Circular Electron Positron Collider

CEPC-SppC Accelerator CDR Status and Perspective

J. Gao

Institute of High Energy Physics

CAS, Beijing

The 1st workshop on applications of high energy Circular Electron-Positron Collider（CEPC） synchrotron radiation source

December 6, 2017, IHEP, Beijing

Contents

- CEPC CDR physics and accelerator design goals
- CEPC CDR baseline and alternative options
- CEPC CDR baseline design progress status
- CEPC CDR accelerator hardwares and R&D progresses
- SppC status and high field magnet R&D
- CEPC-SppC site selection and implementation
- CEPC-SppC international and industrial collaborations
- Conclusions

Historical recall: from AdA to LEPII

Accelerators driven by physics motivation (e+e- collision)

60's

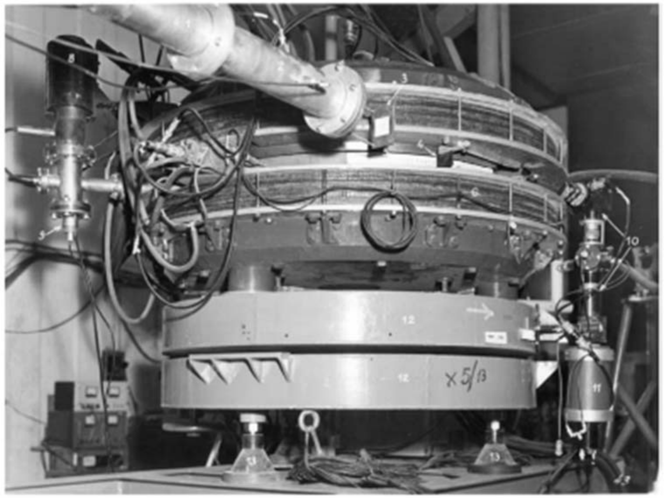


图 1　在 1964 年拍摄的 AdA 照片[5]

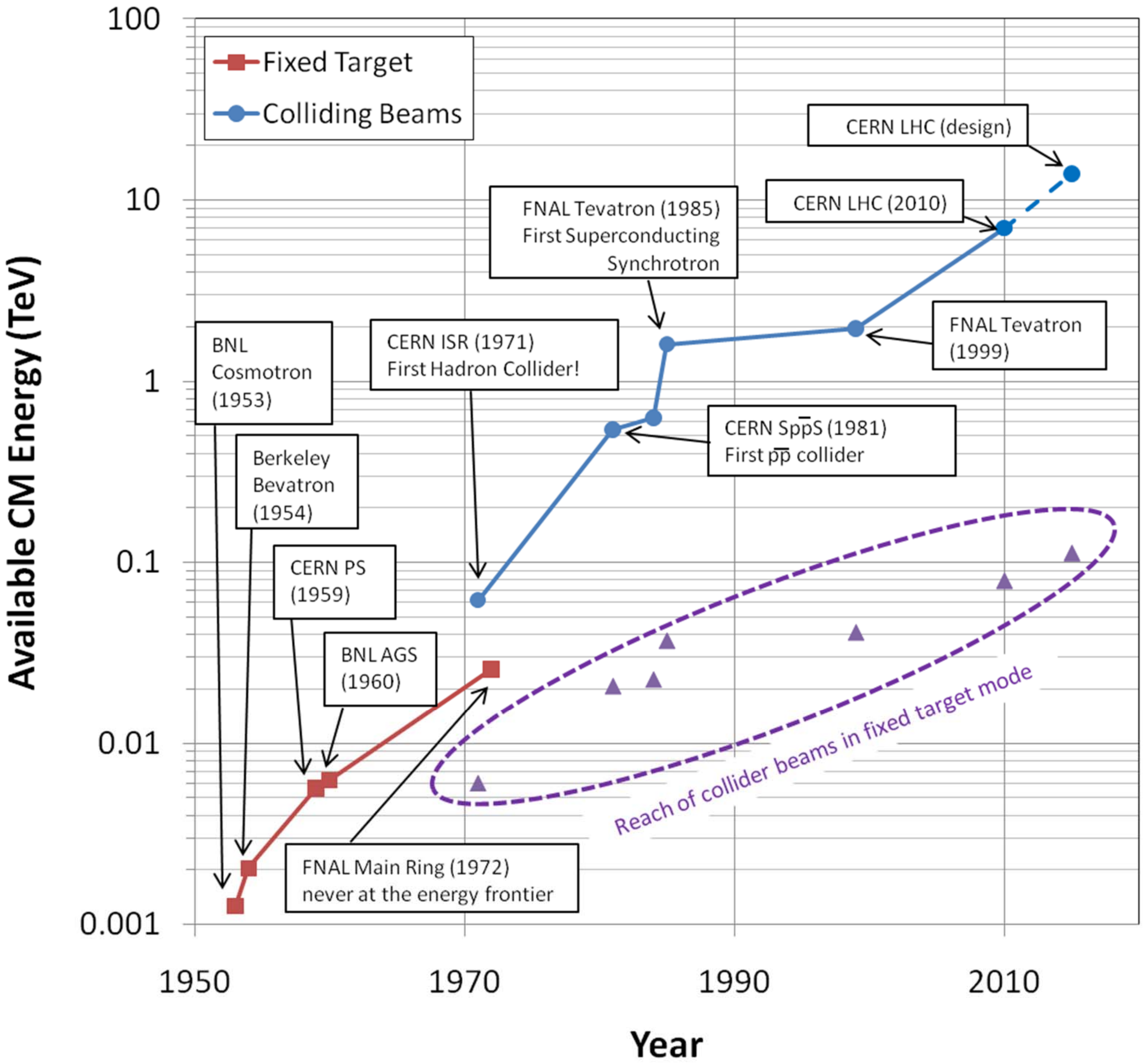
Figure 1　Photo of AdA in 1964[5]

LEPat CERN

90's

AdA e+e- storage ring collider in operation at LAL, Orsay, France

Evolution of the Energy Frontier (hadron)



~a factor of 10
every 15 years

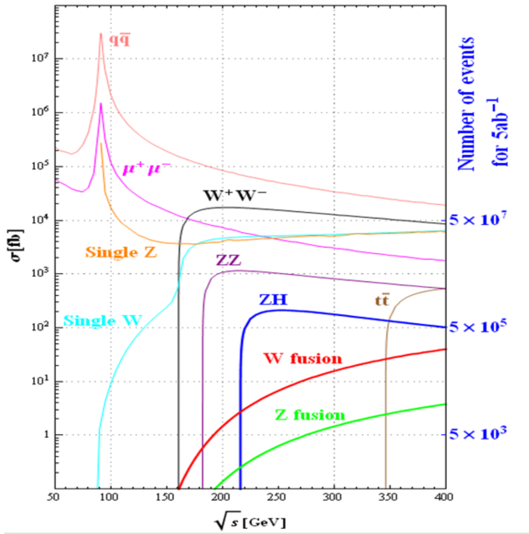
Physics Goals of CEPC-SppC

- **Electron-positron collider (90, 160，250, 350 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

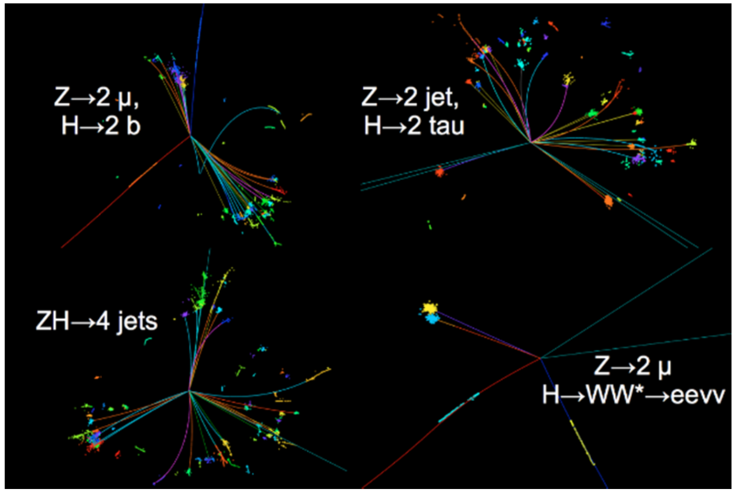
Precision measurement + searches:

Complementary with each other !

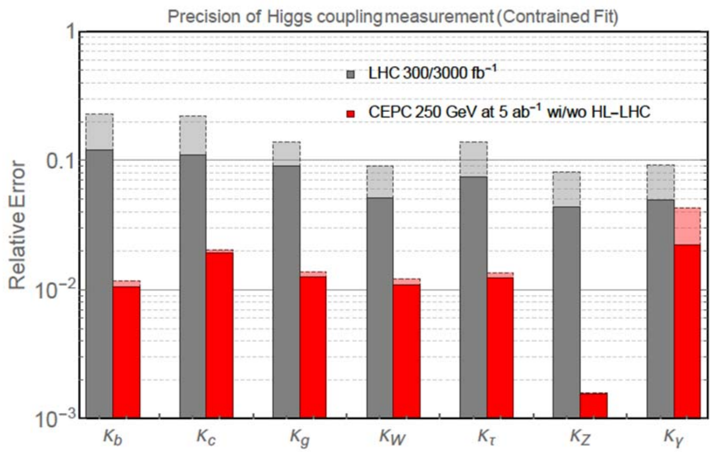
CEPC physics potentials



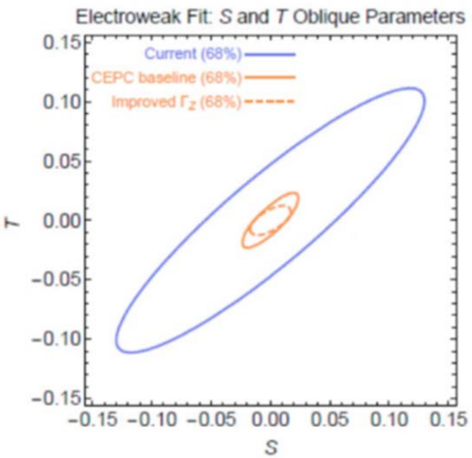
Cross sections for Major SM physics processes at the electron positron collider (without beam polarization)



Simulated Higgs signal with different decay final states at 250 GeV center of mass electron positron collisions, using PFA oriented detector design



Anticipated accuracy on Higgs properties at CEPC and at LHC/HL-LHC



Anticipated electro-weak precision of the CEPC and comparison to current accuracy

CEPC Design –Higgs Parameters

Parameter	Design Goal
Particles	e+, e-
Center of mass energy	2*120 GeV
Luminosity (peak)	>2*10^34/cm^2s
No. of IPs	2

CEPC Design – Z-pole Parameters

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

CEPC-SPPC Timeline (preliminary and ideal)

CEPC

2015 | 2020 | 2025 | 2030 | 2035

Pre-studies
(2013-2015)

R&D
Engineering Design
(2016-2022)

Construction
(2022-2028)

Data taking
(2028-2038)

1st Milestone: Pre-CDR (by the end of 2014) ;2nd Milestone: R&D funding from MOST (in Mid 2016);
3rd Milestone: CEPC CDR Status Report (by the end of 2016); 4th Milestone: CEPC CDR Report (by the end of 2017);5th Milestone: CEPC TDR Report and Proto R&D (by the end of 2020);6th Milestone: CEPC construction start (2022);

SPPC

2020 | 2030 | 2040

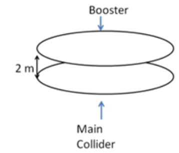
R&D and CDR
(2014-2030)

Engineering Design
(2030-2035)

Construction
(2038-2045)

Data taking
(2045-2060)

CEPC CDR Accelerator Chain



10 GeV

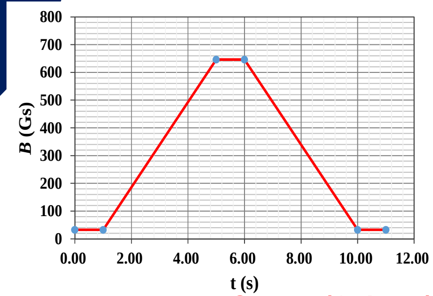
Injector

Electron

Positron

Booster

Energy Ramp
10 ->45/120GeV



Booster Cycle (0.1 Hz)

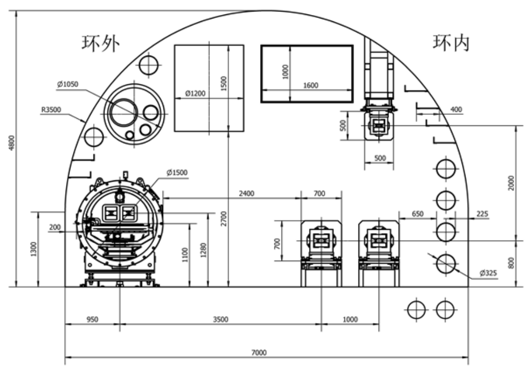
Three rings in the sane channel:
- CEPC & booster
- SppC

- Double Ring
- Common cavities for Higgs
- Two RF sections in total
- Two RF stations per RF section
- 14 modules per RF station
- 28 modules per RF section
- 56 modules in total
- Six 2-cell cavities per module
- One klystron for two cavities

Main Ring

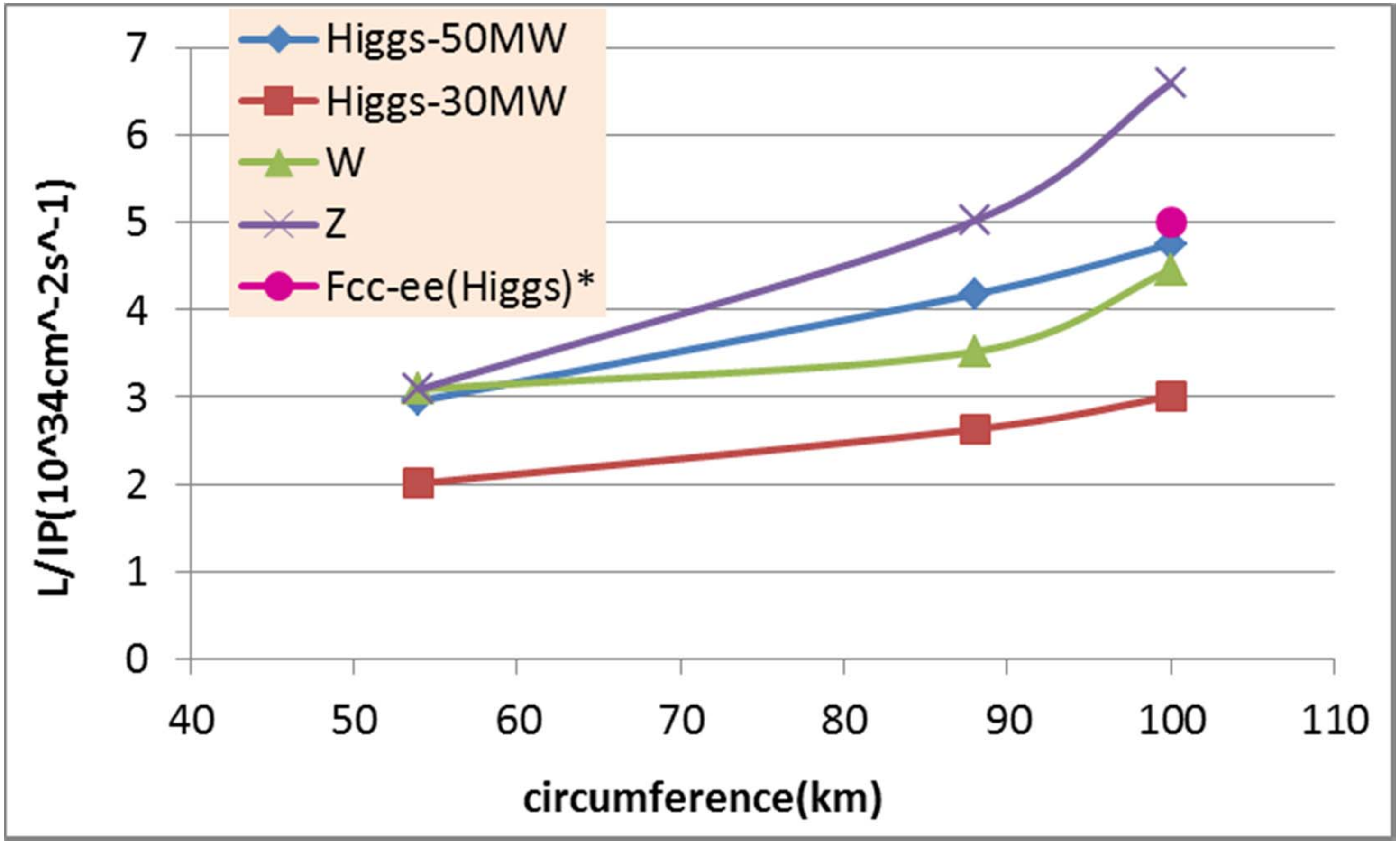
45/120 GeV

C=100km



CEPC Luminosity vs Circumference

CEPC 100km decied in Nov. 2016

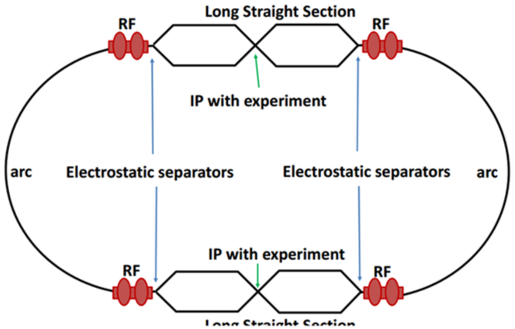


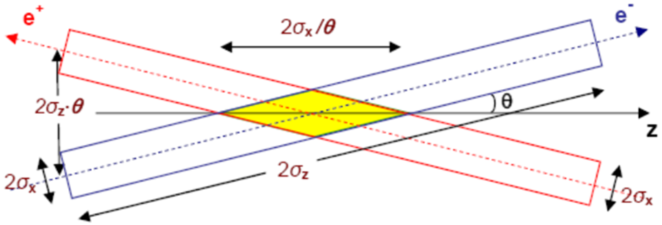
* Fabiola Gianotti, Future Circular ColliderDesign Study, ICFA meeting, J-PARC, 25-2-2016.

Parameters for CEPC double ring (HL)

Dec 2016， beta_y=1mm

	H-high lumi.	*H-low power*		*W*	*Z*	
Number of IPs	2	2	2	2	2	2
Energy (GeV)	120	120	120	80	45.5	45.5
Circumference (km)	100	100	100	100	100	100
SR loss/turn (GeV)	1.67	1.67	1.67	0.33	0.034	0.034
Half crossing angle (mrad)	15	15	15	15	15	15
Piwinski angle	2.5	2.5	2.5	3.57	5.69	5.69
N_e/bunch (10^{11})	1.12	1.12	1.12	1.05	0.46	0.46
Bunch number	555	333	211	1000	16666	65716
Beam current (mA)	29.97	17.98	11.4	50.6	367.7	1449.7
SR power /beam (MW)	**50**	**30**	**19**	16.7	12.7	50
Bending radius (km)	11	11	11	11	11	11
Momentum compaction (10^{-5})	0.96	0.96	0.96	3.1	3.3	3.3
β_{IP} x/y (m)	0.3/0.001	0.3/0.001	0.3 /0.001	0.1 /0.001	0.12/0.001	0.12/0.001
Emittance x/y (nm)	1.01/0.0031	1.01/0.0031	1.01/0.0031	2.68/0.008	0.93/0.0049	0.93/0.0049
Transverse σ_{IP} (um)	17.4/0.055	17.4/0.055	17.4/0.055	16.4/0.09	10.5/0.07	10.5/0.07
ξ_x/ξ_y/IP	0.029/0.083	0.029/0.083	0.029/0.083	0.0082/0.055	0.0075/0.054	0.0075/0.054
RF Phase (degree)	123.3	123.3	123.3	149	160.8	160.8
V_{RF} (GV)	**2.0**	**2.0**	**2.0**	**0.63**	**0.11**	**0.11**
f_{RF} (MHz) (harmonic)	650	650	650	650 (217800)	650 (217800)	
Nature σ_z (mm)	**2.72**	**2.72**	**2.72**	**3.8**	**3.93**	**3.93**
Total σ_z (mm)	2.9	2.9	2.9	3.9	4.0	4.0
HOM power/cavity (kw)	0.75(2cell)	0.45(2cell)	0.28(2cell)	1.0 (2cell)	3.2(2cell)	12.5(2cell)
Energy spread (%)	0.098	0.098	0.098	0.065	0.037	0.037
Energy acceptance (%)	1.5	1.5	1.5			
Energy acceptance by RF (%)	1.8	1.8	1.8	1.5	1.1	1.1
n_γ	0.26	0.26	0.26	0.26	0.18	0.18
Life time due to beamstrahlung_cal (minute)	52	52	52			
F (hour glass)	0.83	0.83	0.83	0.84	0.91	0.91
L_{max}/IP (10^{34}cm^{-2}s^{-1})	5.42	3.25	2.06	4.08	18.0	70.97





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.

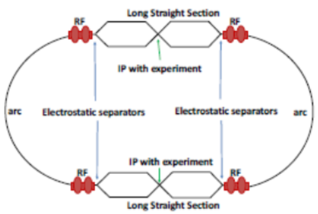


Figure 1: Schematic of the 'bowtie' idea (not to scale)

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

IHEP-AC-LC-Note2013-012

ILC-物理-2013-08

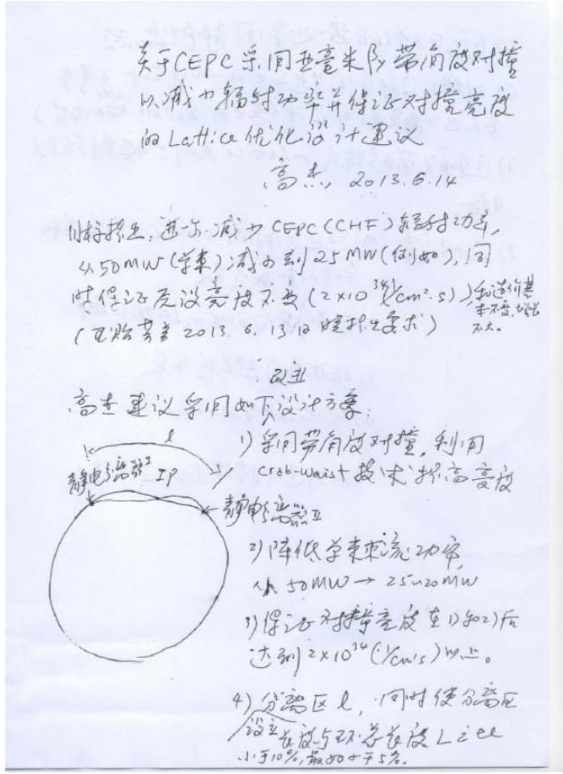
June 16th, 2013

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

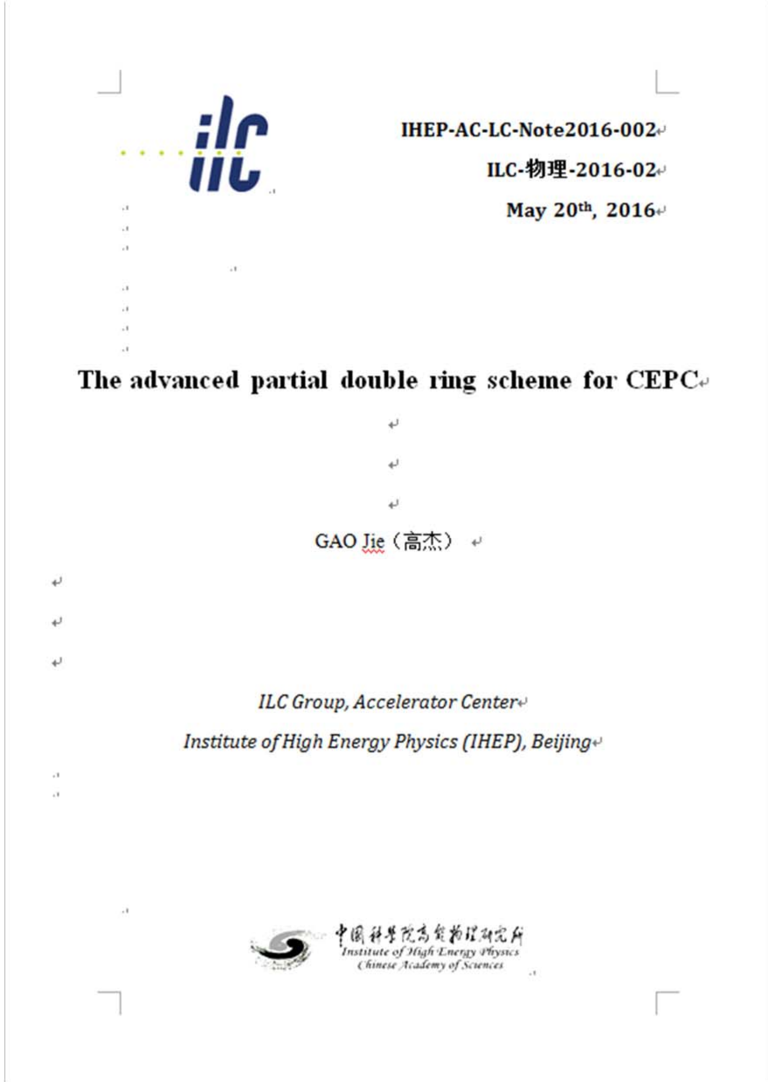


Partial Double Ring (DPR) was proposed independently at IHEP and CERN：

1）J. Gao, IHEP-AC-LC-Note 2013-012

2）M. Moratzinos and F. Zimmermann，2015 (IPAC 2015 M. Moratzinos and F. Zimmermann)

