Исследование динамической апертуры

Структура 28_20

Changes

- From version 10
  - decreased crossing angle from 30 mrad to 20 mrad
  - increased byip from 2 mm to 3 mm
  - increased coupling from 0.005 to 0.016875=0.005*(3/2)^3
  - as a result K2_crab=unchanged, xi_y=unchanged, T_toushek expect to increase (3/2)^3=3 times
- From version 11
  - increased number of cells from 12 to 18
  - decreased cell phase advance from 1/4 to 1/6
- From version 12
  - increased crossing angle from 0.02 to l1_cross = 0.03;
  - increased energy to 2 GeV
- From version 17
  - trying to reduce fringes detuning
  - increased length of QO, Q1 from 0.3 to 0.37,
  - increased dl1 from 0.13 to 0.185
  - matched phase in IR arc matching section
- From version 18
  - Increase number of cells from 18 to 24
- From version 19
  - Decreased number of cells from 24 to 18
  - Full IR with CCYS, CCXS, CRAB, ARC
- From version 20
  - Increased number of cells from 18 to 24
  - Full IR with CCYS, CCXS, CRAB, ARC
- From version 21
  - Number of cells is 24
  - Full IR with CCYS, CCXS, CRAB, ARC
  - Decreases alfa_yx_q in IR
- From version 22
  - Decreased crossing angle to 25e-3
  - Increased bxip, emit_x by Dx in WIGGLER
  - bxip = 0.15; byip = 0.003; l1_cross = 0.025; r1_cross = -0.025;
  - cell: qx=qy=1/6, 24 cells
  - Save-5 from Save-1 introduced 4 dipoles around wiggler
  - Adjusted phase in IR MS, chosen 27_5
- From version 27
  - Decreased crossing angle to 25e-3
  - Increased bxip, emit_x by Dx in WIGGLER
  - bxip = 0.15; byip = 0.003; l1_cross = 0.025; r1_cross = -0.025;
  - **cell: qx=qy=1/8, Ncells=24**
  - Chosen 28_20

The reasoning (FODO)

$$\varepsilon_x \approx C_\mathrm{q}\gamma^2\varphi^3\frac{8}{\mu^3} = C_\mathrm{q}\gamma^2\frac{1}{\nu^3}\left(\frac{L_{cell}}{\Pi}\right)^3 = C_\mathrm{q}\gamma^2\frac{1}{(\nu\, N_{cell})^3}$$

$$\mathcal{H} \approx L\,\varphi^2\frac{8}{\mu^3} = \frac{1}{\pi\nu^3}\frac{L_{cell}}{N_{cell}^2}$$

$$(K_1L)_{1,2} \approx \pm\frac{\mu}{L} = \pm\left(\frac{C_q\gamma^2}{\varepsilon_x}\right)^{\frac{1}{3}}\frac{4\pi}{\Pi}$$

$$\nu = \frac{\mu}{2\pi}$$
$$L_{cell} = 2L$$
$$\Pi = N_{cell}L_{cell}$$
$$\varphi_{cell} = 2\varphi = \frac{2\pi}{N_{cell}}$$

$$(K_2L)_{1,2} \approx \pm\frac{1}{L^2\varphi}\frac{\mu^3}{4} = \pm\frac{C_q\gamma^2}{\varepsilon_x}\frac{8\pi^2}{\Pi^2}$$

$$\beta_x \approx L\left(1+\frac{1}{\mu}\right) = \frac{L_{cell}}{2}\left(1+\frac{1}{\pi\nu}\right)$$

To increase N_{cell} but keep $\varepsilon_x = const$
decrease ν keeping $\nu \times N_{cell} = const$
than $R_{da} \propto \varepsilon_x N_{cell}^2 L_{cell}$ will increase

$$R_{da} \propto \frac{1}{K_2L\,\beta_x} \propto \frac{\varepsilon_x}{4\pi^2C_q\gamma^2}\frac{\Pi^2}{L_{cell}} = \frac{\varepsilon_x}{4\pi^2C_q\gamma^2}N_{cell}^2L_{cell}$$

$$\frac{R_{da}}{\sqrt{\varepsilon_x\beta_x}} \propto \frac{\sqrt{\varepsilon_x}}{C_q\gamma^2}N_{cell}^2\sqrt{L_{cell}} \propto \sqrt{N_{cell}L_{cell}}$$

The reasoning (beam-beam, luminosity)

$$\mathcal{L} = \frac{\gamma}{2er_e} J \frac{\xi_y}{\beta_y^*} \qquad L_{int} = \sqrt{\frac{\pi}{2}} \frac{\sigma_x}{\tan\theta}$$

$$\frac{1}{T_{Touschek}} \propto \xi_y \frac{\tan\theta}{\varepsilon_x \sqrt{\varepsilon_y \beta_y^*}}$$

$$K_2 L = \frac{1}{2\theta} \sqrt{\frac{\beta_x^*}{\beta_x}} \frac{1}{\beta_y^* \beta_y}$$

$$\mu_x = \pi m, \mu_y = \frac{\pi}{2}(2n+1)$$

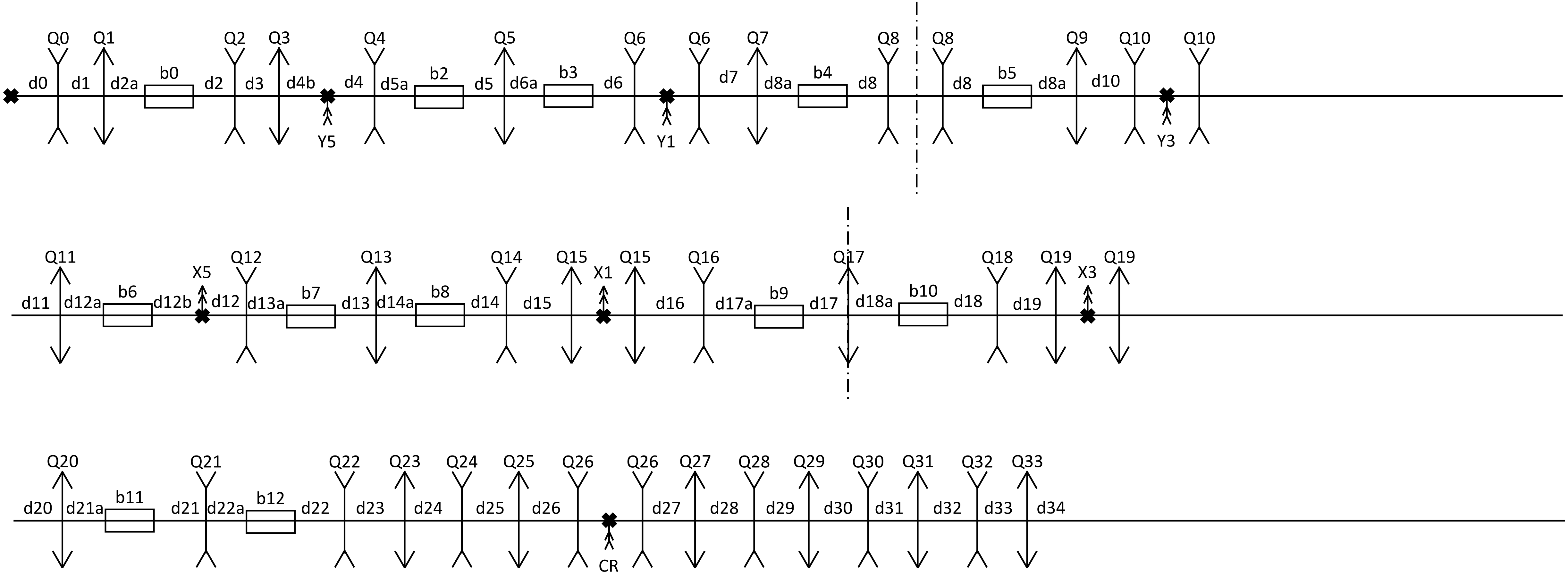
$$\xi_y = \frac{N_p r_e}{2\pi\gamma} \sqrt{\frac{\beta_y^*}{\varepsilon_y}} \frac{1}{\sigma_z \tan\theta}$$

$$\xi_x = \frac{N_p r_e}{2\pi\gamma} \frac{\beta_x^*}{(\sigma_z \tan\theta)^2}$$

With respect to 22_11

1. Decrease $\theta \to \times \frac{5}{6}$, increase $\beta_x^* \to \times \frac{3}{2}$, increase $\varepsilon_x \to \times 3$ leads to $L_{int} \to \times 2.5 = 2.6mm \approx \beta_y^* = 3mm$. Good!
2. $\sigma_z = const$
3. Increase $\varepsilon_x \to \times 3$. Good for $T_{Touschek}$!
4. Decrease of coupling $\varepsilon_y = \kappa\varepsilon_x \to \times \frac{0.006}{0.02} \times 3 \approx const$. Acceptable.
5. Increase $\xi_y \to \times 2$ by increasing $N_p \to \times 2$
6. Resulting in $\mathcal{L} \to \times 2$. Good!
7. Resulting in $\frac{1}{T_{Touschek}} \propto \times 2 \times \frac{5}{6} \times \frac{1}{3} \approx \frac{1}{2}$. Good!
8. Resulting in $\xi_x \to \times 2 \times \frac{3}{2} \times \left(\frac{6}{5}\right)^2 \approx 4.3$. Acceptable.

