Project Narrative
Cover Page

Company Name and Address:	**Particle Beam Lasers, Inc. 18925 Dearborn Street Northridge, CA 91324-2807**
Principal Investigator:	**John Keane**
Project Title:	**Design of a demonstration of Magnetic Insulation and study of its application to Ionization Cooling for a Muon Collider**
Topic Number: 38	**Advanced Concepts and Technology for High Energy Accelerators**
Subtopic Letter: b.	**Technology for Muon Colliders and Muon Beams**

Identification and Significance of the Problem or Opportunity and Technical Approach

a) Introduction to Muon Colliders

The U.S. Department of Energy is interested in the development of novel devices and instrumentation for use in producing intense muon beams suitable for muon colliders and for other applications. A Muon Collider might allow the study of High Energy Physics at energies higher than practical with more conventional technologies. Such a facility would be much smaller than conventional High Energy Physics facilities such as proton-proton colliders (such as the LHC [ref 1]), or electron positron colliders (such as the ILC [ref 2] or CLIC [ref 3]). Figure 1 illustrates this advantage showing, on the same scale, the LHC, ILC, CLIC, and a Muon Collider. The energies given are the center-of-mass energies for the electron or muon colliders, where the full particle energies are available. For the proton-proton case the energy given is the approximate energy in the individual proton-proton collisions that are available for high energy physics studies. Muon colliders allow the high energy study of point-like collisions of leptons without some of the difficulties associated with high energy electrons, such as the synchrotron radiation requiring their acceleration to be essentially linear and, for this reason, long. Muons can be accelerated in smaller rings and offer other advantages, but they are produced only diffusely and they decay rapidly, making the detailed design of such machines difficult.

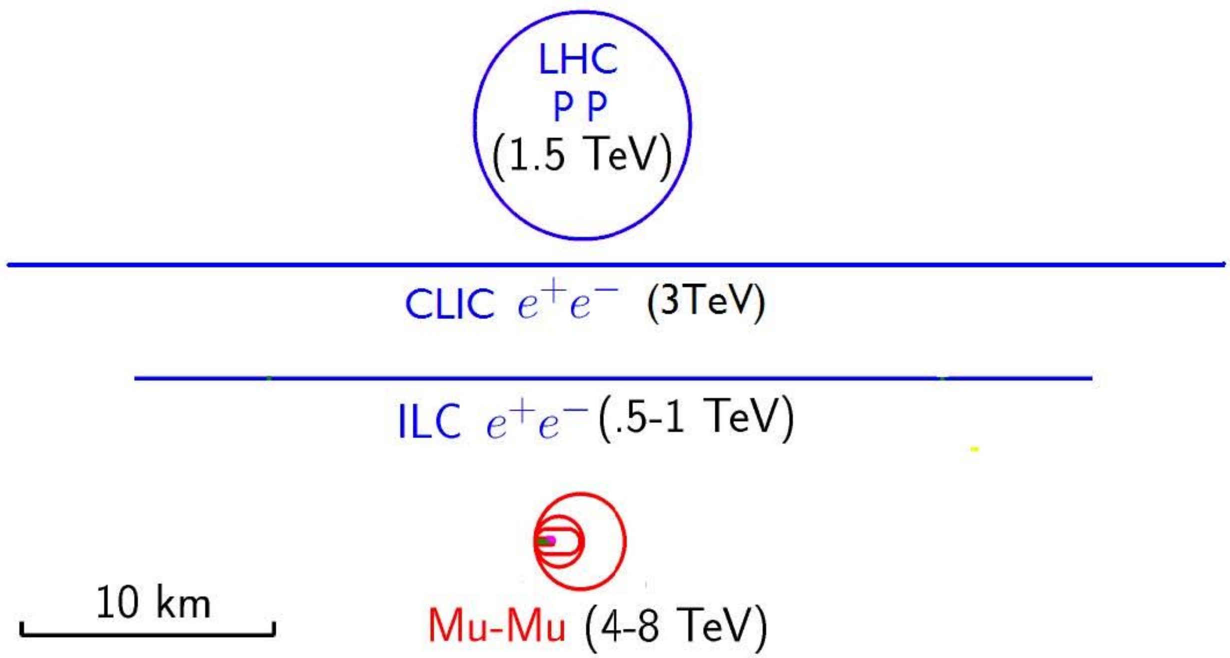

Figure 1 Relative sizes and effective available energies of High Energy Physics facilities

There are two significant technical challenges in the development of the required intense muon beams. The first is the production and collection of the muons, and the second is the reduction of the phase space (cooling) of the muon beam in order to obtain the required beam properties. Such cooling involves the reduction of the beam's extent in 6-D phase space, i.e. in each of the three space and three momentum dimensions. The only technique that is fast enough for muon beam cooling is ionization cooling [ref 4]. In this process, the magnitudes of 3-dimensional momentum vectors of the muon particles are reduced via energy loss in an ionizing media, followed by the subsequent restoration of only the longitudinal momentum component with rf power.

Lattices have been designed and simulated that appeared to provide the needed ionization cooling for a muon collider [ref 5], but these lattices required that the rf used for reacceleration should operate in strong axial magnetic fields that provided the muon focusing. Subsequently, experiments have shown that rf cavities did not operate well in these magnetic fields. A titanium window was punctured in one experiment [ref 6], and several experiments have shown reduces operating gradients [refs 7,8] and, when taken apart showed severe damage [ref 7]. Two solutions have been proposed:

a) filling the rf cavities with high pressure hydrogen gas – this has been shown to remove the above problem, but may not work with the intense ionizing muon beam; and

b) magnetic insulation. This SBIR proposal is to design an experiment to test this idea, and to study its application to the required lattices for a muon collider.

