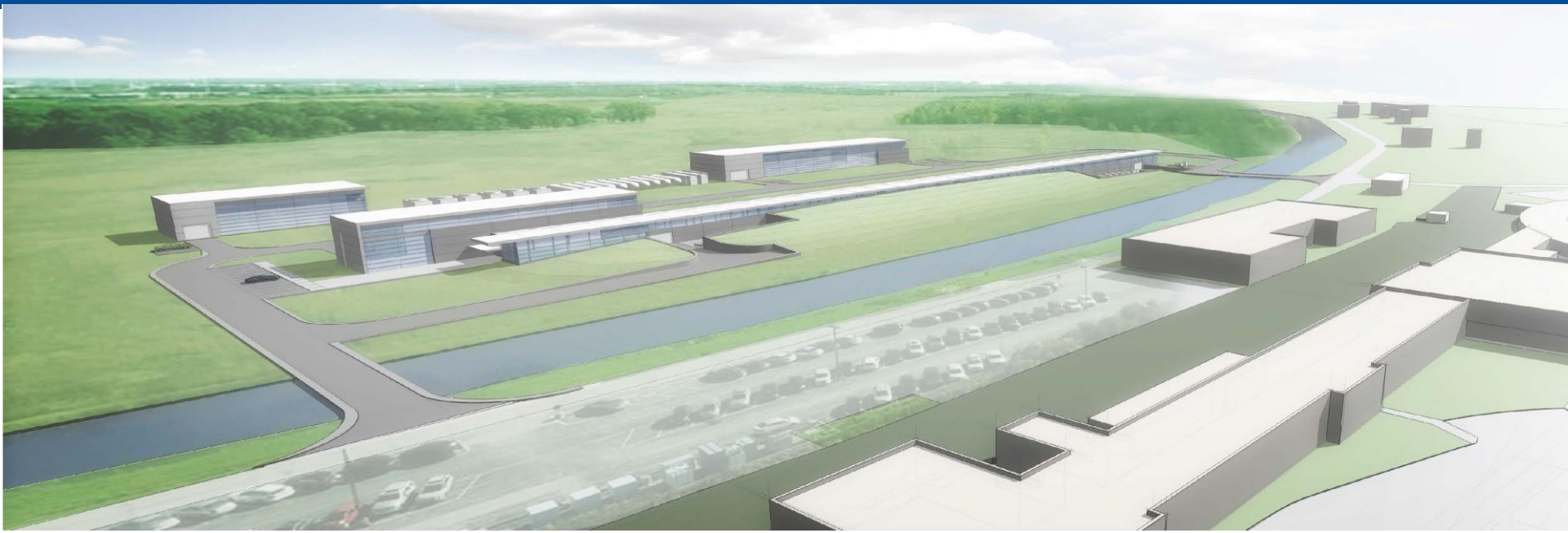


121.3.4 Linac – HWR (Half-Wave Resonator)

SC Acceleration Modules and Cryogenics

Zachary Conway

PIP-II Director's Review

19-21 September 2017

In partnership with:
India Institutes Fermilab Collaboration
Istituto Nazionale di Fisica Nucleare
Science and Technology Facilities Council

Outline

- Who am I and Organization
- Half-Wave Resonator (HWR) cryomodule requirements.
- HWR cryomodule design overview.
- Scope/deliverables.
- Interface control document for the HWR cryomodule.
- Fabrication and testing status.
- FNAL ESH&Q and Argonne HSE (Health, Safety and Environment)
- Risk assessment.
- Cost.
- Future schedule.
- Summary.

Argonne National Laboratory - Accelerator Development Group:

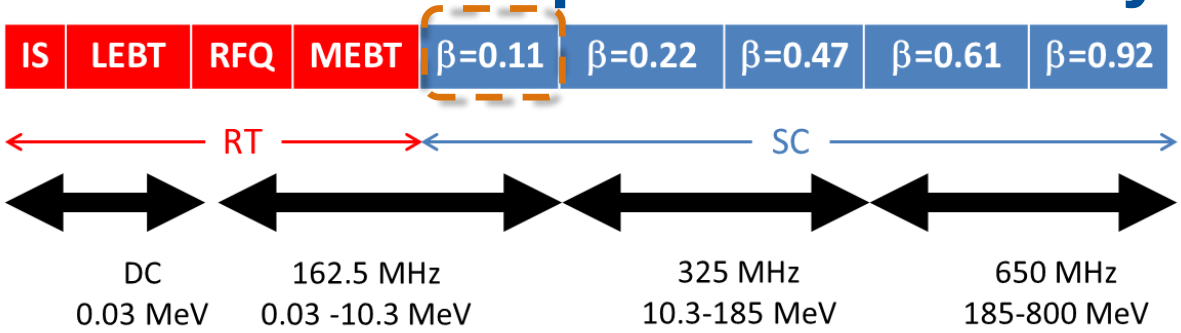
- Designing, building and commissioning superconducting accelerators since 1977.
  - Kenneth W. Shepard still works ½ day per week and started in 1977.
- I was Ken's graduate student and have been working in the field of SRF since 2007 (date of my Ph.D.).
- My experience:
  - Superconducting resonators spanning ion/electron velocities from 0.05c to c.
  - All ancillary hardware.
  - 6 different types of superconducting resonator cryomodules operating at 2.0 or 4.5 K.
  - Superconducting accelerator commissioning.

