Status of CEPC collider ring

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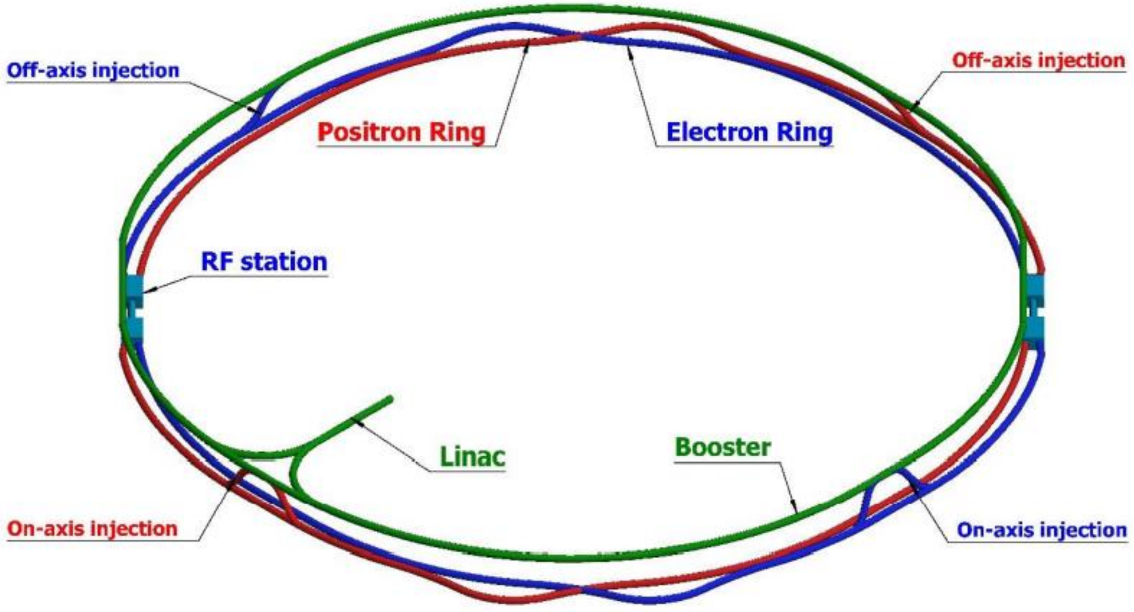
Design requirement of the CEPC collider ring

- SR power 30MW (50 MW upgradable), 100km, 2 IPs
- Crab waist collision
- Local chromaticity correction for the interaction region
- Non-interleaved sextupoles
- Correction of sawtooth orbit
- Shared cavities for two beam @ tt, Higgs
- Dual aperture dipole and quadrupole magnets
- Spin polarized beam @ Z
- Asymmetric interaction region
- Compatible of $t\bar{t}$/H/W/Z modes
- Compatible with SPPC



Status of the CDR scheme

Error Correction

B. Wang, Y. Y. Wei

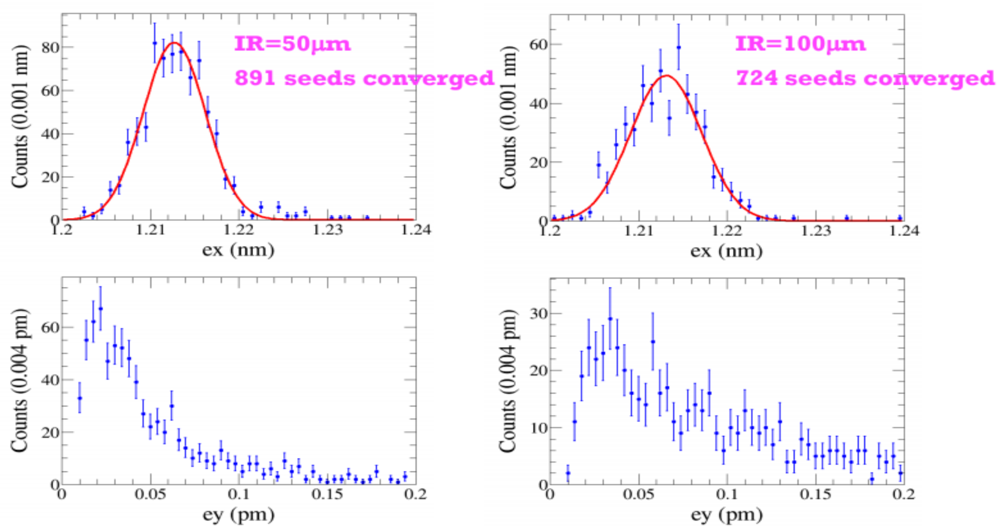
More robust correction of error effects

IR=50μm

Component	Δx (mm)	Δy (mm)	$\Delta\theta_z$ (mrad)	Field error
Dipole	0.10	0.10	0.1	0.01%
Arc Quadrupole	0.10	0.10	0.1	0.02%
IR Quadrupole	**0.05**	**0.05**	**0.05**	
Sextupole	0.10	0.10	0.1	

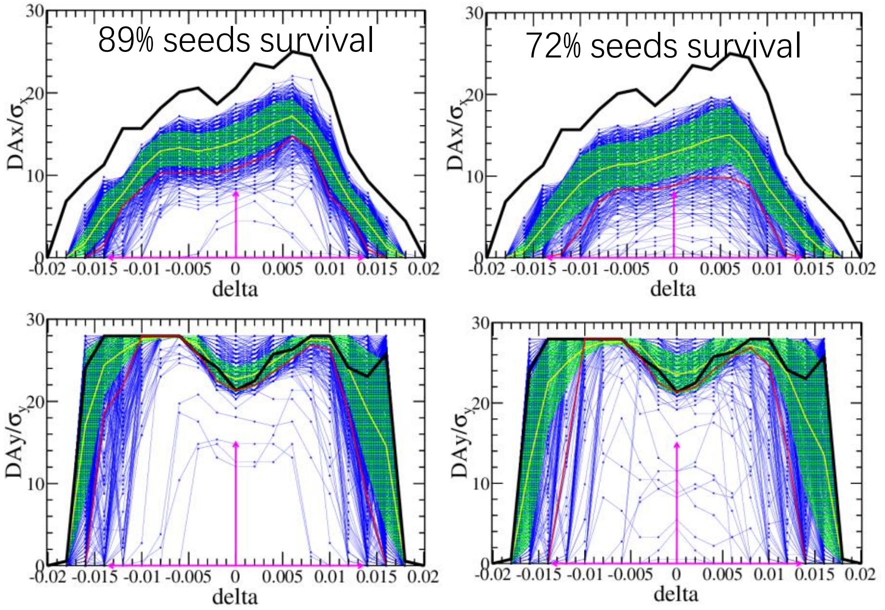
IR=100μm

Component	Δx (mm)	Δy (mm)	$\Delta\theta_z$ (mrad)	Field error
Dipole	0.10	0.10	0.1	0.01%
Arc Quadrupole	0.10	0.10	0.1	0.02%
IR Quadrupole	**0.10**	**0.10**	**0.10**	
Sextupole	0.10	0.10	0.1	



