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Berkeley National Laboratory

Muon Collaboration

NCRF R&D Programs and Plans

MUTAC Meeting,
FNAL, January 14, 2003

Derun Li, J. Corlett, A. Ladran, J. Staples,
S. Virostek, M. Zisman,
Lawrence Berkeley National Laboratory
A. Moretti, Z. Qian, FNAL
R. A. Rimmer, Jlab; J. Norem, ANL,
M. Sharoa (Ph.D. student), Y. Torun, IIT

NCRF R&D Programs & Plans

- Progress and current status
  - Finished 805 MHz open cell cavity test at Lab G
  - Significant progress on 805 MHz closed cavity tests with
    - copper windows without magnetic field - 34 MV/m
    - copper windows with 2.5 T magnetic field - 16 MV/m
    - Be windows were installed and tests are in progress
  - Cavity surface inspection & multipactings
  - Conditioning, Dark current, X-Rays and RF breakdown
  - 201 MHz cavity (Study-II) design is nearly complete, and ready for prototype. Vendor qualifications are in progress
  - 201 MHz cavity design has been proposed for use in MICE
  - Progress on cavity terminations: foils and grids

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RF tests on 805 MHz Cavity

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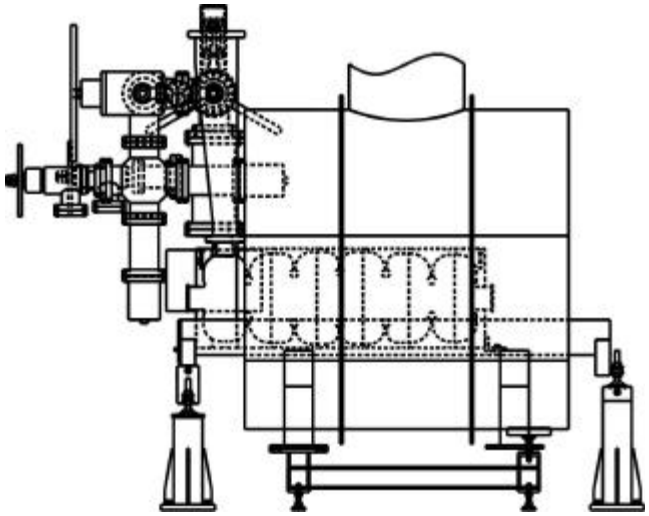
- Finished open cell cavity tests: history (Torun's talk)
  - Tested with & without the magnetic field
  - Reached peak surface field of 53 MV/m and 23.5 MV/m acceleration gradient on cavity axis
  - Magnetic quench moved the cavity off axis
  - Conditioning with magnetic field led to puncture of Ti foil
  - Significant surface damages were observed
  - Strong dark currents and X-rays were measured
  - Work was documented in a Ph.D. thesis (Wu) and a paper was submitted to PR ST (Norem)



805 MHz open cell cavity at Lab G

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RF tests on 805 MHz Cavity

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- Closed cell cavity test: progress and status

Purpose: further study on

- high gradient accelerating structure for muon cooling channels at high peak surface field → possible surface damage
- engineering of RF cavities with Be windows or grids
- cavity conditioning and operation in a strong magnetic field for either solenoidal or gradient mode
- multipactings, dark current and x-ray radiation levels versus the gradient; their influence on detectors nearby

- High power tests started with two Cu windows in March 2002
- Tests resumed in Sept. 2002 again with a new thin Cu window
- Tests are in progress now with TiN Be windows starting 12/02

