Fermilab U.S. DEPARTMENT OF ENERGY | Office of Science

# 650 MHz Scope and Status

Fumio Furuta, L3 Technical

PIP-II SRF/Cryo Integrated Workshop

14 May 2020

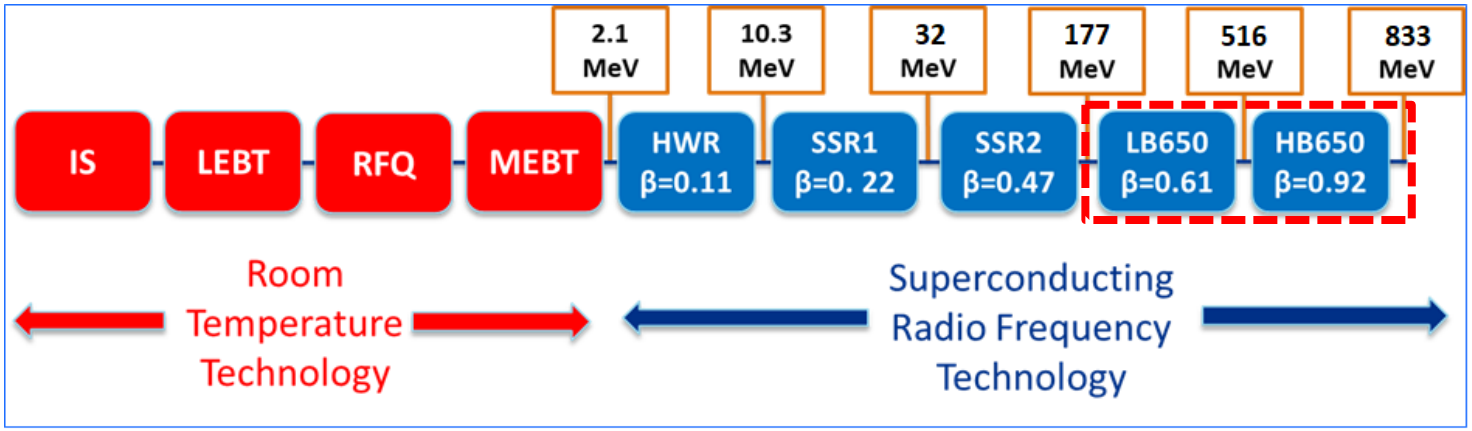
A Partnership of:

US/DOE
India/DAE
Italy/INFN
UK/UKRI-STFC
France/CEA, CNRS/IN2P3
Poland/WUST

# Outline

- Scope
- Requirements
- Interfaces
- Technical Status
- Summary

# Technical Scope/Deliverables




| Cryomodule | Number (prototype + installed) | Cavity number | Magnet number | Testing | Notes |
|---|---|---|---|---|---|
| LB650 | 1 pre-production<br>9 production | 4 | 0 | Full test at Partner & Fermilab | Integrated design |
| HB650 | 1 prototype<br>4 production | 6 | 0 | Full test at Fermilab | Integrated design |

- ❑ All but 1 cryomodule to undergo transatlantic transportation
- ❑ Scope from design to delivery of qualified CMs to Linac

# Requirements

Defined & traceable in Teamcenter

- Physics Requirements Documents (PRD)
  - SRF Cavity Parameters PRD: *TC# ED0010221*
  - Cryogenic Heat Load PRD: *TC# ED0008200*

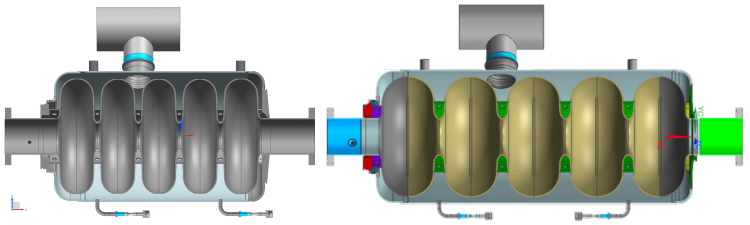
- Functional Requirement Specifications (FRS)
  - LB650 CM FRS: *TC# ED0001830*
  - HB650 CM FRS: *TC# ED0001322*

- Technical Requirement Specifications (TRS)
  - LB650 CM TRS: *TC# ED0009658*
  - HB650 CM TRS: *TC# ED0009659*

