Introduction

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650 MHz Low Beta CM Pre-Production PDR

8 March 2021

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

Outline

- PIP-II Introduction
- 650 MHz Scope & Partners
- CM Development Plan & Schedule
- Requirements & Acceptance Flow-down
- Dressed Cavity Status

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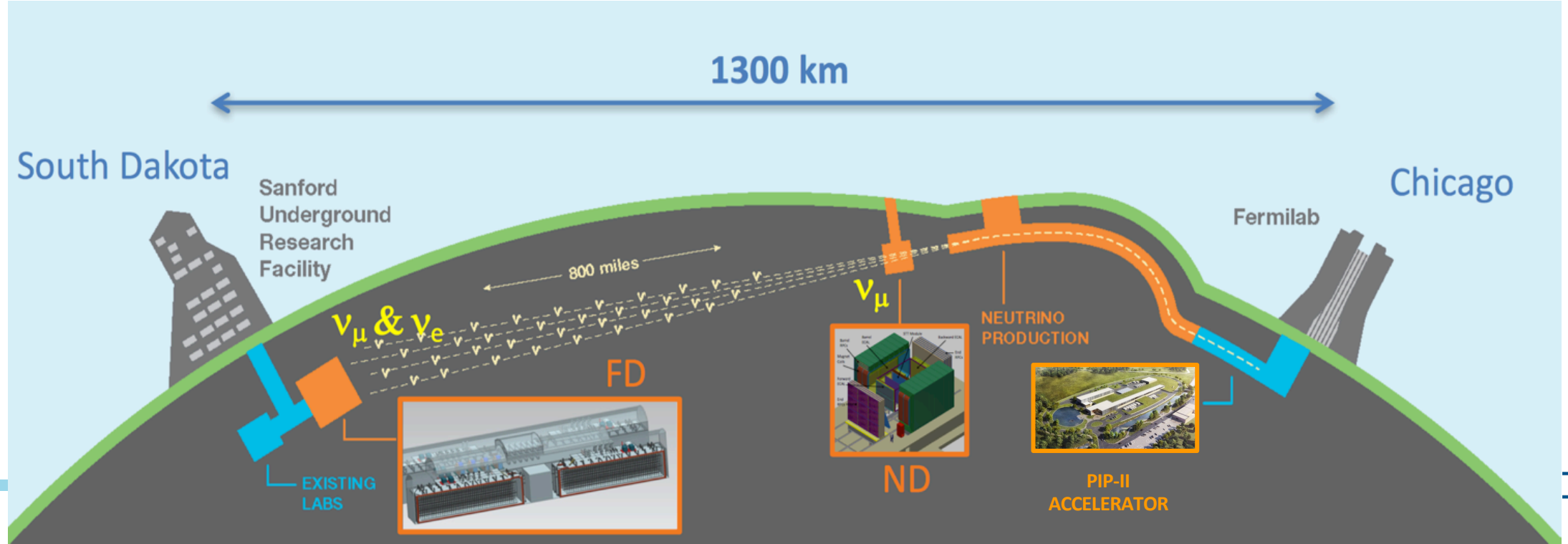
PIP-II / LBNF / DUNE

- Powerful proton beams (PIP-II)
  - 1.2 MW upgradable to multi-MW to enable world's most intense neutrino beam
- Dual-site detector facilities (LBNF)
  - Deep underground cavern (1.5 km) of 70kt liquid argon fiducial volume
  - A long baseline (1300 km)
- Deep Underground Neutrino Experiment (DUNE)
  - Liquid Argon – the next-generation neutrino detector



PIP-II Mission

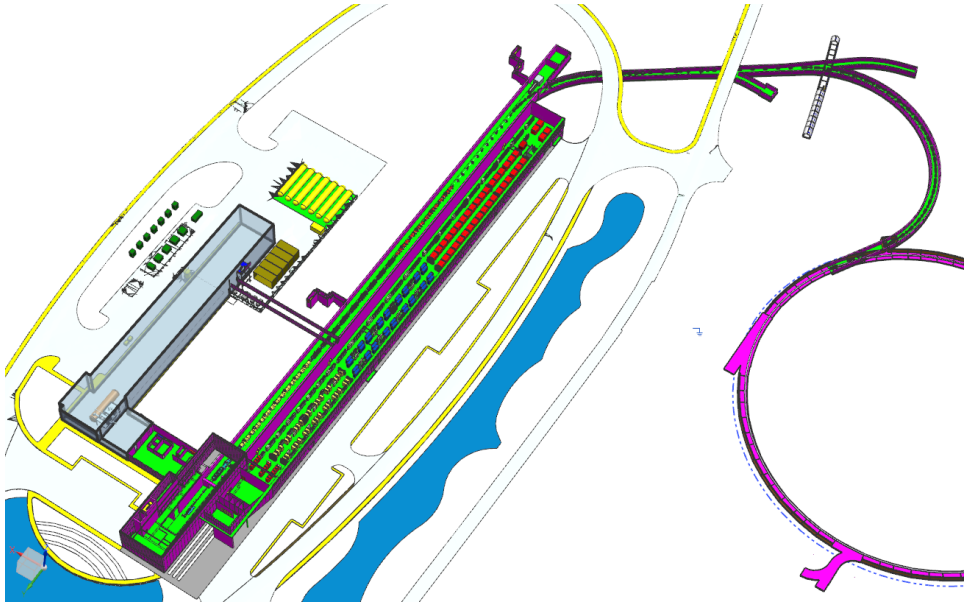
PIP-II will enable the world's most intense beam of neutrinos to the international LBNF/DUNE project, and a broad physics research program, powering new discoveries for decades to come.

PIP-II linac capabilities

Beam Power
- 1.2 MW proton beam
- Upgradeable to multi-MW

Flexibility and multi-user capability
- Compatible w/ CW-operations
- Customized beams
- Multi-user delivery

