Report of Project Manager

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Outline

- Introduction
- Challenges
- Ionization cooling
- R&D management process
- R&D overview
- Funding status
- FY06 accounting
- Recent R&D accomplishments
- FY07 budget
- FY07 plans
- 5-year R&D plan (reminder)
- Summary and outlook

Introduction

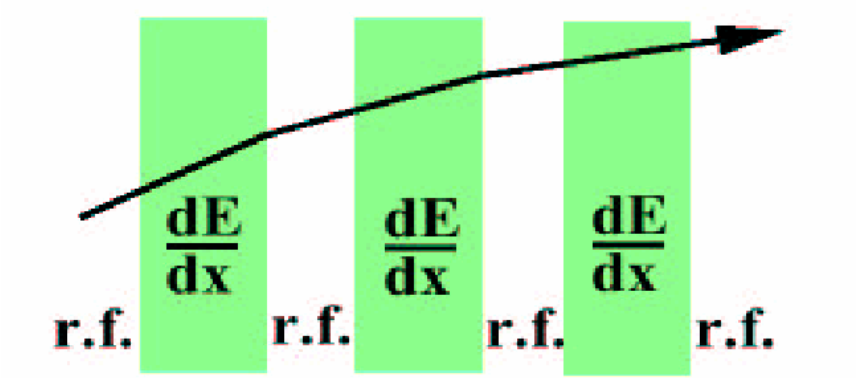
- U.S. Neutrino Factory and Muon Collider Collaboration (NFMCC) explores techniques for producing and accelerating intense muon beams
  - near-term focus: muon storage ring to serve as source of well characterized neutrinos ("Neutrino Factory") for long baseline experiments (≈3000 km)
  - longer term focus: Muon Collider
    - Higgs Factory operating at few hundred GeV or energy-frontier collider operating at several TeV (interest in both increasing)
  - both machines difficult but have high scientific potential
    - either facility requires sustained R&D program
      - a feature common to modern projects (LHC, ILC,...)

Challenges

- • Challenges of a muon-based facility (Neutrino Factory or Collider)
  - muons have short lifetime (2.2 μs at rest)
    - puts premium on rapid beam manipulations
      - high-gradient NCRF (in magnetic field) for cooling
      - presently untested ionization cooling technique
      - fast acceleration system
  - muons are created as tertiary beam ($p \rightarrow \pi \rightarrow \mu$)
    - low production rate ⇒
      - target that can handle multi-MW beam
    - large muon beam transverse phase space and energy spread ⇒
      - ionization cooling
      - high-acceptance acceleration system and decay ring
- Cooling requirements for Muon Collider much more stringent than for Neutrino Factory

Ionization Cooling

- Ionization cooling 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



Ionization Cooling

- There is also a heating term
  - with SR it is quantum excitation
  - with ionization cooling it is multiple scattering
- Balance between heating and cooling gives equilibrium emittance

$$\frac{d\varepsilon_N}{ds} = -\frac{1}{\beta^2}\left|\frac{dE_\mu}{ds}\right|\frac{\varepsilon_N}{E_\mu} + \frac{\beta_\perp (0.014\,\mathrm{GeV})^2}{2\beta^3 E_\mu m_\mu X_0}$$

cooling heating

$$\varepsilon_{x,N,equil.} = \frac{\beta_\perp (0.014\,\mathrm{GeV})^2}{2\beta m_\mu X_0 \left|\frac{dE_\mu}{ds}\right|}$$

  - prefer low $\beta_\perp$ ($\Rightarrow$ strong focusing), large X_0 and dE/ds ($\Rightarrow$ H_2 is best)

R&D Management Process

- Each year, R&D groups propose an annual program to the Technical Board, based on NFMCC budget guidance from DOE
- PM prepares budget based on this input
  - subsequently approved by Technical Board, Executive Board, and Co-Spokespersons
  - budgets determined by R&D program, not by "institutional commitments"
- After budget finalized, PM negotiates milestones with each institution based on the R&D plan
  - milestones specify dates and deliverables
    - a "report card" is generated at year's end to audit performance
- PM summarizes annual spending and accomplishments in a detailed report for MCOG and DOE at the end of each year
  - report also includes non-DOE information insofar as it is available