ex = 1.2127±0.0035 nm
ey = 0.050± 0.0015 pm
ey/ex = (0.0041± 0.0001)%

ex = 1.2131±0.0040 nm
ey = 0.0777± 0.0023 pm
ey/ex = (0.0064± 0.0002)%



—DA of bare lattice —mean value —lower limits at 90%

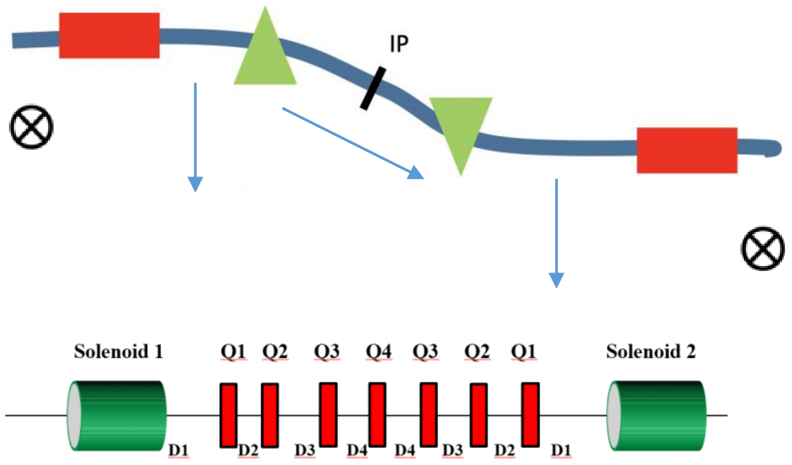
—DA of each seed —statistic errors

Z-pole polarization

W.H. Xia, Z. Duan, Y. W. Wang, J. Gao

Design of spin rotators in the CEPC CDR lattice

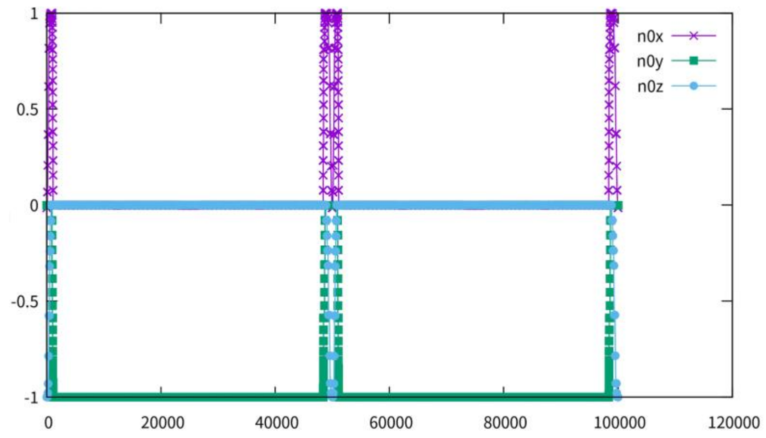
- Implemented solenoid spin rotators (~100 m each) into the first short straight sections near IR
- **The spin rotators do rotate the spin direction as expected**
- But the limited space results in a very compact design with superconducting quadrupoles
- The local contribution to the chromaticity is very large, no DA after insertion
- A new modular design of spin rotator is ongoing to **reduce the quarupole strength and chromaticity**.



Solenoids		Quadrupoles		Drifts	
Length (m)	Field strength (T)	$\frac{\partial B_y/\partial x}{B\rho}$ (m^{-2})	Length (m)	Length (m)	Total Length (m)
1.48895	8	Q1: -0.83 Q2: 1.35 Q3: -0.90 Q4: -0.82	0.8	D1: 0.2 D2: 0.2 D3: 0.2 D4: 0.1	9.97796

	SPIN ROTATOR 1，3	SPIN ROTATOR 2，4	Final focus Quads
X chromaticity	-2107. 72	-1767. 22	-125. 188
Y chromaticity	-2526. 059	-8016. 724	-3754. 209

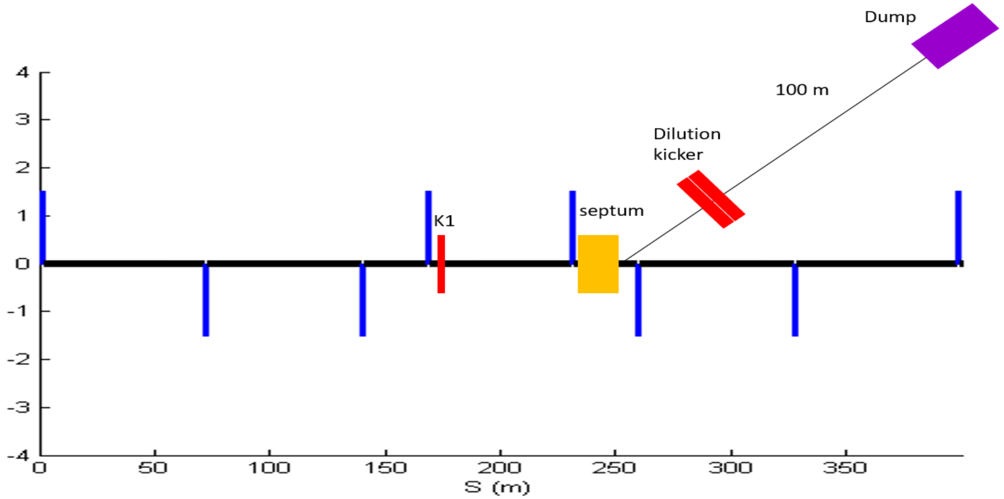
Polarization direction w/ spin rotators



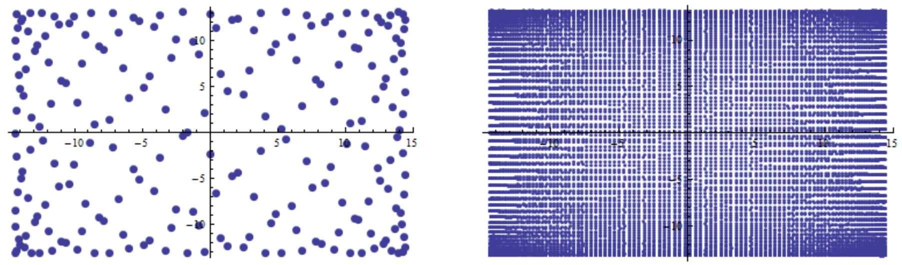
Beam dump

X. H. Cui, Z. J. Ma, G. Y. Tang et al

1. One Dump for each of the electron and positron collider ring;
2. Use one kicker and one septum to get the beams into the dump line, so all bunches can be dumped in one turn;
3. **Horizontal and vertical dilution kickers** are used to change the position of different bunches at the dump, in order to reduce the beam damage to the dump.



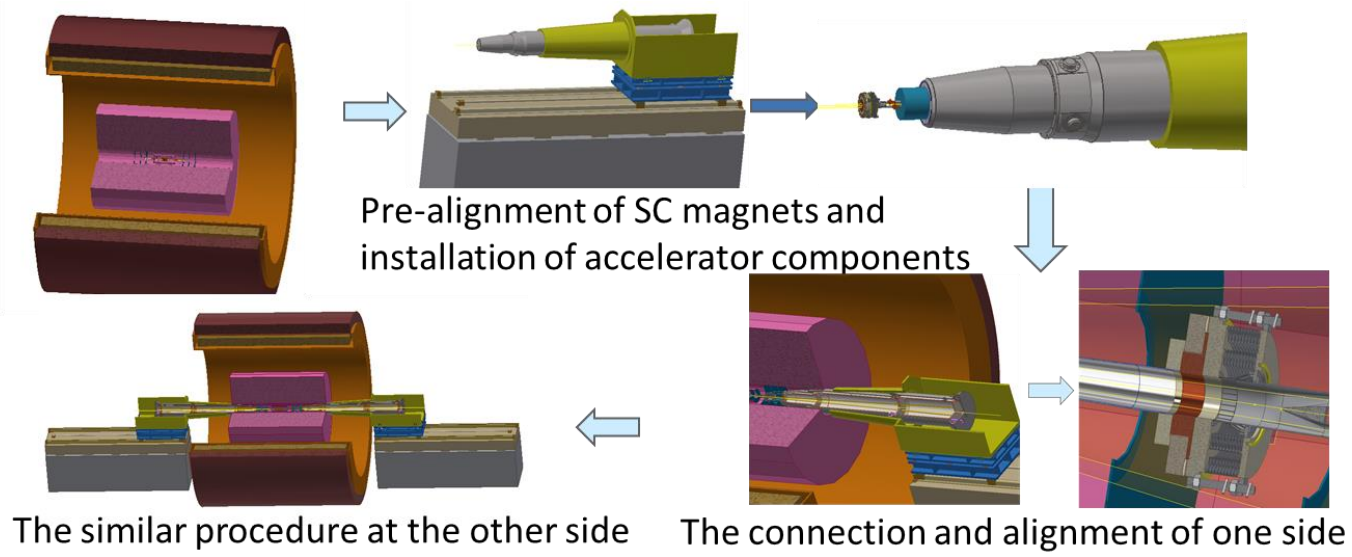
① The Bunch distribution on the dump surface is first assumed to be 25cm x 25cm; Each bunch 2D-Gaussian: $\sigma\_x \sim 3mm$, $\sigma\_y \sim 0.3mm$
② Dilution kicker strength vibrate in 1e5 Hz.



