

REPORT ON THE LAKE ARROWHEAD WORKSHOP ON ADVANCED ACCELERATION CONCEPTS\*

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Abstract

We review the present status of the field of New Acceleration Concepts, as presented at the Lake Arrowhead workshop, held at the beginning of 1989. Many new and promising results have been obtained recently, and the field is actively developing. We discuss briefly some of the main results presented at the workshop.

1. Introduction

The Lake Arrowhead Workshop on Advanced Accelerator Concepts was held in January 1989, and is the fourth of a series of Workshops that started at Los Alamos in 1982,<sup>1</sup> and continued at Malibu<sup>2</sup>, and Madison<sup>3</sup>, to bring together people working on new mechanism of particle acceleration.

During these years the field has seen a remarkable progress: some of the new concepts presented at Los Alamos have been proved experimentally; new theoretical ideas have been introduced, and older ideas refined. Many new ideas have also been already incorporated in the design of electron-positron TeV linear colliders. The number of scientists and institutions involved in this research has also grown substantially. Among the recent results one can mention the demonstration of wakefield acceleration in a plasma and in a dielectric, the development of the relativistic klystron, the production of high brightness electron beams using photoinjectors, the studies of electron emission from photocathodes and the switching of high voltage on a picosecond time scale.

Most of this work has been discussed at Lake Arrowhead, and will be reported in the Proceedings of this workshop.<sup>4</sup>

It is also important to notice that there is now one accelerator, the Advanced Accelerator Test Facility (AATF), at Argonne National Laboratory,<sup>5</sup> dedicated to experimental work on advanced accelerator concepts, in particular wake-field accelerators. The AATF can produce two bunches, one to excite the wake-field and one to measure it, separated by a time distance variable on a picosecond time scale. It has been in operation for some years, and has already produced important results. Another dedicated accelerator, the Accelerator Test Facility (ATF) at Brookhaven National Laboratory,<sup>6</sup> is being built now, and will be available from 1990. The ATF is an accelerator, high power laser system, and will be mainly dedicated to laser acceleration experiments. The main characteristics of the AATF and the ATF are given in Tables 1 and 2.

The meeting opened with a talk by A. Sessler,<sup>7</sup> looking at the development of particle accelerators in the past thirty years: "Circular Accelerators: History and physical principles". The present situation was then reviewed by D. Sutter,<sup>8</sup> who gave a presentation of the ongoing experimental and theoretical activities, in the USA, on advanced accelerator concepts. A list of the principal groups now engaged in experimental work in the USA, and their main field of activities, following Sutter's presentation, is:

Energy	21 MeV
Pulse Length	<10 ps
Driver Bunch Charge	>1 nC
Witness Bunch Charge	>1 pC
Momentum Spread	2%

Electron Energy	50 MeV
Pulse Length	5 ps
High Current Mode:	
Peak Current	100 A
Normalized Emittance	5 mm mrad
Low Current Mode:	
Peak Current	1 mA
Normalized Emittance	0.01 mm mrad
C02 Laser Power	100 GW
Pulse Length	5 ps
YAG Laser Power	200 MW
Pulse Length	5 ps

- ANL – advanced accelerator test facility; wakefield acceleration; plasma focusing;
- BNL – accelerator test facility; laser acceleration; high brightness photoinjector; switched power;
- LBL – two beam accelerator, FEL driven (with LLNL); relativistic klystron (with LLNL and SLAC);
- SLAC – relativistic Klystron (with LBL and LLNL); high gradient structures;
- LANL – high brightness photoinjector;
- LLNL – relativistic klystron (with SLAC and LBL); FEL as power sources (with LBL);
- UCLA – beat wave accelerator; plasma lens;
- Spectra Tech. – inverse Cerenkov accelerator (with UCSB);
- Rochester – switched power;
- Maryland, Cornell, NRL – collective effects accelerators; propagation of high intensity beams; high power RF sources.

Theoretical work is also being done in most of the institutions mentioned above, as well as in Fermilab, UCSD, and other places.

