DIELECTRIC COLLIMATORS FOR LINEAR COLLIDER BEAM DELIVERY SYSTEM*

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Abstract

In this paper, dielectric collimator concepts for the linear collider are described. Cylindrical and planar dielectric collimator designs for CLIC and ILC parameters are presented, and results of simulations to minimize the beam impedance are discussed. 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 mis-steered 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. Last year clear progress has been made in the improvement of the CLIC collimation system presented in [6-8]. It includes study of the collimation efficiency, optimizing the collimator apertures; design of spoiler and study of its thermal fracture limit, and luminosity loss due to collimator wakefield effects. Significant progress has also been made in the development of codes for realistic simulations (e.g. BDSIM-PLACET interface), allowing collimation studies simultaneously including wakefield effects and production of secondary particles [6].

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 [5], *dielectric collimators* for the CLIC Beam

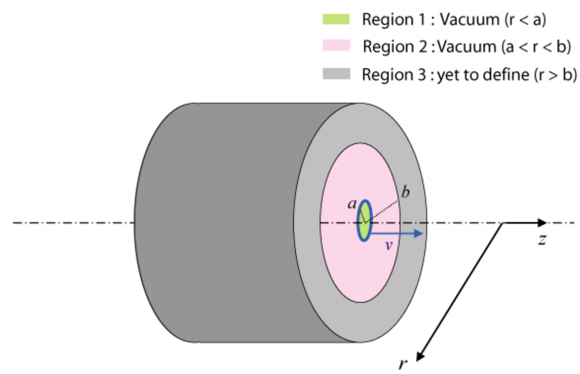

Figure 1: Cylindrical geometry of the double layer collimator model. Copper, graphite and ceramic inner layers have been considered.

Delivery System have been discussed with a view to minimize the BDS collimation wakefields [5]. The dielectric collimator concept was introduced as of results 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 Advanced Accelerator R&D group has developed in last decade new 2D and 3D simulation tools (Waveguide-09, Multibunch-09 and BBU-3000) for the wakefield and beam dynamics studies in cylindrical and planar dielectric loaded waveguides. Based on these simulation codes, a successful set of experiments has been carried out at the Argonne Wakefield Accelerator (AWA) facility with a high charge, (typically 20 – 40 nC), short, (1 – 4 mm) electron drive beam generating TM_{01} mode electromagnetic Cherenkov radiation (wakefields) while propagating down a vacuum channel.

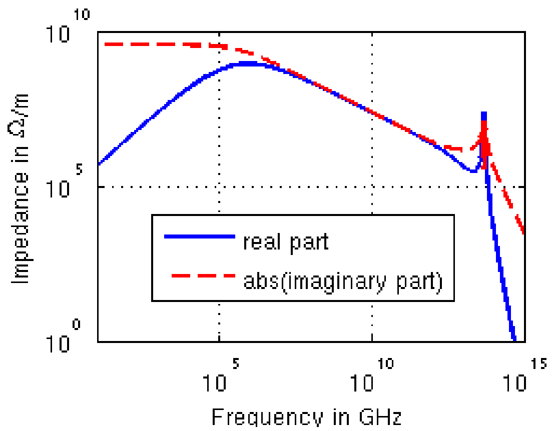

Figure 2: Example of impedance simulations. [5,12]

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 of 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.

Wake field could be easily achieved analytically by the direct solution of the Maxwell system. We considered copper coated (copper consider to be a perfect conductor) dielectric pipe ($\varepsilon = 5$, diameter is 16 mm) with the vacuum channel inside (diameter is 0.2 mm), and CLIC beam parameters.

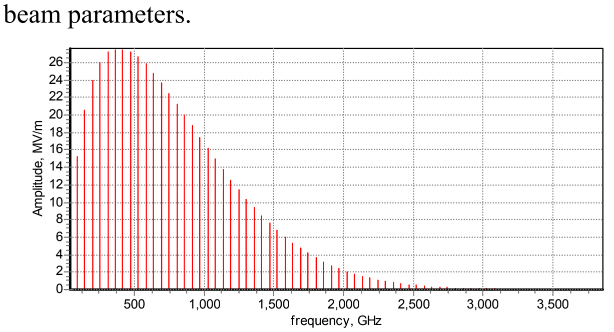

Figure 3: Longitudinal Cherenkov radiation spectrum for the 200 um collimator aperture and CLIC beam parameters.

