



Progress of SPPC main ring lattice design

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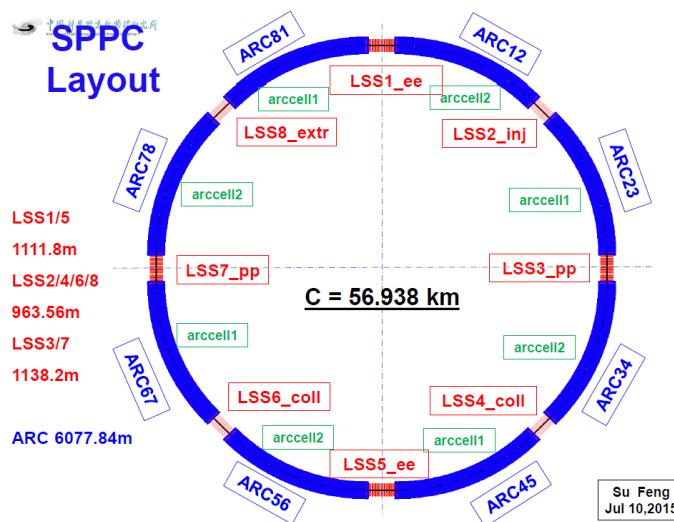
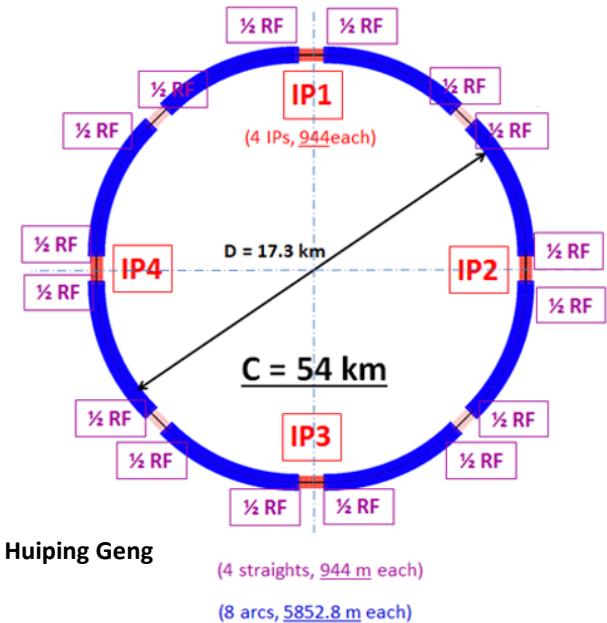
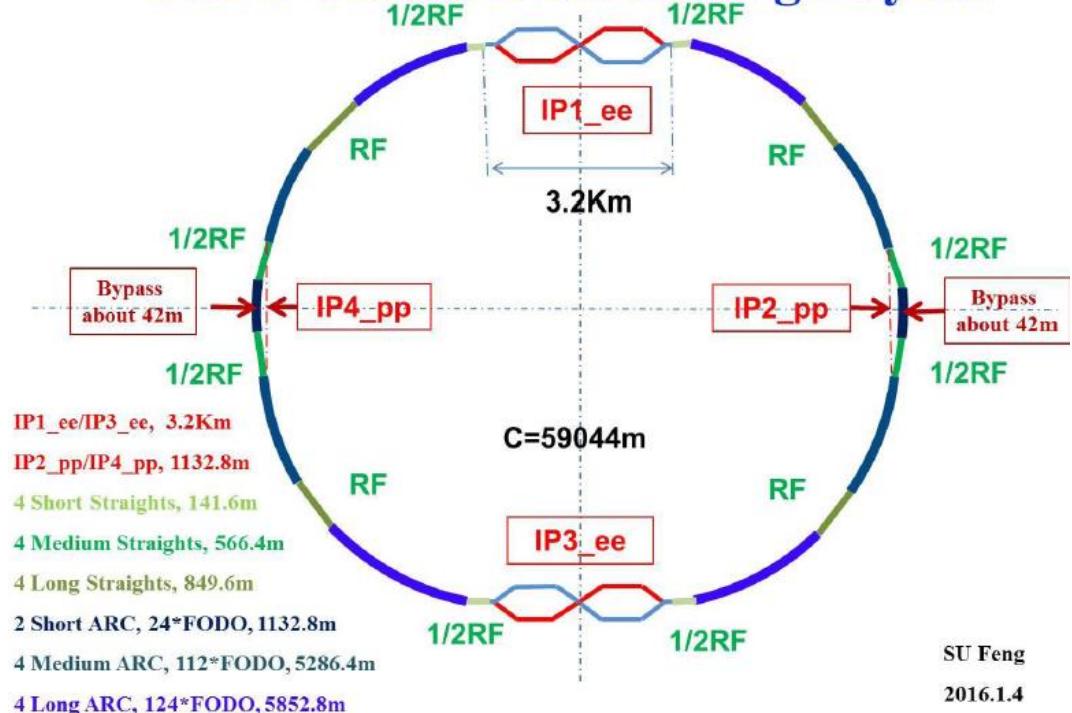
Outline

- Background
- ARC design
- Dispersion Suppressor
- Consideration of IR
- Summary



Background

CEPC Partial Double Ring Layout





SPPC main parameters

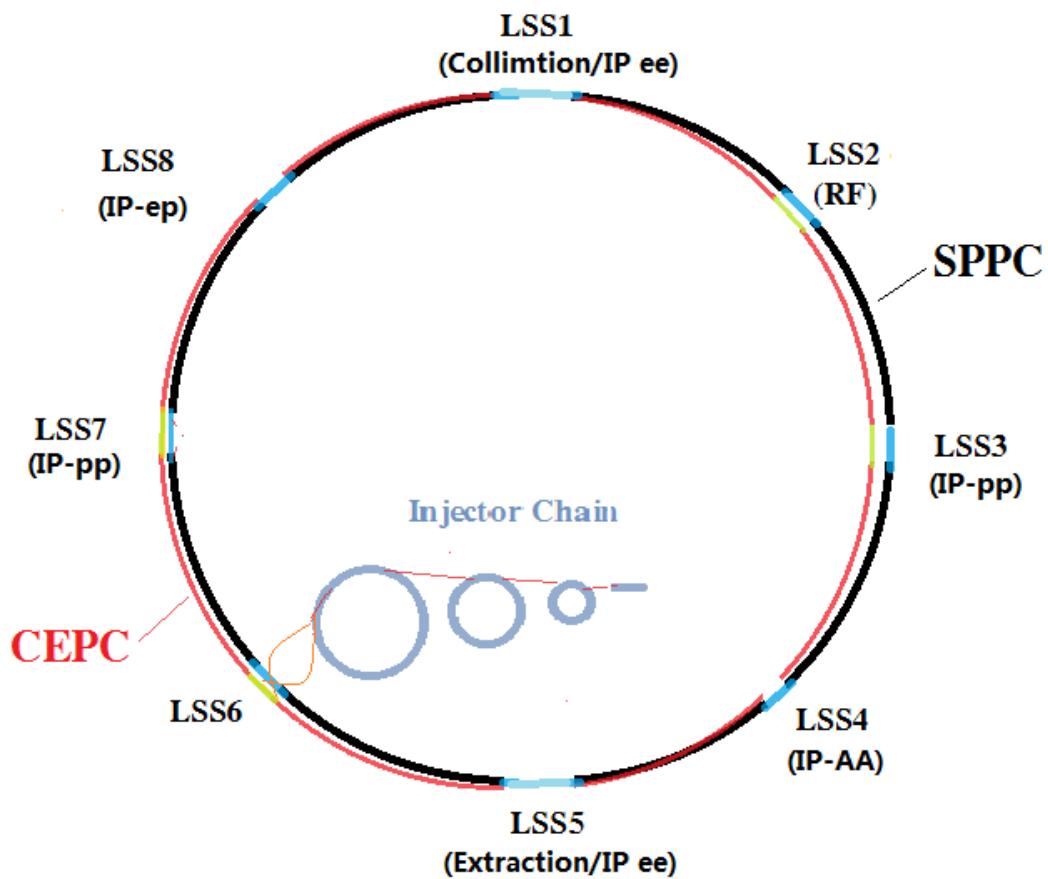
Parameter	Value	Unit
Circumference	54.36	km
C.M. energy	70.6	TeV
Dipole field	20	T
Injection energy	2.1	TeV
Number of IPs	2	
Peak luminosity per IP	1.2E+35	cm ⁻² s ⁻¹
Beta function at collision	0.75	m
Circulating beam current	1.0	A
Bunch separation	25	ns
Bunch population	2.0E+11	
SR heat load @arc dipole (per aperture)	56.9	W/m



