ICFA

International Committee for Future Accelerators

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BEAM DYNAMICS NEWSLETTER

No.6

edited by

K.Hirata, S.Y.Lee and F.Willeke

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Contents

ICFA BEAM DYNAMICS PANEL

K. Hirata[1], Chair

KEK, National Laboratory for High Energy Physics

I will report the present and planned activities of the panel. Its mission is to encourage and promote the international collaboration on beam dynamics studies for the present and future accelerators. The materials below are based on the agreement among panel members.

1 ICFA Advanced Beam Dynamics Workshops

We hold workshops on the beam dynamics. The aim of our workshops is different from that of many other workshops and conferences. The topics should be *general* but *special* at the same time:

- The topics of the workshops are *general* because subjects are not to be oriented to particular projects of particular laboratories. The subject is not project oriented but is chosen for the general interest from beam dynamics point of view.
- The topics are chosen to be rather *specialized* in order to make it possible that small number of specialists work together deeply on particular issues, instead of telling each other on what they have achieved. The workshop is not a mini-conference. We do not necessarily expect many participants.

At present, the following workshops are being considered:

1. Beam-Beam Issues for Multibunch, High-Luminosity Colliders, 18 to 20 May 1995, at Joint Institute for Nuclear Research, Dubna. See the announcement from the panel in this issue.
2. Space Charge Dominated Beams and High Brightness Beams for Advanced Applications, Oct. 11-13, 1995, at Bloomington Indiana.
   Contact person: S.Y. Lee (SHYLEE@ucs.indiana.edu).
3. Nonlinear Dynamics in Particle Accelerators, 2 to 6 September 1996 at Arcidosso, Italy.
   Contact person: C. Pellegrini (claudio@vesta.physics.ucla.edu).
4. Physics of Beam Cooling, autumn 1996 in Novosibirsk.

The details will appear in the following issues of the beam dynamics newsletters.

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2 ICFA Schools on Beam Dynamics

The schools are to encourage young accelerator physicists in developing countries in particular. The panel agreed that the school should be organized in developing countries, because not many people can attend similar schools held in advanced countries. To do so, we have outlined a possible procedure to have a school:

1. A regional ICFA school should encourage regional attendee from developing countries.
2. The ICFA beam dynamics panel should help to organize a regional school in any region upon receiving requests.
3. The local organizers should take care of expenses for students from the region.
4. The beam dynamics panel should help to select a best set of instructors. Instructors should seek traveling expenses from their home institutions, if the local organizers cannot cover them.
5. It is preferable that the local expenses (meal, housing, etc.) for teachers are taken care of by the local organizers.

Those who want to hold a school in their region are encouraged to send their requests to one of the panel members.

3 ICFA Beam Dynamics Newsletters

The Beam Dynamics Newsletter is a place where people in different laboratories know what are going on in other laboratories and who is doing what. It is expected that such information enhances world-wide collaboration and reduces unnecessary duplication of the works.

From this issue, we have changed the policy. Several of new features are

1. you can use equations, figures, and references to report the activity.
2. "letters to the editor" is now open to everybody.
3. we will publish reports on workshops which are interesting to the beam dynamics society.
4. we will publish announcements of workshops and meetings.
5. we will try to publish more frequently than before.

The Instruction to the authors is given in Appendix A.

4 Panel members

The present list of the panel members is given below.

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V.I.Balbekov	IHEP(Protovino)	BALBEKOV@TIGER.SSC.GOV
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Robert H.Siemann	SLAC	SIEMANN@AEW1.SLAC.Stanford.EDU
Ferdinand Willeke	DESY	MPYWKE@DHHDESY3 (BITNET)
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We welcome comments, questions, and requests to the Beam Dynamics Panel.

A Instruction for the Newsletter

ICFA Beam Dynamics Newsletter

Instructions to the authors

November 1994
ICFA Beam Dynamics Panel

Editors in chief:

name	e-mail	
S.Y.Lee	lee@iucf.indiana.edu	The United States and Canada
Ferdinand Willeke	MPYWKE@DHHDESY3	Europe including Russia
Kohji Hirata	hirata@kekvax.kek.jp	Rest of the world

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.

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. Announcements of future Beam Dynamics related international workshops and meetings.
   Those who want to use newsletter to announce their workshops etc. can use it. The length should be within a half page, 11cm (vertically) times 16.5cm (horizontally). Descriptions on the subject, date, place and the contact person should be written.
5. Letters to the editor
   It is a forum open to everyone. Anybody can show his/her opinion on the beam dynamics and related activities, by sending it to one of the editors. The editors keep the right to reject a contribution.
6. Editorial

All articles except for 5) are invitation only. The editors ask for an article according to a recommendation by panel members. Those who want to submit an article are encouraged to contact with a panel member nearby.

The manuscript should be sent to one of the editors in a camera-ready form or in a LaTeX file. In the former case, everything should be within a rectangle of 23.5cm (vertically) times 16.5 cm (horizontally), excluding page number.

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

An example style for a manuscript in LaTeX is given in Appendix B. To avoid wrapping problem, please do not put comments (%) when sending the manuscript through e-mail.

B An example of LaTeX format

For your convenience, I put an example style format for LaTeX.

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\documentstyle[12pt]{article}
\textheight 23.5cm \textwidth 16.5cm
\voffset -20mm \hoffset -5mm
\begin{document}
\vspace{6mm}
\begin{center} \Large\bf{ICFA BEAM DYNAMICS PANEL} \\
\vspace{5mm}
\normalsize
K.~Hirata\footnote{HIRATA@KEKVAX.KEK.JP}, Chair \\
KEK, National Laboratory for High Energy Physics
\end{center}
\vspace{5mm}
I will report ...
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REPORT ON THE SIXTH ADVANCED ICFA BEAM DYNAMICS WORKSHOP

A. Hofmann (ALBERT@CERNVM) and B. Zotter (ZOTTER@CERNVM); CERN

1. Summary

The International Committee for Future Accelerators (ICFA Beam Dynamics Panel) and the University of Madeira held a workshop on synchro-betatron resonances in Funchal, Madeira, Portugal, October 24-30, 1993 which was attended by 25 participants. The different aspects of this topic were introduced by several presentations. This was followed by discussions among all participants and by some work by small teams or individuals. The outcome was summarized on the last day. Contributions and conclusions of the workshop will be published in proceedings.

2. Program

The workshop was planed by an organizing committee consisting of the following members:

R. Baartman, TRIUMF
D. Edwards, (chairman of the ICFA beam dynamics panel), FNAL
J. Hagel (local organizer), University of Madeira
K. Hirata, KEK
A. Hofmann, CERN
A. Piwinski, DESY
G. Roy, (scientific secretary), CERN
B. Zotter, CERN

This committee worked out a program and made a list of nearly 100 people to be invited. The workshop had finally 25 participants who are listed at the end. This number was a little smaller than expected but allowed informal discussions among everybody without the necessity to split up into parallel sessions.

The workshop was supposed to cover theoretical and experimental investigations of synchro-betatron resonances. The different subjects were introduced through short review talks given by some specialists:

A. Piwinski: Observations at DESY
J. Hagel: Single particle analysis
T. Suzuki: Multi particle analysis
D. Brandt: Multi particle tracking
S. Myers: SBR at LEP
K. Cornelis: Observations at LEP
K. Hirata: Beam-beam driven SBR
T. Chen: SBR and crossing angle
Y. Orlov: Observation at CESR

Furthermore some talks about special observations and treatments were presented:

R. Baartman: SBR in TRIUMF
T. Chen: Beam-beam tails
W. Decking: SRB in DORIS III
M. Donald: SBR driven by high order chromatic aberrations
S.Y. Lee: Excitation of synchrotron motion by a closed orbit modulation
W. Moshammer: Simulation of resonances
Y. Orlov: Fourier Analysis of high order incoherent resonances
S. Peggs: SBR effects in hadron machines
S. Peggs: SBR for crystal beam extraction
B. Zotter: Radiation damping in SBR simulation

These presentations stimulated the discussions and initiated further work by individuals and small groups. Due to the relatively small number of participants most of the discussions were held with everybody participating. This interaction between the different participants was rather informal and allowed to obtain detailed information about the theoretical and experimental investigations done in the different laboratories. At the end of the workshop these discussions and the conclusions were summarized. Also, general news from the different laboratories were presented by the participants.

The proceedings have been edited by G. Roy and will be published soon as a Madeira University Report and as well as a CERN report.

2. Organization

The conference was held in the Hotel Savoy, Avenida do Infante, 9000 Funchal, Madeira, Portugal, where also a welcome drink and a conference dinner were held. An excursion around the island was made on Wednesday. All the arrangements in Madeira were well organized. Unfortunately some people had problems to get a visa for Portugal.

The workshop received a generous support by the University of Madeira in three ways. First, J. Hagel spent a lot of time and effort to arrange the conference facilities and accommodations in the hotel Savoy as well as the social events. Second, an important financial contribution was received form the university which made it possible to keep the registration fee relatively small. Finally, the proceedings will be published as Madeira University Report.

3. Participants

Ainosuke Ando
Rick Baartmann
Daniel Brandt
Tong Chen
Karel Cornelis
Winfried Decking
Martin Donald
Miguel Furman
Eliana Gianfelice-Wendt
Johannes Hagel
Werner Herr
Kohji Hirata
Albert Hofmann
Shyh-Yuan Lee
Walter Moshammer
Stephen Myers
Takeshi Nakamuro
King Yuen Ng
Yuri Orlov
S. Peggs
A. Piwinski
Ghislain Roy
Francesco Ruggiero
Toshio Suzuki
Bruno Zotter

Workshop on Future Hadron Facilities in the U. S.

