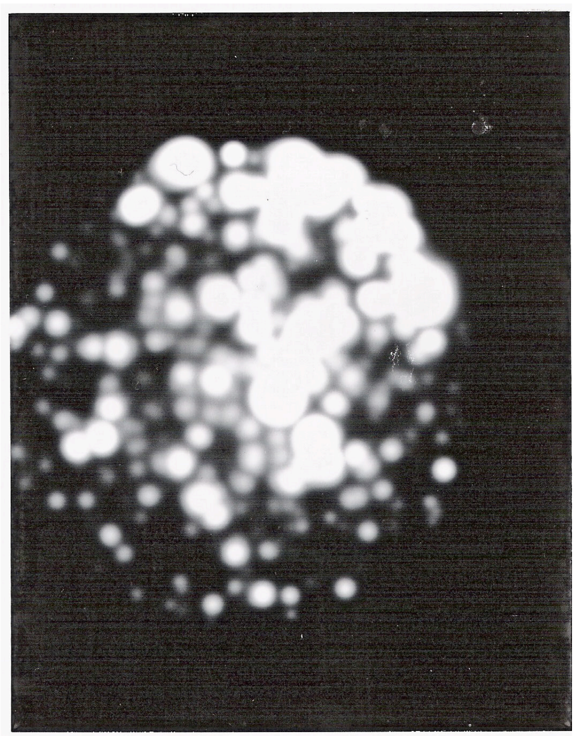
NFMCC Experimental Program and Plans



Yağmur Torun

ILLINOIS INSTITUTE OF TECHNOLOGY

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MuCool

AAC Review

Aug 9, 2007

Fermilab

NFMCC, MuCool and MICE

- Neutrino Factory and Muon Collider Collaboration (NFMCC) aims to tackle technical challenges of Neutrino Factories and Muon Colliders
- MuCool (Fermilab) is developing components for muon ionization cooling
  - Liquid hydrogen absorbers
  - Rf cavities
  - Magnets
  - Instrumentation
  - High power testing in beam
- MICE (RAL) is a system test of a cooling channel section
  - SFoFo cooling cell
  - Low intensity (single-muon)
  - Software bunching
- All are international collaborations

Ionization Cooling

- Muon lifetime is 2.2μs, traditional beam cooling techniques not applicable
  - Ionization cooling works "at the speed of the muon"

$$\frac{d\varepsilon}{ds} = -\frac{\left\langle \frac{dE}{ds} \right\rangle}{\beta^2 E}(\varepsilon - \varepsilon_0)$$

Normalized emittance in solenoidal channel

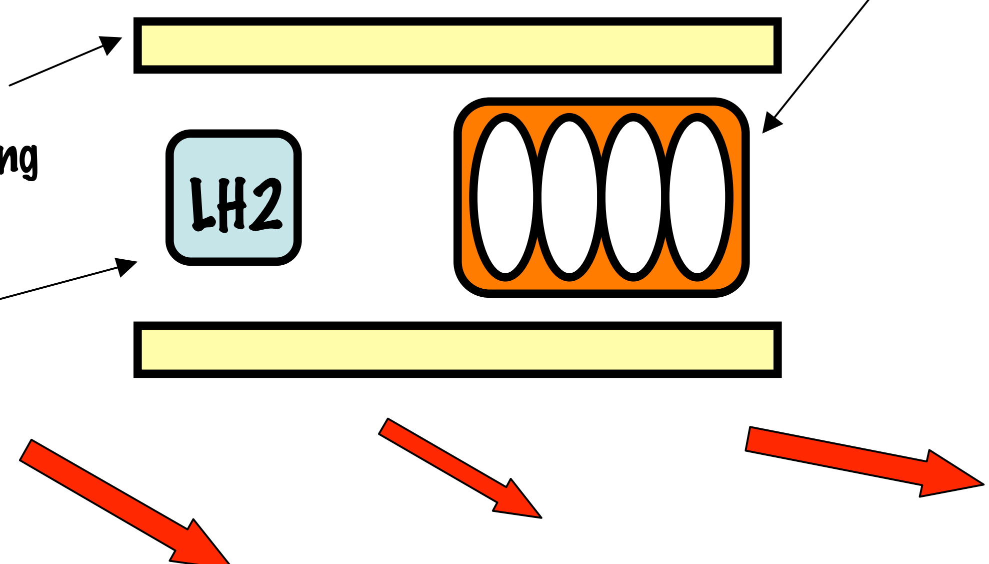
Equilibrium emittance

Solenoidal focusing

$$\varepsilon_0 \sim \frac{\beta_\perp}{\beta \left\langle \frac{dE}{ds} \right\rangle X_0}$$

30 MeV/m

Rf cavities



μ-momentum

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MuCool Collaboration

- Aims to
  - design, prototype and test all cooling channel components
    - perform high-power beam tests
    - support MICE
- Collaborators from US, Japan, UK - national labs & universities
- Spokesperson: A. Bross

- RF development
  - ANL
  - Fermilab
  - IIT
  - Imperial
  - JLab
  - Lancaster
  - LBNL
  - Mississippi

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

- Beam diagnostics
  - ANL
  - Fermilab
  - IIT
  - Princeton

- Solenoids
  - LBNL

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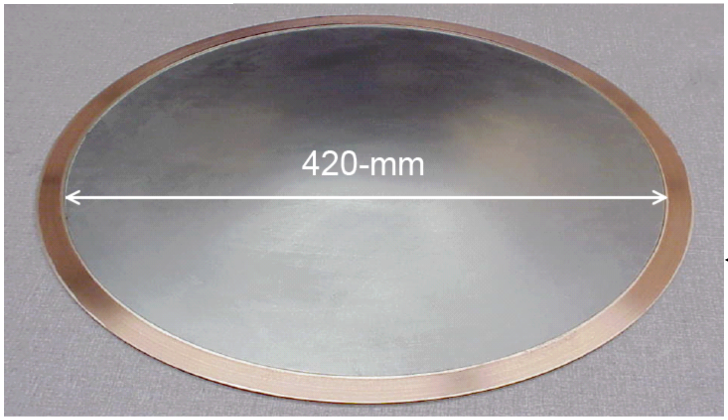
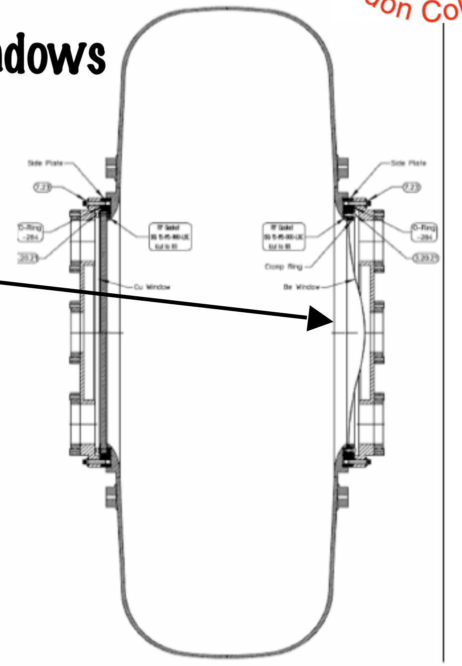
Thin Window R&D