Constrained by geometry



General layout of SPPC



- Use the same CEPC tunnel to build SPPC
- Maximize the beam energy to 70 TeV by using 20 T SC magnets
- 8 arcs, 5737.86 m each
- 4585.6 m dipole length each arc, filling factor is 0.808
- 2 IPs for pp, 1110.55 m each
- 2 IRs for injection and extraction, 740.37 m each
- 2 IRs for ep or AA, 925.615
- 2 IRs for collimation(ee for CEPC), 3.2 km each
- **C = 57856 m**

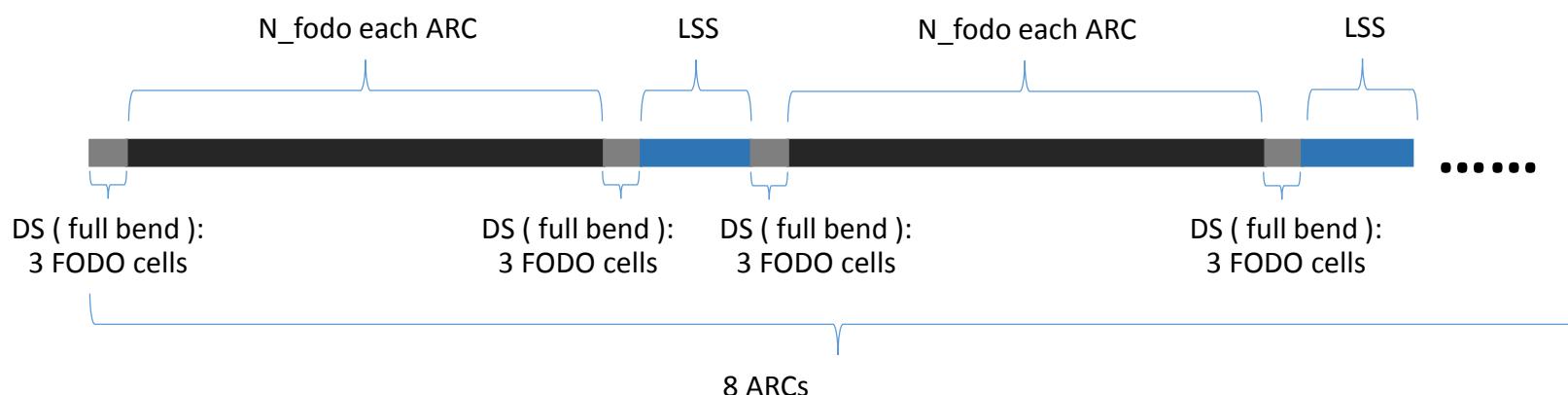


Calculation base on:

Parameters	Beam energy	Strength of Dipole	Bending radius	Total length of dipole	Length of quadrupole	Space between Q and B	Space between B and B	ARC numbers of the ring	Number of DS each ARC	Number of FODO cells each DS
value	35 TeV	20 T	5837.37 m	36677.28 m	6 m	3.5 m	1.4 m	8	2	3

Parameter should be determined:

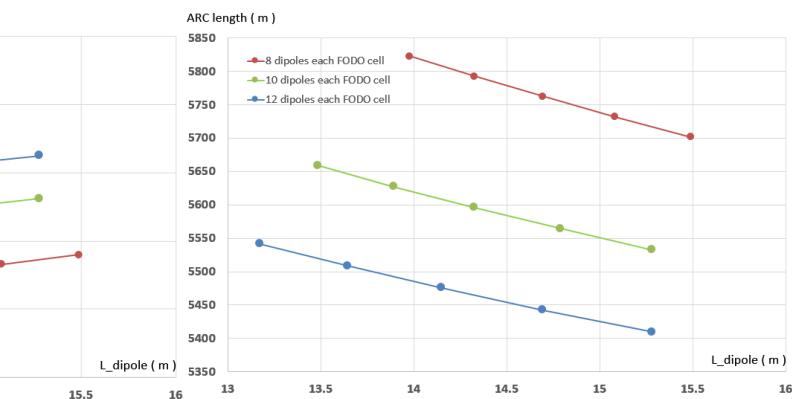
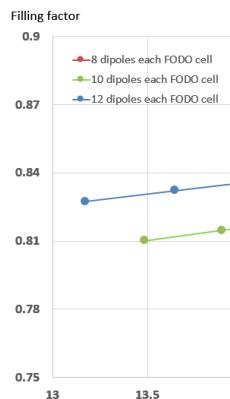
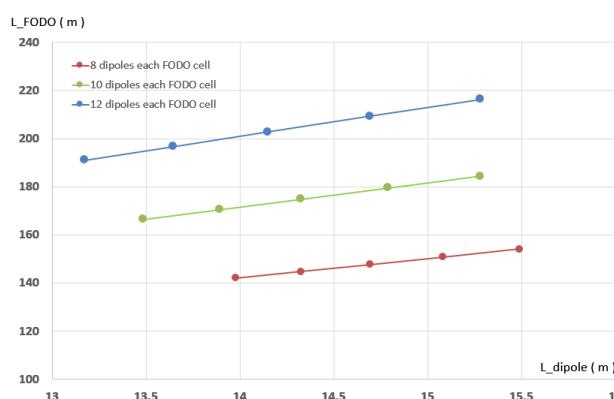
Parameters	Number of Dipoles each FODO cell (N_dipole)	Number of FODO cell each ARC (N_fodo)	Length of dipole	Length of FODO cell	Length of one ARC (including DS of ARC)	Total length of ARC	Filling factor
value	8 or 10 or 12 ?	?	14 -15 m ?	?	?	?	?



$$(N_{fodo} + 6) \times 8 \times N_{dipole} \times L_{dipole} = 36677.28$$



N_dipole each fodo	N_fodo each ARC	L_dipole (m)	L_fodo (m)	Length of one ARC (including DS) (m)	Total length of ARC (m)	filling factor
8	35	13.98	146.221	5995.06	47960.48	0.765
8	34	14.33	149.0165	5960.66	47685.28	0.769
8	33	14.69	151.9554	5926.26	47410.08	0.774
8	32	15.08	155.049	5891.86	47134.88	0.778
8	31	15.49	158.3097	5857.46	46859.68	0.783
10	28	13.48	172.043	5849.46	46795.68	0.784
10	27	13.89	176.1291	5812.26	46498.08	0.789
10	26	14.33	180.4706	5775.06	46200.48	0.794
10	25	14.79	185.0923	5737.86	45902.88	0.799
10	24	15.28	190.022	5700.66	45605.28	0.804
12	23	13.17	198.0917	5744.66	45957.28	0.798
12	22	13.64	203.7379	5704.66	45637.28	0.804
12	21	14.15	209.8022	5664.66	45317.28	0.809
12	20	14.69	216.3331	5624.66	44997.28	0.815
12	19	15.28	223.3864	5584.66	44677.28	0.821





**Constrained by beam optics related
parameters**



FODO cell design

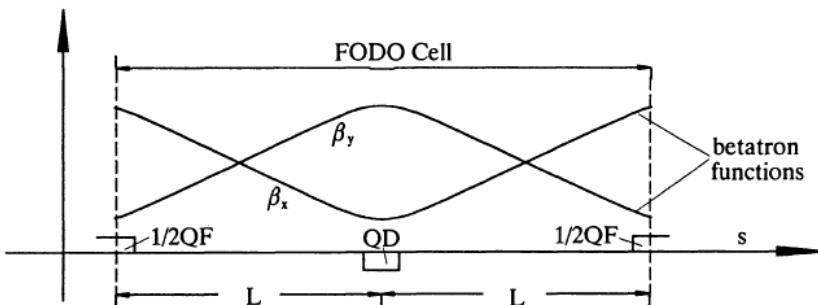


Fig. 6.2. Periodic betatron functions in a FODO channel

$$\mathcal{M}_{\text{FODO}} = \begin{bmatrix} 1 - 2 \frac{L^2}{f^2} & 2L \cdot (1 + \frac{L}{f}) \\ -\frac{1}{f^*} & 1 - 2 \frac{L^2}{f^2} \end{bmatrix} = \begin{bmatrix} \cos \phi & \beta \sin \phi \\ \frac{1}{\beta} \sin \phi & \cos \phi \end{bmatrix}$$

Here $f_f = -f_d = f$, $1/f^* = 2 \cdot (1 - L/f) \cdot (L/f^2)$

$$\left\{ \begin{array}{l} \beta^+ = L \cdot \frac{\frac{f}{L} \frac{f}{L+1}}{\sqrt{\frac{f^2}{L^2-1}}} = L \cdot \frac{\kappa \cdot (\kappa+1)}{\sqrt{\kappa^2-1}} \\ \beta^- = L \frac{\kappa \cdot (\kappa-1)}{\sqrt{\kappa^2-1}} \\ \cos \phi = 1 - 2 \cdot \frac{L^2}{f^2} = \frac{\kappa^2 - 2}{\kappa^2} \end{array} \right. \quad \kappa = \frac{f}{L} > 1$$

For a round beam $\epsilon_x \approx \epsilon_y$ beam diameter or $E_x^2 + E_y^2 \sim \beta_x + \beta_y$

$$d(\beta_x + \beta_y)/d\varphi = 0 \rightarrow \left\{ \begin{array}{l} \kappa_{\text{opt}} = \sqrt{2} \\ \phi_{\text{opt}} = 90^\circ \end{array} \right.$$



Constrained by Max gradient of quadrupoles

Three groups of high gradient quadrupoles for SPPC

- At the IPs: D = 60 mm, Bpole = 20 T;
- In the matching section: D = 60 mm, Bpole = 16 T;
- At arcs: D = 45 mm, Bpole=16 T.

