CEPC IR Design

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TLEP and CEPC IR designs meeting

CEPC low power design

- Idea：

1）reduce operation cost（reduce AC power）
2）reduce the Microwave system cost

- Method：

reduce the IP β_y until reach the low IP β_y , the parameters table shows several sub-mm β_y， to low beta 350um。

- Advantages:

1) Radiation power reduce ， AC power (offer the Microwave power）reduce，klystron numbers reduce。
2) Beam power reduce， loss of heat energy of beam in SC cavity reduce, AC power due to refrigerator reduce (Now Ring Higgs Factory power without this part）。
3）1)+2) AC power reduced remarkably。

CEPC design parameters

Number of IPs	1	1	1	1
Energy (GeV)	120	120	120	120
Circumference (km)	50	50	50	50
SR loss/turn (GeV)	2.96	2.96	2.96	2.96
N_e/bunch (10^{12})	0.79	0.38	0.33	0.28
Bunch number	22	23	21	19
Beam current (mA)	16.9	8.45	6.76	5.07
SR power /beam (MW)	50	25	20	15
B_0 (T)	0.065	0.065	0.065	0.065
Bending radius (km)	6.2	6.2	6.2	6.2
Momentum compaction (10^{-4})	0.38	0.38	0.38	0.38
β_{IP} x/y (m)	0.2/0.001	0.071/0.00048	0.056/0.00042	0.041/0.00035
Emittance x/y (nm)	14.6/0.073	9.5/0.035	9.1/0.031	8.9/0.026
Transverse σ_{IP} (um)	54/0.27	25.9/0.13	22.7/0.11	19.2/0.096
ξ_x/IP	0.103	0.076	0.069	0.06
ξ_y/IP	0.103	0.103	0.103	0.103
V_{RF} (GV)	6	6	6	6
f_{RF} (MHz)	704	704	704	704
σ_z (mm)	2.2	2.2	2.2	2.2
Energy spread (%)	0.13	0.13	0.13	0.13
Energy acceptance (%)	5	5	5	5
γ_{BS} (10^{-4})	13.8	13.8	13.8	13.8
n_γ	0.6	0.6	0.6	0.6
δ_{BS} (10^{-4})	4.3	4.3	4.3	4.3
Life time due to beamstrahlung (minute)	30	30	30	30
F (hour glass)	0.68	0.48	0.45	0.41
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	3.1	2.31	1.97	1.58
AC power/two beam (MW) *	286	143	114	86
Luminosity gain (%)		49	59	69

*AC power for refrigerator is not included

Design challenge

- The IP β reduce， chromatic effect increase， the design of Final focus will be more difficult。

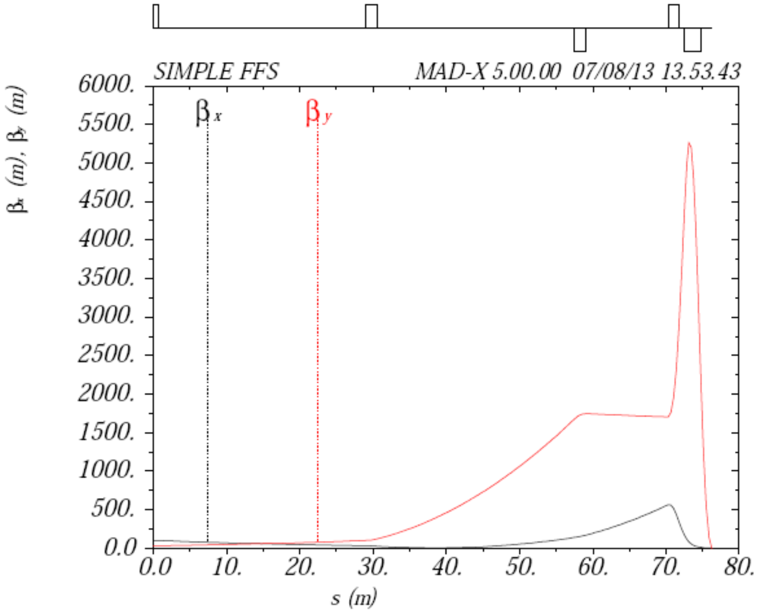
- There is no experience of the IP low β FFS design in Ring collider, refer to the low β IR design in linear collider. But the emittance in Ring is much bigger than in the linear collider, higher order aberrations large, the correction will be more difficult.

Final Focus Design
without chromaticity correction

Final Focus Design without chromaticity correction

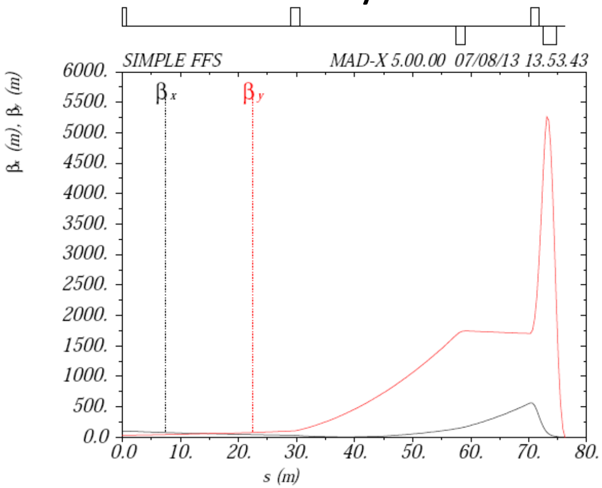
- For βy*=1mm， IR final focus design:
  - $\beta_{x,max}$=570m, $\beta_{y,max}$=4400m
  - Vacuum chamber size： H=48mm, V=9.4mm
  - Quadrupole parameters

	Length (m)	strength (T/m)	Aperture (mm)	Pole strength (T)
QD1	2.25	132	50	6.6
QF2	1.5	104	50	5.2
QD3	1.5	7.4	50	0.37
QF4	1.5	24	50	1.2



Final Focus Design without chromaticity correction

- For βy^*=1mm，IR final focus simple design:
  - $\sigma y^*/\sigma y^*$linear = 3.4
  - Remarkable Chromatic effect
  - For sub-mm βy^* final focus， chromatic effect is more remarkable，correction necessary.



