Circular Electron Positron Collider

CEPC Accelerator CDR - Status

J. Gao

Institute of High Energy Physics

CAS, Beijing

International Workshop on High Energy Circular Electron-Positron Collider

November 6-8, 2017, IHEP, Beijing, China

Contents

Physics Goals of CEPC-SppC

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

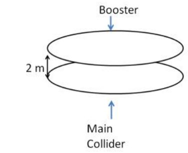
CEPC Design –Higgs Parameters

Parameter	Design Goal
Particles	e+, e-
Center of mass energy	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 CDR Accelerator Chain



10 GeV

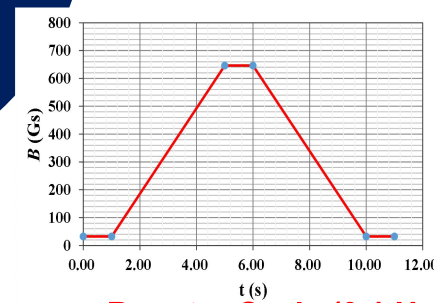
Injector

Electron

Positron

Booster

Energy Ramp
10 ->45/120GeV



Booster Cycle (0.1 Hz)

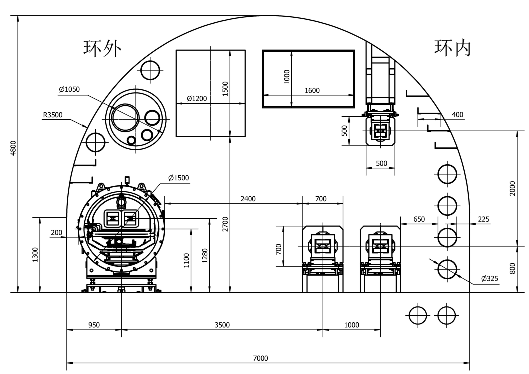
Three rings in the sane channel:
- ➢ CEPC & booster
- ➢ SppC

- 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

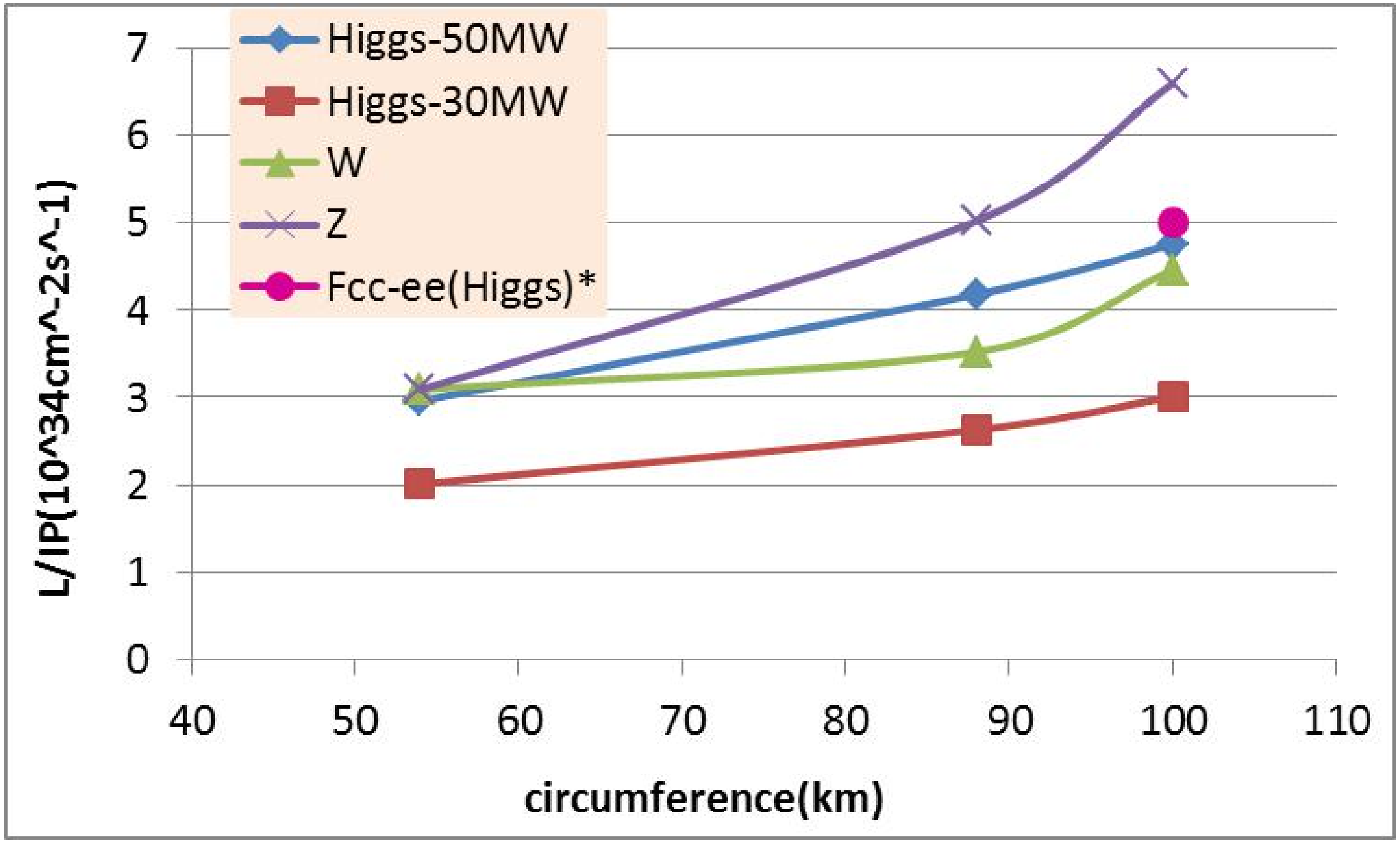
45/120 GeV

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.

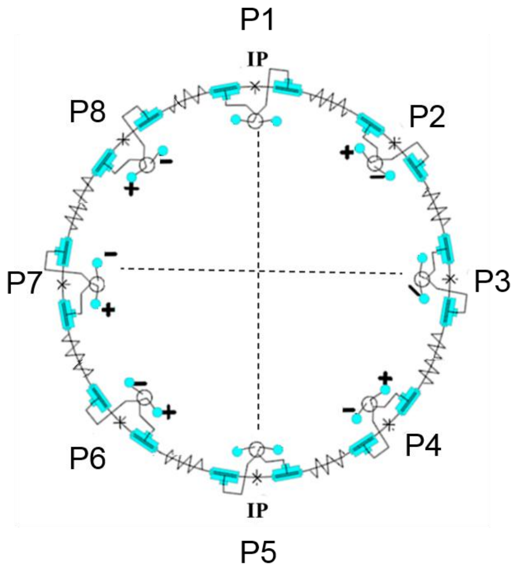
Parameters for CEPC double ring (HL)

Dec 2016， beta_y=1mm

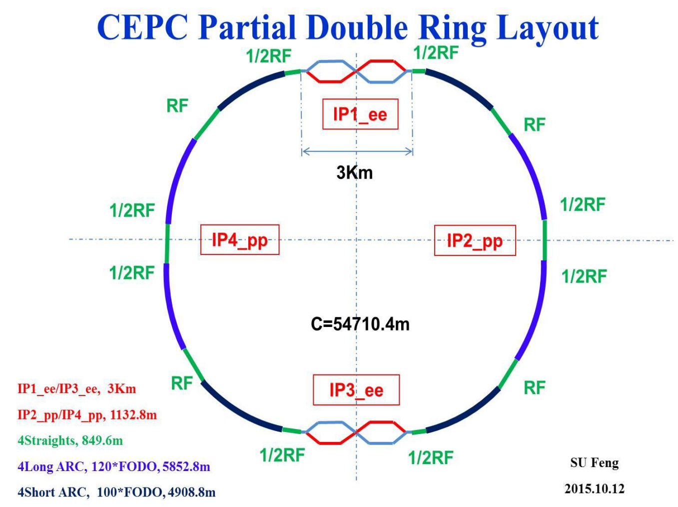
D. Wang

	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

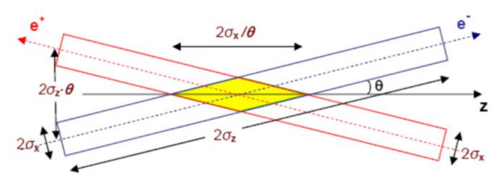
CEPC four options towards CDR



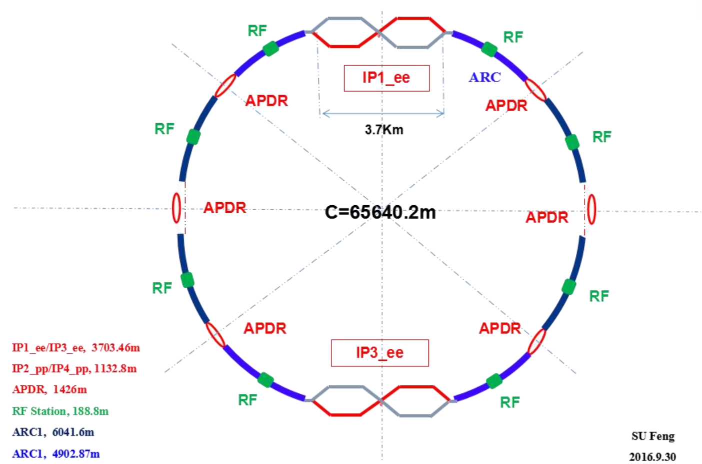
Since Oct 2012



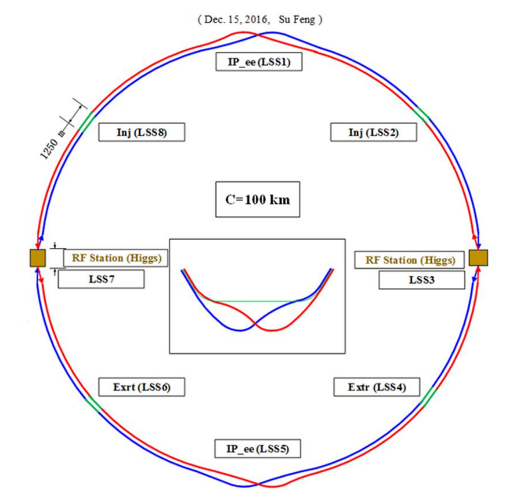
Since May 2015



CEPC Advanced Partial Double Ring Option II

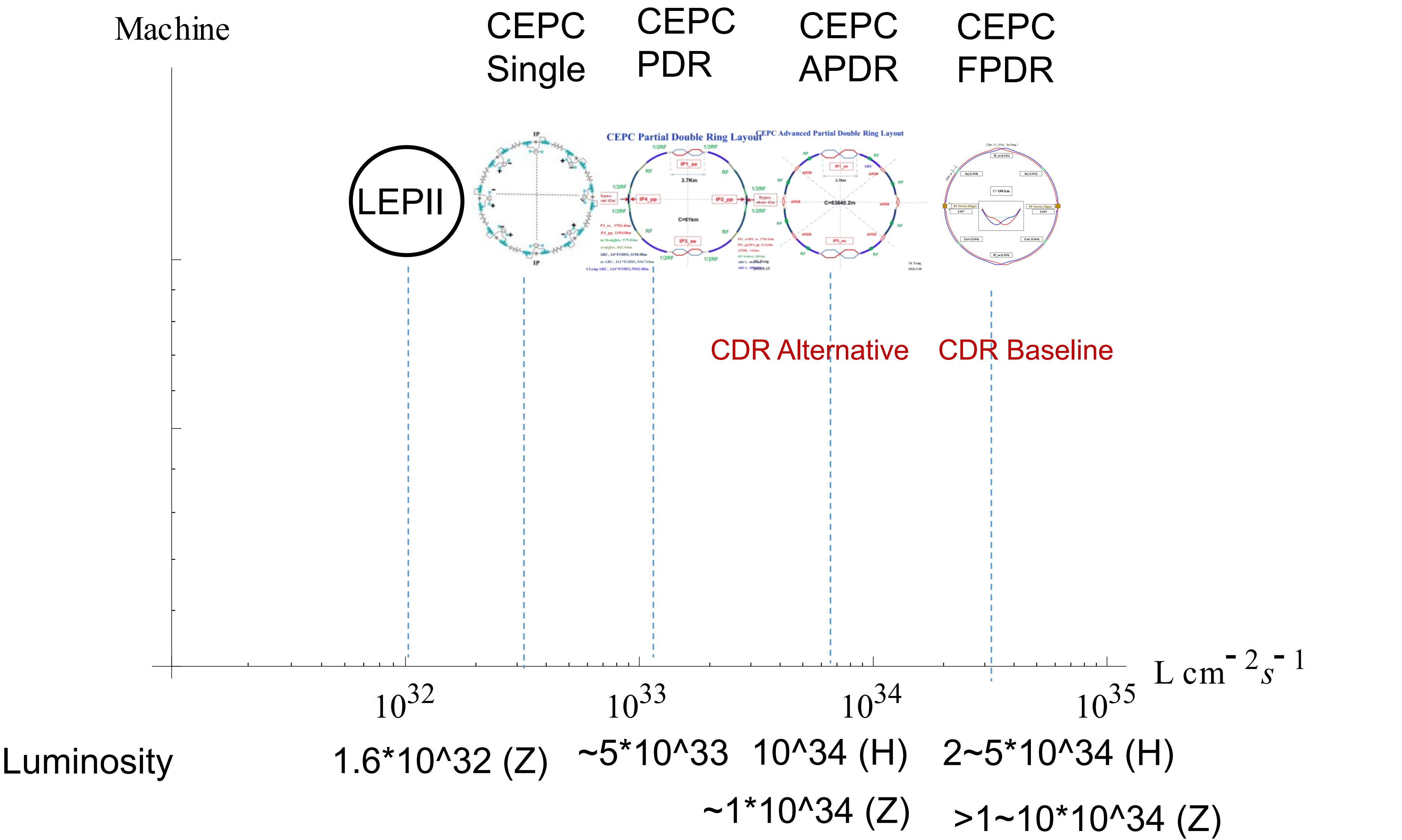


Since May 2016

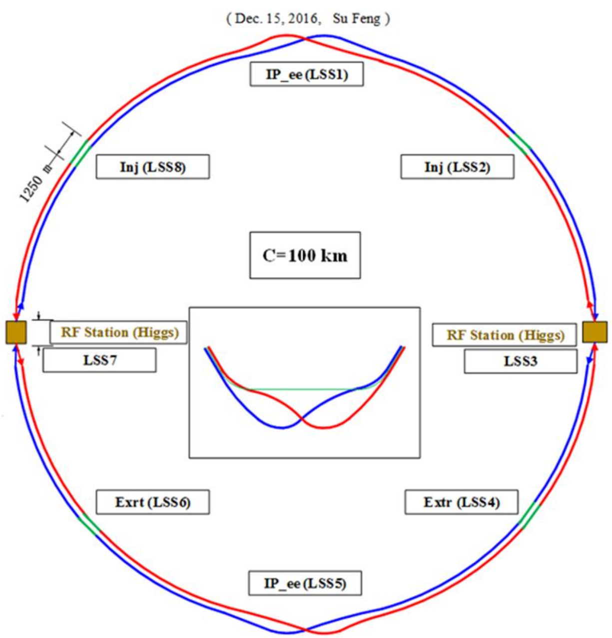


Since Nov 2016

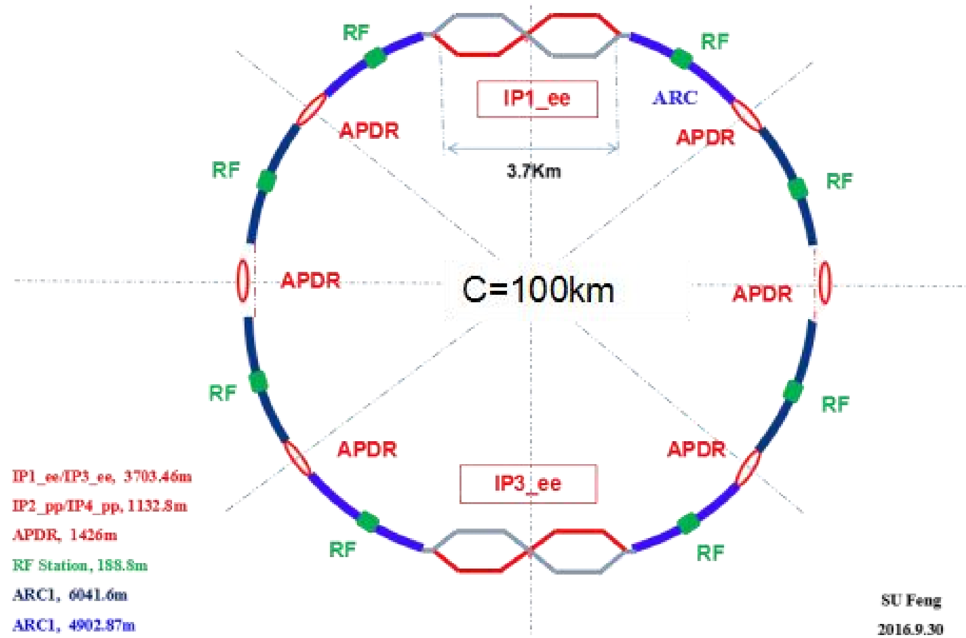
Machine Option Luminosity Potentials



CEPC towards CDR



CEPC Advanced Partial Double Ring Option II



CEPC Baseline Design

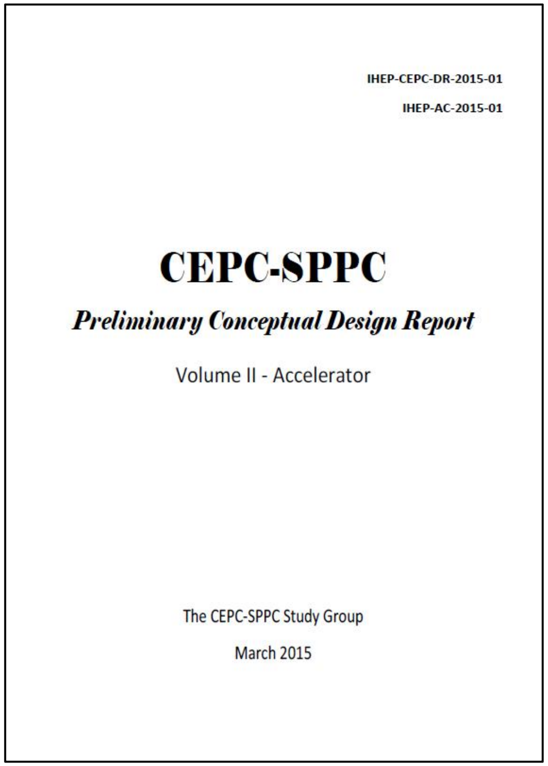
Better performance for Higgs and Z compared with alternative scheme, without bottle neck problems, but with higher cost

CEPC Alternative Design

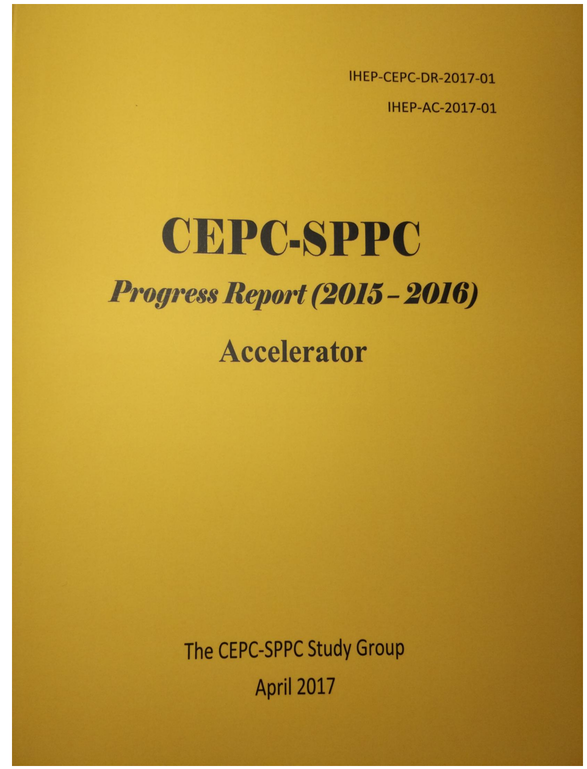
Lower cost and reaching the fundamental requirement for Higgs and Z luminosities, under the condition that sawtooth and beam loading effects be solved

