Intense Muon Beam R&D
and
Muon Ionization Cooling Experiment

LBNL Perspective

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Outline

- Introduction
- Neutrino factory ingredients
- Cooling description
- MUCOOL R&D program
- MICE implementation
- Summary

Introduction

- LBNL AFRD staff involved since 1995 in an R&D program aimed at the eventual construction of a Neutrino Factory and later a Muon Collider
  - both facilities technically very challenging
  - both offer substantial scientific opportunity
- Neutrino Factory offers unprecedented neutrino intensity for studies of neutrino mixing and, hopefully, CP violation in the lepton sector
- Muon Collider would permit a modest scale Higgs Factory
  - later, we hope for energy-frontier facility sited at an existing laboratory (cf. extremely large accelerators like SSC, VLHC, LC
- LBNL is lead lab for U.S. Neutrino Factory and Muon Collider Collaboration (MC), which has 130 members
  - we provided leadership of simulation effort, members of Executive and Technical Boards, MC Spokesperson, and MC Project Manager
  - we provide ongoing technical leadership in RF and magnet systems, plus expertise on cryogenics

Introduction

- Creating a Neutrino Factory requires a significant extension of the accelerator builder's art
  - main technical challenges: high-power (multi-MW) production targets and cooling apparatus
    - hardware requirements and facility performance predictions come from supporting simulation effort
- Goal of hardware R&D: test functionality of integrated systems, not just individual components
  - a car is "just thermodynamics and Maxwell's equations" but most people take a test drive before buying
- Full cooling systems test is the Muon Ionization Cooling Experiment
  - international collaboration, participants from U.S., Europe, Japan

Introduction

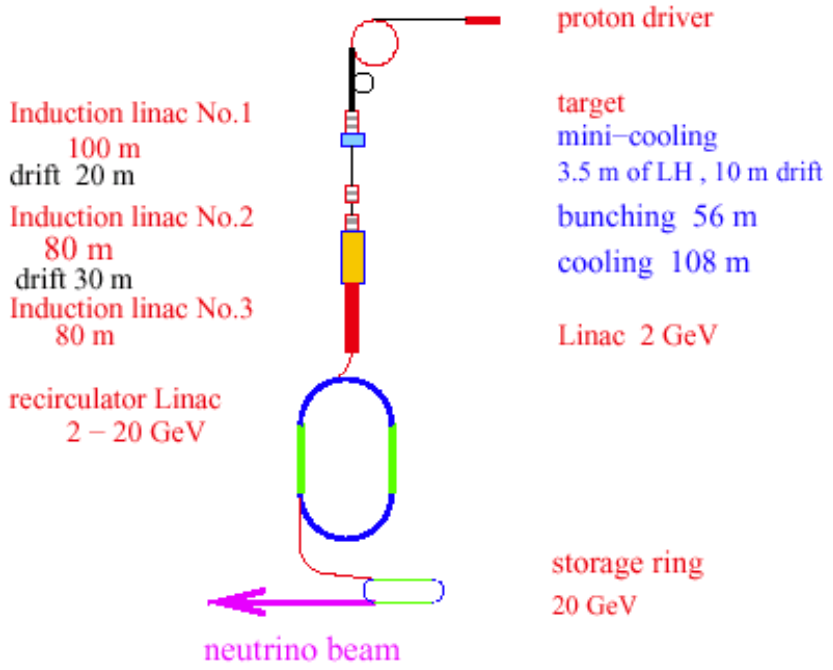
- Motivation for MICE
  - design of high-performance Neutrino Factory (≈4 x 10^{20} ν_e aimed at far detector per 10^7 s year) depends on ionization cooling
    - straightforward physics, but not experimentally demonstrated
- Cooling demonstration aims:
  - to design, engineer, and build a section of cooling channel capable of giving the desired performance for a Neutrino Factory
  - to place this apparatus in a muon beam and measure its performance in a variety of modes of operation and beam conditions
- Must show that design tools (simulation codes) agree with experiment
  - gives confidence that we can optimize design of an actual facility
- Simulations and apparatus tested must be as realistic as possible
  - incorporate full engineering details of all components into simulation

