CEPC Partial Double Ring Lattice Design

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Institute of High Energy Physics

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Outline

1. CEPC PDR Parameter and Lattice Layout
2. CEPC PDR ARC Length Consideration and Redesign
3. CEPC PDR DA Study (NSGAII & DA Optimization)
4. CEPC APDR Scheme
5. CEPC Double Ring Scheme
6. Summary

Outline

1. CEPC PDR Parameter and Lattice Layout

CEPC PDR Parameter

（wangdou20160325）

	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	54	54	54	54
SR loss/turn (GeV)	3.1	2.96	2.96	0.59	0.062
Half crossing angle (mrad)	0	15	15	15	15
Piwinski angle	0	2.5	2.6	5	7.6
N_e/bunch (10^{11})	3.79	2.85	2.67	0.74	0.46
Bunch number	50	67	44	400	1100
Beam current (mA)	16.6	16.9	10.5	26.2	45.4
SR power /beam (MW)	51.7	50	31.2	15.6	2.8
Bending radius (km)	6.1	6.2	6.2	6.1	6.1
Momentum compaction (10^{-5})	3.4	2.5	2.2	2.4	3.5
β_{IP} x/y (m)	0.8/0.0012	0.25/0.00136	0.268 /0.00124	0.1/0.001	0.1/0.001
Emittance x/y (nm)	6.12/0.018	2.45/0.0074	2.06 /0.0062	1.02/0.003	0.62/0.0028
Transverse σ_{IP} (um)	69.97/0.15	24.8/0.1	23.5/0.088	10.1/0.056	7.9/0.053
ξ_x/IP	0.118	0.03	0.032	0.008	0.006
ξ_y/IP	0.083	0.11	0.11	0.074	0.073
V_{RF} (GV)	6.87	**3.62**	**3.53**	**0.81**	**0.12**
f_{RF} (MHz)	650	650	650	650	650
Nature σ_z (mm)	2.14	**3.1**	**3.0**	**3.25**	**3.9**
Total σ_z (mm)	2.65	4.1	4.0	3.35	4.0
HOM power/cavity (kw)	3.6	2.2	1.3	0.99	0.99
Energy spread (%)	0.13	0.13	0.13	0.09	0.05
Energy acceptance (%)	2	2	2		
Energy acceptance by RF (%)	6	**2.2**	**2.1**	**1.7**	**1.1**
n_γ	0.23	0.47	0.47	0.3	0.24
Life time due to beamstrahlung_cal (minute)	47	36	32		
F (hour glass)	0.68	0.82	0.81	0.92	0.95
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	2.04	2.96	2.01	3.09	3.09

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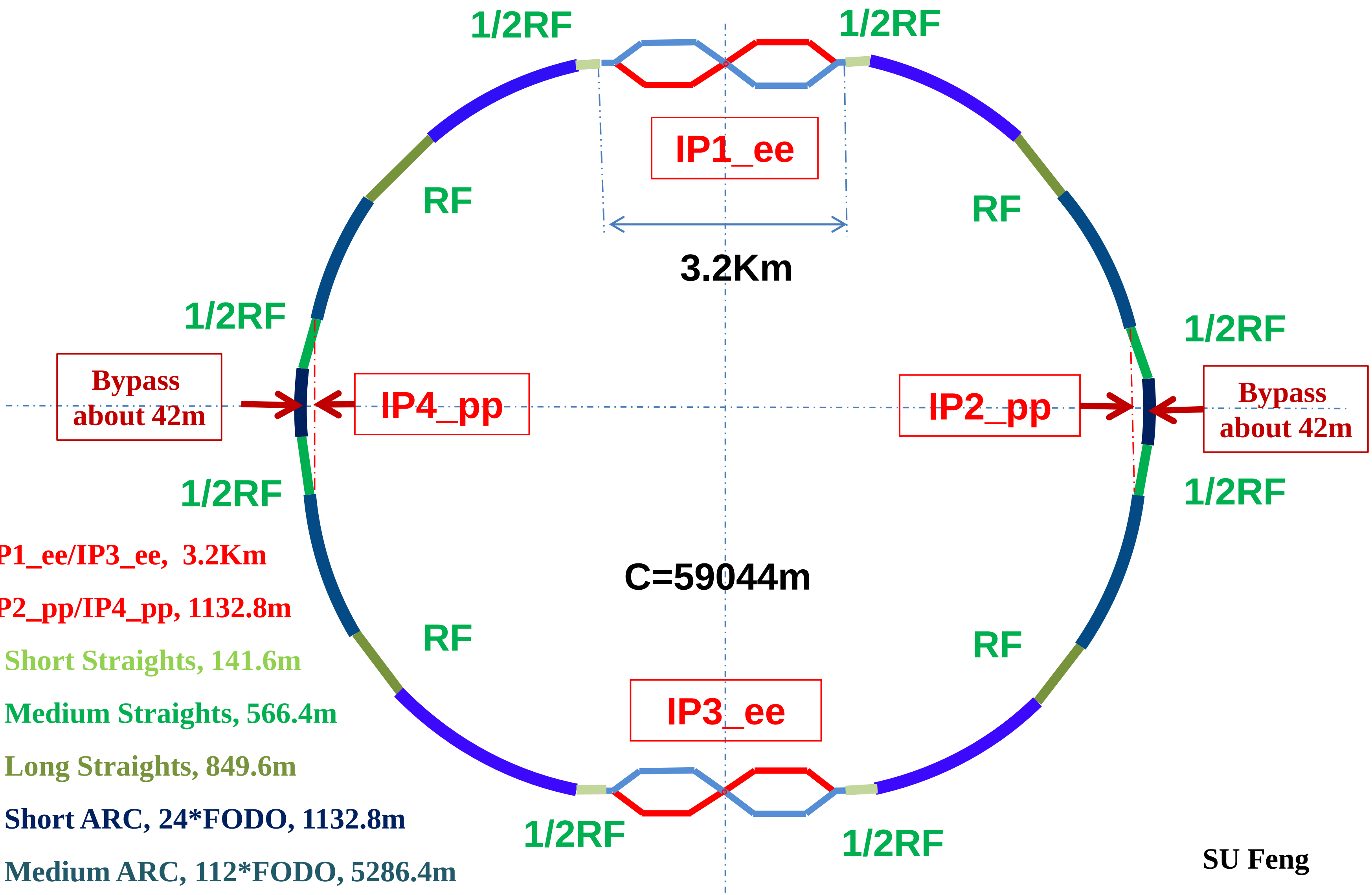
CEPC Partial Double Ring Layout



IP1_ee/IP3_ee, 3.2Km

IP2_pp/IP4_pp, 1132.8m

4 Short Straights, 141.6m

4 Medium Straights, 566.4m

4 Long Straights, 849.6m

2 Short ARC, 24*FODO, 1132.8m

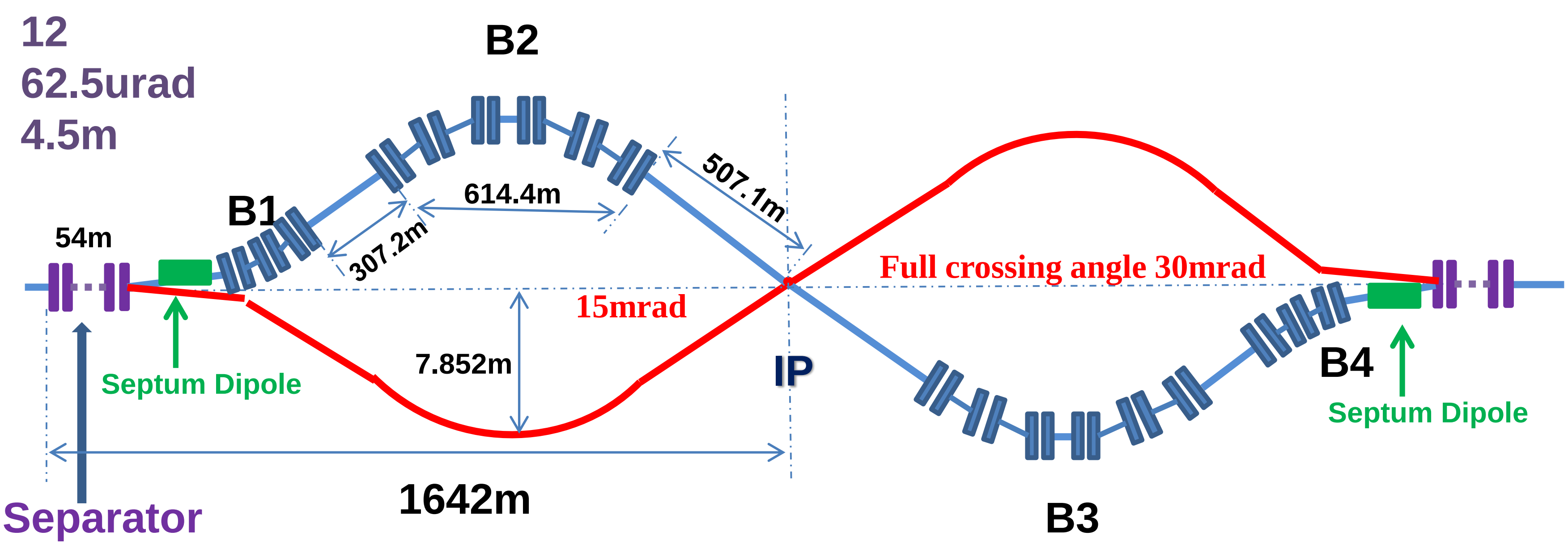
4 Medium ARC, 112*FODO, 5286.4m

4 Long ARC, 124*FODO, 5852.8m

SU Feng

2016.1.4

CEPC Partial Double Ring Layout



For CEPC 120GeV beam:

- **Max. deflection per separator is 66μrad.**

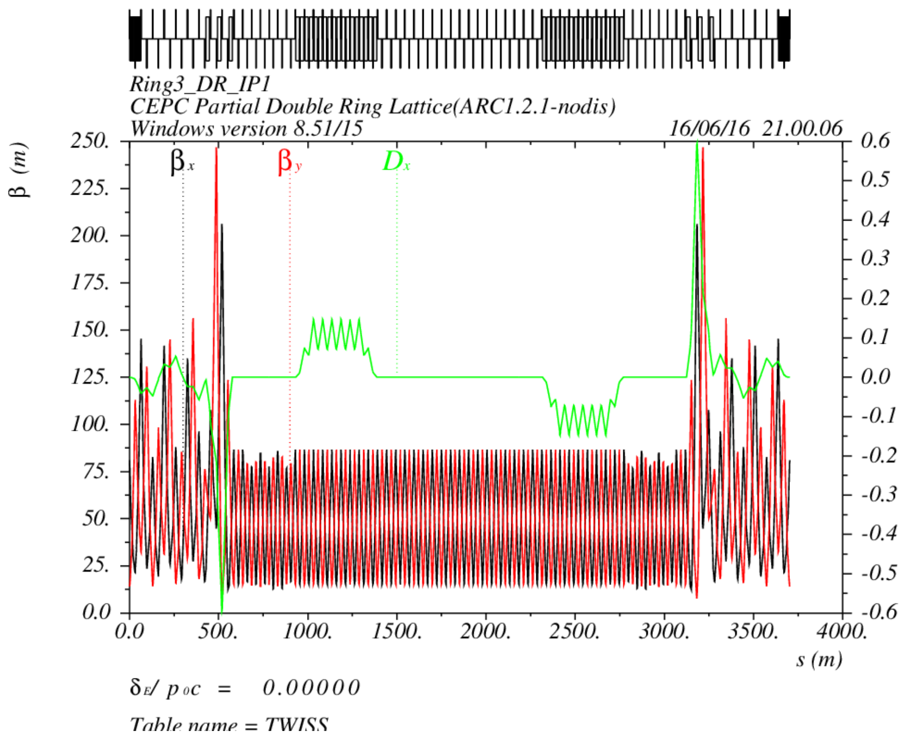
Using Septum Dipole after separator to acquire 15 mrad

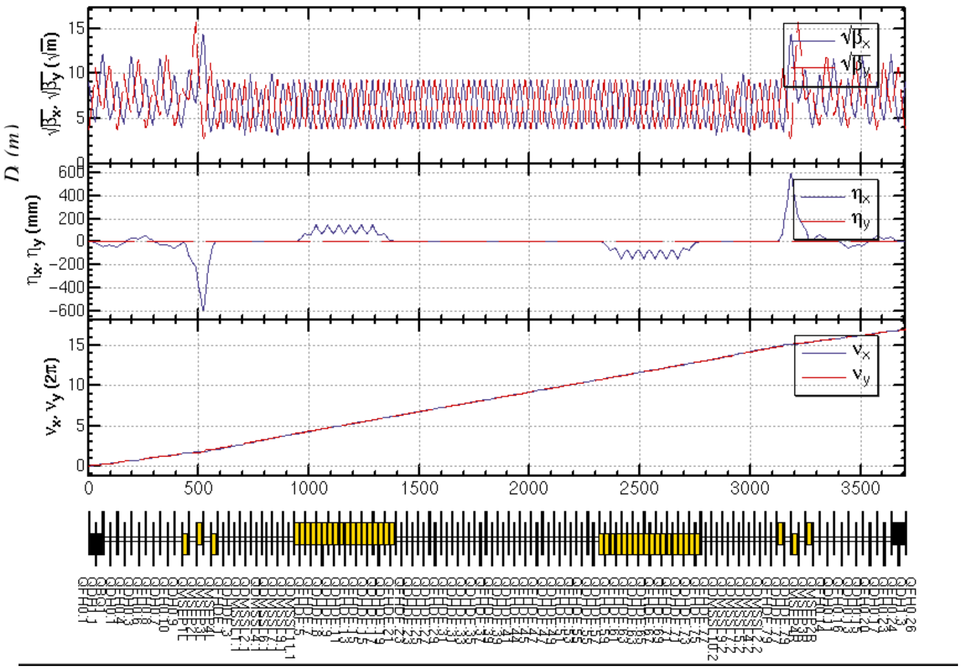
Version 1.0

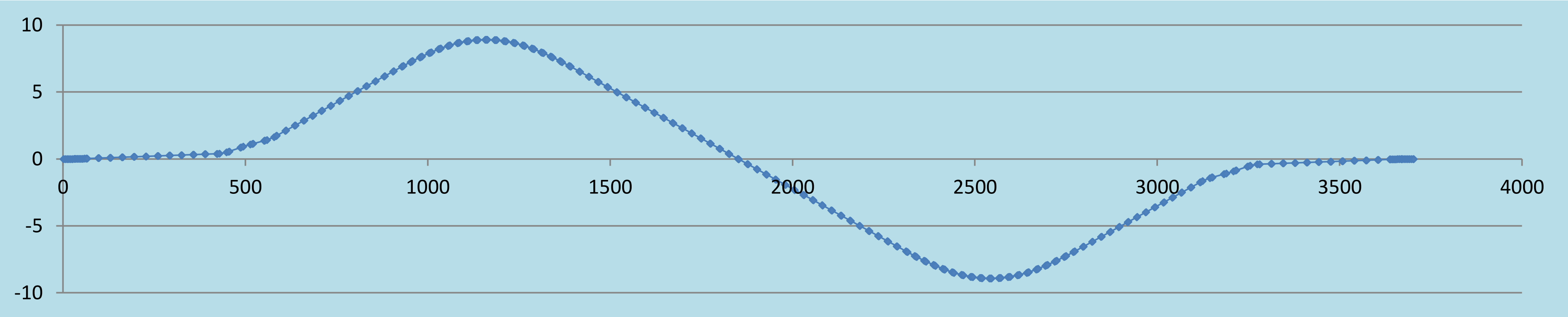
sufeng

2015.12.20

CEPC PDR1.0.3 noFFS







Outline

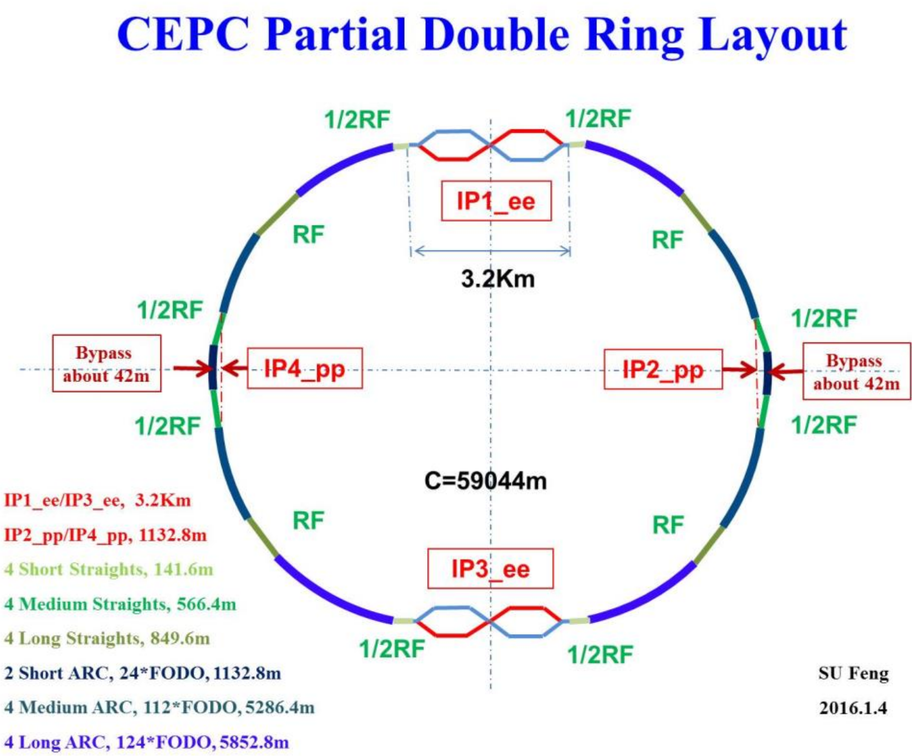
2. CEPC PDR ARC Length Consideration and Redesign

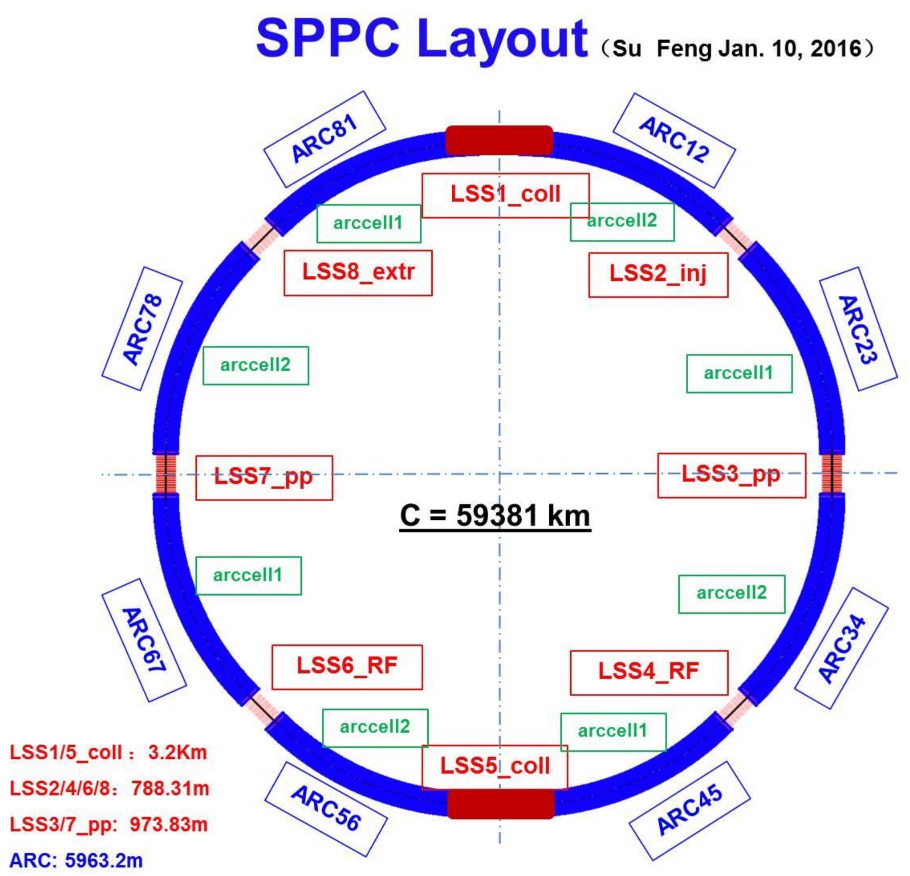
CEPC PDR ARC Length Consideration

The circumference should be also considered of SPPC requirement…

1. **ARC+Straight (>= 53 Km)**
2. **ARC+Straight+PDR**
3. **ARC+Straight+PDR+FFS**

CEPC & SPPC Layout





CEPC ARC Length According to SPPC

Theory:

$E0 = 70 - 100\ \mathrm{TeV}$

$$\gamma = \frac{35\ \mathrm{TeV}}{938.27\ \mathrm{MeV}} = 37313.4$$

$\beta = 1$

$$B\rho = \frac{E0}{c} = 3.1267\ \beta\gamma = 116635.29\ \mathrm{Tm}$$

$B0 = 20\ \mathrm{T}$

$$\rho = \frac{B\rho}{B0} = \frac{116635.29}{20} = 5831.7645$$

$L_{Dipole} = 2\pi\rho = 36642.05\ \mathrm{m}$

ARC filling factor $f1 = 0.8$

$$L_{ARC} = \frac{L_{Dipole}}{f1} = \frac{36642.05}{0.8} = 45802.56\ \mathrm{m}$$

