High Intensity Neutrino Source R&D Program

- 325 MHz SC Spoke Cavities and Test Facility -

Superconducting RF Infrastructure Review
February 2007
Bob Webber

Outline

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- Overview of High Intensity Neutrino Source (HINS) R&D Objectives and Facilities
- 325 MHz superconducting (SC) spoke cavity requirements, plans, and status
- SC spoke cavity test cryostat
- 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

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Three unique concepts addressed by HINS 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 >100 MeV for beam halo control**
  - Demonstrate proof-of-principal of beam quality improvements

HINS R&D Program Facilities Overview

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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 65 MeV to verify and quantify performance**

This all adds up to building and operating a first-of-its-kind superconducting 65 MeV H- linac

325 MHz Superconducting Cavities

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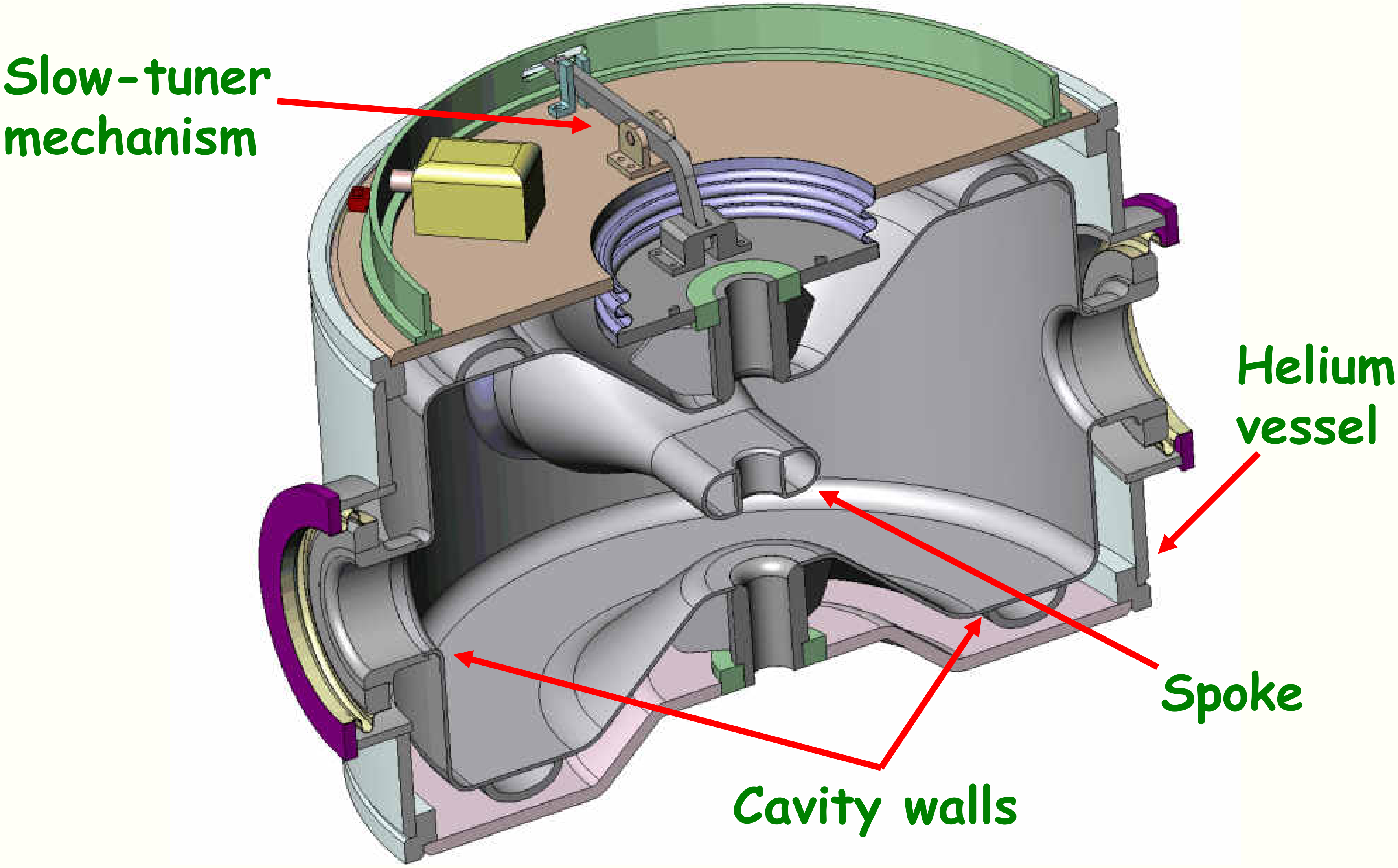
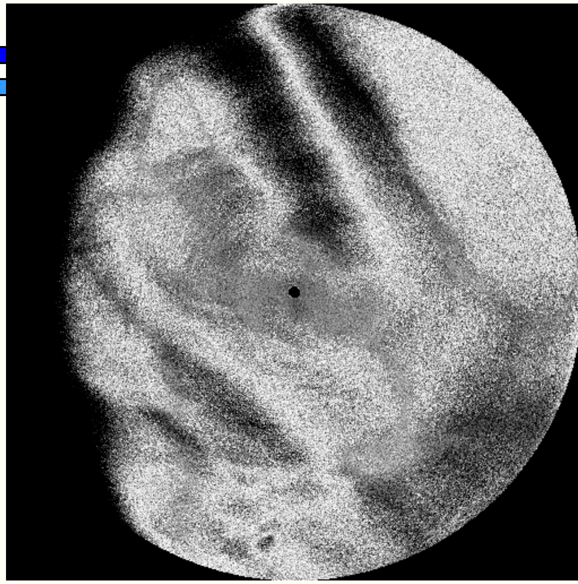
- HINS R&D project requires 29 SC spoke cavities in three cryomodules
  - Two cryomodules of nine SSR1 β=0.22 cavities each and one of eleven SSR2 β=0.4 cavities
    - Nominal 11.5 MV/m accelerating voltage
    - 30 MV/m peak surface field
- The plan is for cavities to be:
  - Built by industry and/or 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*

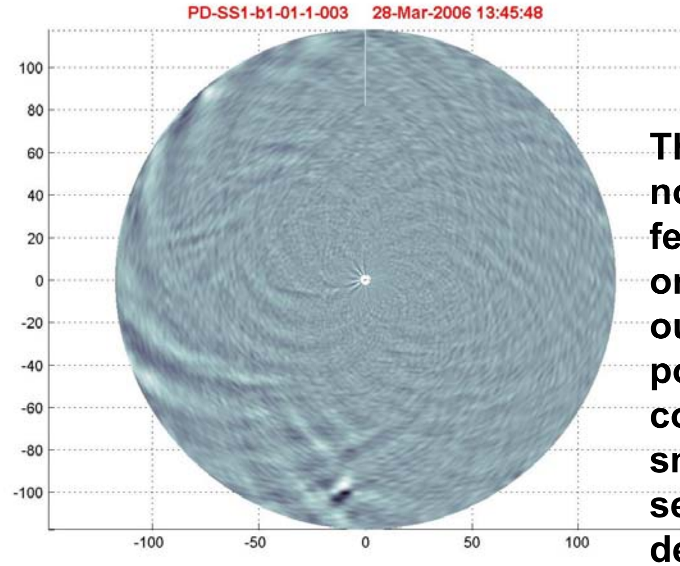
*Note: FNAL MDB offers the only high power 325 MHz RF source

