CEPC Partial Double Ring Lattice Design

and

SPPC Lattice Design

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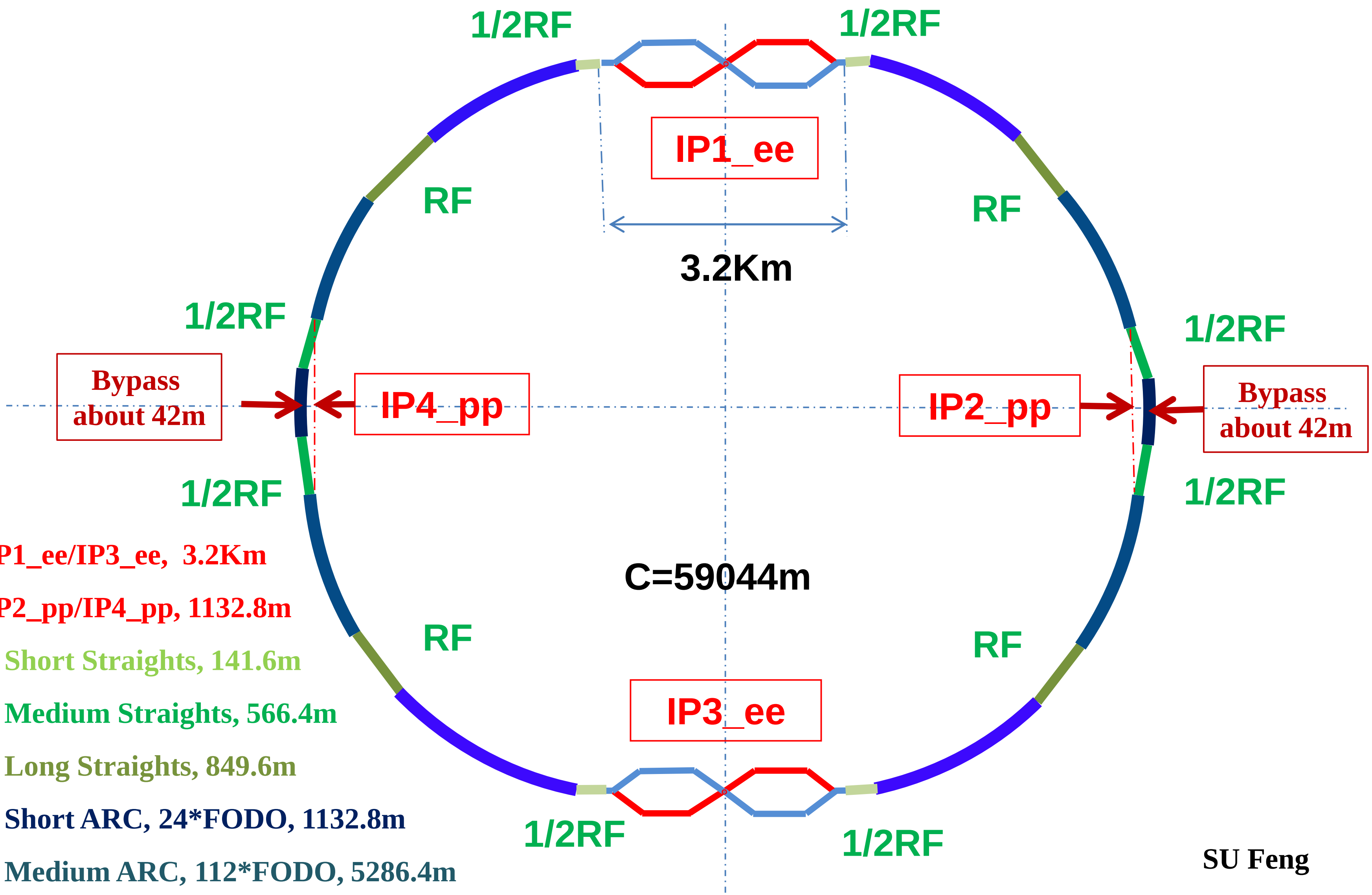
Outline

1. CEPC PDR 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

1. CEPC PDR Lattice Layout

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

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

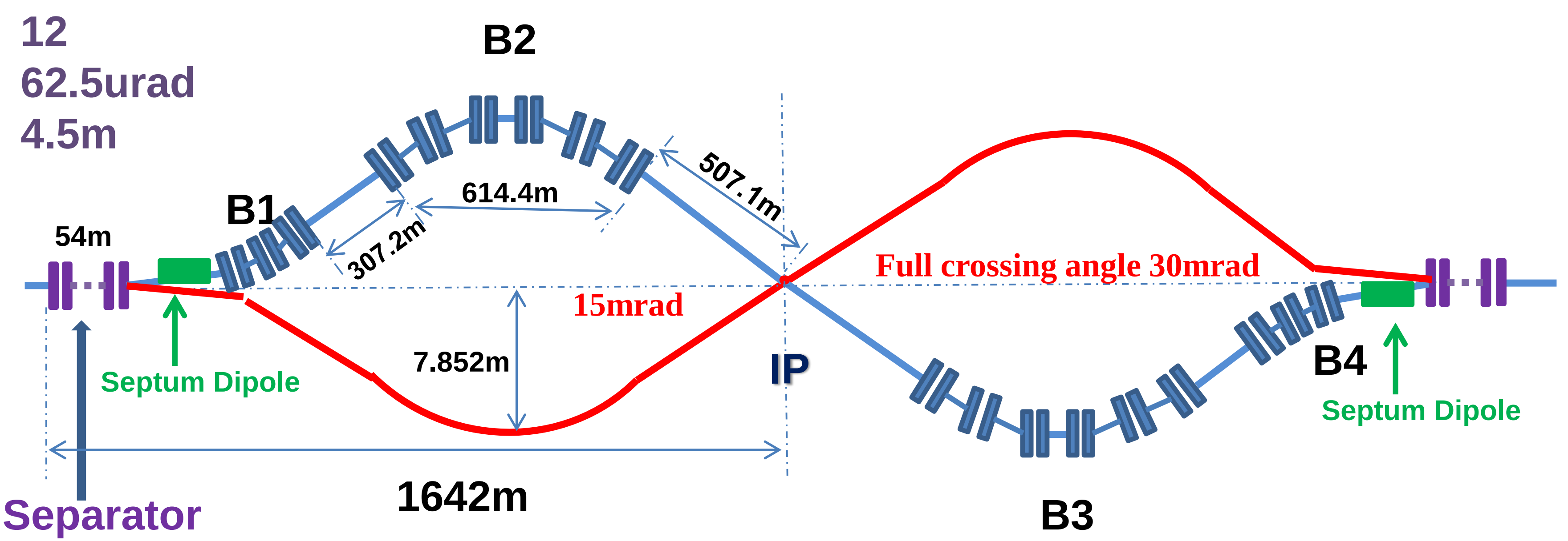
4 Medium ARC, 112*FODO, 5286.4m

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.**

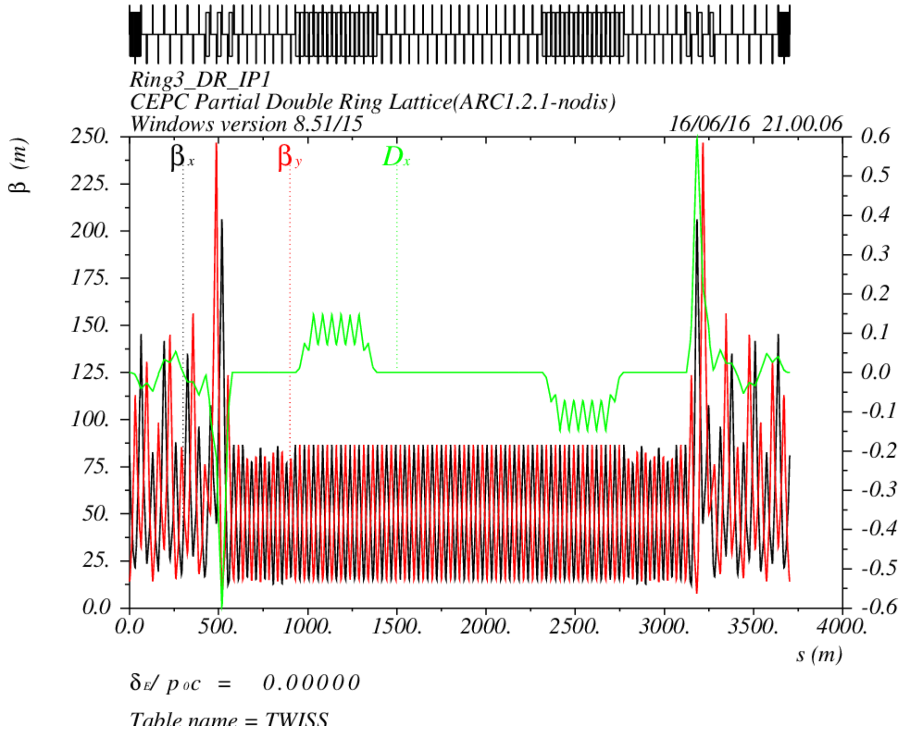
Using Septum Dipole after separator to acquire 15 mrad

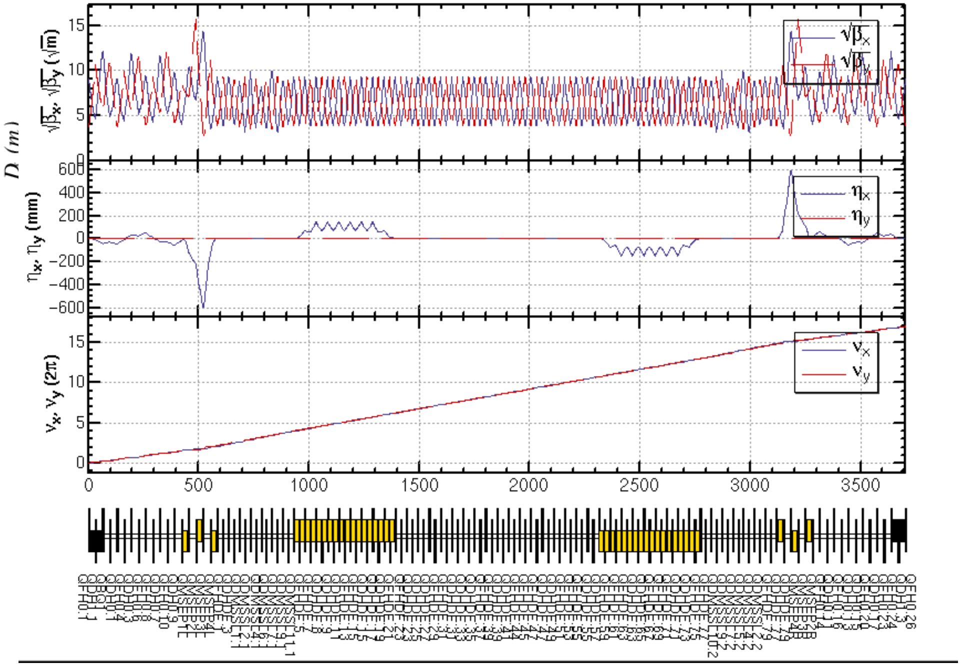
Version 1.0

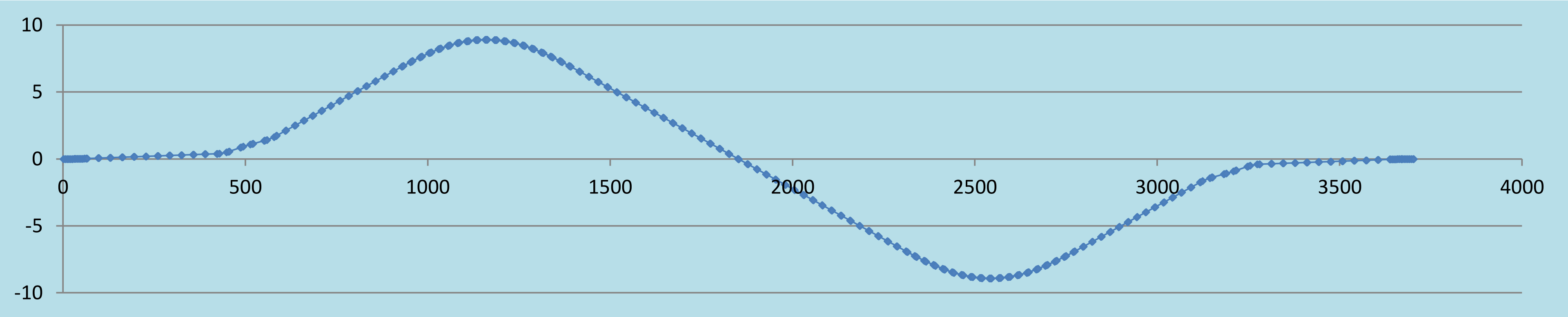
sufeng

2015.12.20

CEPC PDR1.0.3 noFFS







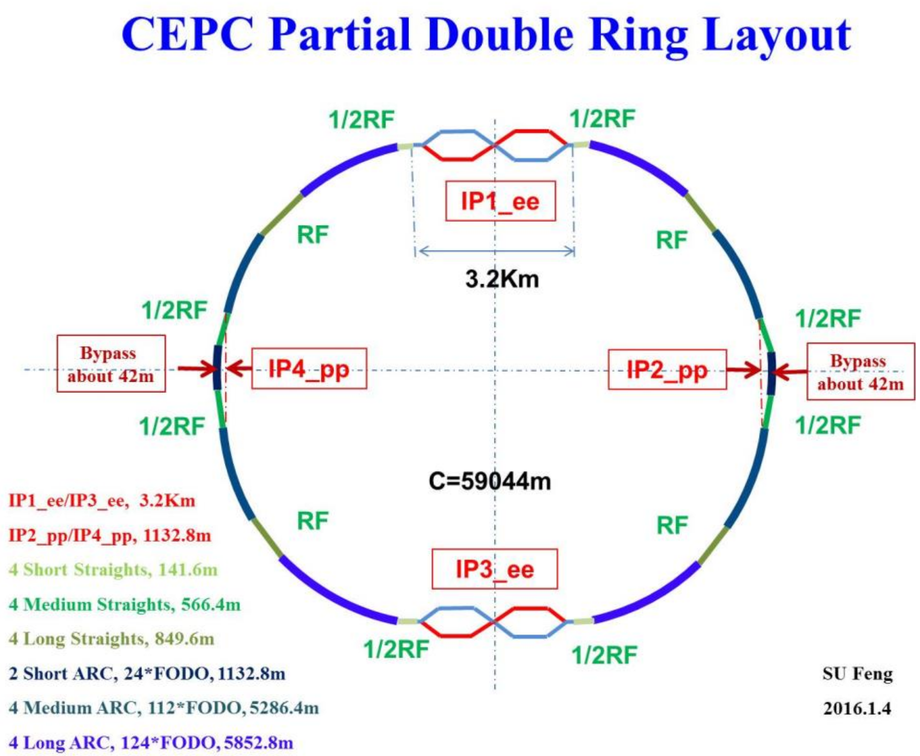
2. CEPC PDR ARC Length Consideration and Redesign

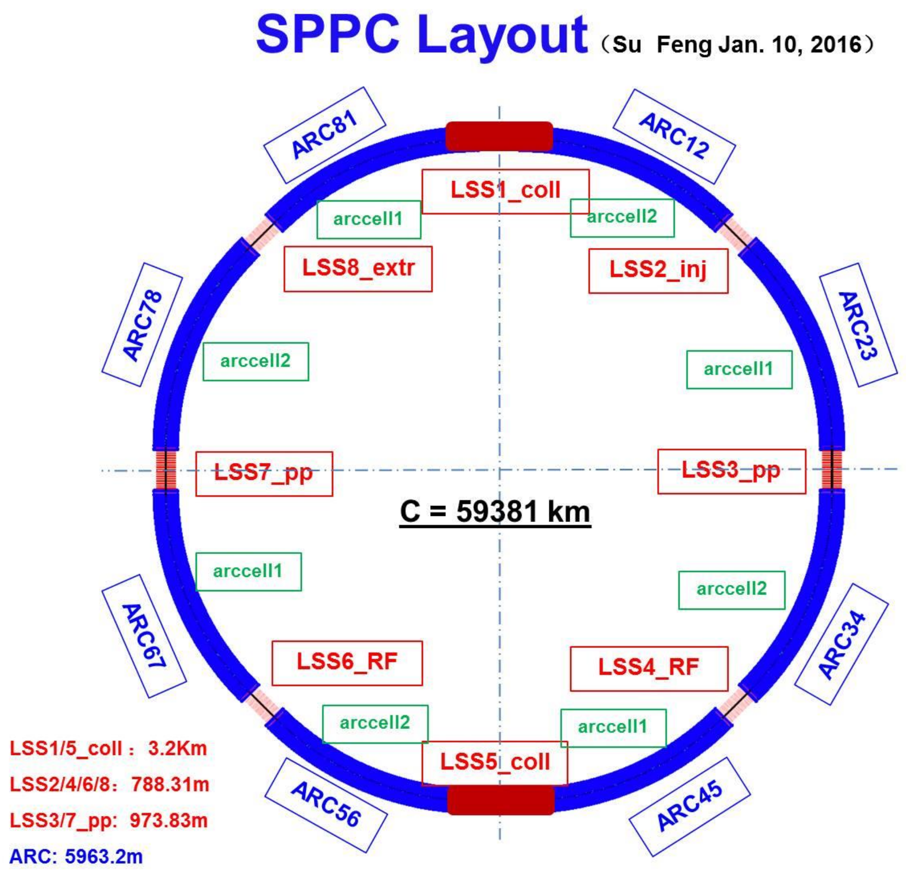
CEPC PDR ARC Length Consideration

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:

$E0 = 70 - 100\ TeV$

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

$\beta = 1$

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

$B0 = 20\ T$

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

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

ARC filling factor $f1 = 0.8$

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

$Lss3pp = Lss7pp = 973.83\ m$

$Lss2 = Lss4 = Lss6 = Lss8 = 788.31\ m$

$\boxed{L1 = 50903.46}$

$Lss1 = Lss5 = 3.3\ km$

$C0 = 57503.46\ m$

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

$L_B = 14.8\ m$

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

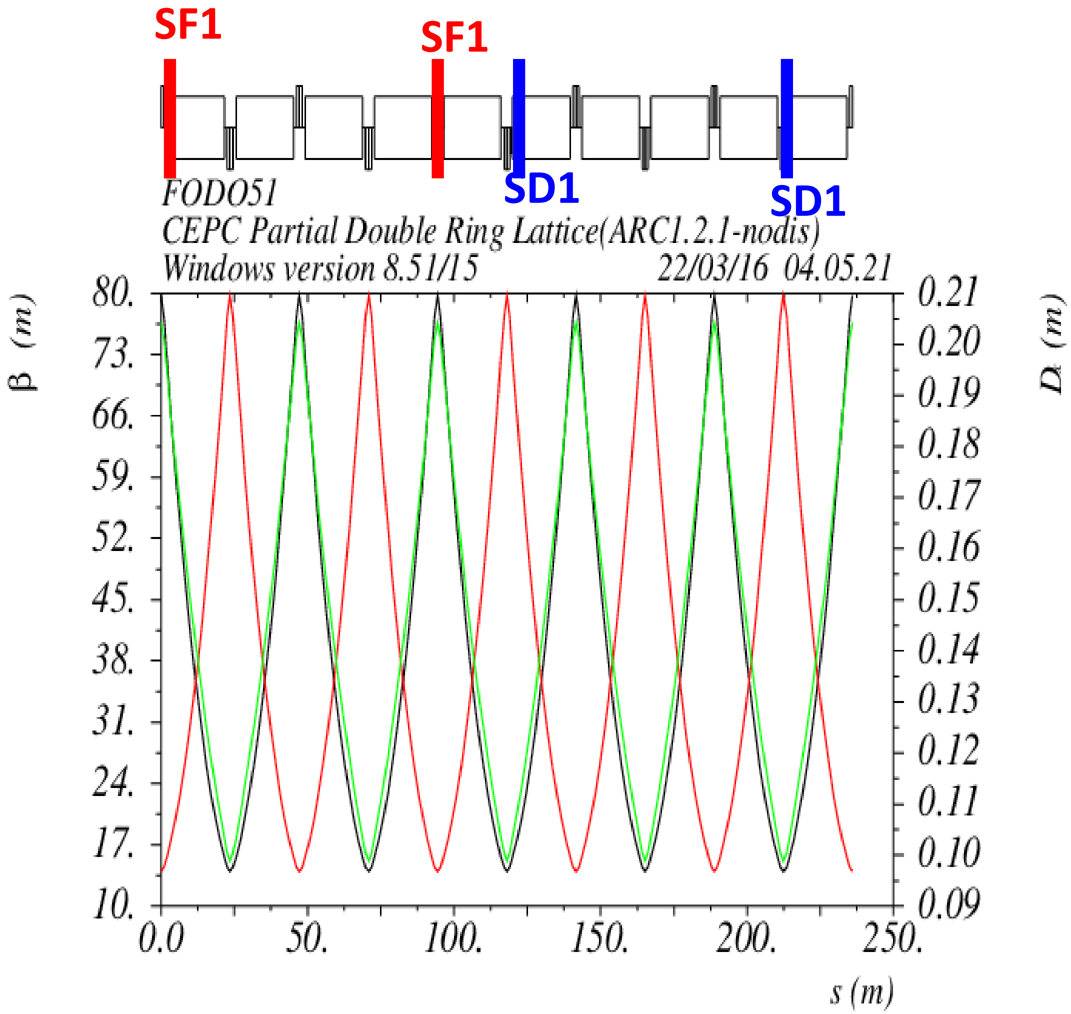
$$ARC: f1 = \frac{14.8*8*38 + 14.8*8*2}{(38+2+2)*144.4} = 0.7809$$

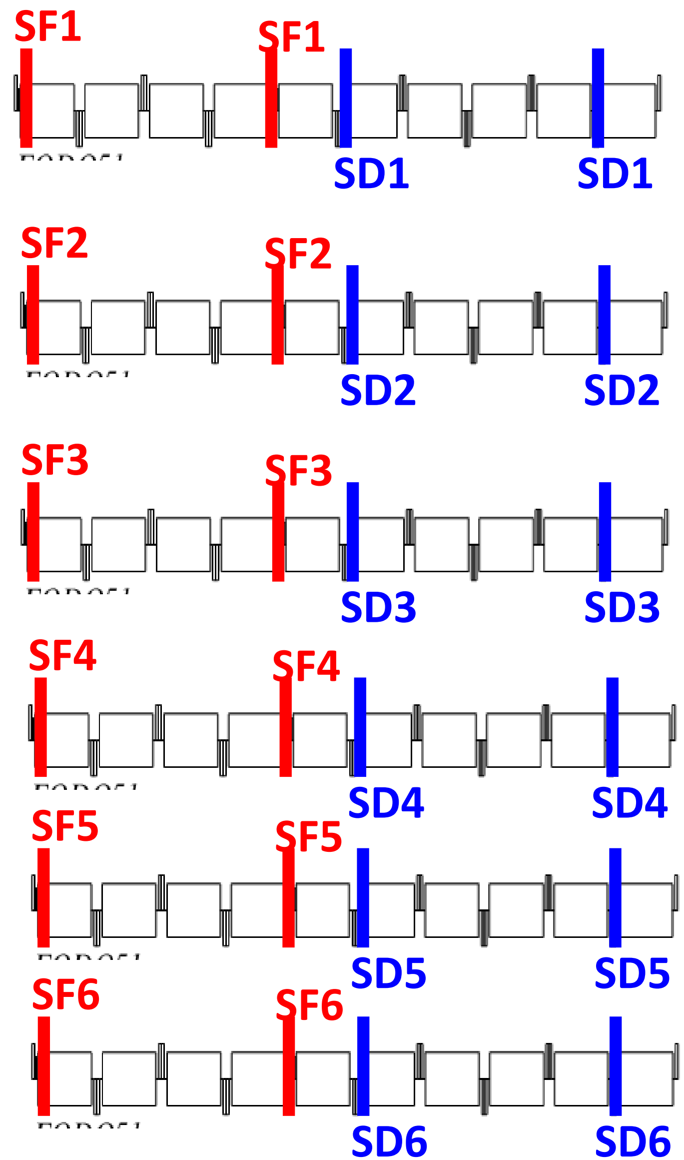
$$L_{ARC} = \frac{37389.85}{0.7809} = 47880.46$$

