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## International particle Accelerator Conference 2024 (Nashville)

### Progress in the Design of the Magnets for a Muon Collider

S.S. Fabbri, Muon Magnets Working Group (author list to be expanded explicitly)

Magnets have been identified as one of the critical technologies for a proton-driven Muon Collider. Within the scope of the International Muon Collider Collaboration we have progressed in the review of requirements, and the development of concepts towards the initial engineering of several of the most critical magnets identified from our previous work. In this paper we present an update of the accelerator magnet configuration for all the parts of the Muon Collider complex, from muon production to collision. We then give details on the specific technologies that have been selected as baseline. Overall, it is clear that a Muon Collider requires very significant innovation in accelerator magnet technology, mostly relying on the success of HTS magnet development. We include in our description a list of options and development staging steps intended to mitigate technical, cost and schedule risk.

### Radiation load studies for the proton target area of a multi-TeV muon collider

Jerzy Mikolaj Manczak, Claudia Ahdida, Luca Bottura, Daniele Calzolari, Rui Franqueira Ximenes, Alessandro Frasca, Anton Lechner, Alfredo Portone, Chris Rogers, Francisco Javier Saura Esteban, Daniel Schulte

Muon production in the multi-TeV muon collider studied by the International Muon Collider Collaboration is planned to be performed with a high-power proton beam interacting with a fixed target. The design of the target area comes with a set of challenges related to the radiation load to front-end equipment. The confinement of the emerging pions and muons requires very strong magnetic fields achievable only by superconducting solenoids, which are sensitive to heat load and long-term radiation damage. The latter concerns the ionizing dose in insulation, as well as the displacement damage in the superconductor. The magnet shielding design has to limit the heat deposition and ensure that the induced radiation damage is compatible with the operational lifetime of the muon production complex. Finally, the fraction of the primary beam passing through the target unimpeded poses a need for an extraction channel. In this study, we use the FLUKA Monte Carlo code to assess the radiation load to the solenoids, and we explore the possible spent proton beam extraction scenarios taking into account the constraints stemming from the beam characteristics and the required magnetic field strength.

### Transient finite-element simulations of fast-ramping muon-collider magnets

Dominik Moll, Jan-Magnus Christmann, Laura A.M. D'Angelo, Herbert De Gersem, Marco Breschi, Luca Bottura, Fulvio Boattini

Conceptual studies for a muon collider identify fast-ramping magnets as a major design challenge. Rise rates of more than 1 T/ms are attainable with normal-conducting magnets, incorporating iron yokes to make sure that stored magnetic energies and inductances stay below reasonable thresholds. Moreover, for energy efficiency, the magnets need to exchange energy with capacitors, such that the electric grid only needs to compensate for the losses. The design of such magnet systems is based on two- and three-dimensional finite-element models of the magnets coupled to circuit models of the power-electronics equipment. The occurring phenomena necessitate nonlinear and transient simulation schemes. This contibution presents the analysis of a two dimensional, non linear and time transient analysis of a bending magnet, energized by a switched resonance capacitor-based circuit which generates a symmetrical current pulse of few ms. The magnet's yoke is represented by a homogenized material refraining from the spatial discretization of the individual laminates, but nevertheless representing the true eddy-current losses. The hysteresis losses are estimated in a post-processing step.

**Conceptual design of the HTS split coil test facility for the Muon Collider cooling section**

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The cooling section of the Muon Collider requires a number of solenoidal coils of various diameters (0.05-2 m) and fields (2-60 T). An unusual feature of the cooling section is that the RF cavities operates under the large magnetic fields and field gradients generated by the focusing elements. Here we present the design of a test facility based on split coils, wound with HTS, to study the performance of RF cavities under magnetic field. The main characteristics are: 330 mm free room temperature bore, uniform 7 T field along 300 mm on axis, coils energized with parallel or antiparallel field: this last configuration provides a gradient field of about 40 T/m. The use of HTS in form of REBCO tape enables magnet operation at 20 K and cooling via solid conduction by cryocoolers. This facility will be a first prototype of the cooling cell magnets that are being designed in cryogen-free layout at 20 K for energy saving and will allow to anticipate system integration concepts. The conceptual design of the facility is almost frozen and the engineering design is well under way. If we get financial support by 2025 we can commission the facility in 2027.

