POWER SAVING OPTIMIZATION FOR LINEAR COLLIDER INTERACTION REGION PARAMETERS*

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Abstract

Optimization of Interaction Region parameters of a TeV energy scale linear collider has to take into account constraints defined by phenomena such as beam-beam focusing forces, beamstrahlung radiation, and hour-glass effect. With those constraints, achieving a desired luminosity of about 2E34 would require use of e+e- beams with about 10 MW average power. Application of the "travelling focus" regime [1] may allow the required beam power to be reduced by at least a factor of two, helping reduce the cost of the collider, while keeping the beamstrahlung energy loss reasonably low. The technique is illustrated for the 500 GeV CM parameters of the International Linear Collider. This technique may also in principle allow recycling the e+e- beams and/or recuperation of their energy.

INTRODUCTION

The motivation for a parameter set with lower beam power is the potential cost reduction of the machine due to the reduced size and cost of the cryogenics system; smaller diameter damping rings, etc. The ILC Reference Design Report (RDR) included a "low power" parameter set [2], but it is not favoured by the detectors, because of larger number of e+e- pairs and higher number of hits of those pairs in the first layers of the vertex detector [3]. Moreover, the RDR Low P option requires using 0.2 mm long bunch, requiring a two stage bunch compressor. The present cost saving option for the ILC only has a single stage bunch compressor. The physics performance of the low power parameter set may be improved by using a "travelling focus" [1]. In this regime, the bunch is lengthened but the hour-glass effect can be overcome by focusing of the opposite bunch. The matched focusing condition is provided by a dynamic shift of the focal point to coincide with the head of the opposite bunch.

PARAMETER SETS

The suggested parameter sets are shown in Table 1. Since analytical predictions are unreliable in a high disruption regime, the beam-beam simulation code Guinea-Pig [4] was used (referred as G-P in Table 1).

The nominal RDR, low power RDR, and a possible new low power parameter sets are compared in Table 1. The travelling focus may be used with a flat longitudinal density distribution, which is illustrated in Figure 2, however a Gaussian distribution works almost as well. This is the case used in Table 1. To maintain the luminosity, stronger focusing at the IP is used for both of the low power sets.

Table 1: Considered Parameter Sets

Parameters	**Nominal RDR**	**Low P RDR**	**Possible new Low P**
E CM (GeV)	500	500	500
N	2.0E+10	2.0E+10	2.0E+10
n_b	2625	1320	1320
F (Hz)	5	5	5
P_b (MW)	10.5	5.3	5.3
$\gamma\varepsilon_X$ (m)	1.0E-05	1.0E-05	1.0E-05
$\gamma\varepsilon_Y$ (m)	4.0E-08	3.6E-08	3.6E-08
β_x (m)	2.0E-02	1.1E-02	1.1E-02
β_y (m)	4.0E-04	2.0E-04	2.0E-04
Travelling focus	No	No	Yes
Z-distribution	Gauss	Gauss	Gauss
σ_x (nm)	639	474	474
σ_y (nm)	5.7	3.8	3.8
σ_z (µm)	300	200	300
G-P dE/E	0.023	0.045	0.036
G-P L ($cm^{-2}s^{-1}$)	2.02E+34	1.86E+34	1.92E+34
G-P L in 1%	1.50E+34	1.09E+34	1.18E+34

The hour-glass effect for normal and for travelling focus conditions is shown in Figure 1 for a beam with 300 micron length. With the travelling focus, the luminosity continues to increase with decreasing beta function, until about half the nominal beta-function.

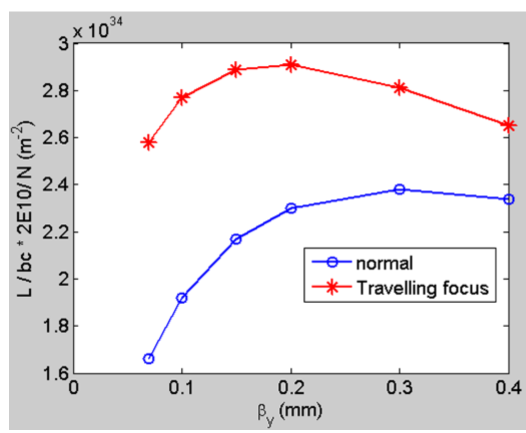

Figure 1: Hour-glass and travelling focus.

The new low power parameters have lower beamstrahlung energy spread compared to the RDR low P set, but it is still somewhat higher than in the nominal case. The luminosity in the 1% peak, an important criterion for physics performance, is somewhat higher than in the RDR low P, but still reduced in comparison with the nominal case.

