Lattice Optimization of the CEPC Collider Ring Towards The TDR

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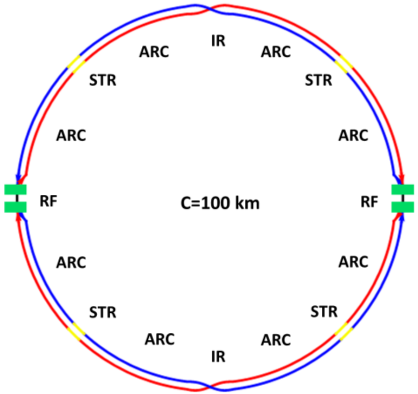
Outline

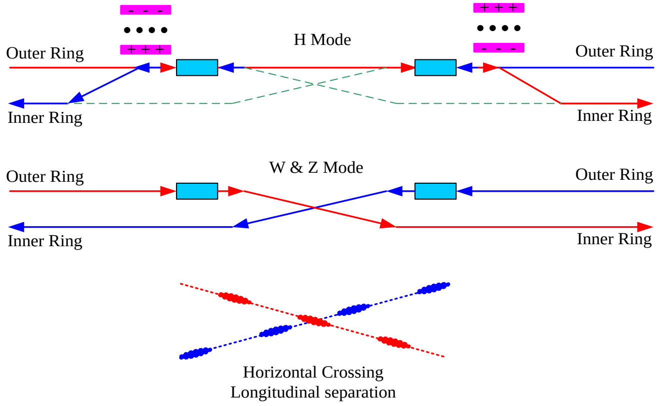
- The CEPC collider lattice design of the conceptual design report (CDR)
- Optimization of the lattice towards the technical design report (TDR)
  - Error correction
  - Injection region
  - Separation region
  - Interaction region

The CEPC collider lattice design of the CDR

Introduction

- The circumference of CEPC collider ring is **100 km.**
- In the RF region, the **RF cavities are shared by two rings 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, bunches will only pass half number of cavities** and can be filled in full ring.