This workshop has been mainly dedicated to a review and discussion of:

- a. RF methods of acceleration;
- b. Plasma methods of acceleration and focusing;
- c. Switched power and high brightness sources;
- d. Wake-fields in media and structures.

In the next section we will review shortly some of the topics discussed at the workshop. More detailed presentations can be found in ref. 4.

2. Acceleration and Focusing in a Plasma

The use of a plasma as a medium to support strong electromagnetic fields to accelerate, or focus, or neutralize particle beams was widely discussed at the workshop. Several ways to excite plasma waves were also discussed: beat waves, wake fields, laser wake fields. Part of this presentations are summarized in the following.

2.1 Wake Field Acceleration in a Plasma

The acceleration of electrons by wake fields in a plasma has been demonstrated experimentally at Argonne on the AATF and was reported by J. Rosenzweig.<sup>9,10,11</sup> This group has measured the energy gain of a test bunch as a function of its distance from the

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wake field producing bunch. From these measurements one obtains an average wave amplitude of 5 MV/m, versus the three expected from linear theory. Two important non linear effects have been observed in the most recent experiments: beam pinching and wave steepening. Beam pinching is predicted to occur, and reduces the bunch radius by about a factor of three. This reduced radius leads to a larger accelerating field, of about 6-7 MV/m, in qualitative agreement with the observations.

An alternative methods of driving the plasma waves, using a short, picosecond, high power,  $10^{15}$  W, laser pulse at a single frequency, was discussed by P. Sprangle.<sup>12</sup> This non resonant excitation of plasma waves can lead to large accelerating fields, >1 GeV/m; the short laser pulse may reduce laser-plasma instabilities; in addition one might have optical guiding of the laser pulse by the plasma.

## 2.2 Laser Beat Wave Acceleration in a Plasma

The UCLA group<sup>13,14</sup> has demonstrated the excitation of plasma beat wave, using a CO<sub>2</sub> laser, to a significant level, corresponding to an accelerating field of 1 to 3 GV/m. The possibility of using this field to accelerate electrons is at the moment limited by the electron beam injector. The group has a program to upgrade this linac, and further improve the experimental system, to produce acceleration in the GeV/m range.

A "photon accelerator", or upshifting of photon frequency due to the interaction of an intense laser field with a plasma, was presented by S. Wilks.<sup>15</sup> A light pulse travel on a plasma wave, similarly to a particle bunch traveling on the wave, and one can transfer energy from the plasma to the wave. A frequency increase of the order of the plasma frequency, or larger, can be obtained, using, for instance a Nd laser.

## 2.3 Plasma Focusing and Beam Neutralization

A review of the work on plasma lenses has been given by T. Katsouleas.<sup>16</sup> The self pinching mechanism for a beam in a plasma has been confirmed in the ANL wake field experiment. The theoretical and simulation work done during the past few years at UCLA, ANL/UW, Slac have characterized these systems and the aberrations they introduce in the beam focus. Two main cases have been considered: the dense plasma lens, with the plasma density larger than the beam density; the underdense plasma lens, when the opposite condition holds. Also the focusing of both electrons and positrons has been considered. This work shows that a plasma lens is a promising device in a linear collider to increase the focusing at the interaction point and increase the luminosity. Calculations have also been done to apply a plasma lens to SLC, where it might increase the luminosity by about one order of magnitude and also provide a test for future linear colliders.

The idea of using a plasma to neutralize particle beams at the interaction point of a linear collider has been introduced recently.<sup>17</sup> For this application the plasma must neutralize both the electric and magnetic fields of the beam, leading to the condition  $k_p a \gg 1$ , or the plasma wave number times the beam radius much bigger than one. In this way one can eliminate the disruption and the beamstrahlung from the effects dominating a linear collider design. The elimination of beamstrahlung reduces the beam energy spread and the background due to the production of photons and the subsequent electromagnetic cascade at the interaction point. This creation of electron-positron pairs at the interaction region, and its effect on the background in a linear collider has been studied recently and was presented at the workshop by P. Chen.<sup>18</sup> The advantage of eliminating the beamstrahlung must also be weighted against the background produced by the plasma.

