06-05-98

Proposed ILC Parameters

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Introduction

In this note, we describe the proposed working parameter set for the KEK-SLAC ILC linear collider and discuss the reasons leading to the values listed; more extensive discussion of the optimization process will be found in subsequent notes.

The parameter set is listed in Table 1 and is compared with the JLC 3-97 parameters and the NLC ZDR parameters in Table 2. The new parameter set has an operating plane which ranges from low IP emittances and high luminosity (cases A) to large IP emittances and smaller luminosity (cases C). Over this range, the bunch charge, bunch length, and IP beta functions are varied, however, the parameters have been chosen so that the tolerances on the accelerating structures are roughly constant. The collider must be designed to operate over the entire parameter range.

In all cases, the parameters were optimized for 120 Hz operation. The scaling to 150 Hz is straightforward—either the beam parameters are held constant and the luminosity and ac power are increased or there are small reductions in the bunch charge and an ensuing loosening of the tolerances. Similarly, scaling to 100 Hz operation is also possible, although, if one wants to maintain the luminosity in this case, the bunch charge must be increased and the beamstrahlung energy loss increases to as much as 15%.

In arriving at the parameters, most of the emphasis has been on cost reduction. Thus, at times, we have sacrificed the rf and ac efficiency to obtain a situation that requires fewer rf power sources or significantly looser tolerances; this will be discussed further below. The other issues considered in the parameter determination include: the bunch spacing and beam pulse length limits, the rf structure length, the iris radii (a/λ), and the upgrade path from 500 GeV to 1 TeV cms; each of these issues will be discussed further subsequently.

RF Power Sources

The parameter set is based on 75MW 1.5μs klystrons and the 4/4 DLDS pulse compression system. The assumed efficiencies are 75% for the modulator, 60%

Table 1. IP and linac parameters for the ILC

	500 GeV			1 TeV		
	A	B	C	A	B	C
CMS Energy (GeV)	520	500	480	1050	1000	950
Luminosity w/ IP dilutions (10^{33})	7.5	6.25	5.0	15	12.5	10
Repetition Rate (Hz)		120			120	
Bunch Charge (10^{10})	0.8	1.0	1.15	0.8	1.0	1.15
Bunches/RF Pulse		87			87	
Bunch Separation (ns)		2.8			2.8	
Injected $\gamma\varepsilon_x/\gamma\varepsilon_y$ (10^{-8}m-rad)		300 / 3			300 / 3	
$\gamma\varepsilon_x$ at IP (10^{-8}m-rad)	400	500	600	400	500	600
$\gamma\varepsilon_y$ at IP (10^{-8}m-rad)	6	10	14	6	10	14
β_x/β_y at IP (mm)	10/0.100	12/0.125	14/0.200	10/0.125	12/0.160	14/0.200
σ_x/σ_y at IP (nm)	280/3.5	350/5.1	422/7.7	197/2.8	247/4.1	300/5.5
σ_z at IP (μm)	100	125	150	100	125	150
Υ (Beamstrahlung Param.)	0.13	0.10	0.08	0.39	0.30	0.22
Pinch Enhancement	1.38	1.36	1.47	1.50	1.47	1.48
Beamstrahlung δ_B (%)	4.4	4.0	2.9	11.9	10.3	8.4
# Photons per e^-/e^+	1.10	1.17	1.10	1.45	1.50	1.45
Rf overhead (%)		8			8	
Average rf phase (deg.)	10.6	11.7	13.0	10.9	11.4	13.1
Linac Tolerances (μm)	16.1	15.2	14.6	13.1	11.7	11.9
Unloaded Gradient (MV/m)		77			77	
Effective Gradient† (MV/m)	59.7	56.7	54.5	59.7	56.7	54.5
Active Linac Length (km)		4.3			8.9	
Power/Beam (MW)	3.4	4.2	4.6	7.1	8.4	9.3
# of Structures per linac		2376			4968	
Structure Length (m)		1.8			1.8	
Structure Iris (a/λ)		0.171			0.171	
Structure Atten. (τ)		0.54			0.54	
Shunt Impedance (MΩ/m)		95			95	
Fill Time (ns)		118			118	
Q		7800			7800	
# of Klystrons per linac		1584			3312	
Klystron Peak Pwr. (MW)		75			75	
Klystron Pulse Length (μs)		1.5			1.5	
Pulse Method		4/4 DLDS			4/4 DLDS	
Pulse Comp. Gain (85% eff.)		3.4			3.4	
RF System Efficiency (%)		38			38	
Total AC Power (MW)		94			191	

† Effective gradient includes rf overhead (8%) and average rf phase cos $\overline{\phi}_{rf}$.