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Test setup at Lab G

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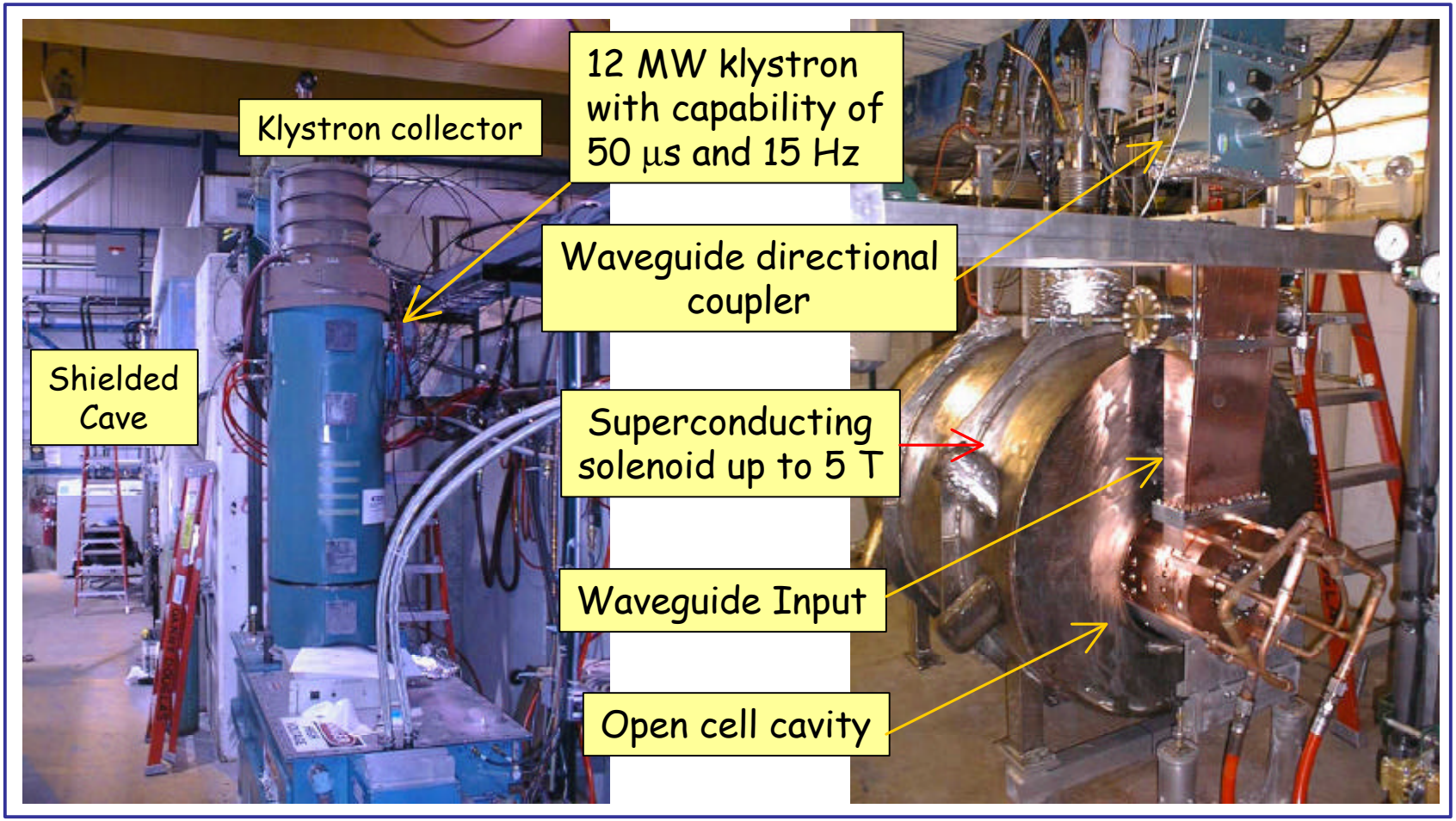
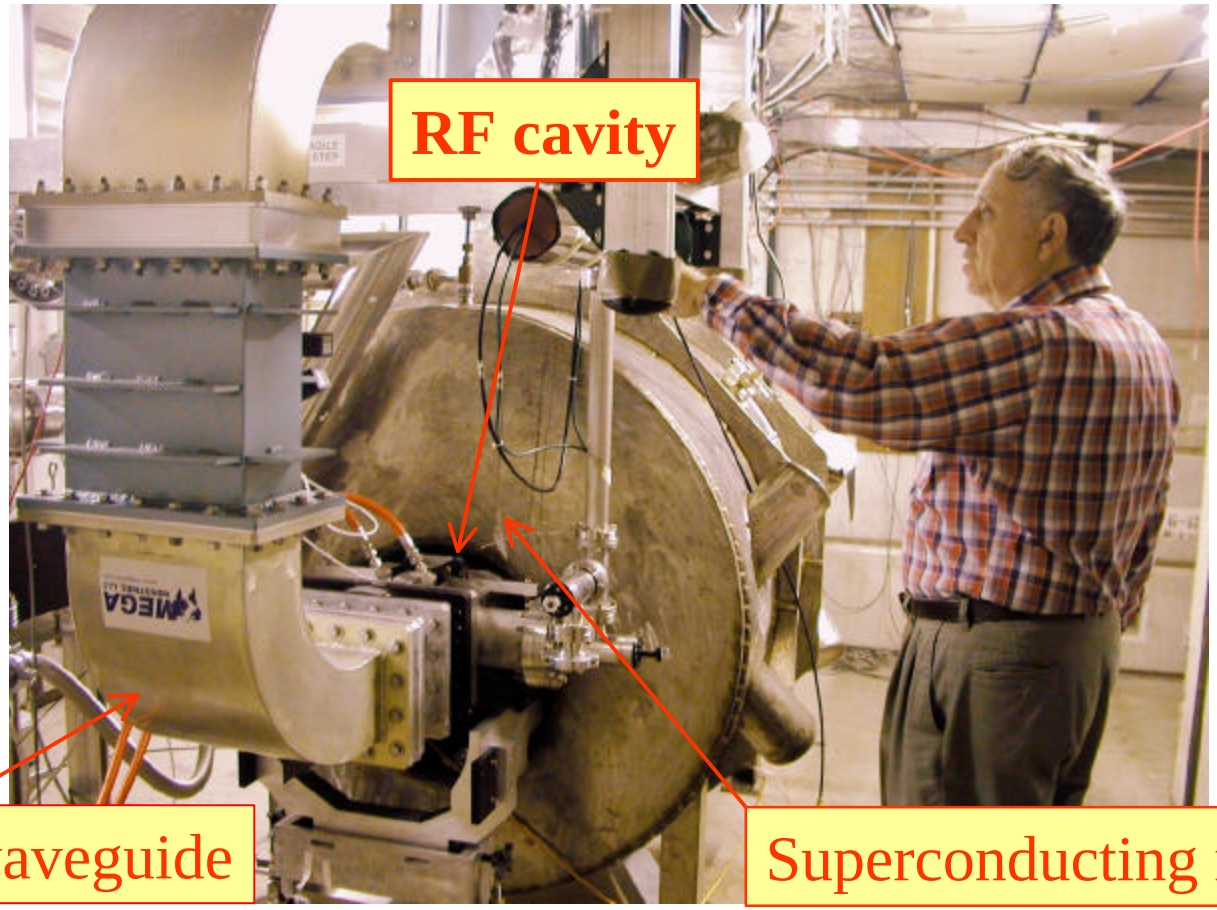
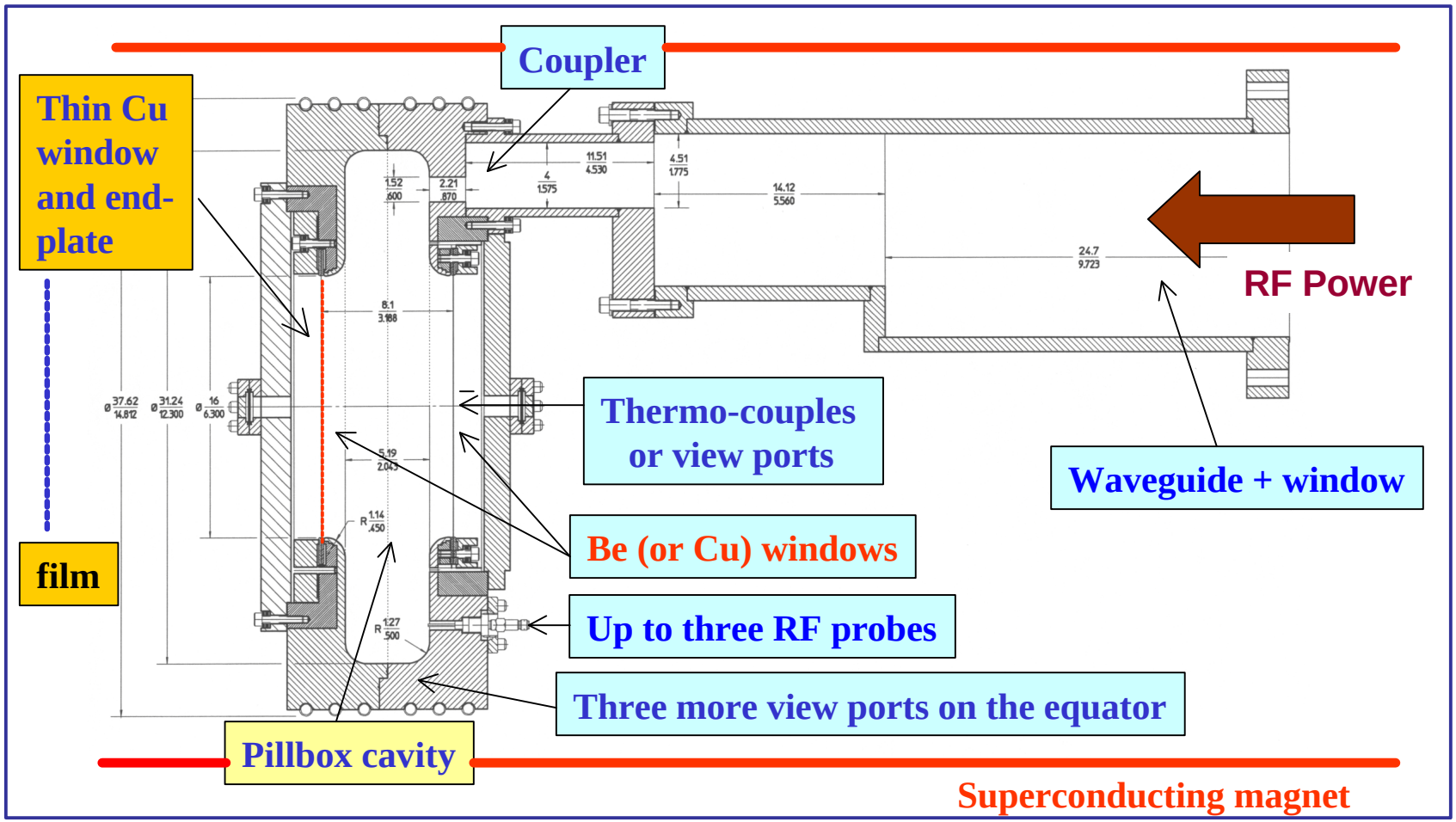


