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From the chairman of ICFA Beam Dynamics Panel

Kohji Hirata (hirata@kekvax.kek.jp)

As perhaps everybody feels, it seems that we are in a particularly important period as accelerator physicists. Despite the financial difficulties all around the world, we are still moving toward the higher energies. Relatedly, we are also moving to the higher brightness for lower energy machines.

It seems to me that, in order to proceed further, the beam dynamics needs some drastic innovation. We should have wider scope of available technologies and deeper theoretical understanding of the behavior of beams. To do so, the interdisciplinary collaborations among accelerator physicists and between physicists of other fields are very important. I hope that the beam dynamics panel promotes this kind of collaboration more and more strongly.

We welcome any suggestions for the activities of the ICFA Beam Dynamics Panel. In particular, we need constructive proposals to strengthen our effort to the above mentioned directions. Please send your opinions to nearby panel members. Your proposal will be discussed seriously in the panel.

The panel members talk each other frequently through e-mail. The next regular panel meeting will be held on 14 June 1996 at EPAC-96.

Working Groups The tau-charm factory working group was approved by ICFA in January this year. The final list of group members is identical with that shown in the December 1995 issue.

The group held the first meeting on February 8, during Beijing Tau- Charm Factory Workshop' 96, February 5-9, 1996. Dr. Perelstein, the chairman of the group, reported as follows. The members attended were as follows: 1. Perelstein E. (JINR, Dubna, BDP); 2. Beloshitsky P.(JINR, Dubna); 3. Chuang Zhang. (IHEP, Beijing, BDP); 4. Dong Wang (IHEP, Beijing); 5. Le Duff J. (LAL, France); 6. Lee Teng (FNAL, USA); 7. Preger M. (Frascati, Italy, on behalf of Luigi Palumbo); 8. Yingzhi Wu (IHEP, Beijing).

The common opinion was that the task of the group is to "identify the beam dynamics problems for the tau-charm factory and review the present understanding for the problems". Especially, it was decided that the most present review may be done on the base of the materials presented in the Beijing workshop. Drs. Yingzhi Wu and Chuang Zhang are responsible for the preparation of such a report to BD Newsletter. The next group meeting is planned to be held during EPAC-96. It was discussed that it will be convenient to devote one day for the tau-charm related problems during the Frascati Workshop (see below).

The other working groups (new acceleration schemes and future light sources) are under construction.

Future Workshops

1. The 11th Advanced ICFA Beam Dynamics Workshop on *BEAM COOLING and INSTABILITY DAMPING*, 18-26 June 1996 on board the ship from Moscow to Nizhny Novgorod and back.
2. The 12th Advanced ICFA Beam Dynamics Workshop on *Nonlinear and Collective Phenomena in Beam Physics*, Arcidosso Italy on September 2 to 6, 1996.

3. Advanced ICFA Beam Dynamics Workshop on *High Luminosity Colliders*, Frascati Italy in autumn 1997.
4. Advanced ICFA Beam Dynamics Workshop on *2nd Generation Plasma and laser Accelerators*, Kyoto Japan in autumn 1997.

WWW Now, we have the home pages of the ICFA Beam Dynamics Panel in US, Europe, and Japan. They are essentially the same and contain the Newsletters, Future Workshops, and other informations useful to accelerator physicists. Each also contains some informations interesting locally.

- http://www.indiana.edu/~icfa/icfa.html. (new address)
- http://hpariel.cern.ch/jowett/icfa/icfa.html.
- http://130.87.74.156/ICFA/icfa.html.

Panel Members There were some changes of the membership of the panel. Ferdinand Willeke has resigned from the panel member. Besides the normal job of a panel member, he has worked hard as an editor of the Newsletter as well as its distributor. H. Mais (DESY), J.Jowett (CERN), P.Chen (SLAC), P.Colestock (Fermilab), and I.Hofmann (GSI) have become new members. The present panel members are listed in the backcover.

The ICFA Beam Dynamics Newsletter No. 10

S.Y. Lee (shylee@indiana.edu), Indiana University

The Beam Dynamics Newsletter, published by the ICFA Beam Dynamics Panel, is to encourage international collaboration in beam physics and technology. It provides a forum for discussion, information exchange, and news on new discoveries in our field. The forum should generate a cohesive force to bring together our community. Active and constructive participation of beam physicists and engineers to the NEWSLETTER and beam dynamics ACTIVITIES are essential elements in achieving these goals.

Active participation of our community can be measured by the activity reports submitted by many accelerator physics groups in universities and national laboratories. Research works reported by leading high energy laboratories, such as the Fermilab, CERN, DESY, BNL, UNK, and LBL show clearly that our field is vibrant, healthy and active. At the same time, we are very pleased to find interesting research activities in universities, such as Kyoto University, Rutherford Appleton laboratory, LAL/Orsay, Michigan State University, Institute of Modern Physics at Lanzhou China, and Indiana University. Since universities provide education service to young accelerator scientists, their participation in the beam physics research is an integral part of our community. However, this is easy to say and hard to do, particularly in the economical hard time. When everybody struggles for survival in government grants, we forget easily the needs of a bigger community. For the goodness of our beam physics division, we have to resolve our differences. Good physics should be encouraged, inter-laboratories-universities collaboration should be strengthened, and research areas should be consolidated to provide a more coherent direction for our beam physics community.

Letters to the Editors

Dear S.Y.,

There is an announcement in this issue of a series of mini-workshops on high intensity, high brightness hadron beams. This series is co-sponsored by four laboratories: Fermilab, BNL, CERN and KEK.

In today's hadron accelerator world, there are two frontiers: high energy and high intensity. The former includes the Tevatron, HERA and the future LHC. The latter covers even a wider spectrum, e.g., the Main Injector currently under construction at Fermilab, the 50-GeV Japan Hadron Project that is being designed at KEK and INS, the PS upgrade at CERN, the AGS upgrade at Brookhaven, and others. The high intensity is often coupled with the requirement of high brightness, especially when the beam is to be used in a collider.

There are many major technical issues that are common to high intensity and high brightness hadron beams. For example,

- Higher order modes in rf cavities;
- Transition crossing;
- Longitudinal and transverse emittance budget;
- Coalescing and debunching-rebunching;
- Instabilities and feedback system design;
- BPM and orbit measurement requirement and implementation;
- Lattice mismatch problem;
- Beam losses at injection, etc.

The purpose of this mini-workshop series is to investigate these problems in a coherent and collaborative way. Each workshop will focus on a specific subject. These will be the "real" workshops in the sense that the number of presentations are limited and small working groups are the main part of the workshop. There will be no formal proceedings; summary reports from working groups will be provided to participants.

We believe this series will benefit the accelerator community in general. We hope that ICFA will give its support to this activity.

Sincerely,

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Beam Dynamics Activities at Fermilab

Pat Colestock (Colestock@adcalc.fnal.gov)

Tevatron

Extensive studies are underway to understand the ultimate intensity limitation in the Tevatron Collider from beam-beam induced tune shifts and the spread due to the nonlinear long-range interaction that can arise with separated beams. The luminosity of the Tevatron will increase by at least one order of magnitude in the context of future upgrades and it is essential to understand the limits imposed by the beam-beam interaction. Beam dynamics in the Tevatron has been studied using tracking methods in the "weak-strong" approximation (Mishra, Assadi). These calculations included higher-order multipoles and magnetic element misalignments. The nonlinearities introduced lead to the deleterious effects of resonance excitation and tune spreads. Based on these tracking studies, the strength of three- mode coupling has been derived from the results. A new method for depicting this interaction in tune space has been developed.

Moreover, Michelotti has shown that the required abort gap in a train of colliding bunches will result in an unbalanced beam-beam kick on the end bunches for the 36x36 case in Run II, resulting in a potentially deleterious tune shift for these end bunches. This result, related to the PACMAN effect, may be the most serious limitation on the luminosity in the near future. This result has been confirmed by several methods of analysis, and was recently confirmed experimentally in a series of pilot experiments in the Tevatron. (Goderre, Bagley, Marriner) Consequently, studies are underway to mitigate the problem in planned versions of the Collider with increased numbers of colliding bunches.

A model of the Tevatron has been implemented in the Control Room which can be used on line to analyze machine performance(Holt, Braun). This model involves a sophisticated direct access feature which effectively creates a virtual machine through interaction with the control system. The model is being developed to be as accurate a representation of machine performance as possible. The ability to directly compare model predictions with data will lead to rapid improvement of the theoretical understanding of the machine.

Collective phenomena in the Tevatron are being studied on a number of fronts. A complete theoretical analysis of the impedance of the Tevatron is being updated by K. Y. Ng, based on recent operational experience. Moreover, studies of closely-spaced bunches in the Tevatron (Assadi) indicate a class of slowly-growing longitudinal modes whose evolution becomes highly nonlinear, resulting in strongly non-Gaussian stationary bunch shapes. Efforts are underway to determine aspects of machine impedance from the observed nonlinear coherent behavior. (Gerasimov, Colestock) In other work, extensive studies of the head-tail instability have been carried out (Goderre, Marriner) which indicate a strong influence of coupling on the instability threshold.

In other work, bunched-beam synchrotron echoes have been generated in the Tevatron. (Assadi, Colestock) The evolution of the echo indicates a strong influence of some, as yet, unidentified noise source. Efforts are underway to quantify the echo behavior and to determine the connection between the echo evolution and sources of diffusion in the Tevatron.

It is known that coupling can play an important role in the Tevatron, and efforts are underway to permit a rapid measurement of the coupling using a time-domain kick in conjunction with turn-by-turn measurements at multiple locations. (Annala, Yang) The system is also useful for beta-function measurements and checks of the lattice model.

Main Ring

Even though the useful life of the Main Ring will soon come to end as the Main Injector project enters its final construction phase, the Main Ring has proven to be a fruitful arena in which to study beam instabilities, and this information may prove important as many of the components, in particular the rf cavities, will be reused for the Main Injector. A valuable study was recently completed in which the transverse impedance of the Main Ring was measured using trains of bunches (Chou, Jackson). The observed impedance was found to be consistent with the long-observed transverse instability believed to be a primary limit to increased intensity in the Main Ring.

In other work, an ongoing effort is directed toward the improvement of coalescing, which may well be required in the Main Injector and other future machines at Fermilab. A recent upgrade of the system was one of the important improvements which led to record- breaking Collider luminosities. (Wildman, Kourbanis) However, even higher intensities are planned in the future, and studies have been conducted to understand limitations, and possible solutions, due to beam loading and longitudinal coupled-bunch modes. In other work, a study was carried out to improve the efficiency of passage through transition by shaping the rf potential well. (MachLachlan, Bhat, Kourbanis)

Booster

Continuous progress has been made in increasing Booster performance by the use of new damper systems in controlling instabilities (McGinnis, Steimel). However, it is expected that the intensity limit, due to the space charge tune shift, has now been once again reached after the successful commissioning of the Linac Upgrade Project which elevated the injection energy into the Booster. To permit further intensity increases, a novel two ring scheme has been proposed (Ankenbrandt) which employs the use of H^- ion acceleration.

Accumulator

A study has been carried out to modify the Debuncher lattice in order to improve the critical cooling efficiency in that machine. (Olivieri, Church) A ramped corrector system was employed to change the mixing factor in a favorable way through the cooling cycle. In related work, a major revamping of the stochastic cooling model is underway, using a novel time-domain approach (Gerasimov). The specific characteristics of the cooling hardware have been explicitly incorporated to provide as accurate a model as possible. In other work, studies have been conducted to understand the stability boundary in the machine resulting from the accumulation of trapped ions (Werkema). Substantial improvements in performance were realized during the recent Collider Run by an increase in the ion clearing voltages applied to the beam at a series of locations around the Antiproton Accumulator. However, it is expected that trapped ions will again play a role as intensities are increased in the future. In other work, a study of longitudinal echoes was carried out in the unbunched Accumulator beam to ascertain the weak diffusion rates present in that device (Spentzouris, Colestock). Near classical echo dependence was observed, resulting in a diffusion measurement which was in rough agreement with the level expected from Coulomb scattering.

Recycler

A major effort is underway to design a new permanent magnet ring which can be constructed in the Main Injector tunnel, for the purpose of recycling and cooling valuable antiprotons following a Collider store. (Jackson) This would enable a substantial increase in integrated luminosity, which depends largely on the availability of antiprotons. The ring is also to be composed of permanent magnets which would permit the store to survive short power failures, which have traditionally been a prime cause of antiproton losses during operation. The critical aspects of permanent magnet design have been carried out (Foster), and prototyping is now underway. An important issue is the viability of stochastic cooling (McGinnis, Marriner) and electron cooling (MachLachlan, Nagaitsev) to cool the recovered antiprotons. Theoretical studies are underway to determine the equilibrium conditions in the machine, as well as the optimal mix of cooling methods.

