Circular Electron Positron Collider

Introduction to CEPC-SppC

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SLAC, USA

Contents

- General background and status of CEPC
- CEPC/SppC design goals and options
- Key accelerator design issues towards CDR
- CEPC/SppC international collaborations

From BEPC to BEPCII

BEPC was completed in 1988 with luminosity $1\times10^{31}cm^{-2}s^{-1}$ @1.89GeV
BEPC II was completed in 2009
Luminosity reached on April 5, 2016: $10\times10^{32}cm^{-2}s^{-1}$ @1.89GeV

After BEPCII what is the next high energy collider?

Important reminds

- ➢CEPC-SppC is proposed in Sept. 2012, right after Higss discovery at CERN by LHC in July 2012

- ➢"C" in CEPC doesn't stands for China, but "Circular" and mostly for high energy physics "Community". CEPC is of the Community, by the Community and for the Community

- ➢ILC, CEPC, FCC(ee) are proposed tools to produce Higgs (+ others) through e+e- collision

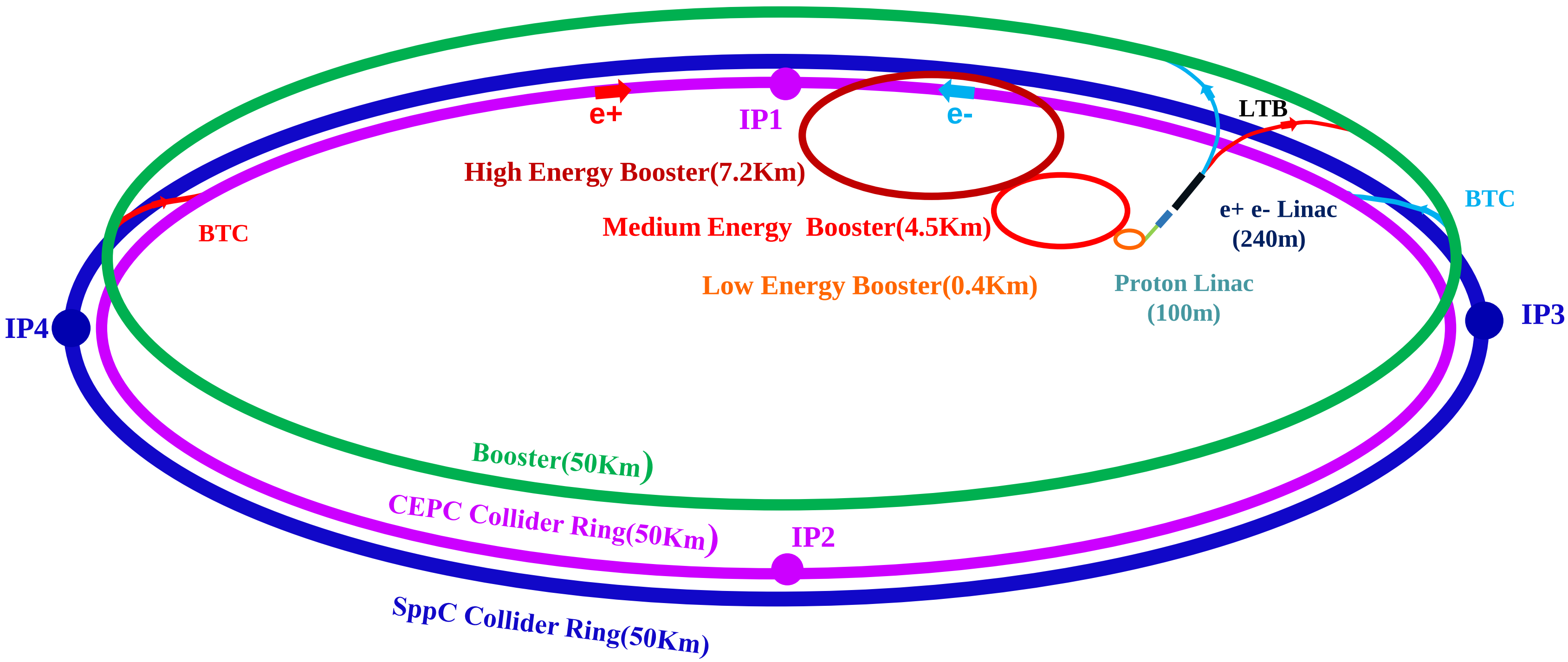
- ➢ILC, CEPC, FCC(ee) have many common technologies and task force overlapes

- ➢The succeed of the community is the succeed of any of them

- ➢In Oct. 30, 2015, Chinese government cleared next five year plan and beyond on science with the following statement: "Actively propose and lead the international science plans and big scientific projects (积极提出并牵头组织国际大科学计划和大科学工程) "

CEPC+SppC

- Thanks to the low mass Higgs, it is possible to build a Circular Higgs Factory(CEPC), followed by a proton collider(SppC) in the same tunnel
- Looking for Hints ➔ direct searches



ICFA Statements

- ICFA meeting of Feb. 2014 at DESY, Hambourg, stated:

ICFA supports studies of energy frontier circular colliders and encourages global coordination

- ICFA meeting of July 2014 in Spain, stated:

… ICFA continues to encourage international studies of circular colliders, with an ultimate goal of proton-proton collisions at energies much higher than those of the LHC.

AsiaHEP/ACFA Statement on ILC + CEPC/SPPC

AsiaHEP and ACFA reassert their strong endorsement of the ILC, which is in a mature state of technical development. The aim of ILC is to explore physics beyond the Standard Model by unprecedented precision measurements of the Higgs boson and top quark, as well as searching for new particles which are difficult to discover at LHC. The Higgs studies at higher energies are especially important for measurement of WW fusion process, to fix the full Higgs decay width, and to measure the Higgs self-coupling. In continuation of decades of world-wide coordination, we encourage redoubled international efforts at this critical time to make the ILC a reality in Japan. The past few years have seen growing interest in a large radius circular collider, first focused as a “Higgs factory", and ultimately for proton-proton collisions at the high energy frontier. We encourage the effort lead by China in this direction, and look forward to the completion of the technical design in a timely manner.

Kyoto, Janan, April, 2016

Physics of CEPC (SppC)

- **Electron-positron collider(90, 250 GeV)**
  - **Higgs Factory（10^6 Higgs）:**
    - **Precision study of Higgs(m_H, J^{PC}, couplings), Similar & complementary to ILC**
    - **Looking for hints of new physics**
  - **Z & W factory（10^{10} Z^0）:**
    - **precision test of SM**
    - **Rare decays ?**
  - **Flavor factory: b, c, τ and QCD studies**
- **Proton-proton collider(~100 TeV)**
  - **Directly search for new physics beyond SM**
  - **Precision test of SM**
    - **e.g., h^3 & h^4 couplings**

Precision measurement + searches:

Complementary with each other !

CEPC Design –Higgs Parameters

Parameter	Design Goal
Particles	e+, e-
Center of mass energy	240 GeV
Luminosity (peak)	2*10^34/cm^2s
No. of IPs	2

⇒ one million Higgs from 2 IPs in 10 years

CEPC Design – Z-pole Parameters

Parameter	Design Goal
Particles	e+, e-
Center of mass energy	45.5 GeV
Integrated luminosity (peak)	>1*10^34/cm^2s
No. of IPs	2
Polarization	Consider in the second round

CEPC Design – Guidelines

- Build an underground tunnel for a Higgs factory
- Use the same tunnel for a future *pp* collider:
  - The tunnel cross section should be big enough to accommodate an *e+e-* collider, a booster and a *pp* collider
  - The straight sections should be long enough to accommodate large detectors and complex collimation systems of a *pp* collider
  - It should allow to run both *e+e-* and *pp* experiments simultaneously
  - Within the budget limit, the tunnel circumference should be made as large as possible
- Keep options open for:
  - Super Z
  - *e-p* and *e-A* colliders
  - Light source
  - XFEL

CEPC Design - PreCDR

- Tunnel circumference: ~54 km
- Tunnel size: 6.0 m (LEP tunnel: 3.6 m)
- 8 arcs and 8 straight sections: 4 straight for IPs and RF, another 4 for RF, injection and beam dump, etc.
- A 6 GeV linac on the surface (with the option for an FEL in the future)
- A full-energy 120 GeV Booster in the tunnel
- A 240 GeV e+e- Collider in the same tunnel underneath the Booster
- **A single beam pipe** for both e+ and e- beams (similar to LEP, CESR)
- Synchrotron radiation budget: 50 MW per beam
- Two SRF systems:
  - Booster: 1.3 GHz 9-cell cavity, similar to the ILC, XFEL, LCLS-II
    32 cryomodules, 256 cavities
  - Collider: 650 MHz 5-cell cavity, similar to the ADS, PIP-II
    96 cruomodules, 384 cavities

CEPC-SPPC Timeline (preliminary)

CEPC

2nd Milestone: 13th Five Year Plan R&D

2015 | 2020 | 2025 | 2030 | 2035

Pre-studies (2013-2015)	R&D Engineering Design (2016-2020)	Construction (2021-2027)	Data taking (2028-2035)

1st Milestone: Pre-CDR (by the end of 2014) → R&D funding request to Chinese government in 2015 (China's 13th Five-Year Plan 2016-2020)

SPPC

2020 | 2030 | 2040

R&D (2014-2030)	Engineering Design (2030-2035)	Construction (2035-2042)	Data taking (2042-2055)

Current Status of CEPC

- **Pre-CDR completed**
  - **No show-stoppers**
  - **Technical challenges identified ➔ R&D issues**
  - **Preliminary cost estimate**
- **R&D issues identified and funding request underway**
  - **Seed money from IHEP available: 12 M RMB/3 years**
  - **MOST: ~ 80 M RMB / 5yr, 36M RMB has been proved in June 2016**
  - **Onters topical issue funds from NSFC, CAS and the Science and Technoogy Bureau of Beijing Municipal: ~9M RMB**
  - **Working towards CDR, Accelerator by 2016 and Detector by 2017**
  - **A working machine on paper solving the problems left by Pre-CDR**
- **Site selections**
- **Internationalization & organization**

IHEP-CEPC-DR-2015-01

IHEP-EP-2015-01

IHEP-TH-2015-01

Can be downloaded from

http://cepc.ihep.ac.cn/preCDR/volume.html

CEPC-SPPC

Preliminary Conceptual Design Report

Volume I - Physics & Detector

403 pages, 480 authors

The CEPC-SPPC Study Group

March 2015

IHEP-CEPC-DR-2015-01

IHEP-AC-2015-01

CEPC-SPPC

Preliminary Conceptual Design Report

Volume II - Accelerator

328 pages, 300 authors

The CEPC-SPPC Study Group

March 2015

Luminosity from colliding beams

- For equally intense Gaussian beams

Collision frequency

Particles in a bunch

Geometrical factor:
- crossing angle
- hourglass effect

$$L = f \frac{N_b^{\ 2}}{4\pi\sigma_x\sigma_y} R$$

Transverse beam size (RMS)

- Expressing luminosity in terms of our usual beam parameters

$$L[\text{cm}^{-2}\text{s}^{-1}] = 2.17\times10^{34}(1+r)\xi_y \frac{E[\text{GeV}]I[\text{A}]}{\beta_y[\text{cm}]}$$

where $$\xi_y = \frac{r_e N_e \beta_y}{2\pi\sigma_y(\sigma_x+\sigma_y)}:$$

Maximum Beam-beam tune shift analytical expressions for lepton and hadron circular colliders

For lepton collider:

$$\xi_{y,\max} = \frac{2845}{2\pi}\sqrt{\frac{T_0}{\tau_y \gamma N_{IP}}}$$

$$\xi_{y,\max} = \frac{2845\gamma}{1}\sqrt{\frac{r_e}{6\pi R N_{IP}}}$$

r_e is electron radius
γ is normalized energy
R is the dipole bending radius
N_{IP} is number of interaction points

$$\xi_{x,\max} = \sqrt{2}\,\xi_{y,\max}$$

J. Gao, Nuclear Instruments and Methods in Physics Research A 533 (2004) 270–274

J. Gao, Nuclear Instruments and Methods in Physics Research A 463 (2001) 50–61

For hadron collider:

$$\xi_{\max} = \frac{2845\gamma}{f(x)}\sqrt{\frac{r_p}{6\pi R N_{IP}}}$$

where r_p is proton radius

$$f(x) = 1 - \frac{2}{\sqrt{2\pi}}\int_0^x \exp\left(-\frac{t^2}{2}\right)dt$$

$$x^2 = \frac{4f(x)}{\pi \xi_{\max} N_{IP}} = \frac{4f^2(x)}{2845\pi\gamma}\sqrt{\frac{6\pi R}{r_p N_{IP}}}$$

J. Gao, "Review of some important beam physics issues in electron positron collider designs", Modern Physics Letters A, Vol. 30, No. 11 (2015) 1530006 (20 pages)

J. Gao, et al, "Analytical estimation of maximum beam-beam tune shifts for electron-positron and hadron circular colliders", Proceedings of ICFA Workshop on High Luminosity Circular e+e- Colliders – Higgs Factory, 2014

Constraints for parameter choice

- Limit of Beam-beam tune shift

$$\xi_y = \frac{2845}{2\pi}\sqrt{\frac{U_0}{2\gamma E_0 N_{IP}}} \times F_l *$$

F_l: ξy enhancement by crab waist

J. Gao*

- Beam lifetime due to beamstrahlung

BS life time: 30 min

$$\frac{N_e}{\sigma_x \sigma_z} \le 0.1\eta \frac{\alpha}{3\gamma r_e^2}$$

1) V. Telnov, arXiv:1203.6563v, 29 March 2012
2) V. Telnov, HF2012, November 15, 2012

- Beamstrahlung energy spread

$A=\delta_0/\delta_{BS}$ ($A \geq 3$)

- HOM power per cavity

$$P_{HOM} = k(\sigma_z) e N_e \cdot 2I_b \le 1kw$$

*1) J. Gao, emittance growth and beam lifetime limitations due to beam-beam effects in e+e- storage rings, **Nucl. Instr. and methods A**533（2004）p. 270-274.

* 2) J. Gao, Review of some important beam physics issues in electron positron collider designs, **Modern Physics Letters A**, Vol. 30, No. 11 (2015) 1530006 (20 pages)

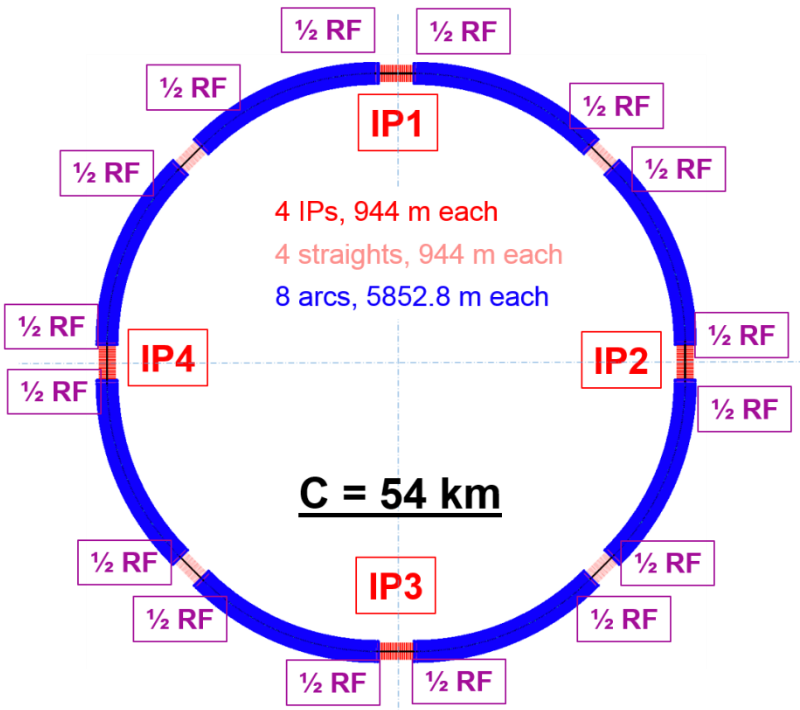
3) D. Wang, J. Gao, et al, Optimization parameter design of a circular e+e- Higgs factory, **Chinese Physcis C**，Vol. 40, No. 1 (2016) 017001-017007

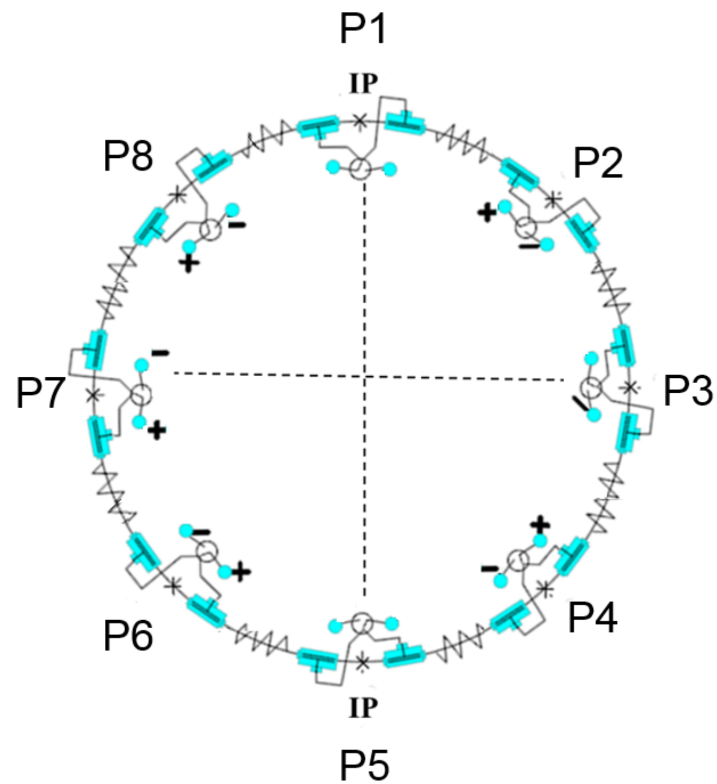
4) D. Wang. J. Gao, eta al, Optimization parameter design of a circular e+e- collider with crab-waist, to be submitted to **Chinese Physcis C**

Main parameters for CEPC (Pre-CDR)

Parameter	Unit	Value	Parameter	Unit	Value
Beam energy [E]	GeV	120	**Circumference [C]**	m	54420
Number of IP[N_{IP}]		2	**SR loss/turn [U_0]**	GeV	3.11
Bunch number/beam[n_B]		50	**Bunch population [Ne]**		3.71E+11
SR power/beam [P]	MW	51.7	**Beam current [I]**	mA	16.6
Bending radius [ρ]	m	6094	**momentum compaction factor [α_p]**		3.39E-05
Revolution period [T_0]	s	1.82E-04	**Revolution frequency [f_0]**	Hz	5508.87
emittance (x/y)	nm	6.12/0.018	**β_{IP}(x/y)**	mm	800/1.2
Transverse size (x/y)	μm	69.97/0.15	**$\xi_{x,y}$/IP**		0.116/0.082
Beam length SR [$\sigma_{s.SR}$]	mm	2.17	**Beam length total [$\sigma_{s.tot}$]**	mm	2.53
Lifetime due to Beamstrahlung	min	80	**lifetime due to radiative Bhabha scattering [τ_L]**	min	52
RF voltage [V_{rf}]	GV	6.87	**RF frequency [f_{rf}]**	MHz	650
Harmonic number [h]		117900	**Synchrotron oscillation tune [ν_s]**		0.18
Energy acceptance RF [h]	%	5.98	**Damping partition number [$J\varepsilon$]**		2
Energy spread SR [$\sigma_{\delta.SR}$]	%	0.13	**Energy spread BS [$\sigma_{\delta.BS}$]**	%	0.08
Energy spread total [$\sigma_{\delta.tot}$]	%	0.16	**n_γ**		0.23
Transverse damping time [n_x]	turns	78	**Longitudinal damping time [n_ε]**	turns	39
Hourglass factor	Fh	0.692	**Luminosity /IP[L]**	$cm^{-2}s^{-1}$	2.01E+34

CEPC Pretzel Scheme

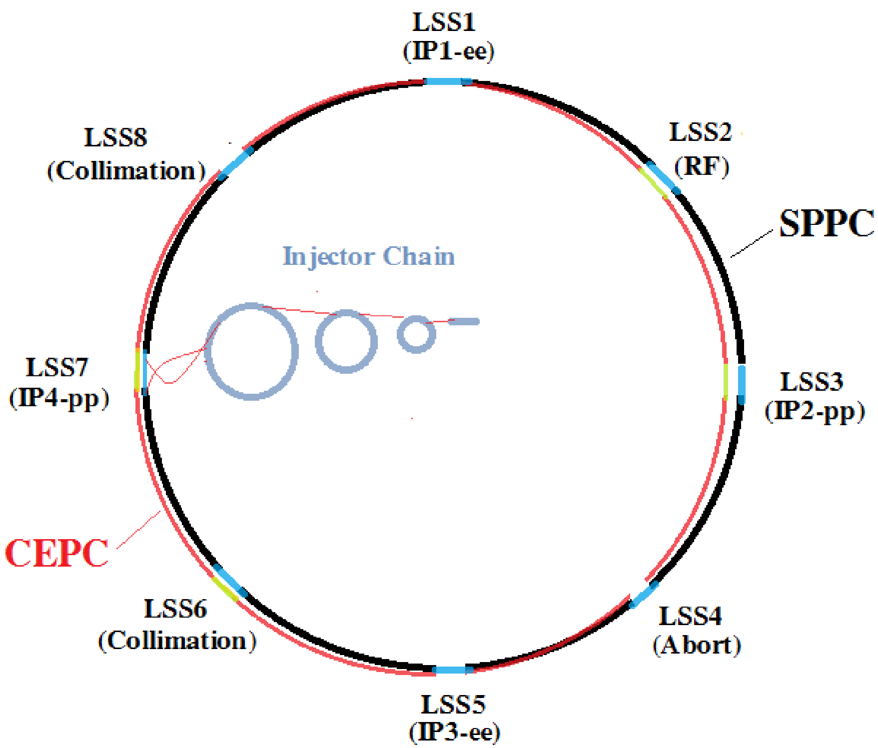




- 48 bunches / beam, 96 parasitic collision points (~ 500 m spacing)
- Horizontal separation, no off-center orbit in RF section
- One pair of electrostatic separators for each arc (green)
- One pair of electrostatic separators for P2, P3, P4, P6, P7, P8

H.P. Geng

SppC General design



- 8 arcs (5.9 km) and long straight sections (850m*4+1038.4m*4)

Parameter	Value
Circumference	54.36 km
Beam energy	35.3 TeV
Dipole field	20 T
Injection energy	2.1 TeV
Number of IPs	2 (4)
Peak luminosity per IP	**1.2E+35 $cm^{-2}s^{-1}$**
Beta function at collision	0.75 m
Circulating beam current	1.0 A
Max beam-beam tune shift per IP	0.006
Bunch separation	25 ns
Bunch population	2.0E+11
SR heat load @arc dipole (per aperture)	56.9 W/m

SPPC Layout

LSS1/5

1107m

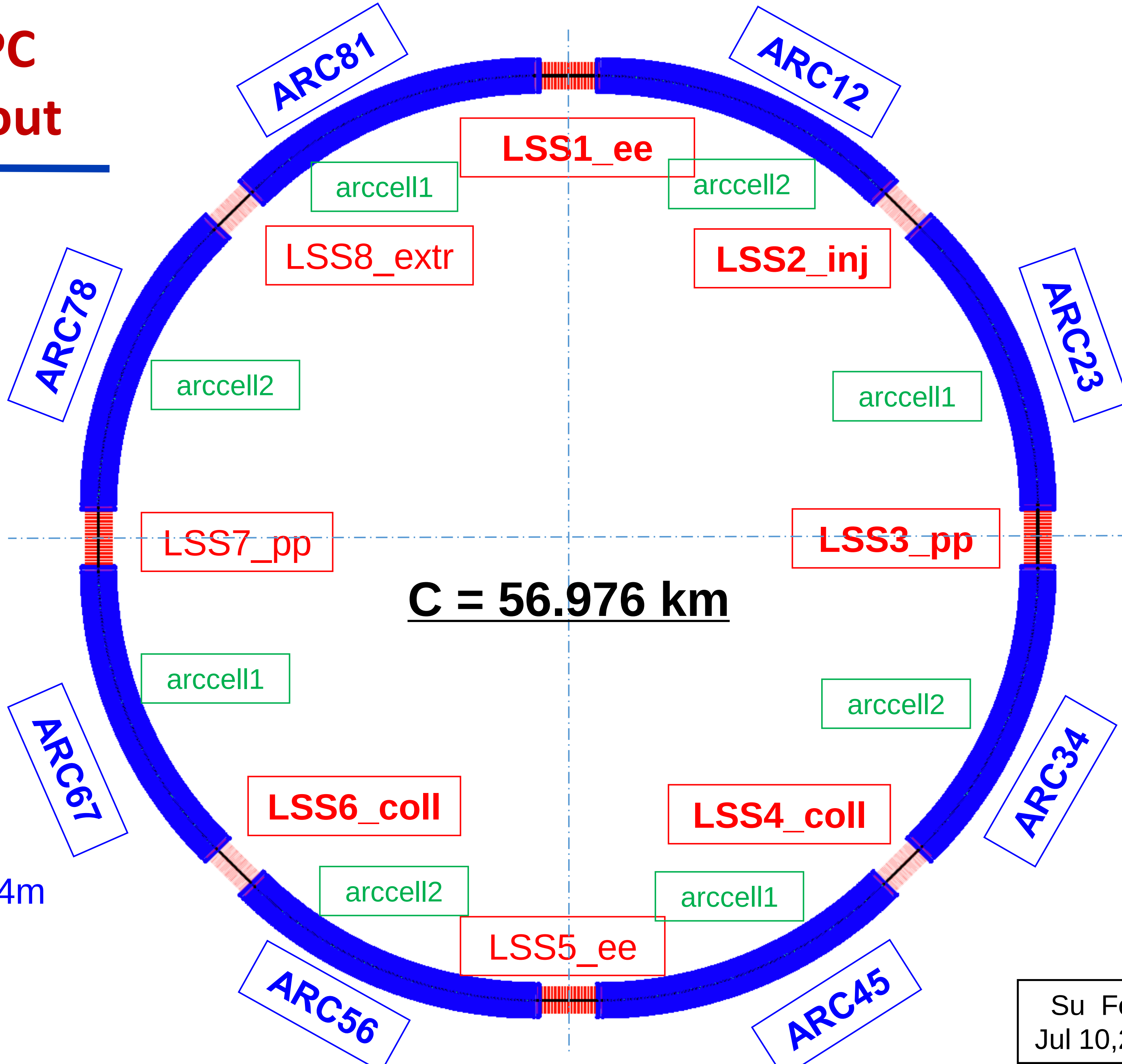
LSS2/4/6/8

959.4m

LSS3/7

1244m

ARC 6077.84m



Su Feng
Jul 10,2015

SPPC Parameter Choice and Optimize

Table 1: SPPC Parameter List.

