

MuCool

ICAR Meeting May 19, 2004 Mary Anne Cummings



The MuCool Collaboration

Mission

- **Design, prototype and test all cooling channel components**
- υ Perform high beam-power engineering test of cooling section
- **u** Support MICE (cooling demonstration experiment)
- Consists of 18 institutions from the US, Europe, and Japan

RF Development ANL Fermilab IIT LBNL Univ. of Mississippi

Beam Diagnostics ANL Fermilab IIT Princeton Univ. of Chicago Absorber R&D Fermilab IIT KEK NIU Oxford UIUC Univ. of Mississippi Univ. Osaka

Solenoids LBNL Cooling Demonstration (MICE) ANL BNL Fermilab Fairfield IIT Iowa JLab LBNL NIU UCLA UCCA UCCRiverside UIUC Univ. of Chicago Univ. of Mississippi



Al Moretti, FNAL

- Rather loose A WBS structure has not yet been inflicted on the collaboration:
 - υ Spokesperson:

υ Technical Area Leaders:

≻RF:

Alan Bross

> RF Diagnostics:
 > Absorbers:
 > MuCooL Test Area:
 Derun Li, LBNL
 Yagmur Torun, IIT
 Mary Anne Cummings, NIU
 Milorad Popovic, FNAL



SFOFO Cooling Lattice

- R&D Focus of MuCool
 - υ Component testing Fermilab
 - $_{\sigma}$ High Power, both RF and Beam
 - υ System test MICE @ RAL





Research and Development Challenges

- > Can NCRF cavities be built that provide the required accelerating gradients?
 - υ AND operate in multi-tesla fields!
- > Can the heat from dE/dx losses be adequately removed from the absorbers?
 - v On the order of 100's W for a neutrino factory
- Can the channel be engineered with an acceptably low thickness of nonabsorber material in the aperture?
 - υ Absorber, RF, & safety windows
- Can the channel be designed & engineered to be cost effective?



MuCool Test Area

The MuCooL Collaboration Enters a new Era



MuCool Test Area



Facility to test all components of cooling channel (not a test of ionization cooling)

- υ At high beam power
 - σ Designed to accommodate full Linac Beam
 - $_{\sigma}$ 1.6 X 10¹³ p/pulse @15 Hz
 - 2.4 X 10¹⁴ p/s
 - ≈ 600 W into 35 cm LH_2 absorber @ 400 MeV
- **υ** RF power from Linac (201 and 805 MHz test stands)
 - $_{\sigma}$ Waveguides pipe power to MTA





MTA



- The MTA is becoming our focus of Activity
 - υ LH₂ Absorber tests
 - υ RF testing (805 and 201 MHz)
 - **υ** Finish Cryo-Infrastructure
 - v High pressure H₂ gas absorbers
 - υ High Intensity Beam







Compressor Room Access Pit













Access Pit







MTA Experimental Hall







KEK LH₂ Absorber







MTA Experimental Hall From Linac (Lots of Activity)









MTA – Near Term Schedule

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MTA – RF Configuration





MTA Cryo-Infrastruture



Compressor Room

• Two 400 HP 2-stage oil injected screw compressors

Refrigerator Room

- Tevatron satellite refrigerator to be operated on 5 K mode and 14 K mode (3" DE, 3" WE)
- Helium and nitrogen Dewar



MTA High Intensity Beam Tests



- FNAL Study group has been formed to design 400 MeV beamline for the MTA
 - $\upsilon \quad \textbf{Under Craig Moore}$
 - σ External Beams Department
 - υ Develop Engineering Design
 - σ **Cost**
 - σ **Schedule**
 - υ Safety Analysis
 - $_{\sigma}\,$ Linac Area and Beamline
 - $_{\sigma}$ Shielding Assessment for MTA
 - Essentially Complete
 - υ Preliminary thoughts
 - Spin" beam in order to provide large (30 cm) aperture
 - Instead of large Quads
 - Simpler and therefore Cheaper
 - υ Timeline still driven by resource



MTA Shielding Assessment



Conclusions from Present Study

- ν A credible beam accident at MTA is less severe than normal operation.
- ν At normal operation the following classification is suggested (Fermi RCM):
- Berm above target hall Controlled Area of minimal occupancy (0.25 – 5 mrem/hr);
- ν Access pit Radiation Area with rigid barriers/locked gates (5 – 100 mrem/hr);
- Cryo room Radiation Area with rigid barriers/locked gates (5 – 100 mrem/hr);
- Compressor room Controlled Area of minimal occupancy (0.25 – 5 mrem/hr);
- Parking lot Normal (not controlled) area (dose rate below 0.05 mrem/hr).



