Lattice for collimation

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Outline

- LHC Collimation System
  - Principles of the two-stage collimation
  - Betatron collimation
  - Momentum collimation
- Some consideration of SPPC collimation
  - Single diffractive scattering
  - New ideas about SPPC collimation
- Next to do

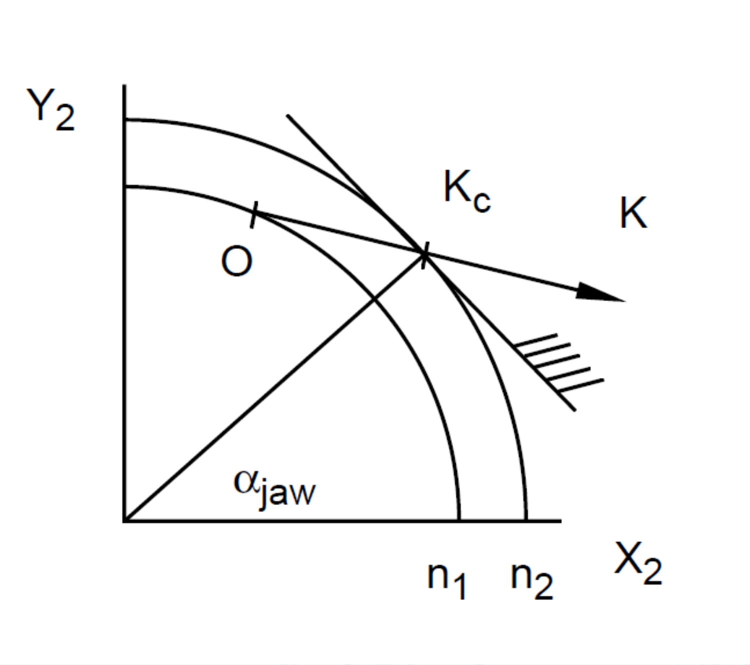
LHC Collimation System

- Principles of the two-stage collimation

$$A_0 = (n_1 \cos\alpha, 0, n_1 \sin\alpha, 0)$$

$$A_1 = (n_1 \cos\alpha, K\cos\phi, n_1 \sin\alpha, K\sin\phi)$$

α: X-Y azimuth
K: polar variables
ϕ: X'-Y' azimuth



$$M_{ij} = \begin{pmatrix} \cos\mu_x & \sin\mu_x & 0 & 0 \\ -\sin\mu_x & \cos\mu_x & 0 & 0 \\ 0 & 0 & \cos\mu_y & \sin\mu_y \\ 0 & 0 & -\sin\mu_y & \cos\mu_y \end{pmatrix}$$

$$A_2 = \begin{pmatrix} n_1 \cos\alpha\cos\mu_x + K\cos\phi\sin\mu_x \\ -n_1\cos\alpha\sin\mu_x + K\cos\phi\cos\mu_x \\ n_1\sin\alpha\cos\mu_y + K\sin\phi\sin\mu_y \\ n_1\sin\alpha\sin\mu_y + K\sin\phi\sin\mu_y \end{pmatrix}$$

- Asking for $X_2' = Y_2' = 0$

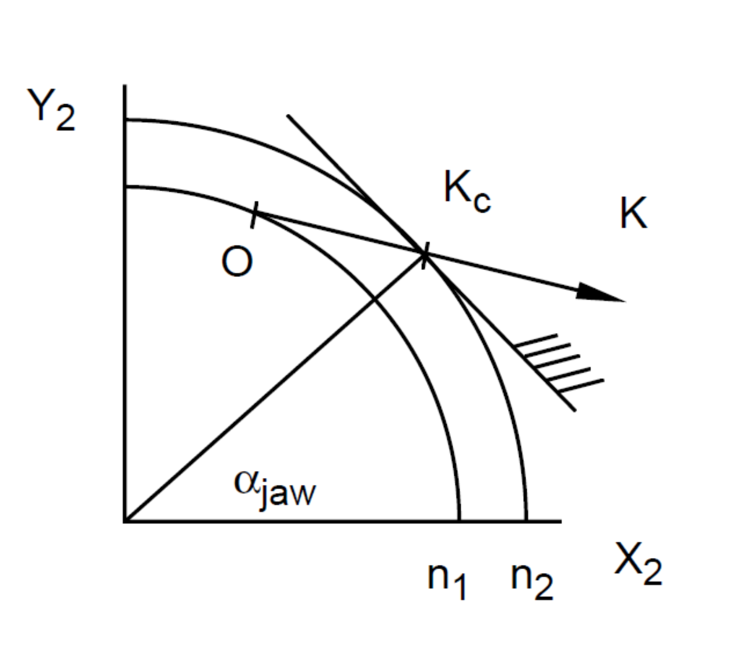
$$\tan\mu_x = \frac{K\cos\phi}{n_1\cos\alpha}, \tan\mu_y = \frac{K\sin\phi}{n_1\sin\alpha}$$

α, ϕ are free variables, $A_2 = A_{cut} = n_2$

$$K = K_c = \sqrt{n_2^2 - n_1^2}$$

Writing

$$\tan\mu_0 = \frac{K_c}{n_1} = \frac{\sqrt{n_2^2 - n_1^2}}{n_1}$$



We get

$$\tan\mu_x = \tan\mu_0 \frac{\cos\phi}{\cos\alpha}, \tan\mu_y = \tan\mu_0 \frac{\sin\phi}{\sin\alpha}$$

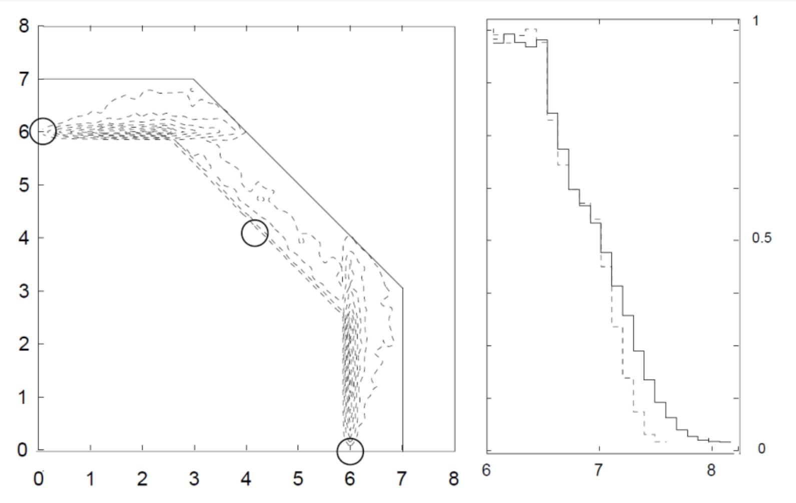
$$\tan\alpha_{jaw} = \frac{\sin\alpha\cos\mu_y + \tan\mu_0\sin\phi\sin\mu_y}{\cos\alpha\cos\mu_x + \tan\mu_0\cos\phi\sin\mu_x}$$

The octagonal primary and flat secondary collimators

$$\tan\mu_x = \tan\mu_0 \frac{\cos\phi}{\cos\alpha}, \tan\mu_y = \tan\mu_0 \frac{\sin\phi}{\sin\alpha}$$

$$\tan\alpha_{jaw} = \frac{\sin\alpha\cos\mu_y + \tan\mu_0 \sin\phi \sin\mu_y}{\cos\alpha\cos\mu_x + \tan\mu_0\cos\phi\sin\mu_x}$$

