# R&D Program and Budget

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*CENTER FOR BEAM PHYSICS*

**Neutrino Factory and Muon Collider Collaboration Meeting–Shelter Island**
**May 9, 2002**

# Outline

- Introduction
- Recent R&D accomplishments
- Present R&D activities
- Budget
- Summary

# Introduction



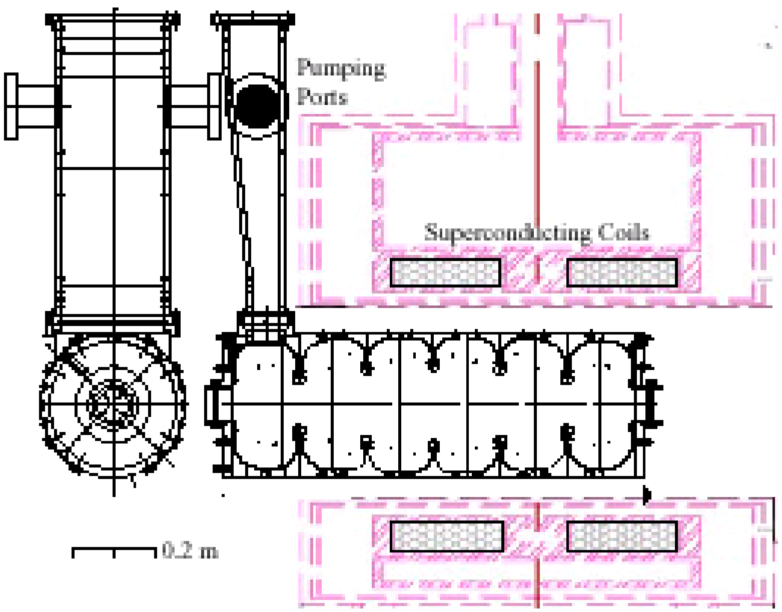
- MC has made good technical progress in the past year
  - despite weaker funding compared with previous years
- We went through B&B process and had very positive MUTAC review
- Hardware development continues to be major focus (and major expense) for MC
  - simulations are also important (and comparatively cheap)
    - Study-II did us a lot of good at MUTAC and Snowmass
    - ring cooler studies and cost optimization changes (e.g., RF phase rotation system) have potential for improving design concepts
      - gaining a better understanding of performance and cost of FFAG scheme will also be useful
- Here, I will summarize recent progress, describe current activities, and indicate some of the work to be done in future years
  - budget matters will also be covered

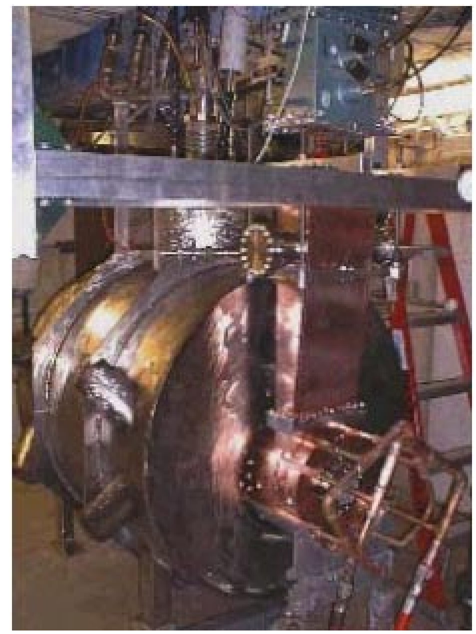
# Recent R&D Accomplishments

- Much was accomplished in the past few years, despite decreased funding
  - first round of target tests completed (C rod, Hg jet)
  - first rf cavity tested (reached 24 MV/m)
  - completed Study-II (6x performance increase, 25% cost reduction)
  - began pressure tests on absorber windows
  - began 201 MHz SCRF cavity design

