SUMMARY OF THE 1986 LINEAR ACCELERATOR CONFERENCE

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Ladies and Gentlemen:

The 13th linear accelerator conference is approaching its end now. This conference series started 25 years ago. After the talks of this morning on linear colliders I think that we are likely to be very busy for the next 25 years, too.

When I looked the first time at the program of this conference, there were some very immediate thoughts and impressions: firstly, the fraction of - I will say classical proton and ion linac topics - is shrinking and that, as it was expressed in the introduction, the pendelum is swinging to the electron linac side. Secondly, as high energy physics has rediscovered the advantages of linac schemes for getting ultrarelativisitc electron beams, there is a larger overlap of the linac community in advanced techniques and technologies. The linac field has become wider in many respects. Thirdly, and that was when I came to the end of the program, I thought that it was somewhat bold of me to agree to give this summary talk in front of colleagues who have written by their own work considerable parts of the history of linear accelerators. But as the chairman of this meeting considered a tradition what in Darmstadt was still a precedent, namely that a chairman of the previous meeting should give the summary and as Prof. zu Putlitz has to take care of the 600th anniversary of the Heidelberg university, I felt obliged to do this also in another respect, namely to keep the memory that this conference was once outside the north American continent. And as I saw that the format of the last meeting in Darmstadt, which was suggested by zu Putlitz, was essentially kept, I concluded that having the conference in 1984 in Europe was considered more as an excursion than an escapade. This makes it easier to imagine having another meeting once again on another continent, perhaps in 1990. That would reflect the increasing international participation of this meeting established by our colleagues here in the United States.

Coming back to my third item I shall not try in my summary to embed this conference in the historical development line of linacs or to make general outlines. I kept the minutes of the meeting and will present them to give your reflections on what happened in the past week some guidiance. Minutes which are of a personal nature and which probably do not address all topics of this so far largest linac conference appropriately. I apologize for that at the very beginning.

After the welcome of Dr. Loew, deputy director of SLAC and chairman of this conference, we had a remarkable historical talk by Dr. Alvarez. He recalled the early decades of proton linac development. We learned that the choice of the 200 MHz for proton linacs was safely based on 3000 radar units. We heard about the growth and the realization of the Alvarez structure idea in a 32 MeV linac and of the application of phase stability and strong focusing in it. Interesting for me was the description of the gap between textbook knowledge and accelerator designer's real life as I had sometimes the same experience in struggling with Bessel and Hankel functions for reentrant cavity design. I think this contribution might be a nice supplement for today accelerator textbooks, even in the computer age.

The induction linear accelerator is now a vigorous member of the linac community. It can provide kA beams of electrons up to many MeV. The unwanted cavity modes which cause beam break-up instabilities are better understood and one is able to do something by proper cavity design. The laser-ion guidance concept using a plasma channel by laser ionization of a low pressure gas has proven to be very successful. There is a wide and still growing field for applications as was seen by many contributions, especially for FEL for rf and light generation, for relativistic klystrons and radiation processing, to name just a few. Ion acceleration seems possible, too. We will return to this in a few minutes.

Then we had a lecture on semantics. From our teacher Bob Jameson we learned that the comparison forms of exotic are esoteric, and extraterrestric. I think, and that is a more serious comment, that it was a good idea to have the two talks on linac applications in the program. Everybody knows that work is going on on neutral beam development and that part of the knowledge for that came and comes still from the linac community. Despite that, and I think the ambivalence of this statement is now absolutely evident, accelerator builders should contemplate time to time the question of what else can be done with linacs in addition to fundamental research, which has been the prominent motivation to design and construct linacs. We have in comparison to other sciences enormous financial resources. This imposes responsibility. So it was good to hear that about 2500 linac devices are in use for medical application. Industrial radiography is a wide spread tool. High energy ion implantation seems to be needed in the future. Color processing of gemstones might be a tempting field for people who want to earn more money.

For lunch we had a new experience for linac conferences. Instead of sitting in a cafeteria, there was a garden-party, and the trust in good weather seems to be so high in this part of the world that the poster boards also were set up outside. There was another, and I think very successful first. Namely a couple of 5 minute appetizers before each poster session in the auditorium, and snacks and music at the end to bring people together. It is remarkable how much information can be compressed into 5 minute bunches.

To design new accelerator structures, to play with ideas and codes is one side of the linac business. To construct machines which are running reliably 24 hours a day,the whole year, is the other side. One of the main concerns in real life is to have reliable, efficient, right sized, cheap etc. rf sources. Here we learned that we have now two development lines, the airborn and the terrestrial. The airborn looks for modular, light weight, compact, low power modules, which can be combined to form high power units. The terrestrial is dominated by the goal of very high power modules, as future collider schemes aim for the highest possible gradients. There was a real market of developments to be seen at the poster session on the latter. Just to name a few: the Lasertron, the multibeam klystron, the gyroklystron, the relativistic klystron, which may offer solutions for the next linac generations. It is almost sure that the other line will have spin-offs for everyday linac applications, discussed before. However, I am a little bit concerned that people within the linac community might become

reluctant to exchange ideas with each other, and to have as open discussions as in the past. But I think that the contacts are so good that they will not be affected.