R&D Overview

- NFMCC R&D program has the following components:
  - simulation and theory effort in support of Neutrino Factory and Muon Collider design
  - development of high-power target technology (Targetry)
  - hardware development of cooling channel components (MUCOOL)
- NFMCC also participates in four international endeavors:
  - MICE (ionization cooling demonstration)
  - MERIT (high-power Hg-jet target)
  - EMMA (demonstration of non-scaling FFAG system)
  - ISS (simulation studies of Neutrino Factory design)
- Hardware development continues as major focus of NFMCC activity
- Simulation effort aimed at reducing Neutrino Factory cost ("Study IIa") gave good results in APS neutrino study
  - increased performance, lower cost

Funding Status

- Since FY03, the NFMCC DOE budget has been nearly flat-flat
  - we remain hopeful of getting increased support from DOE and NSF

Year	DOE-base ($M)	DOE-NFMCC ($M)	TOTAL ($M)
FY00	3.3	4.7	8.0
FY01	3.0	3.2	6.2
FY02	3.0	2.8	5.8
FY03	2.1	1.4	3.5
FY04	2.2	1.8[a)]	4.0
FY05	1.9	1.7	3.6
FY06	1.8	2.1[b)]	3.9
FY07	1.8	1.8	3.6

[a)] Includes $0.4M supplemental funds
[b)] Includes $0.3M supplemental funds

Funding Status

- We are presently committing funds to MICE and MERIT
  - and supporting the International Design Study (ISS → IDS)
- By juggling projects across fiscal year boundaries and careful prioritization, we continue to make progress, but
  - only "contingency" on deliverables is time
  - simulation effort weakened by lack of post-docs
  - BNL simulation effort has atrophied
  - MICE common fund contribution (£3K per Ph.D.) about to start
- Hardware development continues as major focus of FY07 activity
- Simulation effort aimed at reducing Neutrino Factory cost ("Study IIa") gave good results
  - ISS used this as its basis, upcoming IDS likely will also
  - EMMA design also builds on NFMCC concepts

Funding Status

- Simulations of Muon Collider scenario also progressing well
  - MCTF created at Fermilab
  - schemes compatible with NF "front end" being explored
    - solidifies the R&D connection between the two types of facility
  - Muon Collider design will benefit greatly from this new effort
    - NFMCC wants to participate fully
      - but we are stretched thin to do so
- Here I will cover:
  - FY06 accounting and R&D accomplishments
  - FY07 budget and status of current activities

FY06 Accounting

- FY06 budget finalized by Spokespersons and PM in October, 2005
- Both MICE and MERIT are a significant draw on resources
  - substantial M&S funding now being used
- Missing element in our present program is MuCool coupling coil
  - needed to investigate degradation in achievable gradient with magnetic field (seen in 805 MHz cavity tests)
- We are continuing to pursue opportunities for obtaining a coupling coil
  - two options in the U.S. being pursued for FY07
    - MRI grant from NSF (U.-Miss., just submitted)
    - negotiations with ICST-Harbin

FY06 Accounting

- **FY06 NFMCC budget (only DOE-NFMCC funds)†**

Institution	COOLING /MICE	TARGETRY /MERIT	ACCEL./ COLLIDER	RESERVE	TOTAL ($K)
BNL		405			405
FNAL	45				45
LBNL[a,b]	980			70	1050
ANL	150				150
IIT	85				85
Mississippi	20	25	20		65
Princeton		105			105
UCLA	25		45		70
UC-Riverside			20		20
ORNL		95			95
Jlab	5		5		10
TOTAL ($K)	**1310**	**630**	**90**	**70**	**2100**

[a]Includes MICE funding of $620K.

[b]Includes supplemental funding of $300K for MUCOOL coupling coil.

†Also: salary support from BNL, FNAL, LBNL; support from NSF of $1M ($750K MRI + $100K 3-yr grant); support of Muons, Inc. via SBIR grants

FY06 Accounting

- **Supplemental request submitted to DOE in January 2006 (priority order)**
  - **priorities decided in discussions between Spokespersons and PM**

Item	Request ($K)
1) Coupling coil design and construction	975
2) Support for MICE design, commissioning, operations, and analysis	350
3) Support for International Scoping Study	100
TOTAL	1025

- **$300K for item 1 obtained from this request**
  - **in the hope that an NSF MRI award would cover the rest**
    - **which unfortunately did not happen**

FY06 Accounting

- Main goals for FY06
  - complete fabrication of Targetry test magnet
    - continue with Hg-jet target fabrication
  - continue development of MUCOOL Test Area (MTA) at FNAL (cryogenics)
  - continue high-power tests of 805 MHz NCRF cavity
  - begin tests of 201-MHz NCRF cavity
  - continue 201-MHz SCRF development (NSF supported)
  - obtain funding for MICE (ongoing struggle!)
  - continue exploring and optimizing 6D cooling performance