## International Conference on Magnetism 2024 (Bologna)

**Transient modeling of fast-ramping normal-conducting muon-collider magnets**

Dominik Moll, Jan-Magnus Christmann, Laura A.M. D'Angelo, Herbert De Gersem, Marco Breschi, Luca Bottura, Fulvio Boattini

Conceptual studies for a muon collider identify fast-ramping magnets as a major design challenge. The required field ramp rates up to 4.5 kT/s pose a grave obstacle for the use of superconducting coils for several reasons: performance limitations, field quality, as well as energy efficiency. A feasible alternative is provided by energy-efficient normal-conducting magnets and high efficiency energy storage and power management . The design of such magnet systems is based on two- and three-dimensional finite-element representations of the magnets coupled to circuit models of the power-electronics equipment. The occurring phenomena necessitate nonlinear and transient simulation schemes. This contribution presents a two-dimensional, nonlinear and time-transient analysis of different bending magnets energized by a switched resonance capacitor-based circuit, which generates a symmetrical current pulse of a few ms. The magnet's yoke is represented by a homogenized material refraining from the spatial discretization of the individual laminates, but nevertheless accurately representing the eddy-current and hysteretic losses.

## Applied Superconductivity Conference 2024 (Salt Lake City)

**Muon Collider Magnets - Design, Research and Development Status**

L. Bottura, F. Boattini, B. Caiffi, S. Fabbri, S. Mariotto, L. Quettier, M. Statera, and the Muon Magnets Working Group (author list to be expanded explicitly)

A Muon Collider is an exciting option for a discovery machine at the energy frontier, one of the priority R&D lines within the scope of the European Strategy for Particle Physics (ESPP), also appearing prominently in the recommendation of the US Particle Physics Project Prioritization Panel (P5). Magnets for the various areas of the collider complex pose grand challenges, and have been identified as crucial technology. The main performance demands and an initial selection of technology options that could meet such demands have been reported in previous work. In this paper we provide a general update on the advances in the conceptual design and associated R&D work, focusing on the areas of most significant progress. We also expand on the timeline of the development, the crucial milestones, and options for staging.

**Challenges and Perspectives of the Muon Collider Ring Superconducting Magnets**

B. Caiffi, L. Alfonso, A. Bersani, L. Bottura, S. Farinon, F. Mariani, S. Mariotto, D. Novelli, A. Pampaloni, T. Salmi and the Muon Magnets Working Group (author list to be completed)

The International Muon Collider Collaboration (IMCC) has been formed with the aim of delivering a feasibility study on a Muon Collider facility, as recommended by the European Strategy for Particle Physics and supported by the European Union through the Grant Agreement 101094300. Such facility would allow to study frontier physics with a 10 km collider ring and a muon center of mass energy of ~10TeV. Several technical challenges must be faced due to the short lifetime at rest of such particles (2.2 µs): a compact collider ring is then mandatory to maximise the number of interactions, requiring the highest magnetic field achievable. Furthermore, a large aperture is needed for the magnets to host the shielding of the decay products heat deposition. Finally, combined magnets must be used, to minimise the length of the straight sections and consequently the radiation hazard caused by the collimated neutrino beams. All these constraints require to exploit cutting edge technology for all the components, especially for the superconducting magnets.
In this contribution, we will present the main challenges of such magnets, focusing on the performance limits of the available technology and the possible design choices. The pros and cons of the NbTi and Nb3Sn LTS material as well as the ReBCO HTS will be analysed, comparing costs, mechanical structure feasibility and ease of protection from quench, taking into consideration also the sustainability of the cooling and the compatibility with the beam dynamics constraints. The general work-plan overview will be illustrated and a tentative schedule discussed.

**Preliminary Design of a Block-Coil Magnet for the Muon Collider Ring.**

L. Alfonso, A. Bersani, L. Bottura, B. Caiffi, S. Farinon, F. Mariani, S. Mariotto, D. Novelli, A. Pampaloni, T. Salmi and the Muon Magnets Working Group (author list to be completed)

In the framework of the IMCC (International Muon Collider Collaboration), a feasibility study for a collider ring 10 km long with muons having a center of mass energy of ~10 TeV is currently being studied. The superconducting magnets represent one of the most challenging components of the collider stage of such a facility: indeed, the need for high fields, large apertures and dipole + quadrupole combined function require technological choices at the edge of the status of the art. These requirements arise from the short lifetime at rest of the muons, 2 µs, which brings the need for a compact collider to maximize the luminosity and large bore magnets to accommodate adequate shielding for the decay products. Furthermore, long straight sections must be avoided to mitigate the dose hazard induced by the collimated neutrino beams produced by the muon decay, hence dipoles and quadrupoles must be combined in the same magnets. In this contribution we will present the preliminary 2D design of a superconducting magnet based on the block-coil concept that meets the requirements needed for the muon collider ring, focusing both on the electromagnetic and mechanical aspects.