Reliability



PIP-II Scope

800 MeV H– linac
- Warm Front End & SRF section

Linac-to-Booster transfer line
- 3-way beam split

Upgraded Booster
- 20 Hz, 800 MeV injection
- New injection area

Upgraded Recycler, Main Injector
- RF in both rings

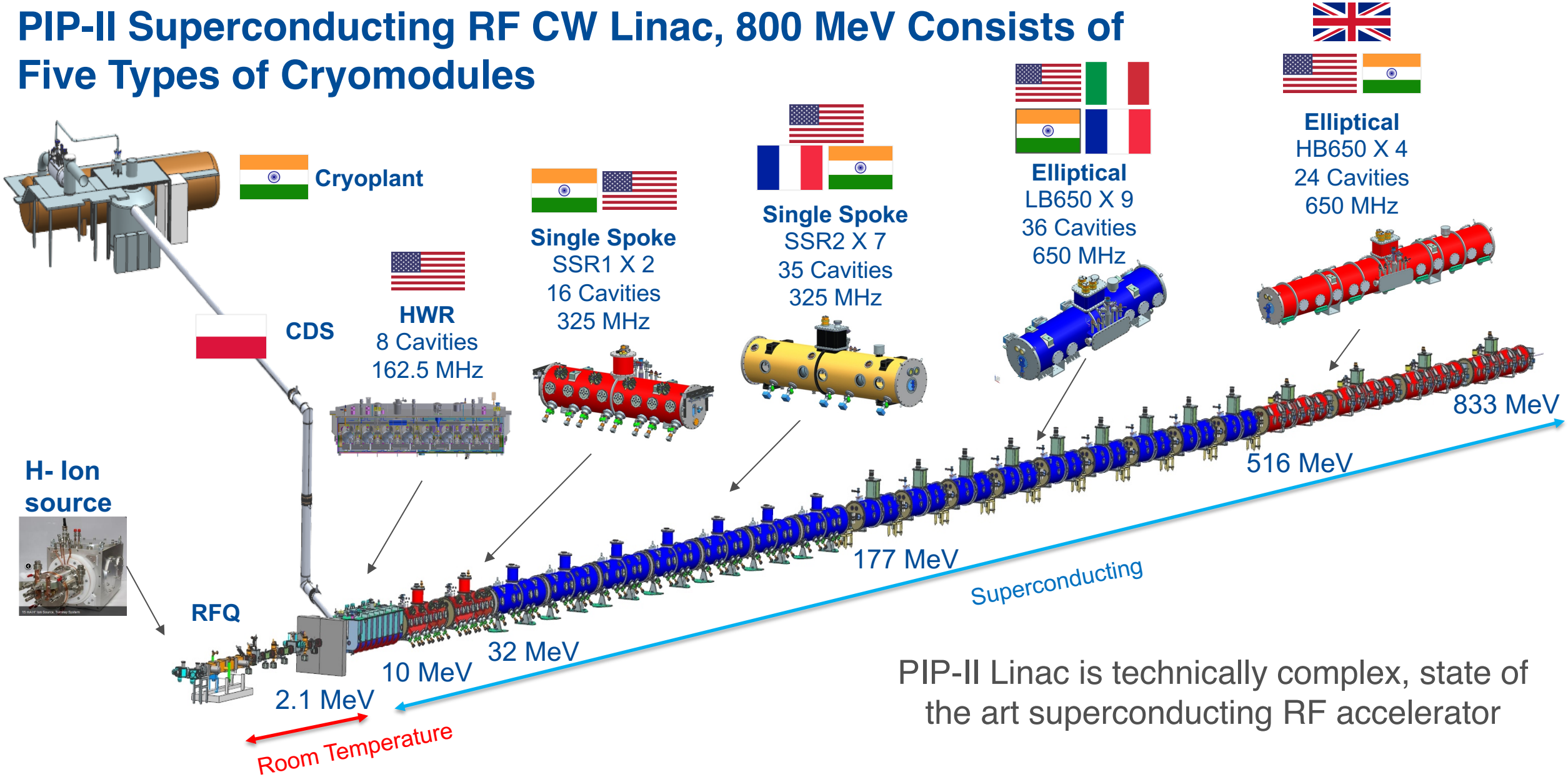
Conventional facilities, incl.
- Site preparation
- Cryoplant Building
- Linac Complex
- Booster Connection

The PIP-II scope enables the accelerator complex to reach 1.2 MW proton beam on LBNF target.

Slide courtesy L. Merminga

Slide courtesy L. Merminga

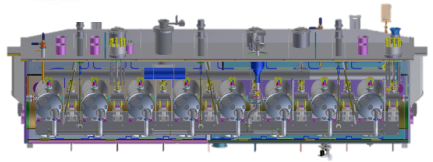
PIP-II Superconducting RF CW Linac, 800 MeV Consists of Five Types of Cryomodules



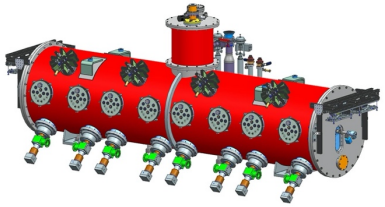
PIP-II Linac is technically complex, state of the art superconducting RF accelerator

PIP-II is the world's highest energy and power CW proton linac, and the U.S. first accelerator project to be built with major international contributions