New idea： Advanced PDR （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）

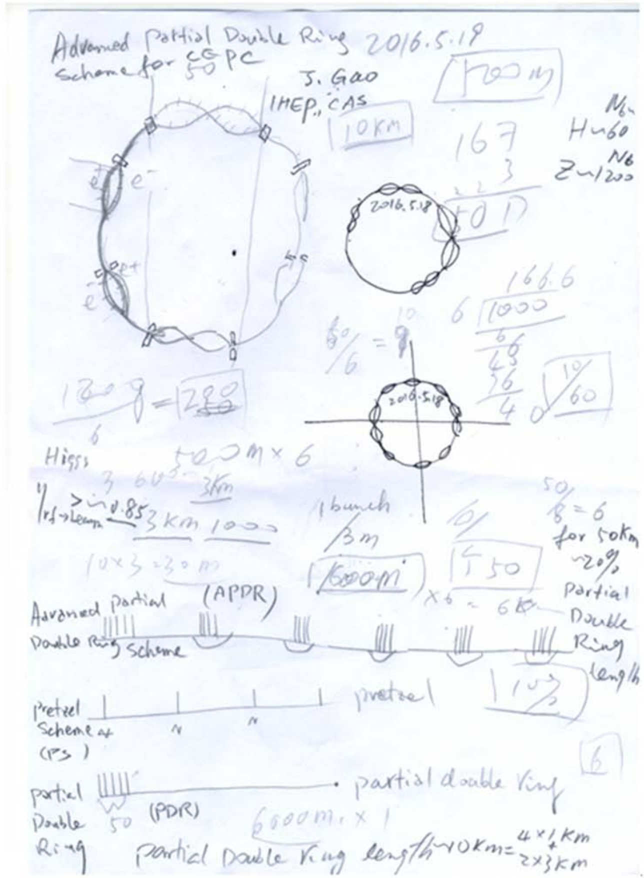
ILC Group, Accelerator Center

Institute of High Energy Physics (IHEP), Beijing

中国科学院高能物理研究所

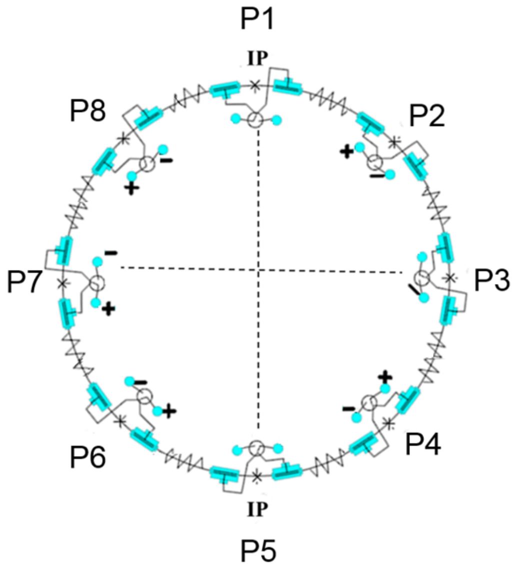
Institute of High Energy Physics

Chinese Academy of Sciences

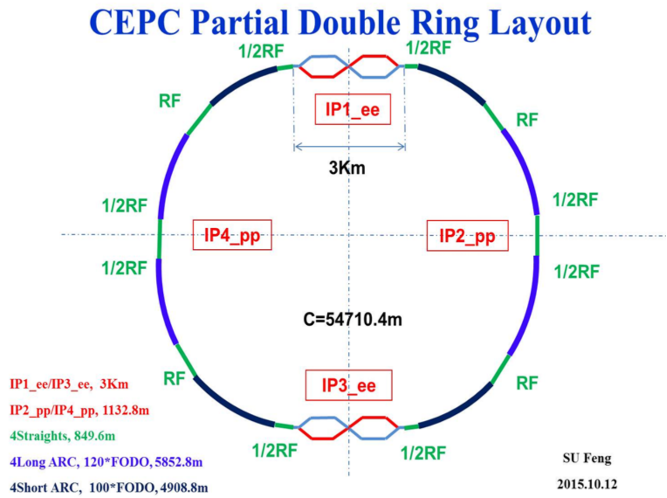


To solve the problem of the beam loading effect in RF system

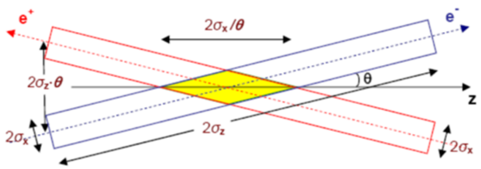
CEPC four options towards CDR



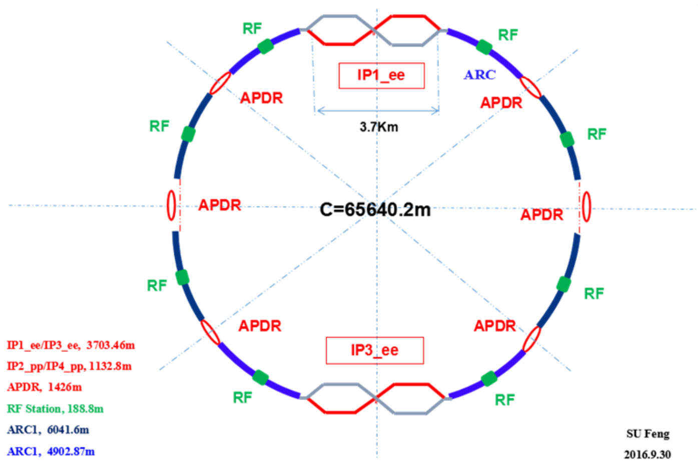
Since Oct 2012



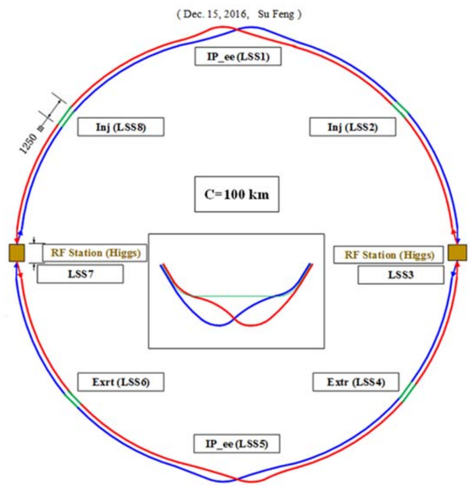
Since May 2015



CEPC Advanced Partial Double Ring Option II

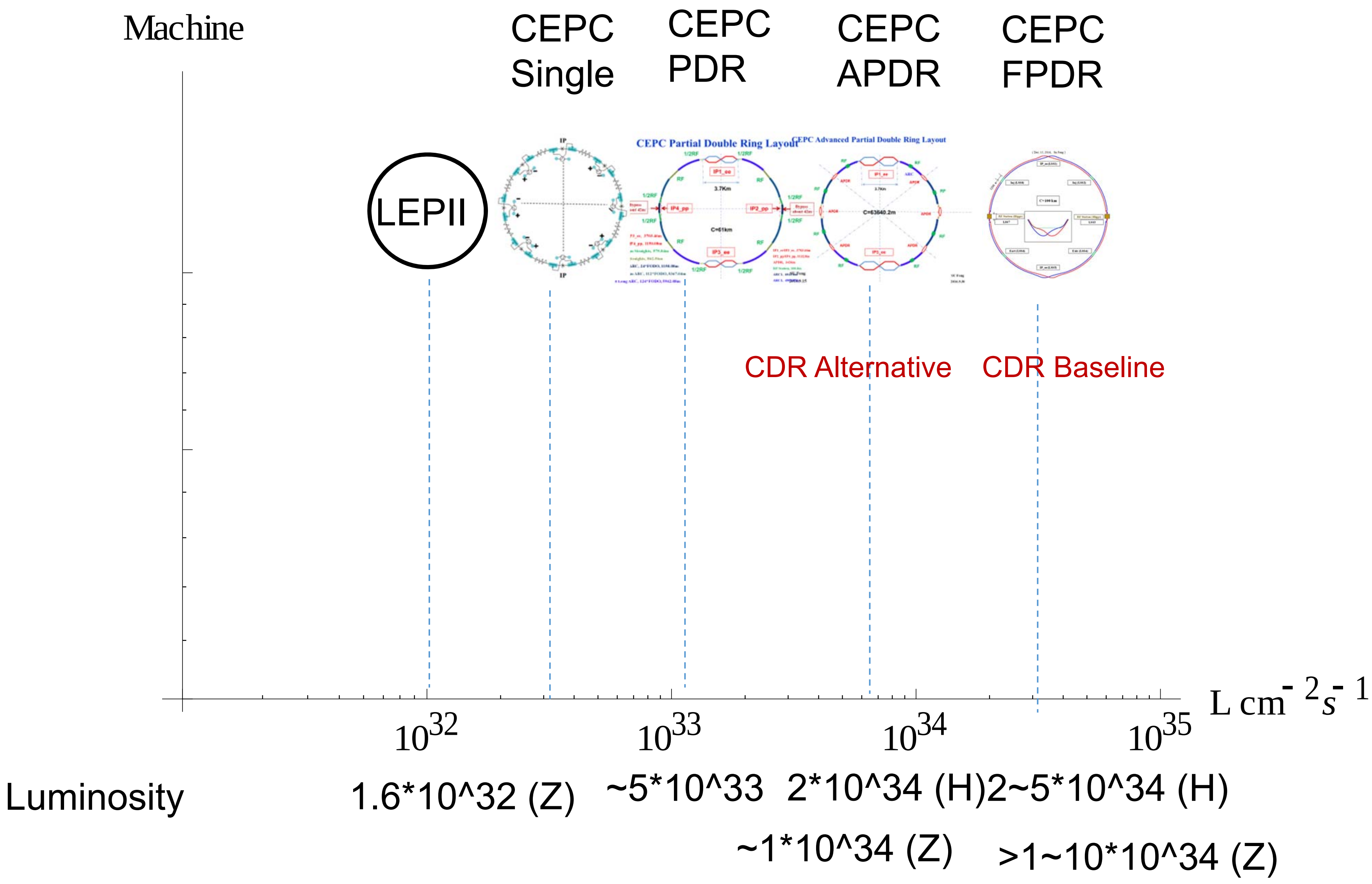


Since May 2016

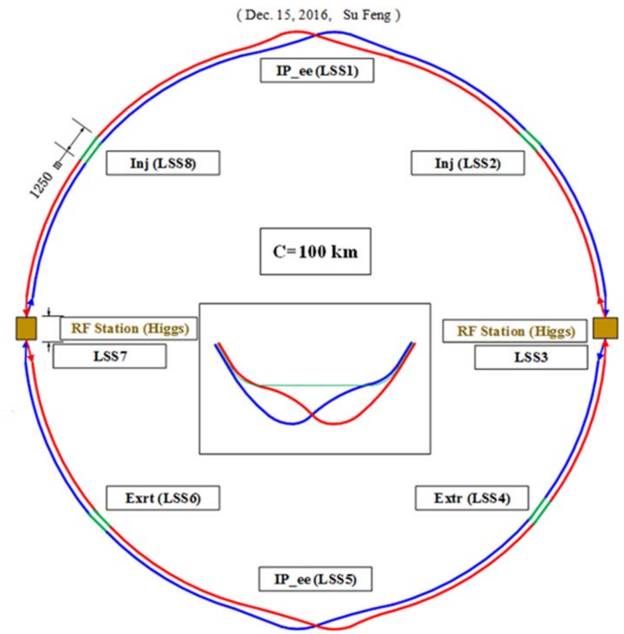


Since Nov 2016

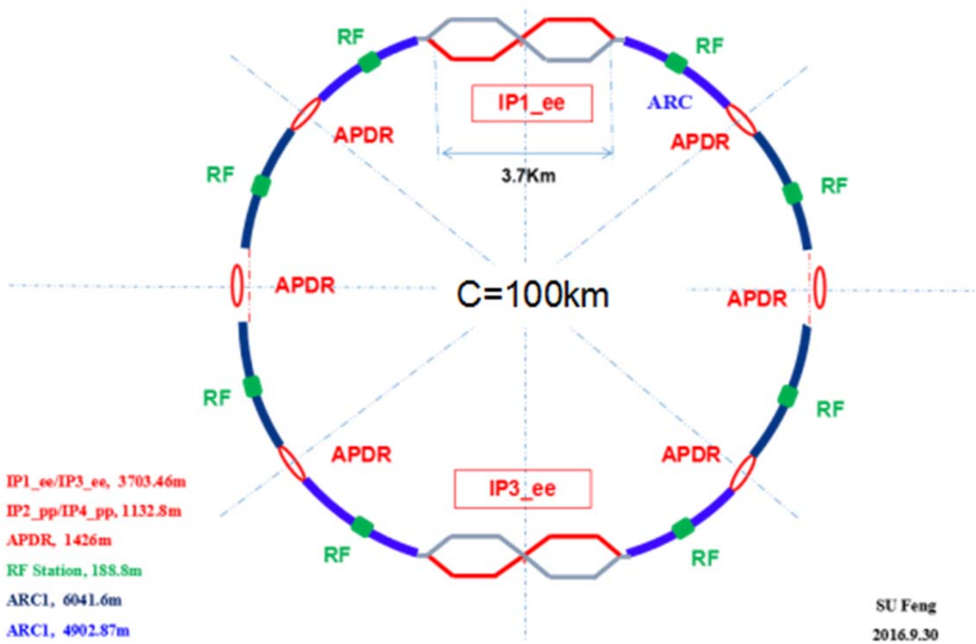
Machine Option Luminosity Potentials



CEPC towards CDR



CEPC Advanced Partial Double Ring Option II



CEPC Baseline Design

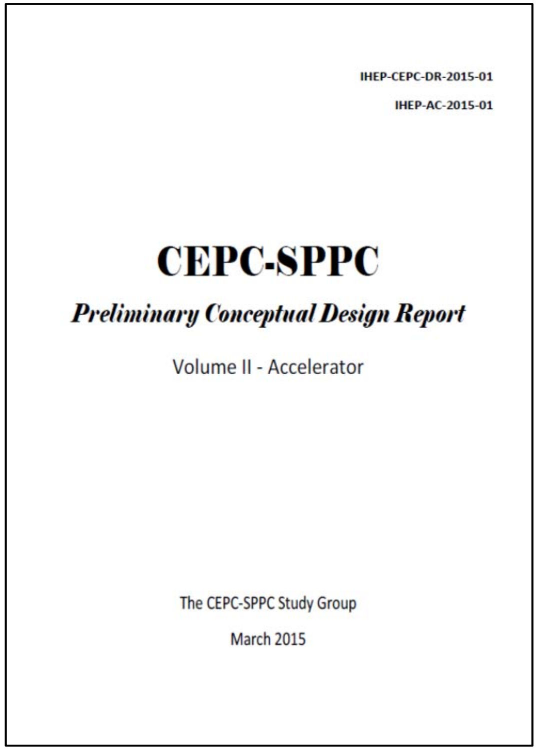
Better performance for Higgs and Z compared with alternative scheme, without bottle neck problems, but with higher cost

CEPC Alternative Design

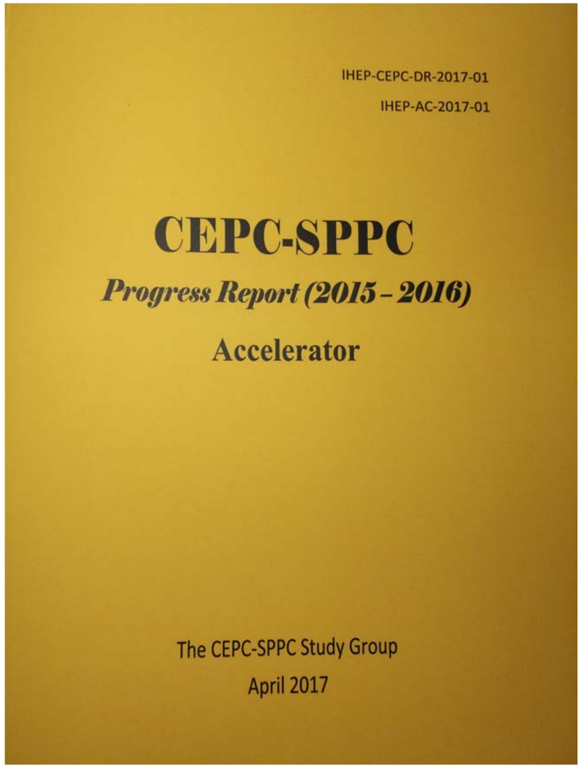
Lower cost and reaching the fundamental requirement for Higgs and Z luminosities, under the condition that sawtooth and beam loading effects be solved

CEPC-SppC from Pre-CDR towards CDR

http://cepc.ihep.ac.cn

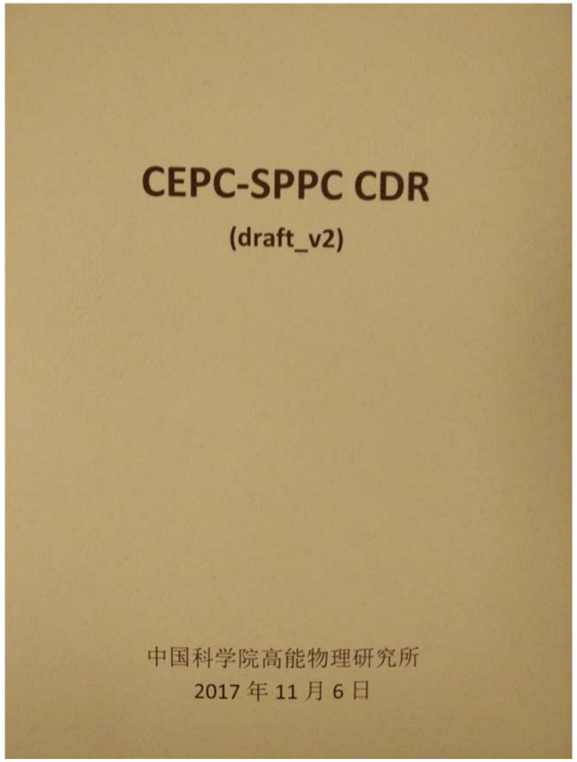


March 2015



April 2017

CEPCSppC baseline and alternative
decision processe recorded



Nov 2017
CEPC-SppC CDR
Preliminary Draft

CEPC CDR will be completed at the end of 2017

CEPC-SppC CDR Table of Contents

CEPC-SPPC CDR Table of Contents (v2, 10/19/2017)

CEPC-SPPC CDR Timeline

November 4-5, 2017	CDR mini-review
November 6-8, 2017	CEPC workshop
November 9-10, 2017	CEPC IAC meeting
December 2017	Complete draft of each chapter
January – February 2018	Editing, final draft, limited no. of printing
March 2018	CDR international review
March-April 2018	Final version, online, also mass printing
April 2018 CEPC workshop	Mass distribution of printed copies

CEPC CDR parameters (high lumi) （βy^*=1mm）

	tt	*Higgs*	*W*	*Z*
Number of IPs	2			
Energy (GeV)	175	120	80	45.5
Circumference (km)	100			
SR loss/turn (GeV)	7.61	1.68	0.33	0.035
Half crossing angle (mrad)	16.5			
Piwinski angle	1.05	2.82	4.39	14.2
N_e/bunch (10^{10})	24.15	15	3.6	4.8
Bunch number	34	248	5220	16666
Beam current (mA)	3.95	17.9	90.3	384.5
SR power /beam (MW)	**30**	**30**	**30**	13.4
Bending radius (km)	10.9			
Momentum compaction (10^{-5})	1.14			
β_{IP} x/y (m)	1.2/0.0037	0.36/0.001	0.36/0.002	
Emittance x/y (nm)	2.24/0.0045	1.21/0.0037	0.54/0.0018	0.17/0.0029
Transverse σ_{IP} (um)	51.8/0.13	20.9/0.061	13.9/0.060	7.91/0.076
ξ_x/ξ_y/IP	0.067/0.121	0.026/0.076	0.009/0.055	0.007/0.0565
V_{RF} (GV)	8.93	2.14	0.465	0.053
f_{RF} (MHz) (harmonic)	650 (217500)			
Nature bunch length σ_z (mm)	2.54	2.72	2.98	3.67
Bunch length σ_z (mm)	3.3	3.57	3.7	6.78
HOM power/cavity (kw)	0.49 (5cell)	0.53 (2cell)	0.32(2cell)	1.33(2cell)
Energy spread (%)	0.14	0.098	0.066	0.037
Energy acceptance requirement (%)	1.37	1.39		
Energy acceptance by RF (%)	2.67	2.06	1.48	0.75
Photon number due to beamstrahlung	0.19	0.29	0.11	0.25
Lifetime due to beamstrahlung (hour)	1.0	1.0		
Lifetime (hour)		0.33 (20 min)	3.5	7.4
F (hour glass)	0.89	0.81	0.96	0.986
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	**0.43**	**2.87**	**4.1**	**10.6**

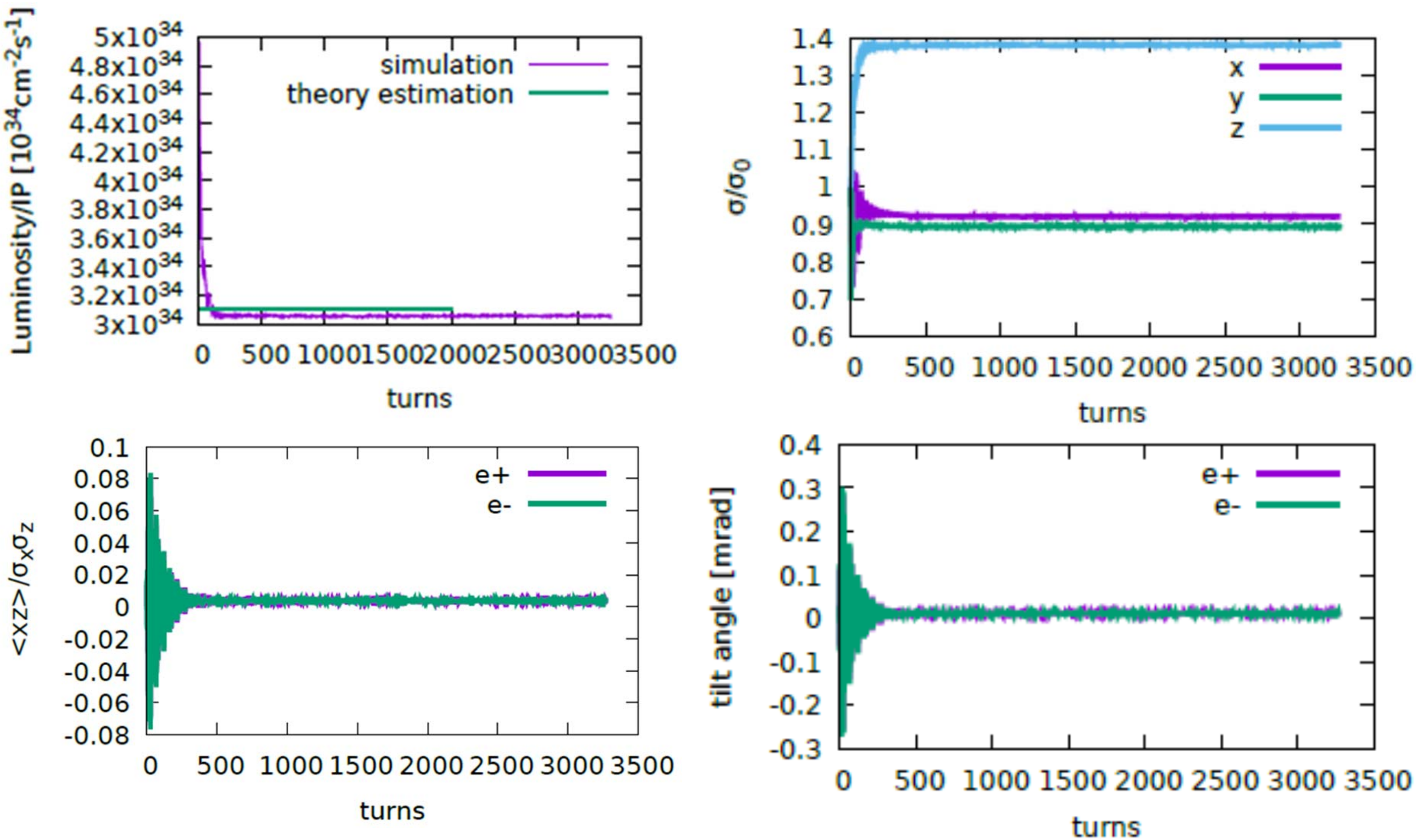
CEPC CDR Parameters

beta_y=2mm

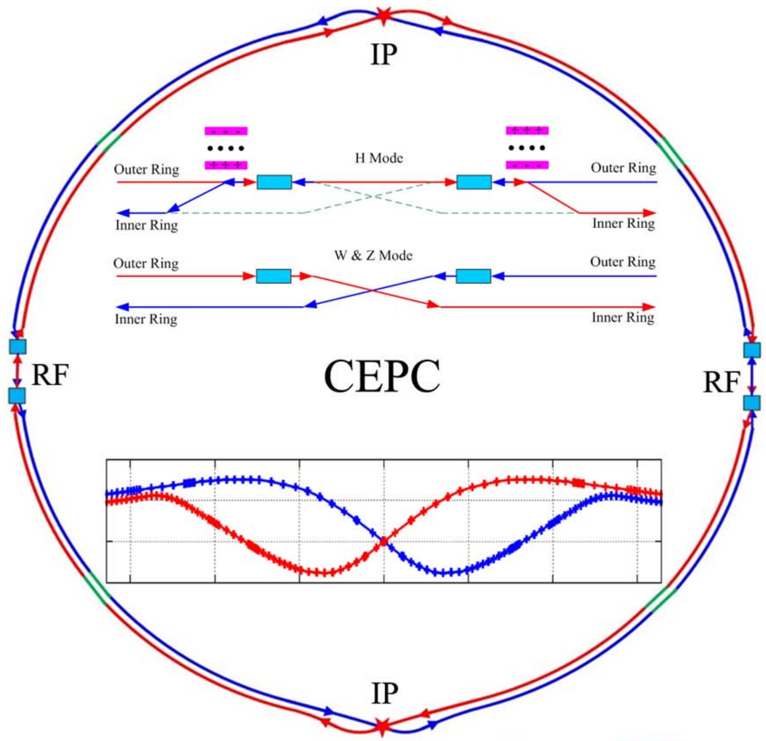
	Higgs	*W*	*Z*
Number of IPs	2		
Energy (GeV)	120	80	45.5
Circumference (km)	100		
SR loss/turn (GeV)	1.68	0.33	0.035
Half crossing angle (mrad)	16.5		
Piwinski angle	2.75	4.39	10.8
N_e/bunch (10^{10})	12.9	3.6	1.6
Bunch number	286	5220	10900
Beam current (mA)	17.7	90.3	83.8
SR power /beam (MW)	30	30	2.9
Bending radius (km)	10.9		
Momentum compaction (10^{-5})	1.14		
β_{IP} x/y (m)	0.36/0.002		
Emittance x/y (nm)	1.21/0.0036	0.54/0.0018	0.17/0.0029
Transverse σ_{IP} (um)	20.9/0.086	13.9/0.060	7.91/0.076
ξ_x/ξ_y/IP	0.024/0.094	0.009/0.055	0.005/0.0165
RF Phase (degree)	128	134.4	138.6
V_{RF} (GV)	2.14	0.465	0.053
f_{RF} (MHz) (harmonic)	650		
Nature bunch length σ_z (mm)	2.72	2.98	3.67
Bunch length σ_z (mm)	3.48	3.7	5.18
HOM power/cavity (kw)	0.46 (2cell)	0.32(2cell)	0.11(2cell)
Energy spread (%)	0.098	0.066	0.037
Energy acceptance requirement (%)	1.21		
Energy acceptance by RF (%)	2.06	1.48	0.75
Photon number due to beamstrahlung	0.25	0.11	0.08
Lifetime due to beamstrahlung (hour)	1.0		
F (hour glass)	0.93	0.96	0.986
L_{max}/IP (10^{34}cm^{-2}s^{-1})	2.0	4.1	1.0

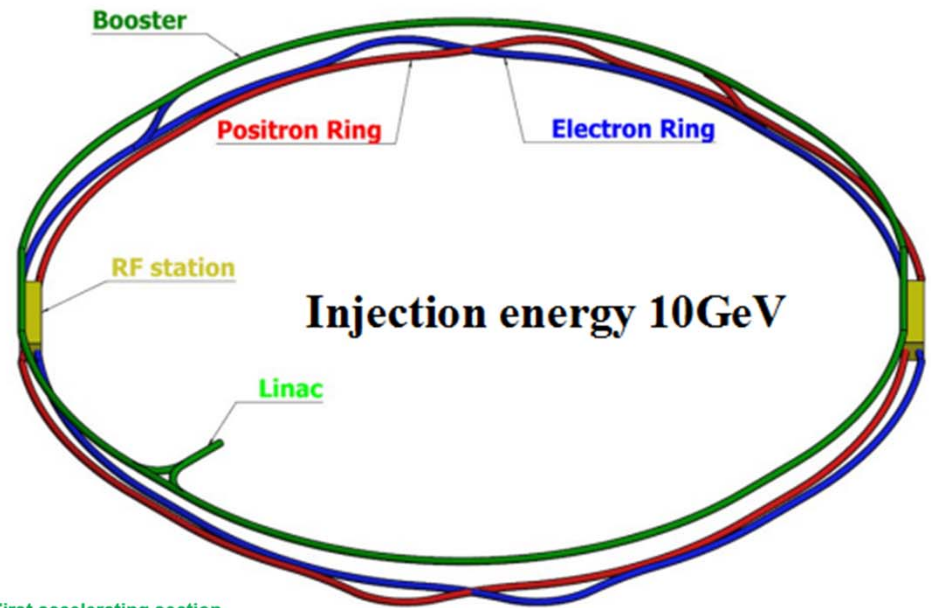
Beam-beam simulation-100km (H-HL)

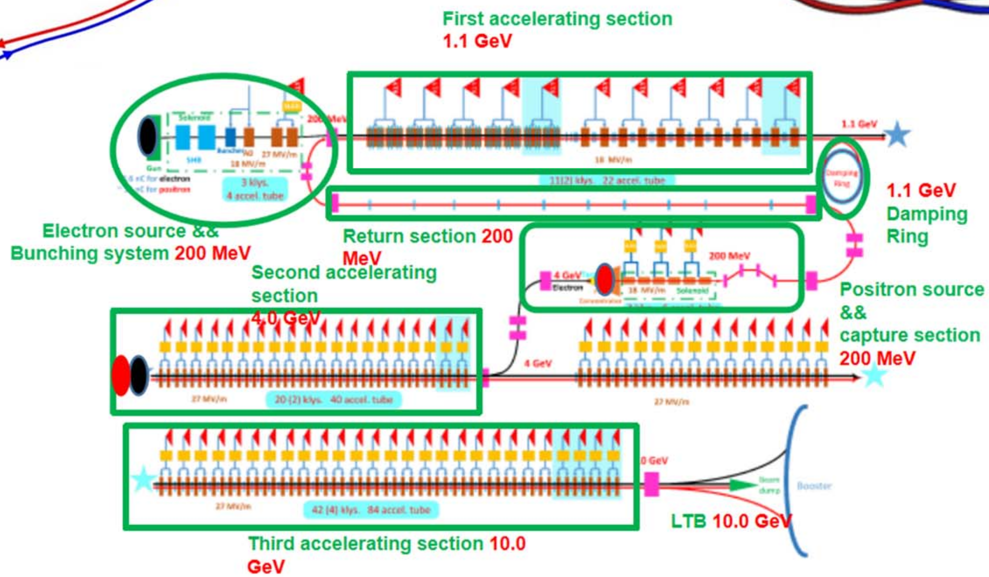
- 161202-100km-2mm-h-highlum, (0.51,0.55,0.037)



CEPC CDR Layout

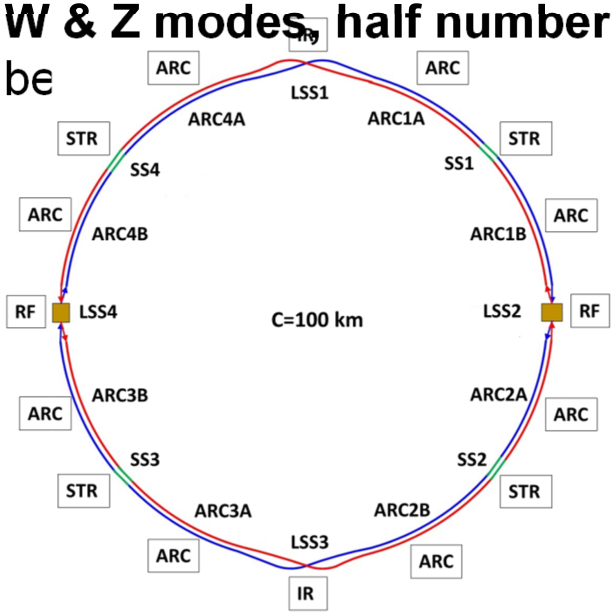


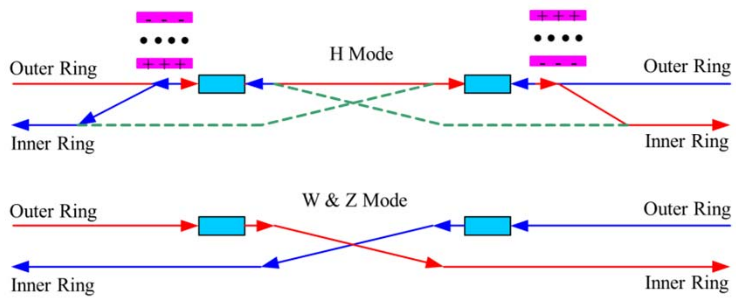




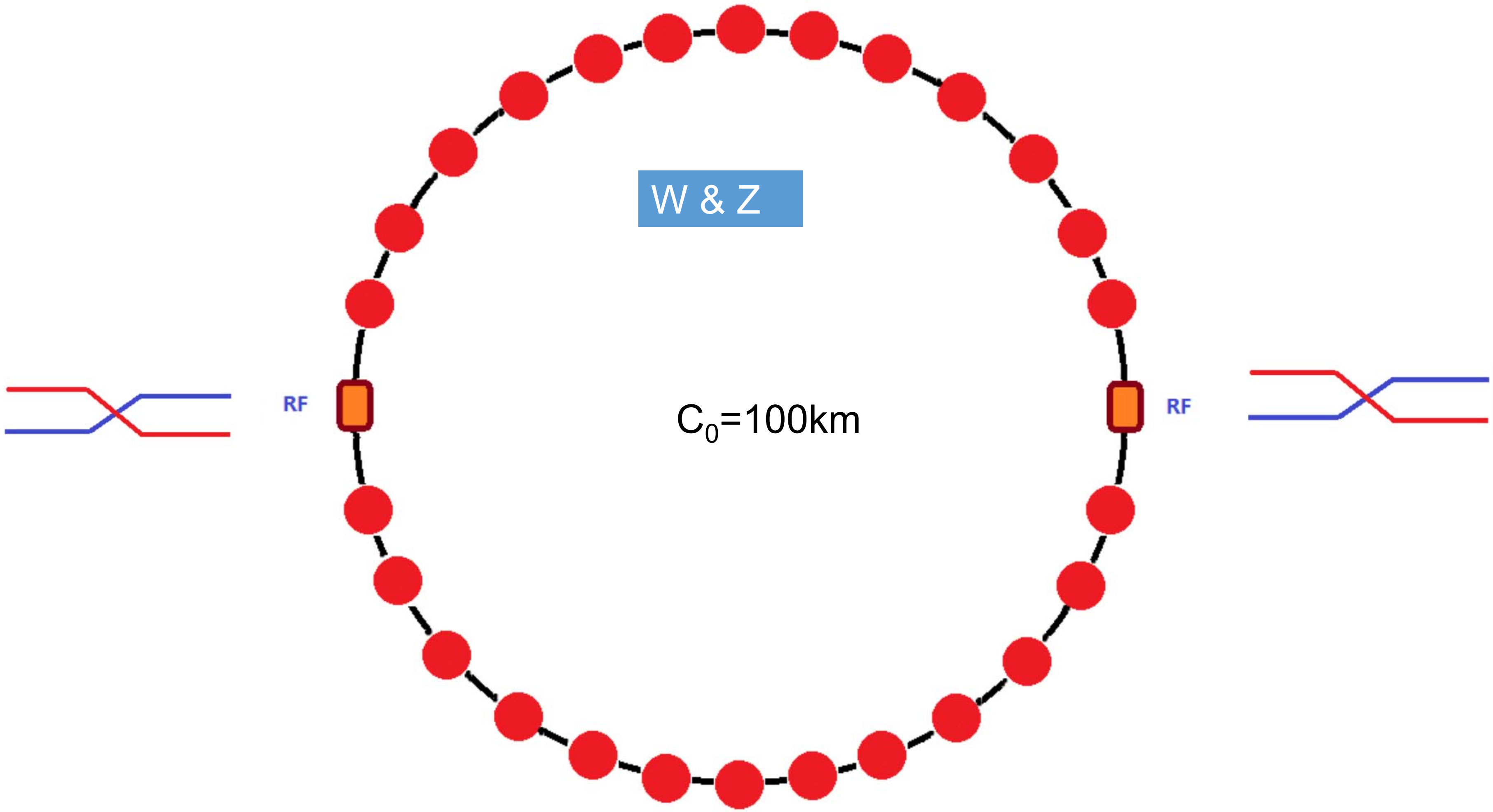
CEPC Collider Ring

- The circumference of CEPC collider ring is **100 km**.
- In the RF region, the **RF cavities are shared by two ring for H mode**.
- **Twin-aperture of dipoles and quadrupoles is adopt in the arc region** to reduce the their power. The distance between two beams is 0.35m.
- Compatible optics for H, W and Z modes
  - For the **W and Z mode**, the optics except RF region is got by **scaling down the magnet strength with energy**.
  - For H mode, all the cavities will be used and bunches will be filled in half ring.
  - **For W & Z modes, half number of cavities will be used** and bunches can be

