Report of the Group on Beam-Beam Effects in Circular Colliders

Author
Furman, M A

Publication Date
1991-05-01

LBL-31015

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

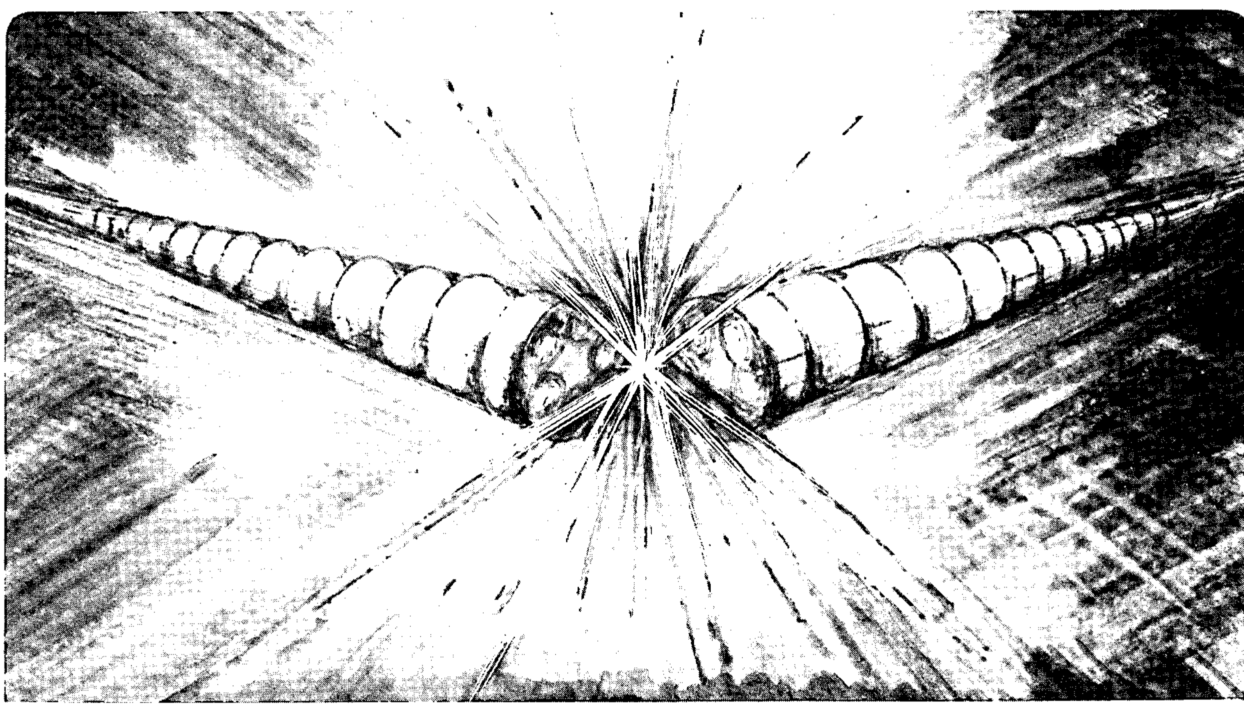
Accelerator & Fusion Research Division

Presented at the 7th ICFA Workshop on Beam Dynamics, Los Angeles, CA, May 13–16, 1991, and to be published in the Proceedings

Report of the Group on Beam-Beam Effects in Circular Colliders

M.A. Furman

May 1991



Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

DISCLAIMER

LBL-31015
ESG Note-145

REPORT OF THE GROUP ON BEAM-BEAM EFFECTS IN CIRCULAR COLLIDERS*

MIGUEL A. FURMAN
Accelerator and Fusion Research Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720, U.S.A.

ABSTRACT

We present a summary of the discussions and conclusions of the working group on beam-beam effects for circular colliders. This group was part of the larger beam-beam dynamics group at the 7th ICFA Workshop on Beam Dynamics, on the subject "Beam-Beam and Beam-Radiation Interactions," held at UCLA, May 13–16, 1991.