The state-of-the-art PIP-II Superconducting RF Systems

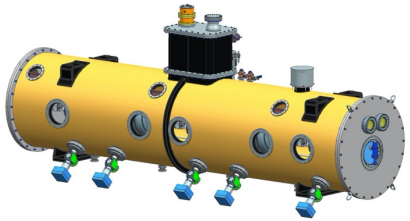


5.9 m



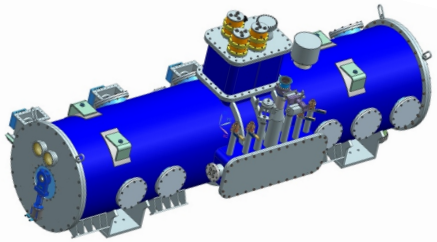
5.3 m

2023



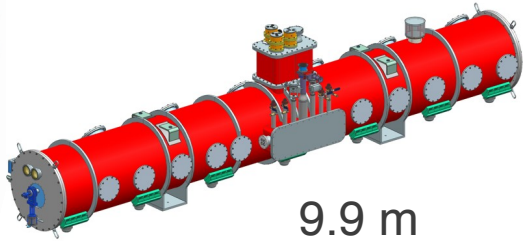
6.5 m

2023

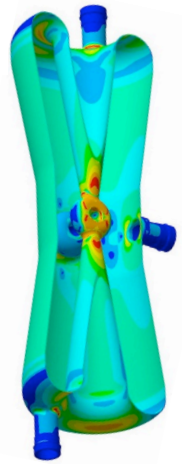


5.5 m

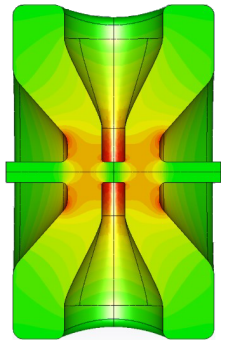
2021-22



9.9 m

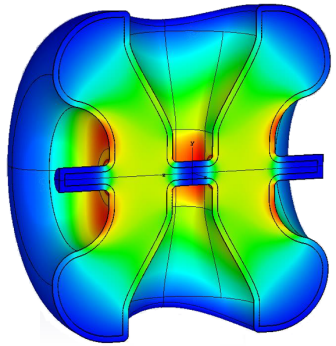


Half Wave Resonator
β=0.11 Q_0 =0.85x10^{10}

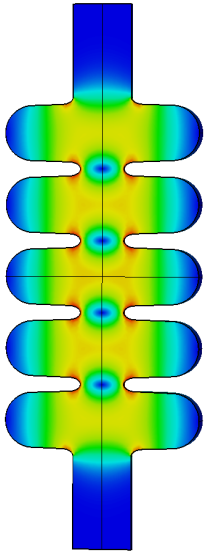


Single Spoke
SSR1
β=0.22 Q_0 =0.82x10^{10}

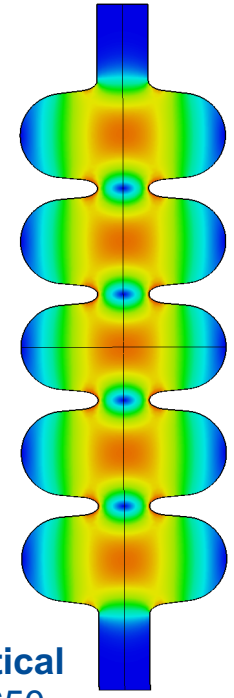
2022



Single Spoke
SSR2
β=0.47 *Q_0 =0.82x10^{10}



Elliptical
LB650
β=0.61 *Q_0 =2.4x10^{10}



Elliptical
HB650
β=0.92 *Q_0 =3.3x10^{10}

✓ Performance validated ✓ Testing in progress Dates: component built

*state-of-the-art performance requirement

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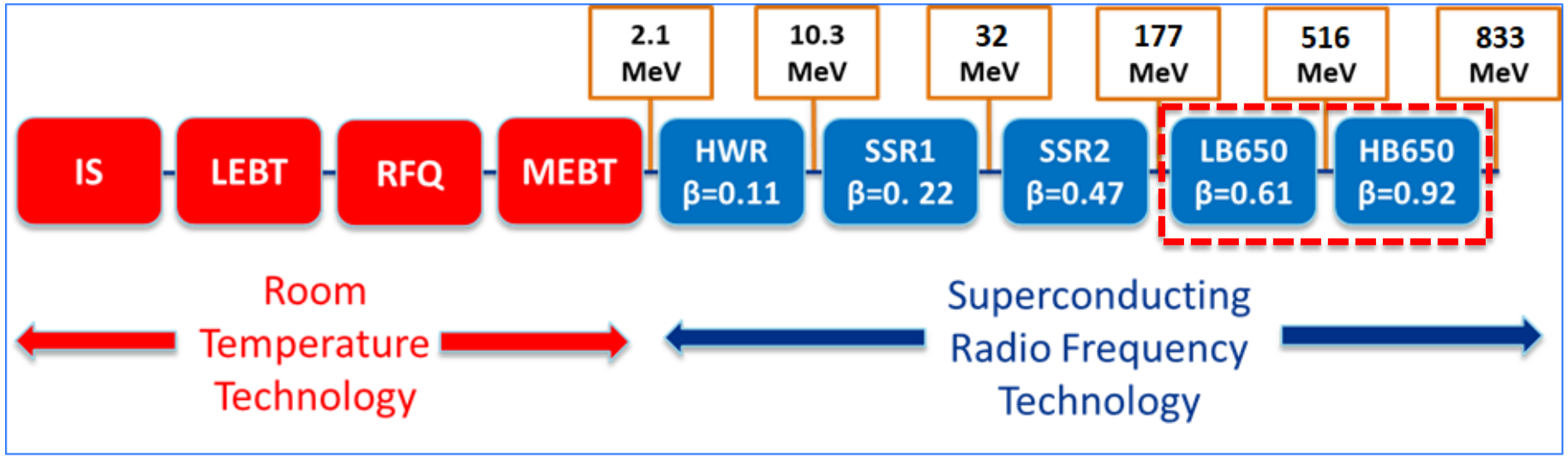
650 MHz Scope



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

LB650 Hardware Scope

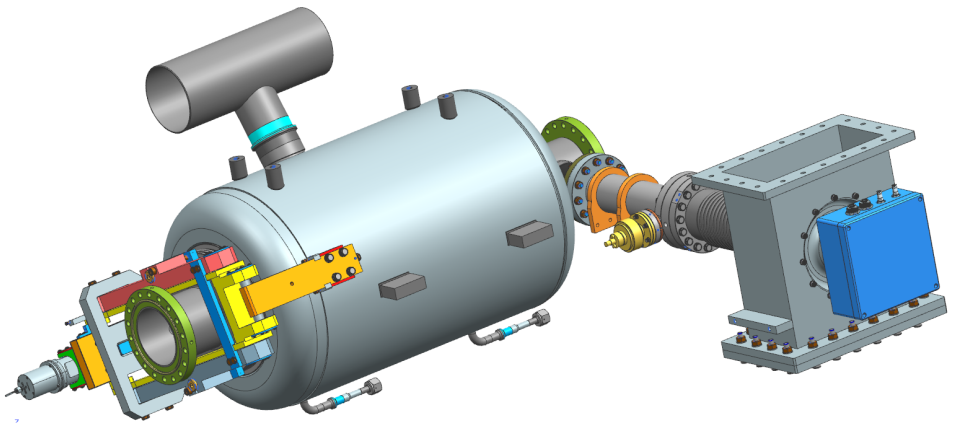
- LB650 – DOE and Partner contributions

	Item	Quantity	DOE	DAE	CEA	INFN
LB650 pre-prod CM (not installed in linac)	Cryomodule	1			1	
	Instrumentation & Valves	1	1			
	Jacketed Cavities	4	4	2		2 (bare)
	Couplers	4	4 + 2	2		
	Tuners	4	4 + 1	2		
	Transport Frame	1			1	
LB650 CM1-9	Cryomodule	9			9	
	Instrumentation & Valves	9	9			
	Jacketed Cavities	36		4		36 + 2
	Couplers	36	36 + 4	4		
	Tuners	36	36 + 4	4		
	Transport Frame	1			1	

LB650 Partnerships

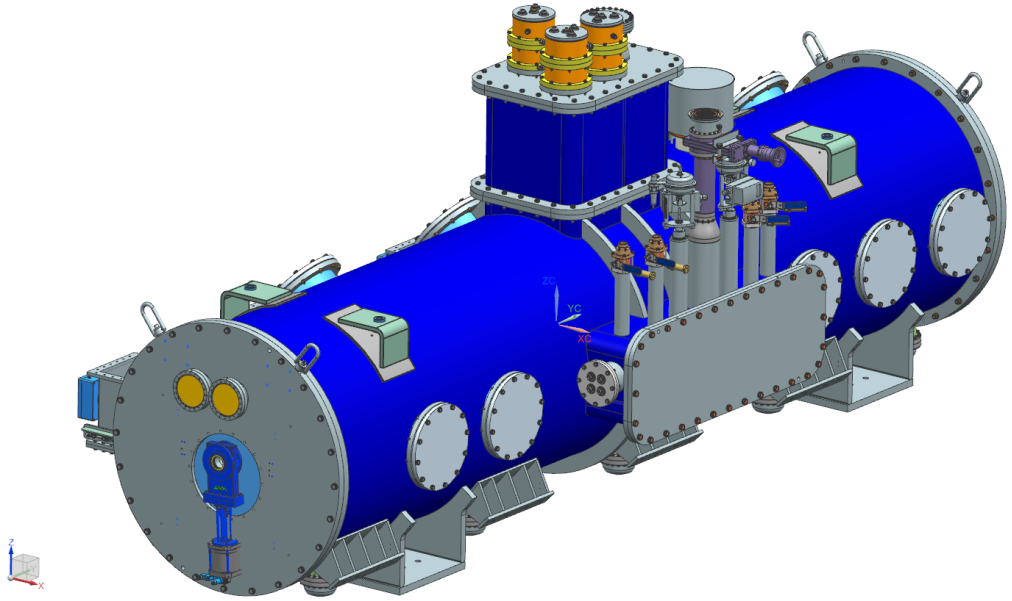
DRESSED CAVITY (cavity + coupler + tuner)

- India: Department of Atomic Energy (DAE)
  - Bhabha Atomic Research Center (BARC)
  - Variable Energy Cyclotron Center (VECC)
- Italy: Istituto Nazionale di Fisica Nucleare (INFN)
- USA: Fermi National Accelerator Laboratory (FNAL)



CRYOMODULE

- France: Commissariat à l'énergie atomique, Saclay (CEA)
- USA: Fermi National Accelerator Laboratory (FNAL)



