Consideration about new damping ring layout

FCCee Injector Studies Mini-workshop
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Thanks to: P. Craievich, K. Oide, S. Ozdemir, T. Raubenheimer, F. Zimmermann, A. Santis
for their comments during WP4 meetings

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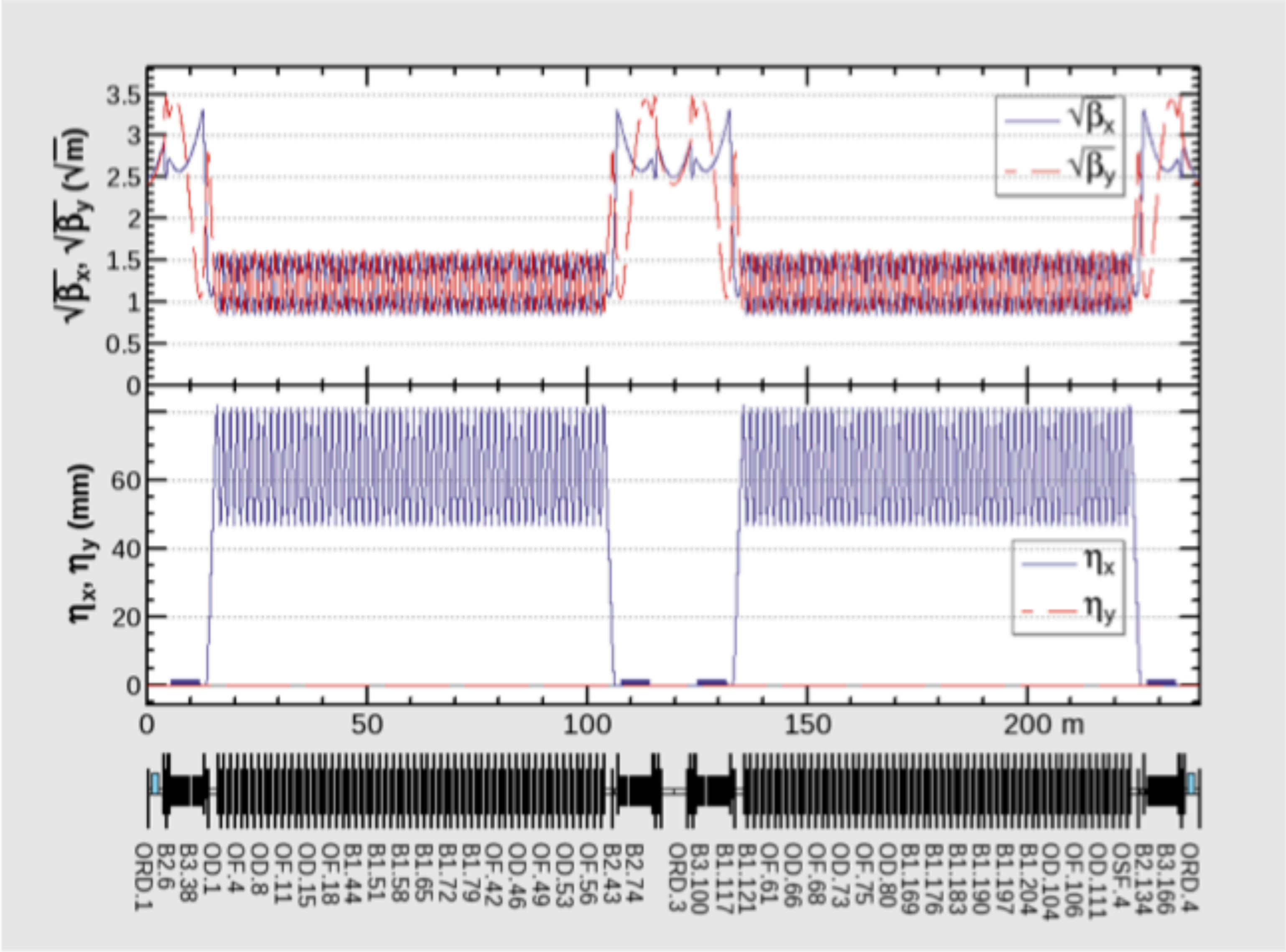
Content

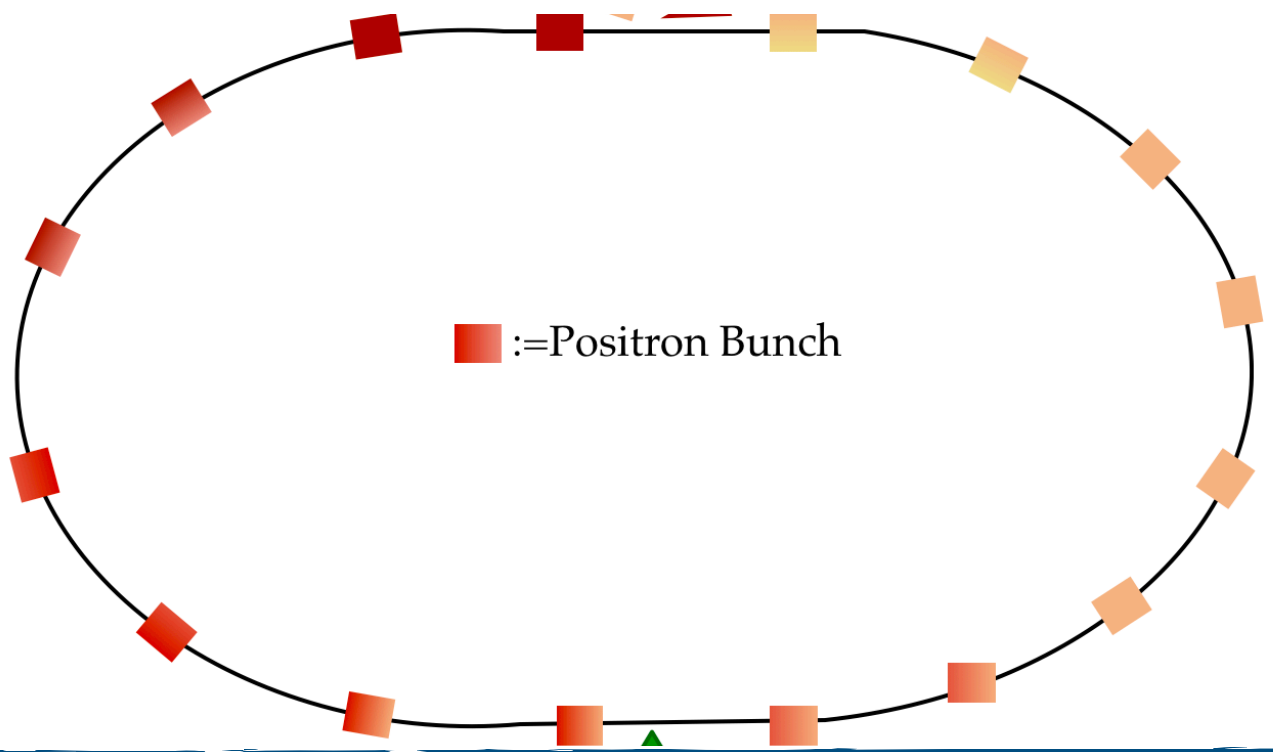
- Review of the "CDR" and "after CDR" version of the DR
- DR design requirements
- Analytical calculations for a possible new design
- MADX results
- Comparison of the new proposal with the "after CDR" version and "CDR" version
- Next steps, questions and discussions

Salim Ogur et. al.



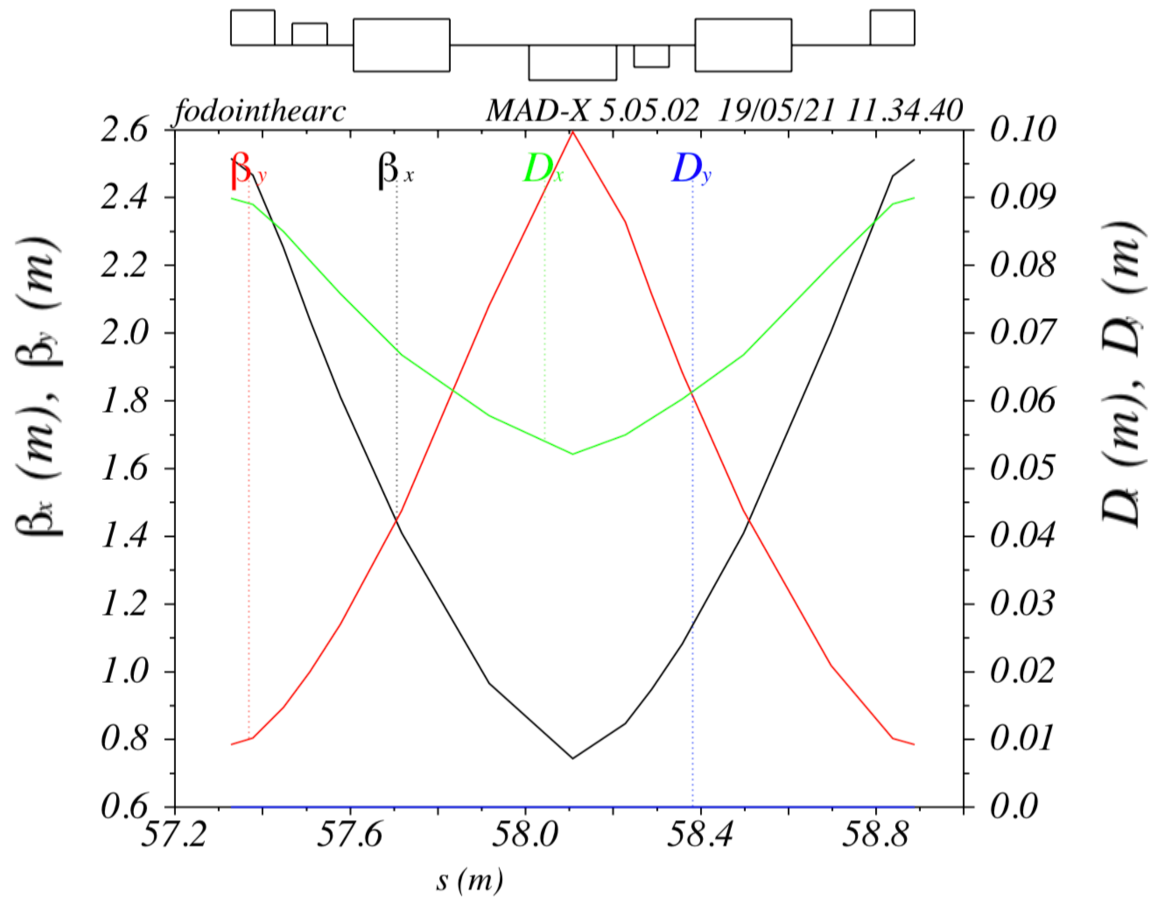
Parameters	Value
Circumference	242 m
Energy	1.54 GeV
Bunch intensity	2.1E10
Number of trains x bunches in a train	8 x 2 bunches
Transverse Damping Time	10.5 ms
Store time for a train	40 ms
Energy loss per turn	0.225 MeV
SR Power loss	15.7 kW