Introduction

- Challenges of MICE
  - for cost reasons, we use only a few cells of a cooling channel
    - ⇒ emittance reduction will be small in absolute terms ($\mathcal{O}$(10%))
      - need to measure emittance reduction at level of 10^{-3}
  - operating high-gradient RF cavities in solenoidal field and with field terminations (windows or grids) [LBNL lead role]
  - operating LH_2 absorbers with very thin windows and consistent with safety regulations [LBNL involvement]
- LBNL participation in MICE will be an invaluable training opportunity for students and/or post-docs
  - involvement of PD or NSD staff in MICE would be very good
- Participation in muon R&D program and MICE are investments in our long-term future in neutrino science
  - gives "seat at the table" for machine construction and the science

Neutrino Factory Ingredients

- Neutrino Factory comprises these sections
  - **Proton Driver**
    (primary beam on production target)
  - **Target and Capture**
    (create π's; capture into decay channel)
  - **Phase Rotation**
    (reduce ΔE of bunch)
  - **Cooling**
    (reduce transverse emittance of beam)
    ⇒Muon Ionization Cooling Experiment
  - **Acceleration**
    (130 MeV → 20–50 GeV with RLAs)
  - **Storage Ring**
    (store muon beam for ≈500 turns; optimize yield with long straight section aimed in desired direction)

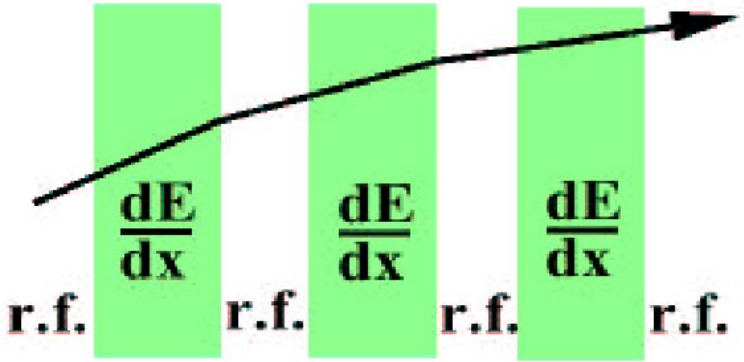


Study-II Neutrino Factory Layout

- Not an easy project, but no fundamental problems found to date

Cooling Description

- The need to cool the muons quickly dictates the approach to be used
  - muon lifetime in rest frame is 2.2 μs
    - "standard" stochastic cooling approach is much too slow
    - use novel technique of ionization cooling (tailor-made for muons)
- Analogous to familiar SR damping process in electron storage rings
  - energy loss (SR or dE/dx) reduces p_x, p_y, p_z
  - energy gain (RF cavities) restores only p_z
  - repeating this reduces $p_{x,y}/p_z$ and thus transverse emittance