# Recent R&D Accomplishments

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

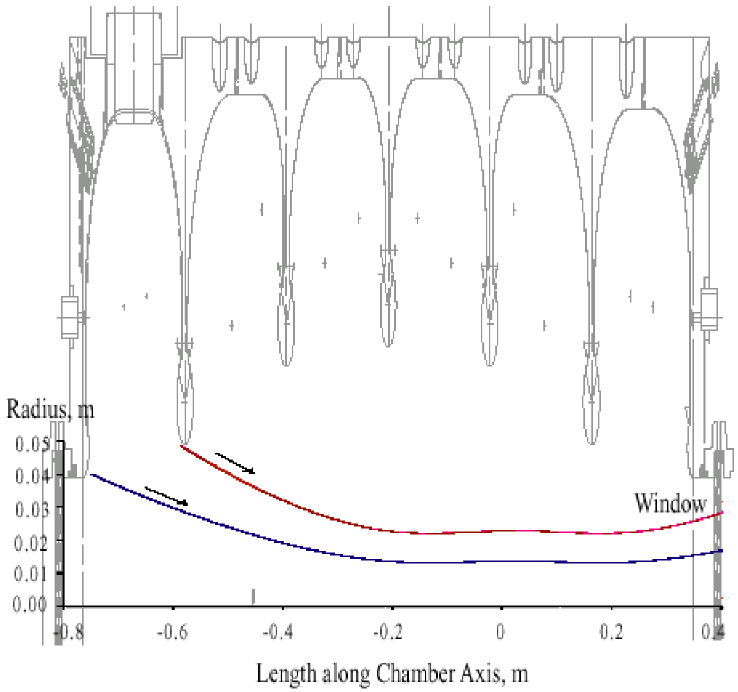


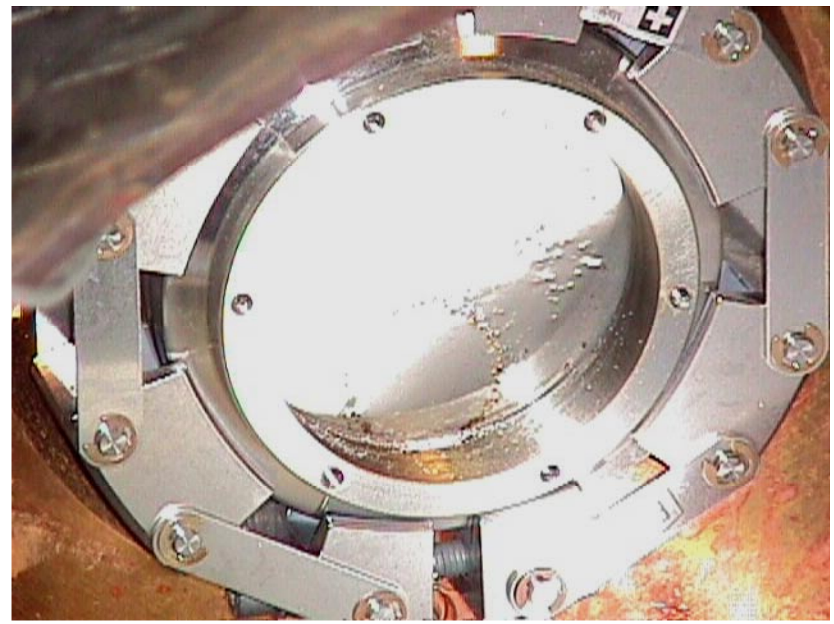



# Recent R&D Accomplishments

Muon Collaboration

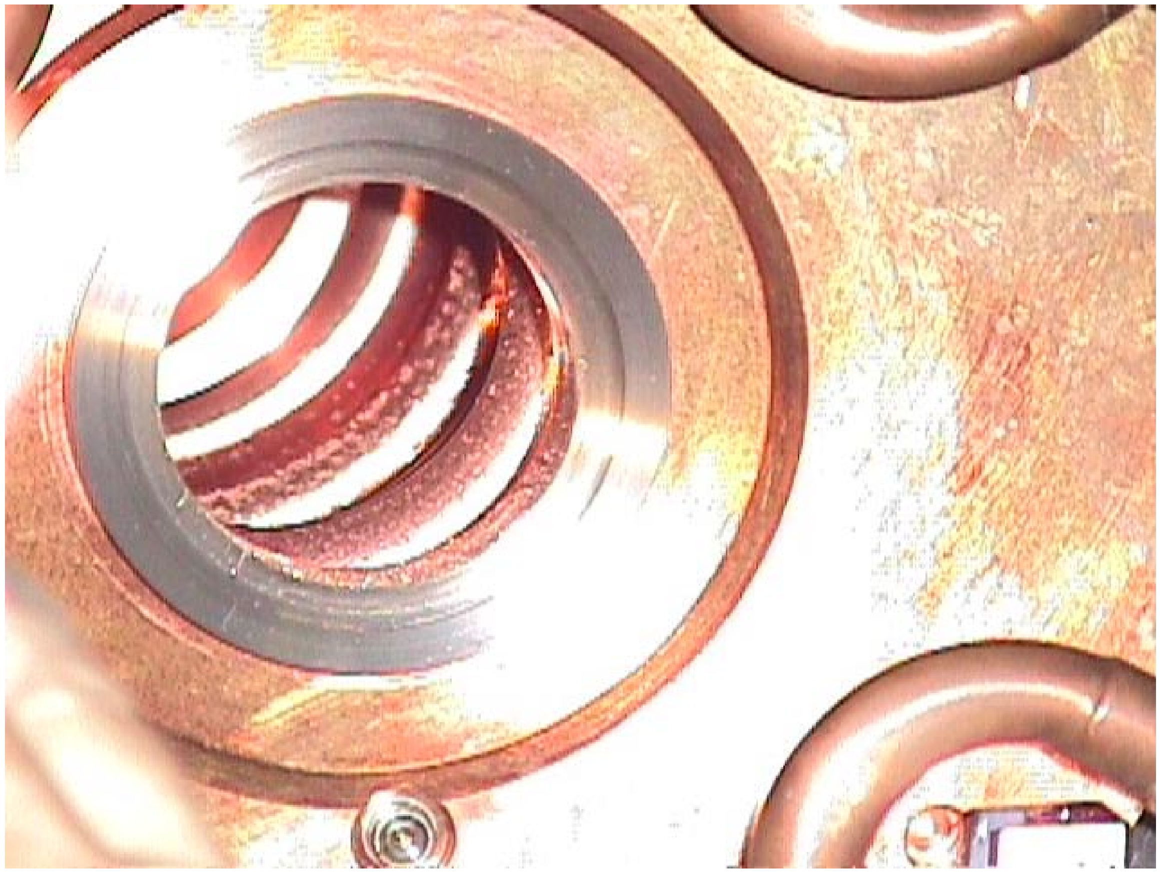
- Evidence for "rings" on window (images of irises)



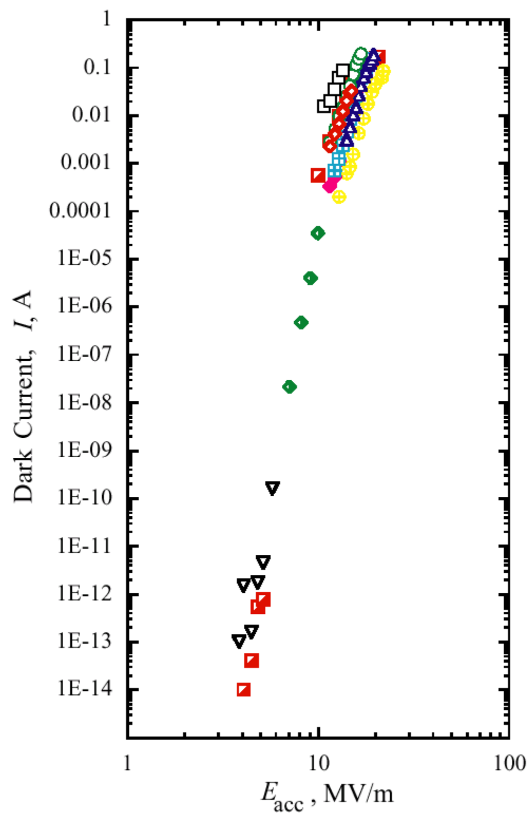
# Recent R&D Accomplishments

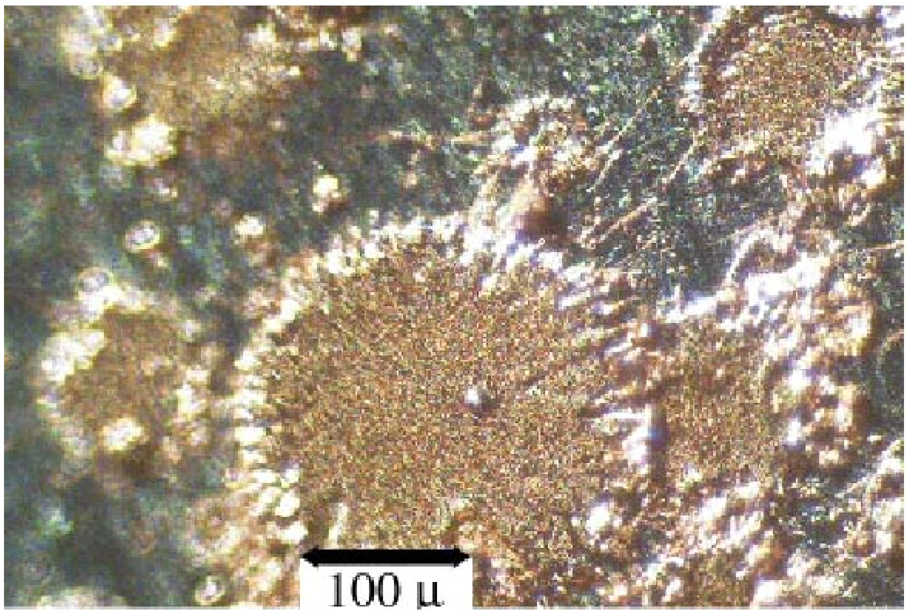
— also see damage on irises



# Recent R&D Accomplishments

- Dark currents found to be very large ($\propto E^{10}$) (Norem)
  - — copper splashes appear on to window when solenoid field present



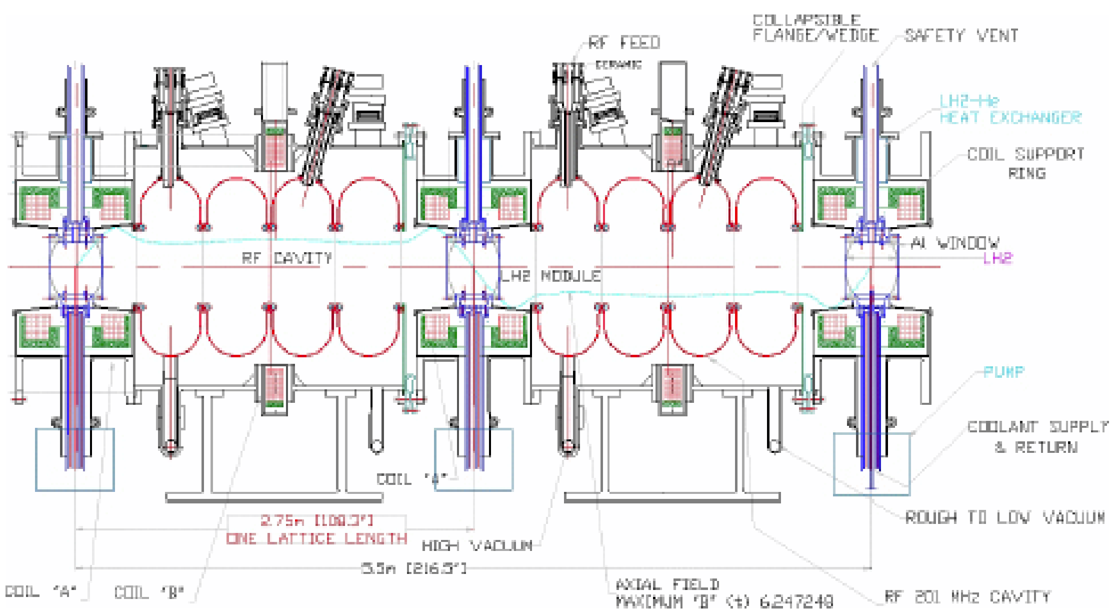




  - — overall behavior typical of many cavities (not understood in detail)

# Recent R&D Accomplishments

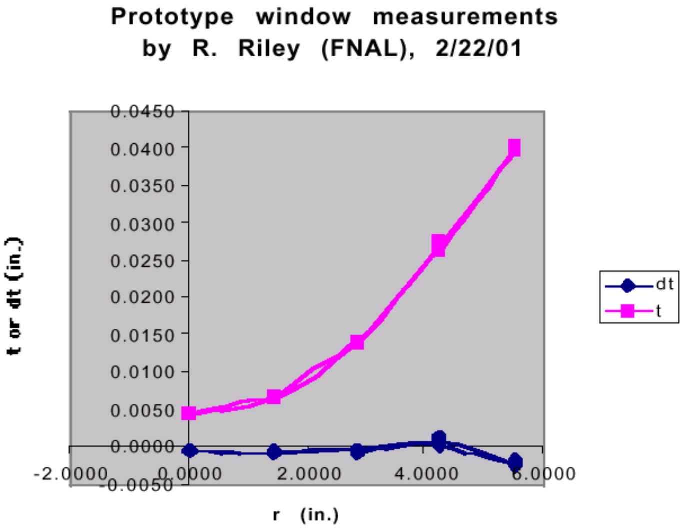
Muon Collaboration

- Study-II permitted integrated look at an entire Neutrino Factory
  - compared with earlier Study, performance increased 6x, at estimated cost of 75%
    - cost decrease due to lower energy (20 GeV), eliminating one RLA
- Engineering and cost estimate give credibility to Neutrino Factory concept



