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BEAM COLLIMATION STUDIES FOR THE ILC POSITRON SOURCE[*†]

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Abstract

Results of the collimation studies for the ILC positron source beam line are presented. The calculations of primary positron beam loss are done using the ELEGANT code. The secondary positron and electron beam loss, the synchrotron radiation along the beam line and the bremsstrahlung radiation in the collimators are simulated using the STRUCT code. The first part of the collimation system, located right after the positron source target (0.125 GeV), is used for protection of the RF Linac sections from heating and radiation. The second part of the system is used for final collimation before the beam injection into the Damping Ring at 5 GeV. The calculated power loss in the collimation region is within 100 W/m, with the loss in the collimators of 0.2 – 5 kW. The beam transfer efficiency from the target to the Damping Ring is 13.5%.

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BEAM COLLIMATION STUDIES FOR THE ILC POSITRON SOURCE*

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Abstract

Results of the collimation studies for the ILC positron source beam line are presented. The calculations of primary positron beam loss are done using the ELEGANT code [1, 2]. The secondary positron and electron beam loss, the synchrotron radiation along the beam line and the bremsstrahlung radiation in the collimators are simulated using the STRUCT code [3]. The first part of the collimation system, located right after the positron source target (0.125 GeV), is used for protection of the RF Linac sections from heating and radiation. The second part of the system is used for final collimation before the beam injection into the Damping Ring at 5 GeV. The calculated power loss in the collimation region is within 100 W/m, with the loss in the collimators of 0.2-5 kW. The beam transfer efficiency from the target to the Damping Ring is 13.5%.

RESULTS OF SIMULATIONS

The positrons generated in a thin Ti target are captured, accelerated, separated from the shower and then transported to the Damping Ring (DR) [2]. The beam is accelerated from 0.125 to 0.4 GeV in the first normal conducting (NC) RF section located at S=65-100 m, and then to 5 GeV in the superconducting (SC) RF section at S=5194-5451 m.

Since the beam from the target has a large tail, the beam pipe in the first 60 m of positron line is designed with a large aperture corresponding to the beam acceptance of 475 μm·rad. However, for practical reasons the aperture and, therefore, acceptance are reduced in the following NC RF section (130 μm·rad) and in the 400 m region upstream of the DR (90 μm·rad). Therefore, to avoid large losses in these regions, the collimators must intercept most of the lost particles in the first 60 m of the beam line where energy is low. The latter also helps to minimize the total power loss since it is proportional to energy of the lost beam.

The positron line contains sextupoles which affect large amplitude particles and therefore must be taken into account for selecting the collimator apertures. To verify the sextupole distortion of the positron amplitudes, beam tracking using STRUCT was performed for the "small" and "large" beam emittance values (2.45 and 245 μm·rad, respectively). Then the equivalent β functions based on the tracked beam size and emittance ($\beta = \sigma^2/\epsilon$) were compared, as shown in Fig. 1 for three selected regions. The large oscillations of β functions in case of the "large" emittance tracking confirm a strong sextupole effect at large particle amplitude. This non-linear beam enlargement is taken into account for selecting the collimator apertures. Fig. 2 shows another example of distortion of beam vertical phase space at the collimator ABHM2 (S=5514 m) for three cases of initial beam emittance of 500×130 μm·rad, 368×96 μm·rad, and 41×41 μm·rad. Note that emittance of 368 μm·rad at initial energy of Pc=0.125 GeV corresponds to 9.2 μm·rad at 5 GeV at entrance into the DR. The latter is the acceptance of the Damping Ring. Positrons outside of this acceptance will be lost and therefore must be efficiently collimated in the positron line.