CEPC-SppC CDR Baseline Decided in Jan. 2017

http://cepc.ihep.ac.cn



March 2015



April 2017

CEPCSppC baseline and alternative decision processe recorded

CEPC CDR will be completed at the end of 2017

CEPC CDR Parameters

beta_y=2mm

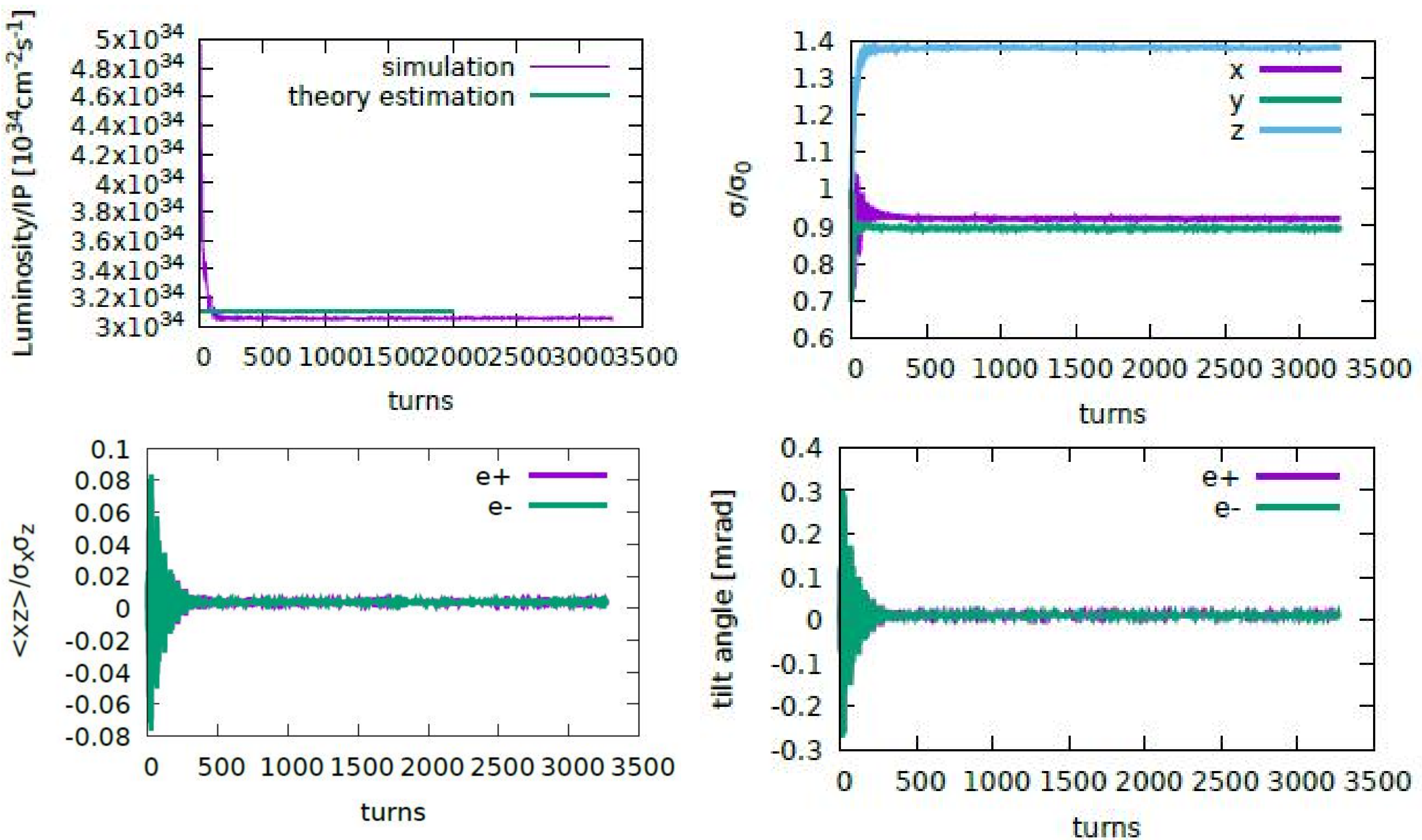
D. Wang

	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

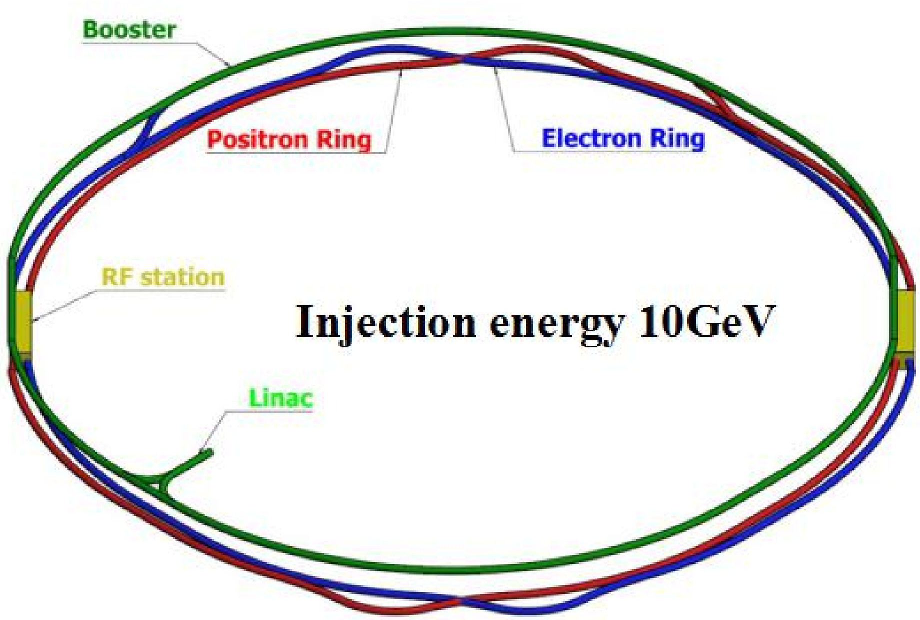
Beam-beam simulation-100km (H-HL)

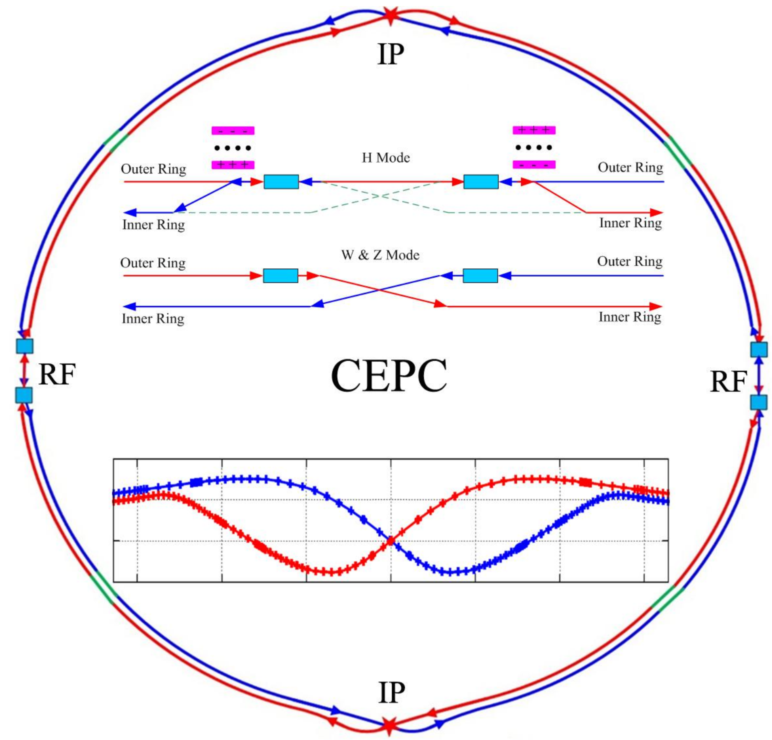
Y. Zhang

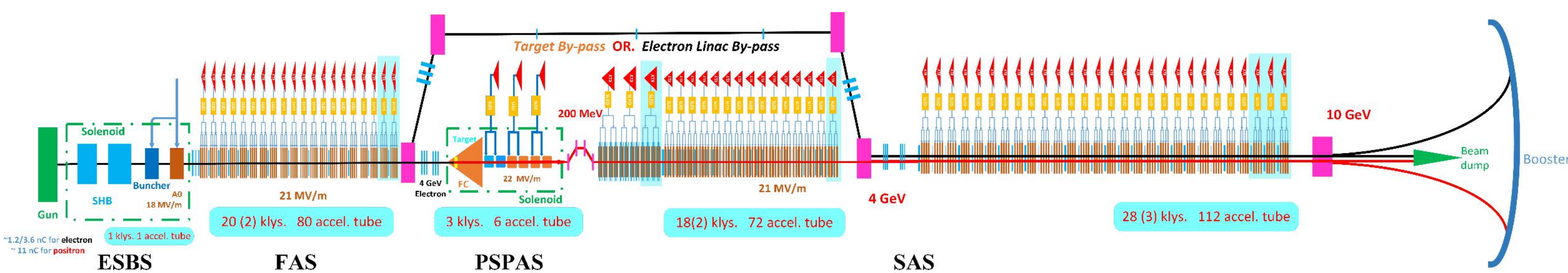
- 161202-100km-2mm-h-highlum, (0.51,0.55,0.037)



CEPC CDR Layout

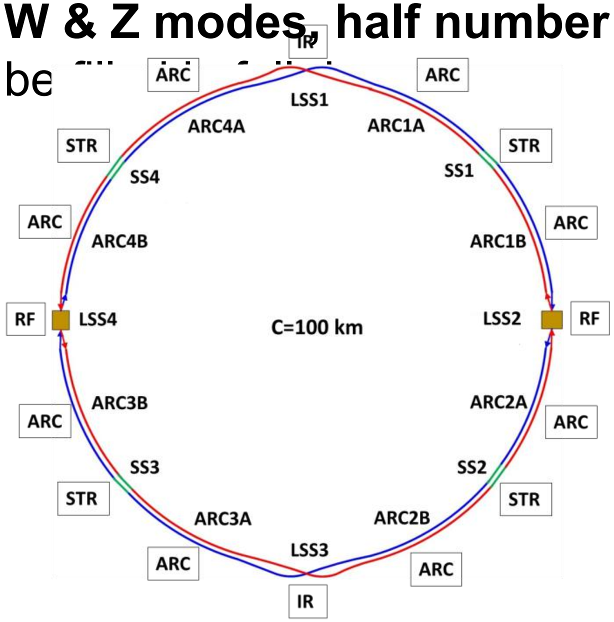


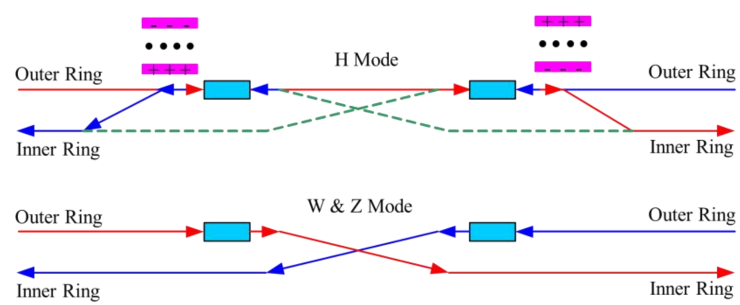




CEPC Collider Ring

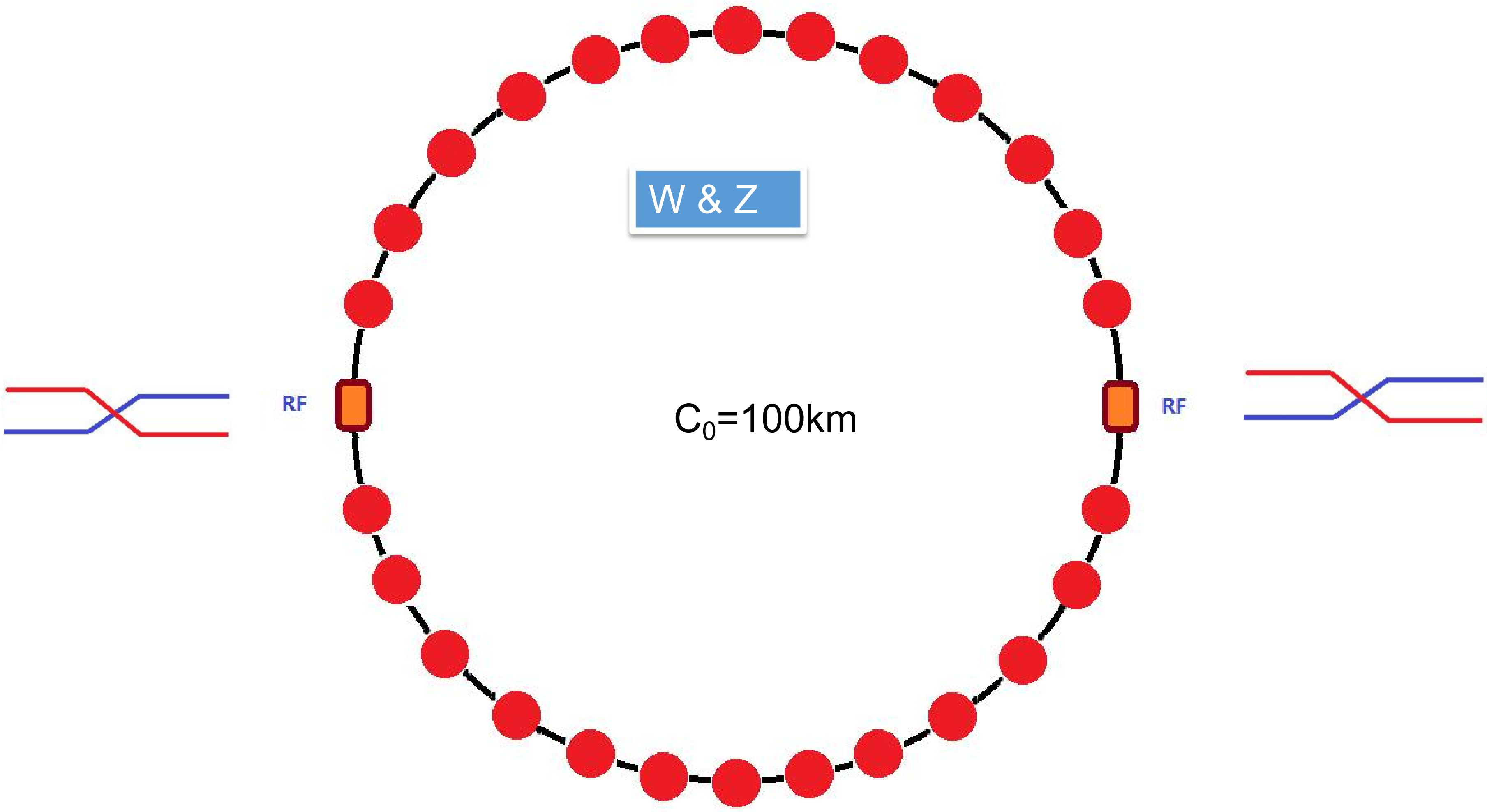
- The circumference of CEPC collider ring is **100 km**.
- In the RF region, the **RF cavities are shared by two ring for H mode**.
- **Twin-aperture of dipoles and quadrupoles is adopt in the arc region** to reduce the their power. The distance between two beams is 0.35m.
- Compatible optics for H, 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





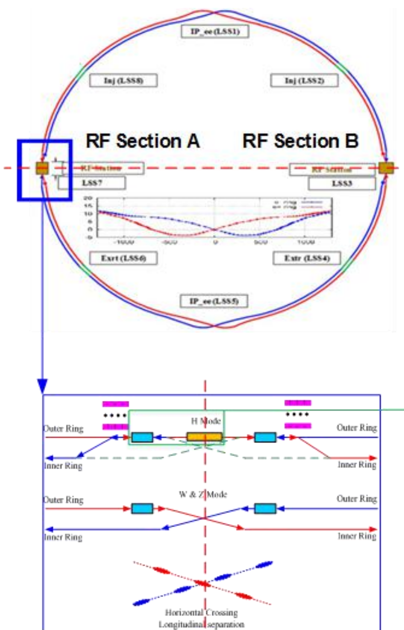
CEPC H, W and Z bunch distributions

C.H. Yu



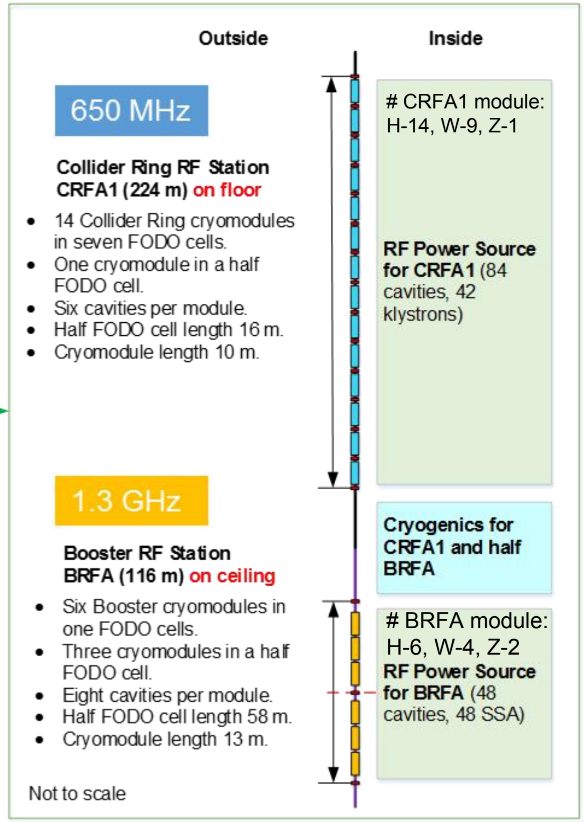
CEPC SRF System Layout

J.Y. Zhai



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.

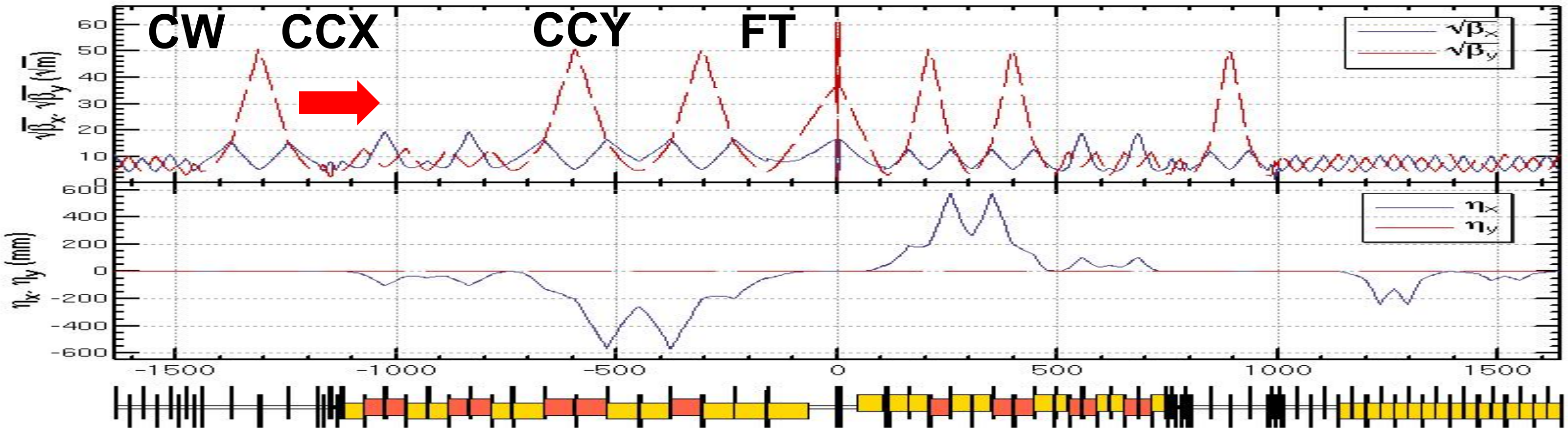
Input coupler power limit 300 kW, variable, low heat load, be short to reduce cryomodule diameter.

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

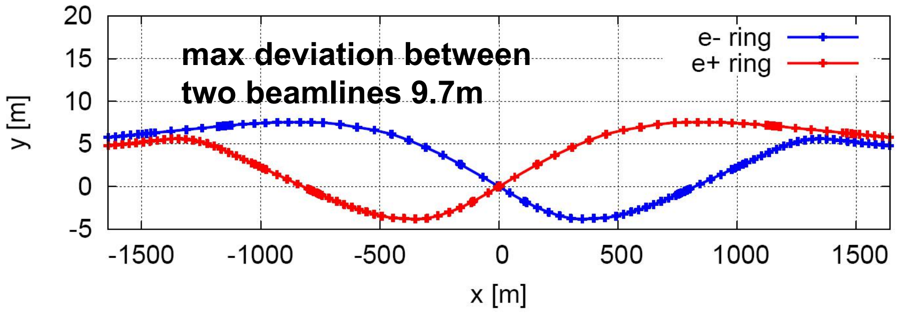
Linear Optics of Interaction Region

Y.W. Wang

- 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**.

