SLAC-PUB-10554
July 2004

BEAM DELIVERY LAYOUT FOR THE NEXT LINEAR COLLIDER*

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Abstract

This paper presents the latest design and layout of the NLC Beam Delivery System (BDS) for the first and second interaction region (IR). This includes the beam switchyard, skew correction and emittance diagnostics section, the collimation system integrated with the final focus, the primary and post linac tune-up beam dumps, and the arcs of the second interaction region beamline. The layout and optics are optimized to deliver design luminosity in the entire energy range from 90 GeV to 1.3 TeV CM, with the first IR BDS also having the capability of being extended to multi-TeV.

REQUIREMENTS AND CONSTRAINTS

The physics need to maximize the luminosity and energy reach sets the requirements on the layout of the Beam Delivery Systems (BDS) for the 1st and 2nd Interaction Region (IR). Ideally, both IRs should have equal capabilities up to at least 1.3 TeV in the Center of Mass (CM), with the same luminosity to within ~ 30%.

However, in order to provide one IR with the possibility of extending to multi-TeV, it must have a straight-ahead tunnel, and therefore the two IRs can never be identical. The 2nd IR needs a big bend to separate the beamlines and to create the desired crossing angle of 30 mrad, for compatibility with gamma-gamma collisions. Since the big bend consumes some of the beamline, the BDS of the second IR has to be shorter than for the first IR.

The luminosity loss due to synchrotron radiation in a Beam Delivery scales with energy as $\Delta L/L \sim \gamma^{7/4} / \Lambda^{5/2}$ where Λ is the BDS length. Although the required BDS length scales only slowly with energy, as $\Lambda \sim \gamma^{7/10}$, the luminosity loss can be significant when the length is decreased. This drives the design to have the lengths of both BDS systems as close as possible. Moreover, while there is flexibility to reduce the bend angles in the BDS for the upgrade to multi TeV, the angle of the big bend has to stay fixed, giving a hard limit on the achievable energy in the 2nd IR. One more constraint is that one has to provide adequate spatial separation between two IR halls, both for radiation and vibration isolation. With the present shorter BDS, the detectors must be separated in the longitudinal direction to provide sufficient transverse separation. This makes the e+ and e- BDS of the 2nd IR unequal in length.

Given these contraints, we have nonetheless found a solution which is able to maximize the performance of both IRs and allows nearly equal luminosity up to 1.3 TeV CM, as described below.

BEAM DELIVERY LAYOUT

The 1st IR in the NLC has a 20 mrad crossing angle and is located in the straight ahead tunnel, following the linac. The 2nd IR should have a 30 mrad crossing angle to be compatible with gamma-gamma option. The beamlines are separated in a Switchyard, where the Big Bend (a historical name from when a large bend was thought to be required to remove muons) takes the beam to the 2nd IR. The 2nd IR has to be located within the angle formed by the two linacs to minimize the length of shared beamline while providing IR separation. Assuming the IR1 net angle is zero, the angle of the Big Bend needs to be 25 mrad.

To preserve the luminosity of the 2nd IR, the emittance growth in the Big Bend due to synchrotron radiation is held to less than 30% up to a beam energy of 650 GeV. An optimized 25 mrad Big Bend, composed of combined function FODO cells, would require about 600 m length. This would occupy a too much of the available 1430 m length used by the BDS of the 1st IR, significantly shortening the length of the 2nd IR BDS, and reducing its performance to below requirements.

An alternative is to abandon the constraint of zero net angle for the 2nd IR BDS, which causes the bend angles in the energy collimation section and in the Final Focus to be of opposite sign. A “one-way-bending” BDS for the 2nd IR has a net angle of approximately 8 mrad, reducing the angle required from the Big Bend to about 17 mrad. Since the emittance growth in the Big Bend scales as angle^3/length^2, this halves the length. The one-way-bending BDS may require a curved tunnel and will have lmited performance at multi-TeV, but allows better performance up to a TeV because of the longer BDS.

