Lattice design and dynamic aperture optimization for CEPC main ring

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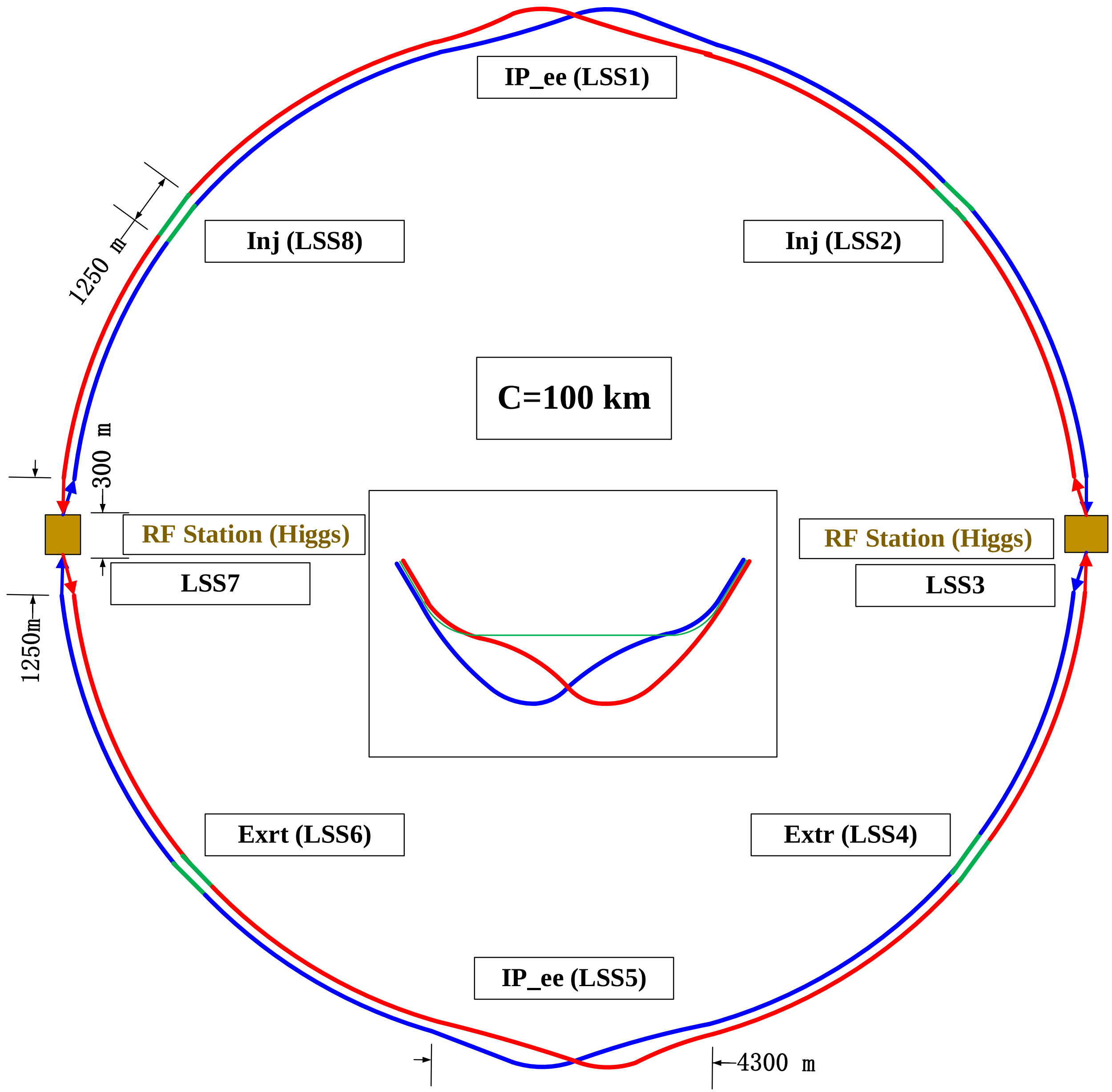
Outline

- Fully partial double ring scheme
  - Lattice design and geometry
  - Dynamic aperture study
- Partial double ring scheme
  - Lattice design
  - Dynamic aperture study
- Mitigation of sawtooth effects for partial double ring scheme

Layout of fully partial double ring

(Dec. 15, 2016,　Su Feng)



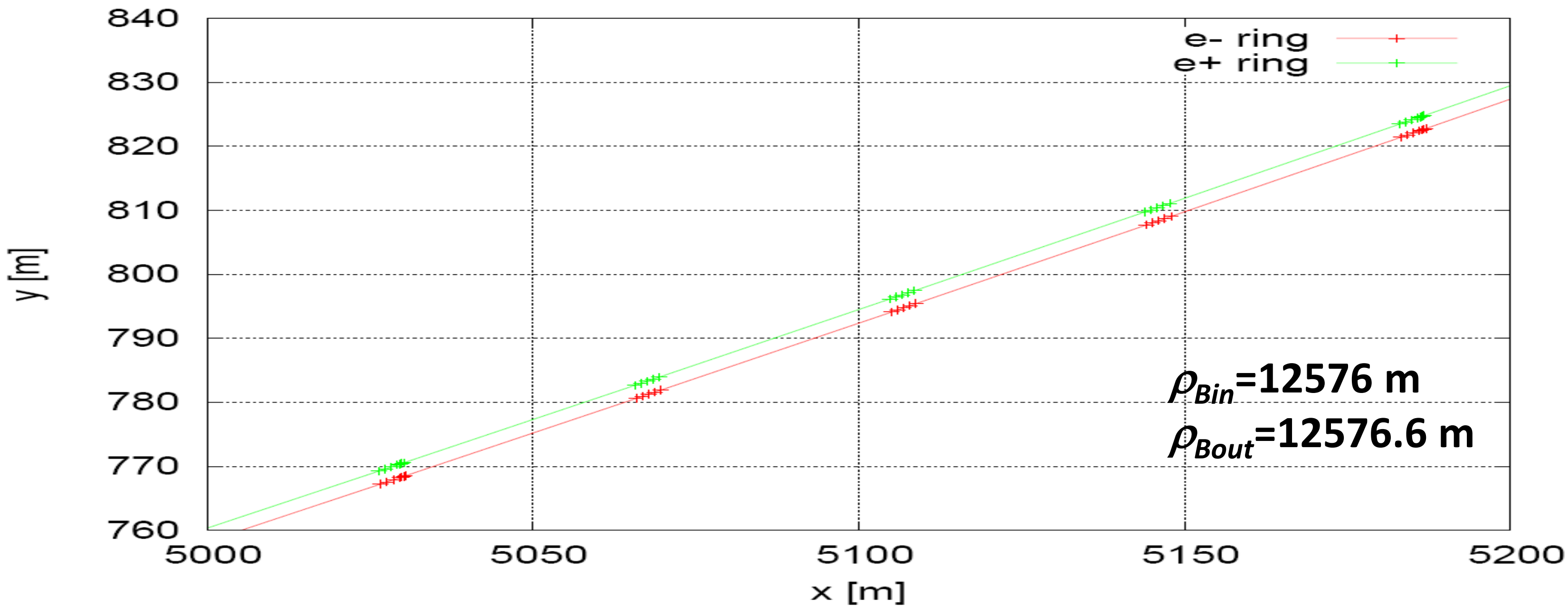
CEPC parameters for C=100km

D. Wang, this conf., HKUST

	Pre-CDR	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)	54	100	100	100	100	100
SR loss/turn (GeV)	3.1	1.67	1.67	0.33	0.034	0.034
Half crossing angle (mrad)	0	15	15	15	15	15
Piwinski angle	0	2.9	2.9	3.57	5.69	5.69
N_e/bunch (10^{11})	3.79	0.97	0.97	1.05	0.46	0.46
Bunch number	50	644	425	1000	10520	65716
Beam current (mA)	16.6	29.97	19.8	50.6	232.1	1449.7
SR power /beam (MW)	51.7	50	33	16.7	8.0	50
Bending radius (km)	6.1	11	11	11	11	11
Momentum compaction (10^{-5})	3.4	1.3	1.3	3.1	3.3	3.3
β_{IP} x/y (m)	0.8/0.0012	0.144 /0.002	0.144 /0.002	0.1 /0.001	0.12/0.001	0.12/0.001
Emittance x/y (nm)	6.12/0.018	1.56/0.0047	1.56/0.0047	2.68/0.008	0.93/0.0049	0.93/0.0049
Transverse σ_{IP} (um)	69.97/0.15	15/0.097	15/0.097	16.4/0.09	10.5/0.07	10.5/0.07
ξ_x/ξ_y/IP	0.118/0.083	0.0126/0.083	0.0126/0.083	0.0082/0.055	0.0075/0.054	0.0075/0.054
RF Phase (degree)	153.0	131.2	131.2	149	160.8	160.8
V_{RF} (GV)	6.87	**2.22**	**2.22**	**0.63**	**0.11**	**0.11**
f_{RF} (MHz) (harmonic)	650	650 (217800)	650 (217800)	650 (217800)	650 (217800)	
Nature σ_z (mm)	2.14	**2.72**	**2.72**	**3.8**	**3.93**	**3.93**
Total σ_z (mm)	2.65	2.9	2.9	3.9	4.0	4.0
HOM power/cavity (kw)	3.6 (5cell)	0.64 (2cell)	0.42 (2cell)	1.0 (2cell)	1.0 (1cell)	6.25(1cell)
Energy spread (%)	0.13	0.098	0.098	0.065	0.037	0.037
Energy acceptance (%)	2	1.5	1.5			
Energy acceptance by RF (%)	6	2.2	2.2	1.5	1.1	1.1
n_γ	0.23	0.26	0.26	0.26	0.18	0.18
Life time due to beamstrahlung_cal (minute)	47	52	52			
F (hour glass)	0.68	0.95	0.95	0.84	0.91	0.91
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	2.04	3.1	2.05	4.08	11.36	70.97