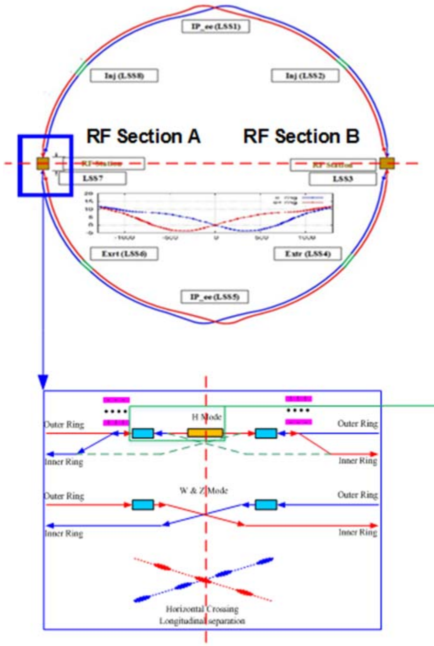




CEPC H, W and Z bunch distributions

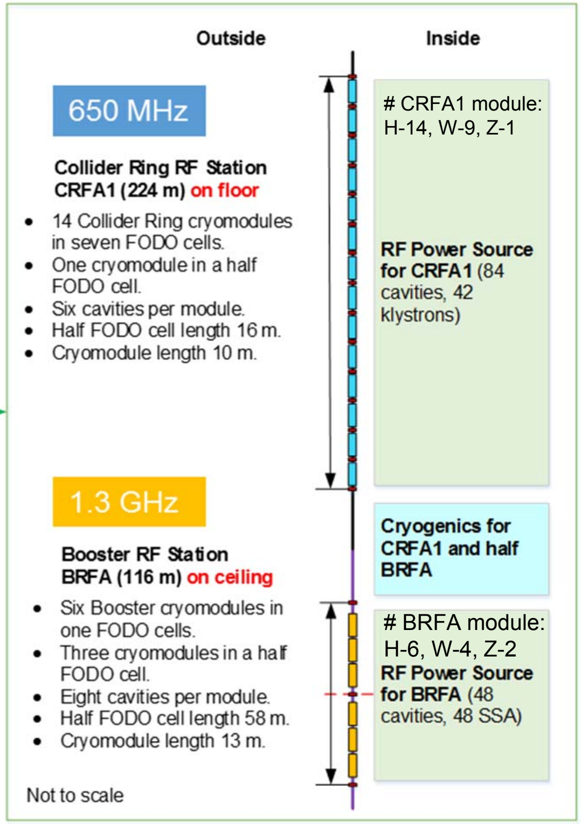


CEPC SRF System Layout



RF Section A

- Two Collider Ring RF Stations CRFA1 (84 cavities in 14 cryomodules) and CRFA2 (84 cavities in 14 cryomodules) (blue)
- One Booster RF Station BRFA (48 cavities in 6 cryomodules) (orange)
- Straight section length between CRFA1 and CRFA2: 368.6 m



	H	W	Z
Collider Ring	**650 MHz 2-cell cavity**		
Lumi. / IP (10^{34} $cm^{-2}s^{-1}$)	2	4	1
RF voltage (GV)	2.14	0.465	0.053
Beam current (mA)	17.7 x 2	90.2	83.7
Cavity number	336	108 x 2	12 x 2
SR power (MW)	30	30	2.9
2 K cavity wall loss (kW)	6.4	1	0.1
Booster Ring (extraction)	**1.3 GHz 9-cell cavity**		
RF voltage (GV)	1.83	0.7	0.36
Beam current (mA)	0.53	0.53	0.51
Cavity number	96	64	32
RF input power (MW) avg.	0.1	0.02	0.01
2 K wall loss (kW) avg.	0.2	0.1	0.03

- Same cavities for H, W, Z and one-time full installation
- Common collider cavities for H, independent for W & Z

CEPC Collider Ring SRF Parameters

	H	W	Z
SR power / beam [MW]	30	30	2.9
RF voltage [GV]	2.14	0.465	0.053
Beam current / beam [mA]	17.7	90.2	83.7
Bunch charge [nC]	20.6	5.8	2.6
Bunch length [mm]	3.5	3.7	5.2
Cavity number in use / beam (650 MHz 2-cell)	**336**	216	**24**
Gradient [MV/m] (with margin for HV-H & RF trip)	**13.8**	9.4	9.6
Input power / cavity [kW] (with margin for HL-H)	179	**278**	242
Klystron power [kW] (2 cavities / klystron)	800	800	800
HOM power / cavity [kW]	**0.48**	0.33	0.11
Optimal Q_L	1.1E6	3.1E5	3.8E5
Optimal detuning [kHz]	0.24	1.0	**1.0**
Q_0 @ 2 K at operating gradient (long term)	**1E10**	1E10	1E10
Total cavity wall loss @ 4.5 K eq. [kW]	22.7	6.7	0.8

Optimized for the Higgs mode of 30 MW SR power per beam, with enough operating margin and flexibility.

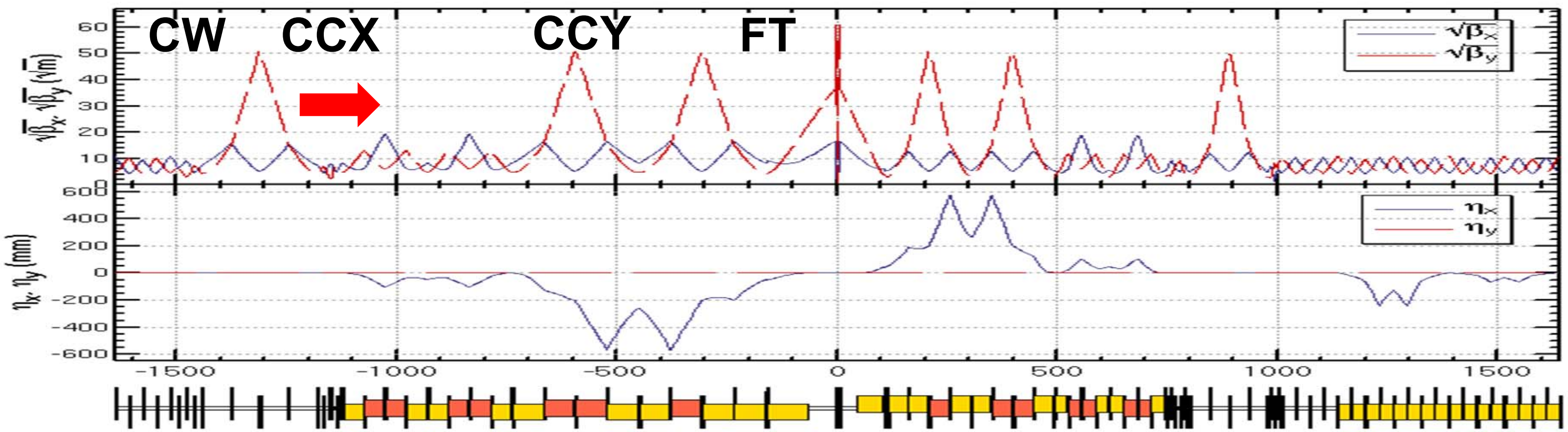
cavity determined by coupler power capacity, less is better for W and Z to reduce the detuning. 2-cell is a balance of gradient, beam loading and HOM power and damping.

Input coupler power limit 300 kW, variable, low heat load, be short to reduce cryomodule diameter.

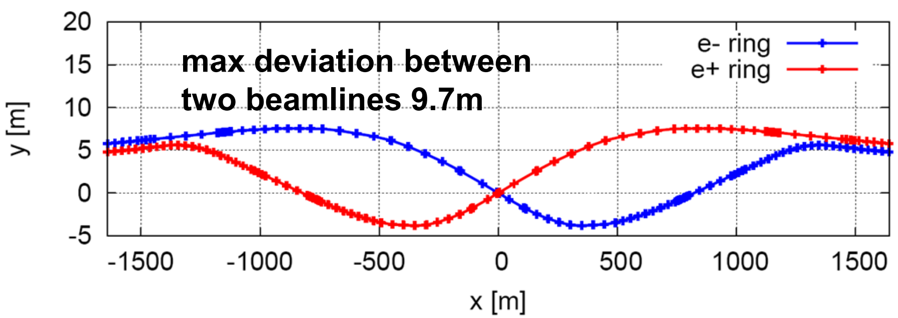
Cavity acceptance Q_0 > 4E10 (N-doping), module horizontal test > 2E10 (clean assembly and magnetic hygiene)

Linear Optics of Interaction Region

- Provide local chromaticity correction of both plane
- **L*=2.2m, θc=33mrad, GQD0=151T/m, GQF1=102T/m**
- IP upstream of IR: **Ec < 100 keV within 400m, last bend Ec = 47 keV**
- IP downstream of IR: Ec < 300 keV within 250m, last bend Ec = 95 keV
- The vertical emittance growth due to solenoid coupling is less than 4%.
- Relaxed optics for injection can be re-matched easily as the **modular design**.

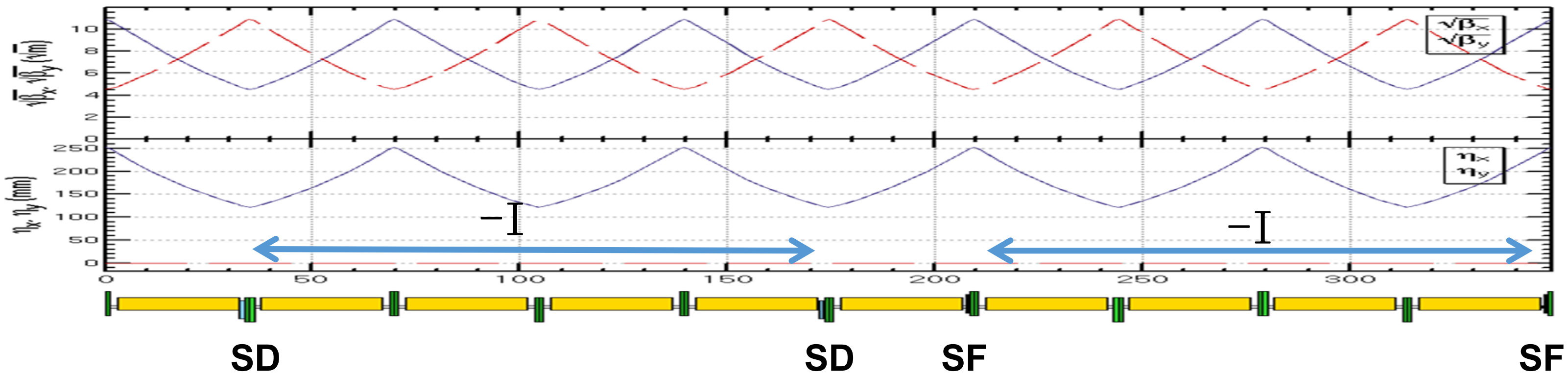


L*= 2.2m
βx*= 0.36mm
βy*= 2mm
GQD0≅-151T/m
GQF1≅102T/m
LQD0=1.73m
LQF1=1.48m

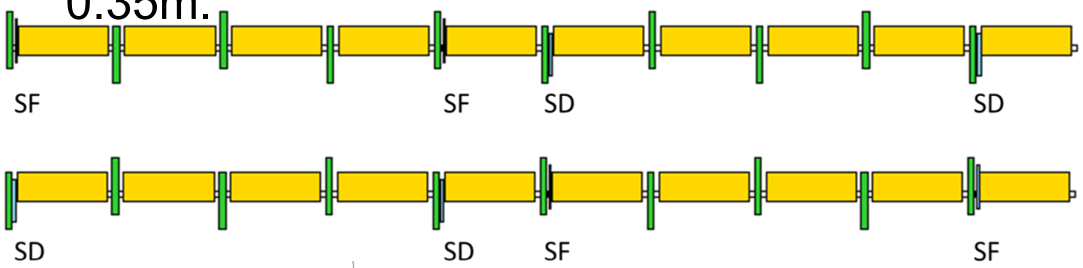


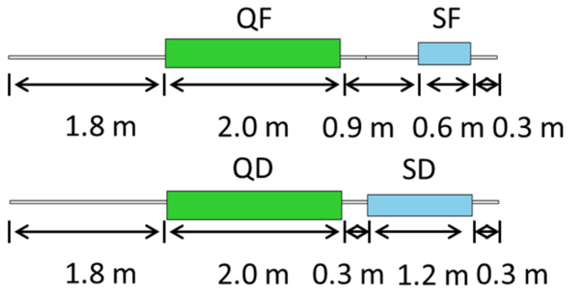
Linear Optics Design of ARC Region

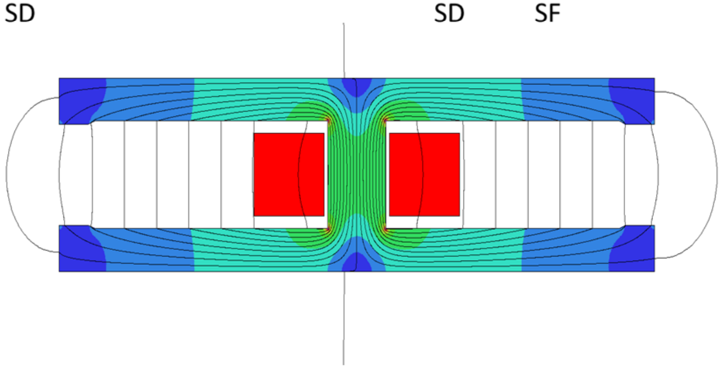
- **FODO cell, 90°/90°, non-interleaved sextupole scheme, period =5cells**

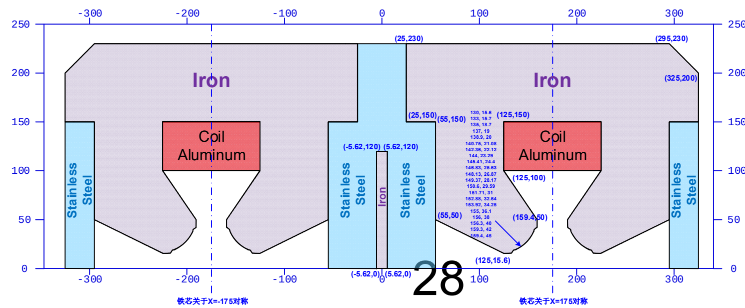


- **Twin-aperture of dipoles and quadrupoles is adopt in the arc region** to reduce the their power. The distance between two beams is 0.35m.



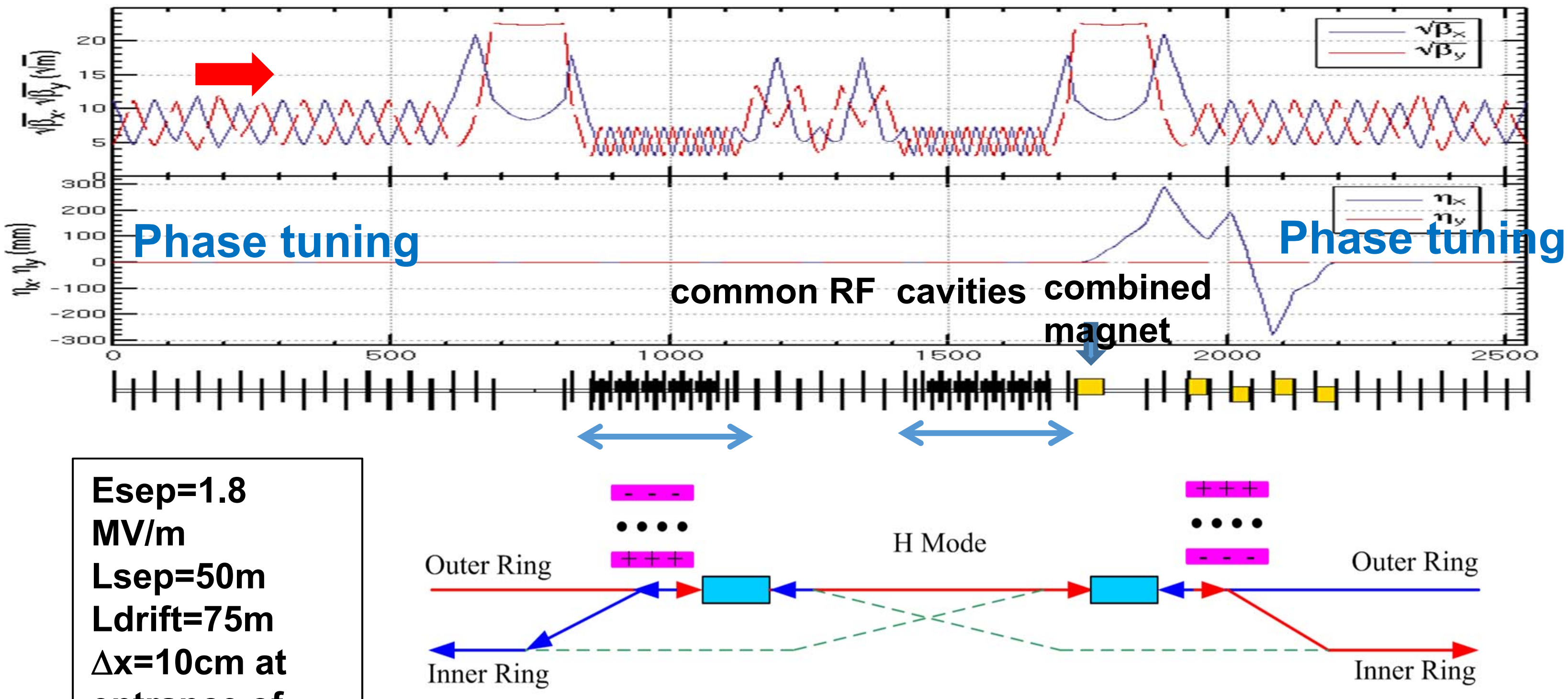






Optics Design of RF Region

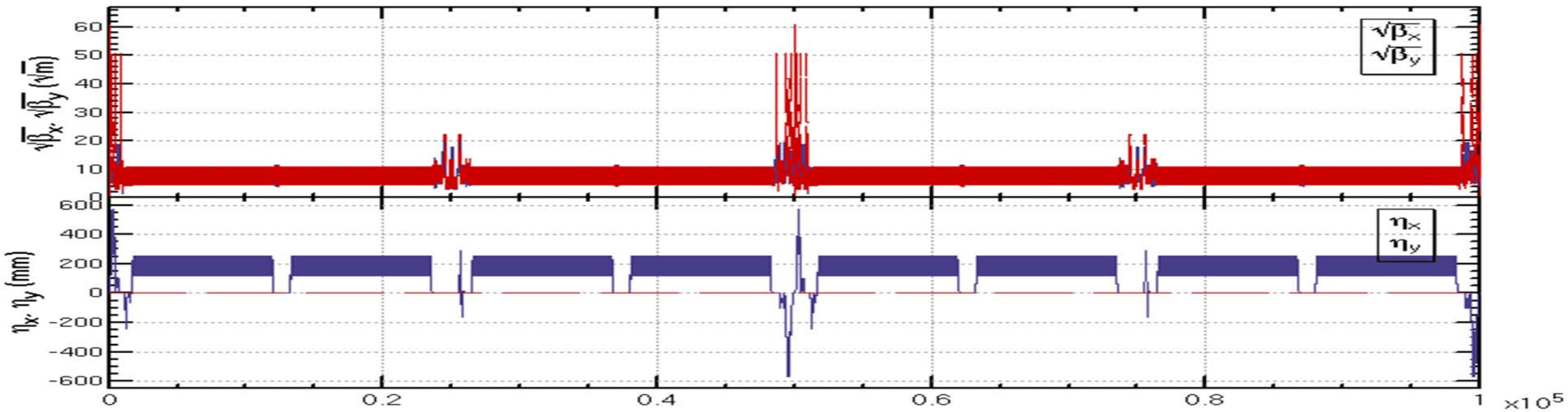
- **Common RF cavities** for e- and e+ ring (Higgs)
- An electrostatic separator combined with a dipole magnet to avoid bending of incoming beam(ref: K. Oide, ICHEP16)
- **RF region divided into two sections for bypassing half numbers of cavities in Z mode**

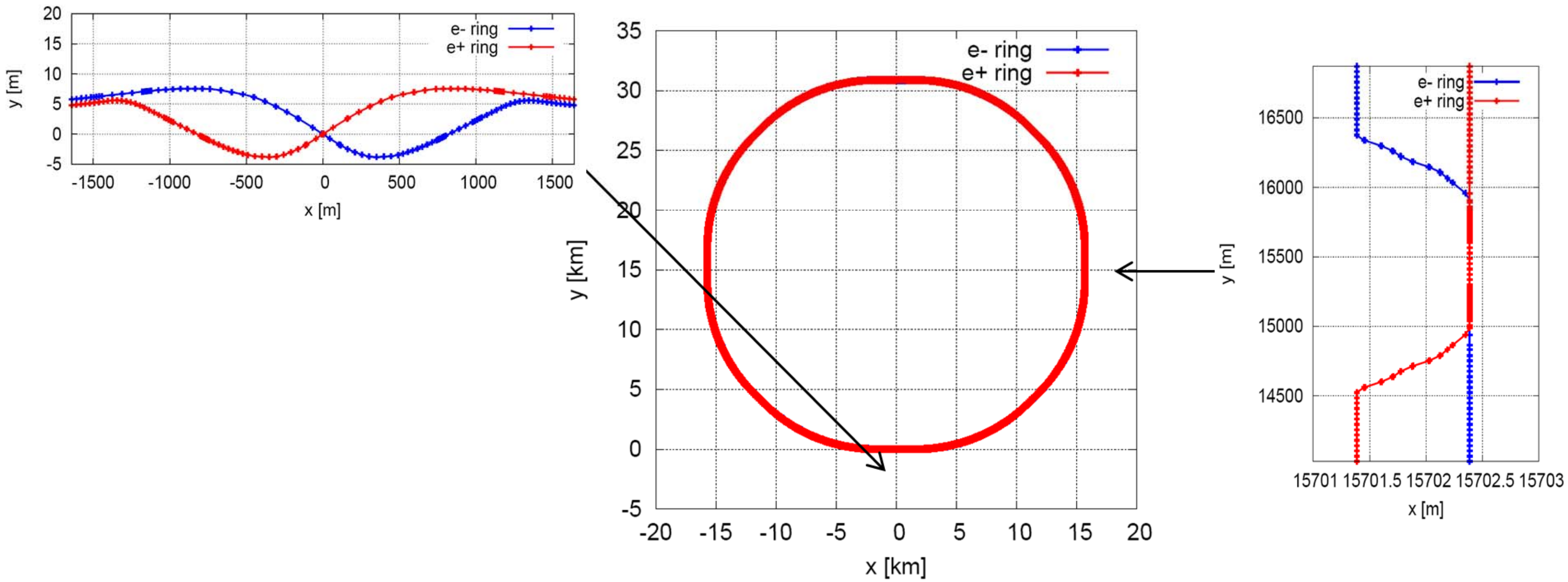


Esep=1.8 MV/m
Lsep=50m
Ldrift=75m
Δx=10cm at entrance of quad

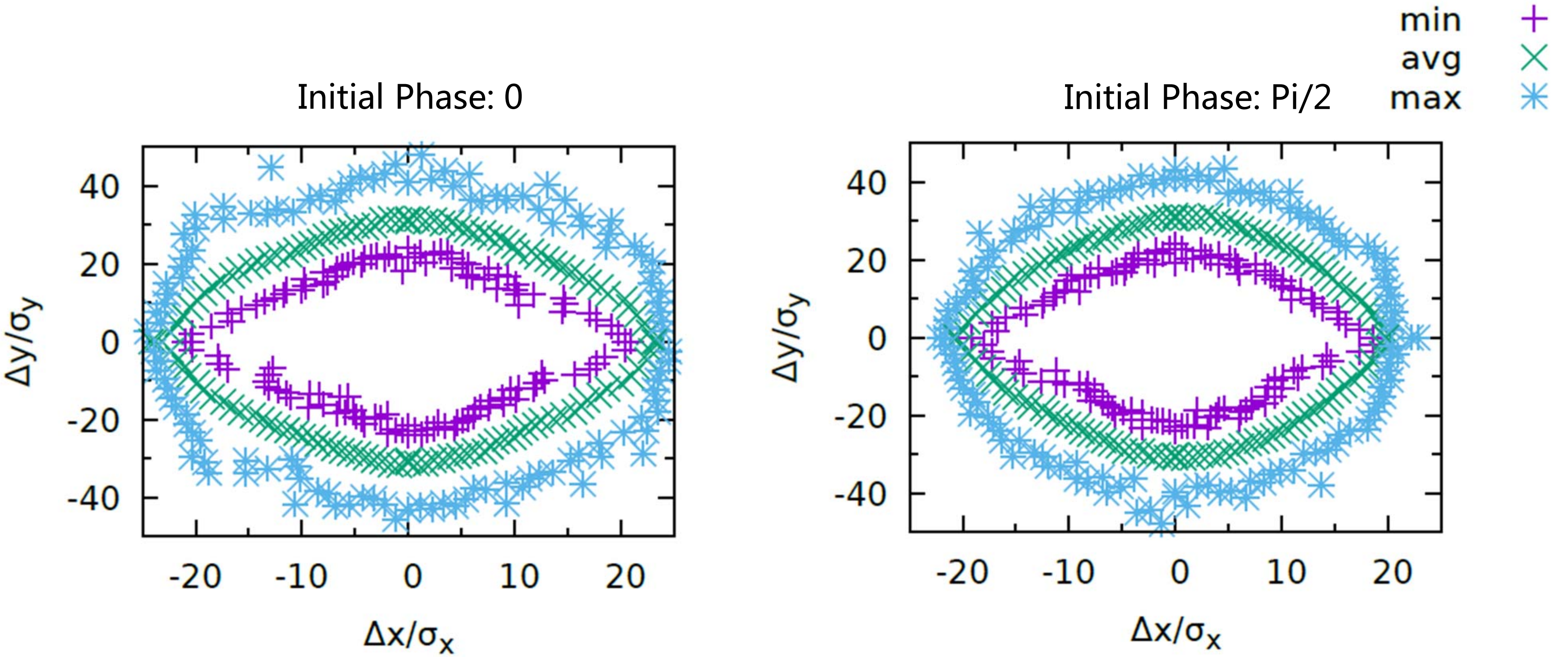
Linear Optics of the Collider Ring

- An optics fulfilling requirements of the parameters list, geometry, photon background and key hardware.





On Momentum Dynamic Aperture (CEPC-Higgs)

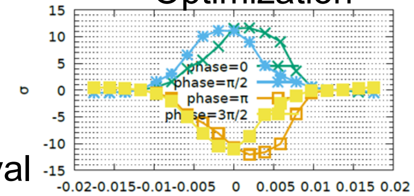


100 samples are tracked. 200 turns are tracked.

Synchrotron motion, synchtron radiation in dipoles, quads and sextupoles, tapering, Maxwellian fringes, kinematical terms, crab waist are included.

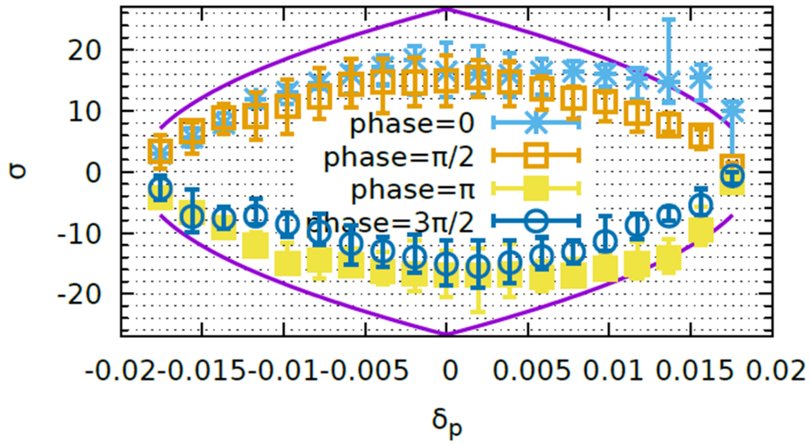
Off momentum Dynamic Aperture
(CEPC-Higgs)

W/O Optimization

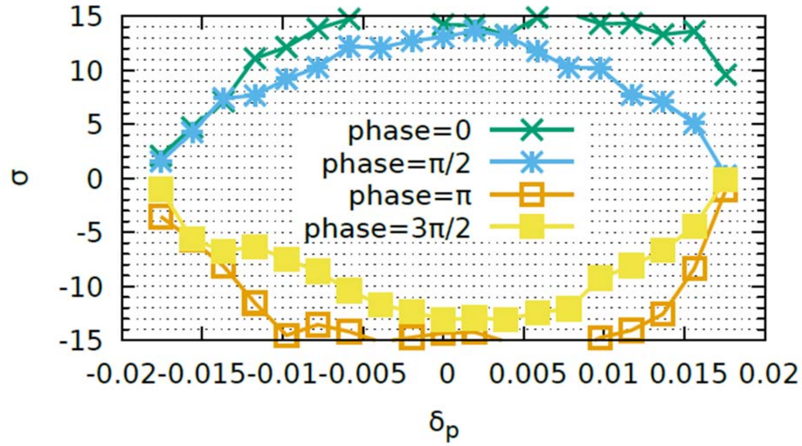


Momentum Acceptance: 0.017

Error bar means min and max



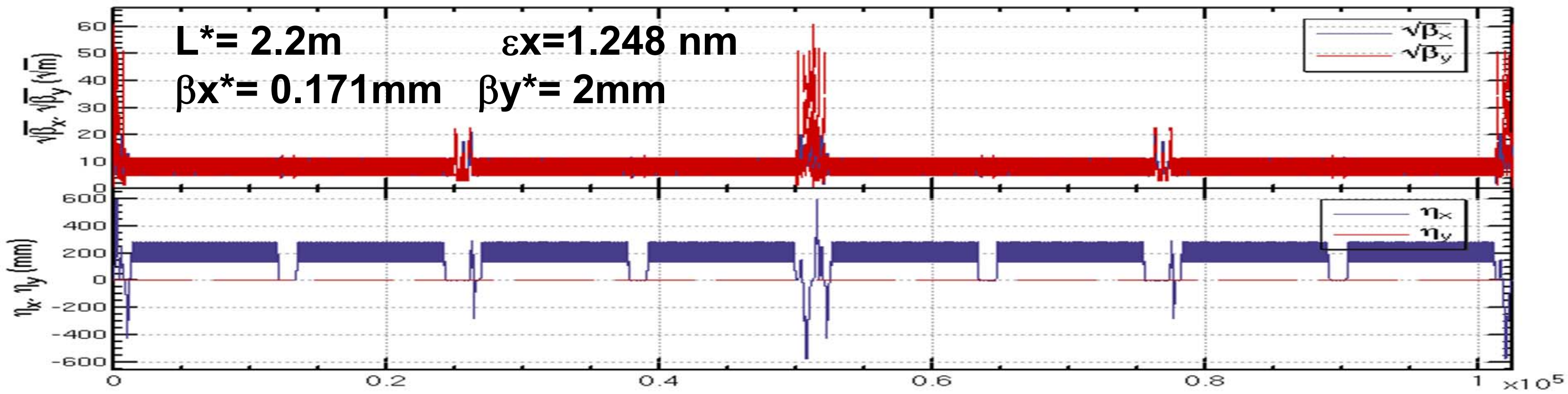
90% survival

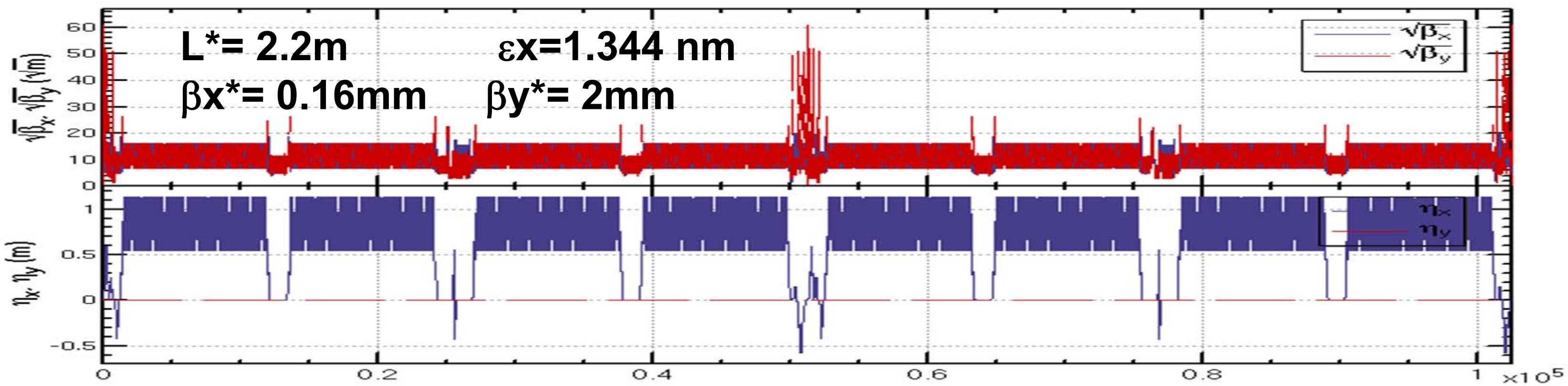


100 samples. Radiation fluctuation is included. 0.3% emittance coupling. 200 turns are tracked.

