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COLSIM – Summary of Deliverables within the EUROTeV Programme

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Abstract

A summary is presented of the COLSIM task within the EUROTeV Workpackage "Integrated Luminosity Performance Studies" (ILPS). The man sub-tasks include: non-linear collimation systems, simulation of collimators using BDSIM, and collimator wakefield simulations. These sub-tasks are summarised and key references provided.

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1 Non-Linear Collimation Systems

Conventional collimation systems are generally based on linear optics; the study [1.1] within COLSIM has been focused on the nonlinear collimation concept for CLIC based on skew-sextupoles, which can be adapted more generally to both linear and circular colliders. The performance of the scheme was evaluated by means of tracking studies using the codes MAD, and Placet, and the luminosity was computed using the beam-beam interaction code Guinea-Pig. This system fulfils the function of machine protection against errant beams with energy offset ≥ 1.5 %. Another important feature of this system is the spoiler survival for the case of direct beam impact; by the “sextupolar effect” the beam transverse energy density is reduced at the energy spoiler, increasing thereby the spoiler survival probability. The optics of the CLIC nonlinear collimation system was further optimized by local correction of high order aberrations (2^{nd}, 3^{rd}, and 4^{th} order) using two additional non-linear elements: a skew octupole and a normal sextupole. In this way, the simulation results gave a luminosity and energy bandwidth comparable to those for the conventional linear optics.

The collimator wake-field effects on the luminosity due to the horizontal collimators misalignment are very similar for both linear and nonlinear systems. In this case similar luminosity acceptance curves have been obtained. However, the wake-field effects due to a misalignment of the vertical collimators are lower for the nonlinear collimator system, because of its higher betatronic collimator apertures.

Since the collimation requirements for linear colliders designed to operate at center-of-mass energy around TeV are similar to those for the LHC, an alternative nonlinear system for the Phase-II betatronic cleaning in the LHC was presented. Its performance and cleaning efficiency were studied by tracking using the code Sixtrack. By adjusting optics and collimator settings, a considerable improvement of the cleaning efficiency was obtained, up to the level of the linear system for the vertical direction. A careful study is still necessary to further optimize the orientation and positions of secondary collimators to achieve the same level of efficiency as the linear system for the cleaning of the horizontal and radial halo components. A nonlinear collimation system allows a larger aperture for the mechanical jaws and thereby reduces the collimator impedance. It was shown how the module of the horizontal effective impedance is reduced by about a factor 2 and the vertical one by about a factor 3 compared to the LHC Phase-I IR7 insertion. Consequently, using the nonlinear collimation system, the coherent tune shift for the most critical coupled bunch mode has been reduced by about a factor 2 with respect to the Phase-I IR7 insertion. According to the results obtained for CLIC and LHC, it was concluded that a nonlinear collimation system using skew sextupoles for the case of linear and circular colliders appears to be competitive with the corresponding linear systems.

2 Simulation of Collimators Using BDSIM

BDSIM [2.1] is a Geant4 based accelerator tracker code that enables fast tracking of beam particles combined with full simulation of secondary particles and their subsequent propagation. It was developed extensively and implemented within EUROTeV; during this time upgrades have included an extension to the gmad interface in order to define new materials. These materials, and an extended predefined set of materials, can be used as the material for the outer volume of beam-line elements. The gmad parser has also been modified in order to correctly handle nested and inverted beam-lines. Particle trajectories can be logged via hits in “Samplers”, which can be placed at any location between beam-line elements. Sampler output has been upgraded to include particle time of flight, global coordinates and path length. A new kicker element has been introduced, and the “rbend” element modified to rotate properly the frame of reference. Laser-wire elements have been included and set up to allow multiple laser-wires with individually set wavelengths and laser directions in a single beam-line. Finally, work has been continued on routine maintenance and to ensure compatibility with updates to Geant4 and the main Linux compilers. Benchmarking tests were performed for particle tracking, electromagnetic and hadronic physics processes and the BDSIM distribution was deployed on the GRID to increase the performance [2.2]. The extension to the “xsif” format, which allows more detailed accelerator component geometry descriptions, was developed and the corresponding module included in the distribution [2.3].