FY06 Accounting

- **Before funds were distributed, each institution provided milestones agreed upon by PM**
  - **milestones (example below) reflect budget allocations for each institution, including base program funds**

ANL [Norem]

Milestone	Date	Deliverable
Begin 805 MHz cavity testing at MTA	Feb-06	Inspection
Begin studies of small sample materials in the 805 MHz cavity	Mar-06	Inspection
Write up initial experimental results on pulse length dependence of breakdown	Jun-06	NFMCC note
Write up initial experimental results on coatings with Atom Probe Tomography	Aug-06	NFMCC note
Write up model of conditioning, pulse length and frequency dependence of breakdown	Sep-06	NFMCC note

BNL [H. Kirk]

Milestone	Date	Deliverable
Test pulsed 15-T solenoid at MIT	Feb-06	NFMCC presentation
Complete fabrication of Hg-jet	Jun-06	Inspection
Begin integration test of Hg jet in pulsed solenoid	Sep-06	NFMCC presentation
Continue support for NFMCC web pages	Sep-06	Inspection
Test MERIT cryogenics cold valve box	Jul-06	Inspection
Simulation of FFAG ring for ISS	Aug-06	ISS report

ORNL [Gabriel]

Milestone	Date	Deliverable
Award Hg loop fabrication contract	Feb-06	P.O. written
Begin testing Hg loop at ORNL	May-06	Inspection
Ship Hg loop to MIT	Jul-06	Inspection
Complete acquisition of tool box items	Jul-06	Inspection
Complete initial testing of integrated system at MIT	Sep-06	Inspection

FY06 Accounting

- **Summary of FY06 spending:**

Institution	Collaboration		Base Program	Overall	Contact
	Committed ($K)	Uncommitted ($K)	Committed ($K)	Total ($K)	
ANL	150	0	50	200	J. Norem
BNL [1]	515	260	921	1436	H. Kirk
FNAL [2]	182	120	1683	1865	A. Bross
LBNL [3]	956	615	316	1271	M. Zisman
ORNL	135	50	85	220	T. Burgess
Princeton U.	105	0	200	305	K. McDonald
UCLA	70	0	57	127	D. Cline
UC-Riverside	16	0	0	16	G. Hanson
Mississippi	65	0	0	65	D. Summers
IIT [4]	87	9	0	87	D. Kaplan
Jlab	10	1.3	0	10	R. Rimmer
NSF MICE Support [5]	*445*	*505*	*0*	*445*	*D. Kaplan*
TOTALS [6]	**2291**	**1055**	**3311**	**5603**	
	2736	*1559*		*6048*	

NOTES:

[1] Uncommitted funds for MERIT experiment.
[2] Uncommitted funds for MTA cryogenics and beam line ($120K).
[3] Includes $119K in uncommitted Project Reserve funds maintained by LBNL
[4] Only DOE funds. NSF funding reported separately.
[5] Funds allocated to IIT as primary contractor.
[6] DOE totals in Roman type; *additional NSF funding shown in italics*.

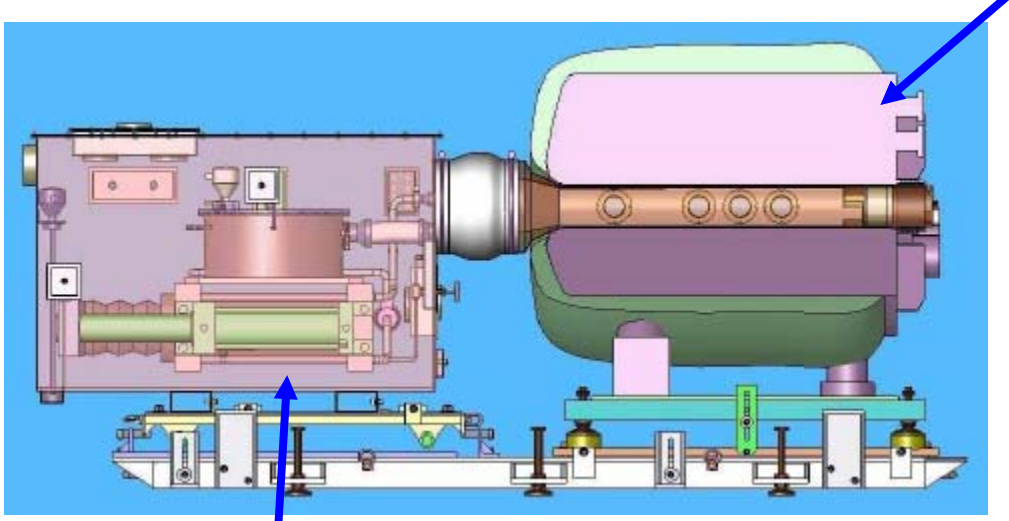
Recent R&D Accomplishments

- R&D progress was made on all fronts:
  - Targetry/MERIT
  - Cooling/MICE
  - Acceleration
  - Simulations/ISS