Whole Ring (H, Z)

- Whole ring of H & Z lattice

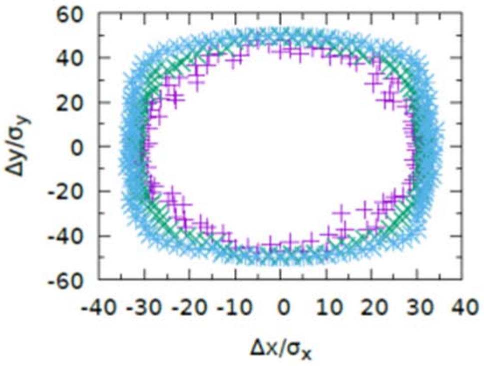




W

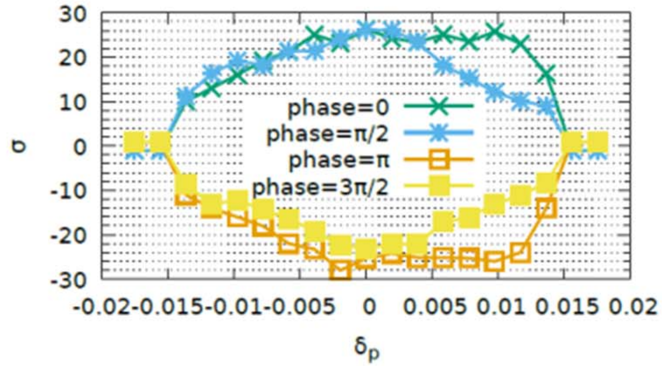
30*40

On Momentum Dynamic Aperture



Momentum Acceptance: 0.015

Minimum DA of 100 Samples



Radiation fluctuation is included. 0.3% emittance coupling.
1000 turns are tracked.

Z-pole design goal

$23\sigma_x \times 20\sigma_y$ & 0.004

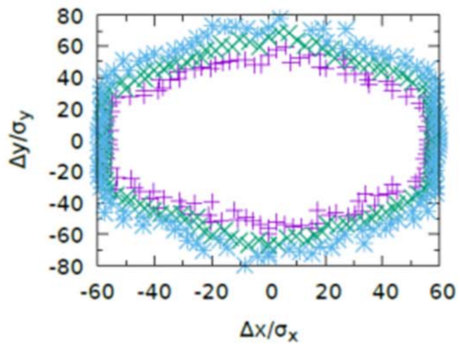
Z-pole achieved values (OK)

$52\sigma_x \times 50\sigma_y$ & 0.007@ Z

Z-pole

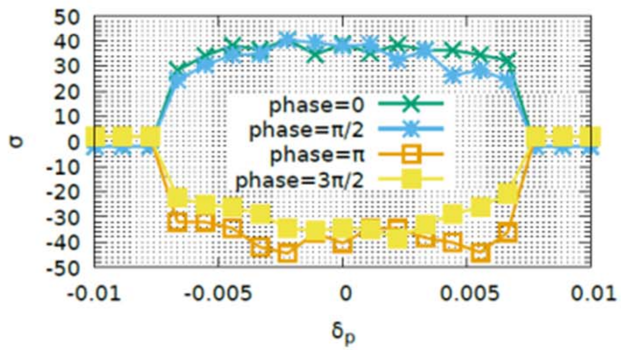
50*50

On Momentum Dynamic Aperture



Momentum Acceptance: 0.75%

Minimum DA of 100 Samples



Radiation fluctuation is included. 1.7% emittance coupling.
3000 turns are tracked.

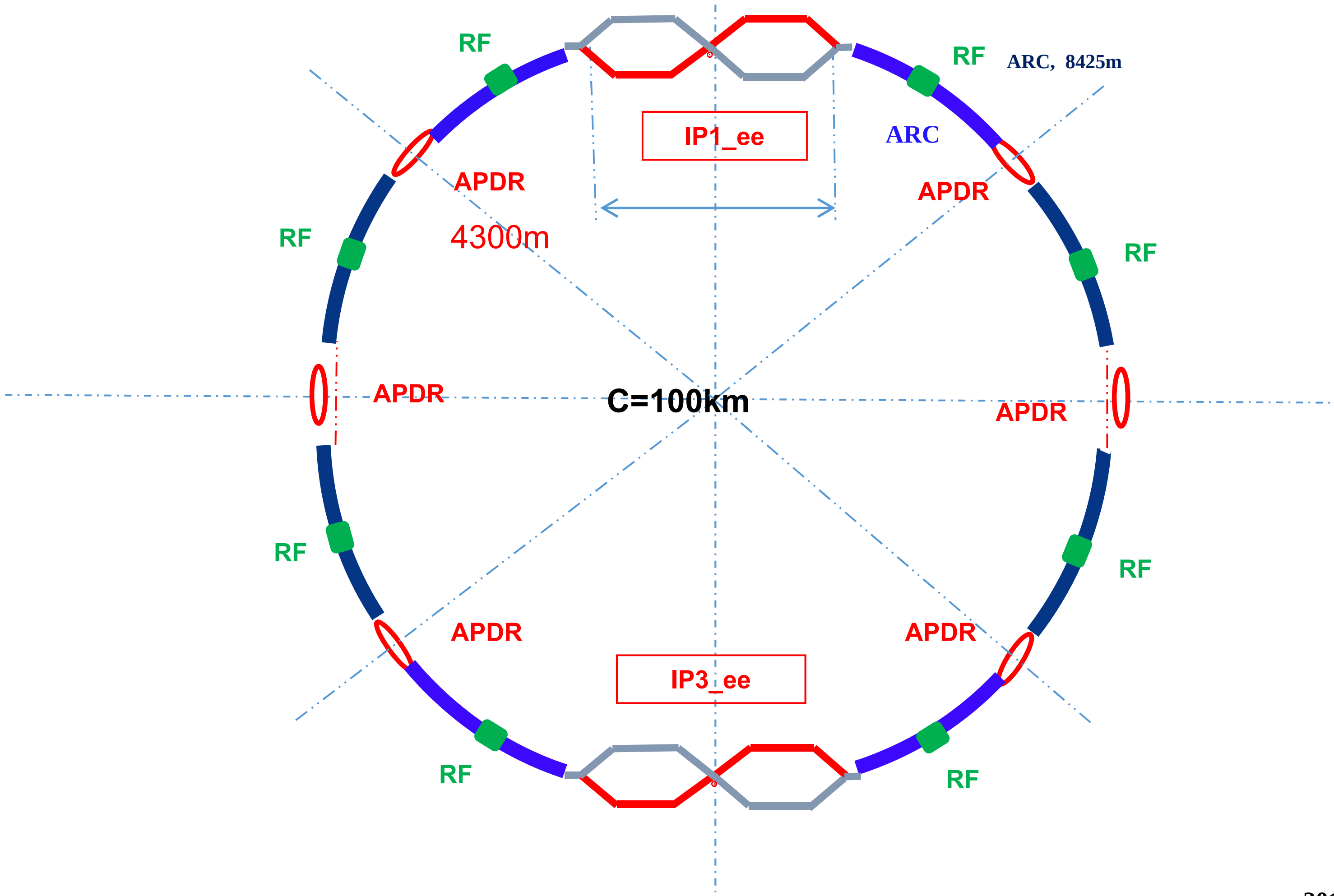
CEPC CDR Design Status

CEPC Collider Ring

Parameter	Symbol	Unit	Goal	Status
Beam Energy	E	GeV	120	**120**
Circumference	C	km	100	**100.006**
Emittance	$\varepsilon_x/\varepsilon_y$	nm·rad	1.21 / 0.0036	**1.208 / -**
Beta functions at IP	β_x/β_y	m	0.36 / 0.002	**0.36 / 0.002**
Energy acceptance	$\Delta P/P$	%	1.2	**1.7**
DA requirement	DA_x/DA_y	σ	16 / 7	**20 / 20 (w/o errors)**

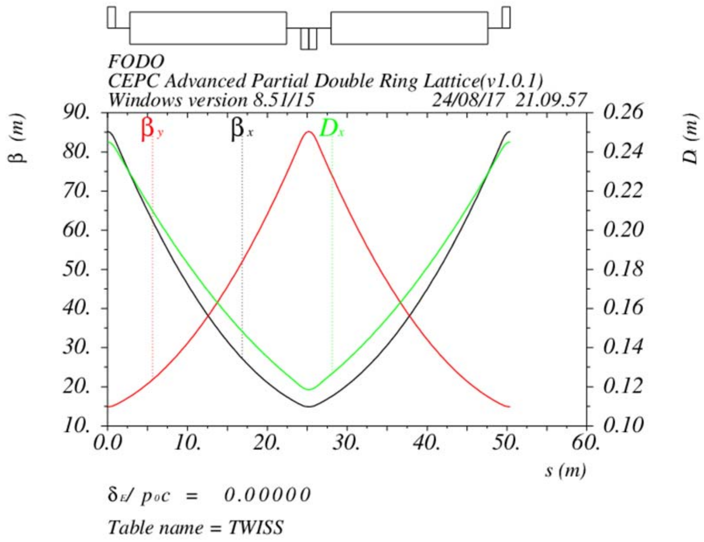
CEPC Advanced Partial Double Ring (Alternative)

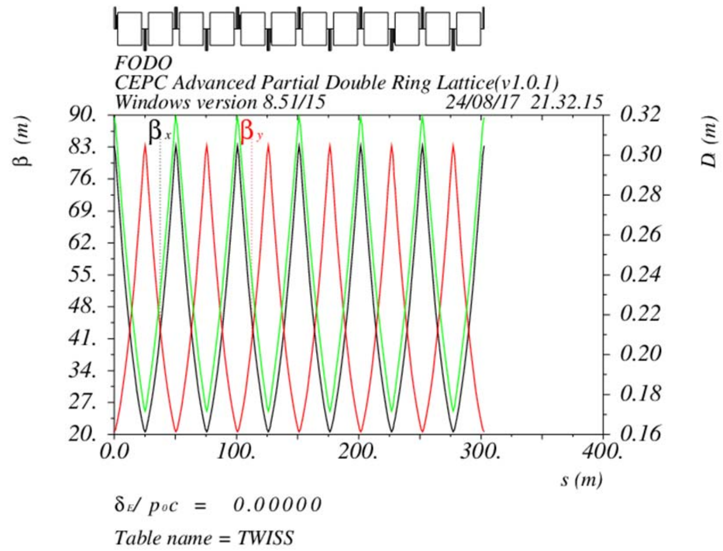
F.Su
D.J. Xiao

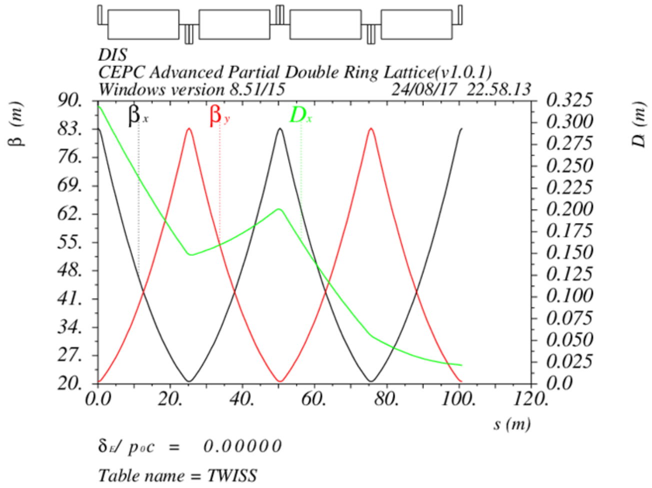


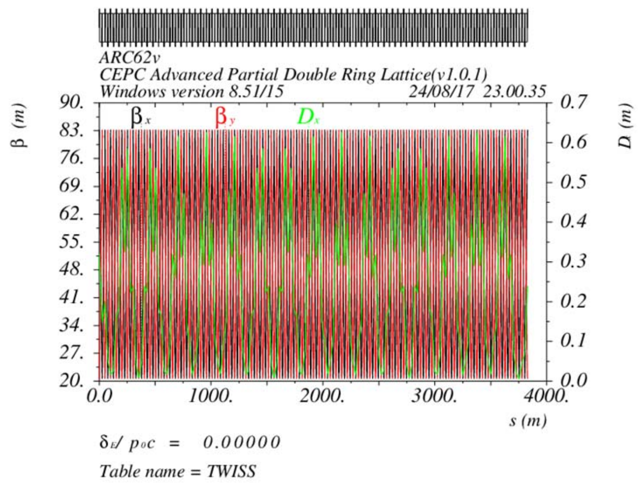
2017.8.22

APDR Lattice Design









CEPC MDI Layout

Interaction region: Machine Detector Interface

Session MDI: Chenghui Yu
CDR: Chapter 10

One of the most complicated issue in the CEPC detector design

Full partial double ring

Updated baseline parameters:

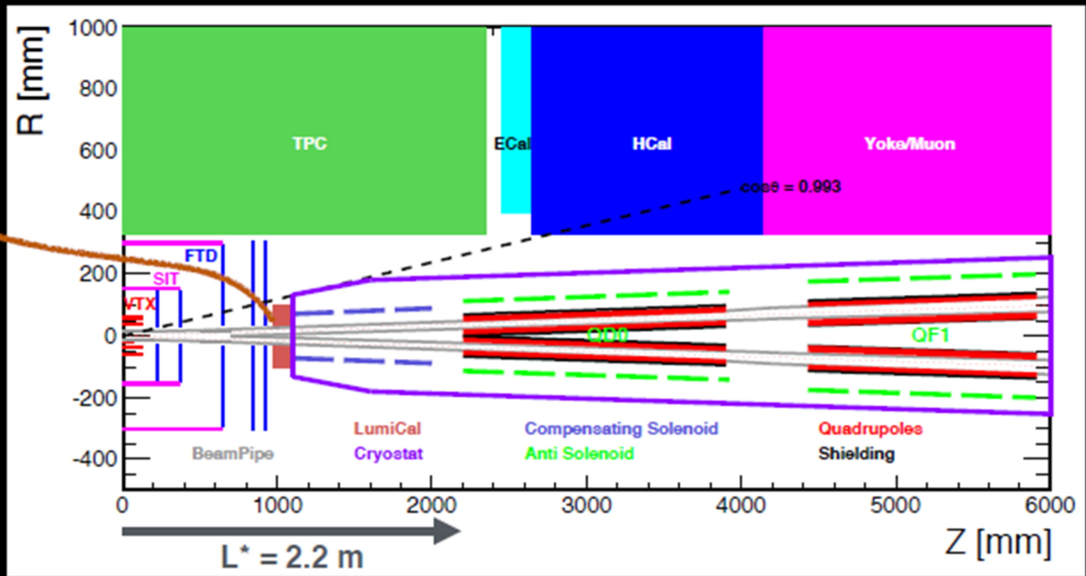
- Head-on collision changed to crossing angle of **33 mrad**
- Focal length (L^*) increased from 1.5 m to **2.2 m**
- Solenoid field reduced from 3.5 T to **3 T**

LumiCal

Lumi unc: 1×10^{-3}

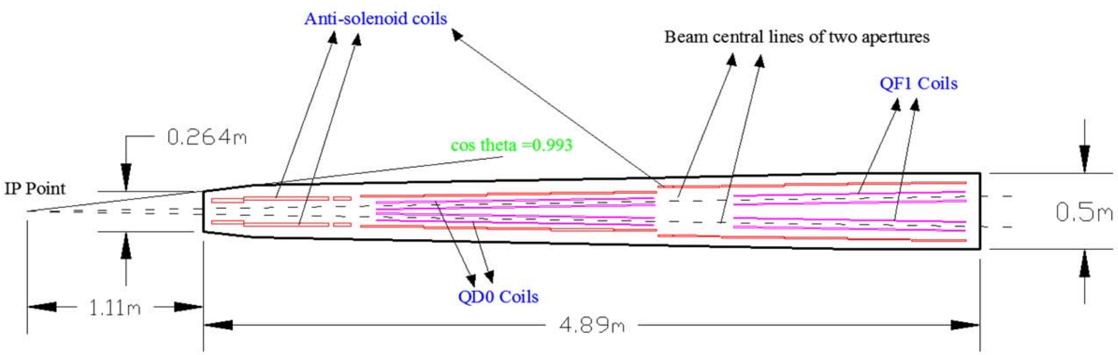
Session MDI: Suen Hou
CDR: Chapter 10

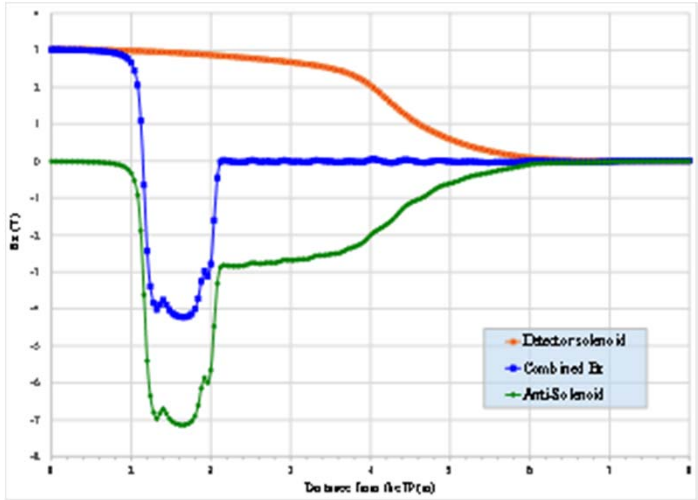
(studies lead by Vinca and Academia Sinica)

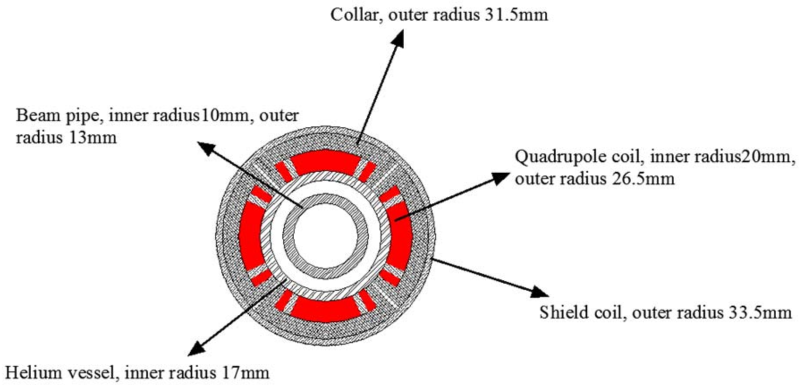


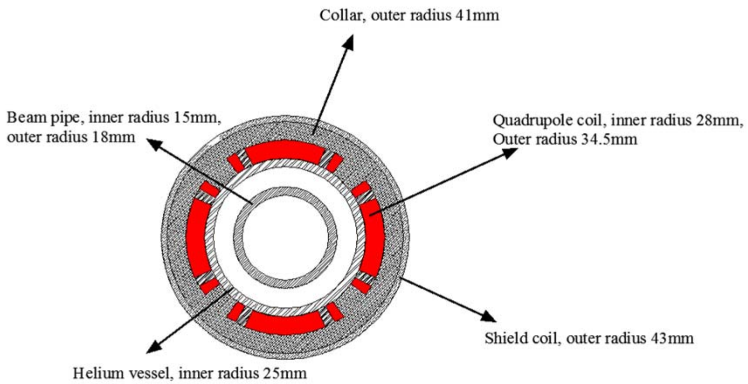
Magnet	Field Strength	Length	Inner Radius
QD0	151 T/m	1.73m	19 mm

IR superconducting magnets









CEPC Booster

Booster parameters

Injection Energy		H	W	Z
Bunch number		286	1044	2180
Transmission efficiency	%	0.95	0.95	0.95
Bunch population		3.86×10^{9}	1.08×10^{9}	4.87×10^{9}
Bunch charge	nC	0.618	0.17	0.078
Beam current	mA	0.53	0.542	0.51
Ramping time	s	5	3	1
Energy spread	%	0.2		
SR loss/turn	GeV	0.000077		
Momentum compaction factor	10^{-5}	2.09		
Emittance in x	nm rad	200		
RF voltage	GV	0.09		
Longitudinal fractional tune		0.12		
RF energy acceptance	%	2.51		
Damping time	s	86.94		
Bunch length(rms)	mm	1		

Extraction Energy		**H**	**W**	**Z**
Bunch number		286	1044	2180
Transmission efficiency	%	0.95	0.95	0.95
Bunch population		3.86×10^{9}	1.08×10^{9}	4.87×10^{9}
Bunch charge	nC	0.618	0.17	0.078
Beam current	mA	0.53	0.542	0.51
Ramping time	s	5	3	1
Energy spread	%	0.0966	0.00805	0.037
SR loss/turn	GeV	1.59	0.314	0.033
Momentum compaction factor	10^{-5}	1.93	2.09	2.12
Emittance in x	nm rad	3.1	1.56	0.51
RF voltage	GV	1.83	0.7	0.36
Longitudinal fractional tune		0.11	0.12	0.11
RF energy acceptance	%	0.71	1.56	2.18
Damping time	ms	50.06	169.73	922.94
Bunch length	mm	3.22	2.1	1.19

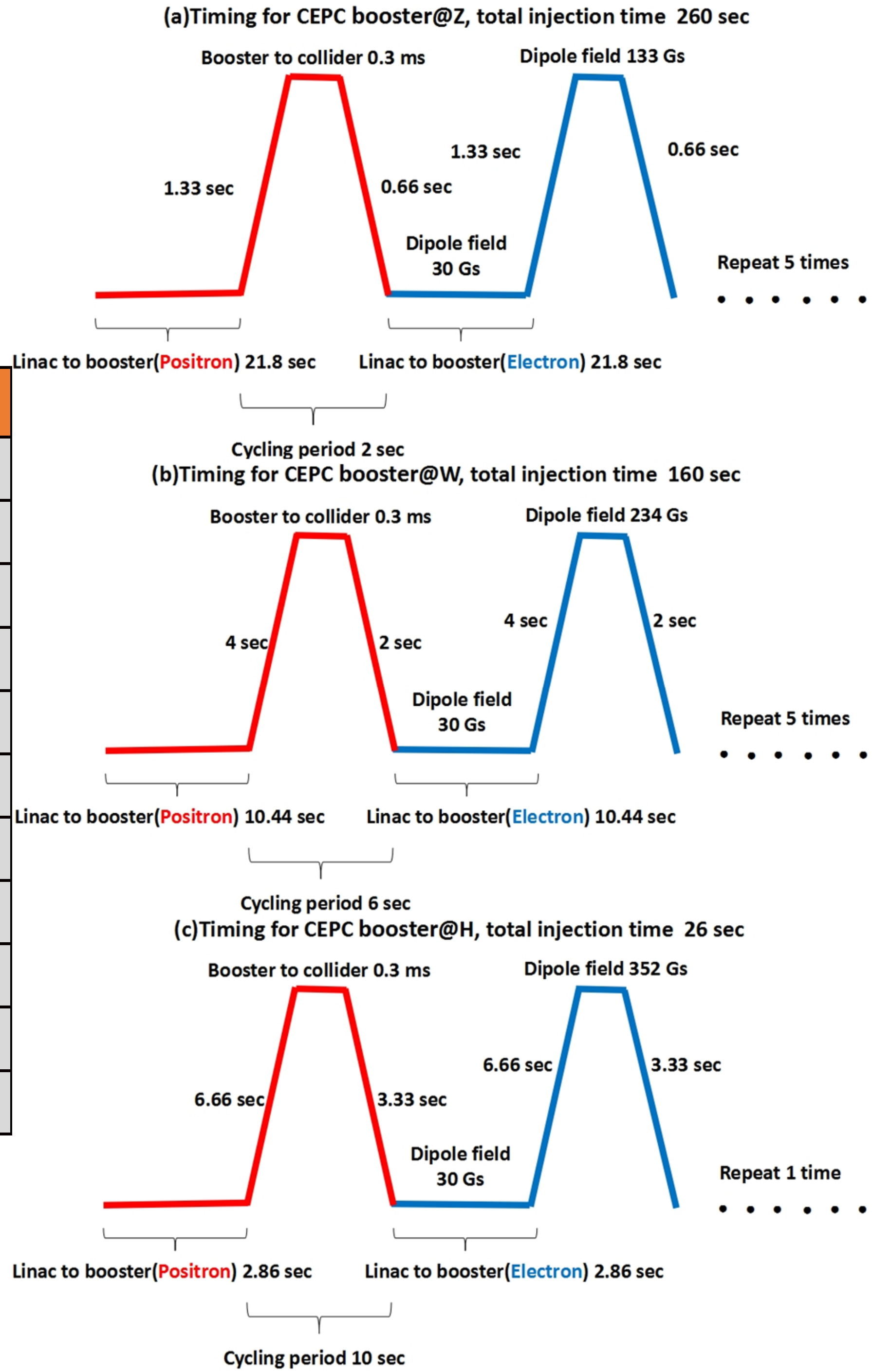
CEPC Booster SRF Parameters

10 GeV injection	**H**	**W**	**Z**
Extraction beam energy [GeV]	120	80	45.5
Bunch charge [nC]	0.62	0.17	0.078
Beam current [mA]	0.53	0.53	0.51
Extraction RF voltage [GV]	1.83	0.7	0.36
Extraction bunch length [mm]	2.9	2.0	1.1
Cavity number in use (1.3 GHz TESLA 9-cell)	96	64	32
Gradient [MV/m]	**18.4**	10.5	10.8
Q_L (over-coupled)	1E7	1E7	1E7
Cavity bandwidth [Hz]	**130**	130	130
Beam peak power / cavity [kW]	8.8	2.6	0.5
Input peak power per cavity [kW] (with detuning)	14.1	4.4	3.4
Input average power per cavity [kW] (with detuning)	**1**	0.4	0.3
SSA peak power [kW] (one cavity per SSA)	25	25	25
HOM average power per cavity [W]	0.4	0.15	0.10
$\mathbf{Q_0}$ @ 2 K at operating gradient (long term)	**1E10**	1E10	1E10
Total average cavity wall loss @ 4.5 K eq. [kW]	0.8	0.3	0.1

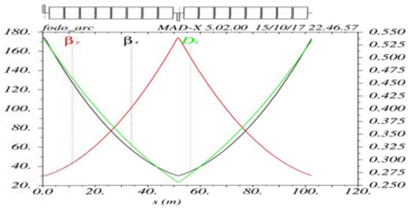
CEPC Booster

Timing

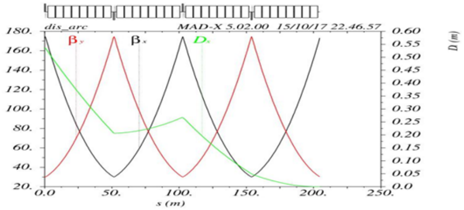
		H	W	Z
Injection times		1	5	5
Revolution frequency	Hz	2997.92	2997.92	2997.92
Bunch number		286	1044	2180
Transmission efficiency	%	95	95	95
Bunch charge	nC	0.62	0.17	0.078
Beam current	mA	0.53	0.54	0.51
Linac repetition rate	Hz	100	100	100
From linac to booster	sec	2.86	10.44	21.80
From booster to collider	us	333.56	333.56	333.56
Ramp cycling period	sec	25.72	32.88	47.60
Total injection time	sec	25.72	164.40	238.00



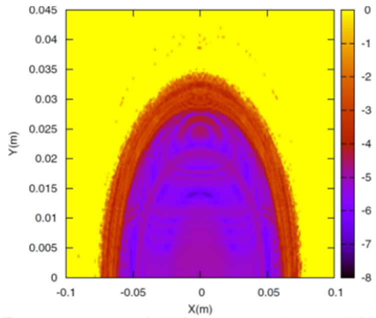
CEPC Booster Design Status



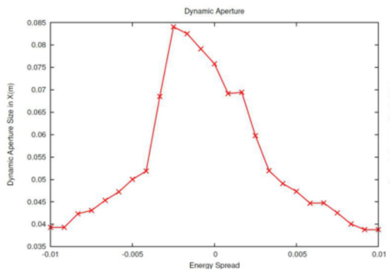
The twiss function of a FODO cell



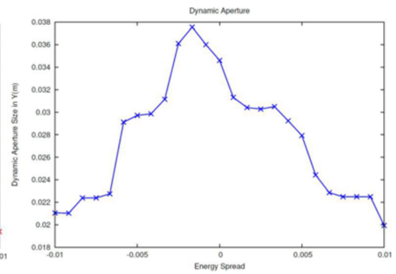
The twiss function of a dispersion suppressor



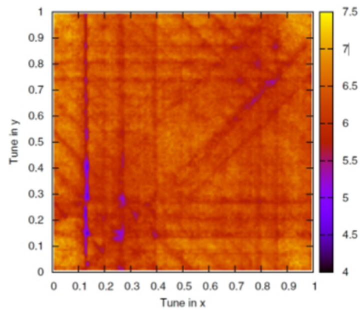
Frequency map analysis for on-momentum particles



