6BA Lattice for FCC_ee injector Damping Ring

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General considerations

The DR requirements are fixed by the Booster Ring (BR) parameters (see Injector Table)

Land footprint is defined by the available space (~120x120 m^2)

Realistic design would imply:

- Dipoles Field < 1T (normal conducting)
- Wiggler Field < 1.9 T (normal conducting)
- Quadrupole Gradient k_Q < 50 T/m (5.25 m^{-2} in MAD units)
- Sextupole strength k_S< 1700 T/m^2 (182 m^{-3} in MAD units)
- Minimal element spacing L_δ > 8 cm
- Element length: L_{QUA} > 20 cm, L_{SXP} (L_{OCT}/L_{KCK}/...)> 10 cm

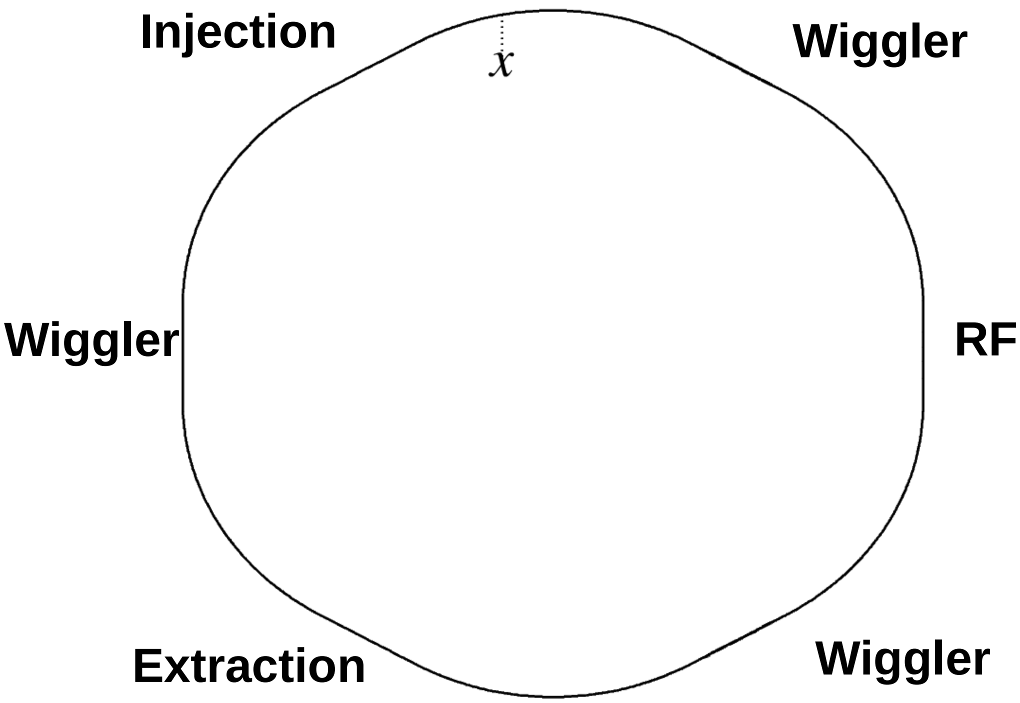
Ring layout

Hexagonal shape: 6 Arcs + 6 Straight

Arcs based on Six Bend Achromat (6BA)

Straight sections used for specialized purpose: Injection or extraction, wigglers, RF cavity

