

High Intensity Neutrino Source R&D Program

- 325 MHz SC Spoke Cavities and Test Facility -

**Superconducting RF Infrastructure Review
February 2007
Bob Webber**

Outline of This Talk



- **Overview of High Intensity Neutrino Source (HINS) Front-End R&D Objectives and Facilities**
- **325 MHz superconducting (SC) spoke cavity requirements, plans, and status**
- **SC spoke cavity test cryostat status**
- **HINS Meson Detector Building facility and status, including 325 MHz RF system**
- **Concept, role, and status of ferrite vector modulator for high power RF control**
- **Status of Room Temperature (RT) accelerator components as front-end for SC spoke cavities**
- **Conclusion**

Accelerator Physics Focus of HINS R&D



Three unique concepts addressed by HINS Front-End R&D:

- **Transition to SC cavities for non-relativistic H⁻ ions at 10 MeV**
 - Develop, design, and fabricate high-gradient, SC spoke structures
 - Demonstrate control of Lorentz de-tuning with this type cavity under conditions of pulsed high-power RF
 - Demonstrate first acceleration of beam in this type of structure
- **Use of a single, high-power RF source to drive multiple cavities, both room-temp and SC, for a non-relativistic beam**
 - Develop, design, and fabricate ferrite vector modulators for high power RF control
 - Demonstrate amplitude/phase control of multiple cavity system at high power
- **Use of solenoidal optics to >60 MeV for beam halo control**
 - Demonstrate proof-of-principal of beam quality improvements

HINS R&D Program Facilities Overview



To address accelerator physics questions for a new concept, low-energy superconducting Linac we will construct and test key components and integrate them into a demonstration accelerator in Meson Detector Building

- Pulsed 2.5 MW, 325 MHz klystron RF power source
- 325 MHz high power RF component test facility for studying RF power control devices
- Test stand for 325 MHz RT cavities and a test cryostat for 325 MHz SC spoke cavities
- Ion source and RFQ as a 2.5 MeV beam source
- 10 MeV Room Temperature Linac
- Three 325 MHz SC spoke cavity cryomodules
- All accelerator sections to be operated with beam up to 60 MeV to verify and quantify performance

This all adds up to building and operating a first-of-its-kind superconducting 60 MeV H- linac

325 MHz Superconducting Cavities



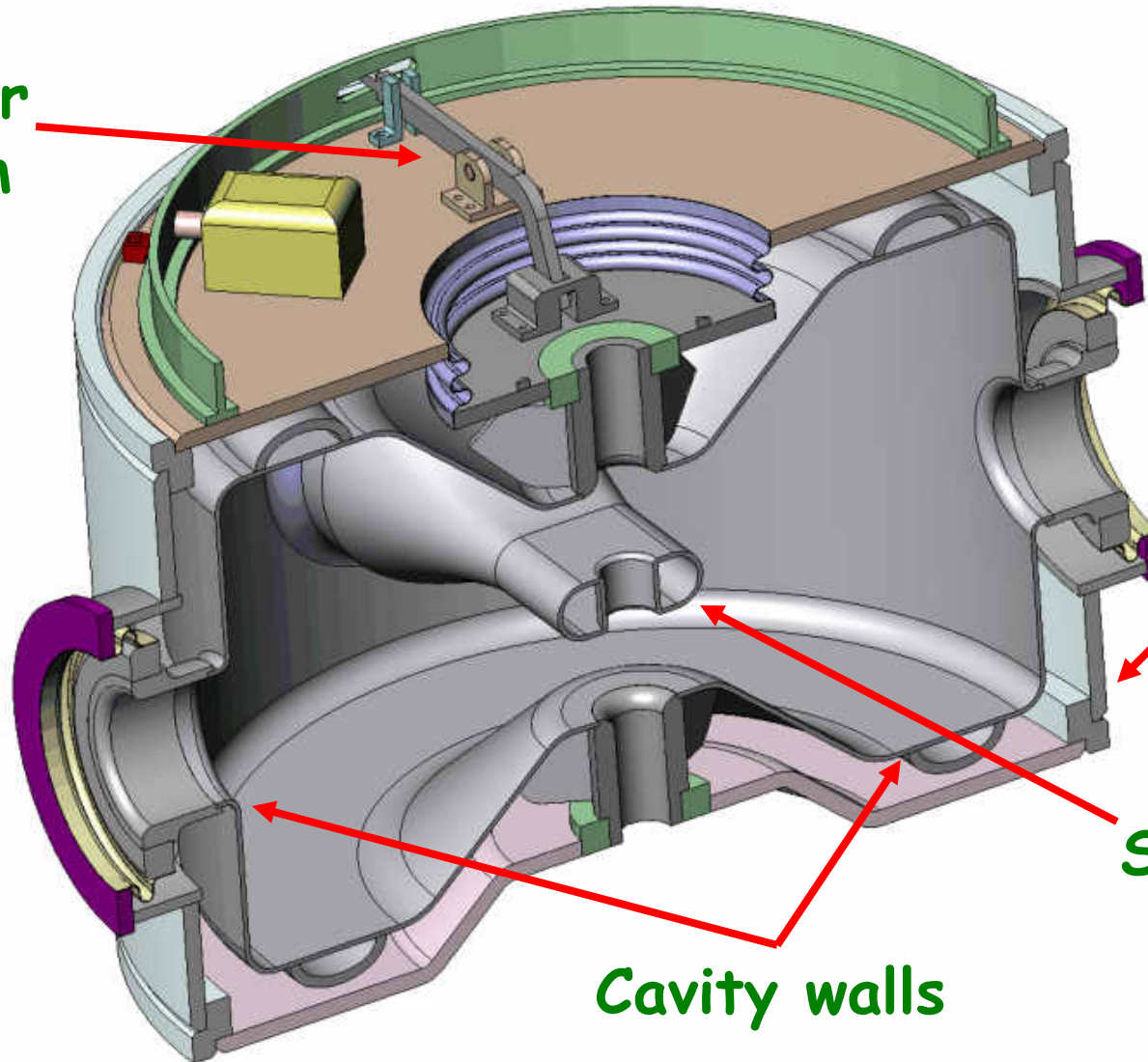
- **HINS Front-End R&D project requires 29 SC spoke cavities in three cryomodules**
 - **Two cryomodules of nine SSR1 $\beta=0.22$ cavities each and one of eleven SSR2 $\beta=0.4$ cavities**
 - **Nominal 11.5 MV/m accelerating voltage**
 - **30 MV/m peak surface field**
- **The plan is for cavities to be:**
 - **Built by industry and/or Inter University Accelerator Centre, New Delhi, India (in negotiations)**
 - **Processed at ANL**
 - **Fitted in He vessel at ANL or FNAL**
 - **Cryo and RF power tested in test cryostat at FNAL MDB***
 - **Assembled into cryo string at FNAL MP9 CAF**
 - **Installed into cryomodule at FNAL Industrial Center Building**
- **Cryomodule tests will be at FNAL MDB***

