CONSTRUCTION STATUS OF THE SUPERCONDUCTING LINAC AT RIKEN RIBF

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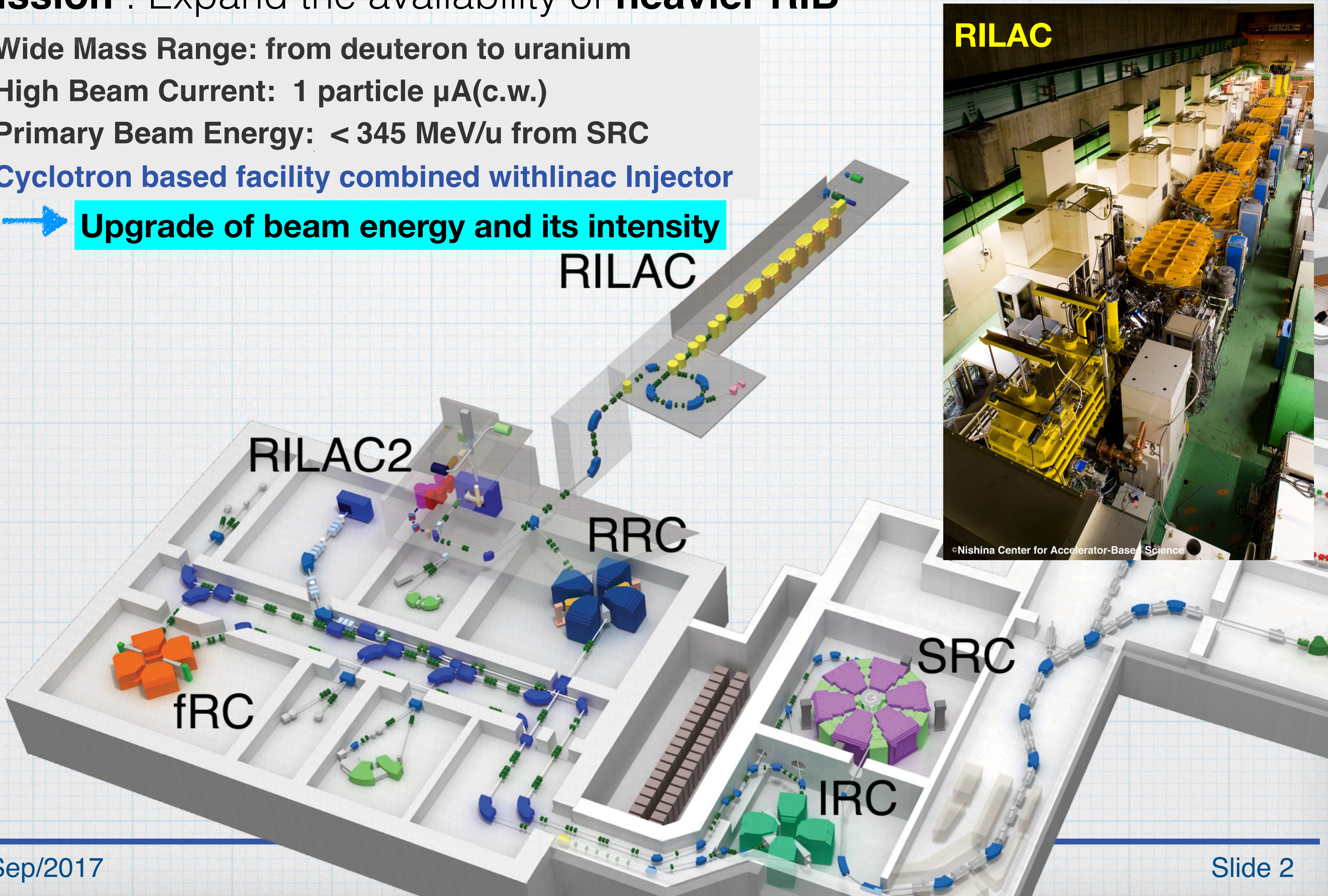
RIKEN Radio-Isotope Beam Factory

Mission : Expand the availability of **heavier RIB**

- Wide Mass Range: from deuteron to uranium
- High Beam Current: 1 particle μA(c.w.)
- Primary Beam Energy: < 345 MeV/u from SRC
- Cyclotron based facility combined withlinac Injector

→ **Upgrade of beam energy and its intensity**



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Outline

1. Overview

- Upgrade Plan of the RIKEN Heavy Ion LINAC (RILAC)
- Overview of RIKEN Superconducting LINAC
- Superconducting QWR developed at RIKEN

2. Development of SC-QWR

- SC-QWR for SRILAC
- Prototype cavity
- Cavity production
- Microphonics
- Cryomodule

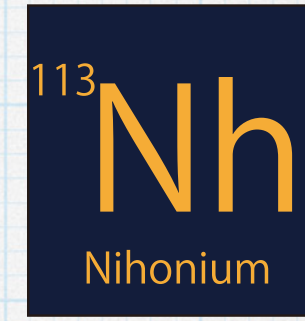
3. Other Issues

- Installation to the existing beam line
- Differential Pumping System

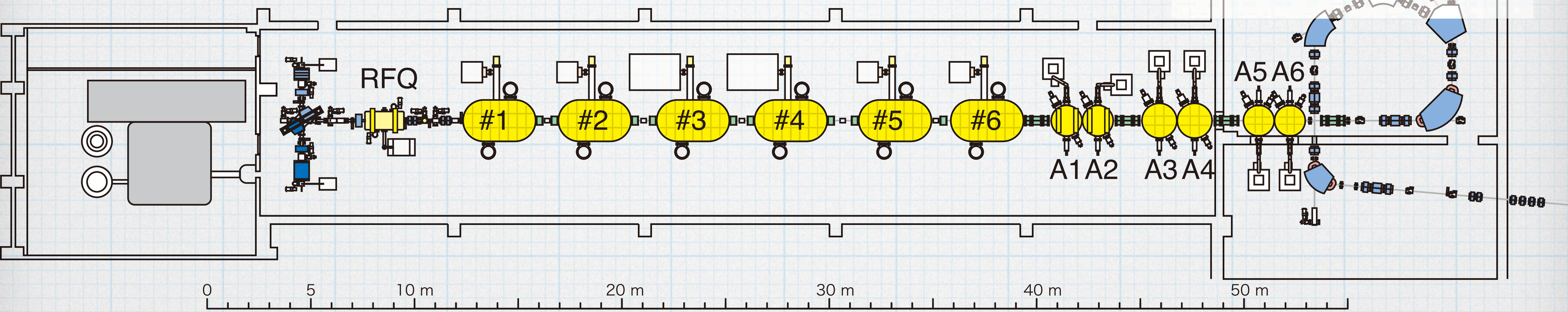
Summary

1. OVERVIEW

Upgrade Plan of the RIKEN Heavy Ion LINAC (RILAC)



- RILAC consists of RFQ and 12 DTLs to provide intense heavy-ion beams to perform super heavy element search (SHE) experiment.
- For 113 element $^{70}Zn^{14+}$ (**A/q = 5**) was accelerated to **5 MeV/u**.
- To continue SHE experiment challenging the 8th row of the periodic table of elements (A≧119), accelerating voltage upgrade is undergoing aiming to provide intense heavier ion beams with higher energy.



RIKEN Heavy Ion Linac (RILAC)

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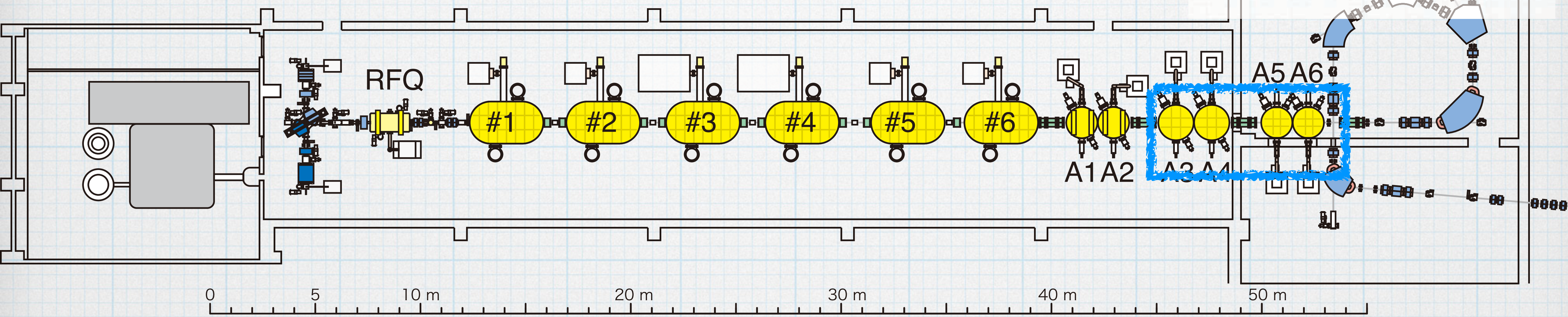

- Upgrade Goal: Ions **A/q = 6** are accelerated up to **6.5 MeV/u**.
- The last four DTL tanks will be replaced by superconducting linac based on quarter wave resonator.

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113 Nh
Nihonium

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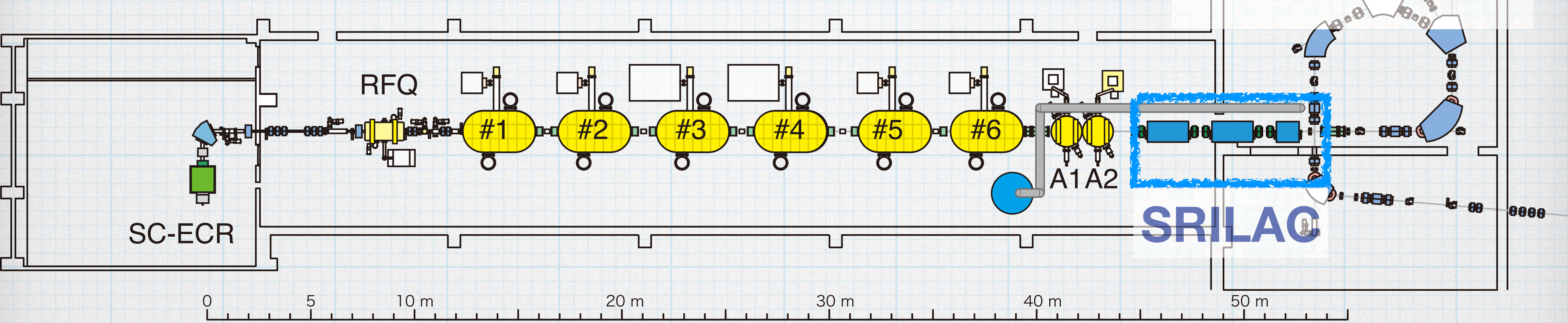

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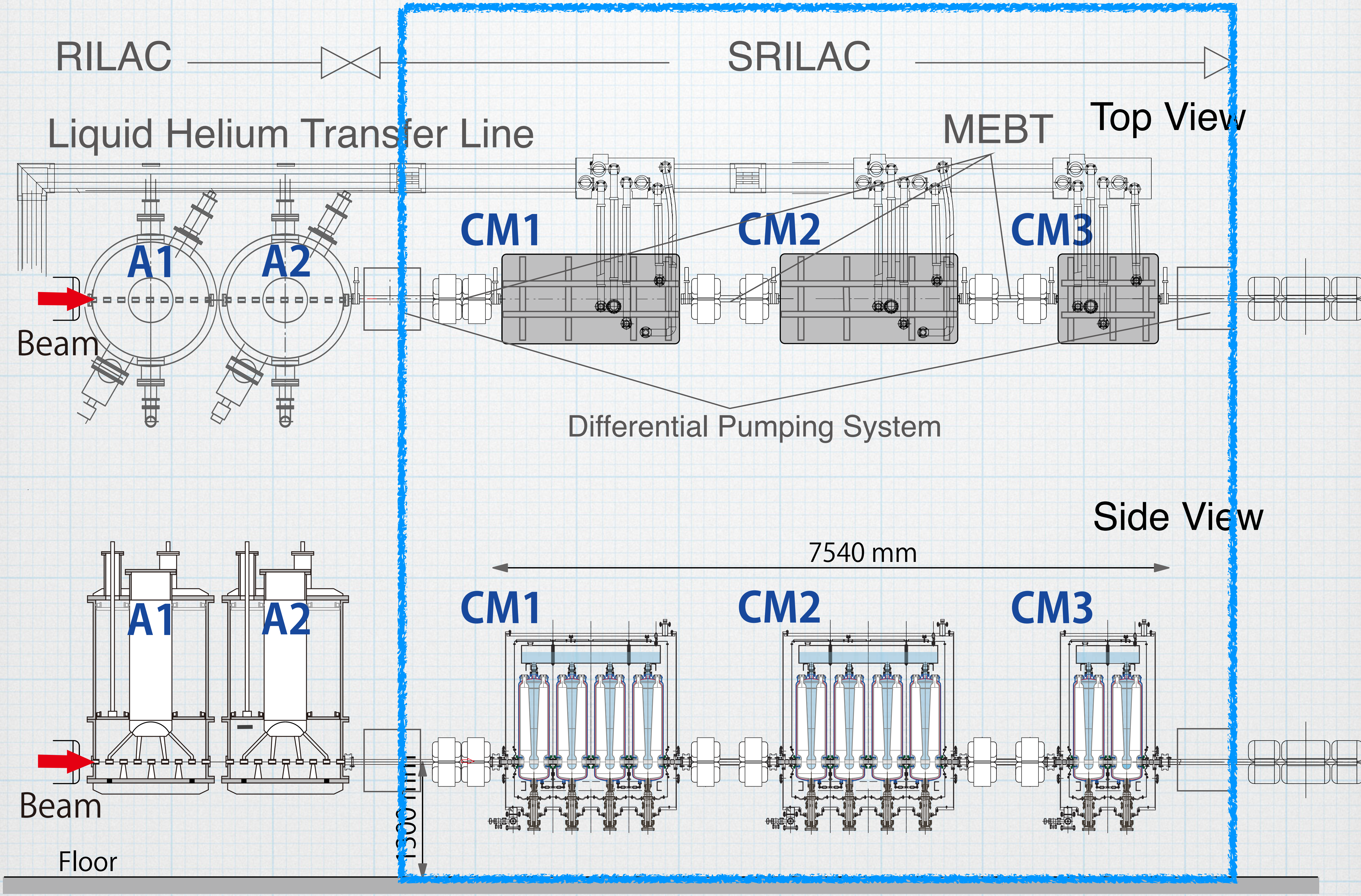
Overview of SRILAC



Overview of SRILAC

Design Parameters	
Number of cavities	10 QWRs
Frequency (MHz)	73.0 MHz (c.w.)
E_{inj} (MeV/u)	3.6 (A/q = 6)
E_{ext} (MeV/u)	6.5
Gap Voltage (MV)	1.2 MV
Synchronous Phase (deg.)	-25
E_{acc} (MV/m)	6.8
Target Q_0	1×10^9 at 4.5K
Beam Current (μA)	<100 μA
RF bandwidth(Hz)	±60
Q_{ext}	1×10^6 — 4.5×10^6
Amplifier Output Power (kW)	7.5

