Review of North American

Neutrino Factory R&D

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Outline

- Introduction
- R&D program activities
- MICE activities
- Summary

Introduction

- For purposes of this talk, "North American" will be interpreted to encompass only the work of the U.S. Muon Collaboration (MC)
  - this reflects pragmatism, not a geopolitical viewpoint!
- MC is attacking Neutrino Factory R&D problems on a broad front
  - also exploring Muon Collider issues
    - many of which are common to Neutrino Factory
- Much has happened since NUFACT01
  - went through "B&B" process (HEPAP Subpanel) and got positive response
  - Snowmass response to our effort also encouraging
    - support for neutrino physics (lower priority than LC e^+e^- physics)
- Most recent MUTAC review (October '01) was very favorable
  - they could see the progress

Introduction

- B&B report supportive of accelerator R&D in general, and muon accelerator R&D in particular

RECOMMENDATION 5:

We recommend that vigorous long-term R&D aimed toward future high-energy accelerators be carried out at high priority within our program.

2.5.1 Scenarios with an Onshore Linear Collider

Significant U.S. participation in the worldwide neutrino program, possibly including use of a new proton decay detector

2.5.2 Scenarios with an Offshore Linear Collider

A major new neutrino facility in the U.S., with significant international participation, as part of the worldwide neutrino program. The facility might be coupled with a new proton decay detector

A focused accelerator R&D program aimed at future accelerator facilities, such as a very large hadron collider or a multi-TeV lepton collider

5.4 Accelerator R&D

We give such high priority to accelerator R&D because it is absolutely critical to the future of our field. ... As particle physics becomes increasingly international, it is imperative that the United States participate broadly in the global R&D program.

Introduction

- Hardware development remains major focus (and major expense) for MC
  - simulations are also important (and comparatively cheap)
    - Study-II did us a lot of good at MUTAC and Snowmass
    - ring cooler studies also have potential for improved designs
- MICE activities are becoming a significant part of MC program
- Here, I will summarize progress and describe current activities

R&D Program Activities

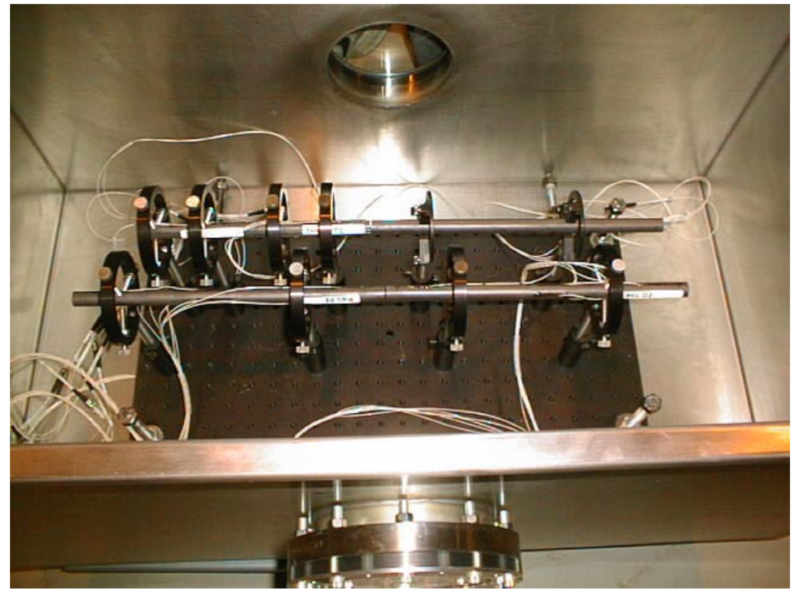
- Targetry (McDonald)
  - — initial beam tests of target (solid and liquid) completed
    - both C rod and Hg jet studied at AGS (24 GeV)
      - C-C composite gives lower beam stress; may be okay at 4 MW
        - limit may be radiation damage or sublimation losses
  - — C sublimation tests performed at ORNL (Haines)
    - results predict 1 month lifetime at 1.2 MW
      - He atmosphere should increase lifetime
      - tests of this under way

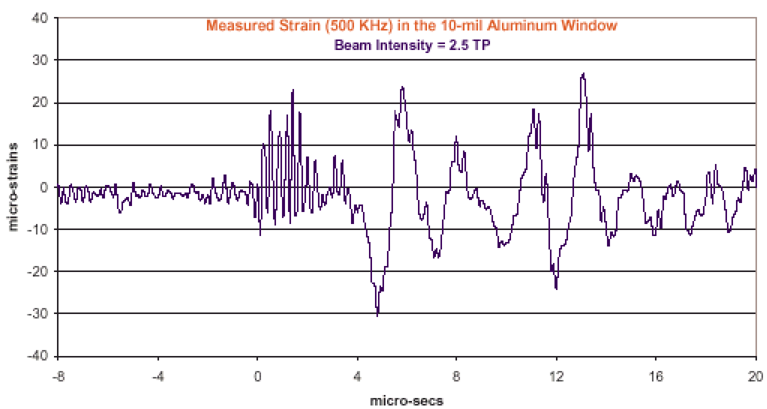
R&D Program Activities

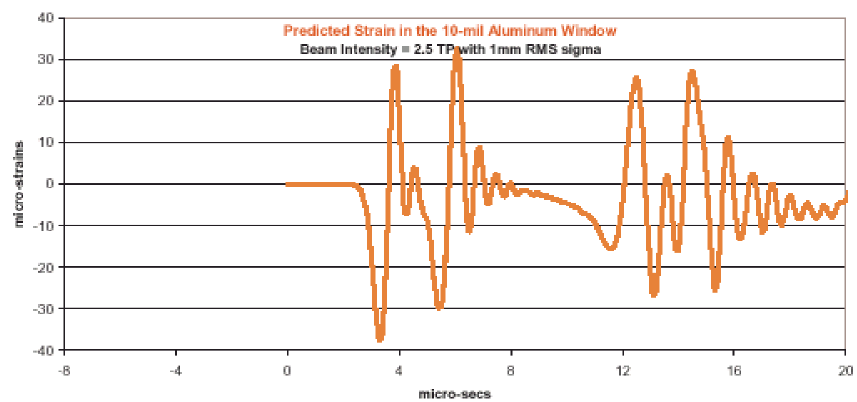
- Hg jet appears to work as expected
  - dispersal happens well after the proton pulse and droplet velocities are reasonable (tens of m/s)
- open questions for Hg jet: injection into ≈20 T field and nonlinear jet dynamics at full proton intensity
  - designing test magnet to permit experimental study of its effects
  - upgrading AGS extracted beam intensity (goal is 1.6×10^{13} ppp)
  - designing Hg jet system capable of required 20–30 m/s velocity
- continuing simulation program to predict and interpret effects