**Preliminary Electromagnetic and Mechanical Design of a Cos-theta Dipole for the Muon Collider Project.**

F. Mariani, L. Alfonso, A. Bersani, L. Bottura, B. Caiffi, S. Farinon, F. Mariani, S. Mariotto, D. Novelli, A. Pampaloni, T. Salmi and the Muon Magnets Working Group (author list to be completed)

Within the framework of the International Muon Collider Collaboration (IMCC), an innovative feasibility study on a Muon Collider accelerator complex is currently under development, granted by the European Union through the Agreement 101094300. The proposed goal aims to develop a 10 km collider ring accelerating muons at approximately 10 TeV in the center-of-mass frame. To achieve this target, several requirements on the collider design arise to maximize the luminosity despite the short lifetime of this type of particle at rest. Despite being operated in steady-state mode, the superconducting magnet dipoles of the main collider are presently evaluated as the most challenging technological development of the design study. High levels of magnetic field above 10 T are presently foreseen with a magnet bore diameter of at least 150 mm to accommodate a tungsten shielding for the muon decay heat deposition. To minimize the radiation dose, coming from the collimated neutrino beams, different types of combined dipole and quadrupole are also considered in the lattice reducing the straight sections in the collider at the expense of the magnet performances and feasibility. An analytical analysis of possible magnet performances with the available technology has been already developed suggesting different working points for the magnet design. In this contribution, a first proposal of 2D cos-theta electromagnetic and mechanical designs is provided comparing the analytical approach with FEM-optimized configurations. Nb3Sn and HTS superconducting magnet designs have been evaluated to estimate the maximum possible expected performances of the collider, minimize the magnet cost, and deal with the requirements for the cryogenic cooling of the entire accelerator complex.

**A new approach to analytical and numerical analysis of dipole and quadrupole performance limits for a Muon Collider**

D. Novelli, L. Alfonso, A. Bersani, L. Bottura, B. Caiffi, S. Farinon, F. Mariani,
S. Mariotto, A. Pampaloni, T. Salmi and the Muon Magnets Working Group (author list to be completed)

In accordance with the guidelines set forth in the Updated European Strategy for Particle Physics [1], the International Muon Collider Collaboration [2] has been initiated to assess the feasibility of a muon collider facility with a center-of-mass energy of 10 TeV [3]. The primary challenges stem from the brief muon lifetime at rest, which is limited to 2.2 µs. Addressing this demanding condition necessitates the incorporation of advanced technologies in magnets, RF systems, targets, shielding, and cooling [4]. To minimize collimated neutrino beams resulting from muon decay and reduce the impact of radiation background around the facility, the straight sections in the collider ring must be minimized. Achieving this goal involves integrating beam optics quadrupoles with bending dipoles featuring a high magnetic field (> 10 T) and gradient (> 100 T/m) within a large aperture (150 mm). These stringent constraints require cutting-edge technologies in material selection, mechanical layout, quench protection, shielding, and cooling. This contribution explores the performance limits of potential candidate materials for such magnets, specifically LTS Nb3Sn and HTS REBCO, regarding the maximum field, mechanical stress, and stored energy. We present an original approach that allows us to explore the achievable phase space of parameters using both analytical expressions and the FEM software ANSYS, handled by a Python code. Using this approach, we will show the obtained results for dipoles, quadrupoles, and selections of combined function magnets.
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(PDF) A Work Proposal for a Collaborative Study of Magnet Technology for a Future Muon Collider.
[3] L. Bottura et al. "A Work Proposal for a Collaborative Study of Magnet Technology for a Future Muon Collider", arXiv: 2203.13998, https://doi.org/10.48550/arXiv.2203.13998.
[4] Accettura, C., Adams, D., Agarwal, R. et al. Towards a muon collider. Eur. Phys. J. C 83, 864 (2023). https://doi.org/10.1140/epjc/s10052-023-11889-x.