3D Model of β=0.22 cavity/vessel

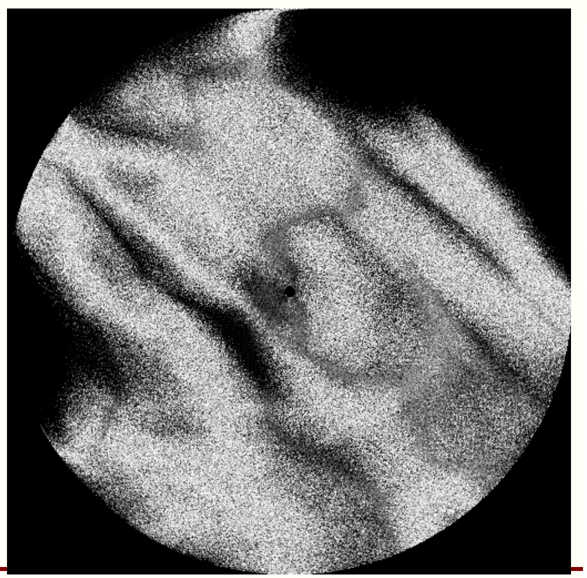


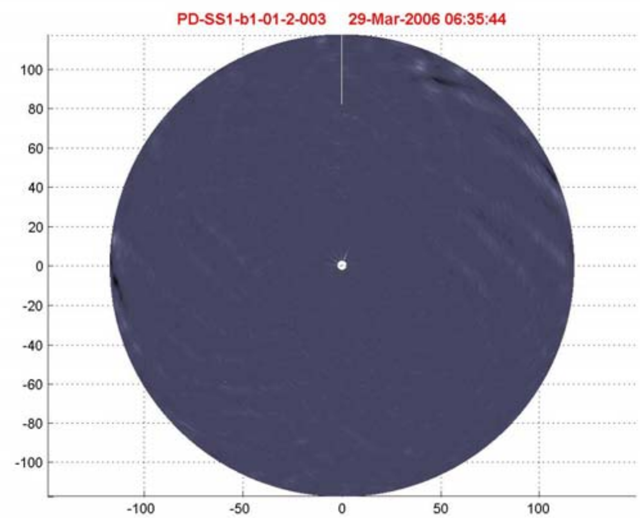
HINS Utilization of Eddy Current Scanner





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



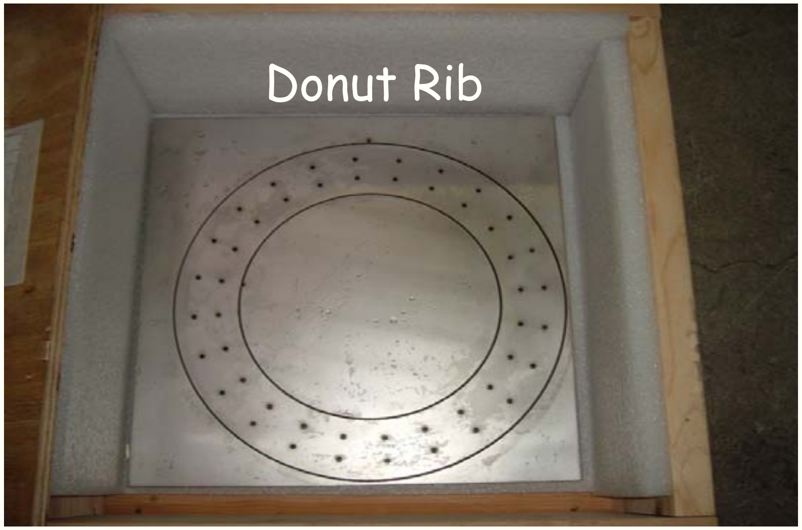


The scanning results do not show any remarkable features except for two: on side 1, close to the outer rim at the 6:00 position is a signal which could be given by a smooth and shallow, but several mm wide depression that we could identify by visual inspection. The other feature, especially visible after 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

325 MHz Superconducting Cavity Status

- Two β=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

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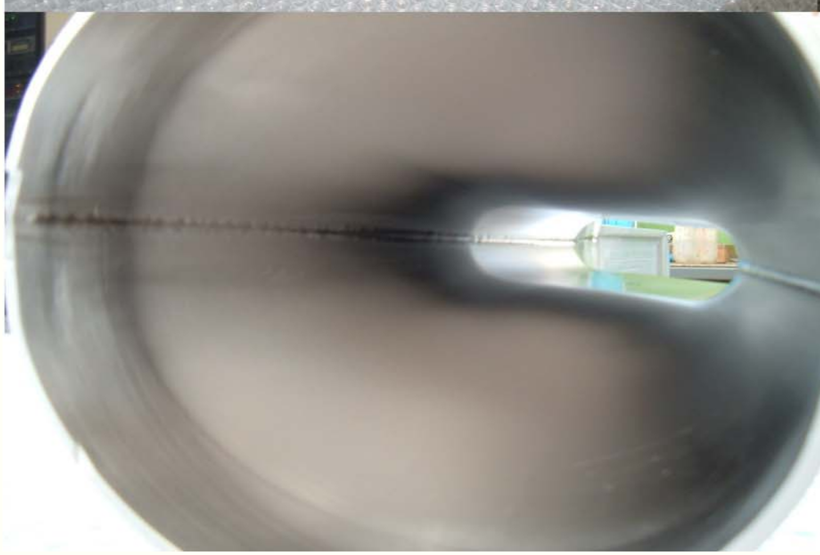


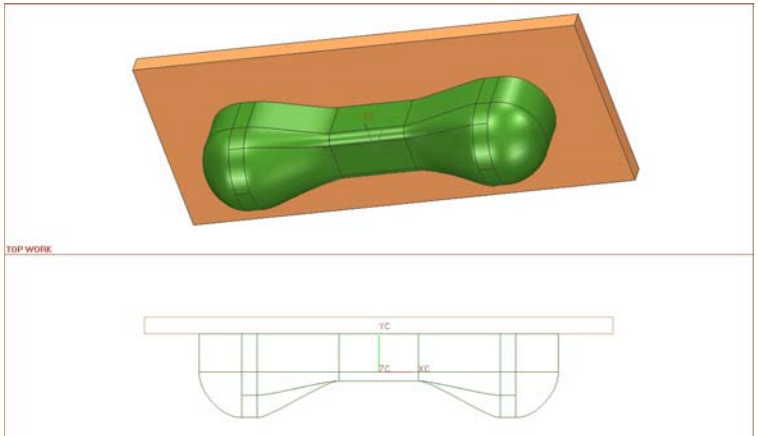
FNAL

325 MHz single spoke resonator

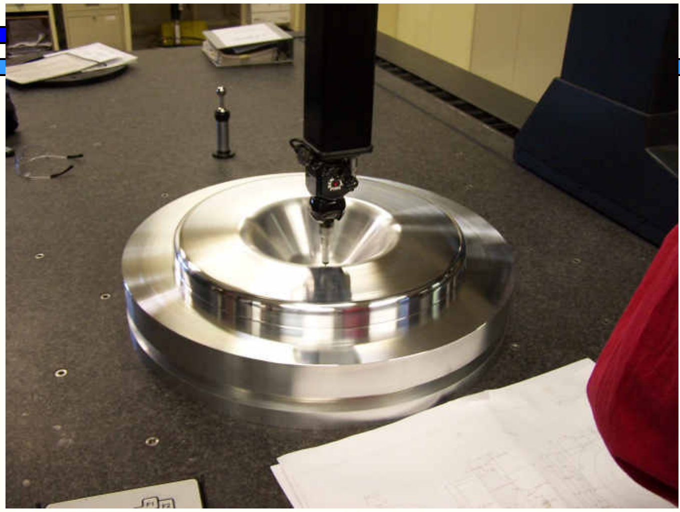
Welded spoke

E.ZANON S.p.A.