Density of secondary halo



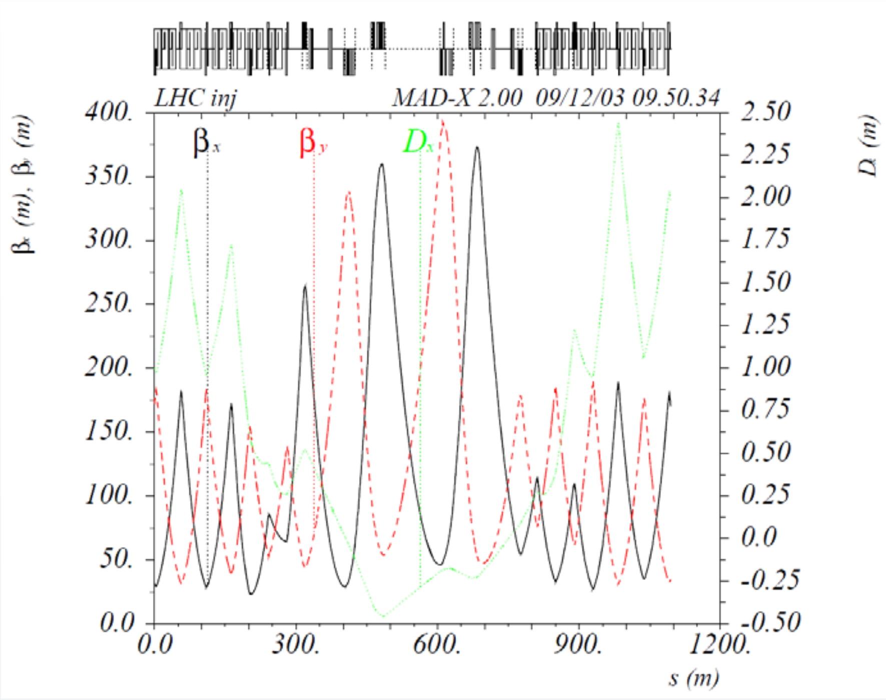
α	ϕ	μ_x	μ_y	α_{jaw}
0	0	μ_o	-	0
0	π	$\pi-\mu_o$	-	0
0	$\pi/2$	π	$3\pi/2$	-μ_o
0	$-\pi/2$	π	$3\pi/2$	μ_o
$\pi/4$	$\pi/4$	μ_o	μ_o	$\pi/4$
$\pi/4$	$5\pi/4$	$\pi-\mu_o$	$\pi-\mu_o$	$\pi/4$
$\pi/4$	$3\pi/4$	$\pi-\mu_o$	$\pi+\mu_o$	$\pi/4$
$\pi/4$	$-\pi/4$	$\pi+\mu_o$	$\pi-\mu_o$	$\pi/4$
$\pi/2$	$\pi/2$	-	μ_o	$\pi/2$
$\pi/2$	$-\pi/2$	-	$\pi-\mu_o$	$\pi/2$
$\pi/2$	π	$\pi/2$	π	$\pi/2-\mu_o$
$\pi/2$	0	$\pi/2$	π	$\pi/2+\mu_o$

- the concept of a phased approach for LHC collimation
- Relies on the fact that difficulties and performance goals for the LHC are distributed in time

Phase	N_{coll}	Setting	Stages	n_1 $[\sigma_\beta]$	n_2 $[\sigma_\beta]$	n_3 $[\sigma_\beta]$	Performance	Cleaning inefficiency (ideal)
1	62	Injection IR3	2	8.0	9.3		Initial	
		Injection IR7	2	6.0	7.0			$(6.3\ldots12.6)\times10^{-3}$ at 10 σ_r
		Collision IR3	2	15.0	18.0			
		Collision IR7 (β^*=1 m)	3	6.0	8.5	14.0		$(0.5\ldots1.5)\times10^{-3}$ at 14 σ_r
		Collision IR7 (β^*=0.5 m)	3	6.0	7.0	10.0		$(1.1\ldots3.3)\times10^{-3}$ at 10 σ_r
2	92	Injection IR3	2	8.0	9.3		Nominal	
		Injection IR7	2	6.0	7.0			$(6.3\ldots12.6)\times10^{-3}$ at 10 σ_r
		Collision IR3	2	15.0	18.0			
		Collision IR7	3	6.0	7.0	10.0		$(0.2\ldots2.0)\times10^{-3}$ at 10 σ_r
3	96	Injection IR3	2	8.0	9.3		High lumi.	
		Injection IR7	2	6.0	7.0			$(6.3\ldots12.6)\times10^{-3}$ at 10 σ_r
		Collision IR3	2	15.0	18.0			
		Collision IR7	3	6	7	10.0		$(0.2\ldots2.0)\times10^{-3}$ at 10 σ_r
(4)	112	Injection IR3	2	8.0	9.3		Maximum	
		Injection IR7	2	6.0	7.0			$(5.7\ldots11.4)\times10^{-3}$ at 10 σ_r
		Collision IR3	2	8.0	9.3			
		Collision IR7	3	6.0	7.0	10.0		$(0.2\ldots2.0)\times10^{-3}$ at 10 σ_r

Betatron collimation

- Symmetric design
- D between Q7L and Q7R is kept small
- Phase advances in the normal conducting region are 0.5*2π and 0.4*2π in the horizontal and vertical plane



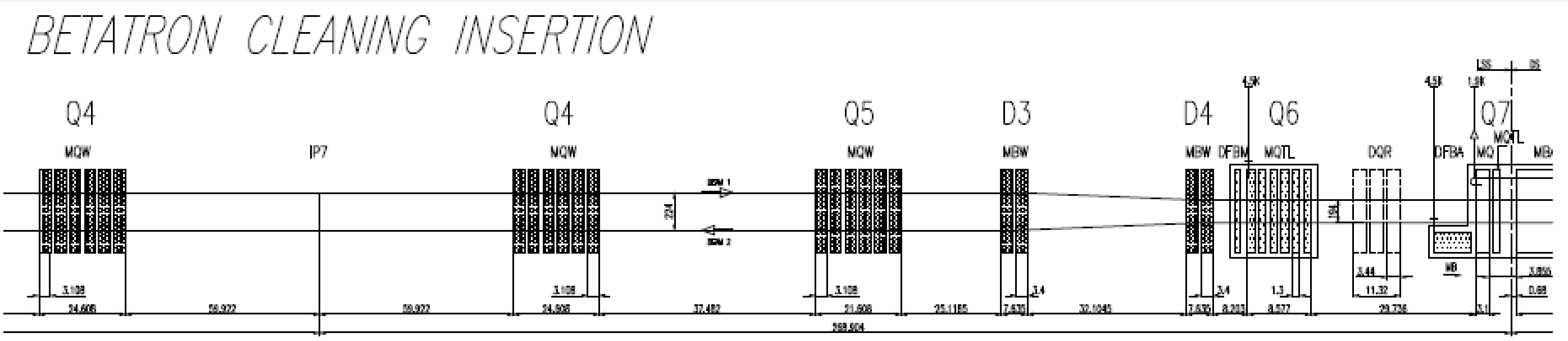


Figure 3.10: The right-hand side of the matching section in IR7.