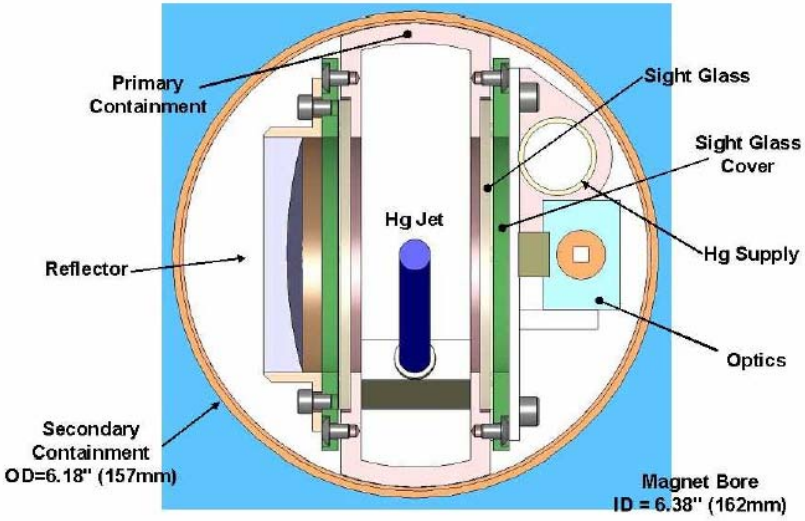
Recent R&D Accomplishments

- Proposal for MERIT experiment approved at CERN in April 2005
- Concept for Hg jet system for CERN target test experiment developed in collaboration with ORNL
  - first beam ~July, 2007

15-T pulsed solenoid



Hg circulation



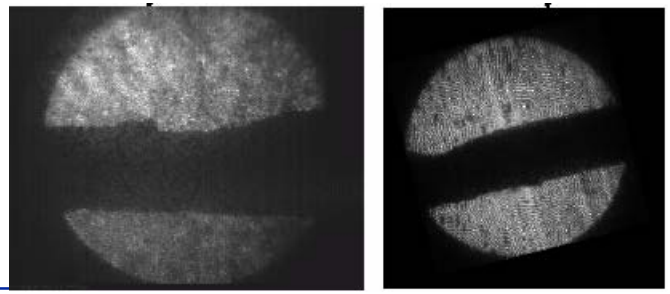
Optical diagnostics

Recent R&D Accomplishments

- Fabrication of 15 T magnet completed
  - tested successfully to full field at MIT
- Hg-jet system assembled at ORNL and tested with magnet at MIT