$\boxed{L1 = 52981.42}$

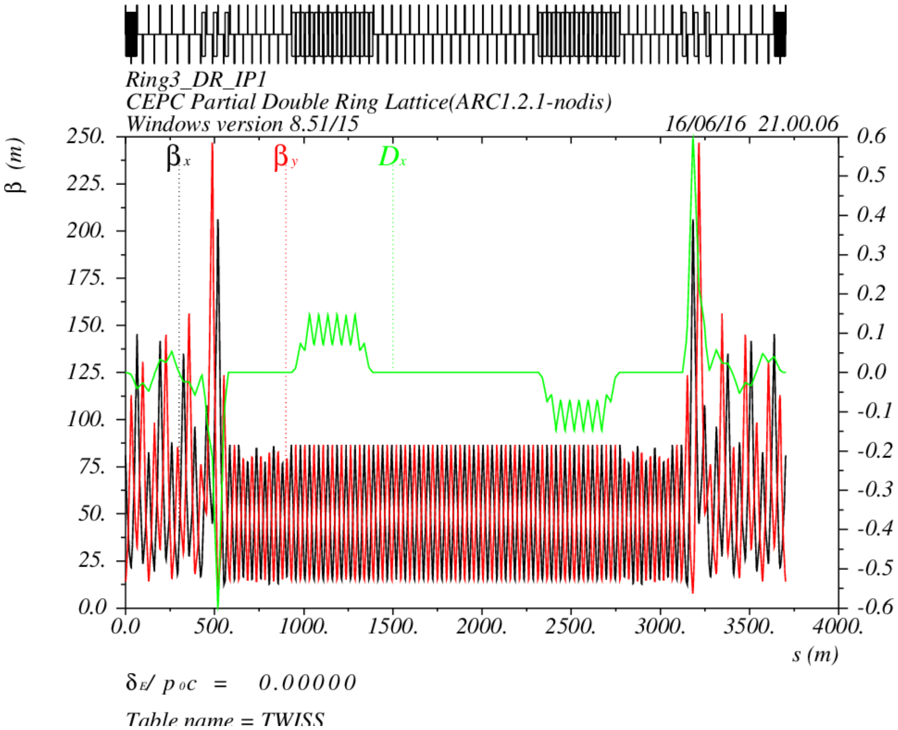
$C0 = 59581.42$

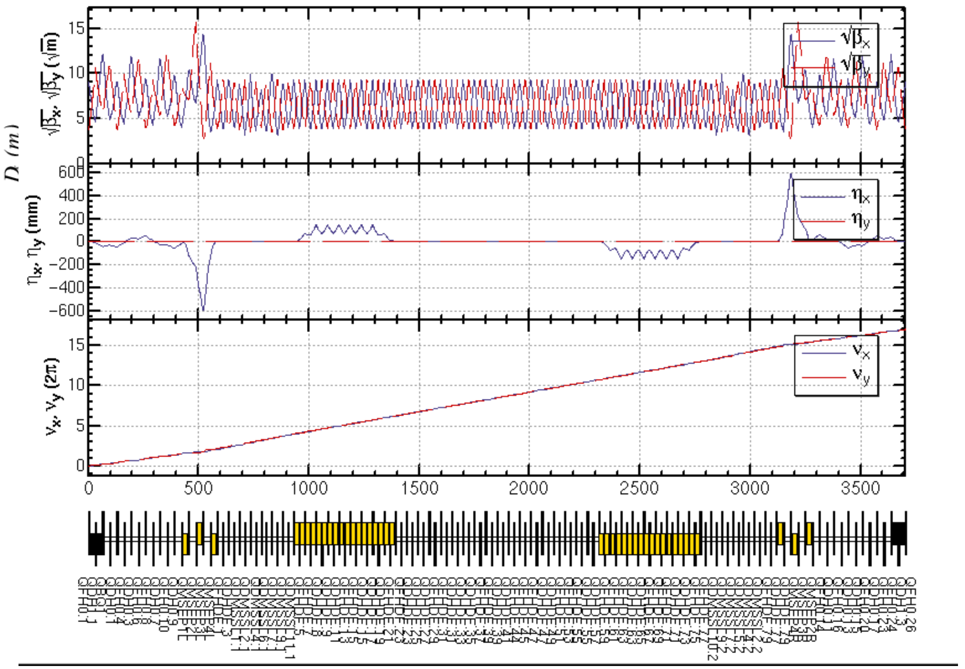
New ARC FODO 90/90 non-interleave

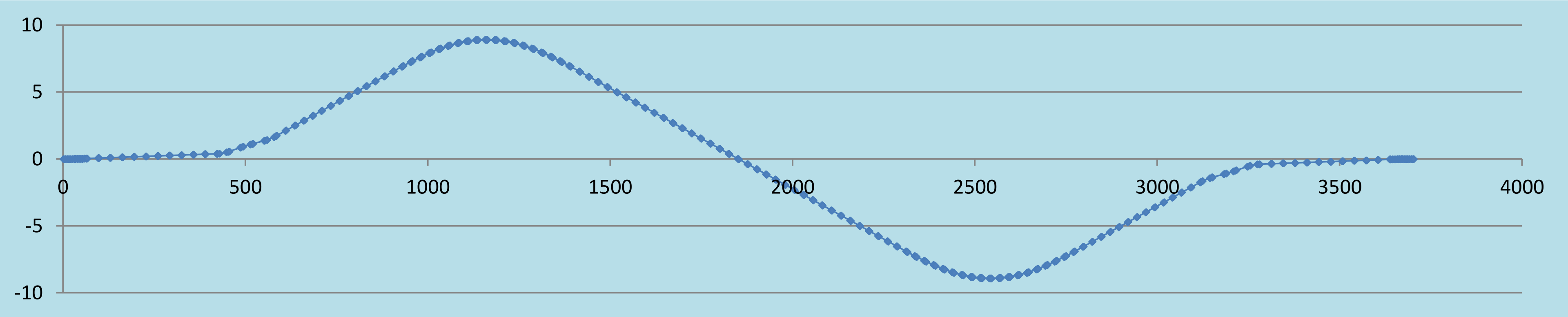




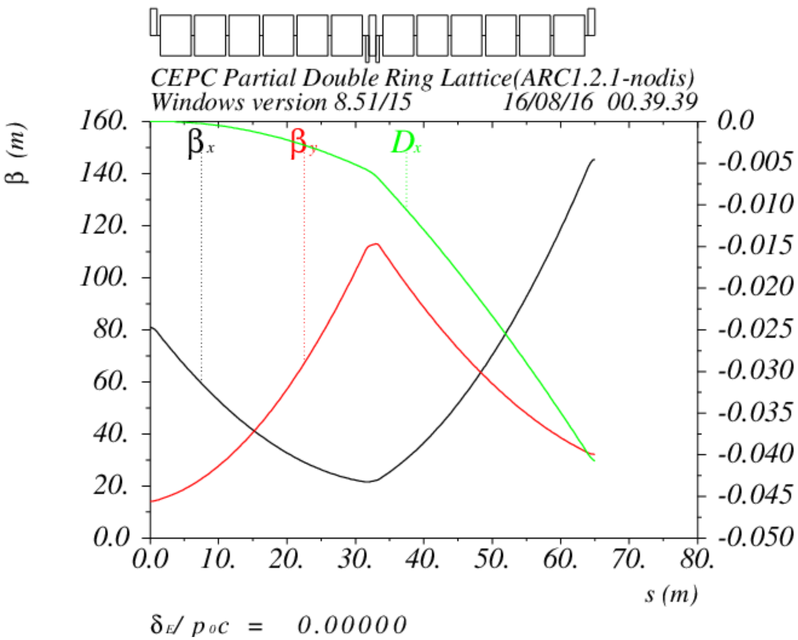
CEPC PDR1.0.3 noFFS

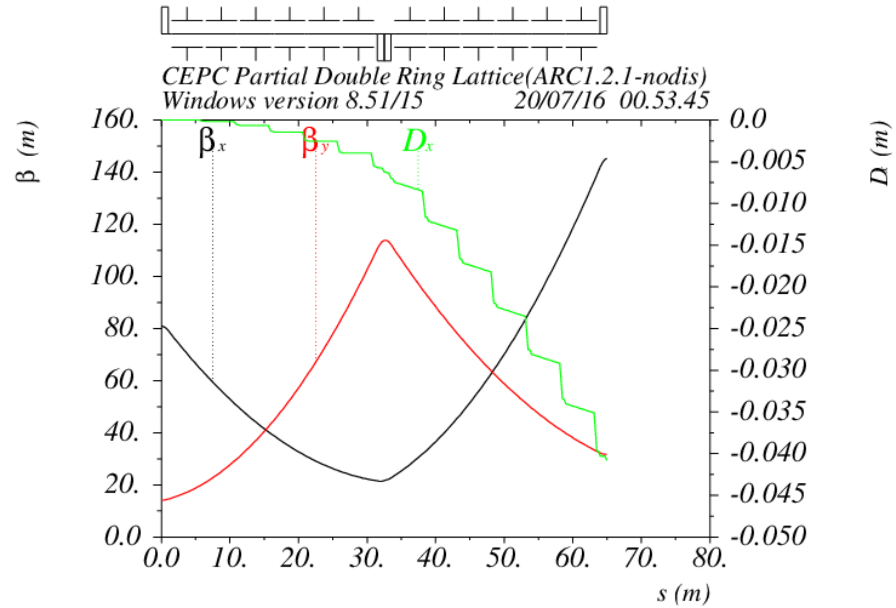


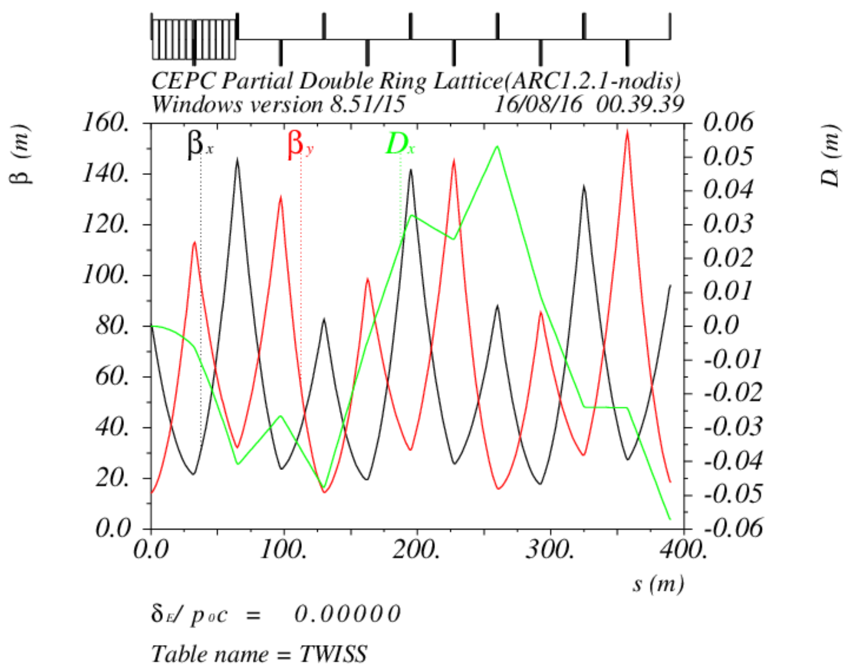


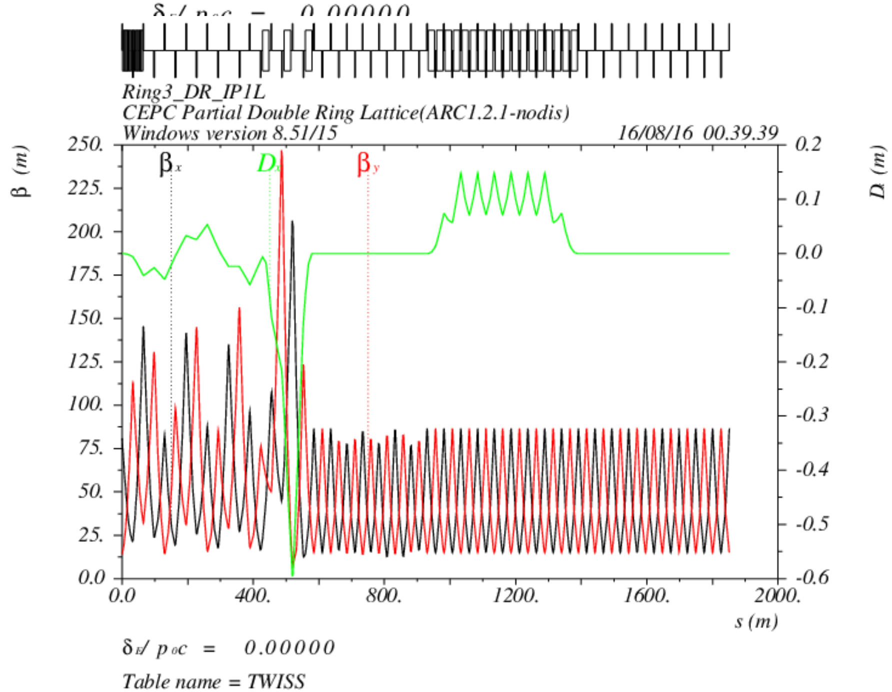


CEPC PDR1.0.3 noFFS









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	$2.7\cdot10^{-8}$ 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

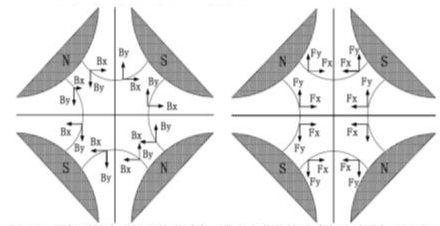
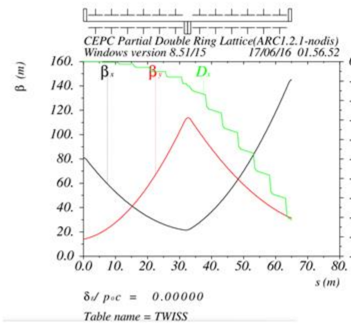
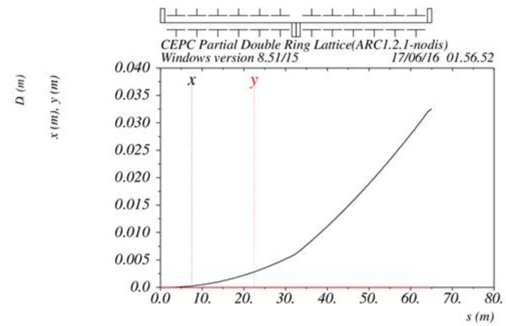


图 2.2 四极磁铁中磁场及粒子受力（带负电荷的粒子垂直于纸面向里运动）

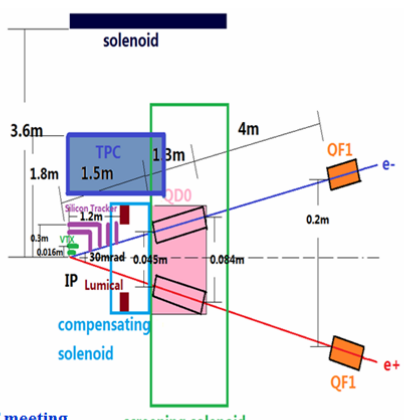




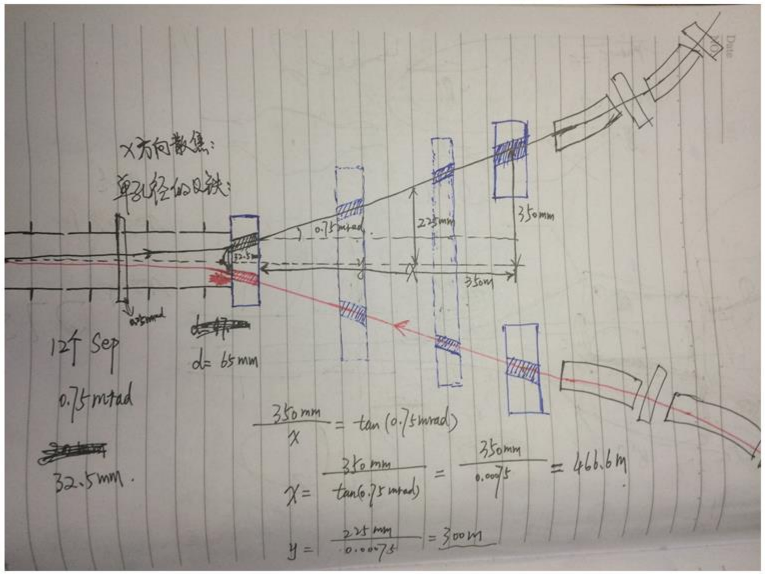
Design Progress of QD0 in partial double ring

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

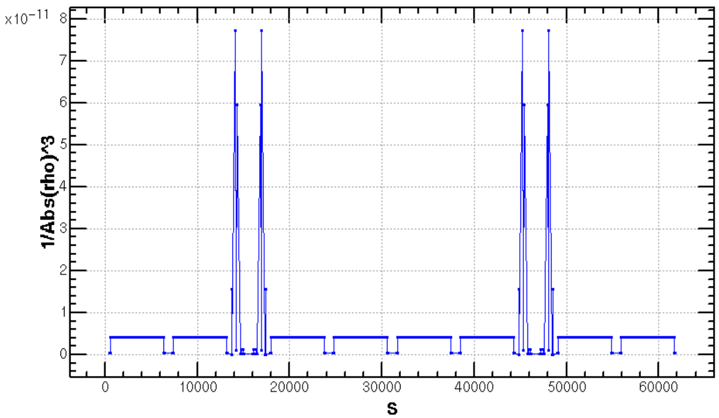
Name	Magnetic length (m)	Field gradient (T/m)	Coil inner radius (mm)
QD0	1.3	200	12.5

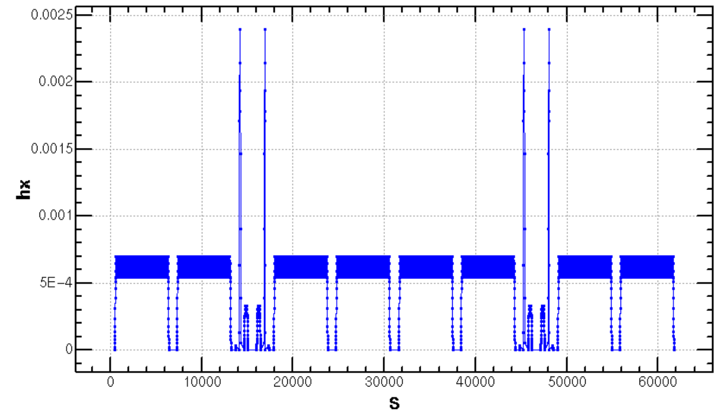


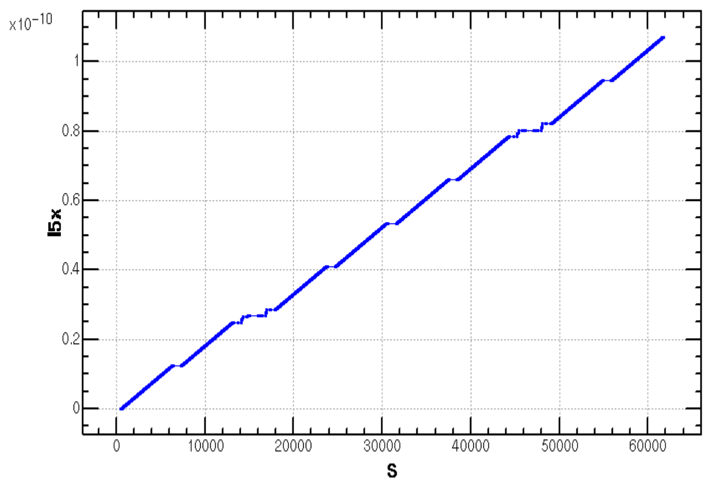
Dual Aperture Q

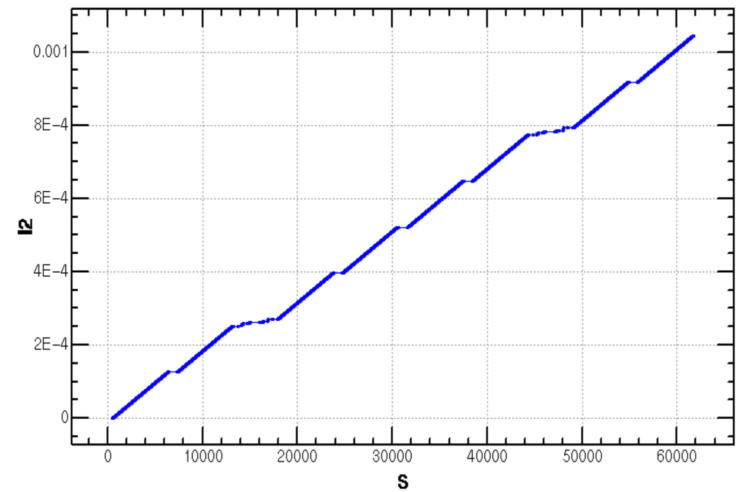


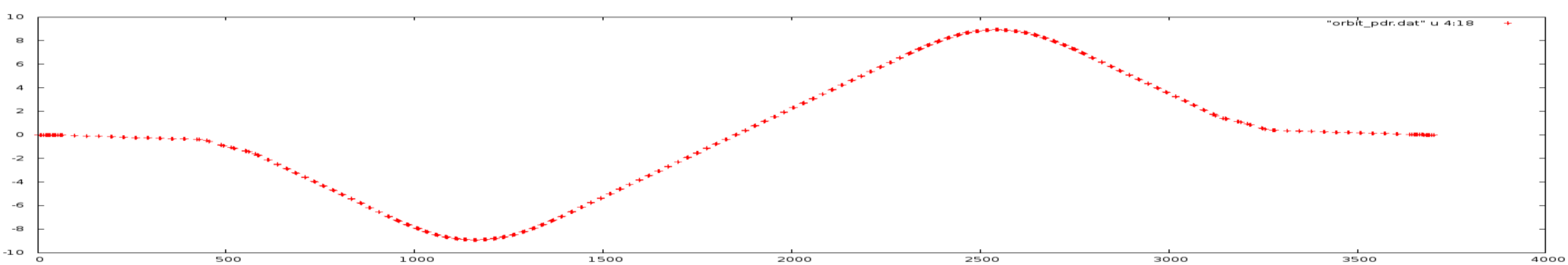
Emittance Increase (2.06nm->2.1668nm)











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

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

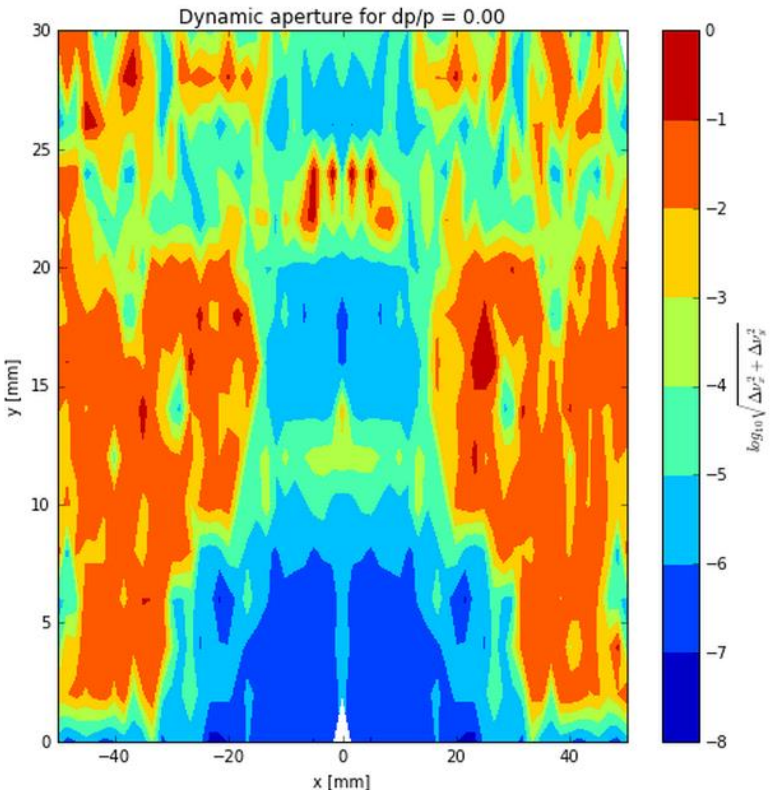
SF1.K2
SF2.K2
SF3.K2
SF4.K2
SF5.K2
SF6.K2

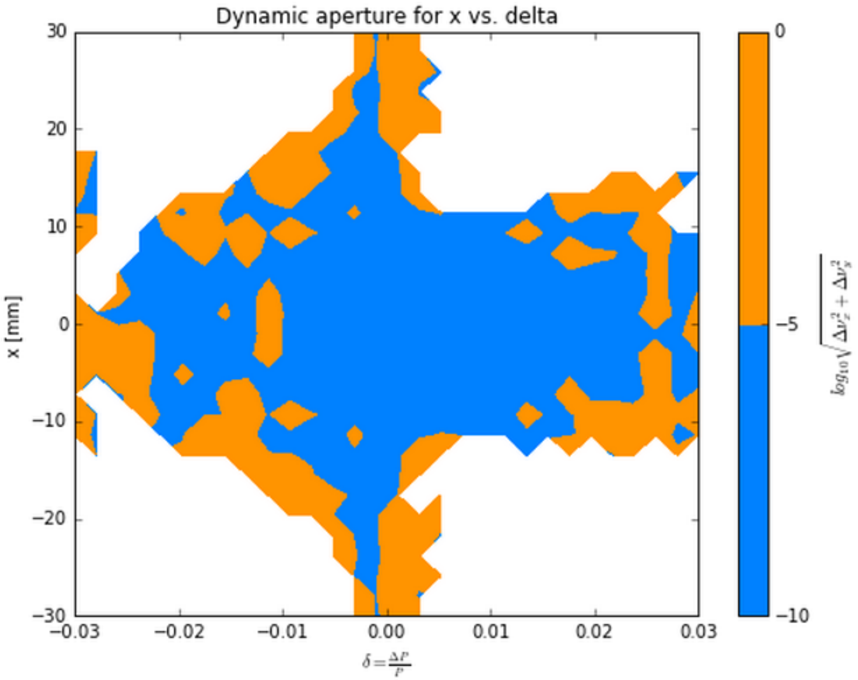
SD1.K2
SD2.K2
SD3.K2
SD4.K2
SD5.K2
SD6.K2

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)



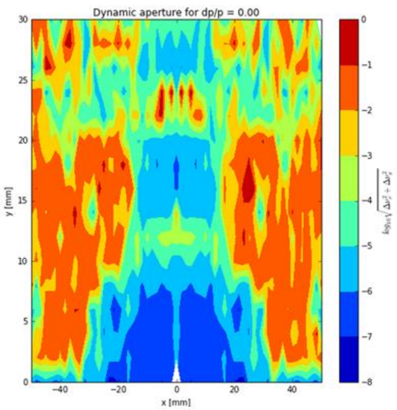


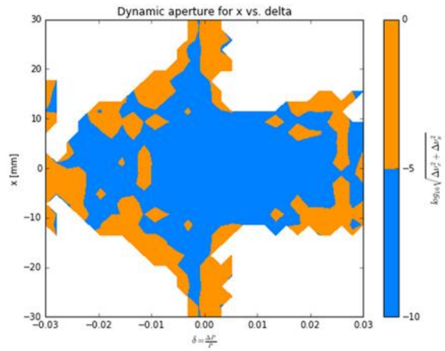
Betx： 80.992367
bety： 14.172123
2nm
Sizmax： 402.47um
Sigmay： 9.22um

X： 60 Sigma
Y： 813 Sigma

2 groups

Nonlinear Driving Term (ARC)



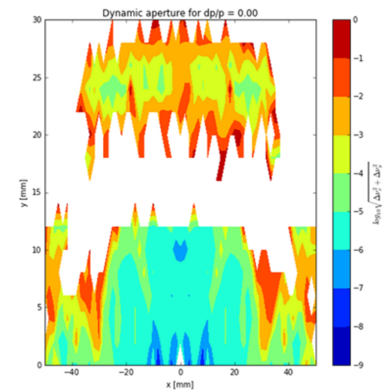


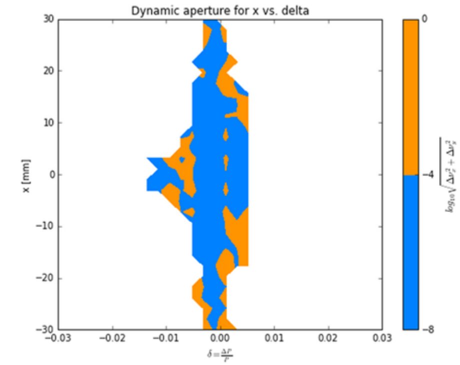
Betx: 80.992367
bety: 14.172123
2nm
Sizmax: 402.47um
Sigmay: 9.22um

X: 60 Sigma
Y: 813 Sigma

2 groups

Nonlinear Driving Term (ARC-20160630)



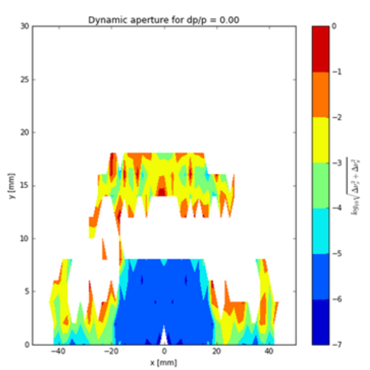


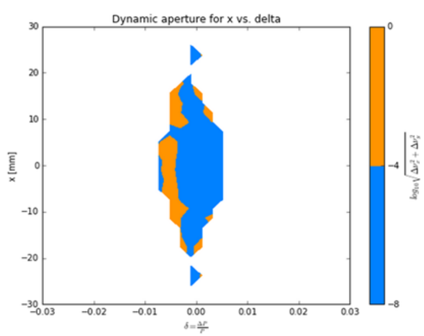
Betx: 80.992367
bety: 14.172123
2nm
Sizmax: 402.47um
Sigmay: 9.22um

X: 60 Sigma
Y: 813 Sigma

96 groups

Nonlinear Driving Term (ARC-20160707)



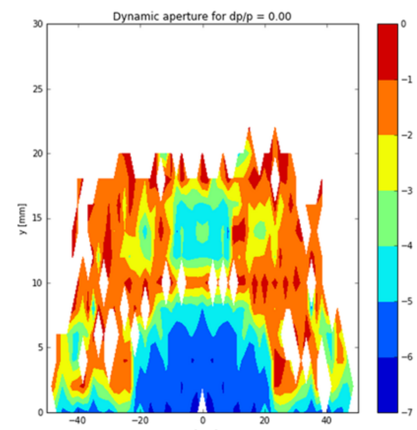


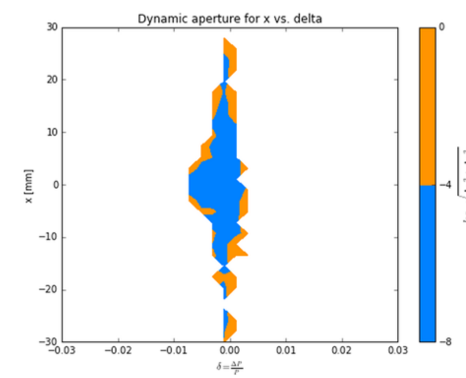
Betx: 80.992367
bety: 14.172123
2nm
Sizmax: 402.47um
Sigmay: 9.22um

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

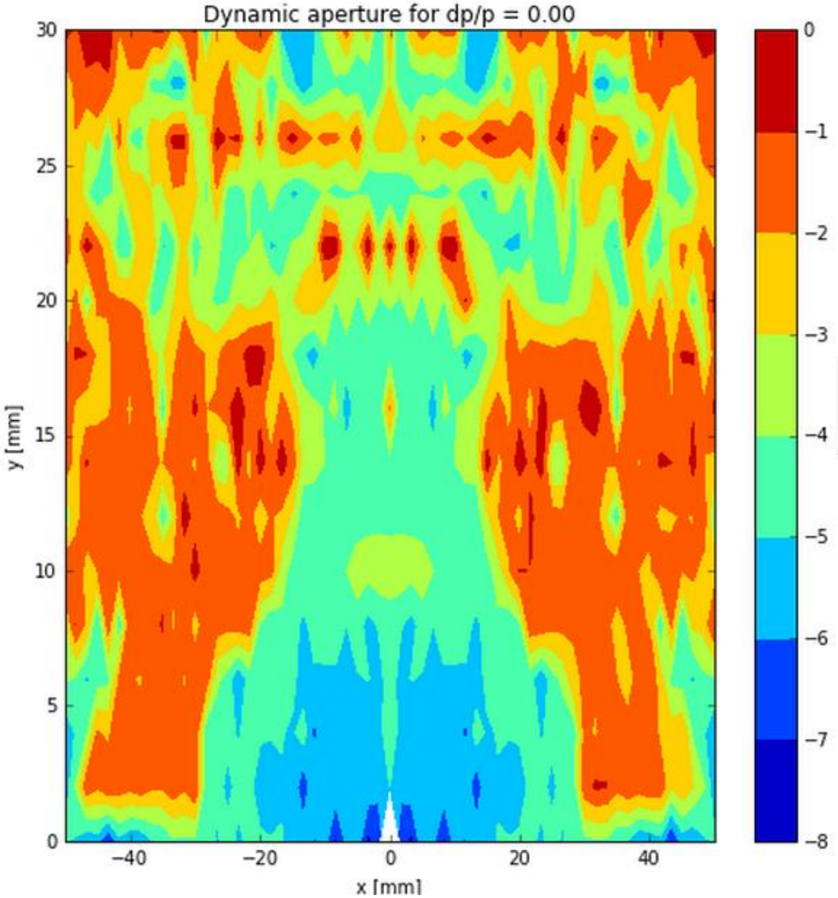
Nonlinear Driving Term (ARC)

