Development of alumina ceramics vacuum chamber for J-PARC

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Japan Atomic Energy Agancy

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Collaborators

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- Tomei Sugano (MHI)
- Norio Ogiwara (JAEA)
- and many engineers

Outline

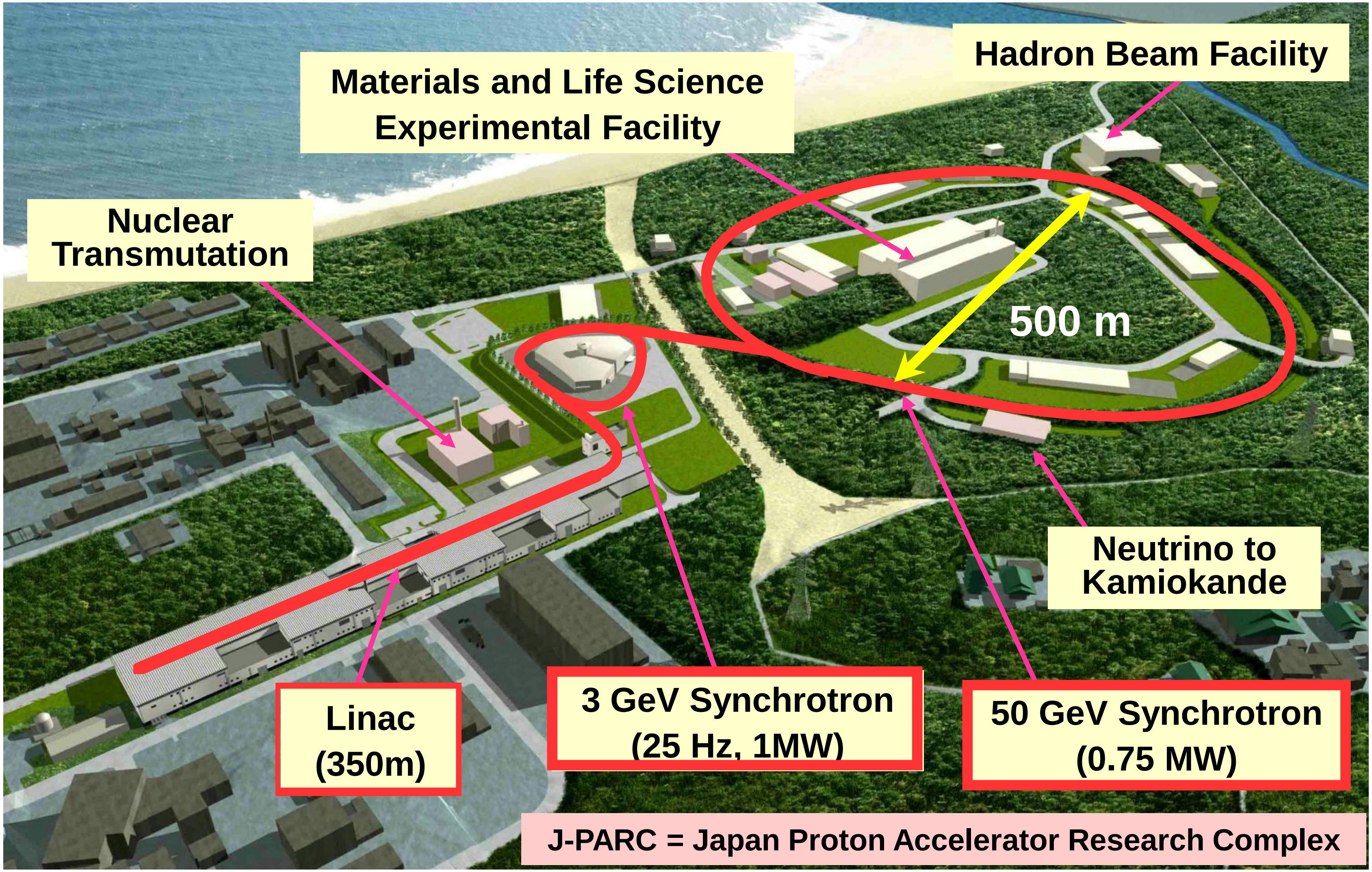
- Introduction
  - J-PARC project
  - Requirements for vacuum chamber
  - Key issue for production of alumina ceramics vacuum chamber
    - Mechanical strength
    - Production process

- Production
  - How to product long and wide aperture alumina vacuum chamber.

- Characteristics of alumina ceramics vacuum chamber
  - Outgassing rate
  - Temperature measurements under magnet operation
  - Impedance measurements with coaxial wire method
  - Beam study at KEK-PS

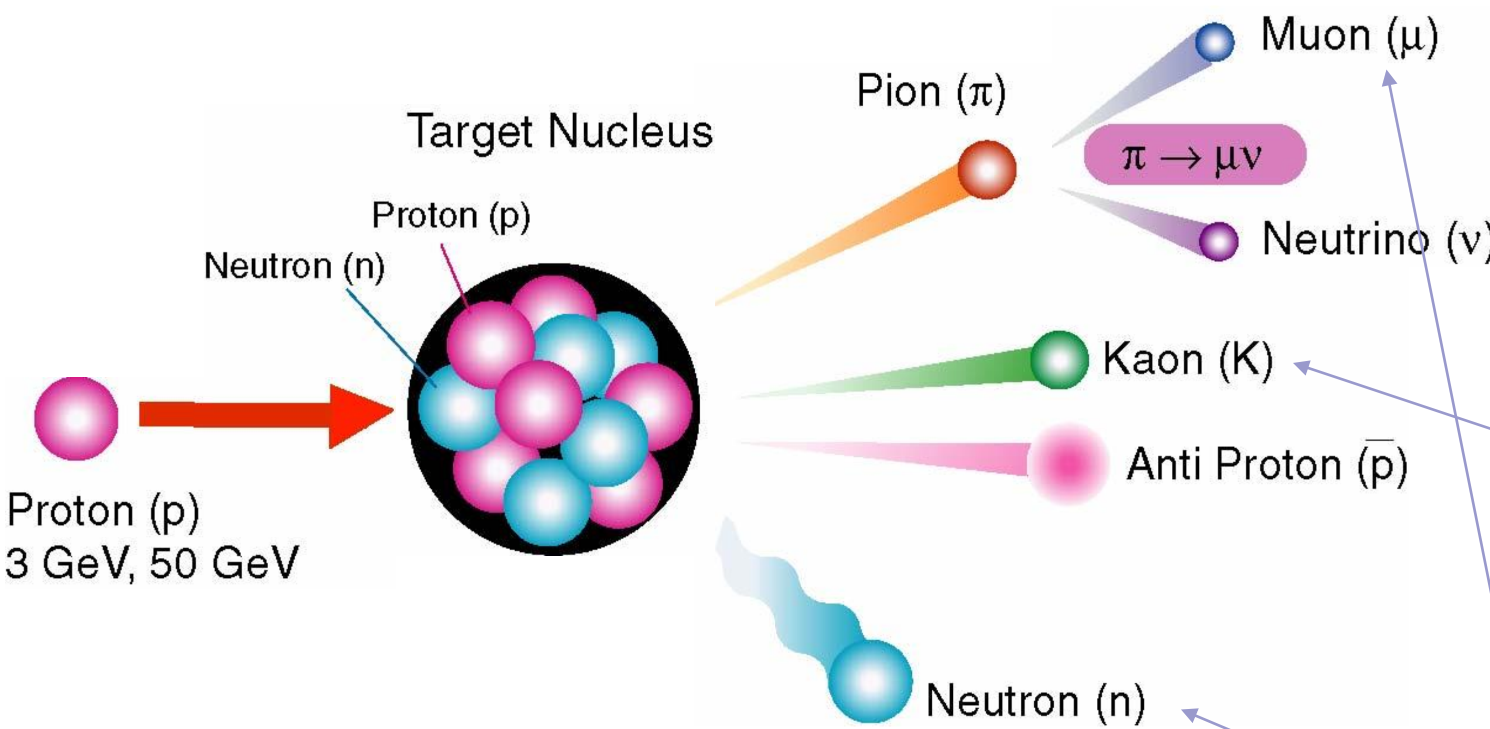
- Summary
  - Summary and present status