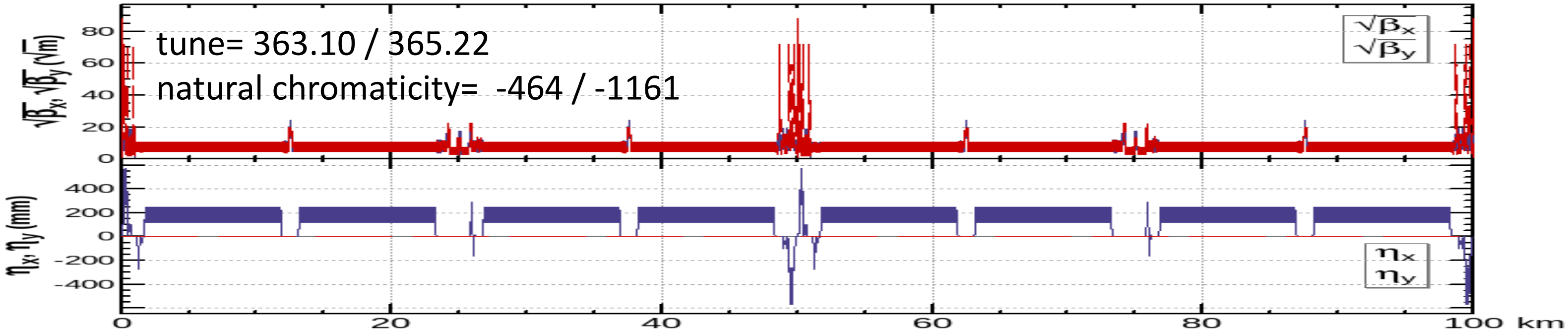


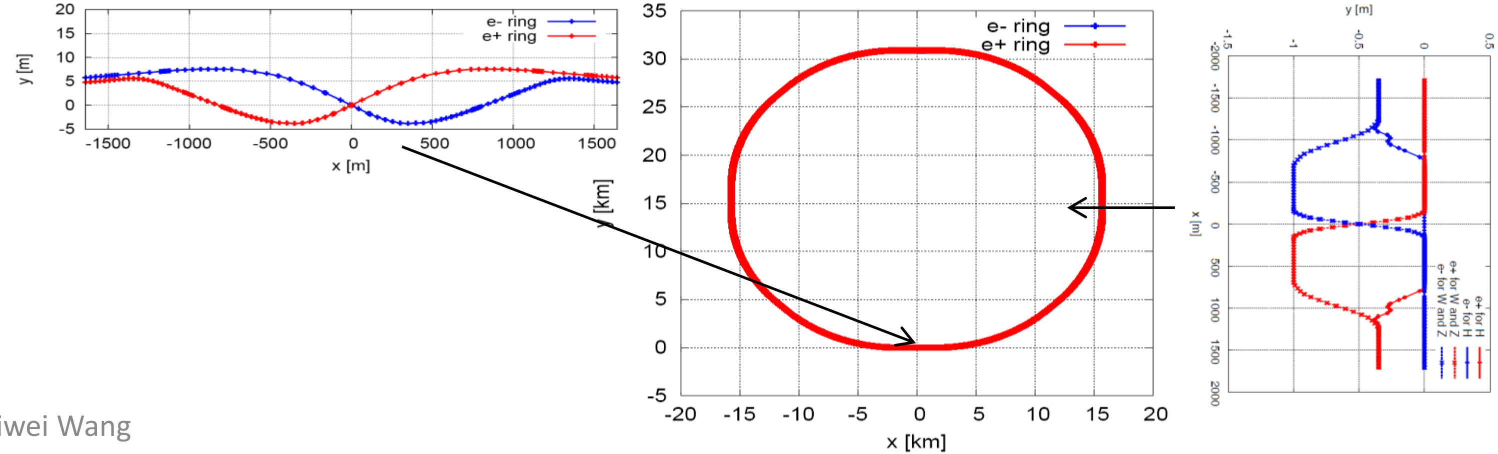
	Higgs	*W*	*Z*（*3T*）	*Z*（*2T*）
Number of IPs	2			
Beam energy (GeV)	**120**	**80**	**45.5**	
Circumference (km)	**100**			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	**16.5×2**			
Piwinski angle	**3.48**	**7.0**	**23.8**	
Number of particles/bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number (bunch spacing)	**242 (0.68μs)**	**1524 (0.21μs)**	**12000 (25ns+10%gap)**	
Beam current (mA)	17.4	87.9	461.0	
Synchrotron radiation power /beam (MW)	**30**	**30**	**16.5**	
Bending radius (km)	10.7			
Momentum compact (10^{-5})	1.11			
β function at IP β_x* / β_y* (m)	**0.36/0.0015**	**0.36/0.0015**	**0.2/0.0015**	**0.2/0.001**
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0024	0.54/0.0016	0.18/0.004	0.18/0.0016
Beam size at IP σ_x/σ_y (μm)	20.9/0.06	13.9/0.049	6.0/0.078	6.0/0.04
Beam-beam parameters ξ_x/ξ_y	**0.018/0.109**	**0.013/0.123**	**0.004/0.06**	**0.004/0.079**
RF voltage V_{RF} (GV)	2.17	0.47	0.10	
RF frequency f_{RF} (MHz) (harmonic)	650 (216816)			
Natural bunch length σ_z (mm)	2.72	2.98	2.42	
Bunch length σ_z (mm)	4.4	5.9	8.5	
HOM power/cavity (2 cell) (kw)	0.46	0.75	**1.94**	
Energy spread (%)	0.134	0.098	0.080	
Energy acceptance requirement (%)	**1.35**	**0.90**	**0.49**	
Energy acceptance by RF (%)	2.06	1.47	1.7	
Photon number due to beamstrahlung	0.082	0.050	0.023	
Beamstruhlung lifetime /quantum lifetime* (min)	80/80	>400		
Lifetime (hour)	**0.43**	**1.4**	**4.6**	**2.5**
F (hour glass)	0.89	0.94	0.99	
Luminosity/IP *L* ($10^{34}cm^{-2}s^{-1}$)	**2.93**	**10.1**	**16.6**	**32.1**

by D. WANG et al

Optics of the collider ring

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





Dynamic aperture requirements

- Dynamic aperture requirements

	Higgs	W	Z
with on-axis injection	$8\sigma_x \times 15\sigma_y \times 1.35\%$	-	-
with off-axis injection	$13\sigma_x \times 15\sigma_y \times 1.35\%$	$15\sigma_x \times 9\sigma_y \times 0.9\%$	$17\sigma_x \times 9\sigma_y \times 0.49\%$