Tev33

An exploratory study is underway to investigate the feasibility of achieving 10^{33} luminosity in the present Tevatron Collider, with appropriate modifications to the existing hardware. (Marriner) A key issue is the generation of adequate amounts of antiprotons, which may require innovation in a number of areas. Other issues include the enhancement of proton production in the low energy machines, and the control of the large tune shifts expected in the Tevatron. A subset of this study is the Recycler described above.

Main Injector

The effects of higher-order multipoles and magnetic element misalignments on Main Injector performance have been studied in detail to ensure a sufficiently large dynamical aperture in the Main Injector (Mishra). The calculations have been used as an input in the design and construction of the Main Injector magnets.

A correction scheme has also been developed to reduce the effects of unwanted multipoles. Calculations have shown that the expected aperture exceeds the Main Injector specification of 40π mm-mr (normalized 95%) at injection. The larger octupoles and the random variation of the quadrupole strengths were found to be the limiting factor on the dynamical aperture. An algorithm using magnetic correctors, along with magnet shuffling, makes it possible to reduce the effects of magnet errors, which should provide a larger aperture at all energies, especially for 120 GeV slow extraction.

Muon Collider

A multi-laboratory effort is underway to realize a viable design for a future muon-muon collider (Neuffer, Noble). Considerable progress has been made over the last year in identifying the essential issues in the design and in formulating possible technical solutions. A prime issue is the handling of backgrounds at the detectors, which have been calculated to be severe (Mokhov). Other issues include the feasibility of fast ionization cooling, and the generation of very bright proton sources for muon production. Many other issues await detailed study.

Photoinjector

Studies are underway to perfect a high-charge, laser-driven electron gun. (Colby, Rosenzweig) Theoretical studies of the space-charge dominated gun, capture cavity, and linac have been carried out using PARMELA, and a prototype gun has been constructed. Tests are now underway to verify the gun's operation and to provide information for the design of a second-generation gun.

Advanced Acceleration

The prospect of the construction of an advanced acceleration device using the short-bunch rf gun described above is being studied. (Colestock, Rosenzweig) A promising method employs two short electron bunches, the first as a driver, and the second as a witness bunch, in a staged approach to acceleration. Very large accelerating gradients are theoretically possible (1 GeV/m).

Report on the RHIC Polarized Beams Project

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The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory allows for the unique possibility of colliding polarized proton beams at energies up to 250 GeV and luminosities to 2×10^{32} cm^{-2}s^{-1}. Funding from the Institute of Physical and Chemical Research (RIKEN), Japan, is allowing for the construction of Siberian Snakes and Spin Rotators for each of the two RHIC rings, as well as for polarimeters, spin flip devices, and associated hardware and instrumentation. (In addition, RIKEN is funding upgrades to the PHENIX detector for spin physics.) The Siberian Snakes are inserted on opposite sides of the RHIC lattice for each of the two counter-rotating rings and Spin Rotators are located on each side of the two major interaction points which allow the spin orientation to be altered from the vertical plane to the longitudinal plane.

Overview of Project Elements

A summary list of the major hardware components for the project is provided in Table 1. Each Siberian Snake consists of a set of four superconducting helical dipole magnets. The magnets will be capable of producing a central field of roughly 4 T which spirals through 360° over a length of approximately 2.4 m. Four such magnets, each independently powered, can generate a spin rotation from vertically up (the nominal stable spin direction for the synchrotron) to

Snakes	4
Rotators	8
Spin Flippers	2
Polarimeters	2
Power Supplies, Controls	60

Table 1: RHIC Polarized Beams Systems Hardware

vertically down, with no net excursions of the particle trajectory. Two Snakes, with their rotation axes 90° apart, are sufficient to overcome the depolarizing resonances in the RHIC acceleration cycle. The Spin Rotators are similarly constructed; by altering the "handedness" of two of the helical magnets, and using slightly different fields, the spin can be made to rotate from the vertical to the longitudinal direction using otherwise-identical hardware.

To provide RHIC with polarized beams capability a total of 4 Snakes and 8 Rotators are required. Thus, 48 individual full-helical dipole magnets will be constructed. The four magnets needed to create one Snake or one Rotator will be mounted inside of a modified RHIC Dipole Magnet cryostat. Since it is desirable to independently power the four magnets within the cryostat, the required current should be minimized in order to keep the heat leak due to the power leads as small as possible. Thus, the magnets will have hundreds of turns of superconducting wire as opposed to a smaller number of turns of cable. This poses a technical challenge to the construction of these high-field magnets. Present parameters of the Snake and Rotator helical dipole magnets are shown in Tables 2 and 3. The field strengths of the Snake magnets are constant during the acceleration process, while the appropriate fields in the Rotator magnets are beam energy dependent. This is due to the fact that there is a final horizontal bend between the Rotators and the Interaction Point which further precesses the spin vector by an amount dependent upon the beam energy.

Number of helical magnets				4
Total length [m]				10.56
Magnet bore [mm]				100
Helical Magnets				Field [Tesla]
		length[m]	handedness	
1		2.4	righthanded	1.19
2		2.4	righthanded	−3.86
3		2.4	righthanded	3.86
4		2.4	righthanded	−1.19
Max. orbit excursion @ injection [mm]				14.7 (hor), 31.5 (ver)
Total field integral [Tm]				24.3
Orbit lengthening [mm]				1.82

Table 2: Parameters of the Siberian Snake magnets

Number of helical magnets			4	
Total length [m]			10.56	
Magnet bore [mm]			100	
Helical Magnets			Field [Tesla]	
	length[m]	handedness	@ 25 GeV	@ 250 GeV
1	2.4	righthanded	2.05	3.38
2	2.4	lefthanded	2.65	3.14
3	2.4	righthanded	2.65	3.14
4	2.4	lefthanded	2.05	3.38
Max. orbit offset @ injection [mm]			24.1 (hor), 10.0 (ver)	
Total field integral [Tm]			22.6	
Orbit lengthening [mm]			1.25	

Table 3: Parameters of the Spin Rotator magnets

Project Status

The major effort during the past year can be grouped into hardware development and accelerator physics. As for the hardware, the primary objective has been the development of the technology to be used in making the 48 magnetic modules required for the Rotators and Snakes. Two approaches to the magnet construction are being investigated. The first approach consists of an ordered wound cable placed into helical grooves which are cut into an aluminum cylinder. Thin sheets of epoxy-impregnated fiberglass are placed between layers of cable, and the entire assembly is cured to produce a firm wire matrix. A prototype coil using this technique has been built and tested at BNL and a full-field "slotted magnet" is now being constructed. The second approach is one in which the cable is bonded directly onto a stainless steel cylinder, the cable being wound into a helical pattern using a multiple-axis winding machine. This "Direct Wind" technique for the helical magnets is being investigated in industry by AML, Inc., of Palm Bay, Florida, under contract with BNL. During the next few months, two Direct Wind and one Slotted model magnets will be constructed and a decision will be made for which technology to further pursue for the RHIC helical dipoles. A full-length model magnet of the chosen technology will be produced by early 1997 leading into production of the final coils.

In parallel with the hardware R&D, much work has been performed in the area of accelerator physics. A computer code (SPINK[1]) has been written which allows the spin of particles to be tracked repeatedly through the RHIC lattice. This has allowed the study of resonance crossing during the acceleration process of RHIC. The code is being upgraded to allow for the studies of individual helical dipole magnet errors and their effects on the beam polarization. This will allow us to better specify the magnet requirements. Meanwhile, other magnet issues have been studied. In particular requirements for field uniformity, magnet alignment tolerances, and perturbations to the integrated field strength have been investigated for their effects on RHIC performance and specifications have been generated. Tolerances in the Snake magnet design are rather lenient, since these magnets are held at constant field during ac-

[1]A. Luccio, "Numerical Spin Tracking in a Synchrotron," BNL-52481, September 1995.

celeration and storage. However, the Rotator magnets will be adiabatically turned on after the beams reach collision, and thus their control as well as tolerances on their field strength and alignment must be monitored closely. The most important parameter appears to be the total integrated field along the longitudinal axis of each helical dipole magnet. The Rotator magnets have fields which start and end horizontally, and this component must integrate to zero to within a few tens of Gauss in order to avoid unwanted vertical orbit errors which could enhance imperfection resonances. Thus, trim coils may need to be added to these devices to ensure proper operation.

Another area of the project receiving some theoretical attention during the past few months has been polarimetry. Various possible layouts of a polarimeter using inclusive pion production have been studied which use either a single sweeping magnet or a series of toroid magnets for particle analysis. Colleagues from IHEP have helped with the calculations of the acceptance of the system, while RIKEN has helped with the design of possible toroids for use in this area. This work is ongoing.

To assist in documenting the progress and understanding of the polarized beams project, a new documentation category has been formed at BNL. Spin Notes are compiled by the AGS Department at BNL, and can be obtained from the AGS Accelerator Division secretary. A complete list of Spin Note titles can be found on the World Wide Web at

http://www.ags.bnl.gov/~roser/rhicspin.html.

Future Work

The majority of the work over the next year will be to prepare for final production of the accelerator system elements. In particular, final pre-production R&D for helical dipole magnets and magnet assemblies, including cryostat and associated hardware, will be performed. The specification of the magnetic elements — such as field quality, quench performance, alignment criteria — will be finalized, based on measurements of the prototype magnets, as well as further accelerator physics calculations.

Further development of the polarimeter specifications will proceed during the next year, including target development. In addition, work will commence on the specification of hardware to perform spin flips during beam storage. This is an important procedure to both reduce systematics during data taking, as well as for accurately measuring the spin tune of the collider. The spin flip can be generated by artificially inducing a spin resonance using dipole fields which fluctuate at the spin precession frequency, much akin to nuclear magnetic resonance. Thus, the system will need to include AC magnets in the RHIC accelerator operating at 40 kHz, which may pose an interesting technical challenge. Work on this system is just underway.

The schedule and anticipated funding profile call for production of the superconducting helical dipole magnets to begin in the Spring of 1997, and other hardware, such as polarimeters, spin flippers, power supplies and controls to be procured during 1998-99. The goal is to have as much hardware (especially Snake magnets) in place during the initial start-up of RHIC in 1999 which would allow for colliding transversely polarized beams. The entire compliment of hardware for colliding longitudinally polarized beams could conceivably be installed by Spring 2000.

Beam Dynamics Activities at DESY

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In this contribution I will summarize some of the recent beam dynamics activities at DESY. These activities can be roughly divided into two main parts:

- beam dynamics of linear colliders (relevant to the design and construction of the test facilities SBLC, TESLA and TESLA-FEL)
- work related to a better understanding and improvement of the performance of HERA, PETRA, DORIS and DESY

The largest component of a next generation linear collider is the main linac, which has to provide a beam not only of very high energy but also of very high quality (i.e. intensity, emittance, energy spread etc.). Degradation of the beam quality can be due to misalignments and vibrations of the main linac components such as RF cavities and focusing magnets. The misalignment and the resolution of the beam position monitors are also very important since this determines the possibility to control the beam quality by various correction methods. A crucial point for all designs is to deliver a sub-micron beam spot size at the interaction point in order to achieve the desired luminosity of $L > 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. A key issue in this context is the generation and preservation of small beam emittances. The use of a multi-bunch scheme introduces another complication due to strong transient beam loading and excitation of higher dipole modes in the accelerator sections.

All these problems require detailed beam dynamics investigations. The beam dynamics of the TESLA and SBLC designs is studied by several members of an international collaboration. Two computer codes (DILEM (Saclay) and L (DESY, TH-Darmstadt)) have been developed, which are used to study the single and multi-bunch dynamics in a linear collider including several beam based alignment techniques. More information can be found in (1), (2), (3) and (4).

The work related to circular accelerators was concentrating on

- nonlinear dynamics
- collective phenomena and impedances
- polarization dynamics

The dynamic aperture in the HERA proton ring has been investigated experimentally and the results have been compared with tracking calculations. These calculations are based on a complex model of the accelerator using magnetic field measurements for each individual magnet in the ring. The simulation results reproduce reasonably well the measurements of the dynamic aperture (5),(6),(7).

Furthermore, various modulational effects have been studied. The combined effect of non-linear fields and tune modulation with fast and slow frequency components results in an enhanced emittance growth and increased loss rate in hadron storage rings. In the proton storage ring of HERA a fast harmonic tune modulation is caused by ripples in the power supplies and a slow tune modulation by the ground motion in the HERA tunnel. The recognition of the damaging effect of fast tune modulation frequencies on the particle dynamics initiated attempts to compensate for the fast frequency components in HERA. The fast tune modulation frequencies in the proton beam can be measured with a phase-locked loop and the compensation can be established by generating an additional external tune modulation with the same frequency but with a 180° phase difference. This compensation scheme led to a significant reduction of the proton loss rate during luminosity operation (8). The observed particle diffusion agrees qualitatively and quantitatively with analytical estimates (9),(10).