Superconducting QWR developed at RIKEN(1/2)

- **QWR** :λ/4 TEM coaxial cavity with two acceleration gaps
- Optimized for acceleration of low β ions (**β=0.08**)
- Low operation frequency **73.0 MHz (c.w.)**
- Operating temperature **4.5 K**
- RF performance was set as **V_{gap} 1.2 MV with wall loss 8 W**

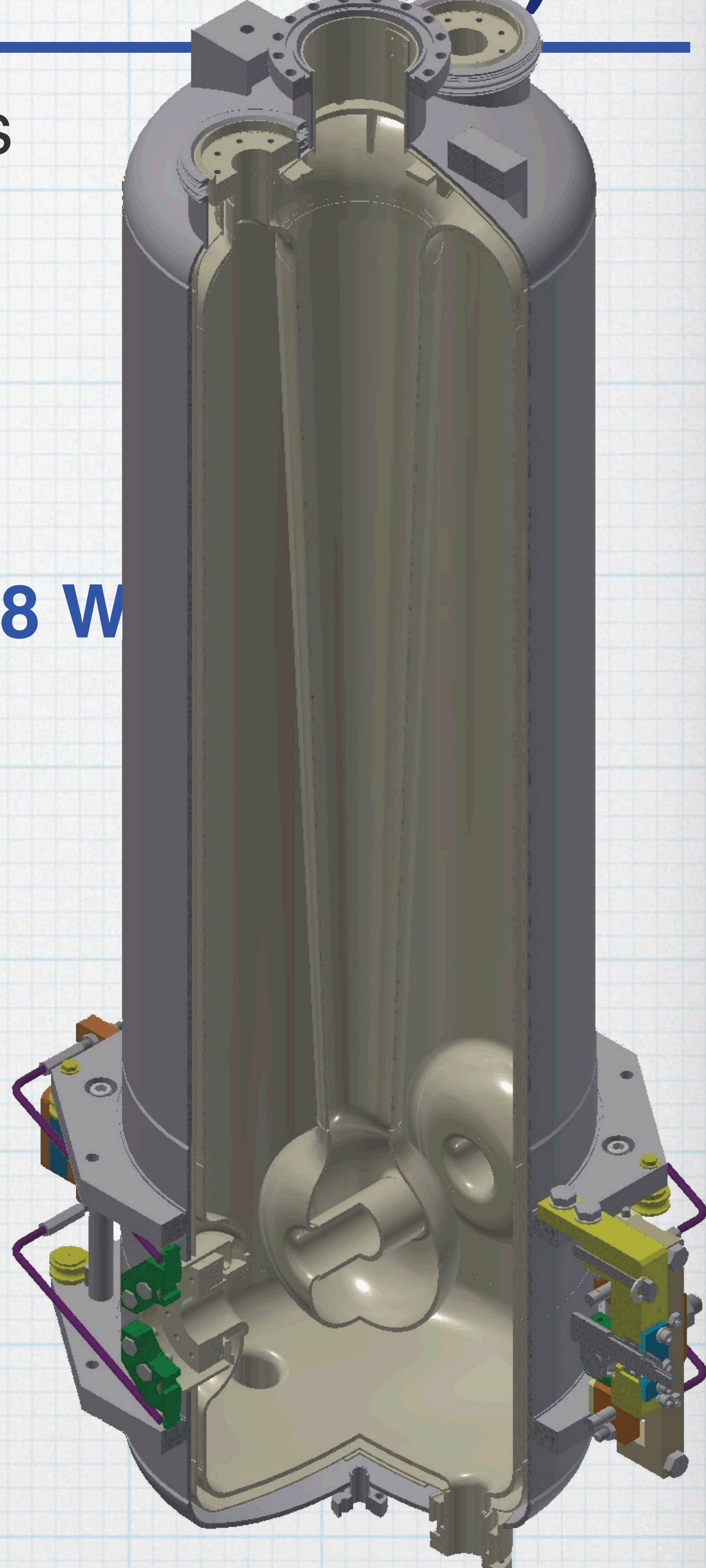
.

Target:Q_0=1E9 @ E_{acc} = 6.8 MV/m

- Beam aperture 40^{Φ}

Design work:

- **Conical shaped stem** improves rf performance and rigidity for pendulum vibration.
- **Tilted drift tube faces** to correct steering effect

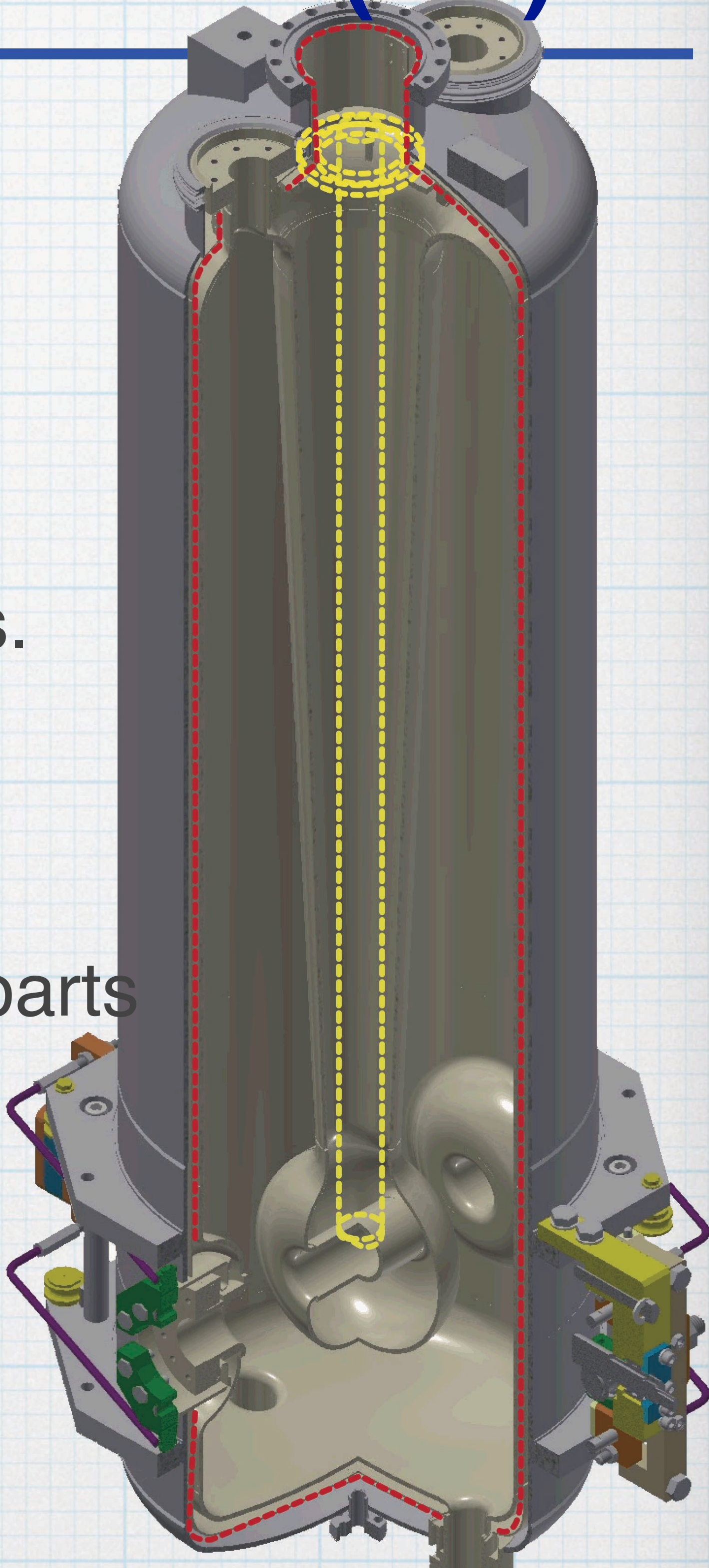


Schematic RIKEN QWR

Superconducting QWR developed at RIKEN(2/2)

From the SRF technological point fo view:

- **Conical shaped stem**
- **Tilted drift tube faces**
- Surface polishing by **BCP** is adopted.
- **Dynamic tuning** was realized by pressing beam ports.
- **Titanium** helium vessel
- **Magnetic shield** placed inside the helium vessel
  - →To minimize the effect of possible magnetization of parts
  - →To make easier to assemble CM
- **Mechanical damper** (red dashed line)
  - →To mitigate detuning due to microphonics
- **Single window Power Coupler**



Schematic RIKEN QWR

Development of prototype cavity is required.

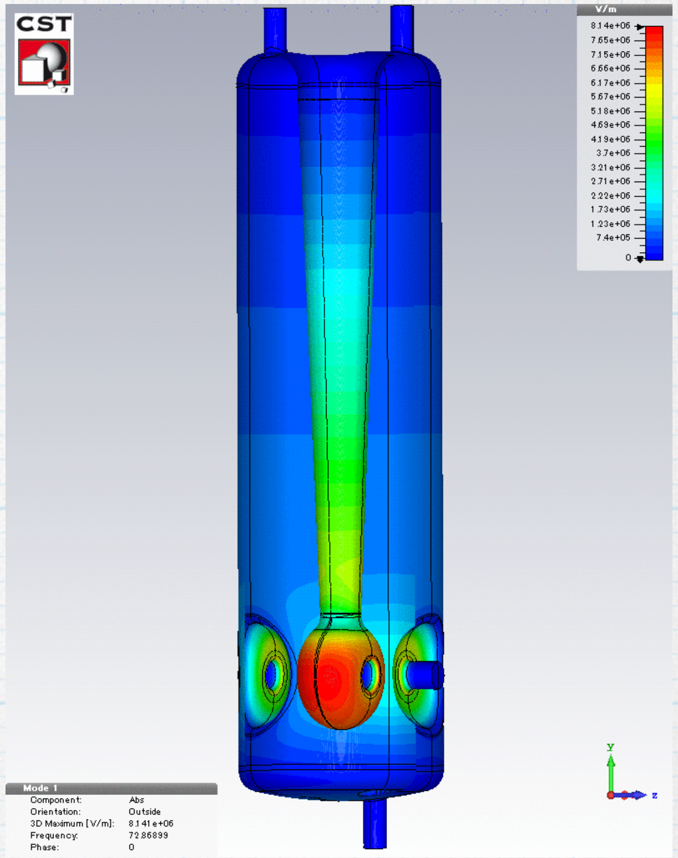
2. Development of SC-QWR and CMs

Superconducting QWR developed at RIKEN

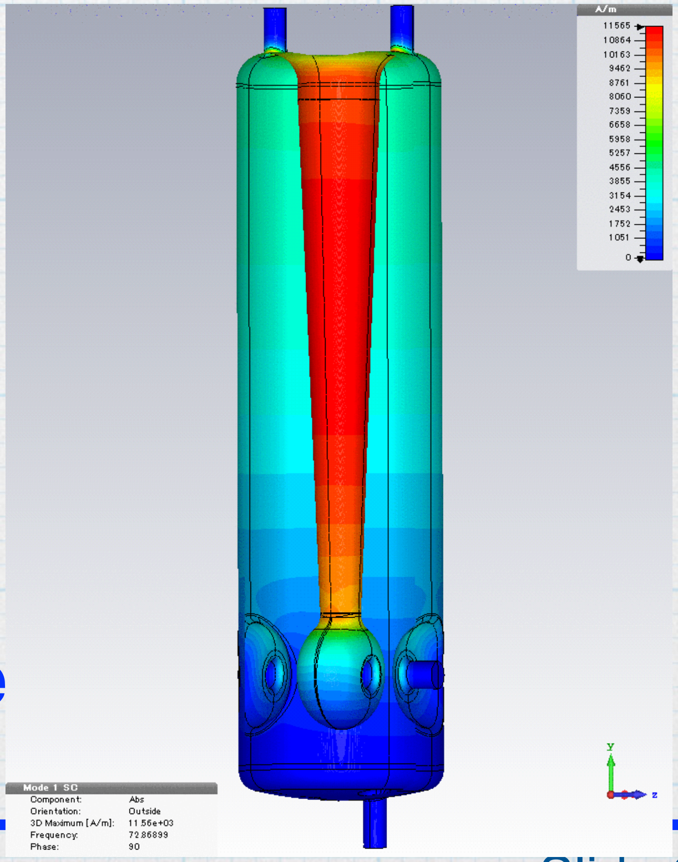
- RF simulation by Microwave Studio (CST).
- Minimize the ratio of E_{peak} and B_{peak} to E_{acc}
- Maximize R_{sh}/Q_0 and G

Parameters	
Frequency (MHz)	73.0 MHz (c.w.)
Optimum β	0.08
R_{sh}/Q_0 (Ω)	578
G (=R_{sh}/Q_0)	22.4
V_{acc}(MV)	2
E_{acc} (MV/m)	6.8
E_{peak}/E_{acc}	6.0
B_{peak}/E_{acc}	9.5
Target Q_0	1×10^9 (4 K)