bunch distributions at the dump for Higgs mode, and Z mode

MDI integration and alignment

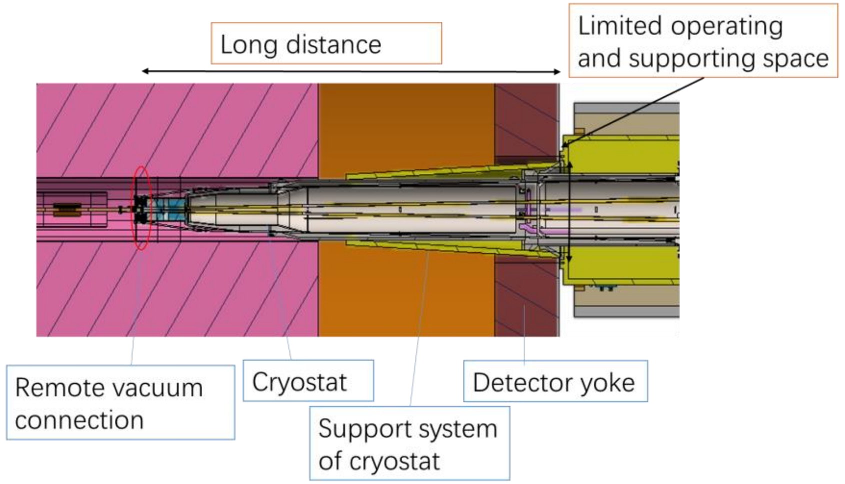
by H. J. Wang, S. Bai et al



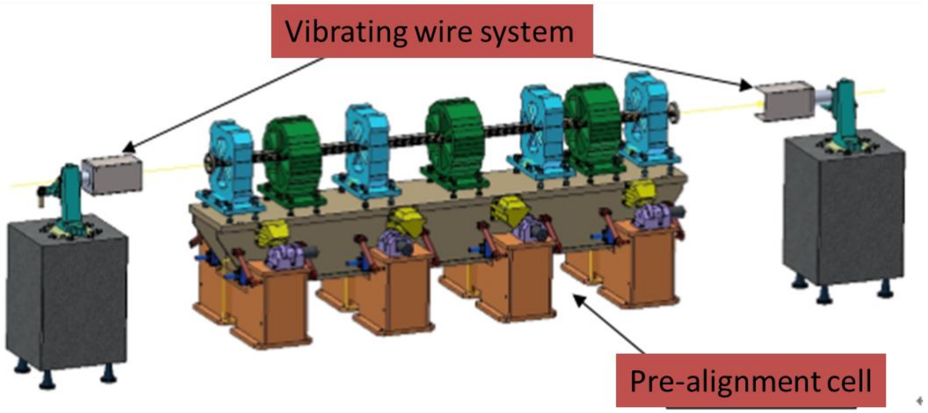
Alignment scenario:

- Pre-align the SC magnets using vibrating wire system to “certain location” to compensate the **effect of loads.**
- Align the SC magnets in two cryostats using optical system.
- Measure misalignment using SSW and adjust by corrector magnets meet the alignment requirements.

SSW: single stretched wire



VWS is a candidate pre-alignment method, accuracy of magnet centers: ≤10 μm



Status of the high luminosity scheme

Key parameters of high luminosity scheme

C. Yu, Y. W. Wang, Y. Zhang, S. Bai, Y. Zhu, D. Wang, J. Gao et al

Key parameters of CDR scheme for Higgs

- **L*=2.2m, θc=33mrad, βx*=0.36m, βy*=1.5mm, Emittance=1.2nm**
  - Strength requirements of anti-solenoids B_z~7.2T
  - Two-in-one type SC quadrupole coils (Peak field 3.8T & 136T/m)

Key parameters of high luminosity scheme for Higgs

- **L*=1.9m, θc=33mrad, βx*=0.33m, βy*=1.0mm, Emittance=0.64nm**
  - Strength requirements of anti-solenoids B_z~7.2T (6.8T with a shorter solenoid)
  - Two-in-one type SC quadrupole coils (Peak field 3.8T & 141T/m) with room temperature vacuum chamber & Iron yoke

Reduction of the length from IP to 1st quadrupole **without changing the front-end position of the FD cryo-module**

- To make the lattice robust and provide good start point for DA

Status of beam parameters

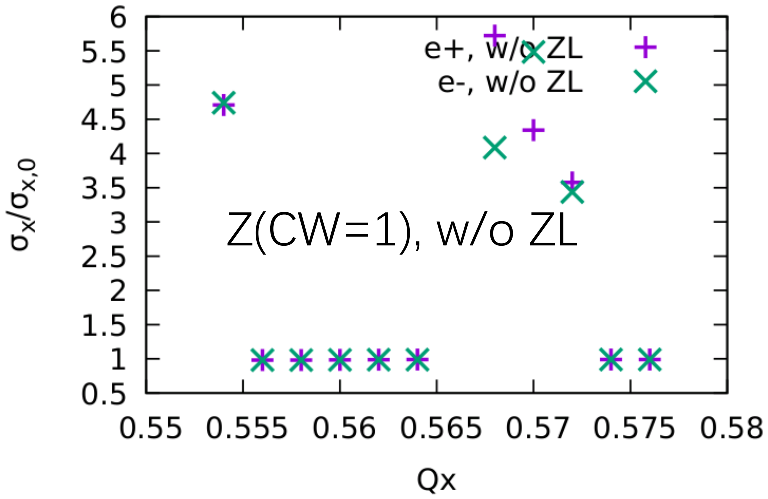
	ttbar	Higgs	W	Z
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	30			
Half crossing angle at IP [mrad]	16.5			
Bending radius [km]	10.7			
Energy [GeV]	180	120	80	45.5
Energy loss per turn [GeV]	9.1	1.8	0.357	0.037
Piwinski angle	1.21	5.94	6.08	24.68
Bunch number	35	249	1297	11951
Bunch population [10^10]	20	14	13.5	14
Beam current [mA]	3.3	16.7	84.1	803.5
Momentum compaction [10^-5]	0.71	0.71	1.43	1.43
Beta functions at IP (bx/by) [m/mm]	1.04/2.7	0.33/1	0.21/1	0.13/0.9
Emittance (ex/ey) [nm/pm]	1.4/4.7	0.64/1.3	0.87/1.7	0.27/1.4
Beam size at IP (sigx/sigy) [um/nm]	39/113	15/36	13/42	6/35
Bunch length (SR/total) [mm]	2.2/2.9	2.3/3.9	2.5/4.9	2.5/8.7
Energy spread (SR/total) [%]	0.15/0.20	0.10/0.17	0.07/0.14	0.04/0.13
Energy acceptance (DA/RF) [%]	2.3/2.6	1.6/2.2	1.2/2.5	1.3/1.7
Beam-beam parameters (ksix/ksiy)	0.071/0.1	0.015/0.11	0.012/0.113	0.004/0.127
RF voltage [GV]	10	2.2	0.7	0.12
RF frequency [MHz]	650	650	650	650
HOM power per cavity (5/2/1cell)[kw]	0.4/0.2/0.1	1/0.4/0.2	-/1.8/0.9	-/-/5.8
Longitudinal tune Qs	0.078	0.049	0.062	0.035
Beam lifetime (bhabha/beamstrahlung)[min]	81/23	39/18	60/717	80/182202
Beam lifetime [min]	18	12.3	55	80
Hour glass Factor	0.89	0.9	0.9	0.97
Luminosity per IP[1e34/cm^2/s]	0.5	5.0	16	115

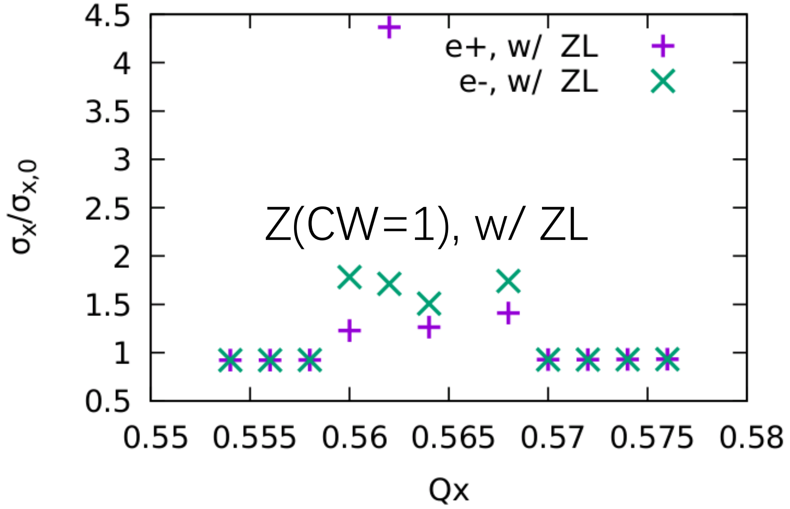
Y. W. Wang, D. Wang, Y. Zhang, J. Y. zhai et al

Beam-beam simulation

Y. Zhang

- ttbar:
  - even with strong SR damping, 3D flip-flop appear easily without CW and longitudinal impedance
  - Real lattice design should consider asymmetric energy distribution (ref: K. Oide)
- Higgs: Ne=14e10 is preferred considering beamstrahlung lifetime
- Z: **Stable tune area** with both beam-beam and impedance is significant smaller than the case with beam-beam only.
- More check should be done, including code itself (especially ttbar)