Dynamic aperture as a function of energy spread in X direction



Dynamic aperture as a function of energy spread in Y direction



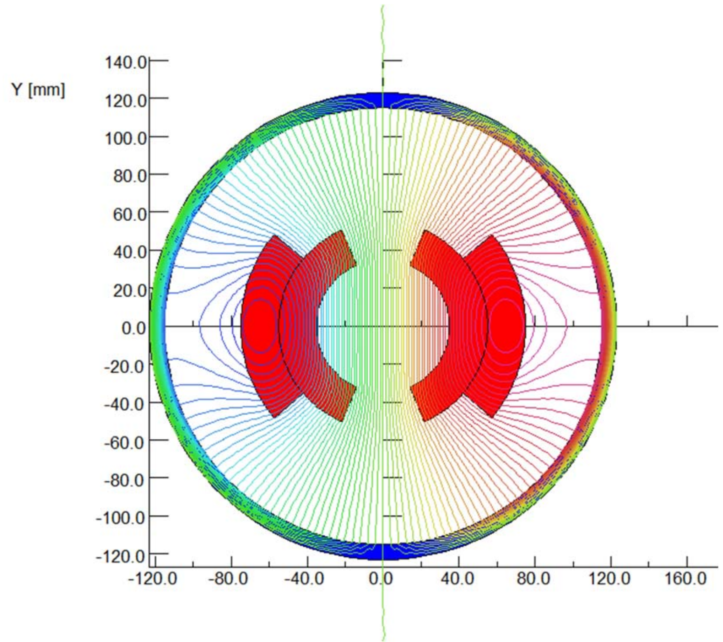
Tune scan for CEPC booster lattice

Parameters	Design goals	Design results
Beam current (mA)	<0.8	0.54
Emittance in x (nm rad)	<3.6	3.1
Dynamic aperture for 0.5% off-momentum particles	>3σ	8.5σ
Energy acceptance	>1%	2.5%
Timing	Meet the top-up injection requirements	√

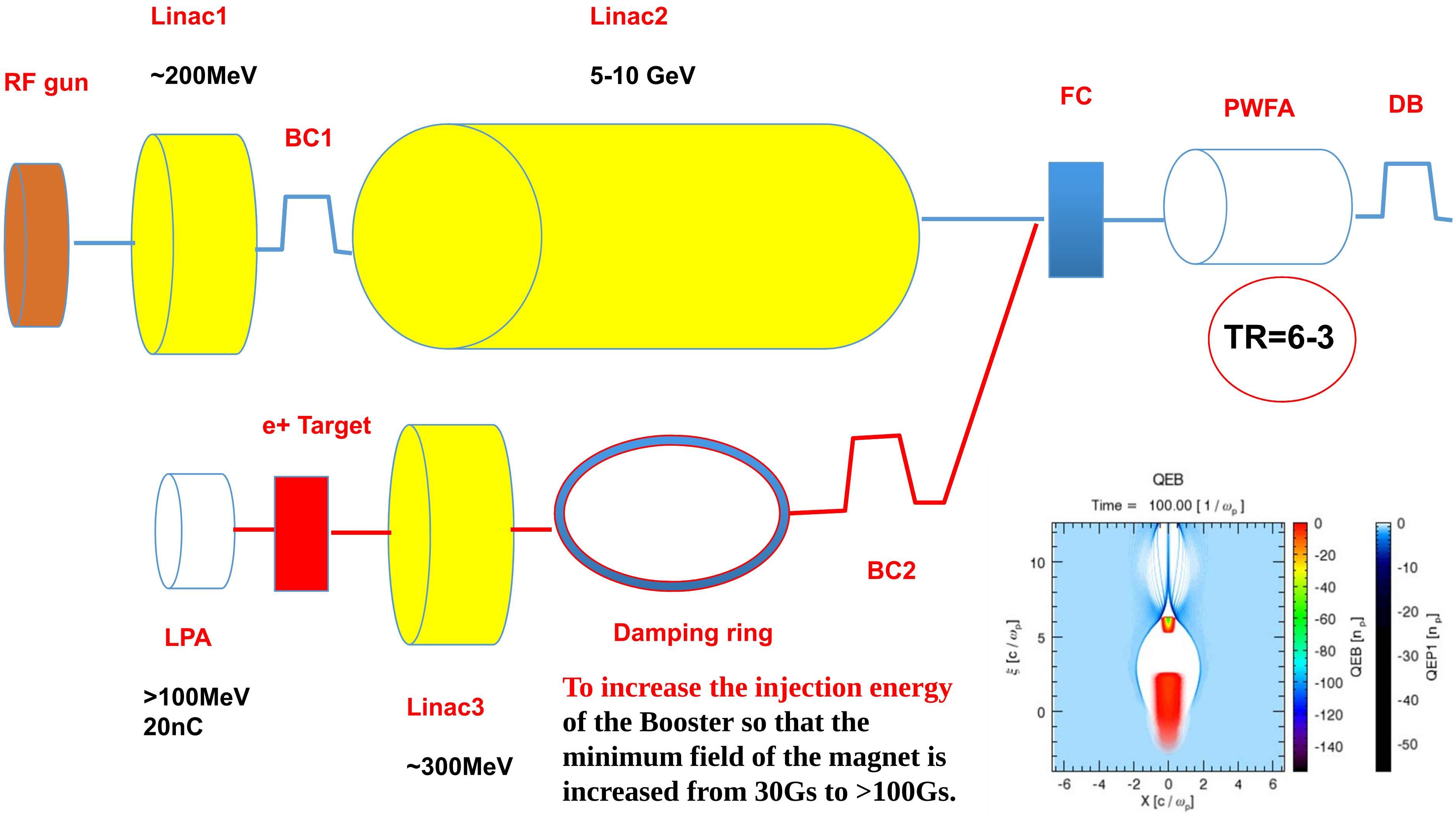
CEPCB Low Field Dipole Magnets

The ways to improve the field qualities of the low field magnets

- **To increase the injection energy of the Booster so that the minimum field of the magnet is increased from 30Gs to 100Gs.**
- **To develop high quality silicon steel laminations with very low remnant field.**
- **To design and develop the low field magnet without magnetic core like superconductor dipole magnets.**

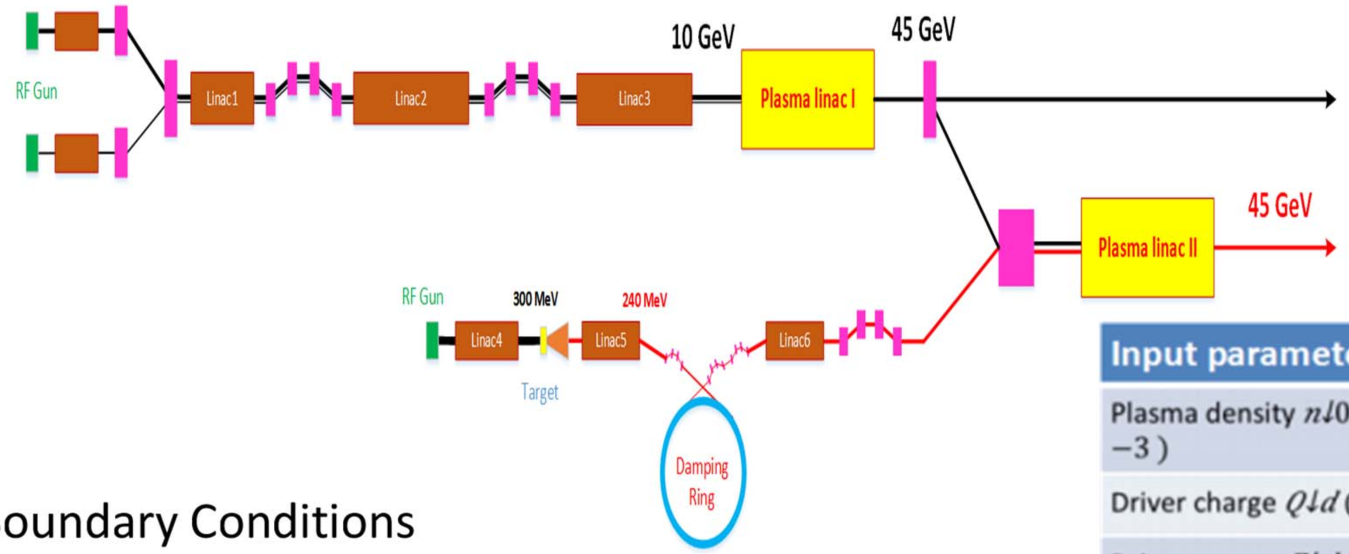


A High Energy CEPC Injector Based on Plasma Wakefield Accelerator



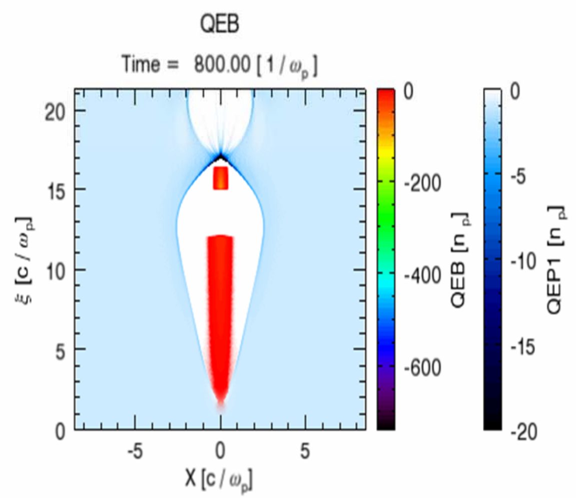
To increase the injection energy of the Booster so that the minimum field of the magnet is increased from 30Gs to >100Gs.

Overall Concept Design based on single stage PWFA (TR=3.5) for CEPC injector



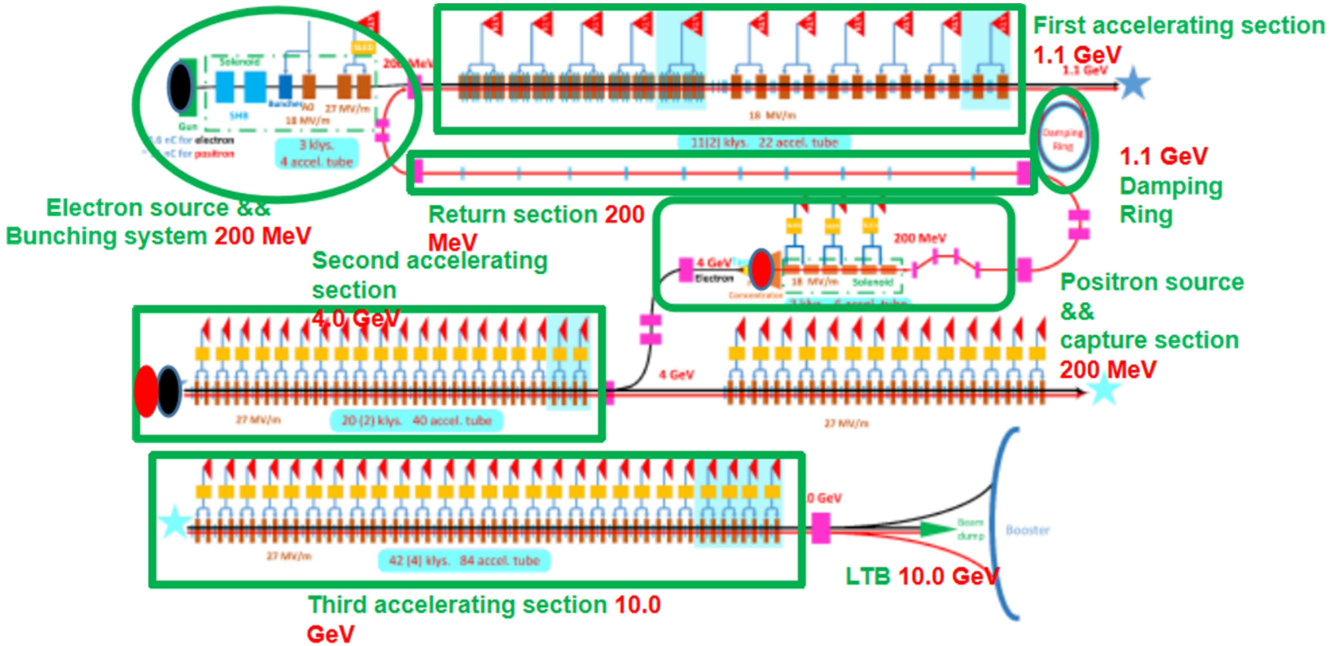
Boundary Conditions

- Beam average power (kW 100Hz)
- Beam charge per-bunch (nC)
- Beam energy spread (0.2%)
- Beam geometric emittance (<0.3mm mrad)
- Positron generation and acceleration



Input parameters	
Plasma density n_0 (cm^{-3})	5.15×10^{16}
Driver charge Q_d (nC)	6.47
Driver energy E_d (GeV)	10
Driver length L_d (μm)	285
Driver RMS size σ_d (μm)	10
Driver normalized emittance ϵ_{nd} ($mm\ mrad$)	10
Trailor charge Q_t (nC)	1.25
Trailor energy E_t (GeV)	10
Trailor length L_t (μm)	35
Trailor RMS size σ_t (μm)	5
Trailor normalized emittance ϵ_{nt} ($mm\ mrad$)	100

CEPC Linac Injector

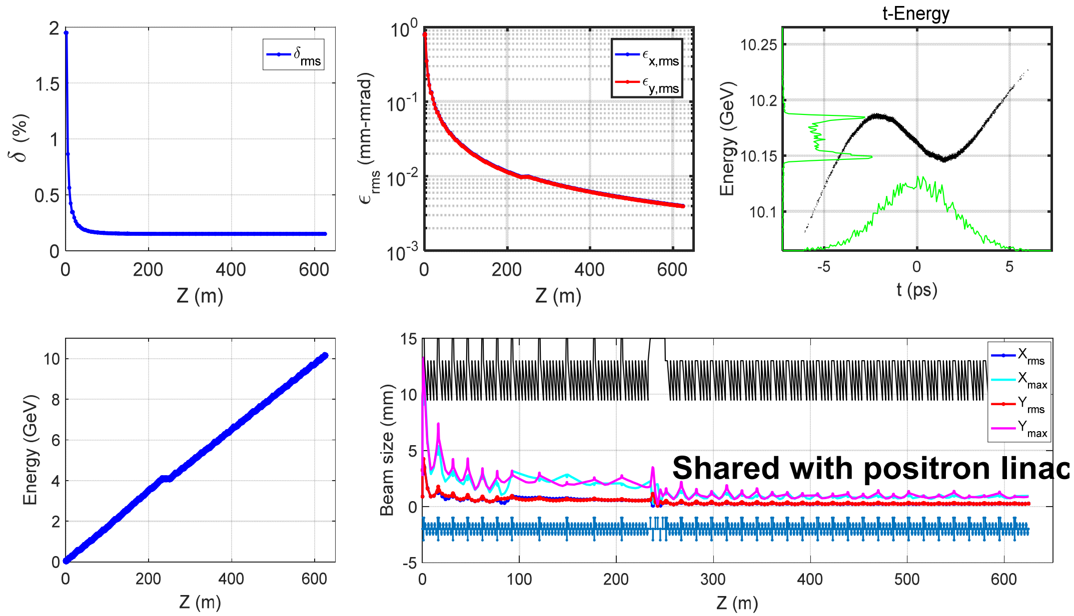


Parameter	Symbol	Unit	Value
e^- /e^+ beam energy	E_{e-}/E_{e+}	GeV	10
Repetition rate	f_{rep}	Hz	100
e^- /e^+ bunch population	$Ne-/Ne+$		$>6.25\times10^9$
		nC	>1.0
Energy spread (e^- /e^+)	σ_E		$<2\times10^{-3}$
Emittance (e^- /e^+)	ε_r	nm· rad	<300
e^- beam energy on Target		GeV	4
e^- bunch charge on Target		nC	10

Electron Linac Design

- **Low charge mode**
  - 3 nC && 10 GeV without bypass
  - Energy spread (rms): 0.15%
  - Emittance (rms): 5 nm
- **Bypass scheme**
  - electron transport line bypass
    - ***Simplicity***
    - A bit higher cost, more magnets
  - target bypass
    - Moveable target: alignment & mechanics
    - Low energy part for positron linac is week focusing for high energy electron, e.g. quadrupoles and correctors

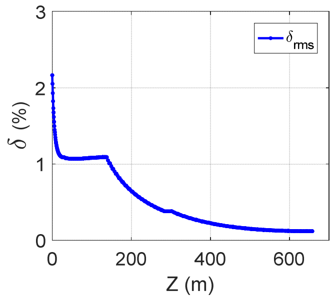
Energy spread (e^- /e^+)	σ_E		$<2\times10^{-3}$
Emittance (e^- /e^+)	ε_r	mm· mrad	<0.3

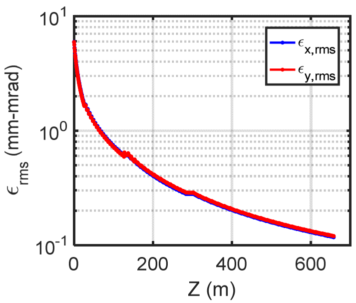


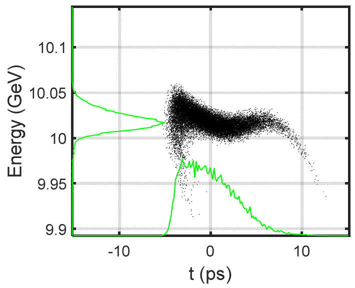
Positron Linac Design

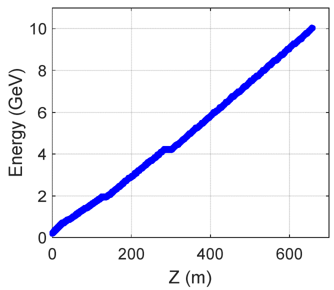
- Positron linac
  - 3 nC && 10 GeV
  - Energy spread (rms): 0.12%
  - Emittance (rms): 120 nm

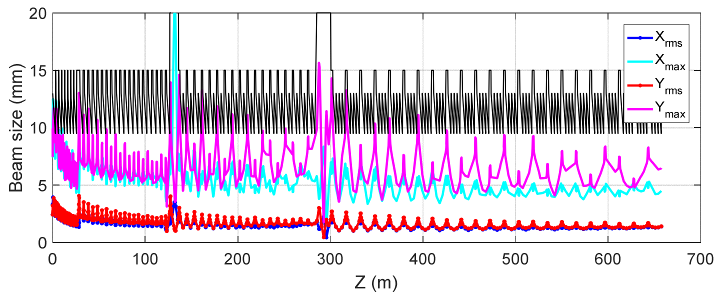
Energy spread (e^- /e^+)	σ_E		<2$\times10^{-3}$
Emittance (e^- /e^+)	ε_r	mm· mrad	<0.3

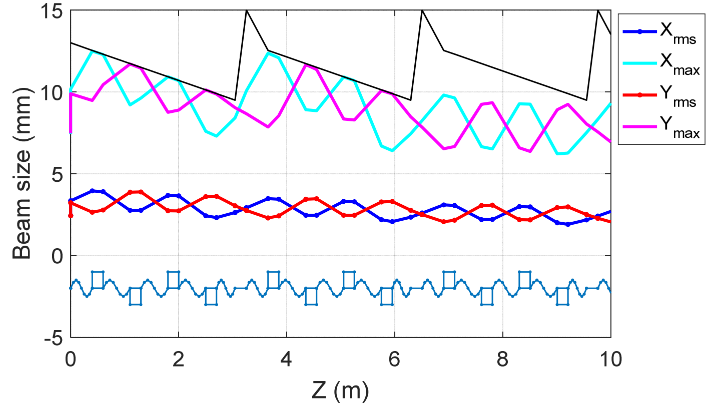












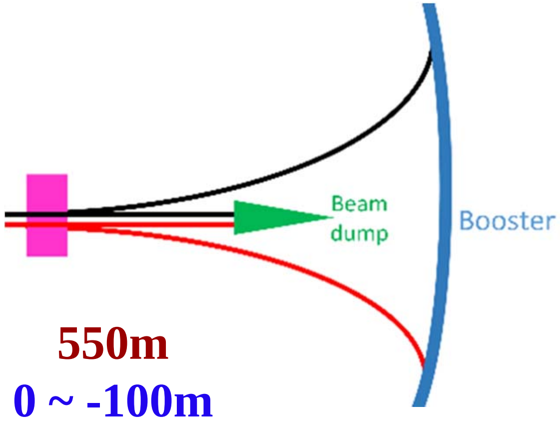
Beam loss: 2%

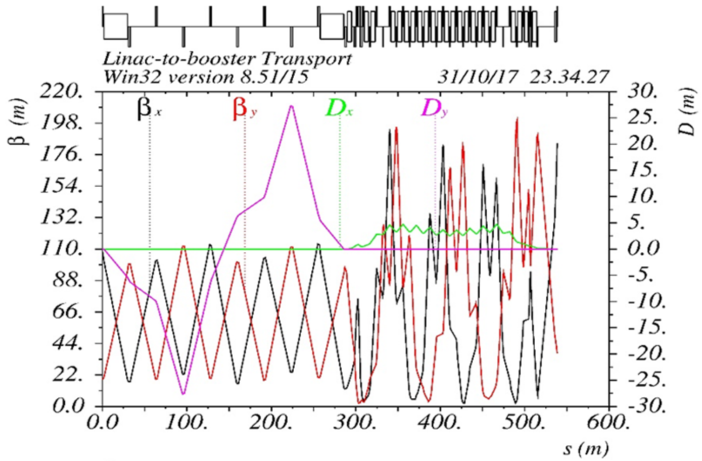
CEPC Linac Injector CDR Status

Parameter	Symbol	Unit	Goal	Status
e^-/e^+ beam energy	E_{e-}/E_{e+}	GeV	10	10/10
Repetition rate	f_{rep}	Hz	100	100
e^-/e^+ bunch population	$Ne-/Ne+$		$>6.25\times10^{9}$	$\sim1.875\times10^{10}$ $\sim1.875\times10^{10}$
	$Ne-/Ne+$	nC	>1.0	1.0/3.0*
Energy spread (e^-/e^+)	σ_E		$<2\times10^{-3}$	1.5×10^{-3} 1.4×10^{-3}
Emittance (e^-/e^+)		mm· mrad	<0.3	0.005/0.12**
e^- beam energy on Target		GeV	4	4
e^- bunch charge on Target		nC	10	10

* Enough allowance and high bunch charge requirement possibility or potential
** Without errors

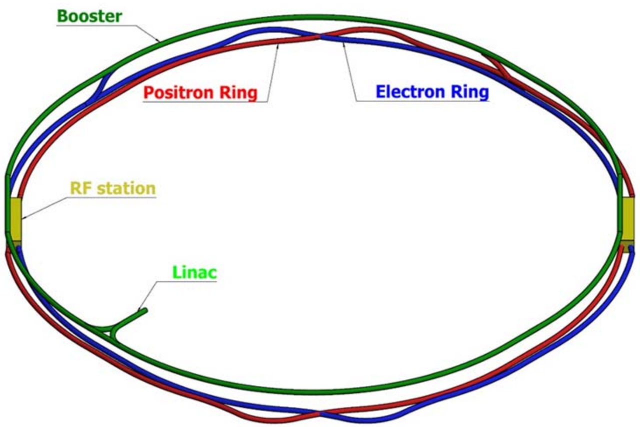
CEPC Linac to Booster: Transport Line

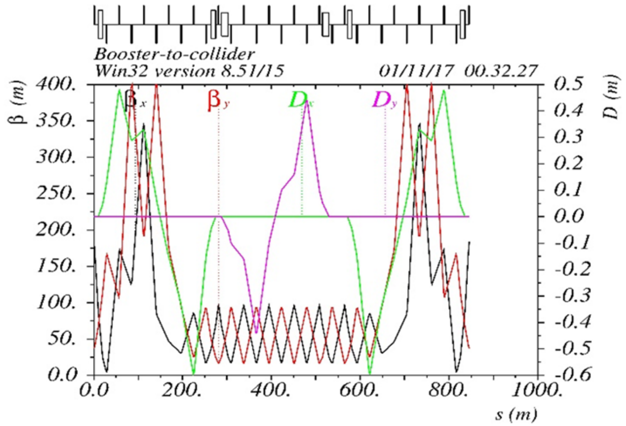




Transfer efficiency 99%

CEPC Booster to Collider Ring: Transport Line





- **The total transfer efficiency > 90%   (99%*92%*99%)**
- Satisfy the requirement of topup operation for H, W and Z

Electric Power Demand Estimated for CEPC

System	Location and electrical demand(MW)						Total (MW)
	Ring	Booster	LINAC	BTL	IR	campus	
RF power source	160	7.68	1.75				169.43
Cryogenics	16.8						16.8
Converter for magnets	98.5	10.5	5.7	2			116.7
Experimental devices					14		14
Dedicated services	6	3	1	0.5			10.5
Utilities	40		2	0.5	3		45.5
General services	13		1	0.3	1	12	27.3
Total	334.3	20.18	11.45	3.3	18	12	**400.23**

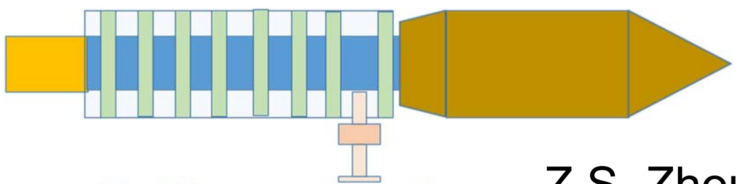
↓

350MW

Further electrical power reduction →**350MW**

Supposing that：

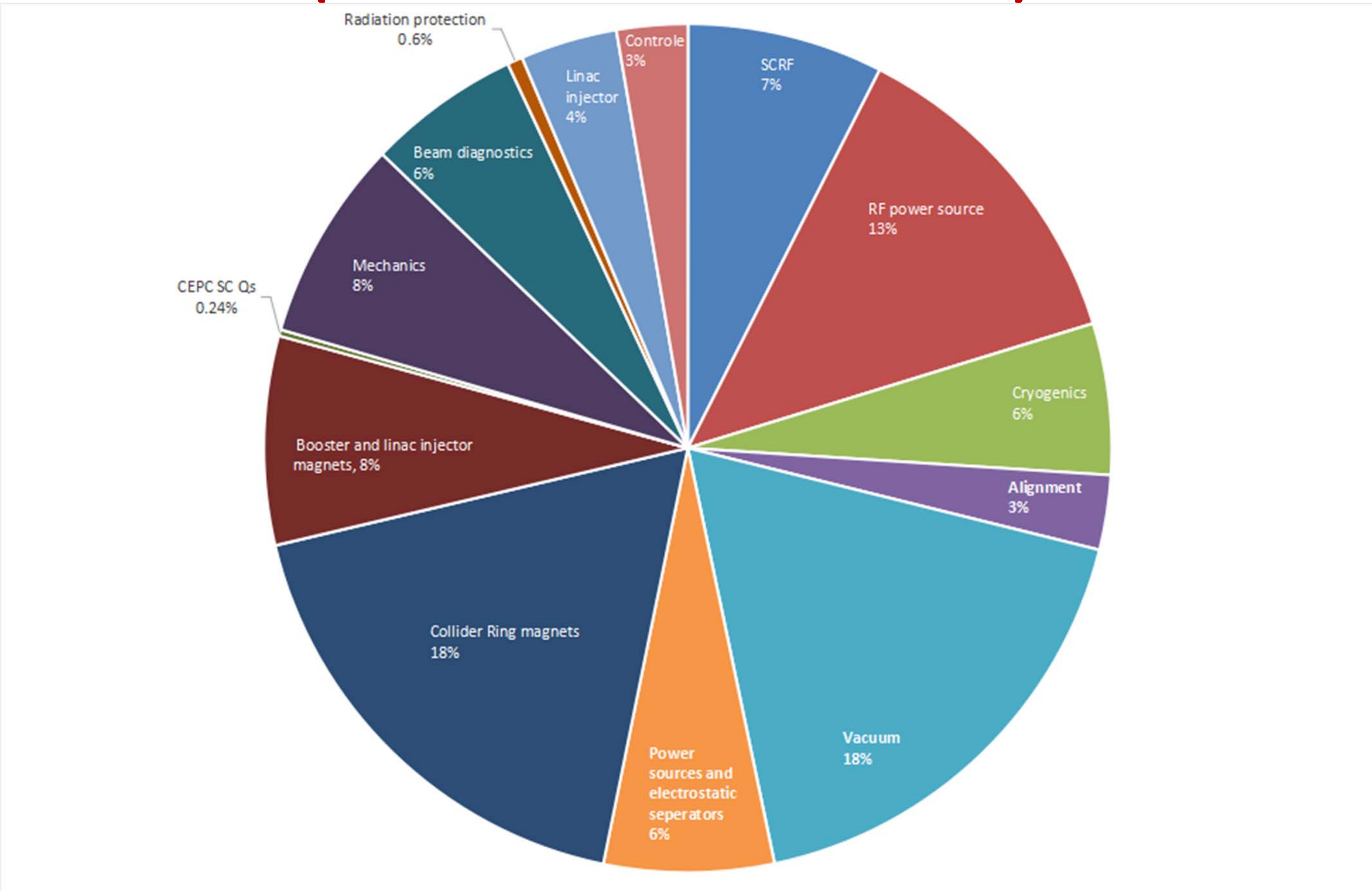
Klystron efficiency ↑(higher， 80%)
Cable loss ↓ (lower)
Magnet aperture ↓ (optimized)
• • • • • •



High Efficiency RF cavity section

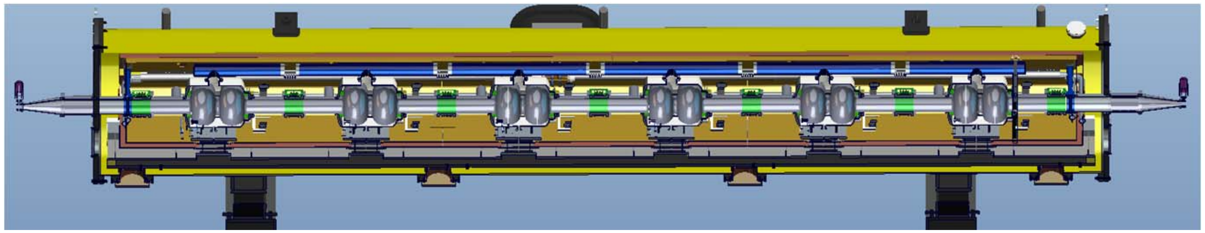
Z.S. Zhou

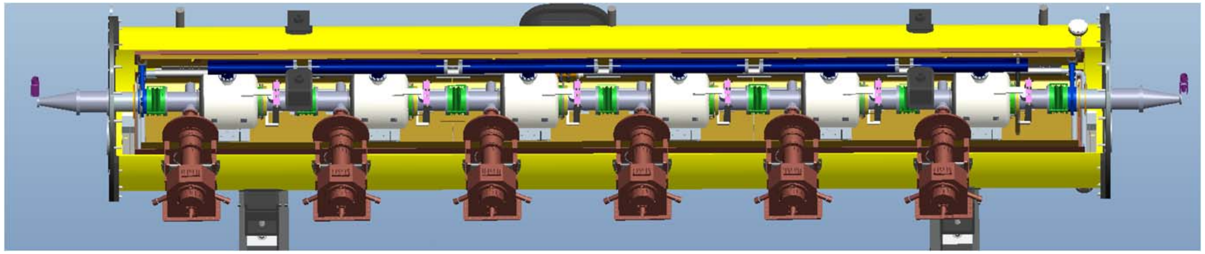
CEPC Cost Distribution of Accelerator (no detector and no tunnel)



CEPC 650 MHz Cavity Cryomodule

- Structure based on ADS cryomodule. High Q requirement drives new design features (fast cool down and magnetic hygiene).
- Fast cool down rate is supposed to be 10 K/min during 45 K to 4.5 K.
- Ambient magnetic field at cavity surface should be less than 5 mG. Magnetic shielding and demagnetization of parts and the whole module should be implemented for the magnetic hygiene control.