R&D Program Activities

- Target mover and C target assembly in the A3 line at BNL (H. Kirk)

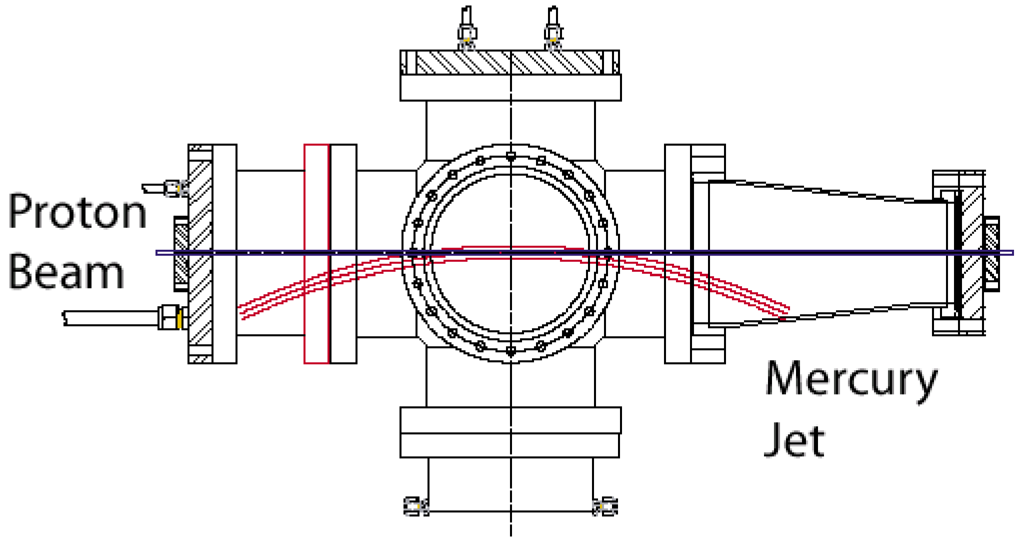




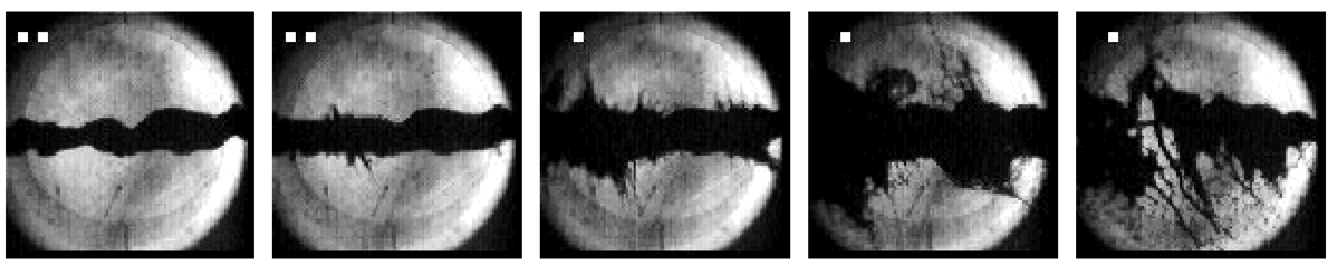


R&D Program Activities

- **Mercury-jet target tested at BNL**

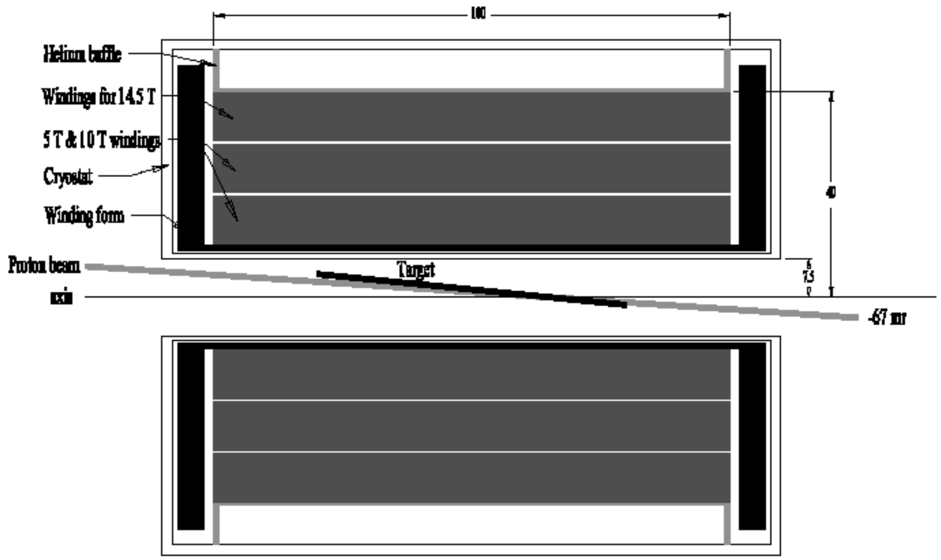


1-cm-diameter Hg jet in 2e12 protons at $t = 0, 0.75, 2, 7, 18$ ms.



