CHAPTER 2

The Megatables

Table 2.1, Table 2.2, Table 2.3, Table 2.4, Table 2.5, and Table 2.6 contain summary information for all the machines.

TABLE 2.1: Overall parameters

	TESLA		**JLC-C**		**JLC-X/NLC**[a]		**CLIC**	
Center of mass energy [GeV]	500	800	500	1000	500	1000	500	3000
RF frequency of main linac [GHz]	1.3		5.7	5.7/11.4[b]	11.4		30	
Design luminosity [10^{33} cm^{-2}s^{-1}]	34.0	58.0	14.1	25.0	25.0 (20.0)	25.0 (30.0)	21.0	80.0
Linac repetition rate [Hz]	5	4	100		150 (120)	100 (120)	200	100
Number of particles/bunch at IP [10^{10}]	2	1.4	0.75		0.75		0.4	
Number of bunches/pulse	2820	4886	192		192		154	
Bunch separation [nsec]	337	176	1.4		1.4		0.67	
Bunch train length [μsec]	950	860	0.267		0.267		0.102	
Beam power/beam [MW]	11.3	17.5	5.8	11.5	8.7 (6.9)	11.5 (13.8)	4.9	14.8
Unloaded/loaded gradient[c] [MV/m]	23.8 / 23.8[d]	35 / 35	41.8/31.5	41.8/31.5 / 70/55	65 / 50		172 / 150	
Total two-linac length [km]	30	30	17.1	29.2	13.8	27.6	5.0	28.0
Total beam delivery length [km]	3		3.7		3.7		5.2	
Proposed site length [km]	33		33		32		10.2	33.2
Total site AC power[e] [MW]	140	200	233	300	243 (195)	292 (350)	175	410
Tunnel configuration[f]	Single		Double		Double		Single	

[a]Numbers in ( ) for the JLC-X/NLC correspond to the NLC design with 120 Hz repetition rate.

[b]The 1 TeV JLC-C collider uses a C-band rf system for the first 200 GeV of each linac followed by an X-band rf system for the remaining 300 GeV of acceleration—the X-band rf system would be identical to that described for the JLC-X band collider.

[c]The main linac loaded gradient includes the effect of single-bunch (all modes) and multibunch beam loading, assuming that the bunches ride on crest. Beam loading is based on bunch charges in the linacs, which are slightly higher than at the IP.

[d]With the present site layout for TESLA, 23.4 MV/m was the required energy gain per meter of accelerator structure. A detailed analysis by the ILC-TRC revealed that the gradient has to be increased to 23.8 MV/m when rf phasing, especially for BNS damping, is taken into account.

[e]Total site power includes AC for linac rf and cooling systems as well as power for all other beam lines and site facilities.

[f]The single tunnel layout has both the klystrons and accelerator structures in the main linac tunnel while the double tunnel layout places the klystrons and modulators in a separate enclosure. In the CLIC scheme, the main linac uses a single tunnel since there are no klystrons or modulators associated with it. However, the 300 m-long CLIC drive beam accelerator has a double tunnel layout.