In addition to these modulational effects, the effect of quadrupole noise on the emittance growth of protons in HERA has been studied theoretically and by simulation (11). In (12) it was shown how random fluctuations in the tune, beam offsets and beam size in the presence of the beam-beam interaction lead to significant particle diffusion and emittance growth in hadron colliders. It was found that far from resonances high frequency noise causes the most diffusion while near resonances low frequency noise is responsible for the large emittance growth observed. Comparison of different fluctuations shows that offset fluctuations between the beams causes the largest diffusion for particles in the beam core.

Other activities included:

1. Crossing angle option for HERA. This study has shown that a small horizontal crossing angle ($<$ 5mrad) is permissible at carefully chosen tunes between 0.29 and 0.30 (13).
2. Investigation of the non-linear effects of wiggler and undulator fields on the beam dynamics of particle storage rings in the case of DORIS III (14)
3. Rigorous estimates of long-term stability by application of differential algebra with rigorous remainder bounds (15)
4. The influence of damping in non-linear fields on electron motion in storage rings (16).

Concerning the collective phenomena in storage rings there have been simulation studies of head-tail instabilities in HERA involving multi-particle tracking in the presence of the realistic wake-fields of an accelerating cavity (17). In (18) the impedance of selected components of the HERA proton ring was investigated.

Another important topic studied extensively at DESY was the polarization dynamics in storage rings. Whereas polarized electron beams are handled routinely in HERA (19),(20) there is now growing interest in obtaining also polarized proton beams. Since there is no radiative polarization mechanism effective like in the electron case (at least for energies up to a few TeV) there are two main problems - acceleration of polarized particles and preservation of the polarization at high energies over long times (luminosity run time). Various theoretical and numerical investigations of the coupled spin-orbit motion are in progress - partly in collaboration with the Ann Arbor SPIN collaboration. In particular, the following topics are studied (V. Balandin, D.P. Barber, N. Golubeva, K. Heinemann, G. Hoffstaetter, M.Vogt):

1. Computation of equilibrium spin distributions in polarized beams with perturbation theory, normal form theory and long term averaging.
2. Effective placement of Siberian Snakes in the HERA proton ring and analysis of the effect of Siberian Snakes on the equilibrium distribution of spins.
3. Analysis of long-term spin motion by tracking through nonlinear spin-orbit systems (see also (21)).
4. Symplectic approximations of non-linear beam transfer maps and orthogonal approximations of non-linear spin transfer matrices using differential algebraic methods including misalignments and fringe field effects.

5. Consistency of different spin splitting ideas with current knowledge of the Stern-Gerlach force

There have been further beam dynamics activities in the framework of an EC Net on "Nonlinear and stochastic beam dynamics". More details about this European collaboration will be published separately in a future issue of this NEWSLETTER.

A list of cited articles (put in brackets () in the main text) concludes this summary.

1. R. Brinkmann "Beam Dynamics in Linear Colliders - what are the Choices" DESY M-95-10 (1995)
2. M. Drevlak "On the Preservation of Single- and Multi-Bunch Emittance in Linear Colliders" DESY 95-225 (1995)
3. M. Drevlak, R. Wanzenberg "Beam Dynamics in the SBLC" DESY M-95-05 (1995)
4. M. Drevlak, R. Wanzenberg "Beam Dynamics in the SBLC" PAC, Dallas 1995
5. F. Willeke "Comparison of Measured and Calculated Dynamic Aperture " PAC, Dallas 1995
6. O. Bruening, W. Fischer, F. Schmidt, F. Willeke "A Comparison of Measured and Calculated Dynamic Aperture of the HERA Proton Ring at Injection Energy" DESY HERA 95-05 (1995)
7. W. Fischer "An Experimental Study of the Long-term Stability of Particle Motion in Hadron Storage Rings" DESY 95-235 (1995)
8. O. Bruening, F. Willeke "Reduction of Particle Losses in HERA by Generating an Additional Harmonic Tune Modulation" PAC, Dallas 1995
9. O. Bruening, K.H. Mess, M. Seidel, F. Willeke "Measuring the Effect of an External Tune Modulation on the Particle Diffusion in the Proton Storage Ring of HERA" DESY HERA 94-01 (1994)
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Beam Dynamic Activities at CERN

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LEP

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As described in the previous newsletter, recent work on LEP has focused on maximizing performance at the higher energies now becoming accessible with the installation of the large superconducting RF system for LEP2. Low emittance lattices, the dynamic aperture at high energy and means to maximize the single bunch current at injection are high priorities.

Most operation at 46 GeV during 1995 used a "bunch-train" scheme allowing 12 bunches per beam. The parasitic beam-beam encounters near the interaction point generated many side-effects including orbit separations and vertical dispersion of opposite sign at the interaction points. These complicated the precise calibration of the collision energy which is required at LEP. Understanding these effects required the self-consistent calculation of distinct orbits and optics for each of the 24 bunches in the two-beam system.

The pilot run with 4 bunches per beam at 65 and 68 GeV in November 1995 showed that very small vertical beam sizes and larger values of the beam-beam parameter become accessible at higher energy. Luminosities in excess of $3 \times 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ were achieved. It was also possible to cope with e^+e^- tune splits and other effects due to energy-sawtoothing and the highly asymmetric RF configuration at the time.

Detailed information on recent developments at LEP can be found in the Proceedings of the Sixth LEP Performance Workshop, held at Chamonix in January 1996, CERN SL/96-05 (DI), edited by J. Poole. These are also available on the World-Wide Web at

http://www.cern.ch/CERN/Divisions/SL/publications/chamx96/pdftoc.html

LHC

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Work is proceeding to evaluate and improve the flexibility of the LHC lattice. An optical "distortion" was identified to occur when the antisymmetry condition was imposed on a two-cell dispersion suppressor. It is overcome by supplementing the arc ends with weak quadrupole pairs. These, and some other, quadrupoles, will also be used to produce differential tune shifts between Ring 1 and Ring 2. The chromaticity correction scheme has been reviewed; it is strong enough to cover uncertainties likely to arise in operation as to the source of the chromatic perturbation (quadrupoles or a fraction of the dipole imperfections). A four-family correction scheme to further decrease the second-order chromaticity is under consideration. A new strategy has been prepared to simulate the field imperfections of the main magnets: this will take into account the possible variation of the so-called systematic component from one production line to another.

A critical review of resistive losses in the LHC beam screen, taking into account anomalous skin effect and surface roughness, has triggered a programme of surface resistance measurements at different temperatures, frequencies and magnetic field intensities. This will provide a realistic heating budget for the LHC cryogenic system. Preliminary calibration results indicate that an absolute precision of a few per cent can be reached by comparing the quality factors of symmetric and antisymmetric modes in a transmission line with two inner conductors. Theoretical investigations and the recent successful measurements of longitudinal beam echoes in the SPS may open new interesting perspectives for particle diffusion and impedance measurements both in the SPS and in LHC. Analytical and numerical impedance estimates are in progress for different machine components, such as sliding RF contacts, kickers, experimental chambers or button-like ceramic electrodes for vacuum leak detection. These are combined with the study of magnetic Laslett coefficients and transient space-charge effects, including field penetration in a resistive wall.

CERN PS

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The main effort of beam dynamic activities in the CERN PS is dedicated to the preparation of the LHC beam. There are theoretical and experimental studies on subjects like:

- Non linear effects (e.g. stray fields) in the PS to SPS transfer, generating possible transverse emittance blow-up due to mismatch.
- Transverse and longitudinal collective effects at different times during the acceleration, e.g., during debunching and rebunching at 26 GeV/c. Note that at the end of this year a first prototype of a 40 MHz cavity will be installed in the machine and possible coupled bunch instabilities due to its impedance will have then to be investigated and cured.
- PS Booster to PS mismatch measurements and optimization.
- Automatic minimization of the closed orbit at different energies.
- Preparation of beams with special characteristics (e.g. very small longitudinal emittances or very short bunches, etc.) to test stability thresholds both in the PS and SPS.

Concerning other operational beams:

- Optimization of the 5 turns extraction to SPS of the high intensity ($> 2.5 \times 10^13$ppp) proton beam (e.g. trajectory equalization of the 5 beam slices with fast kickers in the transfer line).

- Preparation of special calibrated fast extracted beams at 3.5 GeV/c for Energy Amplifier tests (TARC experiment).
- Slow extraction of Pb ions and fast extraction of positrons for LHC detector tests.

Some PS machine physicists actively participate in the design of a medical accelerator for oncological hadrontherapy (TERA Project).

PS Booster

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In view of the increased average current (due to high-intensity operation for ISOLDE) and the ensuing beam losses, theoretical (simulation) and experimental studies were performed with the aim of explaining the observed loss patterns and preparing a future loss collimator system. Since multi-stage collimation is not very efficient in a densely packed machine with a regular lattice, alternative collimator designs like mini-wire-septa have been studied.

Other topics presently under study are the sensitivity of the optics of the transfer line Linac2-to-Booster, the extension of ABS (Automated Beam Steering) to this line, analysis of improved closed orbit correction (four rings mechanically linked) and a kind of microwave instability occurring only in Ring 4 (partially responsible for beam loss at higher energy). Processing of the longitudinal beam transfer function (BTF) signal has been improved and will be tested in operation.

Beam Dynamics Activities inside UNK Project at IHEP

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Now, the beam dynamics work at IHEP goes on, mainly, within the UNK Project which is now under realization.

Longitudinal Feedbacks.

Considerable effort has been continued to outline the feasible technical contours and make mutually consistent the two band-pass longitudinal feedback (FB) systems foreseen near RF. These are:

a) A DC-coupled RF FB around a final power amplifier to counteract heavy pulsed beam loading of accelerating cavities and strong coherent instabilities inflicted by the cavity fundamental mode, and

b) An AC-coupled beam FB to damp longitudinal injection errors and ensure better stability against coupled-bunch lower-order odd multipole instabilities.

Both the FBs having their bandwidths significantly exceeding the revolution frequency while the UNK's bunch-length being long enough, of utmost importance is the adequate understanding of the FBs' effect on coupled-bunch motion of the beam at dipole, quadrupole and sextupole within-bunch modes.

To this end, the frequency-domain impedance approach to linear longitudinal coupled-bunch beam FBs in a proton synchrotron has been worked out. Essentially, it puts on a formal quantitative basis a commonly used intuitive notion that a FB is seen by the beam as an artificial coupling impedance controlled from the outside.

However, to account for cross-talk between various field and beam current harmonics inflicted by frequency down- and up-mixing inside the FB circuit, an impedance matrix must be introduced as a natural concept to gain insight into 'FB & beam' dynamics. This matrix has, at most, three non-trivial elements per row, these being expressed through the FB's path transfer functions and its set-point parameters.

The impedance approach to a beam FB has at least two plain advantages:

a) The FB's effect is readily mounted into the well-established theory of coherent instabilities. This allows a straightforward application of the advanced techniques developed there by now: beam transfer functions, threshold maps, Landau damping rates, beam stability safety margins, handling of coupled-bunch motion, etc.

b) Destabilizing effect of beam environment is commonly available in the similar terms of the coupling impedances, and thus may be naturally taken into account during the FB's design.

The frequency-domain treatment of the beam FB does not necessarily imply that this FB is a narrow-band one. The wider the FB's bandwidth, the less sensitive is the FB's impact to the particular azimuthal mode processed, the coupled-bunch FB gradually turning into a bunch-by-bunch FB.

Still, the frequency-domain formulae easily account for the adverse effect of the finite response times of a real pick-up, an acting device and electronics, which may not be a simple matter to deal with when the beam FB is viewed entirely from the time domain.

The impedance treatment has been applied in practice to tailor out the general contours of a) a now standard (D. Boussard) RF feedback scheme around the final power amplifier with one-turn time delay and two loops of automatic voltage control (the in-phase and quadrature ones) having unequal gains, and b) a beam FB employing, as an acting device, a pair of issued over-coupled RF cavities driven in quadrature to the net accelerating voltage. Being run together, the FBs proposed are shown to yield beam parameters which comply with the UNK Project's requirements.

Now, we are planning to develop a time-domain computer model of the FB circuits and link it to a macro-particle tracking code so as to get the details of 'beam & FB' behavior that can hardly be gained otherwise: start-up transients, emittance growth along bunch trains injected, allowable down-sampling rates in signal processing, operation in non-linear (saturated) regimes, etc.

