Collider reference configuration & Radial Build for CC/IR (and arcs)

15th May 2025

Goals of the discussion

→ Agreement on a **baseline for the collider** final focus quadrupole (and possibly other magnets) radial build taking the operating temperature, cost and other constraints into account.

→ Establishment of **common design constraints** for the muon collider ring lattice (IR, CC and ARC sections), developed in agreement between the **Beam Optics and Magnet WPs**.

→ Identification of the **remaining issues and inputs** still to be provided by each WPs.

Key Questions / Issues

Magnet input:

- What are the upper limits on the performance of the SC magnets: **maximum field/gradient (or sextupolar component) vs magnet aperture** given a fixed operating temperature and cost per meter?
- What is the **element interconnection length & bending magnetic field** along the interconnection?
- What **magnet length** is practically achievable for HTS magnets?
- What is the feasibility of **reducing the wobbling period** (L_P) from 600m to 100m: require increasing the horizontal dipolar component in all the magnets. What is the practically achievable additional horizontal field in the magnets?
- How can we **tune the combined-function magnets** once they are built? Are there independent knobs for the dipolar and quadrupolar components?

Key Questions / Issues

Cryogenics input:

- What **operating temperature for HTS magnets** is compatible with cryogenic systems? Is it conceivable to have multiple cryogenic systems to enable higher operating temperatures for magnets with lower field/gradient requirements in different sections of the collider ring?
- What is feasible in terms of **tungsten shielding thickness** for heat load and radiation damage in the different sections of the collider ring? (heat load limits versus operating temperature)

Current assumptions for collider design:

→ Ap. = $5\sigma + \boldsymbol{5cm}, \mathrm{T_{op}} =$ **10K** (CC, MS, Arcs)

→ Ap. = $5\sigma + \boldsymbol{4cm}, \mathrm{T_{op}} =$ **4.5K** (IR)

Key Questions / Issues

Beam optics input:

- Where does the **current lattice design** stand in terms of magnet constraints? Are we far from what is technically feasible for the magnets? **How the magnet constraints impact the lattice performance?**
- Feasibility to adjust the design to meet the magnet constraints by slightly adapting the optics.

Other considerations:

- How many years of operation do the magnets need to sustain? (Radiation damage reaches the limits for few IR quadrupoles after 5 years)