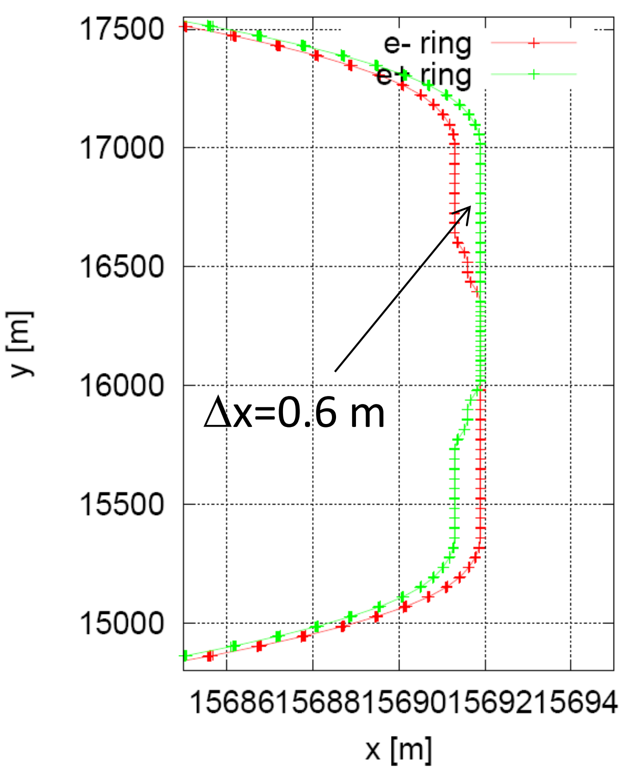
Lattice design and geometry for ARC region

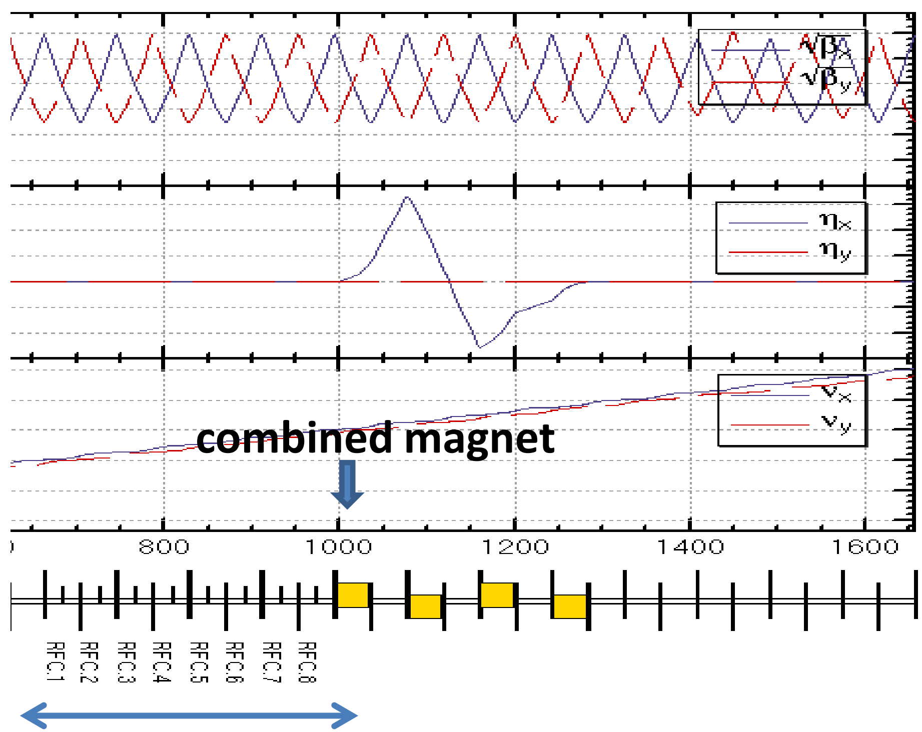
- **FODO cell, 90°/90°, non-interleaved sextupole scheme**
  - period N=5cells
  - all 3rd and 4th resonance driving terms (RDT) due to sextupoles cancelled, except small 4Qx, 2Qx+2Qy, 4Qy, 2Qx-2Qy
  - **tune shift dQ(Jx, Jy) is very small**
    - DA on momentum: large
  - **Chromaticity dQ(δ) need to be corrected with many families**
    - DA off momentum: with many families to correct dQ(δ) and –I break down



Lattice design and geometry for RF region

- **Common RF region** for e- and e+ ring
- An electrostatic separator, combined with a dipole magnet to avoid bending of incoming beam (ref: Oide, ICHEP16)
- Deviation of outgoing beam is Δx=0.6 m, $\Delta\theta$=0



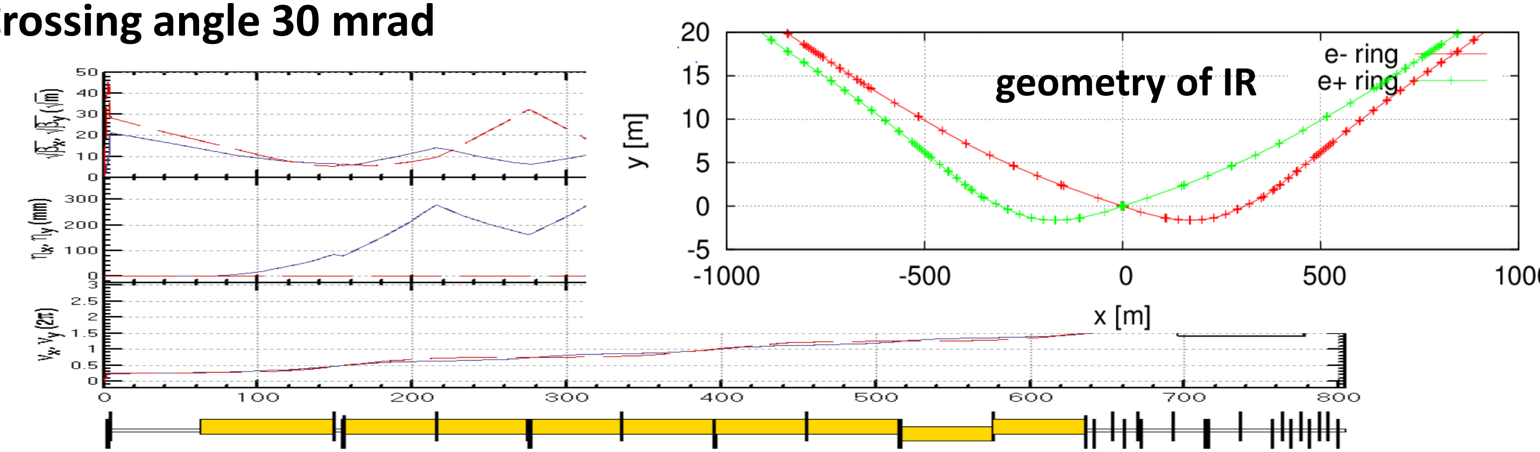


common RF region

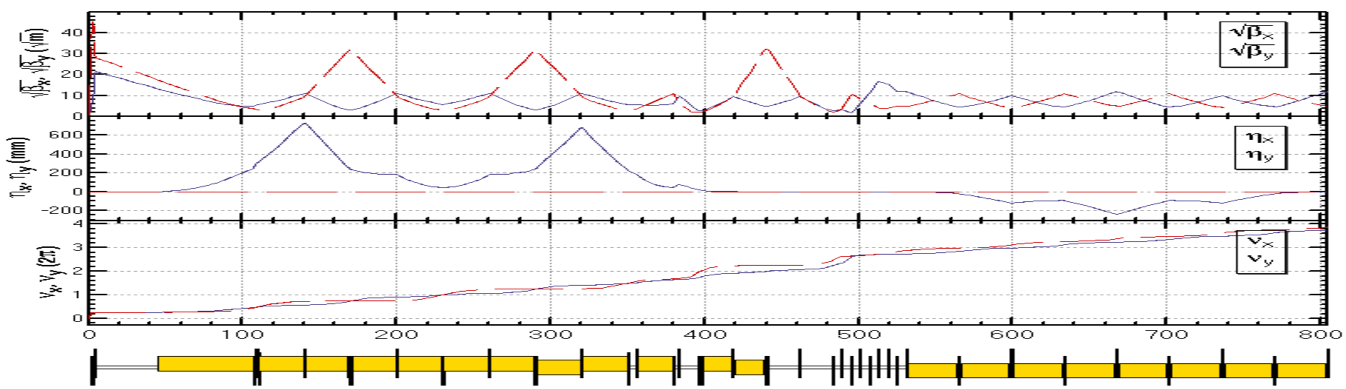
Lattice design and geometry for interaction region