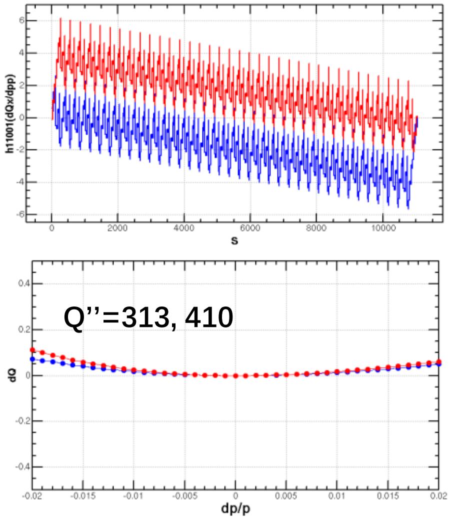


Design of high luminosity lattice

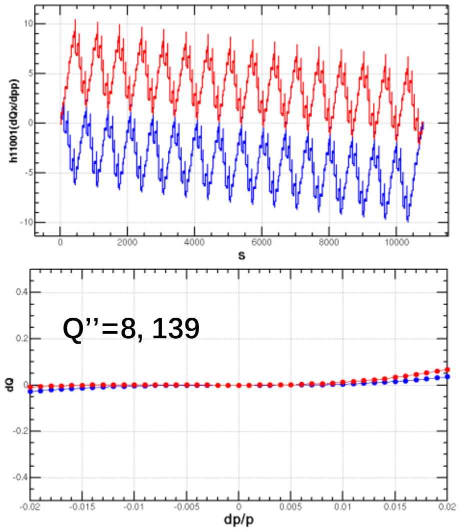
- Shorter cell length to squeeze the emittance from CDR **1.2nm to 0.64nm**
- Maximization of bend filling factor to minimize the synchrotron radiation
- **Optimization of the quadrupole radiation effect** (QD0 2m to 2.5m)
- **Better correction of energy dependent aberration**
- Reduction of dynamic aperture requirement from injection
- **Reduction of the length from IP to 1st quadrupole** without changing the front-end position of the FD cryo-module (2.2m to 1.9m)

Optimization of the ARC aberration

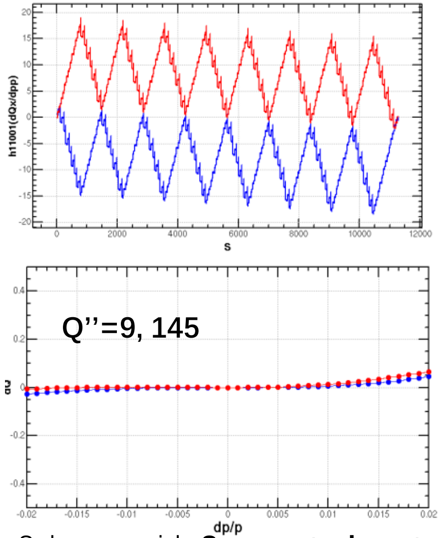
- 2^{nd} order chromaticity is a main aberration for the optimization of momentum acceptance with 2-repeated sextupole scheme.
  - In previous versions, 2^{nd} order chromaticity generated in the ARC region are corrected with IR knobs (phase advance or K1).
  - However, the IR knobs will generate distortions at IP (beta, alfa and dispersion) **especially for the horizontal plane**.
- A lattice with **4-repeated sextupoles**
  - much less 2^{nd} order chromaticity for the horizontal plane
  - not too sensitive to the errors



Scheme with **2 repeated sextupoles**
Proposed by K. Oide



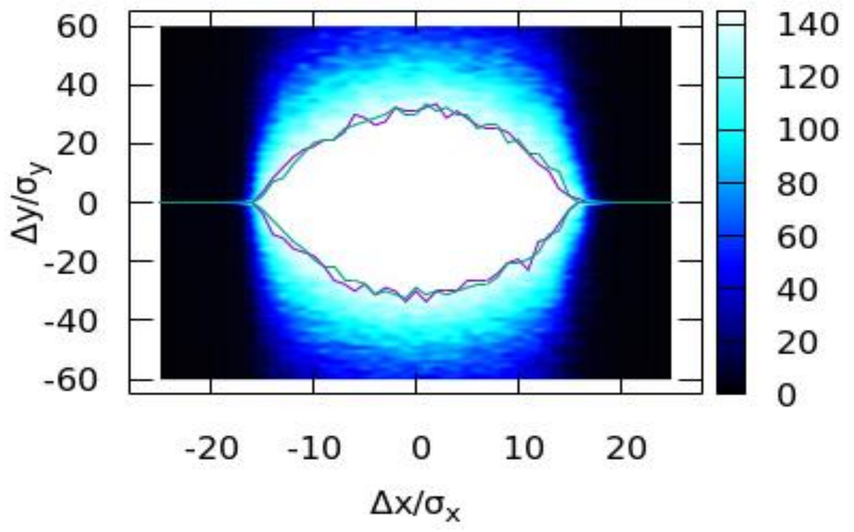
Scheme with **4 repeated sextupoles**
Proposed by Yiwei Wang

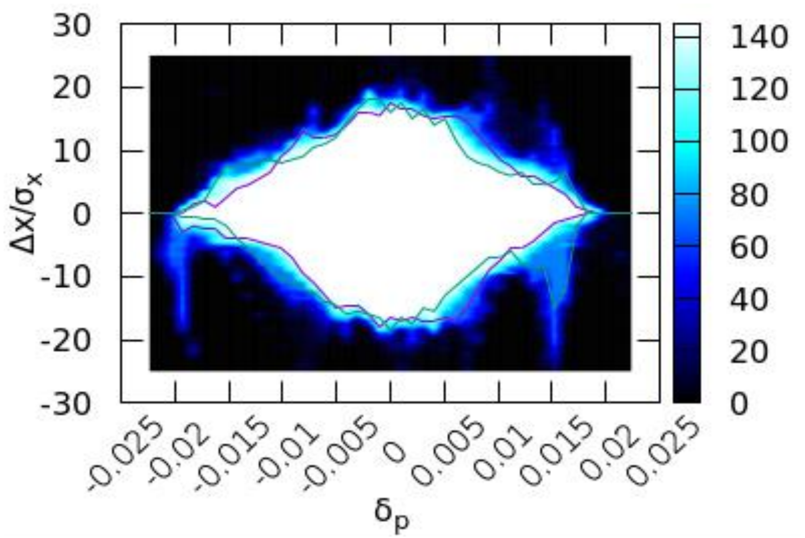


Scheme with **8 repeated sextupoles**
Proposed by Tianjian Bian

Dynamic aperture optimization

- With better correction of energy dependent aberration and shorter L* (without changing the front-end position of the final doublet cryo-module)
- Further optimization with algorithm of multi objective differential evolution (by J. Wu, Y. Zhang, Y. W. Wang)
- **Dynamic aperture w/o error at Higgs energy fulfills the requirements**.