Magnetic insulation is a concept that has been known for some time in applications with pulsed voltages. The principle is simple: magnetic fields are introduced at right angles to the voltage gradient. Electrons emitted from a surface are thought to initiate electrical breakdown in the presence of external magnetic fields. The electrons are accelerated by the electric field, focused by the magnetic field, and cause damage and breakdown when they hit another surface. If there is a magnetic field at right angles to this electric gradient then the electrons will be bent back to their source, will be unable to gain significant energy, and will thus not be able to cause a breakdown.

Magnetic insulation applied to rf is a very recent concept [ref 9] that has yet to be observed. It requires that a cavity be designed in which the magnetic fields are made perpendicular to the electric fields. In this case it requires that they be parallel to the cavity surfaces where the rf electric fields are high. This proposal is to design the first experiment that would demonstrate the effect in an accelerating cavity, and study its application to cooling for a Muon Collider.

b) A Cooling Scenario for a Muon Collider

Introduction

Muon colliders were first proposed by Budker in 1969 [ref 10], and later discussed by others [ref 11]. A more detailed study was done for Snowmass 96 [ref 12], but in none of these was a complete scheme defined for the manipulation and cooling of the required muons.

The only published complete scheme for production and cooling a muon beam for muon colliders [ref 5]. The parameters of three specified muon colliders were presented, and a complete production and cooling scenario described.

The scheme starts with the front end of a proposed neutrino factory [ref 13] that yields bunch trains of both muon signs. Six dimensional cooling, using emittance exchange, in gentle helical lattices, reduces the longitudinal emittance until it becomes possible to merge the trains into single bunches, one of each sign. Further cooling in all dimensions is applied to the single bunches in further gentle helical lattices. Final transverse cooling to the required parameters is achieved in 50 T solenoids. Preliminary simulations of each element have been done at some level.

We will first describe the components of this system and then discuss the problems in the final cooling whose solution this study would address.

Collider Parameters and Cooling Scenario

Table 1 Parameters of 3 Muon Colliders using the same capture and cooling scenario.

E(center of mass) (TeV)	1.5	4	8
Luminosity (10^{34} cm^2 sec^{-2})			
Beam-beam tune shift	0.1	0.1	0.1
Muons per bunch (10^{12})	2	2	2
Average ring bending field (T)	5.2	5.2	10.4
Focus parameter beta (mm)	10	3	3
Rms fractional momentum spread (%)	0.09	0.12	0.06
Fractional transmission from capture to ring	0.07	0.07	0.07
Repetition Rate (Hz)	13	6	3
Proton Driver Power (MW)	4	1.8	0.8
Transverse emittance in ring (pi mm mrad)	25	25	25
Longitudinal emittance in ring (pi mm mrad)	72,000	72,000	72,000

Table 1 gives parameters for muon colliders at three energies. Those at 1.5 TeV correspond to a recent collider ring design [ref 14]. The 4 TeV example is taken from the 96 Study [ref 15]. The 8 TeV is an extrapolation assuming higher bending fields and more challenging intersection parameters. All three use the same muon intensities and emittances, although the repetition rates for the higher energy machines are reduced to control neutrino radiation.

Fig. 2a shows a schematic of the components of the system. Fig. 2b shows a plot of the longitudinal and transverse emittances of the muons as they progress from production to the specified requirements for the colliders. The subsystems used to manipulate and cool the beams to meet these requirements are indicated by the numerals 1-9 on the figures.

Muon Production

The muons are generated by the decay of pions produced by proton bunches interacting in a mercury jet target [ref 16]. These pions are captured by a 20 T solenoid surrounding the target, followed by an adiabatic lowering of the field to a decay channel.

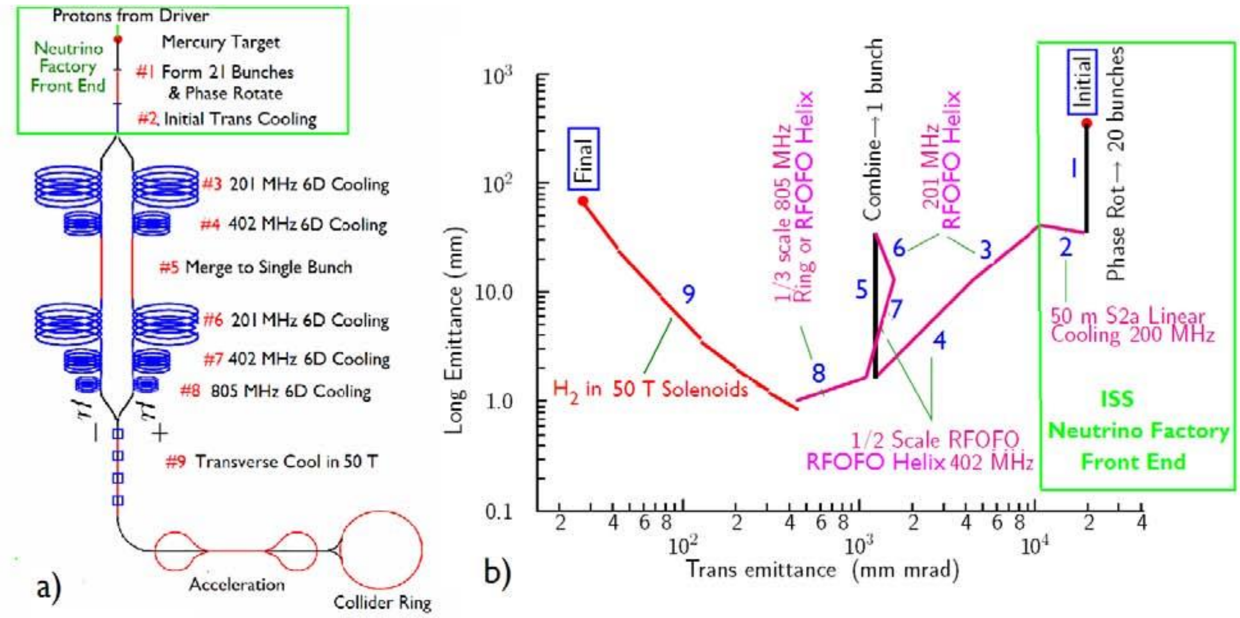

Figure 2 Proposed complete Scheme for a Muon Collider: a) Muon Collider Schematic
b) Plot of longitudinal emittance vs. transverse emittance for each of the step.