Back-up/ Preparatory Work

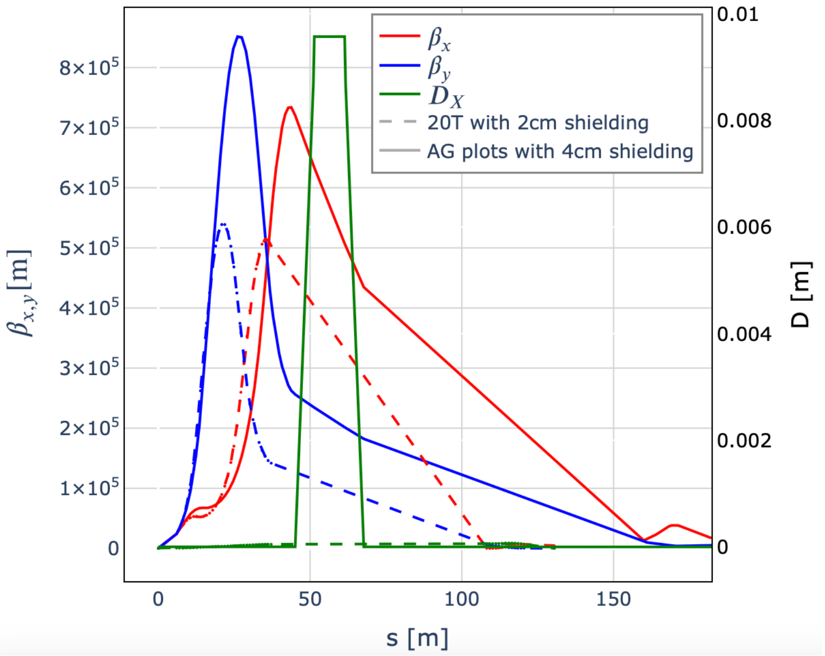
Beam optics perspective

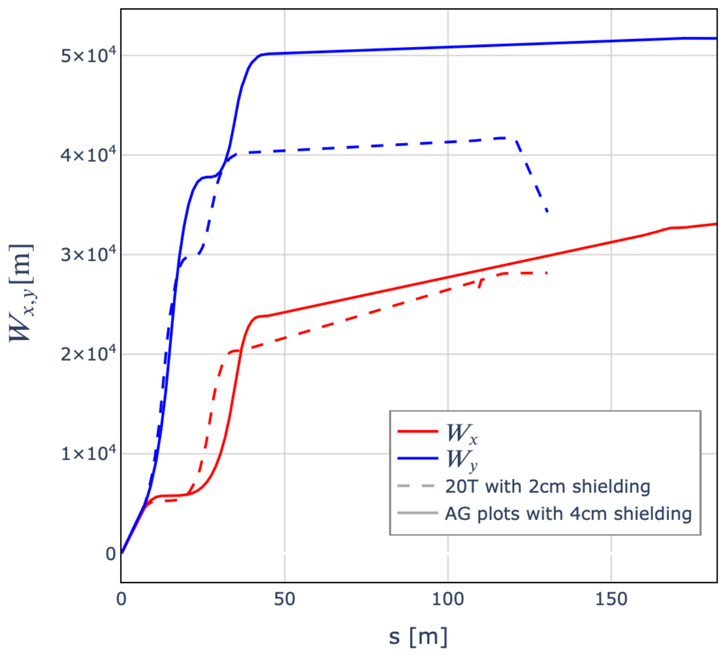
Magnets requirements → 'Technological constraints' in the design

- Highest possible dipolar and multipolar fields for large apertures.
- Excellent field quality (sensitivity to unwanted multipolar components).

Impact of magnet performance and W shielding on the lattice performance:

- Conceivable to match β^* with any given magnetic field BUT main issues from chromatic aberrations (large for small β^* and worse for smaller IR quadrupole gradients)!





