Neutrino Factory R&D

in the U.S.

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Outline

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

Introduction

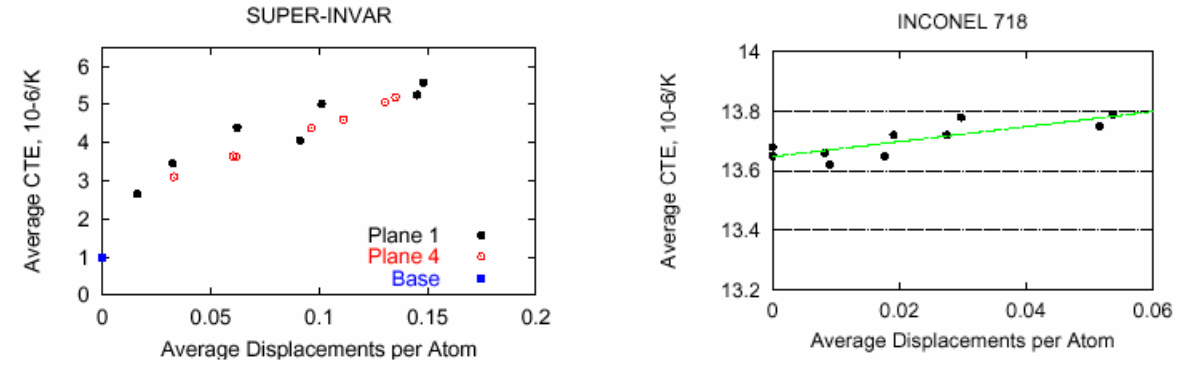
- An R&D program aimed at the production, acceleration and storage of intense muon beams is under way in the U.S.
  - under auspices of U.S. Neutrino Factory and Muon Collider Collaboration (MC)
    - support comes from DOE, NSF, State of Illinois, and U.S.–Japan
- Enhanced considerably by corresponding programs in Europe and Japan
- Attacking R&D problems of intense muon beams on a broad front
- In this talk I will describe the activities and plans of the MC
- Program has been (negatively) impacted by funding cuts in the past year
  - but we continue to make good technical progress

R&D Program Progress

- Targetry
  - initial beam tests of target (C rod and Hg jet) completed at AGS
    - no running in FY03 and likely FY04 as well, a major impediment
  - C sublimation tests ongoing at ORNL (Haines, Gabriel)
    - initial results in vacuum indicate 1 month lifetime at 1.2 MW
      - He-atmosphere tests will follow
  - developing bunch-merging technique to increase proton intensity
    - earlier tests done with 4 Tp/pulse (design value 16 Tp/pulse)
  - 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
    - designing Hg jet system capable of required 20–30 m/s velocity
    - continuing simulation effort to predict and interpret effects

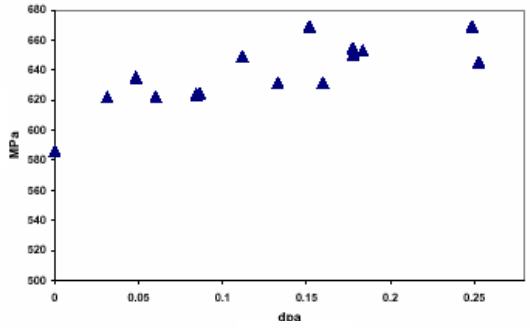
R&D Program Progress

- Radiation testing of candidate solid-target materials (Super-Invar and Inconel) carried out at BNL (Kirk, Simos) with 200 MeV p beam
  - looked at both CTE and tensile strength changes
    - big changes in Super-Invar CTE with dose, less with Inconel