Reported by:
S. D. Holmes (holmes@admail.fnal.gov)
Fermi National Accelerator Laboratory

A workshop on "Future Hadron Facilities in the U.S." was held at the Indiana University Cyclotron Facility over the period July 6-10, 1994. Workshop participation included 52 registrants from 17 institutions in the United States and from CERN in Europe. The workshop was held under the auspices of the Accelerator Physics, Technologies, and Facilities Working Group of the American Physical Society/Division of Particles and Fields Long Term Planning Study. This study has been organized by the DPF to examine future research directions and opportunities for the U.S. High Energy Physics community follogic , evolving program l of the SSC project .

The specific goals of the Indiana workshop were three-fold:

1. To develop a defensible parameter list for a $2\text{x}10^{33}$ $\text{cm}^{-2}\text{sec}^{-1}$, 2 x 2 TeV, luminosity and (or) energy upgrade of the Tevatron $\bar{p}$ - p collider at Fermilab.

2. To develop a defensible parameter list for a $1\text{x}10^{34}$ $\text{cm}^{-2}\text{sec}^{-1}$, 30 x 30 TeV p - p collider.

3. To identify R&D requirements for achieving the stated parameters.

The two facilities examined were chosen because they were felt to span the potential needs of the U.S. HEP community following the completion of the Main Injector upgrade at Fermilab, and through and beyond the period of utilization of the LHC in Europe. It was felt that the necessary R&D required to realize either of these facilities would likely provide a strong basis for nearly any direction that the community wished to move in the realm of hadron facilities over the next twenty years or so. The work of this meeting rests upon and extends previous studies of higher energy/luminosity options in the Tevatron tunnel, as chronicled in the 1988 Snowmass Proceedings, and the extensive design and development work completed at the SSC Laboratory.

Six working groups were established in the areas of magnets, cryogenics/vacuum, antiproton sources, injectors, interaction regions, and lattice/beam dynamics. These groups were assisted by two teams with overall responsibility for coordinating study and evaluating parameters for each of the two facilities mentioned above.

Design Issues: 2 x 2 TeV $\bar{p}$ - p Collider at Fermilab

Design issues in the construction at Fermilab of a 2 x 2 TeV $\bar{p}$ - p collider, operating at $2\text{x}10^{33}$ $\text{cm}^{-2}\text{sec}^{-1}$ were studied. Such a facility represents a factor of twenty improvement in luminosity, and a factor of two energy enhancement over performance expected following the Main Injector upgrade. It should be noted that the energy and luminosity upgrades can be considered separately. Implementation of the luminosity enhancements alone would result in the same beam parameters but one half the luminosity of the full upgrade.

The primary design issue for this facility is the antiproton production/accumulation rate. An accumulation rate of $9\text{x}10^{11}$ $\bar{p}$/hour is required to support a luminosity of $2\text{x}10^{33}$ $\text{cm}^{-2}\text{sec}^{-1}$. This represents nearly a factor of twenty beyond the present performance of the Antiproton Source at Fermilab, and a factor of six beyond the performance expected in the Main Injector era. In addition a new facility is required in which up to 10^{13} antiprotons can be stored prior to injection into the collider. The current accumulation capability of the Antiproton Accumulator is about $2\text{-}3\times10^{12}$ antiprotons. Potential solutions to these issues are related to an increase in the number of protons targeted per hour and increased stochastic cooling bandwidth. At least one, and perhaps two, new rings are required.

Secondary design issues are related to providing the required magnetic fields and gradients, and understanding beam stability and dynamics with large numbers of bunches in each beam. The achievement of 2 TeV in the existing Tevatron tunnel requires dipole magnets operating at 8.8 T and quadrupoles in the interaction regions with gradients of 210 T/m. The dipole field required is a factor of 33% beyond that achieved in the SSC development program and is comparable to current achievements in the LHC program. The achievement of this field is not considered a major challenge. Development of the large aperture, 210 T/m quadrupole represents a greater challenge. The development of such a magnet would probably closely parallel the development of the interaction region quadrupoles required for the LHC program. It should be noted that the magnet design is strongly impacted by the potential need to support a slow extracted beam program at 2 TeV. The decision of whether to include such a performance specification would have to be made fairly early in the development program

A number of potential issues relating to operations with a large number of bunches deserve further study. These include the long range beam-beam interaction, intrabeam scattering, issues related to the production and preservation of low emittance, and single beam instabilities. Many of these issues could be addressed through beam studies in the Tevatron.

Many of the beam dynamics issues referred to above could be ameliorated through reduction of the number of bunches. The motivation for operating with large numbers of bunches is reduction of the number of interactions per crossing at the detectors. For example, with a luminosity of 2×10^{33} $cm^{-2}sec^{-1}$ the number of interactions/crossing seen in the detectors ranges from 2.5 to 17 as the number of bunches is varied between 750 and 108. It is obvious that a dialog between accelerator and detector designers will have to take place early within the developmental period of such a facility in order to select the appropriate number of bunches.

For a luminosity upgrade of the Tevatron unaccompanied by an energy upgrade essentially all the above issues remain with the exception of those related to magnet development.

Design Issues: 30 x 30 TeV p - p Collider

Design concepts for a collider operating at an energy a factor of four beyond LHC and a factor of one-and-a-half beyond the SSC were investigated. While the energy of such a facility is only 50% higher than that planned for the SSC, it was recognized fairly quickly that the design and operational issues of such a machine would be quite different due to the enhanced role of synchrotron radiation. A proton collider operating at 30 TeV per beam, with dipole fields of 10 T or greater would represent the first hadron facility in which the role of synchrotron radiation went beyond being irrelevant, as at the Tevatron, or a nuisance, as at LHC and SSC. Radiation damping in a 30x30 TeV collider has a significant impact on the operating characteristics. Every effort must be taken to understand how best to utilize synchrotron radiation as an aid for simplifying the design of the facility.

The number one design issue in such a facility is clearly the dipole magnets. Fields of 10-15 T are required to keep the size of the ring manageable (where manageable means equal to the SSC). Quadrupoles with gradients of 250 T/m are required for the interaction regions. Achieving fields above 10 T will not be easy. It is felt that 10 T is achievable but probably represents the maximum reach of the currently employed NbTi/cosθ technology. Going past 10 T will require new technology. It is difficult to predict at the moment a rate of development for such technologies.

Synchrotron radiation damping, with damping times of 4-5 hours, is shown to have a substantial positive impact on the performance of a 30x30 TeV collider. However, one must remove the heat generated within the cold magnets. The linear heat load for the parameters described in the workshop is three times that being planned for in the LHC. As in the case of the Tevatron upgrade there is a strong coupling between relaxing the challenges to the accelerator builders at the expense of interactions per crossing seen by the experimenters. In this case fewer bunches reduces the magnitude of the synchrotron radiation heat load. For the example examined at the workshop, a luminosity of 1×10^{34} $cm^{-2}sec^{-1}$ is obtained with a bunch spacing of 100 nsec accompanied by 60 interactions/crossing.

Options for staging such a facility, e.g. starting out with lower energy or with a single ring and proton-antiproton collisions, were not examined in this study. In general one would expect the luminosity achievable to scale with energy as the energy is lowered (at a fixed circumference), and the proton-antiproton luminosity to be approximately a factor of ten lower than the proton-proton case.

Conclusions

Upgrading the Fermilab $\bar{p}$ - p collider complex to either 1×10^{33} $cm^{-2}sec^{-1}$ at 1x1 TeV, or to 2×10^{33} $cm^{-2}sec^{-1}$ at 2 x 2 TeV is an aggressive goal. Increasing the antiproton production rate by a factor of 6 beyond that anticipated following completion of the Main Injector is the key. Several ideas exist for accomplishing this, but none are mature at this stage. Further design and development work are required to generate assurance of achieving this performance. Long range beam-beam effects are likely to be important if the Tevatron were configured to run with many (>100) bunches at high ($>1\times10^{33}$) luminosity. Machine studies in the Tevatron could shed further light on this issue.

A proton-proton collider operating at $\geq$ 60 TeV in the center-of-mass, and with a luminosity of 1×10^{34} $cm^{-2}sec^{-1}$, is a reasonable goal for the next hadron facility following the LHC. The possibility of utilizing synchrotron radiation emittance damping to enhance the performance, and simplify the construction, of a next generation hadron collider looks promising enough to warrant further attention. An operating energy in the range of 25 - 40 TeV/beam would require 12.5 $\pm$ 3 T dipoles. As in all high energy hadron facilities, magnets are the key. A reinvigorated U.S. superconducting magnet R&D program will be needed to support these aims. Facility cost will clearly be a significant design consideration and needs to be integrated into thinking on even the most preliminary designs. Cost minimization through simplification of injector performance specifications, utilization of existing facilities and infrastructure, optimization of fabrication and procurement strategies, and staging all deserve considerable thought.

There is a real trade off between relaxation of accelerator parameters and increasing the number of interactions per crossing in each of these facilities. There must be a close interaction between accelerator and detector designers to identify an optimum bunch spacing.