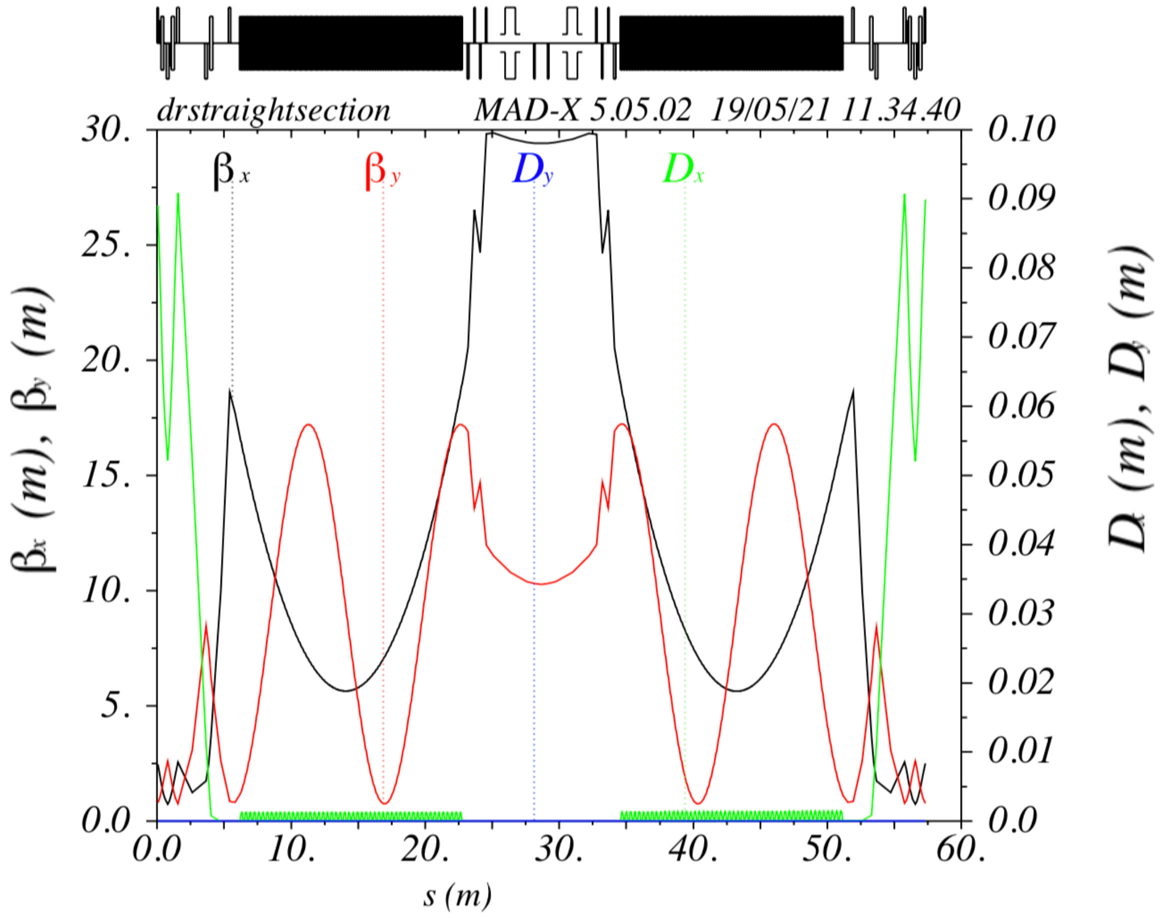
- **8 train** with **50 ns** bunch spacing
- **Emittance**: damping to nm scales from micro-m.
- **FODO** lattice
- Racetrack layout (each arc has 57 units)
- Dipoles: 21cm, 0.66 T, 1.552 degree
- 2+2 wigglers (6.64 m - 1.8T) in straight sections

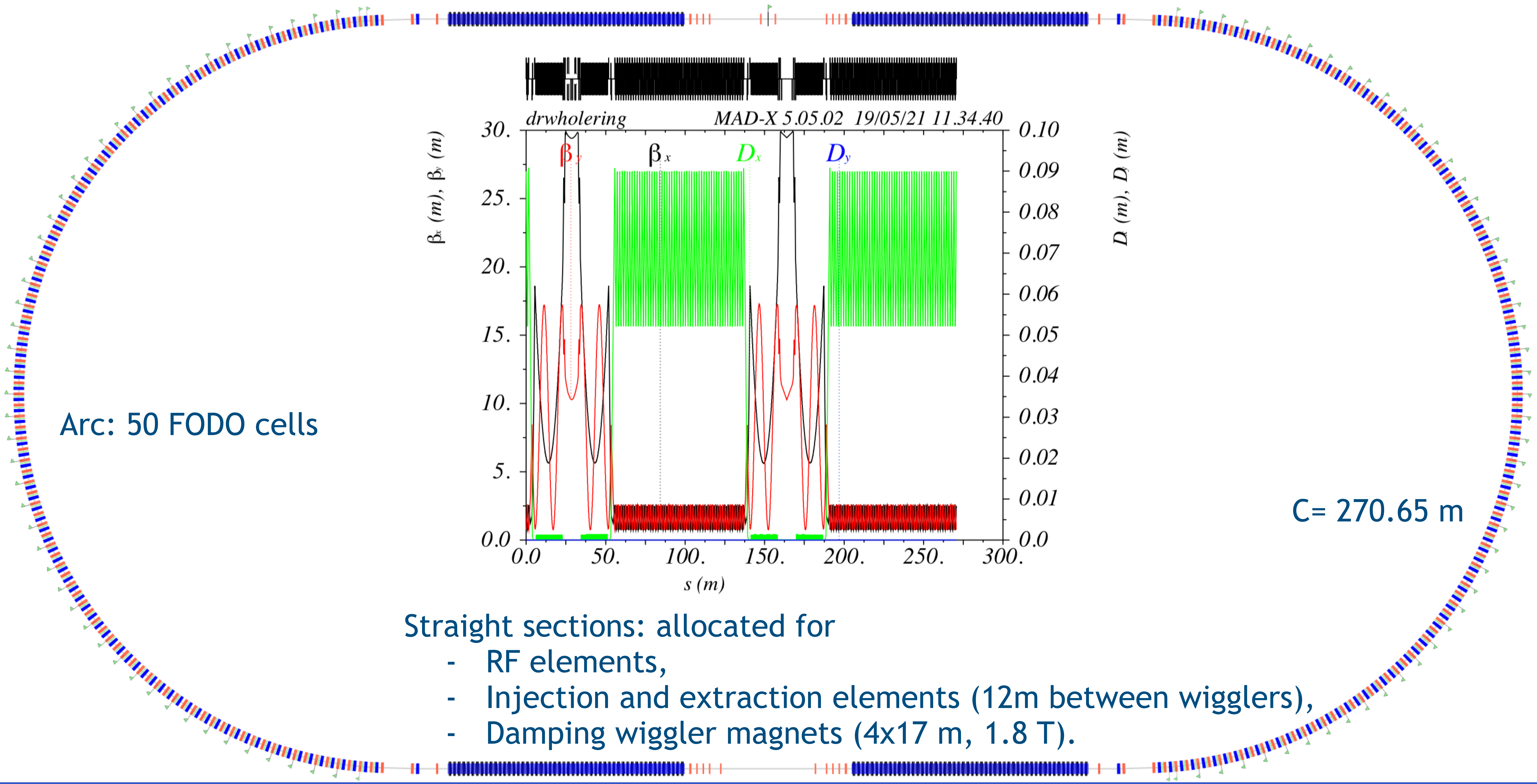


Review of "after CDR" version of the DR

- The **purpose** of the damping ring design is to **accept** the **1.54 GeV beam** coming from the linac (1), **damp the positron/electron beams** and provide the **required beam characteristics** for injection into the linac (2).
- The DR design was done by **S. Ogur** and **K. Oide** and the design study was taken over (early 2021) by **C. Milardi, O. Blanco, A. De Santis.**







Straight sections: allocated for

- RF elements,
- Injection and extraction elements (12m between wigglers),
- Damping wiggler magnets (4x17 m, 1.8 T).

Clarification/updating of the required parameters

- We have organized meetings to discuss the existing design (CDR and after CDR version) and agree on having a clear definition of the required parameters**.**
  - https://indico.cern.ch/event/1100972/, WP4 Meetings
  - https://indico.cern.ch/event/1090786/, WP4 Meetings
  - TheDR of FCC-e^+e^- Injector Complex, internal discussion.

- It has been crucial to provide **clear requirements** about **the DR design** before taking the **existing design a step further** or considering **another design proposal**.

Clarification/updating of the required parameters

- **According to the discussions, the following table summarizes the requirement parameters that we agreed on for the DR design:**

Required Parameters	
Energy [GeV]	1.54
Circumference [m]	~250 m
Stored time [ms]	40
Damping time (hor.) [ms]	≈10
Extraction geo. emittance (hor.) [nm.rad]	≈5
Number of bunches	16
Energy spread @ extraction [%] (rms.)	-
Injection type	on axis
Number of straight sections	3
Injected Parameters	
Injected emittance (h) (e^-/e^+) [nm.rad/μm.rad]	5.5/1.29
Injected emittance (v) (e^-/e^+) [nm.rad/μm.rad]	6/1.22
Injected momentum spread [%] (e^-/e^+) (rms.)	0.2/5
Injected bunch length (e^-/e^+) (mm)	1/3.4

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changes by latest discussions:

required emittance and damping time parameters are changing. New targets are;

- **2 nm.rad** for horizontal emittance
- **7.5 ms** for horizontal damping time.

