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Status of the Interaction Region Design for the 10TeV Muon Collider

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Content: Status of the IR Design for the 10TeV Muon Collider

1

No significant changes to the IR lattice design since the previous MDI workshop (https://indico.cern.ch/event/1402725/)

→ Reminder of the main Requirements & Challenges

→ Overview of the collider ring (see also specific presentation)

2

Multiple iterations on the IR and CC sections to mitigate Beam-Induced Background (BIB) and improve momentum acceptance.

- Versions with different constraints & Performances
- Comparison of IR versions → Lattice design impacts the BIB

3

Interaction region lattice design:

- Current IR lattice design & Updates

Requirements & Overview of the Collider Ring

10TeV Muon Collider

$$\mathcal{L} = \frac{1}{4\pi}\frac{N_p^2}{\varepsilon\beta^*} f_r\, f_{hg} \frac{\gamma T_\mu}{T_{rev}}$$

Parameter	Symbol	Value
Beam energy	E	$5000\ GeV$
Luminosity per IP	$\mathcal{L}$	$\sim 20 * 10^{34} cm^{-2}\ s^{-1}$
Bunch population	N_p	$1.8\ *\ 10^{12}$
Repetition rate	f_r	$5\ Hz$
Normalized transverse rms emittance	$\varepsilon_{nx} = \varepsilon_{ny}$	$25\ \mu m$
Geometric transverse rms emittance	$\varepsilon_{gx} = \varepsilon_{gy}$	$0.528\ nm$
Longitudinal emittance	ε_l	$0.314\ eVs$
Rms bunch length	σ_z	$1.5\ mm$
Relative rms energy spread	$\delta = \frac{\sigma_E}{E}$	$0.1\ \%$
Beta function at IP	$\beta_x^* = \beta_y^*$	$1.5\ mm$
Circumference	C	$\sim 10\ km$

Requirements & Challenges

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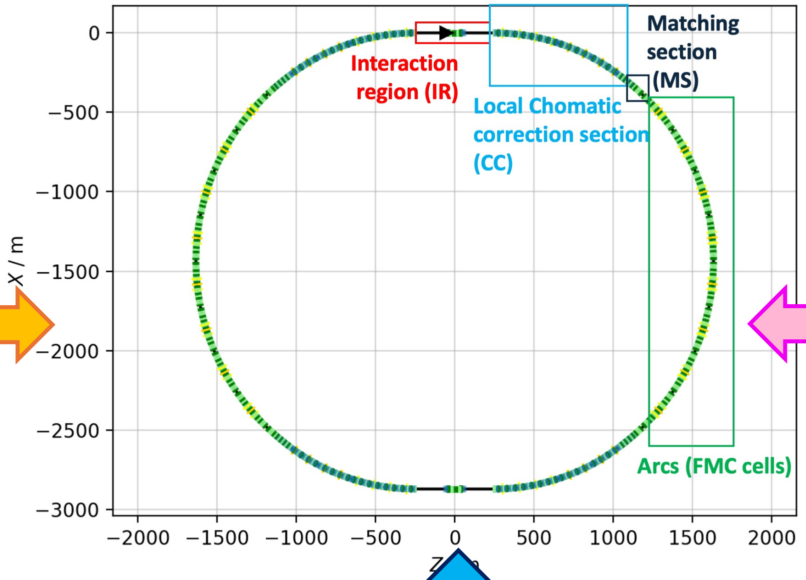
Limitations on the magnetic Fields & Gradients

→ Large **magnet aperture** and sensitivity to unwanted multipolar components.

→ **High magnetic field** required (HTS) with **good field quality**



Short muon lifetime

→ **BIB** to mitigate and **W shielding needed** inside the magnets.

→ **Neutrino radiation** must remain negligible at Earth's surface: **minimal straight sections.**

Goals & Beam constraints

❖ $\boldsymbol{\beta^*_{x,y} = 1.5mm}$ (=σ_z)

❖ $\boldsymbol{\delta = 0.1\%}$

Strong chromatic effects
→ CC section

❖ $\alpha_c \sim 0$ → FMC arc cells

❖ Circumference ~10 km

Required performance:

