Muon Collaboration

MuCool Overview and Plans

Muon Cooling R&D
MUTAC 05
A. Bross

The MuCool Collaboration

- **Mission**
  - Design, prototype and test all cooling channel components
  - Perform high beam-power engineering test of cooling section
  - Support MICE (cooling demonstration experiment)

- Consists of 18 institutions from the US, Europe, and Japan

RF Development
ANL
Fermilab
IIT
JLAB
LBNL
Univ. of Mississippi

Beam Diagnostics
ANL
Fermilab
IIT
Princeton

Absorber R&D
Fermilab
IIT
KEK
NIU
Oxford
UIUC
U. Mississippi
U. Osaka

Solenoids
LBNL

Cooling Demonstration (MICE)

ANL	LBNL
BNL	NIU
Fermilab	UCLA
Fairfield	UC Riverside
IIT	UIUC
Iowa	U. Chicago
JLab	U. Mississippi
KEK	U. Osaka

MuCooL Management Structure

- Spokesperson and Technical Area Leaders:
  - Spokesperson: Alan Bross
  - Technical Area Leaders:
    - RF: Al Moretti, FNAL; Derun Li, LBNL
    - RF Diagnostics: Yagmur Torun, IIT
    - Absorbers: Mary Anne Cummings, NIU; Shigeru Ishimoto, KEK
    - MuCooL Test Area: Barry Norris, FNAL

Outline

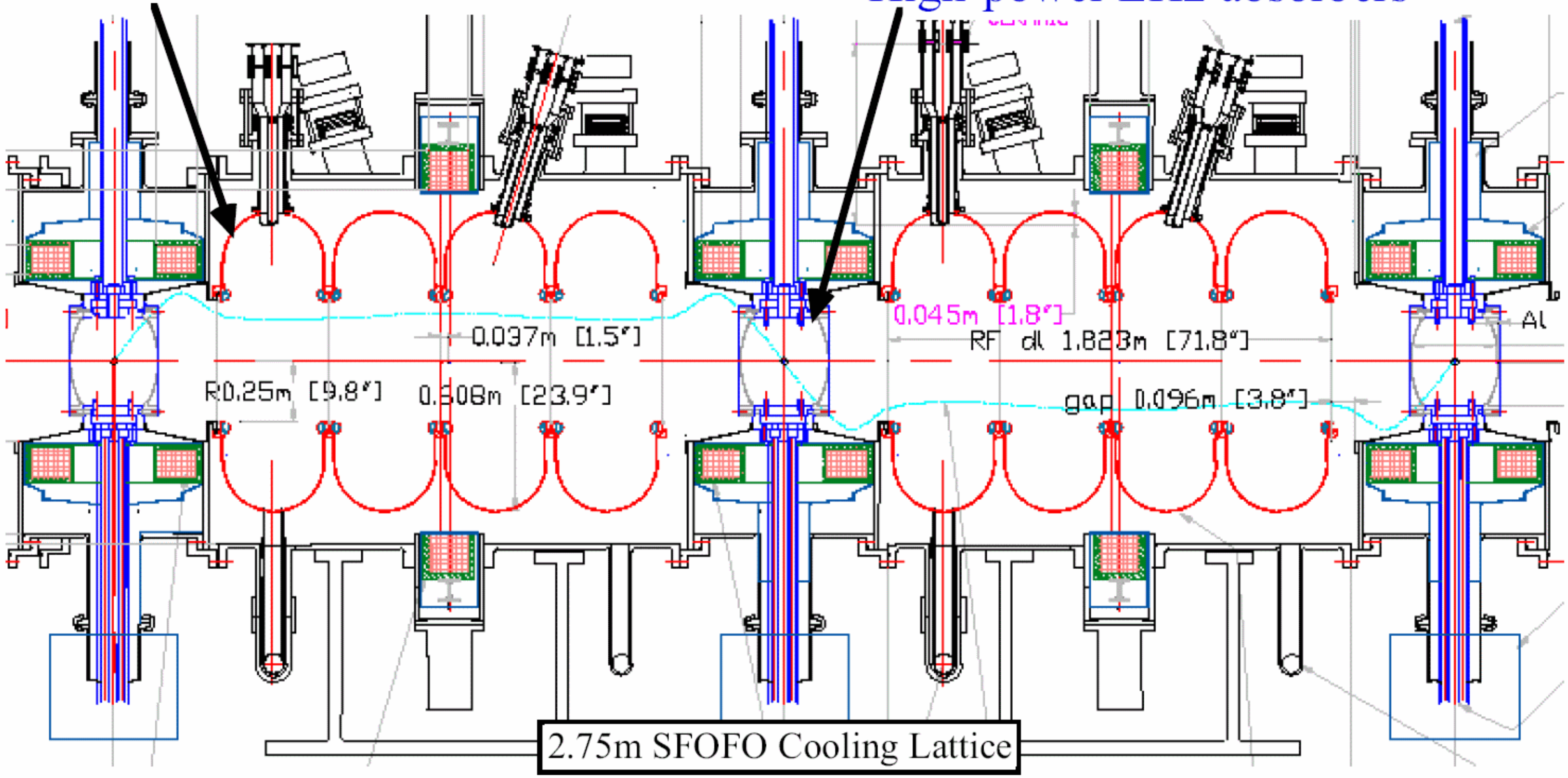
- I will give overview of the status of the MuCool R&D Program
  - MuCool Test Area & Beam line
  - RF
  - LH_2 absorber
- Detailed MuCool presentations will be tomorrow
  - 201 MHz NCRF: Studies and Plans — Li
  - 805 MHz NCRF: Studies and Plans — Norem
  - LH_2 Absorber R&D — Ishimoto
  - LH_2 Absorber Window R&D — Cummings

SFOFO Cooling Lattice

- **R&D Focus of MuCool**
  - *Component testing Fermilab*
    - High Power
      - Both RF and Beam
  - *System test - MICE @ RAL*

SFOFO Cooling Lattice

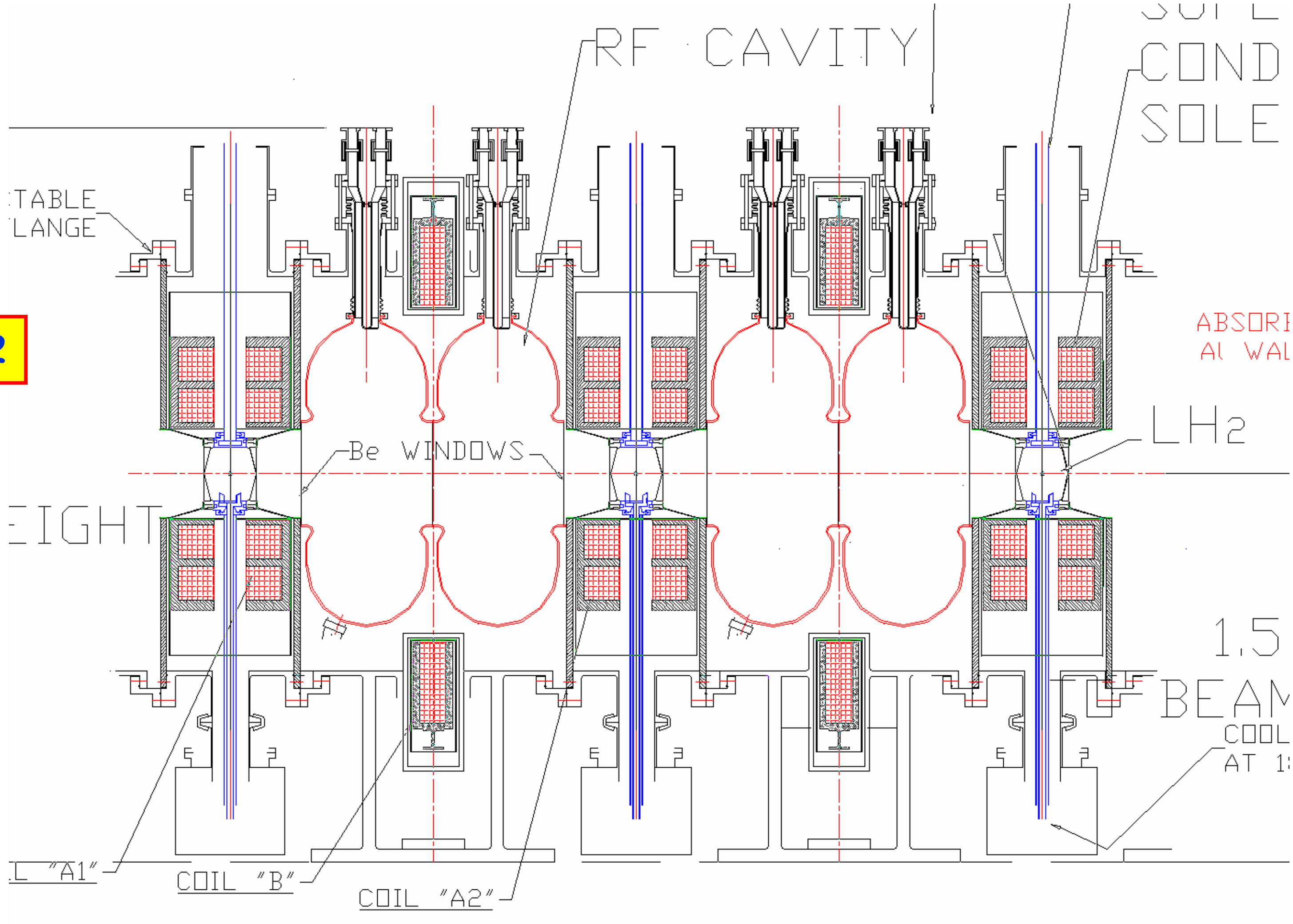
- High-gradient normal-conducting RF
- High-power LH2 absorbers