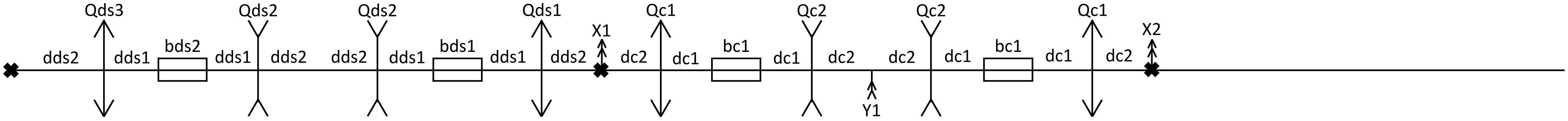
Optics: IR

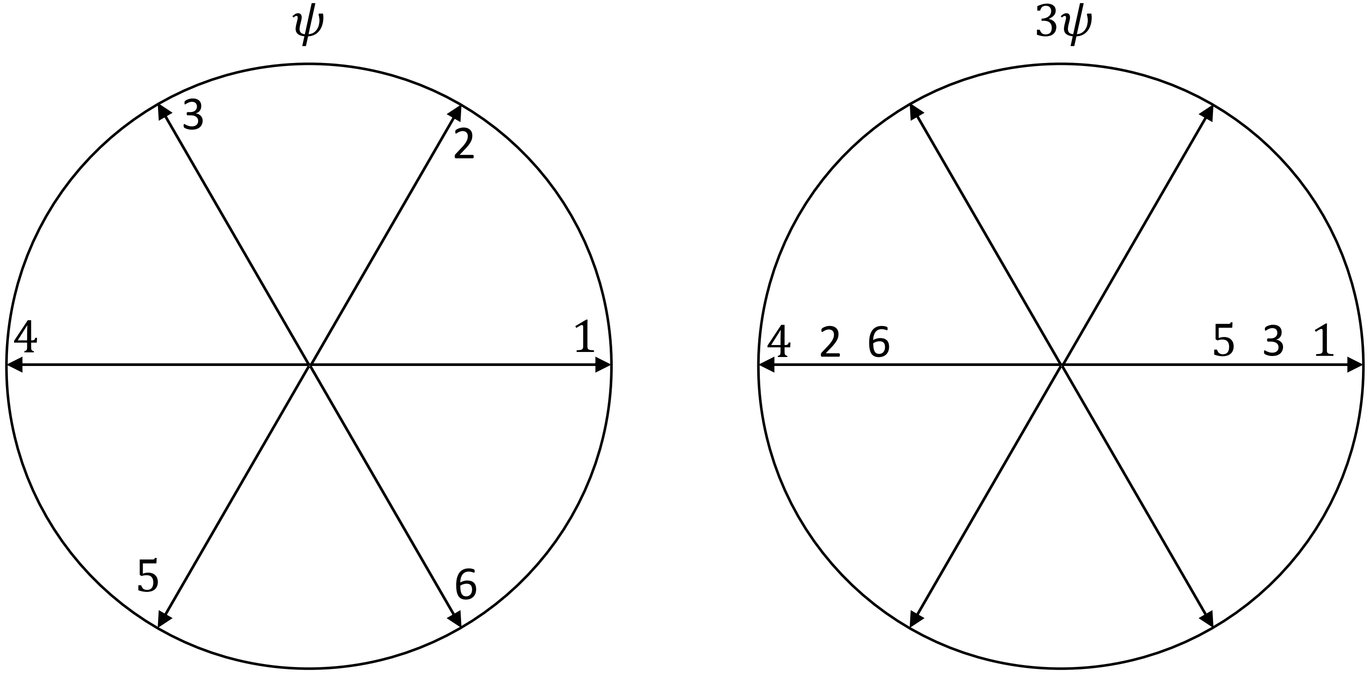


$$K_2L = \frac{1}{2\theta}\sqrt{\frac{\beta_{0x}}{\beta_x}}\frac{\cos\mu_x}{\cos 2\mu_y}\frac{1}{\beta_{0y}\beta_y}\ \text{incoming}$$

$$K_2L = -\frac{1}{2\theta}\sqrt{\frac{\beta_{0x}}{\beta_x}}\frac{\cos\mu_x}{\cos 2\mu_y}\frac{1}{\beta_{0y}\beta_y}\ \text{outgoing}$$

Optics: cell





2^{nd} order achromat

24 cells with $\mu_{x,y} = \frac{\pi}{3}$

Not large chromaticity.

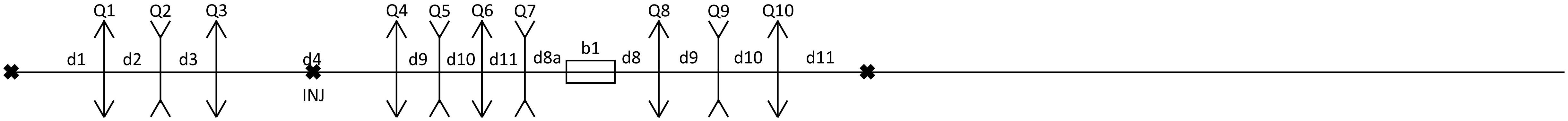
Expected large DA.

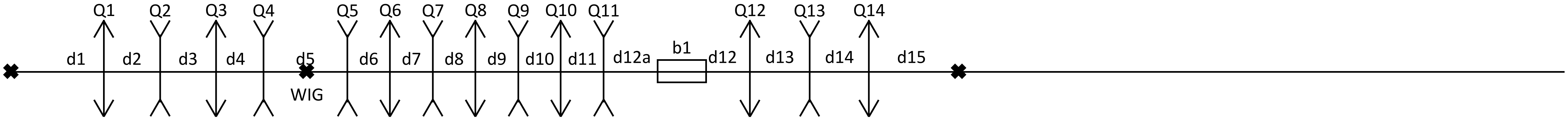
Possible 24 cells with μ

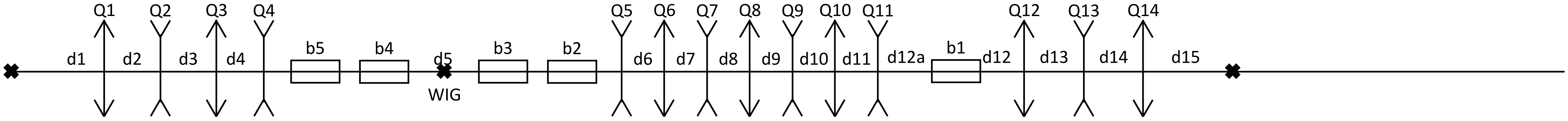
$\mu = \frac{\pi}{3}$: $24\frac{4\pi}{12} = 8\pi$

$\mu = \frac{\pi}{2}$: $24\frac{6\pi}{12} = 12\pi$

Optics tech


Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
Q9
Q10
d1
d2
d3
d4
INJ
d9
d10
d11
d8a
b1
d8
d9
d10
d11


Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
Q9
Q10
Q11
Q12
Q13
Q14
d1
d2
d3
d4
d5
WIG
d6
d7
d8
d9
d10
d11
d12a
b1
d12
d13
d14
d15


Q1
Q2
Q3
Q4
b5
b4
b3
b2
Q5
Q6
Q7
Q8
Q9
Q10
Q11
Q12
Q13
Q14
d1
d2
d3
d4
d5
WIG
d6
d7
d8
d9
d10
d11
d12a
b1
d12
d13
d14
d15

