Argonne NATIONAL LABORATORY

Overview of the HWR Project: Technology, ES&H and QA

P.N. Ostroumov

Physics Division

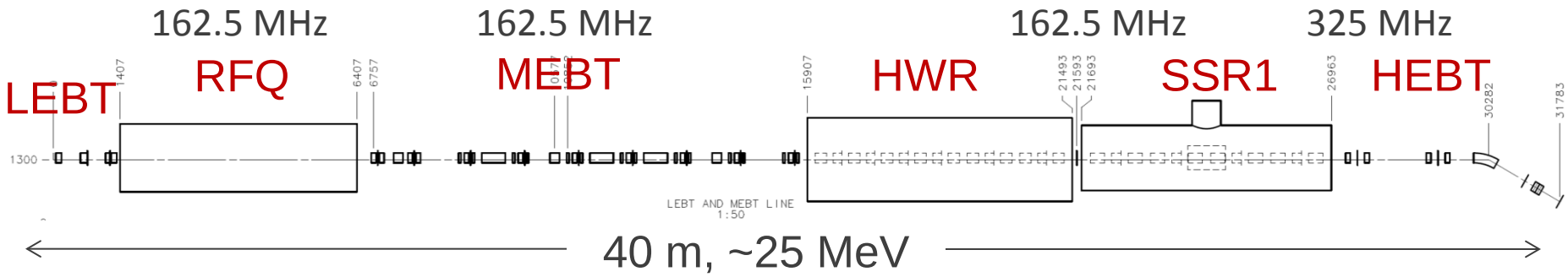
October 15, 2013

U.S. DEPARTMENT OF ENERGY

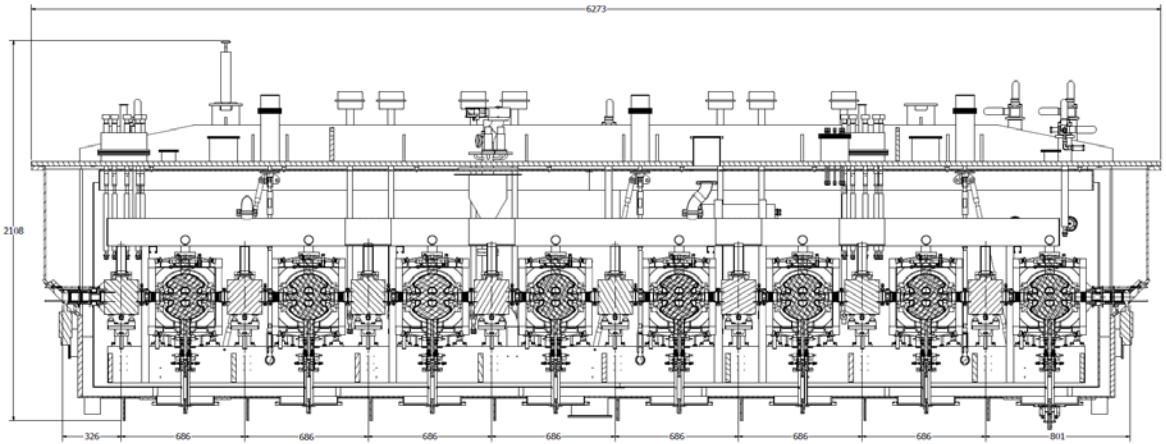
Content

- HWR Project scope
- Technical progress since the last Review in March 2012
- Revised milestones
- Status of prototype cavities
- Cavity sub-systems
  - RF coupler
  - Slow tuner
- SC solenoid and BPM testing
- Production cavities
- ES&H approach
- Quality assurance and Quality control
- Plans for cryomodule assembly
- Nearest tasks
- Summary

PXIE Layout and HWR Cryomodule



- 8 HWRs operating at 162.5 MHz
- Acceleration of H^- beam from 2.1 MeV to 10 MeV in CW regime
- Total accelerating voltage: 1.7 MV×8=13.6 MV



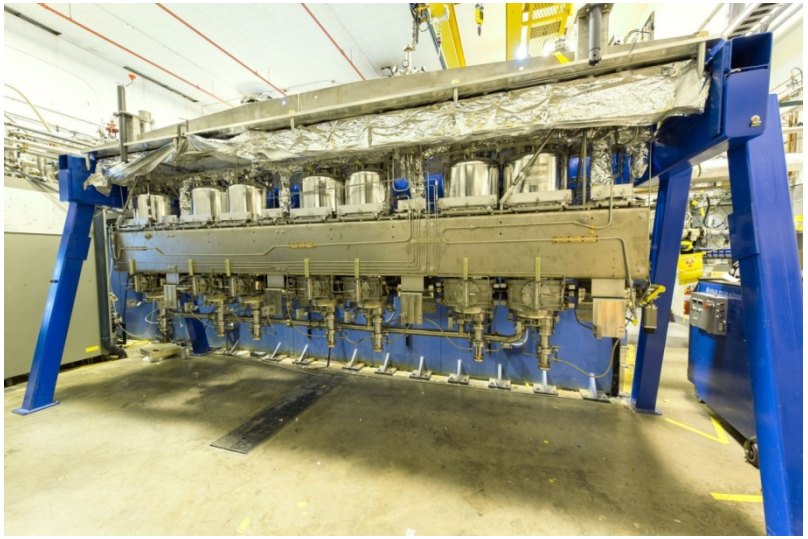
- Favorable beam dynamics as compared to the 325 MHz cavities: higher accelerating gradients, less defocusing, linear motion in longitudinal phase space