15-T solenoid + Hg system in test location at MIT

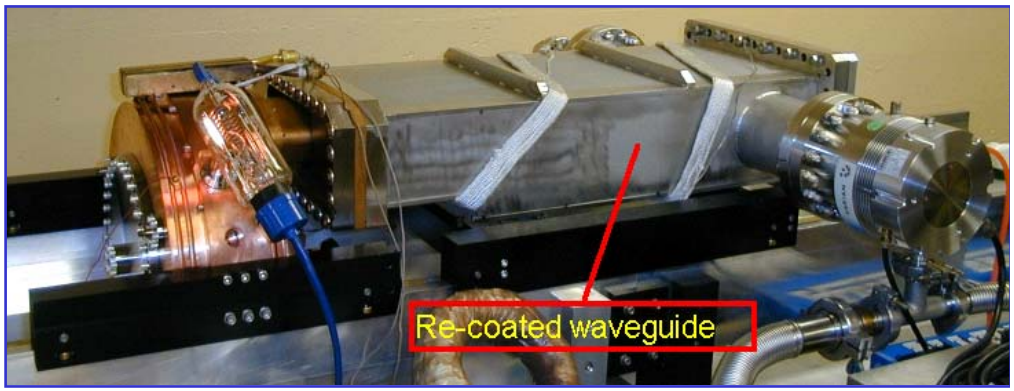
Hg jet system assembled at ORNL



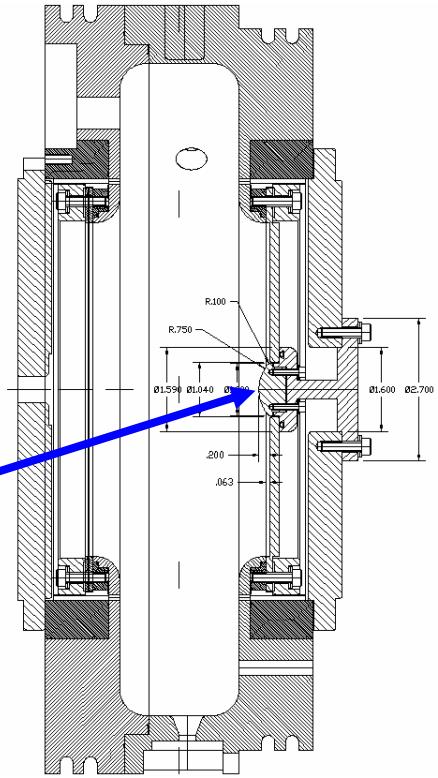
Hg jet images: 7 T; 20 m/s

Recent R&D Accomplishments

- RF test plan prepared for both 805 MHz and 201 MHz
- 805-MHz program (now resumed) uses pillbox cavity with replaceable windows or "buttons"
  - cavity fits in bore of MTA (née Lab G) solenoid
  - will efficiently study materials and coatings (long overdue)



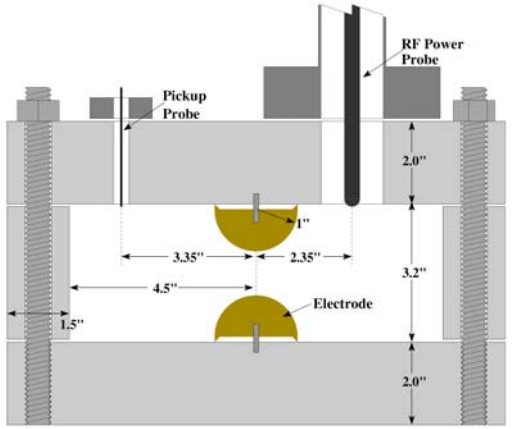
"Button" for materials tests



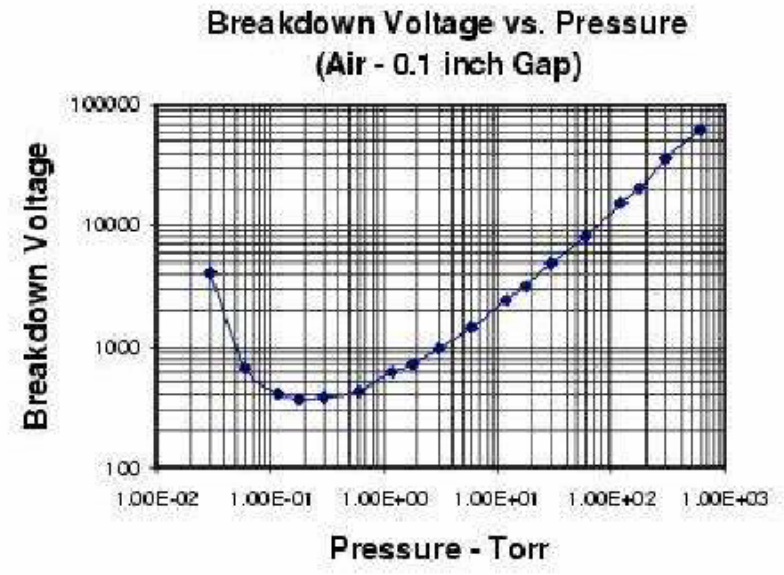
Recent R&D Accomplishments

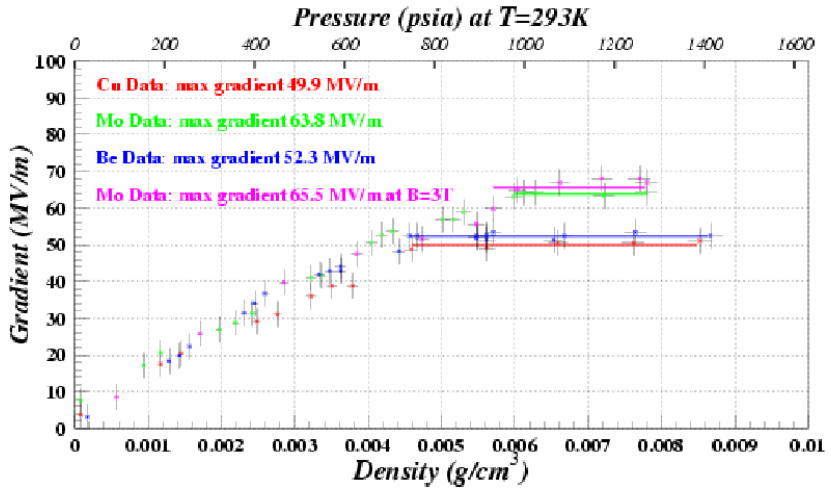
- Tested pressurized version of button cavity (**Muons, Inc.**)
  - use high pressure H_2 gas to limit breakdown

