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ICFA Beam Dynamics Panel: Introduction

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The Beam Dynamics Newsletter is published by ICFA Beam Dynamics Panel to encourage international and interdisciplinary collaboration in beam dynamics. We welcome active and constructive participations of anyone to the Newsletter and the Panel. Please find the panel members nearby (see below) and tell your opinion to them.

WWW Now, new home pages of the ICFA Beam Dynamics Panel were created in US and in Japan (still in a trial stage). They contain the Newsletters, Future Workshops, and other informations useful to accelerator physicists.

- http://bronze.ucs.indiana.edu/~shylee/icfa.html or http://www.iucf.indiana.edu/~sylee/icfa.html.
- http://info.desy.de/library/eljnl.html (Europe).
- http://130.87.74.156/ICFA/icfa.html (Japan).

Working Groups in the Panel As noticed in the previous issue, we have three working groups in the panel. Their activities will be shown in the Newsletters. (In this issue, the report for the **tau-charm** working group is included.

- new acceleration schemes (Pellegrini is the leader):
- future light source (Laclare is the leader):
- tau-charm factory (Perelstein is the leader): please see his report in this issue.

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ICFA and the ICFA Beam Dynamics Panel

John Peoples
Chairman, International Committee for Future Accelerators (ICFA)

1 ICFA

ICFA is an international organization where discussions can take place on international aspects of high energy physics, in particular the large accelerators that are at the heart of this field. It has broad international representation according to a formula for membership by the different regions of the world; it has connections to other international scientific bodies such as the International Union of Pure and Applied Physics (IUPAP).

Although ICFA has no means of ensuring that any of its recommendations are carried out, because of its broad international representation, it can act as a "conscience" of the field and its recommendations can also influence national or regional activities. A good description might be that ICFA is a facilitator. More formally its aims, as redefined in 1985, are as follows:

"To promote international collaboration in all phases of the construction and exploitation of very high energy accelerators.

To organize regularly world- inclusive meetings for the exchange of information on future plans for regional facilities and for the formulation of advice on joint studies and uses.

To organize workshops for the study of problems related to super high-energy accelerator complexes and their international exploitation and to foster Research and Development of necessary technology."

ICFA's origins go back to the late 1960's, with formal creation in 1976. Currently, there are three major activities.

1.1 ICFA Meetings

The Committee meets about twice a year to consider topics concerning future accelerators and often related subjects like instrumentation, accelerator technology, and also high energy physics research and technology. Items that have been discussed recently include international usage of major high energy physics facilities, possible tau-charm factories, and international collaboration on R&D towards a TeV linear e+e- collider.

1.2 ICFA Seminars

About every three years, ICFA organizes a several day Seminar on Future Perspectives in High Energy Physics, where review talks are give on the state of accelerators and high energy physics around the world. There are usually about 150 attendees from all world regions involved in the field, and government science administrators are increasingly attending. The next Seminar will be held in Tsukuba (Japan) on 14-18 October 1996.

1.3 ICFA Panels

Several years ago it was realized that there were many accelerator and high energy physics topics of a technical nature where international discussion was valuable, and where expertise beyond that of the ICFA members was needed. Because of this, ICFA panels on specific technical topics were set up. At present there are two panels, on Instrumentation, Innovation and Development, and on Beam Dynamics. Other panels have existed in the past for limited periods, and others will be created as the need arises.

2 ICFA Beam Dynamics Panel

As indicated above, the ICFA Beam Dynamics Panel was created by ICFA to provide expertise on a subject of importance to present and future accelerators. The Panel provides a valuable service to the community by bringing together experts for workshops and seminars on outstanding problems in the field; it also alerts the field to new problems and solutions more rapidly than by formal publication. Just one example of the type of activity that the Panel undertakes is its current work on beam dynamics aspects of a tau charm factory; this is an important subject since such a machine is the subject now of considerable world-wide discussion. It is probably true that, to paraphrase the old expression, if the ICFA Beam Dynamics Panel did not exist, something very similar would have to be invented.

TAU-CHARM FACTORY WORKING GROUP

E.A.Perelstein[1], the leader of the group

The Tau-Charm Factory (TCF) design has involved research groups of many centers starting from Prof. J. Kirkby TCF proposal at 1987[1]. The first collider proposal was made by J. Jowett at 1987[2]. This design was based on standard scheme of collisions: large horizontal emittance and zero dispersion function at the interaction point. It included many important features, such as two separate rings for electrons and positrons, micro-beta insertions, wigglers using for an emittance control etc. This design was an original point for the next ones. The first wide discussion of the TCF problems was at Stanford Workshop on TCF at 1989[3] then proceeded at numerous workshops [4-8].

Starting from 1990 the TCF designs based on standard scheme aroused in Orsay[9], Stanford[10], CERN-Spain[11] and Dubna[12]. The TCF design with the monochromatization scheme using for ITEP (Moscow) was proposed at 1991 by collaboration ITEP, JINR and BINP[13] and next one with a monochromatization and polarized particles was studied at[14].

The next step was done when the versatile lattices have been studied to combine advantages of standard scheme, monochromatization and crossing angle schemes in one collider design[15]. There was CERN and Dubna cooperative studies aimed for construction of TCF at these places.

Now we have the TCF designing activity at Argonne, Beijing, Dubna and Novosibirsk. The main scientific goals of designing were formulated at Marbella workshop as follows[5]:

1. The peak luminosity must be around the tau-lepton production threshold energy of E$\simeq$2 GeV (E being the beam energy) and higher than 10^{33} cm^{-2}s^{-1};
2. The TCF must provide a high average luminosity, of the order of half the peak luminosity;
3. High luminosity must be provided in a wide energy range from E$\simeq$1.5 GeV (J/ψ physics) up to 2.85 GeV (charmed baryon physics);
4. Around specific energies (i.e. J/ψ resonance and tau pair production threshold) a centre-of-mass energy resolution of 100 keV or less is desirable which requires beam monochromatization;
5. Polarized beams simultaneously with monochromatization are also of a special interest.

There was the Tenth ICFA Beam Dynamics Panel Meeting on 17 May 1995 at Joint Institute for Nuclear Research, Dubna, Russia (also on 2 May 1995 at Hyatt Regency Hotel, Dallas) where the Beam Dynamics Panel decided to create working groups in the panel (see Beam Dynamics Newsletter, No.8, August,1995, p.3). The creation of the working groups is the official appeal of the panel on the special importance and urgentness of the subjects for the high energy accelerator society.

One of the new created groups is the tau-charm factory working group (Perelstein is the leader): its mission is to encourage the construction of at least one tau-charm factory in the world by promoting studies of related beam dynamics problems and investigating optimized

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machine designs. The working group has to study some problems of the TCF beam dynamics issues, the optimum ways to have high luminosity combined with the versatile lattice for several operation modes, and some beam instability issues. These studies will not be aimed to any particular design for a laboratory but to some common key TCF issues in the beam dynamics.

The duration of the group is three years and it is extendable if approved by the panel. The group will hold meetings, workshops etc when needed. The group leader has to report the activities of the group at least once a year in the panel meetings and newsletters.

The 29th ICFA meeting was held in Beijing on 11 August and it was decided to make a statement that a tau-charm factory is important. Related to this, the tau-charm working group is encouraged.

The preliminary list[2] of the TCF working group members is as follows:

E. A. Perelstein	JINR, Dubna	the leader, panel member
Yu. I. Alexahin	JINR, Dubna	
P. F. Beloshitsky	JINR, Dubna	
Chuang Zhang	IHEP, Beijing	panel member
Dong Wang	IHEP, Beijing	
Ying-Zhi Wu	IHEP, Beijing	
V. V. Parkhomchuk	BINP, Novosibirsk	
D. V. Pestrikov	BINP, Novosibirsk	panel member
L. Palumbo	INFN, Frascati	panel member
J. Le Duff	LAL, Orsay	
A. A. Zholents	LBL, Berkeley	
Lee Teng	ANL, Argonne	
S. Kamada	KEK, Tsukuba	

The items of the TCF working group activity will be well-known problems identified at the previous workshops[3-8]:

1. Design study to obtain the maximum luminosity in a wide energy region and the best possibility of the monochromatization using versatile magnet lattices and wigglers.
2. The longitudinal polarization study and a problem of an interference of longitudinal polarization with monochromatization.
3. Comparative study of different designs to reach the maximum luminosity and fulfill the most of the physics challenges.
4. Further theoretical(including simulations) and possible experimental study of beam-beam interaction in the monochromatization and crossing angle schemes aimed to obtain available values of the beam-beam parameters.
5. Study of a beam life time dependence on beam-beam parameters.
6. Study of instabilities and possible feed-back system designing.
7. Accelerator-detector interference and interaction region design. Background problems.
8. Engineering problems.

[2]The list should be approved by ICFA.

The first working group meeting place have been discussed by the preliminary working group members. The most acceptable will be EPAC-96, Barcelona, June, 10-14, 1996, but some problems would be discussed on the Beijing Workshop on TCF in February 1996.

The TCF beam dynamics problems will be included in the planned Advanced ICFA Beam Dynamics Workshop on beam dynamics issues for e+e- high luminosity colliders, considered for June 1997, Frascati.

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Report on the 8th ICFA advanced beam dynamics workshop on the space charge dominated beams and applications of high brightness beams

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The 8th ICFA beam dynamics workshop on the space charge dominated beams and applications of high brightness beams was held in the FOURWINDS resort hotel at Bloomington from Oct. 11- Oct.13, 1995. The workshop was attended by 94 physicists from 10 countries (England, France, Germany, Japan, Italy, Sweden, Switzerland, Taiwan, Russia, and US). The agenda and talks of the workshop will remain available from WWW page: **http://www.iucf.indiana.edu:80/~sylee/icfa8ws8.html**. Plenary talks are listed as follows:

Thomas Wangler	The emittance, concept and growth mechanisms
Grahame Rees	Space-charge tune shift, fast resonance traversal, and current limits in circular accelerators
Tom Fessenden	Summary Report of the 1995 Symposium on Heavy Ion Fusion held at the Princeton Plasma Physics Laboratory Sept. 6-9, 1995.
Jim Alessi	State of the art in ion sources
Mario Weiss	Beam dynamics and performance of high intensity RFQ
Bob Garnett	Linear Accelerator for tritium production (100 mA 1 GeV)
Michel Pabst	Critical beam dynamical issues in neutron Spallation source
Alex Friedman	Induction-accelerator HIF status and feasibility (Driver Configurations for Heavy Ion Fusion)
Steve Holmes	Critical beam dynamics issues in hadron colliders
R. Sheffield	Beam dynamics issues relevant to the fourth generation light source
Gilbert Guignard	High-brightness beam emittance growth and preservation in CLIC
Robert Palmer	Status of mu-mu Collider Conceptual Design

Summary talks of the workshop were presented by workshop chairmen:

M. Reiser	Space charge dominated beam Experiments
I. Hofmann	Theory
K.J. Kim	beam dynamics relevant to ultrashort pulse electron beams

Talks presented in the experiment working group are

Simon Yu	LBL experiments
John Barnard	LLNL HIF Experiments
J.G. Wang	Experimental studies on longitudinal dynamics of space charge dominated beams
Samar Guharay	Critical issues for developing efficient LEBT for intense, high brightness ion beams

