

UNIVERSITÀ DEGLI STUDI DI MILANO







COMBINED-FUNCTION MAGNETS FOR A MUON COLLIDER

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1. Introduction

In the scenario of the Muon Collider, the short muon lifetime (2.2 μ s at rest) poses several challenges in developing magnets, RF systems, targets, shielding, and cooling. One major concern is the **flux of neutrinos** produced by muon decay in the collider ring, which necessitates minimizing **straight sections**. This constraint makes conventional FoDo cells unsuitable, requiring the development of combined-function magnets that integrate **bending with (de)focusing or chromaticity correction functions**.



In this work, the technological limits of this new type of magnets will be presented, and a feasibility study will be illustrated for the main arc dip+quad combined-function magnet.

2. Performance Limits

• Quadrupole inside a dipole



For each temperature:

Main assumptions:

- ReBCO aspirational cost 2500 EUR/kg
- 400 kEUR/m for each magnet
 (coil + iron + structures + labor)



- Cos-theta cross section in the approximation of a sector coil.
- **Python-ANSYS interface** to automatically run many different geometries and optimization loops.



- Maximum coil width: 80 mm each
- Maximum allowed stress on the coils: 400 MPa
- Fujikura FESC AP Tape, cable with filling factor of 0.011
- Rigid structure for the mechanical simulations



These graphs show the **performance limit curves** for **QUAD-DIP COMBINED FUNCTION MAGNETS** at 4.5K, 10K, and 20K, in plots of dipole magnetic field vs. quadrupole gradient. Each **curve of a different color** corresponds to a **different magnet aperture**. For a fixed aperture, **the area under the curve is the allowed area** for identifying a target design, while **the area above the curve is the prohibited area** where some maximum limit (stress, margin, quench protection or cost) will be exceeded.

3. Feasibility Study One of the most promising technologies available today is Nb₃Sn cables, while a lot of R&D is still required for HTS. What performance can be achieved with a combined-function quad+dip magnet using this cable? How far are we from meeting the beam optics requirements?

Removing the constraint of having the quadrupole inside and the dipole outside, the study revealed that the best configuration is having a quadrupole inside and a combined function outside with $B1[T] / (B2[T/m]*R_{aperture}) = 1.4$, that means with a stronger dipolar component.



4. Extension to Sextupoles

The same work can be done for **SEXT-DIP COMBINED FUNCTION MAGNETS**, which are essential in the arc and in the chromaticity correction and matching sections. Below are the plots with the limit curves for B1+B3 magnets, obtained using the same assumptions and method used for B1+B2 magnets:



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Conclusion: These plots represent the starting point to redefine the requirements for the combined-function magnets. The study on the specific design will continue to explore different configurations and to prove the reliability of the limit curves.

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