BDSIM was used extensively for the ILC BDS simulations. The implementation of the ILC 20 mrad and 2 mrad interaction region designs within BDSIM was completed and the energy deposition due to pairs and radiative Bhabhas on beam-line elements in the extraction line of these IRs was determined [2.4]. The results for the ILC collimation system and extraction lines were checked against MARS and STRUCT simulations [2.5]

More recently, the major developmental work has been the inclusion of an interface to Placet in order to allow the application of transverse wake-field kicks in collimator elements [2.6] and to simulate the halo repopulation by secondary particles generated from halo interaction with the collimation system. Wake-fields clearly have a significant effect on the residual beam halo at the entrance to the final CLIC quadrupole [2.7]. This effect of the wake-fields reducing the number of particles near the edge of the collimation depth is of potential benefit; however the inclusion of secondary particles into the simulation reduces this effect.

3 Collimator Wakefield Simulations

A detailed study of what are the possible regimes for the intra-bunch wake fields excited in a collimator was initiated in 2006. Geometric wake fields can be inductive or diffractive, depending on the smoothness of the tapering, with an intermediate regime that requires a different approach. Resistive wall wake fields can be long-range, short-range or intermediate, paying special attention to the fact that, in the very short-range case, the frequencies involved could become high enough as to require the ac conductivity of the material to be included in the model. Using a semi-analytical approach and having developed a new formula for the resistive wall wake field in the intermediate range regime, the self-induced kick felt a bunch going through a collimator can be calculated and the relative routine, tested first as stand alone for the several different cases, was then successfully implemented in the PLACET code [3.1]. Using the new version of PLACET, bunches could be tracked through the CLIC-BDS including the effects of the wake fields of the collimators, and the luminosity loss due to collimator misalignments and/or jitters of the incoming beams was estimated [3.2, 3.3]. The quadrupole term of the wake field, which accounts for the first order dependence of the kick on the position of the witness particle, was always included through a typical Yokoya weighting of the coefficients in the expression of the kick. More elaborate nonlinear expressions were implemented in PLACET later in 2007 to take into account of near-wall effects in a more correct way [3.4].

Effects of wake fields in the collimators of the ILC-BDS have been investigated using principally the Merlin simulation program, and also, to a lesser extent, PLACET. The collimators being proposed for the ILC come much closer to the beam than any previously considered, having apertures of millimetres rather than centimetres. This means that the kicks on particles due to wakefields induced in the collimator by preceding particles in the bunch are larger than commonly experienced, and also the very small emittance of the ILC bunches means that the effects of such kicks on the emittance, and thus the luminosity, are much more serious.

Transverse wakes have commonly been considered using the lowest order dipole mode wake field, in which the effect on a particle is independent of its deviation from the beam axis. This has meant that the treatment can be fairly simple. We have studied the effect of higher order modes, showing how they can be introduced into Merlin in a computationally efficient way [3.5]. We used expressions for geometric wakes found in the literature, and have discovered a new way of evaluating resistive wakes which avoids the various approximations and 'regimes' of existing models and their implementations

Results show that geometric wakefield effects are very much larger than those of resistive wakefields, even for the materials proposed (such as Tantalum, Tungsten and Graphite) for collimation systems [3.6]. Higher order modes were investigated using Merlin [3.7, 3.8, 3.9, 3.10]. Only circular collimators could be considered for this as the equivalent formalism has not yet been ascertained for apertures without azimuthal symmetry. (We are still working on this problem, but it is considerably more complicated.) This shows that the effects of higher order modes become important only under conditions where the beam is so far off axis that the luminosity will have fallen catastrophically anyway. The results suggest that higher order modes do not have effects large enough to need consideration.

As said above, the PLACET code does include rectangular apertures using the Yokoya Ansatz (the so-called 'quadrupole' term, however this is not the same as the m=2 'quadrupole' effect). The comparisons we have performed between PLACET and Merlin agree reasonably well [3.11, 3.12].

We participated in the collimator wakefield tests at SLAC End Station A. Measurements were taken of the deflection of bunches by a wide range of different collimator shapes, materials and apertures. Results are in reasonable agreement with the various predictions [3.13, 3.14, 3.15].

We have studied the extraction of real-space wake fields ('delta wakes') from the impedances calculated by EM solver programs. This involves a numerical Fourier transform, and a technique was found to include the fact that the wake function is known to be causal (particles can only affect later particles, no earlier ones) in the formalism of the transformation. This has already shown that these wakes are considerably different from simple models previously proposed [3.16].

We have also studied the modeling of energy deposition when particles impinge on the collimator. We showed that energy distributions predicted by GEANT4 are compatible with those predicted by FLUKA and EGS [3.17, 3.18]. These give temperature rises such that the collimator can survive the direct impact of several bunches undamaged, which actually exceeds the requirements imposed: there is ample time for the beam abort system to divert subsequent bunches to a beam dump. We have also looked at similar energy depositions in the positron source [3.19-3.23]

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