Summary on Beam Delivery, Final Focus and Collimation Systems in Linear Colliders

A. Faus-Golfe, IFIC-Univ. of Valencia, Spain

Abstract

This report summarizes the session II: "Beam Delivery, Final Focus and Collimation Systems in Linear Colliders" of the Nanobeam 2002 workshop. The requirements, optics design and shortened layouts of modern Beam Delivery Systems (BDS), the progress on simulation tools and the ultimate limits are some of the topics discussed during this session.

1 INTRODUCTION

The role of the BDS in a linear collider (LC) is: focus and collide the beams at the Interaction Point (IP), remove or collimate the beam halo to reduce the detector background and provide beam diagnostics for the upstream machine.

In the following we describe the recent optics design of BDS reported during the session. The new developments in these systems go into the direction of a substantial shortening of collimation section in combination with a compact final focus. The combination of these two factors makes possible a reduction of the overall system length and subsequently a reduction of the cost. But an optimum balance between length and performances needs to be found. The optics design for these systems is in a state of flux and an experimental verification of the new ideas in an existing facility at lower energy could be very useful.

We then discuss the progress on simulation codes for optics design, luminosity performance, machine background and banana effects. We conclude by opening the discussion about the ultimate limits on beam demagnification and luminosity and what R&D will be necessary to test the new ideas.

2 FINAL FOCUS SYSTEMS

Final-focus systems need to provide a very strong focusing of the beams at the IP ($\beta^* = 0.1$ mm) and subsequently a very strong defocusing immediately after ($\beta \simeq 90$ km). The correction of chromatic and geometric aberrations becomes the principle design challenge. As a consequence these systems have extremely tight alignment tolerances and the stabilization techniques are very important. There are two approaches to the problem:

- Non-local correction using dedicated chromatic correction sections upstream of final telescope [1].
- Compact local correction [2].

A brief description of the conceptual design, advantages and disadvantages of these two approaches was made at the start of the session by N. Walker in "Beam Delivery Systems for Pedestrians" [3]. The advantages of the non-local correction system are essentially: the high symmetry (orthogonal tuning) and the simplicity of the optics design. The main disadvantages are: the high order aberrations (bandwidth limit), the shorter l^*, the long length ($\simeq$ kilometers) and the bad scaling to higher energies. This kind of system has been used and tested at SLC and FFTB. For the compact local correction the advantages are: the high-bandwidth, the short length ($\simeq 500$ m) and the longer l^*. The disadvantages are: the difficulties in the balance of geometric and δ^2 terms and the complexity of the optics design. They are currently proposed for the next generation of linear colliders, but have never been tested in practice.

The optics solutions for a compact final focus for TESLA and CLIC has been described in detail by J. Payet in "Designing the TESLA Interaction Region with $l^* = 5$ m" [4] and by F. Zimmermann in "CLIC Beam Delivery System" [5] respectively. The difficulties in correcting second order aberrations has been pointed out in the two cases. The discussion during the session and throughout the workshop about this question has resulted in two explicit design recipes for this kind of final-focus optics [6, 7].

During the discussion another important point was the usefulness of testing this kind of schemes in existing test facilities at low energy. Two test facilities containing a compact final focus system are under consideration at SLAC/SPHINX/LINX and KEK/ATF. The complete description of the ATF proposal can be found in [8] and has been presented by J. Urakawa in "A Plan of ATF Final Focus Test Beam Line" in Session 8: Generation of Low Emittance Beams [7]. Furthermore an extension of CTF-3 is being considered and the main ideas of the proposal are reported in [9].

3 COLLIMATION SYSTEMS

The collimation systems must fulfill three functions: (1) reduce the background in the particle physics detectors by removing particle at large betatron amplitudes or energy offsets, which otherwise would be lost downstream generating muons near the collision point, or emit synchrotron radiation photons in the final quadrupoles that could strike sensitive detector elements; (2) withstand the impact of a full bunch train in case of machine failure; (3) to avoid wakefields that might degrade the orbit stability or dilute the beam emittance.

The main issues in the design of this kind of system are: (1) the efficiency in removing the halo by scraping it away; (2) the Interaction Region (IR) layout and choice of FFS optics defines the collimation requirements (synchrotron radiation); (3) the mechanical collimator jaws with typical gaps of tens beam σ (few hundred μm to 1 mm); (4) the constraints imposed in order not degrade the luminosity (optical aberrations, collimator wakefields); (5) the mechanical protection issues (typical average beam power densities are several GW/mm^2).

There are various types of linear and non-linear collimation systems that fulfill in some extent these requirements. The solutions are based in two types of design philosophy:

- Optically blow-up beam sizes so collimators have big gaps and can survive a hit by the beam. These systems are long ($\simeq$ kilometers), with very large β-functions and tight optical tolerances and without linear problems.

