Project X Collaboration meeting, November 27-28, 2012 FNAL

HWR Cryomodule Development

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Physics Division

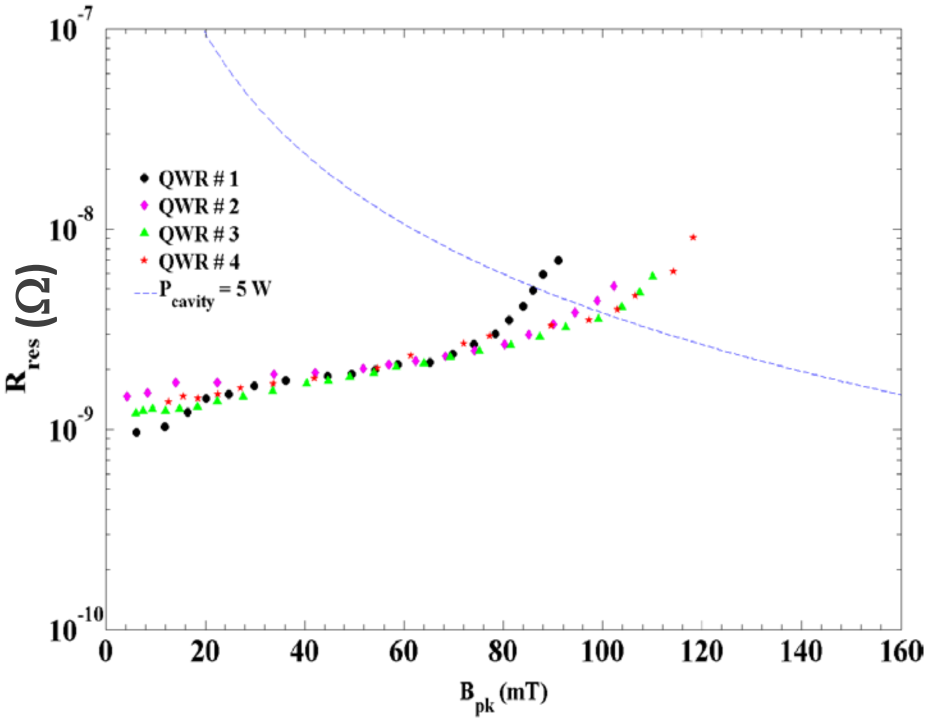
November 28, 2012

Content

- SRF technology at ANL
- Status of current and future work on HWR cryomodule
- HWR development and fabrication
- RF coupler
- BPM
- SC solenoid
- Cryomodule vacuum vessel
  - Mechanical design
  - Engineering analysis
- Near future work

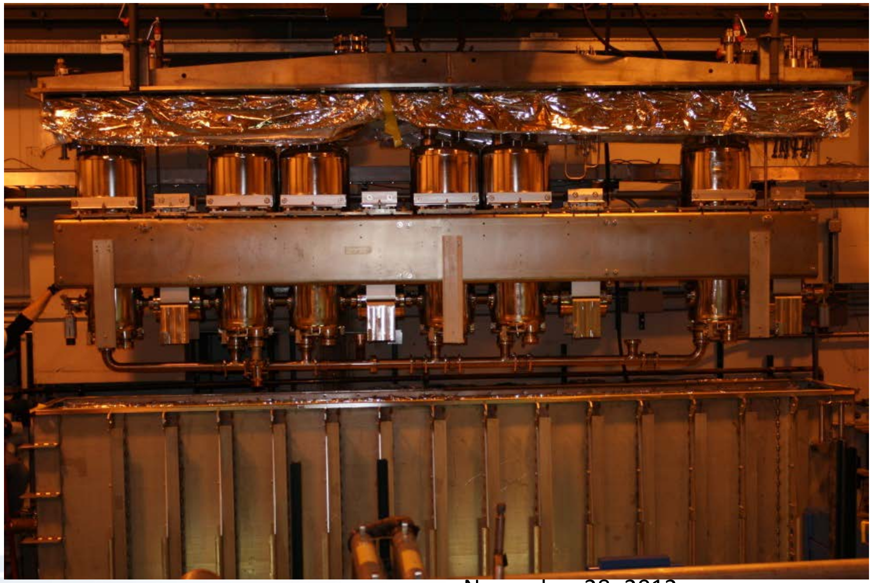
SRF Technology for PXIE HWR

- Recent progress at ANL with 72 MHz QWRs and cryomodule
- 2K testing: at 80 mT, V_0=3.6 MV, residual resistance is just ~2 nΩ
- Very low X-ray radiation below 80-100 mT
- Several cavities exceed the best ILC cavity performance in E_{PEAK}
- State-of-the-art design and fabrication technology is demonstrated



Gaining Experience with ATLAS Cryomodule Assembly

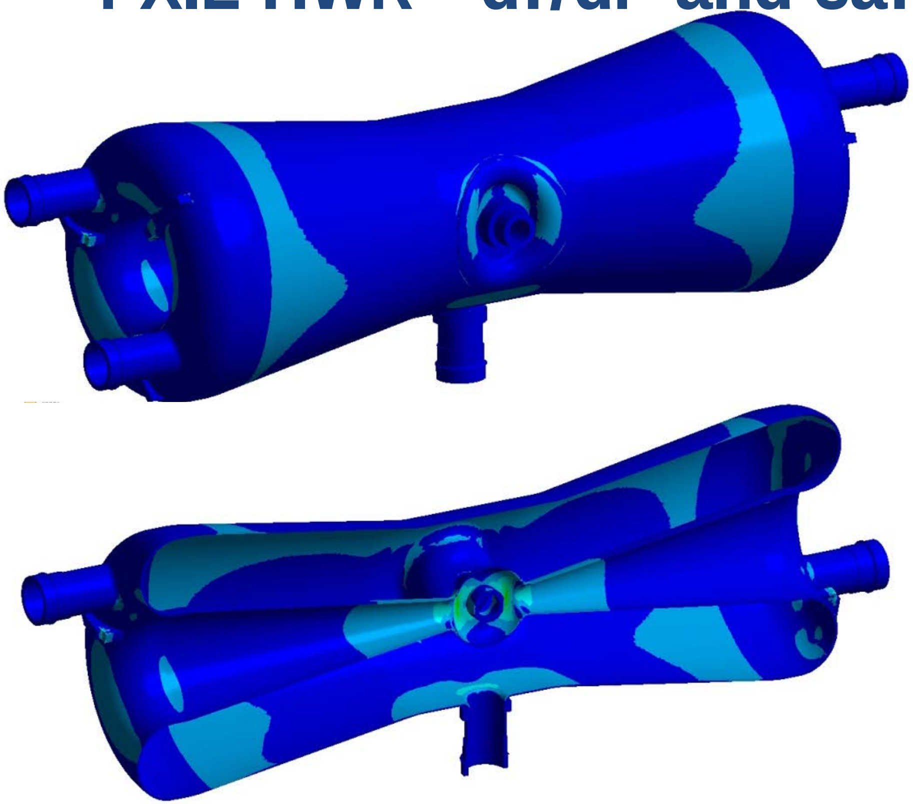
- Clean-room assembly of all components
- Fitting of vacuum, helium manifolds
- Alignment of cavities and solenoids - ±0.25 mm is achievable
- Alignment of the strongback – shrinkage is as expected in all directions
- Engineering cold test of the cryostat at LN temperature
- Measurements of heat load to LN - 160 W



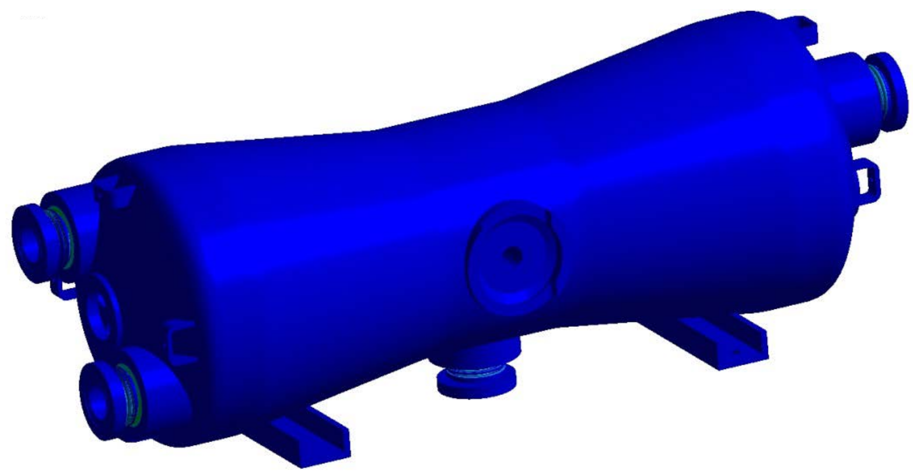
Activities Since April-12 Collaboration Meeting

- Mechanical design and engineering analysis of the HWRs are complete
- Pressure vessel safety analysis passed joint ANL-FNAL safety review and safety analysis documentation are complete
- Niobium parts for 2 HWRs are being fabricated
  - One cavity is being built with Wah Chang Nb, another one - with CABOT Nb
  - Fixturing for wire EDM and EBW is being fabricated
- SC solenoid includes return coil and 4 dipole coils
  - Prototype solenoid has been built at Cryomagnetics and jacketed at Meyer Tool
  - Will have ASME pressure vessel stamp
- High-power, 10-kW, RF coupler
  - Ready for cold testing in January-February 2013
- Beam Position Monitor
  - All components are finished, being welded and will be ready for cold testing in January-February 2013
- Cryomodule design is nearly complete
  - Vacuum vessel safety review is expected in March 2013