HWR Project Goals and Associated Scope of Work

- Develop, design, build, provide off-line pre-commissioning, deliver and install a cryomodule comprising 8 SC solenoids, 8 half wave resonators and 8 BPMs
  - Satisfy all functional requirement specifications (FRS)
  - FRS has not changed since February 2012
- Primary technical challenges
  - Unique for 2 mA CW proton linac
  - Must provide 1.7 MV per cavity
  - Compact lattice
  - HWR includes 10-kW RF coupler and slow tuner
  - SC solenoid with steering coils in both focusing planes
  - "Cold" BPMs in each focusing period
  - Alignment of multiple solenoids and BPMs with ±250 μm accuracy (FRS specs are ±500 μm)
  - Alignment of multiple cavities with ±500 μm accuracy
  - When built and tested it will be the first 2K cryomodule for TEM-class cavities

Recent Experience of ANL's Accelerator Development Group

- 4K cryomodule has been built and commissioned off-line in 4 years
  - Beam commissioning in December 2013
- 21 MV voltage by 7 QWRs
  - Design specs is 17.5 MV
- Four 9-Tesla solenoids

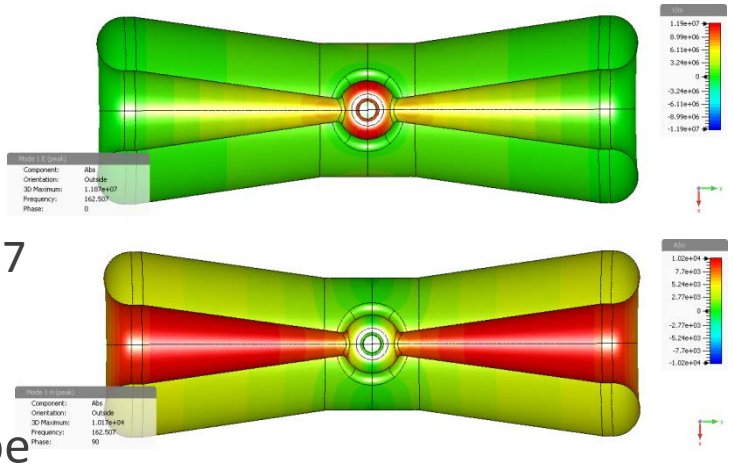


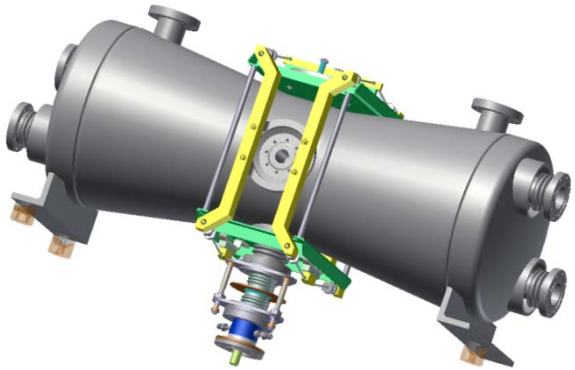
HWR Cryomodule Review in March 2012

- The project started in October 2011
  - Originally cryomodule concept included 9 cavities and 5 SC solenoids, no BPMs
  - Beam physics studies resulted in 8 cavities, 8 solenoids, 8 BPMs. FRS was changed accordingly in February 2012.
- Originally cryomodule beam commissioning was scheduled in Q2FY16
  - Current schedule is 4QFY17
- HWR multi-physics design was completed with excellent EM properties.
- Design of a 10-kW variable RF coupler was proposed
- Plan for RF surface treatment was developed
- Conceptual design of 2K cryomodule was presented: top loaded cryostat, modification from ATLAS 4K cryomodules
  - Compact
  - JT exchanger is inside the cryomodule
  - 6-Tesla solenoids with steering coils and without any iron shielding
  - Titanium rail strongback
  - Alignment hardware to provide accuracy of ±250 μm

Resonator Design Features as Reported in March 2012

- Highly optimized
  - Increased shunt impedance
  - “Donut” shape of the CC drift tube to eliminate quadrupole component of the accelerating field
  - Excellent EM properties. The design voltage is 1.7 MV which corresponds to E_{PEAK} = 38 MV/m and B_{PEAK} =44 mT
- Four 2-inch diameter ports for EP, 2 ports will be used for pumping and pick-up loops, one more port is for the high power coupler
  - Blending radius on toroid-port joints is 0.5” – significant development by AES to minimize B_{PEAK}
- Pneumatic slow tuners
- 10-kW variable RF coupler, fast tuner is not required
  - 4-kW RF power will provide 40 Hz window at 1 mA
  - Expected microphonics is < 1 Hz rms