Test setup at Lab G (cont'd)



The cavity and diagnostics



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Cavity Design Parameters

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- Frequency: 805 MHz measured 805.135 MHz[Cu]
- Shunt Impedance: 803.03 MHz [Be]
  - 38 MΩ/m (Z_0); 32 MΩ/m (ZT^2); [$Z = V_{\{0,T\}}^2/P$]
- Quality factor: Q_0 = 18,800 measured 15,080 [Cu]
- Coupling Constant: 12,750 [Be]
  - β_c = 1.0 at critical coupling; measured 1.08 [Cu]
  - An example: At <E> = 30 MV/m, 1.18 [Be]

    2 MW peak input power is required. 350 watts average on the cavity, 52 watts on [Cu] (66 watts [Be]) windows at duty factor of 1.8×10^{-4} in 12 μs pulse length and 15 Hz repetition rate.

Milestones

- Test in March-April, 2002:

  Two thick Cu windows at no magnetic field

  - RF conditioning went smoothly, no surprises
  - Good vacuum ~ a few times 10^{-8} Torr
  - Reached 34 MV/m acceleration gradient on axis within a few weeks with little sparking rate (~ 1/25,000)
  - No dark current was measured due to these thick copper windows
  - No damage was found from the surface inspections on the cavity and the windows
  - A new thin Cu window was installed afterwards allowing for measurements of dark current and x-rays

Milestones (cont'd)

- Test in September - November, 2002:

  A new thin Cu window w/o magnetic field

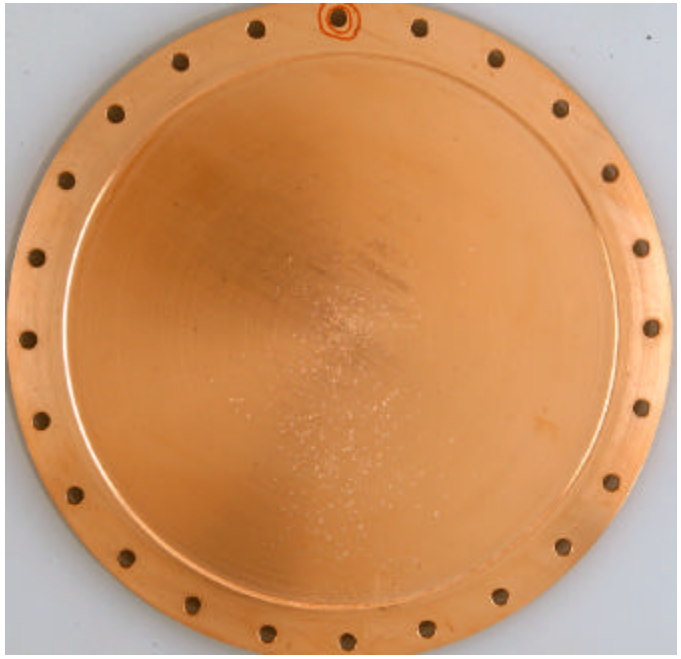
  - First conditioned the cavity without magnetic field up to about 20 MV/m (make sure it works as it should be …)
  - The same good vacuum at a few times 10^{-8} Torr
  - Superconducting magnet on at 2.5 T in solenoidal mode
  - Reached 16 MV/m after many weeks conditioning
  - Many multipacting zones were observed and much harder to go through
  - Very high radiation levels were measured (~ 1000 times higher), compared with no magnetic field case

Milestones (cont'd)

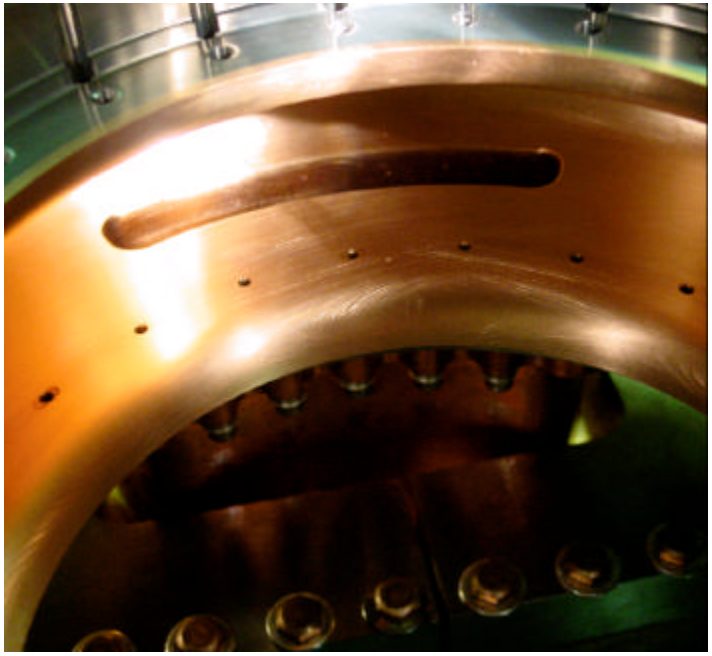
- Test in September - November, 2002 (cont'd):
  - A possible healing process was discovered:
    High radiation level resulted from conditioning with magnetic field decreases when continuing conditioning without the magnetic field, which suggests a possible self surface healing process (or the damages surface being re-conditioned)
  - The self healing process is reproducible
  - Window surface inspection found there are many pitting at the window around the center region
  - Copper dust appeared at the bottom edge of the windows
  - No surface damage was found on the cavity body and the coupler

