

SPPC Lattice Design and DA Study

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Outline

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

Outline

1. SPPC Parameter Choice and Optimize

SPPC Parameter Choice and Optimize

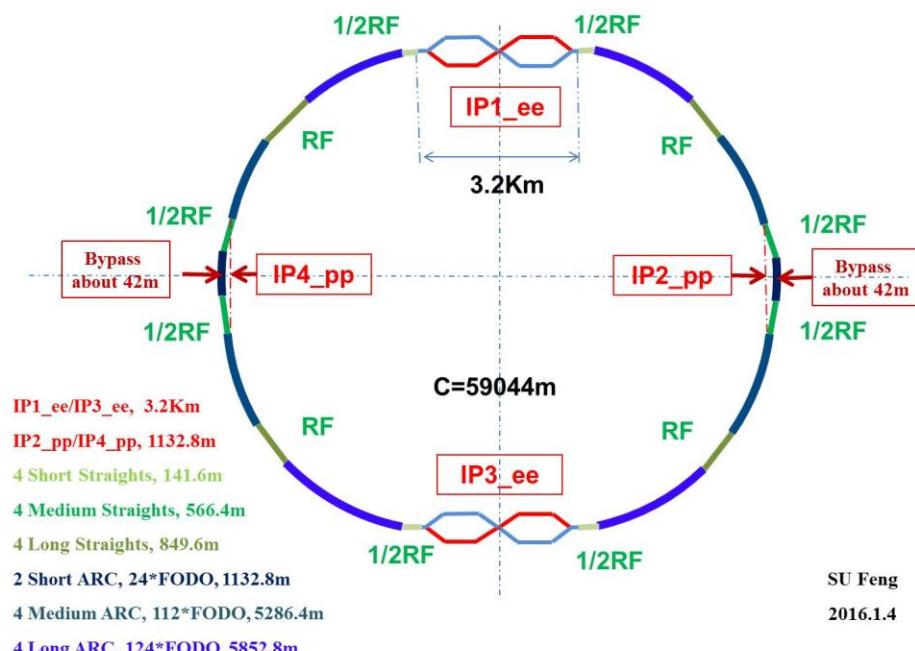
Table 1: SPPC Parameter List.

Version 201503

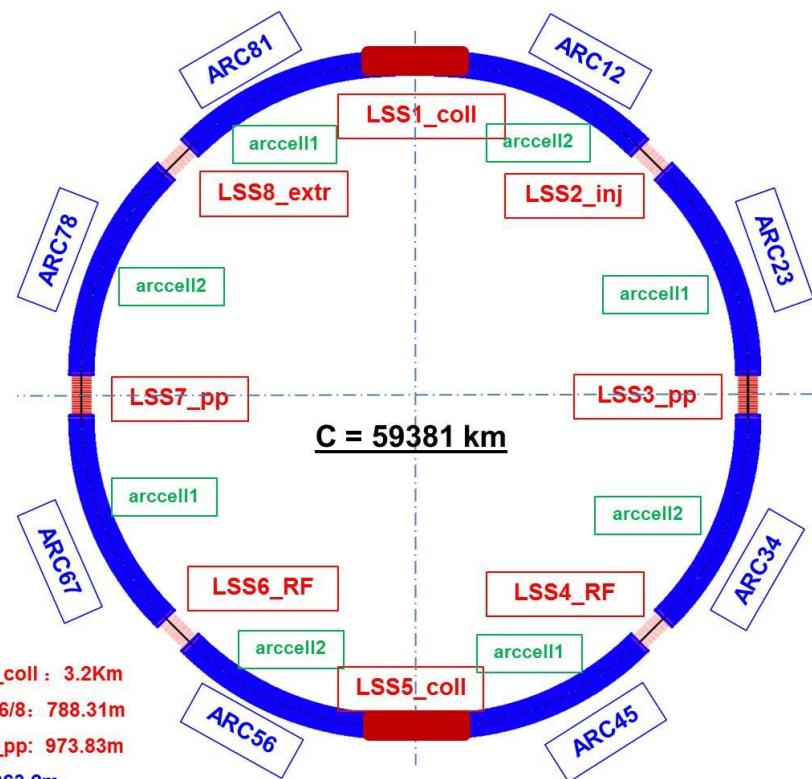
	SPPC(Pre-CDR)	SPPC-54.7Km	SPPC-100Km	SPPC-100Km	SPPC-78Km
Main parameters and geometrical aspects					
Beam energy [E_0]/TeV	35.6	35.0	50.0	68.0	50.0
Circumference [C_0]/km	54.7	54.7	100.0	100.0	78.0
Dipole field [B]/T	20	19.69	14.73	20.03	19.49
Dipole curvature radius [ρ]/m	5928	5922.6	11315.9	11315.9	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

CEPC & SPPC Layout

CEPC Partial Double Ring Layout



SPPC Layout (Su Feng Jan. 10, 2016)



SPPC ARC Parameter Choice

Theory:

$$E_0 = 70 - 100 \text{ TeV}$$

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

$$\beta = 1$$

$$B_P = \frac{E_0}{c} = 3.1267 \quad \beta\gamma = 116635.29 \text{ Tm}$$

$$B_0 = 20 \text{ T}$$

$$\rho = \frac{116635.29}{B_0} = \frac{116635.29}{20} = 5831.7645$$

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

$$\text{ARC filling factor } f_1 = 0.8$$

$$L_{\text{ARC}} = \frac{L_{\text{Dipole}}}{f_1} = \frac{36642.05}{0.8} = 45802.56 \text{ m}$$

$$L_{\text{ss3pp}} = L_{\text{ss7pp}} = 973.83 \text{ m}$$

$$L_{\text{ss2}} = L_{\text{ss4}} = L_{\text{ss6}} = L_{\text{ss8}} = 788.31 \text{ m}$$

$$L_1 = 50903.46$$

$$L_{\text{ss1}} = L_{\text{ss5}} = 3.3 \text{ km}$$

$$C_0 = 57503.46 \text{ m}$$

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

$$\text{Betax: } 244.878/42.57 \quad (\epsilon_n = 4.1 \mu\text{m})$$

$$\text{Betay: } 42.569/244.869$$

$$E \text{ (Collision: 35TeV)} \quad (\text{Injection: 2.1TeV})$$

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

$$\epsilon \text{ (Collision: } 1.099 \times 10^{-10} \text{ m} = 0.1099 \text{ nm)} \quad (\text{Injection: } 1.83 \times 10^{-9} \text{ m} = 1.83 \text{ nm})$$

$$\sigma \text{ (Collision: } 1.66 \times 10^{-4} \text{ m} = 166 \mu\text{m)} \quad (\text{Injection: } 6.76 \times 10^{-4} \text{ m} = 676 \mu\text{m})$$

$$R = 20 * \sigma_{\text{inj}} = 13.52 \text{ mm}$$

$$D = 27.04$$

$$L_B = 14.8 \text{ m}$$

$$\text{FODO : } f_1 = \frac{14.8 * 8}{144.4} = 0.8199$$

$$\text{ARC : } f_1 = \frac{14.8 * 8 * 38 + 14.8 * 8 * 2}{(38 + 2 + 2) * 144.4} = 0.7809$$

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

$$L_1 = 52981.42$$

$$C_0 = 59581.42$$

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

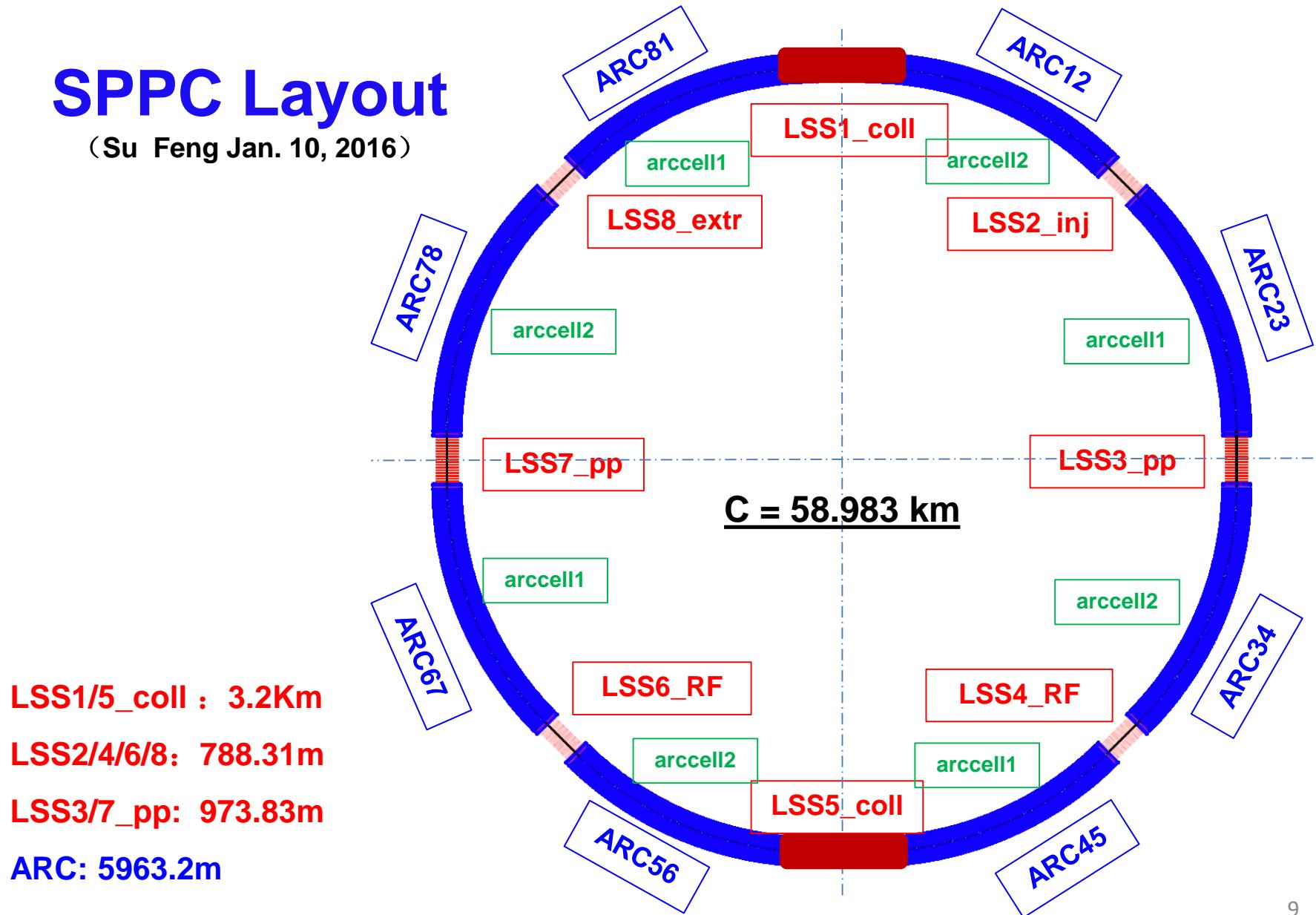
Outline

2. SPPC Lattice Layout and Design:

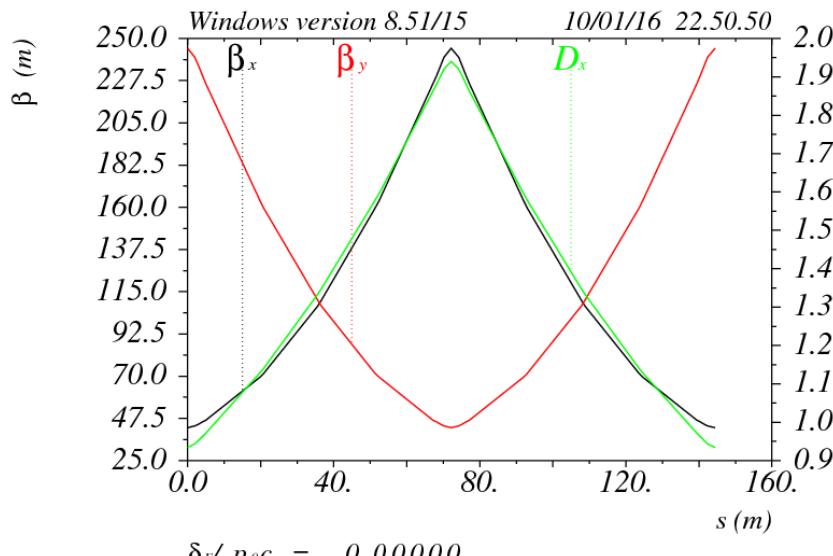
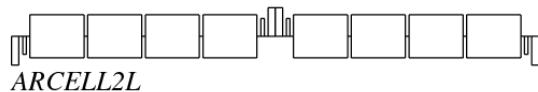
- a. FODO Cell and ARC**
- b. Dispersion Suppressor Section**
- c. Long Straight Section**
- d. IR**