Phase Rotation and initial cooling

The first manipulation (#1), referred to as Phase Rotation [ref 17], converts the initial single short muon bunch with very large energy spread, into a train of 14-21 bunches with much reduced energy spread. The initial bunch is allowed to lengthen and develop a time energy correlation in a 110 m drift. It is then bunched into a train, without changing the time energy correlation, using rf cavities whose frequency varies with location falling from 333 MHz to 201 MHz. Then, by phase and frequency control, the rf accelerates the low energy bunches and decelerates the high energy ones. Muons of both signs are captured and then (#2) cooled transversely in a linear channel using LiH absorbers, periodic alternating 2.8 T solenoids, and 201 MHz rf. All the components up to this point are identical to those described in a recent study [ref 13] for a Neutrino Factory.

6D cooling before merge

The next stage (#3) cools simultaneously in all 6 dimensions. The RFOFO (Reverse FOcus-FOcus) lattice [ref 18] uses 3 T solenoids for focus, weak dipoles (generated by tilting the solenoids) to generate dispersion, wedge shaped liquid hydrogen filled absorbers, where the cooling takes place, and 201 MHz rf, to replenish the energy lost in the absorbers. The dipole fields cause the lattices to curve, forming a gentle upward or downward helix (see Fig. 3a). The following stage (#4) uses a lattice essentially the same as #3, but with twice the field strength, half the geometric dimensions, and 402 instead of 201 MHz rf.

Instead of the gentle helical RFOFO lattices for 6D cooling described here, a planar wiggler lattice is being studied [ref 19]. Such a lattice would cool both muon signs simultaneously, thus greatly simplifying the system.

Bunch merge

Since collider luminosity is proportional to the square of the number of muons per bunch, it is important to use relatively few bunches with many muons per bunch. However, capturing the initial muon phase space into single bunches requires low frequency (approx 30 MHz) rf, and thus low gradients, resulting in slow initial cooling. It is thus advantageous to capture initially into multiple bunches at 201 MHz and merge them after cooling allows them to be recombined into a single bunch. This recombination (#5) is done in two stages: a) using a drift followed by 201 MHz rf, with harmonics, the individual bunches are phase rotated to fill the spaces between bunches and lower their energy spread; followed by b) 5 MHz rf, plus harmonics, interspersed along a long drift to phase rotate the train into a single bunch that can be captured using 201 MHz. Work is ongoing on the design and simulation of a system with the low frequency rf separated from a following drift in a wiggler system with greater momentum compaction to reduce the length and decay losses.

6D cooling after merge

After the bunch merging, the longitudinal emittance of the single bunch is now similar to that at the start of cooling. It can thus be taken through the same, or similar, cooling systems as #3 and #4: now numbered #6 & #7.

One more stage (#8) of 6 dimensional cooling is employed, using 12 T magnets, hydrogen wedge absorbers, and 805 MHz rf. Figure 3b shows the cooling lattice as simulated in reference [ref 5].

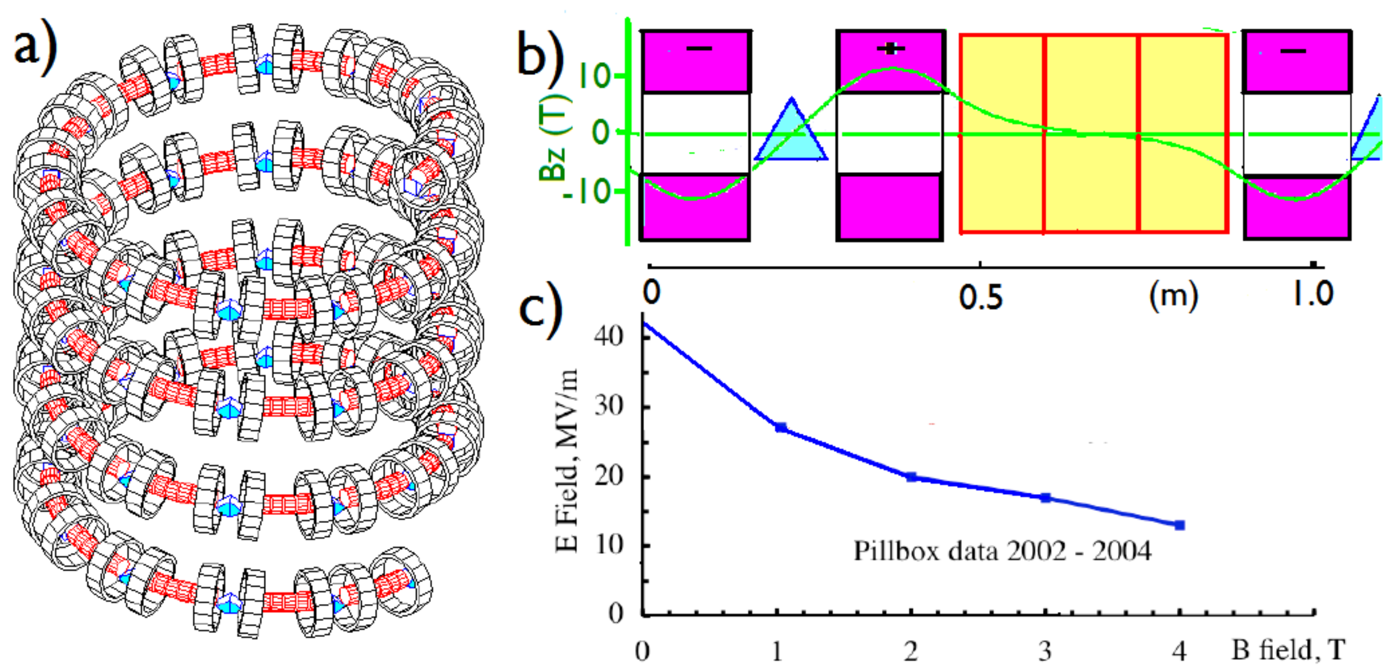

Figure 3 a): Low pitch helical arrangement for final 6 D ionization cooling channel; b): Detail of published lattice for the final 6 D ionization cooling channel; c) Observed drop in maximum gradient with applied external axial magnetic field.