Design parameters ultimate

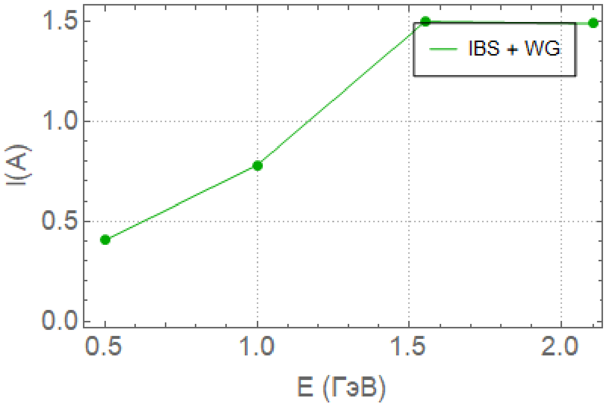
E(MeV)	**500**	**1000**	**1550**	**2100**
Π(m)	388.742337640177			
F_{RF}(MHz)	350.118202616599			
2θ(mrad)	50			
β_x^*/β_y^* (mm)	150/3			
I(A)	0.4	0.78	1.5	1.5
$N_{e/bunch} \times 10^{-10}$	0.8	1.55	5.7	9
N_b / q	408/454	408/454	213/454	134/454
U_0(keV) / V_{RF}(kV)	1.57/590	24.8/1160	137/1800	401/2650
ν_s	0.0226	0.00225	0.0225	0.0234
δ_{RF}(%)	1.6	1.6	1.54	1.5
$\sigma_e \times 10^3$ (SR/IBS+WG)	0.1/0.8	0.3/0.6	0.5/0.8	0.7/0.9
σ_s(mm) (SR/IBS+WG)	2.7/13	5/9.8	8.4/13	13/15
ε_x(nm) (SR/IBS+WG)	2/66	8/34	19/31	35/31
$\varepsilon_y/\varepsilon_x$	0.006	0.006	0.006	0.006
$L_{HG} \times 10^{-34} (cm^{-2}s^{-1})$	0.03	0.26	1.4	2
ξ_x/ξ_y	0.005/0.03	0.008/0.05	0.01/0.1	0.01/0.1
$\tau_{Touschek}$ (s)	909	910	1146	2090
$N_{cells}(\mu)$	$24(\pi/4)$			

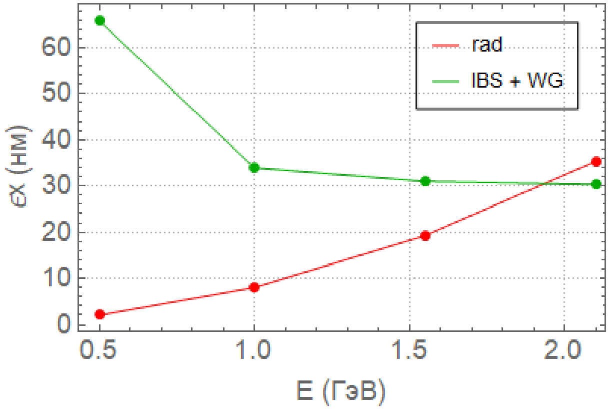
$$\mathcal{L} = \frac{\gamma}{2er_e} J \frac{\xi_y}{\beta_y^*}$$

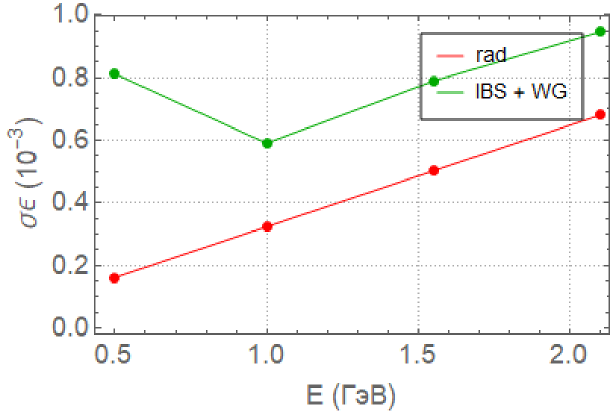
β_y^* wants to decrease to 2.5 mm,
because
$L_{int} = 2.65\ mm$ at 2.1 GeV
$L_{int} = 2.66\ mm$ at 1.55 GeV
$L_{int} = 2.71\ mm$ at 1.0 GeV
$L_{int} = 2.6\ mm$ at 0.5 GeV

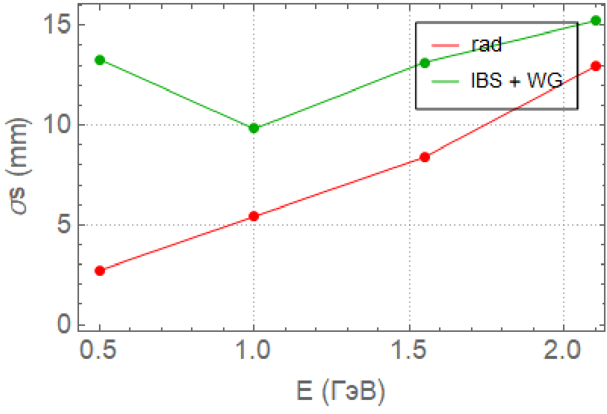
Limitation due to $\varepsilon_x \sim 30nm$

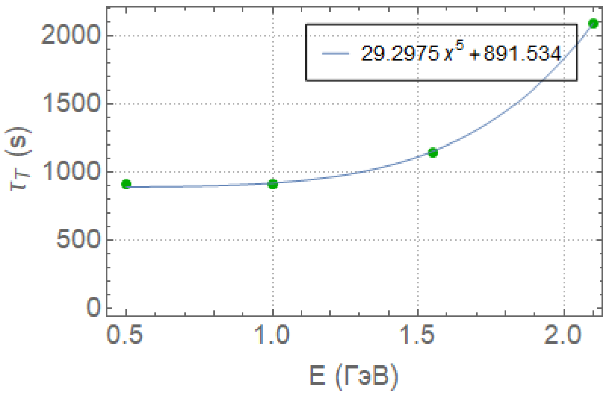
Touschek and total analysis, ultimate

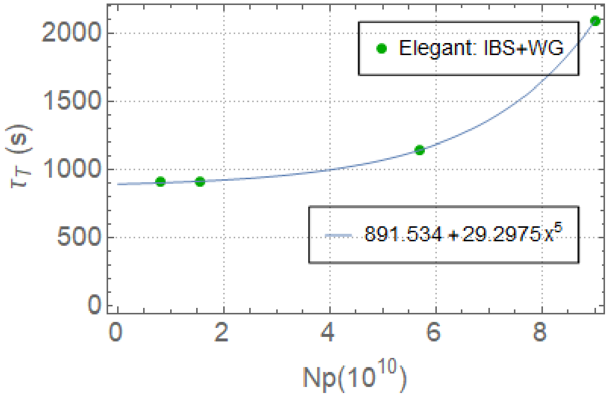


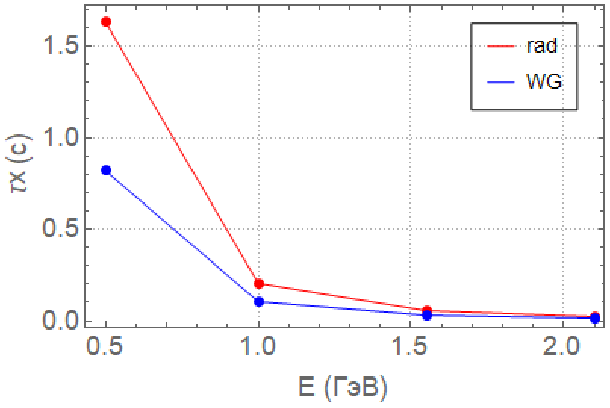


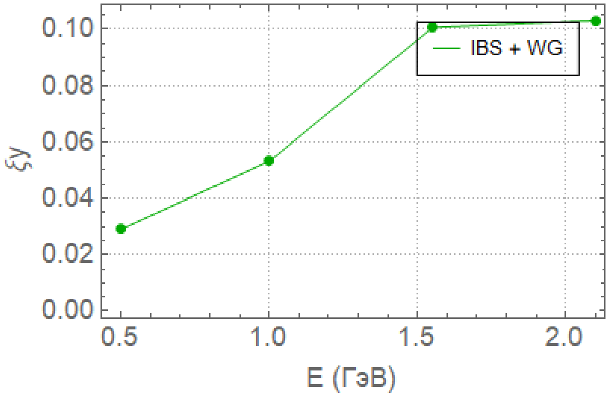












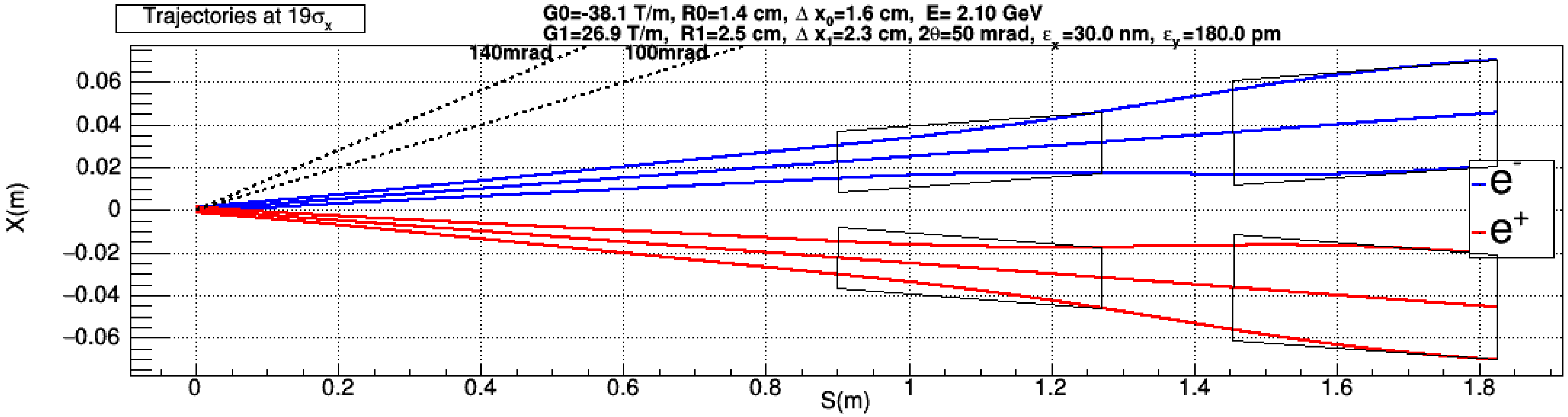
Trajectory at E=2.1 GeV, $\varepsilon_x = 30$ nm