What is J-PARC - facilities -



Joint Project between JAEA and KEK

What is J-PARC - Three goals at J-PARC -

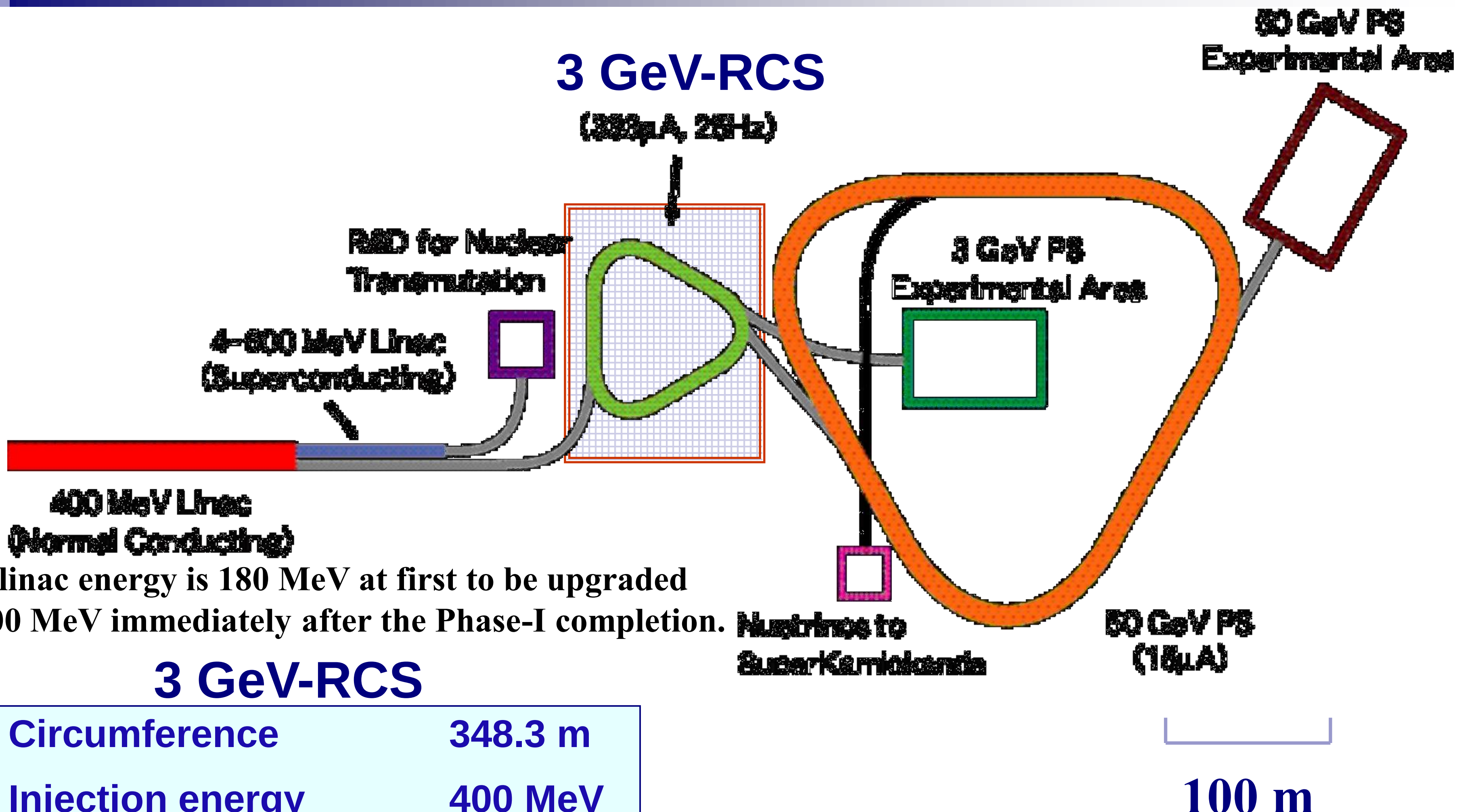


Need to have high-power proton beams

→ MW-class proton accelerator (current frontier is about 0.1 MW)

- Materials & Life Sciences at 3 GeV
- Nuclear & Particle Physics at 50 GeV
- R&D toward Transmutation at 0.6 GeV

J-PARC accelerators



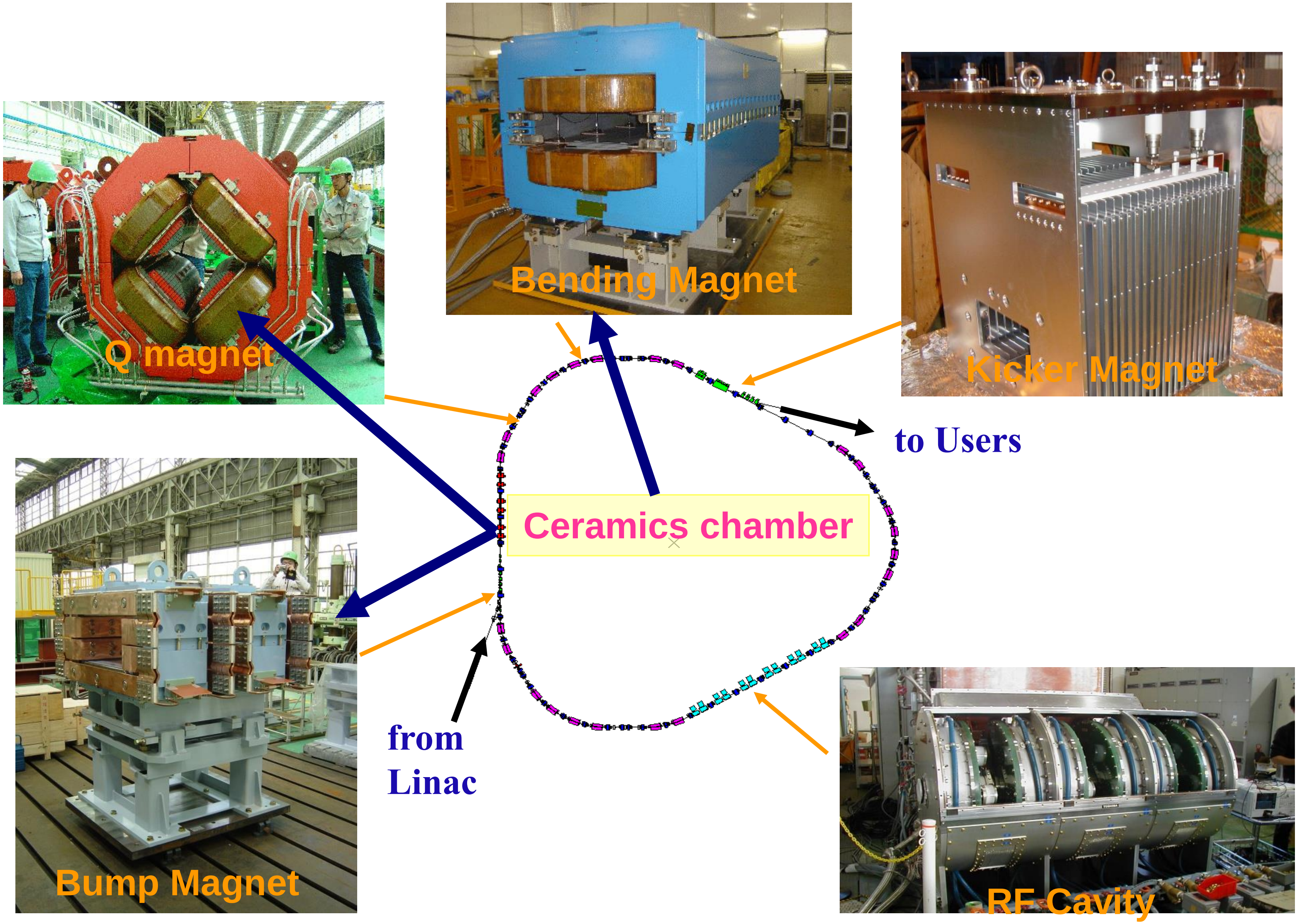
The linac energy is 180 MeV at first to be upgraded to 400 MeV immediately after the Phase-I completion.