Version 201607

	SPPC(Pre-CDR)	SPPC-59.2Km	SPPC-100Km	SPPC-100Km	SPPC-80Km
Main parameters and geometrical aspects					
Beam energy[E_0]/TeV	35.6	35.0	50.0	65.0	50.0
Circumference[C_0]/km	54.7	59.2	100.0	100.0	80.0
Dipole field[B]/T	20	19.70	15.52	19.83	19.74
Dipole curvature radius[ρ]/m	5928	5921.5	10924.4	10924.4	8441.6
Bunch filling factor[f_2]	0.8	0.8	0.8	0.8	0.8
Arc filling factor[f_1]	0.79	0.78	0.78	0.78	0.78
Total dipole length [L_{Dipole}]/m	37246	37206	68640	68640	53040
Arc length[L_{ARC}]/m	47146	47700	88000	88000	68000
Straight section length[L_{ss}]/m	7554	11500	12000	12000	12000
Physics performance and beam parameters					
Peak luminosity per IP[L]/ $cm^{-2}s^{-1}$	1.1×10^{35}	1.20×10^{35}	1.52×10^{35}	1.02×10^{36}	1.52×10^{35}
Beta function at collision[β^*]/m	0.75	0.85	0.99	0.22	1.06
Max beam-beam tune shift per IP[ξ_y]	0.006	0.0065	0.0068	0.0079	0.0073
Number of IPs contribut to ΔQ	2	2	2	2	2
Max total beam-beam tune shift	0.012	0.0130	0.0136	0.0158	0.0146
Circulating beam current[I_b]/A	1.0	1.024	1.024	1.024	1.024
Bunch separation[Δt]/ns	25	25	25	25	25
Number of bunches[n_b]	5835	6315	10667	10667	8533
Bunch population[N_p] (10^{11})	2.0	2.0	2.0	2.0	2.0
Normalized RMS transverse emittance[ε]/μm	4.10	3.72	3.62	3.10	3.35
RMS IP spot size[σ^*]/μm	9.0	8.85	7.86	3.04	7.86
Beta at the 1st parasitic encounter[$\beta 1$]/m	19.5	18.70	16.36	68.13	15.31
RMS spot size at the 1st parasitic encounter[σ_1]/μm	45.9	43.20	33.31	55.20	31.03
RMS bunch length[σ_z]/mm	75.5	56.60	65.68	14.88	70.89
Full crossing angle[θ_c]/μrad	146	138.23	106.60	176.66	99.28
Reduction factor according to cross angle[F_{ca}]	0.8514	0.9257	0.9247	0.9283	0.9241
Reduction factor according to hour glass effect[F_h]	0.9975	0.9989	0.9989	0.9989	0.9989
Energy loss per turn[U_0]/MeV	2.10	1.97	4.45	12.71	5.76
Critical photon energy[E_c]/keV	2.73	2.60	4.11	9.02	5.32
SR power per ring[P_0]/MW	2.1	2.01	4.56	13.01	5.89
Transverse damping time [τ_x]/h	1.71	1.946	2.08	0.946	1.28
Longitudinal damping time [τ_ε]/h	0.85	0.973	1.04	0.473	0.64

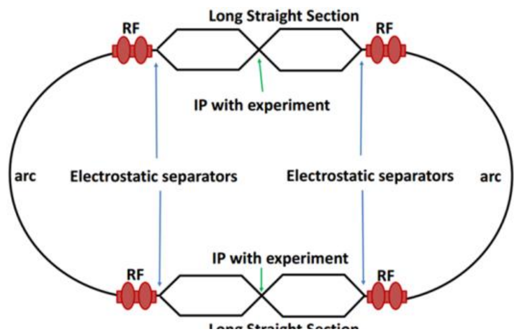
Difficulties of CEPC single ring scheme

	H		*Z*	
	Pre-CDR	*Low-HOM*		
Number of IPs	2	2	2	
Energy (GeV)	120	120	45.5	
Circumference (km)	54	54	54	
SR loss/turn (GeV)	3.1	3.1	0.062	
N_e/bunch (10^{11})	3.79	1.0	0.13	
Bunch number	50	187	4800	100
Beam current (mA)	16.6	16.6	55.5	1.1
SR power /beam (MW)	51.7	50	3.45	0.072
Bending radius (km)	6.1	6.1	6.1	
Momentum compaction (10^{-5})	3.4	3.4	3.4	
β_{IP} x/y (m)	0.8/0.0012	0.06/0.001	0.4/0.0012	
Emittance x/y (nm)	6.12/0.018	6.13/0.018	0.9/0.018	
Transverse σ_{IP} (um)	69.97/0.15	19.2/0.13	18.9/0.15	
ξ_x/IP	0.118	0.031	0.072	
ξ_y/IP	0.083	0.074	0.028	
V_{RF} (GV)	6.87	6.87	0.68	
f_{RF} (MHz)	650	650	650	
Nature σ_z (mm)	2.14	2.13	1.5	
Total σ_z (mm)	2.65	2.4	1.5	
HOM power/cavity (kw)	3.6	1.0	0.55	0.01
Energy spread (%)	0.13	0.13	0.05	
Energy acceptance (%)	2	1.5		
Energy acceptance by RF (%)	6	6.1	4.5	
n_γ	0.23	0.21	0.028	
Life time due to beamstrahlung_cal (minute)	47	46		
F (hour glass)	0.68	0.66	0.82	
L_{max}/IP (10^{34}cm^{-2}s^{-1})	2.04	2.1	1.04	0.022

Main problems left in Pre-CDR

- Pretzel scheme is difficult in design, operation, fexibility and stability
- High AC power
- Booster with very low magnetic field (30 Gauss for 6GeV injection compared with 3 Gauss backgroud magnetic field in BEPCII tunnel) and small dynamic aperture
- Very low luminosity for Z with single ring
- Very small DA at 2% energy spread
- The clear criterion for reaching CDR requirement on DA with beam-beam effects and magnetic errors
- **What is the goal of CEPC CDR?**

In short, Pre-CDR is a "design" even not working on paper



IHEP-AC-LC-Note2013-012

ILC-物理-2013-08

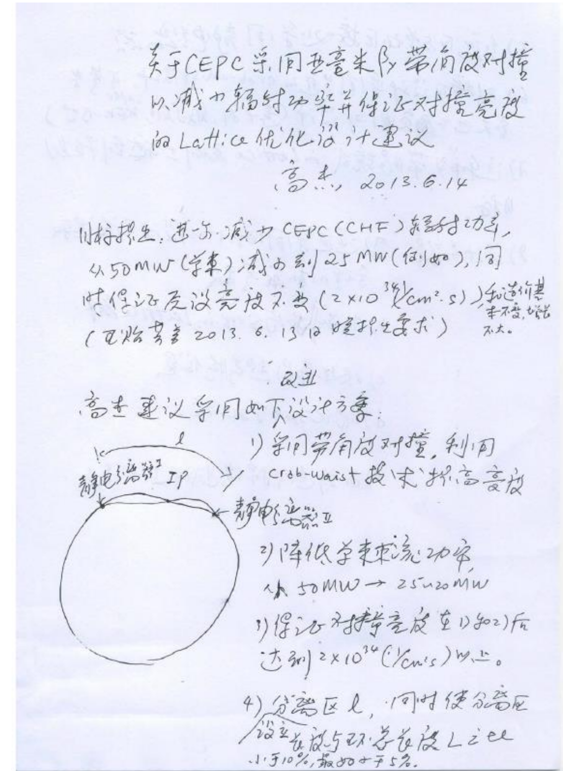
June 16th, 2013

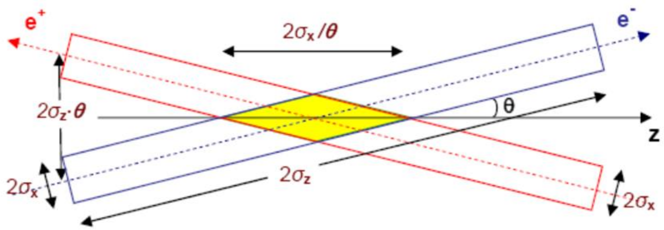
关于CEPC采用亚毫米β_y带角度对撞以减少辐射功率并保证对撞亮度的Lattice优化设计建议

高杰

ILC Group, Accelerator Center

Institute of High Energy Physics (IHEP), Beijing





MITIGATING PERFORMANCE LIMITATIONS OF SINGLE BEAM-PIPE CIRCULAR e^+e^- COLLIDERS

M. Koratzinos, University of Geneva, Switzerland and F. Zimmermann, CERN, Geneva, Switzerland.

Abstract

Renewed interest in circular e^+e^- colliders has spurred designs of single beam-pipe machines, like the CEPC in China, and double beam pipe ones, such as the FCC-ee effort at CERN. Single beam-pipe designs profit from lower costs but are limited by the number of bunches that can be accommodated in the machine. We analyse these performance limitations and propose a solution that can accommodate O(1000) bunches while keeping more than 90% of the ring with a single beam pipe.

SINGLE BEAM-PIPE LIMITATION

The CEPC collider [1] is a single beam-pipe e^+e^- collider with the main emphasis on 120 GeV per beam running with possible running at 45 and 80 GeV. Bunch separation is ensured by a pretzel scheme and the maximum number of bunches is limited to 50. This very small number of bunches for a modern Higgs factory introduces luminosity limitations at 120 GeV, and severe limitations at any eventual 45 GeV running.

A machine of the size of CEPC at 120 GeV ought to be designed to be operating at the beam-beam limit and not reach the beamstrahlung limit first. The best way to reach this goal is by keeping the bunch charge low and emittances as small as possible. A large momentum acceptance also helps. Another way (and the route chosen for the CEPC) is to keep the bunches as long as possible, but this gives rise to lower instability thresholds as well as to geometric luminosity loss. According to our calculations and with reasonable assumptions for the length of the FODO cell and phase advance, we arrive at an optimal number of bunches of around 120 at 120 GeV [2]. The accommodation of this number of bunches with the pretzel scheme would be more demanding.

For an eventual running at 45 GeV the limit of 50 bunches would be inadequate, as hundreds of bunches would be needed to explore the full potential of the machine [2].

THE 'BOWTIE' DESIGN

Without changing the basic design philosophy of the

apart transversely so that separate beam pipes and magnetic elements can be used to manipulate the electron and positron beams individually, and without any parasitic collisions. The length of the electrostatic separator section would be around 100 m on both sides of the straight section. Since now the beams travel in separate beam pipes, great flexibility about the choice of collision angle is ensured. The FCC-ee is pursuing a crab waist approach which gives excellent performance at low energies and where the crossing angle is 30 mrad.

Assuming a total length of the double beam pipe to be 2×2000m, and assuming that bunches within a train can be separated longitudinally by as little as 2 m (7 ns) then 2×1000 bunches for each species can be accommodated in the machine.

The ratio of single to double beam pipe would be ~4/52 or about 8%. Note that the cost increase would be much smaller than the above figure and actually the cost per luminosity unit would be greatly improved.

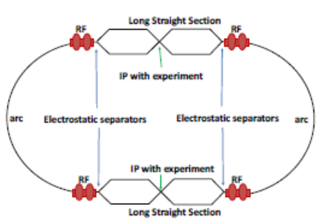


Figure 1: Schematic of the 'bowtie' idea (not to scale)

ELECTROSTATIC SEPARATORS

For illustration purposes we have chosen the LEP electrostatic separators [3]. These were 4 m long, 11 cm wide and the maximum operating voltage was 220 kV. Each separator produced a maximum deflection of 145

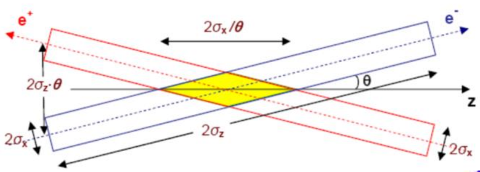
Partial Double Ring (DPR) was proposed independently at IHEP and CERN：

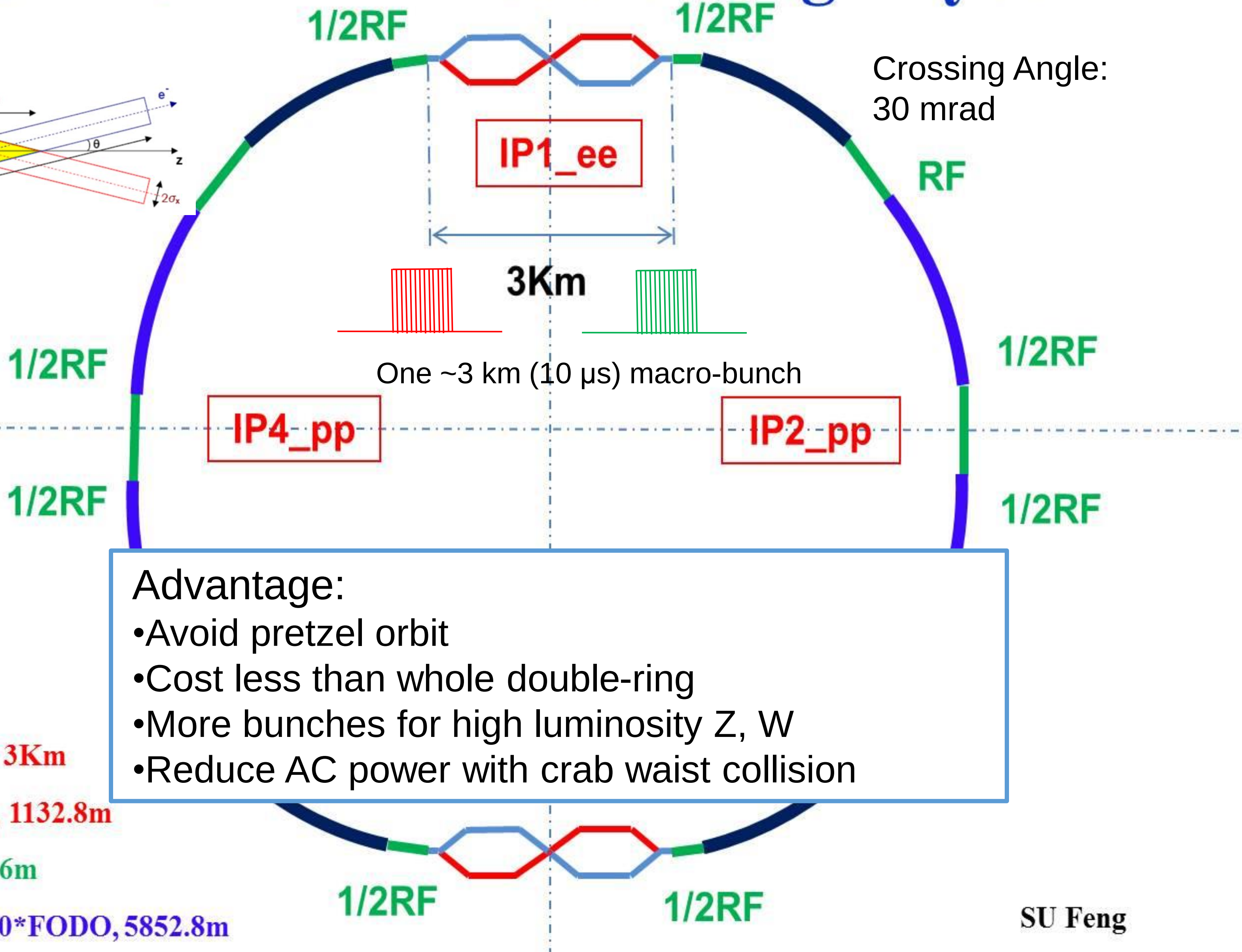
1）J. Gao, IHEP-AC-LC-Note 2013-012

2）M. Moratzinos and F. Zimmermann，2015

(IPAC 2015 M. Moratzinos and F. Zimmermann)

CEPC Partial Double Ring Layout





Advantage:
- Avoid pretzel orbit
- Cost less than whole double-ring
- More bunches for high luminosity Z, W
- Reduce AC power with crab waist collision

IP1_ee/IP3_ee, 3Km

IP2_pp/IP4_pp, 1132.8m

4Straights, 849.6m

4Long ARC, 120*FODO, 5852.8m

4Short ARC, 100*FODO, 4908.8m

SU Feng

2015.10.12

Parameter for CEPC partial double ring （wangdou20160325）

	Pre-CDR	*H-high lumi.*	*H-low power*	*W*	*Z*
Number of IPs	2	2	2	2	2
Energy (GeV)	120	120	120	80	45.5
Circumference (km)	54	54	54	54	54
SR loss/turn (GeV)	3.1	2.96	2.96	0.59	0.062
Half crossing angle (mrad)	0	15	15	15	15
Piwinski angle	0	2.5	2.6	5	8.5/7.6
N_e/bunch (10^{11})	3.79	2.85	2.67	0.74	0.46
Bunch number	50	67	44	400	1100
Beam current (mA)	16.6	16.9	10.5	26.2	45.4
SR power /beam (MW)	51.7	50	31.2	15.6	2.8
Bending radius (km)	6.1	6.2	6.2	6.1	6.1
Momentum compaction (10^{-5})	3.4	2.5	2.2	2.4	3.5
β_{IP} x/y (m)	0.8/0.0012	0.25/0.00136	0.268 /0.00124	0.1/0.001	0.1/0.001
Emittance x/y (nm)	6.12/0.018	2.45/0.0074	2.06 /0.0062	1.02/0.003	0.62/0.0028
Transverse σ_{IP} (um)	69.97/0.15	24.8/0.1	23.5/0.088	10.1/0.056	7.9/0.053
ξ_x/IP	0.118	0.03	0.032	0.008	0.005/0.006
ξ_y/IP	0.083	0.11	0.11	0.074	0.084/0.073
V_{RF} (GV)	6.87	**3.62**	**3.53**	**0.81**	**0.12**
f_{RF} (MHz)	650	650	650	650	650
Nature σ_z (mm)	2.14	**3.1**	**3.0**	**3.25**	**3.9**
Total σ_z (mm)	2.65	4.1	4.0	3.35	4.0
HOM power/cavity (kw)	3.6	2.2	1.3	0.99	0.99
Energy spread (%)	0.13	0.13	0.13	0.09	0.05
Energy acceptance (%)	2	2	2		
Energy acceptance by RF (%)	6	**2.2**	**2.1**	**1.7**	**1.1**
n_γ	0.23	0.47	0.47	0.3	0.27/0.24
Life time due to beamstrahlung_cal (minute)	47	36	32		
F (hour glass)	0.68	0.82	0.81	0.92	0.95
L_{max}/IP (10^{34}cm^{-2}s^{-1})	2.04	2.96	2.01	3.09	3.61/3.09

Parameter for CEPC PDR-100km

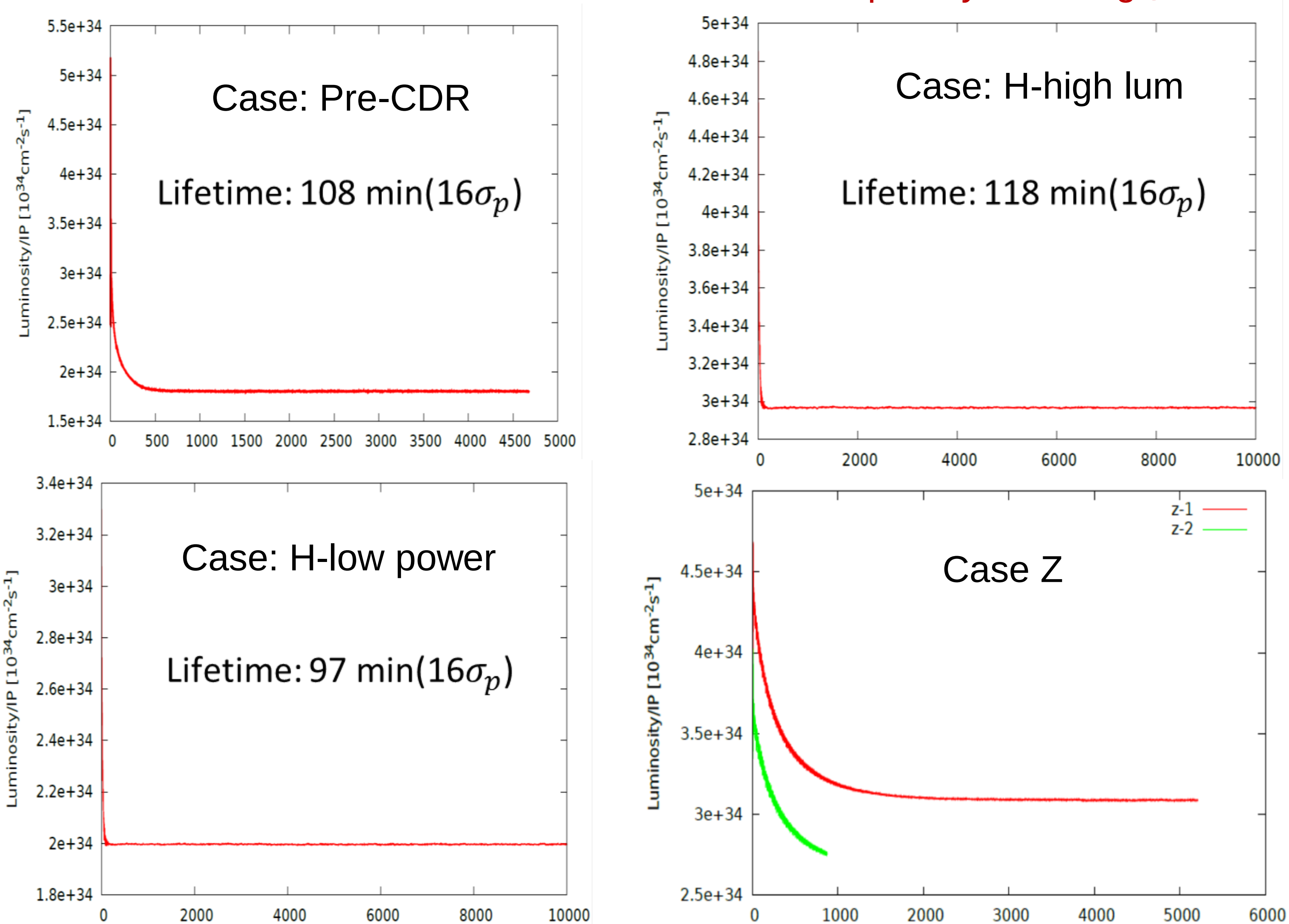
（wangdou20160329）

	H-high lumi.	*H-low power*	*W*	*Z*	
Number of IPs	2	2	2	2	
Energy (GeV)	120	120	80	45.5	
Circumference (km)	100	100	100	100	
SR loss/turn (GeV)	1.7	1.7	0.33	0.034	
Half crossing angle (mrad)	15	15	15	15	
Piwinski angle	2.0	2.83	8.65	15.8	
N_e/bunch (10^{11})	1.43	1.22	0.42	0.165	
Bunch number	436	307	2400	15800	182260
Beam current (mA)	30	18	48.7	125.3	1449.7
SR power /beam (MW)	50	30	16.0	4.3	50
Bending radius (km)	11	11	11	11	
Momentum compaction (10^{-5})	1.8	1.4	1.4	1.3	
β_{IP} x/y (m)	0.297/0.0011	0.3/0.0011	0.1/0.001	0.1/0.001	
Emittance x/y (nm)	1.63/0.0049	1.03/0.003	0.46/0.0014	0.14/0.00065	
Transverse σ_{IP} (um)	22/0.074	17.6/0.59	6.8/0.037	3.8/0.026	
ξ_x/IP	0.033	0.025	0.003	0.002	
ξ_y/IP	0.083	0.083	0.055	0.054	
V_{RF} (GV)	**3.1**	**2.25**	**0.41**	**0.053**	
f_{RF} (MHz)	650	650	650	650	
Nature σ_z (mm)	**2.45**	**2.77**	**3.8**	**3.94**	
Total σ_z (mm)	2.94	3.33	3.9	4.0	
HOM power/cavity (kw)	2.3	1.1	0.98	0.97	11.3
Energy spread (%)	0.1	0.1	0.065	0.037	
Energy acceptance (%)	1.46	1.4			
Energy acceptance by RF (%)	**3.5**	**2.2**	**0.9**	**0.7**	
n_γ	0.27	0.28	0.26	0.18	
Life time due to beamstrahlung_cal (minute)	40	49			
F (hour glass)	0.8	0.85	0.96	0.985	