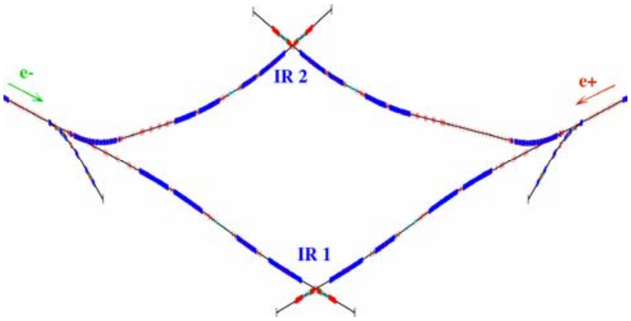

Figure 1: Layout of NLC Beam Delivery Systems for two IRs. Anamorphic scale (the transverse direction is stretched about a hundred times). Straight-ahead BDS for the 1st IR and one-way-bending BDS for 2nd IR.

The layout of the NLC BDS for both IRs is shown in Fig.1. The Big Bend is reduced to 10 cells from 23 cells (length of a cell is 23 m). The IPs are separated by about

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Presented at the 9th European Particle Accelerator Conference (EPAC 2004), 7/5/2004 - 7/9/2004, Lucerne, Switzerland

25 m in transverse and 150 m in longitudinal direction (Beam arrival time constrains the path difference between the two IRs to be equal to the damping ring circumference 300 m). The available space allows a full length BDS (1430 m) in 3 of the 4 arms, all except for 2nd IR e- line, where 1100 m is available (Fig.1 shows an earlier version with 970 m BDS in the 2nd IR arms). The almost equal lengths of the BDS make their performance very similar.

The layout of the NLC Switchyard is shown in Figure 2. The optics of the switchyard region includes skew correction, emittance diagnostic and extraction sections (see Figure 3).

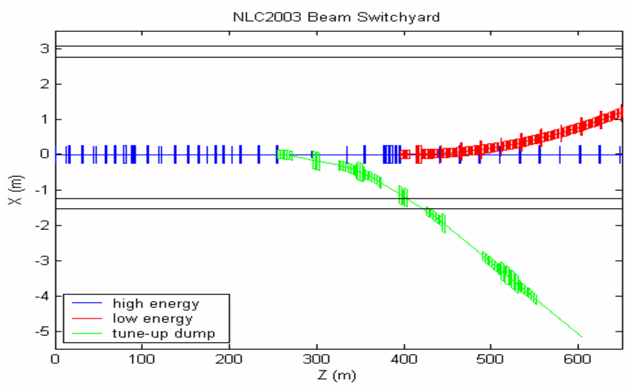

Figure 2: Layout of the NLC Switchyard. The post-linac and 1st IR beamline is shown in blue (straight ahead), the 2nd IR Big Bend is in red (bends up in the figure), and the post linac tune-up dump is in green (bends down).

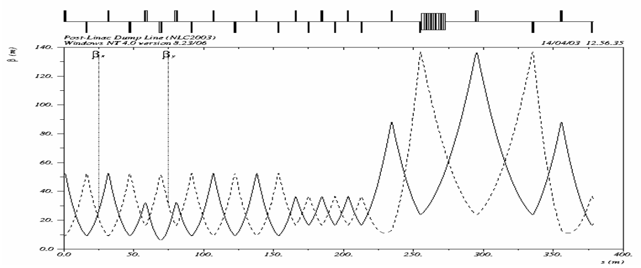

Figure 3: Optics of the Switchyard region of the straight-ahead beamline showing the skew correction, emittance diagnostic and extraction sections.

The design of the post-linac tune-up dump line includes a small vertical bend in addition to the horizontal to locate the dump below the nominal grade of the tunnels. The dumps would be used for commissioning and tuning and can take the full bunch train with nominal charge, emittance, and beam size and with full machine rate (120 Hz) corresponding to 13 MW for 750 GeV per beam. The beam sizes at the dump are enlarged to 1 mm. The dump beamline has ±20% energy acceptance. The dump kicker parameters are scaled up from the SLC Sector 2-9 kicker. The dump line magnets have 8 cm bore diameter. The length of the dump is 350 m, horizontal offset of the dump enclosure (vault) is 5 m and vertical offset is -1 m.

