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Parameter Choice for ILC (Very Low Charge Case)

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ILC Design Philosophy

- Required Colliding energy, luminosity
- Backgroud noise (low) and beam quality (good)
- Operational condition (stable)
- Technical constrains (realisable)
- Damping ring (small space charge effect, reasonable circumference...)
- Total AC power (reasonable)

Parameter Relations (1)

Luminosity

$$L = \frac{f_{rep} N_b N_e^2}{4\pi\sigma_x\sigma_y} H_D$$

Disruption parameter

$$D_{x,y} = \frac{2 r_e N_e \sigma_z}{\gamma\sigma_{x,y}(\sigma_x + \sigma_y)}$$

Beamstrahlung induced energy spread

$$\delta_B = \frac{2 r_e^3 N_e^2 \gamma}{3\sigma_x\sigma_y\sigma_z} F(R)$$

$$F(R \gg 1) = 1.3 / R$$

$$R = \frac{\sigma_x}{\sigma_y}$$

Parameter Relations (2)

$$n_\gamma \approx \frac{2\alpha r_e N_e}{\sigma_x}$$

$R \gg 1$

(per incident particle)

$$N_{Had} = \frac{1}{4\pi}\left(\frac{N_e}{\sigma_x}\right)^2 \frac{\sigma_x}{\sigma_y} H_D n_\gamma^2 \sigma_{\gamma\gamma\to Had}$$

(per crossing)

$$\sigma_{\gamma\gamma\to Had} = 4.2\times 10^{-35}\, m^2$$

r_e Classical radius of electron

N_e Particle population inside a bunch

Parameter proposal for ILC from IHEP, China (1)

$$L = f_{rep} N_b \left(\frac{N_{had}}{n_\gamma^2 \sigma_{\gamma\gamma \to Had}} \right)$$

- W_{cm}=500GeV
- Luminosity $L = 2 \times 10^{34} cm^{-2} \bullet s^{-1}$
- Beamstrahlung energy spread $\delta_B = 0.03$
- Mean number of beamstrahlung photons
- per Electron $n_\gamma = 0.8$
- Number of hardronic events per crossing $N_{Had} = 0.125$

(Low background noise)

Parameter proposal for ILC from IHEP, China (2)

- *Disruption parameter* $D_y = 9$ $H_D = 1.5$

(Operationally stable, small kink instability)

- *R=103 (flat beam)*

- $N_e = 6\times10^9$ *Very* Low Charge (VLC) is good for many things

$$\frac{\sigma_x}{\sigma_y} = \frac{16\pi\alpha^2 r_e^2 N_{Had}}{H_D n_\gamma^4 \sigma_{\gamma\gamma\to Had}}$$

Parameter proposal for ILC from IHEP, China (3)

- $$\sigma_x = \frac{\pi r_e^3 H_{had}}{2.6\,\delta_B \alpha H_D n_\gamma \sigma_{\gamma\gamma\to Had}}$$ $$\sigma_x = 3.1\times 10^{-7}\, m$$
- $$\sigma_y = \frac{r_e n_\gamma^3}{41.5\,\delta_B \alpha^3}$$ $$\sigma_y = 3\times 10^{-9}\, m$$
- $$\sigma_z = \frac{r_e n_\gamma^2 \gamma}{4.6\,\delta_B \alpha^2}$$ $$\sigma_z = 1.2\times 10^{-4}\, m$$
- $$R = \frac{\sigma_x}{\sigma_y} = \frac{16\pi\alpha^2 r_e^2 N_{Had}}{H_D n_\gamma^4 \sigma_{\gamma\gamma\to Had}}$$ $$R = 103$$

Parameter proposal for ILC from IHEP, China (4)

- $$\beta_x = \frac{3.5\pi\gamma r_e^3 N_{Had}}{\delta_B H_D \sigma_{\gamma\gamma\to Had} n_\gamma^2}$$ $$\beta_x = 0.012m$$
- $$\beta_y = \sigma_z / 0.75$$ $$\beta_y = 1.6\times10^{-4} m$$
- $$\gamma\varepsilon_x = \frac{\pi r_e^3 N_{Had}}{23.4\delta_B H_D \alpha^2 \sigma_{\gamma\gamma\to Had}}$$ $$\varepsilon_{n,x} = 3.74\times10^{-6} m*rad$$
- $$\gamma\varepsilon_y = \frac{0.75 n_\gamma r_e^3}{374\delta_B \alpha^4}$$ $$\varepsilon_{n,y} = 2.72\times10^{-8} m*rad$$

Parameter proposal for ILC from IHEP, China (5)

- $$N_e = \frac{\pi r_e^2 N_{Had}}{5.2\delta_B H_D \alpha^2 \sigma_{\gamma\gamma\to Had}}$$

  $$N_e = 0.6\times 10^{10}$$

- $$\frac{N_e}{\sigma_x} = \frac{n_\gamma}{2\alpha r_e}$$

- $$f_{rep} N_b = \frac{L n_\gamma^2 \sigma_{\gamma\gamma\to Had}}{N_{Had}}$$

  $$f_{rep} N_b = 43010$$

- $$P_b = \frac{\pi e W_{cm} r_e^2 n_\gamma^2 L}{10.4 H_D \delta_B \alpha^2}$$

  $$P_b = 10.3 MW$$

Parameter proposal for ILC from IHEP, China (6)

- If $f_{rep} = 8Hz$ then $N_b = 5376$
- $T_{bunch-seperation-ring} = 10.5ns$
- $T_{bunch-seperation-linac} = 150ns$
- $I_{beam} = 6.45mA$ $T_{beam} = 0.8ms$

*Assuming damping ring's circumference is 17km.