$Lss3pp = Lss7pp = 973.83\ \mathrm{m}$

$Lss2 = Lss4 = Lss6 = Lss8 = 788.31\ \mathrm{m}$

$\boxed{L1 = 50903.46}$

$Lss1 = Lss5 = 3.3\ \mathrm{km}$

$C0 = 57503.46\ \mathrm{m}$

In Practice:

ARC CELL

	LQ	DQS	LS	DSB	LB	DBB
SPPC	4m	1m	0.5m	1m	14.8m	1m
FCC-hh	6.3137m	1m	0.5m	2.184m	14.3m	1.36m

B max [T]	G max [T/m]	k1	k2
19.61	582.156	4.9899E-3	0

Pre-CDR:

Dipole: L=15m B=20T

Quadrupole:

D = 45 mm B_{pole}=16 T

G=711.1T/m K1=6.097*10^-3

Betax: 244.878/42.57

Betay: 42.569/244.869

(ϵ_n =4.1um)

$$\epsilon = \frac{\epsilon_n}{\gamma}$$

E (Collision: 35TeV)

(Injection: 2.1TeV)

ϵ (Collision: 1.099*10^-10m=0.1099nm)

（Injection: 1.83*10^-9m=1.83nm）

σ（Collision: 1.66*10^-4m=166um）

（Injection: 6.76*10^-4m=676um）

R=20*σ_{Inj}=13.52mm

D=27.04

$L_B = 14.8\ \mathrm{m}$

$$FODO : f1 = \frac{14.8 * 8}{144.4} = 0.8199$$

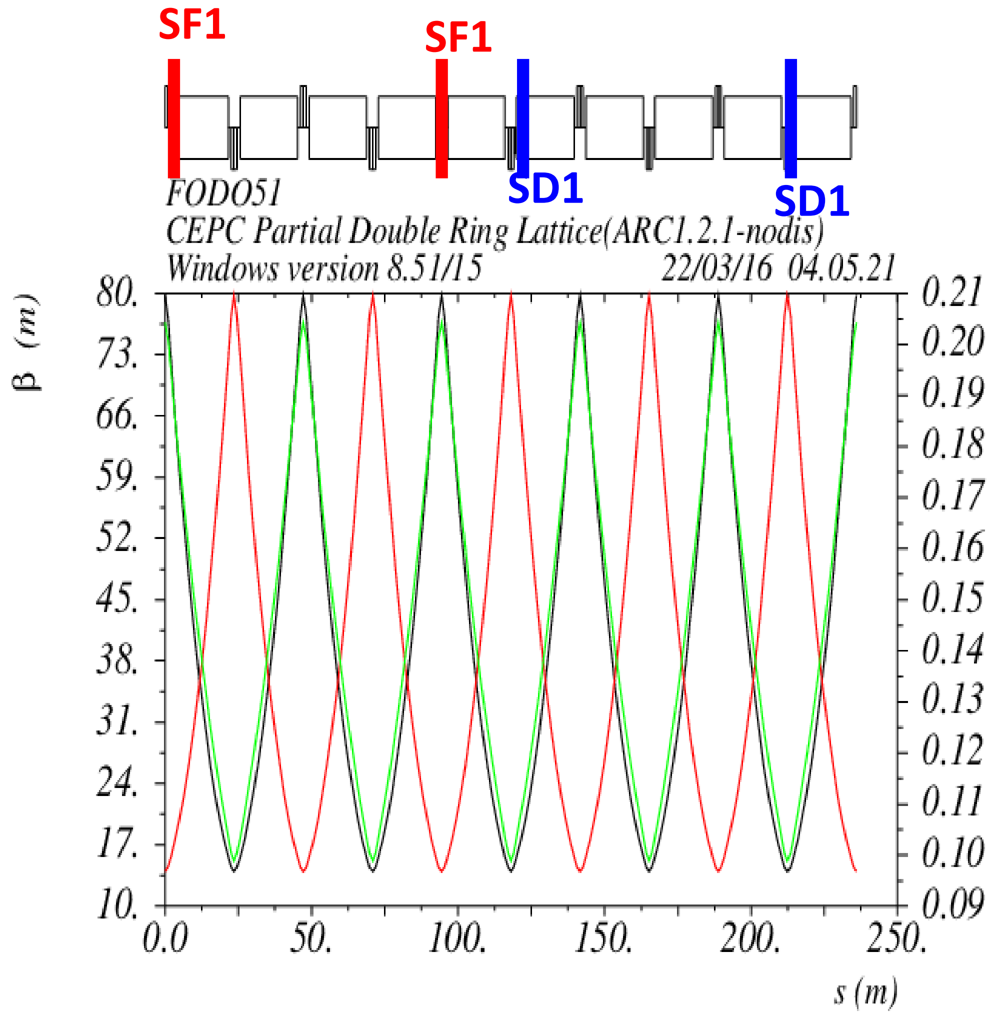
$$ARC : f1 = \frac{14.8 * 8 * 38 + 14.8 * 8 * 2}{(38 + 2 + 2) * 144.4} = 0.7809$$

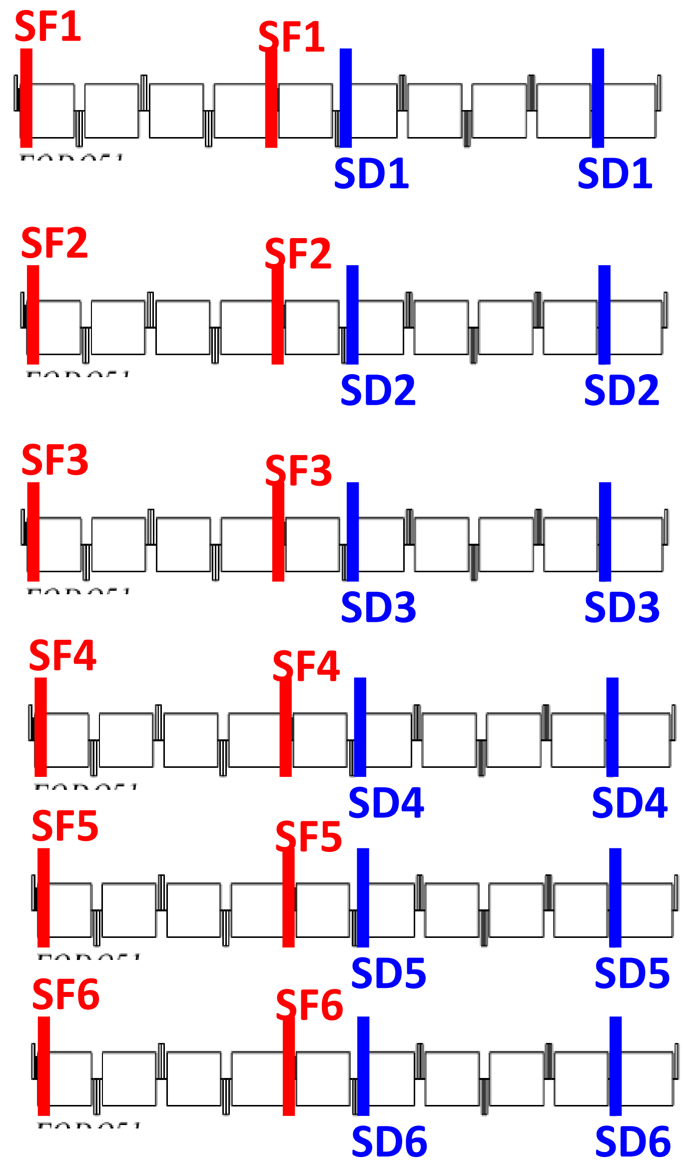
$$L_{ARC} = \frac{37389.85}{0.7809} = 47880.46$$

$\boxed{L1 = 52981.42}$

$C0 = 59581.42$

New ARC FODO 90/90 non-interleave





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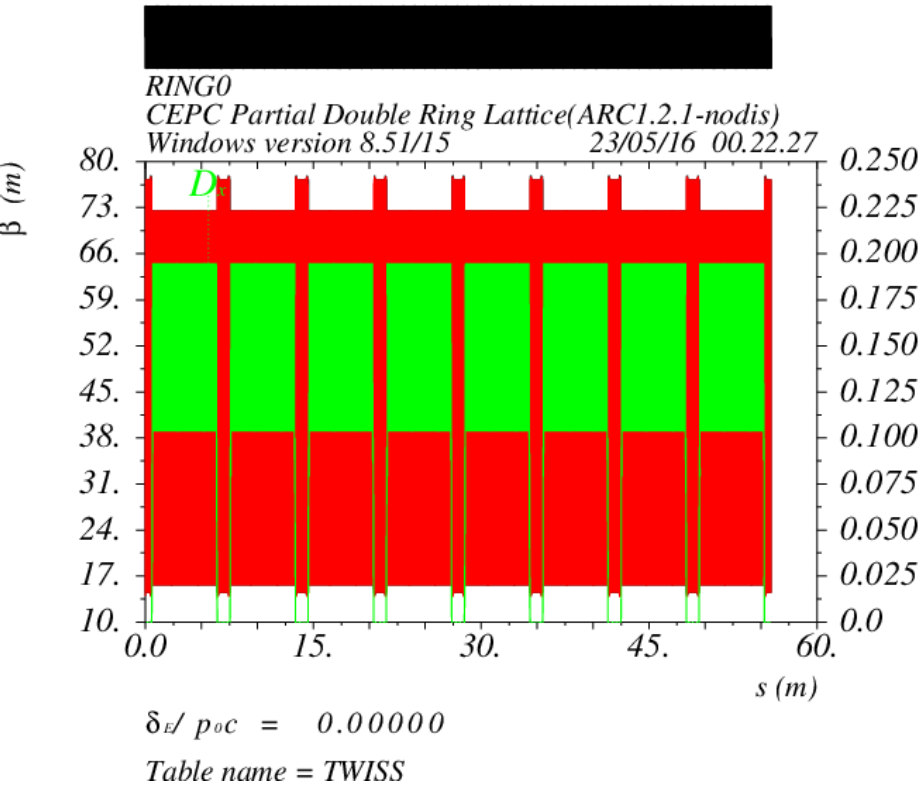
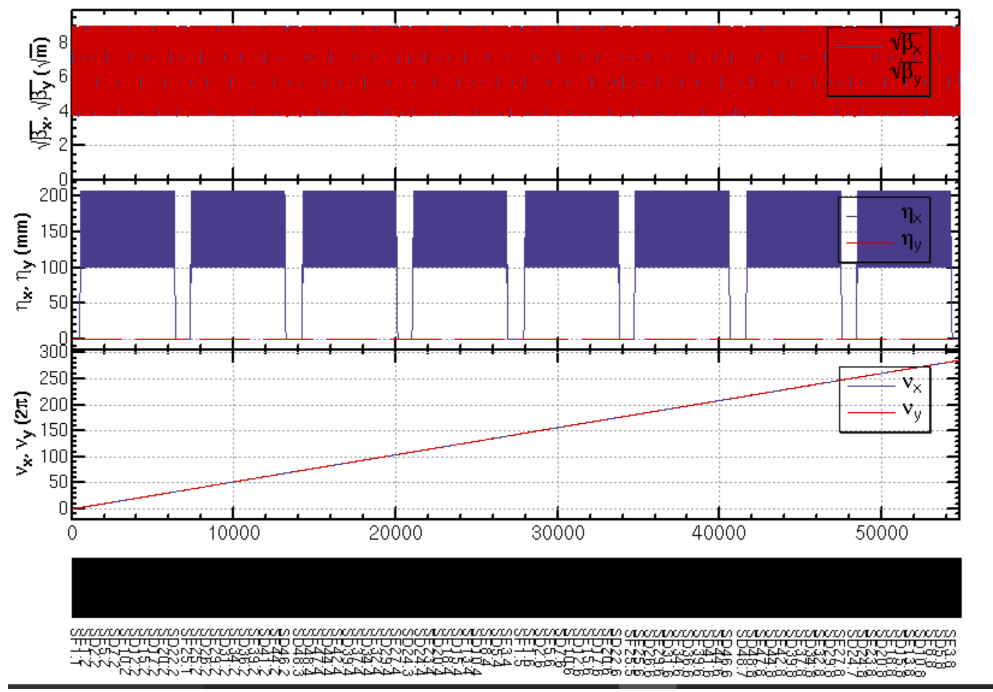
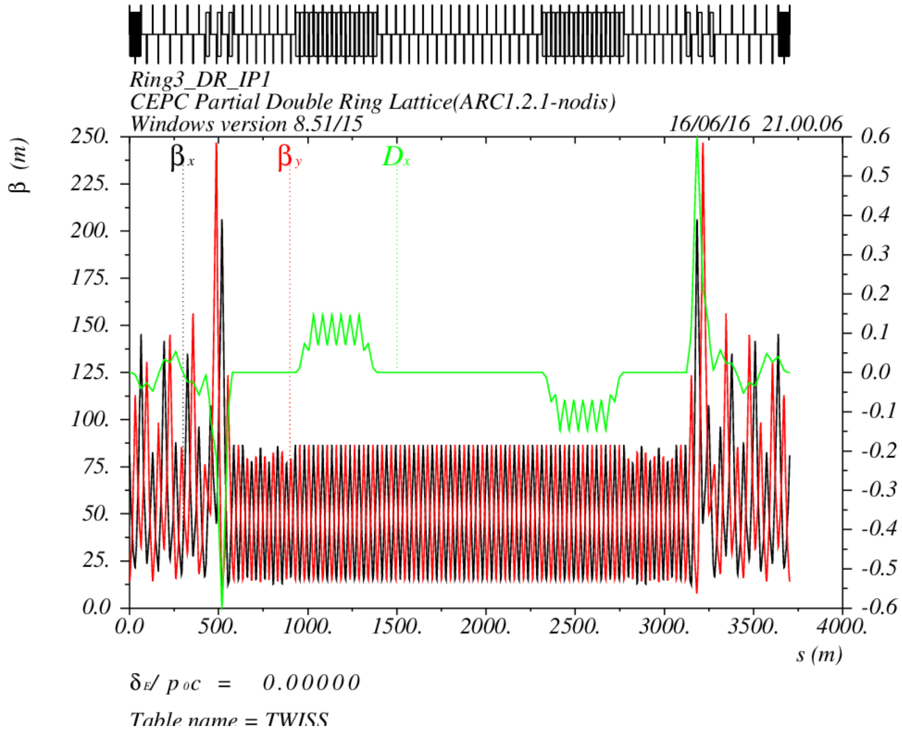
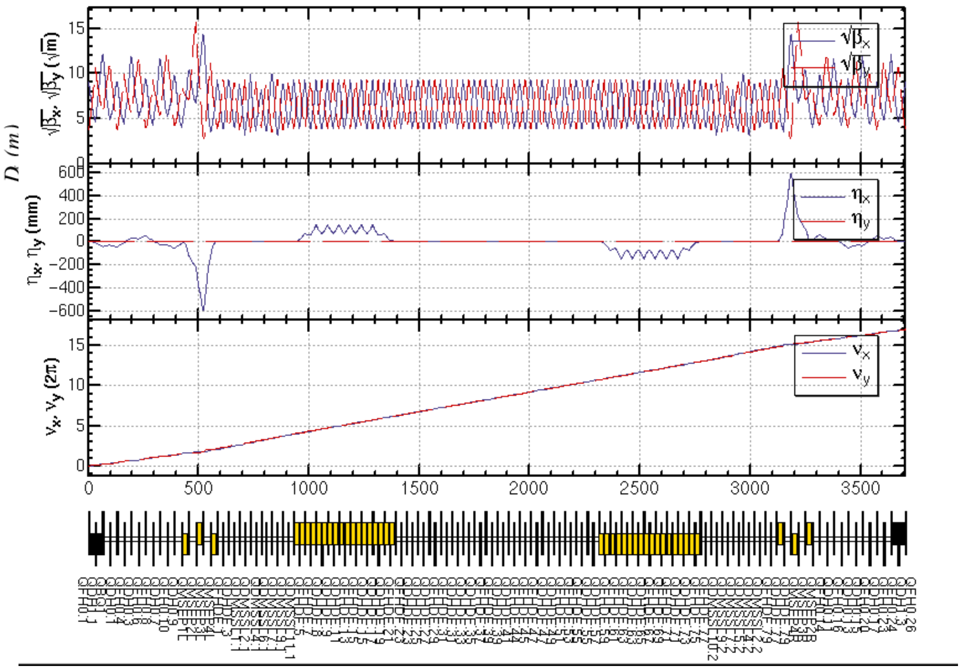
CEPC ARC