3 GeV-RCS

• Circumference	348.3 m
• Injection energy	400 MeV
•Extraction energy	3.0 GeV
• Repetition rate	25 Hz
• Output power	1.0 MW

➡ **High repetition ratio & High power**

3 GeV synchrotron - components -



Requirements for vacuum chamber

- Minimize of eddy current effect
  - Main magnets are operated with 25 Hz
    - Metal duct

      Big Ohmic loss and undesirable multi pole components should be induced.

      For example, 0.1 mm thickness titanium

      Ohmic loss > 1 kW/m and Sextupole component > 1 x 10^{-4}
    - Ceramics duct

      No Ohimic loss and multi pole components !

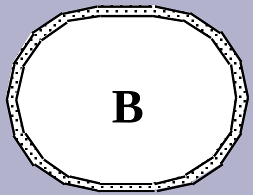
- Minimize of chamber impedance
  - Big chamber impedance causes beam instability !
    - Metal duct
      - Thick duct : RF shield is NOT Necessary, Thin duct : RF shield is Necessary !
    - Ceramics chamber
      - RF shield is Necessary !

- Minimize of chamber maintenance

➡ Developing the titanium flanged alumina ceramics vacuum chamber with RF shield

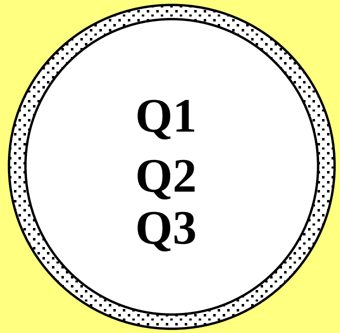
Requirements for chamber – Size & Cross section -

Dipole Magnets



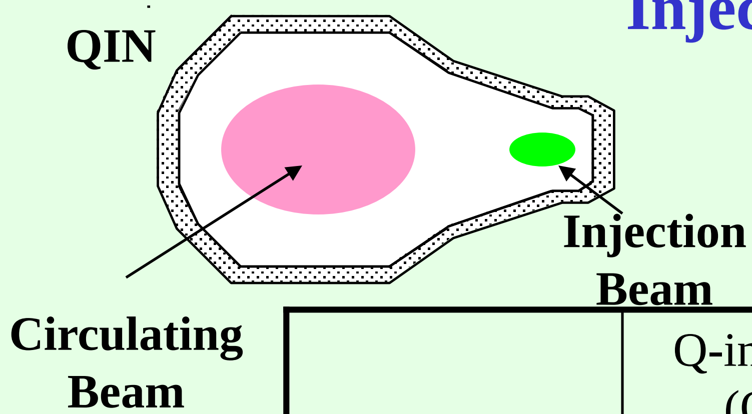
Inner size (mm)	187 x 245
Length (mm)	3500
Shape	15^o bend

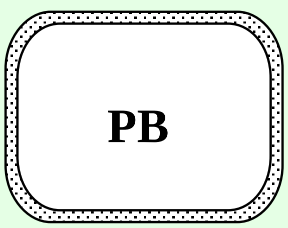
Quadrupole Magnets

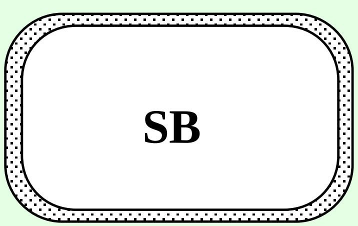


	Q1	Q2	Q3
Inner dia. (mm)	377	297	257
Length (mm)	1500	1600	1300

Injection Magnets







	Q-injection (QIN)	Painting Bump (PB)	Shift Bump (SB)
Inner size(mm)	Max. 500	350 x 250	460 x 270
Length(mm)	1500	770	1350

Key issues for production

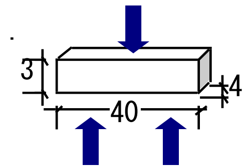
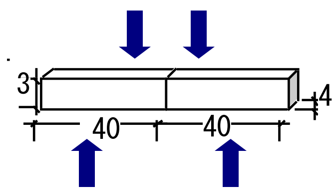
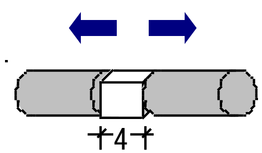
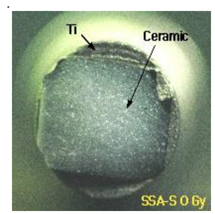
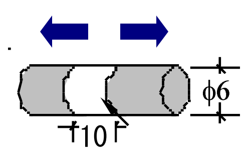
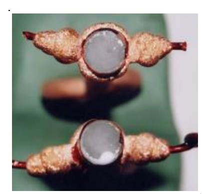
- Mechanical strength
  - High mechanical strength is needed.
    - Alumina ceramics
    - Ceramics-ceramics joint
    - Ceramics-titanium joint
    - RF shield

  ➡ **Mechanical strength was measured !**

- How to produce the ceramic chamber.
  - Properties : Long length & Large aperture size
  - RF shield
    - The design principle of the RF shield is
      - Shielding the electromagnetic fields produced by the beam
      - Compromising the shielding efficiency and eddy current loss
      - Simplifying production and maintenance process

    ➡ **How to realize these concepts !**
  - Mass production : ~ 100 chambers

Mechanical strength

	Sample & Method	Broken Point (picture)	Broken Point	Strength (MPa)
Ceramics				> 300
Ceramics-Ceramics			Metallized layer (Mo-Mn)	>250
Ti-Ceramics			Ceramics adjacent to the joint	>100
PR Cu-Ceramics			Metallized layer (Mo-Mn)	>40

Mechanical strength was sufficient
for alumina ceramics vacuum chamber with RF shield.