Report on the " Workshop on Non-Linear Dynamics: Theory and Experiments", held in Arcidosso, Italy, September 4-9 1994

(Max Cornacchia, SLAC)

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A " Workshop on Non-Linear Dynamics: Theory and Experiments" was held in Arcidosso, Italy, from the 4th to the 9th of September, 1994. The Workshop was sponsored by the US Department of Energy, the University of California at Los Angeles, the Stanford Linear Accelerator Center, the National Institute for Nuclear Physics (INFN, Italy), the National Institute for Alternative Energy Sources (ENEA, Italy), and the Trieste Synchrotron (Italy). It attracted 65 experts on beam dynamics in particle accelerators, mathematicians of non-linear dynamics, and even an expert on planetary motion. Arcidosso is a medieval town in Southern Tuscany, close to the city of Sienna. The meeting took place in the historically evocative scenario of the 11-th century Aldobrandescan castle atop a hill dominating the nearby valley. The castle was restored in 1989, and preserves all the atmosphere and raggedness of medieval times.

The participants were presented with a choice of four groups, each addressing a particular problem. For each Group there was a Speaker, who gave the opening lecture, and a Coordinator, who led the discussions and presented a summary of the work on the last day.

The Workshop was organized in such a way as to leave as much time as possible to discussions and to minimize the number of formal plenary talks. There were four invited lectures on Monday the 5th and four summary talks in the afternoon of Friday the 9th. Contributed talks were not held and were replaced by exhibits in a Poster Room, displayed for the full duration of the meeting.

The Group on "Experimental Techniques and Observations" (Speaker: Susumu Kamada, KEK; Coordinator: Walter Scandale, CERN) was charged with discussing the broad question of "what non-linear experiments have been done and should be done to improve confidence in the performance of hadron, ion and lepton colliders ?". In his plenary lecture, Kamada gave a historical overview of the last 10 years of non-linear experiments around the accelerator laboratories. The second part of the talk described the machine modeling and non-linear dynamics experiments carried out at TRISTAN. The meetings of the Working Group covered a wide range of topics and were attended by approximately 15 participants. The general format was to have informal presentations from representatives of various laboratories to stimulate discussions. These covered a wide range of experimental techniques, from turn- by-turn monitoring of coherent oscillations following a "kick", to mapping x,y oscillations into tune spaces to identify important resonances. One of the most discussed topics was various techniques for accurately deriving oscillation frequencies using only a relatively small number of turn-by-turn position measurements, which would allow frequency domain study of the evolution of the motion and provide the means to compare with theory. Several participants contributed to this discussion. As an example of healthy cross fertilization of two different fields, I will mention a report from the "Bureau des Longitudes, Astronomie et Systemes Dynamiques". J. Laskar described a technique for determining the fundamental frequencies of a dynamical system to very high accuracy, using a relative small number of sample points. This method was introduced in the study of the stability of the solar system, where it permitted numerical estimates of the size of the chaotic zones.

The Group on "Beam-Beam and Multiparticle Effects in Storage Rings" (Speaker: Alexander Zholents; Coordinator: Robert Siemann) was asked to examine the problem of the beam-beam and space charge factors that determine luminosity and lifetime limits in storage rings. Zholents' plenary talk included a survey of the status of understanding based on the experimental evidence acquired so far. The beam-beam interaction is responsible for a) beam core blow up, b) tail production, c) lifetime reduction and background problems. Zholents remarked that the common opinion is that most of the observed effects are caused by non-linear resonances driven by the beam, and he emphasized the need for more experiments and cooperative efforts amongst the colliding beam facilities. One of the conclusions of the Working Group discussions (led by Robert Siemann, about 10 members) agreed that beam-beam effects are likely produced by non-linear single particle motion. Small errors in the magnet lattice may be important, although it is not yet clear what particular parameters (Amplitude dependent tune ? Energy dependent tune ? Driving terms of resonance ?) are the most critical. The Group recommended that more measurements of linear and non-linear optics parameters driven by magnetic non linearities be performed in colliding beam facilities. Other topics of discussions included the question of two rings and unequal energy colliders (flexibility recommended), parasitic crossing (effect varies, depending on the optics), and beams crossing at an angle (mixed results from computer simulations).

The Group on "Understanding of Non-Linear Effects and Losses" (Speaker: Ferdinand Willeke; Coordinator: John Irwin), addressed the following question: "what are the physical effects determining performance limitations in storage rings ?". In his lecture, Willeke covered the effects of non-linear fields on lifetime, emittance growth and loss of proton beams. Recent experimental results from HERA were presented. Overall, there is a good qualitative understanding of the effects which influence beam loss and emittance growth. Given the enormous complexity of the phase space dynamics in accelerators, the most visible shortcoming at the present time is the lack of appropriate averaging methods that would allow characterizing few important "global" parameters. After the three and half days of discussion, the conclusions of the Working Group were summarized by John Irwin. For lepton storage rings, the damping of oscillations requires a loss mechanism that is fast. Therefore, resonances and associated parameters (tune variation with amplitude and momentum) are still reckoned to be the most important factors. The simulation of tails has received considerable attention recently (relevant to Φ and B factories), with results that are not yet totally consistent. In proton storage rings, the effects are more subtle, involving diffusion, noise and modulation. It was shown that the beam loss rate measured at HERA (with scrapers) fits a diffusion model well. However, still in HERA, the dynamic aperture at injection, as measured by kicking the beam, is a factor of two smaller than the one computed over 20,000 turns. This is cause for concern and various hypothesis were postulated to explain the discrepancy. Irwin said that a deeper understanding of the fast loss process in 4-D phase space is needed.

The "Theoretical and Computational Techniques Group" (Speaker: Leo Michelotti, FNAL; Coordinator: Franck Schmidt, CERN) was asked to comment on the question: "what can and what cannot be calculated (and predicted) with confidence ?". Michelotti opened the topic with a talk giving a historical perspective of the search for theoretical and computational algorithms applicable to accelerator orbit dynamics from the Moser and Deprit transformations to the Lie Operators and Exponential Maps. On the subject of computer simulations , Michelotti emphasized the importance of reaching a consensus, within the community, of a general purpose computer language and programming protocol that lends itself to object-oriented programming. A suitable language, for this purpose, is C++. This Working Group consisted of about 15 people. In his summary, Schmidt said that the Group agreed that tracking is still the most reliable tool. For this reason, fast processing capability will continue to play an important role in future improvements. Maps and Normal Forms are well suited to understanding and correcting non-linear fields. The mechanism of phase space structures and its effect on particle losses has improved, but still defies a complete and clear picture, and more work is needed. In particular, a reliable theoretical model for diffusion of particles to large amplitudes is still missing. The study of the evolution of particle distributions in non-linear fields is showing good promise, and it is hoped that it will be pursued further.

International Workshop on Collective Effects in Large Hadron Colliders

Montreux, Switzerland
17-22 October 1994

E. Keil (keil@cernvm)

This workshop was attended by some 40 participants from a dozen institutes. Its goal was to review and discuss the present understanding of collective single-beam and beam-beam effects, both theoretical and experimental, from the large hadron colliders which were or are in operation. i.e. HERA, Sp$\bar{p}$S, and Tevatron, and to analyze its consequences for the design of future hadron colliders, in particular the LHC. Introductory plenary talks, describing the state of art at the beginning of the workshop were presented on beam-beam effects, and on single-beam effects.

The observations of beam-beam effects were described by J. Marriner (Fermilab) for the Tevatron, O. Brüning (DESY) for HERA, and R. Schmidt (CERN) for the Sp$\bar{p}$S. W. Herr (CERN) gave a preview of the beam-beam effects in the LHC.

Observations of single-beam effects werde presented by S. Assadi (Fermilab) for the Tevatron. Previews of single-beam effects were discussed by S. Peggs (BNL) for RHIC, and F. Ruggiero (CERN) for the LHC. J. Gareyte (CERN) summarized the LHC parameters.

Contributed talks covered a wide variety of subjects: L Vos on "Ground Motion in LEP and LHC", T. Scholz on "A TEM Resonance Based Method for Measurement of Small Beam Coupling Impedances", R. Cappi on "Higer-Order Mode Transverse Instability at 1 GeV in the PS", Y.H. Chin on "Collective Effects in the KEK B-Factory", R. Baartman on "New Criterion for Single Bunch Stability", F. Galluccio on "Head-Tail Instability in HERA", S. Peggs on "Head-Tail and Coupling Chromaticity", S. Kurrenoy on "Transverse Coupled-Bunch Instability in LHC", S. Petracca on "Debye Potentials and EM Reciprocity for Computing Beam Impedances in General Perturbed Pipes", V.P. Yakovlev on "Analysis of LHC Liner Design", K. Hirata on "Beam-Beam Collisions with a Crossing Angle", E. Chapochnikova on "Transverse Mode Coupling for Leptons in the SPS", W. Höfle on "Longitudinal Feedback in LHC". L. Palumbo on "Collective Effects in DAΦNE".

Three working groups were formed, (i) on beam-beam effects, chaired by F. Willeke (DESY), (ii) on impedances, chaired by A. Chao (SLAC), and (iii) on single-beam dynamics, chaired by S. Peggs (BNL). The three chairmen presented summaries of the conclusions of their respective working groups at the end. The proceedings of the workshop will be published as a special issue of Particle Accelerators.

An International Workshop on Single-Particle Dynamics in Large Hadron Colliders will be held in the autumn of 1995. Its goals are to review and discuss the present understanding of single-particle dynamics, both theoretical and experimental, in the large hadron colliders which were or are in operation. i.e. HERA, Sp$\bar{p}$S, and Tevatron, and to analyze its consequences for the design of future hadron colliders, in particular the LHC.