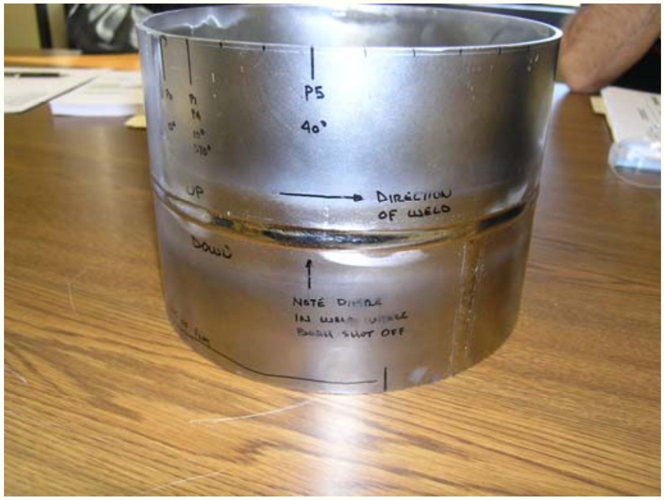
Roark Progress



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

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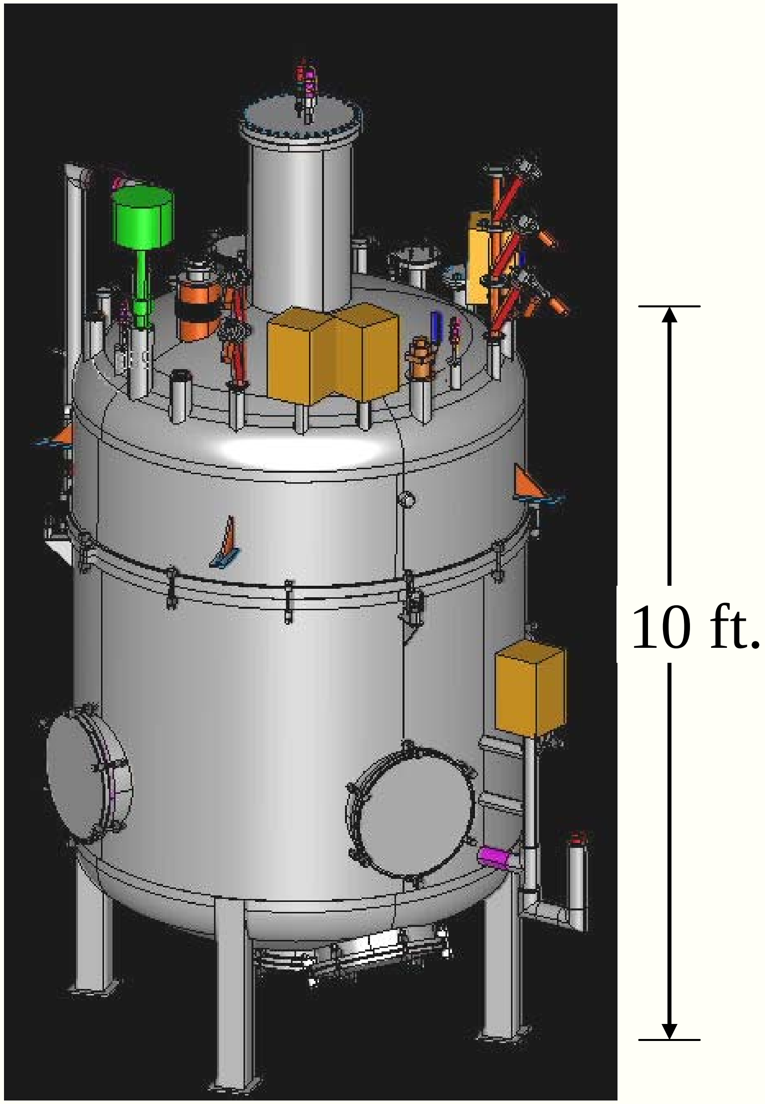
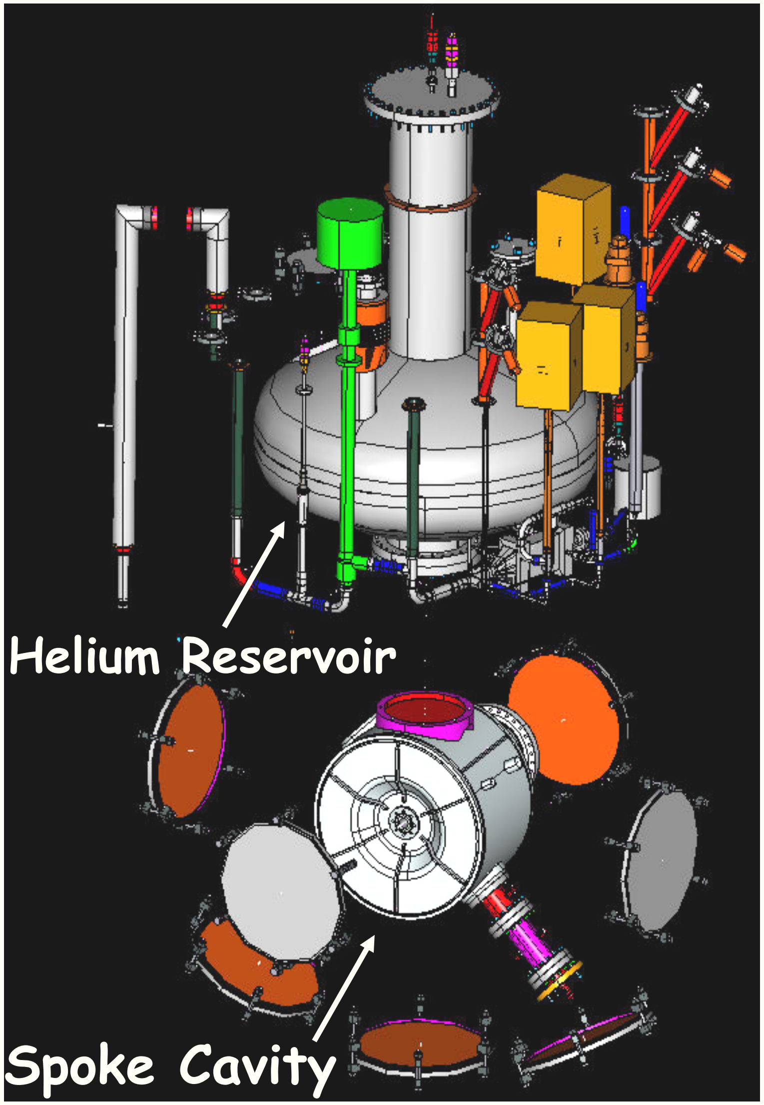
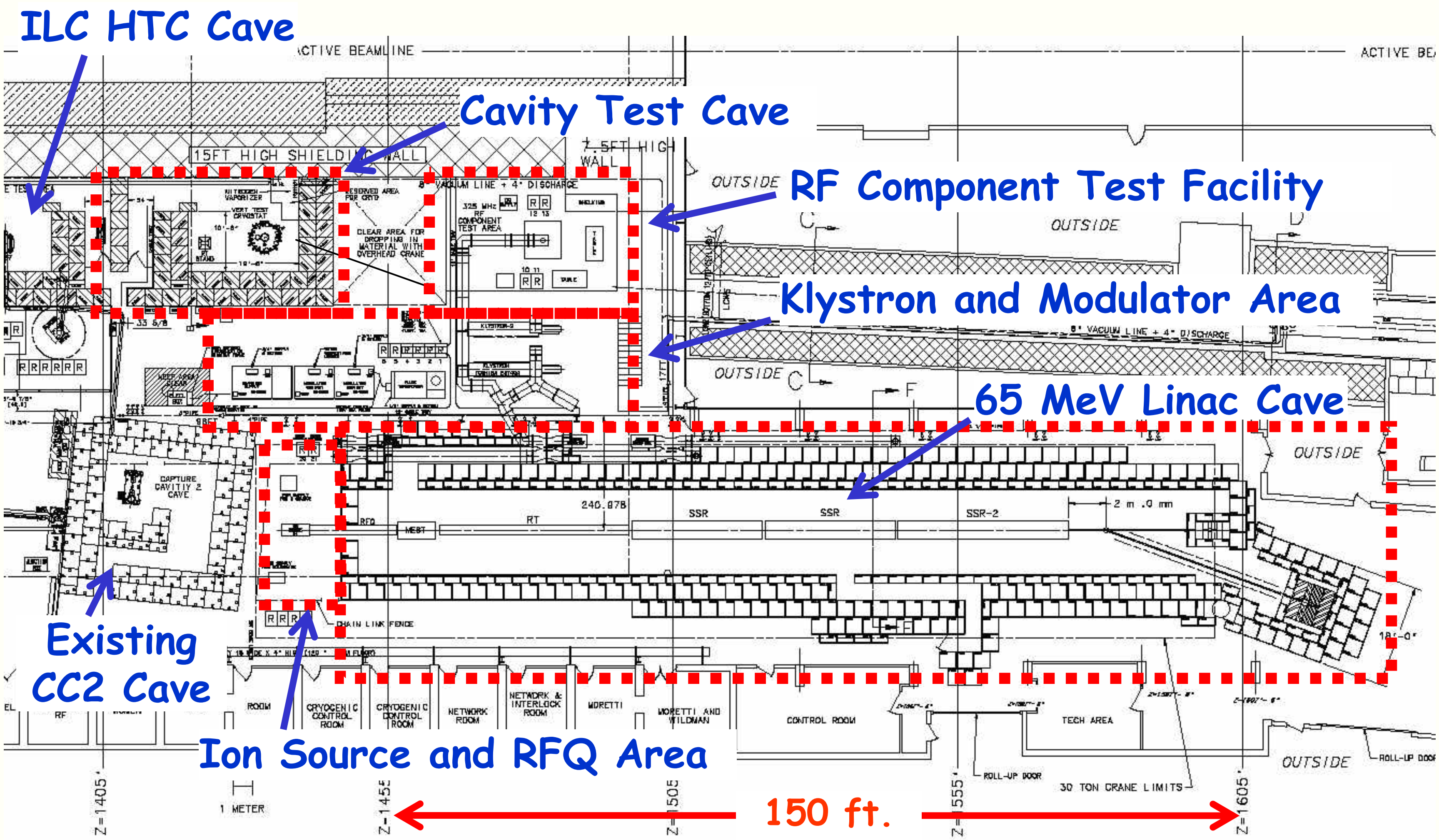
- Cryostat is based on concepts of Ken Shepard for ANL- RIA
  - Sized for any HINS spoke cavity, including triple-spoke
  - Designed for full, pulsed power cavity testing
  - Designed to house solenoid focusing magnet as well as cavity under test (to check for magnetic field effects)
  - Capable of supporting 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