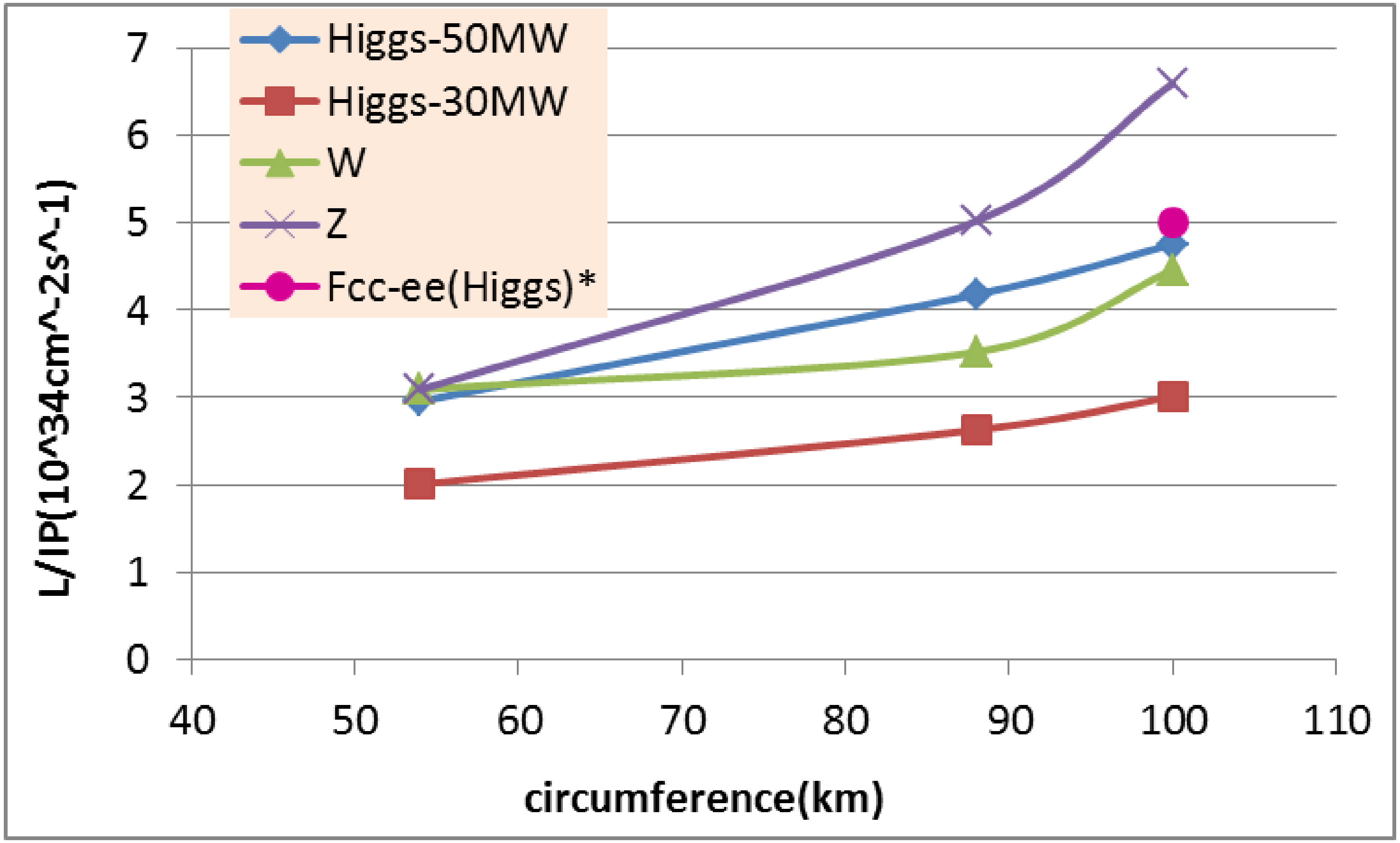
Beam-beam simulation

IBB: Strong-Strong Beam-Beam Code with Beamstrahlung effect

Developed by Y. Zhang@IHEP

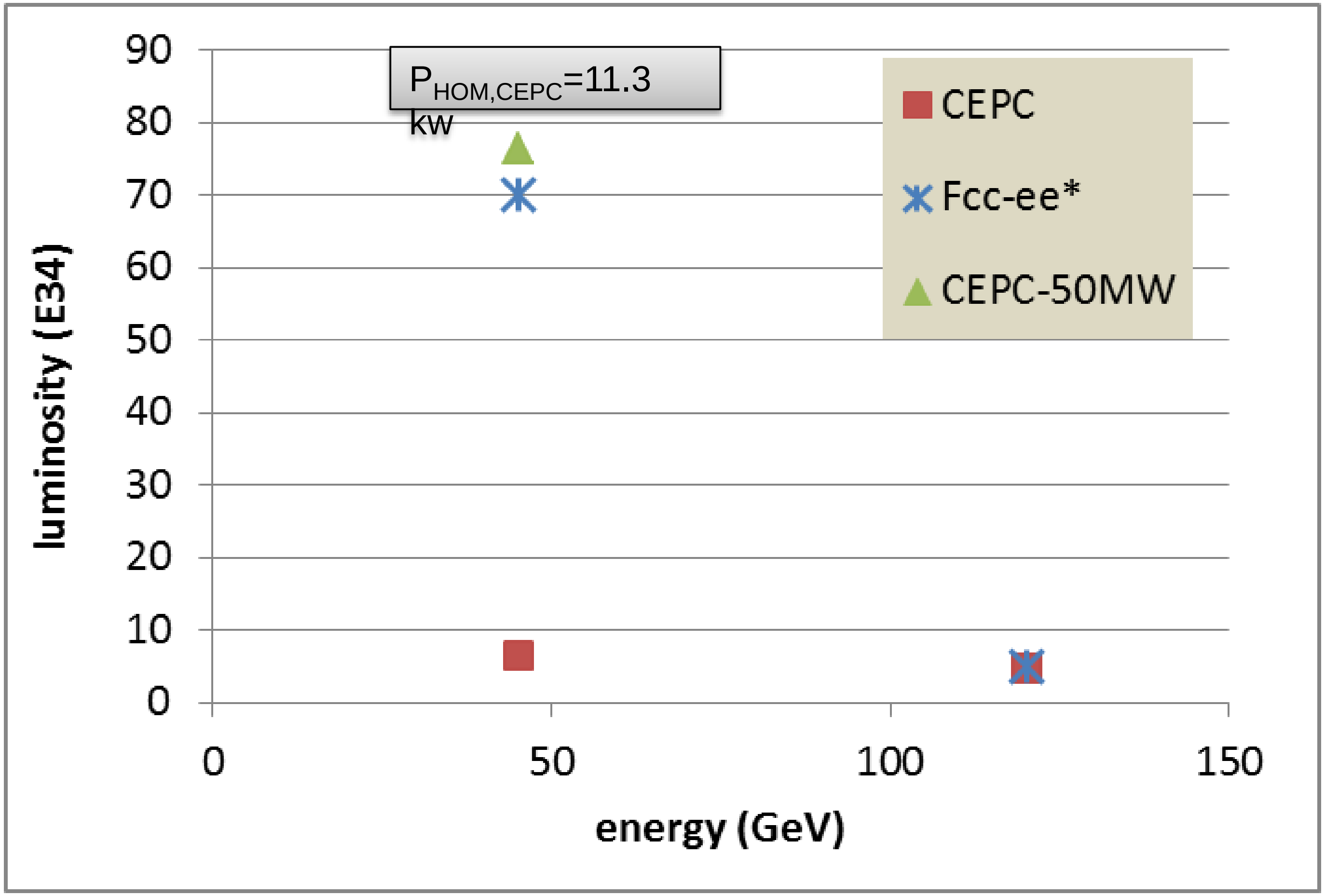


CEPC PDR Luminosity vs circumference



* Fabiola Gianotti, Future Circular ColliderDesign Study, ICFA meeting, J-PARC, 25-2-2016.

100km CEPC PDR vs Fcc-ee



- The large difference of Z is due to the constraint for RF HOM power

* Fabiola Gianotti, Future Circular ColliderDesign Study, ICFA meeting, J-PARC, 25-2-2016.

CEPC vs LEP2

Parameter	CEPC			LEP2	
Physics working point	H		Z		Z
Energy/beam [GeV]	120		45.5	105	45.6
Circumference [km]	54		54	27	
Single ring/double ring	Partial double			Single	
Pretzel scheme	No			Yes	
Bunches/beam	67	44	1100	4	12
Bunch population [10^{11}]	2.85	2.67	0.46	4.2	1.96
Emittance [nm]	2.45/0.0074	2.06 /0.0062	0.62/0.0028	38	
IP beta [mm]	250/1.36	268 /1.24	100/1	1500/50	2000/50
Beam current [mA]	16.9	10.5	45.4	3	4.2
Luminosity/IP x $10^{34}cm^{-2}s^{-1}$	2.9	2.0	3.1	0.0012	0.0034
Energy loss/turn [GeV]	2.96		0.062	3.34	0.12
Synchrotron power [MW]	50	31	2.8	22	1.1
RF voltage [GV]	3.6	3.5	0.12	3.5	
f_{RF} [MHz]	650			352	352

CEPC vs ILC

Parameter	CEPC		ILC	
Physics working point	H	Z	H	
Energy/beam [GeV]	120	45.5	125	250
Linear/circular	circular		linear	
Bunches/beam	67	1100	1312	1312
Bunch population [10^{11}]	2.85	0.46	0.2	0.2
Normalized emittance [nm]	575342/1738	55205/249	10000/35	10000/35
IP beta [mm]	250/1.36	100/1.0	13/0.41	11/0.48
IP RMS veritcal beam size [nm]	100	53	7.7	5.9
Beam current [mA]	16.9	45.4	5.8	5.8
Luminosity/IP x $10^{34}cm^{-2}s^{-1}$	2.9	3.1	0.97	2.05
Energy loss/turn [GeV]	2.96	0.062	No	
f_{RF} [MHz]	650	650	1300	1300
Average number of photons / particle n_γ	0.47	0.24	1.16	1.72

Main ring (no FFS and patial double ring) Design Philosophy

Sextupole scheme	interleave	Non-interleave technique (phy, num)
60 ° /60°	n=6 **All 3rd RDT due to sextupoles cancelled** **All 4th RDT except 2Qx-2Qy due to sextupoles cancelled** **dQ(Jx,Jy): accumalte to be large** **dQ(δ): small even with 2 families** DA on momentum: easy to optim. DA off momentum: easy to optim.	-
90 ° /60 °	**n=12** **All 3rd RDT due to sextupoles cancelled** **All 4th RDT except 4Qx due to sextupoles cancelled** **dQ(Jx,Jy): accumalte to be large** **dQ(δ): small even with 2 families** DA on momentum: easy to optim. DA off momentum: easy to optim.	-
90 ° /90 °	n=4 **All 3rd RDT due to sextupoles cancelled** **4th RDT except 4Qx, 2Qx+2Qy, 4Qy, 2Qx-2Qy due to sextupoles cancelled** **dQ(Jx,Jy): accumalte to be large** **dQ(δ): small even with 2 families** DA on momentum: **-** DA off momentum: -	n=5 **All 3rd and 4th RDT due to sextupoles cancelled** **dQ(Jx,Jy): small** **dQ(δ): correct with many families** DA on momentum: easy to optim. DA off momentum: with many families to correct dQ(δ) and –I break down
other	DA & RDT…	

CEPC main ring low emittance arc – 90°/90°

- Length of FODO cell: 37.5m
- Phase advance of FODO cells: 90/90 degrees
- Emittance: 2.3nm, αp=1.02E-5
- Bunch length: 3.1mm

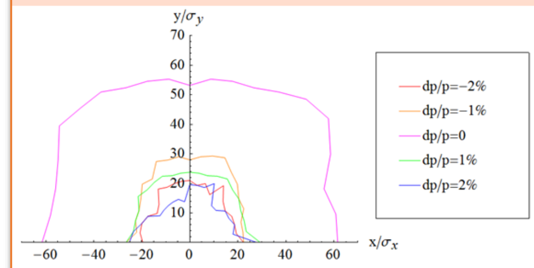
- Dispersion supressor:

Angle(BDIS1)=3.50284406482E-3

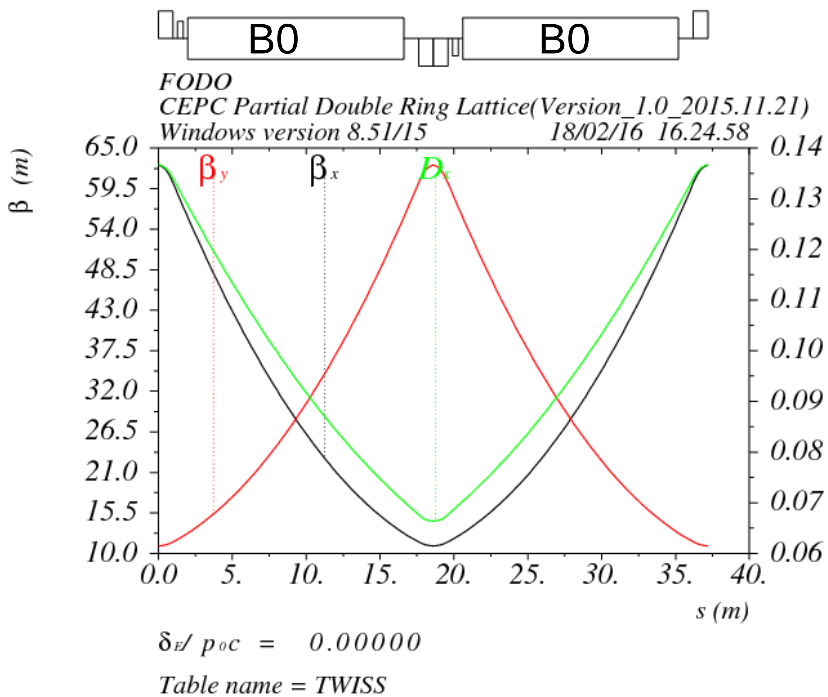
Angle(BDIS2)=-7.78931580723E-4

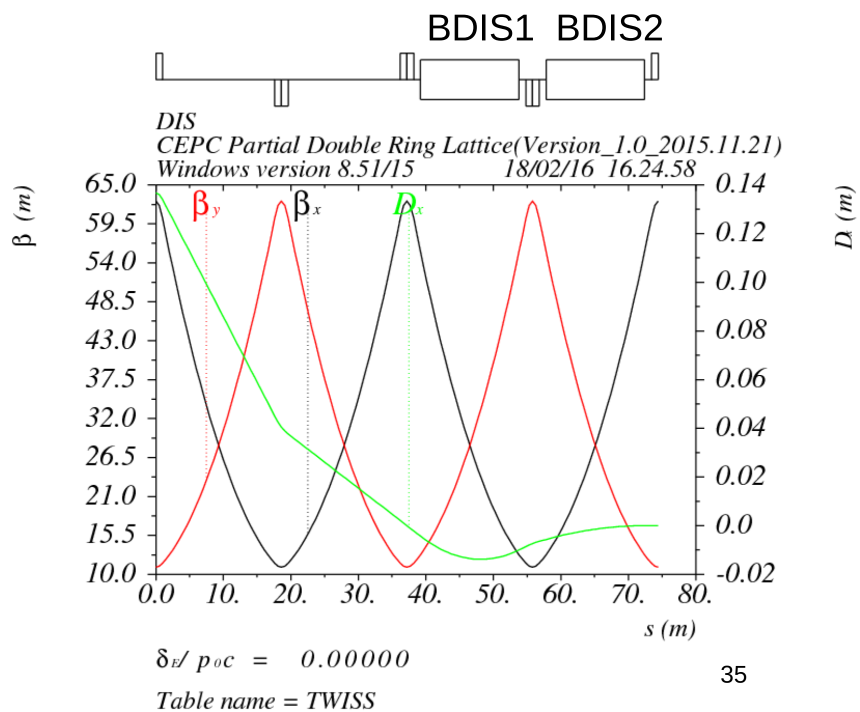
Angle(B0)=2.723923E-3

ARC_4 **90/90 non-interleaved**

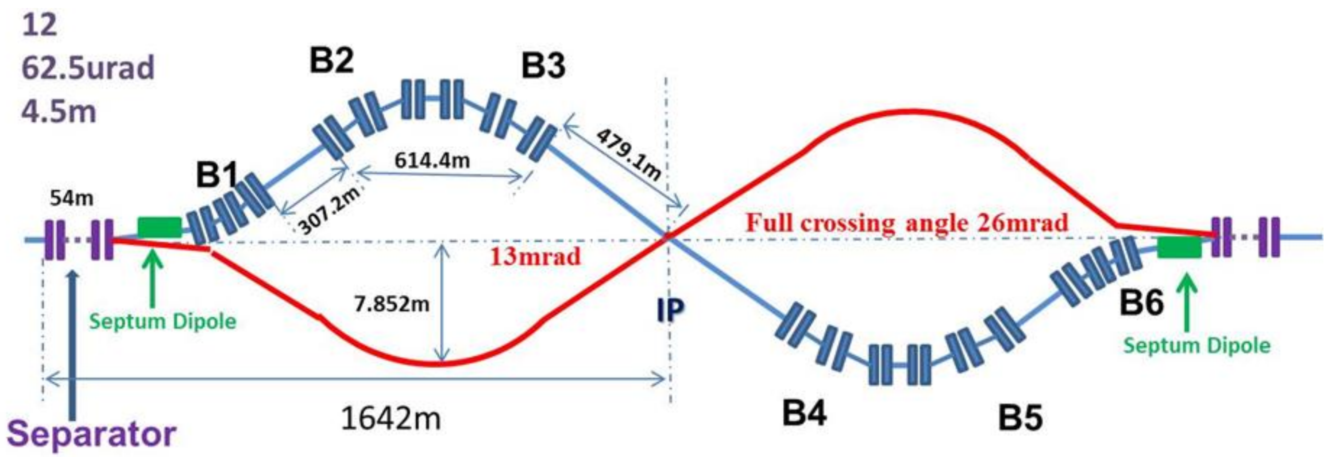


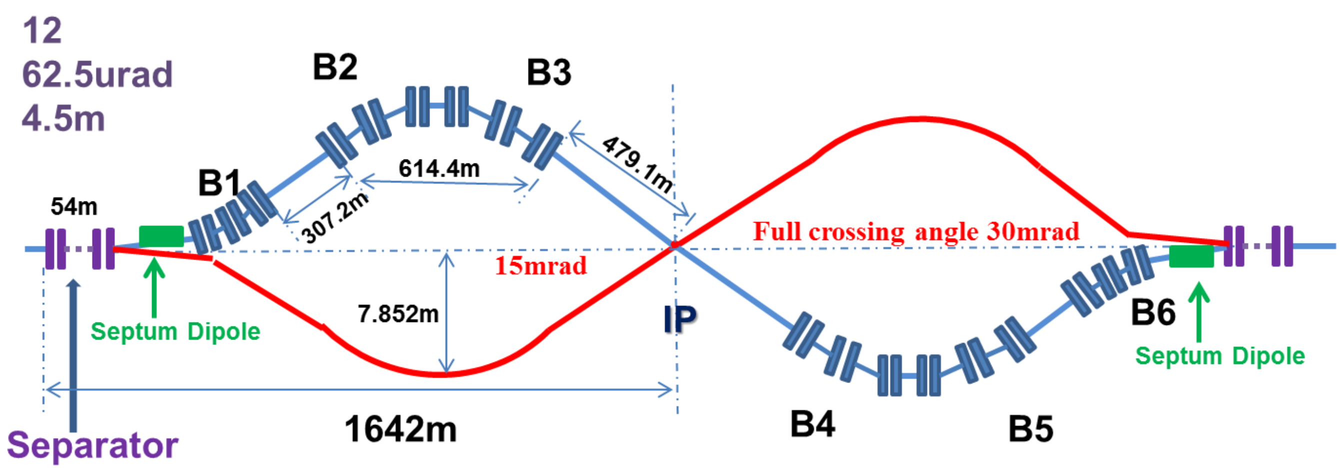
SF1 =(L =.3999999999999997 K2 =.9680546863397813)
SD1 =(L =.3999999999999997 K2 =-1.8843252788338383)





CEPC Partial Double Ring Lattice





For CEPC 120GeV beam:

- **Max. deflection per separator is 66μrad.**

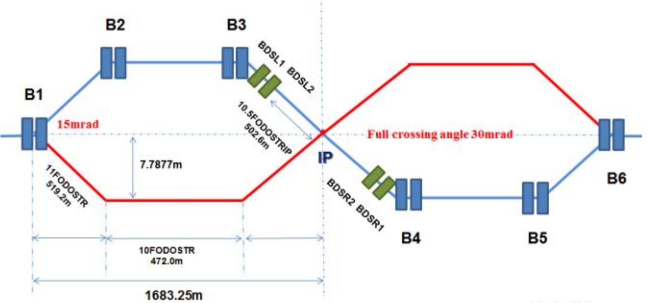
Using Septum Dipole after separator to acquire 15 mrad

