SUMMARY OF THE 1988 LINEAR ACCELERATOR CONFERENCE

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We are now coming to the end of another Linear Accelerator Conference, the fourteenth in a long series which started at Brookhaven in 1961. The first linac conference which I attended was held at MURA in 1964. At that time, the vast majority of authors dealt with protons and ions, and electron linac papers were in a small minority. After a strong swing of the pendulum, the program now is more balanced. In any case, regardless of the particles which we accelerate, I believe that we can consider ourselves very proud because this fourteenth conference has been a superb one. Papers have been excellent in substance as well as in presentation. The substance, as will be evident from these Proceedings, testifies to the vitality and the progress in our field. The format and the presentations in turn testify to the good judgment of the Organizing and Program Committees which set the physical and intellectual framework for this meeting, and to the dedication of the authors who obviously made a special effort to transfer their information in an interesting, efficient and timely way. For this, you should all be congratulated and thanked.

It is now my turn to live up to the tradition, as Chairman of the previous linac conference held at SLAC in 1986, of attempting to summarize what you have taught us in the last four and a half days. As usual, this is a difficult and risky task, given the wealth and variety of the papers and the short time to assimilate, sort out and do justice to all this information. However, I will proceed, trying to strike acceptable compromises between completeness and dullness, selectivity and even-handedness, brevity and superficiality.

Our program consisted of approximately 45 invited papers, 35 five-minute presentations, about 140 posters and at least three excellent video presentations. After the banquet, we also enjoyed an interesting lecture by Robert Wyatt on George Gershwin which he accompanied with a fine piano performance of his music.

In order to summarize the various conference topics, I have divided them into the following categories:

Theory

Computer codes

Devices

Technologies and techniques

Actual low and medium energy machines for nuclear physics, injection into storage rings and FEL's

Very high energy $e^{\pm}$ linear colliders

Heavy ion fusion

For each category I will try, where possible, to outline present and future trends.

Starting with *Theory*, I would like to single out the work on wakefields generated by ultra short bunches presented by J. J. Bisognano, the calculations on beam breakup for multiple bunches presented by R. Gluckstern, and the work on beam-beam effects at the interaction point of linear colliders presented by K. Yokoya. All three of these topics are at the heart of the physics that concerns us in the design of both present and future linacs.

In the area of computer codes, there is clearly an explosion in the diversity, sophistication and quantity of available new programs for all sorts of applications and simulations. In this area, I would like to single out the presentation on higher-order beam optics made by E. A. Heighway, the paper on the use of electromagnetic particle-in-cell codes by K. Eppley, and the latest developments in the codes for calculations of electromagnetic fields by T. Weiland. The progress that has been made with the introduction of numerous new features such as the use of dielectrics and 3-D is most impressive: witness, for example, the simulation of the entire HERA vacuum chamber, as shown in the Weiland paper. Witness also the interesting computer video movies on wakefields presented by R. Cooper, and on emittance growth in the ALS pre-injector, by C. H. Kim.

Moving on to *Devices*, I have subdivided these into electron guns, polarized proton sources, ion sources, new types of lenses, RFQ's, accelerator structures, RF sources and positron sources.

Leaving the discussion of the latter two for later, let me start with electron guns. The important developments in this field have been and will continue to be in the area of dispenser cathodes, as for example those using osmium, which have helped us improve the performance of our high power klystrons at SLAC; in the area of photocathodes of various types which are now being used for lasertrons and various low-emittance linacs; and in the area of hybrid cathodes (field and photo-emission) as proposed by the group at Orsay.

The field of polarized proton sources also seems to be developing rapidly, to the point where these will soon become competitive in emitted current with regular sources, as we heard from J. Alessi. As far as ion sources are concerned, we heard a comprehensive review by R. Geller of Electron Cyclotron Resonance sources, their status and recent developments, which seems to indicate that within a few years these ECR devices will be in place in a large fraction of ion accelerators in the world.

Regarding new lenses and perhaps not-so-new lenses, we heard a presentation by C. L. Olson on achromatic lens systems for high current ion beams, an ingenious paper on laced permanent magnet quadrupole drift tube magnets by B. Feinberg, *et al.*, and the resuscitation of the Gabor lens, presented by J. Palkovic, *et al.*.

Moving on to RFQ's, I find it difficult to do justice to all the papers concerning these devices, the calculations, constructional details of the vacuum chambers, the characteristics of the vanes and rods, and their overall performance in various machines and environments. For an overall summary, I refer you to the presentation by A. Schempp on recent progress in this field. If we follow his predictions and extrapolations, we will see that in the next few years RFQ's will appear in the front-end of most proton and ion machines, relegating all Cockcroft-Walton injectors to museums . . . .