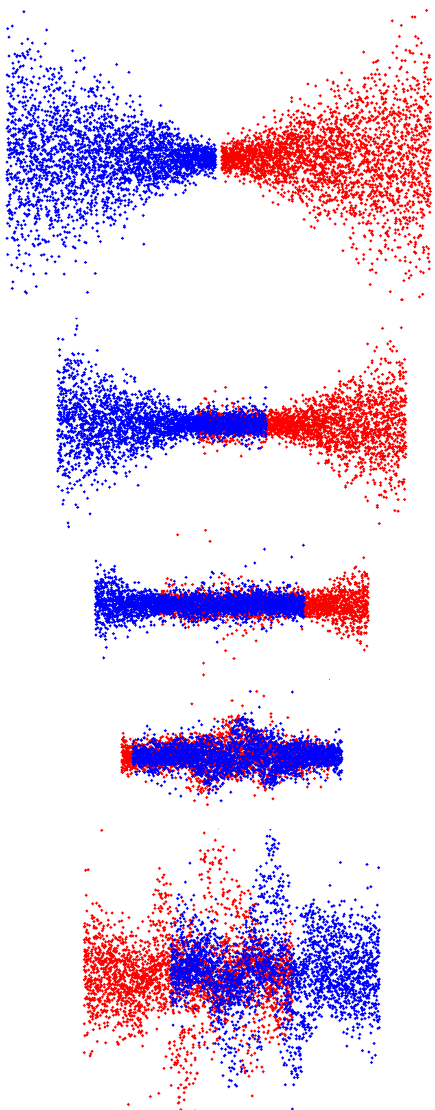

Figure 2: Illustration of travelling focus (flat z-distribution).

The travelling focus simulated by Guinea-Pig is illustrated in Fig.2. The moving focus and beam-beam force keep the beams focused on each other. For optimal focusing, one is in a regime of higher disruption, which causes higher sensitivity to any beam offset, as illustrated in Fig.3. Thus, operation of the intratrain feedback and intratrain luminosity optimization is more challenging.

One of the important criteria for detector performance is the number and distribution of e+e- beam-beam pairs in θ-P_t coordinates, as shown in Fig.4, in particular the location of the edge of the distribution. For the new low P parameters, the edge is about the same as nominal. However, the total number of pairs is about twice as large in both low P cases.

The travelling focus can be created in two ways. The first way is to have small uncompensated chromaticity and coherent E-z energy shift δE/δz along the bunch. One has to satisfy $\delta E\ k\ L^*_{eff} = \sigma_z$ where k is the relative uncompensated chromaticity. The δE needs to be 2-3 times the incoherent spread in the bunch. Thus, the following set may be used: δE=0.3%, k=1.5%, L^*_{eff} =6m.

The second way to create a travelling focus is to use a transverse deflecting cavity giving a z-x correlation in one of the FF sextupoles and thus a z-correlated focusing. The cavity would be located about 100m upstream of the final doublet, at the π/2 betatron phase from the FD. The needed strength of the travelling focus cavity can be compared to the strength of the normal crab cavity (which is located just upstream of the FD): $U_{trav.cav.}/U_{crab.cav.} = \eta_{FD}\ R_{12}^{cc}/\ (L^*_{eff}\ \theta_c\ R_{12}^{trav})$. Here η_{FD} is dispersion in the FD, θ_c full crossing angle, R_{12}^{trav} and R_{12}^{cc} are transfer matrix elements from travelling focus transverse cavity to FD, and from the crab cavity to IP correspondingly. For typical parameters η_{FD} =0.15m, θ_c =14mrad. R_{12}^{cc} =10m, R_{12}^{trav} =100m, L^*_{eff} =6m one can conclude that the needed strength of the travelling focus transverse cavity is about 20% of the nominal crab cavity.

Tracking studies, and possibly mitigation of higher order aberrations, are needed for both these methods.

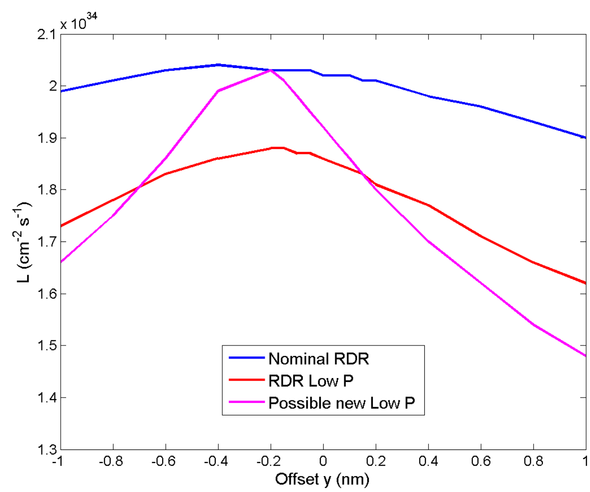

Figure 3: Luminosity versus beam offsets.

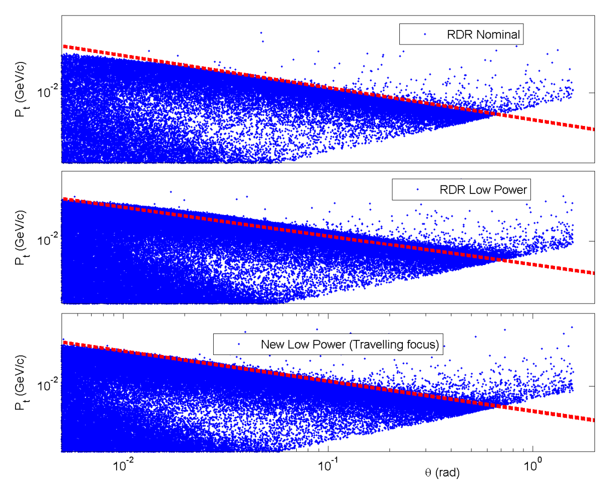

Figure 4: Distribution of e+e- pairs.