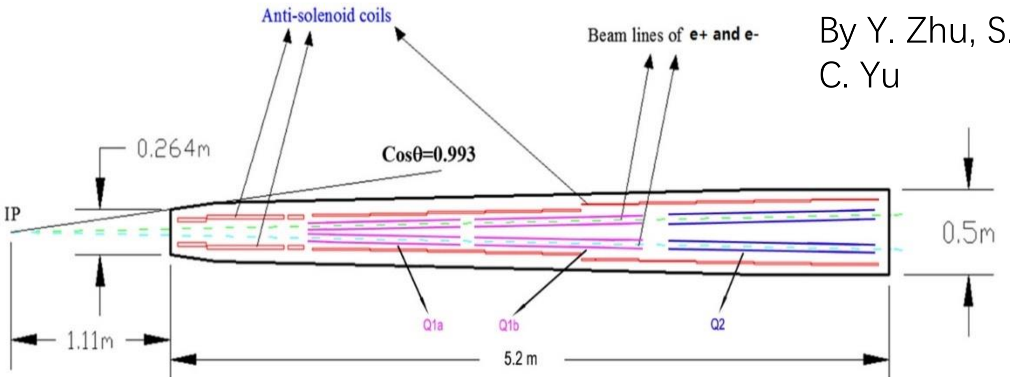


Achieved (w/o error): $16\sigma_x \times 32\sigma_y \times 1.9\%$

Goal (w/ error): $8\sigma_x \times 15\sigma_y \times 1.6\%$

Interaction region for all modes

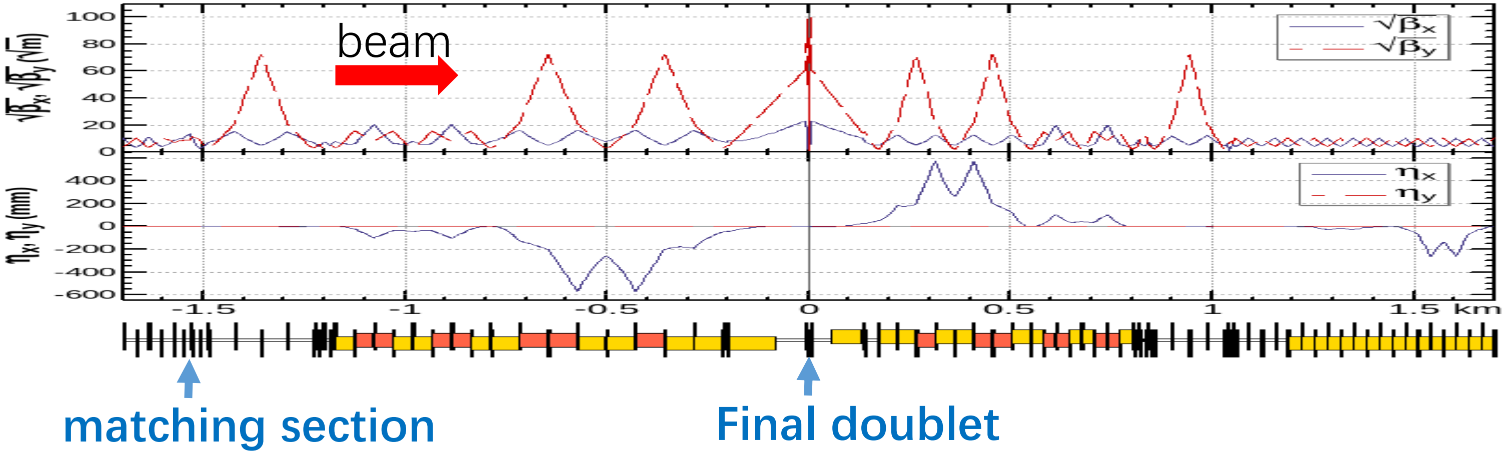
- For the interaction region, the IP beta functions are refitted with the different combination of final doulets and the matching quadruples.



By Y. Zhu, S. Bai, C. Yu

	QD	QF
Z	Q1a	Q1b+Q2
W/H	Q1a+Q1b	Q2
ttbar	Q1a+Q1b+Q1c	add quads

Higgs: L*=1.9m, LQ1A=1.22m, LQ1B=1.22m, LQ2=1.5m, d=0.3m, GQ1A=142T/m, GQ1B=96T/m, GQ2=56T/m



ARC region for all modes

- Z and W modes need larger momentum compaction factor αp and thus larger emittance εx, Qs
  - To suppress the impedance instability at Z mode
  - To increase stable tune area if considering beam-beam effect and impedance consistently at W and Z modes

Microwave instability

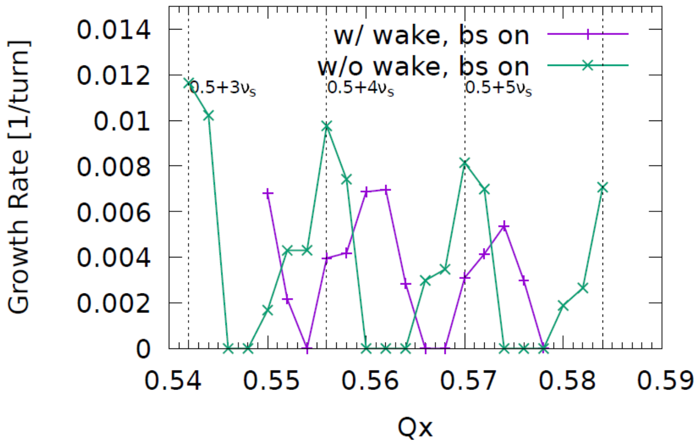
$$I_{th} = \frac{\sqrt{2\pi}\alpha_p \frac{E}{e}\sigma_{e0}^2\sigma_l}{R\left|\frac{Z_\parallel}{n}\right|_{eff}}$$

Na Wang,
CEPC Day, March 2020

Transverse mode coupling instability

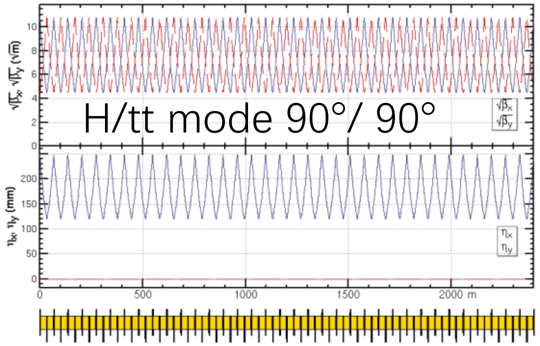
$$I_0^{th} = \frac{2Q_s\omega_0 E/e}{\sum_j \beta_{\perp,j}k_{y,j}}$$

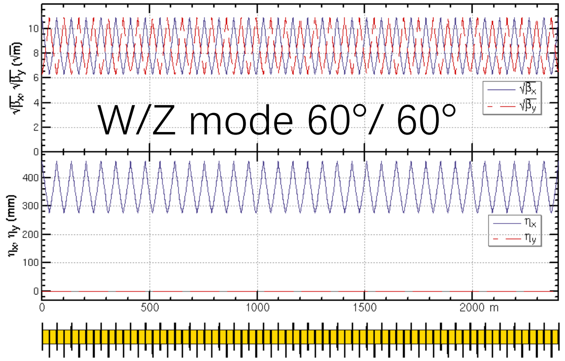
stable tune area with both beam-beam and impedance (Z mode 90/90)



Yuan Zhang

- **Phase advance reduced from 90° to 60°** and 29% additional sextupoles for W and Z