R&D Program Activities

- Concept for test target solenoid (5, 10, 14.5 T capability) (MIT)



	Units	Case#1	Case #2	Case #3
Peak on-axis field	T	5.0	10.0	14.5
No. of 0.54 MVA power supplies	- -	1	4	4
Mode of ganging supplies	- -	none	2 x 2	2 x 2
Initial temperature	K	84	74	30
Number of turns utilized	- -	1200	1200	1800
Charge time	sec	7.2	6.3	15.3
Temperature rise at end of pulse	K	5.8	21.7	48.3
Cumulative heating at end of pulse	MJ	2.7	9.1	15.2

R&D Program Activities

- Cooling
  - much of the MC activity falls under the MUCOOL heading (Geer)
    - includes R&D on rf cavities, absorbers, solenoids, ring coolers
  - experimental rf work to date being done at 805 MHz; 201 MHz cavity is designed, but fabrication has not begun
    - issues include breakdown and dark current suppression
      - these limit usable gradient
  - absorber work going on in Illinois (ICAR supported) and Japan (U.S.-Japan funding)
    - U.S. focus: development and testing of thin windows; engineering of fluid flow and cryogenics
      - goal is to test absorber (in solenoid) 1 year from now
    - consideration of LH_2 safety has begun (proximity to "ignition source" likely means containment windows seen by the beam)

R&D Program Activities

— solenoid work is aimed mainly at cost and reliability issues

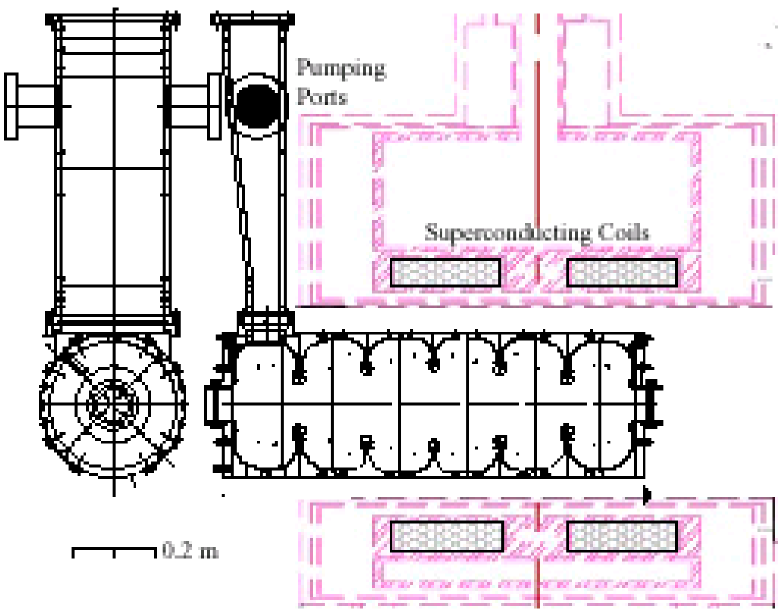
- designs challenging but not beyond the state of the art

— experimental program on cooling complemented by simulation work

- exploring ideas to optimize performance and reduce costs
  - looking at rf bunching and phase rotation to replace induction linacs assumed in Study-II
  - working on "ring coolers" to provide 6D emittance reduction
- working on MICE simulations as benchmark for interpreting results

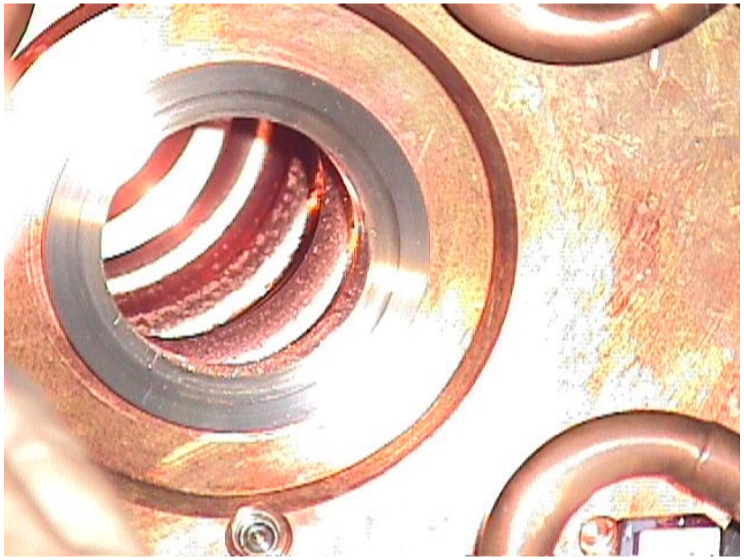
R&D Program Activities

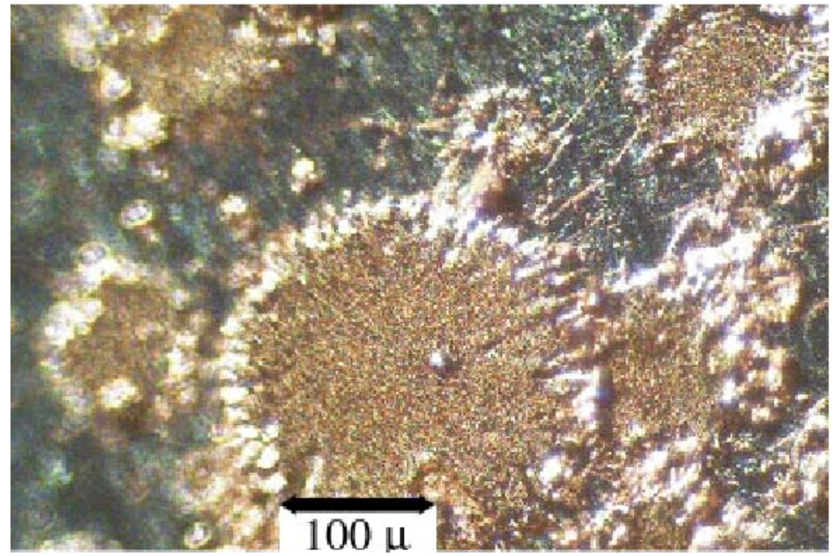
- **Open-cell 805 MHz cavity reached 24 MV/m accelerating gradient (53 MV/m peak surface field) (Moretti)**
  - **note that cavity is only partially in the magnetic field, making interpretation of results more difficult**



R&D Program Activities

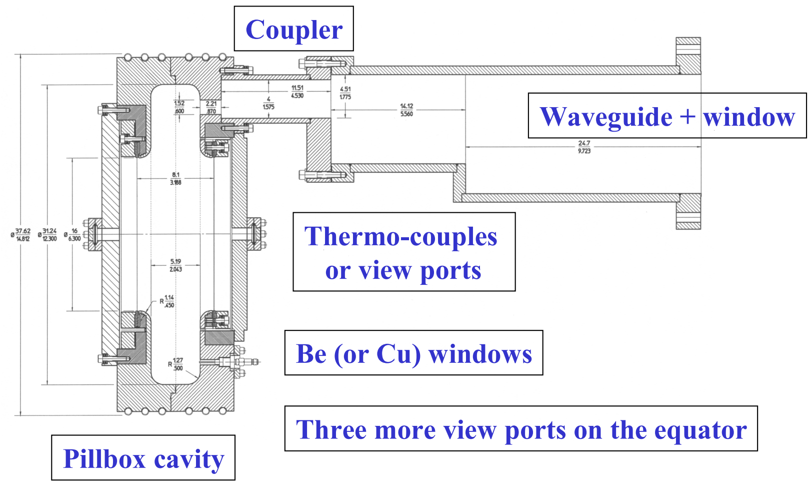
- Iris damage and corresponding copper deposition on window observed