Beam Dynamics Activities at LNLS

Pedro F. Tavares[1]

LNLS - Brazilian National Synchrotron Radiation Laboratory

The main task of the LNLS Accelerator Physics Group over the past few years has been the design of an electron storage ring optimized for the production of synchrotron radiation. The design stage is essentially finished and most machine components are now in the production phase (the status of the project as a whole has been recently reviewed[1]). The table below shows the main parameters of this machine.

Energy	1.15	GeV
Injection energy	100	MeV
Nominal current	100	mA
Circunference	93.212	m
RF frequency	476	MHz
Bending Field	1.4	T
Number of bending magnets	12	
Number of quadrupoles	36	
Number of sextupoles	18	
Natural emittance (standard mode)	70.3	nmrad
Horizontal tune	5.27	
Vertical tune	2.17	
Natural bunch length	62	ps

Table 1: Main UVX parameters

The overall machine design matches the criteria for a third generation light source with a few peculiarities. Perhaps the most important one, as far as beam stability is concerned, is the fact that the injector is a 100 MeV linear accelerator, so that current accumulation must take place at low energy, where collective effects (intra-beam scattering, multi-bunch instabilities, ion-trapping) are likely to present important limitations. Note also that the nonlinear aberrations introduced by the chromaticity correction sextupoles (located in the dispersive archs) are corrected by means of sextupolar coils located inside the quadrupoles in the non-dispersive straight sections.

A major feature of this machine is its flexibility: five different operation modes have been studied , including a low-emittance (30 nm rad) mode (for applications demanding high brilliance photon beams), a low-beta mode (to provide for a small-gap insertion device, such as a mini-wiggler) and a quasi-isochronous mode, to provide very short electron bunches (down to 3 ps rms length).

All standard design issues, such as the effects of excitation, multipole and alignment errors, dynamic aperture, closed orbit correction have been analysed with analytical[2] as

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well as numerical tools (tracking codes, particularly PATPET)[3, 4]. As a result of the simulations, tolerance requirements have been set for the magnets and their power supplies as well as for the alignment system.

Standard techniques have been used to study collective effects both at injection and at the nominal energy as a means to validate the overall design (and in particular the vacuum chamber design) in terms of the maximum attainable beam current. High order modes of the RF cavity have also been studied both numerically and experimentally, and the measured/calculated parameters of these modes have been used to establish instability growth rates.

Second order effects in the longitudinal dynamics for the quasi-isochronous mode have been studied in detail[6] and the existence of an anomalous equilibrium bucket in the longitudinal phase-space has been demonstrated.

The trapping of ions (especially at injection)[5] has been studied in detail and a clearing system consisting of resistively coated ceramic electrodes has been designed. The design aims at reducing the beam coupling impedance of the (large number of) electrodes in the machine. Electrodes cover a significant fraction of the machine circumference, and are present inside the dipole vacuum chambers. Considerable effort has been devoted to the understanding of various aspects of the Physics of ion trapping[7, 8]. An experimental study was conducted in collaboration with the LPI group at CERN in the Electron Positron Accumulator. In this study, bremsstrahlung photons produced in collisions of the circulating electrons with trapped ions were used as a probe to obtain information on the composition and density of the ion cloud. The study suggests the presence of highly ionised atomic species in the EPA neutralisation pockets.

Recently a recirculation line was designed as an alternative to the proposed low-energy injection scheme[9]. The recirculation would provide a safety margin for the injection process by increasing the injection energy to 200 MeV. The optics of the recirculator was analysed in detail, with special attention to second order aberrations, which were particularly important due to space constraints (existing LINAC tunnel) imposed on the geometry of the line. The recirculating scheme is now considered as a possible future upgrade of the LNLS facility, but it should not be built for the moment.

At present the activities of the group include a close collaboration with the magnet group to assess the results of magnetic measurements as compared with the specifications obtained via simulation with the aim of defining magnet acceptance criteria. There is also collaboration with the diagnostics group in order to determine the necessities of beam diagnostics in view of commissioning. Algorithms for automated closed orbit correction are being developed in collaboration with the control group. As a pre-requisite for this and other beam dynamics related algorithms to be implemented in the control-system, a database of machine optical parameters and component characteristics is being built. Finally, a new design for the injector front-end (80 keV gun + low energy transport line) is being developed, with the aim of improving beam transport efficiency in this region.

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Beam Dynamics Study with BEPC

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As the China's first high energy accelerator project, the Beijing Electron-Positron Collider (BEPC) began in October 1984, the first beam in the storage ring was obtained by the end of 1987 with no RF power. The collision between electron and positron beams was realized in October 1988. The collider has been put into operation since the beginning of 1989. The BEijing Spectrometer (BES) was moved into the interaction region in May 1989, since then the collider has provided beams for high energy physics experiments as well as synchrotron radiation research in parasitic or dedicated mode. The maximum luminosity reaches $8 \times 10^{30} cm^{-2}s^{-1}$ at 2 GeV, with the average peak about $6 \times 10^{30} cm^{-2}s^{-1}$ for the routine operation. The exciting physics results with BES in τ/charm region and the accomplishment of synchrotron radiation application with Beijin Synchrortron Radiation Facility (BSRF) have justified our efforts on construction of BEPC. The beam dynamics studies with BEPC are concentrated on the machine performance and its future plans.

The beam dynamics group of BEPC has closely worked at the daily performance of the collider, whose 15 members, including 3-4 graduated students, joined the commissioning and operation team, most of them, as shift leaders. It is hard to take the shifts though, they learn more about the beam behaviour in the machine, and worked out its problems. The studies on the second beam injection, particle loss during ramping and squeezing, the beam lifetime reduction during collision and dedicated synchrotron radiation operations were carried out. As the results, the typical injection duration reduced from a few hours of early days to some 30 minutes, and the particle loss less than 5 %, while the machine duty factor reached more than 80 %.

To optimize the machine performance, a few task groups were formed working at the lattice and configuration study, the lattice correction study, the study on BEPC as a light source, beam transport and injection Study and application software development.

Many calculations and simulations were carried out together with the commissioning and machine experiments. Taking advantage of the flexibility of the BEPC lattice, dozens of the configurations have been worked out optimized for different beam energy and various particle intensity. Operating β^* of 8.5 cm, contrasting to 10 cm of the design value, helps the better luminosity. The study shows the high luminosity is possible with even lower β^*.

For the BEPC-size machines, the dispersion free section in the interaction region may be too short to find the right phases for skew quadrupoles. After a careful study a scheme with an additional pair of SQ's near by the symmetric points was tested. The results were in good agreement with the theoretical prediction, and the luminosity kept the same as if there were no solenoid perturbation in the ring.

One of the feature of BEPC is that the machine serves two purpose, i.e., high energy physics experiments and synchrotron radiation applications, whose requirements to beams are different, as for beam emittance just the other way around. The natural beam emittance ϵ_{x0} for collision configuration is as large as 0.66 mm·mrad for the expected luminosity, while the ϵ_{x0} for SR mode should be as small as possible to provide even brighter photon beams. Great efforts were made to reduce the emittance for the dedicated SR operation, and finally reached 0.076 mm ·mrad. The insertion devices would disturb the colliding operation especially for such a collider operating at τ/charm region, and attention has been paid to the compensation of wiggler effects.

The control system of BEPC was transplanted from SPEAR and modified to meet the BEPC requirements. The system has performed well with BEPC. In the meantime, some improvements were accomplished in order to meet the requirements of BEPC operation and future plans. In the aspects of machine physics software, including configuration control, orbit correction, beam energy calibration and others, a few new functions were introduced and proved to be useful and reliable by the operation.

The study groups on nonlinear effects, single beam phenomena, beam-beam effects work at their subjects both phenomenologically and analytically, taking advantage of the machine in operation.

The chromaticity correction sextupoles introduce the major part of the nonlinearities in storage rings. Based on the computer simulation, the effects were intensively studied. On the other hand, perturbation functions were applied to evaluate the nonlinearities and its correction and relevant formulae derived. The nonlinearities contributed from the machine imperfection was studied with a derived formula on tune spread. The nonlinear single beam and beam-beam effects are being studied together with the collective beam phenomena.

There was no serious beam instability detected in BEPC though, interesting beam phenomena have been observed and studied. The maximum single bunch currents of 85 mA were stored in the ring at the energy of 1.1 GeV. Vertical beam blow-up was observed with increasing of the beam intensity. In the multibunch case, the obtainable currents were very sensitive to the filling pattern, as well as the RF parameters. Although the maximum currents of 200 mA with 4 bunches were reached at injection energy, the phenomena have not yet well understood. The study on the coupled bunch instability is being carried on. The bunch length and its lengthening are a critical issue in the point of minimum β^* application. The bunch length was measured for various RF voltage, bunch currents and beam energies with a streak camera and a harmonic monitor, and then the scaling low for BEPC bunch lengthening was derived. To reduce the bunch length, a group of people has been working at the impedance measurement and its reduction. In the meantime, the study on the microwave instability went on and a method to avoid such an instability in storage rings by using negative momentum compaction factor was proposed.

BEPC has operated close to the beam-beam limit, in which the maximum allowable colliding beam currents are limited by the beam-beam parameters $\xi \sim 0.04$. Working points of BEPC are below integers at $\nu_x \sim 5.8$ and $\nu_y \sim 6.7$ for collision, the relation between beam-beam effects and machine tunes was investigated and scanned in the tune diagram for higher luminosity. To scale with beam energy, the experimental formulae of $I_{max} \propto E^{2.7}$ and $L_{max} \propto E^{5.2}$ were obtained. In the meantime, the coherent beam-beam tune shifts were measured and, to explain the behaviour, a theoretical model was developed.

