Possibility of JLC Luminosity Upgrade

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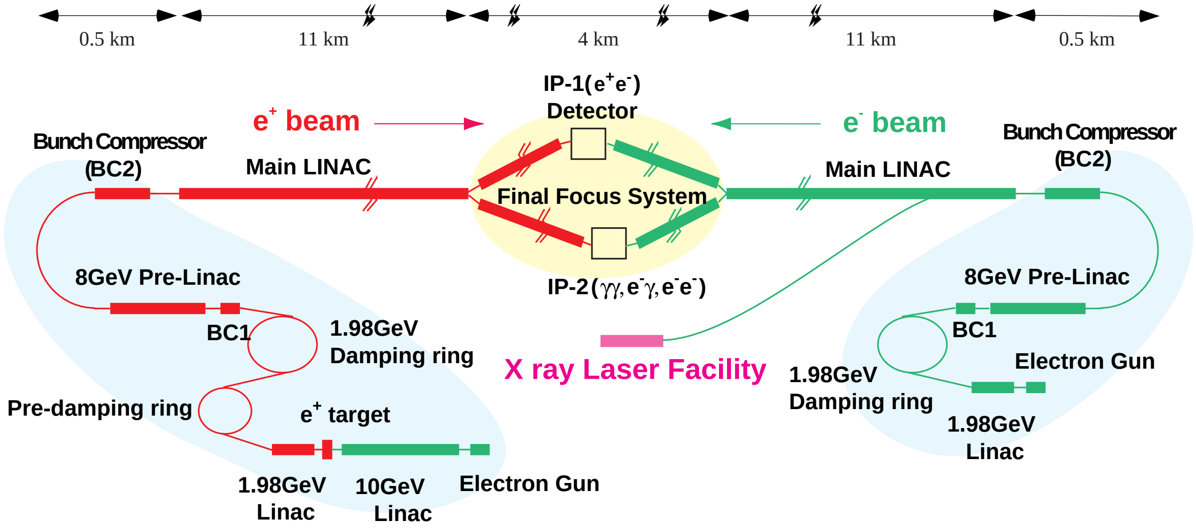
At $E_{CM} = 500$GeV,

JLC: L=0.9×10^{34} v.s. TESLA: L=4×10^{34}

JLC is lasy? TESLA is crazy?

- Think of Luminosity Upgrade of JLC
- $E_{CM} \le 500$GeV only



Present Parameters of JLC and TESLA (500GeV CM)

(Notes on the next page)

		JLC1)			TESLA2)
		A	B	C	
Luminosity	10^{34}/cm^{2}s	0.88	0.82	0.73	3.00
Nominal Lum.3)	10^{34}/cm^{2}s	0.64	0.62	0.50	1.62
Rep rate	Hz	150	150	150	5
Bunch Population	10^{10}	0.75	0.95	1.10	2
No. of bunches/pulse		95	95	95	2820
Bunch separation	ns	2.8	2.8	2.8	337
Beam power/beam	MW	4.28	5.42	6.28	11.3
Unloaded gradient	MV/m	72.3	72.3	72.3	21.7
Loaded gradient4)	MV/m	57.6	55.5	53.9	21.7
Bunch length σ_z	μm	90	120	145	400
$\gamma\epsilon_x$ (DR exit)	10^{-6}m	3	3	3	
$\gamma\epsilon_y$ (DR exit)	10^{-6}m	0.03	0.03	0.03	
$\gamma\epsilon_x$ (IP)	10^{-6}m	4	4.5	5.0	10
$\gamma\epsilon_y$ (IP)	10^{-6}m	0.06	0.10	0.14	0.03
β_x^*	mm	10	12	13	15
β_y^*	mm	0.1	0.12	0.20	0.4
IP beam size σ_x^*	nm	286	332	365	553
σ_y^*	nm	3.15	4.97	7.57	5.0
Disruption param D_x		0.094	0.117	0.135	0.3
D_y		7.64	7.83	6.52	33
Pinch enh. H_D5)		1.38	1.33	1.47	1.8
Υ_{ave}		0.129	0.105	0.092	0.03
δ_{BS}	%	4.02	3.82	3.65	2.8
n_γ		1.02	1,12	1.19	2.0