1. Summary of Issues Considered

There were discussions on two topics: new collider design, and simulation issues. In the first category, Ivanov[1] gave a presentation on Novosibirsk's ϕ factory project, a 510 MeV $\times$ 510 MeV machine with a peak luminosity of (3–10) $\times 10^{33}$ cm^{-2} s^{-1}, scheduled to be completed in 1997. He also mentioned an asymmetric B factory, a 4 GeV $\times$ 7 GeV machine with a luminosity of 5×10^{33} cm^{-2} s^{-1}.

Most of the time spent by the group was devoted to discussions on beam-beam simulation issues. Ivanov's talk on the ϕ factory included a section on simulation results. Hirata[2] gave a talk, at a plenary session of the workshop, emphasizing the coherent modes approach to the beam-beam problem. Furman[3] presented results on beam-beam simulations for the proposed SLAC/LBL/LLNL B factory, a 3.1 GeV $\times$ 9 GeV machine with a luminosity of 3×10^{33} cm^{-2} s^{-1}. Koga[4] presented results of a study performed with a one-dimensional particle-in-cell code (PIC) for the SSC. Irwin[5] briefly described an "acceleration" algorithm that allows one, in principle, to shorten considerably the simulation time required to study the development of tails in a beam. Ziemann[6] gave a talk on generalizations of the Bassetti-Erskine[7] calculation of the electric field produced by a modified Gaussian charge distribution (Gaussian $\times$ polynomial, with rotated axes) in the context of applications to single-pass colliders such as the SLC. A simulation issue of long-bunch effects was brought up by Ivanov in his talk, emphasizing the detrimental effect of the longitudinal electric field; the importance of this effect was apparently first pointed out by Derbenev and Skrinsky;[8] more recently it has been addressed by Hirata *et al.*[9]

* Work supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Division, of the U.S. Department of Energy under Contract no. DE-AC03-76SF00098.

2. Discussions and Conclusions

The members of the group opined that the main problem facing beam-beam simulations at present is the reliable study of the tails of the beam distribution. The tails determine the beam lifetime and are, therefore, important in determining the average luminosity. This is a key figure of merit for presently proposed "factories," whose designs emphasize reliability of operation and high luminosity; hence the renewed interest in this issue.

The core of the beam, which determines the short-term average luminosity, is studied effectively with "strong-strong" simulations, in which both beams are represented by a few hundred "superparticles." The beams evolve dynamically under their mutual influence, and the time scale that determines the approach to equilibrium is the damping time, which is typically several thousand turns. Thus strong-strong simulations for ~20,000 turns are deemed reliable in the study of the beam core. PIC codes are in principle more accurate because they solve Maxwell's and Newton's equations approximately consistently during the beam-beam collision. These simulations are therefore more interesting but also, of course, much more time-consuming.[4,11] Another kind of calculation often used involves "weak-strong" simulations, in which the "weak" beam evolves dynamically while the "strong" beam's distribution is held fixed. These simulations are obviously much faster than strong-strong simulations, and are very useful, for example, in performing tune scans and in detailed studies of resonance effects. The consensus of the group was that weak-strong simulations are reliable when the more realistic strong-strong simulations show that, for the same set of parameters, only one of the beams has significant dynamical evolution. This is actually the case seen in many experimental situations and in strong-strong simulations, hence the usefulness of this approximation.

The tails of the beam, on the other hand, involve particles at large amplitude and very long time scales. In this case, strong-strong and even weak-strong simulations are thought to be hopeless with present-day computers, at least if one wants results with a reliability comparable to that usually achieved in beam core studies. Numerical "acceleration" algorithms[5,10] are promising in this respect, although they need to be tested further for reliability and accuracy. Although interesting analytic work has been done for simplified models,[12] the members of the working group expressed the belief that the dynamics of the tails is probably not universal because it probably depends on the lattice and machine nonlinearities. They opined, in conclusion, that a coherent and useful body of knowledge is lacking in this area of long-time dynamics of beam tails.