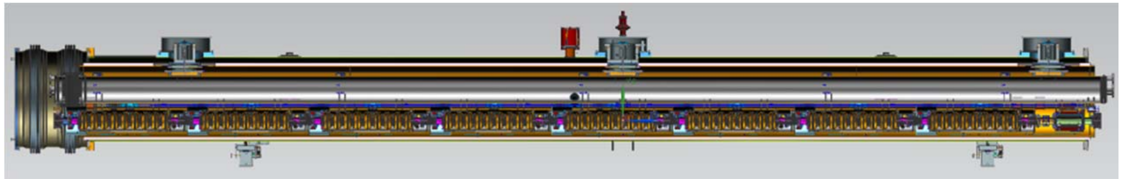


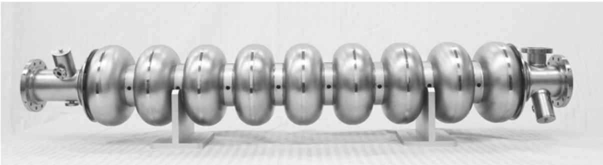


Overall length (flange to flange, m)	8.0
Diameter of vacuum vessel (m)	1.3
Beamline height from floor (m)	1.2
Cryo-system working temperature (K)	2
Number of cavities and tuners	6
Number of couplers	6
Number of RT HOM absorbers	2
Number of 200-POSTs	6
Static heat loads at 2 K (W)	5
Alignment x/y (cavities) (mm)	0.5
Alignment z (mm)	2

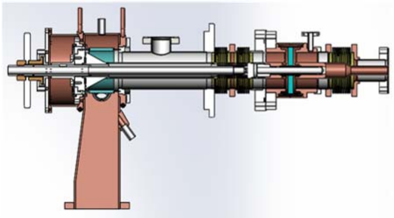
1.3 GHz SRF Technology for CEPC Booster

XFEL and LCLS-II type cryomodule, without SCQ. Technology R&D in synergy with Shanghai XFEL (SCLF). No big challenge.

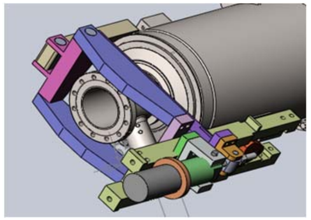




TESLA cavity. Nitrogen-doped bulk niobium and operates at 2 K. $Q_0 > 3 \times 10^{10}$ at 24 MV/m for the vertical acceptance test. $Q_0 > 1 \times 10^{10}$ up to 20 MV/m for long term operation.



XFEL/ILC/LCLS-II or other type **variable power coupler**. Peak power 30 kW, average 4 kW, Q_{ext} 1E7-5E7, two windows.



XFEL/LCLS-II type **end lever tuner**. Reliability. Large stiffness. Piezos abundance, radiation, overheating. Access ports for easy maintenance.

A New SRF Facility

Platform of **A**dvanced **P**hoton **S**ource Technology
R&D, Huairou Science Park, Huairou, Beijing

Construction: 2017 - 2019
Ground Breaking: May 31, 2017

4500 m² SRF lab

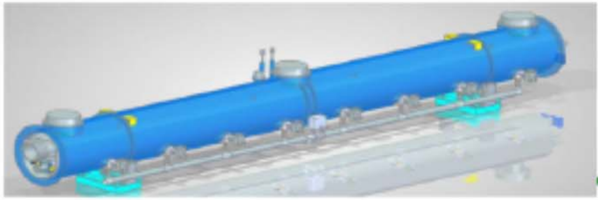
- 500M RMB funded by city of Beijing
- Construction: May 2017 – June 2020
- Include RF system & cryogenic systems magnet technology, beam test, etc.

Cryomodule Development and Production for SCLF

Shanghai Coherent Light Facility (SCLF)

SCLF Cryomodule Performance

- 1.3GHz 8x9cell cavity-string
- 8 tunners
- 8 power couplers
- 16个HOM couplers
- 1 Magnetic shielding
- 1 sc magnet
- 1 BPM
- 1 cryotat
- ...



Cavity Performance

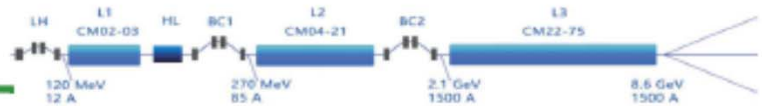
RF frequency	1.3 GHz
Temperature	2.0 K
Cavity length	1.038 m
Vertical test	>25 MV/m
Operation	>16 MV/m
Q0	> 2.7×10^{10}

Cryomodule Performance

CW RF Voltage	≥ 128 MV
Dark current	< 1 nA
Heat load 2 K	< 93 W
5 K	< 25 W
45 K	< 215 W

- SCLF is a newly proposed MHz high rep-rate XFEL, based on an 8 GeV CW SRF linac;
- This facility will be built in a 3.2 km long tunnel (38m underground) at Zhang-Jiang High Tech Park, across the SSRF campus in Shanghai;
- This XFEL facility includes 3 undulator lines and ~10 experimental stations in phase one, it can provide the XFEL radiation in the photon energy range of 0.2 -25 keV.
- The project proposal was recently approved by the central government in April 2017, and now it is in the feasibility study phase, aiming at commencing the tunnel construction in 2018.

Nominal performance of the SCLF linac

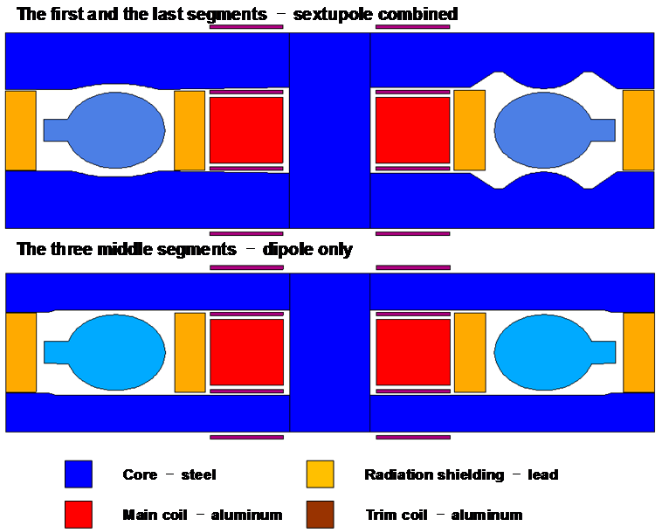


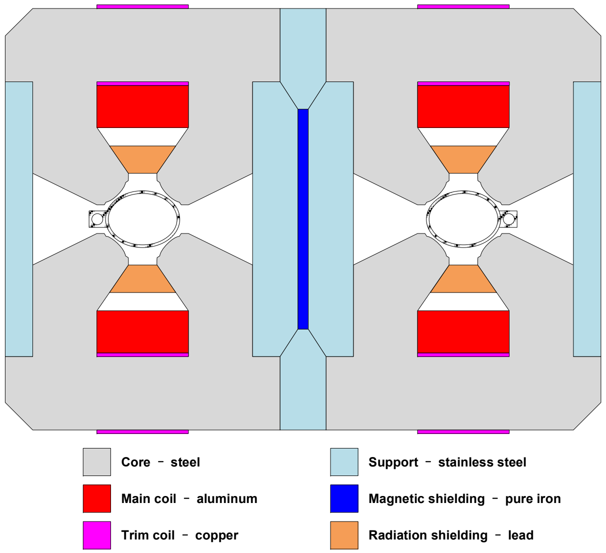
	No. of CM's	Avail. Cavities	Powered. Cavities	Gradient (MV/m)	E_{out} (MeV)	σ_z-out (mm)	σ_δ-out (%)	ϕ_{rf}	R_{56} (mm)
L0	1	8	7	16.3	120	1	0.04	0	
L1	2	16	15	13.6	326	1	0.383	-12.7	
HL	2	16	15	12.5	270	1	1.468	-150	
BC1	-	-			270	0.144	1.468		-55
L2	18	144	135	15.5	2148	0.144	0.368	-29	
BC2	-	-			2148	0.0072	0.368		-37
L3	54	432	406	15.5	8653	0.0072	0.086	0	

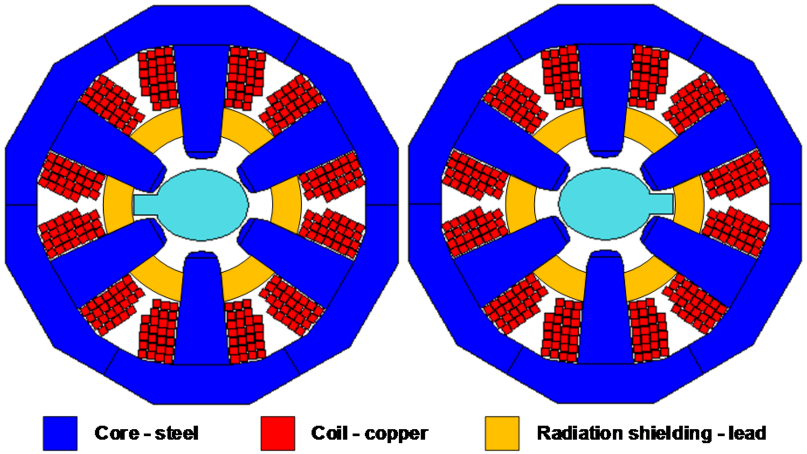
IHEP will provide one test cryomodule (8-cavities), and 100 9-cell cavities for SCLF

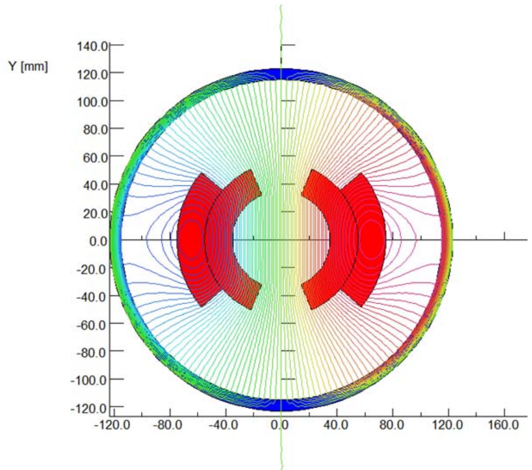
excellent exercise for CEPC

Designs of Dual Aperture CEPC Magnets



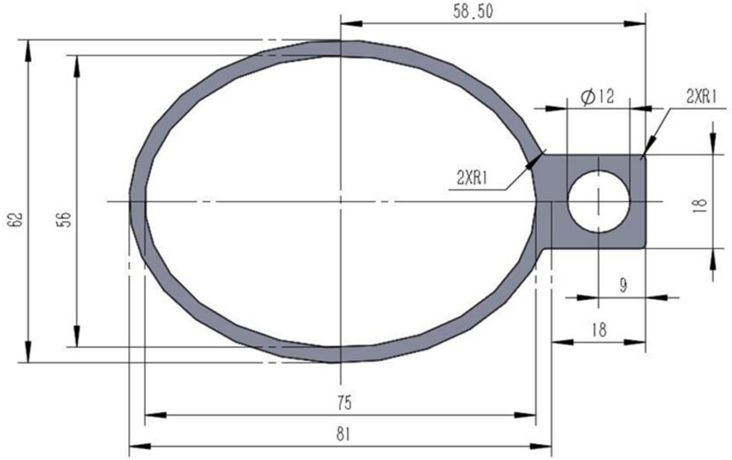






Booster Dipole

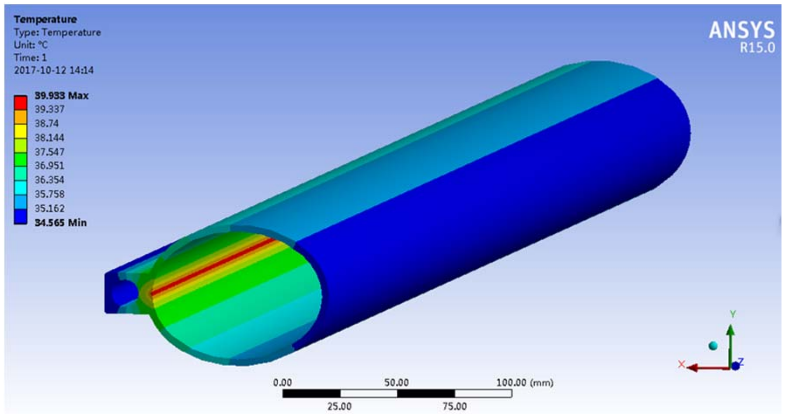
Dipole Vacuum Chamber of Electron Storage Ring

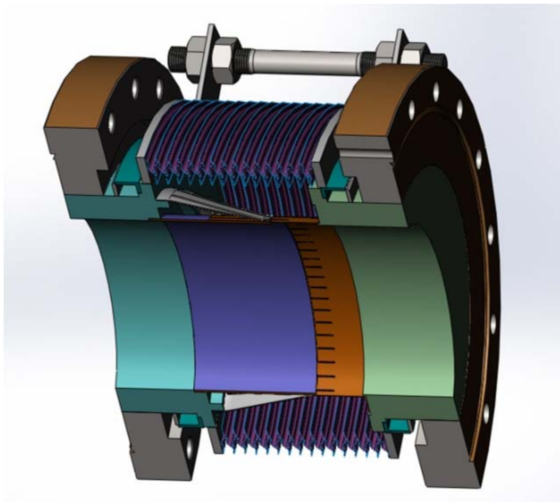


Aluminum vacuum chamber
(elliptic 75×56, thickness 3, length 6000)

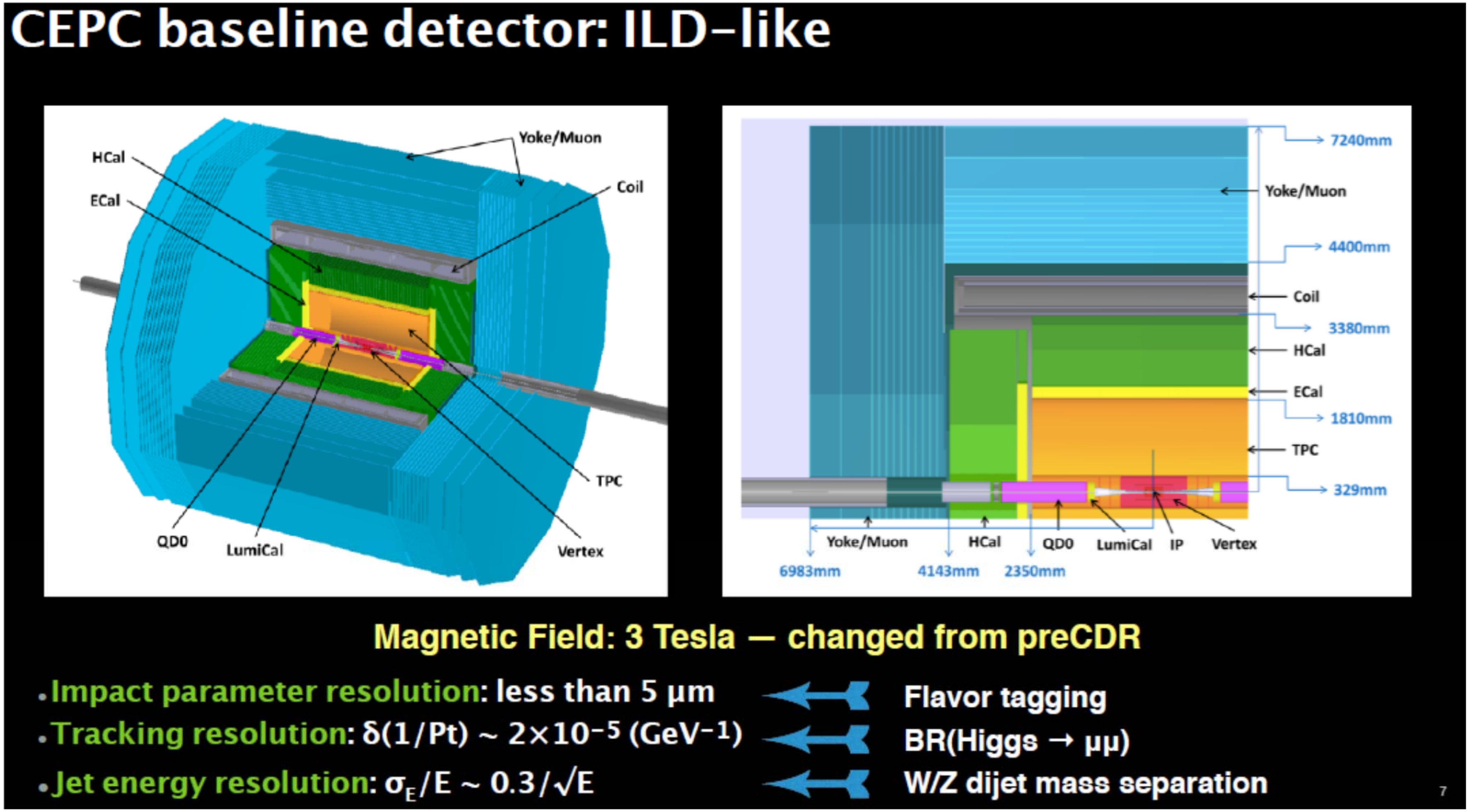
The aluminum chamber manufacturing procedure is:

- Extrusion of the chambers,
- Machining of the components to be welded,
- Chemical cleaning,
- Welding of the water connections and flanges,
- Leak detections.





CEPC Detector



SppC Status

SppC Design Scope (201701 version)

Top priority: reducing cost!
Instead of increasing field

- **Baseline design**
  - Tunnel circumference: 100 km
  - Dipole magnet field: 12 T, iron-based HTS technology (IBS)
  - Center of Mass energy: >70 TeV
  - Injector chain: 2.1 TeV
- **Upgrading phase**
  - Dipole magnet field: 20 -24T, IBS technology
  - Center of Mass energy: >125 TeV
  - Injector chain: 4.2 TeV (adding a high-energy booster ring in the main tunnel in the place of the electron ring and booster)
- **Development of high-field superconducting magnet technology**
  - Starting to develop required HTS magnet technology before applicable iron-based wire is available
  - ReBCO & Bi-2212 and LTS wires be used for model magnet studies and as an option for SPPC: stress management, quench protection, field quality control and fabrication methods

SPPC Parameter Choice and Comparation

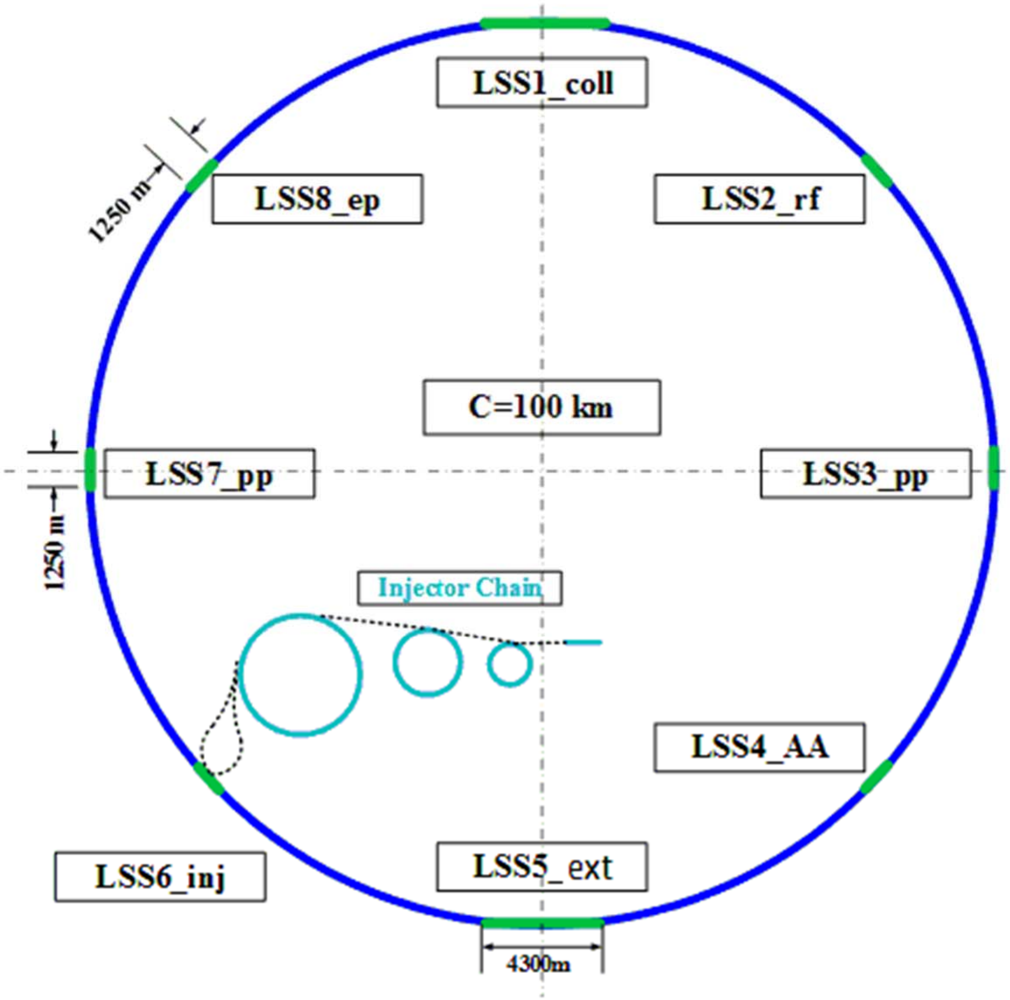
Table 2: SPPC Parameter list(2017.1)[4].[6]

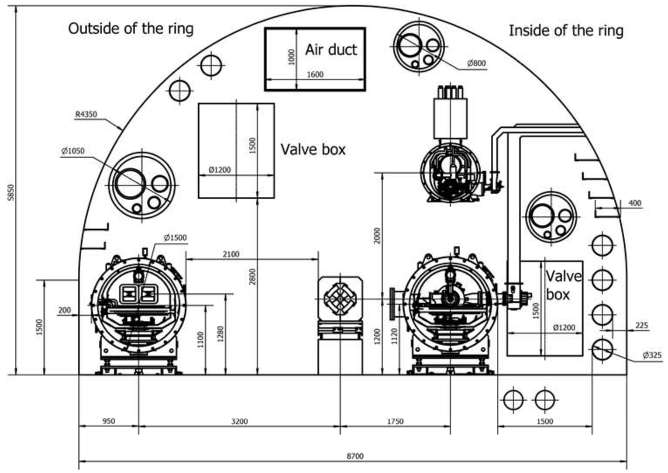
	SPPC (Pre-CDR)	SPPC 61Km	SPPC 100Km	SPPC 100Km	SPPC 82Km	SPPC phase 1	SPPC phase 2
Main parameters and geometrical aspects							
c.m. Energy[E_0]/TeV	71.2	70	100.0	128.0	100.0	75.0	125.0-150.0
Circumference[C_0]/km	54.7	61.0	100.0	100.0	82.0	100.0	100.0
Dipole field[B]/T	20	19.88	16.02	19.98	19.74	12.00	20-24
Dipole curvature radius[ρ]/m	5928	5889.64	10676.1	10676.1	8441.6	10415.4	-
Bunch filling factor[f_2]	0.8	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	0.78	-
Total dipole length [L_{Dipole}]/m	37246	37006	67080	67080	53040	65442	-
Arc length[L_{ARC}]/m	47146	47443	86000	86000	68000	83900	-
Straight section length[L_{ss}]/m	7554	13557	14000	14000	14000	16100	-
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}	1.01×10^{35}	-
Beta function at collision[β^*]/m	0.75	0.85	0.99	0.22	1.06	0.71	-
Max beam-beam tune shift per IP[ξ_y]	0.006	0.0065	0.0068	0.0079	0.0073	0.0058	-
Number of IPs contribut to ΔQ	2	2	2	2	2	2	2
Max total beam-beam tune shift	0.012	0.0130	0.0136	0.0158	0.0146	0.0116	-
Circulating beam current[I_b]/A	1.0	1.024	1.024	1.024	1.024	0.768	-
Bunch separation[Δt]/ns	25	25	25	25	25	25	-
Number of bunches[n_b]	5835	6506	10667	10667	8747	10667	-
Bunch population[N_p] (10^{11})	2.0	2.0	2.0	2.0	2.0	1.5	-
Normalized RMS transverse emittance[ε]/μm	4.10	3.72	3.59	3.11	3.35	3.16	-
RMS IP spot size[σ^*]/μm	9.0	8.85	7.86	3.04	7.86	7.22	-
Beta at the 1st parasitic encounter[$\beta 1$]/m	19.5	18.67	16.26	69.35	15.31	22.03	-
RMS spot size at the 1st parasitic encounter[σ_1]/μm	45.9	43.13	33.10	56.19	31.03	41.76	-
RMS bunch length[σ_z]/mm	75.5	56.69	66.13	14.62	70.89	47.39	-
Full crossing angle[θ_c]/μrad	146	138.03	105.93	179.82	99.29	133.65	-
Reduction factor due to cross angle[F_{ca}]	0.8514	0.9257	0.9247	0.9283	0.9241	0.9265	-
Reduction factor due to hour glass effect[F_h]	0.9975	0.9989	0.9989	0.9989	0.9989	0.9989	-
Energy loss per turn[U_0]/MeV	2.10	1.98	4.55	12.23	5.76	1.48	-
Critical photon energy[E_c]/keV	2.73	2.61	4.20	8.81	5.32	1.82	-
SR power per ring[P_0]/MW	2.1	2.03	4.66	12.52	5.90	1.13	-
Transverse damping time [τ_x]/h	1.71	1.994	2.032	0.969	1.32	4.70	-
Longitudinal damping time [τ_ε]/h	0.85	0.997	1.016	0.4845	0.66	2.35	-

SPPC main parameters (updated)

Parameter	Unit	Value		
		PreCDR	CDR	Ultimate
Circumference	km	54.4	100	100
C.M. energy	TeV	70.6	75	125-150
Dipole field	T	20	12	20-24
Injection energy	TeV	2.1	2.1	4.2
Number of IPs		2	2	2
Nominal luminosity per IP	$cm^{-2}s^{-1}$	1.2e35	1.0e35	-
Beta function at collision	m	0.75	0.75	-
Circulating beam current	A	1.0	0.7	-
Bunch separation	ns	25	25	-
Bunch population		2.0e11	1.5e11	-
SR power per beam	MW	2.1	1.1	-
SR heat load per aperture @arc	W/m	45	13	-

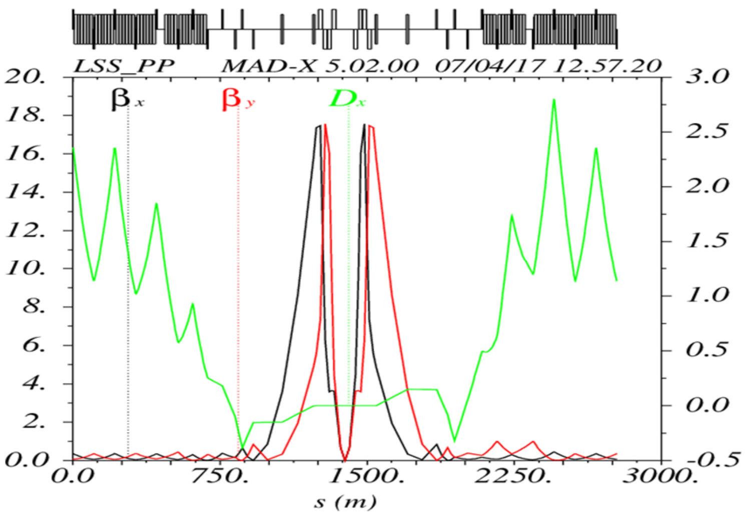
SPPC Layout


LSS1_coll
LSS2_rf
LSS3_pp
LSS4_AA
LSS5_ext
LSS6_inj
LSS7_pp
LSS8_ep
C=100 km
Injector Chain
1250 m
1250 m
4300m

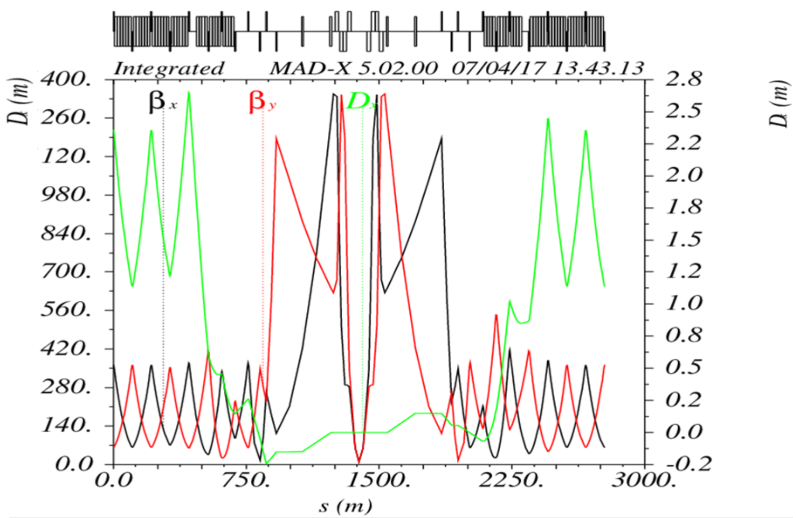

Outside of the ring
Inside of the ring
Air duct
Valve box
Valve box
950
3200
1750
1500
8700

SppC lattice design

- Different lattice designs
  - Different schemes (100 TeV and 75 TeV @100 km)
  - Lattice at injection
  - Compatibility between CEPC and SPPC
  - Arc cells, Dispersion suppressors, insertions



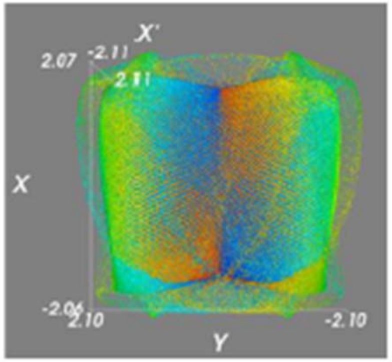
IP: at collision

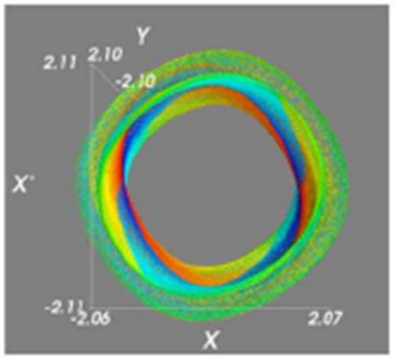


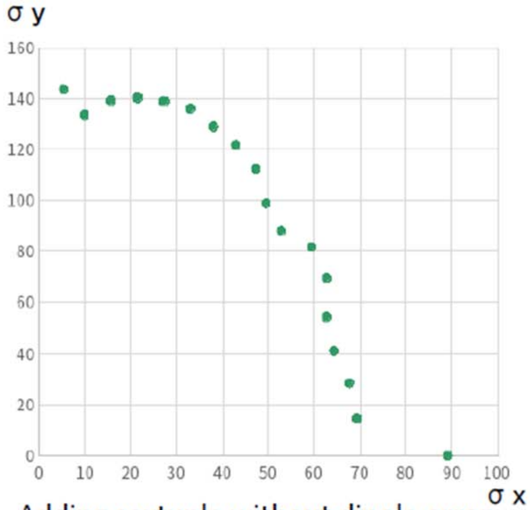
IP: at injection

Dynamic aperture study

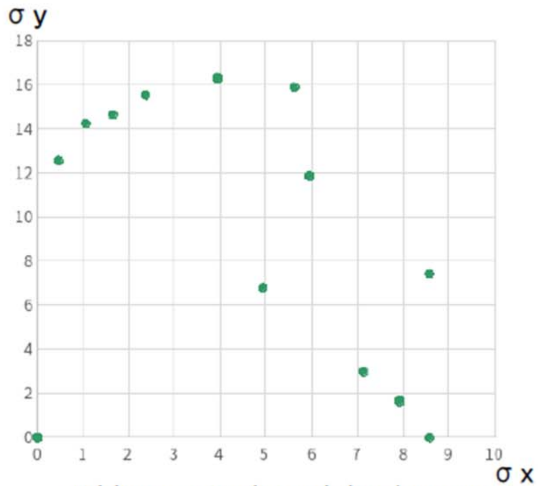
- At collision energy
- At injection energy
  (Sixtrack code)