Aberration	Contribution to beam size(m^2)
R33	2.51E-14
R34	4.79E-14
T336	5.15E-13
T346	2.71E-13

L* (m)	1.5	1.5	1.5	1.5
β_{IP} x/y (m)	0.2/0.001	0.071/0.00048	0.056/0.00042	0.041/0.00035
Emittance x/y (nm)	14.6/0.073	9.5/0.035	9.1/0.031	8.9/0.026
Transverse σ_{IP} (um) (linear)	54/0.27	25.9/0.13	22.6/0.11	19.2/0.096
Transverse σ_{IP} (um) (estimated)	-/0.59	-/0.542	-/0.542	-/0.540
Transverse σ_{IP} (um) (simulation)	55.0/0.93			

Local-compact FFS design

L=3.5m*

Local-compact final focus design

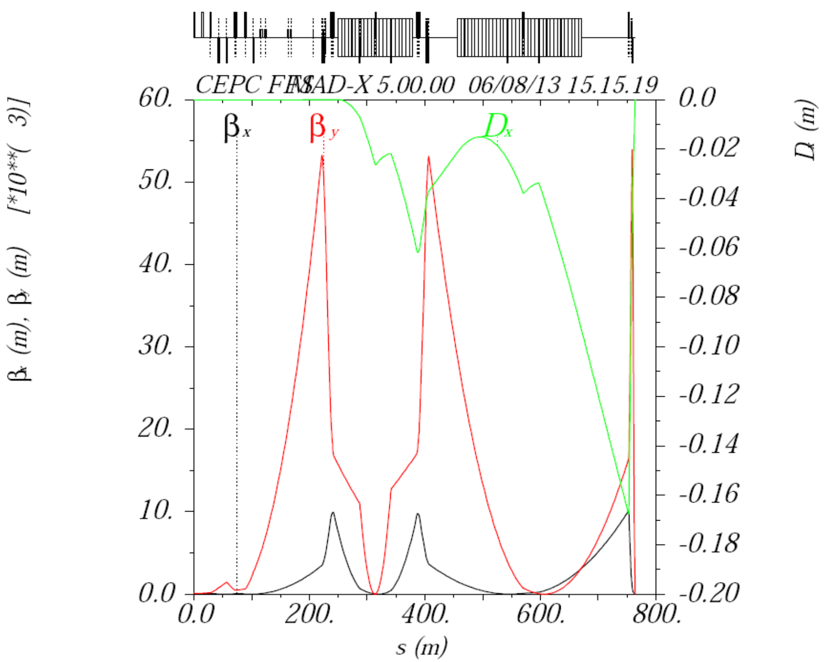
- β_y* much similar to the ILC IR design， first we tried the local chromaticity correction scheme (ILC type final focus)

	CEPC	CEPC	CEPC	CEPC	ILC 500GeV baseline
L* (m)	3.5	3.5	3.5	3.5	3.5
β_{IP} x/y (m)	0.2/0.001	0.071/0.00048	0.056/0.00042	0.041/0.00035	0.011/0.00048
Emittance x/y (nm)	14.6/0.073	9.5/0.035	9.1/0.031	8.9/0.026	0.02/0.00008
Energy spread (%)	0.13	0.13	0.13	0.13	0.124/0.070(e-/e+)
σ_z (mm)	2.2	2.2	2.2	2.2	0.3
Transverse σ_{IP} (um)	54/0.27	25.9/0.13	22.7/0.11	19.2/0.096	0.474/0.006
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	3.1	2.31	1.97	1.58	1.8

CEPC Final focus lattice Design

- β_y^* =0.35mm（15MW）design:
  - ILC type Final focus
  - $\beta_{x,max}$=10000m, $\beta_{y,max}$=50000m
  - Vacuum chamber size：H=190mm, V=23mm
  - Quadrupole parameters

	Length (m)	strength (T/m)	Aperture (mm)	Pole strength (T)
QD0	2.2	0.15	190	11.5
QF1	2.0	0.07	190	5.48

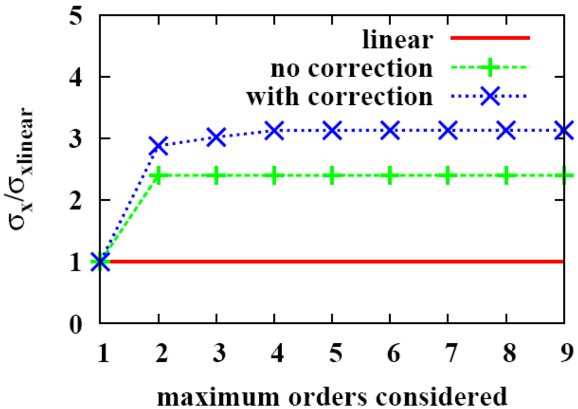


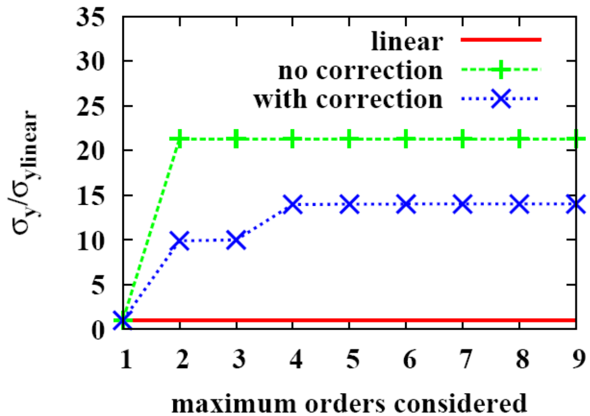
	CEPC
L* (m)	3.51
β_{IP} x/y (m)	0.041/0.00035
Dx’	0.0082
Emittance x/y (nm)	8.9/0.026
Energy spread (%)	0.13
σ_z (mm)	2.2
Transverse σ_{IP} (um)	19.2/0.096
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	1.58

Chromaticity correction

- Due to the emittance much larger than ILC， high order aberration increase. T126, T122, T166, T346 and T324 are no longer the biggest ones to be corrected.
- Sextupoles strength optimization， reduce the aberrations.
- $\sigma y^*/\sigma y^*_{linear}$ = 15, far away from the aim, need optimization.
- σx^* increase.