Beam Instabilities.

A study was undertaken of a long-standing issue on how to relate beam stability safety margins of a conventional beam model (a closed train of identical and equispaced bunches) to those of any arbitrary beam which is a subset of the former (basic) one, say, due to gaps, unequal population of bunches, etc.

To this end, a technique to find a sufficient criterion of transverse or longitudinal asymptotic (at $t \to \infty$) stability of a beam with unequal bunches (partial orbit filling or bunch trains included) interacting with an arbitrary impedance in a synchrotron was developed.

It proceeds from a standard problem statement — to find eigenmodes of a conventional beam with a symmetric bunch spacing. For an impedance treated, the problem is solved with computer in the uncoupled multipole approximation. In such an approximation, the beam oscillation mode indices are those of usual coupled-bunch modes (discriminated by a phase shift between adjacent bunches) and of radial modes of the multipole oscillation in question.

Formally, this problem is put down as a matrix eigenvalue one, where the dimension of the matrix coincides with the number of radial modes considered. Impedance is sampled at frequency lines separated by bunch-to-bunch recurring frequency. Therefore, a matrix of moderate dimension (a few dozens) covers a large bandwidth, being, nevertheless, amenable to a straightforward search for the matrix spectrum with available computer codes.

Any state of an arbitrary beam may be represented as a linear superposition of eigenvectors of the symmetric beam. Then, its complex eigenvalues and non-diagonal Gram matrices of eigenvectors are used to find boundary of a convex numerical field of complex Rayleigh-Ritz ratios which yield an 'upper' estimate of eigenvalue loci and, thus, stability safety margins for any arbitrary beam which is a subset of the basic one, irrespective of its particular azimuthal structure.

The prior qualitative outcome is as follows. Stability of the basic beam ensures that of a subset beam only in a case when the bunch inner multipole motion is confined to a single isolated radial mode (like, say, in a 'macro-particle' bunch model). Any non-rigidness of the multipole motion occurring due to impedance bandwidth extension tends to expel the eigenvalue locus boundary beyond that of the basic beam, which is a clear symptom of deteriorating, though potentially so, the situation with beam stability.

This technique was applied in practice to study transverse resistive-wall head-tail instability of a bunched beam in the UNK. It was shown that the broad-band performance of the resistive-wall impedance only slightly affects the threshold predictions. The upper estimate of the stability margin can be obtained with a good accuracy via the model of beam without any azimuthal gaps. Now, this approach is planned to be applied to detailed studies of the dynamical impact of the low-pass beam transverse FB intended to counteract the strong resistive-wall instability and damp transverse injection errors.

RF Noise Diffusion.

Following the pioneering works at CERN PS and LEAR, we have initiated a feasibility study of the ultra-slow beam extraction scheme for the UNK with a filtered external longitudinal RF noise excitation to shape out the particle flux into the extraction resonance. This extraction procedure is to be applied to a bunched circulating beam, the longitudinal phase-plane position of the resonant betatron frequency being put near (and inside) longitudinal separatrix. Technically, the noise might be fed through the foreseen beam FB channel tuned in quadrature to the net accelerating field. The goal is to provide a good-quality spill throughout a 20 sec 600 GeV flat top.

The work proceeds through two paths: numerical solution of the diffusion equation (the Finite Element Technique) which pulls in noise power spectrum, and, to complement and verify, macro-particle tracking involving the noise samples with the same spectrum. A few problems have emerged and now treated in attempts to reduce the expected spill ripple: a limited ability to govern diffusion coefficient due to unavoidable sampling of noise spectrum at (odd) multipole harmonics, a relatively short spill duration required as measured in the inherent scale of diffusion time available at practically feasible noise peak-to-peak corridor, etc.

Impedance Calculations.

Development of a technique to calculate longitudinal beam coupling impedance (BCI) of a vacuum chamber with many small heterogeneities (insertions) which cross-talk via propagating waves has been continued.

Earlier, we have used boundary condition $E_z(z) = -\zeta(z)H_\vartheta(0)$ to link a longitudinal electric field in the insertion area to a magnetic field in its center. In such an approximation, the electric field is driven by variation of magnetic flux trapped by a hole, or expelled out by a bulge; therefore $\zeta \propto \omega$. The chamber BCI was expressed in terms of quantities $\propto \int \zeta \, dz$ which were interpreted as inherent impedances of the insertions.

Analytical formulae of BCI for simple systems (a chamber with a single insertion, a symmetrical system) and numerical solutions for more complicated cases were obtained on this basis. The results to follow seem to be the most noteworthy ones:

a) A very sharp peak of the BCI occurs just before the chamber cut-off frequency;

b) Above the cut-off, the impedances of (almost) symmetrical systems are fast-oscillating functions of frequency, amplitude of the oscillations depending on the chamber wall conductivity. In this case, the contributions of the insertions to the net BCI are non-additive;

c) Violation of the symmetry reduces magnitude of the oscillations. These disappear, and the net BCI turns additive w.r.t. the inherent impedances of the insertions, given the symmetry violation is enough strong;

d) If the latter is the case, the BCI above the cut-off would not exceed $60N$ Ohm, N being the number of insertions. This is due to escape the field energy out of insertion via propagating waves with dissipation ultimately inside the resistive walls.

Some of these results for insertions like a hole do comply with results available from the other authors. However, a discrepancy shows itself for insertions like a bulge which would have had an inductive impedance at lower frequencies, whereas our technique has predicted, formally, a negative inductance.

An idea put forward recently by S.Kurennoy and G.Stupakov shows the way to overcome this problem. Indeed, studying the impedance at lower frequencies, they have shown that the longitudinal electric field around an insertion can be excited not only by a capture of the magnetic flux, but also because of polarization of the insertion by transverse electric field of the beam. To extend their observation to higher frequencies, the boundary condition mentioned above should be modified as $E_z(z) = -\zeta_H(z)H_\vartheta(0) + \zeta_E(z)E_r(0)$ (a conformal mapping technique might be applied to calculate the coefficients ζ).

By doing so, the discrepancy just mentioned is eliminated, in particular, the behavior of BCI at lower frequencies and the absence of peak just below the cut-off for a bulge is explained. Above the cut-off, employment of the improved boundary condition does not affect the results quantitatively. Of course, there are some quantitative consequences which are more pronounced for bulges rather than for holes.

Now, this analytical basis is used for development of software to treat impedances of the UNK's vacuum chamber that contains thousands of various insertions.

Beam Dynamics Activities at LAL/Orsay,

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Superconducting Linear Collider

Nowadays, there are six projects for future linear colliders, TESLA, SBLC, NLC, JLC, VLEPP, and CLIC. Among these, TESLA project is the only superconducting machine. Since the TESLA design accelerating field 25 MV/m is far above the electron emission capture field strength of 15 MV/m, the captured electrons may be accelerated to a very high energy before finally hitting the cavity walls (the distance between the two adjacent quadrupoles will be almost 50 m at the end of the main linac). This intrinsic defect can be avoided by pushing the RF frequency higher because the critical capturing electric field strength increases linearly with the RF frequency. In [1, 2], we have proposed a 3 GHz S-band Superconducting Linear Collider (SSLC) which escapes from the dark current problem at 25 MV/m accelerating gradient (since it has a critical capture field of 36 MV/m). A beam parameter list has been proposed. The single and multibunch beam dynamics simulation results suggest that the HOM quality factor is damped lower than 10^5, the quadrupole and the cavity misalignment tolerances are about 20 μm and 200 μm respectively. The energy spread within a single bunch is about 0.3 %. The peak RF power through the main coupler is 36 MW, and the total wall plug ac power (including the refrigerator power) is less than 80 MW.

Two Beam Linear Collider (CLIC)

Since 1994, we have collaborated with the CLIC group on the CLIC Test Facility (CTF). After numerous beam dynamics simulations which compare the drive beam behaviors in the 4.5 m long LIL accelerating structure (which has been used since the beginning of CTF) and in the 1 m long SERA-II accelerating structure working at LAL for the high gradient experiments, it was found that the multibunch emittance blow-up in the SERA-II is much smaller than that in the LIL structure [3], and in consequence, SERA-II has been proposed to replace LIL in 1995. In collaboration with CLIC group, LAL has been responsible for the design and the construction of a pair of so-called High Charge Structures (HCS) for CTF-2 with 0.53 % frequency difference between the two sections (which work on $11\pi/12$ mode [4]) in order to compensate the multibunch energy spread at the exit of the two accelerating structures. The two accelerating sections with symmetrical couplers will be delivered to CERN in 1996.

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Beam Dynamics Activities at NSRF

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There are three separate groups at NSRF (Nuclear Science Research Facility); namely, Nuclear Physics Group, Laser Spectroscopy Group, and Accelerator Science Group. Accelerator Science Group is the largest one which currently involves five staff scientists and seven graduate students. NSRF is located on the Uji campus of Kyoto University where a 100 MeV electron linac as well as a 7 MeV proton linac have been installed. For the future study of photon radiation, a 300 MeV electron ring is now under construction. In addition to research in various accelerator technologies, theoretical and numerical works have been performed.

Ion Linacs

For the last ten years, the main task at NSRF had been the development of compact ion linacs including RFQ, DTL, DAW, *etc.* In particular, we have constructed a four-vane RFQ and an Alvarez DTL, both operating at 433.3 MHz[1, 2, 3]. The RFQ is about 2m long and accelerates proton beams from a multi-cusp ion source up to 2 MeV. It is followed by the DTL whose output energy is 7 MeV. Since the drift-tube diameter is only 55 mm, permanent magnet quadrupole (PMQ) lenses have been used. As the PM material, we adopted the so-called NEOMAX made mainly of Nd, B, and Fe[4]. Some machine parameters of these linacs are listed below:

RFQ (50keV → 2MeV)		DTL (2MeV → 7MeV)	
vane length	2.195 m	cavity length	1.868 m
cavity diameter	170 mm	inner diameter	451 mm
minimum aperture radius	2 mm	number of drift tubes	28
characteristic radius	3 mm		
intervane voltage	80 kV	RF	
design transmission efficiency	95 % (30 mA)	frequency	433.3 MHz
		repetition rate	180 Hz (max.)
		duty	1 % (max.)

In collaboration with NISSIN Electric Co., a CW RFQ for heavy ion beams has been built intended for the application to ion implantation technology[5]. It is a 4-rod RFQ operating at 33.3 MHz. Since the first beam test in 1992, various ions such as He^+, N^{2+}, C^+, *etc.* have been successfully accelerated with the transmission efficiency of over 80 %. In recent experiments, continuous B^+ beams of 0.8 mA have been obtained.

To optimize the design of a low-β linac for multi-purpose use, extensive cold model tests have also been done collaborating with Mitsubishi Atomic Power Industries, Inc[6]. We are especially interested in cheap, compact, and easy-to-maintain structures commercially attractive. From this point of view, the optimum combination of ion linacs, including 4π-mode DTL, alternating-phase-focusing (APF) structure, *etc.* has been investigated.

Disk-And-Washer (DAW) linacs have been studies as an option of a high-β structure not only for ions but also for electrons[7]. DAW contains outstanding features such as high stability, good vacuum property, high shunt impedance, *etc.* It was found that the mode-overlapping problem could be overcome by the biperiodic support configuration with a careful choice of the tank diameter. Among various types of washer support, the biperiodic L-support is currently explored by employing the MAFIA code and cold models. A power model is under construction.

Electron Machines

The construction of a 100 MeV electron linac was completed last year[8]. It consists of three accelerating tubes, 3m long each. 100 mA electron beams with the pulse duration of 1 msec are now available. This machine is to be used as an injector for a small storage ring presently under construction. The storage ring, called KSR, has a race-track shape with a double achromatic lattice, and accelerates electron beams delivered from the linac up to 300 MeV[9]. The critical wave length of radiation at the bending section is 17 nm. The straight section of KSR is 5.62m long, where the installation of an insertion device is planned to generate radiation with much shorter wave length. The main design parameters of the electron machines are as follows:

Linac (100keV $\to$ 100 MeV)		KSR (100MeV $\to$ 300 MeV)	
operating mode	$2\pi/3$	circumference	25.689 m
operating frequency	2857 MHz	superperiodicity	2
shunt impedance	53 MΩ/m	bending angle	60
accelerating gradient	15 MV/m	radius of curvature	0.835 m
design current	100 mA	length of the straight section	5.619 m
repetition rate	20 Hz (max.)	horizontal tune	2.75
		vertical tune	1.25

Theoretical Activities

The theoretical works which have been done for the last several years are summarized below:

(a) In connection with the technological activities described above, beam dynamics of low-β linear structures has been studied both numerically and theoretically. In particular, the possibility of using an APF linac in a low energy region is examined[10]. Collaborating with Accelerator Theory Group of Maryland University, we have found some criteria useful for an APF design.