SPPC Layout

(Su Feng Jan. 10, 2016)



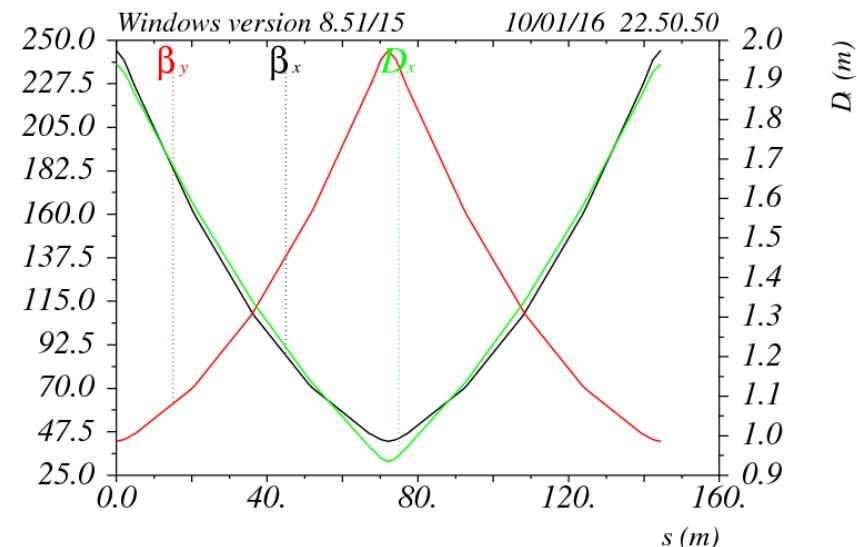
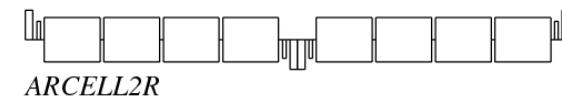
FODO Cell in ARC



arccell1

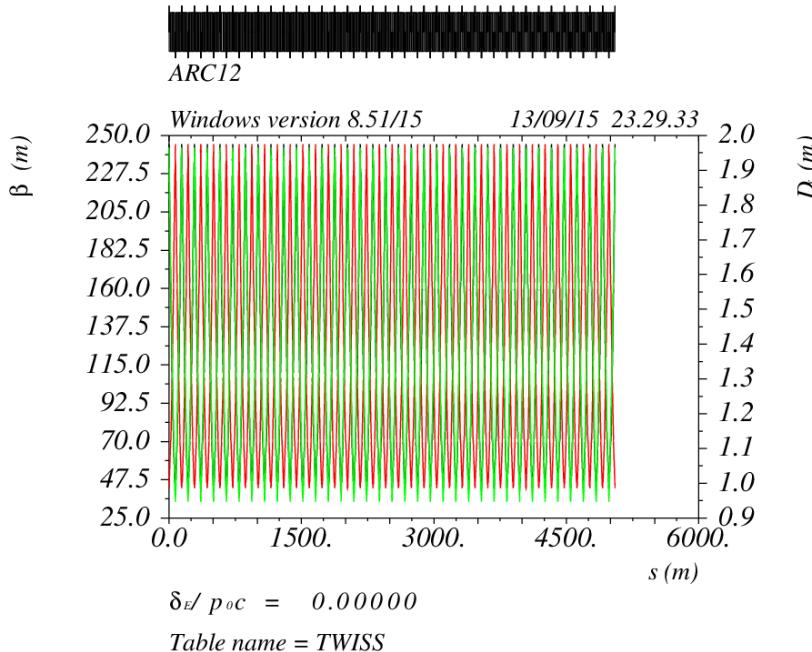
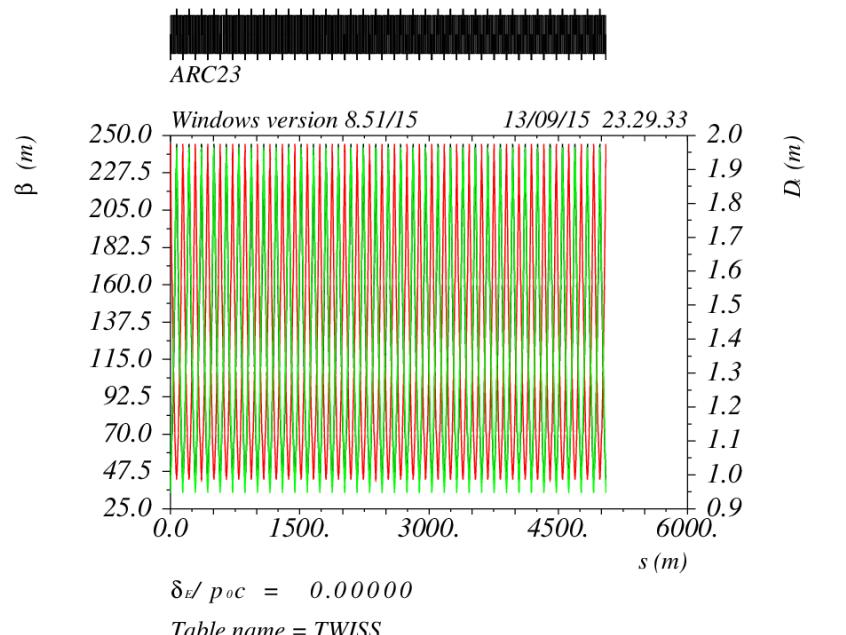
L=144.4m

Betax: 244.878/42.57
Betay: 42.569/244.869



arccell2

ARC (ARCDSP,36 CELL, ARCDSPR)