The near future improvement of BEPC aims at its luminosity upgrading for high energy physics experiments and brightness enhancement for synchrotron radiation research. To serve the purposes, intensive beam dynamics studies were carried out.

Among the luminosity upgrading proposals, the mini-β insertion was the most promising one. Several schemes had been calculated in which one with permanent quadrupoles was adopted. As the machine was with non-full energy injection, the introduction of permanent field elements would bring a perturbation during the ramping and squeezing. Number of configurations for different beam energies were calculated and simulated before the decision was made. The most crucial factor for BEPC mini-β is the bunch length. The present bunch length around 5 cm is too long for the mini-β of 3.6 cm to be succeeded, and intensive study has been carrying on together with RF and impedance groups.

Emittance control and single interaction point collision are the other two ways to enhance the luminosity. However, the bunch currents have to be increased as well in these two schemes, which would lengthen the bunch further. Taking advantage of lattice feasibility, the beam emittance can be adjusted in a wide range, and wigglers placed in the arcs are also applied to control the emittance, whose side effects were studied. The cross angle and miscollision were detected during the single IP commissioning. To solve these problems, studies are under way.

A scheme to increase luminosity without hurting bunch length, and so mini-β, is pretzel, which was successfully used in CESR and LEP. The optics, the sextupole correction, the parasitic beam-beam effects and the multi-bunch instability were investigated for BEPC pretzel scheme with 6-7 bunches in each beam.

More insertion devices will be installed into the storage ring in order to provide more beam lines and higher flux photons. The collective effects, compensation for the wiggler perturbation, and the orbit steering are the subjects being studied.

There are advantages and disadvantages for the machine like BEPC serving two purposes of both HEP and SR. For the long term development, two individual projects in the BEPC site, i.e., a τ-charm factory and a third generation light source, were proposed. Two teams are working at the potential projects and many beam dynamics issues are involved.

Similar to other designs, the energy region of Beijing τ-charm Factory (BTCF) is chosen as 1.5~2.5 GeV. The design luminosity is 1×10^{33} and $2.2 \times 10^{32} cm^{-2} s^{-1}$ for the standard and monochromator optics respectively. Working at the beam energy of 2~2.5 GeV, the proposed Beijing Light Source (BLS) is being designed as a bright and wide band synchrotron radiation source with superconducting bending magnets in it and beam emittance lower than 10 nm·rad.

Many challenges exists with BTCF and BLS. To ensure the high quality of machine performance, the lattice must be carefully optimized, the impedance should be well controlled and the couple bunch instability needs to be studied and cured. With the experiences in construction and operation of BEPC and the worldwide collaboration in the accelerator community, our design studies for BTCF and BLS will surely be succeeded.

The results of beam dynamics studies with BEPC were incorporated in the proceedings of Workshop on BEPC Luminosity Upgrades, had been held in 1991 at IHEP, Beijing, and published in many other proceedings of national and international conferences as well as in the physics journals.

Brookhaven National Laboratory

Beam dynamics activities at BNL proceed on several fronts, with electrons protons and heavy ions. This work is naturally described under four sub-headings, with separate reporters, for each of the main BNL accelerator centers:

1. **AGS** Alternating Gradient Synchrotron (Thomas Roser[1])
2. **ATF** Accelerator Test Facility (Ilan Ben-Zvi[2])
3. **NSLS** National Synchrotron Light Source (Sam Krinsky[3])
4. **RHIC** Relativistic Heavy Ion Collider (Steve Peggs[4])

AGS, the Alternating Gradient Synchrotron

After commissioning the AGS Booster the AGS accelerator complex has served a diverse and growing number of high energy and nuclear physics experiments ranging from rare Kaon decay experiments requiring very high intensity 24 GeV slow extracted proton beam to the study of Gold on Gold collisions at about 11 GeV per nucleon. The two modes of operation, high intensity proton operation and heavy ion operation, probe quite different areas of beam dynamics although there is some overlap. Recently polarized proton beams have again been accelerated at the AGS to an energy of about 11 GeV. This time a partial Siberian Snake was used to avoid depolarization from the numerous imperfection spin resonances.

High Intensity Issues

A long term effort to increase the proton beam intensity has recently culminated in a circulating beam intensity of 4×10^{13} protons at the current AGS extraction energy of 24 GeV. The maximum intensity reached in the AGS Booster is 1.7×10^{13} protons at 1.5 GeV. The incoherent space charge tune shift in the Booster is about 0.4 and therefore required an extensive effort to study and correct many half-integer and third integer stopbands. Even so the vacuum chambers in the Booster are equipped with external windings that are driven by the emf voltage picked up from the dipole pole-pieces and compensate almost completely the multipoles from the eddy currents in the vacuum chambers, correction coefficients proportional to the remanent field, the ramping field and the field change had to be measured and corrections were implemented for each of a total of 8 stopband lines. Although mostly complete this effort is still continuing and is conducted in collaboration with KEK [1].

Four Booster cycles are accumulated in the AGS making it necessary to store the high intensity proton bunches for up to 0.5 s at the relatively low energy of 1.5 GeV. To reduce the space charge tune shift and maintain beam stability the bunches are made long in two steps. First in the Booster, just before transfer, a coherent quadrupole mode is driven and the bunches are transferred when they are the longest. This technique allows bunch shape manipulation in the moving bucket at high rf voltage. Second, by injecting the bunches

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off-center into the AGS buckets they are made even longer. With the phase loop open, a coherent dipole synchrotron oscillation is begun. As was shown by Cappi et al [2], in the presence of an additional voltage with a high harmonic number the bunch filamentation process leads to a smooth and flattopped bunch profile [3].

To accelerate the high intensity proton bunches a new AGS rf system with the final power amplifiers coupled directly to the 10 cavities and "fast feedback" loops was installed and a transition energy jump system was implemented. Both systems were essential for reaching the record intensity of 4×10^{13} protons-per-pulse. However, using the jump puts constraints on the maximum longitudinal beam emittance because the jump process increases the machine dispersion five times. Future increases in the beam intensity will require a continuing effort to maintain beam stability without increasing the longitudinal emittance using longitudinal and transverse dampers.

Heavy Ion Acceleration

1994 was the third year that Gold beams have been accelerated to about 11 GeV/nucleon at the AGS. The Gold beam is used for fixed target experiments to study relativistic heavy ion collisions. In the future Gold beams will be accelerated in RHIC to 100 GeV/nucleon to study Gold on Gold collisions at a center-of-mass energy of 200 GeV/nucleon. The collider program, in particular, requires high intensity and low beam emittances. The acceleration of Gold beams has been made possible by the completion of the AGS Booster with its ultra-high vacuum ($\sim 2 \times 10^{-11}\, Torr$) that allows the acceleration of only partially stripped Gold ions.

The sequence of acceleration and stripping is being optimized for highest beam intensity and lowest beam loss from charge exchange processes with the residual gas. As part of this effort a Gold beam with only 15 electrons stripped off was accelerated in the Booster during this years heavy ion run. An unexpected, strongly intensity dependent beam loss was measured for which as yet no explanation was found. In the future a Gold beam with a higher charge state will be used to meet the beam requirements for RHIC. So far a circulating beam intensity of 3×10^8 Gold ions was reached in the AGS [4].

Polarized Proton Acceleration

During acceleration of polarized protons in the AGS, the beam spin polarization is partially lost when the spin precession frequency passes through depolarizing resonances. These resonances occur when the number of spin precessions per revolution $G\gamma$ ($G = 1.793$ is the anomalous magnetic moment of the proton, $\gamma = E/m$) is equal to an integer (imperfection resonances) or equal to $kP \pm \nu_y$ (intrinsic resonances). Here $P = 12$ is the superperiodicity of the AGS, $\nu_y = 8.8$ is the typical vertical betatron tune and k is an integer. The depolarization is caused by the small horizontal magnetic fields present in all ring accelerators which, at the resonance condition, act coherently to move the spin away from the stable vertical direction. Traditionally, the depolarizing resonances in the AGS were corrected by the tedious harmonic correction method for the imperfection resonances and the tune jump method for the intrinsic resonances.

The experiment E-880 at the AGS, a collaboration of Indiana, BNL, ANL, KEK and TRUIMF, has recently demonstrated the feasibility of polarized proton acceleration using a local 9° solenoidal spin rotator, also called a 5% partial Siberian Snake in reference to a full

Siberian Snake, which rotates the spin by 180°. A polarized proton beam was accelerated to about 11 GeV with no observable depolarization from passing through 18 imperfection resonances [5]. The depolarization was limited to the 3 intrinsic resonances which, in the future, can be overcome with the proven tune jump method. At an energy of 25 GeV, the polarized protons will be transferred to RHIC, opening up the possibility for a 250 GeV on 250 GeV polarized proton collider.

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ATF, the Accelerator Test Facility

Most of the beam dynamics activities at the Brookhaven National Laboratory Accelerator test Facility (ATF) have to do with the development of photoinjectors. The ATF guns operate at 2856 MHz and mostly they are of the two cell variety. Theoretical and experimental work are combined in order to improve the brightness of these devices as well as the cost, cathode quantum efficiency and lifetime.

Experimental Work

The details of the experimental work has been contributed by X.J. Wang. Other participants in the experiments at the ATF are K. Batchelor, I. Ben-Zvi, D. Palmer and X. Qiu.

