

# OPEN-MIDPLANE DIPOLES FOR A MUON COLLIDER\*

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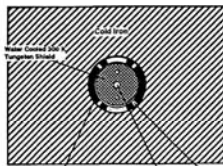


## Abstract

For a muon collider with copious decay particles in the plane of the storage ring, open-midplane dipoles (OMD) may be preferable to tungsten-shielded cosine-theta dipoles of large aperture. The OMD should have its midplane completely free of material, so as to dodge the radiation from decaying muons. Analysis funded by a Phase I SBIR suggests that a field of 10-20 T should be feasible, with homogeneity of  $1 \times 10^{-4}$  and energy deposition low enough for conduction cooling to 4.2 K helium. If funded, a Phase II SBIR would refine the analysis and build and test a proof-of-principle magnet.

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## Motivation for Open Midplane Dipole Design



- Superconducting coils in muon collider dipoles are subjected to a large number of decay particles (a few kW/m) from short lived muons. One way to protect the coils is to use Tungsten liner.
- However, that increases size of the magnet.
- Angular distribution of the decay particles is highly anisotropic with a large peak at the midplane (Mokhov).
- In previous open midplane dipole designs were trapped in non-superconducting material at the midplane. Different versions of this design have been examined earlier by M. Green and P. McIntyre, etc.

Conventional cosine theta design with Tungsten Liner

In the proposed open midplane design, there will be no structure at the midplane.

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## Why a True Open Midplane Design?

By open midplane, we mean truly open midplane:

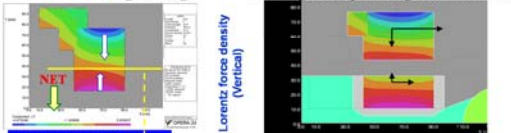
- Particle spray from detector deposit energy in a warm (~80 K) absorber sufficiently away from the superconducting coils and support structure.
- In some earlier "open midplane designs", although there was "no conductor" at the midplane, there was some "other structure" between the upper and lower halves of the coil.
- Those designs, though avoided a direct hit from primary shower, created secondary showers in that "other structure". The secondary shower then deposited a significant amount of energy in the superconducting coils.
- Earlier designs, therefore, did not work as well in protecting coils against large energy deposition.

## Challenge: How to design a magnet where coils on either side of the midplane repulse each other?

- > In conventional designs the upper and lower coils rest (react) against each other. This does allow structure free midplane.
- > In a truly open midplane design, the target is to have no structure between upper and lower coils.

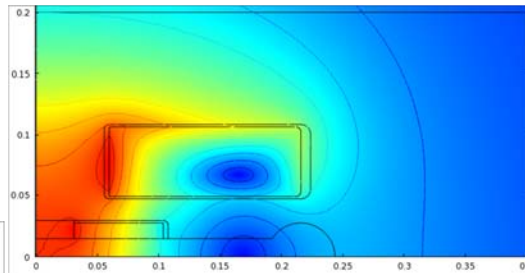
Original Design

New Design Concept to navigate Lorentz forces

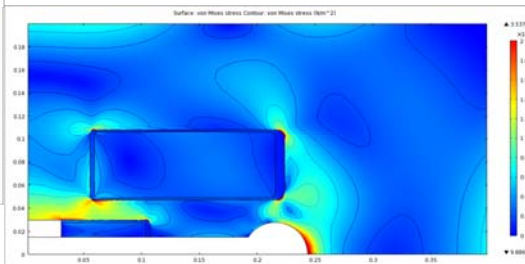


Since there is no downward force on the lower block (there is slight upward force), we do not need much support below if the structure is segmented. The support structure can be designed to deal with the downward force on the upper block using the space between the upper and the lower blocks.

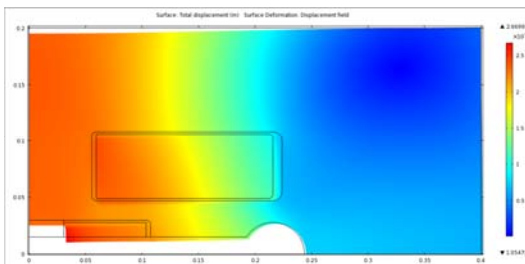
## 10 T Open Midplane Dipole



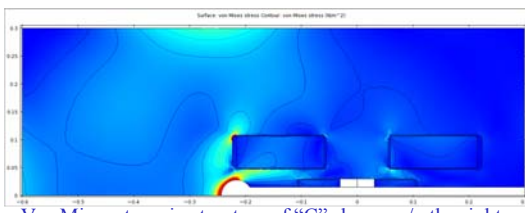
Cross section & field magnitude in 1st quadrant of a 10 T Open Midplane Dipole. Half-gap = 15 mm; structural support:  $x_{\max} = 40$  cm;  $y_{\max} = 20$  cm. Muon beam is at  $[0, 0]$ . Lobed end of keyhole accommodates a radiation absorber of tungsten.



Contours of von Mises stress,  $\sigma_M$ . The maximum value to the right of the keyhole is 246 MPa at 10 T; the average tension in the web is ~150 MPa.



Predicted deformation, magnified twentyfold.