As far as accelerator structures are concerned, particularly the ones operating at $\beta = 1$, one should mention several

developments: a) the still growing values of the shunt impedance being reported for various new designs; b) the resurgence of the disk-and-washer structure, in which the problem of transverse modes seems to have been overcome (a feature which now makes it a possible candidate for the new Fermilab linac); c) the study of highly damped slotted structures for future colliders using multiple bunches, presented by R. Palmer; d) the use of RF focusing in various electron bunchers by D. Tronc and A. Setty; and e) the ability of some of the new structures, as shown by J. P. LaBrie, *et al.*, to carry and dissipate extremely high average RF power (150 kW/m with an electron bunch power of up to 250 kW).

We now come to *Techniques and Technologies.* In this category, I would like to include the following topics: the formation and transport of high brightness beams, laser guiding, new acceleration techniques and test facilities, RF superconductivity, and computer control and modeling.

To start out with high brightness beams, their formation, transport and acceleration, it is well known that this work has multiple applications in the field of injector physics, plasma heating, heavy ion fusion and SDI. In these areas, I would like to mention the comprehensive studies by M. Reiser and his colleagues at the University of Maryland, and T. Wangler and his colleagues at LANL.

The work on laser guiding is also making progress, even though it has been used only by the group at LLNL for the time being. On this topic, we heard a status report by G. Caporaso on its application to the ATA machine. Apparently, there are some new developments in this field, particularly in the observation of emittance growth as a function of time, leading to a reduction in the usable pulse width. Clearly, we can expect to witness more developments in this innovative method of laser guiding in the years to come.

In the field of new acceleration techniques, we heard several talks on the use of wakefields and other methods. In this respect, very active experimental work is already being carried out at the Advanced Accelerator Test Facility (AATF) at ANL, as presented by J. Simpson. In the next two years we can also expect new developments from the group at UCLA on beatwave experiments, and from the ATF at Brookhaven which will test laser acceleration and other techniques.

As for RF superconductivity, the frontal attack on this field finally seems to be bringing it to a state of technological maturity. The massive collective effort mounted by Cornell, CEBAF, Wuppertal, CERN, DESY, KEK, Saclay, various private companies, and most recently Frascati, is now resulting in what appear to be practical structures capable of operating at 5-10 MV/m with a high degree of confidence. Here, for a good summary I first refer you to the general status review of RF superconducting projects given by D. Proch. Second, beyond the present use of high thermal conductivity niobium, innovative R&D on Nb_3Sn and high T_c superconductors is covered in a paper by H. Padamsee. And third, looking to the more distant future and very large-scale applications, note the paper by R. Sundelin which considers the possibility of superconducting RF for extremely long and high-energy linear colliders. Individual papers on superconducting machines with their special characteristics can be found in the same section of the Proceedings.

Finally, regarding instrumentation, control and modeling, I believe that it is worthwhile to point out the obvious, namely that the advent of computer control has completely revolutionized our field in the last twenty years. There is scarcely a hardware function or a beam parameter left that can escape computer scrutiny. As a result, not only have accelerator physics experiments on existing machines become much more systematic but, as shown by M. Lee, it is now possible to predict and optimize the operation of present and future machines through ever more sophisticated models and the use of expert systems.

I am now coming to the topic of *Actual Linear Accelerators*, those which are used for nuclear physics, injectors into various storage rings, and linacs for FELs. Here we have had a large number of status reports which I will categorize in terms of the particles which they accelerate. Regarding protons and ions, we heard about developments and new plans for ATLAS at ANL, the UNILAC at GSI, the proton linac at IHEP in Beijing, the BEVELAC at LBL, the new proposed linac for Fermilab, progress on the meson factory at the INR in Moscow, design studies for heavy ion injectors into the PS and SPS at CERN, and studies of various hadron facilities in Europe and in Japan.

Regarding the electron machines, we heard good progress reports on the superconducting accelerator at Darmstadt, the MAMI microtron at Mainz, the EROS linac and stretcher ring at Saskatoon, the NBS/LANL racetrack microtron, the LIL e^+e^- injector for LEP, and the injector at LBL for the ALS synchrotron light facility.

As far as linear accelerators for FEL's are concerned, we are witnessing an enormous surge of activity in the areas of high current and low emittance beams, and the study of photocathodes for the production of some of these beams. Laboratories which are active in these areas and from where we can expect interesting results in the next few years are LLNL, LANL, Physics International, Boeing, TRW, JAERI in Japan, Utrecht, Orsay, Frascati and probably others.

Finally, to come to our hosting laboratory, let us mention a number of general and specific reports from CEBAF, among which I want to single out the paper by W. Diamond and R. Pico on the status of the injector, in which a few days ago the electron gun and the chopper system began to operate successfully. Hence, we can say that the CEBAF beam is launched. Congratulations for this first nice achievement!