Issue: does beam ionization result in breakdown of gas?



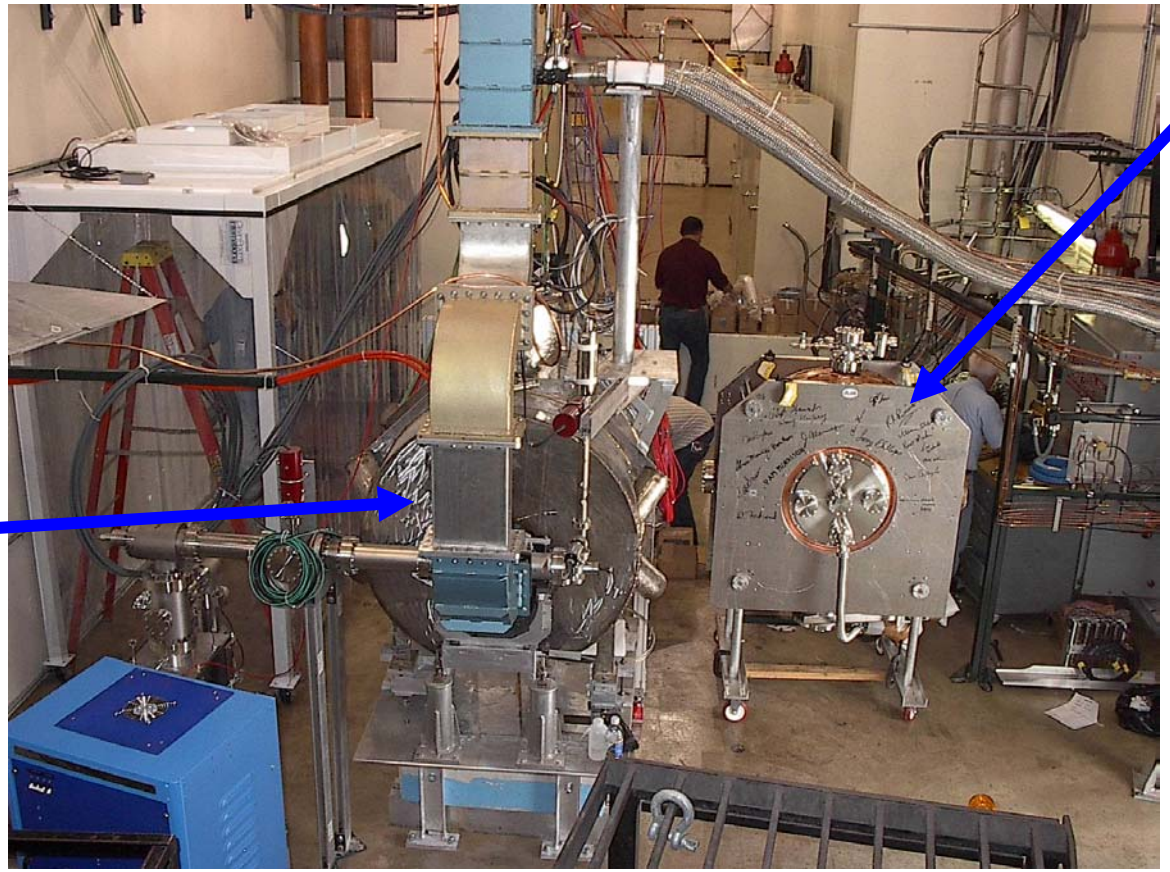
Offers hope of handling breakdown problem