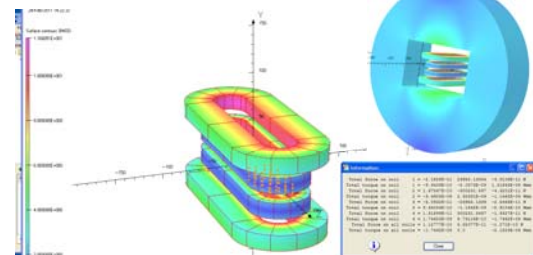
Von Mises stress in structure of "C" shape, w/o the right-hand absorber, to eliminate its backscattering of radiation; maximum  $\sigma_M$  to left of keyhole = 353 Mpa.

## PROOF-OF-PRINCIPLE OMD

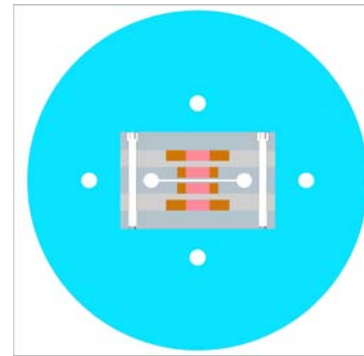
Goal of the proposed Phase II SBIR: Design, build and test an open-midplane dipole with the following features:

- Magnetic Lorentz forces on the inboard conductors hold them away from the midplane, so that they need no structure at midplane
- The short-sample field should be ~10 T.
- The conductor is  $Nb_3Sn$ , as in a full-size 10-T OMD.
- The OMD incorporates most pertinent cold-mass components—support structure, iron yoke and keyhole to accommodate a hypothetical warm absorber.
- The OMD meets all constraints on stress, strain and deformation.

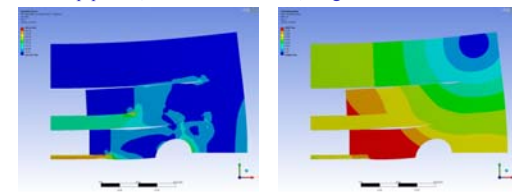
Demonstration of such a magnet will advance both muon collider feasibility and magnet technology, being the first test of a magnet with only magnetic support of inboard coils.



Racetrack coils and coils & yoke (collar omitted for clarity).  $B_0 = 9.7$  T at computed short-sample current.



X-section of the proposed proof-of-principle OMD. Conductor is brown; structure is grey (stainless steel) or blue (iron). The four white circles are for tie rods to restrain end plates that resist end forces. The midplane gap would, in a muon collider, accommodate a beam pipe and, at its dumbbell ends, tungsten absorbers.



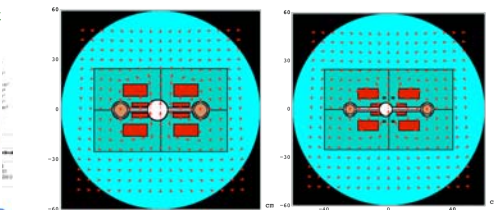
Left: Von Mises stress at  $B_0 = 10.7$  T (design 9.7 T),  $\text{Max} \approx 400$  MPa

Right: Total deformation  $\delta$ ;  $\delta_{\max} = 87 \mu$ ;  $\text{Max } \delta$  of coil  $\approx 20 \mu$ .

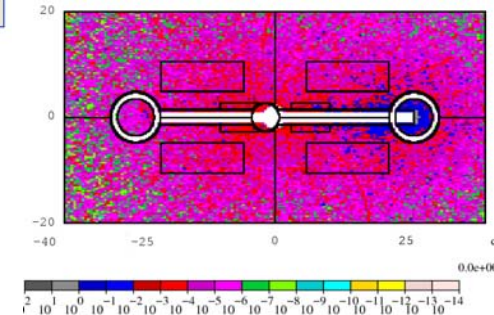
## ENERGY DEPOSITION STUDIES

- In a 1.5 TeV center-of-mass muon collider storage ring, muons decay to electrons at a rate of  $5 \times 10^9$ /s per meter of ring
- Assume two counter-circulating muon beams of 750 GeV, with  $2 \times 10^{12}$  muons per bunch at a rep rate of 15 Hz.
- At the downstream end of a 6-m-long dipole the peak power density is 0.13 mW/g on the right (inward) side of the bend and 0.05 mW/g on the left side.
- For the outboard bar the respective peak power densities are 0.14 mW/g and 0.07 mW/g.

These values are comfortably below those considered acceptable [Mokhov, PAC 2003].



MARS model of cross section of 6-meter-long open-midplane dipoles and sagitta orbit with (Left) two, and (Right) three coils per quadrant. The red blocks are superconducting coils; the arrows indicate the direction of the magnetic field.



Energy deposition from a unidirectional muon beam at the downstream end of a 6-m-long OMD with half gap of 15 mm.

Note that the tungsten absorber has a slot in its left side, to reduce backscattering from the absorber.

## SUMMARY

A Phase I SBIR has advanced the feasibility of open-midplane dipoles for the storage ring of a muon collider. A proposed Phase II SBIR would refine these predictions of stresses, deformations, field quality and energy deposition. Design optimizations would continue, leading to the fabrication and test, for the first time, of a proof-of-principle dipole of truly open-midplane design.

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