## 3. RF Acceleration

The general trend in RF acceleration for application to high gradient linacs, and in particular for linear colliders, is to use higher frequencies, 10 GHz or more, to increase the limit on field breakdown, and reduce the power needed for a given accelerating

field. At these high frequencies, both the power sources, and the accelerating structure, have to be developed, and much work is being done in both areas.

Relativistic klystrons are being developed by a LBL-SLAC-LLNL collaboration, using the induction linac technology to provide the driver beam, and the progress in this area was reviewed by R. Miller,<sup>19</sup> together with the work on pulse compression techniques. Relativistic klystrons at 8.5 GHz, producing up to 75 MW, and at 11.4 GHz, producing up to 200 MW, have been tested at Livermore, and more systems are being developed. Work is also being done on sub harmonic klystrons with an output frequency of 11.4 GHz.

RF sources at lower frequencies, few GHz, using Intense Relativistic Electron Beams, with currents in the KA range and energies up to a few MeV, were reviewed by M. Friedman.<sup>20</sup> Power level of several GW, have been obtained and extracted into the atmosphere, with high, 35%, efficiency. Preliminary designs exist for larger power machines. The progress in gyrokystron development at Maryland and their future program was discussed by Striffler.<sup>21</sup> Theoretical calculations predict for a four cavity gyrokystron, at 10 GHz, an output power of 40 MW, with an efficiency of 40%, and a gain of 60 dB. This system is near to completion.

A new version of the Two Beam Accelerator scheme using the Free Electron Laser as a power source was discussed by Wurtele.<sup>22</sup> It solves the problem of phase stability, and offers an attractive alternative for a high frequency, high gradient linac.<sup>23,24</sup>

## 4. Switched Power

The first experimental results on voltage switching using a laser and a photoemitter were recently obtained at Rochester.<sup>25</sup> This group was able to switch a field of about 0.25 MV/m in a time of 18 ps, between two cylindrical disks. The ratio of applied voltage to the on axis voltage was about 4, in qualitative agreement with the calculated value. These results encouraged people to look at possible future applications of switched power systems, in particular the possibility of using them to power a high brightness photoinjector, in alternative to RF systems. The possibility of obtaining very high gradient, of the order of 1.5 GeV/m, over a few millimeters and for a time of the order of a picosecond, opens a very attractive option for the construction of a high brightness electron gun.<sup>26</sup> When coupled with the high current density measured at Brookhaven from a metal photocathode, this system could provide an electron beam brightness two order of magnitude larger than the best obtained up to now.

### 4.1 Photocathodes Results of BNL

Emission from metal photocathodes has been studied at Brookhaven by Srinivasan-Rao and Fischer.<sup>27</sup> These authors have studied the photoemission from metals and measured the current density and quantum efficiency with a strong electric field applied on the cathode surface, up to  $3 \times 10^8$  V/m. They have shown that it is possible to obtain very large current densities, up to  $10^5$  A/cm<sup>2</sup>, and a quantum efficiency of about 1/1000, when a field of about 30MV/m is applied to the cathode surface. It is planned to use one of these metal cathodes at the ATF during 1990, and this could lead to improved performance for this accelerator. A more distant application is to switched power electron guns.

## 5. Other Acceleration Concepts

### 5.1 Wake Field Acceleration in a Dielectric

The results on the experimental work on dielectric wake field accelerators being done at Argonne, were reported at the meeting by W. Gai.<sup>28,29</sup> Theoretical work being done at Argonne and Los Alamos was also reported by M. Jones.<sup>30</sup> The experimental technique is similar to that used for the plasma wake field acceleration experiments, using a driving and a witness beam. In the experiment a wake field is excited in a hollow cylindrical dielectric medium,

surrounded by a metallic cylinder, and is used to accelerate particles. Several dielectrics have been used, including Steatite, with a constant of about 5.9, polystyrene, with 3.1, and nylon, with 3.9. The observed accelerating field is of the order of 0.3–0.5 MeV/m, and is limited by the driving beam current and emittance. An upgraded AATF beam could produce much larger accelerating gradients. There is good agreement between the calculations and the observations.