- **Experimental measurement of higher order effects in the RF gun** A series of experiments has been undertaken designed to measure the dipole mode caused by the waveguide and RF gun cavity coupling slot. The dipole mode effect will cause the beam steering and beam profile modification. This can be studies in the ATF in-line injection system by varying the laser beam profile.

- **Flat beam production and transportation** This research initiative is done in collaboration with R. Miller of SLAC. The goal is to investigate flat beam production from photocathode RF gun. The motivation is the application in linear collider. Initially we are planning to produce a flat beam with beam aspect ratio 5 from a symmetric RF gun with a quadrupole magnets transport line.

- **Short Beam production** The ATF Nd:Yag laser has a FWHM of 10 ps, there are several experiments require short electron beam pulse (by factor 2). We are now investigating several techniques to produce short electron pulse, such as pulse compression in the RF gun and magnetic pulse compression.

Modeling of the Brookhaven ATF High-Brightness Inline-Injection System

The modeling work of the inline injection system of the ATF has been done by J. Gallardo and H. Kirk, and is reported by H. Kirk.

The purpose of this work has been to investigate the performance of the emittance correction scheme that was incorporated into the injection system of the ATF. The studies have been carried out by modeling the injection system with the $2\frac{1}{2}$ -d simulation code PARMELA [1]. The optimization procedure incorporates three main elements of the system: an rf-photocathode gun, a solenoid pair and the linac sections. Previous results from this analysis have already been reported [2].

A bright beam at the exit of an RF gun does not assure an equivalent beam at the final focus of an experiment. The transport of the beam in conjunction with space-charge forces must be an integral part of the study. A principal cause of emittance dilution in a low-energy section is space-charge forces; however, the interplay of space-charge forces with solenoidal forces [3] can lead to a reduction of the transverse emittance inside the linac.

Results

We have examined the applicability of Carlson's emittance correction scheme at higher frequencies and launch acceleration gradients than have been previously considered. The Brookhaven Accelerator Test Facility (ATF) currently constists of a $1\frac{1}{2}$ cell S-band rf gun capable of accelerating gradients in excess of 100 MV/m. The injector is followed by two linac sections each of which can boost the electron bunches to energies of up to 35 MeV. We have explored possible launch parameter space using the computer code PARMELA. Our initial results have shown that the correction of space-charge induced emittance growth is indeed possible. Figure 1 shows an example of a solution incorporating parameter values well within reach of the ATF rf system.

This result confirms that the emittance compensation technique works when applied to an S-band gun operating with peak axial electric fields at 100 MV/m.

We have pursued this result further by obtaining the minimum transverse emittances achievable when operating the rf gun with different accelerating gradients. The results of this analysis is shown in Fig. 2. The strong upturn of emittance at lower accelerating gradients implies that it is advantageous to apply high accelerating gradients at the electron source. These high gradients reduce the development of emittance growth but do not seriously detract from the ability to compensate for the emittance growth that does occur. The upturn in emittance at high accelerating gradients is due to the growing dominance of rf dynamical forces at the gun apertures.

We conclude that technique of compensation of emittance growth due to the presence of space-charge forces works well for an S-band $1\frac{1}{2}$-cell RF gun operating at field accelerating gradients up to 160 MV/m.

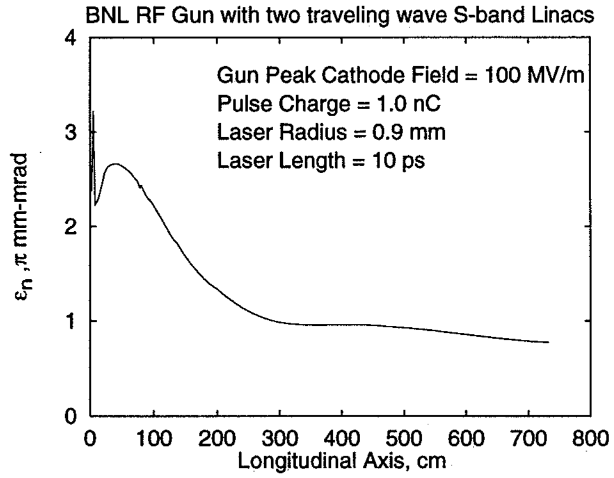

Figure 1: Invariant transverse emittance ϵ_n vs. distance z; the plane of the photocathode is 62 cm from the linac entrance.

Wake-Field Effects (reported by J. Gallardo)

An intense pulse of electrons traveling down a linear accelerator, interacts with the linac structure (non-perfect conducting walls, change of radius of the beam pipe at irises and apertures) and generate electromagnetic fields known as wake fields which are left behind [4,5,6]. If the beam current is high, the wake fields are strong and consequently have the potential to significantly affect the particle distribution and the emittance of the beam may grow. This deterioration of the beam quality will decrease the high brightness of the beam and compromise the performance of any one of the applications (short wavelength Fels or linear colliders) for the electron beam. In particular this effect may impose an important constraint on the shortest wavelength achievable with an FEL, as $\epsilon_{x,y} \leq 2\pi\lambda$.

The wake field generated by the head of the beam can be decompose into several components each producing different dynamical effects on the the tail of the beam: a) the monopole component or longitudinal wake field consists of longitudinal electric fields which are uniform across the cross section of the beam pipe but are function of the beam longitudinal variable η. This component give rise to an energy variation or energy spread within the length of the pulse ; b) dipole component or transverse wake field, generated by an off axis motion which deflects the tail of the bunch in the same direction of the displacement of the head; c) quadrupole component cause by a pulse having a transverse spatial distribution that is not axial symmetric. The effect of this component is to change the transverse distribution of the tail without affecting the center and head of the pulse for a properly centered beam.

It is also well known that the longitudinal wake field effects can be minimized by adjusting the position of the pulse respect to the phase of the RF in the linac and the transverse wake fields can be, in principle, eliminated by proper alignment of the linac and very accurate beam injection. The quadrupole component is much smaller than the other two components and therefore will be ignored; however, we notice that this component cannot be compensated even if perfectly centered, if the charge distribution in the beam is not cylindrically symmetric.

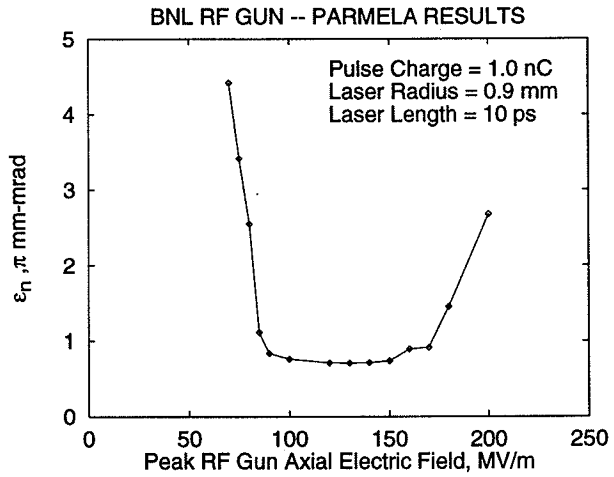

Figure 2: Invariant transverse emittance ϵ_n vs. the cathode peak electric field; the plane of the photocathode is 62 cm from the linac entrance.

Numerical Results

We have modified the code Parmela to include the effects of wake fields in the dynamics of the electrons. The new subroutine reads the average wake field potentials for SLAC-type linac [7], compute an spline interpolation and save the result for later use; as the particles cross the end of the traveling wave cell, wake field forces are applied according to a simple impulse approximation.

The monopole wake field $W_0(\eta_i - \eta_k)$ changes the energy of the particles as follows, $\Delta T_k = -L\sum_{i=1}^{k-1} W_0(\eta_i - \eta_k)$, where ΔT_k is the change of kinetic energy of the examined k-th particle, L is the length of the cell and the sum is over all the particles ahead of the examined k-th one.

The dipole wake field $W_1(\eta_i - \eta_k)$ causes deflection for a misaligned beam, and is given by, $\Delta x'_k = (r_e L/\gamma_k)\sum_{i=1}^{k-1} W_1(\eta_i - \eta_k)x_i$, where the notation is the same as before and r_e is the electron classical radius, γ_k is the normalized energy of the examined k-th particle and x_i is the transverse displacement of each one of the particles ahead of the examined k-th one.

The result of the simulations are shown in Fig.3; there it is shown, for a 1 nC beam, the transverse emittance versus z for several displacement and injection angles of the beam at the entrance of the linac. We observe a deterioration of the emittance close to a factor of 2 respect to the best value quoted above for a maximum displacement of 1mm. Assuming an alignment tolerance of 0.5 mm we expect a final emittance $\epsilon_n \approx 1.4$ mm-mrad.

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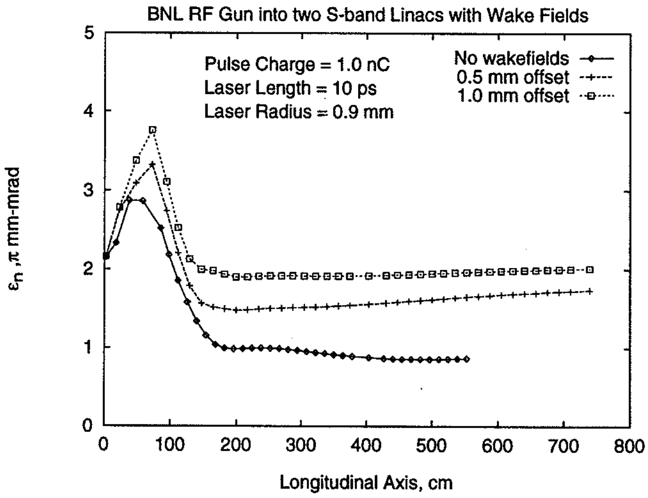

Figure 3: Invariant transverse emittance ϵ_n vs. distance z, displaying the effects of wakefields.