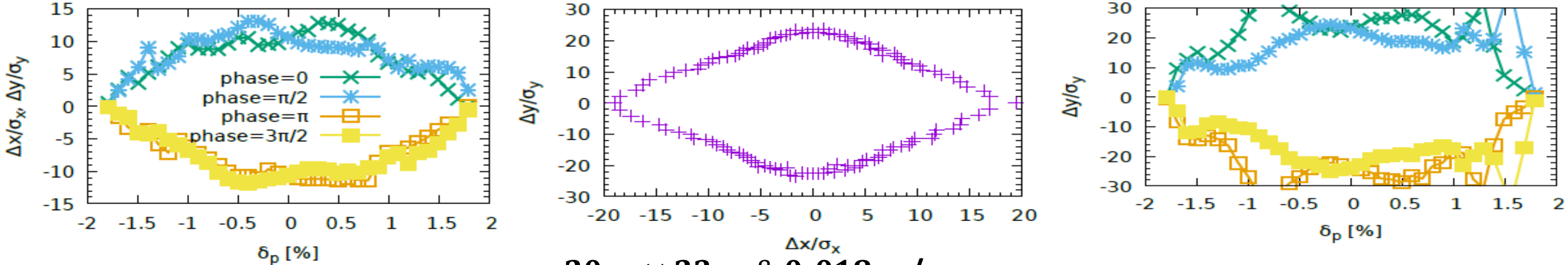
- Start point of the optimization
  - Nonlinearity optimized term by term with 10 families of sextupoles in the IR and 4 families of sextupoles in the ARC.
- Optimize dynamic aperture directly with MODE (Y. ZHANG, IHEP)
  - With **10 families of sextupoles in the IR, 32 families of sextupoles in ARC and 8 phase advances**

Dynamic aperture result (w/o errors)

by Y. ZHANG, et al

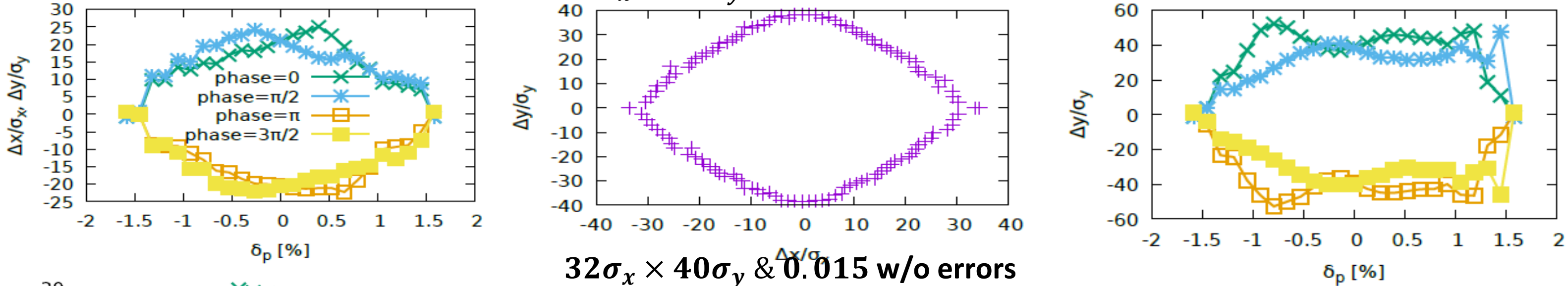
Tracking in SAD w/ synchrotron radiation damping, fluctuation(100 samples), energy sawtooth and tapering, 145/475/2600 turns(H/W/Z, 2 damping times), 4 initial phases

Higgs



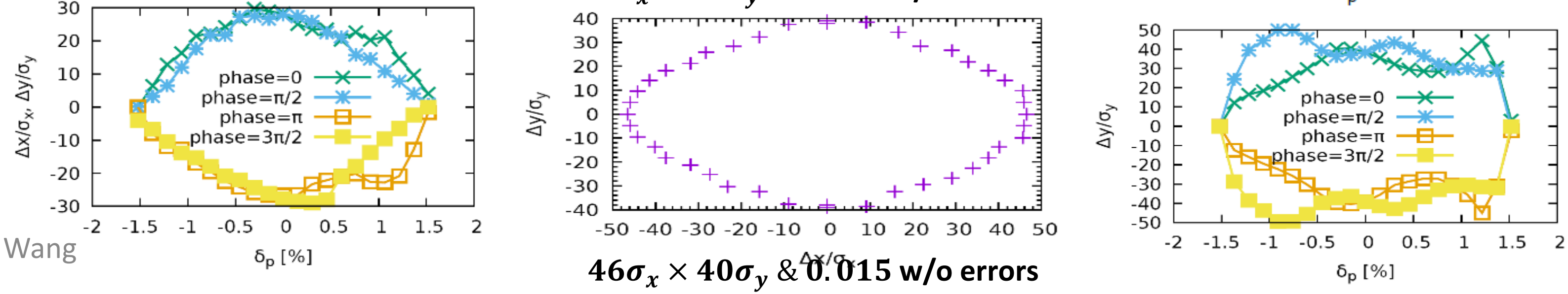
$20\sigma_x \times 23\sigma_y$ & 0.018 w/o errors

W



$32\sigma_x \times 40\sigma_y$ & 0.015 w/o errors

Z



$46\sigma_x \times 40\sigma_y$ & 0.015 w/o errors

Optimization of the lattice towards the technical design report (TDR)