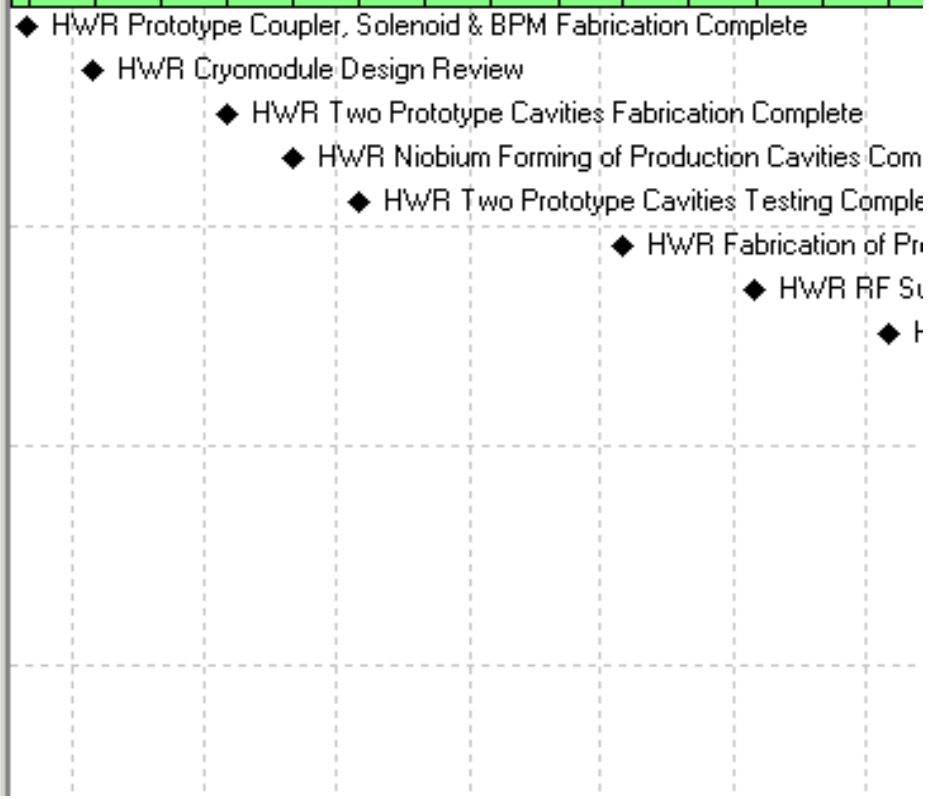


Major Milestones

- 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



Progress since March 2012 Review

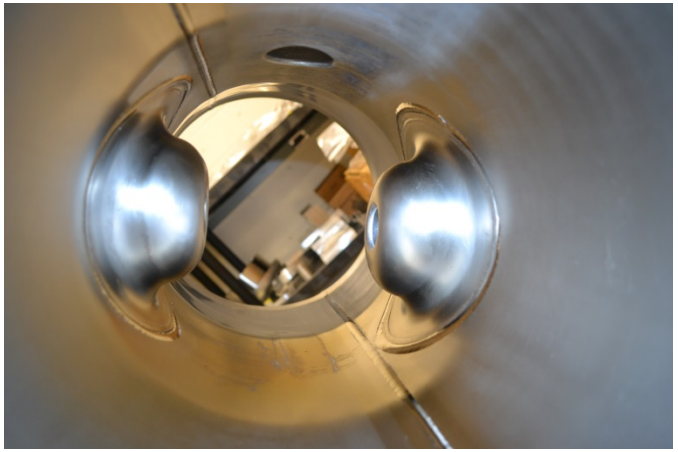
- ANL/FNAL pressure safety Review of the HWR design, May 2012
- Design, engineering and safety analysis of the HWRs were complete in July 2012
  - Structural analysis of HWR: 2 bar at 300K and 4 bar at 2K, 20 kN force applied by slow tuner (required force is less than 10 kN)
- Two HWRs are being fabricated
  - The first cavity is ready for the frequency tuning with the following EBW to complete Nb cavity
  - 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
    - Next milestone is the prototype cavity testing by the end of March 2014. We are confident in meeting this milestone.
- Forming of Nb parts for 7 production cavities complete – milestone of 12/31/13

Progress since March 2012 Review (continued)

- 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
- Internal ANL Technical Review of the engineering design of the cryomodule: August 30, 2012
- ANL/FNAL technical and safety review of the cryomodule design: May 16, 2013. Detailed structural analysis has been performed and documented for this review.
- Cryomodule design is complete
  - 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 except sub-atmospheric bayonet and helium relief port are ready for procurement and fabrication

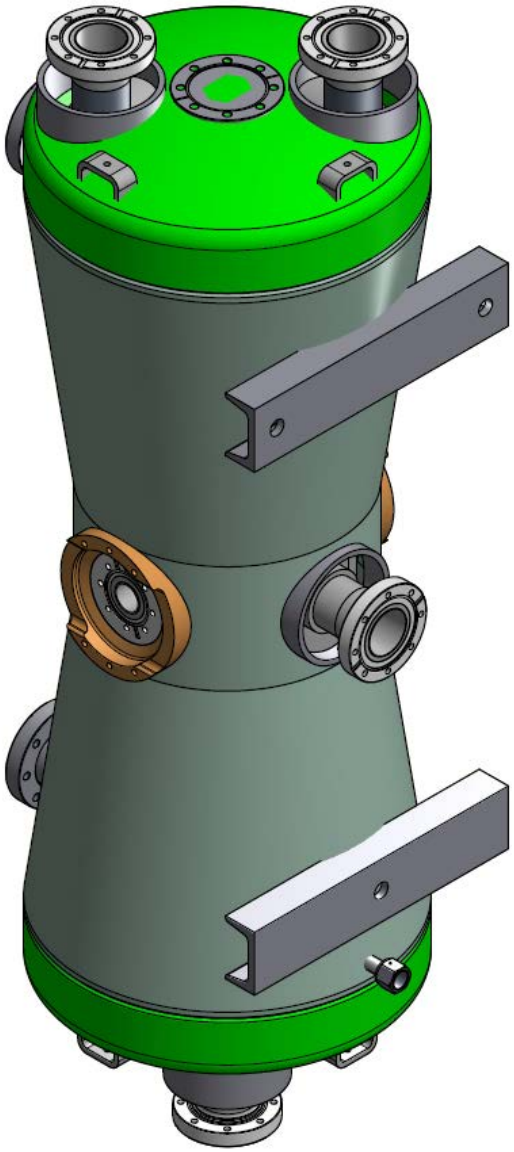
Prototype Cavities

- The first cavity (PXIE cavity) is ready for frequency measurements and to proceed with trimming of CC and OC