Consideration for a new DR Design

- **Reasons to review the DR design:**
  - A large number of elements are used in the current DR (232 dipole magnets were used)
  - Magnetic field (there is no obstacle to make it higher: 0.66 T dipole magnet field)
  - Long damping wiggler (revised design after CDR included 68 m, CDR version had 26.5 m)
  - Straight sections (3 straight sections might be better in terms of NLD and considering damping wiggler magnets)
  - Not optimum phase advance were chosen for the beam emittance

- **New approach:**
  - Higher magnetic field which makes damping time shorter **(positive)**
  - Less magnets **(positive)** which make larger emittance **(negative)**
  - Optimum phase advance for the FODO lattice **(positive and negative)**
  - Three straight sections **(positive)**
  - Robinson wiggler are introduced

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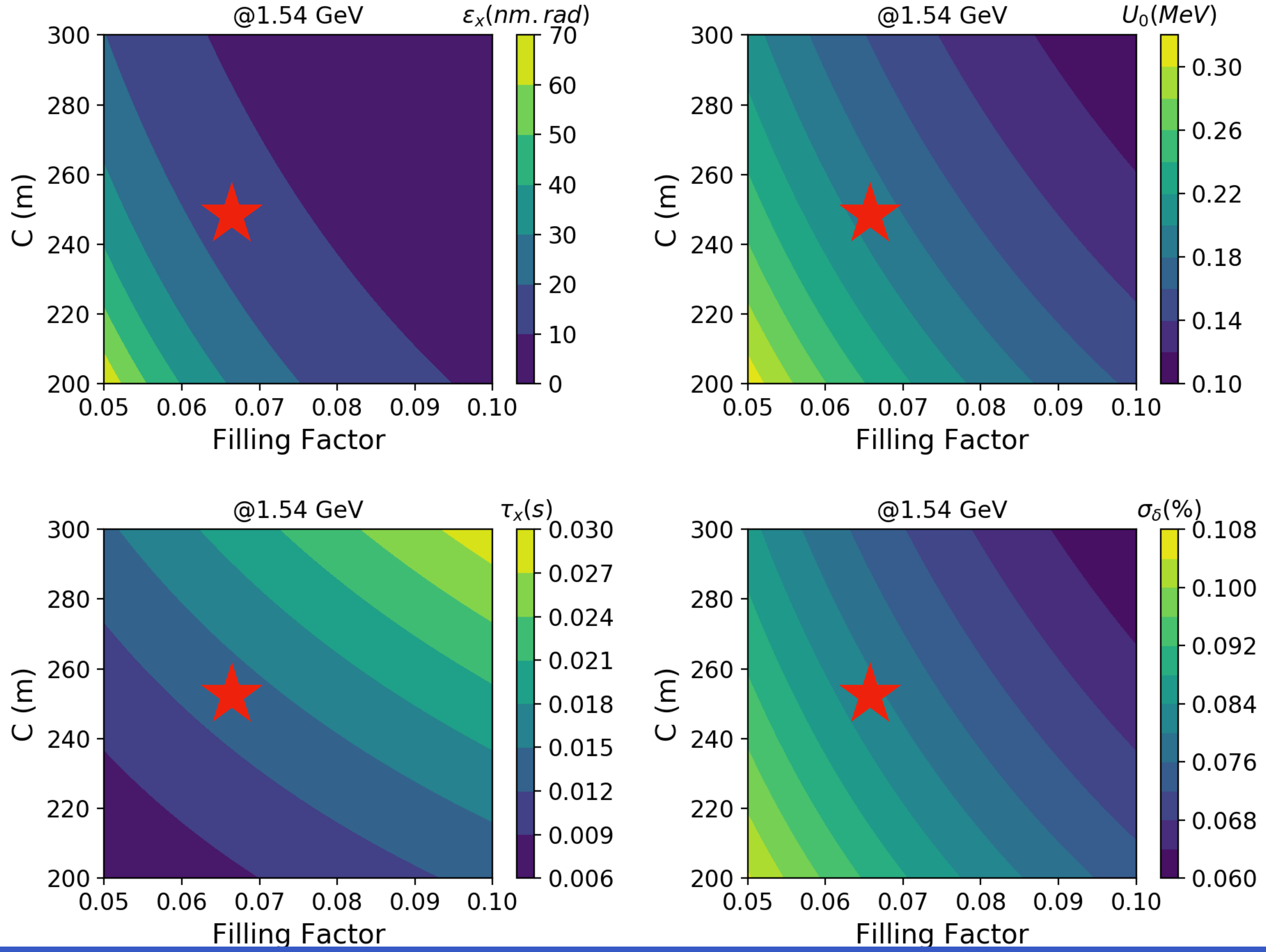
Parameter scaling



$$U_0 = \frac{2\pi \, . \, C_\gamma \, . \, E^4}{F \, . \, C}$$

$$\tau_x = \frac{3.E_0 \, . \, FF \, . \, C^2}{4.\pi^2 \, . \, r_0 \, . \, E \, . \, c \, . \, \gamma^2}$$

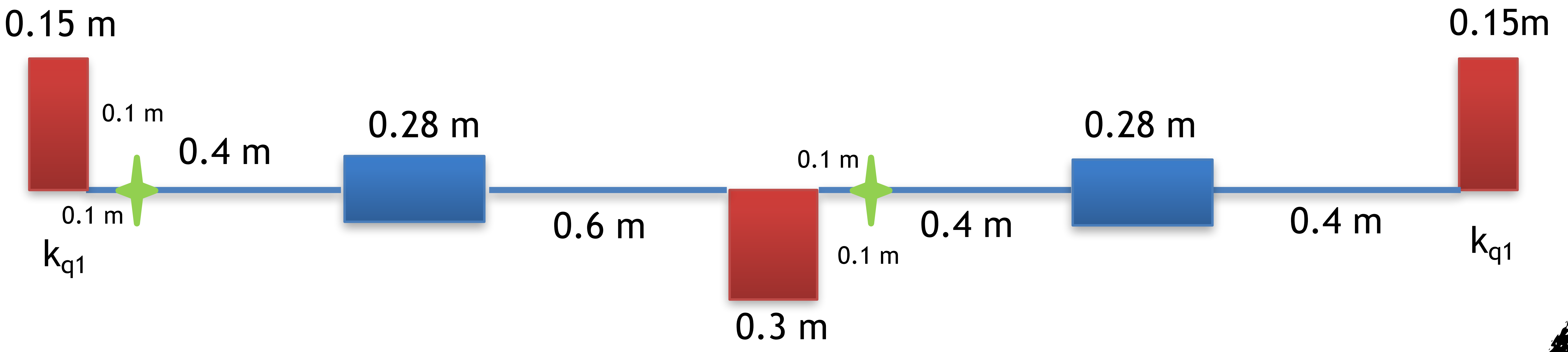
$$(\sigma_\delta)^2 = \frac{C_q \, . \, \gamma^2 . 2\pi}{F \, . \, C}$$

$$\epsilon_x = \frac{F_{lattice} \, . \, C_q \, . \, \gamma^2 \, . \, (2.\pi)^3 \, . \, l^3}{F^3 \, . \, C^3}$$

$$F = \frac{N \, . \, l}{C}$$

FODO Cell and Layout

The design of the DR composes of 3 arcs and 3 straight sections.
Arcs consist of 11 FODO cells and each of the straight sections have 4 FODO cell (without dipole magnets)

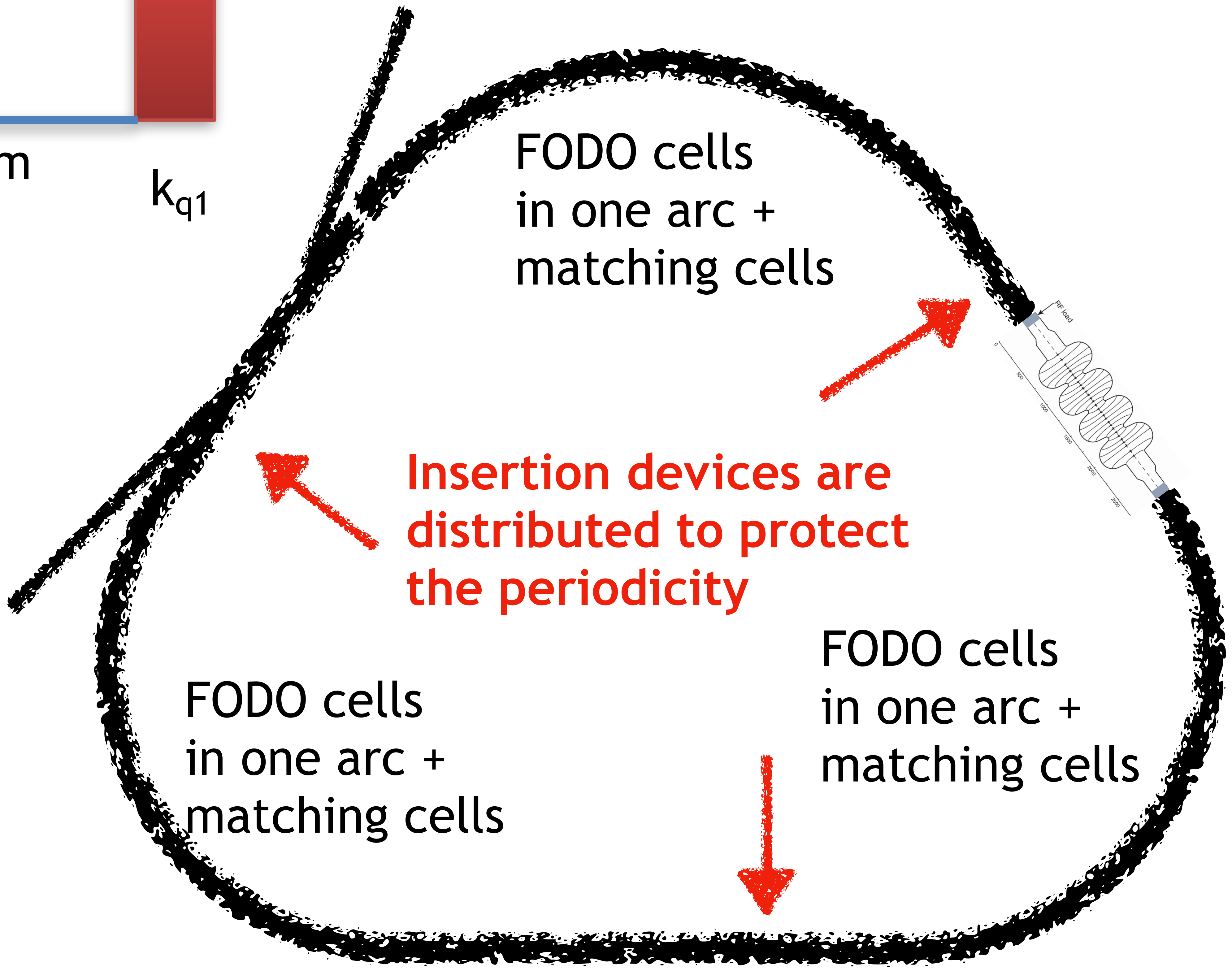


Plan:
Around 255 m circumference, straight sections are allocated for:

- injection and extraction,
- RF,
- DW

First results:

Emittance is around 16 nm.rad
Damping time is around 15 ms
Energy spread is around 0.08%
Energy loss per turn 0.17 MeV



Damping wiggler

- In the current design, the damping time is manipulated with the help of damping wiggler magnet.
- **Damping wiggler (DW)** magnet consists of a **series** of **dipole magnet** poles defecting the beam periodically in opposite directions.
- They are used to enhance radiation damping and thus **impact** the energy loss per turn **(U_o)**, energy spread **(σ_s)**, transverse emittance **(ε_x)**, damping time **(τ_x)**.