TABLE 2.2: Linear colliders: electron and positron sources

	TESLA		JLC-C		JLC-X/NLC[a]		CLIC	
	500 GeV	800 GeV	500 GeV	1000 GeV	500 GeV	1000 GeV	500 GeV	3000 GeV
Repetition Rate [Hz]	5	4	Same as JLC-X/NLC		150 (120)	100 (120)	200	100
Number of bunches/train	2820	4886			192		154	
Bunch spacing [ns]	337	176			1.4		0.67	
Electron Source								
Style	Subharm. buncher				Subharm. buncher		Subharm. buncher	
e^- beam energy[b] [GeV]	0.5				0.08		0.2	
Number particles/bunch [10^{10}]	2.3				0.8		0.625	
Polarization [%]	80				80		75	
Emittance [rms] $\gamma\varepsilon_x$ / $\gamma\varepsilon_y$ [μm·rad]	40 / 40				100 / 100		7	
Bunch length Δz_{FWHM} [mm]	8				10		7	
Bunch energy spread $\Delta E/E_{FWHM}$ (%)	1				2		2	
Positron Source								
Style	Undulator				Conv. target		Conv. target	
e^+ beam energy[b] [GeV]	0.29				0.250		0.2	
Number particles/bunch [10^{10}]	2.0	1.4			0.9		0.84	
Polarization [%]	0				0		0	
Emittance [edge] $\gamma\varepsilon_x$ / $\gamma\varepsilon_y$[c] [μm·rad]	14,000				30,000 / 30,000		90,000 / 90,000	
Bunch length Δz_{FWHM} [mm]	5				15		7	
Bunch energy spread $\Delta E/E_{FWHM}$ [%]	7				15		10	
Incident beam energy [GeV]	250–150				6.2		2	
Target material / thickness [r.l.]	Ti / 0.4				WRe / 4		WRe / 4	
Number of targets	1				3		1	
Incident beam spot size [mm]	0.7				1.6		2	
Yield at damping ring[d] [e^+ / e^-]	2 at 500 GeV / 1 at 300 GeV				>1		0.7	

[a]Numbers in ( ) correspond to US site with 120 Hz repetition rate.
[b]Beam energy is given at the end of the injector system.
[c]Positron emittance is listed as the 'edge' emittance although the TESLA design specifies an rms value—the edge emittance listed is 1.4 times the specified rms value for TESLA.
[d]Yield is evaluated as number of captured e^+ at the system exit or in the damping ring versus number of incident e^-.

TABLE 2.3: Damping rings

	TESLA		JLC-C		JLC-X/NLC[a]		CLIC	
	500 GeV	800 GeV	500 GeV	1000 GeV	500 GeV	1000 GeV	500 GeV	3000 GeV
Damping Ring Systems								
Damping ring complex energy [GeV]	5		Same as JLC-X/NLC		1.98		2.424	
Number of rings in complex	2				3		3	
Number of bunches/train	2820	4886			192		154	
Number of particles/bunch [10^{10}]	2	1.4			0.8		0.42	
Bunch spacing [ns]	20	11.5			1.4		0.66	
Injected beam emit.[b] $\gamma\epsilon_{e+}$ / $\gamma\epsilon_{e-}$ [μm·rad]	14,000 / 40				45,000 / 150		10	
Extr. beam emit.[b] $\gamma\varepsilon_x$ / $\gamma\varepsilon_y$ [μm·rad]	8.0 / 0.020	6.0 / 0.010			3.0 / 0.020		1.6 / 0.005	0.45 / 0.003
Positron (Pre-)Damping Rings[c]								
Ring circumference [m]	17,000				231		No design	
Number of trains stored	1				2			
RF frequency & voltage [MHz/MV]	500 / 54				714 / 1.5			
Wiggler length [m]	432				50			
Damping times ($\tau_x/\tau_y/\tau_z$) [ms]	28 / 28 / 14				5.8 / 5.8 / 2.9			
Tunes ($\nu_x/\nu_y/\nu_z$)	72.28 / 44.18 / 0.100				11.45 / 5.45 / 0.011			
Bunch len. σ_z & energy spr. $\frac{\sigma_E}{E}$ [mm / %]	6.0 / 0.13				5.1 / 0.08			
Equil. beam emit. $\gamma\varepsilon_x$ / $\gamma\varepsilon_y$ [μm·rad]	8.0 / 0.014	6.0 / 0.010			30 / 30			
Electron Damping Ring[d]								
Ring circumference [m]	17,000				300		375	
Number of trains stored	1				3		9	
RF frequency & voltage [MHz/MV]	500 / 34				714 / 1.1		1500	
Wiggler length [m]	284				46		158	
Damping times ($\tau_x/\tau_y/\tau_z$) [ms]	44 / 44 / 22				4.8 / 5.0 / 2.6		2.7 / 2.7 / 1.4	
Tunes ($\nu_x/\nu_y/\nu_z$)	72.28 / 44.18 / 0.10				27.26 / 11.13 / 0.004		69.21 / 29.63 / 0.004	
Bunch len. σ_z & energy spr. $\frac{\sigma_E}{E}$ [mm / %]	6.0 / 0.10				3.6 / 0.09		1.3 / 0.14	
Equil. beam emit. $\gamma\varepsilon_x$ / $\gamma\varepsilon_y$ [μm·rad]	8.0 / 0.014	6.0 / 0.010			2.2 / 0.013		0.62 / 0.007	