**Analytical estimation of quench protection limits in insulated, non-insulated, and metal-insulated ReBCO accelerator dipoles and quadrupoles**

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Future particle accelerators require high-field dipole and quadrupole magnets to guide the particles inside the collider ring. Magnets based on High-Temperature Superconductors (HTS) are an attractive option as they allow operation with higher magnetic field and higher operation temperature compared with the Low-Temperature Superconductor (LTS) based options. However, the HTS technology is not yet mature and one of the limiting issues presently seems to be their protection in case of an unwanted resistive transition, i.e., a quench. The quench in high-field, high-current density HTS magnets tends to lead to a relatively fast temperature rise and slowly raising resistive signal making it difficult to detect the quench and discharge magnet current in time to prevent damage by overheating. Indeed, the problem is considered so severe in traditional magnets with insulated cables that magnet designers are seeking to circumvent the problem by developing magnet technologies based on non-insulated or partially insulated (metal-insulated) winding technologies. In these cases, the magnet current can by-bass the quenched segment and the peak temperature remains lower. However, in high current density operation, also the non-insulated options will have limitations from the quench point of view and the quench temperatures should be analyzed. In this contribution we present a method for analytical estimation of the protection limits in insulated, non-insulated and metal-insulated magnet options. The equations can be used in early stages of magnet design to assess the feasibility and performance requirements of the eventual protection systems. The work stems from the International Muon Collider Study and the results shown here review the protection limits in the dipoles and quadrupoles designed for its collider ring. We discuss how different magnet design parameters such as the coil cross-section, cable composition, and operation conditions impact the protectability of the magnet. It is worth noting, that at this stage the quench analysis considers only an adiabatic estimation of the magnet peak temperature. Other potentially critical aspects such as voltages and mechanical stresses must be considered with more detailed models as the magnet designs

**Development of a ReBCO non/metal-insulated 40 T solenoid for the Muon Collider**

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In the quest to explore the fundamental properties of particles at the energy frontier, the International Muon Collider Collaboration (IMCC) has made significant progress in the conceptual design study of a Muon Collider (MC). Central to this effort is the development of the various MC's magnet systems, particularly the Ultra-High-Field (UHF) solenoids needed for the MC's final cooling stage. At this purpose, CERN recently presented a conceptual design of a 40 T solenoid characterized by very compact coils [1]. This groundbreaking magnet, featuring a 50 mm free bore with 1 % field homogeneity over 0.5 m length, operates fully superconducting at 4.2 K using ReBCO tapes. Its design comprises several tens of Non/Metal-Insulated (N/M-I) single pancakes. The pancakes are longitudinally stacked one over the other and supported radially by a stiff mechanical structure that also applies a 200 MPa radial precompression to counter Lorentz force-induced stresses. Except for a few pancakes at the magnet extremities, all the pancakes are identical with a winding outer radius of 9 cm.
This paper presents an overview of the various ongoing activities at CERN to realize this ambitious project. Key highlights include the procurement and characterization of conductors, development of specialized tools for manufacturing the pancakes and for testing the feasibility of large radial precompression on them. Additionally, we discuss the progress in developing mechanical and thermal electro-dynamics models for this magnet, strategies for of its protection in quench scenarios, and advancements in solenoid manufacturing technologies. The paper concludes with a glimpse into future plans, underlining our commitment to pushing the boundaries of particle physics research.