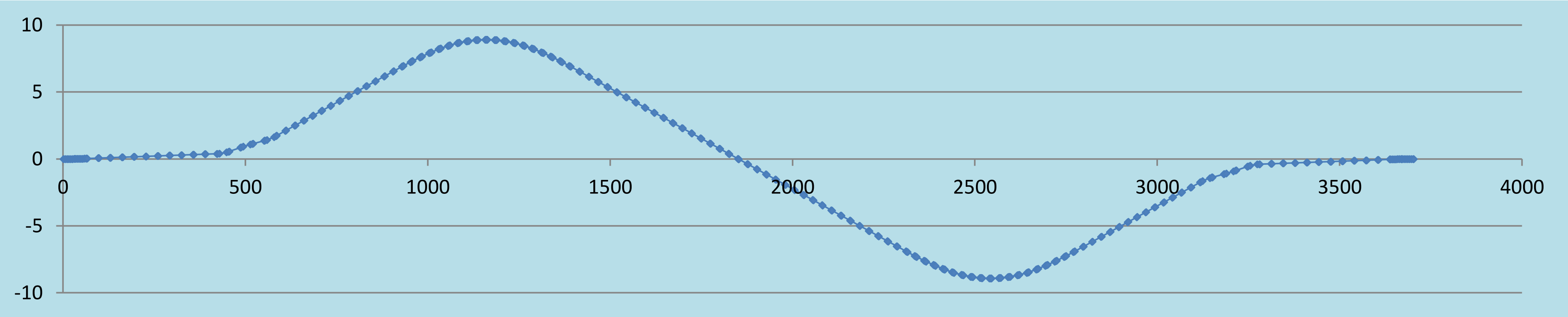




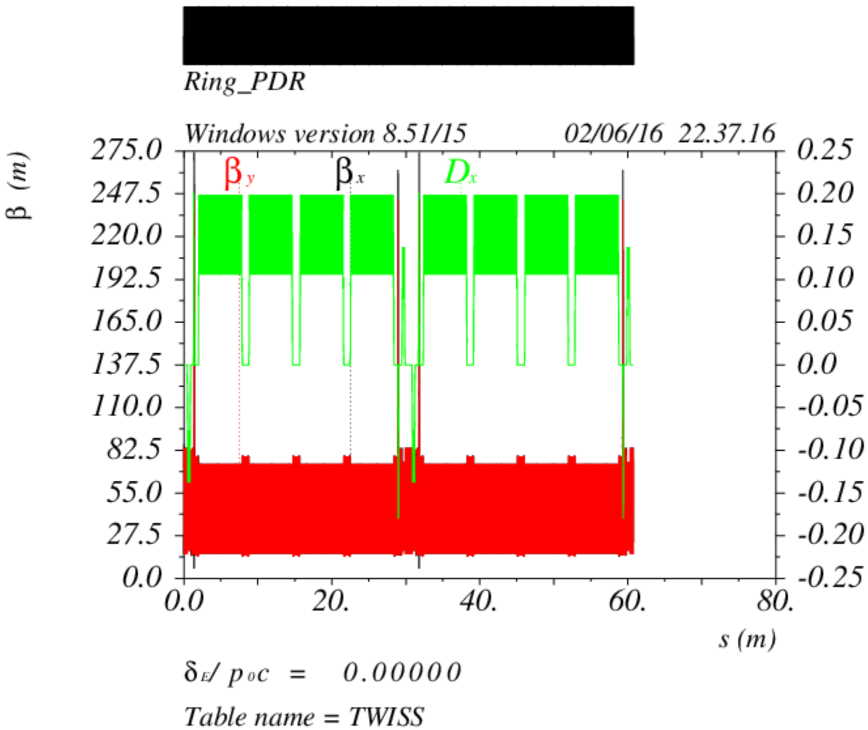
CEPC PDR1.0.3 noFFS

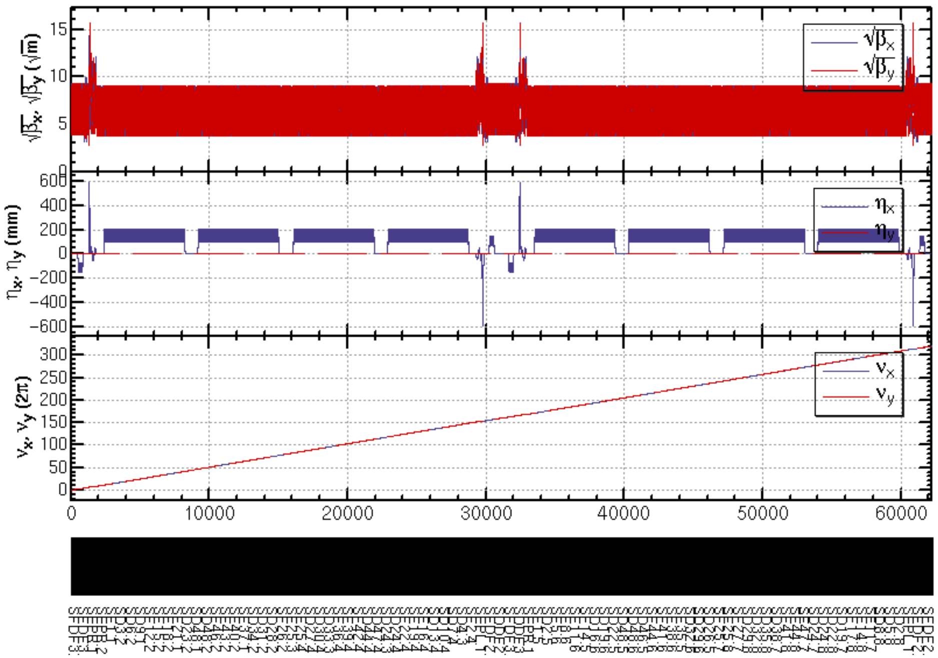




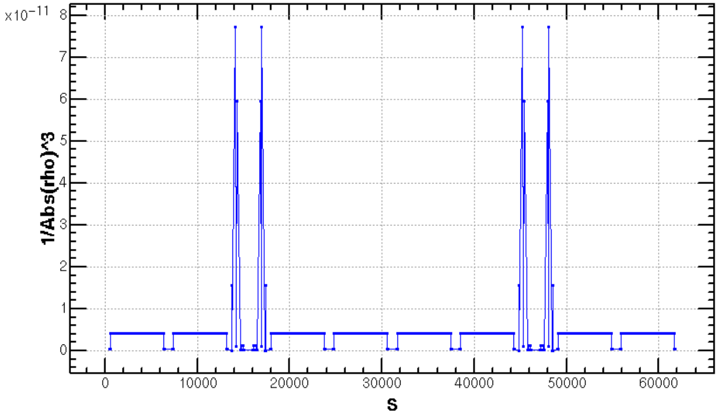


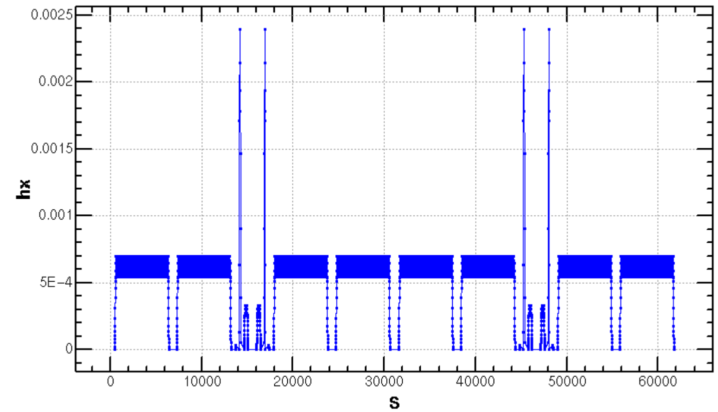
CEPC ARC+PDR

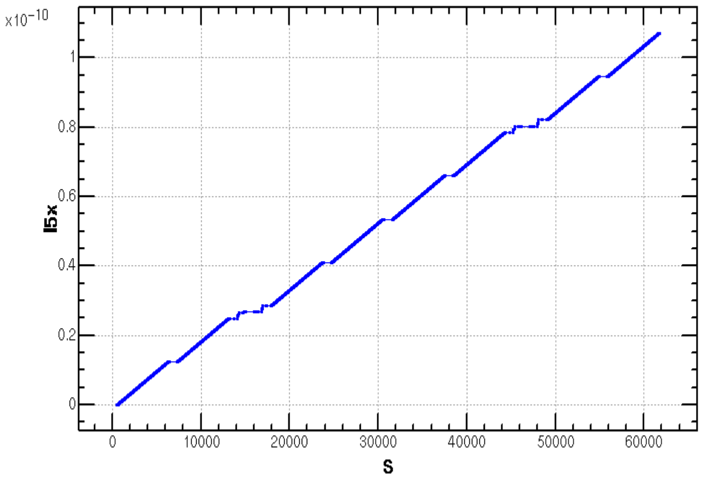

Ring_PDR
Windows version 8.51/15
02/06/16 22.37.16
β (m)
D (m)
β_y
β_x
D_x
s (m)
δ_E/p_0c = 0.00000
Table name = TWISS

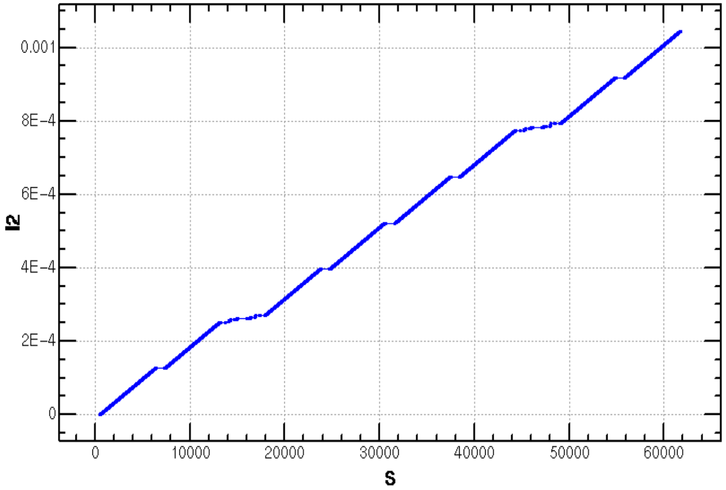

$\sqrt{\beta_x}, \sqrt{\beta_y}$ ($\sqrt{m}$)
η_x, η_y (mm)
ν_x, ν_y (2π)

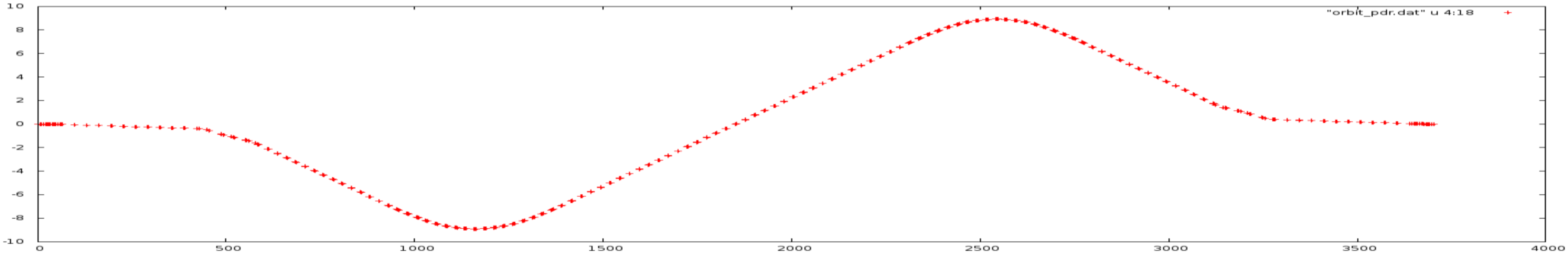
Emittance Increase (2.06nm->2.1668nm)











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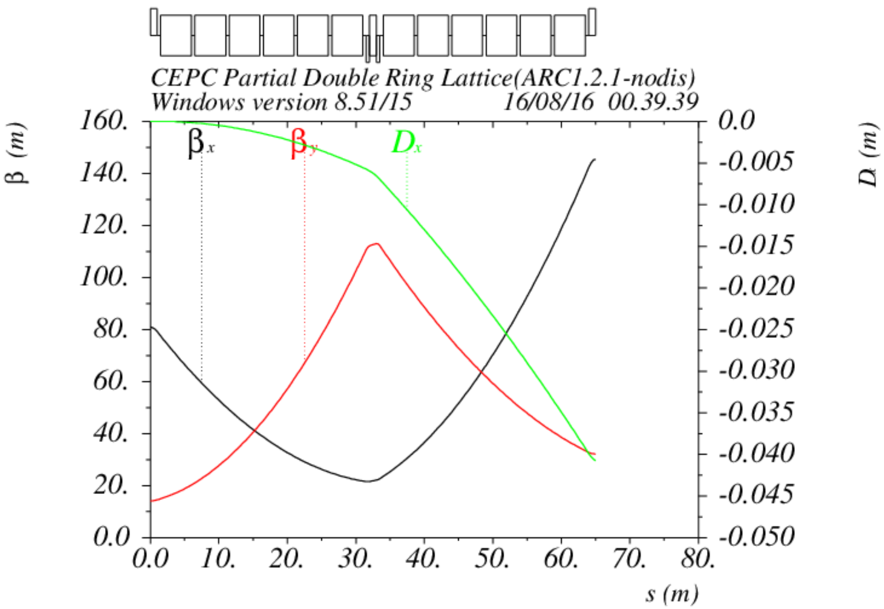
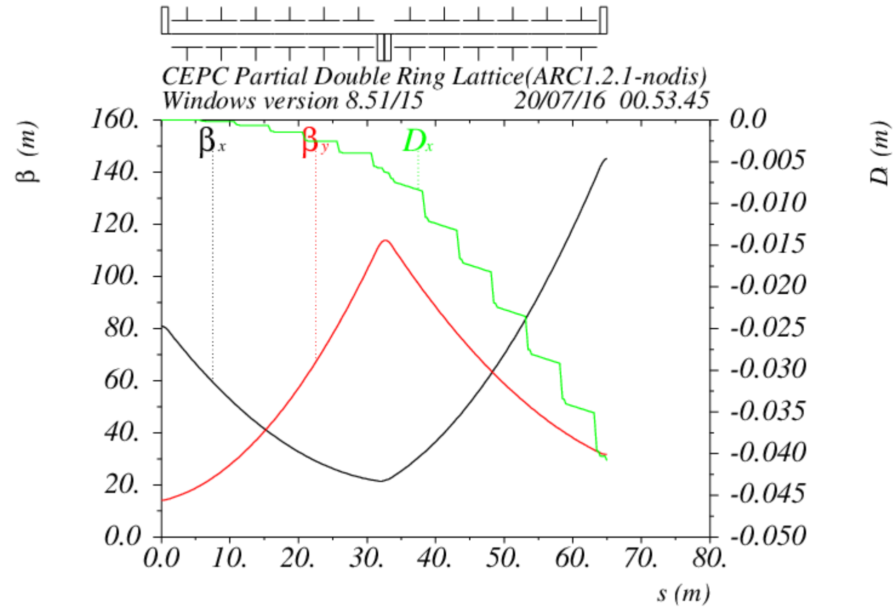
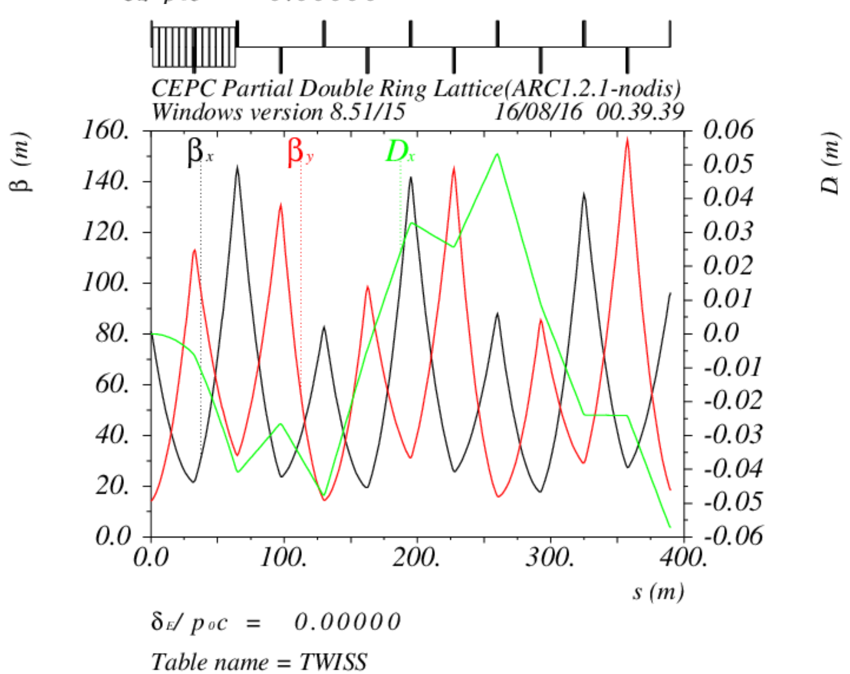
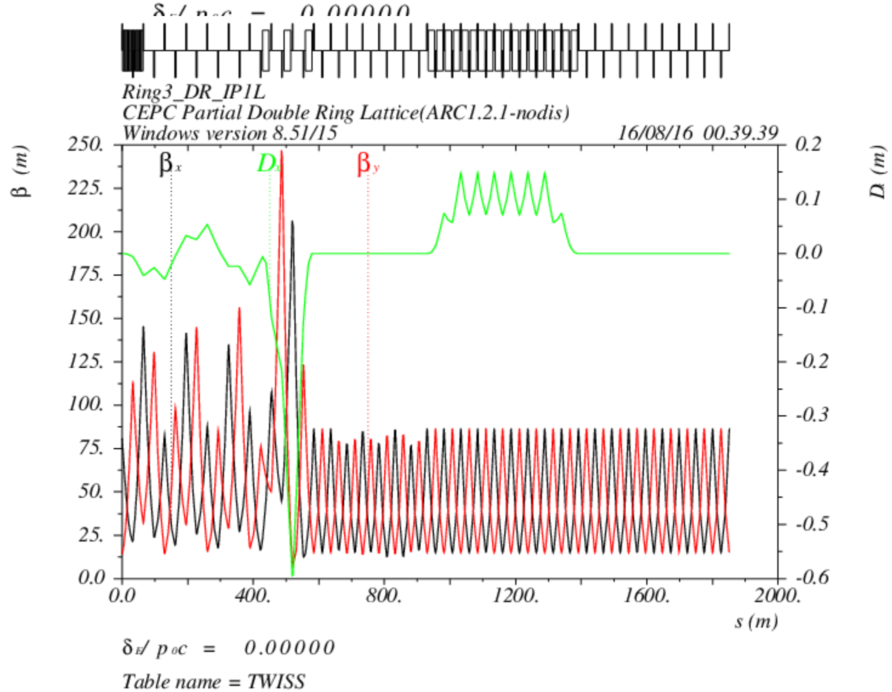








Electrostatic Separator in LEP

Separator length	4.5 m
Inner diameter of separator tank	540 mm
Electrode length	4.0 m
Electrode width	260 mm
Nominal gap	110 mm
Maximum operating field strength	20 kV/cm
Maximum operating voltage	± 110 kV
Max. deflection per separator at 55 GeV	145 μrad
Conditioning voltage on the test bench	± 200 kV
Conditioning voltage after installation	± 160 kV
Maximum voltage for vernier adjustment	± 35 kV
Range of vernier adjustment at 55 GeV	76 μm
Horizontal good field region (1% limit)	± 80 mm
Maximum tilt per electrode	± 5 mrad
Pumping speed of sputter ion pumps	800 l/s
Pumping speed of sublimation pumps	1300 l/s
Nominal vacuum pressure in the low-beta insertions	$2.7 \cdot 10^{-8}$ Pa
Number of separators per collision point	4
Total number of separators	32
Total number of high voltage circuits	32

L=4.5m

$L_{electrode}$=4.0m

E_{field}=2MV/m

E=55GeV

Angle=145urad

E=120GeV

Angle=66urad

Defocusing Quadrupole

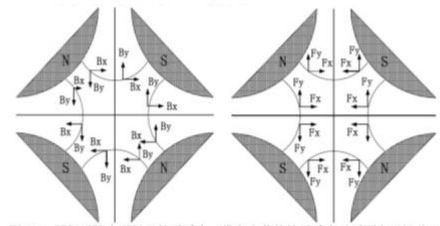
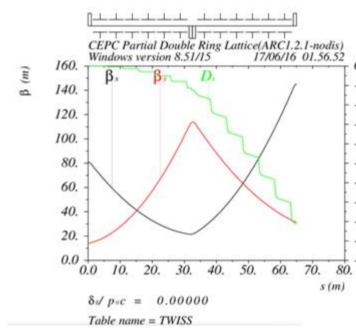
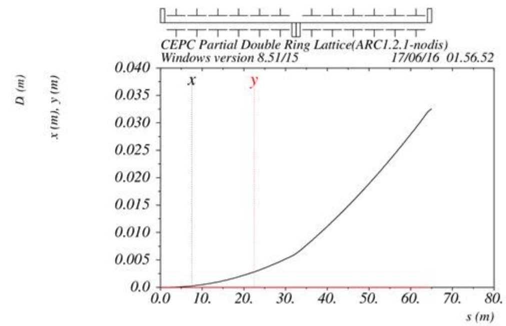


图 2.2 四极磁铁中磁场及粒子受力（带负电荷的粒子垂直于纸面向里运动）

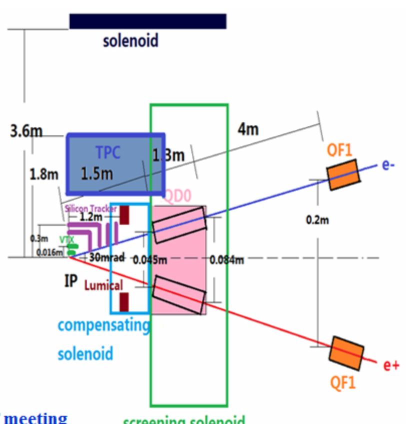




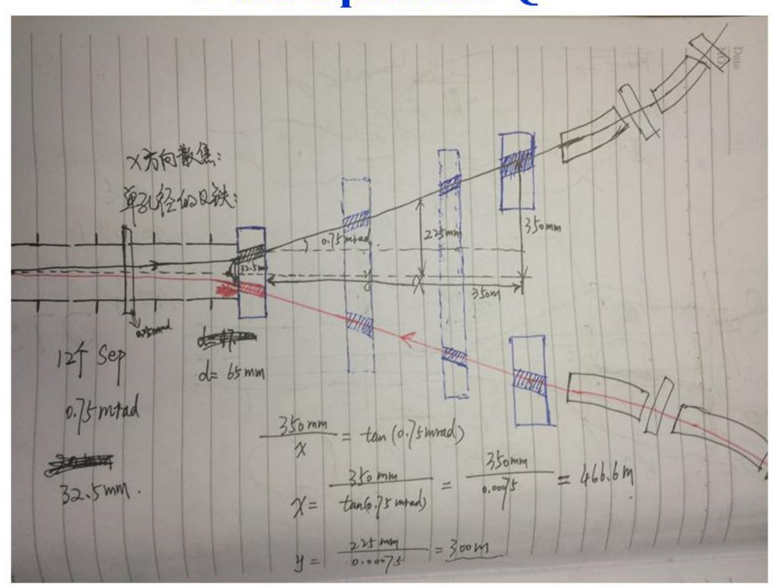
Design Progress of QD0 in partial double ring

❖ Compact high gradient QD0 quadrupole magnets are needed in interaction region of the CEPC partial double ring.