Subrata Nath	Beam funneling in high intensity proton linacs
W.T. Weng	Measurements of AGS booster and AGS beams
Mike Blaskiewicz	Reducing space charge tune shift with a barrier cavity
Ed Crosbie and K. Symon	Injection into a circular machine with a KV distribution
Sergie Nagaitsev (IUCF)	Ways to reduce space charge effects: beam heating
Irving Haber	Maryland expt
Simon Yu	LBL expt.:
Ingo Hofmann	GSI expt

Theoretical approaches in space charge dominated beams are listed as follows:

Irving Haber	Maryland/NRL/LANL: PIC tracking
Rob Ryne	Symplectic computation of Lyapunov exponent and application to halo formation
Chi-ping Chen	Halo formation and chaos in space charge dominated beams
Yuri Batygin	On space charge dominated beam transport without emittance growth and Nonlinear beam dynamics in heavy ion transport line
J.M. Lagniel	Nonlinear resonances in space-charge dominated beams
A. Riabko	Overlapping resonances and chaos in halo formation
Dave Grote	3-D particle-in-cell simulations of space-charge-dominated: Emittance growth due to energy spread, bends, and "energy effect" aberrations in ESQ's
Bill Sharp	Longitudinal "resistive wall" and fluid/envelope models of space-charge dominated HIF beams
A.C. Piquemal	Theoretical and numerical studies of halo in intense ion beams emittance growth or routes to reversibility in charged particle beams
W.W. Lee	Delta-f simulation of space charge effects
David Bruhwiler	Lowest-order phase space structure of a simplified beam halo Hamiltonian
K. Bongardt	Halo containment in the ESS linac to ring transfer line
G. Rees	High Intensity Features of the spallation sources ESS and ISIS
C. Prior	Transverse and Longitudinal Tracking Studies for ESS and ISIS
Y.C. Chae	Argonne: beam dynamics issues in the Argonne NSS proposal
E. Lessner	Longitudinal tracking studies for ANLPSS

Talks presented in the electron beam working groups are

M.G. Mazarakis	High voltage and high brightness electron accelerator with foil-less diode
Tom Katsouleas	Beam Issues for Plasma Accelerators
Hongxiu Liu	Space charge effects in recirculating UV FEL Driver Accelerator
Bruce Carlsten	Emittance growth in bends
K.J. Kim	Coherent Radiation in bends
Luca Serafini	Analytical studies of space charge dominated beams in RF photo-injectors

Sunao Kawasaki	Behavior of high-brightness microbeam in a periodic focusing system
A. Molodozhentsev	Beam dynamics problems with quasi-isochronous storage rings
S.Y. Lee	Minimum emittance for combined function DBA lattices

Three working groups held a joint session on Fokker-Planck approach and statistical methods in the space charge dominated beams. Joint working group talks are listed as follows:

S. Machida & Y. Shoji	Space-charge Effect in Synchrotron (KEK Booster)
Ingo Hofmann	Collective Theory of Equipartitioning
C.L. Bohn	Conceptual foundation for Fokker-Planck approach to space charge effect
J. Struckmeier	Fokker Planck approach to emittance and entropy growth
Steve Lund	Thermal equilibration of beams
M. Reiser	Proposed RF Linacs with beams in thermal equilibrium
Patrick O'Shea	Thermodynamics Potential and Emittance growth
K. J. Kim	Entropy and emittance in e-beams and radiation

The proceedings will be published in AIP conference proceedings. Many important talks are presented in the workshop. Besides the workshop talks, panel members led by Prof. Gluckstern present many relevant beam dynamics topics for next few years.

Issues presented at the 8th ICFA beam dynamics workshop panel discussions

Panel Chair: R.L. Gluckstern (rlg@quark.umd.edu)

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Introductory Comments to the Panel Discussion on SCBD (Session VIII)

The panel members are drawn from several different communities:

- Those with interest in high current ion linacs (APT, spallation sources, etc.)
- Those with interest in heavy ion fusion
- Those with interest in high current electron linacs
- DOE perspective
- ICFA perspective

We shall hear briefly from each, followed by questions first from other panel members, then from members of the audience.

Comments from Panel members

Tom Wangler (LANL)

Beam physics needed in proton LINAC applications

A new generation of proton linacs that can deliver high beam power are being considered for a number of important applications throughout the world. The beam physics is important because of the need to control beam losses, which create radioactivation of the accelerator. Except for applications requiring circular machines, such spallation neutron sources, emittance growth itself is not the main concern, but rather the outer part of the beam distribution known as the beam halo. I will present what I believe are the beam-physics areas needing more study and development that directly relate to the needs of the proton-linac applications.

1. Beam Halo:

   Transverse mismatch of the beam has been well established as an important mechanism for producing halo. Progress in this area has resulted not only from numerical simulations, but also from an analytic model of the interaction of individual particles with the core, which provided understanding of the physics. The particle-core model has been applied to both uniform and periodic-focusing channels, and it has shown that a resonance between the core breathing oscillation, and the individual particle motion is a main cause of particles acquiring large amplitudes. It is found that there is a maximum amplitude for the resonantly driven particles, which provides some guidance for choosing the aperture sizes to avoid beam loss. Although there still seems to be a lack of a complete consensus about whether matched beams in quadrupole channels can produce halo, these seems to be good agreement about most other features of halo produced by the transverse dynamics. The important unanswered questions, include a) Is there still a maximum halo amplitude when many modes are excited by a beam mismatch? b) What are the characteristics of halo produced by longitudinal mismatch? This is a very important problem because the longitudinal beam-measurements needed to ensure good longitudinal matching are much more difficult. Very little progress has been made so far in the study of halo from longitudinally mismatched beams. c) How important is chaos in the halo formation? Is it important for beams of moderate tune depression? d) Can halo scraping be effective, and how should it be implemented?

2. Equipartitioning

   More systematic study is needed to extend Hofmann's work on the x-y problem, beginning with the r-z problem. Most of the following questions were already identified in Hofmann's talk. What are the thermal-asymmetry thresholds needed to produce energy transfer between planes? What time scales are involved? Does energy transfer proceed until equipartitioning is established? Is halo formed as a result, and is there a maximum amplitude?

3. Space-Charge Codes

   Space-charge-code development is important if we are going to be able to predict fractional beam losses at the level of 10^{-5} fractional losses, or about 10^{-8} /m. Furthermore we would like to carry out beam simulations with at least 10^7 particles to have adequate statistical confidence that the total beam losses are sufficiently low. For a perspective, the real number of particles per bunch is about 10^9. Because of the difficulty of benchmarking the codes against experiment, it may be necessary to carry out such computations with more than one space-charge code to provide some checks.

4. Experimental Measurements

   Measurements are necessary for benchmarking the codes. Ideally, this means measurements of transverse and longitudinal beam halo are necessary. Such measurements are not easy because the beam diagnostics must be capable of detection of the beam distribution over a large range of intensity.

5. Matching into RFQ's

   Beam matching of a high-intensity dc beam into an RFQ has not been easy. High-intensity RFQ's have ended up with less RFQ output current than was predicted by the simulation codes, and this has generally been attributed to poorly matched beams at injection. This is not a problem for radioactivation, because of the low energy of the lost beam. The issue is the ability to deliver the design value of the beam current. Both experimental and computational studies may be required to address this problem.

These five areas are some of the most important. They will most likely require experiment, theory, and computational methods to make maximum progress.

Discussion after Wangler presentation:

- Gluckstern: Referring to the particle-core model, to avoid particle losses is it best to choose the apertures outside the outer separatrix of the resonance region, or is the better strategy to relax the aperture requirement and concentrate on controlling the mismatch?
- Wangler: The effective threshold for generating large particle amplitudes and beam halo from mismatch is very low; a mismatch of only 10pretty large amplitudes. It will be difficult to guarantee that you can match even this well, especially longitudinally. Therefore, until we know more, I believe it is prudent to keep the apertures outside the outer separatrix. Ultimately the goal should also be to control the mismatch, but I think we are not yet in a position to claim we can do it.
- Friedman: We are the ideas for making 10^7 particle simulations of real linacs?
- Wangler: We don't have good answers for this. This is what we think we need to do, but at present our large runs have about 10^5 particles.

Ingo Hofmann (GSI) **Remarks concerning the issue of halo & loss:**

- The present understanding of halo origin seems to focus on the concept of an oscillating nonlinearity due to mismatch (core oscillations) + particles (in general assumed outside the core, i.e. in the "halo region") driven into nonlinear resonance by the core oscillations. It may be necessary to extend the analysis beyond the presently studied envelope mismatch modes for the core and include the effect of higher order mismatch modes as well. Can we ignore small initial amplitudes of such modes? This raises also question of self-consistency: does the model predict how particles get from a realistic initial distribution into the halo region?

- There is still a big gap between linac design codes and "modelled simulations" looking at specific modes and resonances. The latter presently focus on infinitely long beams, which are also symmetric in the two transverse degrees of freedom. Hence, one parameter (i.e. the tune depression) seems enough to describe high phase space density. By going to ellipsoidal bunches (symmetric in the two transverse degrees of freedom) three parameters are required to describe the bunch adequately. These can be, for instance, the transverse rsp. Longitudinal tune depressions and the ratio of semi-axi or - equivalently - "temperatures". The latter leads to the question of "equipartitioning". A warning seems in place here: on the short time scales considered in linacs collisions play a negligible role and it may be more appropriate to discuss the question of temperature exchange in terms of collective instabilities and nonlinear resonances rather than stressing too much thermodynamics.

Alex Friedman (LLNL)

Some thoughts on Beam Dynamics issues in Induction-Accelerator Based Heavy Ion Fusion

In general, Heavy-Ion Fusion driver development involves a simultaneous optimization of two budgets, one describing the beam emittance and the other the driver cost. The fusion target gain (energy multiplication) increases as the beam spot size is reduced (there is less radiation converter mass to heat), and this leads to a reduced cost of electricity. If HIF is to provide cost-effective electric power, the driver must produce a set of beams with an appropriate energy per ion, a large enough current, and a small enough emittance to hit the converters, and must do so at an attractive price. Other issues such as lifetime and availability are important as well, but can be folded into a life-cycle cost.

$$\text{emittance} \quad \longleftrightarrow \quad \text{cost}$$

As part of the author's formal talk earlier in the meeting, a "taxonomy" of the beam dynamics issues associated with induction HIF was presented. The comments made by the author as a panelist supplemented that material and are reproduced below.