Although possibly only of academic interest, a particular parameter set was identified that may illustrate the conceptual feasibility of beam and/or energy recovery for linear collider, see Table 2.

Table 2: Nominal Parameter Set and an Academic Exercise Energy Recycle Set

Parameters	Nom. RDR	E-Recycle
E CM (GeV)	500	500
N	2.0E+10	5.0E+09
n_b	2625	11000
T_{sep} (ns)	369.2	90.0
I_{ave} in train (A)	0.0087	0.0089
f_{rep}(Hz)	5	5
P_b (MW)	10.5	11.0
$\gamma\varepsilon_X$ (m)	1.0E-05	4.0E-06
$\gamma\varepsilon_Y$ (m)	4.0E-08	2.0E-08
$\beta_{x/y}$ (mm)	20 / 0.4	20 / 0.4
$\sigma_{x/y}$ (nm)	639 / 5.7	404 / 4.0
σ_z (mm)	0. 3	0.6
D_y	19.0	21.2
U_{ave}	0.047	0.009
δ_B	0.023	0.002
$P_{beamstrahlung}$ (MW)	0.24	0.024
n_{gamma}	1.29	0.53
H_d	1.70	1.53
Geom L ($cm^{-2}s^{-1}$)	1.14E+34	6.69E+33
L ($cm^{-2}s^{-1}$)	1.95E+34	1.02E+34

The E-recycle set has ten times smaller energy spread after collision as seen in Table 2 and Fig.5 show that about 92% of the disrupted beam has an energy offset less that a percent. Thus, 92% of the beam could be decelerated down to about 10GeV, where dumped (or possibly recovered). Despite the large disruption, the emittance of the disrupted beam does not limit its deceleration – Fig.6 shows that the beam is contained in x within 200mm*mrad (and much smaller in y).

After collisions, the beams, following the 14mrad crossing angle trajectory, would enter a separate beamline to go around the Beam Delivery System, and be brought back to the ends of the opposite linac. Collimation of about 8% of the beam may be done on the way. This beamline, going around the BDS, could also create $\lambda_{RF}/2$ of path difference, if needed for the beam to RF time matching. If the beam is decelerated in the same accelerating structures, the train structure with mini-trains and gaps can be arranged to avoid collisions of accelerating and decelerating bunches in the linac. The length of mini-trains needs to be equal to the full length of the beam delivery and the gap between mini-trains equal to twice the linac length to the extraction point plus the BDS length. However this arrangement of the train lengthens the pulse and the cryogenic losses. A cleaner possibility may be to use a cryomodule with dual aperture (like LHC magnets) with independent accelerating and decelerating structures.

The crabbed waist [5] may also be a way (assuming limitations on minimal β^* are solved) to optimize the energy recycle parameter set.

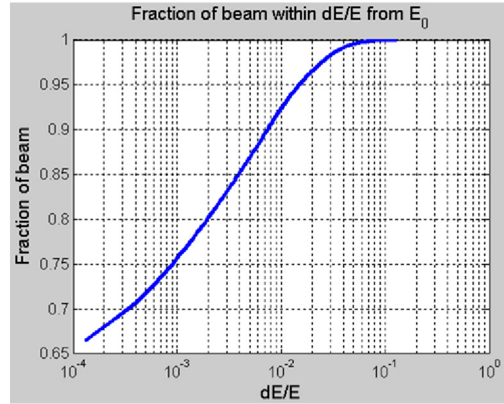

Figure 5: Cumulative distribution of disrupted beam for an academic exercise energy recycle parameter set.

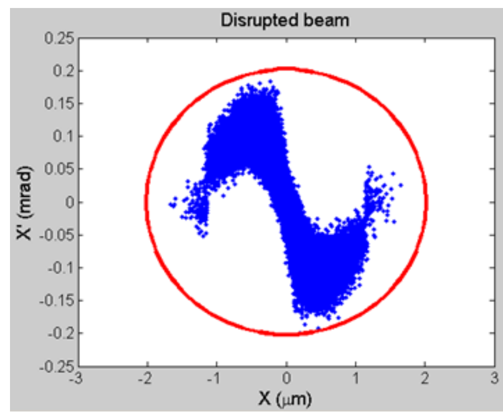

Figure 6: X-X' for disrupted beam of E-recycle set. The red circle corresponds to 200mm*mrad emittance.

CONCLUSION

A possible new low power parameter set for ILC is presented. This new Low-P option is under consideration for adoption in the ILC.

An academic exercise on an energy and/or beam recycling parameter set for linear collider is discussed, illustrating the wide range of options to which the Beam Delivery System can adapt.

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