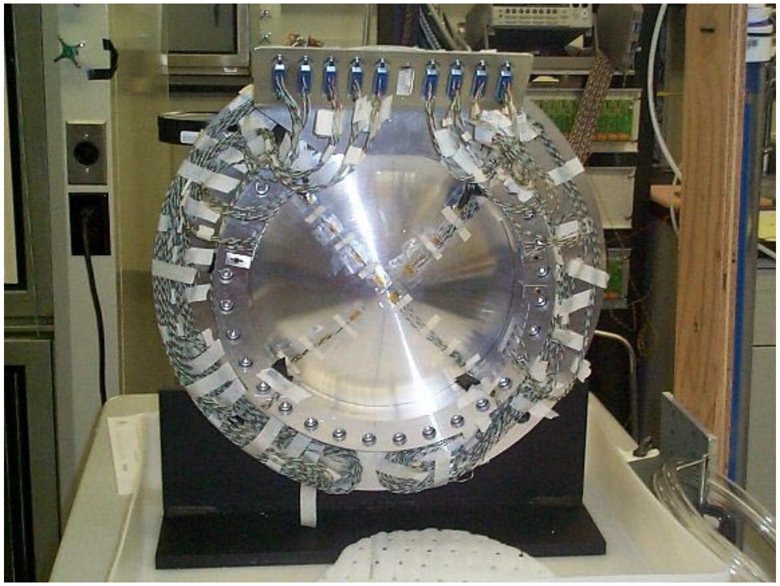
# Recent R&D Accomplishments

- Absorber work focused initially on thin window fabrication
  - windows as thin as 125 $\mu$m machined from solid Al (Summers)
  - tapered profile gives good compromise between strength and thickness requirements

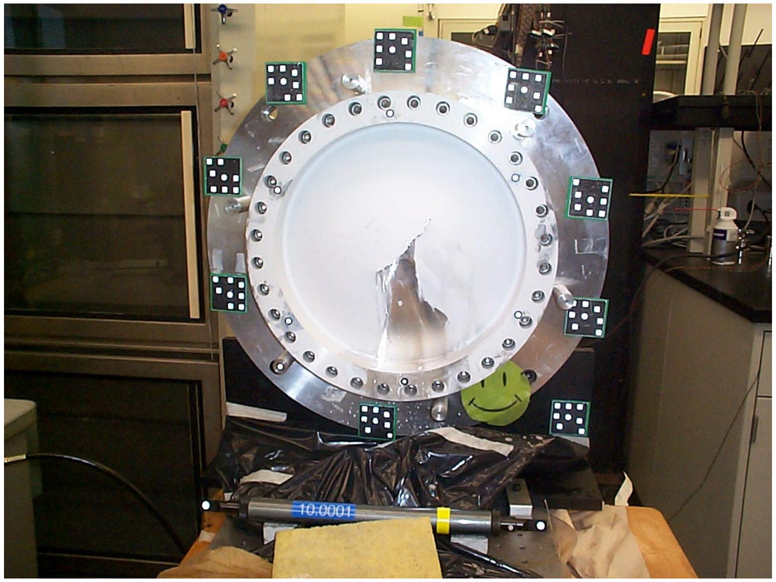



# Recent R&D Accomplishments

- we are also breaking them (on purpose) at NIU (Cummings)
  - 125 μm window breaks at 44 psi (3 atm), 340 μm window at 120 psi (8 atm)
  - goal is to verify FEA calculations ($LH_2$ safety requirement)
    - so far, so good



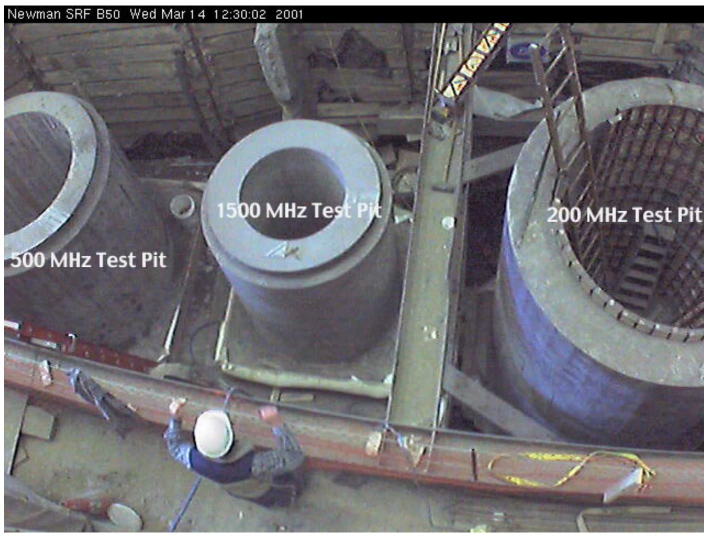
Window outfitted with strain gauges



Rupture of 340 μm window

# Recent R&D Accomplishments

- Work on 201 MHz SCRF cavity for the acceleration system made good progress (Padamsee, Hartill)
  - cavity fabrication done in collaboration with CERN
  - test facility being set up at Cornell




# Present R&D Activities

- MUTAC and MCOG made a number of recommendations to MC based on October review
  - specifics discussed in the context of our current activities
- General MUTAC comments
  - liked Study-II work, but suggested that we now move on to other activities
  - acknowledged that our R&D support level is insufficient and recommended an increase, especially for hardware development
  - encouraged international R&D approach, especially for MICE
    - suggested we thoroughly understand ideas from other groups, e.g., CERN scheme and Japanese FFAG scheme
  - felt that too much emphasis on Muon Collider was premature
    - but, encouraged "common" work on emittance exchange
  - pointed out the need for realistic planning and priorities

# Present R&D Activities

- Our actions:
  - no "Study-III" planned this year
  - simulation of CERN scheme under way (as MICE activity)
    - but no collaboration with Japan on FFAGs planned this year
      - reflects lack of personnel, not lack of interest
  - emphasizing Neutrino Factory and "common" aspects over Collider-specific
  - long-range planning should be a focus here, where MC meets together as a whole
    - sadly, budget restrictions make these meetings a too-rare occurrence

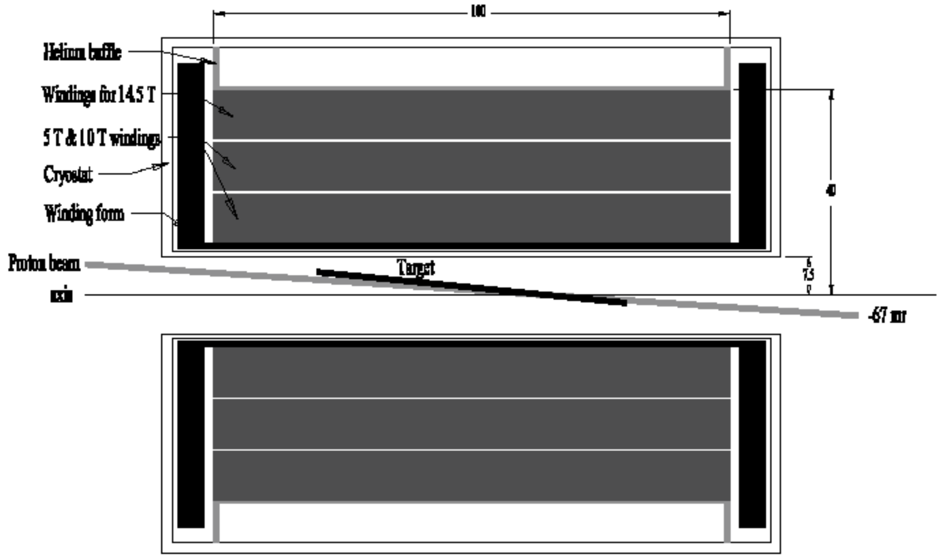
# Present R&D Activities



- Targetry
  - E951 has produced impressive results
  - open questions for Hg jet: injection into ≈20 T field and nonlinear jet dynamics at full proton intensity
  - recommend considering lower field target solenoid for cost and technical risk reduction
  - questioned whether priority of experiments justifies expense
    - MCOG advised that we continue experiments as planned in view of their importance to all muon-related HEP experimental efforts
- Our actions:
  - designing test magnet to permit experimental study of its effects
  - designing jet system capable of required 20–30 m/s velocity
    - copy from Lac Léman?
  - continuing simulation program to predict and interpret effects