Milestones (cont'd)

Images of the cavity and windows after conditioning with magnetic field



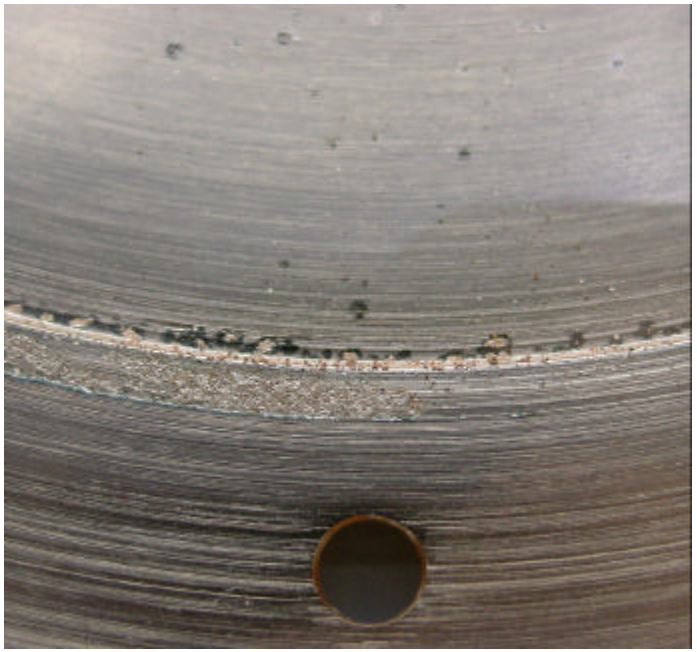
Cu window



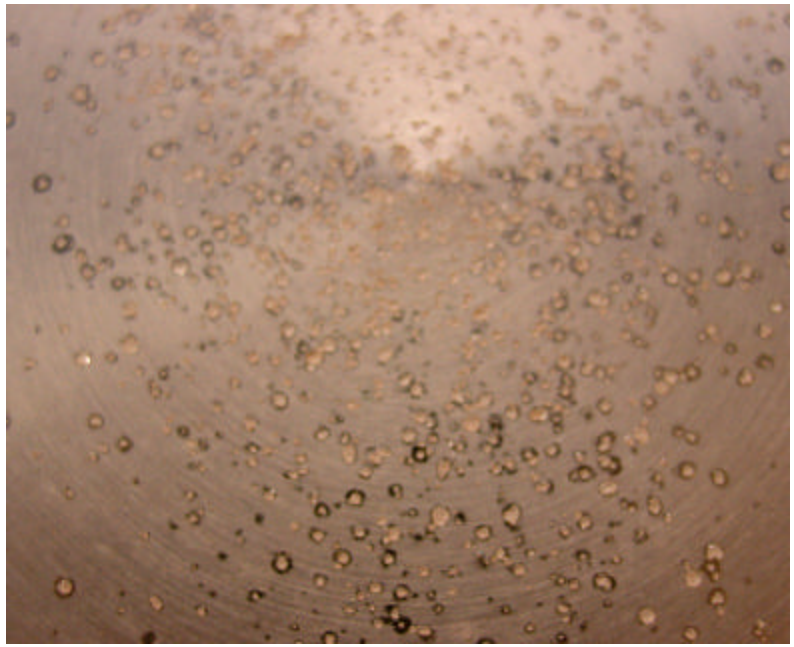
Coupling slot

Milestones (cont'd)

Close-up view images of the windows



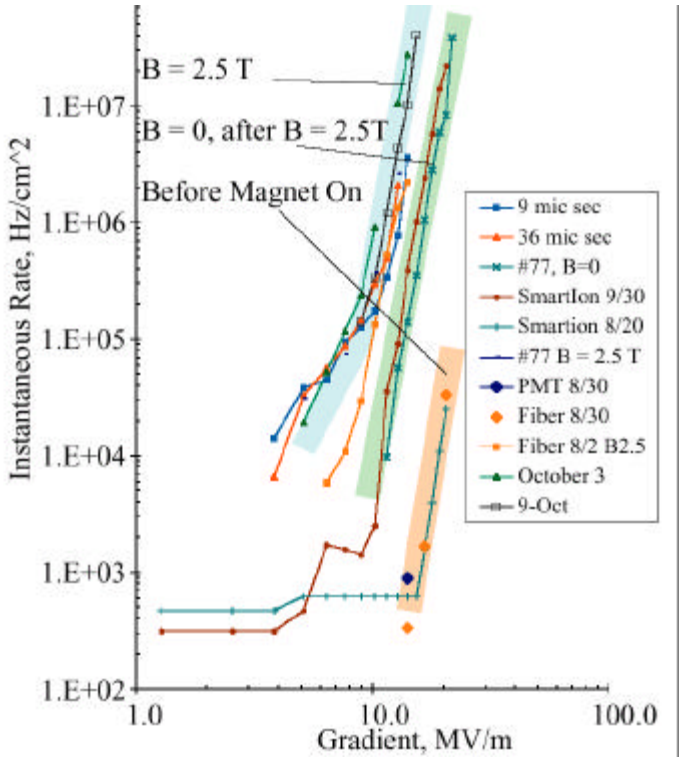
"copper dust" appeared at the window bottom edge



Pitting at the window center region

Milestones (cont'd)

- Preliminary data analysis suggests two-plate type multipactings (MP) are dominating effects
- with the magnetic field
  - electron motions stay same in z
  - strong focus channels are formed by 2.5 T field, compared to ~ 0.1 T of RF magnetic field at 30 MV/m of gradient
  - Electrons follow the B field spirally depending on initial conditions
  - More focused and trapped electrons are likely to produce higher x-ray flux, and cause damages in sparking
  - MP starts from center and scans radially outwards



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805 MHz cavity test status

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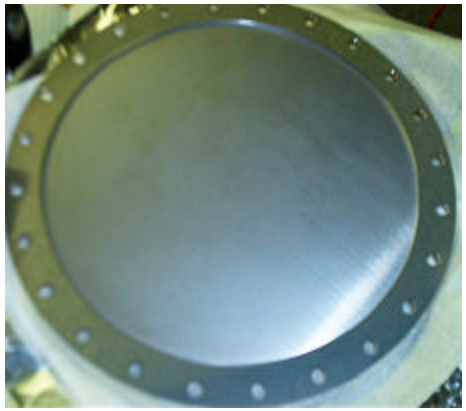
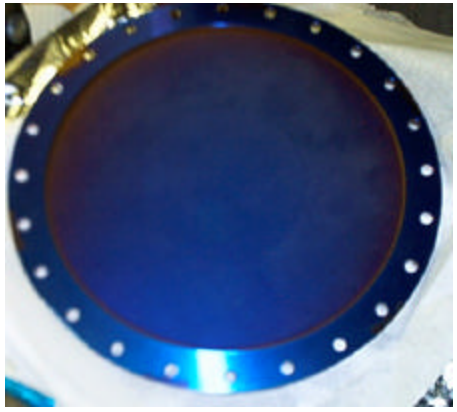
- Cu window surface inspection and further data analysis are in process