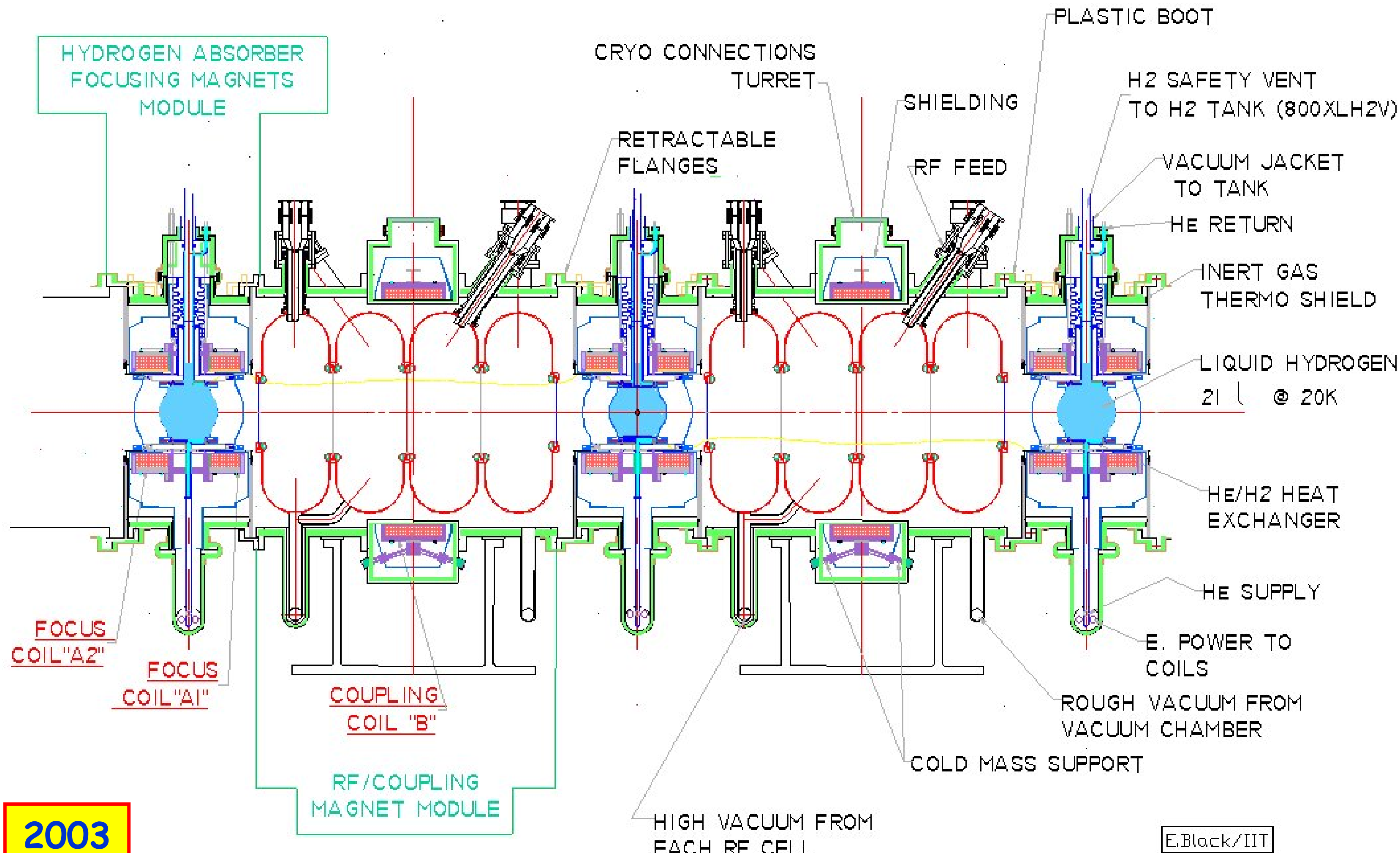
2001

SFOFO Cooling Lattice

2002



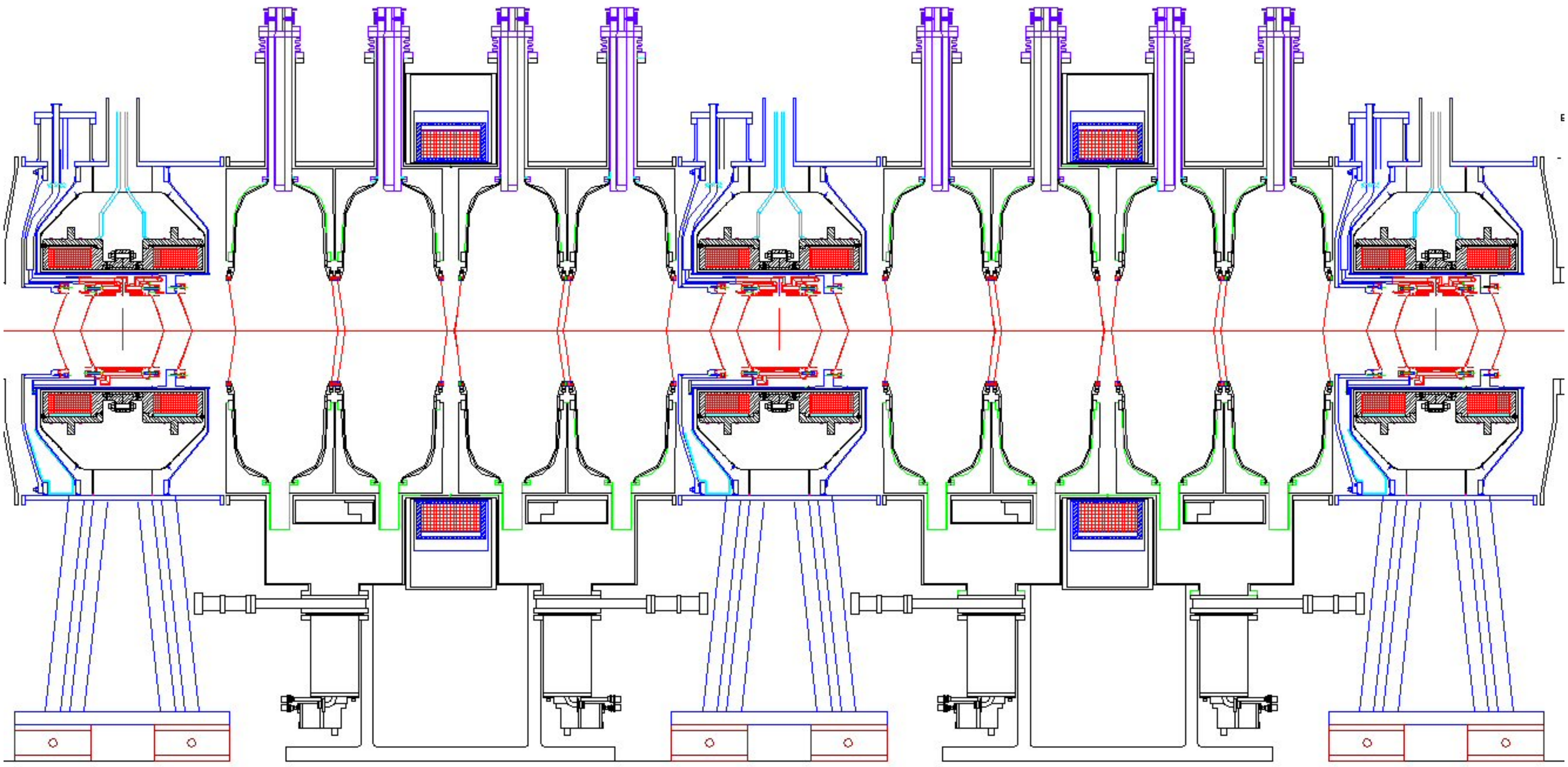
SFOFO Cooling Lattice



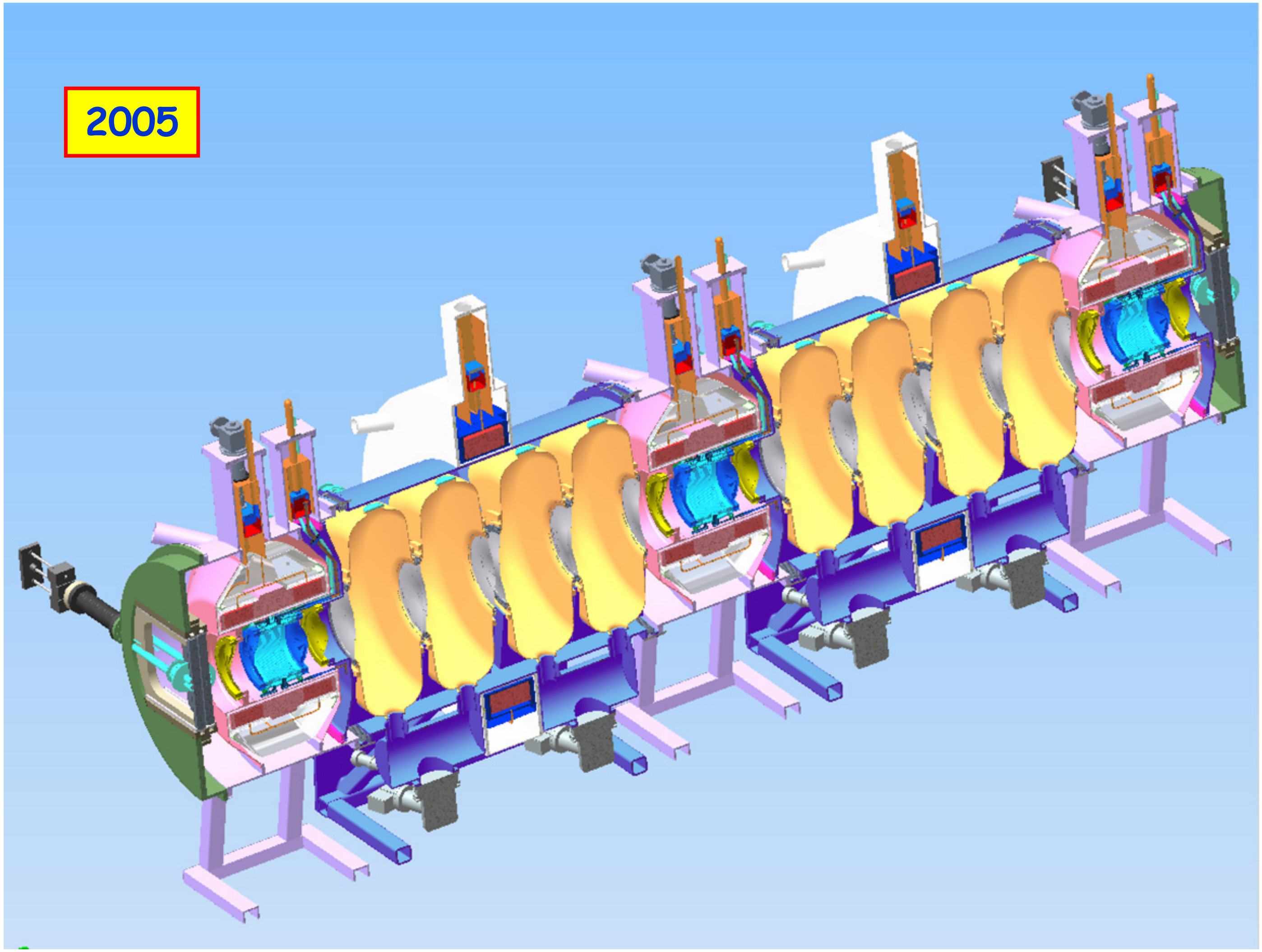
2003

SFOFO Cooling Lattice

2004



SFOFO Cooling Lattice



Research and Development Challenges

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

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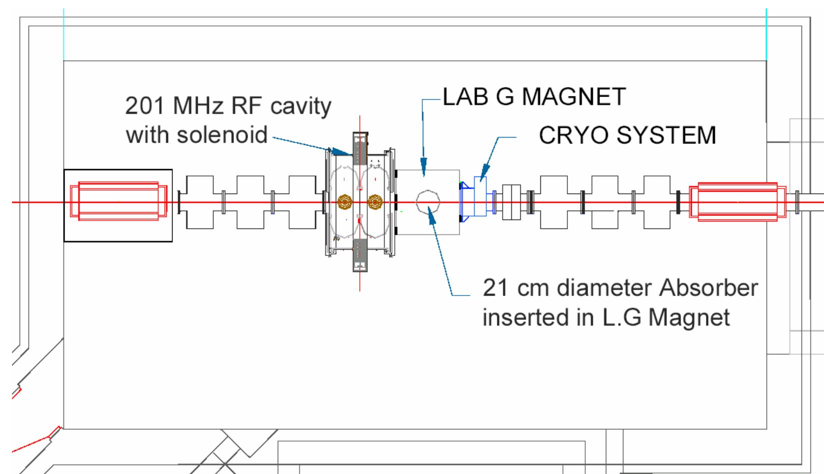
MuCool Test Area

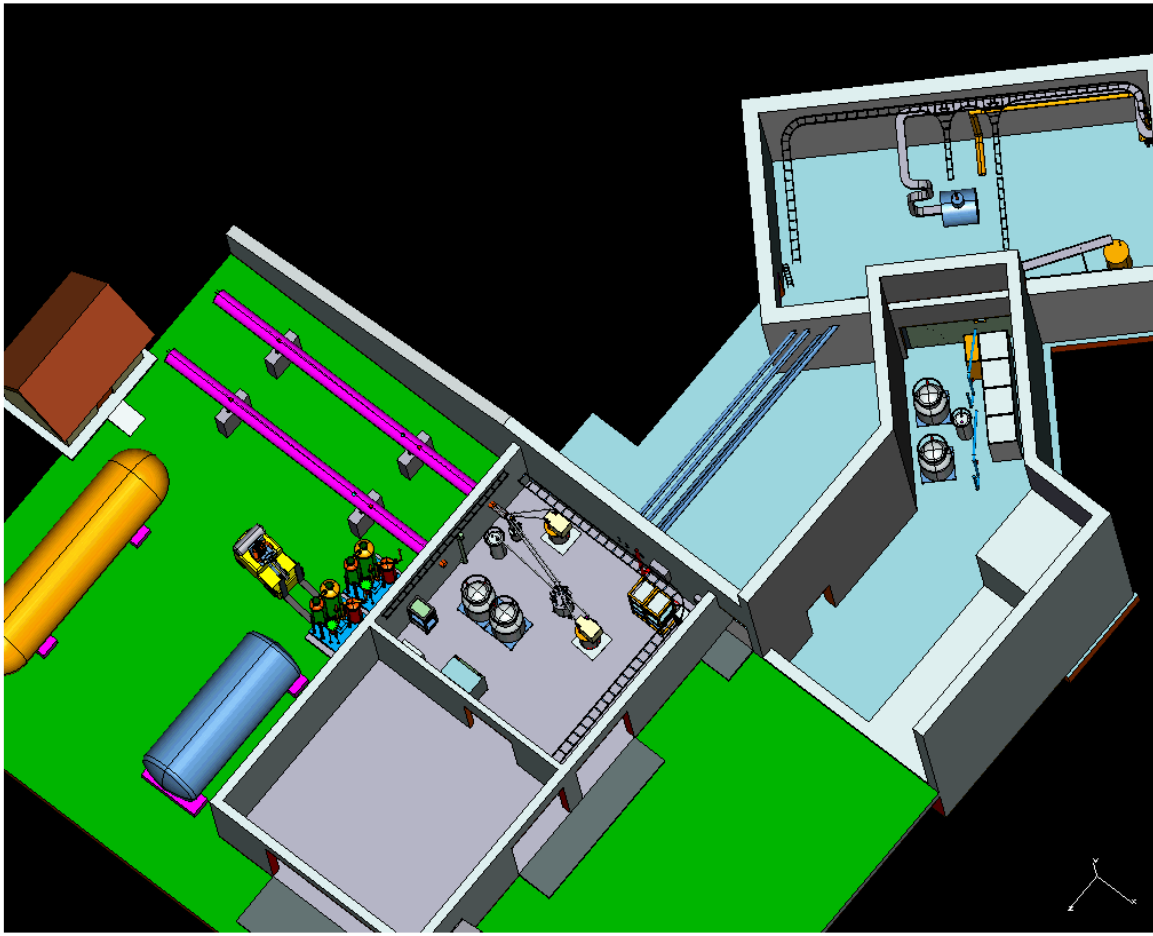
MuCool Test Area

- Facility to test all components of cooling channel (not a test of ionization cooling)
  - At high beam power
    - Designed to accommodate full Linac Beam
    - 1.6 X 10^{13} p/pulse @15 Hz
      - 2.4 X 10^{14} p/s
      - ≈ 600 W into 35 cm LH_2 absorber @ 400 MeV
  - RF power from Linac (201 and 805 MHz test stands)
    - Waveguides pipe power to MTA



MTA

- The MTA is the focus of our Activities
  - LH_2 Absorber tests
  - RF testing (805 and 201 MHz)
  - Installing Cryo-Infrastructure
  - High pressure H_2 gas-filled RF
  - High Intensity Beam
    - Will start with low intensity