    - yield strength increases but material gets more brittle

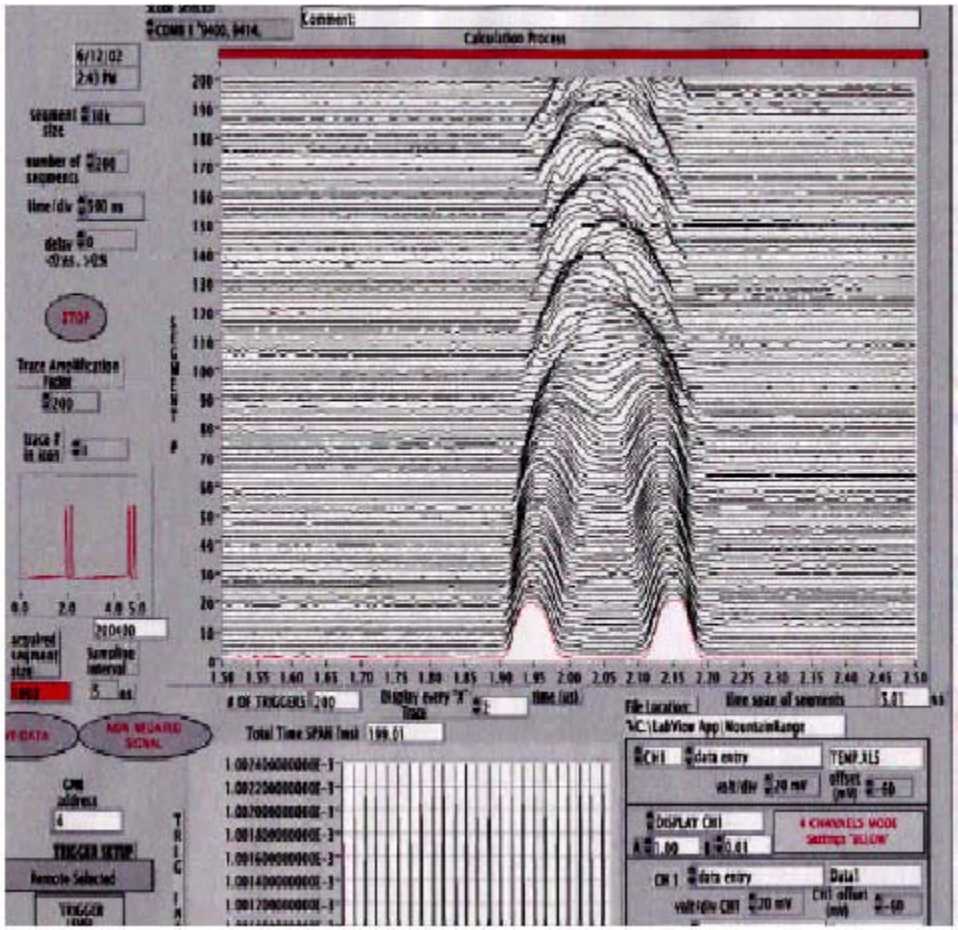
Yield (MPa)



dpa

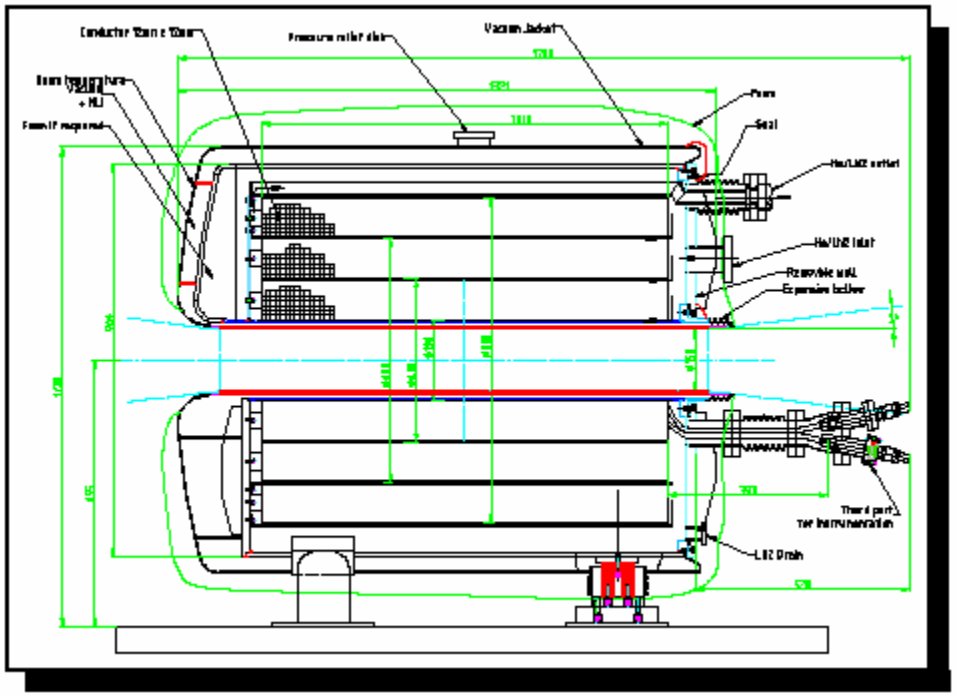
R&D Program Progress

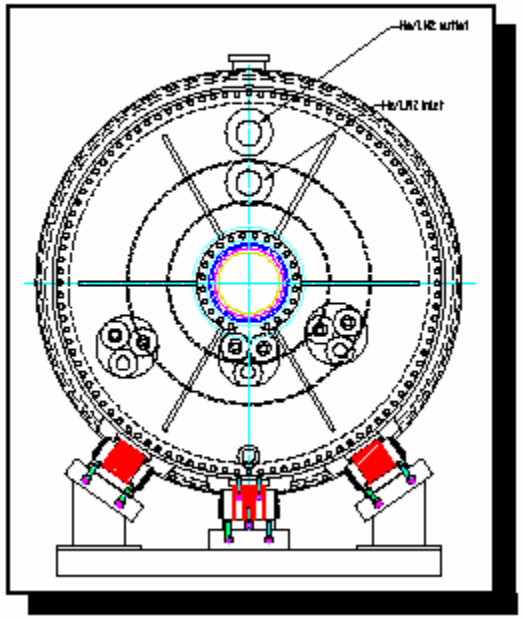
- Bunch merging (h = 12 → h = 6) at AGS gave extracted proton bunch of 10 Tp (desire 16 Tp)
  - technique needs development, but is clearly workable



