Contents

What's New in ICFA Beam Dynamics Panel

Kohji Hirata, chairman (hirata@kekvax.kek.jp)

Introductions to the activity of the panel have been given in the previous two issues. On 17 May 1995, we had a panel meeting in Dubna, Moscow. Here, I will report some of the new decisions made then.

Newsletter

- It is decided that it will be published every 4 months, April, August and December.
- New genre of articles is approved: "review of beam dynamics problems".
  - This is a place to put forward unsolved problems and not to be used as the achievement report.
  - Thus the priority should not be claimed. Only the real writer(s) should show name(s). Acknowledgment is discouraged.
  - It should not be distributed as a lab-report.
  - Clear and short highlights on the problem is encouraged.
  - It is by invitation only.
- The home page of WWW for the Beam Dynamics panel is opened in DESY library home page. The most recent issue of the Newsletter and the list of future workshops/meetings will be shown.

  WWW file address is "HTCP://info.desy.de.library.bdnl0495.ps".

Working Groups in the Panel It was decided to create working groups in the panel. The creation of the working groups is the official appeal of the panel on the special importance and urgency of the subjects for the accelerator science society. The working groups, their leader and their missions are as follows:

- new acceleration schemes (Pellegrini is the leader): its mission is to promote the beam dynamics study on possible and realistic acceleration schemes for future very high energy accelerators by inter-laboratory and international collaborations.

- future light source (Laclare is the leader): its mission is to promote the beam dynamics study of possible and realistic schemes for future advanced light sources by inter-laboratory and international collaborations.

- tau-charm factory (Perelstein is the leader): its mission is to encourage the construction of at least one tau-charm factory in the world by promoting studies of related beam dynamics problems and investigating optimized machine designs.

Proceedings of the previous Advanced ICFA Beam Dynamics Workshops We have had seven workshops. In the panel meeting, it was discussed that we should show how to obtain their proceedings.

1. *Proceedings of the ICFA workshop on Low Emittance e^+e^- Beams; Brookhaven National Laboratory; March 20-25, 1987*, J. B. Murphy and C. Pellegrini, Eds., BNL 52090, UC-28, [Particle Accelerators and High Voltage Machines -TIC-4500],1987.

2. *Second Advanced ICFA Beam Dynamics Workshop on Aperture-Related Limitations of the Performance and Beam Lifetime in Storage Rings; Lugano, Switzerland; 11-16 April 1988*, J. Hagel and E. Keil, Eds., CERN 88-04, 29 July 1988.

3. *Third Advanced ICFA Beam Dynamics Workshop on Beam-Beam Effects in Circular Colliders; Akademgorodok, Novosibirsk, 29 May - 3 June 1988*, I. Koop and G. Tumaikin, Eds., Institute of Nuclear Physics, Siberian Division of the USSR Academy of Sciences 1990.

4. *Fourth Advanced ICFA Beam Dynamics Workshop on Collective Effects in Short Bunches; KEK, Japan, 24-29 September 1990*, K. Hirata and T. Suzuki, Eds., KEK Report 90-21 February 1991 A, 1991.

5. *Advanced Beam Dynamics Workshop on Effects of Errors in Accelerators, their Diagnosis and Corrections; Corpus Christi, TX 1991*, A. Chao, Ed., Conference Proceedings no.225; Particles and Fields series 48; American Institute of Physics, 1992.

6. *Synchro-Betatron Resonances*, in preparation and will be published from Madeira university.

7. *Beam-Beam Issues for Multibunch, High-Luminosity Colliders* , will be published as a J.I.N.R. Report.

Panel Members

Ainosuke Ando	SPRING8	ando@sp8sun.spring8.or.jp
V.I.Balbekov	IHEP(Protovino)	balbekov@balbekov.IHEP.SU
Kohji Hirata	KEK	hirata@kekvax.kek.jp
Albert Hofmann	CERN	albert@cernvm.cern.ch
Chen-Shiung Hsue	SRRC	hsue@phys.nthu.edu.tw
Jean-Louis Laclare	ESRF	bouvet@esrf.fr
Andrei N. Lebedev	LPI	anlebede@npad.fian.msk.su
S.Y.Lee	Indiana Univ.	lee@iucf.indiana.edu
Luigi Palumbo	INFN-LNF	lpalumbo@vaxlnf.lnf.infn.it
Claudio Pellegrini	UCLA	claudio@vesta.physics.ucla.edu
Elcuno A. Perelstein	JINR	perel@ljap12.jinr.dubna.su
Dmitri Pestrikov	BINP	pestrikov@inp.nsk.su
Robert H.Siemann	SLAC	siemann@aew1.slac.stanford.edu
Ferdinand Willeke	DESY	mpywke@dsyibm.desy.de
Chuang Zhang	IHEP(Beijin)	zhangc@bepc3.ihep.ac.cn

REPORT ON THE SEVENTH ADVANCED BEAM DYNAMICS WORKSHOP ON BEAM - BEAM ISSUES FOR MULTIBUNCH, HIGH - LUMINOSITY CIRCULAR COLLIDERS

E. Perelstein, (PEREL@NUSUN.JINR. DUBNA.SU)
Joint Institute for Nuclear Research

1 SUMMARY

The International Committee for Future Accelerators (ICFA Beam Dynamics Panel) and the Joint Institute for Nuclear Research held a workshop on beam- beam issues for multibunch, high- luminosity circular colliders in Dubna, Russia, May 18-20, 1995 which was attended by 39 participants. The goal of the workshop was to discuss the current understanding of limitations due to beam-beam and conventional instabilities on the performance of the future multibunch, high-luminosity colliders (like Phi-, Tau-Charm and B-Factories). A plenary sessions was followed by working group discussions. Contributions of participants and conclusions of the workshop will be published in the workshop Proceedings.

2 PROGRAM

The workshop was planned and held by

The International Advisory 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

The Organizing Committee:
A.N. Sissakian (Chairman), E. Perelstein (Vice-Chairman), D. Pestrikov, A. Romanov, P. Beloshitsky (scientific secretary)

The Program Committee:
B. Chirikov, N. Dikansky, J.Le Duff, K. Hirata, J. Jowett, E. Keil, K. Oide, D. Pestrikov, A. Piwinski, D. Rice, P. Zenkevich

The workshop supported a plenary session and three working groups:
I. Beam-Beam Instability with Crossing Angle (chair T. Cheng);
II. Multibunch Head-on Beam-Beam Effects (chair V. Balbekov);
III. Multibunch Beam-Beam Manipulations (chair E. Perelstein).

2.1 plenary session

1. A. Sissakian JINR Opening Remarks

2. K. Hirata ICFA Opening Remarks
3. A. Piwinski, DESY Beam-beam observation and its analysis with DORIS
4. H. Burkhardt, CERN Beam Lifetime and Beam-Beam Tails in LEP
5. K. Hirata, KEK Crossing angle issues in KEKB
6. M. Furman, A. Zholents, LBL Parasitic Collisions in PEP-II
7. J. Welch, CESR Crossing Angle Experiment and its Analysis at CESR
8. Y. Shatunov, BINP Beam-Beam Issues in BINP Electron-Positron Factories
9. V. Parkhomchuk, BINP C-Tau Factory at Novosibirsk
10. E. Perelstein, JINR Tau-Charm Factory at JINR
11. S. Ivanov, IHEP Recent and Ongoing Beam Dynamics Activity inside UNK Project

2.2 Working groups

2.2.1 Working group I:

The first working group analyzed the experimental situation and the simulation results on beam- beam effects with crossing angle. In particular, the lifetime problem, peak luminosity performance regarding synchro-betatron resonances, and future experiments were discussed. The importance of finding a good working point in the tune space for crossing angle collision was underlined. Based on our past experience, the tolerable normalized crossing angle ($\phi\sigma_z/\sigma_x$ for horizontal crossing with ϕ being the half crossing angle, σ_x the horizontal beam size and σ_z the bunch length) is about 0.09.

The list of talks presented is as follows:

1. T. Chen, SLAC Crossing angle and lifetime: simulation, analysis, measurements and more simulations
2. D. Pestrikov, BINP Effect of the Bunch Length on Strength of Synchro-Betatron Resonances Due to Crossing Angle

2.2.2 Working group II:

The second working group focused mainly on beam-beam simulations, where lifetime and tail distribution problems, strong- strong approximation and beam coherence problem were studied.

The list of talks presented is as follows:

1. A. Zholents, LBL Lifetime and Tail Simulations for Beam-Beam Effects in PEP-II B Factory.
2. D. Shatilov, BINP Simulation of Beam-beam at Large Amplitudes and of the Life Time of Colliding Bunches
3. E. Simonov, BINP Beam-Beam Simulation in the Strong-Strong Approximation
4. V. Shiltsev, BINP Decoherence of a Gaussian Beam due to Beam-Beam Interaction
5. A. Gerasimov, FNAL Toward a theory of coherent beam-beam steady-state oscillations
6. D. Parkhomchuk, BINP Coupling Correction for the Beam-Beam Optimization

2.2.3 Working group III:

The third working group discussed the BINP experimental program on VEPP-4M including a study of beam- beam effects with a large vertical dispersion at interaction point, influence of parasitic interaction points for multibunch collider on luminosity and lifetime as well as defining of an optimal vertical dimensions of colliding beams. Two reports were presented concerning on beam dynamics in crab-crossing collision scheme. The list of talks presented is as follows:

1. G. Tumaikin, BINP Beam-Beam Study Program at VEPP-4M
2. Y. Funakoshi, KEK Simulations on Crab Cavity System
3. Y. Alexahin, JINR Beam-Beam Effect on Transverse coupling
4. Y. Alexahin, JINR Synchro-Betatron Coupling in Crab Cavities
5. Y. Alexahin, JINR Monochromatization as an option for High Luminosity
6. V. Yakimenko, BINP Lattice of C-Tau at Novosibirsk

3 ORGANIZATION

The workshop proceeded at International Conference Hall, JINR, Dubna. Dubna is approximately 100 km from Moscow International Airport Sheremetjevo. The JINR provided participants the trip from airport to Dubna. Workshop Proceedings will be published as JINR report. The Organizing Committee provided the financial support for Former Soviet Union participants thanks to the Russian Government and Russian Fundamental Investigation Foundation support.