Final transverse cooling in high field solenoids

It is the design and optimization of this part of the system that the proposed study would be devoted to.

At the end of stage #8 the transverse emittance is about one order of magnitude greater than required, but the longitudinal emittance is about two orders of magnitude less, i.e. better, than that required. This low longitudinal emittance allows us to do the final cooling in a channel without dispersion or wedges: a channel that cools only in the transverse direction and allows the longitudinal emittance to rise.

To attain the required final transverse emittance, the cooling needs stronger focusing than is practical with 6-D cooling lattices. But higher fields are possible in a linear channel that cools only in the transverse dimensions. The higher the field, the lower the equilibrium emittance; and since the lowest possible emittance is desirable, we propose the use of the highest available DC magnet fields. The highest DC magnet we know of is the 45 T hybrid solenoid [ref 20] at the National High Field Magnet Lab (NHFML) in Florida. Since this magnet has been operating for some time, and improvements in technologies, such as high temperature superconductors (HTS) have occurred since, it has been assumed that DC fields of 50 T should be possible, and have used this value in preliminary studies [ref 5].

The cooling would occur in a liquid hydrogen column on the axis of the solenoid. But even a 50 Tesla field, with muons near their ionization minimum (approximately 300 MeV/c) cannot focus the muons tightly enough to reach our desired final emittance. But if the momentum is allowed to fall to of the order of 30 MeV/c, then the resulting increased focus strength, combined with the greater energy loss rate, allows one to reach the requirement. Operating at such a low momentum has the disadvantage that the energy loss rate is rising rapidly with falling energy, resulting in a rapid increase in the energy spread and thus the longitudinal emittance. However, as we have noted above, the earlier 6-D cooling has lowered the longitudinal emittance to a value far below that needed. So the rise in longitudinal emittance, resulting from cooling at such a low momentum, can be tolerated.

Theoretical studies [ref 21] have suggested an alternative to the use of the very high field solenoids for the final cooling. Indeed, these theoretical studies suggest cooling to significantly lower final transverse emittances than discussed here. But no lattice that achieves the required parameters has been defined, and the problem seems very hard.

c) Problems with required rf operation in magnetic fields

The parameters of the rf systems in the early phase rotation and the 6-D cooling lattices are summarized in Table 2. The magnetic fields are the maximum values on the rf cavities in the simulated designs.

Table 2: Parameters of rf in the phase rotation and 6 dimensional cooling lattices

Stage	Frequency	gradient	Magnetic field
	MHz	MV/m	T
Phase rotation	201	15	2
First 6 D (#3 & #6)	201	12	3
Second 6D (#4 & #7)	402	18	6
Final 6D (#8)	805	18	5

Experimental studies at 805 MHz [refs 6, 7] and a more recent one at 201 MHz [ref 8] have show serious problems when such rf cavities are operated in significant axial magnetic fields.

In an early test of a multi-cell 805 MHz cavity [ref 6], acceleration gradients seemed little effected by the field but damage was done to a titanium vacuum window and vacuum lost. The cause appeared to be electrons emitted at a high gradient location on an iris being focused by the magnetic field to the window

A later test of a single ‘pill box’ cavity with beryllium windows on both sides found a severe reduction in achievable surface gradients as a function of the strength of the magnetic field (see figure 3c). Inspection showed considerable pitting on the copper iris surfaces. More recently, a test of a 201 MHz cavity without field achieved 21 MV/m, but in the 0.6 T fringe field of a 4.5 T magnet achieved only 10 MV/m, and when tested again without filed could not again achieve more than 18 MV/m. So in all cases, operation of the rf in magnetic fields equal to, or even less than, those specified, showed damage and most suffered serious loss of achievable gradient.

This problem is under study by the MuCOOL collaboration [ref 22] and alternative designs using a) high pressure hydrogen gas, and b) magnetic insulation, are under study.

The use of high pressure hydrogen in a Helical Cooling Channel (HCC) [ref 23] has been investigated. The realistic integration of rf into these channels remains to be defined. High pressure gas could also be used in RFOFO lattices and simulations [ref 24] are encouraging. However it is yet to be determined experimentally if the gas will not break down or become too resistive in the presence of the intense muon beams passing through them.

The particular case of the use of magnetic insulation is the subject of this proposal.

d) Magnetic Insulation of rf

It has been proposed [ref 9] that the observed damage and breakdown is due to electron beams emitted at asperities on one side of the cavity, being focused by the magnetic field to another surface. The solution proposed in this reference is to employ ‘magnetic insulation’. In this concept, an external magnetic field is introduced at right angles to the electric field. Magnetic fields have been tried to reduce rf breakdown, but those fields did not use the specific solution embodied in magnetic insulation. This is a concept has been long ago proposed for high voltage pulse applications, but never, to our knowledge, proposed for an rf application.

The novel idea is to employ externally applied magnetic fields with their direction parallel to any surface exposed to high rf electric field gradients. A pillbox cavity placed in a uniform field parallel to its flat faces (see Figure 4a) would provide the simplest demonstration of the principle, although it is not a useful accelerating cavity.