R&D Program Progress

- **Engineering study of 5–15 T magnet for E951 at BNL completed (Kirk, Titus)**





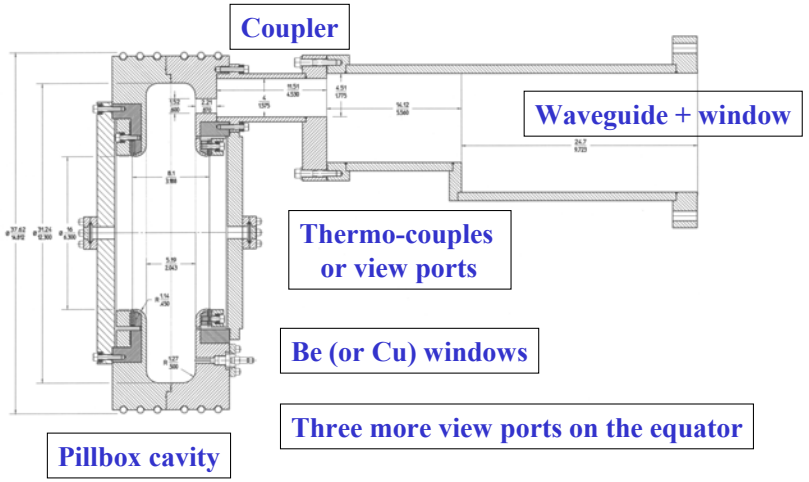
Stage	Field (T)	Power (MW)	Coolant	Temperature (K)
1	5	0.6	N_2	84
2	10	2.2	N_2	74
3	15	2.2	H_2	30
3a	15	4.5	N_2	70

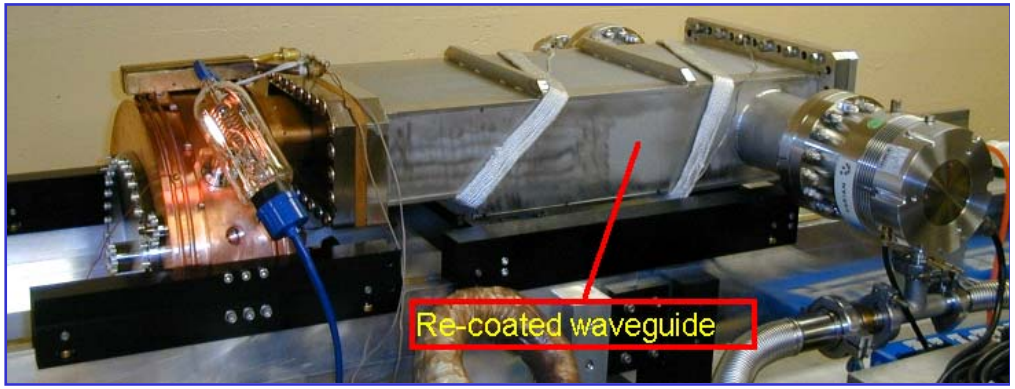
R&D Program Progress

- Cooling
  - includes hardware R&D on rf cavities, absorbers, solenoids
    - cooling channel cavities immersed in solenoid field ⇒ must be NC
  - rf work to date done at 805 MHz; 201 MHz cavity designed now
    - issue: limits to gradient (breakdown; dark currents)
  - absorber work going on in Illinois (ICAR supported) and Japan (U.S.-Japan funding)
    - development and testing of large, thin windows
    - consideration of hydrogen safety implications is well along
      - proximity of LH_2 to "ignition source" requires additional containment windows seen by beam
      - solutions being developed initially in the context of MICE
  - solenoid work is aimed mainly at cost and reliability issues