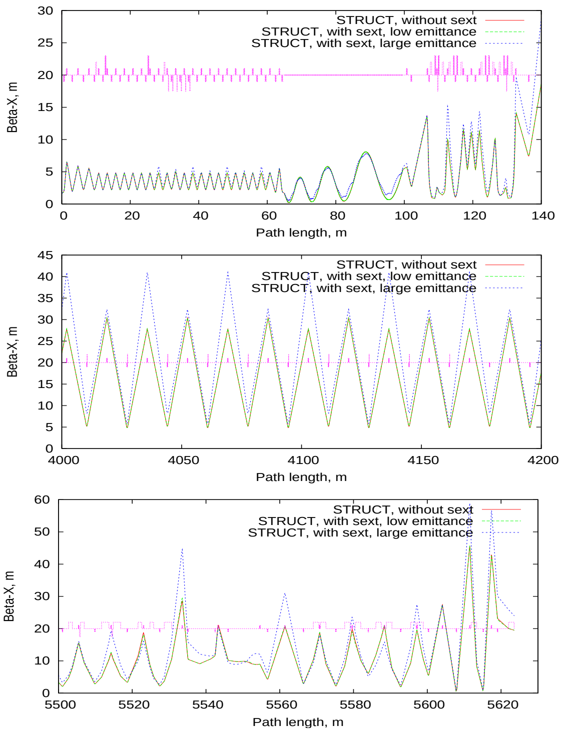

Figure 1: Horizontal β functions in 3 regions without sextupoles (red) and with sextupoles based on "small" (green) and "large" (blue) beam emittance.

There are several regions in the beam line which may be used for collimation: S=0-40 m for amplitude collimation in the beginning of beam line; S=5440-5485 m for amplitude collimation at the end of beam line before injection into the Damping Ring; S=105-135 m for momentum collimation with phase advance of 2π between opposite sign dispersion peaks (Fig. 3); S=5500-5530 m for momentum collimation with phase advance of π between same sign dispersion peaks. Dispersion region S=10-30 m is not optimal for momentum collimation because phase advance between opposite sign dispersion peaks is π which would allow to intercept only half of off-momentum particles.

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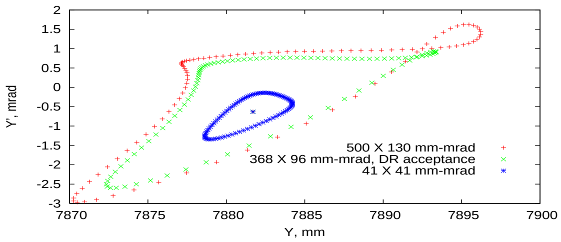

Figure 2: Vertical phase space at the collimator ABHM2 for initial beam emittance of 500×130 μm·rad (red), 368×96 μm·rad (green), and 41×41 μm·rad (blue).

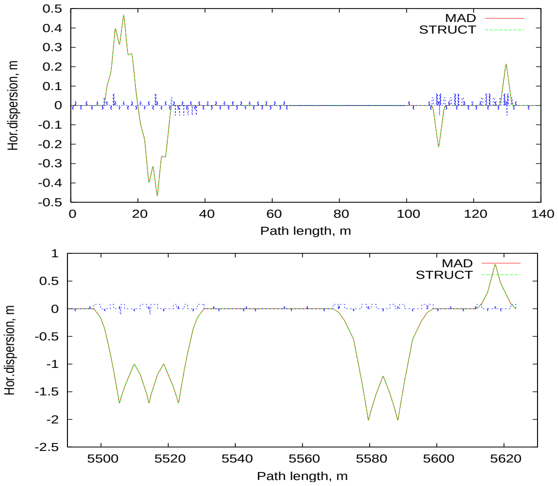

Figure 3: Horizontal dispersion along the transport line.

Table 1 lists parameters of all the collimators. The first 11 momentum and amplitude collimators are used to remove the large initial beam tail and to protect the first NC RF section from large losses. The last six amplitude and two momentum collimators [4], located at the end of the beam line, are used to clean the beam before injection into the DR. The copper collimator jaws are positioned at the beam envelope for $\epsilon_{x,y}$=500×130 μm·rad at Pc=0.125 GeV. This corresponds to $\epsilon_{x,y}$=12.5×3.25 μm·rad at Pc=5 GeV. The masks MSK2-6 are placed at $\epsilon_{x,y}$=115 μm·rad.

Positron momentum distribution along the beam line with the collimation is shown in Fig. 4. The transverse distribution near entrance into the DR shows that the beam tail is mostly in the vertical plane, therefore a tighter vertical collimation is used. The positron spread in the X and Y phase space at entrance into the DR is shown in Fig. 5, and the corresponding positron "emittance" distribution, calculated as $\epsilon_{x,y} = \epsilon_x + \epsilon_y$, is presented in Fig. 6 for beam without and with collimation at $\epsilon_{x,y}$=500×130 μm·rad. The number of particles outside of the DR acceptance of $\epsilon_{x,y} = \epsilon_x + \epsilon_y = 9.2$ μm·rad is calculated based on the lattice functions at this location.

Table 1: Rectangular collimator parameters.