*and more for cavities, coupler and tuners,,*

# Requirements

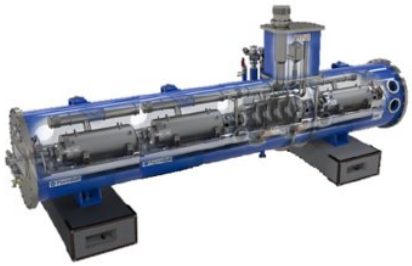
- 650MHz Cavities, Couplers, Tuners

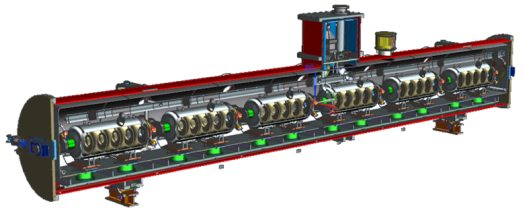


| | Units | LB650 | HB650 |
|---|---|---|---|
| Geometrical/Optimal beta | | 0.61/0.65 | 0.92/0.971 |
| Energy gain at optimal beta | MV | 11.9 | 19.9 |
| Operating cavity gradient | MV/m | 16.9 | 18.8 |
| Maximum cavity gradient in VTS | MV/m | 20 | 24 |
| Unloaded cavity quality factor | | $2.4\times10^{10}$ | $3.3\times10^{10}$ |
| Unloaded cavity quality factor in VTS | | $2.6\times10^{10}$ | $4.0\times10^{10}$ |
| Cavity operating temperature | K | 2.0 | 2.0 |
| 2 K dynamic heat load per cavity + coupler | W | < 20 | < 22.5 |
| Cavity longitudinal stiffness | kN/mm | < 5 | < 5 |
| Sensitivity to LHe pressure fluctuations | Hz/mbar | < 25 | < 25 |
| Coupler power | kW | 35 | 50 |

# Requirements

- 650 MHz Cryomodules





| | Units | LB650 | HB650 |
|---|---|---|---|
| Energy for section | MeV | 177 to 516 | 516 to 833 |
| $\beta_g$ | | 0.61 | 0.92 |
| Cavities per cryomodule | | 4 | 6 |
| Cryomodule flange-to-flange length | m | 5.52 | 9.92 |
| 2 K heat load | W | < 80 | < 131 |
| 5 K heat load | W | < 25 | < 27 |
| 30 – 50 K heat load | W | < 125 | < 188 |
| Environmental magnetic field | mG | ≤ 5 | ≤ 5 |
| Transverse cavity alignment error, RMS | mm | 0.5 | 0.5 |
| Angular cavity alignment error, RMS | mrad | 1 | 1 |

# Interfaces: *PIP-II ICD Master*

- Interfaces well defined & revision controlled in Teamcenter

| L2 Sys | L3 WBS | L3 System Name | L3 Sys | ICD TC ID |
|---|---|---|---|---|
| SRFCryo | 121.02.04 | 650 MHz Cryomodules (650MHz) | 650MHz | ED0010433 |

**RF power distribution**

The design of 650MHz high power coupler waveguide needs to be compatible with RF power distribution (HPRF) from the RF power amplifier.

| Unique L3-L3 ID | Interface # | Interface ID | Interface Name |
|---|---|---|---|
| 1954 | 2 | 1954-002 | HB650 RF power input connection (650MHz) |

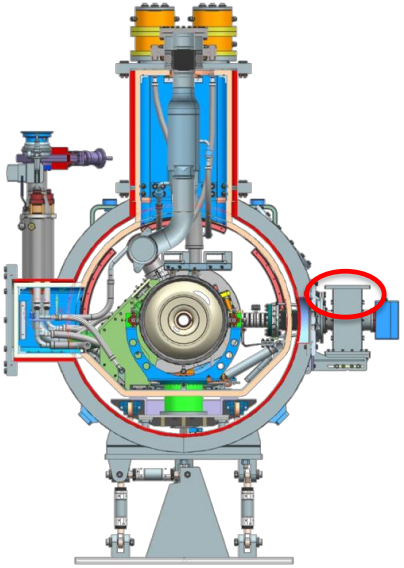
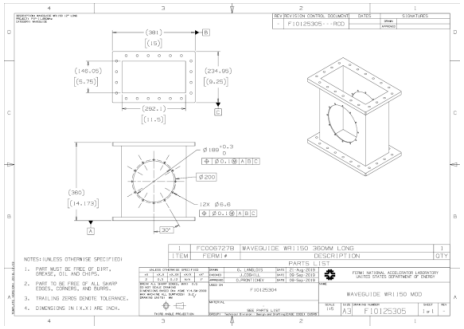
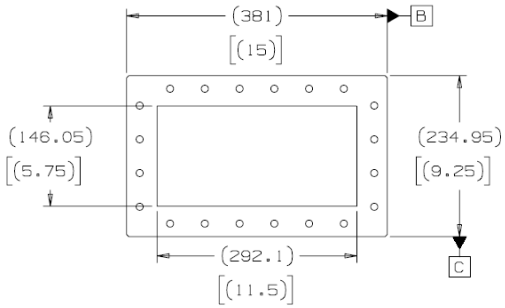