***Note: FNAL MDB offers the only high power 325 MHz RF source**

3D Model of $\beta=0.22$ cavity/vessel



Slow-tuner
mechanism



Helium
vessel

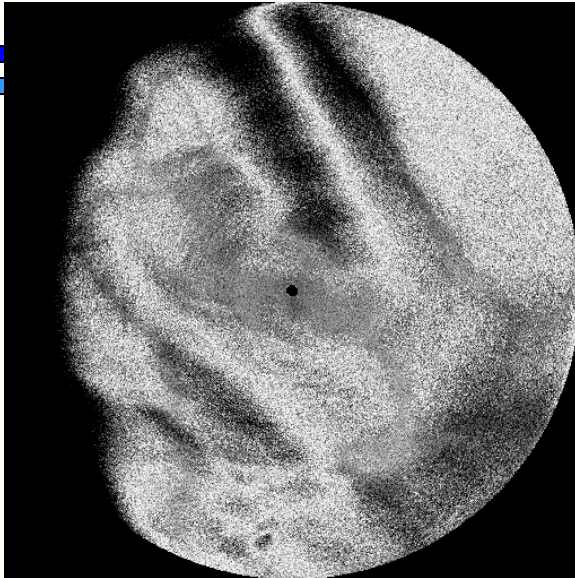
Spoke

Cavity walls

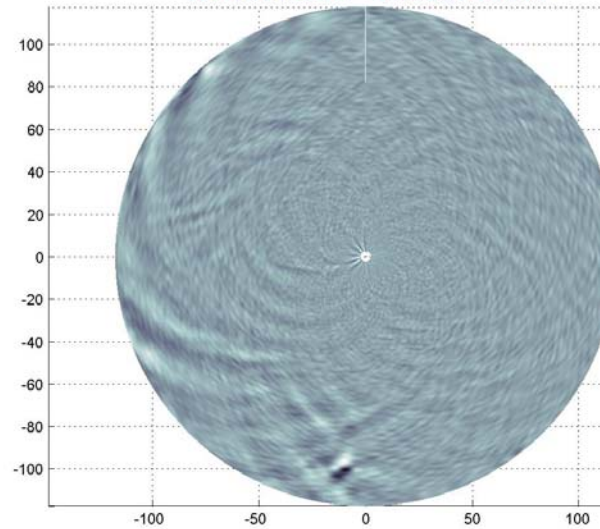
HINS Utilization of Eddy Current Scanner



Fermilab

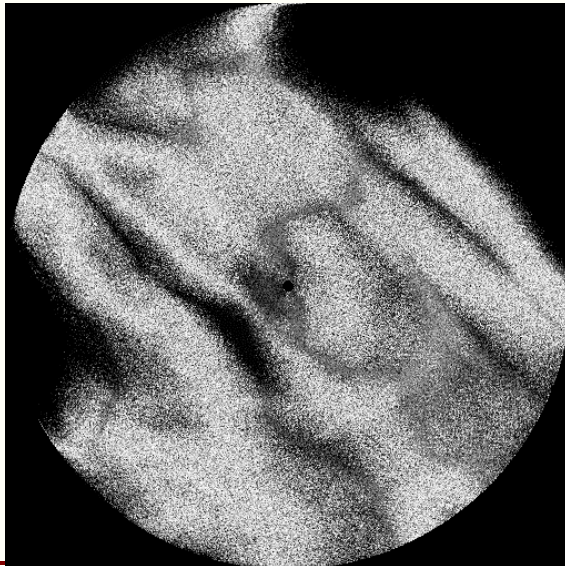


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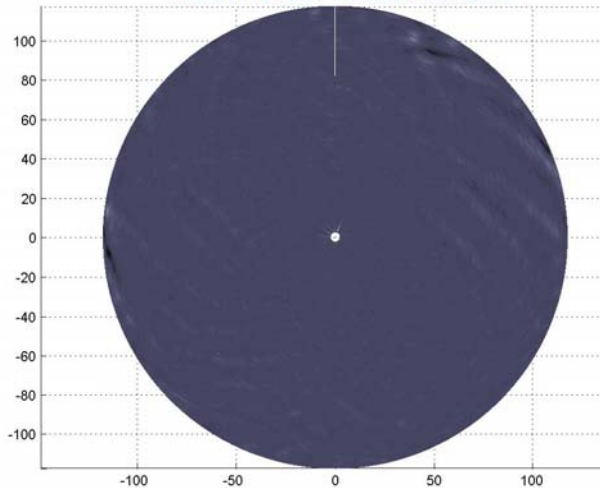


The scanning results do not show any remarkable features except for two: on side 1, close to the outer rim at the 6:00 position is a signal which could be given by a smooth and shallow, but several mm wide depression that we could identify by visual inspection. The other feature, especially visible after filtering on side 2 are faint lines parallel to the edges, probably micron size “ripples” on the surface perpendicular to the rolling direction. We believe that both those features are not detrimental to RF operation. – Pierre Bauer

Square 1 sides 1&2, run 3, scan left, filter right



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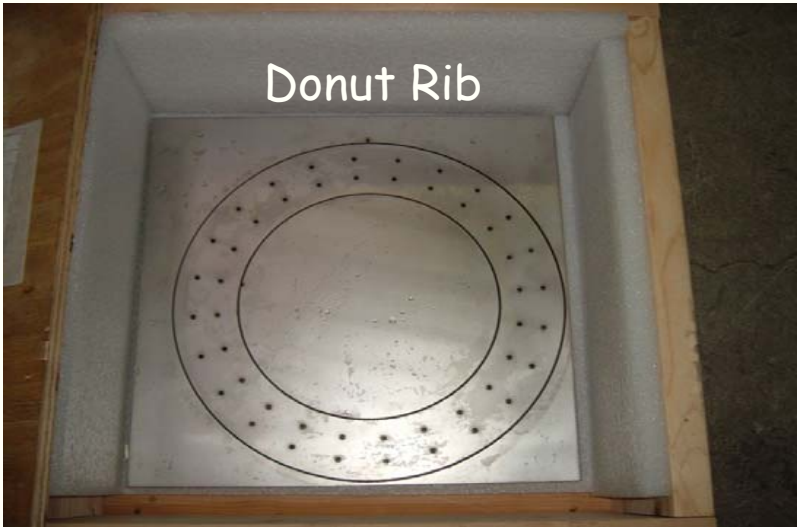
February 13-14, 2007

325 MHz Superconducting Cavity Status



- **Two $\beta=0.22$ cavities are presently in fabrication**
 - **One at Zanon in Italy**
 - **One at Roark Welding and Engineering in Indiana**
- **Delivery from Zanon of first single-spoke niobium fabrication is expected around end of March 2007**
- **Roark is learning the niobium fabrications technology; that cavity will come a few months later**
- **Design of helium vessel is nearing completion in FNAL Technical Division**
- **Parts for prototype of slow tuner are on-hand and assembled for testing at cryogenic temperatures on “dummy” cavity**
- **Design of fast tuner is in early stages at FNAL**