Solution of the Maxwell system leads to the expansion of the longitudinal components of the electric and magnetic field by the eigenfunctions of the transverse operator. Field spectrum could be also found as a transverse operator spectrum.

On Fig. 3 and Fig. 4 longitudinal electric field spectrum and longitudinal electric field wake are presented. One can see that spectrum has a maximum at about 500 GHz and decreasing at lower and higher frequencies.

This result is in good agreement with the previous calculations of the shunt impedance [5,12], where the real part has a maximum at the gigahertz region.

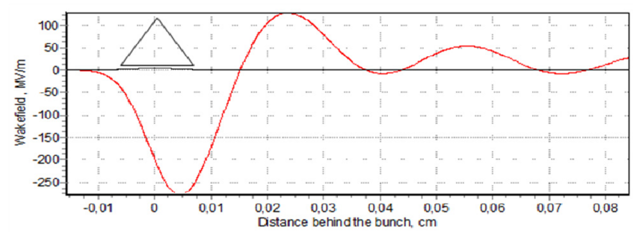

Figure 4: Wake inside the bunch for the 200 um collimator aperture and CLIC beam parameters.

We also have calculated multibunch wakefield assuming coherent sum of a single bunch wakes. In the Fig. 5 multibunch wakefield is presented.

It is worth to mention here that proper treatment of the conductivity will majorly affect the result. One can expect some shift of the spectrum maximum to the 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 low frequency region, however it could be omitted 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, 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 simplified Debye formula with the quadratic frequency dependence of conductivity could be used. Introducing such kind of dispersion into considering system one should expect suppression of high frequency wakes. For an accurate calculation, however, full Debye formula for both real and imaginary parts of the dielectric permittivity is preferable.

The research program include: (1) develop numerical and analytic models of the dielectric collimators by introducing conductivity options into the Waveguide09 and Multibunch09 codes previously developed by Euclid; (2) evaluation of the 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 the dielectric based collimator design for the CLIC/ILC Beam Delivery System parameters. Simulations of the demonstration experiments at the FACET facility for the chosen collimator design.

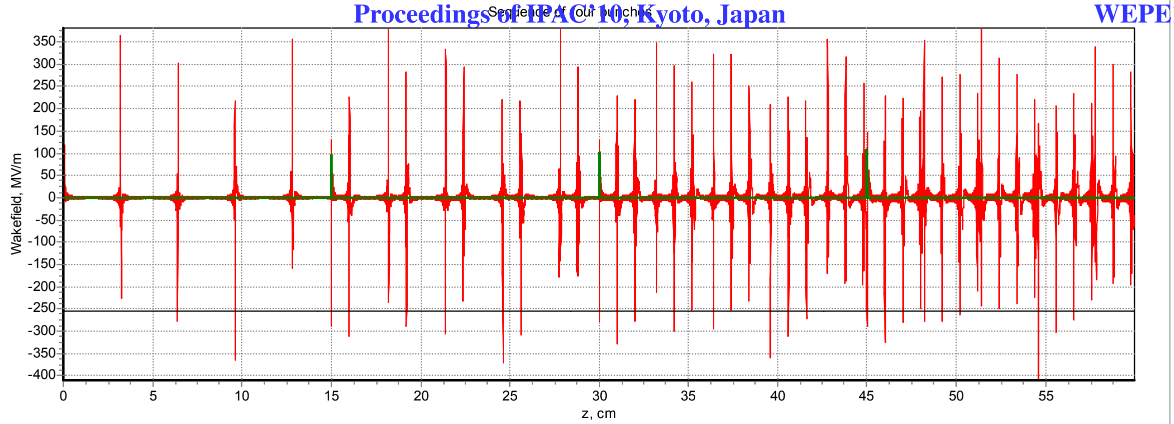

Figure 5. Multibunch Cherenkov radiation spectrum for the 200 um collimator aperture and CLIC beam parameters, 8mm thickness.

SUMMARY

At present stage of the project we have calculated wakefield for ceramic collimator 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.

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