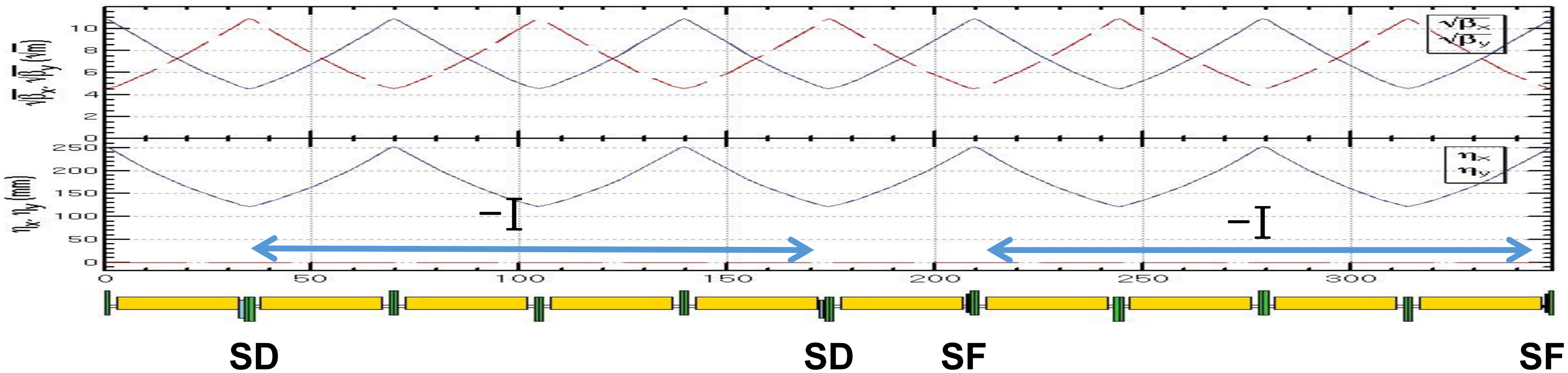


L*= 2.2m
βx*= 0.36mm
βy*= 2mm
GQD0≅-151T/m
GQF1≅102T/m
LQD0=1.73m
LQF1=1.48m

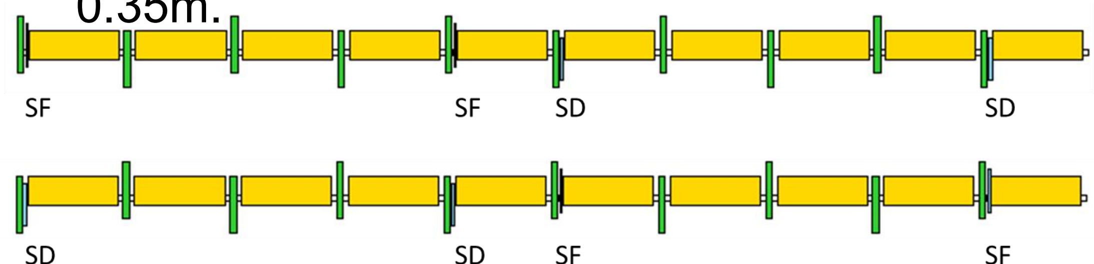


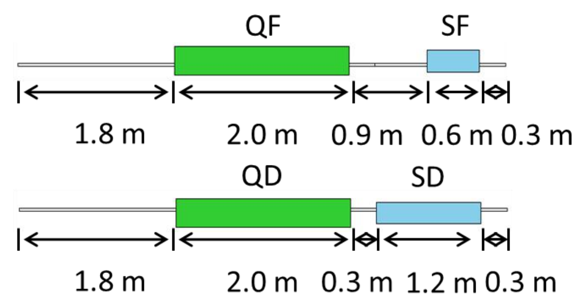
Linear Optics Design of ARC Region

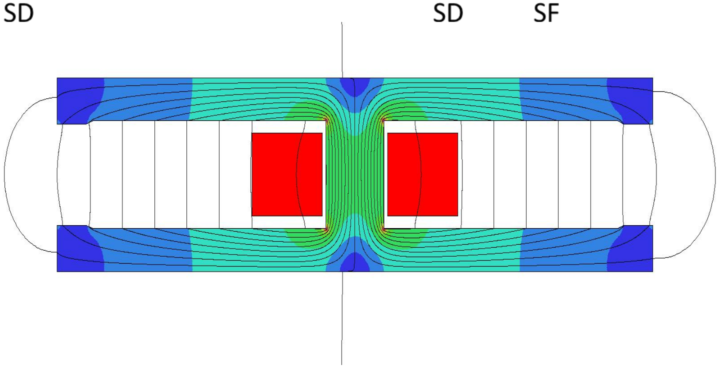
- **FODO cell, 90°/90°, non-interleaved sextupole scheme, period =5cells**

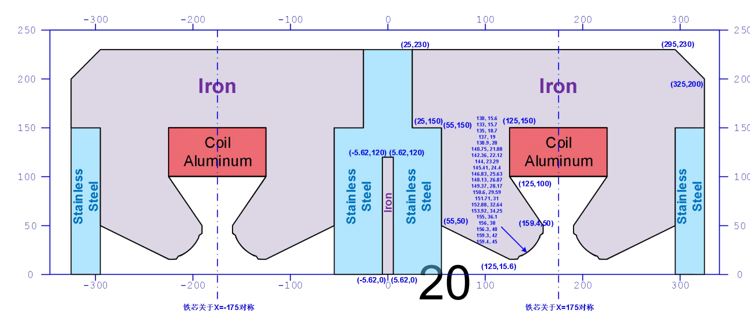


- **Twin-aperture of dipoles and quadrupoles is adopt in the arc region** to reduce the their power. The distance between two beams is 0.35m.



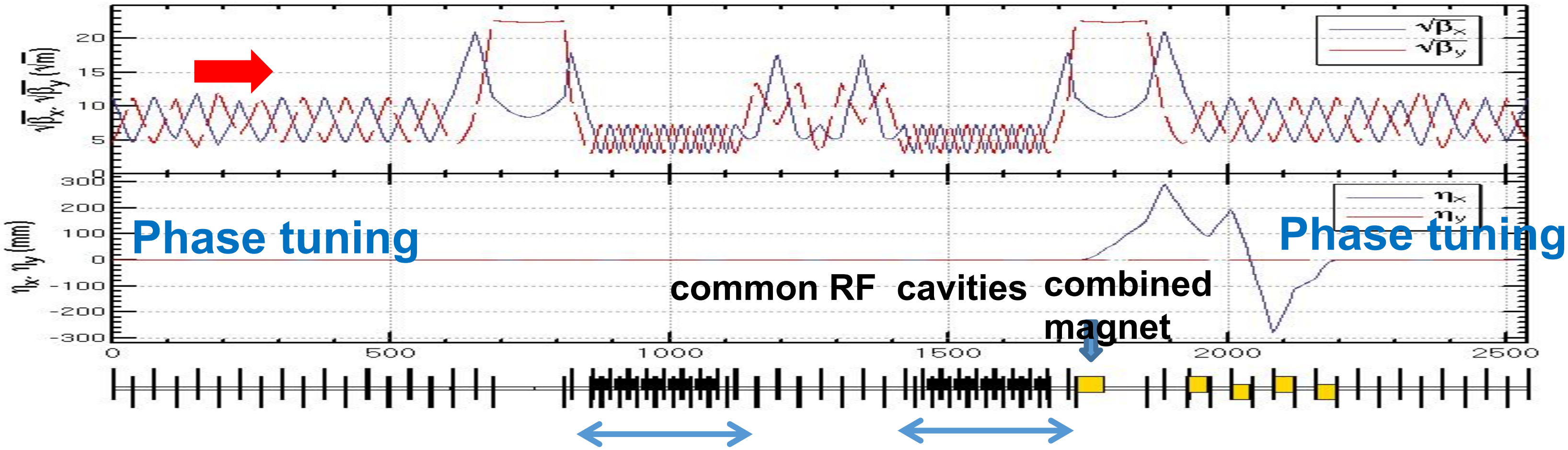




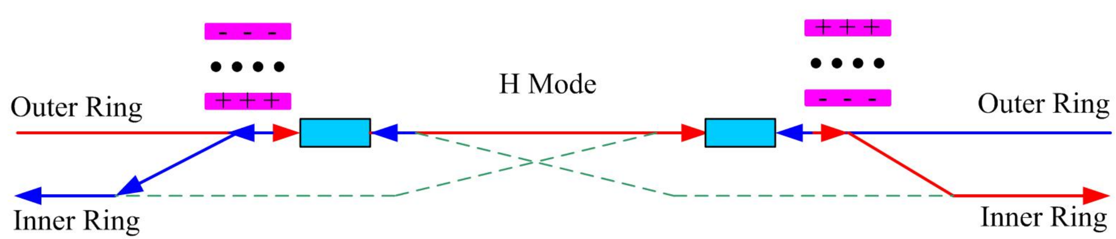


Optics Design of RF Region

- **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**

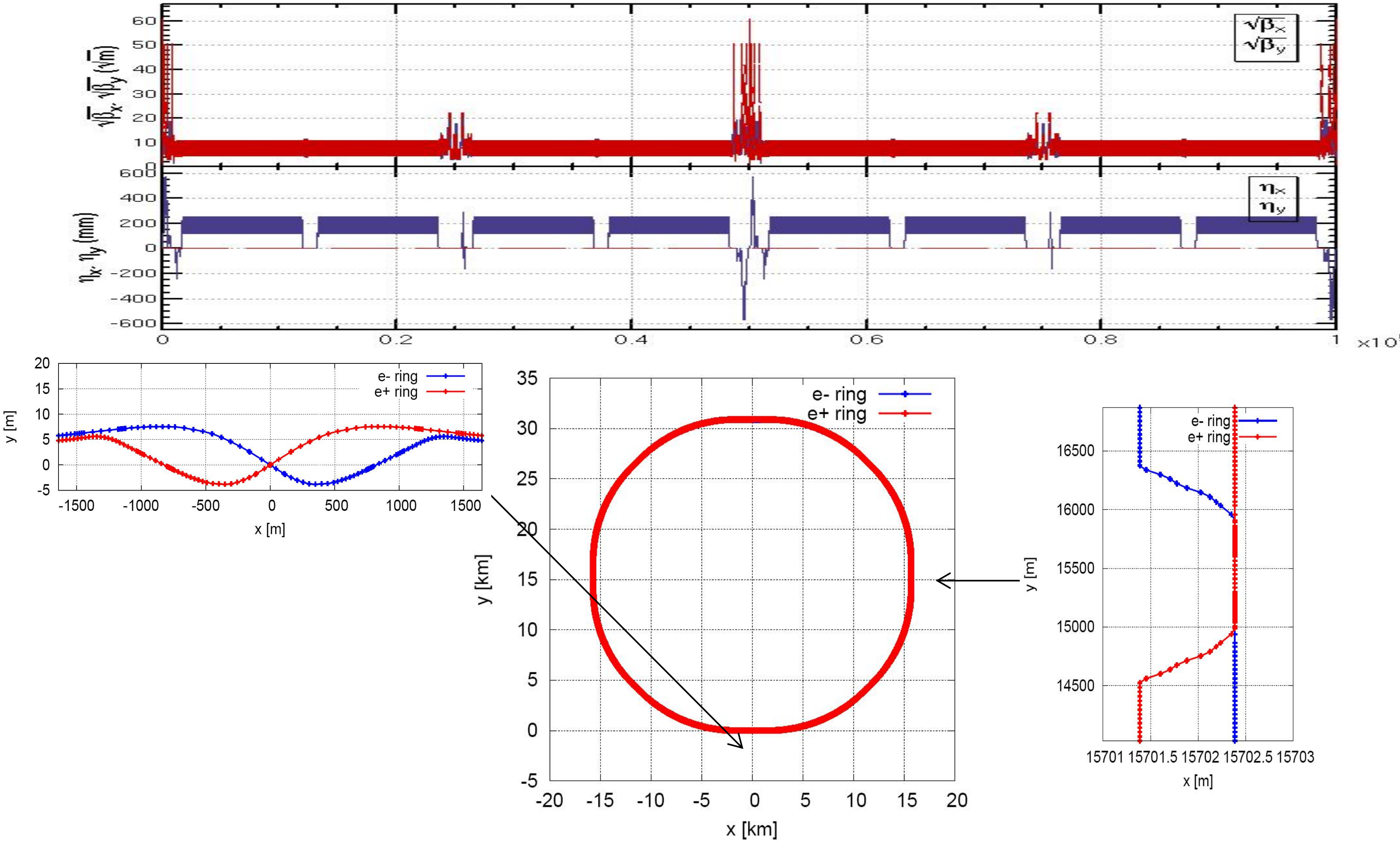


Esep=1.8 MV/m
Lsep=50m
Ldrift=75m
Δx=10cm at entrance of quad



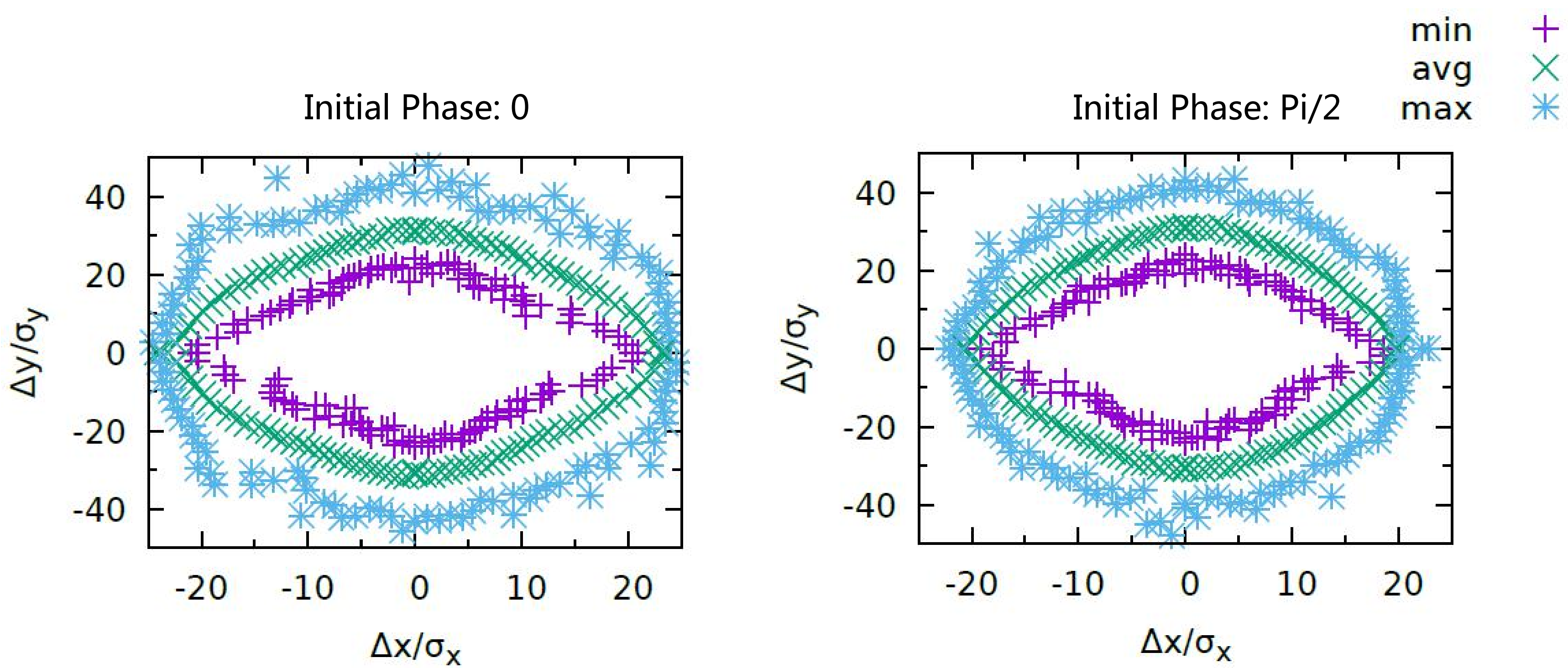
Linear Optics of the Collider Ring

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



On Momentum Dynamic Aperture (CEPC-Higgs)

Y. Zhang

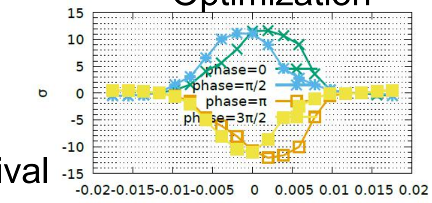


100 samples are tracked. 200 turns are tracked.

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

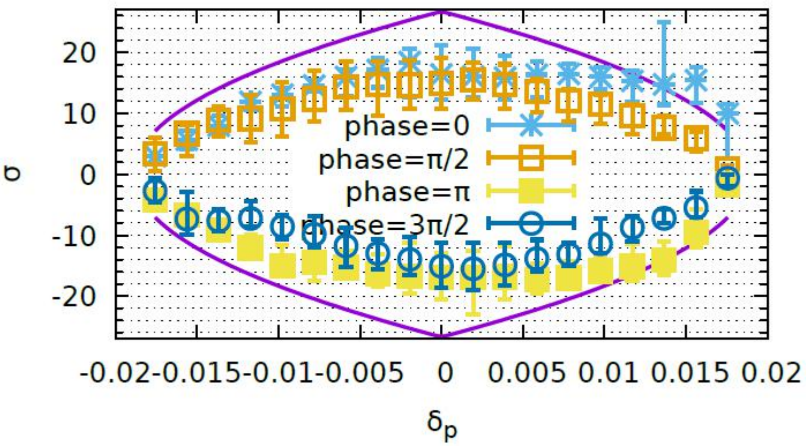
Off momentum Dynamic Aperture

W/O Optimization

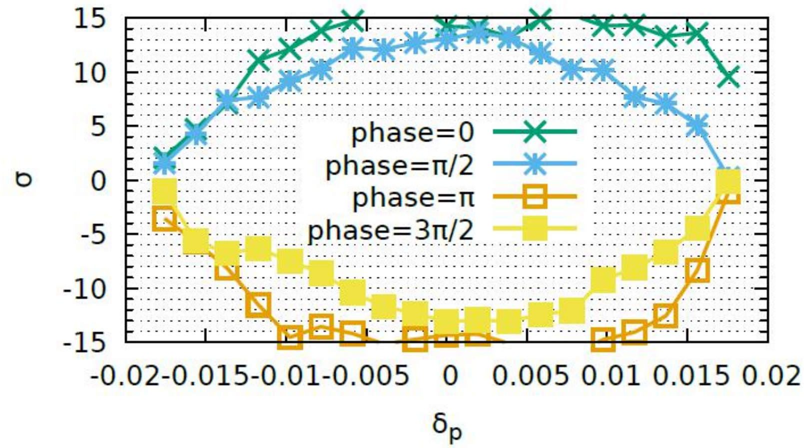


Momentum Acceptance:
0.017

Error bar means min and max



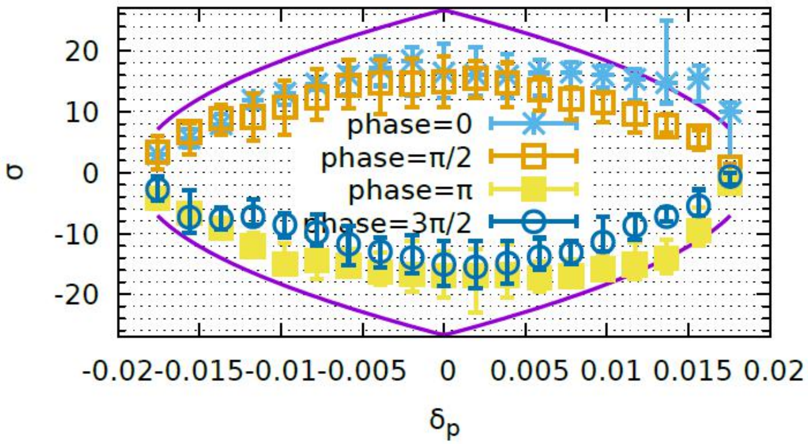
90% survival



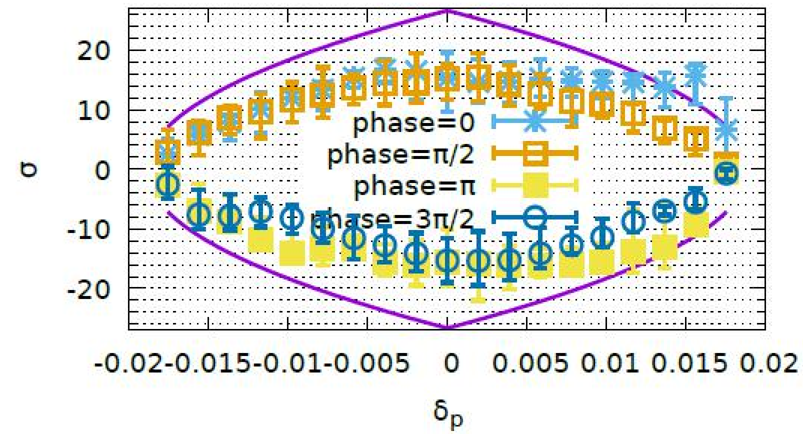
100 samples. Radiation fluctuation is included. 0.3% emittance coupling. 200 turns are tracked.