PXIE HWR – df/dP and Safety Analysis



Prototype Cavities
df/dP = + 5.4 kHz/atm



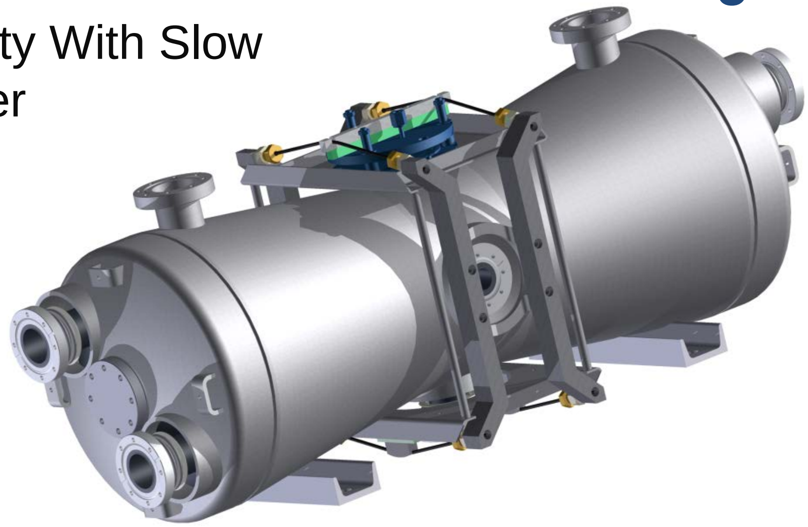
S.S. Helium Jacket
Stress; Red > 30.0 ksi

Nb Cavity Stress Red > 5.5 ksi

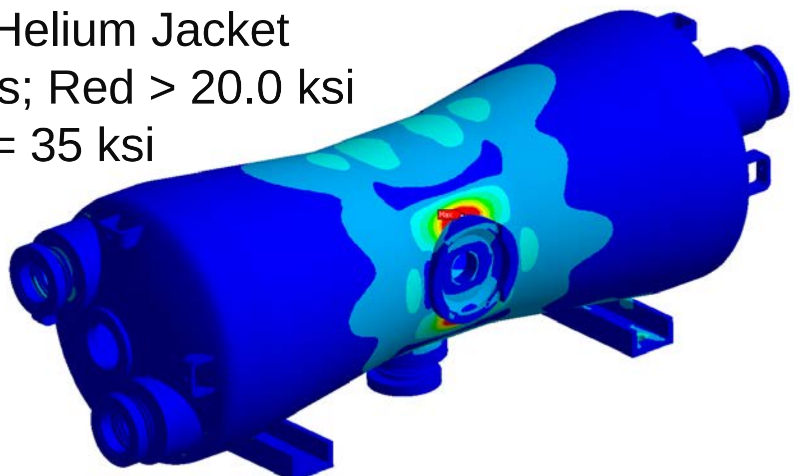
- Half-wave resonator design used for safety analysis – passed.
- Results shown here reflect the properties of the prototype resonator being fabricated.
- Results are excellent for RF amplitude/phase stabilization and will be confirmed with the prototype.

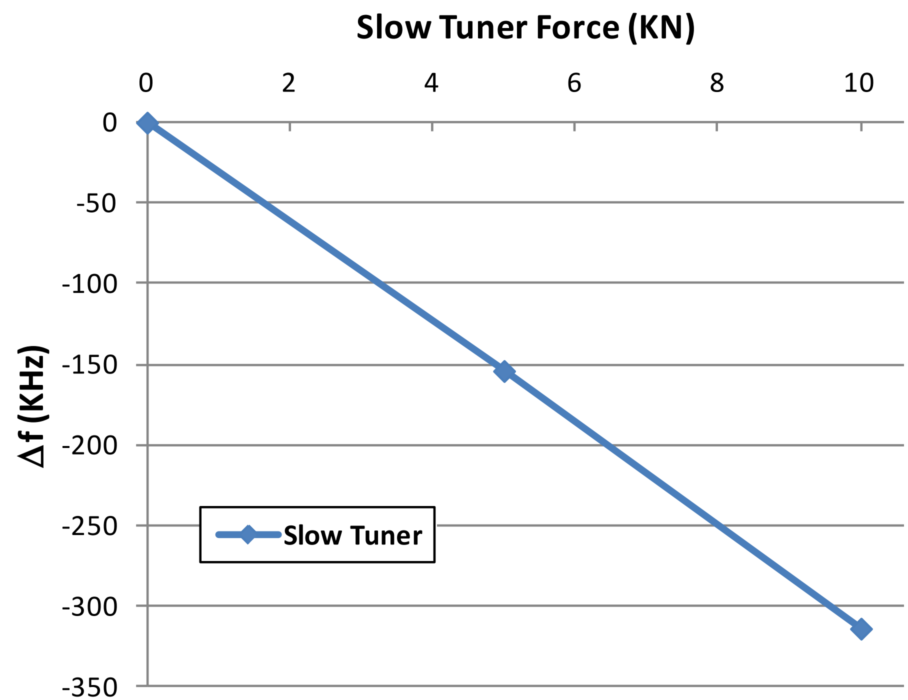
PXIE HWR - Slow Tuning

Cavity With Slow Tuner



S.S. Helium Jacket Stress; Red > 20.0 ksi Max = 35 ksi

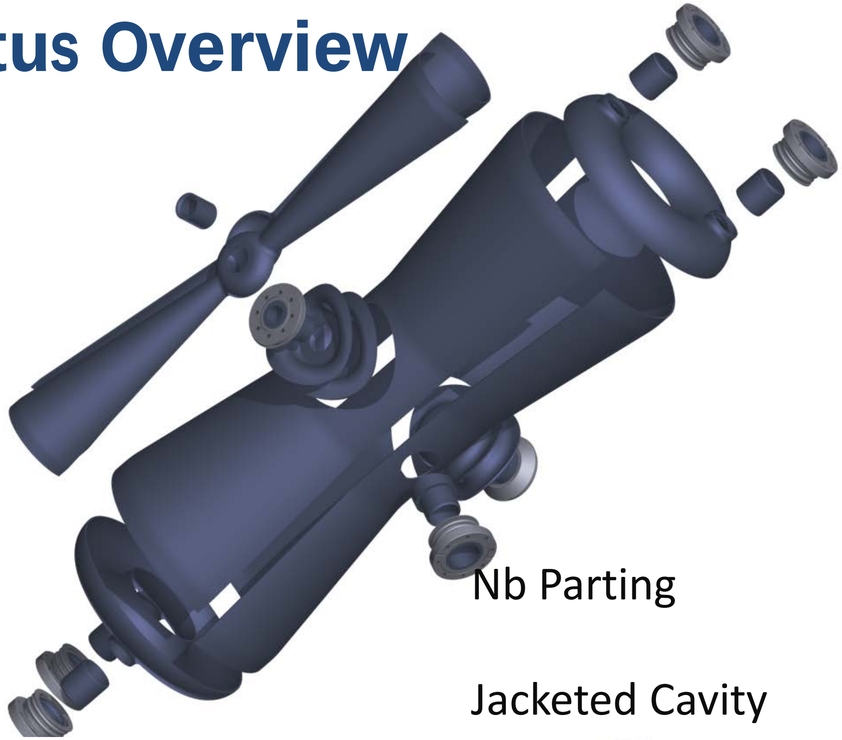




- 310 kHz tuning range with 2,250 lb (10 kN) applied slow tuner with current models
- Figures shown use room temperature (RT) properties of cavity. At R.T. cannot use full slow-tuner stroke.

PXIE HWR - Fabrication Status Overview

- Major cavity parts status:
  - Reentrant nose and doubler plates – received.
  - Toroids – To be delivered first week of December.
  - Center conductors – @ ANL.
  - Outer conductors – waiting on Al for forming die to arrive.
- Two sets of parts are being formed to make two prototypes.
  - One from ATI Wah Chang material.
  - One from Cabot Supermetals material.
  - Some Nb rod from Tokyo Denkai is being used.