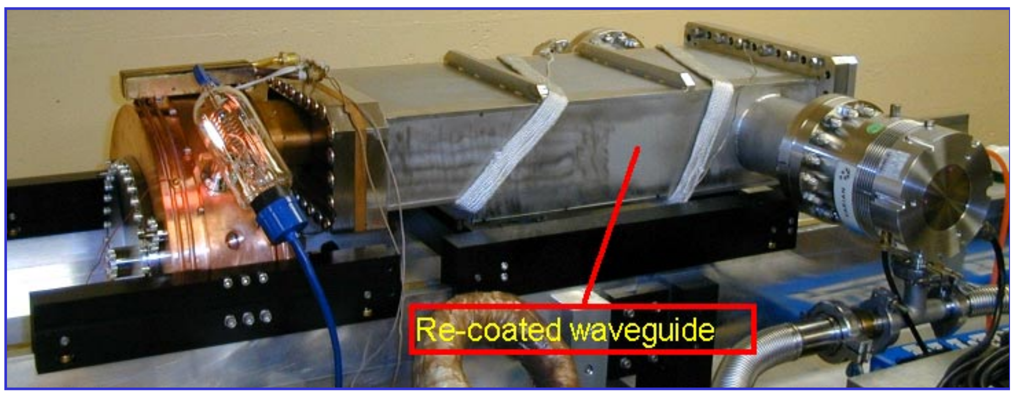




R&D Program Activities

- Now focusing on pillbox cavity having replaceable windows (or grids) (Li)
  - cavity reached 34 MV/m (goal was 30 MV/m)



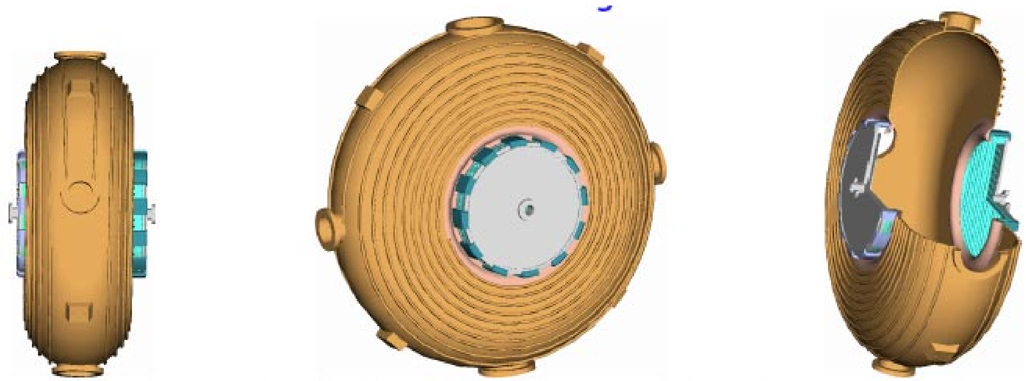


R&D Program Activities

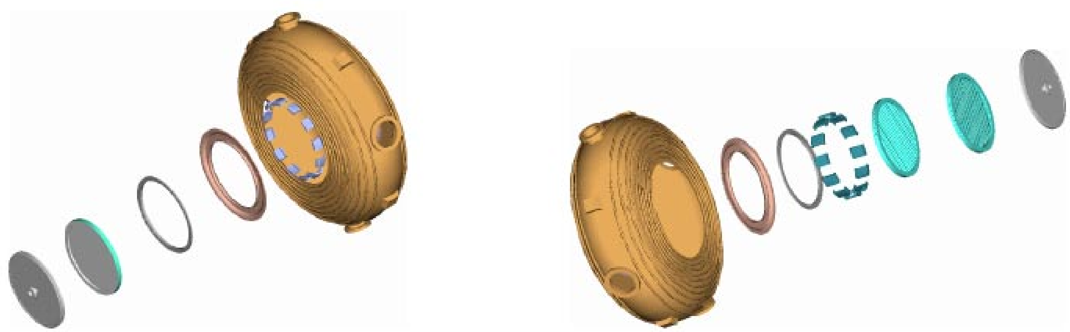
- Dark currents found to be very large ($\propto E^{10}$) (Norem)
  - now preparing for dark current studies with pillbox cavity
    - requires thinner foil and exit window
- Dark current results for open-cell cavity documented (MC Note 235)
    - workshop planned at Fermilab next year, in conjunction with LC
    - this issue has implications for MICE
- Plan to study cleaning and coating techniques, initially using replaceable windows to modify cavity properties

R&D Program Activities

- 201 MHz rf cavity design is well along (Rimmer, Li, Ladran)