Beam Dynamics Activities at Argonne National Laboratory

Y. Cho (yc@aps.anl.gov)

(July 17, 1995)

Many groups from several different Divisions are carrying out beam dynamics work at Argonne National Laboratory. These activities include work associated with the Advanced Photon Source commissioning program, feasibility studies of 1- and 5-MW proton accelerator systems for spallation neutron sources, a feasibility study of a tau/charm factory, the study of acceleration by wakefields, RFQ code development, beam dynamics work at the ATLAS superconducting heavy ion linac facility, and a design study for a radioactive-beam facility. The following is a brief description of current ANL activities in beam dynamics, and is divided into the following categories:

- I Advanced Photon Source
- II Proton Rapid Cycling Synchrotrons: Proton Sources for Spallation Sources and a 2-TeV on 2-TeV Muon-Muon Collider
- III RFQ and Proton Linacs
- IV Tau-Charm Factory
- V Wakefield Accelerator Project
- VI ATLAS Heavy Ion Accelerator Facility

I Advanced Photon Source

Beam Dynamics Studies During Commissioning

(L. C. Teng and G. Decker)

For the past few months the commissioning of the Advanced Photon Source (APS) at Argonne National Laboratory has produced a great deal of information on the various component accelerators, especially the 7-GeV storage ring [1, 2]. The 1104-m circumference storage ring lattice is composed of 40 double-bend-achromat (Chasman-Green) cells spaced by 40 straight sections, each about 6 m long. In addition to the four quadrupoles forming the achromat with the dipoles, a quadrupole triplet is placed at each end of the straight section for adjusting the β-functions. Each cell has three chromaticity-adjusting sextupoles, plus four sextupoles placed in the zero-dispersion regions to cancel the harmful harmonics. This greatly enlarges the ring dynamic aperture. The design linear parameters of the ring are $\nu_x = 35.22$, $\nu_y = 14.30$; $\beta_x = 14.17$ m, $\beta_y = 10.0$ m (mid-straight section); $\xi_x =$ -64.7, $\xi_y =$ -26.4; $\epsilon_x = 8.2$ nm-rad. The rf system has a frequency of f = 351.93 MHz corresponding to a harmonic number h = 1296. The beam dynamics studies performed so far are understandably rather preliminary.

The APS is equipped with a flexible, high performance control system based on EPICS (Experimental Physics and Industrial Control System). The efficient interface of a large number of sophisticated beam diagnostics to EPICS has been a significant factor in the success of commissioning efforts. Thus, we are capable of carrying out many interesting beam dynamics experiments.

I.1 Tracking Experiments

(M. Borland, G. Decker, L. Emery)

The beam position monitor (BPM) system consists of nine BPM stations consisting of four capacitive button pickups per cell and is equipped with fast electronics for single-bunch single-passage measurements [3]. In addition to being very useful for the initial commissioning, the BPM system is useful for a wide range of beam dynamics studies. For example, it can easily be used to make phase plots of transverse motions. This has actually been done for the positron accumulator ring. In the booster synchrotron and the storage ring the single-passage capability of the BPM system has been used to derive the integral and fractional parts of ν_x and ν_y from the oscillation geometry of the beam. Pulsed injection magnets and a similarly powered vertical "pinger" are used to shock excite the beam. FFTs of beam history data collected turn by turn allow a direct measure of the fractional tunes. One easily observes the effects of coupling with this technique.

I.2 Chromaticity and Coupling Correction

(G. Decker, S. Milton, M. Borland)

There are 20 skew quadrupoles installed in the storage ring for adjusting the horizontal/vertical coupling. These have been use to decouple the ring using the minimum attainable separation between the tunes ν_x and ν_y as a gauge.

The effects of the chromaticity sextupoles on the chromaticities have been shown to be quite close to design. It has also been observed that the beam indeed becomes unstable at negative chromaticity values. This is especially clear in the vertical plane. We now set the chromaticity normally at +2 in both planes.

I.3 Electro-optics

(A. Lumpkin, B. Yang)

We have a synchro-scan dual-sweep streak camera which has been used to do some preliminary measurements of the bunch length [4]. The results indicate that at low intensities the FWHM is ≈45 ps, in fair agreement with the theoretical natural bunch length. At a high intensity of over 8 mA the bunch is lengthened by more than a factor 3 to a FWHM of ≈140 ps. These values are all obtained at a measured rf voltage of 6.5 MV, substantially below the design value of 9.5 MV. The data obtained at this stage of commissioning are quite encouraging. They also indicate that the streak camera will be a very useful instrument for future experiments. Studies of the vertical instability induced by lowering the vertical chromaticity at modest (3 to 5 mA) beam intensities have been initiated using streak camera techniques.

I.4 Beam Lifetime

(H. Bizek, M. Borland, G. Decker)

One of the challenges of APS commissioning is the attainment of acceptable beam lifetime (10 hours or greater) with small aperture insertion device vacuum chambers installed [5]. The first small gap chamber has a full vertical aperture of 12 mm and later chambers will have gaps of 8 mm or less.

Measurements of beam lifetime with vertical scrapers indicate that these small gap chambers does not significantly affect the beam lifetime. At present, the lifetime is limited mainly by poor vacuum, which will be improved by the modification of NEG pumps. Once the ring vacuum achieves the 1 x 10^{-10} Torr, the design vacuum at zero current, Touschek scattering is expected to be significant with bunch intensities near the design maximum 5 mA distributed among a nominal 20 bunches. Lattices with reduced values of $\beta_y$at the insertion device straight sections should permit the use of apertures as small as 5 mm, and prototype chambers with this aperture have been produced, in addition to the production 12 mm and 8 mm types. Studies are underway to test these lower emittance lattices.

I.5 Mechanical Vibration Studies and Closed Orbit Feedback

(S. Sharma, D. Mangra, S. Kim, Y. Chung)

A great deal of effort has been devoted to measuring vibrations of the storage ring quadrupoles and girders due to ambient sources of excitation including the general ground vibrations [6]. We have obtained a commercially available visco-elastic damping pad which, when mounted on the bottom of the girder feet, effectively damps the vibration amplitude of the lowest frequency (11 Hz) vibration mode. These pads are now being installed.

We have planned to use both global and local feedback systems to stabilize the beam from whatever vibrations there may be [7, 8]. A local feedback system is installed and under test. The global system is still being assembled. Digital position data from the BPM system is collected and corrections performed on the closed orbit at a 4 kS/s rate. This allows submicron control and stabilization of insertion device and bending magnet source points with $\geq$ 100 Hz bandwidth.

I.6 Hydrodynamic Leveling System

(H. Friedsam)

We have a hydrodynamic leveling system in construction for the storage ring. Such a system has been applied very successfully at ESRF. Relative vertical elevation changes on the order of a few nanometers are detectable. Investigations are underway for the incorporation of this information in a vertical closed orbit correction algorithm.

I.7 Further Machine Improvements

Of particular interest at APS and at other synchrotron radiation facilities is the use of insertion devices with extremely small apertures. In support of this effort, a low emittance lattice (4.2 nm-rad) including the low vertical beta feature is under consideration. The lower value of β_y will improve the Coulomb scattering lifetime and reduce resistive wall effects caused by small vertical apertures [9]. Lower emittance will enhance insertion device brilliance, a key performance parameter.

A related topic of interest is that of incremental top-up without interruption of x-ray user experiments, i.e., with photon shutters open. Typically, the photon shutters at synchrotron light sources are closed for injection. If a means of safely permitting injection during user beam time could be devised, one could contemplate the effective use of the machine in a small lifetime mode, for example with extremely small apertures. Continual replenishment of losses would allow acceptable operation. Another potential of top-up is the regulation of stored beam intensity, minimizing thermal effects on beamline optical components and reducing the need for scaling of experimental data with stored beam intensity.

References:

1. J. N. Galayda, “The Advanced Photon Source.”
2. G. Decker, “APS Storage Ring Commissioning and Early Operational Experience.”
3. A. Lumpkin, D. Patterson, X. Wang, E. Kahana, W. Sellyey, A. Votaw, B. Yang, R. Fuja, W. Berg, M. Borland, L. Emery, G. Decker, S. Milton, ”Initial Diagnostics Commissioning Results for the Advanced Photon Source (APS).“
4. A. Lumpkin, B. Yang, W. Gai, W. Cieslik, “Initial Tests of the Dual-Sweep Camera System Planned for APS Particle-Beam Diagnostics.”
5. H. M. Bizek, “Effects of Vertical Aperture on Beam Lifetime at the Advanced Photon Source (APS) Storage Ring.”
6. G. Decker, Y. G. Kang, S. Kim, D. Mangra, R. Merl, D. McGhee, S. Sharma, “Reduction of Open-Loop Low Frequency Beam Motion at the APS.”
7. Y. Chung, D. Barr, G. Decker, J. Galayda, J. Kirchman, F. Lenkszus, A. Lumpkin, A. J. Votaw, “Implementation Status of the Global and Local Beam Position Feedback Systems for the Advanced Photon Source Storage Ring.”
8. Y. Chung, E. Kahana, J. Kirchman, A. Lumpkin, J. Meyer, E. Prouviez, K. Scheidt, E. Taurel, A. Ando, S. Sasaki, A. Taketani, “Local Beam Position Feedback Experiments on the ESRF Storage Ring.”
9. Y-C Chae, “Investigation of Resistive Wall Instability in the 7-GeV APS Storage Ring.”

II Proton Rapid Cycling Synchrotrons: Proton Sources for Spallation Sources and a 2-TeV on 2-TeV Muon-Muon Collider

II.1 Lattices for a 2-GeV Rapid Cycling Synchrotron (RCS) for a 1-MW Spallation Source

(Y. Cho, Y.-C. Chae and E. A. Crosbie)

Lattice studies for a 30-Hz RCS delivering 1-MW beam power were performed. The injection energy is 400 MeV and the extraction energy is 2 GeV. The number of accelerated protons per pulse is 10^{14}, resulting in a time-averaged current of 0.5 mA. The RCS is designed to fit an existing building that formerly housed the ZGS. The design features include high transition energy, dispersion-free straight sections for rf cavities and H^- injection, good dynamic aperture, and tolerance to construction imperfections. The chosen lattice type uses FODO cells with missing dipoles to suppress dispersion in the straight sections. The periodicity-4 lattice has a transition gamma of 5.4 and a dynamic aperture much greater than 750 π mm mr. The required acceptance is 375 π mm mr. Sensitivity analyses arising from multipole imperfections and alignment tolerances have been performed. The H^- injection facilitates transverse phase space painting in both planes. Details of the 2-GeV machine design are included in the recently completed feasibility study of a 1-MW spallation source [1].

[1] "IPNS Upgrade - A Feasibility Study," ANL Report ANL-95-13, (April, 1995).

II.2 Lattices for a 10-GeV Rapid Cycling Synchrotron (RCS) for a 5-MW Spallation Source

(Y.-C. Chae and Y. Cho)

A 10-GeV RCS is under study to reach 5 MW proton beam power for a future spallation source. The 10-GeV RCS will accept a 2-GeV beam from the 1-MW spallation source. Here again, 90° phase-advance FODO cells are used to construct the lattice. The missing dipole scheme is again used to suppress dispersion in the straight section cells. A periodicity-3 lattice with a circumference four times that of the 2-GeV RCS meets all requirements. The 10-GeV RCS requires about 1.5 MV peak rf voltage which translates to a requirement of 150 m of length for the cavity system. The lattice has more than 200 m of straight section available for the cavities. Injection into this RCS is a simple single-bunch transfer from the 2-GeV ring to a waiting bucket. Since only a single bunch is involved in this scheme, the plan is to inject into a moving bucket rather than into a stationary bucket. Injection into a moving bucket avoids a very fast change of the synchronous phase angle during the initial part of acceleration cycle.