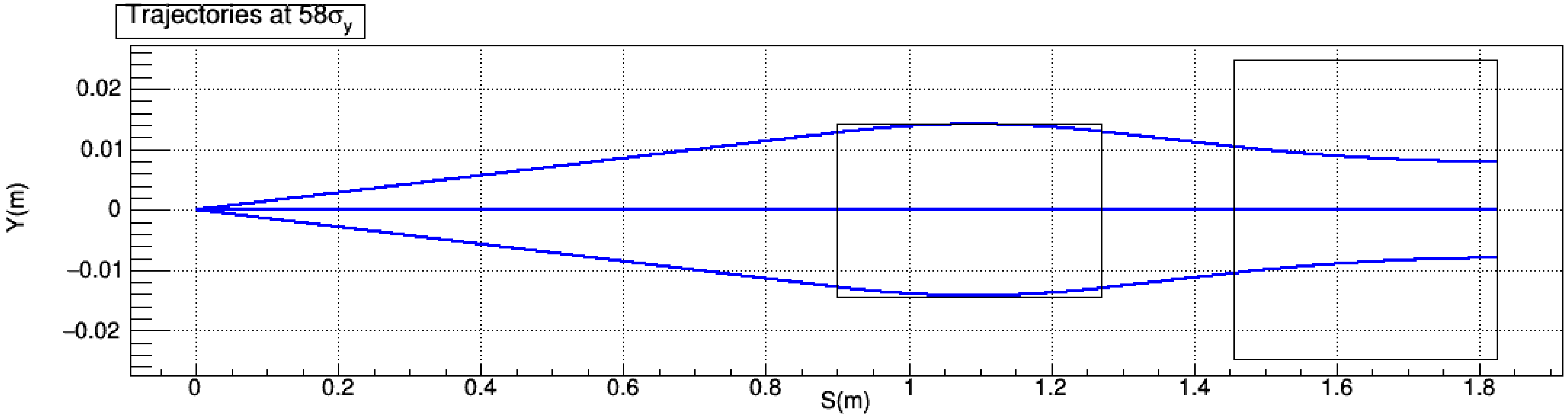
Q0 pole field is -0.545734 T
Aperture Q0 (R): x=0.014333
Aperture Q0 (R): y=0.0141642
Length Q0: L=0.37 m

Q1 pole field is 0.667722 T
Aperture Q1 (R): x=0.0247954
Aperture Q1 (R): y=0.0141642
Length Q1: L=0.37 m

Dx0=0.0163383
Dx1=0.0231671

Sigma_x IP(m)=6.7082e-05
Sigma_y IP(m)=7.34847e-07





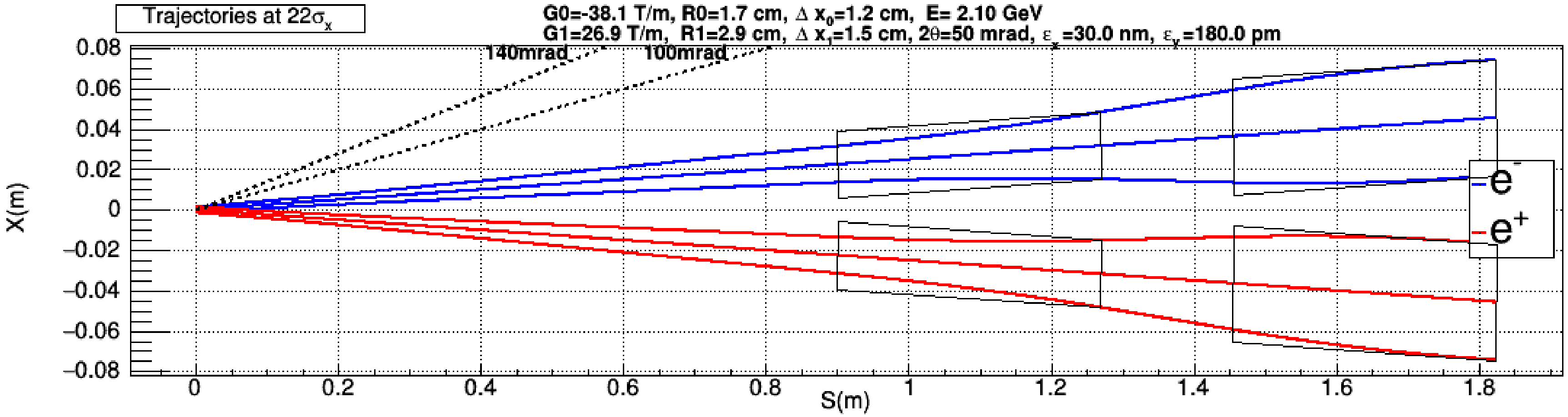
Trajectory at E=2.1 GeV, $\varepsilon_x = 30$ nm

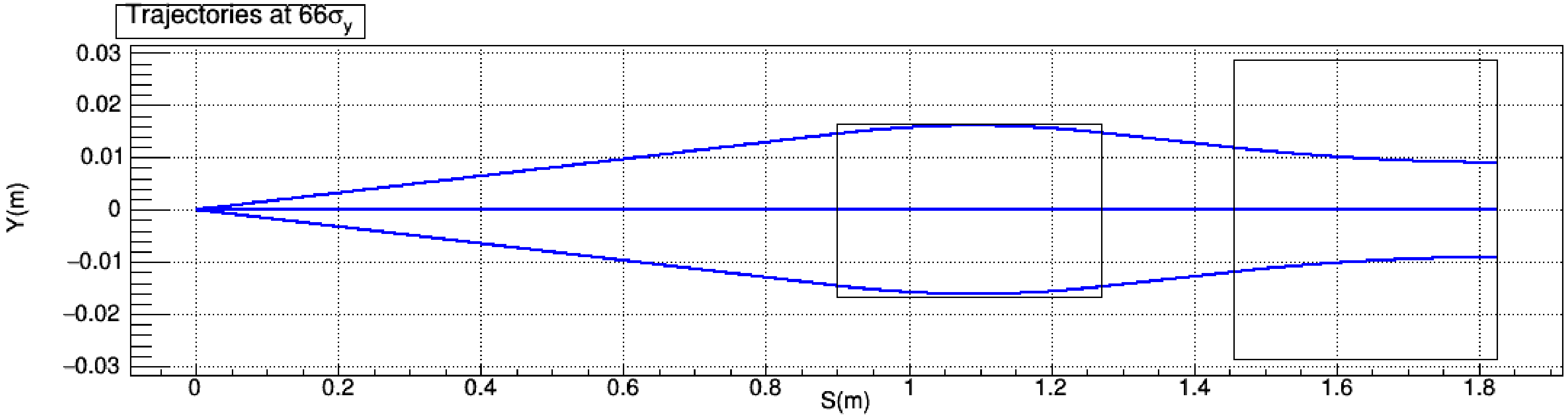
Q0 pole field is -0.631902 T
Aperture Q0 (R): x=0.0165961
Aperture Q0 (R): y=0.0161179
Length Q0: L=0.37 m

Q1 pole field is 0.773151 T
Aperture Q1 (R): x=0.0287105
Aperture Q1 (R): y=0.0161179
Length Q1: L=0.37 m