L* (m)	3.5
β_{IP} x/y (m)	0.041/0.00035
Emittance x/y (nm)	8.9/0.026
Transverse σ_{IP} (um) (linear)	19.2/0.096
Transverse σ_{IP} (um) (no correction; estimated)	-/1.25
Transverse σ_{IP} (um) (no correction; simulation)	45.8/2.03
Transverse σ_{IP} (um) (with correction; simulation)	59.8/1.33





Chromaticity correction

- Reducing the emittance makes final focus correction easier， but beam lifetime and luminosity will be reduced too.
  - Keep the emittance
- Reduce the L* to make the chromaticity smaller

$$\xi_y \propto \frac{L^*}{\beta_y^*}$$

Number of IPs	1	1	1	1	1
Energy (GeV)	120	120	120	120	120
Circumference (km)	50	50	50	50	50
SR loss/turn (GeV)	2.96	2.96	2.96	2.96	4.61
N_e/bunch (10^{12})	0.79	0.38	0.33	0.28	0.29
Bunch number	22	23	21	19	12
Beam current (mA)	16.9	8.45	6.76	5.07	3.38
SR power /beam (MW)	50	25	20	15	15.6
B_0 (T)	0.065	0.065	0.065	0.065	0.1
Bending radius (km)	6.2	6.2	6.2	6.2	3.98
Momentum compaction (10^{-4})	0.38	0.38	0.38	0.38	0.19
β_{IP} x/y (m)	0.2/0.001	0.071/0.00048	0.056/0.00042	0.041/0.00035	0.07/0.00035
Emittance x/y (nm)	14.6/0.073	9.5/0.035	9.1/0.031	8.9/0.026	4.3/0.022
Transverse σ_{IP} (um)	54/0.27	25.9/0.13	22.7/0.11	19.2/0.096	17.3/0.087
ξ_x/IP	0.103	0.076	0.069	0.06	0.129
ξ_y/IP	0.103	0.103	0.103	0.103	0.129
V_{RF} (GV)	6	6	6	6	6.6
f_{RF} (MHz)	704	704	704	704	659
σ_z (mm)	2.2	2.2	2.2	2.2	2.2
Energy spread (%)	0.13	0.13	0.13	0.13	0.16
Energy acceptance (%)	5	5	5	5	5
γ_{BS} (10^{-4})	13.8	13.8	13.8	13.8	16.3
n_γ	0.6	0.6	0.6	0.6	0.7
δ_{BS} (10^{-4})	4.3	4.3	4.3	4.3	5.9
Life time due to beamstrahlung (minute)	30	30	30	30	3
F (hour glass)	0.68	0.48	0.45	0.41	0.41
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	3.1	2.31	1.97	1.58	1.33
AC power/two beam (MW) *	286	143	114	86	89
Luminosity gain (%)		49	59	69	38

Local compact FFS design

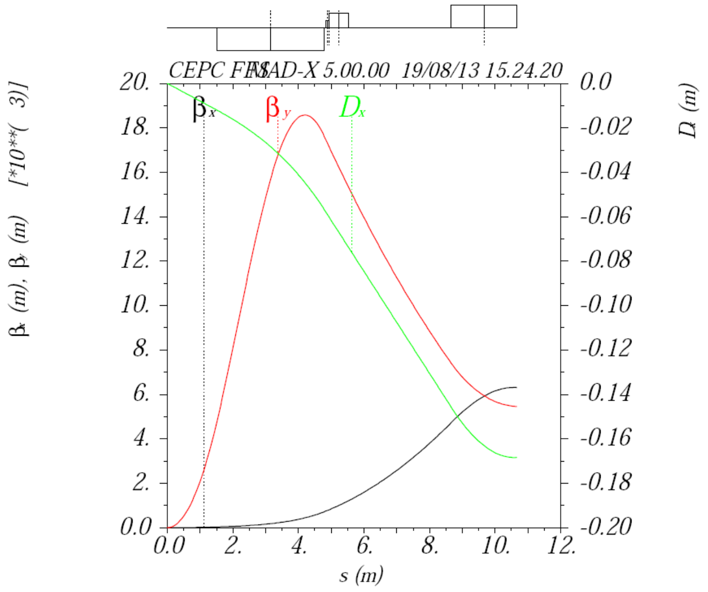
L^*=1.5m

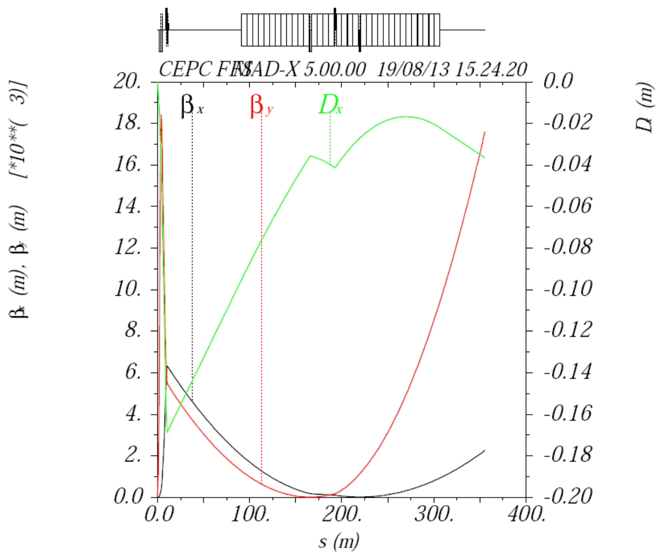
IP parameters (25MW, 1.5m)