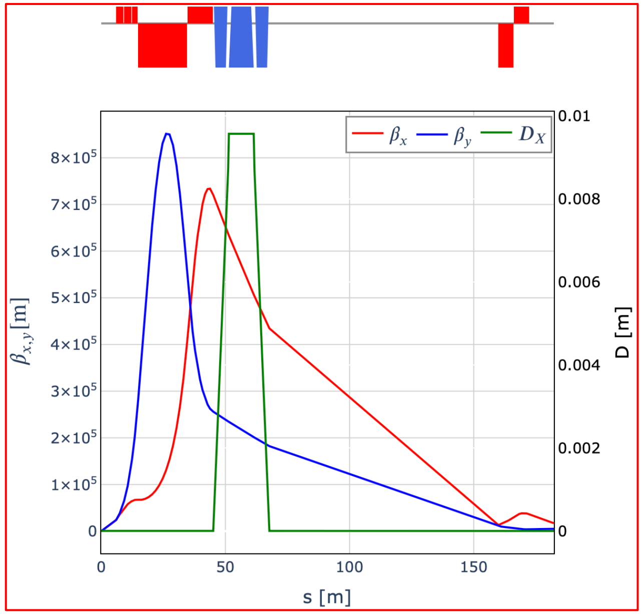
→ Transverse DA: ~ 3-4σ

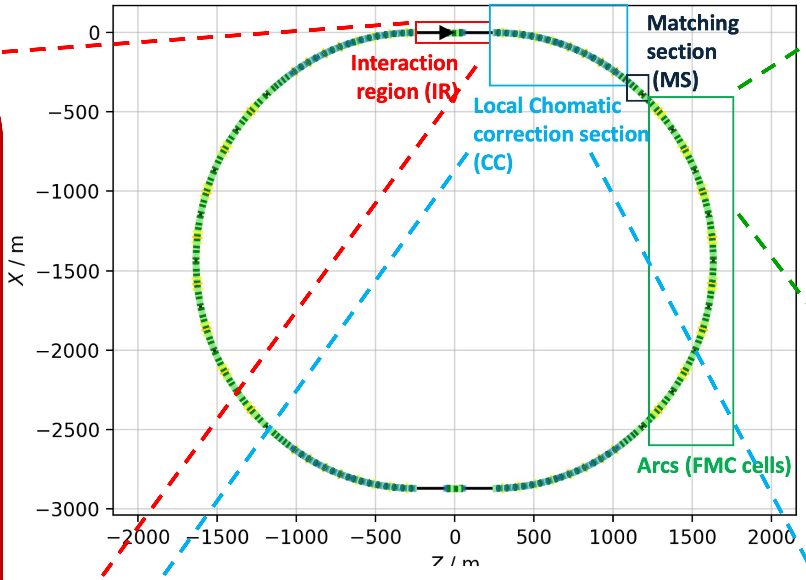
→ Momentum acceptance: ~2-3 σ

Overview of the Collider Ring

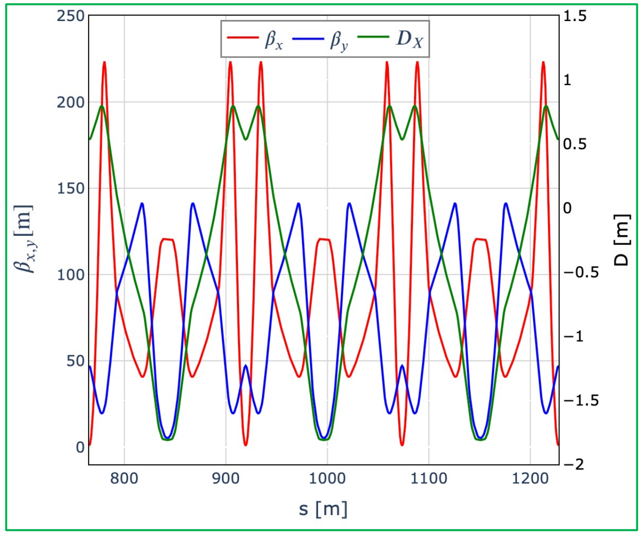
This presentation

Interaction region (IR)

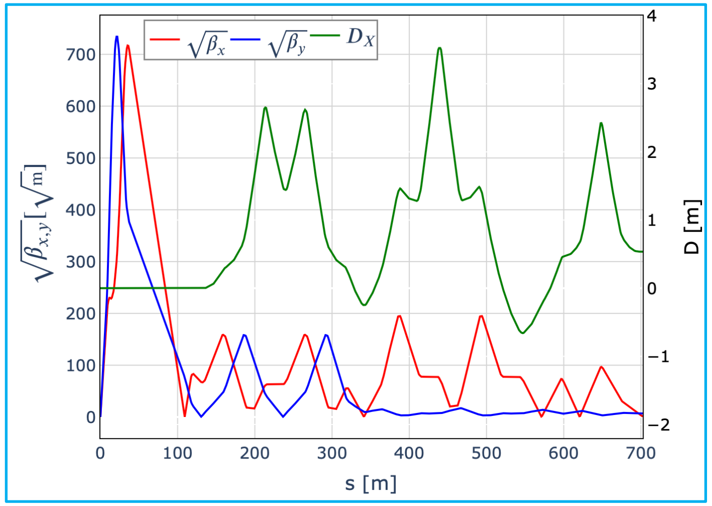




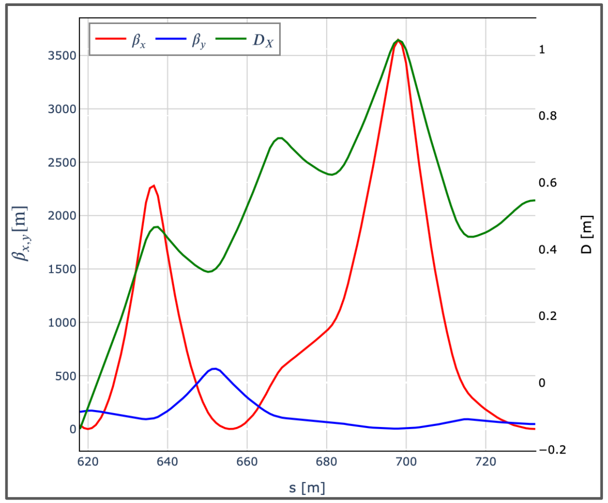
FMC Arcs



Chomatic correction section (CC)



Matching section (MS)



