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Consideration of crab waist scheme in CEPC

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Head on &crab waist

	Head-on	Crab waist(θ-half crossing angle)
Beam-beam parameter	$\xi_x = \frac{N_e r_e \beta_x}{2\pi\gamma\sigma_x(\sigma_x+\sigma_y)}$, $\xi_y = \frac{N_e r_e \beta_y}{2\pi\gamma\sigma_y(\sigma_x+\sigma_y)}$,	Piwinski's angle: $\phi = \frac{\sigma_z tan\theta}{\sigma_x}$, $\sigma_{x,eff} = \sigma_x\sqrt{1+\phi^2}$, $\xi_x = \frac{N_e r_e \beta_x}{2\pi\gamma\sigma_{x,eff}(\sigma_{x,eff}+\sigma_y)}$, $\xi_y = \frac{N_e r_e \beta_y}{2\pi\gamma\sigma_y(\sigma_{x,eff}+\sigma_y)}$,
Hour glass factor	$F_h = \frac{\beta_y}{\sqrt{\pi}\sigma_s} e^{\frac{\beta_y^2}{2\sigma_s^2}} K_0(\frac{\beta_y^2}{2\sigma_s^2})$	$\sigma_{s,eff} = \frac{\sigma_x}{\theta}$, $F_h = \frac{\beta_y}{\sqrt{\pi}\sigma_{s,eff}} e^{\frac{\beta_y^2}{2\sigma_{s,eff}^2}} K_0(\frac{\beta_y^2}{2\sigma_{s,eff}^2})$
luminosity	$L = \frac{N_e^2 n_b f_0}{4\pi\sigma_x\sigma_y} F_h$	$L = \frac{N_e^2 n_b f_0}{4\pi\sigma_{x,eff}\sigma_y} F_h$

Consideration at high energy(H)

Collision scheme	Head-on(Pre-CDR)	Crossing angle
Beam energy [GeV]	120	120
Current[mA]	16.6	16.6
No.bunches	50	50
Ne[10^{11}]	3.79	3.79
$\beta_{IP}(x/y)$[m]	0.8/0.0012	0.8/0.0012
ε_x[nm]	6.12	6.12
ε_y[pm]	18.4	18.4
$\sigma_{s,tot}$[mm]	2.65	2.65
θ[mrad](half crossing angle)	0	15
Piwinski's angle ϕ	0	0.56<1
ξ_x	0.118	0.118
ξ_y	0.083	0.083
F(crossing angle factor)	1	0.86
L/IP[10^{34}]	2	1.37

$60^{\circ}\text{FODO} \rightarrow 90^{\circ}\text{FODO} : \varepsilon_x \rightarrow \frac{1}{3}\varepsilon_x, \alpha_p \rightarrow \frac{4}{9}\alpha_p,$

ϕ →0.44<1, crab waist scheme can not be realized.

Consideration at low energy(Z)

- Scale from Higgs energy(90° FODO),we got ε_x and σ_s at low energy(Z):

$$\varepsilon_x \propto \gamma^2, \quad \sigma_s = \frac{\alpha_p R \sigma_e}{v_s} \propto \gamma^{3/2},$$

$$\varepsilon_x = 0.29\text{nm}, \qquad \sigma_s = 0.27\text{mm}.$$

So Piwinski's angle: $\phi = 0.27$

- V_{RF} ↓, σ_s ↑⇒Piwinski's angle ↑:

$$V_{RF} = 0.094\text{GV}\text{时}, \qquad \sigma_s = 3\text{mm}, \quad \phi = 3$$

Parameters at low energy(Z) head-on vs. crab waist

Collision scheme	Head-on	Crab waist
Beam energy [GeV]	45.5	45.5
Current[mA]	4.37	4.37
P[MW]	0.27	0.27
No.bunches	2000	200
Ne[10^9]	2.47	24.7
$\beta_{IP}(x/y)$[m]	0.8/0.0012	0.8/0.0012
ε_x[nm]	0.29	0.29
ε_y[pm]	0.88	0.88
σ_s[mm]	0.27	3
θ[mrad](half crossing angle)	0	15
Piwinski's angle ϕ	0	3
ξ_x	0.04	0.04
ξ_y	0.03	0.09
L/IP[10^{33}]	1	3

Conclusions

- At high energy(H), we can not use crab waist for present lattice.

- At low energies(Z)crab waist scheme can provide higher luminosity than head-on collision.

The tentative parameters

parameter	FCC-ee crab waist (2 IPs)			
	Z (IPAC'15)	Z (this design)	t (IPAC'15)	t (this design)
E_{beam} [GeV]	45.5	45.6	175	←
current [mA]	1450	←	6.6	←
$P_{SR,tot}$ [MW]	100	95	100	94
no. bunches	45154	←	51	←
N_b [10^{11}]	0.66	←	2.6	←
ε_x [nm]	0.13	0.15	2	1.83
ε_y [pm]	1.0	1.0	2	1.83
β^*_x [m]	0.5	1	0.5	1
β^*_y [mm]	1	1	1	2
RF frequency [MHz]	400			
RF voltage [GV]	0.4	0.08	11	9.6
circumference [km]	100	99.938	100	99.938
mom. comp. [10^{-5}]	0.5	0.936	0.5	0.936
synchrotron tune	-0.03	-0.018	-0.07	-0.0856
$\sigma_{z,SR}$ [mm]	1	3.4	2.31	2.4
$\sigma_{z,tot}$ [mm] (w	2.8		2.83	
$\sigma_{\delta,SR}$ [%]	0.037	0.041	0.202	0.138
$\sigma_{\delta,tot}$ [%] (w beamstr.)	0.127		0.248	
θ_c [mrad]	30			
Piwinski angle	5.3	←	1.8	←
L* [m]	2	2.2	2	2.2
beam-beam param.	0.07		0.06	
beam-beam param.	0.18		0.12	
luminosity/IP [10^{34}	247		2.6	

FCC-ee Parameters

Version 2.0 (2014-09-05)	LEP2	FCC-ee Z	FCC-ee W	FCC-ee H	FCC-ee tt
Circumference [km]	26.7	100			
Bending radius [km]	3.1	11			
Beam energy [GeV]	104	45.5	80	120	175
Beam current [mA]	3.04	1450	152	30	6.6
Bunches / beam	4	16700	4490	1360	98
Bunch population [10^{11}]	4.2	1.8	0.7	0.46	1.4
Beam size at IP s* [mm] - Horizontal - Vertical	 182 3.2	 121 0.25	 41 0.084	 22 0.044	 45 0.045
Energy loss / turn [GeV]	3.34	0.03	0.33	1.67	7.55
SR power / beam [MW]	11	50			
Total RF voltage [GV]	3.5	2.5	4	5.5	11
RF frequency [MHz]	352	800			
Luminosity / IP [10^{34} $cm^{-2}s^{-1}$]	0.012	28.0	12.0	6.0	1.8
Luminosity lifetime [min](1)	434	298	73	29	21

(1) Luminosity lifetime corresponds to 4 IPs.