From 《CEPC-SPPC Pre CDR》

Max gradient of quadrupoles:

At the IPs:

$$\frac{dB_y}{dx} = \frac{20T}{0.03m} = 666.7 \text{ T/m}$$

$$K_{max} = \frac{\frac{dB_y}{dx}}{B\rho} = \frac{666.7 \text{ T/m}}{20T \cdot 5837m} \approx 0.00571$$

At the IPs:

$$\frac{dB_y}{dx} = \frac{16T}{0.03m} = 533.37 \text{ T/m}$$

$$K_{max} = \frac{\frac{dB_y}{dx}}{B\rho} = \frac{666.7 \text{ T/m}}{20T \cdot 5837m} \approx 0.00457$$

At the IPs:

$$\frac{dB_y}{dx} = \frac{16T}{0.0225m} = 711.1 \text{ T/m}$$

$$K_{max} = \frac{\frac{dB_y}{dx}}{B\rho} = \frac{666.7 \text{ T/m}}{20T \cdot 5837m} \approx 0.00605$$

Constrained by beta function

$$\varepsilon_n = 4.1 \mu\text{m}, E_{inject} = 2.1 \text{ TeV}$$

$$\sigma = \sqrt{\varepsilon \cdot \beta} = \sqrt{\frac{\varepsilon_n}{\gamma} \cdot \beta}$$

$$n_{b_\sigma} = \frac{\text{Aperture}}{\sigma}$$

where aperture at arcs is: 22.5 – 5 = 17.5 mm

For FODO structure with 90 deg phase advance, K value and β_{max} can be estimated by:

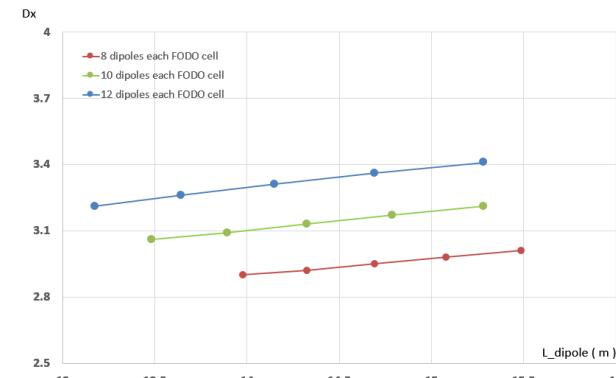
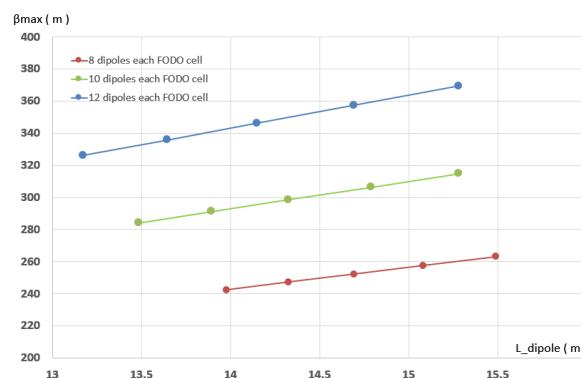
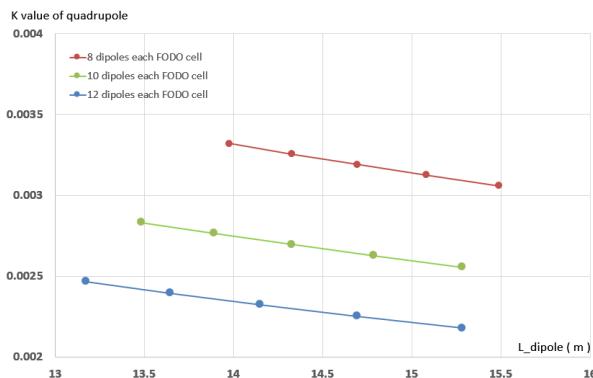
$$K = \frac{2\sqrt{2}}{L_{FODO} \times L_{quadrupole}}$$

$$\beta_{max} = L_{FODO} \times \left(1 + \frac{\sqrt{2}}{2}\right)$$



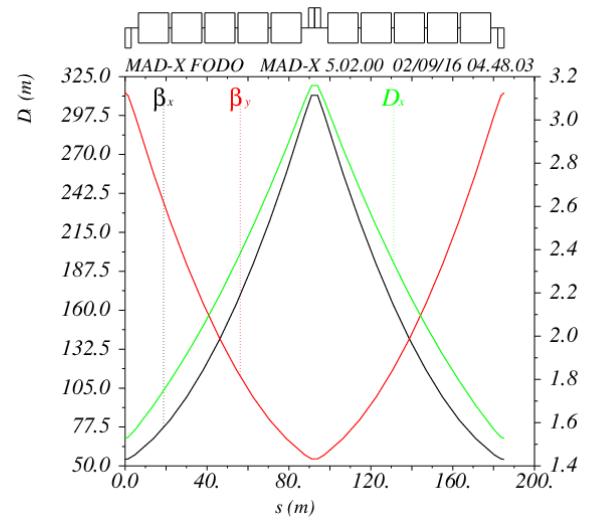
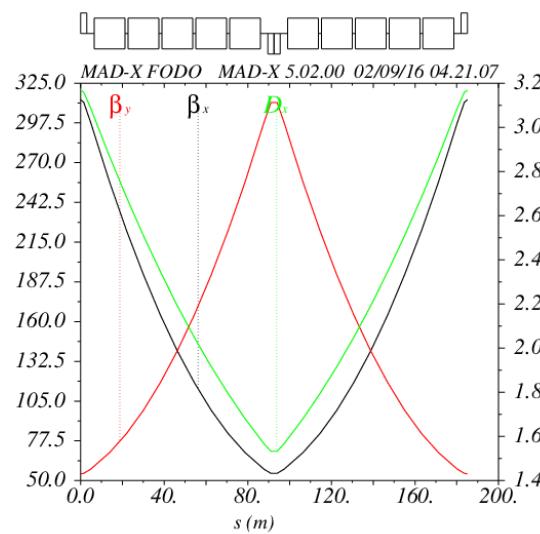
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N_dipole each fodo	N_fodo each ARC	L_dipole (m)	L_fodo (m)	K	Bmax (m)	Dx (m)	nbσ
8	35	13.98	146.22	0.00322	249.61	2.90	25.88
8	34	14.33	149.02	0.00316	254.39	2.92	25.64
8	33	14.69	151.96	0.00310	259.40	2.95	25.39
8	32	15.08	155.05	0.00304	264.69	2.98	25.13
8	31	15.49	158.31	0.00298	270.25	3.01	24.87
10	28	13.48	172.04	0.00274	293.70	3.06	23.86
10	27	13.89	176.13	0.00268	300.67	3.09	23.58
10	26	14.33	180.47	0.00261	308.08	3.13	23.29
10	25	14.79	185.09	0.00255	315.97	3.17	23.00
10	24	15.28	190.02	0.00248	324.39	3.21	22.70
12	23	13.17	198.09	0.00238	338.16	3.21	22.23
12	22	13.64	203.74	0.00231	347.80	3.26	21.92
12	21	14.15	209.80	0.00225	358.15	3.31	21.61
12	20	14.69	216.33	0.00218	369.30	3.36	21.28
12	19	15.28	223.39	0.00211	381.34	3.41	20.94





N_dipole each fodo	N_fodo each ARC	L_dipole (m)	L_fodo (m)	Length of one ARC (including DS) (m)	Total length of ARC (m)	filling factor
8	35	13.98	146.221	5995.06	47960.48	0.765
8	34	14.33	149.0165	5960.66	47685.28	0.769
8	33	14.69	151.9554	5926.26	47410.08	0.774
8	32	15.08	155.049	5891.86	47134.88	0.778
8	31	15.49	158.3097	5857.46	46859.68	0.783
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12	20	14.69	216.3331	5624.66	44997.28	0.815
12	19	15.28	223.3864	5584.66	44677.28	0.821



Parameters summary:

- $D_{qb} = 3.5 \text{ m}$
- $D_{bb} = 1.4 \text{ m}$
- $L_q = 6 \text{ m}$
- $L_d = 14.789 \text{ m}$
- $L_{cell} = 185.09 \text{ m}$
- $K_q = 0.0026$
- betax: 313.526 / 54.634 m
- betay: 54.617 / 313.492 m



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Dispersion Suppressor



If we simply want to continue the FODO structure of the arc through the Long straight section—but with vanishing dispersion. The boundary conditions are:

$$D(s) = D'(s) = 0,$$

$$\beta_x(s) = \beta_{x\text{ arc}}, \quad \alpha_x(s) = \alpha_{x\text{ arc}},$$

$$\beta_y(s) = \beta_{y\text{ arc}}, \quad \alpha_y(s) = \alpha_{y\text{ arc}}$$

Adjust the strength of dipoles? Or the strength of quadrupoles?