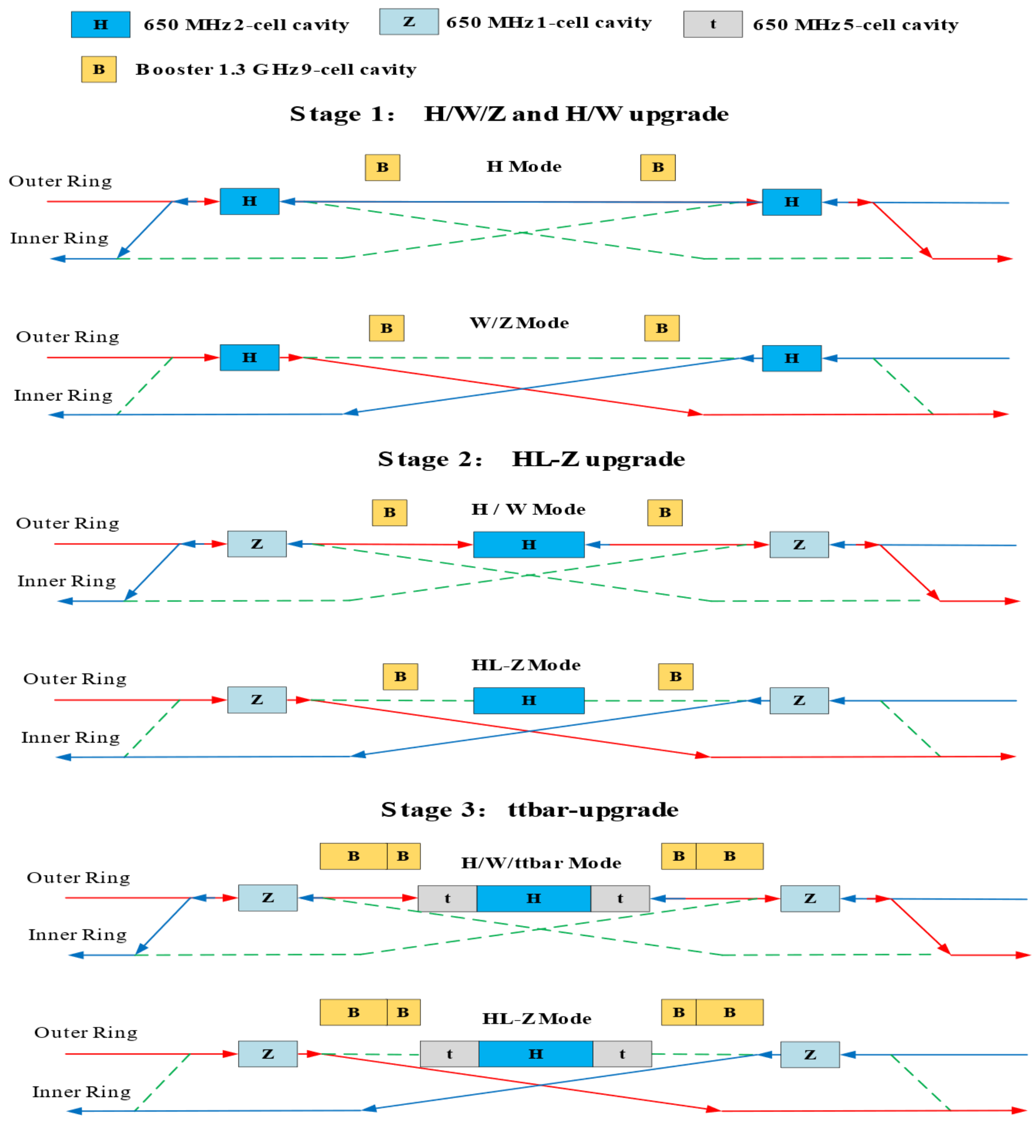


Magnets comparison

SC magnet in IR	Higgs (CDR)	Higgs (high lumi.)
SC QD0 and QF1	**L*=2.2m**, d=0.6m, QD0: **2.0m**, 136T/m QF1: 1.48m, **111T/m**	**L*=1.9m**, d=0.3m, QD0: **2.5m**, 142T/m, 96T/m QF1=1.5m, **56T/m**
SC anti-solenoids	maximum 7.2T	maximum 7.2T
SC sextupoles	VSIRD: 0.6m, 1308 T/m^2 HSIRD: 0.8m, 1506 T/m^2 VSIRU: 0.6m, 1250 T/m^2 HSIRU: 0.6m, 1600 T/m^2	VSIRD: 0.6m, 1209 T/m^2 HSIRD: 0.8m, 1679 T/m^2 VSIRU: 0.6m, 1548 T/m^2 HSIRU: 0.6m, 1130 T/m^2 (safety factor 20% for strength)

Main magnets in ARC	Higgs (CDR) Quantity, length and field	Higgs (high lumi.) Quantity, length and field
Dipoles (dual aperture)	2320, 28.686 m, 373 Gs	2944, 21.7 m, 390 Gs (**Quant +27%, total length -4%**)
Quadpoles (dual aperture)	2320, 2 m, 8.4 T/m	2944, 3 m, 10.6 T/m (**Quant +27%, total length +90%**)
Sextupoles (single aperture)	SF: 896, 0.7 m, 506 T/m^2 SD: 896, 0.7 m*2, 506 T/m^2	SF: 1024, 0.7 m, 1100 T/m^2 SD: 1024, 0.7 m*2, 1129 T/m^2 (**Quant +14%, total length +14%**)

RF staging for compatible modes



- 1st priority of the Higgs running and flexible switching
- Low cost at early stage
- Get high luminosity for all modes

Stage 1 (H/W run)

- Layout and parameters are same with CDR except longer central part
- Medium or low luminosity at Z

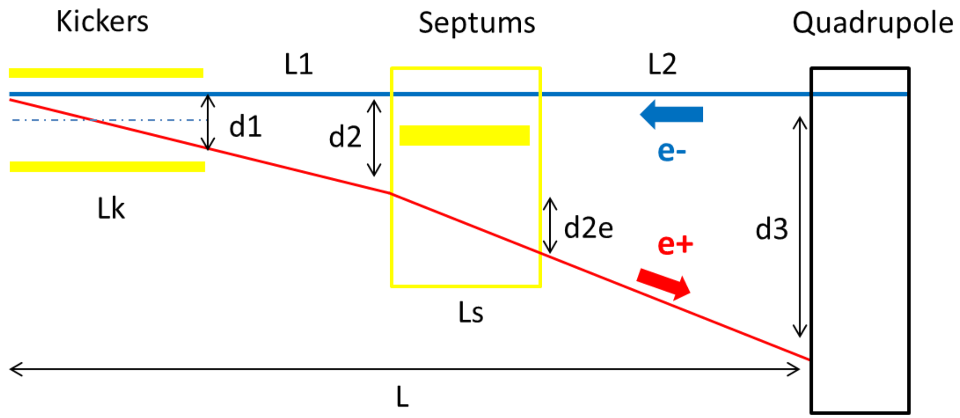
Stage 2 (HL-Z upgrade)

- **Move Higgs cavities to center and add high current Z cavities.**
- **By-pass low current H cavities.**

Stage 3(ttbar upgrade):

- Add ttbar cavities (low current, high gradient, high Q)
- Nb3Sn@4.2 K or others to significant reducing the cost of cryo-system and AC power.

Alternative separation scheme at RF region



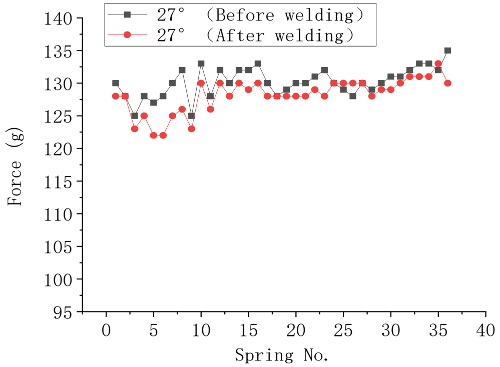
- With kicker instead of electro-static separator to reduce the impedance contribution (proposed by Jinhui Chen)
- Study on the field stability is undergoing.

	Kicker	Septum	
Integrated strength BL [T*m]	0.1624	1.4	
Strength B [Guass]	203	1000	Field for up to 182.5GeV. Septum is weak to suppress emittance growth.
Effective length Leff [m]	8	14	
Half width of good field region Hgf/Vgf [mm]	10.1/3.8 @ 5E-4	18.9/3.8 @ 5E-4	Kicker: 18σx+3mm+d1/2, 18σy+3mm Septum: 18σx+3mm+d2e/2, 18σy+3mm
Half width of beam stay clear Hbsc/Vbsc [mm]	9.6/3.6	9.2/3.6	18σx+3mm, 18σy+3mm
Septum width width [mm]	-	5	

R&D Progress of CEPC vacuum system

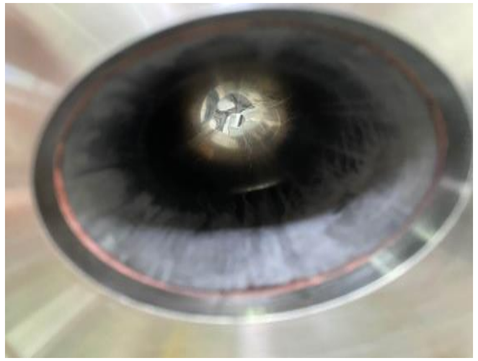
Y. S. Ma et al

- **RF shielding bellows**: Contact force is uniformly from different fingers and meets the target of 125±25g. Two prototypes of RF shielding bellows have been fabricated.



- **NEG coating**: 2m long vacuum pipe have been coated to explore the coating parameter at geometrical shape of 56×75. 6m long vacuum chambers will be coated by moving the solenoid by a horizontal coating equipment .

- **Vacuum chamber**: The prototypes of copper & aluminum vacuum chambers with a length of 6 m have been fabricated and tested, which meet the engineering requirements.



Modification on chamber shape

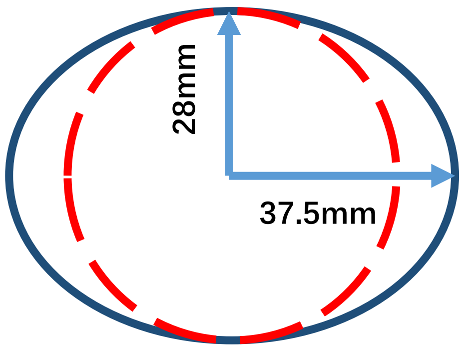
Y. D. Liu, Na Wang

Beam physics:

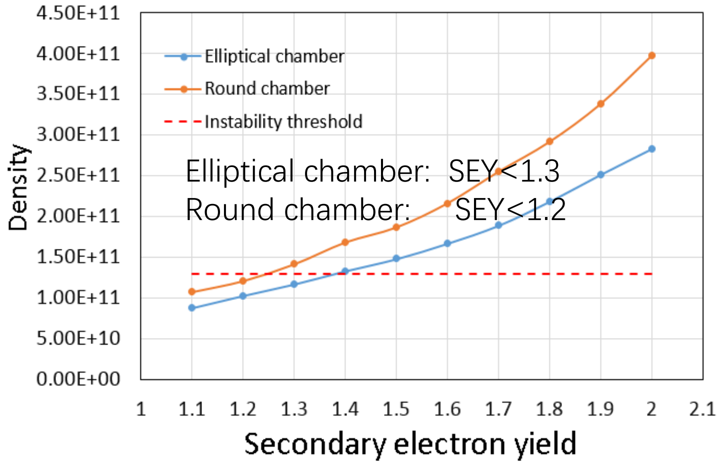
- Solution on quadrupole wakes and betatron tune shift
- Electron cloud density increased
    - can be controlled by NEG coating
- Serious instability caused by resistive wall impedance
    - strictly limit NEG coating thickness < 200nm