$$\tau_x = \frac{3E_0}{2\pi r_0 c^2} \frac{C}{B\gamma^2 (J_x + F_w)} \quad ; \quad F_w = \frac{L_w B_w^2}{4\pi B^2 \rho}$$

- **In our proposal, we have increased the dipole magnetic field, which makes damping time short. It is also reduced by damping wiggler.**

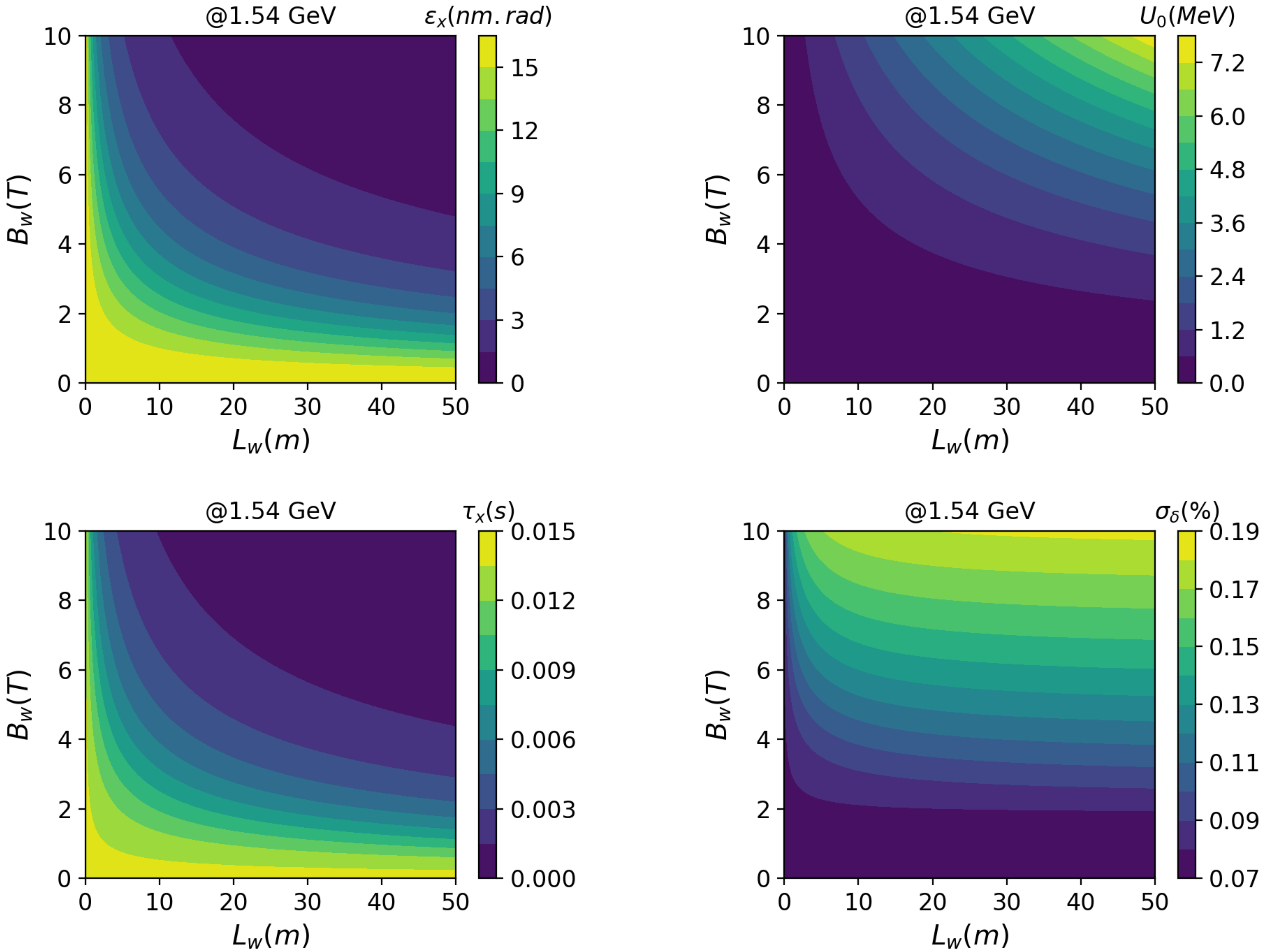
$$\sigma_s = \gamma \left(\frac{B c_q (1 + F_w \frac{B_w}{B})}{B\rho (3 - J_x + 2F_w)} \right)^{1/2}$$

$$\epsilon_x = \frac{c_q \gamma^2}{12(1 + F_w) J_x} \left(\frac{e_r \theta^3}{\sqrt{15}} + \frac{\beta_{xw} F_w \beta_w^2 \gamma^3}{16 (B\rho)^3} \right)$$

- **For smaller emittance; the phase advance are optimized and damping wiggler are used.**

$$U_o = 2\pi c_q \frac{E^4}{Nl} (1 + F_w)$$

Damping wiggler



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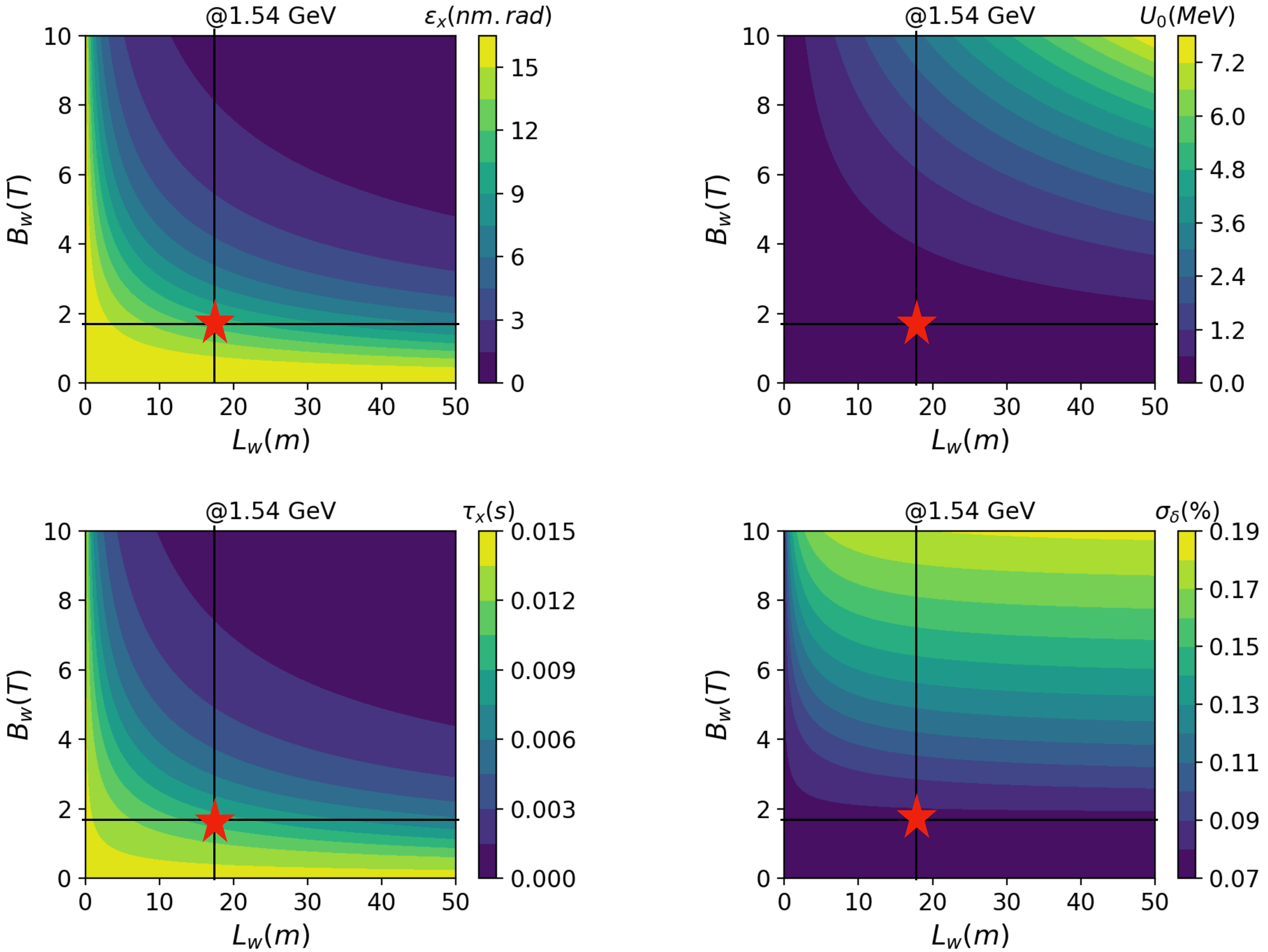

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Damping wiggler

We considered that reducing **emittance and damping time** with a combination of **damping wiggler and Robinson wiggler** could be a good solution in terms of saving some money and space for DR rather than using much longer damping wiggler.

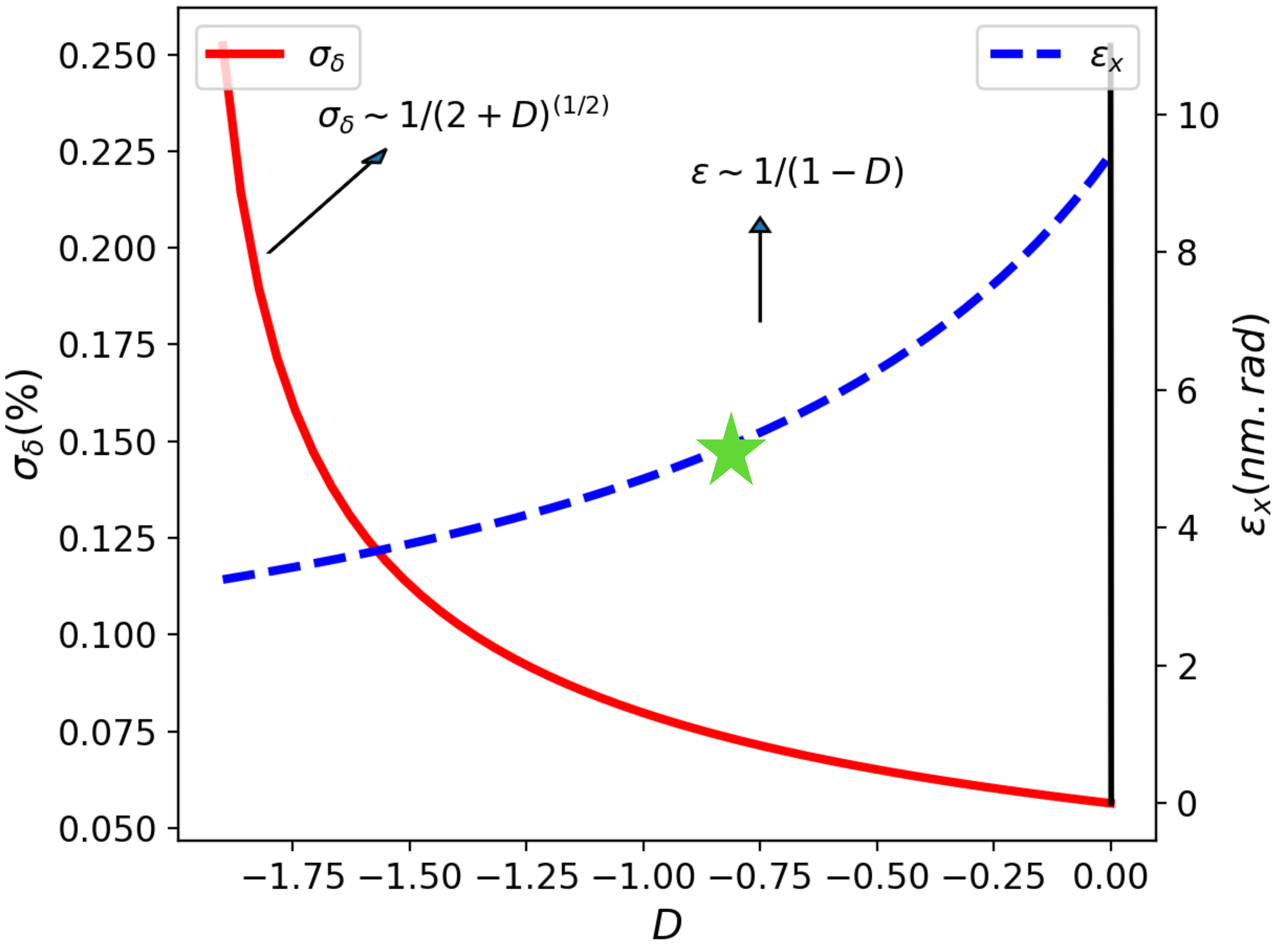
In this case, inserting around **18 m damping wiggler with 1.8 T** can reduce the **emittance up to 9 nm.rad** (it should still be reduced) and **the damping time up to 10 ms** (it is enough for damping time).