Version 1.0

sufeng

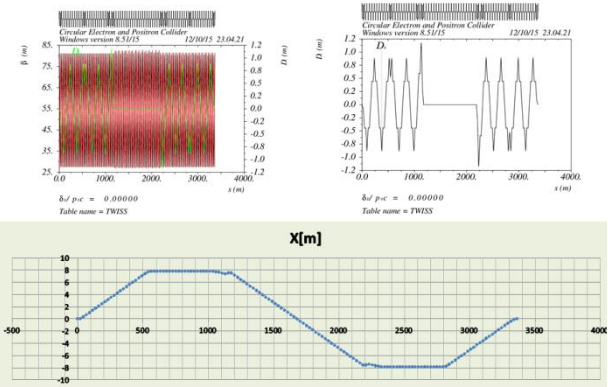
2015.12.20

CEPC Partial Double Ring Layout



Version0.0
sufeng
2015.10.12

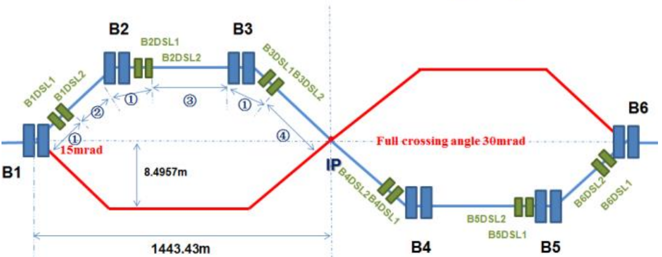
Orbit (DR_RING_e1) Version0.0



Dipole Strength Version0.0

	Angle(mrad)	L(m)	Rho(m)	Brho(E0/c) (T/m)	B(T)	Ek(KeV)	KeV/m
B0	3.506	19.6	5590.42	400	0.07155	685.173	34.9578
B1	-7.5	19.6	2613.33	400	0.15306	1465.71	74.7813
B2	7.5	19.6	2613.33	400	0.15306	1465.71	74.7813
B3	2.499894	19.6	7840.33	400	0.05102	488.551	24.9261
BDSL1	-19.865386	19.6	986.641	400	0.40542	3882.26	198.075
BDSL2	29.865598	19.6	656.273	400	0.60950	5836.59	297.785
BDSR2	-29.865598	19.6	656.273	400	0.60950	2836.59	297.785
BDSR1	19.865686	19.6	986.641	400	0.40542	3882.26	198.075
B4	-2.499894	19.6	7840.33	400	0.05102	488.551	24.9261
B5	-7.5	19.6	2613.33	400	0.15306	1465.71	74.7831
B6	7.5	19.6	2613.33	400	0.15306	1465.71	74.7831

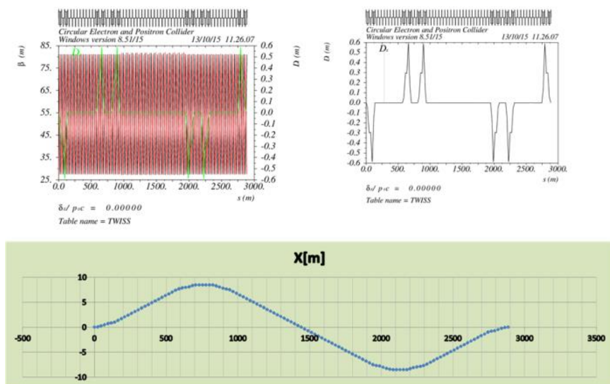
CEPC Partial Double Ring Layout



① : 141.6m (3FODO)
② : 424.8m (9FODO)
③ : 94.4m (2FODO)
④ : 502.6m (10.5FODO)

Version0.1
sufeng

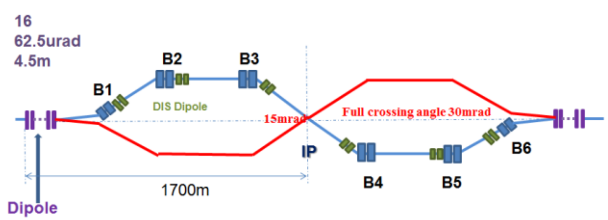
Orbit (DR_RING_e1) Version0.1



Dipole Strength Version0.1

	Angle(mrad)	L(m)	Rho(m)	Brho(E0/c) (T/m)	B(T)	Ek(KeV)	KeV/m
B0	3.506	19.6	5590.42	400	0.07155	685.173	34.9578
B1	-5.0	19.6	3920.0	400	0.10204	977.143	49.8542
B1DSL1	9.9336755	19.6	1973.09	400	0.20273	1941.32	99.0417
B1DSL2	-14.93323	19.6	1312.51	400	0.30476	2918.38	148.897
B2	5.0	19.6	3920.0	400	0.10204	977.143	49.8542
B2DSR1	-9.933058	19.6	1973.09	400	0.20273	1941.32	99.0417
B2DSR2	14.93292	19.6	1312.51	400	0.30476	2918.38	148.897
B3	5.0	19.6	3920.0	400	0.10204	977.143	49.8542
B3DSR1	-9.93336	19.6	1973.09	400	0.20273	1941.32	99.0417
B3DSR2	14.93323	19.6	1312.51	400	0.30476	2918.38	148.897

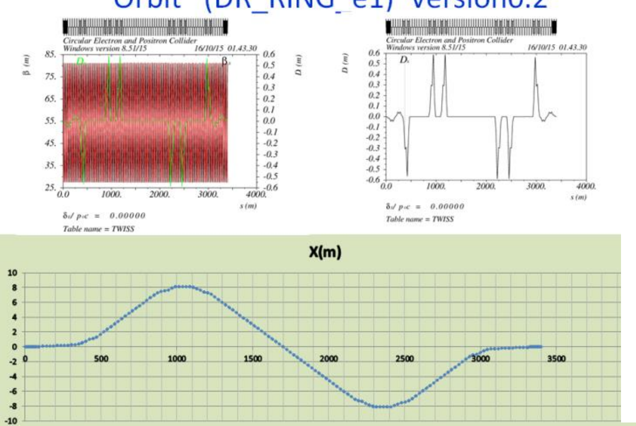
CEPC Partial Double Ring Layout



For CEPC 120GeV beam:
➢Max. deflection per separator is **66μrad**.
Using Dipole after seperator to acquire 15 mrad

Version 0.2
sufeng
2015.10.15

Orbit (DR_RING_e1) Version0.2

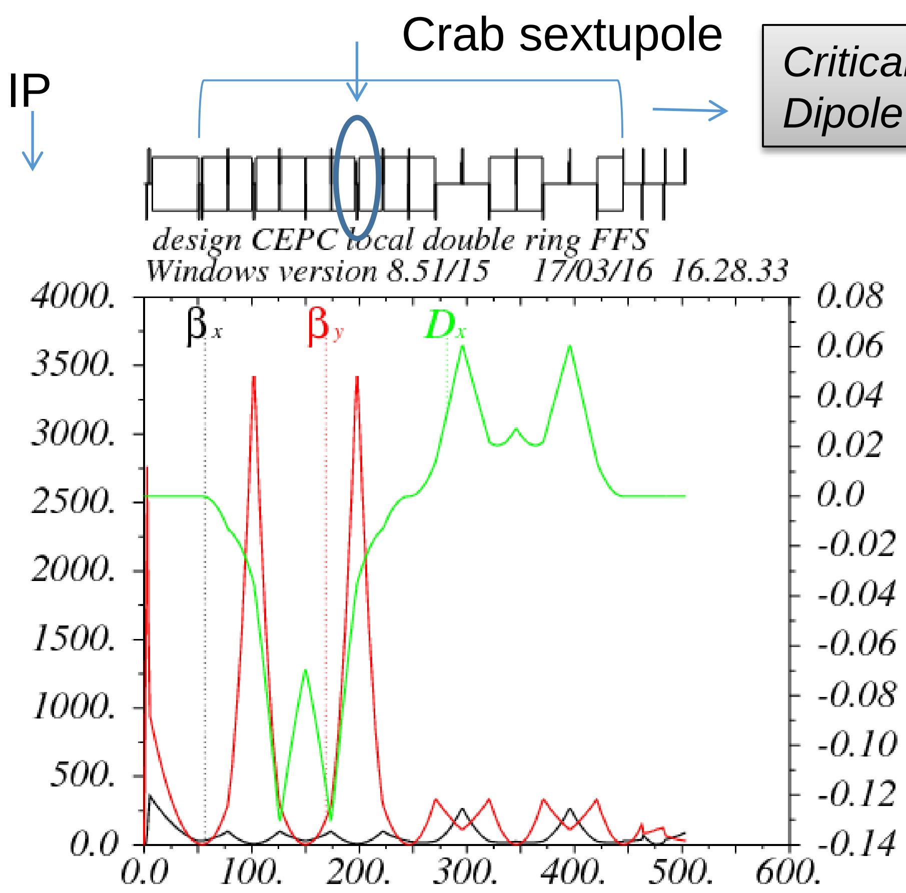


Dipole Strength Version 0.2

	Angle(mrad)	L(m)	Rho(m)	Brho(E0/c) (T/m)	B(T)	Ek(KeV)	KeV/m
B0	3.506	19.6	5590.42	400	0.07155	685.173	34.9578
Bsp	0.0625	4.9	78400	400	0.00510	48.8571	9.97
B1	-4.416	19.6	4438.41	400	0.09012	863.031	44.031
B1DSL1	9.021	19.6	2172.71	400	0.18410	1962.96	89.947
B1DSL2	-14.187	19.6	1381.55	400	0.28953	2772.55	141.456
B2	5.0	19.6	3920.0	400	0.10204	977.143	49.8542
B2DSR1	-9.933058	19.6	1973.09	400	0.20273	1941.32	99.0417
B2DSR2	14.93292	19.6	1312.51	400	0.30476	2918.38	148.897
B3	5.0	19.6	3920.0	400	0.10204	977.143	49.8542
B3DSR1	-9.93336	19.6	1973.09	400	0.20273	1941.32	99.0417
B3DSR2	14.93323	19.6	1312.51	400	0.30476	2918.38	148.897

Partial double ring FFS design with crab sextupoles

Betax=0.25m
Betay=0.00136m
K2hs=26.8 m^{-3}
K2vs=32.2 m^{-3}



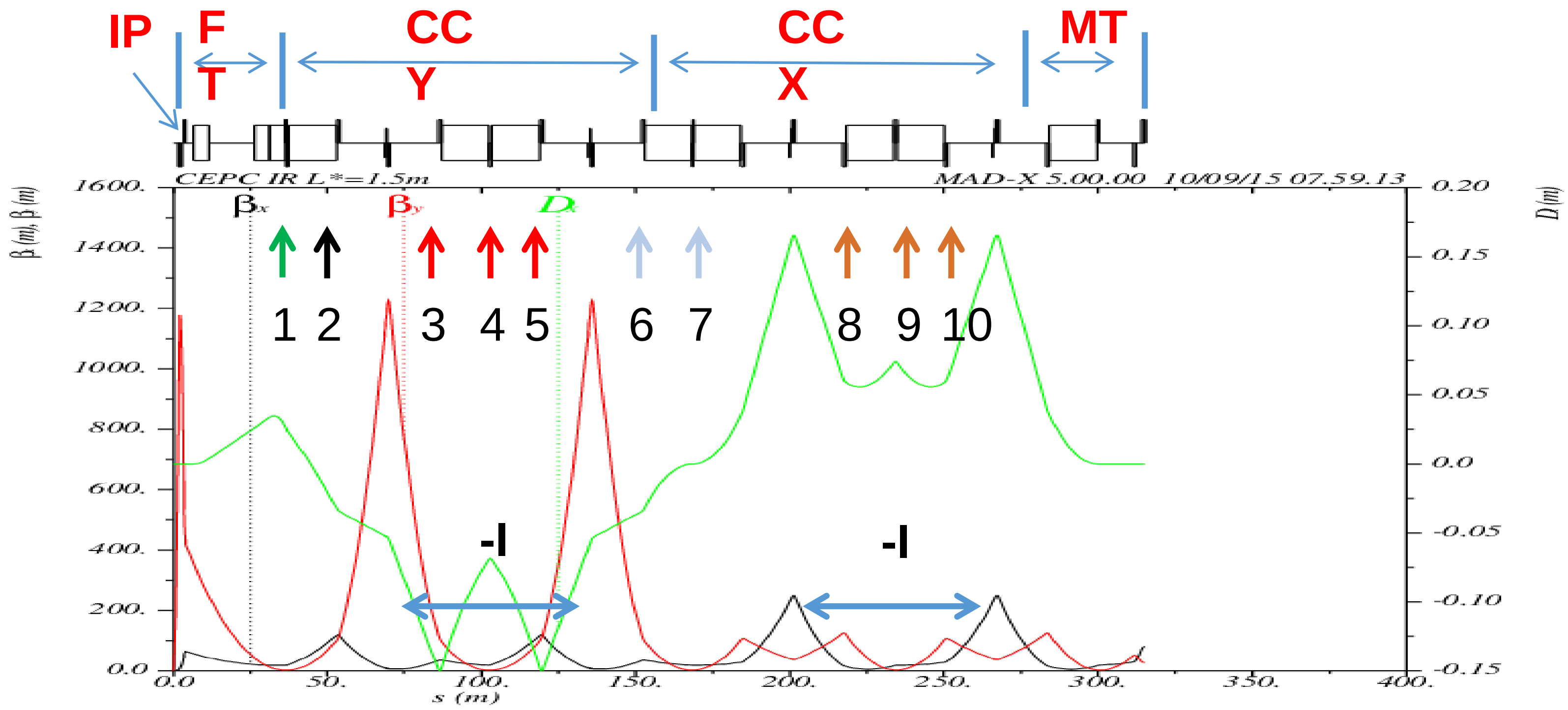
*Critical energy: E*c=190 keV
Dipole strength: B=0.019 T

➢ The second FFS sextupoles of the CCS-Y section work as the crab sextupoles.

IR Design and sextupoles (Y.W. Wang et al)

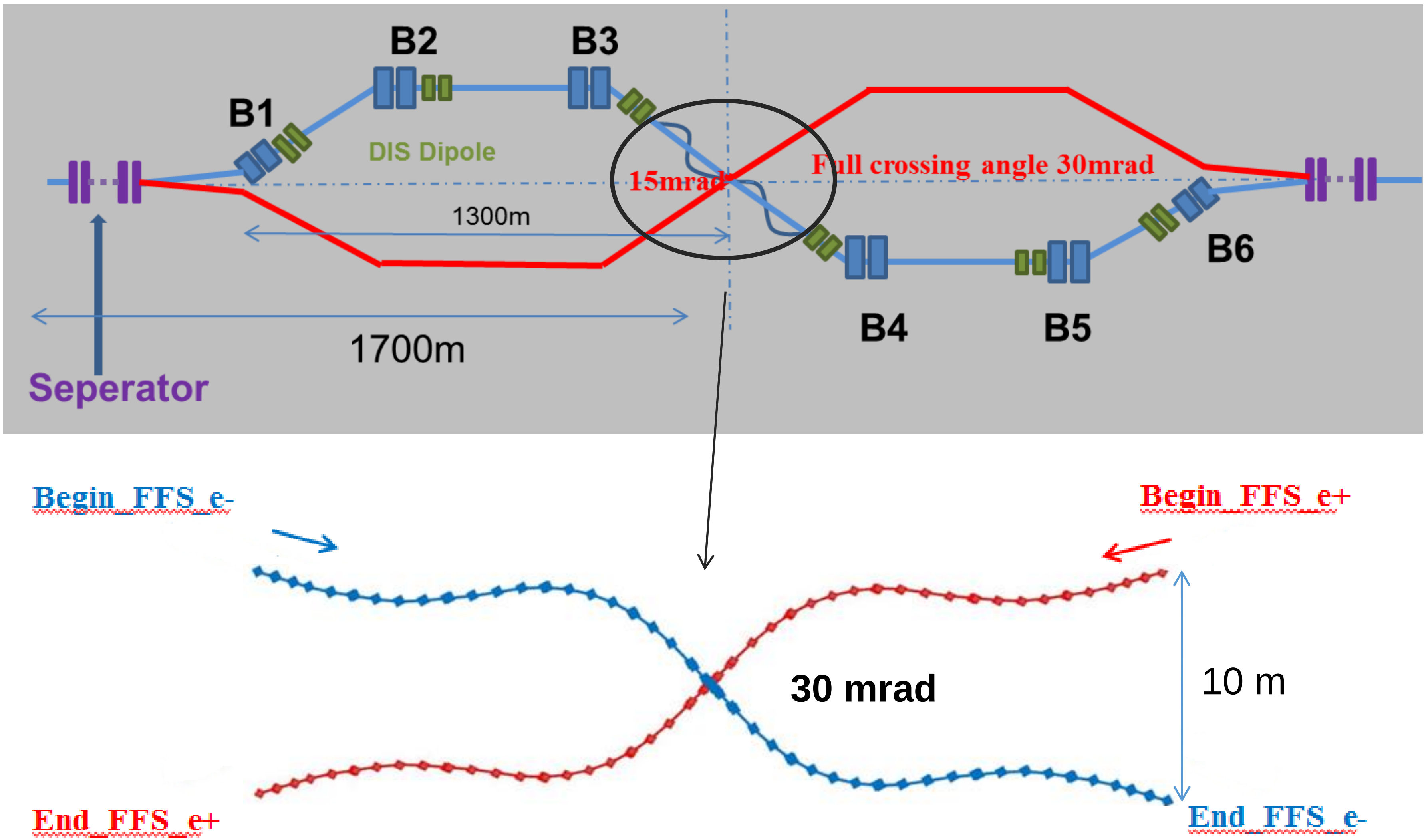
- Idea from Brinkmann
  - correct the high order chromaticity, break down of –I, second order dispersion

FFS_3.0mm_v3.0_Sep_2015, Yiwei Wang



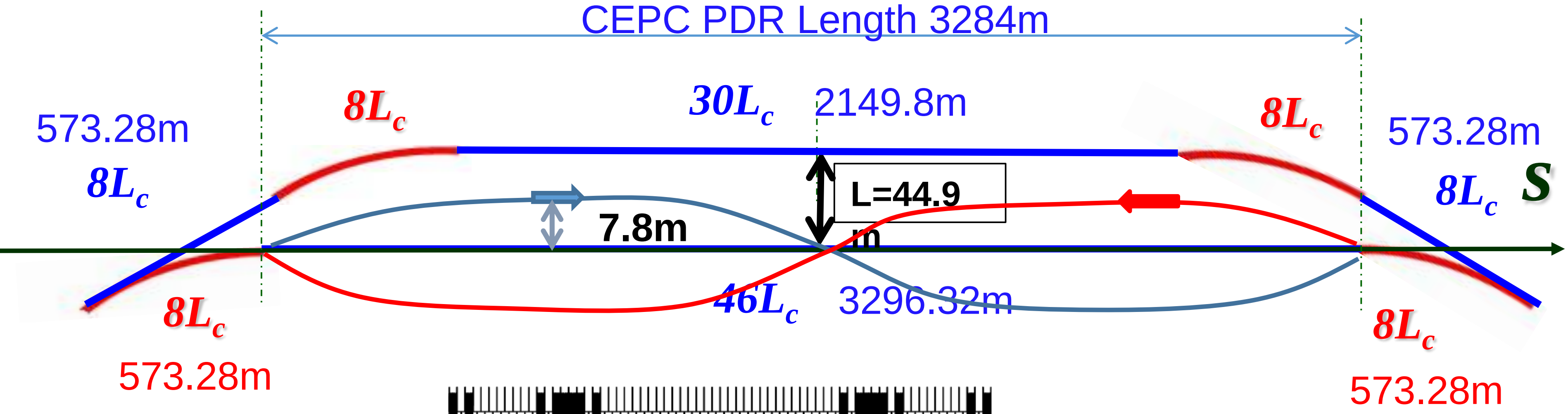
Machine	Author	Parameters	Requirements on FFS design	Features of FFS lattice	Reference
CEPC (PDR)	Dou Wang	L*=1.5m β*=0.25/0.00136 ε=2.45 κ=0.3% Bz=3.5T θc=30mrad	• Local chromaticity correction • Gradient of FD ≤ 200 T/m • SR from the dipoles within 500 m from IP Eγ,c ≤ 190 keV.	• Crab waist collision • Anti-symmetrical IR lattice • need multipoles to correct chromaticity order by order • need large number of ARC sextupoles to optimize momentum acceptance	D. Wang, IPAC16, THPOR010
CEPC (SR)	Yiwei Wang	L*=1.5m β*=0.8m/3mm ε=6.12nm κ=0.3% Bz=3.5T θc=0	• Local chromaticity correction • Gradient of FD ≤ 300 T/m	• Head on collision • Symmetrical IR lattice • with Brinkmann sextupoles to optimize momentum acceptance	Y. Wang, IPAC16, THPOR012
FCC-ee	Katsunobu Oide	L*=2.2m β*=1m/2mm ε=1.26nm κ=0.2% Bz=2T θc=30mrad	• Local chromaticity correction • Gradient of FD ≤ 100 T/m • SR from the dipoles within 500 m upstream of the IP Eγ,c ≤ 100 keV.	• Crab waist collision • Asymmetrical IR lattice • with large number of ARC sextupoles to optimize momentum acceptance	K. Oide, IPAC16, THPOR022
FCC-ee	Anton Bogomyagkov	L*=2.0m β*=0.5m/1mm ε=2.1nm κ=0.2% Bz=? θc=26mrad	• Local chromaticity correction • Gradient of FD ≤ 100 T/m • SR from the dipoles within 250 m from IP Eγ,c ≤ 100 keV.	• Crab waist collision • Asymmetrical IR lattice • With additional sextupoles to correct chromaticity up to 3rd order	A. Bogomyagkov et. al., IPAC16, THPOR019
a Higgs factory	Yunhai Cai	L*=4.0m β*=0.2m/2mm ε=4.5nm κ=0.1% Bz=? θc=0	• Local chromaticity correction	• Head on collision • Symmetrical IR lattice • with multipoles to correct chromaticity order by order	Y. Cai, Lattice for a Higgs Factory, FCC Week 2016

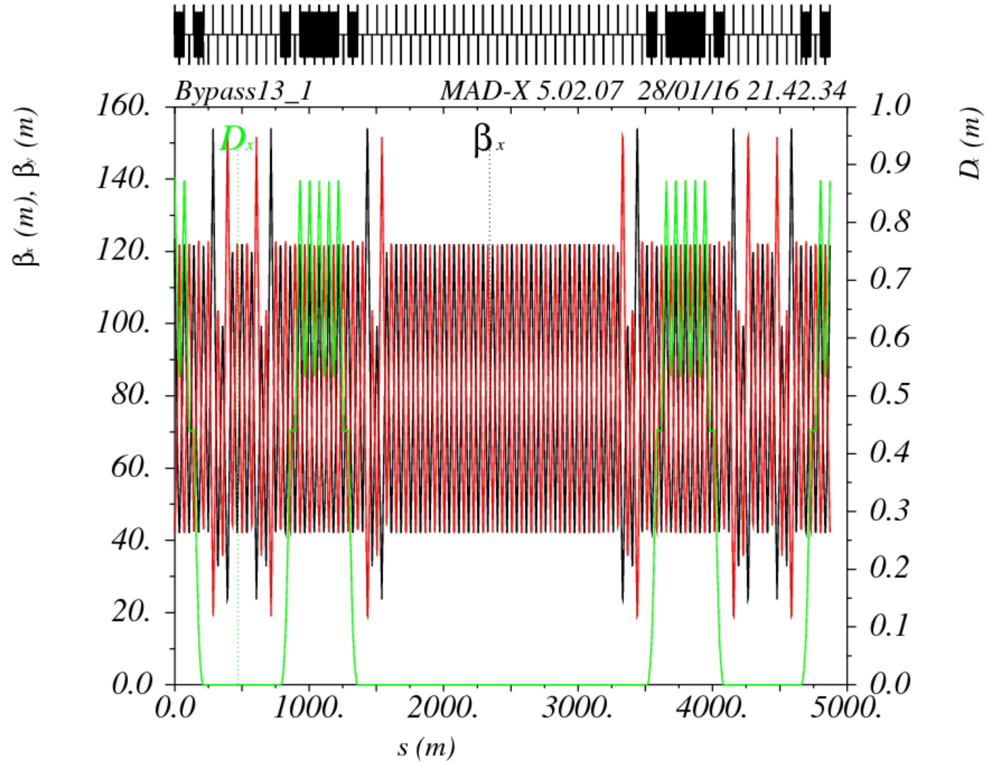
Combine with partial double ring lattice