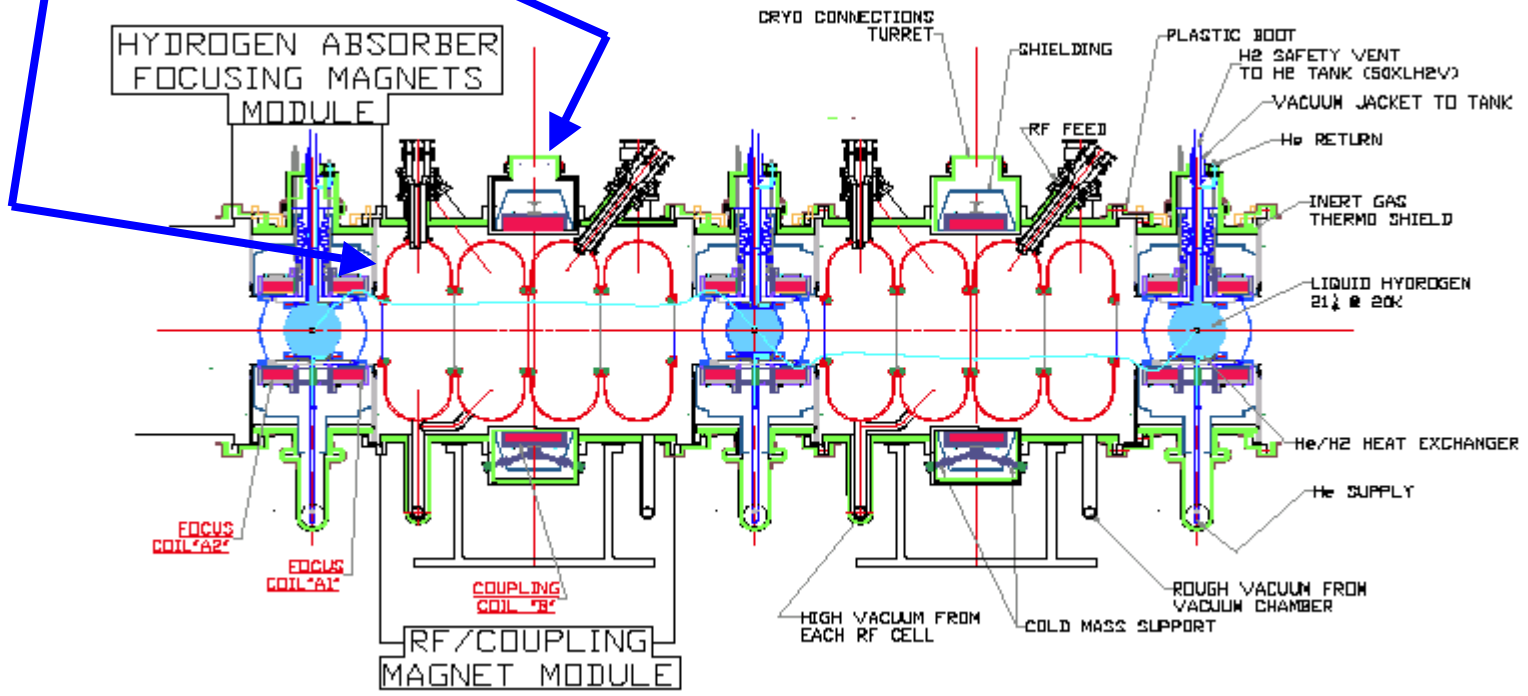


MUCOOL R&D Program

- Basic ingredients of a cooling channel are:
  - absorbers to give energy loss (LH_2, capable of handling ~100 W)
  - RF cavities to restore energy lost in absorbers (16 MV/m, 201 MHz)
  - solenoid magnets to contain the muons as they traverse the channel ($B \approx 5$ T)
- U.S. MUCOOL R&D program has substantial effort in place to develop required hardware components for cooling channel
  - $1–1.5M per year activity; 15–20 FTE
- MUCOOL will build and test prototypes of the absorber and 201-MHz RF cavity needed for MICE, and possibly the coupling coil as well
  - solenoid similar to focusing coils already built and operated
  - facility for component testing now under construction at Fermilab
- Supporting theory and simulation effort is well-matched to LBNL skills (but needs augmentation via post-docs/students)