The Novosibirsk ϕ factory design, mentioned above, has intense round beams with a bunch length comparable to β^*, the beta-function at the interaction point (all four emittances are equal, and all four β^*'s are equal). From the perspective of beam-beam dynamics, the round shape is thought to be advantageous over the flat shape because simulations suggest that it allows achieving a higher[13] beam-beam parameter ξ. Furthermore, the equality of the four beta-functions implies that there is no modulation of ξ

with the path length s. However, the strong variation of $\beta(s)$ near the interaction point produces a nonzero dB_θ/dt (B= magnetic field) and therefore a nonzero longitudinal electric field E_z. The resultant longitudinal defocusing force can lead to particle losses, which may be a problem for beam lifetime.[8] This may, in turn, impose a constraint on the lowest practical value that can be chosen for β^* for a given beam parameter choice. The parameter regime for which the effect is important should be clarified, and the effect included in simulations. Other consequences[14] of this strong modulation, generally referred to as the "hourglass effect," include a possible reduction of the luminosity, and a modulation of ξ with s whenever the four β^*'s are not all equal. This modulation implies that particles at the head and tail of the bunch can have substantially larger values of ξ than the particles at the center of the bunch, which may affect the beam lifetime. Apparently none of the beam-beam studies done for any of the proposed "factories" have yet included this longitudinal electric field in strong-strong simulations.

It also seems to be the case that none of beam-beam simulations for any of the proposed B factories have yet included the effects of lattice nonlinearities. However, simulations and experimental measurements for CESR have shown that, at least in this case, sextupole magnets do not have a significant effect on the luminosity performance.[15] It is probably the case that magnet nonlinearities have a more important effect on the beam lifetime, especially if the machine operates near the beam-beam limit. At present, this interesting issue remains open.

3. Acknowledgements

I am grateful to S. Rajagopalan for help in summarizing the group discussions, and to M. Zisman for valuable comments.

4. References

1. P. Ivanov, these proceedings.

2. K. Hirata, these proceedings.

3. M. A. Furman, these proceedings; see also *An Asymmetric B Factory Based on PEP: Conceptual Design Report,* LBL PUB-5303/SLAC-372/CALT-68-1715/UCRL-ID-106426/UC-IIRPA-91-01, Feb. 1991.

4. J. Koga, these proceedings; see also T. Tajima and J. Koga, Proc. *Nonlinear Dynamics and Particle Acceleration*, Tsukuba, Oct. 1990, Y. Ichikawa and T. Tajima, eds., AIP Conf. Proc. **230**, 236 (1991); T. Tajima and J. Koga, *Part. Accel.* **28**, 125 (1990).

5. J. Irwin, these proceedings, and Proc. *Third Advanced ICFA Beam Dynamics Workshop,* Novosibirsk, May–June 1989, p. 123.

6. V. Ziemann, SLAC–PUB–5582, June 1991.

7. M. Bassetti and G. A. Erskine, CERN-ISR-TH/80-06.

8. Ya. S. Derbenev and A. N. Skrinsky, Proc. *Third All Union Particle Accelerator Conf.*, Moscow, Oct. 2–4, 1972, p. 386 (in Russian).

9. K. Hirata, H. Moshammer, F. Ruggiero and M. Bassetti, in *Beam Dynamics Issues of High Luminosity Asymmetric Collider Rings*, A. M. Sessler, ed., AIP Conf. Proc. **214**, 389 (1990).

10. S. Milton, to appear in the Proceedings of the 1991 Particle Accelerator Conference, San Francisco, May 1991.

11. S. Krishnagopal and R. Siemann, to appear in the Proceedings of the 1991 Particle Accelerator Conference, San Francisco, May 1991.

12. J. Tennyson, Physica **5D**, 123 (1982); A. L. Gerasimov, Physica **D41**, 89 (1990); A. Gerasimov and R. Siemann, Proc. *Workshop on Nonlinear Problems in Future Particle Accelerators*, Capri, Italy, 1990, W. Scandale and G. Turchetti, eds., World Scientific.

13. S. Krishnagopal and R. Siemann, in *Beam Dynamics Issues of High Luminosity Asymmetric Collider Rings*, A. M. Sessler, ed., AIP Conf. Proc. **214**, 278 (1990), and *Phys. Rev.* **D41**, 2312 (1990).

14. M. A. Furman, LBL report no. LBL-30833, May 1991, to appear in the Proceedings of the 1991 Particle Accelerator Conference, San Francisco, May 1991.

15. G. Jackson and R. Siemann, *Nuclear Instruments and Methods* **A286**, 17 (1990).

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
INFORMATION RESOURCES DEPARTMENT
BERKELEY, CALIFORNIA 94720