Parameter proposal for ILC from IHEP, China (7)

Beam current $I_b = 6.45 mA$

Beam pulse length 0.8ms

Peak power per cavity (Eac=35MV/m) is 234kW

$Q_{ext} = 3.16\times10^6$ ($Q_0 = 6\times10^9$, or over coupling factor 1.72 with $Q_0 = 1\times10^{10}$)

Fill time 0.536ms

Rf pulse length 1.34ms

Total AC power is around 100MW

Parameter proposal for ILC from IHEP, China (8)

- Relation between the damping ring characteristic parameters and the beam parameters at IP:

$$\frac{\gamma_d^{2}\sigma_{zd}}{L_d} \geq \frac{33 N_e \delta_B \alpha^3}{\pi^2 \xi_{sc,y} n_\gamma^{2} r_e}\sqrt{\frac{H_D \sigma_{\gamma\gamma\to Had}}{N_{Had}}}$$

Where L_d is the damping ring circumference, σ_{zd} is the bunch length after bunch Lengthening, γ_d is the normalized damping ring's energy, and $\xi_{sc,y}$ is the tolerable space charge tune shift.

Parameter proposal for ILC from IHEP, China (9)

If TESLA type damping ring is adopted

- Damping ring Length Ld=17km
- Ed=5GeV, $N_e = 6\times10^9$ damping time $\tau_y = 28ms$
- Bunch length inside the damping ring:

$\sigma_{z,d} = 8mm$ after bunch lengthening

- Space charge tune shift (y):

$$\xi_{sc,y} = -\frac{r_e N_e L_d}{(2\pi)^{3/2}(\varepsilon_{n,x}\varepsilon_{n,y})^{1/2}\beta^2\gamma_d^2\sigma_{z,d}}$$

$$|\xi_{sc,y}| = 0.075$$

Parameter choice for damping ring (10)

- Damping ring Length Ld=17km
- Ed=5GeV, $N_e = 6\times 10^9$ damping time $\tau_y = 28ms$
- Space charge tune shift (y):

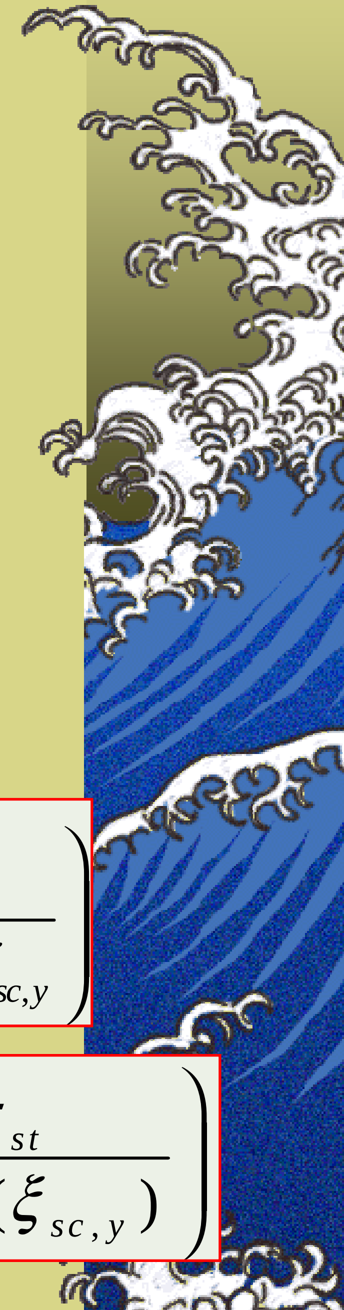
$$\xi_{sc,y} = -\frac{r_e N_e L_d}{(2\pi)^{3/2} (\varepsilon_{n,x}\varepsilon_{n,y})^{1/2} \beta^2 \gamma_d^2 \sigma_{z,d}}$$

- Stored time: $\tau_{st} = 200ms$
- Particle's lifetime due to nonlinear space charge forces

$$\tau_{sc,y}(\xi_{sc,y}) = \frac{\tau_y}{2}\left(\frac{3}{\sqrt{2}\pi\xi_{sc,y}}\right)^{-1} \exp\left(\frac{3}{\sqrt{2}\pi\xi_{sc,y}}\right)$$