- Keep β-functions relatively small. In such a case the systems are shorter and manageable, they present better optical and wakefield performances, there are a loose in tolerances and the beam could destroy the collimator ("consumable collimator", NLC approach).

A brief description on this subject "to set the scene" has been made by N. Walker at the start of the session in "Beam Delivery Systems for Pedestrians" [3]. The present baseline design for the CLIC collimation with an alternative non-linear collimation system using three skew sextupoles and a single vertical spoiler system was presented by F. Zimmermann in "CLIC Beam Delivery System" [5]. As in the case of the compact final focus system during the discussion the necessity of a practical test of both kind of systems in order to compare their respective performances was pointed.

Finally a description of the post-linac collimation experience in NLC that includes the effect of the primary and secondary particles, self-defense techniques and the wakefields was presented by P. Tenenbaum in "Post-Linac Collimation in Linear Colliders". More could be found in [10].

4 SIMULATION TOOLS

Much progress has been made through full simulation. Some aspects were treated in some extent during the session.

From the point of view of BDS optics design the question addressed was: is it possible to get an "engine" for designing these systems? The question is open and it will be necessary to make much more effort to find a suitable code which is capable to match not only the linear optics but also the non-linear terms efficiently.

Another important aspect of the simulation tools is the capability to predict the machine performances. During the session a comparison of the most popular codes from the point view of the luminosity performances was presented by S. Redaelli in "Simulation Tools for Luminosity Performance" [11]. The goal of this work is to put errors bars on results of simulation for luminosity performance. These code comparisons could be used as a tool to assess the confidence in simulations results and to point out the systematic errors of performance predictions for each code. Four codes used for tracking through CLIC BDS have been compared. The codes are: MAD8 (CERN), DIMAD (SLAC), Merlin (DESY) and Placet (CERN). In all cases luminosity calculations have been made with full simulation (hour-glass, pinch, beamstrahlung, e^+e^- production) with GuineaPig interfaced with all programs. We could conclude that all tools are set-up and ready for the luminosity performance study. The estimated beam sizes based on Gaussian fits of particle distributions and on luminosity calculations are consistent with the effective values calculated with GuineaPig luminosity simulations. The codes are in good agreement for luminosity predictions if the same synchrotron radiation model is used, but there are considerable differences for halo particles at large amplitude (3σ). This is a point that has to be studied in the future.

We do not forget that at the end of an accelerator sits a detector. The detector needs to see the signal clearly and to last at least one decade. This assumes low machine-related background. These backgrounds are due to: particle loss in the BDS, synchrotron radiation in the BDS and FFS, muon production in spoilers and collimators, neutron production in the BDS and beam dumps, bremsstrahlung of beam gas in BDS...A variety of tools to simulate these effects is now emerging which will lead to independent cross-checks and development. The most used codes are: DECAY TURTLE&MUCARLO (SLAC), MARS (Fermilab), Geant3 (SLAC) and BDSIM (A Geant4 Based BDS simulator). An overview of the performance of these codes has been made by G.A. Blair in "Simulation Tools for Machine Backgrounds" [12]. Furthermore a dedicated study of the muon production in Geant4 was presented by H. Burkhardt in "Muon Background Simulation and Geant4" [13]. As the codes develop, it is increasingly important to apply consistent cross-checks. Although CPU is limited it is necessary to pin down the tails of distributions.

The combined effect of wakefields and dispersion in the main linac and beam-beam interaction at the IP has been shown to be able to result in a severe luminosity loss in spite of a very small emittance growth. This effect is sometimes referred as the banana effect due to the visual appearance of the phase space that the bunch occupies. It is possible, at least partly, to recover the luminosity by optimizing the collision angle and offset. An update of the effect for TESLA, NLC and CLIC considering not only the static imperfections, but also the dynamic imperfections, as the ground motion, was presented by D. Schulte in "Update on banana simulations" [14]. A strong beam-beam interaction is considered for the calculations with the static machine model. One can conclude from the study that the static effect can almost be cured by optimizing the beam offsets and angle at the IP. However the impact of dynamic effect on the optimization procedure remains to be investigated. The cure of centroid offsets due to dynamic effects needs a Beam Position Monitor (BPM) based feedback. In TESLA pulse-to-pulse is not sufficient and an intra-pulse feedback can certainly be used. The cure of the banana effects require luminosity based feedback, i.e. fast luminosity measurement. An intra-pulse feedback could also help in the case of TESLA. Furthermore the non-IP feedbacks (stabilization of magnets other than final doublets, quadrupole jitter, intra-pulse pulse trajectory feedback before the BDS) are also important. In all cases a more detailed study of the feedback seems necessary, to better understand the interplay of different feedback systems. Further study is required to determine if the effect of static imperfections can be tuned out in a dynamically moving machine.