**Mechanical design of a ReBCO non/metal-insulated 40 T solenoid for the Muon Collider**

C. Accettura, A. Bertarelli, B. Bordini, L. Bottura, A. Dudarev, A. Kolehmainen, T. Mulder, F. Sanda, G. Vernassa

In the framework of the design studies of a Muon Collider the design of Ultra-High-Field (UHF) magnets is a crucial part, particularly for the MuC's final cooling stage. To address this, CERN has recently introduced a conceptual design for a 40 T solenoid characterized by very compact pancake coils.
Due to the high magnetic field and operating current density (approximately 600 A/mm$^2$), the Lorentz forces acting on the winding are extremely large. Consequently, the mechanical design, along with quench protection, represents the most significant challenge in the development of this magnet. An additional mechanical complexity is constituted by the strong anisotropy and low strength of, ReBCO tapes.
This article focuses on the mechanical design of the proposed 40 T. The primary objective of this design is to keep the stresses induced in the coils by Lorentz forces below materials admissible limits.
Initially, the paper presents a conceptual design based on analytical calculations relying on the application of a radial pre-compression (approximately 200 MPa) to the pancake coils by shrink-fitting, prior to energization. Subsequently, a finite element analysis is performed, introducing various nonlinearities (material, geometric, plasticity) to optimize the magnet's design. The study also investigates a hybrid solution, in which the initial coil loading is obtained by a combination of shrink-fitting and mechanical compression by a clamped conical connection based on shrink discs.
The highly anisotropic mechanical properties of the tape, which are not extensively documented in current literature, were investigated by a series of dedicated tests relying on specially designed tooling. This design and experimental testing complements the simulation efforts by allowing to derive and implement in the models more accurate material properties.

In conclusion, the proposed magnet design exemplifies a synergistic integration of experimental work and simulation efforts.

**Elasticity and Fracture Toughness of ReBCO HTS at Room Temperature and 120 K.**

G. Vernassa, G. Kermouche, J. M. Bergheau, L. Bottura, H. Felice, B. Bordini, S. Kalacska, M. Rusinowicz, S. Sao-Joao

The need for strong steady magnetic fields, above 40 T, raises several new challenges in the design of superconducting magnets. As a start, the field requested exceeds the limitations of the consolidated LTS technologies, leading us to the use of HTS technology. Besides the difficulty of making HTS magnets, the challenges at ultra-high field are found in the structural mechanics, driven by electromagnetic forces, and quench protection, due to the high stored energy density.
ReBCO, the leading candidate for ultra-high field magnets, is produced in the form of thin tapes, consisting of multiple layers of different materials with very diverse nature and properties. Understanding the elastic behavior of these materials is crucial for both the magnet design process and advancing technological development to meet end-product requirements. However, the small size of HTS makes it impractical to employ macroscopic mechanical tests for characterizing elasticity, plasticity, and toughness. An accurate characterization of the mechanical properties of the materials at the appropriate scale requires hence resorting to novel techniques.
In this paper, we propose a methodology to measure elasticity and toughness of REBCO materials, at the scale of the tape's constituents, based on nanoindentation and micropillar splitting techniques. The measurements obtained with this technique are compared to the values found in the literature and to those specified by the manufacturers.
While the field of nanomechanical testing has matured sufficiently to characterize small-scale properties of materials like REBCO at room temperature, the mechanical characterization of properties at cryogenic temperatures, approaching the operational temperatures of magnets, remains a significant challenge even today, despite its crucial importance. Therefore, we then focus on the development of the nanomechanical testing at low temperatures (120 K), and the results of the measurements are compared to those previously obtained at room temperature. The paper concludes by highlighting the main results of our initial test and the forthcoming developments in the field of nanomechanical testing to aid in the design of HTS superconductors.In this paper, we propose a methodology to measure elasticity and toughness of REBCO materials, at the scale of the tape's constituents, based on nanoindentation and micropillar splitting [ref] techniques. We then focus on the development of such nanomechanical tests at low temperatures, close to 120 K. The paper concludes by highlighting the main results of our initial test and the forthcoming developments in the field of nanomechanical testing to aid in the design of HTS superconductors.

**Thermo-Electromagnetic Design, Operation and Quench Simulations of the 40 T HTS NI Final Cooling Solenoids for a Muon Collider**