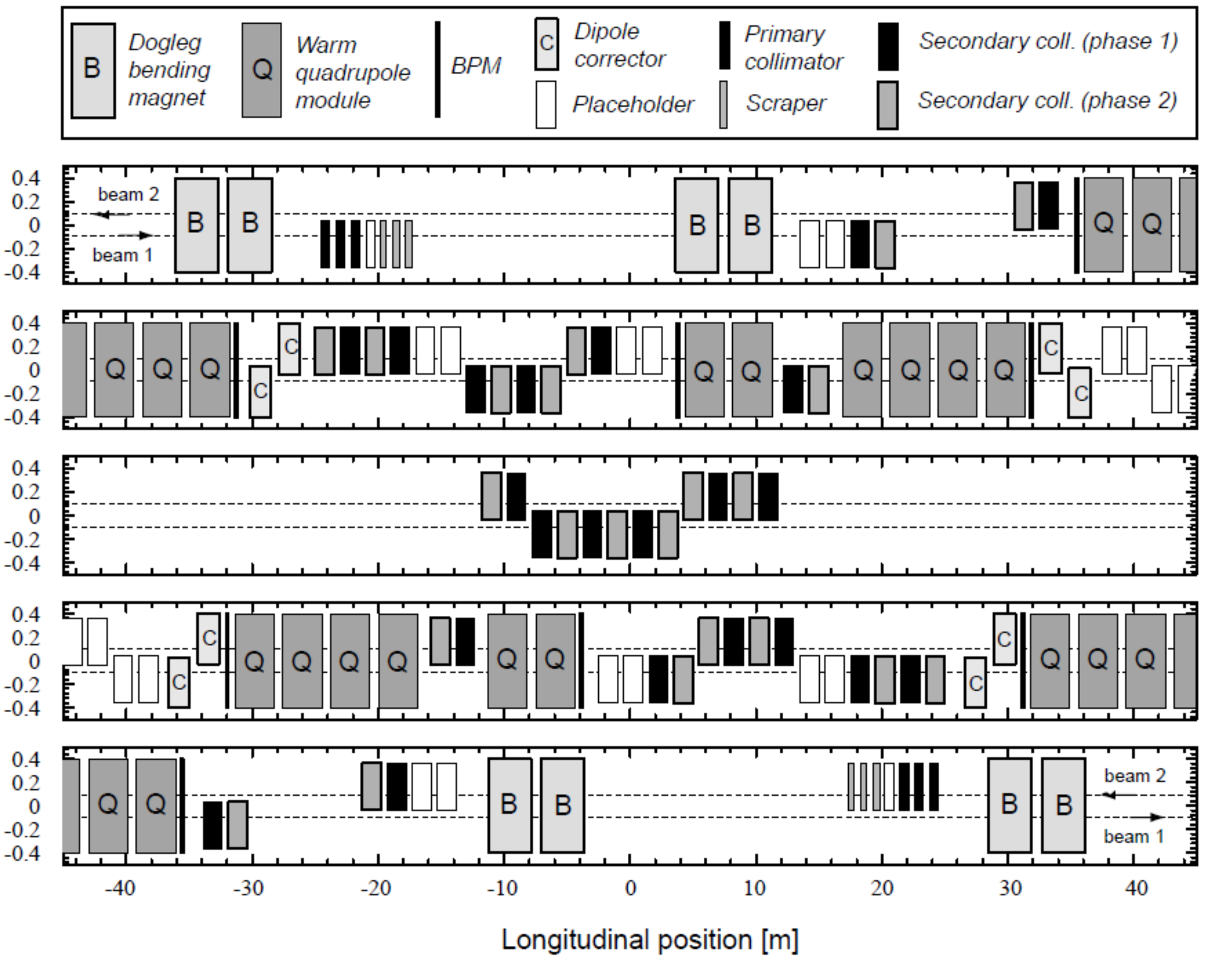
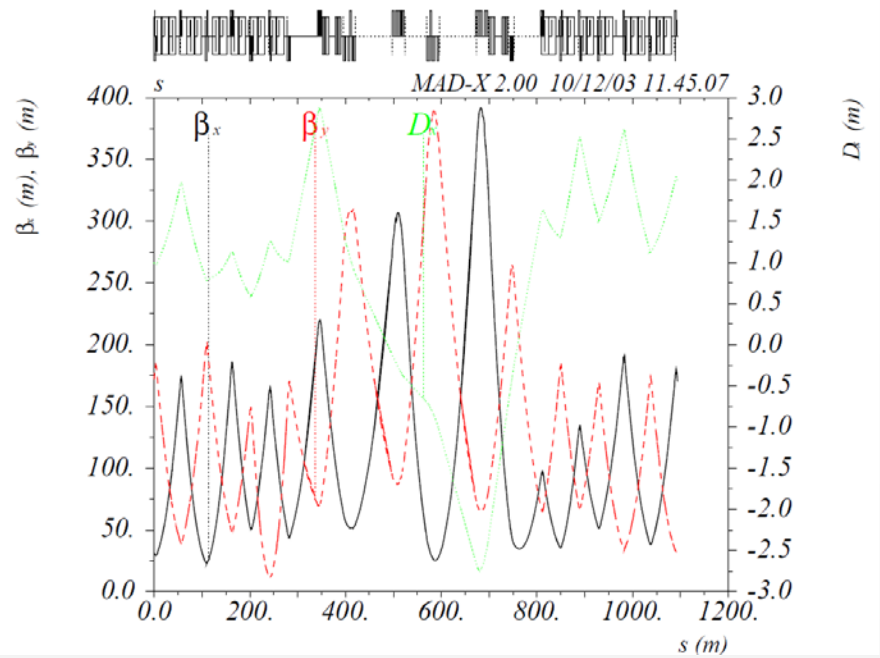


Figure 18.8: Longitudinal layout for the betatron cleaning insertion in IR7.

Name	Distance from IP7 [m]	Azimuth [°]	Half gap [mm]
TCP.D6L7.B1	-204.17	90.0	1.2
TCP.C6L7.B1	-203.17	0.0	1.7
TCP.B6L7.B1	-202.17	135.0	1.4
TCP.A6L7.B1	-201.17	45.0	1.4
TCSG.B6L7.B1	-165.67	41.1	1.7
TCSG.A6L7.B1	-161.67	141.5	1.7
TCSG.B5L7.B1	-102.27	146.7	2.0
TCSG.A5L7.B1	-98.27	40.5	2.0
TCSG.E4L7.B1	-76.97	90.0	1.3
TCSG.C4L7.B1	-47.77	134.4	2.1
TCSG.B4L7.B1	-6.97	0.0	1.9
TCSG.A4L7.B1	-2.97	135.7	1.8
TCSG.A4R7.B1	1.03	44.2	1.8
TCSG.B4R7.B1	49.73	135.7	2.1
TCSG.A5R7.B1	88.23	44.7	2.2
TCSG.B5R7.B1	92.23	134.0	2.2
TCSG.C5R7.B1	104.23	90.0	2.1
TCSG.D5R7.B1	108.23	57.9	2.1
TCSG.E5R7.B1	112.23	122.8	2.0
TCSG.6R7.B1	146.83	0.5	2.9
TCP.D6R7.B2	204.18	90.0	1.2
TCP.C6R7.B2	203.18	0.0	1.6
TCP.B6R7.B2	202.18	135.0	1.4
TCP.A6R7.B2	201.18	45.0	1.4
TCSG.B6R7.B2	165.48	41.7	1.7
TCSG.A6R7.B2	161.48	140.8	1.7
TCSG.B5R7.B2	102.26	146.6	2.0
TCSG.A5R7.B2	98.26	40.3	2.0
TCSG.E4R7.B2	76.93	90.0	1.3
TCSG.C4R7.B2	47.74	135.6	2.1
TCSG.B4R7.B2	11.00	0.0	1.9
TCSG.A4R7.B2	7.00	136.6	1.8
TCSG.A4L7.B2	-9.00	43.4	1.8
TCSG.B4L7.B2	-49.74	136.1	2.1
TCSG.A5L7.B2	-88.26	45.0	2.2
TCSG.B5L7.B2	-92.26	133.7	2.2
TCSG.C5L7.B2	-104.26	90.0	2.1
TCSG.D5L7.B2	-108.26	58.3	2.1
TCSG.E5L7.B2	-112.26	122.3	2.0
TCSG.6L7.B2	-146.72	0.5	2.9