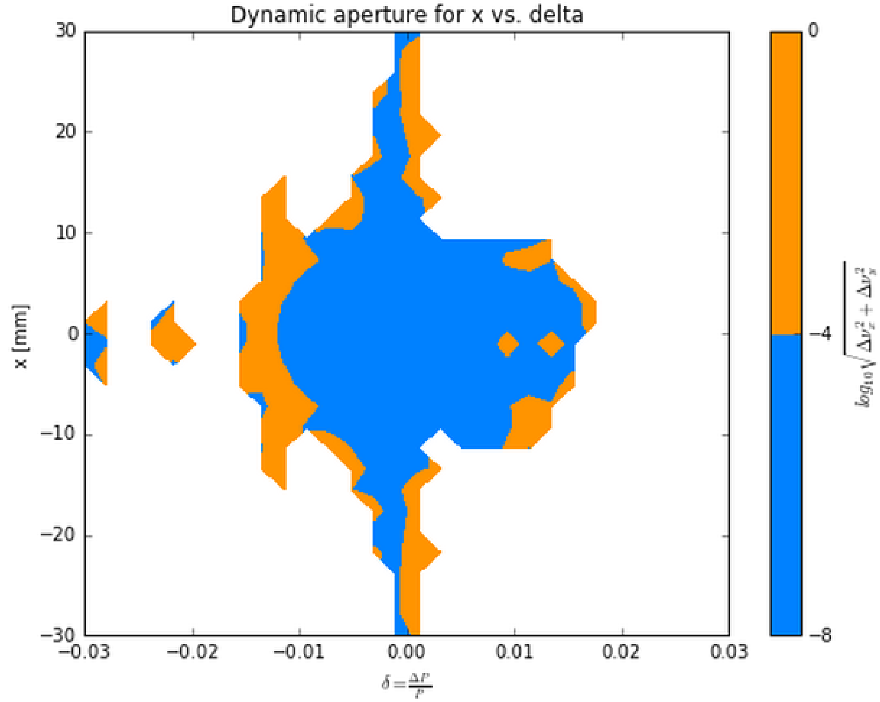
```
In [7]: cepc.ring.geth1()
        cepc.ring.h1

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': (-6.7117007239114013e-06+2.4007420051930239e-08j),
         'h11002': (-5459.1975174445843+3.0300657816173526e-12j),
         'h11110': (7.6489916699494385e-06+4.3427621676528361e-07j),
         'h22000': (-8.6121626494394287e-06-9.2768459580838868e-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)

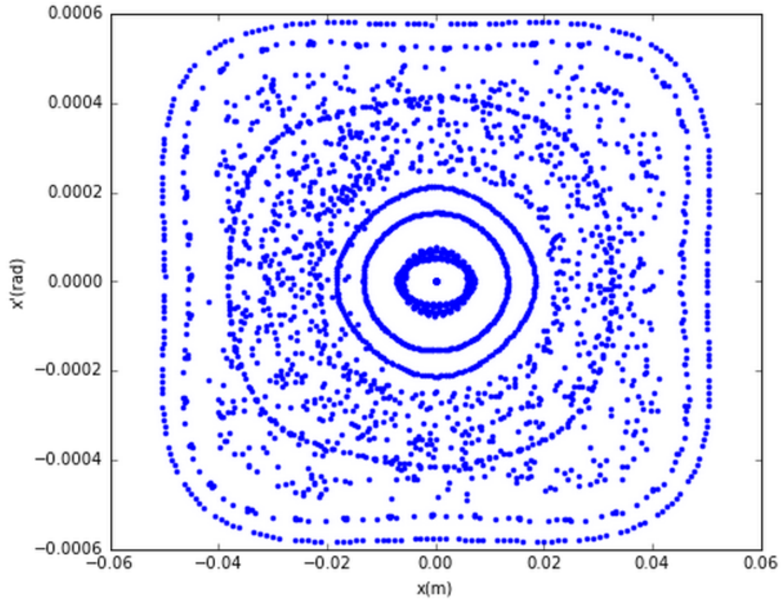


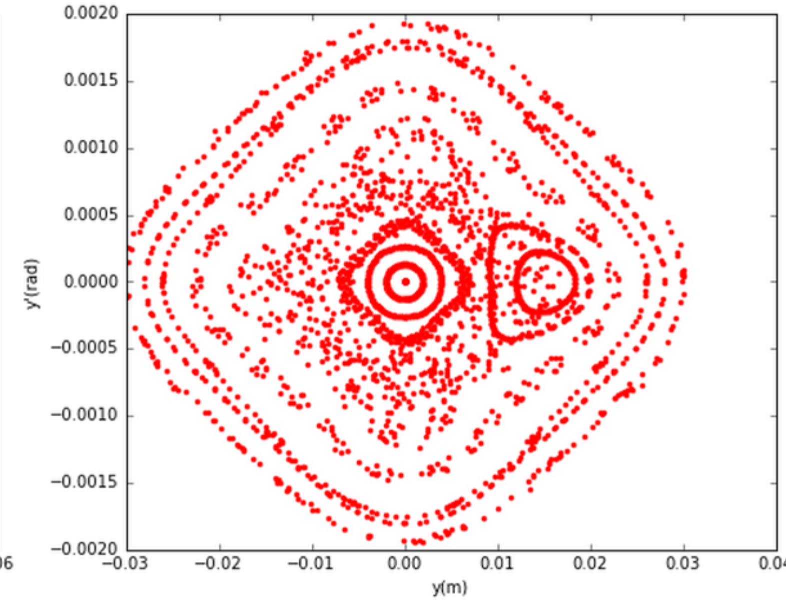


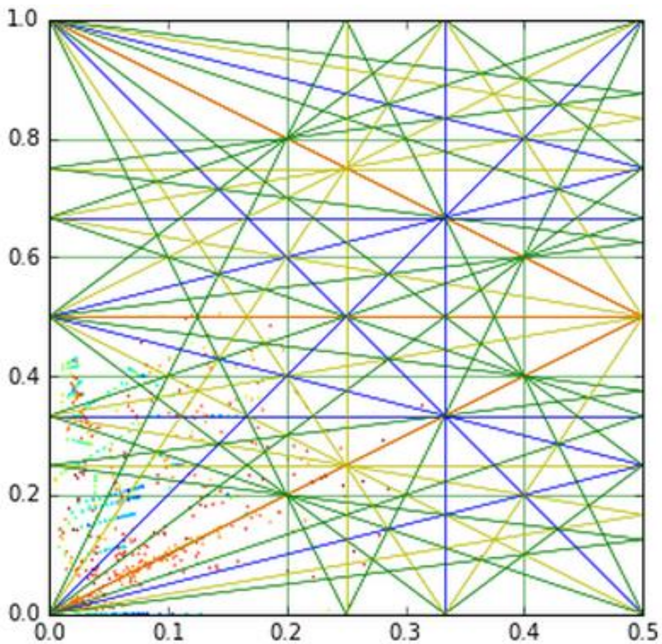
Betx： 80.992367
bety： 14.172123
2nm
Sizmax： 402.47um
Sigmay： 9.22um

X： 45 Sigma
Y： 780 Sigma

2 groups







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

Out[3]: {'h00111': (5.742221251626866+0j), 'h11001': (5.6703595956706225+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)}
```

4. CEPC APDR Scheme

New idea：APDR

IHEP-AC-LC-Note2016-002

ILC-物理-2016-02

May 20th, 2016

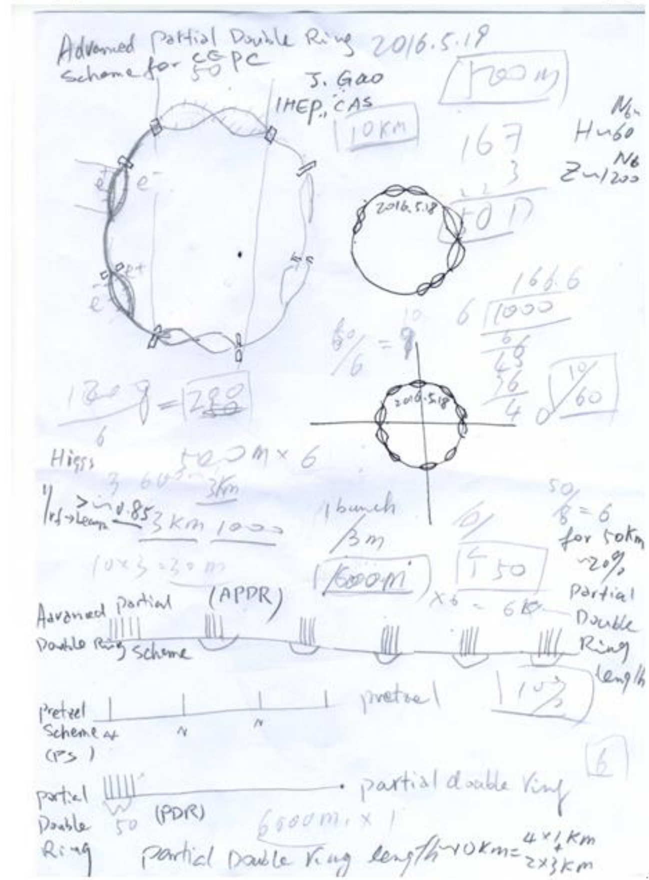
The advanced partial double ring scheme for CEPC

GAO Jie（高杰）

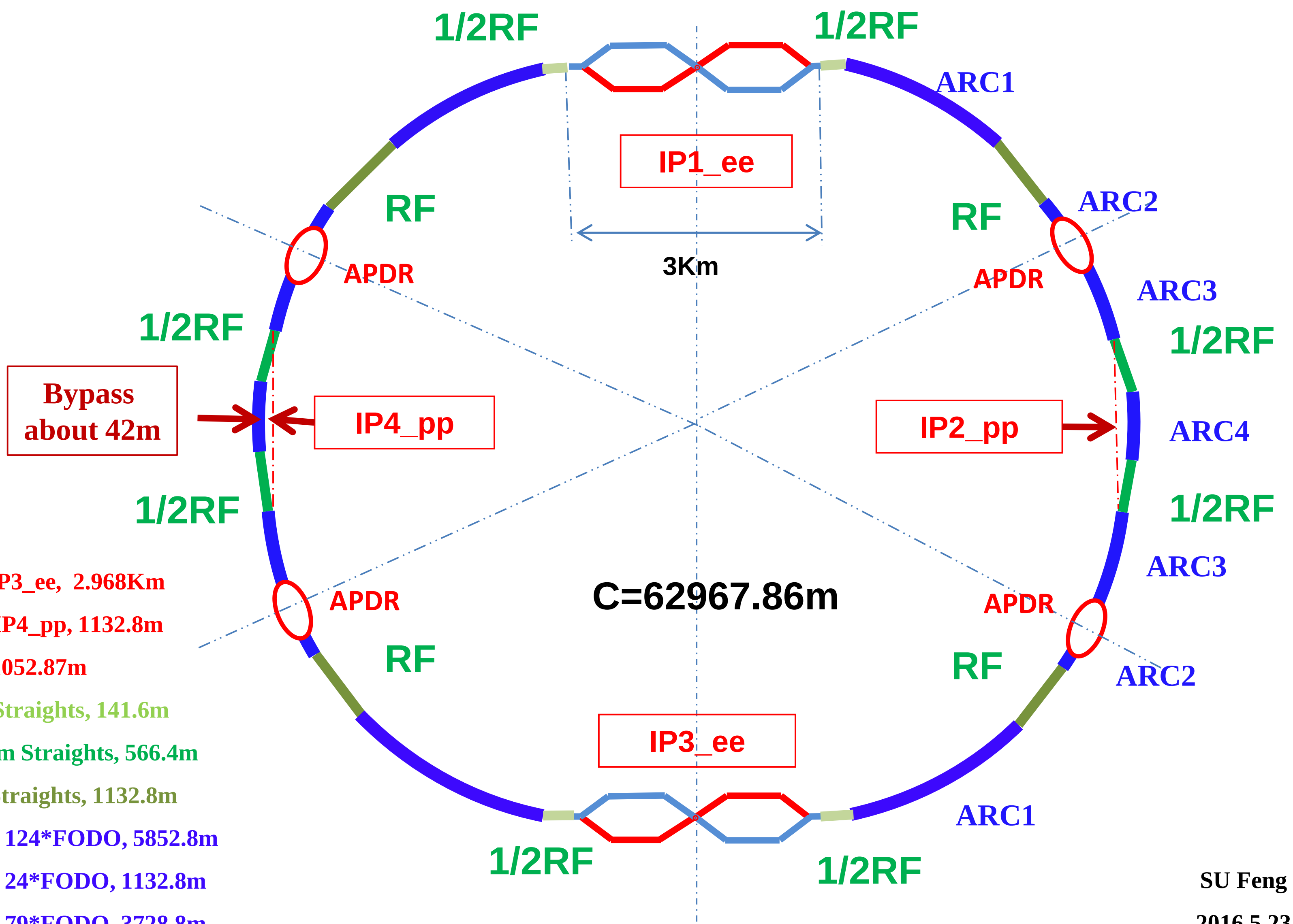
ILC Group, Accelerator Center

Institute of High Energy Physics (IHEP), Beijing

中國科學院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences



CEPC Advanced Partial Double Ring Layout 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

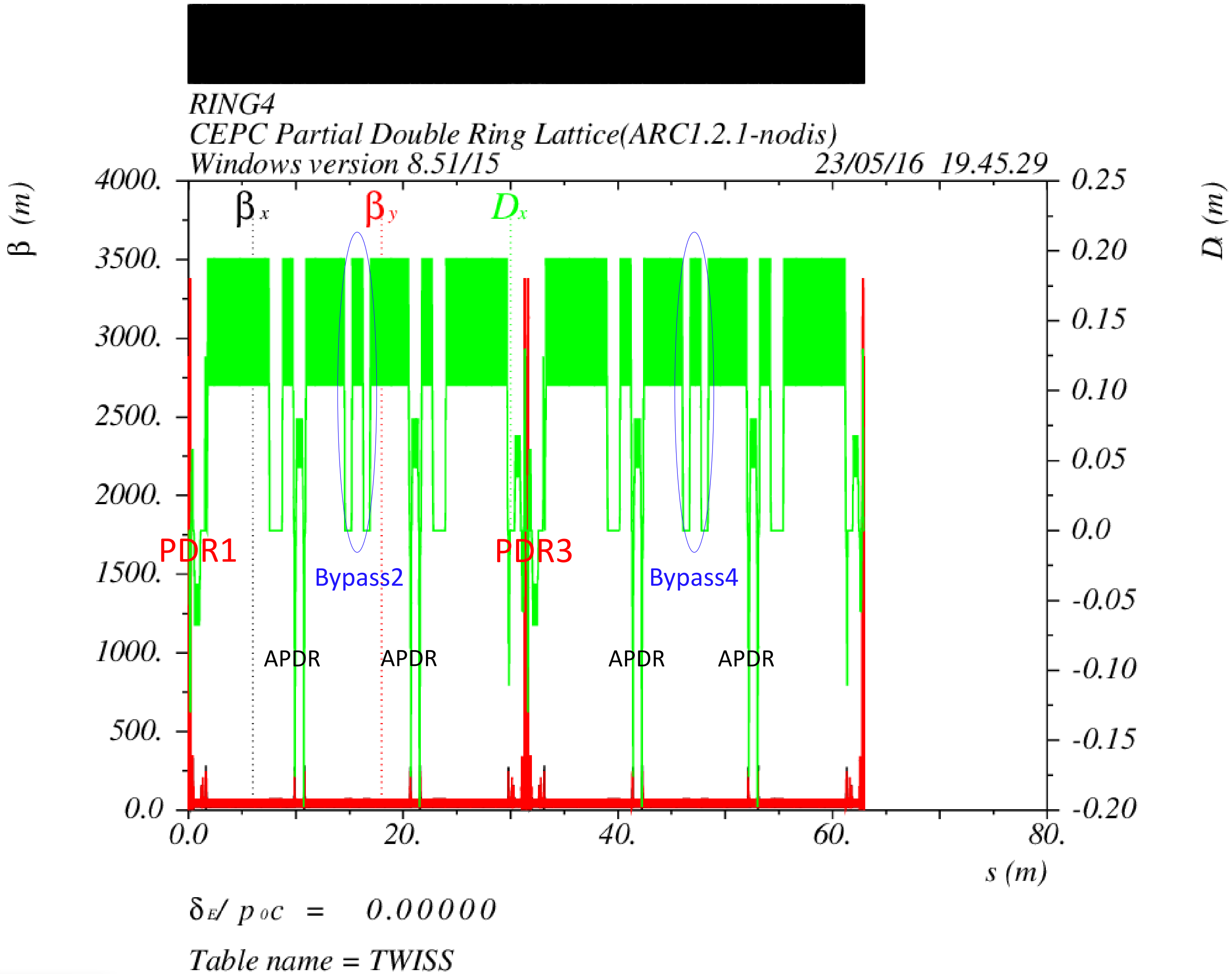
4 ARC3, 79*FODO, 3728.8m

2 ARC4, 24*FODO, 1132.8m

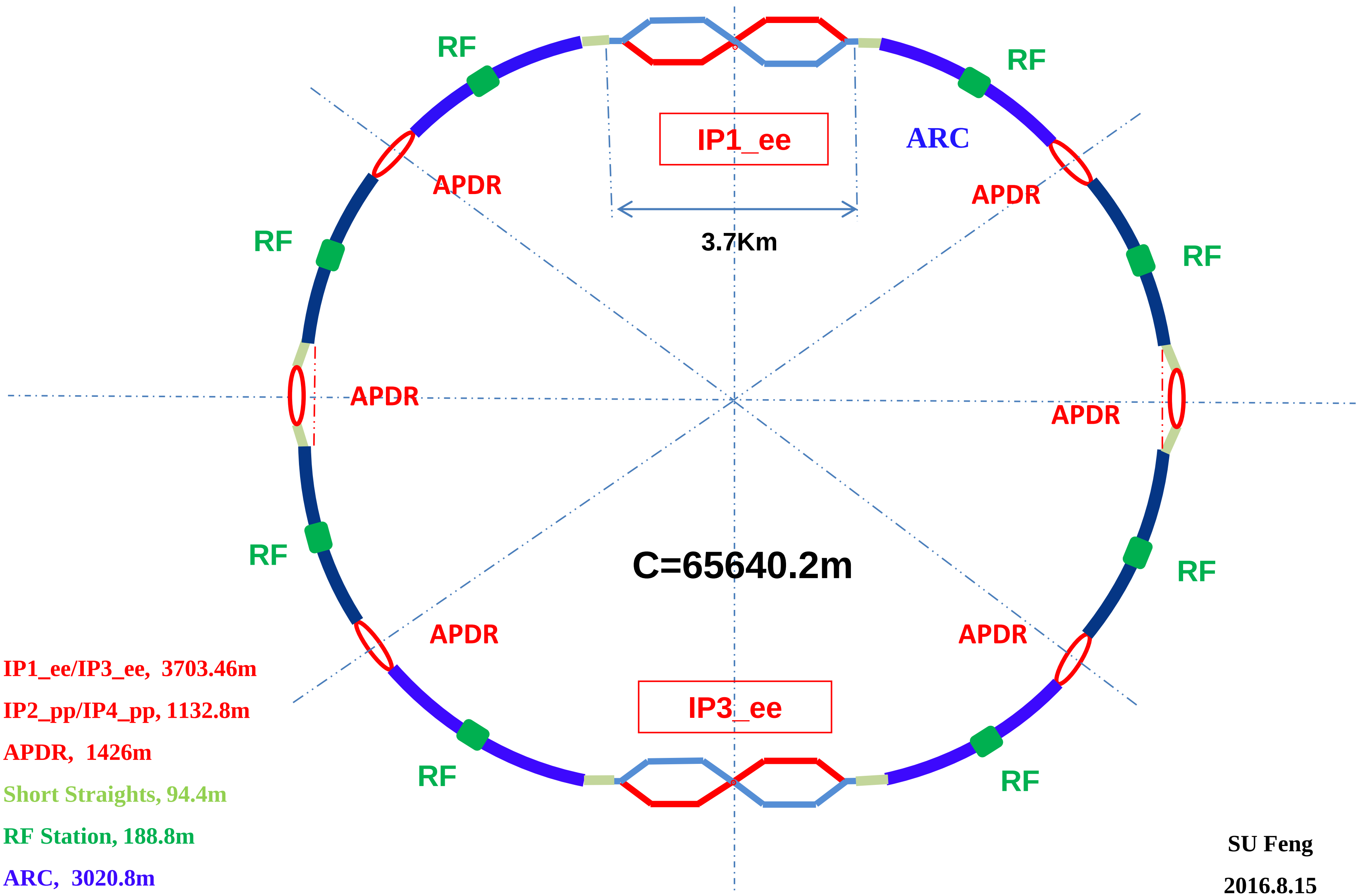
SU Feng

2016.5.23

CEPC Advanced Partial Double Ring Optics I



CEPC Advanced Partial Double Ring Layout II



IP1_ee/IP3_ee, 3703.46m

IP2_pp/IP4_pp, 1132.8m

APDR, 1426m

Short Straights, 94.4m

RF Station, 188.8m

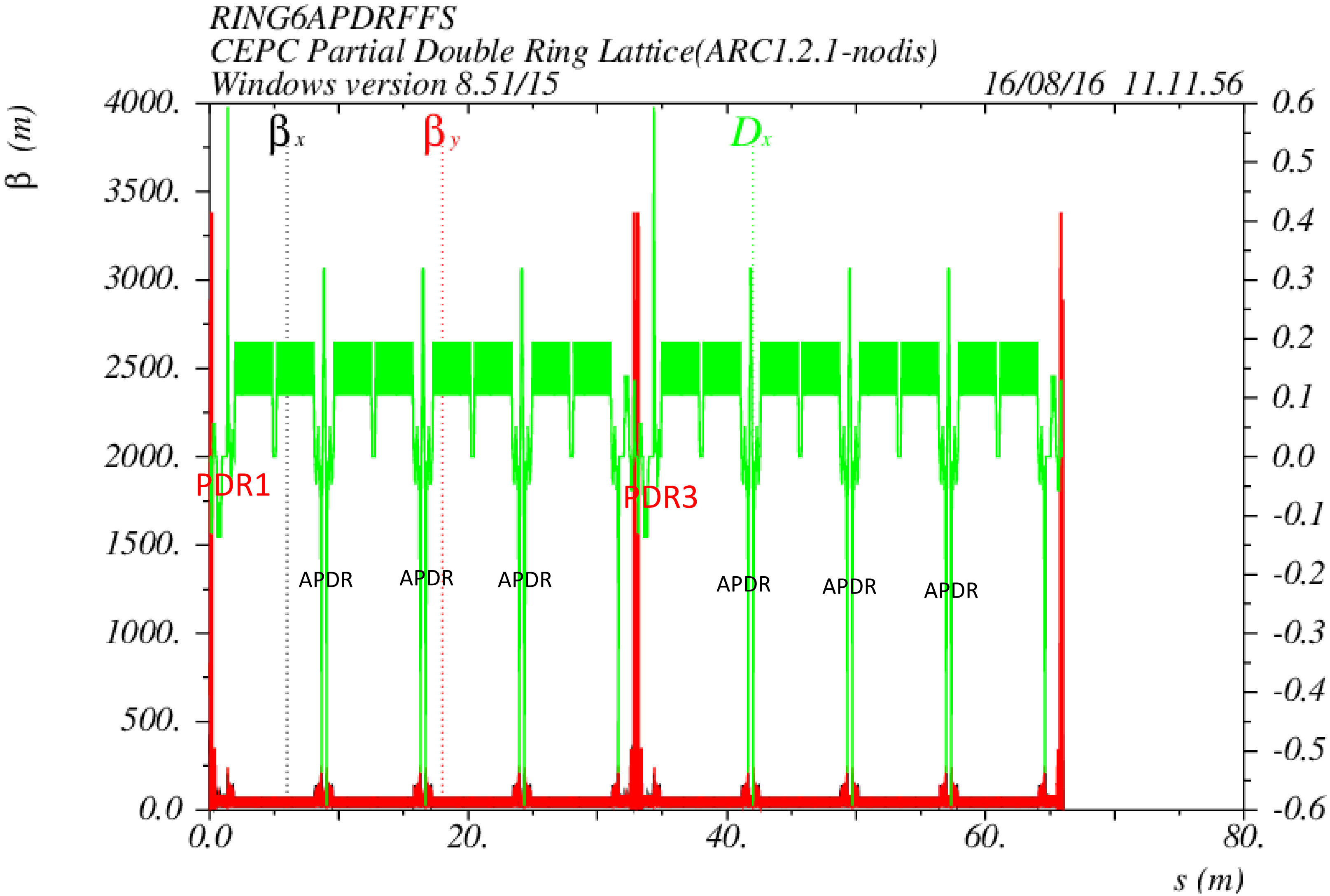
ARC, 3020.8m

SU Feng

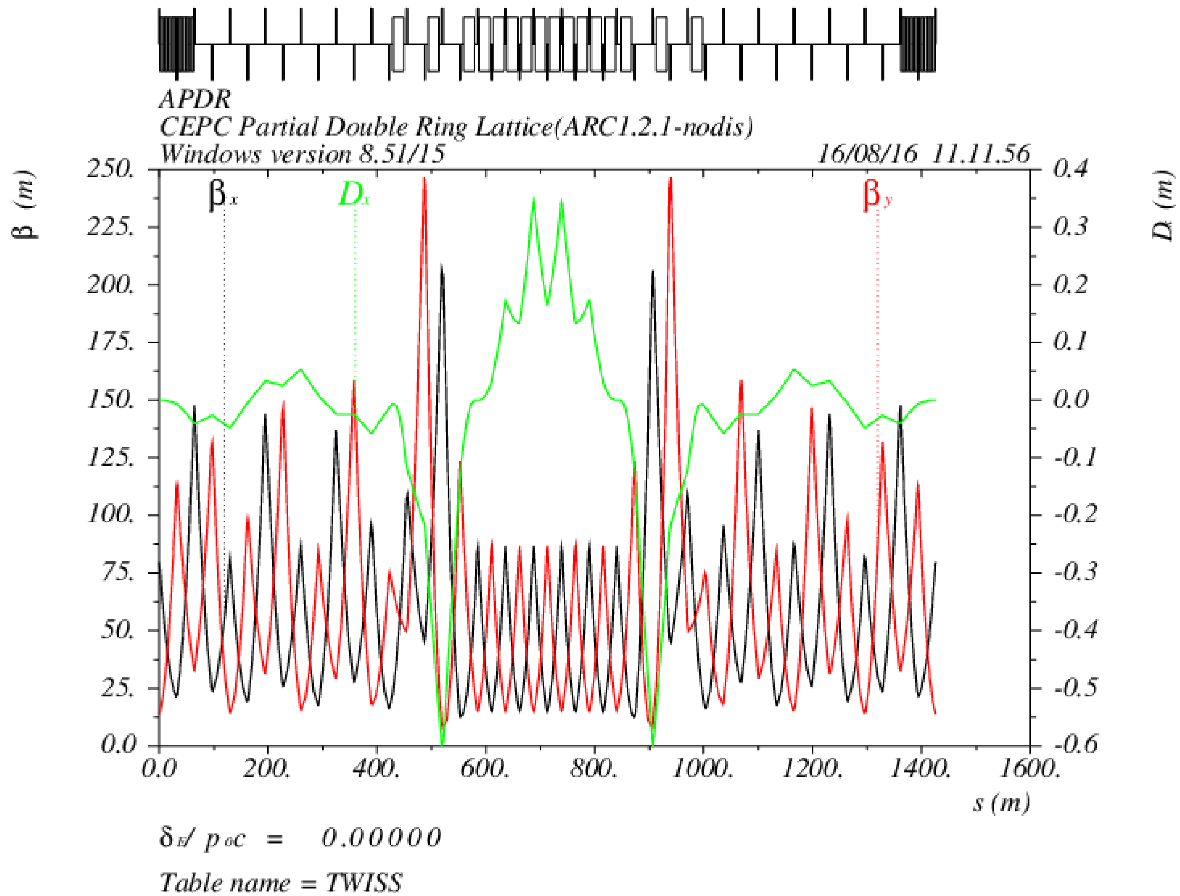
2016.8.15

CEPC Advanced Partial Double Ring Optics II

[redacted]