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NSLS, the National Synchrotron Light Source

There is an active program of accelerator physics at the NSLS aimed at improving the reliability, stability and brightness of the synchrotron radiation sources. Subjects of interest include: orbit measurement and control; lattice modeling; reduction of vertical emittance; phenomena limiting injection to high current; operation of a fourth harmonic bunch lengthening RF cavity to increase lifetime on VUV-Ring; and development of novel insertion devices. Recently, on the X ray Ring we have successfully operated a small gap undulator with a full vertical beam aperture of only 3.8 mm, with no degradation of beam lifetime. This provides strong support for the belief that small gap, short period devices will play an important role in the future. We are now installing an elliptically polarized wiggler built in collaboration with Argonne National Laboratory and BINP in Novosibirsk. This device has a vertical wiggler field produced by permanent magnets and a horizontal wiggler field produced by electric coils capable of AC operation up to 100 Hz, providing the possibility of achieving time dependent circular polarization.

Orbit Stability

Of major importance has been the improvement of the orbit stability of both the X Ray and VUV storage rings. New RF receivers designed by Jack Bittner [1] for the beam position monitors (capacitively coupled pick-up electrodes) were developed, yielding high precision orbit measurements with a low noise level of 5 microns in a 300 Hz bandwidth. The design of the receivers provides orbit position measurements independent of electron beam intensity. Ongoing development work [2] is aimed at further increasing the dynamic range of the receivers.

A group led by Li Hua Yu at the NSLS developed the first global orbit feedback systems. [3] These systems are very successful [4] and reduce orbit variations below 30 Hz by a factor of 5 to 10 from ambient values. Recent work on orbit correction algorithms by Eva Bozoki, Aharon Friedman [5] and Yong Tang [6] has allowed significant improvement in the initial placement of the electron beam at the beginning of a fill. Work is now proceeding on the design of a digital global orbit feedback system. [7] On the X Ray Ring we also have local orbit feedback systems for each of the insertion devices, providing an improvement in orbit stability below 30 Hz over the global system results by an additional factor of 5-10. Recent developments by Om Singh have provided a decoupling of the local and global systems making them insensitive to orbit glitches, which in the past occasionally resulted in the feedback systems going into oscillation.

Brightness Enhancement

In the X Ray ring we are working toward increasing the source brightness by an order of magnitude. [8] The increase of brightness will be achieved by increasing the current from 250 ma to 440 ma and reducing the vertical emittance from 1 nm down to 0.2 nm. In December 1992, the RF group installed an additional RF cavity in the X Ray Ring [9], increasing the total number of cavities to four. Under Manny Thomas' guidance a new RF amplifier chain was added to drive this cavity. Together with Norman Fewell and Richard Heese, the RF group then was able to increase the stored current to 440 ma at 2.58 GeV, with the insertion devices turned off (500 ma has been achieved at 2.50 GeV). We are now working to provide the protection of the vacuum chamber necessary to allow operation at the increased current with the insertion devices operating. Through the work of James Safranek [8], a lower emittance of 0.2 nm has been achieved. When we increase the current, we will be able to move to an operational schedule with only one injection per day.

Thinking further into the future, Eric Blum [10] has shown that B factory technology could be used to obtain an order or magnitude more flux by increasing the X Ray Ring current to 2.4 Amp and the energy to 3 GeV. Of course such an upgrade would require a major modification to the facility and a significant shutdown. The major changes to the storage ring would be a higher frequency RF system and a copper vacuum chamber. The development of high flux x-ray optics would be an important component of this upgrade. To assure rapid filling and minimize thermal cycling of beamline optics, a full energy injector would be constructed.

Lattice Modeling

The high precision orbit measurement system has made possible very accurate determination of the response matrix between excitation of closed orbit correction dipoles and orbit deviation at the position monitors. James Safranek [11] has used this data to obtain a model of the X Ray Ring lattice. His fitting procedure determines individual quadrupole strengths, calibration factors of correction dipoles and position monitors, and of course, the betatron functions and dispersion. He is now extending this work to include horizontal-vertical coupling.

R&D Straight Section X13

Development programs for two new insertion devices are underway utilizing the R&D straight section X13: a small gap undulator [12] and an elliptically polarized wiggler. [13] The small-gap undulator built by George Rakowsky is situated at the center of a low-beta insertion, where the electron beam is focussed down to a very small size ($\sigma_y = 7$ microns). Utilizing a variable gap vacuum chamber designed by Peter Stefan we have been able to operate [14] with a 7 mm magnet gap and a vertical beam aperture of only 3.8 mm, with no loss of lifetime at an electron current of 300 ma. The undulator has a period length of 16 mm and is comprised of twenty periods. Operating with K = 0.7, it produces a very high brightness beam [10(17) ph/sec, mm(2), mrad(2), 0.1% bandwidth] from the first harmonic at 3 KeV, and copious X Rays at 9 KeV from the third harmonic. Details of the small gap undulator experiment will be published in the near future. [14] Our results indicate that the vertical beam aperture can be reduced below the present hardware limit of 3.8 mm before the lifetime will be reduced. This raises the possibility of operating an undulator with a period length of 8 mm and a K value near unity, by utilizing an in- vacuum type undulator such as that developed by Yamamoto et al. [15]

The elliptically polarized wiggler [16], analyzed by Aharon Friedman [13], has been built in collaboration with Argonne and BINP in Novosibirsk. The vertical wiggler field is produced by a hybrid permanent magnet and the horizontal field by an electromagnet capable of either AC or DC operation. In AC operation, the device will produce radiation with an oscillating circular polarized component. Installation is now underway.

Bunch Lengthening Cavity in VUV Ring

In the VUV Ring the electron beam lifetime has been extended by utilizing a fourth harmonic RF cavity operating at 211 MHz to lengthen the bunches. This cavity has been in operation for several years in a passive mode [17] whereby the field induced in the cavity by the electron beam acts back on the bunch in such a manner as to lengthen it. In this passive mode of operation, conditions for optimum bunch lengthening only occur at a single current. Recently, Richard Biscardi [18] has successfully driven the harmonic cavity by an external transmitter providing increased bunch lengthening over the full range of operating currents. This active mode of operation provides longer lifetime, and a more constant longitudinal bunch profile versus current than does the passive operation. Normal VUV ring operations are now carried out with the 211 MHz cavity powered. Bunch length monitoring under development by Steve Kramer [19], will be an important diagnostic for the harmonic cavity operation.

In the future, increasing the operating energy of the VUV Ring from 750 to 850 MeV may prove advantageous, providing an increase in lifetime and a hardening of the spectrum. Also, the idea of providing a top-off mode of operation continues to be of interest. Steve Kramer, Manager of the VUV Ring, is leading the analysis of these possibilities.

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RHIC, the Relativistic Heavy Ion Collider

Superconducting magnets are now arriving at their full industrial production rate, and are being installed in the RHIC tunnel. Normal conducting magnets in the 600 meter AGS-to-RHIC transfer line will transport beam for the first time in September 1995. Transport through one sextant of superconducting magnets is scheduled for fall 1996, and circulating beam is expected in 1999.

Collective Effects

Many authors contributed to the recent report "Collective Instabilities in RHIC" [1], which is a comprehensive survey of beam impedance sources and instability mechanisms in RHIC. The report identifies fast kicker impedance reduction, and transverse mode coupling calculations, as important topics in which the "state of the art" bears improvement.

Extensive bench measurements and calculations of the fast injection kicker performance are in progress, examining both electrical and beam impedance characteristics. It is probable that the cylindrical ceramic vacuum chamber in each kicker module will have an internal Titanium coating approximately 0.25μm thick. This lowers the broadband impedance at frequencies below 1 GHz, and strongly suppresses a couple of quite narrow resonances in the 1.5 GHz to 3.0 GHz range. The kicker risetime is marginally degraded.

Standard transverse mode coupling calculations do not yet properly incorporate the (good and bad) effects of space charge interactions, which are important at injection into RHIC. This was one of the topics of discussion at the recent "LHC Collective Effects Workshop" (Montreux), since the SPS and RHIC are in very similar parameter regimes. Although there is reason to believe that transverse mode coupling will NOT in general be a problem for RHIC, we are very interested in the continuing developments on this front at the SPS.

In part as a response to transverse mode coupling uncertainties, development of the time domain instability simulation code KRAKEN has begun. One of the goals of this program is to incorporate a fully realistic model of RHIC wake fields, as contained in a comprehensive SYBASE database that is briefly described in "Collective Instabilities in RHIC". More modest goals include, for example, confirmation that the resistive wall wake field is not a destructive head-tail source (with RHIC parameters), and investigation of the effects of momentum dependent betatron coupling (see below).

Polarised Protons

More attention is being paid to proton spin dynamics in RHIC, now that the probability of a strong external contribution to the polarisation funding has significantly increased. The nominal plan includes 2 Siberian snakes and 4 spin rotators in each RHIC ring. Each of the 12 devices will be constructed from 4 helical dipole modules, 2.4 meters long, with a maximum field of about 4 Tesla. The field in each "helix" rotates smoothly through 2π radians. Some of the wire wound helices are left handed, and some are right handed. A half-length prototype helix is nearing completion at BNL.