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- Characteristics of alumina ceramics vacuum chamber
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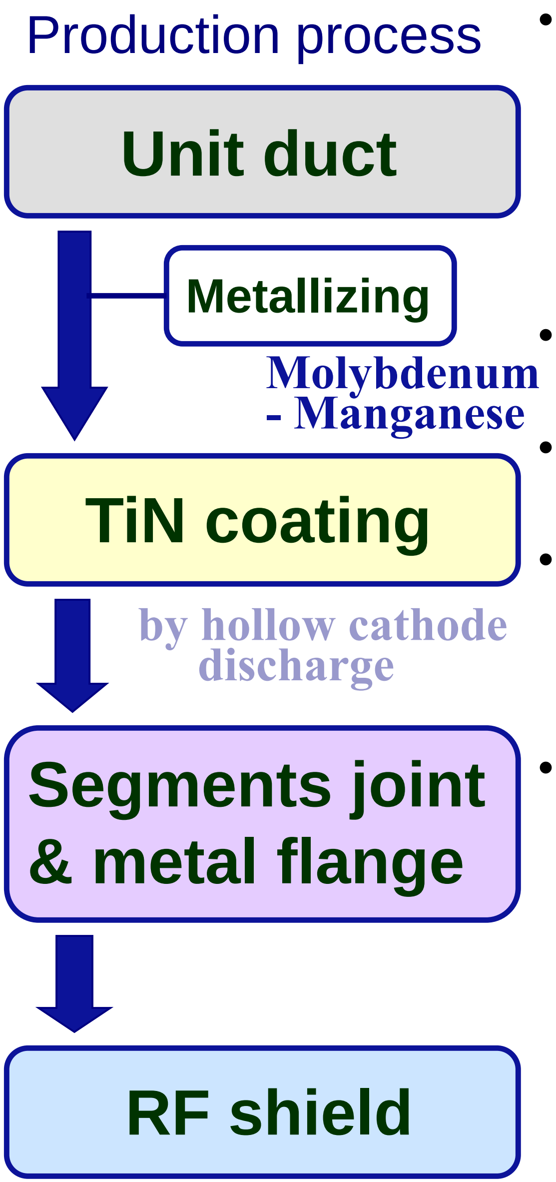
Production process of ceramics chamber



- **Unit duct**
  - which are ~0.8 m long should be produced with sufficiently large wall thickness (~7.5 mm) in order to minimize deformation during sintering.
  - Only outside surface and edges of the sintered duct are grind or polished to obtain the required duct size.
- **Mo-Mn metallizing** was printed the ends and outside surface of the duct.
- **TiN film** of ~15 nm in thickness was coated inner surface of the duct in order to reduce secondary electron emissions.
- **The segments were jointed** by Mo-Mn metallizing the ends and brazing with Cu-Ag eutectic alloy. **The Ti-flanges** were welded to a Ti-sleeve attached to ceramic segments by metallizing and brazing.
- **RF shield**
  - The design principle of the RF shield is
    - Shielding the electromagnetic fields produced by the beam
    - Compromising the shielding efficiency and eddy current loss
    - Simplifying production and maintenance process
  - **The copper stripes** of ~0.5 mm in thickness and 5 mm in width were electro-formed on outer surface of the duct.
  - At one end of the duct, each stripe were cut due to **capacitors** of 330 nF in order to prevent the eddy current induced by the magnets.