CEPC Booster Bypass at IP1/3 Option1

F. Su



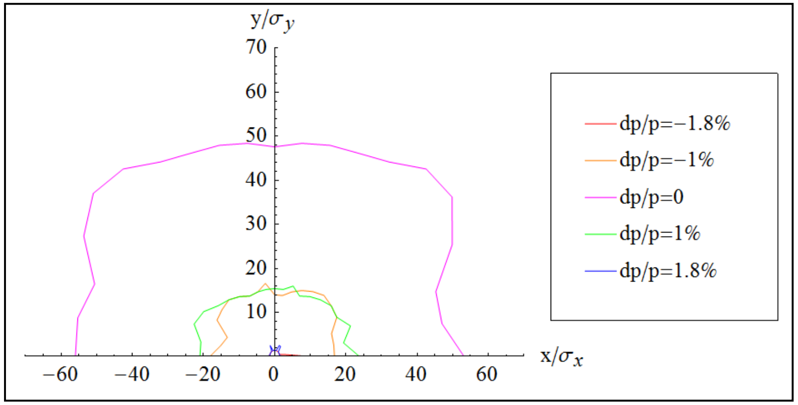


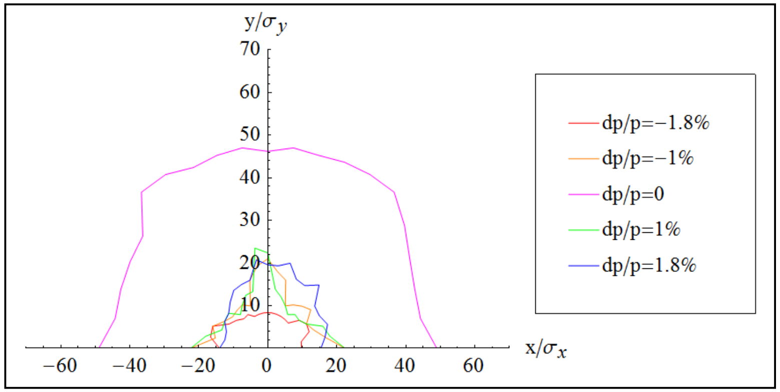
Cell length=71.66m

DA of the whole ring

We are studying DA of CEPC main ring in three steps:
1) Main ring without Partial Double Ring (PDR)
2) Main ring with PDR but without Final Focus System (FFS)
3) Main Ring with PDR and FFS

Example: DA CEPC of of case 2)

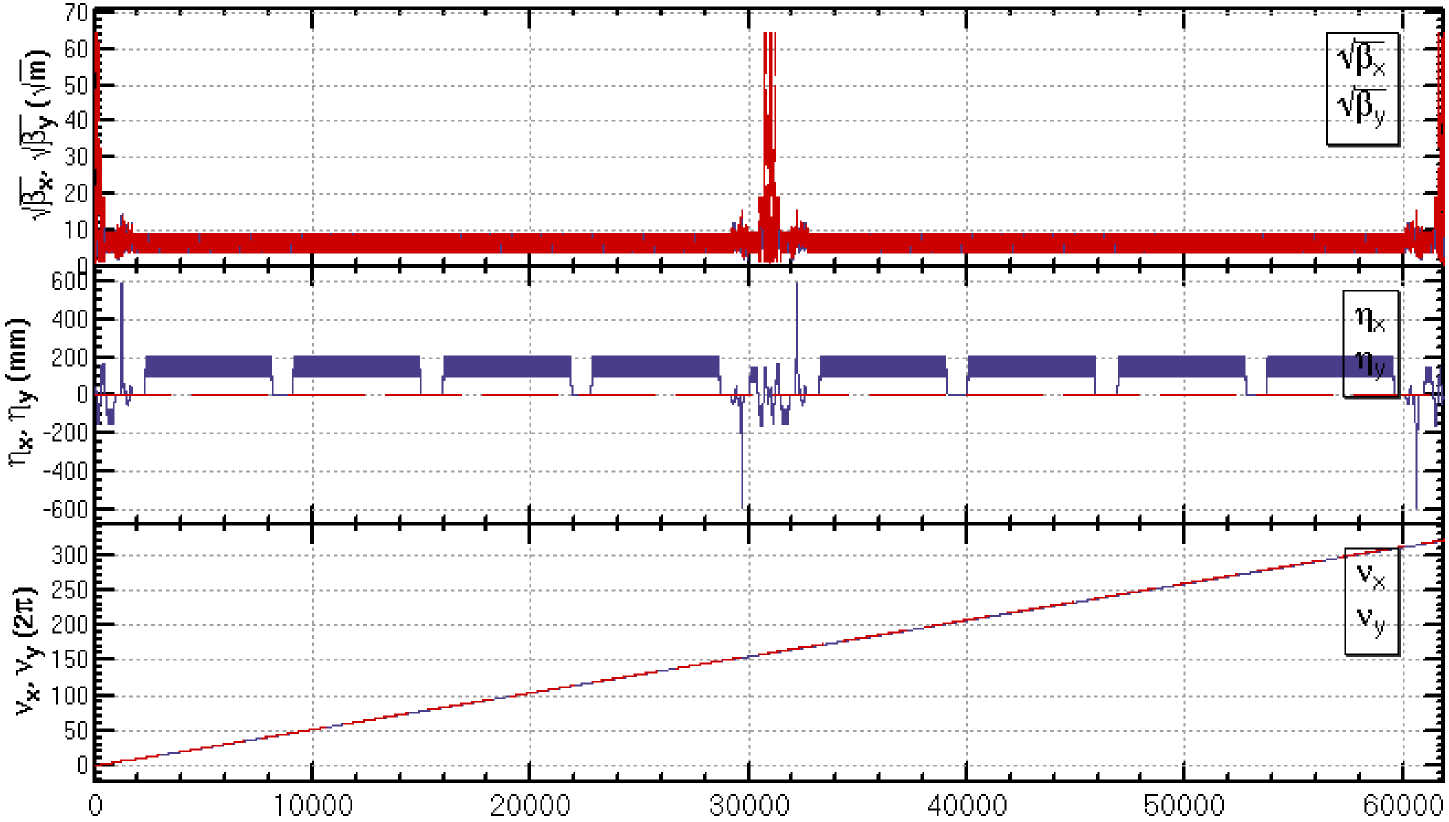




Result of July 30, 2016, by Y.W. Wang

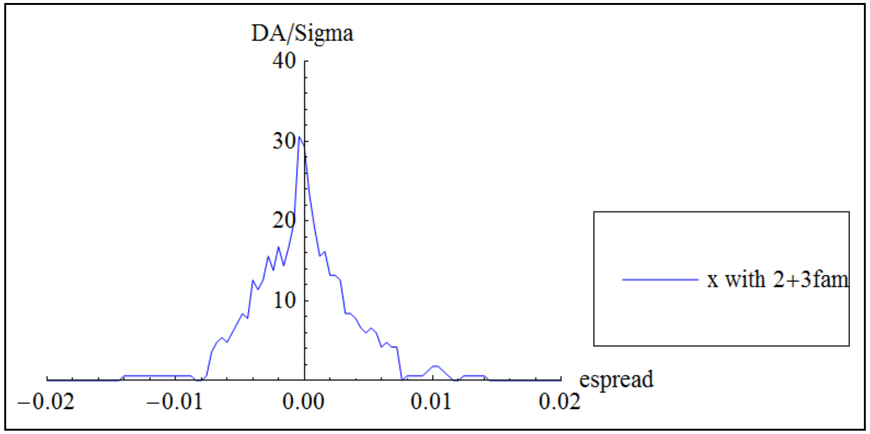
ARC+PDR+IR lattice

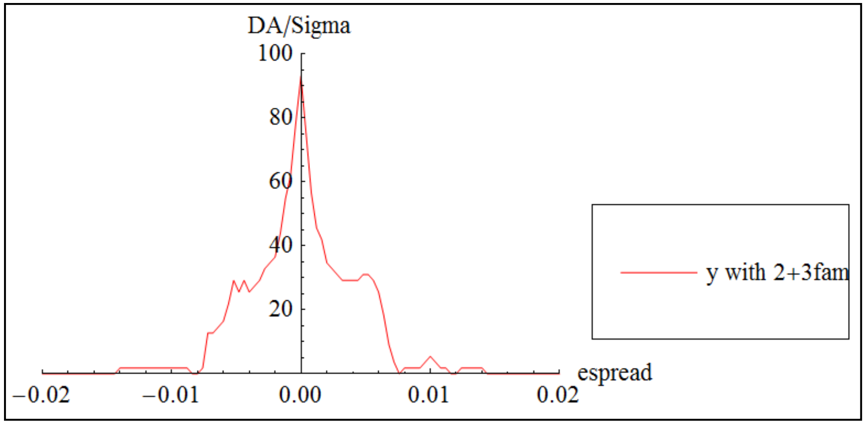
- A lattice of the whole ring (ARC+PDR+IR) fulfilling the design parameters is ready.
- Dynamic aperture optimization for this lattice is under going.



Preliminary Dynamic aperture result for ARC + PDR+IR

- Preliminary dynamic aperture result
  - With 2 families in ARC + 3 families in IR
  - W/O error of the magnets
  - Synchrotron motion included
  - Tracking with around 1 times of damping time
  - Coupling factor κ=0.003 for εy
  - Optimization with much more families is undergoing





Cluster to be used

	DA Task	Optim. Methods	Time/case	One optim. time	Time of optimization	CPU	SIngle and Partial double rings
1	CEPC Dynamic Aperture Optimization	Differential Evolution	20min	100,00 h	10?	500-2000	All
2	CEPC Dynamic Aperture Optimization	Genetic Algorithm（each genergation 5000 seeds，100 interations）	6min	50,000 h	10?	1000-2000	All
3	CEPC Dynamic Aperture Optimization	Downhill Simplex	1min	400 h	10?	100-200	All
Total	CEPC Dynamic Aperture Optimization		27min	60,400 h	10?	1600-4200	All

1000CPU，Estimated optimization time=60400×10/1000/24=25days

New idea：APDR

IHEP-AC-LC-Note2016-002

ILC-物理-2016-02

May 20th, 2016

The advanced partial double ring scheme for CEPC

GAO Jie（高杰）

ILC Group, Accelerator Center

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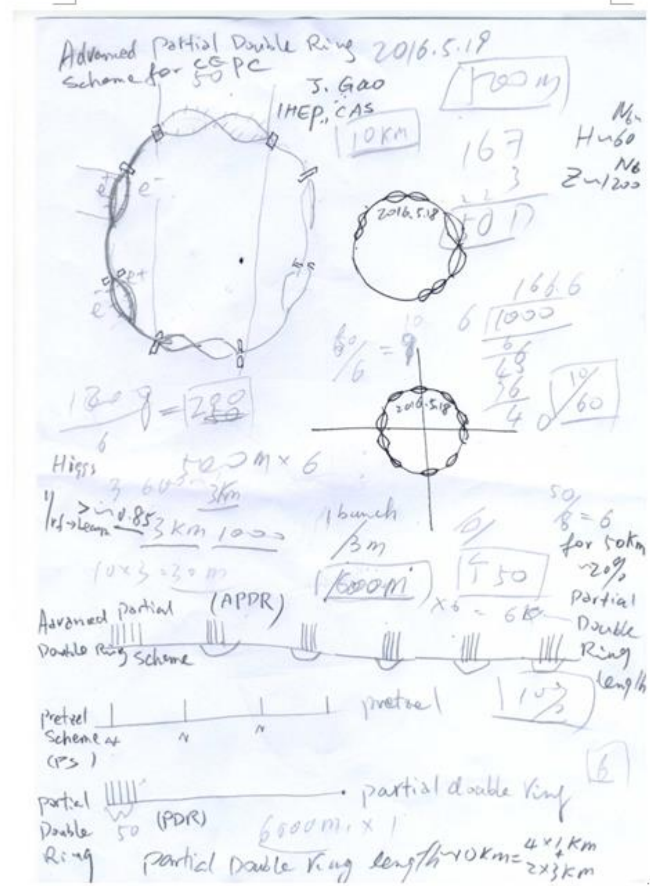
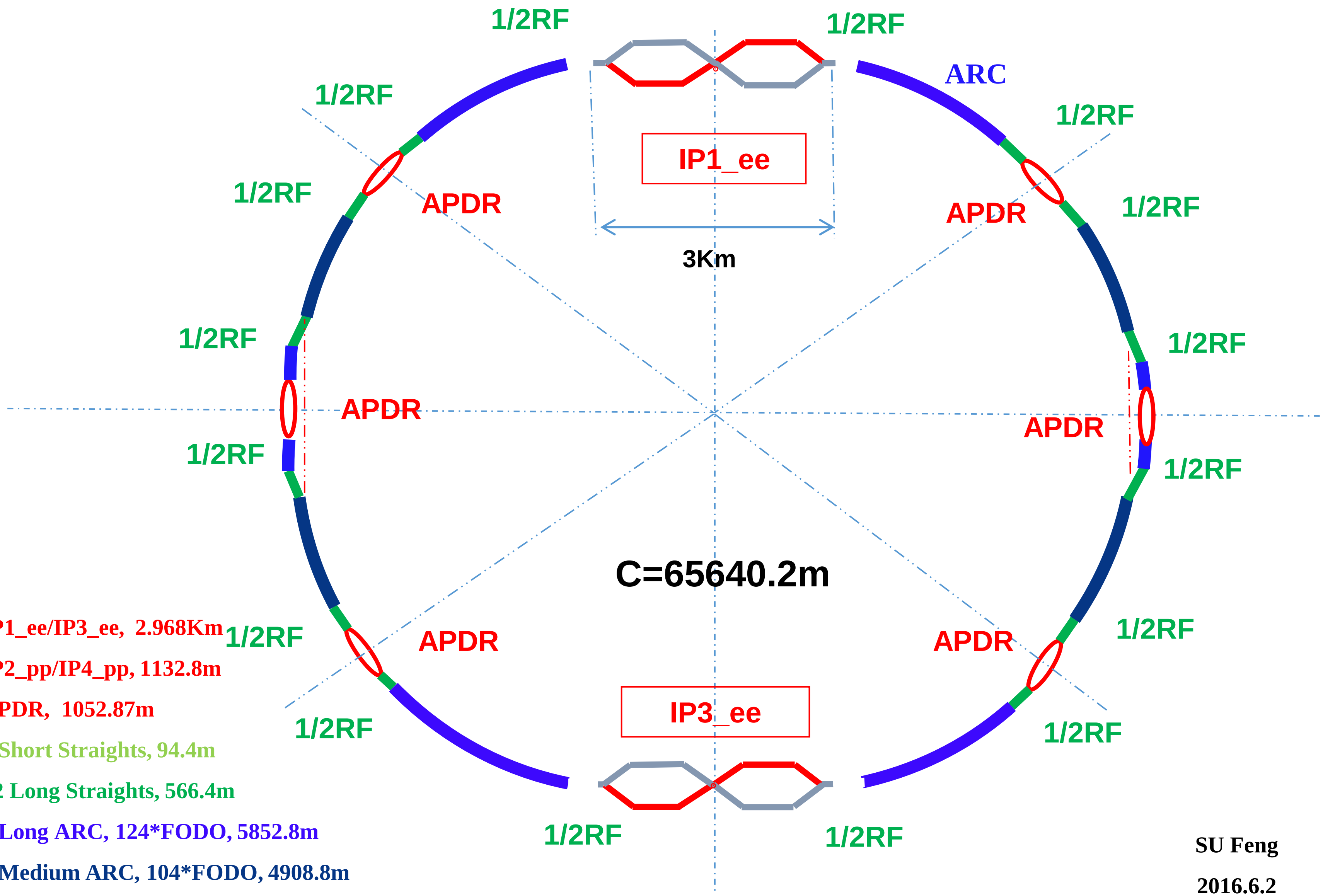
Institute of High Energy Physics
Chinese Academy of Sciences



CEPC Advanced Partial Double Ring Layout II



IP1_ee/IP3_ee, 2.968Km

IP2_pp/IP4_pp, 1132.8m

APDR, 1052.87m

4 Short Straights, 94.4m

12 Long Straights, 566.4m

4 Long ARC, 124*FODO, 5852.8m

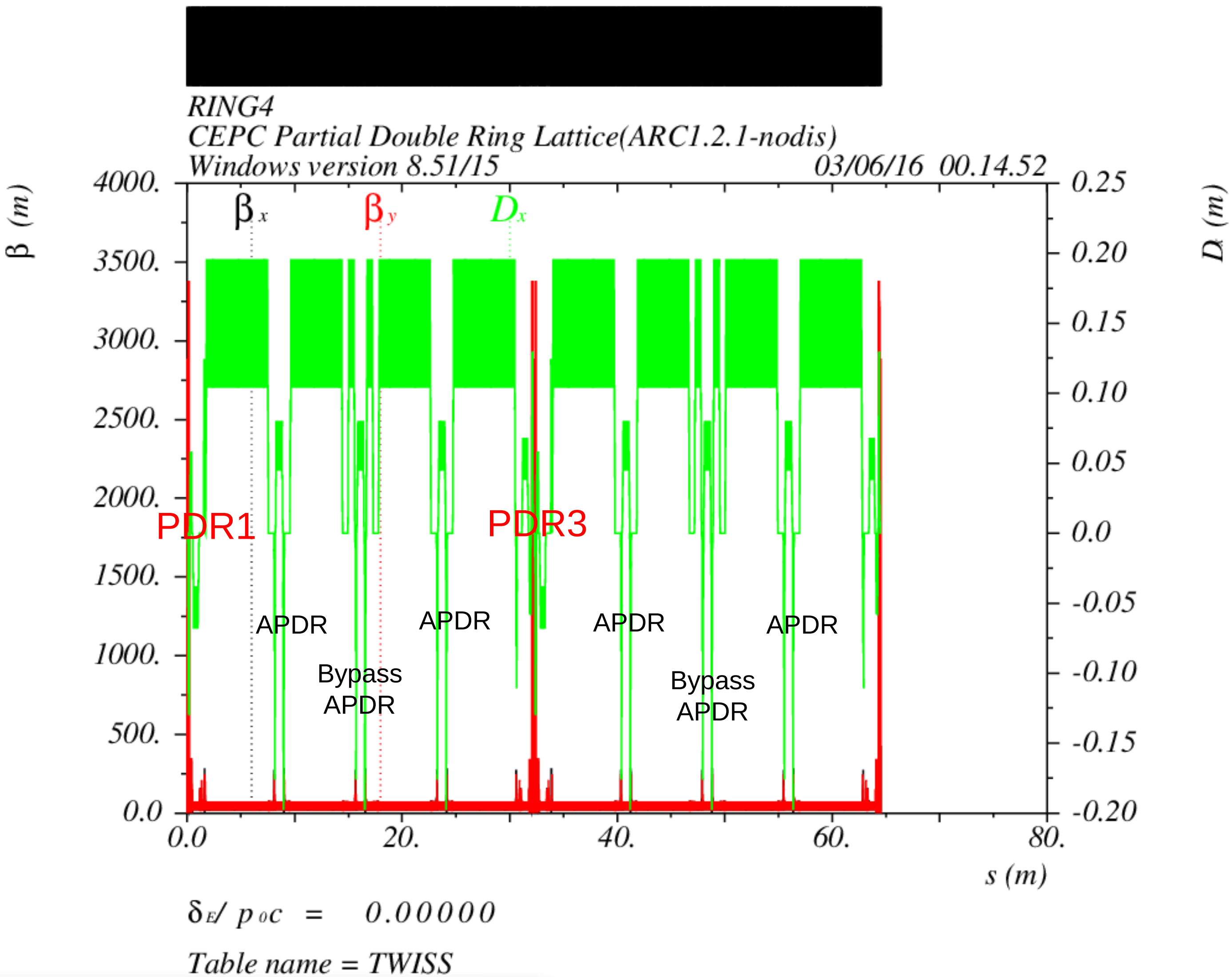
4 Medium ARC, 104*FODO, 4908.8m

4 Short ARC, 14*FODO, 660.8m

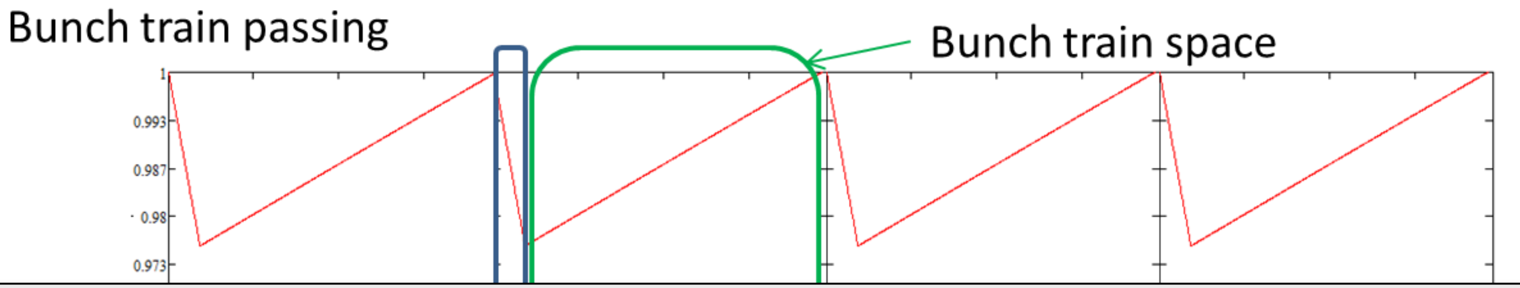
SU Feng

2016.6.2

CEPC Advanced Partial Double Ring Optics



CEPC APDR SRF considerations



- The 8-double ring and 6-double ring seem available when using the same parameter as PDR(V_{RF}=3.62GV) for HL. The 8-double ring has a lower phase variation than the 6-double ring .
- The phase region is from 35.2-33 degree for bunches in a bunch train for the 8-double ring HL mode. The phase region is from 35.2-32.3 degree for the 6-double ring HL mode.
- The bunch energy gain in each cavity is constant.
- The RF to beam efficiency is ~100%.