II.3 Longitudinal Beam Dynamics Studies for a Rapid Cycling Synchrotron

(Y. Cho, E. Lessner, K. Symon)

The rapid cycling synchrotron (RCS) of the proposed IPNS Upgrade is designed to accelerate a high intensity proton beam from 400 MeV to 2 GeV, delivering 1.04 x 10^{14} protons at a repetition rate of 30 Hz. The beam power is 1 MW. The synchrotron magnet system is energized with a dual resonant power supply system which uses a 20-Hz magnet excitation rate and a 60-Hz reset rate, keeping an overall 30-Hz rate. This reduces the peak voltage requirement by one third. Simulation studies that take into account space charge effects were used to achieve low loss conditions during injection, capture and acceleration, while maintaining a large beam momentum spread to avoid the microwave instability. The high beam intensity and relatively low injection energy produce strong space charge fields that modify the particle distribution and reduce the bucket area, degrading the capture efficiency.

For an accurate estimate of the space charge forces it is important to reduce the statistical fluctuations introduced by the relatively coarse ensemble of macro particles used in the simulations. This is done by binning the projected phase distribution by the cloud-in-cell method. The cell grid is chosen fine enough to retain the structure of the bunch distribution, yet coarse enough to attenuate the short wavelength noise due to the finite number of macroparticles. The data is then fast-Fourier transformed and filtered by an algorithm whose cut-off frequency is increased as the bunch shortens during the cycle. The simulations also take into account that the capacitive geometrical factor which represents the image forces resulting from the space charges, varies during the acceleration cycle as the beam radius decreases. The tracking code was tested extensively. It was shown to correctly predict the negative mass instability threshold when run above the transition energy. The tracking results agree closely with the results obtained with the ESME code from FNAL.

We studied the effects of various parameters such as rf voltage programming and chopped bunch length of the incoming linac beam against capture efficiency. The tracking simulations led to the establishment of an rf voltage programming for the RCS that best meets the requirements of low loss and large momentum spread. It is expected that the energy spread of the linac beam is $\pm$ 2.5 MeV. The highest capture efficiency is obtained by chopping the beam so that it occupies 75% of the ring and by injecting it into a 7 eV sec waiting bucket, corresponding to an rf voltage of 40.5 kV. During the 0.5 msec of the injection period the voltage is raised from 40.5 kV to 66.9 kV to prevent beam losses. This rapid increase of the voltage is crucial to overcome the space charge forces that increase as the particle density in the ring increases. At the end of injection, the bucket area is 9 eV sec and the bunch occupies 80% of the bucket. From the end of injection into 7.5 msec of the acceleration cycle, the voltage is raised as to maintain a 9 eV sec bucket area, and reaches 169.0 kV at that time. In the remaining part of the cycle the bucket area is manipulated to increase the beam momentum spread. From 7.5 msec to 12.5 msec (middle of the acceleration cycle), the voltage is maintained at 169.0 kV, while the bucket area increases from 9.0 to 11.3 eV sec. The voltage is then decreased from 169.0 kV to 113.9 kV at extraction. The voltage for the latter part of the cycle is maintained high to ensure a synchrotron frequency fast enough to allow the particles in the bunch to follow the rapid change of the synchronous phase. At all times during the cycle, the momentum spread is above the microwave instability threshold.

Presently, we are investigating the injection of the 2-GeV beam into a 10-GeV RCS. The latter has a circumference four times larger that the former and accelerates the beam from 2 GeV to 10 GeV, also at a repetition rate of 30 Hz. For this machine, harmonic numbers of 8 or 12 are being considered. Preliminary studies indicate that the 2-GeV beam is best matched into an 11 eV sec bucket at about 0.5 msec of the 10-GeV machine acceleration cycle.

II.4 Coupling Impedance Estimation and Collective Instability Analyses for the 2-GeV, 1-MW and 10-GeV, 5-MW Rapid Cycling Synchrotron

(K. Harkay, E. Lessner and Y. Cho)

Intensity-dependent collective instabilities are an important consideration in the 1-MW, 2-GeV rapidly-cycling synchrotron (RCS) for the IPNS Upgrade. Comprehensive calculations were performed to estimate the machine coupling impedance in the RCS. Instability thresholds were then obtained for both the longitudinal and transverse planes. Beam parameters such as the $\Delta p/p$ and peak current were obtained through simulation studies of beam capture and acceleration using the code CAPTURE-SPC, a longitudinal tracking code that includes the effects of space charge (E. Lessner, ANL). Through the analysis, we have arrived at an rf voltage profile and beam parameters that avoid both the instabilities and beam loss.

The impedance is dominated by the effects of space charge, giving -220j Ω (longitudinal Z/n) and -2.8j MΩ/m (transverse) at injection energy. The rf shield, extraction kickers, rf cavities and beam position monitors (BPMs) also contribute to the impedance. To minimize the space charge impedance, the vacuum chamber is constructed with a special rf shield, similar conceptually to that used at ISIS, which follows the beam envelope. Compared to a fixed-radius rf shield, this contour-following scheme reduces the space charge impedance by about 30%. The impedance due to the rf cavity higher-order-modes (HOMs) was computed using results from URMEL-T modeling. Finally, the impedance due to the rf shield, extraction kickers, and BPMs were calculated using conceptual designs and standard assumptions.

In the longitudinal plane, the microwave instability is potentially the most dangerous and was studied in detail. A conservative approach was adopted to ensure that the momentum spread, $\Delta p/p$, was sufficient to satisfy the Keil-Schnell stability criterion modified for bunched beams. The microwave instability threshold depends mostly on the space charge impedance, and the instability can be driven by the broadband rf cavity HOM impedance. Studies were performed to choose an rf voltage profile which provides adequate bucket area and beam momentum spread. Using results from tracking, a detailed analysis of the stability diagram was also made. The beam remains in the stable region through acceleration, where, at extraction energy, the $\Delta p/p$ is 1% and the bunching factor (peak current/circulation current) is less than 0.2.

In the transverse plane, the head-tail instability was analyzed. The instability threshold again depends on the space charge impedance, and the instability can be driven by the resistive wall and kicker impedance. With a chromaticity corrected to zero, the rise-times of the first few head-tail modes are about 1 msec. These lowest modes are stabilized at the natural chromaticity. Stability can be also be achieved by adding octupoles to provide a tune spread, a technique employed at the KEK and CERN Boosters and elsewhere. The octupole strength required allows sufficient dynamic aperture. Adding a tune spread to stabilize the collective instabilities can conflict with the desire to minimize the tune spread to avoid the single-particle resonance. Therefore, operating parameters were calculated for an active feedback system, giving an electric field of about 1 kV/m for a 0.5-m kicker.

Similar analyses are underway for a 5-MW, 10-GeV RCS which receives beam from the 2-GeV RCS. It is expected that a contour-following rf shield will not be required since the space charge impedance is reduced by a factor of between 5-10 over acceleration and, therefore, a thin steel vacuum chamber can be used. Preliminary simulations and calculations show that a $\Delta p/p$ of about 1% is sufficient for stability. The issue of beam loading due to the higher peak current is to be addressed. Calculations to determine the requirements for stability against head-tail effects are ongoing.

II.5 Injecting a Kapchinskij-Vladimirskij (K-V) Distribution into a Proton Synchrotron

(E. Crosbie and K. Symon)

In order to achieve a maximum space charge limit in a proton synchrotron, it is desirable to inject a K-V distribution. The K-V distribution requires that all injected particles have the same total transverse oscillation energy, and also that they are distributed uniformly throughout the entire energy shell. This requires that we paint the injected beam uniformly in the three independent dimensions of the energy shell. In order to make the result insensitive to the details of the process such as betatron tunes, coupling parameters, injection time, etc., we use widely separated time scales for the painting processes in the three dimensions. We have devised practical ways of achieving this, and have checked them with computer simulations. The resulting space charge density distributions are very nearly uniform within a circular beam cross section.

II.6 Proton Source for a μ^+ μ^- Collider

(Y. Cho, Y.-C. Chae, K. Harkay, E. Lessner)

The accelerator parameters for the 10-GeV, 5-MW proton source described above are quite similar to the proton source parameters for the proposed 2-TeV on 2-TeV μ^+ μ^- collider. Particular parameters that must be optimized for the collider are the final beam bunch length and harmonic number to match into the muon production and capture system.

III RFQ and Proton Linac

III.1 RFQ Beam Dynamics

(G. E. McMichael, Technology Development Division)

In collaboration with the Chalk River Laboratory (CRL), the RFQCOEF and RFQTRAK codes [1] developed by J. Diserens to run on the CRL Cyber mainframe and Silicon Graphic workstations, were installed on a SPARC workstation. A PC-compatible version of RFQCOEF was completed prior to the cessation of the RFQ work at Chalk River. RFQCOEF is a program that will calculate the coefficients for the expression for the radiofrequency potentials within an RFQ accelerator. RFQTRAK is a beam dynamics program that uses the finite-element method to represent the 3-D space-charge and image-charge potentials within such an accelerator. Present effort is directed to modifying RFQTRAK to run on Pentium-based PC's, improving the user interface of the complimentary RFQ design and analysis codes in use at Argonne, and the design and analysis of high-current proton/deuteron RFQ's or RFQ's for radioactive beams.

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III.2 Beam Dynamics Study of a 400-MeV Proton Linac

(M. White and Y. L. Qian)

The injector for the 2-GeV RCS is a 400-MeV proton linac system that consists of an H-ion source, a beam chopper system, a 2-MeV rf quadrupole (RFQ), a ramped-gradient drift tube linac (RGDTL) section to match into a 70-MeV DTL, and a 330-MeV coupled-cavity linac. Other parameters are: a repetition rate of 30 Hz, a beam pulse length of 0.5 msec, and a beam pulse current of about 50 mA. An initial beam dynamics study for the system have been performed by personnel from AccSys Technology, Inc. Further studies are planned for this year and will address review committee recommendations.

III.3 Space Charge Effects in a Low Energy (400-MeV) Beam Transport Line

(E. Lessner)

Longitudinal space charge effects in the beam transport between the linac and the RCS were calculated by simulating the time-development of the envelope equations of a parabolic line density distribution. The low energy transfer line (LET) has a total length of 157.3 m and transports the 400 MeV beam from the linac into the RCS. It consists of three regions: a 90° horizontal bend near the linac, a 3.05-m vertical translation from the linac elevation to the RCS elevation, and a 72° bend near the RCS. The output beam from the linac DTL has an energy spread of +/- 0.8 MeV and a phase spread of ± 8.0 degrees. The beam average current is 50 mA. The DTL frequency is 1275 GHz, corresponding to 2.5 x 10^8 particles per microbunch. Space charge effects, including image forces, cause the energy spread to grow from 0.8 MeV to 1.22 MeV at 97.7 m of the transport line, where the phase spread is 180° and the microbunches start to overlap. From this point on, the space charge forces decrease due to the overlap. For comparison, the phase spread due to the initial energy spread only (no space charge) is 120° , at 97.7 m. Simulations using a six-dimensional tracking code are currently being performed to account for the energy spread due to space charge forces and the bend regions.