201.25 MHz cavity conceptual design

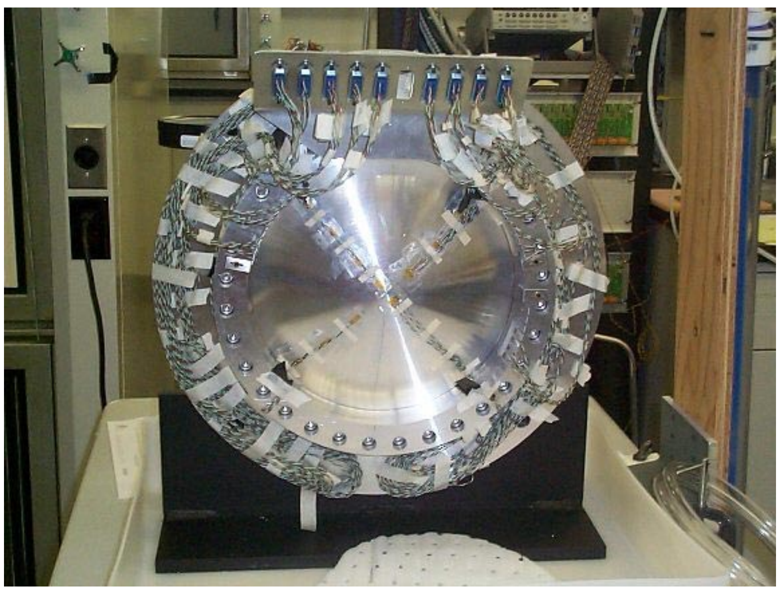


Exploded views showing foil and grid mounting hardware

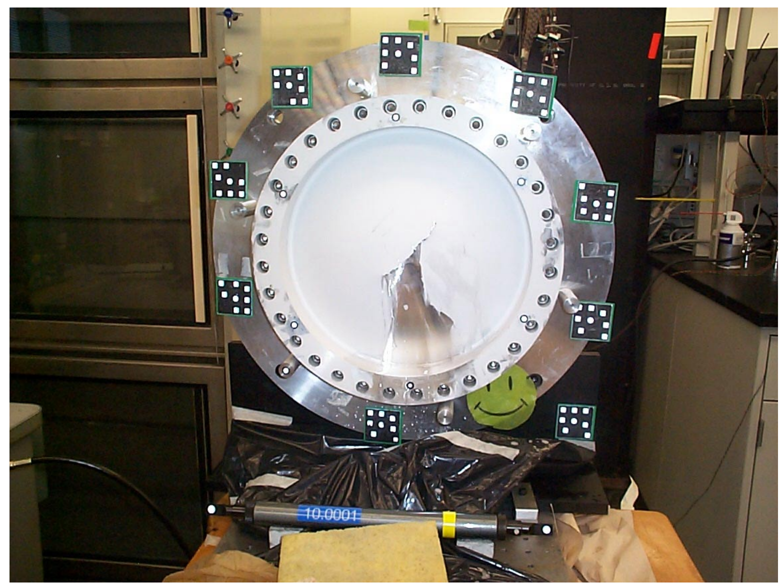
— options for both stepped Be windows and grids are available

R&D Program Activities

- Absorber work focused initially on thin window fab (Cummings, Kaplan)
  - windows as thin as 125 μm machined from solid Al (Summers)
  - testing involves breaking them (on purpose) at NIU (Cummings)
    - 125 μm window breaks at 3 atm, 340 μm window at 8 atm
    - goal is to verify FEA calculations (LH_2 safety requirement)