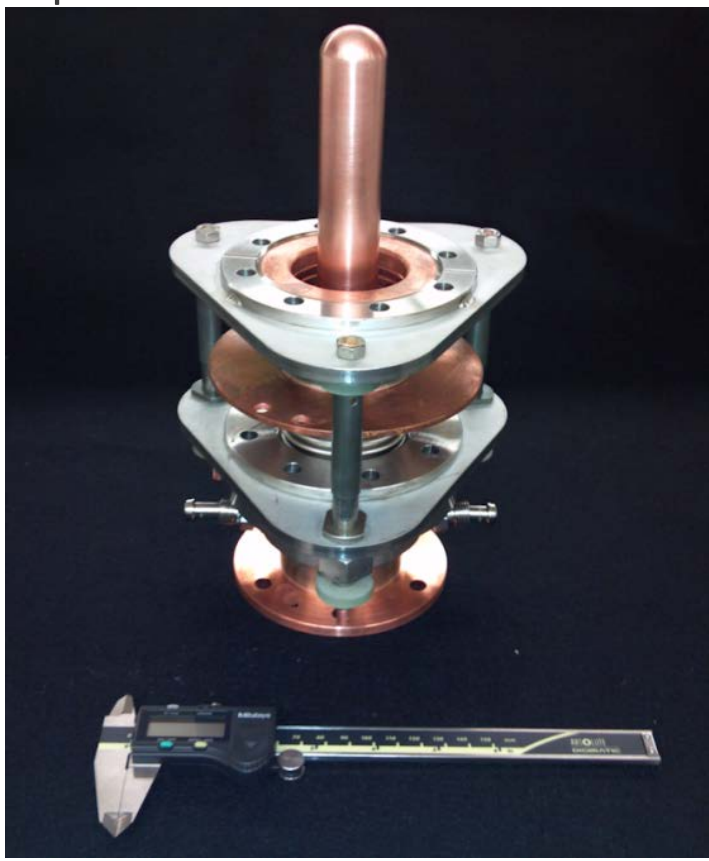
Prototype Cavities (continued)

- Cavity #2 (CABOT cavity)
  - EBW of re-entrant noses on week of 10/21
- Helium vessel
  - 1/8'' thick SS vessel
  - Submit SOW and 3D model to Meyer Tool for quotation on week of 10/21
  - Build and install helium vessel: mid-January 2014
- Electropolishing, HPR: February 2014
- Cold testing of the first prototype cavity: March 2014
- If schedule permits, 625C baking at FNAL furnace



10-kW Variable Coupler

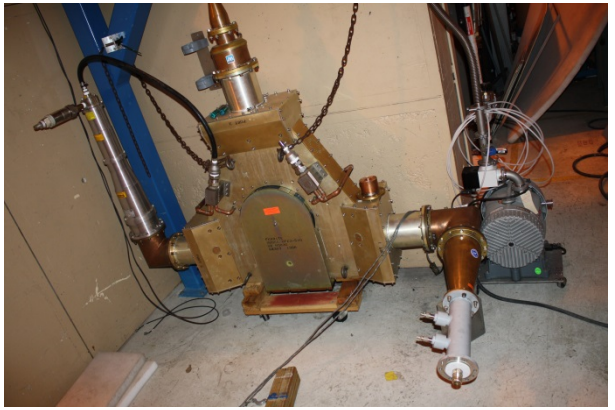
- Based on successful development of 4-kW input coupler (1-5/8” coax) for 72 MHz cavities
- Increased diameter of the outer conductor, 2”
- 1” stroke, 70K cooled alumina window, 5K intercept
- Two RF input couplers have been built
- Testing has been performed at 72 MHz and 162.5 MHz
- No multipacting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



RF Coupler Test

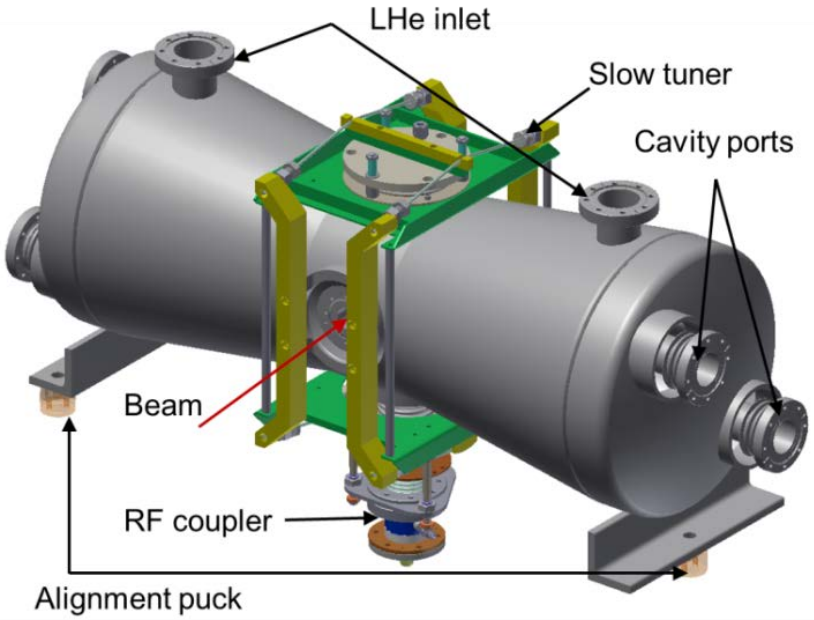
- Many thanks to Ralph Pasquinelli and his team for vigorous effort with amplifier and ferrite circulator
- Amplifier and circulator were moved to ANL and operated for these tests