IV Tau-Charm Factory

IV.1 Beam-Beam Limit in a Collision Plane with Non-zero Dispersion

(L. C. Teng)

The conventional expression for the beam-beam parameter (tune-shift), ξ, and the empirical limiting value of about 0.05 were obtained for collisions at zero dispersion. The only effect in this case is that of the electromagnetic kick by beam 2 on the betatron motion of the particle in beam 1 and vice versa. When the dispersion is non-zero, there is also a synchrotron motion and a synchro-betatron coupling. The effect of the beam-beam kick can be expected to be more complicated.

Although this has been studied before [1, 2], we are re-investigating the phenomenon both analytically and by numerical tracking. The work has not yet progressed very far, but we expect that it should give an idea of the consequent variation in the beam-beam limit, especially the dependence of the variation on the magnitude of the dispersion, D, at the interaction point. It is doubtful though that this study will yield reliable quantitative result seeing that even for zero dispersion, hence pure betatron motion, the beam-beam limit of $\xi \approx 0.05$ was obtained only empirically and even today there is no conclusive and convincing theoretical explanation of the behavior of the beam-beam limit. Therefore, it is important to do an empirical study of this phenomenon at some collider facility whenever an opportunity arises.

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IV.2 Parameter Studies for a Tau-Charm Factory

(E. A. Crosbie and L. C. Teng)

A small effort at Argonne has been devoted to the design study of a Tau-Charm Factory (TCF). A TCF is a high luminosity (L $\geq$ $10^{33}/\mathrm{cm}^2/\mathrm{sec}$) electron/positron collider with total center of mass (COM) energy adjustable from 3 to 6 GeV. The physics that can be studied using such a facility is quite extensive and interesting. For production of charmonium states, the J/ψ in particular, the cm energy spread should be reduced to roughly equal the widths of these states.

A great deal of work has already been done on the design of a TCF [1]. Our effort is a re-examination and critique of the design rationale and features, and an update of the parameters. Our starting principle and desire is to make the design as simple as possible and to keep the retuning required for different energies at a minimum. Following previous designs we store the e^+ and e^- beams in two separate rings vertically displaced. Each ring consists of two identical 75-m-long 180° Arcs which are composed of FODO cells with horizontal dispersion suppressors at the ends. The Arcs are joined by two 116-m long straight sections. In one Straight the beams are kept separate and are transported by simple cell structures. This "Utility Straight" is used for collider functions: injection, abort, rf, scrapers, etc. In the other Straight, the "Interaction Straight," the beams are brought vertically together to collide head-on. This Interaction Point is, of course, in the middle of the particle detector system.

The emittance and the energy spread of the beam are controlled by the parameters of the Arcs and are designed to have the "neutral" values of $\epsilon_0 = 140$ nm-rad and $(\sigma_\mathrm{E}/\mathrm{E})_0 = 0.0004$. They can be adjusted over a sufficiently wide range by Robinson wigglers located in the gaps at the ends of the Arcs which compose the dispersion suppressors. To get high luminosity one minimizes the β-values at the IP and maximizes the beam currents, both are however limited by the beam-beam interaction, ξ. The beam-beam limit has a time-tested empirical value of $\xi \approx 0.04$. For head-on collisions the spacing between bunches in a beam must be sufficiently large ($\approx$10 m) so that at the neighboring bunch crossing locations on either side of the IP (5 m for 10 m bunch spacing) the beams are sufficiently separated and the electromagnetic interactions between them are negligible.

For the "standard arrangement" the vertical (and horizontal) dispersion at the IP is zero, namely, $\mathrm{D_y} = \mathrm{D_y}' = 0$. The COM energy spread is simply that of the beams. To reduce the COM energy spread we arrange the vertical dispersions for the two beams to have large equal and opposite values at the IP. The COM energy spread is then scaled down by the factor (beam vertical betatron width)/(beam vertical dispersion width). This is known as the "monochromator arrangement" and is to be used for charmonium production. The formulations for these arrangements are all well known. However, the considerations and emphases in selecting the parameters to satisfy the requirements are somewhat different here.

For the Interaction Straight matching, going away from the IP we have first a superconducting quadrupole doublet used commonly by both beams to produce the mini-β values at the IP. The beams are then separated vertically by a string of three electrostatic separators. After a short drift space the beams are sufficiently far apart to be further separated by first a septum magnet, then pairs of dipole magnets with opposite fields. Geometry, dispersion and β-matchings to the Arcs are, then, accomplished by a series of dipoles and quadrupoles. In the matching section we endeavored to keep the maximum β-values low, so that chromaticity corrections can be made with sextupoles located only in the Arcs while maintaining sufficiently large dynamic aperture over a sufficiently large energy spread.

The design, construction and operation of the TCF are conceived to proceed in four phases.

Phase I "Standard arrangement." Here we use Robinson wigglers to increase the emittance to ϵ_s = 560 nm-rad and reduce the beam energy spread to $(\sigma_{\rm E}/{\rm E})_0 = 0.00034$. The beam-beam limit is reached at the intensity of 1.5 x 10^{11} particles per bunch. With ${\beta_x}^* = 0.06$ m, ${\beta_y}^* = 0.01$ m and 10-m long bunch spacing, the luminosity is expected to reach 1.1 x $10^{33}/\text{cm}^2/\text{sec}$.

Phase II "Monochromator arrangement." A lower emittance is preferred for this arrangement. Robinson wigglers are used "in reverse" to reduce the emittance to $\epsilon_m = 70$ nm-rad and increase the beam energy spread to $(\sigma_{\rm E}/{\rm E})_0 = 0.000566$. With ${\beta_x}^* = 0.01$ m, ${\beta_y}^* = 0.0855$ m, and ${\rm D_y}^* = \pm\ 0.4$ m the beam-beam limit gives a maximum intensity of 1.8 x 10^{11} particles per bunch and a corresponding luminosity of 1.3 x $10^{33}/\text{cm}^2/\text{sec}$. The COM energy spread for this arrangement is reduced down to the J/ψ width of 0.086 MeV at 3.1 GeV. After phase II is implemented there, will be no need to go back to phase I. The good energy resolution is presumably advantageous or acceptable for all experiments. Indeed, one may want to skip phase I altogether.

Phase III Super-high luminosity. One may want to introduce finite crossing angle to reduce the bunch spacing, say, by a factor 3. One must then employ the "crab crossing" geometry so as to obtain a gain in luminosity close to the same factor 3. If the "monochromator arrangement" cannot be implemented for this finite-angle crab-crossing geometry, one may want to retain the capability of going back to phase II for charmonium production.

Phase IV Collision of longitudinally polarized beams is useful for the study of symmetry conserving and symmetry breaking physics. This can be provided in principle, but will clearly be difficult and costly to implement. In any case one must retain the capability of going back to the unpolarized arrangements.

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[1] see, e.g., J. M. Jowett, Frontiers of Particle Beams: Factories with e^+e^- Rings, edited by M. Dienes, M. Month, B. Strasser, S. Turner (Springer Verlag, 1994); and the many references given in this paper.

V Beam Dynamics Studies in the Argonne Wakefield Accelerator (AWA) Project

(Jim Simpson - jdsimpson@anl.gov)

V.1 Studies of Single Bunch BBU in Dielectric Loaded Waveguides

J. Simpson, (W. Gai, A. Kanareykin (St. Petersburg, Russia))

The necessarily large beam-waveguide coupling and large beam currents present in wakefield accelerator devices are sources of potentially devastating BBU effects on the "drive" beam. Detailed simulations have led to good understanding of the effect and how it can be alleviated.

Wake function in the order of a MV/m/nC are required in wakefield devices of interest. Although the beam pulses are short (typically 3-4 ps rms) and the lowest order deflecting mode (HEM11) frequency is usually lower than that of the dominant accelerating mode (TM01), BBU effects are very strong for even small alignment errors. However, a preliminary, self-consistent line-charge simulation suggested that even small amounts of external periodic focusing (FODO) would reduce BBU to acceptable levels. This happens because a large longitudinal wake function produces a rapidly increasing head-to-tail energy spread on the beam pulse which, in the presence of focusing, leads to a rapidly changing tune spread distribution along the pulse. More detailed Monte-Carlo simulations which included wake functions through 3rd order octupole modes have confirmed the effectiveness of the damping scheme. The use of helical quadrupole focusing (a little better but technically difficult to provide) and solenoidal fields (requiring unreasonably high field strength to achieve good control) were also simulated in these studies. The conclusion is that BBU can be controlled relatively easily using inexpensive permanent magnet quadrupoles.

V.2 Photoinjector Beam Dynamics

(P. Schoessow, J. Power, C. H. Ho)

The AWA group is presently commissioning a very high current (100 nC/30 ps) L-band photoinjector. As part of the design process for this novel device, extensive use was made of numerical simulations of beam dynamics using both the PARMELA and TBCI-SF codes. In order to ameliorate space charge effects in this intense beam a number of new features were developed for the AWA gun. The laser wavefront is curved so that electrons are emitted from the cathode earlier at larger radii. This serves to minimize space charge blowup near the photocathode. Generating the electrons in this way also creates a correlation between beam energy and radial position which may then be compensated by introducing spherical aberration into the focusing solenoids.

The efficacy of these methods was first verified by simulations, and parameter studies were performed to optimize bunch length and spot size at the linac exit. Part of the experimental program at the AWA is checking the agreement between beam dynamics simulations and experiment in this high current regime. The data so far exhibits qualitative agreement with the simulations for the flat bunch case, and work is underway to incorporate laser bunch shaping into the system.

A second gun (4.5 MeV/ 1nC/10 ps) was designed using the same methodology and will serve to generate a witness beam for wakefield acceleration experiments.

VI Beam Dynamics Activities at ATLAS

(J. A. Nolen, R. C. Pardo, K. W. Shepard, J.-W. Kim, and students)

VI.1 Activities Related to the Present ATLAS Facility

VI.1.1 Bunching Studies for the ATLAS Positive-Ion Injector

(R. C. Pardo and R. Smith)

The bunching system of the ATLAS Positive Ion Injector consists of a four-frequency harmonic buncher, a beam-tail removing chopper, and a 24.25 MHz spiral resonator sine-wave buncher. The system is designed to efficiently create beam pulses of approximately 0.25 nsec FWHM for injection into and acceleration by the ATLAS superconducting linac. Studies of the effect of space charge on the performance of this system have been undertaken and compared to simulations as part of the design process for a new bunching system to be developed for a second ion source. Results of measurements and studies indicate that the present system suffers significant bunching performance deterioration at beam currents as low as 5 e-micro-Amps for ${}_{238}U^{26+}$ at a velocity of $\beta = 0.0085$. The low beam current tolerance of the present system is in good agreement with computer simulations. Studies of two bunching system design alternatives to the present one have been undertaken. The best of the two options indicate that good bunching results can be realized for beam currents as high as 300 e-micro-Amps for light ions with a large charge-to-mass ratio and even higher currents are acceptable for the heaviest beams such as uranium. (paper presented at the 1995 Particle Accelerator Conference)

VI.1.2 Transverse Emittance Systematics Measured for Heavy-Ion Beams at ATLAS

(J. A. Nolen, T. A. Barlow, K. A. Beyer, and K. A. Woody)

The horizontal and vertical beam emittances and ellipse parameters are determined at the ATLAS superconducting heavy-ion linac by the well-known method of measuring the beam width at a profile monitor downstream of a quadrupole magnet as a function of the magnet current. Typically six base-to-base beam widths are measured and used in a least-squares fit to an algebraic expression for the three unknown ellipse parameters. The algorithm was derived from the first order matrix equation for the beam sigma matrix transform through the quadrupole singlet and drift to the profile monitor. To date the emittances of five beams from ${}_{12}C^{4+}$ to ${}_{238}U^{26+}$ have been measured at the entrance of the Positive-ion Injector Linac, yielding normalized values mostly in the range of 0.25-0.30 π mm-mr. These measurements will be extended systematically to several locations to identify possible sources of emittance growth and to develop more systematic beam tuning procedures. (paper presented at the 1995 Particle Accelerator Conference)

VI.2 Activities Related to a New Radioactive Beam Facility Proposal

VI.2.1 Accelerator Complex for a Radioactive Ion Beam Facility at ATLAS

A complete “Working Paper” is available on the World Wide Web at http://www.phy.anl.gov. A shorter version summarizing the accelerator concept was presented by J. A. Nolen at the 1995 Particle Accelerator Conference.