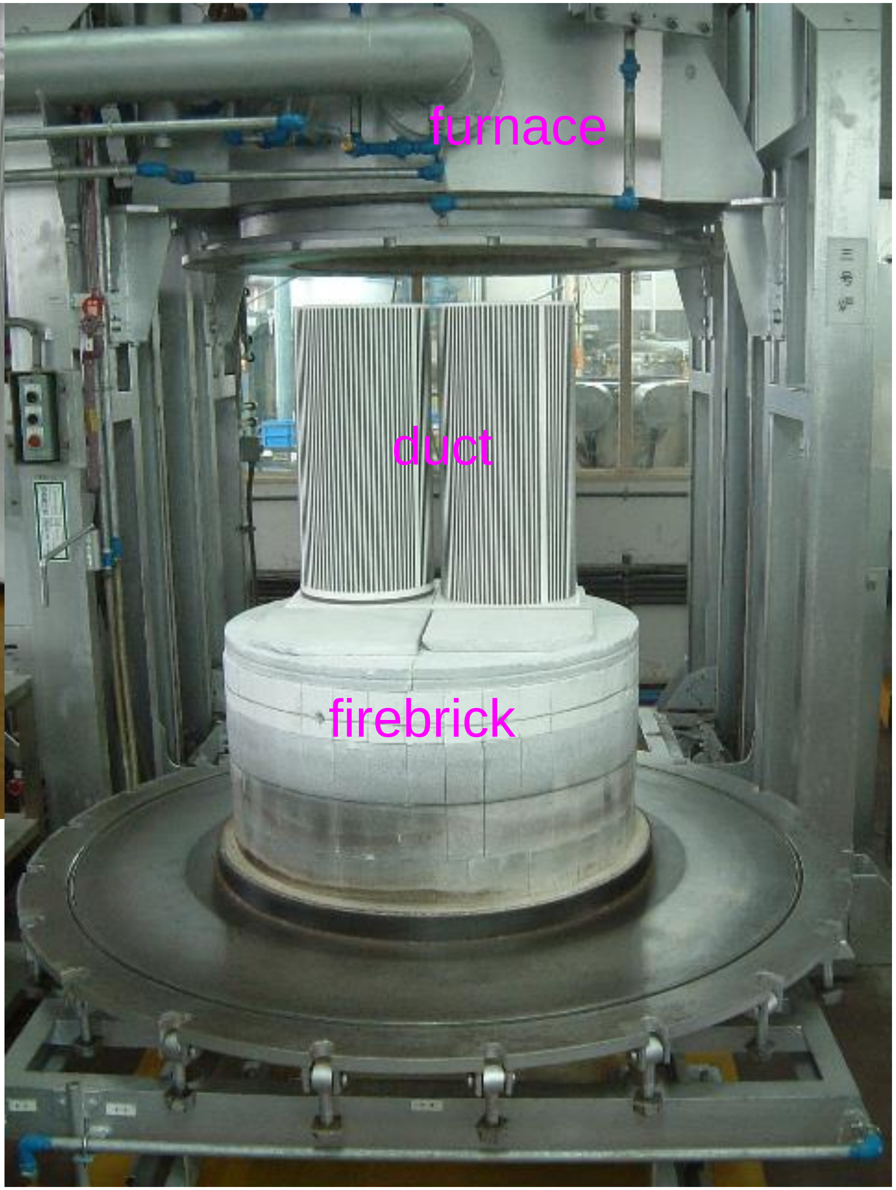
Production of unit duct

for quadrupole magnet

for dipole magnet

- Sinter temperature : 1650 ^{o}C
- Circumstance : in air

Metallizing



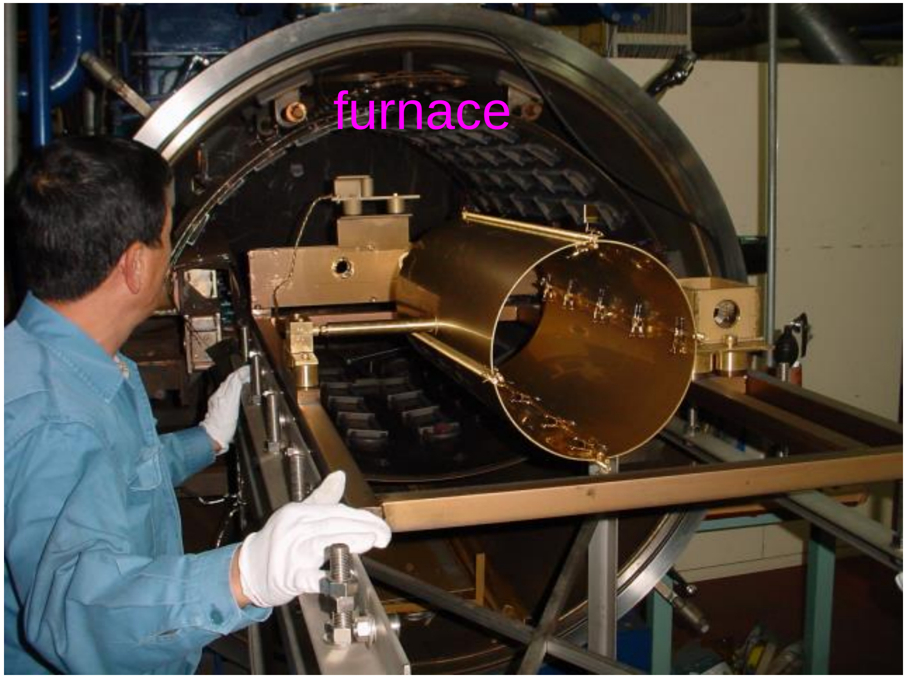
Mo-Mn metallizing was printed the ends and outside surface of the duct.

- Mo-Mn paste was painted
- Sinter temperature : 1350 ^{o}C
- Circumstance : in wet hydrogen

TiN coating - method -

Hollow cathode discharge method

TiN film of ~15 nm in thickness was coated inner surface of the duct in order to reduce secondary electron emissions.

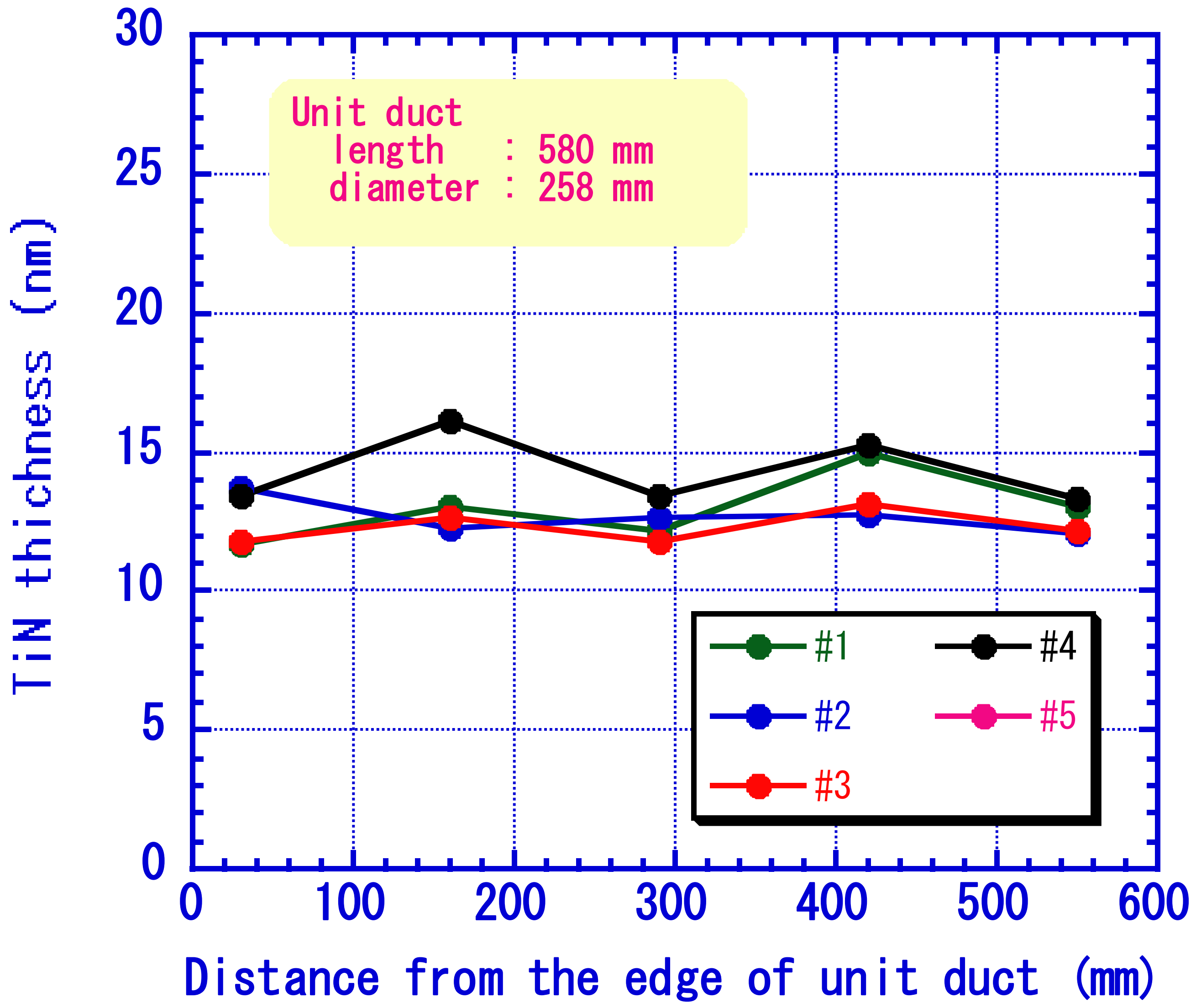


TiN coating

- Hollow cathode discharge method
- Circumstance : in vacuum
- Thickness of TiN : 10 ~ 15 nm