# Present R&D Activities

- Concept for test target solenoid (5, 10, 14.5 T capability; ≈$1.5M)




| | 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 |

# Present R&D Activities

- MUCOOL
  - ionization cooling remains primary R&D issue for MC
    - ⇒ development and integration of hardware
  - complete fabrication of absorbers for filling tests and, later, beam tests
  - complete MTA as test bed for absorbers and 201 MHz rf cavities
- Our actions:
  - pushing ahead on MTA construction
  - ongoing plans to develop and integrate hardware (rf cavity, absorber, solenoids) in MTA
    - work on absorbers and instrumentation slowed in favor of MTA
  - developing long-range plans based on (hopefully) realistic funding levels

# Present R&D Activities

## MUCOOL Test Area (MTA)

Original area

Present area

What it will look like when completed

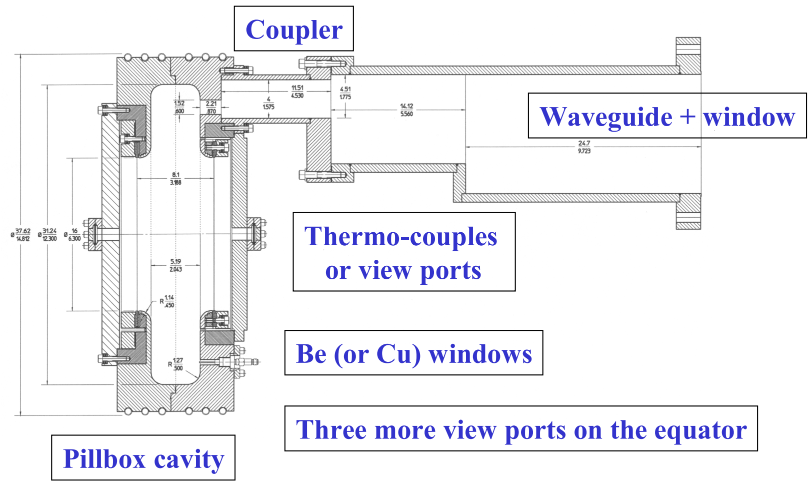
# Present R&D Activities

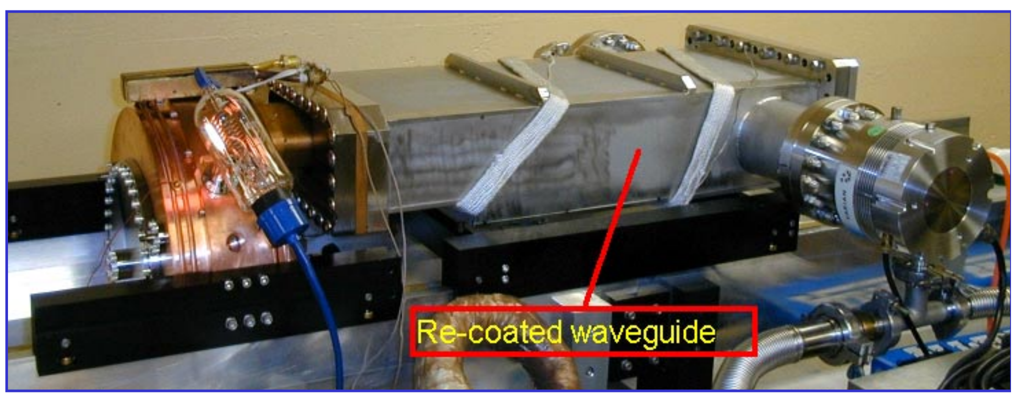


- Normal conducting rf
  - need to understand source of dark currents
  - take dark current issue seriously
    - some breakdown tests can be done DC at Cornell
    - cleanliness and careful processing will help (as for SCRF)
  - make contact with others doing high-gradient NCRF R&D
  - evaluate trade-offs of 805 and 201 MHz R&D
    - but, do not *go* down too many parallel paths
  - need to study problems with actual hardware (not just simulations)
  - quantify running scenario in terms of acceptable breakdown rate

# Present R&D Activities

- Our actions:
  - 805 MHz program now **focusing on pillbox cavity** having replaceable windows (or grids) (Li, Rimmer)



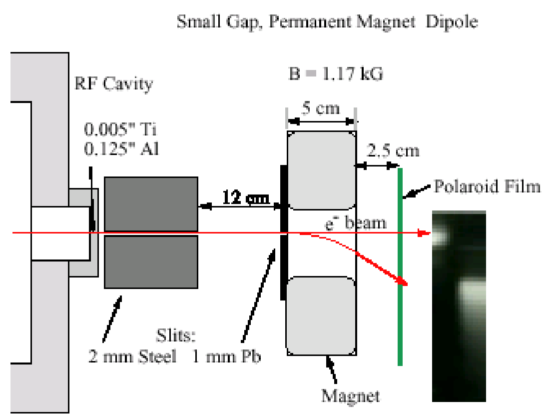
# Present R&D Activities

– dark current results for open-cell cavity are documented

  - MC note 235 prepared
  - workshop planned at Fermilab this fall
    - include experts from NC and SC rf communities

– continuing dark current studies in Lab G with pillbox cavity (fits in bore of Lab G solenoid)

  - will analyze energy spectrum of electrons



# Present R&D Activities

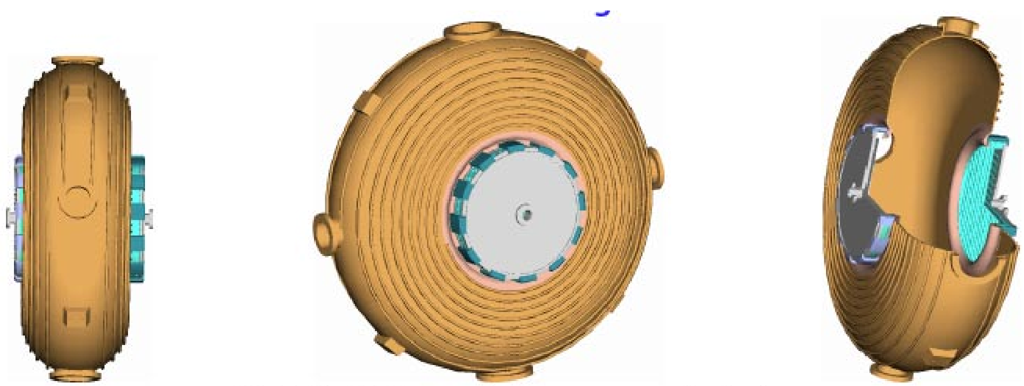


- Plan to study cleaning and coating techniques
  - initial experiments will make use of replaceable windows of pillbox cavity

