Muon collider ring

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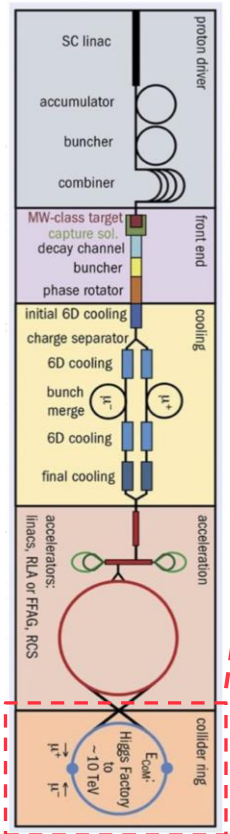
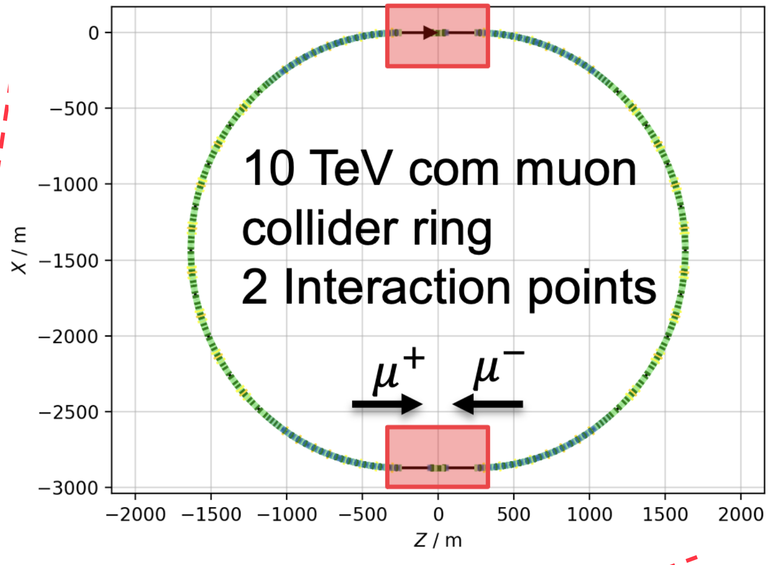
Collider ring





3 TeV: MAP project
10 TeV: work in progress

Muons:

- Muon beam production → large emittance
- Mass ~105 MeV
- Lifetime ~2.2 μs in muon rest frame

Luminosity:

$$\mathcal{L} = \frac{1}{4\pi} \frac{N_1 N_2}{\sigma_x^* \sigma_y^*} n_b f_r \, f_{hg} \frac{\gamma T_\mu}{T_{rev}}$$

$$\sigma^* = \sqrt{\varepsilon \, \beta^*}$$

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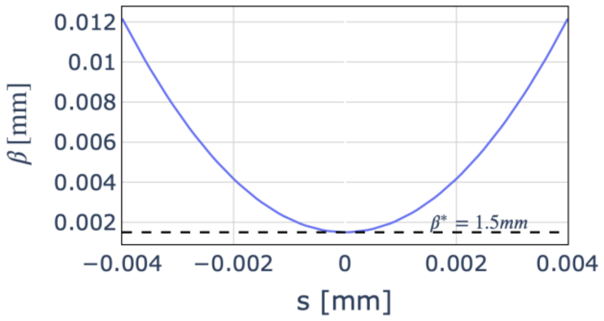
Beam properties depending on the injector complex

- Increase the bunch population
- Minimize the emittances

- Small β^* (β at the interaction point)

Hourglass effect: limitation on β^*



➢ $\sigma_z = \beta^*$

Final Focusing triplet in the interaction region:

β-function in the triplet around the IP: $\beta(s) \sim \frac{s^2}{\beta^*}$

→ Strong quadrupoles in the Final Focusing triplets with large aperture (large β-functions).

→ Strong chromatic effects.

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 geometric rms emittance	ε_L	$70\ mm$
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	$\sim 10\ km$

Muon collider: Challenges

Relative rms energy spread	δ	$0.1\ \%$
Beta function at IP	$\beta_x^* = \beta_y^*$	$1.5\ mm$

- Very **small $\boldsymbol{\beta}^*$** at IP → β of ~700-800 km in the Final Focusing (FF) quadrupoles
- **Large** relative **energy spread**

FF quadrupoles introduce large chromatic effects that must be corrected with sextupoles in a **local chromatic correction section**:

- W (Montague functions): describe variations of Twiss α and β for (small) momentum offsets.
- Q' (Chromaticity): Variation in tune with respect to momentum.