Collimator name	Length (m)	X/Y aperture half-size (mm)		Distance from line entrance (m)
C1R	0.1	29.5	15.1	0.200
C2R	0.1	46.5	12.9	1.000
C3R	0.1	37.6	26.5	2.600
C4R	0.1	49.7	21.2	4.270
C5R	0.1	44.8	19.5	10.321
C6R	0.1	38.2	22.8	11.571
C7R	0.1	37.6	23.1	12.321
C8RMOM	0.1	45.1	19.6	15.320
C8RMOMa	0.1	45.8	19.7	26.120
ABL1	0.1	45.5	21.0	31.121
ABL6	0.1	41.7	26.5	37.371
MSK2	0.1	20.6	21.0	60.130
MSK3	0.1	22.0	17.4	61.030
MSK4	0.1	17.8	23.7	62.680
MSK5	0.1	22.6	12.6	63.800
MSK6	0.1	14.4	14.5	64.600
ABLM1	0.1	10.3	14.4	109.750
ABLM2	0.1	18.8	13.7	129.850
ABH1	0.2	21.2	15.8	5451.809
ABH2	0.2	12.4	19.7	5459.201
ABH4	0.2	7.2	10.1	5468.244
ABH5	0.2	8.5	8.7	5470.641
ABHM1	0.2	7.3	10.7	5505.688
ABHM2	0.2	12.6	13.6	5514.475

Table 2: Positron beam power loss along the beam line.

Beam loss (W)				Transfer rate (%)
C1R-C8aR 0-30 m	ABL collim. 30-140 m	ABH collim. 5170-5520 m	Total 0-5630 m	
without collimators				
2.46E+03	2.24E+03	3.35E+03	8.04E+03	21.3
with collimators at $\epsilon_x = 500 \times 130$ $\mu m \cdot rad$				
6.83E+03	1.95E+03	9.59E+03	1.84E+04	15.5
with collimators at $\epsilon_x = 500 \times 130$ $\mu m \cdot rad$ and 5 masks at $\epsilon_{x,y} = 115$ $\mu m \cdot rad$				
8.90E+03	3.57E+03	4.41E+03	1.69E+04	13.5

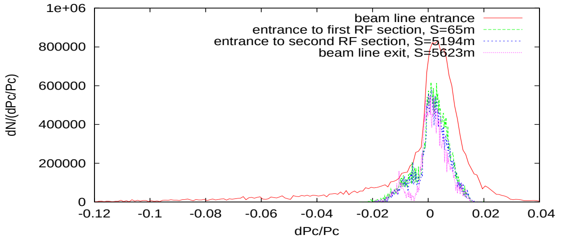

Figure 4: Positron momentum distribution at various positions along the beam line with the collimation.

The positron power loss along the beam line is presented in Table 2. The initial number of positrons at the target in the tracking simulations is 250000, and the number of survived positrons is 79115 at entrance into the positron beam line and 33850 at the Damping Ring entrance. Therefore, the transfer efficiency from target to DR is $33850/250000 = 13.5\%$. To achieve the design value of 3e+10 particles per bunch at the Damping Ring entrance, this efficiency requires $\sim$7e+10 particles per bunch at entrance into the positron beam line.

Calculation of beam loss distributions for the primary positrons, secondary charged particles, and synchrotron and bremsstrahlung radiation photons are shown in Fig. 7

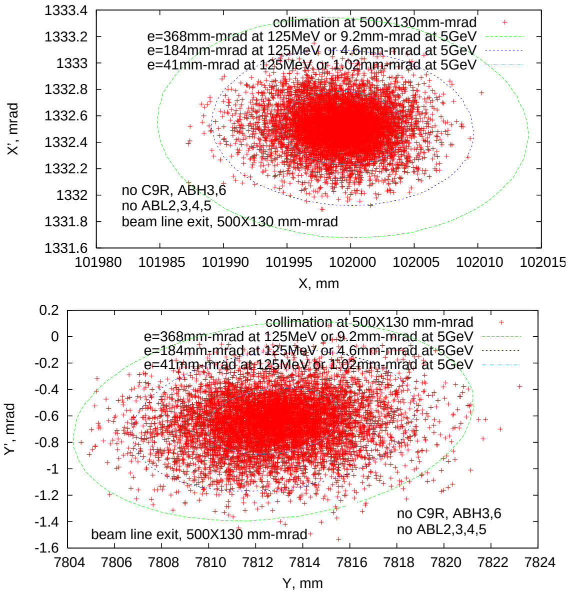

Figure 5: X and Y phase space at entrance into the Damping Ring. The DR acceptance is shown by green ellipse.