P.S If we would like to use only damping wiggler without Robinson wiggler; we need to use more than 50 metres.

Thus, in the next slide I am showing analytical calculation to see the effect of Robinson wiggler (after we added 18 m and 1.8 T damping wiggler)

Robinson Wiggler Magnet

- The **Robinson wiggler** (RW) is composed by a series of combined function magnets.
- It impacts the damping partition ($D = I_4/I_2$) by modifying the 4th synchrotron radiation integral (I_4).



$$\epsilon_0 = c_q \gamma^2 \frac{I_5}{J_x I_2} \quad \approx 1/(1-D)$$

$$\sigma_\delta^2 = c_q \gamma^2 \frac{I_3}{J_z I_2} \quad \approx 1/(2+D)^{1/2}$$

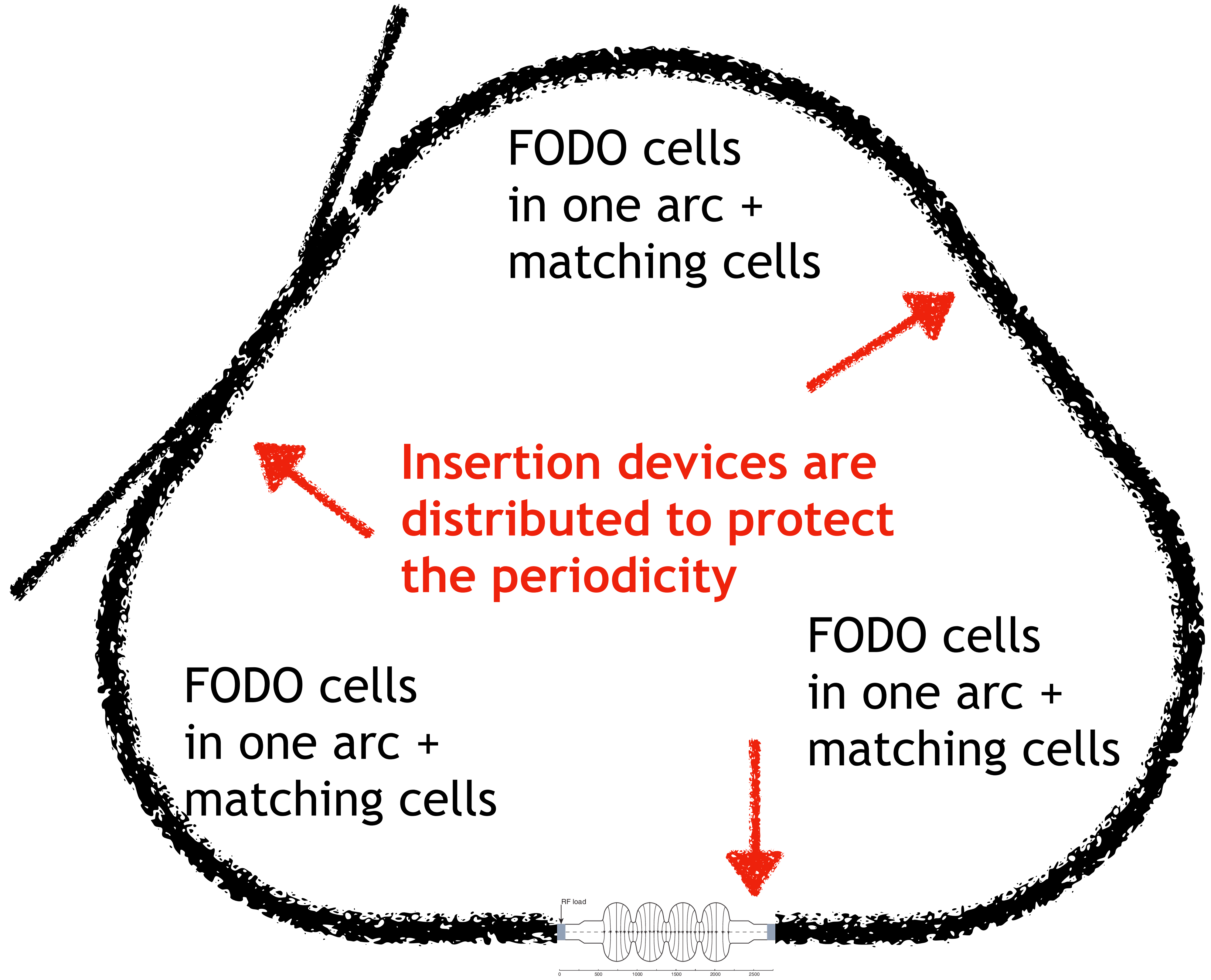
$$J_x \tau_x = J_y \tau_y = J_z \tau_z = 2\frac{E_0}{U_0} T_0 \quad \approx 1/(1-D)$$

$$U_0 = \frac{c_\gamma}{2\pi} E^4 I_2 \quad \approx I_2$$

$D = I_4/I_2$

Layout

- Based on analytical and numerical calculations, a new layout are provided for the DR.
- The design of the DR composes of 3 arcs and 3 straight sections.
- Arcs consist of 11 FODO cells and each of the straight sections have 4 FODO cell (without dipole magnets)