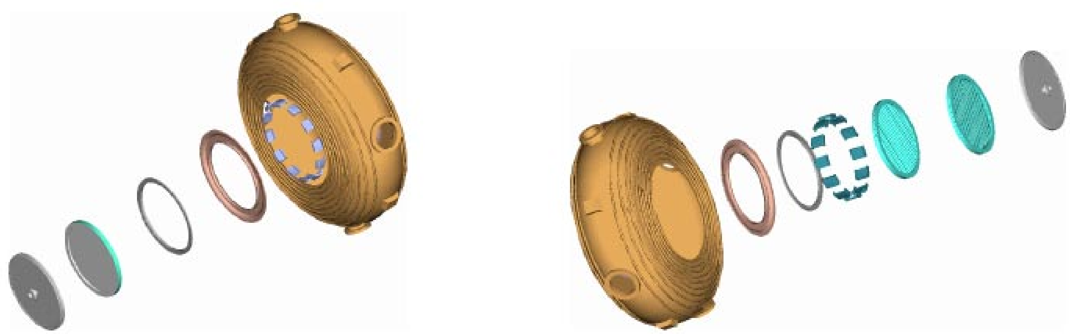
# Present R&D Activities



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



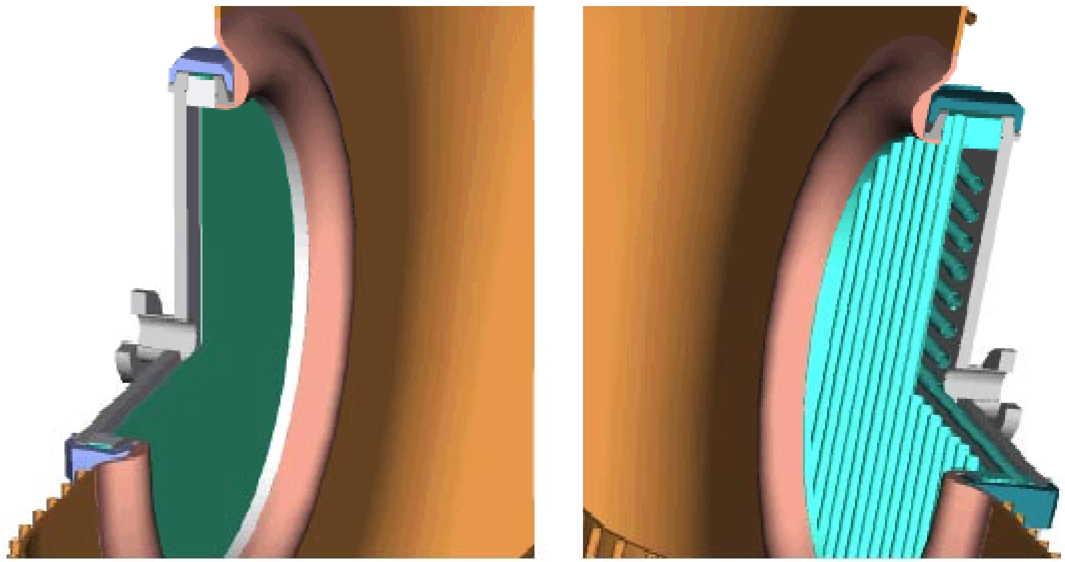
201.25 MHz cavity conceptual design



Exploded views showing foil and grid mounting hardware

# Present R&D Activities

— options for both stepped Be windows and grids are available



detail views of foil and grid assemblies

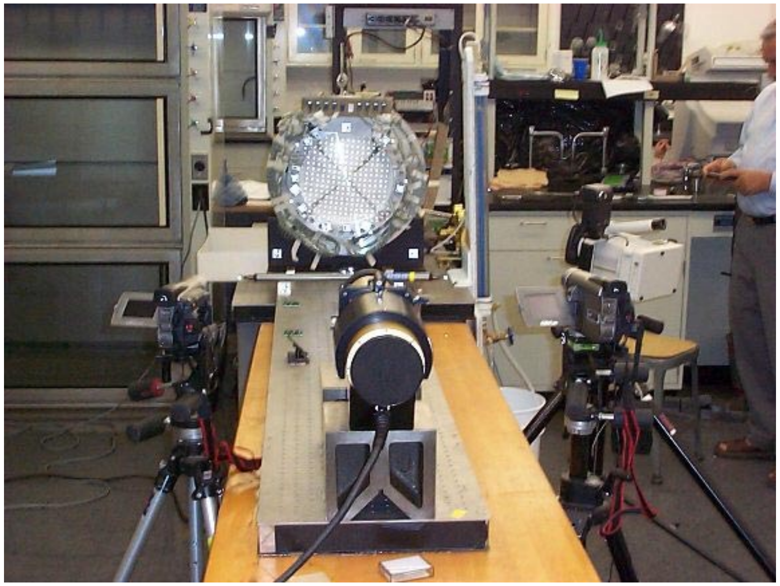
# Present R&D Activities

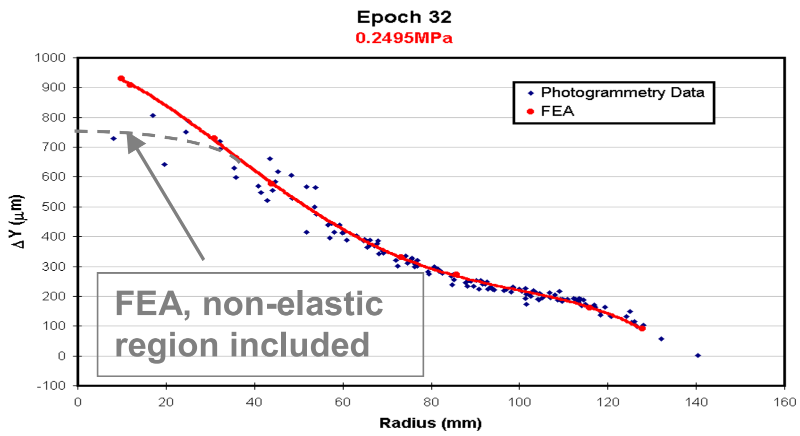


- $LH_2$ absorbers
  - work is advancing
  - encourage optical monitoring of window deformation
  - investigate quench effects on Al window (calculations and experiments)
    - though not stated, this applies to rf cavity Be windows as well (initial estimates look okay)

# Present R&D Activities

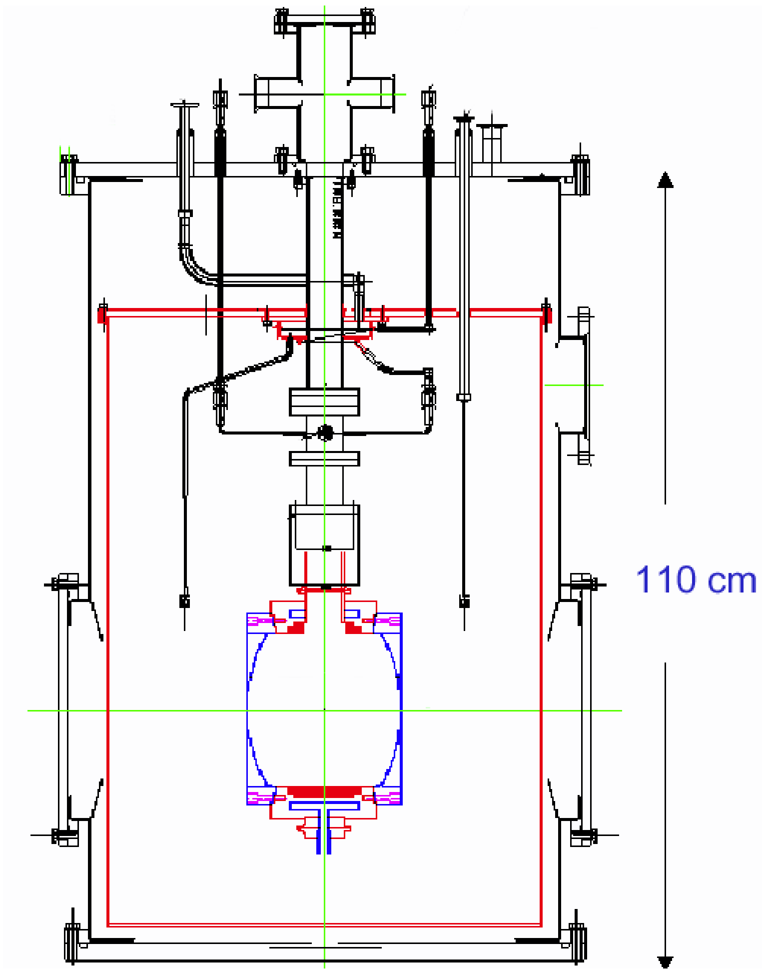
- Our actions:
  - tests of windows will continue
  - hydrogen safety considerations being evaluated
    - alternative approaches with fewer safety issues will also be explored





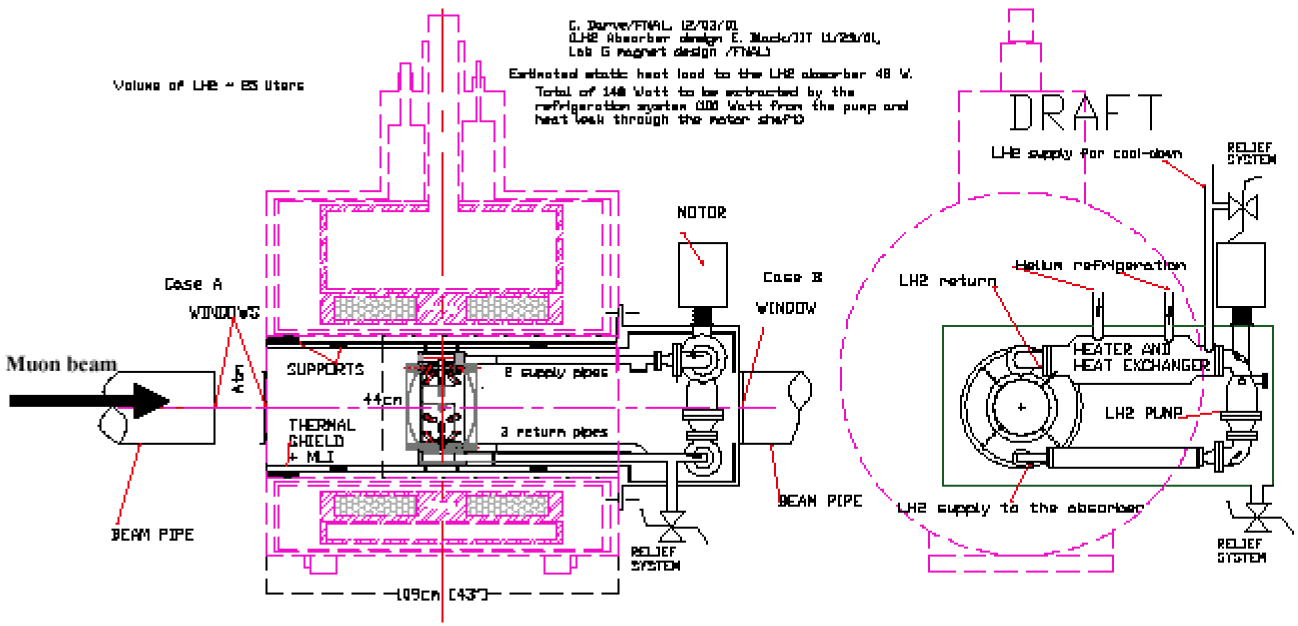
# Present R&D Activities

- Test dewar for convection cooled absorber at KEK (Ishimoto)