- Experiments :

  Beam dynamics research for HIF can and does make good use of scaled experiments to explore the critical issues. These include:

  - The 4-into-1 beam combiner experiment about to be fielded at LBNL
  - The small, scaled ESQ injector used as a test-bed for the recently-completed full-scale 2 MeV injector at LBNL
  - The planned ILSE facility and program of experiments, which will employ beams with driver-scale radius and line-charge density but having reduced ion mass and energy
  - Experiments in magnetic transport, bending and recirculation at LLNL, leading up to an operational prototype Small Recirculator with key dimensionless parameters similar to those of a driver
  - Electron beam experiments at the University of Maryland exploring a variety of issues in transverse and longitudinal beam dynamics

Researchers in the field are fortunate in that (1) beam dynamics is readily scalable, and key dimensionless parameters are readily identified, in marked contrast with systems governed by atomic physics, wall interactions, etc.; (2) shot-to-shot repeatability is excellent, implying that a detailed picture of the beam particle distribution function can be built up over many shots. Also, small changes can be measured; thus it is often unnecessary to follow a beam over a long distance, and a relatively short and inexpensive experiment suffices; and (3) planned ring experiments at LLNL and the University of Maryland will facilitate the study of those phenomena that require a long path length for proper study, such as growth of unstable waves on the beam, wave reflection, the effects of imperfect longitudinal confinement, and "slow" equilibration mechanisms.

- Theory and Simulations

  In contrast with some fields of study, theory and simulations for Heavy Ion Fusion (and for space-charge dominated beam applications in general) are typically kept relevant and well-coupled to experiments, except in those cases (driver-scale specific issues) where it is necessary to study systems which do not yet exist. A hierarchy of tools is available, ranging from simple envelope models, through single-particle tracking and fluid models, to full discrete-particle (usually particle-in-cell, or PIC) simulations, including detailed 3-D calculations. In many ways the accelerator is a simpler system to model than (e.g.) a magnetic fusion device, since the beam resides in an induction linac for only 100 plasma periods. Furthermore, the physics does not generally require that a wide range of space- or time-scales be captured for a useful description. However, in some cases it is necessary to resolve the thin Debye length-scale sheath at the edge of the beam, and/or short axial wavelengths (the beam radius) which arise during collective equilibration. There are good opportunities to benchmark the theoretical and numerical tools versus experiments, and this is important since those same tools are used to predict the behavior of planned and proposed machines. True source-to-target modeling is a real possibility. Full PIC simulations of the beam in an induction linac appear to be within reach (after further code development and optimization), and particle simulations of LLNL's planned Small Recirculator over the full 15 (nominal) laps have been carried out using the WARP3d code. However, full PIC simulation of a driver-scale recirculator, with its long path length, will remain out of reach for a long time, requiring that a hierarchy of tools be used. Some calculations are inherently challenging. The production of halo particles often involves "rare" events, and capturing such events with good statistics requires that a very large number of simulation particles be used. Increased understanding has been gained through the combination of analytic theory, clever model calculations, and large-scale simulations.

- Personal Views and Priorities

  The use of self-consistent models should be expanded. Detailed study which relies on an unrealistic beam state may yield misleading results.

  In general, "realistic" beam models should be used, and K-V equilibria should be employed with great care, and avoided when possible. Researchers have been misled by instabilities in K-V beams that do not arise in beams with realistic, smooth particle distributions. Ideally, the full 6-D particle distribution of the beam at a fixed time (or fixed plane) might be obtained from experiment and used to specify the beam at the beginning of a simulation. However, this in general will not be possible, and the use in simulations of beams formed "by injection" (that is, by simulating the injection process) is recommended when possible.

It will be important for practitioners to learn from each other, both across sub-fields and among those practicing theory, experiment, and simulation. In HIF it is also necessary to work both "forward from the source" and "backward from the target."

Technology development hasn't been discussed much at this meeting, but it serves to define the realm of possibilities. It is important for experimenters and theorists to communicate well with those involved in technology development, and to promote promising activities.

Three "feedback loops" ought to be encouraged and kept healthy:

$$\begin{array}{rcl} \text{Desirable} & \longleftrightarrow & \text{Possible} \\ \text{Fusion Driver} & \longleftrightarrow & \text{Present}-\text{day experiment} \\ & \text{Theory \& Modeling} & \\ \updownarrow & & \updownarrow \\ \text{Experiment} & \longleftrightarrow & \text{Technology} \end{array}$$

In general, HIF researchers in the U.S. and Europe appear to be doing well at identifying the important issues and making progress on them, within resource constraints. Cooperation with other researchers who are also concerned with space-charge effects is leading to real benefits.

W.T. Weng (BNL)

Comments on issues related to pulsed spallation neutron source

The typical design parameters for a 5 MW pulsed spallation neutron source are a proton synchrotron with an energy of a few GeV, an intensity of about 3×10^{14} ppp, and a repetition rate of around 50 Hz. Such a facility exceeds the current best performing proton synchrotron (for example ISIS – 800 MeV, 2×10^{13} ppp, 50 Hz, and the AGS – 28 GeV, 6×10^{13} ppp, 1 Hz) by a factor of 20 to 50 in total proton flux per second. Therefore the biggest challenge in the design of the next generation PNS is the particle loss in the injection and acceleration process. The typical loss of a few percent in today's accelerators has to be reduced to less than a tenth of a percent to keep the radiation effects to an acceptable level. To achieve that goal, the following areas need more R&D.

1. Charge distribution and halo formation in the linac and synchrotron.
2. Space charge effect at injection and methods of multi-turn injection to minimize particle losses. Issues such as painting, resonance corrections, second harmonic cavity, rf feedback, $\cdots$ etc., naturally come in here.
3. Coherent instabilities and their prevention and cures.
4. Reliable H^- source capable of delivering more than 100 mA.
5. Prototype chopper and stripping foil design.
6. Scraping, collimation and radiation shielding of beam.
7. Accelerator machine studies on critical processes.

Kwang-Je Kim (LBNL)

Beam Dynamics of Ultrashort, High-Brightness Electron Beams

Ultrashort, high-brightness electron beams would have important applications in the future, for example, in TeV linear colliders, x-ray free electron lasers, and short pulse synchrotron radiation generation. The beam parameters required for these applications are very demanding–the bunch length less than a picosecond, the energy spread less than 0.1 less than a few mm-mrad, and the pulse charge of about one nC. There are also more speculative applications, such as in developing compact, high energy accelerators based on the laser acceleration schemes, for which the requirements are even tighter.

Prerequisite to generating such beams is a thorough understanding of the beam generated electromagnetic field, and its effects on the beam qualities. Although the topic is not new for longer pulse beams, some new effects have been identified recently which could have a significant impact on the design of the accelerators producing ultrashort, high-brightness beams. The main goal of the Ultrashort Bunch Working Group was to understand and evaluate these effects in various accelerator schemes.

For linacs, two important components for generation of ultrashort, high brightness beams are the laser driven RF photocathode gun invented recently at LANL and the the bunching section. The space charge effect plays important role in both of these components: It is important in the RF photocathode gun because the beam at the beginning is non-relativistic. In a bunching section, where the orbit has a bend, the space charge effect turns out to be important even at relativistic energies. For storage rings, an isochronous design has been proposed for storing ultrashort beams. The collective instabilities in such a ring behave similar to the linac instabilities, and must be analyzed accordingly. In the following we summarize each of these topics separately:

The beam dynamics in laser driven RF photocathode gun have been investigated by several authors. The original study based on the analysis of the individual particle trajectory resulted in a simple analytic estimate of the emittance growth as the beam travels from the photocathode surface to the cavity exit. However, the growth is due primarily to the fact that the phase space ellipses at different locations along the bunch are not aligned with each other because of the variation in the space charge force. It is important for the operation of the laser driven RF photocathode gun as a source of ultrashort, high brightness electron beam that the phase space ellipses be realigned by means of a focusing element in the gun. This so called emittance compensation scheme has been modeled by detailed numerical simulation and tested conclusively by experiment. However, a clear analytical understanding of the operation of the scheme has been lacking, which could provide guidelines for practical designs. The Working Group discussed two recent approaches, which appear to be promising toward obtaining such an understanding. One is based on an envelope equation, and explains the emittance compensation by the phenomena that the solution of the envelope equation approaches to an invariant envelope. Another is based on an emittance evolution equation, and describes the emittance growth in two parts; a reversible part driven by the free energy stored in the electrostatic field, for which the emittance compensation is applicable, and an irreversible part arising from the entropy change. One should note that both approaches are based on the concepts and the formalisms developed by the ion beam community. The interaction between the electron beam and the ion beam communities during the workshop may hopefully result in a deeper understanding of the beam dynamics in both fields.

Space charge effects are normally negligible for highly relativistic beams moving in a straight pass because of the cancelation of the electric and the magnetic forces. However, two effects are identified recently which could be significant for relativistic, bunched beams moving in a curved pass, as in a bunching section. One effect arises from an incomplete cancelation of the electric and magneto forces for beams on a curved orbit. For unbunched beams, it was established sometimes ago that the effect of the residual force, referred to as the centrifugal space charge force, is canceled by the potential depression in the beam. Recent analysis shows that, for a bunched beam, the centrifugal space charge force remains uncanceled. The second effect is the phenomena that the coherent synchrotron radiation emitted by the trailing part overtakes and exerts force on the leading part of the bunch. Both the centrifugal space charge effect and the coherent synchrotron effect could lead to an energy change of particles within an achromatic bend, which in turn could lead to an emittance growth. Recent estimates indicate that the effects could be large, placing severe constraints on the design of the bunching section. During the working group discussion, different methods to evaluate these effects were discussed, with which a more accurate calculation could hopefully be made.

Recently, there have been some theoretical and experimental studies on the storage ring operation with a small momentum compaction factor for storing short bunches. In the limit of the vanishing momentum compaction, the relative longitudinal motion of the particles in the bunch stops. It was pointed out during the Working Group session that the collective instabilities then behave more like those in an extended linac rather than in a conventional storage ring. The main collective effects in a linac– and therefore in an isochronous storage ring–are the head-tail energy split in the longitudinal dimension and the beam break-up instability in the transverse dimension. The implication of these effects on the operation of isochronous storage rings are being evaluated.

Comments from the panel:

- *T. Wangler*: In principle the physics of space-charge-induced ion emittance growth also apply for electrons. The difference is that electrons leave the dc injector moving at about half the speed of light, and are accelerated to near the speed of light very quickly. Unlike ions, the electrons avoid the low-beta region, where space-charge effects are most important, and spend little time in the medium beta region.

Alex Chao (SLAC)
Emittance of Linear Colliders

Linear colliders require beams with high intensities and low emittances. For example, the 250 GeV NLC design requires $N = 0.7 \times 10^{10}$, $\epsilon_{Nx} = 5$ mm-mrad, $\epsilon_{Ny} = 0.05$ mm-mrad at the collision point, to yield a luminosity of 6×10^{33} cm^{-2}s^{-1}. The figure of merit for a linear collider (luminosity), however, is somewhat different from that for, e.g., an FEL (brightness). The luminosity scales as $\frac{N^2}{\epsilon_N}$, while the brightness scales as $N/\epsilon_N^2\ell_z$, where ℓ_z is the bunch length. The optimization of a linear collider therefore is not identical to optimizing the brightness. In particular, in a linear collider, a large N is more useful than a small ϵ_N, while the opposite is true if one tries to optimize the brightness. Also, bunch length does not matter when one optimizes luminosity.

Almost all issues concerning low emittances discussed in the workshop are relevant to a linear collider. Space charge effect is critical at the gun. Wake fields, halos, misalignments, and jitters are important emittance spoilers in the linac. Nonlinearities, halos are important in the final focus. Among these issues, due to its long linacs, the wake field effects carry a heavier weight than many other applications, while due to its high beam energy, the importance of the space charge effects is restricted only to the gun area.