Zanon - Water Jet Cut of Reactor Grade Niobium



Zanon – Formed Parts



Outer Shell



Spoke Collars

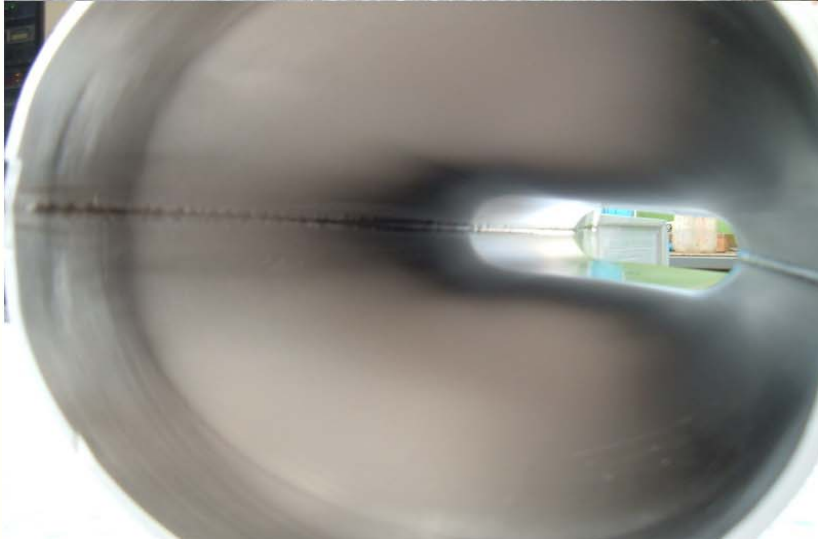


Outer
End Wall

Half-spokes
and Inner End
Wall



Zanon – spoke weldment



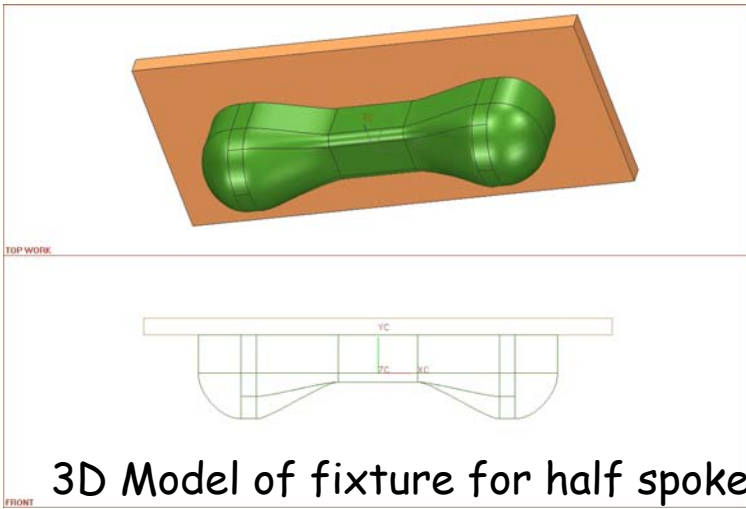
*FNAL
325 MHz single spoke resonator*

Welded spoke

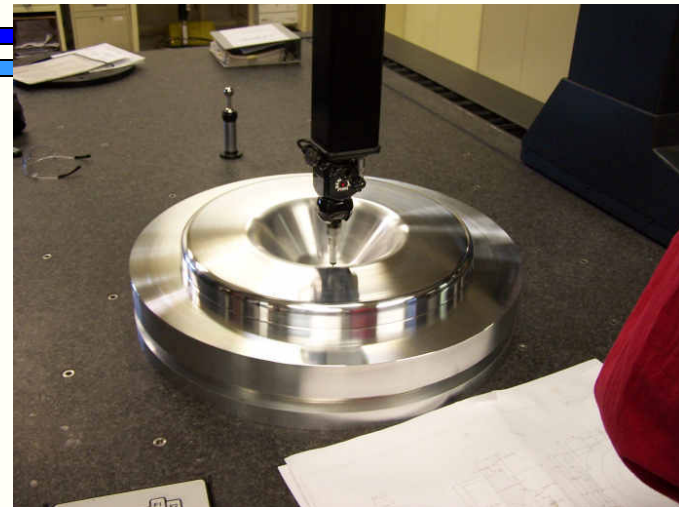


E.ZANON S.p.A.

Roark Progress



3D Model of fixture for half spoke forming



CMM check of end wall fixture



Weld Sample



Beam pipe and power coupler brazed transitions (ANL)

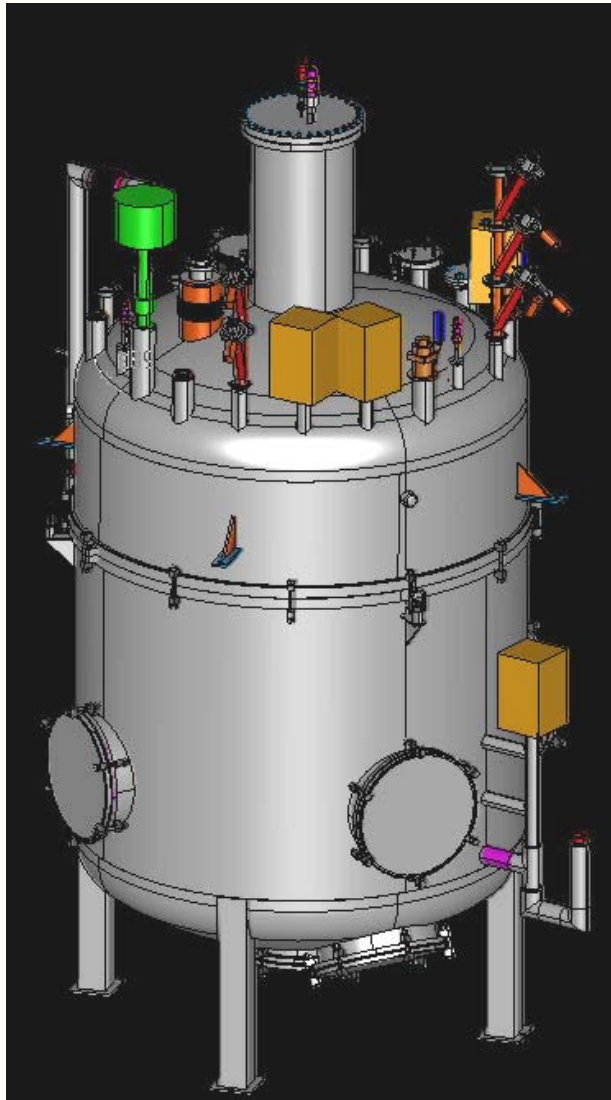


Spoke Cavity Testing -Test Cryostat

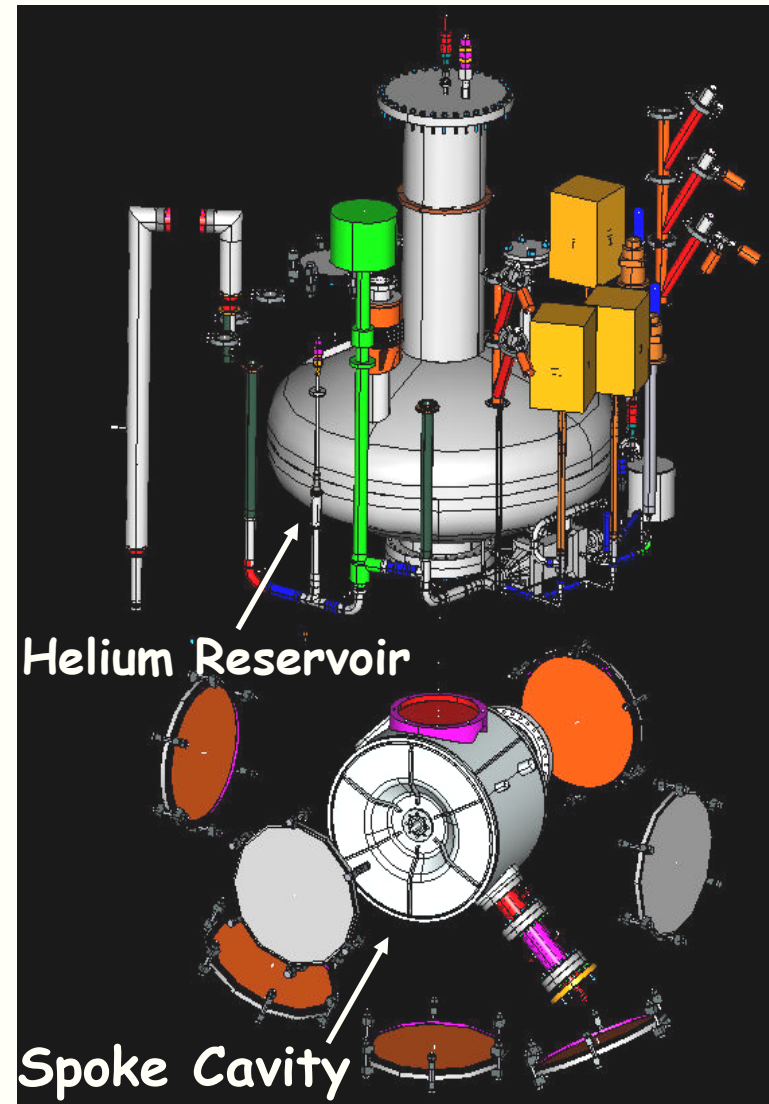


- **Cryostat is based on concepts of Ken Shepard for ANL- RIA**
 - **Sized for any HINS spoke cavity, including triple-spoke**
 - **Designed for full, pulsed power cavity testing**
 - **Designed to house solenoid focusing magnet as well as cavity under test (to check for magnetic field effects)**
 - **Capable of supporting 2°K operation if necessary**
- **Design is complete and procurement package is ready, but on-hold due to budgetary constraints**
- **Will operate off existing Meson cryo plant**
- **Cryogenics transfer line design underway**
- **12-14 month fabrication/installation time anticipated before ready to accept cavities**