DS consideration

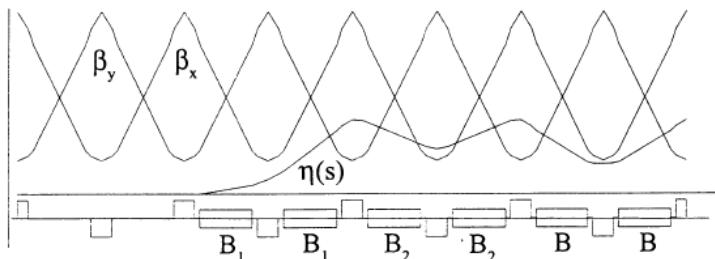


Fig. 6.14. Dispersion suppressor lattice

Change the strength of the bending magnets only

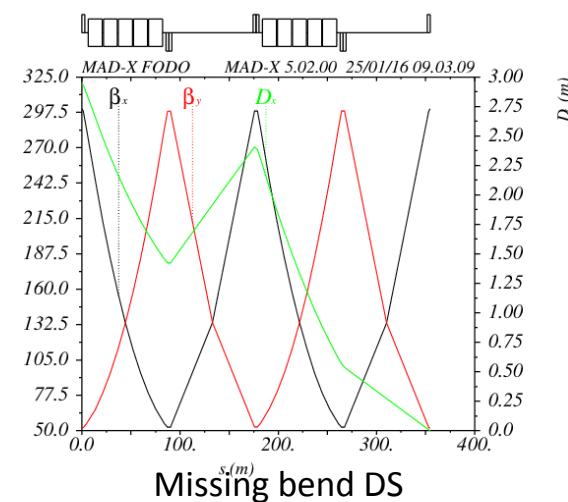
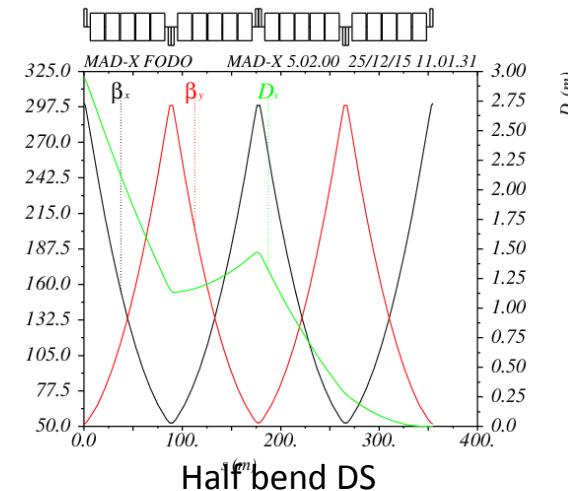
$$\theta_1 = \theta \cdot \left(1 - \frac{1}{4 \cdot \sin^2 \psi} \right)$$

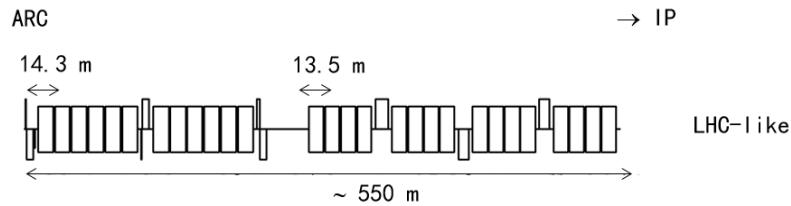
and

$$\theta_2 = \theta \cdot \left(\frac{1}{4 \cdot \sin^2 \psi} \right),$$

where

$$\theta = \theta_1 + \theta_2.$$

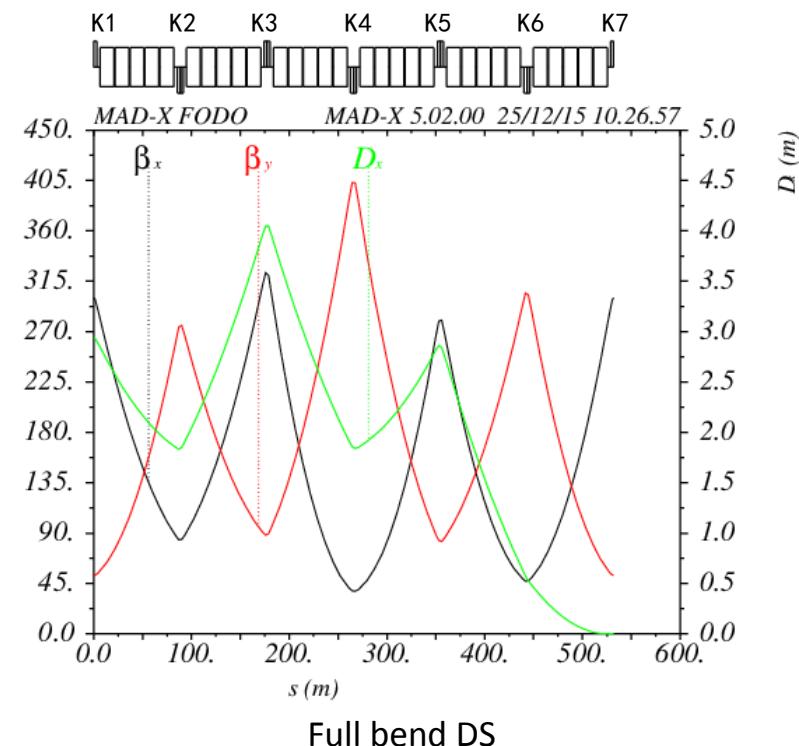




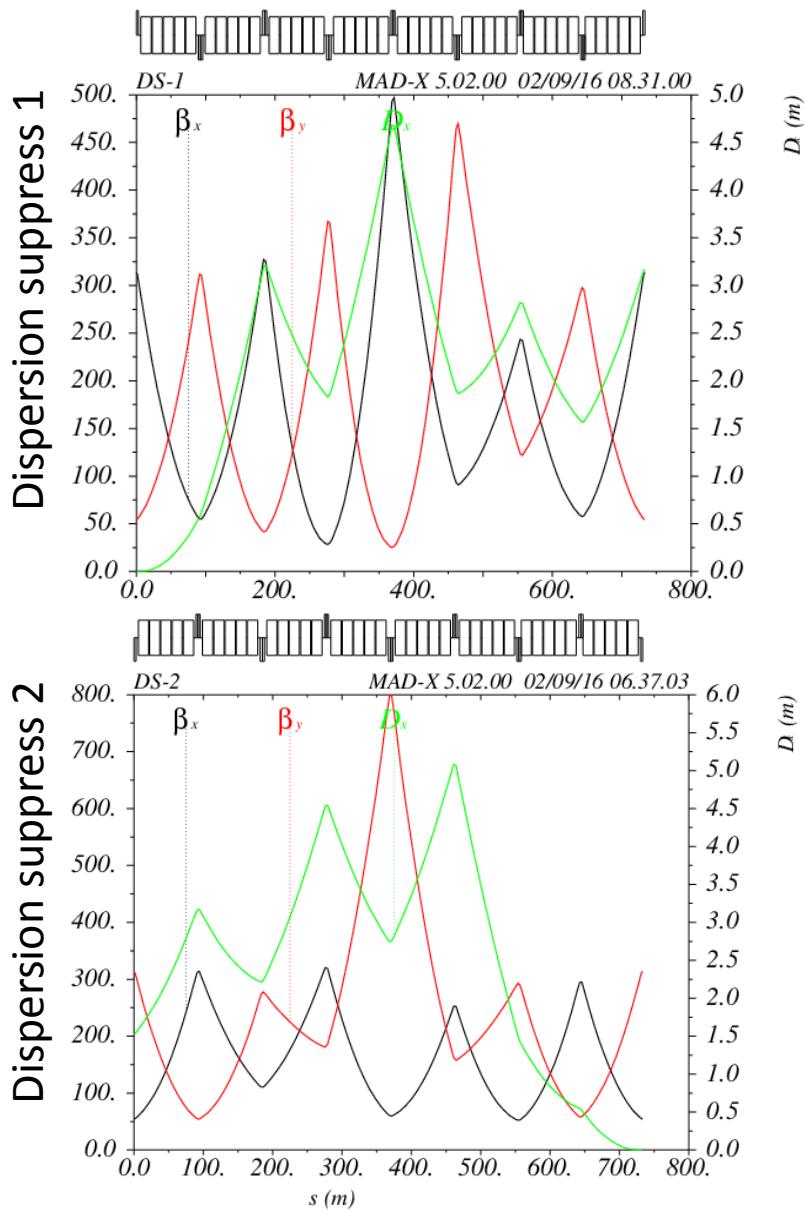
The aim of the DS in LHC:

- adapt the LHC reference orbit to the geometry of the LEP tunnel;
- cancel the horizontal dispersion;
- help in matching the insertion optics to the periodic solution of the arc.