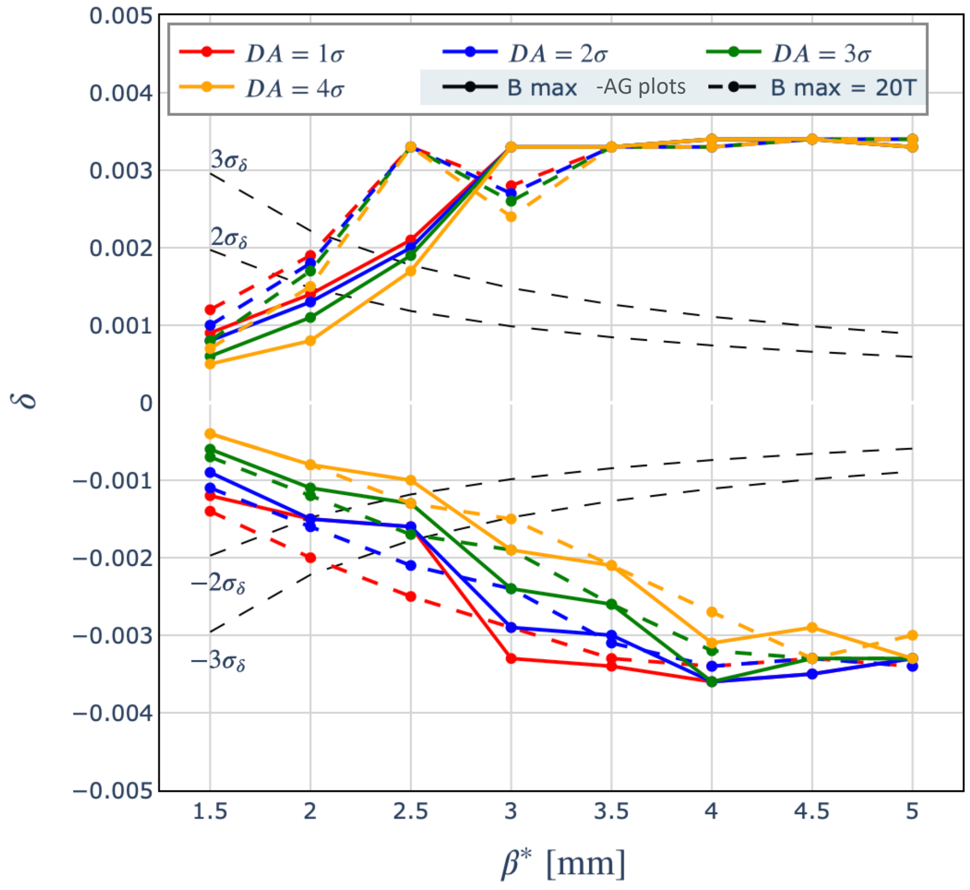
Beam optics perspective

- Sensitivity study on β^* with different magnet constraints:

  → Slightly reduced momentum acceptance with IR quadrupole fields meeting AG plots constraints compared to the results found with IR maximum quadrupole field set to 20T (for small β^*).

- No unique solution for the collider lattice: a given luminosity does not directly correspond to a lattice with specific set of magnet constraints!

  → It is not possible to define a unique set of magnet constraints that would allow to meet the target performances.



Radial build for collider arc magnets

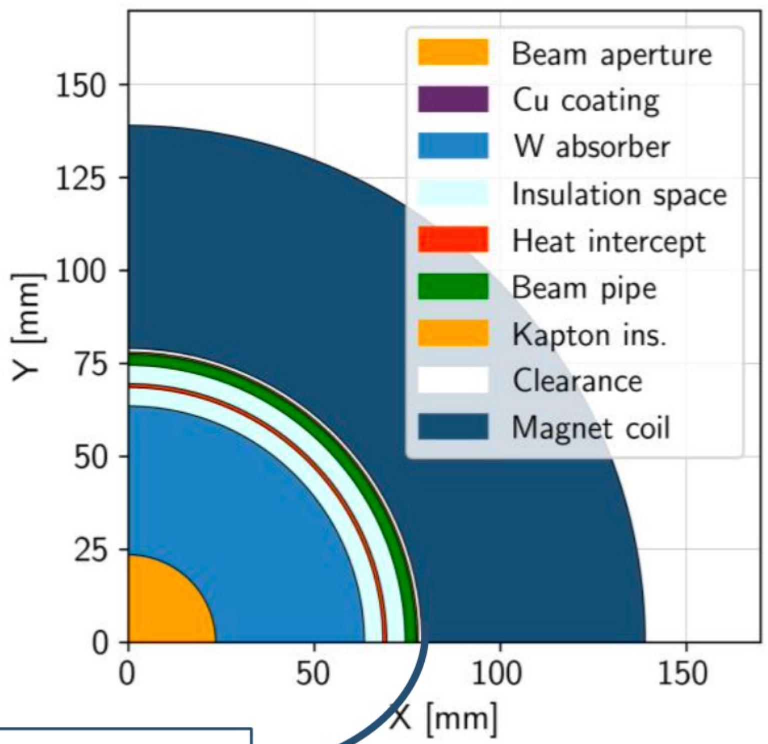
$$\text{Aperture} = \boxed{5\sigma} + \text{W shielding} + \boxed{1.51\text{cm}}$$

Optics design - work in progress { Note: in the current design, 5 σ is less than 23 mm.

Can't be reduced further?