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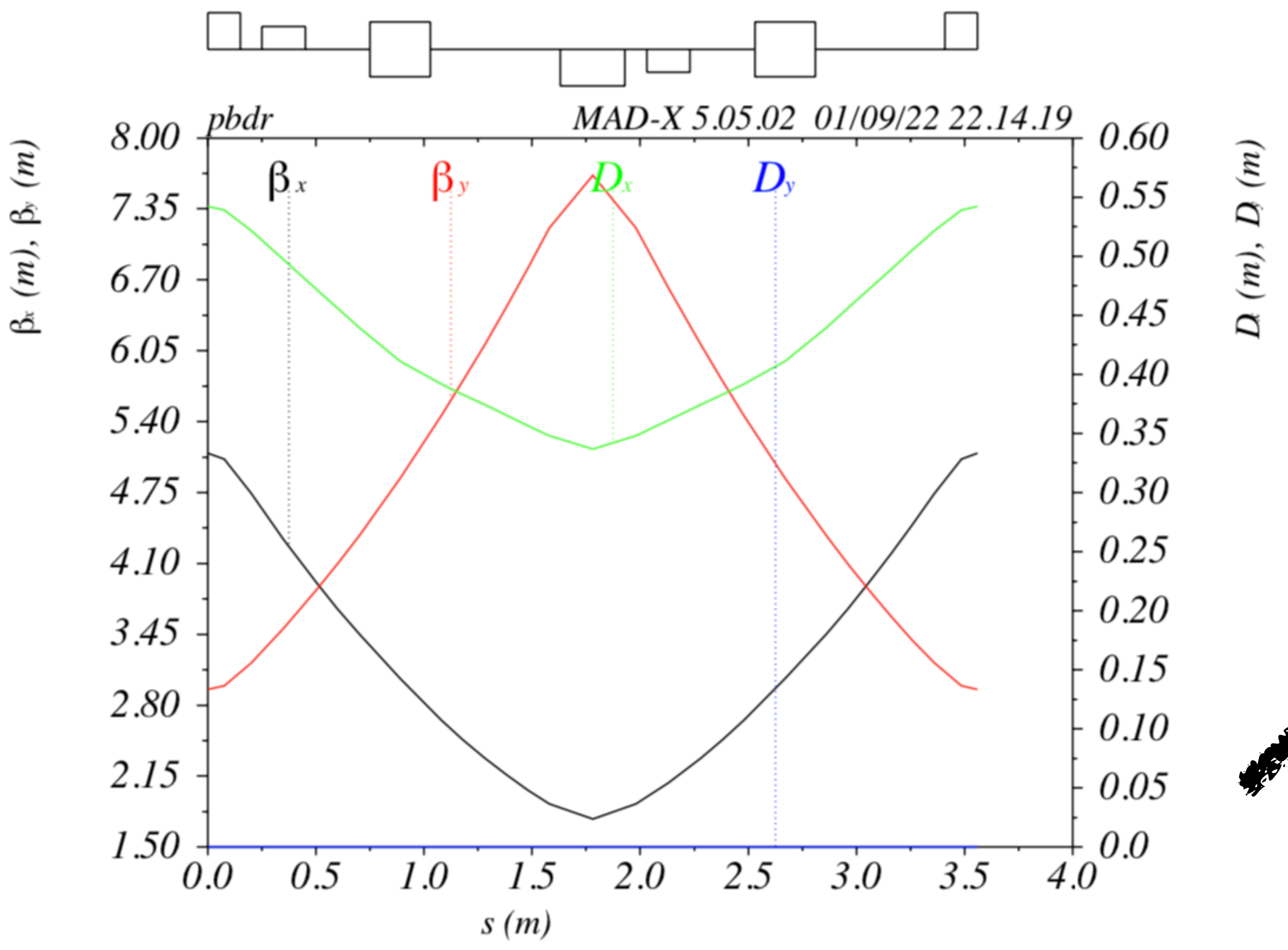
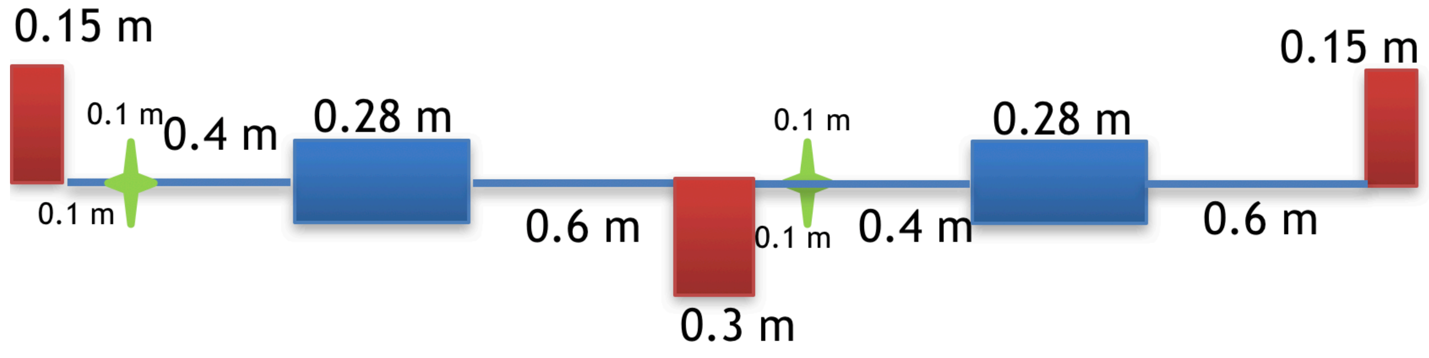
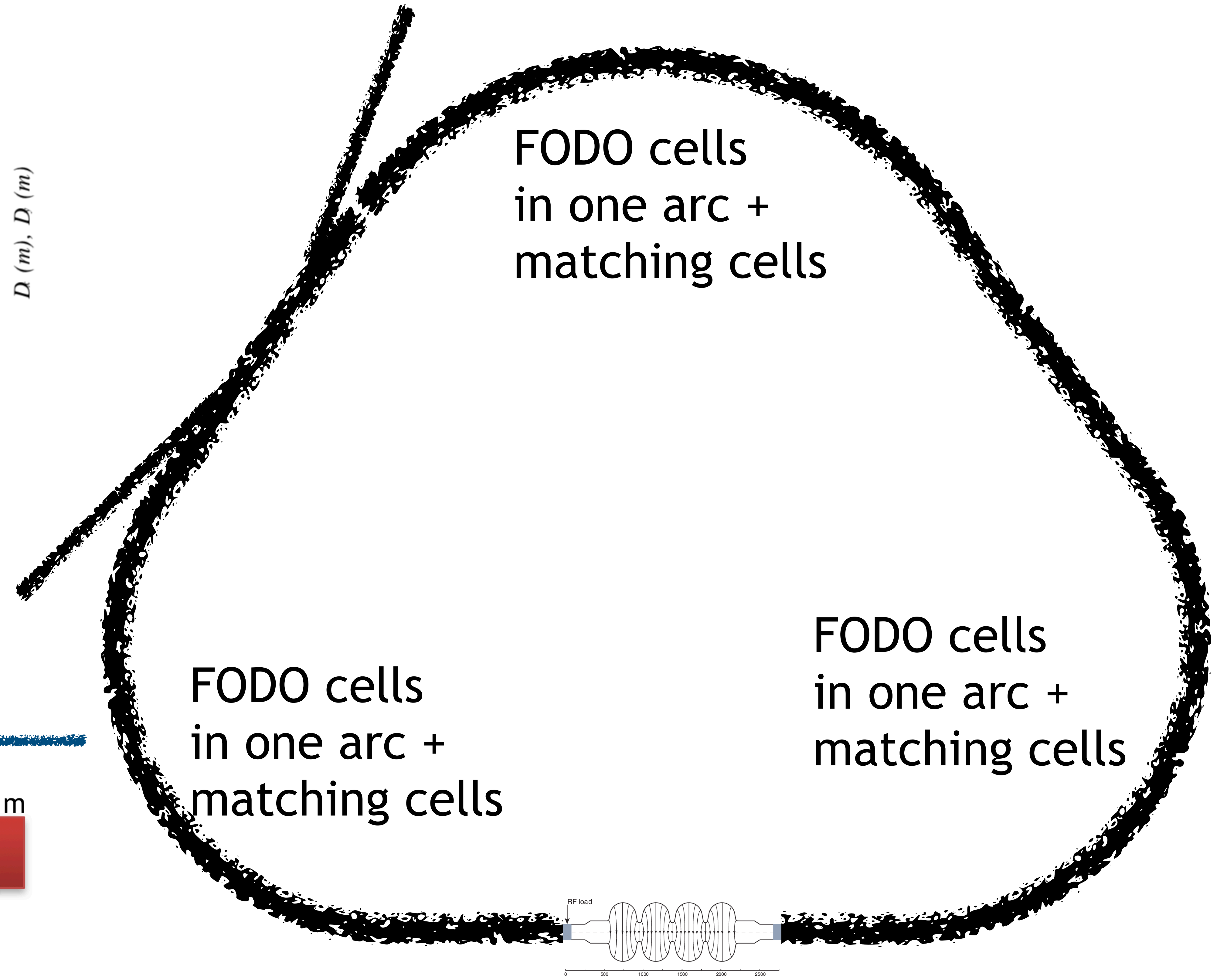