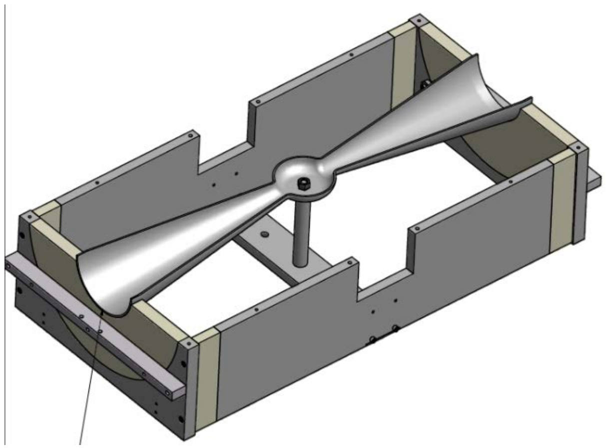


Nb Parting

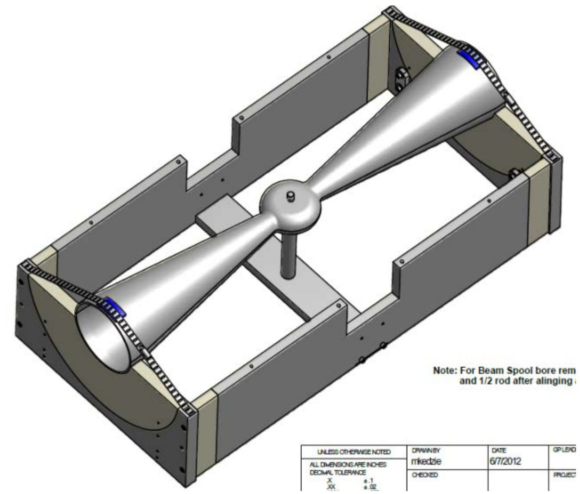
Jacketed Cavity

Fixturing for Wire EDM and EBW is Being Built

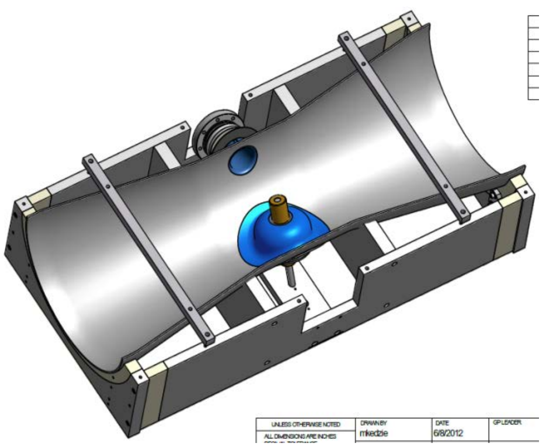
- EDM trimming of the CC



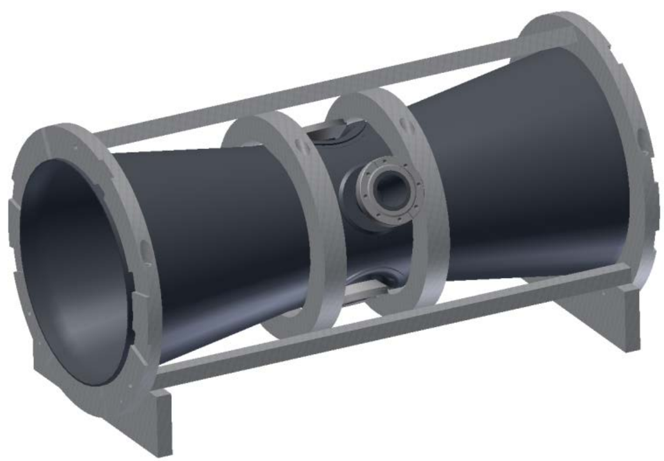
Trimming of the CC length



- EDM trim of the OC-halves length



OC length

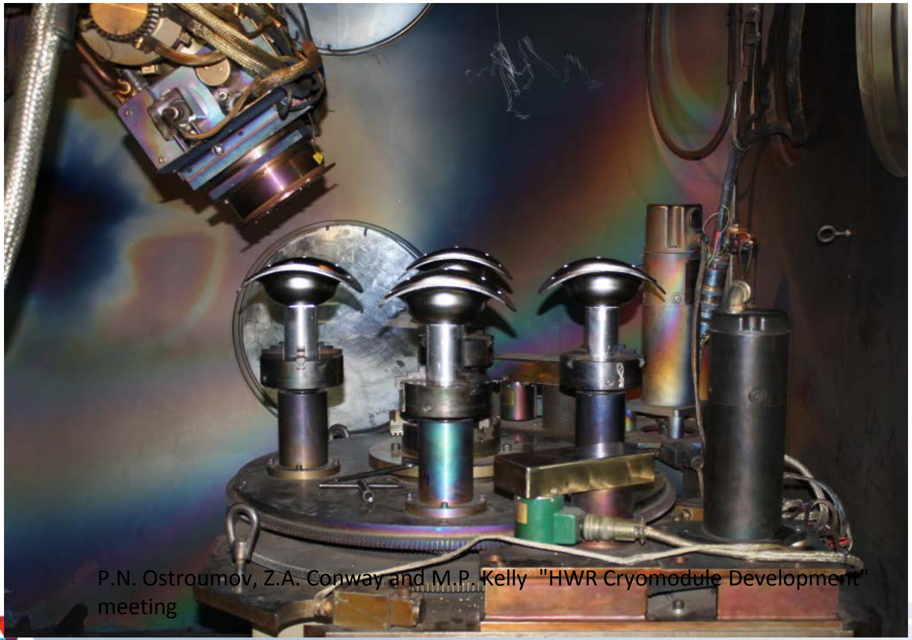


HWR Prototype - Reentrant Nose Assemblies

STEP 1: Cleaned & Inspected

STEP 2: Etched & Assembled in Clean Room

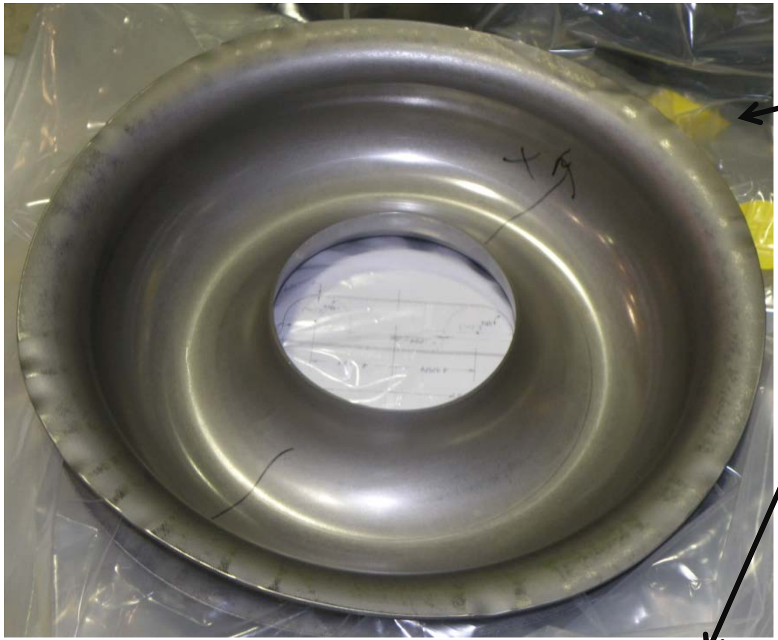
STEP 3: Electron Beam Welding



STEP 4: Cleaned & Inspected Again

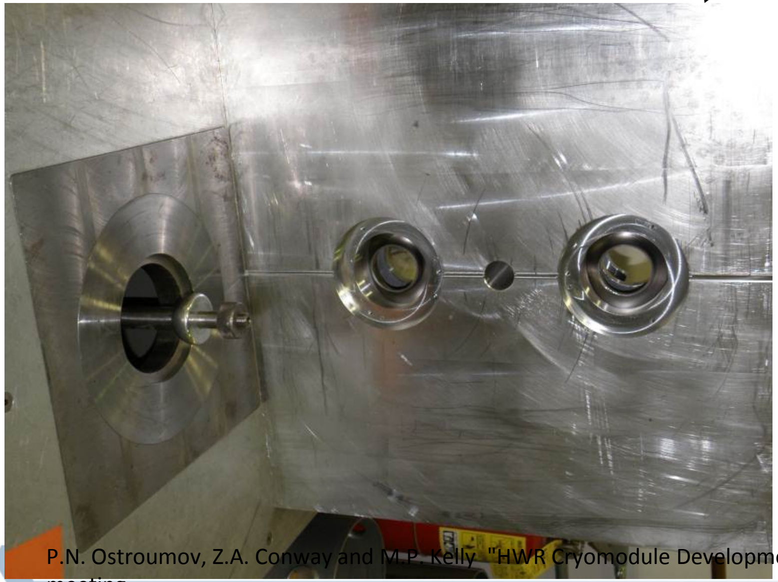
P.N. Ostroumov, Z.A. Conway and M.P. Kelly "HWR Cryomodule Development" meeting

HWR Prototype - Toroids



Toroid, inner conductor trimmed.

Branch pull hardware.



Finished toroids. Two more to go.
@ANL on Nov. 29.

HWR Prototype - Center Conductors

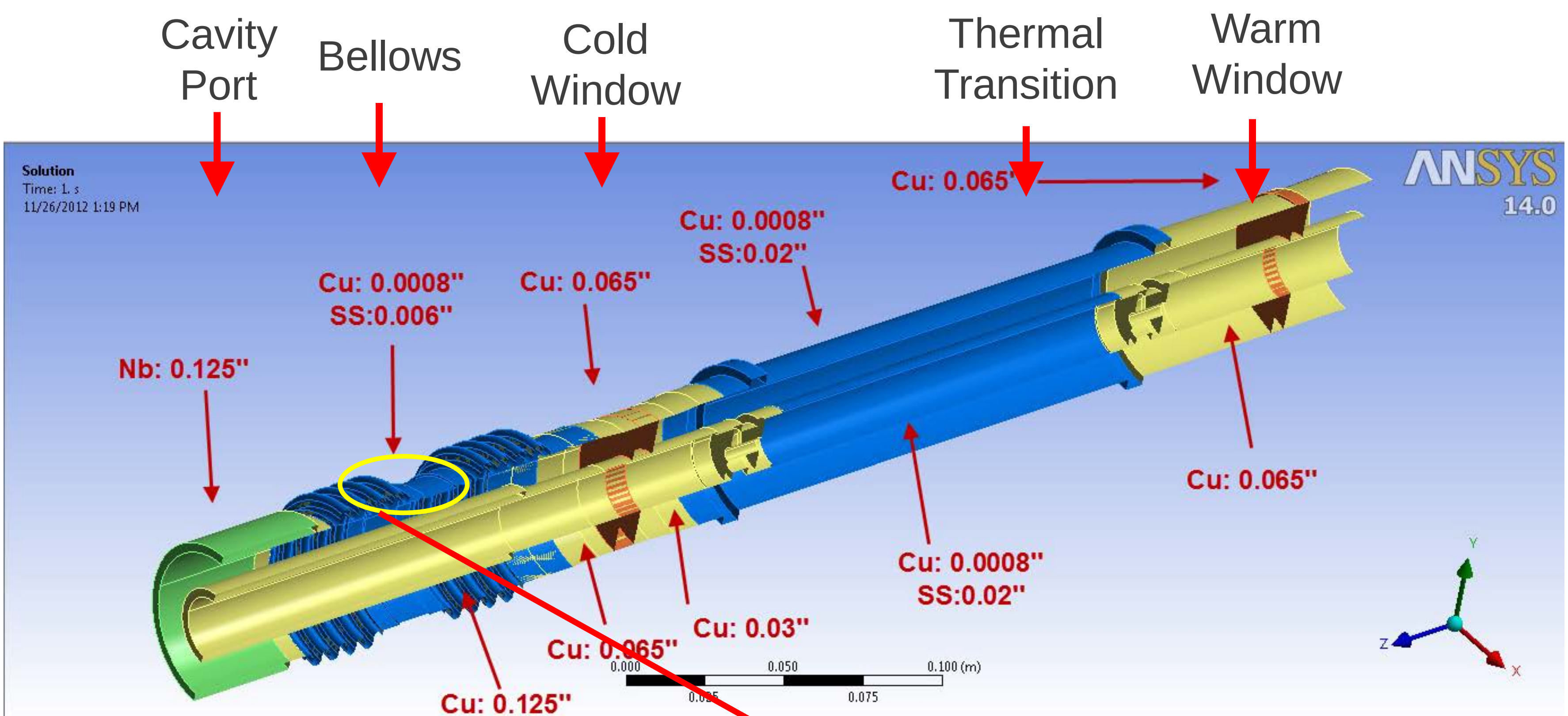
Center Conductor Pre-Forming

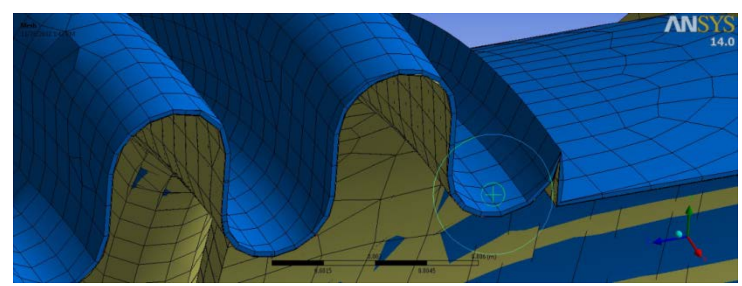
Center Conductor Post-Forming

Center Conductors Arrived at ANL on Tuesday, Nov. 27.