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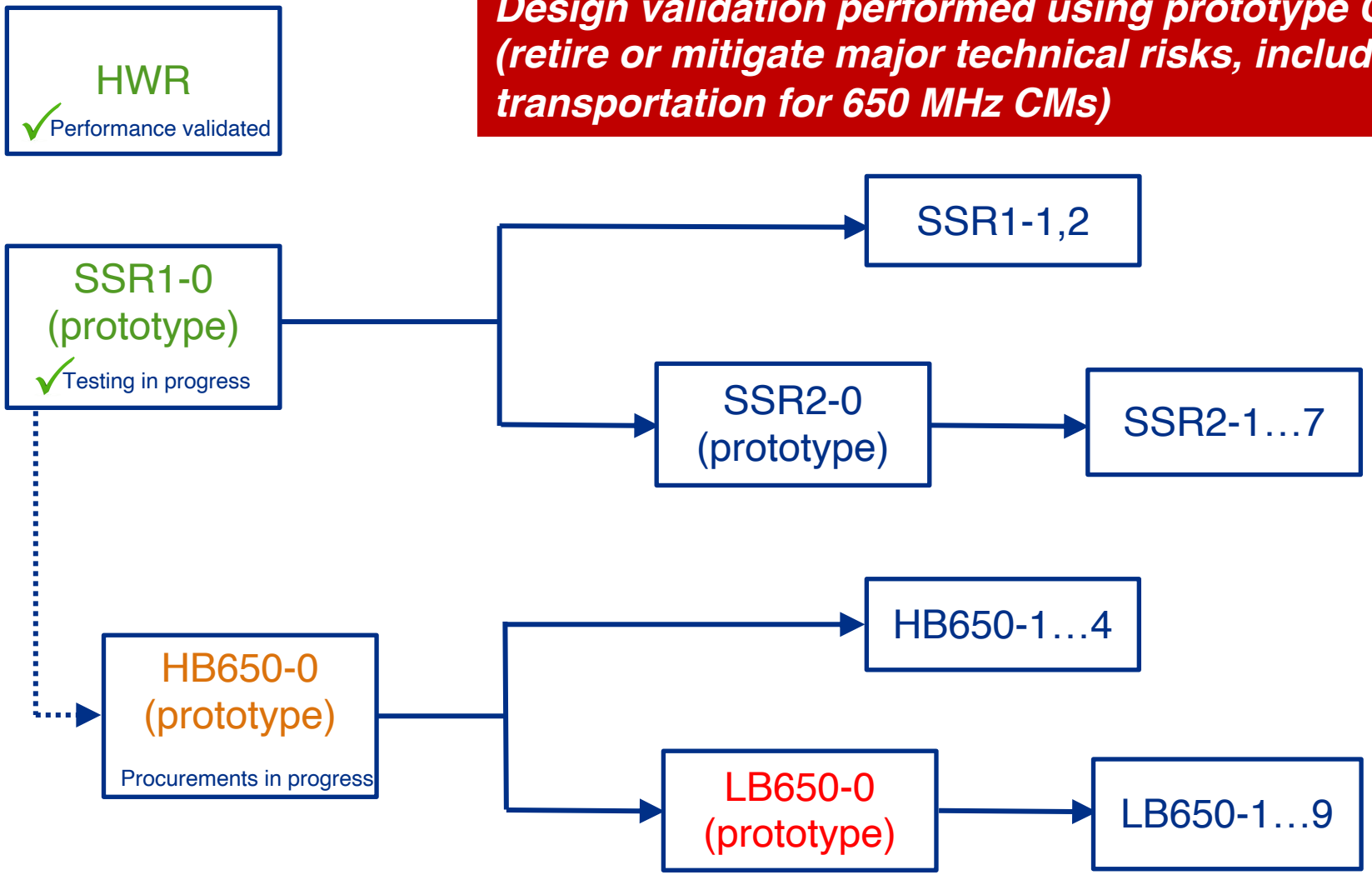
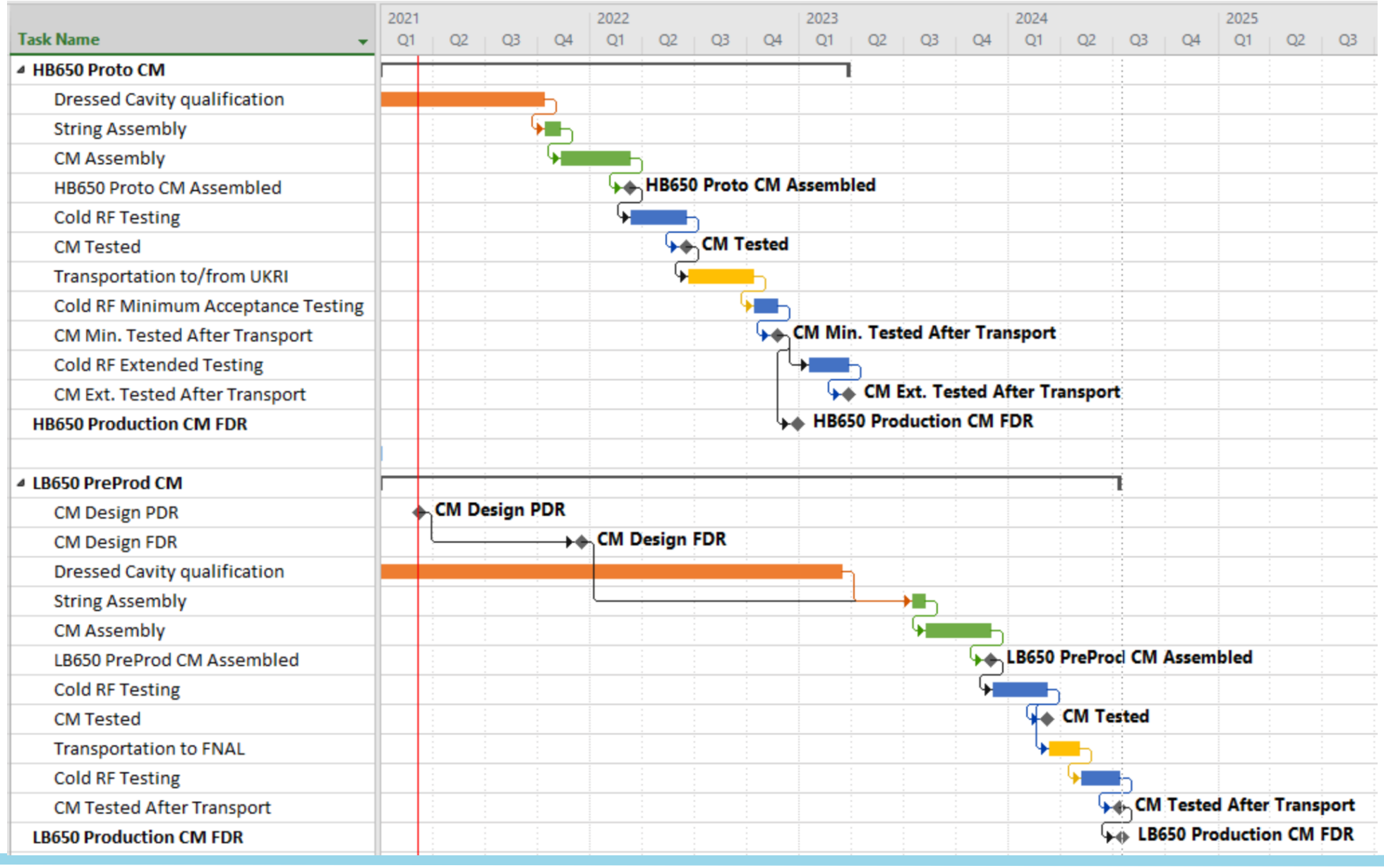
Cryomodule Development Plan

Design validation performed using prototype CMs (retire or mitigate major technical risks, including transportation for 650 MHz CMs)