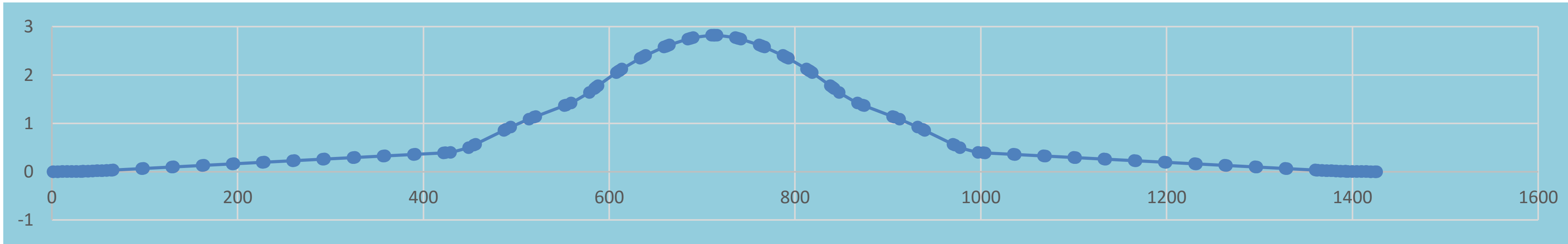


APDR Part

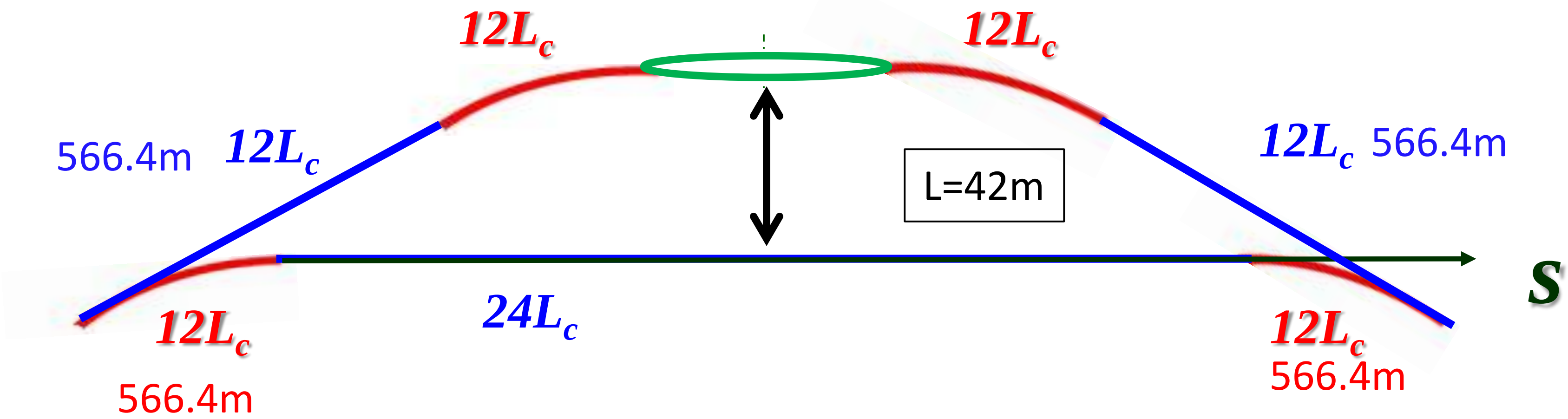


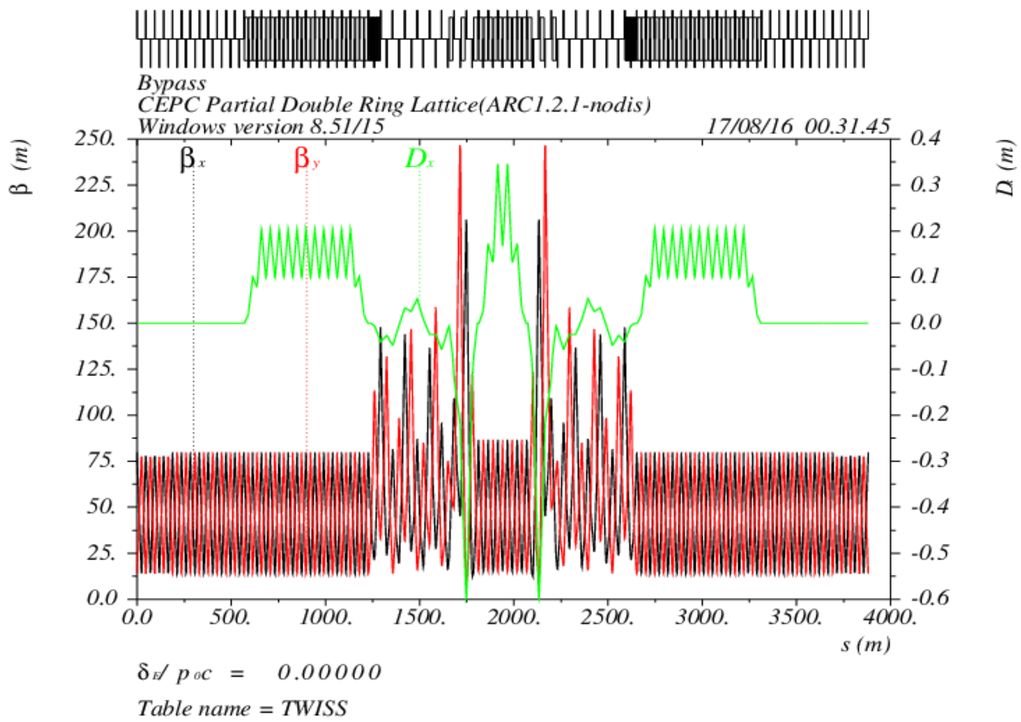
Need update

1426m



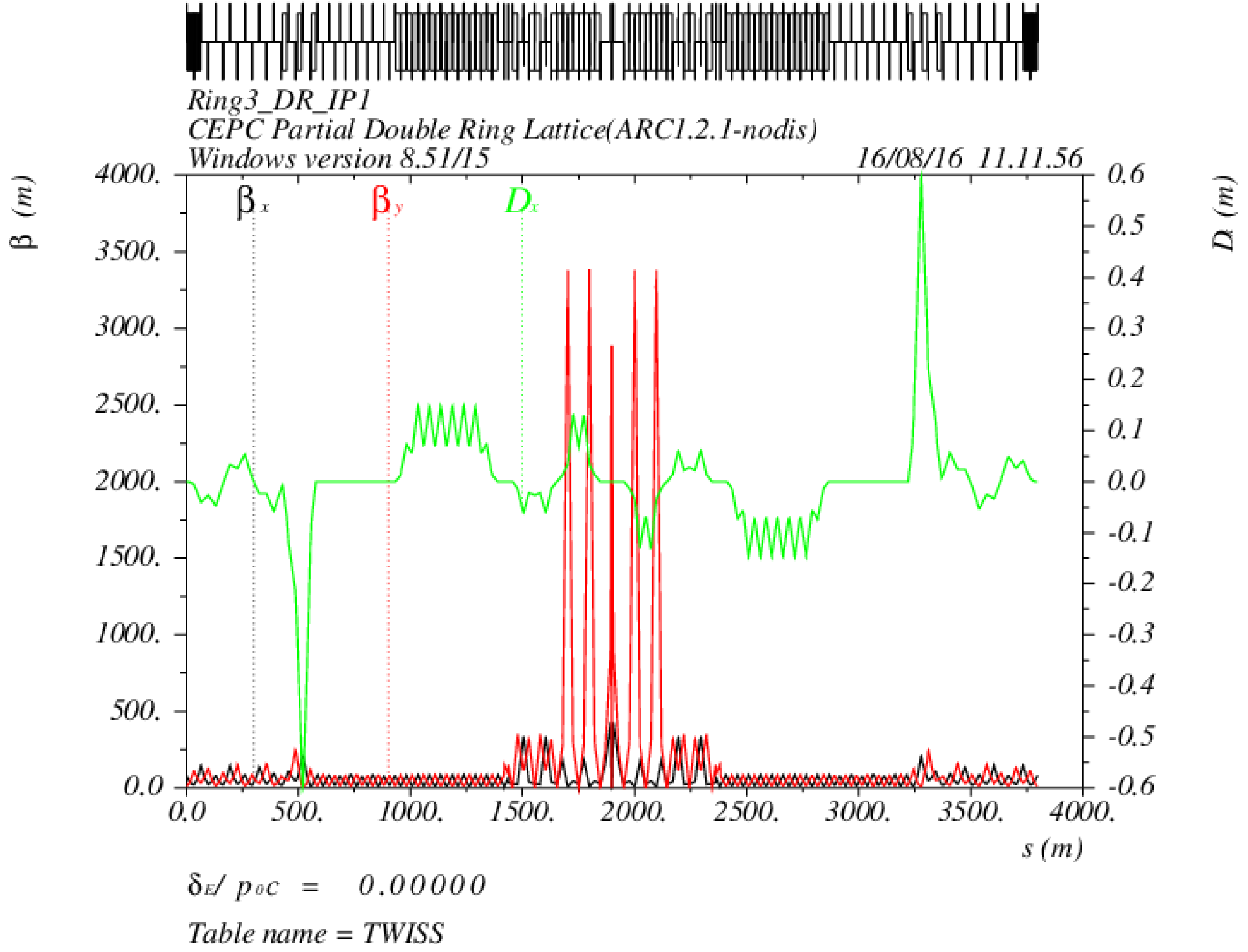
Bypass Part at IP2/4





Cell length=47.2m

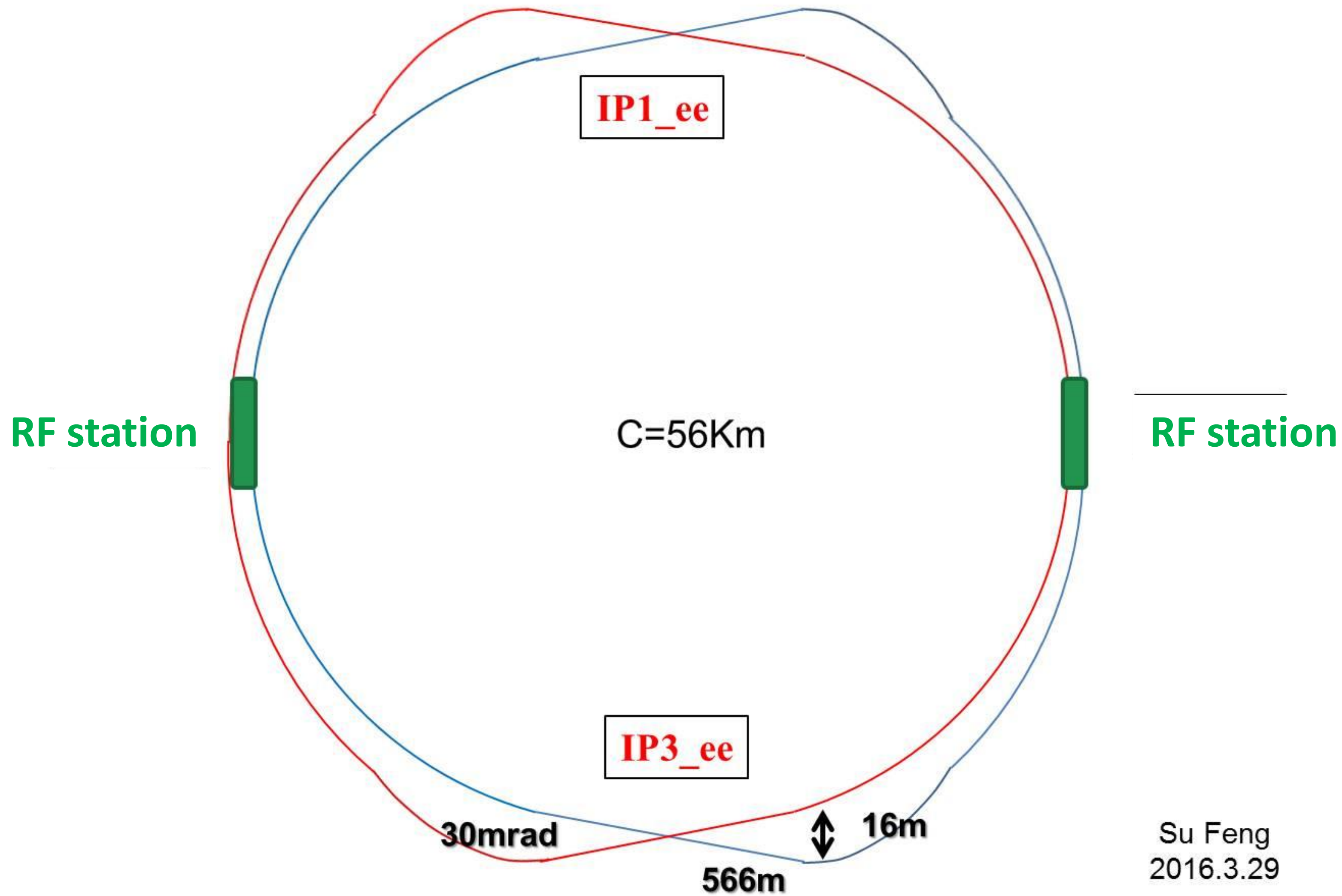
PDR Part



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)
β_x
β_y
D_x
D (m)
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

5. CEPC Double Ring Scheme

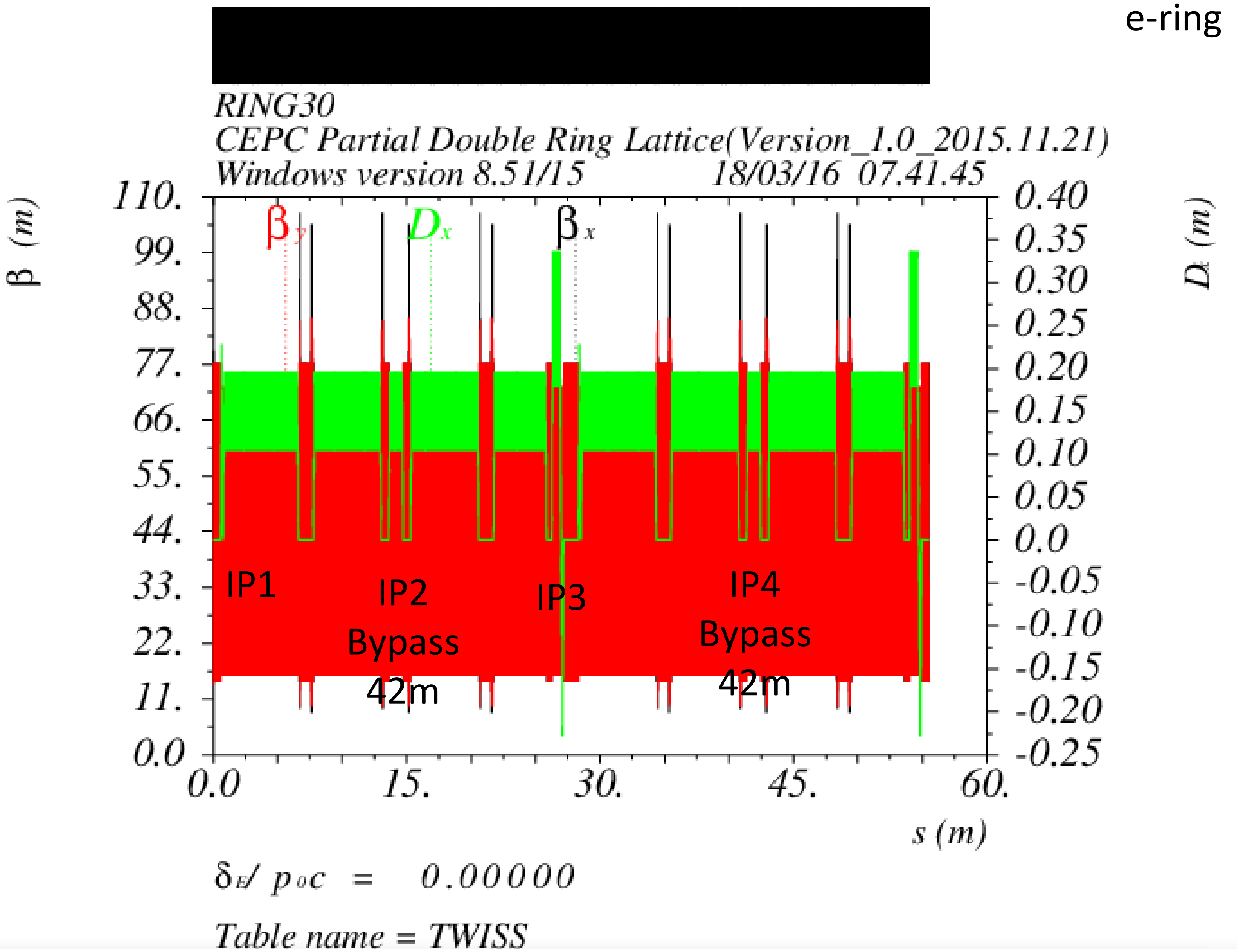
CEPC Double Ring Scheme Layout



Su Feng
2016.3.29

Double Ring Scheme

e-ring



6. Summary

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.
- We may divide the sextupoles into more families to optimize the DA.
- The linear lattice of PDR may also be optimized.

中国科学院高能物理研究所
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SPPC Parameter Choice and Lattice Design

Feng Su, Jie Gao, Yukai Chen, Jingyu Tang, Dou Wang

Yiwei Wang, Sha Bai, Tianjian Bian, Dengjie Xiao

International Symposium on Higgs Boson and Beyond Standard Model Physics

Shandong University, Weihai, August 18, 2016

Outline

1. SPPC Parameter Choice and Optimize
2. SPPC Lattice Layout and Consideration
3. SPPC Lattice Design:
   a. FODO Cell and ARC
   b. Dispersion Suppressor Section
   c. Long Straight Section
   d. IR
4. SPPC Dynamic Aperture Study
5. Summary

1. SPPC Parameter Choice and Optimize

SPPC ARC Parameter Choice

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

$L_B = 14.8\ \mathrm{m}$

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

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

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

$\boxed{L1 = 52981.42}$

$C0 = 59581.42$

SPPC Parameter Choice and Optimize

Table 1: SPPC Parameter List.

Version 201503

	SPPC(Pre-CDR)	SPPC-54.7Km	SPPC-100Km	SPPC-100Km	SPPC-78Km
Main parameters and geometrical aspects					
Beam energy[E_0]/TeV	35.6	35.0	50.0	68.0	50.0
Circumference[C_0]/km	54.7	54.7	100.0	100.0	78.0
Dipole field[B]/T	20	19.69	14.73	20.03	19.49
Dipole curvature radius[ρ]/m	5928	5922.6	11315.9	11315.9	8549.8
Bunch filling factor[f_2]	0.8	0.8	0.8	0.8	0.8
Arc filling factor[f_1]	0.79	0.79	0.79	0.79	0.79
Total dipole length [L_{Dipole}]/m	37246	37213	71100	71100	53720
Arc length[L_{ARC}]/m	47146	47105	90000	90000	68000
Straight section length[L_{ss}]/m	7554	7595	10000	10000	10000
Physics performance and beam parameters					
Peak luminosity per IP[L]/ $cm^{-2}s^{-1}$	1.1×10^{35}	1.2×10^{35}	1.52×10^{35}	1.02×10^{36}	1.52×10^{35}
Beta function at collision[β^*]/m	0.75	0.85	0.97	0.24	1.06
Max beam-beam tune shift per IP[ξ_y]	0.006	0.0065	0.0067	0.008	0.0073
Number of IPs contribut to ΔQ	2	2	2	2	2
Max total beam-beam tune shift	0.012	0.013	0.0134	0.016	0.0146
Circulating beam current[I_b]/A	1.0	1.024	1.024	1.024	1.024
Bunch separation[Δt]/ns	25	25	25	25	25
Number of bunches[n_b]	5835	5835	10667	10667	8320
Bunch population[N_p] (10^{11})	2.0	2.0	2.0	2.0	2.0
Normalized RMS transverse emittance[ε]/μm	4.10	3.72	3.65	3.05	3.36
RMS IP spot size[σ^*]/μm	9.0	8.85	7.85	3.04	7.86
Beta at the 1st parasitic encounter[$\beta 1$]/m	19.5	18.70	16.51	64.1	15.36
RMS spot size at the 1st parasitic encounter[σ_1]/μm	45.9	43.2	33.6	51.9	31.14
RMS bunch length[σ_z]/mm	75.5	56.5	65	15.8	70.6
Full crossing angle[θ_c]/μrad	146	138	108	166	99
Reduction factor according to cross angle[F_{ca}]	0.8514	0.9257	0.9248	0.9283	0.9248
Reduction factor according to hour glass effect[F_h]	0.9975	0.9989	0.9989	0.9989	0.9989
Energy loss per turn[U_0]/MeV	2.10	1.97	4.30	14.7	5.69
Critical photon energy[E_c]/keV	2.73	2.60	3.97	9.96	5.25
SR power per ring[P_0]/MW	2.1	2.0	4.4	15.1	5.82
Transverse damping time [τ_x]/h	1.71	1.80	2.15	0.86	1.27
Longitudinal damping time [τ_ε]/h	0.85	0.90	1.08	0.43	0.635

SPPC Parameter Choice and Optimize

Table 1: SPPC Parameter List. **Version 201607**

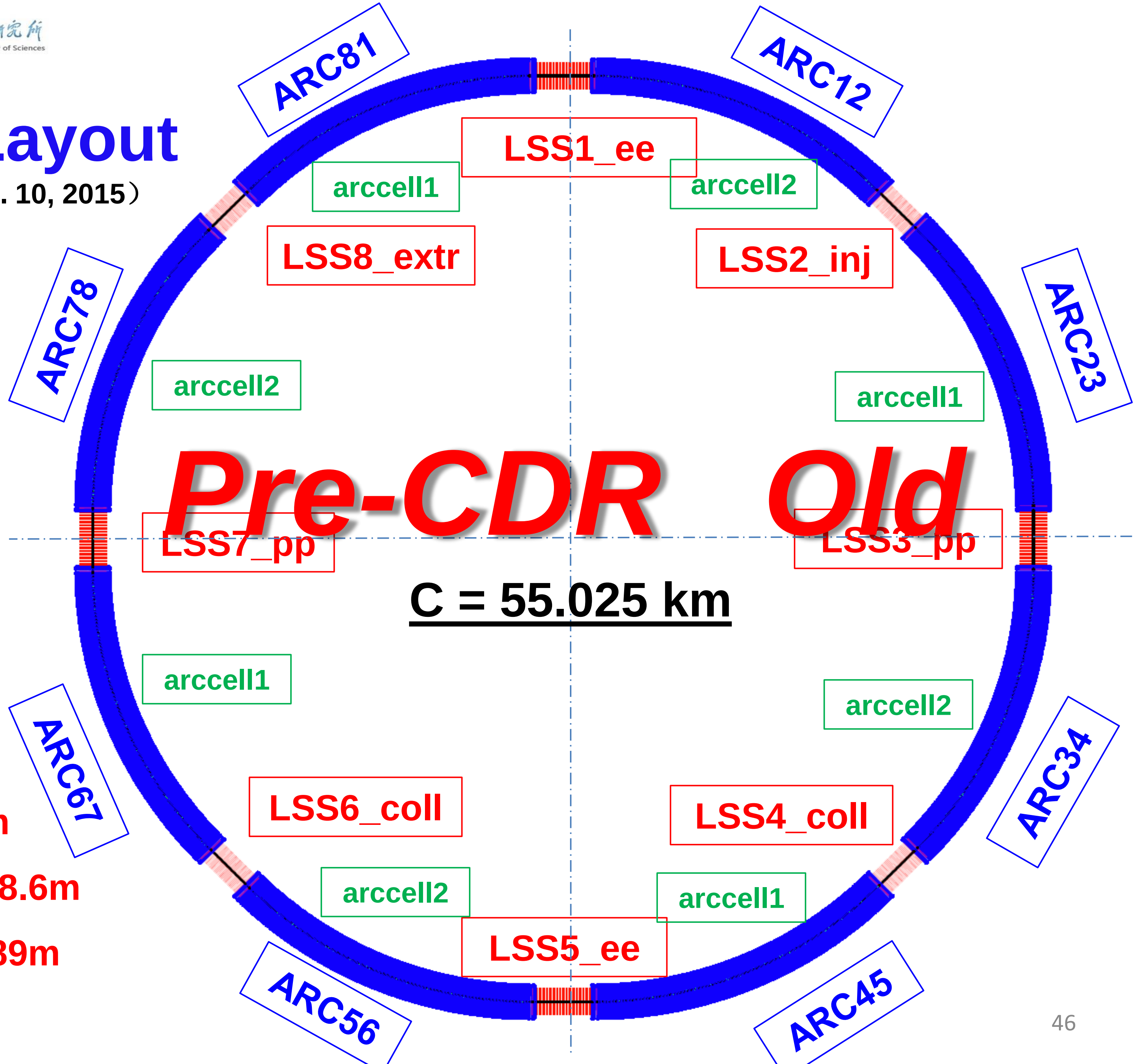
	SPPC(Pre-CDR)	SPPC-59.2Km	SPPC-100Km	SPPC-100Km	SPPC-80Km
Main parameters and geometrical aspects					
Beam energy[E_0]/TeV	35.6	35.0	50.0	65.0	50.0
Circumference[C_0]/km	54.7	59.2	100.0	100.0	80.0
Dipole field[B]/T	20	19.70	15.52	19.83	19.74
Dipole curvature radius[ρ]/m	5928	5921.5	10924.4	10924.4	8441.6
Bunch filling factor[f_2]	0.8	0.8	0.8	0.8	0.8
Arc filling factor[f_1]	0.79	0.78	0.78	0.78	0.78
Total dipole length [L_{Dipole}]/m	37246	37206	68640	68640	53040
Arc length[L_{ARC}]/m	47146	47700	88000	88000	68000
Straight section length[L_{ss}]/m	7554	11500	12000	12000	12000
Physics performance and beam parameters					
Peak luminosity per IP[L]/ $cm^{-2}s^{-1}$	1.1×10^{35}	1.20×10^{35}	1.52×10^{35}	1.02×10^{36}	1.52×10^{35}
Beta function at collision[β^*]/m	0.75	0.85	0.99	0.22	1.06
Max beam-beam tune shift per IP[ξ_y]	0.006	0.0065	0.0068	0.0079	0.0073
Number of IPs contribut to ΔQ	2	2	2	2	2
Max total beam-beam tune shift	0.012	0.0130	0.0136	0.0158	0.0146
Circulating beam current[I_b]/A	1.0	1.024	1.024	1.024	1.024
Bunch separation[Δt]/ns	25	25	25	25	25
Number of bunches[n_b]	5835	6315	10667	10667	8533
Bunch population[N_p] (10^{11})	2.0	2.0	2.0	2.0	2.0
Normalized RMS transverse emittance[ε]/μm	4.10	3.72	3.62	3.10	3.35
RMS IP spot size[σ^*]/μm	9.0	8.85	7.86	3.04	7.86
Beta at the 1st parasitic encounter[$\beta 1$]/m	19.5	18.70	16.36	68.13	15.31
RMS spot size at the 1st parasitic encounter[σ_1]/μm	45.9	43.20	33.31	55.20	31.03
RMS bunch length[σ_z]/mm	75.5	56.60	65.68	14.88	70.89
Full crossing angle[θ_c]/μrad	146	138.23	106.60	176.66	99.28
Reduction factor according to cross angle[F_{ca}]	0.8514	0.9257	0.9247	0.9283	0.9241
Reduction factor according to hour glass effect[F_h]	0.9975	0.9989	0.9989	0.9989	0.9989
Energy loss per turn[U_0]/MeV	2.10	1.97	4.45	12.71	5.76
Critical photon energy[E_c]/keV	2.73	2.60	4.11	9.02	5.32
SR power per ring[P_0]/MW	2.1	2.01	4.56	13.01	5.89
Transverse damping time [τ_x]/h	1.71	1.946	2.08	0.946	1.28
Longitudinal damping time [τ_ε]/h	0.85	0.973	1.04	0.473	0.64