• Beam aperture (5σ)	23.5 mm radius
• Cu layer beam screen	0.01 mm thick
• Tungsten absorber	40 mm thick
• Insulation space	5 mm thick
• Heat intercept	1 mm thick
• Insulation space	5 mm thick
• Beam pipe	3 mm thick
• Kapton insulation	0.5 mm thick
• Clearance	1 mm thick
• Coil pack*	(60 mm thick)

*thickness TBD, placeholder



Coil aperture 158 mm

P. Tavares Coutinho Borges De Sousa, https://indico.cern.ch/event/1250075/contributions/5357594/

Radiation load to the final focusing magnets

- **Limiting factor:** **total ionizing dose (TID)** in organic materials insulation, spacers etc.)
- **Design target: 5-10 MGy/y → 50 MGy** during the collider lifetime.
- We assume an **operational time of 1.2×10^7 s / year** with **5–10 years operation**.
- The **damage is cumulative**. In case of extended collider use lower limits must be taken.

Table: radial build for superconducting magnets

Shield radial build	Thickness (mm)
beam screen	0.01
shield	2.53
shield support +thermal insulation	1.1
cold bore	0.3
insulation (kapton)	0.05
clearance + liquid helium	0.01
Sum	4

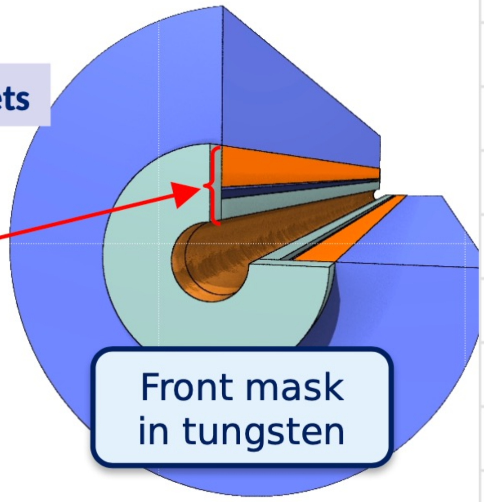


Table: radiation load for each magnet in the final focus

Name	L [m]	Shield thickness [cm]	Coil aperture (radius) [cm]	Peak TID [MGy/y]
IB2	6	4.53	16	1.3
IB1	10	4.53	16	3.1
IB3	6	4.53	16	4.9
IQF2	6	2.53	14	7.7
IQF2_1	6	2.53	13.3	4.6
IQD1	9	2.53	14.5	1.1
IQD1_1	9	2.53	14.5	3.7
IQF1B	2	2.53	10.2	6.4
IQF1A	3	2.53	8.6	3.6
IQF1	3	2.53	7	3.5