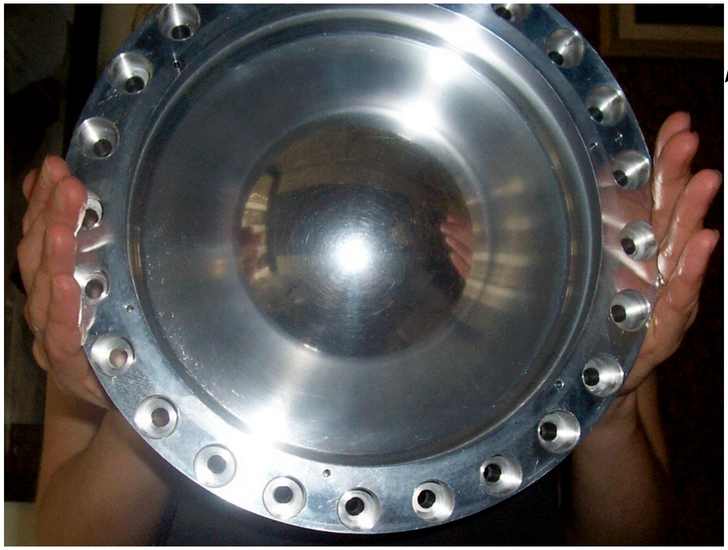


Absorber, vacuum, rf cavity windows

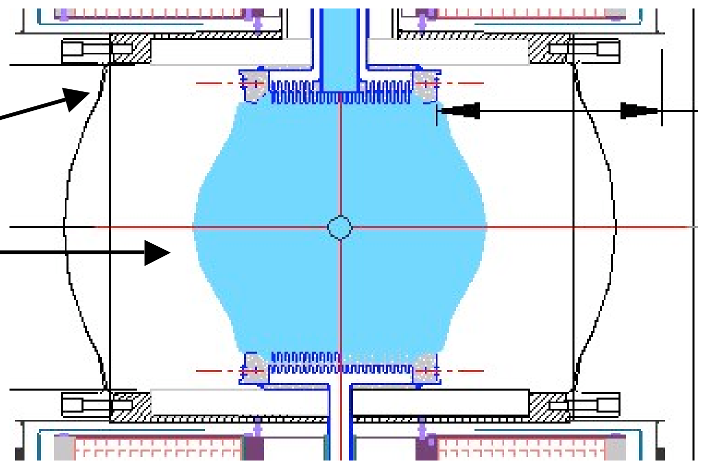
Curved Be window
constant thickness



Doubly inflected (bellows) Al window
optimized thickness profile
for absorber body



MICE convection
absorber in AFC
module



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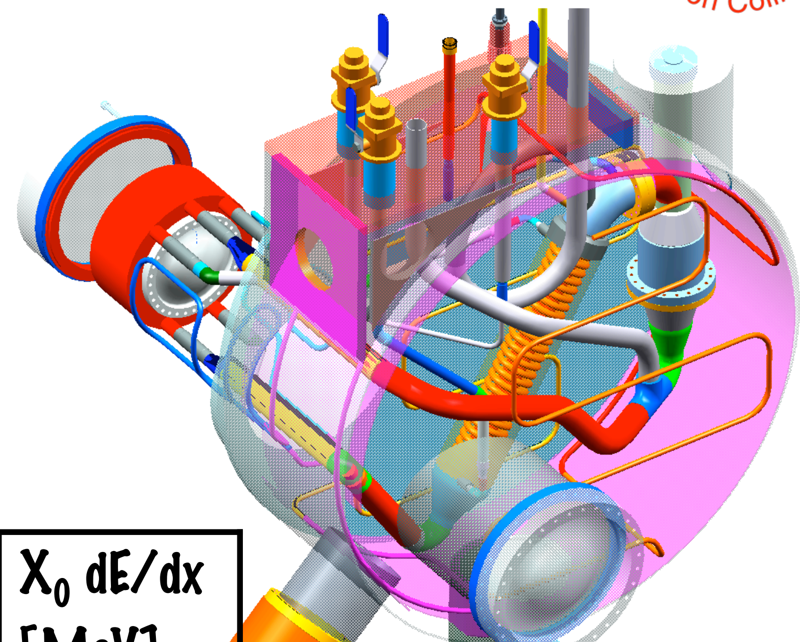
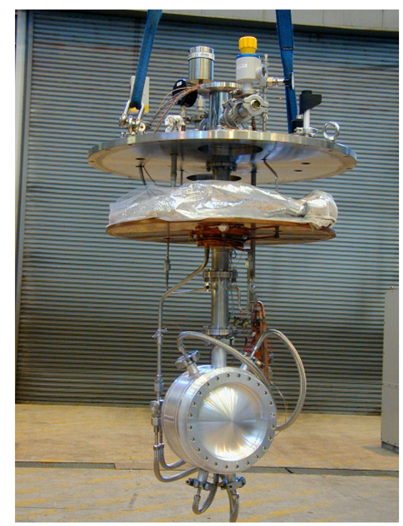
Absorber R&D

- Liquid Hydrogen
  - Forced flow
    - Force LH2 flow to external heat exchanger
    - turbulence inducing nozzles
  - Convection
    - beam and internal heaters set up internal flow
    - GHe heat exchanger acts on absorber walls
    - KEK absorber tested at MTA
- Solid LiH