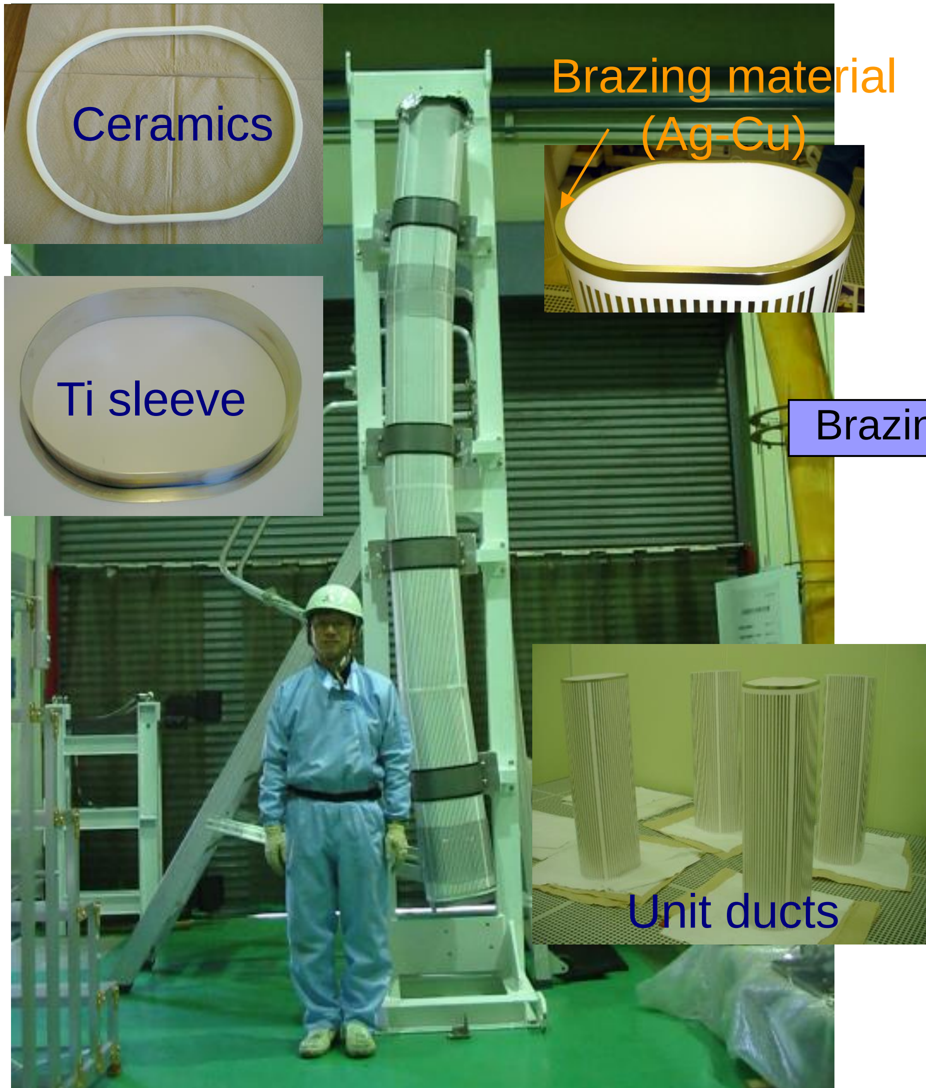
TiN coating - thickness -

- Uniformity of thickness of TiN coating



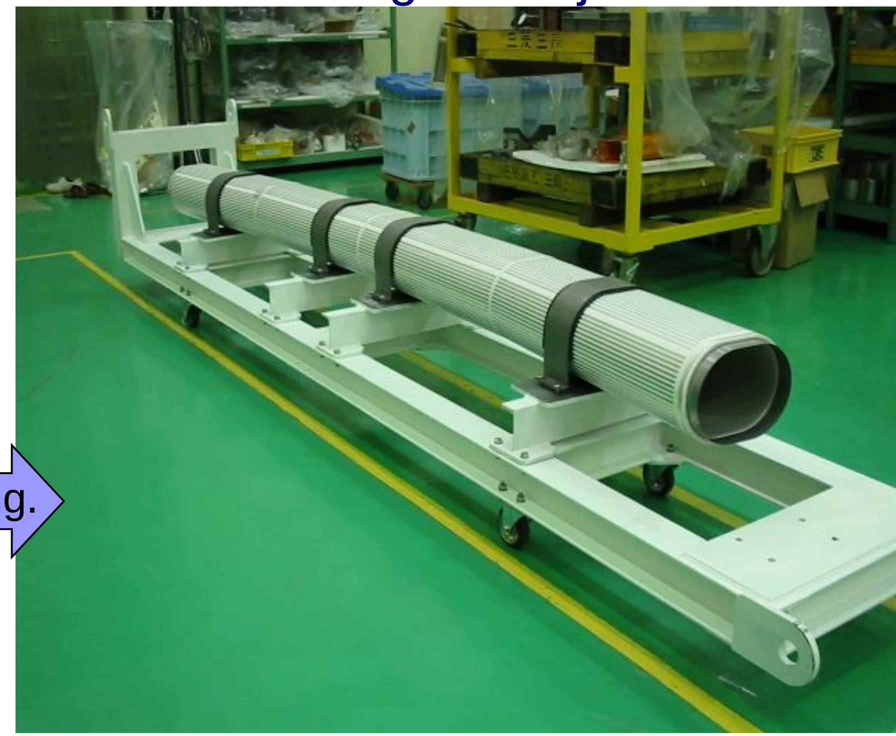
Segments joint and metal flange

Housing of ceramics duct
for dipole magnet



Brazing.

Segments joint



Ti sleeve and Ti flange

RF shield

Electroforming method

- Copper stripes were formed by electroforming method in which stripes of Mo-Mn metallizing layer were first sintered on the exterior surface and the overlaid by PR electroformed copper (a Periodic current Reversal method).

- The electrical conductivity of PR electroformed copper is almost the same as oxygen-free copper.

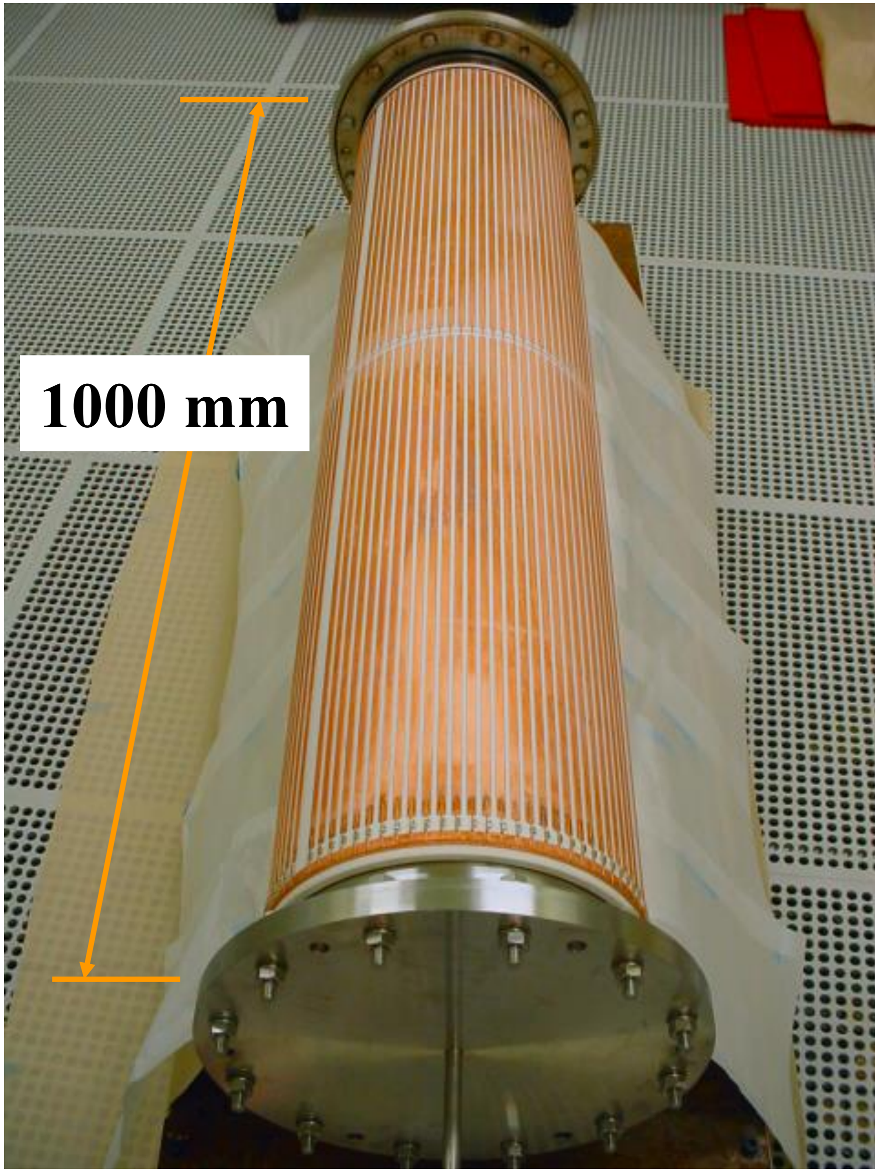
- The copper stripes
  - Thickness : ~0.5 mm
  - Width : ~5 mm