The use of non linear dielectrics, and of current pulse shaping, to further increase the accelerating field, is now being studied,<sup>31</sup> and could lead to a dielectric based wake field accelerator with an accelerating gradient in the range of 100MV/m.

## 5.2 Other Concepts

Several experiments, utilizing the unique possibility offered by the ATF of combining a high quality electron beam with a high power CO<sub>2</sub> laser, are being considered or are in an advanced state of preparation, and were discussed at the workshop. Although these concepts have been studied now for some time, the possibility of testing them will become possible only when the ATF will be operational.

High gradient acceleration in conducting structures at optical frequencies was discussed by R. Palmer.<sup>32</sup> He reported on the experiment of laser acceleration in preparation at Brookhaven using a "colonnade structure", an open-linac like structure illuminated by the CO<sub>2</sub> laser, and also on the work done to design and build these structures at a 10 μm scale. In this experiment one should achieve a field of about 1 GeV/m.

W. Kimura discussed another experiment being constructed for the ATF, the Inverse Cerenkov Accelerator.<sup>33</sup> In the experiment one should be able to achieve an acceleration of 10 MeV, using the ATF CO<sub>2</sub> laser. The laser optics for this experiment has already been developed and can focus axially a polarized laser beam using an axicon.

The construction of an Inverse FEL accelerator utilizing the ATF has also been proposed,<sup>34</sup> with the present laser one can achieve an accelerating gradient of about 100MeV/m. The possibility of a plasma enhanced Inverse FEL, raising the accelerating gradient from about 100 to 500 MeV/m, was also discussed.<sup>35,36</sup>

A new plasma based accelerator concept, the Mirrortron,<sup>37</sup> was introduced at the workshop by R. Post. It utilizes the transient space-charge electric fields generated by rapidly pulsing sequentially a series of local mirror fields in a linear array of mirror cells. This system seems to be particularly suitable for the acceleration of multiply stripped heavy ions.

G. Decker presented the theory of a synchrotron radiation accelerator, utilizing the field near two bunches symmetrically deflected in a magnetic field.<sup>38</sup> The general theory of wake-fields in a structure, and their effects on beam dynamics, was reviewed by S. Chattopadhyay.<sup>39</sup>

## 6. High Brightness Beams and Laser Technology

A review of the recent progress in the production and propagation of high brightness beams was given by Reiser.<sup>40</sup> Advanced accelerator applications for high energy physics, like linear colliders, or FELs, require beam with high brightness and small energy spread. Much progress, including the use of laser driven photocathodes, and a better understanding of the causes of emittance blowup during the initial production and transport, has been achieved recently, and leads us to believe that a next generation of sources with higher brightness will become available in the near future.

Recent progress in laser technology, which could find applications directly for acceleration, or also for photoinjectors, were reviewed at the workshop by Byer,<sup>41</sup> Ewing,<sup>42</sup> and Darrow.<sup>43</sup> Considerable progress is taking place in the technology to produce tabletop Nd-Yag or similar types of lasers, at the 10-Terawatt power level, with 10 J in one picosecond at 1 μm, based on a system comprising an oscillator followed by chirping and pulse

compression, and amplification. Great improvements in coherence, power and efficiency of solid state lasers has also been achieved by replacing the traditional flashlamps with diode laser array pumping. Similar improvements are also occurring for gas lasers.

## 7. Conclusions

The field of advanced accelerator concepts has seen a remarkable progress during the last few years. Plasma and wakefield acceleration has been demonstrated. One can foresee similar progress in the area of laser acceleration when the Brookhaven ATF will start operation. Other ideas for using plasmas to focus particle beams, and to produce beam neutralization at the interaction point of a collider have also been developed.

The development of high brightness beams and high gradient linacs can also have in the near future a strong impact in other fields, like FELs and synchrotron radiation sources. This cross fertilization with other fields can reinforce the interest and activity on advanced accelerator concepts, and make it even more productive.

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