(b) The longitudinal and transverse coupling impedance of an iris in a beam pipe has been theoretically obtained, again, in collaboration with the Maryland group[11]. A variational expression is given for the quick and accurate evaluation of the iris impedance. The theory has been generalized to calculate the impedance of periodic irises.

(c) The stability of electron bunches traveling in a large storage ring has been analyzed[12]. The effect of the cavity wakes generated by several preceding bunches has been studied, assuming that the wakes are well damped in a single revolution time. This situation is similar to what happens in the bunch train operation in LEP. It is found that, as far as a macro-particle approximation is concerned, a finite offset of a preceding bunch may cause a sort of BBU effect on the trailing bunches.

(d) In collaboration with LBL and CERN, laser cooling of fast circulating beams has been investigated. A novel method has been proposed to realize three-dimensional laser cooling in a storage ring[13]. The idea is based on developing a synchrobetatron coupling such that the longitudinal laser cooling effect can be extended to the transverse degrees of freedom. As the coupling source, the so-called coupling cavity operating in a TM_{210} mode as well as dispersion at an ordinary RF cavity have been considered. It has been shown that the proposed method works excellently, at least, while beams are in an emittance-dominated state.

(e) To establish a clear understanding of space-charge effects in dense ion beams, several simulation codes have been developed. In particular, we have recently studied halo formation from intense round beams in a uniform focusing channel[14]. The space-charge code employed in this work is designed for the study of the breathing-mode oscillations excited by an initial beam-size mismatch. Based on a number of simulation runs with realistic phase-space distributions, we have correctly evaluated halo intensity and maximum halo extent as a function of tune depression as well as the size of an initial mismatch. The work is being generalized, taking into account the periodic change of external restoring force.

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Beam Dynamics Activities at Institute of Modern Physics of China

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Introduction

The Institute of Modern Physics (IMP) is one of the major nuclear physics research center under Chinese Academy of Sciences. It is equipped with a large heavy ion cyclotron complex (HIRFL) and other accelerators. The Heavy Ion Research Facility at Lanzhou (HIRFL) consists of an injector SFC (Sector Focusing Cyclotron) with energy constant K=69 and a main accelerator SSC (Separated Sector Cyclotron) with energy constant K=450. Light ions (C, N, O and so on) can be accelerated to 100 MeV/u and heavier ions can be accelerated to 7 MeV/u with energy spread of 3×10^{-3} and emittance of 8 π mm.mrad. The SFC is a 1.7 m isochronous cyclotron that was converted from a 1.5 m classical one with Penning Ion Gauge (PIG) ion source. The first beam was extracted from SSC in December 1988.

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In order to increase the number of ion species and improve the beam qualities, an Electron Cyclotron Resonance (ECR) ion source replaced the PIG ion source in 1992. Meanwhile the axial injection system was designed and built, and the SFC was upgraded to meet the requirements of the external injection system.

To meet the needs of nuclear physics, astrophysics and atomic physics, particularly for studies of using Radioactive Ion Beam (RIB), a multi-functional Cooling Storage Ring (CSR) has been proposed. The CSR consists of two rings, one is a main ring (CSRm) with a circumference of 141 m and the other one is an experimental ring (CSRe) having a circumference of 94 m. Both of two rings are equipped with electron cooling system. The heavy ion beams from the two injectors (SFC and SSC) will be accumulated, cooled and accelerated in the main ring and then extracted for producing RIB by using projectile fragmentation, or highly charged heavy ions. The secondary beams can be injected into the experimental ring to perform experiments with internal targets. The preliminary conceptual design of HIRFL - CSR has been carried out and the proposal was submitted to Chinese Academy of Sciences and Government.

Beam Dynamics Activities

HIRFL

During the reform and upgrade of the injector SFC as well as the design and commissioning of the main accelerator SSC, the following beam dynamics studies have been carried out.

(1) The scheme and beam properties of HIRFL were chosen on the basis of the requirements of heavy ion nuclear experimental research and its application research and studies of the characteristics of separated sector cyclotron according to our conditions.

(2) Beam optics of the external injection system of SFC has been studied to meet the requirements of ECR ion source.

(3) To meet the needs of the external injection system, the central region of SFC and the spiral electrostatic inflector, to bend the beam direction by 90° and bring the ion trajectories onto the median plane, have been designed.

(4) The equation of motion of the charged particle in the central region of SFC had been integrated analytically to study the ion trajectories. To select an optimum initial phase and to match the optics requirement of the inflector, a bump magnetic field introduced by the plug at the region of 10 cm has been adopted.

(5) To study the beam behavior in SFC in detail, acceleration simulation has been done.

(6) Isochronous magnet fields of SFC and SSC have been set on the basis of the magnetic field mapping of the main coils and trim coils at 7 reference field levels.

(7) Beam optics of the beam transport line from SFC to SSC with one stripper and two bunchers has been calculated. The beam phase space match with the injection system of SSC has been considered seriously.

(8) The characteristics of separated sector cyclotron have been investigated in detail.

(9) The properties of particle orbit have been studied at the conditions of linear approximation and non-linear approximation respectively.

(10) To keep good beam quality and high beam transport efficiency, the optimized parameters of the injection and extraction systems of SSC have been chosen. A bump coil has been adopted to realize the single turn extraction for some ions with smaller turn distances.

(11) The beam vertical oscillation at the injection region of SSC was observed during the commissioning. It was caused by the horizontal component of the magnet field (about 50 Gauss) of the injection magnetic channel MSi3. There was a angle of 5mrad between the median planes of the magnetic channel MSi3 and SSC. After adjustment of the position of MSi3 the oscillation was disappeared.

Some studies corresponding to following items are in progress.

(1) For some reasons the beam transportation efficiency from ECR to SFC is not satisfactory now. The beam optics system is redesigned and the beam transport line will be reformed. In order to increase the transport efficiency, the energy of beams extracted from ECR will be increased and the buncher in the line will be improved. At some operation modes the half-frequency bunching method will be adopted.

(2) Optimization of the isochronous magnetic field is under way.

Table 1. Main parameters of CSR

Ring	CSRm	CSRe
Circumference (m)	141.051	94.034
Average radius (m)	22.449	14.9674
$B\rho_{max}/B\rho_{min}$ (T.m)	10.584/0.64	6.4/0.91
Magnetic field ramping rate (T/s)	1.5	1.5
Acceptance		
$\varepsilon \perp$ (π mm.mrad)	25	40
Δ p/p (%)	1.5	1.0
Electron cooling section		
E_{emax} (KeV)	165	165
length (m)	2.7	2.7
RF-system		
harmonic number	1	1
$f_{max}/f_{min}(MHz)$	2.0/0.2	2.3/0.45
stations and voltages (n $\times$ KeV)	2 $\times$ 7	4 $\times$ 7
Vaccum (Torr)	1 $\times 10^{-10}$	1 $\times 10^{-10}$

CSR

To design the Cooling - Storage Ring, some beam dynamics studies have been carried out and some of them are going on now.

(1) The main parameters of the CSR have been determined by keeping in mind the current trends in accelerator design, the requirements of nuclear experimental research and the matching conditions with HIRFL. The main parameters are listed in Table 1.

(2) The continuous beam operation mode will be realized in CSRe.

(3) Two possible operations for RIB internal target experiment in CSRe have been studied (for long lifetime of 0.1s - 5.0s and for short lifetime of 0.1ms - 100.0ms respectively).

(4) The lattice of CSRm and CSRe have been designed. The closed-orbit correction has been investigated.

(5) Lifetime of stored ion beam has been calculated in detail by taking into account the ion interaction with electrons in the electron cooler and the residual gas molecules.

(6) Two schemes of beam accumulation have been investigated carefully. One is the multiple single-turn injection (cooling accumulation) which will be used for CSRm to accumulate the heavy ions. The other is the multi-turn injection and RF stacking method. On the other hand, fast extraction of CSRm and single turn injection for CSRe will be adopted.

(7) The process of electron cooling for heavy ion beams has been carefully investigated and the preliminary design of the cooling system has been accomplished.

(8) The calculation of dynamic aperture for CSR is under way.

Some of above items and other beam dynamics issues are being studied in detail.

Beam Dynamics Activities at National Superconducting Cyclotron Laboratory

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Coupled Cyclotron Upgrade

(F. Marti, R. York)

The National Superconducting Cyclotron Laboratory (NSCL) plans to significantly increase both primary and radioactive beam intensities. By coupling the laboratory's two superconducting cyclotrons (K500 and K1200, $K=E{\cdot}A/q^2$), it is possible to take advantage of the much greater intensities of the lower charge states from the ion source without sacrificing the final beam energy. Beam from an Electron Cyclotron Resonance (ECR) ion source will be accelerated in the K500 and then transported to the K1200 where it will be stripped to a higher charge state and accelerated to final energy. Primary beam intensities will be increased orders of magnitude ($\leq\sim 10^{13}$ particles/sec) and the maximum energy ($\leq\sim$ 200 MeV/u), particularly for heavy ions, will be increased several times over that presently available.

Radioactive beams are created at the NSCL by the technique of in-flight separation. A primary beam is placed on a thin ($\Delta E/E \approx 10\%$) production target. The radioactive species produced have a significant forward momentum and a downstream magnetic chicane is used to select a particular species which is then used to perform nuclear physics experiments. The fragment separator optics is generally an I transform from the production target image to the fragment separator output. Within the chicane, an intermediate image in a high dispersion region is used to select for p/q followed by a specially shaped degrader were the z dependent momentum loss removes the p/q ambiguity. The present fragment separator has a momentum limit of ~1.5 GeV/c and a case-specific capture efficiency which is generally a few percent. A new fragment separator is planned which will have a momentum limit of ~1.9 GeV/c and a capture efficiency better than 50 %. With the increased primary beam intensities and fragment separator efficiency, radioactive beam intensity increases approaching 10^3 are predicted.

The K500 beam injection into the K1200 has been evaluated to obtain the incoming beam phase space requirements. These requirements have been used to specify the matched beam functions and correction magnet characteristics. The injected beam will traverse the fringe field from the main superconducting coils, the return yoke, and finally along the edge of a hill where there is both a magnetic field gradient and electric field. The strongly focusing fields along this path have been modeled in detail with the magnetic field determined by a combination of measurements and 3D calculations and the electric fields determined by 3D relaxation calculations.

Since its initial operation in 1982, the K500 has operated in the first harmonic (h=1 where $h=\omega_{rf}/\omega_o$) mode. The coupled cyclotron operation requires the K500 to operate with h=2 and with a narrow phase width (3^o rf). An h=2 central region and spiral inflector was designed using the orbit codes MYAXIAL, INFLECTOR, and Z3CYCLONE. The code predictions were used to determine the optimal position of the first turn phase slit, turn pattern at the main probe, and transmission efficiency for a beam of 3^o FWHM phase width. The calculations were in quantitative agreement with the measured differential trace for orbit radii $\leq$15 cm. The measurements and calculations were in qualitative agreement at larger radii with both showing a decrease in turn separation between 23 and 32 cm and a larger separation at larger radii. Good agreement was also found for the beam transmission efficiency.

Cyclotron Optics

(F. Marti)

Over the last seven years, the K1200 cyclotron has successfully operated in a multi-ion, variable energy mode with frequent (daily) changes in energy and ion species. Reliable beam extraction in a non-linear magnetic field region with fully saturated soft iron quadrupoles requires the accurate specification of approximately 50 initial cyclotron parameter values. To achieve the present operational efficiency, computer codes which utilize measured magnetic field maps including the effects of the 21 isochronizing trim coils and imperfections are used to reliably determine the initial parameter values. We are now upgrading these codes to make them more generally applicable and to improve the user interface.

S800 Spectrograph

(B. Sherrill)

The NSCL is nearing completion of the S800 magnetic spectrograph system. The spectrograph will be used for the study of the resonance properties of nuclei and for experiments to study nuclear structure using radioactive nuclear beams. Superconducting technology was used throughout the device to reduce both the construction and operating costs. The spectrometer design specifications are a maximum bending power of 4 T-m, a solid angle of 20 msr, and an energy resolution of 10^4 for an energy acceptance of 10 %. The spectrometer

(QQDD) consists of two large-bore quadrupoles and two dipole magnets each with a 75 degree bend. The S800 system has a high resolution analysis beamline which will be used for dispersion matching both stable and radioactive beams. This will provide high energy resolution independent of the beam energy spread.