Project Organization

- Cryomodule and subcomponents designed by FNAL and ANL.
- ANL is fabricating and assembling the half-wave resonator (HWR) cryomodule.
- At ANL:
  - Group Leader = Mike Kelly.
  - Technical Lead = Zack Conway.
- FNAL:
  - Project liaison: Andrei Lunin (attends weekly status meetings at ANL and provides interface between FNAL/ANL).
  - Project Engineer: Allan Rowe

WBS 121.3.4 Linac – HWR System Req. TC# ED0001313 Tech. Spec. for HWR Cryomodule

Charge #1



Cryomodule type	Cavities per CM	# CMs	CM length (m)	Q_0 at 2K (10^{10})
HWR	8	1	5.93	0.5
SSR1	8	2	5.2	0.6
SSR2	5	7	6.5	0.8
LB650	3	11	3.9	2.15
HB650	6	4	9.5	3

- **The half-wave resonator (HWR) cryomodule contains 8 β = 0.11 HWRs and 8 6 T solenoids with integrated x-y dipole steering coils.**
- **The HWR cryomodule is planned to operate cw with a beam current of up to 2 mA to accelerate the beam from 2.1 – 10.3 MeV.**

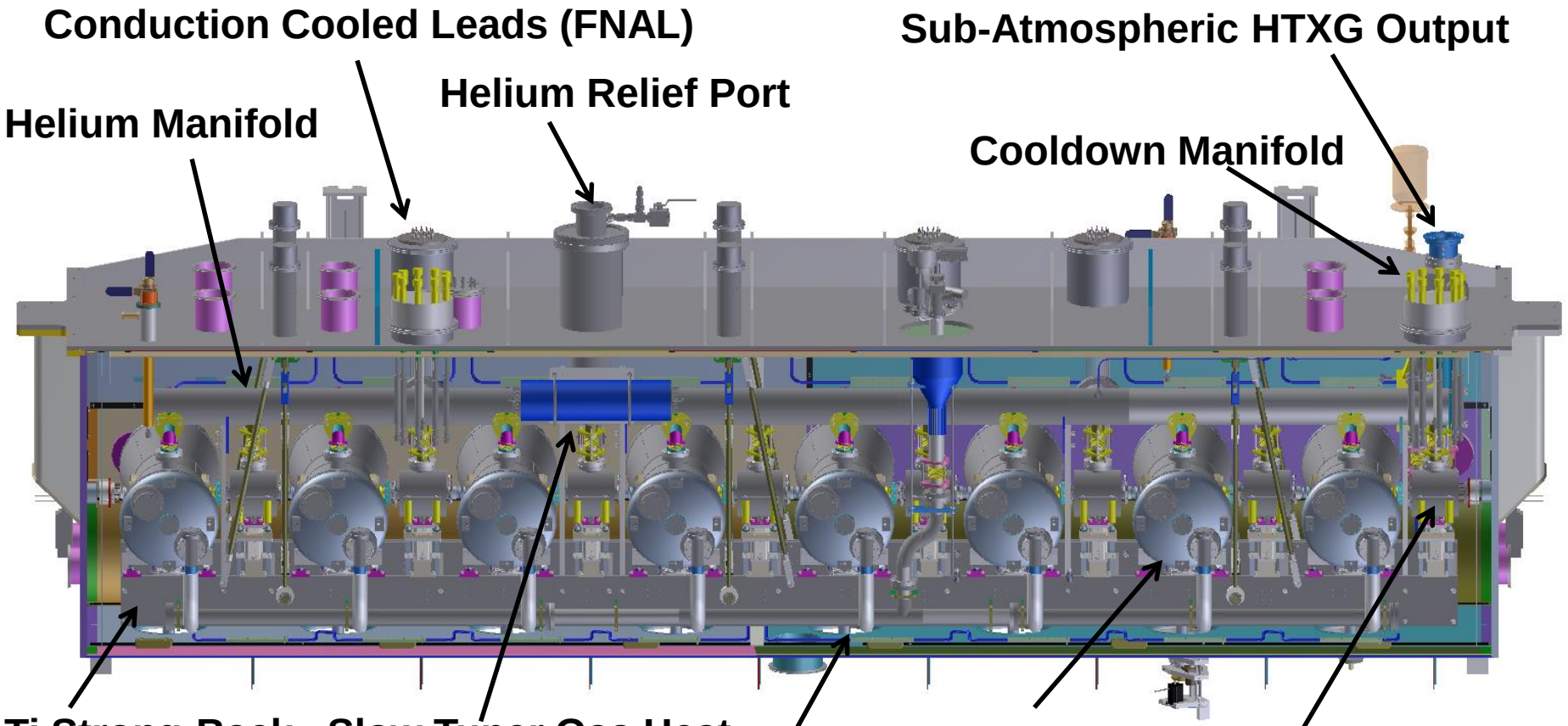
Interface Control

Charge #1

- **TC# ED0001313: Technical Specification for the Interfaces of the FNAL Project-X Half-Wave Resonator Cryomodule:**
  - **Interfaces, operating limits, connection types, locations and their functions are described.**
  - **Detailed pin diagrams for all electrical connections.**
  - **All mechanical connections are specified along with their flanges and purpose.**
  - **Alignment hardware and monitoring capabilities described.**
  - **Comprehensive description of all cryogenic interfaces with operating limits.**
- **Interfaces extend from the up- to the down-stream beam line flanges.**
- **The interface control document has been modified to suit the developing needs of the project.**
- **Technical specification for the interfaces is supplemented with ~weekly documented integration meetings.**