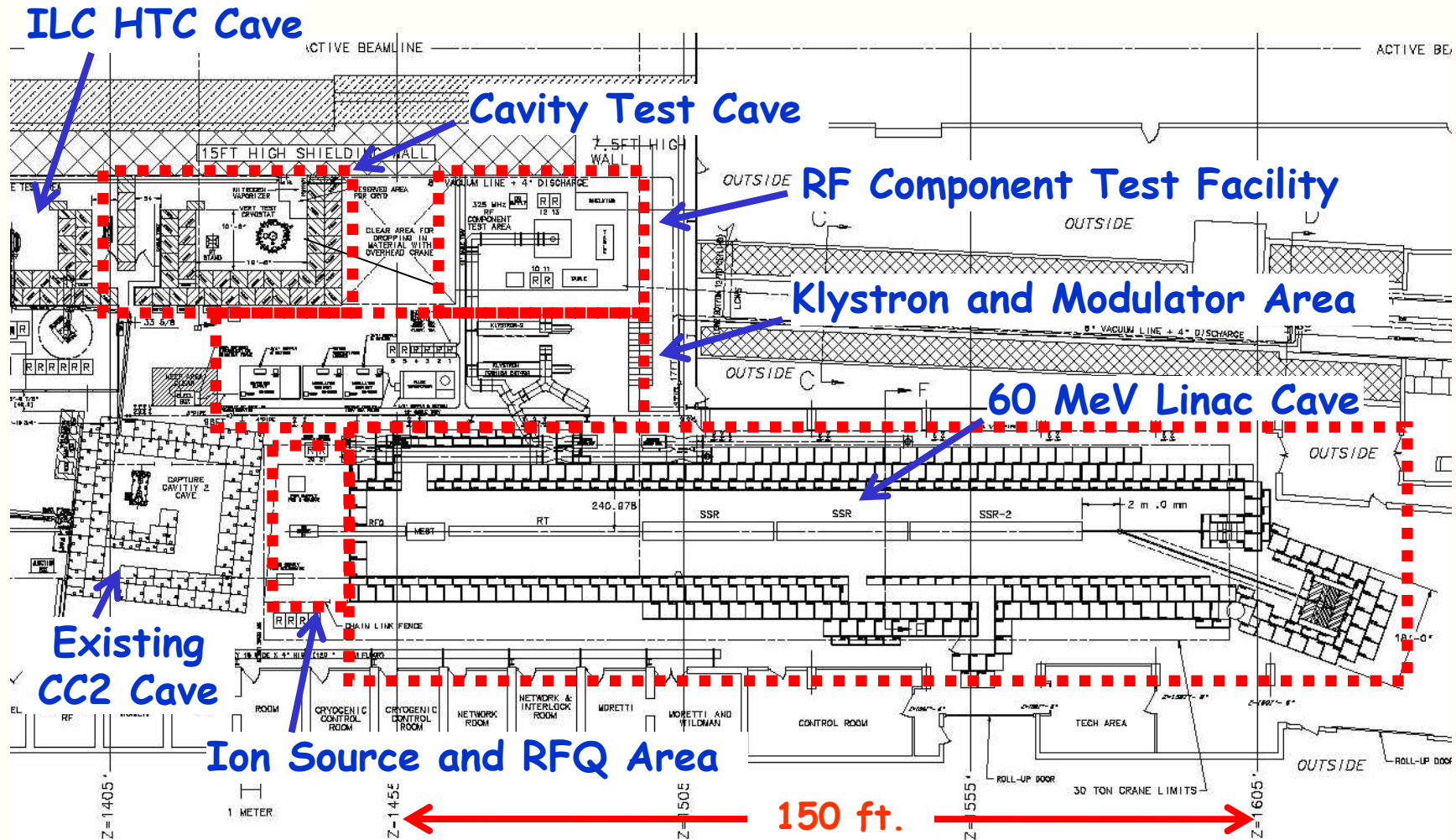
Test Cryostat Solid Model



10 ft.



HINS Floor Plan in Meson Detector Building



325 MHz RF System



- **Specifications:**
 - **325 MHz**
 - **2.5 MW modulator/klystron system**
 - **4msec pulse length and 1.5% duty factor**
- **Utilities and infrastructure in are place**
- **Modulator is installed and tested into resistive load; final interlock check-out is proceeding**
- **Klystron is installed as is waveguide to the test load and into the RF component test cage**
- **RF power transmission lines to cavity test cave are now being installed**
- **Anticipate RF power from klystron within 6 weeks**