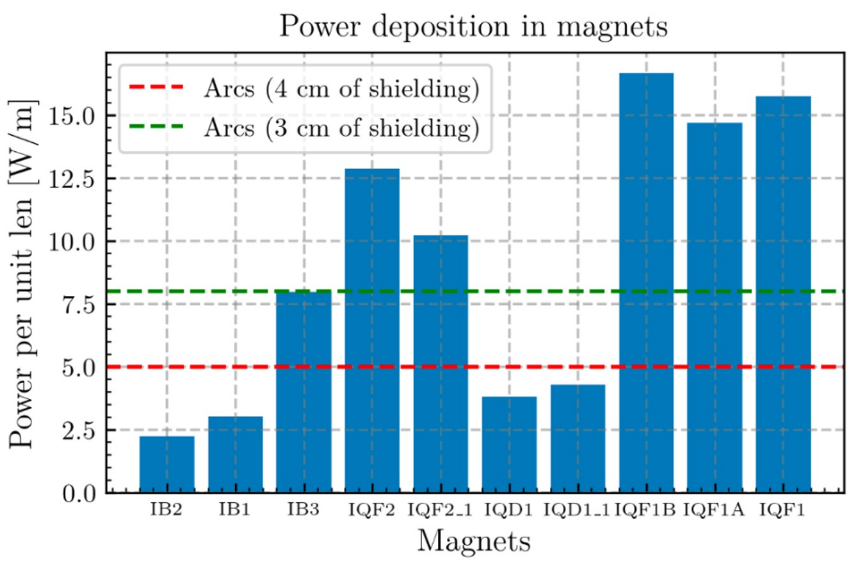
@D. Calzolari

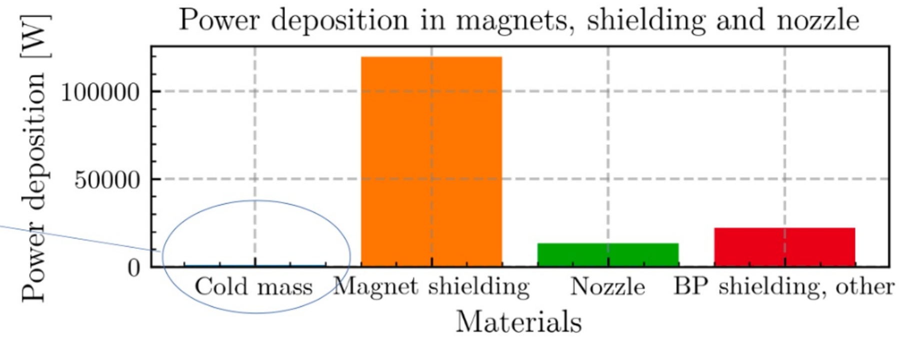
Power load to the final focusing magnets

- **Limiting factor: total power to the cold mass**
- **Design target:** 1/2% of the radiated power in the arcs, more margin in the IR?
- Decay product total power in the MDI around 160 kW → up to 15 W/m in cold mass

Table: power load for each magnet in the final focus

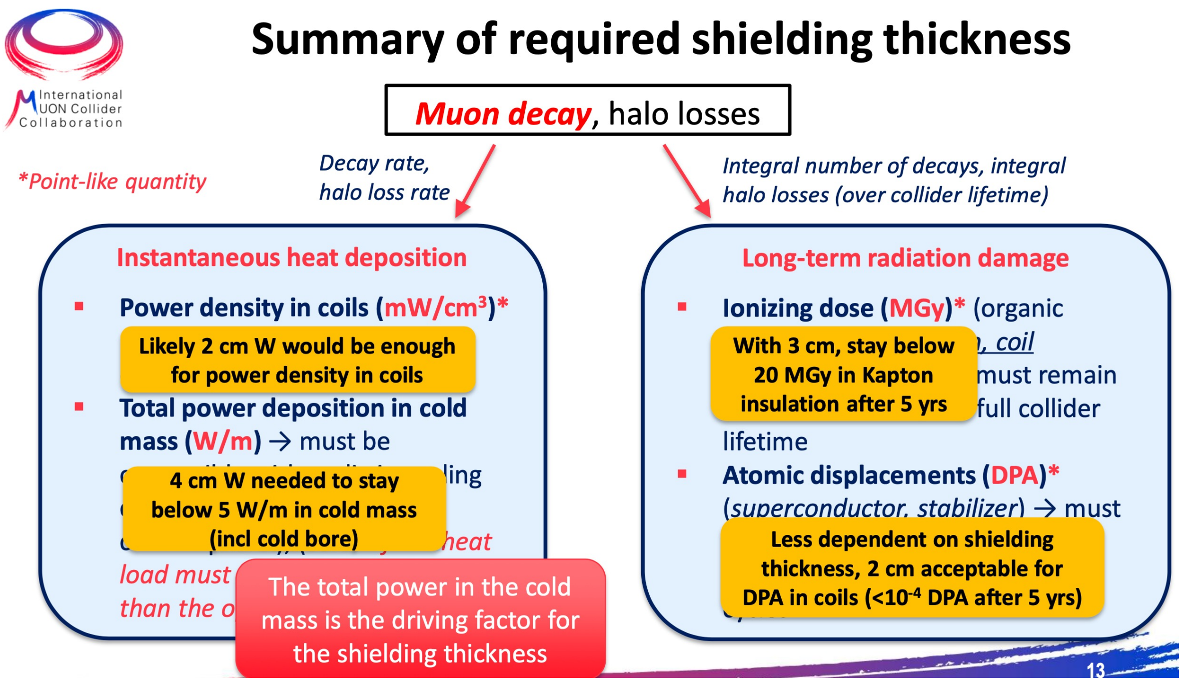
Name	L [m]	Power in element [W]	Power per meter [W/m]	Power fraction [%]
IB2	6	13.5	2.2	0.4
IB1	10	30.3	3.0	0.6
IB3	6	47.8	8.0	1.6
IQF2	6	77.2	12.9	2.5
IQF2_1	6	61.3	10.2	2.0
IQD1	9	34.3	3.8	0.8
IQD1_1	9	38.6	4.3	0.8
IQF1B	2	33.3	16.7	3.3
IQF1A	3	44.1	14.7	2.9
IQF1	3	47.2	15.7	3.1