[a]Numbers in table correspond to NLC damping ring designs with 120 Hz repetition rate.

[b]Injected emittances are assumed round but different for e^+ and e^- while extracted emittances are equal for e^+ and e^- but asymmetric. All emittances are rms values except the injected positron emittance which is the 'edge' emittance although the TESLA design specifies an rms value—the edge emittance listed is 1.4 times the specified rms value for TESLA.

[c]Positron Ring table describes TESLA e^+ ring and JLC-X/NLC/CLIC positron pre-damping rings.

[d]Electron Ring table describes TESLA e^- ring and JLC-X/NLC/CLIC electron and positron main damping rings.

TABLE 2.4: Pre-linacs and bunch compressors

	TESLA		JLC-C		JLC-X/NLC[a]		CLIC	
	500 GeV	800 GeV	500 GeV	1000 GeV	500 GeV	1000 GeV	500 GeV	3000 GeV
Electron booster linac (e^- source → damping rings)								
Initial and final energy [GeV]	0.5 / 5.0		Same as JLC-X/NLC		0.08 / 1.98		0.2 / 2.424	
RF frequency [GHz]	1.3				2.8		1.5	
Unloaded and loaded gradient[b] [MV/m]	20.0 / 20.0				19.3 / 16.2		21.0 / 17.0	
Total length [m]	305				164		150	
Positron booster linac (e^+ source → damping rings)								
Initial and final energy [GeV]	0.29 / 5.0				0.25 / 1.98		0.2 / 2.424	
RF frequency [GHz]	1.3				1.4		1.5	
Unloaded and loaded gradient[b] [MV/m]	20.0 / 20.0				14.1 / 12.5		21.0 / 17.0	
Total length [m]	400				164		150	
First stage bunch compressor								
Initial and final bunch length [mm]	6.0 / 0.3				4.0 / 0.5		1.3 / 0.33	
Initial and final energy spread [%]	0.13 / 2.7				0.09 / 1.0		0.13 / 0.54	
RF frequency [GHz]	1.3				1.4		3	
RF voltage [MV]	890				139		154	
Total length [m]	400				51		80	
Pre-linac (damping rings → 2nd bunch compressor)								
Initial and final energy [GeV]	Not needed				1.98 / 8.0		2.424 / 9.0	
RF frequency [GHz]					2.8		3	
Unloaded and loaded gradient[b] [MV/m]					19.3 / 16.8		26.0 / 21.0	
Total length [m]					485		360	
Second stage bunch compressor								
Initial and final bunch length [mm]	Not needed				0.5 / 0.11		0.33 / 0.035	
Initial and final energy spread [%]					0.25 / 1.5		0.14 / 1.36	
RF frequency [GHz]					11.4		30	
RF voltage [MV]					583		592	
Total length [m]					212		90	

[a] Numbers in table correspond to NLC design with a 120 Hz repetition rate.

[b] The linac loaded gradient includes the effect of single-bunch (all modes) and multibunch beam loading, assuming that the bunches ride on crest. Beam loading is based on bunch charges in the linacs, which might be slightly higher than at the IP.