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1) Aug.8.1998 version of JLC/NLC with revised rep rate for JLC. Crossing angle not included. There are minor differences mainly due to the fine adjustment to E_{CM}=500GeV.
   "A","B","C" refer to the three different operation conditions of the same machine. "A" is prefered but, in case the small emittance growth quoted cannot be achieved due to some reason, the machine should be able to operate with "B" or "C" which accept larger emittance growth with small loss of luminosity but requires more charge.
   The final beam energy is higher in "A" than in others because the beam loading is less. Thus, the original table gives slightly different values of the beam energy for the three cases. This is not convenient for the purpose of comparison, we have fine-adjusted the beam energy to E_{CM}=500GeV. (Tables coming later are similar.) Therefore, strictly speaking, the parameters quoted here give fractional values for the numbers of klystrons, sections, etc.

2) Updated in Aug.1998. Taken from
   `http://www.slac.stanford.edu/xorg/ilc-trc/Table1_1/table1_1.html`

3) $f_{rep} n_b N^2/4\pi\sigma_x^*\sigma_y^*$

4) Acceleration energy divided by the cavity length.

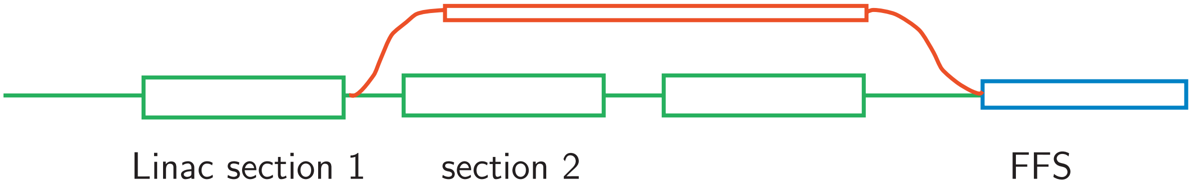
5) Includes geometric reduction due to the hour-glass effect and the pinch effect.

6) Tolerance against the transverse short-range wake. Normalized to the case of "A" at 500GeV, for which 15μm is adopted in the official list. Tolerance against the long-range wake will become tighter in hi-lum parameters than in "A" but it is not the dominant effect provided the RDDS (JLC/NLC cavity type) works as designed. The alignment tolerance for quadrupole will also become tighter because of the reduced vertical emittance.

7) Total cavity length multiplied by 1.25 for the space for magnets, monitors, etc. Does not include the final focus.

Rules of Upgrade

- Use the same linac (klystrons, pulse compressors, accelerating structures, etc.). Only the length should be adjusted.
- Use the same damping rings.
- Expect some improvement of alignment (linacs and DR).
- All the system (in particular, the sub-harmonic buncher) can accept the bunch spacing of 1.4 nsec.
  This means the lowest frequency is 714 MHz.
- All the system (DR, bunch compressor, linac) can accept a larger loading (up to factor ∼1.3 over "C").
- The positron generator has to be designed for higher pulse charge (up to factor ∼1.3 over "C").
  The above two are not absolute requirements (needed only for "Y" later).
  At least "C" must be achieved.
- Bypass for low energy operation is ready.



Steps of Upgrade

Take "A" as the basic parameter set.

Step $\boxed{\text{X}}$

(1) Bunch spacing $t_b = 2.8\text{nsec} \searrow 1.4\text{nsec}$
No. of bunches $n_b = 95 \nearrow 190$
keeping pulse length $n_b t_b$, but
Bunch charge $N = 0.75\times 10^{10} \searrow 0.55\times 10^{10}$

- Requires more charge per pulse (but still same as in "C"),
- No change of luminosity, but $N \searrow$ causes
- cavity alignment tolerance relaxed and
- beamstrahlung reduced.