Technique on vacuum, magnets and power supply:

- Easier manufacture of vacuum chamber
- Lower power consumption of magnets



from elliptical to round

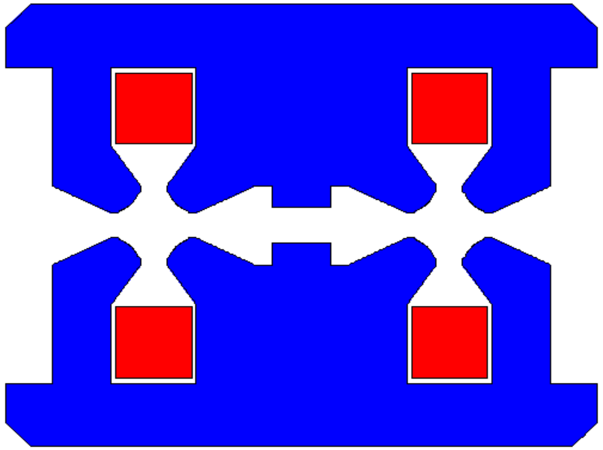


Optimization of the dual-aperture quadrupole

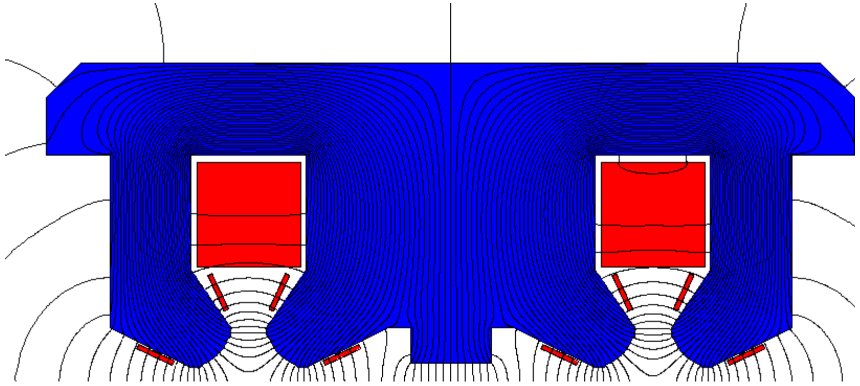
M. Yang

- Add a shim at the center
  - The b1 and b3 component can reduce a lot.
  - The harmonics varies a little at different energy.
  - No large variation introduced by the trim coil.

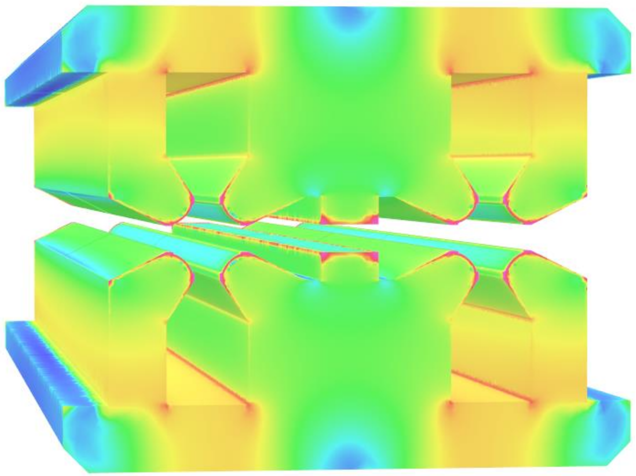
2D results				
E=120GeV	No center shim		Center shim	
n	Bn/B2-L	Bn/B2-R	Bn/B2-L	Bn/B2-R
1	1557.30	-1557.27	-13.51	13.53
2	10000	10000	10000	10000
3	126.14	-126.18	-1.11	1.06
4	0.52	0.52	0.51	0.53
5	1.70	-1.71	-0.02	0.01
6	-0.04	-0.03	-0.04	-0.03



F/D design



F/D design with trim coils



3D bmod

Optimization the final quadrupoles

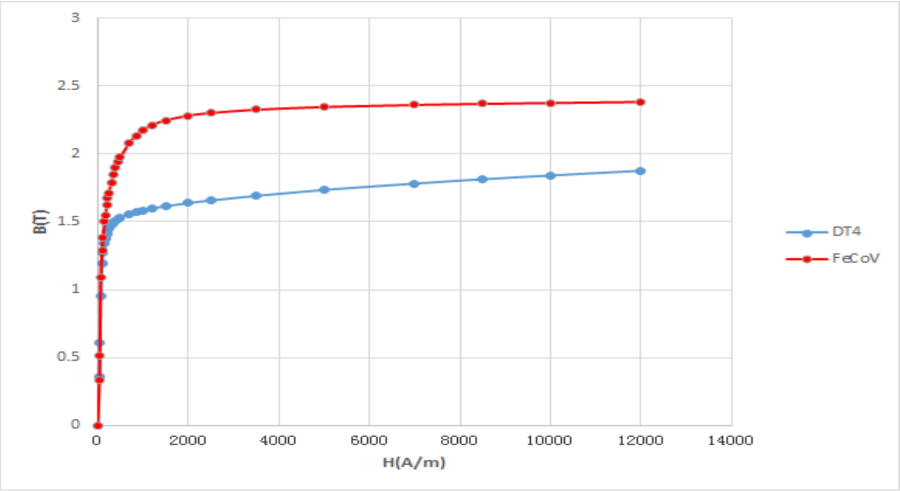
Y. S. Zhu

- Different design options of CEPC Q1a have been studied and compared.
- With relaxed dipole field requirement (< 30 gauss) and use FeCoV yoke, the magnet weight can be significantly reduced (55% of origin).
- Using one layer coil, magnet weight can be further reduced. (42% of origin)

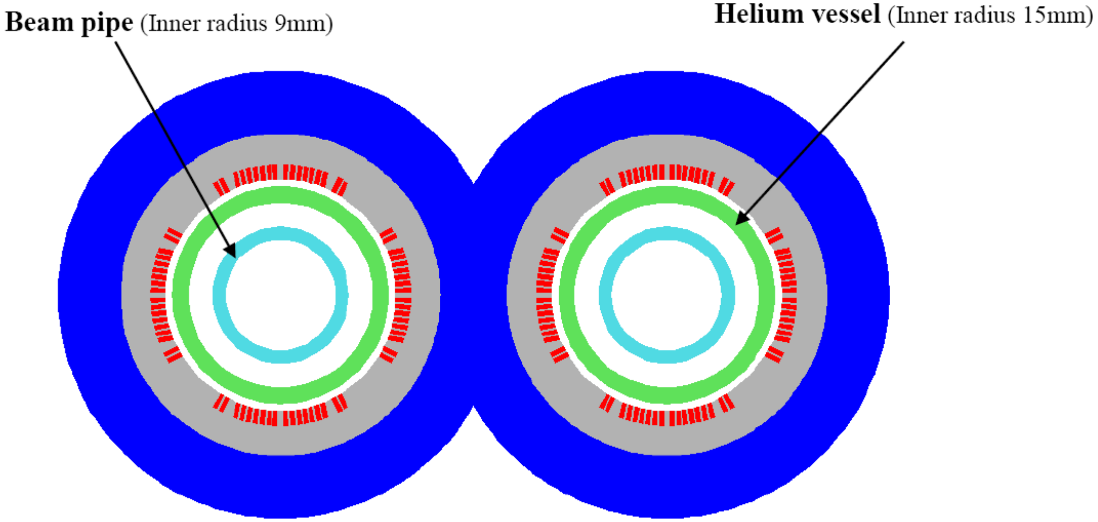
✓ Recommendation:

Baseline design: 2 layers coil, FeCoV yoke;

Alternative design: 1 layer coil, FeCoV yoke.