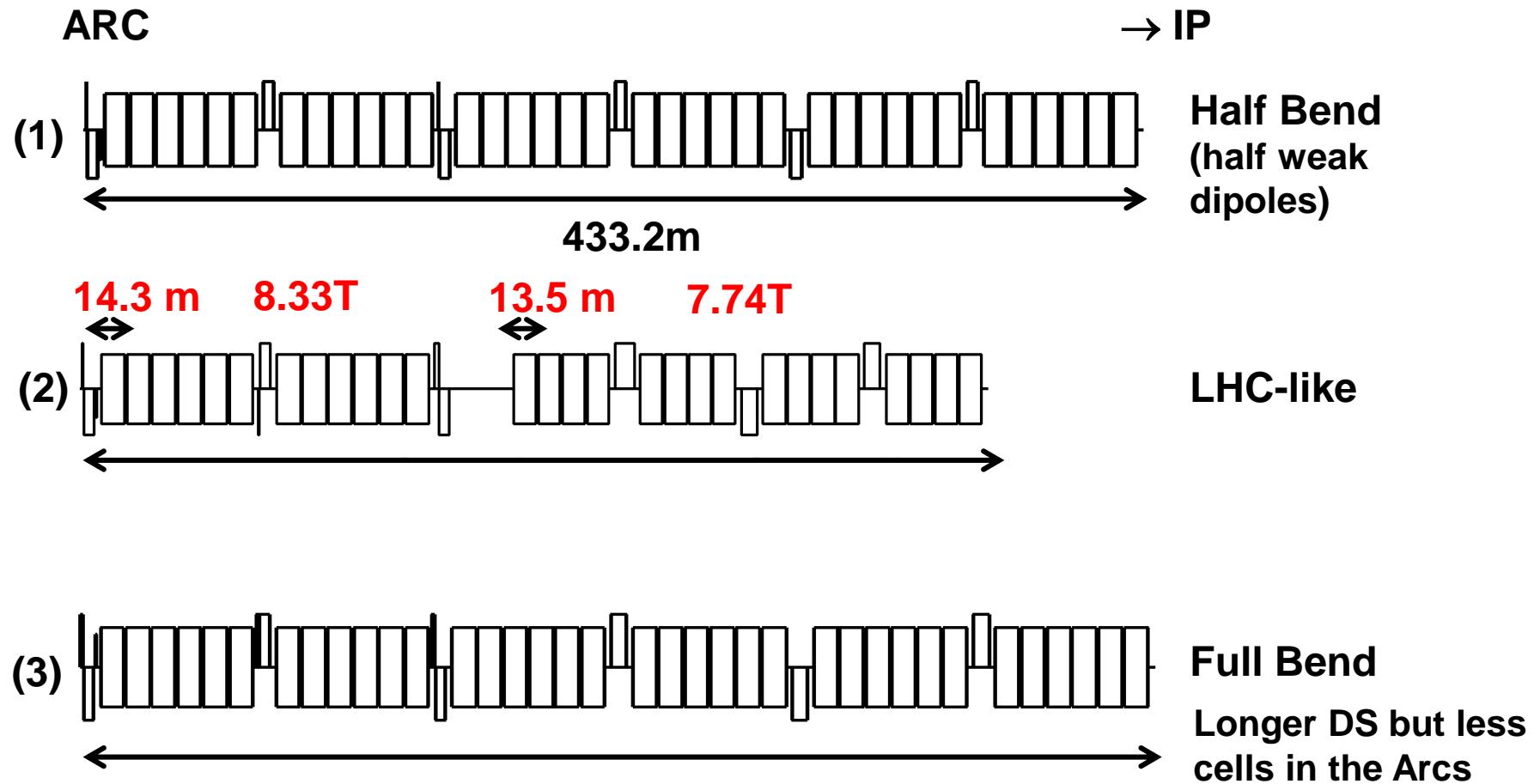


ARC23
ARC45
ARC67
ARC81

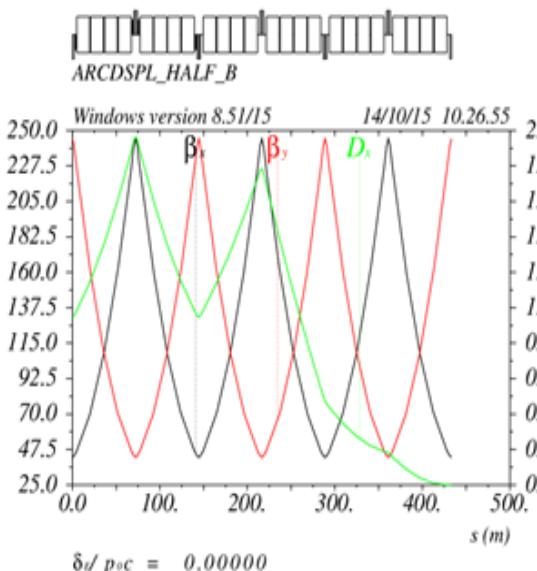
L=5963.2m

ARC12
ARC34
ARC56
ARC78

Dispersion Suppressor (DS) types

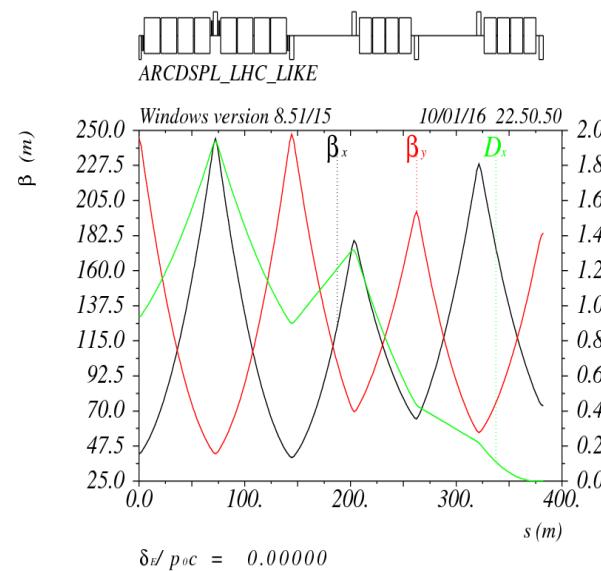


(1) Half Bend



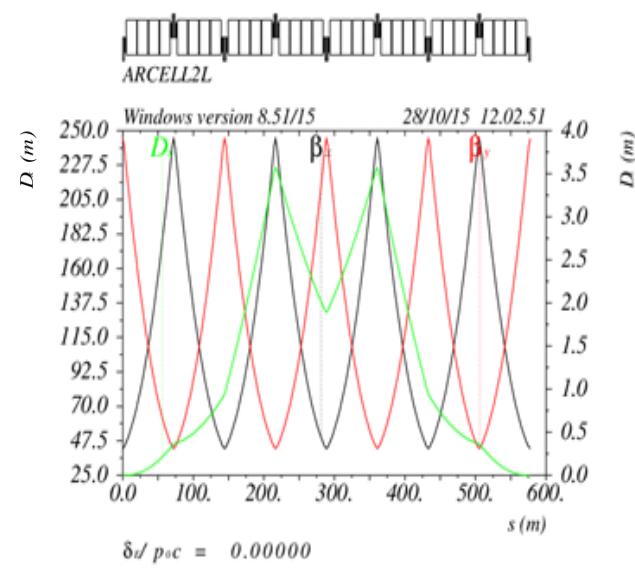
L=433.2m

(2) LHC Like



L=382.4m

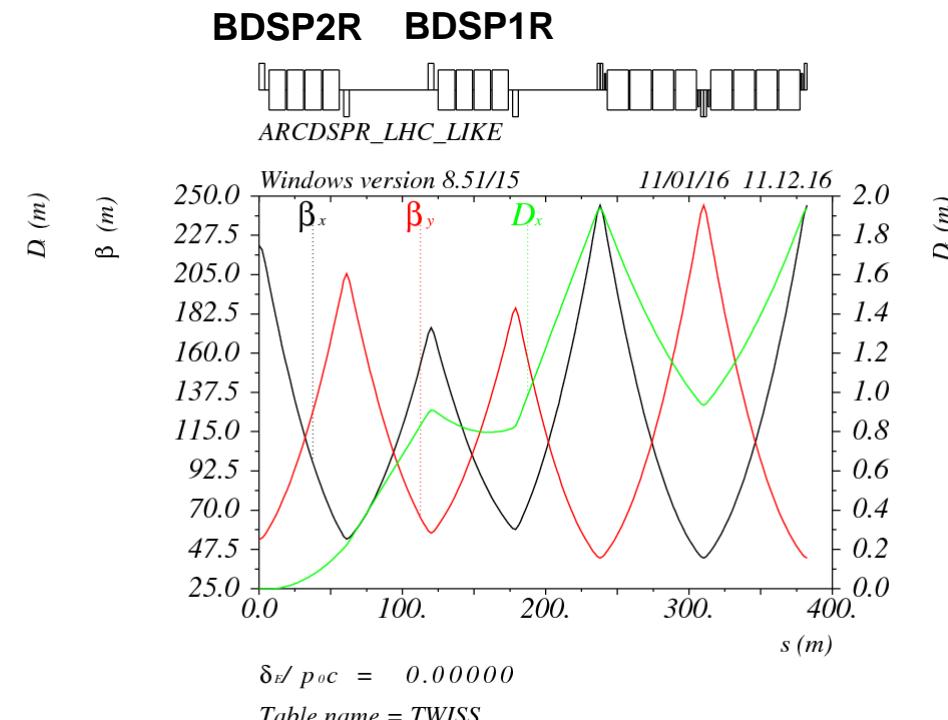
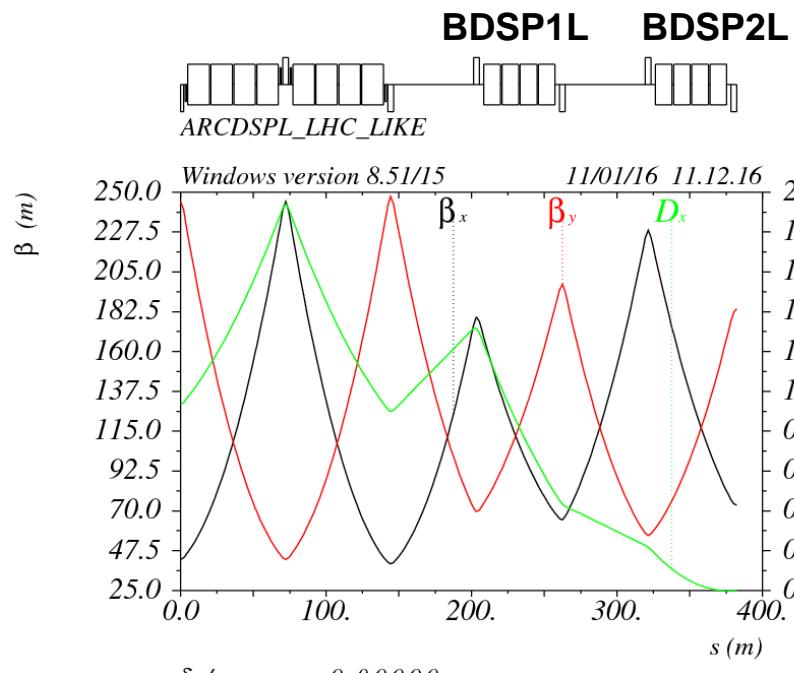
(3) Full Bend



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)



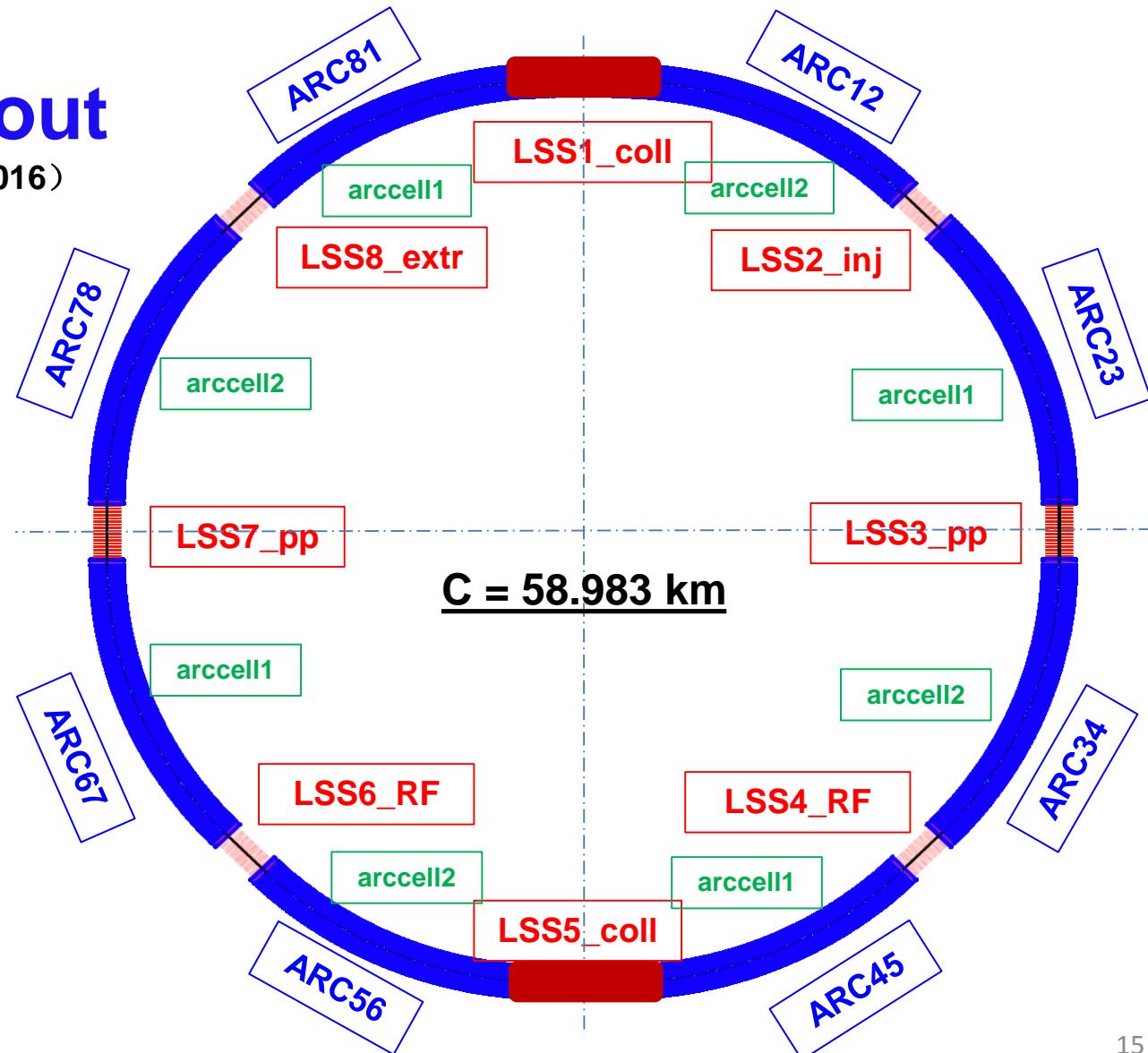
382.4m

	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)