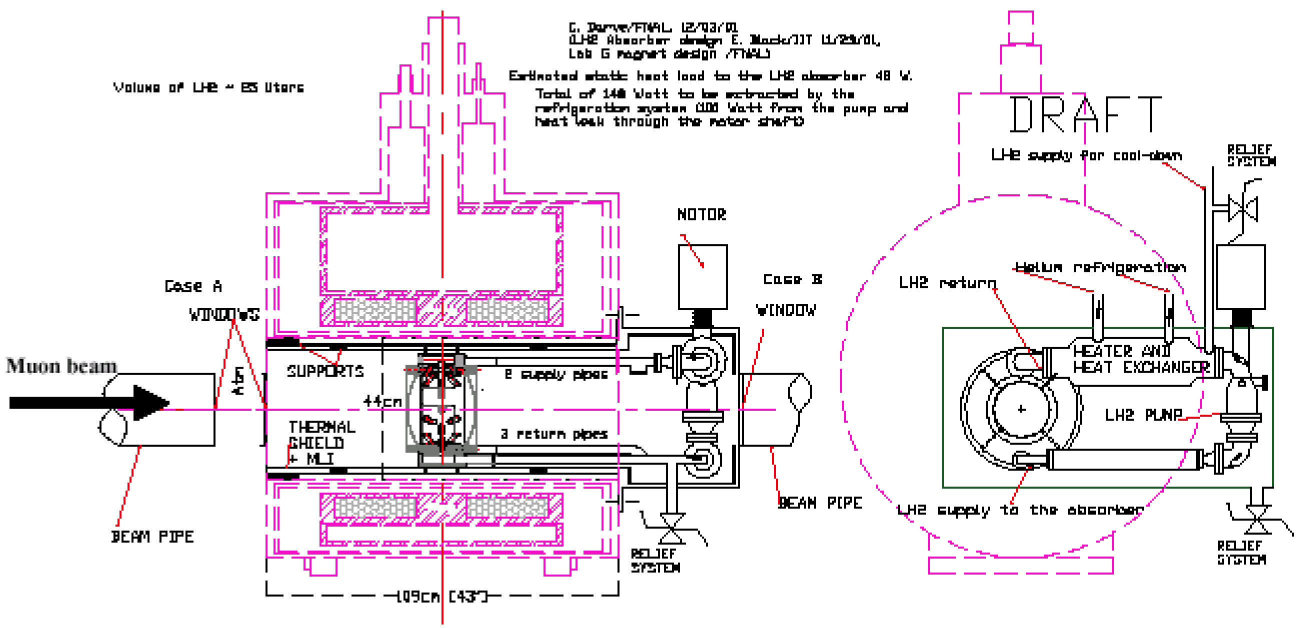
Window outfitted with strain gauges



Rupture of 340 μm window

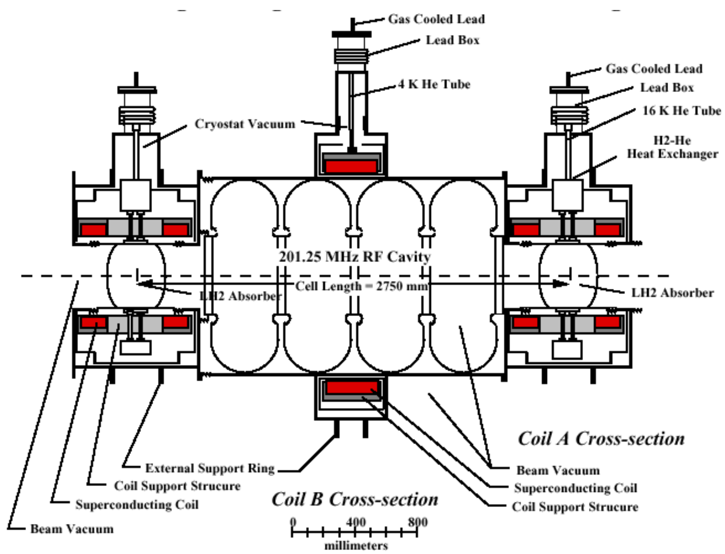
R&D Program Activities

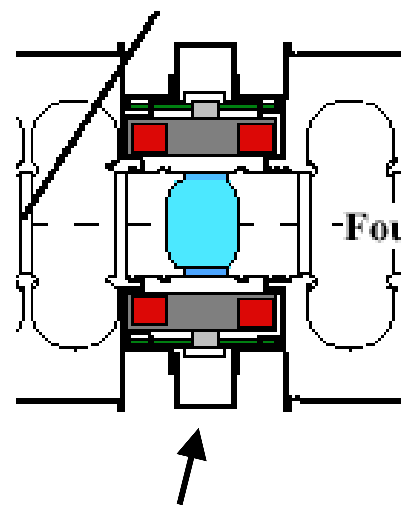
- First forced-flow absorber design under way (Black)
  - compatible with bore of existing Lab G solenoid



R&D Program Activities

- Solenoids (Green)
  - evaluating design with integrated absorber (cheaper and easier)





Original concept

  - other issues related to mechanical engineering and operational aspects
    - e.g., quench effects for adjacent, opposite-polarity solenoids
  - initial evaluation of failure scenarios will begin (in context of MICE)

Berkeley Lab

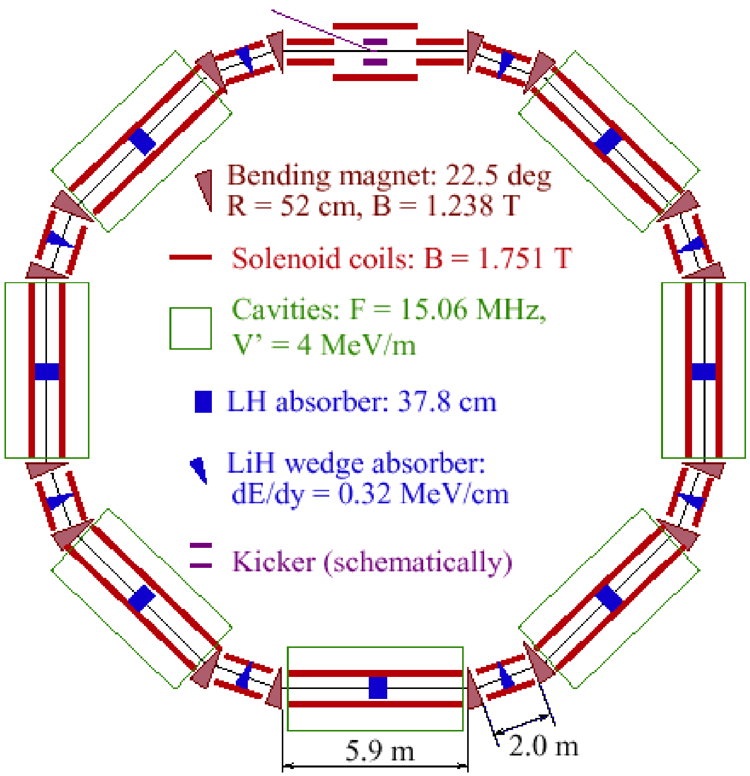
R&D Program Activities

Muon Collaboration

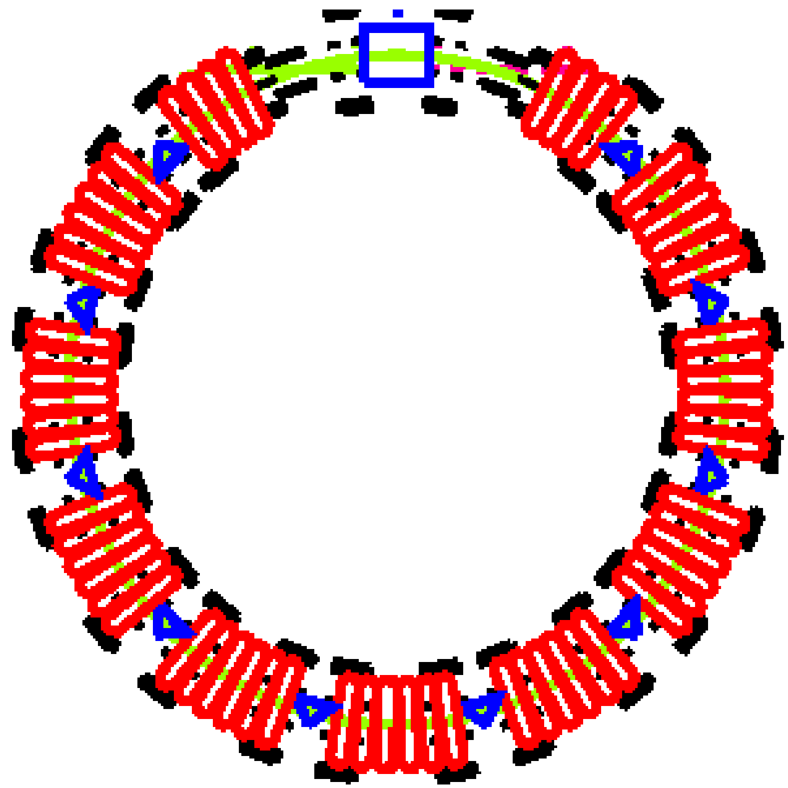
- Simulations
  - created separate group to focus on ring coolers (R. Raja)
    - bringing nonlinear dynamics experts into the fray (via ICAR+NSF)
  - emittance exchange/ring coolers important due to potentially significant payoff (Neutrino Factory and/or Collider)
    - highest priority: develop technically feasible design
  - revisiting use of FFAG for acceleration system
    - workshop planned at LBNL October 7–18 (Berg)

R&D Program Activities

- Ring cooler permits 6D cooling...on paper (Balbekov; Palmer)
  - based on wedge absorbers in dispersive regions of a ring



