Project Narrative
Cover Page

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Project Title:	Study of a Muon Collider Dipole Magnet System To Reduce Detector Background and Heating
Topic No: 64	Advanced Concepts and Technology for High Energy Accelerators
Subtopic: (b)	Technology for Muon Colliders and Muon Beams

Identification and Significance of the Problem or Opportunity and Technical Approach

1. Scientific Case for a $\mu^+\mu^-$ Collider

The concept of a muon collider was revived at a workshop in Napa, CA in 1992 [1, 2] and studied in subsequent workshops [1]. A collider that uses muons instead of electrons can be circular, saving space and rf cost compared to a linear collider. The recent P5 committee strongly endorsed the study of a muon collider.

The physics motivation for a muon collider is compelling. A low-energy collider could produce millions of Higgs for study. A collider of, say, 1.5 TeV could build upon the discoveries at the LHC to refine understanding of the new particles [2]. Polarized muons could be used [1]. A muon collider can also be a neutrino factory. A schematic of this machine is shown in Fig. 1, extracted from the muon collider task force document.

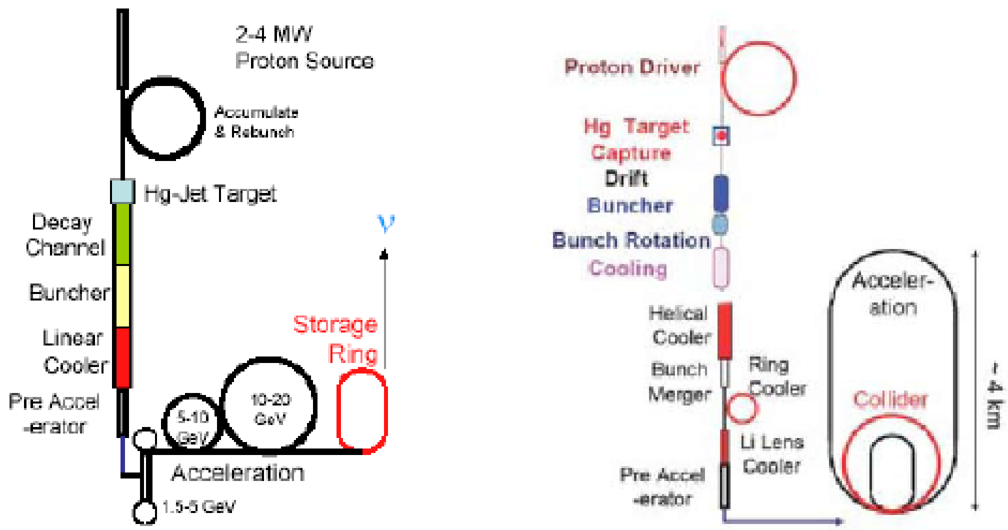
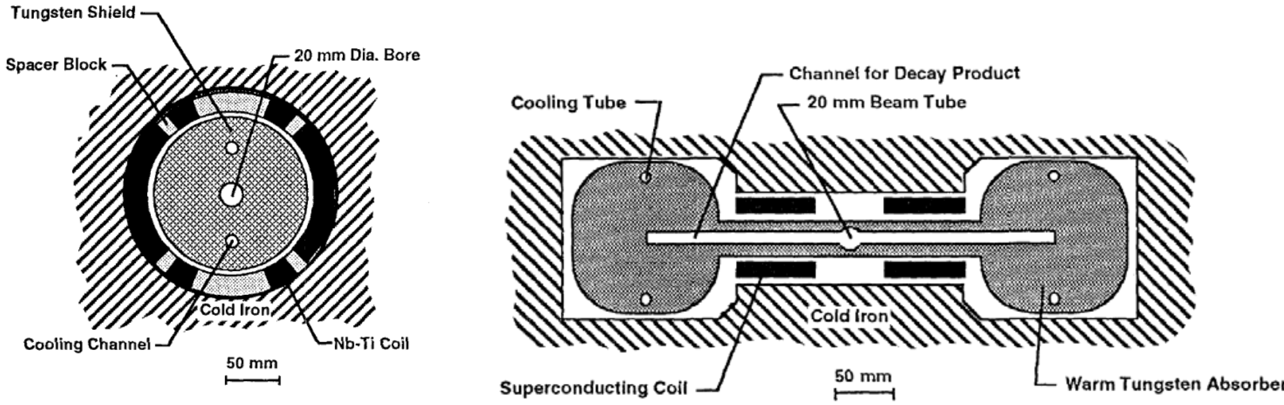


Fig. 1. Schematic of a Muon Collider and Neutrino Factory

A muon collider is technically extremely challenging. It needs many orders of magnitude of 6D cooling of the $\mu^\pm$ to achieve the very low emittance required for high luminosity; 6D cooling has yet to be demonstrated. However, many new ideas are being pursued, and the MICE experiment at RAL will soon test transverse cooling.

An additional challenge is radiational heating. Muon decay, via $\mu^\pm \rightarrow e^\pm + \nu + \bar{\nu}$, from the ~$10^{12}$ muons in the ring emits radiation whose heating can be so intense as to quench the superconducting dipoles that steer the muon beam [1]. To absorb the radiation with tungsten is expensive, and it increases the magnet size and cost (see Fig. 2a). An alternative is to move out of harm's way the dipole-magnet conductor most at risk from radiational heating—that near the plane of the muon beam. This is the concept of the open-midplane dipole magnet, (see Fig. 2b). A primary goal of this SBIR is to study the feasibility of the design for a high-field magnet using HTS wherever the intensity of ambient field or heating deposition demands it. HTS is appealing because of its high radiation tolerance (likely long-term, as well as short-term) as well as for the high magnetic field that it can generate.



Figs. 2a & b. Left: Cosine theta magnet with tungsten absorber 65 mm thick. Right: First concept of an open-midplane dipole for a muon collider (see Nucl. Phys. B, 51A, 1996, 166). The warm-iron split dipole will have less than 0.1 percent of the muon decay-product power deposited within the superconducting coils.

2) Current Understanding of the Muon Collider Lattice

In 1995 the first study of the lattice of a muon collider was carried out by A. Garren et al. [1]; Table 1 summarizes its parameters. M. Green (then of LBNL) designed an appropriate dipole magnet [4]. It required a large amount of tungsten to shield the coils from the heating from muon-decay radiation and beam halo. Therefore he suggested a novel geometry to dodge much of the beam debris—the open-midplane design [4]. This geometry was also examined by McIntyre et al. for a somewhat higher field magnet [5] and later by Parker, Gupta et al. [6]. A. Garren is an employee of Particle Beam Lasers, Inc.