MTA Tour

805 MHz

201 MHz

MTA Experimental Hall

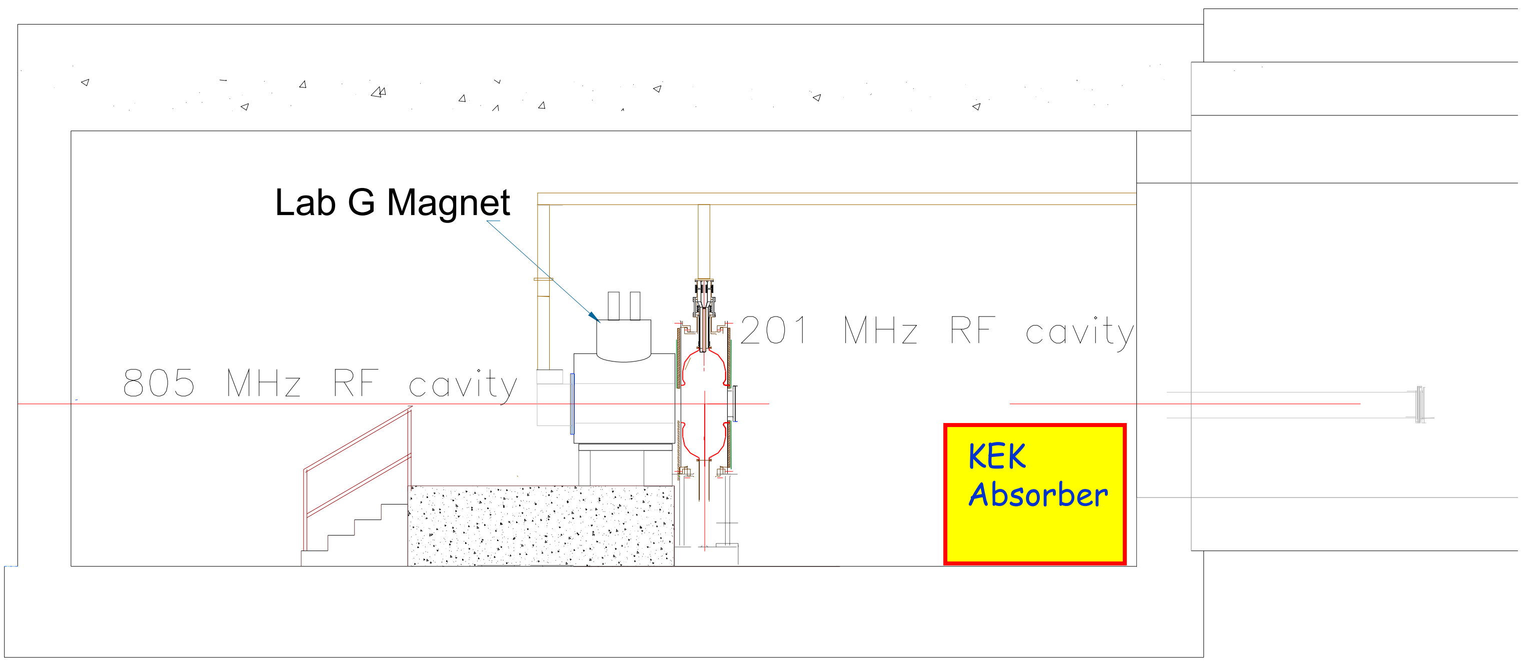
MTA Tour

KEK LH_2 Absorber

MTA – Near Term Test Program

- 805 MHz Pill Box preparation complete 5/30/05
- 805 MHz high-power testing begins 6/1/05
  - TiN coated curved Be windows tests
  - Various B field configurations
- 201 MHz cavity arrives Fermilab 5/16/05
- 201 MHz cavity ready for testing 6/6/05
- LH_2 Absorber test 9/05
  - Second phase of testing with KEK convective absorber
- Low intensity beam extracted to MTA 12/05

MTA – RF Configuration



Currently plan to operate either RF or LH_2/H_2 tests, but not both simultaneously. We are discussing with the Laboratory how we can work in both modes simultaneously.

RF Configuration

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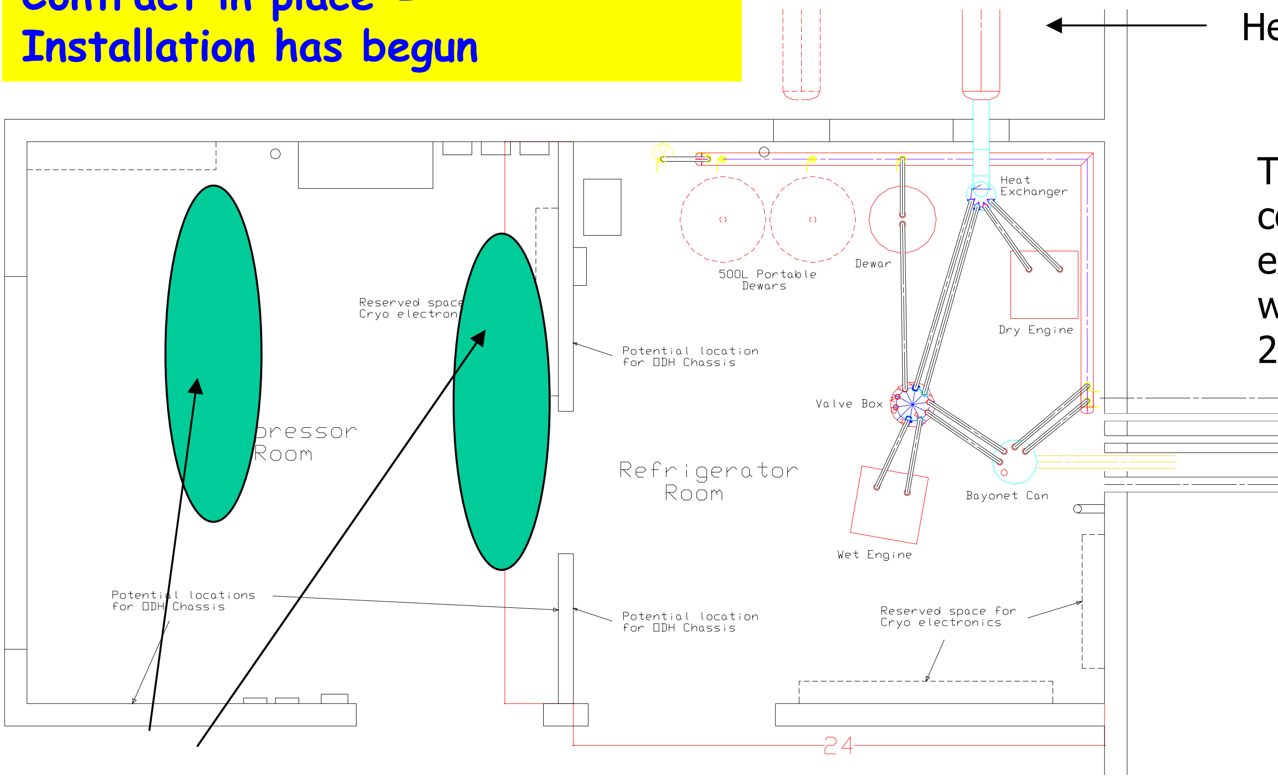
MTA Cryo-Infrastruture

Contract in place -
Installation has begun



Heat exchanger

Transfer line connections to experimental hall which includes 5K, 20K, 80K circuits

Towards Experimental Hall

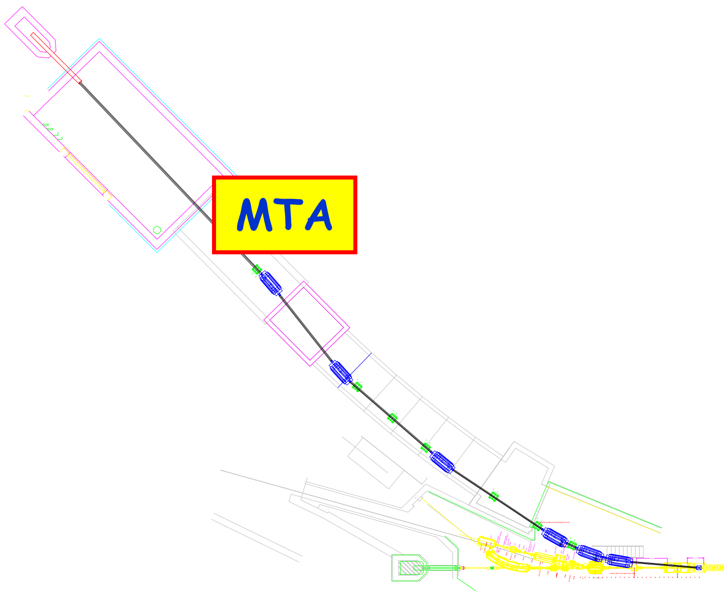
Compressor Room

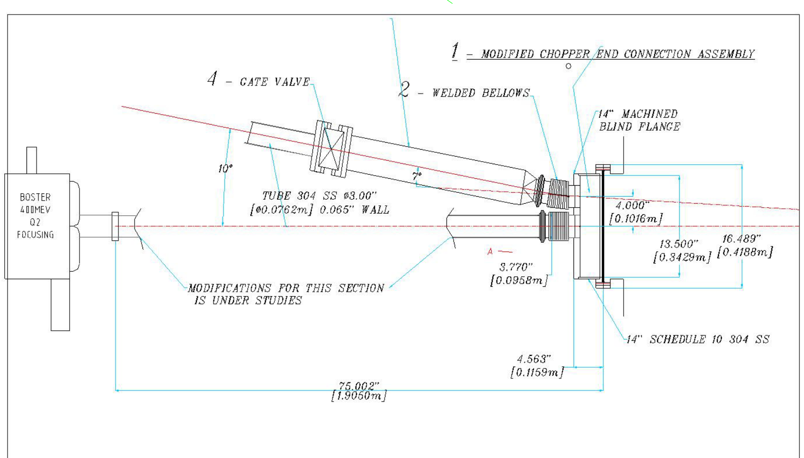
- Two 400 HP 2-stage oil injected screw compressors