New test started in 12/02 and is going on now with TiN Be windows (10, 20 mills)

- Two TiN Be windows were installed in 12/02
- The cavity is under testing without magnetic field at Lab G (≤ 16 MV/m)
  - Good vacuum 5×10^{-9} Torr
  - Less multipactings were observed and low x-rays were measured
  - Reached 12 MV/m gradient at 24 μs pulse length and 5 Hz repetition rate
  - Cavity resonant frequency shifts appeared (maybe due to RF heating or resonating with RF pulses





TiN Be windows

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201 MHz NCRF R&D: cavity

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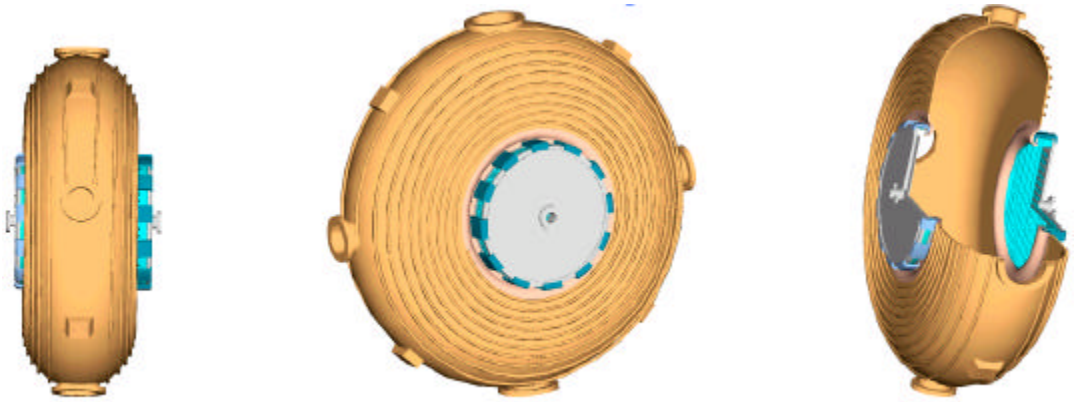
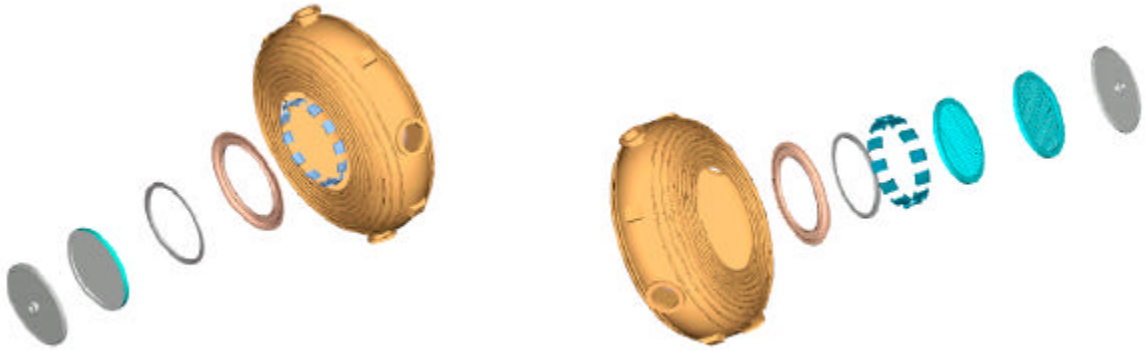
- Cavity design is nearly completed
- Vendor qualification is in progress
- Start prototype