*Figure 13: Cross section of the HB650 Cryomodule*






TC number: F10125305; WAVEGUIDE WR1150 MOD

Example

# Interfaces: *HB650 CM ICD*

- HB650 CM interfaces drafted: ED0011227

| | Bare Cavity | Jacketed Cavity | Tuner | Coupler - cold part | Coupler - warm part | Cryomodule - Fermilab | Cryomodule - CEA | Cryomodule - STFC | Cryomod |
|---|---|---|---|---|---|---|---|---|---|
| Bare Cavity | | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 |
| Jacketed Cavity | 101 | | 201 | 202 | 203 | 204 | 205 | 206 | 207 |
| Tuner | 102 | 201 | | 301 | 302 | 303 | 304 | 305 | 306 |
| Coupler - cold part | 103 | 202 | 301 | | 401 | 402 | 403 | 404 | 405 |
| Coupler - warm part | 104 | 203 | 302 | 401 | | 501 | 502 | 503 | 504 |
| Cryomodule - Fermilab | 105 | 204 | 303 | 402 | 501 | | 601 | 602 | 603 |
| Cryomodule - CEA | 106 | 205 | 304 | 403 | 502 | 601 | | 701 | 702 |
| Cryomodule - STFC | 107 | 206 | 305 | 404 | 503 | 602 | 701 | | 801 |
| Cryomodule - RRCAT | 108 | 207 | 306 | 405 | 504 | 603 | 702 | 801 | |
| EP | 109 | 208 | 307 | 406 | 505 | 604 | 703 | 802 | 901 |
| HPR | 110 | 209 | 308 | 407 | 506 | 605 | 704 | 803 | 902 |
| VTS | 111 | 210 | 309 | 408 | 507 | 606 | 705 | 804 | 903 |
| STC | 112 | 211 | 310 | 409 | 508 | 607 | 706 | 805 | 904 |
| STFC Cavity Processing facility | 113 | 212 | 311 | 410 | 509 | 608 | 707 | 806 | 905 |
| STFC Cavity testing facility | 114 | 213 | 312 | 411 | 510 | 609 | 708 | 807 | 906 |
| RRCAT Cavity Processing facility | 115 | 214 | 313 | 412 | 511 | 610 | 709 | 808 | 907 |
| RRCAT Cavity testing facility | 116 | 215 | 314 | 413 | 512 | 611 | 710 | 809 | 908 |

Examples

**103**
The bare cavity shall connect to the cold part of the coupler.

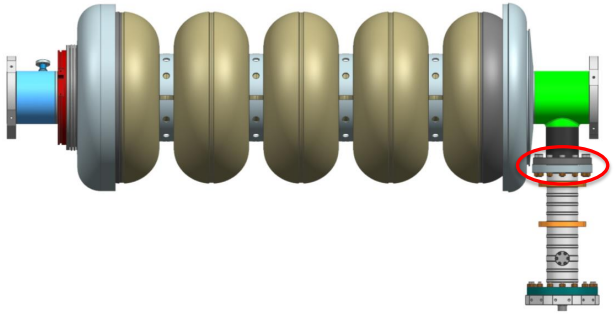


*Figure 1: Design of the bare cavity with the cold part of the coupler*

*Figure 7: HPR Assembly – HB650 configuration*

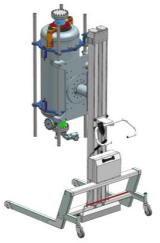
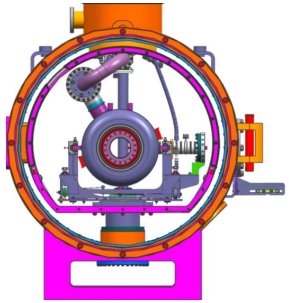


*Figure 8: Lifting cart for HB650 cavity*

**211**
The design of the jacketed cavity is compatible with STC at Fermilab.



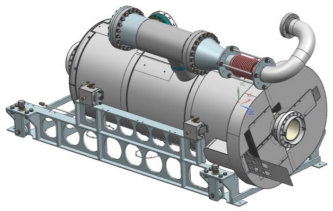
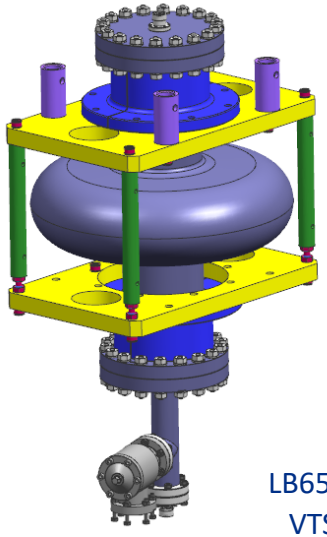