- Provide **local chromaticity correction for only vertical plane**
- Keep ARC sextupoles and final doublet on phases for horizontal chromaticity correction
- **Crossing angle 30 mrad**

L*= 1.5m
βx*= 0.144mm
βy*= 2mm
GQD0= -200T/m
GQF1= 200T/m
LQD0=1.69m
LQF1=0.90m

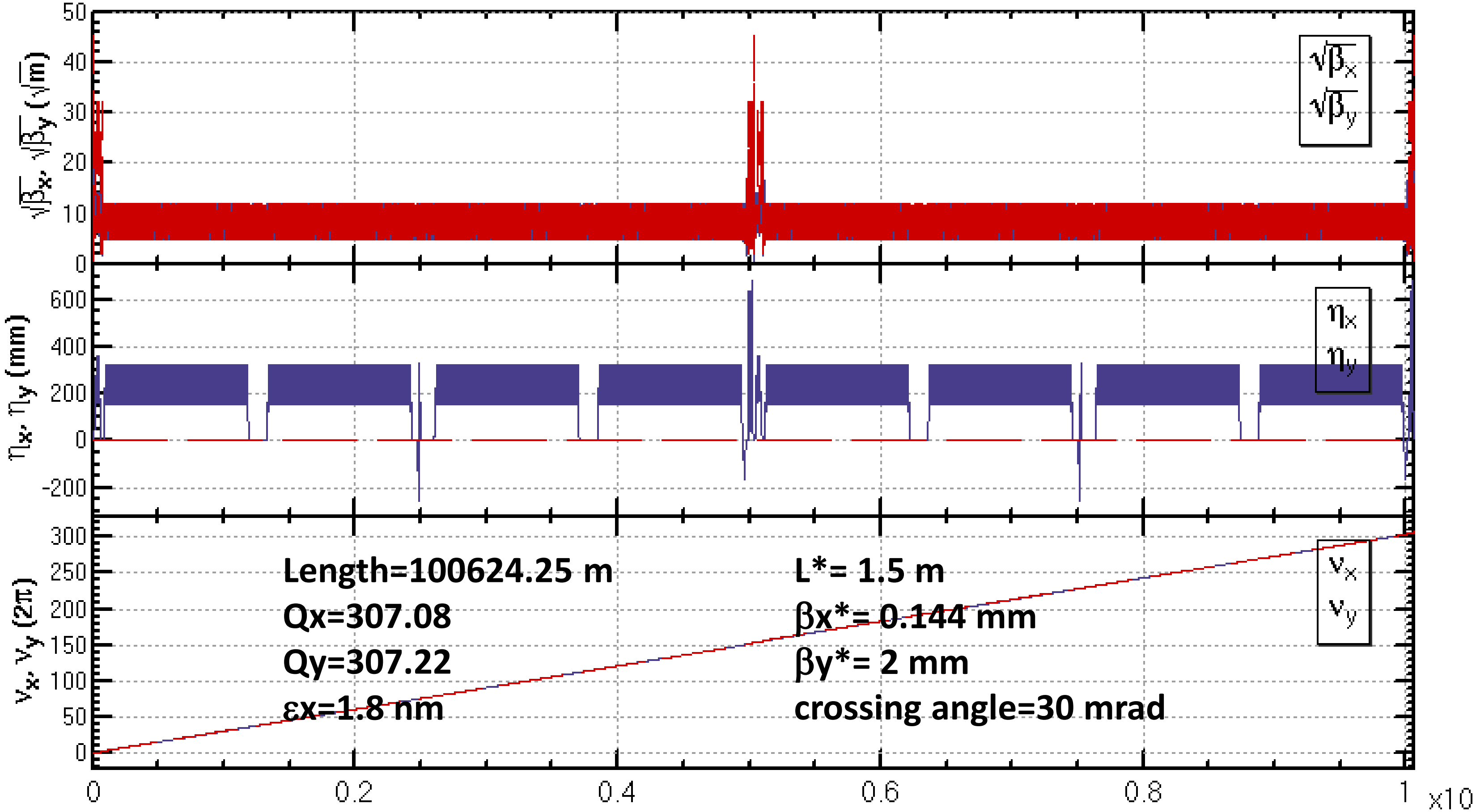


IR of IP upstream   Ec < 100 keV within 280m



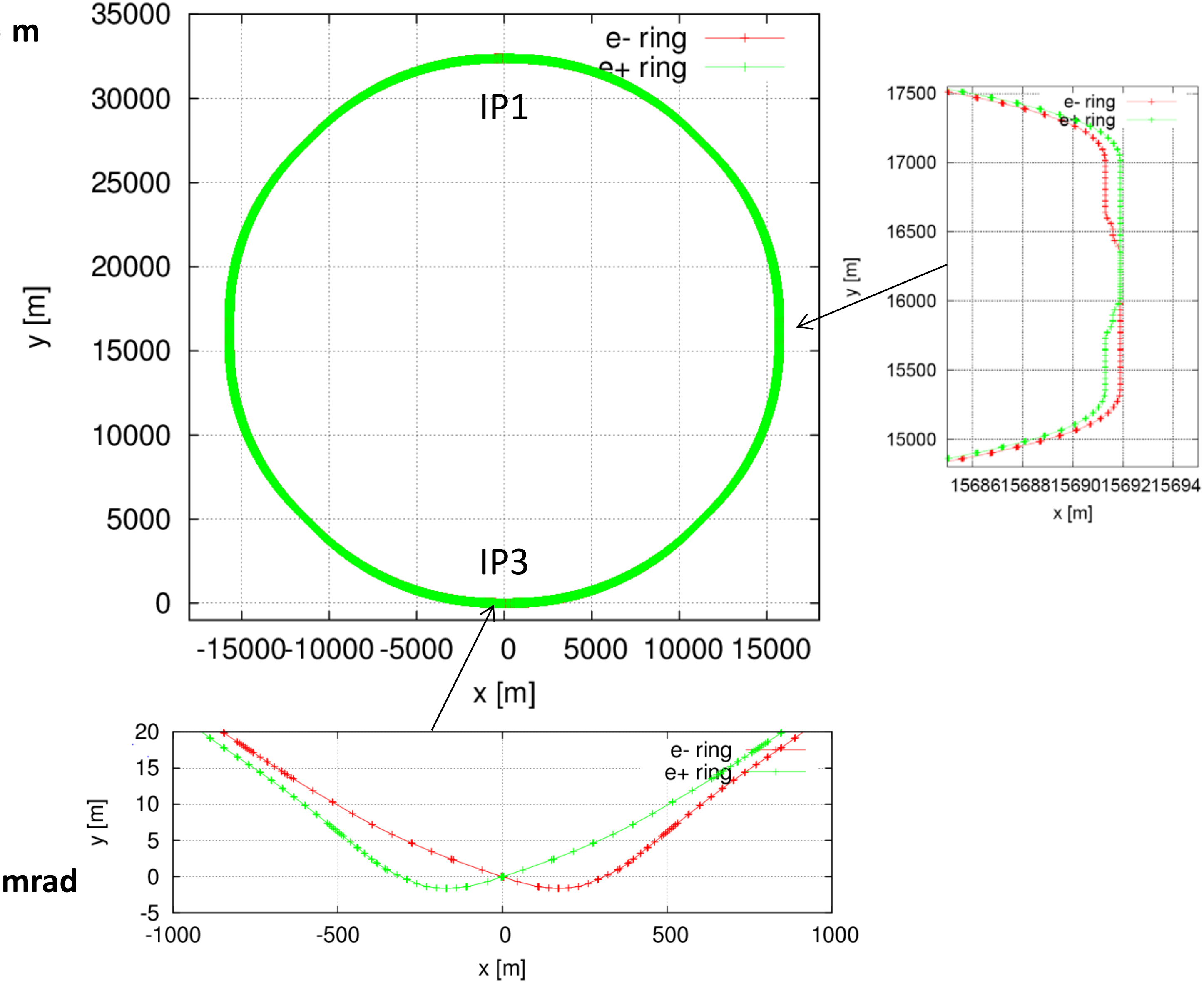
IR of IP downstream   Ec < 500 keV within 200m