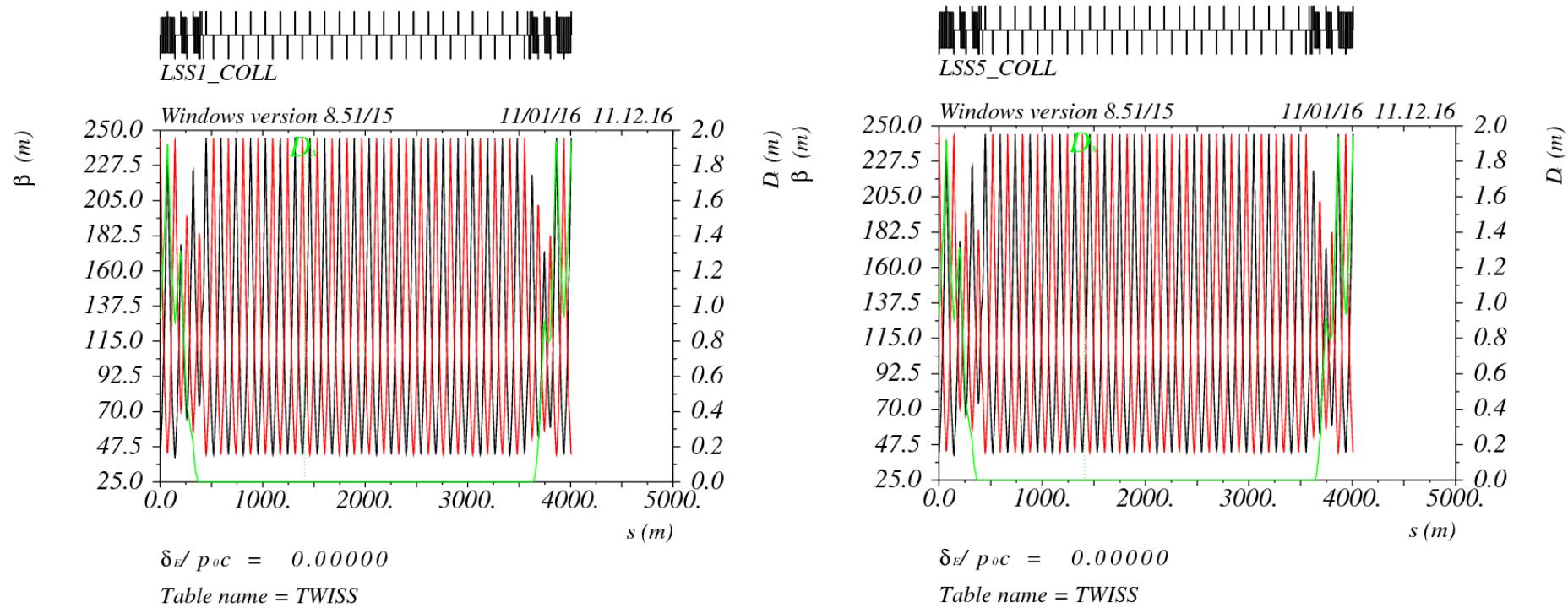
LSS1/5 coll : 3.2Km

LSS2/4/6/8: 788.31m

LSS3/7 pp: 973.83m

ARC: 5963.2m

LSS1/5_coll

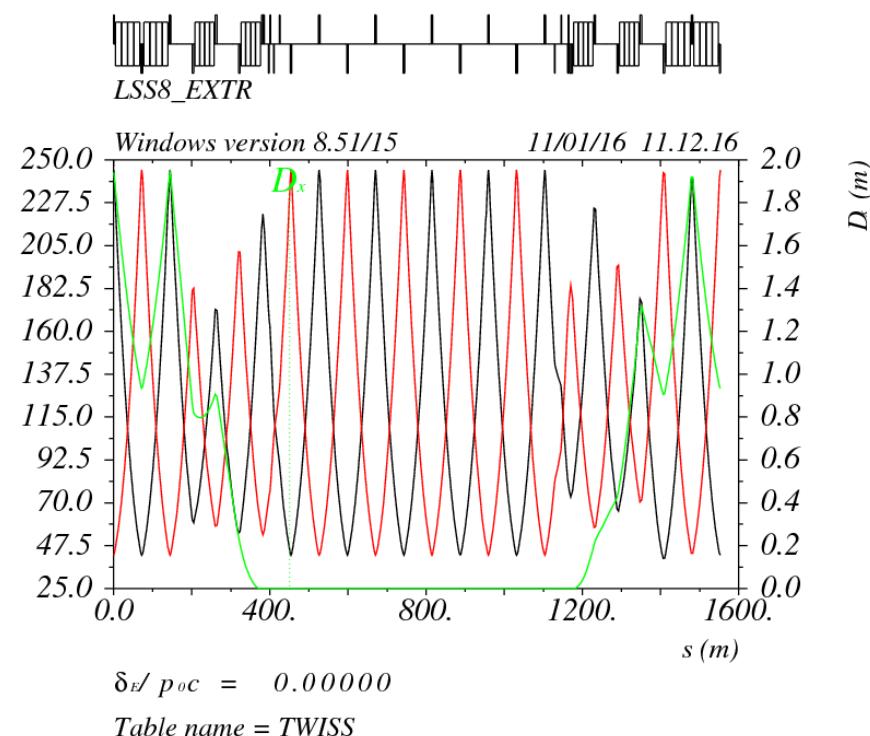
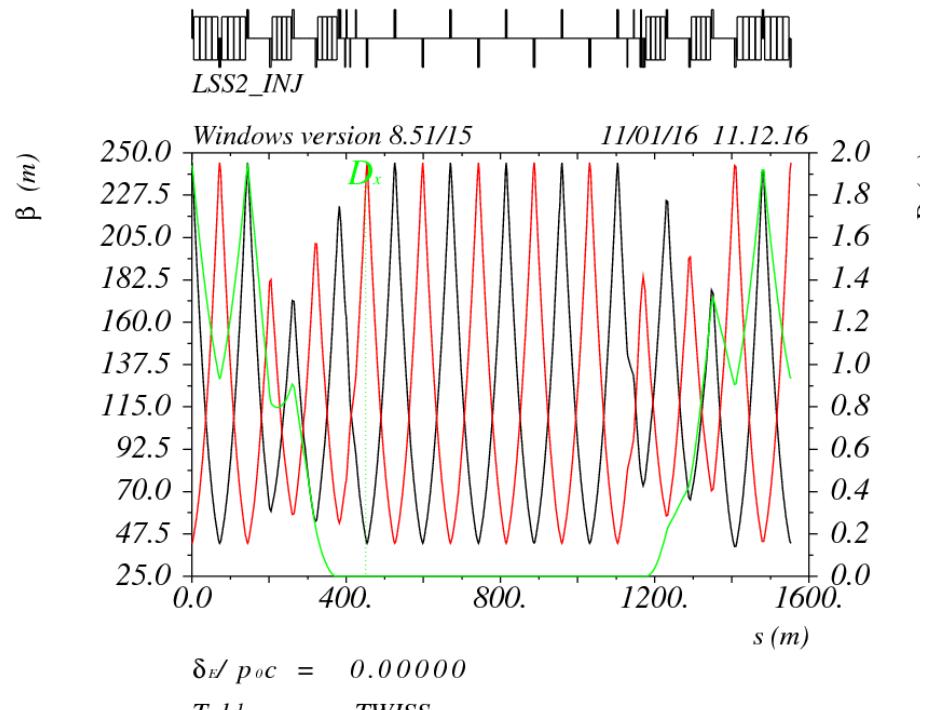


$$L=3243.106\text{m}$$

ARCDSP, ARC_to_STR, 21.5*STRCELL, STR_to_ARC, ARCDSPR

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

LSS2_inj/LSS8_extr

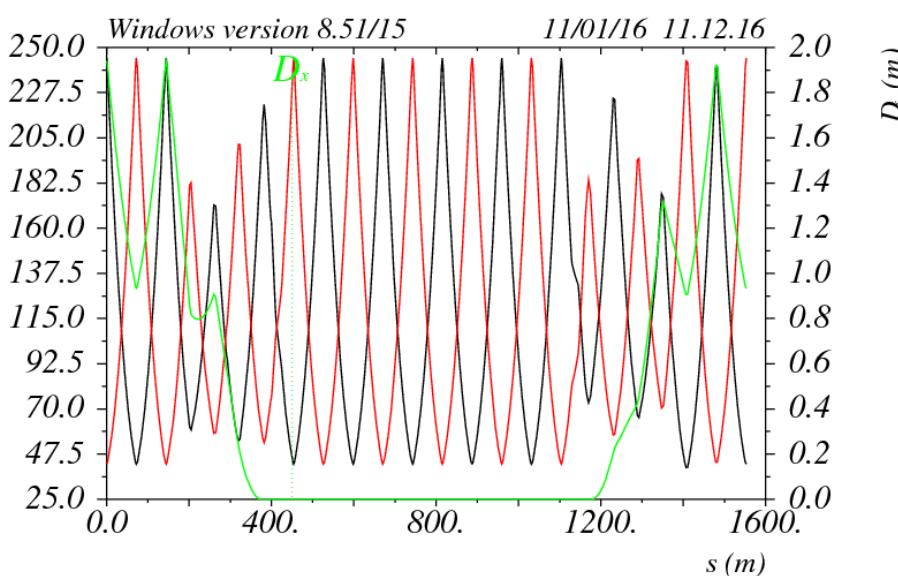
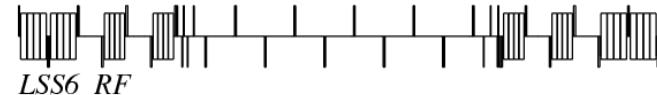
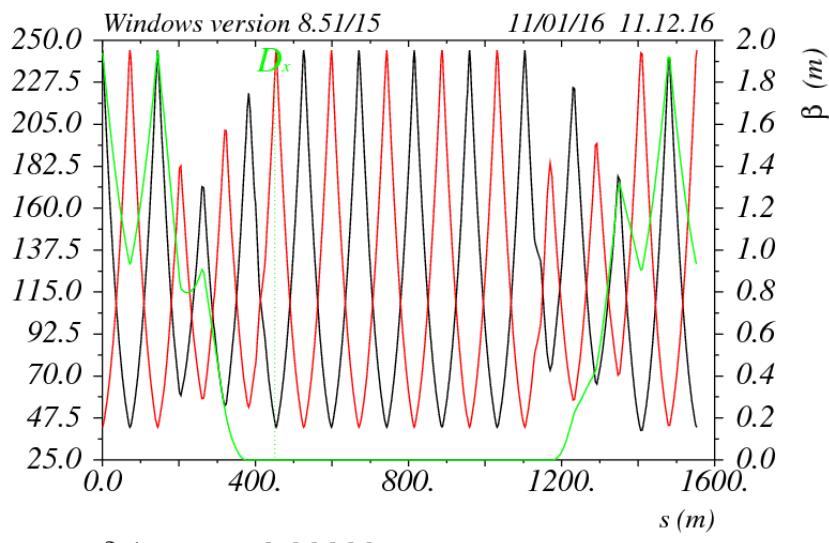
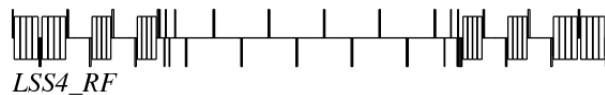


L=788.306m

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

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

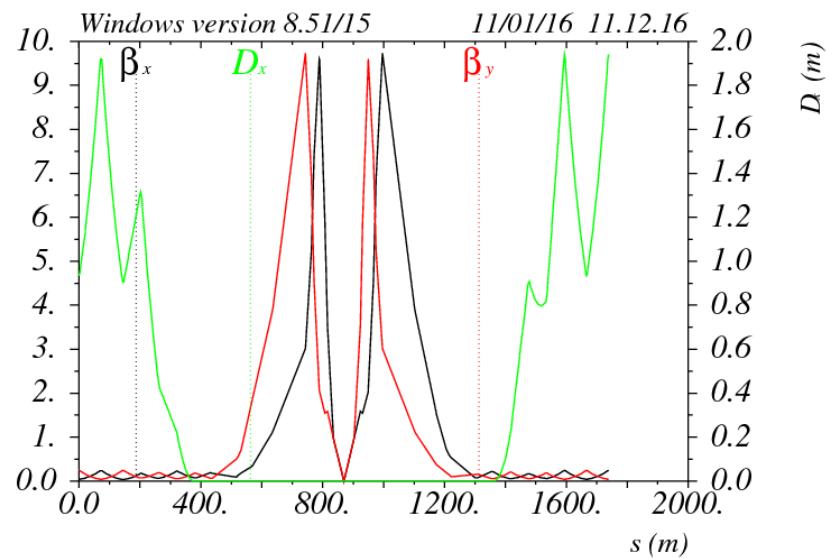
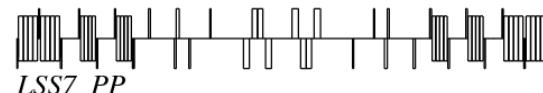
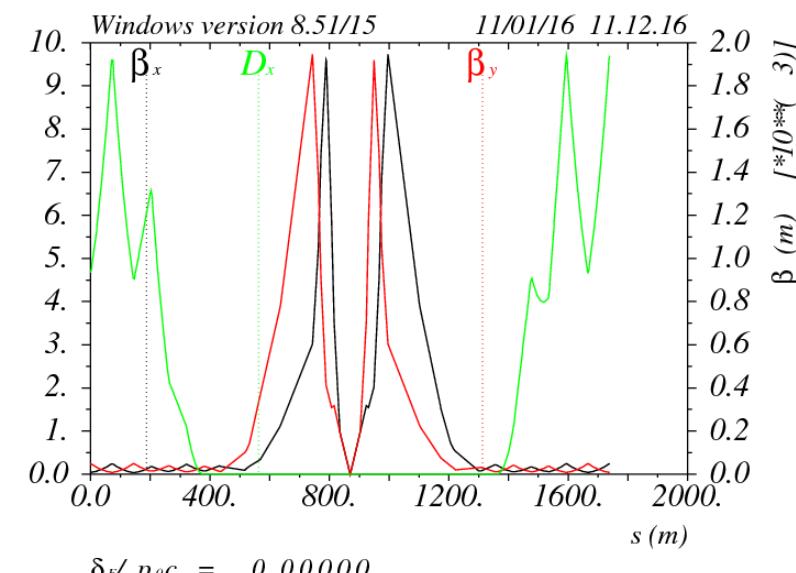
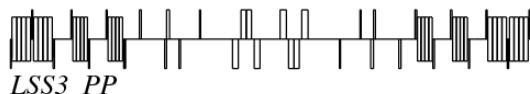
LSS4/6_rf



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

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

LSS3_pp/LSS7_pp



L=973.829m

ARCDSP, ARC_to_STR, 21.5*STRCELL, STR_to_ARC, ARCDSPR

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

Beta: 0.75m

Crossing angle: 146urad

	K1(m^-2)	G (T/M)	L(M)	β_{max}
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