Since the superconducting heavy ion linac ATLAS is an ideal post-accelerator for radioactive beams, plans are being developed for expansion of the facility with the addition of a driver accelerator, a production target/ion source combination, and a low q/m pre-accelerator for radioactive ions. A working group including staff from the ANL Physics Division and current ATLAS users are preparing a radioactive beam facility proposal. Some specific issues for the acceleration of exotic beams from very low velocities with very low q/m are addressed below.

VI.2.2 A Low-Charge-State Injector Linac for ATLAS

(K. W. Shepard and J. W. Kim)

The design of a low-charge-state linac which is capable of accelerating, for example, $_{132}Sn^{1+}$ for injection into the existing heavy-ion linac ATLAS is discussed. The injector linac is intended for radioactive beam applications, and will accelerate a low-charge-state beam to energies of 800 - 1000 keV/nucleon, at which point the ions can be stripped to charge states sufficiently high to be injected into ATLAS. A primary design goal has been to extend the very good longitudinal beam quality typical of ATLAS to low charge state beams. The proposed injector linac consists of several elements. First, a gridded-gap four-harmonic buncher and a short (normally-conducting) 12 MHz RFQ structure, both operating on a 350 kV open-air variable-voltage platform. and then an array of 25 MHz and 50 MHz superconducting inter-digital accelerating structures interspersed with superconducting quadrupole transverse focusing elements. Numerical ray-tracing studies indicate that a transverse acceptance greater than 0.2 π mm-mrad can be obtained while simultaneously limiting longitudinal emittance growth to a very few keV-nsec. (paper presented at the 1995 Particle Accelerator Conference)

VI.2.3 Longitudinal Emittance Oscillation in a Superconducting Drift Tube Linac

(J. W. Kim and K. W. Shepard)

In drift tube Linacs a beam energy spread results from the finite beam size. Radial variation of the axial accelerating field induces a beam energy spread, which, in general, will accumulate as the beam passes through successive drift tubes. This work shows that under some conditions of periodic transverse focusing and longitudinal phase focusing, the correlation between the longitudinal and transverse motion can be used to the accumulation of energy spread. The process of achieving such a correction has been demonstrated for a particular tuning using a ray-tracing program which models a low velocity and low charge state linac designed for radioactive ion beams.

The design of an ISOL-type radioactive beam facility utilizing the present ATLAS accelerator as a secondary beam accelerator is in progress at Argonne. One requirement for such a project is a low charge state injector linac for the ATLAS superconducting linac. A key issue with such an injector linac is to maintain small longitudinal emittance while maximizing transverse acceptance. These two requirements tend to conflict since acceleration of a finite size beam through a drift tube linac increases the beam energy spread because of radial variation of the accelerating field. The variation is quadratic in the lowest order, causing longitudinal beam quality to deteriorate rapidly with increasing beam radius. The beam energy spread is inversely proportional to the wavelength of the slow wave in the drift tube structure, thus becoming worst at low particle velocities.

The longitudinal emittance increase could in principle accumulate throughout the acceleration process. However, by proper matching of longitudinal phase focusing to the periodic transverse focusing structure, emittance growth can be limited by using the correlation between longitudinal and transverse phase spaces. This process is clearly manifested in numerical ray-tracing studies performed in the design of the low charge state (q/A = 1/66), low velocity($\beta = 0.004$) injector linac. A simplified explanation of the correction mechanism has been developed, and presented along with detailed numerical ray-tracing results at the 1995 Particle Accelerator Conference. (paper presented at the 1995 Particle Accelerator Conference)

VI.2.4 A Concept for Emittance Reduction of DC Radioactive Heavy-Ion Beams

(J. A. Nolen and J. C. Dooling)

Numerical simulations indicate that it should be possible to use an electron beam to strip 1+ DC radioactive ion beams to 2+ or higher charge states with on the order of 40-80% efficiency. The device, which we call an Electron-Beam Charge-State Amplifier, is similar to an Electron Beam Ion Source, except that it is not pulsed, the beams are continuous. The 2+ beams are obtained in a single pass through a magnetic solenoid while higher charge states may be reached via multiple passes. An unexpected result of the ion optics simulations is that the normalized transverse emittance of the ion beam is reduced in proportion to the charge-state gain. Ion beams with realistic emittances and zero angular momentum relative to the optic axis before entering the solenoid will travel though the solenoid on helical orbits which intercept the axis once per cycle. With an ion beam about 2 mm in diameter and an electron beam about 0.2 mm in diameter, the ion stripping only occurs very near the optic axis, resulting in the emittance reduction. The performance of such a device depends critically on the assumption of zero angular momentum of the individual ions. We are setting up an ISOL-type ion source at a test stand to do detailed emittance studies and test the assumption of zero angular momentum. (paper presented at the 1995 Particle Accelerator Conference)

Beam Dynamics Activities in DAΦNE Project

L. Palumbo (lpalumbo@vaxlnf.lnf.infn.it)
Laboratori Nazionali di Frascati, INFN Via E. Fermi, 40, 00044 Fsascati (I)

DAΦNE Status The e^+e^- ϕ-factory DAΦNE is presently under construction in Frascati (Italy)[1]. It is designed as a double ring system with a maximum number of 120 bunches/beam. The short term luminosity goal is L $=1.3\times\ 10^{32}$ (cm^{-2} sec^{-1}) with 30 bunches while the designed luminosity L = 5.2 $\times10^{32}$ (cm^{-2} sec^{-1}) should be achieved in a period of at least 2 years of continuous operation.

The accelerator complex consists of e^+e^- LINAC, e^+e^-Accumulator/damping ring, twin ring collider. The tender phase is almost complete and the various components are under construction. The high current-performance of the LINAC have been successfully tested at TITAN Beta factory. The LINAC is now being installed at LNF and will be fully operational by December 1995. The installation of the accumulator, with Oxford Instruments the main contractor, is scheduled for September 1995, while the beam tests will begin in January 96. The beginning of the collider commissioning is scheduled for the end of 1996, and the start of experimental runs for mid 1997.

Luminosity Strategy Since high luminosity is the most important issue in the DAΦNEϕ-factory, much attention was paid to the design luminosity strategy and the beam-beam interaction effects. An extensive analytical and numerical study have been undertaken in order to choose a working point far from dangerous incoherent and coherent beam-beam non-linear resonances and having, at the same time, a reasonable dynamic aperture.

For a careful choice of the working point in DAΦNE , a computer code to simulate the beam-beam interactions, using the weak-strong model, has been developed. Bunches with Gaussian distributions, in both the horizontal and vertical planes, with N particles (N $\leq$ 500 for computing time reasons) are tracked over a large number of turns ($>$ 1 damping time). The code takes into account crossing angle, sextupoles, noise and damping effects. Synchrotron motion and bunch length effects will be included in the near future.

At present, $\nu_x = 5.13$ and $\nu_y = 6.10$ are considered to be a possible working point candidate [2]. Systematic studies on the effect of one and two interactions per turn with different tunes are in progress.

Like other factory projects, the high number of bunches has the nasty side-effects of parasitic crossings, which contribute to the beam -beam tune shift parameter, i.e. tune spread and a possibility of additional non-linear resonances. In order to reduce the parasitic crossing effect, the scheme with the bunches colliding at a 12.5 mrad horizontal half crossing angle is adopted.

To avoid geometric reduction of luminosity ("hour-glass" effect, $\sigma < b_y$= 4.5 cm) and to provide a satisfactory Touschek lifetime, the bunch length σ_s has been chosen to be equal to 3 cm as a reasonable compromise.

The flat beam scheme was adopted in order to make the machine less critical with respect to the sextupolar correction and dynamical aperture, and to minimize the parasitic longitudinal beam-beam effects.

In principle, a substantial luminosity increase could be obtained by increasing beam-beam tune shift parameter ξ. Unfortunately, it seems not possible to achieve arbitrary large values of ξ without incurring in serious limitations. Besides the physical mechanism of the ξ limitation, which is very involved and far from having been solved theoretically in a conclusive way, there is an experimental experience over most existing and past colliders that the maximum ξ achieved lies in the range of 0.04±0.015. The values of 0.04 have been chosen for the DAΦNE machine.

High Order Terms in Low-Beta Magnetic Elements The two rings of the ϕ-factory share two Interaction Regions (IRs) where opposite beams travel off axis and cross at the Interaction Point (IP) at a horizontal angle of ±12.5 mrad. Two detectors, for KLOE [3] and FI.NU.DA.[4] experiments, will be installed in the IRs. The lattice designs of each region are determined by the detector characteristics, and include the detector solenoid, the compensating solenoids, and low beta quadrupoles. For the collider commissioning, a DAY-ONE design of the IRs consisting of low-beta quadrupoles only (without detectors) is foreseen.

Due to the beam-beam crossing angle the beam orbits pass off-axis inside low beta quadrupoles and solenoids. The nonlinearities arising from the fringing fields are therefore particularly important.

Once the field behavior of a magnetic element is known, by means of either 3-D codes or magnetic measurements, it is possible to approximate the data with a recently proposed analytical model [5]. The fields are expanded in polynomial terms which satisfy Maxwell equations up to any order, and the analytical representation substantially reduce the computing time in numerical tracking simulations.