E-field



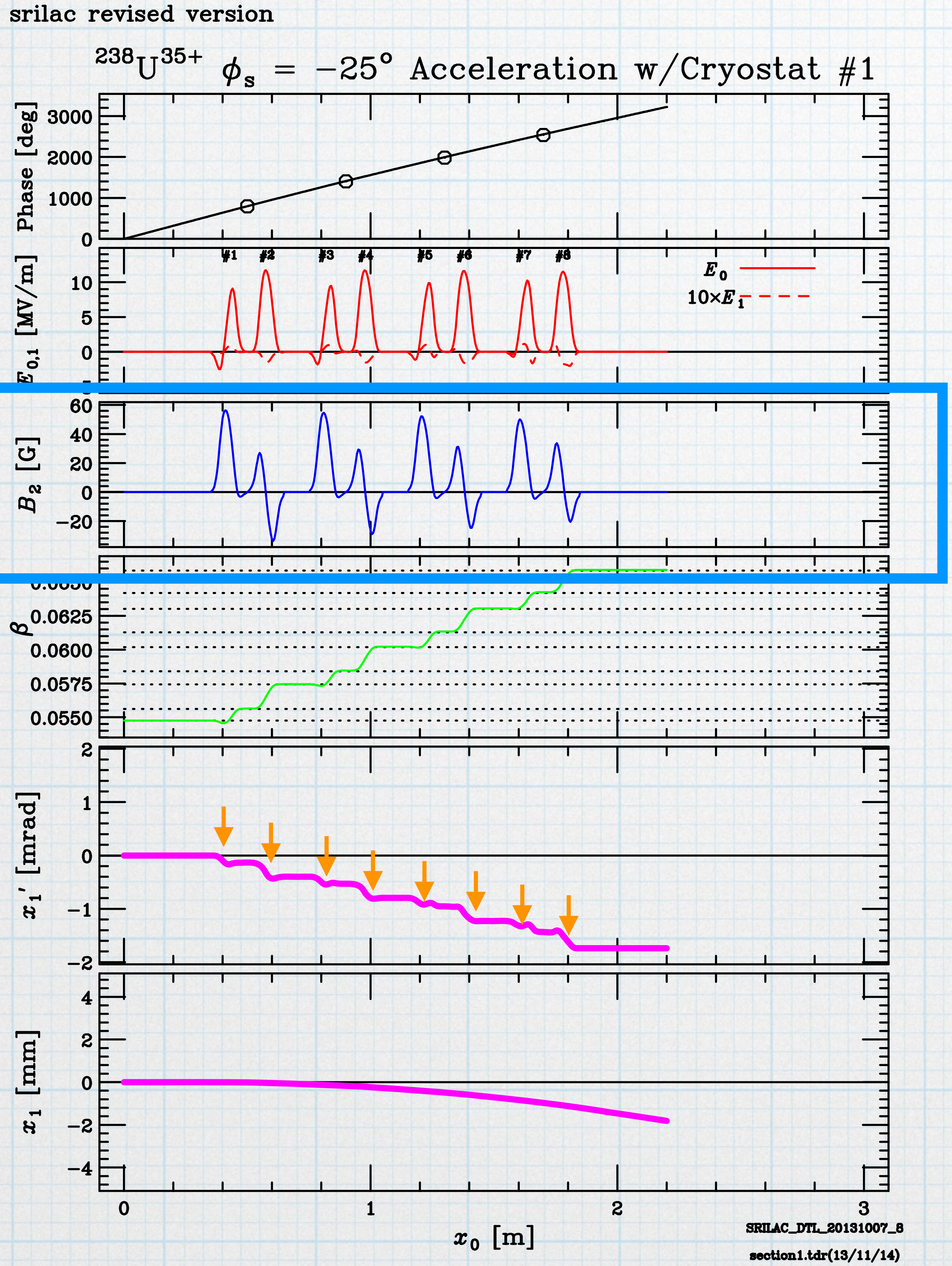
H-field

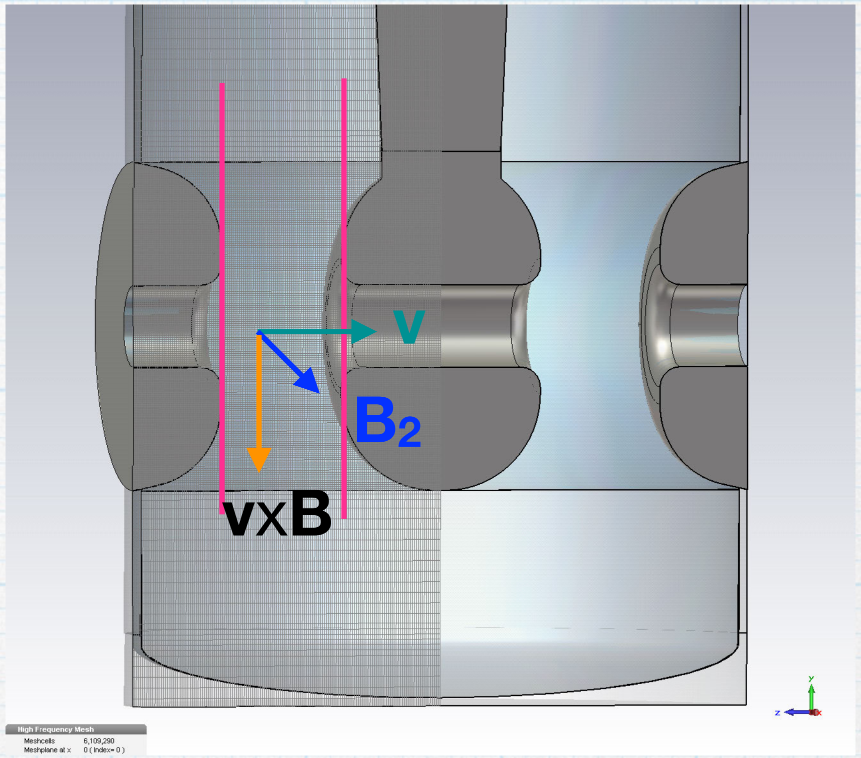


Optimization taking a balance of the RF performance and its manufacturability.

Correction of Beam Steering by Magnetic Field

P.N. Ostroumov and K.W. Shepard, Phys. Rev. ST Accel. Beams 4(2001)110101





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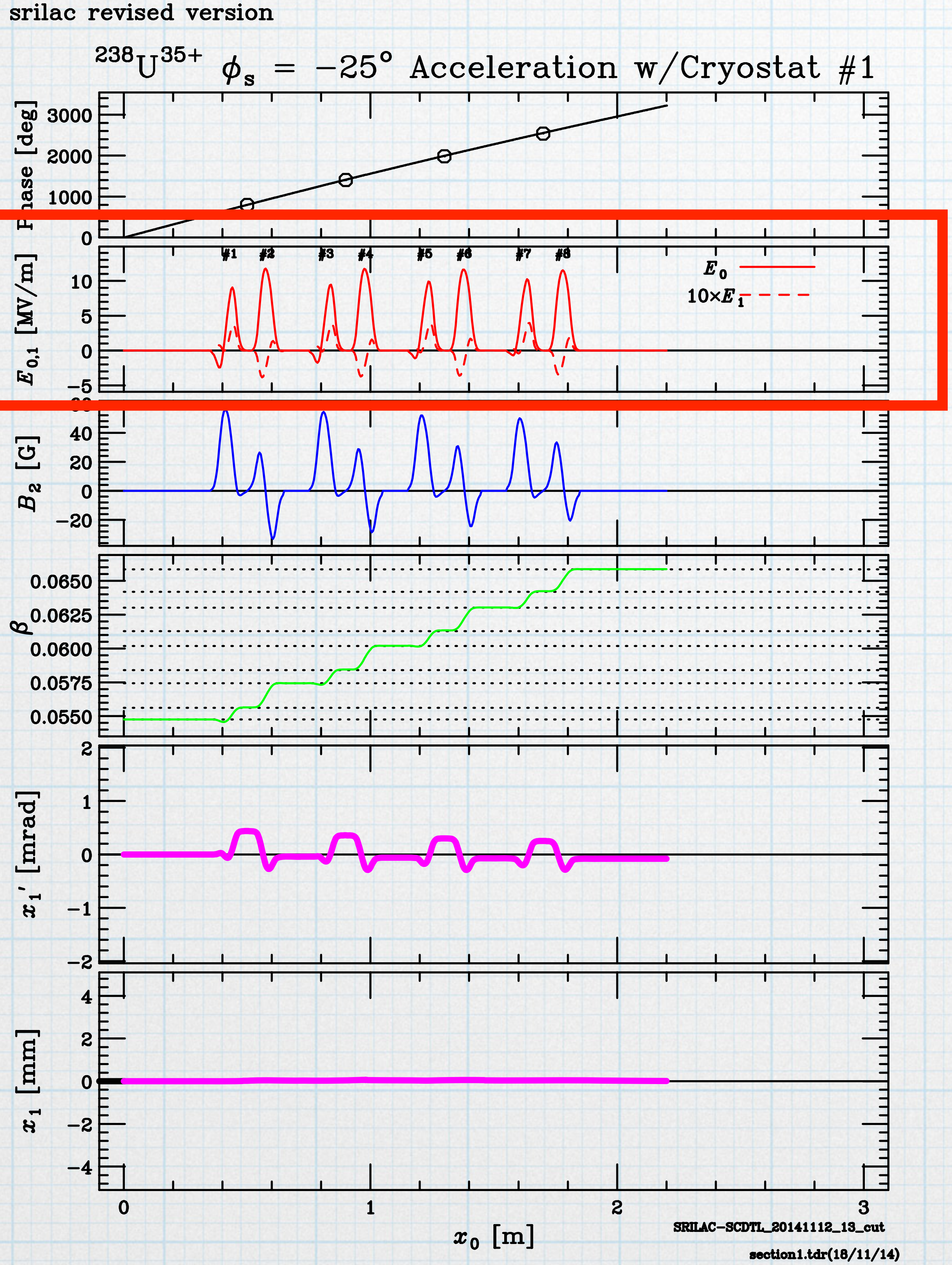
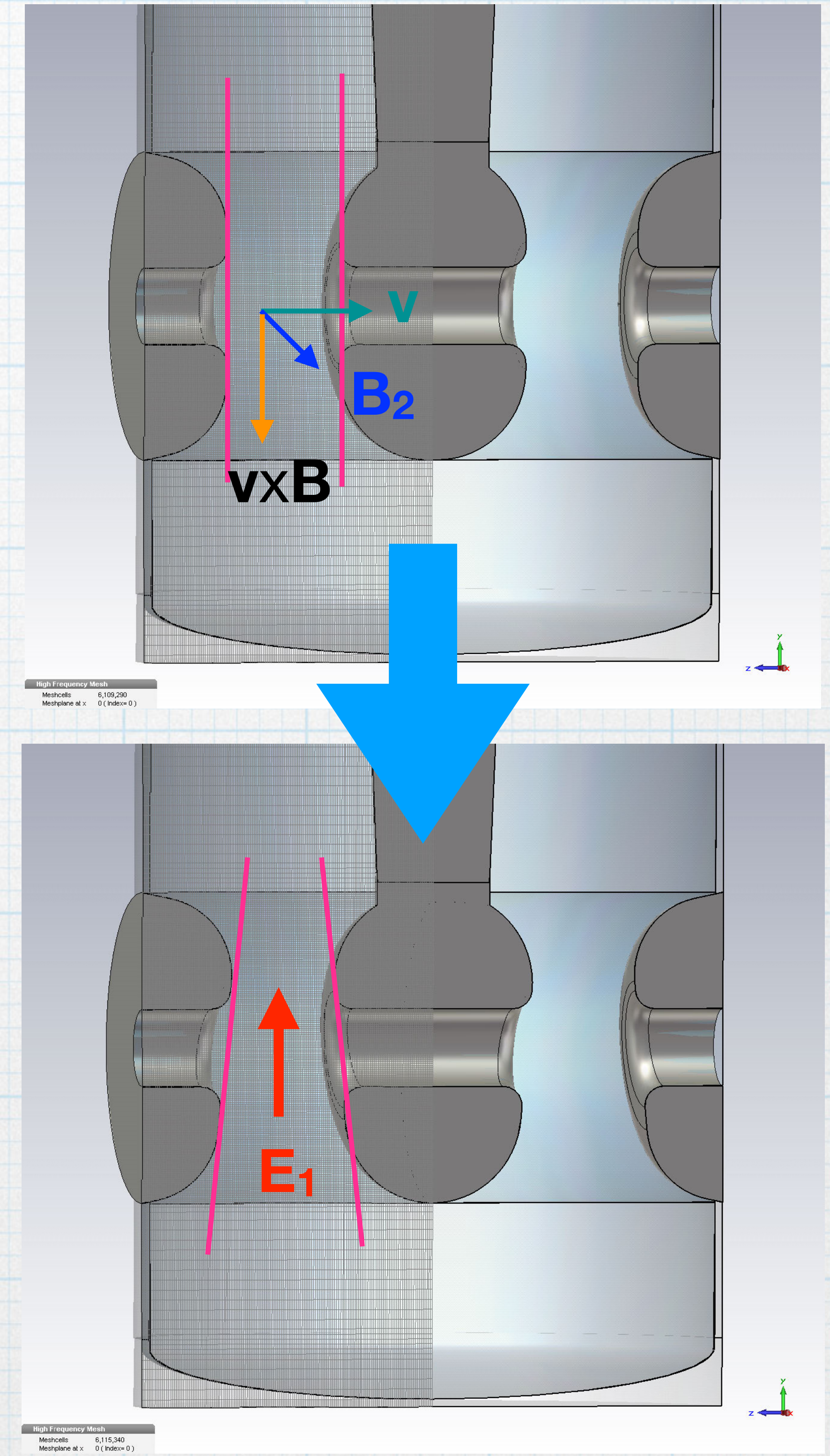
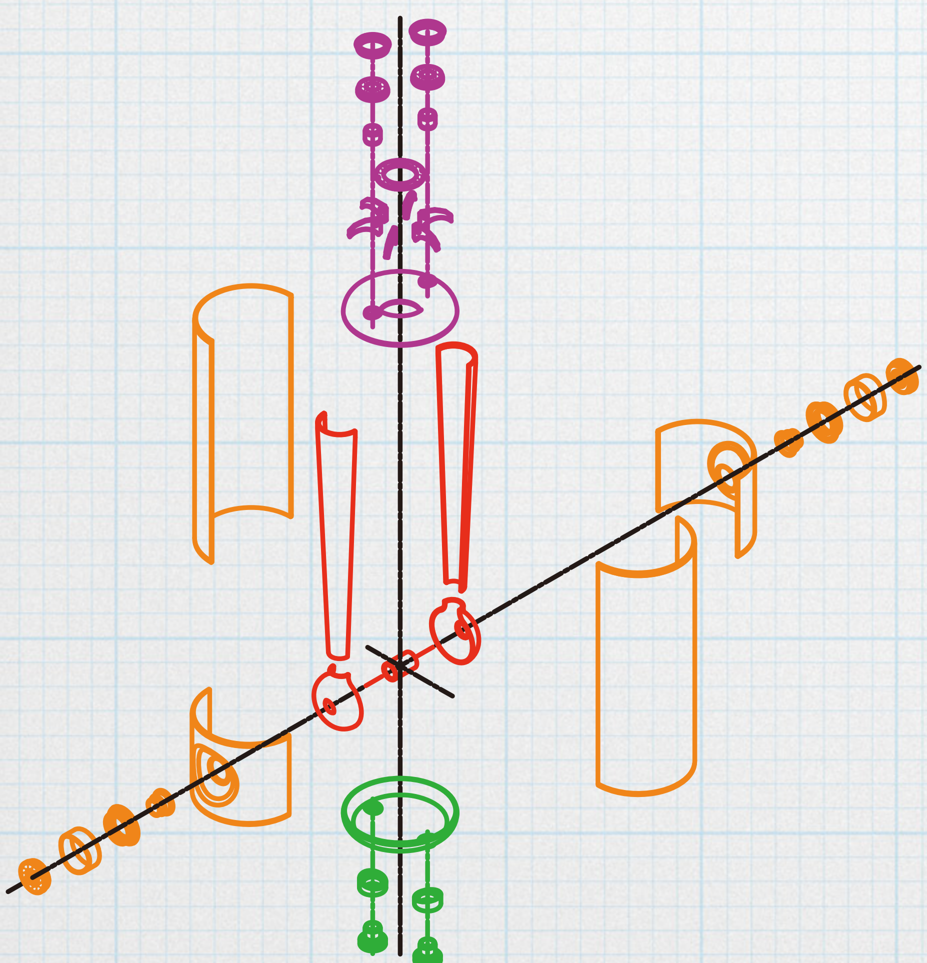




Prototype Cavity

- Prototype cavity was developed to validate fabrication processes.
- Nb sheets with RRR 250
- For **frequency tuning**, RF measurements during assembly were performed by clamping the parts together to determine the amount of cuts of the upper and lower straight sections.
- Surface process of **BCP** was adopted.



