Status of HWR Cryomodule Development

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Physics Division

December 17, 2013

Content

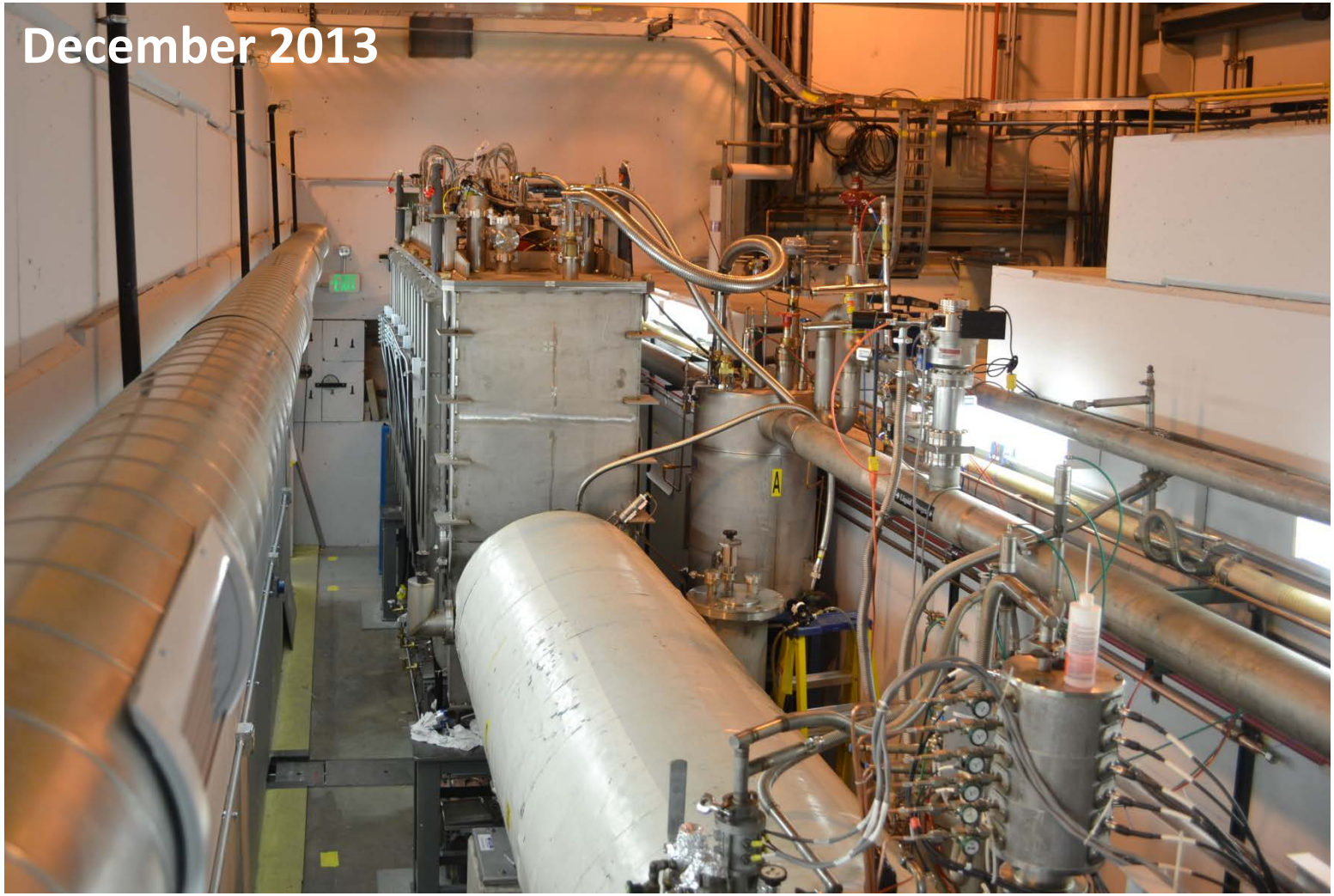
- Recent experience with the cryomodule commissioning
- Status of prototype cavities
  - Fabrication issues
  - Frequency tuning
- Cavity sub-systems
  - RF coupler
  - Slow tuner
- SC solenoid and BPM testing
- Production cavities
- Cryostat vacuum vessel
- Alignment
- Near future tasks
- Summary

Recent Experience with New Cryomodule

- 4K cryomodule has been built and commissioned off-line
  - Installed in the tunnel
  - Beam commissioning will be started in January
- 21 MV voltage by 7 QWRs
  - Design specs is 17.5 MV
- Four 9-Tesla solenoids

Cryomodule was Installed at Permanent Location

- LHe cool down is in progress



Recent Progress: Cavities

- Fabrication of 2 HWRs is in the final stage.
  - The frequency tuning is complete for both cavities and cavities are ready for the following EBW to complete Nb cavity – takes place next 2 days
- Fabrication of two prototype cavities took longer than expected
  - The original fabrication plan has been revised to avoid warping of the outer conductors during the welding
  - We had to form new outer conductor halves, schedule was delayed by 4 months
  - The original milestone is the prototype cavity testing by the end of March 2014. Actual testing will take place in April-May.

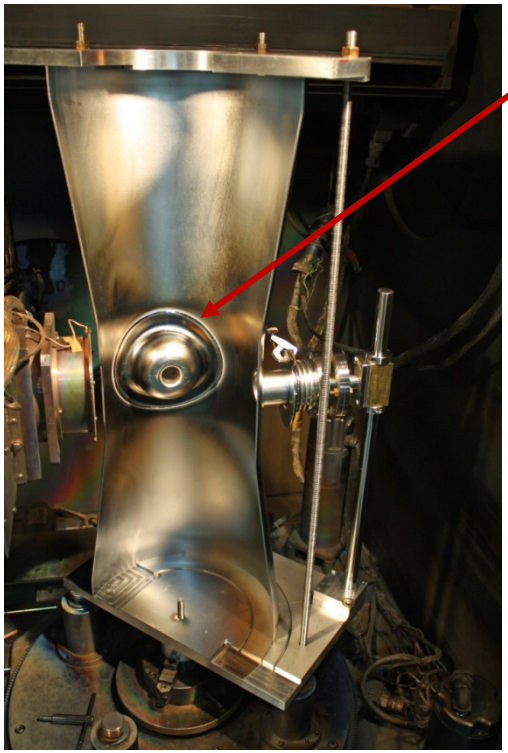
- **Forming of Nb parts for 7 production cavities complete – milestone of 12/31/13**

Recent Progress: Cryomodule and Sub-Systems

- Cryomodule design is complete
  - ANL/FNAL technical and safety review of the cryomodule design: May 16, 2013. Detailed structural analysis has been performed and documented for this review.
  - The drawings for cryostat vacuum vessel, lid, thermal and magnetic shield are ready to send out for the bids
  - Detailed drawings for all components of cold mass are being checked to get ready for procurement and fabrication
- 10-kW RF coupler cold testing up to 9 kW at 162.5 MHz RF power has been performed
- SC solenoid includes a return coil and X-, Y-dipole coils
  - Prototype solenoid has been built by Cryomagnetics and jacketed at Meyer Tool
  - Has been tested in TC3 together with 72 MHz QWR
- Beam Position Monitor: fabrication complete and RF testing demonstrated design performance

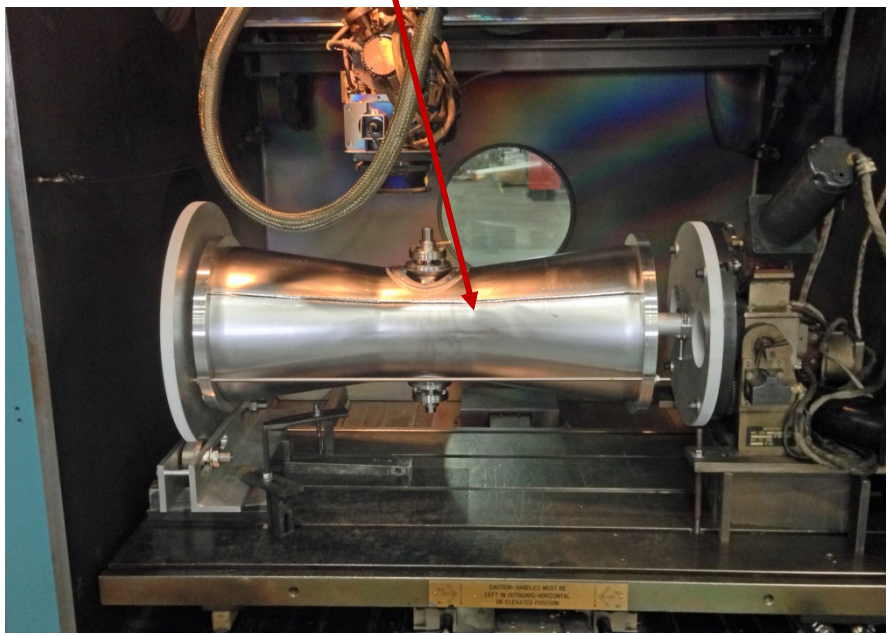
Fabrication Issues

- Welding the re-entrant nose into the housing half produced too much of warping
- Changed to the welding of the nose to whole housing