HWR Cryomodule Design

Charge #1



2.2 m X 2.2 m X 6.2 m

PIP-II

HWR Cryomodule Reviews

Charge #1

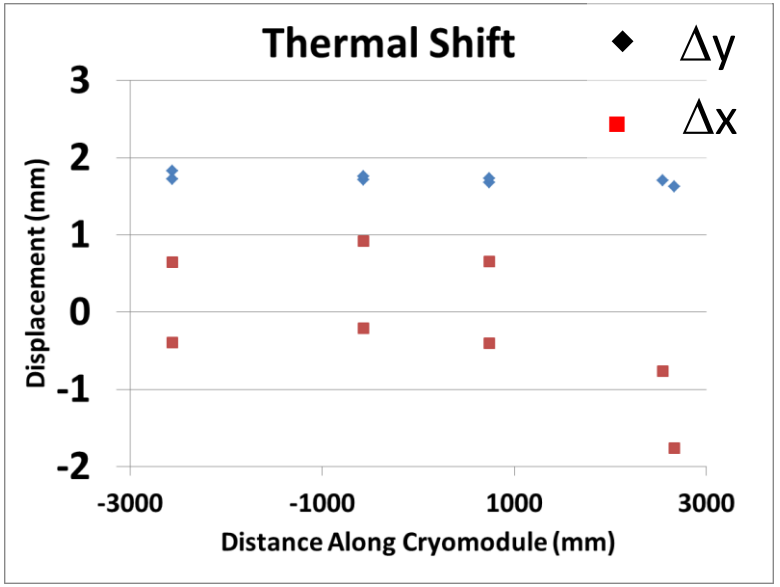
- **Design/safety reviews for the HWRs and cryomodule were held at Argonne (ANL) with FNAL and ANL subject matter experts performing the reviews:**
  - **HWR review 5/17/2012, and**
  - **cryomodule review 5/16/2013.**
- **All design reviews were conducted in compliance with ANL's procedures, LMS-PROC-305.**
- **Procurement readiness reviews were carried out at ANL.**