TABLE 2.5: Main linac parameters

	TESLA		JLC-C		JLC-X/NLC[a]		CLIC	
	500 GeV	800 GeV	500 GeV	1000 GeV[b]	500 GeV	1000 GeV	500 GeV	3000 GeV
Initial Energy [GeV]	5.0		8.0		8.0		9.0	
RF frequency [GHz]	1.3		5.7	5.7/11.4	11.4		30	
Unloaded/loaded[c] gradient [MV/m]	23.8 / 23.8[d]	35 / 35	41.8 / 31.5		65 / 50		172 / 150	
Overhead for fdbk & repair [%]	2		0		5		6	6
Overhead for off-crest operation [%]	0.4		0		5		7	5
Active two-linac length [km]	21.6	23	15.4	12.2/12.5	11.1	22.4	3.6	22.0
Total two-linac length [km]	30	30	17.1	29.2	13.8	27.6	5.0	28.0
Total number of klystrons	572	1212	4276	3392/4640	4064	8256	448	
Total number of modulators	572	1212	4276	3392/580	508	1032	448	
Klystron peak power [MW]	9.7		50	50/75	75		50	
Klystron repetition rate [Hz]	5	4	100	100	150 (120)	100 (120)	200	100
Klystron pulse length [μsec]	1370		2.8	2.8/1.6	1.6		16.7	92
Pulse compression ratio	1		5	5/4	4		32×4	32×22
Pulse compression gain	1		3.6	3.6/3.4	3.0		32×4	32×22
RF pulse length at linac [μsec]	1370		0.55	0.55/0.40	0.40		0.13	0.13
Number of sections	20592	21816	8552	6784/13920	12192	24768	7272	44000
Section length [m]	1.04		1.8		0.9		0.5	
a/λ (range if applicable)	0.15		0.171–0.126		0.210–0.148		0.225–0.175	
v_g/c [%]	—		3.6–1.1		5.1–1.1		10.4–5.2	
Filling time [ns]	4.2×10^5	5.1×10^5	285		120		30	
Q Unloaded	10^{10}		9772		9055–8093		3628–3621	
Shunt impedance [MΩ/m]	10^7		54.1		81.2		20.2–27.1	
Total AC power for linacs[e] [MW]	95	160	175	280	188 (150)	254 (305)	105	319
Wall plug $\rightarrow$ Rf efficiency [%]	37.3		24.1	26	28.0		40.3	
RF $\rightarrow$ beam efficiency [%]	62.4	56.5	25.9	28.7	31.5		23.1	

[a] Numbers in ( ) for the JLC-X/NLC correspond to the NLC design with 120 Hz repetition rate.

[b] The 1 TeV JLC-C collider uses a C-band rf system for the first 200 GeV of each linac followed by an X-band rf system for the remaining 300 GeV of acceleration—the X-band rf system would be identical to that described for the JLC-X band collider. Numbers in the table that are missing are simply found from values in the JLC-C (500) and the JLC-X (500) columns.

[c] The main linac loaded gradient includes the effect of single-bunch (all modes) and multibunch beam loading, assuming that the bunches ride on crest. Beam loading is based on bunch charges in the linacs, which are slightly higher than at the IP.

[d] With the present site layout for TESLA, 23.4 MV/m was the required energy gain per meter of accelerator structure. A detailed analysis by the ILC-TRC revealed that the gradient has to be increased to 23.8 MV/m when rf phasing, especially for BNS damping, is taken into account.

[e] Total AC power includes power for the cryo-plant in a superconducting facility and it includes power for cooling water in a normal conducting facility. It does not include power for distribution and it does not include power for magnets, movers, instrumentation or lighting.