In the NLC design, damping rings are required to damp the emittances before the beams are injected into the long linacs. One question one may ask is whether the beam emittances right after the gun can be made small enough that these damping rings can be avoided. To inject the beams into the linacs directly from the gun, we must consider round beams. For the NLC, this means we should consider $\epsilon_{Nx} = \epsilon_{Ny} = 0.5$ mm-mrad. Such a small emittance seems achievable (within a factor of 2) by the state-of-art rf photocathode guns, but only for electrons. For positrons, a damping ring seems necessary.

One may also ask if NLC can be built as a laser accelerator. This means replacing the klystrons by lasers as power source. Let f be the ratio of the rf wavelength to the laser wavelength ($f \gg 1$). For acceleration, we then imagine miniaturizing the size of the rf structures by a factor f. The problem with this laser accelerator is that the number of particles per bunch N must scale down by a factor f in order to keep beam loading effects in check. To avoiding losing luminosity, we need then to increase the collision rate by a factor of f and to reduce the emittance by a factor of f. The increase of collision rate by f is a difficult technical challenge. The reduction of emittance by a factor of f is in principle achievable for electrons by collimating the emission area at the cathode. If $\lambda_{\rm rf} = 2.6$ cm and $\lambda_{\rm laser} = 10\mu$m, the resulting emittance would then be $\epsilon_N = 1.2 \times 10^{-4}$ mm-mrad. This incredibly small emittance is required for a weak beam bunch with $N = 2.7 \times 10^6$. It fortunately does not (yet) violate the fundamental uncertainty principle limit of $\epsilon_N = \frac{\hbar}{2mc} = 1.9 \times 10^{-7}$ mm-mrad. There remains the question whether it is possible to reduce the positron emittance by a factor of f, even with weak beam bunches.

S. Holmes (Fermilab)

Round Table Comments on Beam Intensity Issues in Hadron Colliders

Comments and Observations

- Lower emittance in the hadron collider complex is (almost) always desirable.
- In hadron facilities the problem isn't at the front end. H^- injection and coalescing allow increase in the beam intensity and/or phase space density. Emittance preservation is much bigger issue than creation of low emittance.
- Mechanism(s) for emittance dilution due to space-charge in low energy synchrotrons are not well understood.
- Raising the injection energy has proven effective in improving performance significantly in low energy synchrotrons (for example the FNAL linac upgrade and the BNL Booster).
- Beam-beam interactions can be a limitation in TeV range proton-antiproton colliders. The long-range becomes important with more bunches and in high energy proton-proton machines with parasitic crossings.
- High energy proton-proton machines will place ever higher premium on low emittance (because of the impact of synchrotron radiation).

- Intrabeam scattering will be significant in colliders operating in the year 2000 (i.e. the Tevatron and RHIC).

Areas Requiring Attention

- Effort should be invested into developing a better understanding of the role of space-charge in low energy synchrotrons
- Improved diagnostics, dampers, kickers are required to minimize dilution during transfers.
- Bunched beam stochastic cooling with cooling times of a few hours would be extremely beneficial in combating emittance growth due to intrabeam scattering, power supply noise, rf noise, etc.
- Medium energy electron cooling presents an opportunity for creating low emittance beams beyond the space-charge regime. This technology should be developed.
- A better understanding of long-rang beam-beam effects will be required in future hadron colliders.

In the end the solution may be to make the proton beam energy high enough that beam is synchrotron radiation damped.

Discussions after Holmes' presentation:

- Wangler: Given what we now know about controlling emittance in hadron colliders, how difficult would it have been to achieve the design luminosity for SSC, had it been built.
- Holmes: It would have been a challenge, but I think it was doable.

Kohji Hirata (ICFA Beam dynamics panel chairman, KEK)

ICFA is the organization for high energy physics. For this purpose, it has the beam dynamics panel. The mission of the panel is to encourage and promote the international collaboration for the present and future accelerators. There, however, does not exist "the beam dynamics for high energy accelerators". All the knowledge obtained from all the accelerators is useful for all the accelerators. There is no limitation for the issues treated by the beam dynamics panel. The panel might be a good place to construct the beam dynamics society, like other societies in physics, high energy society for example. The panel encourages the more collaboration within the space-charge community, between different communities in accelerator physics, and between other communities in physics.

R.L. Gluckstern (Univ. of Maryland)

Closing Comments

The perspectives presented by the panel members have been extremely interesting. Moreover, the significant occurrence at this workshop is that the different communities have come together to consider important problems of overlapping interest. We hope this continues.

I would like to make some comments about the work on high intensity ion beam transport, in which I am also a "player".

- It seems likely that we have identified the primary source of halos: a resonance between a coherent oscillation of the beam (breathing mode?) and the non-linear motion of individual particles in the beam.
- From analytic and simulation studies of a K-V beam one can predict the halo boundaries. The time frame for halo growth is not yet well understood. In fact one needs another mechanism (instability?) to get the ions to the region where they can generate the halo.
- Further studies are needed on non-KV beams
- Further studies are needed on 3-D beam bunches
- Further studies are needed on AG focusing and the role of chaos.
- Further studies are needed on other beam modes and other resonances
- Much is being learned from envelope studies
- Further study is needed to determine the role played by thermal effects and equipartitioning
- Further experiments on collective beam effects in space charge dominated beams will be very useful
- The work on the Fokker-Planck equation seems interesting, but it is directed toward understanding how a mismatched beam seeks a new equilibrium. For almost matched beams, it may not be of direct use.

Let us again thank the panelists for a very interesting discussion and our hosts, including Prof. S.Y. Lee, for organizing and implementing such a productive workshop.

Discussion after Gluckstern's talk:

- Wangler: My interpretation of the particle-core model is that the K-V core part of the model, represents the high-current central density of a typical particle distribution in a linac, which is peaked in the center and falls off at the edge. The K-V core in the model gives us approximate fields that are seen by the few particles in the tails. Given this interpretation, there is no problem answering the question how the particles got outside the core. There were already there as part of the original particle distribution. What the model then shows is that the mismatched beam core drives the outer particles in resonance and their amplitudes become very large, forming a halo.

Comments from workshop participants

S.Y. Lee (Indiana University)

On the systematic experimental measurements and theoretical analyses of high intensity beam parameters

Halo formation has been extensively studied extensively by numerical simulations. It has been shown to be related to nonlinear parametric resonances, particularly overlapping resonances, resulting from the mismatched space charge dominated beam in the LINAC structure. These nonlinear resonances are characteristically similar to those of circular synchrotrons, where nonlinear resonances have been studied experimentally and theoretically. To better understand the physics of halo formation, better theory has to be developed. This means that we should gain knowledge of the parametric resonances in the global parametric space.

Experimental measurements of the beam properties in the global parametric space, e.g. *the space perveance, the phase advance, and the mismatch parameters* are essential to understand the validity of the simplified KV model vs the thermal beam distribution model. Since the resonance driving term for the space charge dominated beam is basically a universal function (Coulomb force) of the beam property. These systematic measurements can be used to gain confidence of our model studies.

M. Reiser (Univ. of Maryland)

I have two questions and some comments. The first is a question to Alex Chao:

- M. Reiser: "You mentioned the two options for achieving the luminosity in linear colliders - higher beam current or lower emittance - and you pointed out that increasing the beam current would be the preferred option. But in view of the high average power in a future linear collider, which is in the 100 MW range, this choice is not so obvious to me and lowering the emittance to the extent that this is feasible would appear to be preferable."
- A. Chao : I agree that increasing the current is the preferred choice only as long as other considerations such as average power do not impose a limit.
- M. Reiser: The second contribution is a comment to the statements by Tom Wangler and Bob Gluckstern. "Tom Wangler and Bob Gluckstern discussed the importance of the halo problem in high-current linacs and what has been learned in theoretical and computer simulation studies. I would like to point out that these studies as well as our electron beam experiments on halo formation in mismatched beams at Maryland are concerned with long or continuous beams. In future work the much more difficult problem of halo formation in bunched beams must be addressed. Here, the coupling between longitudinal and transverse motion and the associated equipartitioning via space charge forces and the combined effects of transverse and longitudinal beam mismatch must be taken into account. This is a very challenging task for the theoreticians and experimentalists. As we pointed out in our talk (M. Reiser and N. Brown), a design where the beam is in thermodynamic equilibrium -throughout the entire rf linac or at least in the more critical low-energy region - appears to be an attractive way of avoiding or minimizing particle losses via halo formation."

C. Chen (MIT)

I'd like to add one area to Tom Wangler's list of areas of research on beam dynamics in high-current accelerators, namely, the role of charge density inhomogeneities in halo production. Indeed, recent studies by Qian Qian, Ron Davidson and myself [Phys. Rev. E51, 5216 (1995)] have shown that nonlinear space-charge forces due to beam density nonuniformities not only can induce chaotic particle motion, but also can cause a small fraction of particles to escape from the beam interior to form a halo.

Tom Katsouleas (USC)

After 3 days of interesting talks, many involving PIC simulations, I was struck by the observation that almost all of the PIC simulation output was in the form of particle plots. PIC codes are powerful tools, full of useful information. However, it appeared that field diagnostics were rarely turned on or presented. This is something like chopping down trees with a chainsaw with its engine turned off. Turn on the field and energy plots and the ω and k spectra of the collective modes that we think are responsible for the isotropization of the beam temperature. Then perhaps we will learn what modes are.

A similar problem of anisotropic temperature relaxation was recently encountered in laser-ionized gases (of the type used for plasma accelerators). The transverse laser field results in a high $T_\perp$ and cold $T_{||}$ plasma. Subsequent thermalization is observed on a time scale much faster than a collision period. Through PIC simulations the thermalization mechanism was found to be the Weibel instability [W. Leemans, *et al.*, Phys. Rev. A **46**, 1091 (1992)] – a zero frequency mode with a characteristic wave number. Perhaps a similar mechanism is responsible for the isotropization observed in heavy ion beams.

K. Bongardt (KFA)

For high intensity proton linacs, the high energy transfer line, either to a target station or to a following ring, suffers from space charge forces. In a longitudinal 'drift' the rms energy spread increases due to longitudinal space charge forces, even for energies above 1 GeV (=1000 MeV). As a consequence of this rms energy spread increase the design of an achromatic bending section gets complicated. The space charge forces cause also filmentation of the longitudinal phase space area. One way to reduce this filamentation is to keep the beam bunched which can be in conflict for the application of a bunch-rotator in order to reduce the energy spread. As the bunch length is increasing in the longitudinal 'drift', image forces cannot be neglected as the bunch length is comparable to the beam pipe diameter.

Another important effect that you didn't mention that affects short-pulse spallation neutron sources is in the transfer line between the linac and the ring. The beam debunches, and becomes very space-charge dominated in the longitudinal dimension. Thus it can become very difficult to control the longitudinal emittance. This is a very serious problem.