Center Conductors Ready For EDM

RF Coupler ANSYS Mechanical and EM Model





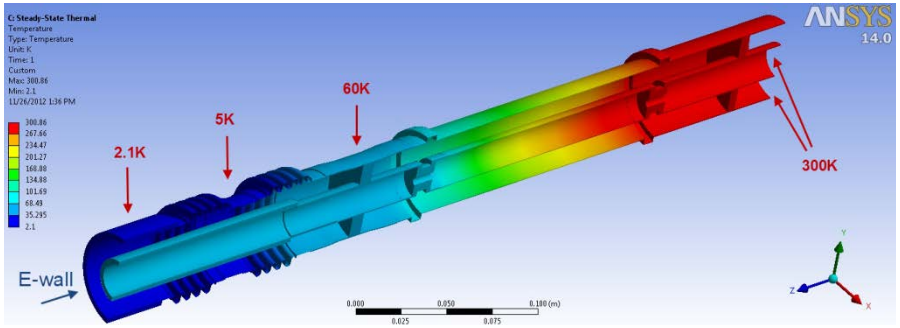
http://iopscience.iop.org/1748-0221/7/11/P11004

0.006" Stainless bellows with 0.0007" (20 microns of copper)

RF Coupler

- A 15 kW RF-coupler appropriate 162 MHz cavities has been modeled
  - Reflections are low ~-30 dB
  - No significant heating in bellows, ceramic, or center conductor
  - Heat flow to the liquid helium is calculated <100 mW
  - Any coupler multipacting could be mitigated by center conductor bias

ANSYS Temperature Map: 15 kW full reflection (overcoupled)



Software	ANSYS	CST
Frequency, MHz	162.5	
Input power, kW	15	
Total heat flow to 2K, W	0.078	0.165
Total heat flow to 5K, W	2.34	2.49
Total heat flow to 60K, W	11.2	11.8

Prototyping of the RF coupler

- A fabrication issue with adhesion of the 2” ceramic window has been resolved (controlled & slow furnace cool down to reduce stresses)
- Bellows plating completed in July 2012
- High power testing in January 2012 when cavity/rf amplifier are available

MYAT 2” to 1-5/8” adapter

20 microns of copper plating on a 150 micron thick stainless steel bellows

Cold window assembly

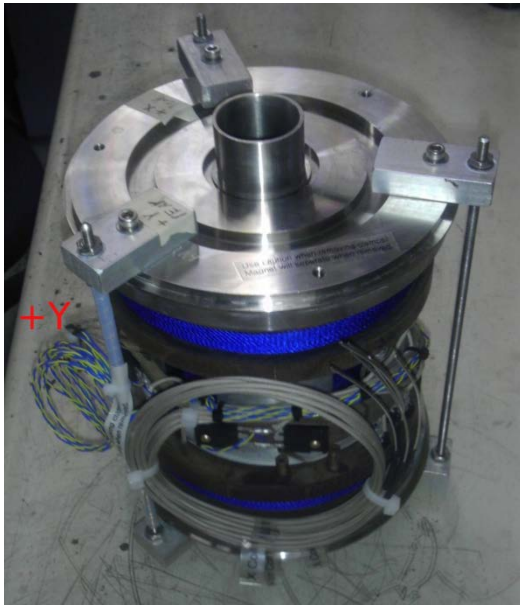
Cold window plus bellows assembly

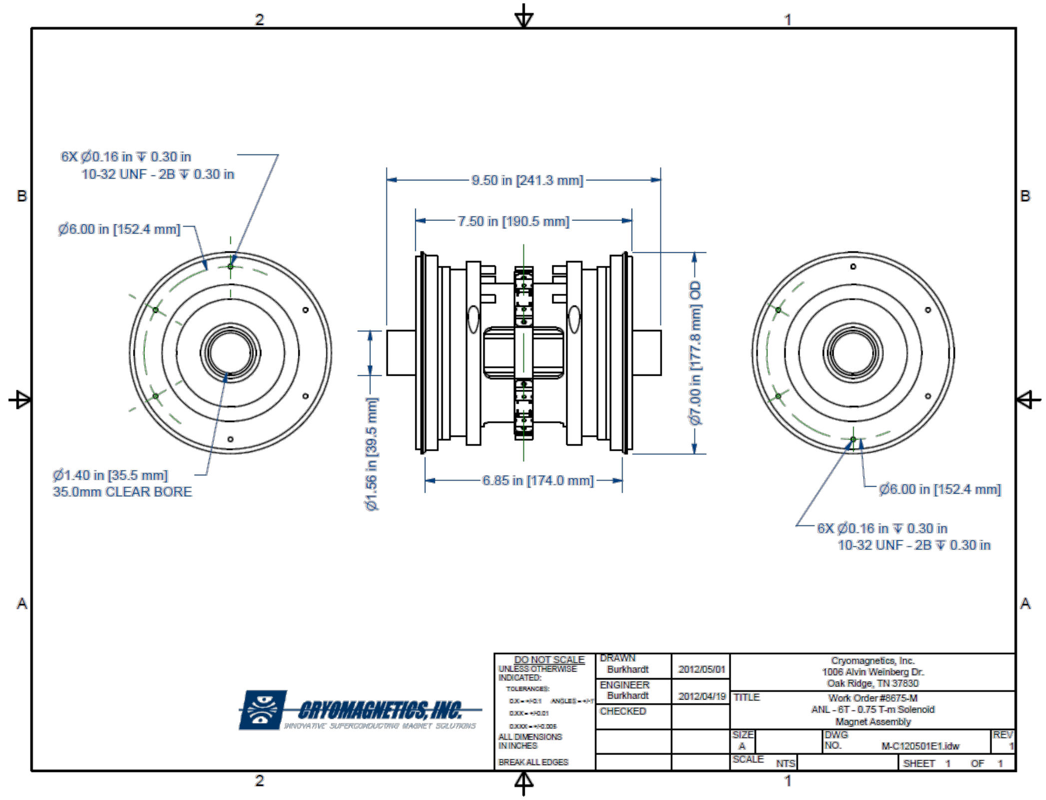
SC Solenoid for PXIE HWR Cryomodule:

Magnet Specifications

Wire	Niobium-Titanium
Operating temperature	1.8-4.6 K
Magnetic field integral	∫Bzdz = 0.75 T-m
Operating current	82 A
Inductance	1.1 H
Shielding	B<100 G: z >= 15 cm
Steering coils	0.2 T, 30 T-mm
Bore diameter	35 mm

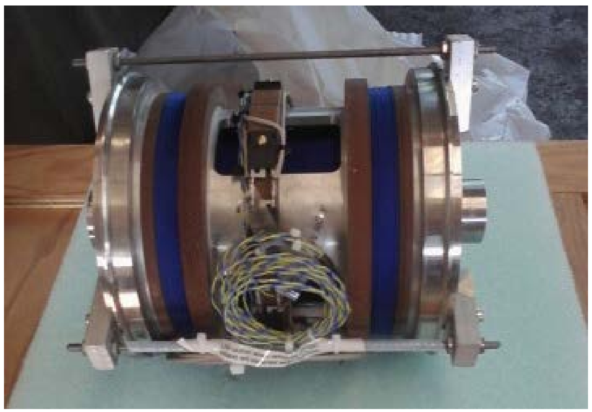
Cryomagnetics 0.75 T-m SC solenoid



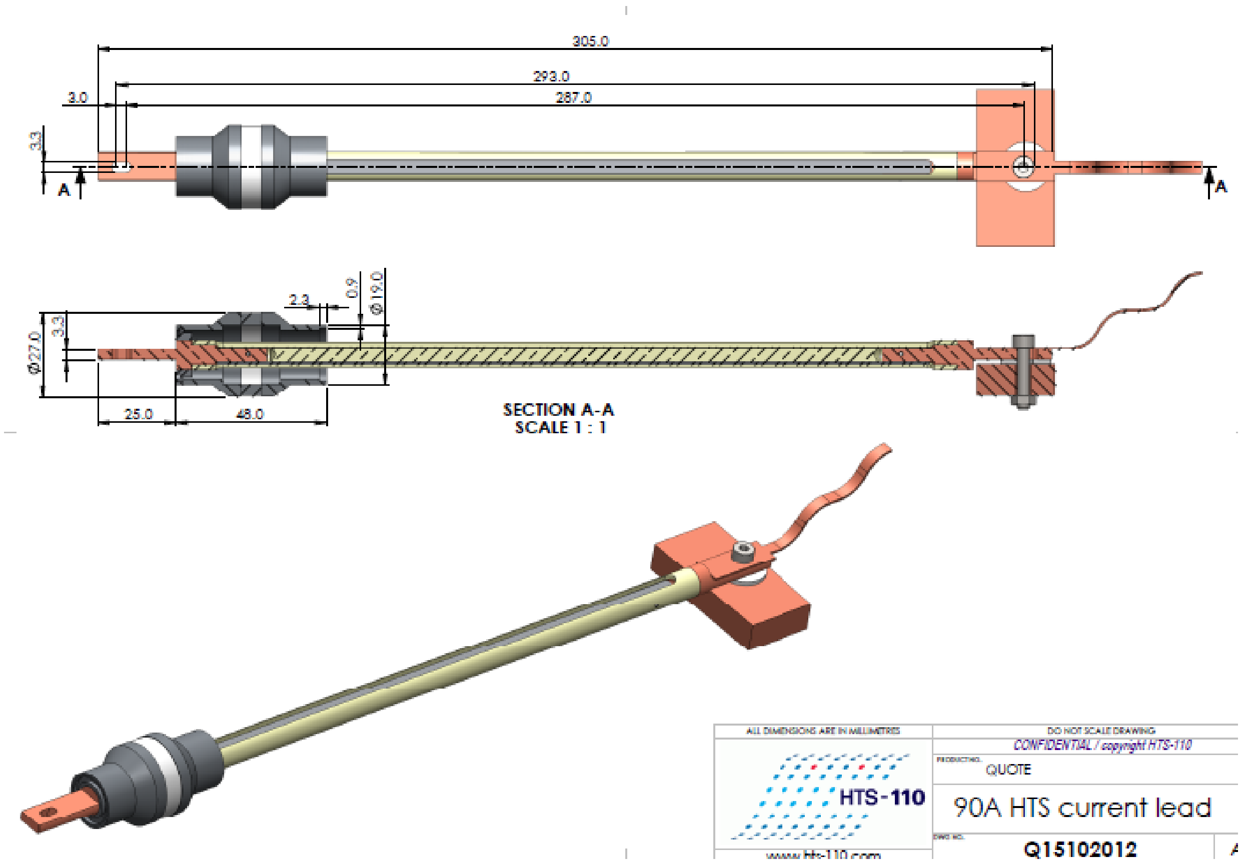


- Bare magnetic 'dunk test' in 4 K dewar at Cryomagnetics, Inc. in October 2012
- Main coil current tested up to 87.25 A (5 A above nominal)
- X,Y steering coil current tested up to 40 A
- All three coils successfully re-charged after an induced quench