Playing with optical functions possible to have super-periodicity of three (as for the triangle shaped DR)



Six Bend Achromat (Mod 2)

Six Bend Achromat cell (6BA-v4.0)

L_{cell} = 10.60 m
L_{dipole} = 0.5-0.7 m (B_d = 0.7563 T)
N_{qua} = 15
L_{qua} = 0.30 m
N_{sxp} = 6
L_{sxp} = 0.20 m
MAD-X Output:

```
-----------------------------------------
  B6A CELL v4.0
-----------------------------------------
d_delta          =            0.08 ;
d_0              =             0.3 ;
d_1              =             0.1 ;
d_2              =             0.2 ;
d_3              =             0.2 ;
d_4              =             0.4 ;
d_5              =             0.4 ;
d_6              =             0.3 ;
d_7              =             0.3 ;
d_8              =             0.4 ;
d_9              =             0.2 ;
d_10             =             0.1 ;
-----------------------------------------
b6a_kq1          =        -2.49899 ;
b6a_kq2          =         4.77148 ;
b6a_kq3          =        -3.03173 ;
b6a_kq4          =         3.36248 ;
b6a_kq5          =        0.803115 ;
b6a_kq6          =        -1.95099 ;
b6a_kq7          =        -1.48641 ;
b6a_kq8          =         3.98903 ;
-----------------------------------------
b6a_ks1          =    -76.44393826 ;
b6a_ks2          =     142.8261129 ;
b6a_ks3          =    -161.0564271 ;
-----------------------------------------
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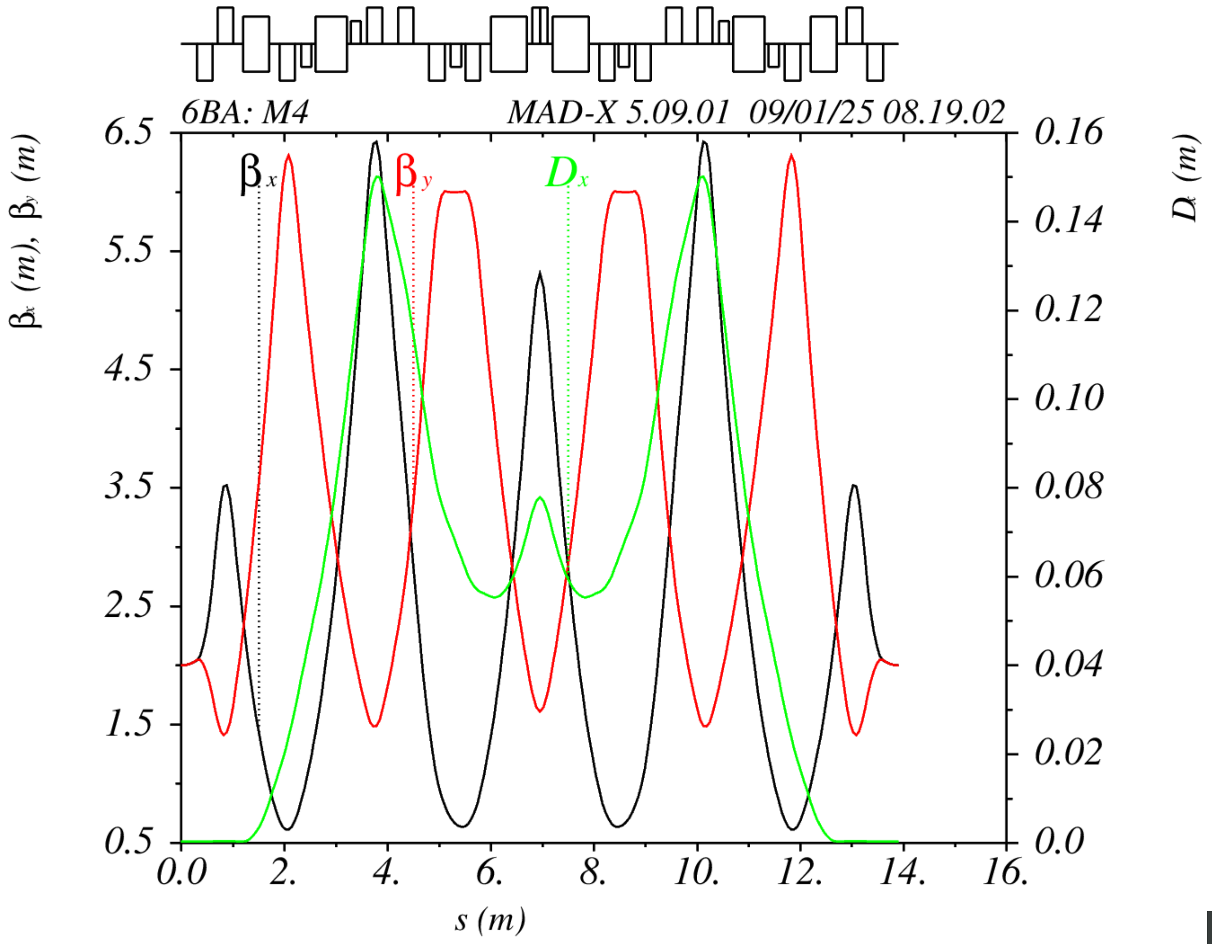
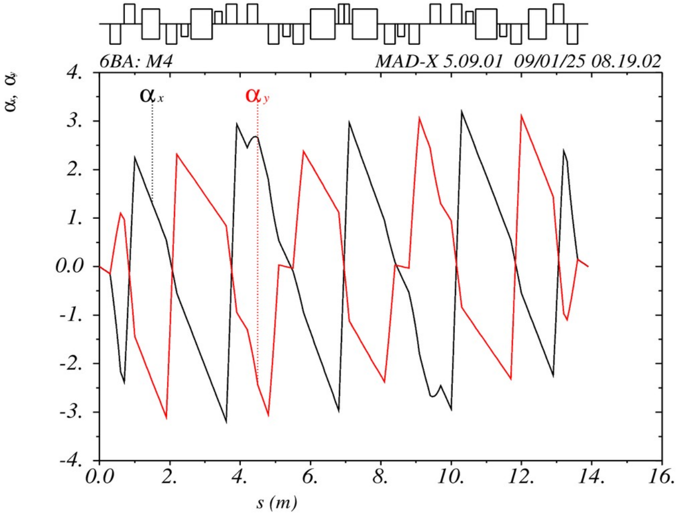
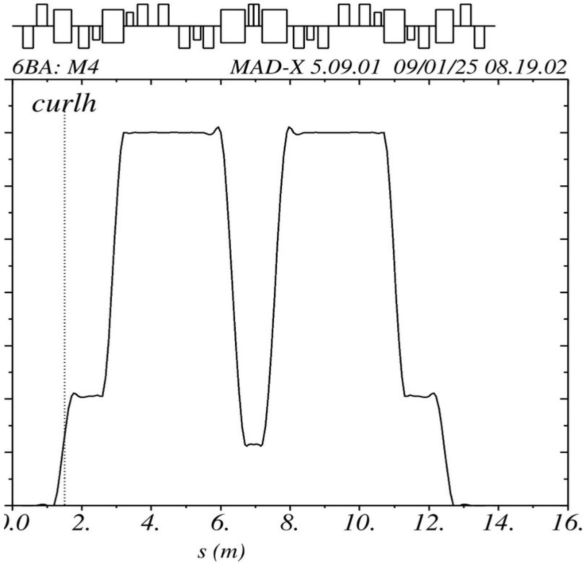
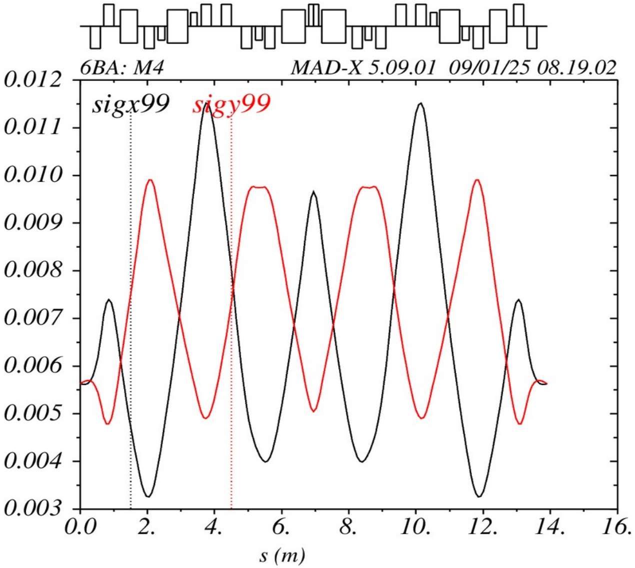