LHC-like DS



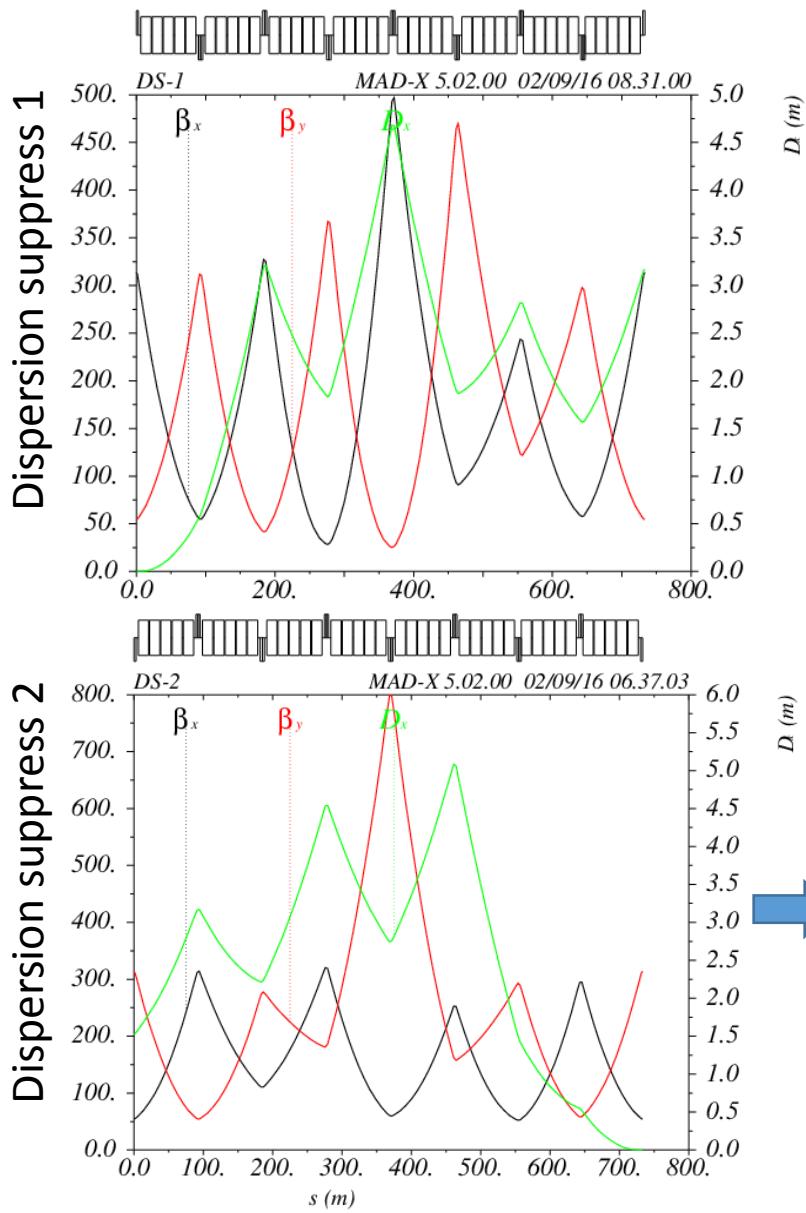
Full bend DS



Full bend DS for SPPC

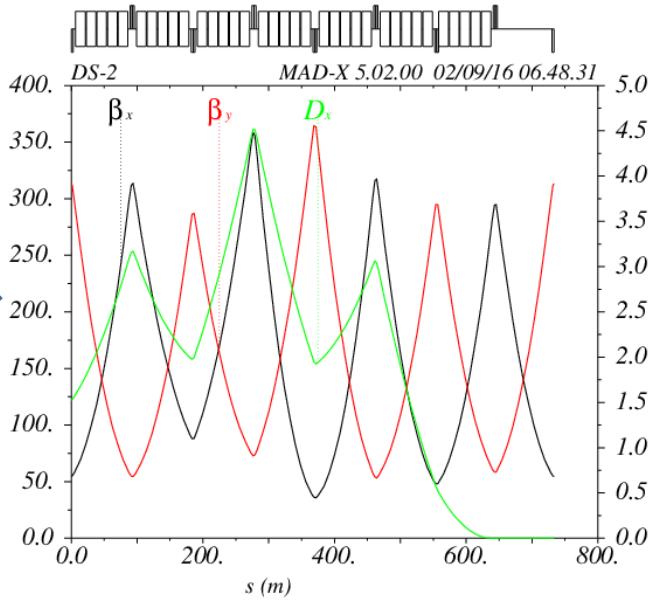
kq1	0.00260
kq2	-0.00275
kq3	0.00284
kq4	-0.00237
kq5	0.00261
kq6	-0.00257
kq7	0.00238
kq8	-0.00306
kq9	0.00260

kq1	-0.00260
kq2	0.00220
kq3	-0.00180
kq4	0.00216
kq5	-0.00205
kq6	0.00259
kq7	-0.00193
kq8	0.00268
kq9	-0.00260



Full bend DS for SPPC

kq1	0.00260
kq2	-0.00275
kq3	0.00298
kq4	-0.00313
kq5	0.00270
kq6	-0.00260
kq7	0.00227
kq8	-0.00217
kq9	0.00260



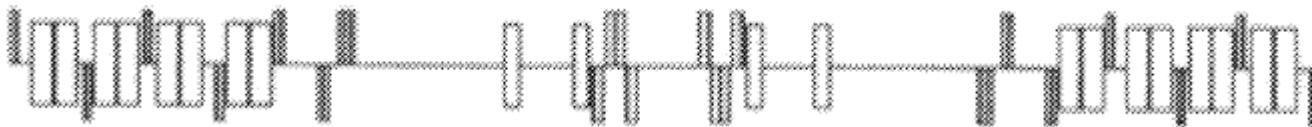
kq1	-0.00260
kq2	0.00234
kq3	-0.00244
kq4	0.00258
kq5	-0.00249
kq6	0.00291
kq7	-0.00262
kq8	0.00274
kq9	-0.00260



Consideration of SPPC Interaction Region (IR)



Generally description of LHC interaction region



Lattice of LHC high-luminosity insertion

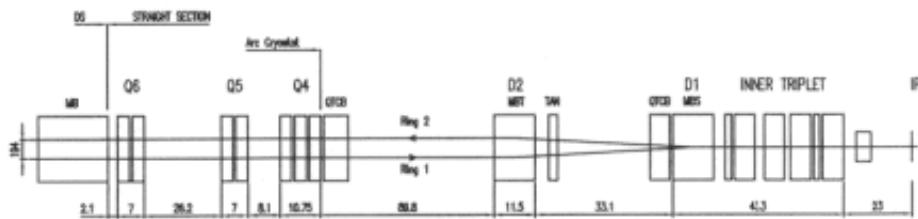


Figure 5: Layout of the left low- β Insertions 1 and 5

- Free space of 23 m on each side of the IP; note however that a secondary particle absorber is placed 19 m from the IPs;
- Low- β (or ‘inner’) quadrupole triplet;
- Pair of separation dipoles;
- The matching (or ‘outer’) quadrupole triplet.