Material	X_0 dE/dx [MeV]
GH2	259
LH2	254
G/LHe	183
LiH	151
Li	136



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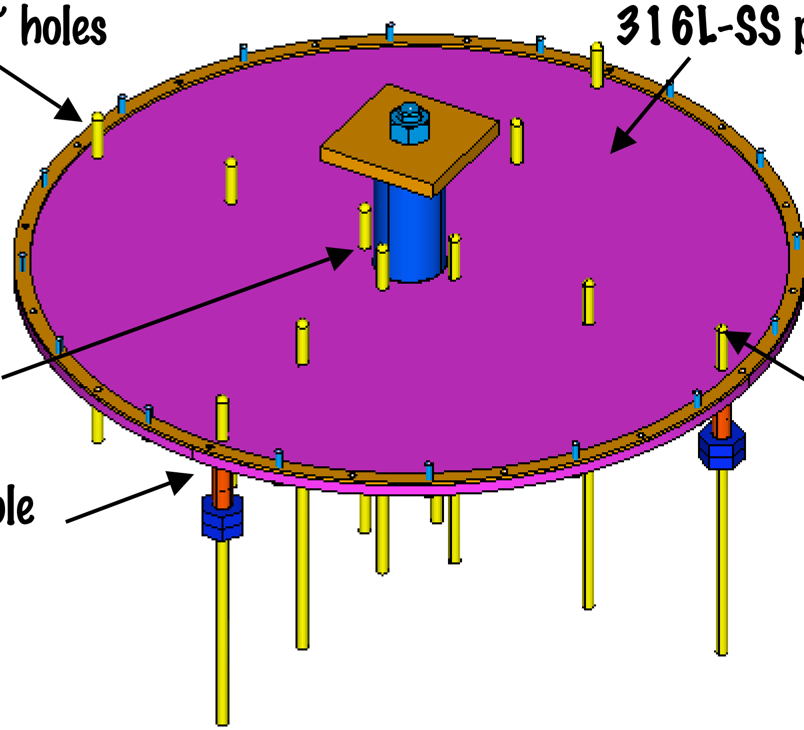
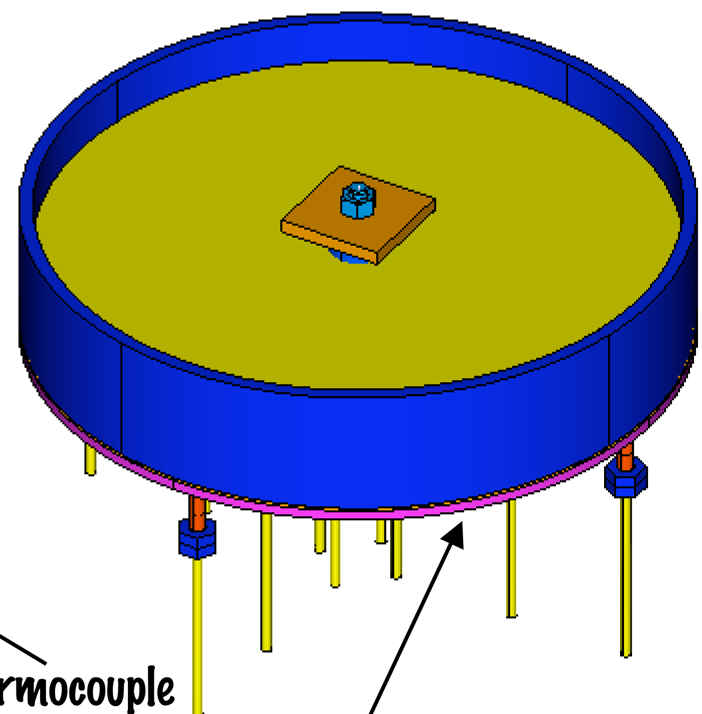
LiH Absorber R&D

Casting in glove box under Ar gas atmosphere:

- Solid LiH granules to be heated in stainless steel "ladle" to 100 F above melting point of LiH (1372 F or 750 C)
- Molten LiH poured into container, vibrated as the LiH solidifies
- Remove screws and nuts, slide the end cover out





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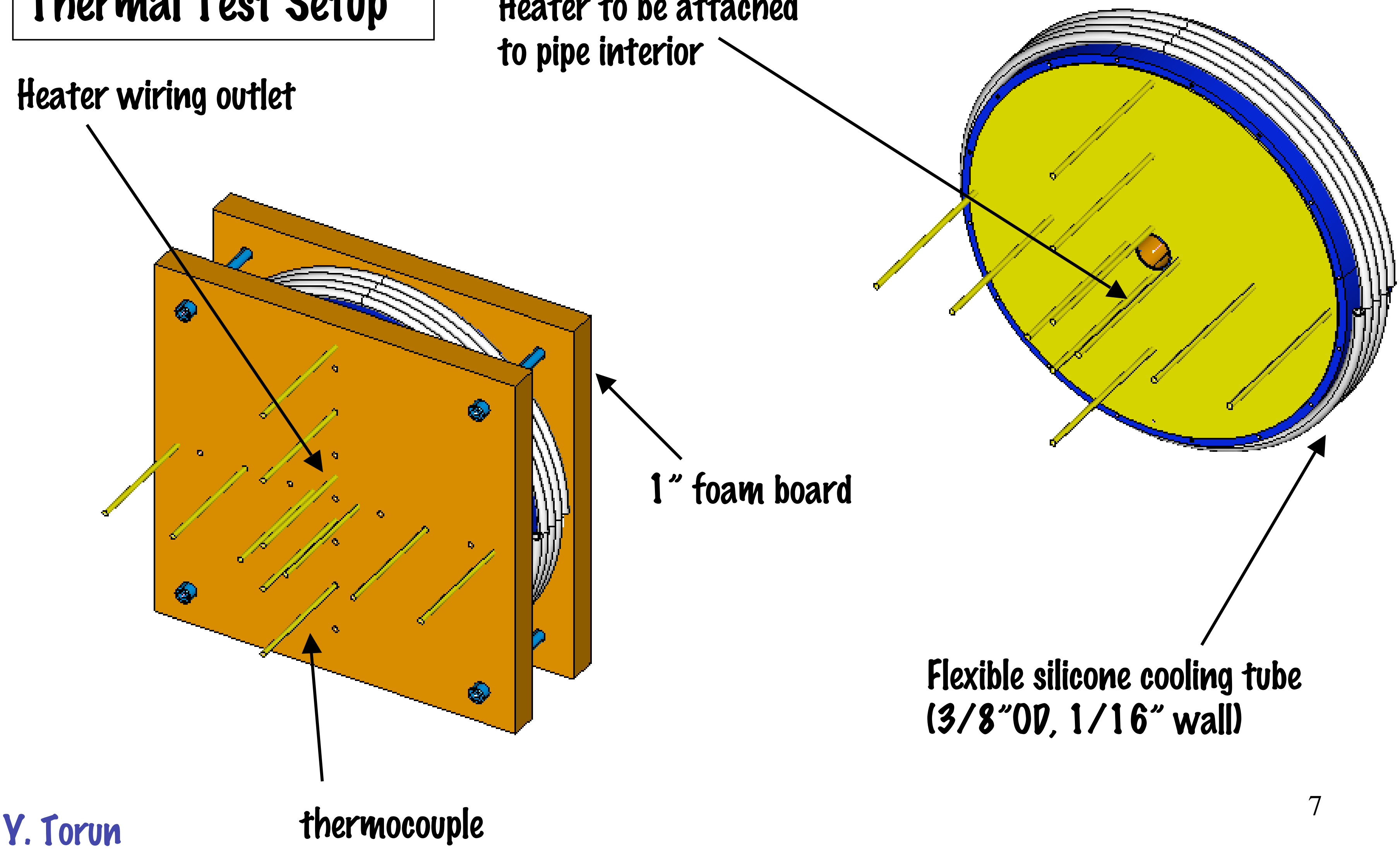
LiH Absorber R&D