The analysis of the three IR designs [6] with these models has shown that there are different effects of the fringing fields on the machine behavior: one is a modification of the linear optics, due to the dependence of the linear field gradient around the trajectory which can be easily computed and matched to the ring arc optics. There is also an effect of non linear coupling between vertical and horizontal betatron oscillations, which for some tune values can produce a vertical emittance increase for particles in the tails of the horizontal distribution. In the considered cases this increase is not dangerous (a maximum of 15% on the vertical invariant). Anyway, if necessary, it can be corrected by shifting the machine tune. Finally there is the well known dependence of the tune shift on the amplitude, due to the pseudo-octupolar field components, which being present in all the ring quadrupoles, are to be included in the dynamical aperture calculations. *(C. Biscari)*

Single Bunch Dynamics In order to achieve high luminosity, it is planned to store in the single bunch a current of about 44 mA. With the latest lattice parameters, according to numerical simulations, the bunch current is at the limit of the microwave instability threshold, while the bunch shape is strongly affected by the potential well distortion which lengthens the bunch from 1cm (natural length) up to 2.2 cm [7]. The simulations have been performed with the standard tracking methods [8,9] using as wake function the wake potential of a short gaussian bunch (s=2.5 mm) computed with ABCI and MAFIA [10,11]. These results agree with the semi-analytical estimate of the bunch-lengthening in the turbulent regime [12]. Coupling of radial and azimuthal modes [13] is under investigation in order to asses the mechanism leading to the turbulence threshold. Bunch-lengthening control by means of a third harmonic cavity has been thoroughly examined in both active and passive regimes [14].

The transverse mode coupling instability does not seem to be the limiting instability for DAΦNE. The estimate has shown that the nominal bunch current is about one order of magnitude lower than the threshold due to such an effect.

Multibunch Instabilities

The basic design choice of achieving the required luminosity with a high total current, distributed over a large number of bunches, makes the operation very critical with respect to coupled bunch instabilities. These instabilities have been identified since the very beginning of the project as a potentially severe limit on the ultimate achievable luminosity. For these reasons, one of the primary goals in the machine design was to reduce to a minimum the number of vacuum chamber elements creating parasitic HOMs capable to drive the multi-bunch instability and at the same time a big effort was undertaken to develop means for damping both the HOMs and the instabilities.

This task is accomplished by properly designing the RF cavity and by coupling off the HOMs, through loops or waveguides to extract energy from the resonant fields, thus reducing the quality factor and the shunt impedance. The residual excitation of the beam oscillations is expected to be damped by means of a bunch by bunch digital feedback system based on a digital signal processor under construction at SLAC in the framework of a collaboration with SLAC and LBL [15]. A time domain simulation code has been developed in order to investigate the effectiveness of the feedback system on the beam dynamics[16,17,18].

A novel and interesting solution for extracting RF power from the cavity consists of a wide band waveguide to coaxial transition developed at Frascati laboratory which allows one to use external standard 50 W loads [19] and avoid using dissipating materials in ultra high vacuum.

During the design and tests of a ALS-type strip line longitudinal kicker it was found that this component itself was characterized by harmful HOMs trapped inside the surrounding tank. An overdamped RF cavity used as longitudinal kicker has been recently proposed [20] and tested at LNF. It is characterized by a peak shunt impedance of about 750 W and a bandwidth of 220 MHz; longitudinal and transverse HOMs of such a cavity are also strongly damped. Time domain simulations have confirmed the effectiveness of such a device [21].

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BEAM DYNAMICS PROBLEMS IN A MUON COLLIDER

R.B. Palmer[1],
Brookhaven National Laboratory, P. O. Box 5000, Upton, New York 11973-5000

INTRODUCTION

Lepton (e^+e^-) colliders have the valuable property of producing simple, single-particle interactions with little background, and this property is essential in the exploration of new particle states. However, extension of e^+e^- colliders to multi-TeV energies is severely performance-constrained by beamstrahlung, and cost-constrained because two full energy linacs are required[1]. On the other hand μ's (heavy electrons) have negligible beamstrahlung, and can be accelerated and stored in rings.

The liabilities of μ's are that they decay, with a lifetime of 2.2×10^{-6} s, and that they are created through decay into a diffuse phase space; in addition the decay products are likely to create large backgrounds at the final focus points making the detector design a challenge. The first problem is overcome by rapidly increasing the relativistic γ factor; at 2 TeV for example, the lifetime is 0.044 s, sufficient for storage-ring collisions. The second can be dealt with by cooling. The possibility of μ colliders has been introduced by Skrinsky et al.[2], Neuffer[3], and others. More recently, several workshops and collaboration meetings have greatly increased the level of discussion[4],[5]. In this note we discuss the beam dynamics problems encountered in one particular scenario for a 2 + 2 TeV collider[7]. Tb.1 shows parameters for the candidate design. This scenario includes a high-intensity μ-source, μ-cooling, and acceleration and storage in a collider. The complete cycle is repeated at 30 Hz.

[1]PALMER@BNL.GOV

Table 1: Summary of Parameters of 2 + 2 TeV $\mu^+\mu^-$ Collider

Beam energy	TeV	2
Beam γ		19,000
Repetition rate	Hz	30
Muons per bunch	10^{12}	2
Bunches of each sign		1
Normalized rms emittance ϵ_n	mm mrad	50
Average ring mag. field B	T	6
Effective turns before decay		900
β^* at intersection	mm	3
Luminosity $\mathcal{L}$	cm^{-2}s^{-1}	10^{35}

SYSTEM COMPONENTS

Proton Driver

The μ-source driver is a high-intensity rapid-cycling (30 Hz) proton synchrotron. The protons are targeted to produce pions, which are then allowed to decay into the required muons. A recent study[6] suggests that an optimum proton energy may be 10 GeV. In this case, with some conservatism (we allow an extra factor of two for potential loss), we require a total of about 10^{14} protons at 30 Hz. This specification is almost identical to that studied[8] at ANL for a spallation neutron source. The only difference is the number of bunches: 2 of 5×10^{13} instead of 1 of 10^{14}. One of which is for making μ^-, the other for μ^+. Both are brought on to the same target.

In order to minimize the longitudinal emittance of the produced pions it is desirable to target relatively short bunches of protons with rms bunch length less than 3 ns (1 m). An RF sequence must thus be designed to phase rotate the bunch prior to targeting. The total final momentum spread, based on the ANL parameters (95% phase space of 4.5 Vs per bunch), is modest (6 %, or 2.5 % rms), but if the compression were to take place in a relatively low-field, fast-cycling synchrotron, then the space charge tune shift just before extraction would be very large (≈ 1.5). A separate superconducting compression ring is thus needed (reducing the tune shift to ≈ 0.15), or some other more exotic solution must be found.

Target and Pion Capture

The target could be Cu (24 cm by 12 mm diameter) or Be (70 cm by 2 cm diameter), although Cu would be preferred because of its higher pion multiplicity. Pions are captured from the target by a high-field hybrid solenoid that surrounds it. A field of 28 T, and radius of 7.5 cm are consistent with what is currently available[9]. The pions can then be matched, using a suitable tapered field[10] into a long (350 m) solenoidal decay channel. A field of 7 T and radius of 15 cm for the decay channel seems reasonable and matches the capture acceptance.

Monte Carlo studies indicate that such a system captures almost 40% of the produced pions. Using the Wang[11] formula for pion production, the program calculates a yield of $0.22\,\mu$'s, of each sign, per initial proton. However, for a Cu target, a higher multiplicity is expected and would consequently give, yet, a higher yield.

Phase Rotation Linac

The pions, captured by a solenoid focus system (and the muons into which pions decay) have a huge energy spread, from 0 - 3 GeV (rms/mean $\approx$ 100%), and would be difficult to transport and to handle in any subsequent system. It is thus proposed to introduce a linac along the decay channel, whose frequencies and phases are chosen to decelerate the fast particles and accelerate the slow ones; i.e. to phase rotate the muon bunch.

After phase rotation the rms bunch length is 6 m, and the rms momentum spread is reduced to about 15 %. Unfortunately at such frequencies the linacs cannot phase rotate both signs in the same bunch: hence, the need for two bunches. The phases must be set to rotate the μ^+'s of one bunch and the μ^-'s of the other.

Ionization Cooling

For collider intensities, the phase-space volume must be reduced within the μ lifetime. Cooling by synchrotron radiation, conventional stochastic cooling and conventional electron cooling are all too slow. Optical stochastic cooling[12], electron cooling in an plasma discharge[13] and cooling in a crystal lattice[14] are being studied, but are not by any means certain. Ionization cooling of muons[15] seems relatively straightforward.

In ionization cooling, the beam loses both transverse and longitudinal momentum as it passes through a material medium. Subsequently, the longitudinal momentum can be restored by coherent reacceleration, leaving a net loss of transverse momentum. Ionization cooling is not practical for protons and electrons because of nuclear scattering (p's) and bremsstrahlung (e's) effects in the material, but is practical for μ's because of their low nuclear cross section and relatively low bremsstrahlung.

This cooling is obtained in a series of about 20 cooling cells. Each cell consists of a section of Be ($\approx 0.7\,m$) or Li ($\approx 2\,m$) placed in a region of the lattice with a low $\beta_\perp$, a linac ($200\,MeV$), and a matching bend with dispersion where wedges can be introduced to interchange longitudinal and transverse emittance.

For the early cells, when the emittance is still large, a sufficiently low $\beta_\perp$ can be obtained with solenoids. In later cells, when the emittance is lower and a lower $\beta_\perp$ is required, current carrying cooling rods ($\approx$ 2 m long, if Li) which serve both to maintain the low $\beta_\perp$ and reduce the beam energy could be employed. In a Li rod, with surface fields of 10 T (as achieved in Li lenses at Novosibirsk, FNAL and CERN [16]), a $\beta_\perp$ of 1.7 cm can be achieved, and the emittance is reduced to about 10^{-4} m. But this is still a factor of ≈ 3 above the emittance goal of Tb.1. A final stage might consist of short sections of Be at even lower $\beta_\perp$ insertions. Alternatively, the additional transverse emittance reduction can be obtained by cooling more than necessary longitudinally, and then exchanging transverse and longitudinal phase-space with a thick wedge absorber.

In all these cells, lattices are required with adequate momentum acceptance, matching in and out of the low beta insertions, appropriate momentum compaction and control of emittance growth from space charge, wake field and resistive wall effects. In addition it would be desirable to economize on linac sections by forming groups of cells into recirculating loops.

Acceleration

Following cooling and initial bunch compression (of the order of 0.2 m) the beams must be accelerated to full energy (2 TeV). A single linac of this energy would work, but would be expensive, and would not utilize our ability to recirculate μ's in rings. A conventional synchrotron cannot be used because the muons would decay before they were accelerated. A fast cycling synchrotron could be used but, because it would be limited to low magnetic fields, would be very large. The best solution seems to be a recirculating linac (similar to CEBAF). If acceleration is done in 20 recirculations, then only 100 GeV of linear accelerator is required.

In practice, a cascade of at least 3 recirculating linacs (e.g., with maximum energies of 20 GeV, 200 GeV and 0.2 TeV) would be needed. The μ-bunches would be compressed on each of the return arcs, and be bunched finally to the required length of 3 mm at full energy. The two higher energy recirculators must be superconducting for two reasons: the store time is far too long for conventional cavities, and the wall power consumption with conventional cavities would be too high. The total muon beam power is 38 MW. It is hoped to achieve at least 30% efficiency with superconducting cavities, giving a wall power consumption of 127 MW. The gradients assumed are below those assumed for TESLA. They may be over conservative in view of the shorter pulse duration in this application than assumed in TESLA. The muon linac beam dynamics is complicated by transverse HOM because of the large number of muons per bunch, about a factor of 100 higher than electrons in TESLA. The HOM power is estimated to be $\approx 100\,\mathrm{W/m}$. As in the TESLA design, this would required a coupler section to remove this HOM power.