R&D Program Progress

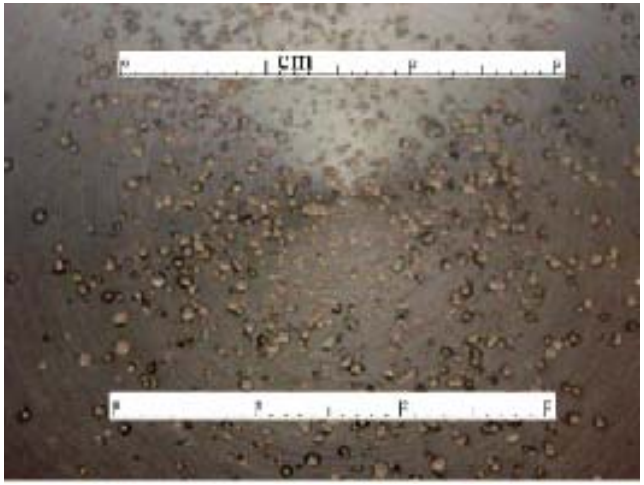
- Present tests use pillbox cavity with replaceable windows (or grids) (Li)
  - cavity fits in bore of Lab G solenoid





R&D Program Progress

- Pillbox cavity reached 34 MV/m in Lab G with no solenoid field (Moretti, Norem, Li, Rimmer, Torun, Gruber)
  - with solenoid performance worse (18 MV/m), radiation levels higher
    - field seemingly enhances likelihood of physical damage
      - but, some evidence for healing by reprocessing without field
- Cavity disassembled in December to inspect windows, internal surfaces
  - some pitting of window seen, with copper "dust" at bottom of cavity

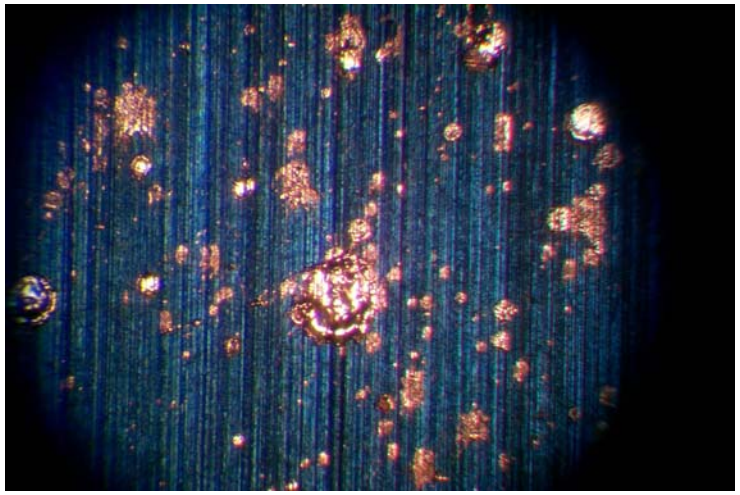


Copper window after using solenoid

R&D Program Progress

- TiN-coated Be windows were next installed and tested
  - no conditioning problems seen without magnetic field

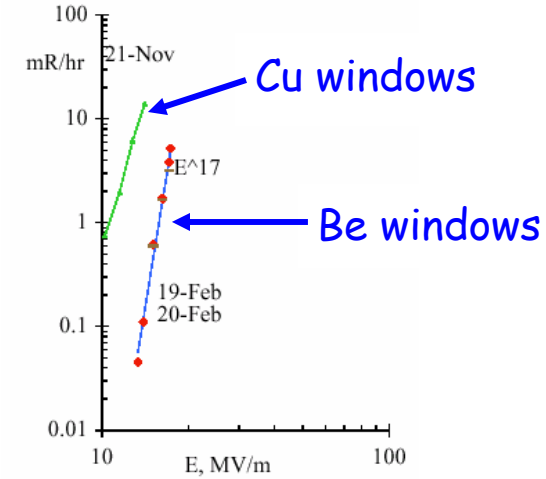
    ⇒parallel plate geometry does not cause big problems
- Found no damage to Be surface, but sputtered Cu is present
  - suggests need to focus more on copper body than on windows
- We will explore coatings that may help



Be windows with sputtered copper

R&D Program Progress

- Even with magnetic field present, background rates for Be are lower than for Cu under comparable conditions



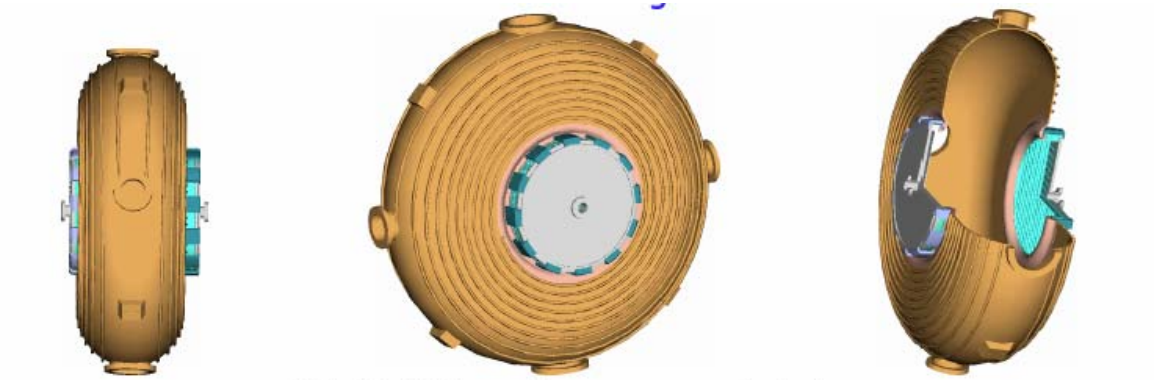
- Workshop on High-Gradient RF Cavities to be held at ANL, October 7–9, 2003