Field evolution in cavity

Field decrease vs. various initial field gradient of the cavity

SC SRF System for Different CEPC Design Options

8 double ring	*Pre-CDR J.Y. Zhai20160327*	*PDR(HL) J.Y. Zhai20160408*	*APDR(HL)*	*APDR(HL V_{RF}=3.62)*	*APDR (H-low power V_{RF}=3.53)*	*APDR (H-low power)*	*APDR (Z)*
Number of IPs	2	2	2	2	2	2	2
Energy (GeV)	120	120	120	120	120	120	45.5
Circumference (km)	54	54	54	54	54	54	54
SR loss/turn (GeV)	3.1	2.96	2.96	2.96	2.96	2.96	0.062
Half crossing angle (mrad)	0	15	15	15	15	15	15
Piwinski angle	0	2.5	2.5	2.5	2.6	2.6	8.5
N_e/bunch (10^{11})	3.79	2.85	2.85	2.85	2.67	2.67	0.46
Bunch number	1	1	17x4	17x4	11x4	11x4	275x4
Beam current (mA)	16.6	16.96	17	17	10.5	10.5	45.4
SR power /beam (MW)	53.2	51	50	50	31.2	31.2	2.8
Bending radius (km)	6.1	6.2	6.2	6.2	6.2	6.2	6.1
V_{RF} (GV)	6.87	**3.65**	**5.16**	**3.62**	**3.53**	**5.16**	**0.357/0.12/0.12**
f_{RF} (MHz)	650	650	650	650	650	650	650
Cavity No.	384	384	498	384	384/768/192	498	48/16/16
Cavity gradient	15.8	20.6	22.6	20.6	20/20/20	22.6	16.2/16.3/32.6
Accelerating phase	63.1	35.2	55.3-55	35.2-33	33-31.6/33-31.6/33-31.6	55.3-55	80.1-79.9/58.9-56.9/58.9-58
CW power/cavity （kW）	275	263.4	201	260	163.3/81.6/326.6	126	117/350/350
Peak power/train (kW)	/	2220	1389	1389	843	843	884
Total Power （MW）	105.6	**382.5**	**100.4**	**100.4**	**62.7**	**62.7**	**5.6**
Cell/cavity	5	2	2	2	2/1/4	2	2/2/1
Cavity/module	4	**6**	**6(3,2)**	**6**	**6/12/3**	**6(3,2)**	**6/2/2**
Module/station	6	10	10(11）	8	8/8/8	10(11）	1/1/1
Total module	96	64	126	64	64/64/64	126	8/8/8
R/Q (Ω)	514	206	206	206	206/103/412	206	206/206/103
G	268	268	268	268	268	268	268
HOM loss factor/cavity (V/pC)	1.8	0.54	0.54	0.54	0.54/0.27/1.08	0.54	0.54/0.54/0.27
HOM power/cavity (kW)	3.6	0.8	0.838	0.838	0.485/0.24/0.97	0.485	0.36/0.36/0.18
Working Temperature （K）	2	2	2	2	2	2	2
Q0	4E10	**2E10**	**2E10**	**2E10**	**2E10**	**2E10**	**2E10**
τ（ms）	1.156	0.097	1.263	0.811	1.242	2.045	2.243/0.76/0.76
QL	2.36e6	1.97e5	2.579e6	1.656e6	2.53e6	4.18e6	4.58e6/1.55e6/1.55e6
Bandwidth(kHz)	0.28	3.3	0.126	0.196	0.128	0.077	0.071/0.209/0.209
Detuning F (kHz)	-0.27	**-1.16**	**-0.180**	**-0.138**	**-0.083**	**-0.111**	**-0.234/-0.347/-0.347**
Stored energy/cavity(J)	158.7	**107.4**	**126.9**	**107.4**	**100**	**126.9**	**65.3/65.3/133**
Frev(kHz)	5.484	5.484	5.484	5.484	5.484	5.484	5.484
Gap length TB (us)	/	0.3-160	20	20	20	20	20
η(RF to beam efficiency)(%)	100	27%	~100	~100	~100	~100	~100
Vc decrease(%)	/	/	1.6	2.5	1.6	1	1.7/5.3/2.5
TB/τ	/	1.7	0.0158	0.025	0.0098	0.0098	0.0089/0.0263/0.0263

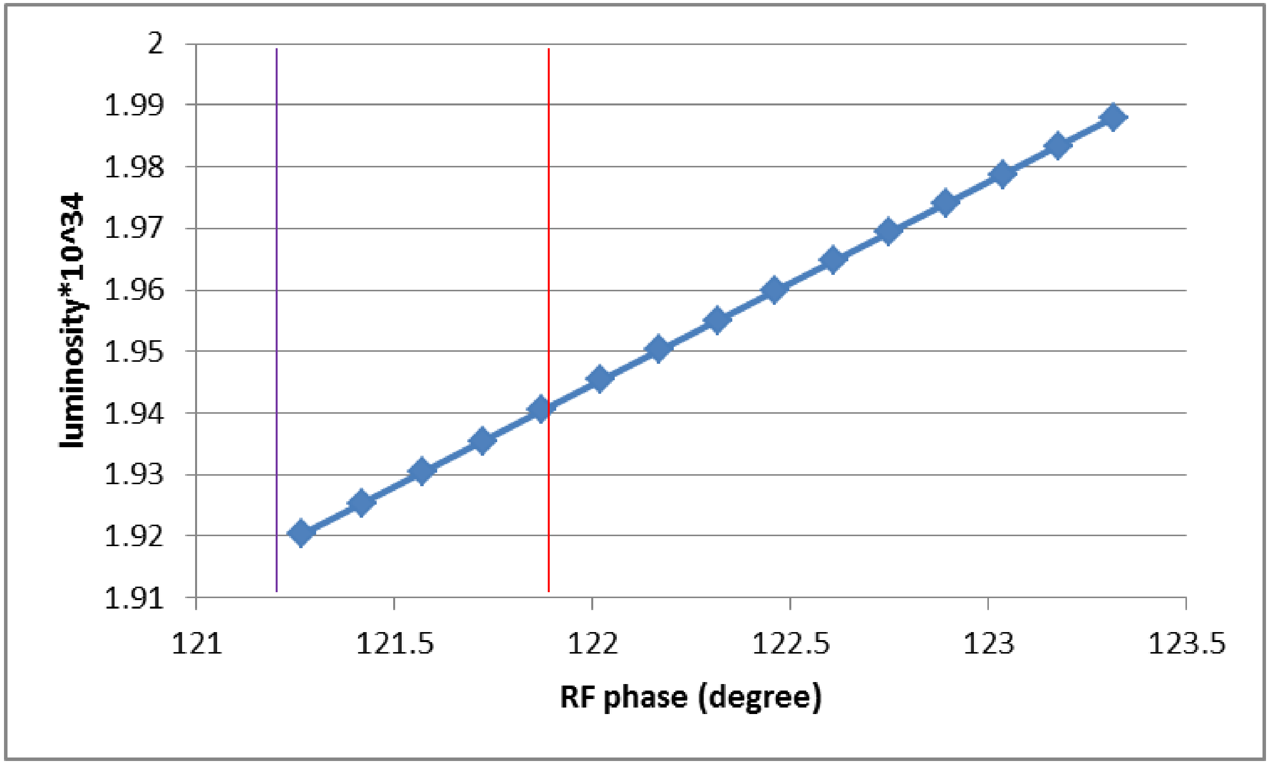
Beam loading effects of APDR

Bunch No.	Pre CDR (CW, $P_g=P_{avg}$)		PDR (CW, $P_g=P_{pulse}$, very low RF efficiency)		APDR 6 ring (H-low power, CW, $P_g=P_{avg}$)		APDR 8 ring (H-low power, CW, $P_g=P_{avg}$)	
	Vrf	Phase shift	Vrf	Phase shift	Vrf	Phase shift	Vrf	Phase shift
1	1	0	1	0	1	0.00	1	0.00
2	1	0	1	0	0.9984	−0.16	0.9984	−0.14
3	1	0	1	0	0.9968	−0.31	0.9968	−0.28
4	1	0	1	0	0.9952	−0.47	0.9952	−0.42
5	1	0	1	0	0.9936	−0.63	0.9936	−0.56
6	1	0	1	0	0.992	−0.79	0.992	−0.70
7	1	0	1	0	0.9904	−0.94	0.9904	−0.84
8	1	0	1	0	0.9888	−1.10	0.9888	−0.98
9	1	0	1	0	0.9872	−1.26	0.9872	−1.12
10	1	0	1	0	0.9856	−1.41	0.9856	−1.26
11	1	0	1	0	0.984	−1.57	0.984	−1.40
15	1	0	1	0	0.9776	−2.20		
50	1	0	1	0				
67			1	0				

Assume V_{rf} is constant at the first bunch of bunch trains and the change of V_b is negligible.

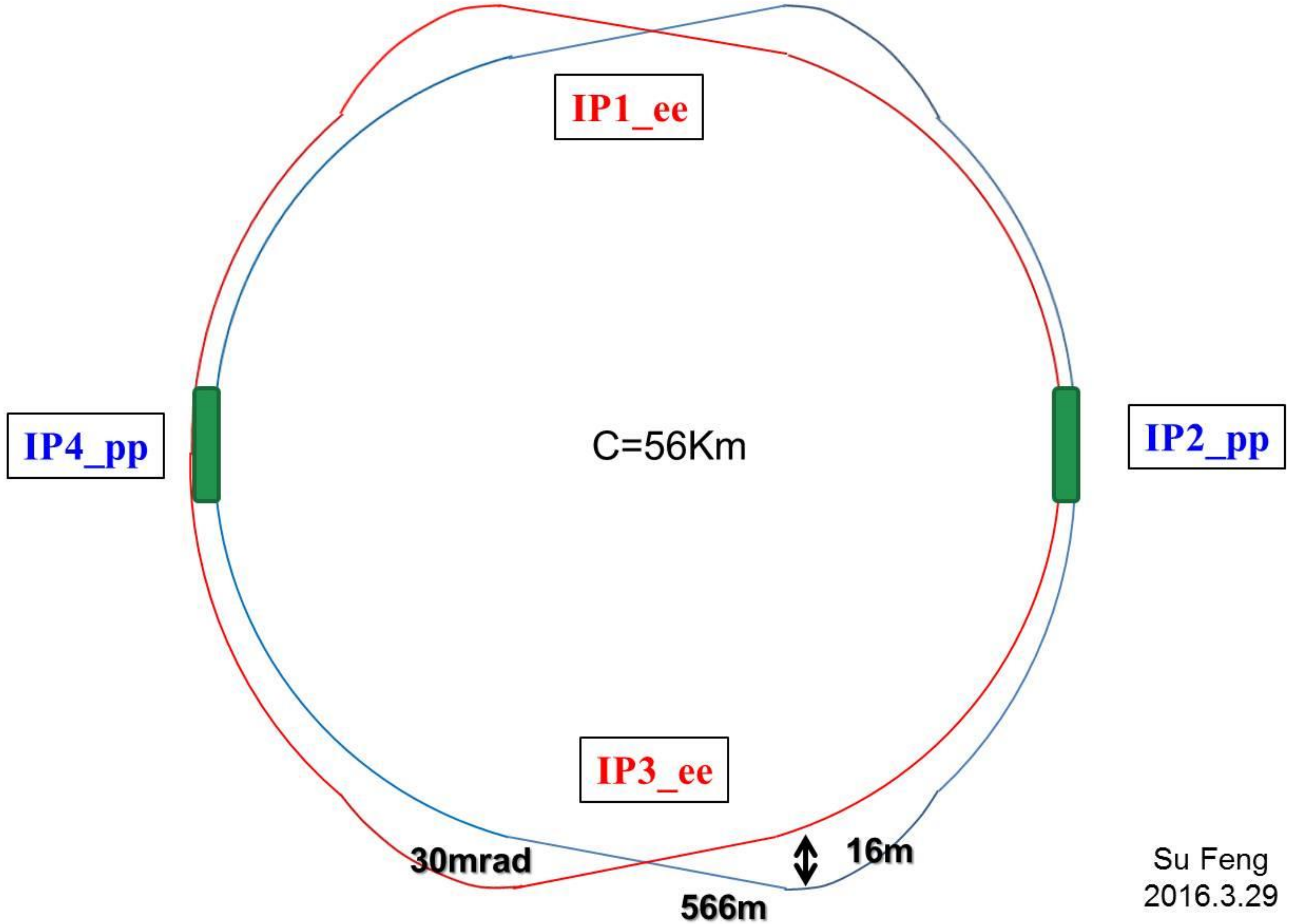
By Zhenchao Liu

Luminosity error with RF phase adjustment

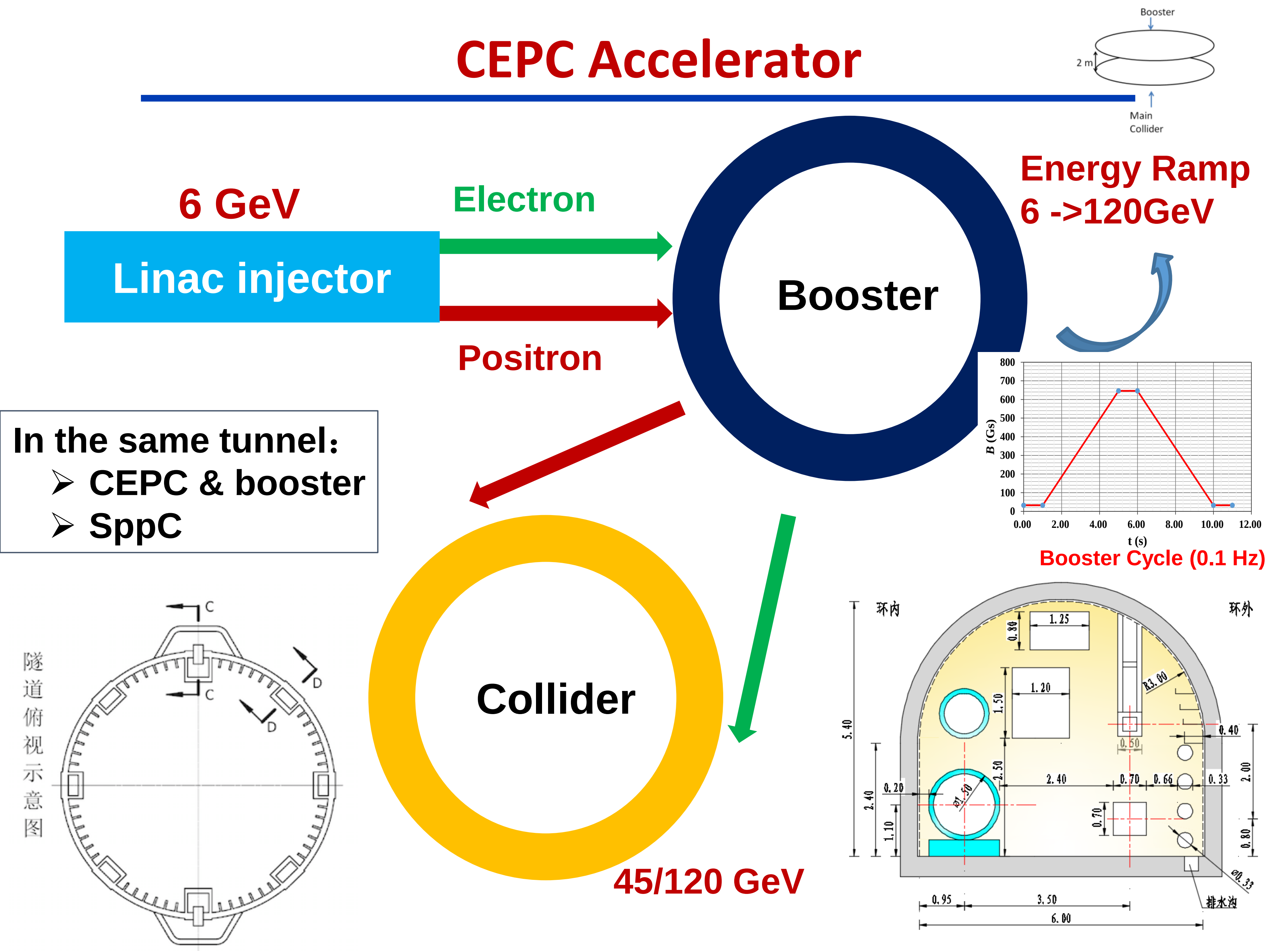


Error of luminosity: ~ -3.5% (6 ring), ~-2.4% (8 ring)

CEPC Double Ring Scheme Layout



CEPC full double ring scheme is also under look…

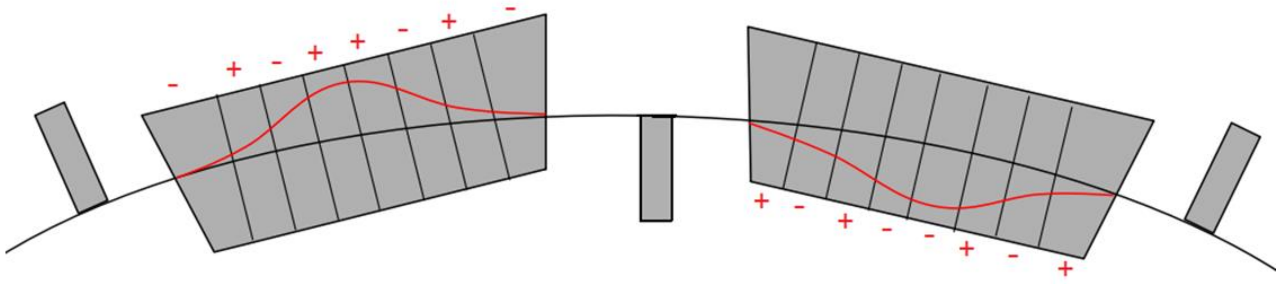


CEPC Accelerator
Booster
2 m
Main Collider
6 GeV
Linac injector
Electron
Positron
Booster
Energy Ramp
6 ->120GeV
B (Gs)
t (s)
Booster Cycle (0.1 Hz)
In the same tunnel:
➢ CEPC & booster
➢ SppC
Collider
45/120 GeV
隧道俯视示意图
C
D
环内
环外
排水沟

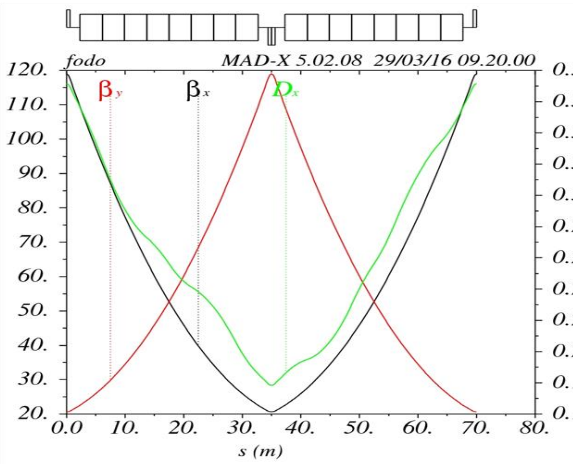
CEPC Booster Design

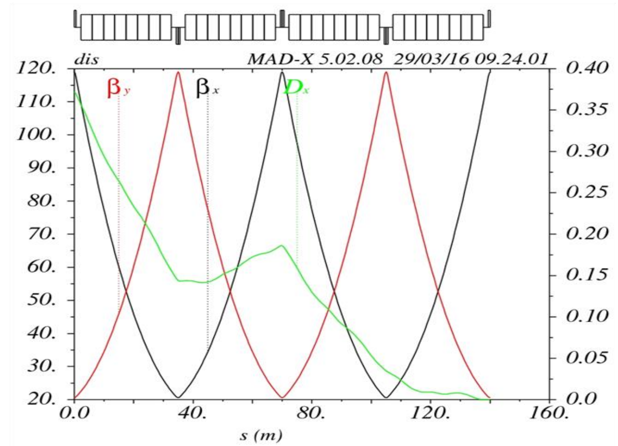
1) Normal Low field Bend Scheme

2) Wiggling Bend Scheme



- **90 degree FODO**
- **FODO length:70 meter**





Booster Parameters

- **Parameter List for Alternating Magnetic Field Scheme.**

Parameter	Unit	Value
Beam energy [E]	GeV	6
Circumference [C]	km	63.84
Revolutionfrequency[f_0]	kHz	4.69
SR power / beam [P]	MW	2.16
Beam off-set in bend	cm	1.2
Momentum compaction factor[α]		2.33E-5
Strength of dipole	Gs	**-129.18/+180.84**
n_B/beam		50
Lorentz factor [g]		11741.71
Magnetic rigidity [Br]	T·m	20
Beam current / beam [I]	mA	0.92
Bunchpopulation[N_e]		2.44E10
Bunch charge [Q_b]	nC	3.91681
emittance-horizontal[e_x] inequilibrium	m·rad	6.38E-11
injected from linac	m·rad	3E-7
emittance-vertical[e_y] inequilibrium	m·rad	0.191E-11
injected from linac	m·rad	3E-7

Parameter	Unit	Value
RF voltage [Vrf]	GV	0.2138
RF frequency [frf]	GHz	1.3
Harmonic number [h]		276831
Synchrotronoscillationtune[n_s]		0.21
Energy acceptance RF	%	5.93
SR loss / turn [U0]	GeV	5.42E-4
Energyspread[s_d] inequilibrium	%	0.0147
injected from linac	%	0.1
Bunch length[s_d] inequilibrium	mm	0.18
injected from linac	mm	~1.5
Transversedampingtime[t_x]	ms	4.71
	turns	
Longitudinaldampingtime[t_e]	ms	4.71
	turns	

Booster Parameters

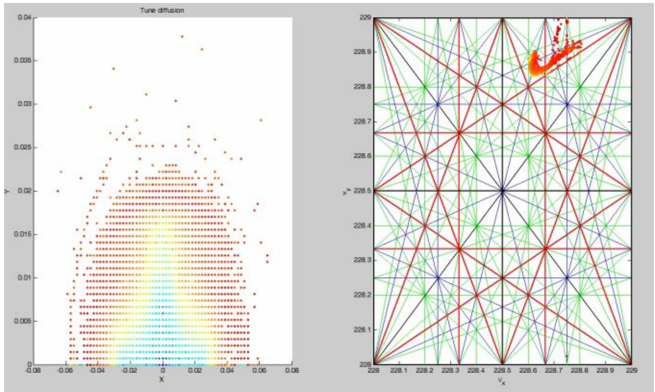
• Parameter List for Alternating Magnetic Field Scheme.

Parameter	Unit	Value
Beam energy [E]	GeV	120
Circumference [C]	km	63.84
Revolutionfrequency[f_0]	kHz	4.69
SR power / beam [P]	MW	2.16
Beam off-set in bend	cm	0
Momentum compaction factor[α]		2.54E-5
Strength of dipole	Gs	**516.71**
n_B/beam		50
Lorentz factor [g]		234834.15
Magnetic rigidity [Br]	T·m	400
Beam current / beam [I]	mA	0.92
Bunchpopulation[N_e]		2.44E10
Bunch charge [Q_b]	nC	3.91681
emittance-horizontal[e_x] inequilibrium	m·rad	3.61E-9
injected from linac	m·rad	3E-7
emittance-vertical[e_y] inequilibrium	m·rad	0.1083E-9
injected from linac	m·rad	3E-7

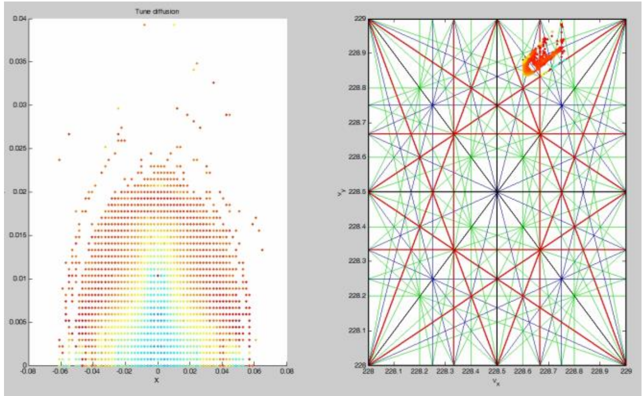
Parameter	Unit	Value
RF voltage [Vrf]	GV	6
RF frequency [frf]	GHz	1.3
Harmonic number [h]		276831
Synchrotronoscillationtune[n_s]		0.21
Energy acceptance RF	%	4.57
SR loss / turn [U0]	GeV	2.34
Energyspread[s_d] inequilibrium	%	0.12
injected from linac	%	0.1
Bunch length[s_d] inequilibrium	mm	1.36
injected from linac	mm	~1.5
Transversedampingtime[t_x]	ms	21.76
Longitudinaldampingtime[t_e]	ms	