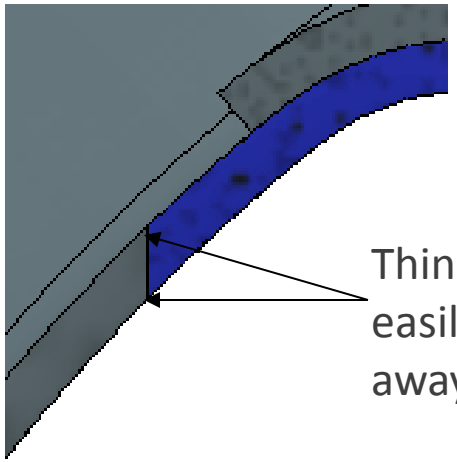


Welding Nose into housing half

Welding Nose into whole housing

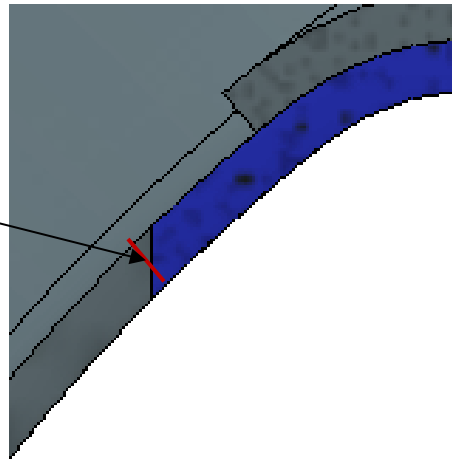


EBW of Re-entrant Noses to Whole Housing

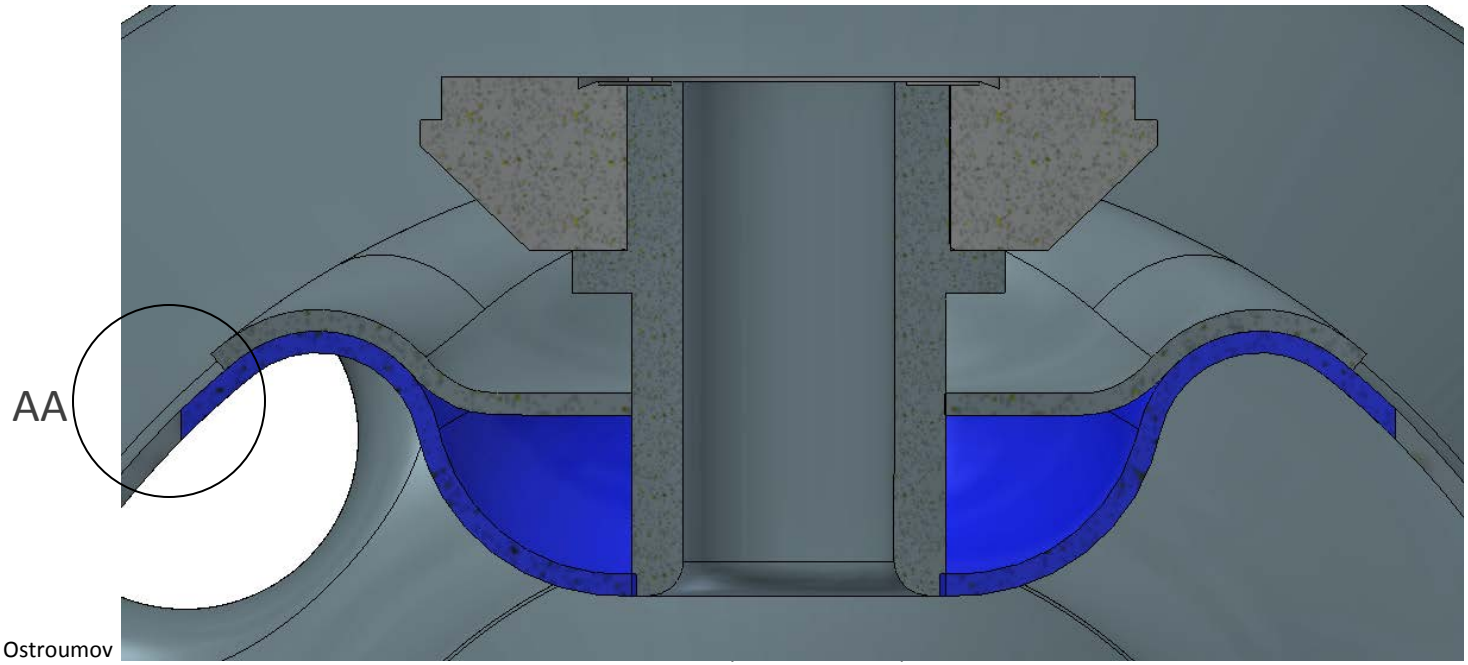


Thin sharp edges can easily overheat and melt away during welding

Solution keep joint perpendicular to surface



ReEntrant Nose section view

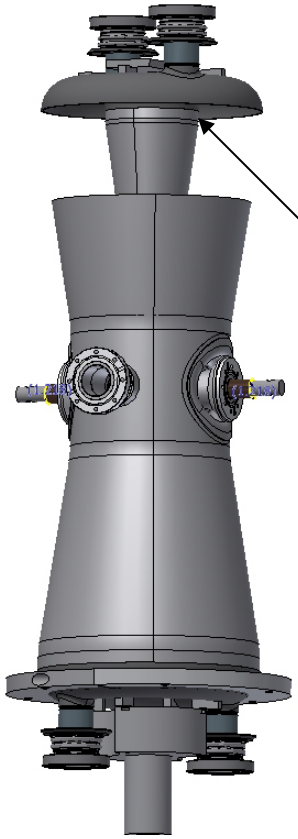


Frequency Tuning

- Multiple cuts (wire EDM) of the central and outer conductor heights

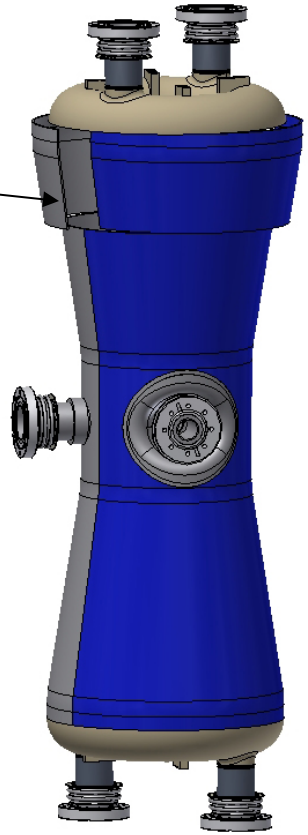
Summary	ΔF (kHz)	Freq. (MHz)
Cavity 2.0 K Operating w/ 1/2 tuner compression		162.500
Cavity 2.0 K Operating Range	±80	
Cavity 2.0 K, No Slow Tuner		162.580
Cavity 4.2 K	5	162.585
Cavity 293 K	-231	162.355
Cavity 293 K, no vacuum	-49	162.305
Cavity 293 K, pre-EP	-54	162.251
Target Frequency After Helium Jacketing		162.217
Target Frequency After Nb Welding		162.217
Target Frequency Without Weld Shrinkage		161.997

Remaining Welds after Frequency Tuning



Weld short section
Clam Shells
Thru welds

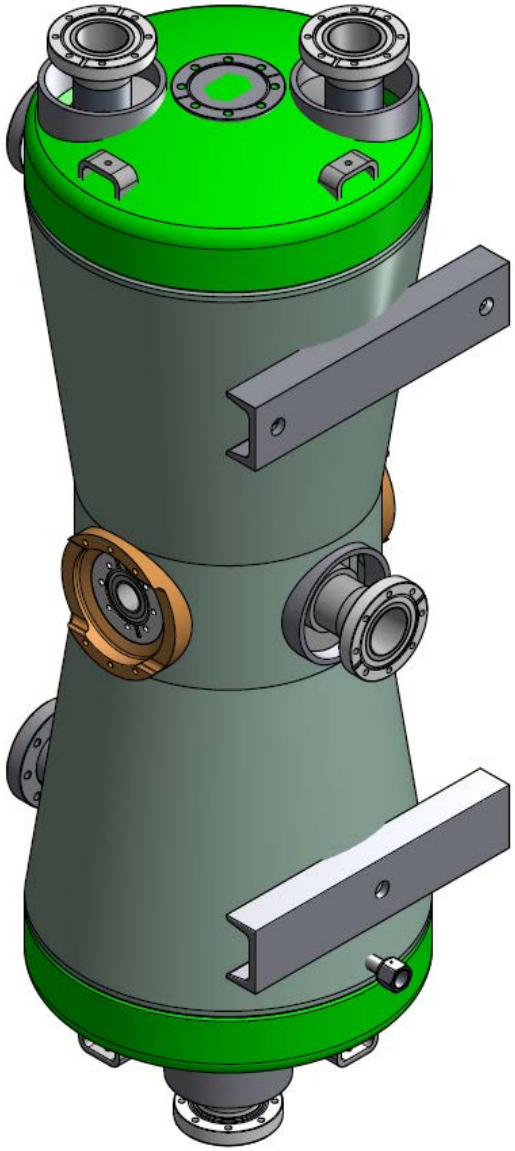
Weld 2nd Toroid to
Center Conductor
Keyhole weld