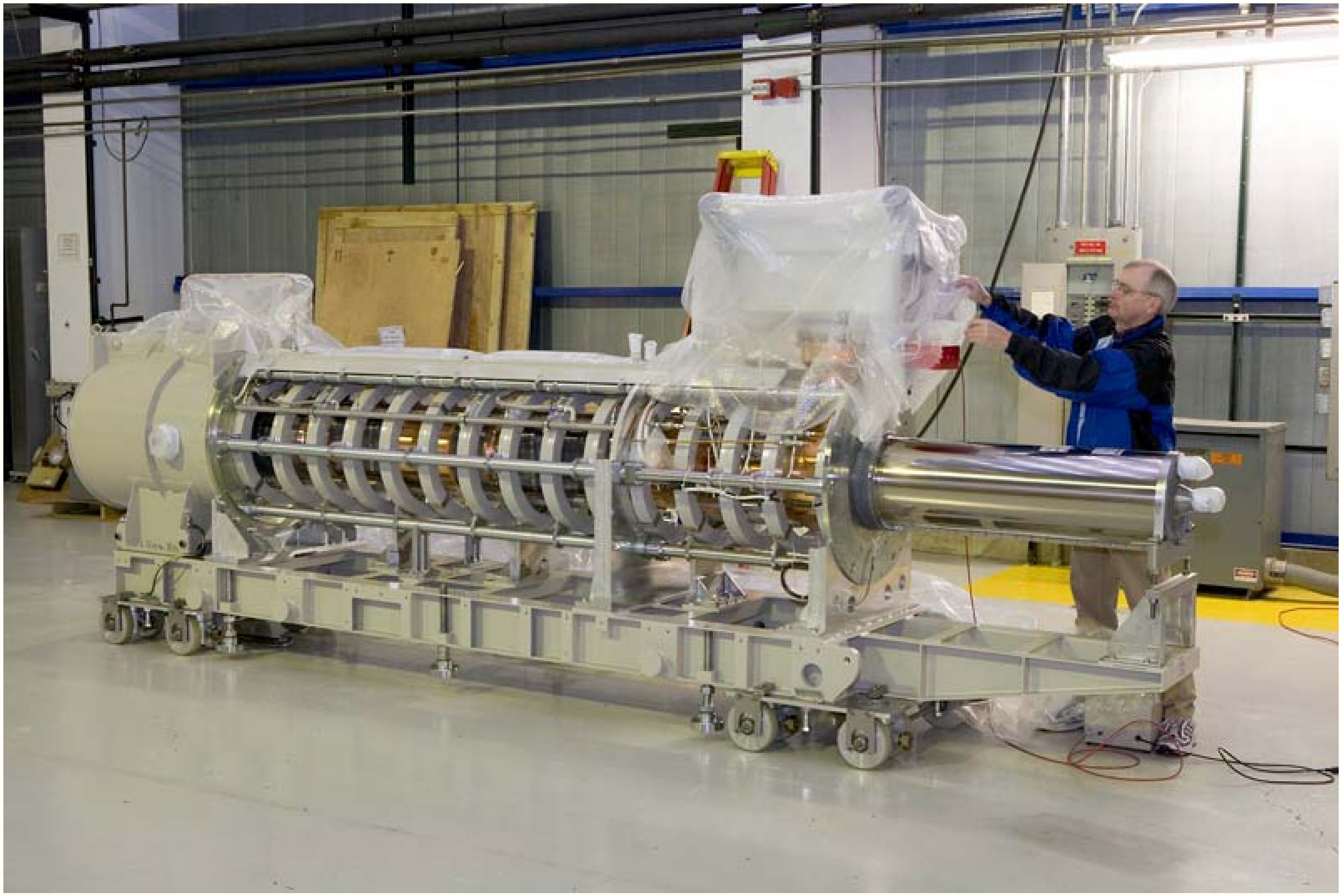
HINS Floor Plan in Meson Detector Building



325 MHz RF System

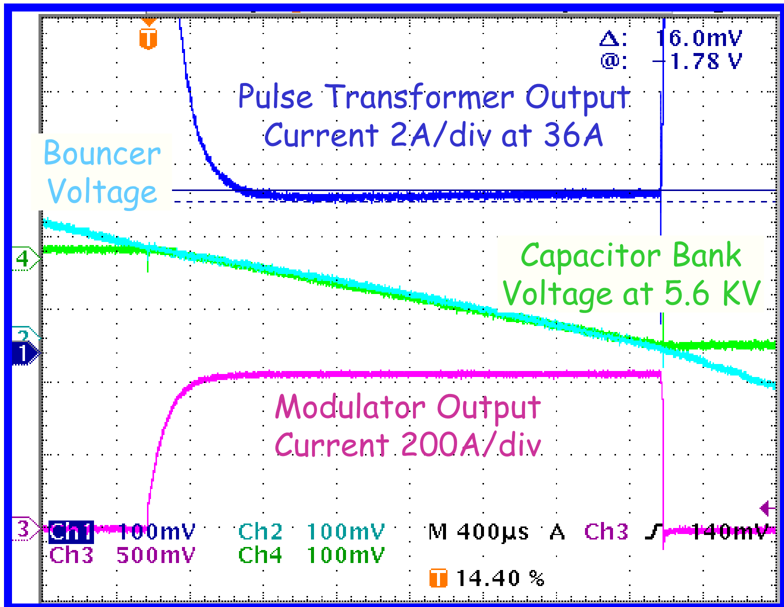
- Specifications:
  - 325 MHz
  - 2.5 MW modulator/klystron system
  - 4msec pulse length and 1.5% duty factor
- Utilities and infrastructure in are place
- Modulator is installed and tested into resistive load; final interlock check-out is proceeding
- Klystron is installed as is waveguide to the test 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