Six Bend Achromat cell (6BA)





Beam envelope (98%)



$$\epsilon_{inj}(h/v) = 2.38 \text{ mm mrad}$$

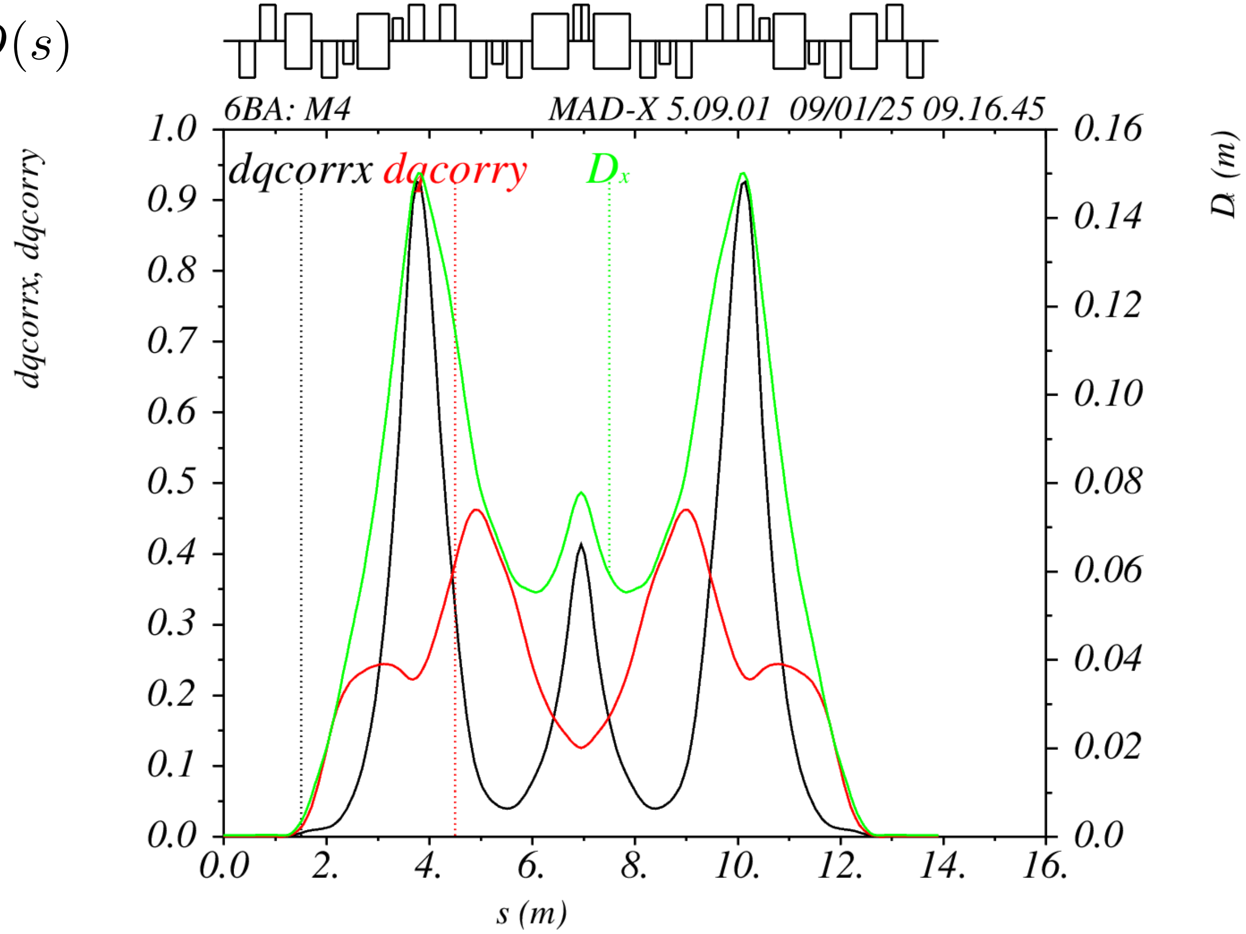
6BA Cell: Sextupoles

$$\Delta\xi_{xy}(m_S) \propto m_S \int ds\beta_{x,y}(s)D(s)$$

Sextupoles placements have been optimized in order to ensure the minimal strengths

Three family have been defined two for the vertical correction and one for the horizontal

The chromaticity correction is localized only in the arcs for the whole ring.



Straight sections elements

Injection/extraction sections

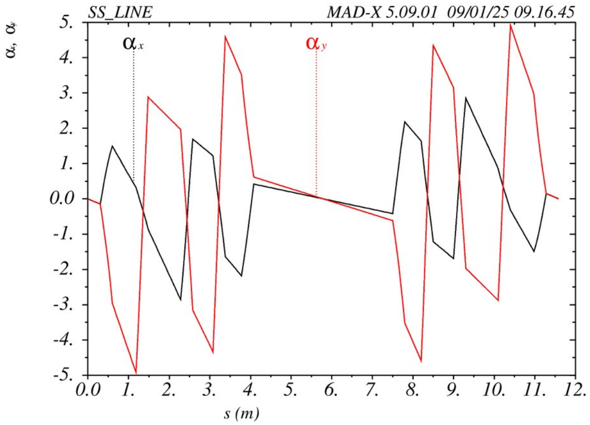
L_{SS} = 11.58
L_{free} = 3.42 m

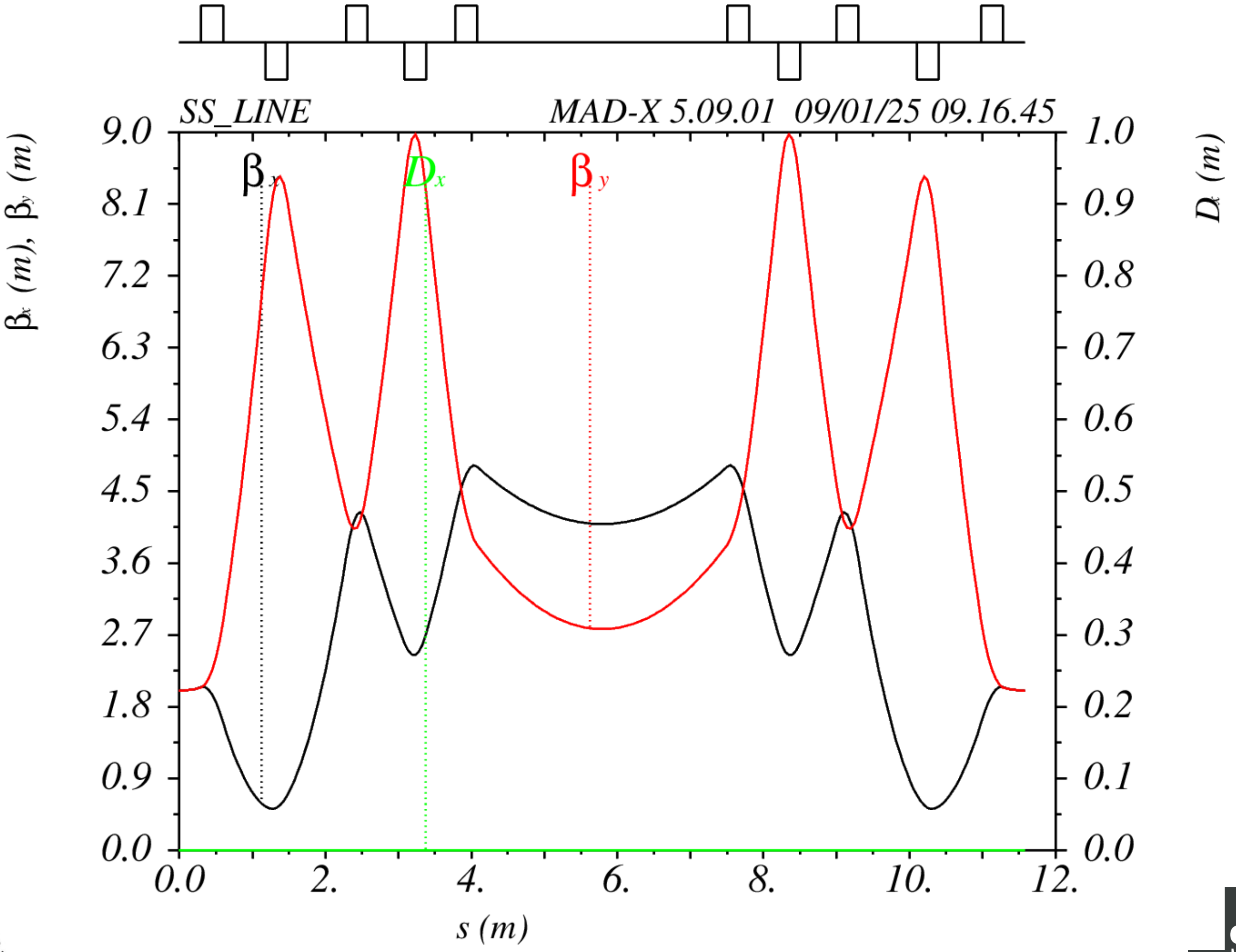
STRAIGHT SECTIONS:
----

ss_ld1	=	0.3 ;
ss_ld2	=	0.58 ;
ss_ld3	=	0.8 ;
ss_ld4	=	0.5 ;
ss_ld5	=	0.4 ;
ss_ld6	=	1.71 ;

----

sskq1	=	3.38578576 ;
sskq2	=	-3.287172054 ;