Lattice design of whole ring



Geometry of whole ring

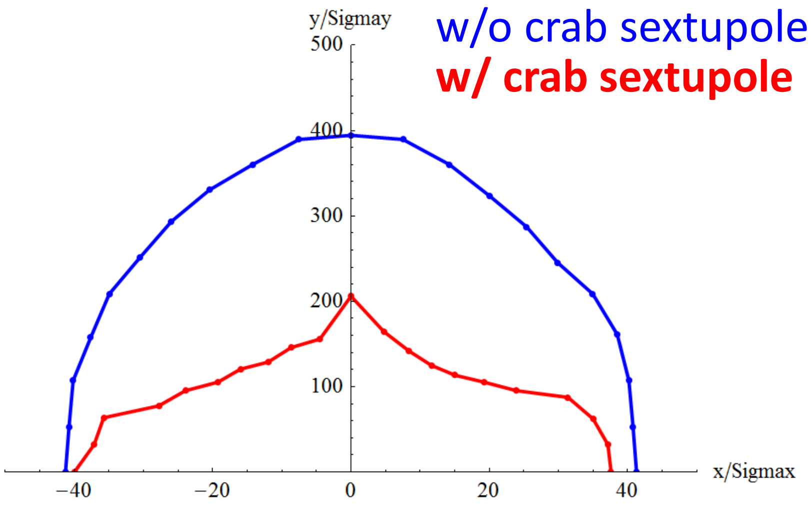
Length=100624.25 m
Qx=307.08
Qy=307.22
εx=1.8 nm



L*= 1.5 m
βx*= 0.144 mm
βy*= 2 mm
crossing angle=30 mrad

Dynamic aperture

- Dynamic aperture study
  - Bare lattice
  - Synchrotron motion included
  - **w/o damping**
  - Tracking with around 1 times of damping time
  - Coupling factor κ=0.003 for εy
  - Working point (0.08, 0.22)
- On momentum DA is large enough to go ahead.
- Further work on DA study for Fully partial double ring scheme is undergoing



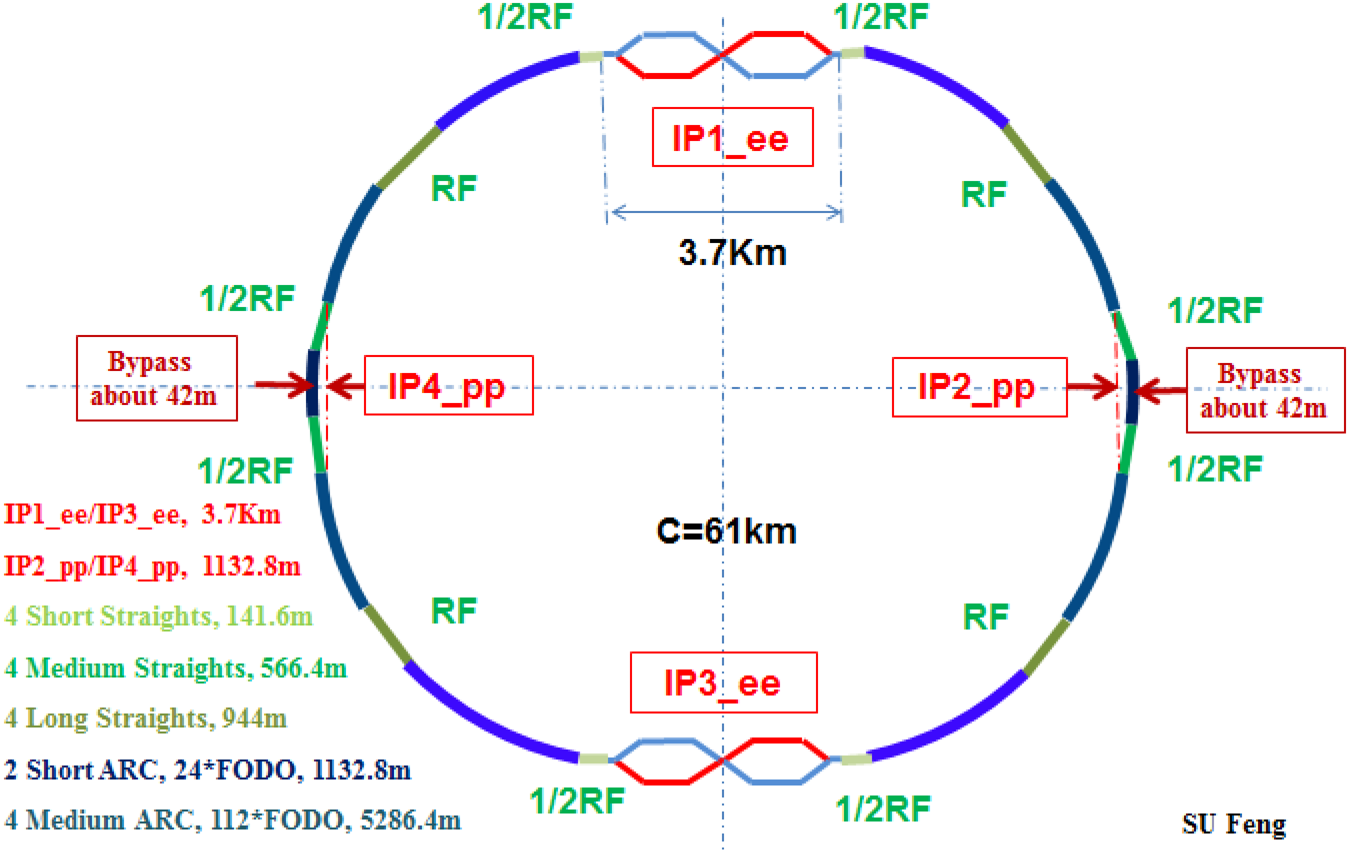
w/o crab sextupole

40 $\sigma x \times 400\ \sigma y$

w/ crab sextupole

38 $\sigma x \times 180\ \sigma y$

CEPC Partial Double Ring Layout



IP1_ee/IP3_ee, 3.7Km

IP2_pp/IP4_pp, 1132.8m

4 Short Straights, 141.6m

4 Medium Straights, 566.4m

4 Long Straights, 944m

2 Short ARC, 24*FODO, 1132.8m

4 Medium ARC, 112*FODO, 5286.4m

4 Long ARC, 124*FODO, 5852.8m

SU Feng

2016.9.15

CEPC parameters for C=61km

D. Wang, SEP 2016

	Pre-CDR	*H-high lumi.*	*H-low power*	*W*	*Z*
Number of IPs	2	2	2	2	2
Energy (GeV)	120	120	120	80	45.5
Circumference (km)	54	61	61	61	61
SR loss/turn (GeV)	3.1	2.96	2.96	0.58	0.061
Half crossing angle (mrad)	0	15	15	15	15
Piwinski angle	0	1.88	1.84	5.2	6.4
N_e/bunch (10^{11})	3.79	2.0	1.98	1.16	0.78
Bunch number	50	107	70	400	1100
Beam current (mA)	16.6	16.9	11.0	36.5	67.6
SR power /beam (MW)	51.7	50	32.5	21.3	4.1
Bending radius (km)	6.1	6.2	6.2	6.2	6.2
Momentum compaction (10^{-5})	3.4	1.48	1.48	1.44	2.9
β_{IP} x/y (m)	0.8/0.0012	0.272/0.0013	0.275 /0.0013	0.1/0.001	0.1/0.001
Emittance x/y (nm)	6.12/0.018	2.05/0.0062	2.05 /0.0062	0.93/0.0078	0.88/0.008
Transverse σ_{IP} (um)	69.97/0.15	23.7/0.09	23.7/0.09	9.7/0.088	9.4/0.089
ξ_x/IP	0.118	0.041	0.042	0.013	0.01
ξ_y/IP	0.083	0.11	0.11	0.073	0.072
V_{RF} (GV)	6.87	**3.48**	**3.51**	**0.74**	**0.11**
f_{RF} (MHz)	650	650	650	650	650
Nature σ_z (mm)	2.14	**2.7**	**2.7**	**2.95**	**3.78**
Total σ_z (mm)	2.65	2.95	2.9	3.35	4.0
HOM power/cavity (kw)	3.6	0.74	0.48	0.88	0.99
Energy spread (%)	0.13	0.13	0.13	0.087	0.05
Energy acceptance (%)	2	2	2		
Energy acceptance by RF (%)	6	**2.3**	**2.4**	**1.7**	**1.2**
n_γ	0.23	0.35	0.34	0.49	0.34
Life time due to beamstrahlung_cal (minute)	47	37	37		
F (hour glass)	0.68	0.82	0.82	0.92	0.93
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	2.04	3.1	2.01	4.3	4.48