DA with Beam-Beam(beamstrahlung)

Beam-Beam Off



Beam-Beam On

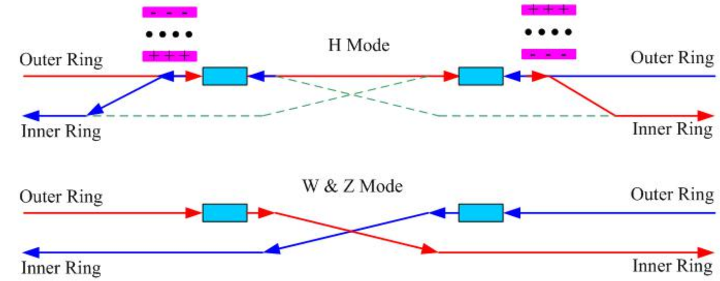


Z-pole Lattice

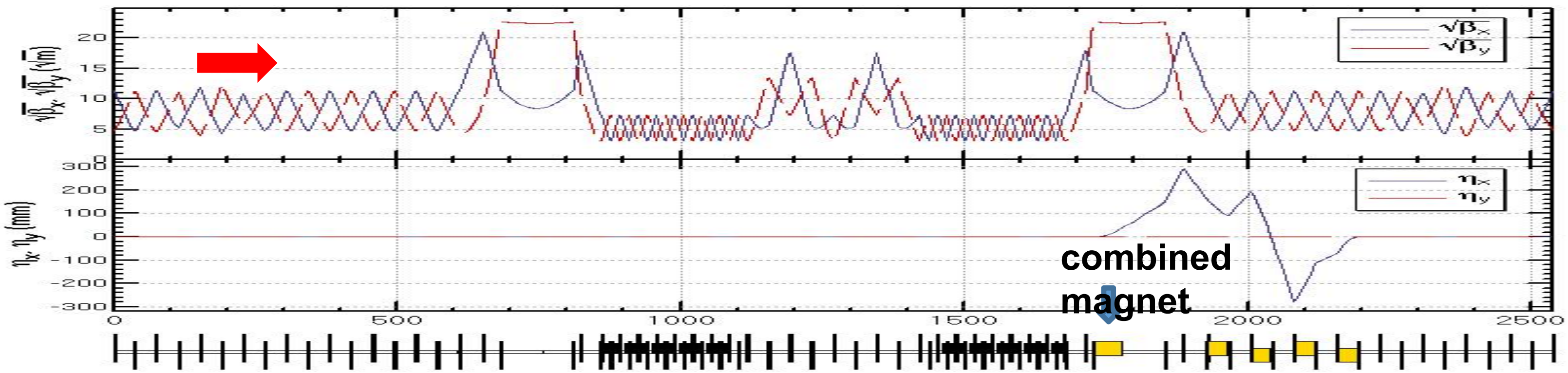
Y.W. Wang

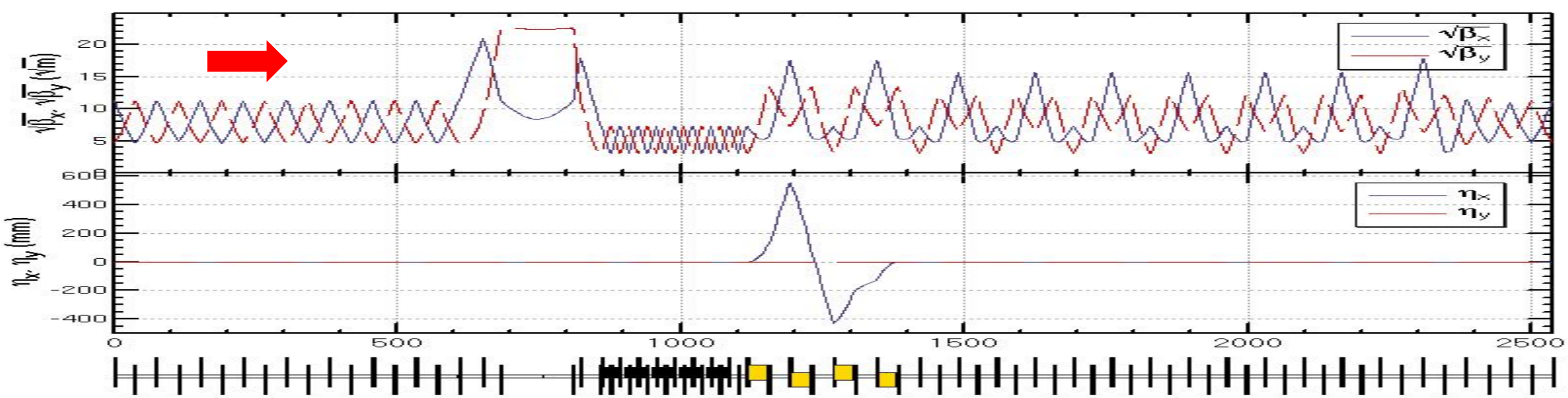
- Z lattice should be compatible with the H lattice
  - Layout of the magnets should be kept except the RF region
    - Keep the geometry of H lattice by keeping all the bends
    - Fulfill the parameters of Z by re-matching the strength of other magnets
  - **ARC region: Two FODO cells combined into one FODO cell in Z mode**
  - **RF region: half numbers of cavities in H mode bypassed in Z mode**
  - Interaction region: matching section re-matched

RF region (H, Z)



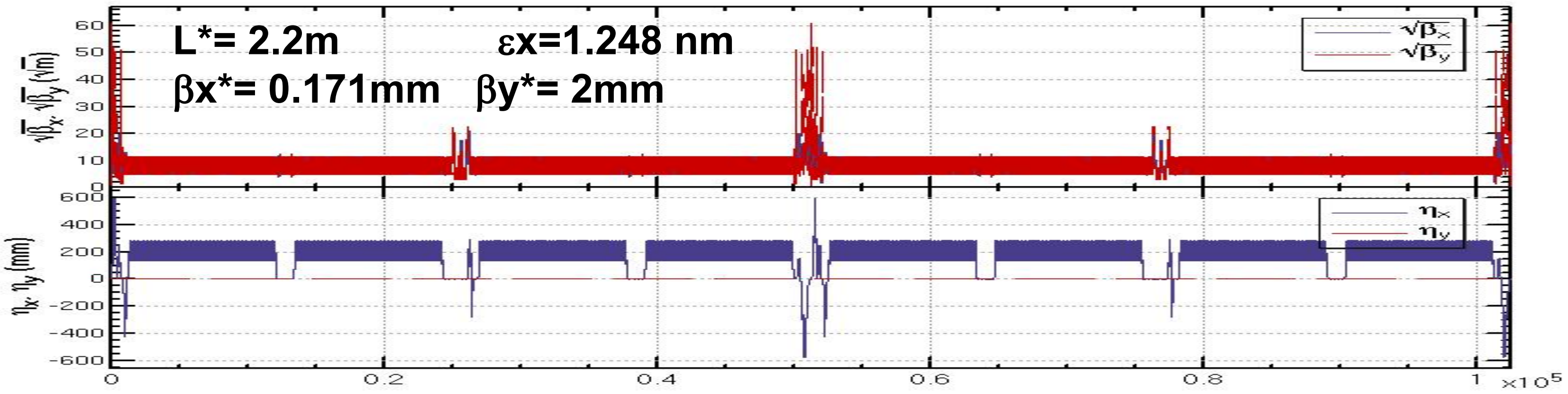
- RF region in H & Z lattice
  - half numbers of cavities in H mode bypassed in Z mode
    - fulfill the RF requirement and allow bunches filled in whole ring

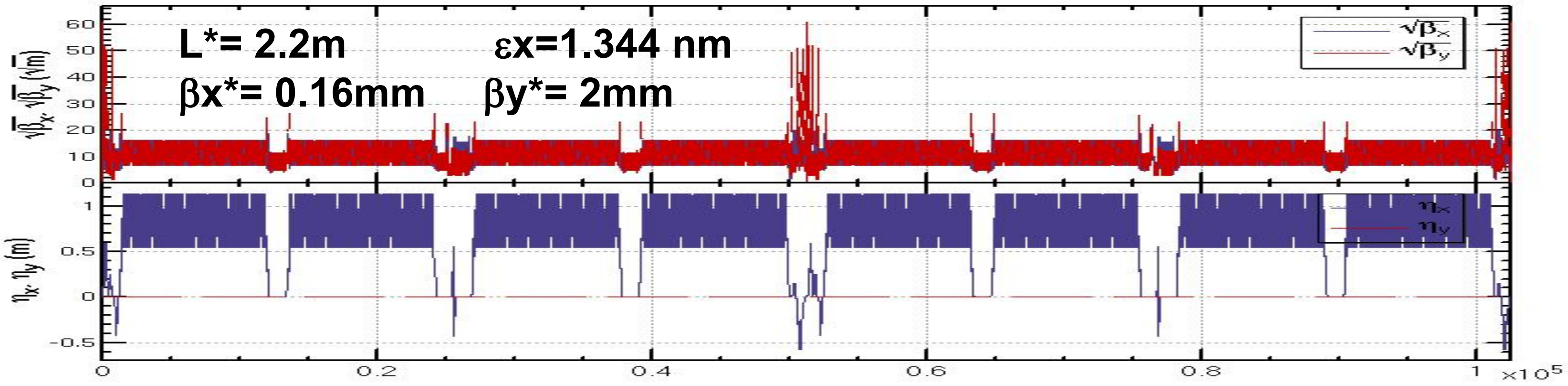




Whole Ring (H, Z)

- Whole ring of H & Z lattice



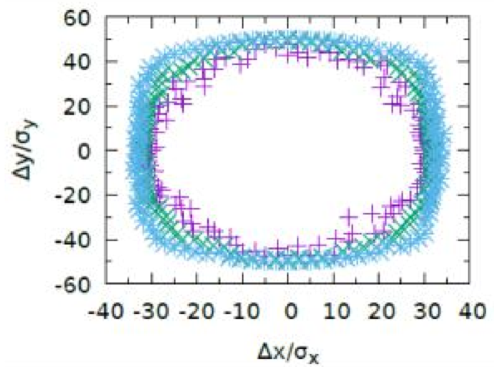


Y. Zhang

W

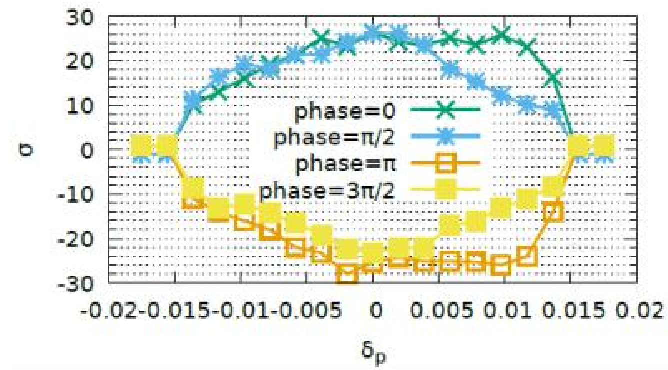
30*40

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.

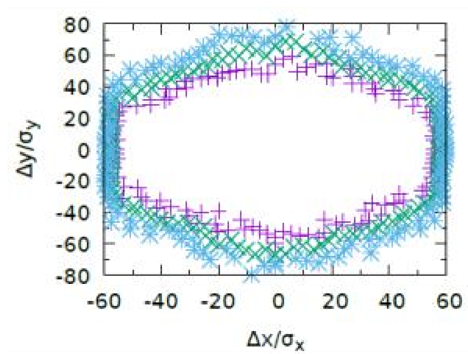
Z-pole design goal

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

Z-pole

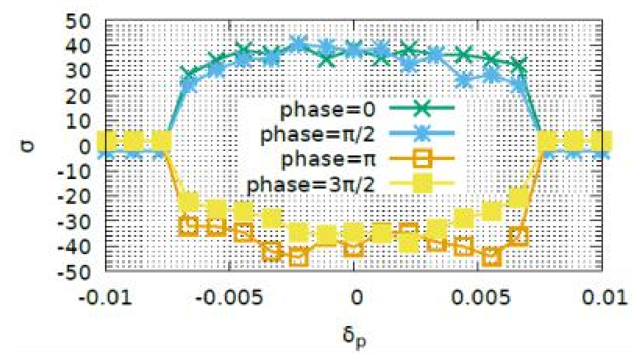
50*50

On Momentum Dynamic Aperture



Momentum Acceptance: 0.75%

Minimum DA of 100 Samples



Z-pole achieved values (OK)

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

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

Impedance and Collective Instabilities

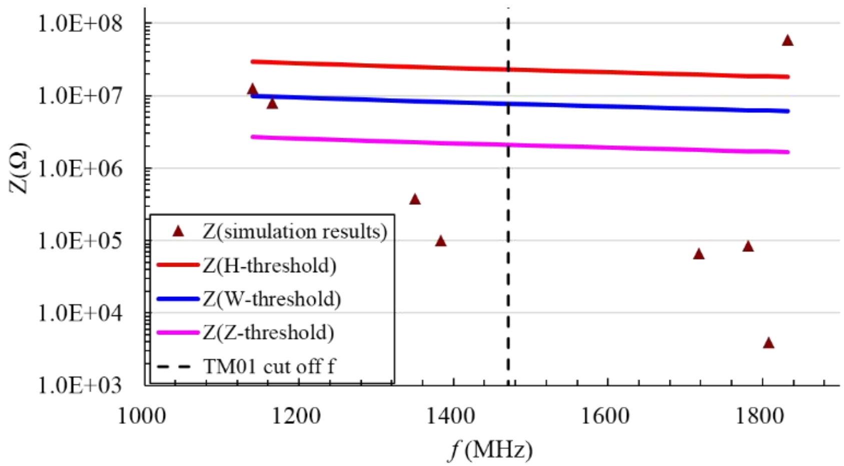
N. Wang

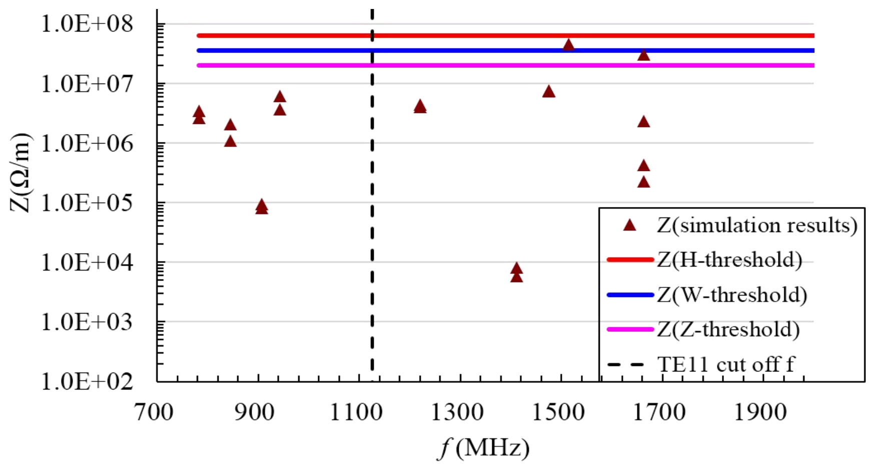
Components	Number	R, kΩ	L, nH	$Z_{\|\|}/n$, mΩ	k_{loss}, V/pC	ky, kV/pC/m
Resistive wall	-	15.3	866.8	16.3	432.3	23.0
RF cavities	336	11.2	-72.9	-1.4	315.3	0.41
Flanges	20000	0.7	145.9	2.8	19.8	2.8
BPMs	1450	0.53	6.38	0.12	13.1	0.3
Bellows	12000	2.3	115.6	2.2	65.8	2.9
Pumping ports	5000	0.01	1.3	0.02	0.4	0.6
IP chambers	2	0.2	0.8	0.02	6.7	1.3
Electro-separators	22	1.5	-9.7	0.2	41.2	0.2
Taper transitions	164	1.1	25.5	0.8	50.9	0.5
Total		**32.9**	**1079.7**	**20.6**	**945.4**	**32.1**

At the design bunch intensity, the bunch length will increase 30% and 40% for H and Z respectively. Bunch spacing >25ns will be needed to eliminate the electron cloud instability (28ns is chosen)

HOM Damping Results

H.J. Zheng





- Monopole modes impedance per cavity (cavity impedance thresholds with feedback and parking cavities in beamline)
- Without frequency spread

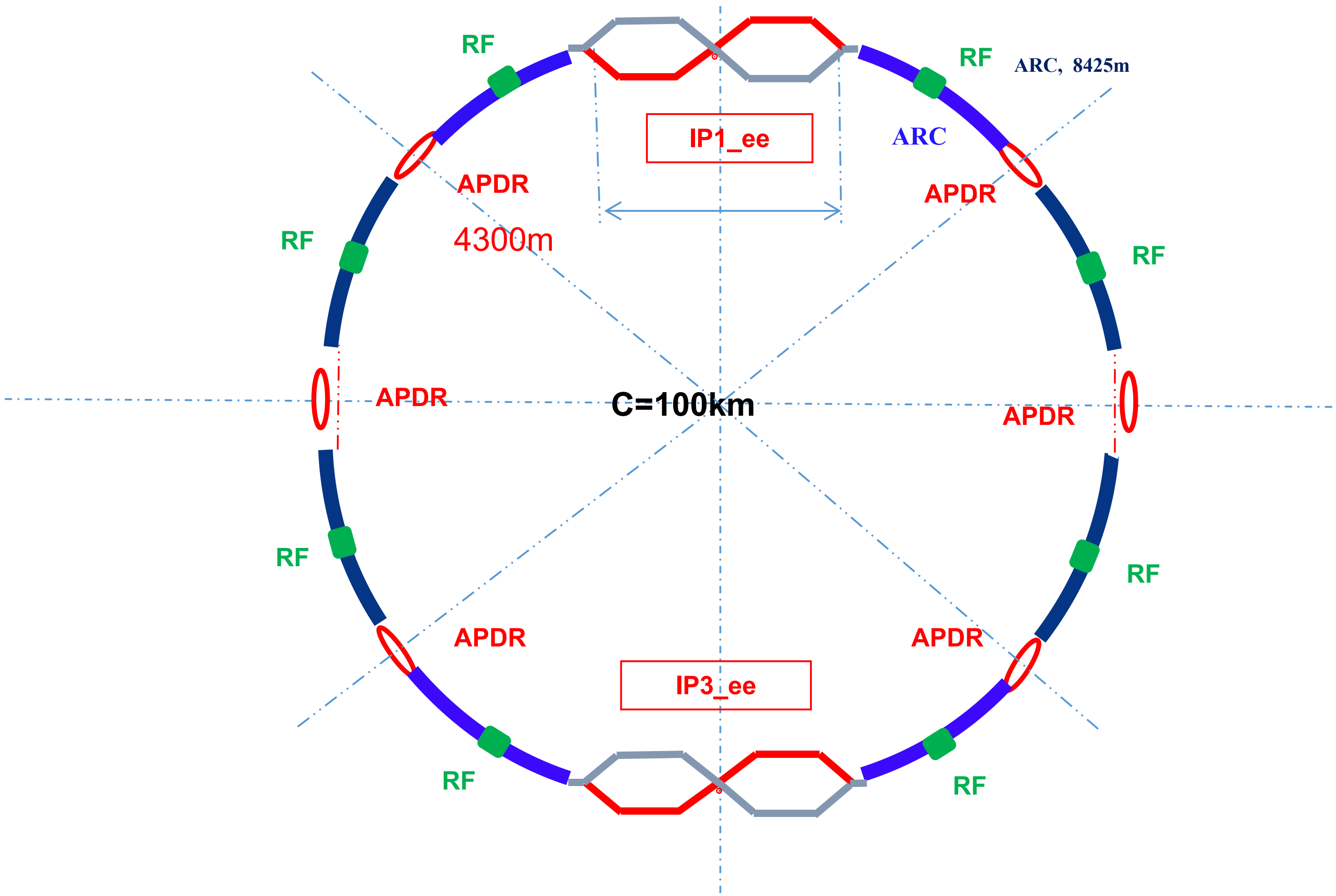
- Dipole modes impedance per cavity (cavity impedance thresholds with feedback and parking cavities in beamline)
- Without frequency spread

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)**

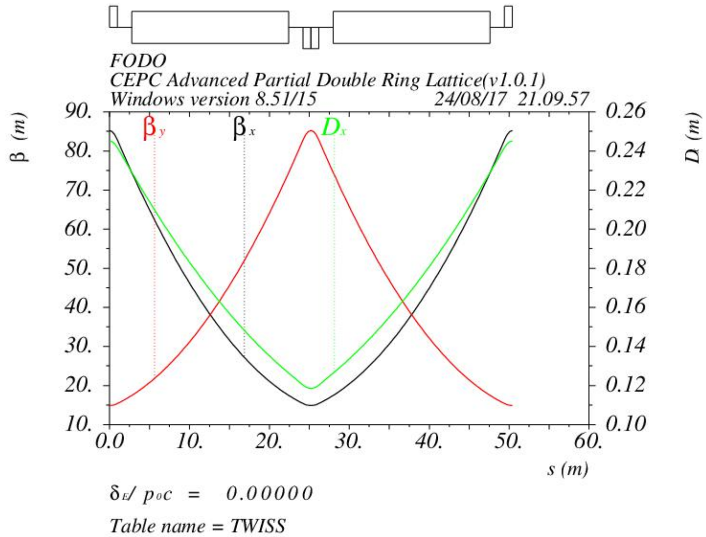
CEPC Advanced Partial Double Ring (Alternative)

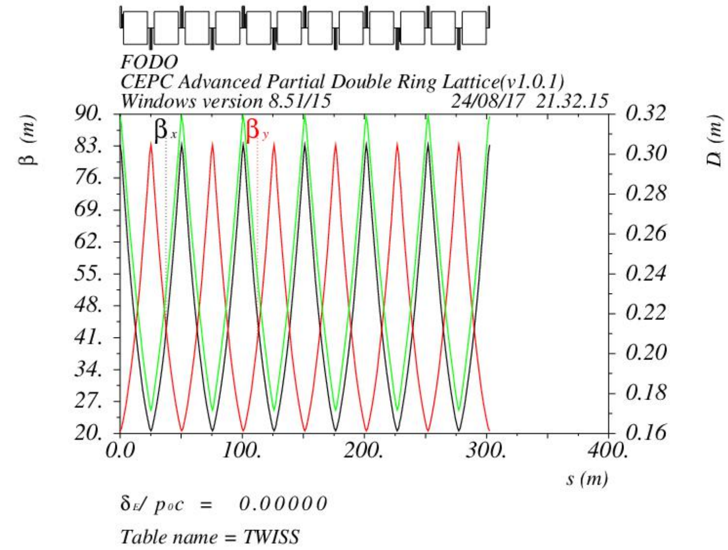


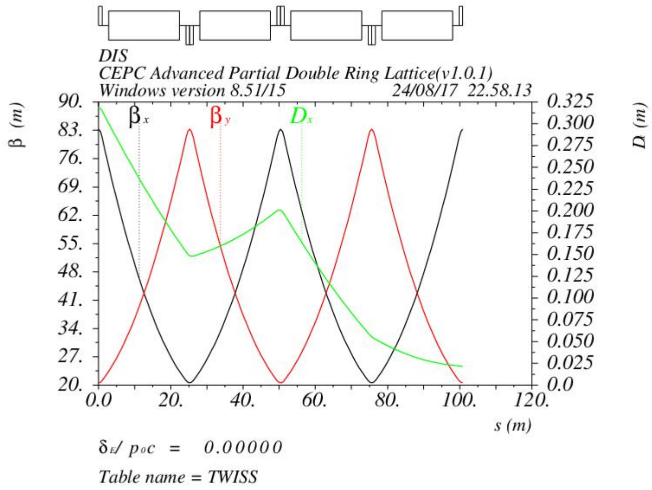
F.Su
D.J. Xiao

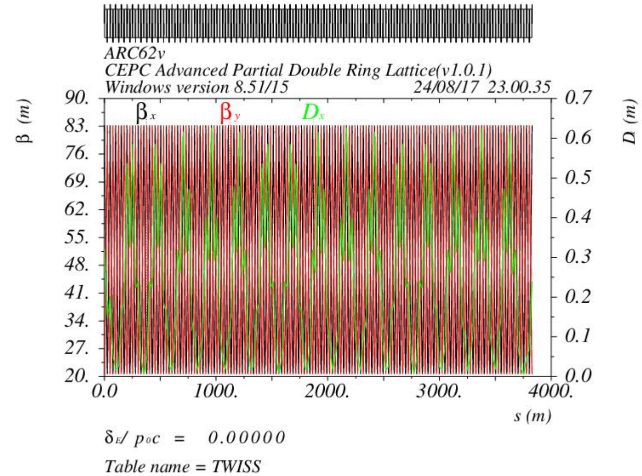
2017.8.22

APDR Lattice Design









CEPC APDR Main Ring RF Parameters

D.J. Gong

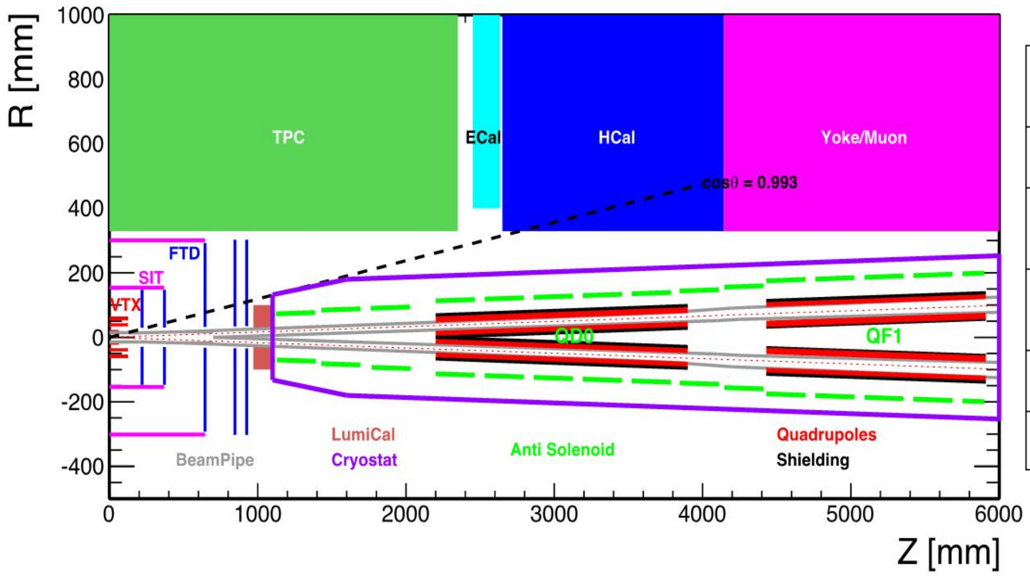
For APDR Z-pole baseline, only the large emittance case can work.