2. SPPC Lattice Layout and Consideration

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

SPPC Layout

（Su Feng, Jul. 10, 2015）



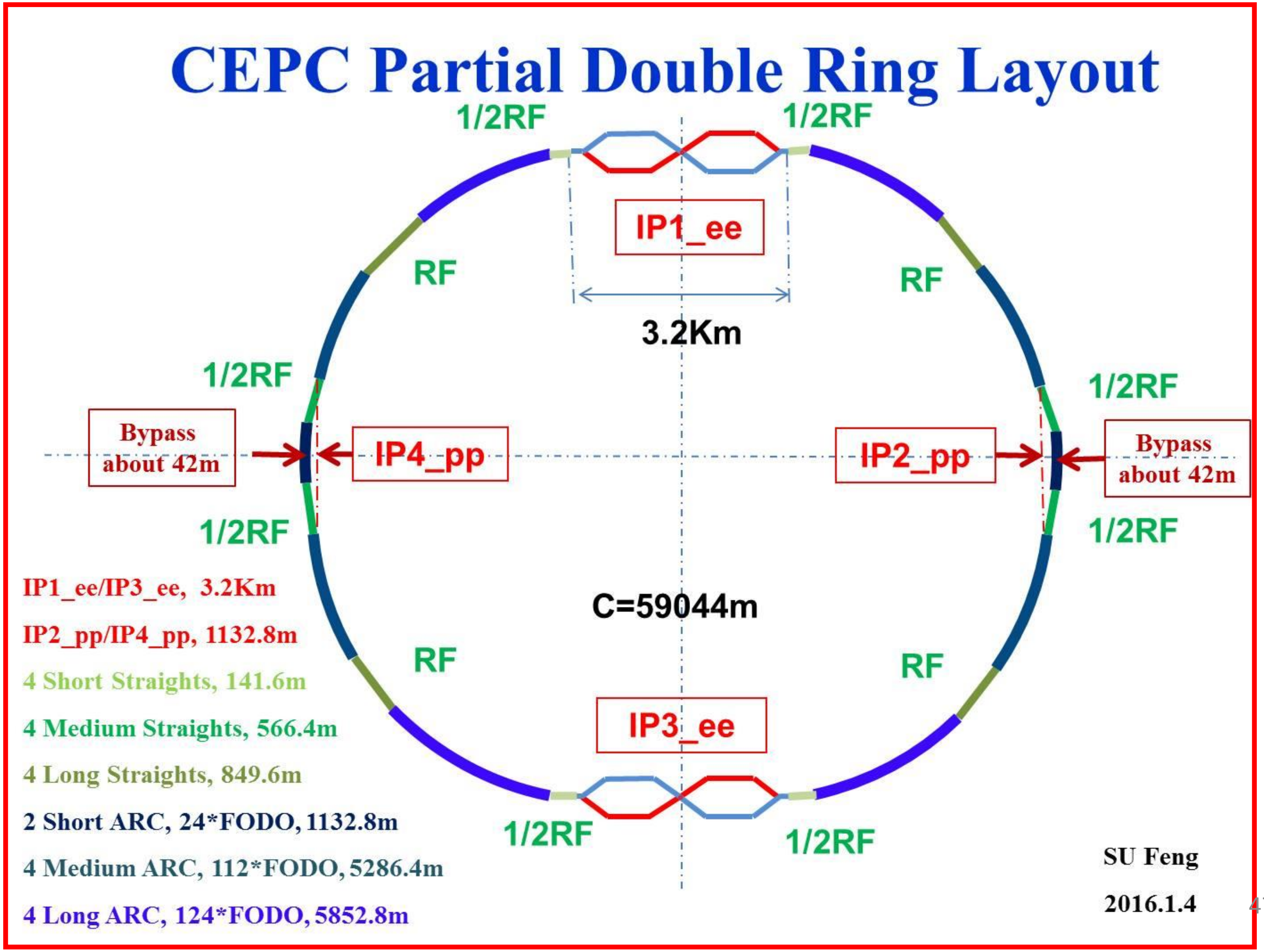
LSS1/5 : 1083m

LSS2/4/6/8 : 938.6m

LSS3/7 : 1070.89m

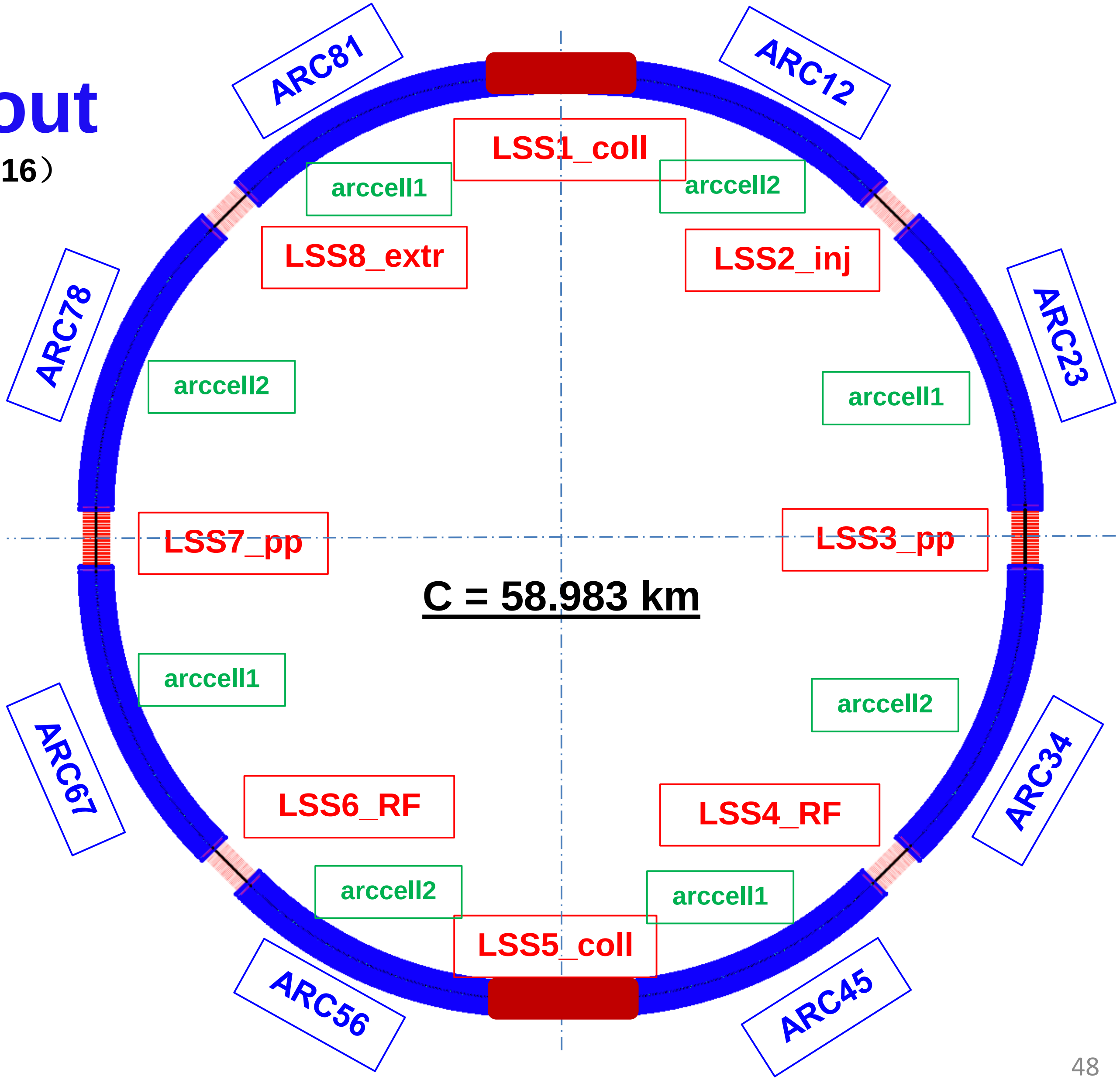
ARC 5920.4m

Consideration of CEPC New Layout with PDR



SPPC Layout

（Su Feng Jan. 10, 2016）



LSS1/5_coll： 3.2Km

LSS2/4/6/8： 788.31m

LSS3/7_pp: 973.83m

ARC: 5963.2m

3. SPPC Lattice Design:

a. FODO Cell and ARC

b. Dispersion Suppressor Section

c. Long Straight Section

d. IR

Parameter Estimate for ARC Cell

Theory:

$E0 = 70 - 100$ TeV

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

$\beta = 1$

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

$B0 = 20$ T

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

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

ARC filling factor $f1 = 0.8$

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

Lss3pp = Lss7pp = 973.83 m

Lss2 = Lss4 = Lss6 = Lss8 = 788.31 m

$\boxed{L1 = 50903.46}$

Lss1 = Lss5 = 3.3 km

C0 = 57503.46 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

$L_B = 14.8$ m

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

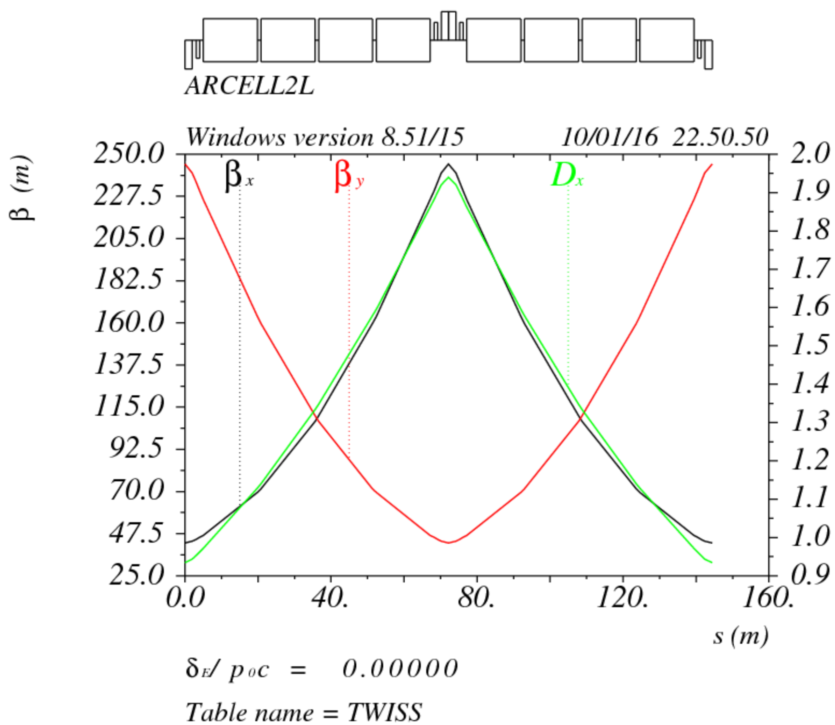
$$ARC: f1 = \frac{14.8*8*38 + 14.8*8*2}{(38+2+2)*144.4} = 0.7809$$

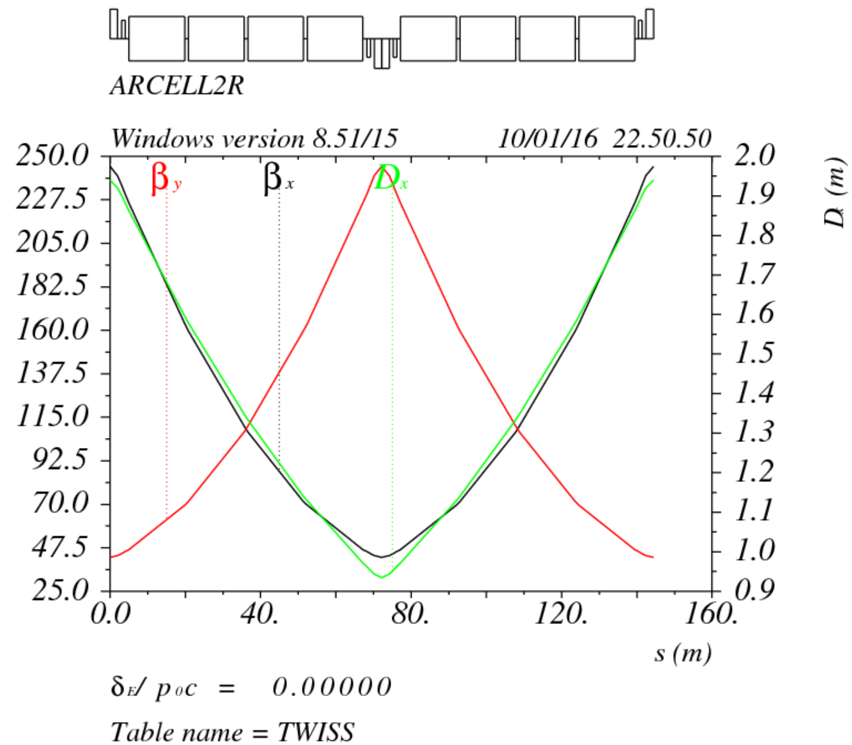
$$L_{ARC} = \frac{37389.85}{0.7809} = 47880.46$$

$\boxed{L1 = 52981.42}$

C0 = 59581.42

FODO Cell in ARC

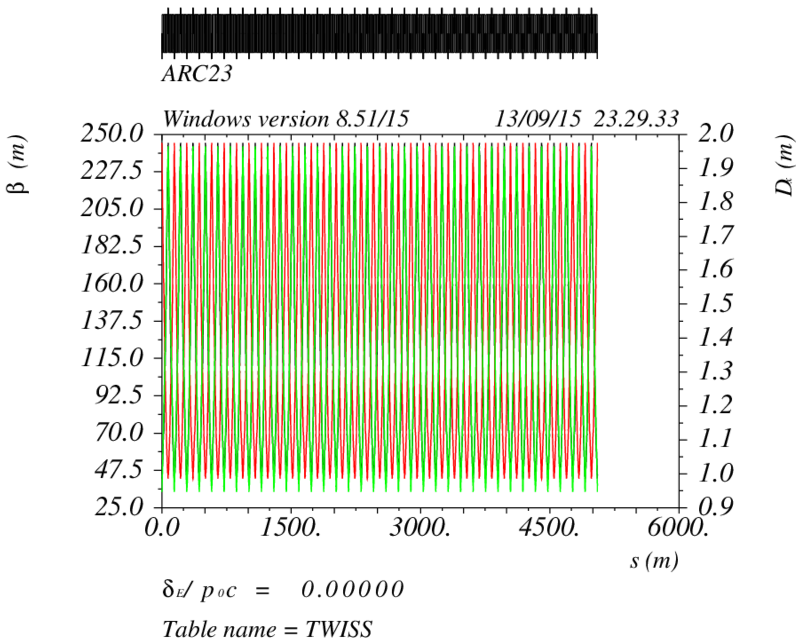


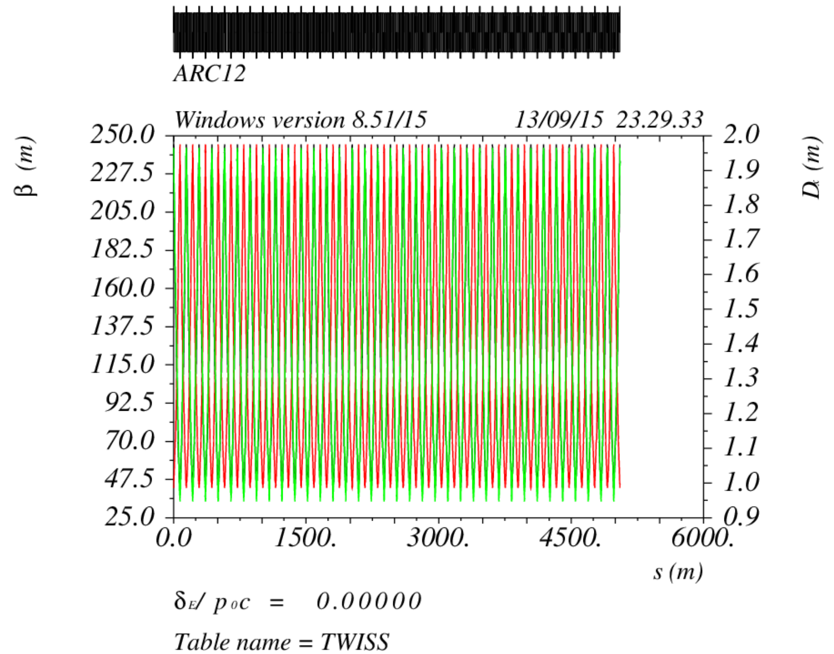


arccell1 | L=144.4m | arccell2

Betax: 244.878/42.57
Betay: 42.569/244.869

ARC (ARCDSPL,36 CELL, ARCDSPR)



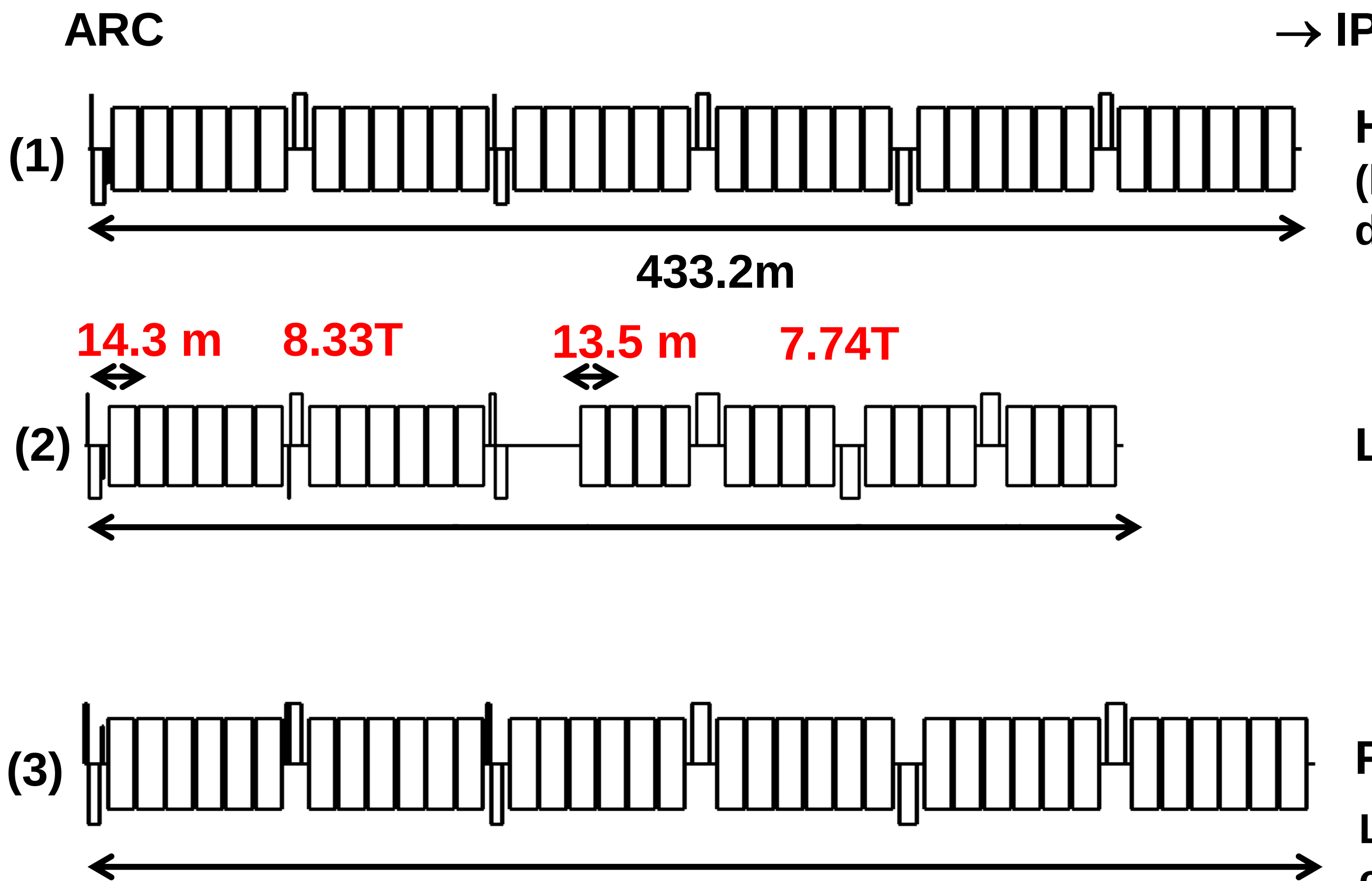


ARC23
ARC45
ARC67
ARC81

L=5963.2m

ARC12
ARC34
ARC56
ARC78

Dispersion Suppressor (DS) types



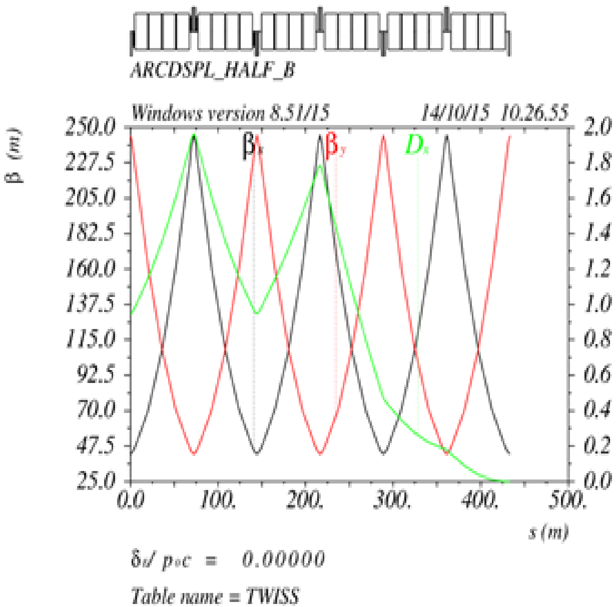
Half Bend
(half weak dipoles)

LHC-like

Full Bend

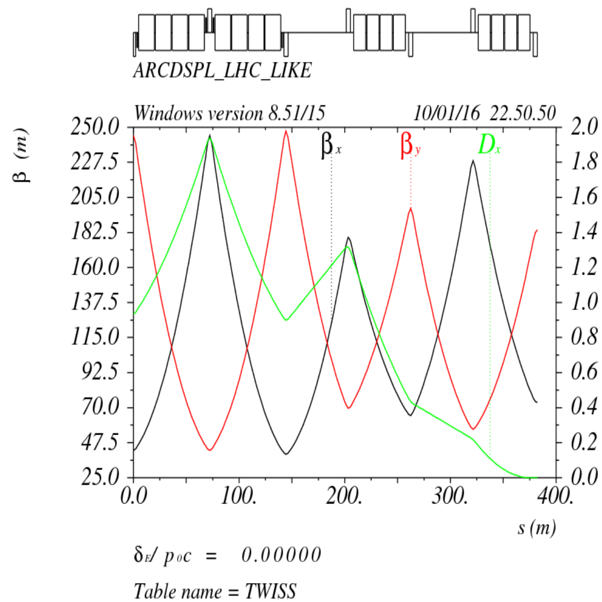
Longer DS but less cells in the Arcs

(1) Half Bend



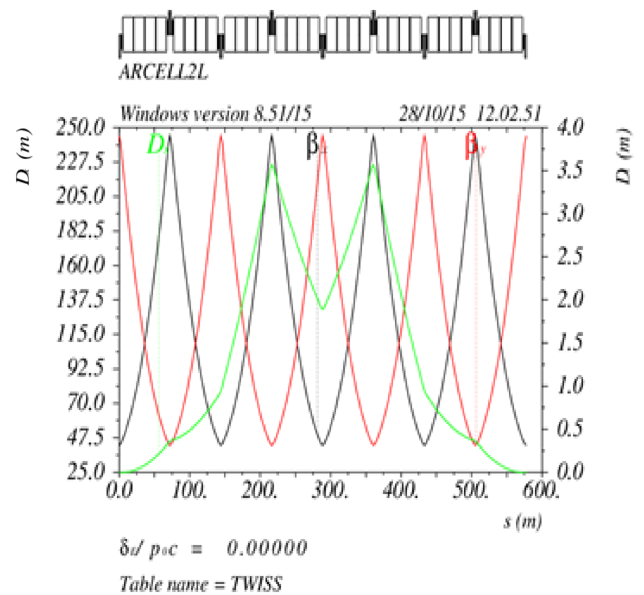
L=433.2m

(2) LHC Like



L=382.4m

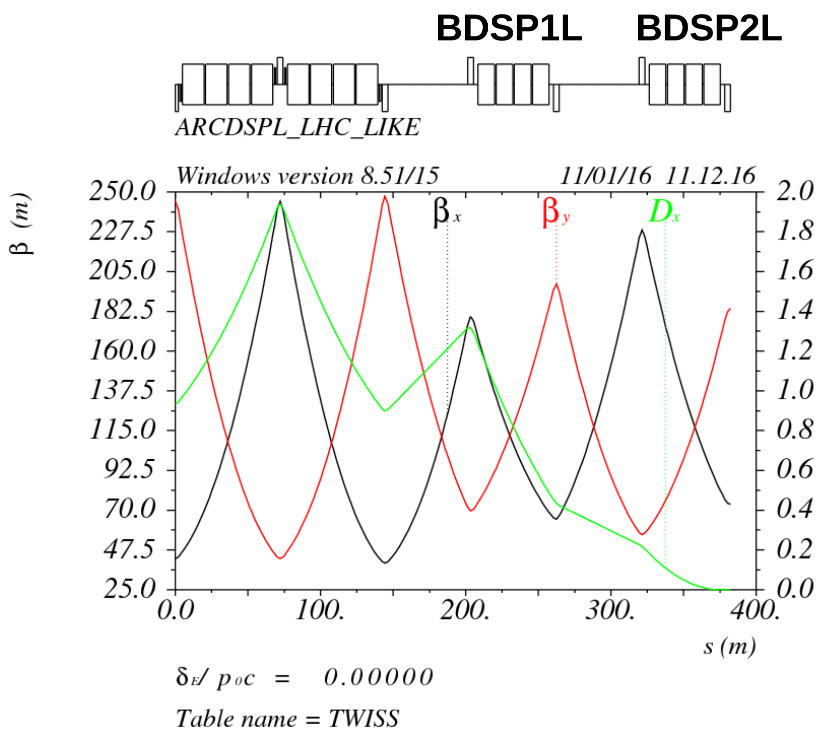
(3) Full Bend

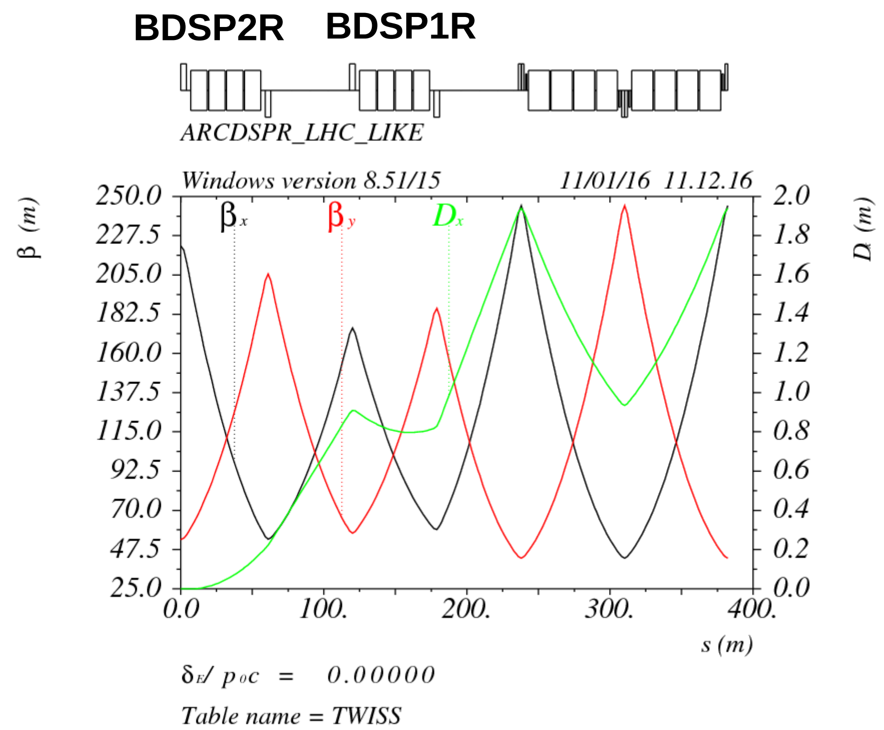


L=577.6m

	BDSP1L	BDSP2L	BDSP1R	BDSP2R	B0	
(1)	9.805	9.805	9.805	9.805	19.61	(T)
(2)	18.93	18.93	18.93	18.93	19.61	(T)
(3)	19.61	19.61	19.61	19.61	19.61	(T)

Dispersion Suppressor (DS)