- IP parameters
  - BETX := 0.071;
  - ALFX := 0;
  - BETY := 0.00048;
  - ALFY := 0;
  - DX := 0;
  - DPX := -0.00795452718;
  - BLENG := 2.2E-3; !bunch length (m)
  - ESPRD := 1.3E-3; !energy spread (1)
  - EMITX := 9.5E-9;
  - EMITY := 0.035E-9;
  - D0->L = 1.5;

Refit IP to QF1

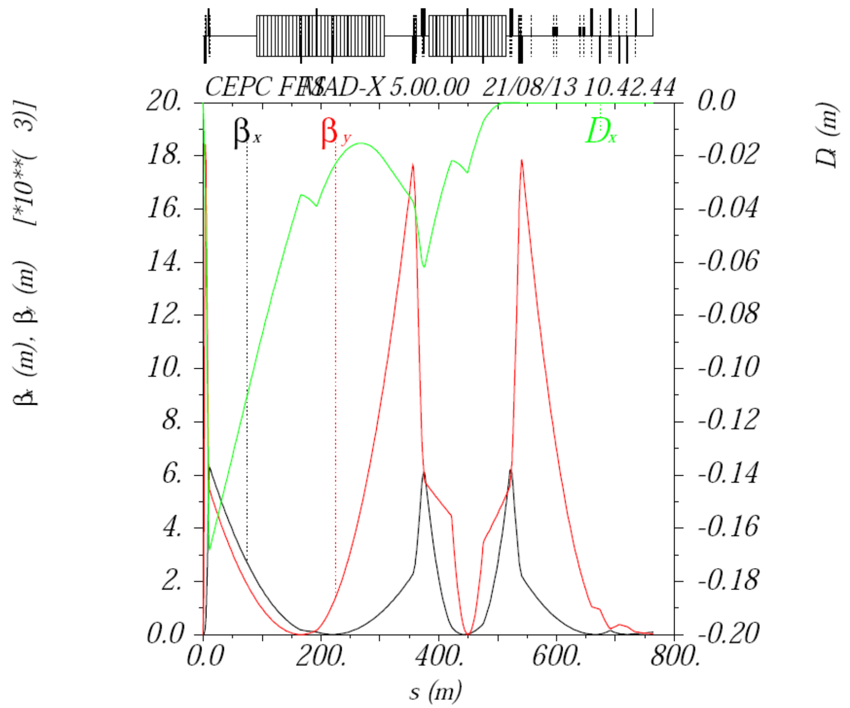
- Fit five variables :
  - QD0 length
  - QF1 length
  - Pole-tip strength of QD0
  - Pole-tip strength of QF1
  - Distance between QD0&QF1