The spectrograph bends (disperses) vertically and rotates horizontally, which decouples the momentum from the scattering angle measurements. The optics are point-to-point in the dispersive plane and point-to-parallel in the scattering plane. Accurate ($\leq$2 mr) measurement of the scattering angle of the reaction products was a key design specification. The precision scattering angle measurements will allow software correction of the optics; hence hardware correction of higher order aberrations was not necessary. The process of reconstructive correction of aberrations is discussed briefly in the section on theoretical developments.

Accelerator Theory Group

(M. Berz)

The work of the group is centered mostly on the applications of modern map methods to the understanding of nonlinear motion in accelerators and spectrographs.

We are working on a new method to determine not only the Taylor map of a certain particle optical system, but also a guaranteed bound on the remainder of the Taylor approximation, which can be achieved with methods of **Remainder Differential Algebras (RDA).** The details behind the theory of the method have been developed, and implementation in the code COSY INFINITY has begun; using a first release of the related software, various preliminary results have been obtained and documented in [2] and the chapter of Fuchi and Berz in [1].

The work on RDA is of key importance in connection with the development of methods to assure **Guaranteed Bounds for Long Term Stability.** Normal form and other methods allow the determination of approximate invariants around a fixed point of the dynamical system under consideration, and as first pointed out by Warnock [3], they can be used to bound long-term survival times. A rigorous formulation of these ideas requires both bounds for the Taylor remainder of the maps, as well as verified global optimization of highly complex functions, both of which are possible using the RDA techniques [4].

In connection with the S800 spectrograph being constructed at NSCL, a new method was developed that allows the **Reconstructive Correction of Aberrations of Spectrographs** via measurements in two planes directly from the knowledge of the map of the system [5]. The method has been implemented in our code COSY and is also being used at a variety of places outside NSCL, most notably perhaps for the study of the CEBAF spectrometers. Any such reconstructive correction hinges on the ability to compute accurate maps for actual **Measured Fields**. In this respect, part of the recent work focused on the development of a fast technique for the computation of fringe field effects [6]. A second approach currently being developed is based on the direct use of the measured data without evoking any model approximation, which utilizes the method of Gaussian interpolation. Besides reconstructive correction, studies were performed how one can correct all aberrations of systems with high degrees of symmetry. Recently this work on a systematic method to design **High-Order Achromats** has been completed [7]. It has been applied to several practical designs including a system completely free of all aberrations up to order five.

Another part of the work of the group is connected to **Spin Dynamics.** A new DA method to compute and analyze spin maps has been developed [8]. Perhaps the most extensive application of these methods is taking place at DESY, where they are used extensively for high-precision spin dynamics simulations.

The techniques described above and many others have been implemented in our code **COSY INFINITY** [9] and a chapter in [1]. In February 1996, Version 7 of the code was officially released to the currently registered users of about 140. COSY was used as the main computation tool in a course given by our group at the Seattle US Particle Accelerator School, and a COSY user's meeting took place in February 1996 in Santa Fe.

Connected to the general question of efficient differentiation, which at least indirectly underlies a significant part of the work on aberrations and perturbation theories relevant in Beam Physics, we recently organized the Second SIAM Conference on Computational Differentiation, which took place in Santa Fe in February 1996 and attracted more than 100 participants [1]. The work we are doing on **Nonarchimedean Analysis** studies many of the general problems connected to computational differentiation in a broader sense than what is necessary for conventional Beam Physics (see the chapters of Berz and Shamseddine/Berz in [1]). The current status of the theory has recently also been discussed in depth at a summer school presented in Northern Italy last September.

Besides research, another important component of the work in the group are **Educational Activities.** Besides the training of currently four graduate students and one undergraduate, courses were given at the US Particle Accelerator School as well as the 1995 Studienstiftung Summer School in Italy. Courses in the newly developed Accelerator Physics Curriculum continue to attract students, and it is currently being studied to what extent courses could be telecast outside of MSU.

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Accelerator physics activities at Indiana University[1]

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Currently, IUCF has been funded by the NSF to construct an injector synchrotron for the IUCF Cooler Ring. The Cooler Injector Synchrotron, with 1/5 circumference of the Cooler Ring, will serve as the injector to the Cooler Ring. Protons can be accelerated from 7 MeV to 80 MeV or higher (up to 220 MeV) for Cooler injection. The project began in September 1994. The expected commissioning date will be early 1997. A proposal for a 15-20 GeV storage ring, called Light Ion Spin Synchrotron (LISS), for medium energy nuclear physics research has also recently been proposed to the NSF. Besides the machine design studies, topics of Accelerator physics research are listed as follows.

Nonlinear Experiments at the IUCF Cooler Ring

Nonlinear beam dynamics experiments began in 1990. Major results of our experiments are listed as follows.

Linear betatron coupling [1]: By transforming the 4D Poincaré maps into the Poincaré surface of subsection, we can determine the linear coupling resonance strength and the phase. The eventual goal is to understand the evolution of particle distribution when the betatron tunes move across the linear coupling line. We will study the evolution of beam distribution function as a function of resonance crossing rate.

Nonlinear sum and difference resonances [2]: Transforming the measured Poincaré maps at the $\nu_x \pm 2\nu_z = \ell$ nonlinear resonance into the resonance rotating frame, invariant tori can be obtained. Using these nonlinear invariant tori, we can derive the nonlinear Hamiltonian, which can then be compared with the nonlinear modeling. Using the normal form to analyze experimental data is a topic of our study.

Nonlinear 1D betatron parametric resonances and betatron tune modulations, [3, 4]: We have studied the properties of the 1D parametric resonances, where the Poincaré maps have been used to derive the 1D betatron Hamiltonian [3]. In past few years, E778 [5] and CERN [6] experiments verified the sensitivity of the decay time of the coherent signals and the beam lifetime on the modulation frequencies, which implied that the betatron tune modulation can lead to chaotic motion near the betatron resonance islands. The remaining important task is to measure detailed beam motion inside resonance islands, which can provide detailed understanding of diffusion mechanism of betatron tune modulation.

Longitudinal beam dynamics with rf phase and voltage modulation [7]: Making local expansion near betatron resonances, the betatron motion in action-angle variable resembles the synchrotron motion. Thus the physics of betatron tune modulation is "equivalent to" that of rf phase modulation to the synchrotron motion. We thus carried out a series of experiments to understand the synchrotron beam dynamics with rf phase modulation [7]. In this series of experiments, we were able to observe bifurcation of resonance islands, damping path of particle motion toward stable fixed points via electron cooling, tori in parametric resonance islands, etc. We extended our experiments with modulating dipole field, which was used to

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simulate the ground vibration or the current ripple in dipoles. This resulted in a betatron-synchrotron coupling [8]. Because of phase space damping due to electron cooling, the beam particles were observed to damp incoherently to parametric resonance islands, which rotated about the center of synchronous phase space. The bunch shape was also observed to follow the local potential well and displayed also hysteresis phenomena [9].

Beam dynamics of a double rf system: In an effort to increase the cooler beam intensity, we studied beam properties of a double rf system. First of all, the bunched beam intensity was observed to increase by a factor of 4 when a double rf system was used. However, we also found that the system is much more susceptible to rf phase or voltage modulation [10]. The dominant excitation modes are odd synchrotron modes due to rf phase modulation. In the presence of electron cooling, these synchrotron modes become attractors. Measurements of these attractors provides us with the phase space location of parametric resonances [11].

Hopf Bifurcation: During our machine studies, we frequently observed the onset of a beam instability when the velocity of protons differed from that of cooling electrons. This instability has been investigated in past few years. After careful analyses, we finally realized that the instability corresponded to a Hopf bifurcation, where the proton beam became a ring in the phase space, i.e., a limit cycle attractor [12]. Physically, how does this happen? The damping force, called drag force, experienced by the proton due to the cooling electrons is a nonlinear function of the relative momentum. When the velocity of the cooling electrons is equal to the velocity of the synchronous particle, the nonlinearity can reduce effectively damping rate for particles with large synchrotron amplitudes. However, when the velocity of the cooling electron differs from that of the synchronous particle, the linear damping term can be canceled by the higher order terms at a particular synchrotron amplitude, i.e. a negative resistance instability. This particular synchrotron amplitude is the amplitude of the limiting cycle. The onset of bifurcation was shown to be related to the electron temperature [12]. Using the amplitude of the limit cycle attractor we can measure the cooling drag force with relative velocity between the longitudinal and transverse velocity spreads of cooling electrons. Our experiments shows clearly that the cooling force exhibits a double peak [12]. Our experiments confirm experimentally the two-component electron cooling theory.

Beam diffusion mechanism: In October 1994, we measured the evolution of a longitudinal beam profile while a small secondary rf system was modulated harmonically. although data analysis is still continuing, our data show that $\sigma^2(t)$ does not exhibit a simple diffusion-like characteristic. To understand the mechanism of "anomalous diffusion" is a topic of our study in coming years.

Halo formation in space charge dominated beams

More recently, we have been working on the beam dynamics of space charge dominated beam transport problems. The Kapchinskij-Vladimirskij envelope equation can be transformed into Hamiltonian formalism [13]. Let (R, P) be the *conjugate envelope phase space* coordinates for space charge dominated beams in an axial-symmetric transport channel. The KV Hamiltonian is given by $H = \frac{1}{4\pi}P^2 + V(R)$, where

$$V(R) = \frac{1}{4\pi}k(\theta)R^2 - \frac{1}{2\pi}K\ln R + \frac{1}{4\pi R^2}$$

is the envelope potential, K is the normalized space charge perveance, $k(\theta) = k(\theta + 2\pi)$ is the focusing function, and $\theta = 2\pi s/L$ is the azimuthal coordinate along the path of the transport channel. With the help of envelope Hamiltonian, dependence of the envelope function on beam parameters can be derived analytically.

Coupling the particle Hamiltonian with the envelope Hamiltonian, parametric resonances of the particle Hamiltonian due to envelope oscillations of a mismatched beam can be derived analytically. We find that the Hamiltonian dynamics depends on only a single effective space charge parameter, the ratio of the space charge perveance to the focusing strength. The onset of global chaos exhibits a first order phase transition like behavior when the amplitude of envelope oscillations for a mismatched beam is larger than a critical value. This global chaos can greatly enhance the halo formation [14]. We have studied the space charge dominated beam in a periodic focusing channel [14], where Floquet transformation is needed to understand the halo formation.

Spin Dynamics

In spin dynamics studies, there are (1) the snake experiments at the IUCF Cooler Ring (A. Krisch, spokesperson) and (2) the partial snake experiment E880 at the AGS. The AGS E880 is intended to study the feasibilities of using a partial snake to overcome spin resonances in high energy synchrotrons (a collaborative effort of Indiana/BNL/ANL/TRIUMF/KEK). We have installed a room temperature 4.7 Tesla-meter solenoid magnet in the AGS I20 straight subsection for the AGS partial snake experiment, where we study the possibility of overcoming all imperfection resonances up to 25 GeV. The first experiment was successfully tested in April 1994 [15]. An experimental run in December 1994 had tested polarized beam acceleration with a 5% partial snake and tune jump. Intrinsic spin resonance correction in medium energy proton synchrotrons is a technically difficult task. Successful completion of our experiments can provide high energy polarized proton beams for RHIC, where snake resonances and overlapping spin resonances are important [16].

These experiments also bear important implications to the conceptual design of the Light Ion Spin Synchrotron (LISS) at IUCF, where a 15-20 GeV/c light ion storage ring is considered to be an important facility for medium energy nuclear physics experiments.

Particle Dynamics in quasi-isochronous storage rings

A possible method to attain short electron bunches is to employ quasi-isochronous (QI) storage rings, where the phase slip factor $\eta = \eta_0 + \eta_1 \frac{\Delta p}{p}$ is designed to be nearly zero. Recently, we show that the QI dynamics system can be transformed into a universal Weierstrass equation, where the QI Hamiltonian becomes

$$H_{\rm QI} = \frac{1}{2}p^2 + \frac{1}{2}x^2 - \frac{1}{3}x^3.$$

Here $x = -\frac{\eta_1}{\eta_0}\frac{\Delta p}{p}$, $p = \frac{dx}{dt}$ are conjugate phase space coordinates with time $t = \nu_s \theta$, ν_s is the small amplitude synchrotron tune, and θ is the orbiting angle. The solution of the QI Hamiltonian is given by by the Jacobian elliptic function. Including synchrotron radiation damping and rf phase modulation, the QI equation of motion becomes

$$x'' + Ax' + x - x^2 = -\omega_m B \sin \omega_m t,$$

where $A = \lambda/\nu_s$ is the effective damping coefficient with damping decrement λ, and $\omega_m = \frac{\nu_m}{\nu_s}$ and $B = \frac{\eta_1}{\eta_0 \nu_s} a$ are the effective rf phase modulation tune and amplitude. Note that rf phase modulation amplitude is particularly enhanced in QI dynamical system [17], where we show that the QI dynamic system can exhibit a sequence of period-two bifurcation toward global chaos in a region of parameter space. We show that the stability of the QI dynamic system is determined by the 1:1 and 2:1 parametric resonances. Our current effort is to study the multi-particle dynamics with quantum fluctuation, potential well distortion, and intrabeam scattering.

