Luminosity Optimization at 250GeV

K. Yokoya

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Basic Formulas

- The luminosity

$$\mathcal{L} = f_{rep} \frac{n_b N^2}{4\pi\sigma_x\sigma_y} H_D \qquad (1)$$

- Can be written in terms of beam power and beastrahlung loss

$$\mathcal{L} \approx C \frac{P_B}{E} \sqrt{\frac{\delta_{BS}}{\epsilon_{y,n}}} \min\left(1, \sqrt{\sigma_z/\beta_y}\right) \qquad (2)$$

  - C : universal constant
  - PB = beam power
  - The last factor express the hour-glass effect approximately
  - δ_{BS} = beamstrahlung energy loss

$$\delta_{BS} = \left\langle -\frac{\Delta E}{E} \right\rangle \approx 0.836 \frac{N^2 r_e^3 \gamma}{\sigma_z \sigma_x^2}, \qquad (\Upsilon \ll 1,\ \sigma_x \gg \sigma_y) \qquad (3)$$

  - Beam size at IP

$$\sigma_x = \sqrt{\frac{\epsilon_{x,n}\beta_x^*}{\gamma}} \qquad (4)$$

Luminosity Scaling

- Naive scaling
  - (1) and (4) gives $L \sim E$ (constant $\beta_{x,y}$)
- However, the form (2) says L can be ~1/E, if
  a. P_B independent of E
  b. δ_{BS} independent of E
- (a) is realized in "10 Hz collision"
  (i.e., same beam power with 10Hz@250GeV and 5Hz@500GeV)
  - But this is not realistic in the 250GeV in staging
    - Cost saving too small
- (b) is possible?
  - TDR parameter set says δ_{BS} ~ 1% at 250GeV
  - If 4% beamstrahlung is acceptable, luminosity can be doubled

How to Increase Beamstahlung

- Increase bunch charge
  - N → aN, (n_b → n_b/a so that PB does not change)
  - Then, δ_{BS} → $a^2\delta_{BS}$, L → aL
  - But this will
    - Make the out-coming angle of pairs sqrt(a) times
    - Changes of DR dynamics, alignment tolerance of ML
  - → unacceptable
- Shorter bunch length
  - σ_z → σ_z/a,
  - Then, δ_{BS} → $a\delta_{BS}$, Can make β_y smaller (hour-glass),
  - → L increases
  - But this will
    - Make the out-coming angle of pairs sqrt(a) time
  - → unacceptabl
- Smaller horizontal beam size
  - σ_x → σ_x/a
  - Then, δ_{BS} → $a^2\delta_{BS}$, L → aL

How to reduce σ_x ?

- The simplest way is to reduce β_x
- But this will make the beam angle spread at IP larger

$$\theta_x^* = \sqrt{\frac{\epsilon_{x,n}}{\gamma \beta_x^*}} \qquad (5)$$

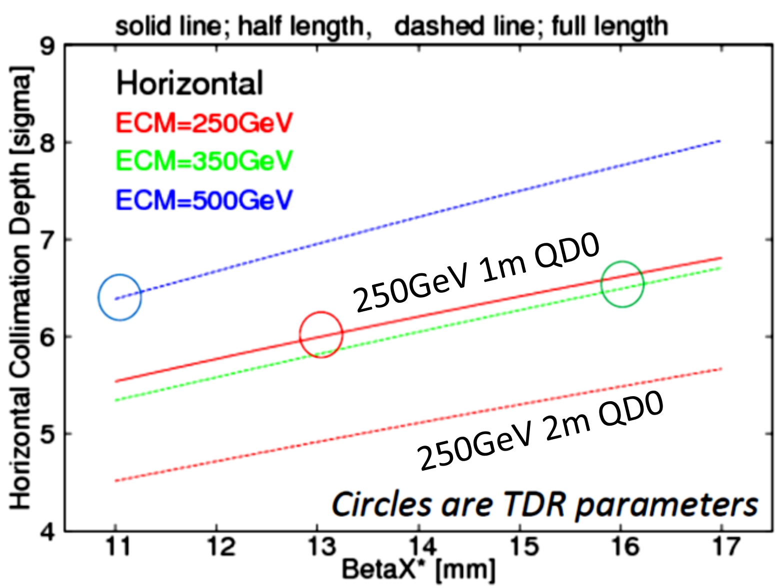
- → larger beam size at the final quad QD0
- Synchrotron radiation from tail particles hit the quad, causing back ground
- These particles must be collimated out upstream
- The horizontal collimation depth is already ~ 6 σ_x