Dx0=0.0118136
Dx1=0.0153394

Sigma_x IP(m)=6.7082e-05
Sigma_y IP(m)=7.34847e-07





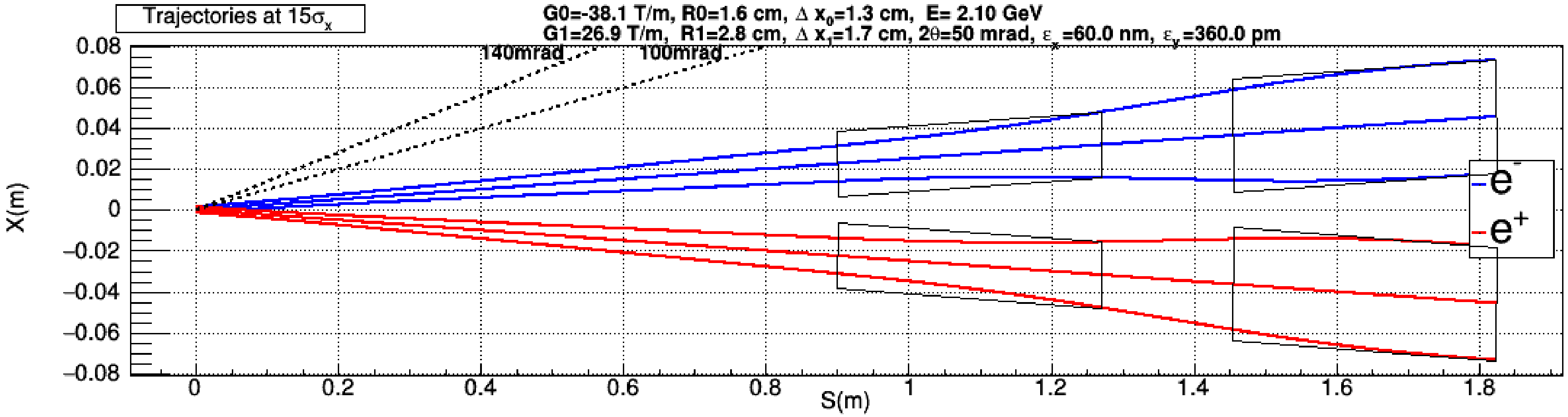
Trajectory at E=2.1 GeV, $\varepsilon_x = 60$ nm

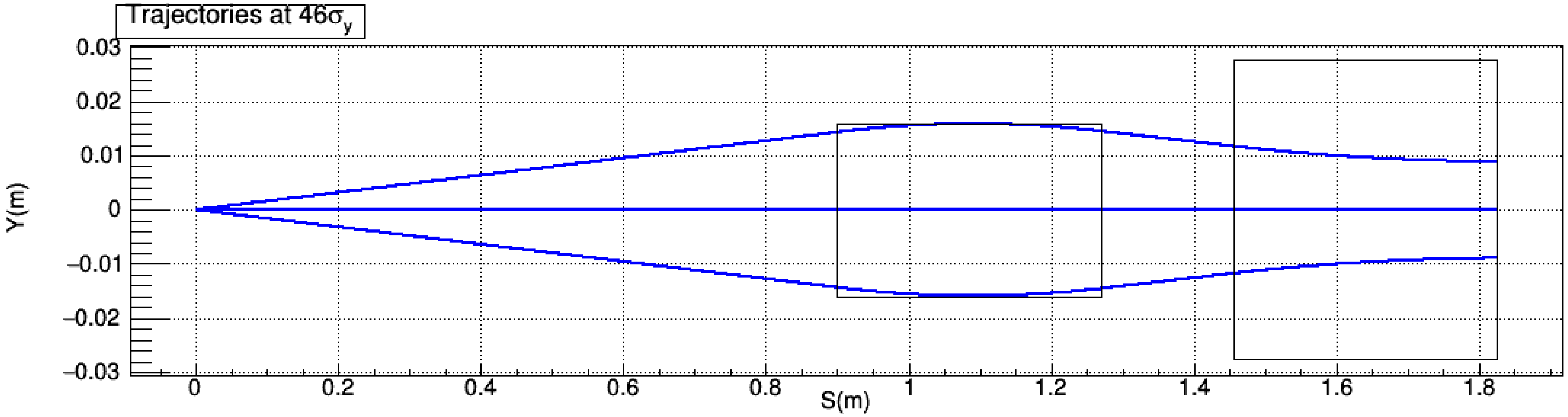
Q0 pole field is -0.609303 T
Aperture Q0 (R): x=0.0160025
Aperture Q0 (R): y=0.0158868
Length Q0: L=0.37 m

Q1 pole field is 0.745501 T
Aperture Q1 (R): x=0.0276837
Aperture Q1 (R): y=0.0158868
Length Q1: L=0.37 m

Dx0=0.0130003
Dx1=0.0173923

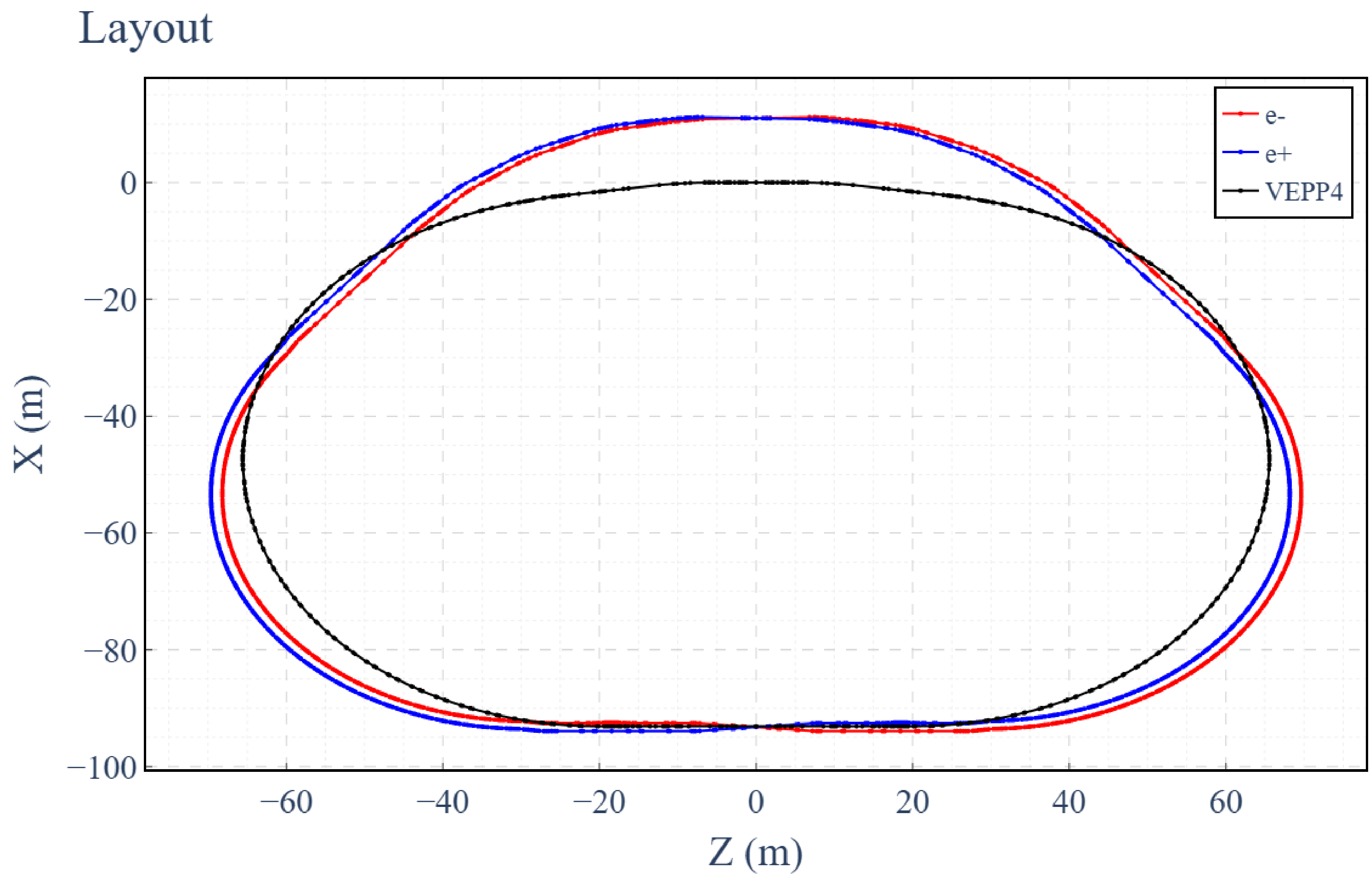
Sigma_x IP(m)=6.7082e-05
Sigma_y IP(m)=7.34847e-07