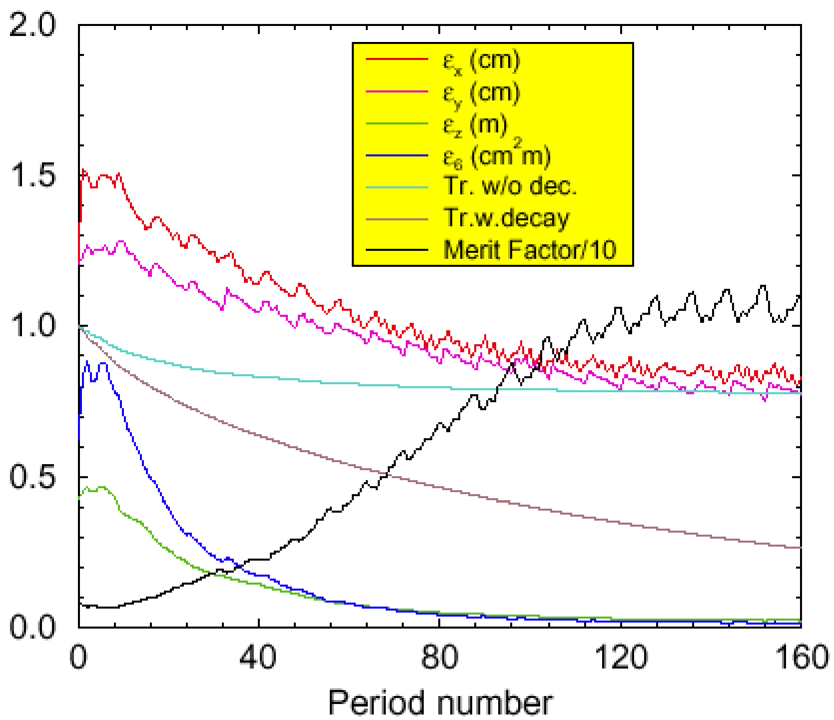
Dipole ring (Balbekov)



Bent solenoid ring (Palmer)

R&D Program Activities

- **Performance looks interesting...if we can figure out how to inject and extract beam**



Injected beam:
Transverse emittance 1.21 cm
Longitudinal emittance 42.6 cm
6D emittance 62.6 cm^3.

The beam after 20 turns:
Transverse emittance 0.80 cm
Longitudinal emittance 2.3 cm
6D emittance 1.49 cm^3
Transmission without decay 77.8%
Transmission with decay 26.3%
Merit factor 11.0

- **Idea for full-aperture kicker exists (Palmer, Reginato)**
  - **— but implementation looks expensive**

R&D Program Activities

- To test hardware, building MUCOOL Test Area at Fermilab (Popovic)
  - absorber, solenoid, and 201 MHz rf cavity will be integrated here

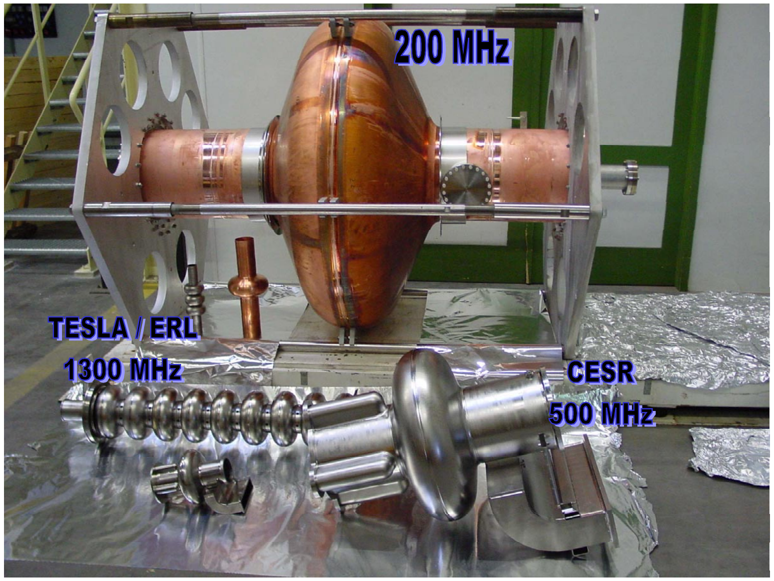
Original area

Present area

What it will look like when completed

R&D Program Activities

- 201 MHz SCRF cavity for acceleration system under test at Cornell (Hartill, Padamsee)
  - cavity fabrication completed in collaboration with CERN
  - first result: 3 MV/m, limited by power cable arc
    - *Q* is 10^{10} at low field
  - developing designs for ancillary items (input coupler, HOM coupler, tuner) based on existing experience, e.g., KEKB