  http://www.hep.anl.gov/rf/

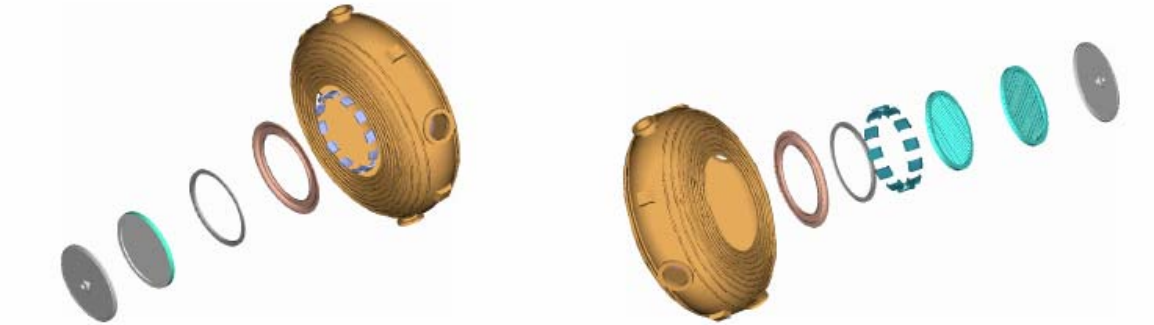
  — contact: Jim Norem

R&D Program Progress

- 201 MHz rf cavity design nearly complete (Rimmer, Li, Ladran, Virostek)



201.25 MHz cavity conceptual design

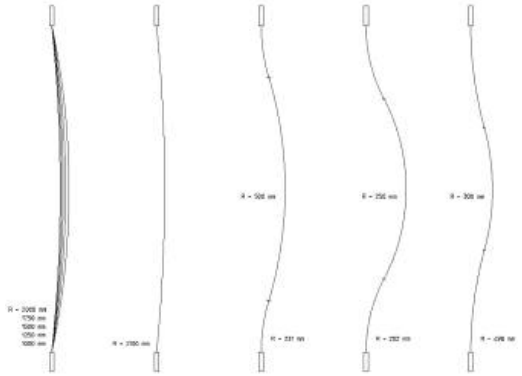


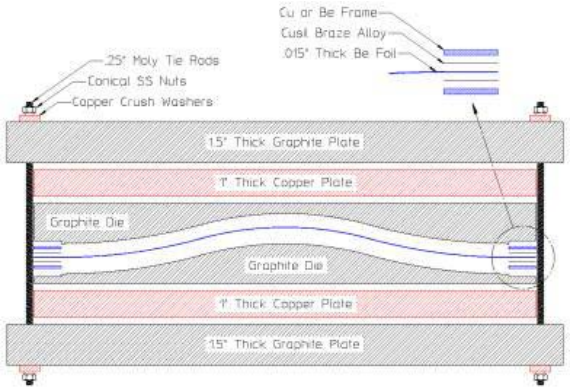
Exploded views showing foil and grid mounting hardware

- options for either Be windows or grids are included
- fabrication began this year; completion in about 1 year

R&D Program Progress

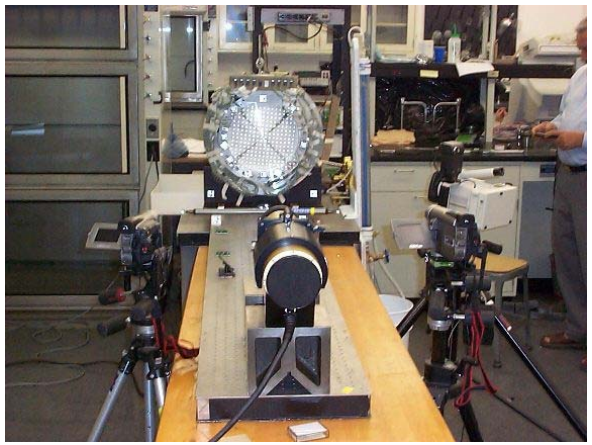
- Ideal cavity termination would be perfectly conducting and transparent to muon beam, and would not affect cavity frequency
  - initial concept was to use prestressed flat Be foils
    - even at 805 MHz, it was difficult to maintain flatness when window is heated by rf
    - frame had to be very thick, making windows costly
  - new concept (Virostek, Lau, Li, Rimmer) uses pre-curved windows that bow predictably
    - with proper design, stresses remain quite low as the foil heats