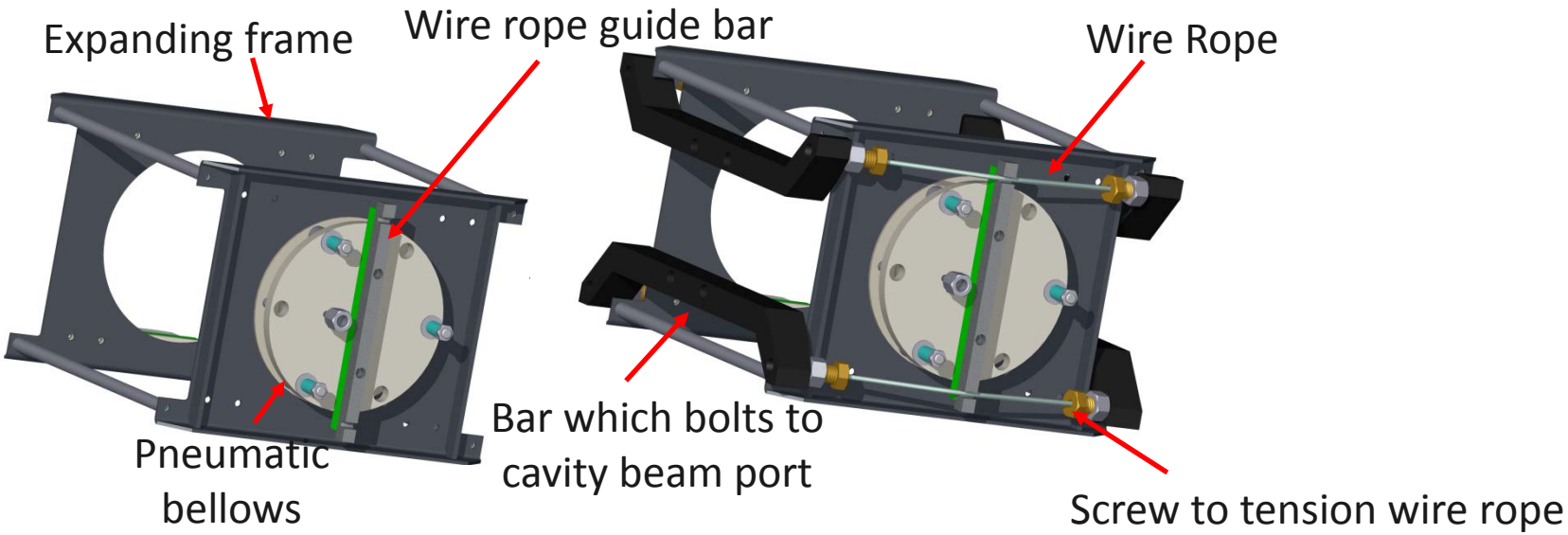
75 kW 162 MHz ferrite circulator



Slow Tuner

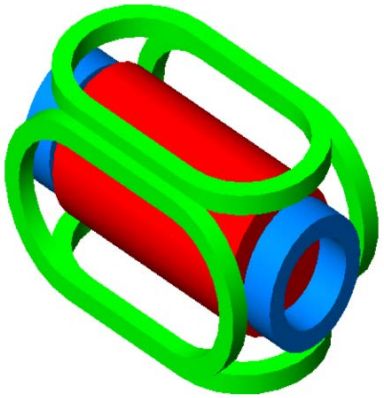
- Pneumatic slow tuner has been in use at ATLAS for 3 decades
- Recent modifications were related to ARRA cryomodule
  - Generate 6000 pound force by applying He pressure up to 90 psi
  - Some modifications of sliding parts to provide smooth frequency adjustment with ~1 Hz resolution