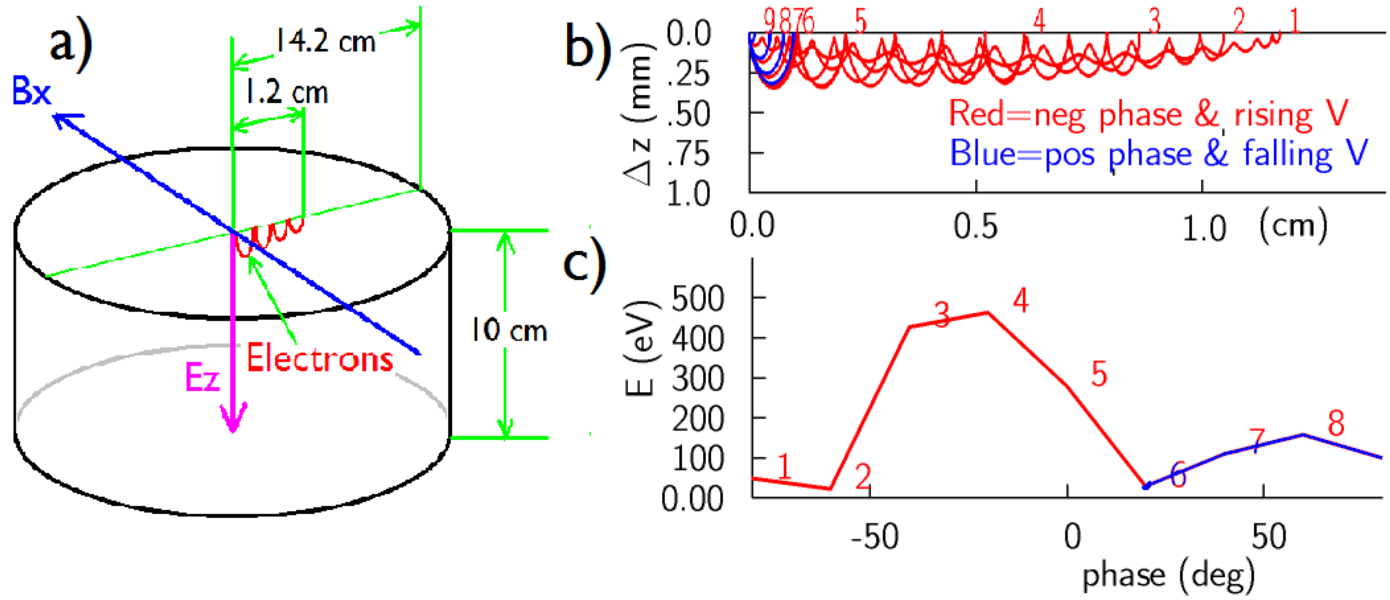

Figure 4: The principles of rf magnetic insulation; a) schematic of magnetic insulation simulation in a pill-box cavity at right angles to an external magnetic field; b) simulated electrons leaving the center of one face of the cavity; c) the energies of the returning electrons as a function of the rf phase when they were emitted.

Simulations with a program CAVEL show that electrons, emitted from a surface are initially accelerated by the electric field away from that surface. Then, as they attain significant momentum, they are deflected by the magnetic field and directed back to the surface. Depending on their phase of emission, they may after a single half loop, return to the surface, or, at early phases, they may make several loops (see Figure 4b), but they always return to the surface with less than a kilovolt (see Figure 4c) so they can do no damage.

For a useful cooling lattice, the idea is to place the primary focus coils in the irises of open multi-cell cavities, and shape the walls of the cavity to follow the magnetic field lines. Figure 5a shows a simple example of this principle applied to a single rf cavity with just two coils, one on either side of the cavity. This is the example that would form the basis of a demonstration experiment to be built and test in a second phase SBIR, and who's design is the primary goal of this phase I proposal.

The secondary objective of this phase I proposal is to study more complex lattices for use in different stages of 6-D cooling. Figure 5b shows a conceptual design of a lattice for use in the final 6-D cooling stage.

The outer 'bucking' coils are introduced to shape the field lines so that the resulting cavity shape is more efficient with higher average acceleration for a given maximum surface gradient.

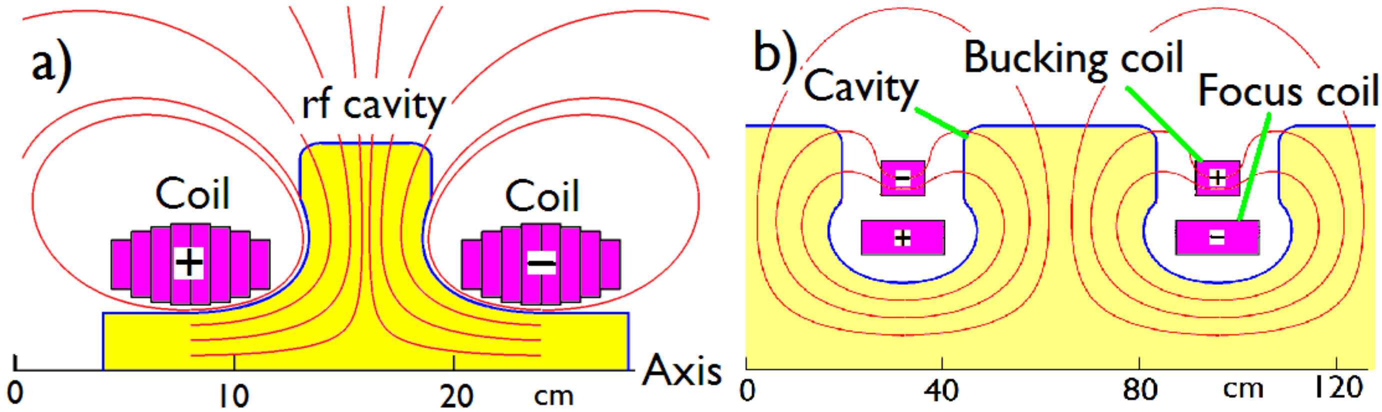

Figure 5a: A simple demonstration of magnetic insulation of rf, with one cavity and two coils. Figure 5b: The conceptual design of a multi-cell magnetically insulated lattice with outer 'bucking coils' to shape the fields, and thus the cavity shapes to improve their efficiency.