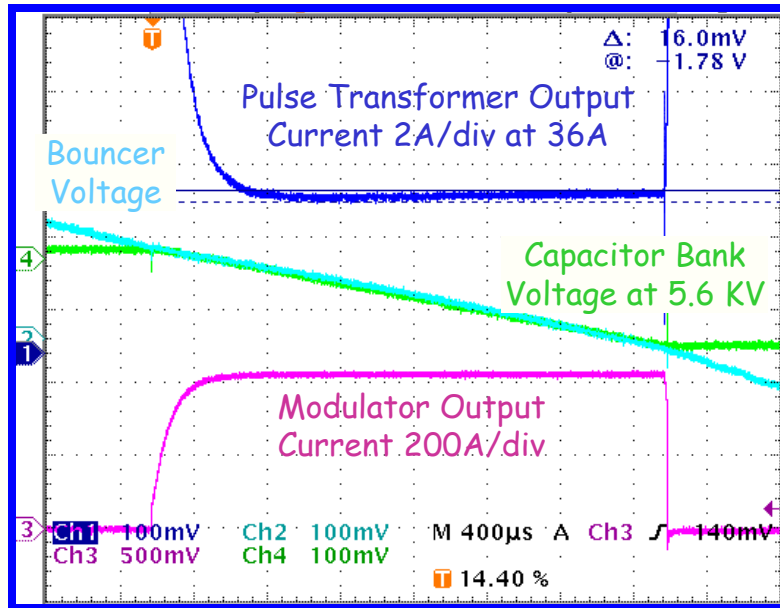
Toshiba 325 MHz 2.5 MW Klystron



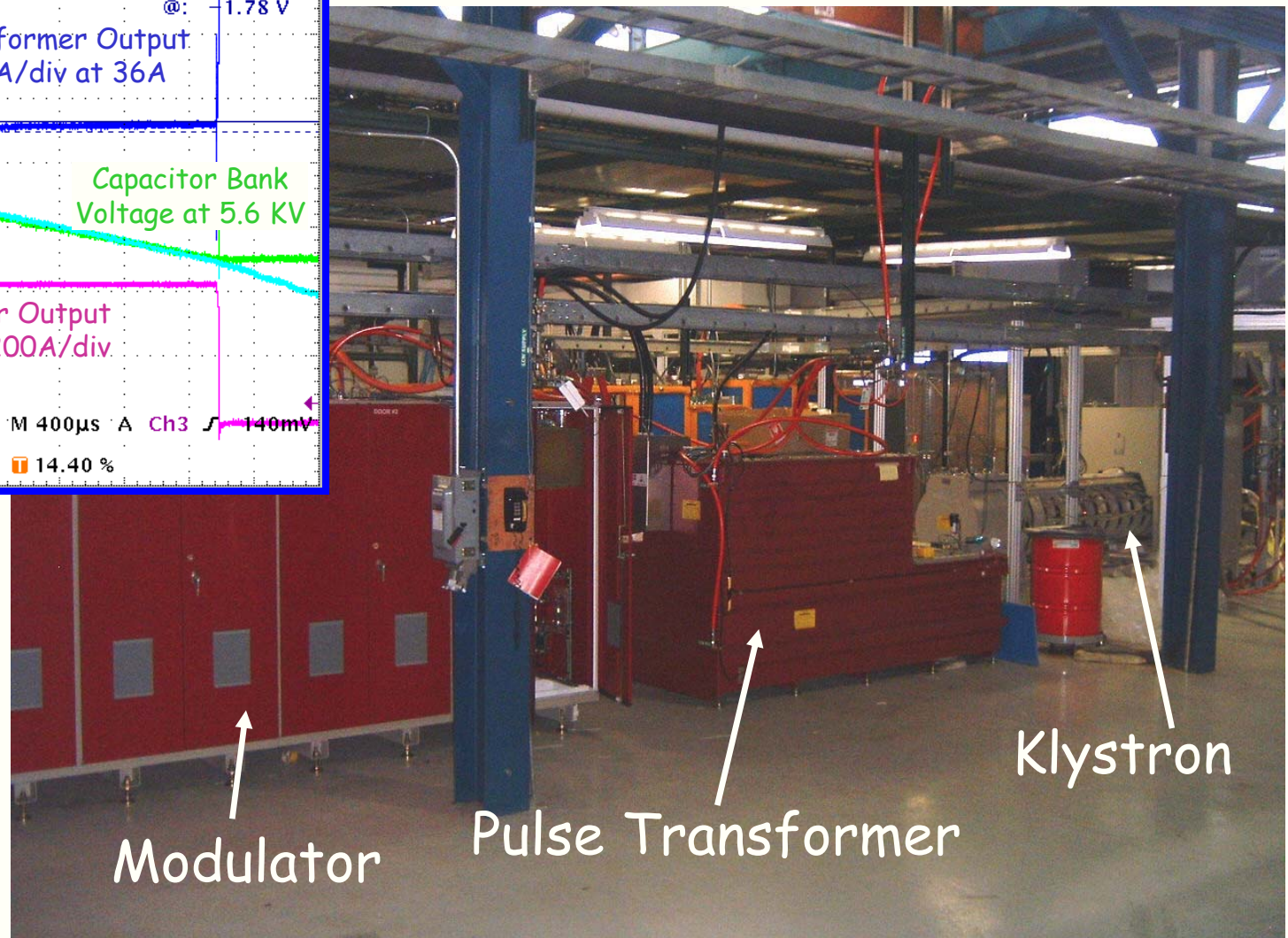
Klystron and Waveguide Installation



Modulator and Pulse Transformer



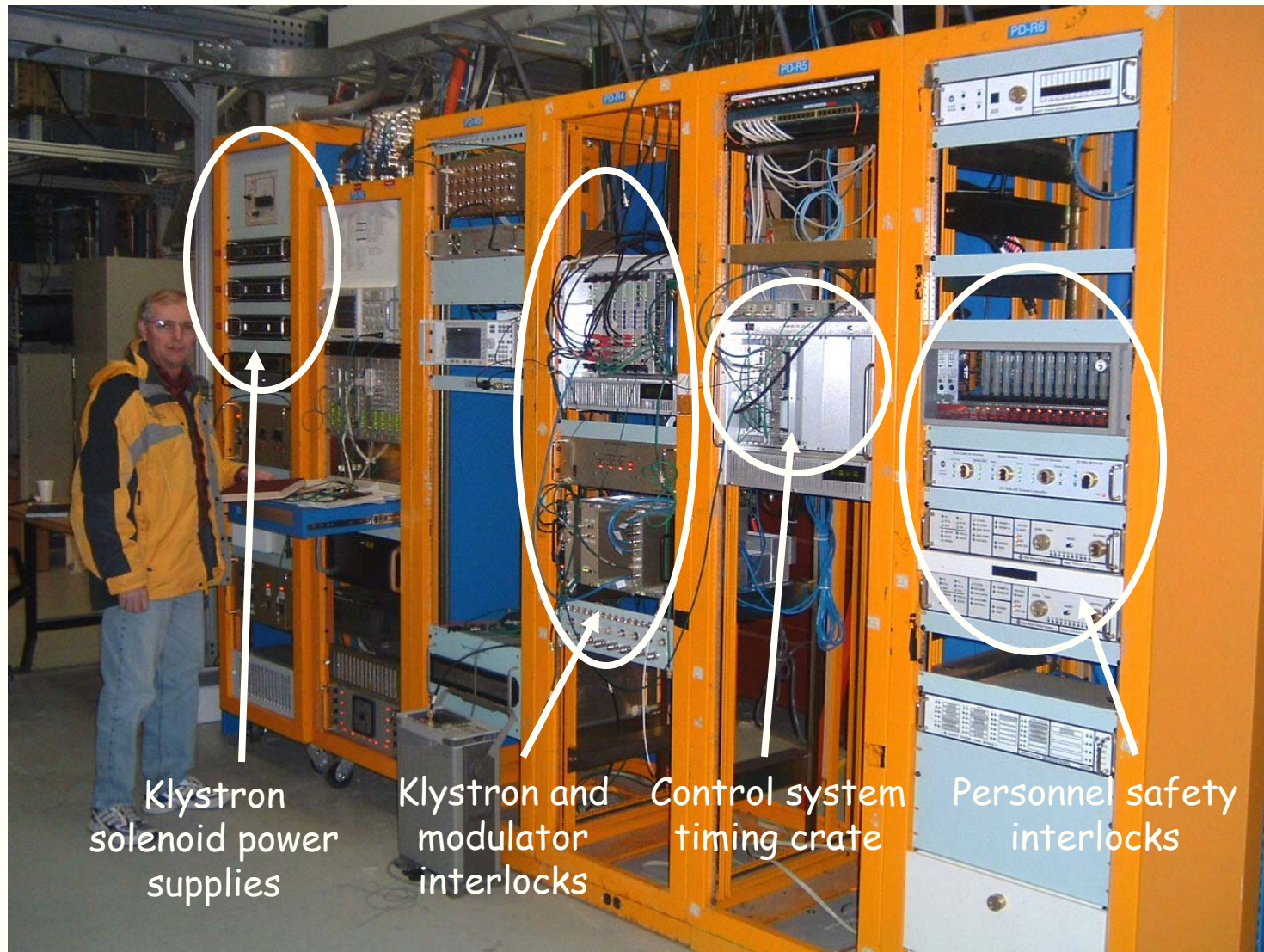
Modulator Signals at
5.6 KV into
Resistive Load
February 2, 2007