sskq3	=	3.906317017 ;
sskq4	=	-3.514177296 ;
sskq5	=	1.976167573 ;



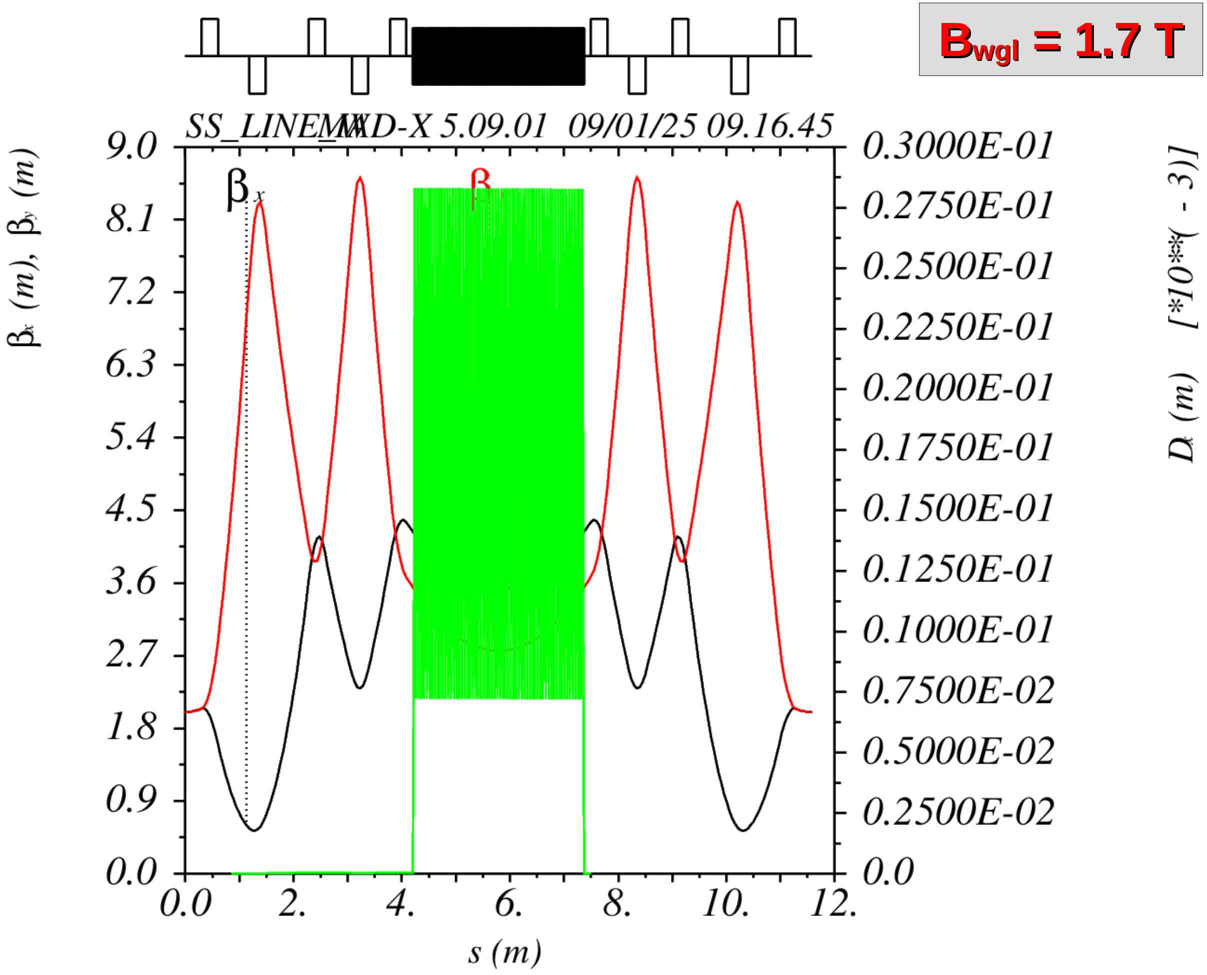


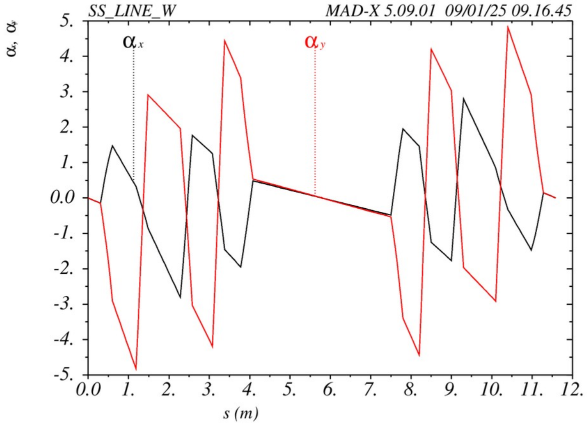
Wiggler sections

L_{SS} = 11.58
L_{free} = 3.42 m

```
----------------------------------------
 STRAIGHT SECTIONS:
----------------------------------------
ss_ld1      =        0.3 ;
ss_ld2      =       0.58 ;
ss_ld3      =        0.8 ;
ss_ld4      =        0.5 ;
ss_ld5      =        0.4 ;
ss_ld6      =       1.71 ;
----------------------------------------
sswkq1      =    3.333698249 ;
sswkq2      =   -3.307536882 ;
sswkq3      =    3.976927425 ;
sswkq4      =   -3.535394196 ;
sswkq5      =    2.033934488 ;
----------------------------------------
```

B_{wgl} = 1.7 T

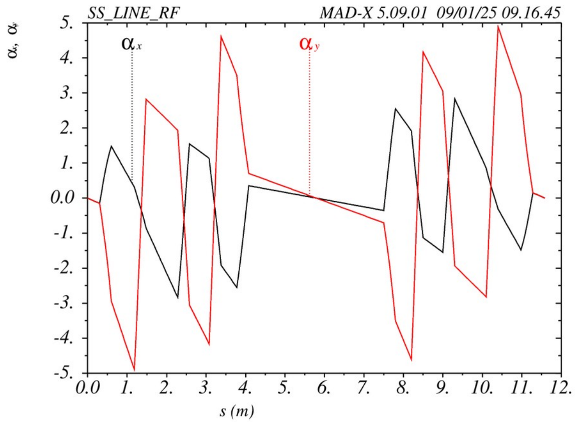


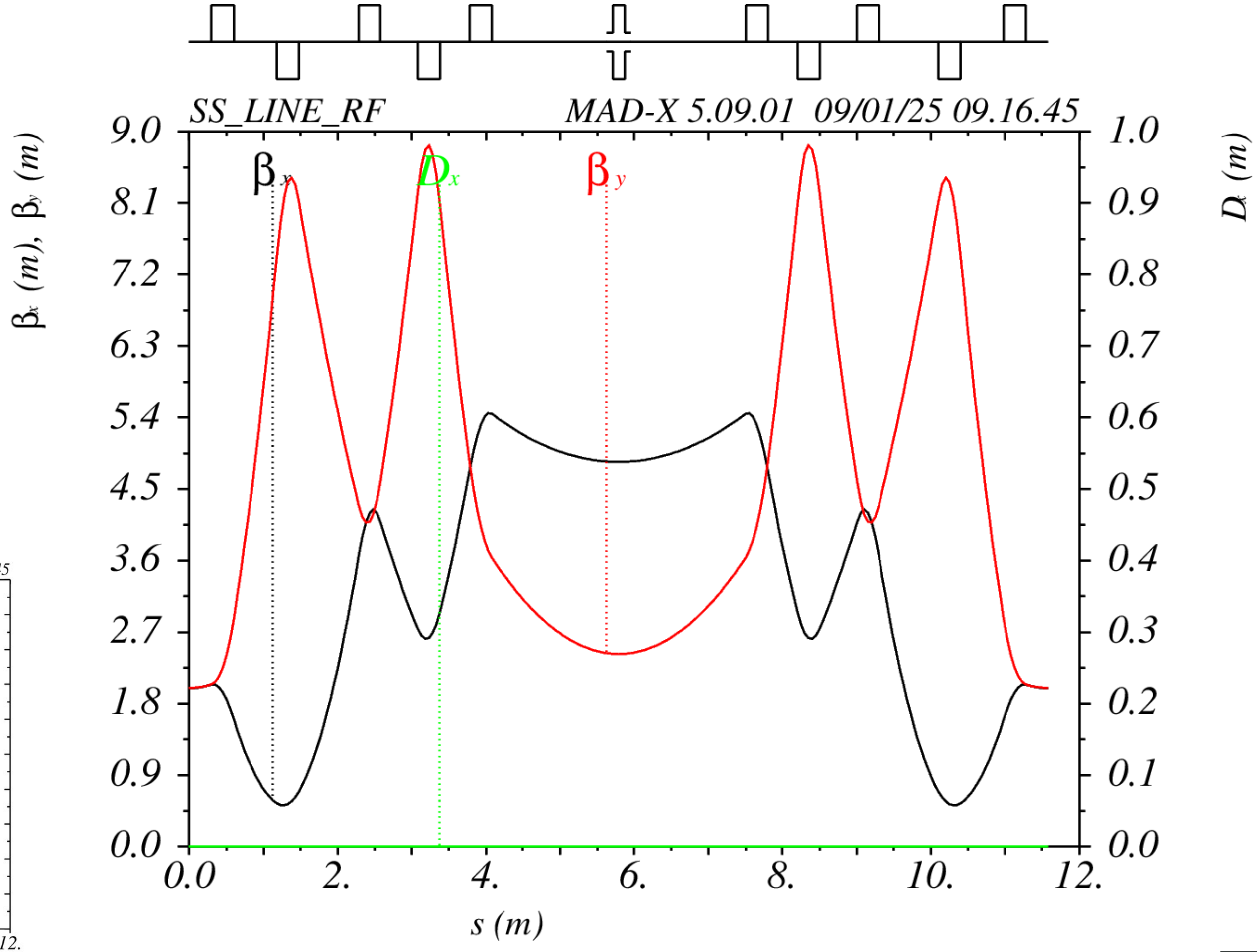


RF sections