HWR Cryomodule Mock Assembly

Cryomodule Testing

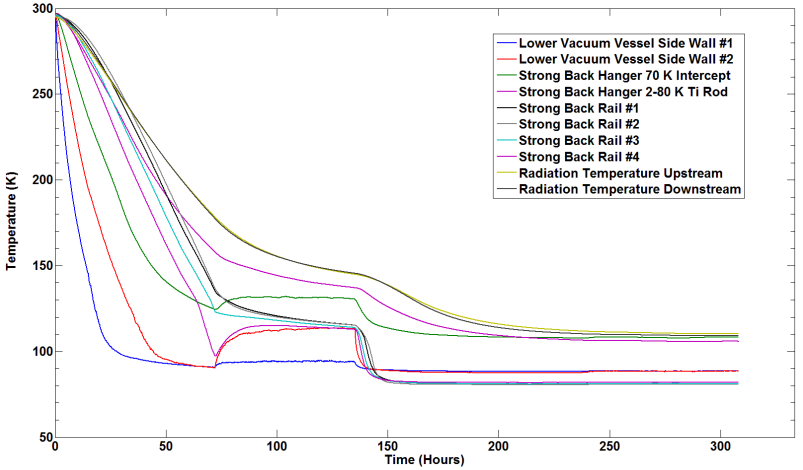
Cryomodule Alignment

Alignment Measurements

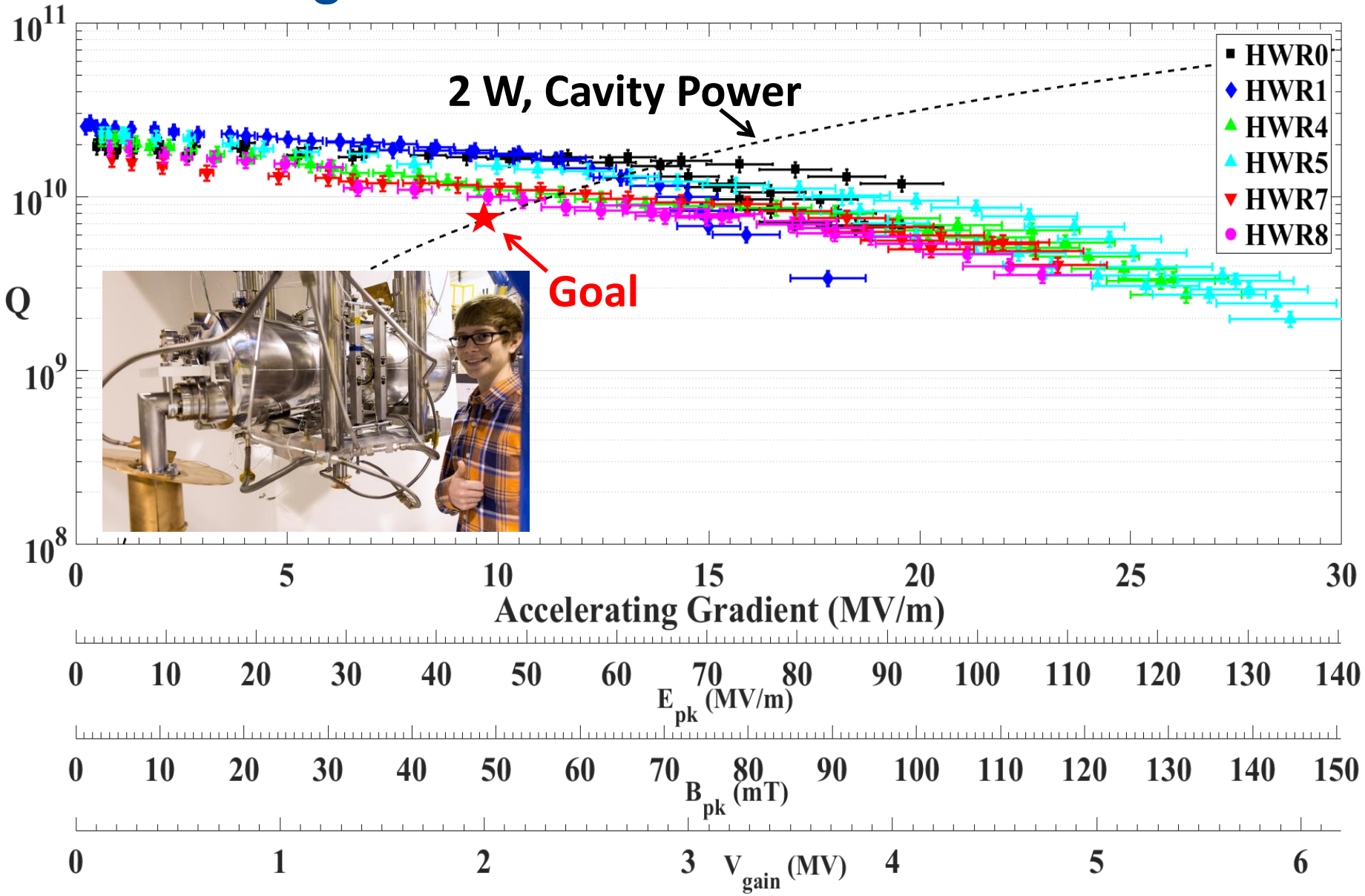


Cryomodule Assembly

Cool Down Data



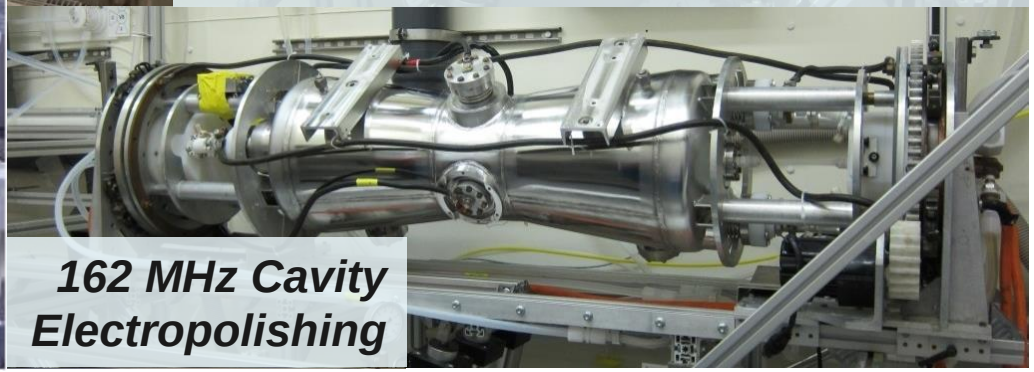
HWR Testing


2 W, Cavity Power
Goal
HWR0
HWR1
HWR4
HWR5
HWR7
HWR8
Q
Accelerating Gradient (MV/m)
E_pk (MV/m)
B_pk (mT)
V_gain (MV)

ANL/FNAL Collaboration on Surface Processing

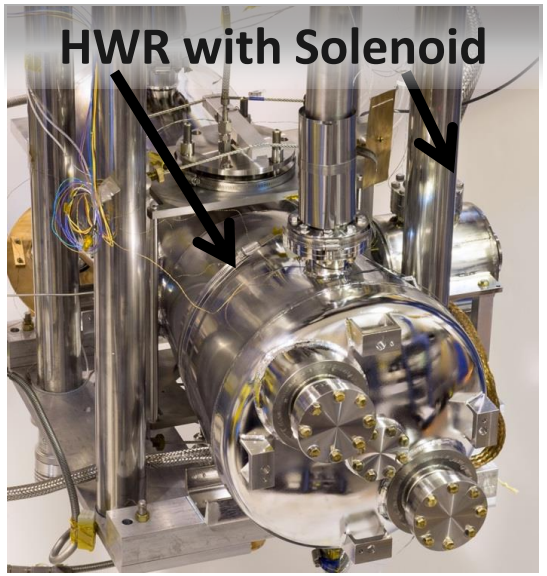
325 MHz Spoke Cavity BCP

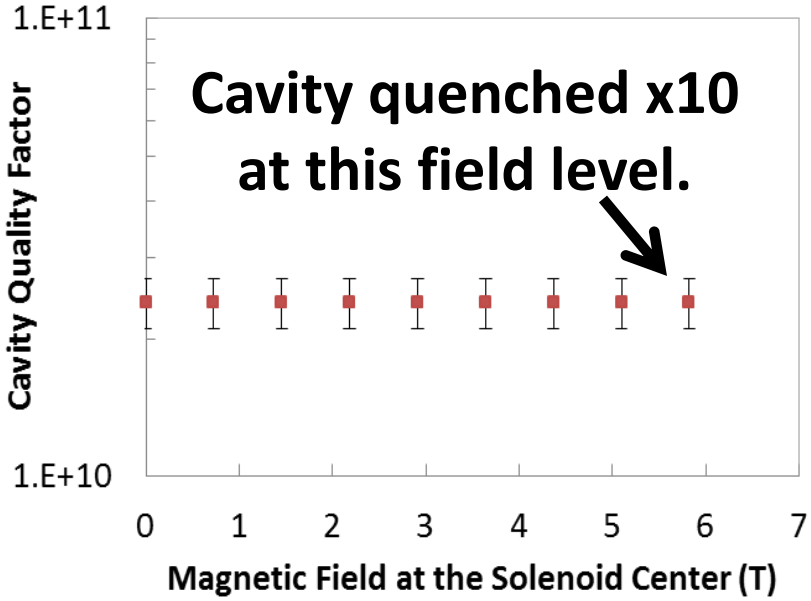
650 MHz Cavity Electropolishing



HWR/Solenoid Testing

- To decrease the accelerator lattice length we have integrated x-y steering coils into the focusing solenoid package.
- Important design issue:
  - Minimize stray field @ the RF cavity to prevent performance degradation due to trapped magnetic flux.
- Measured RF surface resistance with a sensitivity of ±0.1 nOhm before and after each quench of the cavity.
- The cavity was quenched with the solenoid and the steering coils energized.
- No quantifiable change to the cavity RF surface resistance.