Performance with errors

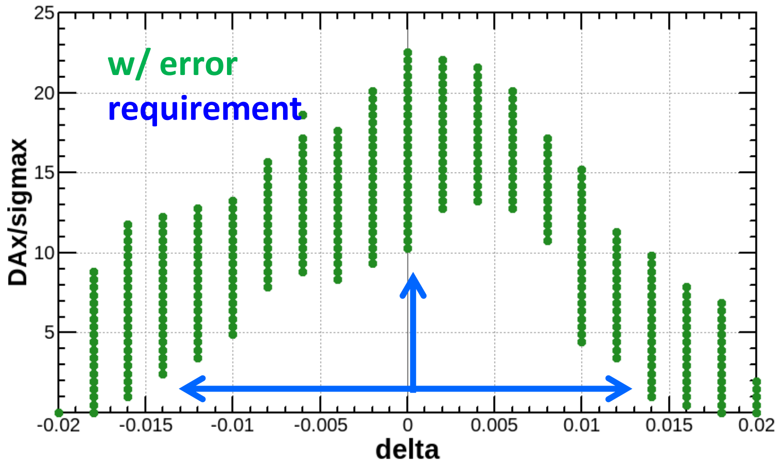
- Relaxed requirement of alignments and filed errors compared with CDR
- Stronger corrections made (Yuanyuan WEI's talk)

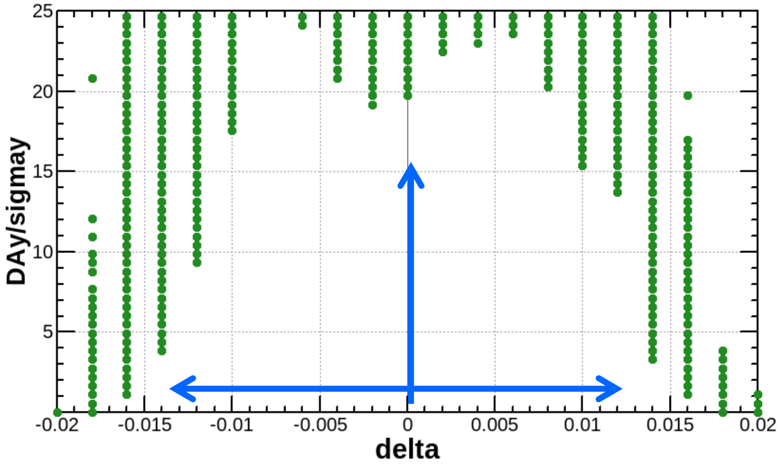
Component	Δx (um)	Δy (um)	$\Delta\theta_z$ (urad)
Arc quadrupole	100	100	100
IR Quadrupole (w/o FF)	50	50	50
Sextupole	100	100	100

Component	Field error
Dipole	0.01%
Arc quadrupole	0.02%

Performance with errors (cont.)

- Dynamic aperture result for **Higgs mode**
  - Tracking in SAD with radiation damping, fluctuation, energy sawtooth and tapering, 145 turns (2 damping times), initial phases=0
  - Horizontal dynamic aperture decreased significantly with errors. But it still fulfils the dynamic aperture requirement of on-axis injection.



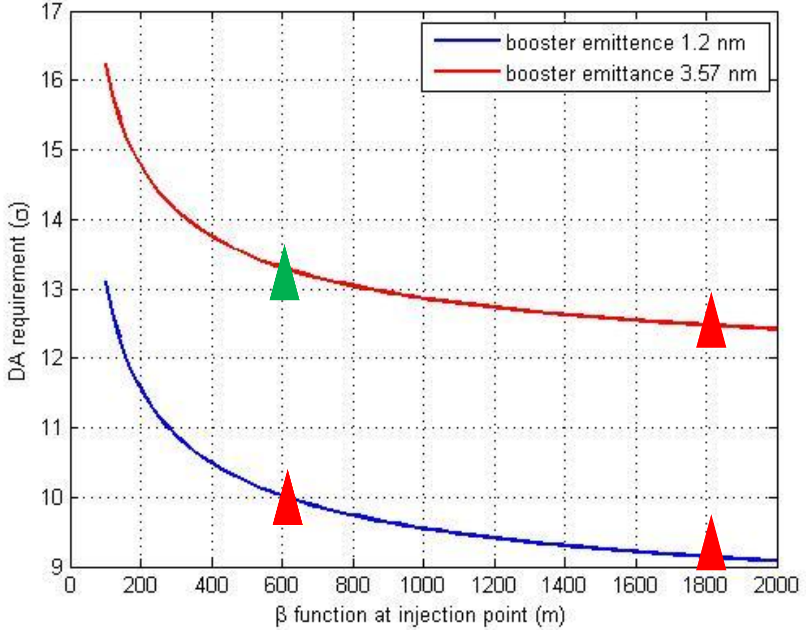


Requirement with on-axis injeciotn $8\sigma_x \times 15\sigma_y$ & 0.0135

Optimization of the injection region

- Trying to relax the dynamic aperture requirement of the off-axis injection scheme
  - **Larger βx at injection point**
  - Smaller injected emittance