(2) Improve the vertical emittance from DR
$\gamma\epsilon_y = 3\times 10^{-8}\text{m} \searrow 2\times 10^{-8}\text{m}$.
and a smaller increase of $\gamma\epsilon_y$ in linac.
(Same relative increase. Multi-bunch blowup and quadrupole magnet alignment become severer.)

(3) Smaller horizontal beta $\beta_x^* = 10\text{mm} \searrow 6\text{mm}$.
Possible because $E_{beam} \ll 500\text{GeV}$.

(4) After all, almost the same beamstrahlung, but
luminosity $\nearrow$ factor ∼1.8.

Step $\boxed{\text{Y}}$

Start from “X”

(1) Further increase of the pulse chage.
Same n_b but $N = 0.55\times10^{10} \nearrow 0.70\times10^{10}$,
Pulse charge larger than in “C” (factor 1.27).

(2) Other parameters are the same as in “X”.

(3) Luminosity ↗ by factor ∼3 over “A”,
but the beamstrahlung stronger.

This is very much challenging for the accelerator system.

- Heavy beam loading everywhere.
- Tight tolerances.

Step $\boxed{\text{Z}}$

When E_{CM} is low (e.g., 120GeV),
beamstrahlung is very weak even in “Y”.
But “Y” is too severe for accelerator.
Let’s start from “X”.

(1) Lower the input horizontal emittance
$\gamma\epsilon_x = 3\times10^{-6}\text{m} \searrow 1\times10^{-6}\text{m}$.
This won’t cause tighter tolerances in the linac.

(2) Luminosity ↗ by factor ∼3.3 over “A”.
Beamstrahlung becomes stronger than in “A”,
but still $\delta_{BS} \approx 1\%$ at 120GeV.

No problem if “X” is OK, except

How to produce $\gamma\epsilon_x = 1\times10^{-6}\text{m}$?

⇒ Laser-Compton Cooling
(V. I. Telnov)

Similar increase of luminosity might be possible
by a smaller β_x^* (if can be designed)
but might cause larger background
due to the increased beam size at the last quads.

Laser-Compton Cooling

Brute-force cooling by the energy loss in a laser field
(like synchrotron radiation).

- Photons go into a forward narrow cone.
  ⇒ mainly energy loss, small transverse kick.
- Higher-energy particles loose more
  but still the stochasticity causes final energy spread.
- Low energy electron and long wavelength laser prefered for smaller stochastic effect
  but higher laser flush energy required.
- Small β's needed for laser efficiency and for smaller transverse effects.

Formulas according to Telnov

E_0	Initial electron energy (GeV).
C	Emittance reduction factor $= E_0/E_f$ (E_f: final energy)
λ	Laser wavelength (μm).
l_e	Electron bunch length $\sim 2\sigma_z$ (mm).
$\beta_{x,y}$	Electron beta function (mm).

$$x_0 = 0.019\frac{E_0}{\lambda} \text{ : Max } \gamma \text{ energy}$$

$$\xi^2 = 4.3\frac{\lambda^2}{l_e E_0} \text{ : Laser nolinearity param}$$

Required laser flush energy

$$A = 25\frac{l_e\lambda}{E_0}(C-1) \quad [J]$$

Final relative energy spread

$$\sigma_{\varepsilon f} = \frac{1}{C}\left[\sigma_{\varepsilon 0}^2 + 0.7x_0(1+0.45\xi)(C-1)\right]^{1/2}$$

Depolarization

$$\frac{\Delta P}{P} = 0.3x_0(1+1.8\xi)$$

Equilibrium emittance

$$\gamma\epsilon_{x,eq} = 0.73\frac{\beta_x}{\lambda}(1+1.1\xi^3) \quad \text{[nm]}$$

$$\gamma\epsilon_{y,eq} = 0.73\frac{\beta_y}{\lambda}(1+1.6\xi) \quad \text{[nm]}$$

Example

Just after the 1st bunch compressor, before pre-Linac.