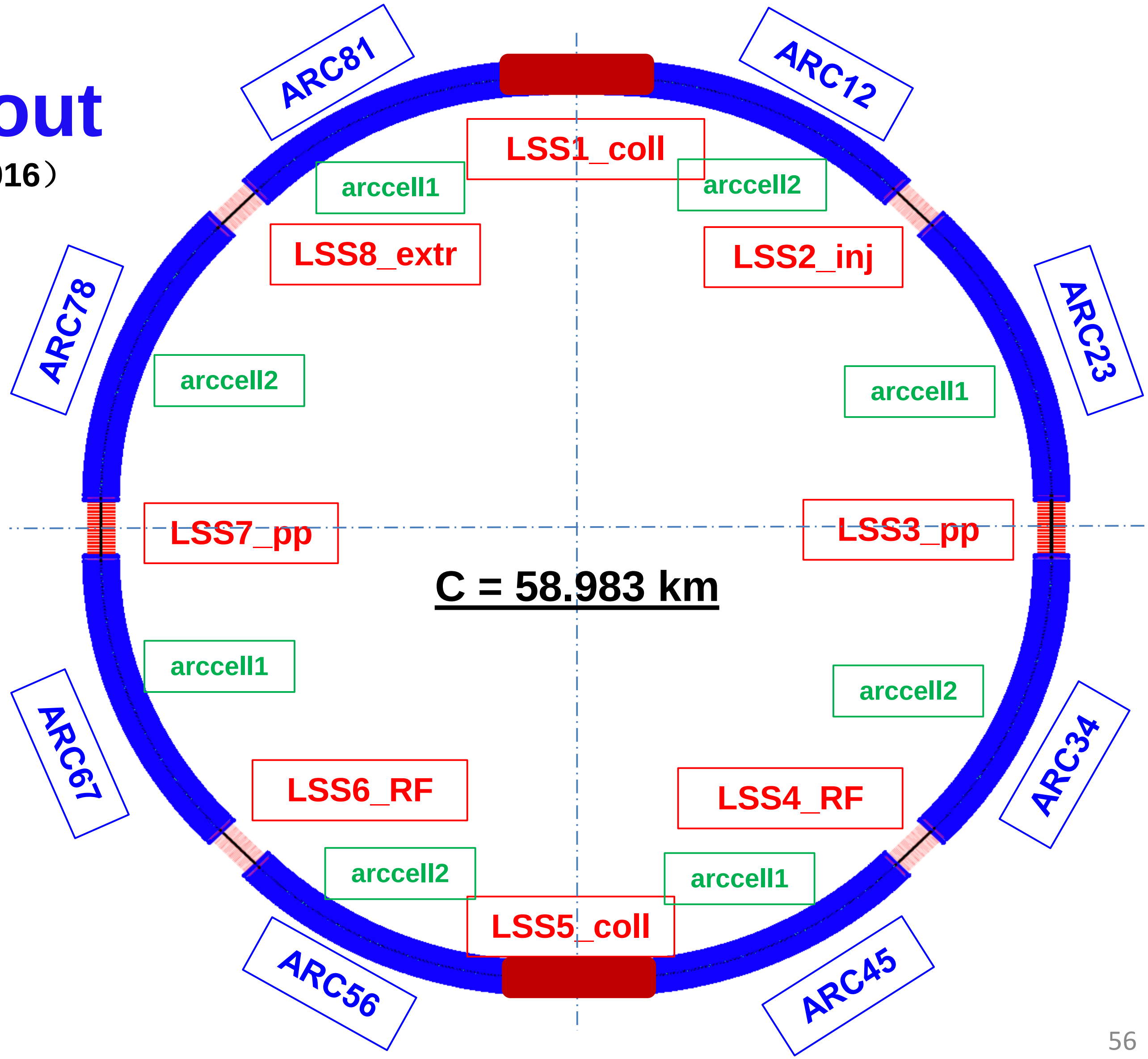
382.4m

	BDSP1L	BDSP2L	BDSP1R	BDSP2R	B0	
B	18.93	18.93	18.93	18.93	19.61	T
L	11.5	11.5	11.5	11.5	14.8	m

Long Straight Section

SPPC Layout

（Su Feng Jan. 10, 2016）



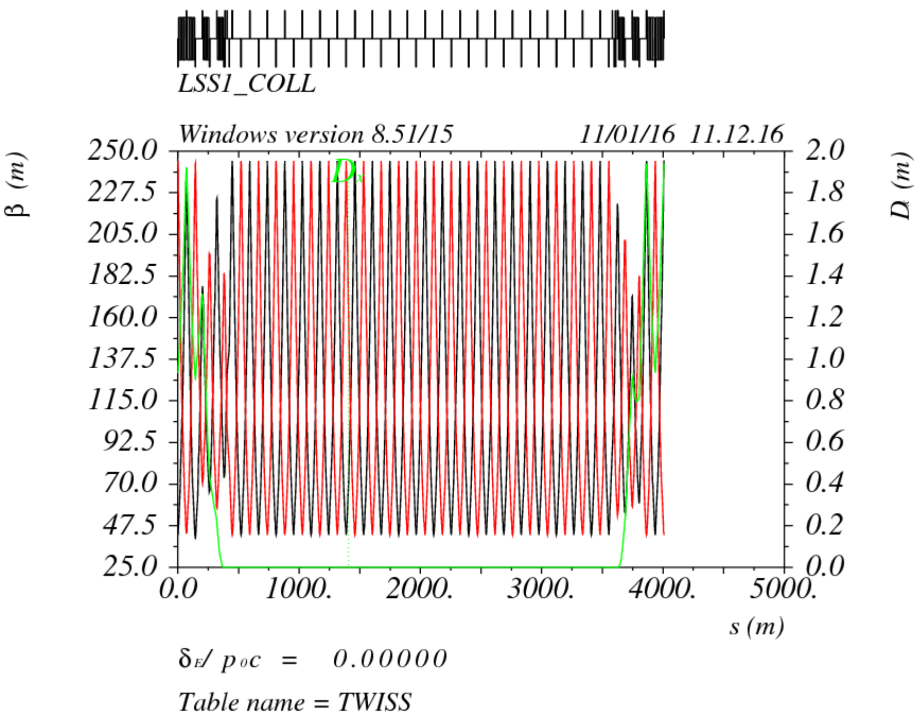
LSS1/5_coll： 3.2Km

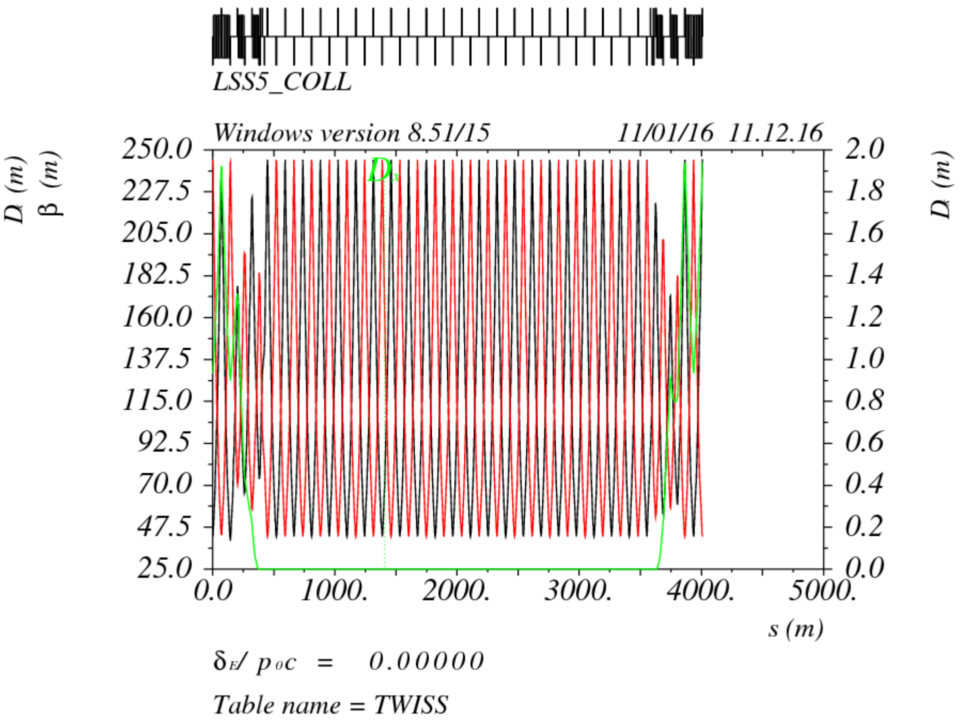
LSS2/4/6/8: 788.31m

LSS3/7_pp: 973.83m

ARC: 5963.2m

LSS1/5_coll



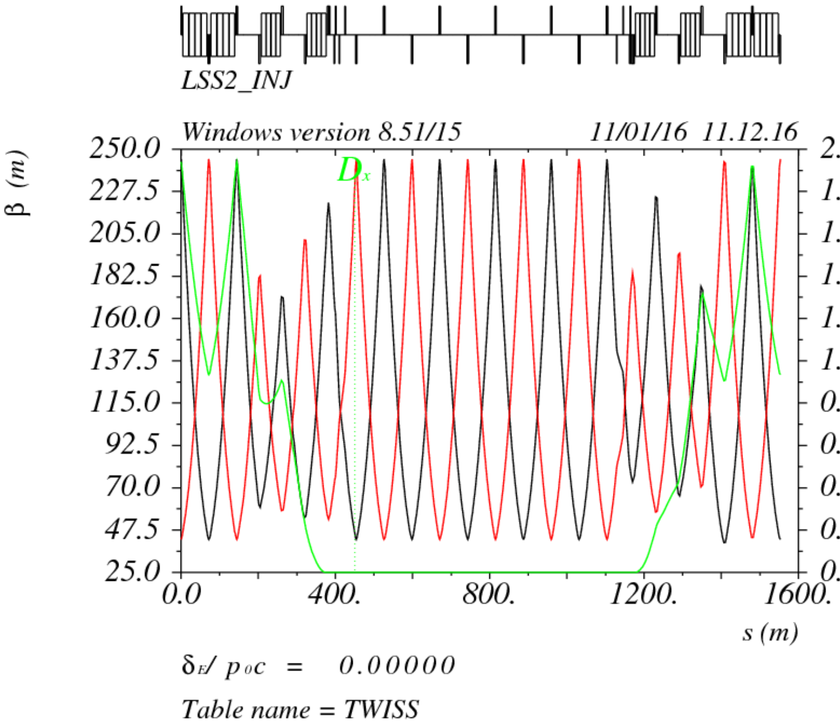


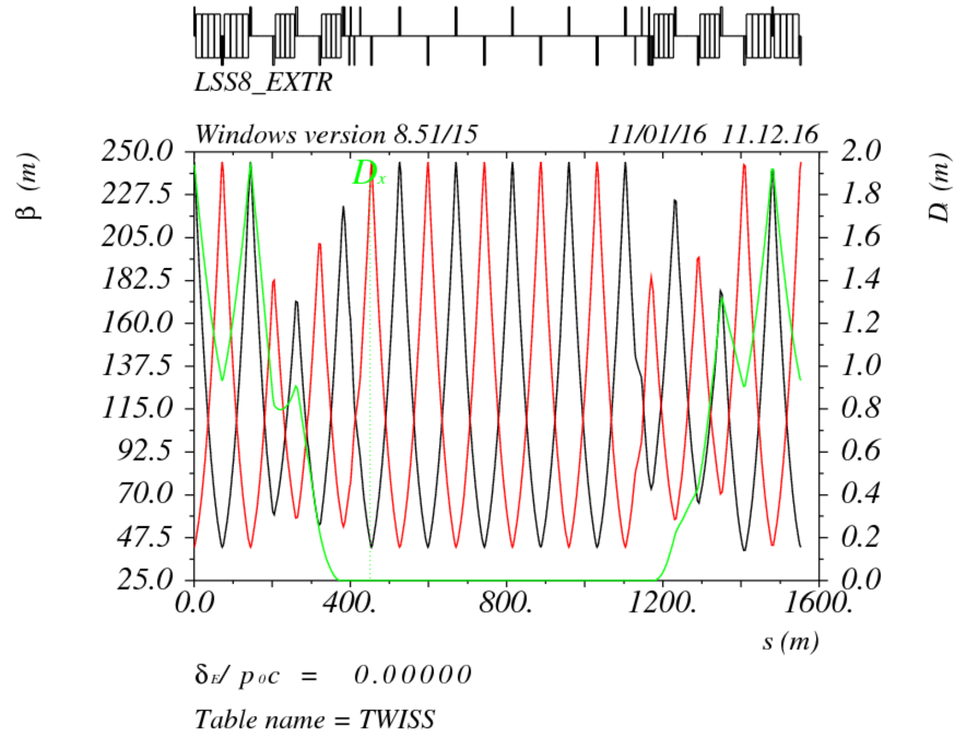
L=3243.106m

ARCDSPL, ARC_to_STR, 21.5*STRCELL, STR_to_ARC, ARCDSPR

382.4m, 71.719m, 3104.6m, 66.789m, 382.4m

LSS2_inj/LSS8_extr



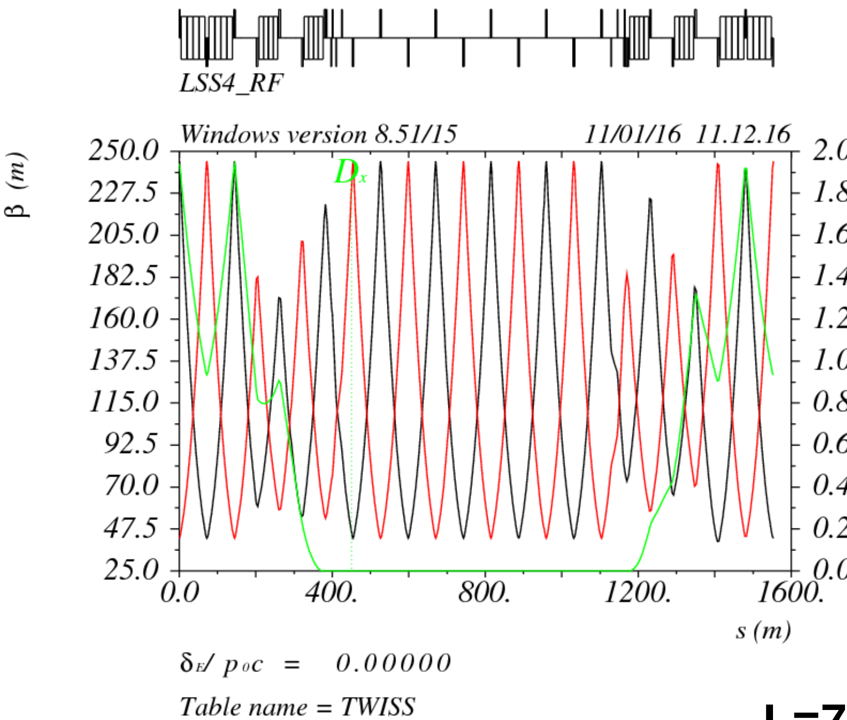


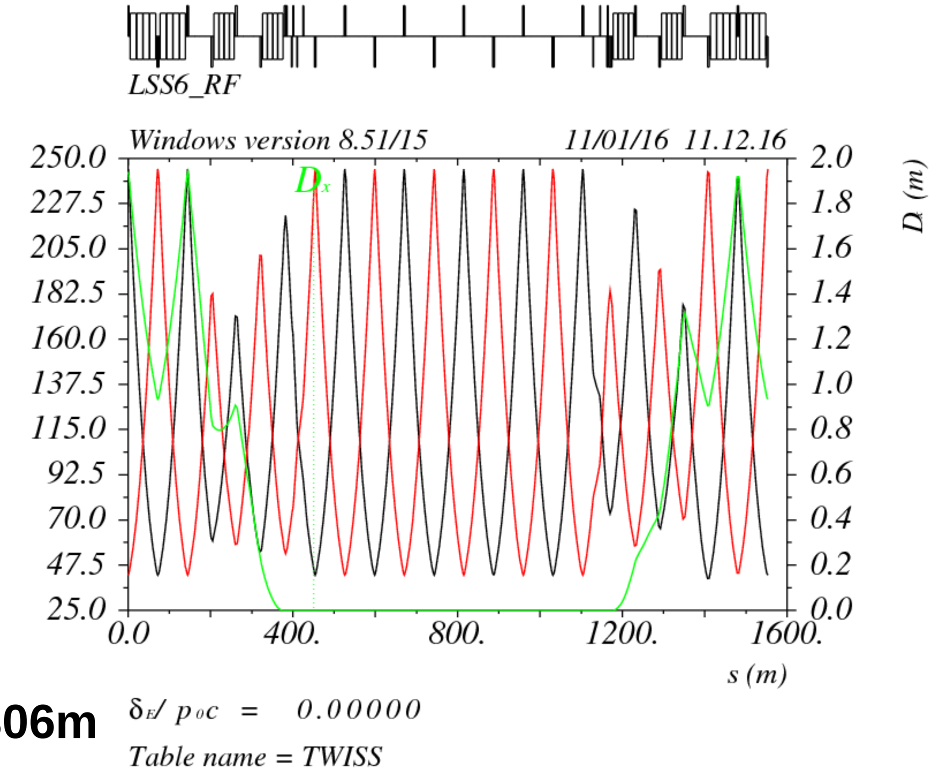
L=788.306m

-ARCDSPR, ARC_to_STR, 4.5*STRCELL, STR_to_ARC, -ARCDSPL

382.4m, 71.719m, 649.8m, 66.787m, 382.4m

LSS4/6_rf



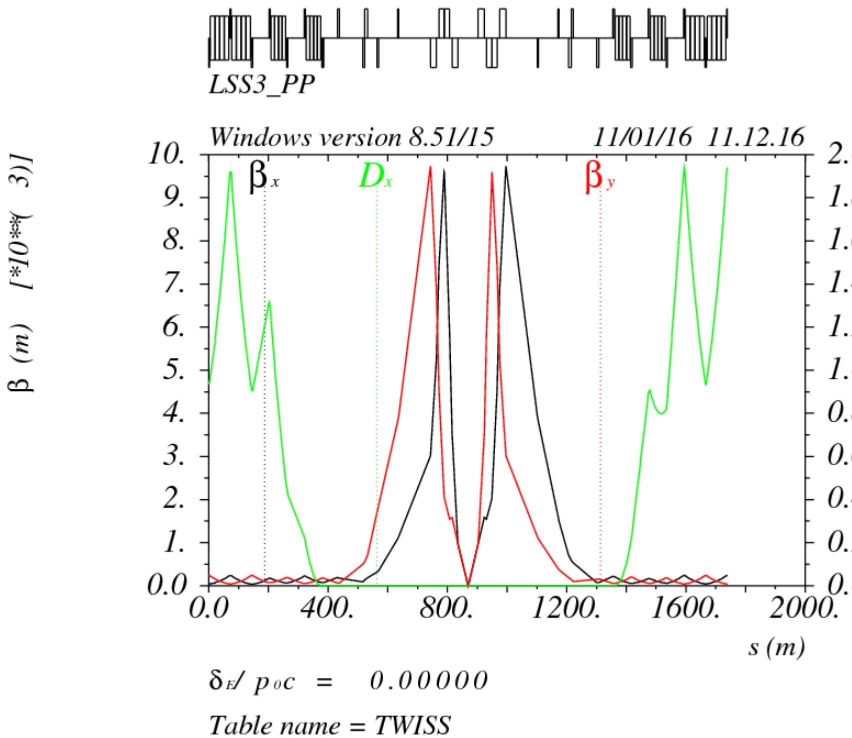


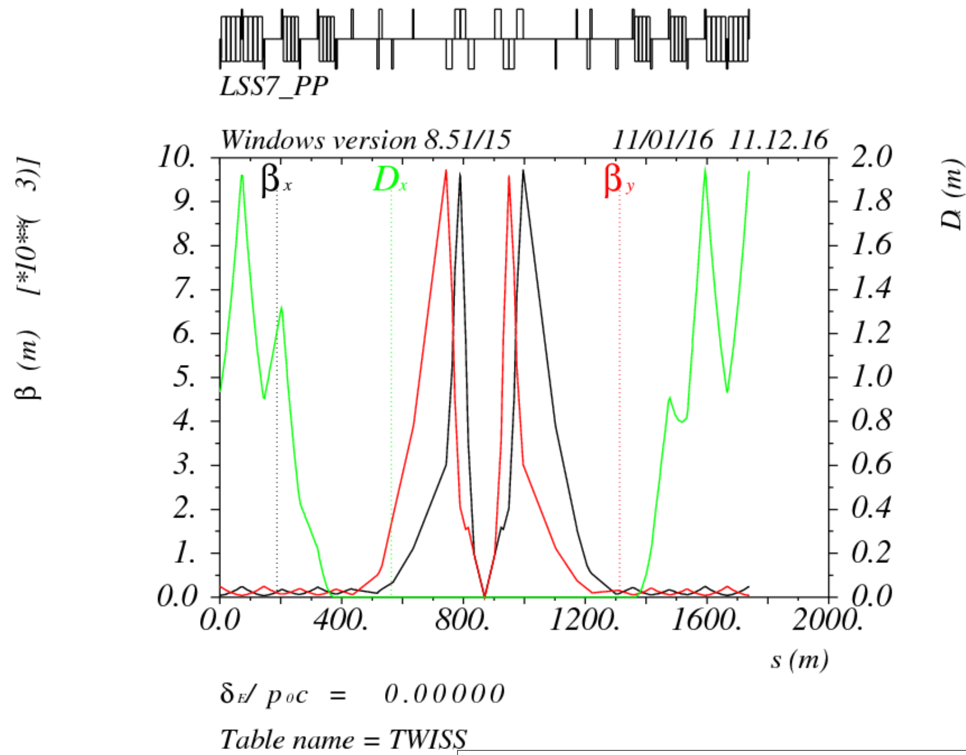
L=788.306m

-ARCDSPR, ARC_to_STR, 4.5*STRCELL, STR_to_ARC, -ARCDSPL

382.4m, 71.719m, 649.8m, 66.787m, 382.4m

LSS3_pp/LSS7_pp





L=973.829m

Beta：0.75m

Crossing angle：146urad

ARCDSPL, ARC_to_STR, 21.5*STRCELL, STR_to_ARC, ARCDSPR

382.4m, 71.719m, 973.829m, 66.789m, 382.4m

Q Strength

	K1(m^-2)	G（T/M）	L(M)	βmax
K1.QT.1R	4.9751e-03	580.428	6	3543.69
K1.QT.A2R	-5.2595e-03	-613.668	9	9601.686
K1.QT.B2R	-5.2595e-03	-613.668	9	9601.686
K1.QT.3R	5.3434e-03	623.369	8	9731.53
K1.QM.4R	-2.2804E-04	-266.04	4	3798.29
K1.QM.5R	8.8592E-04	103.36	4	1506.53
K1.QM.6R	-1.2144E-03	-141.68	4	587.87
K1.QM.7R	1.0640E-04	124.133	4	531.25
K1.QM.8R	-4.2431E-03	-495.028	4	162.20
K1.QT.1L	-4.9751e-03	-580.428	6	3543.69
K1.QT.A2L	5.2595e-03	613.668	9	9601.686
K1.QT.B2L	5.2595e-03	613.668	9	9601.686
K1.QT.3L	-5.3434e-03	-623.369	8	9731.53
K1.QM.4L	2.2804E-04	266.04	4	3798.29
K1.QM.5L	-8.8592E-04	-103.36	4	1506.53
K1.QM.6L	1.2144E-03	141.68	4	587.87
K1.QM.7L	-1.0640E-04	-124.133	4	531.25
K1.QM.8L	4.2431E-03	495.028	4	162.20

Pre-CDR:

IR:

D = 60 mm B_{pole} **= 20 T**

G=666.7T/m K1=5.716*10^-3

R=30mm

20mm=20σ

σ=1mm

β=σ^2/ε=10.03km

Matching section:

D = 60 mm B_{pole} **= 16 T**

G=533.3T/m K1=4.572*10^-3

4. SPPC Dynamic Aperture Study

Definition of Dynamic Aperture

1. **Real World Dynamic Aperture (RW-DA) Definition ➔ W. Fischer:**

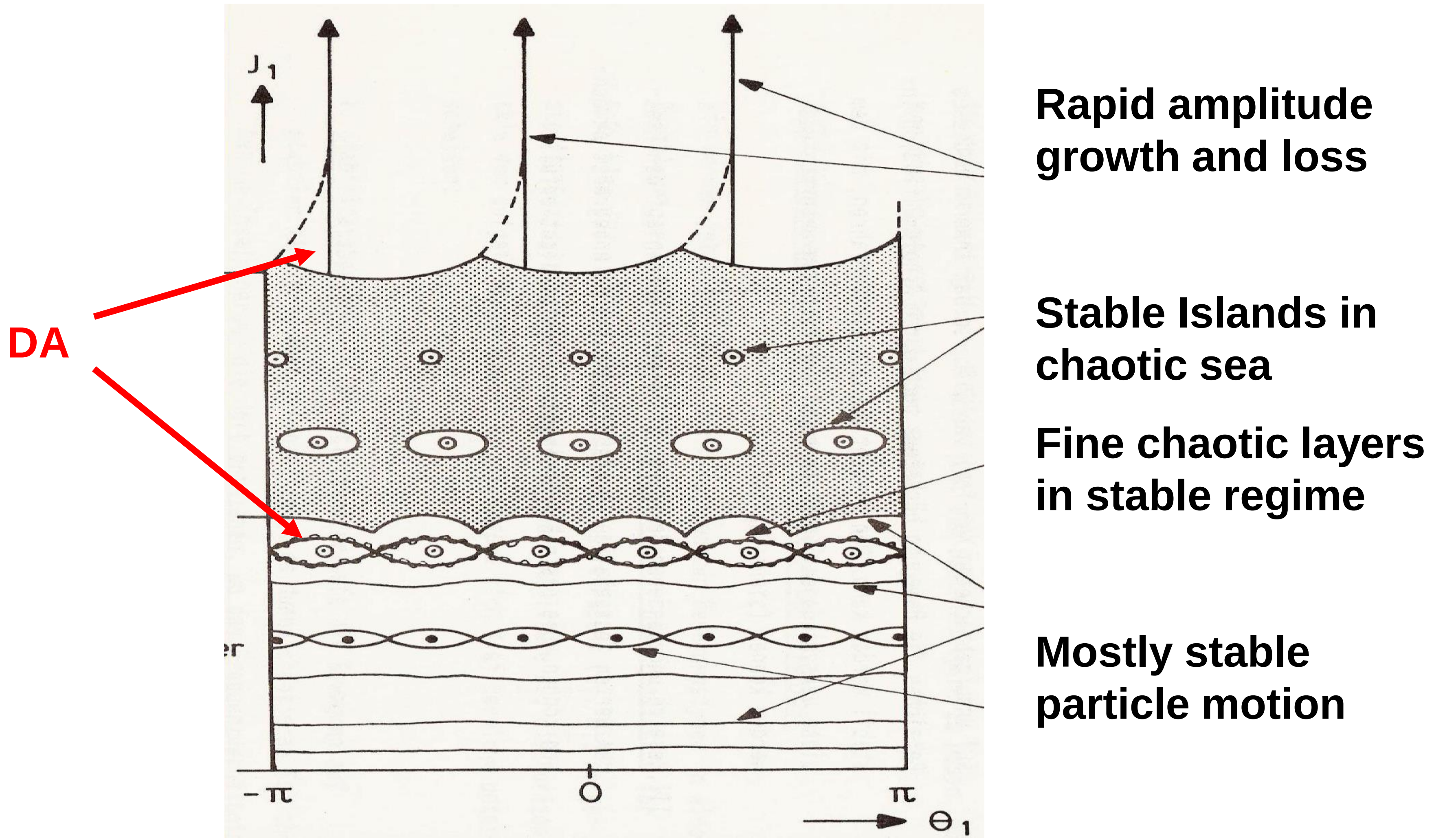
   Largest Amplitude at which particles remain in the accelerator over a time range of interest.

2. **Potential Dynamic Aperture (PO-DA) = Onset of global Chaos**

   - **Largest Amplitude with mainly regular motion.**
   - **Insignificant chaotic layers within the regular regime will be ignored.**
   - **However considerable wide “chaotic spikes” have to be taken into account**

➔ It turns out that the PO-DA is typically too small as RW-DA estimate

Dynamic Aperture Scheme



Chaos Criteria

PO-DA Detection ➔ find amplitude with non-zero Lyapunov Exponent:

$$\lambda = \lim_{N\to\infty} \lim_{d(0)\to 0} \frac{1}{N} \log \frac{d(N)}{d(0)}$$

In practice, the Lyapunov exponent is rarely evaluated directly.

Instead, one follows the evolution of the distance in phase space. Most effectively by using the angular distance that is extremely sensitive to find even weakly chaotic motion.