Shane Koscielniaki (TRIUMF)

Comment after panel discussion ICFA workshop on S-C dominated beams

Numerical methods play an important part in increasing our understanding of complex systems, because of the facility to trivially alter initial and boundary conditions and the force law, and because of the exact repeatability of computer experiments. The problem of the time evolution of a distribution of N ions mutually interacting by Coulombic repulsion (in the beam rest frame) leads to an $N \times N$ step algorithm for the calculation of the forces on the ions when direct methods are employed. Often, the N^2 algorithm is replaced by the PIC or particle-mesh algorithm: charges are assigned to the mesh, fields calculated on the mesh, and forces interpolated to the ion locations; which is a $2N$ algorithm plus some overhead for solving the fields on the mesh. In either case, N^2 or $2N$ we have no method to predict the minimum N to give realistic results; and for the $2N$ algorithm, we have no procedure to relate the mesh dimensions (i.e. number of cells) to the minimum number of particles. It is my opinion that there is essential work to be done here, so that reliable ensemble sizes can be estimated in advance of the detailed numerical simulations.

9th Advanced ICFA Beam Dynamics Workshop: Beam Dynamics and Technology Issues for $\mu^+ \mu^-$ Colliders [1]

October 15-20, 1995 – Montauk, NewYork

R.B. Palmer[2],
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Technical Progress and New Ideas

The basic ideas for a muon collider, and some of its problems, have been reported in an earlier edition of this newsletter. The workshop at Montauk was the fourth to look in more detail at these ideas, and it was the first such meeting sponsored by ICFA.

Much progress on the study of $\mu^+ \mu^-$ colliders has been made. The possibility of a 2 + 2 TeV machine with luminosity of $10^{35}(\mathrm{cm}^{-2}\mathrm{sec}^{-1})$ is still not ruled out. Work on the design of a demonstration 250 +250 GeV machine with luminosity between 10^{32} and 10^{33} is starting. Meanwhile, the physicists have identified a number of topics that would specifically benefit from the use of a $\mu^+ \mu^-$ collider as opposed to an $e^+ e^-$ machine of the same energy.

Proton Driver

Considerable progress was reported on the design of a 5 MW, 10 GeV proton driver. Designs were aimed at delivering two bunches of 5×10^{13} protons in 3 nsec (rms) bunches at 30 Hz. Work was also reported on upgrades to the AGS that would yield a 1 MW beam at 24 GeV: 10^{14} protons per pulse at 2.5 Hz.

Pion Capture

At the previous workshop, it was proposed to capture pions from .5 to 2 GeV using very large lithium lenses. The designs obtained as many as 0.2 μ/p (muons per proton), a value more than two orders of magnitude higher than earlier designs. Now it was reported that even better capture (0.4 μ/p) could be obtained using a single very high field (28 T) hybrid solenoid. If 20 T is used instead of 28 T then there is a loss of only about 20 %, and the solenoid can then be made without a superconducting outsert. A 15 cm bore 20 T water cooled Bitter magnet would (by MIT calculation[3]) use 14 MW. This, though high, is not unreasonable. The elimination of the superconducting coils removes a serious question as to whether such a magnet could operate in the high radiation environment near the target.

[1] Proceedings to be published by AIP Press
[2] PALMER@BNL.GOV
[3] R. Weggel;private communication

Use of both charges

FNAL reported on the use of bent solenoids to separate the charges of pions immediately after the target. Previously we had been able to use only one sign of pion from a given bunch. This new idea might allow the use of both signs and thus double the number of muons per proton.

Cooling

For the first time, a complete, though preliminary, cooling scenario was presented. In this scheme the required low beta focusing was obtained in a FOFO lattice consisting of spaced solenoids. Emittance exchange was achieved by wedges in dispersion regions generated in chicanes also within a FOFO lattice.

Novosibirsk reported on calculations that indicated that a small bore liquid lithium lens should operate with surface fields of 20 T. This is twice as high as we had assumed possible and would give beta functions a factor two smaller than assumed in the above scenario.

Acceleration

In previous workshops, the rapid acceleration of the muons was achieved by a sequence of recirculating accelerators of the CEBAF type. This seemed technically sound but would be expensive, and involved as many as 20 recirculations to minimize this cost.

It emerged at the workshop that these multi-turn recirculating accelerators could be replaced by fast cycling synchrotrons. This represents a major cost reduction in the components that previously seemed likely to dominate the total cost. In the 250 + 250 GeV case the fast cycling magnets could be pulsed (4T, 1 msec pulse length). In the 2 + 2 TeV case pulse magnets would probably consume too much power, but in that case a hybrid of superconducting magnets and counter-rotating permanent magnets seems feasible. Bud Good proposed such rotating magnets many years ago, but there was at that time no compelling reason for it.

Collider Ring

Studies have shown that the requirement of a nearly isochronous lattice can be met without difficulty. Problems remain, however, in obtaining a design for the low beta insertion. Studies of instability problems were reported, but no final conclusions were reached. Pair production at the intersecting point was shown to be large, but the consequences of this remain to be determined.

Remaining Problems

There remain inconsistencies between different pion production codes and between these and the data. There is a lack of data in just that region of production that we would be using.

There are serious questions about the technology and cost of the phase rotation and cooling linacs.

The cooling sequence is not well defined or optimized. There are serious questions of the needed lattice, particle loss and space charge control. The technology of the needed solenoids and possible lithium lenses remain to be studied.

Almost no work has been done on the specification, loading, cost optimization and tolerances of the accelerator superconducting linac.

We still do not have a lattice for the collider. Much progress has been made, but the goal parameters for the 2 + 2 TeV machine are extraordinary. Even if a lattice is obtained there will remain many questions of stability and tolerance. The practicality of our parameters thus remain undemonstrated. The lattice for 250 + 250 GeV should be much easier, but work on it has barely begun.

Background calculations for a 2 + 2 TeV machine done at FNAL are preliminary, and need optimization. This is a potentially critical area and needs much more work. No work has yet been done on the situation for 250 + 250 GeV.

Current efforts

A significant effort is underway at BNL, FNAL, LBL and Novosibirsk. Supporting work has been done by individuals at many other institutions (CEBAF, Fairfield, MIT, Saclay, SLAC, UCLA). There will be a conference on the physics potential of $\mu^+ \mu^-$ colliders in San Francisco Dec 13-15, 1995. Three BNL/FNAL/LBL collaboration meetings are scheduled: Feb 1-2, 1996 at BNL, March 28-29, 1996 at FNAL, May 30-31, 1996 at LBL. There will be a Muon Collider Subgroup at Snowmass 96 Workshop: June 24-July 12, 1996.

Advanced Accelerator Physics School held in Beijing

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The 1995 Beijing Advanced Accelerator Physics School was held during June 14th - 17th in the Institute of High Energy Physics (IHEP), Beijing, China. It was jointly organized by the Chinese Accelerator Society and IHEP. The school, which followed by two years the General Accelerator Physics School organized by the Chinese Accelerator Society, IHEP and CERN in 1993, is another important activity in the field of accelerator physics in China.

Five accelerator physics experts were invited to attend this school. They were Pisin Chen from SLAC, R. C. Fernow from BNL, J. B. Rosenzweig from UCLA, W. Scandale from CERN and K. Yokoya from KEK. They gave sixteen lectures. The main emphasis of their lectures is about new accelerator concepts, including plasma accelerators (P. Chen), near field accelerators (J. B. Rosenzweig) and far field accelerators (R. C. Fernow). Other fields, such as the nonlinear dynamics (W. Scandale) and beam polarization in storage rings (K. Yokoya), were also introduced in their lectures. Several local accelerator physics experts, who came from Chinese institutes and universities, gave eleven seminars in the school. They discussed a few new proposals in China and some recent progress in accelerator physics at the existing accelerators.

Almost 70 students attended this school. They came from many institutes and universities of China. Academician of China Jiaer Chen, Deputy Director of IHEP Shuhong Wang and

Pisin Chen of SLAC, who were the chairmen of the school, gave impressive speeches in the opening and the closing ceremonies. Director General of IHEP Zhiping Zheng gave a warm welcoming talk on the first day and R. C. Fernow summarized the school at the end.

In this school we heard a survey of the most important ideas proposed for new, high gradient accelerators. The ideas that were presented range from highly speculative concepts, such as the crystal accelerator, to ideas with a well-developed mathematical theory, such as the plasma beat wave accelerator (PBWA) and laser wakefield accelerator (LWFA). On the experimental side, proof of principle experiments have been carried out for the inverse Cerenkov accelerator, inverse free electron laser accelerator (IFEL), PBWA, LWFA and dielectric wakefield accelerator. New experiments currently underway are concentrating on achieving higher accelerating gradients and longer interaction lengths. Proposals of experiments to accelerate particles up to 100 MeV and 1 Gev have been made, that will address for the first time real accelerator issues such as emittance preservation, staging and energy spread. The very nice experimental results presented for the plasma lens give us encouragement that a useful plasma device may be available in the near future.

The question was raised during the school if there might be other, as yet undiscovered, accelerator schemes. We believe the answer is yes. New schemes are still being developed, such as the Fabry-Perot dielectric cavity accelerator which was presented at this school by J. Rosenzweig.

This points out the need for better theoretical guidance on the necessary and/or sufficient conditions for acceleration to occur. Robert Palmer made an important step in this direction with his so-called "General Acceleration Theorem". There has been some uneasiness concerning the rigor of Palmer's proof. However, Pisin Chen presented in this school a calculation made by Kirk McDonald that demonstrates that the theorem is correct, at least for one, realistic model of the fields in a laser focus.

All new acceleration schemes must undergo a first stage of understanding where the emphasis is necessarily on demonstrating theoretically and experimentally that acceleration is indeed possible. It is encouraging that our theoretical understanding of some methods at least are moving into a second stage, where other important accelerator issues, such as efficiency, are being considered.

However, none of the advanced accelerator concepts discussed at this school is ready to be used as a working accelerator. Each scheme has its own intrinsic advantages and disadvantages. Each scheme has its own level of theoretical and experimental maturity. There are still many aspects of these schemes that need to be critically evaluated.

Theoretically, the field is wide open to us. Experimentally, it may be possible to add research of this type to existing programs. For example, it may be possible to add an IFEL experiment at an FEL facility, or to study plasma acceleration ideas at an existing plasma physics lab without major additional expense. We also see, as suggested by Pisin Chen, a promising possibility to study the plasma focusing effect on an electron beam or especially on a positron beam of energy from 1.0 to 1.5 GeV, which can be provided by the injector linac of the BEPC at the IHEP, Beijing.

At the conclusion, the school distributed a questionnaires to each student. The answers from the questionnaires showed that the lectures and the seminars were very enlightening to the students. They appreciated the teachers of the school for providing such nice lectures. The answers from the questionnaires also showed that the students have learned a lot in the school in a very short period. The environment and the working conditions of the school were quite satisfactory to the lecturers and the students. The school was very successful, just as expected. It is hoped that a series of schools of this kind, either general or advanced, will be held continually in the future in China.