L_{SS} = 11.58
L_{free} = 3.42 m

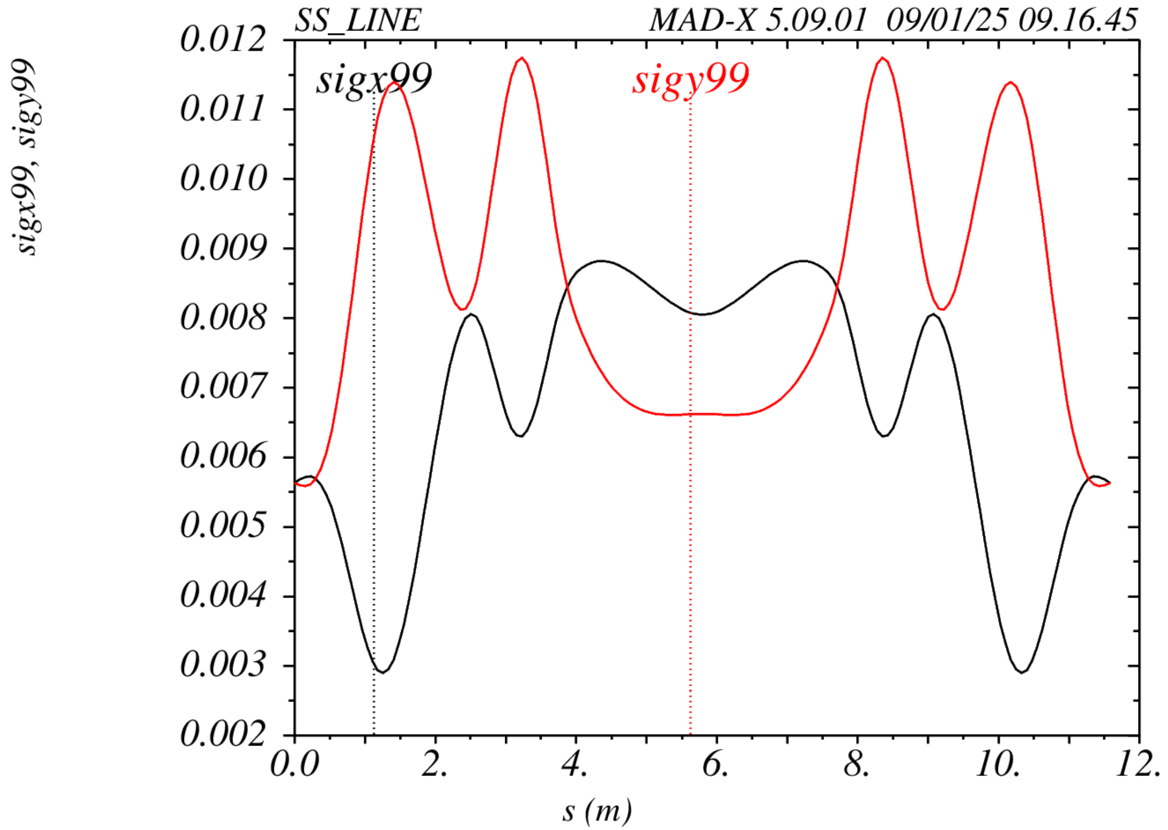
```
----------------------------------------
 STRAIGHT SECTIONS:
----------------------------------------
ss_ld1        =          0.3 ;
ss_ld2        =          0.58 ;
ss_ld3        =          0.8 ;
ss_ld4        =          0.5 ;
ss_ld5        =          0.4 ;
ss_ld6        =          1.71 ;
----------------------------------------
ssrfkq1       =    3.374849605 ;
ssrfkq2       =   -3.263965846 ;
ssrfkq3       =    3.771890122 ;
ssrfkq4       =   -3.513106207 ;
ssrfkq5       =    1.962597868 ;
----------------------------------------
```





Beam envelope in the Straight Sections

$$\epsilon_{inj}(h/v) = 2.38 \text{ mm mrad}$$



Full Ring

Full ring parameters (6BA v4.0)

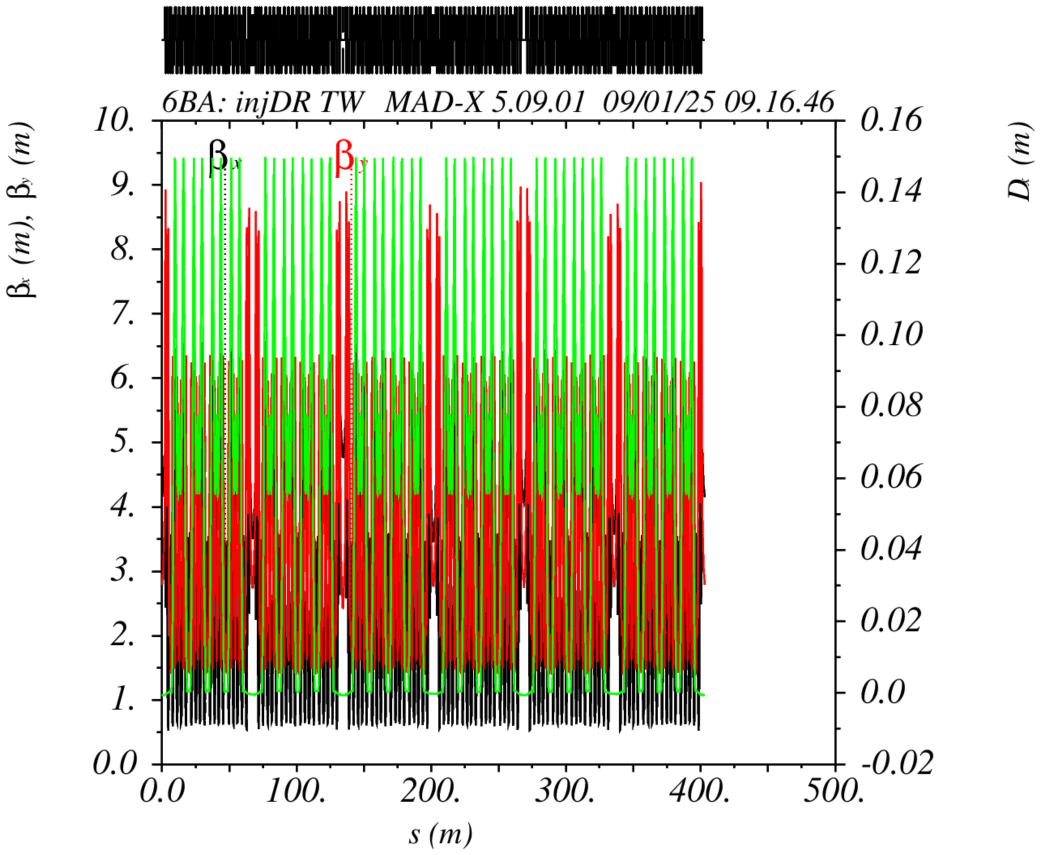
L = 403.09 m