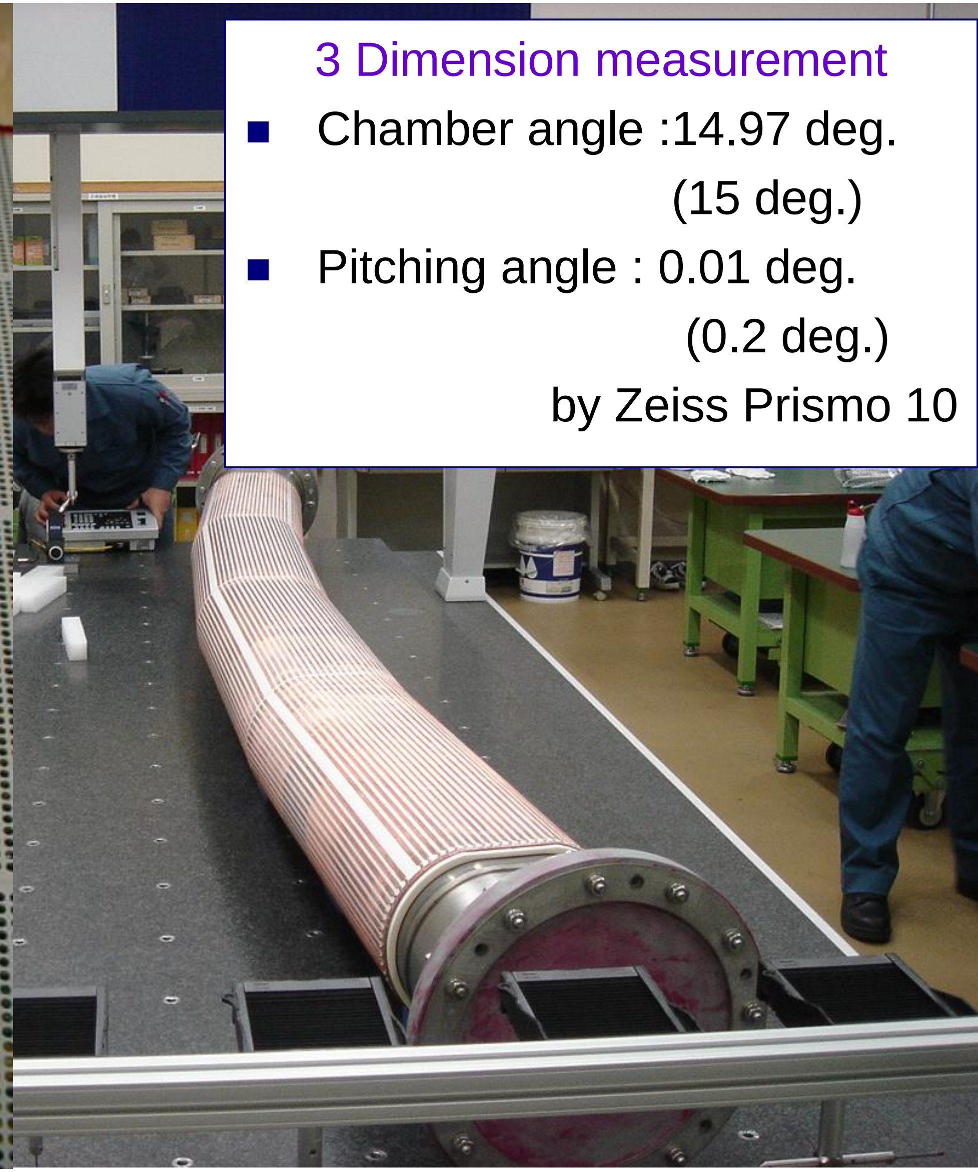
- Each stripe was cut due to capacitors of 330 nF at one end of the duct in order to prevent the eddy current induced by the magnet.

RF shield - pictures -

for quadrupole magnet

for dipole magnet



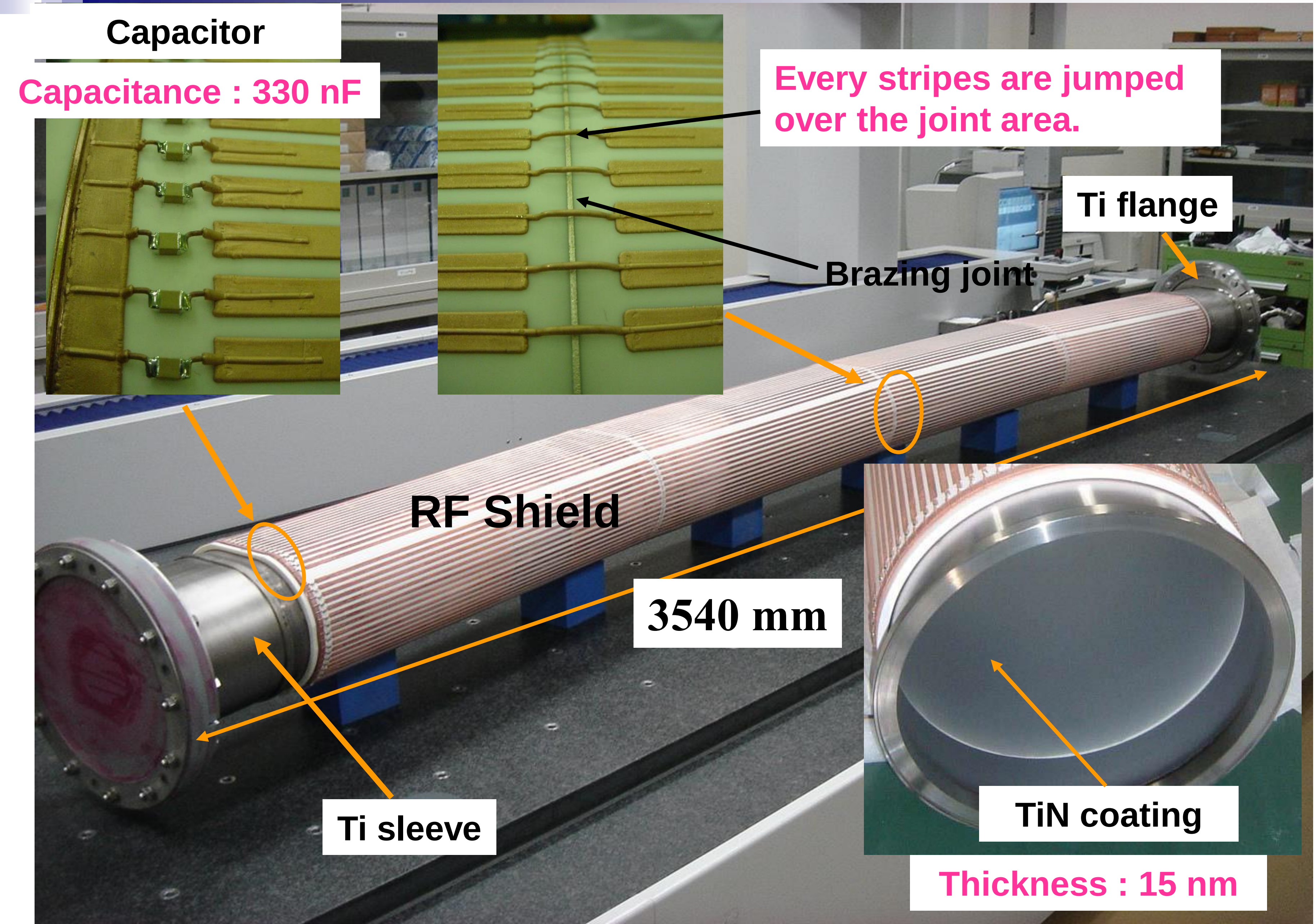


3 Dimension measurement

- Chamber angle :14.97 deg.
  (15 deg.)
- Pitching angle : 0.01 deg.
  (0.2 deg.)