Q Strength

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

Outline

3. SPPC Dynamic Aperture Study

Definition of Dynamic Aperture

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

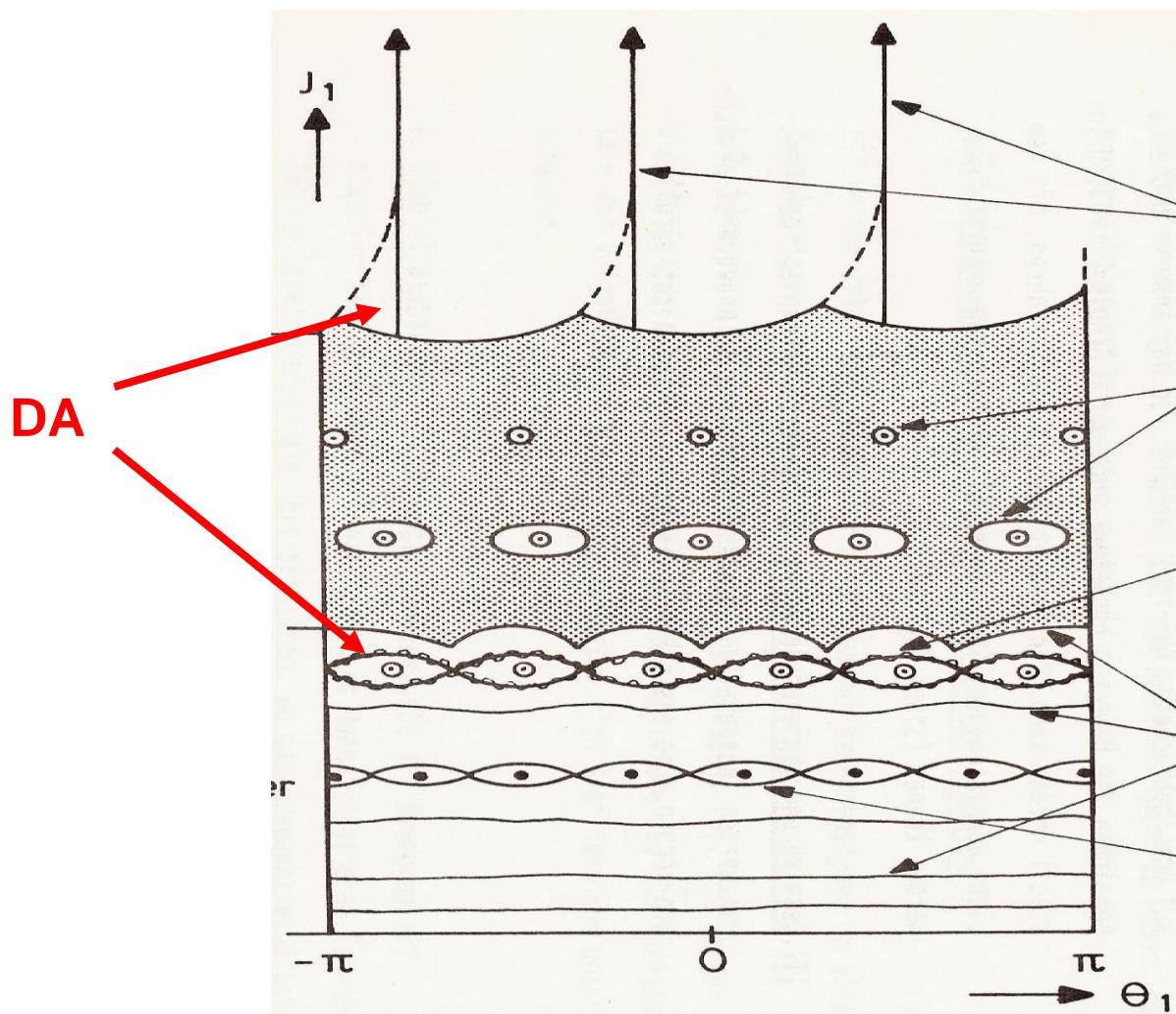
Largest Amplitude at which particles remain in the accelerator over a time range of interest.

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



Rapid amplitude growth and loss

Stable Islands in chaotic sea

Fine chaotic layers in stable regime

Mostly stable particle motion

Chaos Criteria

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

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

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.

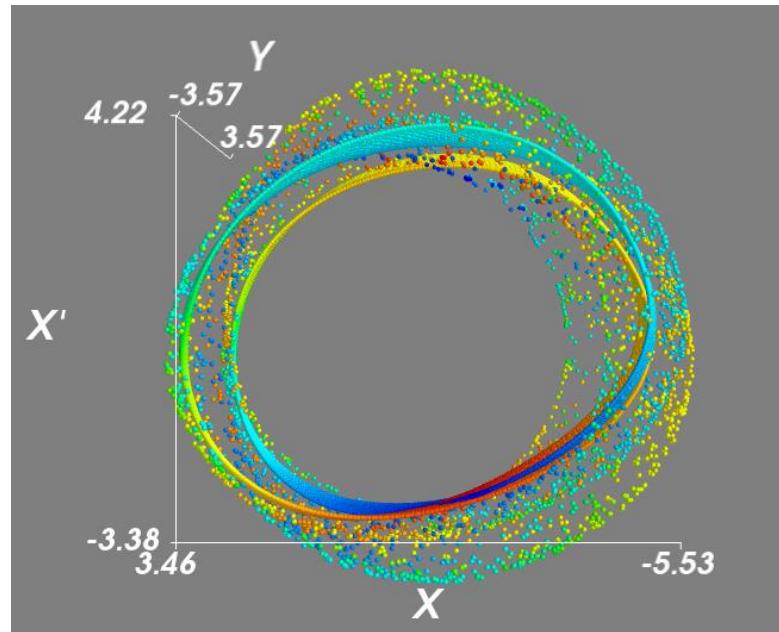
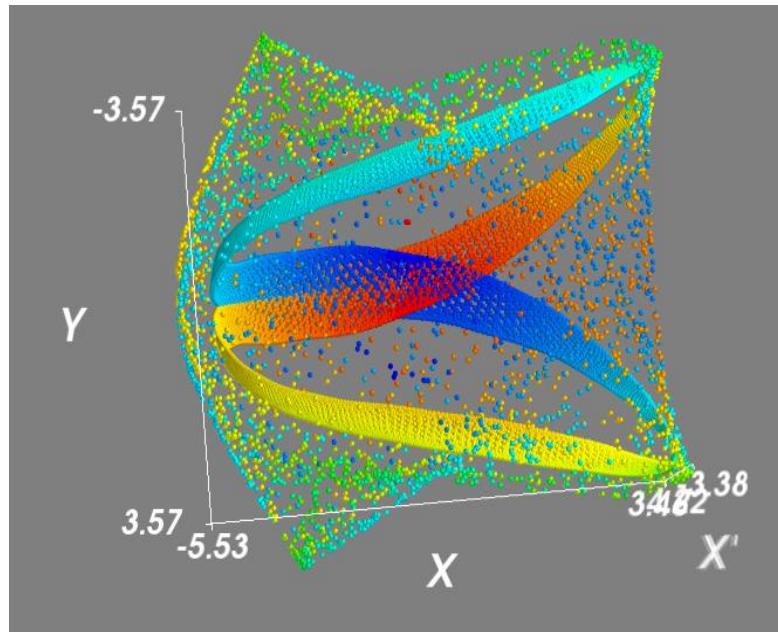
SPPC Main Ring DA *without* low beta pp IR(1/7)

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 ($346 \sigma_x$) in horizontal and 49.16 mm ($315 \sigma_y$) in vertical.

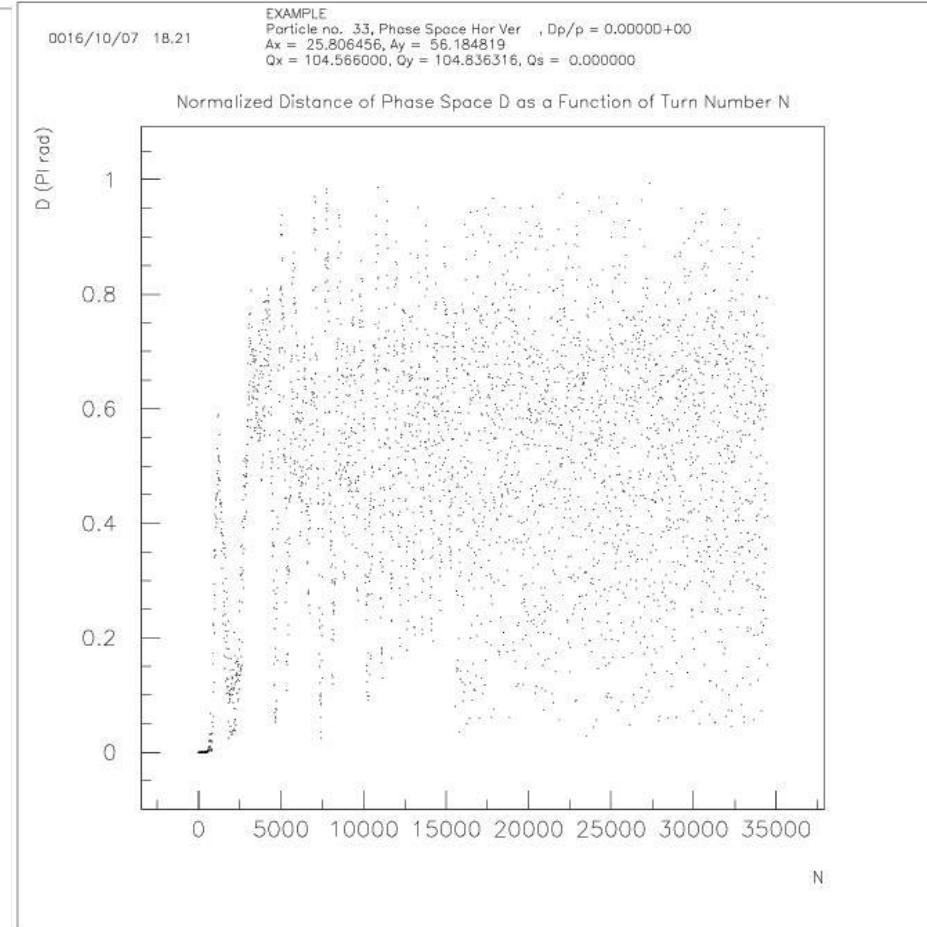
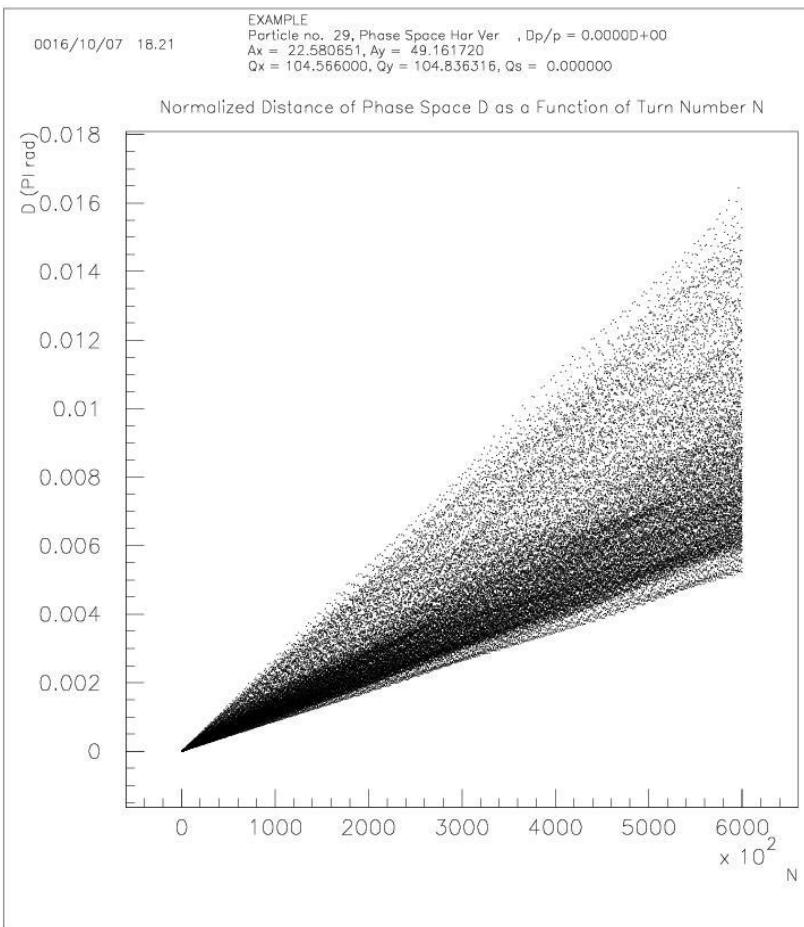
SPPC Main Ring DA *without* low beta pp IR(2/7)