Thermal Test Setup



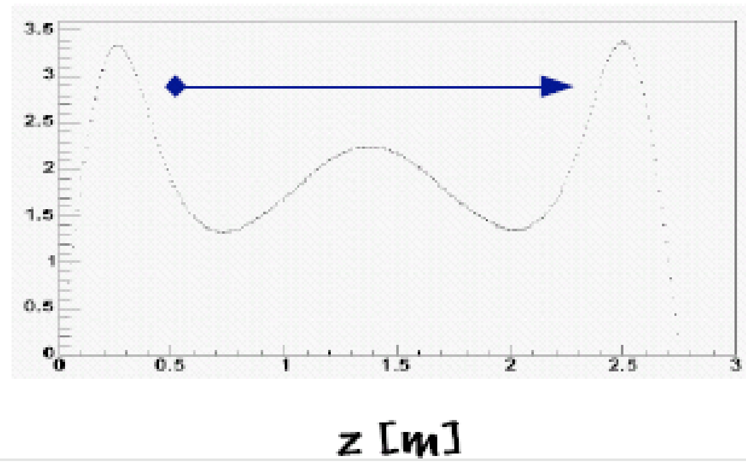
Rf Cavity R&D

- Demonstrate reliable operation in high magnetic field
  - Common to practical cooling schemes (NFMCC baseline)
- Systematic study of breakdown for NC rf in high magnetic field
  - Develop general understanding, explore connection to rest of rf research community (ILC, CLIC, ...)
  - Surface studies through atom probe tomography and molecular cluster simulations (J. Norem ANL, Northwestern)
- Measure rf-induced background rates, spectra and noise for MICE
- Map cavity performance as a function of magnetic field for MuCool/MICE
- Identify and test promising materials, surface treatment, coatings

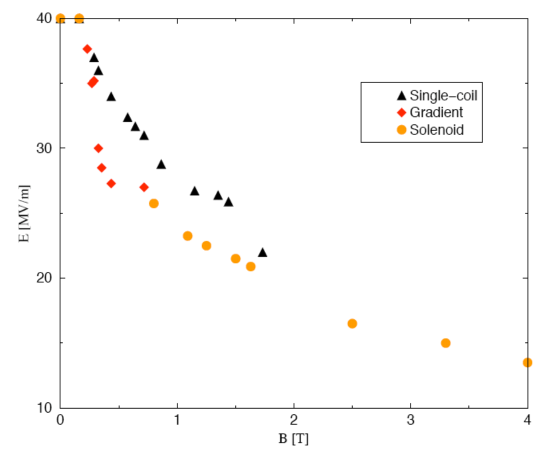
RF Issues

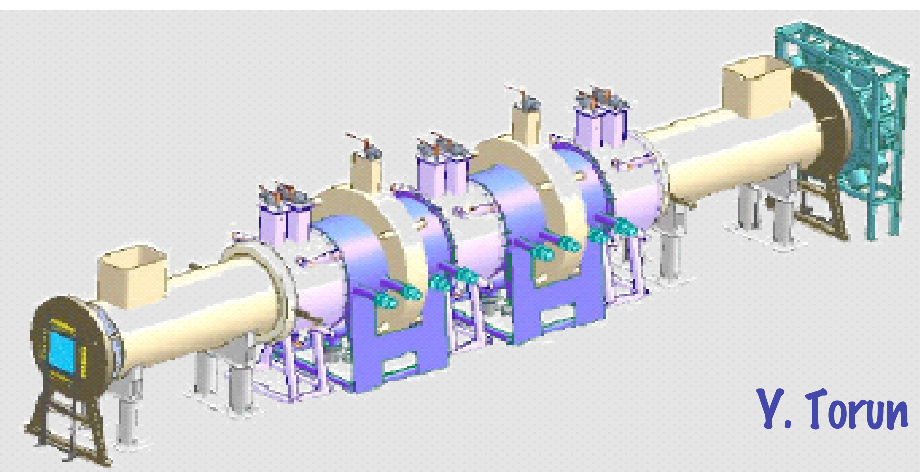
- High-gradient Cu rf cavities in high magnetic field is a significant R&D risk for NFMCC
  - Magnetic field focuses dark currents and lowers onset of breakdown
  - Ionization cooling channel packed with high-stored-energy cavities with thin windows in high magnetic field
  - In MICE, tracking detectors next to rf cavities are subject to x-ray backgrounds
- We need to demonstrate reliable and low-background operation

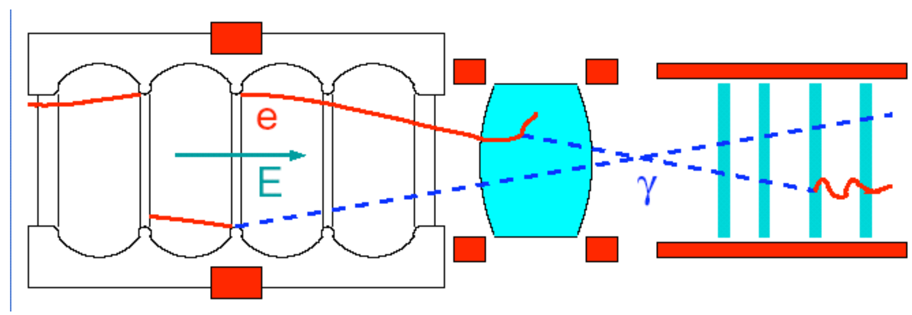
Study II on-axis field [T]



Achieved gradient @ 805MHz [MV/m]