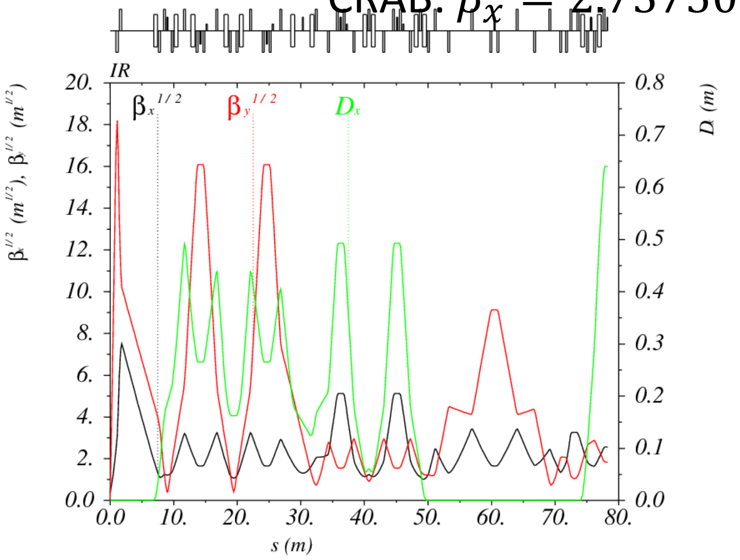
Layout

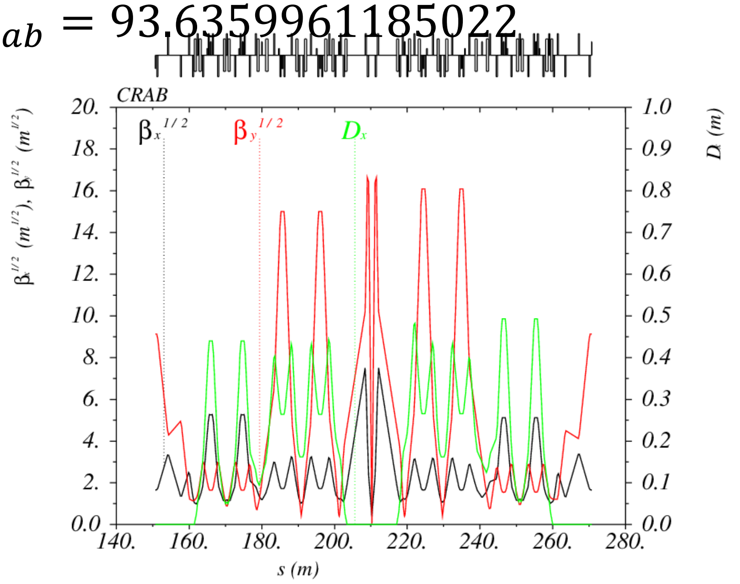
Distance between the beam lines $\Delta R = 1.364$ m

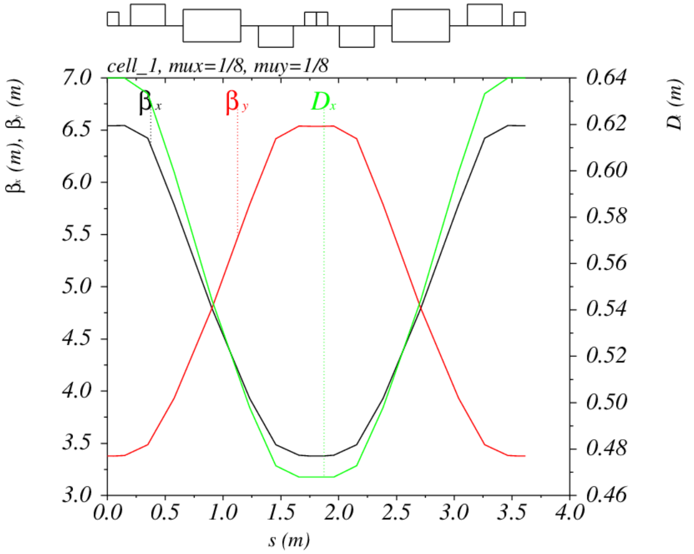


IR, CRAB, cell

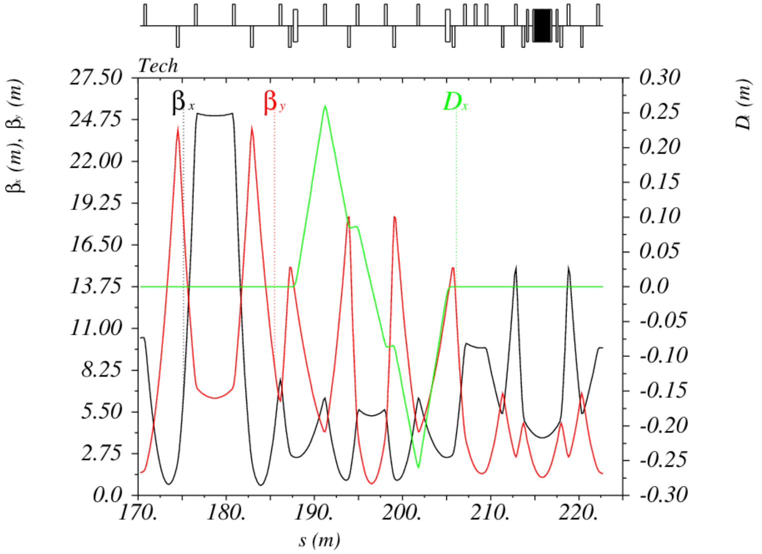
CRAB: $\beta_x = 2.73750890915102$, $\beta_y = 83.3304580816544$, $K2_{crab} = 93.6359961185022$