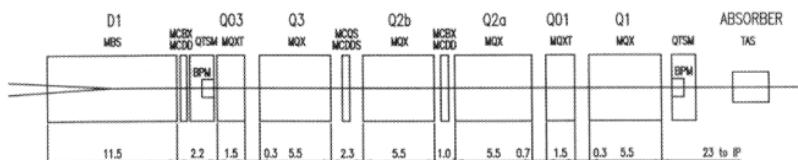
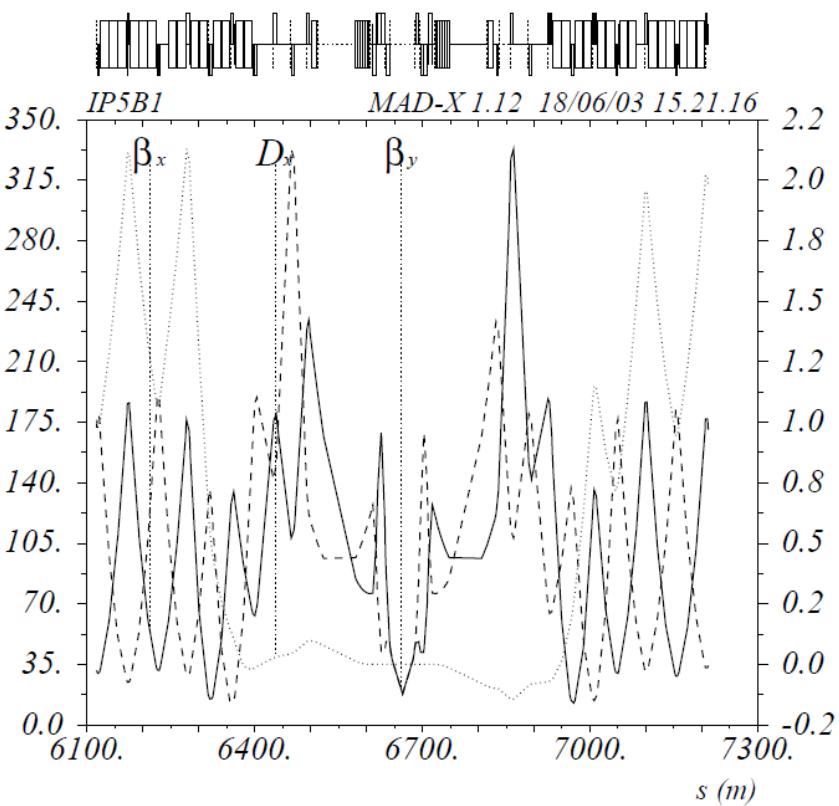
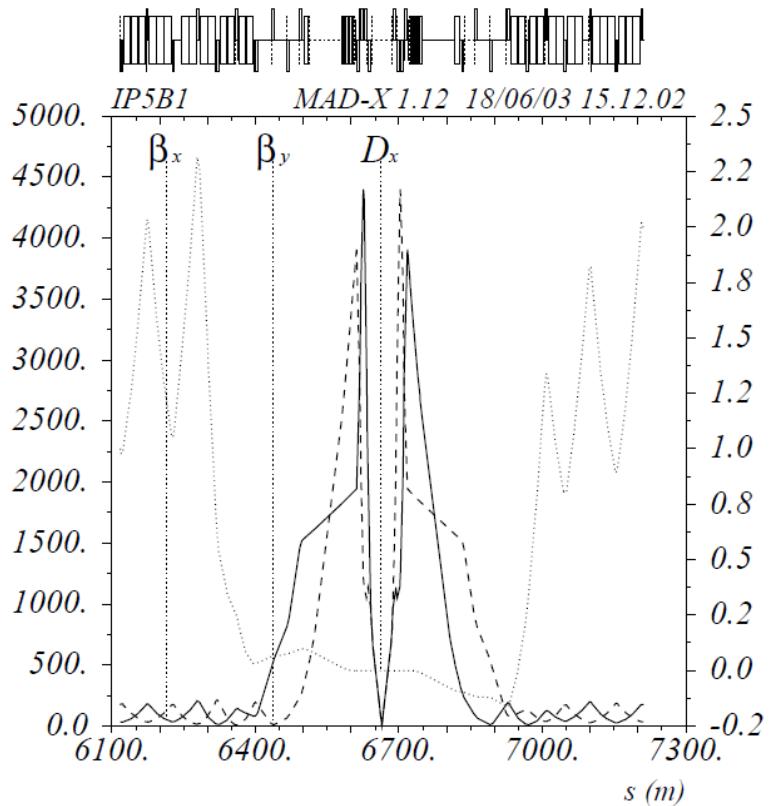


Figure 8: Layout of the left low- β triplet including D1

- Q01, Q02a, Q02b, and Q03: 5.5 m long, 70 mm aperture, powered in series
- Trim quadrupoles Q01 and Q03: 1.5 m long, 85 mm aperture, powered independent.



Optics of LHC interaction region





Optics of FCC-hh interaction region

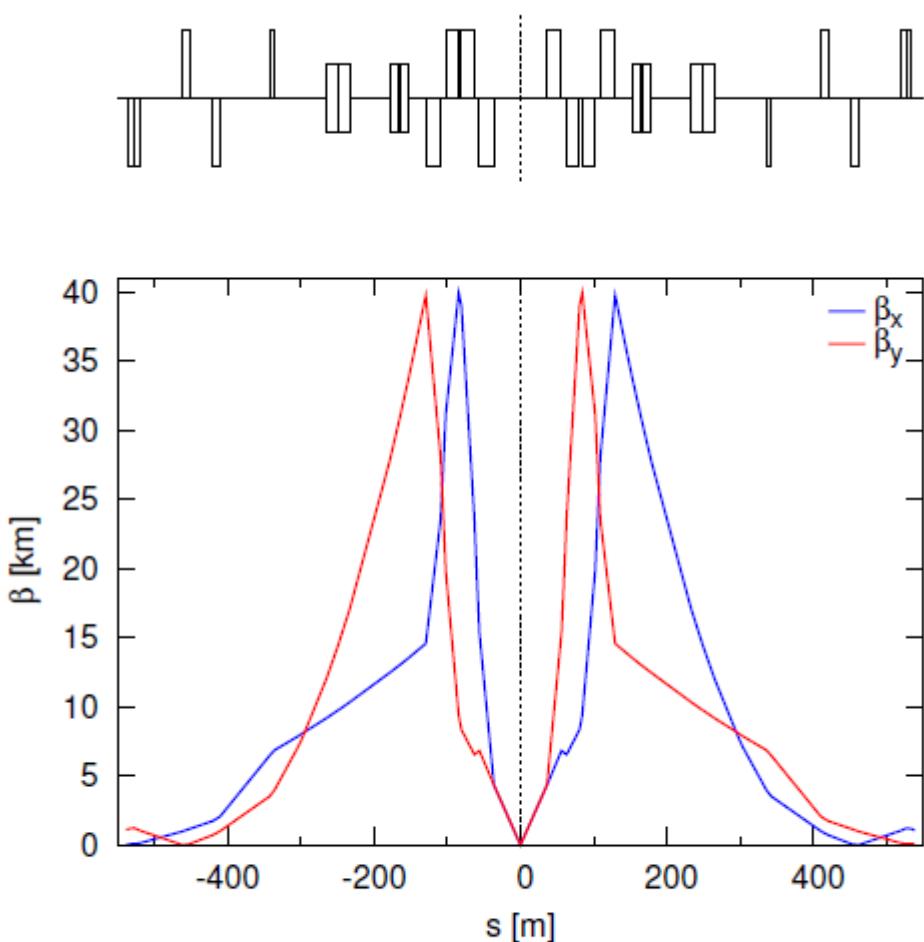


Figure 1: FCC-hh interaction region design with $\beta^* = 0.3$ m and $L^* = 36$ m.

Table 2: Parameters for the free aperture calculation.

B_{\max}	11 T
crossing angle θ	$12 \sigma_p$
Layer thickness [mm]	
- Shielding	15
- Liquid helium	1.5
- Kapton insulator	0.5
- Cold bore	2
- Beam screen	2.05
- Beam screen insulation	2