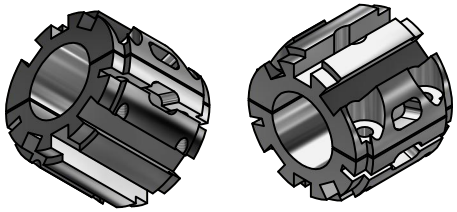
*Figure 10: STC Assembly - HB650 configuration*

# Technical status: *LB650 1-cell Cavity*

- LB650 1-cell cavities
  - INFN has procured three 1-cell cavities to develop electropolishing parameters
  - First set of experiments conducted at INFN
  - One Cavity was shipped from INFN to Fermilab for testing
  - EP/VTS tooling for LB650 is in progress at ANL/FNAL
  - LB650 coupon host cavity being designed at FNAL for process optimization and surface studies



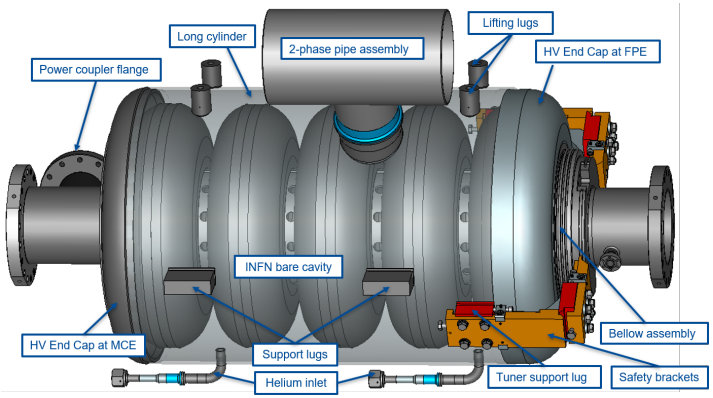
LB650 1-cell on VTS support

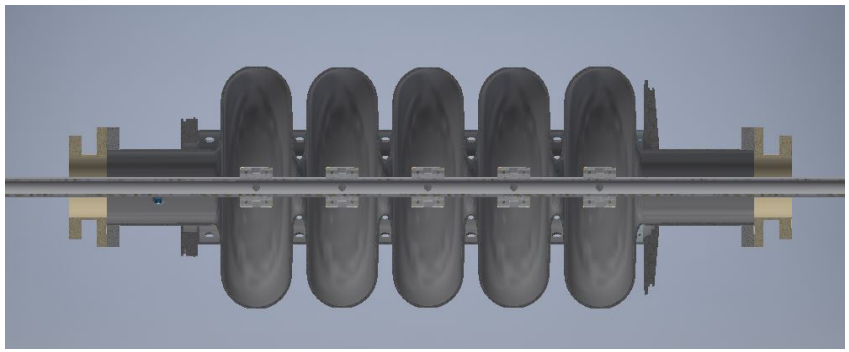


Enhancement piece on EP cathode for LB650

# Technical status: *LB650 5-cell cavity*

- Fermilab
  - proto-Final Design Review completed
  - Working on POs of LB650 Nb materials, cavities, and He vessels
  - EP tooling for LB650 is in progress at ANL/FNAL
- INFN
  - Mechanical design prototyped with two 5-cell cavity order.
  - The first LB650 5-cell has been shipped to Fermilab
- VECC
  - Fabrication of 5-cell cavities begun