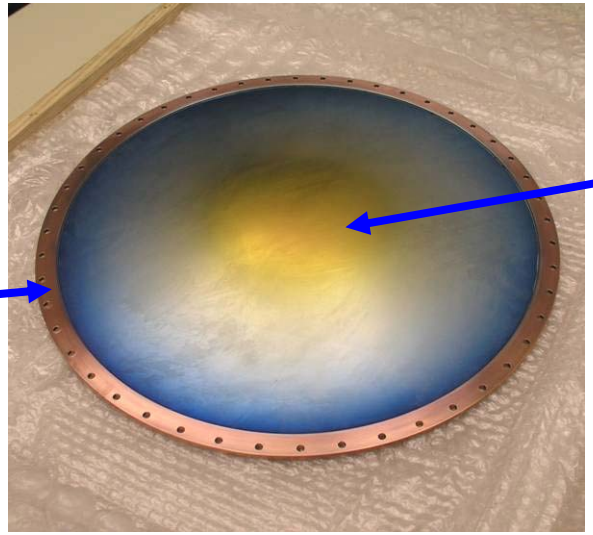
Recent R&D Accomplishments

- Initial tests of 201 MHz cavity very successful
  - cavity quickly reached design gradient of 16 MV/m (no magnetic field)



Recent R&D Accomplishments

- Curved Be windows for 201-MHz cavity fabricated and TiN coated in industry
  - two windows completed
    - just installed in cavity
      - will be tested this year



Recent R&D Accomplishments

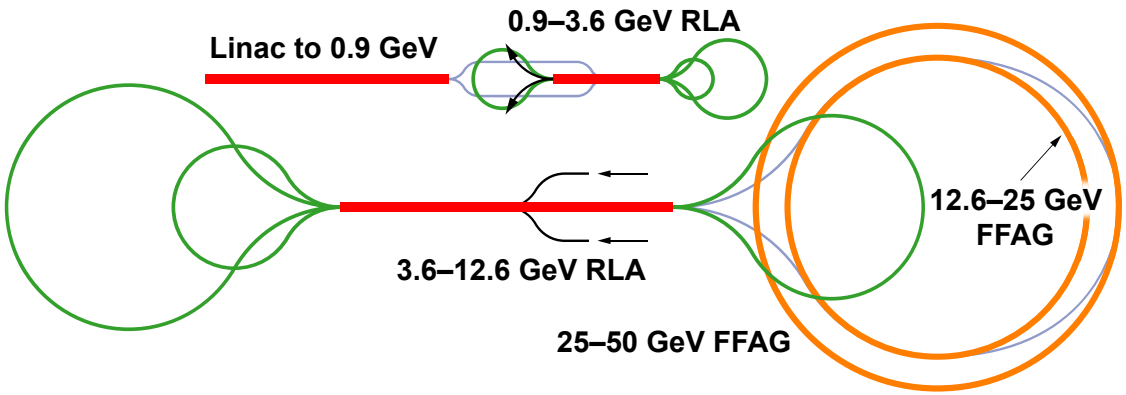
- Work on 201 MHz scrf cavity for the acceleration system has shifted gears
  - now trying to understand *Q* slope in terms of Nb coating properties
- Several 500-MHz cavities prepared to study fabrication techniques
  - hot isostatic pressed Nb-Cu; explosion bonded Nb-Cu
  - spinning of bonded cavity preferred

Bonded

Pressed

Recent R&D Accomplishments

- Simulations
  - main focus in past year was to complete ISS
  - considerable progress made over past few years in simplifying front-end systems while maintaining performance
    - developed RF bunching and phase rotation scheme; simplified cooling channel; FFAG scheme for final acceleration stages
  - NFMCC front end scheme adopted as ISS baseline
    - we also played key role in definition of acceleration scheme...not so simplified



Recent R&D Accomplishments

- Summary of main findings from ISS (report in preparation)
  - preferred proton driver energy is 10 ± 5 GeV
  - Hg-jet target gives optimal muon production for protons in preferred energy range
  - Study IIa front end design is preferred, using simultaneous operation with both muon signs
  - non-scaling FFAG beam dynamics limits performance, so preferred approach will use only one, or at most two, such systems
  - racetrack and triangular rings possible (2 rings needed either case)
    - triangle more efficient if 2 suitable sites operating simultaneously
    - racetrack better for single detector site + no directional constraints
- Continue with IDS for next few years
  - launch formally at NuFact07 (Okayama)

FY07 Budget

- Prepared initial budget for FY07 based on guidance of flat budget
  - Tech Board discussed and approved it
- Budgetary "goal" is to maintain university programs while making some progress on key fabrication activities
- Choices based on the following R&D obligations
  - start on RFCC modules for MICE
  - provide remaining components for MERIT experiment
- Continue seeking funds for MuCool coupling coil
  - for RF cavity tests at MTA
    - NSF, DOE, China
- Finally successful at getting NSF funding for UC-Riverside
  - $133K per year for 3 years
    plus matching contribution from Hanson's UC-R startup funds