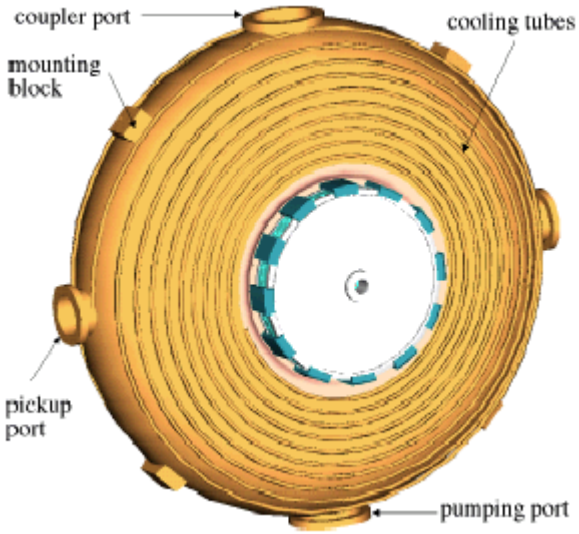
MUCOOL R&D Program

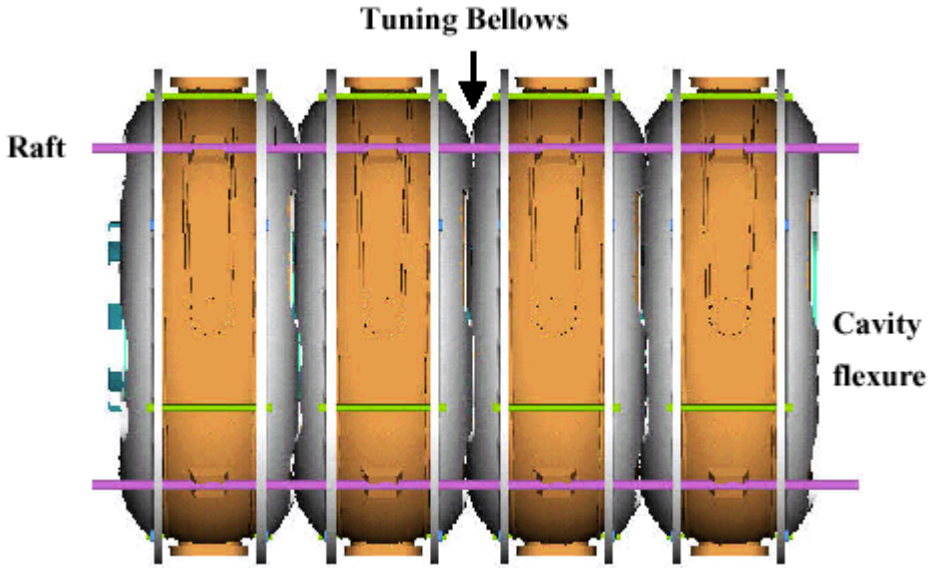
- Cooling channel components must be tightly integrated
  - focus here on LBNL activities and contributions
    - RF cavity module [LBNL MICE contribution]
    - coupling coils (outside RF cavity module) [LBNL MICE contribution]



MUCOOL R&D Program

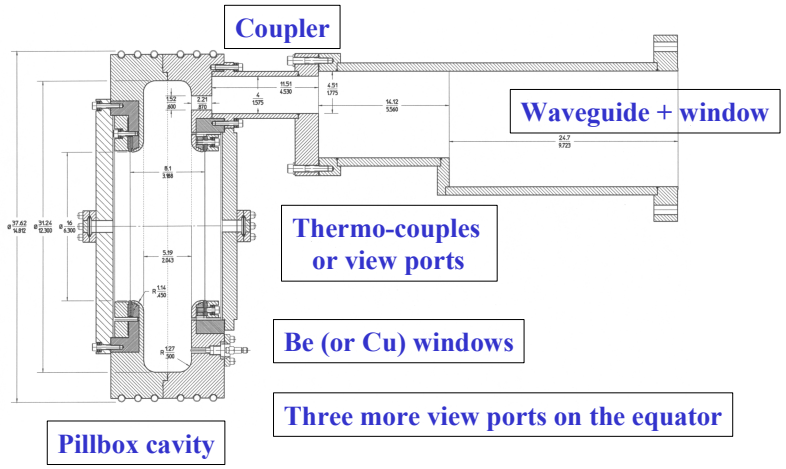
- 201 MHz RF cavity (LBNL)
  - RF module comprises 4 cavities with individual tuner mechanisms
  - cavities use Be foil at each end to increase shunt impedance
  - fabrication of prototype cavity will begin this year

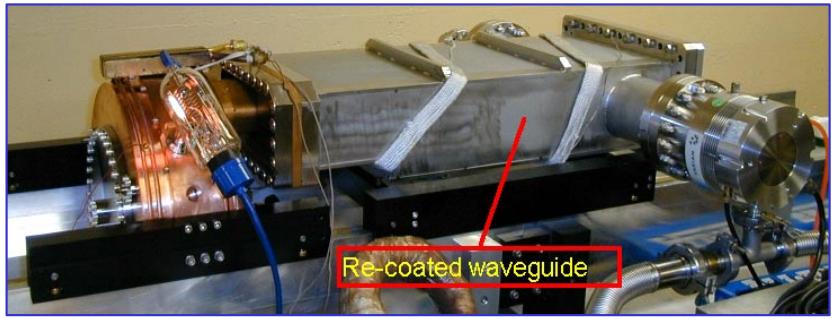




MUCOOL R&D Program

- 805 MHz cavity with foils (LBNL) being tested at Fermilab Lab G
  - gives advance information on:
    - behavior of a high-gradient RF cavity in a magnetic field
    - efficacy of Be window cavity termination