Lattice design for ARC region

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  - period N=5cells
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  - **tune shift dQ(Jx, Jy) is very small**
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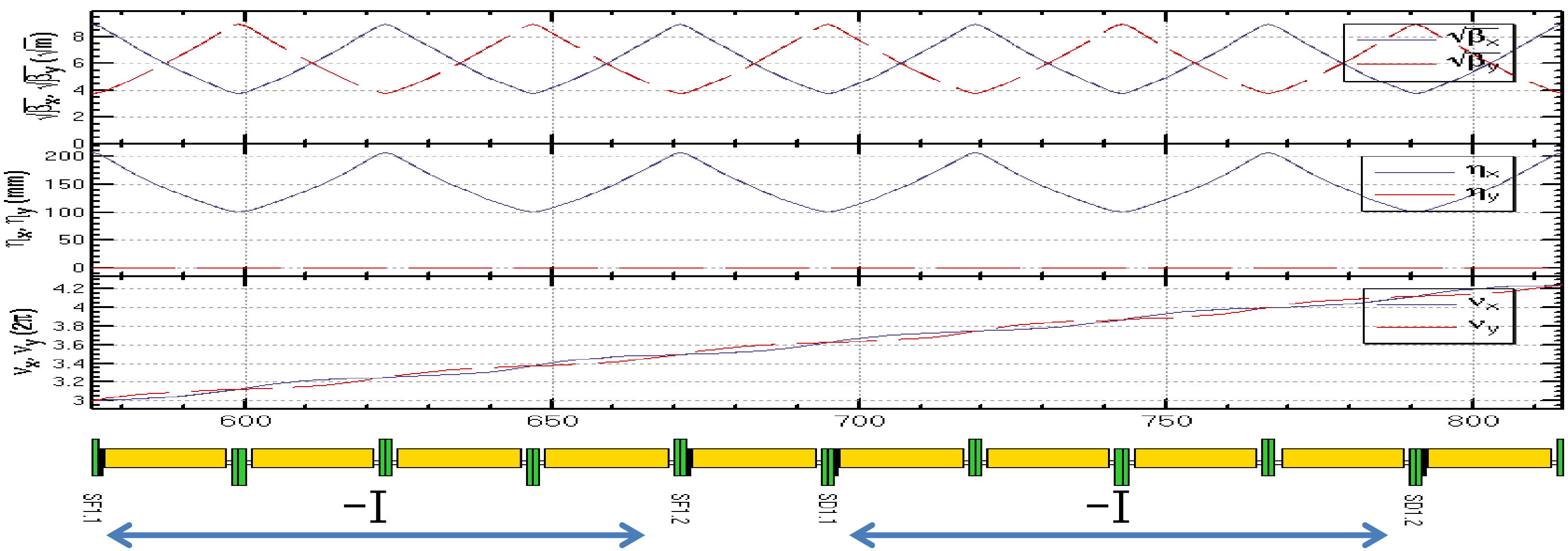
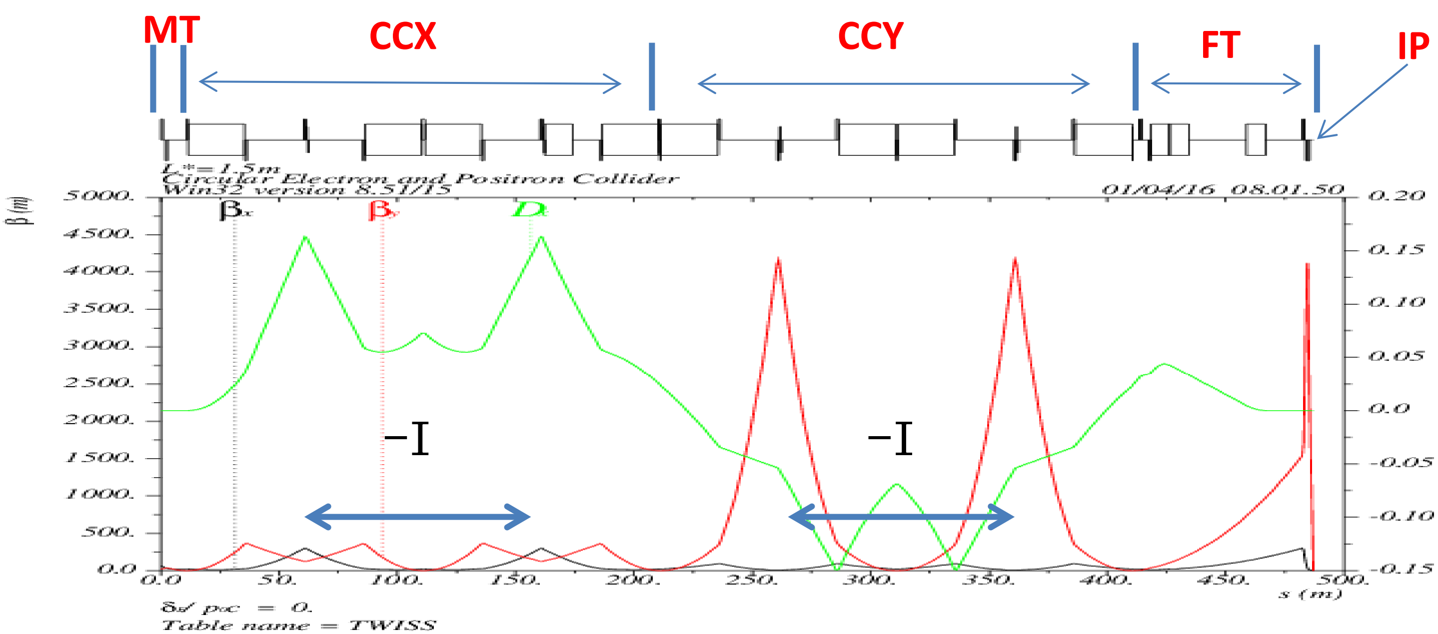


Sextupole configuration

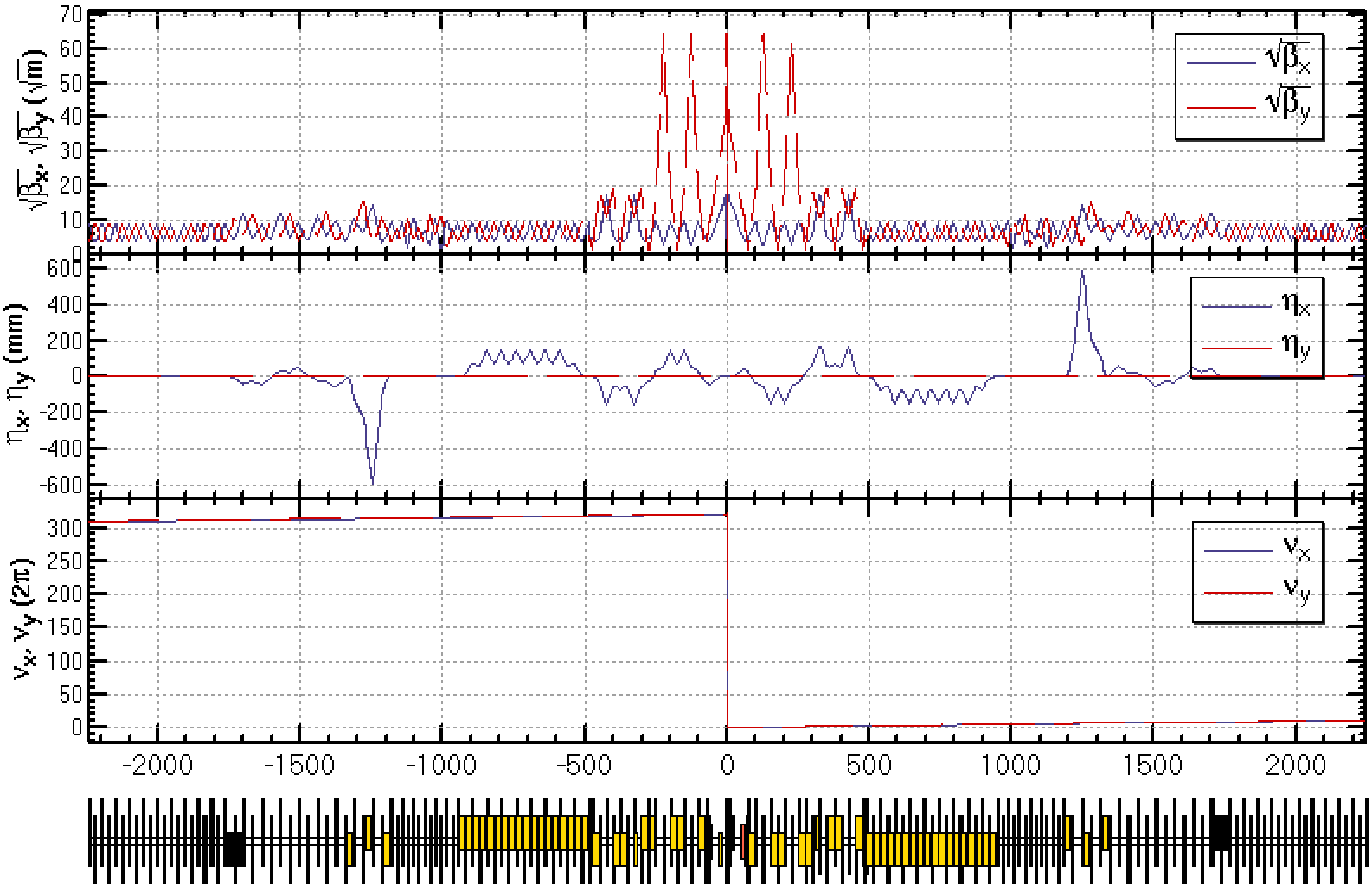
Lattice design for interaction region

- **Local chromaticity correction** with sextupoles pairs separated by –I transportation
  - all **3rd and 4th RDT** due to sextupoles almost cancelled
  - **up to 3rd order chromaticity** corrected with main sextupoles, phase tuning and additional sextupoles
  - **tune shift dQ(Jx, Jy)** due to finite length of main sextupoles corrected with additional weak sextupoles
  - **Break down of –I, high order dispersion** could be optimized with odd dispersion scheme or Brinkmann sextupoles