momentum collimation

- Symmetric design
- momentum range of the *nominal* circulating beam does not exceed $\pm 10^{-3}$
- betatron phase advances in the normal conducting region are 0.5*2π and 0.2*2π in the horizontal and vertical
- the primary collimator jaws in IR3 is at a location with large dispersion and small betatron function



$$\eta_{D,prim}(n_1) \geq \frac{n_1 \eta_{D,arc(with-error)}}{A_{arc,inj}(\delta_p = 0) - (n_2^2 - n_1^2)^{1/2}} = \frac{7 \times 0.205}{12 - (8.2^2 - 7^2)^{1/2}} = 0.185 m^{1/2}, \quad \frac{D'_x}{D_x} = -\frac{\alpha_x}{\beta_x}$$

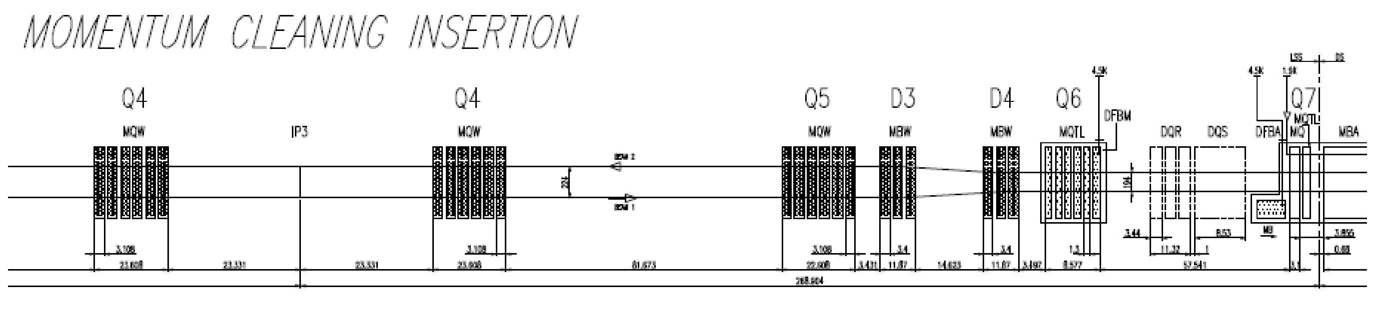


Figure 3.11: The right side of the matching section in IR3.

Make Kc small in a wide range of δ, have to make it independent of δ, $\chi' = 0$

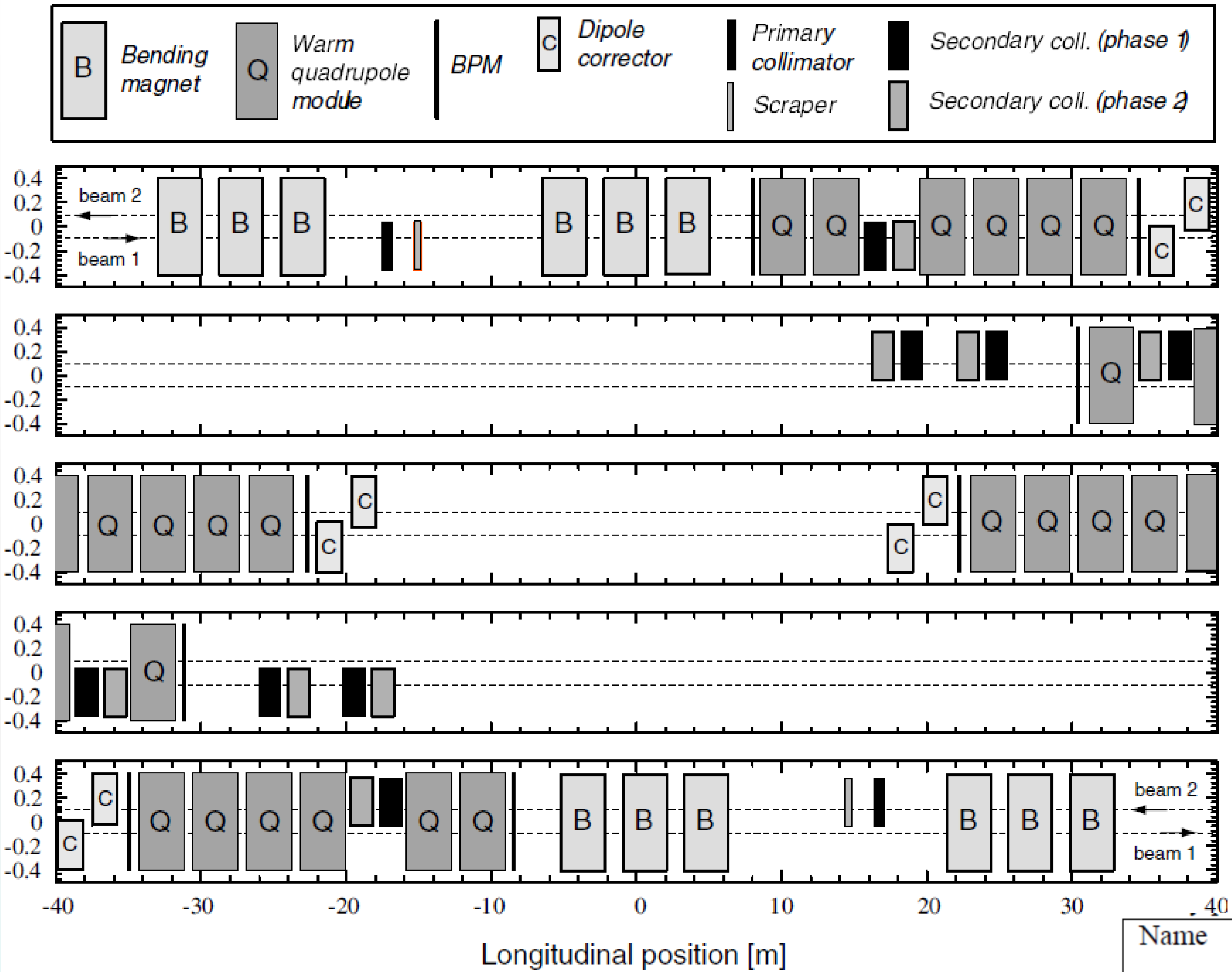
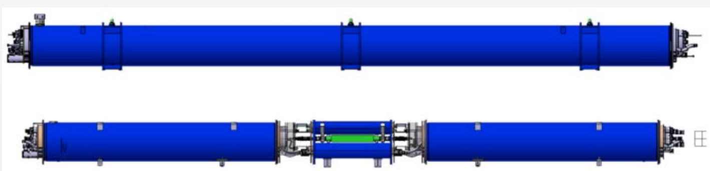


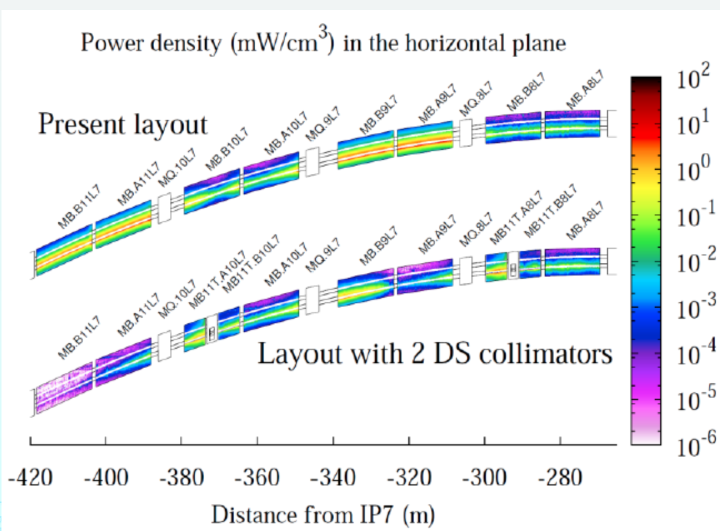
Figure 18.9: Longitudinal layout for the momentum cleaning insertion in IR3.