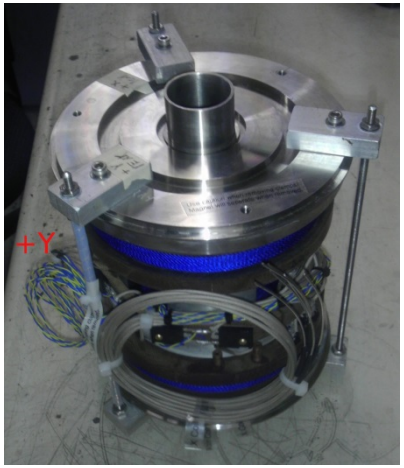


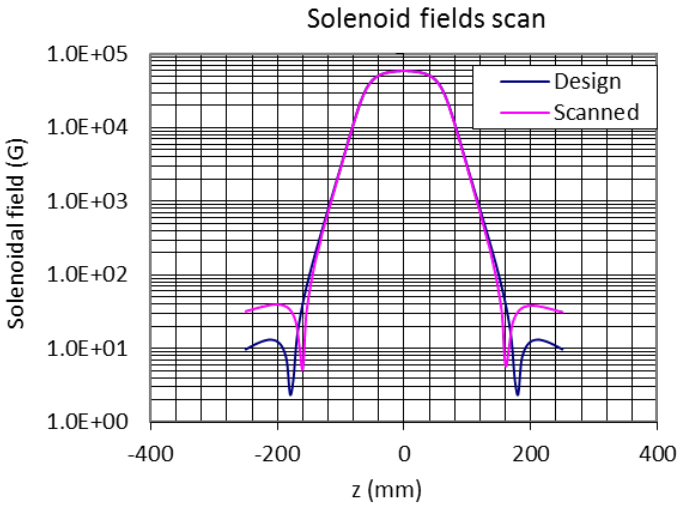


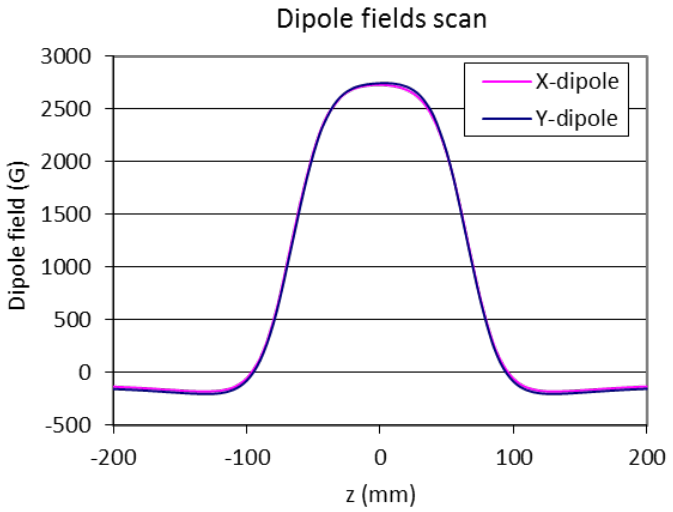
6 Tesla SC Solenoid

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



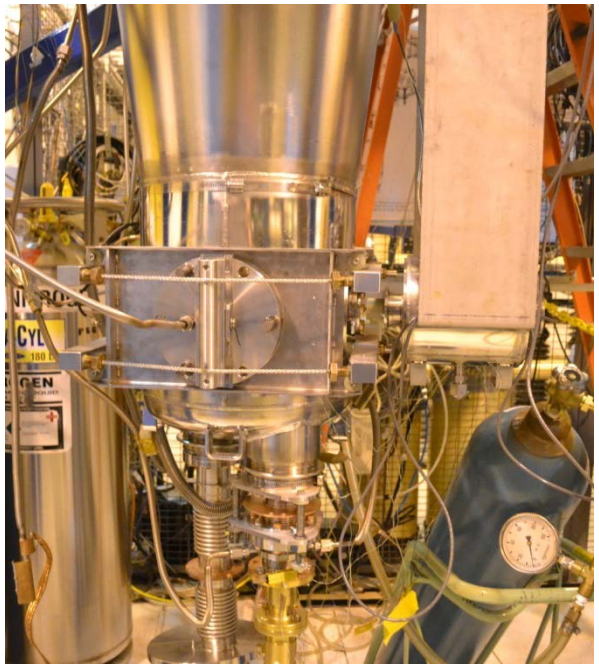




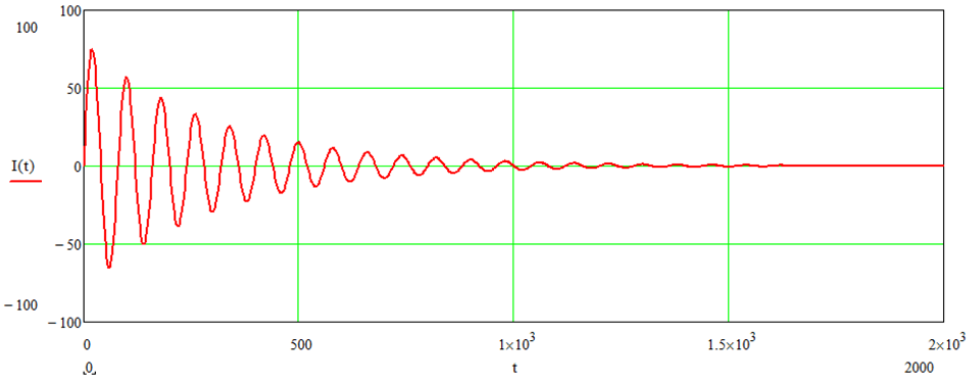


SC Solenoid PS, 4-kW RF Amplifier, Cavity RF Coupler and SC Solenoid

- Many thanks to George Krafczyk and his team for providing solenoid power supply with built-in programmable function for degaussing