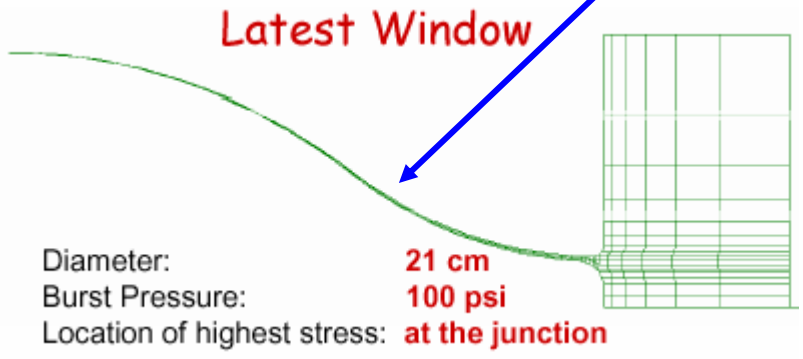




R&D Program Progress

- Absorber group has developed strong, thin windows (Cummings, Kaplan)
  - windows as thin as 125 μm machined from solid Al (Summers)
  - original design destruction tested at NIU (performance okay)
    - 125 μm window broke at 44 psi (3 atm), 340 μm window at 120 psi (8 atm)
    - stronger (⇒thinner) design (Lau, Black) to be tested next
  - developed photogrammetry technique to characterize window behavior





R&D Program Progress

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

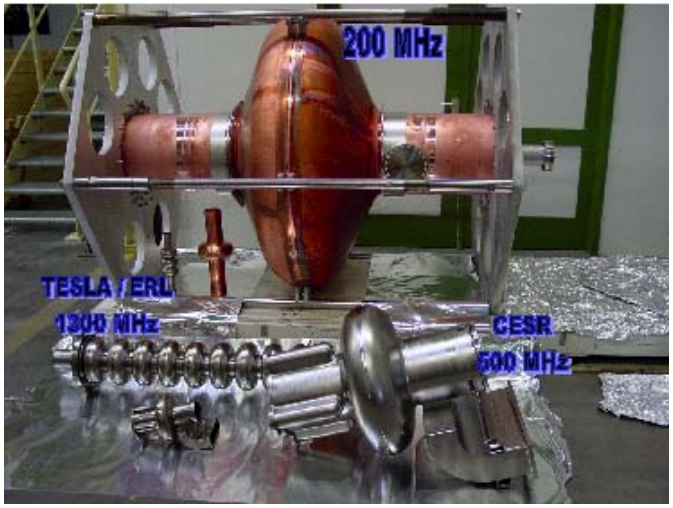
Original area

Stage 2 construction area

What it will look like when completed

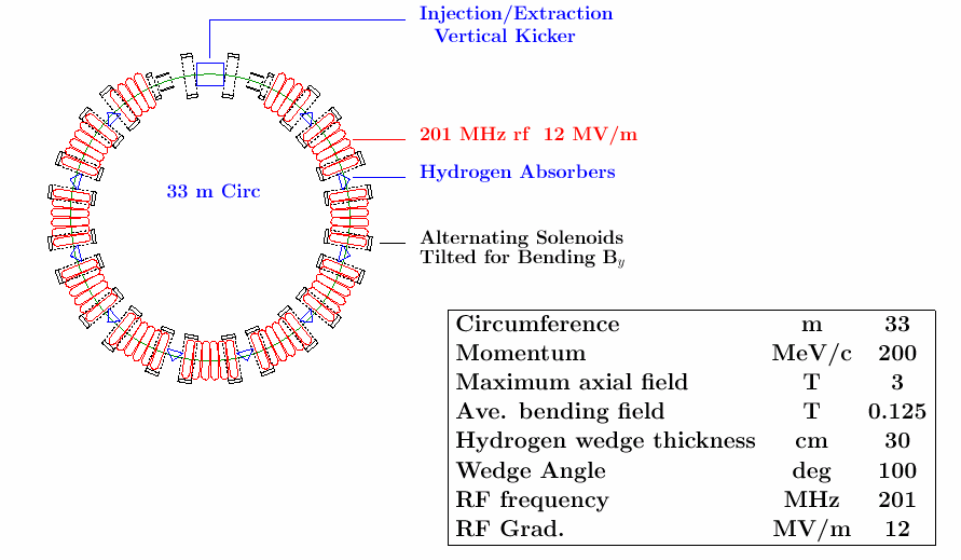
R&D Program Progress

- Work on 201 MHz scrf cavity for the acceleration system made good progress (Hartill, Padamsee; NSF)
  - focusing on achieving gradient, Q, mechanical stability
    - reached 11 MV/m after re-cleaning cavity
    - low-power $Q = 10^{10}$
  - still need to develop designs for ancillary items (input coupler, HOM coupler, tuner) based on existing experience, e.g., KEKB