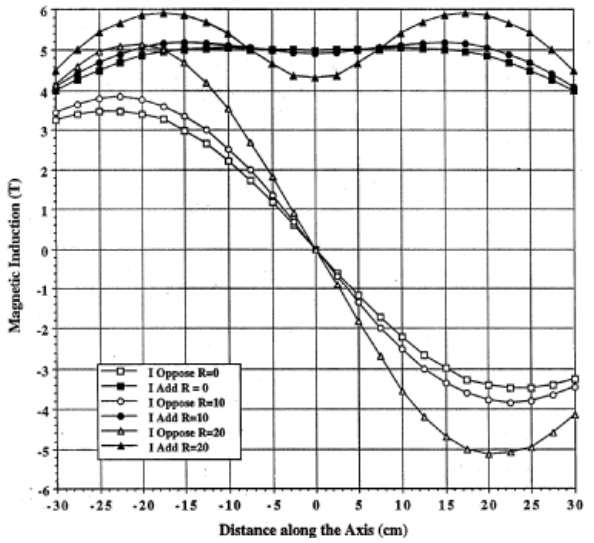




- With copper windows and no magnetic field, cavity reached 34 MV/m (above its 30 MV/m design goal)
  - with B_{sol}, much more sparking and dark current generation observed

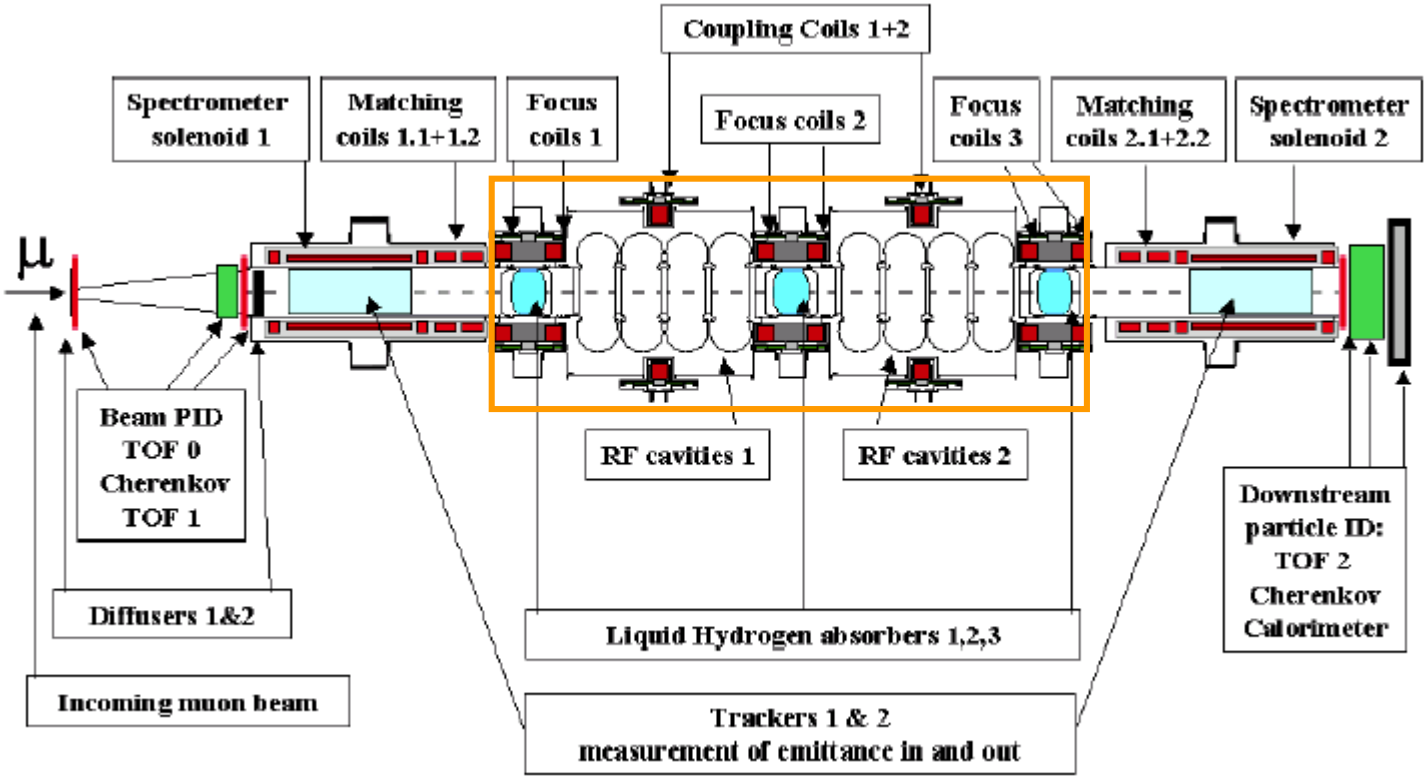
MUCOOL R&D Program

- Test solenoid representative of that needed for cooling channel has been built and tested (LBNL)
  - in "gradient mode" it has parameters similar to focusing coils
  - 805 MHz cavity being tested in this magnet
- Coupling coil prototype planned, but funding not yet available



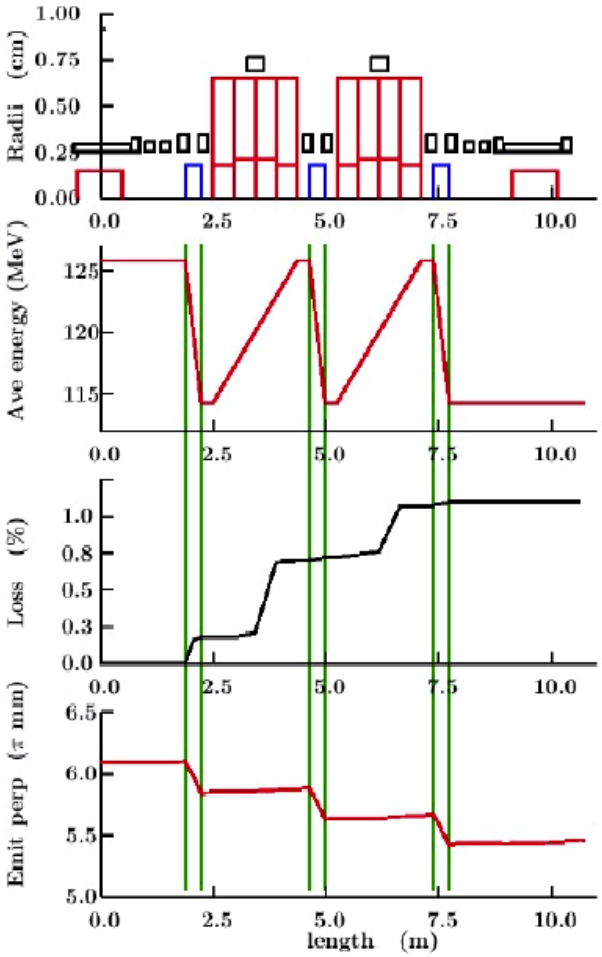
MICE Implementation

- Layout of MICE components
  - one lattice cell of cooling channel components (based on U.S. Study-II configuration) is indicated



MICE Implementation

- Simulations of MICE performance have been done
  - transverse emittance reduction of ≈10% expected



Energy variation

Particle loss

2D ε reduction

MICE Implementation

- Status of MICE
  - formal proposal submitted to Rutherford Appleton Lab (UK) in January, 2003

    http://hep04.phys.iit.edu/cooldemo/micenotes/public/pdf/MICE0021/MICE0021.pdf
  - international review held in February (chaired by Alan Astbury)
    - (favorable) report expected in few months
  - all groups have been encouraged to proceed with seeking funds
    - U.S. proposal ($25M) was submitted to NSF in September 2002
      - DOE-HEP also has a copy of proposal and was encouraged to coordinate funding with NSF
      - we await an answer from NSF "soon"

Summary

- R&D on muon cooling channel components already at an advanced stage
  - LBNL plays key technical role in RF cavity and solenoid design
  - LBNL plays key management role in MC R&D program and MICE
- MICE will assemble and test these components in a realistic beam environment
- Resultant demonstration of muon cooling will validate key concept of Neutrino Factory design
  - and put Muon Collider concept closer to being realized
- LBNL support for muon R&D effort and MICE is critical to preserving and enhancing the option of a future Neutrino Factory
  - we have considerable impact on worldwide effort in muon beam R&D
    - the scientific case for such a facility is very strong
- Muon-beam R&D program serves to bridge gap between cooling science and technology