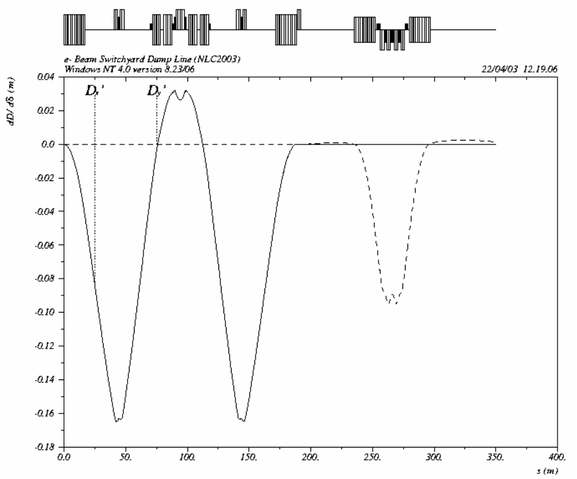

Figure 4: Second order horizontal and vertical dispersion of the post linac tune-up dump, and layout of magnets.

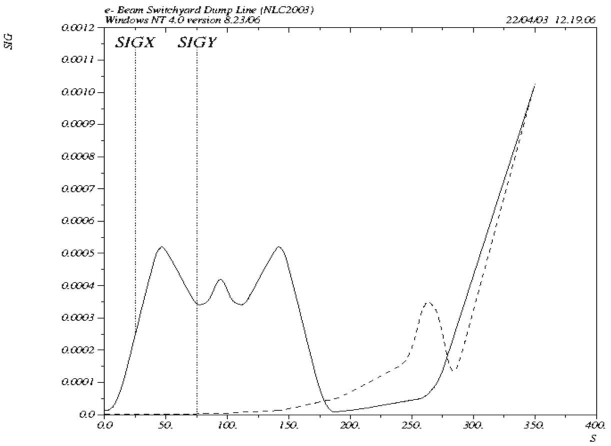

Figure 5: Beam sizes (in meters) in the post-linac tune-up dump.

In the optical design of the post-linac dump beamline both the linear and second order dispersion are brought to zero at the dump (see Figure 4) to maximize the energy acceptance. The beam centroid motion at the dump, calculated with tracking, is less than ±0.5 mm for ±10% energy variation, and less than ±4 mm for ±20% energy variation. The vertical beam size at the dump is 1 mm and its variation is small in the entire ±20% energy range. The variation of the 1mm horizontal beam size is insignificant within the ±10% energy range and it is increased to about 3 mm with 20% energy offset, which is acceptable. The beam size in the dump beamline is shown in Figure 5.

The optics of the Beam Delivery for the 1st IR is shown in Fig.6. In this system, the sign of the bend in the energy collimation system and in the Final Focus, and correspondingly the signs of dispersion, are opposite. As mentioned above, for the 2nd IR the BDS is modified so that the bending occurs in the same direction. The BDS for one of the arms of the 2nd IR is shown in Fig.7. The BDS for the other arm is similar to that shown in Fig.6 except the dispersion is positive.

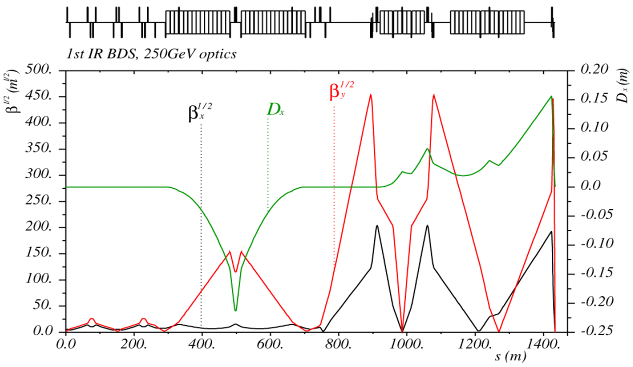

Figure 6: Optics of Beam Delivery System for the first IR.

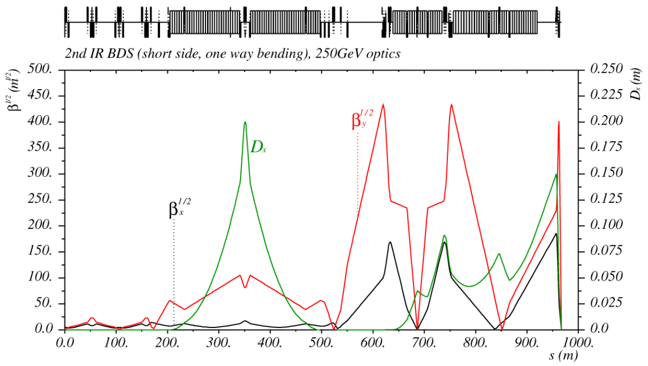

Figure 7: Optics of 2nd IR BDS, e- arm.