Prototype Cavities, Today's Status

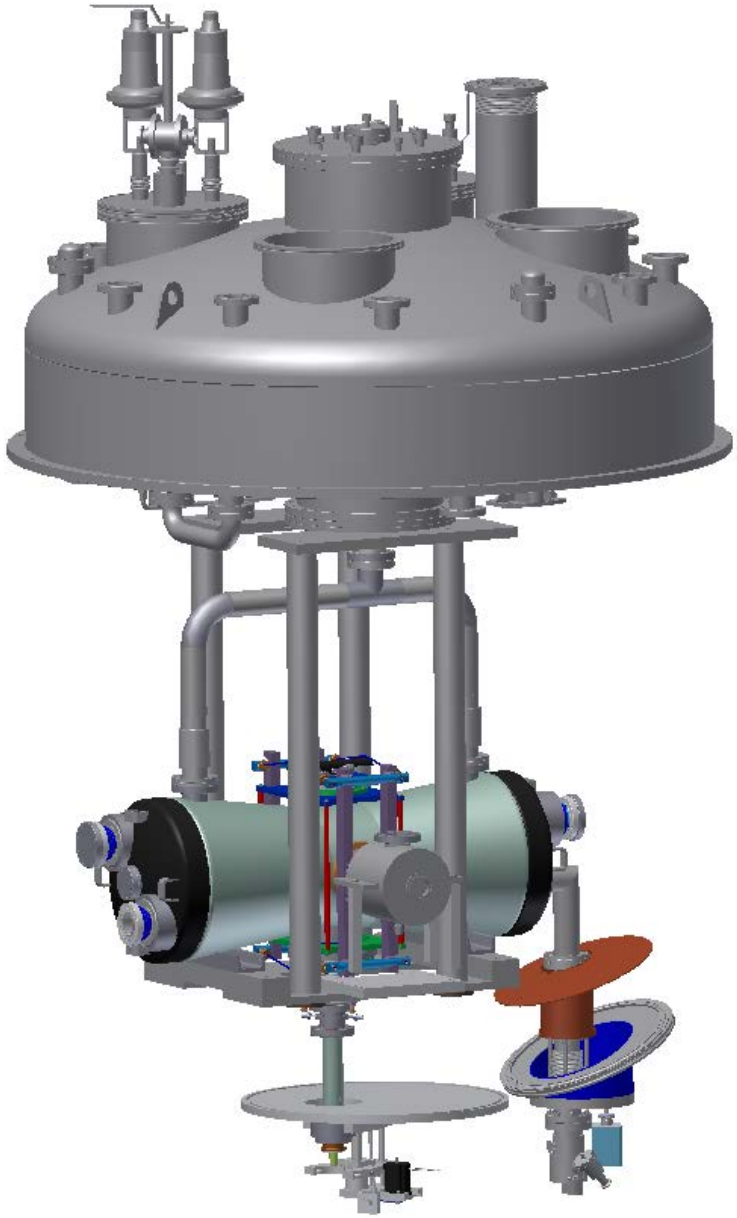
Prototype Cavities, Remaining Work

- Helium vessel
  - 1/8'' thick SS vessel
  - Contract with Meyer Tool was awarded in Dec. 5
  - Helium vessel installed: February 2014
- Electropolishing, HPR: March 2014
- 625 C baking at FNAL furnace: March-April
- Cold testing of the first prototype cavity: April 2014



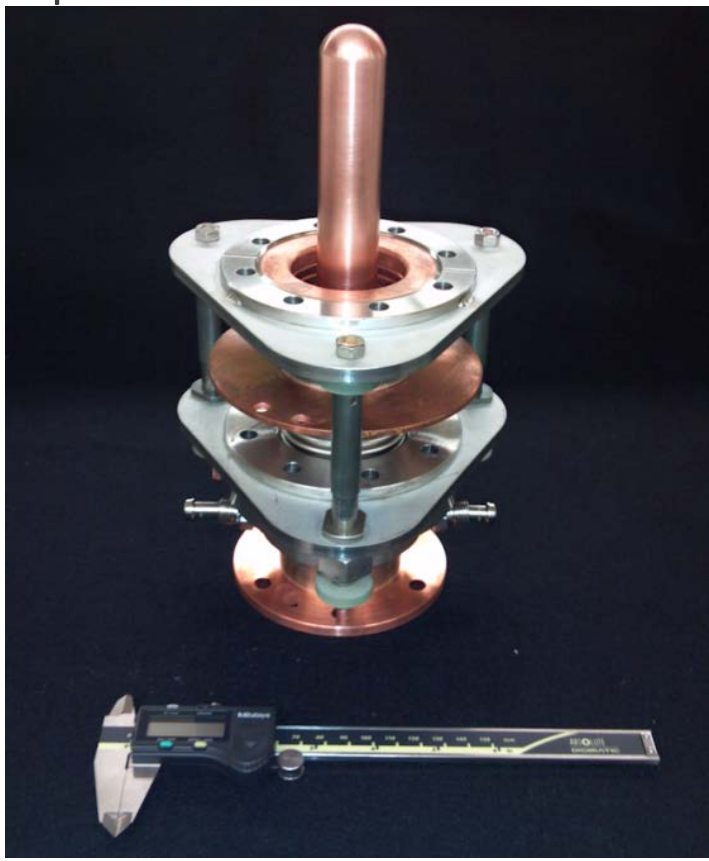
HWR in TC3

- Testing of prototype cavities in TC3
  - 2K capability
- Some new parts are being built
  - Support fixturing
  - LHe supply
  - Evacuation line



10-kW Variable Coupler

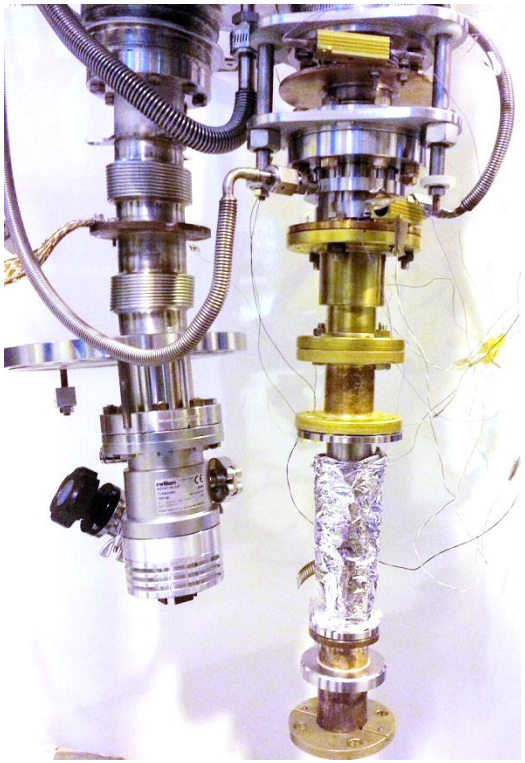
- Based on successful development of 4-kW input coupler (1-5/8” coax) for 72 MHz cavities
- Increased diameter of the outer conductor, 2”
- 1” stroke, 70K cooled alumina window, 5K intercept
- Two RF input couplers have been built
- Testing has been performed at 72 MHz and 162.5 MHz
- No multipacting was observed in full reflection regime in the power range of 0 - 9 kW



Initial RF Test of PXIE RF Coupler

Initial cold testing with 72 MHz QWR at 4 K (off resonance)

- '10 kW' 162.5 MHz RF supply
- Through a 75 kW circulator
- 4 K cavity/coupler flange fitted with Si diode thermometers and a 0-50 Watt heater
- Bellows intercept 'floating' thermally; fitted with Si diodes and a heater
- Cold window cooled with 30 SCFH flowing LN_2 and fitted with Si diodes and a heater
- Thermal transition fitted with a Si diode
- Cavity and insulating vacuum pressure measured

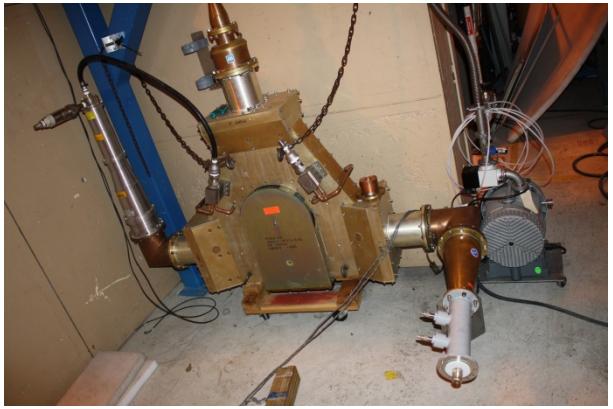


RF Coupler Test

- Ralph Pasquinelli and his team invested significant effort to operate the amplifier and ferrite circulator at ANL
- Amplifier and circulator were moved to ANL and operated for these tests
  - Multiple problems with 10 kW circulator
  - 75 kW circulator requires 95F for nominal operation
- RF coupler testing will resume in January when we have ATLAS cryoplant running