DA results of booster

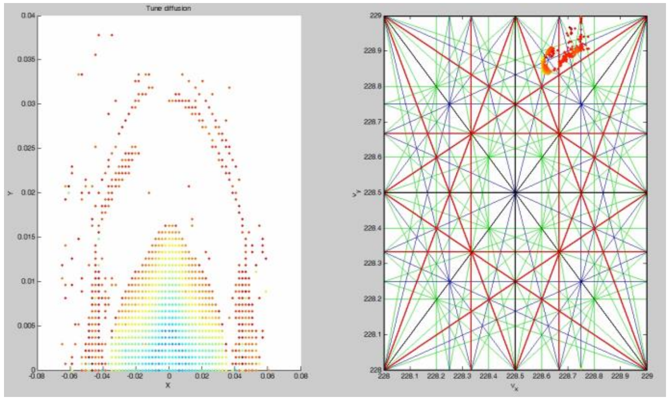
- Tune:190.61/190.88 and cavity on



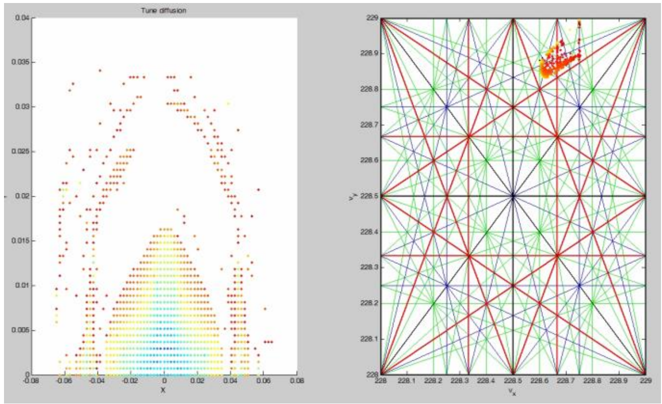
with error, dp=0



with error, dp=0.0



with error, dp=0.01



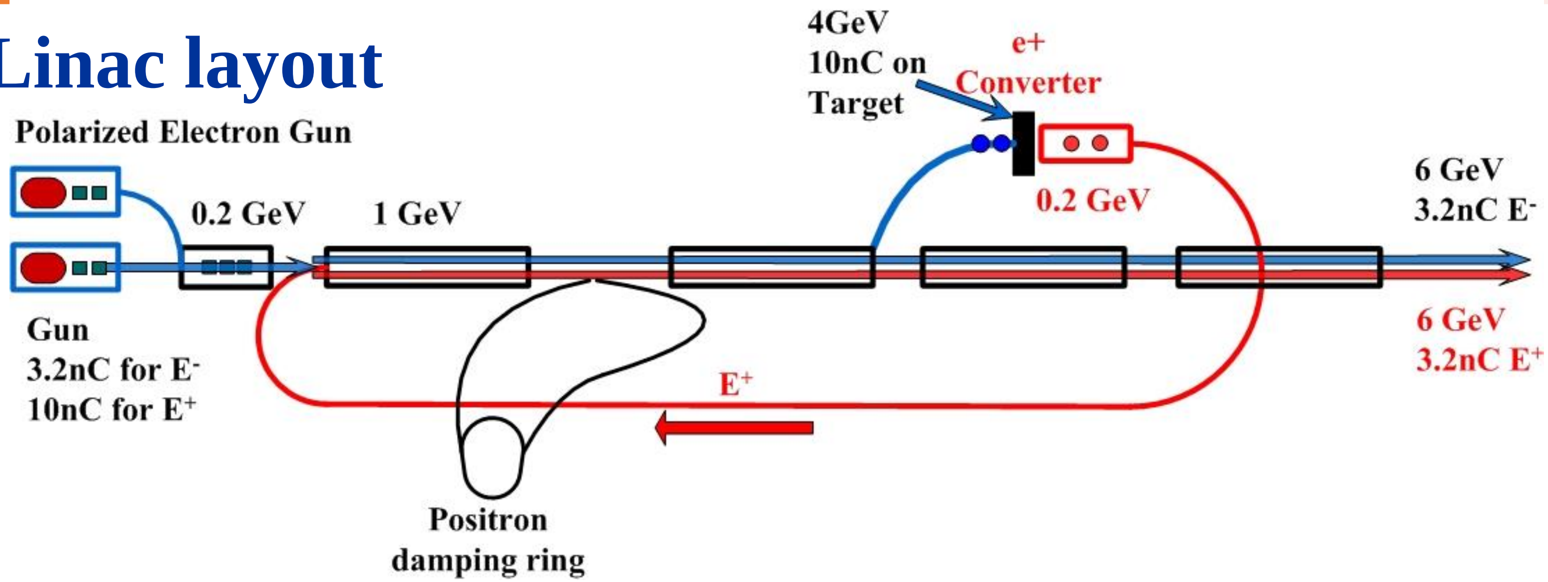
with error, dp=0.01

CEPC Injection linac overview

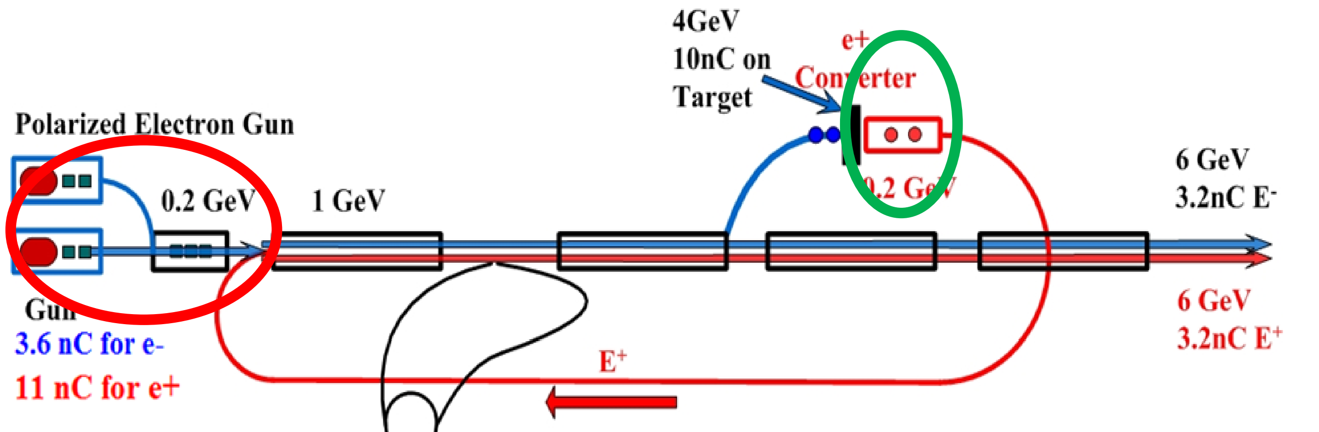
Main parameters

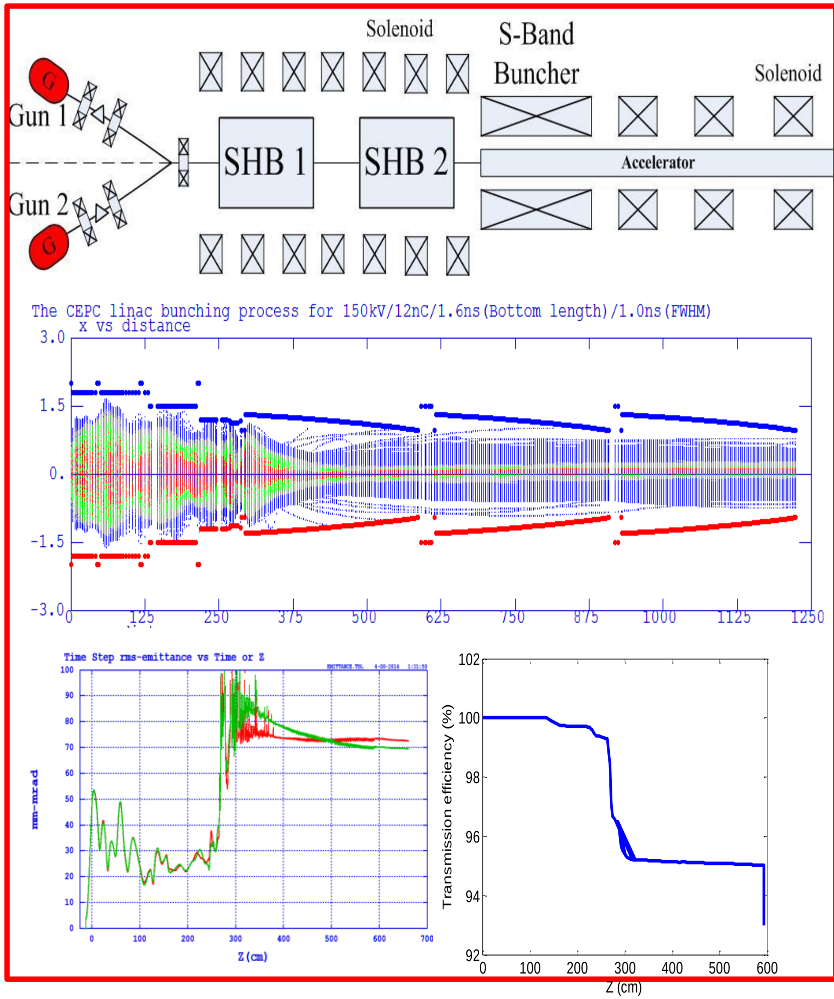
Parameter	Symbol	Unit	Value
E^- beam energy	E_{e-}	GeV	6
E^+ beam energy	E_{e+}	GeV	6
Repetition rate	f_{rep}	Hz	50
E^- bunch population	N_{e-}		2×10^{10}
E^+ bunch population	N_{e+}		2×10^{10}
Energy spread (E^+/E^-)	σ_E		$<1\times10^{-3}$
Emitance (E^-)			0.3 mm· mrad
Emitance (E^+)			**0.3 mm· mrad**

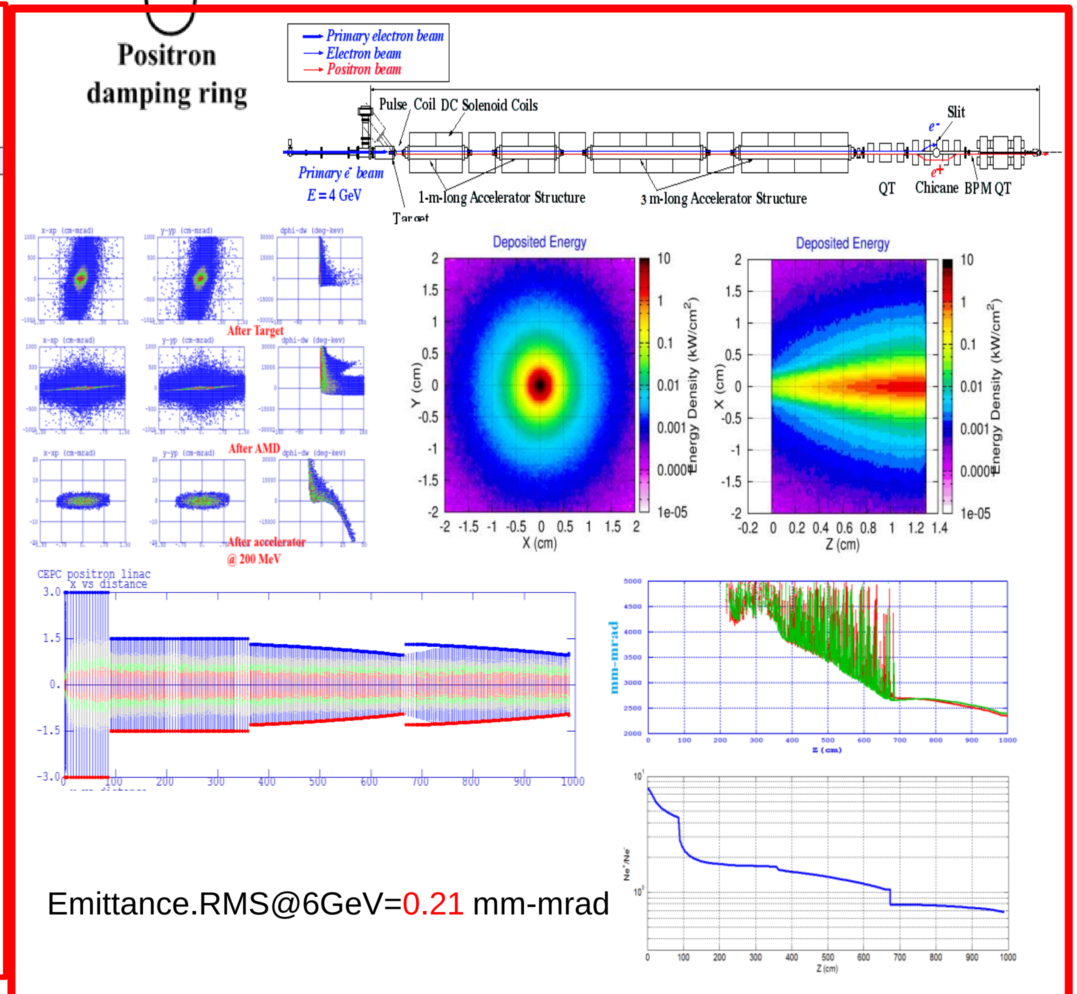
Linac layout



CEPC Injector







Baseline Design in PreCDR

ILD-like with some modifications and considerations

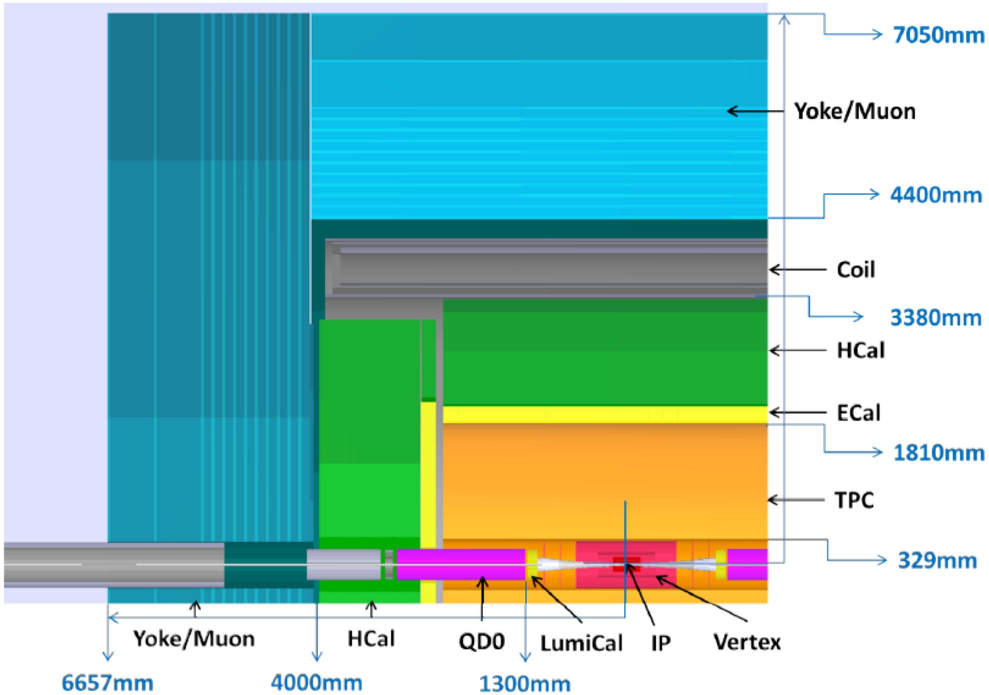
- No push-and-pull → Less Yoke

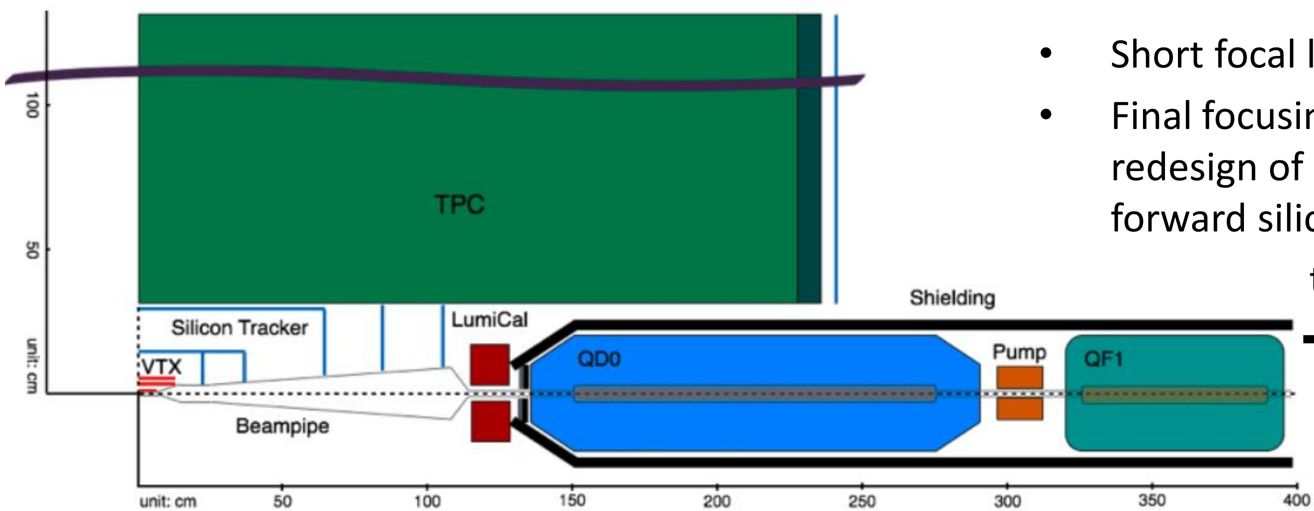
- Shorter L*=1.5m → Challenges for Machine-Detector-Interface (MDI)

- No Power-pulsing → more power consumpti & needs active cooling

- CEPC preCDR

http://cepc.ihep.ac.cn/preCDR/volume.html





- Short focal length L*=1.5m
- Final focusing magnets inside the detector, redesign of QD0/QF1, LumiCal, and reduce forward silicon tracker disk (FTD) to 5 → beam induced background studies

CEPC Vertex and Tracker

➔ **CEPC detector design is driven by critical physics benchmarks.**

- Vertexing $(h \to b\bar{b}, c\bar{c}, \tau^+\tau^-)$
  - ~1/5 $r_{beampipe}$, ~1/30 pixel size (wrt LHC)

$$\sigma_{ip} = 5\mu m \oplus 10\mu m / p\sin^{3/2}\theta$$

✔ CEPC

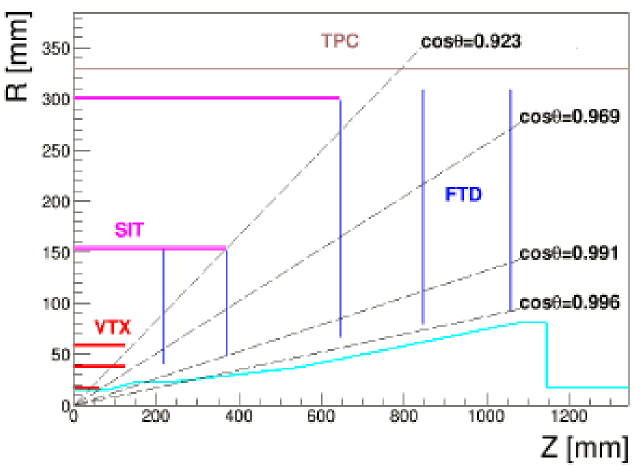
- Tracking $(e^+e^- \to Zh \to \ell^+\ell^- X;\ \text{incl. } h \to \text{nothing})$
  - ~1/6 material, ~1/10 resolution (wrt LHC)

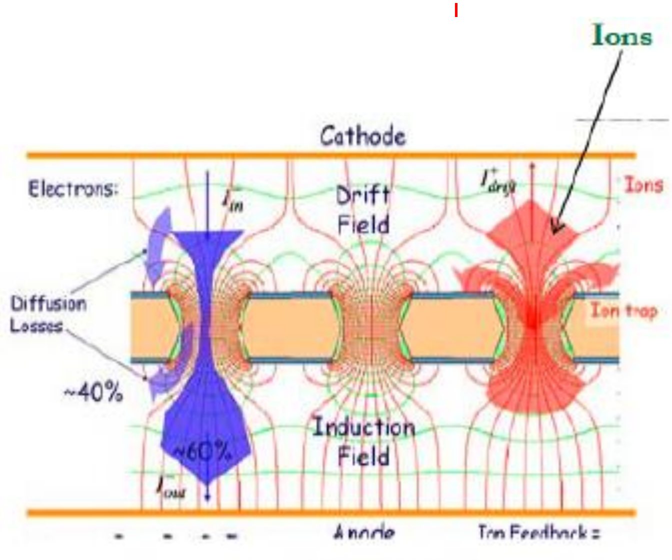
$\sigma(1/p) = 5\times10^{-5}/GeV$ or better

✔ CEPC

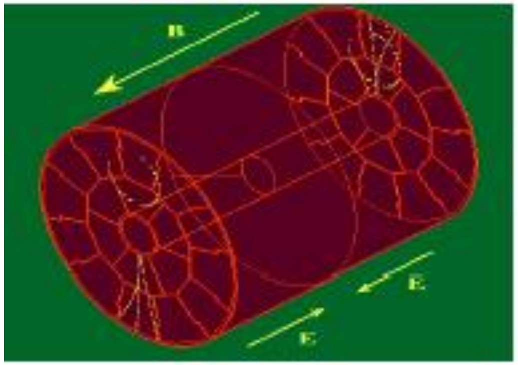
Vertex detector specifications:

- σ_{SP} near the IP: *≤3 μm*
  - → small pixels 16×16μm² or below, digital
- material budget: *≤ 0.15%X_0/layer*
  - → low power circuits, air cooling
- pixel occupancy: *≤ 1 %*
- radiation tolerance:
  - Total Ionising Does *≤100 krad/year*
  - Non-Ionising Energy Loss *≤3×10¹¹ n_{eq}/(cm² year)*
- first layer located at a radius: *~1.6 cm*





IBF of GEM



➔ GEM+Micromegas hybrid detector to significantly reduce TPC ion back flow

CEPC Electromagnetic Calorimeter

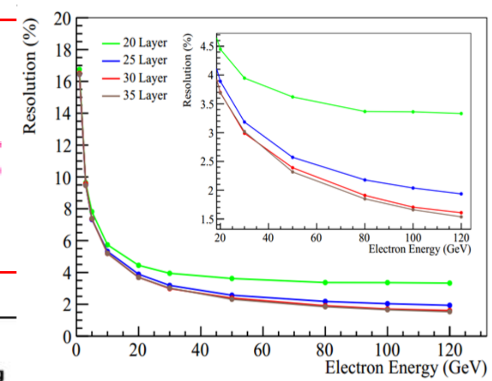
➔ **Concept of Particle Flow Algorithm (PFA) based calorimeters with very fine granularity, compare to ILC, it's less demanding at CEPC.**

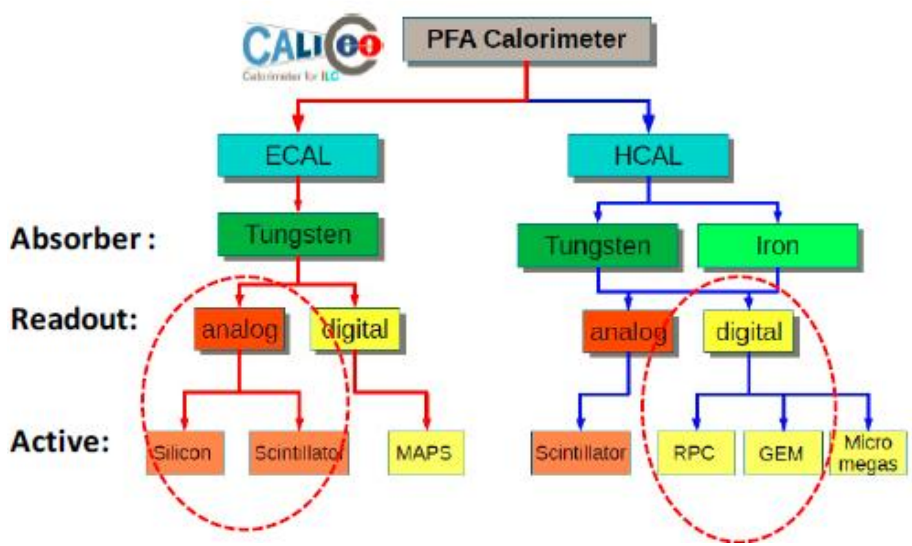
➔ **Re-optimization, exploring new design and active cooling, …**

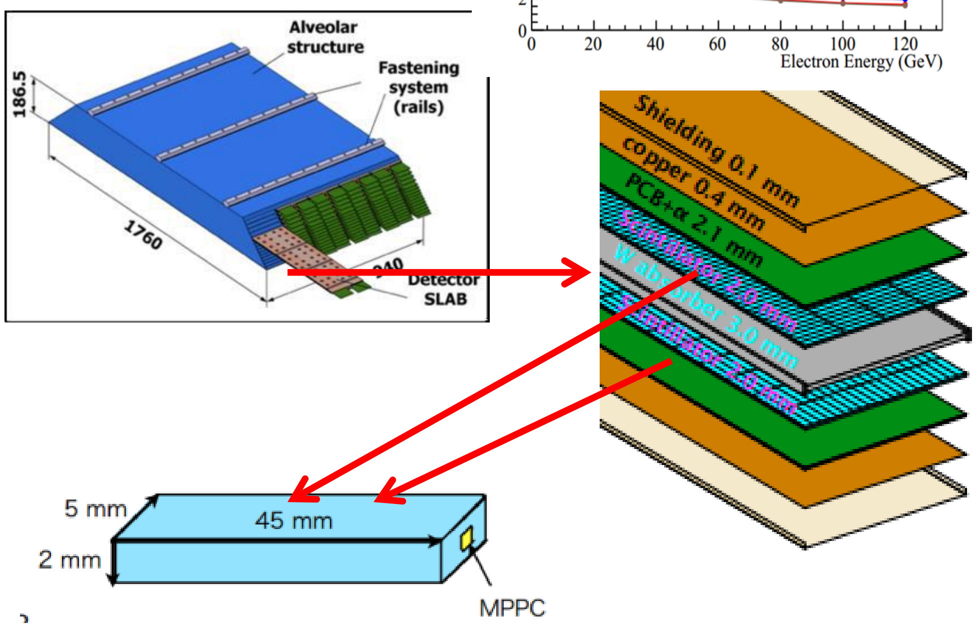
- Jet energy (Higgs self-coupling, W/Z separation)
  - ~1/2 resolution (wrt LHC)

$$\sigma_E / E = 0.3 / \sqrt{E(GeV)}$$

less demanding at CEPC





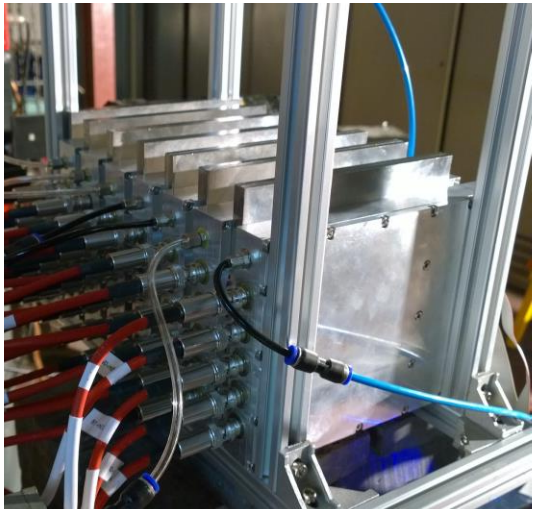


ECAL: Scintillator + W + Scintillator

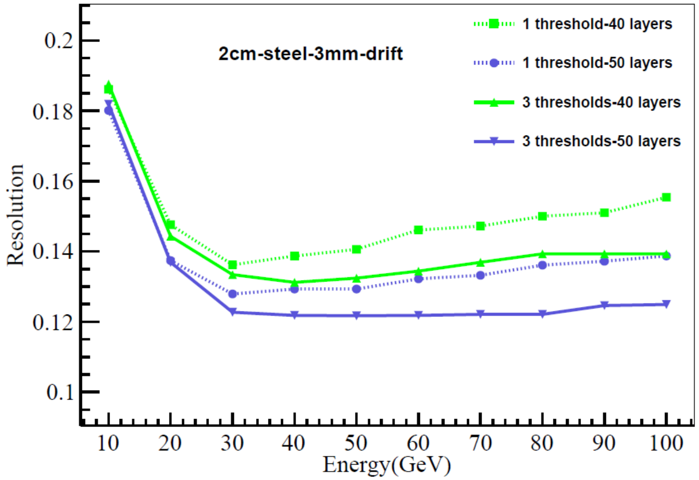
CEPC Hadron Calorimeter

➔ **Concept of Particle Flow Algorithm (PFA) based calorimeters with very fine granularity, compare to ILC, it's less demanding at CEPC.**