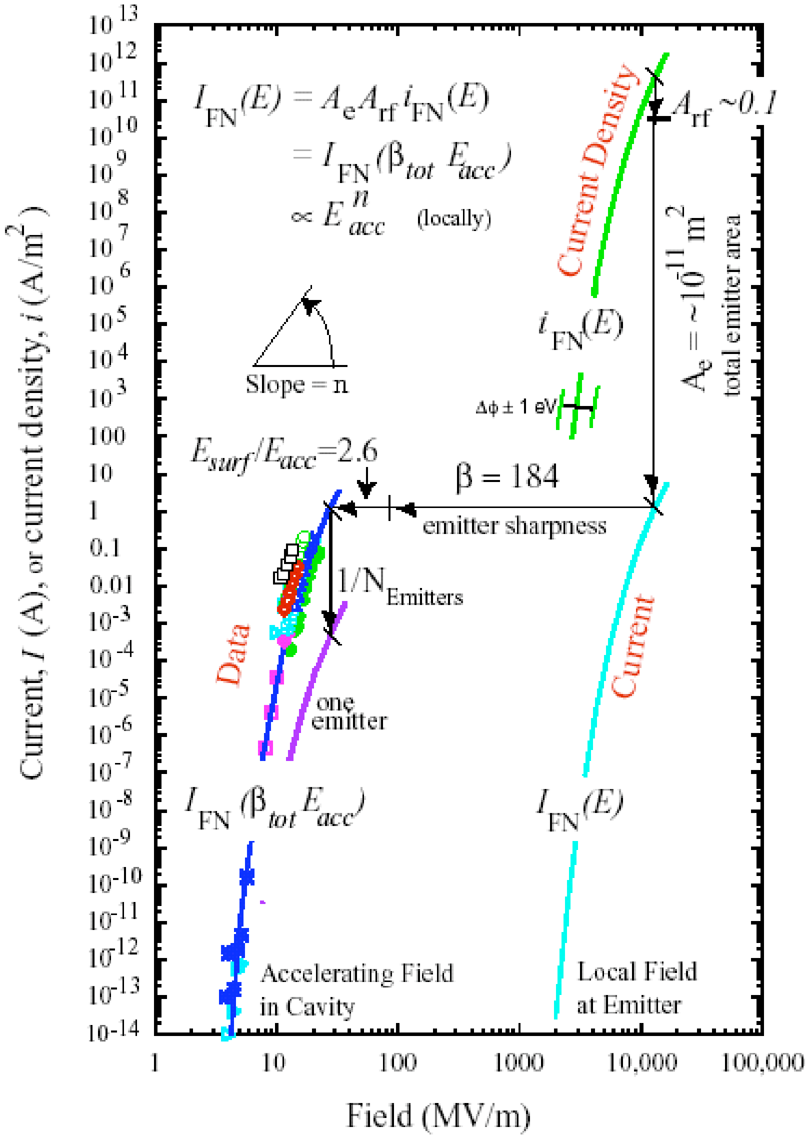


Dark Currents

- Precursor to breakdown
- Electrons tunnel through work function of metal
- Current rises very steeply with field (hard to make measurements)

$$j_{FN}(E) = \frac{A}{\phi}(\beta E)^2 exp\left(-\frac{B\phi^{3/2}}{\beta E}\right)$$

$$n = \frac{E}{j}\frac{dj}{dE} \simeq 2 + \frac{67.4\text{GV/m}}{\beta E}$$



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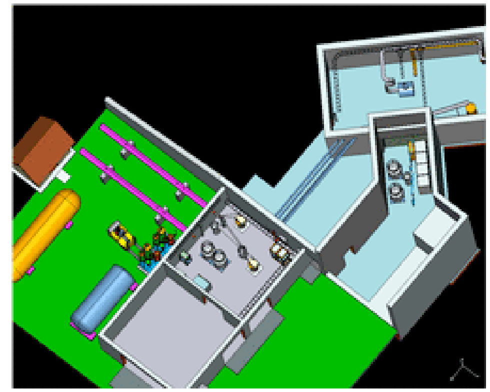
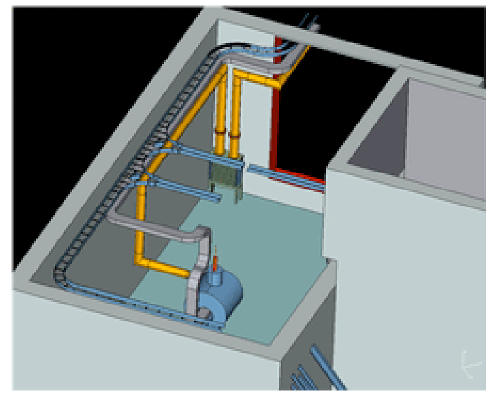
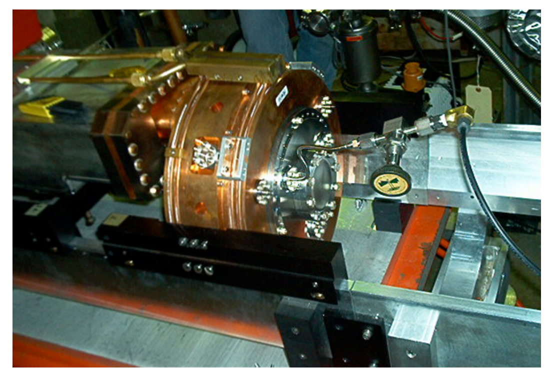
MuCool Test Area



- MTA now has
  - 5T solenoid(3.5T in gradient mode)
  - 5MW @ 201, 12MW @ 805MHz
  - Cryo infrastructure for LN2, LHe, LH2
  - 805, 201MHz pillbox cavities
  - Detectors and cabling for remote diagnostics
  - Clean room for assembly
- Still to be installed/finished
  - Cryo plant [Spring 08]
  - Beamline [Summer 07-Summer 08]
  - Large magnet (coupling coil) [Fall 08]





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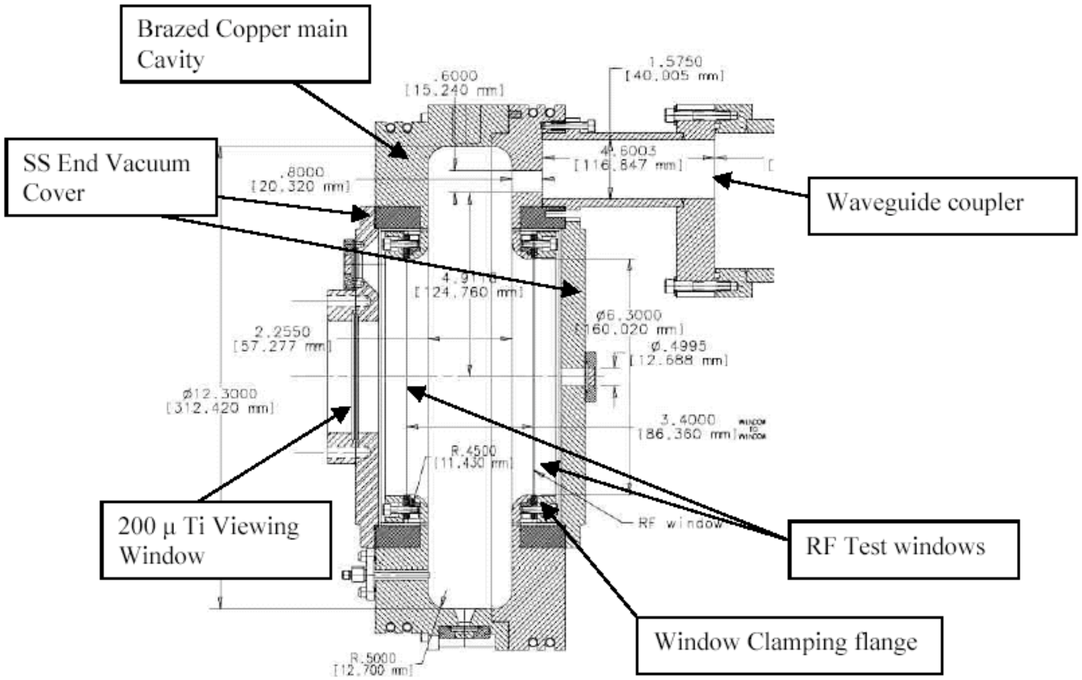
805 MHz Pillbox Cavity