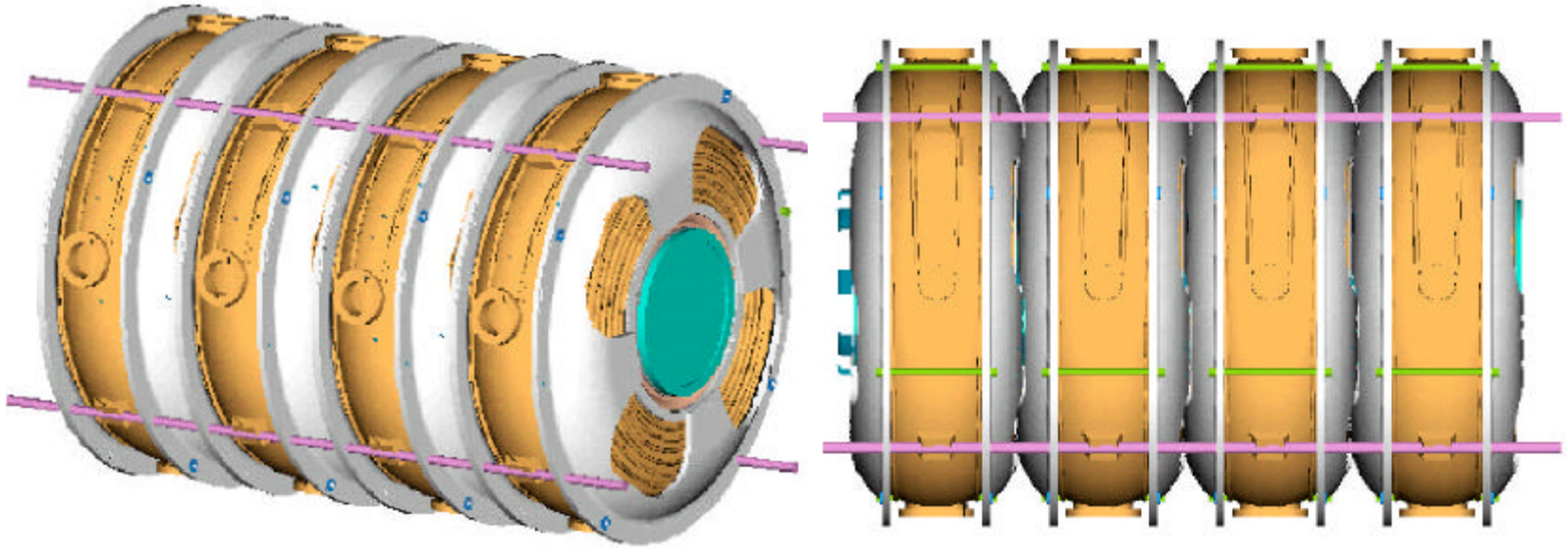
201.25 MHz cavity conceptual design



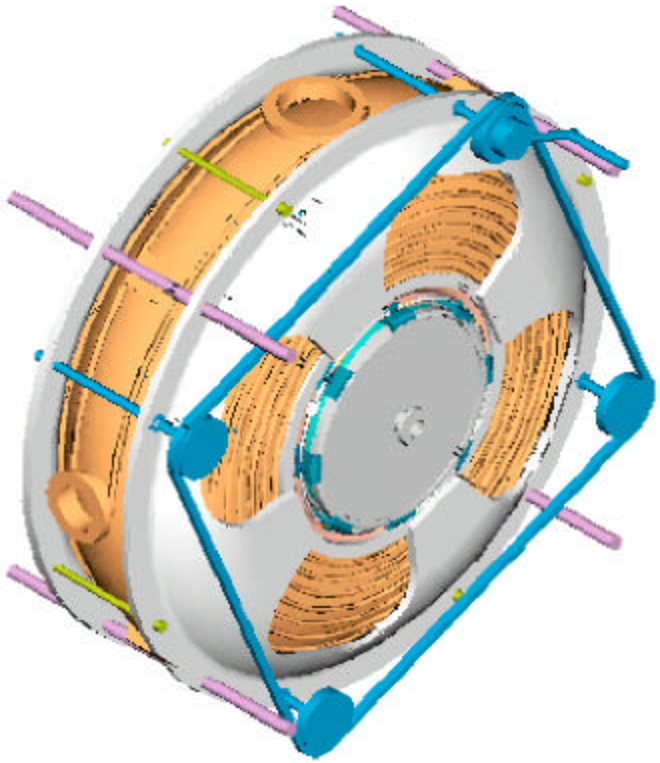
Exploded views showing foil and grid mounting hardware

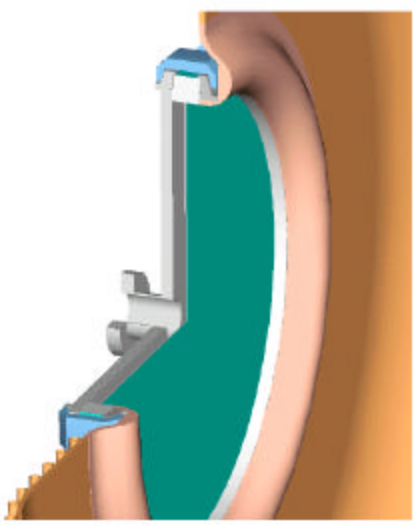
4-cavity assembly

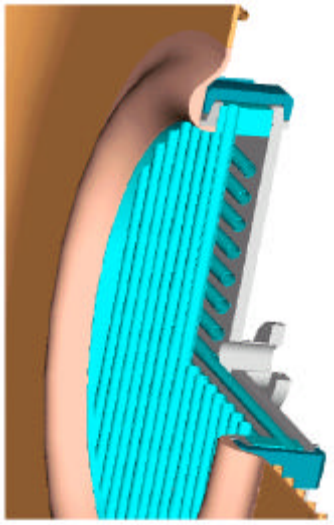
Integration of four 201.25 MHz RF cavities



Be Windows or Grids





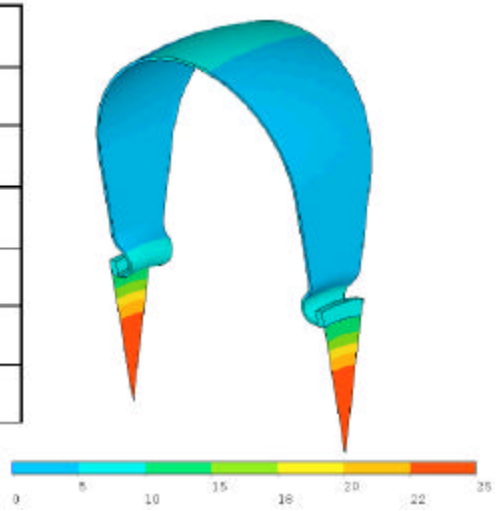


Preliminary cavity design with water cooling channels and tuning mechanism. The cavity design accommodates either Be windows or a grid design.

201 MHz NCRF R&D: E&M and Thermal Analysis

V_{eff} (on crest)	5.76 MV
Length	0.430 m (T=0.827)
$E_o$equivalent	16.2 MV/m
E_{pk} on surface	26.5 MV/m
Peak power per cavity*	4.18 MW
Forward power (3τ filling)	4.63 MW
Average power (0.2% duty factor)	8.36 kW

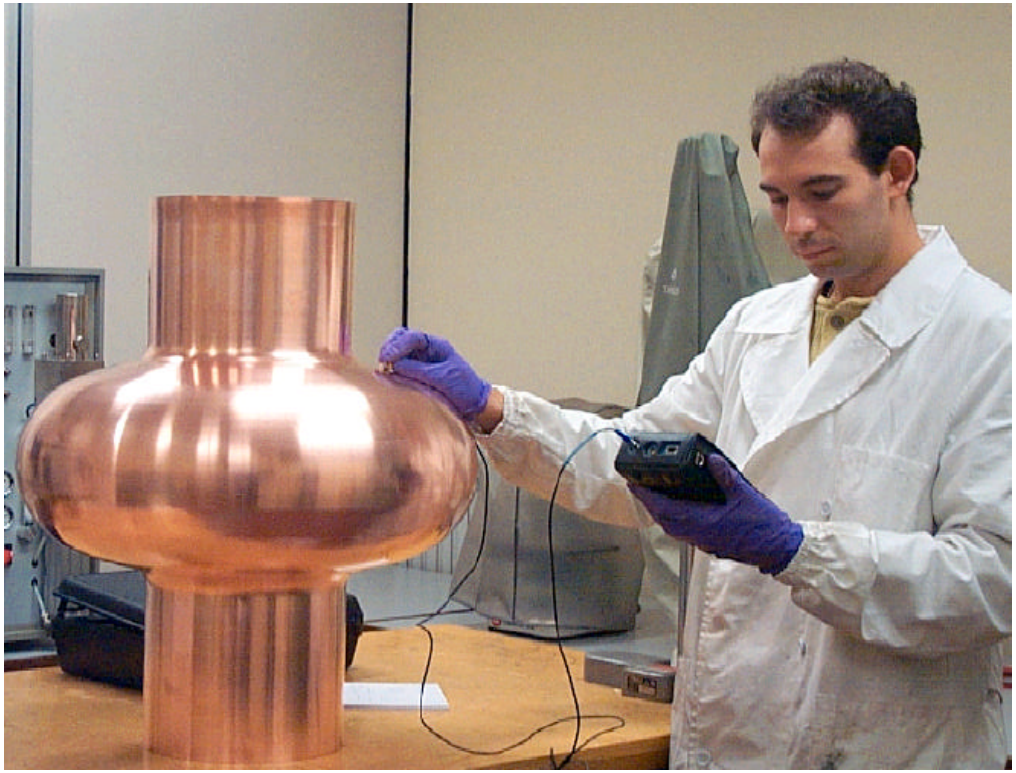
* assumes 85% of the theoretical Q_0



Cavity radius	61.0 cm
Cavity length	43.0 cm
RT^2 [MΩ/m]	21.7
Q_0	55,000

Thermal analysis by ANSYS code assuming 10 kW total RF heating power with water cooling for 21 cm radius and ~ 1.15 mm thickness Be window.