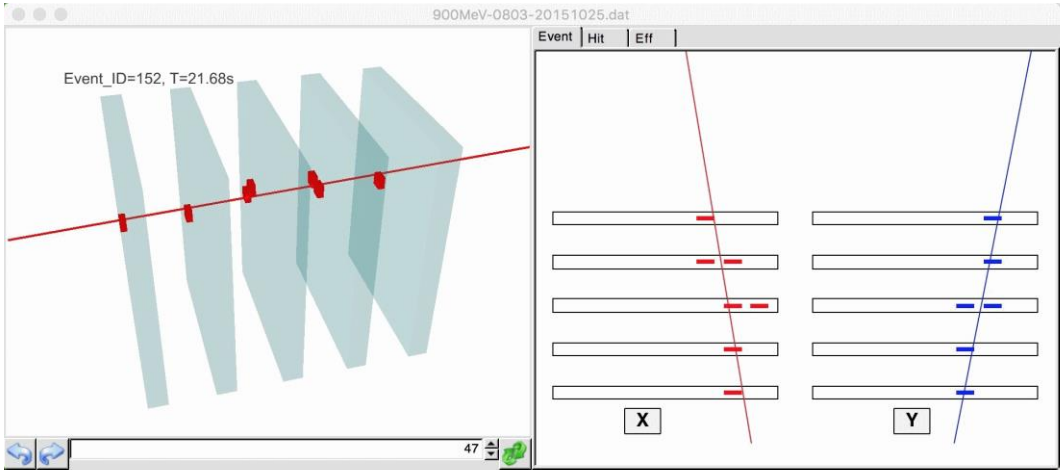
➔ **DHCAL based on gaseous detector (eg. RPC, THGEM).**



- The HCAL consists of a cylindrical barrel system and two endcaps with self-support & negligible dead zone
- Absorber: Stainless steel
- Active sensor: large area RPC or (Thick) GEM
- Digital readout with cell size: 1×1 cm^2

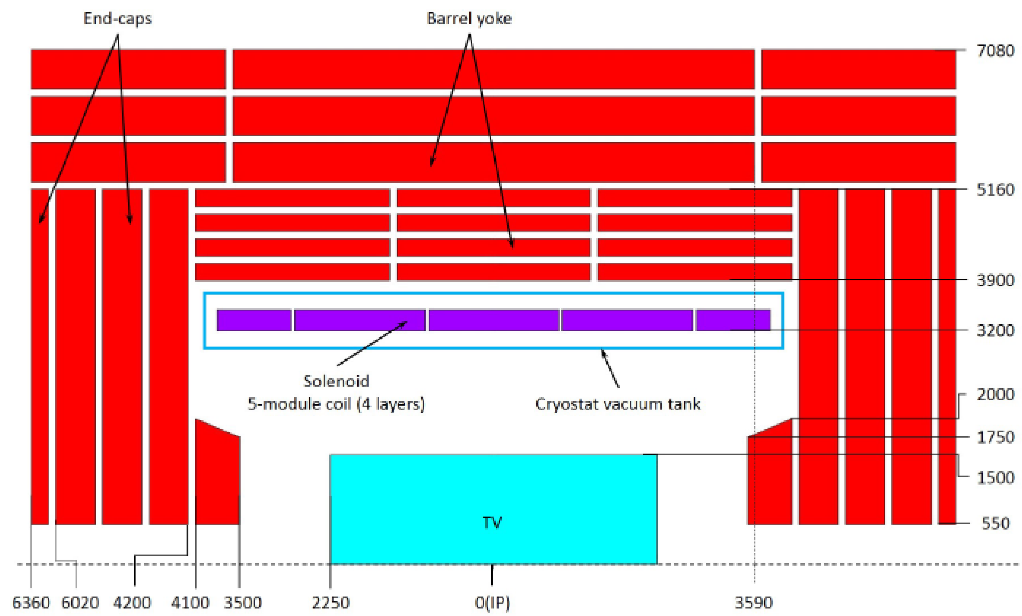


Test beam of THGEM at IHEP, Beijing in Oct. 2015

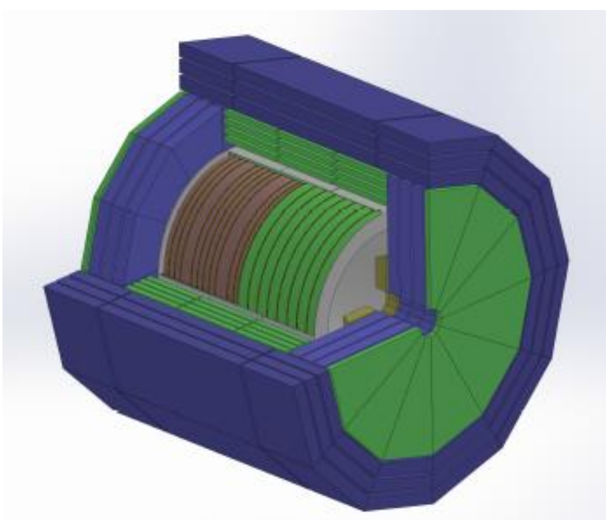


CEPC Magnet

Based on CEPC detector, a **3.5T** central field of superconducting solenoid (similar to CMS design) is required in a warm aperture diameter of 6m and length of 8.05m.



Schematic view of the CEPC detector magnet cross section (Half of the magnet section)



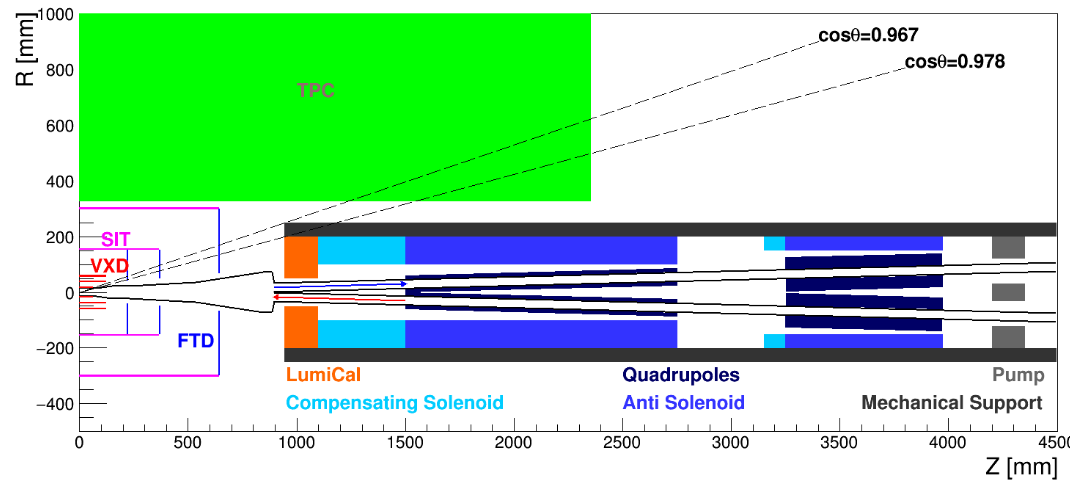
Cryostat inner radius(mm)	3400	Barrel yoke outer radius(mm)	7240
Cryostat outer radius(mm)	4250	Yoke overall length(mm)	13966
Cryostat length(mm)	8050	Barrel weight(t)	5775
Cold mass weight(t)	165	End cap weight(t)	6425
Barrel yoke inner radius(mm)	4400	Total yoke weight(t)	12200

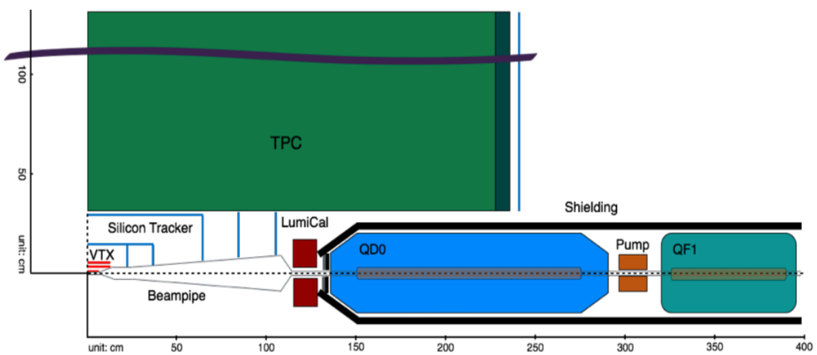
The solenoid central field(T)	3.5	Nominal current(KA)	18.575
Maximum field on conductor(T)	3.85	Total ampere-turns of solenoid(MAt)	23.925
Coil inner radius(mm)	3600	Inductance(H)	10.4
Coil outer radius(mm)	3900	Stored energy(GJ)	1.8
Coil length(mm)	7600	Stored energy per unit of cold mass(KJ/kg)	10.91

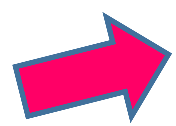
MDI layout and issues : single → local double ring

- Beam background
- Shielding design
- Collimator design
- SC magnet design
- Beam pipe
- Solenoid compensation
- Lumical & fast lumi measurement & feedback

……..



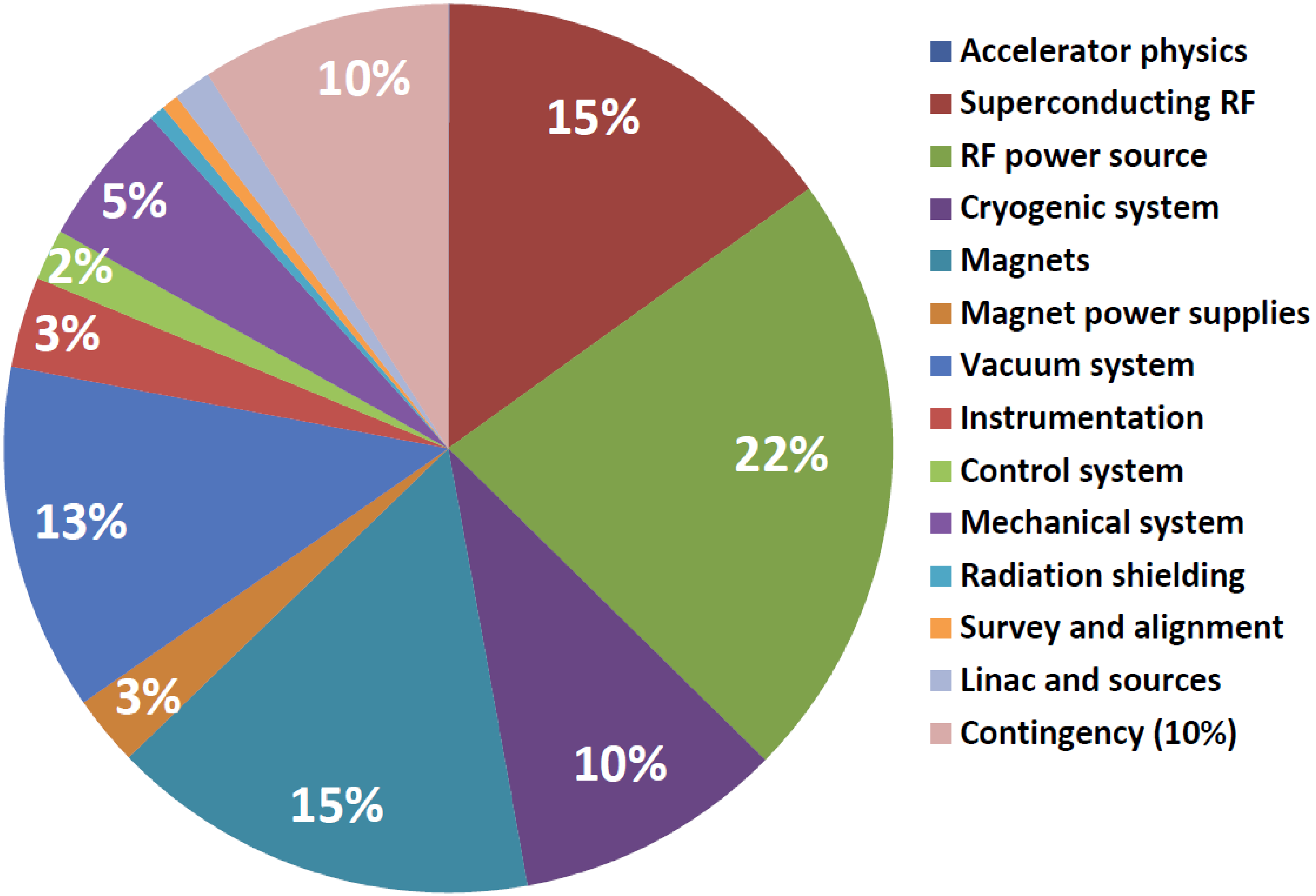




Partial double ring MDI

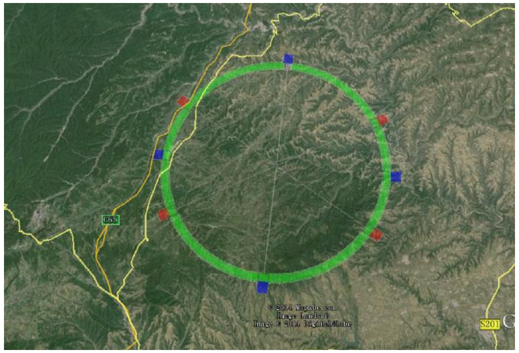
Single ring MDI

CEPC Relative Cost Estimate (single ring scheme)



Site selections (some main places)

1)



2)

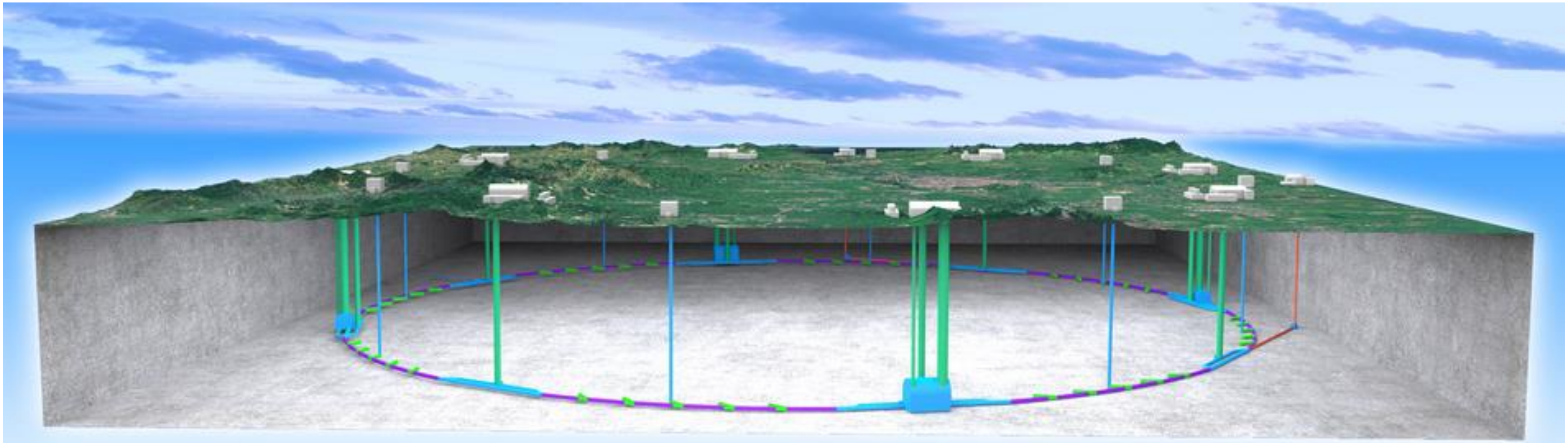
3)

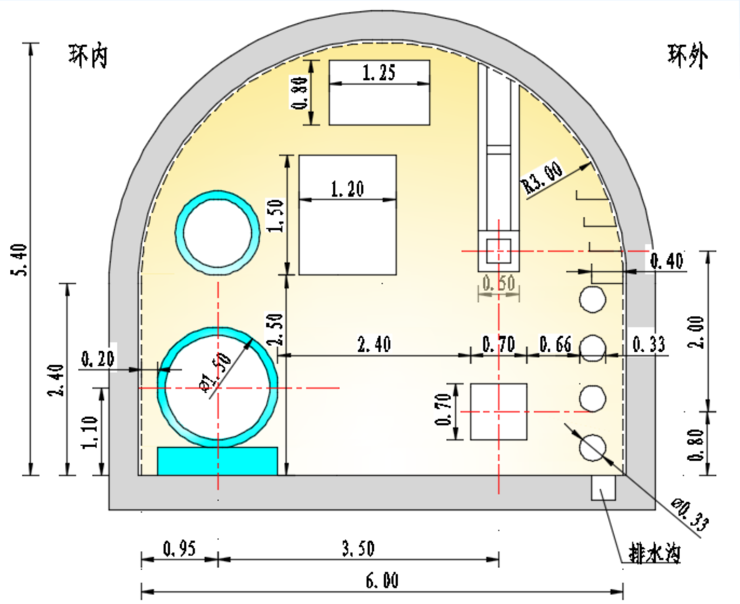
1) Qinhuangdao

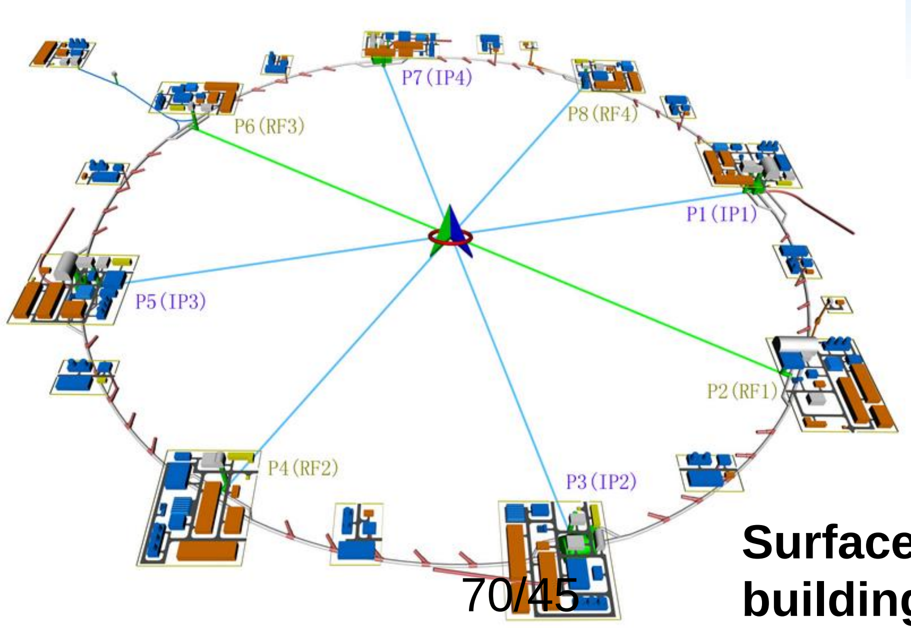
2) Shanxi Province

3) Near Shenzhen and Hongkong

Civil Construction







Surface buildings

International Collaboration

- Limited international participation for the pre-CDR
  - An excise for us
  - Build confidence for the Chinese HEP community

- International collaboration is needed not only because we need technical help
  - A way to integrate China better to the international community
  - A way to modernize China's research system("open door" policy)

- A new scheme of international collaboration to be explored

- An international advisory board has been formed to discuss in particular this issue, together with others

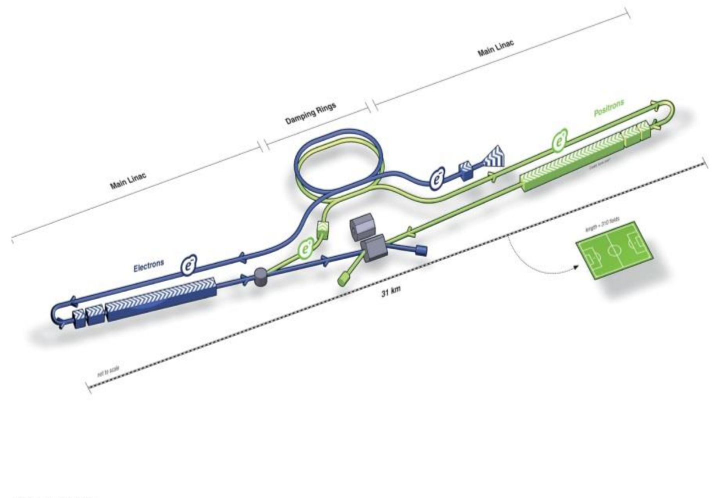
- A number of MoUs have been signed between IHEP and relevant labs, such BINP and VINCA

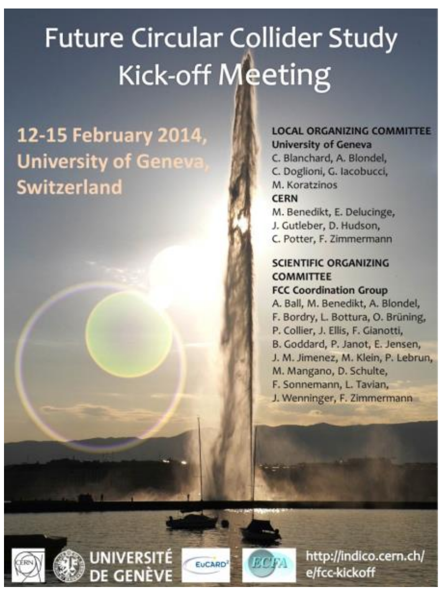
CEPC-LCC-FCC in Synergy

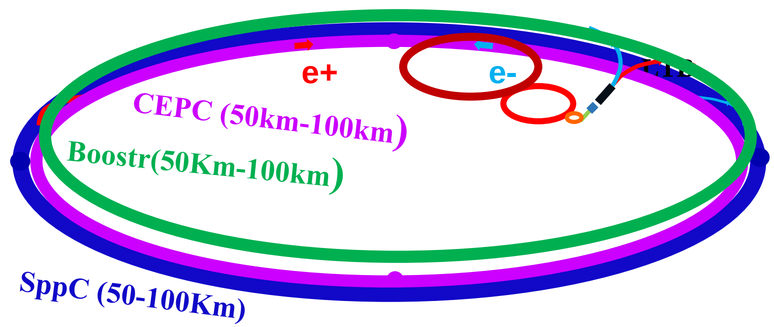
1） Linear colliders： ILC-CLIC
from Higgs energy to 5TeV

2） Circular Colliders： CEPC-SppC e+e- Higgs factory-pp collider at 50~100TeV

3) FCC kick-off meting in Feb., 2014







CEPC – Web :Documentation and Meeting Annoucement

http://cepc.ihep.ac.cn/

CEPC-SppC Study Group Meeting in September 2-3, 2016, Beijing

http://indico.ihep.ac.cn/event/6149/

Concluding remarks

- CEPC shaping well towards CDR with reuiqred physcis goals and with different schemes
- Fund from MOST succeded in June 2016
- Design and key technologies' R&D progress well
- International collaboration has started and will continue to develop towards full scale, which is necessary and important
- Synergies of CEPC/SppC with LCC(ILC, CLIC) and FCC(e+e-,pp) are very important for the community
- **Young generations are the key forces to realize the goals**
- The started CEPC/SppC will continue to progress , and be realized in the future

Thank you for your attention

Thanks go to CEPC-SppC Collaboration colleagues
and international collaborators