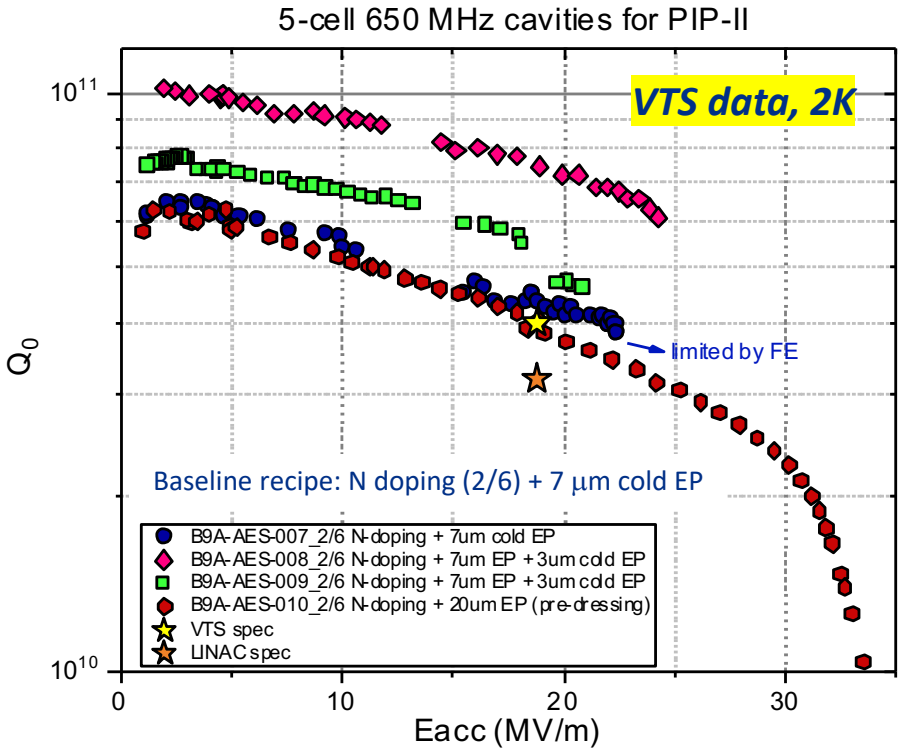


EP cathode with enhancement pieces in LB650

# Technical status: *HB650 B0.9 Cavities*

| B0.9 cavities | VTS (bare) | Jacketing | VTS (dressed) | STC |
|---|---|---|---|---|
| B9A-AES-007 | Qualified | On waiting list | | |
| B9A-AES-008 | Qualified | In progress | | |
| B9A-AES-009 | In progress | | | |
| B9A-AES-010 | Qualified | Completed | Completed | Completed |

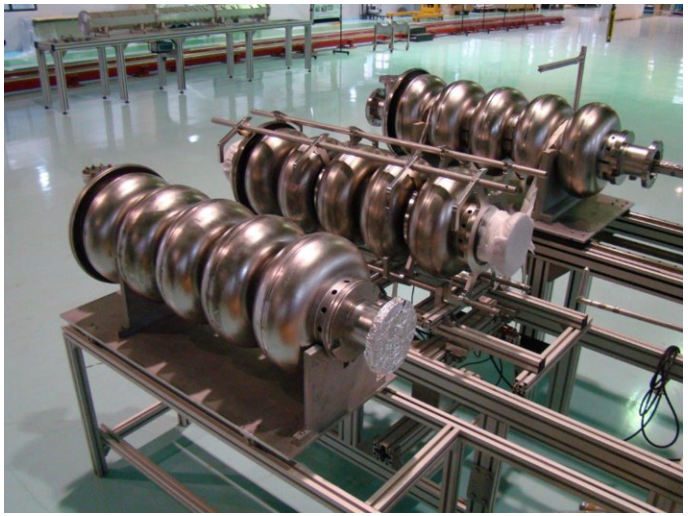




Installation into STC, B9A-AES-010

# Technical status: *HB650 B0.92 cavity*

- β=0.92Cavity prototype FDR completed
  - Baseline HB650 cavity for PIP-II



- RRCAT
  - 4 bare cavities fabricated
  - Processing & testing performed
  - Jacketing of first cavity completed
  - Next: vertical test & horizontal qualification

- FNAL
  - One B0.92 delivered from RRCAT will be tested
  - Nb for 3 cavities ordered & received
  - Order for 3 cavities to be placed soon