100 km, APDR, crossing angle 33 mrad, 2 IPs, 8 RF stations, 8*4km DR.	**H (baseline)**	**Z(large emittance)**	**Z(Small emittance)**
Beam Energy [GeV]	120	45.5	45.5
Luminosity / IP [10^{34} $cm^{-2}s^{-1}$]	2	1.03	1.03
SR power / beam [MW]	32	2.9	1.8
RF freqeuncy [MHz]	650	650	650
RF voltage [GV]	2.1	0.135	0.049
Beam current / beam [mA]	19.2	85.0	53.9
Pulse current/ beam [mA]	119.7	531.0	336.6
Bunch charge [nC]	15.5	4.80	3.52
Bunch length [mm]	2.9	4	4
Bunches / beam	412	5900	5100
Bunches/ train	103	1475	1275
Bunch spacing in a train [ns]	129.4	9.0	10.5
Train spacing Tg [us]	28.3	28.3	28.3
SR loss / turn [GV]	1.67	0.034	0.034
Syncrotron phase from crest [deg]	37.3	75.4	46.1
Loss factor / cell [V/pC]	0.34	0.27	0.27
Effective length per cavity [m]	0.46	0.46	0.46
R/Q per cavity [Ω]	213	213	213
Cell number / cavity	2	2	2
Cavity number / RF station	42	3	2
RF station number	8	8	8
Cavity number (total)	336	24	16

100 km, APDR, crossing angle 33 mrad, 2 IPs, 8 RF stations, 8*4km DR.	**H (baseline)**	**Z(large emittance)**	**Z(Small emittance)**
Acc. Gradient [MV/m]	13.59	12.23	6.66
Cavity voltage [MV]	6.25	5.63	3.06
Input power / cavity [kW]	190	241	229
Cavity per klystron	2	2	2
HOM power / cavity [kW]	0.40	0.22	0.10
Q_0 at operating gradient	1E+10	1E+10	1E+10
Wall loss / cavity @ 2 K [W]	19	15	5
Pb/ cavity [MW]	0.75	2.99	1.03
Opt. QL	1.0E+06	6.4E+05	2.0E+05
Opt. detuning [kHz]	0.25	1.96	1.70
Cavity bandwidth [kHz]	0.7	1.0	3.3
Cavity stored energy [J]	46	38	11
Ng/N	2.1	2.1	2.1
Ng	218	3133	2708
Max relative voltage drop for 4+4 APDR	7.2%	36.0%	41.9%
Max bunch train phase shift for 4+4 APDR [deg]	6.3	8.6	#NUM!

CEPC MDI Layout

S. Bai
H.B. Zhu



MDI parameters	Values
L^* (m)	2.2
Crossing angle (mrad)	33
Strength of QD0 (T/m)	150
Strength of detector solenoid (T)	3.0
Strength of anti-solenoid (T)	7.0

- The Machine Detector Interface of CEPC double ring scheme is about ±7m long from the IP.
- The CEPC detector superconducting solenoid with 3 T magnetic field and the length of 7.6m.
- The accelerator components inside the detector without shielding are within a conical space with an opening angle of cosθ=0.993.
- The e+e- beams collide at the IP with a horizontal angle of 33mrad and the final focusing length is 2.2m
- Lumical will be installed in longitudinal 0.95~1.11m, with inner radius 28.5mm and outer radius 100mm.

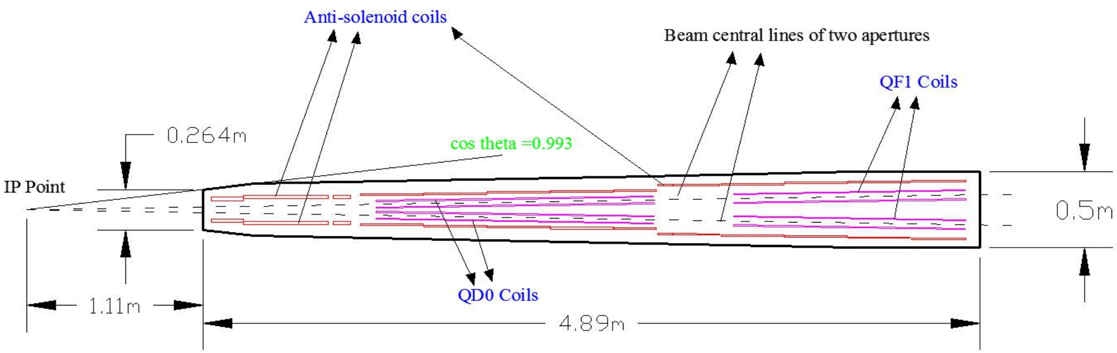
QD0/QF1 Physics Design Parameters

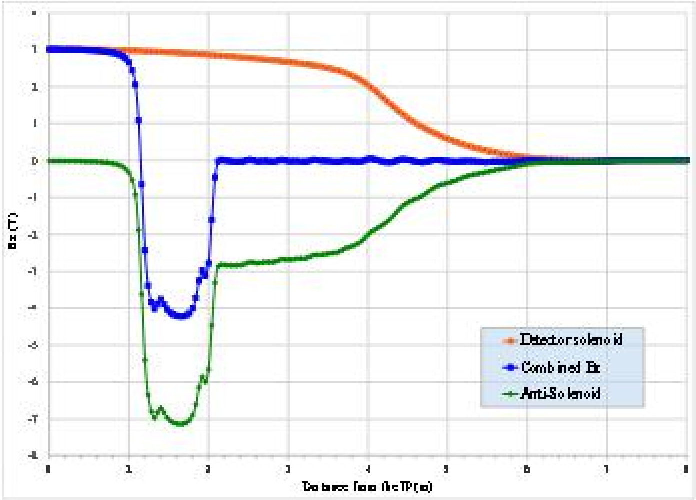
Y.S. Zhu

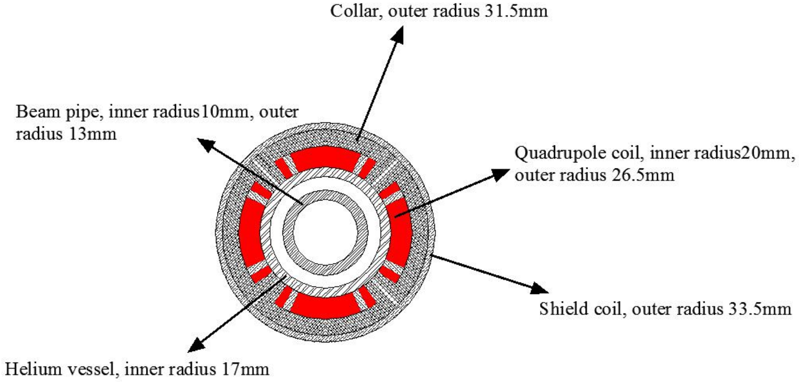
QD0	Horizontal BSC 2（$20\sigma_x$+3）	Vertical BSC 2（$30\sigma_y$+3）	e+e- beam center distance
Entrance	11.17mm	16.27mm	72.61mm
Middle	14.02mm	18.70mm	101.32mm
Exit	19.15mm	17.63mm	129.70mm
Good field region	Horizontal 19.15 mm; Vertical 18.77 mm		
Effective length	1.73 m		
Distance from IP	2.2 m		
Gradient	151 T/m		

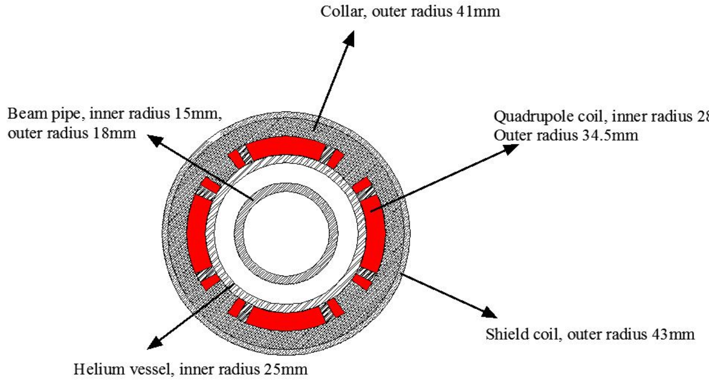
QF1	Horizontal BSC 2（$20\sigma_x$+3）	Vertical BSC 2（$30\sigma_y$+3）	e+e- beam center distance
Entrance	23.04 mm	16.01 mm	146.20 mm
Middle	27.49 mm	14.26 mm	170.63 mm
Exit	28.96 mm	13.68 mm	195.05 mm
Good field region	Horizontal 28.96 mm; Vertical 16.01 mm		
Effective length	1.48 m		
Distance from IP	4.43 m		
Gradient	102 T/m		

IR superconducting magnets

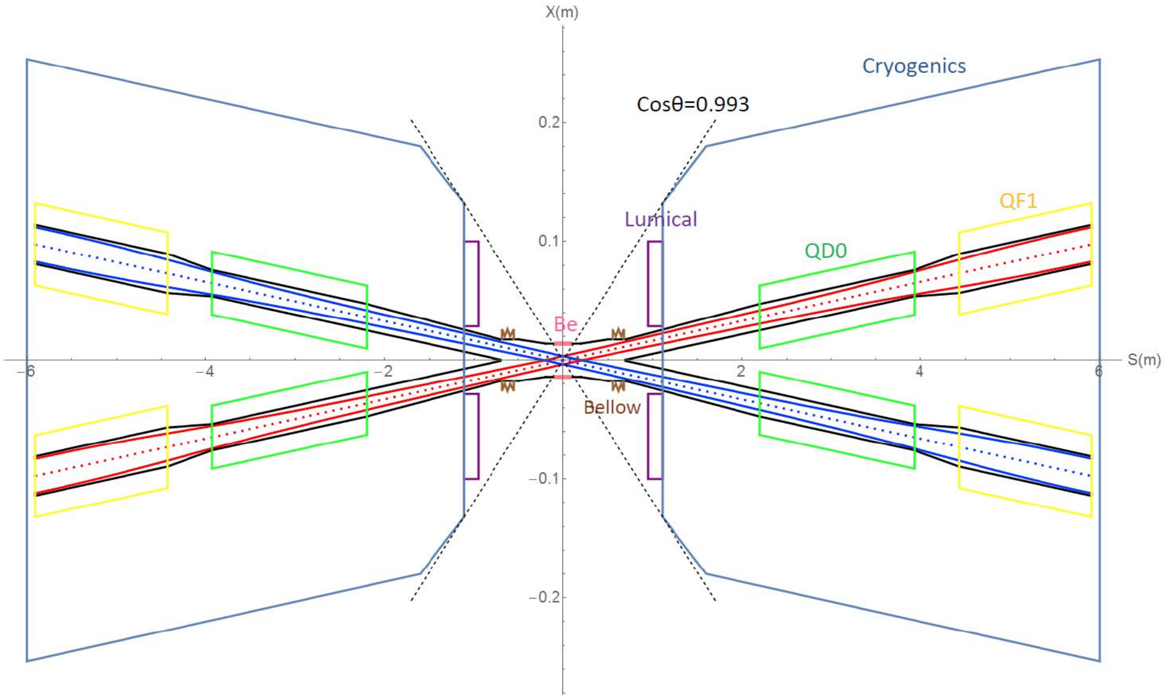






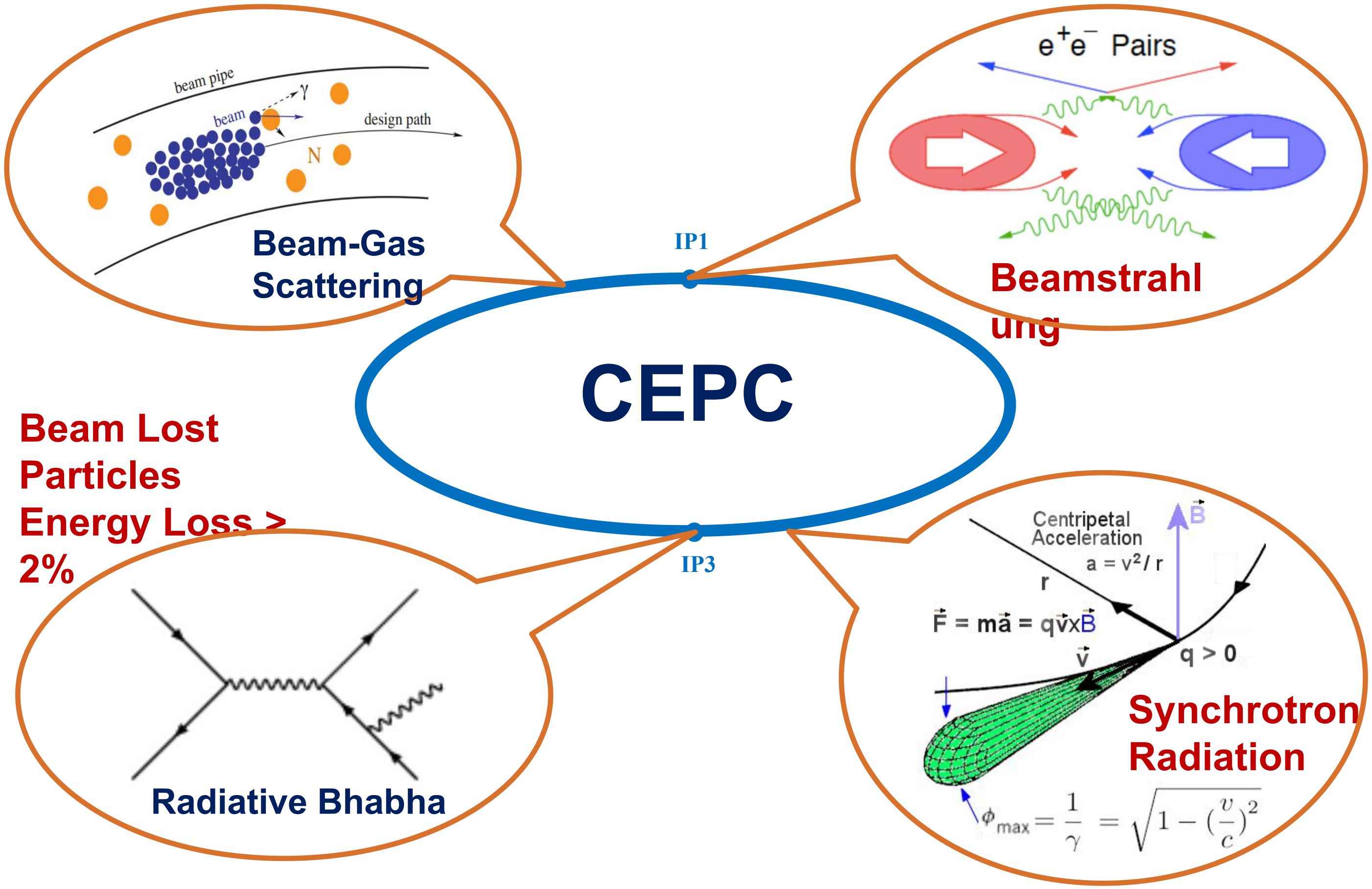


IR Beam Pipes



- The inner diameter of the beryllium pipe ~ 28mm. Length ~14cm in longitudinal.
- Due to bremsstrahlung incoherent pairs, the shape of beam pipe between 0.2~0.5m is selected as cone.
- Bellows for the requirements of installation in the crotch region where is located about 0.7m away from the IP.
- Water cooling structure is considered due to heating problem of HOM.
- Room temperature beam pipe has been adopted within final doublet quadrupoles.

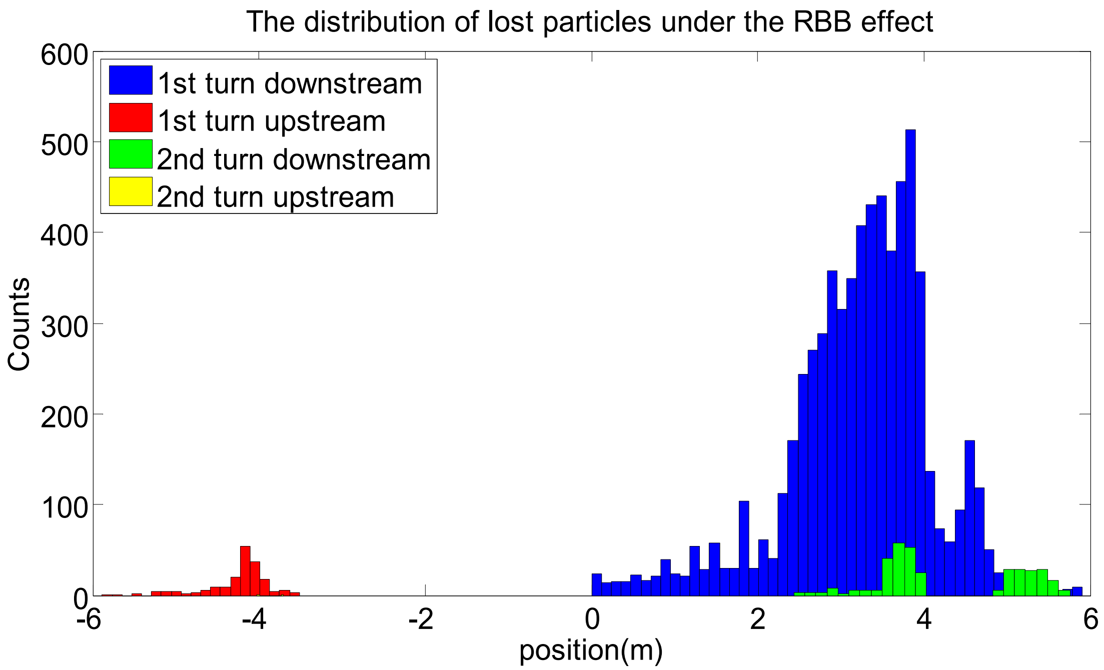
Beam Induced Backgrounds at CEPC



RBB lost particles statistic

~first two turns

- Set aperture according to beam pipe
- RBB generated at IP1, tracking in SAD
- The position and coordinate in phase space of lost particles near the IP are recorded.
- Most the events lost in the detector immediately. A few particles with high energy will lost near the IP after one revolution for a small energy loss.
- Pretty large fraction of events lost in the downstream region, the radiation damage for detector component is.