RF Component Test Area Cage



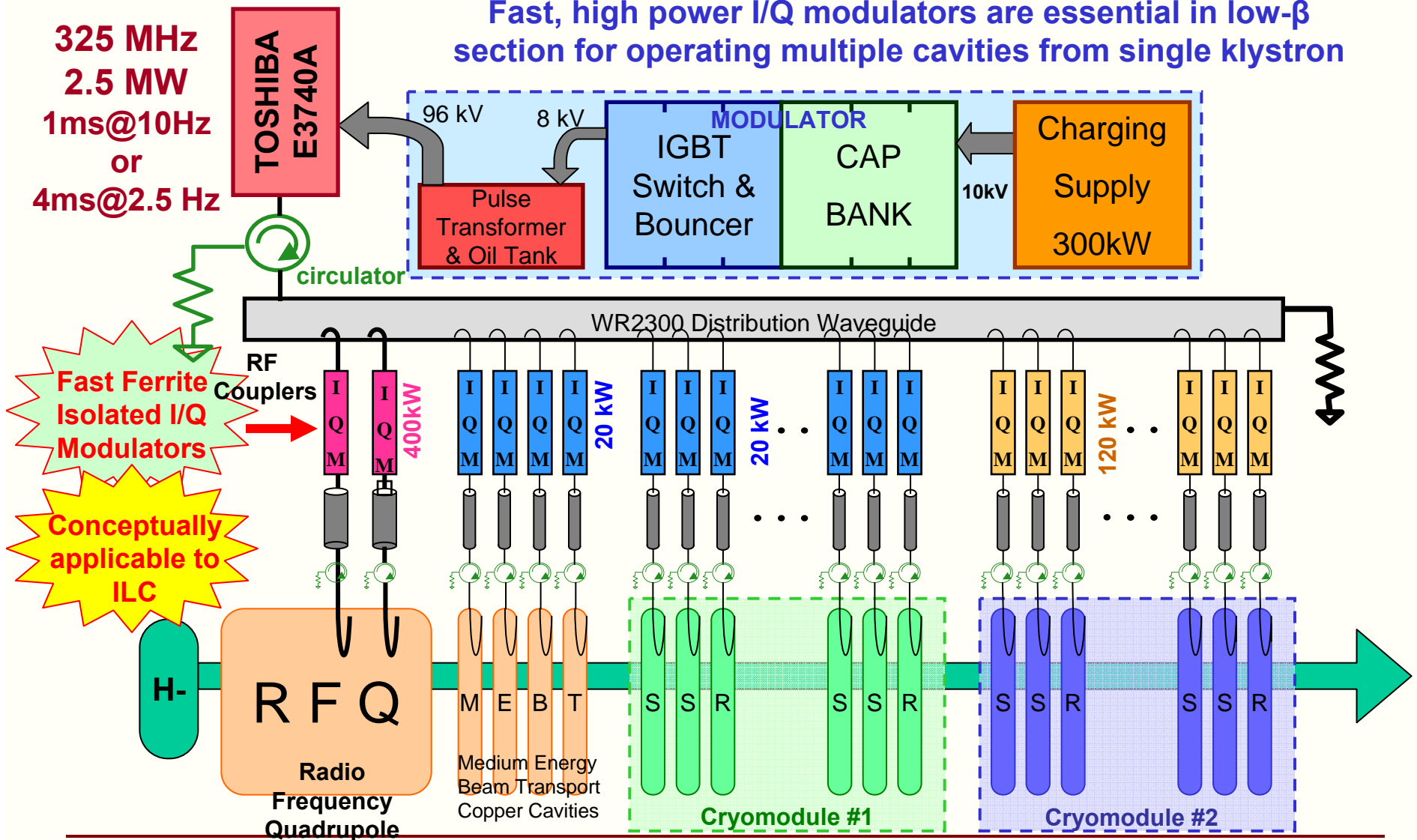
Electronics Installed



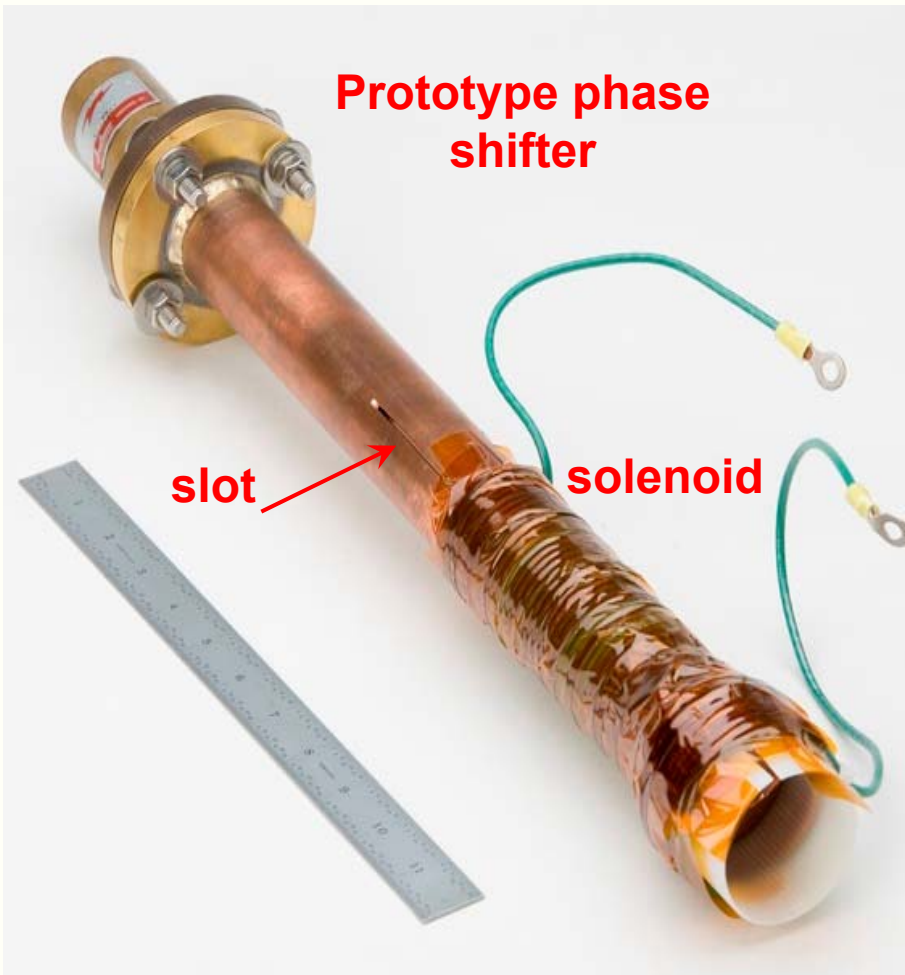
High Power Amplitude/Phase Control



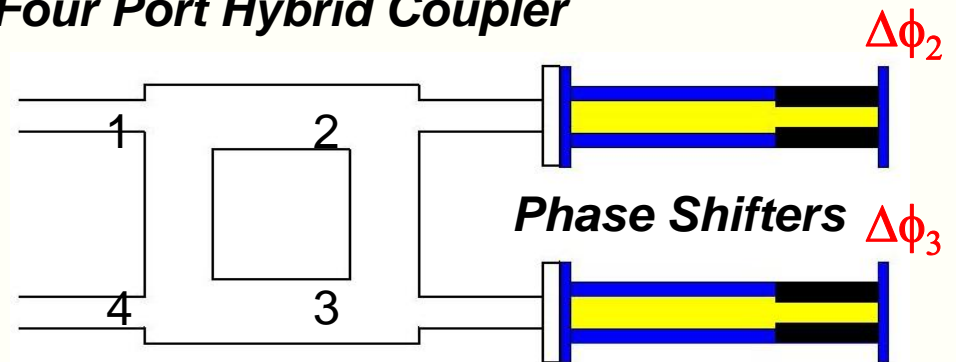
Fast, high power I/Q modulators are essential in low- β section for operating multiple cavities from single klystron



Ferrite Vector Modulator



Four Port Hybrid Coupler



Independently modulates phase and amplitude:

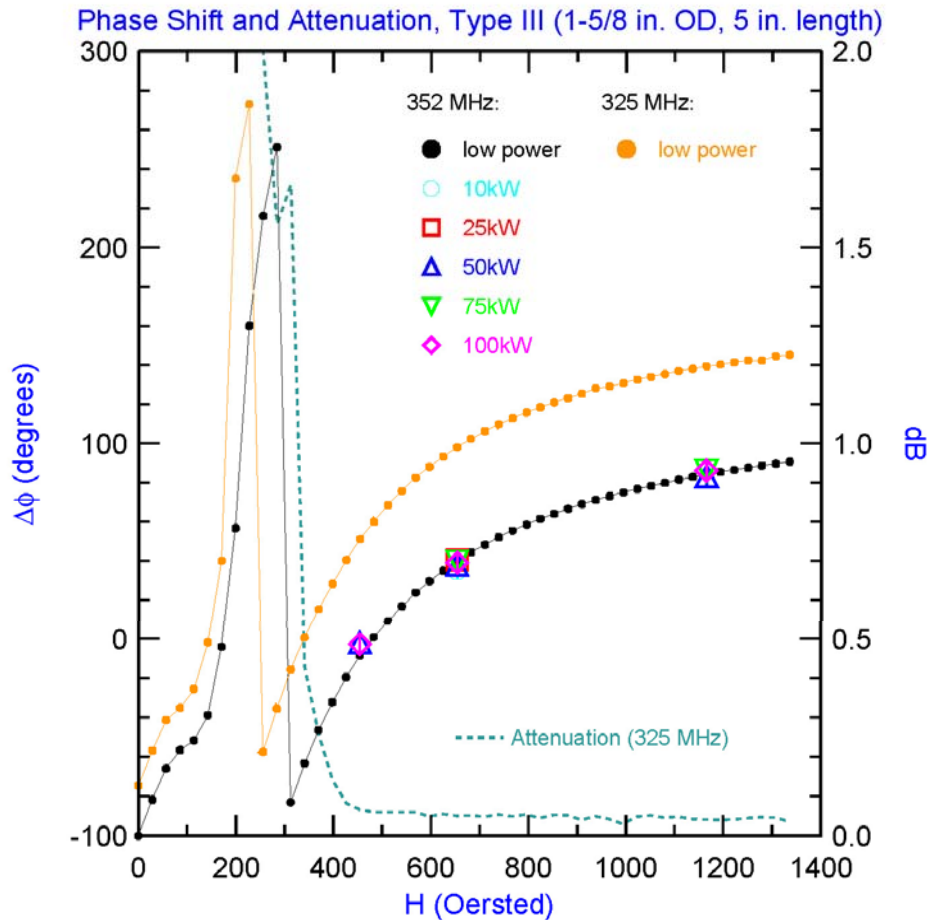
With $\Delta\Phi = (\Delta\phi_2 - \Delta\phi_3) / 2$

$\Sigma\Phi = (\Delta\phi_2 + \Delta\phi_3) / 2$

Output power $\sim \cos^2(\Delta\Phi)$

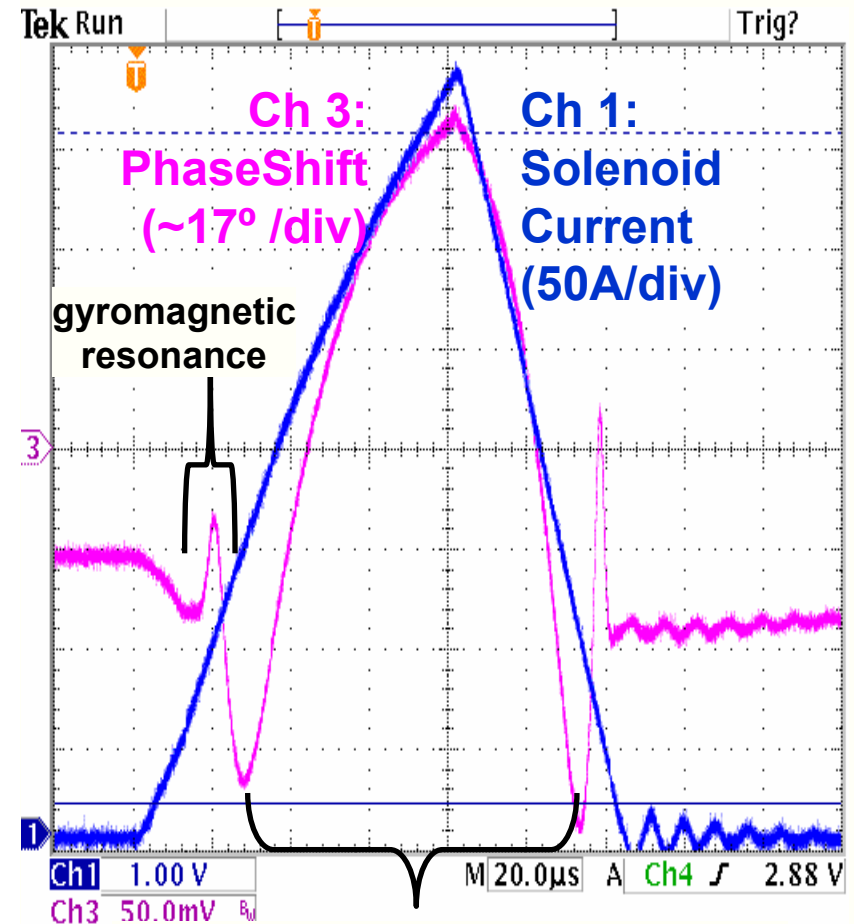
Phase shift $\sim \Sigma\Phi + 3\pi/2$

Phase Shifter High & Low Power Performance



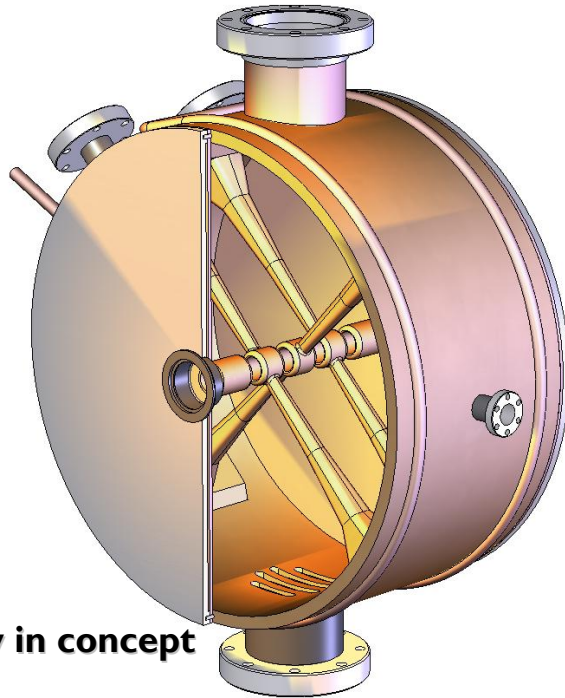
352 MHz power tests at ANL

325 MHz operation frequency



useful phase shift range - low loss
average slew rate 2.2°/usec
(initial spec is 1/usec)

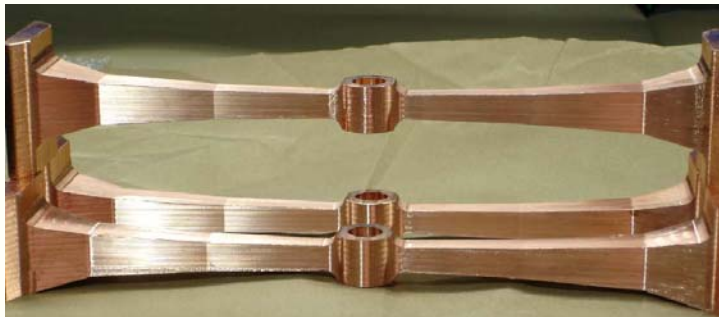
HINS Room Temp Cavity in Production



Cavity in concept



Body wall roughed in and annealed.