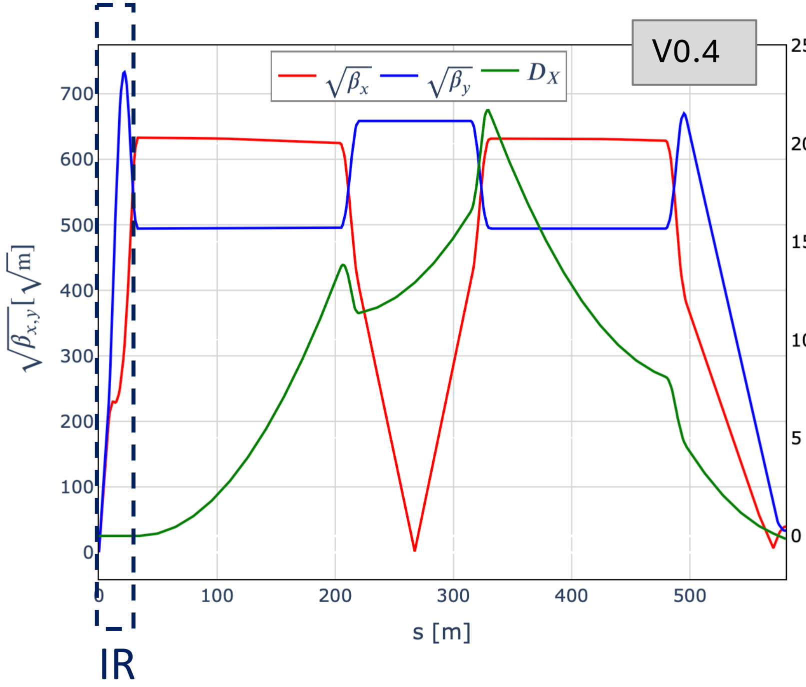
Comparison of IR lattice versions

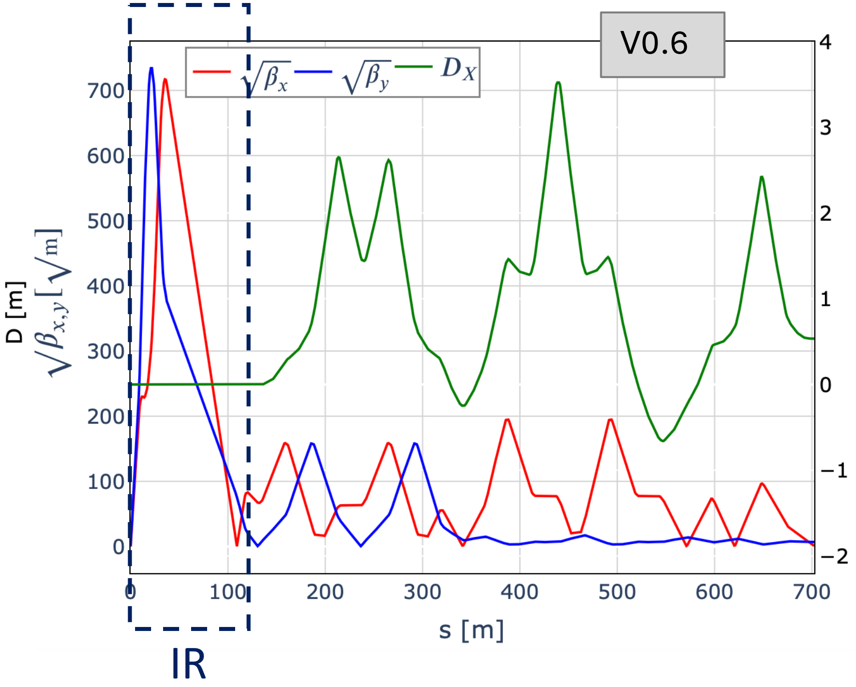
From version v0.4 to the current lattice version

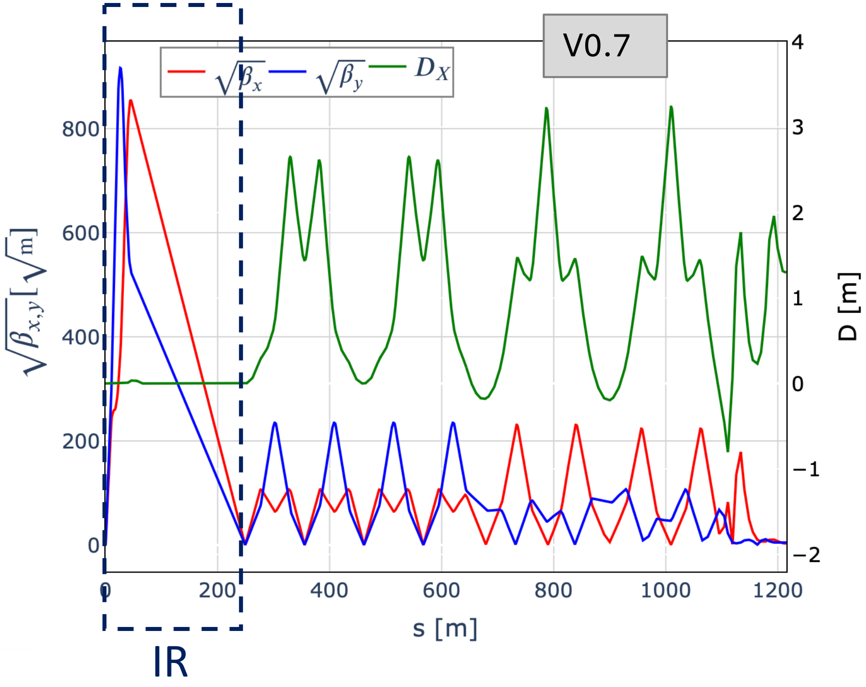
Summary of the collider ring versions

Multiple iterations: still a work in progress.