Code-stamped Liquid Helium Jacket at Meyer Tool, November 2012

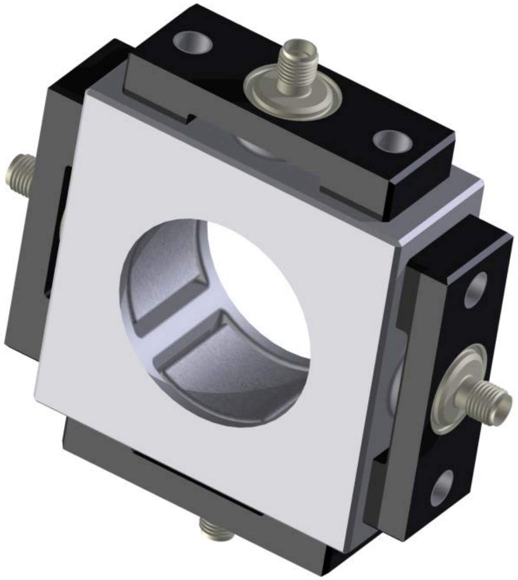


Cryomodule – Conductively Cooled Leads



- High-temperature conduction cooled leads have been ordered from HTS-110.
- The first pair to be delivered in January 2013 for testing.

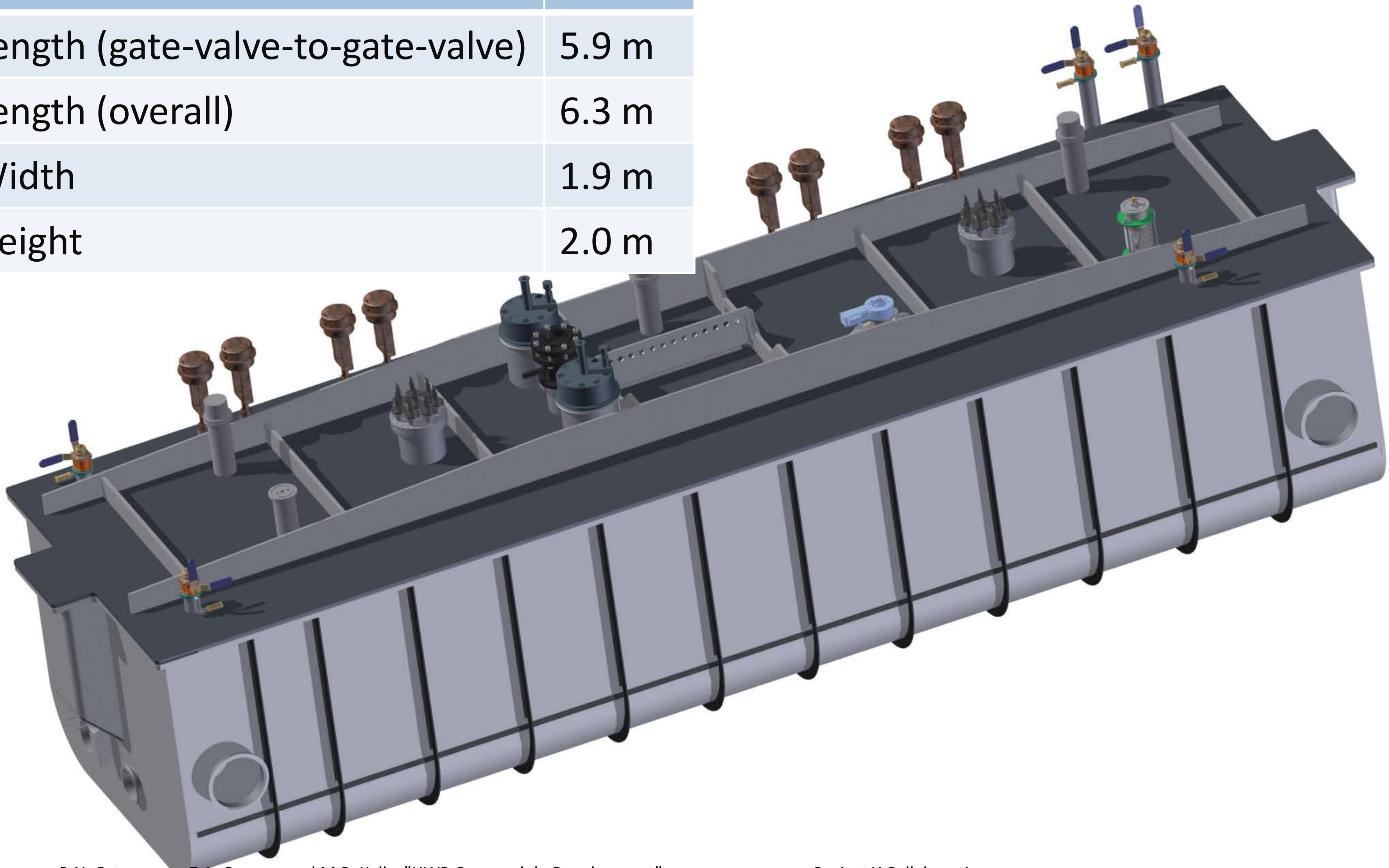
Cryomodule BPM Fabrication Status



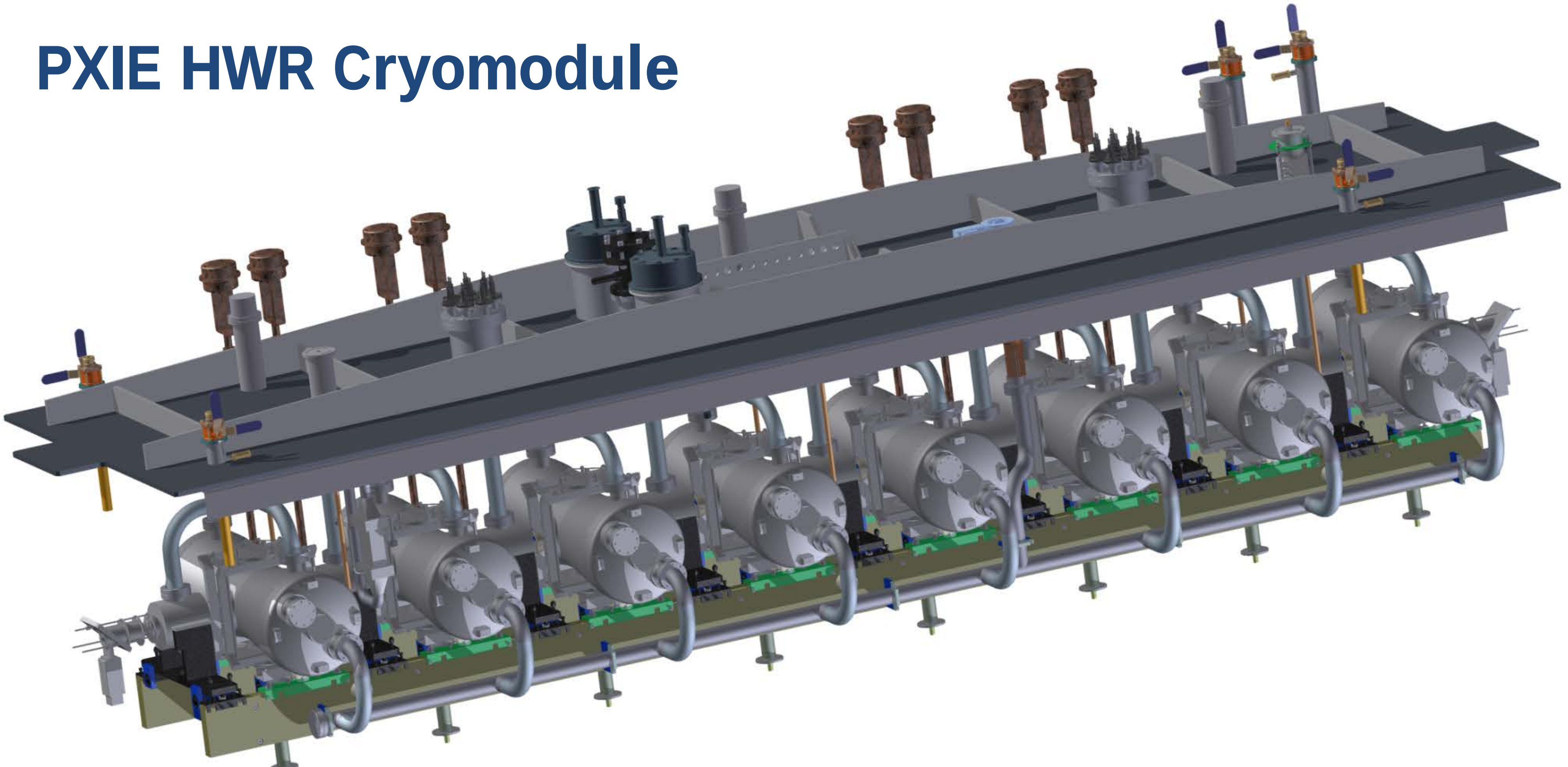
- BPM part machining is complete. Parts to be delivered to ANL between Nov 27-29.
- Next steps:
  - Clean & Inspect.
  - Send BPM body and SMA feedthroughs out for laser welding.
  - Electron beam weld the electrodes to SMA feedthrough center conductors.
  - Offline testing.
  - Online testing.

PXIE HWR Cryomodule

Parameter	Value
Length (gate-valve-to-gate-valve)	5.9 m
Length (overall)	6.3 m
Width	1.9 m
Height	2.0 m



PXIE HWR Cryomodule



- Cryomodule status update.
  - Design status.
  - BPM – parts made need to weld.
  - Conduction Cooled Leads – On order
- Half-Wave Resonator.
  - Due to time constraints discussing cavity RF design only.
  - df/dP.
  - Slow tuning.
  - Prototyping status.