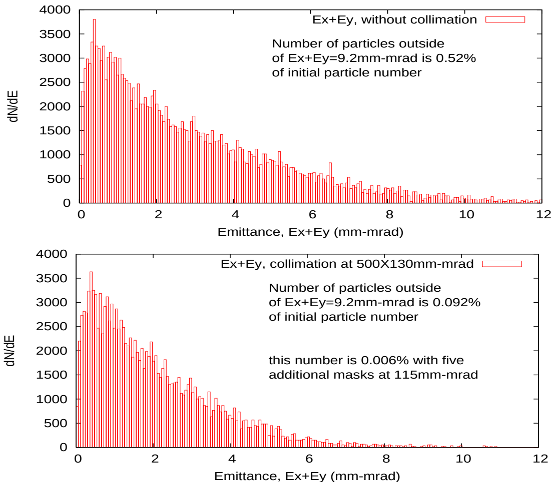

Figure 6: Positron beam "emittance" distribution without (top) and with (bottom) collimation.

and 8 for the collimator jaws at 500×130 μm·rad, with 5 additional masks at 115 μm·rad. The collimators limit the power loss to ∼200 W in the initial 60 cm of the first NC RF section. The photon losses are mostly caused by the bremsstrahlung radiation in the collimators in the regions of S=0-65 m, 110-140 m and 5460-5624 m, and by the synchrotron radiation in the rest of the beam line.

SUMMARY

The calculated power loss in the collimation region is about 100 W/m, with the loss in the collimators of 0.2-5 kW. The positron transfer efficiency from the target to the Damping Ring is 13.5%. Power loss in the beginning of the first NC RF section is about 200 W.

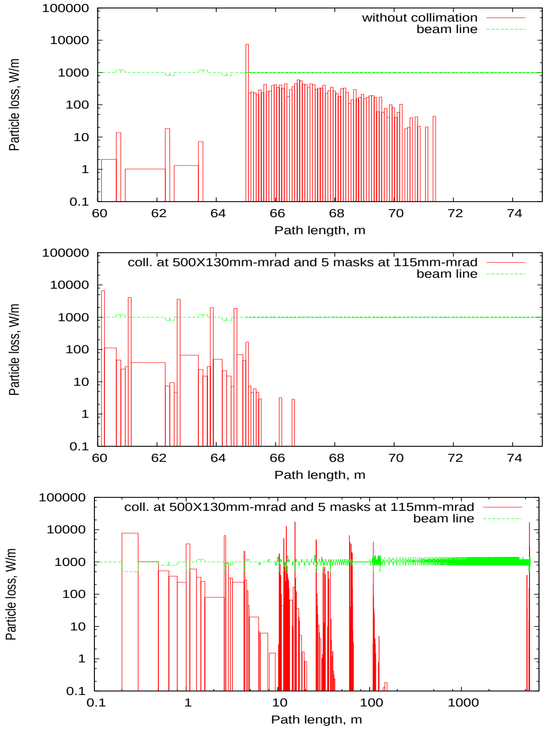

Figure 7: Primary and secondary beam loss distribution in the beginning of the NC RF section without (top) and with (middle) collimation, and along the complete beam line with collimation (bottom).

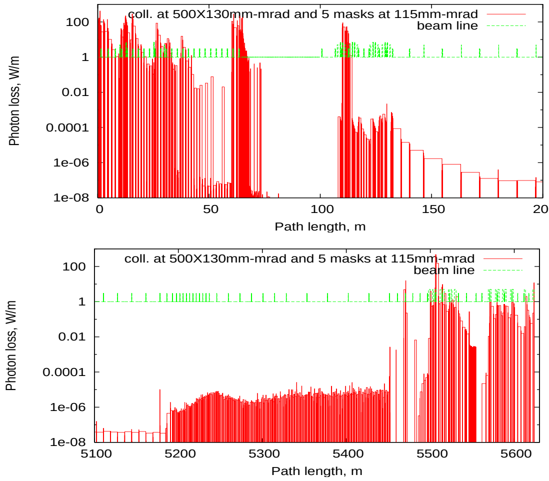

Figure 8: Photon loss distribution along the beam line.

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