Vendor qualifications



Domestic and foreign vendors are identified

Left photo shows Spinning test at a 500 MHz cavity

(Picture courtesy of **Enzo Palmieri**, INFN, Italy)

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Modeling on grids

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- Why grids ?
  - Less scattering and good thermal conduction
  - Cheap
  - Robust

BUT, have to be able to

  - Terminate EM fields
  - Be physically realizable (how to make these grids without brazing joints)

- How well the grids terminate EM fields?
  - Grids have to be physically and electrically connected for good RF termination (i.e. to provide a conducting boundary for RF)
  - Grids can be excited and results field distortion in the cavity
  - MAFIA and ANSYS simulations agree well in frequencies and EM fields

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MAFIA Modeling on grids

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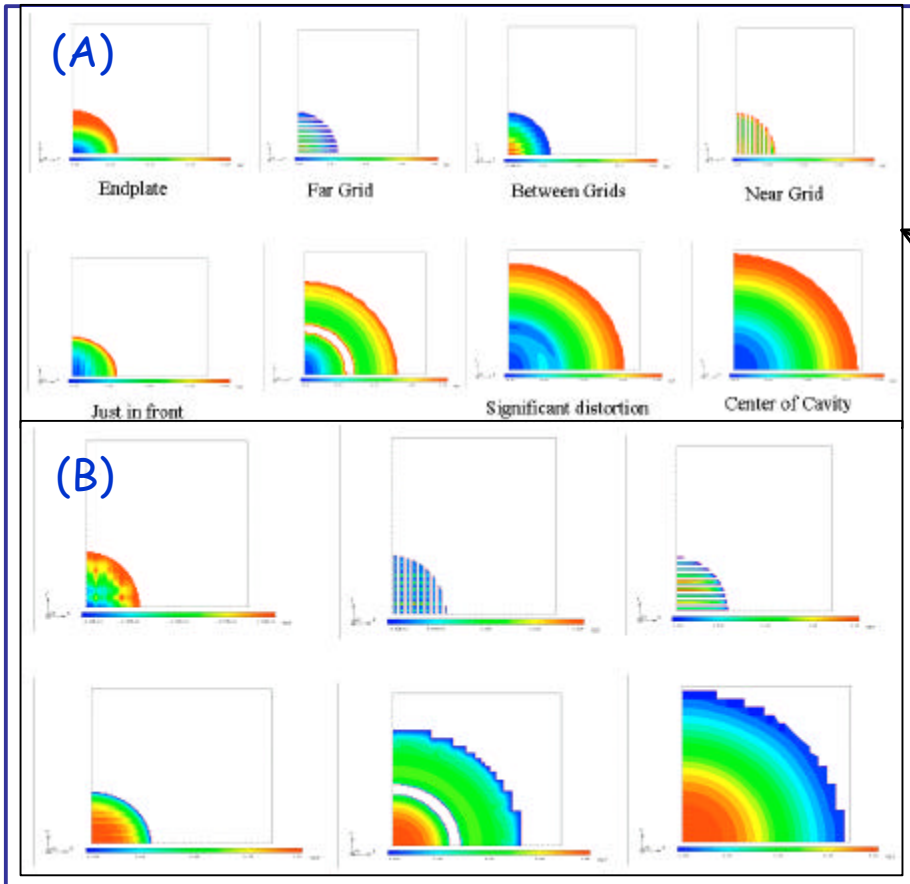
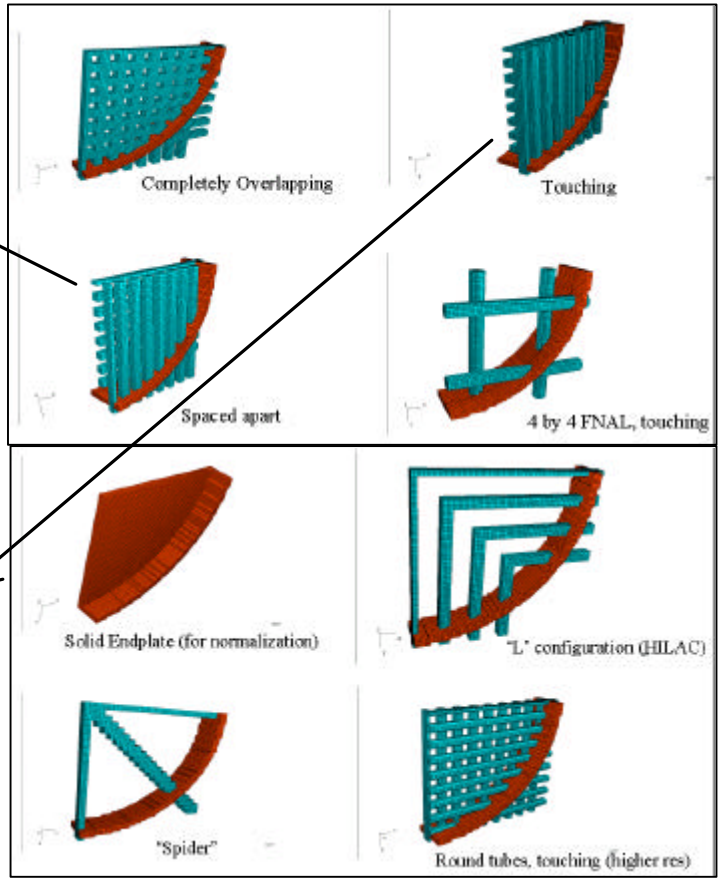