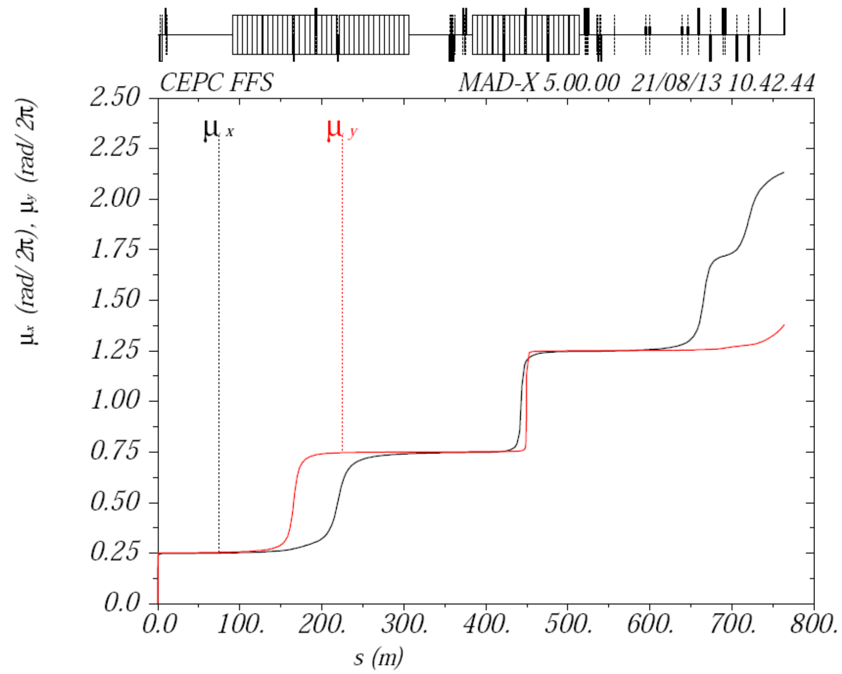




Linear lattice

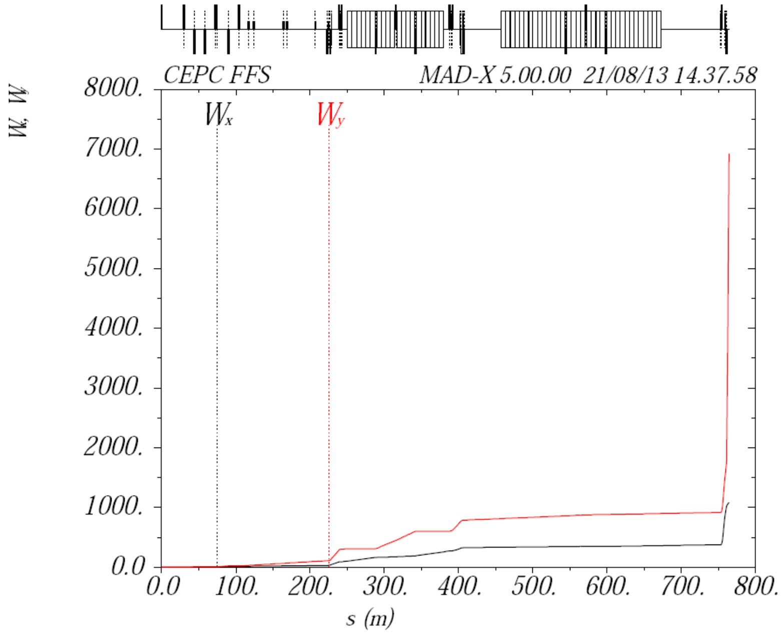
- fit B1, B2 and B5 to obtain Dx=0 and Dpx=0 at exit of B5
- reverse the system, refit QMs to match β and α.

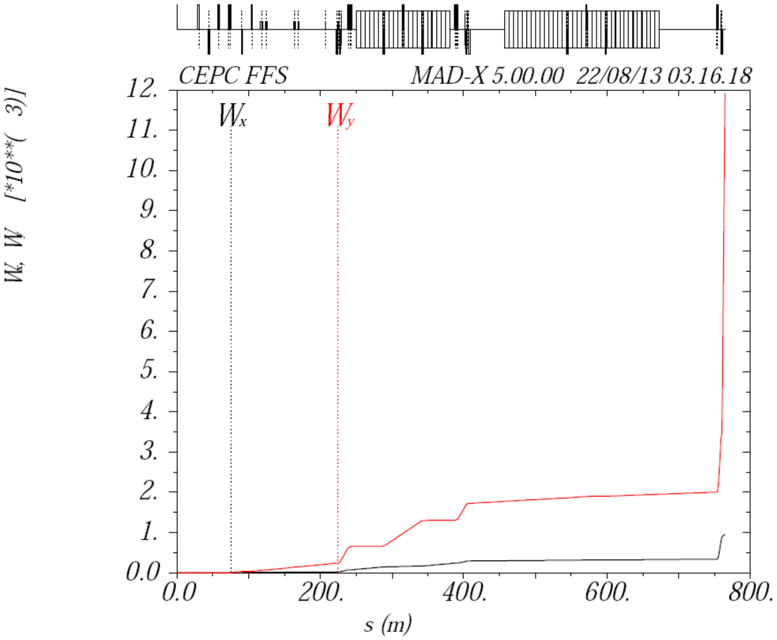




Chromaticity

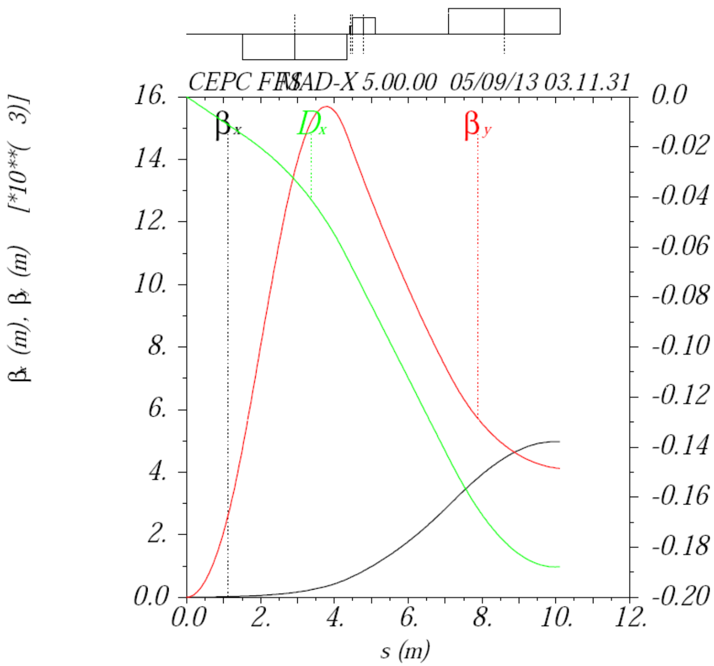
- natural chromaticity decreased (compared with L*=3.5m)

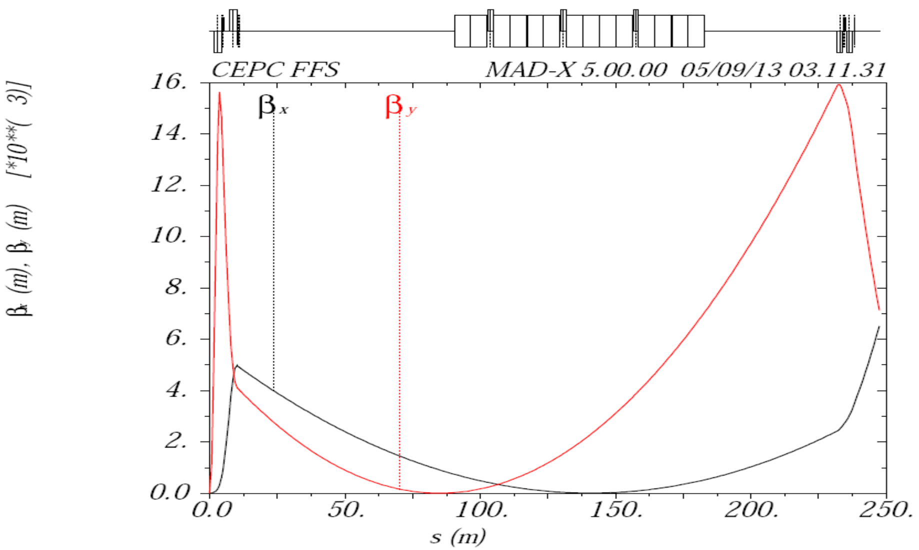




Reduce the length of Bend

- We are tring to reduce the length of the bends as the beam energy of CEPC is lower than the 500GeV ILC.