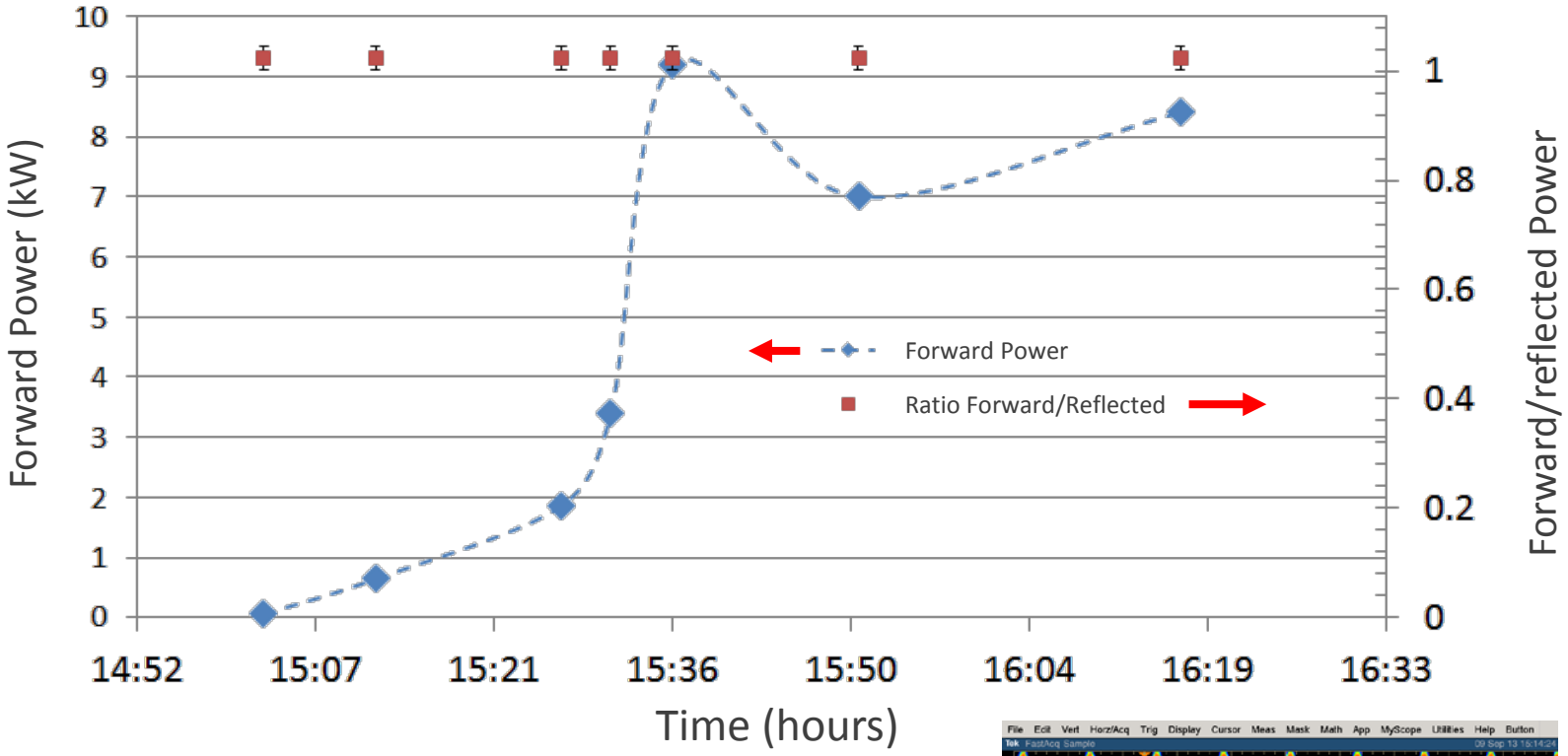
10 kW 162 MHz amplifier

75 kW 162 MHz ferrite circulator

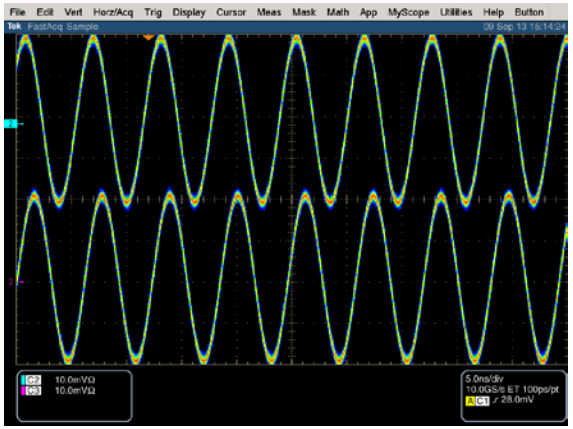


Forward and Reflected Power in Coupler Drive Line

Measured from Dual-directional Coupler Just After Circulator Out

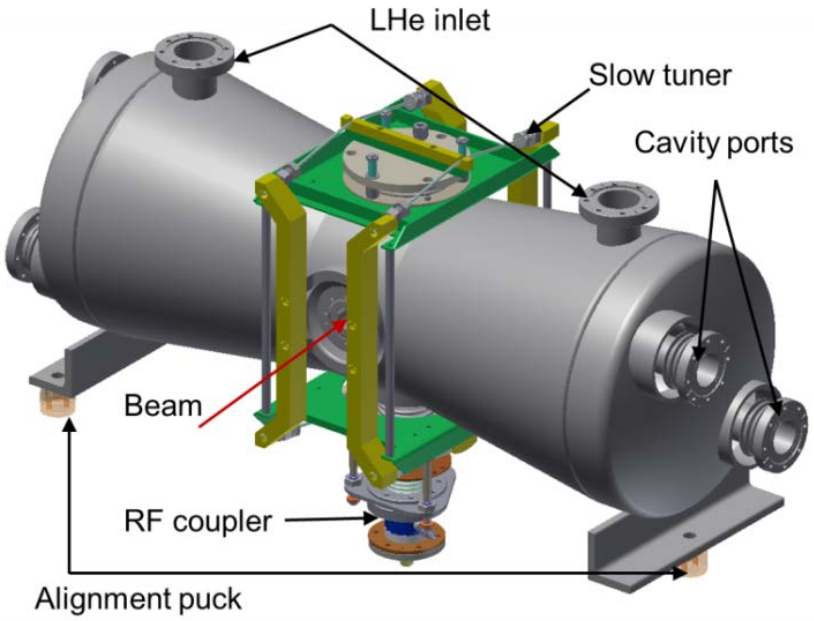


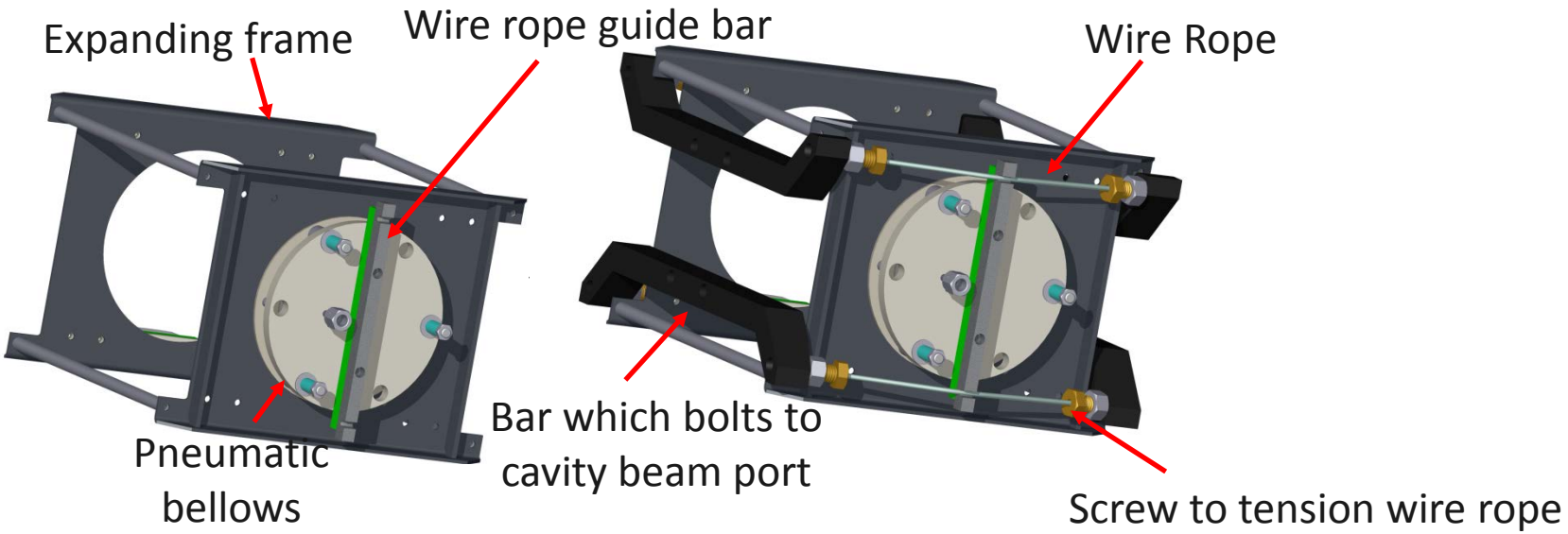
Right panel – Forward and reflected power just after the circulator output measured continuously on digital scope; ***other than for a few seconds during power ramp, no power absorbed in the cavity coupler downstream of directional coupler***



Slow Tuner

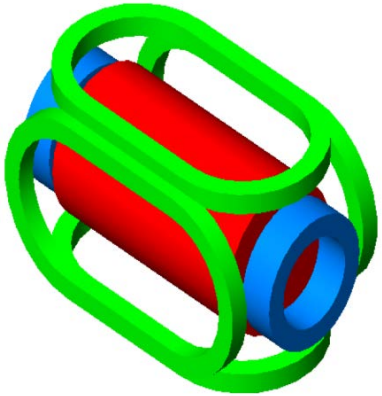
- Pneumatic slow tuner has been in use at ATLAS for 3 decades
- Recent modifications were related to ARRA cryomodule
  - Generate 6000 pound force by applying He pressure up to 90 psi. PXIE HWR needs just 2000 pounds for 160 kHz
  - Some modifications of sliding parts to provide smooth frequency adjustment with ~1 Hz resolution