We now come to the much higher energy machines in the multi-GeV and even TeV range: the $e^{\pm}$ *Linear Colliders.* In this area, during the course of this conference you heard a number of papers on the SLC at SLAC, among which I would like to mention the opening talk by J. Sheppard, and a review of beam dynamics problems by J. Seeman, which he also illustrated with an interesting movie on beam tails due to wakefields. As you heard from these and other SLAC speakers, we are now somewhat behind schedule in producing the Z^0 particles expected in the final focus interaction point of this machine. On the other hand, in the last two years, we have accumulated an enormous amount of knowledge regarding the physics of linear colliders, and these studies have recently culminated in three major results: the successful test of the so-called BNS*damping technique which greatly reduces the sensitivity of wakefields to beam input jitter, the measurement of beam-beam deflections at the final focus, and the generation of beamstrahlung radiation

* This technique owes its name to its proponents, V. E. Balakin, A. V. Novokhatskii, and V. P. Smirnov, of the Institute of Nuclear Science, Novosibirsk.

through the deflection of one bunch by the magnetic field of the opposing one. During the next year, we expect to make a large number of improvements on the SLC machine which hopefully will lead to its successful operation as a particle physics tool, as well as provide a test bed for many ideas regarding the design of future linear colliders. Clearly, between now and the next linac conference, the SLC will continue to be the workhorse in this field and we can expect many more interesting results and papers to come from it.

Meanwhile, as we heard in this morning's session, the study of future $e^{\pm}$ colliders in the TeV energy range is blooming in many of the major laboratories in the world, including the Institute of Nuclear Science in Novosibirsk, KEK, SLAC, LBL, LLNL, the CLIC group at CERN, Orsay, Frascati, SAIC, and others. A two-week workshop on relevant R&D topics being considered at these laboratories will be held at SLAC at the end of November of this year. Work is being done on both general parameter studies and specific problems including power sources, structures, beam dynamics, tolerances, injectors, damping rings, positron sources and final foci. You heard a review this morning by T. Himel about the enormous potential of these machines as particle physics tools, in parallel with the proton-proton physics to be offered by the SSC. It appears to me that all linear collider design studies as well as the specific studies of sub-systems will continue to grow in the next two to four years, but in order of importance, I would like to single out the R&D on power sources which is fundamental to the feasibility of these machines. I hope that in this interim period of two to four years we will be able to sort out which power source or sources (with or without the help of the energy compression technique) among the relativistic klystrons, klystrinos, gyroklystrons, lasertrons, two-beam accelerators of various lengths using either conventional or FEL bunching, will be the most promising candidates, both technologically and financially.

Finally, to come to my last topic, I would like to say that if you worry about your grandchildren, OPEC oil prices, the greenhouse effect, the melting of the polar ice cap, nuclear reactor meltdown, the high price of solar energy, if you are skeptical about tokamaks but do not mind neutrons, then, join those people who are working on heavy ion fusion! You heard, at the end of the opening session on Monday morning, a summary of the 1988 HIF Symposium by T. Godlove. As he told us, definite progress and new plans are being made in this field in the U.S., in Germany, in France, in the Soviet Union and in Japan. So, if you are a utilitarian or somebody looking for a social mission, here is your chance!

This closes my summary of the 1988 Linac Conference program. To conclude, let me thank all of you again for coming to this meeting and for presenting all these good reports. And, just in case you are worried about the continuity of this conference, let me reassure you and give you the good news: yesterday, in an *ad hoc* International Committee meeting, a number of alternatives were considered and, as a result, it was unanimously decided that the 1990 Linac Conference will be held at Santa Fe, September 10-14, 1990, at the Bishop Lodge and that our next chairman will be Dr. Stanley Schriber from LANL. This is an excellent choice!

Before we adjourn, I now would like to thank Dr. H. Grunder and the CEBAF Laboratory for having hosted this conference in this beautiful Kingsmill Center with its excellent accommodations and food. As we heard at the banquet, special thanks are due all the members of the Local Organizing Committee who helped make this conference a memorable one. Among them, I would like to single out Mrs. Annie Soltys, the Conference Coordinator, whose tireless efforts starting in April of last year have resulted in the wonderful organization and success of this conference.

Last but not least, on behalf of all of us, I would like to thank Christoph Leemann, our Chairman, who did such a marvellous job of running this entire conference from beginning to end, and who managed to do so in parallel with all the pressures and multiple obligations with which one must cope during the starting years of a new laboratory such as CEBAF. Let us thank Christoph once more for all he has already done, while reminding him that he still has to publish these Proceedings, and that two years from now he will be standing in my place in Santa Fe, giving you the summary of the 1990 Linac Conference.

Thank you very much.