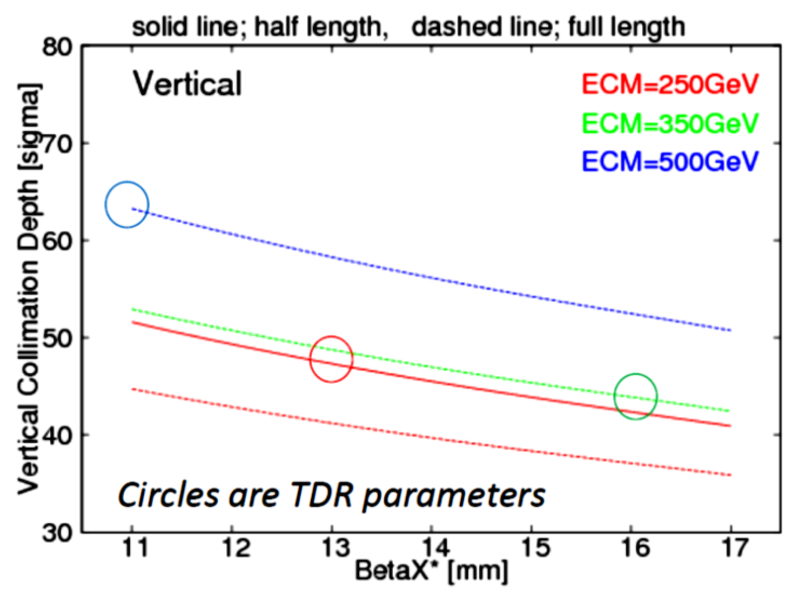
Collimation Depth with TDR Params

The collimation depth for various beam energy

ECM	BetaX*	BetaY*
250GeV	13mm	0.041mm
350GeV	16mm	0.034mm
500GeV	11mm	0.048mm

(QF1 L) = 9.5m*
(QD0 L) = 4.1m*





The circles shows the betas in TDR

T. Okugi

Horizontal Emittance

- σ_x can be reduced by reducing the horizontal emittance from DR
  - Present lattice is presumably conservative
  - Circular colliders assumes much more aggressive horizontal emittance
- If $\varepsilon_{x,n} \rightarrow \varepsilon_{x,n}/a$,
- Then, $\sigma_x \rightarrow \sigma_x$ /sqrt(a), $\delta_{BS} \rightarrow a\delta_{BS}$, L $\rightarrow$ sqrt(a)L.
- This will make horizontal beam angle 1/sqrt(a) smaller.
- If we further make $\beta_x \rightarrow \beta_x$ /a, then L $\rightarrow$ a^2L
- Smaller $\varepsilon_{x,n}$ would also help at other energies
  - Luminosity increase may be small but at least FFS tuning would become easier (allow larger β_x for same σ_x)

Problems

- Obvious problems are
  - Is it possible to reduce $\varepsilon_{x,n}$ of DR?
    - Technically possible?
    - Manpower problem
    - Now, Kiyoshi is trying …
    - Must include studies of e-cloud, FII, etc.
  - Disruption parameter too large

$$D_{x(y)} = \frac{2Nr_e}{\gamma} \frac{\sigma_z}{\sigma_{x(y)}(\sigma_x + \sigma_y)} \qquad (6)$$

  - Disruption parameter too large
    - $D_y \rightarrow aD_y$
    - Present D_y is already ~25
    - Feedback tolerance tighter