Photos taken during fabrication processes of the prototype QWR

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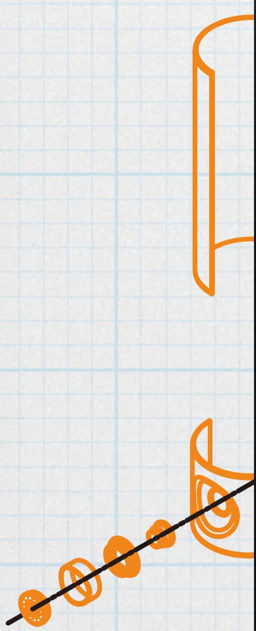
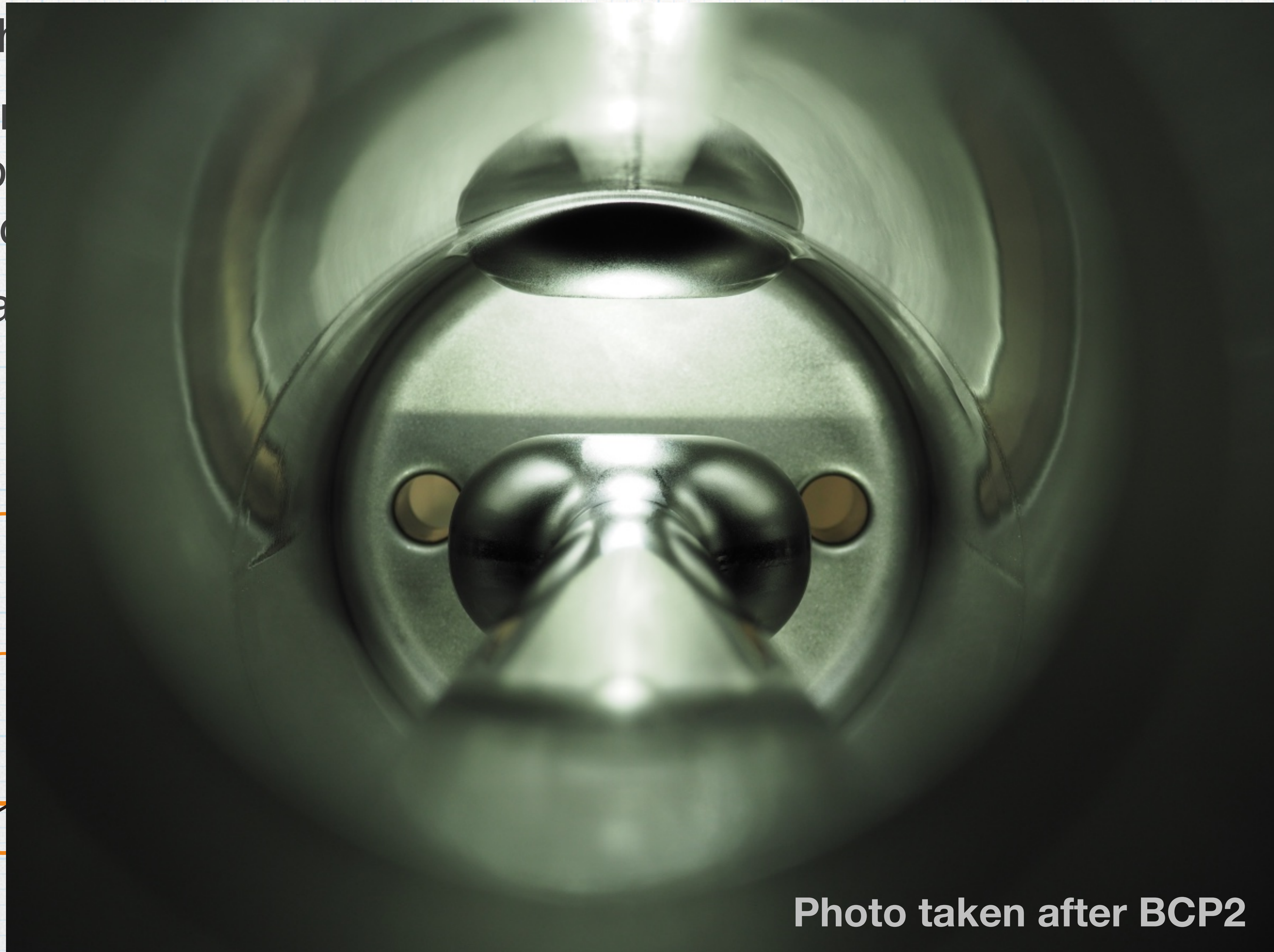
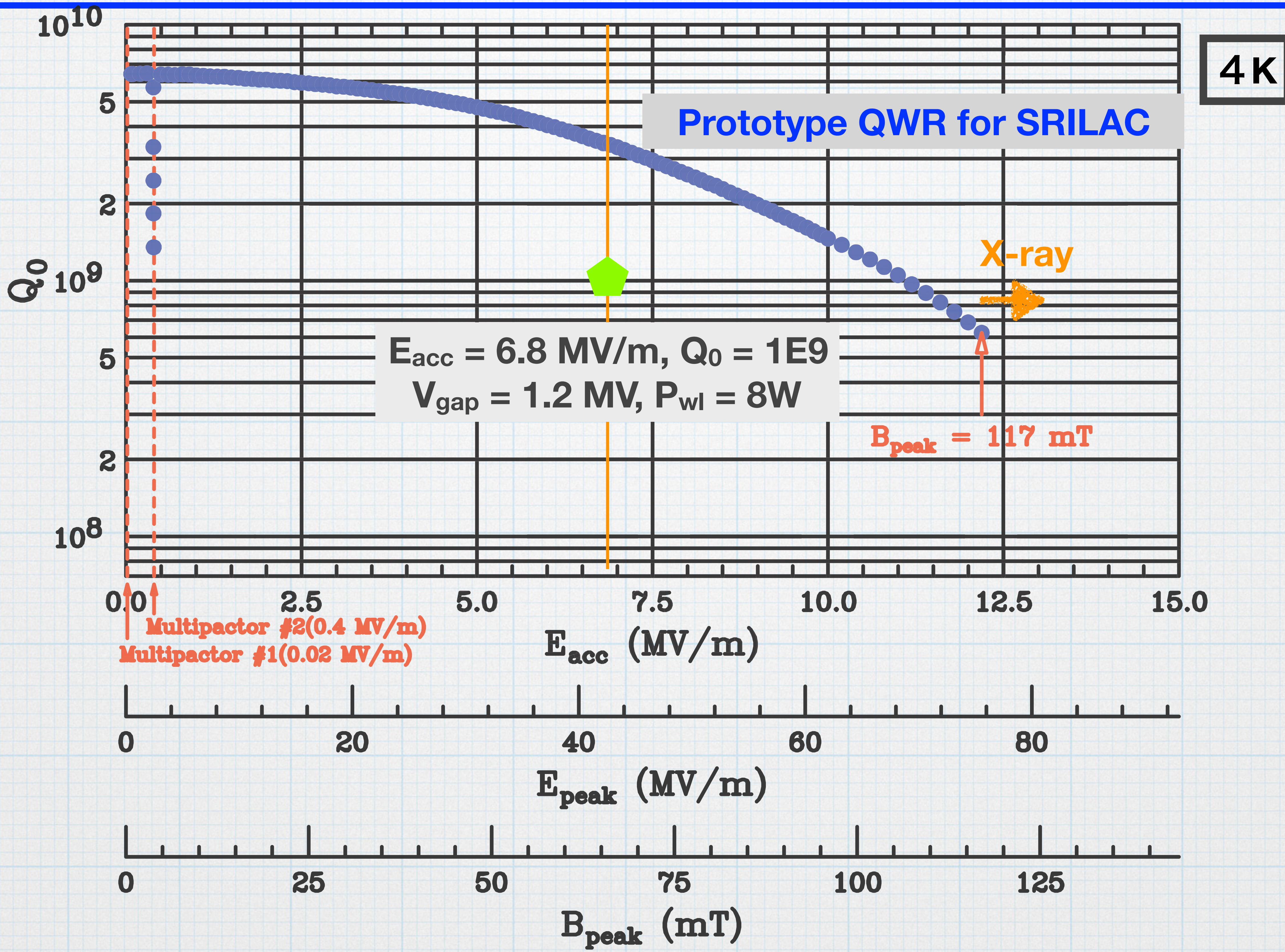




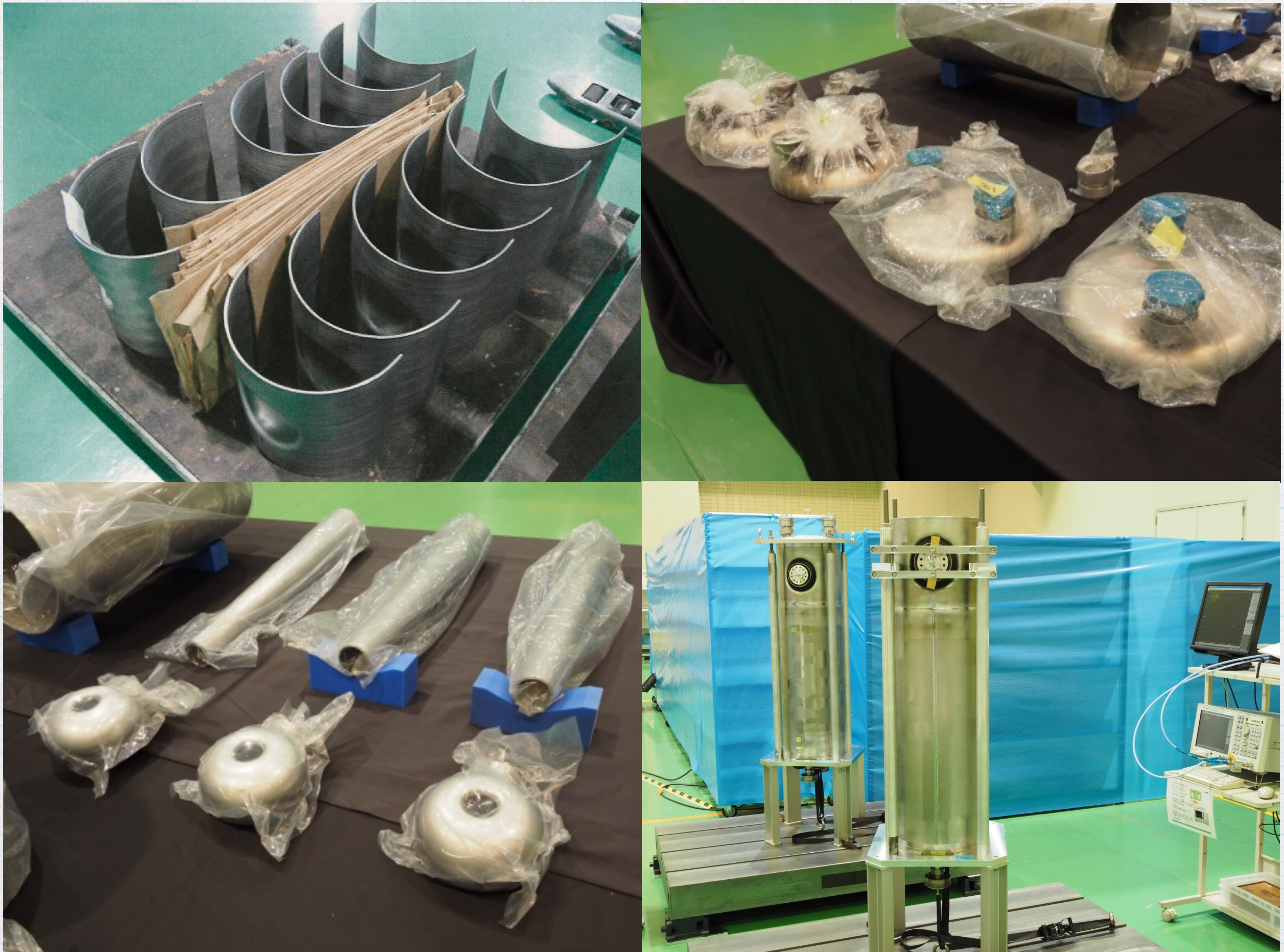
Photos taken during fabrication processes of the prototype QWR

Vertical Test of Prototype Cavity at KEK



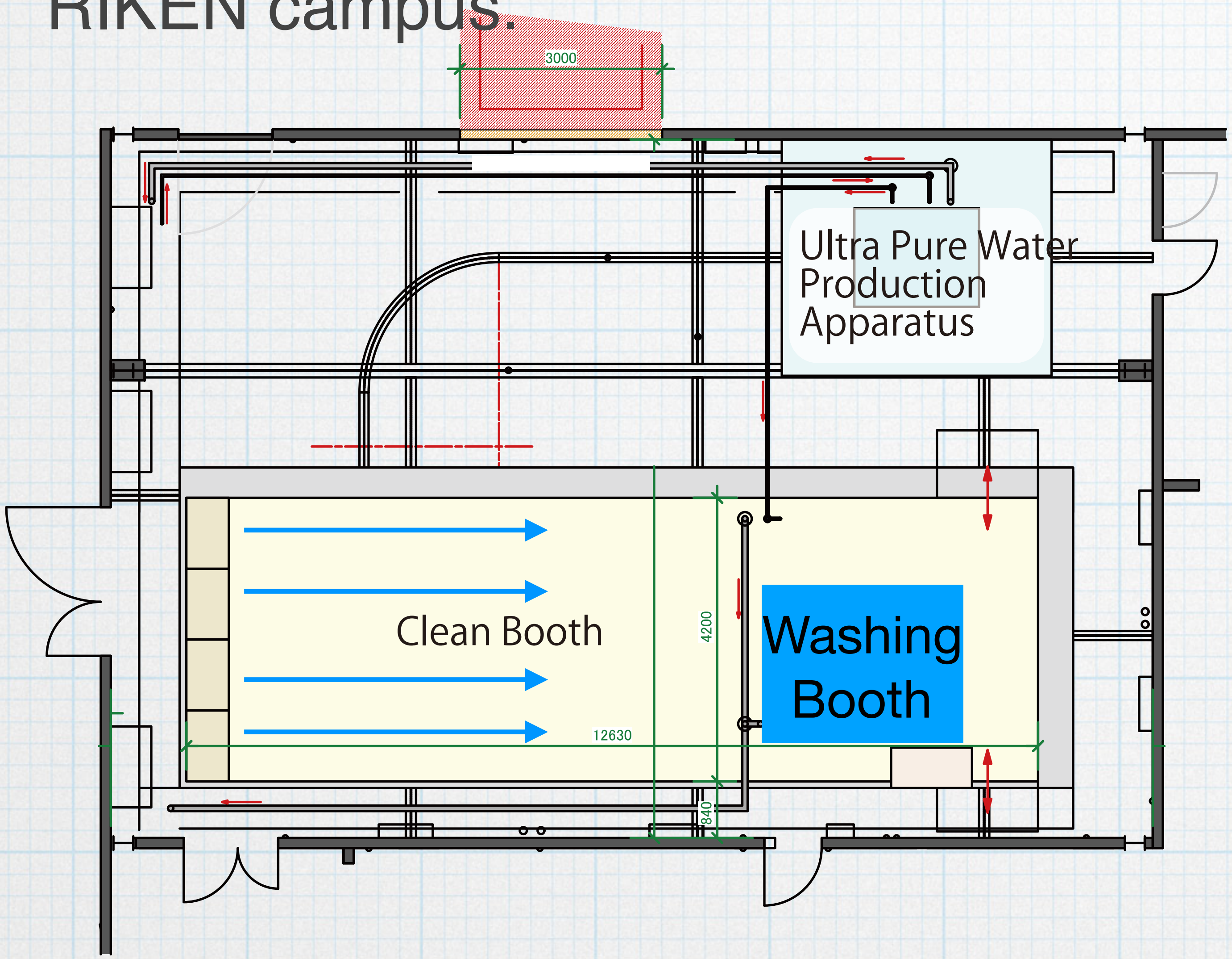
Q_o of 3.5E9 was obtained at E_{acc} of 6.8 MV/m at 4.2 K.