MICE Activities

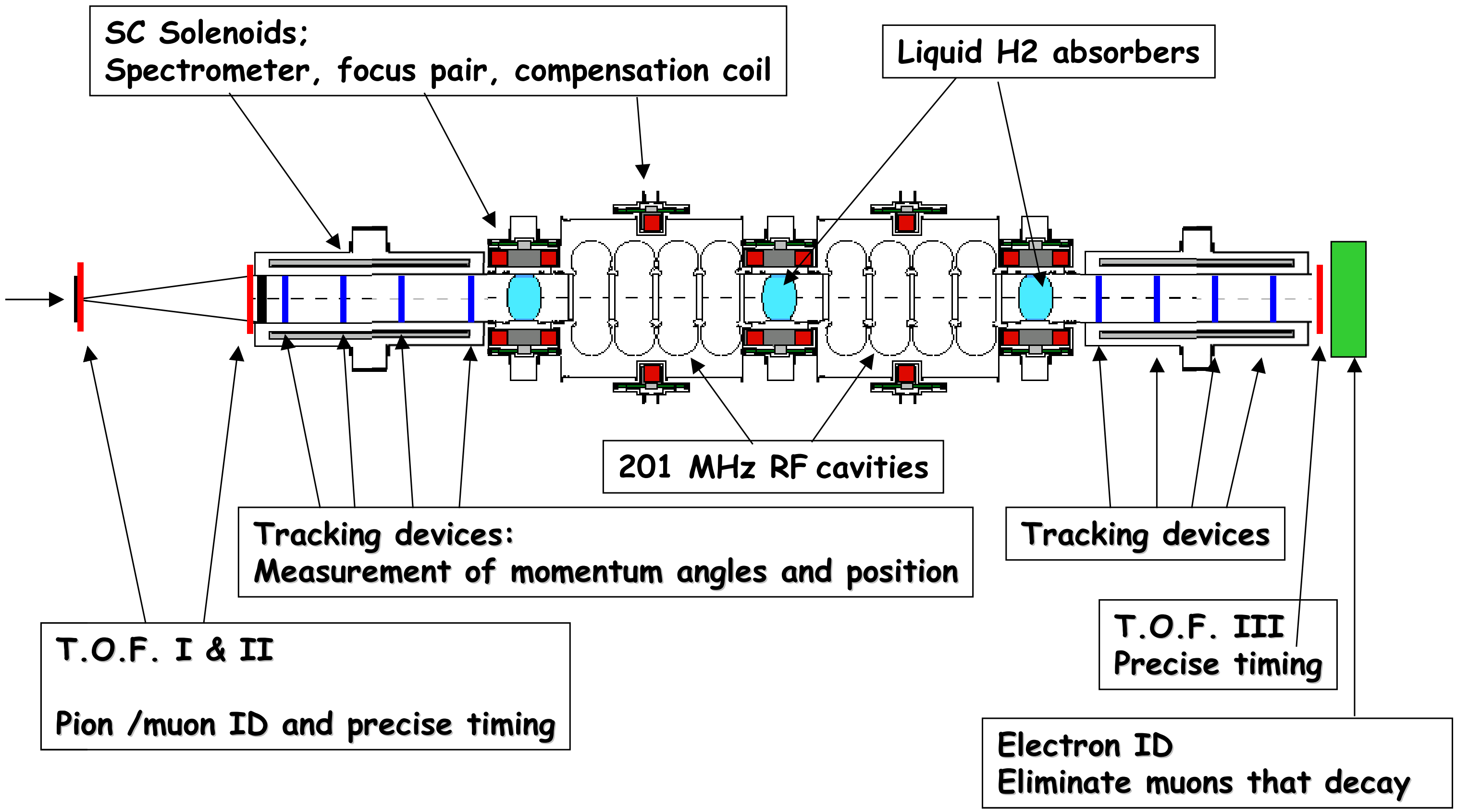
- Motivation for MICE
  - require ionization cooling to build a high-performance Neutrino Factory ($\approx 4 \times 10^{20}$ ν_e aimed at far detector per 10^7 s year)
    - Muon Collider demands even higher performance
  - straightforward physics, but not experimentally demonstrated
    - prudence dictates a demonstration of the key principle
- MUTAC made strong recommendations on MICE at October review
  - encouraged international R&D approach
  - experiment is considered "crucially important demonstration"
- MC is participating in MICE planning and organization
  - Kaplan (U.S. Spokesperson), Geer, and MZ on steering committee
    - Bross, Cummings, Green, Norem, Palmer, Li, Spentzouris are Technical Conveners

MICE Activities

- Cooling demonstration implies:
  - development and testing individual components with challenging operating specifications (done by MUCOOL, "outside" of MICE)
  - showing these components can function properly in close proximity
  - showing that a realistic system can reduce the emittance of muons
- Other requirements
  - show that our design tools (simulation codes) are in agreement with experimental observations
    - important to gain confidence in our ability to optimize the design of an actual facility
      - we test section of "a" cooling channel, not "the" cooling channel
        - simulations are the means to connect the two

MICE Activities

- Baseline option uses 201 MHz (talk by Edgecock, Friday)



MICE Activities

- Anticipated U.S. contributions to MICE: rf cavities, absorbers, focusing coils, simulation studies
- RF cavities
  - planned 201-MHz MUCOOL cavity serves as MICE prototype
    - design done; awaiting construction funds
- Absorbers
  - absorbers being developed for MUCOOL are directly applicable for MICE
    - expect to test both forced-flow (U.S.) and convection-cooled (Japan) designs
      - both should be ready for testing in 1 year
- Solenoid coils
  - U.S. expected to be responsible for "focusing coil" pair
    - tight integration with absorber makes this desirable

MICE Activities

- Simulation studies
  - safety implications of LH_2 have led to considering merits of alternative absorber approaches
  - Palmer, Fernow, and Gallardo evaluated both MICE experiment and Study-II channel for LH_2, LHe, and LiH absorbers
    - LH_2 assumed to require additional safety window, twice the thickness of containment window (probably pessimistic)
    - LHe used in standard absorber configuration (adjusted for same *dE/dx*)
    - LiH was taken as uncoated, again adjusted for same *dE/dx*
  - with these assumptions, performance from all three nearly identical
  - LH_2 still best...but not by much
    - understandable, as neither MICE beamline nor Study-II channel operates near equilibrium emittance
    - improved (thinner) windows make LH_2 more attractive

MICE Activities

—for MICE

Material	L1 cm	L2 cm	L3 cm	Q(mats) mm mrad/cm	$\epsilon_{equilib}$ mm	rate %/m
At Start	$\beta=$	0.4 m		ϵ_o=8.9	mm	
1) H2 only	19.3	0.000	0.000	38.0	1.29	1.95
2) H2 + rfw	18.0	0.000	0.125	47.5	1.61	1.86
3) H2 + Al + rfw	17.5	0.036	0.125	53.3	1.81	1.81
4) H2+Al+Safety+rf	16.4	0.108	0.125	64.9	2.20	**1.71**
5) He + Al + rfw	20.7	0.036	0.125	65.5	2.22	**1.71**
6) Li H + rfw	3.9	0.000	0.125	76.2	2.58	**1.61**

— and for Study-II channel

Material	Ave. μ/p
1) H2 only	$.162 \pm .06$
2) H2 + Al	$.153 \pm .06$
3) H2 + Al + rfw = FS2	$.143 \pm .04$
4) H2+Al+Safety+rf	$.132 \pm .02$
5) He + Al + rfw	$.127 \pm .02$
6) Li H + rfw	$.128 \pm .02$

Summary

- MC program has made excellent progress on all fronts in the past few years
- Strong interest in U.S. to continue to build upon present technical progress
- MC is part of strong international effort for MICE
    - expect to provide hardware and participate in simulation effort
    - new funding sources need to be identified to provide components
- MC and its interaction with colleagues worldwide is viewed in the U.S. as "model" for working on major international projects

— *together*, we must continue the good work!

Contact information

MC homepage:
http://www.cap.bnl.gov/mumu/mu_home_page.html

MC notes listing:
http://www-mucool.fnal.gov/notes/notes.html