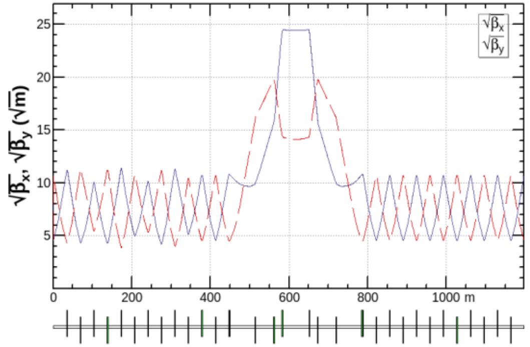
	Higgs	W	Z
with on-axis injection	$8\sigma_x \times 15\sigma_y \times 1.35\%$	-	-
with off-axis injection	$13\sigma_x \times 15\sigma_y \times 1.35\%$	$15\sigma_x \times 9\sigma_y \times 0.9\%$	$17\sigma_x \times 9\sigma_y \times 0.49\%$

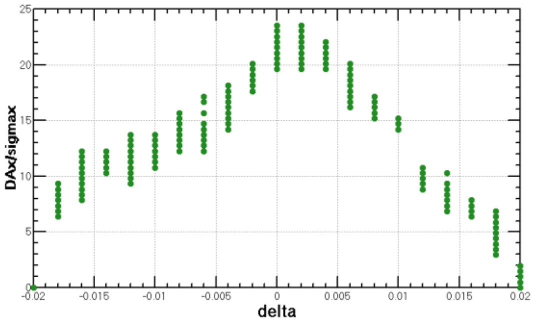


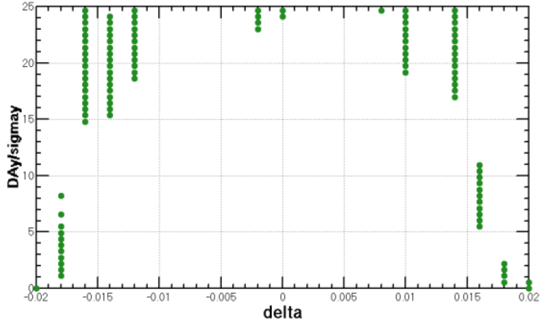
by Xiaohao CUI

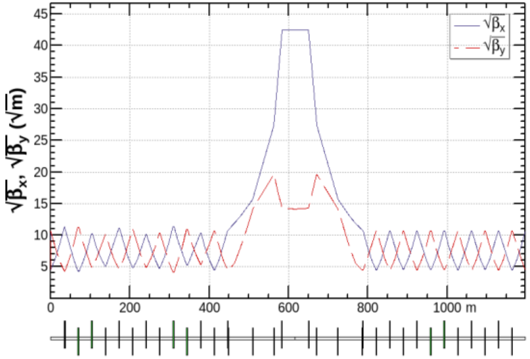
Optimization of the injection region (cont.)

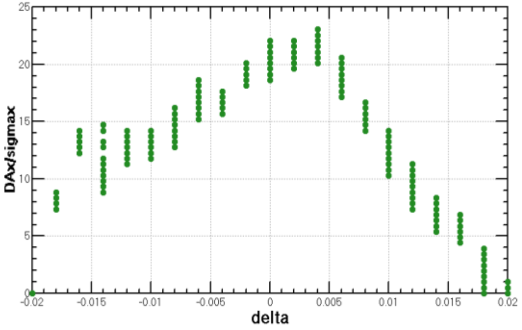
- Larger βx at injection point
  - βx increased from 600m to 1800m
  - Increased horizontal chromaticity is small and the results of DA are almost the same.