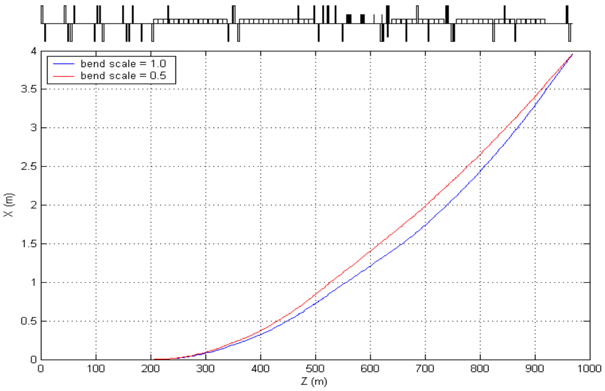

Figure 8: Layout of the e- side 2nd IR BDS for different scale of bend angle in the collimation and Final Focus.

In the first stage of operation, the BDS bend angles will be optimized for the energy range from 90 GeV to 650 GeV CM. When the linac is upgraded for 1000 GeV CM energy reach (by installing accelerator cavities in the second halves of the tunnels), the BDS will also be upgraded. For the BDS upgrade, the Final Doublet will be modified to increase the length of the quadrupoles in order to reduce luminosity loss due to synchrotron radiation in the FD (Oide effect), and the bend angles in the Final Focus will be reduced to about half in order to reduce synchrotron radiation induced energy spread and emittance growth. For the latter, in order to keep the IP position fixed, the angles in the energy collimation system must be increased by about 15%. This is done for both IRs. An example of the layout change for the 2nd IR BDS is shown in Fig.8. One can see that the magnets need to be shifted transversely by 20 cm at most, and the supports will be designed to accommodate this shift. The angle of the outgoing beam changes by about 1.6 mrad which can be accommodated by adjustment in the extraction beamline.

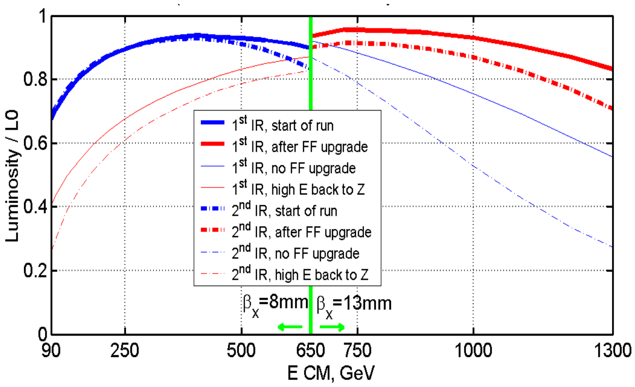

Figure 9: Performance of the 1st and 2nd NLC IRs. Nominal energy spread and synchrotron radiation are included; beam-beam effects are not included. Normalized to geometrical luminosity.

Performance of the NLC 1st and 2nd IR versus energy is shown in Fig.9. In this figure, the luminosity was obtained by tracking, the energy spread and synchrotron radiation are included, but not the beam-beam effects. The luminosity shown is normalized to the geometrical luminosity with ideal beam sizes determined by the nominal beta-function at the IP and nominal emittances (the nominal NLC luminosity corresponds to L/L0=0.93 in Fig.9). One can see, that the 1st and 2nd IR luminosity are equal to within better than 30%, and that the luminosity is close to the nominal in the whole range from 90 GeV to 1.3 TeV. This picture also shows the performance in phase two operation if the BDS is not upgraded. In this case, the luminosity penalty would be 40% and 70% for the 1st and 2nd IR at the maximum energy. The plot also shows the luminosity when returning to lower energy after the BDS has been upgraded. At 90 GeV, the luminosity decrease would be 60% or 70% with constant horizontal beta function. More likely, in this case the IP beta-function would be re-optimized to maximize the luminosity at 90 GeV.

CONCLUSION

The design of the two IRs for NLC have been optimized to maximize the luminosity and to provide nearly equal luminosity for both IRs, within 30%, over the entire energy range from 90 GeV to 1.3 TeV. This will give both interaction regions a similar physics reach.