Large $\boldsymbol{\beta}$ in the FF quadrupoles:

→ Significant magnet aperture and sensitivity to unwanted multipolar components.

→ Very high magnetic field required (HTS technology) with good field quality.

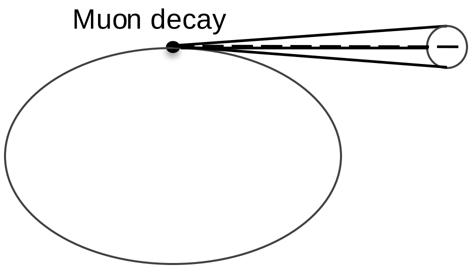
Muon collider: Challenges

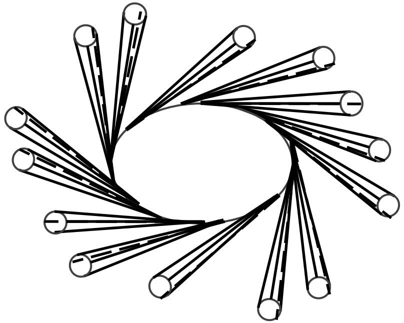
Short bunch length (1.5mm) must be maintained: $\eta = 0 \; (\frac{\Delta f}{f} = -\eta \frac{\Delta p}{p})$; $\alpha_c \sim 0 \; (\frac{\Delta r}{r} = \alpha_c \frac{\Delta p}{p})$

→ **Flexible momentum compaction (FMC) arc cells**

Short muon lifetime → Muon decay

- Ring **circumference** should be as **small** as possible → High magnetic field
- **Neutrinos** emitted in a small cone tangential to the collider ring





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  - →**Fewest possible straight sections** in the lattice: **small drifts** for the element interconnections and **long straight sections** in the **Interaction Region (IR)**
  - →**"Geoprofiler":** Tool to place the ring close to CERN so that the **exit points** from the long straights in the IR are in the **Mediterranean** Sea and in sparsely populated areas of the **Jura**.