LB & HB650 CM Schedules – PreProd / Proto Stage



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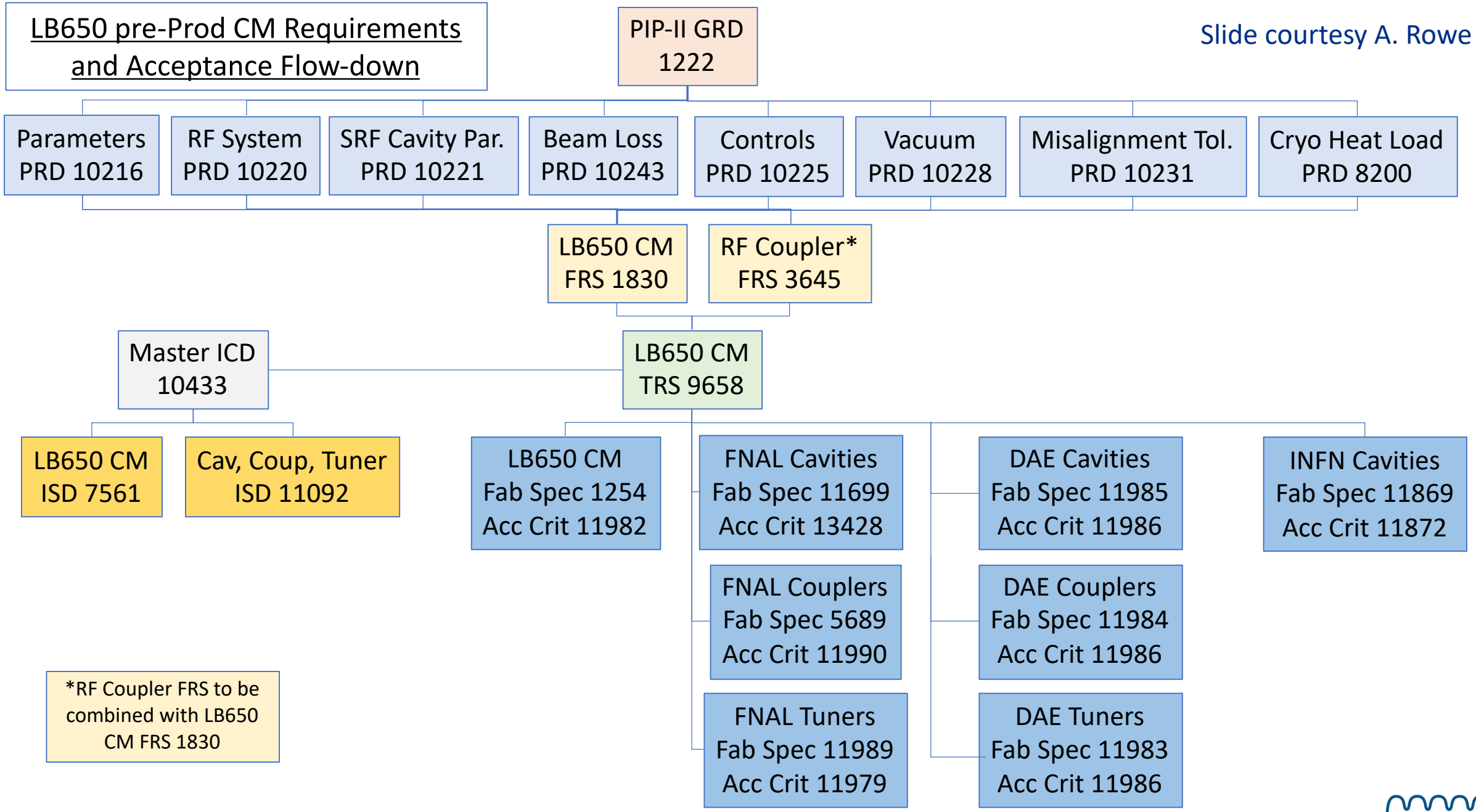
LB650 pre-Prod CM Requirements and Acceptance Flow-down

Slide courtesy A. Rowe



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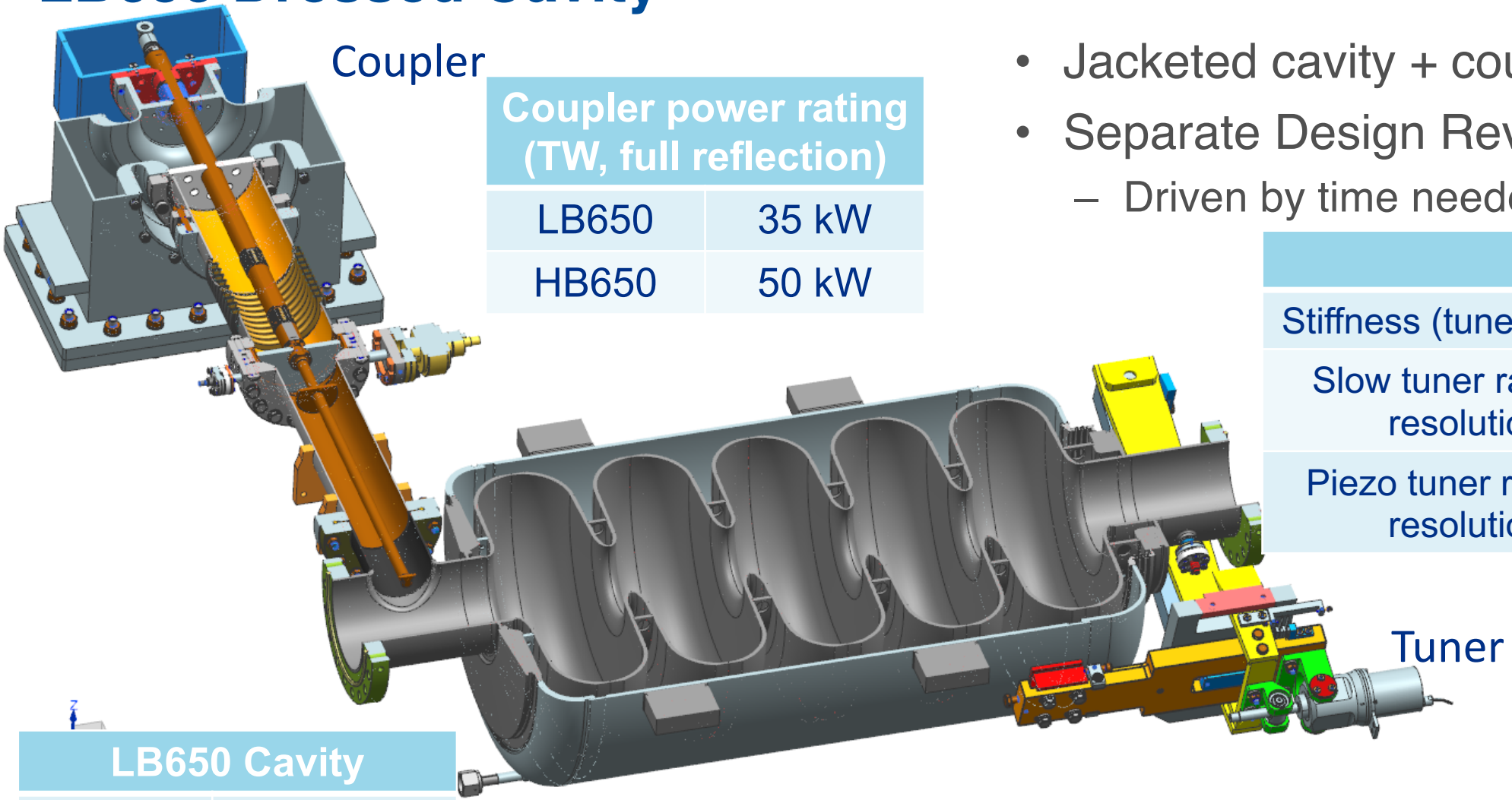
LB650 Dressed Cavity