RF Cavity R and D

ANL/FNAL/IIT/LBNL/UMiss



RF Cavity R&D – Prototype Tests



Lab G RF Test Cave showing 5T SC Magnet 44 cm bore R.I.P. Work to date has focused on using 805 MHz cavities for test

 ν Allows for smaller less expensive testing than at 201 MHz

 υ Lab G work at Fermilab

Unfortunately due to a Klystron failure in the Linac, the Lab G Klystron had to be moved back to the Linac

ν As of December 25, 2003 the Lab G facility ceased operation

We are now moving as rapidly as possible (with a great deal of support from the Fermilab Beams Division) to bring up 805 and 201 MHz RF test capability to the MTA

- υ Moving Vacuum, power, etc systems to MTA
- υ Move Magnet to MTA



RF Cavity R&D – Quick Review

- Open cell cavity reached peak surface field of 54 MV/m (25 on axis)
 - υ Large dark currents
 - σ Damage to windows
 - $_{\sigma}$ Punctured Ti window in worst case
- Closed Cell (single) cavity
 - υ B=0, Cu window Low Bkg.
 - $_{\sigma}$ Reached 34MV/m
 - υ With B field
 - $_{\sigma}$ TiN coated Be window (0.01")
 - $_{\sigma}$ Conditioned to 16MV/m
 - Dark currents then rose
 - σ However, no damage in evidence to Be
 - Copper contamination
 - From iris/flange surface
 - $_{\sigma}~$ At 8MV/m dark currents very low
 - Acceptable for MICE





RF Cavity Closed Cell Magnetic Field Studies



- Data seem to follow universal curve
- Sparking limits max gradient
- Copper surfaces the problem



RF R&D – 201 MHz Cavity Design

Design Complete and Fabrication well under way

- v Expect E^{pk}_{surf} = 26.5 MV/m
- υ Now has curved windows
- υ Goal is to have a 201 MHz cavity under test at Fermilab in the Fall







RF R&D – 201 MHz Cavity Design Tube-Grid Aperture Study

- Finite Element analysis of tube grid design
 - ν First applied to electromagnetic model of 805 MHz cavity
 - $_{\sigma}~$ For Lab G tests
 - ν Field enhancement between 1.4 and 3.6 depending on configuration
 - Figure Emax at tube
 surface/E at cavity
 center



Maximum Surface Field Enhancement

Tube DIA (cm) Grid	0.50	1.00	1.25	1.50
4×4-Connected	3.60			
4×4 -Waffle	2.30	1.80		
6x6 -Waffle		1.64	1.40	1.39
6x6 Middle- Concentrated/Waffle		1.40		



Absorber R and D

IIT/KEK/NIU/Osaka/Oxford/UIUC/UMiss



Absorber Design Issues

2D Transverse Cooling $\frac{d\epsilon_N}{ds} = -\frac{1}{\beta^2} \frac{dE_\mu}{ds} \frac{\epsilon_N}{E_\mu} + \frac{\beta_\perp (0.014 \text{ GeV})^2}{2\beta^3 E_\mu m_\mu L_R}$

and

$$\epsilon_{N,\min} = \frac{\beta_{\perp} (14 \text{ MeV})^2}{2\beta m_{\mu} \frac{dE_{\mu}}{ds} L_R}$$

Figure of merit: M=L_RdE_u/ds M² (4D cooling) for different absorbers

Material	$\langle dE/ds angle_{ m min}$ $({ m MeVg^{-1}cm^2})$	L_R $(m gcm^{-2})$	Merit
GH_2	4.103	61.28	1.03
LH_2	4.034	61.28	1
He	1.937	94.32	0.55
LiH	1.94	86.9	0.47
${ m Li}$	1.639	82.76	0.30
CH_4	2.417	46.22	0.20
Be	1.594	65.19	0.18



Momentum loss is opposite to motion, p, p_x, p_y, ΔE decrease

Accelerator

Momentum gain is purely longitudinal

H₂ is clearly Best -**Neglecting Engineering** Issues Windows, Safety



Absorber Design Issues

Design Criteria

- υ High Power Handling
 - Study II few 100 W to 1 KW with "upgraded" (4MW) proton driver
 - > 10 KW in ring cooler
 - Must remove heat
- v Safety issues regarding use of LH₂ (or gaseous H₂)
 - Window design paramount
 - H_2 containment
 - σ Proximity to RF adds constraints (ignition source)
- ν Window material must be low
 Z and relatively thin in order
 to maintain cooling
 performance





Absorber R&D

 \succ Two LH₂ absorber designs are being studied

 υ Handle the power load differently



Forced-Convection-cooled. Has internal heat exchanger (LHe) and heater – KEK System



Forced-Flow with external cooling loop



Convection Absorber

- Convection is driven by beam power and internal heaters
- LHe heat exchanger removes heat from absorber walls
- Two-dimensional Computational Fluid Dynamics calcs
 - υ Flow essentially transverse
 - υ Max flow near beam
 - υ Heaters required to setup convective loops







Forced-Flow Absorber

Heat removed with external heat exchanger

- υ LH₂ pumped from absorber to heat exchanger
- ν Nozzles in flow path establish turbulent flow
- υ Simulation via 2D and 3D FEA