TABLE 2.6: Linear colliders: beam delivery system and interaction point parameters

	TESLA		JLC-C		JLC-X/NLC[a]		CLIC	
	500 GeV	800 GeV	500 GeV	1000 GeV	500 GeV	1000 GeV	500 GeV	3000 GeV
Beam delivery system length[b] [km]	3.2		3.8		3.8		5.2	
Collimation system length[b] [km]	1.4		1.4		1.4		4.1	
Final Focus system length[b] [km]	1.2		1.6		1.6		1.1	
$\gamma\varepsilon_x^*$ / $\gamma\varepsilon_y^*$ [m·rad $\times 10^{-6}$]	10 / 0.03	8 / 0.015	3.6 / 0.04		3.6 / 0.04		2.0 / 0.01	0.68 / 0.01
$\beta_x^\star$ / β_y^* [mm]	15 / 0.40	15 / 0.40	8 / 0.20	13 / 0.11	8 / 0.11	13 / 0.11	10 / 0.05	16 / 0.07
$\sigma_x^\star$ / σ_y^* before pinch[c] [nm]	554 / 5.0	392 / 2.8	243 / 4.0	219 / 2.1	243 / 3.0	219 / 2.1	202 / 1.2	60 / 0.7
$\sigma_z^\star$ [μm]	300		200	110	110		35	
$\sigma^\star_{\Delta E/E}$[d] [%]	0.14 / 0.04		0.25		0.25		0.25	0.35
Distance between IP and last quad	3.0		4	3.5	3.5		4.3	
Crossing Angle at IP [mrad]	0		7		7 (20)		20	
Disruptions D_x / D_y	0.23 / 25.3	0.20 / 28.0	0.29 / 17.5	0.10 / 10.3	0.16 / 13.1	0.10 / 10.3	0.04 / 6.4	0.07 / 6.3
Υ_0	0.05	0.09	0.07	0.28	0.13	0.28	0.25	5.0
δ_B [%]	3.2	4.3	3.4	7.5	4.6	7.5	4.4	21.1
n_γ [number of γs per e]	1.56	1.51	1.36	1.30	1.26	1.30	0.75	1.53
$N_{\rm pairs}(p_T^{\rm min} = 20$ MeV/c$, \Theta_{\rm min} = 0.2)$	39.4	37.3	10.7	15.0	11.9	15.0	7.2	43
$N_{\rm hadron\ events}$/crossing	0.248	0.399	0.075	0.270	0.103	0.270	0.066	2.26
$N_{\rm jets} \times 10^{-2}$ [$p_T^{\rm min} = 3.2$ GeV/c]	0.74	1.90	0.23	2.27	0.36	2.72	0.29	150.5
Geometric Luminosity[e] [10^{33} cm^{-2}s^{-1}]	16.4	28.1	8.76	18.5	17.7 (14.2)	18.5 (22.2)	16.0	47.0
H_D	2.11	1.90	1.61	1.42	1.49	1.42	1.42	1.70
Luminosity dilution for tuning [%]	0		5		5		10	0
Peak Luminosity[e] [10^{33} cm^{-2}s^{-1}]	34.5	53.4	13.6	24.9	25.1 (20.1)	25.0 (30.0)	21.0	80.0
$L_{99\%}$ [%]	66	62	67	58	64	58	71	41
$L_{95\%}$ [%]	91	86	90	86	85	77	87	53
$L_{90\%}$ [%]	98	95	97	87	94	87	93	62

[a]Numbers in ( ) correspond to US site with 120 Hz repetition rate.

[b]System length includes both incoming beamlines.

[c]For all designs except CLIC, the IP spot sizes are calculated as usual from the emittances and beta functions. With the design emittances in CLIC, nonlinear aberrations in the final focus system increase the final spot size by 20 to 40%.

[d]Energy spread is for electrons / positrons if different.

[e]For the sake of uniformity, the geometric luminosity is simply defined as $N^2/4\pi\,\sigma_x^*\sigma_y^*$ times the number of crossings per second, and in all cases assumes head-on collisions, no hour-glass effect and no pinch. The peak luminosity is calculated using the Guinea Pig program and incorporates all the effects, including the pinch enhancement, hour-glass, and crossing angle where applicable, plus any additional IP dilutions that may be expected.