Coupler power rating (TW, full reflection)	
LB650	35 kW
HB650	50 kW

- Jacketed cavity + coupler + tuner
- Separate Design Review cycle than CM
  - Driven by time needed for development

Tuner	
Stiffness (tuner+cavity)	>40 kN/mm
Slow tuner range & resolution	200 kHz & <2 Hz/step
Piezo tuner range & resolution	1.2 kHz & <0.5 Hz/step

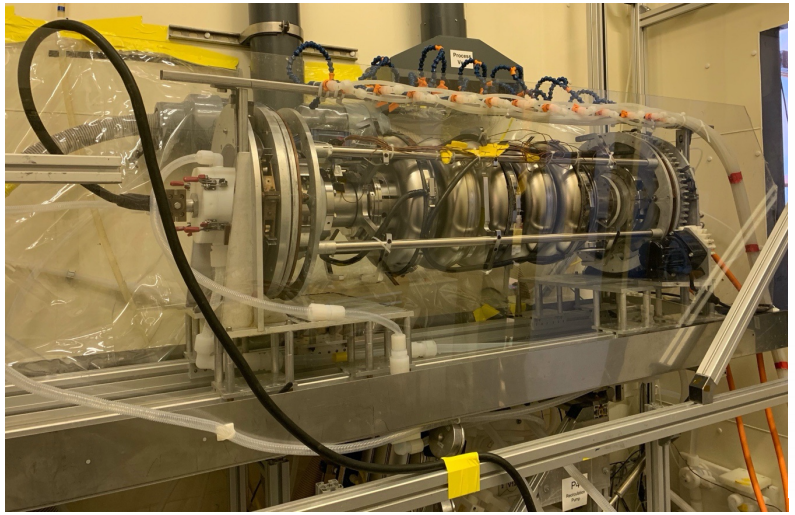
LB650 Cavity	
Q_0	2.4×10^{10}
E_{acc}	16.9 MV/m

Coupler & Tuner common to LB650 & HB650

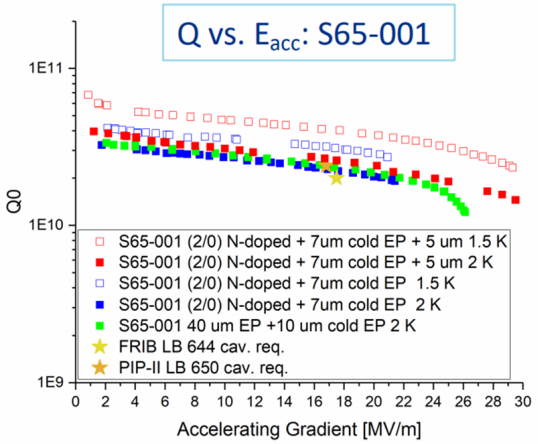
LB650 Cavities

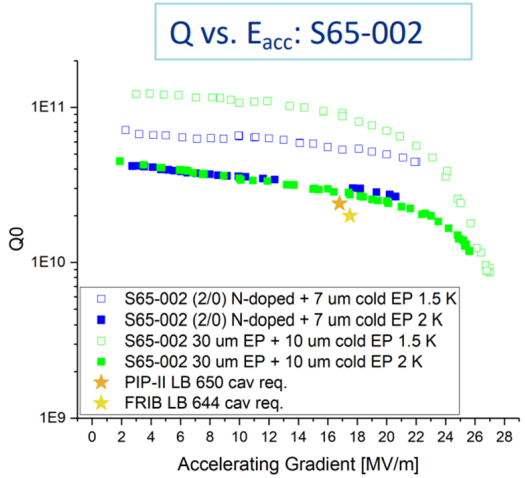
- Prototype cavity validation ongoing
  - First prototype bare cavity INFN contribution arrived in May 2020
  - RF testing in progress
  - Fermilab & VECC cavities being manufactured
- MSU 644 MHz cavities tested, meet PIP-II Q_0, gradient specs

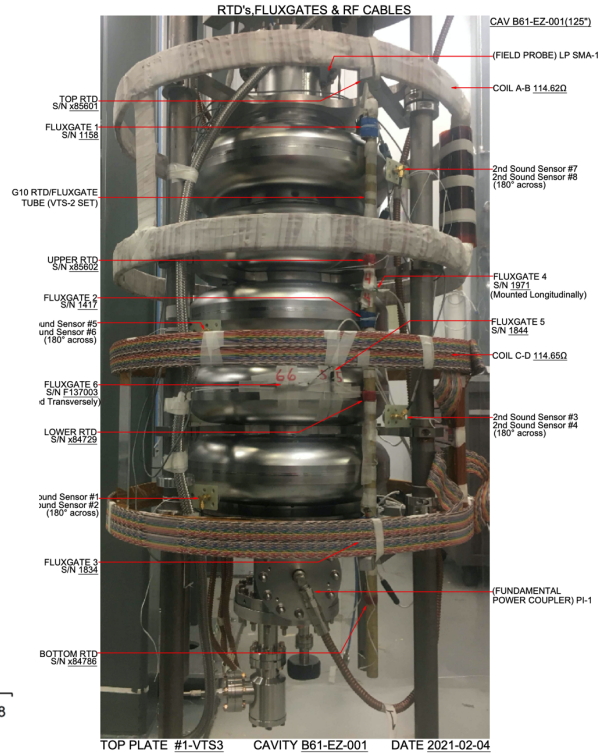
LB650 Cavity	
Q_0	2.4×10^{10}
E_{acc}	16.9 MV/m



B61-EZ-001 on ANL EP stand





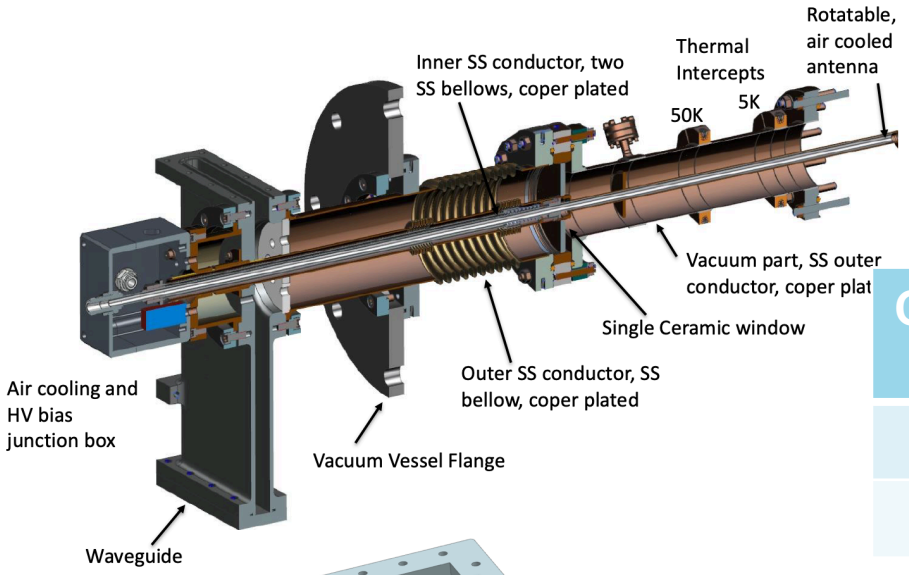


MSU cavities are directly scaled from PIP-II LB650 cavity design.