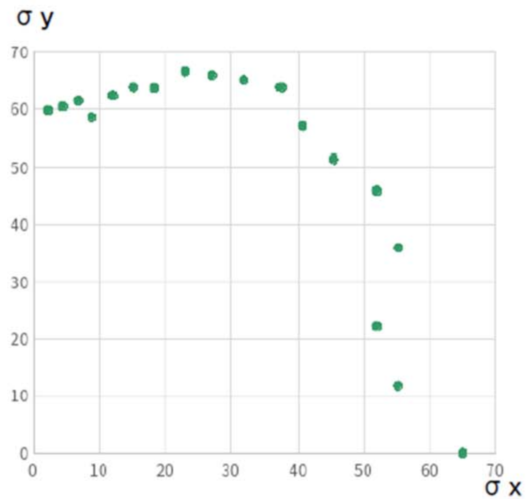




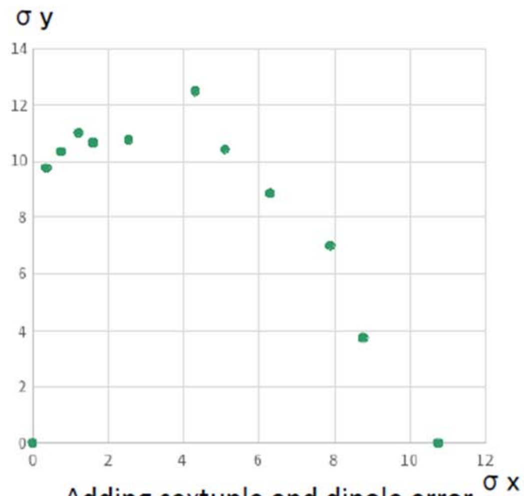
Adding sextuple without dipole error
(chromaticity corrected)



Adding sextuple and dipole error
(chromaticity corrected)



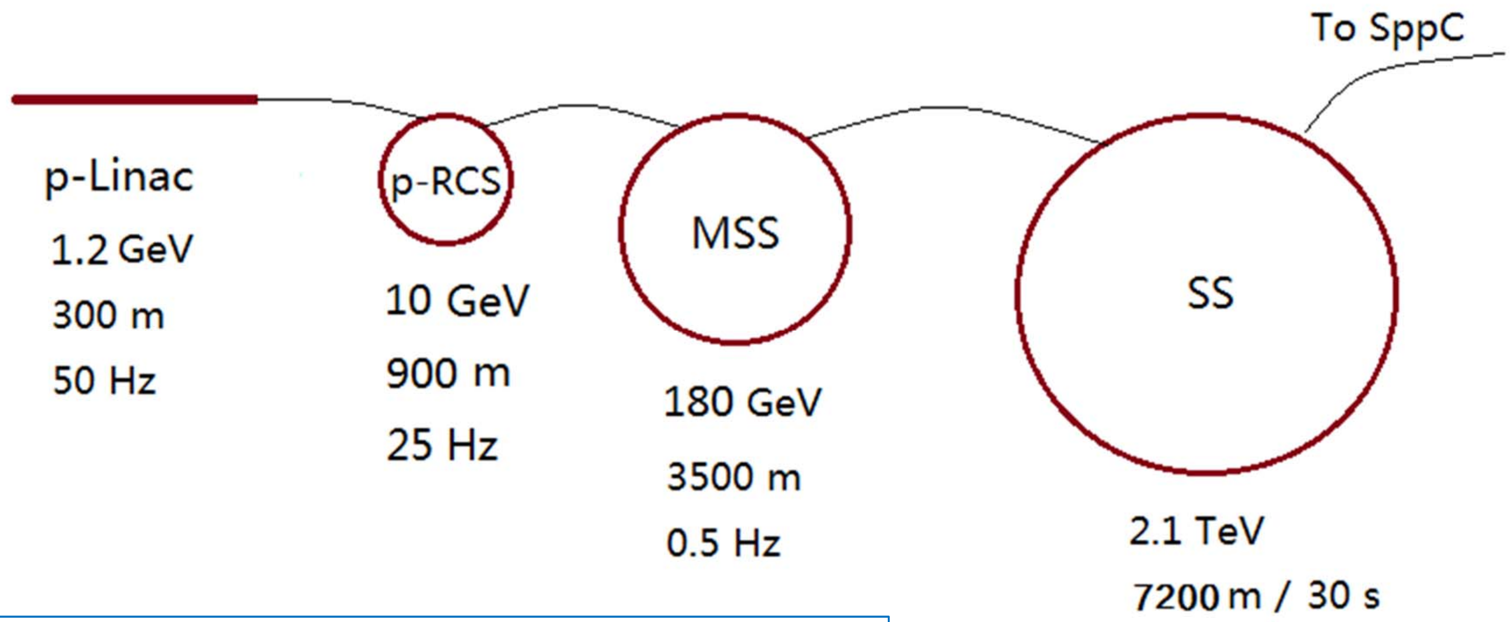
Adding sextuple without dipole error
(chromaticity corrected)



Adding sextuple and dipole error
(chromaticity corrected)

Injector chain

(for proton beam)



p-Linac: proton superconducting linac

p-RCS: proton rapid cycling synchrotron

MSS: Medium-Stage Synchrotron

SS: Super Synchrotron

Ion beams have dedicated linac (I-Linac) and RCS (I-RCS)

Major parameters for the injector chain

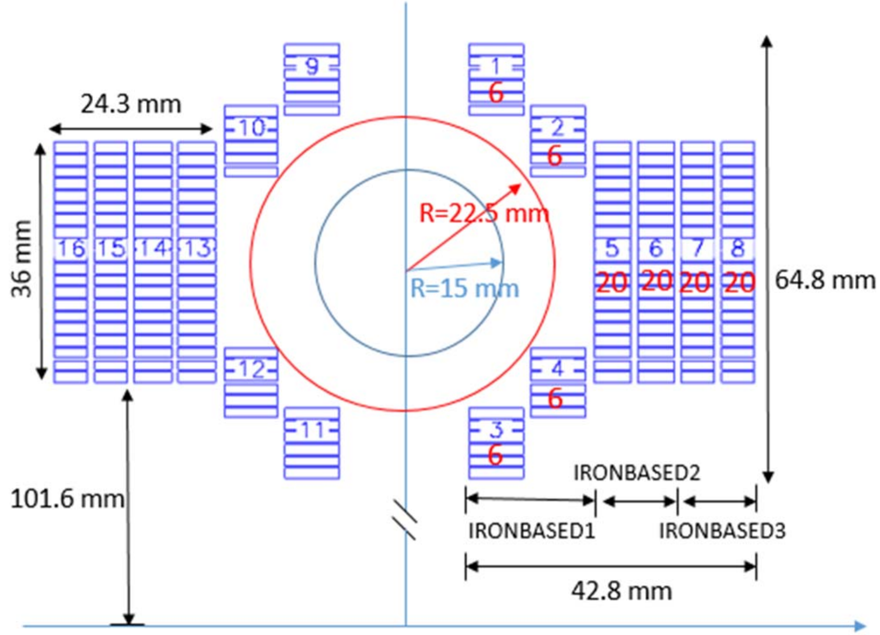
	Value	Unit		Value	Unit
p-Linac			MSS		
Energy	1.2	GeV	Energy	180	GeV
Average current	1.4	mA	Average current	20	uA
Length	~300	m	Circumference	3500	m
RF frequency	325/650	MHz	RF frequency	40	MHz
Repetition rate	50	Hz	Repetition rate	0.5	Hz
Beam power	1.6	MW	Beam power	3.7	MW
p-RCS			SS		
Energy	10	GeV	Energy	2.1	TeV
Average current	0.34	mA	Accum. protons	1.0E14	
Circumference	970	m	Circumference	7200	m
RF frequency	36-40	MHz	RF frequency	200	MHz
Repetition rate	25	Hz	Repetition period	30	s
Beam power	3.4	MW	Protons per bunch	1.5E11	
			Dipole field	8.3	T

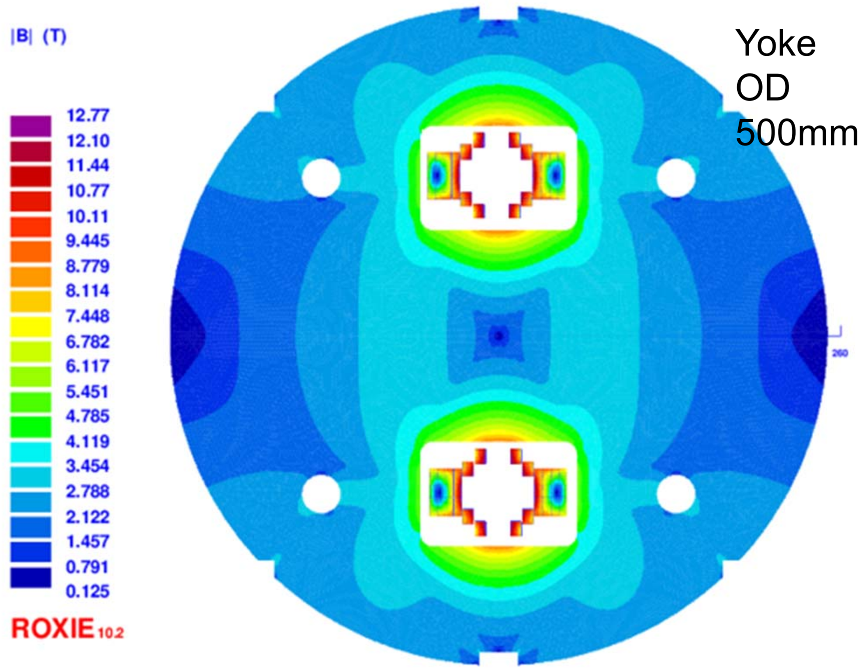
Technical challenges and R&D requirements -High field SC magnets

- Following the new SPPC design scope
  - Phase I: 12 T, all-HTS (iron-based conductors)
  - Phase II: 20-24 T, all-HTS
- New magnet design for 12-T dipoles
- R&D effort in 2016-2018
  - Cables, infrastructure
  - Development of a 12-T Nb3Sn-based twin-aperture magnets (alone, with NbTi, with HTS)
- Collaboration
  - Domestic collaboration frame on HTS superconductors (material, industrial and applications) formed in October 2016
  - CERN-IHEP collaboration on HiLumi LHC magnets

Design of 12-T Fe-based Dipole Magnet

C. Wang, E. Kong (USTC), Q. Xu et al.





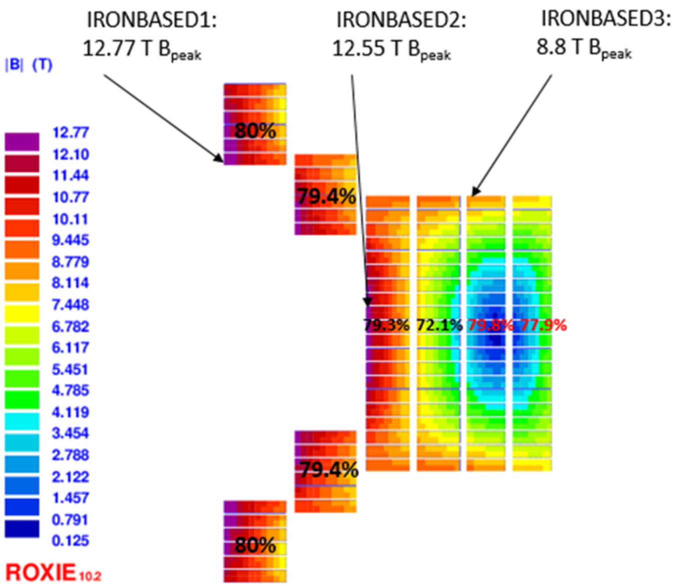


Table 1: Main parameters of the cables

Cable	Hight	Width-i	Width-o	Ns	Strand	Filament	Insulation
IRONBASED 1	8	1.5	1.5	20	IRON-BASED	FE-BASED	0.15
IRONBASED 2	5.6	1.5	1.5	14	IRON-BASED	FE-BASED	0.15
IRONBASED 3	5	1.5	1.5	12	IRON-BASED	FE-BASED	0.15

Table 2: Main parameters of the strand

Strand	diam.	cu/sc	RRR	Tref	Bref	Jc@ BrTr	dJc/dB
IRON-BASED	0.802	1	200	4.2	10	4000	111

For per meter of such magnet, the required length of the iron-based strand: 6.08 Km

Yuhong Zhang

CepC-SppC e-p/A Design Consideration

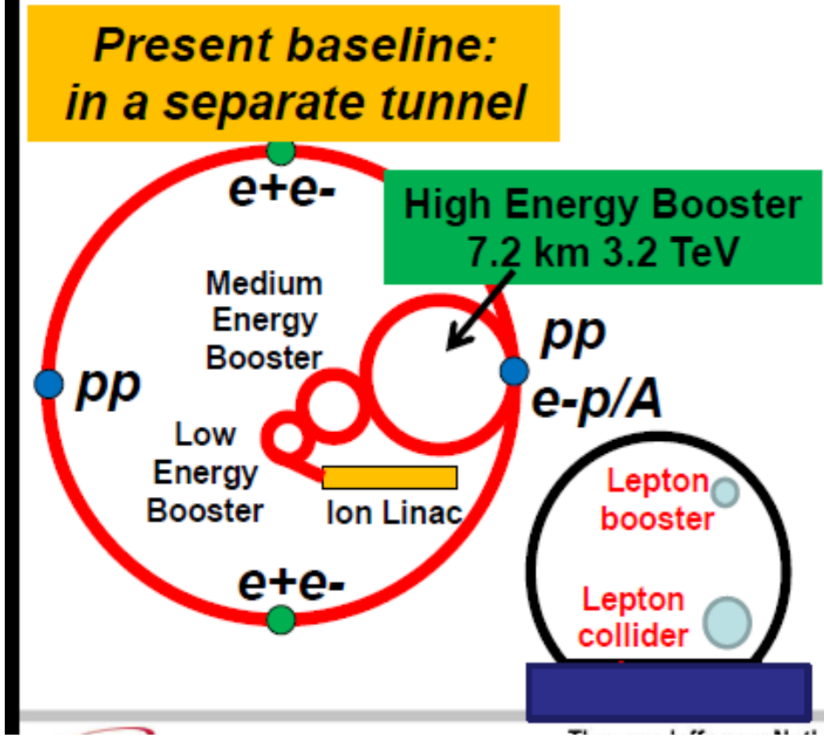
- **Assumption: NO upgrade of *CepC-SppC* for realizing *e-p/A***
  ➔ *e-p/A* performance is determined by beams from *CepC-SppC*
- ***CepC e+e-* collisions and *e-p/A* collision can't be run *simultaneously***
  – Each *CepC* lepton beam has only 50 bunches due to the one-ring design while one proton beam in *SppC* has 3000 to 6000 bunches
  – *CepC* lepton beam is extreme flat (aspect ratio ~330) while a *SppC* proton is basically flat, it is very difficult to have the spot sizes of two beams matched
- **Without the constraint of running e+e- and *e-p/A* collisions simultaneously, the electron beam in *CepC* can be reconditioned to match the proton beam for optimizing the *e-p/A* collision luminosity**
  – Increase electron bunches to 3000
  – Reduce the emittance aspect ratio to make it a round beam
  – Double the beam current (still under 100 MW SR power budget)

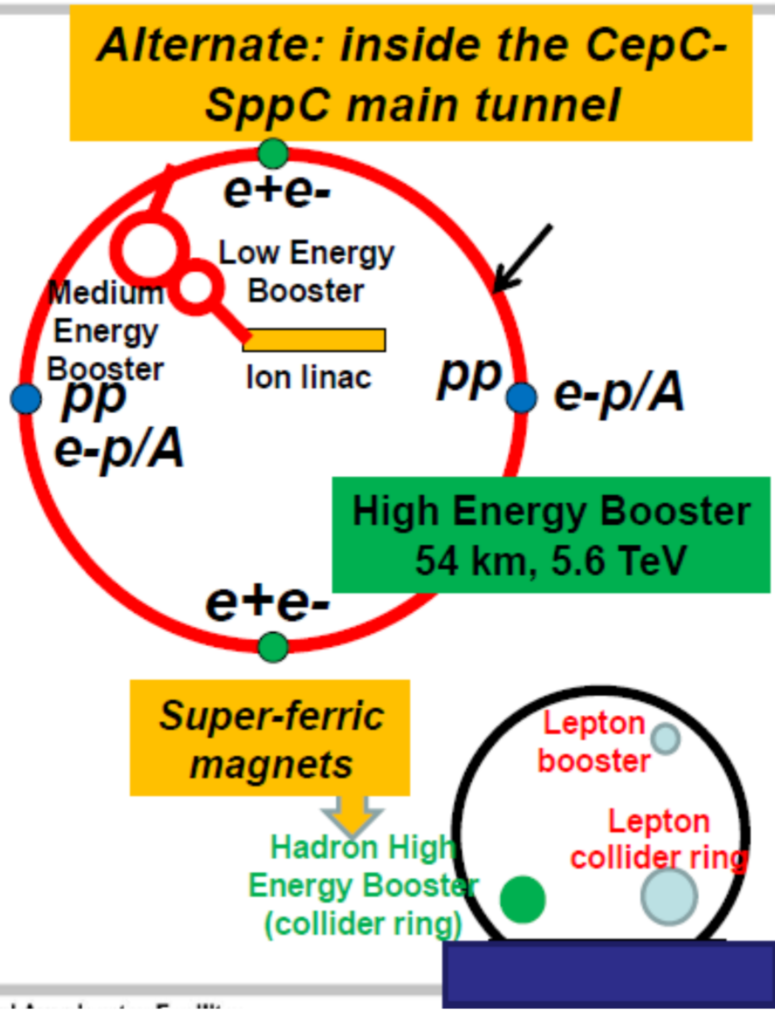
This early design has not been synchronized with the recent change of CepC-SppC baseline (100 km, double ring)

Yuhong Zhang

SppC High Energy Booster (HEB)

Location of HEB	Circum.	Energy	Dipole
	km	TeV	T
Separate tunnel	7.2	3.2	12
In main tunnel	54	5.6	3





Yuhong Zhang

Potential 1st Stage of CepC-SppC e-p/A

Location of the SppC HEB		A separate tunnel		Inside the main tunnel	
Particle		Proton	Electron	Proton	Electron
Beam energy	TeV	2.5	0.12	5.6	0.12
Center-of-mass energy	TeV	1.0		1.64	
No. of collision points (detectors)		1		2	
Luminosity per IP, w/ HG reduction	$10^{33}/cm^2/s$	5.4		8.2	

LHeC: CM energy 1.3 TeV, luminosity $(1.3 \text{ to } 14.4)\times10^{33}$

Particle		p	e	p	e	p	e	p	e
Beam energy (HEB in main tunnel)	TeV	5.6	0.045 (Z)	5.6	0.08 (W)	5.6	0.120 (H)	5.6	0.175 (tt)
CM energy	TeV	1.00		1.33		1.64		2.00	
Luminosity per IP (with HG reduction)	$10^{33}/cm^2/s$	18.0		18.4		8.2		1.57	

Yuhong Zhang

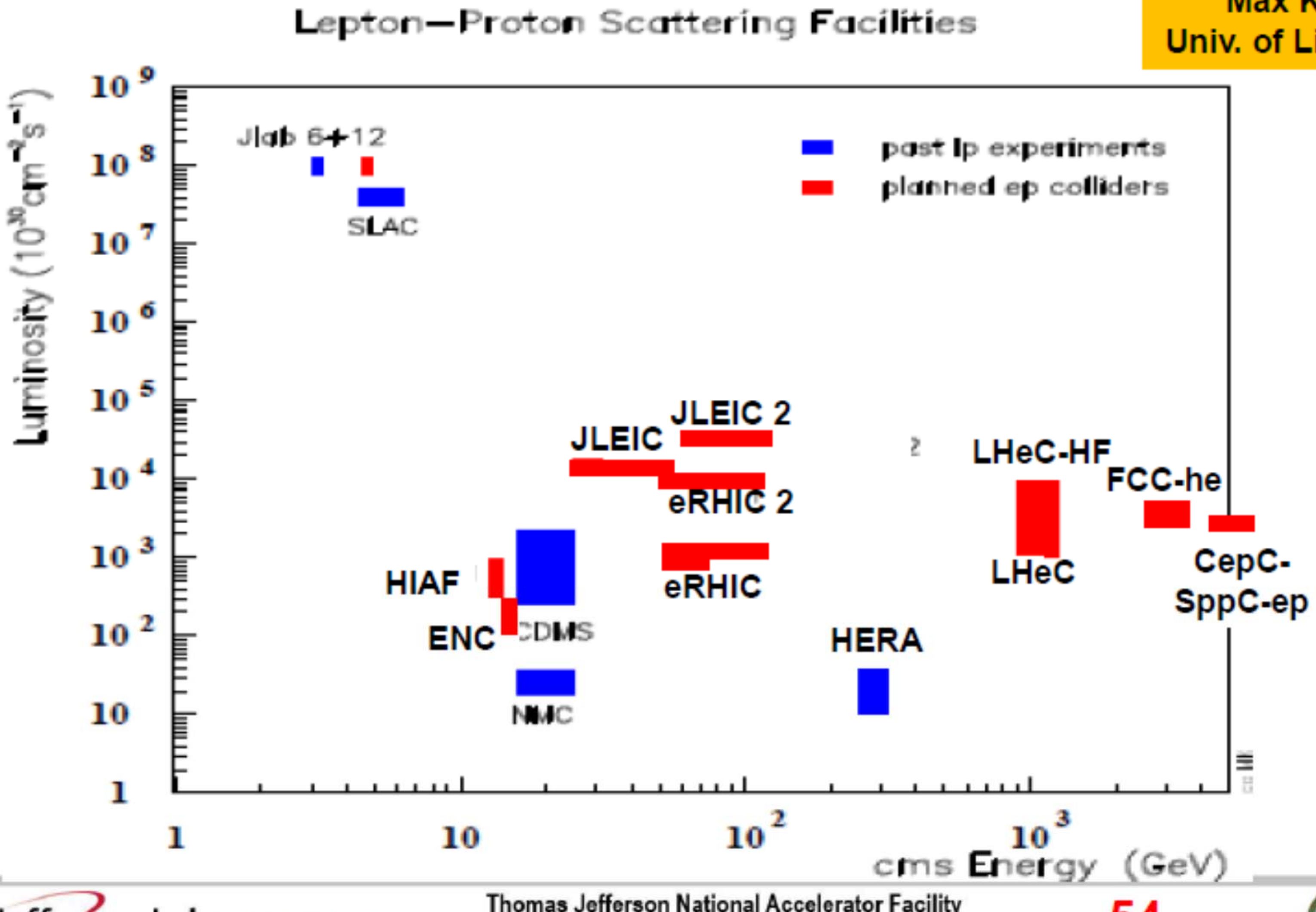
(Preliminary) *CepC-SppC e-p* Parameters

Operational scenario		*e-p* and *pp*		*e-p* only	
Particle		Proton	Electron	Proton	Electron
Beam energy	TeV	3.56	0.12	3.56	0.12
CM energy	TeV	4.1		4.1	
Beam current	mA	860	33.8	430	33.8
Particles per bunch	10^{10}	16.8	0.66	16.8	1.31
Number of bunch		5812	5812	2924	2924
Bunch spacing	ns	25	25	50	50
Bunch repetition rate	MHz	40	40	20	20
Normalized emittance, (x/y)	µm rad	**4.1**	250	**2.35**	250
Bunch length, RMS	cm	7.55	0.242	7.55	0.242
Beta-star (x/y)	cm	75	7.5	75	4.35
Beam spot size at IP (c/y)	µm	9.0	9.0	6.65	6.65
Beam-beam per IP(x/y)		0.0002	0.15	0.0007	0.15
Crossing angle	mrad	~0.8		~0.8	
Hour-glass (HG) reduction		0.904		0.794	
Lumi. per IP, w/ HG reduction	10^{33}/cm^2/s	3.2		4.8	

Yuhong Zhang

A New World of Electron-Ion Collider

Max Klein
Univ. of Liverpool



Domestic Collaboration on HTS

In October 2016, A consortium for High-temperature superconducting materials, industrialization and applications was formed in China, with participation of major research and production institutions on HTS.

China is actually leading the development of Fe-HTS technology in the world; world-first 100-m Fe-HTS wire was made by CAS-Institute of Electrical Engineering in the last year .

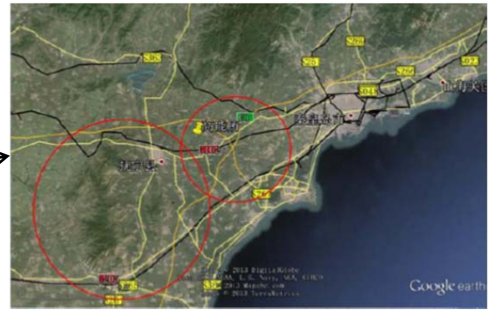
CEPC Site Selections

Bejing

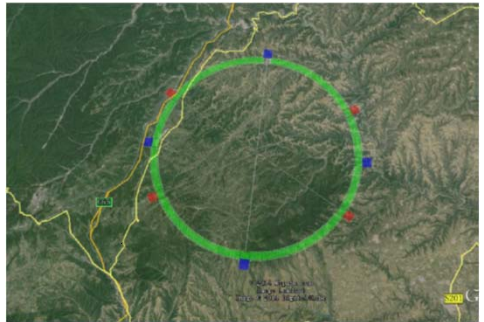
Baoding
(xiong an)

Tianjin 4

1



2



3

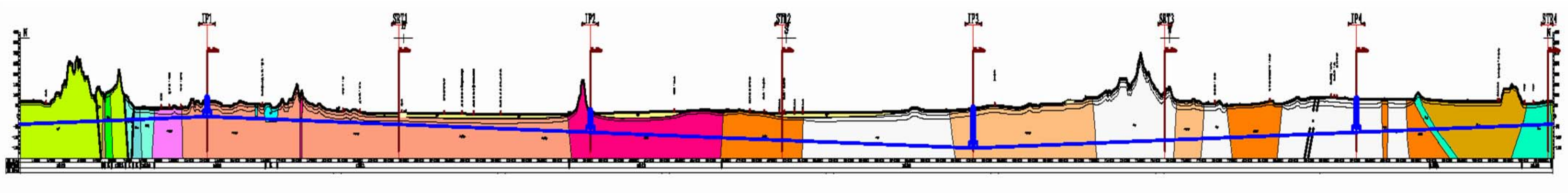
1) Qin huang dao，Heihe （Completed in 2014）

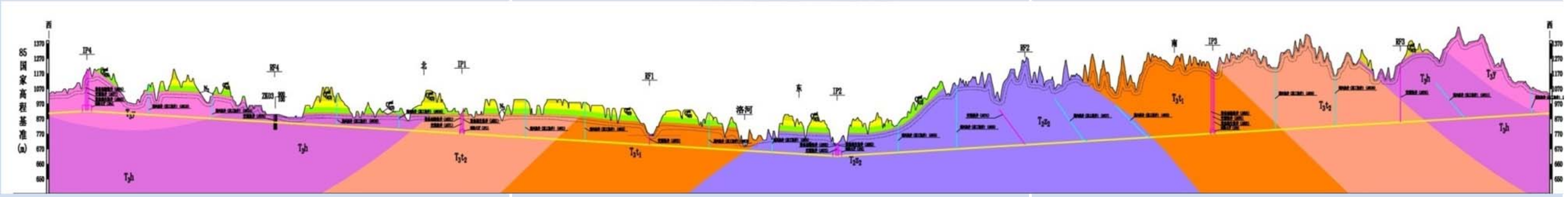
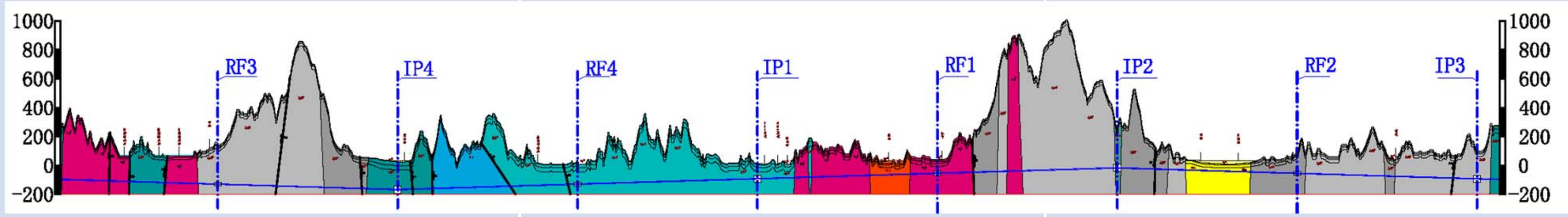
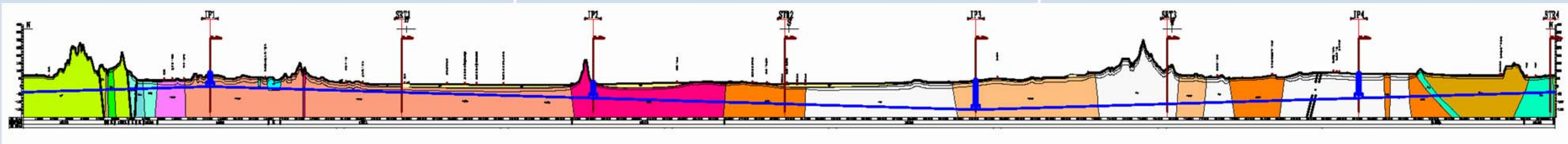
2) Huanging，Shanxi（Completed in 2017)

3)Shen shan，Guangdong (Completed in 2016)

4) Baoding (Xiong an), Hebei (Started in August 2017, near Beijing ~200km t

Longitudinal profile of tunnel （at Funing site, 1）

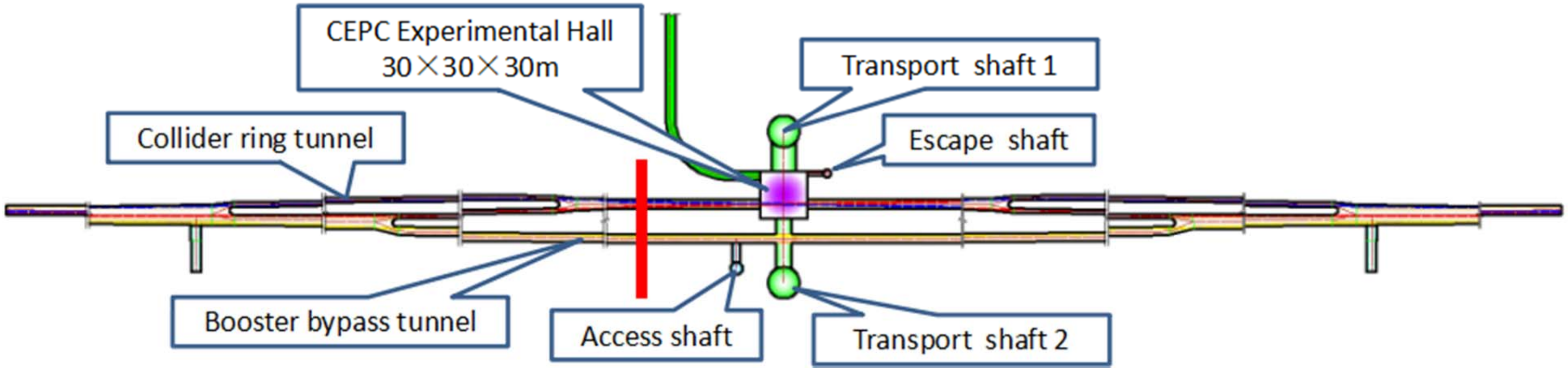


<table>
<tr><th>Item</th><th>Huangling</th><th>Shen-Shan</th><th>Funing</th></tr>
<tr><td rowspan="6">Project layout</td><td colspan="3">Huangling（100km）</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3">Shen-Shan（100km）</td></tr>
<tr><td colspan="3">
</td></tr>
<tr><td colspan="3">Funing（100km）</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Construction difficulty</td><td>Moderate</td><td>Relatively difficult</td><td>Relatively easy</td></tr>
</table>