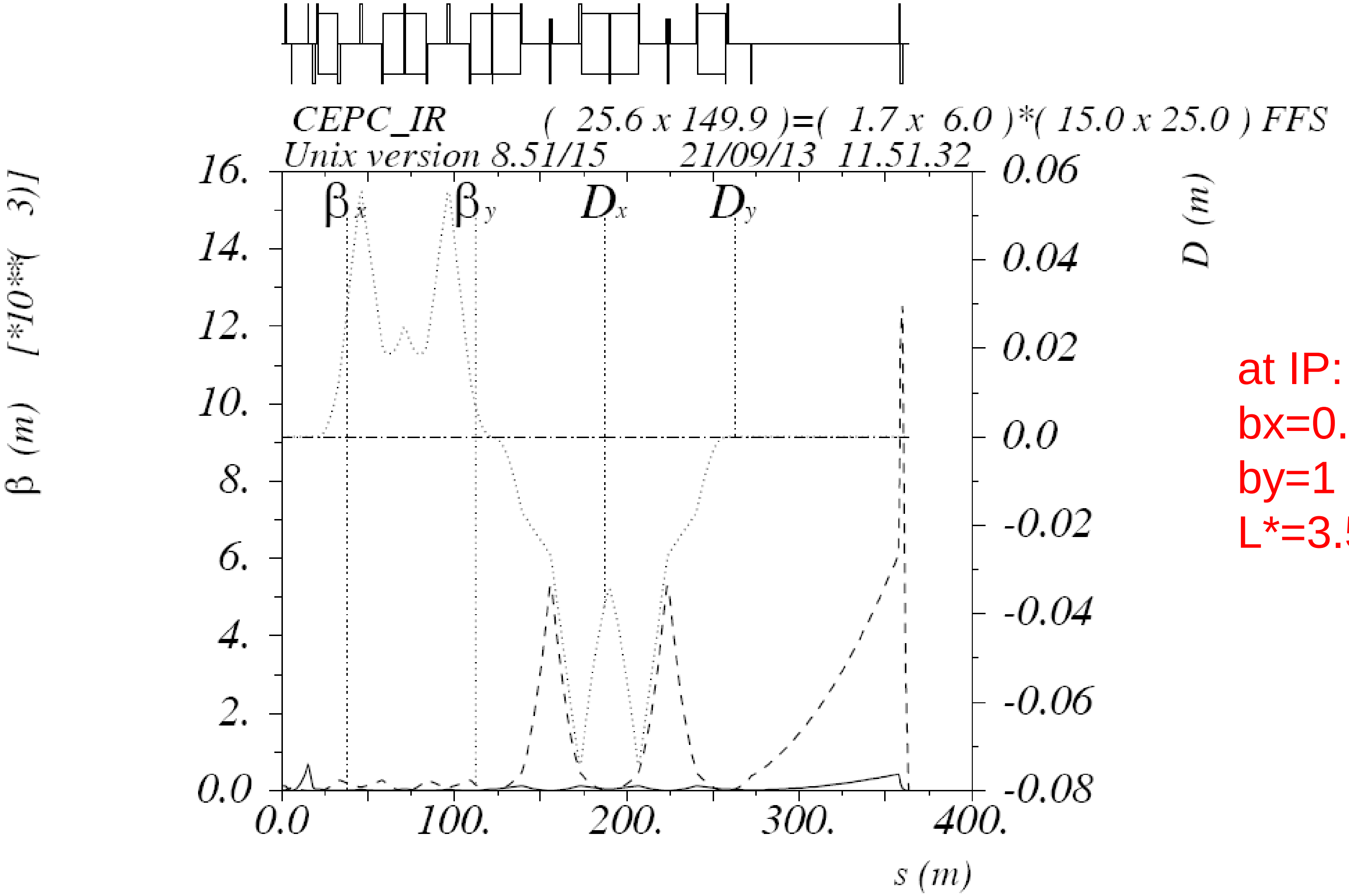
Local non-compact FFS design

Procedure & Method

- The CEPC design parameters :
  two cases of β_y=1mm and β_y=0.35mm.
- FFADA program
- Matching section, CCS, Final Doublet.
- Non-interlaced sextupoles