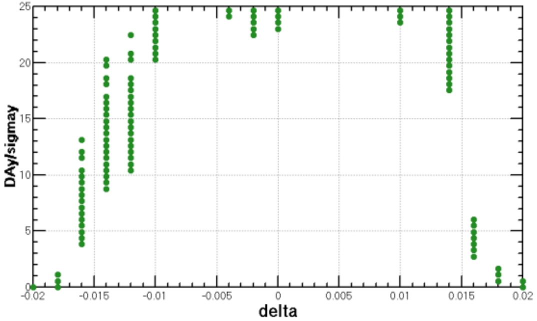






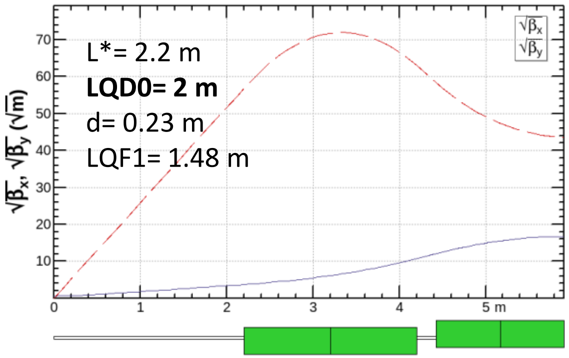


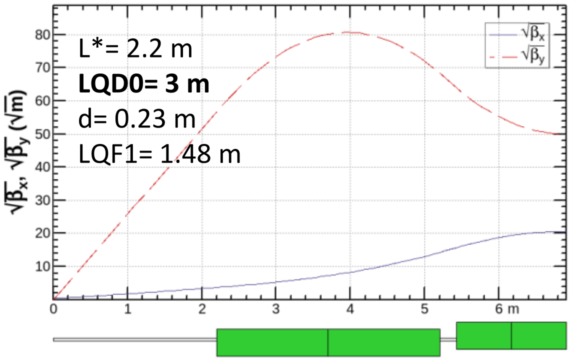


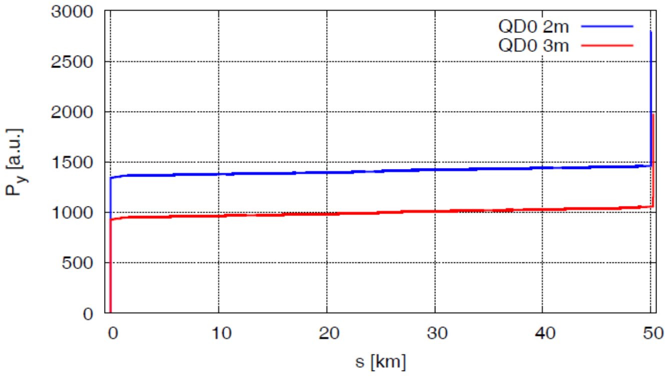


Optimization of the radiation effect due to QD0

- The dynamic aperture reduction due to the damping and fluctuation is significant on the vertical plane.
- Radiation power due to quadrupoles: $P \propto \int B^2 ds \propto \int {K_1}^2 \beta ds \cong \sum (K_1 l)^2 \beta / l$
  - contribution of QD0 dominant
  - longer QD0 will significantly decreased the power on vertical plane and thus help to increase the dynamic aperture

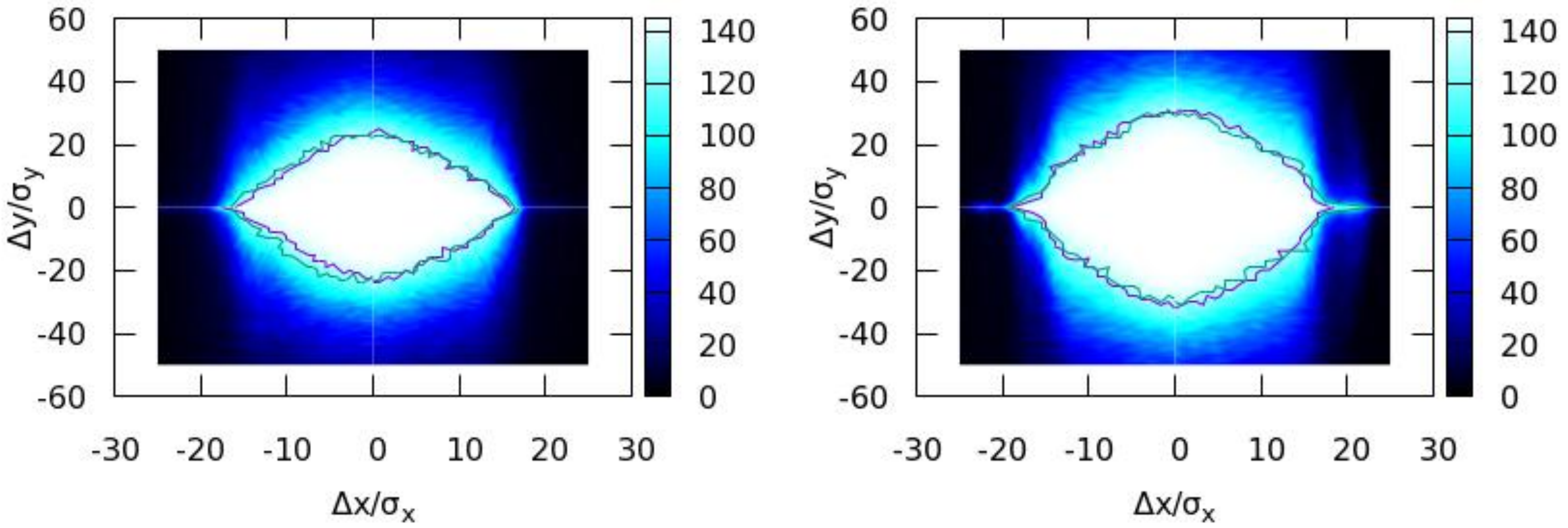






Optimization of the radiation effect due to QD0 (cont.)