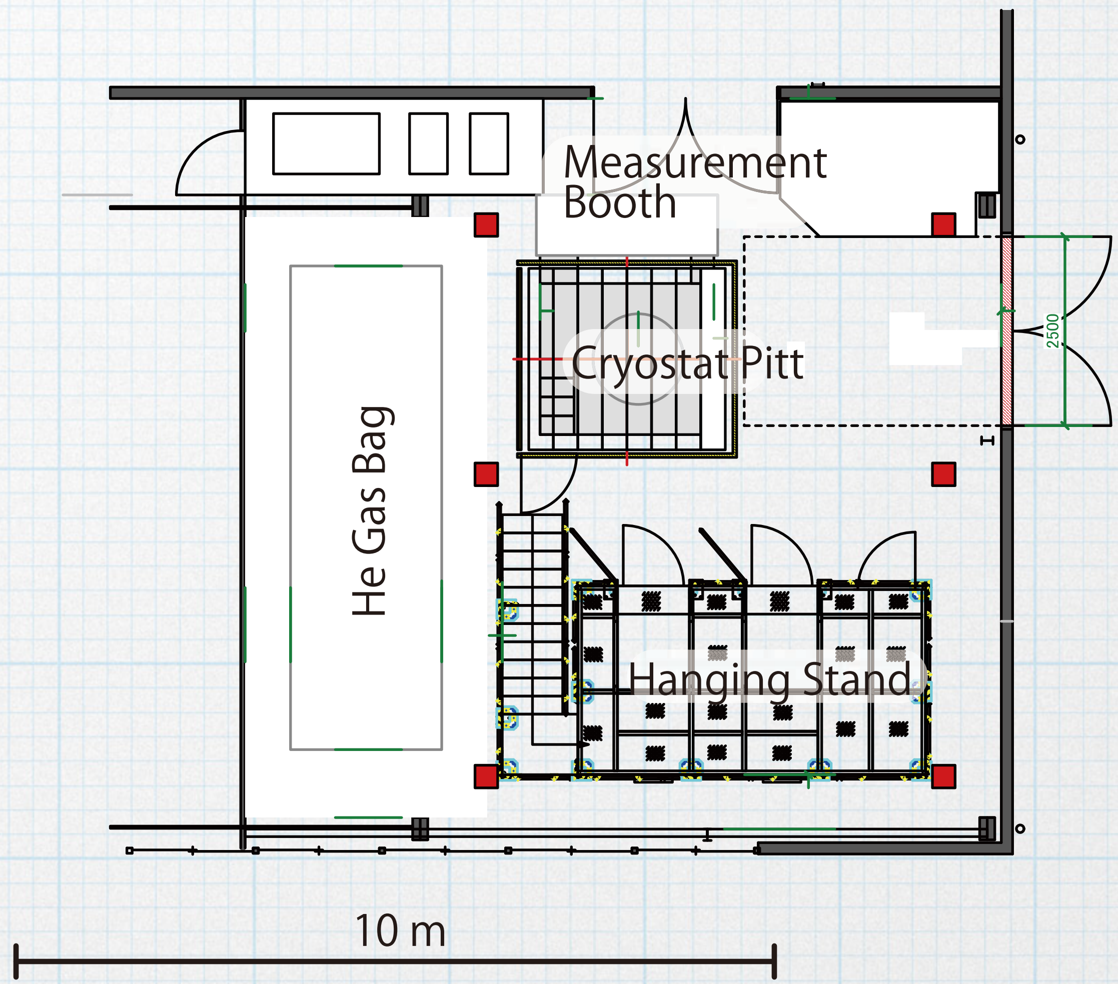
Production of QWRs



SRF Infrastructures

- Clean Room (ISO Class 1) and vertical test facility were prepared at RIKEN campus.

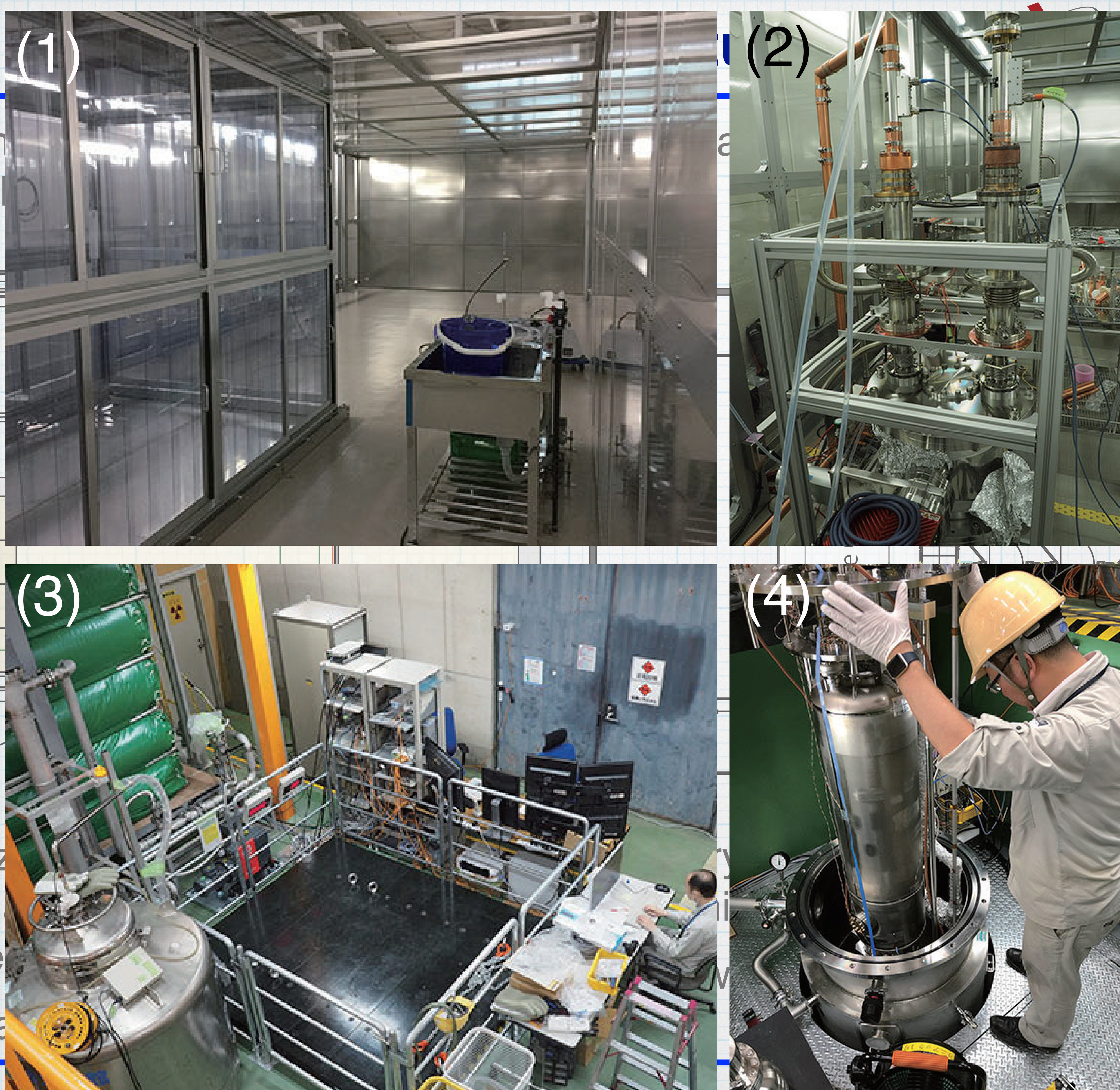




- Horizontal flow clean room equipped with a washing booth with ultra pure water.
- Capable of cryomodule assembly

- Cryostat with mu-metal magnetic shield (B_{BG} = 7.5 mG@10K).
- Two hanger-stands for preparation

- Clean ... a ... t RIKEN



- Horiz ... magnetic with ... G). wate ... reparation
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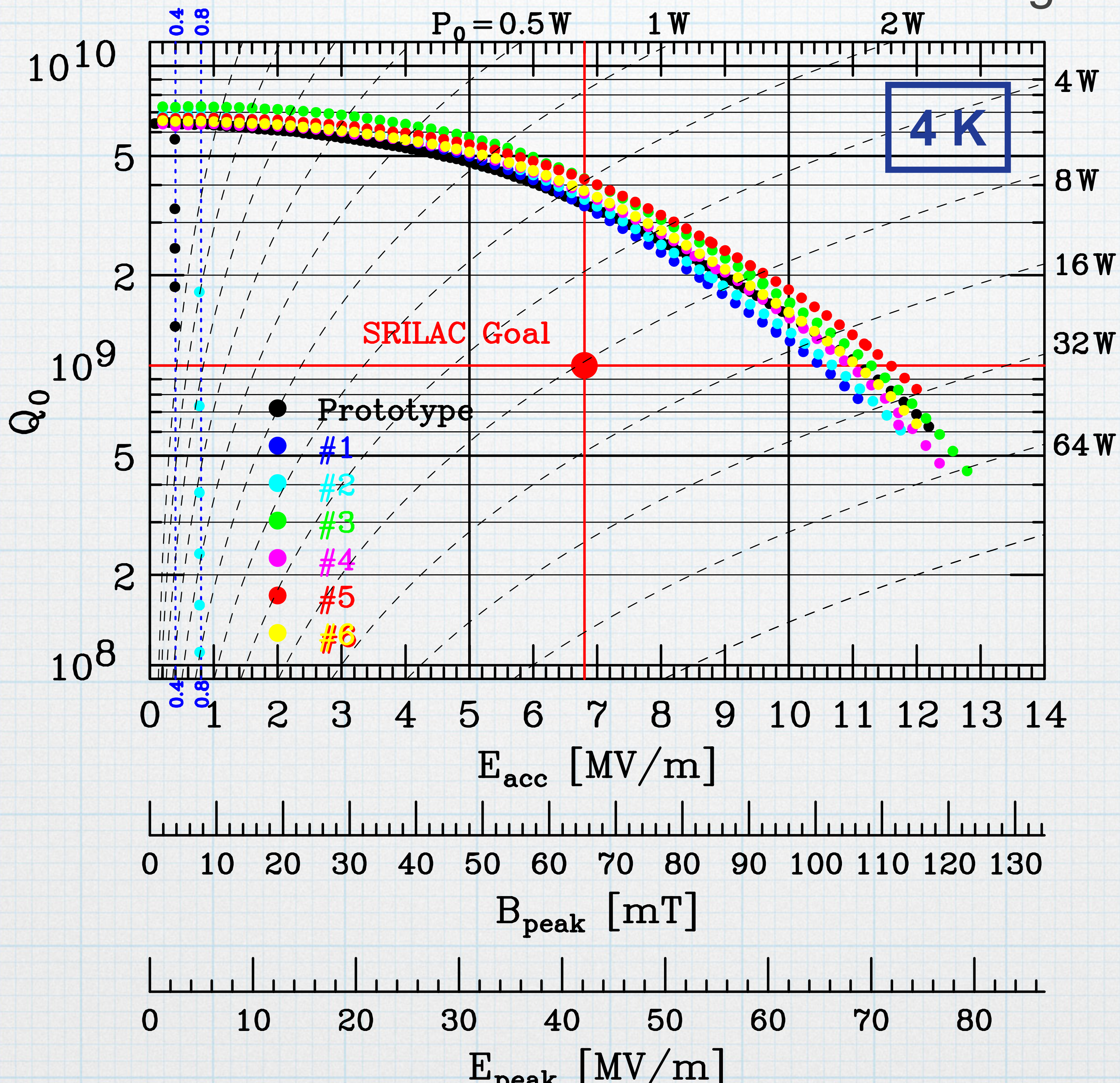
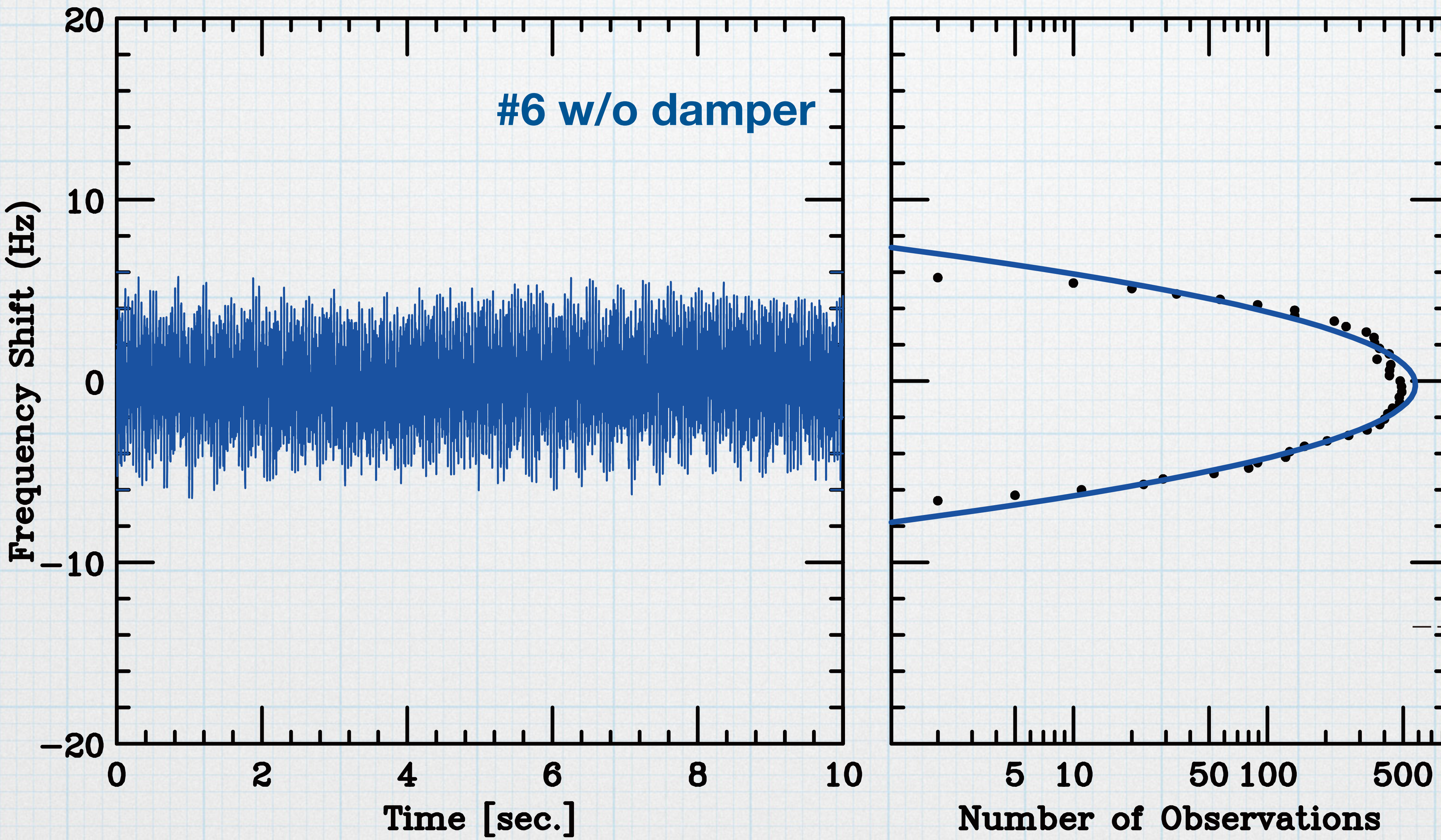
Validation of Bulk Cavities