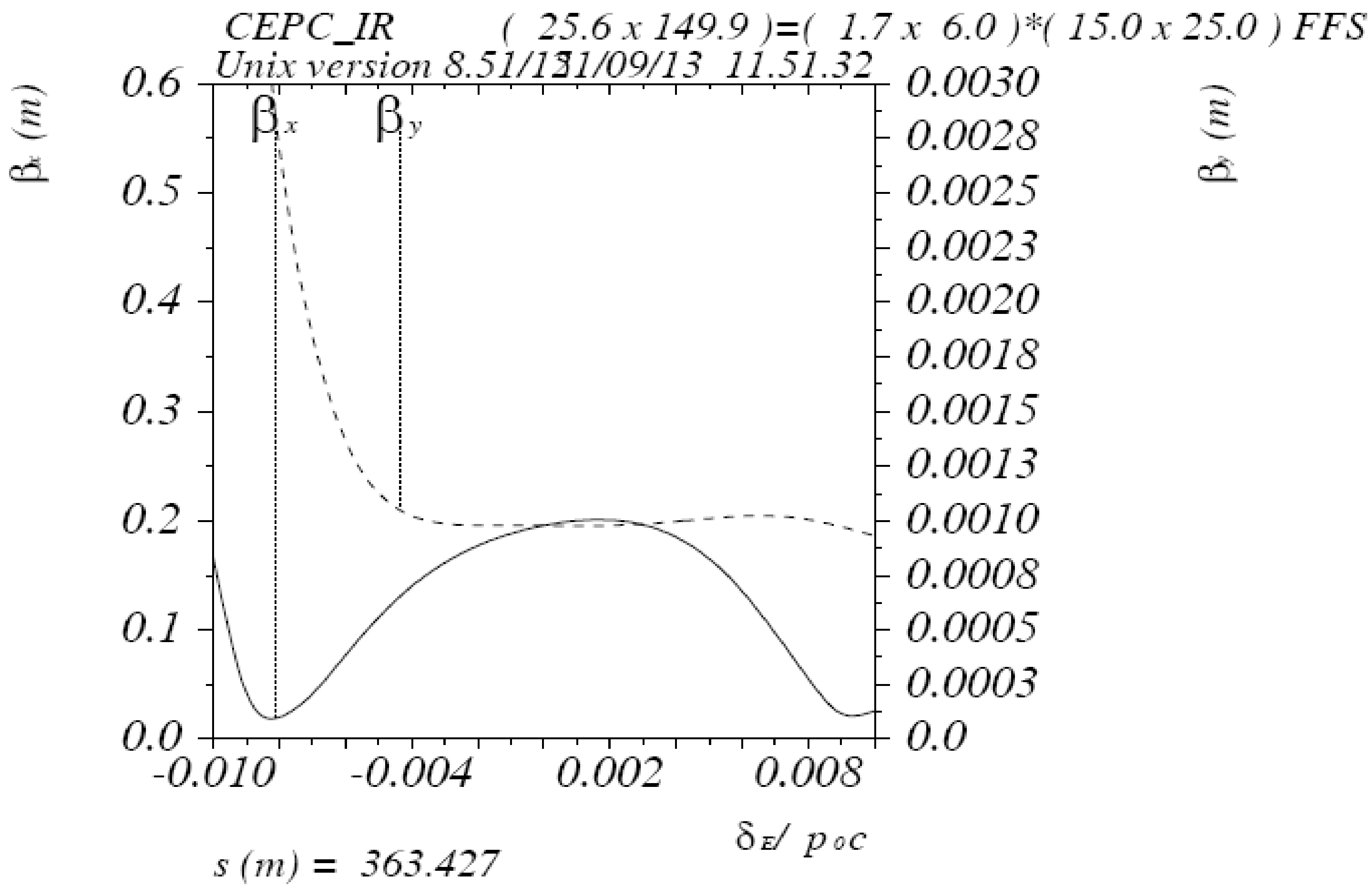
Thanks to Hector and Rogelio for helping me setting up the FFADA program !