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Beam Dynamics Studies at Rutherford Appleton Laboratory, UK.

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The following topics are currently being evaluated:

1. Continued studies for a 5 MW European Pulsed Spallation Neutron Source, ESS.
2. The possibility of a Medical Facility, based on the ISIS synchrotron.
3. Lattice and injection studies for a European Heavy Ion Fusion Project, HIDIF.
4. Continued developement of space charge codes, and
5. Studies of high intensity proton linear accelerators and cyclotrons.

The ESS study has been in progress for 18 months, and will be written up before the end of 1996. RAL is responsible for the design of the rings and beam lines, in collaboration with Universities of Arhus, Uppsala and Naples, and the Hahn Meitner Institute, Berlin. Some aspects of the high power targets are also being evaluated with KFA, Julich.

Fast extraction of a low intensity, low energy beam from ISIS is being considered for use in a medical facility. Limitations of such a beam may direct studies in other directions.

Heavy Ion Fusion Studies have commenced again at RAL, after a 12 year interval. Storage ring lattices have been evaluated for the European HIDIF project, and multi-turn injection studies are in progress. Combined horizontal-vertical injection is being evaluated, using a corner septum, orbit bumps, and varying lattice functions. Space charge effects are important and need to be evaluated carefully. Injection followed by bunched beam laser cooling is also under consideration.

Space charge codes continue to be developed as beam loss considerations are a major concern for all the new high intensity facilities under study. Code development is required for the ESS and HIDIF studies, and also for studies of high intensity linacs and cyclotrons, which are just commencing at RAL.

Tenth Advanced ICFA Beam Dynamics Workshop on Fourth Generation Light Sources

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The Tenth Advanced ICFA Beam Dynamics Panel Workshop on 4th Generation Light Sources was organized at the European Synchrotron Radiation Facility, Grenoble, France, from January 22 to 25, 1996. The workshop attracted 95 external participants from 42 different institutes the world over, based in 12 different countries. About another 40 participants from the ESRF also took part.

The workshop was organized as a mixture of plenary sessions and working group discussions, based on the themes : Scientific Opportunities for 4th Generation Light Sources, VUV/soft X-rays and Hard X-rays, Lattice and stability aspects, Current, lifetime and time structure, Linac Sources, Storage Ring FELs and Insertion Devices. To discuss these topics, we were fortunate to bring together, for the first time, representatives of both synchrotron radiation scientists and accelerator physicists. Such a situation was a prerequisite for the success of the workshop, which, once having established the direction it was to take, resulted in an excellent exchange of ideas. We therefore take this opportunity to warmly thank all the colleagues involved for their active participation.

The following are my personal conclusions that I have drawn from the workshop. I have done my utmost to remain impartial, a difficult task.

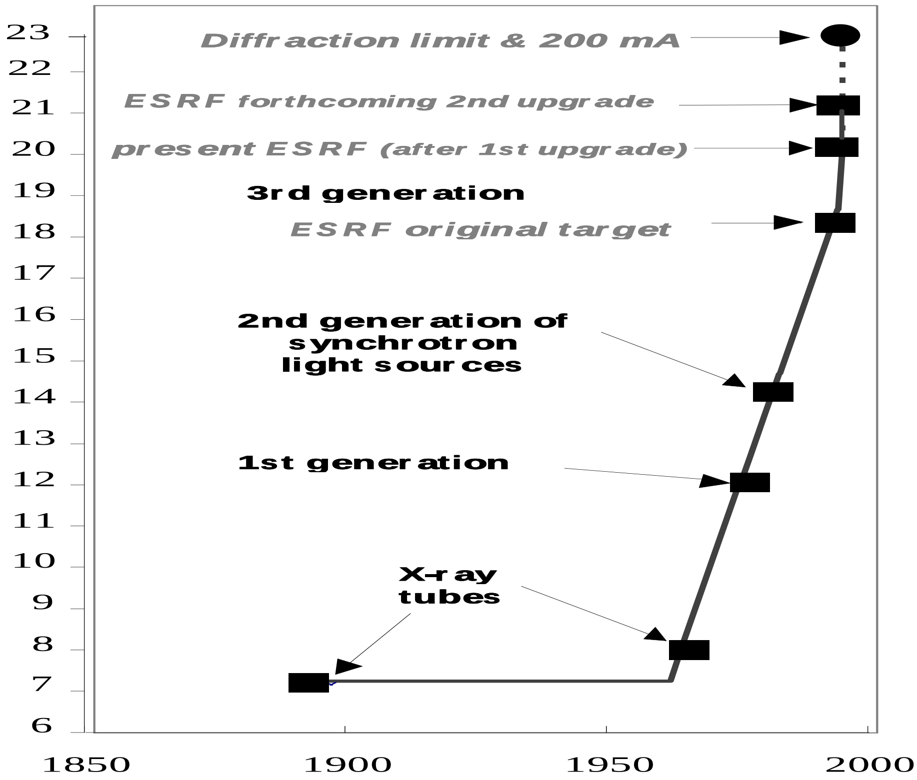
Scientific Conclusions

The scientists, making up one third of the participants, worked very hard within the two working groups on scientific opportunities to provide the other groups with guidelines. The main messages contained in their conclusions are:

- Light Sources of the 3rd generation are fantastic tools. Their scientific use started about two years ago. The performances are well beyond expectations and have already permitted the production of outstanding experimental results. These results will serve scientists for the next 15 to 20 years.
- For the 4th generation light sources to come, there is an excellent scientific case for even more coherence and shorter pulses:

Consequences For 4th Generation Light Source Design

More Coherence More transverse coherence can be achieved by means of electron beams with emittances closer to the diffraction limit. The average brilliance is then the figure of merit.



Logarithm of X-ray Source Average Brilliance

Storage rings

Storage rings were the preferred solution for the 3rd generation light sources with energies ranging from 1.5 to 2.5 GeV for VUV soft X-ray and from 6 to 8 GeV for hard X-ray sources. Their original target was set in the 10^{18} range, 4 orders of magnitude above the second generation sources (see Figure 1). Without exception, all of these storage rings were successfully commissioned and a certain number of them dramatically surpassed their original targets. The ESRF's first upgrade, for instance, allowed the average brilliance to jump from a few 10^{18} to a few 10^{20} combining higher current, lower horizontal emittance, lower coupling and spectrum shimmed undulators. Again with the example of the ESRF in mind, the estimated ultimate limit would be in the range of 10^{21}. Indeed, this further improvement of a factor 5 to 10 could be gained by combining an even lower horizontal emittance with a further reduced coupling. With this second upgrade, the diffraction limit in the vertical plane would be reached for a hard X-ray source. This would place the ESRF, and similar sources of the 3rd generation, two orders of magnitude below the ultimate 10^{23} achievement possible with a storage ring diffraction limited in both planes and with 200 mA current.

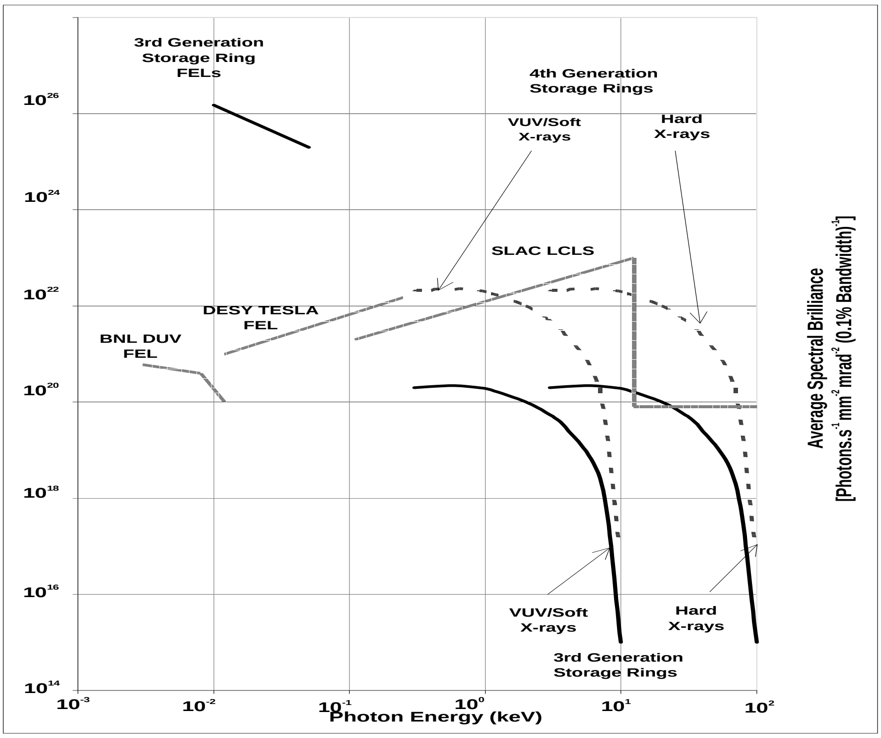
The workshop set at around 10^{22} in average brilliance (a factor of 10 above the planned ESRF second upgrade and a factor of 10 below the ultimate 10^{23} figure) the best extrapolation that could be made for both hard X-ray and VUV soft X-ray storage rings of the 4th generation. This small difference of a factor 10 left between 3rd and 4th generation machines is presumably at the expense of a significant lengthening (factor 2 to 3) of the circumference. Intrabeam scattering would prevent reaching the diffraction limit in both planes.

Linac driven FELs

In a storage ring of a given energy, one needs to increase the circumference to lower the emittance and increase the brilliance. In a linac, lower and lower emittances can be obtained by increasing the energy of the electron beam. With a several GeV linac the diffraction limit for 10 keV X-rays can be reached. Self Amplification of Spontaneous Emission (SASE) from a 30 meter long undulator driven by such a linac beam could lead to average brilliance figures which are, again, in the 10^{22} range.

From the point of view of more coherent beams or equivalently higher average brilliance, as seen today, performances of future storage ring sources and linac driven FELs would be comparable. Contrary to what happened with the 3rd generation light sources, the expected performances would not be dramatically superior to those of upgraded light sources of the previous generation. It is nevertheless true to say that there still might be the odd factor to be gained with (preferably superconducting) linac FELs when increasing the repetition frequency for instance. A summary of the above can be seen in Figure 2.

The difference between the storage ring and linac FEL approaches was discussed at length during the workshop. Storage rings have undergone tens of years of development and their physics is well understood. On the contrary, the SASE principle still remains to be experimentally demonstrated. A second important point to be taken into consideration is that the SASE principle might work for VUV soft X-rays and it might even work for hard X-rays of energies up to 10 keV, but this is definitely to be considered as the upper limit. Above 10 keV, the average brilliance of the linac driven FELs will drop by 3 orders of magnitude, thus falling behind storage ring performances.



Storage ring driven FELs

In the low energy part of the spectrum, up to UV frequencies, one must not forget storage ring driven FELs which, in the forthcoming years, will deliver an average brilliance in the 10^{26} range, 4 orders of magnitude above the previously quoted figures for 4th generation light sources. The goal is to reach wavelengths down to a few tens of nm. Unfortunately, shorter wavelengths are not accessible.

Ultra Short Pulses for Dynamic Studies The production of short pulses was the second main priority.

At present, the majority of synchrotron radiation users do not make use of the time structure of the emitted light. However, fantastic results have already been obtained with third generation storage rings operated in single bunch mode. These sources can produce 10 ps long rms light pulses. There is a good scientific case for 1 ps and the extrapolation to 100 fs makes future prospects even more exciting.

The workshop reviewed the possibility for storage rings to produce such short pulses when operated in a quasi-isochronous mode. However, due to the microwave instability, it is felt that the 1 ps target with a peak brilliance of the order of 5×10^{24} would constitute the upper limit.

With linac FELs, the sub ps range, and in particular 100 fs, could be accessible. For the three projects, BNL DUV FEL, DESY TESLA-FEL, and SLAC LCLS, peak brilliances ranging between 10^{29} and 10^{34} (4 to 9 orders of magnitude larger than the best storage ring figures predicted) are announced. Should the SASE principle prove to be as successful as hoped for, this would make the linac driven FELs genuine light sources for the 4th generation, unbeatable for dynamic studies.

Divided Feelings...