Absorber Windows

DIAMETER

220.00mm

Thin windows are required in all absorber designs

- **Critical design issue** υ
 - σ **Performance**
 - σ **Safety**
- υ First examples made with AL **T6061**



Design Iteration HemiSpherical – Inflected (Now also used for RF)

Containment Windows Absorber Vacuum







Thin Windows Design





Learning to manufacture new window



First window (above)! Second window (below)







"Bellows" Window (FNAL/Oxford)



Current Photogrammetic Test Setup (FNAL)







Photogrammetric data





FEA results on current bellows window design

The current window design has a double curvature to ensure that the thinnest part is membrane stress dominate

Here is the FEA model on the Absorber window. (Note that in the MICE experiment both the Absorber and the Safety windows now have the same pressure load requirements!)





Window wrap-up

- Both software and testing methods are maturing
- Have standardized requirements for Mucool and MICE experiments
- Mucool window approach has passed MICE safety review
- FEA analyses developed for absorber windows now used in other aspects of cooling channel designs (i.e. RF windows)



Gaseous Absorber – Muon's Inc

- Serendipitous exploitation of:
 - υ 19th century science
 - υ Muons unique cooling quality
- Work on STTR Phase II
 - υ 805 MHz test cell
 - $_{\sigma}$ Tested at Lab G
 - ν Cell conditioned at 450 psig @ 80K
 - υ Max stable gradient
 - σ **≈ 80 MV/m**
 - υ Data agree well with Pashen



11/19/03 Lab G Results, Molybdenum Electrodes





Simulation Work

- Cooling Components as mentioned
 - υ Absorbers 2D and 3D Finite Element Analysis (FEA)

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2D Computational Fluid Dynamics (CFD)
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- ν RF Electromagnetic modeling of Be windows and grids
 FEA modeling of window deflection/stress
- Quad-focused cooling channel
- Study II cooling channel
 - $\upsilon~$ GEANT4 simulation including latest window design
- > MICE
 - υ GEANT4 framework developed



MuCool and MICE

- Muon Ionization Cooling Experiment (MICE)
 - υ Demonstration of "Study II" cooling channel concept
- MuCool Collaboration interface to MICE
 - υ Design Optimization/develop of Study II cooling channel
 - σ Simulations
 - υ Detailed engineering
 - σ Full component design
 - σ Systems integration
 - σ **Safety**
 - υ RF cavity development, fabrication, and test
 - υ Absorber development, fabrication, and test
 - v Development of beam line instrumentation
 - MuCool will prototype and test cooling hardware including MICE pieces which the collaboration is responsible
- High-intensity Beam Tests are responsibility of MuCool and are, of course, fully complementary to MICE



MuCool Plans

- Continue development of thin windows for absorbers
 - Already within the material budget of Study II even with the extra windows
- Begin work in the MuCool Test Area (MTA)
 - v KEK LH₂ absorber test first. Phase I complete by mid-May, second set of tests in August
 - υ Provide 201 & 805 MHz capability for MTA
 - υ Move Lab G magnet to MTA
 - **υ** Continue 805 MHz RF studies in Lab MTA (starting in June)
 - $_{\sigma}$ $\,$ Window and grid tests $\,$
 - σ Surface treatment/materials tests
 - Effect on dark current and breakdown
 - υ Provide as much of the cryo infrastructure as funding allows
 - σ Very likely ALL of it
 - υ ~ Fabricate first 201 MHz cavity and bring to MTA for test
 - $_{\sigma}$ $\,$ On Schedule for delivery in Fall $\,$
- > In FY05
 - υ Start 201 MHz RF test program in MTA
 - $_{\sigma}$ 805 MHz testing likely to continue interleaved with 201 testing
 - υ Complete MTA cryo (if needed)
 - υ Fabricate coupling-coil prototype
 - $_{\sigma}$ If funding is available
 - υ Begin installation of 400 MeV beam line from Linac
- In FY06
 - **υ** Bring high intensity beam to MTA
 - $_{\sigma}$. Test complete set of cooling components in high intensity beam



Conclusion

Excellent progress has been made in the last year

- υ MTA is complete
 - $_{\sigma}$ On budget and on schedule
 - HVAC is late
 - Absorber testing underway
 - > RF test program to begin in June (805 and then 201 in Fall)
 - NCRF R&D has demonstrated High Gradient low dark current operation
 - R&D continues in order to continue to push HG Low DC operation in B field
 - Use of Be RF windows looks promising
- υ Design of LH₂ absorbers and windows has matured
 - > "Thin" window required spec appears to have been met
 - > Technological innovation in photogrammetry measurements
- υ Detailed engineering of components has matured
- MuCool is a thriving International Collaboration
 - υ Absorbers Japan
 - υ Absorber/Window design UK
 - υ Addressing many of the needs of MICE