Name	Distance from IP3 [m]	Azimuth [°]	Half gap [mm]
TCP.6L3.B1	-177.35	0	3.87
TCSG.5L3.B1	-142.31	0	2.94
TCSG.A4R3.B1	43.34	0	2.06
TCSG.A5R3.B1	55.20	170.4	2.72
TCSG.B5R3.B1	61.02	11.4	3.05
TCP.6R3.B2	177.45	0	3.64
TCSG.5R3.B2	143.31	0	2.63
TCSG.A4L3.B2	-42.34	0	2.14
TCSG.A5L3.B2	-54.20	170.9	2.60
TCSG.B5L3.B2	-60.02	10.5	2.84

Some consideration of SPPC collimation

- HL-LHC
  - Partical losses in the DS are the highest cold losses around the ring, may pose a certain risk for inducing magnet quenches
  - Single Dsifractive scattering drives the secondary hole to dispersion suppressor(DS)





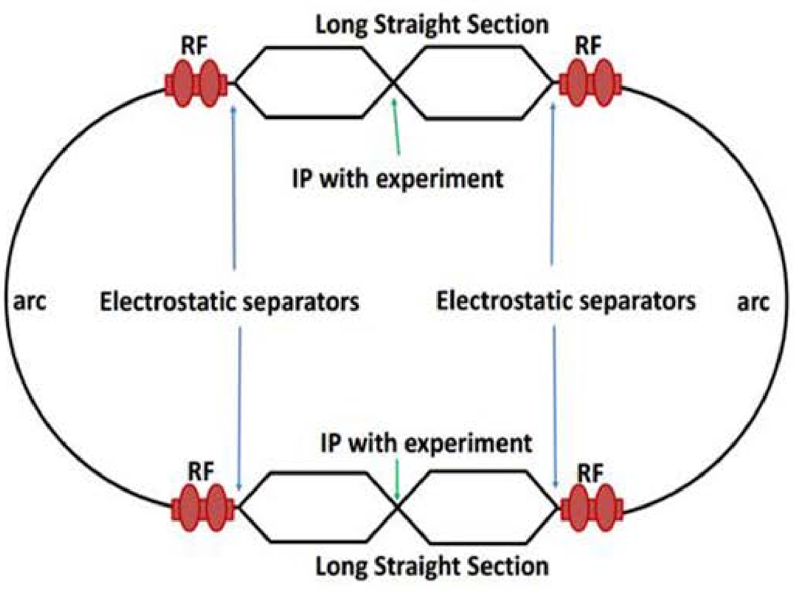
Probobility for SD scattering is

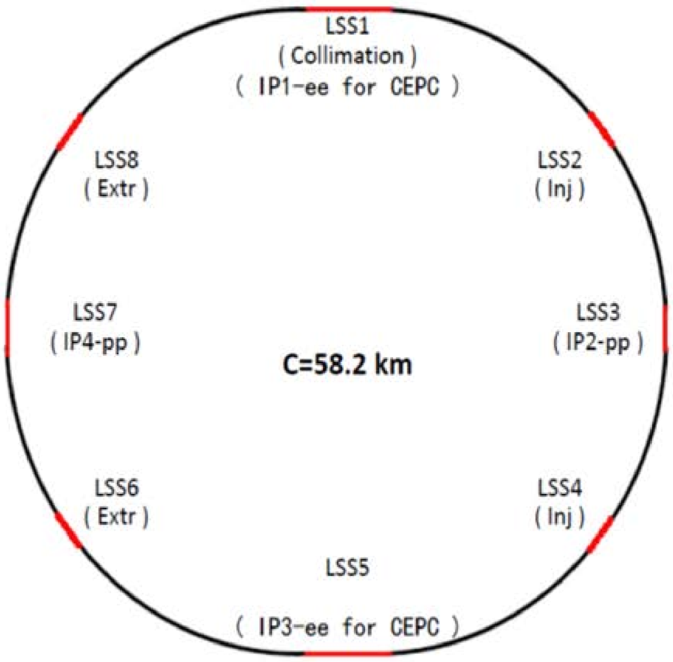
$$P_1 = P_0 \cdot \frac{\sqrt{E_1} \cdot \ln(0.3 \cdot E_1)}{\sqrt{E_0} \cdot \ln(0.3 \cdot E_0)} \qquad \text{With } E_1 > E_0$$

Loss from 7 TeV to 35 TeV factor 7.1

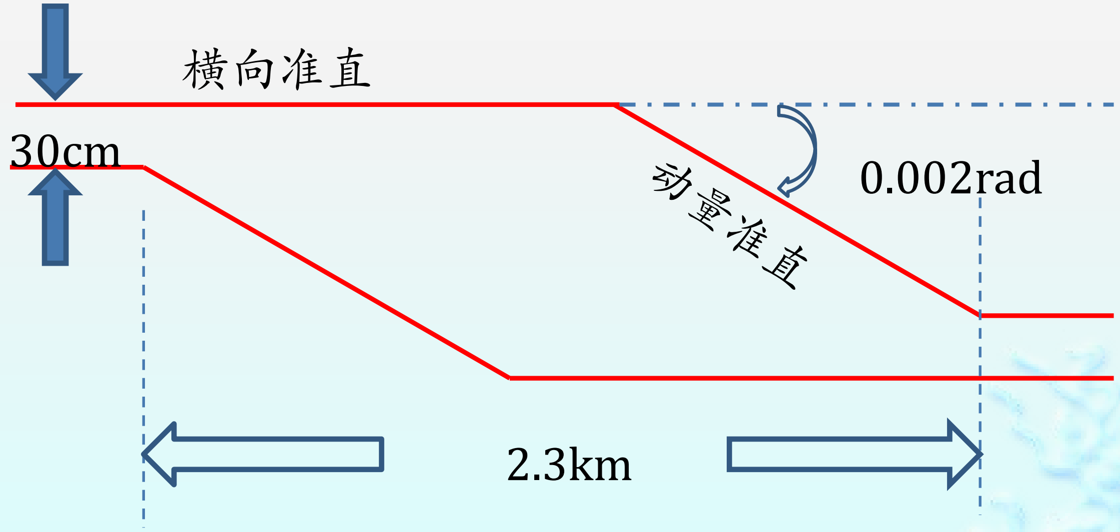
reduces the peak energy deposition by about a factor 10

- We can put the betatron collimation insertion and the momentum collimation insertion into one straight section for SPPC
- CEPC has a 3.5km long straight section





- For LHC, the magnets left and right from the IP are placed symmetrically in straight section for the two beams. But for SPPC, in collimation section, we can place two sets of magnets for two beams respectively, considering that the distance 30cm between the two beams is enough for two series of magnets. It isn't necessary to design symmetrically.
- For new idea, we need to place dipoles in straight section to satisfy the requirement of momentum collimation. The dipoles must be superconducting magnets.