Arc cell





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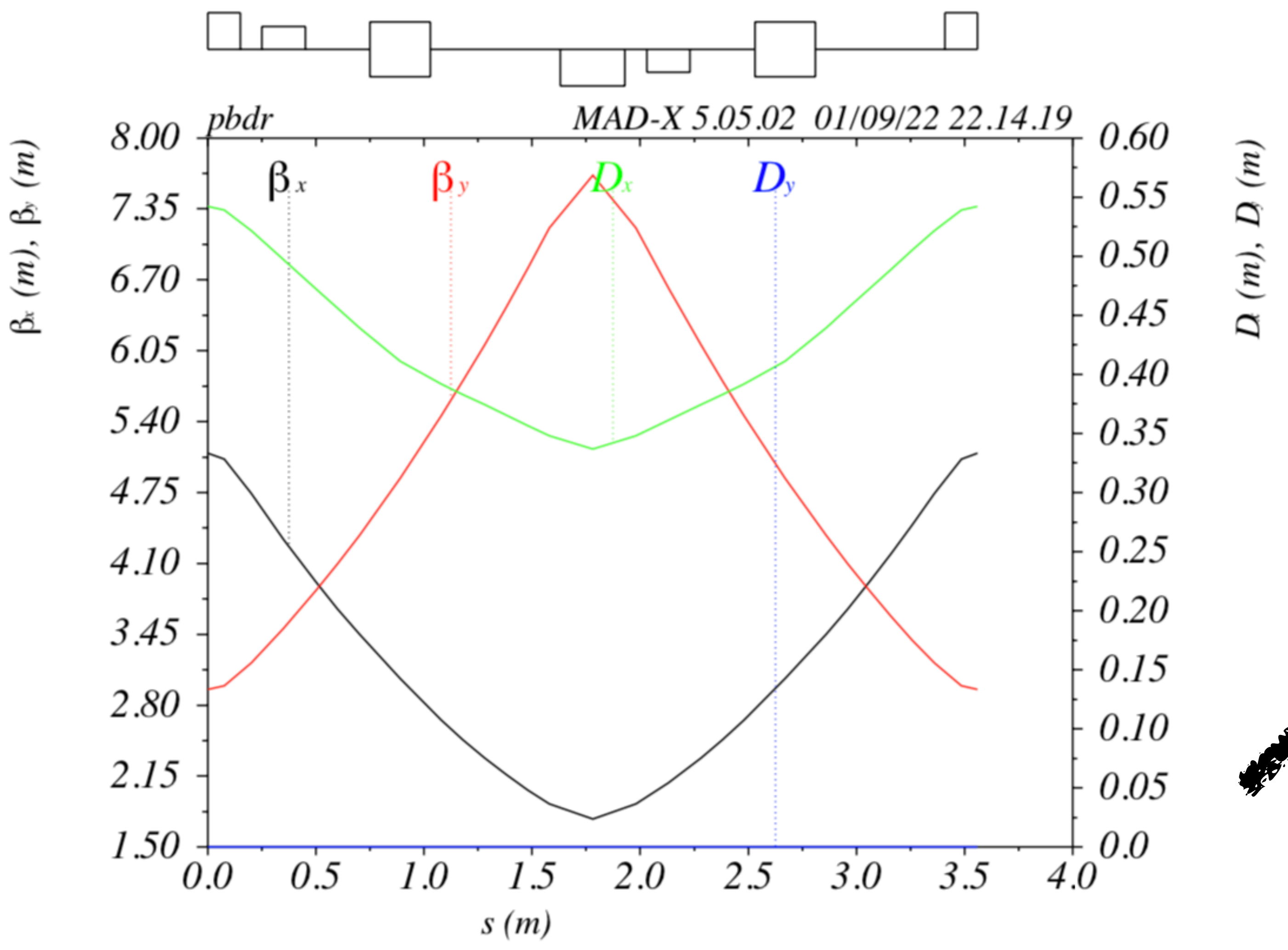
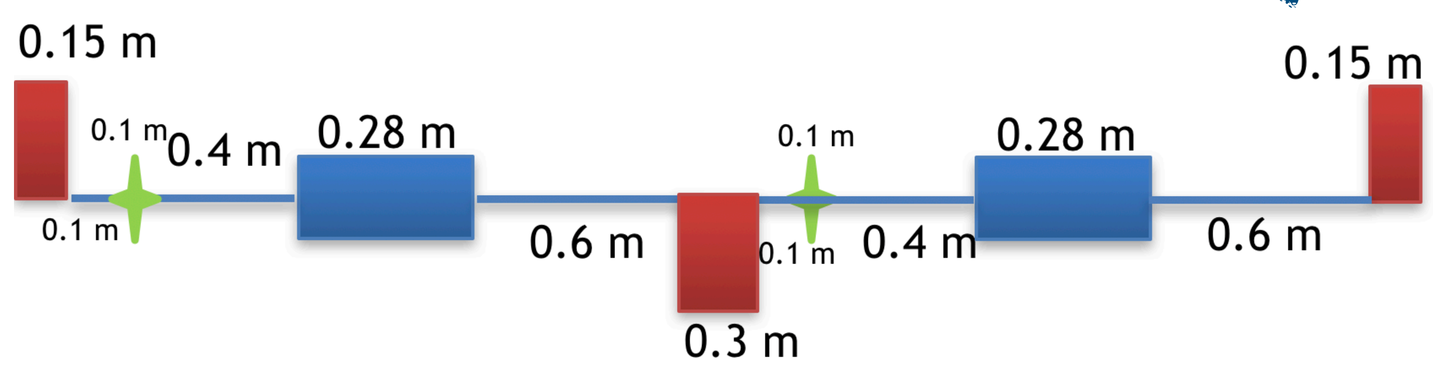
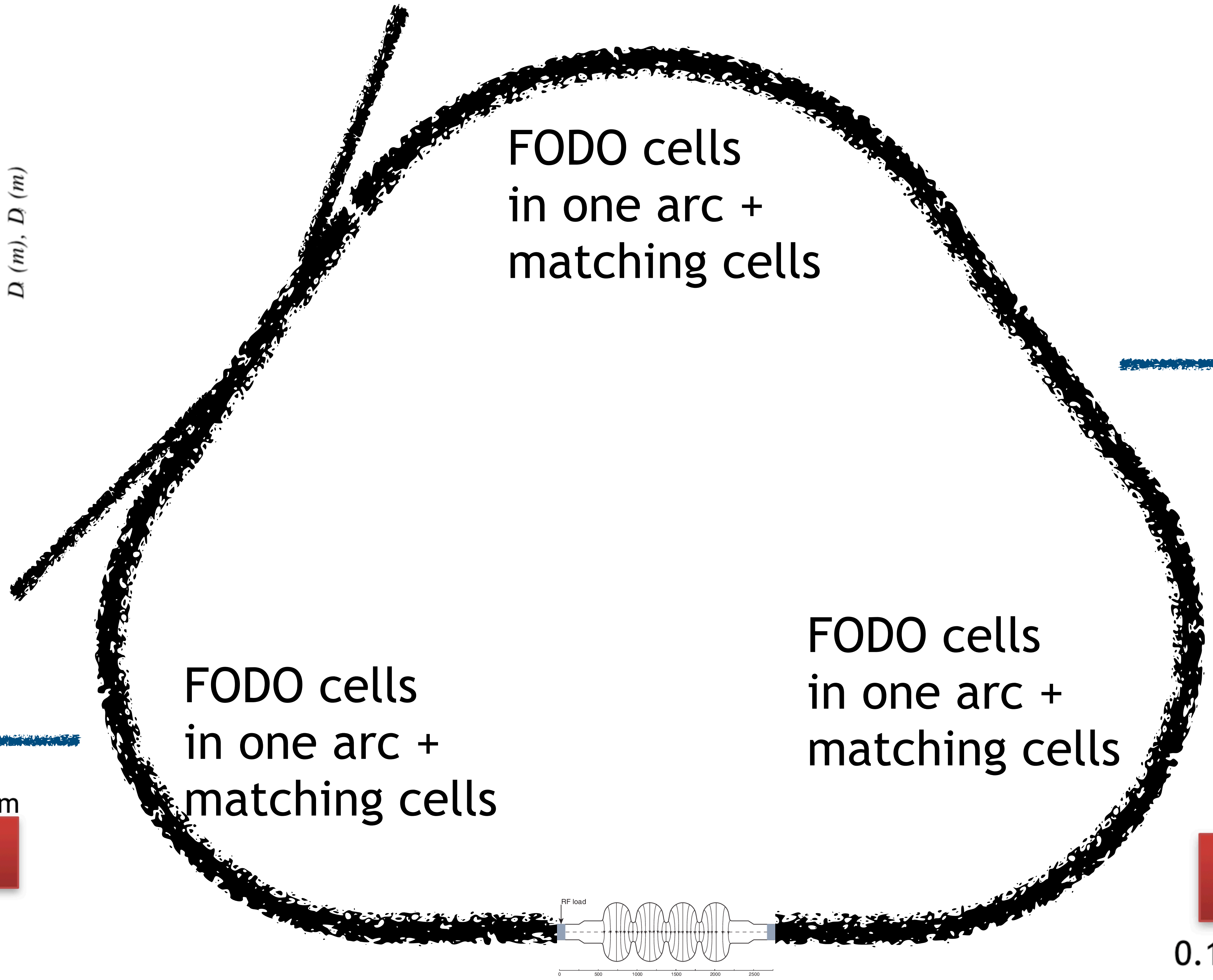
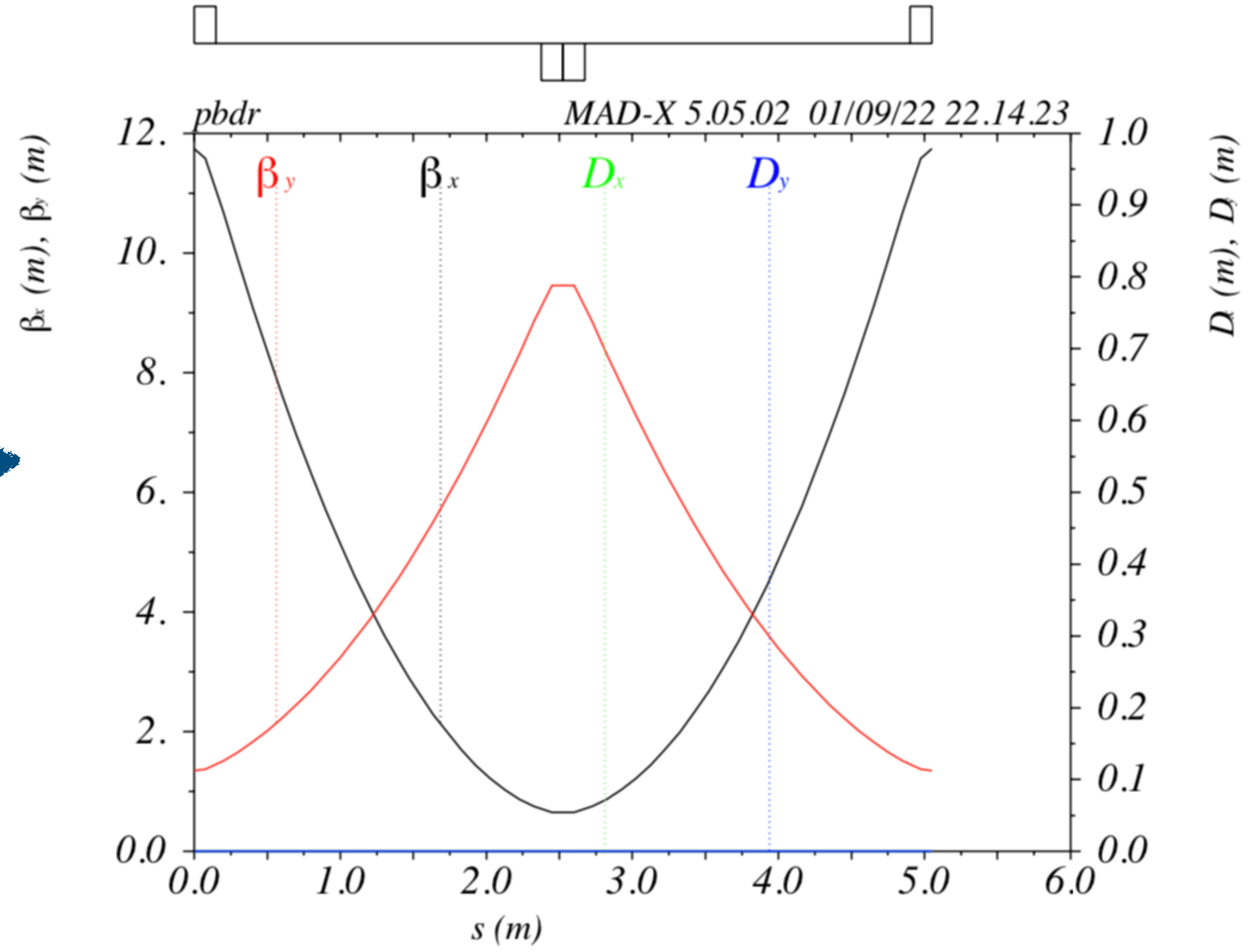