From K. Skoufaris





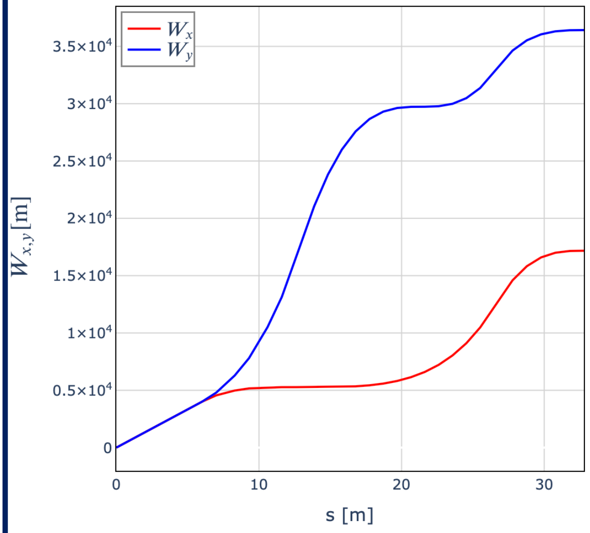


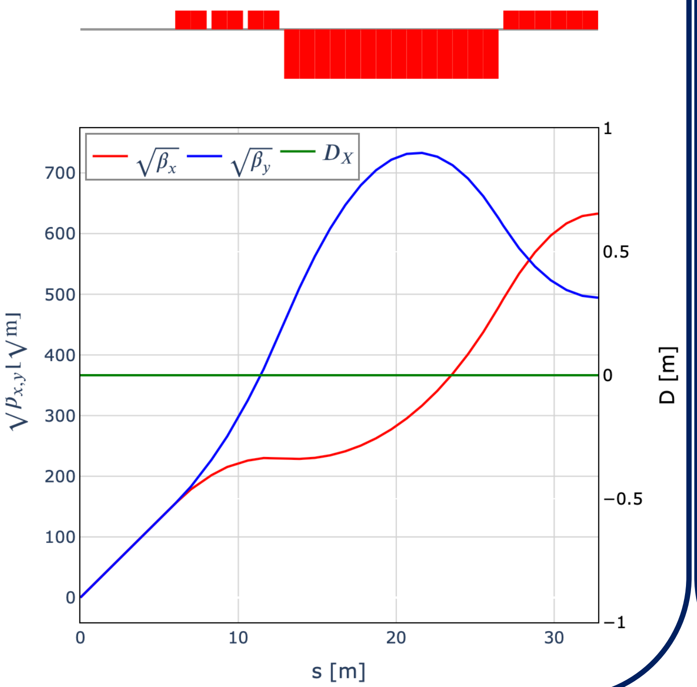
Multiple iterations on the IR and CC to mitigate BIB and try to improve momentum acceptance. Magnetic fields differ from one version to another and (sub-)versions are optimized (or not) with different constraints (for example shielding thickness).

Collider ring versions: Interaction region

Version 0.4:

- No straight section between the FF triplet & CC sections
- 3 pairs of sextupoles in CC
- **Poor Dynamic aperture**

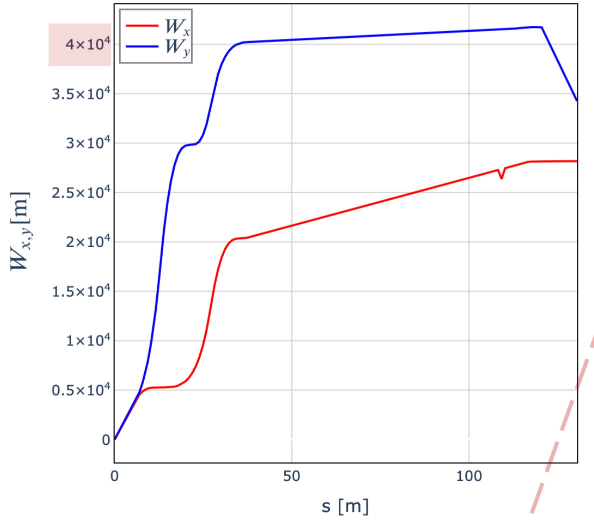


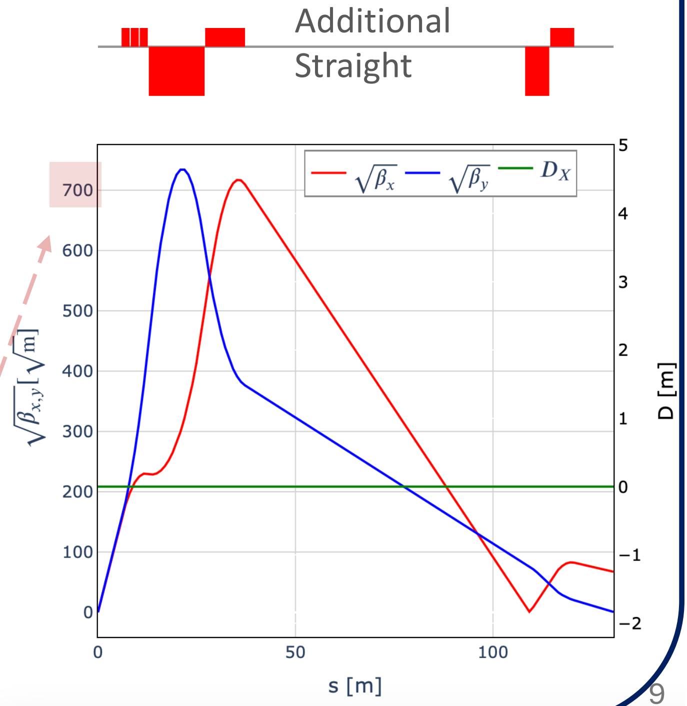


Aperture = 5σ + **2cm**

Version 0.6:

- Long straight section in the IR for smaller β in the CC
- **No chicane**.
- Max **B** set to 20T at the magnet aperture





Aperture = 5σ + **2cm**

Collider ring versions: Interaction region

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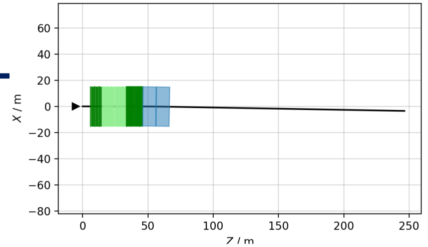
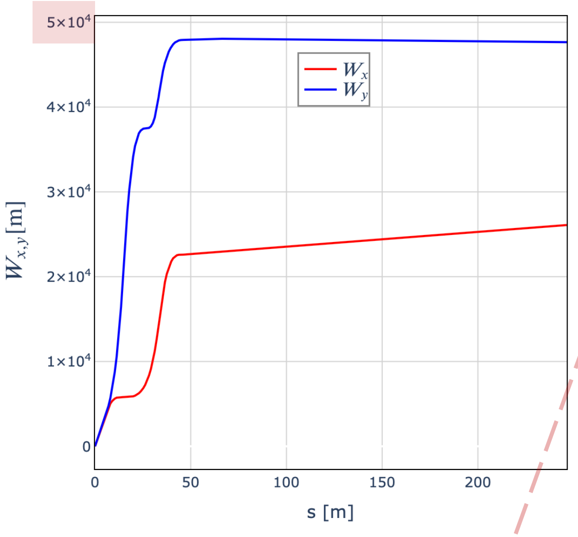
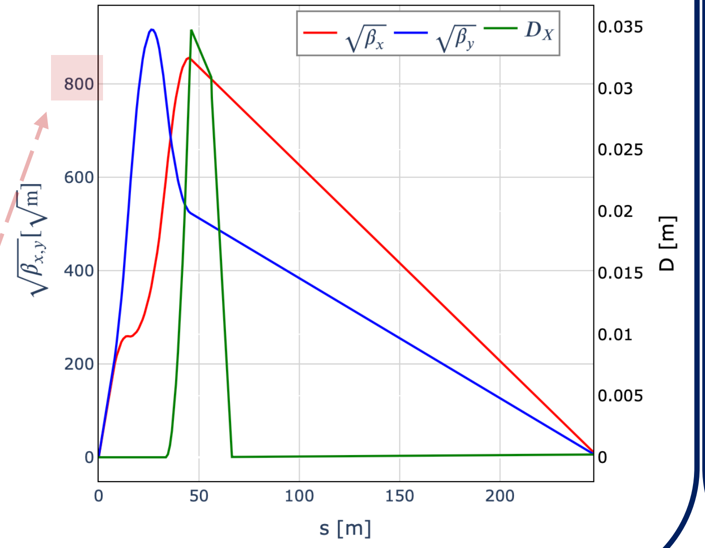


Version 0.7:

- **Chicane** to mitigate BIB
- Last triplet quad = Combined-function magnet
  → **Small residual deflection** after the chicane
- Max **B** set to 20T at the magnet aperture



Additional Chicane

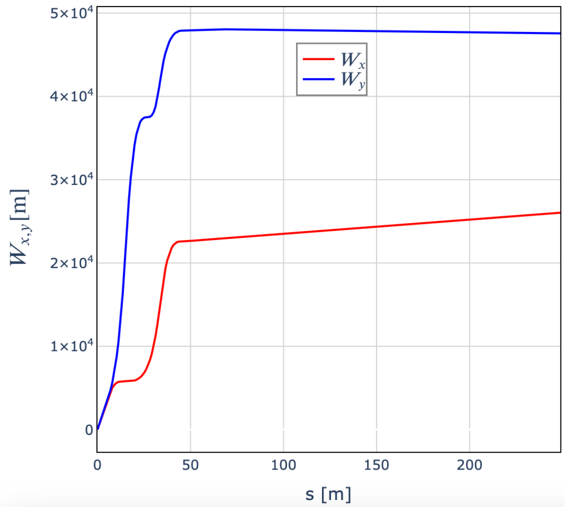


Aperture = 5σ + **4cm**

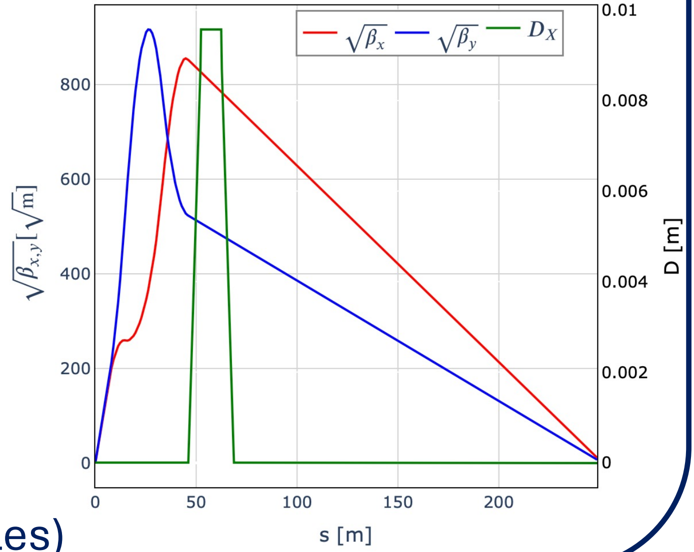
Version 0.8:

- **Chicane** to mitigate BIB.
- **No combined-function FF quads**
- Max **B** set to **20T** at the magnet aperture.