Name	Magnetic length (m)	Field gradient (T/m)	Coil inner radius (mm)
QD0	1.3	200	12.5



Dual Aperture Q



According to CEPC Pre-CDR Magnet Parameter

Dipole magnets	
Quantity	1984
Maximum field strength(T)	0.07
Magnetic gap (mm)	80
Bending angle (mrad)	3.17
Magnetic Length (m)	18
Bending radius (m)	6094
Good field region (mm)	100
Core cross section (W*H) (mm)	450*400

CEPC MQ	
Quantity	2304
Bore diameter (mm)	100
Field Gradient (T/m)	10
Magnetic Length (m)	2.0
Core width and height (mm)	700*700
Core length (mm)	1960

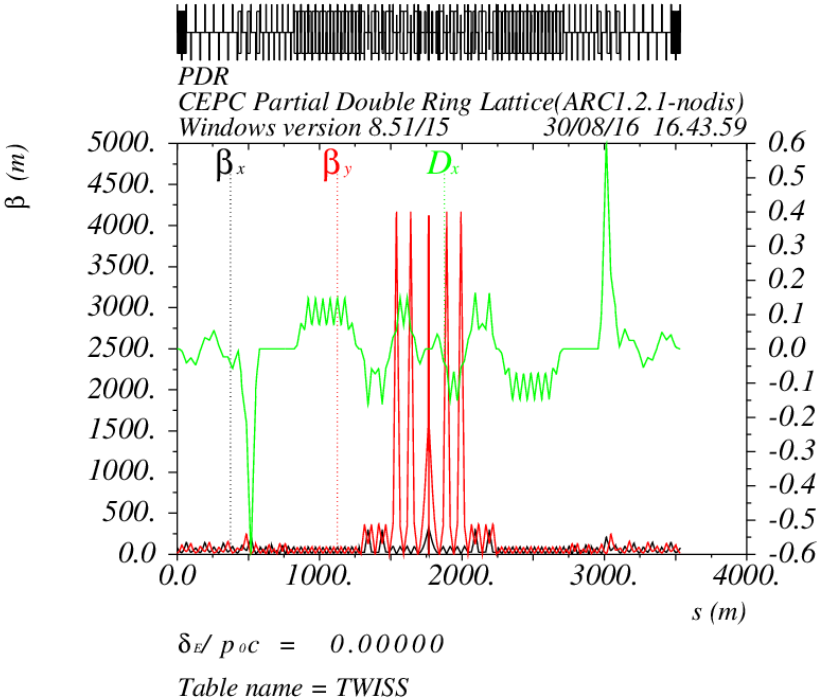
Super Conducting Q in CEPC IR	QF	QD
Field Gradient (T/m)	304	309
Magnetic Length (m)	1.25	0.72
Peak field in coil (T)	7.2	7.1
Coil inner diameter (mm)	40	40
Coil out diameter (mm)	74	74
Cryostat diameter (mm)	400	400
Coil mechanical length (mm)	1500	950

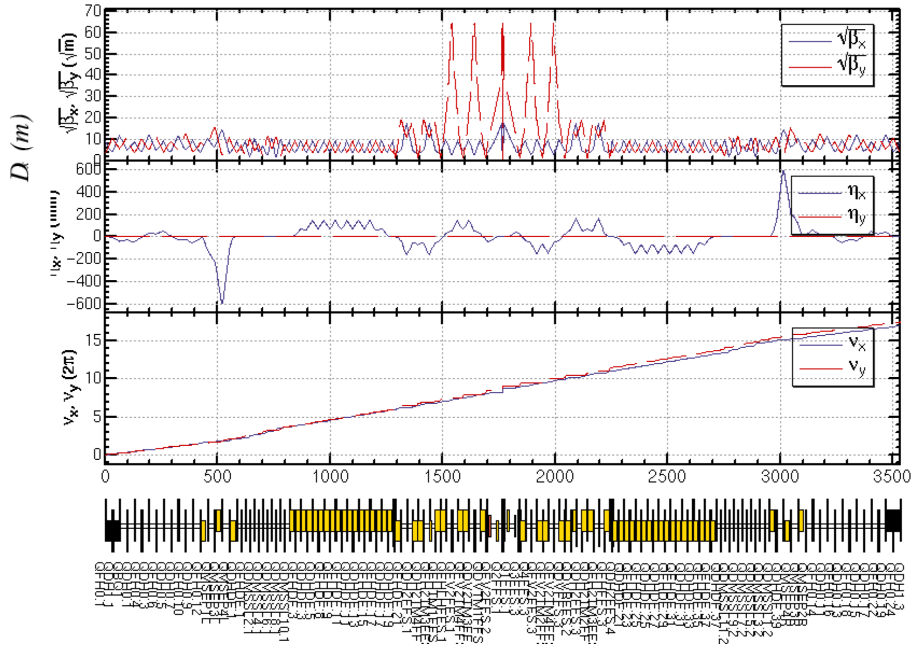
CEPC MS	SD	SF
Quantity	992	992
Aperture diameter (mm)	120	120
Good field region (mm)	100	100
Strength of sextupole field (T/m^2)	180	180
Magnetic Length (m)	700	400
Core width and height (mm)	520	520
Length of iron core (mm)	670	370

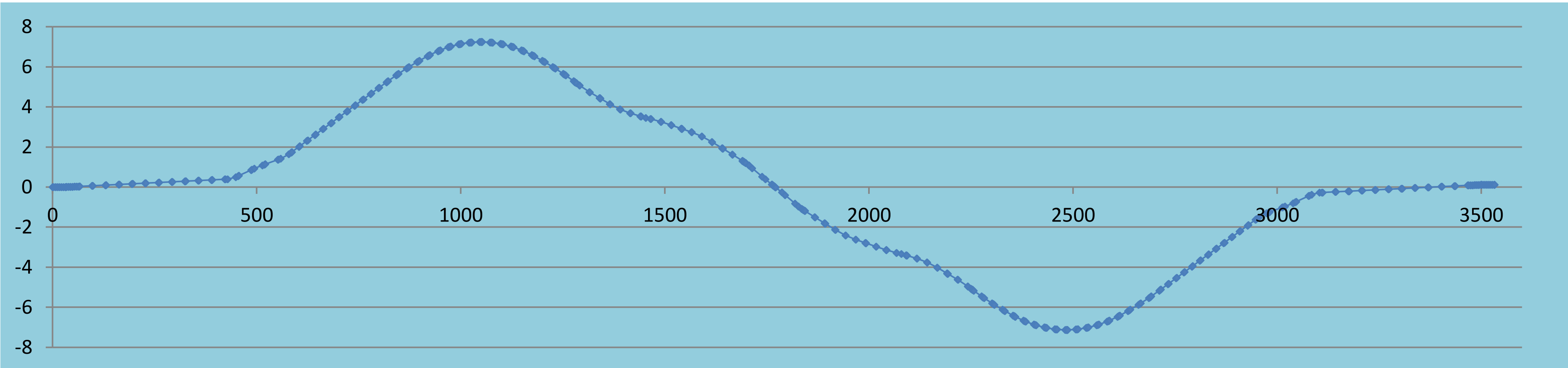
Dipole Strength PDR1.0.3 without FFS

	Angle(mrad)	L(m)	Rho(m)	Brho(E0/c)(T/m)	B(T)	Ek(KeV)	KeV/m
B0	3.205	19.6	6115.44	400	0.06541	626.349	31.956
BSepL	-0.0625	4.5	-72000	400	-0.00556	53.2	11.822
BMatch1L	-8.344	19.6	-2348.99	400	-0.1702	1630.66	83.1967
BMatch2L	1.997	19.6	9814.72	400	0.0407	390.271	19.9118
BMatch3L	-7.653	19.6	-2561.09	400	-0.1562	1495.61	76.3069
B2	2.1428	19.6	9146.91	400	0.04373	418.764	21.3655
B3	-2.1428	19.6	-9146.91	400	-0.04373	418.764	21.3655
BMatch3R	7.653	19.6	2561.09	400	0.1562	1495.61	76.3069
BMatch2R	-1.997	19.6	-9814.72	400	-0.0407	390.271	19.9118
BMatch1R	8.344	19.6	2348.99	400	0.1702	1630.66	83.1967
BSepR	0.0625	4.5	72000	400	0.00556	53.2	11.822

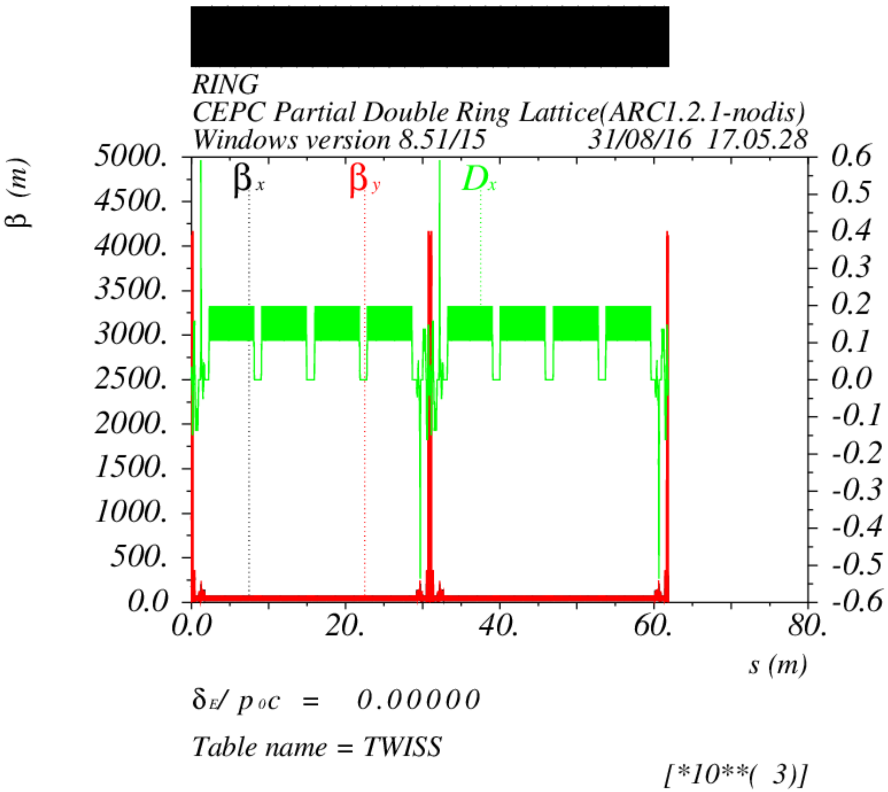
CEPC PDR1.0.3 with FFS (Yiwei20160817)

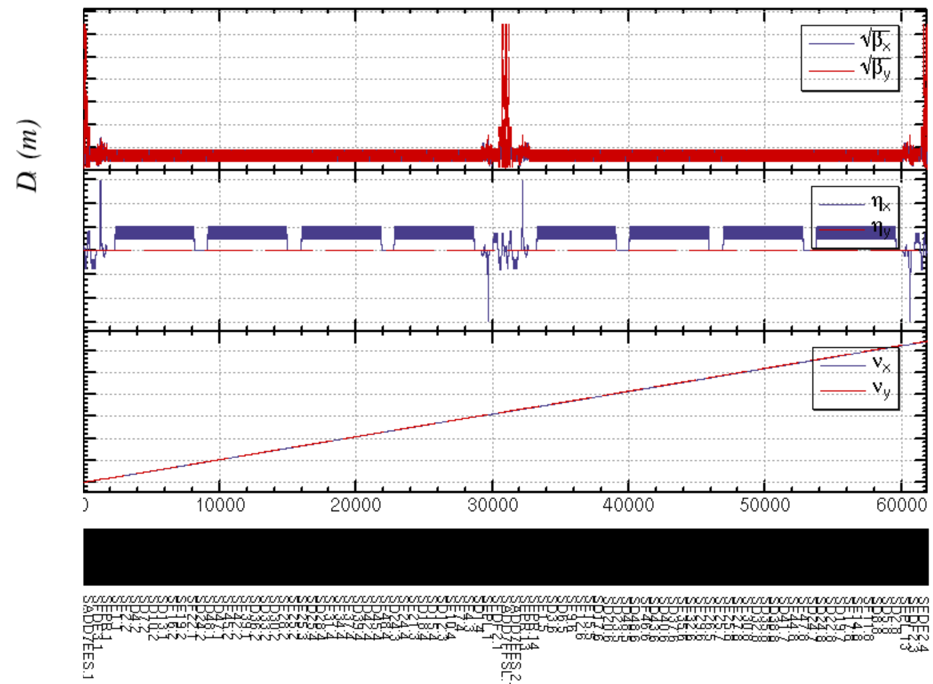




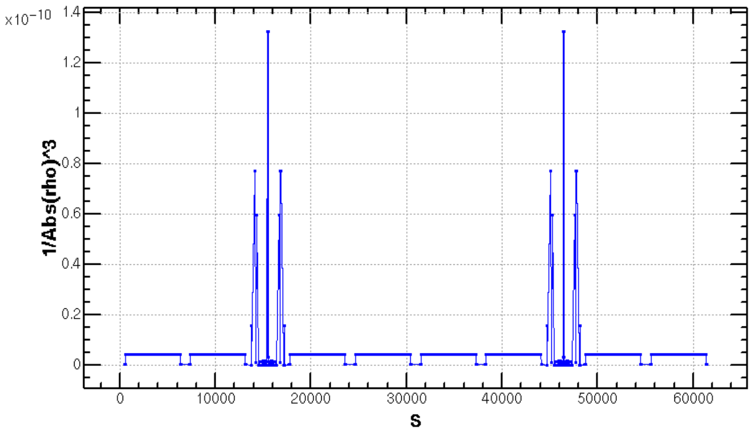


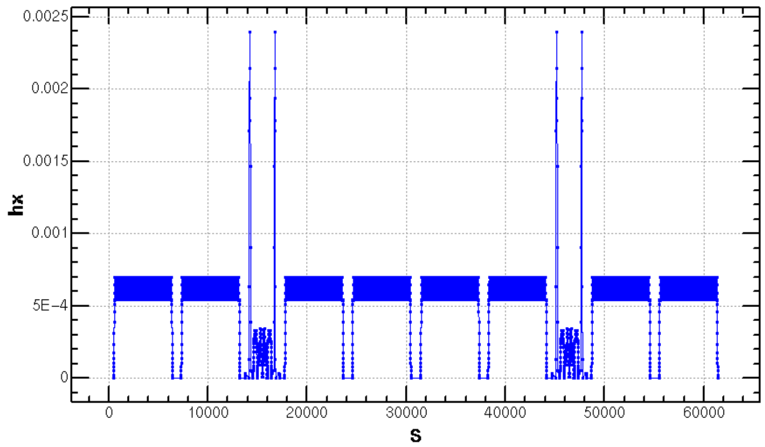
CEPC ARC+PDR_FFS

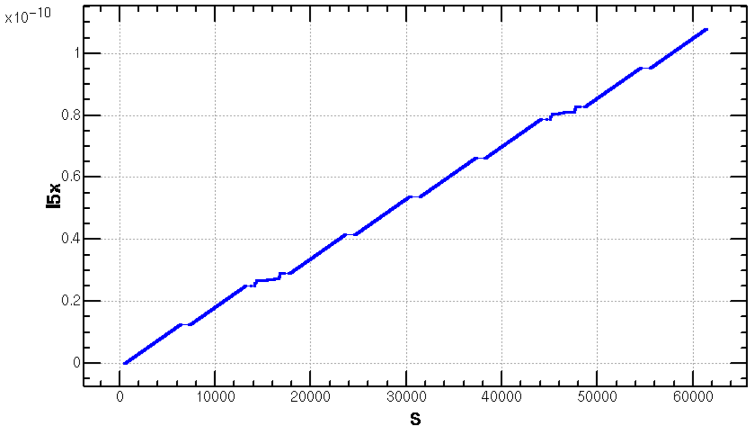


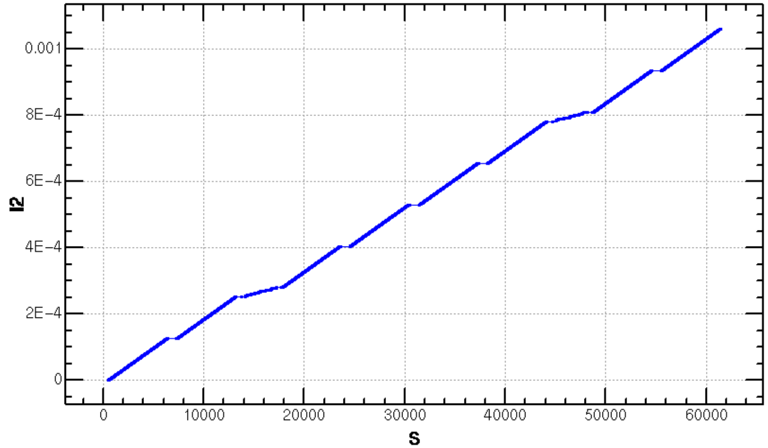


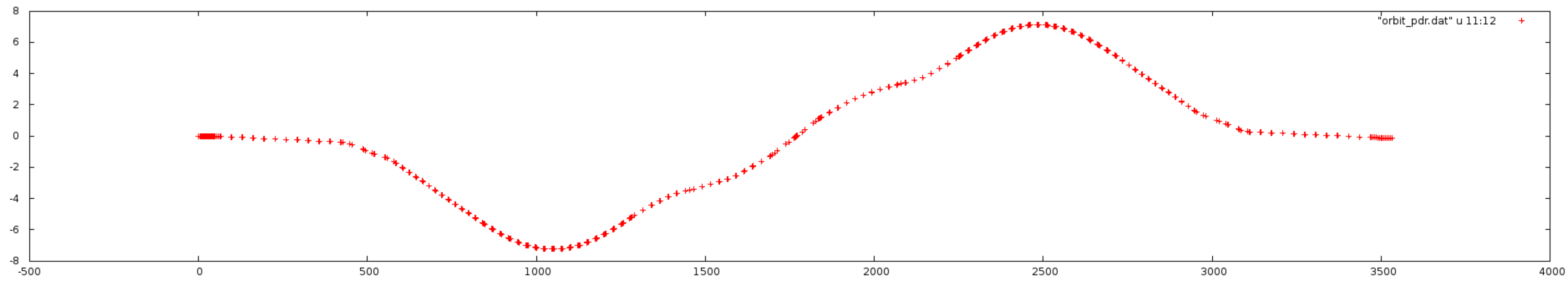
Emittance Increase (2.06nm->2.147368nm)











Outline

3. CEPC PDR DA Study (NSGAII & DA Optimization)

NSGA-II & DA Optimization

'npop': 500,
'ngen': 100,
'nobj': 30,
'nvar': 12,

200CPU
T1=40min
T2=70h

cepc_ndr_0099.txt

Variable

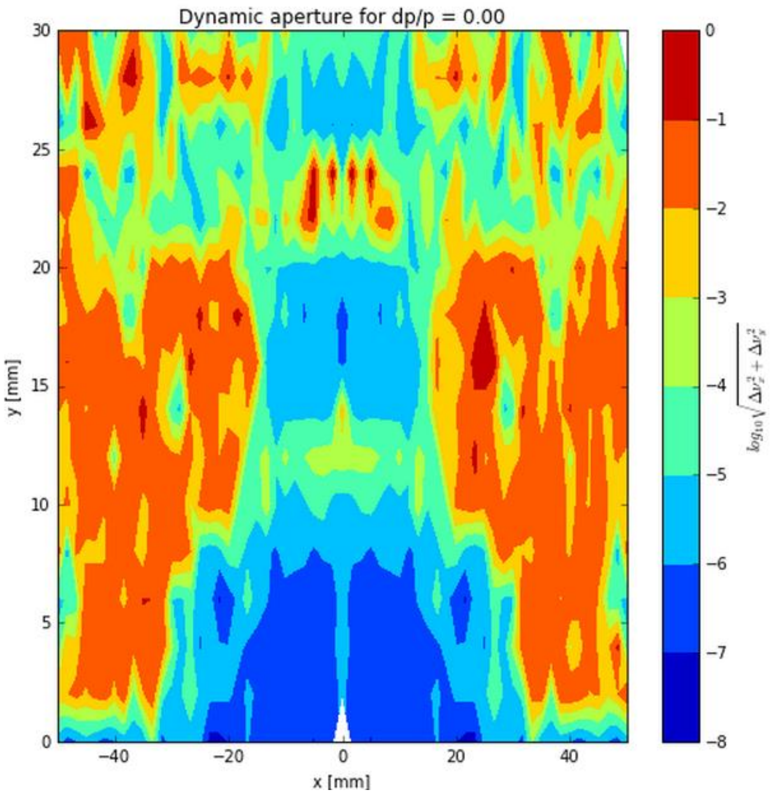
SF1.K2
SF2.K2
SF3.K2
SF4.K2
SF5.K2
SF6.K2

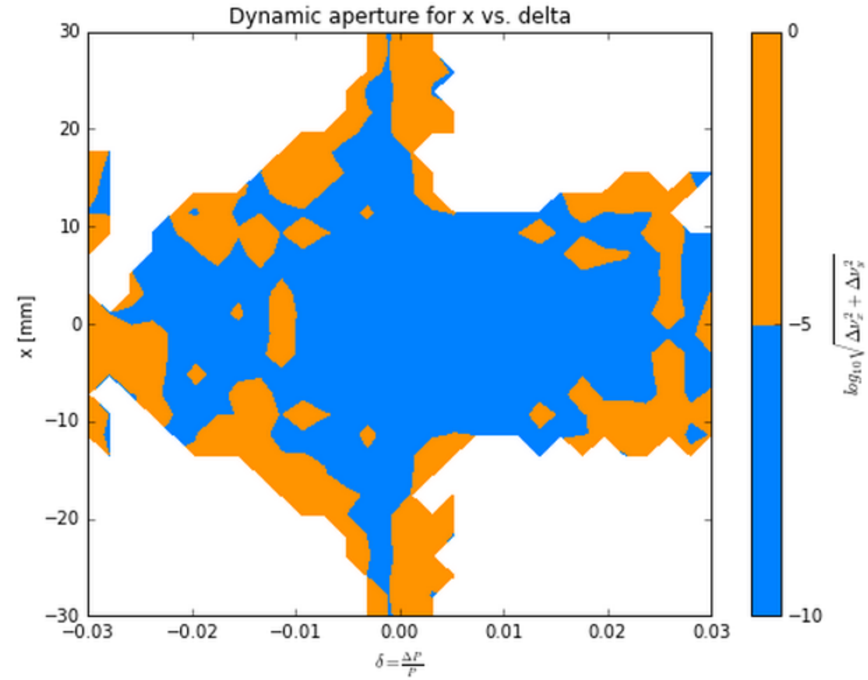
SD1.K2
SD2.K2
SD3.K2
SD4.K2
SD5.K2
SD6.K2

Objective

```
p[nvar+0] = abs(nsls2.ring.h1['h30000'])
p[nvar+1] = abs(nsls2.ring.h1['h21000'])
p[nvar+2] = abs(nsls2.ring.h1['h10110'])
p[nvar+3] = abs(nsls2.ring.h1['h10200'])
p[nvar+4] = abs(nsls2.ring.h1['h10020'])
p[nvar+5] = abs(nsls2.ring.h1['h20001'])
p[nvar+6] = abs(nsls2.ring.h1['h10002'])
p[nvar+7] = abs(nsls2.ring.h1['h00201'])

p[nvar+8] = abs(nsls2.ring.h2['h00310'])
p[nvar+9] = abs(nsls2.ring.h2['h11200'])
p[nvar+10] = abs(nsls2.ring.h2['h10111'])
p[nvar+11] = abs(nsls2.ring.h2['h00112'])
p[nvar+12] = abs(nsls2.ring.h2['h30001'])
p[nvar+13] = abs(nsls2.ring.h2['h11110'])
p[nvar+14] = abs(nsls2.ring.h2['h22000'])
p[nvar+15] = abs(nsls2.ring.h2['h00004'])
p[nvar+16] = abs(nsls2.ring.h2['h00400'])
p[nvar+17] = abs(nsls2.ring.h2['h10201'])
p[nvar+18] = abs(nsls2.ring.h2['h20020'])
p[nvar+19] = abs(nsls2.ring.h2['h10021'])
p[nvar+20] = abs(nsls2.ring.h2['h10003'])
p[nvar+21] = abs(nsls2.ring.h2['h21001'])
p[nvar+22] = abs(nsls2.ring.h2['h31000'])
p[nvar+23] = abs(nsls2.ring.h2['h40000'])
p[nvar+24] = abs(nsls2.ring.h2['h20002'])
p[nvar+25] = abs(nsls2.ring.h2['h00220'])
p[nvar+26] = abs(nsls2.ring.h2['h20200'])
p[nvar+27] = abs(nsls2.ring.h2['h20110'])
p[nvar+28] = abs(nsls2.ring.h2['h11002'])
p[nvar+29] = abs(nsls2.ring.h2['h00202'])
```