LHC95 – International Workshop on Single-Particle Effects in Large Hadron Colliders

Montreux, Switzerland, 15 – 21 October 1995

E. Keil[1], CERN, Geneva, Switzerland

The Workshop on Single-Particle Effects in Large Hadron Colliders was attended by some 59 participants from 19 institutes. The goal was to review and discuss the present understanding of single-particle effects, both theoretical and experimental, from the large hadron colliders which were or are in operation, i.e. HERA, Sp$\bar{p}$S, and Tevatron, and to analyze its consequences for the design of future hadron colliders, in particular the LHC. Three working groups were scheduled, on Dynamic Aperture, chaired by F. Willeke (DESY), on Errors, chaired by R. Talman (Cornell U), and on Maps, chaired by A.J. Dragt (U Maryland), who also gave the summary talks in the final session. The current understanding of the subject of the working groups was presented in introductory talks by S. Peggs (BNL) on Dynamic Aperture, D. Ritson (SLAC) on Errors, and J. Irwin (SLAC) on Maps. Further talks were given by J. Gareyte (CERN) on the LHC, J.R. Cary (U Colorado) on Eliminating chaos to maximize dynamic aperture, J. Ellison (U New Mexico) on The method of averaging in beam dynamics – deterministic and stochastic, J. Hubbard (U Marseilles) on Iterating Hénon maps in the complex domain, and G. Turchetti (U Bologna) on Normal forms and the analysis of nonlinear betatron motion. The working groups heard many talks which covered a wide variety of subjects.

- Y. Alexahine (CERN): Mathematica applications to nonlinear dynamic analysis
- A.Bazzani (U Bologna): Diffusion in betatron motion with a slowly tune modulation
- O. Brüning (CERN): Tune modulation in the proton ring of HERA
- V.V.Danilov and E.A.Perevedentsev (BINP, Novosibirsk, Russia): Integrable maps and invariants for nonlinear accelerator optics
- W. Fischer (DESY): Comparison of measured and computed dynamic aperture for the SPS and the HERA proton ring
- A. Gaus-Golfe (CERN): Does LHC ramp shape matter
- M. Giovannozzi (CERN): Estimate of the dynamic aperture
- R.C. Gupta (BNL): 1. An integral approach between magnet designer and accelerator physicists for field error in the magnets 2. On estimating and minimizing field errors in the magnets

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- B. Holzer (DESY): Impact of persistent and eddy currents on accelerator performance
- F.C. Iselin (CERN): The Class Library for Accelerator System Simulation and Control CLASSIC
- J. Jowett (CERN): Dynamic aperture of LEP2
- J.P. Koutchouk (CERN): On the correction of a_2 in LHC
- E. McIntosh (CERN): Numerical accelerator project NAP
- F. Méot (CEA Saclay): On the effects of fringe fields in the LHC ring
- S. Mishra (Fermilab): Simulations of beam-beam effects in Tevatron
- Q. Qin and S. Weisz (CERN): Dynamic aperture of LHC due to systematic multipoles
- R. Ryne (LANL): Particle tracking on massively parallel processors
- W. Scandale (CERN): A sorting strategy for the magnetic random errors
- T. Sen (DESY): Emittance growth due to fluctuations of tune, closed orbit and beam size
- G.P. Tsironis (Univ. of Crete): Observation of dispersive transport in synchrotron short and long term dynamics in synchrotrons
- L. Walckiers (CERN): 1. What can we expect from the magnetic measurements of the LHC prototypes and series magnets 2. Current and time dependencies of the field quality of the LHC magnets, present knowledge and tentative explanation
- J. Wei (BNL): Magnetic error compensation and computer modeling in RHIC
- V. Ziemann (Uppsala U): 1. Crude scaling laws for the dynamic aperture of LHC from random non-linear errors

The Working Group on Dynamic Aperture concentrated on three issues: (i) Computation of the dynamic aperture and in particular of early indicators, where Lascar's method of frequency analysis is very promising (ii) Measurement of the dynamic aperture in existing machines and comparison with computations, based on Fischer's work on HERA and the SPS (iii) Proposals for future experiments, where earlier experiments in the SPS on the influence of tune modulation will be repeated.

The Working Group on Errors discussed magnet design, magnetic measurements and dynamic effects of the errors in the Tevatron, RHIC, HERA and LHC. The relative chromaticity error induced by persistent currents was estimated, and found to be 1.6 times smaller in LHC than in HERA. Other topics were coupling compensation, correlation between warm and cold measurements, tracking results and crude scaling laws concerning the effect of multipoles on the dynamic aperture, methods to measure the low-order coefficients of the non-linear transfer map. The Working Group on Errors was impressed by reports how the field errors are controlled during the manufacture of the RHIC magnets by measuring and shimming.

Brief Summary of Results of LHC 95 Working Group on Maps

Current and past use of maps was reviewed. It was agreed that single-pass maps (for the case of straight machines such as the NLC) and one-turn maps for (the case of circular machines) give a very useful description of a great deal of what one would like to know about machine performance, and the use of map methods permits routine analysis to arbitrary order (using, for example, normal forms) of the kind one could only have dreamed of using ordinary perturbation theory.

Reported recent advances included the following:

a. The SLAC group described how they have used map methods to design the PEP II B Factory including very rapid dynamic aperture determination using an n Poisson bracket approximation to describe the phase-space action of the one-turn map. They also described how map methods were used to study the beam-beam interaction (in the weak-strong approximation) and how it was important to include nonlinear ring effects in beam-beam simulations (which they were able to do by using map methods). Finally, they described how they had used Lie algebraic map methods in the optimization of the SLC and FFTB final focus systems, and in the design of an NLC final focus system.

b. The Maryland group reported on the approximation of truncated Taylor maps by optimal Cremona maps. (Cremona maps are maps that are polynomial, i.e. have a terminating Taylor expansion, and are yet exactly symplectic.) This work is an extension of Irwin's earlier work on "kick" factorization, and is expected to give substantially improved results. It is anticipated that these new methods will be applied to one-turn maps for the LHC.

c. Members of the Classic Collaboration (SLAC, CERN, Fermilab, Maryland, Colorado, and others) reported on their efforts to provide object oriented code that will implement map methods (among other things) and will be convenient for broad use in the accelerator physics community. In this connection, the Maryland group reported that it should be possible to implement Truncated Power Series Algebra routines and related algorithms that would speed up the computation and manipulation of maps by at least a factor of 10.

d. Berg and Hoffstatter described two approaches to obtaining long-term bounds on orbit stability in storage rings using one-turn maps. Hoffstatter, and perhaps at a later time Berg, will apply these methods to orbit stability in the LHC.

e. Laskar, Robin, Todesco, Bartolini, and others described the use of Frequency Map analysis. This method shows promise of being both an important theoretical tool and a practical on-line tool for use in the control room.

New proposals and suggestions were also made:

a. Irwin and Ziemann described how map coefficients might be measured experimentally. Irwin agreed to test his method on SPS data, and possible experiments on LEP are envisioned.

b. Dragt described how map methods might be used to study ripple effects, and described how tracking with and without ripple could in principle be carried out with equal speed and precision. Schmidt agreed to explore these ideas further with application to the LHC. Dragt also described similar ideas for the treatment of noise. Finally Dragt described how normal form techniques might profitably be combined with both frequency map and Lyapunov analysis. Indeed, Schmidt reported that he had already used such "enhanced" Lyapunov analysis with good results.

Proceedings will be published as a special issue of Particle Accelerators.

Report on the International Workshop on 2nd Generation Plasma Accelerators

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"Zero to 40MeV in under one millimeter"

1 Summary

The quotation above is not an advertisement for an automobile magazine; rather it is one of the highlights of numerous experimental results presented at a recent workshop held in Kardamyli, Greece. 29 participants from 8 countries gathered there on June 26 - 30, 1995, to discuss their research on plasma accelerators. The meeting was co-sponsored by US DOE and the EEC. The purpose of the Workshop was twofold: First it provided a forum for detailed presentation of recent experimental results from around the world. Taken as a whole these represent the "first generation" of plasma experiments; namely, those that demonstrate proof-of-principle of ultra-high gradient acceleration of particles in plasmas (as high as 100 GeV/m was reported). Second, the Workshop focused the attention of the plasma and accelerator community on issues important to demonstrating a "second generation" of plasma accelerators; that is experiments that demonstrate also high current and good beam quality. The Workshop was organized into a $1\frac{1}{2}$ day plenary session with an evening poster session, followed by working group sessions. A brief summary of the Workshop is given below. The full proceedings of the Workshop will be published as a Special Issue of IEEE Transactions on Plasma Science in April 1996. The proceedings can be ordered from IEEE Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

2 Program

The Workshop was planned and held by

- The International Organizing Committee:
  - F. Amiranoff (Ecole Polytechnique, France)
  - R. Bingham, Co-Chair (RAL, UK)
  - A. E. Dangor (Imperial College, UK)
  - U. De Angelis (U. Napoli, Italy)
  - C. Joshi (UCLA, USA)
  - T. Katsouleas, Co-Chair (USC, USA)
  - A. Ogata (KEK, Japan)
  - C. Pellegrini (UCLA, USA)
  - P. Sprangle (NRL, USA)

- The Local Organizing Committee: G. Yanakeas, P. Ponireas, S. C. Katsouleas
- Conference Secretary: S. Mistry

2.1 Plenary Session

State-of-the-art talks:

E. Esarey, Naval Research Lab., USA	Overview of Plasma Accelerators Concepts
A. Modena, Imperial College, UK	The RAL/Imperial College/UCLA/LLNL Single Frequency Laser Experiment
F. Amiranoff, Ecole Polytechnique, France	The Ecole Beat Wave Experiment
C. Clayton, Univ. of Calif., Los Angeles, USA	The UCLA Beat Wave Experiment
W. Kruer, Lawrence Livermore Natl. Lab., USA	The LLNL Single Frequency Experiment
W. B. Mori, Univ. of Calif., Los Angeles, USA	PIC Simulations of Current Laser Experiments
N. Barov, Argonne National Lab., USA	The ANL Particle Wakefield Experiment

2nd Generation talks:

T. Katsouleas, Univ. of Southern Calif., USA	Review of Beam Loading and Beam Quality in Plasma Accelerators
L. Serafini, Inst. Nazionale Di Fisica Nucl.,Italy	Micro-bunch production with RF photo-injectors
C. Pellegrini, Univ. of Calif., Los Angeles, USA	Bunching - New Ideas
A. Ogata, KEK, Japan	Application of Plasma Accelerators to Pulsed Radiolysis
C. Joshi, Univ. of California, Los Angeles,	Challenges for 2nd Generation Plasma USA Accelerators

2.2 Working Groups

- "Channels for guiding beams in plasmas" - N. Andreev, E. Esarey, T. Katsouleas, W. Leemans (Co-Chair), W. Mori, G. Shvets (Co-Chair), C. Siders.

- "Production of short e-bunches and phase locking of electrons to plasma waves"- J. Cary, C. Clayton (Co-Chair), C. Joshi, T. Katsouleas, C. Pellegrini, L. Serafini (Co-Chair).

- "Computational methods" - D. Bernard, P. Bertrand (Chair), A. Ghizzo, W. Mori.

- "Laser plasma physics issues" - F. Amiranoff, N. Andreev, D. Bernard, R. Bingham, E. Esarey, D. J. Frantzeskakis, K. Hizanidis, Y. Kitagawa, W. Kruer, V. Malka, G. Manfredi, J. T. Mendonça, A. Modena (Co-Chair), W. Mori (Co-Chair), Z. Najmudin.

- "Applications" - A. Ogata, D. Umstadter.