Improved in current version!



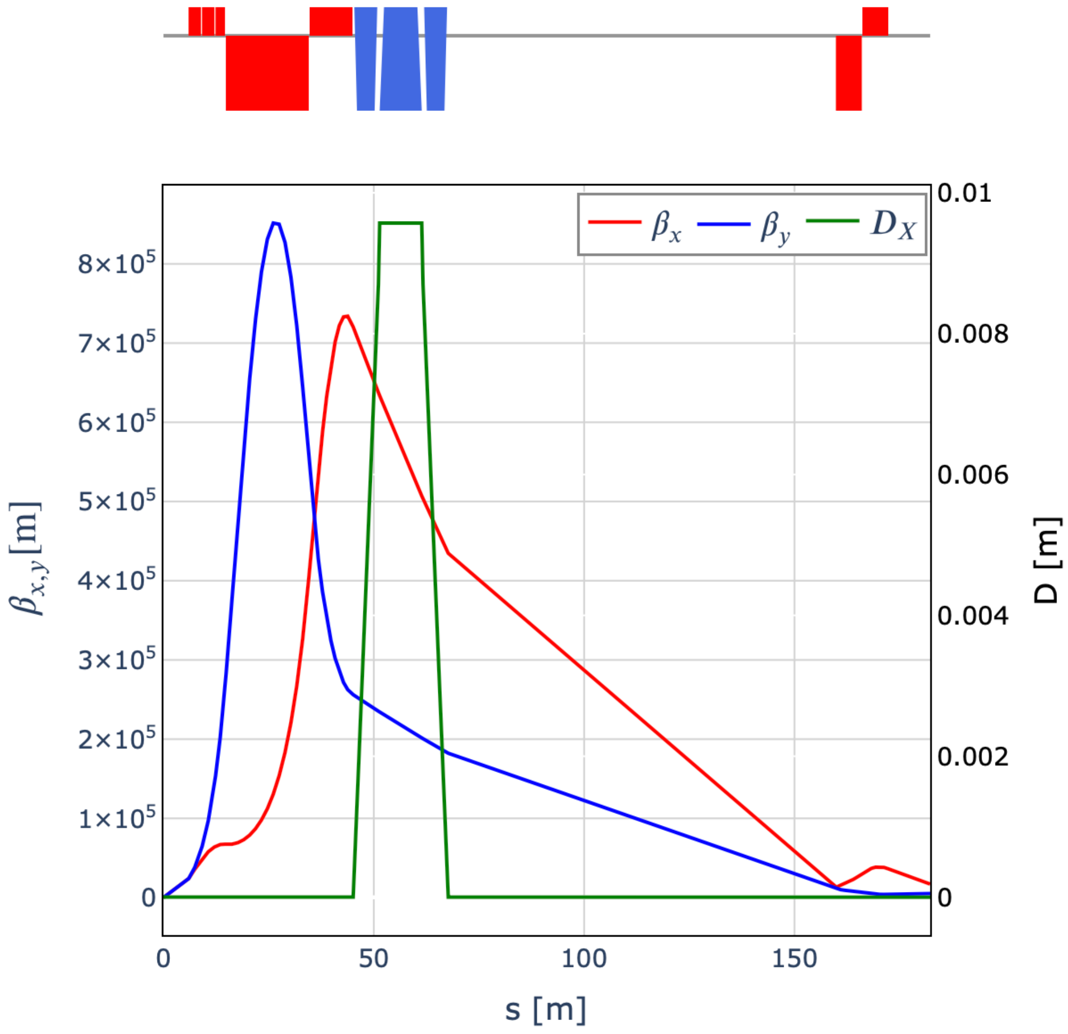
No combined-function



Aperture = 5σ + 4cm
(6cm for chicane dipoles)

Current IR lattice design & Updates

Muon Collider: Interaction region



- **Long drift** for IP ($L^* = 6m$), **triplet** for the final focusing, **chicane** to reduce the BIB, **long straight section** to smoothly reduce the β functions without increasing W functions, **2 quads** at the end to control lattice functions.

