DIELECTRIC COLLIMATORS FOR LINEAR COLLIDER BEAM DELIVERY SYSTEM*

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Abstract

The current status of ILC and CLIC concepts require additional research on wakefield reduction in the collimator sections. New materials and new geometries have been considered recently [1]. Dielectric collimators for the CLIC Beam Delivery System have been discussed with a view to minimize the BDS collimation wakefields [2]. Dielectric collimator concepts for the linear collider are presented in this paper; cylindrical and planar collimators for the CLIC parameters have been considered, and simulations to minimize the beam impedance have been performed. The prototype collimator system is planned to be fabricated and experimentally tested at Facilities for Accelerator Science and Experimental Test Beams (FACET) at SLAC.

INTRODUCTION

The collimation system of the Compact Linear Collider (CLIC) and International Linear Collider (ILC) should simultaneously fulfil three different functions. It must (1) provide adequate halo collimation to reduce the detector background, (2) ensure collimator survival and machine protection against missteered beams, and (3) not significantly amplify incoming trajectory fluctuations via the collimator wake fields. [1-4]. The latter has to take in account additional effects such as secondary particle generation, wakefield kicks, and element misalignments.

The stoppers and collimators are largely based on well-understood designs in regular use at accelerator laboratories all over the world [1]. One of the technical issues in these devices is limiting the deleterious effects of wakefields in the collimators, in particular the geometric wakes of the short spoilers and the resistive-wall wakes of the long absorbers. The wakes are limited by the use of copper coatings on all surfaces in the vacuum system, and by longitudinal tapering of the apertures to limit geometric wakes [2]. At the same time, a CERN preprint that gives an overview of updated CLIC parameters says that the luminosity performance of the CLIC BDS at 3 TeV is comparable to the performance of the latest NLC system when operated at 3 TeV with CLIC beam parameters [3]. The large dispersion was chosen intentionally for CLIC in order to guarantee the energy-collimator survival in case of beam impact. If we opt for carbon as collimator material and give up the possibility of using beryllium, we might reduce the horizontal beam size at the spoiler by a factor of about three [3].

Therefore, wakefield generation by the collimation system is considered a critical issue and has to be optimized to achieve the required collider luminosity. At the same time, current status requires additional research on wakefield reduction at the collimator section. New materials and new geometries have to be considered [8, 12]. In ref. [5], *dielectric collimators* for the CLIC Beam Delivery System have been discussed with a view to minimize the BDS collimation wakefields [5]. The dielectric collimator concept was introduced as a result of recent ideas for LHC collimation, where materials with low conductivities have been implemented to reduce the impedance value at low frequencies [11], and using dielectrics as collimator materials has been proposed as an option [12,19]. As long as composite dielectrics offer a wide range of electrical, mechanical and thermal properties they provide an opportunity to find an optimized solution for the dielectric based collimation system [5,12,19].

Currently, the BDS simulation codes do not allow using dielectric based collimation system studies including wakefield effects directly related to the dielectric properties [7,12,16]. Meanwhile, Euclid Techlabs in collaboration with the ANL Advanced Accelerator R&D group has developed in last decade new 2D and 3D simulation tools (Waveguide-09, Multibunch-09 and BBU-3000) for wakefield and beam dynamics studies in cylindrical and planar dielectric loaded waveguides.

We have also developed a novel hybrid FDTD-Fourier code (Arrakis/SLAB) [8] that we have begun using to model longitudinal and transverse wakefields in collimators. This approach may permit reduction in the memory and computation requirements compared to a full 3D FDTD treatment.

The research program includes: (1) development of numerical and analytic models of dielectric collimators by introducing conductivity options into the Waveguide09, Multibunch09, and Arrakis/SLAB codes previously developed by Euclid; (2) evaluation of wakefield and impedance simulations; (3) optimization of the collimation system parameters for the materials previously tested by Euclid taking into account dielectric constant, conductivity, thermoconductivity and layer thickness; multilayer geometry evaluation; (4) development of a dielectric based collimator design for the CLIC/ILC Beam Delivery System parameters; demonstration experiments at the FACET facility for the chosen collimator design.

DIELECTRICS AS COLLIMATORS

The interest in using dielectric collimators for LHC is the possibility of moving the peak impedance experienced by the beam away from the principal frequency component of the beam. The dependence of the impedance on the frequency can be optimized to match the frequency response of the feedback/stability control system and allow smaller collimator apertures and thus cleaner beams at the collision point. The reason for using dielectric collimators in a linear collider is similar, although the performance is best understood in terms of the direct effects of the wakefields produced by the collimators on the bunch train. The flexibility afforded by the extra parameters available from a dielectric medium (permittivity, conductivity) to the collimator design allows such interesting possibilities as

- passive damping of the wakes via bulk conductivity of the collimator;
- adjustment of the frequency of the collimator wake to detune the wakefield so that the maxima of deflecting fields occur away from the beam micropulses;
- use of metamaterial or photonic band gap inspired geometries to suppress particularly harmful frequencies in the wakefield;
- active tuning of the collimator wake through the use of a nonlinear material;
- use of asymmetric conductivity to suppress particular modes of the wakefield (analogous to the Chojnacki suppressor [6] in dielectric wakefield accelerators).