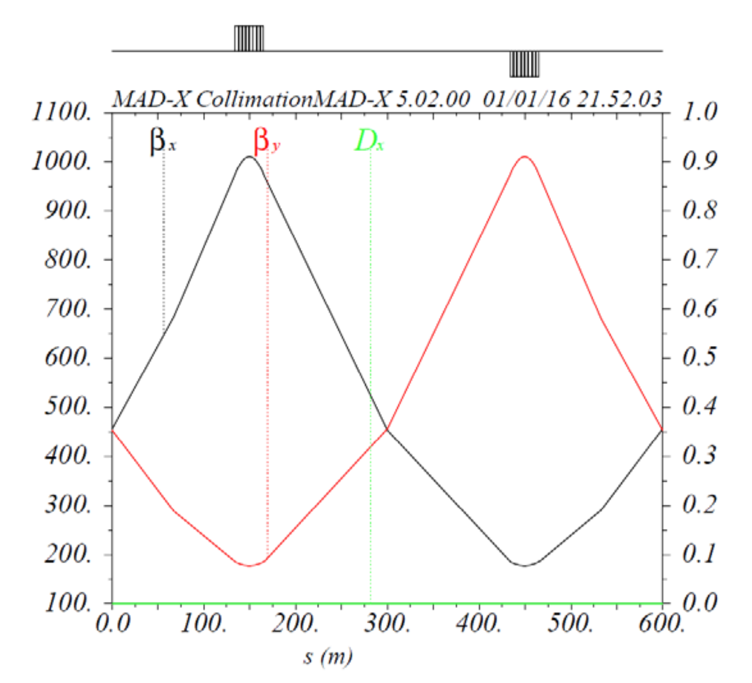
横向准直采用FODO结构

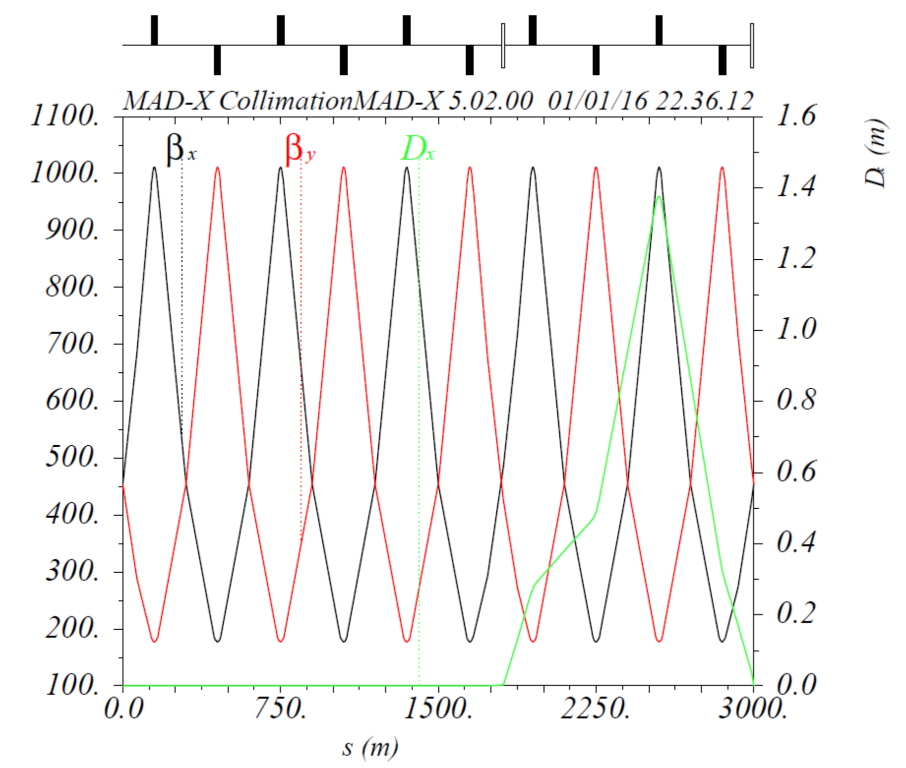
常温四极铁最大聚焦常数计算

$$K_{\max} = 0.000205 m^{-2}$$

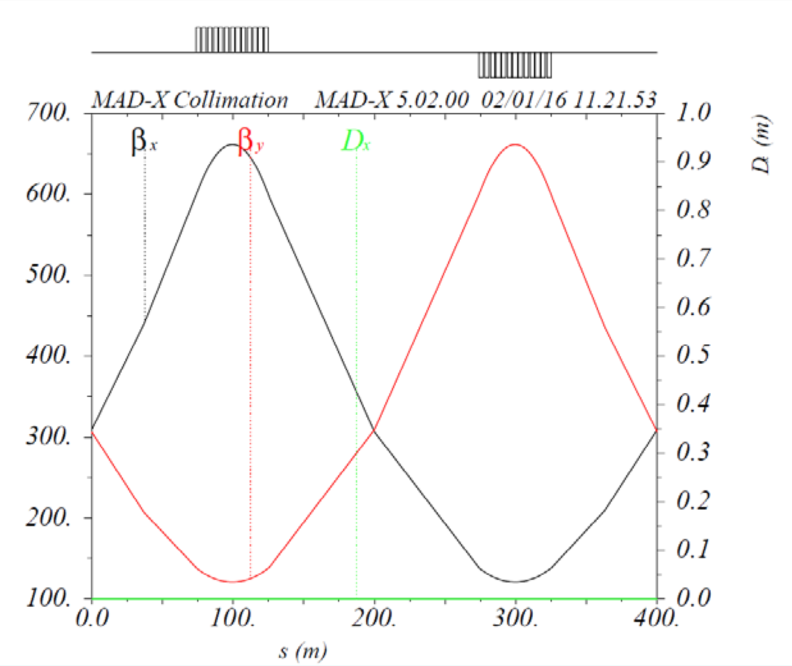
14m，20T超导二极铁最大偏转角

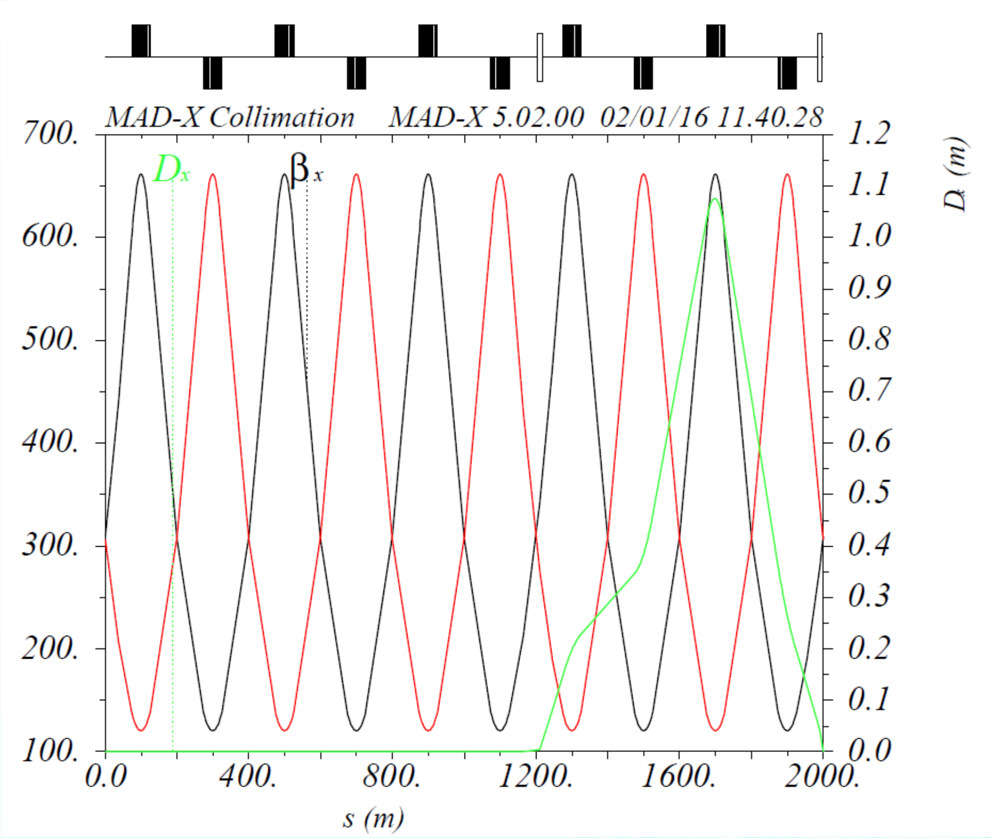
$$\theta_{\max} = 24 mrad$$





Twiss参数	值
Betx/m	456.5888066
Bety/m	453.6563969
Alfx/rad	-1.46966522
Alfy/rad	1.462744516


MAD-X Collimation MAD-X 5.02.00 02/01/16 11.21.53
βx
βy
Dx
700.
600.
500.
400.
300.
200.
100.
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Dx (m)
0.0
100.
200.
300.
400.
s (m)


MAD-X Collimation MAD-X 5.02.00 02/01/16 11.40.28
Dx
βx
700.
600.
500.
400.
300.
200.
100.
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Dx (m)