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

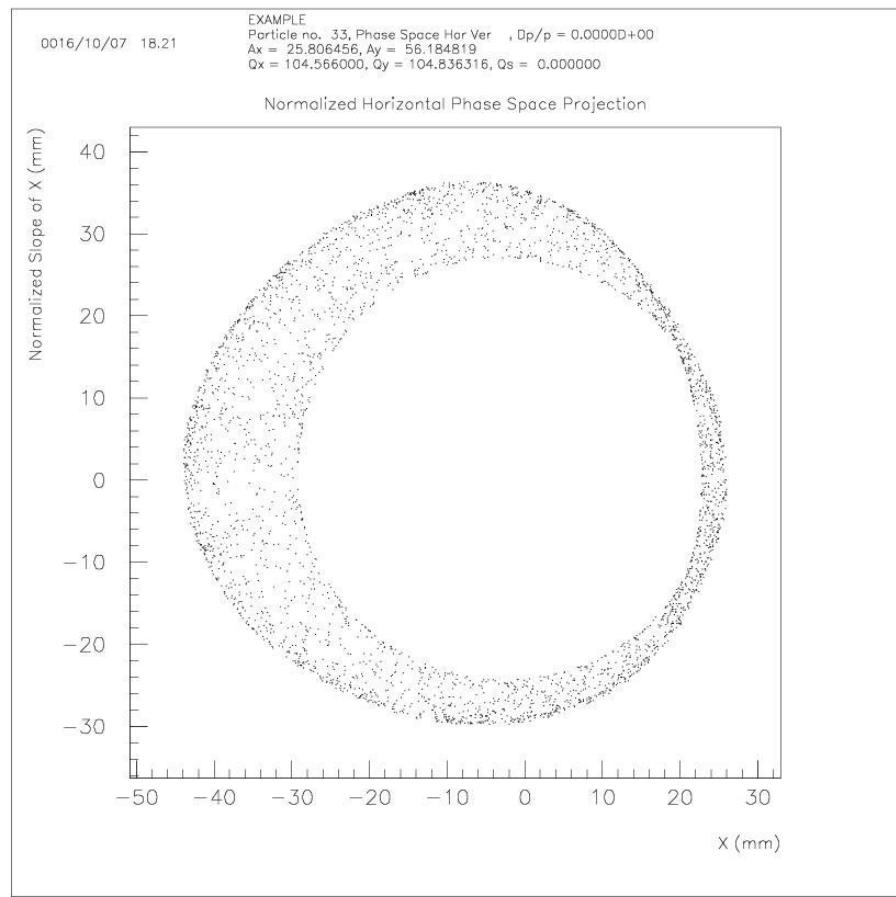
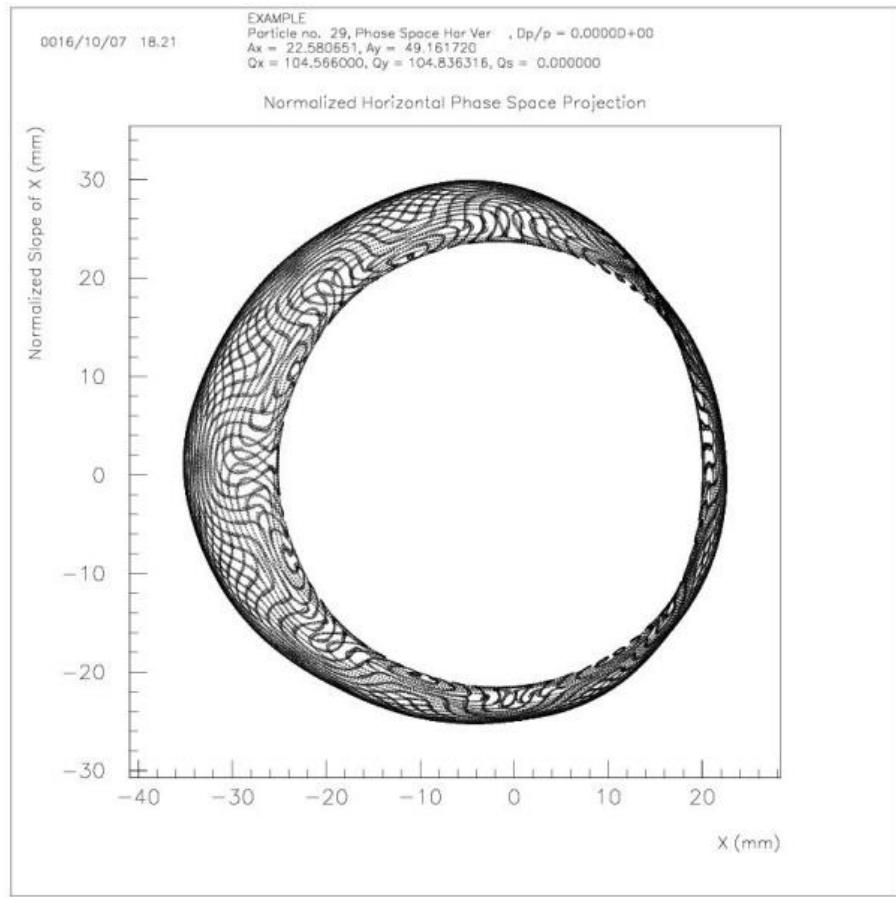
(The solid tie shape shows the regular particles motion which has the largest amplitude, if the amplitude becomes a little larger, the motion will become chaotic, the diffusion points around the solid tie show the chaotic motion. This largest amplitude is the dynamic aperture we want to study.)

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



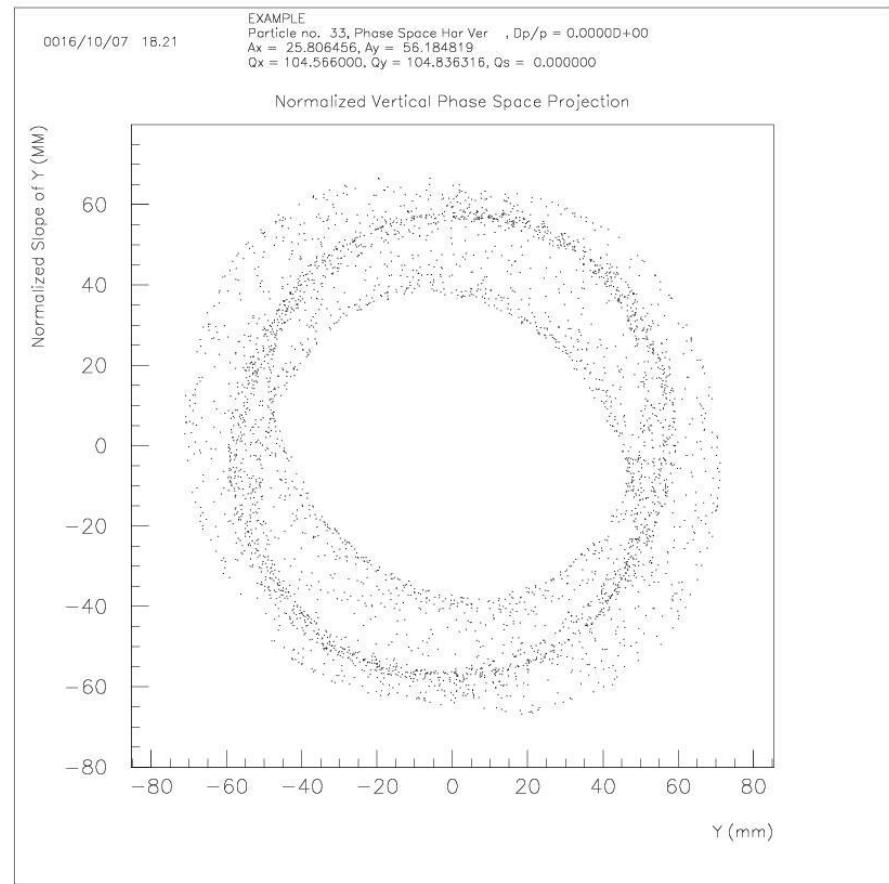
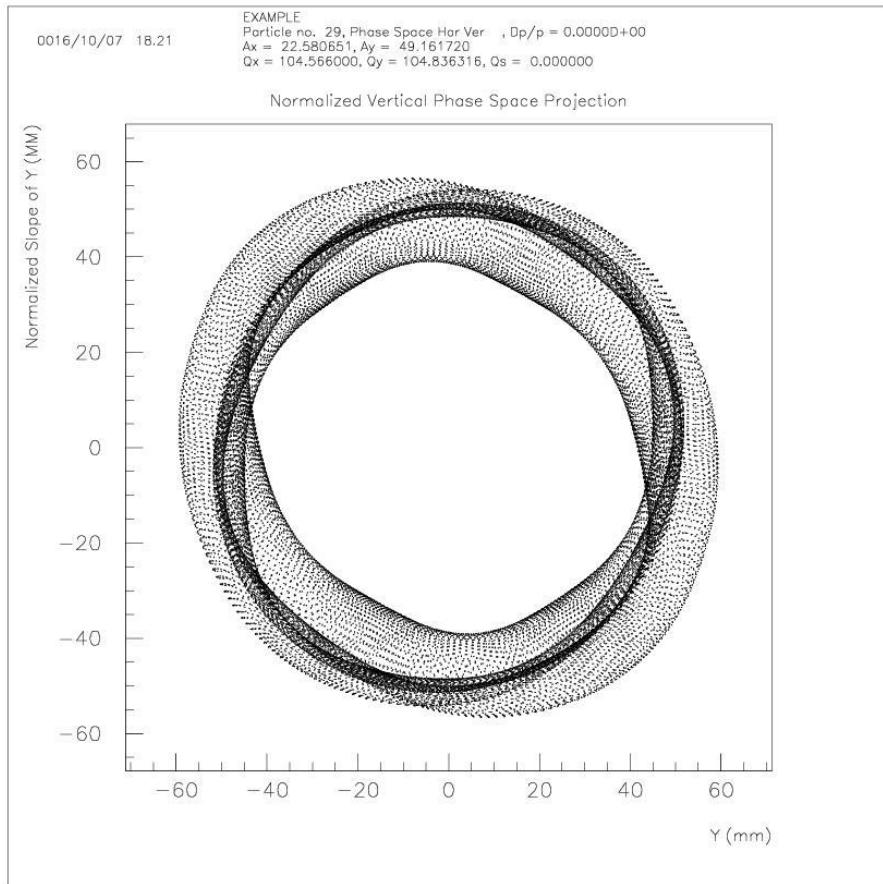
Evolution of the distance of phase space for regular (left) and chaotic (right) motion.