T. Mulder, G. Vernassa, B. Bordini, P. Borges de Sousa, A. Dudarev, E. Ravaioli, A. Verweij, M. Wozniak, and L. Bottura.

The Muon Collider is a proposed accelerator that aims to provide collisions of circulating beams of high-energy muons. The emittance of the muon beam needs to be strongly reduced before it can be accelerated and injected into the collider ring. This is achieved in a cooling channel. The final stage of the cooling channel contains several cooling cells each comprising a so-called 'final cooling' solenoid generating a very high magnetic field. These solenoids are key in strongly reducing the transverse and longitudinal emittance of the beam before acceleration and subsequent injection of the beam into the collider ring. In their current design, the final cooling solenoids produce a homogenous magnetic field of >40 T over a length of approximately 0.5 m and feature a stack of No-Insulation (NI) High-Temperature Superconductor (HTS) pancake coils. Their design is challenging as the stored energy density at nominal current is significant, and the magnet coils are operated near their mechanical limit. An additional challenge of using NI coil technology is that any current ramp causes a part of the current to flow radially between the coil turns during powering. This parallel path for the current increases the time needed to reach the desired field and generates additional Joule heating. Calculations are performed using an in-house developed modeling tool for NI solenoids to mature the design of the magnet's layout and determine a suitable range for its average inter-turn resistance to ensure the magnet to ramp to the nominal field within 6 hours and to limit ramp losses hence cryogenic requirements. The ramp scheme is optimized to allow a more equal distribution of ramp losses over time. Screening currents pose an issue for HTS magnets, as these currents result in additional loss, an additional error in the magnetic field profile, and a significant increase in local mechanical stress in the tape. These effects are included in the calculations and used to further optimize the magnet's geometry. Furthermore, 2D quench simulations have been performed to estimate the temperate, voltage, and Lorentz force distributions and the magnet's general behavior during a quench. These simulations are as well used to evaluate the potential use and effectiveness of several quench protection techniques, including quench back cylinders, quench heaters, and capacitor discharge quench protection techniques. This contribution will present the current state of the thermo-electromagnetic design, operational aspects, and several simulated quench cases of the final cooling solenoid of the Muon Collider.

**Preliminary Design of the Protection Circuit for the 6D Cooling Chain of the Muon Collider**

T. Mulder, S. Fabbri, G. Vernassa, B. Bordini, E. Ravaioli, M. Wozniak, A. Verweij and L. Bottura.

The Muon Collider is a proposed accelerator that aims to provide collisions of circulating beams of high-energy muons. The lifetime at rest of a muon is 2.2 µs and, when it is accelerated, the lifetime can be extended to tens of milliseconds. During this time, the created bunch of muons must be cooled, accelerated, and collided. Cooling of the muon beam, i.e. the reduction of its emittance, occurs in two approximately 1 km long 6D cooling chains with solenoids producing a central magnetic field from 2 T up to 14 T. At the end of the cooling chain, there are several final cooling cells that comprise an ultrahigh-field solenoid for minimizing the beams' emittance before injection into the collider ring. The 6D cooling chain comprises a set of 12 different repeating cells with a combination of relatively large and strongly magnetically coupled superconducting LTS and HTS solenoids. Several of these magnets are positioned near the magnets of neighbouring cells and have opposite polarities resulting in a strong magnetic field gradient in between, a lower magnetic field on the conductor and significant forces between the magnets. If a quench occurs in one magnet, this quench may very well propagate along many magnets in the chain and may require a fast discharge of the magnets in neighbouring cells. In addition, a very high asymmetric force may be acting on the mechanical support structure of the remaining powered magnets. In this contribution, preliminary calculations are made of the requirementsregarding quench protection and powering of the circuits to ensure the magnet's reliable operation and reduce the risk of quench propagation through multiple cells of magnets. In order to resist the very high asymmetric force, the constraintss of the mechanical support structures are discribed.

## Symposium on Fusion Technology (SOFT) (Dublin)

**Advances in Magnet and Shielding Designs for Fusion and High Energy Physics Applications**

L. Giannini, C. Luongo, L. Bottura, D. Leichtle, F4E (to be added)

In this paper, we present first results of an effort carried out in the framework of the EUROfusion/CERN collaboration agreement to develop models and design tools applicable to both fusion devices and accelerator magnets. The study is motivated by the declared need of of compact, high neutron fluence fusion reactors as testbeds for tritium blanket technology, requiring the development of novel magnet concepts and electromagnetic models, as well as the magnet demands of high energy physics for future experiments such as the muon collider or high intensity neutrino factories. Both applications present design challenges revolving around the trade-off between the need for very high fields over a relatively large free bore, while keeping the coils sufficiently far away and properly shielded from radiation to limit heat load and damage. The present focus is on creating design models and tools for superconducting solenoids built exclusively with high-temperature superconductors (HTS), or in a hybrid configuration with low-temperature superconductors (LTS). We use the pinch solenoid magnets for a mirror fusion machine as a case study. The magnetic field requirements and configuration, material limits, structural constraints, and shielding properties are considered while using an optimization model to scan and systematically size the coil/shield combination. The investigation involves conductor selection, mechanical analyses and cooling schemes, using. Moreover, we examine the optimization of magnet stability in operation, surveying radiation-shielding materials and innovative shielding concepts. Similarities of design challenges between fusion devices and accelerator magnets are highlighted.