CEPC Booster

T.J. Bian

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

J.Y. Zhai

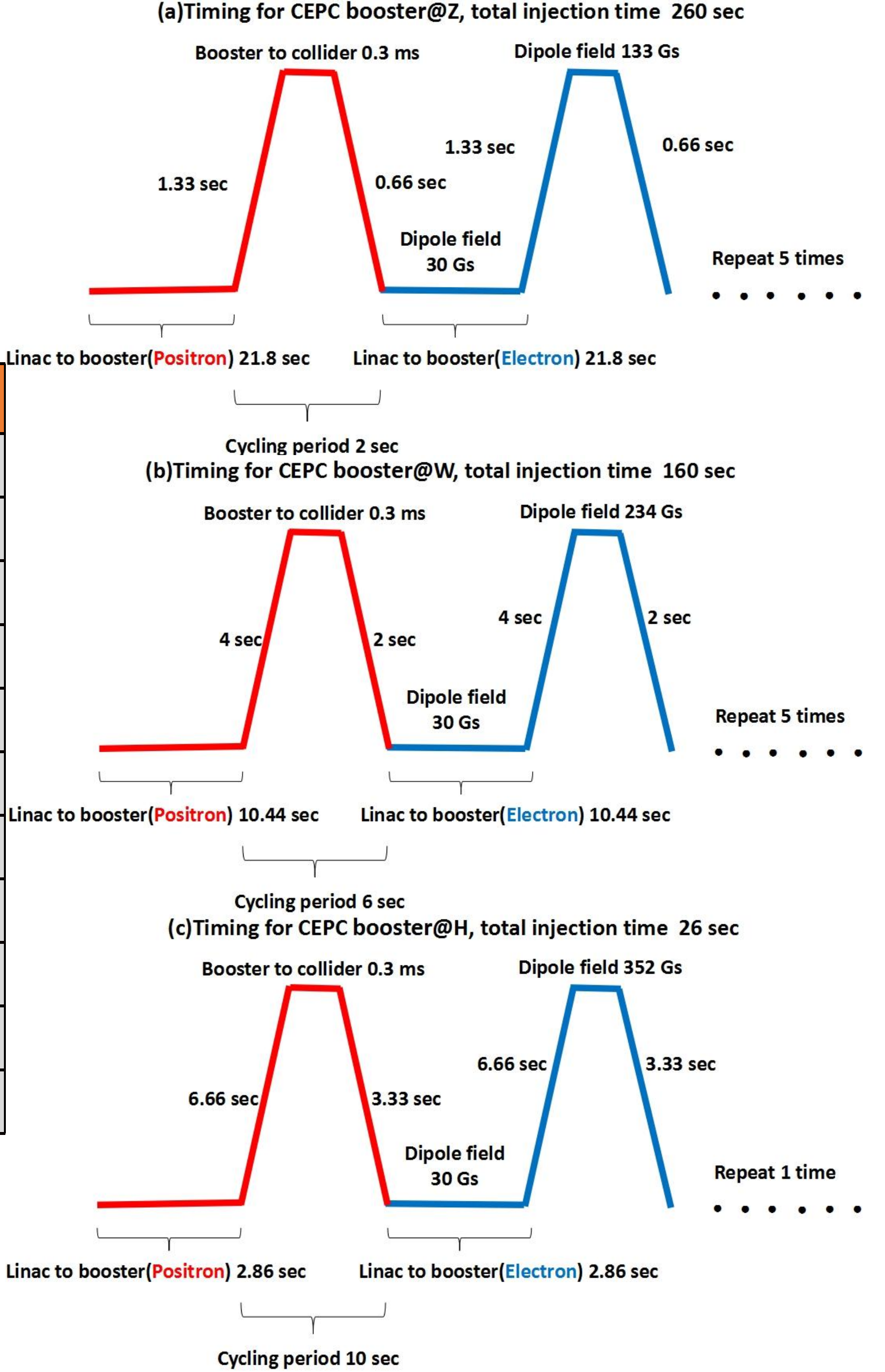
10 GeV injection	H	W	Z
Extraction beam energy [GeV]	120	80	45.5
Bunch charge [nC]	0.62	0.17	0.078
Beam current [mA]	0.53	0.53	0.51
Extraction RF voltage [GV]	1.83	0.7	0.36
Extraction bunch length [mm]	2.9	2.0	1.1
Cavity number in use (1.3 GHz TESLA 9-cell)	96	64	32
Gradient [MV/m]	**18.4**	10.5	10.8
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
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

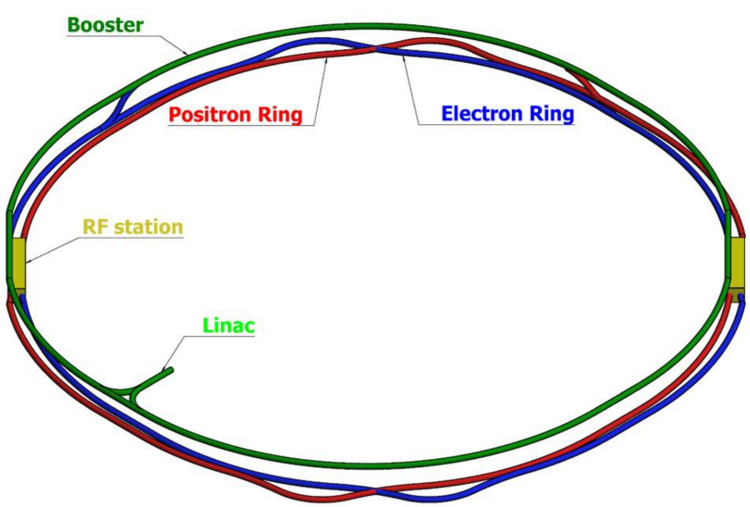
X.H. Cui

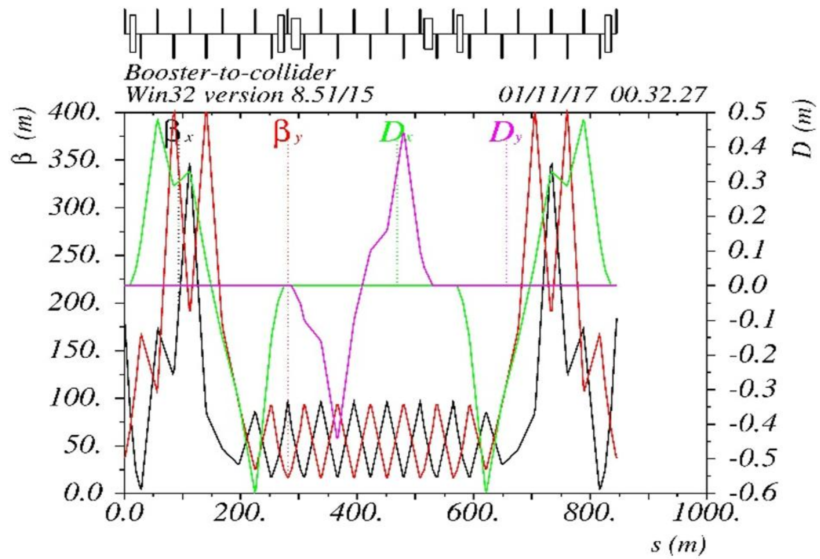
		H	W	Z
Injection times		1	5	5
Revolution frequency	Hz	2997.92	2997.92	2997.92
Bunch number		286	1044	2180
Transmission efficiency	%	95	95	95
Bunch charge	nC	0.62	0.17	0.078
Beam current	mA	0.53	0.54	0.51
Linac repetition rate	Hz	100	100	100
From linac to booster	sec	2.86	10.44	21.80
From booster to collider	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 to Collider Ring: Transport Line

X.H. Cui



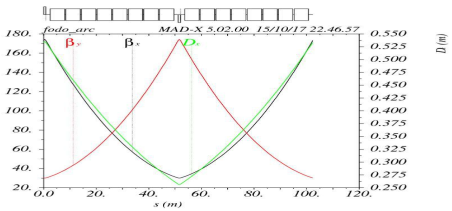


Transfer efficiency 99%

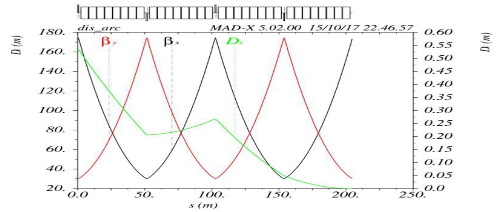
- **The total transfer efficiency > 90%   (99%*92%*99%)**
- Satisfy the requirement of topup operation for H, W and Z

CEPC Booster Design Status

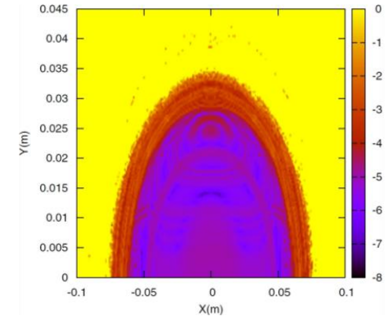
T.J Bian



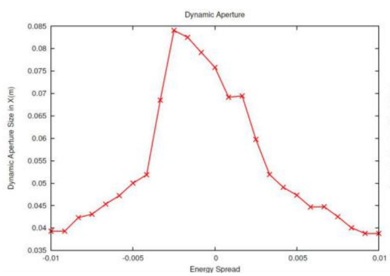
The twiss function of a FODO cell



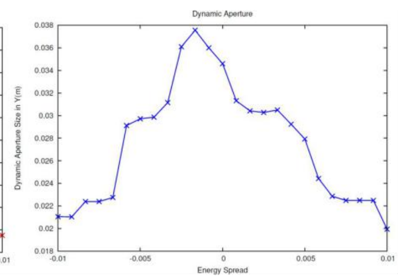
The twiss function of a dispersion suppressor



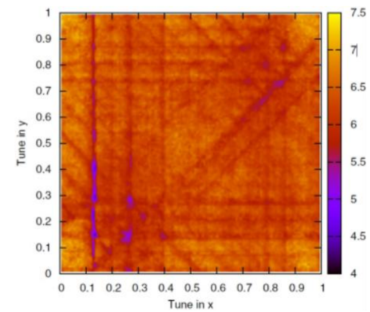
Frequency map analysis for on-momentum particles



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

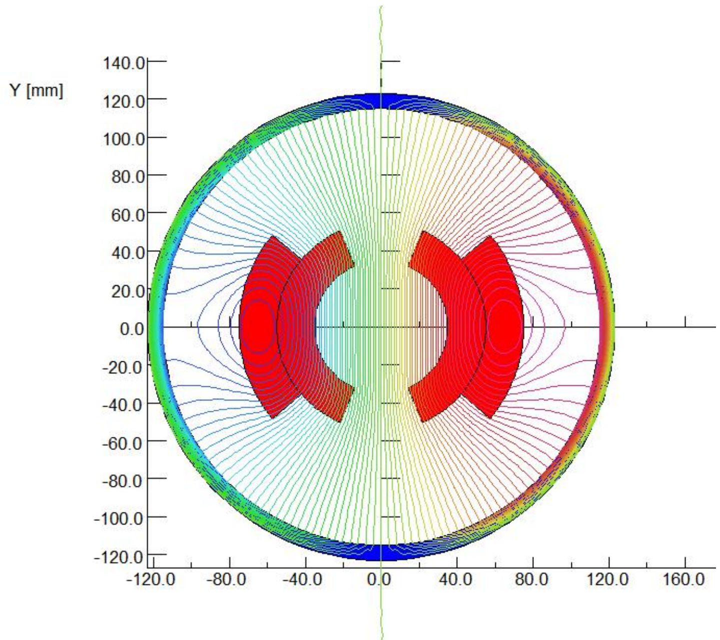
Parameters	Design goals	Design results
Beam current (mA)	<0.8	0.54
Emittance in x (nm rad)	<3.6	3.1
Dynamic aperture for 0.5% off-momentum particles	>3σ	8.5σ
Energy acceptance	>1%	2.5%
Timing	Meet the top-up injection requirements	√

CEPCB Low Field Dipole Magnets

W. Kang

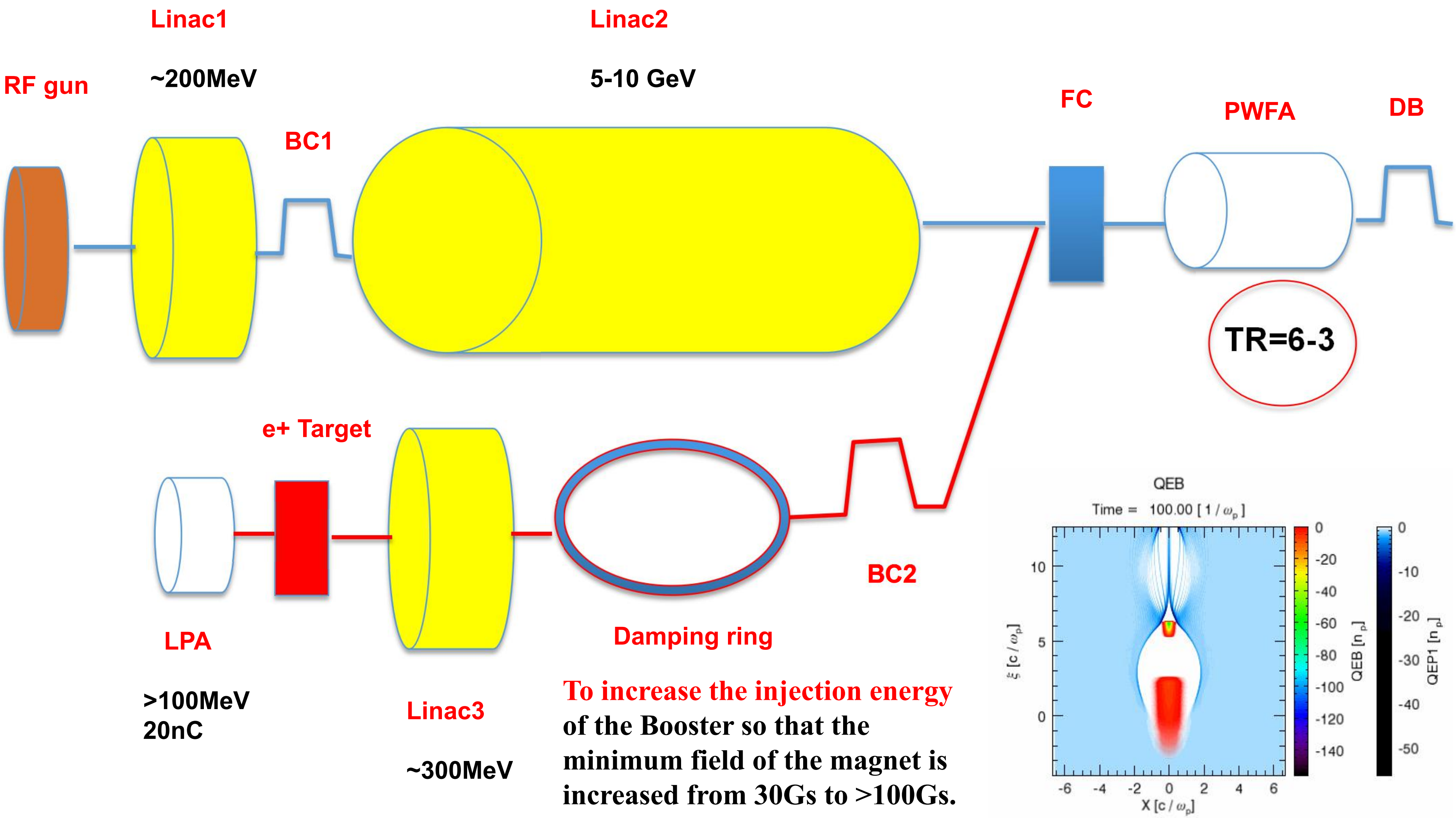
The ways to improve the field qualities of the low field magnets

- 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

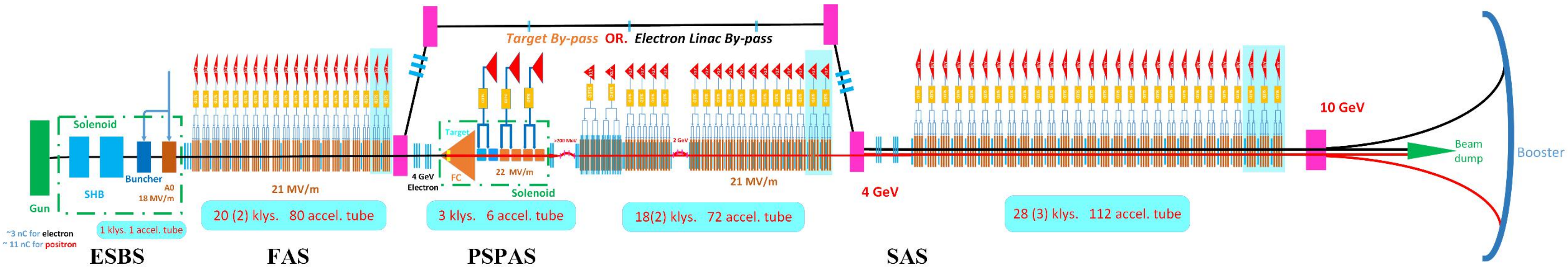
W. Lu



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

CEPC Linac Injector

C. Meng



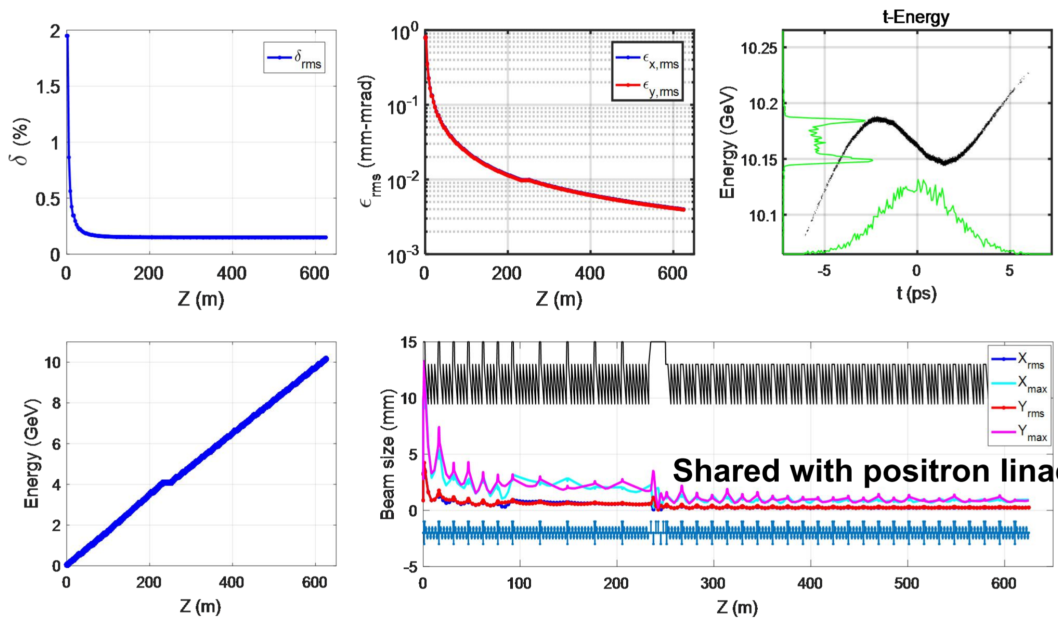
- ESBS (*Electron Source and Bunching System*)
  - Electron energy: 50 MeV
  - Electron bunch charge: 3 nC for electron injection/ 11nC for positron production
- FAS (*the First accelerating section*)
  - Electron beam to 4 GeV
  - High charge mode/ Low charge mode
- PSPAS (*Positron Source and Pre-Accelerating Section*)
  - Positron beam production and capture
- SAS (*the Second accelerating section*)
  - Energy to 10 GeV
- Electron bypass
  - Transport line bypass scheme
  - Target bypass scheme

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

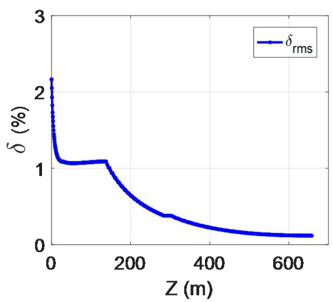
Energy spread (e^- /e^+)	σ_E		<2×10^{-3}
Emittance (e^- /e^+)	ε_r	mm· mrad	<0.3

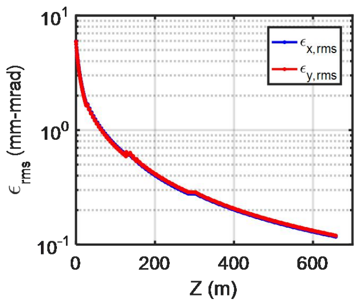


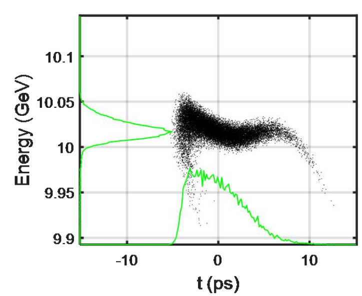
Positron Linac Design

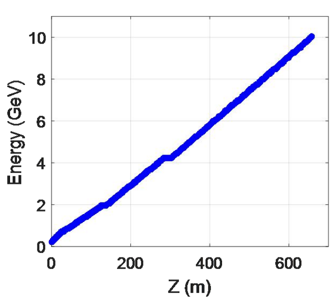
- Positron linac
  - 3 nC && 10 GeV
  - Energy spread (rms): 0.12%
  - Emittance (rms): 120 nm

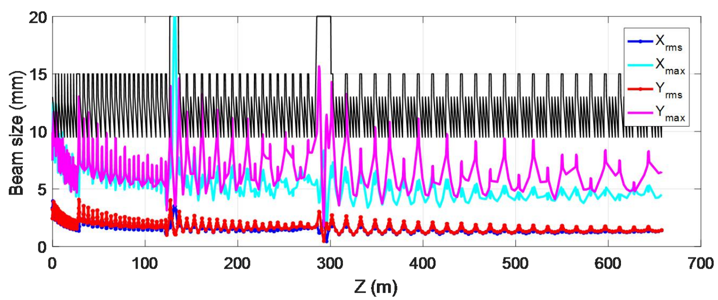
Energy spread (e^- /e^+)	σ_E		<2×10^{-3}
Emittance (e^- /e^+)	ε_r	mm· mrad	<0.3