3 Highlights

Since T. Tajima and J. M. Dawson's seminal proposal in 1979, plasmas have been of interest for their attractive accelerator properties: immunity from breakdown and ultra-high longitudinal electric fields associated with relativistic plasma space-charge waves (of order $\sqrt{n_0}$ V/cm, where no is the plasma density in cm^{-3}). In the last few years numerous experiments around the world have begun to demonstrate this promise. Successful experiments were reported on laser-driven plasma accelerators by the following groups:

- UCLA Beat Wave (C. Clayton, A. Lal, D. Gordon, K. Wharton, K. Marsh, M. Everett, C. Joshi)
- Rutherford Appleton/Imperial College/Lawrence Livermore/UCLA collaboration (A. Modena, Z. Najmudin, A. E. Dangor, C. E. Clayton, K. A. Marsh, W. B. Mori, C. Joshi, C. B. Darrow, V. Malka, C. N. Danson)
- Ecole Polytechnique (F. Amiranoff, F. Moulin, D. Bernard, A. Specka, F. Jacquet, Ph. Miné, B. Montès, P. Poilleux, M. Bercher, A. Debraine, J. M. Dieulot, R. Morano, J. Morillo, J. Ardonceau, B. Cross, G. Matthieussent, C. Stenz, P. Mora, A. Modena, Z. Najmudin)
- KEK/Osaka (A. Ogata, K. Nakajima, T. Kozawa, Y. Yoshida)
- University of Michigan (D. Umstadter)
- University of Texas at Austin (C. W. Siders, S. P. Le Blanc, T. Tajima, M. C. Downer, A. Babine, A. Stephanov, A. Sergeev)
- US Naval Research Laboratory (E. Esarey, P. Sprangle, J. Krall, A. Ting)

Particle beam driven experiments and plasma lens experiments were represented by groups at Argonne National Laboratory and UCLA. The Rutherford experiment is representative of the state-of-the-art. This group used a single 25 TW Nd:glass laser (l = 1mm) incident on a 10^{19} cm^{-}3 density and 3 mm wide gas jet to ionize the gas and excite relativistic plasma waves through a Raman instability. The waves grew to the point of trapping and accelerating electrons out of the background plasma. An energy spectrometer was used to measure the following accelerated beam:

$$\begin{aligned} U &= \quad 30\mathrm{MeV} \\ eN &= \quad 5\pi\mathrm{mm}-\mathrm{mrad} \\ N &= \quad 10^7\mathrm{electrons\ within\ } DU = \pm\% \end{aligned}$$

Maximum electron energies up to the limit of the spectrometer, 40 MeV, were measured. These results appeared recently in A. Modena, et al., Nature Vol. 377, pp. 606-608, Oct. 1995.

It is clear from the workshop that this field is advancing at a fast pace. The working groups identified many issues and ideas for improving the next experiments. Challenges are being met in the areas of laser technology, plasma control, short bunch injection and synchronization, large-scale computational modeling, and beam dynamics in plasmas. For beam dynamists, plasmas offer fertile areas for investigation including unique space charge and non-linear effects such as in the problem of beam matching in time-dependent focusing fields. The workshop also identified several applications for near term compact accelerators with the unique short pulse structure created in plasmas. One example is to use the 30 fs pulses for ultra-fast pump-probe chemistry studies.

Beam Dynamics Activities at CERN

Albert Hofmann (ALBERT@cernvm.cern.ch)

PS (R. Cappi)

In preparation for injection into LHC one has to learn to accelerate and extract a proton beam of high intensity and large momentum spread without having any significant increase of its emittance. Experimental and theoretical (tracking) studies have beam made to investigate the effect of the non-linearities on this beam being at an extreme position before extraction. In particular the dynamic and physical aperture and the effect on the emittance are studied.

PS-Booster (H. Schönauer)

The fast RF capture of Pb ions have been refined and theoretical studies have been made to understand the loss mechanism and the collimation system. The momentum spread at injection is obtained by a beam transfer measurement. The signal processing of this system is being improved to extract signals in the presence of noise.

LEAR (S. Baird)

Much of the available machine development time at LEAR has recently been devoted to the study of very fast (<100 ms) electron cooling of Pb^{52+}, Pb^{53+} and Pb^{54+} ion beams as part of the program to develop a Pb ion injector with sufficient intensity for LHC.

Two fundamental questions have to be answered as soon as possible. Firstly, can such fast cooling times be obtained? For this point it is necessary to produce stable mono-energetic DC electron beams of several hundred milliamps at low energy (around 3KeV). Any velocity spread or fluctuation in the electron beam translates directly into a spread or fluctuation of the ion beam energy. One of the main ideas being tested here is to fully neutralize the electron beam by deliberately trapping, around the electron beam, the stationary ions produced when electrons collide with the residual gas. This neutralization compensates the space-charge induced velocity spread in the electron beam, which would reduce the cooling force. However, attempts to produce a stable fully neutralized electron beam of several hundred milliamps have lead to a number of interesting conclusions on Landau damping, the use of an external feedback system and the beam dynamics of the electron beam itself (Ref CERN/PS 95-15 (AR)).

The second question is what is the loss rate from the cooled ion beam, in the presence of the electron beam, due to recombination of the circulating ions with the cooling electrons. This loss rate was found to be anomalously high for Pb^{53+}, which was the standard charge state used for injection into the PS BOOSTER and LEAR. In fact the beam lifetime for Pb^{53+} was only 2 seconds with the electron cooler on. This is too short to allow for reasonable accumulation for LHC. Subsequent measurements using Pb^{52+} and Pb^{54+} revealed beam lifetimes of around 20 seconds in the presence of electron cooling. The very short lifetime of Pb^{53+} is understood to be caused by an enhancement of the recombination due to a three body process involving the ion, the single outer electron and a cooling electron, called dielectric recombination. This process does not enhance the recombination rate for Pb^{52+} or Pb^{54+} where there is no single valence electron on the ion.

SPS (K. Cornelis, W. Herr)
The SPS operates presently with lead. At the beginning of the acceleration these heavy ions are not very relativistic and the revolution frequency changes more than the RF-frequency range can handle. A phase change is made during the gap between batches of beam. At higher energy the beam is debunched and recaptured and the acceleration continuous using the normal RF-frequency sweep.

The experiments at the SPS to study the feasibility of extracting protons using a bent crystal were continued. A novel design of the crystals proved the existence of the multi pass extraction mechanism and led to high extraction efficiencies.

LEP (A. Hofmann)
The energy of LEP is being upgraded from 46 GeV used during the past years for Z^0 production to about 90 GeV for W production by installing superconducting cavities. Several methods are used to increase the luminosity of LEP2 . At this energy the beam-beam limit might not be reached with the bunch current available at injection. To gain luminosity low emittance lattices have been developed having a phase advance of 108° in the horizontal and 60° or 90° in the vertical plane. These lattices have been tested at 46 GeV with respect to optical properties and achievable bunch currents. The studies are being continued with particular emphasis on dynamic acceptance. Increasing the current per bunch is another way to improve the luminosity at high energy. The transverse mode coupling instability is limiting the intensity at injection. Improvements have been made by increasing the synchrotron tune Q_s which separates the modes more and by lengthening the bunch with dipole wigglers. Finally increasing the number of bunches can give a higher luminosity. A pretzel scheme with 8 bunches per beam has been used in the past. Recently, 4 trains of 2 or 3 bunches have been successfully used. Studies are underway to find which method is most promising to reach a high luminosity.

LHC (J.P. Koutchouk, F. Ruggiero)
The LHC basic lattice design in its version 4.1 was made available in the first part of the year. It features a somewhat longer periodic cell, a dispersion suppressor made of standard arc dipoles and a dedicated RF insertion; the beams are there further separated to 420 mm to allow installing separate RF systems for the two rings, alleviating thereby a rather severe beam loading. The optics activities are now directed to the study of the flexibility and robustness of the lattice and dynamic aperture. MAD++ is being coded based on the CLASSIC project and the Input Language is being upgraded to describe with improved flexibility flat machine structures. An impedance database is being set up with automatic calculation of instability thresholds and parasitic losses. Measurements of RF surface resistance for the beam screen and of beam echoes are scheduled for the next months. Space charge effects are being reviewed and, in particular, the calculation of magnetic Laslett coefficients and of transient phenomena at injection.

CLIC (G. Guignard)
After a recent optimization of the Compact Linear Collider (CLIC) parameters at 500 and 1000 GeV, based on more precise simulations of single bunch emittance control and advanced trajectory correction schemes, it became clear that the high luminosities required by the physics experiments could only be reached in a multibunch mode, when refraining the RF power consumption. Consequently, investigations of beam break-up in a train of a limited

number of bunches (5 to 10) have been launched in order to estimate the effective emittance resulting from oscillation amplitudes growing from the head to the tail of the train. Different conditions are considered. First, a multibunch generalization of the BNS damping principle is analyzed, though its practical implementation is likely to be difficult. Secondly, the effects of a given attenuation of several transverse and longitudinal modes of the long-range wakefields are being estimated in order to establish some working criteria for the design study of either damped or staggered-tuned accelerating sections. Thirdly, one wishes to figure out by how much the focusing can be modified to overconstrain the beam and to reduce long-range effects without upsetting the single bunch stability, for which the whole optics has been optimized up to now.

Beside this major topic, there are beam dynamics developments related to low-energy parts and injection complex which retain our attention. For the CLIC test facility, which will be upgraded to reproduce the two-beam scheme at low-energy, the lattice has been worked out and simulations involving simultaneously high space-charge and strong wakefields due to the 30 GHz RF structures are carried on. Questions related to the bunch compressors and the isochronous arcs of the injection schemes have been addressed. A design that is capable to render isochronous and compact a three-bend achromat does now exist.

Beam Dynamics Activities at Centre for Advanced Technology[1] (CAT)

Narayan C. Bhattacharya[2]
KEK, Accelerator Department[3]

Introduction Two dedicated synchrotron radiation sources, Indus-1 and Indus-2 are planned to be built at this centre. The injector system to these storage rings consists of a 20 MeV microtron and a 700 MeV booster synchrotron. Electrons will be accelerated to 450 MeV for injection into Indus-1 and to 700 MeV for injection into Indus-2.

Indus-1, a 450 MeV electron storage ring has been designed to satisfy users requiring radiation in the range 10-100Å.The critical wavelength of the radiation emitted from its 1.5T bending magnets will be 61Å. A 3T wiggler is also planned to be installed in this ring to provide the radiation of critical wavelength 31Å. The magnetic lattice of the ring consists of four super periods, each having one dipole magnet with a field index of 0.5 and two doublets of quadrupoles. Each super period has a 1.3m long straight section. One straight section will accommodate the injection septum magnet and the other diametrically opposite one, will be used for accommodating the injection kicker. Of the remaining two straight sections, one will be used for the rf cavity and the other for the 3T wiggler. The natural chromaticity of the ring will be corrected by installing two sextupoles in each straight section.