# Present R&D Activities

- Plan to develop absorber compatible with bore of existing Lab G solenoid (Kaplan, Cummings Black)



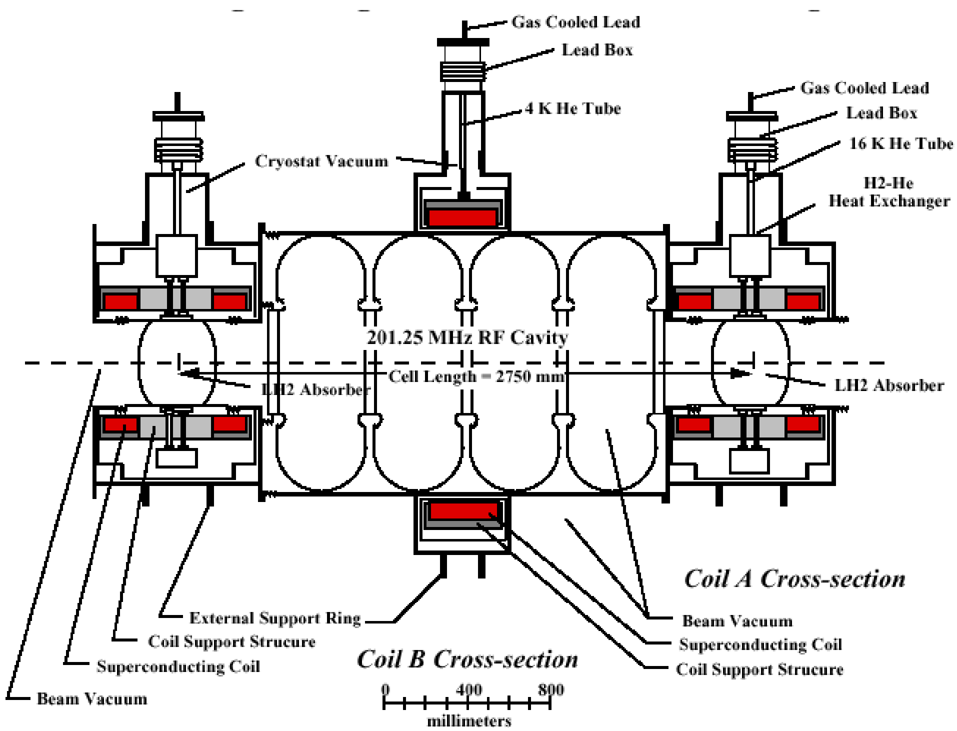
# Present R&D Activities

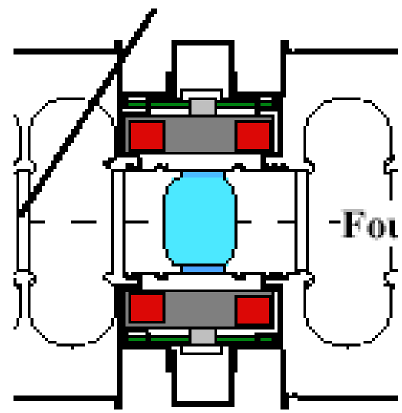


- Solenoids
  - novel problems connected with mechanical engineering and operational issues
  - recommend failure analysis at an early stage, especially for adjacent, opposite-polarity solenoids
- Our actions:
  - initial evaluation of failure scenarios will begin (in context of MICE)
  - quench effects on nearby components will be assessed
  - design with integrated absorber being evaluated
  - Study-II front-end simulations will be updated to reflect latest thinking
    - make this our "standard performance metric" for now

# Present R&D Activities

- Concept of reduced size magnet with integral absorber (Green)
  - should be easier and cheaper



Original concept

# Present R&D Activities

- Comparison of parameters
  - "A" magnet changes look encouraging; "B" magnet changes likely to interfere with rf cavity clearance

| Parameter | New | Old |
|---|---|---|
| Maximum Space for the Cavity (mm) | 1968 | 1966 |
| Number of Cavities per Cooling Cell | 4 | 4 |
| A Magnet Cryostat Length (mm) | 356 | 283 |
| B Magnet Cryostat Length (mm) | 782 | 784 |
| Coil Inside Diameter of the A Magnet (mm) | 518 | 788 |
| Coil Inside Diameter of the B Magnet (mm) | 1313 | 1480 |
| Warm Aperture Diameter of the A Magnet (mm) | 400 | 650 |
| Warm Aperture Diameter of the B Magnet (mm) | 1236 | 1390 |
| Maximum Diameter of Absorber (mm) | 676 | 650 |
| Maximum Cell Stored Energy (MJ) | 5.7 | 13.2 |
| A Coil Maximum Current Density (A $mm^{-2}$) | 119 | 119 |
| B Coil Maximum Current Density (A $mm^{-2}$) | 96 | 96 |
| Maximum Design Warm to Cold Force (MN) | 0.316 | 0.774 |
| Maximum Force Pushing A Coils Apart (MN) | 0.696 | 3.224 |

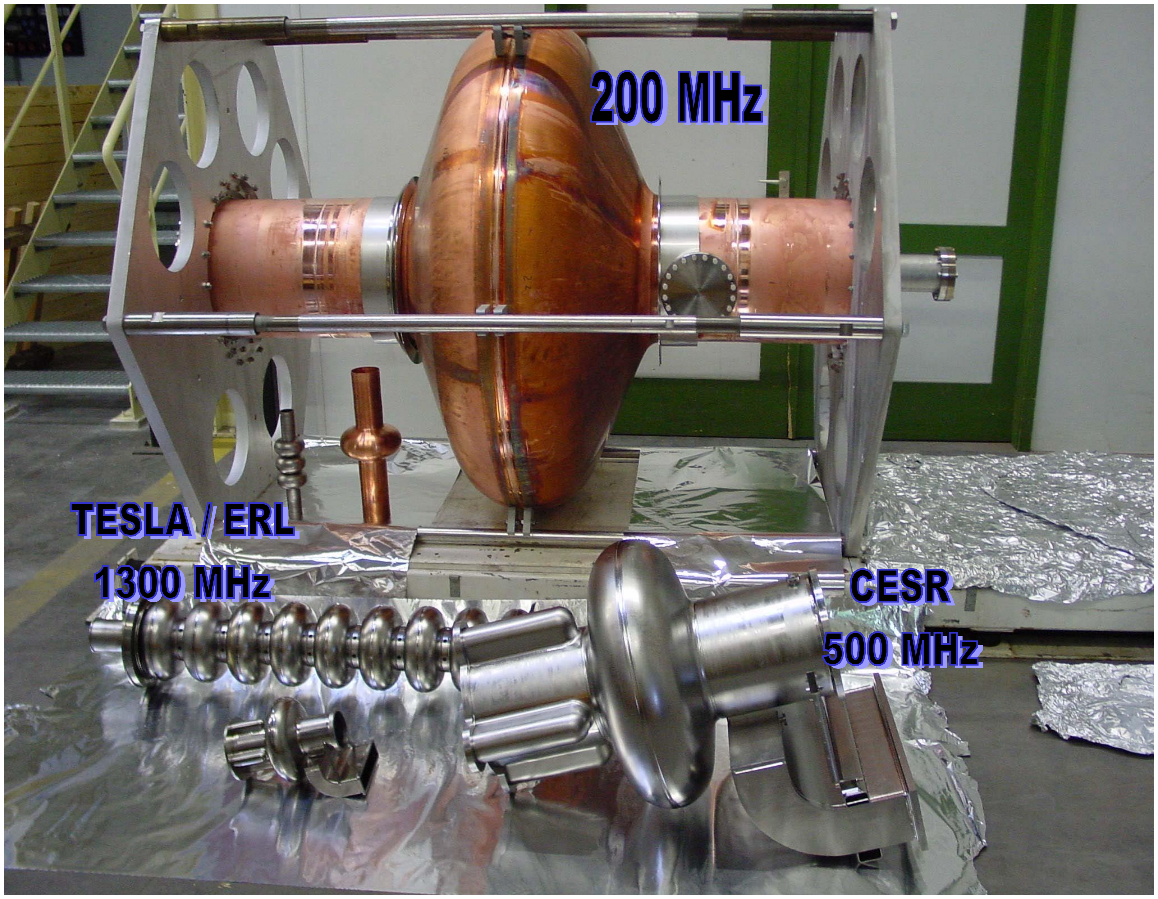
# Present R&D Activities



- Superconducting rf
  - focus on achieving gradient, $Q$, mechanical stability
  - explore cavity cooling schemes
  - develop economical structures
  - develop designs for ancillary items (input coupler, HOM coupler, tuner)
- Our actions:
  - fabricated test cavity (at CERN) and test facilities (at Cornell)
  - doing mechanical design to stiffen cavity
  - looking into spinning technique to reduce fabrication costs
  - designs for ancillary devices will be based on existing experience, e.g., KEKB