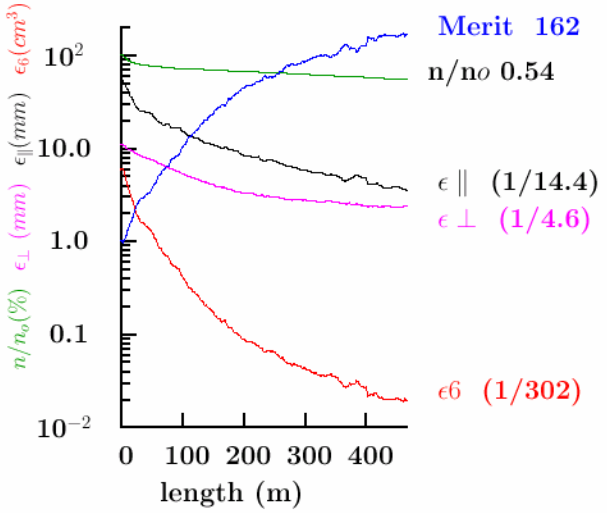


R&D Program Progress

- **Simulations**
  - **separate group to focus on emittance exchange (Raja)**
  - **ring coolers (Balbekov, Palmer) important due to potentially significant cost reduction (Neutrino Factory and/or Collider)**
    - **6D cooling looks promising; injection is an issue**

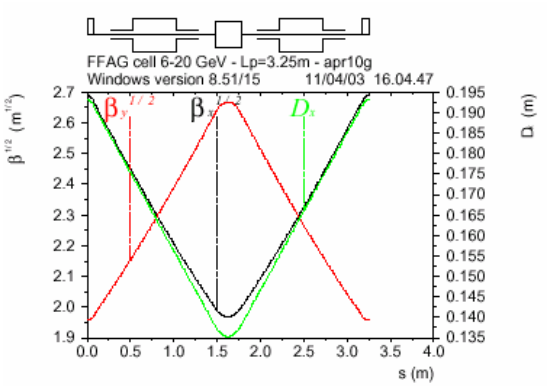


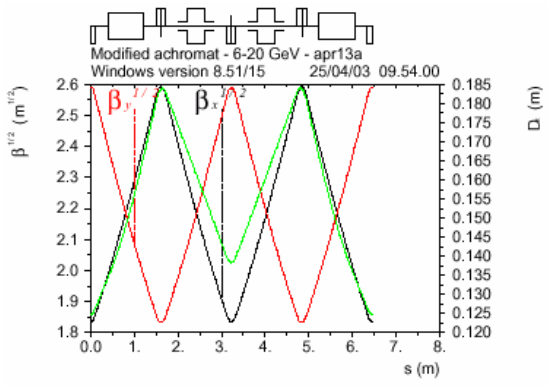
Circumference	m	33
Momentum	MeV/c	200
Maximum axial field	T	3
Ave. bending field	T	0.125
Hydrogen wedge thickness	cm	30
Wedge Angle	deg	100
RF frequency	MHz	201
RF Grad.	MV/m	12



R&D Program Progress

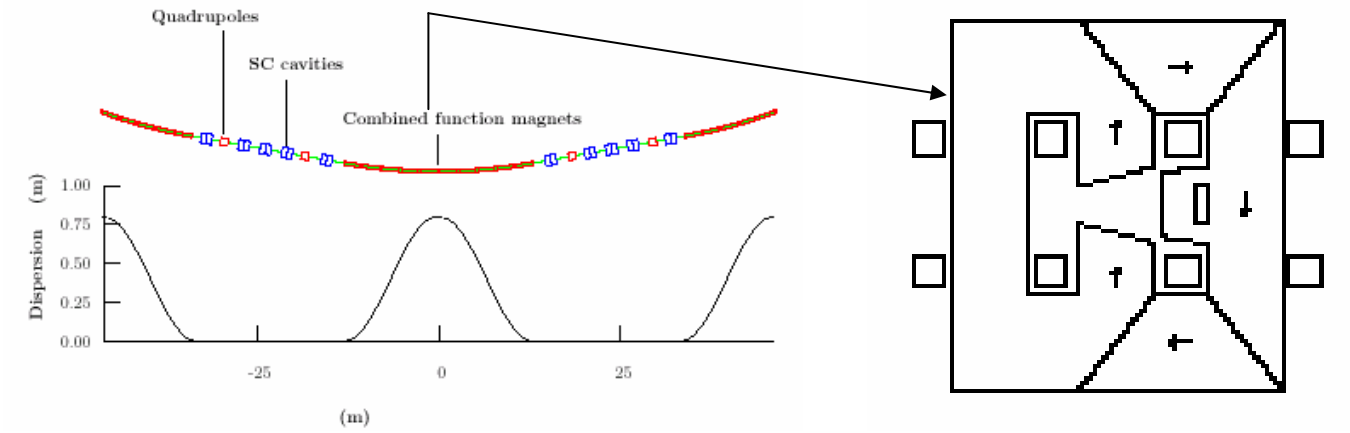
- Looking at alternative acceleration schemes
  - RLA with FFAG arcs (Berg, Johnstone, Keil, Sessler, Trbojevic)