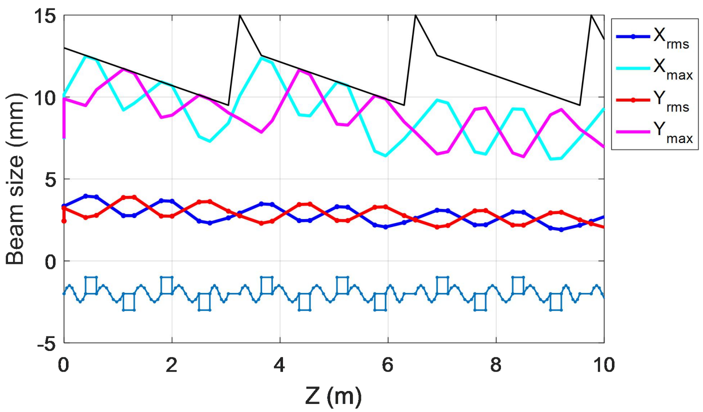






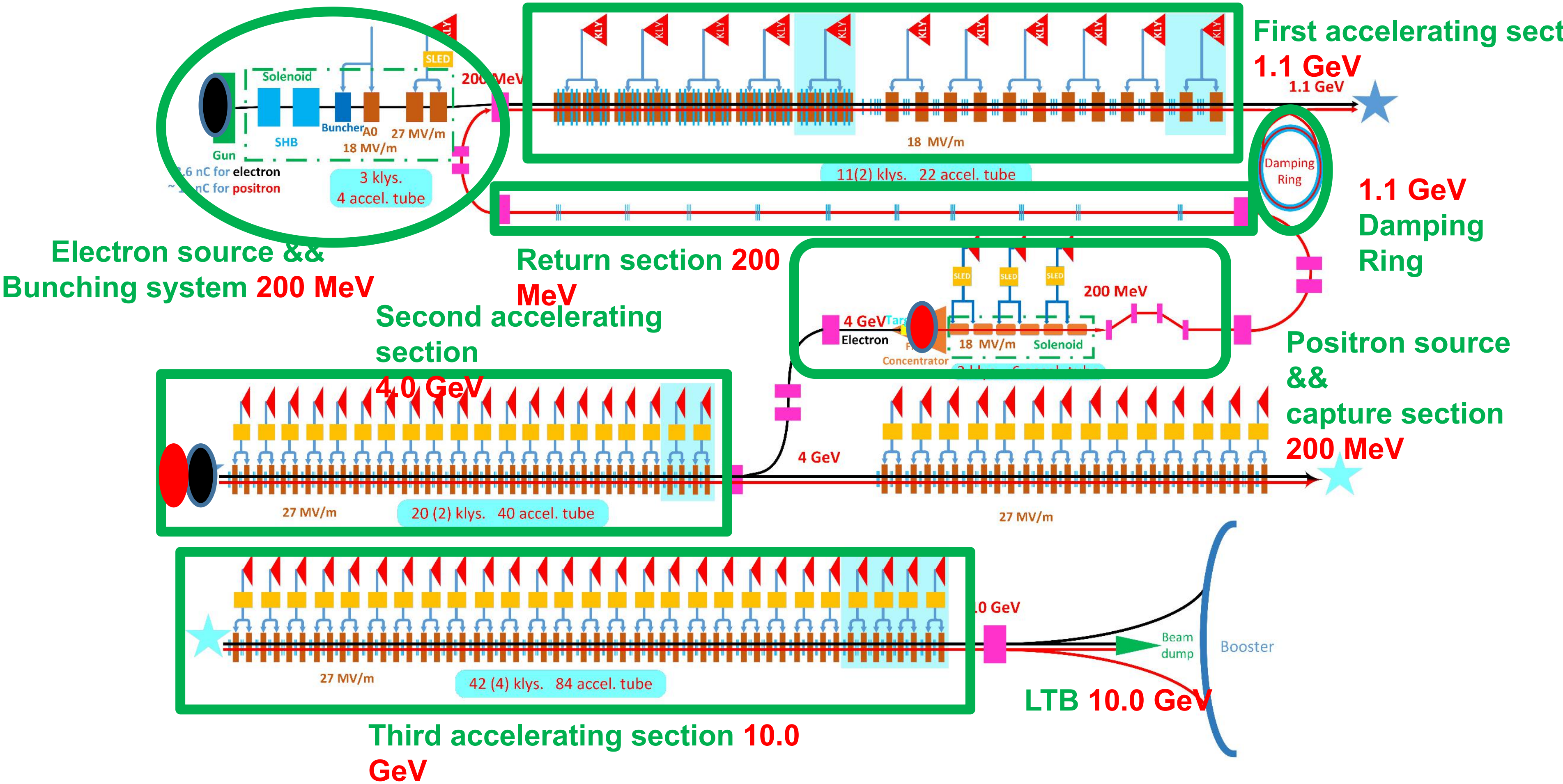






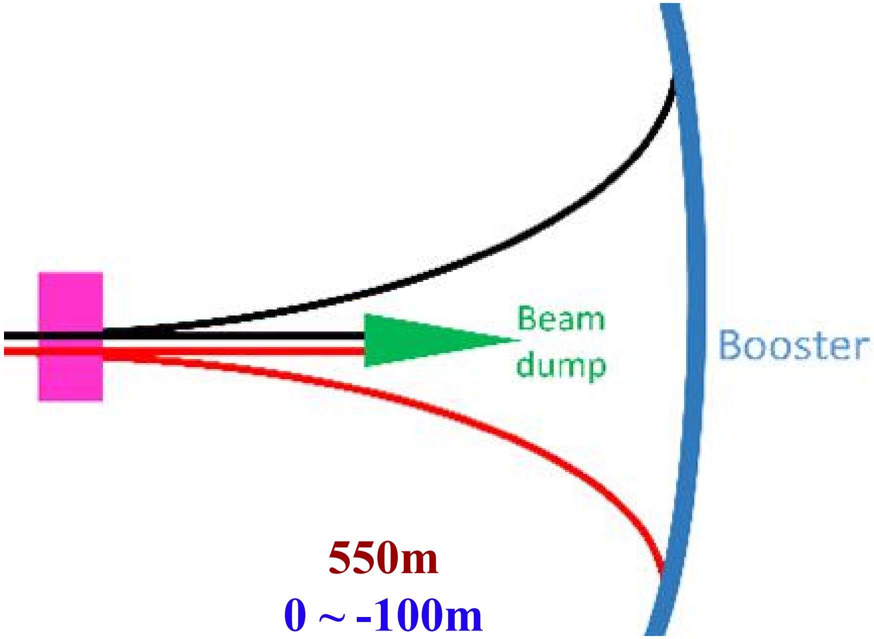
Beam loss: 2%

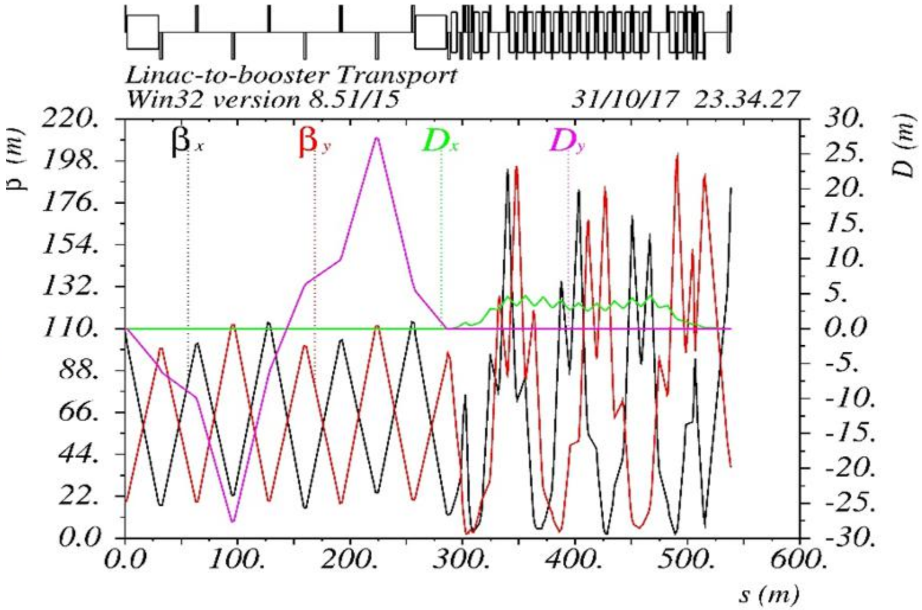
Layout of Linac Injector (with damping ring, option)



CEPC Linac to Booster: Transport Line

X.H. Cui





Transfer efficiency 99%

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

Electric Power Demand Estimated for CEPC

G.P. Lin

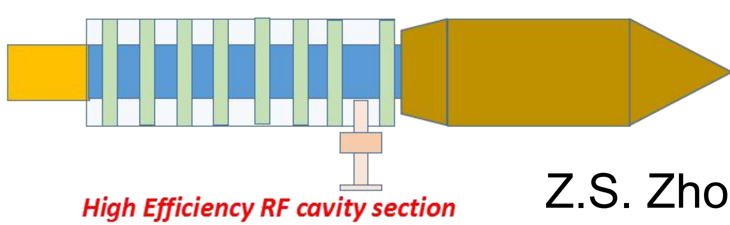
System	Location and electrical demand(MW)						Total (MW)
	Ring	Booster	LINAC	BTL	IR	campus	
RF power source	160	7.68	1.75				169.43
Cryogenics	16.8						16.8
Converter for magnets	98.5	10.5	5.7	2			116.7
Experimental devices					14		14
Dedicated services	6	3	1	0.5			10.5
Utilities	40		2	0.5	3		45.5
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)
- Cable loss ↓ (lower)
- Magnet aperture ↓ (optimized)
- ·······

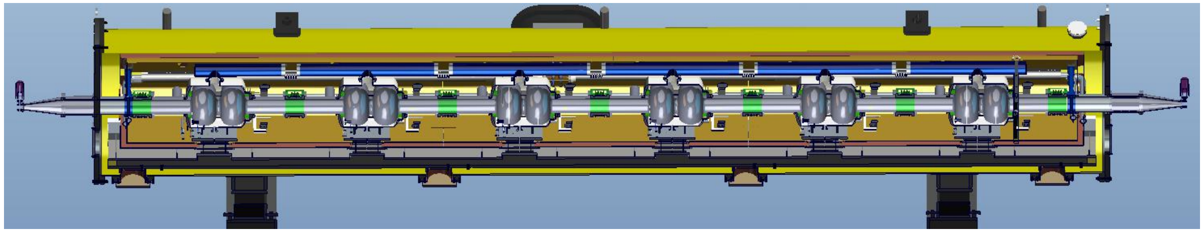


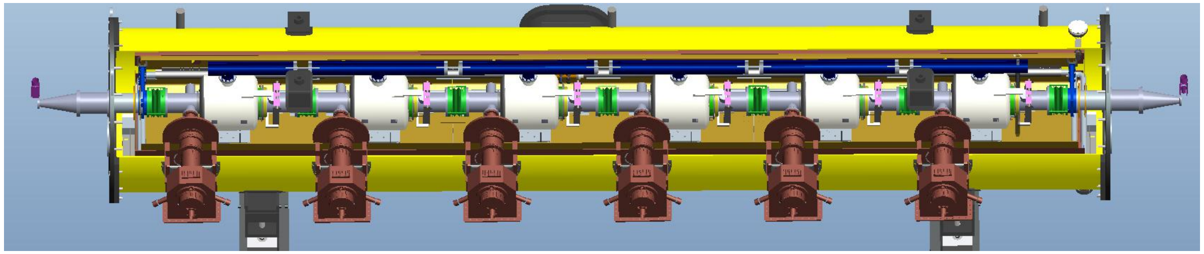
Z.S. Zhou

CEPC 650 MHz Cavity Cryomodule

J.Y. Zhai

- 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.

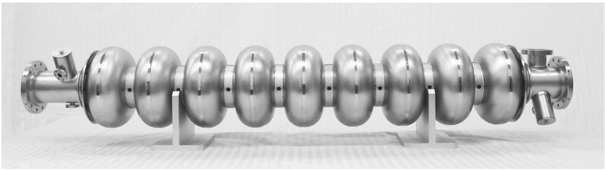




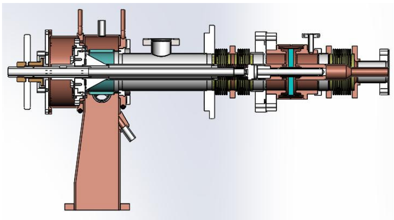
Overall length (flange to flange, m)	8.0
Diameter of vacuum vessel (m)	1.3
Beamline height from floor (m)	1.2
Cryo-system working temperature (K)	2
Number of cavities and tuners	6
Number of couplers	6
Number of RT HOM absorbers	2
Number of 200-POSTs	6
Static heat loads at 2 K (W)	5
Alignment x/y (cavities)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

1.3 GHz SRF Technology for CEPC Booster

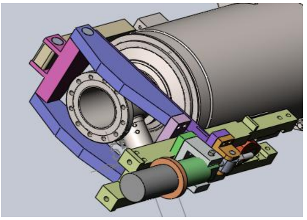
XFEL and LCLS-II type cryomodule, without SCQ. Technology R&D in synergy with Shanghai XFEL (SCLF). No big challenge.



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.

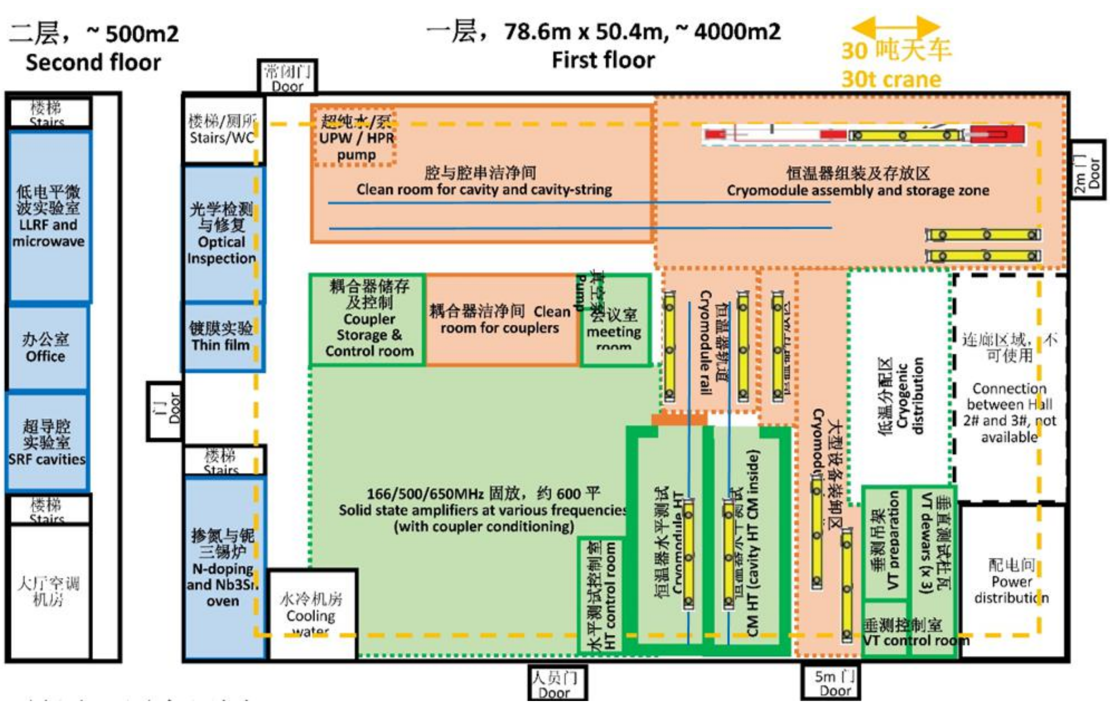


XFEL/ILC/LCLS-II or other type **variable power coupler**. Peak power 30 kW, average 4 kW, Q_{ext} 1E7-5E7, two windows.



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

IHEP New Large SRF Facility



4500 m² SRF lab in the Platform of Advanced Photon Source Technology R&D (PAPS), Huairou Science Park, Beijing.

Mission: World-leading SRF Lab for Superconducting Accelerator Projects and SRF Frontier R&D.

Mass Production: 200 ~ 400 cavities (couplers) test per year, **20 cryomodules** assembly and horizontal test per year.

Construction: 2017 - 2020

Collider Magnet Overview

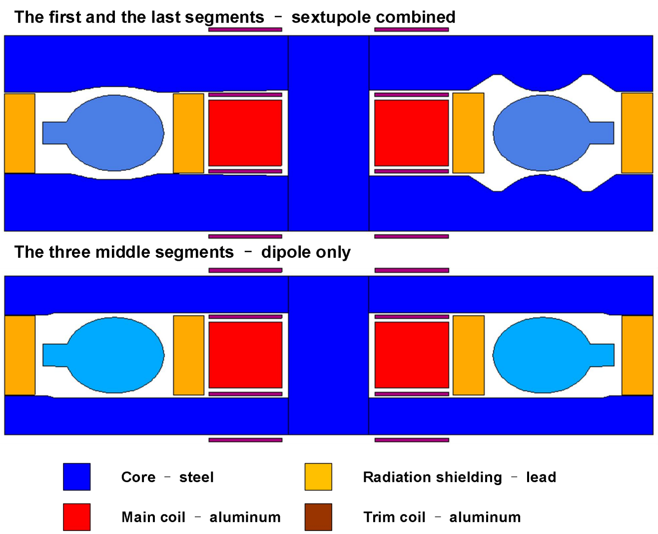
F.S. Chen

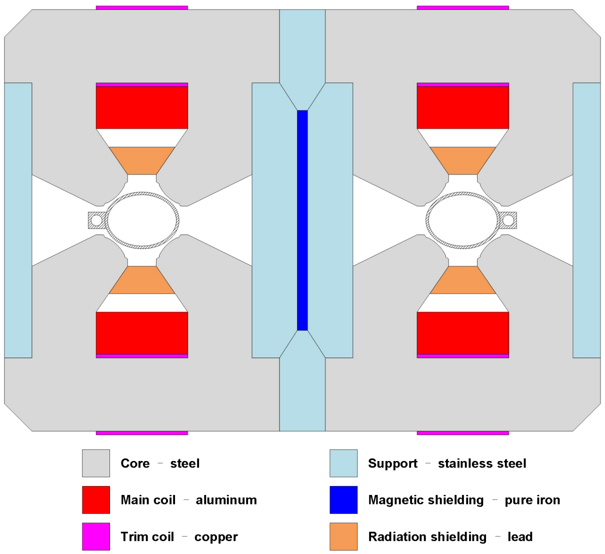
- The magnets cover almost 80% of the 100km ring.

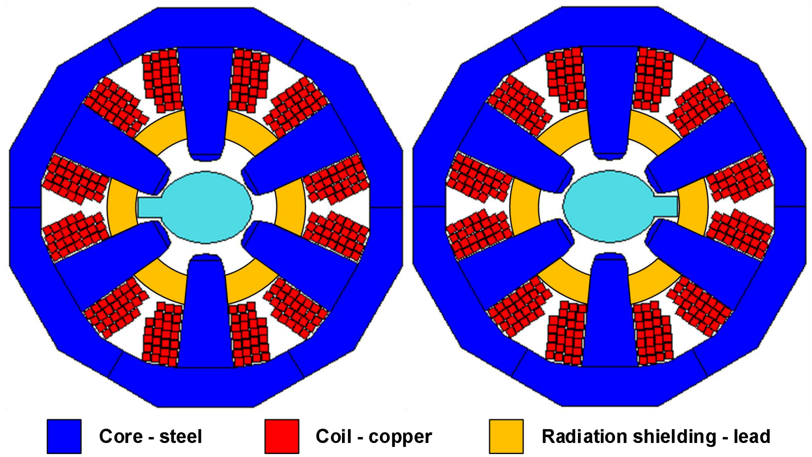
	Dipole	Quad.	Sext.	Corrector	Total
Dual aperture	2368	2232	-	-	9360
Single aperture	33*2	467*2	920*2	2480	
Total length [km]	71.4	5.2	0.8	1.7	79.1
Power [MW]	6.5	36	1.5	2	46

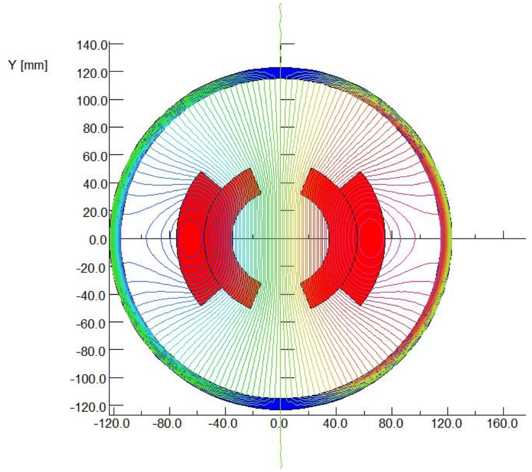
- The most concern issues for collider magnet
  - Manufacturing cost
  - Power consumption
  - Radiation shielding
  - Field quality

Designs of Dual Aperture CEPC Magnets





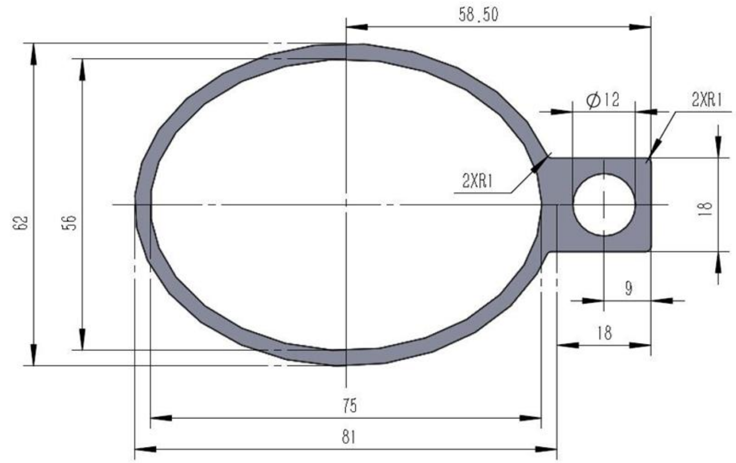




Booster Dipole

Dipole Vacuum Chamber of Electron Storage Ring

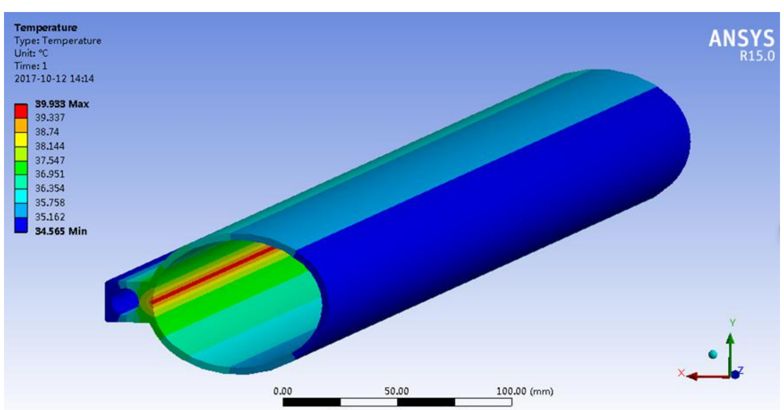
H.Y. Dong

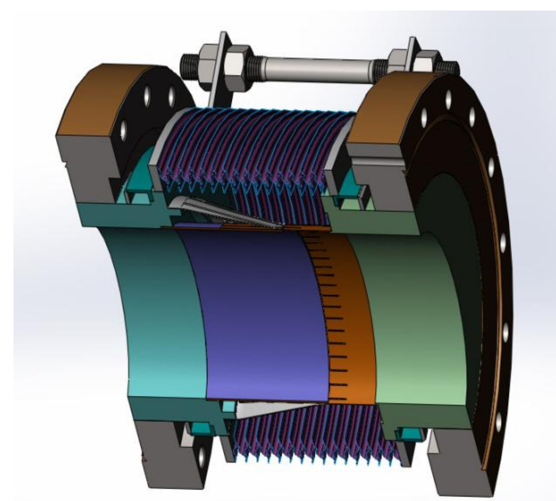


Aluminum vacuum chamber
(elliptic 75×56, thickness 3, length 6000)