Table 1. First Study of a Lattice for a $\mu^+\mu^-$ Collider (A. Garren et al., 1995)

High-Energy/High-Luminosity $\mu^+\mu^-$ Collider (see Nuclear Physics B, 51A, 1996, p. 149)	
Maximum c-of-m energy [TeV]	4
Luminosity L [10^{35}cm^{-2} s^{-1}]	1.0
Circumference [km]	8.08
Time between collisions [μs]	12
Energy spread σ_e [units 10^{-3}]	2
Pulse length σ_x [mm]	3
Free space at the IP [m]	6.25
Luminosity lifetime [No. of turns]	900
rms emittance $\varepsilon^{N}_{x,y}$ [10^{-6} m-rad]	50.0
rms emittance $\varepsilon_{x,y}$ [10^{-6} m-rad]	0.0026
Beta function at IP, β^* [mm]	3
rms beam size at IP [μm]	2.8
Quadrupole pole fields near IP [T]	6.0
Maximum beta function, β_{max} [km]	400
Magnet aperture closest to IP [cm]	12

Beam-beam tune shift per crossing	0.04
Repetition rate [Hz]	15
rf frequency [GHz]	3
rf voltage [MeV]	1500
Particles per bunch [10^{12}]	2
No. of bunches of each sign	2
Peak current $T = \frac{eNc}{\sqrt{2\pi\sigma_x}}$ [kA]	12.8
Average current $T = \frac{eNc}{circum}$ [A]	0.032
Horizontal tune ν_x	55.79
Vertical tune ν_y	38.82

There has been a renewed interest in a muon collider, and new studies of the possible lattice have been carried out using conventional SC dipole magnets. In Fig. 3 we show the schematic of a collider of 1.5 TeV center-of-mass energy [3] by Snopok, Berz and Johnstone. Another study has been carried out by Alexahen and Gianfelice (private communication). This work (Table 2) included some dynamic aperture studies as well that provide insight to the needed aperture in the open-midplane dipoles to be studied here. N. Mokhov (private communication) has estimated a beam gap of 250 mm x 20 mm (H x V), primarily based on energy deposition considerations on previous studies. We use this as our first estimate for the open-midplane dipoles to be studied here. We will use these established parameters in our study for Phase I.

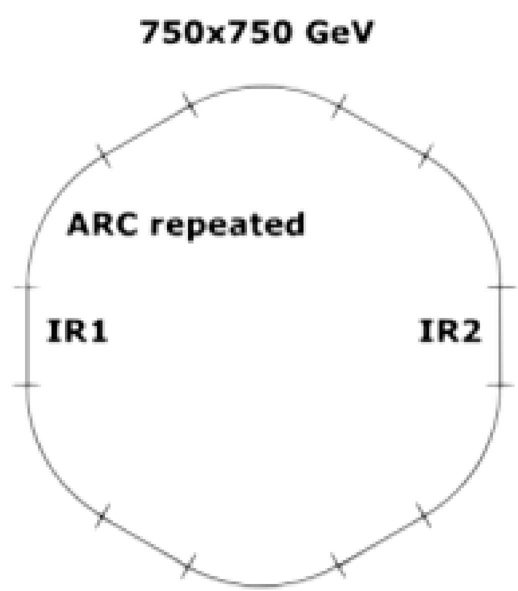


Fig. 3. Schematic of a 1.5 TeV $\mu^+\mu^-$ Collider

Table 2 lists a recent design for a muon collider using conventional 10 T dipole magnets [3]. We use this work as our baseline.

Table 2 Muon Collider Parameters

	Low Emittance	High emittance
Energy (TeV)	0.75+0.75 (γ = 7098.4)	
Average luminosity ($10^{34}/cm^2/s$)	2.7	2
Average bending field (T)	10	6
Mean radius (m)	361.4	500
Number of IPs	4	2
P-driver rep. rate (Hz)	65	60
Beam-beam parameter/IP, ξ	0.052	0.1
β^* (cm)	0.5	1
Bunch length (cm), σ_z	0.5	1
Number of bunches/beam, n_b	10	1
No. of muons/bunch (1e11), N_μ	1	11.3
Norm. transverse emittance(μm), $\varepsilon_{\pm N}$	2.1	12.3
Energy spread (%)	1	0.2
Norm. longitudinal emittance (m), $\varepsilon_{\parallel N}$	0.35	0.14
Total RF voltage (GV) at 800MHz	$406.6 \times 10^3\alpha_c$	$5.6 \times 10^3\alpha_c$
RF bucket height (%)	23.9	2.4
Synchrotron tune	$0.723 \times 10^3\alpha_c$	$0.1 \times 10^3\alpha_c$

Very recently after the favorable P5 committee report on muon colliders there has been new interest in muon colliders. FNAL has formed the Muon Collider Task Force (MCTF) to help coordinate this effort. The MCTF is very interested in the study of SC magnets for the collider. Figure 1 in this proposal comes from the study "Muon Accelerator R&D Program: A Proposal for the Next 5 Years" – (FNAL Note). On page 6 they quote the results of the P5 report as motivation. On page 21 they define the needed lattice design. The report also discusses the possible magnets for the collider ring (or a Neutrino Factory Ring) and to quote "open midplane dipole magnet R&D to assess the viability of this magnet type for the collider ring".

This is in part what we propose here, and to use high temperature superconductor (HTS) magnets of at least 10 T for the High-Field Open-Midplane Dipole is totally consistent with the goals of the MCTF. Collider luminosity scales with magnet field strength. Our goal is the study of the possible magnetic field that may be achieved with HTS magnets and the related mechanical issues with such open midplane magnets. We will start with the 10 T that the FNAL lattice uses, and then study fields up to 20 T.

3) Previous Results on Heating in the Coils from Beam Debris

The decay particles from the circulating muon beams will cause debris that can interact in the dipole coils and cause heating problems. Also, the accumulated dose may degrade the performance of superconducting magnets. Superconducting coils in an open-midplane dipole will absorb some energy but much less than in conventional magnets.

A previous study of the heating in open-midplane magnets was for the LHC (Large Hadron Collider) upgrade in dipole first optics. Figure 4 shows such studies carried out by N. Mokhov of FNAL. This study appears in the proceedings of the PAC05 meeting [7]. The energy-deposition analysis results are shown in Fig. 4. We quote “These peak values are below the estimated quench limit with a necessary safety margin” [7].

The nature of energy deposition in a muon-collider dipole is similar to that in the LHC dipole first optics. But the source of the energy deposition is different. In the LHC the debris (decay particles) emanates from the interaction point between the two counter-rotating beams prior to the dipoles; in a muon collider it originates from the decay of the short-lived muons themselves. This tends to confine the debris to the midplane of the muon-collider system. In an email exchange with Mokhov he indicated that the open-midplane dipole design in the muon collider should offer benefits similar to those in the LHC upgrade studies. It was further stated that “new studies should be made for the muon collider”. One of the key objectives of this proposed work is to determine the heating in the open midplane dipoles for the new collider ring lattice. We expect a reduced background in the collider detector as well. This can be studied in Phase II with our same programs.