Nonlinear Driving Term (ARC)



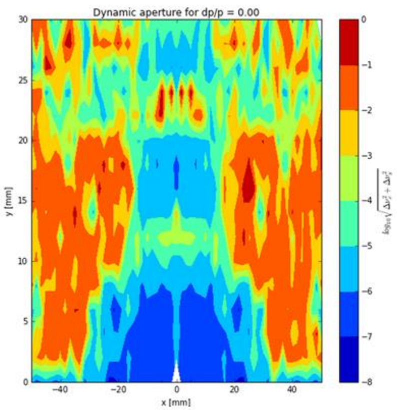


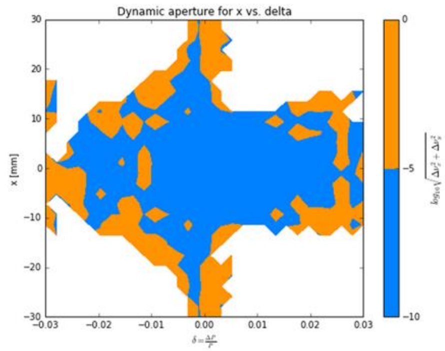
Betx： 80.992367
bety： 14.172123
2nm
Sizmax： 402.47um
Sigmay： 9.22um

X： 60 Sigma
Y： 813 Sigma

2 groups

Nonlinear Driving Term (ARC)



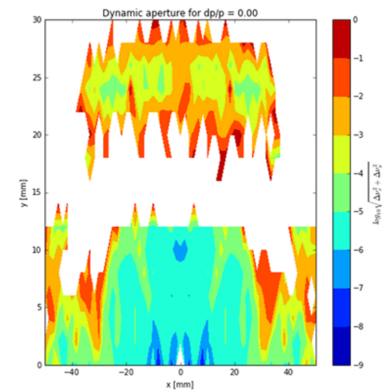


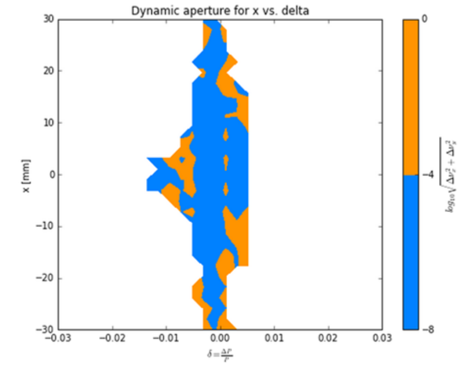
Betx: 80.992367
bety: 14.172123
2nm
Sizmax: 402.47um
Sigmay: 9.22um

X: 60 Sigma
Y: 813 Sigma

2 groups

Nonlinear Driving Term (ARC-20160630)



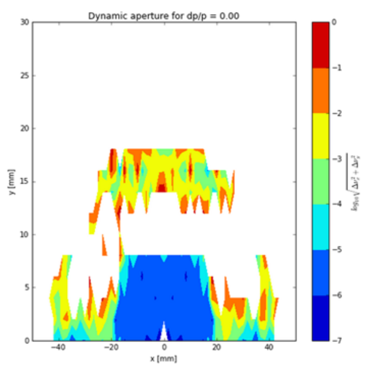


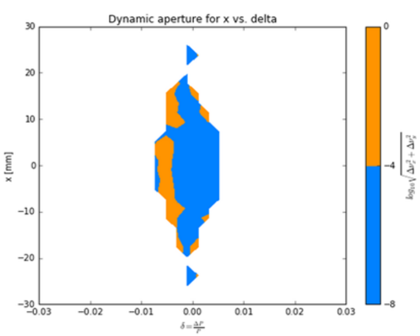
Betx: 80.992367
bety: 14.172123
2nm
Sizmax: 402.47um
Sigmay: 9.22um

X: 60 Sigma
Y: 813 Sigma

96 groups

Nonlinear Driving Term (ARC-20160707)



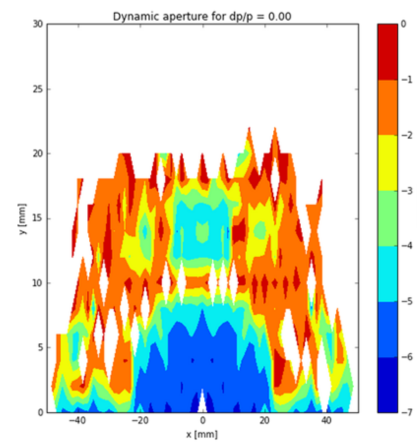


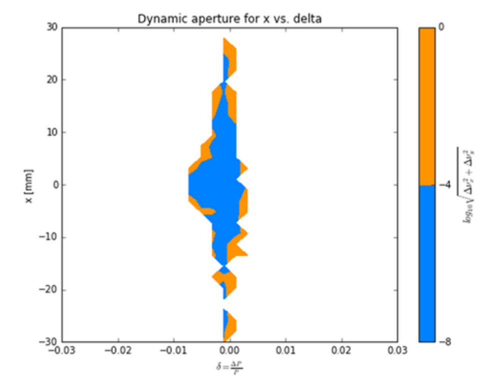
Betx: 80.992367
bety: 14.172123
2nm
Sizmax: 402.47um
Sigmay: 9.22um

X: 60 Sigma
Y: 700 Sigma

96 groups

Nonlinear Driving Term (ARC-20160722)





Betx: 80.992367
bety: 14.172123
2nm
Sizmax: 402.47um
Sigmay: 9.22um

X: 65 Sigma
Y: 813 Sigma

96 groups

Nonlinear Driving Term (ARC)

In [7]:
```
cepc.ring.geth1()
cepc.ring.h1
```

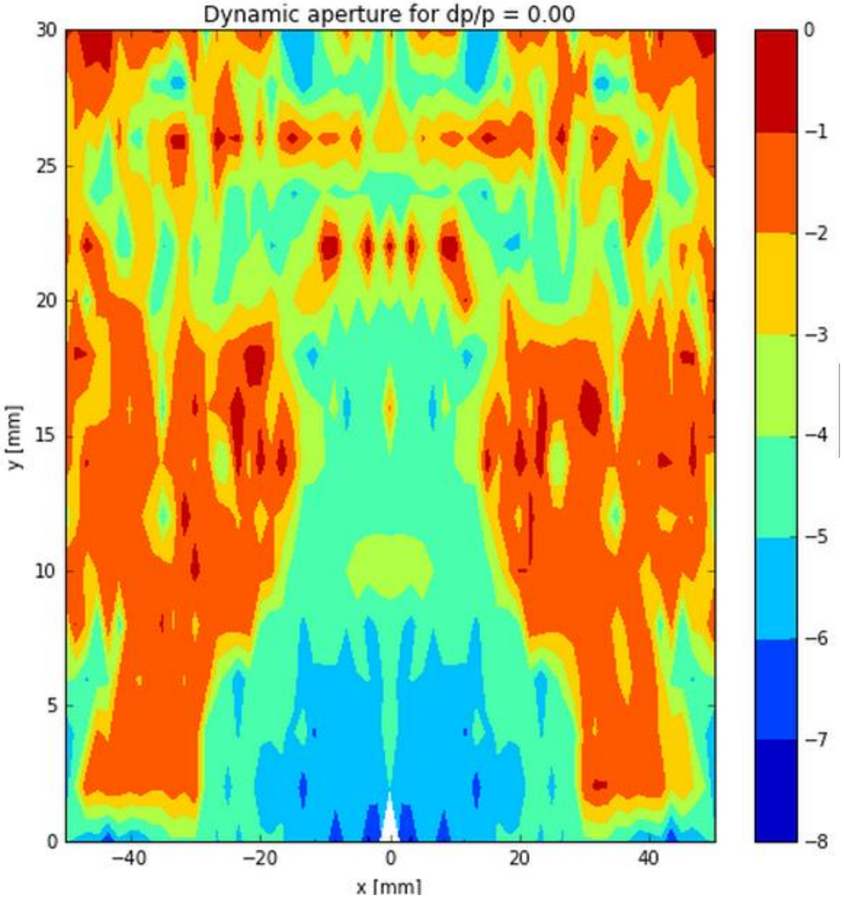
Out[7]:
```
{'h00111': (4.906054441305847+0j), 'h11001': (4.883077561376199+0j)}
```

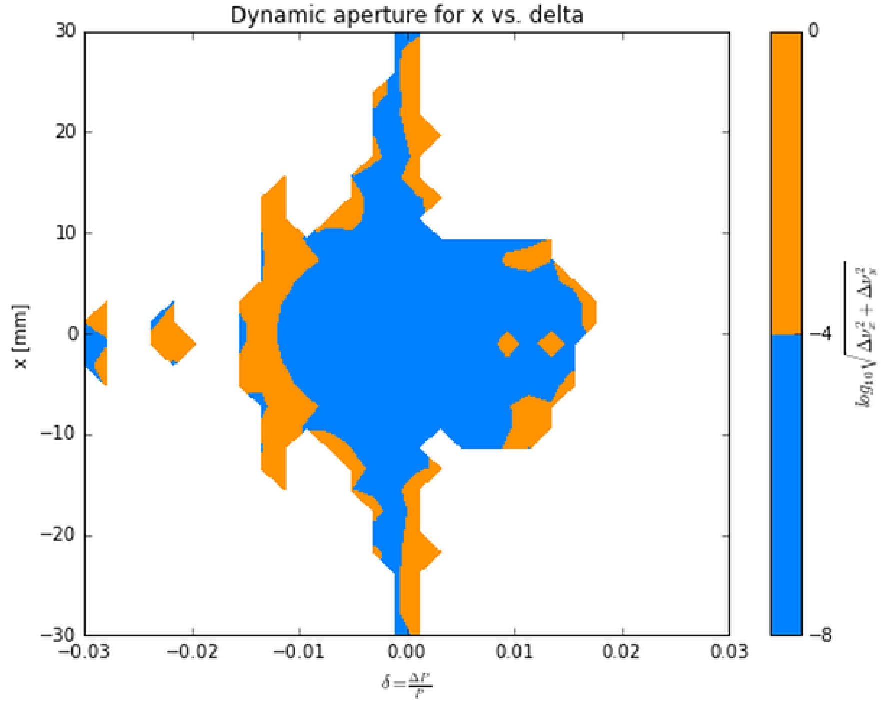
In [8]:
```
cepc.ring.geth2()
cepc.ring.h2
```

Out[8]:
```
{'h00112': (-6713.2390326540426-2.4327666617307564e-12j),
 'h00220': (-6.711700723911401 3e-06+2.4007420051930239e-08j),
 'h11002': (-5459.1975174445843+3.0300657816173526e-12j),
 'h11110': (7.6489916699494385e-06+4.3427621676528361e-07j),
 'h22000': (-8.6121626494394287e-06-9.2768459580838 68e-11j)}
```

Out[7]:
```
---------------------------------------------------------------------------------------------------------------------------------
          s      betax      alfax        mux       etax      etaxp      betay      alfay        muy       etay      etayp
---------------------------------------------------------------------------------------------------------------------------------
  0.000e+00  8.099e+01 -1.141e-14  0.000e+00  2.912e-08 -6.628e-18  1.417e+01 -1.144e-15  0.000e+00 -0.000e+00 -0.000e+00
  5.482e+04  8.099e+01 -1.199e-14  2.861e+02  2.912e-08  3.373e-17  1.417e+01  1.018e-13  2.862e+02 -0.000e+00  0.000e+00

Tune: nux =      286.080, nuy =      286.220

uncorrected chromaticity: chx0 =  -3.643e+02, chy0 =  -3.645e+02

corrected chromaticity:   chx  =   3.444e-01, chy  =   4.578e-01


=* First order driving terms *=
h11001 =     3.791759e+00   +0.000000e+00j
h00111 =     3.466382e+00   +0.000000e+00j

=* Second order driving terms *=
h00112 =     4.271577e+00   -1.784912e-11j
h11110 =    -2.187326e-04   -2.742092e-07j
h00220 =     2.154167e-04   -3.058040e-08j
h11002 =     9.935156e+01   -3.127386e-10j
h22000 =     3.593634e-04   +2.928573e-10j
```

Nonlinear Driving Term (ARC_PDR_20160630)



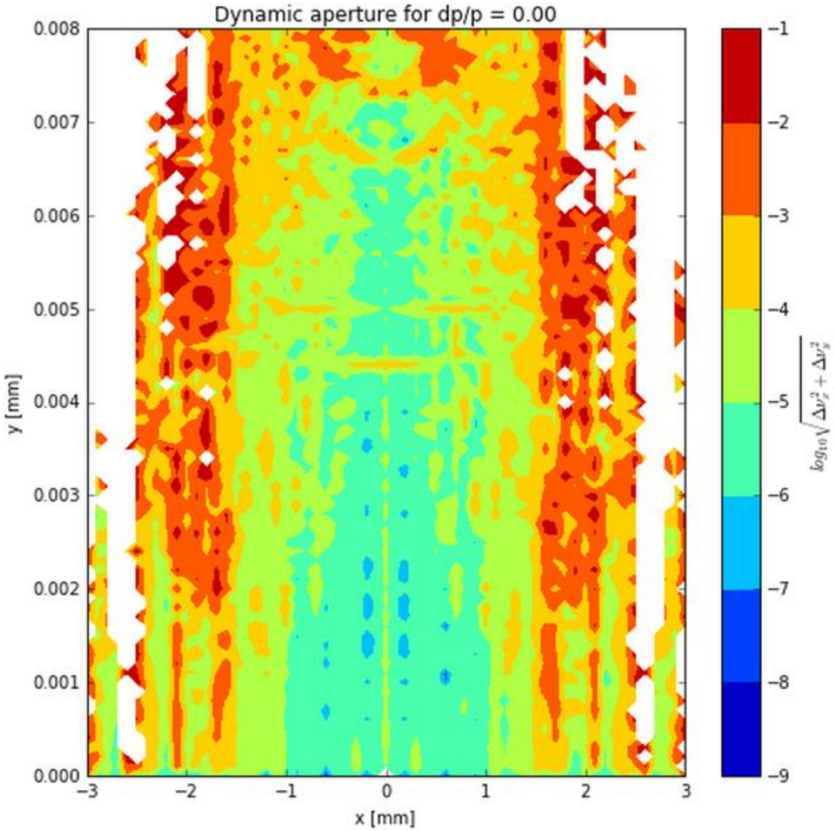


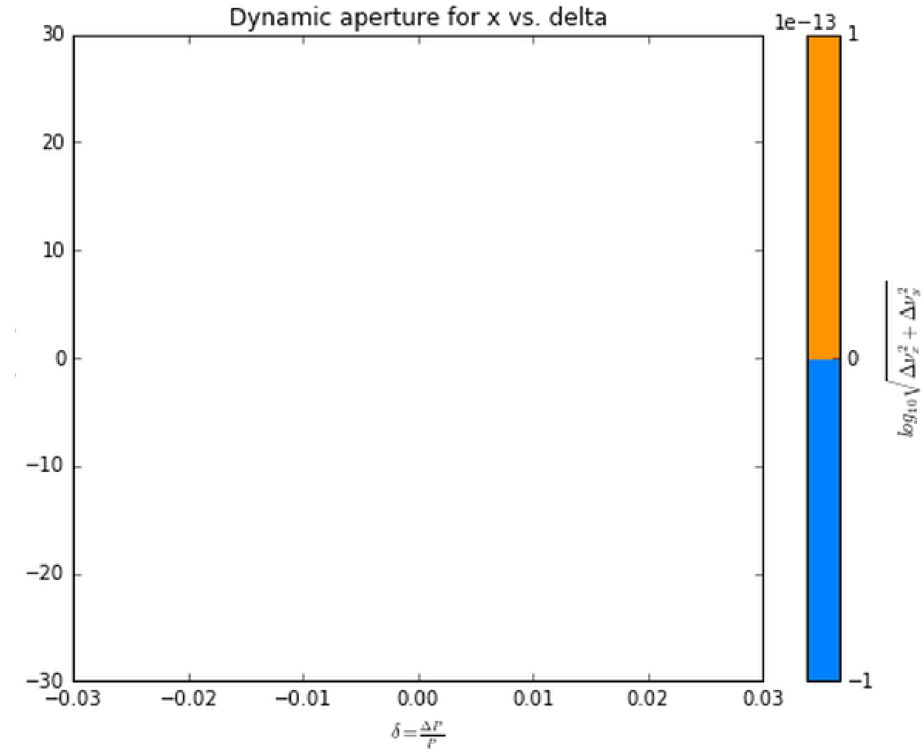
Betx: 80.992367
bety: 14.172123
2nm
Sizmax: 402.47um
Sigmay: 9.22um

X: 45 Sigma
Y: 780 Sigma

2 groups

Nonlinear Driving Term (ARC_PDR_FFS_2016.08.29)