E_0 = 2GeV, λ = 0.5μm, C = 3, l_e = 1mm,
β_x = 20mm, β_y = 4mm.

A = 13 Joule, x_0 = 0.076, ξ = 1.0,
$\sigma_{\varepsilon f}$ = 13%, $\Delta P/P$ = 6.5%,
$\gamma\epsilon_{x,eq}$ = 0.06$\times$10^{-6}m, $\gamma\epsilon_{x,eq}$ = 1.6$\times$10^{-8}m

Problems

- Laser flush energy too large?
- Achromatic optics with β_y=4mm and σ_ε=13% at E=667MeV.
- Acceleration in pre-Linac with initial σ_ε=13%. Energy range 0.667GeV→10GeV. (Or, construct another linac 0.667GeV→2GeV ? L-band?)
- Second bunch compressor with $\gamma\epsilon_x$=1$\times$10^{-6}m

Driving Accelerators Hard.....

(1) Construct one more set of damping ring systems to be operated at 150Hz.

(2) Operate the e^+ linac and bunch compressors at 300Hz.

(3) Split the main linac into 2 parts, operate each at 150Hz.

(4) Use the bypass line.

(5) Get 2× luminosity.

- Cost for extra DRs.
- 300Hz klystrons and modulators for e^+ linac and bunch compressors.
- Low energy part of the main linac needs special configuration....

500GeV (CM) Hi-Lum Parameters of JLC

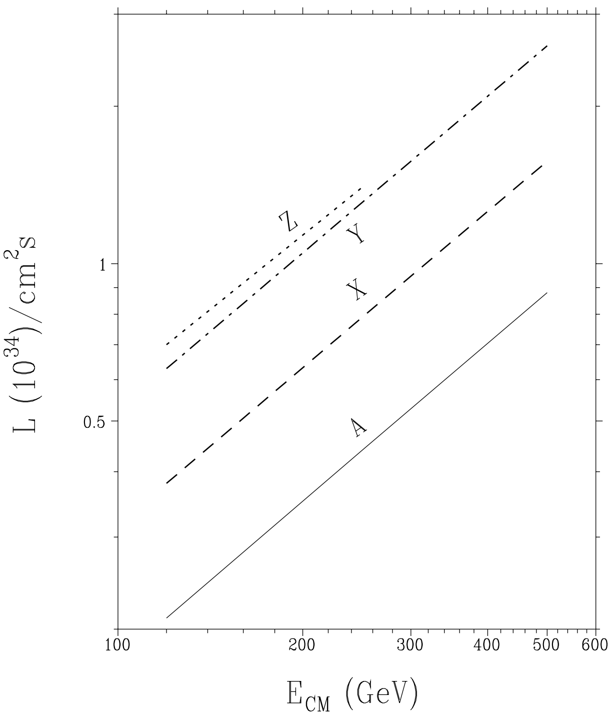
		A	X	Y
Luminosity	10^{34}/cm^{2}s	0.88	1.57	2.61
Nominal Lum.$^{3)}$	10^{34}/cm^{2}s	0.63	1.08	1.75
Bunch Population	10^{10}	0.75	0.55	0.70
No. of bunches/pulse		95	190	190
Bunch separation	ns	2.8	1.4	1.4
Linac length/beam$^{7)}$	km	5.21	5.54	5.97
AC power (2 linacs)	MW	117	126	136
Beam power/beam	MW	4.28	6.28	7.99
Loaded gradient$^{4)}$	MV/m	57.6	54.2	50.2
Bunch length σ_z	μm	90	80	80
$\gamma\epsilon_x$ (DR exit)	10^{-6}m	3	3	3
$\gamma\epsilon_y$ (DR exit)	10^{-6}m	0.03	0.02	0.02
$\gamma\epsilon_x$ (IP)	10^{-6}m	4	4	4
$\gamma\epsilon_y$ (IP)	10^{-6}m	0.06	0.04	0.04
Cavity align. tol.$^{6)}$	μm	15	18	14
β_x^*	mm	10	6	6
β_y^*	mm	0.1	0.1	0.1
IP beam size σ_x^*	nm	286	222	222
σ_y^*	nm	3.15	2.86	2.86
Diagonal angle σ_x^*/σ_z	mrad	3.18	2.77	2.77
Disruption param D_x		0.094	0.102	0.130
D_y		7.64	7.89	10.04
Pinch enh. $H_D{}^{5)}$		1.38	1.45	1.49
Υ_{ave}		0.136	0.146	0.188
δ_{BS}	%	4.42	4.39	6.67
n_γ		1.07	1.01	1.28