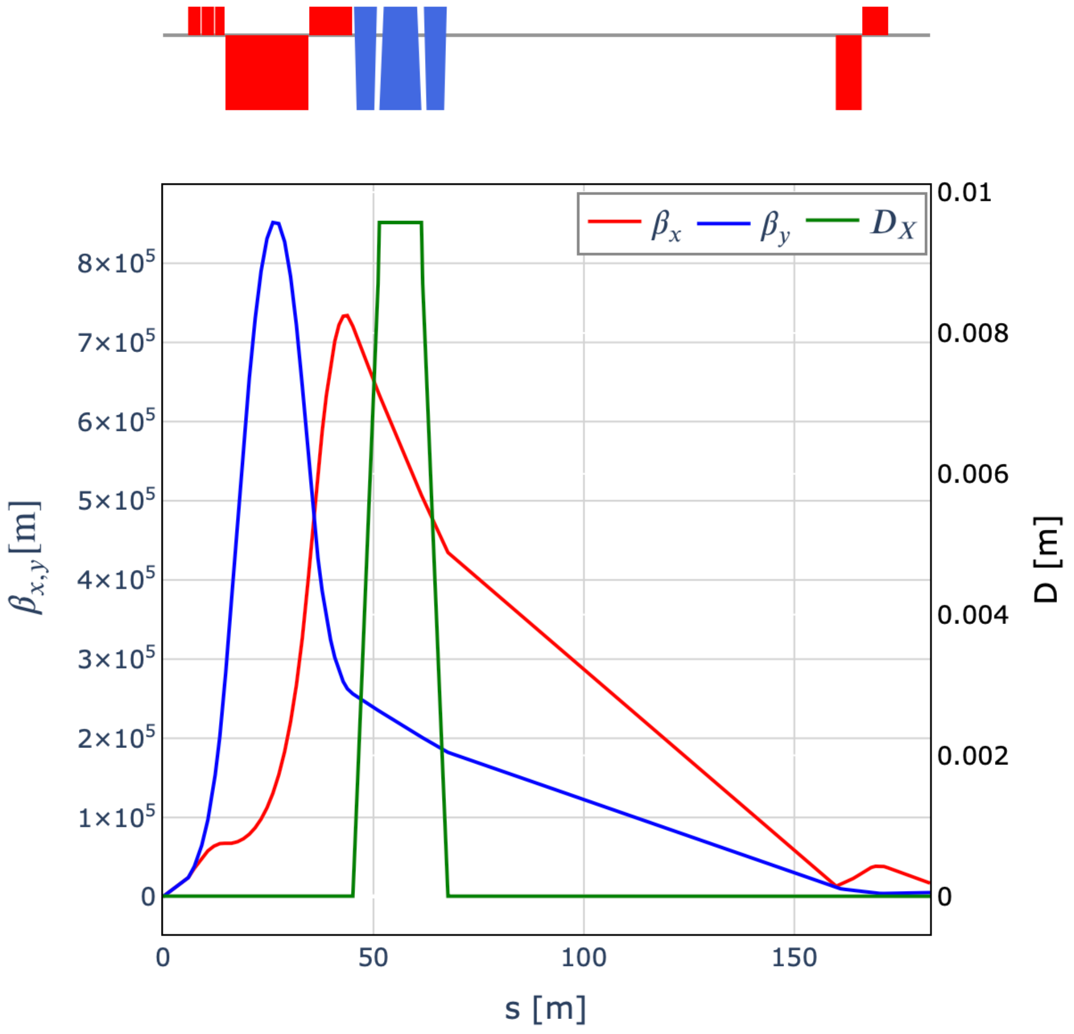
- The IR **long straight sections** result in many secondary particles from muon decay that accumulate. A **chicane** before the FF helps remove these particles as much as possible before reaching the nozzle, with **parameters depending on the BIB requirements.**

Muon Collider: Interaction region

- **No combined-function magnet** in FF triplet. IR quadrupole magnetic fields have been adapted to respect the **AG plots constraints** for HTS quadrupoles with **T = 4.5K.**
- The first quadrupole is divided into three magnets to maximize the field gradient.

Aperture = 5σ + **4**cm
(Aperture = Bore radius)

$$\sigma = \sqrt{\boldsymbol{\beta}\epsilon + \left(D\delta_p\right)^2}$$



Summary

Summary

- No significant changes to the IR lattice design since the previous MDI workshop.
- The IR quadrupole magnetic fields have been adapted to meet AG plots constraints for HTS quadrupoles with T = 4.5K, assuming an aperture = $5\sigma + 4cm$.
- Multiple iterations on the IR and CC sections to mitigate the BIB and improve momentum acceptance.
- The main difference for the IR design is the addition of a long straight section from v0.6 onwards (optics changed in CC to improve momentum acceptance).
- The IR long straight sections generate many secondary particles that accumulate. A chicane before the FF removes these particles before the nozzle, with parameters defined by BIB requirements.

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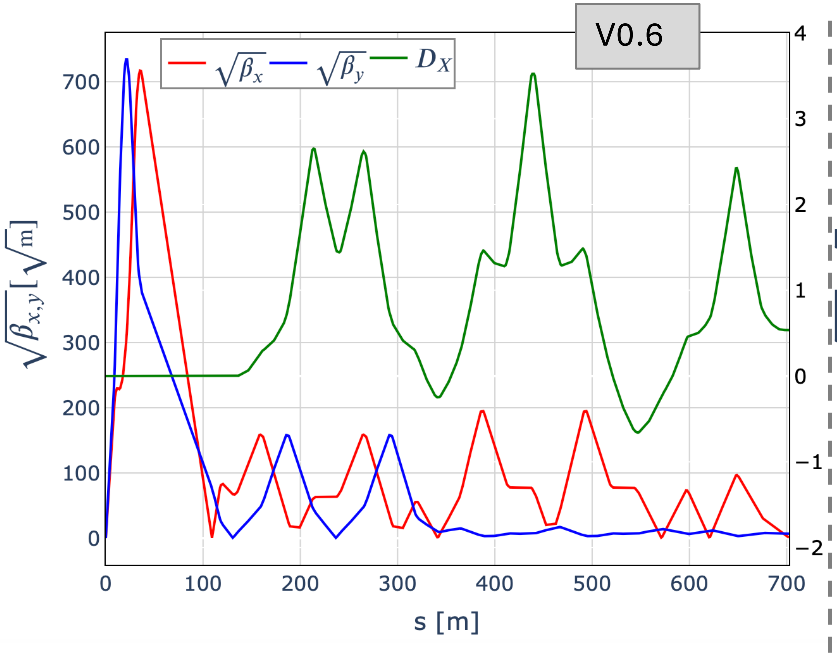
Thank you for your attention