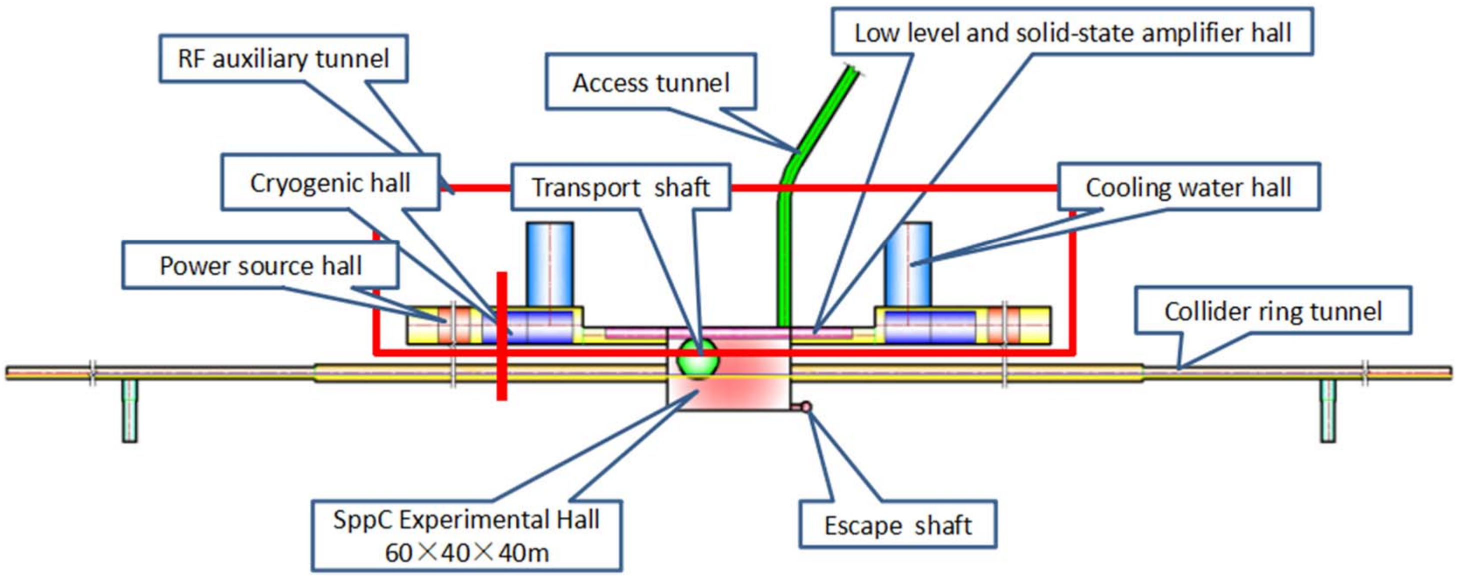
CEPC IP and RF layouts

YREC

IP1 / IP3

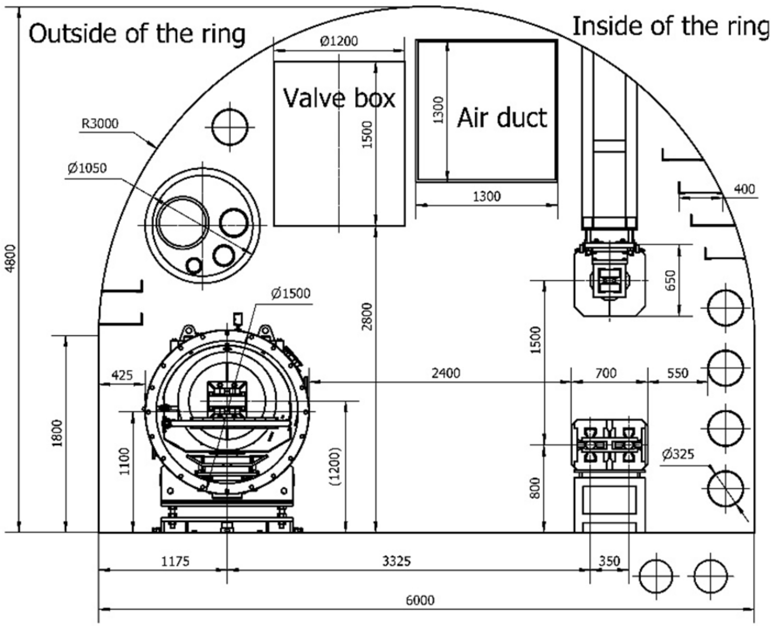


IP2 / IP4

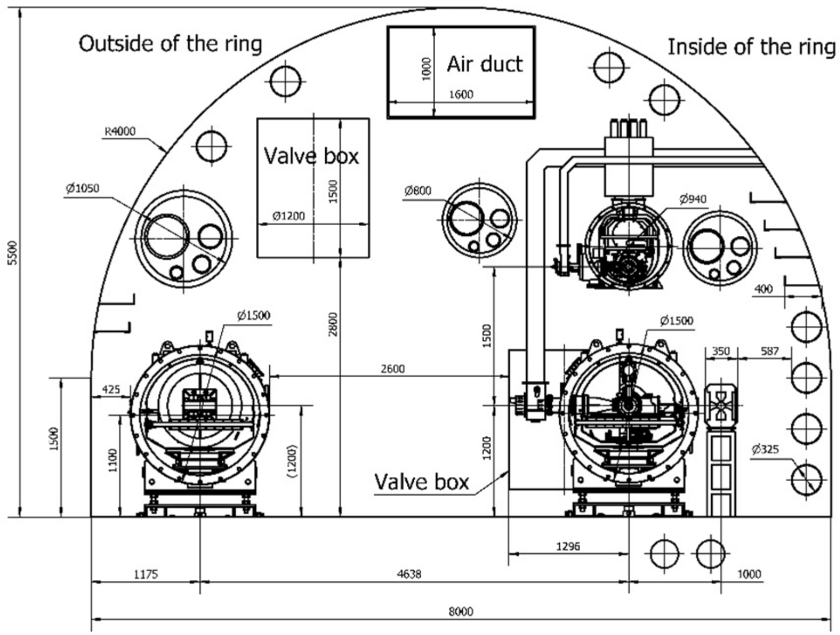


CEPC-SppC Tunnel Cross Sections

Tunnel cross section at arc-section
Width: 6,000 mm. Height: 4,800 mm.



Tunnel cross section at RF-section
Width: 8,000 mm. Height: 5,500 mm.



Mini-review workshop of CEPC-SPPC CDR (Nov. 4-5, 2017)

CEPC-SPPC CDR Mini-review members

Name (alphabetical order)

Anton Bogomyakov	BINP	Russia
Brian Foster	Oxford U.	U.K.
Eugene Levichev	BINP	Russia
Kexin Liu（刘克新）	Peking U.	China
Ernie Malamud	Fermilab	USA
Kazuhito Ohmi	KEK	Japan
Katsunobu Oide	CERN / KEK	Switzerland
Carlo Pagani	U. of Milan / INFN	Italy
John Seeman	SLAC	USA
Sergey Sinyatkin	BINP	Russia
Mike Sullivan	SLAC	USA
Chuanxiang Tang（唐传祥）	Tsinghua U.	China
Lin Wang （王林）	USTC	China
Xiangqi Wang（王相綦）	USTC	China
Akira Yamamoto	KEK	Japan

Sunday, November 5		
08:30 – 09:00 09:00 – 09:30 09:30 – 10:00 10:00 – 10:30	SRF RF power source Cryogenic system Magnet	Jiyuan Zhai Zusheng Zhou Shaopeng Li Fusan Chen
10:30 – 11:00	Coffee (30’)	

Informal Mini-Review of CEPC-SPPC CDR

November 4 – 5, 2017, IHEP, Main Building, Room A415

Agenda (draft v2. 09/14/2017)

Saturday, November 4		
08:30 – 08:35 08:35 – 09:10 09:10 – 09:40 09:40 – 10:10 10:10 – 10:40	Welcome Overview of beam dynamics Parameters Optics Dynamic aperture	Yifang Wang Chenghui Yu Dou Wang Yiwei Wang Yuan Zhang
10:40 – 11:10	Coffee (30’)	
11:10 – 11:40 11:40 – 12:10 12:10 – 12:40	Beam-beam Instabilities Machine-detector interface	Yuan Zhang Na Wang Sha Bai
12:40 – 14:00	Lunch	
14:00 – 14:30 14:30 – 15:00 15:00 – 15:30	Injection and extraction Booster Linac and sources	Xiaohao Cui Tianjian Bian Cai Meng
15:30 – 16:00	Coffee (30’)	
16:00 – 16:30 16:30 – 17:00 17:00 – 17:30 17:30 – 18:30	Synchrotron radiation Overview of SPPC SC magnet for SPPC Discussion	Yadong Ding Jingyu Tang Qingjin Xu All
19:00	Dinner	

CEPC International Collaboration Status-1

International collaboration experts in the CEPC study team:

- ✓ All accelerator subsystem working groups have established data base of potential international collaboration experts

- ✓ All accelerator subsystems have at least one international collaboration expert in the subsystem working groups

International collaboration with major international labs:

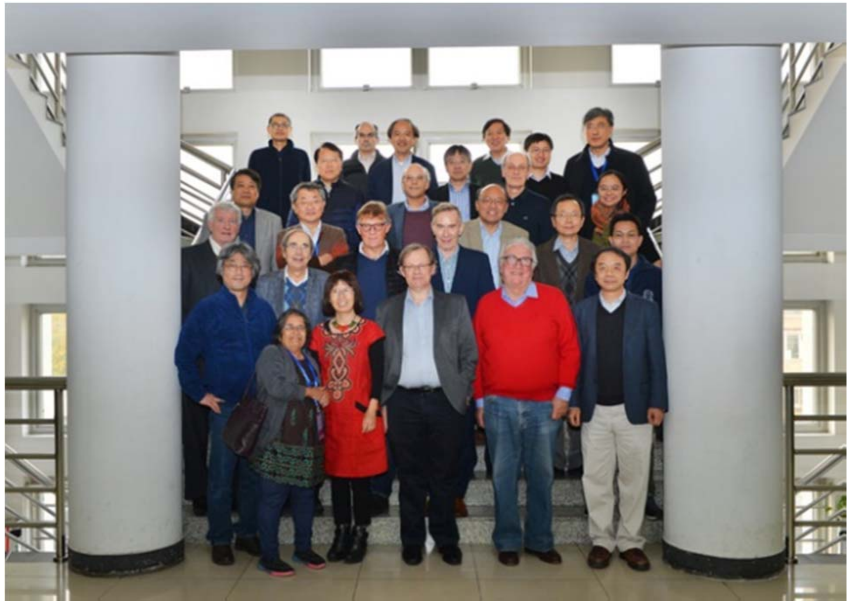
- ✓ IHEP-BINP (Russia) MoU (Jan 2016)

- ✓ IHEP-KEK (Japan) MoU (Sept 2017) (Circular collider), in 2018, two more MoUs on SC magnets and SC Cavity R&D and facbrications

- ✓ IHEP-MEPhI (Russia) (Nov 2017)

More than 20 MoU in general

CEPC International Collaboration Status-2

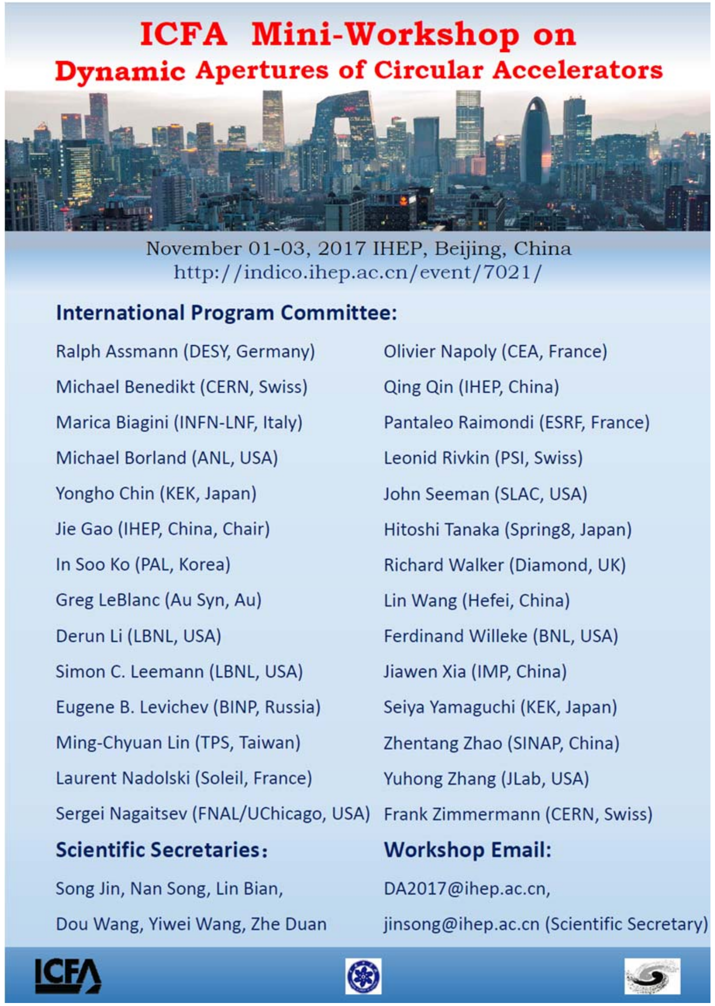


The first CEPC-SppC international
Collaboration Workshop
Nov 6-8, 2017, IHEP, Bejing

The thhird CEPC-SppC International
Advisory Committee Meeting
Nov 8-9, 2017, Beijing

http://indico.ihep.ac.cn/event/6618

ICFA Mini Workshop on Dynamics Aperture of Circular Accelerators



http://indico.ihep.ac.cn/event/7021/

40 participants from USA, Russia, Swiss, Japan, France, Korea, China..., concentrating the key beam dynamic aperture problem for CEPC also...

Experts from pp, e+e-, ep, eA, light source, damping ring for ILC....

CEPC Industrial Promotion Consortium (CIPC)

Established in Nov. 7 , 2017

1) Superconduting materials (for cavity and for magnets)
2) Superconductiong cavities
3) Cryomodules
4) Cryogenics
5) Klystrons
6) Vacuum technologies
7) Electronics
8) SRF
9) Power sources
10) Civil engineering
11) Precise machinary.....

More than 40 companies joined in first phase of CIPC，
and more will join later....

CEPC Funding

HEP seed money

11 M RMB/3 years (2015-2017)

国家重点研发计划
项目预申报书

FY 2016

Ministry of Science and Technology
Requested 45M RMB; 36M RMB approved

项目名称：	高能环形正负电子对撞机相关的物理和关键技术预研究
所属专项：	大科学装置前沿研究
指南方向：	新一代粒子加速器和探测器关键技术和方法的预先研究
推荐单位：	教育部
申报单位：（公章）	清华大学

R&D Funding - NSFC

Increasing support for CEPC D+RDby NSFC
5 projects (2015); 7 projects(2016)

CEPC相关基金名称（2015-2016）	基金类型	负责人	承担单位
高精度气体径迹探测器及激光校正的研究 (2015)	重点基金	李玉兰/陈元柏	清华大学/高能物理研究所 Tsinghua IHEP
成像型电磁量能器关键技术研究(2016)	重点基金	刘树彬	中国科技大学 USTC
CEPC局部双环对撞区挡板系统设计及螺线管场补偿(2016)	面上基金	白莎	高能物理研究所
用于顶点探测器的高分辨、低功耗SOI像素芯片的若干关键问题的研究(2015)	面上基金	卢云鹏	高能物理研究所
基于粒子流算法的电磁量能器性能研究 (2016)	面上基金	王志刚	高能物理研究所
基于THGEM探测器的数字量能器的研究(2015)	面上基金	俞伯祥	高能物理研究所
高粒度量能器上的通用粒子流算法开发(2016)	面上基金	阮曼奇	高能物理研究所
正离子反馈连续抑制型气体探测器的实验研究(2016)	面上基金	祁辉荣	高能物理研究所
CEPC对撞区最终聚焦系统的设计研究(2015)	青年基金	王逵	高能物理研究所
利用耗尽型CPS提高顶点探测器空间分辨精度的研究 (2016)	青年基金	周扬	高能物理研究所
关于CEPC动力学孔径研究(2016)	青年基金	王毅伟	高能物理研究所

~60M RMB CAS-Beijing fund, talent program

~500M RMB Beijing fund (light source)

year 2017 funding request (45M) to MOST
and other agencies under preparation

funding needs for carrying out CEPC design and R&D should be fully met by end of 2018

IHEP ILC Collaboration

IHEP ILC R&D domain:

Since 2005 IHEP accelerator center has setup ILC collaboration group and since 2010 ILC group with administration nature has been established also, which guaranteed the smooth progress of China's participation of ILC international collaboration. The main R&D domais which IHEP participated are as following as shown in Fig. 3.

1) ILC250 GeV and ILC500 GeV parameter optimization design

3) ILC SC accelerator technologies

2) ILC ATF2 beam dynamics and hardwares

4) ILC damping ring design and technologies

5) ILC final focus optimization design and beam-beam effect study

6) ILC positron source target thermodynamics study and polarization source

7) ILC power source: Marx modulator

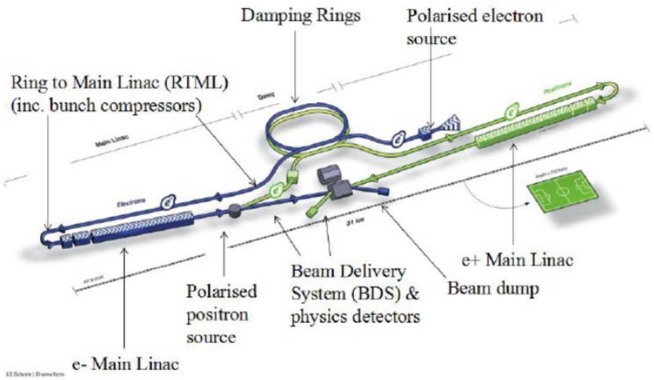


Fig. 3: IHEP ILC collaboration domains

Achievement of IHEP on ILC collaboration:

Since 2005 IHEP participated ILC ATF2 collaboration and fabricated all ATF2 beam line magnets, such as dipole and quadupoles, as shown in Fig. 4. In 2008, IHEP ILC group first demonstrated that on ATF2 the beam size has the potential to reach 20nm instead of 37nm, and due to this important result, ATF2 became a final focus facility not only for ILC but also for CLIC.

Fig. 4: ILC ATF2 beam line magnets

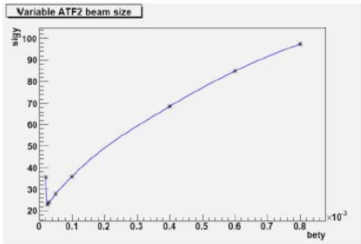


Fig. 5 AFT2 design and beam dynamics studies

Since 2005, IHEP ILC group started to make R&D on 1.3GHz superconducting cavities, from single cell to 9 cell, from fine grain to large grain niobium, from low loss shape, to TELSLA-like, and to TESLA cavities shapes, IHEP becomes the Institute which covers the whole range of the cavity types and materials, as shown in Fig. 5. In addition to cavity R&D, IHEP conducted ILC cryomodule study with both a 1.3GHz single 9cell cavity ILC Test Cryomoulde, including cacity, tunner, high power coupler, LLRF and cryostate, and 12m cryomodule cold mass industrialization for European X-XFEL project, as shown in Fig. 6 and 7. In the domain of 1.3GHz ILC rf power source R&D, IHEP ILC group made industrialization of high power L band Marx modulator and in collaborate with Institute of Electronics, CAS (IECAS), an ILC type 1.3GHz klystron of 10MW has been also constructed and tested by IECAS, as shown in Fig. 8. In the domain of ILC damping ring study, IHEP ILC group made a ILC damping design and made damping fast kicker, as shown in Fig. 9. As for ILC250GeV proposed in 2017, IHEP group made the optimization design for the accelerator parameters.

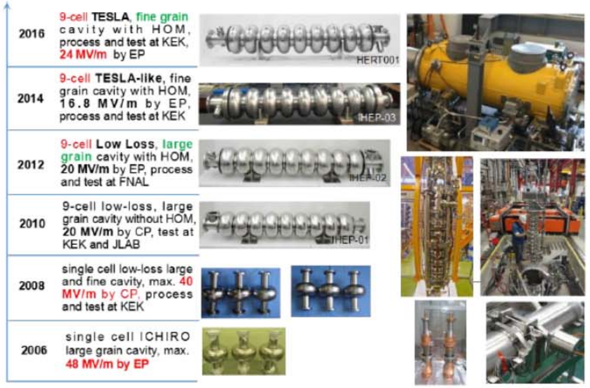


Fig. 5: ILC 1.3GHz 9-cell superconducting cavities

Fig: 6: IHEP ILC test cryomodule

Fig. 7: Euro-XFEL thermostat cryostate industrialization

Fig. 8: L band MarX Modulator and ILC 10MW klystron

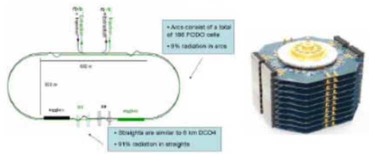


Fig. 9: ILC damping design and fast kiker

Some Important Political Histories Recalled

30年前

“我相信，这件事不会错”

26年前

“中国必须在世界高科技领域占有一席之地”

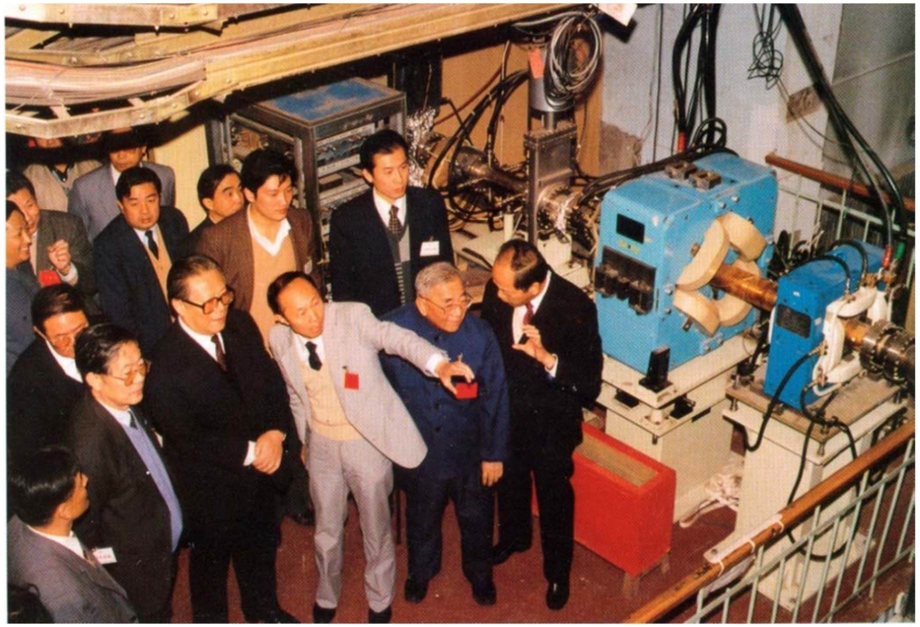
“是一个民族、一个国家兴旺发达的标志”

“这个线不能断了，要不然我们很难赶上世界的发展”

《邓小平文选》第三卷279页

中国前辈科学家们通过**BEPC(II)**，**BES(I,II,III)** 做到了

未来，从“一席之地”到“全面领先”



BEPC使我们在国际高能物理学界占有一席之地，2022年将完成使命。
在经济规模即将达到世界第一时，我们能否为30年后的中国规划一个蓝图，成为世界高能物理领域的领跑者

国家领导人对科技界提出的新希望和新要求

2013年年7月17日习总考察高能所

"中国科学院要牢记责任，

率先实现科学技术跨越发展，

率先建成国家创新人才高地，

率先建成国家高水平科技智库，

率先建设国际一流科研机构。"

"我们要引进和学习世界先进科技成果，更要走前人没有走过的路。科技界要共同努力，树立强烈的创新自信，敢于质疑现有理论，勇于开拓新的方向，不断在攻坚克难中追求卓越。"

《人民日报》2013年07月18日

ICFA前主席对中国能量前沿对撞机计划的认识和判断

ICFA主席，美国费米国家实验室主任，Nigel Lockyer教授，在自然杂志上撰文：“粒子物理：一道走向下一个前沿”

“Particle physics: Together to the next frontier”，

http://www.nature.com/news/particle-physics-together-to-the-next-frontier-1.14364

“如果中国真跑到了前头，这将会改变世界科学的格局”。

“If China does jump ahead, it will change the landscape of science.”

Nature, Volume 504, Issue 7480, 18 December 2013.

中国能花得起这个钱吗 ？

- 文明大国的应有贡献 ？
- 十八届五中全会：“发起国际大科学计划和工程”
- 刘延东在高能所：“希望中科院、高能所在未来的十年，不仅为我们国家的科学事业做出贡献，还应该为世界的科学事业发展、人类的文明进步做出中国人应有的贡献”

BEPC：	**造价/4年/中国1984年GDP ≈ 0.0001**
SSC：	**造价/10年/美国1992年GDP ≈ 0.0001**
LEP:	**造价/8年/欧洲1984年GDP ≈ 0.0002**
LHC：	**造价/10年/欧洲2004年GDP ≈ 0.0003**
ILC：	**造价/8年/日本2018年GDP ≈ 0.0002**
CEPC：	**造价/8年/中国2020年GDP ≈ 0.00005**
SppC：	**造价/8年/中国2036年GDP ≈ 0.0001**

（Y.F. Wang)

2008 北京 奥运开幕式：
造纸、毛笔、活字印刷、太极。。。

2012 伦敦 奥运开幕式：
原子核、**CERN**、互联网

2016全国政协双周协商会（俞正声主席主持， 2016年08.18）

高杰：实施以我为主的尖端重器型国际科技合作与大科学计划
2016年08月18日 | 作者:高杰 | 来源：人民政协报

任何国家要想成为世界科技强国，都必须通过以我为主的国际科技合作与大科学计划的成功实施这场“国际考试”，以证明自身的真实能力与贡献
习近平总书记在全国科技创新大会发表重要讲话指出，我国科技事业发展的目标是到2020年时使我国进入创新型国家行列，到2030年时使我国进入创新型国家前列，到新中国成立100年时使我国成为世界科技强国。党的十八届五中全会公报指出：“深入实施创新驱动发展战略，发挥科技创新在全面创新中的引领作用，实施一批国家重大科技项目，在重大创新领域组建一批国家实验室，积极提出并牵头组织国际大科学计划和大科学工程。”习总书记的讲话和十八届五中全会精神明确了战略目标，也指出了通向目标的行动路径。

高杰：开展国际科技合作与大科学计划
发布时间： 2016-08-24 | 来源： 人民政协报 |
国际科学合作与大科学计划意味着对代表人类最高科学目标的追求，意味着集世界一流的人才、理论设计与工程技术为一身。任何国家要想成为世界科技强国，就必须要通过以我为主的国际科技合作与大科学计划的成功实施来通过这场“国际考试”，以证明和体现自身的真实能力与贡献，因此它也是通往世界科技强国的必经之路。

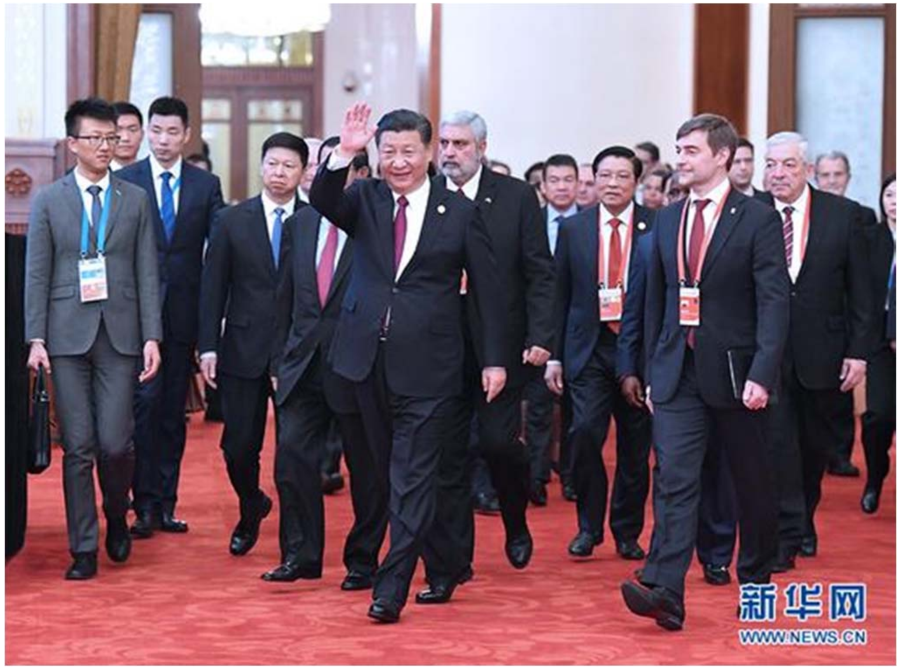
世界上一些国家和地区通过开展国际科技合作与大科学计划走到人类科学技术前沿，积累了一些成功的经验，值得学习和借鉴。这些国际科学合作与大科学计划，都大大促进了科学、技术、文化、教育、经济以及政治和军事领域的发展，积累了丰富经验，取得了大批重要成果，对我国未来的高水平发展具有重要的借鉴意义。

我国科学家根据国家“两个一百年”的发展目标也及时提出了在热核聚变领域的CFETR（中国聚变工程实验堆），在高能物理领域的大型环型对撞机**CEPC-SPPC**（环形正负电子对撞机和超级质子对撞机），在引力波方面的“天琴”计划等，这些都将是具有重要应用与科学价值的国际合作与大科学计划，意义十分重大。对上述项目，希望有关部门能够高度重视，在广泛听取专家意见的基础上尽快进行论证，给予稳定支持，确保国家目标实现，同时着力提升我国在参与的国际大科学工程中的显示度和参与水平。

人民日报评论员:大国大党 就是要有大境界大担当

2017-12-03 21:12:23　来源: 人民日报

2017年12月1日，中共中央总书记、国家主席习近平在北京人民大会堂出席中国共产党与世界政党高层对话会开幕式，并发表题为《携手建设更加美好的世界》的主旨讲话



中国共产党是世界上最大的政党。习近平总书记一再强调："大就要有大的样子。"大国大党，何谓其大？就是要有大抱负，大格局，大境界，大担当。

Conclusions

- CEPC 100km CDR physics and accelerator design goals have been clearly defined
- CEPC Accelerator CDR design goal has been achieved (error needs to be added in next few months before CDR printing in April 2018)
- Hardware design and key technologies' R&D progress well with financial funds prior to full TDR phase started in 2018
- CEPC-SppC siting and implementaion progress well
- International collabotaion and collaboration with indusries progress well
- Young generations played a key role in CEPC team and they are the key forces to realize the goals

Thanks go to

CEPC accelerator team and international collaborators

Thank you for your attention