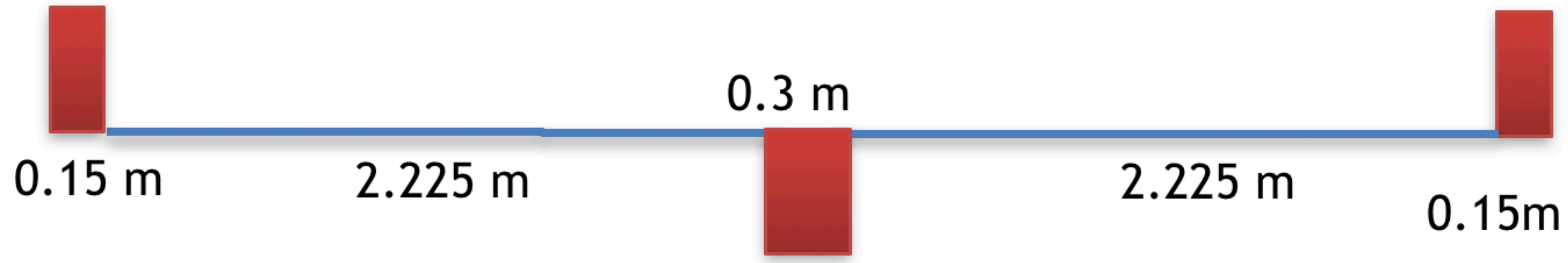
Arc cell







SS cell



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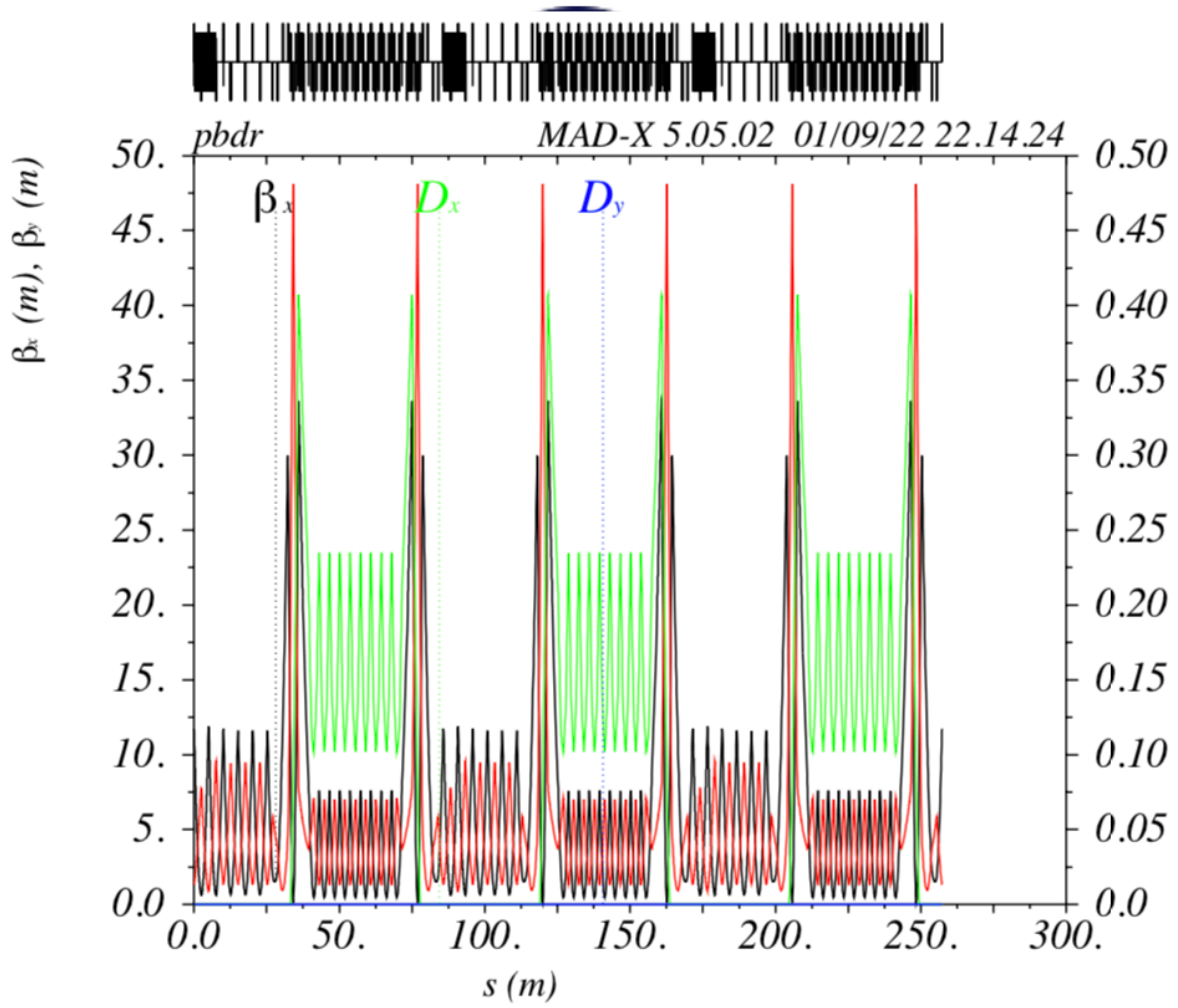
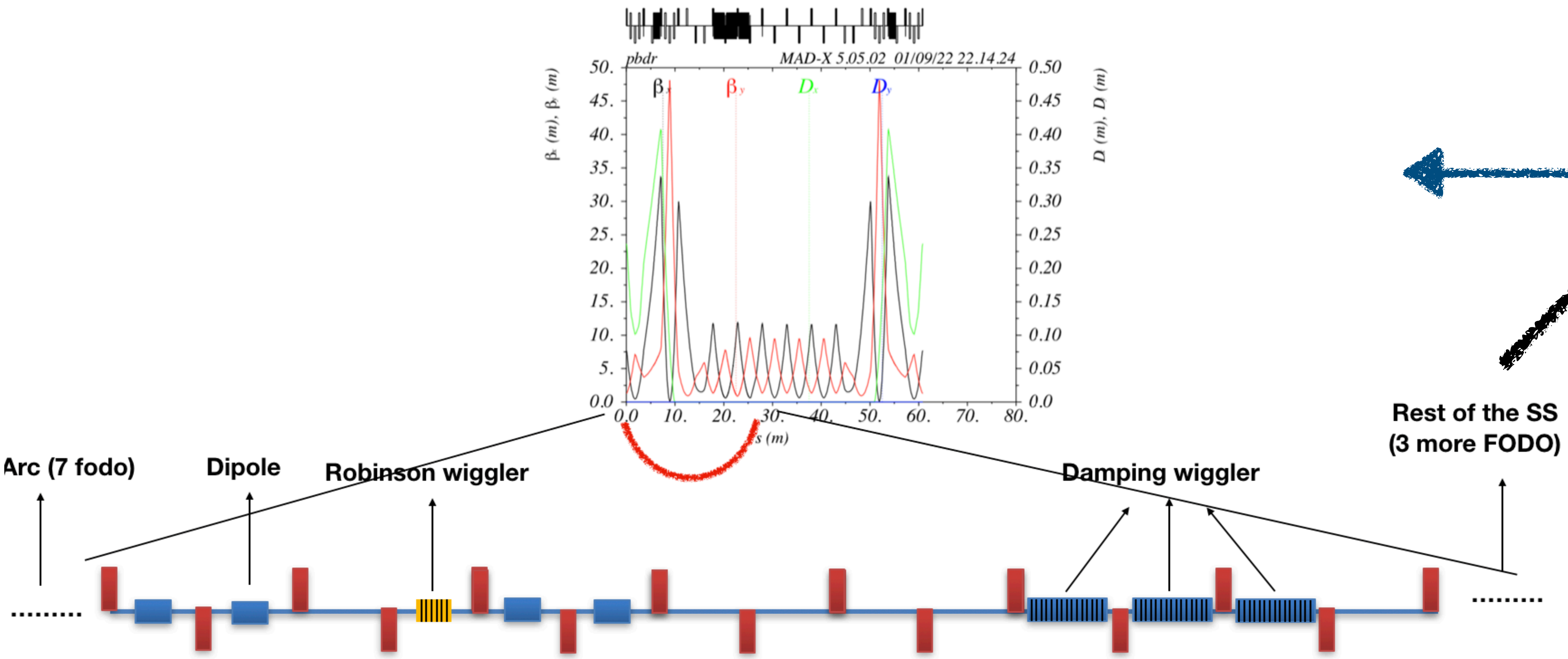


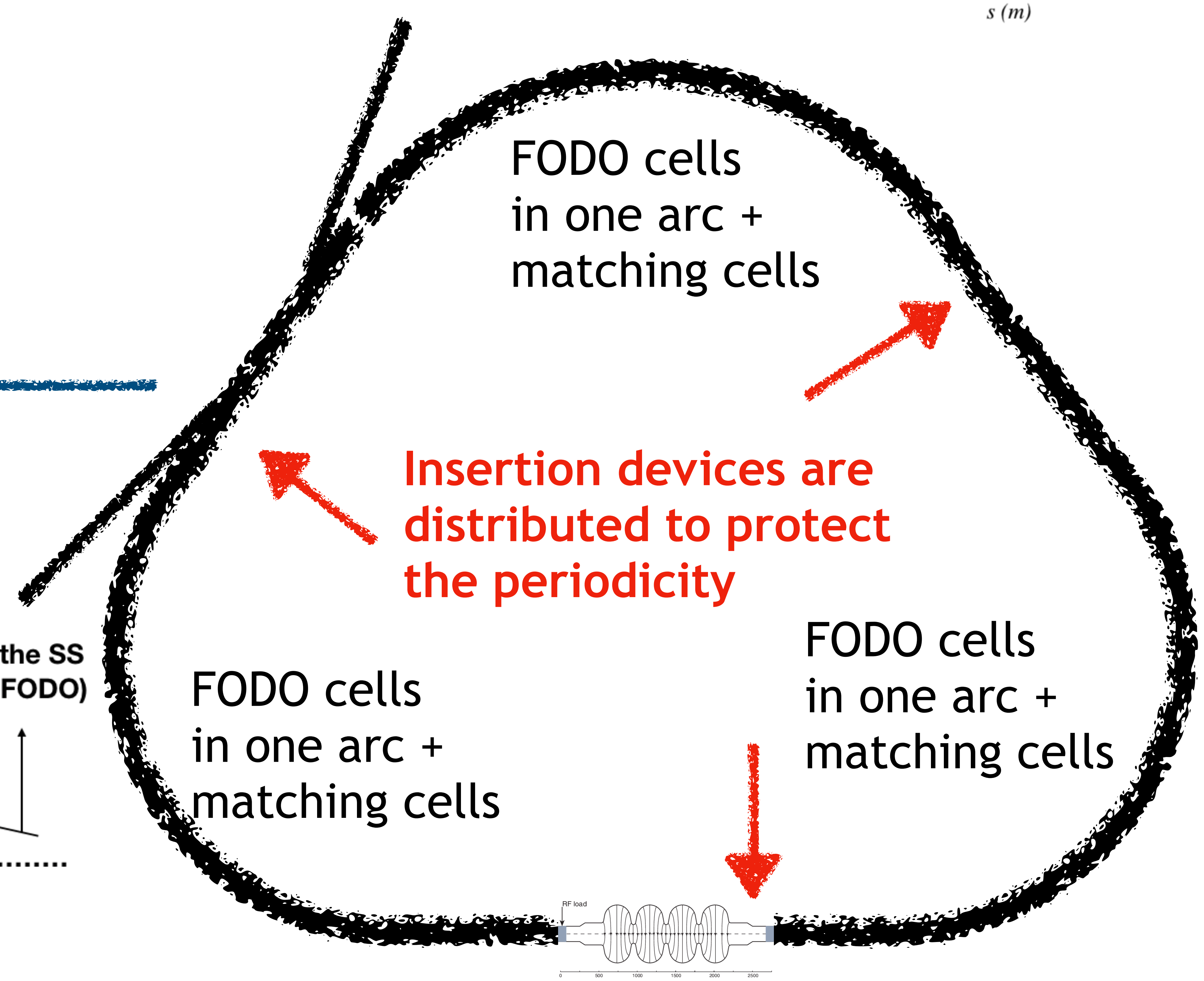
Straight Section (SS) area with 5 cell;

- **3 damping wiggler are allocated (each of them is around 2 m).**

Straight Section (SS) area + matching area as also showing

- **the Robinson wiggler which is allocated to the dispersive area (around 1.3 m).**





Summary and next steps

Parameters	CDR	After CDR	New
Bending magnet quantity*	232	232	**72***
Dipole magnet length [m]	0.21	0.21	**0.28**
Bending angle [degree]	1.55	1.55	**5**
Dipole magnetic field [T]	0.66	0.66	**1.8**
Filling factor	0.2	0.19	**0.07**
Damping wiggler magnet	26.5 m / 1.8 T	68 m / 1.8 T	**18 m / 2 T**
Robinson wiggler magnet	-	-	**3.8 m / 1.2 T**
Circumference	242 m	240 m	**257.31 m**
Emittance	2 nm.rad	1.25 nm.rad	**4.89 nm.rad**
Damping time	10.5 ms	5.9 ms	**6 ms**
Energy loss per turn	0.255 MeV	0.47 MeV	**0.253 MeV**

*** It also cause considerable reduction of the number of other magnets such as sextuples, correctors, BPMs etc.**

Next steps:

- We will **continue to revise the new layout** with the following “new” required parameter changes:
  - **Emittance** should be reduced to **2 nm.rad**.
- In addition, based on internal discussions, we will **avoid** from the **Robinson wiggler** and **dipole magnet** field will be reduced to **1.5 T**.
- **Optimization** and **DA** studies will follow.

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Thank you!

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