- Quarter-scale model for R&D
- Has been running reliably at design gradient (32MV/m) at B=0
- Stable operation with thin curved Be windows
- B-field dependence mapped out in detail to 4.5T
- Other parameters (pulse width, etc.) can be studied
- Different materials and surface prep explored by use of removable buttons (x1.7 field enhancement)
  - Ta, Mo, MoZr, W, Nb, NbTi, Cu, SS, Cr
  - TiN coating
  - EP, GCIB

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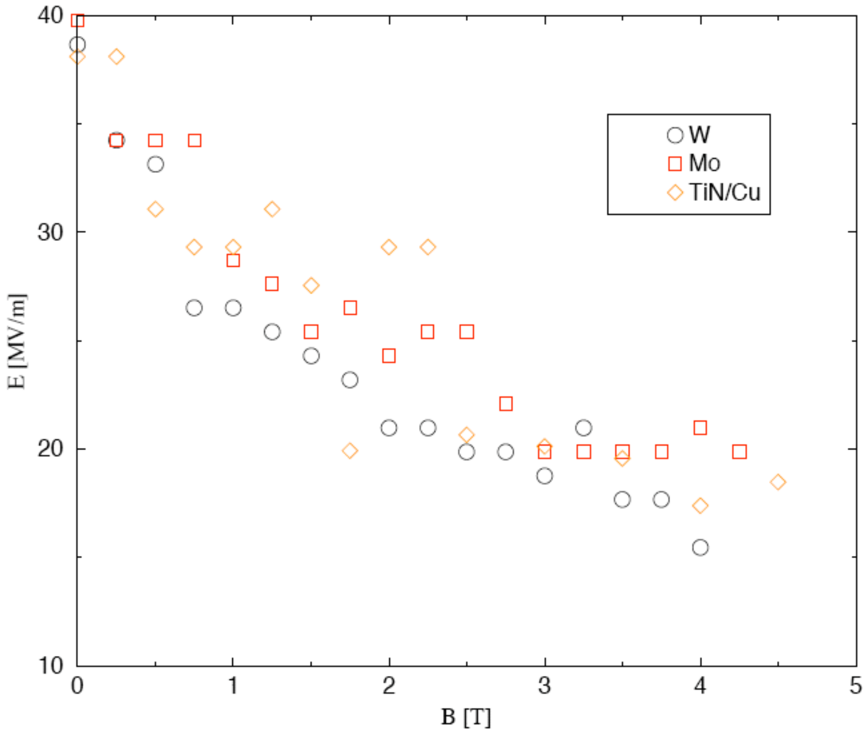
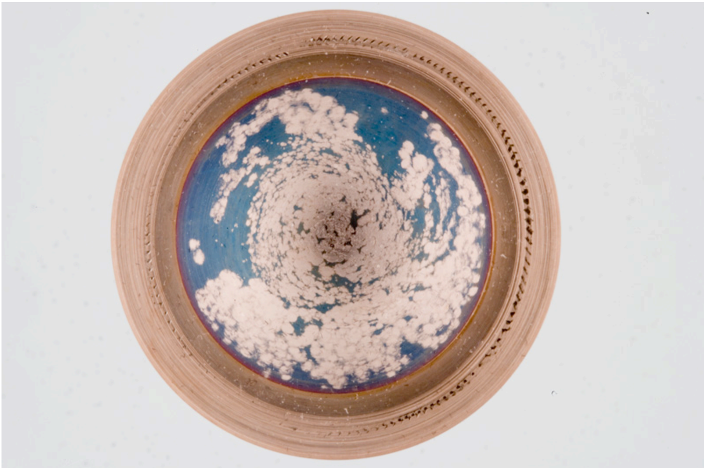
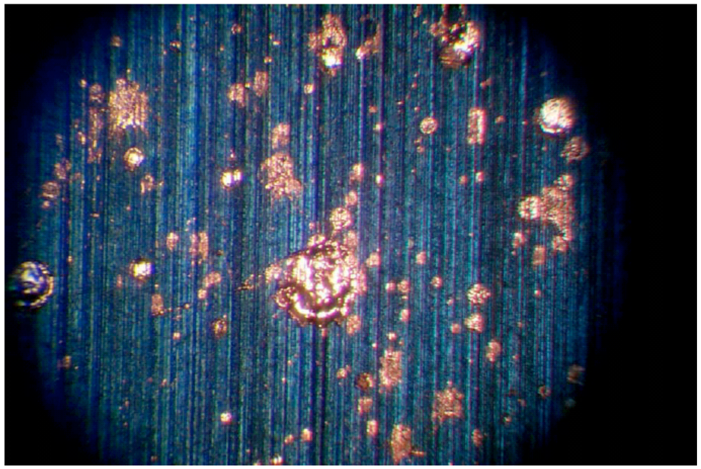
805 MHz Pillbox Cavity



- Currently carrying out button test program with B-field
  - Finished tests with bare Mo, W and TiN-Cu
- TiN coating removed on Cu button
  - But no damage on Cu
  - Reverse of TiN/Be window case
- No visible damage on Mo button
- W button not yet inspected (still installed)