PXIE Cryogenic Loads

- Dynamic Load: 6 nΩ cavity residual resistance.
- Other loads, e.g., radiative heating, come from Functional Requirements Specifications.

Changing Operating Voltage

Parameter	Components	+20%	Design	–20%
Operating Set Point (MV)	Cavities # 1 & # 2	1.2	1.0	0.8
	Cavities # 3 - # 8	2.0	1.7	1.4
2 K Dynamic Heat Load (W)	Cavities # 1 & # 2	1.5	1.1	0.7
	Cavities # 3 - # 8	12.5	8.7	5.7
Total 2 K Load	**Everything**	**29**	**24**	**21**

Estimates vs. Functional Requirements

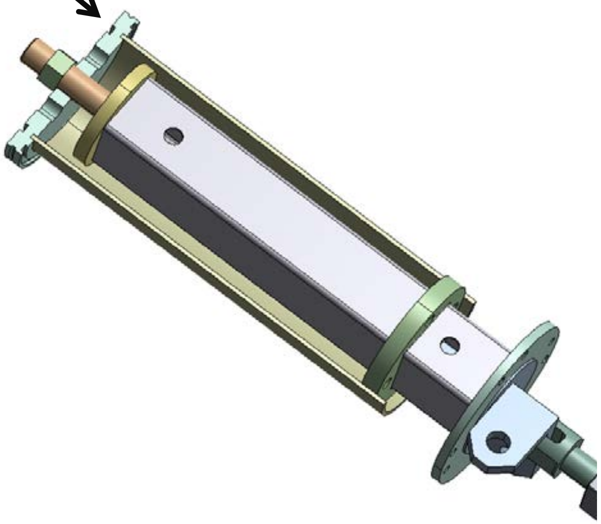
Load	Total	FNAL FRS
2 K	24 W	25 W
5 K	60 W	80 W
70 K	250 W	250 W

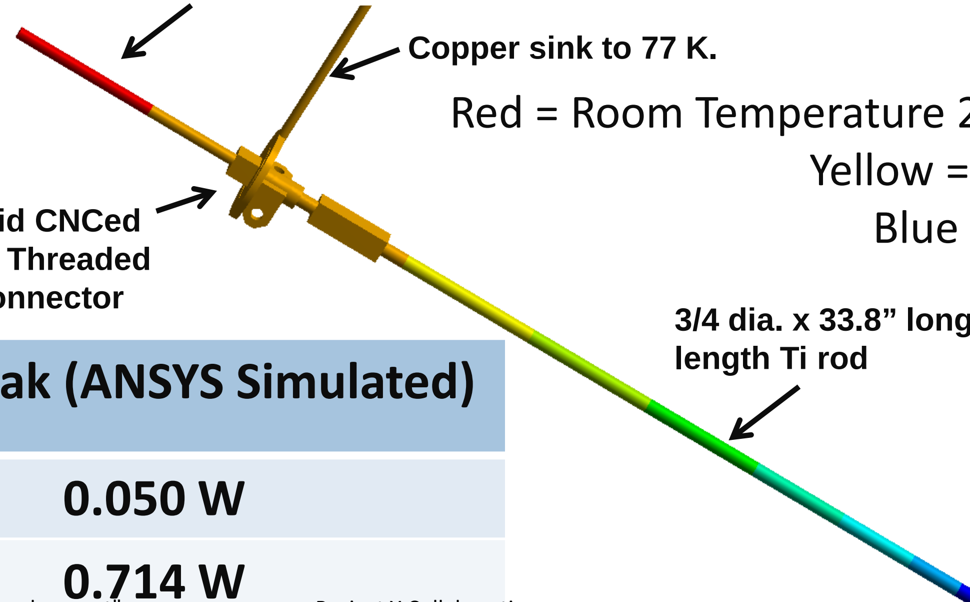
Constraint	FRS Convention
70 -2 K Radiation	0.1 W/m^2
70 – 5 K Radiation	0.1 W/m^2
293 – 70 K Radiation	1.5 W/m^2

Strongback Hanger Thermal Analysis

- Improved hanger design based upon ATLAS upgrade experience.
- Using Grade 5 Titanium, Ti-6Al-4V.
- Structural loads have a factor of safety of 10.
- Low thermal conductivity and contraction.
- The modeling does not include the thermal contact impedance.

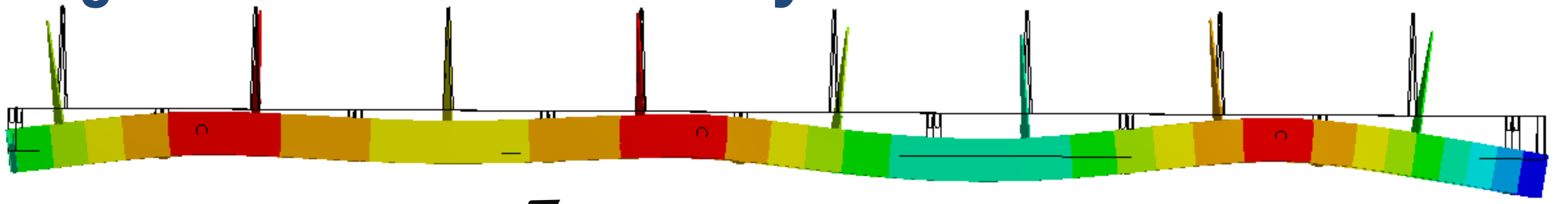
Cryomodule Lid Flange





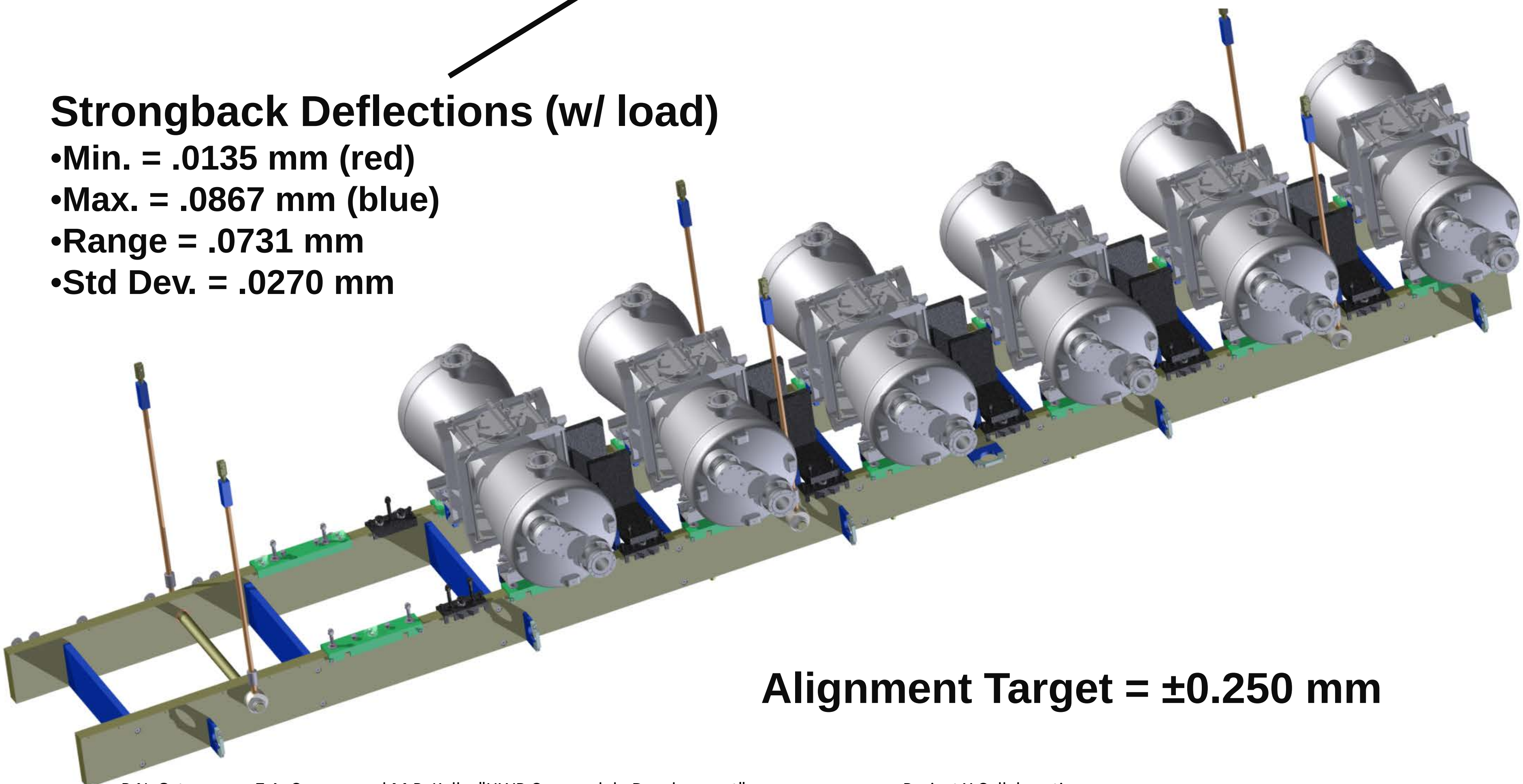
Thermal Transition	Heat Leak (ANSYS Simulated)
2 – 80 K	0.050 W
80 – 293 K	0.714 W