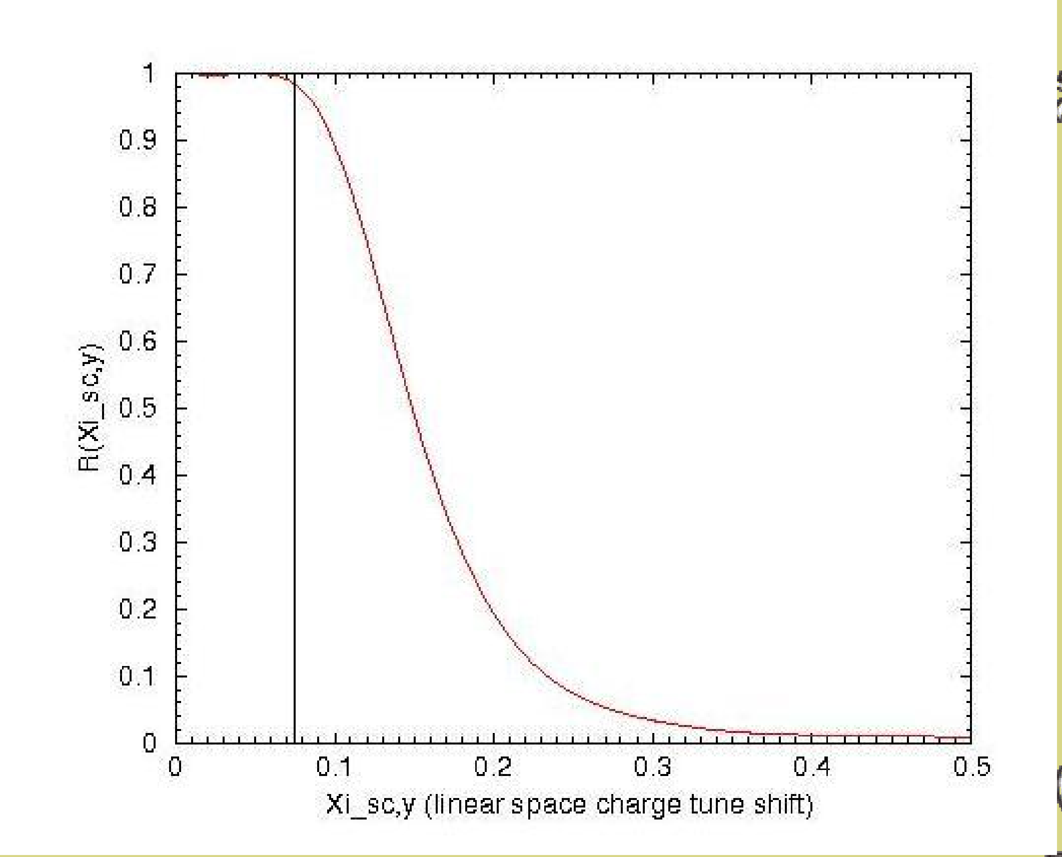
- The relative particle's survival population

$$R(\xi_{sc,y}) = \exp\left(-\frac{\tau_{st}}{\tau_{sc,y}(\xi_{sc,y})}\right)$$



Parameter proposal for ILC from IHEP, China (11)

Particle survival ratio at the ejection



Space charge tune shift

Parameters (selected) for 500 GeV Ecm

	Nominal	Low Q	Large Y	Low P	Very low Q (IHEP)
N/bunch	2E10	1E10	2E10	2E10	6E9
Nb/pulse	2820	5640	2820	1330	5376
Tsep(ns)	307.7	153.8	307.7	461.5	150
I_b (mA)	10.4	10.4	10.4	6.9	6.45
$\gamma\varepsilon y$ (E-8m)	4.0	3.0	8.0	3.5	2.72
β^*x (mm)	20	12	10	10	12
β^*y (mm)	0.4	0.2	0.4	0.2	0.16
σx (nm)	655	495	495	452	310
σy (nm)	5.7	3.5	8.1	3.8	3
σz (mm)	0.3	0.15	0.5	0.2	0.12
Dy	18.5	10.0	28.6	27.0	9
δB	0.022	0.018	0.024	0.057	0.03
$\|\xi_{sc,y}\|$ at 5 GeV	0.167	0.096	0.107	0.167	0.075

On damping ring energy and bunch length choice

If we take damping ring energy being 7GeV, L=17km, and bunch length after bunch lengthening effect $\sigma_z = 6mm$ *, and* $\xi_{sc,y} \approx 0.05$ *the following equation will be satisfied by almost all Tor's parameter lists*

$$\frac{\gamma_d^{\,2}\sigma_{zd}}{L_d} \geq \frac{33 N_e \delta_B \alpha^3}{\pi^2 \xi_{sc,y} n_\gamma^{\,2} r_e} \sqrt{\frac{H_D \sigma_{\gamma\gamma \to Had}}{N_{Had}}}$$

Conclusions

1) After compared "Very Low Q" (VLQ) case with Tor Raubenheimer's low Q case parameter, we have a clear preference among different parameter lists, "Very Low Q" or "Low Q".
2) If 17km damping ring is to be adopted, the damping ring's energy should be 7 GeV instead of 5 GeV. If short ring is adopted(say 6km), damping ring's energy can be adjust accordingly (say 5GeV).
3) The space charge problem in the damping rings should be intrinsically eliminated by parameter choice instead of through coupling technique.