An Example Parameter Set

- Next page, right-most column
  - $\varepsilon_{x,n} \rightarrow \varepsilon_{x,n}/2$, no change of β_x
- However, note that $D_x \sim 0.5$ is not negligible
- This will cause effective σ_x smaller than σ_x/sqrt(2)
- Hence, δ_{BS} larger than $2\delta_{BS}$, L larger than sqrt(2)L
- Beam-beam simulation being done by Daniel Jeans (the bottom row is to be filled by simulation)
- If everything is OK, may try smaller β_x

TDR (Combined TDR_machine_parameters_stamp.pdf and L study parameters 16-02-2012.xlsx

		Baseline						1TeV		New
							Full Power	A1	B1b	Param
Ecm	GeV	200	230	250	350	500	500	1000	1000	250
N	e10	2.0	2.0	2.0	2.0	2.0	2.0	1.737	1.737	2.0
Collision frequency	Hz	5.0	5.0	5.0	5.0	5.0	5.0	4.0	4.0	5.0
Electron linac rep rate	Hz	10.0	10.0	10.0	5.0	5.0	5.0	4.0	4.0	5.0
Nb		1312	1312	1312	1312	1312	2625	2450	2450	1312
Bunch separation	ns	554	554	554	554	554	366	366	366	554
Beam current	mA	5.78	5.78	5.78	5.78	5.78	8.75	7.60	7.60	5.78
PB	MW	4.2	4.8	5.3	7.4	10.5	21.0	27.3	27.3	5.3
sigz	mm	0.3	0.3	0.3	0.3	0.3	0.3	0.25	0.225	0.3
sige(e-)	%	0.206	0.193	0.188	0.156	0.124	0.124	0.083	0.085	0.188
sige(e+)	%	0.187	0.163	0.15	0.1	0.07	0.07	0.043	0.047	0.15
enx	μm	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	5.00
eny	nm	35.0	35.0	35.0	35.0	35.0	35.0	30.0	30.0	35.0
electron polarization	%	80	80	80	80	80	80	80	80	80
positron polarization	%	31	31	31	29	22	22	30	30	31
betax	mm	16.0	14.0	13.0	16.0	11.0	11.0	22.6	11.0	13.0
betay	mm	0.34	0.38	0.41	0.34	0.48	0.48	0.25	0.23	0.41
sigx	nm	904.2	788.7	729.0	683.5	474.2	474.2	480.6	335.3	515.5
sigy	nm	7.80	7.69	7.66	5.89	5.86	5.86	2.77	2.63	7.66
theta_x	μr	56.5	56.3	56.1	42.7	43.1	43.1	21.3	30.5	39.7
theta_y	μr	22.9	20.2	18.7	17.3	12.2	12.2	11.1	11.7	18.7
Dx		0.21	0.24	0.26	0.21	0.30	0.30	0.11	0.20	0.51
Dy		24.3	24.5	24.5	24.3	24.6	24.6	18.7	25.4	34.5
Upsilon (average)		0.013	0.017	0.020	0.030	0.062	0.062	0.128	0.203	0.028
Ngamma (formula)		0.95	1.08	1.16	1.23	1.72	1.72	1.43	1.97	1.62
deltaB (formula)	%	0.510	0.749	0.935	1.416	3.651	3.651	5.330	10.19	1.772
HDx		1.05	1.15	1.18	1.10	1.31	1.29	1.01	1.04	1.77
HDy		4.52	5.03	5.36	4.52	6.07	6.07	3.55	4.03	6.10
HD		1.69	1.84	1.90	1.73	2.09	2.07	1.53	1.62	2.43
Lgeo	1.0E+34	0.296	0.344	0.374	0.518	0.751	1.504	1.768	2.672	0.529
L (formula, no waist shift)	1.0E+34	0.501	0.632	0.712	0.896	1.567	3.117	2.706	4.337	1.285
L (simulation, waist shift)	1.0E+34	0.59	0.73	0.82	1.03	1.79	3.6	3.02	5.11	