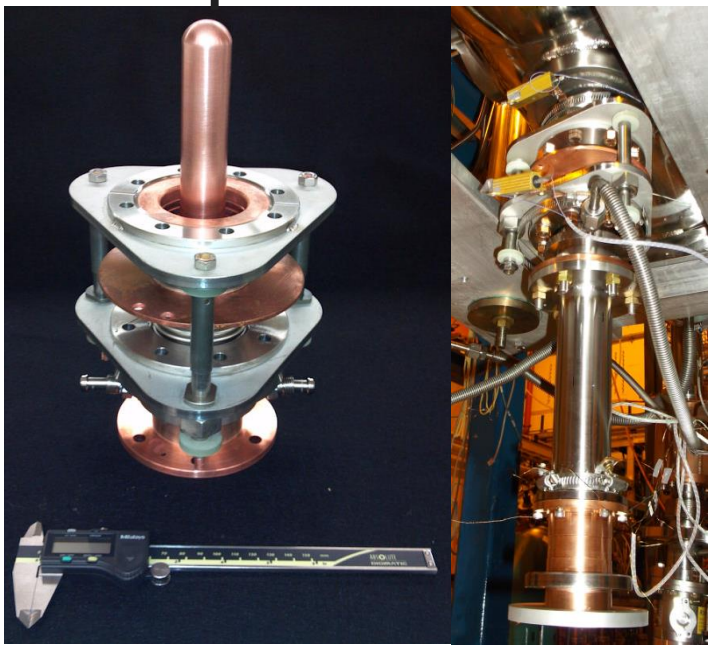


Power Coupler Progress

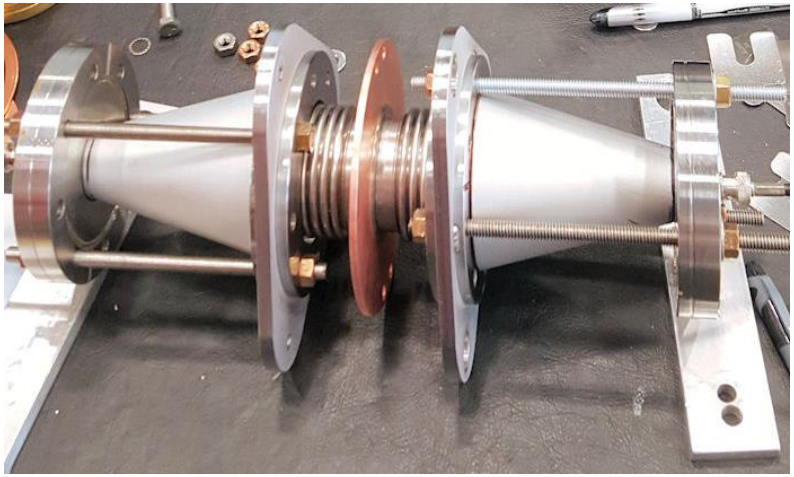
- Power coupler testing on HWRs starting soon.
  - The first HWR is dressed and ready for testing.
- Offline measurements are good.

- Q ~ 10000 or > 80% of calculated value for pure copper for both re-plated bellows
- However, one bellows had a pinhole after stripping and replating
- All 10 bellows assemblies will be re-made and plated at AJ Tuck