One "feature" of an ideal helix is that the reference orbit experiences both solenoidal and skew quadrupole fields [2]. This raises the fear that the snakes, which are on at full strength at injection, might have a very large betatron coupling effect. Until recently, no analytical expression for the 4 x 4 transfer matrix expanded about a generally displaced reference orbit was available [3]. However, there is now reasonable agreement between 2 numerical approaches and 1 analytical approach, in that betatron coupling effects are small enough to be negligible [4]. Work continues.

A major goal in the spin studies is the ability to track particles for about a second or two (real time) up the RHIC acceleration ramp, in order to study the effects of crossing an intrinsic resonance. A concurrent goal is to ensure that the helices do not unduly perturb the non-spin dynamics - for example, through reference orbit displacements of 2 to 3 cm in the snakes. We are currently evaluating the code TEASPOON as the prime contender for this task. TEASPOON is an officially maintained variant of the TEAPOT code which includes spin dynamics. Ideally these studies will use RHIC92.0.4, the official and detailed description of RHIC lattice that is maintained on an (almost) daily basis. TEASPOON has the advantage of understanding one of the many input file dialects that can be generated from the SYBASE database containing RHIC92.0.4 .

Mapping Techniques

A Siberian snake is a good example of a complex object that is conveniently described by a high order Taylor map. Another example is the AGS combined function C magnet fringe field, through which RHIC extracted beam must pass. In either case motion must be integrated through a complicated field model. Development of a Differential Algebra Runge-Kutte integrator that uses the PAC++ environment is making rapid progress. Initially this will generate maps for a helical dipole (and hence for a snake or a spin rotator), but it will be relatively straightforward to extend the integrator to accept more general field models. The primary goal in this "single device map" effort is to perform non-spin tracking using TEAPOT. To this end, TEAPOT must be persuaded to accept Taylor maps presented to it in a standard form.

At the other end of the spectrum, a "one turn map" can be used to track particles around RHIC. One turn maps have historically been mostly used for long time (dynamic aperture) tracking. At RHIC we are much more interested in short time scale (linear aperture) tracking studies in which many particles are tracked on a grid of initial amplitudes inside the "good field" aperture for only a few hundred turns. This enables us to answer "what if .." questions much more flexibly and rapidly than is possible using element-by-element tracking. Figure ?? compares the horizontal smear that is found with element-by-element tracking by TEAPOT (top), and with seventh order map tracking by MTPOT (bottom), in typical RHIC storage conditions. Agreement is good most of the way to the dynamic aperture, where the map representation is inaccurate.

The Coupling Chromaticity

Even if an accelerator is perfectly decoupled on momentum, so that the minimum tune split $\Delta Q_{min} = 0$, particles with a non-zero off momentum parameter $\delta = \Delta p/p$ may not be so fortunate. For example, if the ideal horizontal and vertical tunes and chromaticities are set to be equal, the tune separation is given to first order in δ by

$$\Delta Q = |\mathbf{q} + \mathbf{k}\delta| \tag{1}$$

where $\mathbf{q}$ and $\mathbf{k}$ are two dimensional vectors. The length of $\mathbf{q}$ is minimised by adjusting two (or more) skew quadrupole family circuits. The "coupling chromaticity" vector $\mathbf{k}$ is zero in an error free machine, but in practice has a finite length that comes from chromatic feeddown, due to horizontal dispersion in skew sextupoles or vertical dispersion in erect sextupoles. When $\mathbf{k}$ is of order one or larger, and the tunes are close together, the conditions for head-tail stability are significantly modified. The length of $\mathbf{k}$ has been measured at the Tevatron, CESR, and (by simulation) in RHIC, yielding values of 3.8, 0.5 and 2.1, respectively. Operational consequences have been observed in the Tevatron [5]. Implications for RHIC are under active study.

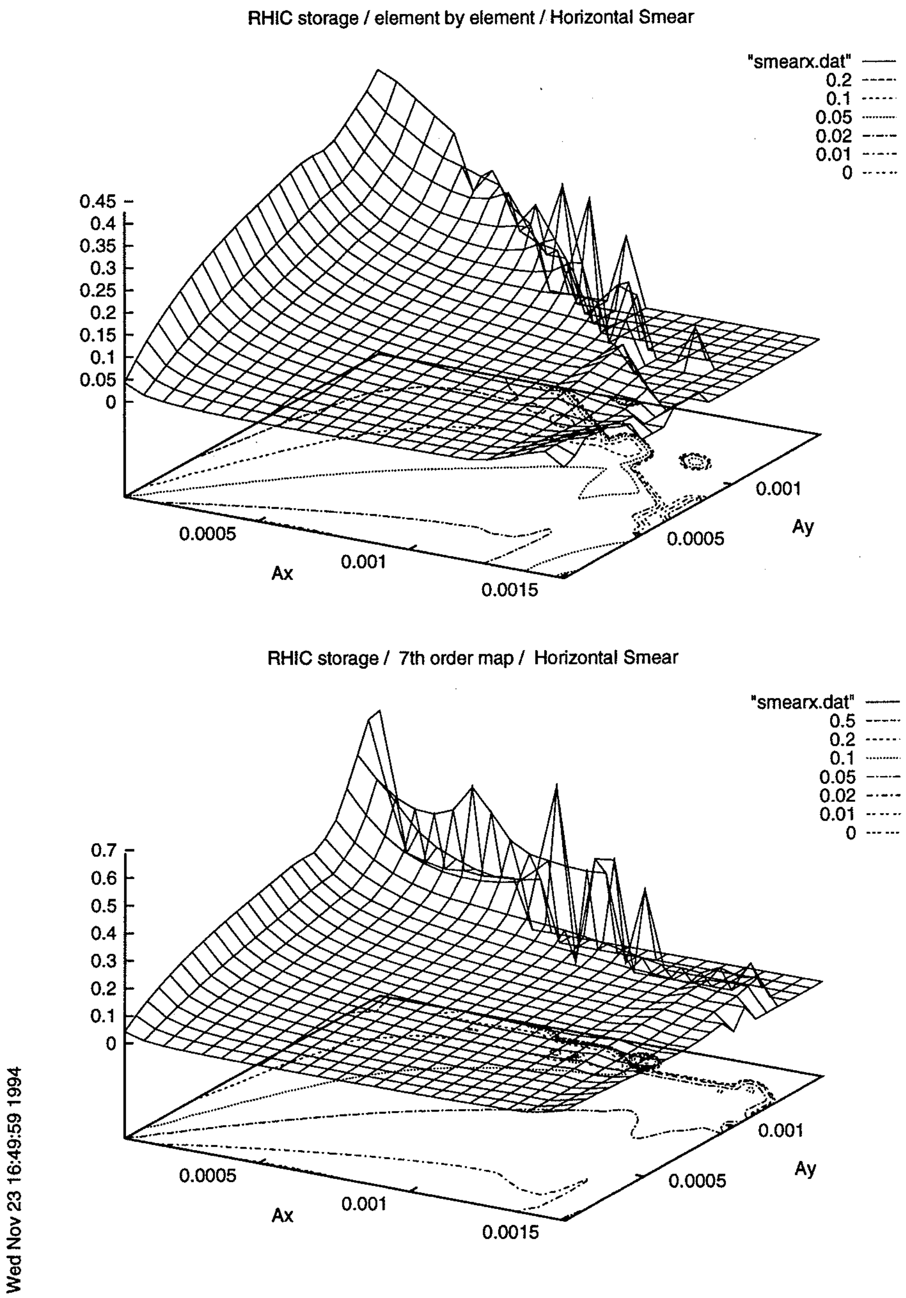

Figure 4: Horizontal smear by element-by-element tracking (top), and by a 7th order map (bottom). About 600 particles are tracked for 256 turns.

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announcement of the beam dynamics panel

Seventh Advanced ICFA Beam Dynamics Workshop

Beam-Beam Issues for Multibunch, High-Luminosity Colliders

18-20 May 1995

Joint Institute for Nuclear Research, Dubna, Russia

The International Committee for Future Accelerators (ICFA) Beam Dynamics Panel and Joint Institute for Nuclear Research will hold a workshop on beam-beam issues for multibunch colliders.

To increase the luminosity in colliders new ideas are under discussion presently. Finite crossing angle scheme now is considered as an option of several projects of new colliders (Phi, Tau-Charm and B Factories). There is a big interest to the experimental studies of the crossing angle collisions at CESR. This Workshop is planned to discuss specially physical and technical aspects of crossing angle schemes, present experimental experience, details of realization. Finite crossing angle with and without crab cavities, technical beam-beam tail, new ideas for high luminosity performance (monochromatic collision etc.) will be the subjects for discussion. Current limitations are also of a strong interest.

A planned number of participants is of 60. A plenary sessions will be along with small working group discussions. Contributions and conclusions of the workshop will be published in proceedings.

International Organizing Committee: A.Ando, V.Balbekov, K.Hirata, A.Hofmann, C.S. Hsue, J.L. Laclare, A.Lebedev, S.Y.Lee, L.Palumbo, C.Pellegrini, E.Perelstein, D.Pestrikov, R.Siemann, F.Willeke, C.Zhang

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Organization: Workshop will be at International Conference Building, JINR, Dubna. Dubna is approximately 100 km from Moscow International airport Sheremetjevo. The accommodation will be at hotel "Dubna". Workshop will be sponsored by JINR.

Requests for general information on the Workshop should be directed to:
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