e) The Proposed Demonstration Experiment

It is proposed to design a single cell 805 MHz cavity, and external solenoid coils to demonstrate magnetic insulation in an accelerating cavity. 805 MHz is chosen because it keeps the apparatus small and because it is available at the Muon Test Area (MTA) at Fermilab. For a real cooling channel at that frequency, fields of the order of 10 T are required (see table 1), but such a high field is not required for a demonstration of magnetic insulation. The experiments have shown serious problems at far lower fields, and the simulations suggest that these problems will be overcome by magnetic insulation with fields of only 1-2 T.

It is apparent in Figure 5a that there is little space between the coils and the cavity wall. For the 10 T required fields in a lattice for muon collider cooling, only superconducting coils at 4 degrees can be used, even with HTS. The rf cavity, on the other hand cannot efficiently be operated below around 77 degrees Kelvin, so there will need to be a thin vacuum insulating space between them. But for a first demonstration, we can use lower magnetic fields and avoid the need for the vacuum space and simplify the experiment. We will study two options:

a) use HTS conductor and operate both coils and cavity at the same temperature at whatever temperature can be obtained by pumping on liquid nitrogen (approx 65 degrees). This should allow fields of 2 - 3 T.
b) use pulsed copper coils at nitrogen temperature. Fields of the order of 1 T should be possible for pulse lengths of the order of 1 second.

Figure 6 shows a sketch of what the experiment might look like with the HTS option. In the pulsed copper coil option, there would be no outer containment, and the whole experiment would be immersed in a foam insulated nitrogen container (beer cooler).

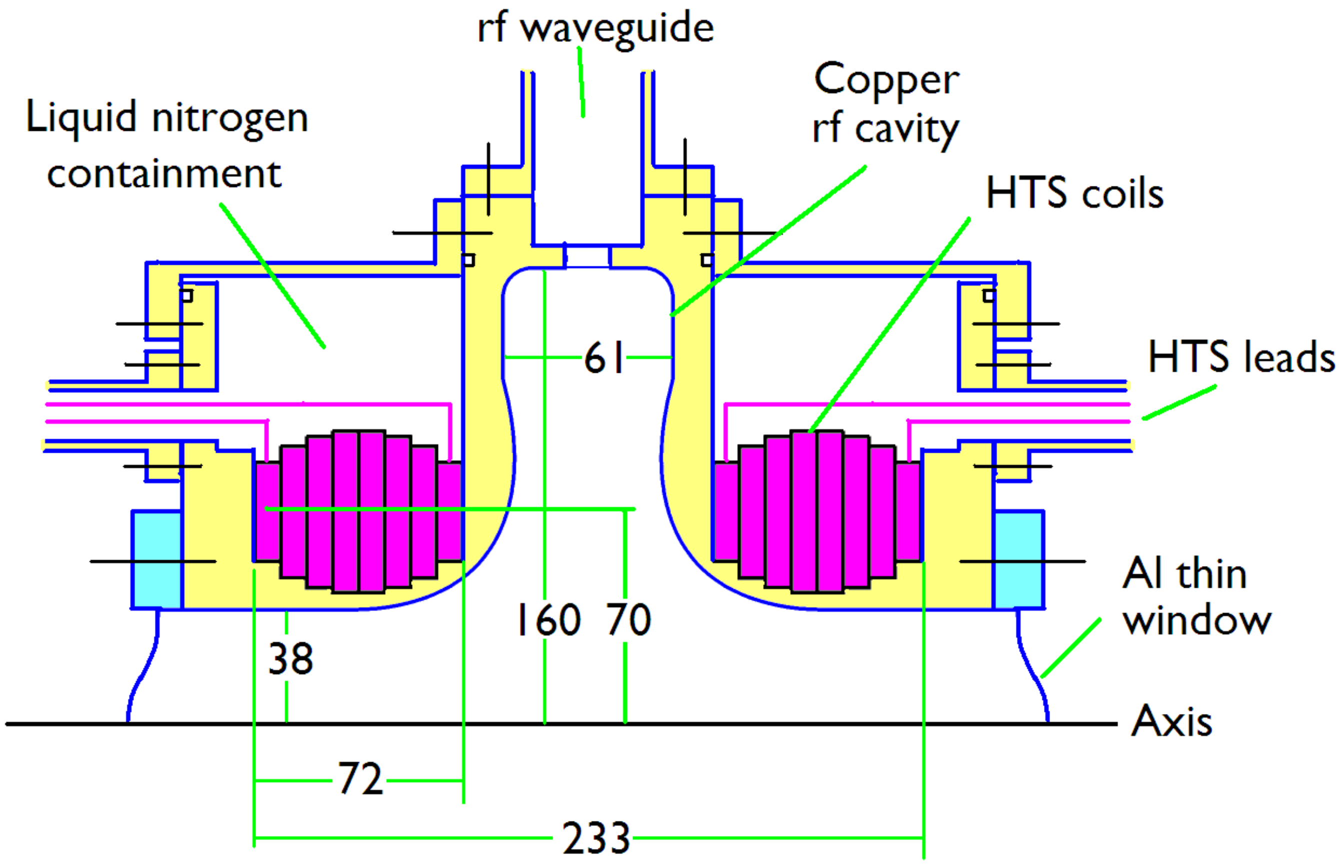

Figure 6: Concept of experiment to demonstrate magnetic insulation

f) Anticipated Public Benefits

Applications for Magnetic Insulation 6-D Cooling for a Muon Collider in USA

1. The 6-D cooling concepts proposed here could be a key component for the development of a $\mu^+\mu^-$ collider in the USA. The HEPAP subcommittee labeled P5 has recently reported a strong support for the study of $\mu^+\mu^-$ colliders. FNAL has set up a "Muon Collider Task Force" [MCTF]. In a recent study by the MCTF the issue of 6-D cooling was at the forefront of the problems for study for a muon collider. The study suggests a 1.5 TeV collider as a starting point. Such a collider could be located on the current 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 about the only 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….” This would require the muon beam to scatter from the fissile material.