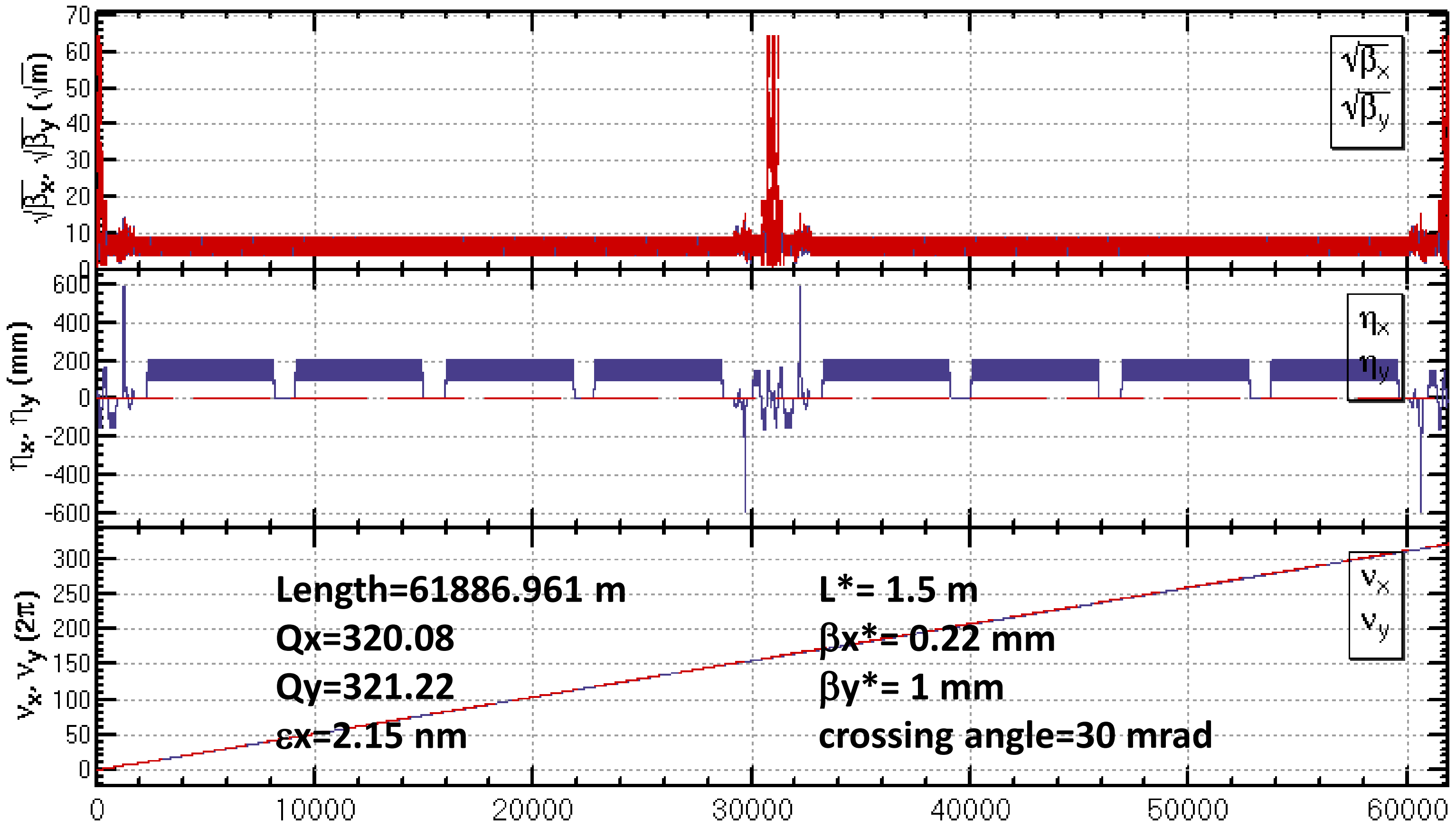


L*= 1.5m
βx*= 0.22mm
βy*= 1mm
GQD0= -200T/m
GQF1= 200T/m
LQD0=1.69m
LQF1=0.90m

Lattice design for PDR region

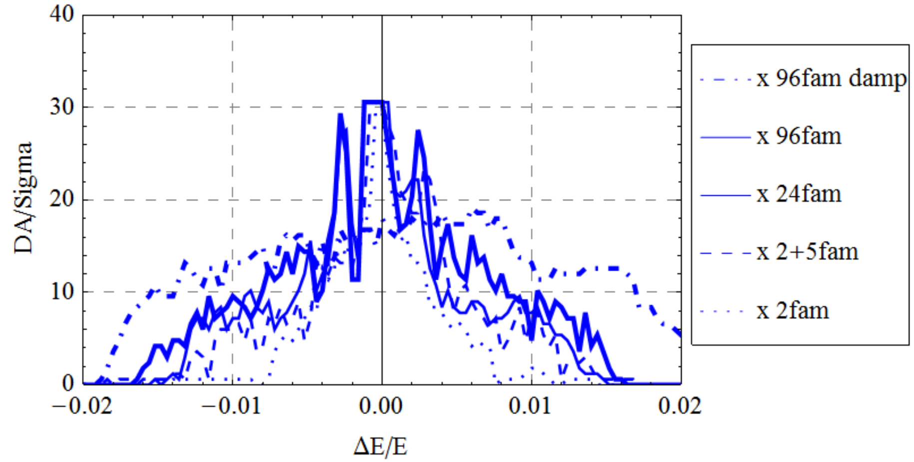


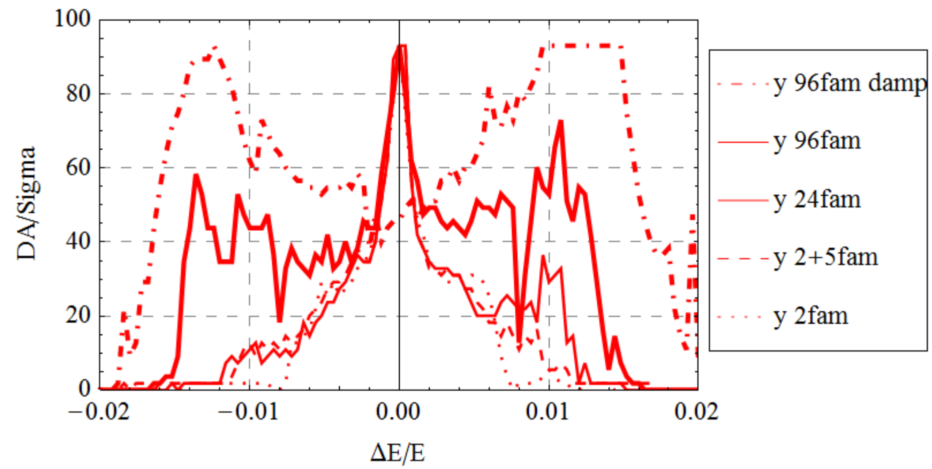
Lattice design for whole ring



Optimization of dynamic aperture

- Dynamic aperture study
  - **Bare lattice**
  - Synchrotron motion included
  - w/o and w/ damping
  - Tracking with around 1 times of damping time
  - Coupling factor κ=0.003 for εy
  - Working point (0.08, 0.22)
  - **Downhill Simplex** algorithm applied
- Further optimization is possible
  - **Larger dispersion** for IR sextupoles
  - **βy*= 1mm -> 2mm** (new parameters)
  - **More families in IR**
- Study of effects such as sawtooth, errors and misalignments, quantum excitation, solenoid field are under going



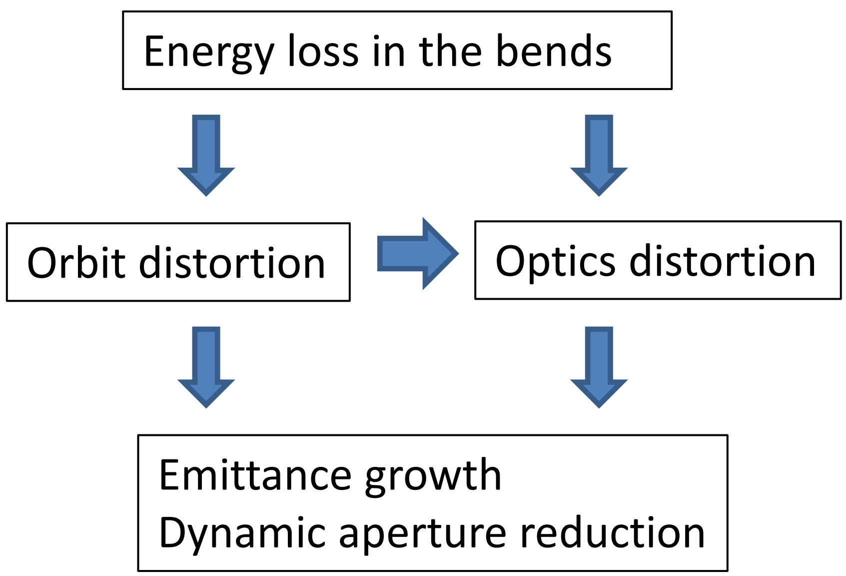


Mitigation of sawtooth effects for partial double ring scheme

Sawtooth effects

- For the partial double scheme, unlike fully partial double ring scheme, the sawtooth orbit can not be corrected by tapering the magnet strength with beam energy along beamline.