BH curve of DT4 and FeCoV



Summary

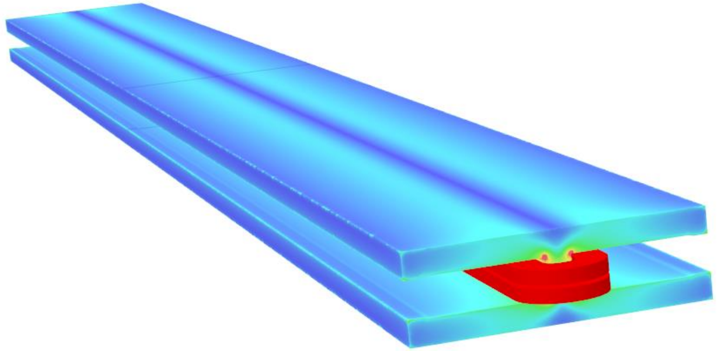
- The collider ring design of CDR scheme is more solid and the R&D based on the CDR scheme is undergoing.
- The high luminosity scheme of CEPC collider ring with $5\times10^{34}cm^{-2}s^{-1}$ & 30MW has been designed by mainly squeezing the $\beta y*$ and emittance.
  - New aberration correction scheme in ARC region
  - Dynamic aperture w/o error at Higgs energy fulfills the requirements.
  - Phase advance reduced from 90° to 60° for W/Z mode to suppress impedance instability and increase stable tune area
  - New RF staging scheme
  - Alternative separation scheme at RF region to reduce the impedance contribution
  - Lower injection emittance from booster
  - The vacuum shape from elliptical to round solve the quadrupole wakes effects
  - For dual-aperture quadrupole, b1 and b3 component can reduce a lot with shim at the center
  - QD0 weight can be reduced to 42% of origin by relaxed dipole field requirement, FeCoV yoke and 1 layer coil
- More work to be done for high luminosity scheme

Backup

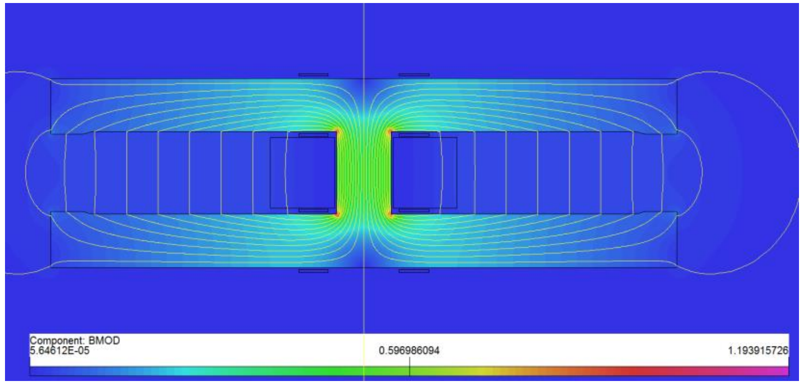
Long dual-aperture dipole design

M. Yang

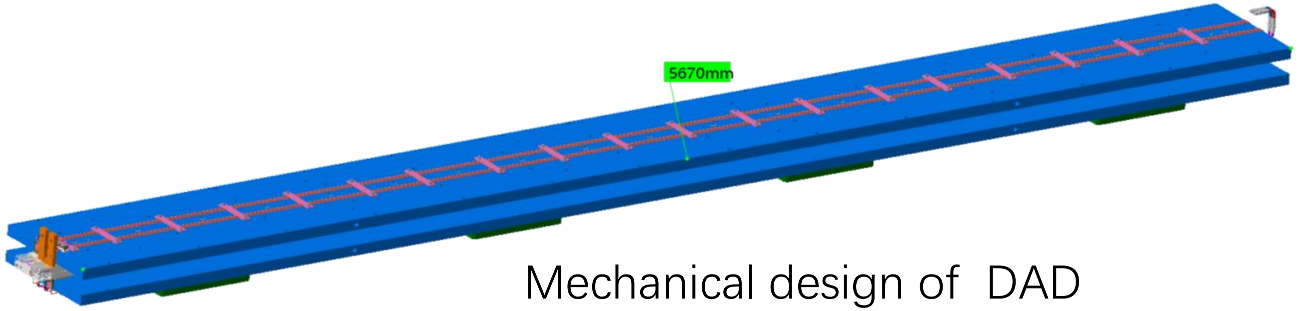
- As the magnetic length is up to 28.7m, a 5.7m pure dipole model will be built to check the field quality, mechanical strength and deformation.
  - Solid iron with DT4;
  - Two turns of aluminum busbars with cooling hole;
  - Anodizing treated insulation coil;
  - Silvered contact face to reduce contact resistance.



3D Bmod of DAD



Cross section of long DAD



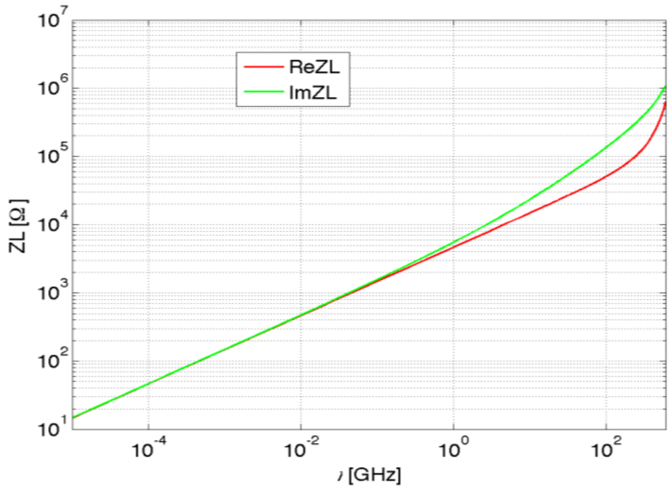
Mechanical design of DAD

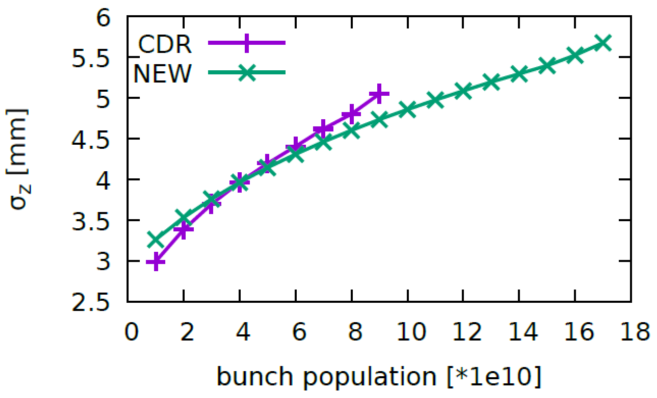
Challenge and Response : Resistive wall impedance instability

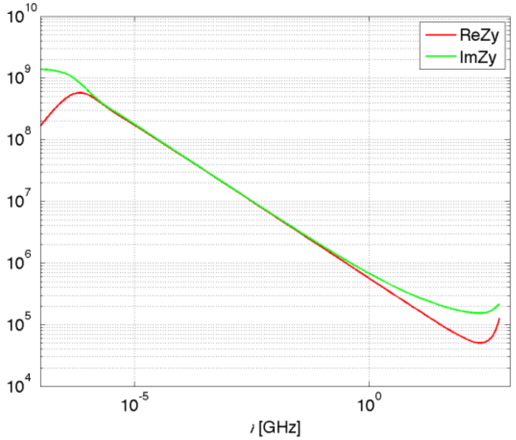
Resistive wall impedance

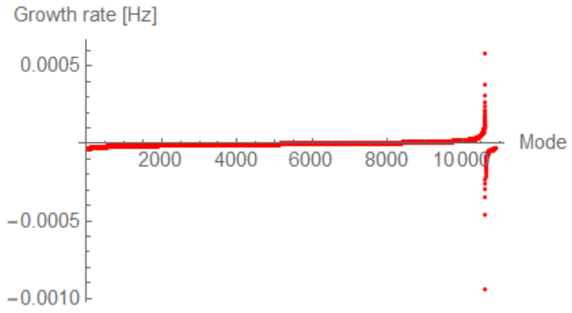
N. Wang's talk on last CEPD Day

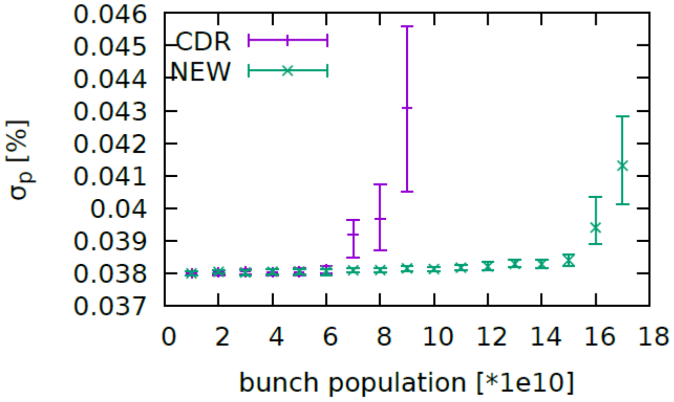
Round pipe of Copper (3mm) with NEG coating (200nm)











High luminosity Z operation:

Bunch lengthening 90%;

Energy spread increasing 4%

Coupled bunch instability

Instability growth time 1.7ms, more efficient feedback for its suppression

Strictly control on the coating thickness for impedance source to restrain the instability!

MDI vacuum layout

by MDI group

- All the accelerator components are within the detective angle of acos0.99.