Muon collider: Challenges

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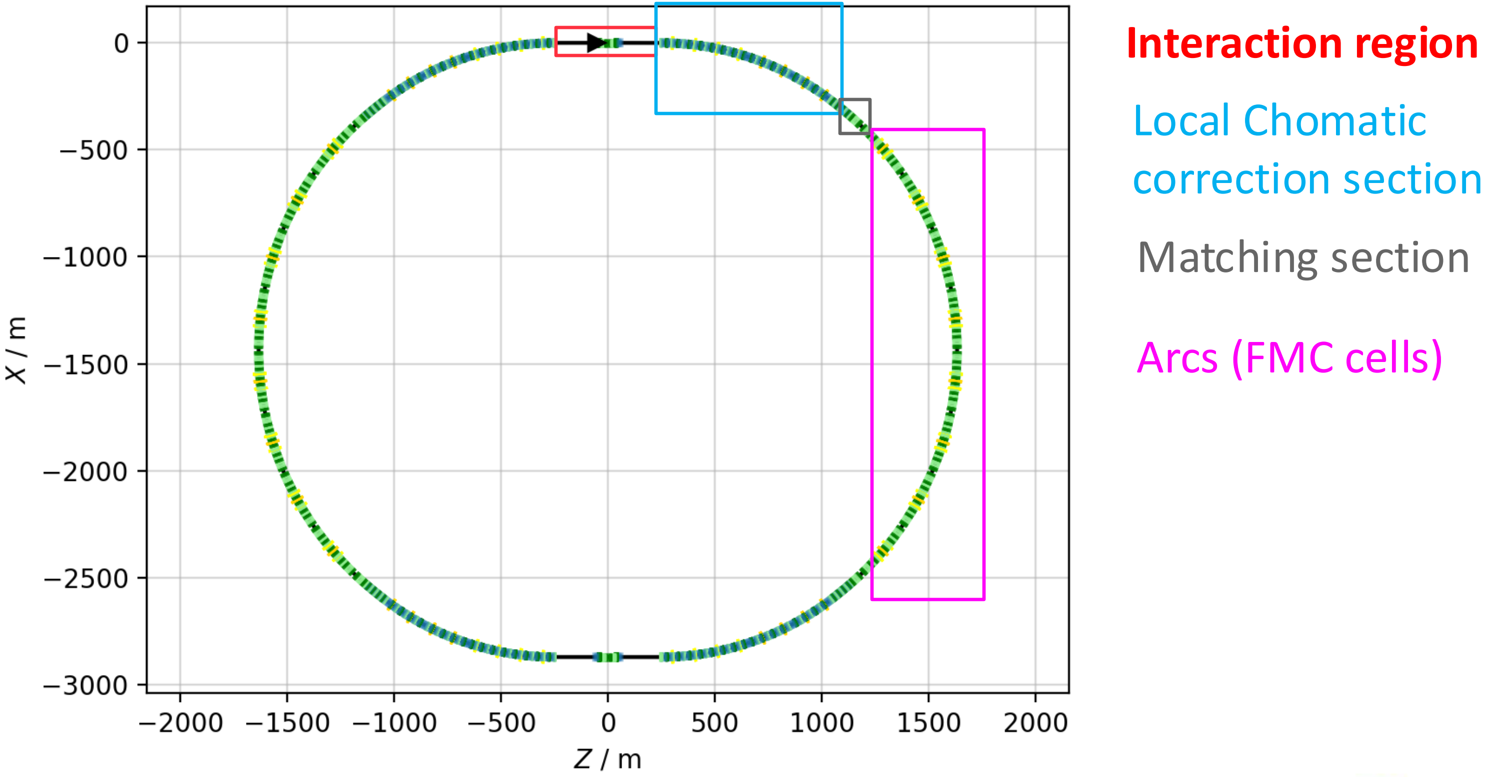
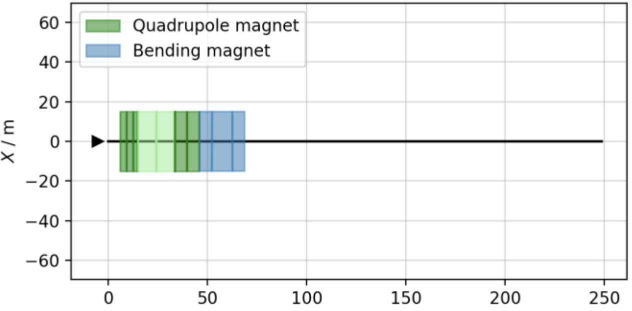
  - → **"Geoprofiler":** Tool to place the ring close to CERN so that the **exit points** from the IR are in the **Mediterranean** Sea or in the **Jura**.
- **Beam-induced background** to be mitigated and **W shielding** (~30-40mm) inside the magnets to absorb shower generated by e+/e-

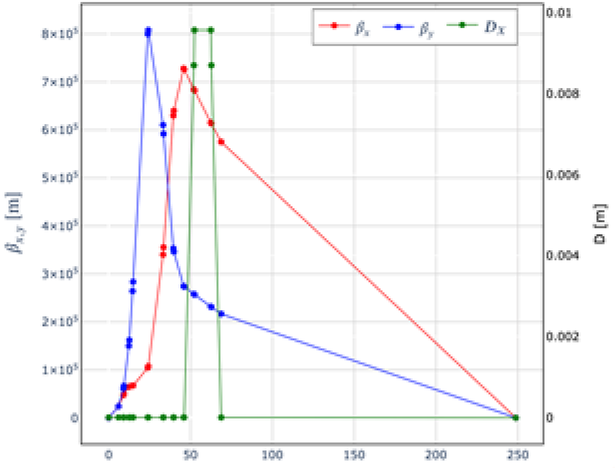
Muon collider

- 10 km collider ring
- Maximum 10 m long magnet
- Maximum field of 16 T for dipoles and 20 T for combined-function magnets
- 30 cm drift for interconnection



Muon Collider: Interaction region





- **Long drift** for IP ($L^* = 6m$), **triplet** for the final focusing, **chicane** to reduce Beam-induced background (BIB), **long straight section** to smoothly reduce the beta functions without increasing W functions.

- The **first quadrupole** is divided into **three magnets** with different field gradients (maximum field set to 20 T at the magnet aperture); **no combined-function magnet** in FF triplet.