Tuesday morning was started with the highlights of the HIF-Symposium held in Washington last week. There exist driver concepts for the inertial confinement fusion with heavy ions both with an induction linac and with rf-linacs plus storage rings, to achieve the desired short pulses of 10 to 20 kA 10 GeV heavy ion beams. There are vital activities on ion sources, high current beam transport, high current linacs, rings, reactors and beam-plasma interaction experiments, even if the general situation is growing more difficult. We learned about the LBL achievements with the MEVVA ion source. The first multiple beam (4x) has been accelerated in an 8 section induction linac and current amplification has been demonstrated. According to new source data a scenario with $q = 3^+$ instead of $q = 1^+$ is being considered, which would shorten the linac considerably. Let me add a few east-Mississippi achievements, too. In the work on high current beam transport one has also to mention the progress at Maryland University, Rutherford Laboratory and GSI, and that the heavy ion RFQ necessary for the rf linac scenario has become operational for mA beams of some MeV at Darmstadt.

Heavy ion fusion was in addition to the RFQ development one of the triggers for the revival of high current beam transport and accelerator physics. It was the trigger for a collated very successful experimental program in this field with solenoids, electrostatic and magnetic quadrupole channels. The understanding of the phenomena involved has made great progress during the last two years not only by computer simulation (the result of which depends sometimes on the number of trajectories) but also by analytical description for two and three dimensions. Characterization of the time development of the emittance growth has also begun. The specialists have entered again the realm of understandable language in relating electrostatic field energy of dc or bunched beams to emittance growth and in describing kinetic energy exchange between coordinates, so called equipartitioning. We heard about that extensively in the talks of M. Reiser and I. Hofmann, and also in the poster presentations of O.A. Anderson, T.Wangler and J. Klabunde. We saw good agreement between theory and experiment. I think the next task to attack is the better understanding of the behavior of partially space charge compensated beams.

The progress on superconducting rf-structures, especially on surface and material technology, was a highlight at the last linac conference. In the meantime this technological progress has been transferred to industry. Acceleration field strengths of 5 - 10 MV/m for multicell structures and more than 20 MV/m for single cell cavities seem to be standard for electron linacs. For ions, pre- or postaccelerator low β-structures of different types are operational at 3 to 4 MV/m or undergoing prototype tests (e.g. at Argonne and Saclay). With this background it is not surprising that the CEBAF crew with new director H. Grunder came out with a superconducting design when the old proposal for a cw high current electron facility was reexamined recently. Two superconducting linacs .5 GeV each will boost the beam to 4 GeV with a four turn recirculation offering also the possibility to extract partial energies at save 200 μA beam current. It is a very appealing design with now proven technology. So we wish good luck for take off. (We need the place also for the next conference.)

The situation in a four decade old continuing battle seems to be clear now. Travelling wave structures are the favorite candidate for very short pulsed beams, whereas for pulse lengths comparable to the rf-filling time standing wave structures are the preferred ones.

On Tuesday afternoon we had a break for an outing on the San Francisco bay. The transport was a typical example for one of the topics of this meeting. Bunches of individuals above the space charge limit of buses have to be diluted. Emittance growth must have something to do with more comfort of particles. The boat trip on the San Francisco bay was a marvellous experience. It need hardly be described and I think you will take home your own pictures and reminiscences from this outstanding evening. The weather was clear, there was not the expected fog. We had the nicest view one can imagine of illuminated San Francisco and the bay area.

We heard about progress and component development of the Stanford Linear Collider on Wednesday morning, of this unique facility which is a milestone in high energy accelerator history. Commissioning is proceeding very well. 32 GeV are achieved now. The construction of the arcs is nearing completion. Part of the experiments is in place already, so that nothing stands in the way to have first experiments in early December this year. There will be a tour this afternoon to also have a look at the hardware. I think this is a most interesting but also most difficult and busy time in an accelerator's life, and we have to appreciate very much that the laboratory has taken over the conference just in this phase of the project.

Everday problems of present and future linac operation were presented in the KEK contribution dealing with materials and material processing. Without such careful technological development work, there is sometimes no progress. The break through in rf-superconductivity is a good example of that.

The RFQ, the radiofrequency quadrupole structure, was the darling of the last linac meeting, where almost one third of the contributions dealt with this field. Now the development goes smoother and somewhat more quietly. But things are steadily improving as was outlined in J. Staples talk and was seen by many contributions. There is obviously still room for ideas in design improvement, better frequency and field tuning, simplification of designs etc.

