Institute of High Energy Physics
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Circular Electron Positron Collider

CEPC collider design and challenges at tt bar energy

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CEPC parameters
(Tentative at tt)

30MW
$0.38*10^{34}cm^{-2}s^{-1}$@ 350GeV
$0.32*10^{34}cm^{-2}s^{-1}$@ 365GeV

If 50MW
$0.63*10^{34}cm^{-2}s^{-1}$@ 350GeV
$0.53*10^{34}cm^{-2}s^{-1}$@ 365GeV

tt based on lattice fcp=0.3% and εx =1.2nm, if fcp=0.2% and εx =0.89nm or even lower, the luminosity at tt will be higher.

	Higgs (high)	*Higgs (CDR)*	*tt*	tt
Number of IPs	2	2	2	2
Beam energy (GeV)	120	120	175	182.5
Circumference (km)	100	100	100	100
Synchrotron radiation loss/turn (GeV)	1.68	1.73	7.61	9.0
Crossing angle at IP (mrad)	16.5×2	16.5×2	16.5	16.5
Piwinski angle	3.78	3.48	0.91	0.89
Number of particles/bunch N_e (10^{10})	17.0	15.0	24.15	26.7
Bunch number (bunch spacing)	218 (0.76μs)	242 (0.68μs)	34	26
Beam current (mA)	17.8	17.4	3.95	3.3
Synchrotron radiation power /beam (MW)	30	30	30	30
Bending radius (km)	10.7	10.7	10.9	10.9
Momentum compact (10^{-5})	0.91	1.11	1.14	1.14
β function at IP β_x^*/β_y^* (m)	0.33/0.001	0.36/0.0015	1.2/0.0037	1.2/0.0037
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	0.89/0.0018	1.21/0.0024	2.24/0.0068	2.46/0.0074
Beam size at IP σ_x/σ_y (μm)	17.1/0.042	20.9/0.06	51.8/0.16	54.4/0.17
Beam-beam parameters ξ_x/ξ_y	0.024/0.113	0.018/0.109	0.077/0.105	0.076/0.103
RF voltage V_{RF} (GV)	2.4	2.17	8.93	10.3
RF frequency f_{RF} (MHz) (harmonic)	650 (216816)	650 (216816)	650 (217500)	650 (217500)
Natural bunch length σ_z (mm)	2.2	2.72	2.54	2.62
Bunch length σ_z (mm)	3.93	4.4	2.87	2.93
HOM power/cavity (2 cell) (kw)	0.58	0.46	0.53 (5cell)	0.49
Energy spread (%)	0.19	0.134	0.14	0.15
Energy acceptance requirement (%)	1.7	1.35	1.57	1.7
Energy acceptance by RF (%)	3.0	2.06	2.67	2.48
Photon number due to beamstrahlung	0.104	0.082	0.19	0.15
Beamstruhlung lifetime /quantum lifetime* (min)	30/50	80/80	60	1.0
Lifetime (hour)	0.22	0.43		0.7
F (hour glass)	0.85	0.89	0.89	0.88
Luminosity/IP *L* ($10^{34}cm^{-2}s^{-1}$)	5.2	2.93	0.38	0.32

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Collider design at tt bar

- CEPC is optimized at Higgs energy. The tt bar running will be based on the hardware for Higgs except adding RF cavities.
  - Lattice design:
    - In the arc and most part of interaction region, magnets strength margin reserved for running at tt bar; just need to make re-matching to keep the same beam size at the 4 final quadrupoles.
    - Error correction: same scheme as normalized strength is the same with Higgs mode
    - Dynamic aperture: The optimization of the DA at tt should be done for **a asymmetric momentum acceptance in order to match the distribution with beamstrahlung (ref: FCC-ee, -2.8% and +2.4%).**
  - **MDI: The critical energy of radiated photon will be 3.5 times (i.e. 91keV and 130keV from last bends of upstream and downstream) but the power will be a bit lower.**
  - RF cavity: space of 5-cell RF cavities is reserved for running at tt bar

Challenges of collider design at tt bar

- No much challenges on the accelerator physics design as not high luminosity is required at tt bar for CEPC.
- MDI: The critical energy of radiated photon will be 3.5 times. The shielding should be stronger. The photon background will be worse.
- RF cavity: high gradient 5-cell RF cavities is necessary