T_{per} = 1.343 μs ;
α_c = 0.000761
Ncel = 24

Q_x = 39.479
Q_y = 21.988

ξ_x = 7.1e-9 (corr) / -49.93 (nat)
ξ_y = 1.4e-8 (corr) / -37.99 (nat)

β_x(max) = 6.67 m
β_y(max) = 9.34 m

U_0 = 571 keV
ΔE = 7.3e-4

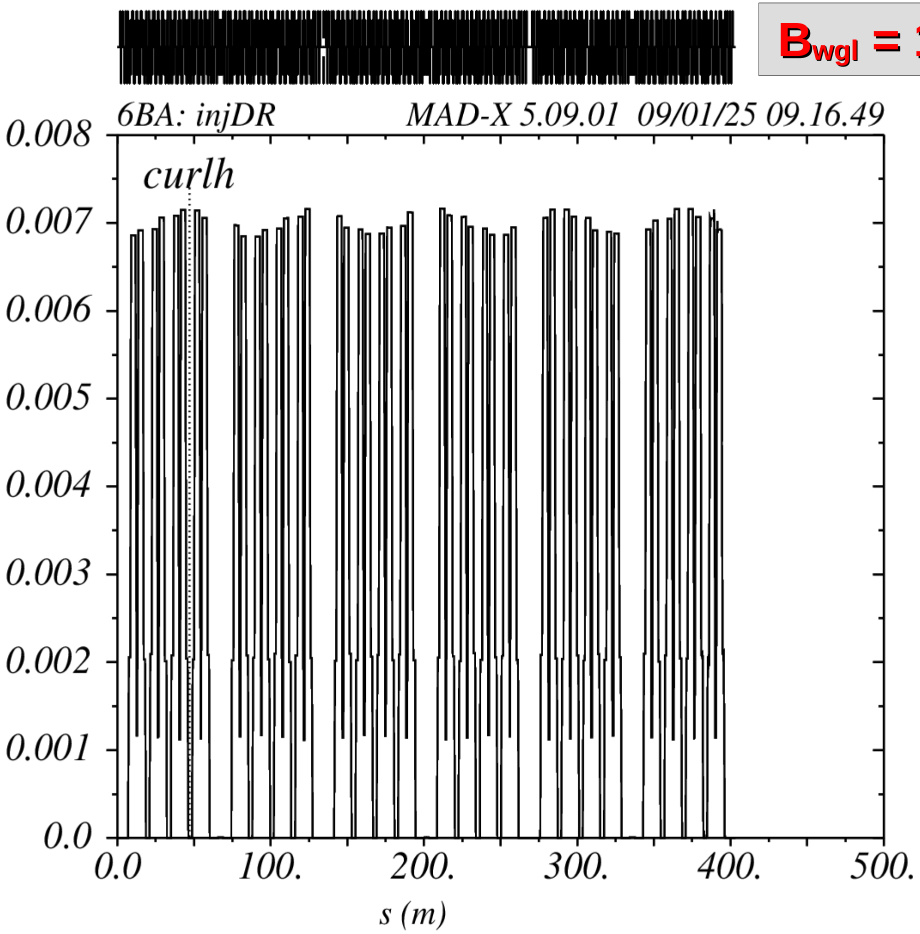


Full ring parameters (6BA Mod 2)

ε = 1.81 nm rad

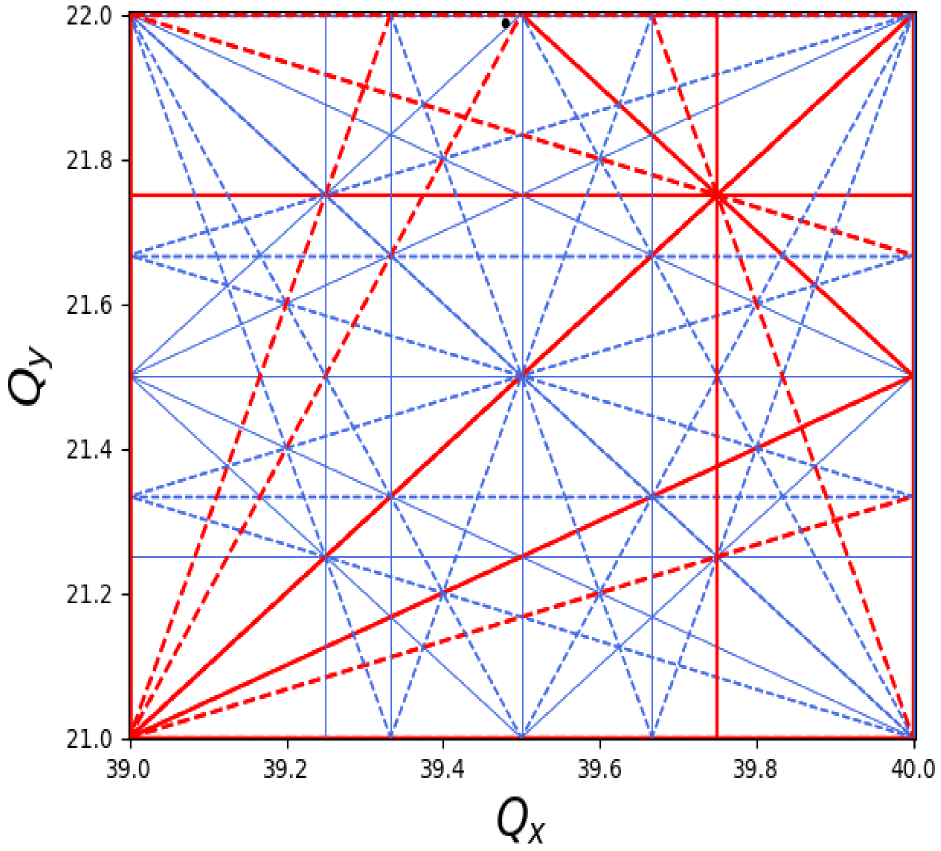
τ_x = 13.5 ms
τ_z = 6.7 ms

Synchrotron integrals:
I_1 = 0.3069323495
I_2 = 0.6063789197
I_3 = 0.0541043725
I_4 = -7.663727305e-05
I_5 = 9.17944843e-05



B_{wgl} = 1.7 T

Working point



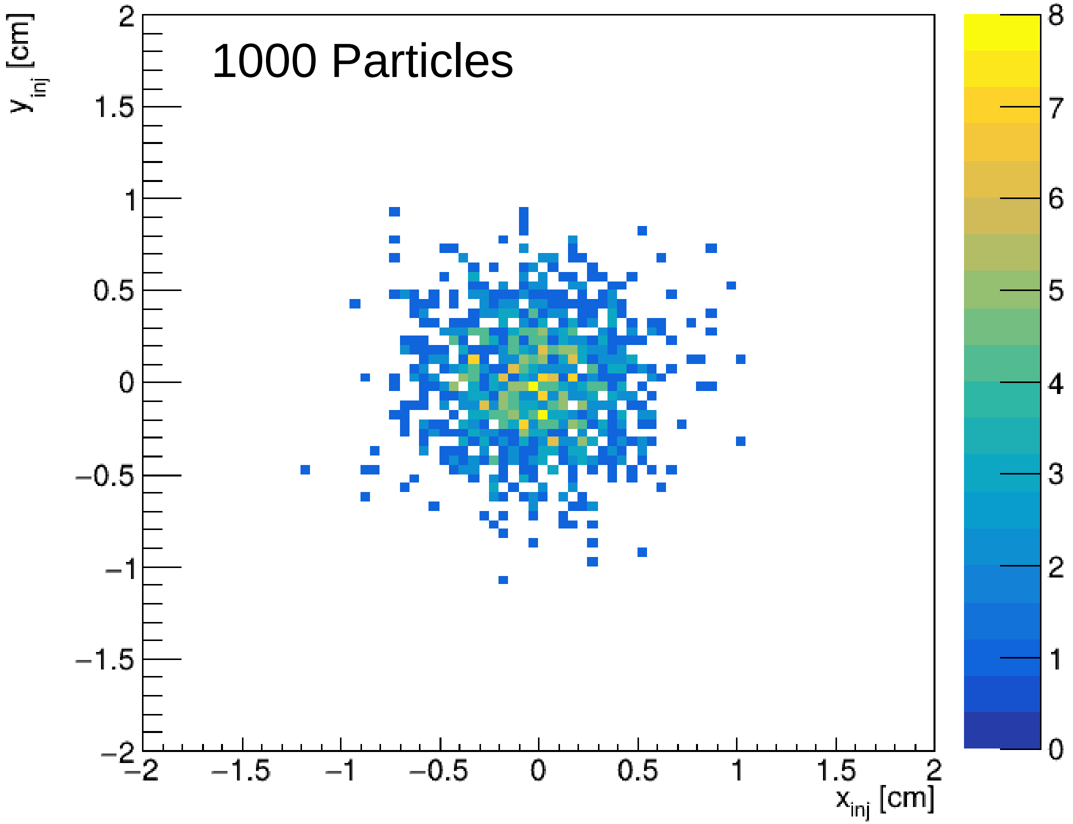
Resonance Diagram:

Solid lines are normal and dashed lines are skew resonance

Red and Blue are systematic and non-systematic resonances, respectively.
Superperiodicity of three (3) has been considered:
SS+Arc+SS_WGL+Arc

Working point have to be revised.