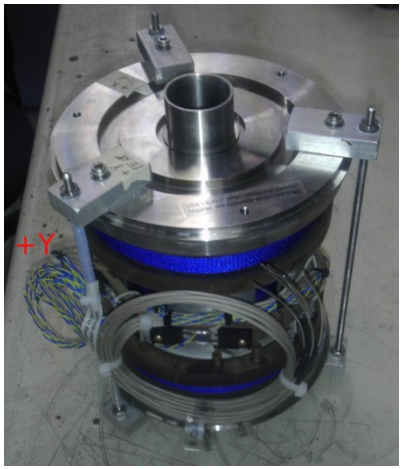


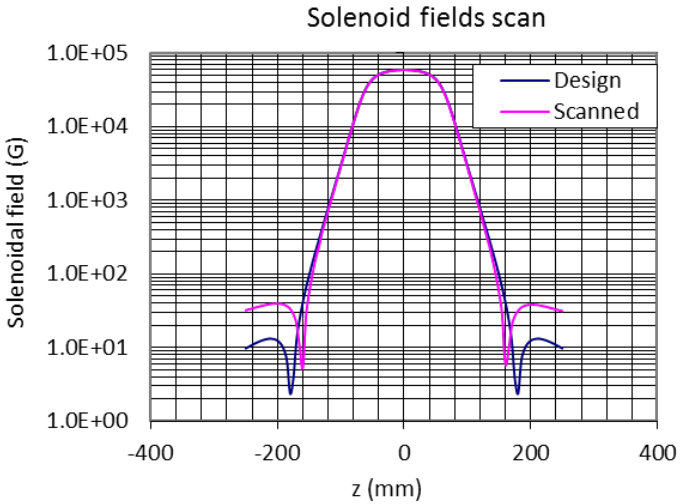


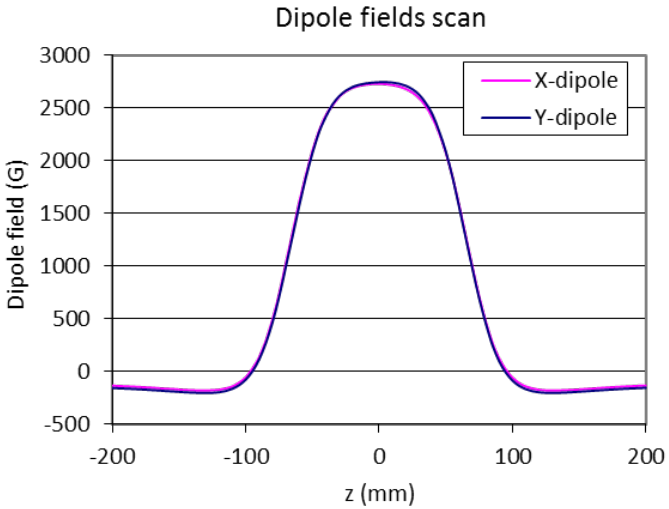
6 Tesla SC Solenoid

- Proposed in 2002, see our paper in LINAC'2002





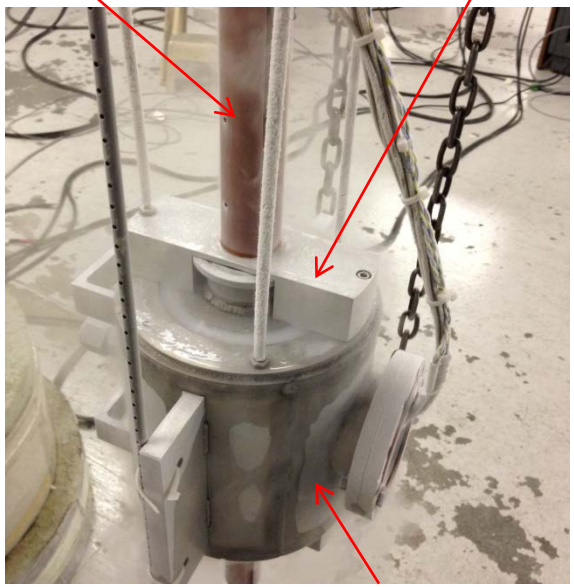




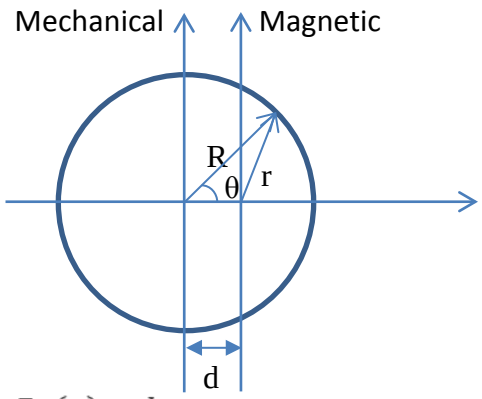
Magnetic Axis Measurement

Rotating rod: Bakelite (Hall sensor attached)

Rotation guide: Aluminum

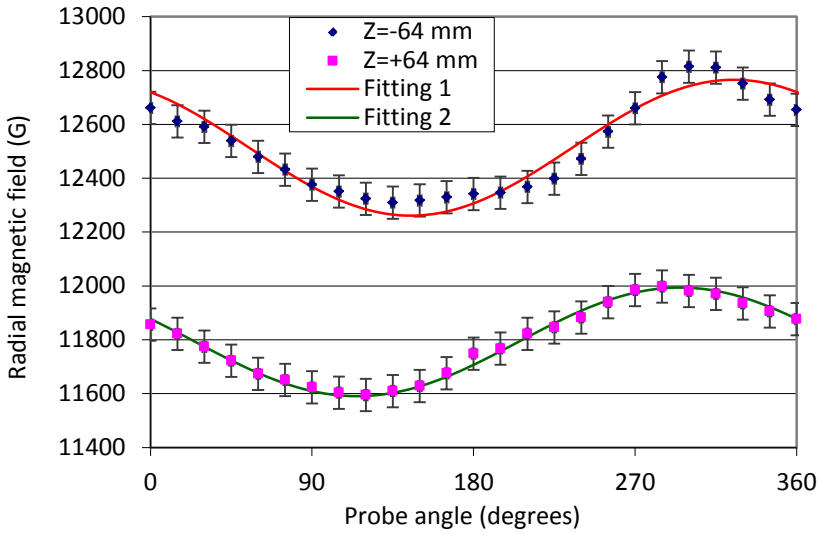


Solenoid housing: Stainless steel 304



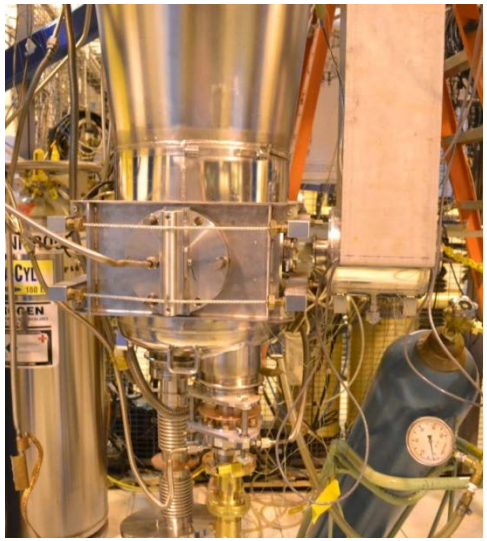
$$B_r(r) = kr \cong kR\left(1 - \frac{d}{R}cos\theta\right), \text{if } d \ll R$$

Magnetic centers at flanges (unit: mm)		
	x	y
Flange 1	-0.30 ± 0.07	0.17 ± 0.04
Flange 2	-0.08 ± 0.02	0.26 ± 0.07

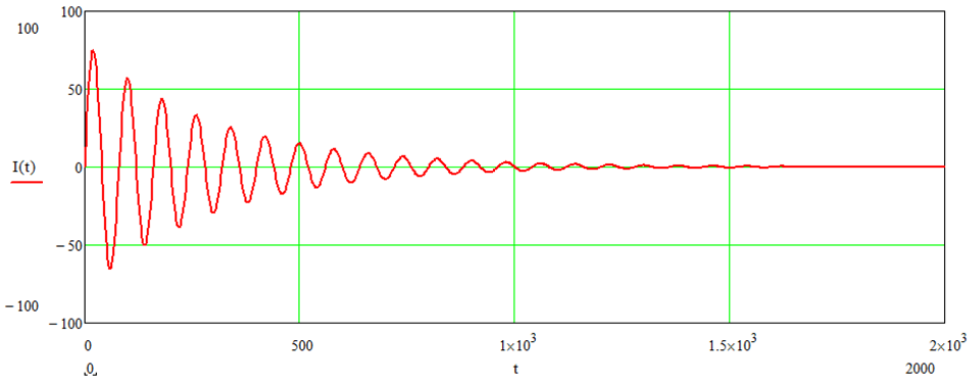


SC Solenoid PS, 4-kW RF Amplifier, Cavity RF Coupler and SC Solenoid

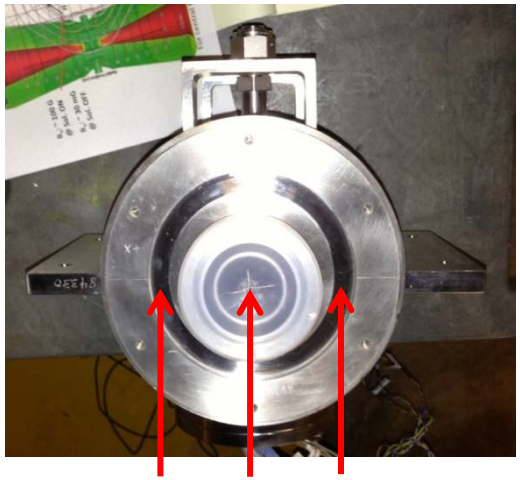
- George Krafczyk and his team provided solenoid power supply with built-in programmable function for degaussing
- Degaussing is required to demagnetize magnetic shielding
- Magnetization on cavity toroid is mainly by the field of dipole coils



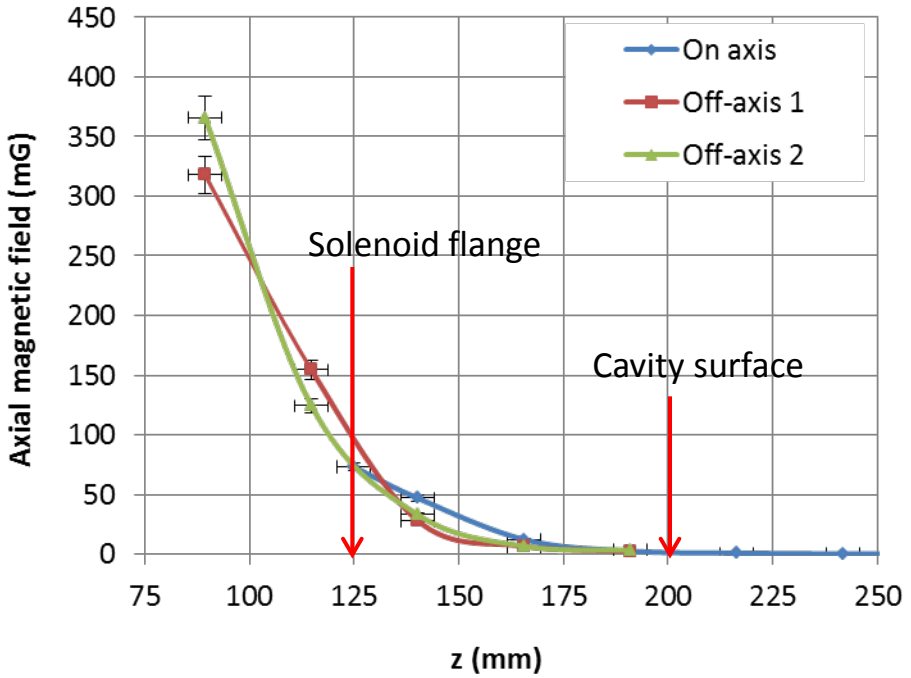
Current profile for degaussing



Residual Magnetic Fields on the Solenoid Axis

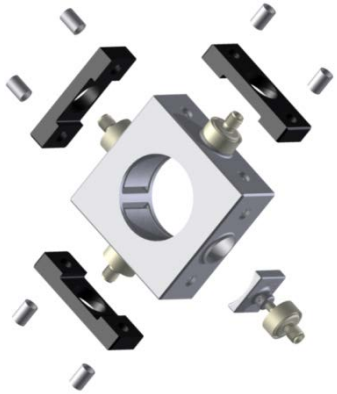


- ~100 mG residual magnetic fields were found on the solenoid flange inside of the cryostat after warm-up.
- The source of that residual fields is inside of the solenoid but it is reduced to 2~3 mG at the cavity surface (cf. R_H = 1 nOhm @ 9 mG, 162.5MHz).