Coupler Hardware



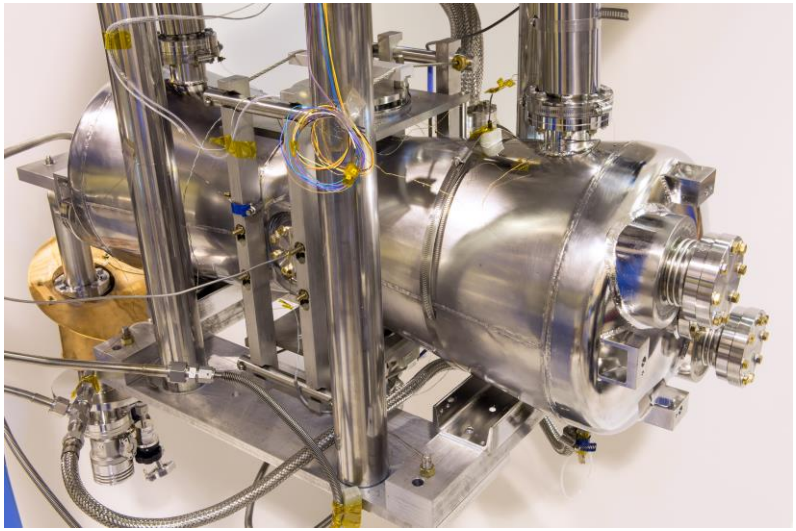
Copper Plating Purity Measurement



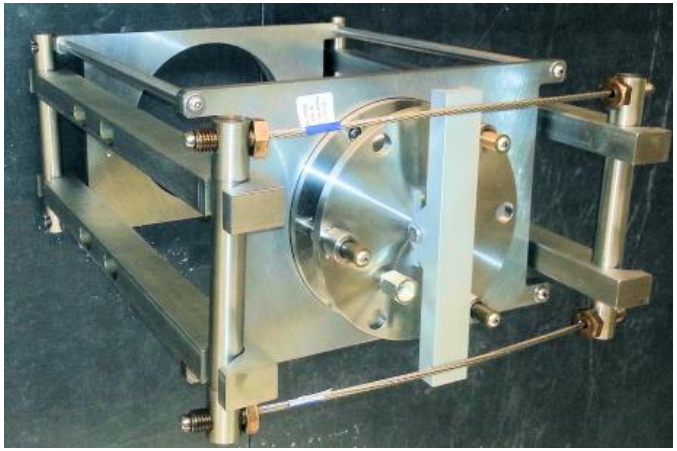
Slow Tuners

- The HWR cryomodule will use pneumatic slow tuners → pneumatic slow tuners have been in operation at Argonne on superconducting cavities since the 1970s.
- Slow tuners are install on all HWRs during offline testing.
  - Slow tuners are actuated through their full range to verify response.
  - 162.5 MHz ± 60 kHz is exceeded for all HWRs
- Slow tuners are operating as planned and testing has demonstrated this.

HWR with Slow Tuner



Slow Tuner



Interfaces

WBS Number	Title	Docdb #
121.3.4.2	BOE Document for 121.3.4.2 HWR PM and Coordination	704 – v18
121.3.4.3.2	BOE Document for 121.3.4.3.2. HWR Cryomodule Final Integration	710 – v13
121.3.4.3.3	BOE Document for 121.3.4.3.3 HWT Cryomodule: Cryomodule RF Test at PIP2IT	713 – v14

- The interfaces for the HWR cryomodule are specified in the Interface Control Document TC# ED0001313

ESH&Q

Charge #4

- **Safety is our highest priority.**
- **Argonne has a robust program to ensure work and environmental safety.**
- **Providing a working piece of hardware goes hand-in-hand with work planning and control at Argonne.**
- **Work at FNAL is being planned in compliance with:**
  - **FESHM, and**
  - **ED0001313 Technical Specifications for the HWR Cryomodule,**
  - **Docdb # 710 HWR Cryomodule Final Integration, and**
  - **Docdb # 713 Cryomodule RF Test at PIP2IT.**

Risk: HWR

- HWR Cryomodule does not meet technical performance requirements

Title	Probability	Probability Score	Impact Score - Cost	Impact Score - Schedul	Risk Rank	P * Impact (k$)	P * Impact (months)
HWR Cryomodule does not meet technical performance requirements	20.00%	2 (L)	2 (M)	3 (H)	2 (Medium)	217	2.4

BOE Summary

Charge #2

WBS Number	Title	Docdb #
121.3.4.2	BOE Document for 121.3.4.2 HWR PM and Coordination	704 – v18
121.3.4.3.2	BOE Document for 121.3.4.3.2 HWR Cryomodule Final Integration	710 – v13
121.3.4.3.3	BOE Document for 121.3.4.3.3 HWT Cryomodule: Cryomodule RF Test at PIP2IT	713 – v14

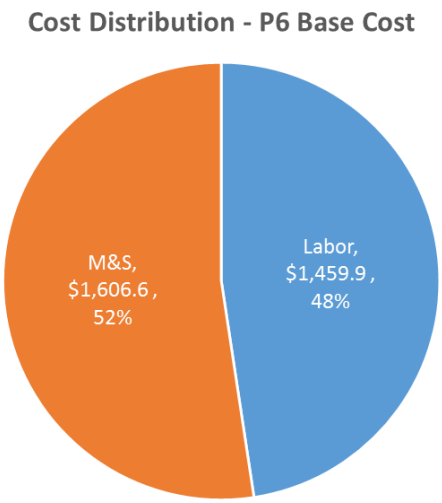
Cost Summary

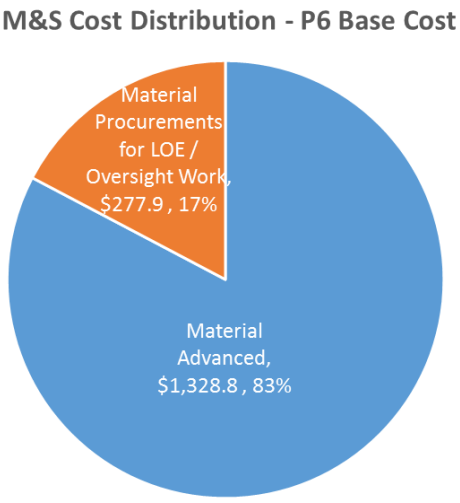
Charge #2

WBS Element	Hours	Labor ($000)	M&S ($000)	Est. Uncertainty ($000)		
121.3.4 - Linac - Half Wave Resonator (HWR)	**P6 Hours**	**P6 Base Cost**	**P6 Base Cost**	**Total**	**% of Base**	**Total Cost Incl. Uncrty.**
121.3.4.2 - Linac - HWR - Project Management and Coordination	972	$ 147.8	$ 3.3	$ 15.4	10.2%	$ 166.5
121.3.4.3 - Linac - HWR - CryoModule (HWR)	8,047	$ 1,312.1	$ 1,603.3	$ 555.3	19.0%	$ 3,470.8
Grand Total	**9,019**	**$ 1,459.9**	**$ 1,606.6**	**$ 570.7**	**18.6%**	**$ 3,637.3**
Note: P6 base cost = BOE + overheads and escalation						