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 Site Selections

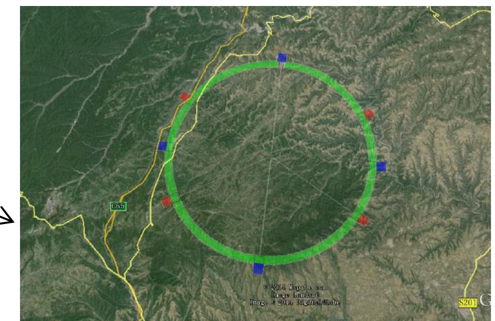
Bejing

Baoding
(xiong an)

Tianjin 4

1

2



3

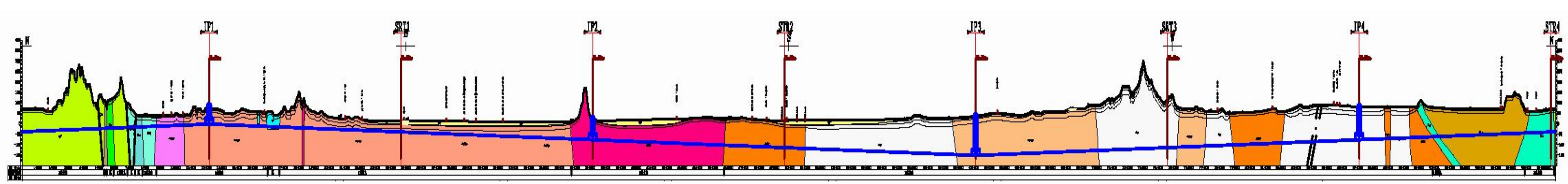
1) Qin huang dao，Heihe （Completed in 2014）

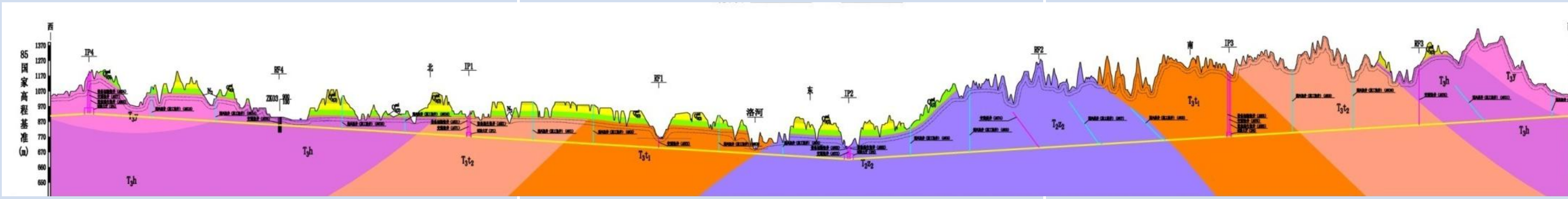
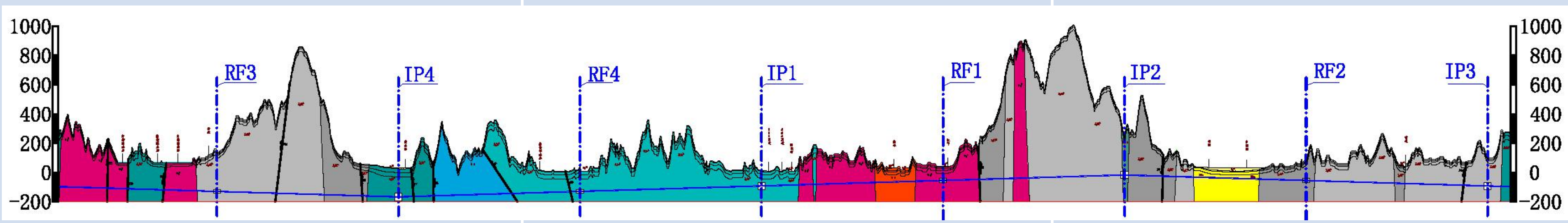
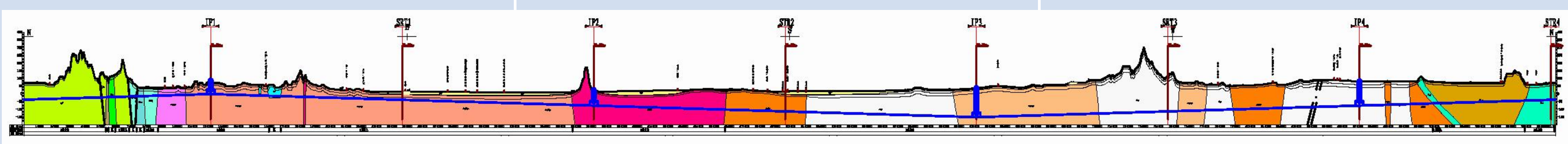
2) Huanging，Shanxi（Completed in 2017)

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）



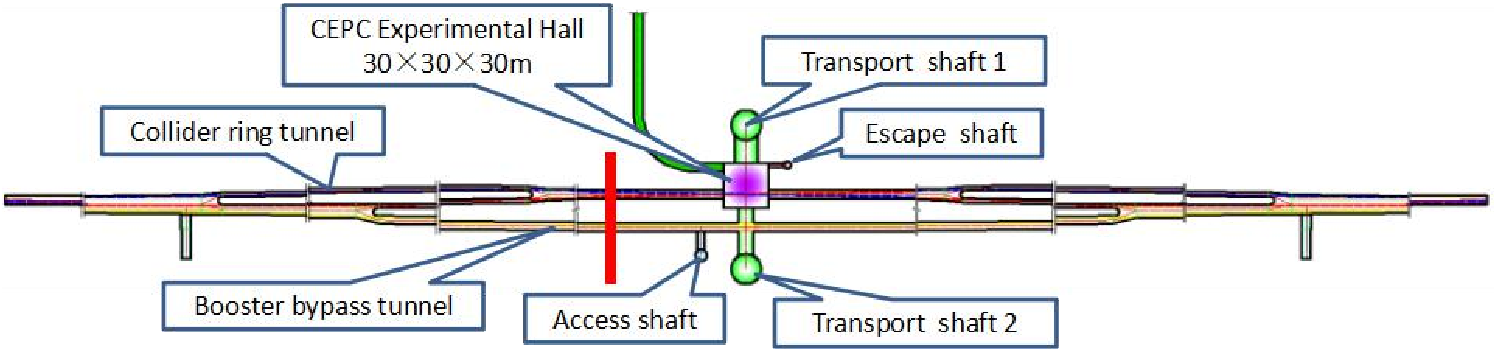
<table>
<tr><th>Item</th><th>Huangling</th><th>Shen-Shan</th><th>Funing</th></tr>
<tr><td>Project layout</td><td colspan="3">Huangling（100km）

Shen-Shan（100km）

Funing（100km）
</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

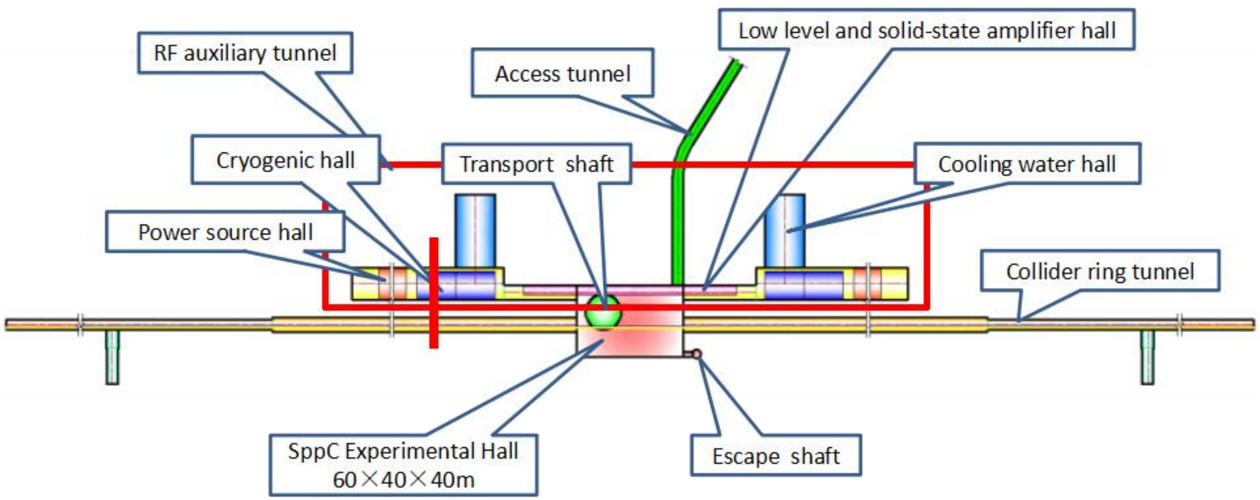
YREC

Y. Xiao

IP1 / IP3

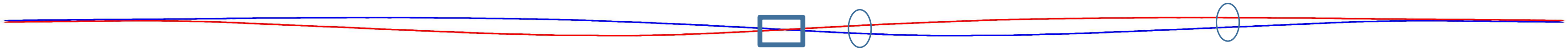


IP2 / IP4



IP Underground

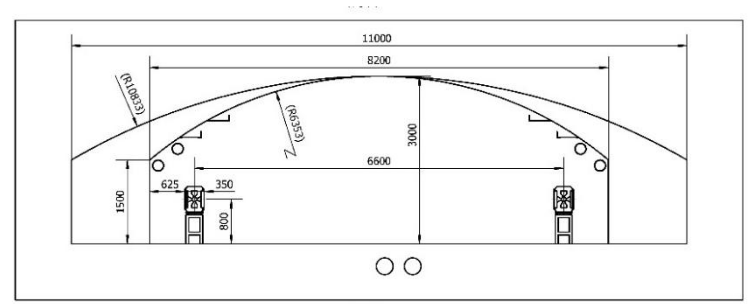
H.J. Wang

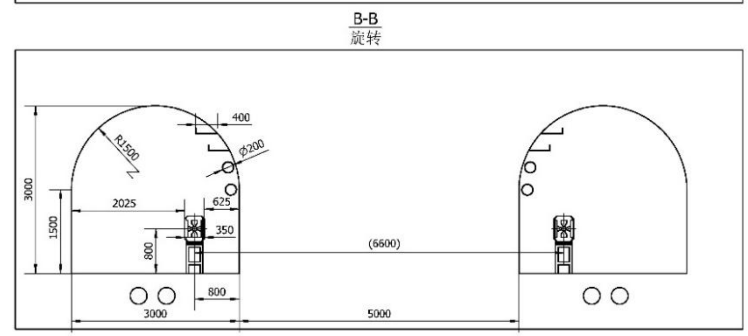


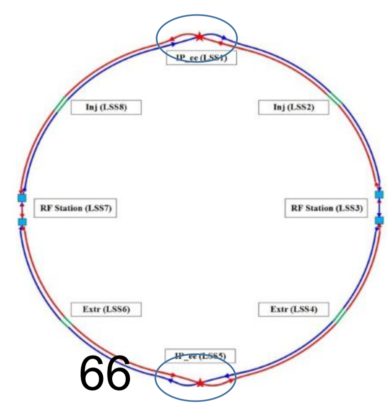
IR section tunnel

- Experimental hall
  - IP1: 30m*30m*30m
  - IP3: 60m*40m*40m

  The detailed not defined now
- Tunnel inner diameter
  - Tunnel enlargement,
  - M: branched into two line: 3m*2
  - N: merged to one tunnel, then contracted to normal diameter
- Bypass tunnels
  - Dedicated to bypass detector for booster in interaction region
  - Tunnel inner diameter: 3m



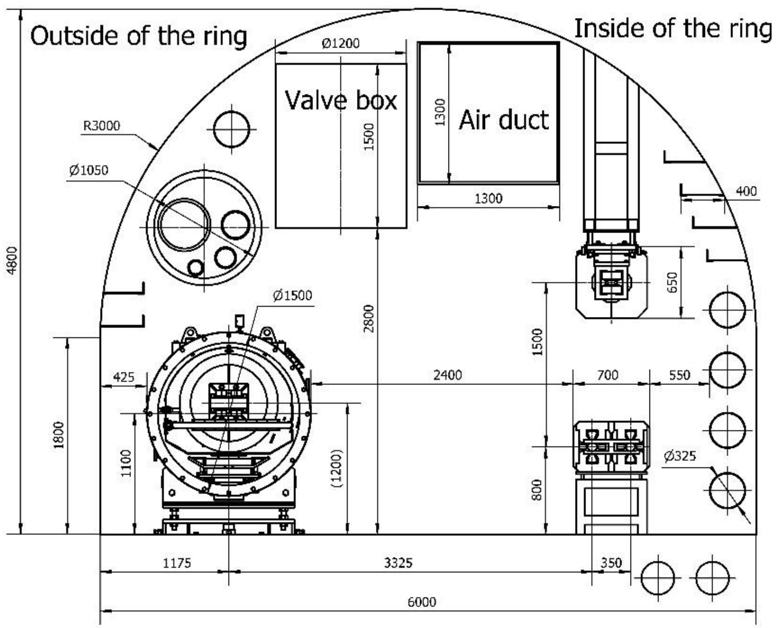




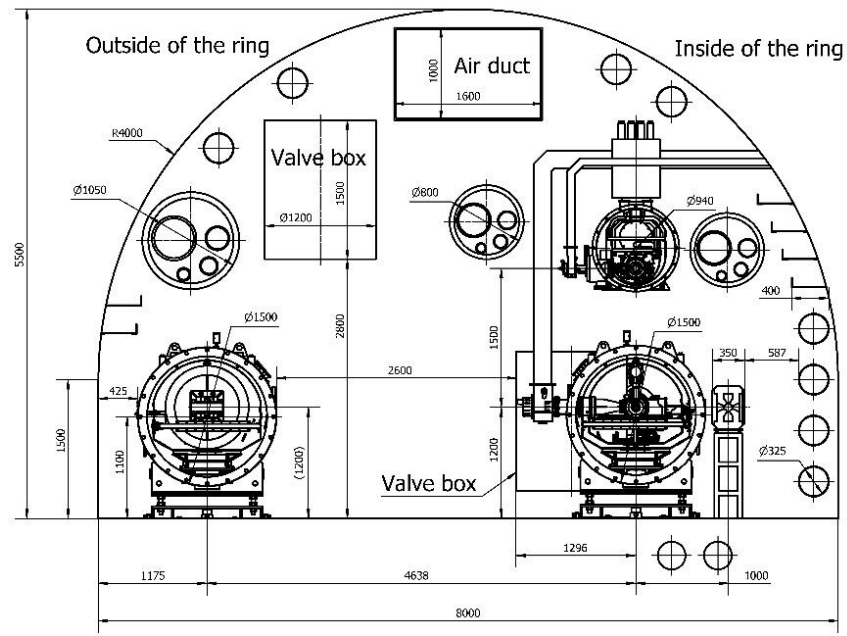
CEPC-SppC Tunnel Cross Sections

J.L. Wang

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



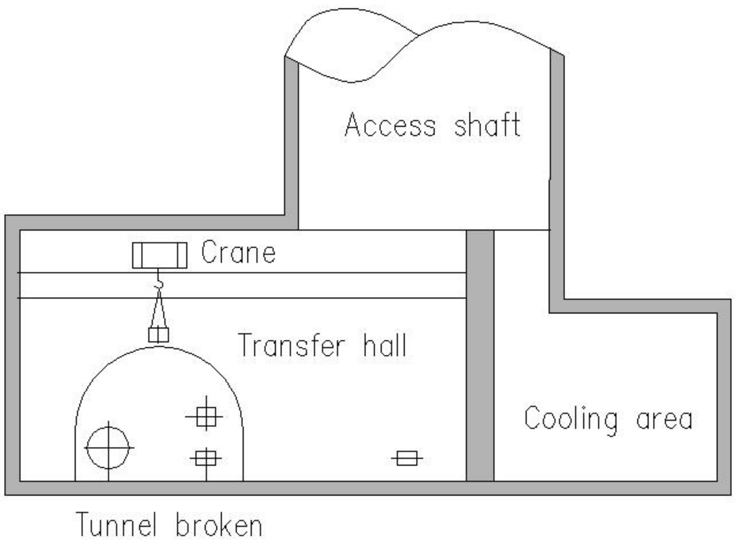
Tunnel cross section at RF-section
Width: 8,000 mm. Height: 5,500 mm.



Vertical Shafts

G.P. Lin

- Access shafts for ring tunnel
  - Function
    - Transport staff and equipment into the ring tunnels.
    - Cable, pipe, duct, etc.
    - Emergency exit
  - One of Φ20m at RF auxiliary tunnel
  - Two of Φ 20m and one of Φ5m at experimental hall
  - One of Φ10m at P2, P4, P6, P8
  - One of Φ 8m at C1-8
  - Two of Φ 5m at transport line tunnel
  - One of Φ 5m at V1-16



- There are magnets or cryostats at each side of tunnel. How to transport equipment?
- At each points, transfer hall is inserted into tunnel where tunnel wall is open.
- The equipment is loaded into transfer hall via shaft, which will be lifted into the middle area of tunnel by crane

Preliminary Scheme (Funing 100km)

YREC

IP1 Surface Buildings

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

The printed draft will be available for discussion during parallel sessions

CEPC International Collaboration Status

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

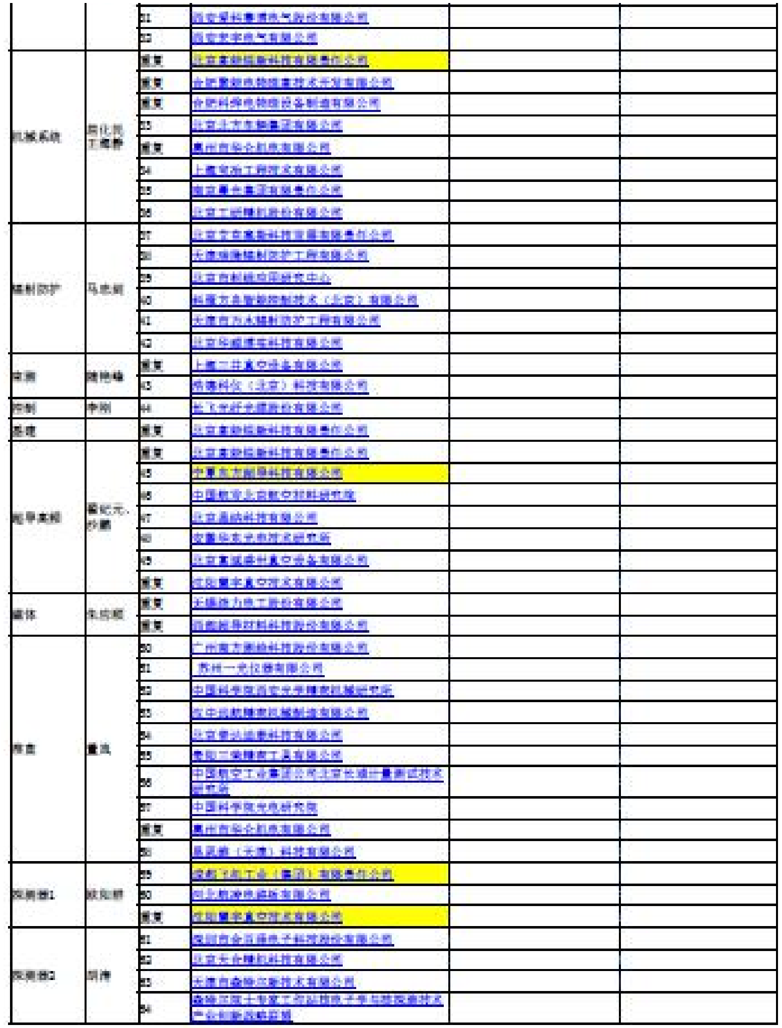
International collaboration with major international labs:

- ✓ IHEP-BINP (Russia) MoU (Jan 2016)
- ✓ IHEP-KEK (Japan) MoU (Sept 2017)
- ✓ IHEP-MEPhI (Russia) (Nov 2017)

More than 20 MoU in general

CEPC-SppC Industrial Promotion Consortium (CIPC)

- helps & guides industry;
- win their support for CEPC;
- enhance CEPC quality, reduce cost;
- ……



To be established in the afternoon Nov. 7 , 2017

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