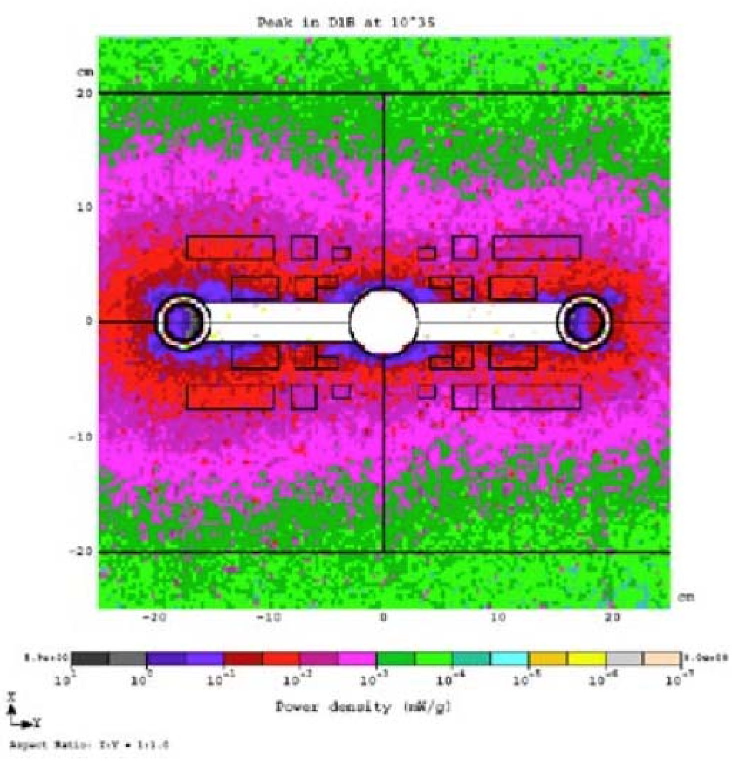


Fig. 4. Heating calculation for LHC circulating beam in an open-midplane dipole [7], by N. Mokhov

The PBL team expects to have several informal discussions with N. Mokhov concerning this project throughout its term. Mokhov is a world expert in calculating the energy deposition from particles transiting through materials.

4) Open-Midplane Dipole

Muons decay rapidly, irradiating nearby matter with energy that can quench a superconductor. A tungsten liner to intercept this radiation and reduce the exposure on the superconducting coils (see Fig. 2a) increases the bore, and hence the cost, of the coils. Green, Willen, McIntyre & others [4, 5, 6] therefore have proposed to banish all conductor from the region most exposed to radiation: near the magnet midplane. However, most of these designs retain support structure under the coils to withstand the Lorentz force of attraction between the coils. Decay particles hit this support structure and create secondary particles that can deposit their energy in the superconducting coils. Bonding the coils to the iron (see Fig. 2b) cannot eliminate this cross-midplane structure; the required bond strength is too high in dipoles of high field.

In the proposed open-midplane design concept (see Fig. 5), the coil cross-section is partitioned so that the vertical force between the coils closest to the midplane is repulsive. Because of this, these coils need no midplane support material; only the beam tube remains as a source of secondary particles. Reducing the midplane gap (the distance between the coil blocks closest to the midplane) significantly increases the field and can improve the field quality and overall magnetic design. This concept has been examined earlier for the LHC IR upgrade for "dipole first optics" [8, 9]. The vertical force between the coil blocks far from the midplane is handled by structure far away from the beam pipe, as shown in Fig. 6.

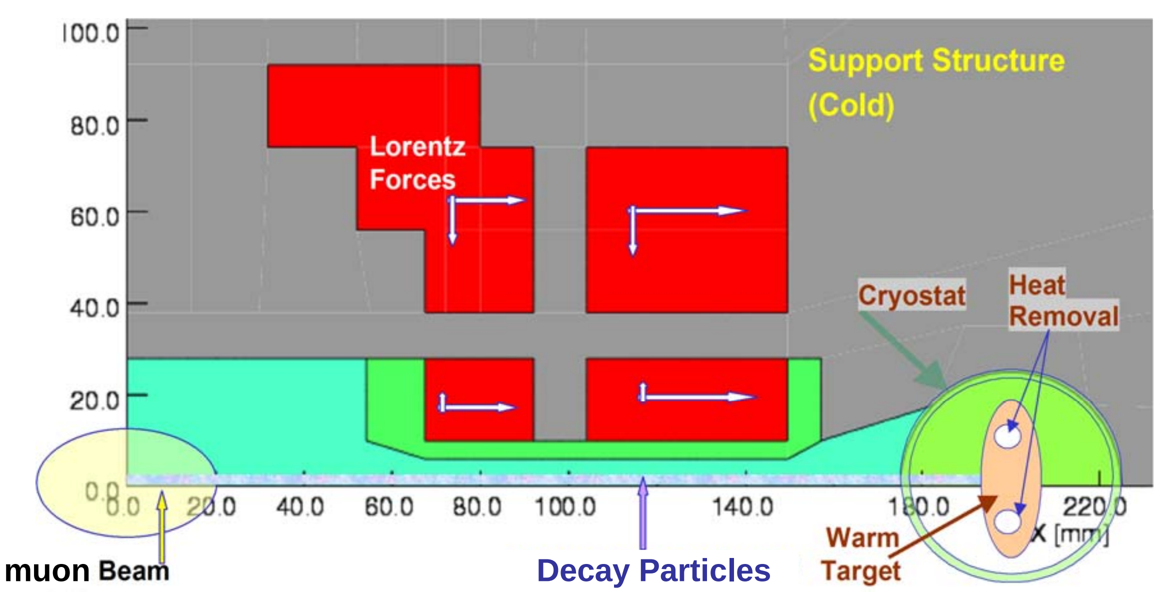


Fig. 5. A conceptual design of the proposed open-midplane dipole for a muon collider.

Among the new technical challenges presented by the concept are: (a) improving the marginal field quality of the dipoles for the LHC IR upgrade [8, 9]; (b) minimizing the peak fields seen by the coils; (c) withstanding large vertical forces with only cantilever support; and (d) minimizing the heat deposition in the cold region. A goal of Phase I is to demonstrate feasibility—i.e., no “show stoppers”—that would preclude a Phase II.