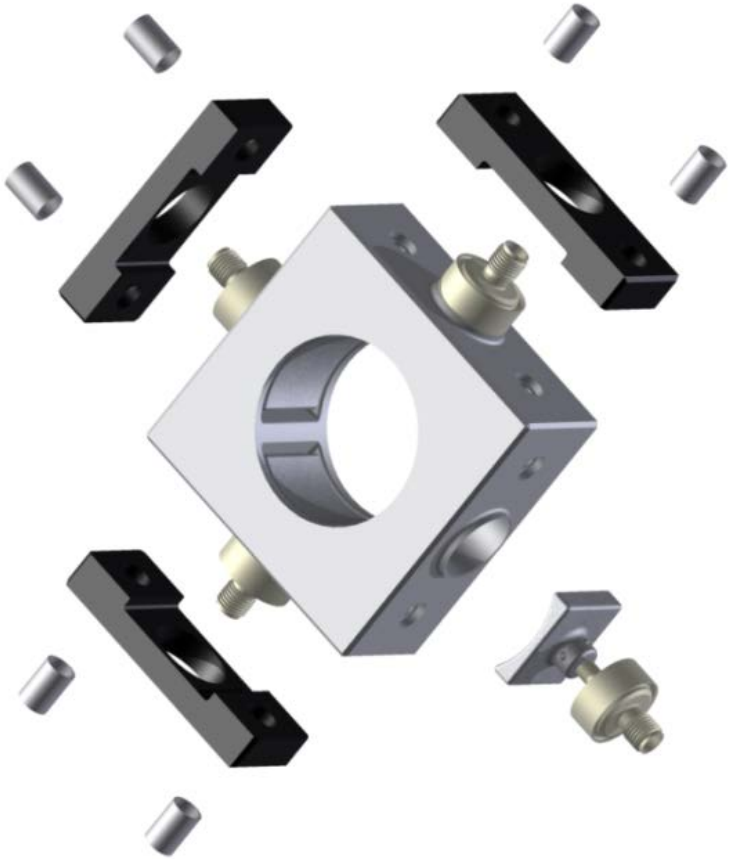


Current profile for degaussing



BPM

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

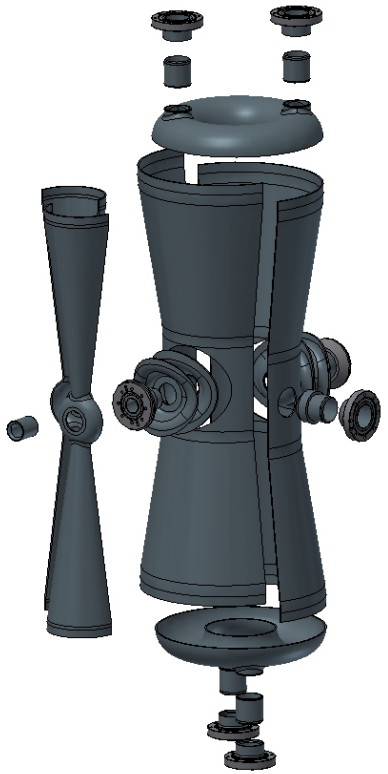


Nb Forming for 7 Production Cavities Complete

- Milestone of December 31, 2013

Traveler Documentation

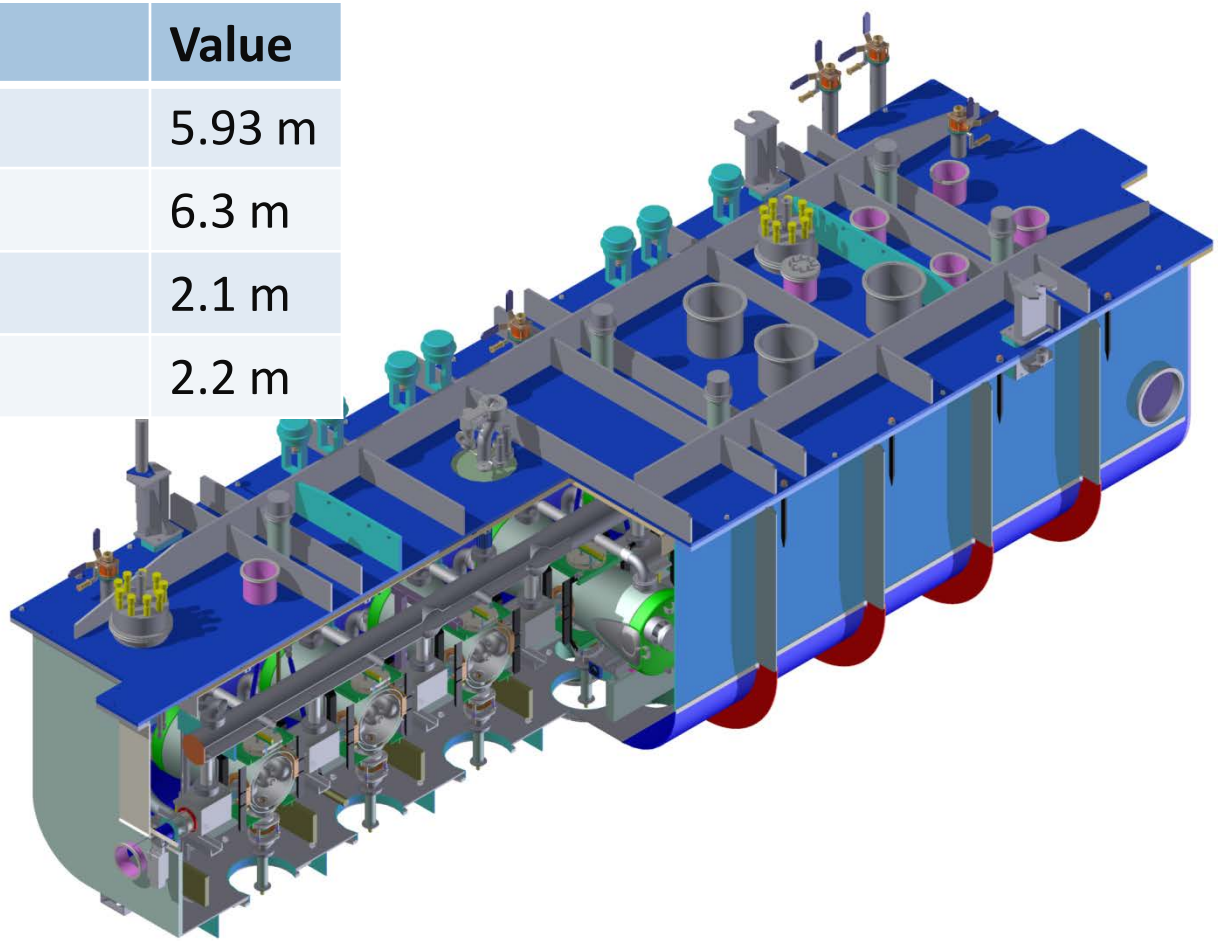
- Contains 45 pages
- Starts with the inspection of niobium sheets used for fabrication of particular cavity
  - Details in Mark's presentation
- Follows cavity through all fabrication steps
  - Inspection of Nb parts formed by AES
  - EBW
  - Wire EDM
  - RF surface treatment
- Starting from frequency tuning cuts, all technical information will be entered to an individual logbook for each cavity



Cryomodule

- The vacuum vessel drawings will be sent out for bids next week
- Most likely, we will end up with Meyer Tool due to the past experience
- Big item in the M&S cost