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

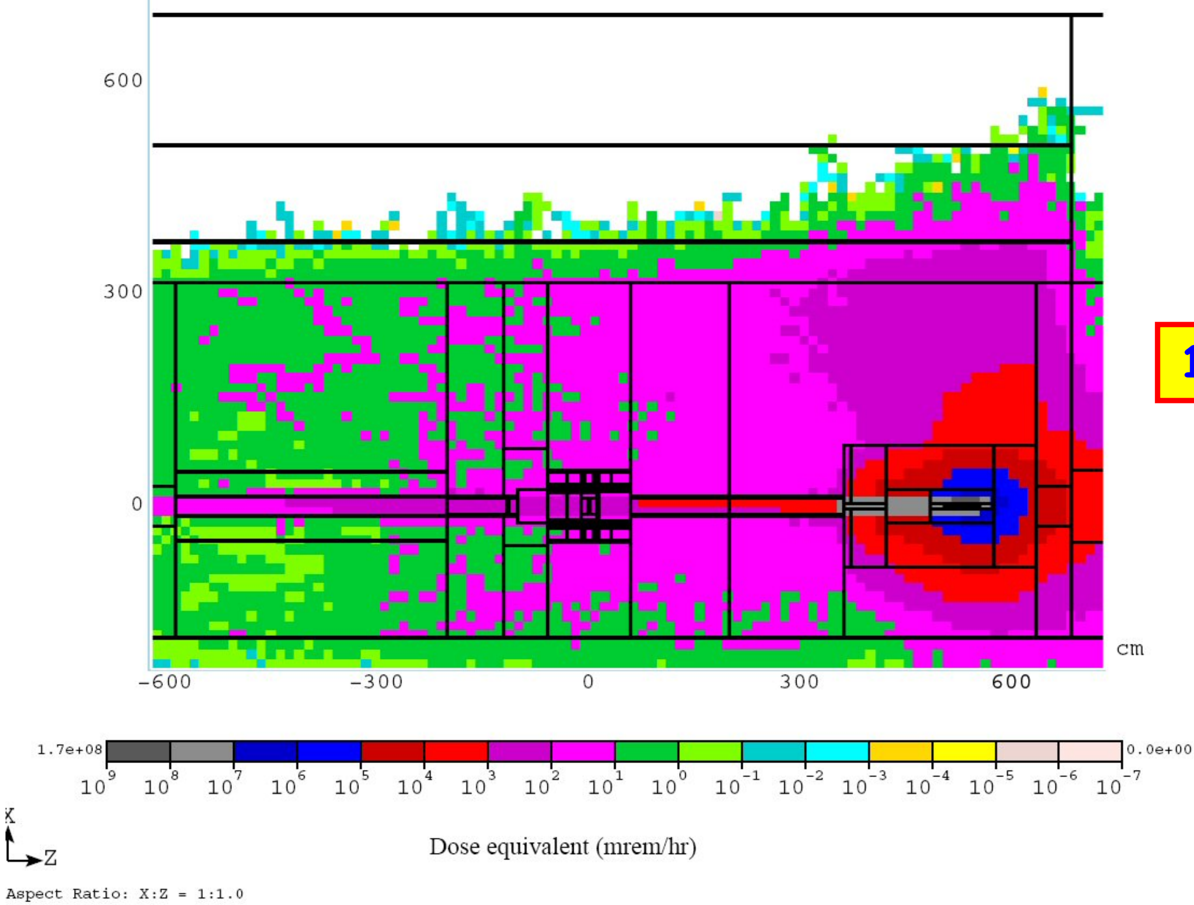




- 400 MeV beamline for the MTA has been designed
  - Under Craig Moore
    - External Beams Department
  - Developed Engineering Design
    - Cost
    - Schedule
  - Safety Analysis
    - Linac Area and Beamline
    - Shielding Assessment for MTA
      - Essentially Complete
  - Current funding levels will not allow us to bring out high-intensity beam
  - Low Intensity Option is now our first priority

MTA Shielding Assessment

- Our study from last year showed that the MTA shielding design was adequate for full intensity Linac beam
- Our new low-intensity first phase of extracted beam has the beam absorber in the MTA hall, however
  - This has been analyzed, and shielding/activation levels are OK