- 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.**

Interaction region – Montague functions

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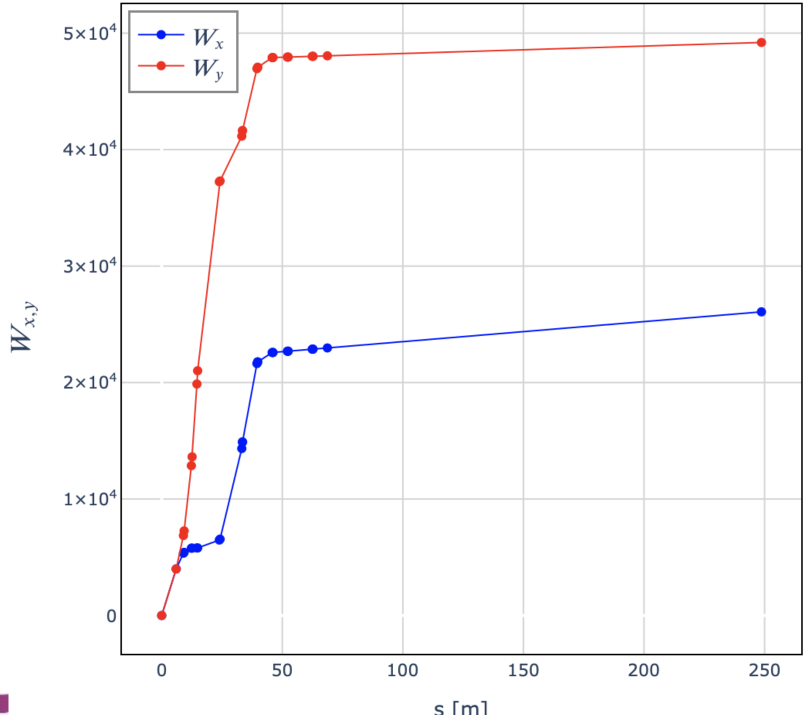
Montague chromatic functions:

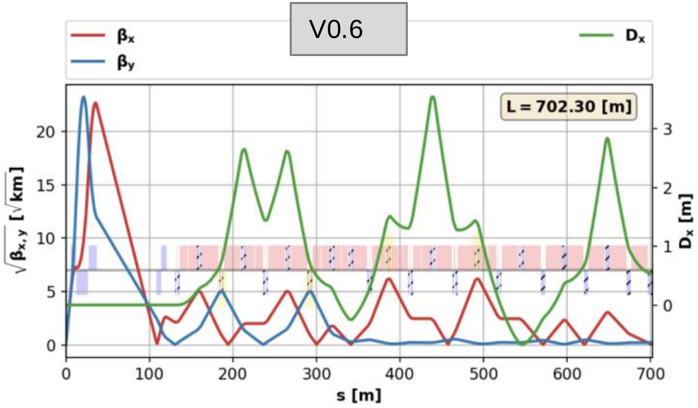
$$W = \sqrt{A^2 + B^2} \quad A = \frac{d\alpha}{d\delta} - \frac{\alpha}{\beta}\frac{d\beta}{d\delta} \quad B = \frac{1}{\beta}\frac{d\beta}{d\delta}$$

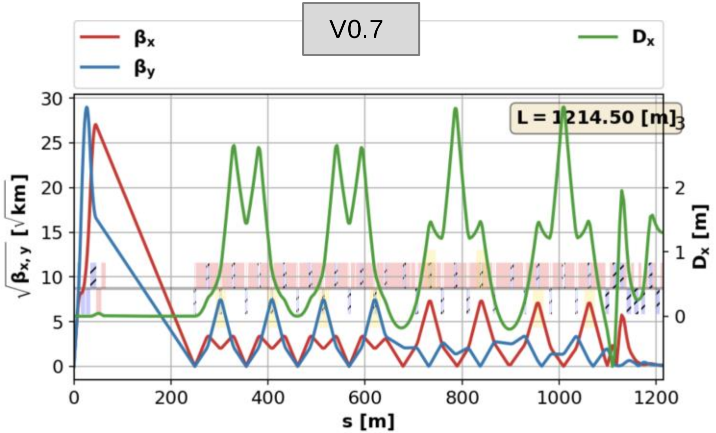
- The very small β^* at the IP induce very large β-function in the strong focusing FF quadrupoles, resulting in **significant chromatic effects**.
- **Very large W functions** at the end of the interaction region.
- Need for a **local chromatic correction section.**



Local Chromatic Correction section (CC)