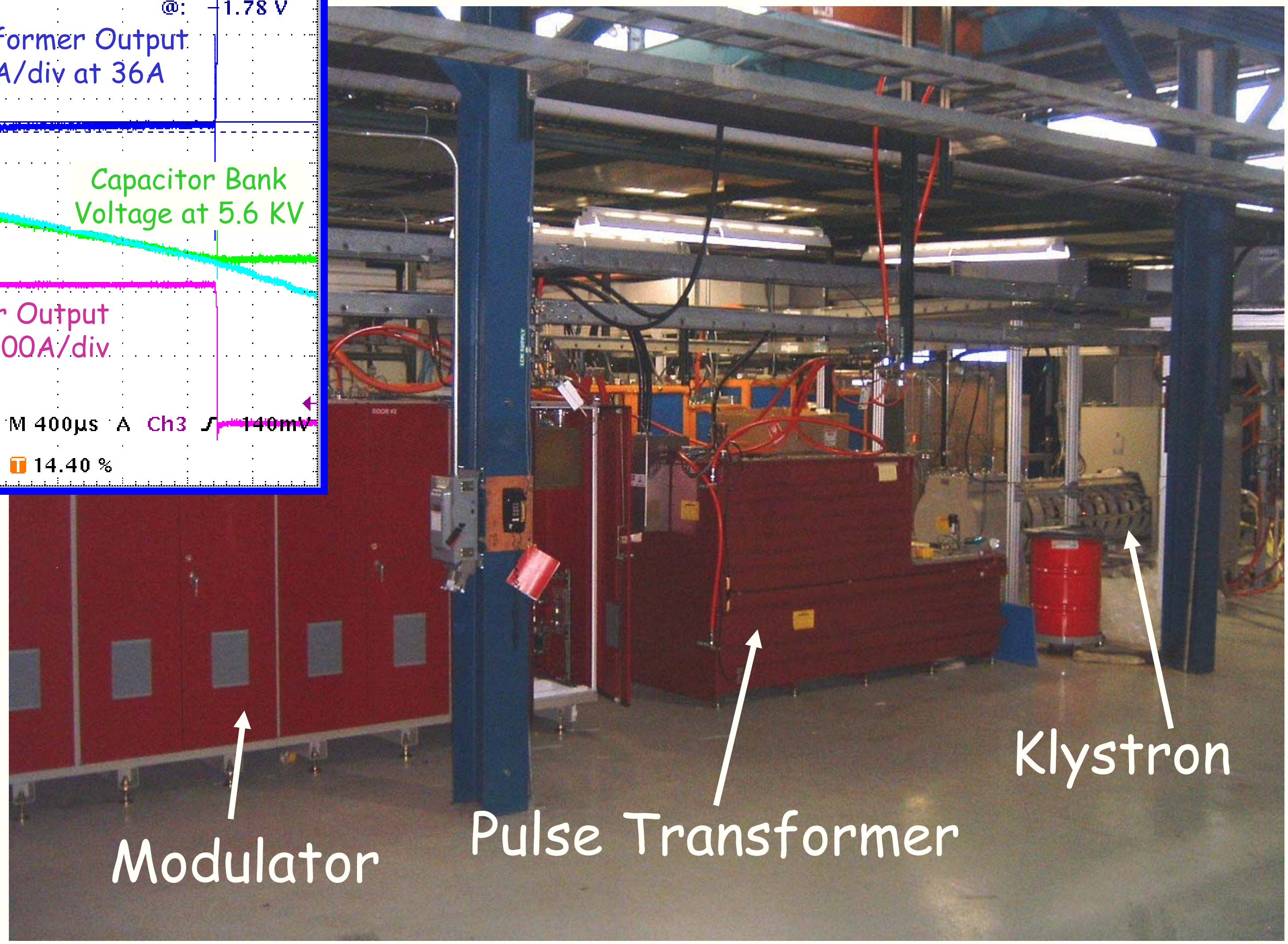


Klystron and Waveguide Installation

Modulator and Pulse Transformer



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



RF Component Test Area Cage