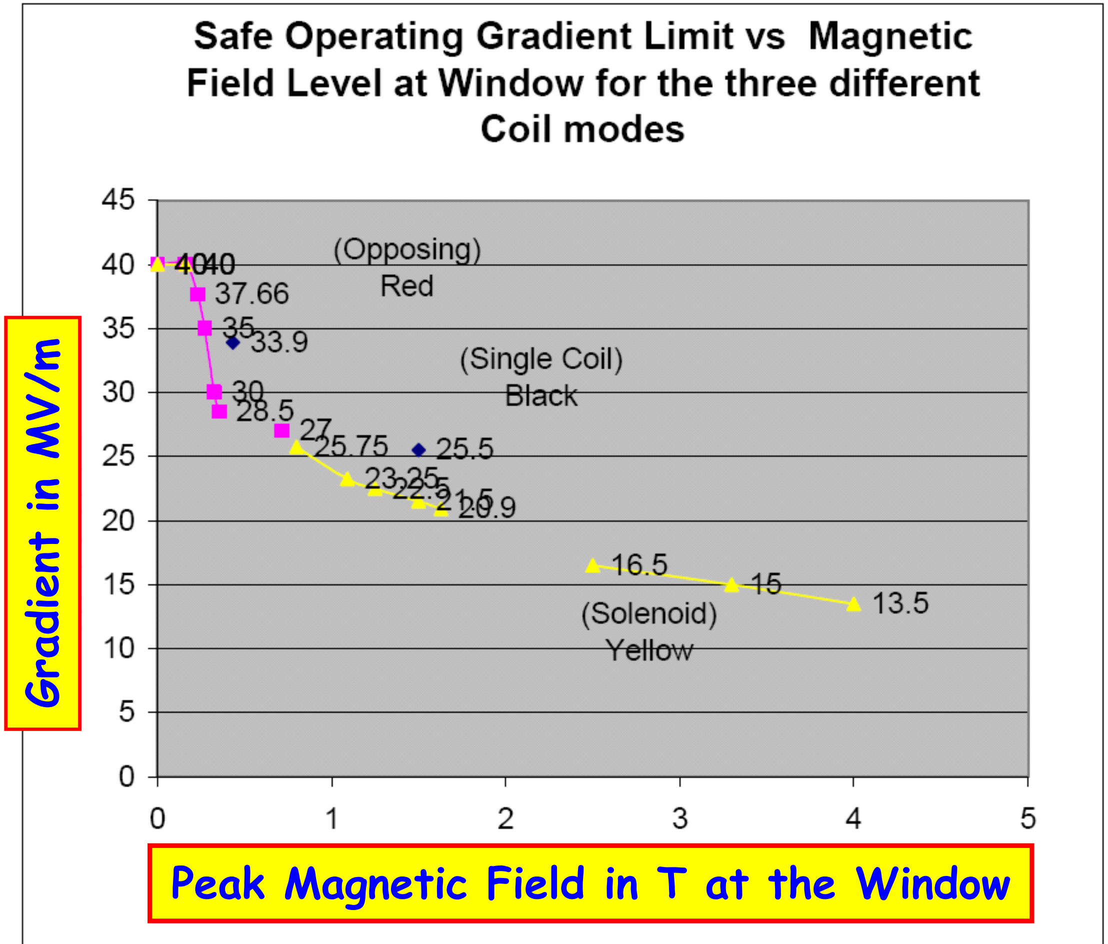


1-2 50us Linac pulses/min

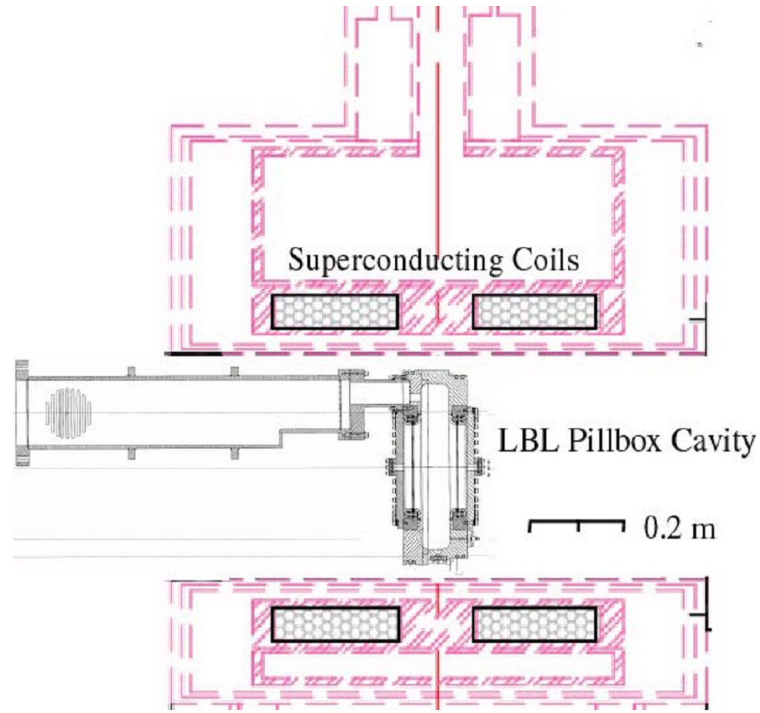
RF Cavity R and D

ANL/FNAL/IIT/LBNL/UMiss

Summary: RF Cavity Closed Cell Magnetic Field Studies (805 MHz)

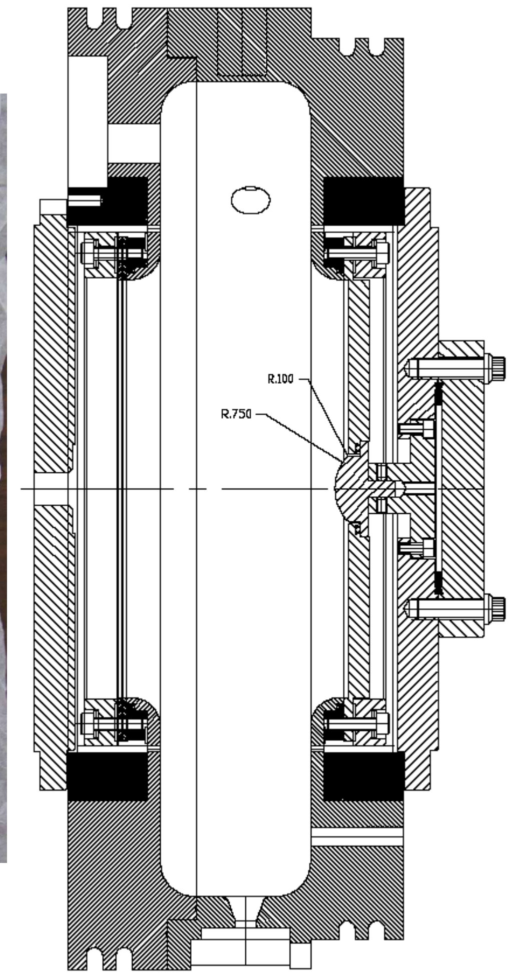


- Data seem to follow universal curve
- Sparking limits max gradient
- Copper surfaces the problem



Phase II of 805 MHz studies

- Study breakdown and dark current characteristics as function of gradient and applied B field in Pillbox cavity
  - Curved Be window Test
    - TiN coated
  - Button test
    - Evaluate various materials and coatings



Local Electrode Atom Probe (LEAP) Tomography

- Atom probe experiments in collaboration with Northwestern U.
  - Prof. David Seidman Jason Sebastian (Northwestern),
  - P. Bauer, C. Boffo (FNAL), J. Norem (ANL)
- Materials studies relevant to both NCRF and SCRF
  - Surface microstructure
  - Surface contamination (oxides etc.)
  - Breakdown and Dark Currents
- Data from these tests can guide for materials/fabrication procedures for RF cavities

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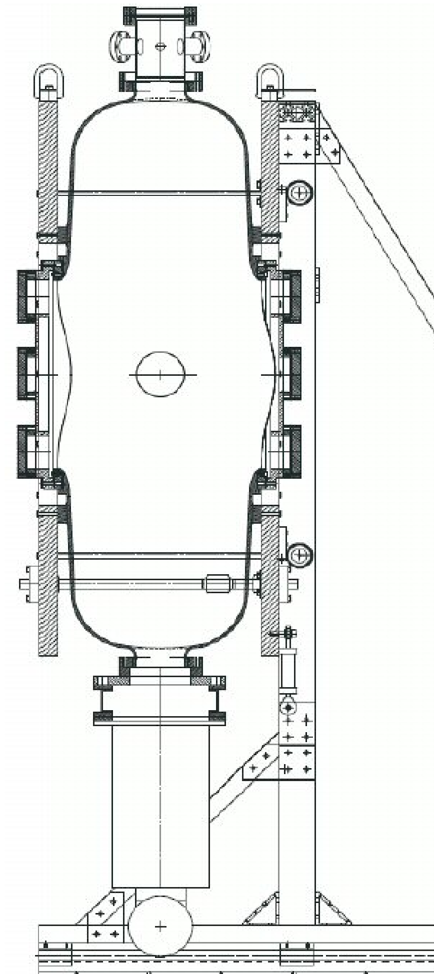
RF R&D – 201 MHz Cavity Design

- Preliminary Testing at JLab (low-power)



Absorber R and D

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

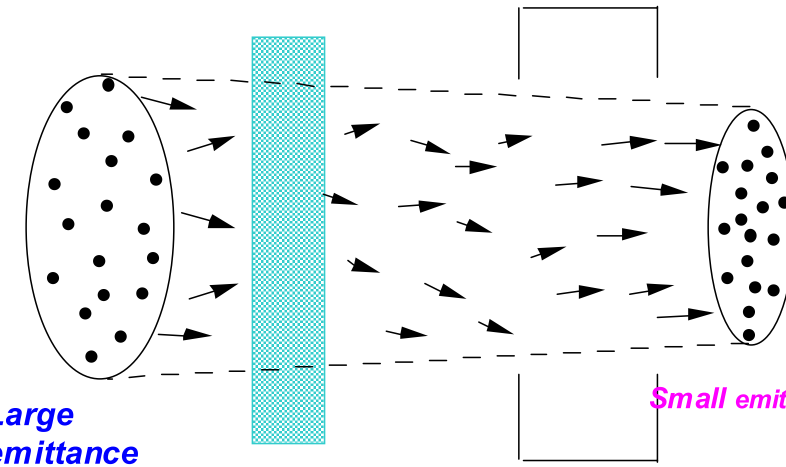
Absorber Design Issues

- **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

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



- **Figure of merit: $M=L_R dE_\mu/ds$**

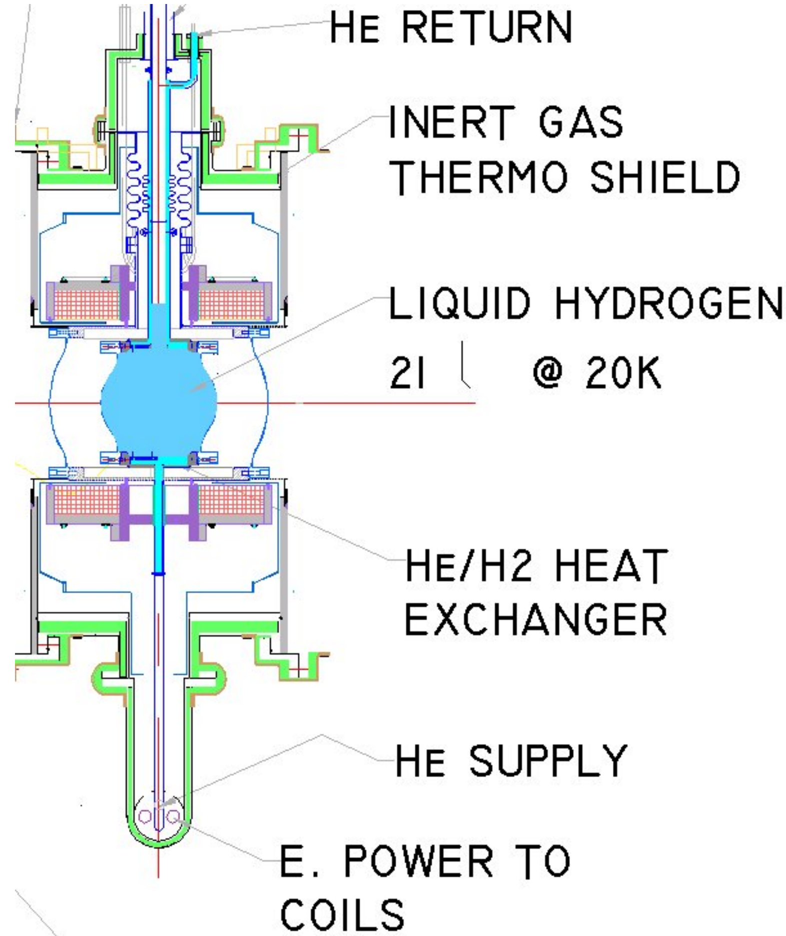
M^2 (4D cooling) for different absorbers