5 QUANTUM MECHANIC LIMITS

Quantum mechanics introduces limits on the spot size and luminosity achievable in LCs. The most fundamental constraints arise from the uncertainty principle and the Fermi-Dirac statistics. Others are due to the quantum fluctuations of synchrotron radiation or bremsstrahlung and pair creation during the beam collision. The investigation about this phenomena and the study of how close to this limit presently proposed LCs (TESLA, NLC and CLIC) are, was made by F. Zimmermann in “Quantum Mechanical Limits on Beam Demagnification and Luminosity” [15]. From this interesting study we conclude that the quantum nature of electrons allows focusing the spot sizes down to about 1 pm. An ultimate limit on the emittance arises from the uncertainty principle and a limit on the β-function from synchrotron radiation in the final quadrupole (Oide limit). According to fundamental constraints, even the Planck scale can be reached with a luminosity that increases as the square of the energy ($L \propto \gamma^2$). The performance of this design, is constrained by Oide effect and beamstrahlung at the IP. Thus, even though the fundamental quantum mechanical limits are still distant, new optics concepts and approaches will be needed for producing, focusing and colliding beams with spot sizes below 1 nm.

6 CONCLUSIONS

The motivation of this session was to answer the following questions:

- What are the requirements to design a modern BDS?
- How can we define collimation efficiency?
- How do we simulate the performance of the system?
- Which experimental verifications of the optics design are needed if any?
- What kind of development tools are needed and how to get them?
- What are the fundamental limits?
- Are there special needs for energy calibration and polarization?
- What R&D do we need?

After the session, we can conclude that most of these questions have been discussed, to varying degree. Some of them are still open, but we have started to think about them; this it is always the first step.

Finally we would like to point out that resources are limited and that the necessity to collaborate is essential in order to guarantee the success of the linear collider.

7 ACKNOWLEDGMENTS

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8 REFERENCES

[1] K.L. Brown, “Basic Optics for the SLC Final Focus”, SLAC-PUB-4811, Dec. 1988

[2] P. Raimondi and A. Seryi, “Novel Final Focus Design for Linear Colliders”, PRL, 86, 17(2000) p.3779.

[3] N. Walker, “Beam Delivery Systems for Pedestrians”, Nanobeams 2002, Lausanne, these proceedings (2002).

[4] O. Napoly and J. Payet, “Designing the TESLA interaction region with l^*= 5 m”, Nanobeams 2002, Lausanne, these proceedings (2002).

[5] M. Aleksa, R. Assmann, G.A. Blair, H. Burkhardt, A. Faus-Golfe, J.B. Jeanneret, S. Redaelli, S. Russenschunck, D. Schulte and F. Zimmermann, “CLIC Bean Delivery System”, Nanobeams 2002, Laussane, these proceedings (2002).

[6] A. Seryi, “Discussion on Design Recipe for a Compact Final Focus,” Nanobeams 2002, Lausanne, these proceedings (2002).

[7] J. Urakawa, “A Plan of ATF Final Focus Test Beam Line,” Nanobeams 2002, Lausanne, these proceedings (2002).

[8] S. Kuroda, “Final Focus Test Optics for the ATF”, presentation in KEK APPI seminar (2002).

[9] R. Assmann, H. Braun, H.Burkhardt, R, Corsini, A. Faus-Golfe, J. Gronberg, S. Redaelli, D. Schulte, M. Velasco and F. Zimmermann,

“Beam-Dynamics Studies and Advanced Accelerator research at CTF3: Compact Final Focus, Laser Compton Scattering, Plasmas,etc.”, Nanobeams 2002, Lausanne, these proceedings (2002).

[10] P. Tenenbaum, “Post-linac Collimation in Linear Colliders”, Nanobeams 2002, Lausanne, these proceedings (2002).

[11] S. Redaelli, “Simulation Tools for Luminosity Performances”, Nanobeams 2002, Lausanne, these proceedings (2002).

[12] G.A. Blair , “Simulation Tools for Machine Backgrounds”, Nanobeams 2002, Lausanne, these proceedings (2002).

[13] H. Burkhardt, “Muon Background Simulations and Geant4”, Nanobeams 2002, Lausanne, these proceedings (2002).

[14] D. Schulte, “Update on Banana Effects”, Nanobeams 2002, Lausanne, these proceedings (2002).

[15] F. Zimmermann, “Quantum Mechanical Limits on Beam Demagnification and Luminosity” Nanobeams 2002, Lausanne, these proceedings (2002).