Ez field for spaced (A) and touching (B) grids



Grids configurations studied

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FEA Modeling on grids

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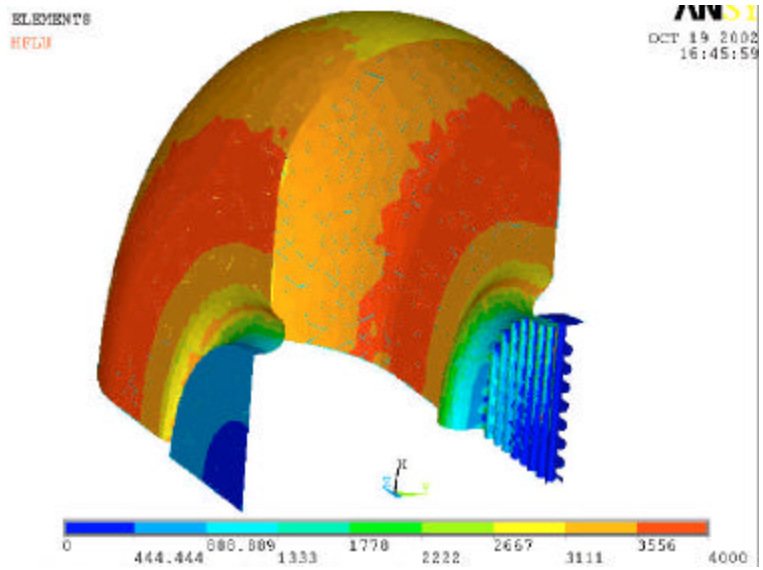
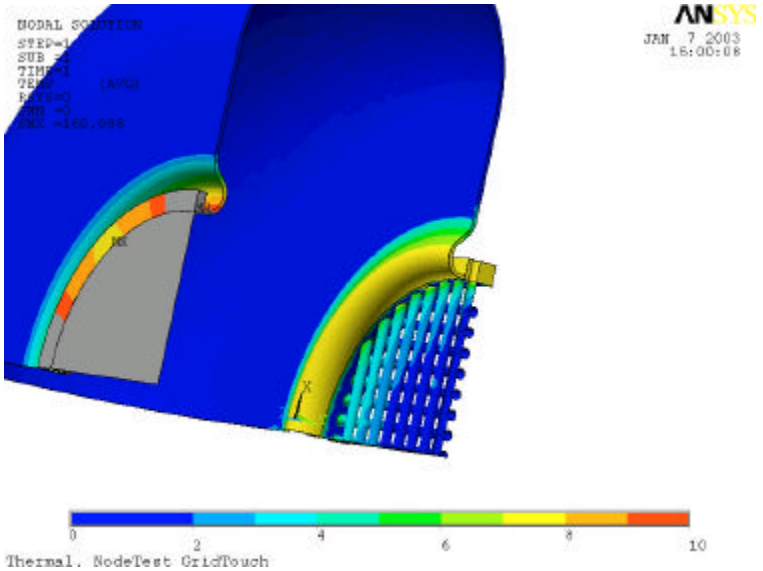


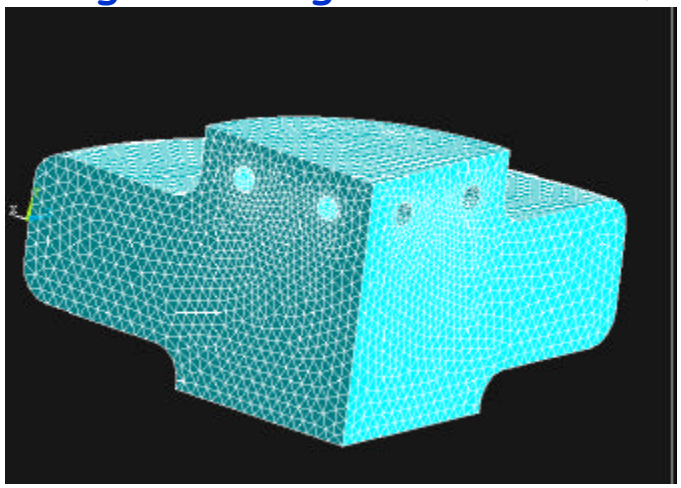


Surface magnetic field (heat flux) calculated using ANSYS

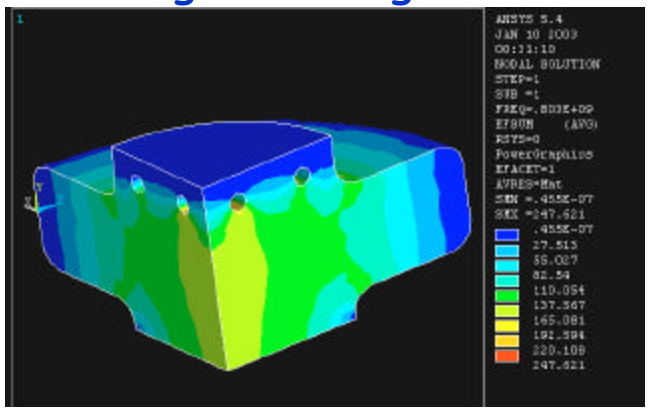
Temperature distribution based on the heat flux calculated by ANSYS code for 10 kW heating power

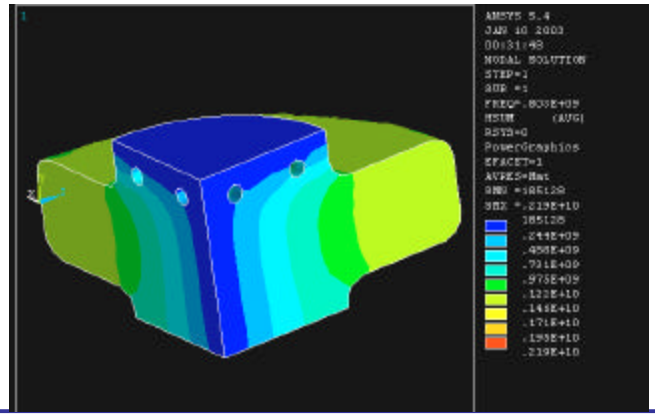
FEA Modeling on grids (cont'd)

M. Sharoa (Ph.D student, IIT) modeled 805 MHz closed cell cavity with grids using ANSYS code, and explored new grid configurations



Meshes for 805 MHz cavity with 4 by 4 grids





Contour plots of electric (up plot) and magnetic fields (lower plot), ready for thermal and mechanical modeling

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R&D Plans for FY03

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- Continue 805 MHz cavity with Be windows tests
  - with magnetic field
  - heat Be windows with different RF power
- Finishing data analysis of experimental results
- Window and cavity surface inspections
- Surface coating effects
- Start 201 MHz cavity prototype
  - qualify vendors
  - e-beam welding tests
  - spinning tests
  - explore non-stressed and pre-curved Be windows
- Start designs of RF coupler and tuners

Summary

- Significant progress on 805 MHz closed cell cavity tests for different windows at the conditions of with and without magnetic fields
- The cavity tests with TiN Be windows are in progress
- More experimental results will be produced → more to study and learn from these tests
- More results on data analysis (Dr. Y. Torun's talk)
- Completed 201 MHz cavity design for MUCOOL and MICE
- 201 MHz cavity prototype is ready to start
- Good progress on FEA modeling for grids (IIT and LBNL)
- Explore no-stressed and pre-curved Be windows (collaboration with Oxford University)