FY07 Budget

- **FY07 NFMCC budget (only DOE-NFMCC funds)†**

Institution	COOLING /MICE	TARGETRY /MERIT	ACCEL./ COLLIDER	RESERVE	TOTAL ($K)
BNL		440			440
FNAL	50				50
LBNL[a]	680			35	715
ANL	150				150
IIT	85				85
Mississippi	42		18		60
Princeton		45			45
UCLA	25		45		70
UC-Riverside			95		95
ORNL		80			80
Jlab	5		5		10
TOTAL ($K)	**1037**	**565**	**163**	**35**	**1800**

[a]Includes MICE funding of $500K.

†Also: salary support from BNL, FNAL, LBNL; support from NSF of $0.1M + $0.75M MRI grant; support of Muons, Inc. via SBIR grants

- **Also submitted MRI request for coupling coil to NSF**

FY07 Plans

- Targetry
  - complete MERIT experiment and prepare to publish results
- Cooling/MICE
  - continue testing of 805 MHz and 201 MHz high-gradient cavities
  - continue MICE experiment, work toward publishing initial results
- Acceleration
  - optimize system design for performance and cost
  - participate in EMMA test program (effort only)
- Simulations
  - participate in Neutrino Factory International Design Study (follow-on to ISS)
  - continue collider studies with aim of completing feasibility study
    - collaborate on MCTF test program

5-Year Plan

- Continued low funding and launching of MICE and MERIT pose challenges for the NFMCC
  - prepared 5-year R&D plan two years ago to indicate funding needs
    - baseline plan assumed "flat-flat" funding
    - incremental plan assumed $0.4M increase (no luck yet)
- Strawman budgets developed for both funding scenarios
  - activities lumped into four broad categories
    - Cooling: MUCOOL component R&D
    - Targetry: development of high power targets and collection systems, including beam tests at BNL, CERN, or elsewhere
    - System Studies: work on acceleration, ring coolers, colliders, performance studies
    - MICE: purchase or fabrication of MICE components

NOTE: common fund contribution was not considered when plan originally formulated

5-Year Plan

- **Summary of baseline (flat-flat) case is**

Activity	FY05	FY06	FY07	FY08	FY09	FY10
Cooling	492	345	345	705	615	225
Targetry	713	640	625	100	100	100
System Studies	195	195	195	295	295	195
MICE	300	620	635	700	790	1280
TOTAL	1700	1800	1800	1800	1800	1800

— **comments:**

- **assumes base program funds remain as in FY06: BNL ($0.9M); Fermilab ($0.6M); LBNL ($0.3M)**
  - **getting harder to accommodate this each year**
- **priorities in FY06–07 are MERIT experiment and MICE solenoids**
- **split between Cooling and MICE somewhat flexible**

5-Year Plan

- Budget details for baseline case

	FY06 ($K)	FY07 ($K)	FY08 ($K)	FY09 ($K)	FY10 ($K)	Sum ($K)
Available	965	980	1405	1405	1505	6260
Cooling	345	345	705	615	225	2235
staff	280	180	180	180	180	1000
absorber	20	20				40
MTA ops.	45	45	45	45	45	225
CC-MUCOOL		100	480	390		970
MICE	620	635	700	790	1280	4025

- MICE needs only $3.4M for half-cell test ⇒ "extra" funds available
  - for contingency, if needed; for subsequent full-cell test, if not
- Full-cell test needs 1 more year, depending on contingency experience and getting additional help from NSF (late cf. MICE schedule)
  - ability to reduce costs by partnerships continues to be explored
    - coupling coils with ICST-Harbin
    - RF cavities with UK groups

Summary and Outlook

- Past year productive but difficult for the NFMCC
  - MERIT hardware completed and shipped
  - 201 MHz NCRF cavity easily reached "no-field" design goal
  - ISS completed, IDS being launched
  - MICE component fabrication launched (spectrometer solenoids and tracker)
  - progress toward self-consistent design of Muon Collider
  - Muons, Inc. initial gas-filled cavity tests encouraging
- Presented our program to HEPAP AARD Subpanel in February 2006
  - got recognition that we were under-funded (but no relief yet)
- Strong MUTAC endorsement of our R&D accomplishments and plans will be needed to maintain or enhance our budget
  - *NFMCC will continue to hold up its end of the bargain!*