Courtesy: *Martina Martinello*

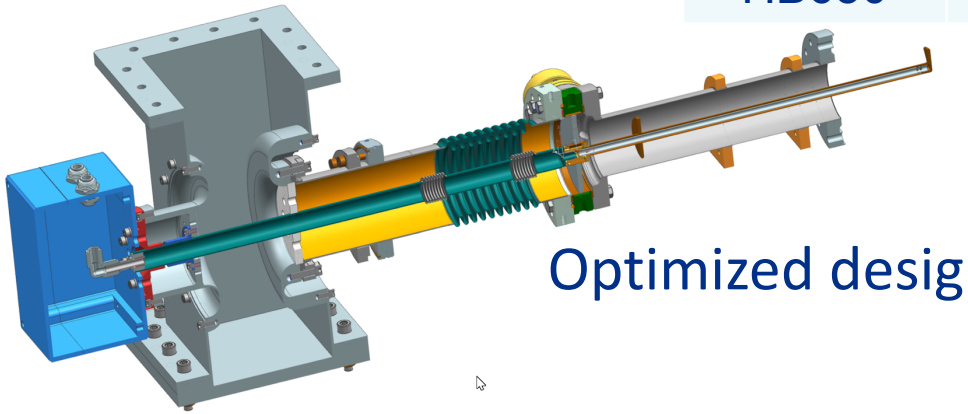
LB & HB650 Couplers

- Prototypes designed, procured, & tested
- Design optimization completed
  - To be validated in HB650 proto-CM