Aperture 100 mm

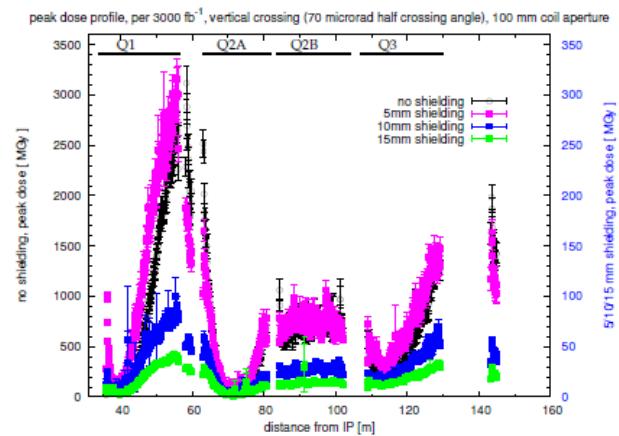
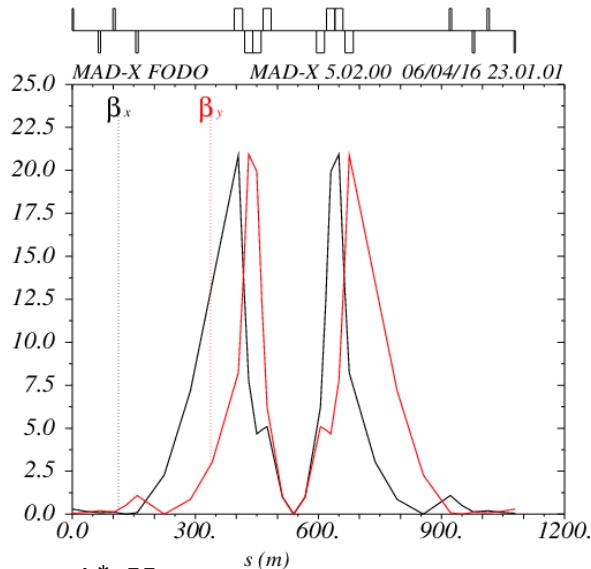
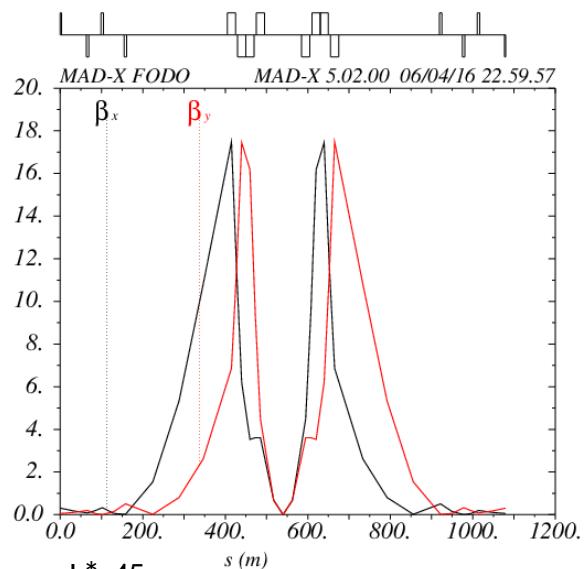
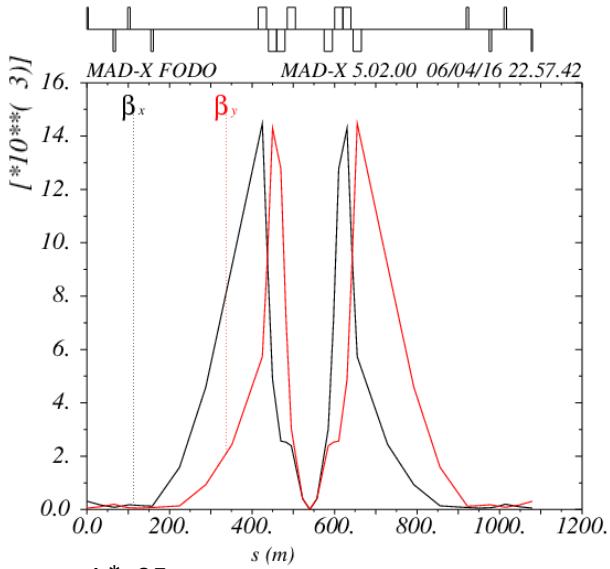
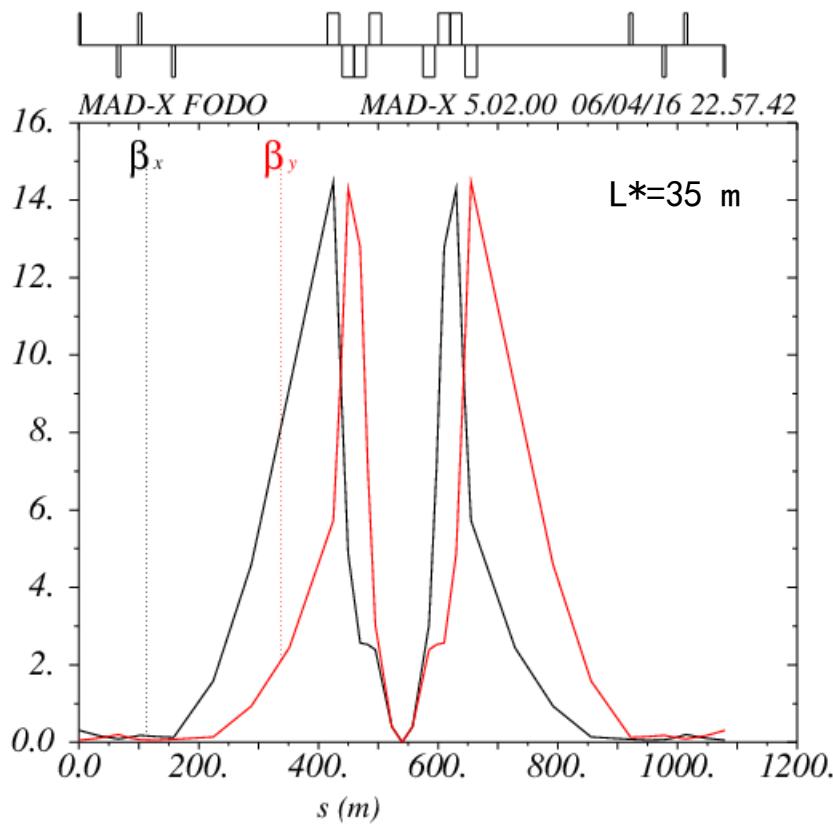


Figure 2: Radiation dose in the triplet magnets from physics debris with (right scale) and without (left scale) shielding. For 15 mm shielding and the shown integrated luminosity of 3000 fb^{-1} , the dose looks acceptable [4].



IR lattice with different L^* of SPPC





Estimate of aperture

$$B_{pole \ max} = 20 \text{ T}$$

$$\varepsilon_n = 4.1 \mu\text{m}$$

$$\sigma = \sqrt{\varepsilon \cdot \beta}$$

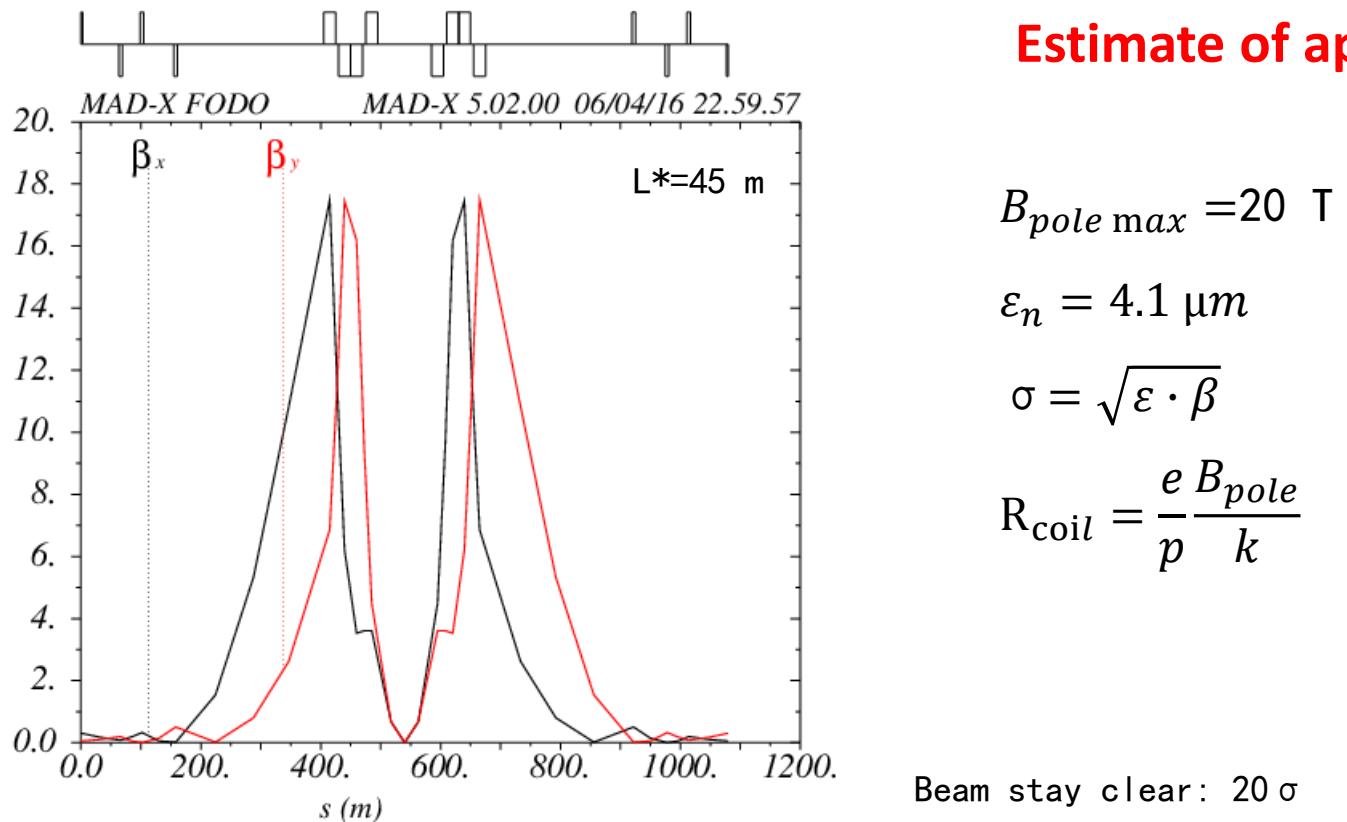
$$R_{coil} = \frac{e}{p} \frac{B_{pole}}{k}$$