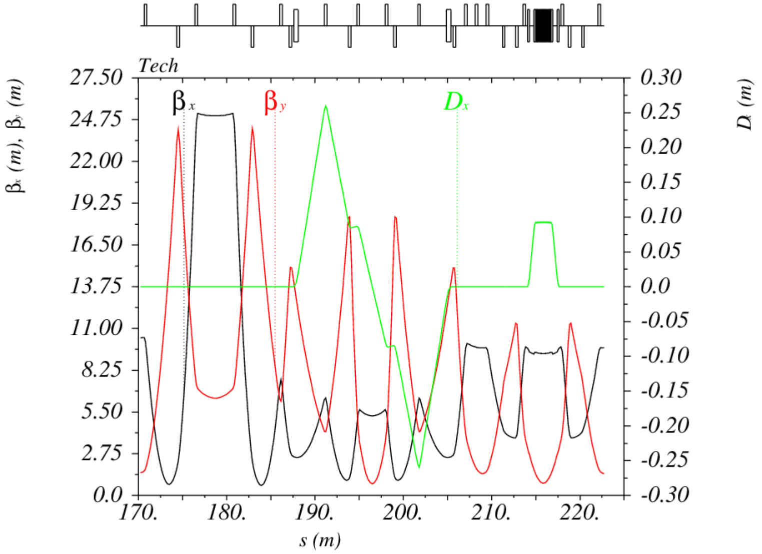




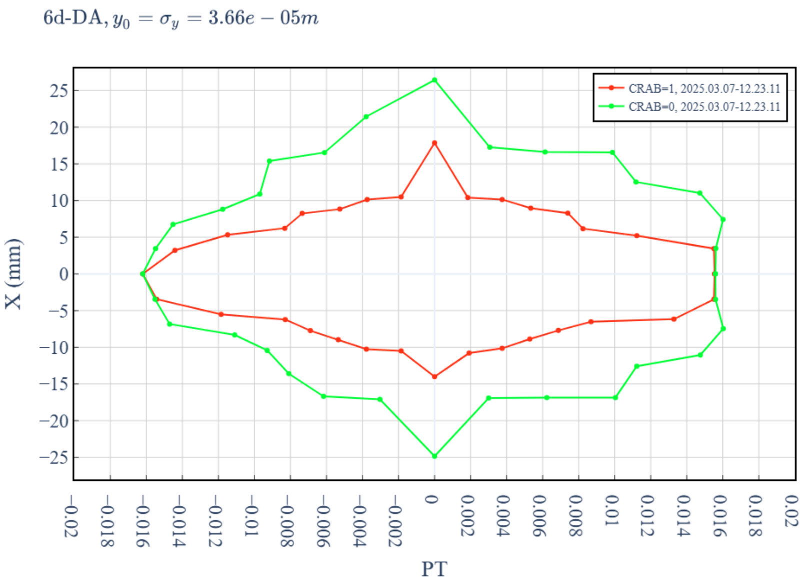
Wiggler is OFF

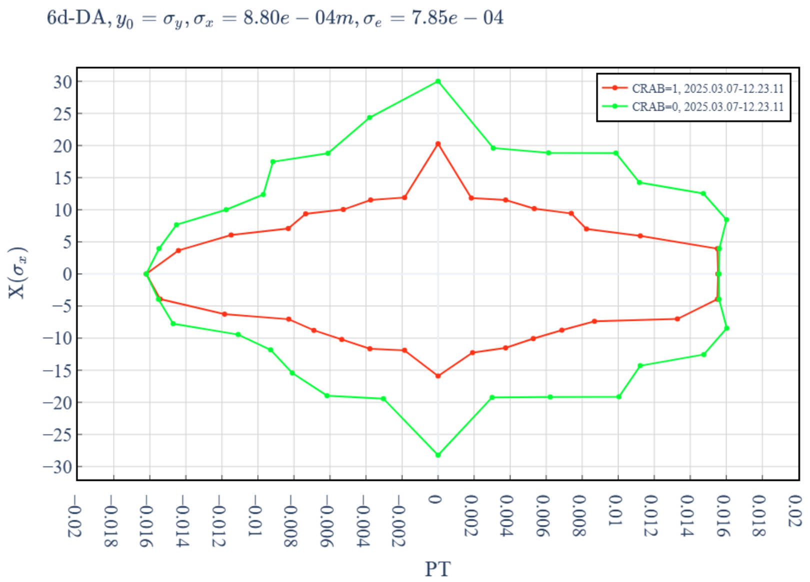


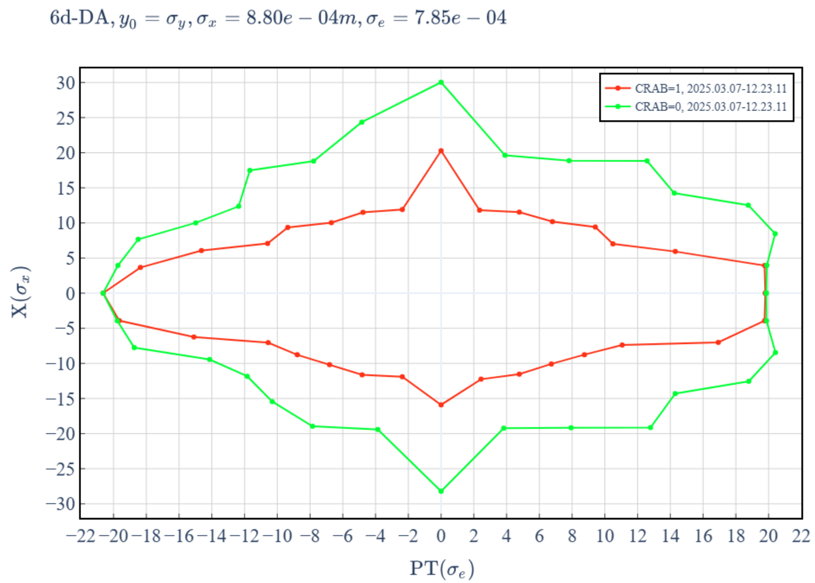
Wiggler is ON



6d dynamic aperture

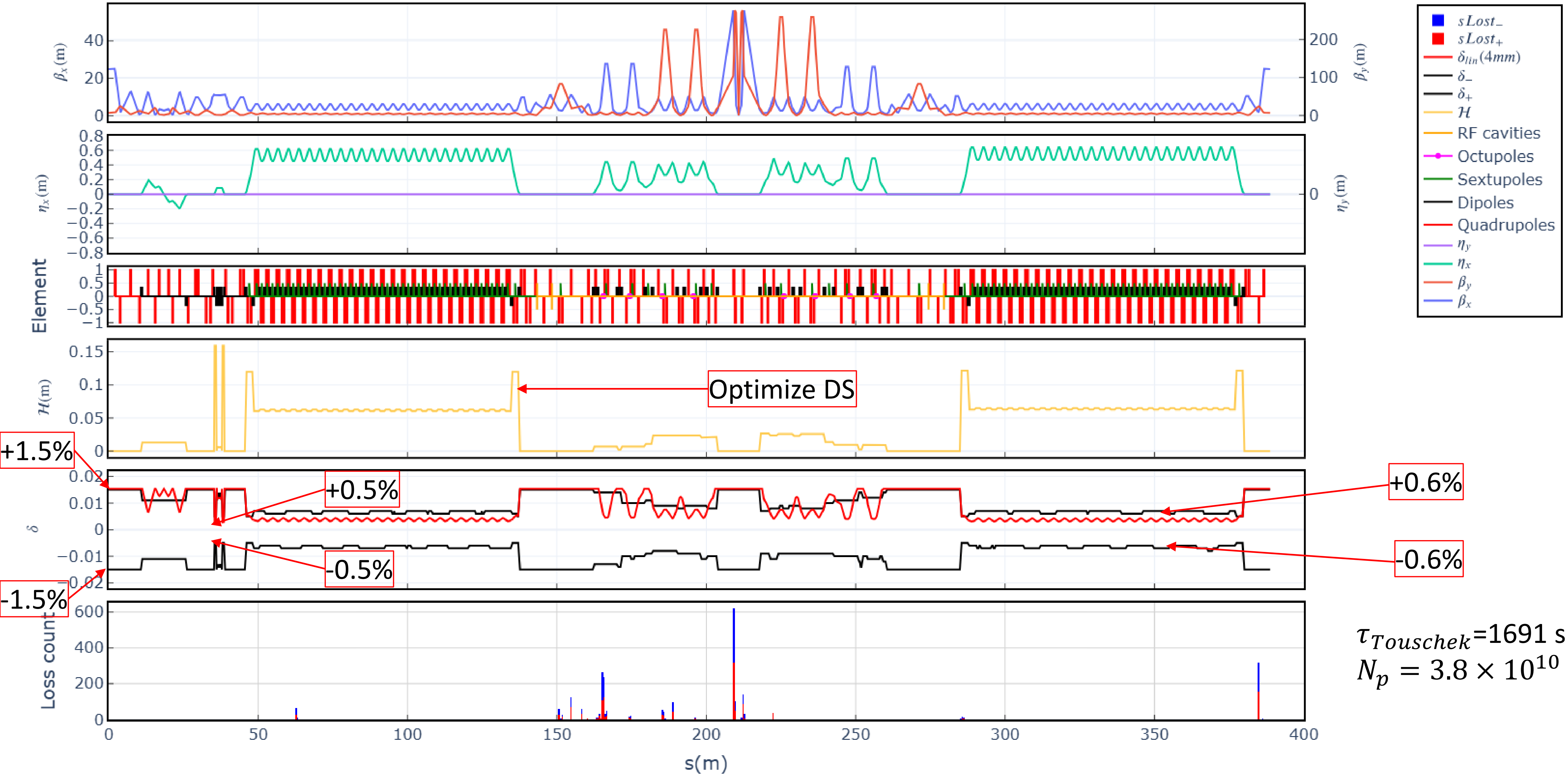

6d-DA, $y_0 = \sigma_y = 3.66e-05m$


6d-DA, $y_0 = \sigma_y, \sigma_x = 8.80e-04m, \sigma_e = 7.85e-04$


6d-DA, $y_0 = \sigma_y, \sigma_x = 8.80e-04m, \sigma_e = 7.85e-04$

	CRAB	$\tau_{Touschek}$	N_p
2025.03.07-12.23.11	1	2281	2.8×10^{10}
2025.03.07-12.23.11	0		2.8×10^{10}
2025.03.07-12.23.11	1	1691	3.8×10^{10}
2025.03.07-12.23.11	0		4.1×10^{10}