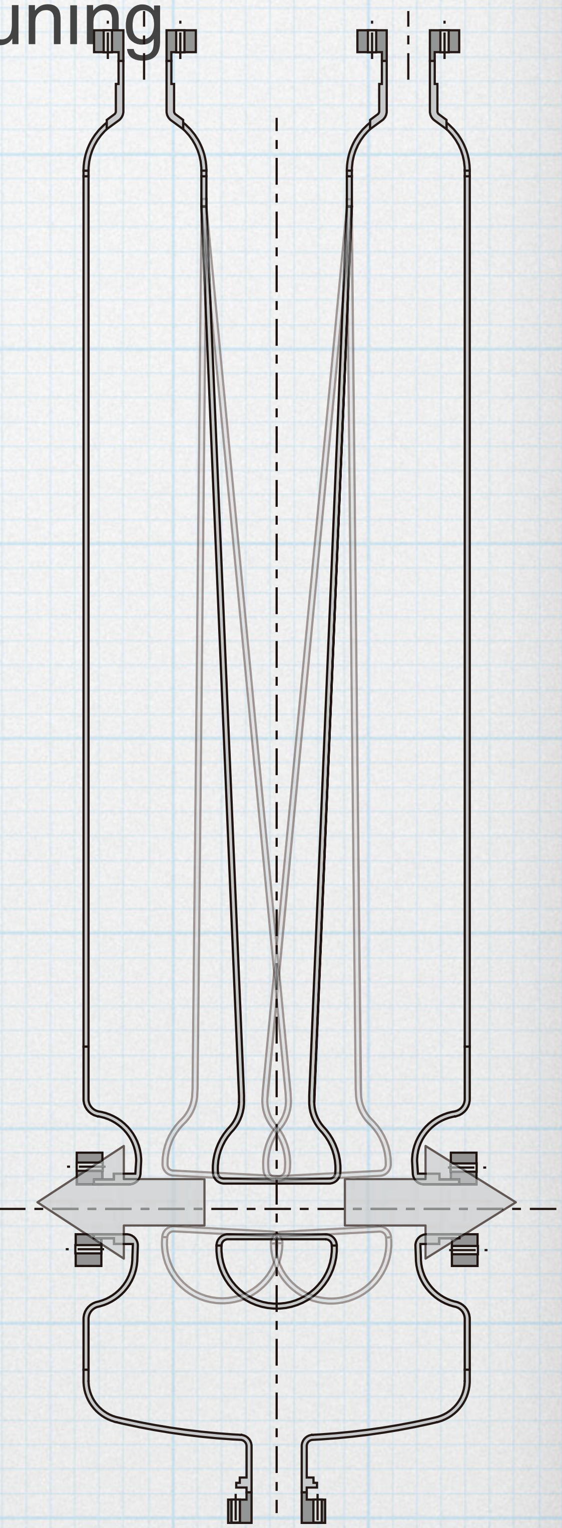
- Validations of six bulk cavities were finished. Proceeding to jacketing.



Microphonics

- Microphonics is an important issue for QWRs
- Pendulum mode vibration induces eigenmode frequency detuning
- Frequency detuning must be controlled within RF bandwidth.





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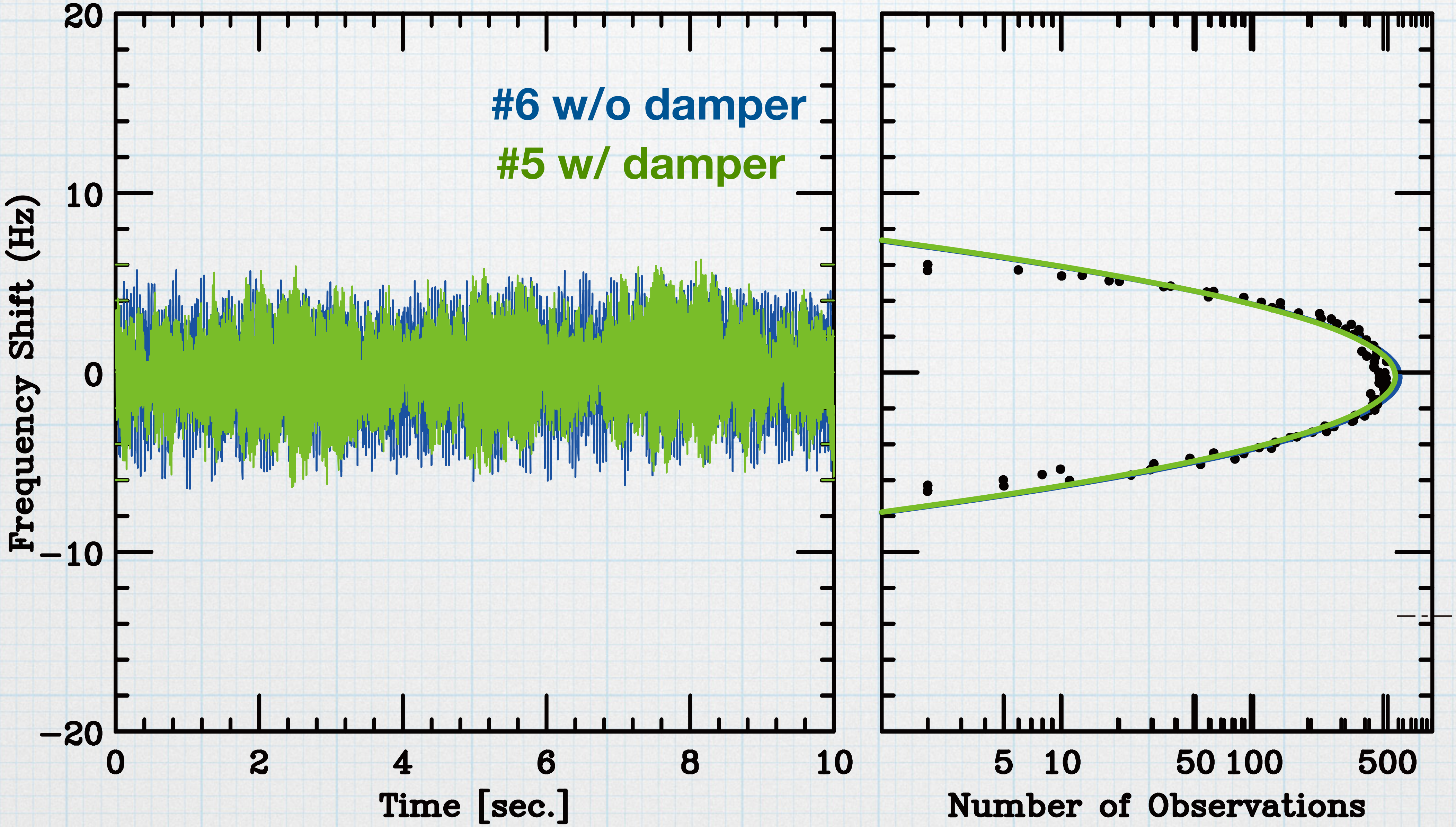
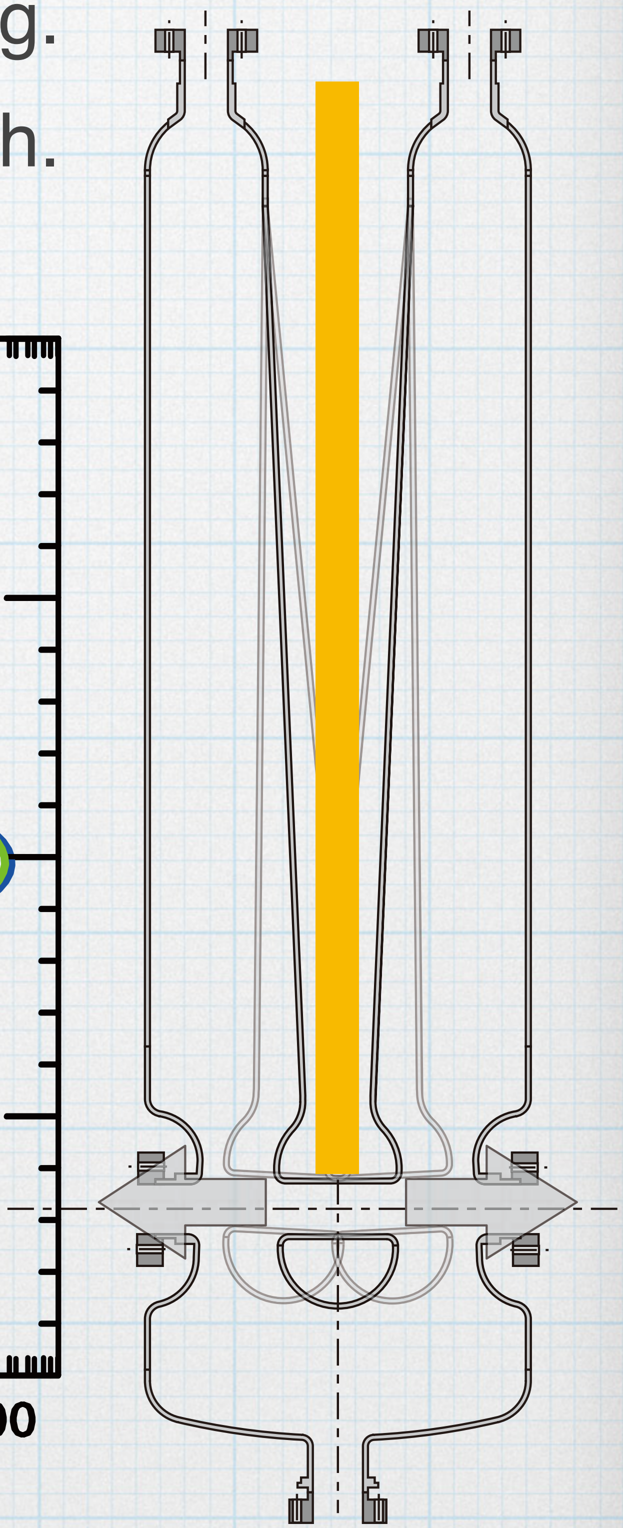
- Pendulum mode vibration induces eigen frequency detuning.
- Frequency detuning must be controlled within RF bandwidth.
- Damper test was performed.