Summary

- CEPC is optimized at Higgs energy. The tt bar running will be based on the hardware for Higgs except adding RF cavities.
- No much changement on the collider design and no much challenges on the accelerator physics design as not high luminosity is required at tt bar for CEPC.
- Two issues of the physics and detector people may concern:
  - a asymmetric momentum acceptance in order to match the distribution with beamstrahlung (ref: FCC-ee, -2.8% and +2.4%).
  - In the interaction region, the critical energy of radiated photon will be 3.5 times (i.e. 91keV and 130keV from last bends of upstream and downstream) but the power will be a bit lower.

backup

FCC-ee parameter
Ref: FCC-ee CDR

		Z	WW	ZH	tt̄	
Circumference	[km]			97.756		
Bending radius	[km]			10.760		
Free length to IP ℓ^*	[m]			2.2		
Solenoid field at IP	[T]			2.0		
Full crossing angle at IP θ	[mrad]			30		
SR power / beam	[MW]			50		
Beam energy	[GeV]	45.6	80	120	175	182.5
Beam current	[mA]	1390	147	29	6.4	5.4
Bunches / beam		16640	2000	328	59	48
Average bunch spacing	[ns]	19.6	163	994	2763[a]	3396[a]
Bunch population	[10^{11}]	1.7	1.5	1.8	2.2	2.3
Horizontal emittance ε_x	[nm]	0.27	0.84	0.63	1.34	1.46
Vertical emittance ε_y	[pm]	1.0	1.7	1.3	2.7	2.9
Arc cell phase advances	[deg]	60/60		90/90		
Momentum compaction α_p	[10^{-6}]	14.8		7.3		
Arc sextupole families		208		292		
Horizontal β_x^*	[m]	0.15	0.2	0.3	1.0	
Vertical β_y^*	[mm]	0.8	1.0	1.0	1.6	
Horizontal size at IP σ_x^*	[μm]	6.4	13.0	13.7	36.7	38.2
Vertical size at IP σ_y^*	[nm]	28	41	36	66	68
Energy spread (SR/BS) σ_δ	[%]	0.038/0.132	0.066/0.131	0.099/0.165	0.144/0.186	0.150/0.192
Bunch length (SR/BS) σ_z	[mm]	3.5/12.1	3.0/6.0	3.15/5.3	2.01/2.62	1.97/2.54
Piwinski angle (SR/BS) ϕ		8.2/28.5	3.5/7.0	3.4/5.8	0.8/1.1	0.8/1.0
Length of interaction area L_i	[mm]	0.42	0.85	0.90	1.8	1.8
Hourglass factor R_{HG}		0.95	0.89	0.88	0.84	0.84
Crab sextupole strength[b]	[%]	97	87	80	40	40
Energy loss / turn	[GeV]	0.036	0.34	1.72	7.8	9.2
RF frequency	[MHz]	400			400 / 800	
RF voltage	[GV]	0.1	0.75	2.0	4.0 / 5.4	4.0 / 6.9
Synchrotron tune Q_s		0.0250	0.0506	0.0358	0.0818	0.0872
Longitudinal damping time	[turns]	1273	236	70.3	23.1	20.4
RF bucket height	[%]	1.9	3.5	2.3	3.36	3.36
Energy acceptance (DA)	[%]	±1.3	±1.3	±1.7	-2.8 +2.4	
Polarisation time t_p	[min]	15000	900	120	18.0	14.6
Luminosity / IP	[10^{34}/cm^{2}s]	230	28	8.5	1.8	1.55
Horizontal tune Q_x		269.139	269.124	389.129	389.108	
Vertical tune Q_y		269.219	269.199	389.199	389.175	
Beam-beam ξ_x/ξ_y		0.004/0.133	0.010/0.113	0.016/0.118	0.097/0.128	0.099/0.126
Allowable e^+e^- charge asymmetry	[%]	±5	±3			
Lifetime by rad. Bhabha scattering	[min]	68	59	38	40	39
Actual lifetime due to beamstrahlung	[min]	> 200	> 200	18	24	18