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



ANL Laboratory Management System (LMS) and ES&H

- A primary objective of this project is to protect the environment and the safety of workers and the general public
- The PXIE-HWR project fully complies with ANL LMS
  - All work is controlled by Work Processing and Control Documents, examples
    - *Cold testing of RF coupler, solenoids*
    - *Chemistry, HPR*
  - All Project Team members are fully trained for the tasks they perform
  - Integrated safety management (ISM) is incorporated into the project planning and execution and includes
    - Defining the work
    - Analyzing all potential hazards
    - Developing and implementing hazard controls
    - Performing work within controls
    - Providing feedback and continuous improvement

LMS and ES&H (continued)

- The Project complies with all applicable ANL and Physics Division ES&H requirements.
  - ANL ES&H Manual and the Physics Division Safety Policy,
  - Physics Division Electrical Safety Manual,
  - Physics Division Radiation Safety Manual,
  - Physics Division Chemical Hygiene Plan,
  - Building 203 Emergency Plan,
  - ATLAS Operating Procedures
- Technical and ES&H reviews:
  - We had 2 general Safety Committee Reviews at ANL with FNAL participants
    - HWR
    - Cryostat
- In addition, engineering and technical design is being performed in accordance to recommendation of FRS

Quality Assurance and Quality Control

- The quality culture is the cornerstone of the project management philosophy
- Quality Assurance for the HWR Cryomodule Project is performed according to ANL LMS Policies and Procedures
- Main purpose of the QA
  - Meet all parameters defined in Functional Requirement Specification (FRS)
    - Possible deviation from FRS parameters will be discussed with FNAL
  - Avoid costly reworks
  - Reduced cost of the project
- General guidance from Tom Mullen, PHY ES&H and QA engineer
- The Project "Quality Professional" is Scott Gerbick– an engineer with 10+ year experience
- A complete cavity traveler has been developed documenting all stages of materials inspection, component fabrication, surface treatment and testing
- Similarly, a complete cryomodule traveler will be developed documenting all stages of materials inspection, cryomodule component fabrication, piping and weld inspections, cryomodule assembly, and testing.

Quality Assurance and Quality Control (continued)

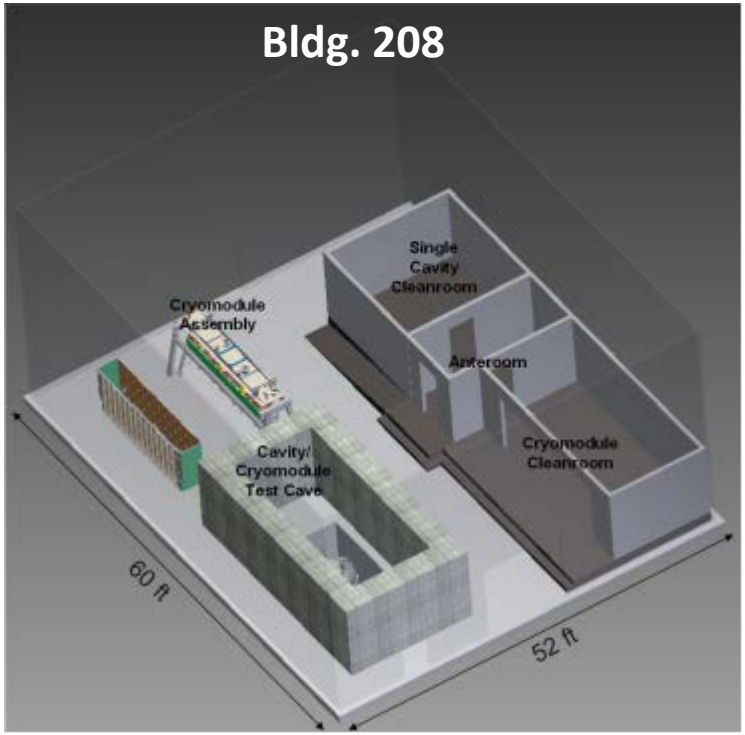
- Our approach for QA and QC was presented in detail during the previous Review
- The primary elements of quality assurance for this project are:
  - Past successful ANL experience
  - Experience of ANL staff
  - Use of experienced vendors
- No quality assurance plans or procedures can substitute for these items.
- Production of prototype cavities assures the results with the production cavities.
- The Project Leader is responsible for implementation and management of the quality assurance plan
- You will hear QA&QC aspects in all following presentations

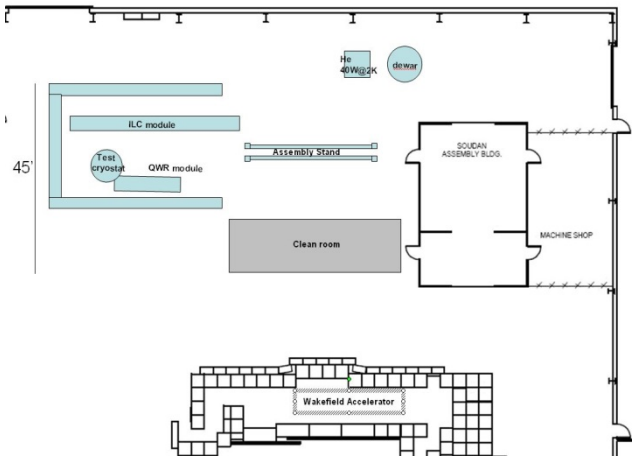
Our Nearest Tasks

- Meet next milestone: cold testing of prototype cavities by the end of March 2014
  - Fabricate one slow tuner by the end of February
  - Deliver HWRs in SS vessel in January 2014
  - EP, HPR in February 2014
- Production cavities
  - Complete EBW and fabricate Nb cavities by the end of FY14
- Cryomodule
  - Send out vacuum vessel drawings for bids and obtain quotes by the end of year
  - 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
- However, we need $250K to install the clean room. This amount is not the part of the project.





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.