Too close to systematic resonances

Tracking results



Only Transverse motion (4D)

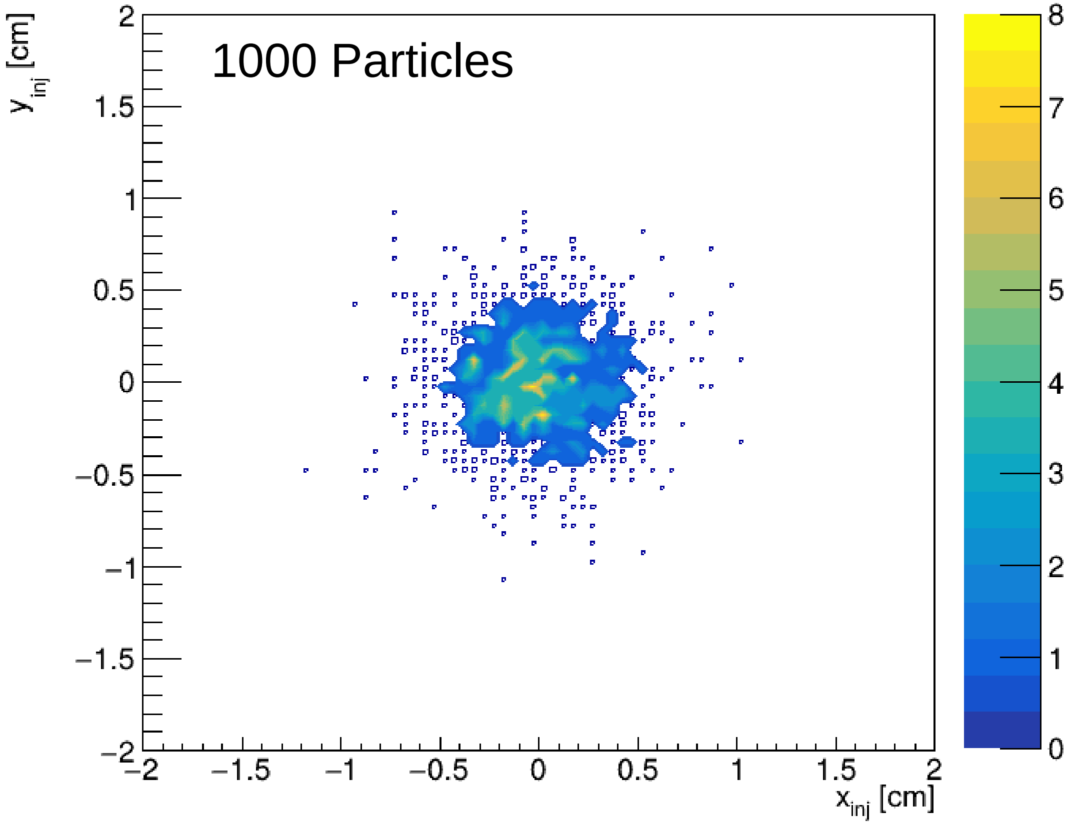
SXP ON

Beam injected in SS section with expected emittance (2.38 mm mrad) in both planes

Tracked for 1000 Turns

Beam Pipe physical apertures:
Horizontal: ± 3.0 cm
Vertical: ± 1.5 cm

Tracking results



Only Transverse motion (4D)

SXP ON

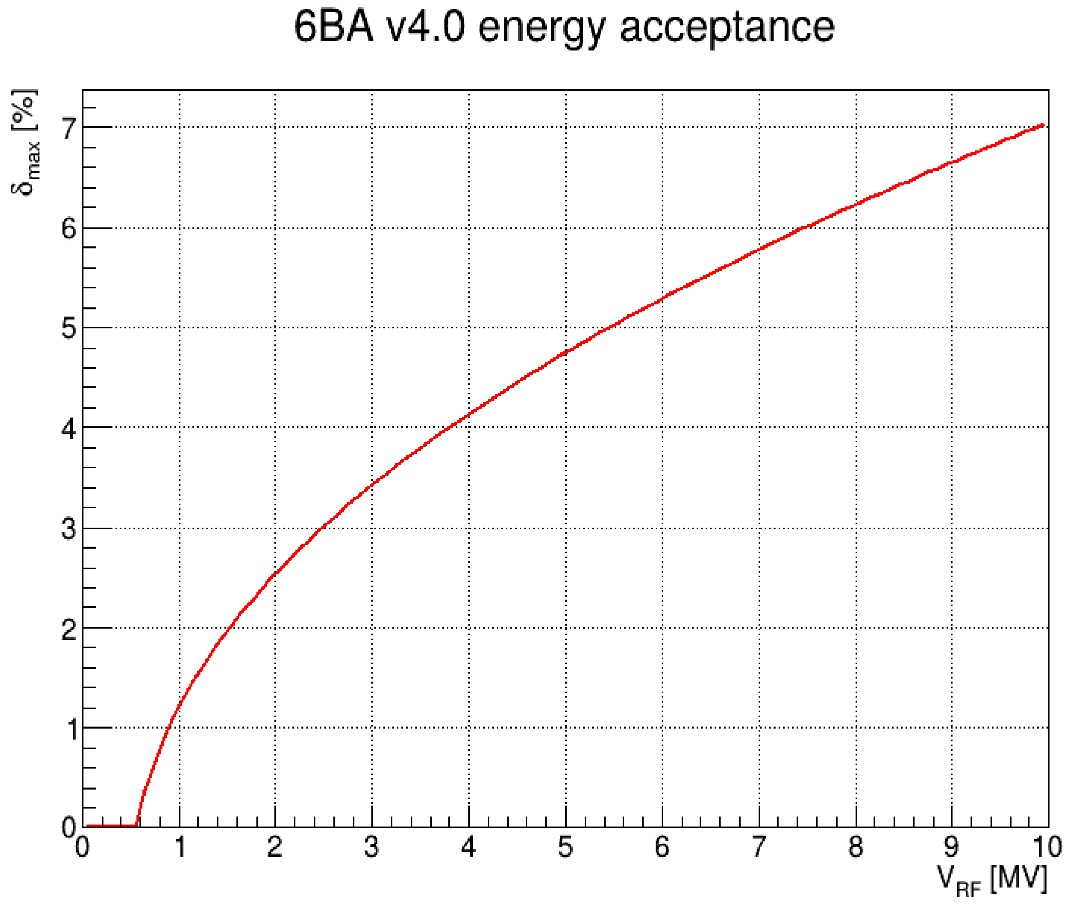
Beam injected in SS section with expected emittance (2.38 mm mrad) in both planes.

Tracked for 1000 Turns

Beam Pipe physical apertures:
Horizontal: ± 3.0 cm
Vertical: ± 1.5 cm

$$\varepsilon_{acc} = \frac{432}{1000} = 43\%$$

Energy acceptance



α_p = 0.000761
h = 537
E_{beam} = 2.86 GeV

Sync. phase

$$\phi_s = \pi - \sin^{-1}\left(\frac{U_0}{eV_{RF}}\right)$$

Sync. tune

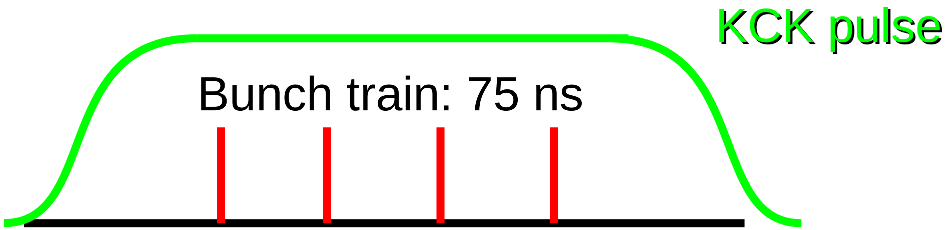
$$\nu_s = \sqrt{-\frac{eV_{RF}}{E_0}\frac{h\alpha_p}{2\pi}\cos\phi_s}.$$

RF Acceptance

$$|\delta|_{\mathrm{max,RF}} = \frac{2\nu_s}{h\alpha_p}\sqrt{1-\left(\frac{\pi}{2}-\phi_s\right)\tan\phi_s},$$

Timing considerations

Minimal damping time



$$n(train) = \frac{T_{per}}{\Delta t + t_K} \simeq 10$$

$$\epsilon(t) = \epsilon_{inj} e^{-\frac{2t}{\tau}}$$

$$T_{store} = -\frac{\tau}{2} \ln \frac{\epsilon_{ext}}{\epsilon_0} \simeq 5\tau$$

$$\tau \leq \frac{n(train) T_{pulse}}{5(\Delta t + t_K)} \simeq 20 \text{ ms}$$