Beam stay clear: 20σ

	betx (m)	bety (m)	max(betx,bety)	k	Rmax (m)	20σ (m)	Space left (m)
QC1	2507.914	3162.335	3162.334871	0.001394	0.122886	0.011791	0.111094622
QC2A	2700.198	13001.68	13001.67751	0.001079	0.15873	0.023908	0.134821257
QC2B	5051.524	14662.16	14662.15659	0.001079	0.15873	0.025389	0.13334041
QC3	14724.35	6223.888	14724.34897	0.001234	0.138784	0.025443	0.113340997
QC4	866.596	1496.423	1496.423348	0.006836	0.025059	0.008111	0.016947975
QC5	493.5448	31.03385	493.5448409	0.002546	0.067299	0.004658	0.062640782
QC6	88.41062	192.9211	192.9211323	0.00392	0.043704	0.002912	0.040791415

Space left for:

- Shielding
- liquid helium
- beam screen
-



Estimate of aperture

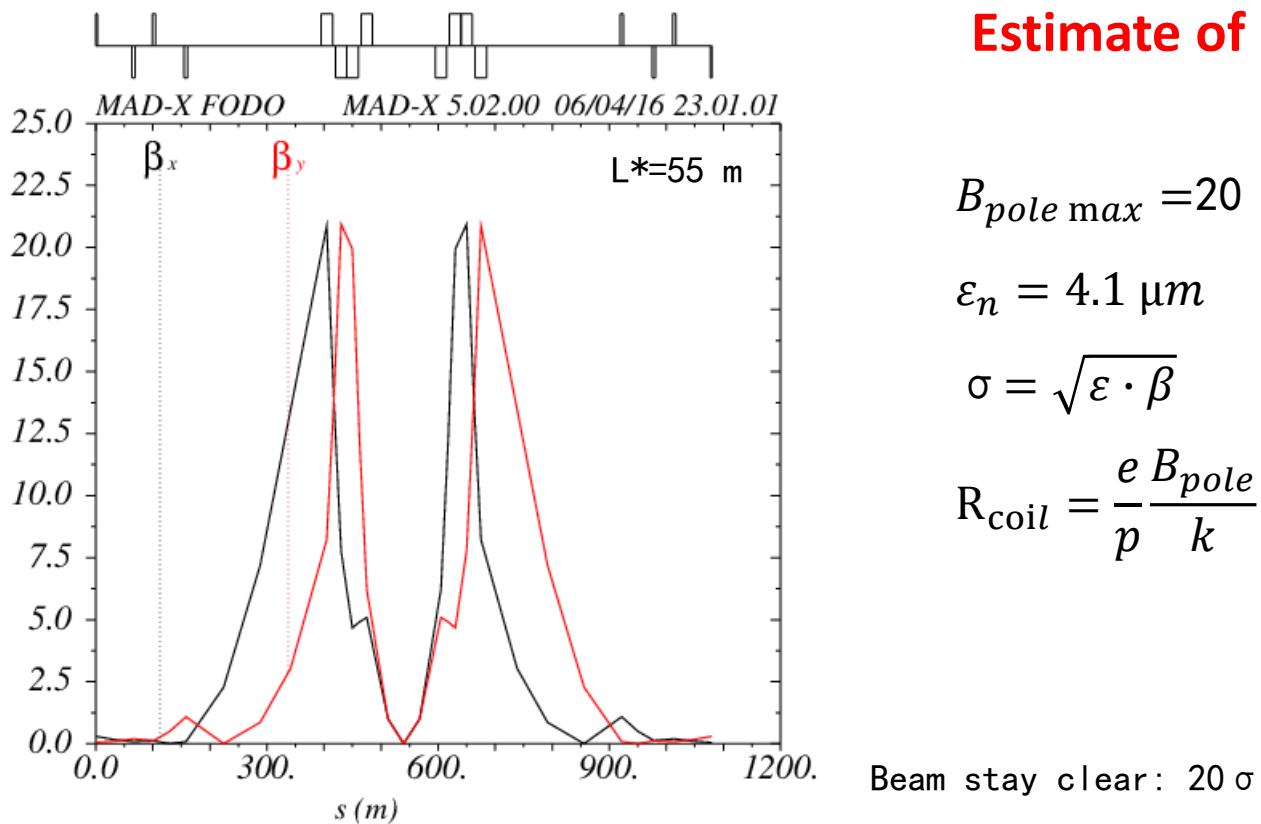
$$B_{pole\ max} = 20 \text{ T}$$

$$\varepsilon_n = 4.1 \mu\text{m}$$

$$\sigma = \sqrt{\varepsilon \cdot \beta}$$

$$R_{coil} = \frac{e}{p} \frac{B_{pole}}{k}$$

	betx (m)	bety (m)	max(betx,bety)	k	Rmax (m)	20σ (m)	Space left (m)
QC1	3611.588	4489.226	4489.225863	0.001237	0.138482	0.014049	0.12443293
QC2A	3528.351	16187.03	16187.02712	0.001039	0.164823	0.026677	0.138146311
QC2B	6213.328	17449.01	17449.00676	0.001039	0.164823	0.027697	0.137125927
QC3	17480.67	6865.033	17480.6737	0.001217	0.140787	0.027722	0.113064243
QC4	20.59461	508.0948	508.0947962	0.005894	0.029064	0.004726	0.02433748
QC5	322.1416	6.878193	322.1415625	0.006125	0.027967	0.003763	0.024204017
QC6	86.91007	196.2574	196.2573751	0.006257	0.027378	0.002937	0.024440634



Estimate of aperture

$$B_{pole \ max} = 20 \text{ T}$$

$$\varepsilon_n = 4.1 \mu\text{m}$$

$$\sigma = \sqrt{\varepsilon \cdot \beta}$$

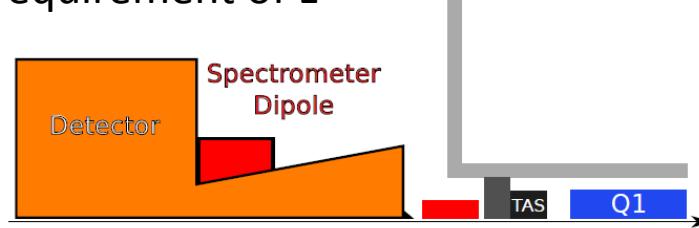
$$R_{coil} = \frac{e}{p} \frac{B_{pole}}{k}$$

	betx (m)	bety (m)	max(betx, bety)	k	Rmax (m)	20σ (m)	Space left (m)
QC1	5085.453	6221.721	6221.720678	0.001123	0.152539	0.016539	0.135999822
QC2A	4669.837	19945.27	19945.27295	0.001002	0.171044	0.029612	0.141431571
QC2B	7771.317	20944.8	20944.80145	0.001002	0.171044	0.030345	0.140698652
QC3	20860.3	8218.014	20860.29823	0.001185	0.144619	0.030284	0.114335144
QC4	84.0685	1088.061	1088.061075	0.004467	0.038349	0.006916	0.031432208
QC5	118.317	142.2668	142.2668388	0.006321	0.027101	0.002501	0.024599559
QC6	84.06724	202.7928	202.7927759	0.002596	0.065991	0.002986	0.063004892



More to do:

- Confirm the requirement of L^*



- **Spectrometer dipole (10 Tm):**
 $z = 14.8 \text{ m}$ to $z = 21 \text{ m}$
- **Detector forward region:**
 $z = 21 \text{ m}$ to $z = 31.5 \text{ m}$
- **End of conical beam pipe:**
 $z = 32.3 \text{ m}$
- **Warm orbit corrector \mathcal{O} (7 Tm):**
 $z = 33 \text{ m}$ to $z = 37.5 \text{ m}$
- **Shielding from TAS:** $z = 38 \text{ m}$ to $z = 40 \text{ m}$
- **TAS:** $z = 40 \text{ m}$ to $z = 43 \text{ m}$
- **Q1:** $z = 45 \text{ m}$ to $z = 75 \text{ m}$

As presented by W. Riegler

One example case of $L^* = 45 \text{ m}$ of FCC

- Confirm the $B_{\text{pole max}}$ of inner triplet
- Confirm the thickness of different layers of inner triplet.
Shielding, liquid helium, beam screen and so on.
- Estimate the magnets' aperture and evaluate the beam stay clear



Summary

- Preliminary lattice design of a 70 TeV collider, using 20 T bending magnets.
- Lattice design constrained by both geometry problem and beam optics problem.
- Full bend DS will lead to both beta and dispersion bump, which will influence other systems such as collimator.

Next to do

- Optimize the lattice design base on the current progress(Arc filling factor, DS matching, IR study)
- Dynamic aperture study



Thanks !