Electronics Installed

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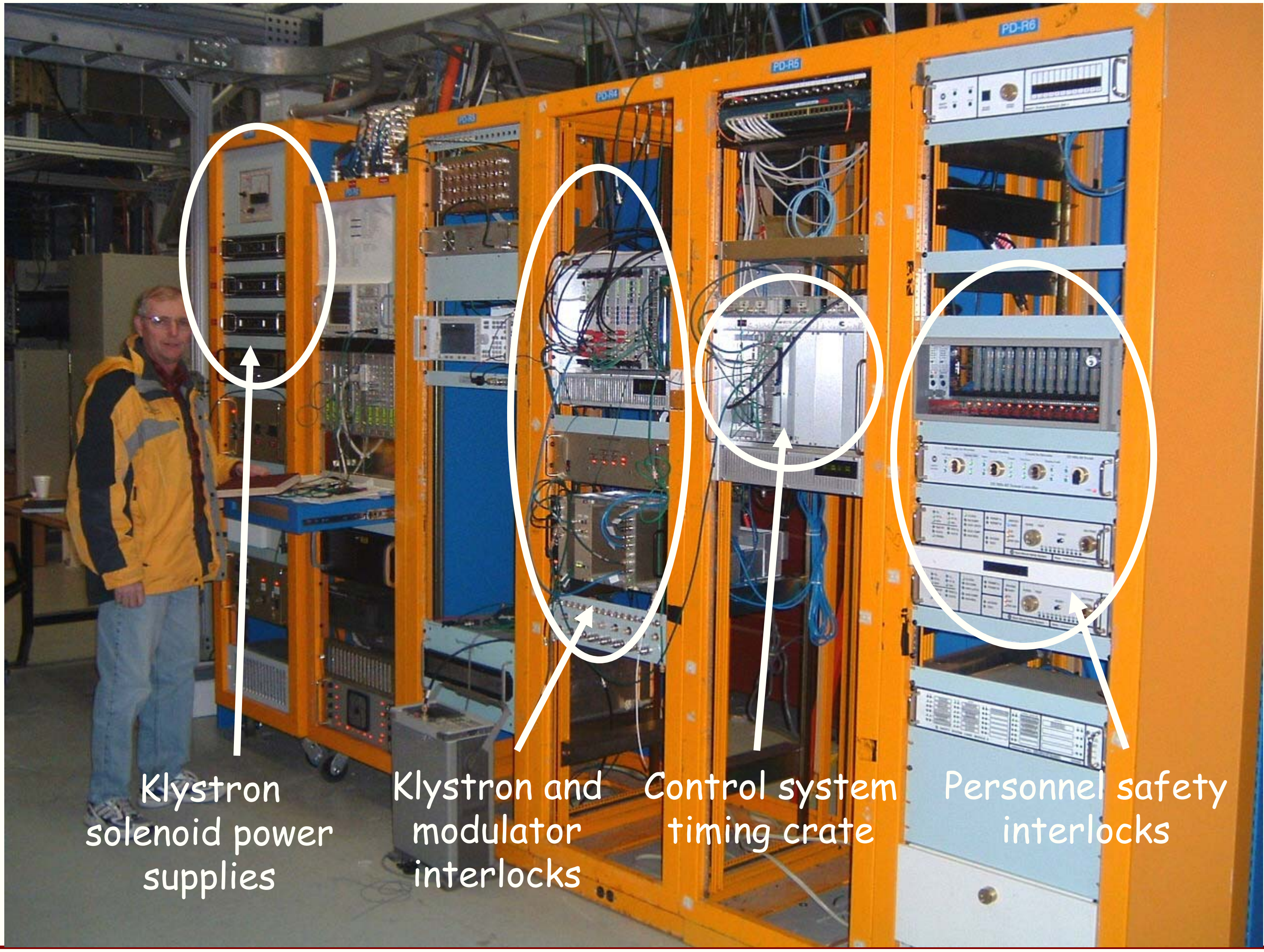
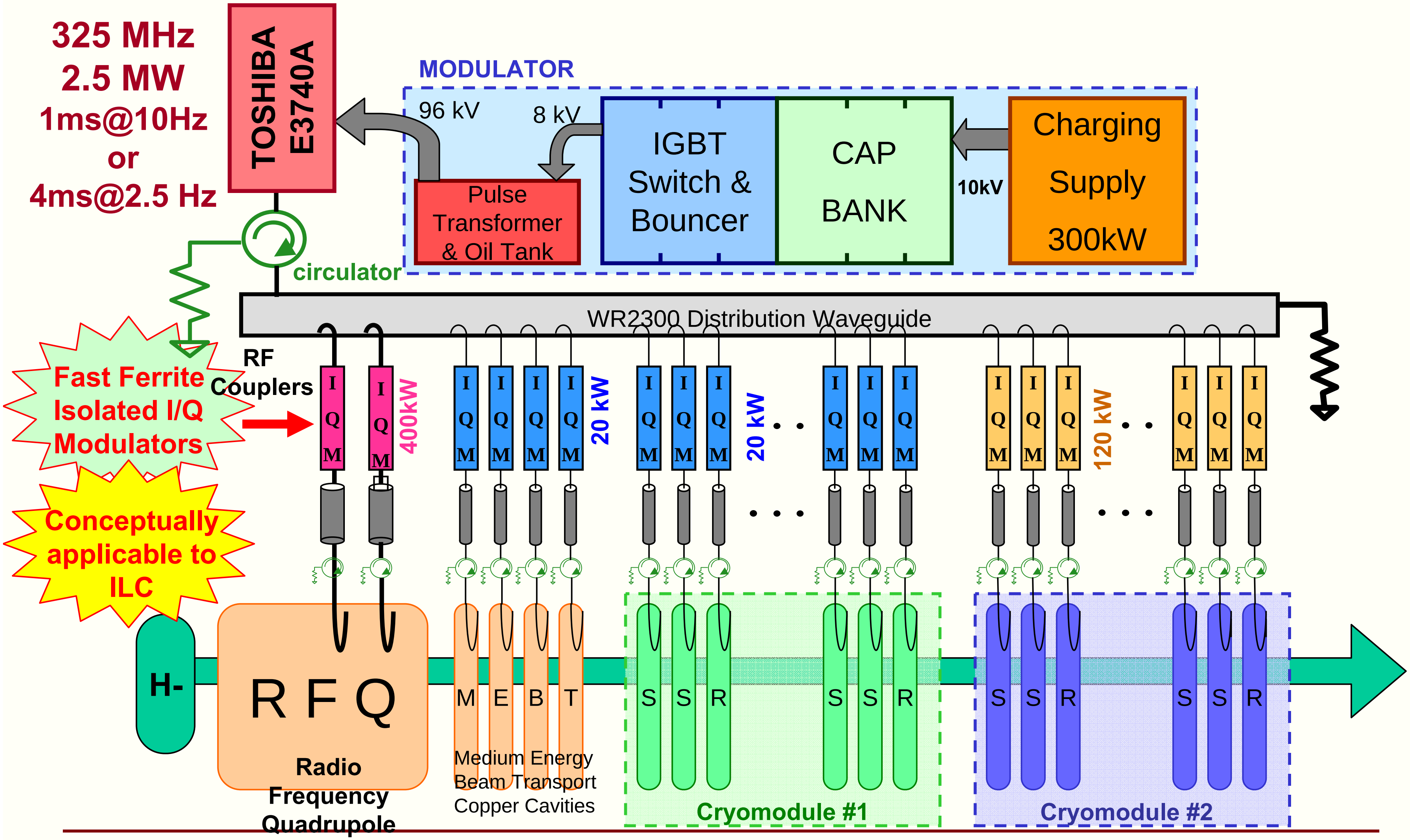
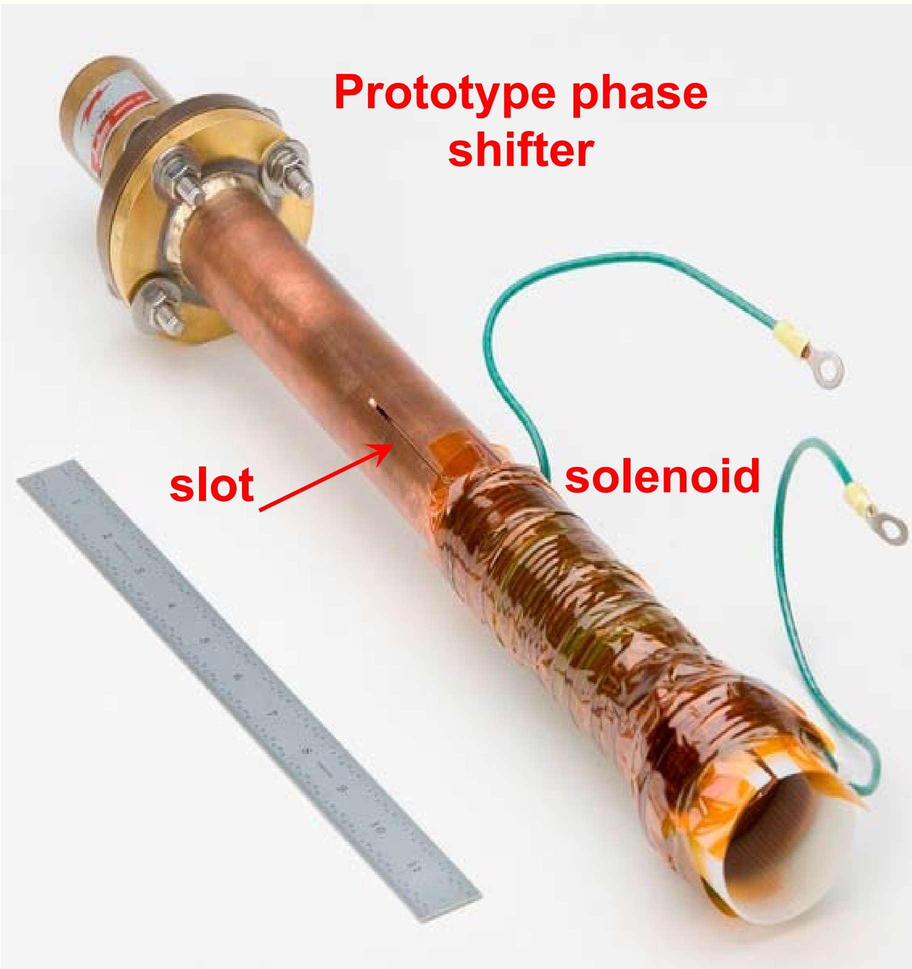