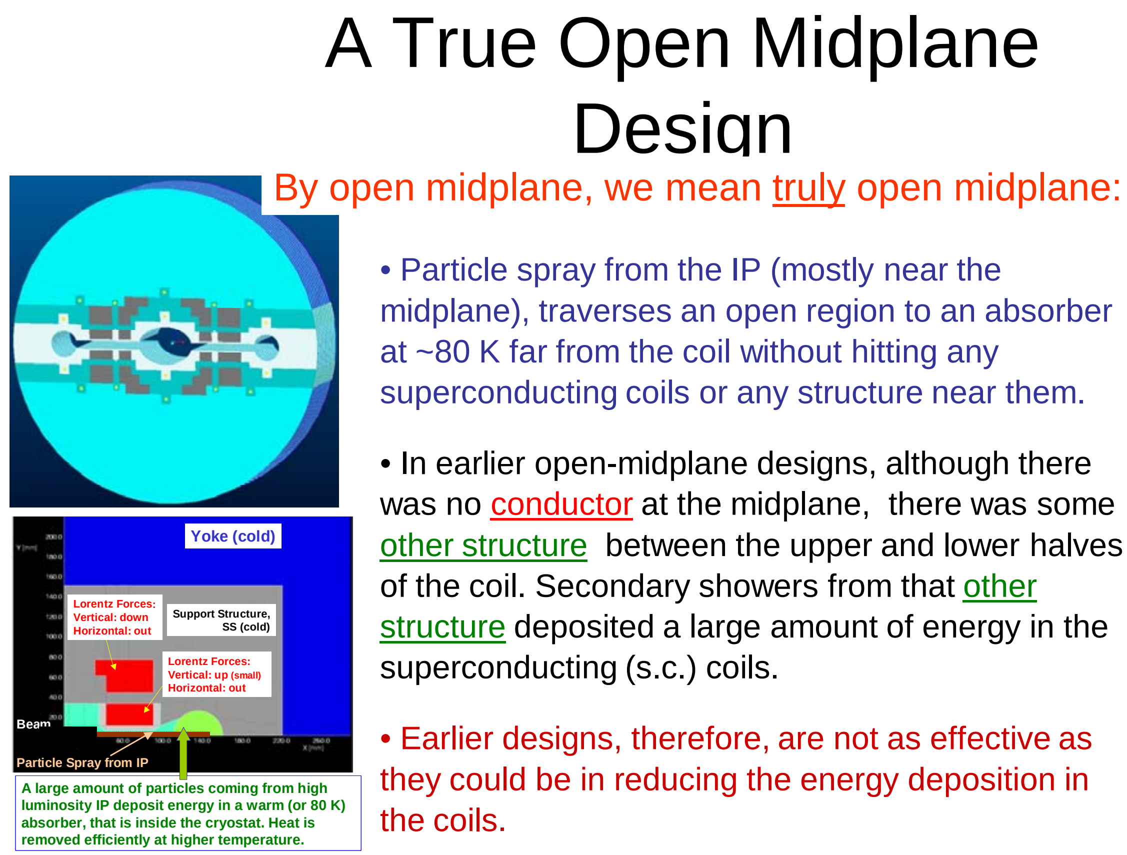


Fig. 6. A true open-midplane design, with no midplane structure to generate secondary-particle emission.

5) High Temperature Superconductor in open-midplane dipole

The use of HTS in open-midplane dipole magnets should allow very high magnetic fields. Figure 7 shows the critical engineering current density in wire (or tape) as a function of field for various superconductors at 4 K (reference 2008: compiled by Peter Lee (NHMFL), $J_e(B)$ at 4.2K for various superconductors). HTS is indispensable for any magnet with a peak field much above 20 T.

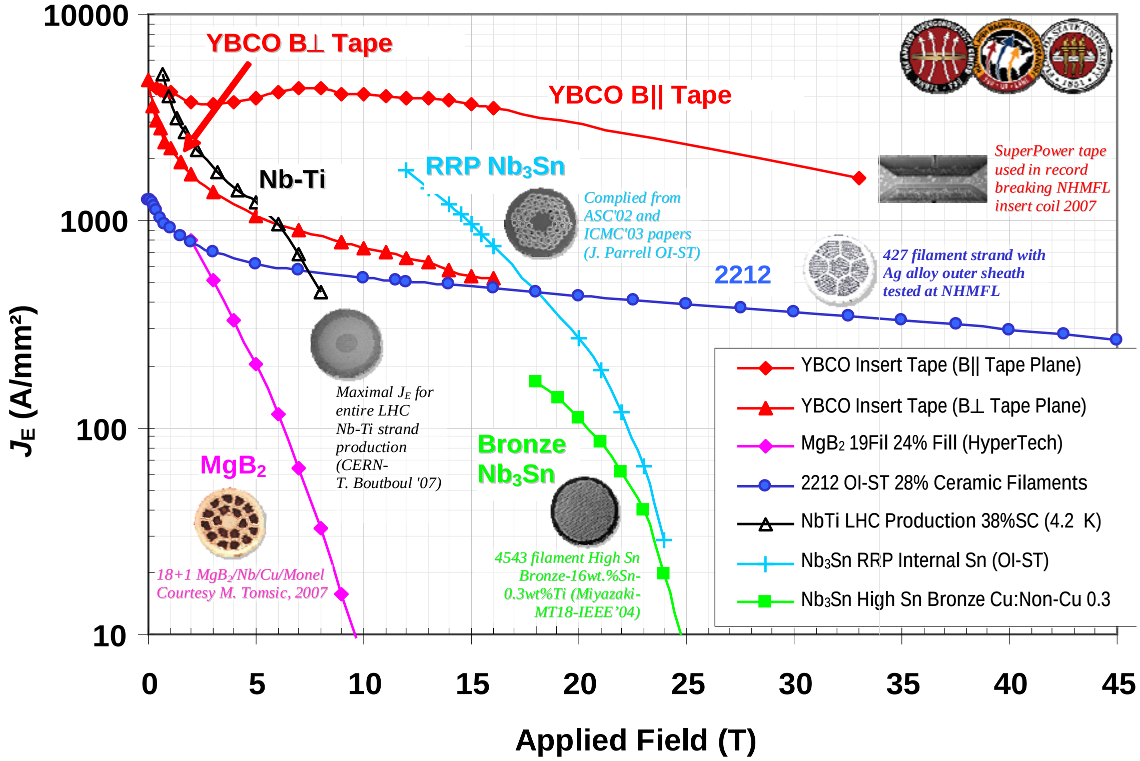
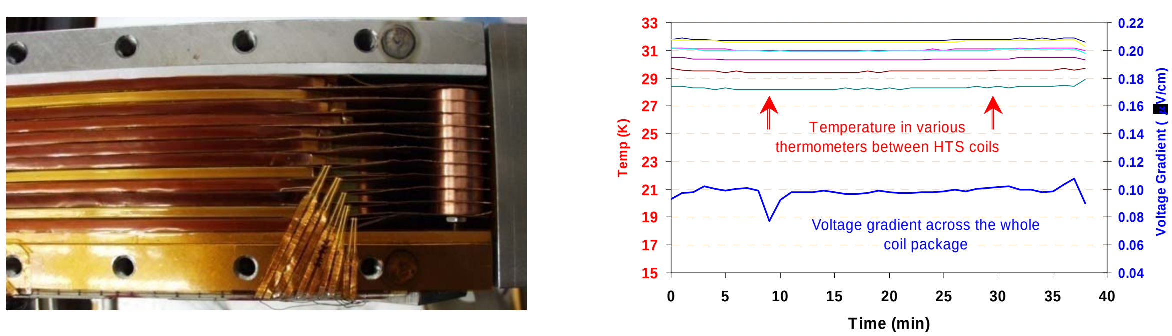