- **Multiple iterations**: still a work in progress



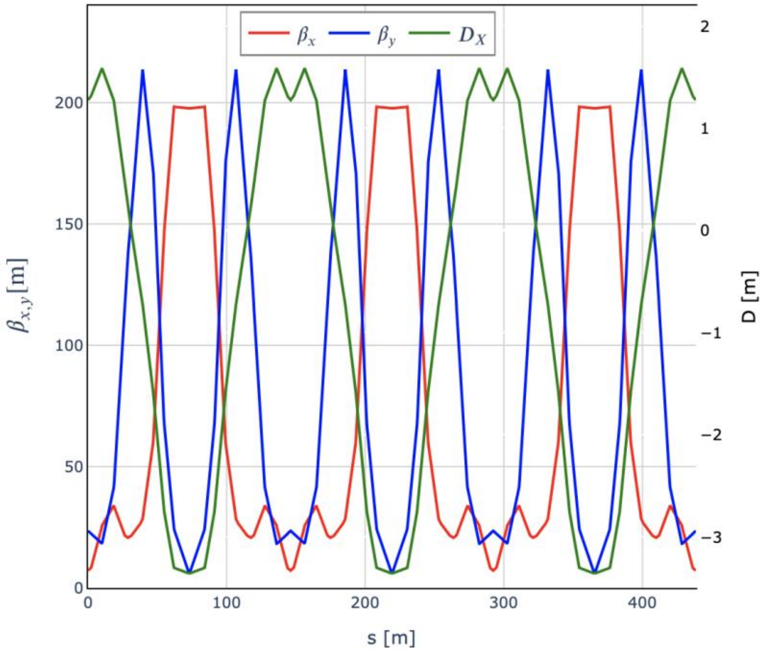


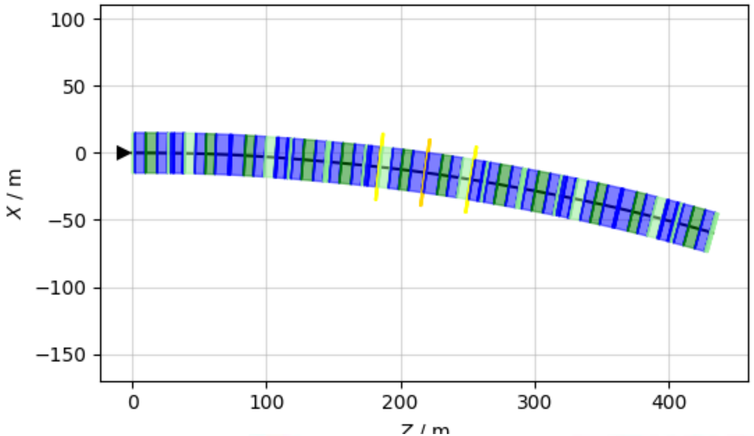
CC design from
K. Skoufaris

- **Sextupoles** at **non-zero dispersion** locations to correct linear chromaticity; put **in pairs** to cancel non-linearities.
- Sufficient dynamic aperture for on-momentum particles, but **requirements not yet met** for the **entire momentum range**.
- Dependence between the CC section and the arcs, as there is **no Q' control in the CC**.
- **Huge sensitivity to phase advance** error between the sextupoles of a pair → poor DA for small errors.
- **No** clear knobs to **control the working point** (transverse tunes) in the current lattice.

Muon collider: Arcs

- **Short bunch length** (1.5mm): $\alpha_c = 0$ → **Flexible momentum compaction (FMC) arcs.**
- The closing of the trajectory on the entire ring is controlled by the dipoles in the arcs.





- Dispersion oscillations to obtain a negative momentum compaction factor in the arcs → $\alpha_c \sim 0$ on the entire ring.
- Linear chromaticities controlled with sextupole pairs.

Summary

- **10 TeV com muon collider** envisaged as high-energy lepton collider. The short lifetime of muons and the **high luminosity** impose **strong constraints** on the **collider ring**.
- Small $\boldsymbol{\beta}^*$ **at IP** (1.5mm) → **Strong-focusing quadrupoles** necessitate a **local chromatic correction section** to maintain a sufficiently large momentum acceptance.
- **FMC cells** are used in the arcs to keep the bunch length short.
- Muon decay products necessitate using **combined-function** and **dipole magnets**. Long **straight sections are placed** to cope with the concerns about neutrino flux.
- A **chicane** in the IR allows for mitigating the **Beam-Induced background**, and **tungsten shielding** copes with heat load and radiation from muon decay products.
- Very **high magnetic fields** with strong constraints on the collider magnets.

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Thank you for your attention

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