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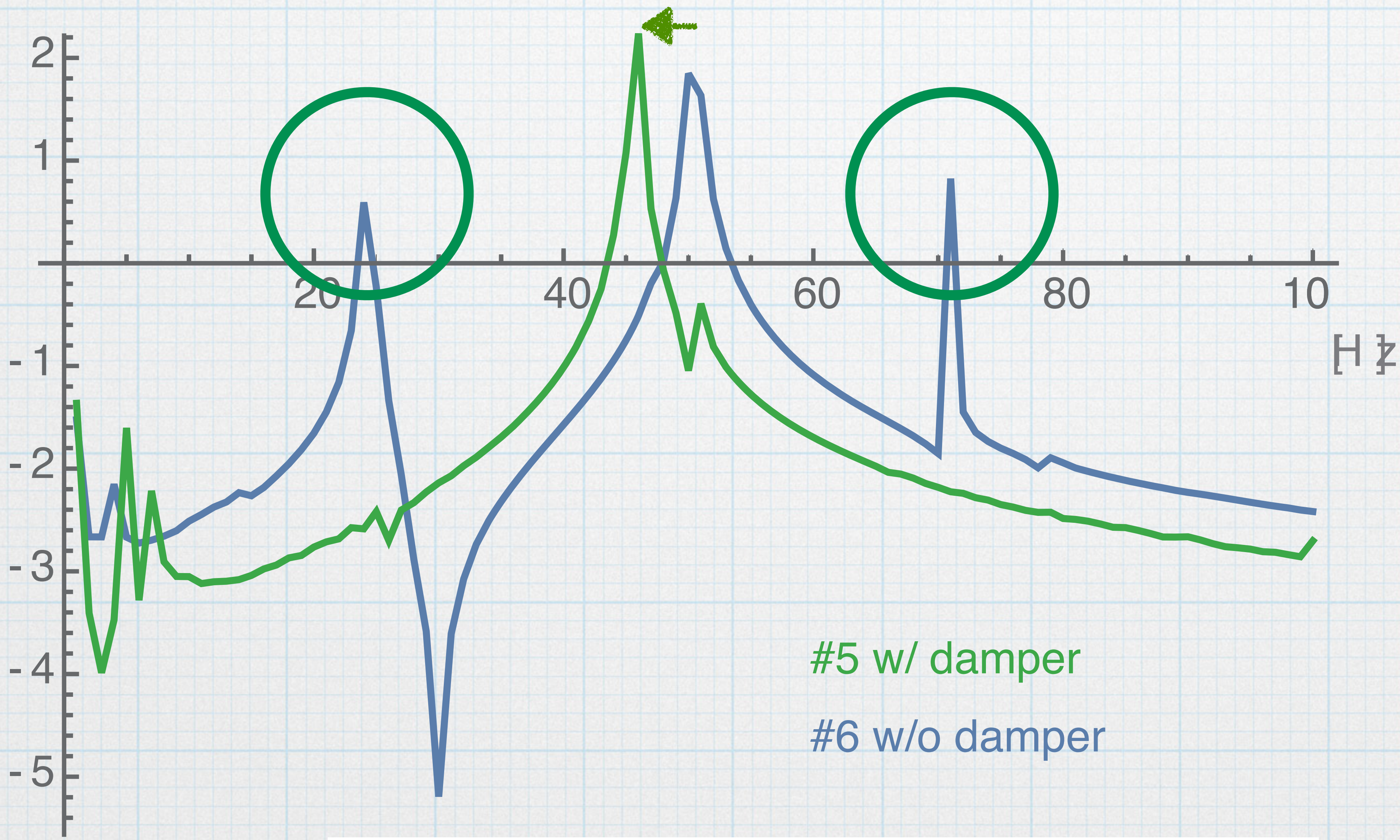
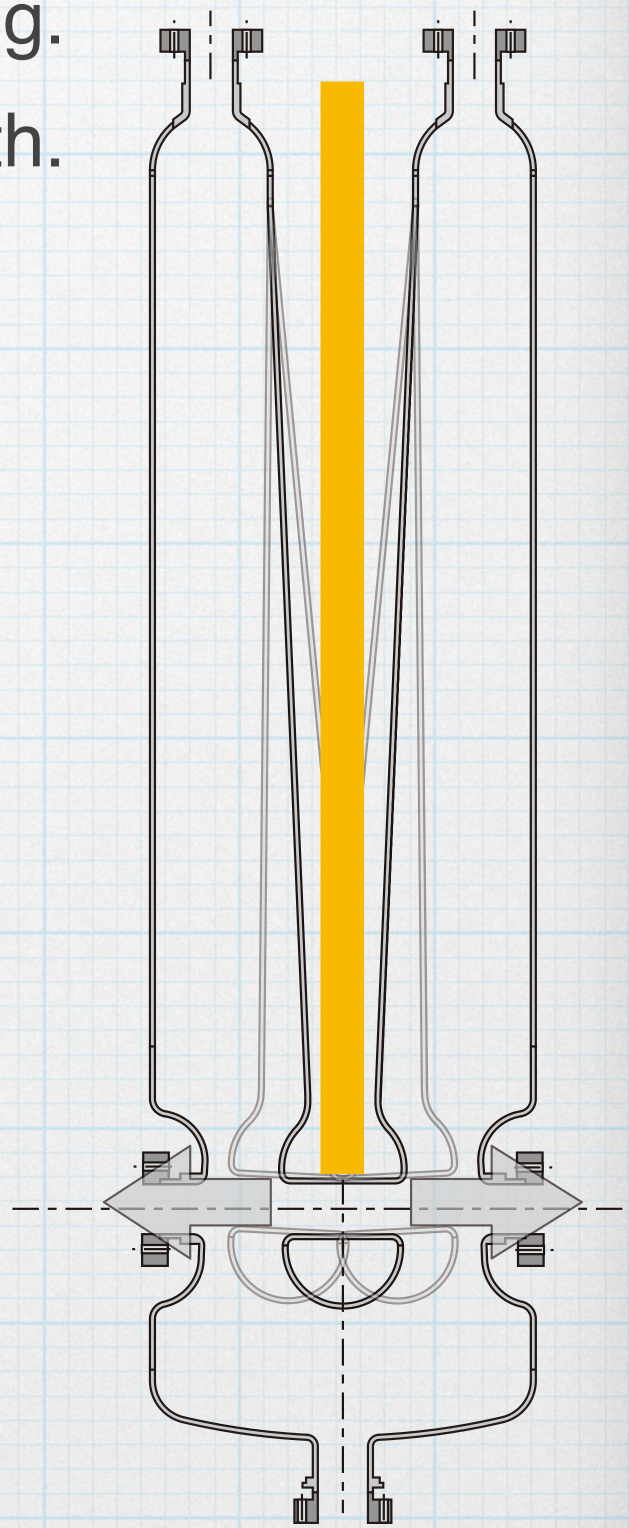
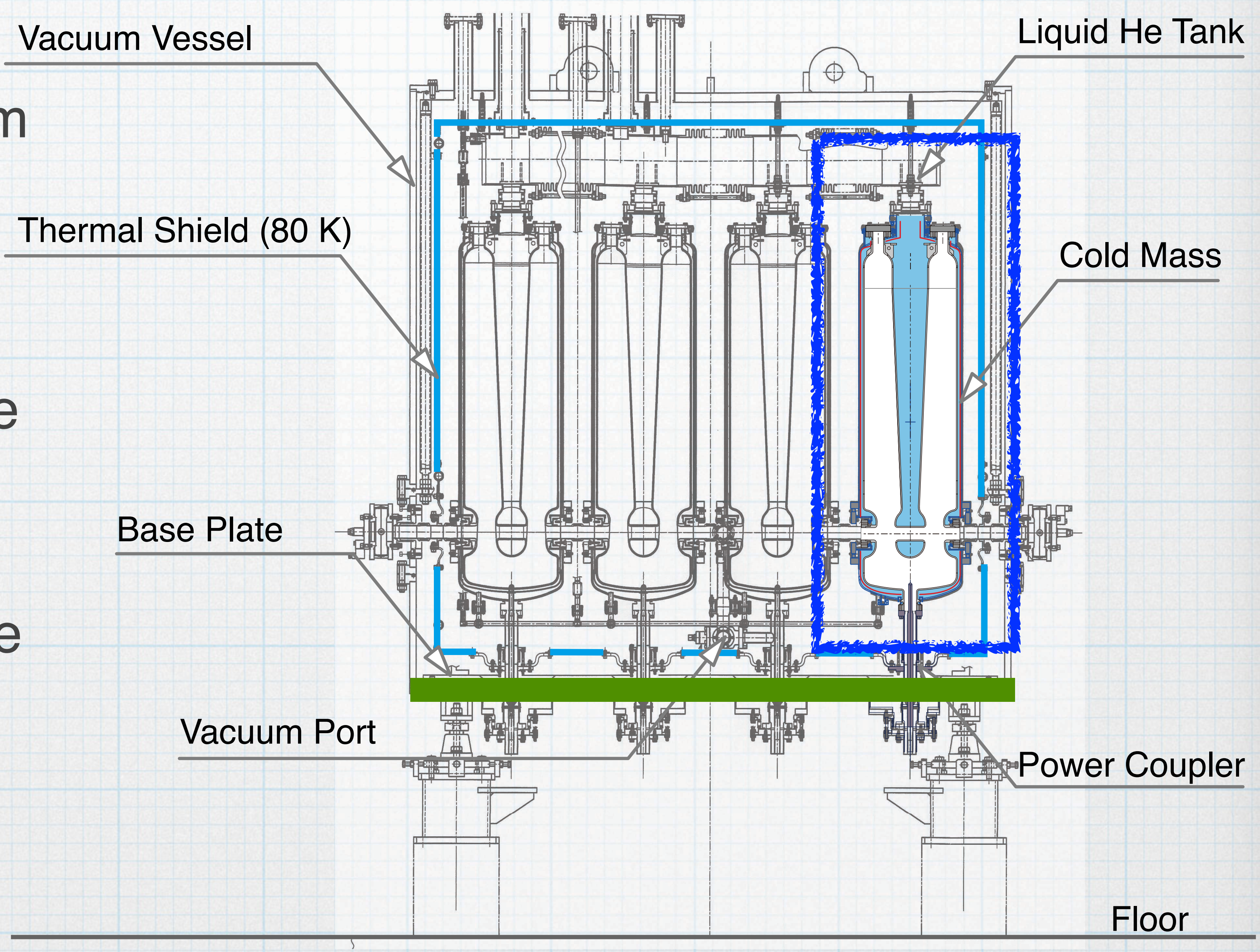




Further investigation is required.

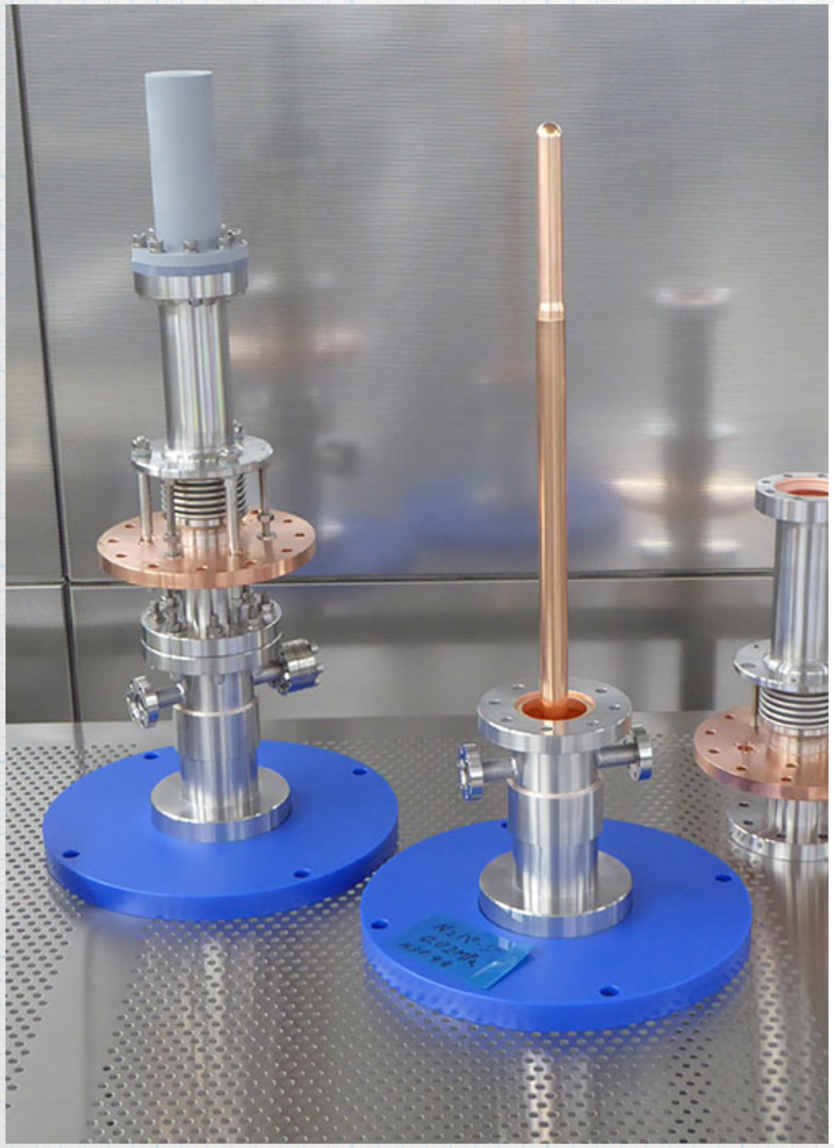
Cryomodule

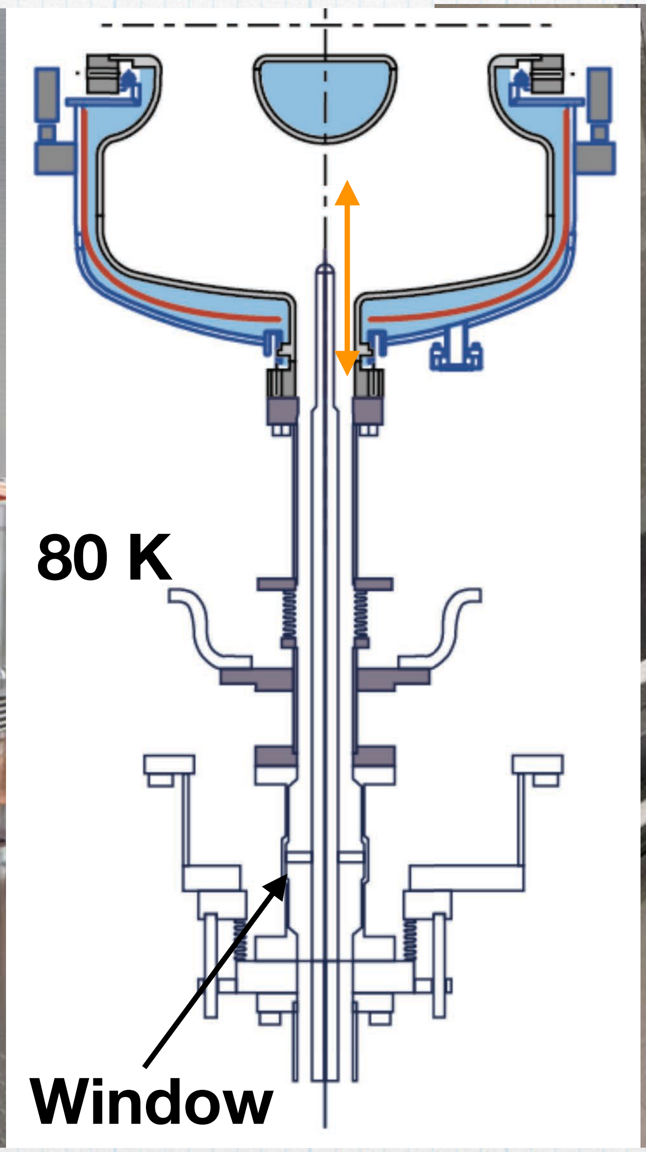
- The cold mass, which consists of a cavity, helium vessel, FPC, magnetic shield inside the vessel and dynamic tuner, is supported by pillars made of G10 from the bottom base plate. → successful reduction of assembly cost
- The cold mass is cooled by 4-K liquid helium provided by a liquid helium cryogenic system using a HELIAL MF refrigerator (Air Liquide).
- The vacuum vessel made of carbon steel helps magnetic field shielding.
- Beam vacuum with oil free pumping system is separated from insulation vacuum.
- Single window PC



Fundamental Power Coupler

- Single window
- Variable coupling (Q_{ext} 1×10^6—4.5×10^6)
- 80 K thermal anchor minimizes heat load to the cold mass.
- A pair of coupler was conditioned using the conditioning resonator.