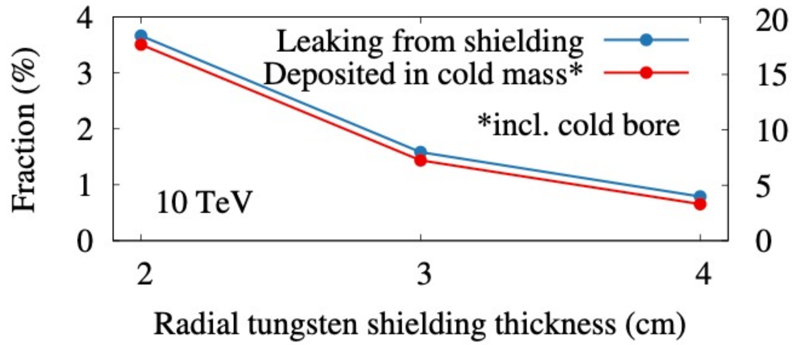


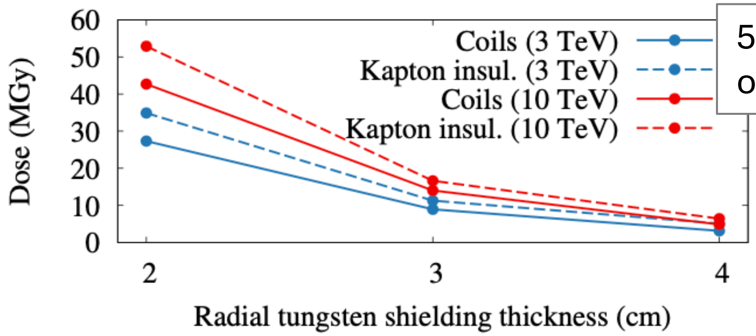
Power deposition & radiation damage Arc magnets

- Limiting factor for the arcs: power load to the cold mass
- Initial assumption: 4 cm shielding for cooling requirements
- If HTS magnets at higher T_{op}(20K?): **4cm → 3cm** for shielding thickness?

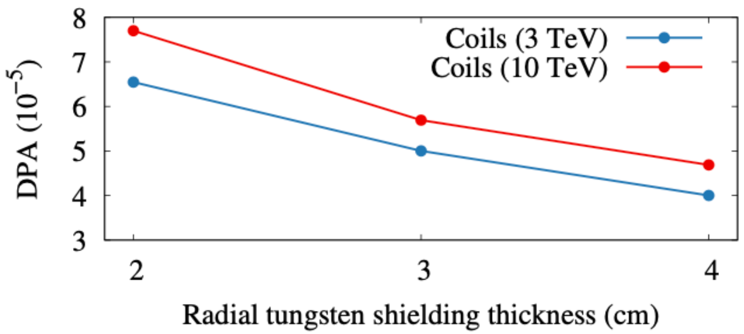


A. Lechner , https://indico.cern.ch/event/1250075/contributions/5342853





5 years of operation



A. Lechner et al., *Radiation shielding studies for superconducting magnets in multi-TeV muon colliders*, IPAC24