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



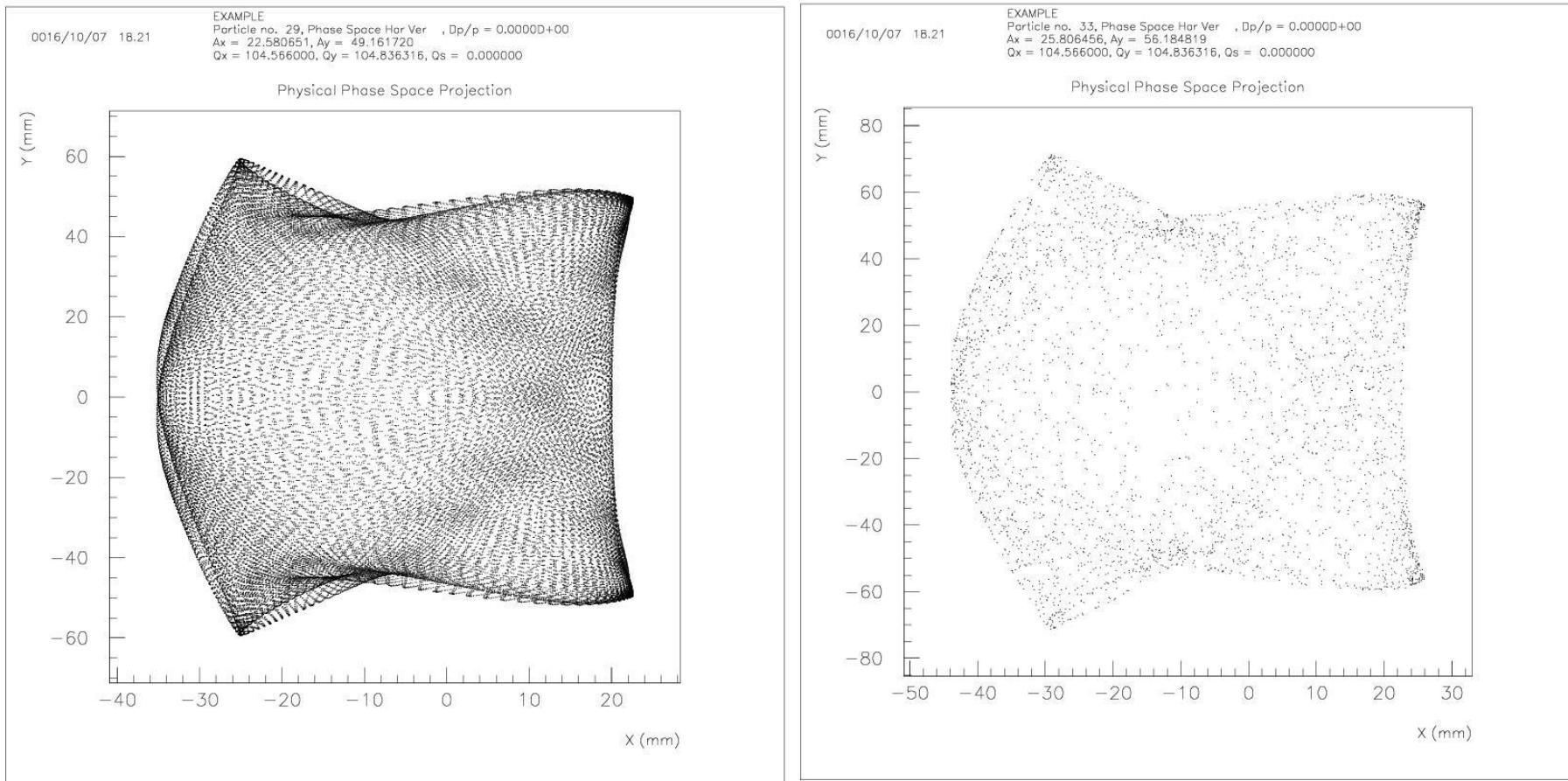
Horizontal phase space projections for regular (left) and chaotic (right) cases.

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



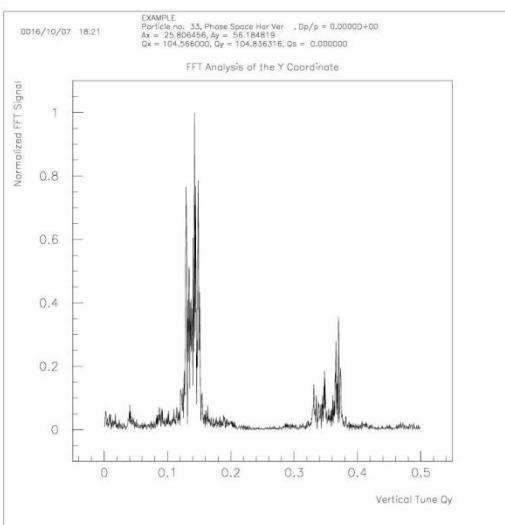
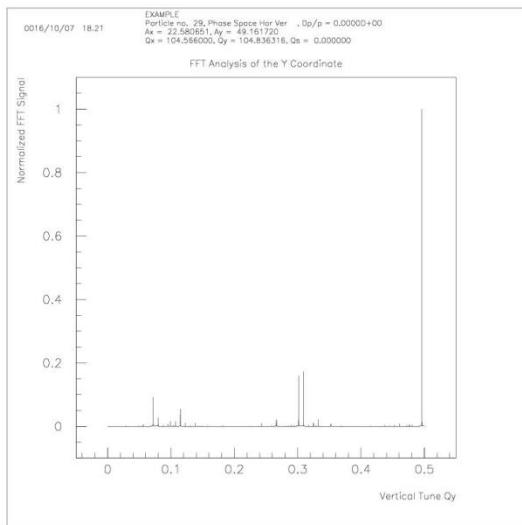
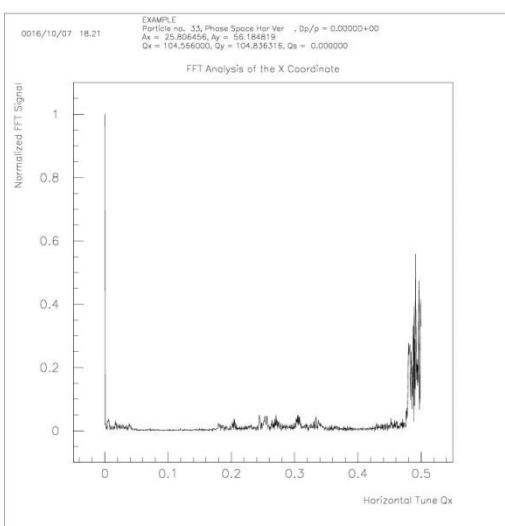
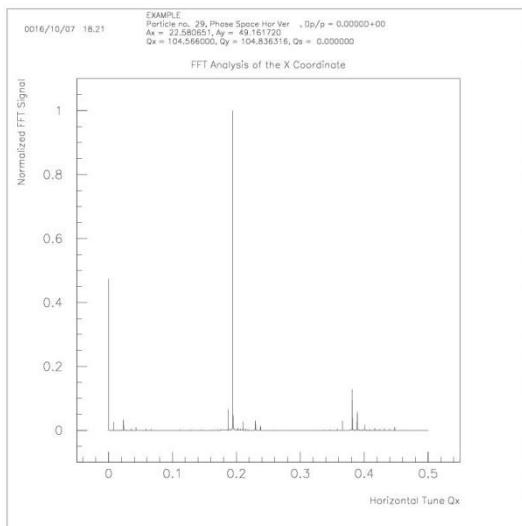
Vertical phase space projections for regular (left) and chaotic (right) cases.

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.

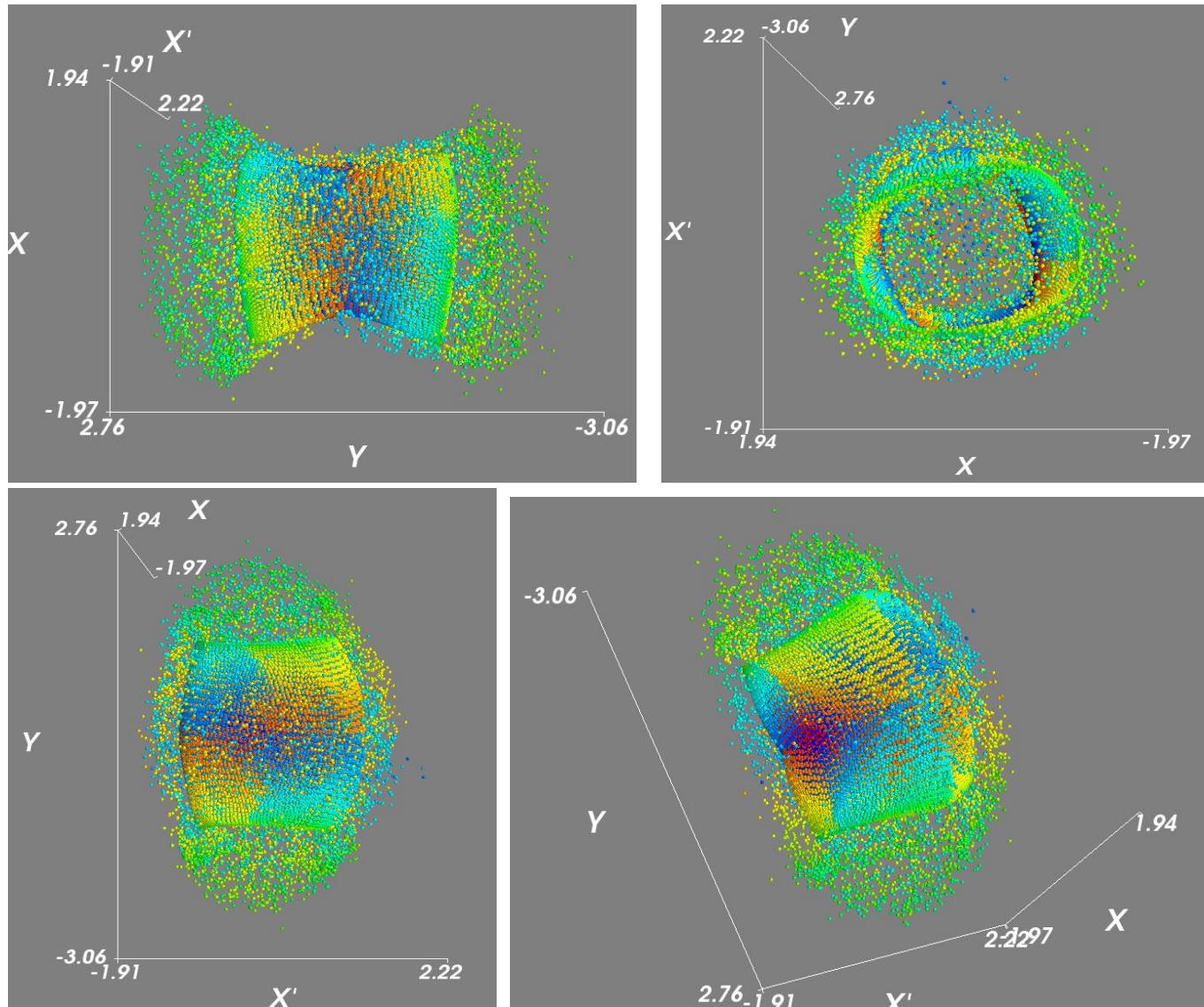
SPPC Main Ring DA with low beta pp IR(1/5)

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 ($126 \sigma_x$) in horizontal and 19.73 mm ($126 \sigma_y$) 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 (126σ) in both horizontal and vertical because the beam size is very small (8.647um).