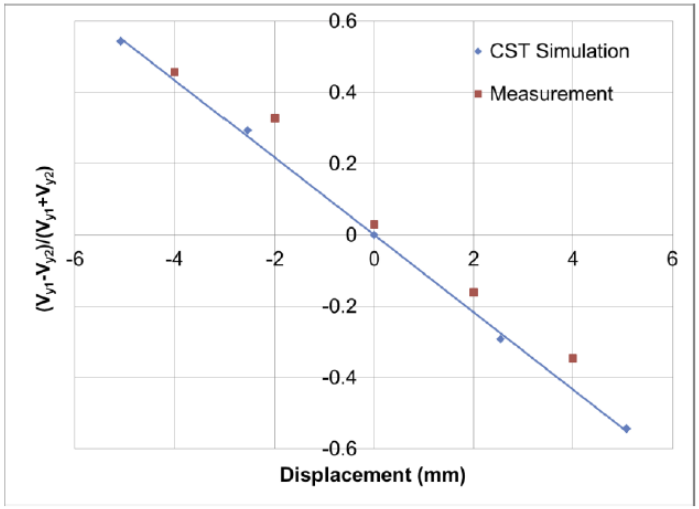


BPM

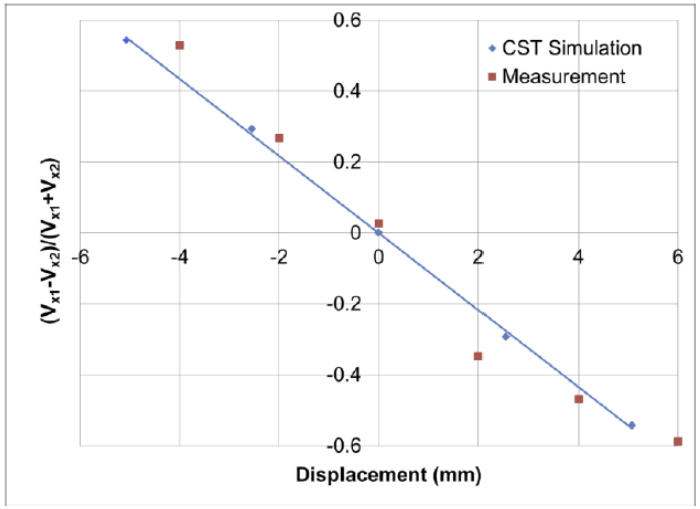
- We have developed, built and tested a BPM which is cleanable and can be mounted next to SC cavities



Vertical Displacement Sensitivity



Horizontal Displacement Sensitivity

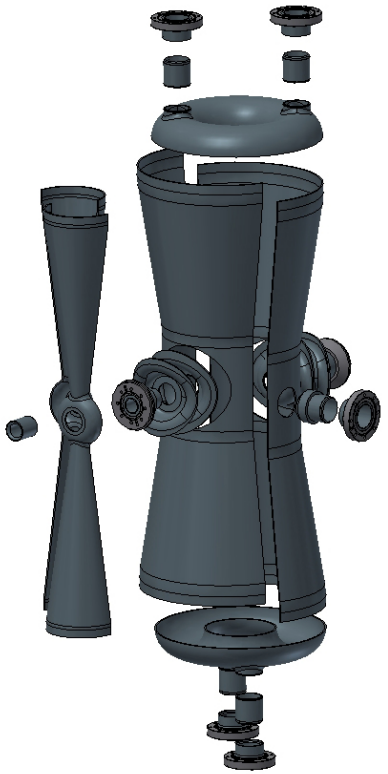


Nb Forming for 7 Production Cavities Complete

- Milestone of December 31, 2013

Traveler Documentation

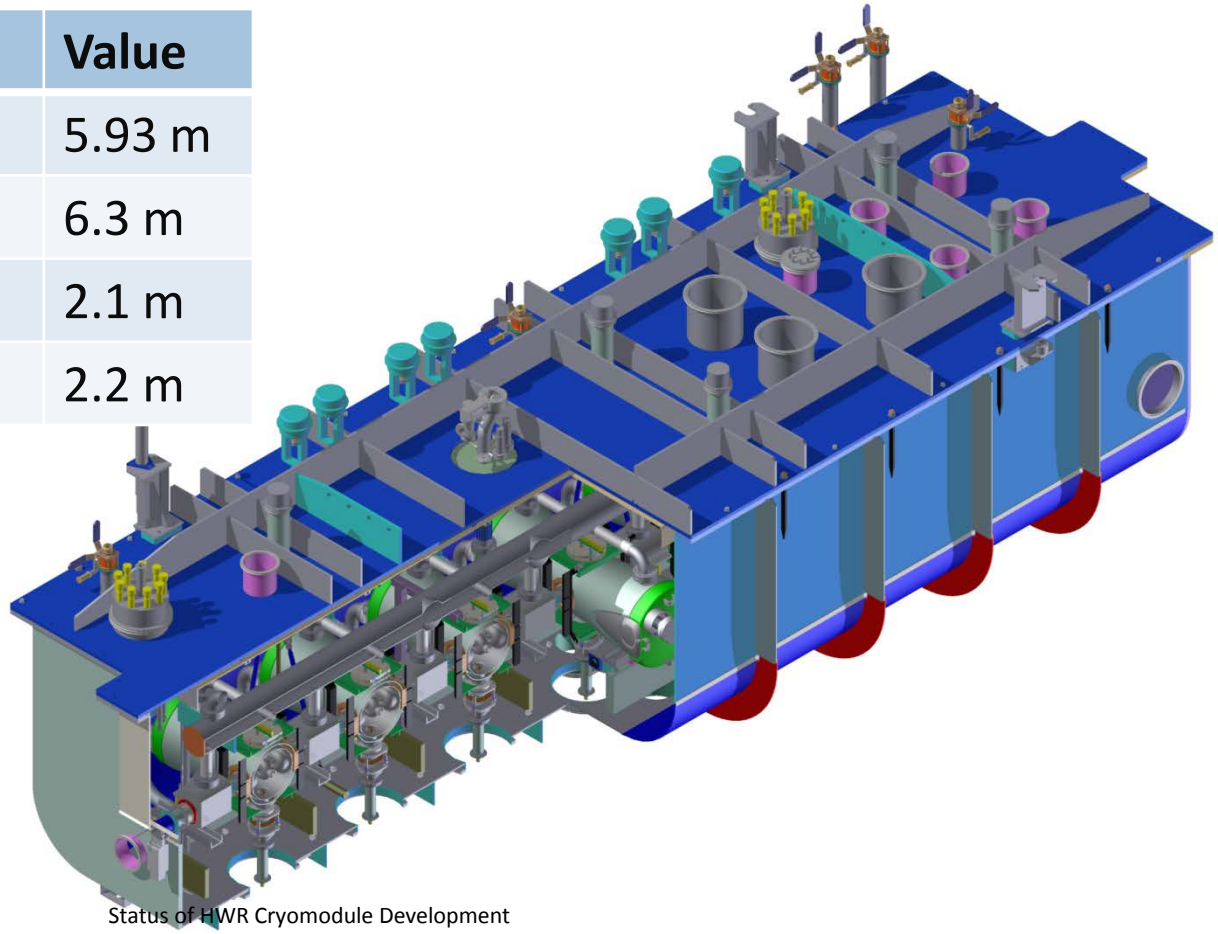
- Contains 45 pages, additional pages will be attached for sub-systems: RF coupler and slow tuner
- Starts with the inspection of niobium sheets used for fabrication of particular cavity
- Follows cavity through all fabrication steps
  - Inspection of Nb parts formed by AES
  - EBW
  - Wire EDM
  - RF surface treatment
- Starting from frequency tuning cuts, all technical information will be entered to an individual logbook for each cavity



Cryomodule

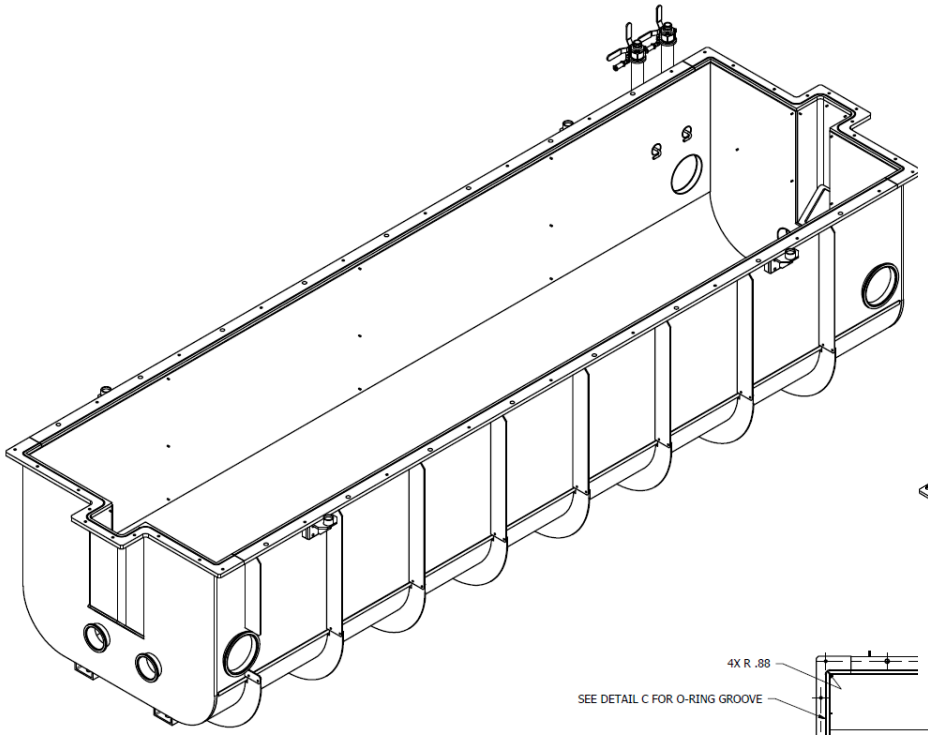
- Vacuum vessel is a big item in the M&S cost
- Detailed drawings for all internal parts (cold mass) are in progress