Betx： 0.219915m

bety： 0.001m

2.147368nm

Sizmax： 21.731um

Sigmay： 0.08026um

X： 46 Sigma

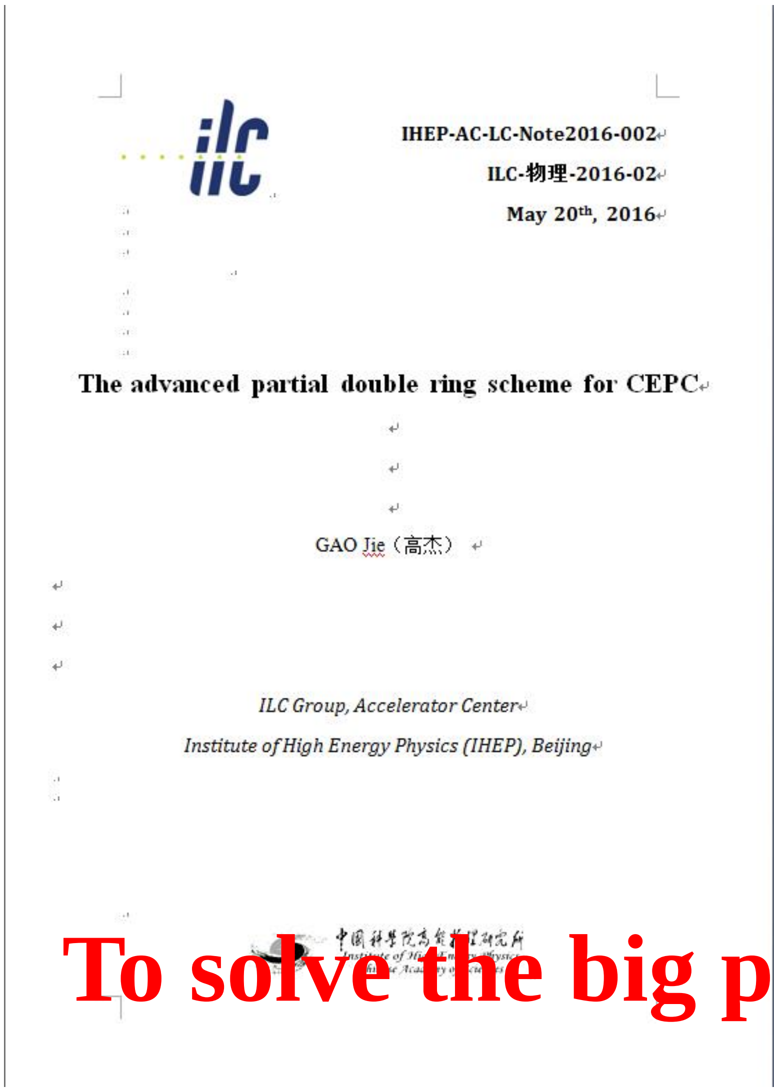
Y： 37 Sigma

2 groups

Outline

4. CEPC APDR Scheme

New idea： Advanced PDR （APDR）



IHEP-AC-LC-Note2016-002

ILC-物理-2016-02

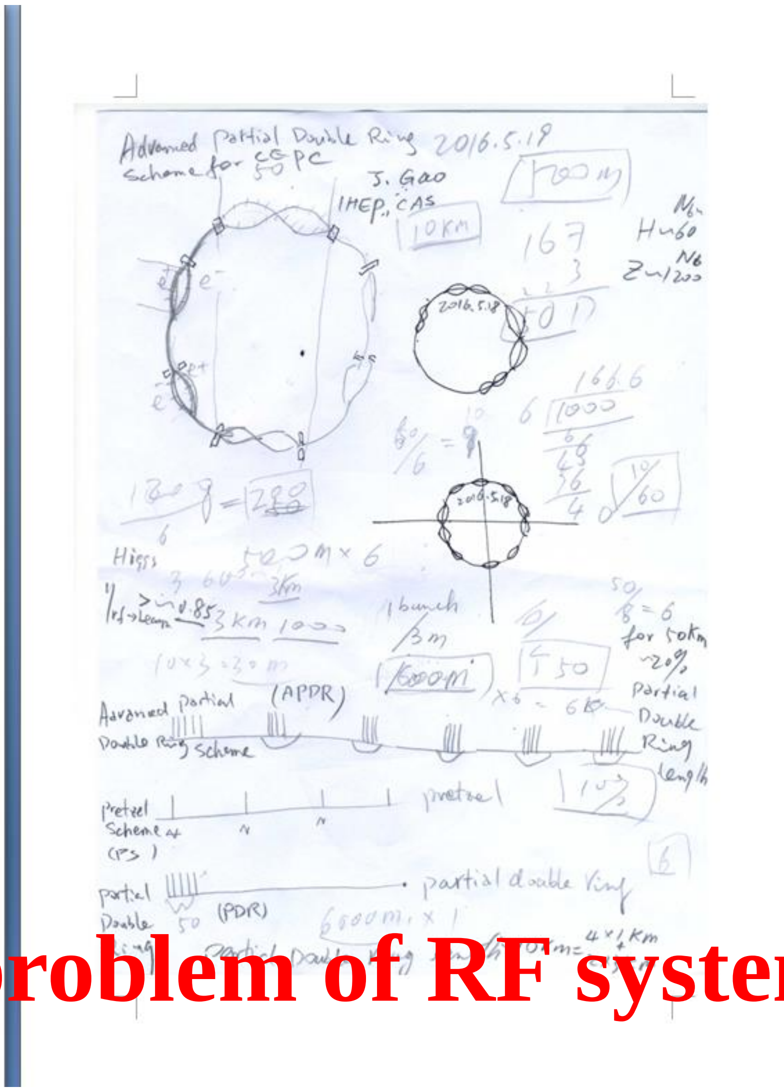
May 20th, 2016

The advanced partial double ring scheme for CEPC

GAO Jie（高杰）

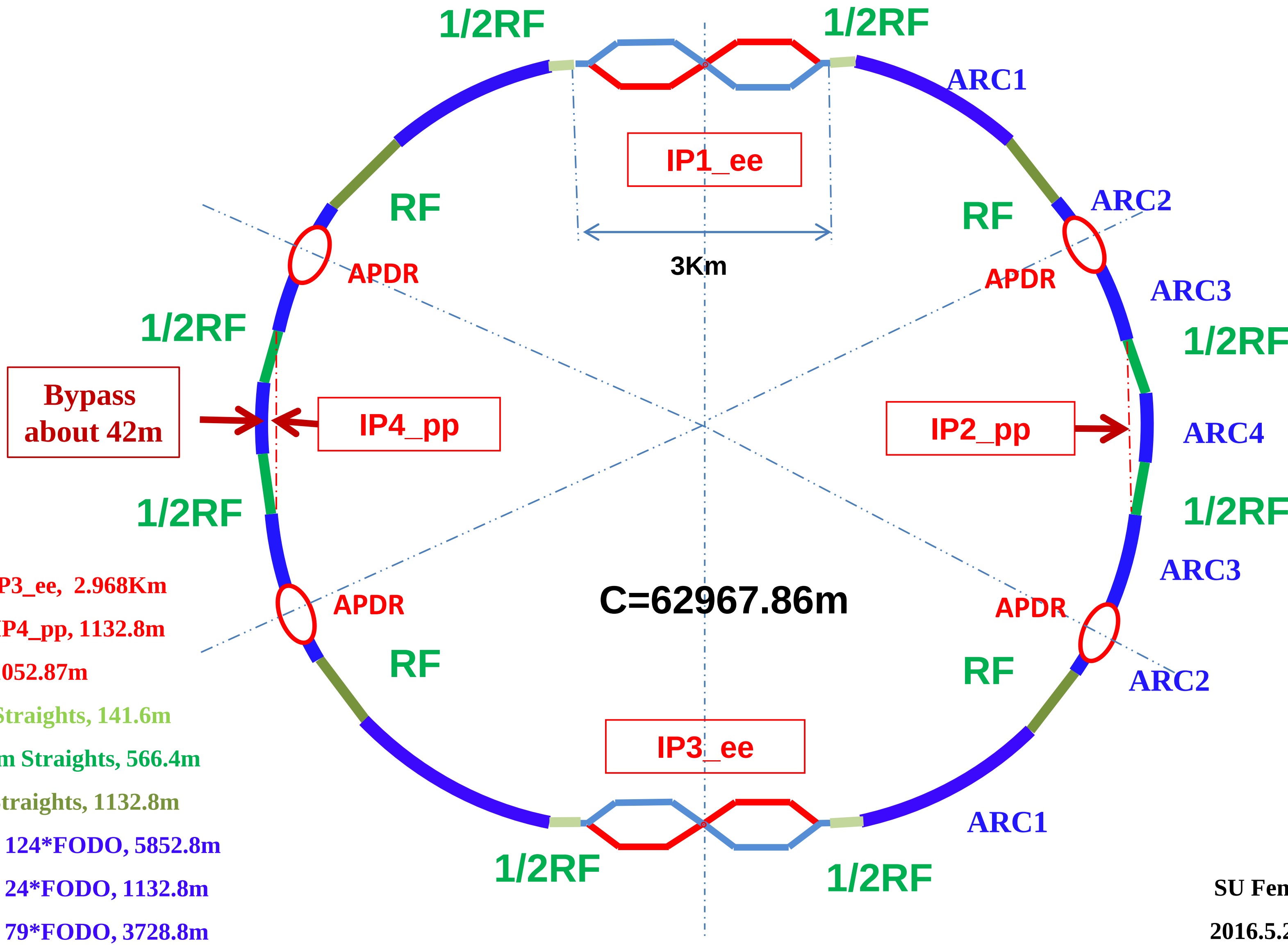
ILC Group, Accelerator Center

Institute of High Energy Physics (IHEP), Beijing



To solve the big problem of RF system

CEPC Advanced Partial Double Ring Option I



IP1_ee/IP3_ee, 2.968Km

IP2_pp/IP4_pp, 1132.8m

APDR, 1052.87m

4 Short Straights, 141.6m

4 Medium Straights, 566.4m

4 Long Straights, 1132.8m

4 ARC1, 124*FODO, 5852.8m

4 ARC2, 24*FODO, 1132.8m

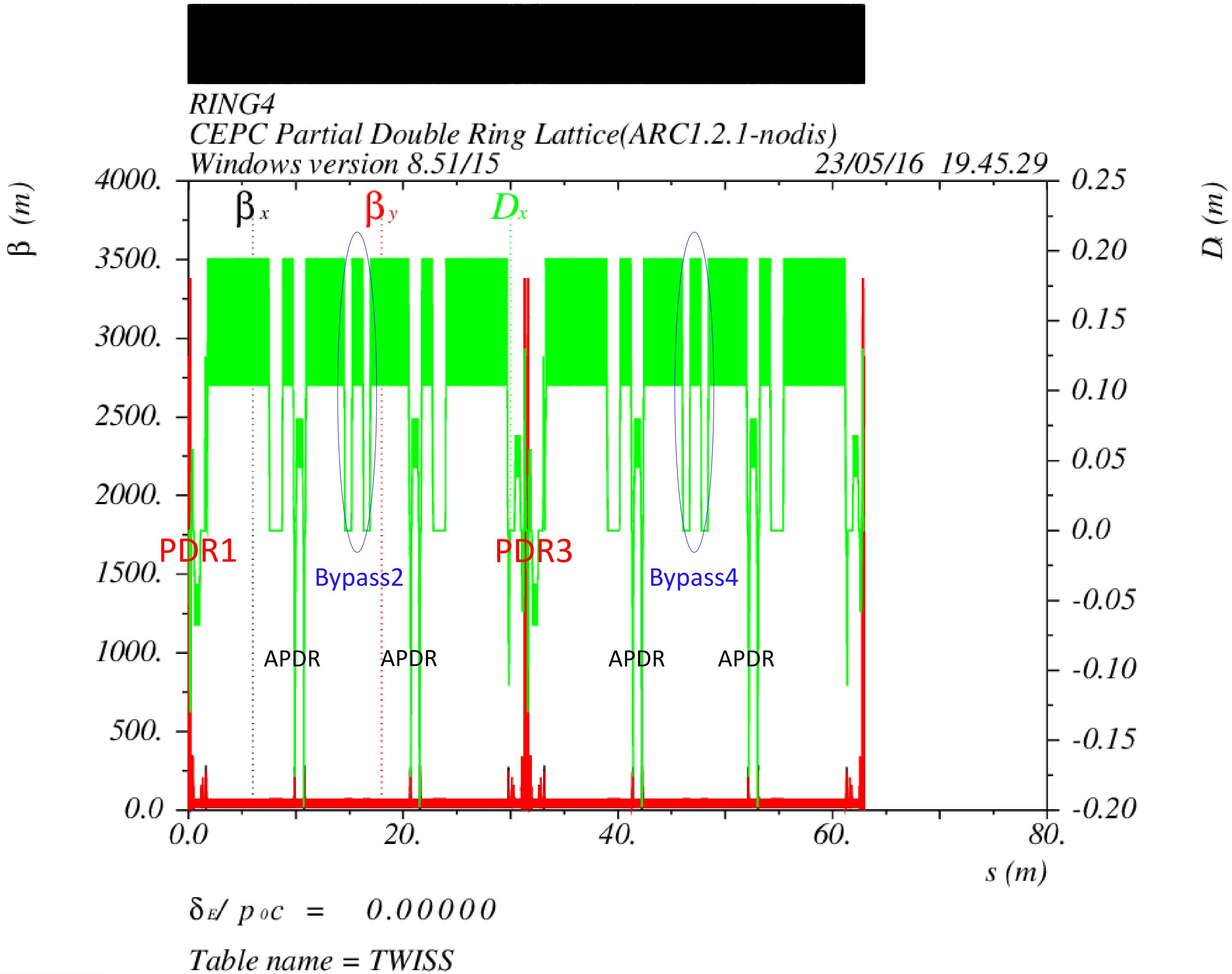
4 ARC3, 79*FODO, 3728.8m

2 ARC4, 24*FODO, 1132.8m

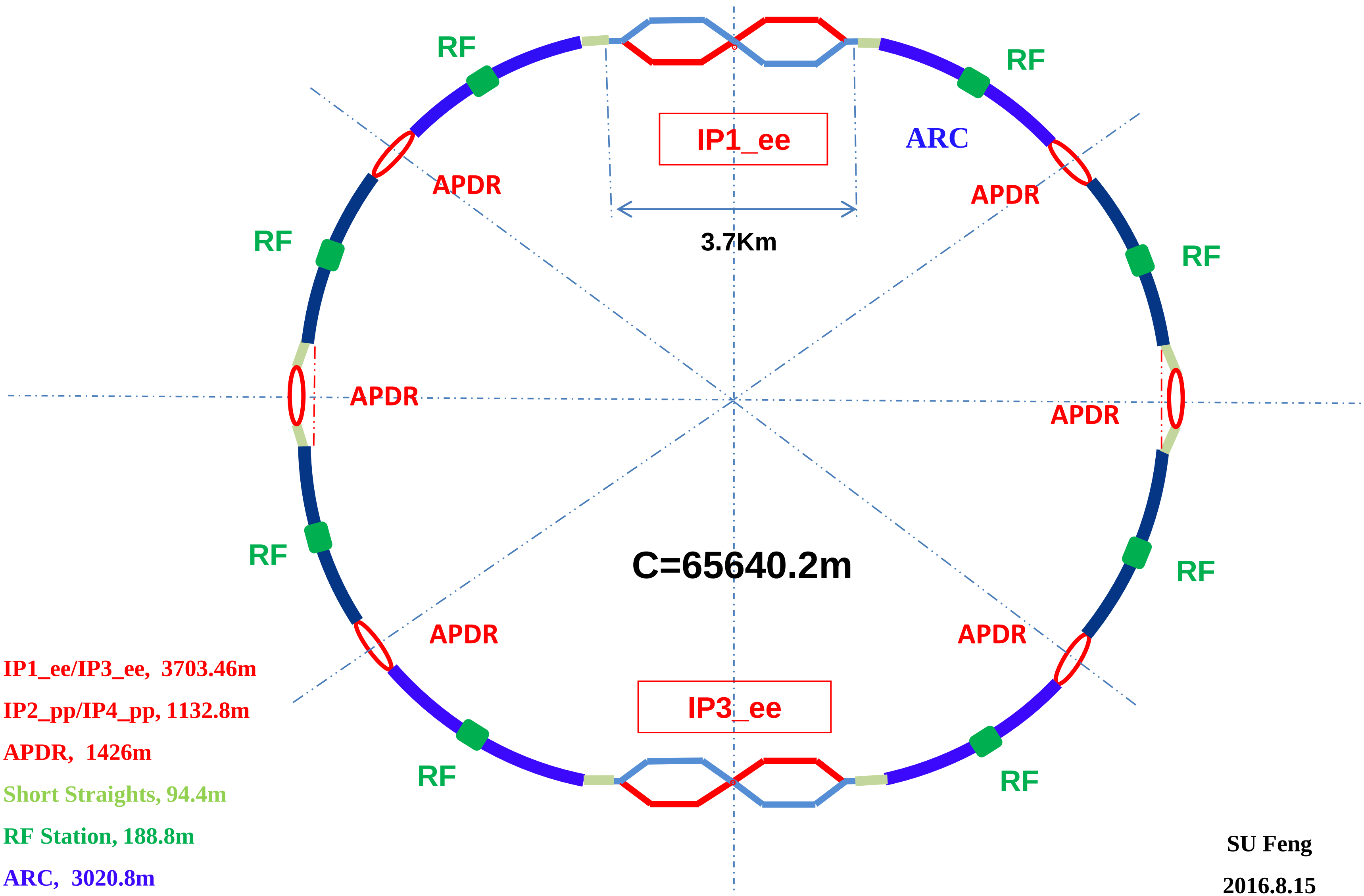
SU Feng

2016.5.23

CEPC Advanced Partial Double Ring Optics I



CEPC Advanced Partial Double Ring Option II



IP1_ee/IP3_ee, 3703.46m

IP2_pp/IP4_pp, 1132.8m

APDR, 1426m

Short Straights, 94.4m

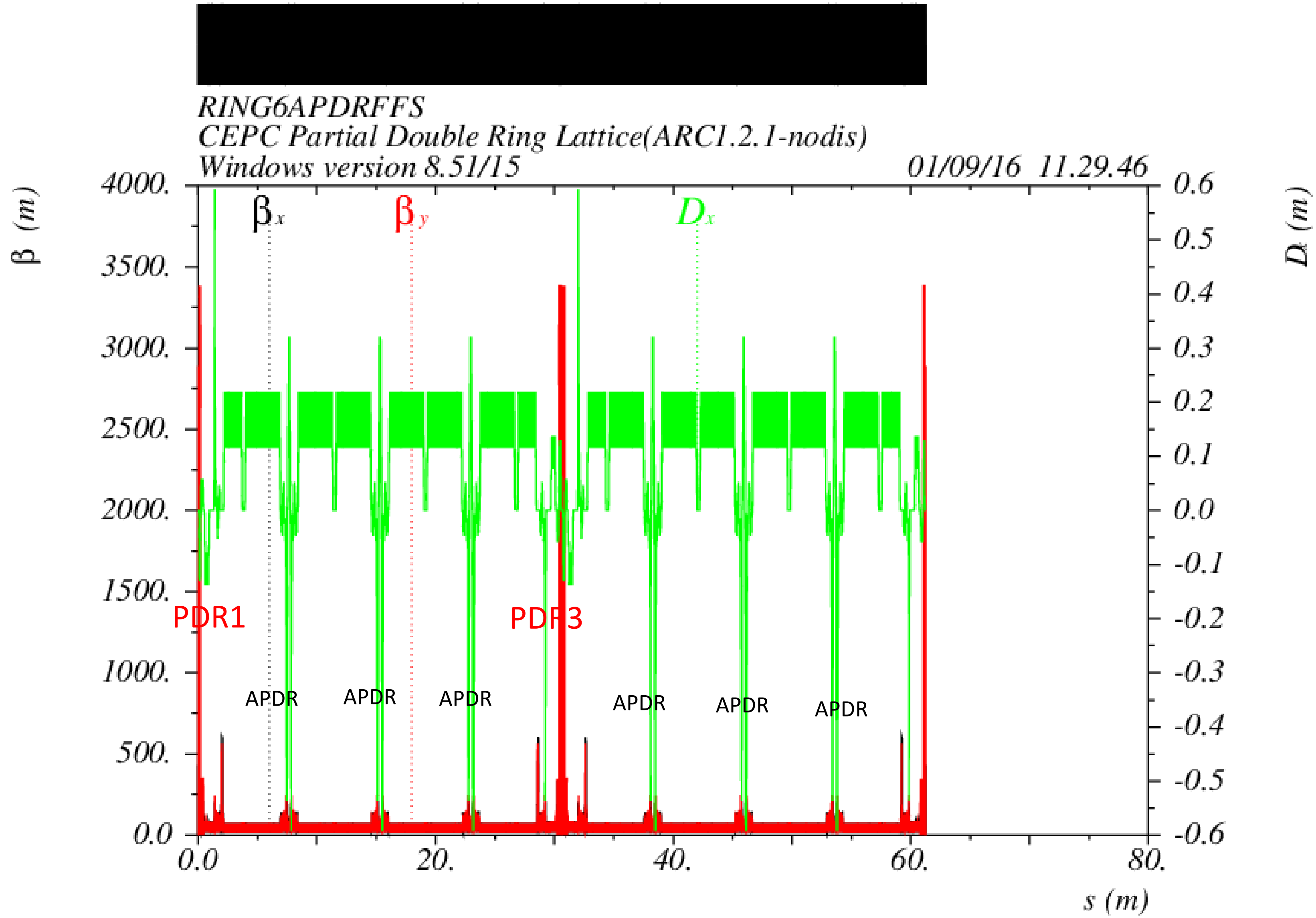
RF Station, 188.8m

ARC, 3020.8m

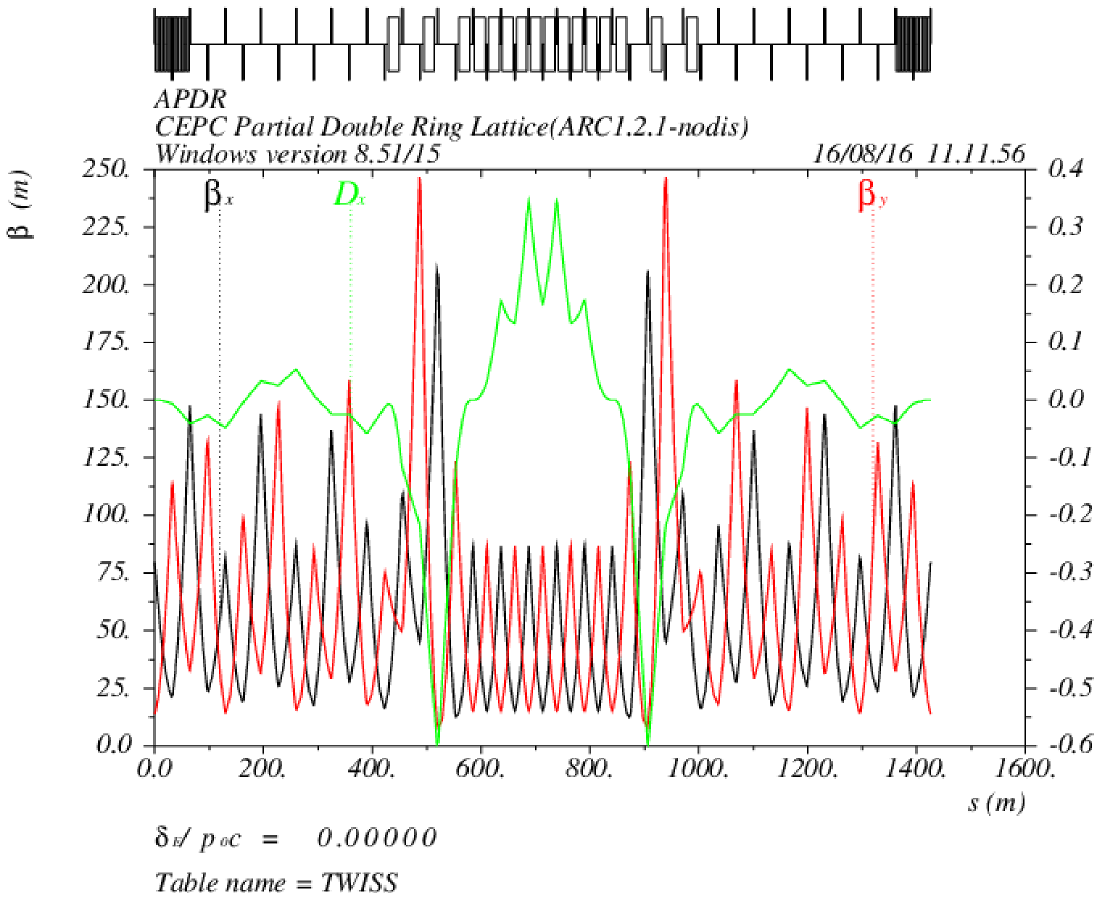
SU Feng

2016.8.15

CEPC Advanced Partial Double Ring Optics II

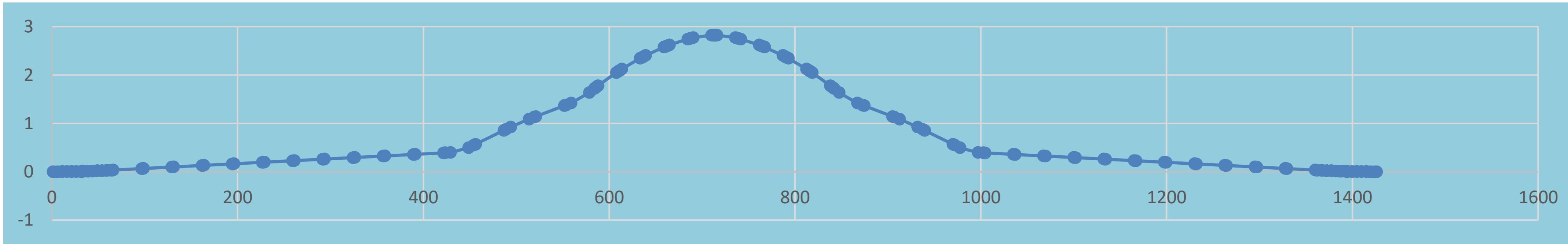


APDR Part

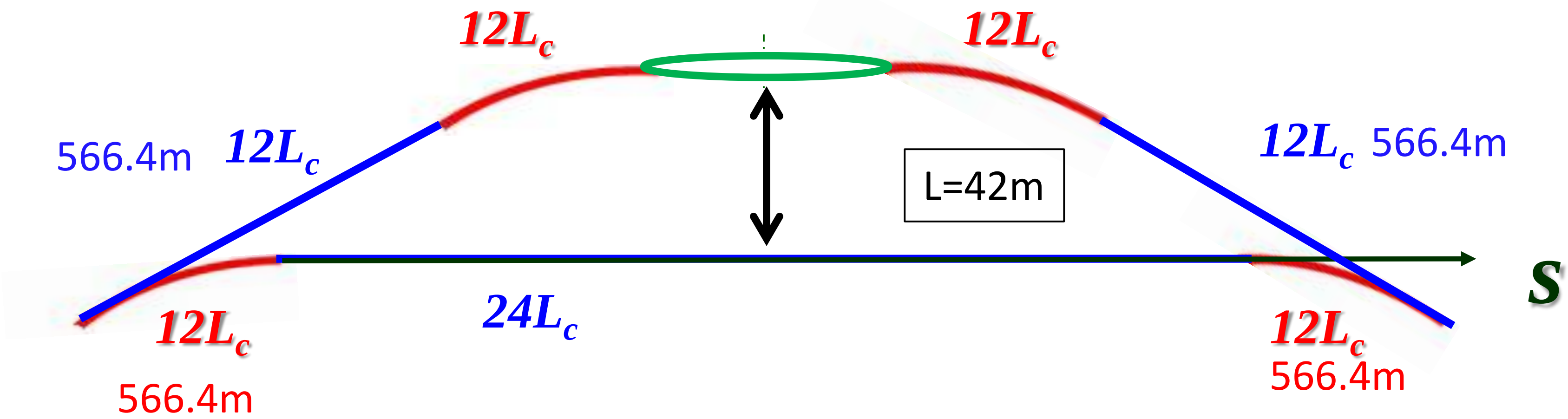


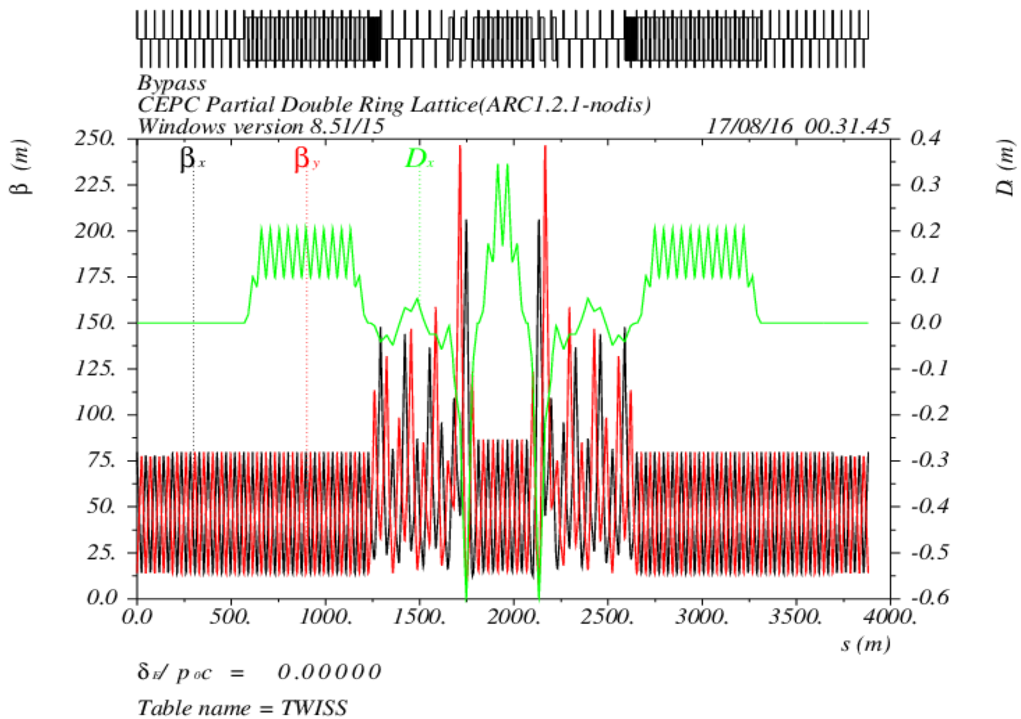
Need update

1426m



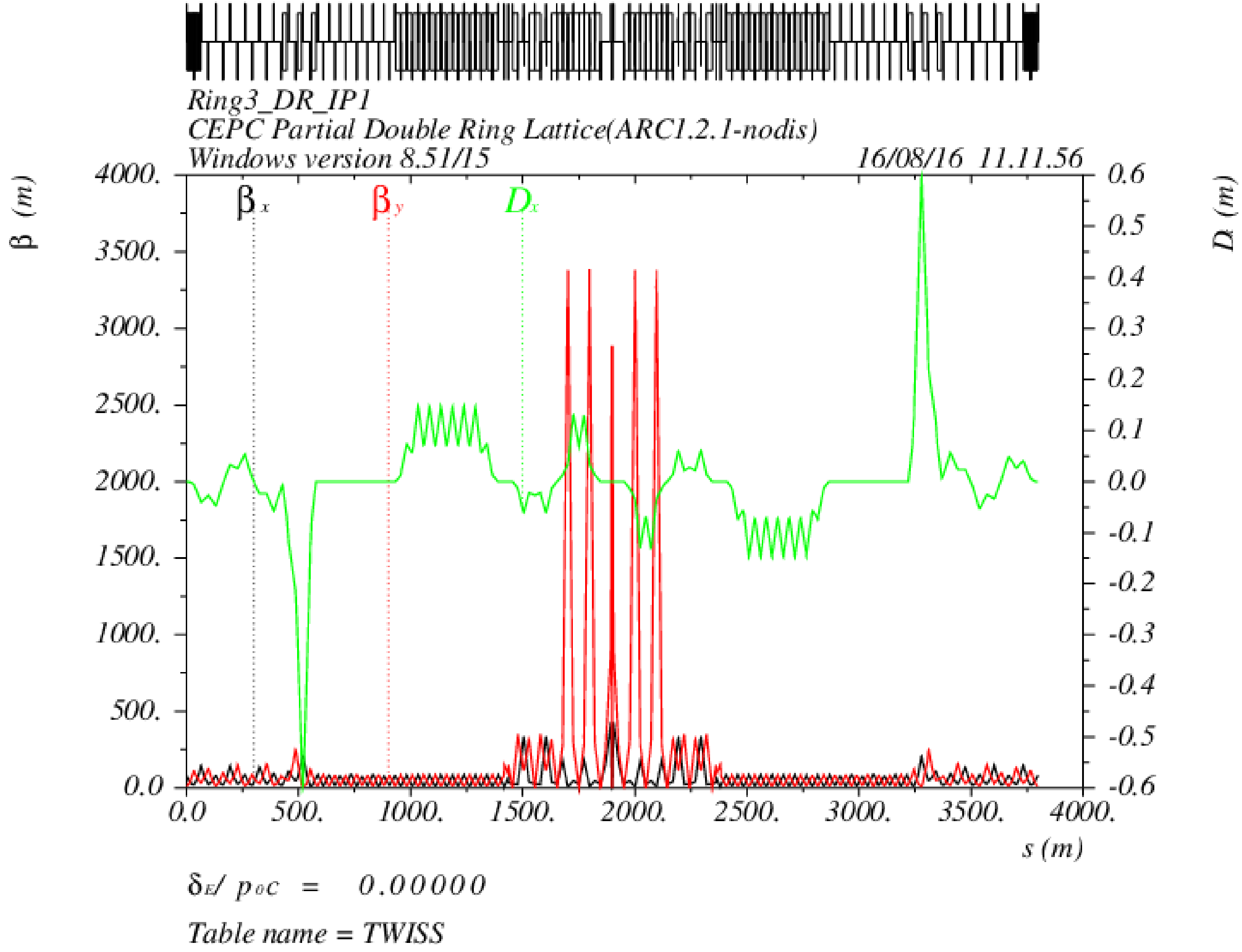
Bypass Part at IP2/4