Strongback Structural Analysis



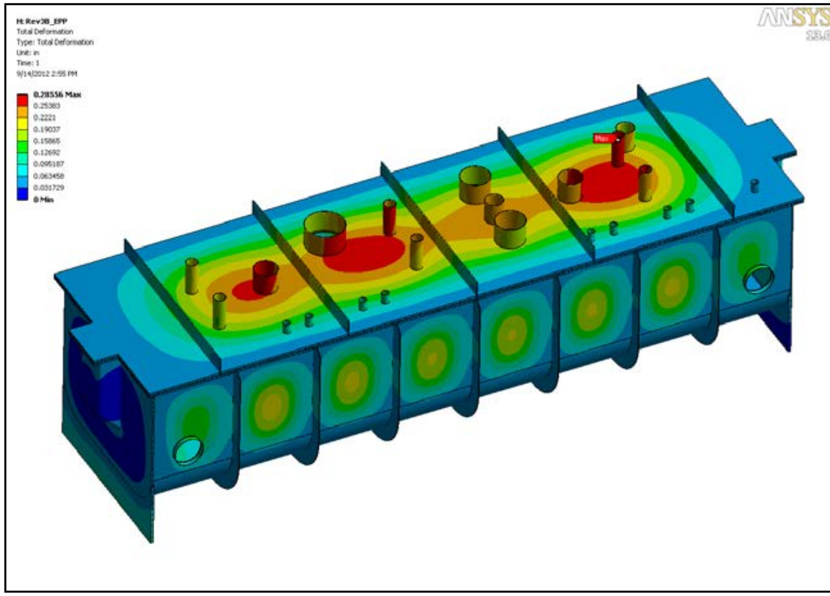
Strongback Deflections (w/ load)

- **Min. = .0135 mm (red)**
- **Max. = .0867 mm (blue)**
- **Range = .0731 mm**
- **Std Dev. = .0270 mm**



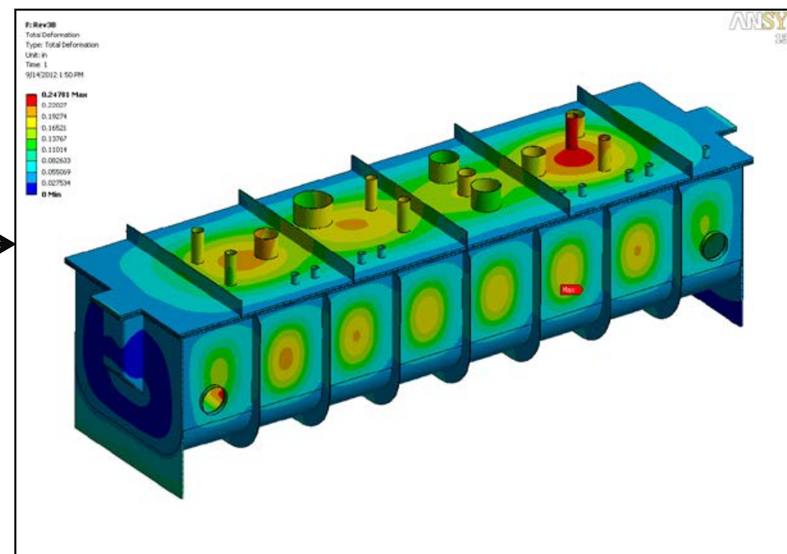
Alignment Target = ±0.250 mm

Cryomodule Safety Analysis



Limit Load Results
•Top left, summed deflection.
•Bottom left, solver output.
Results
•Converged.

Deflection Plots for 1 atm.
•Contours = blue <.11”, .11”<green<.19”, red > .25”
Results
•Maximum wall deflection = .248”
Passes buckling and ratcheting analyses too.
No show stoppers but still need to evaluate final design

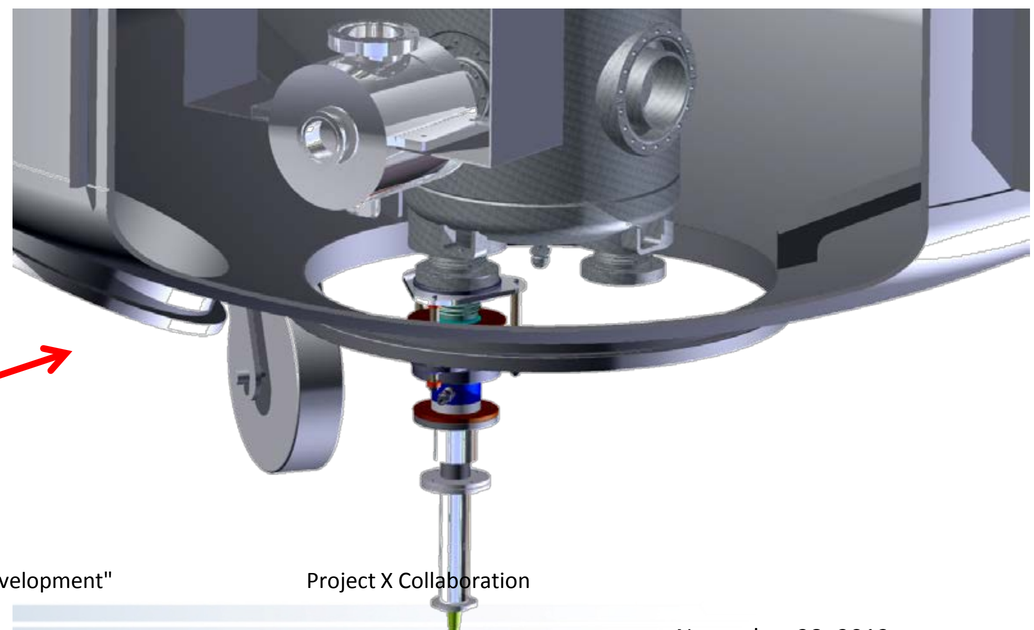


Future Work

- The goal is to complete 2 HWRs by 4QFY13 and provide cold testing by the end of Q1FY2014
- Cold testing of the RF coupler up to 10 kW, SC solenoid and BPM in January-February 2013
- Due to funding constrains in FY13 we can not proceed with
  - Fabrication of Nb parts for production cavities, 7 HWRs
    - This work can be started immediately if funding is available
  - Procurement and fabrication of the cryostat vacuum vessel and other components of the cryomodule (strongback, magnetic and thermal shield, JT exchanger, gate valves, vacuum, helium manifolds,…)
    - This work can be started in April 2013
  - Purchase and fabrication of all SC solenoids, RF couplers, BPMs
    - This work can be started immediately if funding is available

PXIE Solenoid and Coupler 4 Kelvin Cold Testing January 2013

- Planned testing with existing 72 MHz cavity and cryostat
- Coupler testing at 162 MHz at 10 kW in full reflection
  - 4 K at cavity flange
  - 80 K at cold window
  - Thermometry and calibration heaters at 4 K and 80 K
- Solenoid testing with main coil to 80 Amps
  - Lake Shore magnetic field probes to measure stray field and magnetization

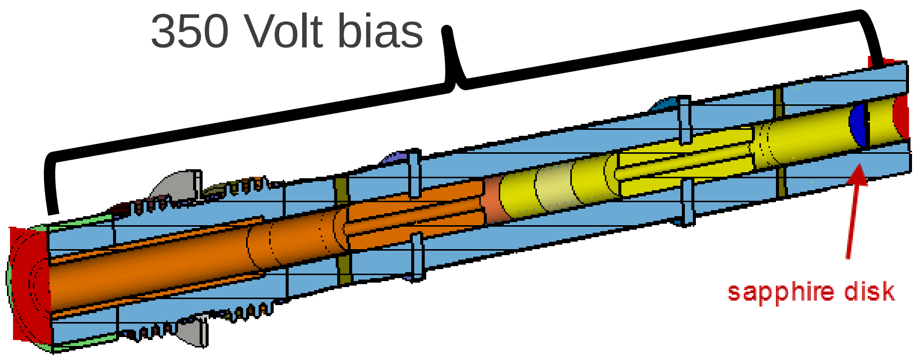


Milestones

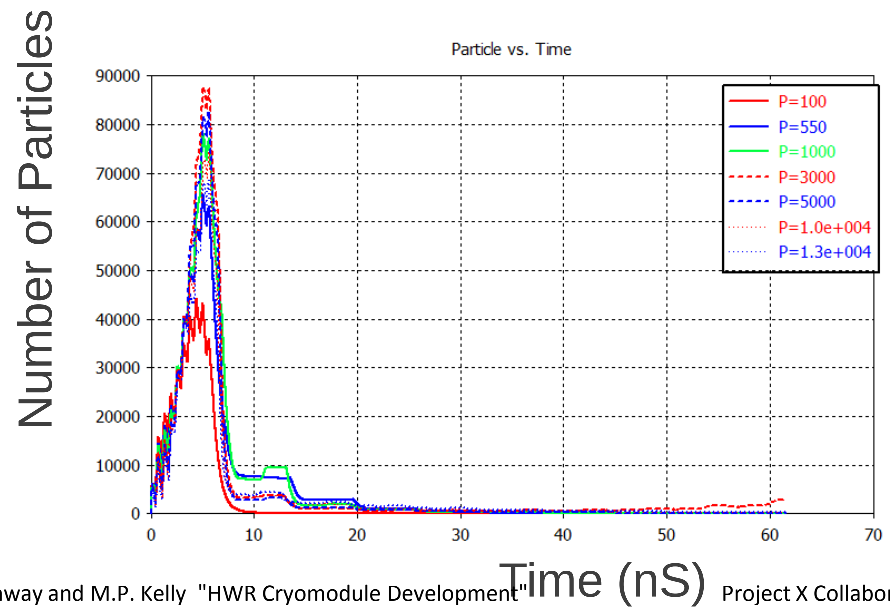
#	Milestone	Date
1	Place contract for niobium dies and forming of the prototype cavity	Q2FY12
2	Conceptual and Preliminary Design complete Niobium for production cavities is delivered and inspected	Q4FY12
3	Complete fabrication of prototypes of (a) 10-kW RF coupler; (b) SC solenoid; (c) BPM	Q1FY13
4	Complete fabrication drawings of the cryostat vessel including thermal and magnetic shields. Design review of the cryomodule. Cold testing of the RF coupler, SC solenoid and BPM.	Q2FY13
5	Fabrication of two prototype cavities complete	Q4FY13
6	Two prototype cavities tested. Start procurement of production cavities, its sub-systems and cryostat vessel if funding is available.	Q1FY14
7	Fabrication of the cryostat vessel complete	Q1FY15
8	Fabrication of production cavities and its syb-systems complete	Q2FY15
9	RF surface processing of HWRs. Cold testing of 50% of HWRs. Engineering cold testing of the cryostat vessel.	Q4FY15
10	Mock-up cavity string assembly	Q2FY16
11	Cryomodule off-line testing complete	Q4FY16
12	Cryomodule installed at PXIE beamline	Q2FY17