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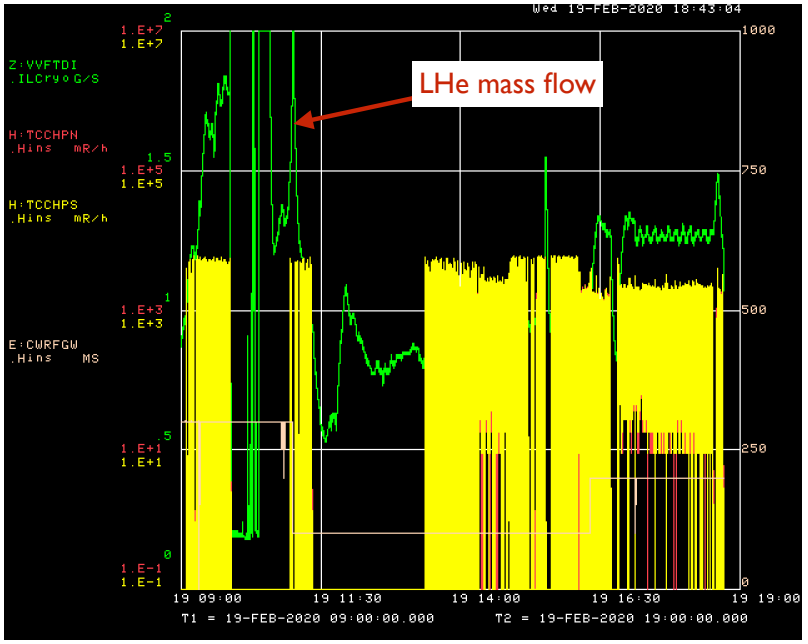
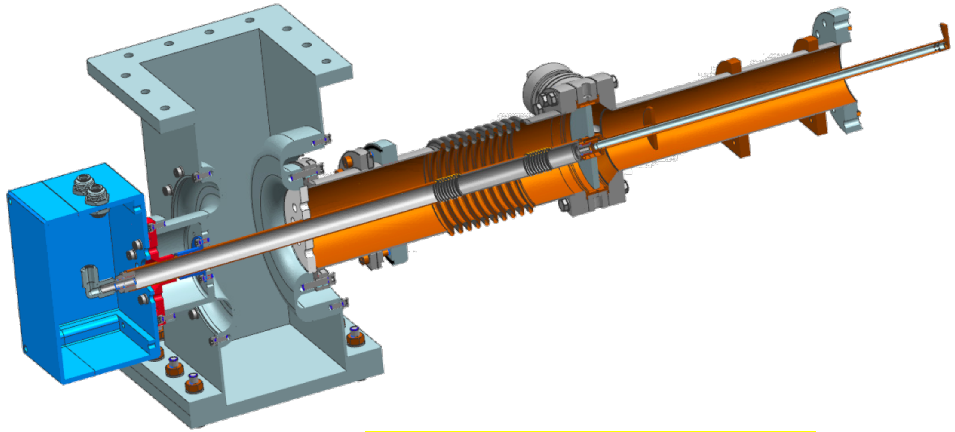
# Technical status: *Couplers*

- ❑ Copper coated cold end chosen as baseline
- ❑ Tested in STC
- ❑ Integrated into cryomodule design
- Diagnostics integration being examined
- ❑ 650 coupler Proto-FDR was held in Feb. 2020
- ❑ Coupler procurement for HB650 proto CM have initiated



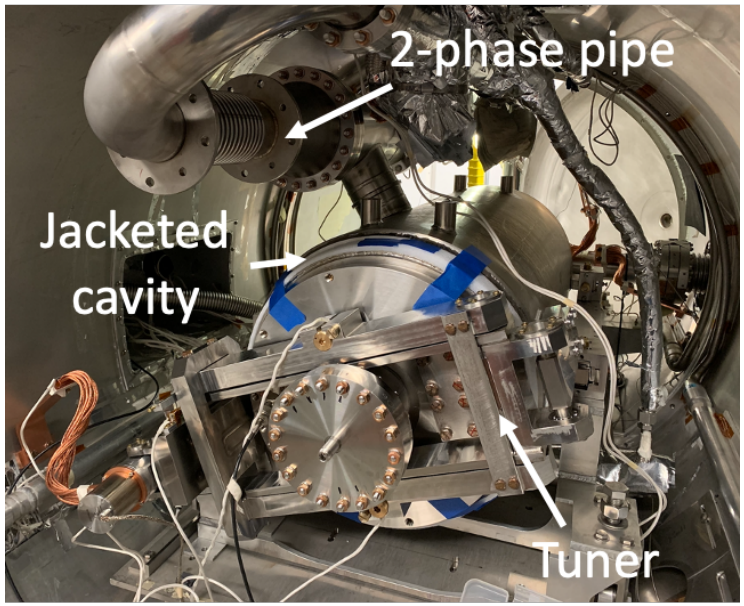
Optimized design

MP event in STC

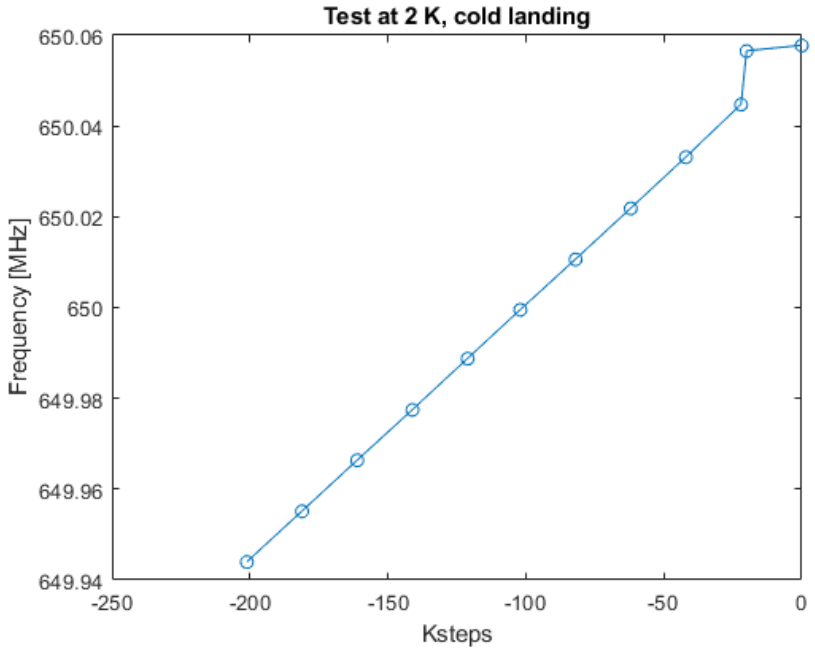
- Cleaned some MP after 20 hours conditioning
- Still persistent MP in 12-16 MV/m and intermittent MP in 7.5-12 MV/m and 16-17.6 MV/m ranges