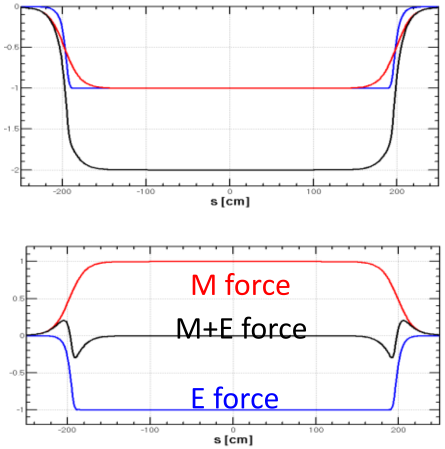
- With longer QD0, the vertical dynamic aperture increased from 23 σy to 30 σy.
- Further optimization of the horizontal dynamic aperture and momentum acceptance is under going.



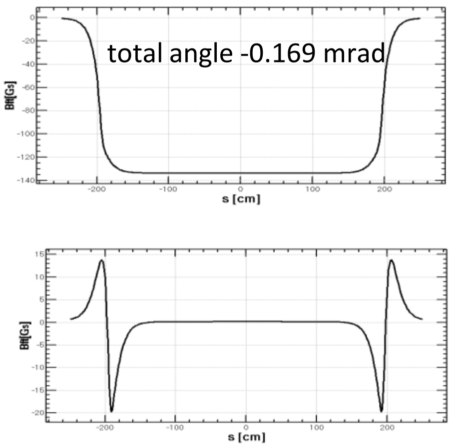
by Yuan ZHANG, Jin WU

Separation region lattice with realistic field

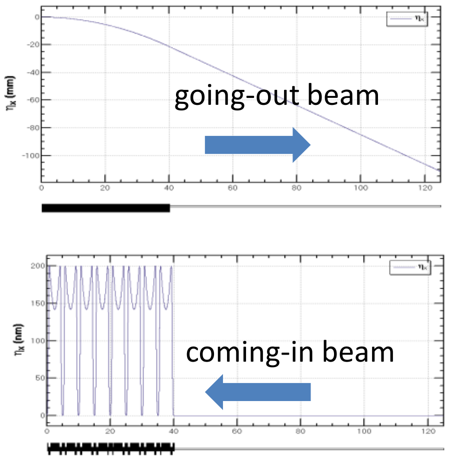
- Simplified lattice in CDR
  - gradient 1.8MV/m, components length 50m , drift 75m, separation at the exit 15cm
  - some margin of separation (15cm) reserved
- Lattice with realistic field from the design of electro-static separator and dipole
  - central gradient 2.0MV/m, components length (4+1) m*8, drift 85m, separation at the exit 11.1cm



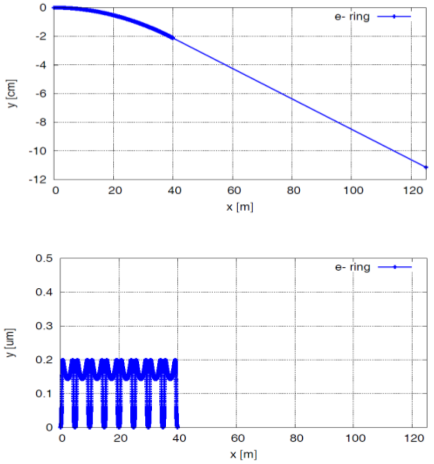
Realistic field
(data from Bin CHEN)