IP β_y=1mm



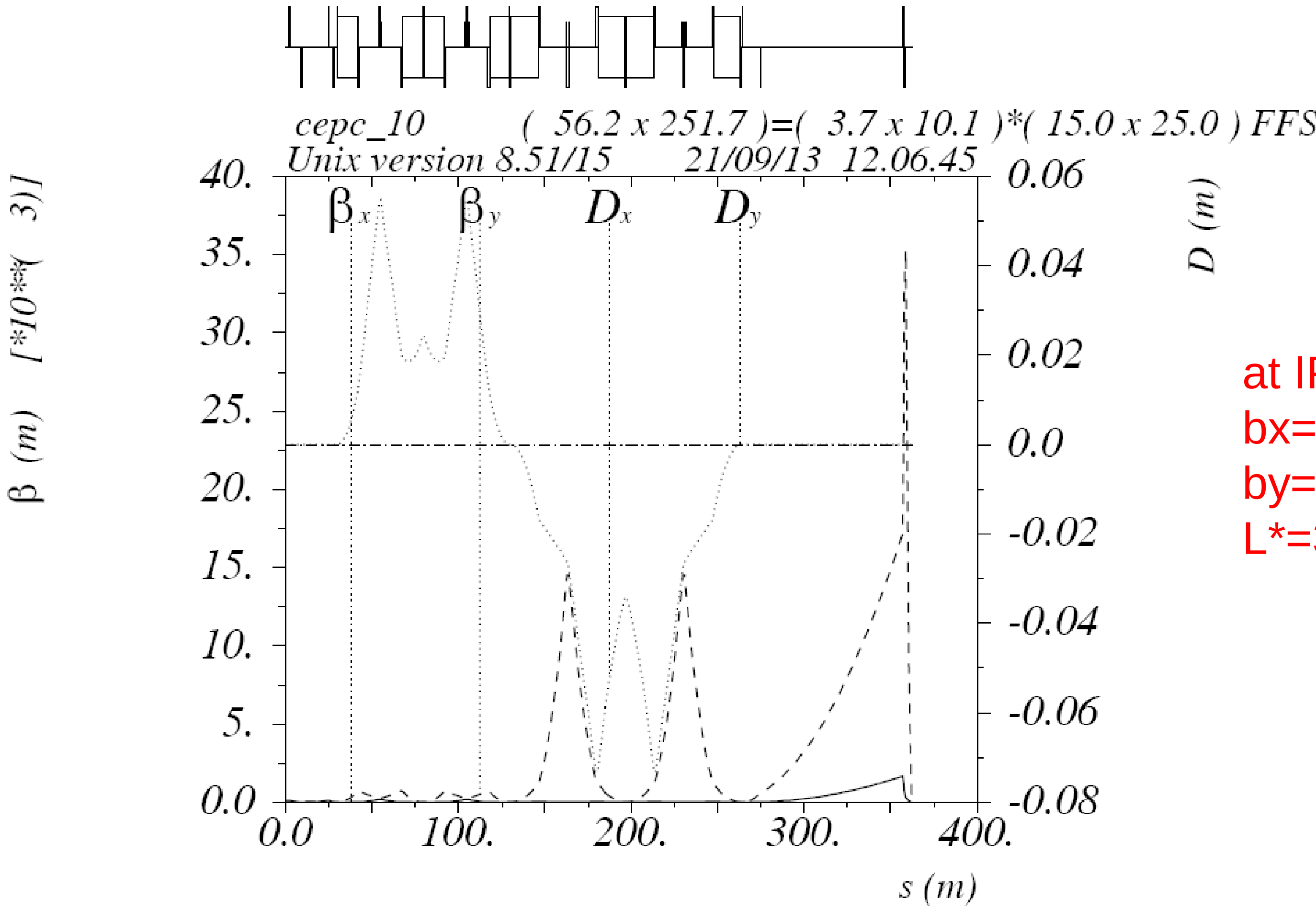
at IP:
bx=0.2 m
by=1 mm
L*=3.5 m

Beta Function at IP vs momentum



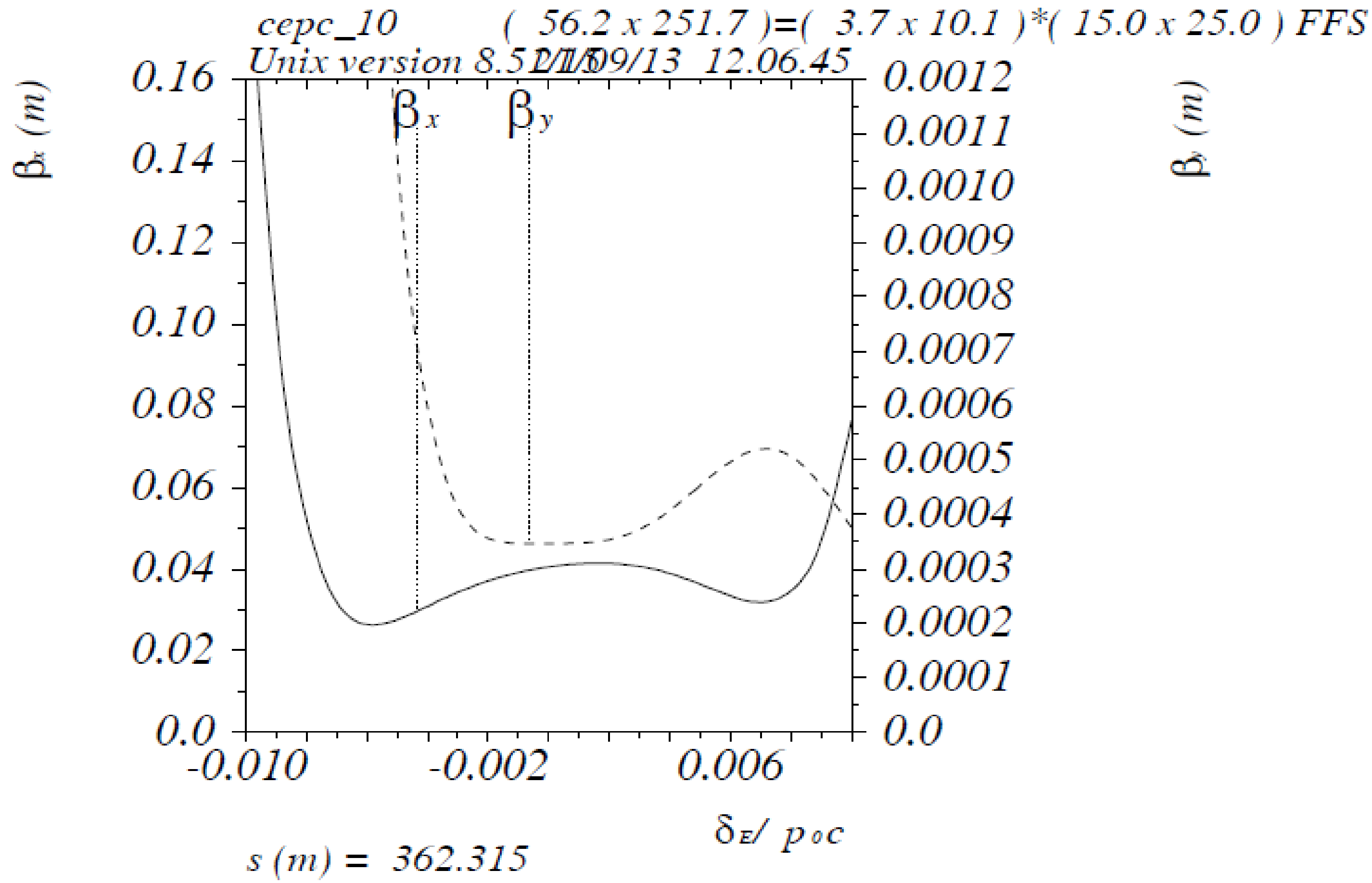
Good region of ±0.4% in Dp/p is necessary for the core in beam distribution.

IP lowβ_y=0.35mm



at IP:
bx=0.041 m
by=0.35 mm
L*=3.5 m

Beta Function at IP vs momentum



Optical bandwidth needs optimization.

Conclusions and Prospects

- For sub-mm β_y* final focus design, chromatic effect is large, correction necessary.
- For the local-compact FFS design, due to the large emittance and low β_y at IP, the high order aberration obvious, we tried to reduce the L* to reduce the chromatic aberrations.
    - Linear lattice design, reduce the bends, shorter length, MAPCLASS optimization for high order aberrations.
- For the local non-compact FFS design, using the non-interlaced sextupoles to reduce the third order “kick”, momentum bandwidth needs optimization.
    - Tracking beam size, MAPCLASS optimization for high order aberrations, momentum bandwidth optimization, Oide effect, error analysis…

Thank you !