The microtron has been designed and commissioned to give a rated electron beam of 20 mA at 20 MeV in 1μs long pulse at a repetition rate of 1Hz.The 20 MeV electrons have been

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[2]narayan@kekvax.kek.jp. Based on information obtained from CAT.
[3]On leave from Variable Energy Cyclotron Centre, Calcutta.

successfully accelerated up to 480 MeV in the booster synchrotron with a stored current of 2mA. Further optimization to increase the current to 20mA is in progress.

Indus-2 will be a 2 GeV electron storage ring optimized for production of x-rays.An expanded Chasman Green lattice has been selected and optimized for this ring. The lattice consists of 8 unit cells each providing a 4.5m long dispersion free straight section for insertion devices. Its unit cell has two 22.5° dipole magnets, a triplet of quadrupoles for the control of dispersion in the achromat section and two quadrupole triplets for the adjustment of beam sizes in the long straight section. In addition the cell will have sextupole magnets for the chromaticity correction and harmonic sextupole magnets for enhancement of dynamic aperture. Its 1.2T bending magnets will provide radiation with a critical wavelength of 3.87Å. This ring may have five insertion devices, however at present two insertion devices are proposed to be installed in the ring. A 5T two period superconducting wiggler will provide radiation with a critical wavelength of 0.93Å.The second insertion device will be a 1.8T multipole wiggler with 6 periods. This device will provide radiation with a critical wavelength of 2.6A. It is also planned to install an undulator in the ring at a later stage to enhance flux and brightness at a particular wavelength.

Beam Dynamics The following beam dynamics studies were carried out at CAT to design the above accelerators.

1. Beam transport lines TL-1 from microtron to booster and TL-2 from booster to Indus-1 and Indus-2 were designed to match the Twiss parameters at the required injection points.

2. The lattices of the various rings were designed by keeping in mind the current trends in accelerator design, particularly Indus-2 which is a third generation x-ray synchrotron source , which will cater to the users in hard as well as soft x-rays with high flux and brightness.Indus-1 is designed with field index of 0.5 to have maximum photon brightness.

3. A three kicker scheme is utilized in booster with multiturn injection of 1μs pulse from microtron where as a single kicker is planned for injection into Indus-1 to take care of stored and injected beam for accumulation of beam current up to 100mA. Four kicker scheme in one straight section is designed for Indus-2.

4. A fast kicker extraction scheme is designed for extraction of the beam from booster.

5. The Closed Orbit Distortions (COD) were estimated for various set of random errors to find out the sensitivity of a particular error in the given machine. The orbit correction is done using the least square minimization which will correct the orbit.

6. Study of the ground vibration and its effect on stored beam in Indus-2.

7. Study of eddy current due to magnetic field ramp in booster synchrotron.

8. Study of ion trapping and its clearance in the storage rings.

9. Beam life time due to various processes viz.Touschek effect, quantum lifetime due to betatron and energy oscillations, elastic and inelastic gas scattering etc. were studied.

10. Photon flux and brightness calculations for radiation from bending magnets and insertion devices such as wigglers and undulators.

11. Estimation of the impedance for the various components of the vacuum chamber envelope.

12. Intensity dependent phenomenon such as potential well distortion, bunch lengthening, microwave instability, and head tail instability etc. due to broad band impedance of the beam surrounding vacuum chamber and the growth rate of longitudinal and transverse coupled bunch instability due to HOMs in rf cavity were studied.

13. The study of nonlinear dynamics in the presence of sextupoles and insertion devices to investigate the dynamic aperture and nonlinear resonances in accelerators.

The following computer codes were developed at CAT to study various beam dynamical parameters:

- ESRO-For linear Lattice calculations along with beam optics matching and COD with its correction and tracking of particles.
- LITI-Lifetime calculation of the beam.
- BRIGHT-for calculation of photon flux and brightness from bending magnets and insertion devices.
- ORBIT-to simulate COD and its correction.
- DYNAM-to study the dynamic aperture and its improvement using harmonic sextupoles.
- EMITTANCE-for estimation of beam emittance from beam profile measurements.

Free Electron Lasers Activity A new FEL concept called the two color FEL was proposed and studied. It involves lasing from two different undulators in two different cavities, but using the same electron beam, to get radiation at two widely separated wavelengths. One dimensional simulations were used to demonstrate the viability of the scheme in the FIR/IR and in the IR/UV. This work has been published in Optics Communication 119(1995)313.

Beam-Beam Interaction A new simulation technique was developed to study the beam-beam dynamics of electron beams with arbitrary distribution and eccentricity. The simulations show that important coherent effects are seen that limit the luminosity. This could be particularly significant for the high luminosity B-Factories that are presently under construction in Japan and USA. This work has been accepted for publication in Physical Review Letters. Work is also being done on studying the beam-beam interaction in muon colliders.

Announcements of the Forthcoming Beam Dynamics Events

Beijing Tau-Charm Factory Workshop'96

February 5 - 10, 1996 in the Lecture Hall of IHEP, Beijing
sponsored by
IHEP and the Center for Chinese Advanced Science and Technology (CCAST)

After the successful construction and operation of BEPC, Chinese scientists are very much interested in the construction of a tau-charm factory in Beijing. The feasibility study has been carried on intensively since early 1995. This international workshop is aimed to further examine the feasibility of the tau-charm factory, discuss key technology issues and to study its design.

All correspondence related to travel, visa, tour and so on should be addressed to:

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Preliminary Announcement

Second Workshop on Medium Energy Electron Cooling

Fermilab, 12 – 14 February 1996

A small workshop was held at Fermilab in February '95 to consider whether electron cooling is a practicable approach to obtaining bright, high intensity antiproton beam to raise Tevatron Collider luminosity above 10^{32}cm^{-2} s^{-1}. It appears that electron cooling will be crucial in the program to push for $\mathcal{L} = 10^{33}$ and beyond. The Laboratory has embarked on an R & D program in electron cooling with a short term aim of cooling antiprotons at 8 GeV with a 200 mA, 4.3 MeV electron beam in a cooling straight of nearly 100 m. There is a longer range goal of increasing the electron beam current by a factor of ten or more. The development program is still in a startup phase, but plans are well along and some beam measurements are underway. This workshop is the first of an intended sequence which will consider opportunities at other installations as well as at the Tevatron.

beam optics space charge dominated transport, cooling section design, gun/collector design, *etc.*
beam physics stability, beam neutralization, cooling performance estimates
instrumentation electron beam characterization, beam alignment
high voltage sources, regulation, operational features

For further information contact James MacLachlan, Fermilab, MS 323, Box 500, Batavia IL 60510, maclachlan@fnal.gov (708)840-4484

preliminary announcement

The 11the Advanced ICFA Beam Dynamics Workshop on Beam Cooling and Instability Damping

dedicated to the 30th Anniversary of the Electron Cooling

on board the ship from St.Petersburg to Moscow 19 - 28 June 1996

I.Meshkov (MESHKOV@NUSUN2.JINR.DUBNA.SU)
Joint Institute for Nuclear Research

TOPICS OF THE WORKSHOP The physics and technique of:

- Electron cooling • Laser cooling • Crystalline beams • Stochastic cooling
- Stochastic cooling at optical frequency • Electron coherent cooling
- Radiation cooling and damping • Muon cooling
- Stabilization of coherent oscillations with feedback systems
- Atomic physics processes related to electron and laser cooling
- Diagnostics of all cooling processes

THE ORGANIZING COMMITTEE

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The Co-operative Organizing Partners are:

- Joint Institute for Nuclear Research
- Budker Institute for Nuclear Physics
- Scientific Council for Accelerator of the Russian Academy of Sciences

Those intending to participate in the Workshop are urgently asked to send their comments. The cost of the Workshop depends significantly on the number of participants.

Questions and Answers Should be sent by e-mail or fax to

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preliminary announcement

12th Advanced ICFA Beam Dynamics Workshop on Nonlinear and Collective Phenomena in Beam Physics: Theory and Experiments

September 2 to 6, 1996

M. Cornacchia[1] and C. Pellegrini[2]

The Workshop will be held in Arcidosso Italy on September 2 to 6, 1996. The workshop will be used to discuss the theoretical and experimental tools needed to study the beam physics for present and future accelerators.

A detailed program will be prepared by the Program Committee. A possible partial list of topics may include:

- single particle non linear beam dynamics, dynamic aperture, beam halos;
- beam dynamics problems in plasma lenses, plasma beatwave and wakefield accelerators, including nonlinear effects and time dependent forces;
- collective effects in the interaction of beams with electromagnetic fields;
- space charge and other collective effects in the production of high brightness beams.

The following working groups are considered:

1. Single Particle Dynamics: Recent advances in nonlinear dynamics, including frequency analysis and mapping.

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2. Production and Dynamics of High Brightness Beams: Advances in production, acceleration, transport and monitoring of high brightness beams, including coherent and radiation effects.
3. Beam Dynamics in Plasmas: Advances in longitudinal and transverse dynamics, emittance preservation and beam loading in plasma systems
4. Plasma Phenomena in Beams: Transverse and longitudinal oscillations in high density relativistic beams, including parametric instabilities and filamentation

One of the main goals of this workshop is to bring together scientists working in different areas, from astronomy to accelerators, plasma, lasers, non linear physics, and we will have all these fields represented at the Workshop and in the Program Committee.

The workshop will be organized with some initial general review presentations, after which the participants will divide in working groups. Individual contributed presentations will be in the form of poster papers, and the posters will be set up and available for discussion for the full duration of the workshop. The advantage of this format is to provide maximum time for interactions between participants.

The workshop is also sponsored by DOE, ENEA, INFN, LBNL, SLAC, UCLA, KEK. More detailed information will be available before the end of 1995.

For information, contact: Melinda Laraneta at UCLA;

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Instructions to the authors

November 1995
ICFA Beam Dynamics Panel

The ICFA Beam Dynamics Newsletter is intended as a channel for describing unsolved problems and highlighting important ongoing works, and not as substitute for journal articles and conference proceedings which usually describe completed work. It is published by the ICFA Beam Dynamics Panel, one of whose missions is to encourage the international collaboration in beam dynamics.

It is published every April, August, December. The deadlines are 15 March, 15 July and 15 November, respectively.

The categories of articles in the newsletter are the following:

1. Announcements from the panel
2. Reports of Beam Dynamics Activity of a group
3. Reports of Beam Dynamics related workshops and meetings
4. Review of Beam Dynamics problems
5. Announcements of future Beam Dynamics related international workshops and meetings.
6. Letters to the editors (It is a forum open to everyone.)
7. Editorial

All articles except for 6) are invitation only. For 6), the editors keep the right to reject the contribution. Those who want to submit articles are encouraged to contact with a panel member nearby. Our preference for the submission of articles to the editors is as follows:

1. in the form of LaTeX file through e-mail: To avoid wrapping problem, please do not put comments (%).
2. computer readable file through e-mail.
3. in a camera-ready form via normal mail: everything should be within a rectangle of 23.5cm (vertically) times 16.5 cm (horizontally), excluding page number.

Figures can be sent as postscript files. For safety, it is better that the originals are sent via usual mail.

Each article should have the title, author's name(s) and his/her/their e-mail address(es).

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Those who want the copies of the newsletter are encouraged to correspond to one of the distributors according to their region. Note that the most recent copy is also available through WWW.

The views expressed in this newsletter do not necessarily coincide with those of the editors. The authors are responsible for their text.