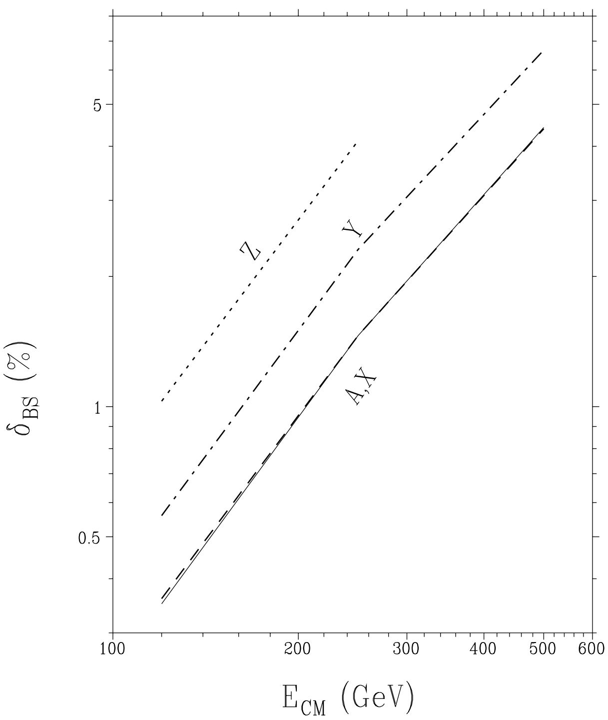
250GeV (CM) Hi-Lum Parameters of JLC

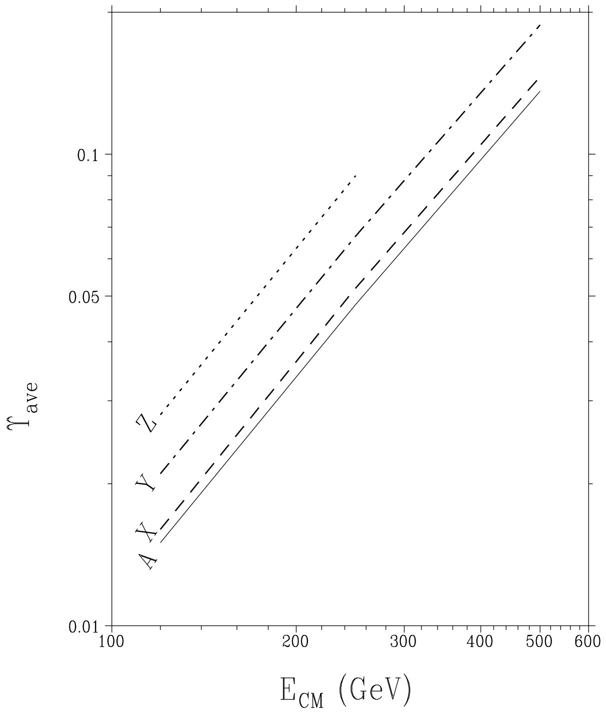
		A	X	Y
Luminosity	$10^{34}/\mathrm{cm}^2\mathrm{s}$	0.44	0.79	1.31
Nominal Lum.$^{3)}$	$10^{34}/\mathrm{cm}^2\mathrm{s}$	0.32	0.54	0.88
Bunch Population	10^{10}	0.75	0.55	0.70
No. of bunches/pulse		95	190	190
Bunch separation	ns	2.8	1.4	1.4
Linac length/beam$^{7)}$	km	2.50	2.65	2.86
AC power (2 linacs)	MW	56	60	65
Beam power/beam	MW	2.14	3.14	4.00
Loaded gradient$^{4)}$	MV/m	57.6	54.2	50.2
Bunch length σ_z	μm	90	80	80
$\gamma\epsilon_x$ (DR exit)	10^{-6}m	3	3	3
$\gamma\epsilon_y$ (DR exit)	10^{-6}m	0.03	0.02	0.02
$\gamma\epsilon_x$ (IP)	10^{-6}m	4	4	4
$\gamma\epsilon_y$ (IP)	10^{-6}m	0.06	0.04	0.04
Cavity align. tol.$^{6)}$	μm	19	23	17
β_x^*	mm	10	6	6
β_y^*	mm	0.1	0.1	0.1
IP beam size σ_x^*	nm	404	313	313
σ_y^*	nm	4.95	4.04	4.04
Diagonal angle σ_x^*/σ_z	mrad	4.49	3.92	3.92
Disruption param D_x		0.094	0.102	0.130
D_y		7.67	7.90	10.06
Pinch enh. $H_D{}^{5)}$		1.38	1.45	1.49
Υ_{ave}		0.048	0.052	0.067
δ_{BS}	%	1.46	1.46	2.31
n_γ		0.80	0.76	0.97