# Present R&D Activities

- 200 MHz SCRF cavity at Cornell (with its smaller siblings)



# Present R&D Activities



- Simulations
  - 6D theoretical development complimented
  - encouraged study of ring coolers, including injection/extraction
  - encouraged analyses with errors included
- Our actions:
  - continue to support theory effort
    - need to evaluate whether resource levels adequate
  - created separate group to focus on ring coolers (R. Raja)
  - bringing nonlinear dynamics experts into the fray (via ICAR+NSF)

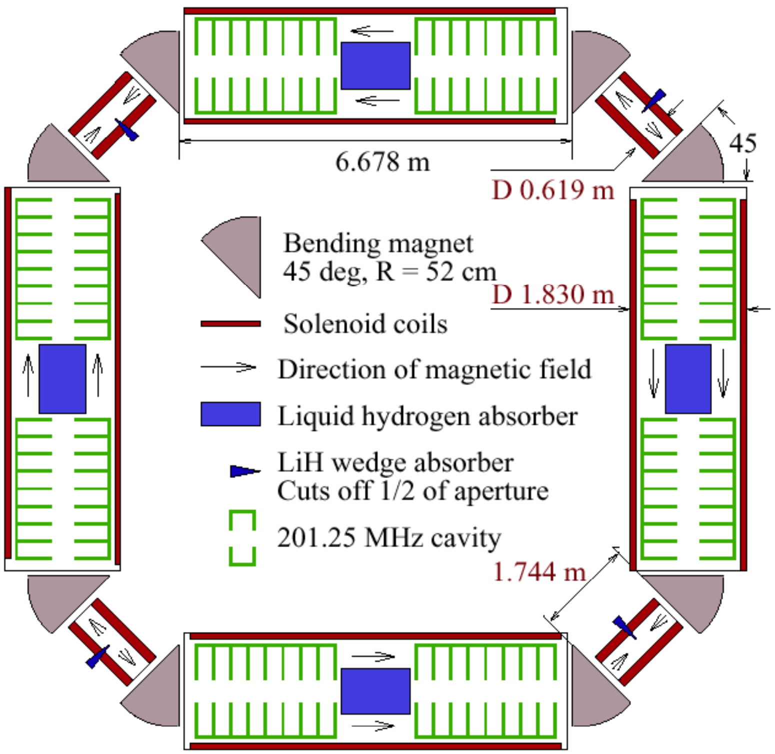
# Present R&D Activities

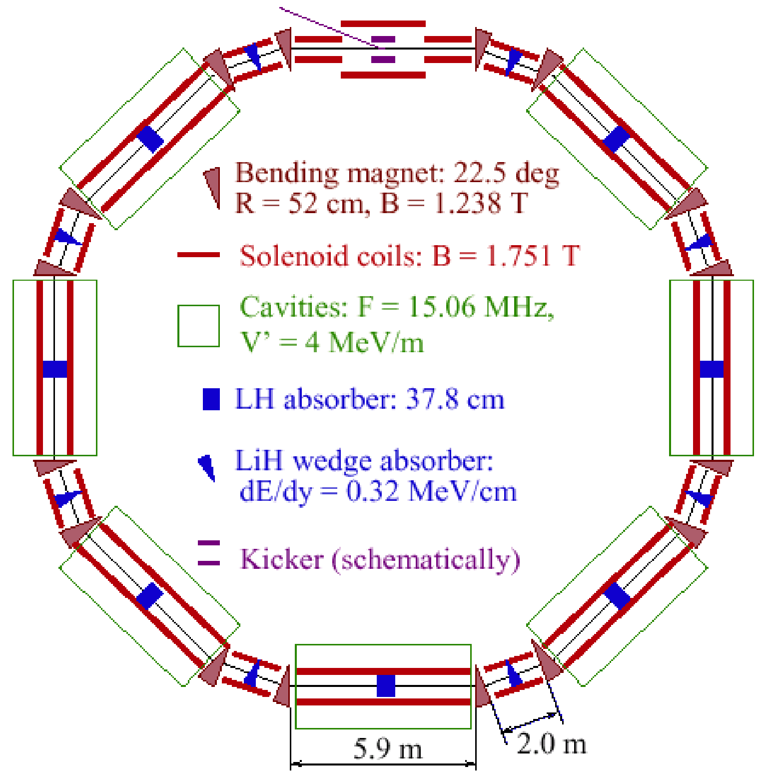


- Emittance exchange/ring coolers
  - important due to potentially significant payoff (Neutrino Factory and/or Collider)
  - keep creative juices flowing (rings, snakes, helical coolers,...)
  - nonlinearities and end fields are important
  - highest priority: solve injection/extraction problems and develop technically feasible design
- Our actions:
  - set up dedicated (and creative) group, with weekly meetings
  - assessing fields of realistic magnets; tools to evaluate effects available
  - idea for injection/extraction being studied (Palmer, Reginato)

# Present R&D Activities

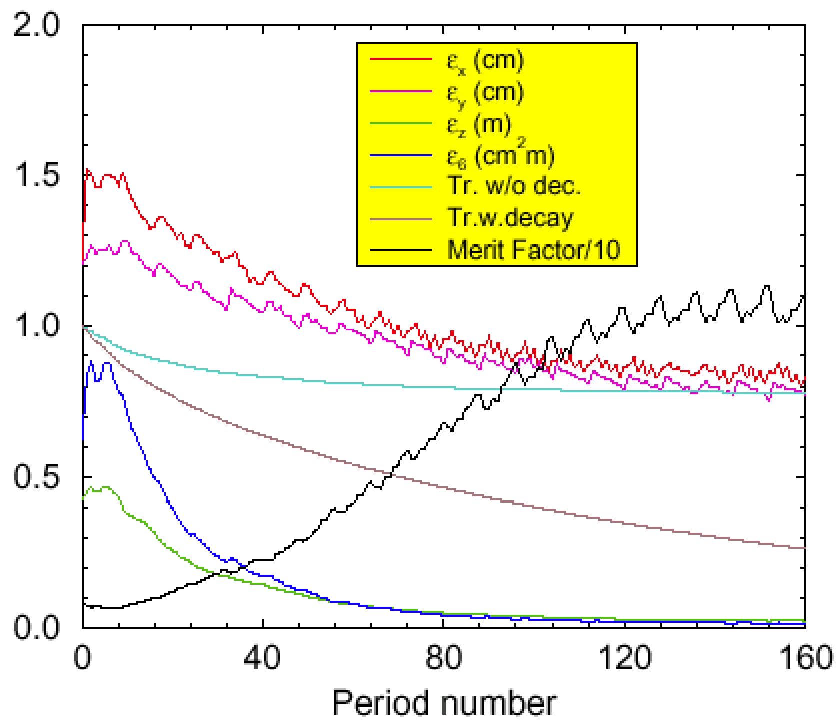
- Ring cooler permits 6D cooling...on paper
  - based on wedge absorbers in dispersive regions of a ring