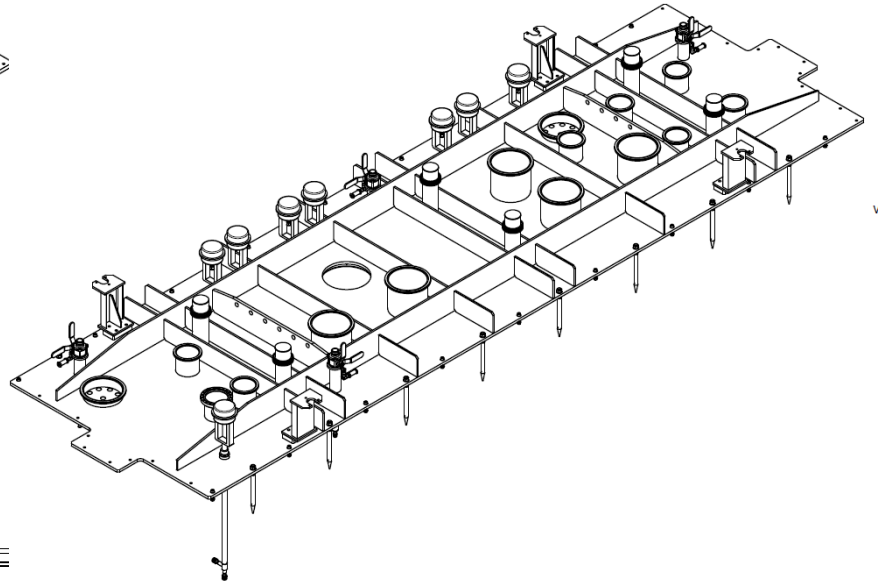
Parameter	Value
Length (beam ports)	5.93 m
Length (overall)	6.3 m
Width	2.1 m
Height	2.2 m



Cryomodule Vacuum Vessel

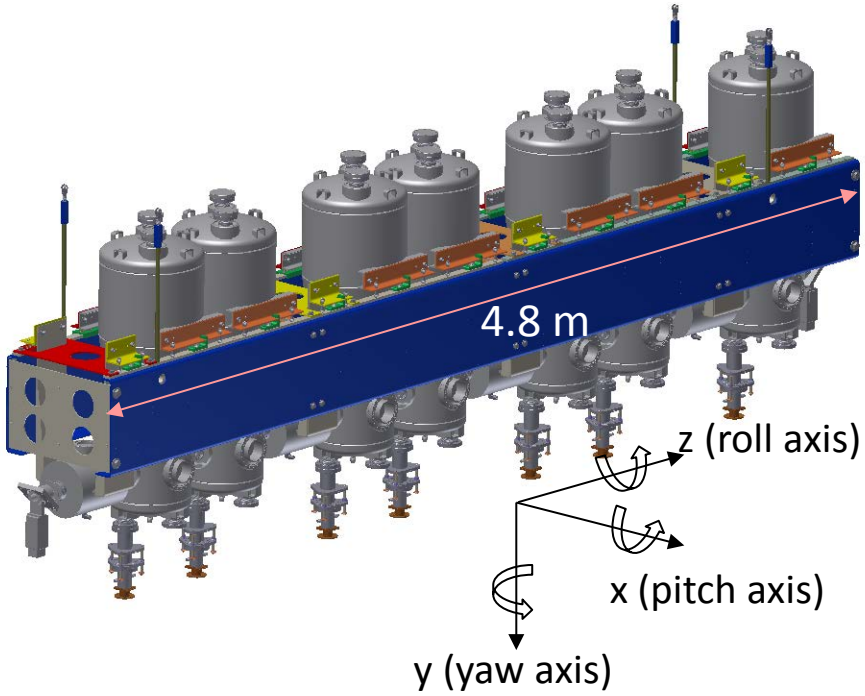
- SOW and all fabrication drawings are ready. The drawings are being reviewed by 3 engineers (M. Kedzie, S. Gerbick and A. Barcikowski)
- Will be sent for bids in January





Experience with Alignment of Cavities and Solenoids in ATLAS Intensity Upgrade Cryomodule

ATLAS Intensity Upgrade Cryomodule



7 QWRs and 4 solenoids operated at 4 K

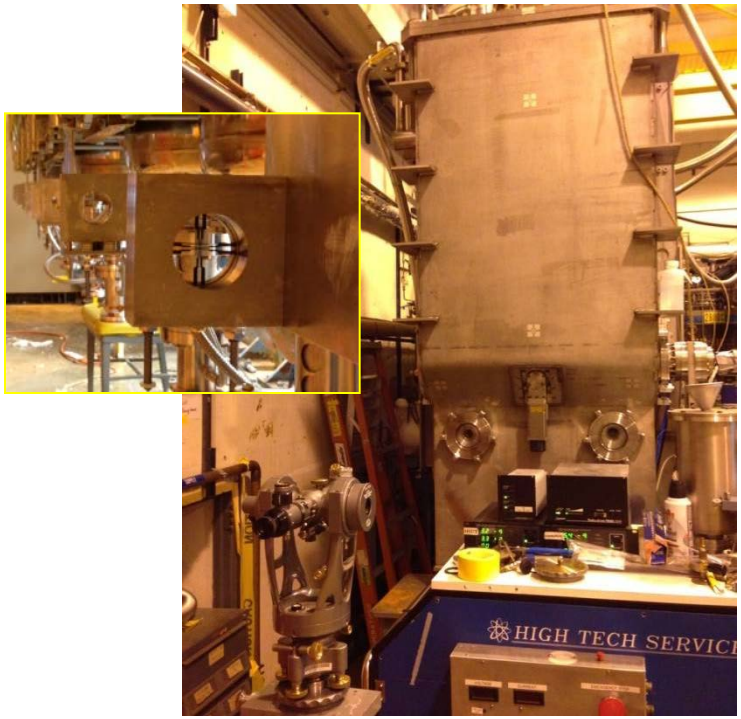
Alignment Tolerances

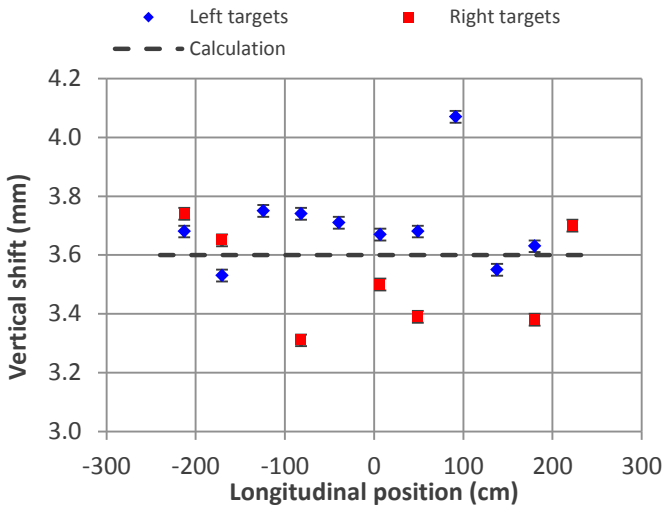
Coordinate	ATLAS Energy Upgrade*	ATLAS Intensity Upgrade**	PXIE HWR	
			FRS***	Goal
x (mm)	±0.5	±0.25	±0.5	±0.25
y (mm)	±0.5	±0.25	±0.5	±0.25
z (mm)	±2	±1	±0.5	±0.5
Pitch (degrees)	±0.2	±0.1	±0.06 (S) ±0.14 (C)	±0.06
Yaw (degrees)	±0.2	±0.1	±0.06 (S) ±0.14 (C)	±0.06
Roll (degrees)	±1	±0.1	±0.06 (S) ±0.14 (C)	±0.06

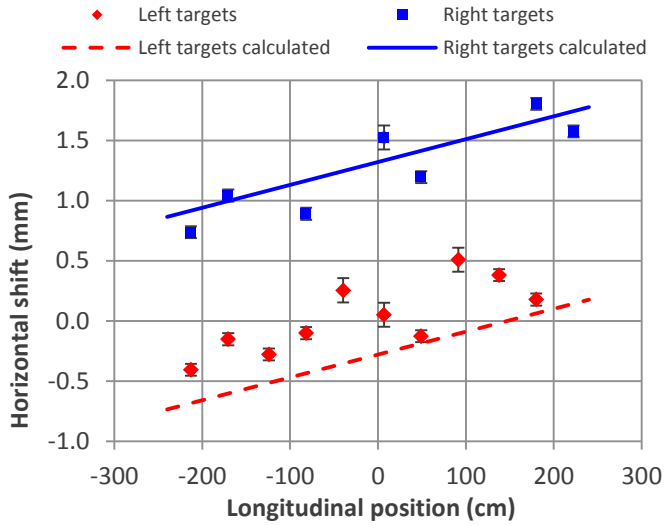
*,** Alignment tolerances for solenoids only