0.0
400.
800.
1200.
1600.
2000.
s (m)

新方案

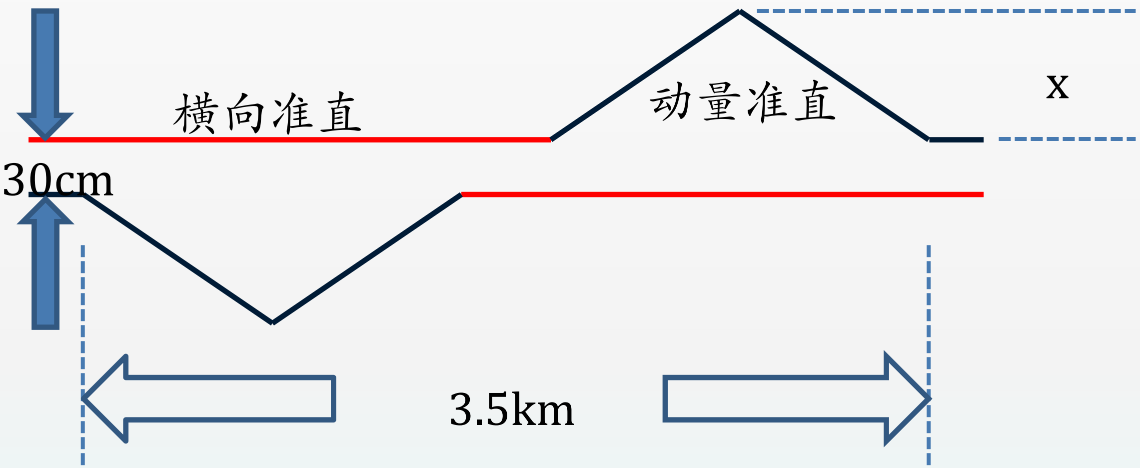
SPPC运行时，若将CEPC的探测器拆除准直段的长度可恢复为3.5km

LHC初级动量准直器 色散3m

SPPC色散要大于3m

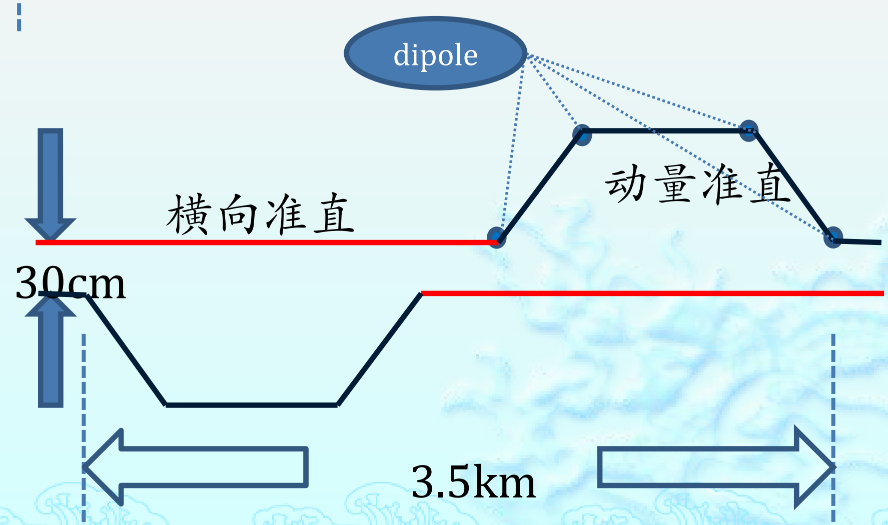
$$\eta_{D,prim}(n_1) \geq \frac{n_1 \eta_{D,arc(with-error)}}{A_{arc,inj}(\delta_p = 0) - (n_2^2 - n_1^2)^{1/2}}$$

两个解决方案：



Version1

Version2



四极铁采用超导铁

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

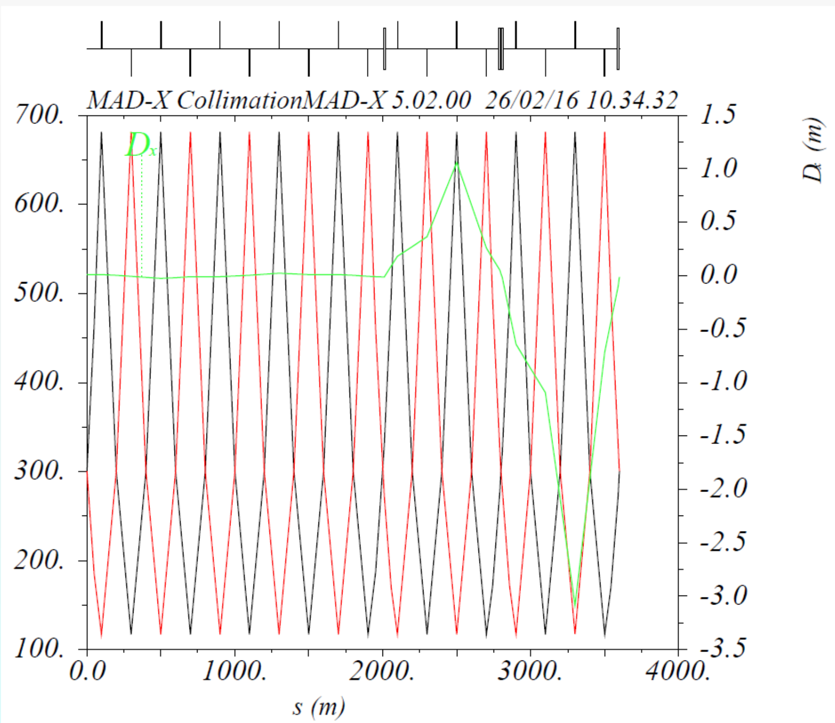
$$B\rho = \frac{(E_0 + E_k)\beta}{ec} = \frac{35TeV}{e \bullet 3\times10^8 m/s} = 1.17\times10^5 T\bullet m$$

$$K_{\max} = \frac{dB_y/dx}{B\rho} = \frac{666.7}{1.17\times10^5} m^{-2} = 0.0057m^{-2}$$