At the higher energies, space charge effects will not be a problem, but as the bunches are compressed wake field and resistive wall effects become serious. Preliminary studies suggest that, with a slight decrease in Q/Z (by widening the irises), and with BNS damping, such effects can be controlled.

μ Storage Ring

After acceleration, the μ^+ and μ^- bunches are injected into the 2- TeV storage ring, with collisions in two low-β^* interaction areas. The beam size at collision is $r = \sqrt{\epsilon_n \beta^*} \approx 2\,\mu m$, similar to hadron collider values. The bunch populations decay exponentially, yielding an integrated luminosity equal to its initial value multiplied by an "effective" number of turns $n_{effective} = 150\ B$, where B is the mean bending field in T. With 9 T superconducting magnets, an average B of 6 T might be obtained, yielding an $n_{effective} \approx 900$. The magnet design is complicated by the fact that the μ's decay within the rings ($\mu \rightarrow e\bar{\nu}\nu$), producing electrons whose mean energy is approximately 1/3 of that of the muons. These electrons travel to the inside of the ring dipoles, but radiate a substantial fraction of their energy, as synchrotron radiation, towards the outside of the ring. A warm tungsten, or other heavy metal, liner of about 2 cm thickness will be required to intercept this radiation.

A relatively conventional lattice has been designed [17], but the rf requirements to maintain the required 3 mm rms bunch length in such a lattice would be large. A low momentum compaction lattice of the type discussed by S.Y. Lee et al[18] might thus be preferred. A preliminary study[19] of resistive wall impedance instabilities indicate that 3 mm bunches of 2×10^{12} muons would have an unacceptable transverse microwave instability. A fully isochronous lattice, with conventional BNS[20] damping, would solve the problem, but is not possible because of the effects of the large angles of trajectories in the insertion regions. The proposed solution is to employ RF quadrupoles to apply the BNS damping[21].

Another problem is the design of chromatic correction for the very low beta ($\beta^* = 3\,mm$) insertions. A triplet design would have maximum beta's of 200-400 km in both directions, and chromaticity ($1/4\pi \int \beta dk$) of 2000-4000. If no correction is employed, as in the lattice in reference [17] then the momentum acceptance ($\approx 10^{-5}$) is much less than that easily obtained by the ionization cooling. It seems clear that a local correction of chromaticity[22] would be required. A preliminary automated[23] study of such a correction system, using a doublet at the final focus, gave momentum acceptances of $\pm 0.1\,\%$ and $\pm 0.6\,\%$ in the two directions, where the β_{max}'s were 1.2 and 0.2 million m respectively. A similar design with the triplet (β_{max}'s both 0.4 million m) would be expected to give about $0.3\,\%$ in both directions. More sophisticated designs [24] should do better. But this estimate is only for a single pass device like a linear collider; the performance for a storage ring remains to be seen.

Detector Background

For the physics user there is a problem of background from μ-decays that occur near the intersection point; and from scattering of any muon halo circulating in the ring.

A first Monte Carlo[25],[26] study assumed a final triplet with interspersed strong dipole bending magnets. These magnets, it was hoped, would help deflect background tracks coming from further down the beam. No chromatic correction scheme or machine lattice was included in this study. The maximum background track densities initiated by muon decays were found on the inside of a vertex detector, and were 480 per cm^2. This is high, but if such a detector were formed of 20 μm by 20 μm, pixels, then the occupancy in these pixels would be only 0.19 %, and the background, consisting mostly of very low energy electrons, could probably be eliminated in track reconstruction.

In a second study of this problem [27], it was found that much of the background in the first study had come from synchrotron radiation of electrons in the bending magnets near the intersection point. Removal of these magnets reduced the peak track densities by factors of between 2 and 5, and reduced the total by an even larger factor. Clearly, more studies are needed, but it seems probable that ways will be found to further improve the situation.

These studies have also shown that severe background can be generated by scattering of tails in the muon beam. A collimation system will be required in a straight section far from the detectors (presumably a quarter way around the ring). No such system has yet been designed.

CONCLUSION

- The scenario for a 2 + 2 TeV, high luminosity collider is by no means complete. Much work remains to be done. More theoretical studies are needed on optimization of pion production, muon phase rotation, cooling scenarios, the collider lattice, radiation effects, and detector background. Technical studies are needed on the design of liquid lithium rods, targeting, high field solenoids, low-frequency high-gradient linacs, multi-beam magnets for the recirculation, and high field magnets for the collider. But no obvious show stopper has yet been found.

- An experimental demonstration of ionization cooling should be made. A letter of intent for such an experiment has been submitted to the BNL AGS.

- If the problems can be overcome, then a $\mu^+\mu^-$ collider may be the best route to study physics at energies higher than those accessible at the LHC or NLC. A 2 + 2 TeV $\mu^+\mu^-$ machine with a luminosity of 10^{35} $cm^{-2}sec^{-1}$ would have a physics reach greater than either of these machines, yet it would be small enough to fit on the BNL or FNAL sites. Its relative cost, however, remains to be seen.

- Efforts are now needed on the design of a "Demonstration Muon Collider" that would employ an upgraded existing proton source, could have a center of mass energy of 0.5 TeV, and might have a luminosity of the order of 10^{32} $cm^{-2}sec^{-1}$. Such a machine, besides being a stepping stone to a higher energy machine, would have the unique capability of searching for the direct channel production of the supersymmetric Higgs particles A and H.

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Letters to the Editors

[from J.L. Laclare (bouvet@esrf.fr)]

Dear Dr. Hirata,:

As a member of the Beam Dynamics Panel, I have often participated in discussions as to what topics should be covered by ICFA workshops, particularly with regards to specific versus broadband items.

Within the panel, and given my job and experience as Project Director of the ESRF, I feel that I act as a representative of the accelerator community for synchrotron light. However, I have been given to understand, although this has not been explicitly mentioned, that synchrotron light is not a fundamental issue for ICFA. For example, when starting to organise the workshop to be held in Grenoble next year on 4th generation light sources, I detected some reticence on the subject.

Yet, I consider that in terms of future accelerators, synchrotron light sources will have a large share, for they are becoming more and more widely spread. Indeed, they concern a scientific community which is equally as large as the one of colleagues participating in elementary particle physics.

In my opinion, therefore, if we cannot find a way of accommodating these topics within the beam dynamics panel, then why not create a panel specifically dedicated to light sources? Obviously it is up to the ICFA to decide, but I feel that this is a discussion which certainly merits going into in depth.

Kind regards,
Jean-Louis Laclare

[from E. Forest (forest@kekvax.kek.jp)]

Hi! Kohji:

Around 1992 I attended a workshop at BNL. At that workshop the issue of C++ and its usage in tracking codes was introduced by Michelotti. In all fairness this was not the first time he had made a case for it. But unlike previous times a movement started in which I was initially involved. I would like to tell your readers why I was excited then and why I am worried now.

Object oriented programming allows us to do two things easily. First it allows us to hide private data which the user should not see or modify. For example, if a common block uses “pi” for the famous constant π, there is always a chance, in FORTRAN, that a subroutine appended by a user changes this constant inadvertently. Secondly, because of data encapsulation and the presence of well-defined and self-contained objects (data+procedures acting on the data), the resulting code is easily maintained and extendable. Of course there is more to it and I am not an expert on computer languages: so forgive me.

In any event, one can “apply” object oriented programming to any code. Indeed one can take famous codes and rewrite them in an object oriented language. In doing so we use the object oriented language as a program manager. MAD is a program manager written in FORTRAN: it contains a “zillion” routines which interact with each other without stepping on each other foot. It is a remarkable achievement to have such a thing written in FORTRAN. Obviously modern languages would permit this more or less for free.

Fortunately we can do much better and we should do much better. It is clear to those who know me well— John Irwin, Alex Chao, Dave Robin, etc... that within weeks of arriving at SSC. It did "table rase" with accelerator theory. There is gotta be a better way to structure the "Courant-Snyder" theory so that it formally encompass effects which are linear, coupled, nonlinear, radiative and stochastic! (Incidently the Bologna group of Turchetti did try to propagate similar ideas at CERN with even less success than I had in the USA). Let me quote Ira Pohl from the University of California at Santa Cruz:

> "Given an empty slate–*tabula rasa*–no simple methodology exist for OOP design, because each design must be strongly tied to the problem domain and reflect its abstractions. Discovering these abstractions is a design philosophy we call *Platonism*. In the Platonic paradigm there is an ideal object. For example, imagine an ideal chair in the heavens and attempt to describe its characteristics. These would be the characteristics shared by all chairs."

The best use of object oriented programming occurs when the objects defined in the code match as closely as possible the objects present in our theories. For years it has been clear to me that there is a way to structure the "single particle dynamics part" of accelerator codes so as to take full advantage of an object that is both physical and mathematical (if certain restrictions apply). Grossly speaking this physical object is an abstract beam line[1] and the mathematical object is the map across this beam line. And, of course, the smallest beam lines may contain only a single magnet or even nothing.

Strictly speaking there are no reasons a priori why the physical magnet, the actual piece of hardware, should have a well defined mathematical counterpart. In fact, it would not if all the fringe fields extended from magnet to magnet. To see this we must take a slightly mathematical/philosophical point of view: suppose for one instant that we only had access to the "Lagrangian of the laboratory". How would the magnets manifest themselves? They would appear as very localized fluctuations in positions of the Lagrangian– places where the partial of L with respect to position is non zero. Cavities would be fixed localized fluctuations that vary with time. If, for some reasons, these fluctuations merge and interact with one another (through Maxwell's Equations), it is no longer possible to construct a theory based on magnets as independent objects. Of course we may still talk about maps through sections of the ring, but this map (i.e. the recipe to propagate rays through this not so-localized fluctuation) cannot be moved independently of its neighbors For example, if an integration step represents a lamination and this lamination is misaligned, then piece of code

[1]It is an arc of circle with frames of references at both ends and a fiducial frame in the middle on which the actual magnet/map is attached. The rotational properties of actuals magnet lowered into this "beam line" are inherited from the beam line. Thus a quadrupole (ALS) can be a bend and vice-versa. The actual decoupling of the beam line and the actual magnet is an essential aspect of the theory.

```
x=x-d_x
y=y-d_y
call quad(k,ds,x,y,px,py)
x=x+d_x
y=y+d_y
```

may be meaningless simply because the motion of one lamination has messed up the field elsewhere in account of Maxwell's equations.