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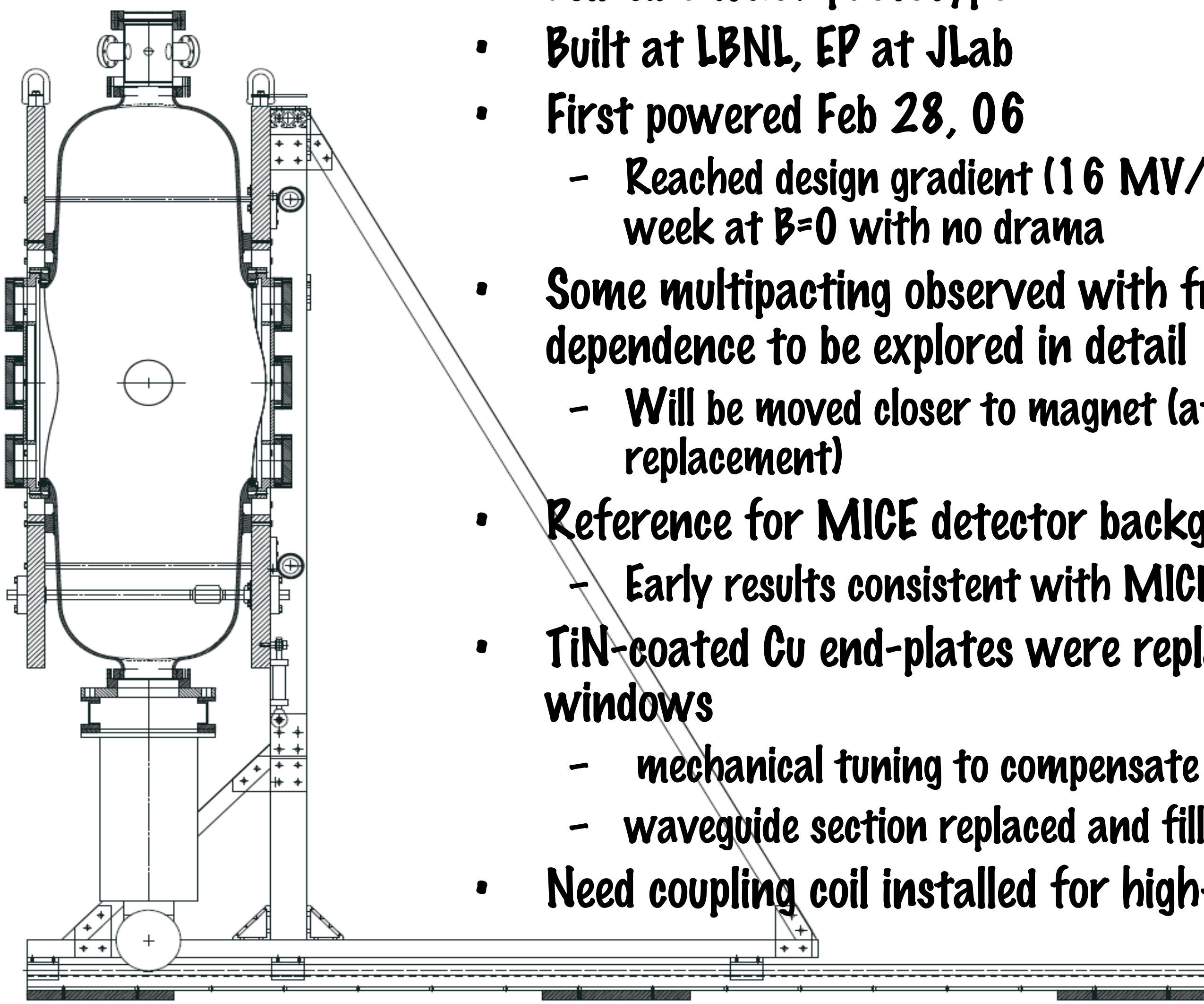
201 MHz Prototype Cavity



- Full-size MICE prototype
- Built at LBNL, EP at JLab
- First powered Feb 28, 06
  - Reached design gradient (16 MV/m @ 4.2MW) within a week at B=0 with no drama
- Some multipacting observed with fringe field, B-field dependence to be explored in detail
  - Will be moved closer to magnet (after cryopump replacement)
- Reference for MICE detector backgrounds
  - Early results consistent with MICE assumptions
- TiN-coated Cu end-plates were replaced with thin Be windows
  - mechanical tuning to compensate for frequency shift
  - waveguide section replaced and filled with SF6
- Need coupling coil installed for high-magnetic-field test

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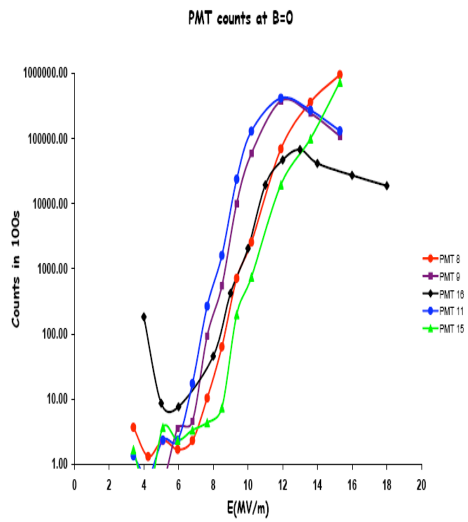
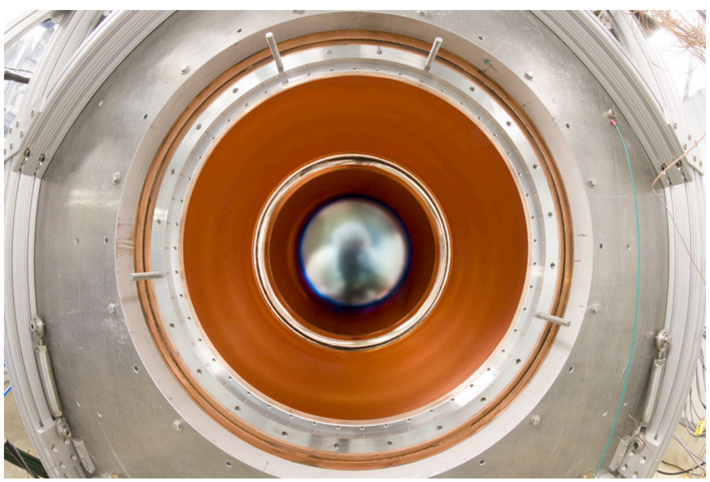
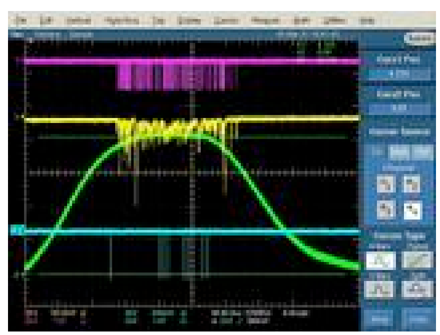
201 MHz Prototype Cavity



- Ready to operate with curved Be windows
  - No visible surface damage
- RF power availability limited
  - Parasitic operation on Linac test station
- Measured backgrounds in a MICE-TOF-like counter
  - Rates comparable to what was assumed in MICE
  - spectra, consistent with expected 1/E shape