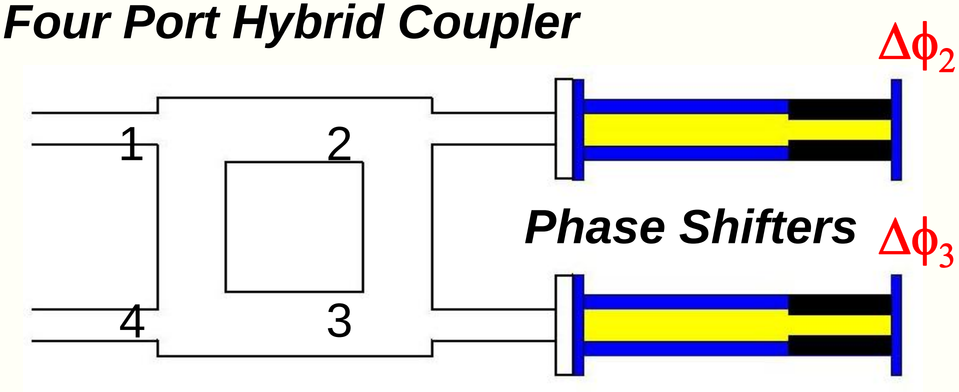
High Power Amplitude/Phase Control



Ferrite Vector Modulator



Four Port Hybrid Coupler



Independently modulates phase and amplitude:

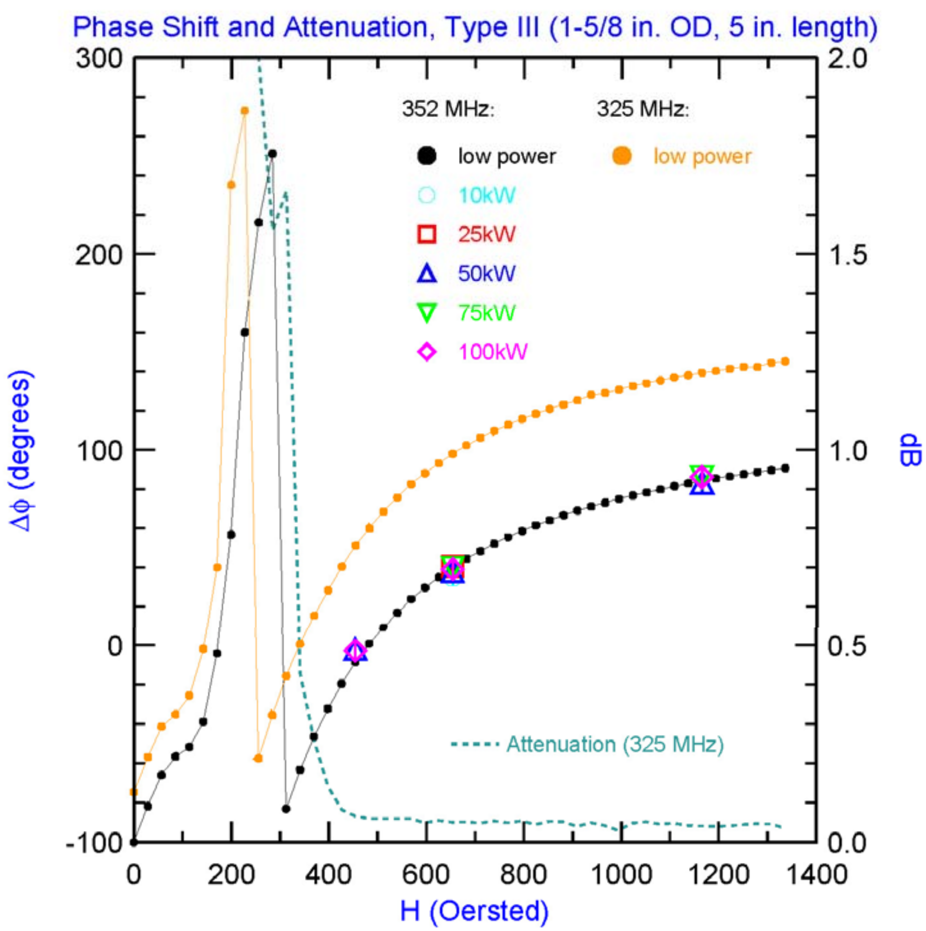
With $\Delta\Phi = (\Delta\phi_2 - \Delta\phi_3) / 2$