# Technical status: *Tuners*

- Tuner design warm validated by Fermilab & Partner
  - Test done on stiffer β=0.9 cavity
  - Short arm tuner for B0.9 cavities
  - Long arm tuner for B0.92 and B0.61 cavities
- Tested in STC
- RRCAT fabricated four B0.92 tuners
- 650 Tuner Final Design Review will be held




Tuner on B0.9 cavity in STC




Tuner studies in STC, 2K

# Technical status: *STC*

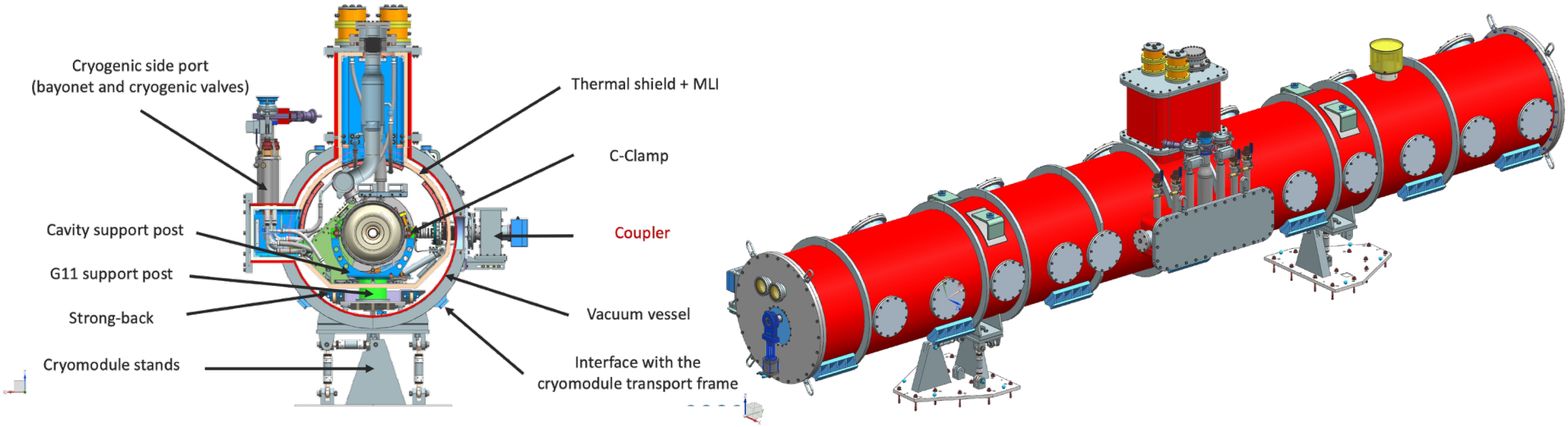
- Commissioned STC for 650 MHz operation, *ED0011810 1st STC test report*
- The cavity, coupler, and tuner tested in STC will be shipped to RRCAT to commission their horizontal test stand
- Lessons Learned from STC was documented and entered to PIP-II LL database: STC LL summary
- Studies on fast cooldown procedures and cool down rate vs. Q0 in STC will be addressed during next STC.
- Optimal cooldown rate is estimated from LCLS-II data, tentatively

Table: Estimation on 650 cavity and cryomodule cooldown mass flow rate

| Cavity Types | Niobium Mass [kg] | Cool down mass flow per cavity [g/s] | Cool down mass flow per cryomodule [g/s] |
|---|---|---|---|
| **LCLS-II** | 21.8 | 4 | 32 |
| **LB650** | 58.6 | 10.7 | 43 |
| **HB650** | 65.3 | 12 | 72 |