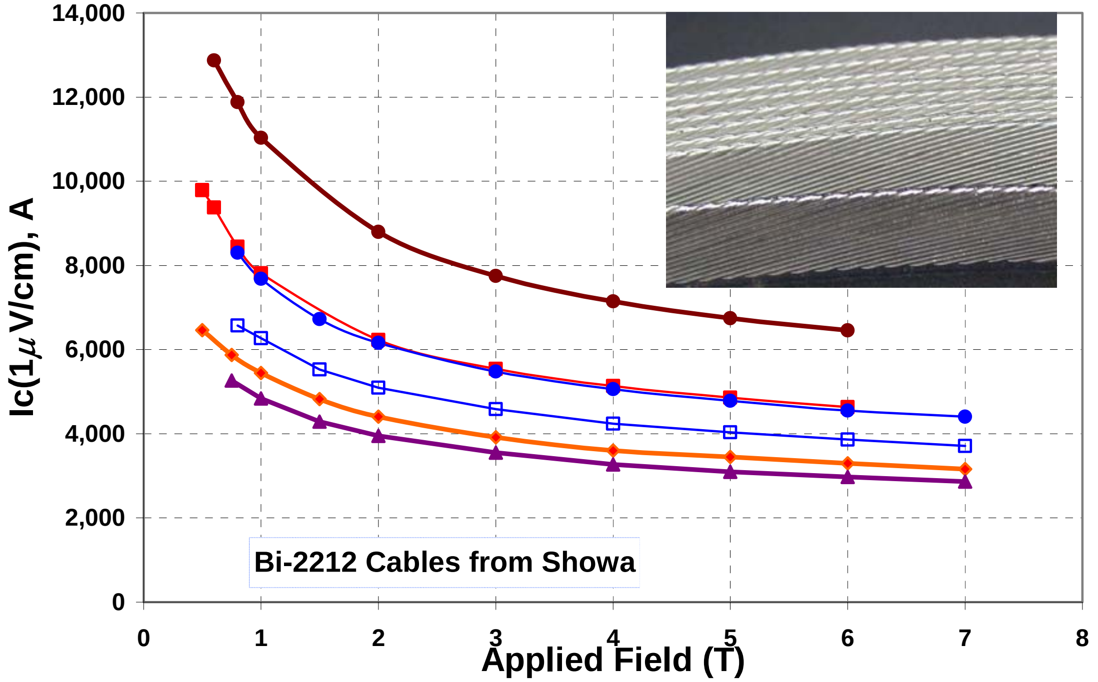
Fig. 7. $J_e(B)$ at 4.2K for different superconductors (compiled by Peter Lee, NHMFL)

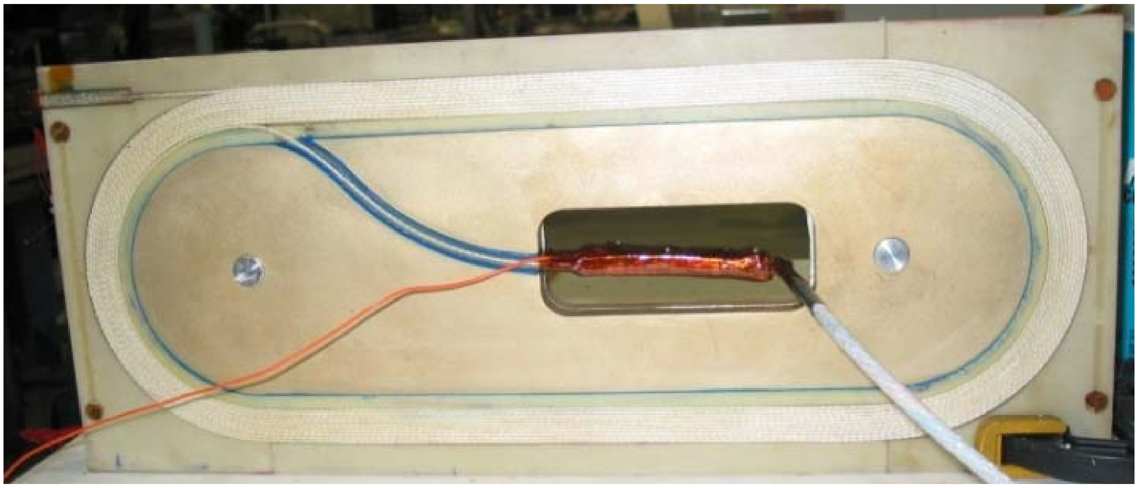
Another major advantage of a HTS is that it can tolerate heat loads much larger than a low-temperature superconductor and may have a higher radiation tolerance than low-temperature superconductors. This was demonstrated by a set of experiments performed at BNL in an R&D HTS quadrupole for the Facility of Radio Isotope Beams (FRIB) [10]. Coils ~300 mm long remained stable despite a heat load of ~25 W throughout the 35-minute experiment (see Fig. 8b). Radiation experiments carried out with the proton beams at BNL [11] showed that YBCO (and also BSCCO) will not deteriorate appreciably in performance during the expected lifetime (~20 years) of these magnets. This radiation hardness is important for a muon collider.



Figs. 8a & b. Left: Heaters between HTS coils for energy deposition experiment. Right: Stable operation of HTS coil in presence of 25 W heat load at 30 K.

To limit the voltage during a quench, the current should be as large as feasible—perhaps several kA. Coils made at BNL in 2003 of BSCCO-2212 Rutherford cable (see Fig. 9) carried over 4 kA [12]. One should expect higher current in coils made with the Bi-2212 now being improved by a DOE conductor-development program. For high current, YBCO might require especially wide tapes (12 mm to 40 mm, rather than standard 4 mm), or several tapes in parallel as, for example, in a Roebel cable.