Dielectrics also have a number of potential difficulties that must be overcome, most significantly ensuring that the dielectric wakes are effectively of lower magnitude than those from the beryllium/copper configuration in the reference design.

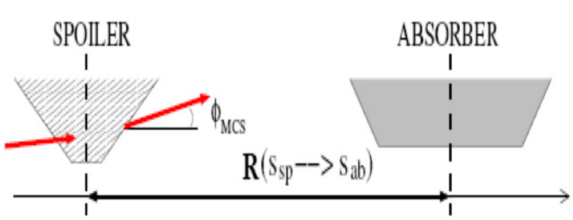

Figure 1: Basic spoiler/absorber configuration.

Euclid Techlabs and the BDS Group of the ILC/CLIC collaboration agreed on a joint research program on dielectric based collimator studies including collimator impedance optimization, beam dynamics simulations, and, finally, preliminary collimator design development. The final dielectric based collimator prototype testing is planned at the new FACET facility at SLAC.

WAKEFIELD CALCULATIONS

Wakefield calculation is one of the most important tasks in the collimator investigation. To achieve low Cherenkov radiation losses we should carefully match collimator parameters.

Wakefields can be easily computed analytically by the direct numerical or analytic solution of the Maxwell system. Some of the analytic results are found in ref. [20].

Full 3D finite difference time domain modelling of the CLIC collimators is a rather demanding problem, more suited to a Grand Challenge project rather than to desktop computing. For example, the memory requirement for a 3D wakefield analysis of a single dielectric CLIC betatron spoiler (Fig. 1) is about 5 GB with a marginally coarse mesh spacing $\Delta z = \sigma_z / 5$. 2D approaches have been suggested using a moving window to compute the short range wakefields only, although it is not clear in this case how the long range transverse wake forces would be treated. We have successfully used a 2D analysis to estimate the transverse forces. In this hybrid approach the x-z geometry is addressed using a 2D FDTD analysis with a Fourier decomposition in the y-direction. We have been following the approach used in ref [8], for the analysis of planar laser-driven accelerating structures. In the limit of an infinitely wide beam in the y-direction, the transverse wake forces vanish, analogous to the cancellation of the radial electric and azimuthal magnetic fields in the TM_{01} mode of a cylindrical accelerating structure.

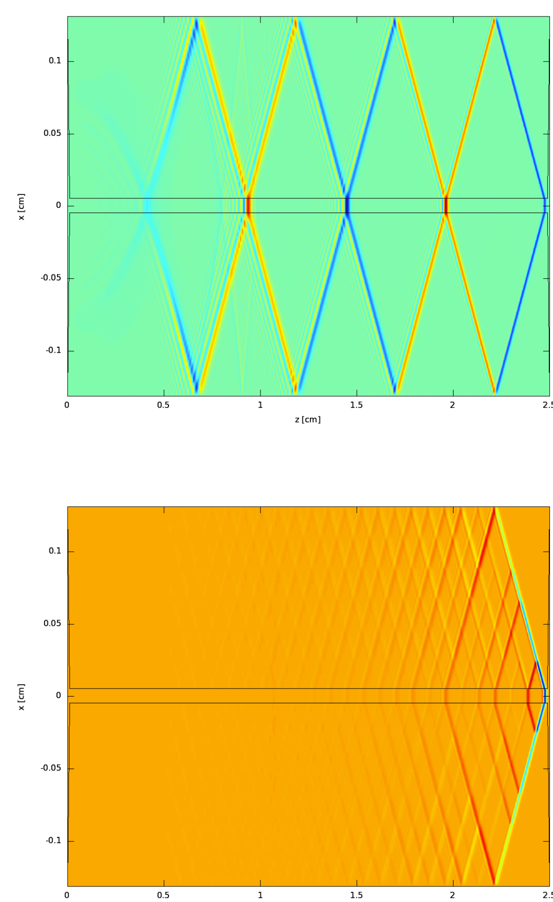

Figure 2: Longitudinal electric field component of Cherenkov radiation in a dielectric collimator without losses (top) and an "anti-Bragg" structure (bottom). The permittivity in both cases is 5. The maximum electric field on axis outside the bunch is about a factor of five larger for the unsegmented case.