W/O correction in PDR region



Estimation of sawtooth effects for CEPC PDR/APDR sheme

- The change of orbit due to energy loss can be corrected in **PDR region** by tapering the strength of magnets.
- This effect in **ARC region** can be eased with more RF stations
  - Maximum of energy deviation

    $$\delta_E = \frac{U_0}{2N_{RF}E} \qquad U_0 = \frac{C_\gamma}{2\pi} E^4 I_2$$

    Maximum of sawtooth orbit $\Delta x \simeq D_x \delta_E$

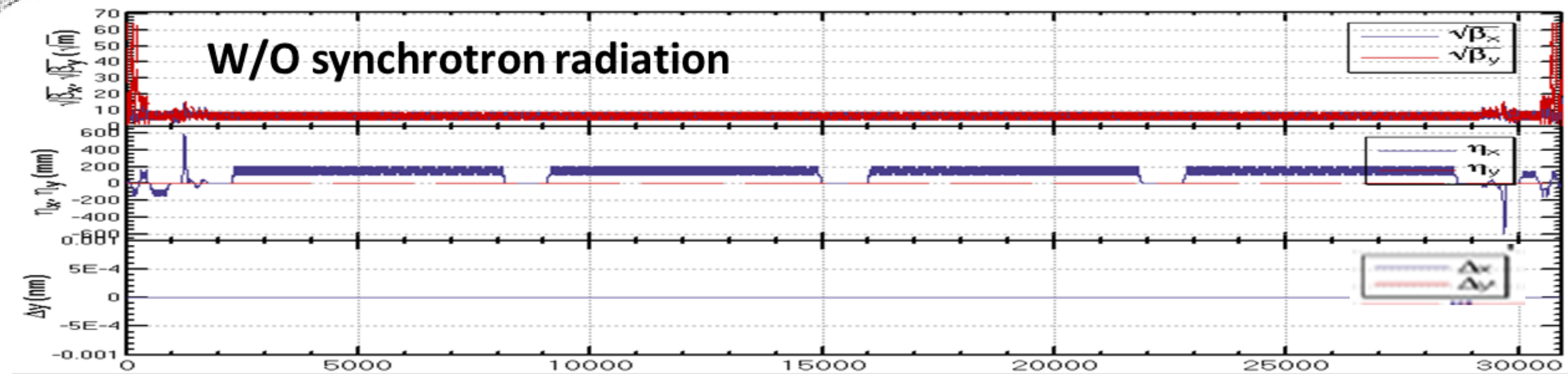
    Beam size $\sigma_x \simeq \sqrt{\beta_x \epsilon_x + (D_x \sigma_E)^2}$
  - With present parameters and lattice design:

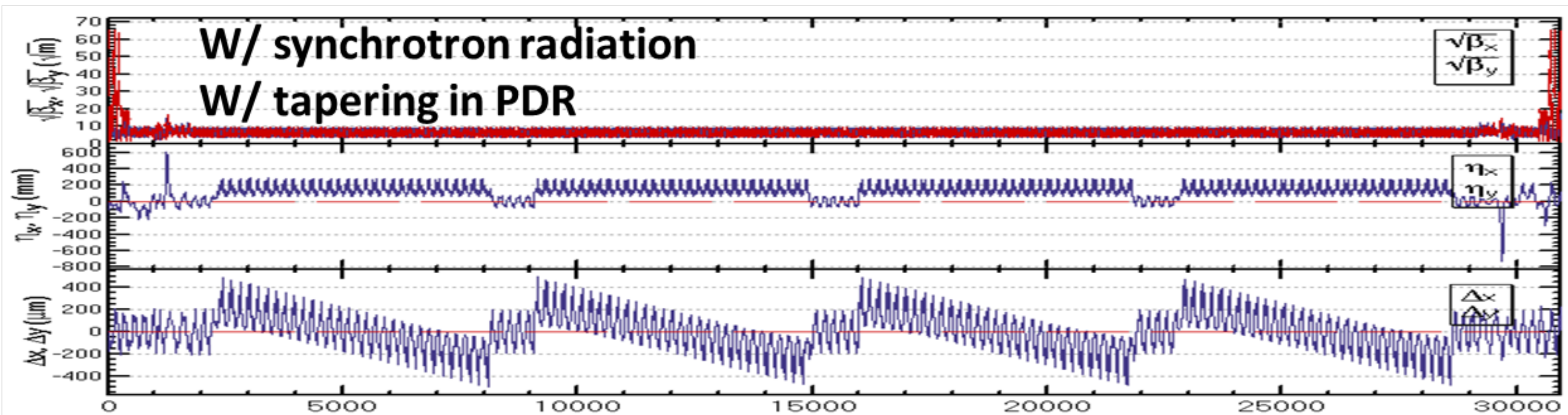
    $$\delta_E = 0.16\,\%,\ \Delta x \simeq 0.33\ \mathrm{mm},\ \sigma_\mathrm{x} \simeq 0.49\ \mathrm{mm},\ \mathrm{thus}\ \frac{\Delta \mathrm{x}}{\sigma_\mathrm{x}} \simeq 0.7$$

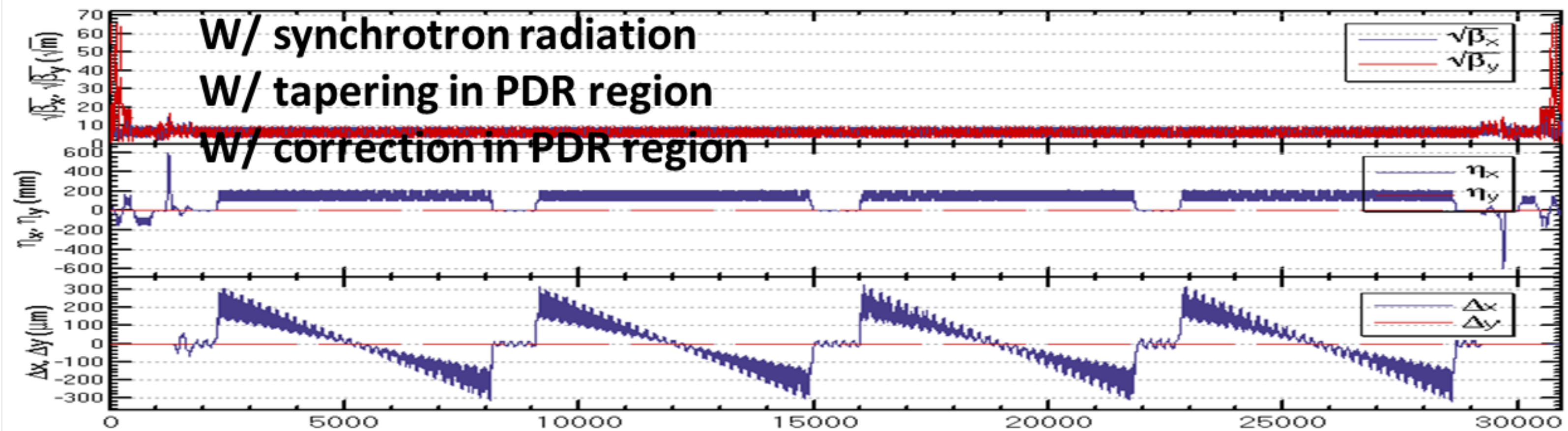
    - Maximum of energy deviation δ_E is much smaller than FCC-ee mainly due to more RF stations (8 stations/2 stations, factor 0.25) and lower energy(120GeV/175GeV, factor 0.32)
    - For PDR, APDR schemes: $\Delta x/\sigma_x \simeq\ 0.7 \times 0.9,\ 0.7 \times 0.8$

    Their relative sawtooth orbits are both less than one sigma of beam size thus should not significantly affect the DA.