# Present R&D 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$^3$

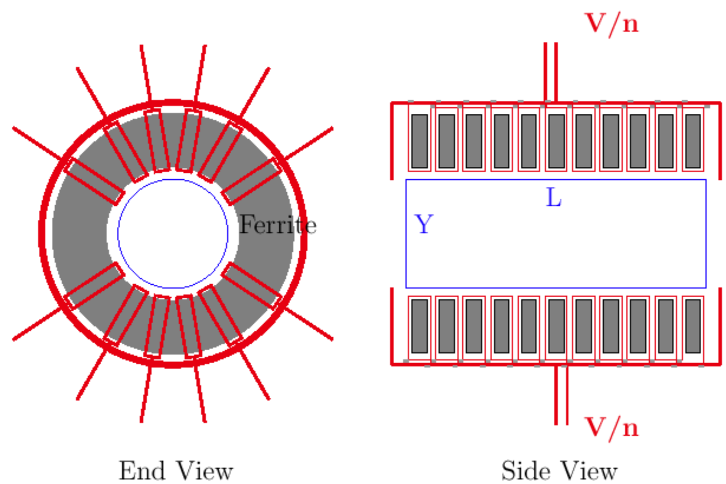
Transmission without decay 77.8%

Transmission with decay 26.3%

Merit factor 11.0

# Present R&D Activities

- Large aperture kicker concept proposed by Palmer and Reginato discussed at recent workshop at LBNL
  - concept appears feasible, but difficult to implement ($\Rightarrow$ expensive)
    - issues:
      - power supplies (need many magnetic pulse compression systems to drive magnet)
      - tolerance of kicker (ferrite or Metglas) to lattice fields



# Present R&D Activities



- International activities
  - closer collaboration with Japanese group on FFAG approach desirable and feasible
  - technical evaluation of different design concepts with common simulation tools would be appropriate goal
- Our actions:
  - evaluation of CERN scheme under way
    - Japanese scheme not yet evaluated
  - must identify effort to look at FFAG scheme

# Budget

- FY02 *MC* budget is

| Institution | COOLING | TARGETRY | COLLIDER | EFFORT[a] | RESERVE | TOTAL ($K) |
|---|---|---|---|---|---|---|
| BNL | | 825 | | | | 825 |
| FNAL | 815 | | | | | 815 |
| LBNL | 470 | | | | 111 | 581 |
| ANL | | | | 215 | | 215 |
| IIT | | | | 83 | | 83 |
| Mississippi | 50 | | | | | 50 |
| Princeton | | 75 | | | | 75 |
| UCB | | | 60 | 30 | | 90 |
| UCLA | 25 | | 50 | | | 75 |
| ORNL | | | | | | 0 |
| JLab | | | | | | 0 |
| TOTAL ($K) | **1360** | **900** | **110** | **328** | **111** | **2809** |

[a]Includes beam simulation and diagnostics effort.

- **Also: salary support from BNL, FNAL, LBNL; support from NSF (mainly Cornell) of $1M; and support from ICAR (≈15 FTE)**
  - **not clear NSF support will continue beyond this year**

# Budget

- In FY02, the MC budget was again reduced
  - $2.809M/$3.180M = 0.88 (⇒ 12% cut!)

| Year | DOE-base ($M) | DOE-MC ($M) | TOTAL ($M) |
|---|---|---|---|
| FY99 | 2.8 | 2.2 | 5.0 |
| FY00 | 3.3 | 4.7 | 8.0 |
| FY01 | 3.0 | 3.2 | 6.2 |
| FY02 | 3.0 | 2.8 | 5.8 |
| FY03[a] | 2.1 | 1.4 | 3.5 |

[a]Present guidance from DOE.

- We need increased funds to build components
- Severe cut in FY03 is surprising and clearly inappropriate in view of
  - considerable technical progress, a good MUTAC review, support from MCOG, and a favorable recommendation from HEPAP

*"We support the decision to concentrate on the development of intense neutrino sources, and recommend continued R&D near the present level of $8M per year. This level of effort is well below what is required to make an aggressive attack on all of the technological problems on the path to a neutrino factory."*

# Budget

- Budget issues
  - MC has no formal mechanism for giving DOE input on future funding needs
    - we do not submit FWPs
    - we do not get a DOE-HEP review as a "program"
  - presently, we simply wait until DOE "gives us a number"
- Rapidly decreasing budgets are unlikely to convey to Lab management (or us) the impression that this is a worthwhile activity

# Budget

- We are in the process of developing detailed out-year budgets now
  - to carry out proposed program in a reasonable time frame will require at least $8M per year
- Since budgets are determined annually based on specific tasks, the values that follow represent only a “typical” split of the funding
  - base program effort

| | |
|---|---|
| BNL | $1.2M |
| FNAL | $1.8M |
| LBNL | $0.5M |
| TOTAL | $3.5M |

  - MC funding

| | |
|---|---|
| MUCOOL | $1.6M |
| Targetry | $1.2M |
| Simulations/ring coolers | $0.8M |
| MICE | $0.9M |
| TOTAL | $4.5M |

# Budget

– **possible "extras"**

| | |
|---|---|
| Acceleration (if not NSF) | $1.0M |
| MBK development | $2.0M |
| MICE component fab | $3.0M |
| AGS primary operation | $1.0M |

## Budget

- FY03 desired activities
  - begin target-solenoid fabrication
  - continue beam tests at AGS
  - continue Be window development and launch grid development
  - continue dark current studies
  - begin fab of high-power 201-MHz NCRF cavity and test solenoid
  - begin $LH_2$ absorber tests (requires completing MTA)
  - develop formal proposal for MICE (international effort)
  - study alternative design approaches (e.g., Japanese FFAG scheme)
- Proposed FY03 budget will not allow most of this to proceed
  - to say nothing of eliminating AGS HEP operation

# Budget

- Strawman priorities (based on budget guidance)
  - Targetry
    - initiate target solenoid coil fabrication (only inner coils)
    - continue target simulations (no beam tests)
  - MUCOOL
    - complete MTA development (no components to test)
    - carry out cavity and dark current tests at 805 MHz
    - complete 201-MHz cavity design (no fabrication; no solenoid)
    - continue absorber window tests (no complete absorber tested)
    - prepare MICE proposal
  - Simulations
    - study emittance exchange and ring cooler design; look at FFAG scheme (consider joint workshop later this year)

# Budget

- Out-year planned activities (focus on hardware...that's where the money is)
  - Targetry
    - fabricate and test Hg-jet system at ≈20 m/s jet velocity
    - fabricate 15 T magnet and test with AGS beam
    - upgrade AGS extracted beam to reach 16 Tp on target
      - requires 9 shifts of beam development
    - test integrated system at full beam intensity
    - continue target simulation program to use in interpreting experimental results
    - operate AGS for E951
      - requires 10 shifts for target tests

*Elimination of AGS running for HEP in FY03 delays our program by 1 year*

# Budget

— MUCOOL

- fabricate and test 201 MHz high-gradient cavity (17 MV/m)
- develop, and test at high gradient, reliable cavity termination system (Be windows or Al grid tubes) at 201 MHz
- characterize dark current effects; develop and test mitigation schemes (cavity surface preparation, coatings)
- fabricate and test $LH_2$ absorbers (both convection-cooled and forced-flow types) with all safety aspects
- fabricate and test solenoid "coupling coil" at full field
- carry out integration tests of all components operating together (cavity, absorber, solenoid)
- provide transfer line for 400 MeV p beam to MTA and test integrated system with beam ("blast test")
- develop low duty factor 12 MW 201-MHz multi-beam klystron (MBK) in collaboration with industry

# Budget

– MICE

- evaluate, and develop if needed, solid absorber (e.g., LiH) as fallback or start-up alternative
- design and fabricate required beamline components for which the U.S. team is responsible (201 MHz rf cavities, absorber, solenoid coils, dark current and timing diagnostics, 5 MW rf power source)
  - final list of responsibilities will be generated as part of proposal preparation process
- ship all components to experimental site and set up systems for experiment
- participate in simulation studies of final configuration
- participate in data taking and data analysis for experiments

# Budget

— Acceleration (*note: not clear that NSF will continue this program*)

- develop full prototype of 201 MHz SCRF system (cavity, tuner, coupler, cryostat) and suitable low-level controls
- operate at high gradient (≈17 MV/m) with acceptable quench performance
- develop high-duty factor version of 201-MHz MBK in collaboration with industry
- build prototypes of challenging RLA magnets (e.g., splitters and recombiners, well-shielded solenoids)
- measure field quality and validate with tracking studies
- demonstrate operation of SCRF in vicinity of solenoids
- develop and cost an FFAG acceleration scenario (in collaboration with Japanese group)

# Budget

- Storage ring
  - develop prototypes of challenging magnets
  - measure field quality and validate with tracking studies
- Ring coolers
  - develop prototypes of challenging magnets
  - measure field quality and validate with tracking studies
  - develop and test wedge absorbers

# Summary

- MC program generally in excellent accord with recommendations from MUTAC (or, maybe, vice versa)
  - strongest support for MUCOOL (largest share of budget)
  - more emphasis on emittance exchange
- We are making good technical progress on all fronts
- Process of developing long-range priorities and plans has begun and will continue here
- Strong enthusiasm in MC to continue to build upon present technical progress
  - but decreasing funding continues to be an impediment
- We (along with MCOG) have presented our case to DOE this week