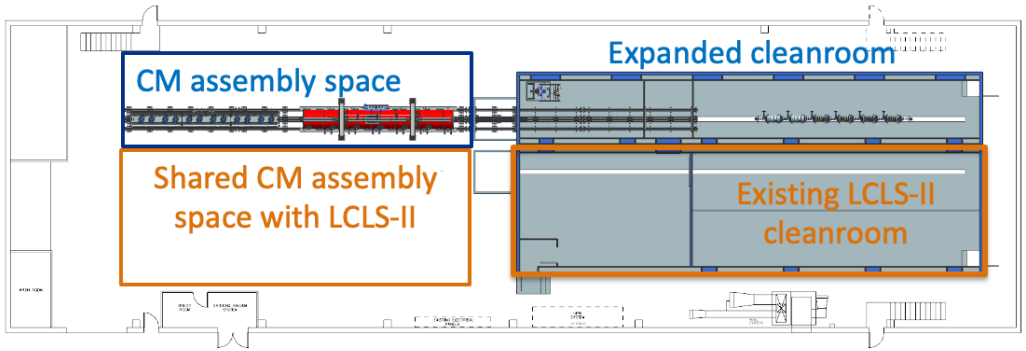
# Technical status: *Cryomodule design*

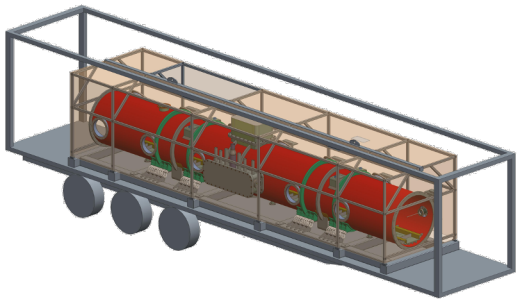
- Integrated engineering design team formed
  - Fermilab is lead for HB650 design, & Partner is lead for LB650
  - Partners participate in sub-system design
- HB650 CM Preliminary Design Review completed, FDR will be held in summer
- Cryomodule design is in final stage
  - String: Cavities, couplers, tuners: prototype stage
  - Strong back & supports: Final design & analysis stage;
  - Thermal design & magnetic shields, piping, vacuum vessel: Final design & analysis stage
- Piping & Instrumentation Diagram
  - Drafted and placed in Teamcenter: F10101087

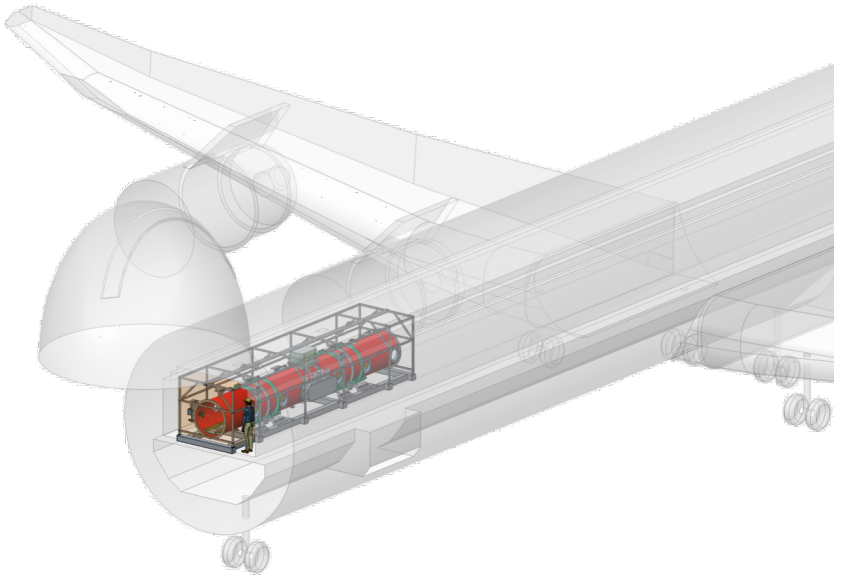


# Technical status: *HB650 proto CM plans*

- Cryomodule assembly plan
  - Assembly optimization ongoing by Partner
  - String & CM assembly to be performed at MP9 building, FNAL
- Transportation testing plan includes function/cold tests
  - Road & air transport assumed
  - CM overseas transportation frame design led by Partner :Preliminary design stage
  - US DoD specification MIL-STD-810H used as reference





# Summary

- Requirements and interface documents are defined and traceable in Teamcenter
- Q0 requirement in VTS had been achieved with B0.9 cavities, efforts will continue to achieve that of B0.92 and B0.61 cavities.
- STC had successfully commissioned for 650MHz, and next STC will address the studies on fast cooldown procedure and optimal cool down rate for 650 cavities.
- Thanks for your attention!