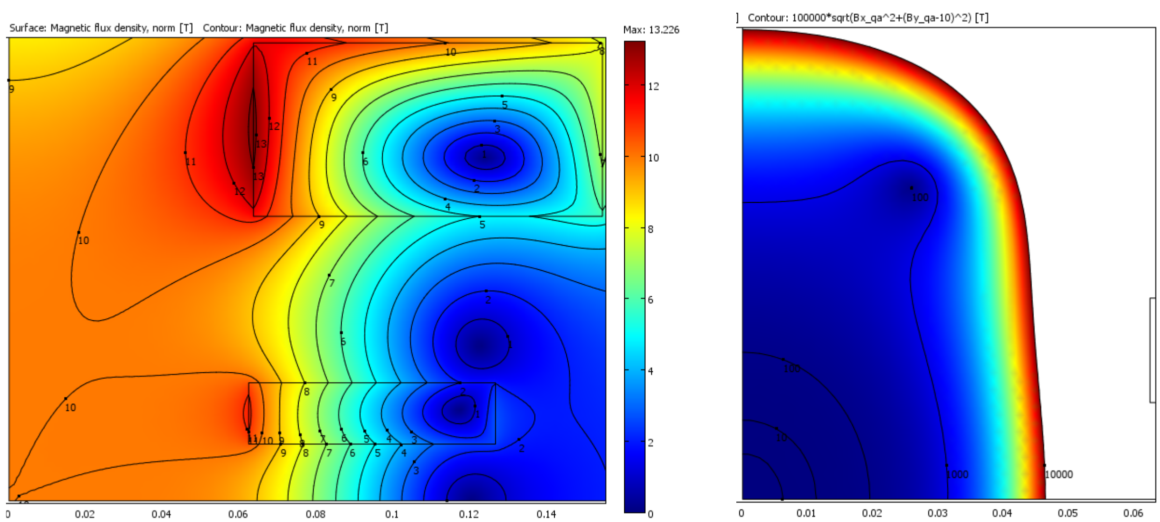


Figs. 9a & b. Top: I_c of 30-strand Rutherford cables made with Bi-2212 wire in a collaboration of BNL, LBNL and Showa. Bottom: One of several coils built and tested in a common-coil configuration at BNL.

HTS is much more expensive than conventional low temperature superconductors (LTS) such as NbTi or Nb_3Sn. However, the elimination of the tungsten liner and consequent reduction in distance between coils on opposite sides of the midplane should reduce the cost penalty of an open-midplane dipole using HTS. Moreover, HTS should perform more reliably, due to its higher temperature margin. One need not use HTS except where the ambient field and heat radiation are especially high. Magnesium diboride (MgB_2) might be appropriate for some coils. One goal of Phase I is to examine these premises and the approximate cost of magnets in the field range of 10 T to 20 T.

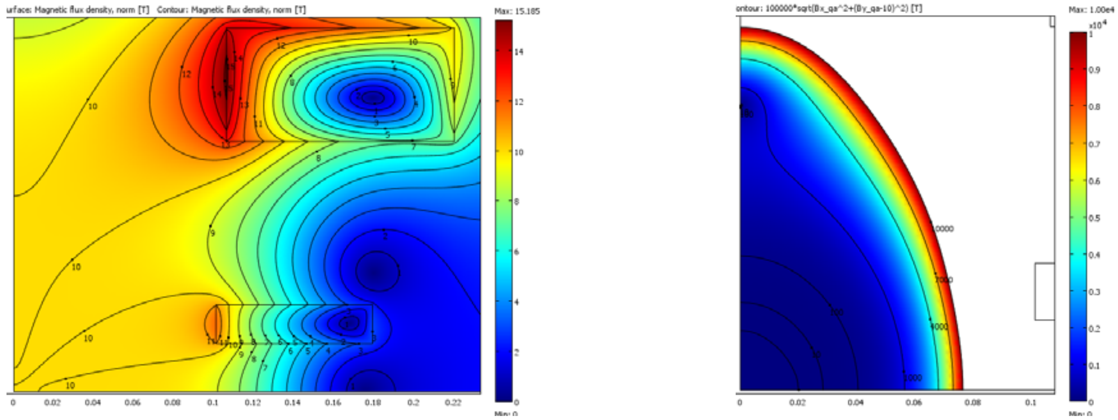
6) Conceptual Magnetic Design

A requirement of any dipole magnet for a muon collider is that it have adequate field quality (field homogeneity). If the magnet midplane is to be truly open, an additional requirement is that Lorentz forces on its inboard windings not attract these windings toward the magnet midplane. The design of Figs. 10a & b achieves both of these objectives. The design achieves a field homogeneity of 0.01% throughout a cross section of radius greater than 20 mm.



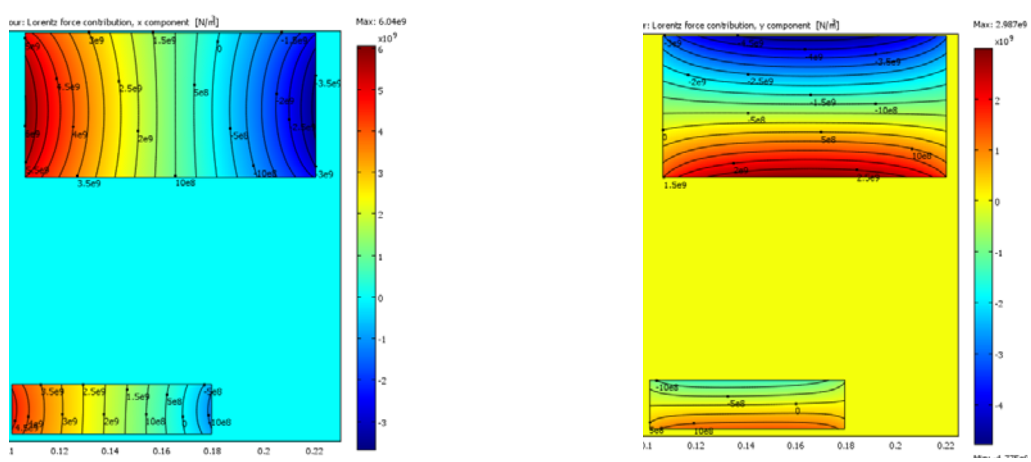
Figs. 10a & b: Open-midplane dipole (infinitely-long) with zero 2nd-order inhomogeneity coefficient and nearly-zero 4th-order coefficient. Left: Field magnitude $|B| = (B_x^2+B_y^2)^{1/2}$. Central field B_0 = 10 T at current density of 400 A/mm^2. Peak field seen by windings is 11.2 T (inboard) and 13.2 T (outboard). Right: Field homogeneity. The 100 ppm (0.01%) contour intercepts the axes at x = 19.6 mm and y = 22.4 mm.

Figures 11 through 13 describe a magnet that requires 55% more conductor but has much better field homogeneity and lower stresses and deflections. This design achieves 0.01% field homogeneity over a cross section that extends horizontally ±40 mm and vertically ±46 mm..

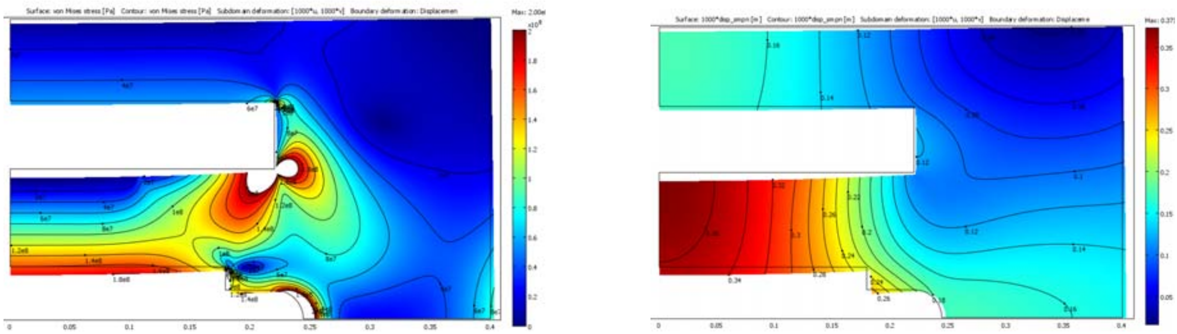


Figs. 11a & b: Open-midplane dipole magnet with zero inhomogeneity coefficients of both 2nd and 4th-order. Left: Field magnitude. Peak field seen by windings is 11.8 T (inboard) and 15.2 T (outboard). Right: Field homogeneity. The 100 ppm (0.01%) contour intercepts the axes at x = 40 mm and y = 46 mm.