A small acceleration ring that uses HTS magnets to produce 300 MeV protons would be ideal to put on a portable system to survey sites for fissile material. We would study the possibility in Phase I as the dipoles are being studied. We consider a ring with a 2m diameter and a possible high gradient accelerator using dielectic. A flip target in the ring to produce pions that decay into muons. The high field HTS magnets are used to keep the ring small and to avoid cryogenics. A schematic of such a ring is shown in Figure 7.

Such a device might be used for nanotechnology and medical studies as well with the μ beam cooled for use that has been investigated before and is discussed later in this proposal.

Compact Muon Source for Homeland Security

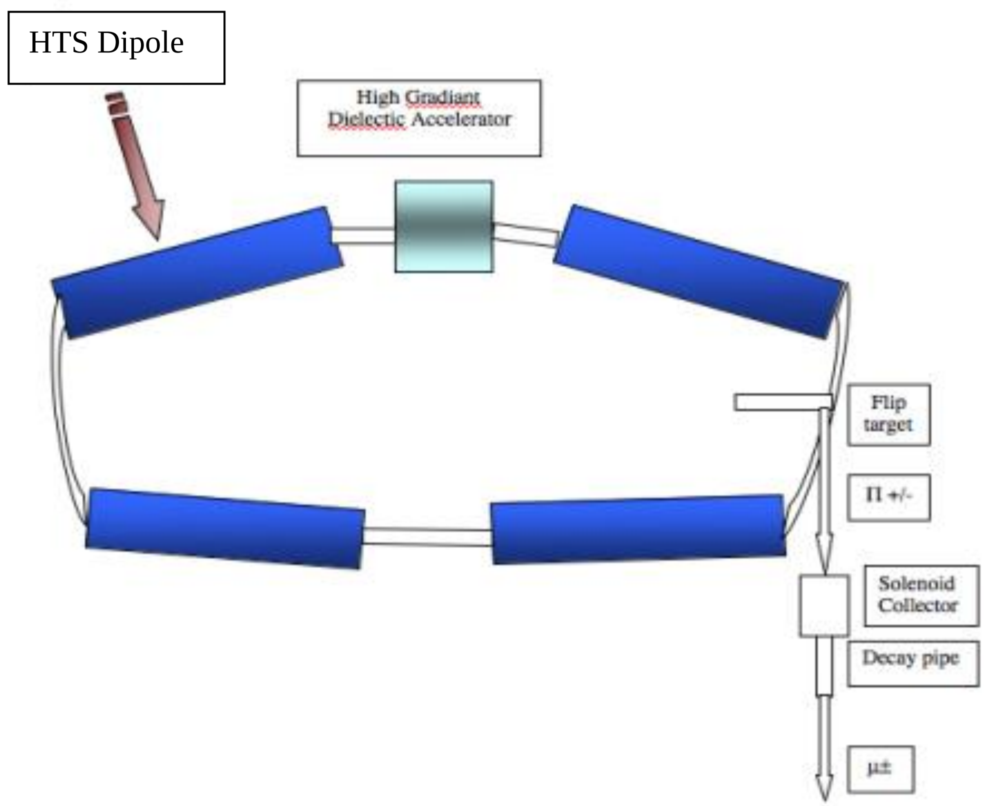

Figure 7:   Compact muon source using HST dipoles and a flip target.

g) Technical Objectives

A) For the design of a demonstration of magnetic insulation

1) Design a combination of coils and cavity geometries to give magnetic insulation on the rf cavity.
2) Study and compare the technical requirements for pulsed copper and HTS coils.
3) Determine forces between the coils and determine the requirements to restrain them.
4) Design the rf cavity and coupling to an rf waveguide.
5) Make engineering drawings of the experiment.
6) Build and test in liquid nitrogen a copper pulsed solenoid coil

B) For the design of magnetically insulated cavities for muon cooling

1) Optimize the magnetically insulated rf reacceleration systems for use in 6D cooling lattices, to maximize their acceleration gradients relative to the maximum surface gradients which will limit the cavity performance.
2) Design LTS, HTS or Nb3Sn coils to provide magnetic insulation of the cavities.
3) Simulate the 6-D cooling performances, and optimize that performance by adjusting the dimensions and magnetic field strengths.

h) Phase I Work Plan and Performance Schedule

Months 1-3:
Study the use of pulsed copper coils and determine if this approach is practical (Weggel).

Study the use of HTS materials and determine their cost and practicality (Scanlan).

Fix the field distributions and thus cavity shape (Stratakis).

Start study of lattices for 6D cooling (Palmer)

Design coils and electrical power requirements for pulsed coil (Weggel, Stratakis)

Months 4 – 6:
Build and test in liquid nitrogen a copper pulsed solenoid coil (Weggel, Stratakis, Magnet Group)

Design outer profile of cavity and coupling to waveguide (Keane)

Simulate magnetic insulation performance (Stratakis)

Design coils, electrical power, and quench protection requirements for HTS coil, if practical (Weggel, Scanlan, Magnet Group)

Continue study of lattices for 6D cooling (Palmer)

Milestone at the end of month 6:

Define the coils, required currents, rf cavity shape, and coupling to wave guide (all).