Version1

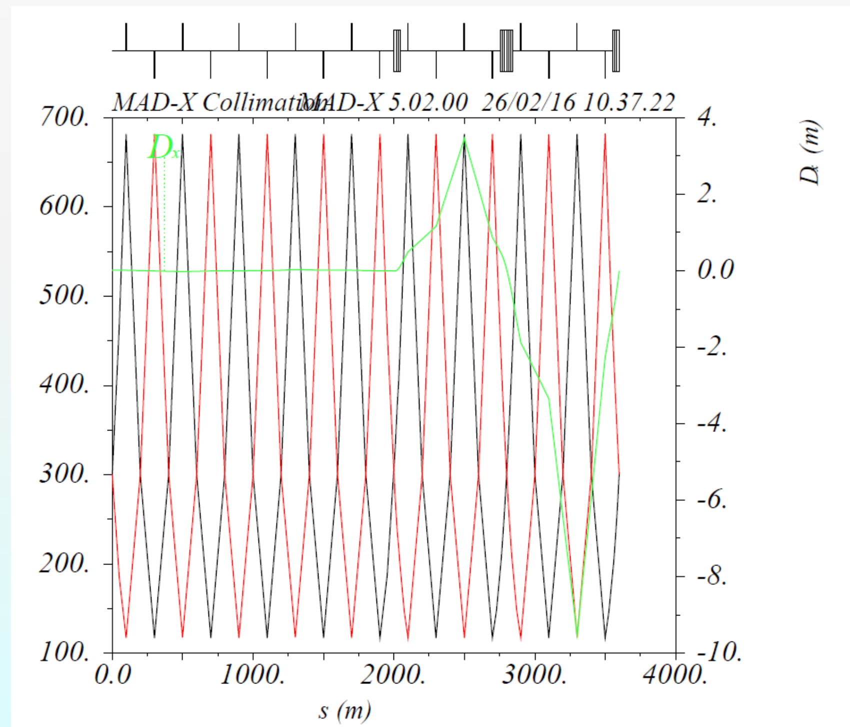
二极铁强度19.2T，长14m，偏转0.0023rad

1+2+1块标准二极铁



X=800*0.0023m=1.84m

3+6+3块标准二极铁

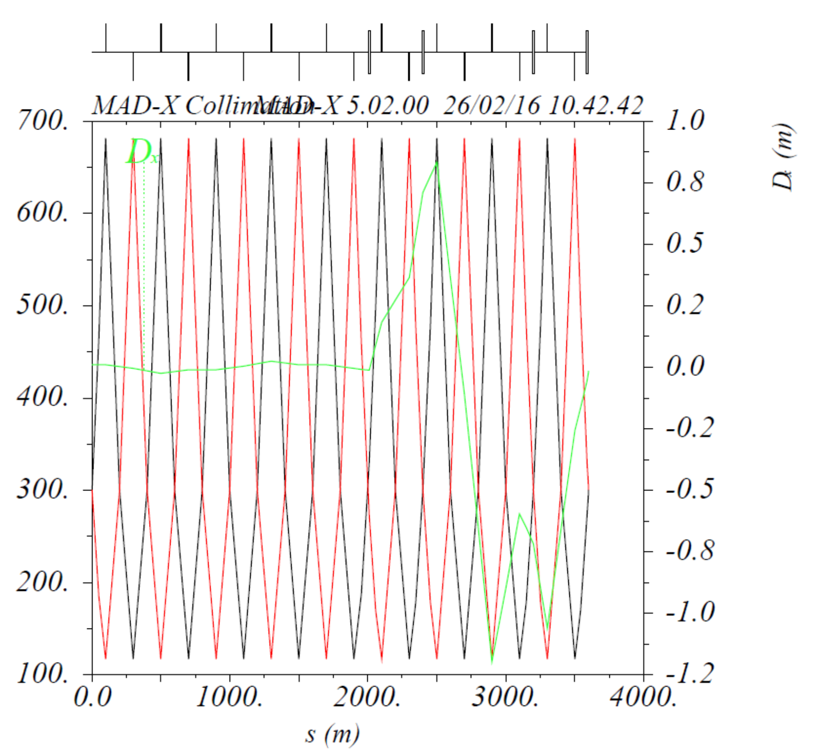


X=800*0.0023*3m=5.52m

Version2

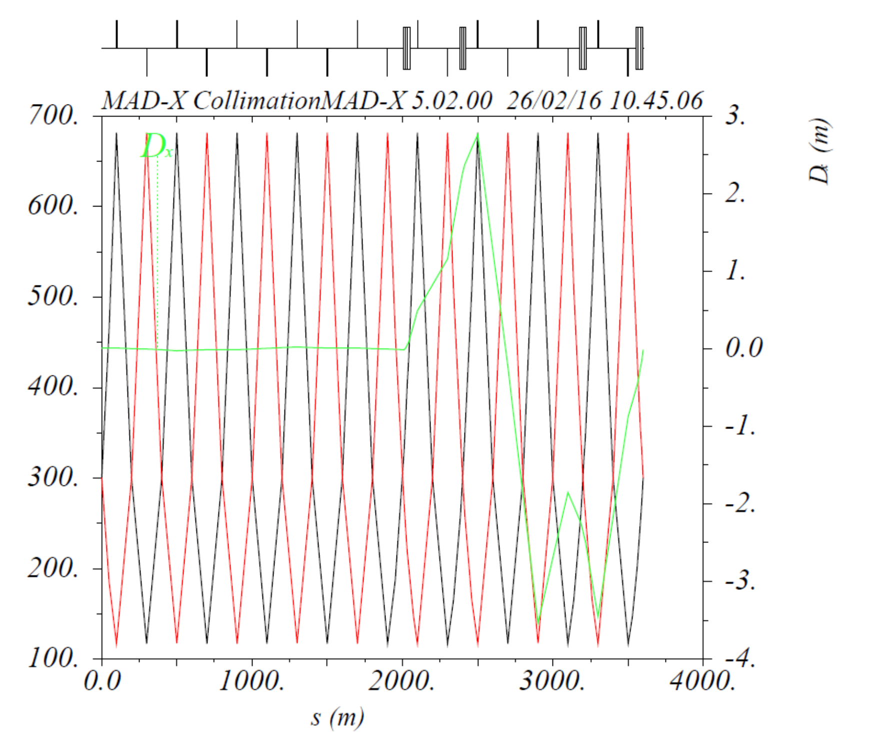
二极铁强度19.2T，长14m，偏转0.0023rad

1+1+1+1块标准二极铁



X=400*0.0023m=0.92m

3+3+3+3块标准二极铁



X=400*0.0023*3m=2.76m

Next to do

- Design lattice for collimation insertion in normal temperature, considering the requirement of the phase advance and the dispersion
- calculate the gap of mult-stage collimator
- Match the collimation section and dispersion suppressor
- ……

Thank you!