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

Output power ~ cos²(ΔΦ) — $\cos^2(\Delta\Phi)$

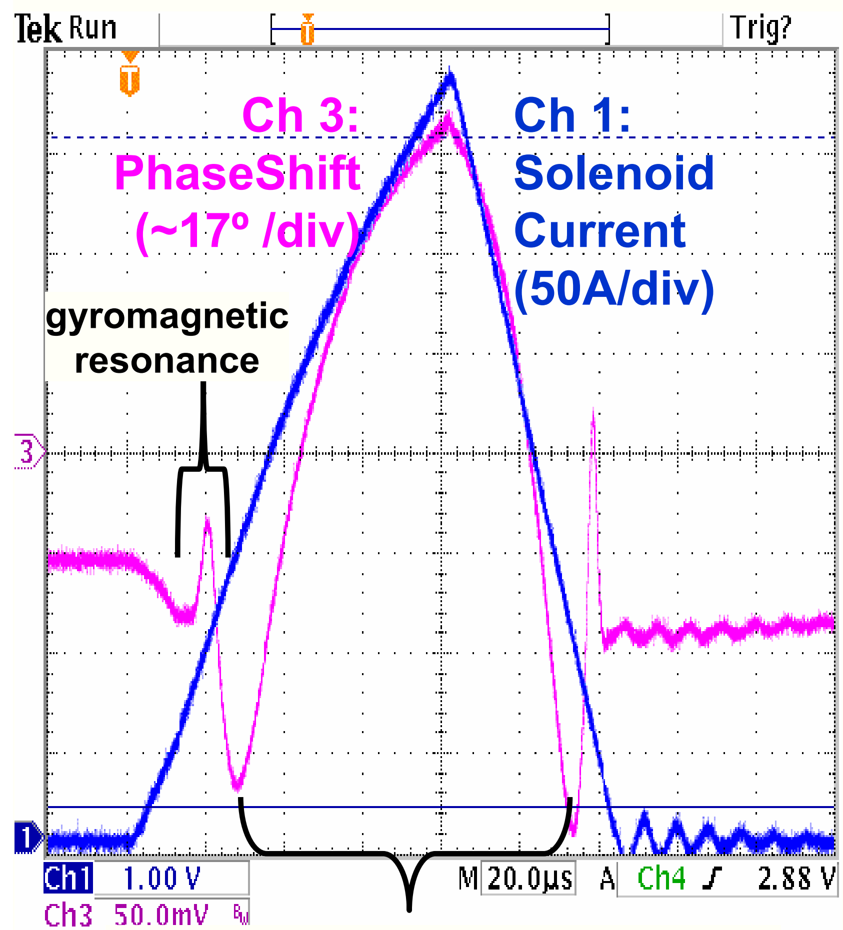
Phase shift ~ $\Sigma\Phi + 3\pi/2$

Phase Shifter High & Low Power Performance



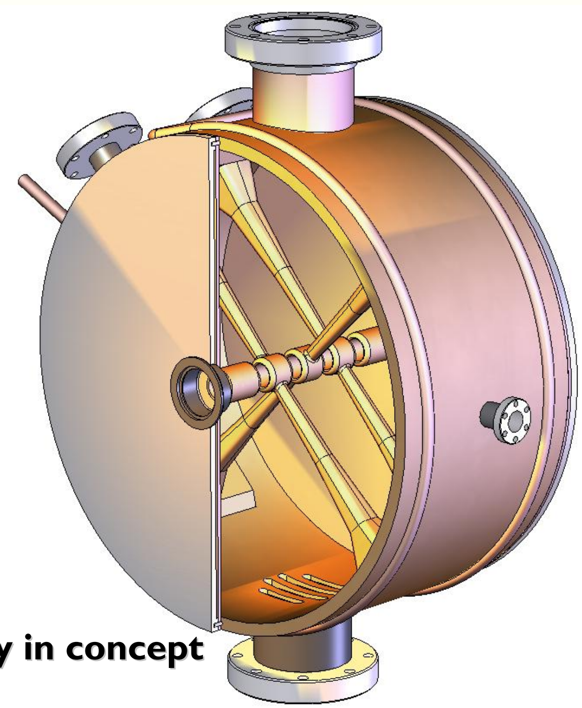
352 MHz power tests at ANL

325 MHz operation frequency



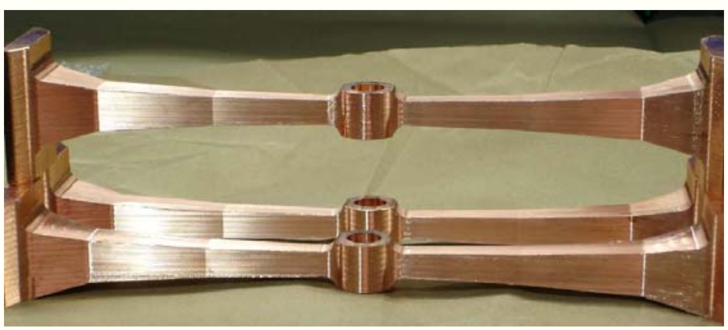
useful phase shift range - low loss
average slew rate 2.2°/usec
(initial spec is 1/usec)

HINS Room Temp Cavity in Production



Cavity in concept

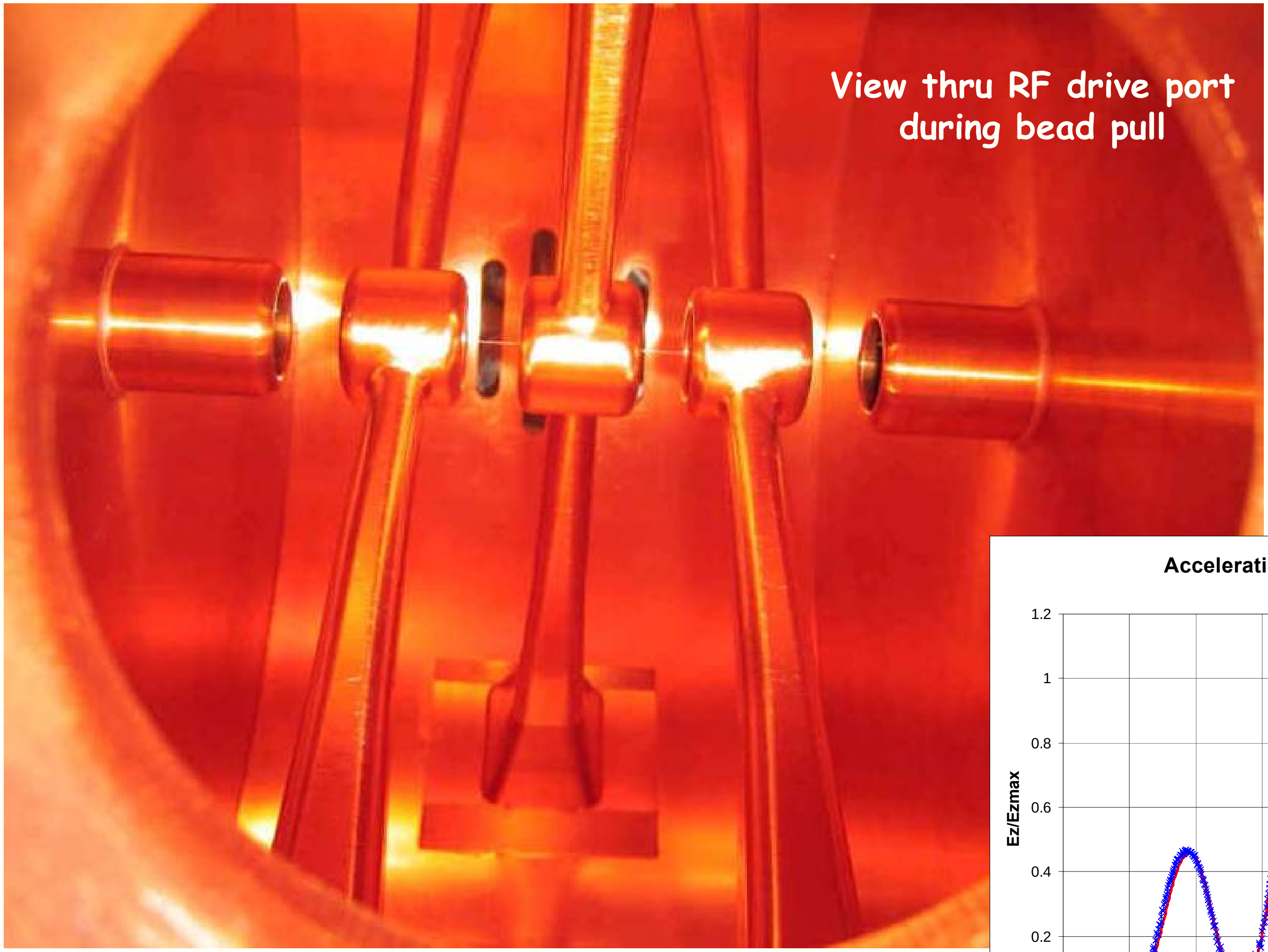
Body wall roughed in and annealed.



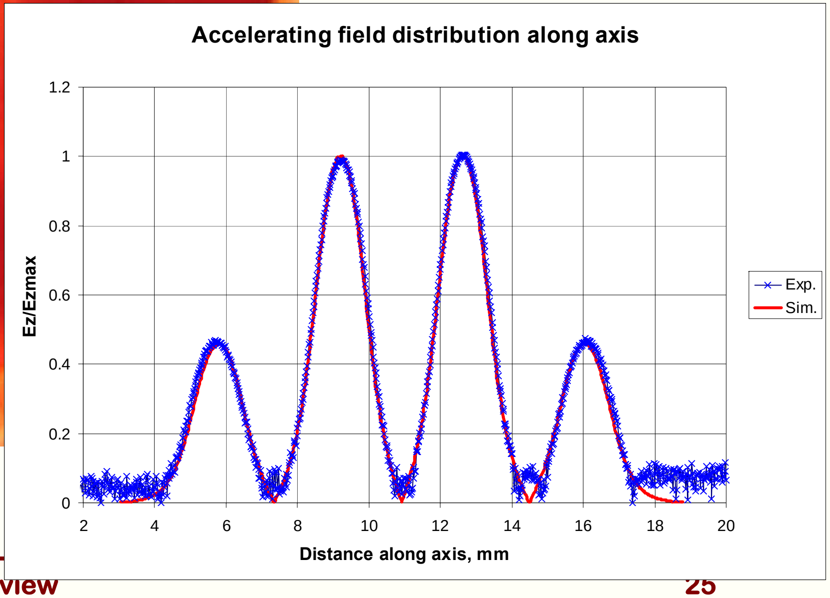
Copper spokes rough machined and annealed

Brazed cavity before welding end walls

Bead Pull thru Completed RT CH-01



Relative field amplitudes
Blue – measured
Red - predicted



HINS R&D Near-Term Schedule Goals

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- 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

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- 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

- Design of the HINS 325 MHz superconducting spoke cavities is well underway
  - β=0.2 design is complete except fast tuner
- Fabrication of the first cavities is progressing quickly
  - One room temperature cavity on hand
  - First superconducting 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
- 325 MHz RF power system is installed and modulator is in final stages of commissioning
- A facility to support testing the SC spoke cavities and cryomodules with and without beam is under construction
- Availability of Fermilab SCRF Cryostring Assembly Facility (shared with ILC) is a key requirement for HINS R&D cavity string and cryostat assembly