Months 7-8:

Make engineering drawing of experiment (Keane)

Continue study of lattices for 6D cooling (Palmer)

Month 9: Prepare Phase I report on the design of a magnetic insulation experiment. Prepare a phase II proposal to build the demonstration experiment, together with design work on lattices for 6-D cooling needed in a muon collider, including study of its engineering challenges.

i) 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 near 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) Other Possible Uses of Cold Muons

a) Possible element selection by muon radiography

Cosmic ray muons were used years ago to study the pyramids in Egypt by L. Alvarez. There could be new commercial uses of very cold energetic muon beams that have been cooled by a gas ring cooler. These beams would likely have to be accelerated to greater than 600 MeV energy in some cases and would need an energy spread of less than 100 keV and a very small spot size. Examples of objects that could be studied at the required energy are:

1) Human head – 60 MeV

2) Homeland security search for fissile materials in trucks (with oil for example) – 600 MeV

b) Other applications of very cold intense beams could be muon catalized fusion. Currently studies of this process show low efficiency. Using cold muons with a clear deceleration might yield higher efficiency. Medical applications are discussed in "Uses of Slow Muons in Life Sciences", K. Nagamina, J. Phys.G.Nucl.Part.Physics 29 (2003), 1507.

c) Use of intense sources of muons in condensed matter studies and nanotechnology and other technology.

d) The 6-D cooled muon beams could have commercial applications such as sub-surface magnetic field measurements in nanotechnology and new ways to study the brain and other medical applications. This could be a by-product of the cooling system for a Neutrino Factory or Muon Collider.

A 6-D cooling system as described here might help collect very large number of cold muons. In principle these muons could be decelerated to low energy by dE/dX systems or other means with a low energy electrostatic device and dE/dX combined. There are two key reasons very cold muons might be useful:

1) The range of the muon can be very small, allowing the muons to stop inside nanostructures (the range of a 1 KeV muon is 8 nm).

2) The polarization of muons can be used to test the magnetic fields inside the structure.

Both of these methods are in use today around the world, but the muon intensities are rather small, i.e. for PSI of order 10^6 to 10^7. We quote from a talk at Nufact04 in Osaka, Japan the advantage of higher muon fluxes: "High quality muon beams (flux, emittance, brilliance) would have great impact on the application of muons in nanoscience (e.g. micro-beam, possibility of lateral resolution on the micro-meter scale and investigation of ~ 100 micron x 100 micron samples".

Several of these schemes to decelerate muons have been pioneered by K. Nagamina at RIKEN.

j) Principal Investigator and Senior Personnel

John Keane, principal investigator, has had 43 years of experience as an RF engineer at Brookhaven National Laboratory. He has worked at BNL's 50 MeV and 200 MeV Linacs, Alternating Gradient Synchrotron (AGS), Heavy Ion Fusion project, National Synchrotron Source (NSLS), and Relative Heavy Ion Source (RHIC). He participated in design, installation and modification of RF systems at these installations. He has extensive experience in RF cavities, transmission lines components, power amplifiers and impedance matching to particle accelerators. Over the course of his career he was Deputy Division Head at the AGS, Chief Electrical Engineer at the AGS and NSLS. He was a member of the DOE review committee that recommended the site for the B-Factory. He has served on numerous RF reviews at DOE laboratories.

Dr Robert Palmer is currently employed only 2/3rds time at Brookhaven National Lab, and will thus be able to devote substantial time to this project. He is an internationally known experimental elementary particle physicist with expertise in superconducting magnets and the science and applications of particle accelerators. He is a winner of an APS Panofsky Prize (for experimental high energy physics) and an APS Wilson Prize (for accelerator physics). He has led the BNL superconducting magnet group, has served as a BNL Associate Director for High Energy Physics, and is now leader of the Advanced Accelerator group in the BNL Physics department. He will join PBL, Inc. as a part-time employee upon award of a SBIR Phase I grant for this work.

Robert J. Weggel is an employee of PBL, Inc. and will participate in this Phase I project. Mr. Weggel has had 40 years of experience as a magnet engineer and designer, first at the Francis Bitter Magnet Laboratory at MIT and also at Brookhaven National Laboratory as well as extensive consulting experience in solenoid 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”. Mr. Weggel will be responsible for studying the pulsed copper coil option for this project.

Dr. Ronald Scanlan is also an employee of PBL, Inc. Dr. Scanlan specializes in superconducting materials and magnets. Prior to his retirement from the LBNL in 2003, he was the Group Leader for Superconducting Wire and Cable Development. He was responsible for the U.S. DOE, Division of High Energy Physics, Conductor Development Program. While at LBNL, he served as Magnet Program Head during the design, construction and testing of the world’s first 13.5 T Nb_3Sn dipole magnet. In 1991, he shared the IEEE Particle Accelerator Conference Award with Dr. Larbalestier “for the development of NbTi superconducting material for high current density in high field superconducting magnets”. He is author or co-author of over 100 publications in the field of superconducting materials and magnets. Dr. Scanlan will be responsible for studying the HTS coil option for this project.

k) Facilities and 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, and currently has active Phase I and Phase II project on developing technology for a muon collider. The company has the capability, experience and administrative infrastructure to carry out the Phase I project proposed. The Brookhaven National Laboratory (Magnet Division) will be a subcontractor on this Phase I project providing mechanical engineering, incidental machining, and software as needed. See attached letter from BNL management.

l) Consultants

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 in accelerating and storage ring structures and investigating commercial applications as well as applications for Homeland Security using a muon beam source. A letter of commitment from Dr. Cline is part of this proposal.

Dr. Diktys Stratakis is an accelerator physicist expert in handling intricate modeling problems. Dr. Stratakis will perform calculations related to the rf cavities associated with this project. A letter of commitment from Dr. Stratakis is part of this proposal.

m) Similar Grant Applications, Proposals, or Awards

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

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