The open-midplane design is capable of exquisite field homogeneity. The simple geometry of Figs. 10 and 11, with just two pairs of conductor blocks, allows the elimination of the inhomogeneity coefficient of order 6 as well as orders 2 and 4. A design with 60% more conductor than in Fig. 11 can increase the 0.01% homogeneity extent to ±85 mm horizontally and ±91 mm vertically! Admittedly, this homogeneity capability may be a challenge to achieve in practice: imperfect placement of the conductor during winding, or displacement of the conductor from thermal contraction or magnetic loads, can threaten to wreck havoc on the homogeneity. However, independently-energizable trim coils, with only a few percent the ampere-turns of the main coils, can restore the homogeneity almost completely.



Figs. 12a & b. Lorentz-force density. Left: Horizontal. The total load on the windings is 2.8 MN (inboard) + 7.4 MN = 10.2 MN. Right: Vertical. The total load toward the magnet midplane is 0 MN (inboard) + 5.4 MN (outboard) = 5.4 MN.



Figs. 13a & b. Stresses and deformations in magnet. Left: Two-dimensional von Mises stress, $\sigma_{vM} \equiv (\sigma_x^2+\sigma_y^2)^{½}$. Right: Total deformation $\Delta r \equiv (\Delta x^2+\Delta y^2)^{½}$ (mm).

Note that the stresses in the web between the windings range up to 180 MPa (26 ksi), even discounting stress concentrations near magnet corners. Note also that the deflection of the windings ranges up to 0.37 mm. Doubling the field to 20 T would quadruple these values. A challenge in pursuing the design of a very-high-field open-midplane dipole magnet will be to limit stresses and deflections to minimize the risk of mechanical failure, magnet quenching, and the degradation of field quality. Phase I proposes to address those goals.

YBCO tape is attractive for its outstanding strength and respectable tolerance of strain. Its current capacity degrades only a few percent with a bending radius of ~10 mm, 0.45% strain and 750 MPa stress. Most high-temperature superconductors are available only in tape geometry, whose current carrying capacity is dependent on field angle, being several times higher in the favorable direction (parallel to the wide face of the tape). In the HTS coils in the proposed design the field is quite favorable.

Phase II Plan for a test fixture for an open-midplane dipole

Among the goals of Phase II is to carry out a more detailed design and build and test HTS coils in a scaled test fixture (consistent with the budget) to demonstrate some of the key elements of the open-midplane dipole geometry. One scenario is to test four short coils (HTS in the pair closer to the midplane; LTS in the pair further away) in a test fixture with open-midplane mechanical structure.

7) Anticipated Public Benefits

Applications for high-field dipole using HTS muon collider in USA

1. The development of a $\mu^+\mu^-$ collider in the USA: The P5 committee recently endorsed the study of other types of lepton colliders beyond the ILC. The magnet study proposed here could yield a 20-T dipole. This could be used in a 1.5 to 3.0 TeV $\mu^+\mu^-$ collider that would fit on the FNAL site.

Homeland Security protection against terrorist's nuclear weapons

2. Recently the USA Homeland Security Department and DOD realized that a muon beam is the only known foolproof method to detect fissile material to make a nuclear bomb (U^{235}). In one recent study call they note: "Advanced knowledge of the physics of a muon source generation including novel acceleration phenomena … ." There is now funding to study such muon-production systems.

A small acceleration ring that uses HTS magnets to produce 500 MeV protons would be ideal for a portable system to survey sites for fissile material. We would study this possibility as the dipoles are being studied. We consider a ring with a 2-m diameter and a high-gradient accelerator using dielectric. A flip target in the ring produces pions that decay into muons. The use of HTS in the magnets allows the field to be high, and hence the ring to be compact, and avoids the complexity of liquid-helium-temperature cryogenics.

Such a device might be used for nanotechnology and medical studies as well. We plan to design such a system, drawing upon data garnered from the HTS conductor studied in this proposal.

An example of such a system using HTS magnets is shown in Fig. 14. Such a system could help protect the USA from WMDs!

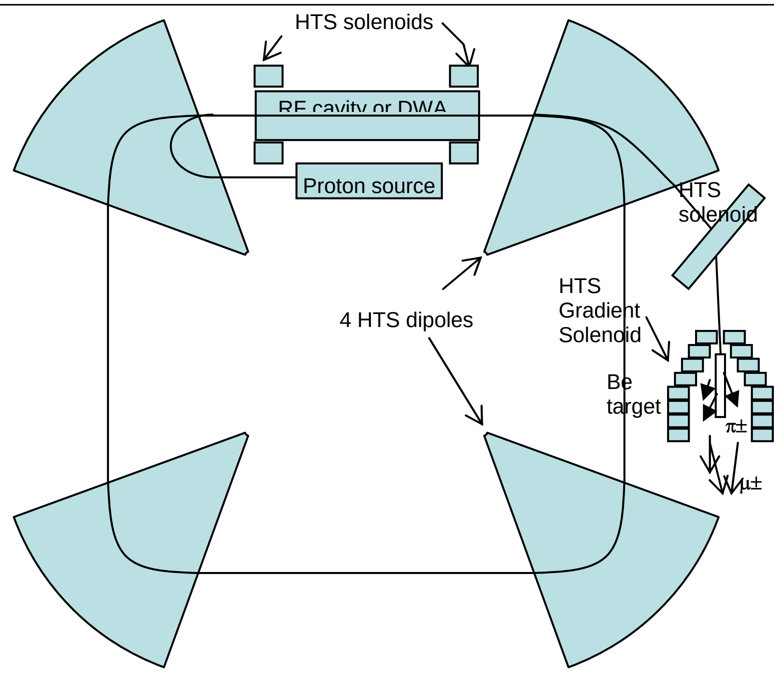


Fig. 14. Compact accelerator ring using RF or high-gradient dielectric acceleration and lightweight HTS dipoles and solenoids. The energetic protons strike a target to produce forward pions that decay into muons.

8) Technical Objectives

The primary objective of Phase I of this proposal is to develop a conceptual and preliminary design of a high-field open-midplane dipole for a muon collider. This R&D is expected to determine if there are any “show stoppers” (We don’t expect any.) and the hardware needed to build and test a “proof-of-principle” test fixture in Phase II. Preliminary design developed in Phase I will have (a) good field quality (~0.01%), (b) magnetically-supported inboard coils and (c) an energy-deposition channel to a warm region far from the coil. The range of feasibility of magnetic field magnitude will be a part of this study. Work will include a conceptual design of the support structure and preliminary structural analysis.