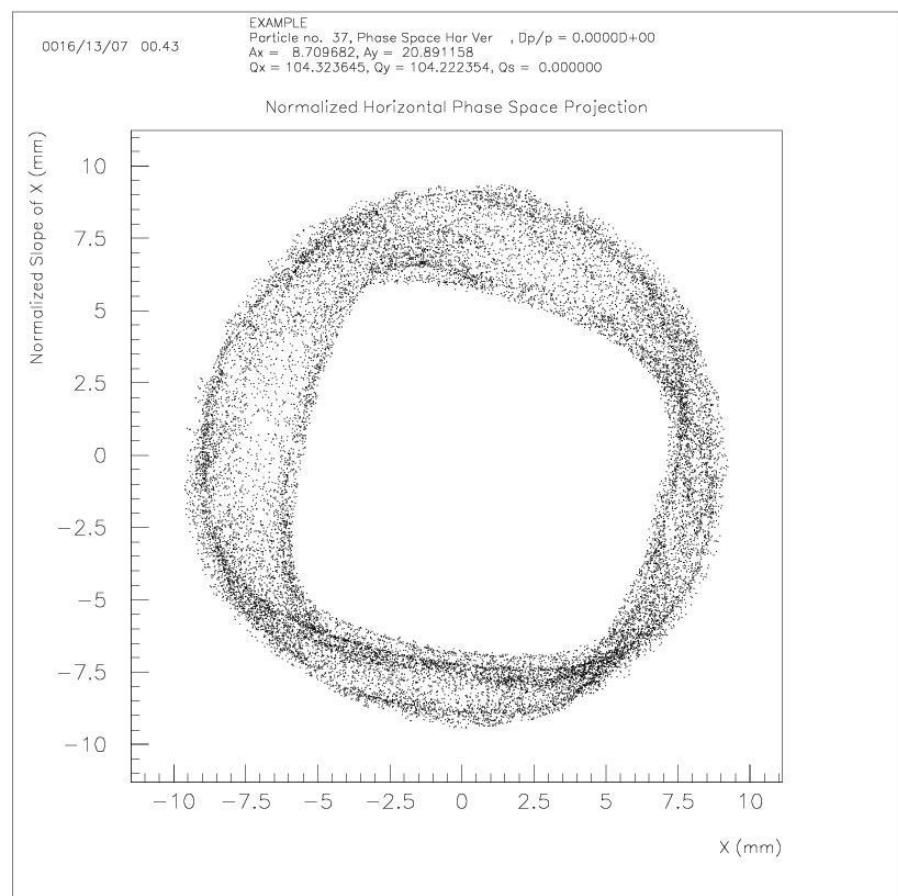
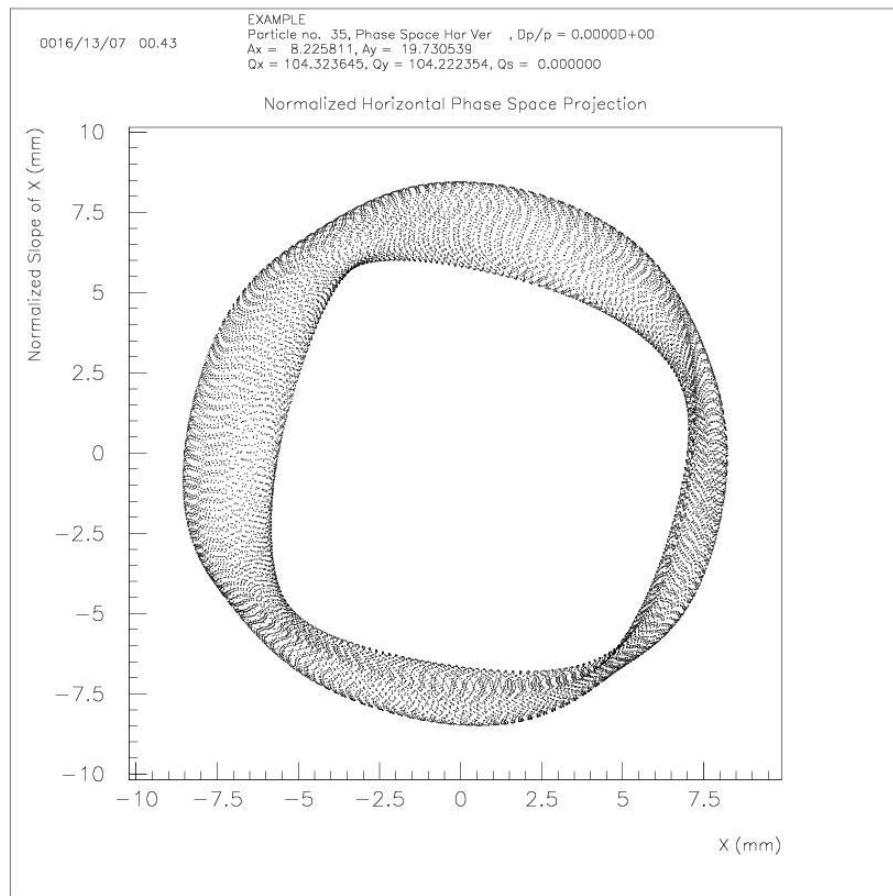
Following figures show the details.

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



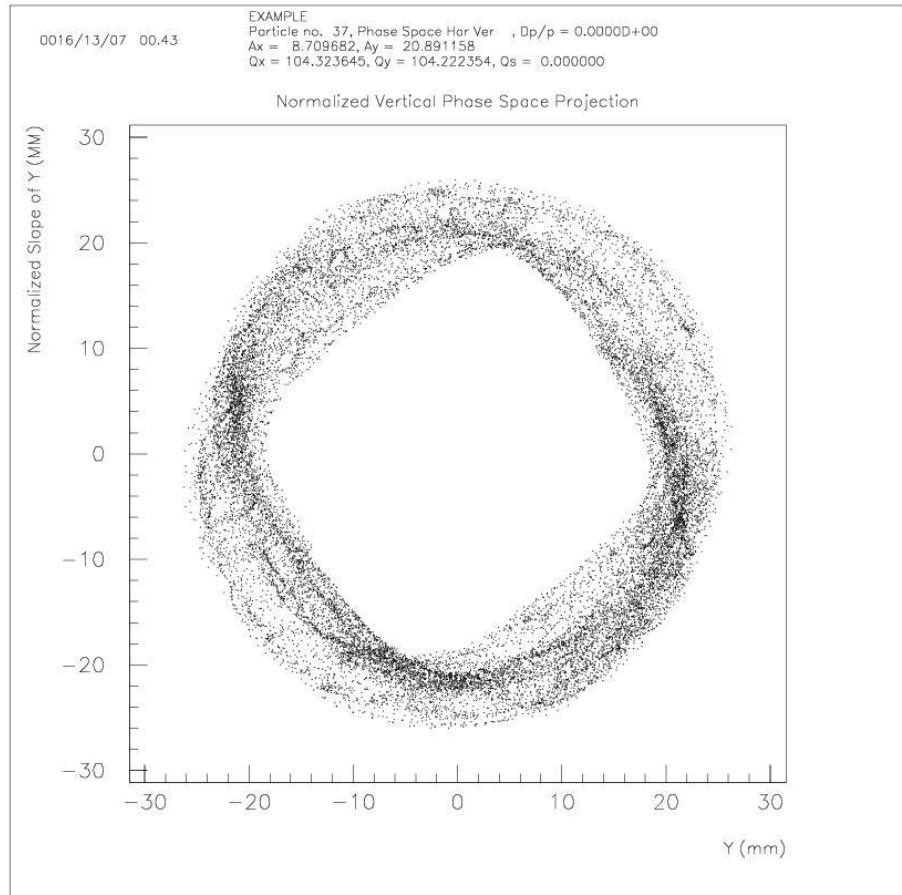
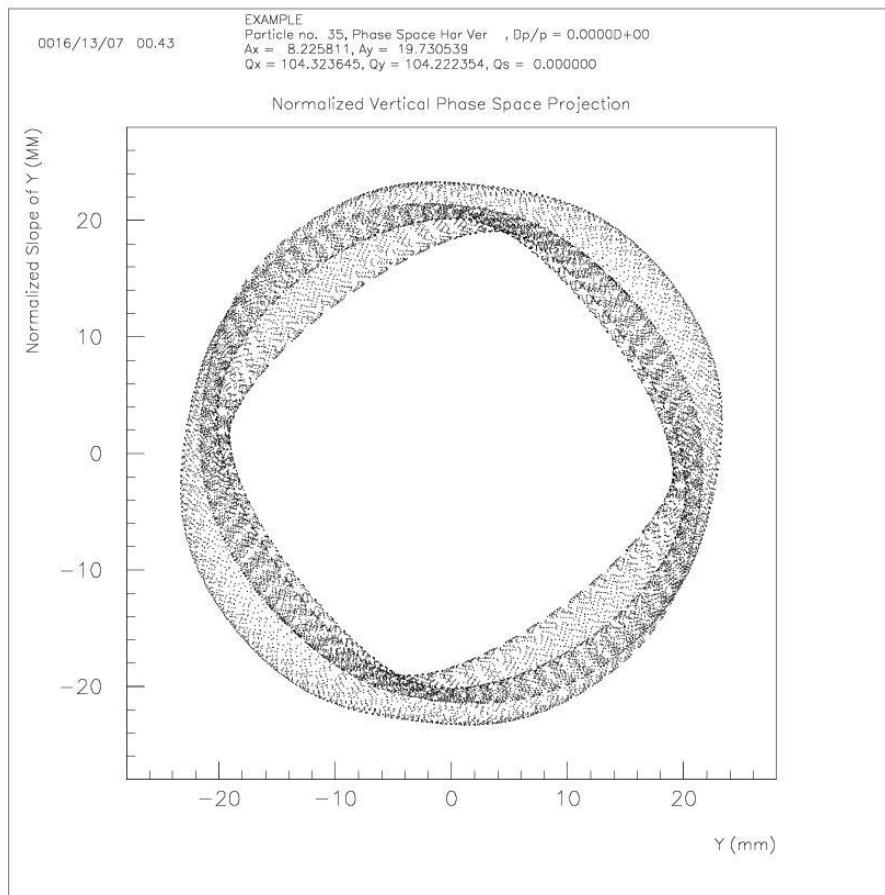
4-Dimension phase space for regular and chaotic motion (cm).

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



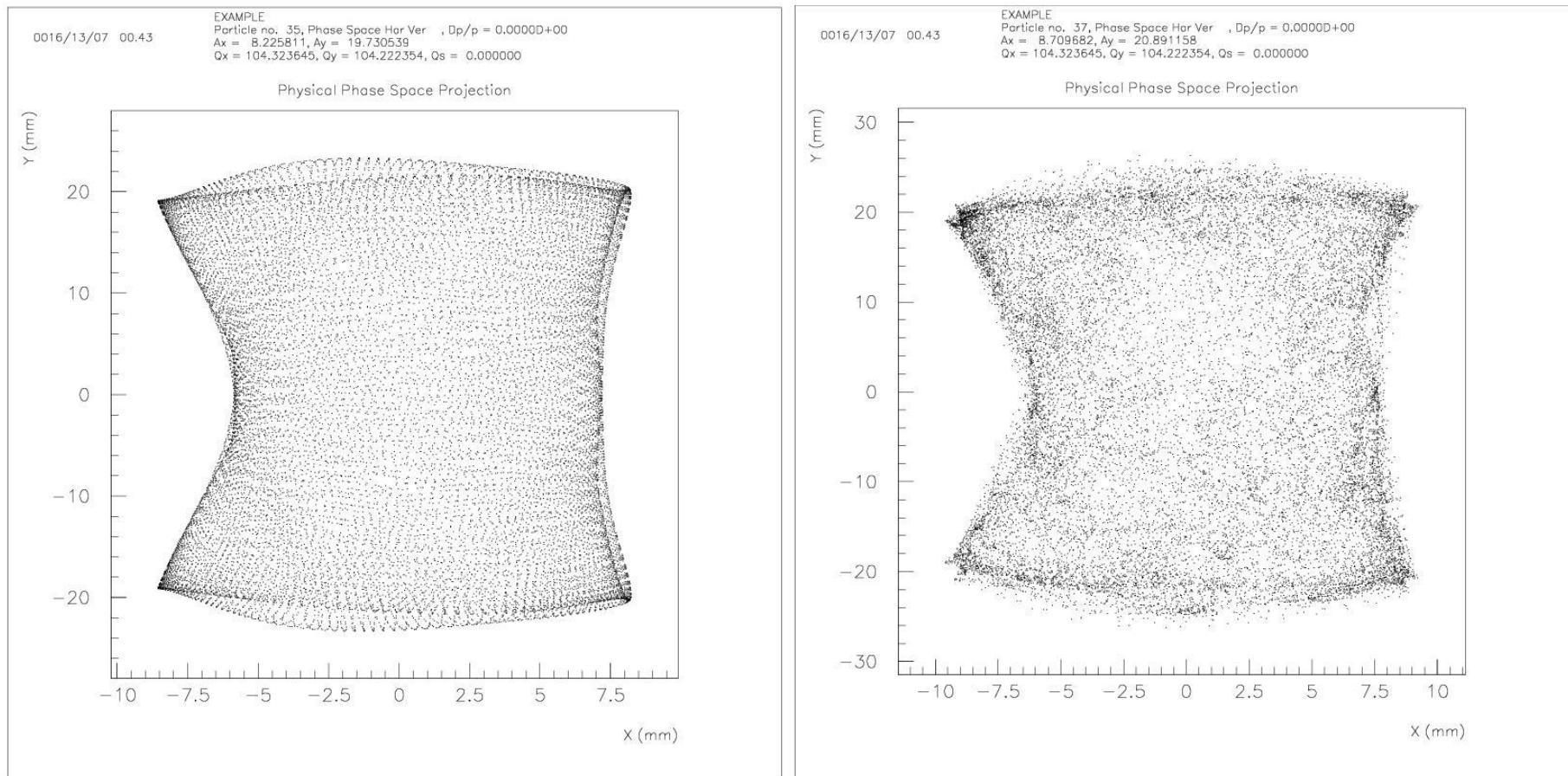
Horizontal phase space projections for regular (left) and chaotic (right) cases.

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.

4. 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.



Thank You !

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