There were about half a dozen RFQ operational in 1984. Today there are many more in use for a variety of applications. RFQ's have helped to extend the capability of existing facilities as for instance at CERN, from where the successful acceleration of oxygen was reported. USSR has entered the fusion driver community with a remarkable 6 MHz heavy ion RFQ.

In connection with RFQ's high current ion sources and the understanding of high current beam formation are indispensable. Currents can be delivered from today's sources in desired quantities. Beam quality is another question and depends mainly on the design of beam extraction and formation systems. Common understanding of beam emittance and of useful beam emittance is still converging. But as in other fields, computer codes and experimental results coincide if adequate experimental techniques are used, so that computer aided system design can help a lot.

Interest in negative ion sources, especially H^- sources has increased again because of stripping injection into synchrotrons and also space applications. There exist several source types based both on surface and volume formation processes, which are not all completely understood, but that is not unusual for

ion sources. Currents of several 10 mA are standard now.

A collaboration of three laboratories DESY, Los Alamos and Jülich provided a whole bunch, or I should better say a bouquet of software for accelerator design. These codes allow the computation of frequencies of rf-resonators of complicated shape in a full 3 D way, the computation of beam cavity, and beam-beam interaction as well as the impedance of arbitrary metal walls surrounding the beam. Thereby a really excellent set of design tools is provided for accelerators of all kinds and for many of the problems discussed at this meeting in connection with beam instabilities. I think it is worth to mention in this context, that Th. Weiland, who was the driving force on this field, has received the 1986 Physics Prize of the German Physical Society for his outstanding work in this field, which is also important for many other areas.

Yesterday we heard about the progress of new accelerator concepts for very high gradient, high energy accelerators such as the two beam accelerator - a talk dedicated to Yuri Orlov -, the plasma, and the wake field accelerator schemes. First experiments have started or are underway. For the two beam accelerator, which is based on high power FEL development high gradient tests by a LBL-LLL collaboration with a 7-cell accelerating structure resulted 180 MV/m from 1 GW rf power. There is a remarkable contrast between the high power figures and finger-size structure.

The plasma acceleration concepts with beat waves and wake fields are undergoing first experimental tests, too. A group of Quebec University has presented a 1 GV/m experiment in a 1.5 mm long plasma.

The wake field experimental set-up at DESY has accelerated driving ring beams of up to 50 A to 8 MeV and compressed to 1 cm.

So ideas are approaching proof.

Permanent magnets used today in many accelerator devices, ion sources, wigglers etc. have not often been applied for linac quadrupole structures. A new design was presented to improve electromagnetic quadrupole performance in very compact units. A whole Alvarez structure with permanent quadrupoles is in operation now in Japan, perhaps a breakthrough.

Electron linacs were the favorite topic of this day. CW-accelerators for electrons seem to be most attractive for experiments, but the best way to do this is still under discussion. CERN announced the first 405 MeV full turn EPA beam from the LEP linac. We learned about various high power beam devices, even if we could not learn all. A 90 MeV linac has recently become operational in Beijing, the superconducting linac at Darmstadt starts commissioning. Very high fields were achieved in single cell test at SLAC, up to 450 MV/m, as we heard again this morning.

FELs are an interesting subject. There are already several devices running, but electron beam quality is still a major demand for an efficiently working FEL. Present investigations show that for FEL injector linacs proper mixing of frequencies, and magnetic compression schemes can lead to desired longitudinal and transverse emittances at high peak beam currents.

Last night we had the conference dinner, a most pleasant event. With a reception and excellent dinner in the faculty club, and later on a fascinating "talk show" conducted by Dr. D.C. Johansen, who walked the way back with us for 3.5 million years to our ancesters. We heard of a new dimension, which could eventually be used in describing accelerating structures: Percentage of genetic distance. One might ask the question what is the genetic distance between plasma beat wave and plasma wake field accelerator, or between the four vane and four rod structure etc.

The talks of this morning are still fresh in your minds so I will not dwell on them again. But I will still draw two conclusions from these talks, which bring me back to the beginning of this summary:
First: There was a time for the proton linacs, but now is the time for the electron linacs.
Second: Therefore, the best place to celebrate the 25th anniversary of this conference was SLAC, with the largest and most unique electron linear accelerator facility.

To this laboratory, to its director Dr. Richter, I would like to express on behalf of the linac community the appreciation for hosting this conference. Thanks go especially to Gregory Loew, the chairman of this meeting, who arranged all the things, who prepared such an excellent program, who provided the pleasant atmosphere, who arranged small and larger social events. Thanks also to the staff who managed all the organization and technical things so well. I want just to single out Elizabeth Farendin, who did such an excellent job in helping to organize us in many details before and during the conference.

Thank you all again.