Energy deposition issues on the coil will be examined, and calculations will be carried out to a level to give guidance on the required gap between the coils (value of the open-midplane gap). A more detailed analysis and calculation will be the subject of Phase II.

An R&D plan for Phase II will be developed. This will include the determination of the basic parameters of the test fixture for a proof-of -principle demonstration.

9) Phase I Work Plan

- Develop parameters of the Open-Midplane Design
    - Specify preliminary field quality requirements
    - Magnet aperture
    - Clear gap (no material)
    - Magnet length
    - Select a value of magnetic field (10 – 20 T)

- Develop magnetic design
    - Coil-to-coil gap
    - Conductor requirements
    - HTS-only vs. hybrid design
    - Conductor choices
    - Preliminary cost of various conductors

- Mechanical design
    - Stress & deflection calculations
    - Preliminary mechanical design concept

- Energy deposition estimates
    - This work will play a major role in determining the open midplane gap
    - We will use our own expertise with the MERIT project to help perform the heating calculations.

10) <u>Phase II</u>

Phase II will have two parts. In the first part we will develop a more detailed engineering design of the dipole that is most suitable for the machine. In the second part, we will build and test a scaled open-midplane dipole cold-mass (scaled both in size and in field) that is consistent with the budget of Phase II and can go in a 13" dewar at BNL.

<u>Part I:</u>

- Based on the parameters of the open midplane dipole developed in Phase I, develop detailed magnetic design
- Carry out detailed mechanical design calculations of the stresses and deflections in the coils
- Design a support structure
- Do cryogenic calculations indicating how energy will be removed. The design will be developed in such a way that it removes most of the energy at a cryogenically-advantageous temperature (≥77 K).
- Detailed lattice design work. Better specifications of field quality requirements.
- Carry out detailed energy deposition calculations. If it is a hybrid design, then determine how much energy is going into HTS and how much into LTS, and the temperature rise in each coil.

<u>Part II:</u>

- Design and build a short R&D cold mass (test fixture) to demonstrate that a magnet with true open-midplane can be built.
- The design may be such that some coils should be of HTS and others of LTS
- This will be a scaled-down version of the above design – both in size and in field.

11) Phase I Performance Schedule

- Determine preliminary good-field aperture: Months 0-5
- Develop parameters of the open-midplane design : Months 0-5
- Study the magnetic field strength that is feasible using HTS conductor: Months 1-8
- Develop magnetic design: Months 1-6
- Mechanical design: Months 5-8
- Energy deposition analysis: Month 8
- Report preparation: Months 8-9

12) Related Research or R&D

Scientific Goals

i) Low-Energy $\mu^+\mu^-$ Colliders

In the model of supersymmetry there will likely be one low-mass Higgs (h_0) and two high-mass (or supersymmetric) Higgs A and H. For the parameter tan ß, larger values lead to a nearly-mass-degenerate system of H and A states, most likely in the 300-500 GeV mass range. Current evidence on SUSY suggests a large value of tan ß. In this case the coupling of H and A to tt and gauge bosons is sharply reduced, making them difficult to produce and study at the Large Hadron Collider or International Linear Collider.

ii) High-Energy $\mu^+\mu^-$ Colliders

The FNAL director has approved a long-range plan to study a 1.5-TeV $\mu^+\mu^-$ collider. The cooling methods proposed here could be important for this plan. This collider is complementary in all ways to the International Linear Collider (ILC) being planned by the international high energy physics community.

iii) Muon Source for WMD (Weapons of Mass Destruction)

A proposal will be submitted to DOD to study a muon source for WMD detection using the magnetic materials determined from this Phase I study and to design a very compact accelerator. We believe this could be a major commercial activity for PBL, Inc. in the future.

13) Principal Investigator and other Key Personnel

Robert J. Weggel will be the principal investigator for this Phase I project. Mr. Weggel has had nearly 50 years of experience as a magnet engineer and designer at the Francis Bitter National Magnet Laboratory at MIT and Brookhaven National Laboratory and as a consultant in magnet design. In the course of his career he has authored over 100 peer-reviewed articles concerning resistive and superconducting magnets as well as hybrid high-field versions. He has had extensive experience optimizing magnets for various uses including solid-state research, accelerator and medical applications. He has co-authored with D.B. Montgomery the book “Solenoid Magnet Design”. Weggel will develop the magnetic and mechanical design of the open-midplane dipole in collaboration with Ramesh Gupta of BNL. Ronald Scanlan, Senior Scientist, will assist Ramesh Gupta in the selection of the conductor and evaluate the impact of energy deposition on the conductor.

14) Facilities/Equipment

The Phase I project will be administered and coordinated from Particle Beam Lasers, Inc. headquarters office in Los Angeles. The company has had several successful SBIR Phase I projects in the past 25 years; it currently has one active Phase I and two active Phase II projects. The company has the capability, experience and administrative infrastructure to carry out the Phase I project proposed. For work under this proposal, the company plans to subcontract with the Superconducting Magnet Division at the Brookhaven National Laboratory for predictions of energy deposition and specification of conductor and magnet parameters such as required field homogeneity.

15) Consultants and Subcontractors

Dr. David Cline is an internationally-known experimental elementary particle physicist with expertise in the science and applications of particle accelerators and storage rings. Dr. Cline will serve as a consultant providing valuable input on physics issues related to the behavior of muon beams through the open-midplane dipole and determining the use of such a dipole for other science applications, e.g. LHC upgrade and Homeland Security, and commercial applications, e.g. the nanotechnology and medical sectors. He will lead the effort to study a HTS system to detect WMD's with energetic muons. A letter of commitment from Dr. Cline is part of this proposal.

Brookhaven National Laboratory (BNL) will be a subcontractor on this project. As a part of the LHC Accelerator Research Program (LARP), BNL has developed an "Open Midplane Dipole" design for one of the options of possible LHC luminosity upgrade. BNL also has significant experience with the high temperature superconductor coil and magnet technology and racetrack coil magnet technology both of which are important to the development of the proposed magnet. The Superconducting Magnet Division at BNL will give its support to the development of the magnetic and conceptual design. This will include development of the parameters such that a proof-of-principle of the concept can be carried out in Phase II. It is possible that previously built Nb3Sn and HTS coils for the common coil design can be used as part of this proof-of-principle magnet in Phase II. The proposed R&D in Phase I will be carried out in a period of nine months at a cost of $10,000. The certifying official at BNL is Mr. Michael Furey, Manager, Research Partnerships. Mr. Furey's telephone number is 631-344-2103 and his e-mail address is mfurey@bnl.gov.

16) Similar Grant Applications, Proposals, or Awards

Particle Beam Lasers, Inc. has no prior, current or pending support for a similar proposal and work.

17) References

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