Cost Drivers and Estimate Maturity

Charge #2

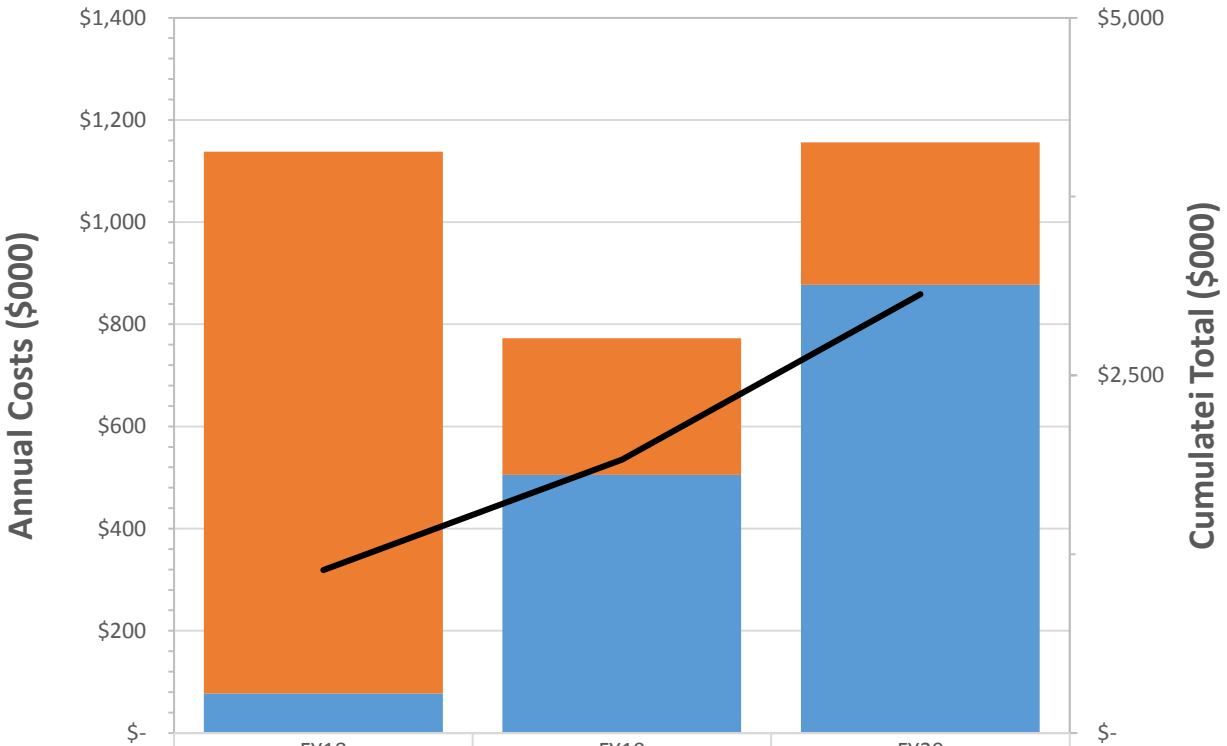




P6 Base Costs = BOE + Overheads + Escalation

Cost Profile – P6 Base Cost Only

Charge #2

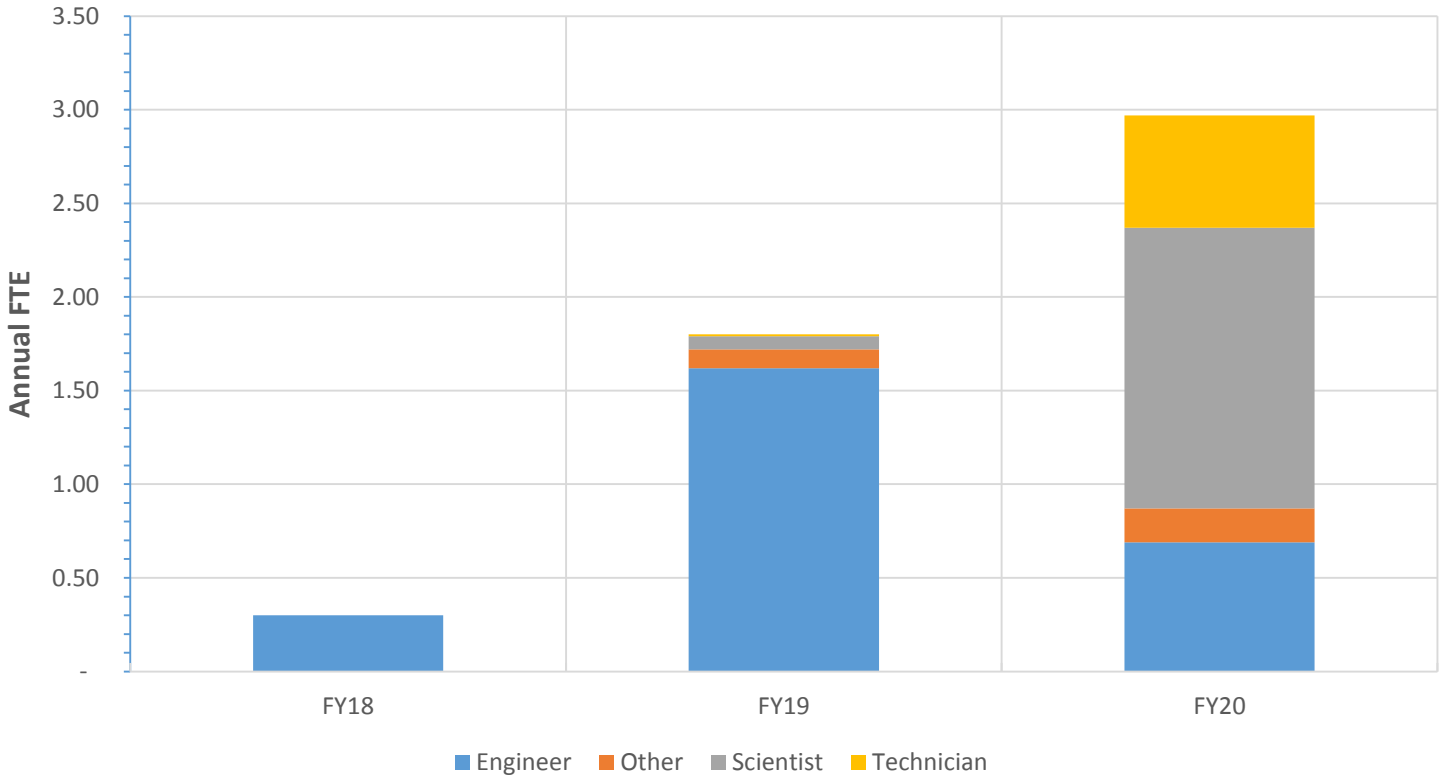


	FY18	FY19	FY20
Material	$1,060.5	$267.5	$278.6
Labor	$77.4	$505.3	$877.2
Cumulative Tot.	$1,137.9	$1,910.7	$3,066.5