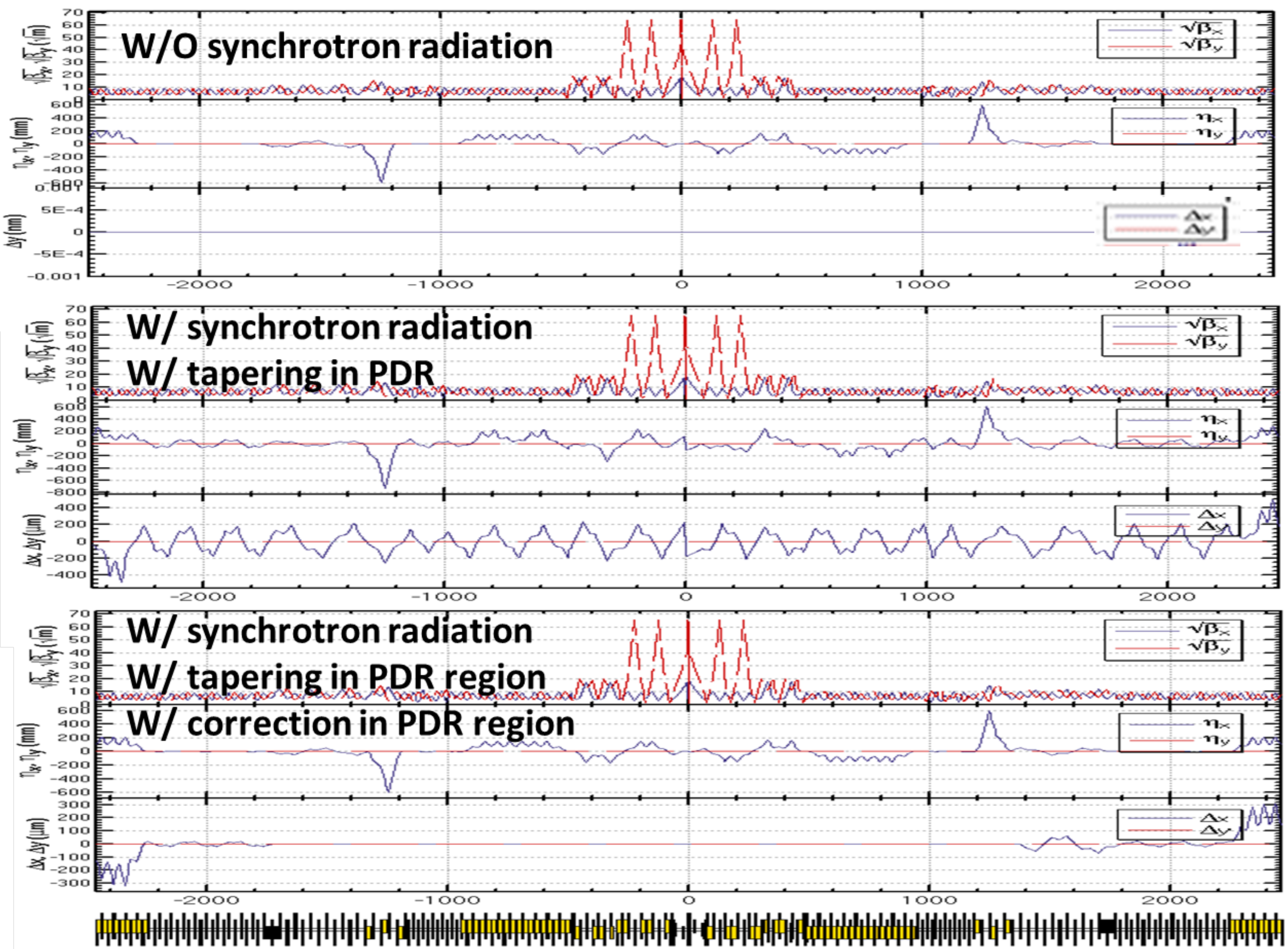
Orbit and optics (whole ring)





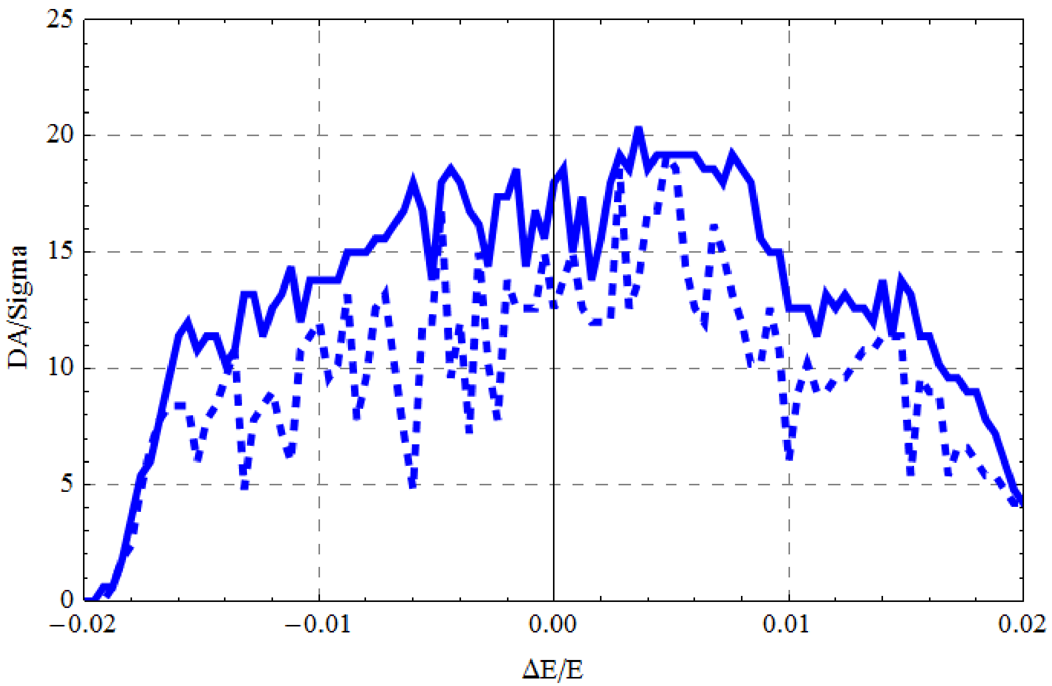


Orbit and optics (PDR region)



Emittance and dynamic aperture

	W/O synchrotron radiation	W/ synchrotron radiation W/ tapering in PDR	W/ synchrotron radiation W/ tapering in PDR W/ correction in PDR region
Emittance	**2.15nm**	**5.50nm**	**2.16nm**



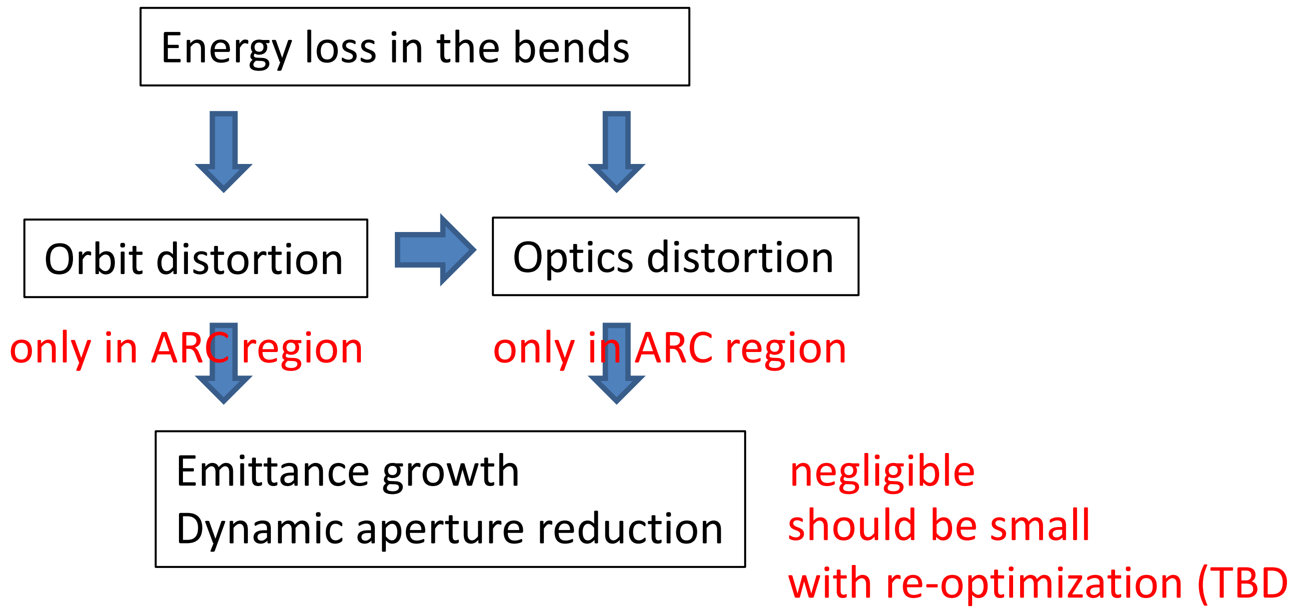
Re-optimization of dynamic aperture with ARC sextupoles considering sawtooth effects is possilble

- as long as we always constraint symetry for two IPs and two beams

DA on horizontal plane (W/ damping)
Hard line W/O sawtooth
Dashed line W/ sawtooth and tapering/correction in PDR region

Sawtooth issue summary

W/ correction in PDR region



Summary

- Fully partial double ring scheme
  - got a preliminary lattice design considering geometry
  - On momentum dynamic aperture is large enough to go ahead.
- Partial double ring scheme
  - got a lattice design
  - Dynamic aperture is achieving the goal
- Mitigation of sawtooth effects for partial double ring scheme
  - With tapering and correction in the PDR region, the orbit and optics distortion only occur in ARC region
  - Emittance growth negligible and dynamic aperture reduction should be small with re-optimizatoin.

Thanks for your attention!