LMA (ring-2025.03.07-12.23.11_1.0crab_sextupole-1.55GeV-4cav.lte) CRAB=1



Optimize DS

+1.5%

-1.5%

+0.5%

-0.5%

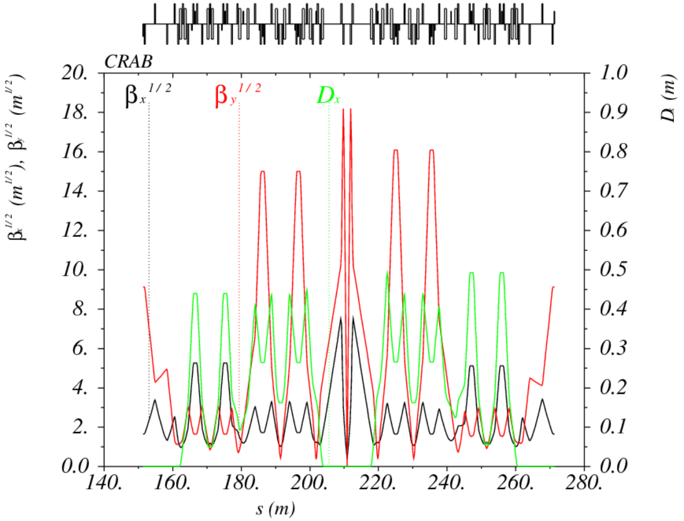
+0.6%

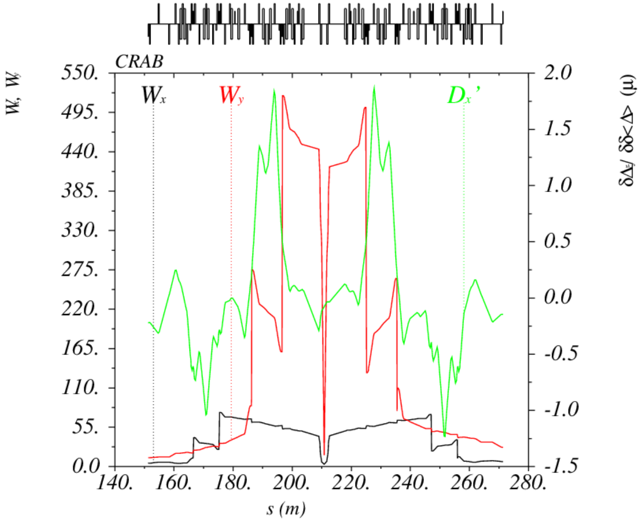
-0.6%

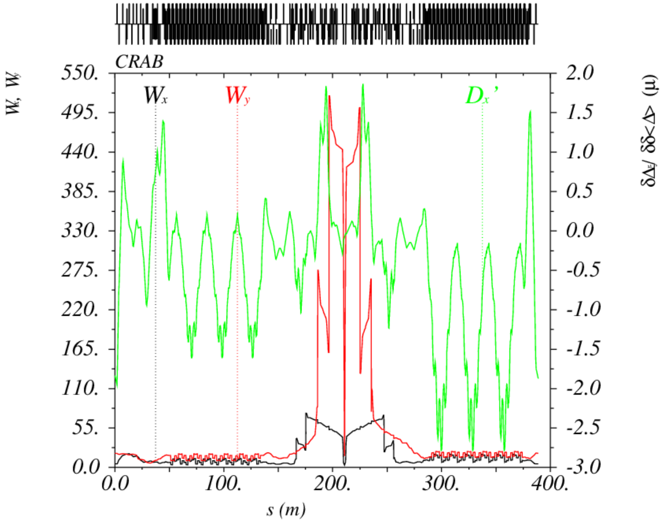
$\tau_{Touschek}$=1691 s

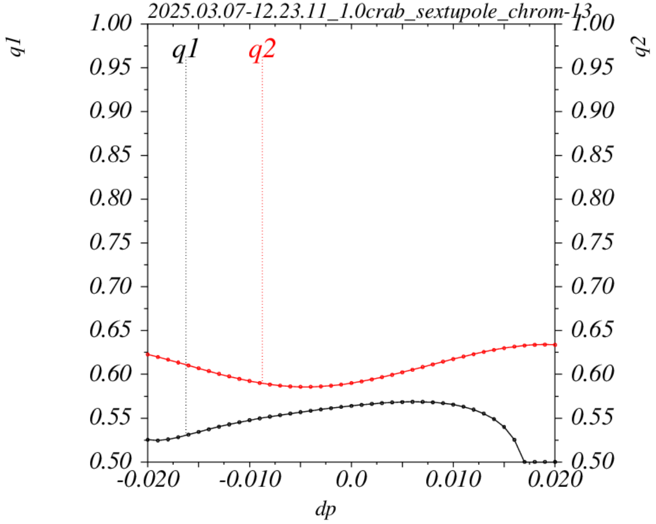
$N_p = 3.8 \times 10^{10}$

Left to Right CRAB (2025.03.07-12.23.11_1.0crab_sextupole_chrom-13.str)









Секступоли и октуполи промежутка встречи

Схема названий:

- “.” – разделитель
- L1 или R1 – левая или правая часть IR
- M – магнит
- S или O – секступоль или октуполь
- X или Y – направление
- Номер
- _1 или _2 – первая или вторая половина

L1.MSY5_1+L1.MSY5_2	
L1.MSY1_1+L1.MSY1_2 = L1.MSY3_1+L1.MSY3_2	CCSY, пара через –I хроматических сеступолей
L1.MOY1 = L1.MOY2	CCSY, пара через –I хроматических октуполей
L1.MSX1_1 + L1.MSX1_1 = L1.MSX3_1+L1.MSX3_2	CCSX, пара через –I хроматических сеступолей
L1.MSX5	
L1.MOX1 = L1.MOX2	CCSX, пара через –I хроматических октуполей
L1.MSCRAB_1 + L1.MSCRAB_2 = -(R1.MSCRAB_1 + R1.MSCRAB_2)	Крабовые секступоли, не крутить

Секступоли и октуполи арок

Схема названий:

- “.” – разделитель
- A1 или A2 – левая или правая арка
- M – магнит
- S или O – секступоль или октуполь
- X или Y – направление
- Номер

A1.MSX1 = A1.MSX4 … A1.MSX19 = A1.MSX22 A1.MSX2 = A1.MSX5 … A1.MSX20 = A1.MSX23 A1.MSX3 = A1.MSX6 … A1.MSX21 = A1.MSX24 A1.MSX25	Секступоли арок, должны быть объедены в –I пары через 4 ячейки
A1.MSY1 = A1.MSY4 … A1.MSY19 = A1.MSY22 A1.MSY2 = A1.MSY5 … A1.MSY20 = A1.MSY23 A1.MSY3 = A1.MSY6 … A1.MSY21 = A1.MSY24	Секступоли арок, объедены в –I пары через три ячейки
A1.MSYDS1, A1.MSYDS2, A2.MSYDS1, A2.MSYDS2	Секступоли в секции подавления дисперсии

Explanation: detuning from quad fringe

$$\Delta\nu_y = \alpha_{yy} j_y + \alpha_{yx} j_x, \qquad \Delta\nu_{yy} = \alpha_{yy} j_y, \qquad \Delta\nu_{yx} = \alpha_{yx} j_x$$

For $\{x = n_x\sigma_x, y = n_y\sigma_y\}$ actions are $\left\{j_x = \frac{n_x^2\varepsilon_x}{2}, j_y = \frac{n_y^2\varepsilon_y}{2}\right\}$

$$\alpha_{yy} = \frac{1}{32\pi}\oint K_1'' \beta_y^2 ds \approx \frac{K_1}{8\pi}\left(\underbrace{\alpha_{1,y}\beta_{1,y}}_{\text{First edge}} - \underbrace{\alpha_{2,y}\beta_{2,y}}_{\text{Second edge}}\right)$$

$$\alpha_{yx} = \frac{1}{8\pi}\oint K_1'\left(\alpha_y\beta_x - \alpha_x\beta_y\right) ds$$

$$\approx \frac{K_1}{8\pi}\left(\underbrace{\alpha_{1,y}\beta_{1,x} - \alpha_{1,x}\beta_{1,y}}_{\text{First edge}} - \left(\underbrace{\alpha_{2,y}\beta_{2,x} - \alpha_{2,x}\beta_{2,y}}_{\text{Second edge}}\right)\right)$$

Explanation: detuning from quad fringe

$$\Delta\nu_y = \alpha_{yy} j_y + \alpha_{yx} j_x, \qquad \Delta\nu_{yy} = \alpha_{yy} j_y, \qquad \Delta\nu_{yx} = \alpha_{yx} j_x$$

For $\{x = n_x\sigma_x, y = n_y\sigma_y\}$ actions are $\left\{j_x = \frac{n_x^2\varepsilon_x}{2}, j_y = \frac{n_y^2\varepsilon_y}{2}\right\}$

For first final focus quadrupole

$$\Delta\nu_{yy} = \alpha_{yy} j_y = \frac{1}{\pi} \frac{{L^*}^3}{\beta_{0,y}^2 L_q^2 \left(1 + \frac{2L^*}{L_q}\right)} \times \frac{n_y^2\varepsilon_y}{2}$$

$$\Delta\nu_{yx} = \alpha_{yx} j_x = \frac{1}{\pi} \frac{L^*}{\beta_{0,x}\beta_{0,y}} \left(2 + \frac{L^*}{L_q}\right) \times \frac{n_x^2\varepsilon_x}{2}$$

With L_q increase $\alpha_{yy} \to 0, \alpha_{yx} \to const$

Explanation: detuning from quad fringe

Starting from IP

$$\alpha_{yx}(Q0) \approx \frac{K_1}{8\pi}\left(\alpha_{1,y}\beta_{1,x} - \alpha_{1,x}\beta_{1,y} - \left(\alpha_{2,y}\beta_{2,x} - \alpha_{2,x}\beta_{2,y}\right)\right)$$

$$= 11 - (-9487)$$

$$\alpha_{yx}(Q1) \approx \frac{K_1}{8\pi}\left(\alpha_{1,y}\beta_{1,x} - \alpha_{1,x}\beta_{1,y} - \left(\alpha_{2,y}\beta_{2,x} - \alpha_{2,x}\beta_{2,y}\right)\right)$$

$$= \underbrace{6966}_{\boxed{\text{First edge from IP}}} - \underbrace{(-235)}_{\boxed{\text{Second edge from IP}}}$$

Замечания

- Окунев. И.: можно ли в ячейках заменить магниты на диполи с градиентом, и убрать линзы.
- Богомягков А.: уменьшить $\mathcal{H}$ в секциях подавления дисперсии.