  - very rapid cycling booster (Summers)

Grain-oriented Si steel



R&D Program Progress

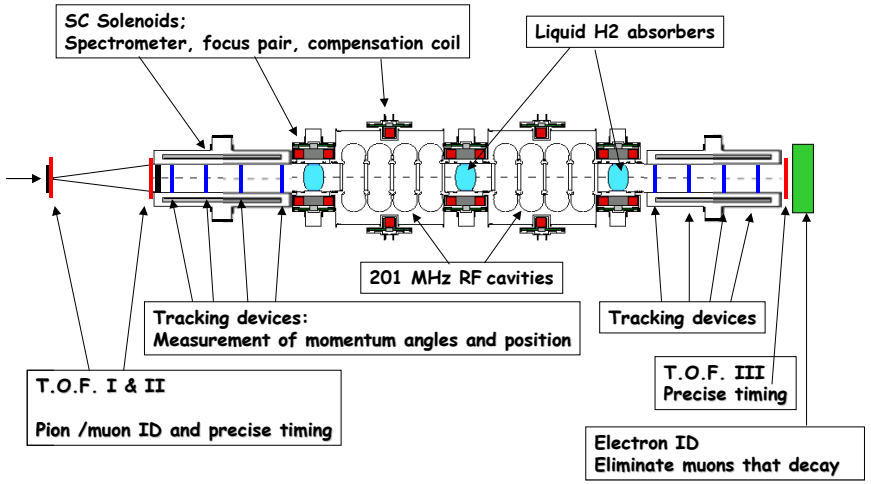
- Preparations for Study III
  - looking at improved approaches to make cost-optimized facility design
    - improved bunching and phase rotation (Neuffer)
    - cooling rings (Balbekov, Palmer, Raja)
    - FFAG acceleration (Berg, Keil, Sessler) or fast cycling booster (Summers)
- Hope is to make this a "world" study, sponsored by RAL
  - participants would come from EU, Japan, and U.S.
- This will be discussed in WG3 on Tuesday, June 10 at 16:00

MICE Activities

- Motivation for MICE
  - straightforward physics, but not experimentally demonstrated
  - prudence dictates demonstration of key principle for expensive facility, $\mathcal{O}$($1B)
- Why should we move forward expeditiously?
  - we have a motivated collaboration, an enthusiastic host lab (RAL), and a solid experiment design ⇒ the time to begin is now
  - experiment forces us to deal with operational and cost issues early
- U.S. groups anticipate providing substantial effort for (international) MICE
  - rf cavities, coupling coils, part of tracker, software development, experiment simulations
  - U.S. team has already submitted funding request to NSF for $24M

MICE Activities

- Basic ingredients of MICE experiment:
  - absorbers to give energy loss (LH_2 capable of handling 100–300 W)
  - rf cavities to restore lost energy (up to 17 MV/m at 201 MHz)
  - solenoid magnets to contain the muons (up to 5 T)
  - diffuser to create large emittance sample
  - upstream diagnostics section to define initial emittance
  - downstream diagnostics section for final emittance and particle ID



MICE Activities

- MICE status
  - proposal submitted in January 2003
    - international review held February 17 (A. Astbury, chairperson)
      - "homework" questions completed in mid-April
    - expect committee to make recommendation this summer
      - we anticipate that they will "strongly recommend" approval of the project

R&D Plans

- Targetry
  - fabricate 15 T magnet and test with AGS (or other) beam
- Cooling
  - fabricate and test 201 MHz high-gradient cavity (17 MV/m)
  - fabricate and test LH_2 absorbers (first convection-cooled, later externally cooled type) with all safety aspects
- Acceleration
  - develop full prototype of 201 MHz SCRF cavity module
- Ring coolers
  - develop engineered concept of complete ring
- MICE
  - design and fabricate our portion of required components
- Study III participation as part of world team

Summary

- U.S. muon beam program continues to make excellent technical progress on all fronts
- Interaction with colleagues worldwide serves as "model" for working together on major international projects
- U.S. team part of strong international effort for MICE
    - international review held February 17
        - decision expected by this summer
- We are developing components that serve as prototypes for MICE
- Budget problems in U.S. and elsewhere causing significant problem

— restoring adequate funding levels in future years is critical to maintaining a healthy international muon beam R&D program

- we continue to work on this

...and so should everybody else here!