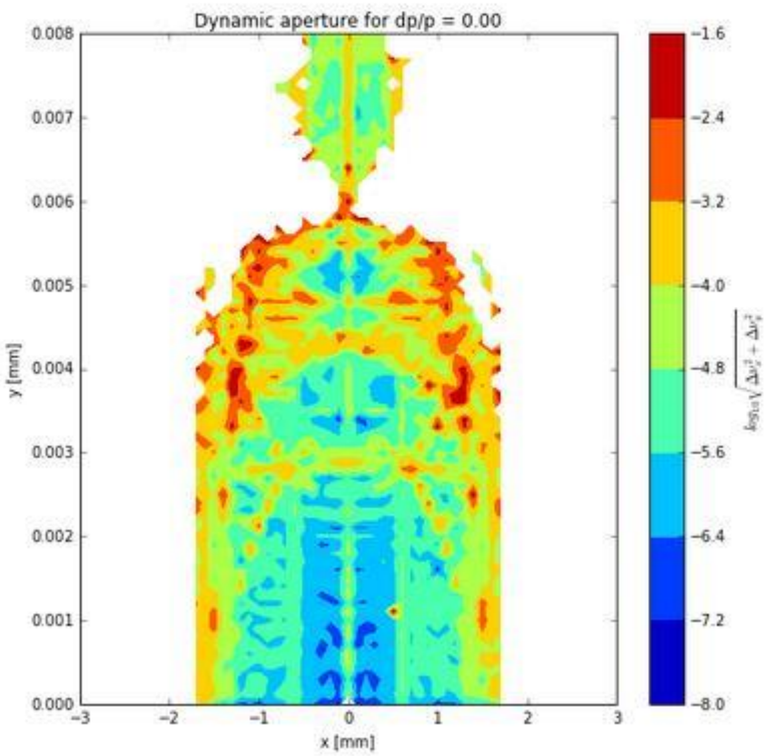


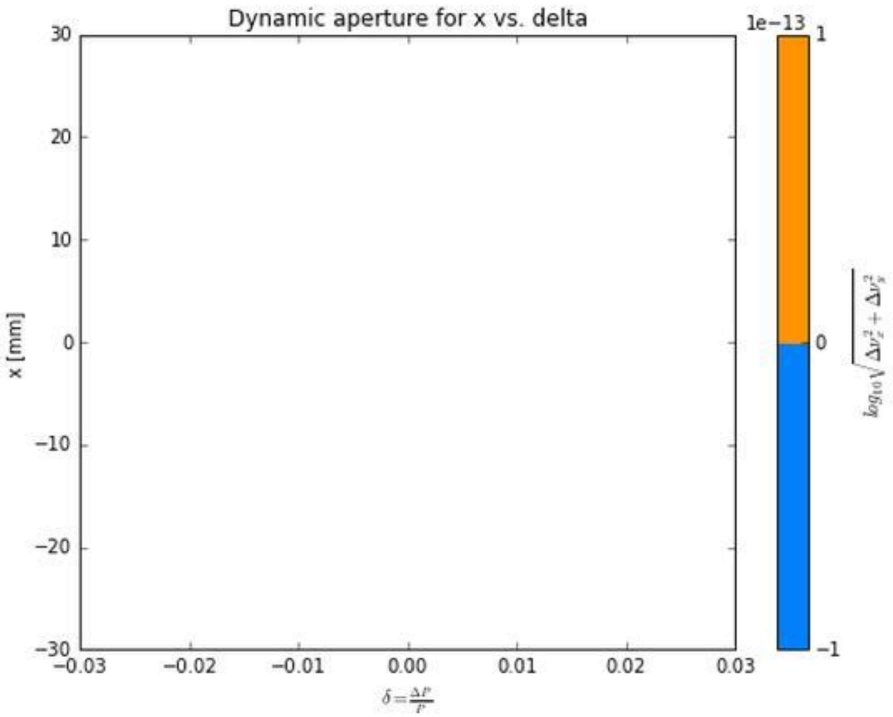
Cell length=47.2m

PDR Part


Ring3_DR_IP1
CEPC Partial Double Ring Lattice(ARC1.2.1-nodis)
Windows version 8.51/15
16/08/16 11.11.56
β (m)
D (m)
β_x
β_y
D_x
4000.
3500.
3000.
2500.
2000.
1500.
1000.
500.
0.0
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
0.0
500.
1000.
1500.
2000.
2500.
3000.
3500.
4000.
s (m)
δ_E/p_0c = 0.00000
Table name = TWISS

Dynamic Aperture of CEPC APDR Option II





Betx： 0.219915m
bety： 0.001m
2.147368nm
Sizmax： 21.731um
Sigmay： 0.08026um

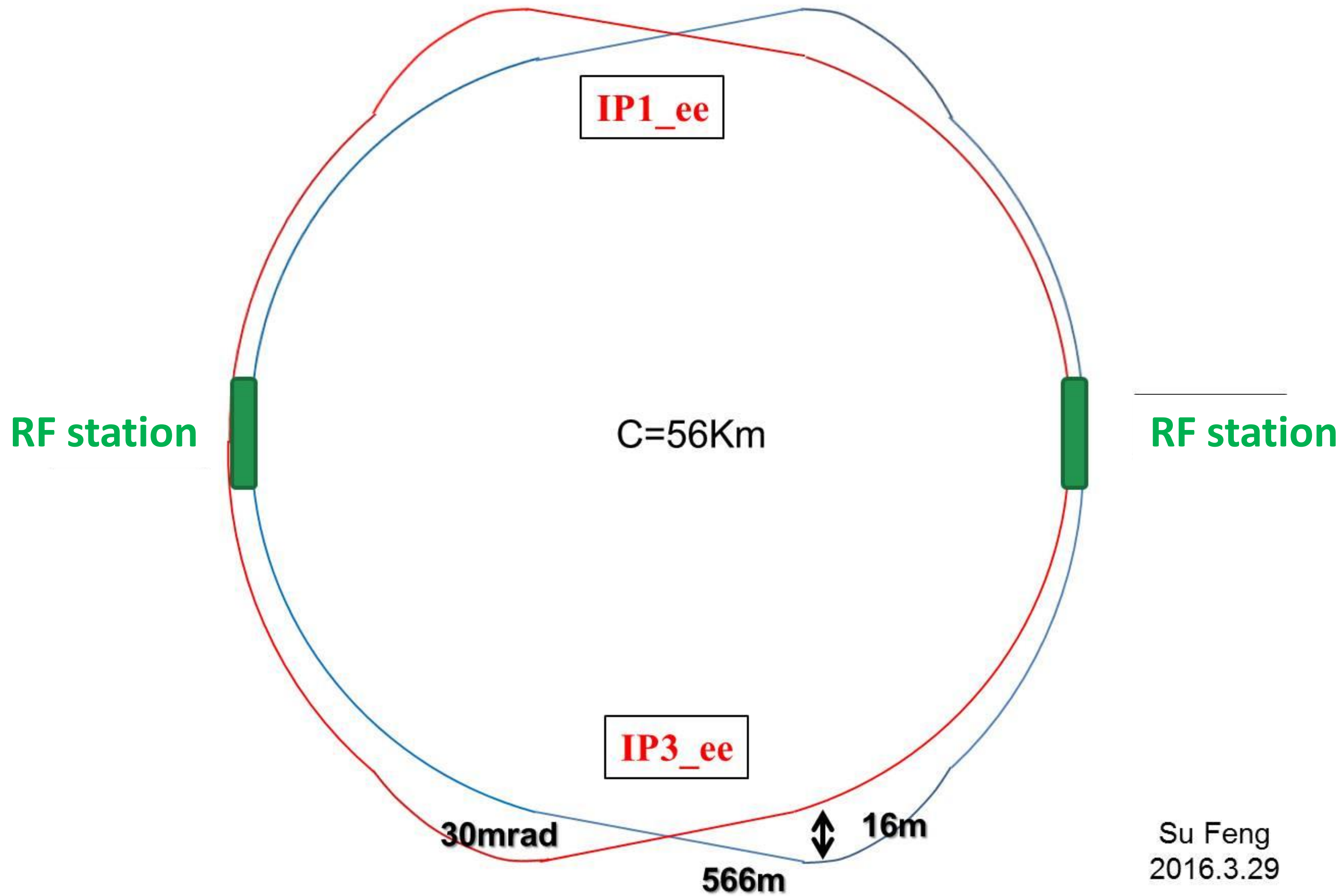
X： 22 Sigma
Y： 25 Sigma

2 groups

Outline

5. CEPC Double Ring Scheme

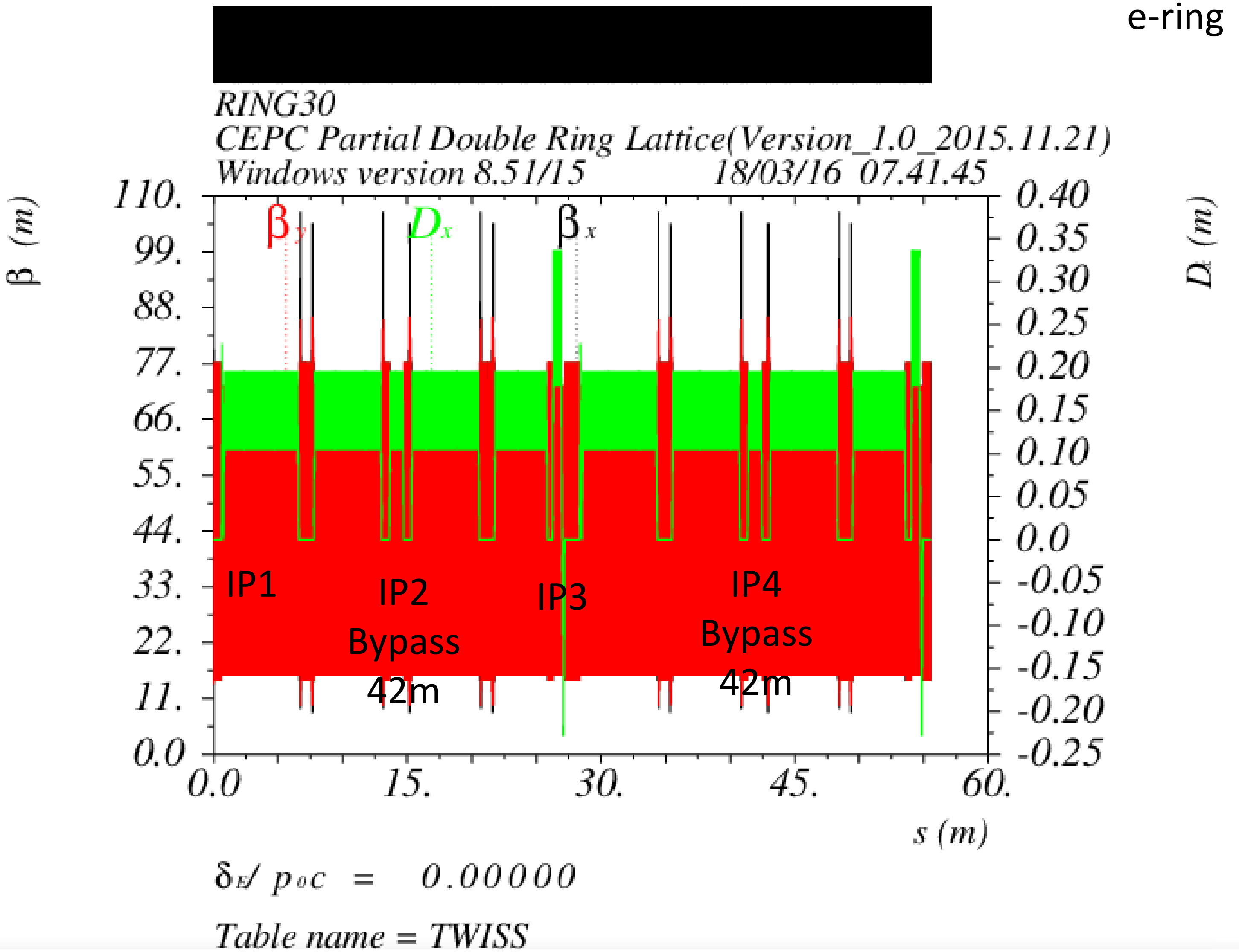
CEPC Double Ring Scheme Layout



Su Feng
2016.3.29

Double Ring Scheme

e-ring



6. Summary

- The first version of CEPC Partial Double Ring Lattice was designed (Version 1.0). The whole length of CEPC PDR is 3781.27m, full crossing angle is 30mrad, maximum distance between two ring is 14.913m.
- The Dynamic Aperture need to be optimized. Now the DA of CEPC with PDR and Bypass(at IP2/4) and without FFS is better than before, but the DA with FFS is not good enough.
- The linear lattice of PDR may also be optimized.

中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

Thank You !

Acknowledge

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- Thanks for Gang Xu, Qing Qin, Yuan Zhang, Yuemei Peng, Qingjin Xu, Xiaohao Cui, Zhe Duan and Yudong Liu’s kind help and beneficial discussion!