Table 2. JLC 3-97 and NLC ZDR (6-96) parameters

	500 GeV		1 TeV	
	JLC 3-97	NLC 6-96	JLC 3-97	NLC 6-96
Luminosity w/ IP dilutions (10^{33})	8.3	5.3	17	11
Repetition Rate (Hz)	150	180	150	120
Bunch Charge (10^{10})	0.70	0.75	0.70	1.10
Bunches/RF Pulse	85	90	85	90
Bunch Separation (ns)	1.4		1.4	
Injected $\gamma\varepsilon_x/\gamma\varepsilon_y$ (10^{-8}m-rad)	300 / 3		300 / 3	
$\gamma\varepsilon_x$ at IP (10^{-8}m-rad)	340	430	340	520
$\gamma\varepsilon_y$ at IP (10^{-8}m-rad)	5	13	5.3	17
β_x/β_y at IP (mm)	10/0.100	10/0.150	10/0.100	12/0.150
σ_x/σ_y at IP (nm)	260/3.1	294/6.3	184/2.3	250/5.1
σ_z at IP (μm)	90	125	90	150
Υ (Beamstrahlung Param.)	0.10	0.09	0.30	0.30
Pinch Enhancement	1.6	1.4	1.6	1.4
Beamstrahlung δ_B (%)	4.4	3.2	9.9	12.6
# Photons per e^-/e^+	1.1	1.0	1.4	1.8
Rf overhead (%)	0	8	0	8
Average rf phase (deg.)	17	15.0	17	8
Unloaded Gradient (MV/m)	73	50	73	85
Effective Gradient† (MV/m)	56	29	56	55
Active Linac Length (km)	4.3	8.2	8.8	8.8
# of Structures per linac	3282	4528	6727	4908
Structure Length (m)	1.31	1.80	1.31	1.80
Structure Iris (a/λ)	0.166	0.180	0.166	0.180
Structure Atten. (τ)	0.61	0.53	0.61	0.53
Fill Time (ns)	106	100	106	100
# of Klystrons per linac	2196	2264	4485	4908
Klystron Peak Pwr. (MW)	67	50	67	75
Klystron Pulse Length (μs)	0.75	1.1	0.75	1.1
Pulse Method	4/3 DLDS	SLED-II	4/3 DLDS	BPC??
Pulse Comp. Gain	3.0	3.6	3.0	3.5
RF System Efficiency (%)	28	28	28	38
Total AC Power (MW)	114	121	234	193

† Effective gradient includes rf overhead and average rf phase cos $\overline{\phi}_{rf}$.

for the klystrons, and 85% for the pulse compression system.

These parameters will be re-evaluated in the future as further R&D is completed on these components. For example, since the quantity for comparison is the energy per rf pulse, an rf power source with a larger peak power and comparably shorter pulse length, as previously proposed at KEK, would utilize a simpler pulse compression system although it might require a more difficult modulator.

Emittance Budgets and Tolerances

The parameter set is based on an emittance budget as described in Table 3. The same budget is presently allocated to both the 500 GeV and the 1 TeV cms parameter sets. The tolerances listed in Table 1 are those on the accelerator structure alignment due to the short-range transverse wakefield assuming that 60% of the emittance budget for the linac is allocated to this single source, e.g. 78% dilution in cases B. It should be noted that although the listed tolerances are looser in the 500 GeV cases, the components must be designed and constructed to attain the 1 TeV tolerances. However, the looser tolerances at 500 GeV will allow for rapid commissioning while optimizing the beam-based alignment techniques.