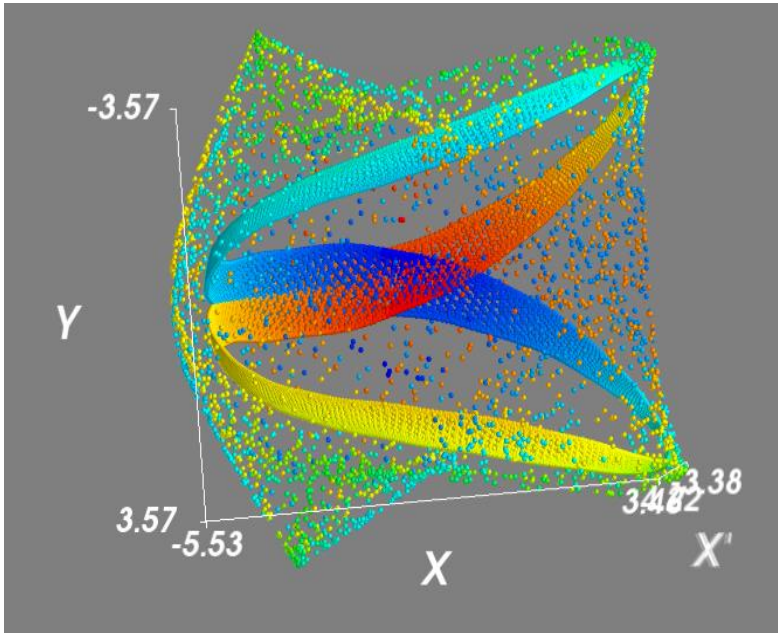
SPPC Main Ring DA *without* low beta pp IR(1/7)

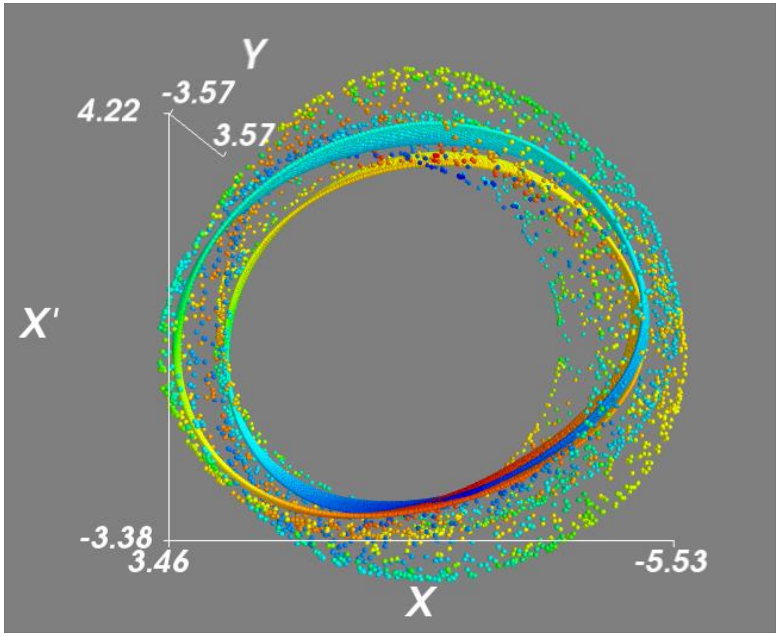
At first, we studied the dynamic aperture of SPPC main ring without interaction region. There are 8 arcs in the main ring and 8 long straight sections. Now we use simple FODO in the long straight section, latter we should optimize the long straight section design for difference use like RF part, injection, extraction and collimation.

Following is the dynamic aperture from Sixtrack.

We can get from the figures that the dynamic aperture is about 22.58 mm (346 σ_x) in horizontal and 49.16 mm (315 σ_y) in vertical.

SPPC Main Ring DA *without* low beta pp IR(2/7)

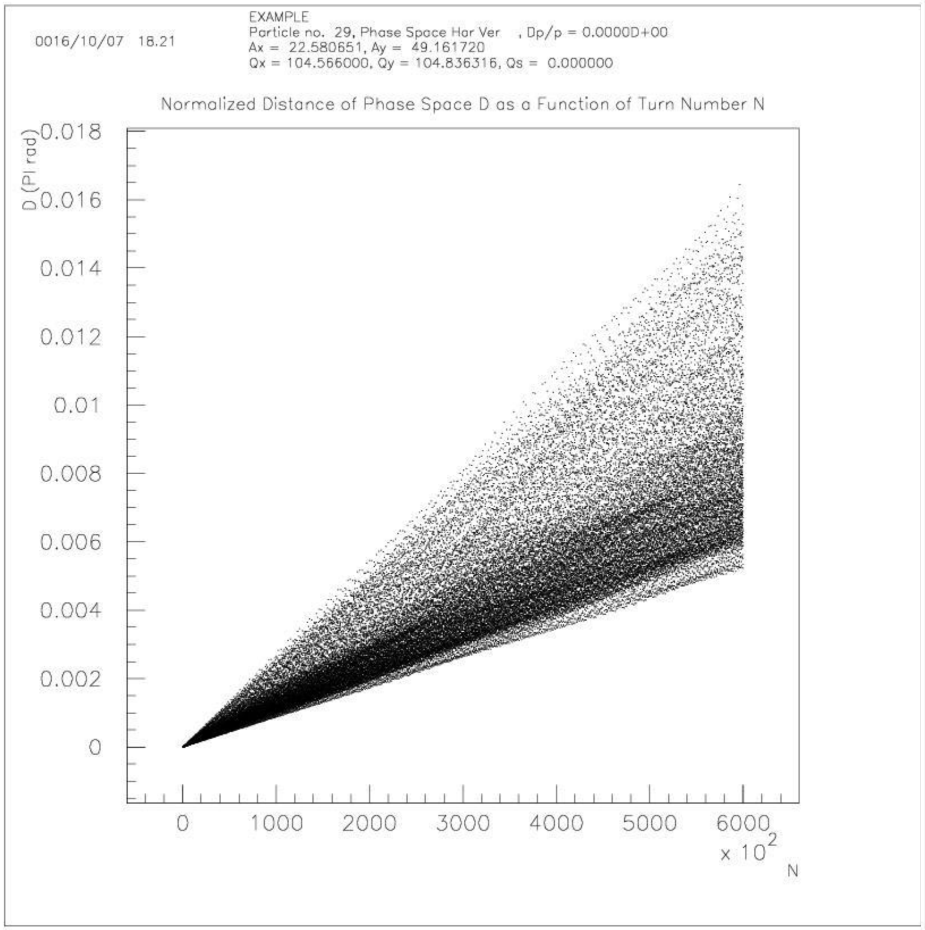


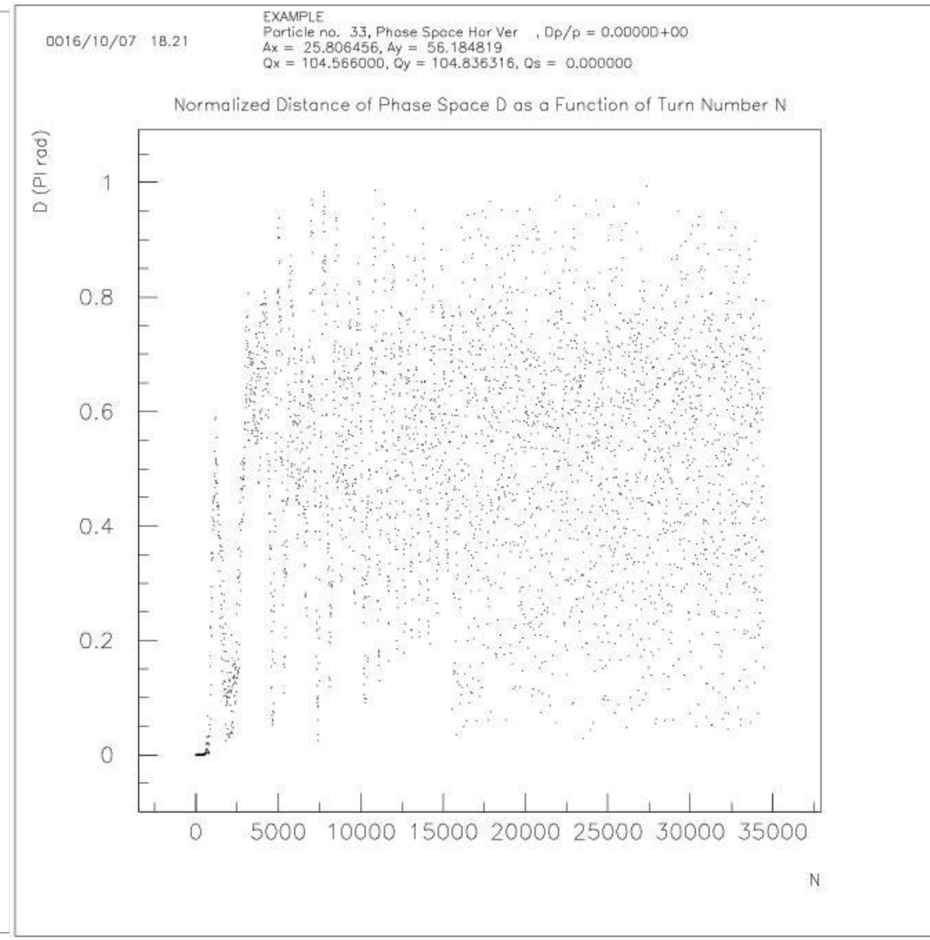


4-Dimension phase space for regular and chaotic motion (cm).

(The solid tie shape shows the regular particles motion which has the largest amplitude, if the amplitude becomes a little larger, the motion will become chaotic, the diffusion points around the solid tie show the chaotic motion. This largest amplitude is the dynamic aperture we want to study.)

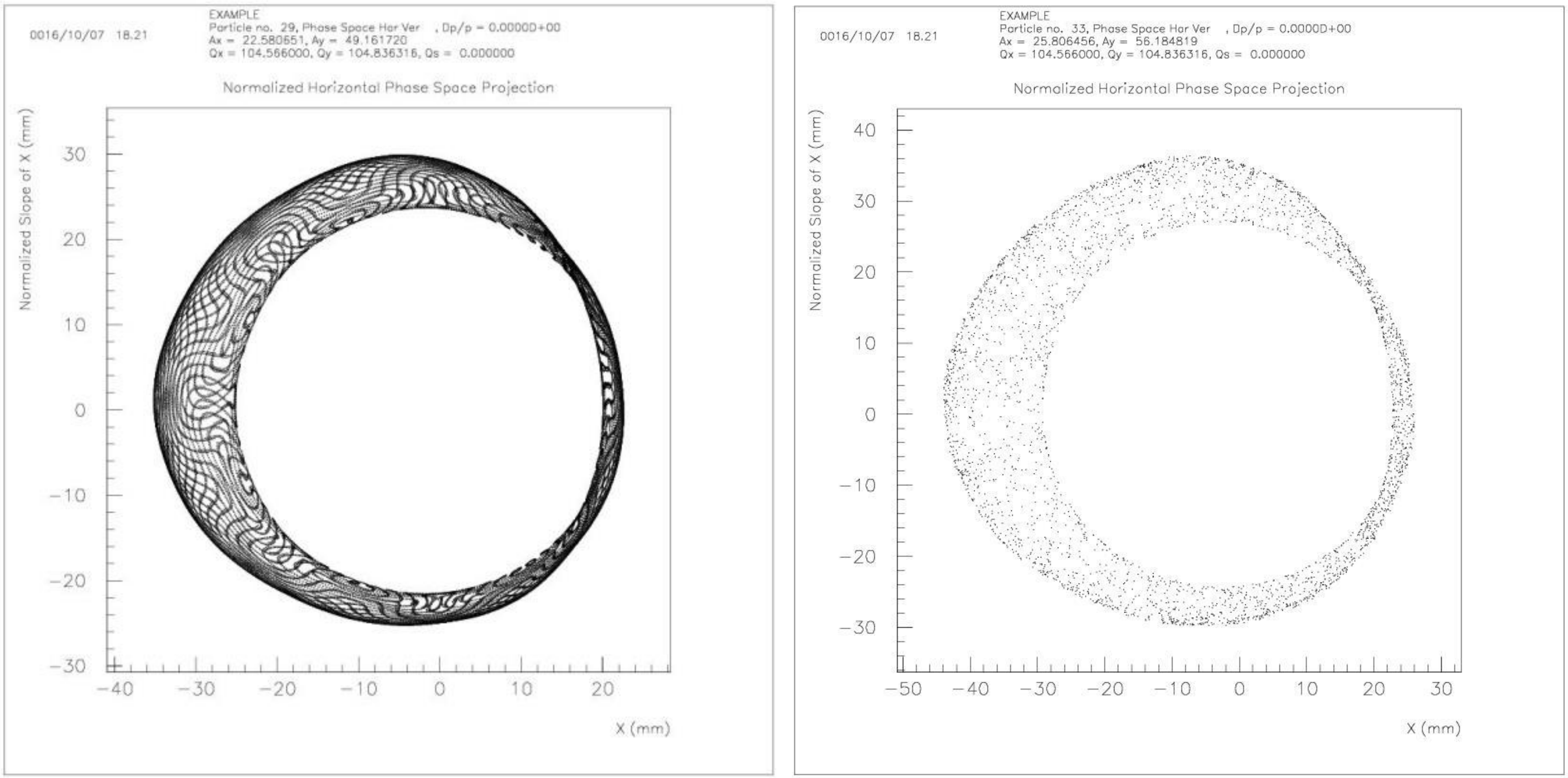
SPPC Main Ring DA *without* low beta pp IR(3/7)





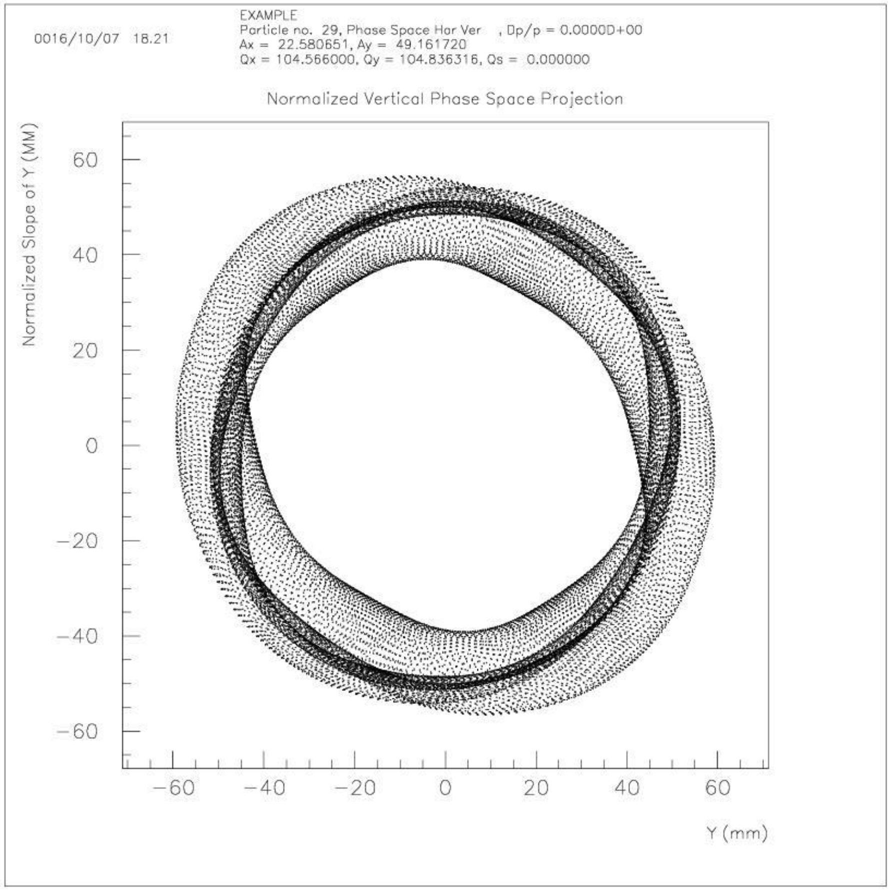
Evolution of the distance of phase space for regular (left) and chaotic (right) motion.

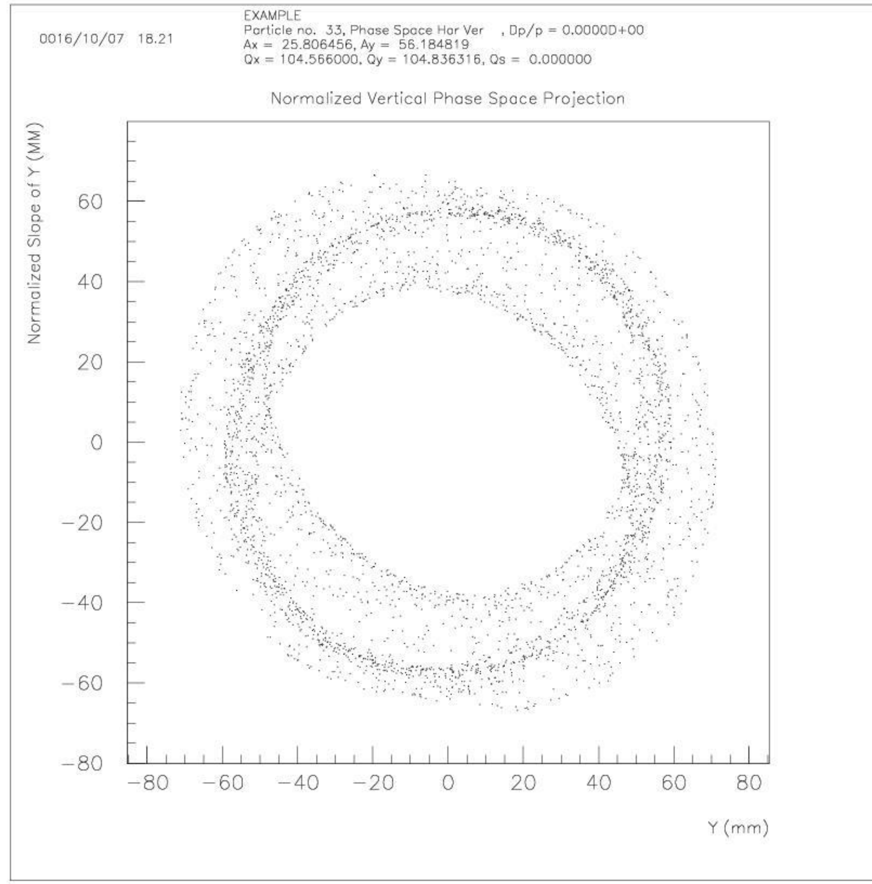
SPPC Main Ring DA *without* low beta pp IR(4/7)



Horizontal phase space projections for regular (left) and chaotic (right) cases.

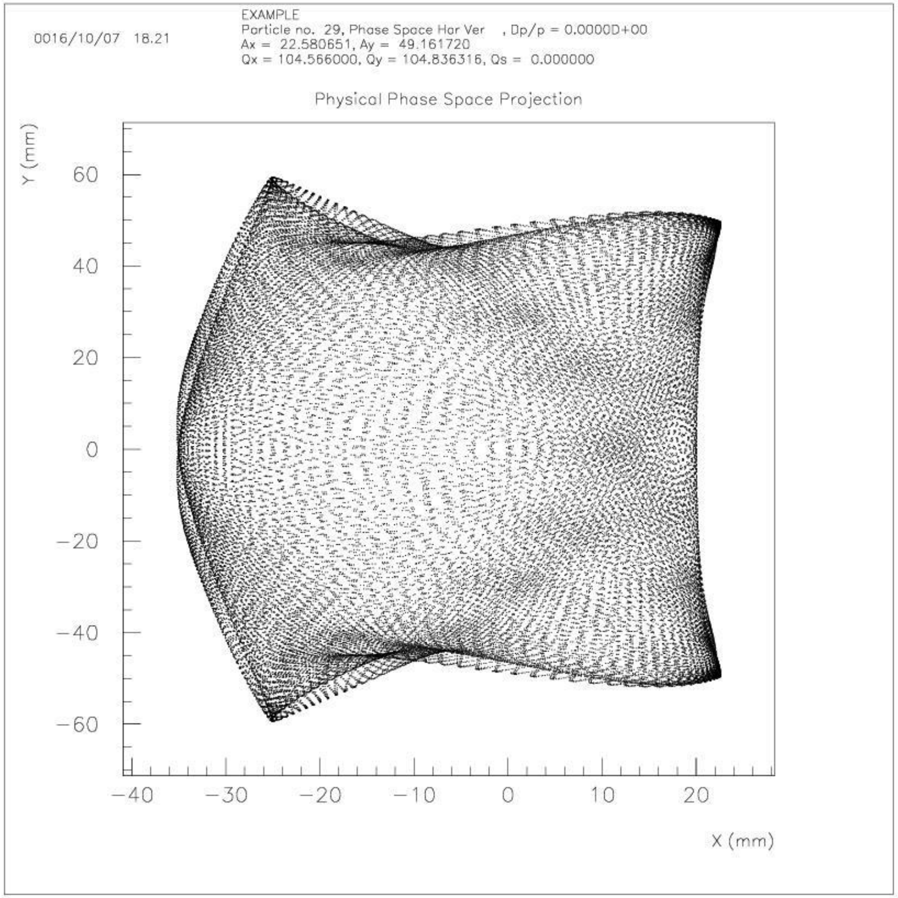
SPPC Main Ring DA *without* low beta pp IR(5/7)

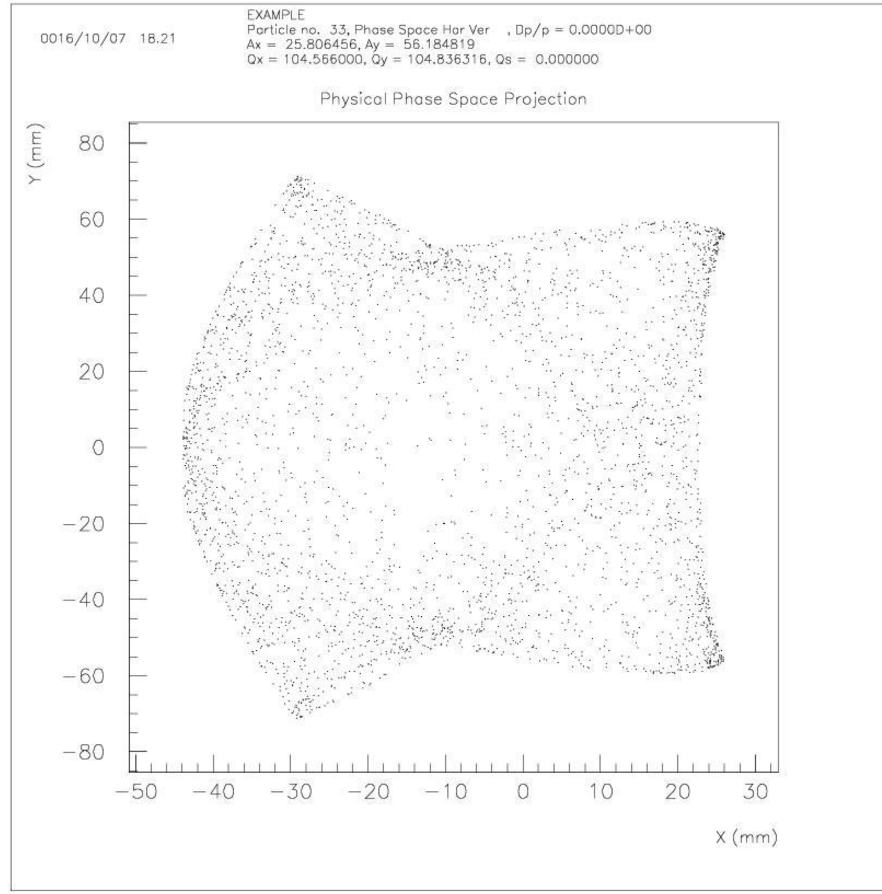




Vertical phase space projections for regular (left) and chaotic (right) cases.

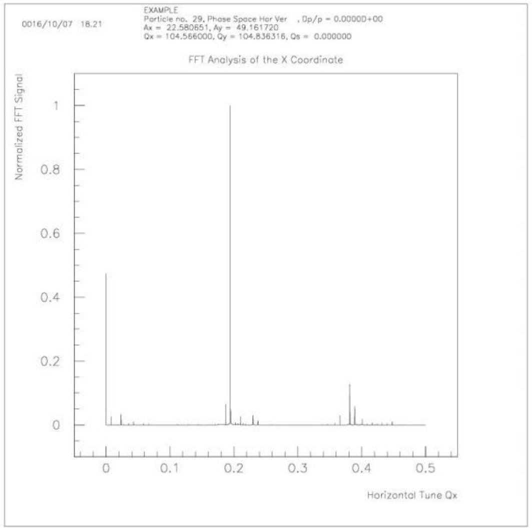
SPPC Main Ring DA *without* low beta pp IR(6/7)

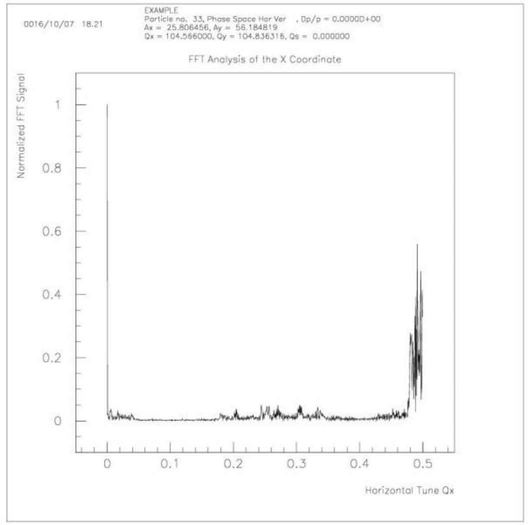




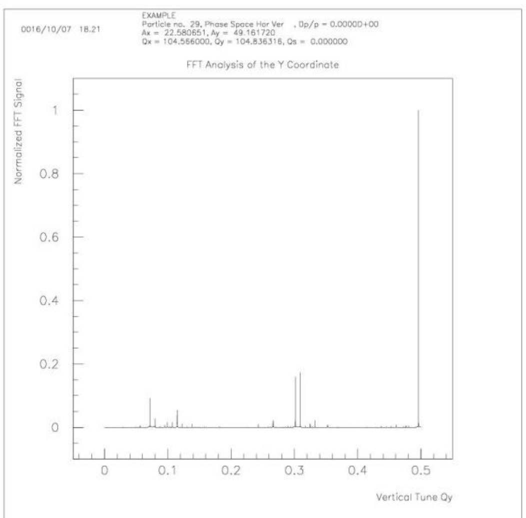
Physical phase space projections for regular (left) and chaotic (right) cases.

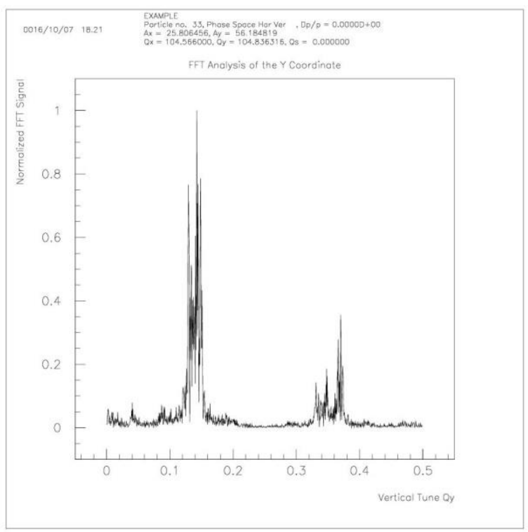
SPPC Main Ring DA *without* low beta pp IR(7/7)





Horizontal FFT-analysis for the regular (left) and the chaotic (right) cases.





Vertical FFT-analysis for the regular (left) and the chaotic (right) cases.