The presence of space charge or impedance effects is far more destructive to the magnet/object because the entire force is non-localized and depends on the data being propagated[2]. Fortunately most of our designs involve localized magnets and even very localized collective effects: beam-beam. Thus, to a very good approximation most magnets are functionally individual entities from the point of view of single particle dynamics. There is another intangible advantage in structuring a theory around concepts which are metaphor of our every day experience. For years I have been saying that I could grind out all sorts of thing in my first years at SSC, despite a mediocre intellect[3], because I was dealing with a simple theory: I had never read any accelerator physics text and that gave me an advantage! Like persons of mediocre ability, I could not explain it to others. But, here came John Irwin and he has done a fantastic job at SLAC lecturing on the rudiment of the theory. In particular how the mathematical objects of the theory (map, Lie operators, etc...) allow us to deal with the "magnet" directly. This should not be a surprise to the students of modern philosophy; a theory based on common metaphors of the language has a greater intuitive power. Let me quote the famous linguist Lakoff on this issue:

> "The most important claim we have made so far is that metaphor is not just a matter of language, that is, of mere words. We shall argue that on the contrary, human *thought processes* are largely metaphorical. This is what we mean when we say that the human conceptual system is metaphorically structured and defined. Metaphors as linguistic expressions are possible precisely because there are metaphors in a person's conceptual system."

And Lakoff later says in his book:

> "The intuitive appeal of a scientific theory has to do with how well its metaphors fit one's experience."

As far as I am concerned a theoretical framework which fits the metaphor exists; I am actually writing a book on it. I have no doubts that it is superior computationally and analytically. After all, a great deal of Oide's SAD is based on the same idea. In fact, the introduction of moment maps for the radiation process was first implemented at KEK in a real tracking code. Personally, I never understood a word of all half-baked formalisms

[2] I mentioned the "Lagrangian of the laboratory." Bengtsson pointed out to me that an abstract class must exist in which the single particle beam line is created. In this class objects relevant to collective effects would exist in parallel with our single particle beam line and exchange information at the data level: coordinates within a bunch for example. This is essential if one models the entire accelerator from gun to detector.

[3] I challenge anyone in the field to produce a worse high school record!

such as Sands integrals until I stumbled on your work and that of Oide (actually, Chao's work was also of great help.) Concerning the moment map, the OOP programmer would say that stochastic effects "know" how to propagate itself through a beam line. By contrast where is the beam line in perturbative calculations in terms of Fourier modes à la Guignard? Everything that is tangible, simple and intuitive has been "Fourier transformed away!"

So, here we are, and the issue is whether or not Irwin and the rest of SLAC will proceed with physical and mathematical rigor in the foreground; or they will succumb to the MADization of their C++ project. I am not against interfaces which allow someone to describe a beam line using the so-called Standard Input Format[4]; but I will be very sad if SLAC compromises from the onset in order to facilitate the absorption into their C++ code of every Tom, Dick and Harry's routine. In the end, physics classes that match the magnet metaphor can be constructed and they will not interfere with a parser based on the Standard Input Format (should one care about it). They will also permit the incorporation of less than consistent routines (should one care about them). The theory metaphorically structured around a magnet/object does not allow much freedom of implementation. No matter how primitive these classes may look at first (take a look at the ones Bengtsson and I engineered), it is imperative that they have in them a structure capable of supporting the beam line as an independent object; an object which knows how to rotate itself, to picture itself, to propagate data through itself (Data=rays,TPSA, stochastic moments, Lie operators, etc...). This task cannot be done by keeping physics and mathematical knowledge in the background. Paraphrasing Pohl I state that a design relevant to beam dynamics must be **strongly** tied to the domain of accelerators and reflects its abstraction. This is the goal Bengtsson and I had set for ourselves before unfortunate events killed everything.

I should finish with an anecdote on the moment maps. When Irwin ask me if I had the Oide effect[5] in our "codes", I replied: "we have classical radiation implemented since 1989 or so." John said yes, but "can it do it in a quad?" I got furious: when I say it is in the code there is no two ways about it. I did not say: "*a formula for it is in the code*" but "*it is in the code*." The moral of the story is this: if the correct theoretical framework is in place for tracking, and if TPSA/DA/LIE tools are accessible, then the very moment one puts radiation into the code (i.e. add one line to the integrator), then we know immediately how to get all the stuff of Sands and more. The theory and the computer classes which are a reflection of this theory *do not allow* any implementation but the correct one. In contrast, CERN sends someone at tax payers' expense to announce to the Americans that such a marvel is now in MAD. I am sorry but this is contemptible! When a code is structured so that the same algorithm (thanks to TPSA/DA/LIE package) can compute any quantity in perturbation theory. Should we send someone to CERN each time we modify the "input deck?" The apparent complexity of these calculation is a symptom of a badly design theory.

So in conclusion, I urge my colleagues at SLAC and elsewhere to construct with great care the physics classes of this new code before a genetically crippled monster is created.

Regards,
Étienne Forest

[4]One should be aware that the Standard Input Format is insufficient: but this does not matter unless it becomes a guide for the design of physics classes.

[5]Radiation on an arbitrary trajectory.

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

The Workshop on Single-Particle Effects in Large Hadron Colliders will be held from 15 to 21 October 1995 in Montreux, Switzerland. The goal is to review and discuss the present understanding of single-particle effects, both theoretical and experimental, from the large hadron colliders which were or are in operation, i.e. HERA, Sp$\bar{p}$S, and Tevatron, and to analyze its consequences for the design of future hadron colliders, in particular the LHC. The program consists of initial plenary talks, presenting the current understanding, three working groups on “Maps”, “Dynamic Aperture”, and “Errors”, respectively, and a final plenary session, summarizing the findings of the workshop. Proceedings will be published.

Registration will be limited. The PREFERRED way of expressing your interest is by submitting an “Online Form” on the World Wide Web. It is reached through the home page of LHC95 which has the URL `http://hpariel.cern.ch/keil/lhc95.html` and also provides a more detailed program. However, an e-mail message to LHC95 at CERNVM.CERN.CH, including your name, full postal address, fax and telephone numbers, and the title of a possible talk about a subject related to the workshop, is also accepted.

9^{th} ICFA WORKSHOP ON ADVANCED BEAM DYNAMICS

Beam Dynamics and Technology Issues for $\mu^+\mu^-$ Colliders

October 15–20, 1995 – Montauk, New York, U.S.A.

Interest in high energy muon colliders has grown considerably in the accelerator community since the *2^{nd} Workshop on Physics Potential and Development of $\mu^+\mu^-$ Colliders* last November in Sausalito. This workshop will continue to examine the main issues affecting the design, realization and physics potential of a $\mu^+\mu^-$ collider.
We plan to have the following working groups:

1)	Muon Production:	Proton source, targeting, π capture and decay. Phase rotation linacs.
2)	Muon Cooling:	Various cooling schemes (ionization, optical stochastic, electron cooling and other novel ideas) and their experimentation.
3)	Machine Design:	Pre-acceleration, recirculating accelerators, collider ring, low beta insertion. Background and heating problems.
4)	Physics/Detector:	Physics at (250 + 250) GeV and (2 + 2) TeV. Trade-off between luminosity and polarization and luminosity and energy spread. Design of detectors.

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ICFA beam dynamics panel

Local Organizer: Juan Gallardo (gallardo@bnlays.bnl.gov)
Contact: Kathleen Tuohy (tuohy@bnlcl1.bnl.gov)
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Organized by the Center for Accelerator Physics, Brookhaven National Laboratory.

For additional information contact Kathleen Tuohy at tuohy@bnlcl1.bnl.gov or
on the *World Wide Web* open URL, http://www.cap.bnl.gov/~cap/mumu/important.html

10th Advanced ICFA Beam Dynamics Workshop on 4th Generation Light Sources

22-25 January 1996
European Synchrotron Radiation Facility, Grenoble, France

The International Committee for Future Accelerators (ICFA) Beam Dynamics Panel recently put forward the idea of holding a workshop on 4th generation light sources, which was received very positively, for it is unanimously felt that now is the right time to organise such an event. The European Synchrotron Radiation Facility in Grenoble was also considered as the ideal place to hold it. In collaboration with ICFA, therefore, the ESRF is organising the workshop, to be held on its site in Grenoble from 22 to 25 January 1996, inclusive.

The workshop will begin after lunch on 22 January, with a full afternoon's plenary session. This will include some introductory talks to the main topics and end with the setting up of working groups. These will meet for the next two days (23-24/1), after a short one hour plenary session each morning. The last day (25/1) will be devoted to the reports of the working groups and to the concluding remarks.

After consultation with the Programme Committee (cf. hereunder), the following themes have been chosen as working group topics :

1. Scientific opportunities for 4th generation light sources A large majority of committee members representing low energy sources felt that in fact two groups on scientific opportunities would be needed, ie one devoted to VUV/soft x-rays and the other to hard x-rays. The two persons introducing the topic (one expert for VUV/soft x-rays and the other one for hard x-rays) will extrapolate from what has already been done, and what is currently available, to arrive at the qualitatively different features of the 4th generation source. Quantitatively it is not possible to talk in terms, say, of an improvement of a factor of 10, for up to two orders of magnitude have already been achieved in some 3rd generation machines compared to their original specifications. What must be defined is a case out of reach of the third generation. Another important aspect is to what extent beamline optics in general and detectors in particular can follow such a leap forward.

2. Lattice and stability in storage rings This topic will address diffraction-limited storage rings and enhanced stability problems. There is a need, as already suggested, to gain a significant factor on emittances of the light beam : novel lattices, beam cooling, etc... Extrapolating from the behaviour of the existing large machines which could be run at a much lower energy could constitute an excellent basis for speculation. Should we aim at a low (and perhaps negative) alpha to produce short pulses?

3. Current, lifetime, time structure in storage rings Extremely short bunches are becoming fashionable and a report will be made of the conclusions of the Brookhaven micro-bunches workshop to be held in September 95. If brilliance is the figure of merit, then a low emittance lattice will be essential. However, the B meson factories are being designed to run currents about 5 times higher than existing 3rd generation light sources. High current can therefore be an asset. Long lifetime conflicts with high current and low emittance. Is the solution topping up?

4. Linac sources What are views on the evolution of linac sources? How far could they go beyond the SLAC proposal or the Tesla one? Could we make use of Compton scattering to produce short and intense pulses of x-rays? Does the small cross section definitively restrict the number of photons per pulse and the quality of the radiation? (more powerful lasers, even better linac beams, recirculators ...)

5. Storage Ring FELs It was thought in the past that a storage ring, because of radiation damping and small achievable emittances, particular in 3rd generation machines, would be ideal to accommodate a Free Electron Laser. What perspectives are there for the 4th generation?

6. Insertion devices The need to talk about existing achievements has been acknowledged (spectrum shimming, phasing of segments, all sorts of polarisation), as well as future developments : short periods, minigap, flexible chambers, in-vacuum IDs, RF and other "exotic" undulators.

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

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The full registration procedure is available on world wide web (url = http://www.esrf.fr). The fee for participating in the workshop, including the proceedings, is 800 FF.

Please address all queries to

T. Bouvet
e-mail bouvet@esrf.fr
tel 76 88 20 12
fax 76 88 20 54"
ESRF, B.P. 220, 38043 Grenoble cedex, France

ICFA Beam Dynamics Newsletter

Instructions to the authors

May 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.

The categories of articles in the newsletter are the following:

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

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

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

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

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

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This issue will appear also in the home page of DESY library:
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The views expressed in this newsletter do not necessarily coincide with those of the editors. The authors are responsible for their text.