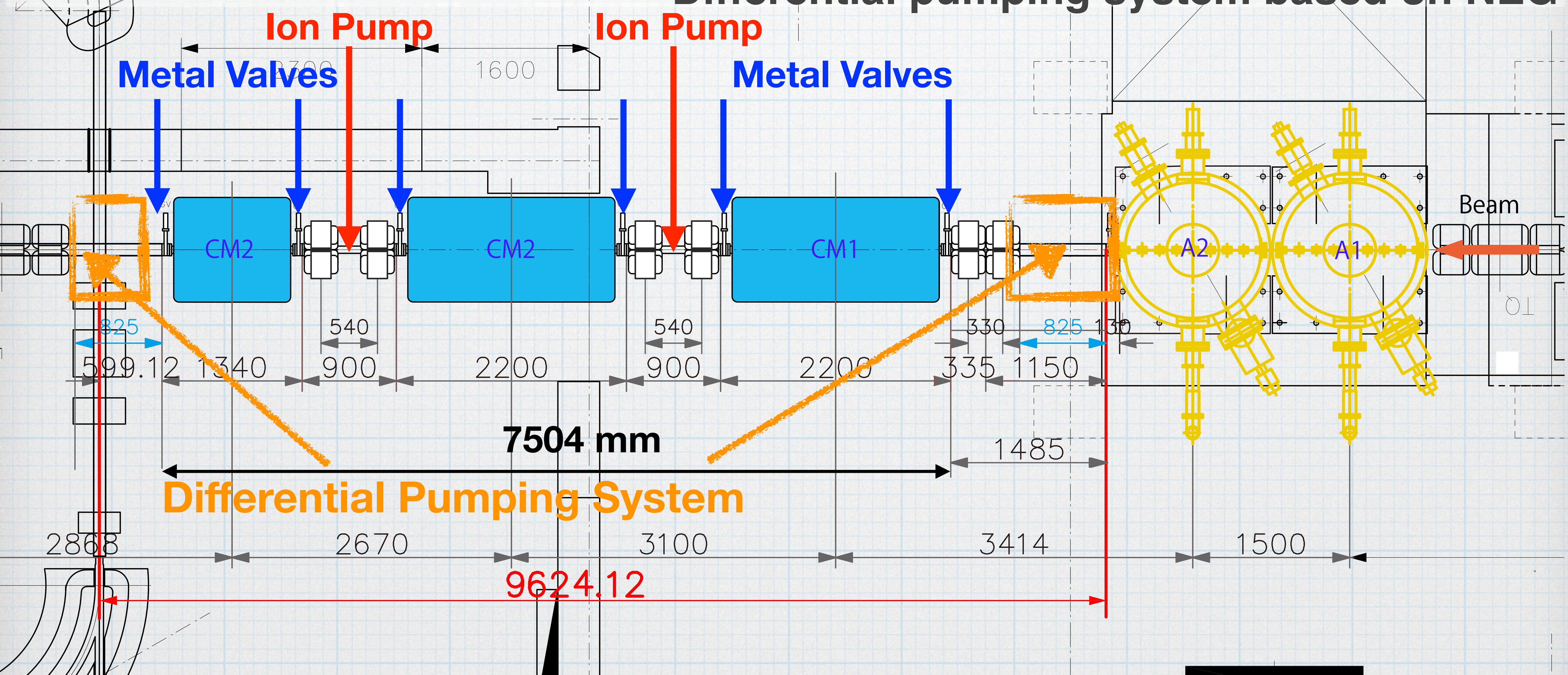


3. Other issues

Installation to the Existing Beam Line

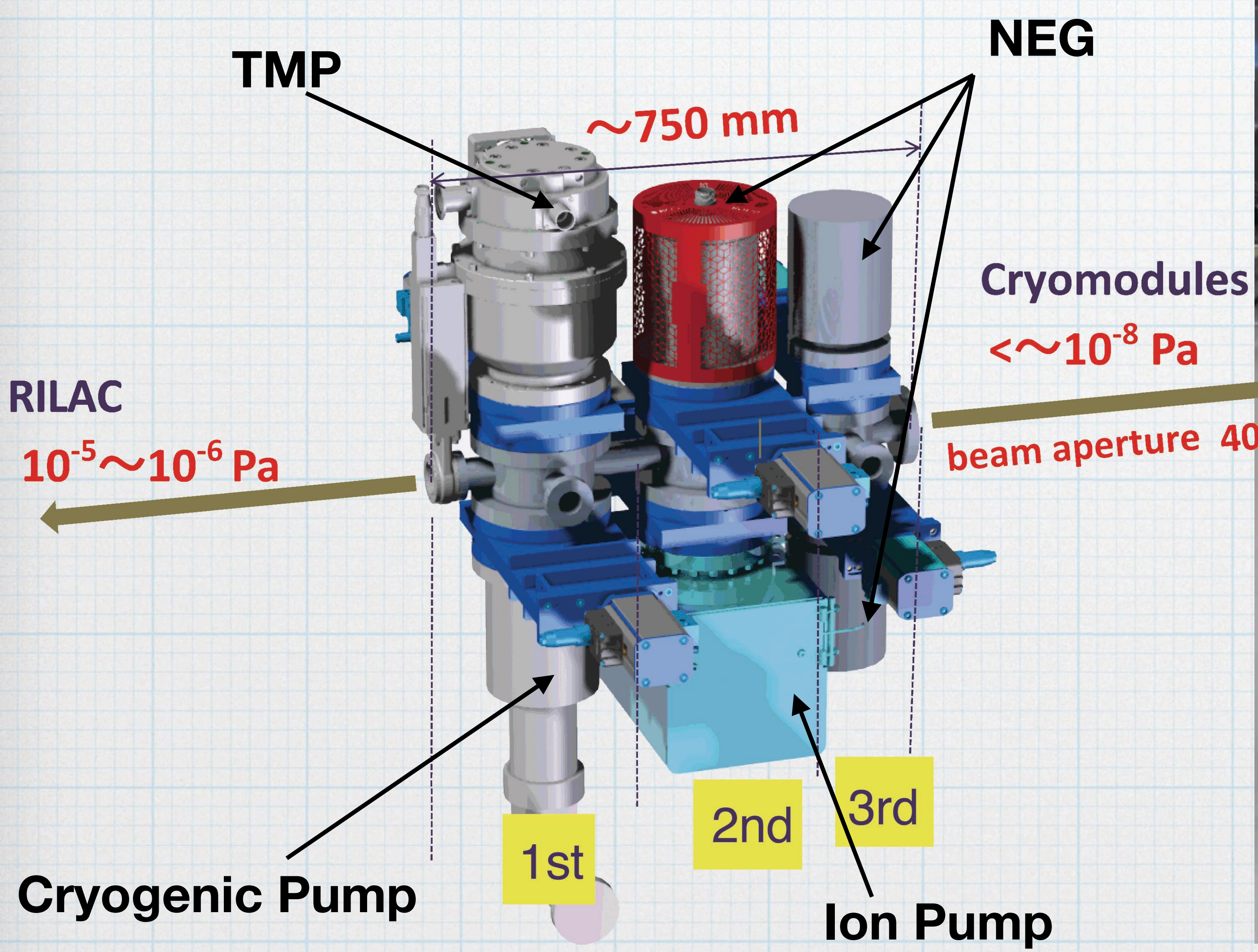
- Destructive beam diagnostic devices such as Faraday cup, wire scanner cause vacuum deterioration and generate dusts. →**BEPM**
- RT frequency tunable DTL has large volume with sliding short plate.
- Vacuum level is 1x10^{-6} to 1x10^{-5} Pa. (Viton O-rings are used at everywhere!)

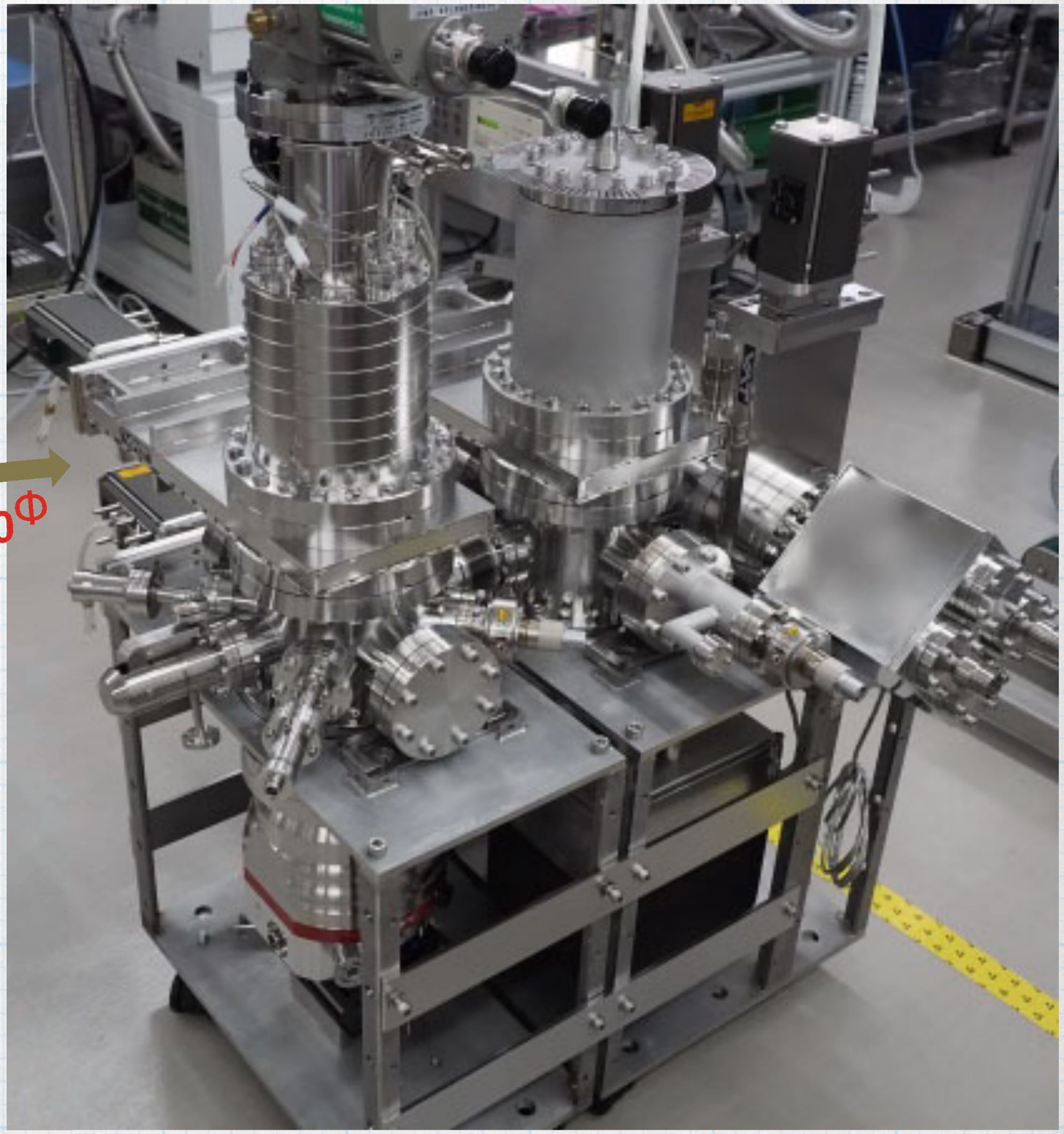
  → **Differential pumping system based on NEG**



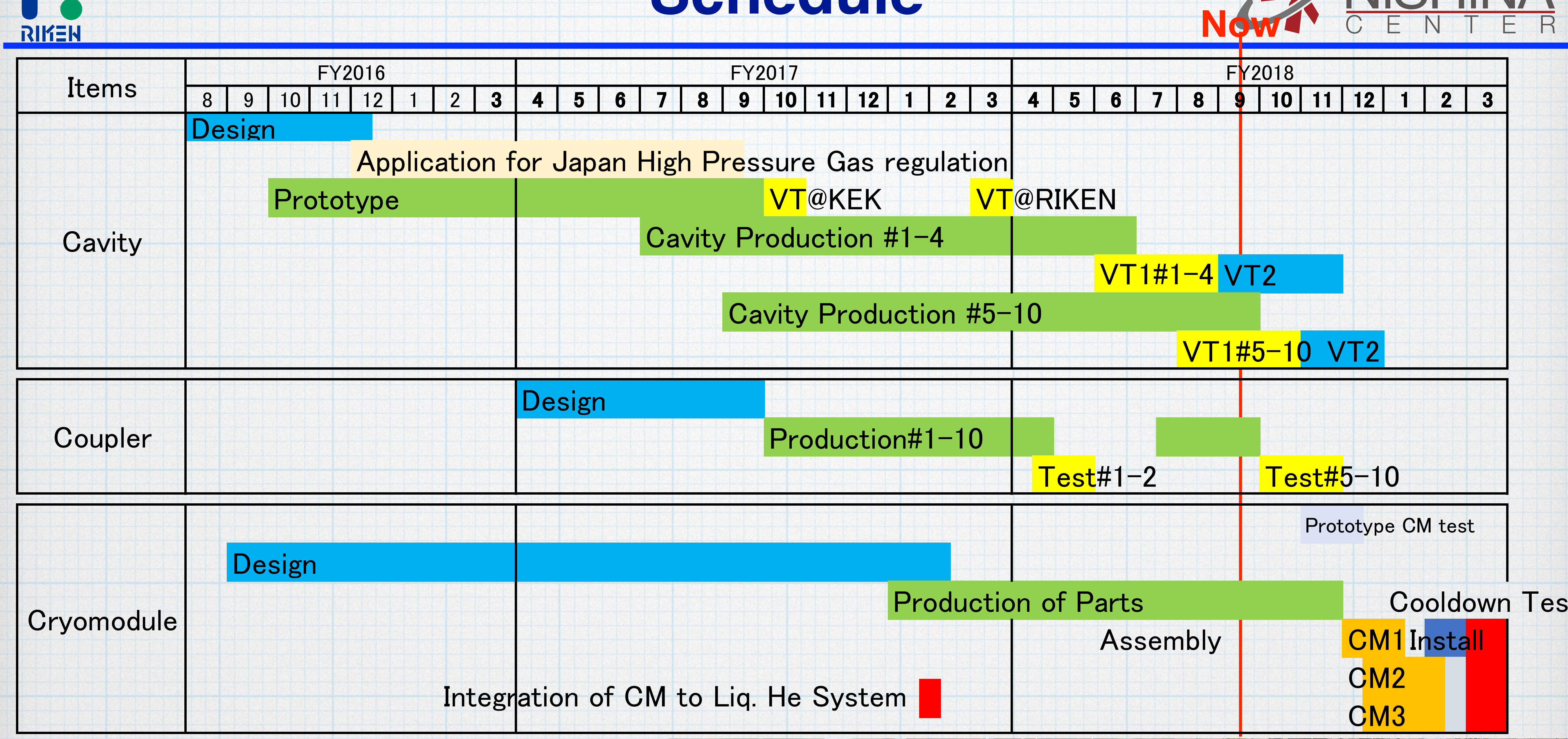
NEG-based Differential Pumping System

- Three stage dust-free system for pressure reduction from the existing beam line vacuum 10^{-5}—10^{-6} Pa to ultra-high vacuum 10^{-8} Pa
- Limited space (<750 mm) with beam aperture diameter 40 mm





Schedule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Items
FY2016
FY2017
FY2018
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4 5 6 7 8 9 10 11 12 1 2 3
4 5 6 7 8 9 10 11 12 1 2 3
Cavity
Design
Application for Japan High Pressure Gas regulation
Prototype
VT@KEK
VT@RIKEN
Cavity Production #1-4
VT1#1-4
VT2
Cavity Production #5-10
VT1#5-10
VT2
Coupler
Design
Production#1-10
Test#1-2
Test#5-10
Cryomodule
Prototype CM test
Design
Production of Parts
Cooldown Test
Assembly
CM1
Install
CM2
CM3
Integration of CM to Liq. He System

Summary

- The RIKEN Heavy-Ion Linac (RILAC) is undergoing upgrade from **5MeV/u for A/q=5** ions to **6.5 MeV/u for A/q=6** ions replacing four RT-DTLs by superconducting linac **(SRILAC).**
- **SRILAC** is based on 73 MHz bulk SC-QWRs processed by **BCP.**
- **Steering Correction is adopted with tilting faces of drift tubes.**
- **RT focusing elements will be installed to MEBT between CMs.**
- R&D of the prototype cavity was performed. Q_0 achieved **3.5×10^9**.
- To date validation of six bulk cavities were finished.
- Newly designed **BEPM** will be employed instead of traditional wire scanners.
- Very compact **DPS** is under developing.

Installation of cryomodules will be completed by the end of FY2018 aiming to start the SHE experiment in FY2019.

Acknowledgement

- Development of the first prototype QWR and its CM for low-beta ions at RIKEN was funded by the ImPACT Program of the Japan Council for Science, Technology, and Innovation (Cabinet Office, Government of Japan).
- The authors are grateful to Dr. A. Kasugai at QST Rokkasho and Prof. K. Saito at FRIB/MSU for technical discussion on design of the cavity and on assembly work.

Thank you for your attention.