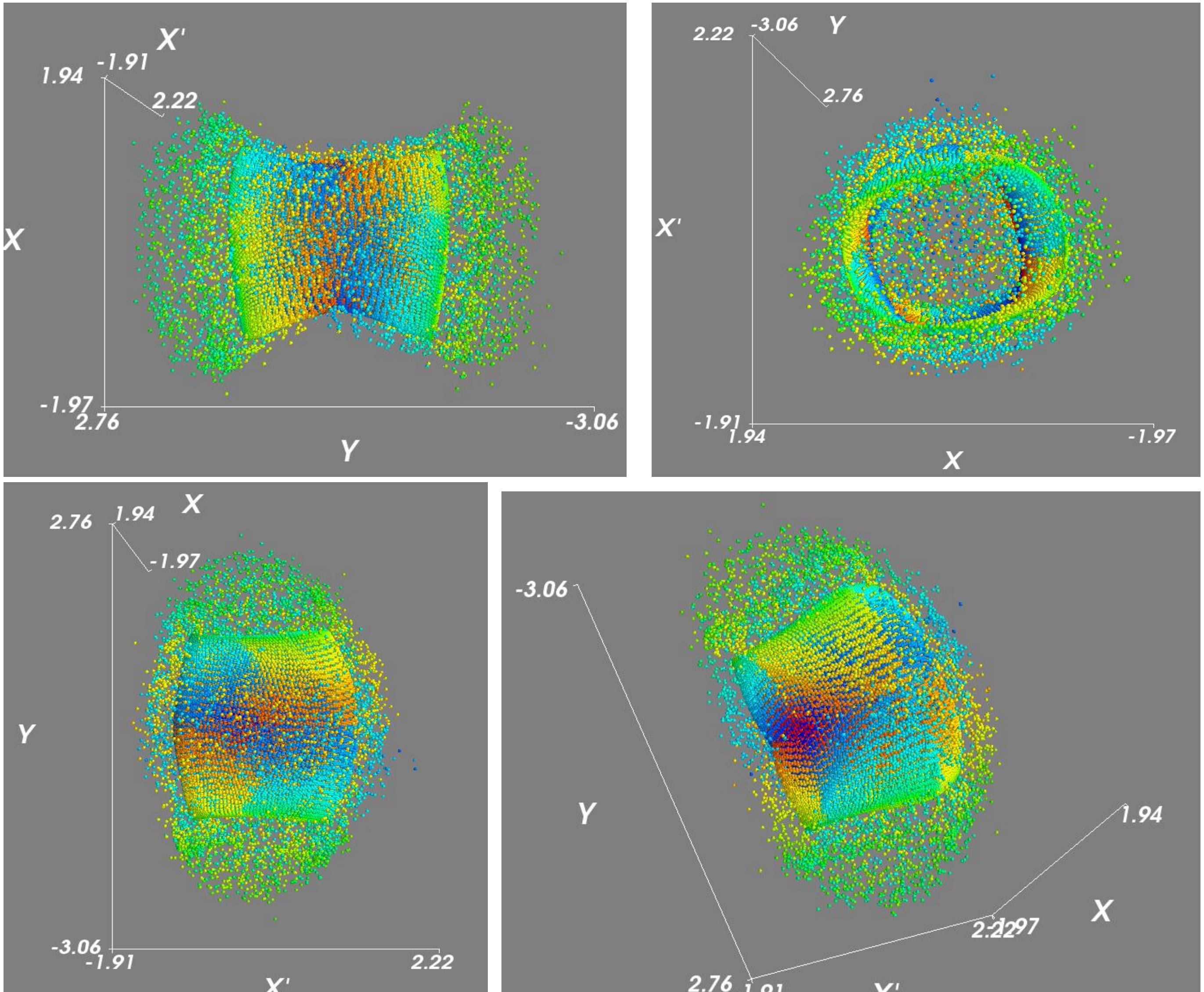
SPPC Main Ring DA *with* low beta pp IR(1/5)

Following is the dynamic aperture with low beta pp interaction region.

The beta function at IP is 0.75m. The maximum beta function in this region is about 9.6 km. The dynamic aperture becomes smaller, 8.22 mm (126 σ_x) in horizontal and 19.73 mm (126 σ_y) in vertical (we keep the same observation point for comparison with the DA without low beta pp IR). At the low beta pp IR point, the dynamic aperture is only 1.089mm (126 σ) in both horizontal and vertical because the beam size is very small (8.647um).

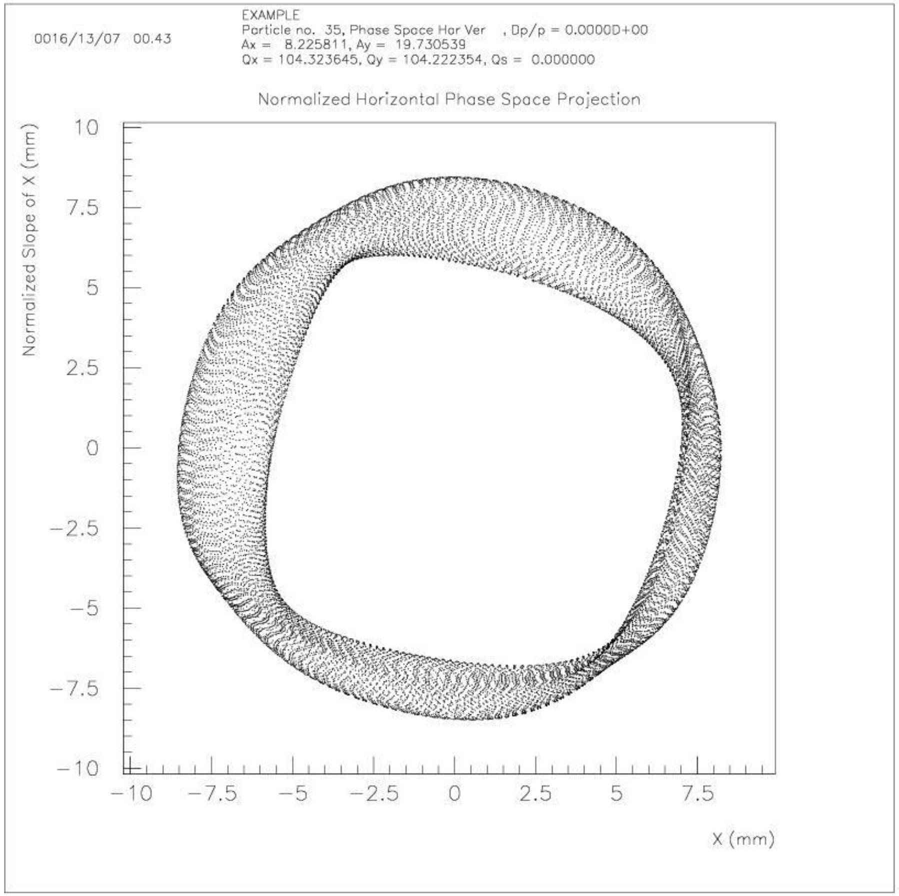
Following figures show the details.

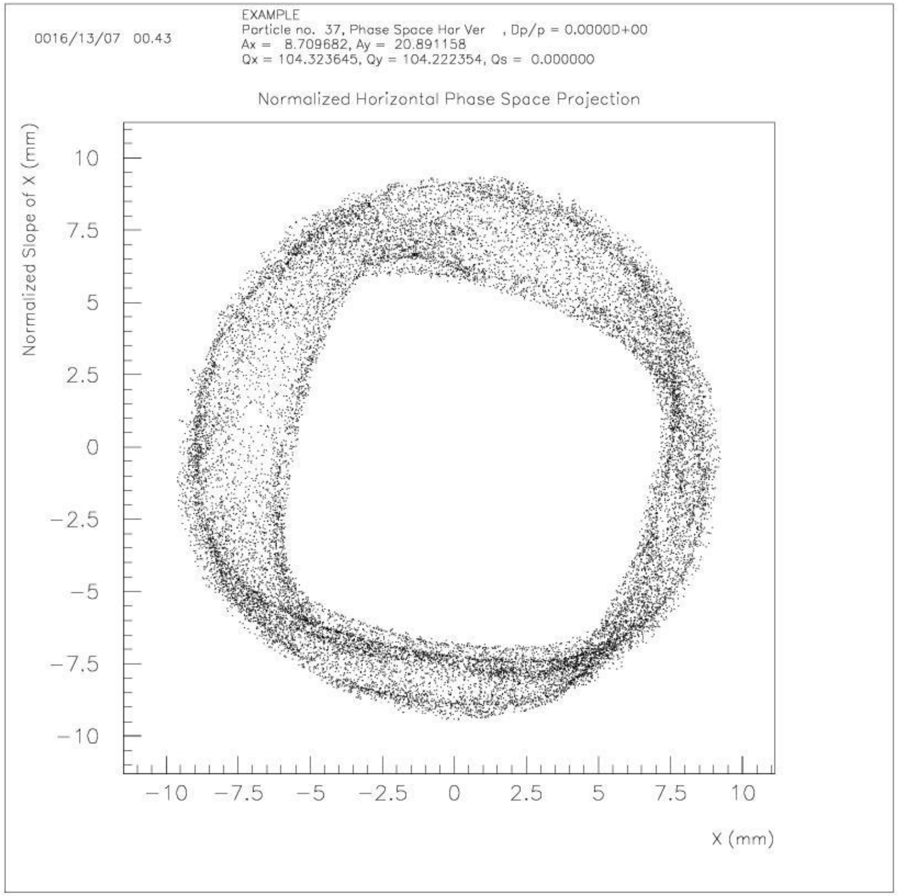
SPPC Main Ring DA *with* low beta pp IR(2/5)



4-Dimension phase space for regular and chaotic motion (cm).

SPPC Main Ring DA *with* low beta pp IR(3/5)





Horizontal phase space projections for regular (left) and chaotic (right) cases.

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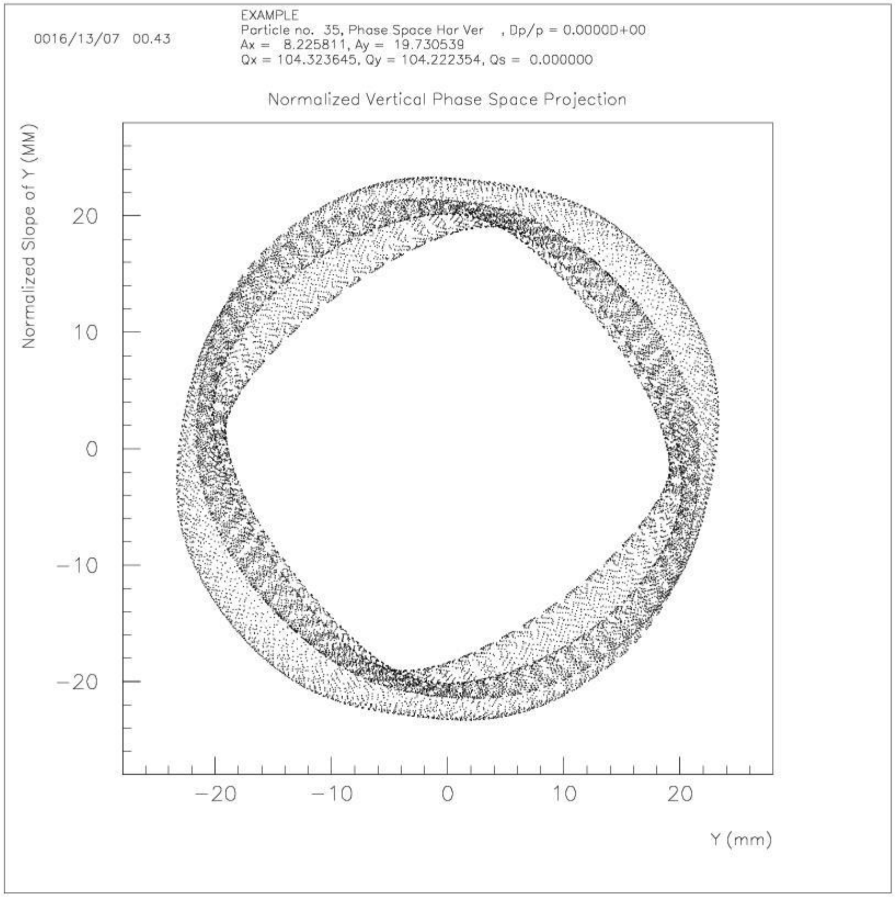
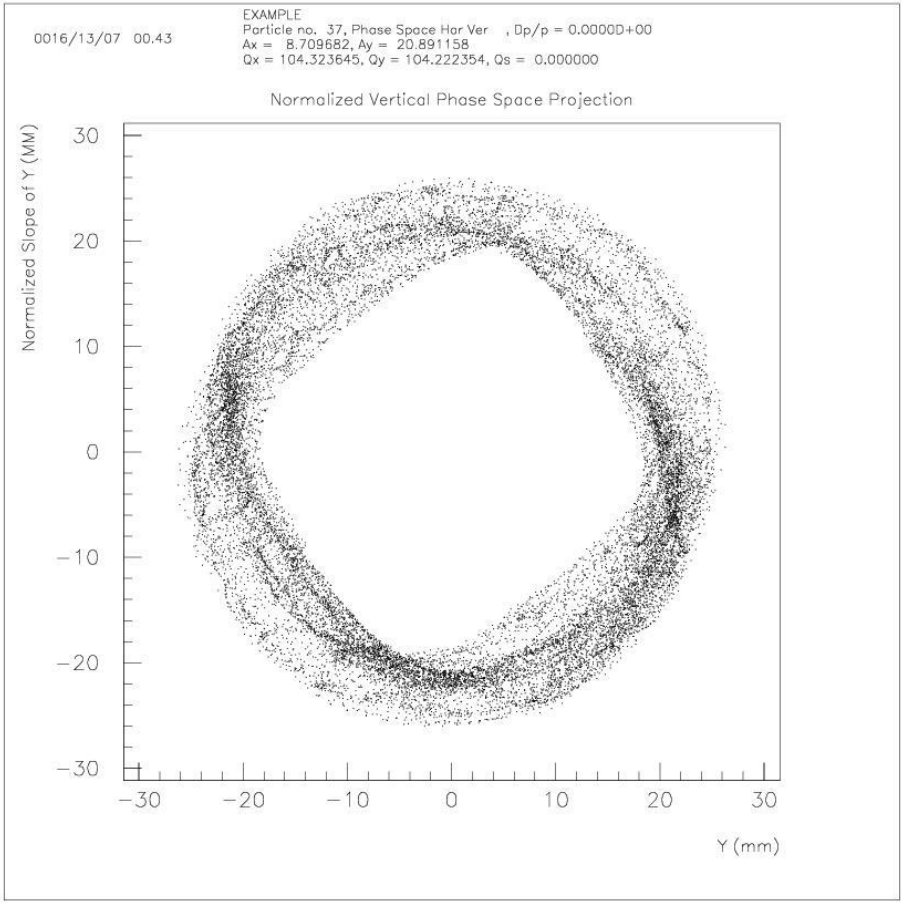
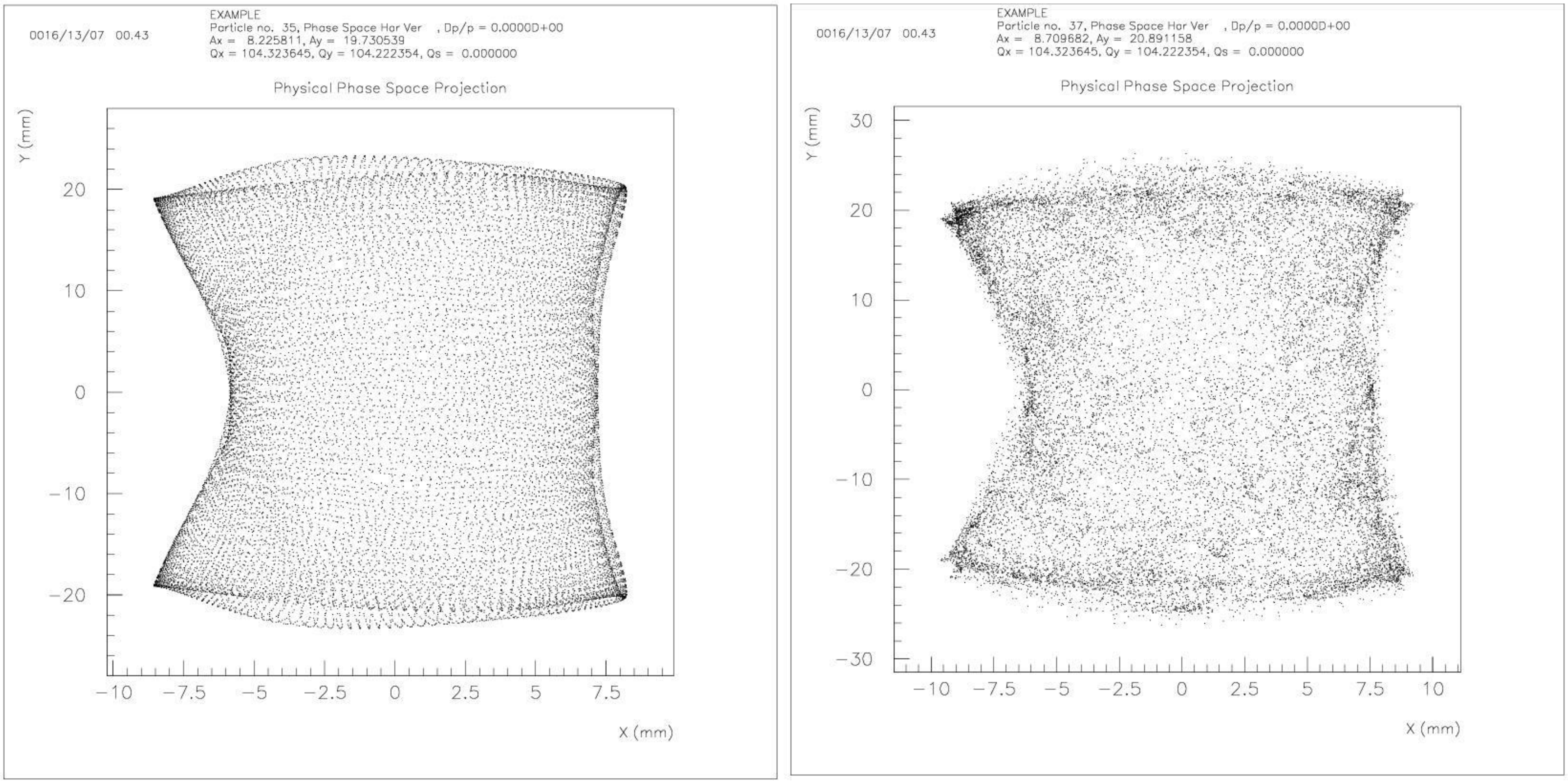
SPPC Main Ring DA *with* low beta pp IR(4/5)





Vertical phase space projections for regular (left) and chaotic (right) cases.

SPPC Main Ring DA *with* low beta pp IR(5/5)



Physical phase space projections for regular (left) and chaotic (right) cases.

5. Summary

- **We optimized the parameter list version201503, we considered the new lattice layout of CEPC PDR and the combination of CEPC and SPPC. The beam energy and length of long straight sections so as the circumference have a little change. We get the newest parameter list version201607.**
- **The first version of SPPC Lattice was designed . Full crossing angle is 146urad. Beta at IP is 0.75um.**
- **A first Dynamic Aperture study and the preliminary DA is showed and it seems not too small. 126 sigma at IR.**
- **The deep beam dynamics study is needed.**

Acknowledge

- The authors would thank Frank Schmidt very much for the help in SixTrack and Dynamic Aperture Study.

- 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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Thank You !

DA Study Strategy and Next Steps(1/3)

1. Nonlinear driving term:

h_{abcde}， a+b+c+d+e=3， 1st order nonlinear driving term

a+b+c+d+e=4， 2nd order nonlinear driving term

1st order chromaticity: h11001, h00111

2nd order chromaticity: h11002, h00112

Tune with amplitude: h11110, h22000, h00220

……

Which term is more important and has strong contribute to dynamic aperture and need more constraints？ （now 0< h11002 and h00112 real part <4000）

2.Population & Generation ?

If each generation has enough population, it will easy to choose the so called well solution for our objective. And the next generation will keep half population from the parent generation and produce half new population. This two parts make up the new generation. Now use 500 population and 100 generation. Is it larger enough to find good solution? Maybe need larger population and generation, like 4000 population and 50 generation.

DA Study Strategy and Next Steps(2/3)

3. Tune footprint, Tune space, Working point choice:

Now the working point is (0.08, 0.22), the second order chromaticity is about -3300 and -3900, it will quickly to the resonance line. We need to plot FMA analyses the tune footprint, choose a space to fit in. We should consider whether the work point is good. Maybe the injection work point can be another choose for large enough DA, and after injection, we rump the work point to (0.08, 0.22) for the high luminosity requirement.

4.Energy acceptance：

2% energy acceptance from Touschek lifetime. The dynamic aperture for 2% energy spread is very small. Is it the limit from FODO structure? The energy spread for FODO lattice need to be study.

DA Study Strategy and Next Steps(3/3)

5. Error tolerance:

The error tolerance for the magnets in the lattice needs to be considered. This will influence the DA obviously. We need a good DA include the error.

6. Thin lens & thick lens:

Now the calculation is treating the elements as thin lens. If the real elements have real length, it need to integrate the whole length. How will the difference be?

7. 90 72 60 degree FODO cell compare and choose:

We need to compare the FODO cell with different phase advance to choose the better design for DA.

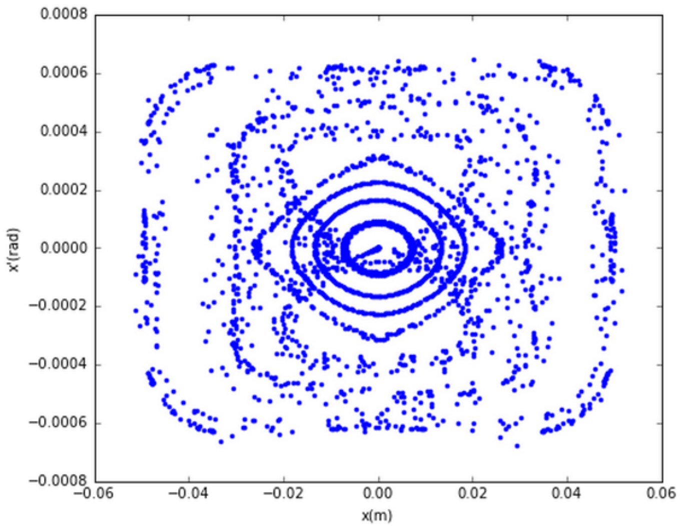
8. How to divided the sextupoles groups?

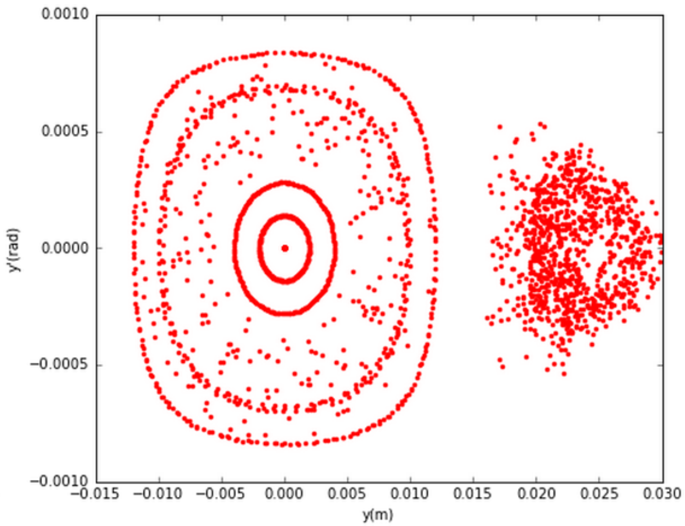
How many group should the sextupoles to be divided? This needs to try.

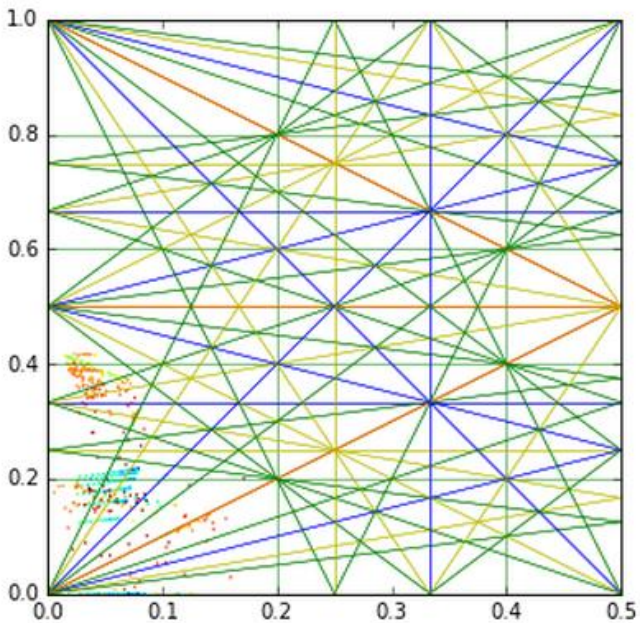
9. Converge of sext:

At the end of optimization and calculation, the strength of sextupoles will be converging to a set of invariable values. This can be an aspect to judge whether the solution is good enough.

Nonlinear Driving Term (ARC-20160630)

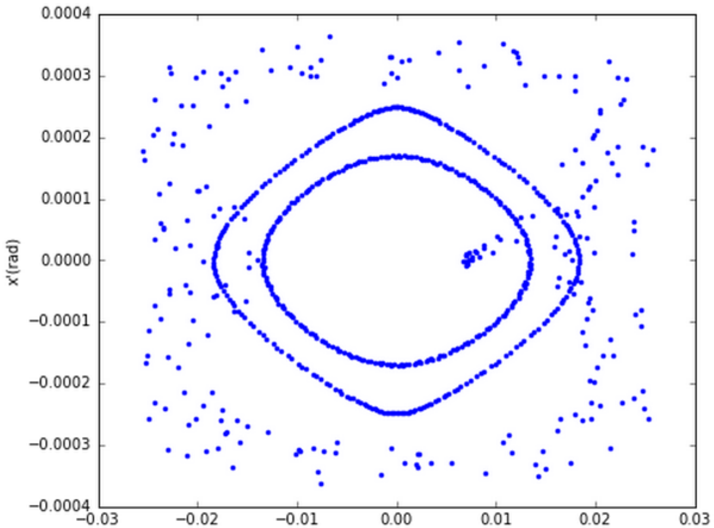


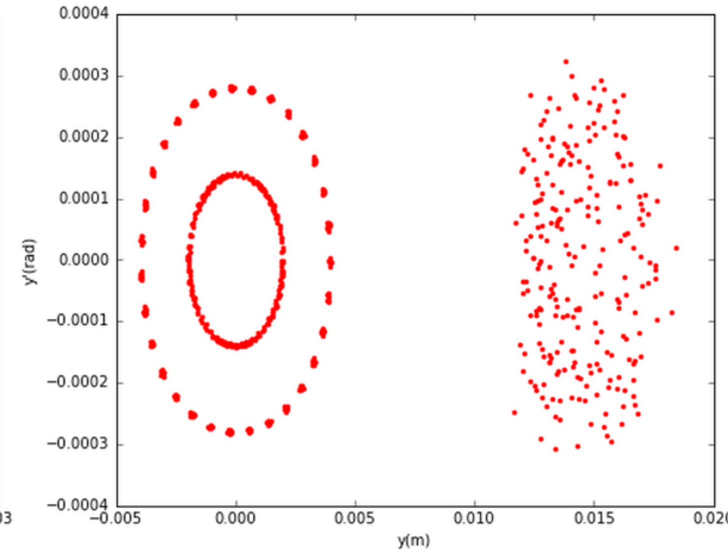


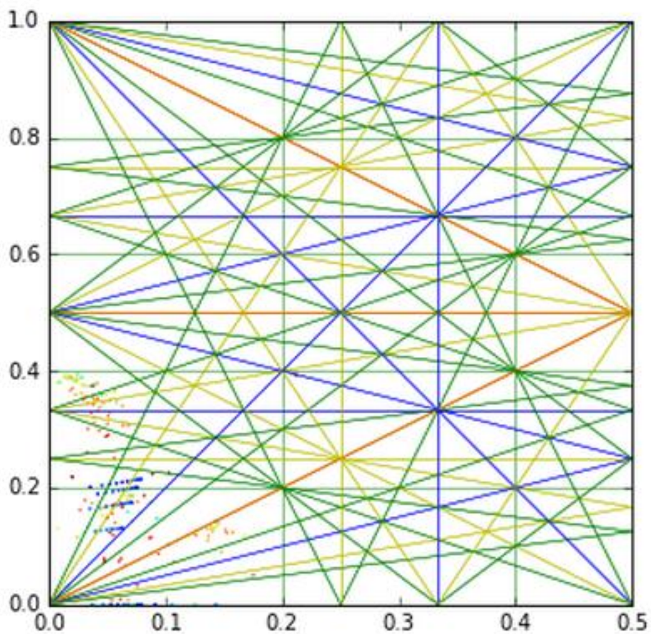


```
In [3]: cepc.ring.geth1()
        cepc.ring.h1

Out[3]: {'h00111': (535.2509470015705+0j), 'h11001': (-21.439032994110715+0j)}

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

Out[4]: {'h00112': (30.331232857591701+9.2544727089971524e-11j),
         'h00220': (-3.3754683901745739e-06-2.3011182292975718e-08j),
         'h11002': (148.26422778627065+8.5042300545373761e-10j),
         'h11110': (5.5074180906773081e-06+1.3316991953615798e-07j),
         'h22000': (-1.1151100710504981e-05+2.8194335754960775e-10j)}
```

Nonlinear Driving Term (ARC-20160707)







In [3]:
```
cepc.ring.geth1()
cepc.ring.h1
```
Out[3]: {'h00111': (177.697545862617+0j), 'h11001': (-167.7457325963326+0j)}

In [4]:
```
cepc.ring.geth2()
cepc.ring.h2
```
Out[4]: {'h00112': (89.794467231475323+4.818871690570603le-11j),
'h00220': (0.00018353679347028032+4.315211299399379 6e-09j),
'h11002': (59.481228639575228-1.4377550755853563e-09j),
'h11110': (-0.00022557045730701295-1.7015486264426727e-07j),
'h22000': (0.00045962349491 68731-1.7098500393331051e-10j)}

Nonlinear Driving Term (ARC-20160722)