Material	$\langle dE/ds \rangle_{min}$ (MeV g^{-1}cm^2)	L_R (g cm^{-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
Li	1.639	82.76	0.30
CH_4	2.417	46.22	0.20
Be	1.594	65.19	0.18

H_2 is clearly Best -
Neglecting Engineering Issues
Windows, Safety

Absorber Design Issues

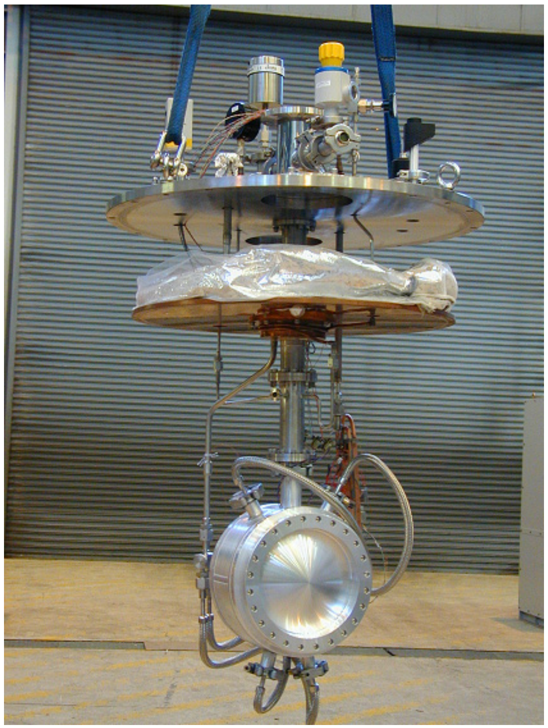
- Design Criteria
  - High Power Handling
    - Study II – few 100 W to 1 KW with "upgraded" (4MW) proton driver
    - 10 KW in ring cooler
      - Must remove heat
  - Safety issues regarding use of LH_2 (or gaseous H_2)
    - Window design paramount
      - H_2 containment
    - Proximity to RF adds constraints (ignition source)
  - Window material must be low Z and relatively thin in order to maintain cooling performance



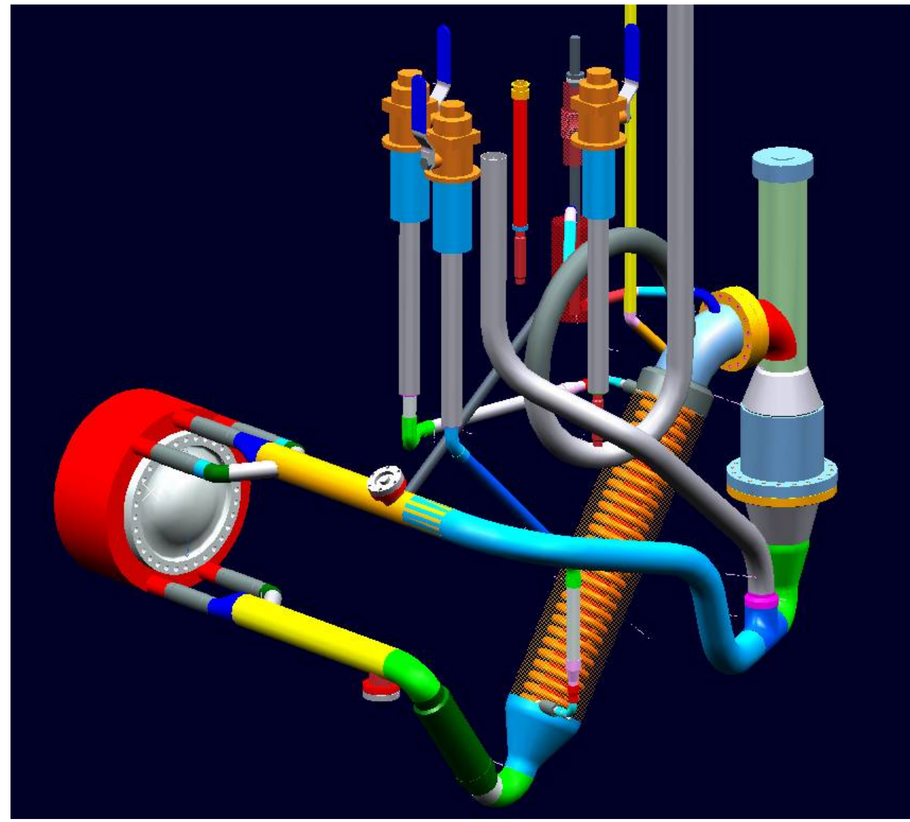
H_2 implies engineering complexity

Absorber R&D

- Two LH_2 absorber designs are being studied
  - Handle the power load differently



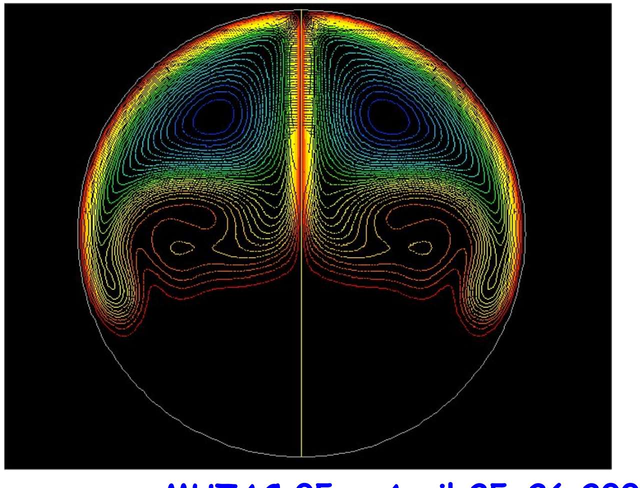
Forced-Convection-cooled. Has internal heat exchanger (LHe) and heater – KEK System