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10. F. Su, J. Gao et al, "CEPC Partial Double Ring Lattice Design", THPOR009, Proceedings of IPAC2016.

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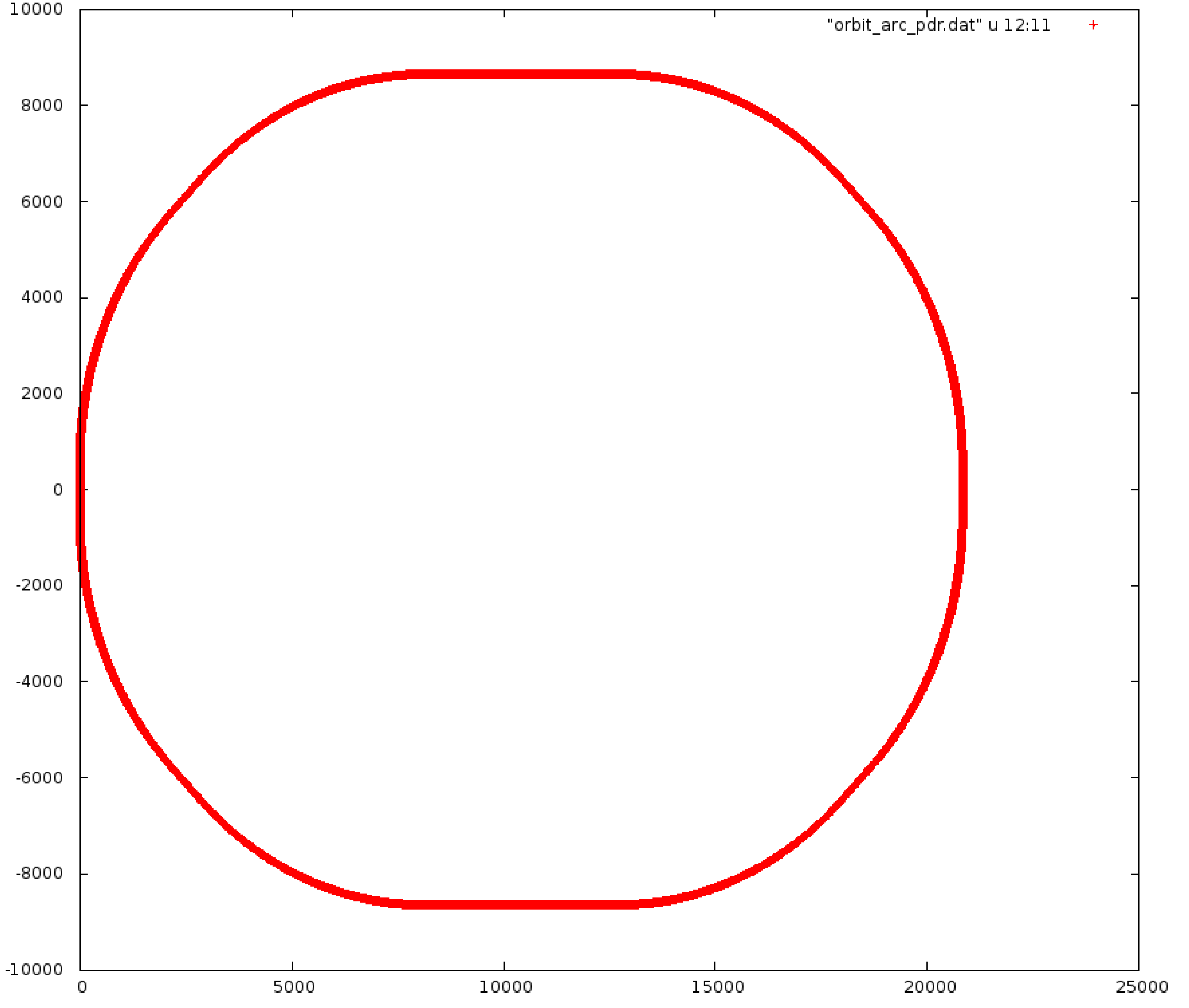
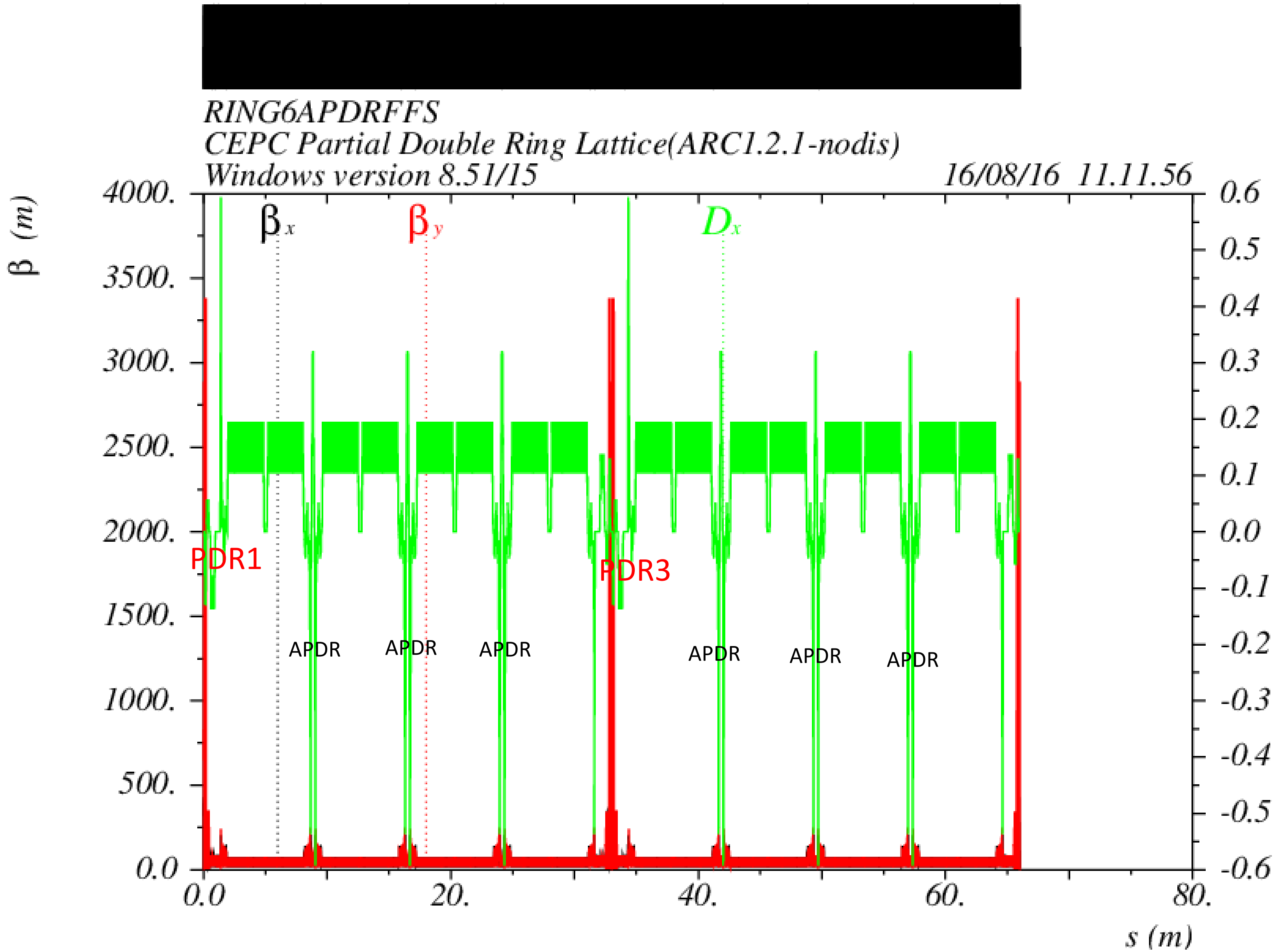
Backup

CEPC ARC+PDR_FFS

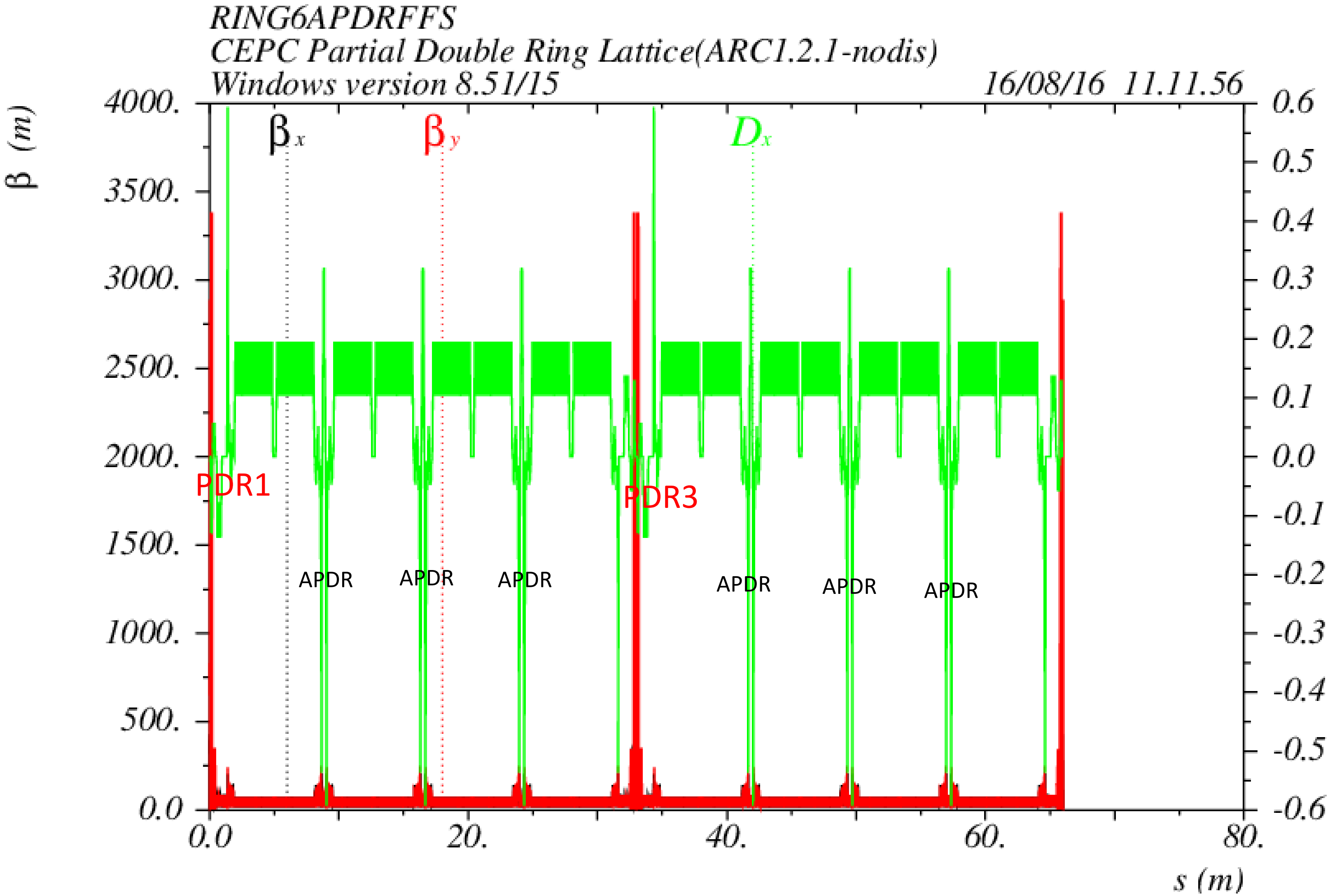


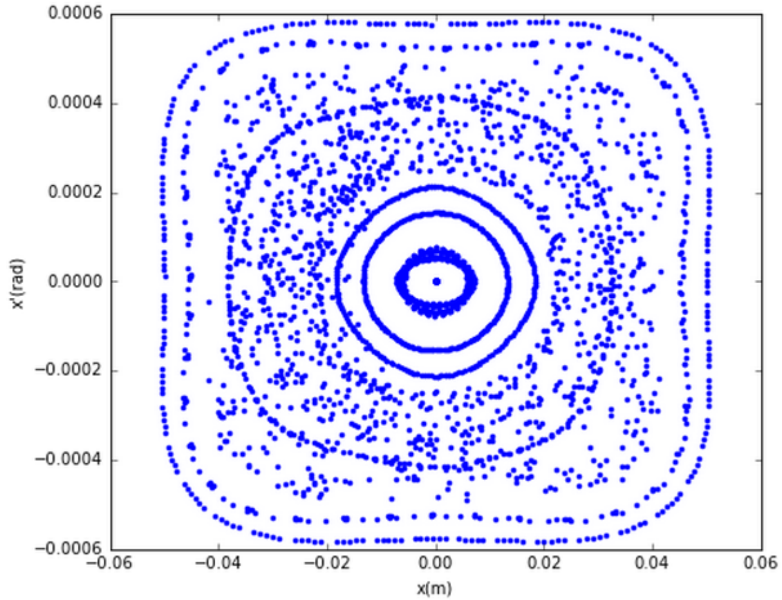
CEPC Advanced Partial Double Ring Optics II

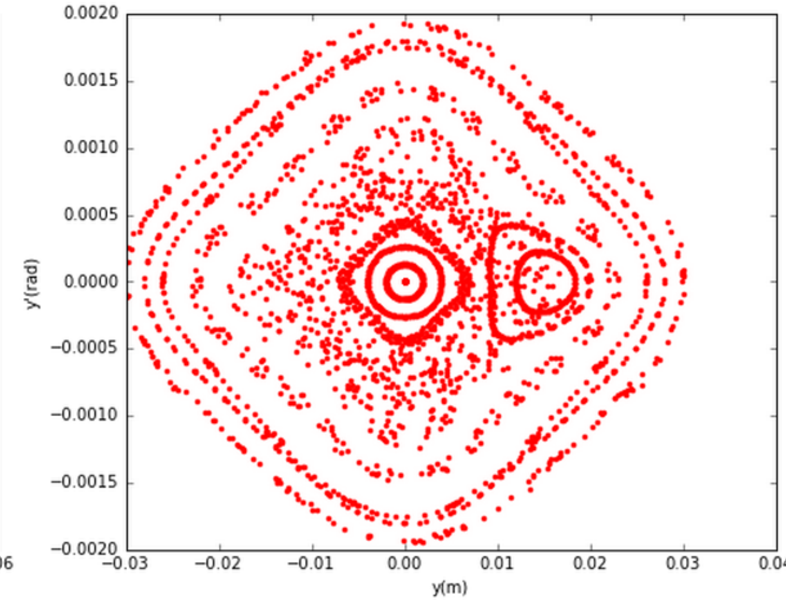


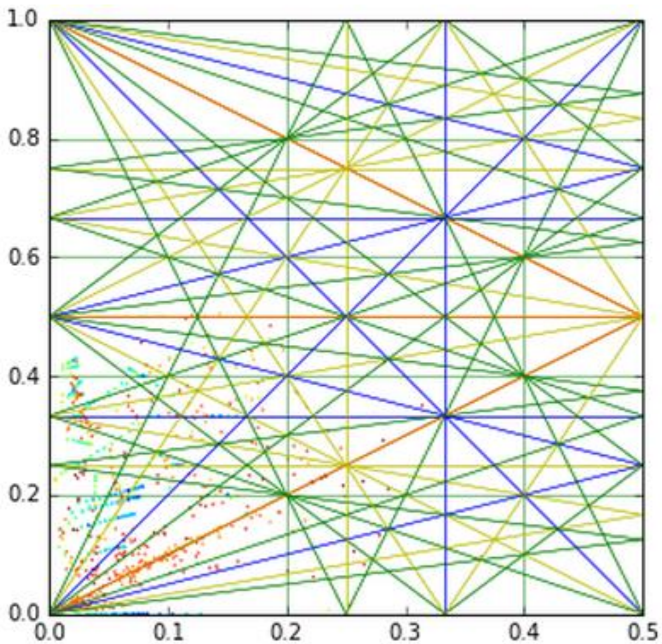
CEPC Advanced Partial Double Ring Optics II

[redacted]



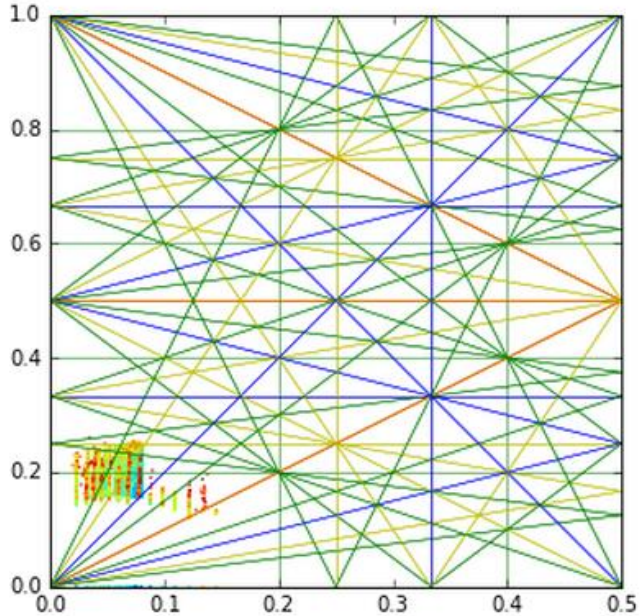




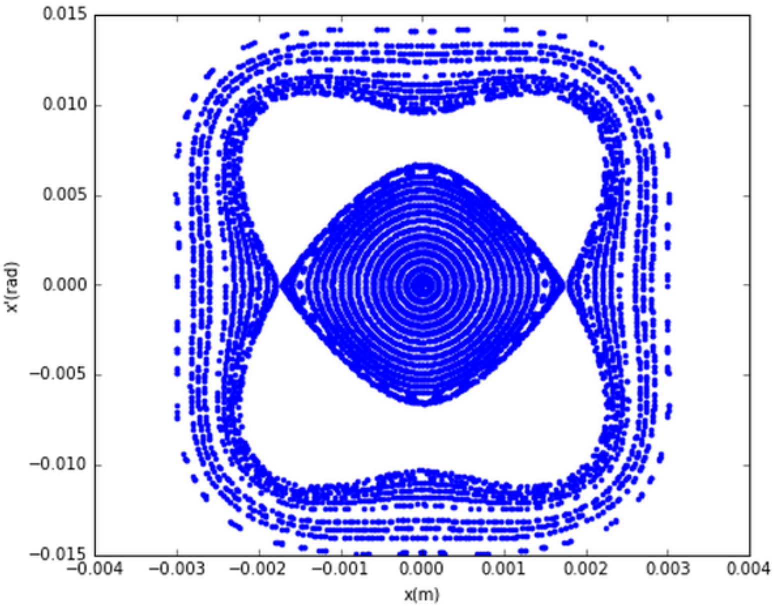


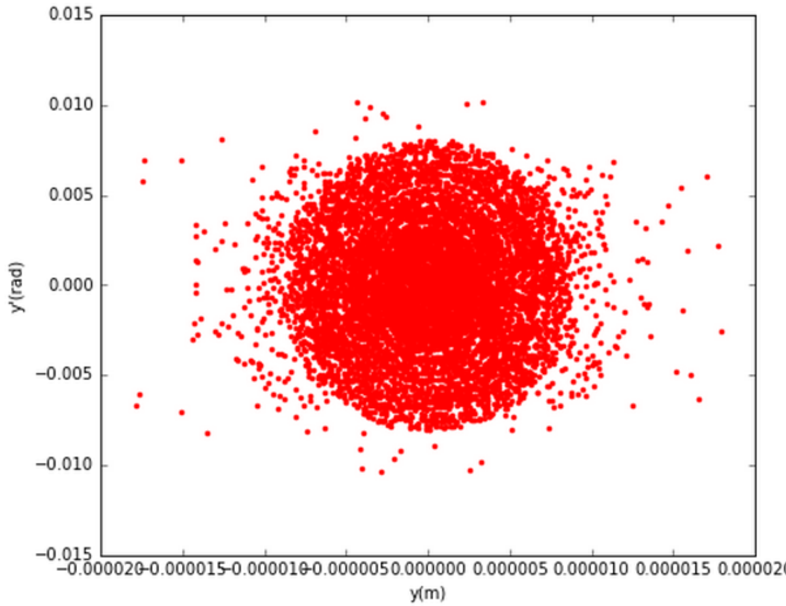

```
In [3]: cepc.ring.geth1()
        cepc.ring.h1

Out[3]: {'h00111': (5.742221251626866+0j), 'h11001': (5.670359595670625+0j)}

In [4]: cepc.ring.geth2()
        cepc.ring.h2

Out[4]: {'h00112': (-8001.8844135165946+2.0997153668544932e-12j),
         'h00220': (0.00021258305237598912-1.5197626779261952e-07j),
         'h11002': (-6646.5151814247183-7.2161998598829769e-12j),
         'h11110': (-0.00019662996670510063+7.9286005150169814e-08j),
         'h22000': (0.00027491287281040234+1.7103984981808873e-10j)}
```

Nonlinear Driving Term (ARC_PDR_FFS_2016.08.29)




```
=* First order driving terms *=
h00111 =     2.179995e+02    +0.000000e+00j
h11001 =     1.483133e+02    +0.000000e+00j

=* Second order driving terms *=
h11002 =    -5.635733e+03    +7.551471e-11j
h11110 =    -5.810324e+04    -1.208943e-04j
h00220 =    -1.788442e+07    -3.719207e-06j
h00112 =    -8.723381e+03    +4.257890e-08j
h22000 =    -3.763891e+03    -1.479907e-09j
```





Dynamic Aperture of CEPC APDR Option II