P6 Base Costs = BOE + Overheads + Escalation

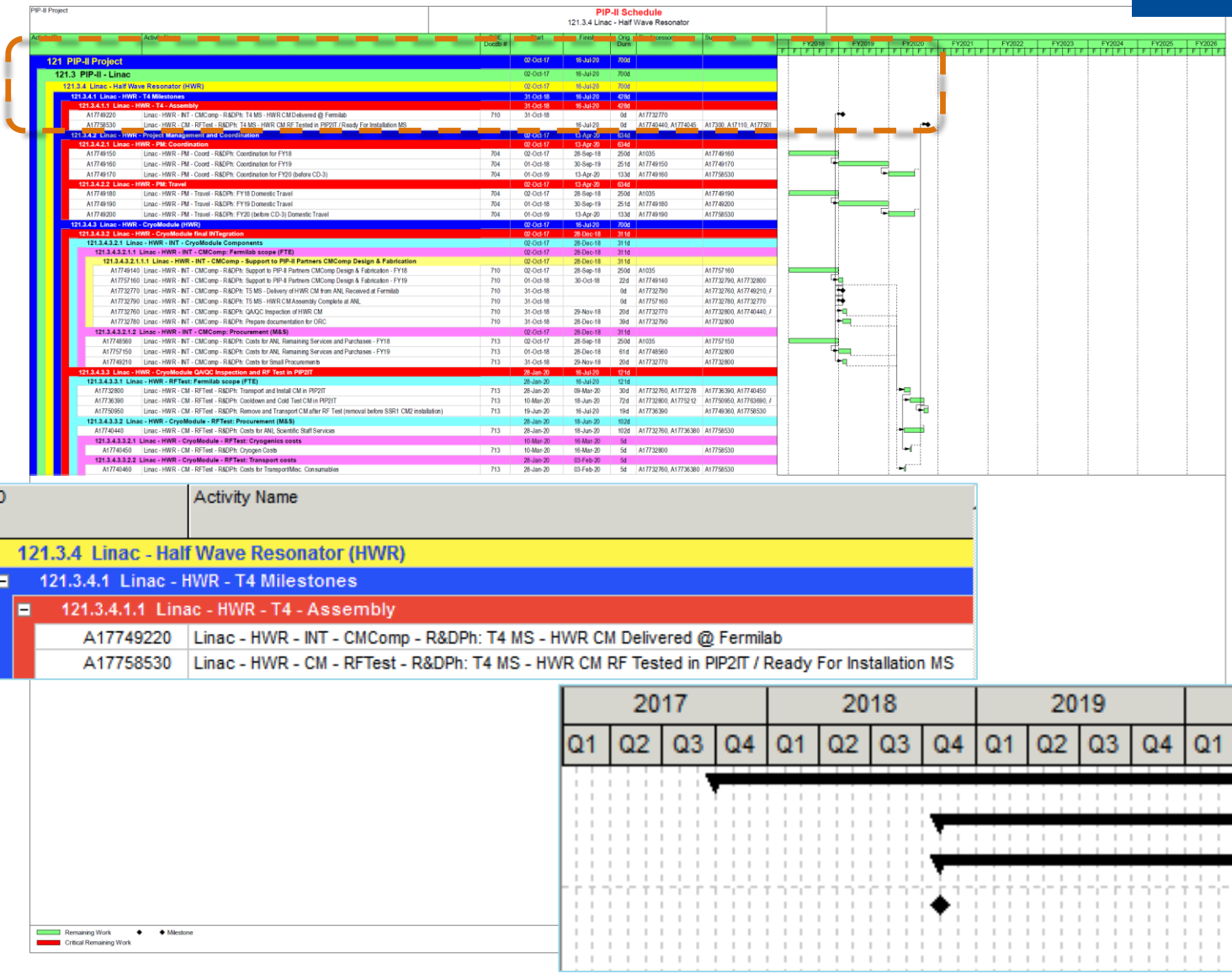
Labor Profile – P6 Hours/FTE

Charge #2



Schedule

Charge #2



Summary

- **Requirements are defined and traceable.**
- **Cryomodule and subsystems are almost finished.**
  - **Then final assembly.**
- **The cryomodule will be finished and ready for PIP-II.**

- **Thank you for your attention.**