synchrotron Source: There were two experiments on generating short X-ray pulses described at this Workshop; at NRL and at LBL. Of these the NRL experimental group (A. Ting) reported preliminary results on detecting the radiation from a 1 MeV electron beam colliding with a 1 \mu m laser beam. The LBL group hopes to generate femtosecond x-ray pulses by colliding the 50 MeV ALS injector beam with a nominally two femtosecond laser pulse at right angle.

IV. Conclusions:

The plasma acceleration sub-field is very dynamic with many groups actively working on experiments. In terms of discovering new physics it is very rich. The beat
wave acceleration scheme has shown impressive acceleration gradients and substantial energy gain for injected electrons. The goal of achieving energy gain in the one GeV range in a single stage that is about 10 cm long appears quite reasonable in the next phase of research on the PBWA. Other plasma acceleration schemes (PWFA & LWFA) are also making significant progress. Plasma lenses are being shown to work for electrons. There is an exciting possibility of testing out the plasma lens scheme at the FTFB facility at SLAC in the near future.

V. Acknowledgments:

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