Backup Slides

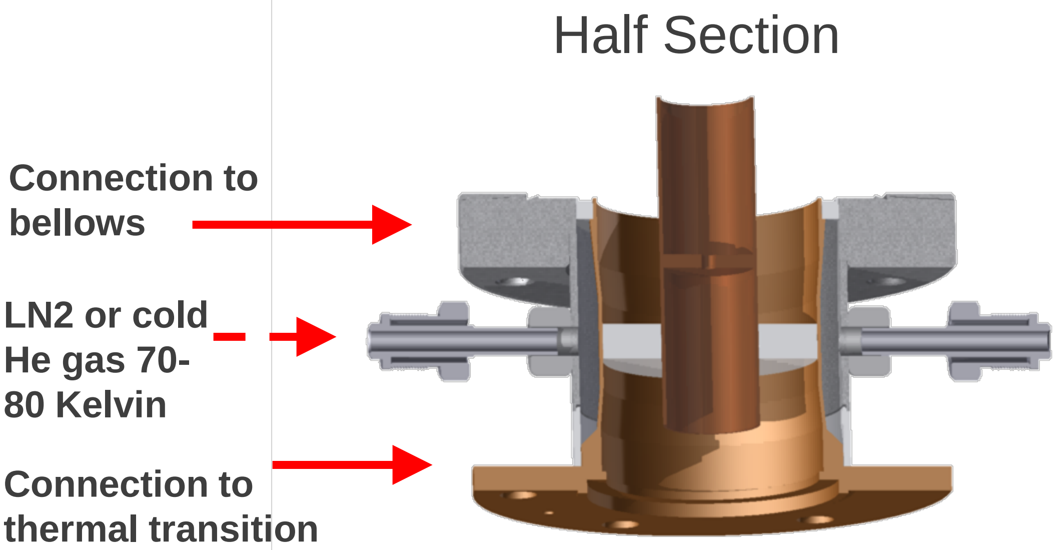
CST Simulations: Multipacting Suppression using a DC bias voltage



The sapphire disk width should be 0.01 – 0.015'' to make very small, S11 ~ -30 dB



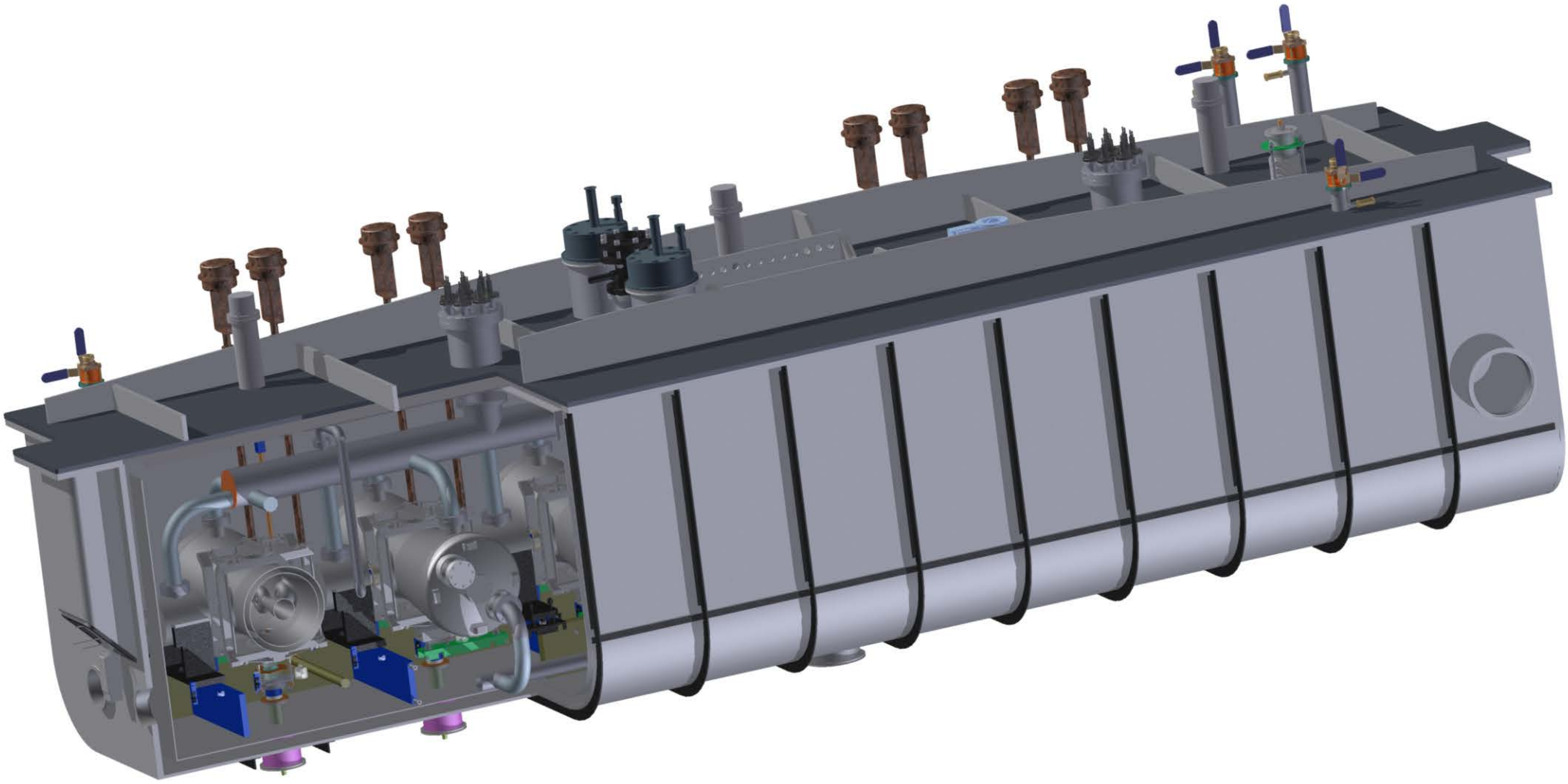
Prototyping Critical Components: Cold RF Window

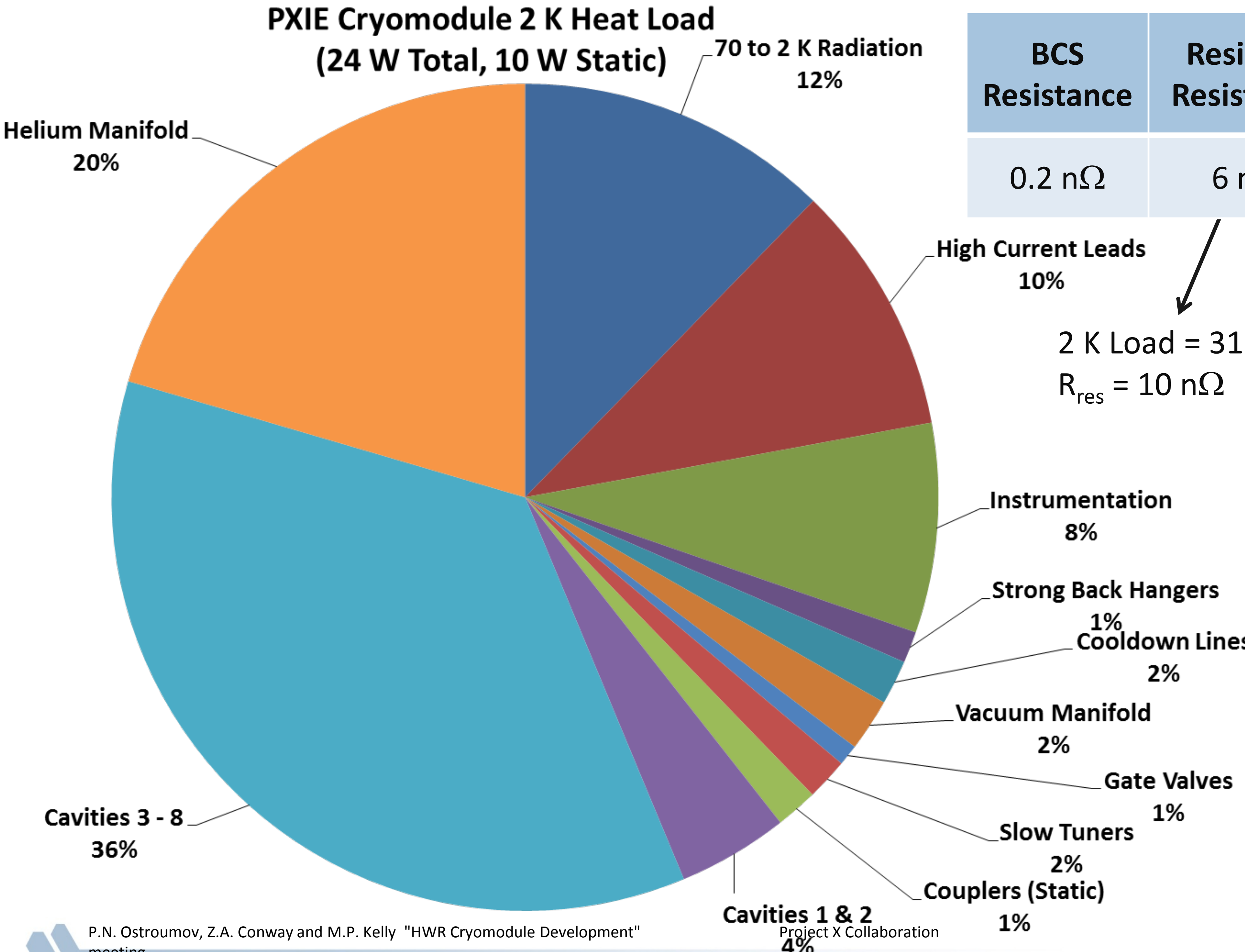


Status: Prior to final brazing at MPF; July 18, 2012

LN2 heat of vaporization	196 J/g
Typical flow	3 gm/s
Max. cooling capacity	588 Watts
Max. static+dynamic loss	20.9 Watts

PXIE HWR Cryomodule





BCS Resistance	Residual Resistance
0.2 nΩ	6 nΩ

2 K Load = 31 W if R_{res} = 10 nΩ

PXIE Cryomodule 5 K Load

- 5 K Thermal intercepts on the:
  - Beam Line Gate Valves.
  - Slow Tuner Lines.
  - Solenoid Leads.
  - Helium System Cryogenic Penetrations.
  - Couplers.
  - Cryogenic Valves.

- No 5 K Thermal Intercepts on the:
  - Strong-Back Hangers.
  - Cool-Down Lines.
  - Vacuum Manifold.
  - Slow Tuner Gas Lines.