*** Half-Wave Resonator Cryomodule for Project X Functional Requirements Specification, Feb. 2012

Alignment Change on Cooldown







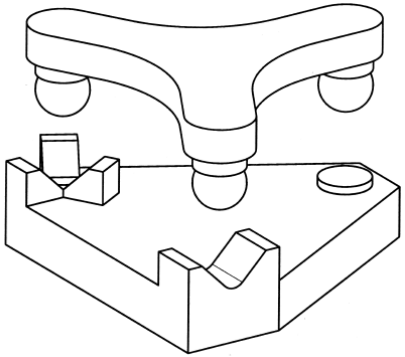
RMS deviation from the fitted beam axis

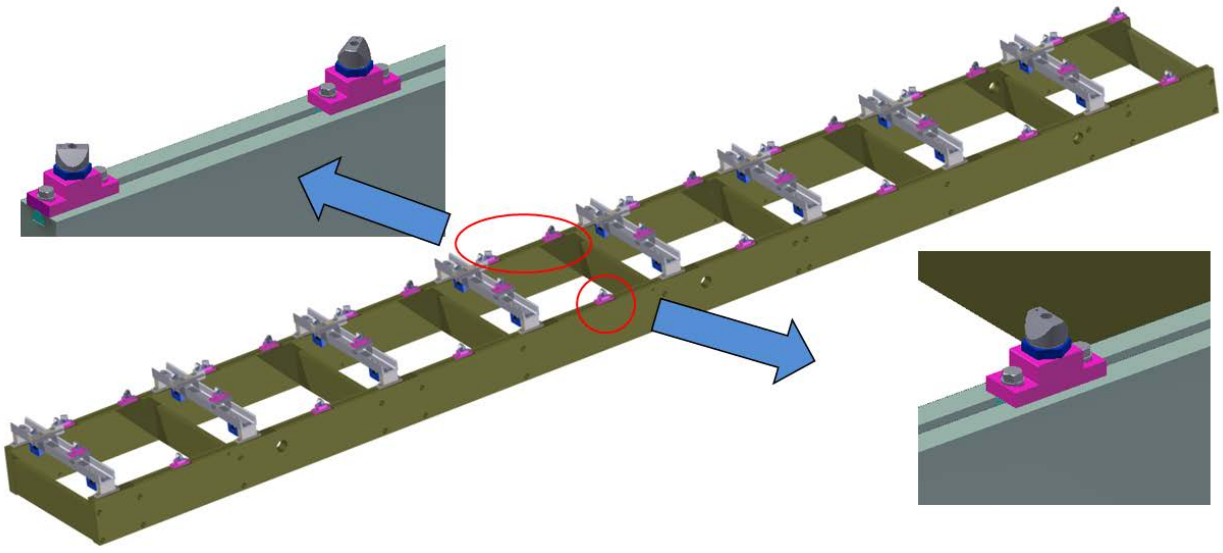
	Solenoids	Cavities
Horizontal	0.12 mm	0.50 mm
Vertical	0.18 mm	0.28 mm

Improvements in PXIE HWR Cryomodule

- Machined Stock Ti bars will be used for the strongback. It will need less effort for the room temperature alignment with advanced position adjustment system.
- Maxwell kinematic coupling will be used in the cavity and solenoid mounts. The beam axis will not have thermal motion on the kinematic mount plane.
- 4 targets will be attached per each cavity and solenoid. Changes in pitch and yaw can be monitored on cooldown.

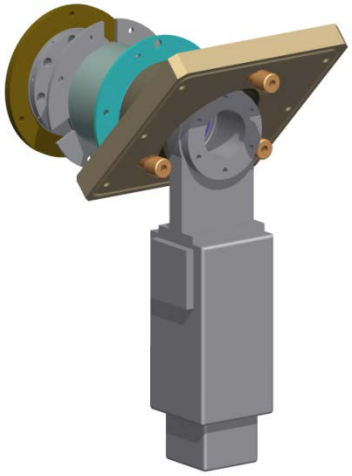
Kelvin type (ATLAS cryomodule) kinematic coupling

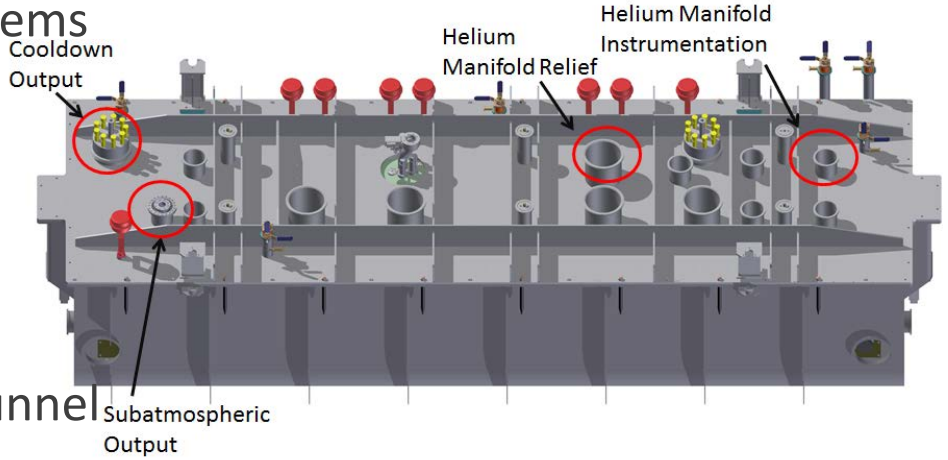




Interface Document ~30 pages, Table of Contents

1. Scope of Work.
2. Beam Line Connections
3. Alignment
4. Magnet Leads
5. Thermometry and Heaters
6. He System Instrumentation and Bayonets
7. Cavity and Cryomodule Vacuum Systems
8. RF System Connections
9. Slow Tuner Connections
10. BPM Connections
11. Lifting Attachment Points
12. Cryomodule Location in the PXIE Tunnel





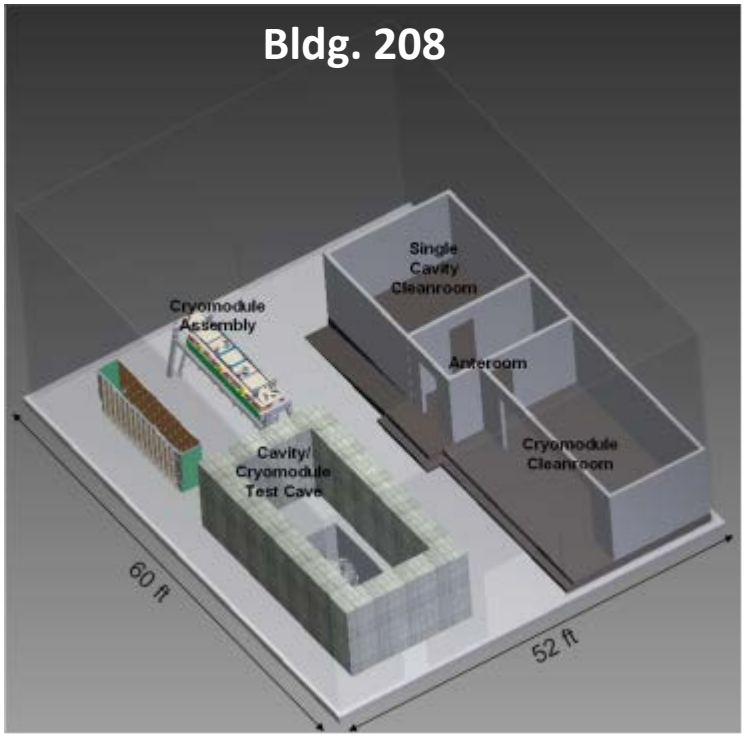
- **Final version will be sent to FNAL in January 2014**

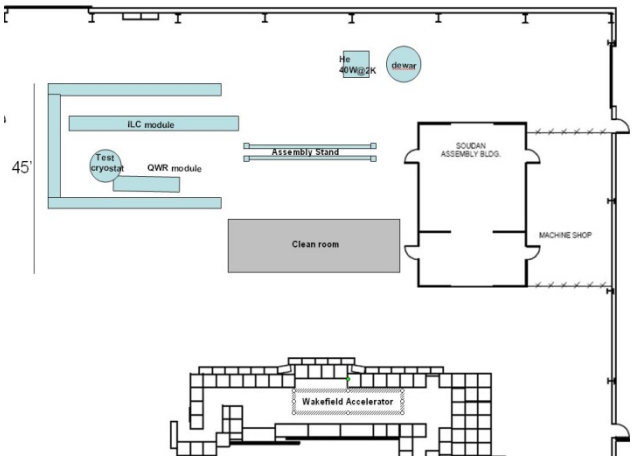
Our Nearest Tasks

- Meet next milestone: cold testing of the first prototype cavity during the third quarter of FY14
  - Fabricate one slow tuner by the end of March
  - Deliver both HWRs in SS helium vessel in February 2014
  - EP, HPR, 625C baking in March 2014
- Production cavities
  - Complete EBW on all 7 Nb cavities by the end of FY14
- Cryomodule
  - Send out vacuum vessel drawings for bids and obtain quotes in January
  - Finalize fabrication drawings for all internal components
- If funding is available we are ready to start procurement of all cold mass components
  - Solenoids, BPMs, vacuum system, helium distribution system, RF couplers, gate valves, beamline spools, cryogenic instrumentation, slow tuners,..

Plans for Cryomodule Assembly and Off-line Testing

- There are 2 hi-bay areas available for the assembly and off-line commissioning of the cryomodule
- Assembly, leak check, cold tests with LN2





Summary

- Focus on the following main tasks in FY14
  - Testing of fully dressed prototype cavities
  - Complete niobium fabrication of production cavities
  - Get ready for procurement of cryostat vessel and components of cold mass. The procurement can be started as soon as funding is available.
- Currently we have a team of skilled engineers, technicians and scientists to work on development and construction of any SRF related task: cavities, cryomodules, RF couplers

Back-up slides

Major Milestones

- Due to the limited funding profile, the schedule was modified for the beam commissioning of the HWR cryomodule in Q4FY17

Layout: PXIE HWR Milestones | Filter All: Milestone, PXIE HWR, Management Milestones, PXIE Schedule

Activity Name	Finish
HWR Prototype Coupler, Solenoid & BPM Fabrication Complete	28-Dec-12*
HWR Cryomodule Design Review	29-Mar-13*
HWR Two Prototype Cavities Fabrication Complete	30-Sep-13*
HWR Niobium Forming of Production Cavities Complete	30-Dec-13*
HWR Two Prototype Cavities Testing Complete	31-Mar-14*
HWR Fabrication of Production Cavities Complete	31-Mar-15*
HWR RF Surface Processing Complete	30-Sep-15*
HWR String Mock Up Complete	31-Mar-16*
HWR Off-Line Testing Complete	30-Sep-16*
PXIE Stage 1 Complete*	30-Nov-16
HWR Cryomodule Delivery To FNAL*	31-Mar-17*
HWR Installation Complete	30-Jun-17
PXIE Stage 2 Complete*	30-Aug-17*
HWR RF Conditioning Complete	30-Aug-17
Beam through the HWR	22-Jan-18
PXIE Stage 3 Complete*	17-Aug-18
HWR Commissioning Complete	17-Aug-18
PXIE Beam Commissioning Complete*	29-Aug-18