The lattice presented is still a work in progress and subject to change in the future

Back-up slides

Summary of the collider ring versions



IR: Aperture = 5σ + **2cm**; No chicane

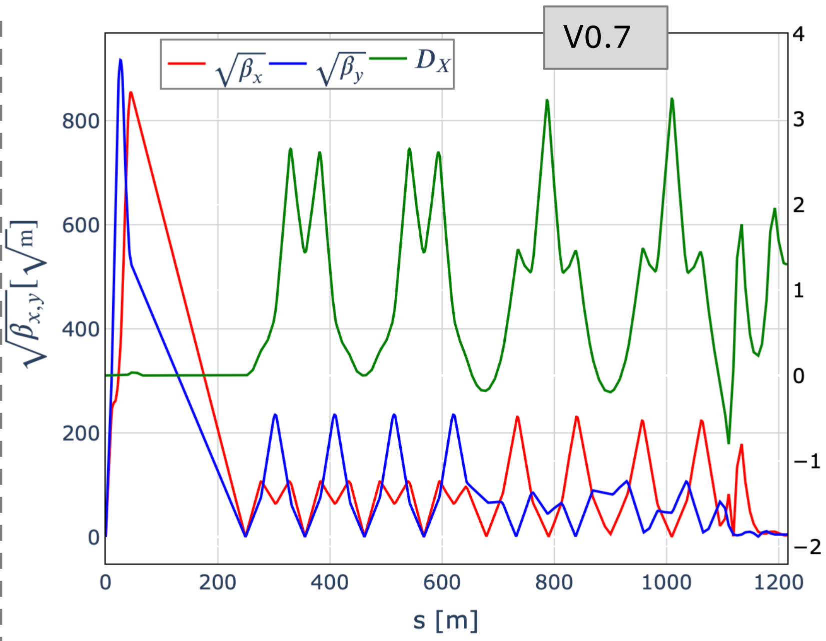
Max **B** set to 20T at the magnet aperture

CC: No Q' control in the CC

Ap. = 5σ + **2cm**

Performances:

DA~ 2.5σ/ 4.5σ for $\delta = -10^{-3}/+10^{-3}$



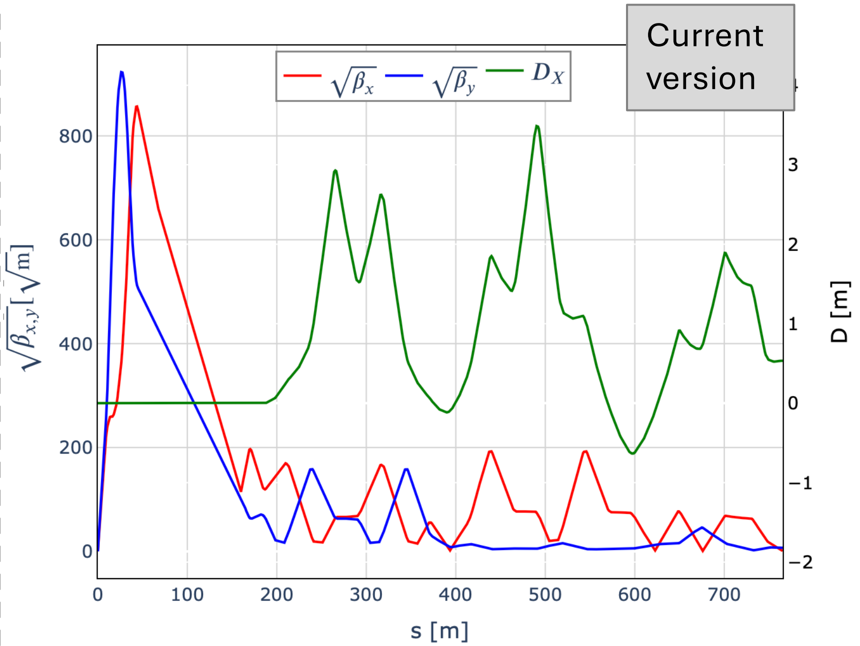
IR: Aperture = 5σ + **4cm** + chicane

Max **B** set to 20T at the magnet aperture

CC: No Q' control and huge sensitivity to phase advance, Ap. = 5σ + **4cm**

Performances:

Particles lost for $\delta = 7 * 10^{-4}$



IR: Ap = 5σ + **4cm**+ chicane + **no combined-function FF quads;** Maximum quadrupole gradients and apertures from AG plot.

CC & Arcs: not yet optimized for 4cm shielding.

Performances:

DA $\sim 2\sigma$ for $\delta = \pm 10^{-3}(1\sigma_\delta)$ for $B_{max} = 20T$

DA $\sim 2\sigma$ for $\delta = \pm 8 * 10^{-4}$

Muon Collider: Interaction region

Montague chromatic functions:

$$W = \sqrt{A^2 + B^2}$$

$$A = \frac{d\alpha}{d\delta} - \frac{\alpha}{\beta}\frac{d\beta}{d\delta} \qquad B = \frac{1}{\beta}\frac{d\beta}{d\delta}$$

- W describe variations of Twiss α and β for (small) momentum offsets.
- The very small β^*at the IP induce very large β-function in the strong focusing FF quadrupoles, resulting in **significant chromatic effects**.

→ **Very large W functions** at the end of the IR.

→ Need for a local Chromatic Correction section.