120GeV (CM) Hi-Lum Parameters of JLC

		A	X	Y	Z
Luminosity	$10^{34}/\text{cm}^2\text{s}$	0.21	0.38	0.63	0.70
Nominal Lum.$^{3)}$	$10^{34}/\text{cm}^2\text{s}$	0.15	0.26	0.42	0.45
Bunch Population	10^{10}	0.75	0.55	0.70	0.55
No. of bunches/pulse		95	190	190	190
Bunch separation	ns	2.8	1.4	1.4	1.4
Linac length/beam$^{7)}$	km	1.08	1.15	1.24	1.15
AC power (2 linacs)	MW	24	26	28	26
Beam power/beam	MW	1.03	1.51	1.92	1.51
Loaded gradient$^{4)}$	MV/m	57.6	54.2	50.2	54.2
Bunch length σ_z	μm	90	80	80	80
$\gamma\epsilon_x$ (DR exit)	10^{-6}m	3	3	3	1
$\gamma\epsilon_y$ (DR exit)	10^{-6}m	0.03	0.02	0.02	0.02
$\gamma\epsilon_x$ (IP)	10^{-6}m	4	4	4	1.33
$\gamma\epsilon_y$ (IP)	10^{-6}m	0.06	0.04	0.04	0.04
Cavity align. tol.$^{6)}$	μm	27	32	24	32
β_x^*	mm	10	6	6	6
β_y^*	mm	0.1	0.1	0.1	0.1
IP beam size σ_x^*	nm	584	452	452	261
σ_y^*	nm	7.15	5.84	5.84	5.84
Diagonal angle σ_x^*/σ_z	mrad	6.48	5.65	5.65	3.26
Disruption param D_x		0.094	0.102	0.130	0.303
D_y		7.67	7.90	10.06	13.56
Pinch enh. $H_D{}^{5)}$		1.38	1.45	1.49	1.55
Υ_{ave}		0.015	0.016	0.021	0.028
δ_{BS}	%	0.35	0.36	0.56	1.03
n_γ		0.54	0.51	0.65	0.89


L $(10^{34})/\mathrm{cm}^2\mathrm{s}$
1
0.5
Z
Y
X
A
100
200
300
400
500
600
E_{CM} (GeV)


δ_{BS} (%)
5
1
0.5
Z
Y
A,X
100
200
300
400
500
600
E_{CM} (GeV)


Υ_{ave}
0.1
0.05
0.01
Z
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X
A
100
200
300
400
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600
E_{CM} (GeV)