Forced-Flow with external cooling loop

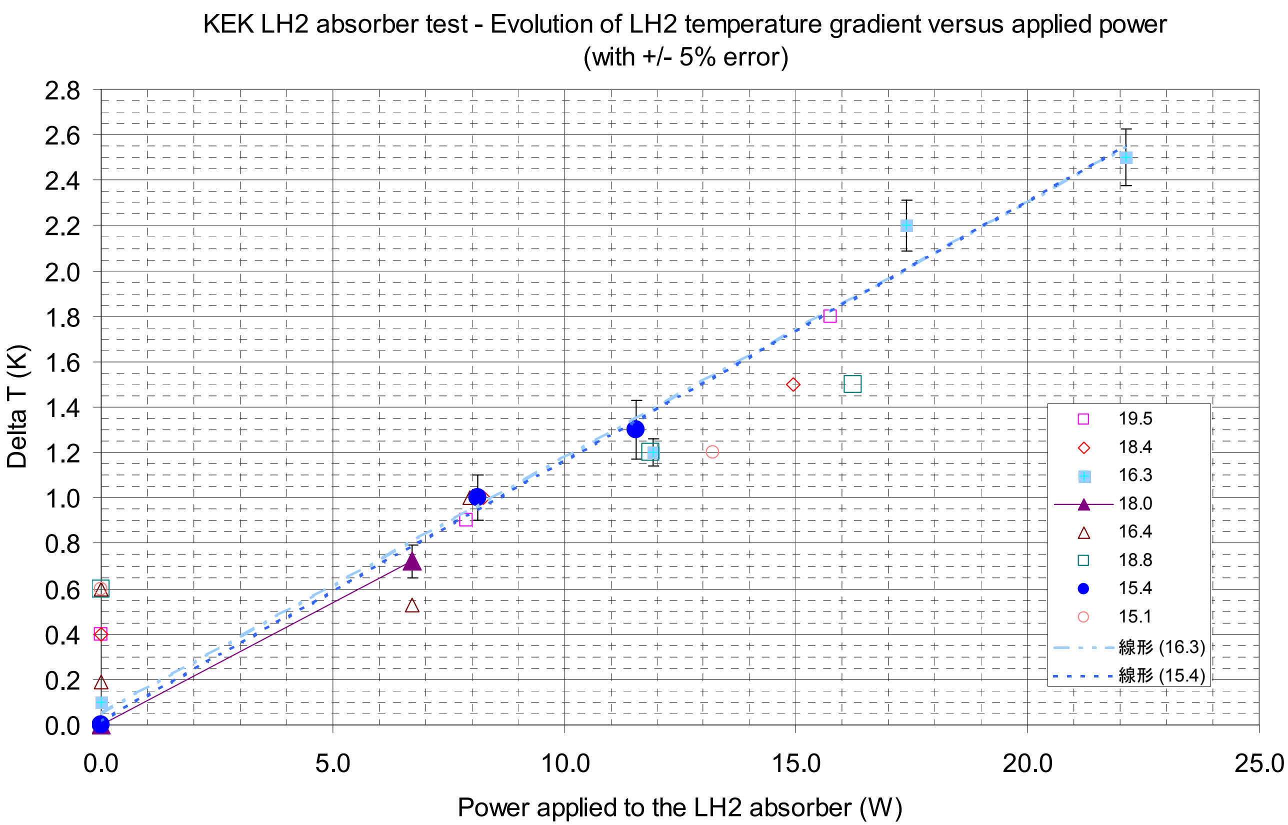
Convection Absorber

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



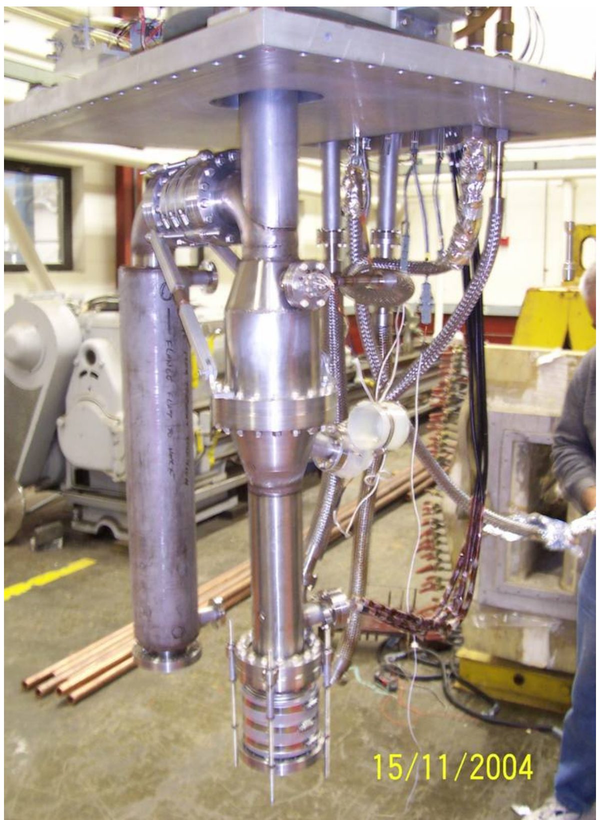
First Results from KEK LH_2 Absorber

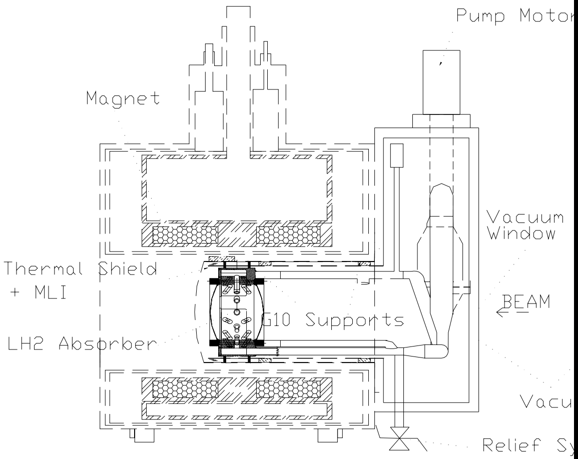
- First fill in July 04 successful
- Demonstrated stable operation
- Measured the LH2 temperature distribution in absorber.
- Measured the cooling power capacity with a G-He heater.
  - To a max of ~ 23W input.

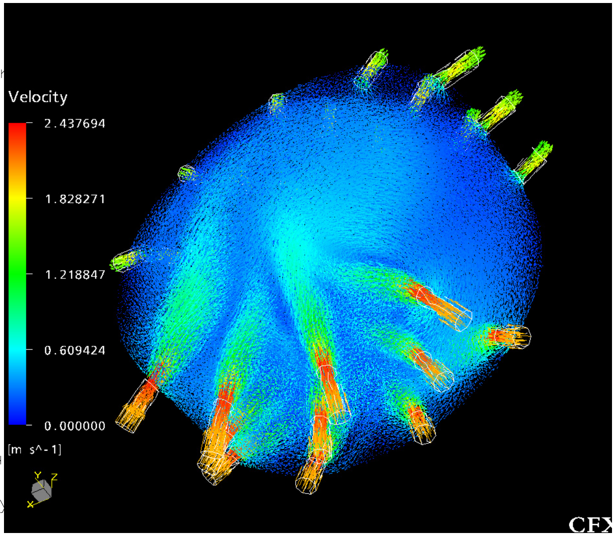


Forced-Flow Absorber

- Heat removed with external heat exchanger
  - LH_2 pumped from absorber to heat exchanger
  - Nozzles in flow path establish turbulent flow
  - Simulation via 2D and 3D FEA
- Preliminary engineering design for implementation in the MTA
  - Have taken possession of cooling loop & heat exchanger from SAMPLE experiment @ Bates/MIT
  - Prototype Absorber manifold has been fabricated

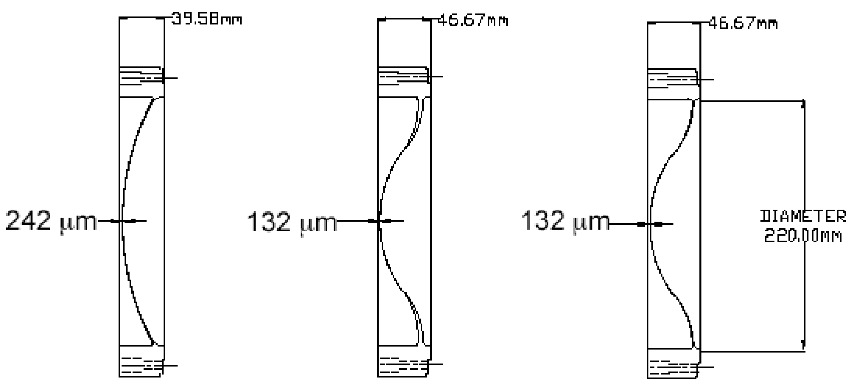






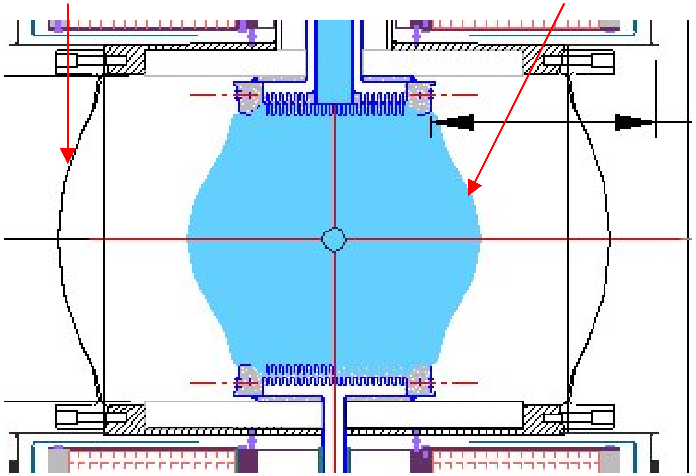
Absorber Windows

- Thin windows are required in all absorber designs
  - Critical design issue
    - Performance
    - Safety
  - First examples made with AL T6061
  - Maybe even thinner with
    - Al-Li alloy - 2195



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

Containment Windows



A. Bross

MuCool and MICE

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

MuCool Plans for the Coming Year

- Continue development of thin windows for absorbers
  - Already within the material budget of Study II even with the extra windows
- After a long pause due to the loss of our 805 MHz RF test facility in Lab G at Fermilab, we are about to start up again
  - 805 MHz RF studies
    - Window and grid tests
    - Surface treatment/materials tests
      - Use information from LEAP studies
  - Start 201 MHz RF test program
    - 805 MHz testing likely to continue interleaved with 201 testing
- Second round of tests with KEK convective absorber
- Complete MTA cryo infrastructure installation
- Installation of 400 MeV beam line from Linac
  - Have the capability for low-intensity experiments
- In FY06
  - Continue RF studies
  - Commission cryo-infrastructure
  - First beam experiment (w/ low-intensity beam)
  - Work to bring high-intensity beam to the MTA
    - As funds allow

Conclusion

- This has been a difficult year with regard to our RF program, but testing is now restarting
  - MTA RF installation is complete and RF testing will resume in June.
    - R&D will to continue to push HG Low DC operation in B field
    - Detailed studies of Be RF windows
    - Advanced tools such as LEAP Tomography will be used to better understand and possibly predict cavity performance
      - Applicable to both NCRF and SCFR
  - LH_2 Absorber program has shown promising results
    - Round II of convective absorber in the Fall
    - Continue engineering of flow-absorber system
      - Needs cryo-infrastructure
  - Continue to address many of the needs of MICE
  - Hope to be able to do the first test with Linac beam by the end of the year
    - Muon's Inc

The MuCool Test Area Potential

- The MuCooL Test Area is becoming a tremendous resource
  - Eventually it will provide a Unique (World-wide) R&D facility
    - Multi-frequency RF test capability (NC and SC)
    - Hydrogen Safety
      - Absorbers
      - Gas-filled RF cavities
    - Cryo-infrastructure (LN, high capacity LHe)
    - High-Intensity beam