Writing Maxwell's equations componentwise in rectangular coordinates and taking the Fourier transform with respect to the horizontal (y) coordinate, we obtain a set of equations which are then discretized using the standard Yee algorithm. While at first it might appear that there is no saving of memory or computation time with this approach, the large transverse size σ_y of the beam means that the beam current is contained within a relatively small range of transverse wave numbers, and thus we can reduce the number of evaluations required for different k_y values.

A numerical demonstration of the flexibility of the dielectric collimator concept is shown in Fig. 2. Here we compare the longitudinal wakefields from a section of a planar collimator for a continuous dielectric (a) and a transversely segmented dielectric (b). The transverse segments in (b) are separated by thin layers of lossy material, and the depth of the layers is chosen to provide a half wavelength phase difference between pairs of segments, approximately cancelling the fields on axis. One could think of this configuration as an "anti-Bragg" structure.

It is worth mentioning here that proper treatment of the frequency dependence of the conductivity will significantly affect the results. One can expect some shift of the spectrum maximum to lower frequencies and decrease of the wake amplitude. Another issue that should be treated carefully is the thickness of the outer layer of the structure. Finite thickness will certainly affect the low frequency region, however it could be neglected in the high frequency region. One should also keep in mind that in case of a perfect conductor model, which is a good approximation of the conductive cover such as copper, for the outer layer of the collimator, the wakefield spectrum will be discrete and have a cut-off frequency in a gigahertz frequency range.

Another important thing that should be treated carefully is the conductivity model of the material. For the initial analysis a simplified Debye formula with the quadratic frequency dependence of conductivity could be used. Introducing this kind of dispersion into the system under consideration one should expect suppression of high frequency wakes. For an accurate calculation, however, the full Debye or Drude formula for both real and imaginary parts of the dielectric permittivity is preferable.

The auxiliary differential equation algorithm is a very general method for including frequency dependent material properties in a FDTD code. Based on our prior experience with numerical models of active media [21] we plan to use this approach for incorporating the Drude formula into Arrakis/SLAB.

SUMMARY

At present stage of the project we have calculated wakefields for ceramic collimators in case of dielectric with zero conductivity is coated with a perfect conductor using CLIC beam parameters.

For more precise modelling we are going now to include the conductivity value in the dielectric model with quadratic frequency dispersion. For decreasing wake amplitude the multilayer structure will be considered with this model.

REFERENCES

[1] J.R.Lopez. ILC-CLIC Beam Dynamics Workshop. CERN, Geneva, 23-25 June, (2009).

[2] R. Tomas. ILC-CLIC Beam Dynamics Workshop. CERN, Geneva, 23-25 June, (2009).

[3] CLIC 2008 Parameters.

[4] R. Assmann et al. Overview of the CLIC Collimation Design. Proceedings of the (2001) Particle Accelerator Conference, Chicago, p.4071.

[5] E. Métral, A. Grudiev, G. Rumolo, B. Salvant, R. Tomàs. Robert Siemann Symposium and ICFA Mini-Workshop, (2009).

[6] E. Chojnacki et al., J.Appl.Phys.69:6257-6260,1991.

[7] Agapov et al. Phys. Rev. ST-Accelerators and Beams, 12 (2009) 081001.

[8] A.Tremaine, J.Rosenzweig and P.Schoessow, Phys.Rev.E56:7204-7216,1997

[9] CLIC'09 Workshop

[10] J.R.Lopez. CLIC Collimation System Review: Optics Issues and Wakefield Effects.

[11] E. Métral et al. Transverse Impedance of LHC Collimators. LHC-PROJECT-Report-1015 ; CERN-LHC-PROJECT-Report-1015.

[12] E. Métral, et al., Impedance Studies for the Phase 2 LHC Collimators. PAC'09, to be published.

[13] J. Barranco, W. Bartmann, M. Benedikt, Y. Papaphilippou. Collimation Considerations for PS2. PAC'09, to be published.

[14] Angal-Kalinin, D ; Bolzon, B ; Brunetti, L ; Dalena, B et al. Status of the CLIC Beam delivery system. PAC'09, to be published.

[15] J. Smith, SLUO LHC Workshop 2009,

[16] R.Tomas, private communication.

[17] Y. Nosochkov et al. SLAC–PUB–13603, (2009). PAC'09, to be published.

[18] http://www-group.slac.stanford.edu/facet/ and http://facet.slac.stanford.edu/

[19] E.Metral. Collimation-Driven Impedance. Conceptual Design Review LHC Phase II Collimation. CERN, 2009.

[20] A. Kanareykin et al., Proc IPAC'10

[21] P.Schoessow, A. Kanareykin, Proc. PAC 2005