Finally, note that because the dilution depends upon the beam charge, the tolerances are comparable for the low and high charge cases even though the budgets are significantly tighter in the low charge cases. However, with the tighter budgets, there is little allowance for other sources of dilution such as betatron coupling or dispersive errors.

Table 3. Proposed ILC Emittance Budgets.

	A	B	C
$\gamma\epsilon_x/\gamma\epsilon_y$ from DR [10^{-8}]	300 / 3		
$\Delta\epsilon_x/\Delta\epsilon_y$ in source (10 GeV) [%]	0 / 0	20 / 50	40 / 80
$\Delta\epsilon_x/\Delta\epsilon_y$ in linacs [%]	20 / 60	20 / 130	30 / 200
$\Delta\epsilon_x/\Delta\epsilon_y$ in beam delivery [%]	10 / 40	20 / 50	30 / 80
$\gamma\epsilon_x/\gamma\epsilon_y$ at IP [10^{-8}]	400 / 6	500 / 10	600 / 14

500 GeV to 1 TeV Upgrade Path

The collider would initially be constructed with components to operate at a cms energy of 500 GeV. The rf modules would be identical to those needed for the 1 TeV operation but only the first half of the linac rf would be installed and the remainder of the linac tunnel would be completed with vacuum spool pieces—all linac quadrupoles would be installed and those at the end of the linac would be operated at half strength to maintain the optics. Finally, to upgrade the beam energy, additional rf modules would have to be installed.

In specifying the parameters for the 500 GeV case, we have chosen to assume the same IP beta functions as at 1 TeV—these would be easily attained by the final focus at the lower beam energy. With these relatively large beta functions, the charge requirements are almost identical to those at 1 TeV. In the future, we will study the option of using lower IP beta functions to reduce the beam charge and thereby easing the beam loading and alignment tolerances for the 500 GeV parameters. The relaxed beam tolerances would simplify the commissioning procedures.

Accelerator Structure Length

Longer structures are thought to have the following advantages: (1) the higher group velocity (for the same fill time) implies smaller wakefields and reduced alignment and construction tolerances, (2) longer structures have smaller transverse mode separation and thereby smaller long-range transverse wakefields reducing the need to interleave a number of structures to reduce the long range wakefield, and (3) longer structures are THOUGHT to cost less because much of the cost is associated with the structure ends. However, longer structure are also thought to be harder to construct and further R&D is needed to see if the construction is possible. A 1.8 meter long structure is assumed in the parameters.

Bunch Spacing and Train Length

There is a significant cost savings associated with reducing the average current in the accelerator and lengthening the bunch train. This reduces the beam loading, thereby reducing the required peak rf power, while requiring a longer rf pulse length which, if it can delivered, reduces some of the inefficiencies in the modulators. In the NLC design, the required number of rf power units was reduced by roughly 30% by going to a 2.8ns bunch spacing.

Furthermore, there do not appear to be hard limits on the bunch train length, although the damping rings become more difficult, the rf pulse compression system becomes larger, and potential limitations such as rf breakdown limits are not understood at this time. However, based on the NLC cost model, there do not appear to be significant gains for a bunch spacing larger than 2.8ns, since the reduction in the number of klystrons is offset by the increase in the DLDS system. Thus, in these parameters, we have assumed a 2.8ns bunch spacing and roughly 90 bunches per train.

However, studies indicate that, with roughly 90 bunches per train, the primary cost benefit arises when increasing the bunch spacing from 1.4 to 2.1ns with little further savings in increasing the spacing to 2.8ns or beyond. In the future, this 2.1ns bunch spacing should be re-considered since it will decrease the length of the DLDS delay lines and simplify the damping rings. In addition, it may allow for further pulse compression (5x rather than 4x), reducing the number of klystrons and modulators although increasing the pulse compressor complexity.

Iris Radius

Finally, the choice of the iris radius and thereby the structure fill time is a balance between the rf-to-beam efficiency and relaxed tolerances, which as described earlier, ease with increased group velocity. In these parameters, the rf efficiency is maximized at an $a/\lambda \approx 0.145$, however, we have chosen an $a/\lambda = 0.17$ and a fill time of 118ns. In this case, the required rf power is approximately 8% more than at the optimum, BUT the alignment tolerances are roughly a factor of 2 looser.