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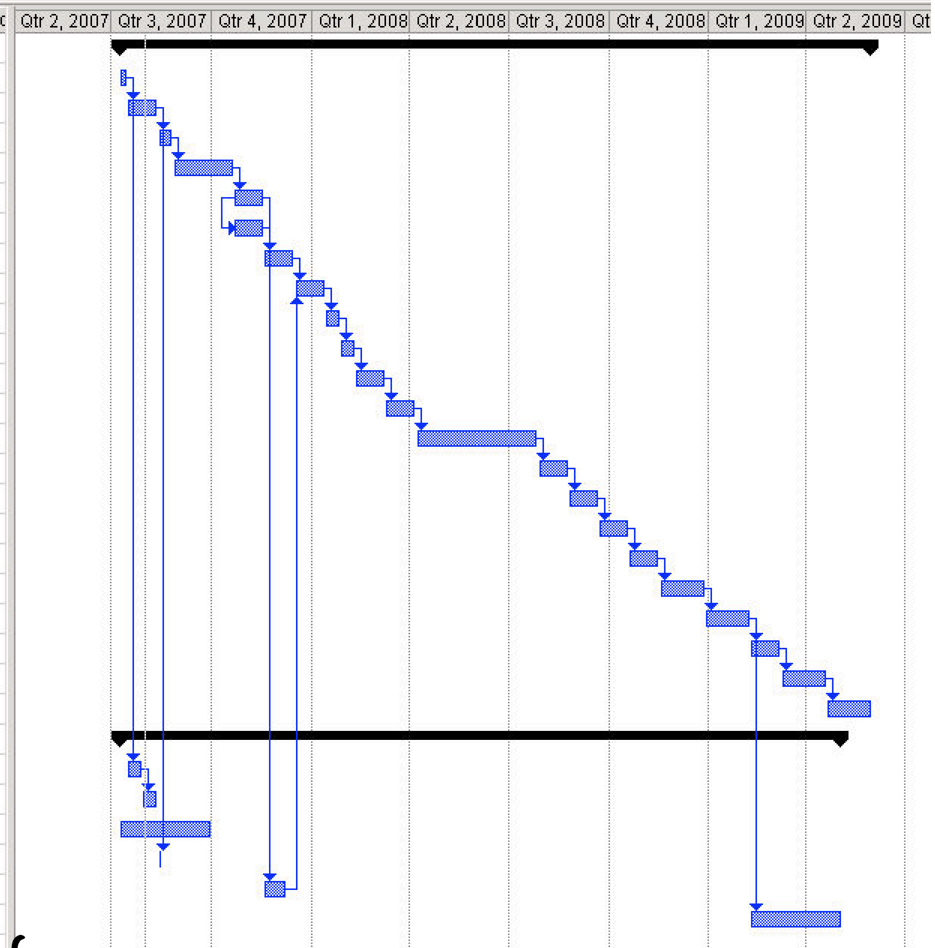
MuCool Status

- RF R&D
  - 805MHz cavity with curved Be windows successfully tested at design gradient
    - mapped B-field dependence, test program with electrodes of different materials
  - 201MHz cavity operated at design gradient with Cu windows, also in small B-field
    - More testing to follow with Be windows
  - Coordinating with Muons Inc. to continue pressurized cavity tests
- MTA infrastructure
  - Diagnostics installed
  - Magnet cryo system operational, running off of dewars
  - Cryogenics plant partially installed
  - Beamline design complete, installation during shutdown
  - Automated RF control system being built for 805MHz
- Absorber R&D
  - New windows available, dedicated test area at Fermilab (Lab 6)
  - Another instrumented LH2 fill test when ready
  - LiH casting fixture designed and parts ordered (delivery early Fall)
- MICE support
  - Scintillating fiber trackers and readout electronics
  - Software (G4MICE)

MTA Schedule

Task Name	Duration	Start	Finish	Predecessors
805 Program	**495 days**	**Mon 7/9/07**	**Fri 5/29/09**	
CMS Pixel Tests	1 wk	Mon 7/9/07	Fri 7/13/07	
805 MHz Button Tests	4 wks	Mon 7/16/07	Fri 8/10/07	2
Hatch Work - No RF	**2 wks**	**Mon 8/13/07**	**Fri 8/24/07**	**3**
805 MHz Button Tests	8 wks	Mon 8/27/07	Fri 10/19/07	4
LH2 Absorber Tests (No RF)	**4 wks**	**Mon 10/22/07**	**Fri 11/16/07**	**5**
Hatch RF Shielding Modification	**4 wks**	**Mon 10/22/07**	**Fri 11/16/07**	**6SS**
805 HP Cell Conditioning	4 wks	Mon 11/19/07	Fri 12/14/07	7
805 MHz Button Tests	4 wks	Mon 12/17/07	Fri 1/11/08	8,29
805 HP Cell Beam Prep	2 wks	Mon 1/14/08	Fri 1/25/08	9
805 MHz Button Tests	2 wks	Mon 1/28/08	Fri 2/8/08	10
805 HP Cell Beam Tests	4 wks	Mon 2/11/08	Fri 3/7/08	11
805 MHz Button Tests	4 wks	Mon 3/10/08	Fri 4/4/08	12
MTA Configuration Change	**16 wks**	**Mon 4/7/08**	**Fri 7/25/08**	**13**
805 HP Cell Beam Tests	4 wks	Mon 7/28/08	Fri 8/22/08	14
805 MHz Button Tests	4 wks	Mon 8/25/08	Fri 9/19/08	15
805 HP Cell Beam Tests	4 wks	Mon 9/22/08	Fri 10/17/08	16
805 MHz Button Tests	4 wks	Mon 10/20/08	Fri 11/14/08	17
805 HP Cell Beam Tests	6 wks	Mon 11/17/08	Fri 12/26/08	18
Installation of MICE Coupling Coil	**6 wks**	**Mon 12/29/08**	**Fri 2/6/09**	**19**
805 MHz Button Tests	4 wks	Mon 2/9/09	Fri 3/6/09	20
805 Test Cell II B field Tests	6 wks	Mon 3/9/09	Fri 4/17/09	21
805 HP Cell II Tests	6 wks	Mon 4/20/09	Fri 5/29/09	22
201 Program	**475 days**	**Mon 7/9/07**	**Fri 5/1/09**	
201 Cavity Conditioning with Be windows	2 wks	Mon 7/16/07	Fri 7/27/07	2
201 Cavity B field Study	2 wks	Mon 7/30/07	Fri 8/10/07	25
201 Vacuum Upgrade	12 wks	Mon 7/9/07	Fri 9/28/07	
Move 201 Cavity	2 days	Mon 8/13/07	Tue 8/14/07	3
201 Cavity B field Study	3 wks	Mon 11/19/07	Fri 12/7/07	6,7
201 Cavity High B field studies	12 wks	Mon 2/9/09	Fri 5/1/09	20



- Installation subject to availability of resources
- R&D program strongly coupled to Linac operations
  - Will review at joint NFMCC-MCTF-MuonsInc vacuum and high-pressure MTA RF Workshop: Aug 22 @ FNAL

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