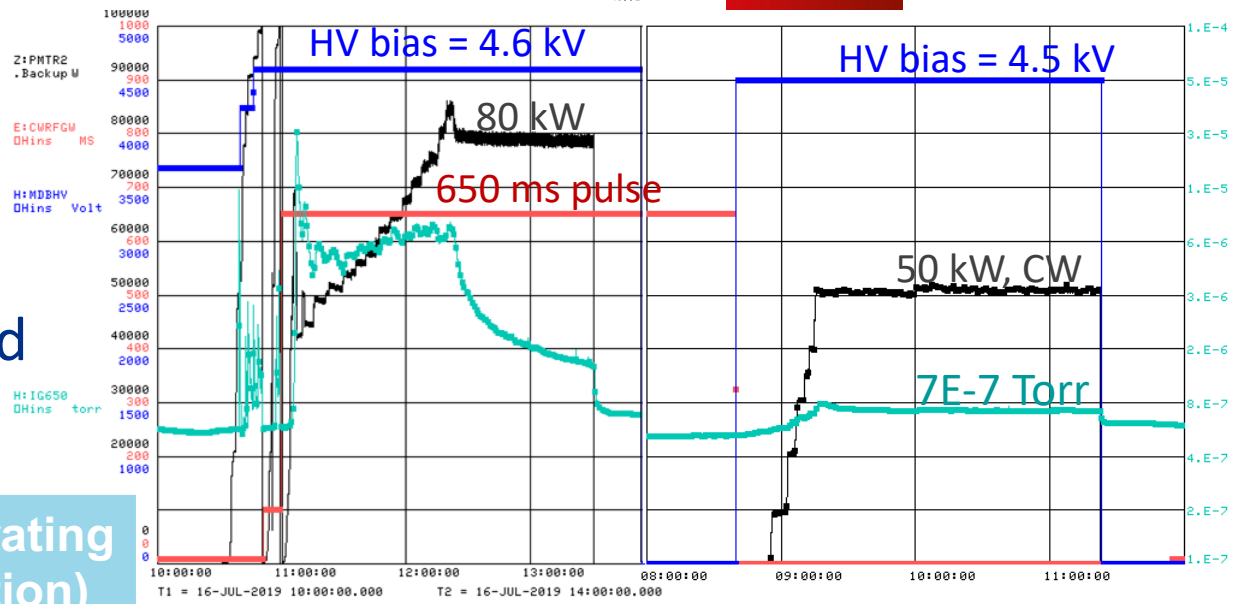


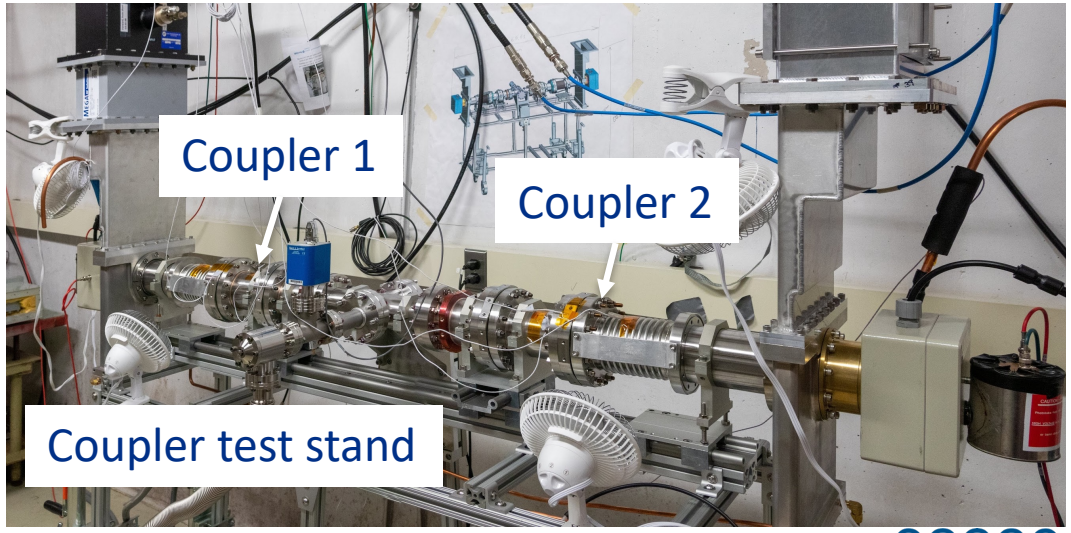
As prototyped

Coupler power rating (TW, full reflection)	
LB650	35 kW
HB650	50 kW



Optimized design

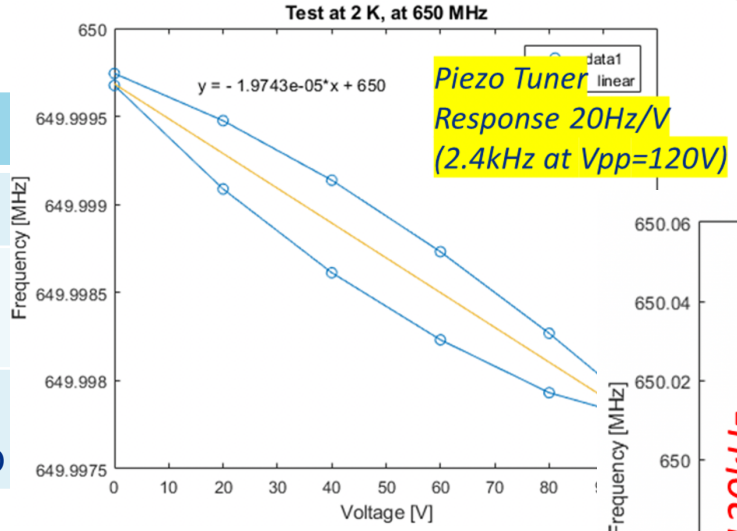


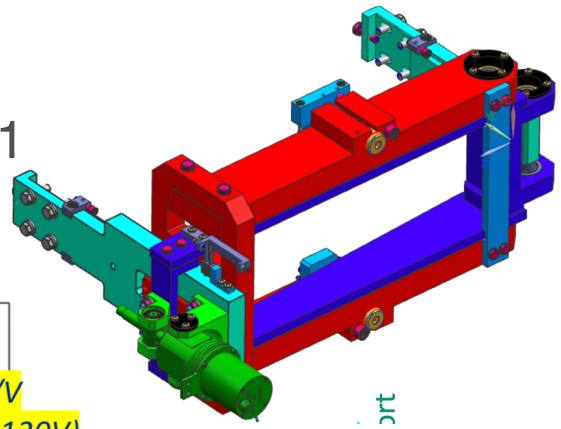


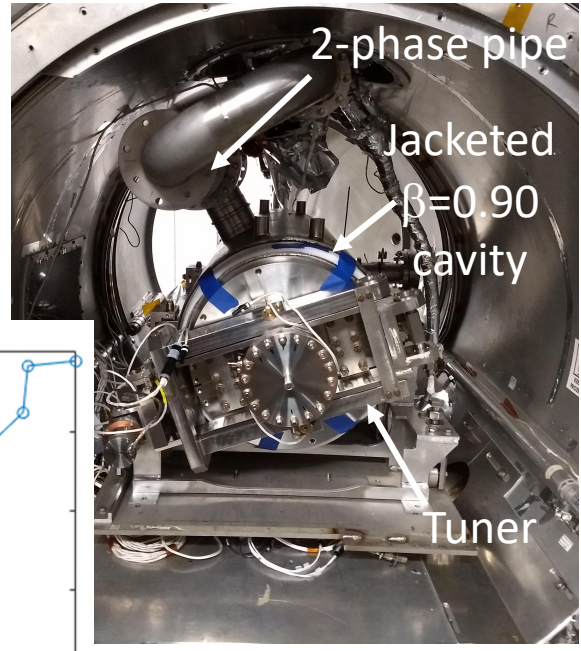
LB & HB650 Tuners

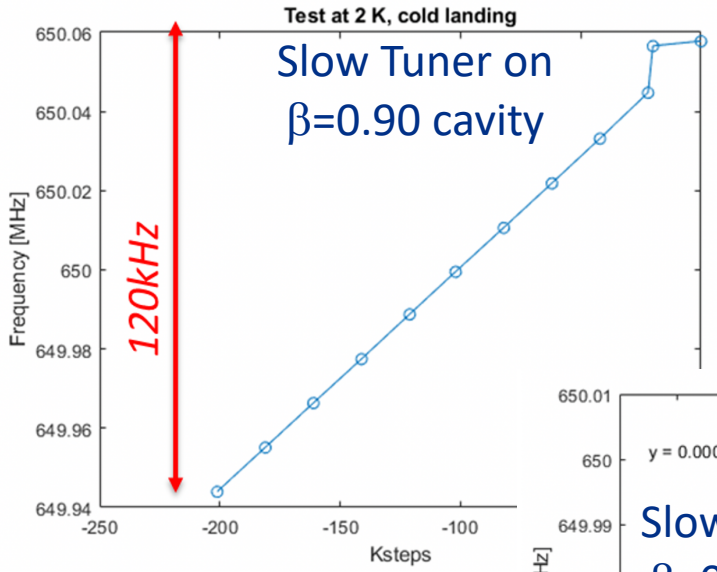
- Tuner design to be validated with β=0.61 cavity in 2021
- Validation process started on β=0.90 cavity in 2020
  - RT & 2 K tests

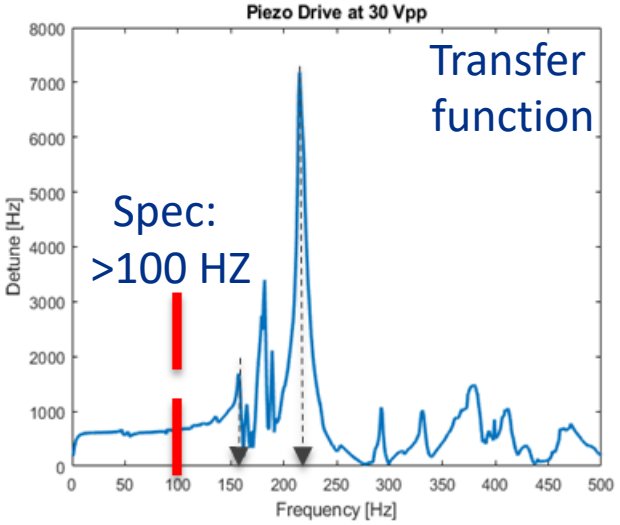
Tuner	
Stiffness (tuner+cavity)	>40 kN/mm
Slow tuner range & resolution	200 kHz & <2 Hz/step
Piezo tuner range & resolution	1.2 kHz & <0.5 Hz/step

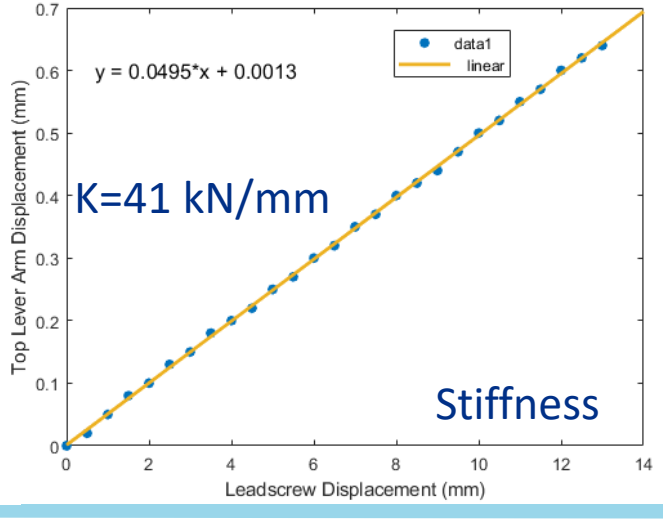




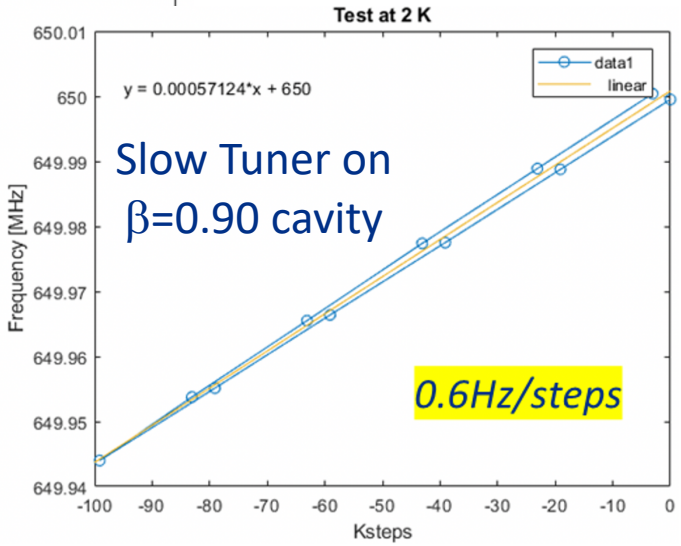








Cavity stiffness:
β=0.90 cavity ~25 kN/mm
β=0.92 cavity <5 kN/mm
β=0.61 cavity <5 kN/mm



Thank you!