A certain number of accelerator physicists in the audience fully advocate that SASE and linac driven sources are the most promising 4th generation light sources. Their deep enthusiasm about the fantastic prospects in terms of peak brilliance and short pulses rubbed off on many of the scientists present.

On the other hand, however, a small group of accelerator physicists abstained from voicing an opinion, presumably remembering all too well the former unsatisfied expectations of FELs, and preferred to reserve their position on this matter until the SASE principle has been experimentally demonstrated.

Medium-term Program and organization

We were given a five year R&D program, with several intermediate milestones, on linac FELs, ending with a full SASE demonstration. Then, and only then, will we be in a position to propose linac FELs as possible 4th generation successors to the present storage rings in 15 to 20 years from now. It is hoped by all that SASE is a success and the research and development program received strong support.

In parallel, studies will be made on 3rd generation rings when operated well below their nominal energy close to the diffraction limit (ESRF storage ring at 2 GeV) and in a quasi-isochronous mode to determine the limits of circular machines in terms of average brilliance, bunch length and peak brilliance.

Several ambitious projects of storage ring driven FELs are in their commissioning phase. All the synchrotron radiation community is attentive to the results.

Similar to the ICFA panel for beam dynamics, and under the Chairmanship of myself, it has been decided to create a panel of accelerator physicists, experts in synchrotron light sources. This committee will be formed in the coming weeks. It will regularly publish a newsletter and organize specialized workshops including the successors to the 1992 Stanford and 1996 ESRF workshops. A call for candidate laboratories will be launched in due time.

The proceedings of this workshop have just been published. Please address any enquiries to : Mrs Trina Bouvet, ESRF, BP 220, 38043 Grenoble cedex, France. Tel : 76 88 20 12, Fax : 76 88 20 54, e-mail : bouvet@esrf.fr

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BTCF Workshop'96 held in Beijing

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Beijing Tau-Charm Factory Workshop'96 (BTCF'96) was held on February 5-9, 1996 at IHEP, Beijing, China. 62 accelerator specialists and physicists coming from laboratories and universities of USA, Europe, Japan, Korea and Russia, together with 170 Chinese physicists, attend the workshop.

On the first day of the workshop, Professor Zhou Guangzhao, President of Chinese Academy of Sciences, expressed in his welcome speech the hope that BTCF would be promoted by more effective cooperation between China and the international high energy physics community.

Professor Zheng Zhipeng, director of IHEP and Professor Wang Shuhong, deputy director of IHEP, demonstrated in their speeches their wills that the workshop would help to improve the initial design of BTCF. They both stressed the importance of international collaboration.

Professor W.K.H.Panofsky, the senior advisor of the US-China Joint Committee on High Energy Physics, highly praised in his opening address the efforts and achievements made in BTCF project by the Chinese high energy physics community. He wished that BTCF will become an international center for tau-charm physics research.

Some common recognitions have been reached during the workshop, among which are:

1. "The Feasibility Study Report on Beijing Tau-Charm Factory (draft)" , having summed up the rich knowledge and experiences in TCF research since 1987 and combined the advantages of a lot of up-to-date technologies, is well qualified for its correct estimation of the scientific value of TCF, the sound judgments on the potential technical difficulties as well as the effective counter measures.

2. Through extensive discussions, much more clearer understanding was gotten concerning the key BTCF technique, just as Professor M. Tigner, advisor of BTCF, summarized, TCF should be the world-level accelerator in the coming century, the technique employed would be the most advanced and effective, namely multibunch, mini-beta and crossing angle collision, as well as superconductivity, radiofrequency and computers. Nevertheless, it is in general not more difficult to construct a TCF than B-Factory. In order to master these techniques, preliminary study is absolutely necessary.

3. BTCF should be built under international cooperation. It is hoped that the international high energy physics community can collaborate with Chinese physicists in the BTCF's R&D. During the workshop many talks had been held friendly between IHEP and ANL, SLAC, KEK and Korea delegates to seek the possibility of collaboration in BTCF's construction.

It is should stressed on the machine as following:

1. The priorities for the machine performance are, in order:
   (a) A peak luminosity of 10^{33} cm^{-2} s^{-1}, and a primary energy range of about 3-5GeV.
   (b) Longitudinal polarization of one or both beams near 3.67 GeV (the prime energy for tau physics) and–within the practical constraints– also at other energies.
   (c) To maintain in the design the potential for future luminosity increases and for operation with monochromator optics.
2. The BTCF collider is a challenging machine that will require careful implementation of state-of-the-art accelerator technologies. However, the design goals of the BTCF are judged to be realistic in view of the performances of accelerators currently in operation or under construction. The close inter- national collaboration that is characteristic of particle accelerator laboratories will be vital for the successful construction of the BTCF.
3. Design of the machine-detector interface near the interaction region requires the accelerator and detector teams to work closely together to ensure optimal use of the restricted physical space and to ensure adequate masking is included to shield the detector from accelerator produced backgrounds.
4. Reliability and continuous operation of the BTCF are important requirements to ensure that the high peak luminosity is translated into a yearly basis. This aspect merits special attention during the design and R&D phases.

The proceedings of the workshop will be published soon to meet the urgent needs of the researchers.

Announcements of the Forthcoming Beam Dynamics Events

Mini-Workshop Series on High Intensity, High Brightness Hadron Beams

The First Mini-Workshop — Transition Crossing

May 20-23, 1996
Fermilab, Batavia, Illinois, USA

Four institutions — the PS Division at CERN, the PS Division at KEK, the AGS Department at BNL and the Main Injector Department at Fermilab — have agreed upon a collaboration for co-sponsoring a mini-workshop series. The purpose of this series is to investigate the major technical issues associated with achieving high intensity, high brightness hadron beams. These mini-workshops will be problem solving-oriented rather than presentations-oriented. In particular, there will be no formal proceedings; summary reports from working groups will be provided to participants. Each mini-workshop will focus on a specific subject. The number of attendees will be limited and will be by invitation only. All these measures are aimed at making this series productive, effective, and useful.

The first mini-workshop will be held May 20-23, 1996, at Fermilab. The subject is transition crossing.

Organizing Committee: Philip Martin (Fermilab, Chairman), Weiren Chou (Fermilab, Convener), Patrick Colestock (Fermilab), Roberto Cappi (CERN), Roland Garoby (CERN), Thomas Roser (BNL), Bill Weng (BNL), Yoshiharu Mori (KEK/INS), Shinji Machida (KEK).

For administrative questions, please contact: Marion H. Richardson, Fermilab, P.O. Box 500, MS 323, Batavia, IL 60510, USA, E-mail: mhr98@fnal.gov, Tel: (708)840-2767, Fax: (708)840-8461.

For technical information, you may also contact: Weiren Chou, Fermilab, P.O. Box 500, MS 323, Batavia, IL 60510, USA, E-mail: chou@adcalc.fnal.gov, Tel: (708)840-5489, Fax: (708)840-8461.

LHC96 — International Workshop on High Brightness Beams for Large Hadron Colliders

The International Workshop on High Brightness Beams for Large Hadron Colliders will take place in Montreux, Switzerland, from 13 to 18 October 1996.

The goal of this workshop is to review and discuss the phenomena in the injector chain which affect the brightness and limit the intensity of the hadron beams for large hadron colliders, in particular the LHC. The processes which cause beam dilution in the circular injectors and the transfer lines between them will be identified. Their diagnosis and methods for fighting them will be discussed. The experience, both theoretical and experimental, from other large hadron colliders, HERA, RHIC, SppS, and Tevatron, will be analyzed, and the consequences for the injector chain of future hadron colliders, in particular the LHC will be studied.

Further information may be found on the World-Wide-Web at the URL:

`http://hpariel.cern.ch/keil/lhc96.html`

THE 11TH ADVANCED ICFA BEAM DYNAMICS WORKSHOP ON "BEAM COOLING and INSTABILITY DAMPING"

dedicated to the 30th Anniversary of the Electron Cooling

18 - 26 June 1996

on board the ship from Moscow to Nizhny Novgorod and back

sponsored by

The Russian Foundation for Fundamental Research

The Russian Ministry of Science and Technology Policy

The Ministry of the Russian Federation for Atomic Energy

The organising Institutions:

Joint Institute for Nuclear Research (Dubna, Russia)

Budker Institute of Nuclear Physics (Novosibirsk, Russia)

Scientific Council for Particle Accelerators of Russian Academy of Sciences

I.Meshkov

Joint Institute for Nuclear Research

(E-mail: MESHKOV@NUSUN2.JINR.DUBNA.SU)

The Purpose of the Workshop The Workshop on Beam Cooling and Instability Damping has a goal to bring together specialists who are dealing with different and numerous methods of particle beams formation, control and regulation. The Workshop is intended to emphasize that all the methods have common physics basis and many approaches and procedures developed in one field can be applied to another one.

A few workshops dedicated to the cooling methods, were performed previous years. However, since the 1994 Montreux Workshop the problems of the cooling technique development have not been revised.This is to be done now because of many new ideas and tendencies appeared in this field. The damping methods, on the other hand, have never been presented to a special workshop dedicated to this specified problem. So the main task of the Workshop is a presentation of the status and development tendencies in the field of the methods of particle beam cooling and their instability damping.

The organizers of the Workshop hope that it will continue and develop the traditions of previous conferences held at Karlsruhe, Legnaro and Montreux.

Topics of the Workshop

- Electron cooling at low energy at medium energy.
- Stochastic cooling in medium energy rings in large colliders (bunched beams).
- Radiation cooling.
- Laser cooling.
- Feedback and damping systems: pickups and kickers, low noise designs, nonlinear and sophisticated feed-back systems.
- New cooling methods and applications of cooling: muon cooling, optical stochastic cooling, stimulated radiation cooling, crystalline beams.
- Atomic processes related to electron and laser cooling.

- Diagnostics of cooling and damping methods.

Call for Papers Abstracts should be mailed to the Workshop Chairman early enough to arrive not later than April 10 1996 Deadline. Abstracts should be camera-ready and should not exceed a typewritten page with a title, authors with no figures and tables.

Fees and Payment The Registration Fee will be USD 800 for a participant. For accompanying persons, USD 700, and for children (age: 8-15), USD 350.

The sum includes the Workshop Fee (organization expenses, a copy of Proceedings, publication,etc), full board, excursion tickets and transportation.

The first part of the total sum should be remitted not later than 10 April 1996 at the following address:

Account No. 170 087 87
Joint Institute for Nuclear Research
The Bank for Foreign Trade of Russia
Serpukhovskoi Val 8, Russia
Cooling and Damping - 96 (C&D-96)

Please quote the name of a participant. The rest of the sum should be paid in CASH at the registration on board. Due to the fact that the Workshop will be held on board the ship, participants are kindly requested to bring NEITHER traveler cheques and NOR credit cards.

For further information, please ask

Workshop Secretary Mrs.N.Dokalenko	E-mail	NATALY@YPR.JINR.DUBNA.SU
International Department	Fax:	7(095)975 23 81 or 7(09621)65-891
Joint Institute for Nuclear Research	Phone:	7(095)926 22 52 or 7(09621)65-011
141980 Dubna, Russia	Telex	911621 DUBNA SU

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

September 2 to 6, 1996

M. Cornacchia(cornacchia@ssrl01.slac.stanford.edu) and
C. Pellegrini(claudio@vesta.physics.ucla.edu)

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 partial list of topics includes:

- 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 workshop will be organized with four initial general review presentations, after which the participants will divide in four 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 working groups and initial talks are:

- Group 1: Single Particle Dynamics: recent advances in nonlinear dynamics, including frequency analysis and mapping. Group Leader: R. Ruth (SLAC), Speaker: K. Oide (KEK)
- Group 2: Production and Dynamics of High Brightness Beams: advances in production, acceleration, transport and monitoring of high brightness beams, including coherent and radiation effects. Group Leader: R. Sheffield (LANL), Speaker: L. Serafini (U. Milan)
- Group 3: Beam Dynamics in Plasmas: advances in longitudinal and transverse dynamics, emittance preservation and beam loading in plasma systems. Group Leader: T. Katsouleas (USC), Speaker: F. Amiranoff (? - to be confirmed)
- Group 4: Plasma Phenomena in Beams: transverse and longitudinal oscillations in high density relativistic beams, including parametric instabilities and filamentation. Group Leader: J. Wurtele (MIT), Speaker: P. Colestock (Fermilab)

For information, contact: Melinda Laraneta at UCLA;

fax	310-206-1091
e-mail	laraneta@physics.ucla.edu

The workshop is sponsored by DOE, ENEA, INFN, LBNL, SLAC, UCLA, KEK, U. of Rome "La Sapienza."

ICFA Beam Dynamics Newsletter

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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 reserve the right to reject the contribution. Those who want to submit articles are encouraged to contact 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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