Effective bending Field along combined component



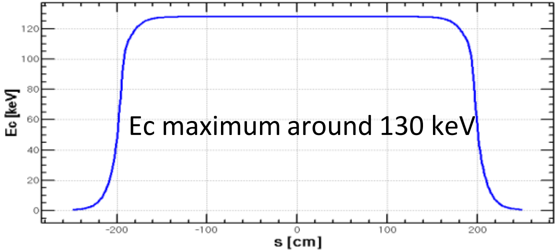
Dispersion function

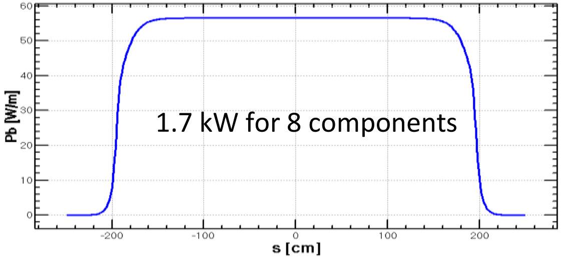


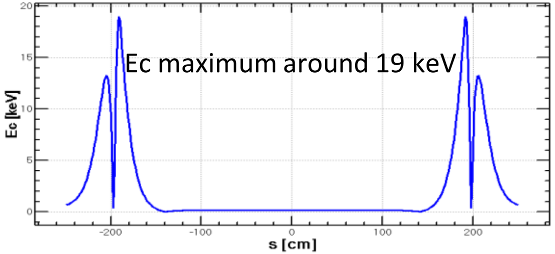
Separation distance

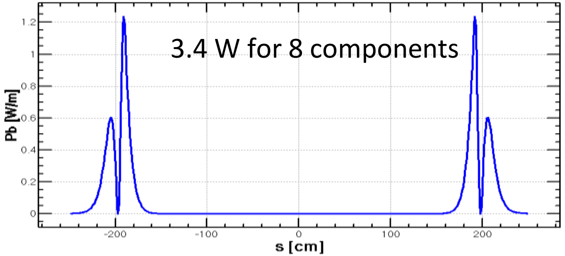
Separation region lattice with realistic field (cont.)

- Critical energy and power of the synchrotron radiation









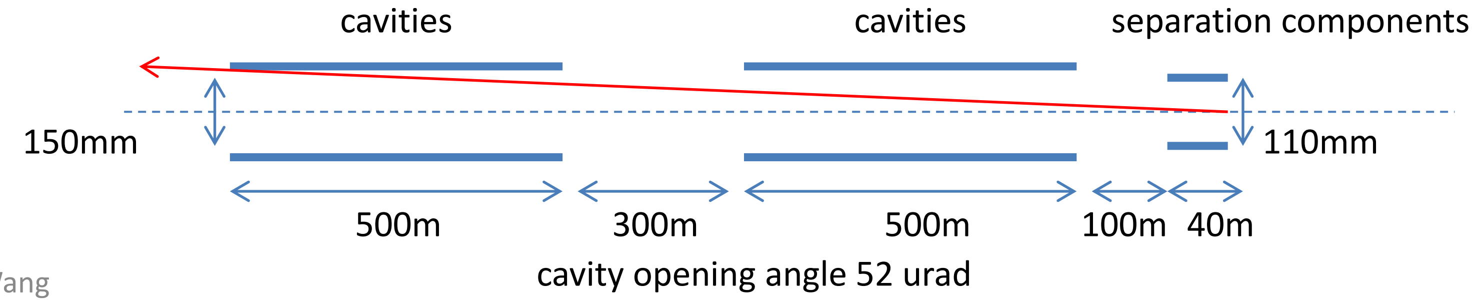
Critical energy of photons

Radiation power along one component

Upper figures for going-out beam
Lower figures for coming-in beam

Separation region lattice with realistic field (cont.)

- For the coming-in beam, the radiation power of **3.4 W is significant if it point to one cavity**. The radiation direction should be checked.
  - **w/o error and injection oscillation, the radiation will pass all the cavities.**
    - Radiation angle θ = 1 urad << cavity opening angle 52 urad
    - forward angle $1/\gamma$ = 4 urad << cavity opening angle 52 urad
  - **w/ error, the radiation will pass all the cavities.**
    - $\Delta x'$ due to injection is the main concern as Δx due to error << cavity iris radius 75mm
    - corrected angle usually smaller than some times of $\sigma x'$=3.5urad << cavity opening angle 52 urad
  - **w/ injection oscillation, the radiation may hit the cavities (3.4W*3%=0.1W).**
    - With top-up injection, the injected current is only 3% of the total current.
    - **The power 0.1 W is tolerable even for one cavity. Some collimators in the RF region will help.**



Conclusion

- Optimization of CEPC collider lattice towards the TDR has been started.
  - Relaxed requirement of alignments and filed errors compared with CDR and stronger corrections made. It fulfils the dynamic aperture requirement of on-axis injection.
  - Larger βx at injection point was made in order to relax the dynamic aperture requirement of the off-axis injection scheme. DA are almost the same.
  - With longer QD0, the vertical dynamic aperture increased from 23 σy to 30 σy. Further optimization of the horizontal dynamic aperture and momentum acceptance is under going.
  - The radiation from the separation components is tolerable for SCRF cavities. Some collimators in the RF region will help.
- Further optimization of the arc quadrupole length, βy^* and so on is undergoing.

Thanks