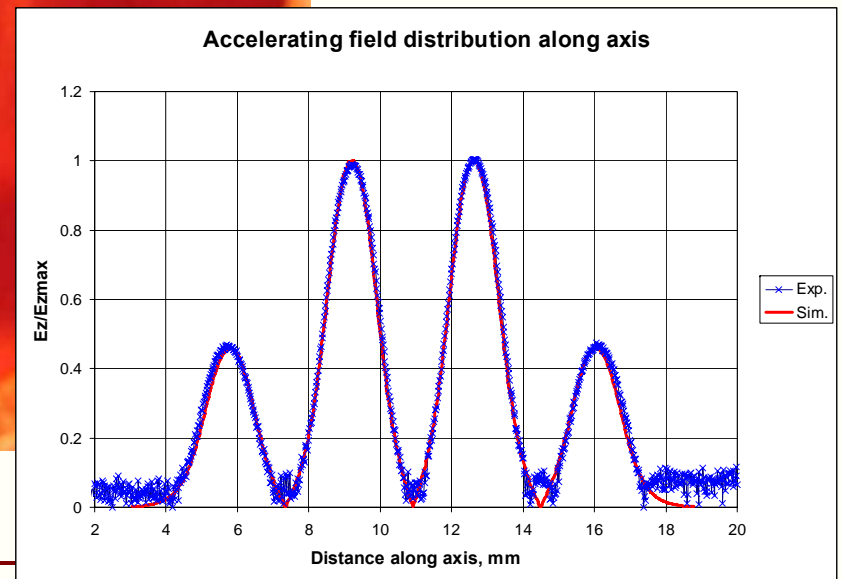
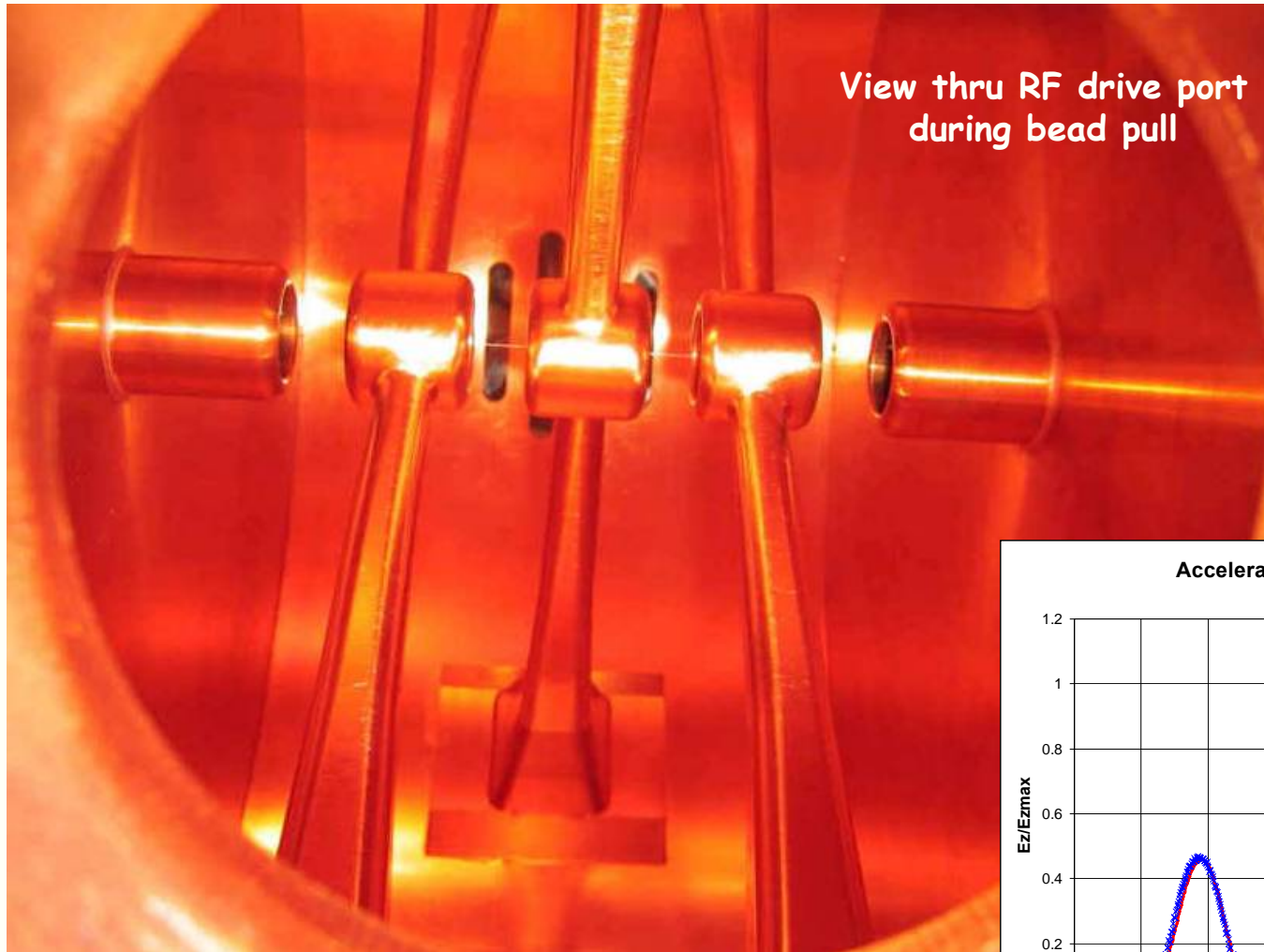


Copper spokes rough machined and annealed



Brazed cavity before welding end walls

Bead Pull thru Completed RT CH-01



HINS R&D Near-Term Schedule Goals



- **325 MHz RF power system commissioning**
 - **February or March 2007**
- **Component testing in RF test area**
 - **Starting April 2007**
- **Room Temp cavity full power tests**
 - **Starting April 2007**
- **Procurement of Test Cryostat**
 - **Spring 2007**
- **Delivery of first SC spoke cavity from Zanon and beginning of processing at ANL**
 - **April 2007**
- **Delivery and power testing of RFQ (now in fabrication)**
 - **Late summer 2007**
- **2.5 MeV beam tests**
 - **By end of 2007**

HINS R&D Schedule Goals



- **Superconducting cavity test cryostat installation**
 - **Early 2008**
- **First SC spoke cavity power tests in test cryostat**
 - **Spring 2008**
- **Linac cave construction and utilities installation**
 - **Starting October 2007**
- **Demonstration of independent RF amplitude & phase control of multiple Room Temperature cavities on single klystron**
 - **October 2008**

Conclusion



- A program to address key accelerator physics and technology questions of a new concept, low-energy superconducting Linac has been described
- There is much progress on 325 MHz SC spoke cavities
 - $\beta=0.2$ design is complete, except fast tuner
 - First $\beta=0.2$ SC cavity fabrication due end of March
- ANL is on tap to do SC spoke cavity chemical processing
- Test cryostat for spoke cavities is ready for procurement
- First RT cavity is on-hand and nearly ready for power tests
- 325 MHz RF power system is installed, modulator is being commissioned, a RF component test facility is being built
- A facility to support testing 325 MHz SC spoke cavities and cryomodules with and without beam is under construction
- Availability of a Fermilab SCRF Cryostring Assembly Facility (shared with ILC) is a key requirement for HINS Front-End R&D cavity string and cryostat assembly