by Zeiss Prismo 10

Ceramics chamber - picture -



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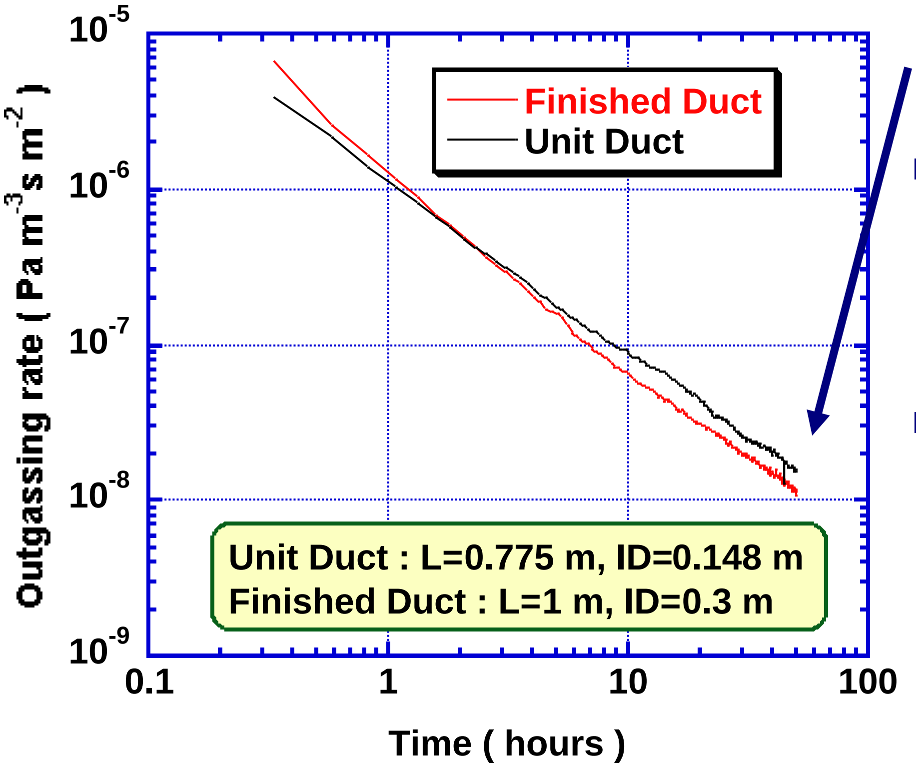
Outgassing rate measurements

- Samples
  - Unit Duct
    - Duct size : 148 mm in diameter and 0.775 m length
  - Finished Duct
    - Duct size : 300 mm in diameter and 1 m length
    - TiN coating : 15 nm coating
- Method : Conductance modulation method



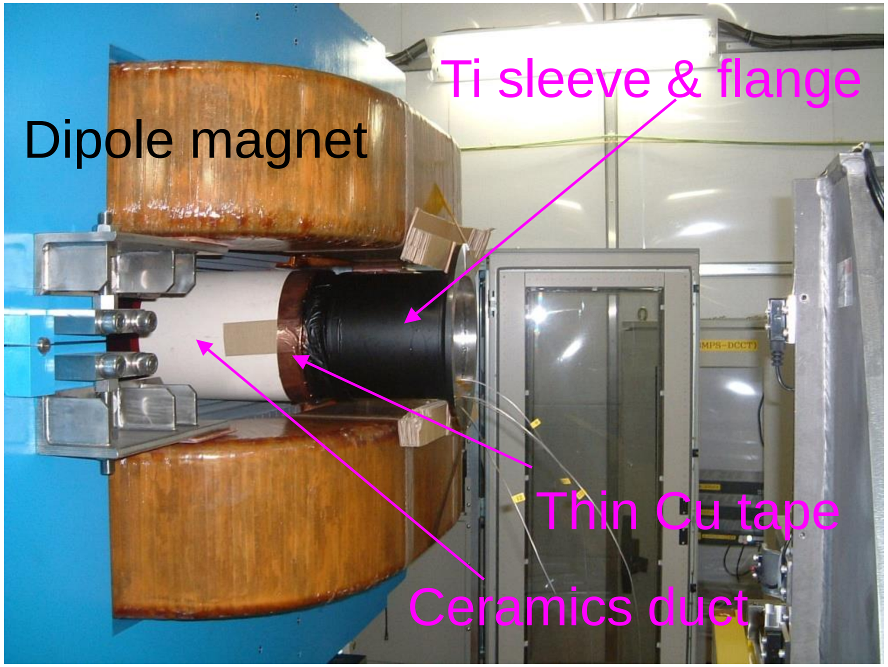
1.2×10^{-8} Pa m^3 s^{-1} m^{-2} after 50 h pumping. → sufficiently low value

- The chamber is kept dry after the Ni plating process, and is heated up to 830 °C in a vacuum furnace during brazing.
- The chamber is sealed by blank flanges. during an electroforming process for producing the rf shied.

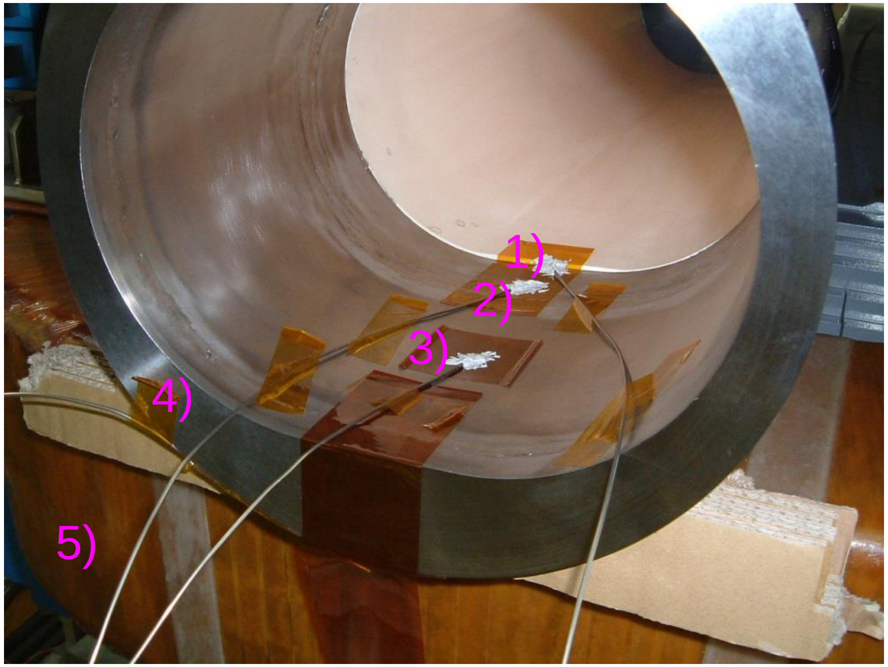
The inner surface of the chamber can be degassed and kept clean.

Temperature measurement - set up -

- Dipole magnet & Duct



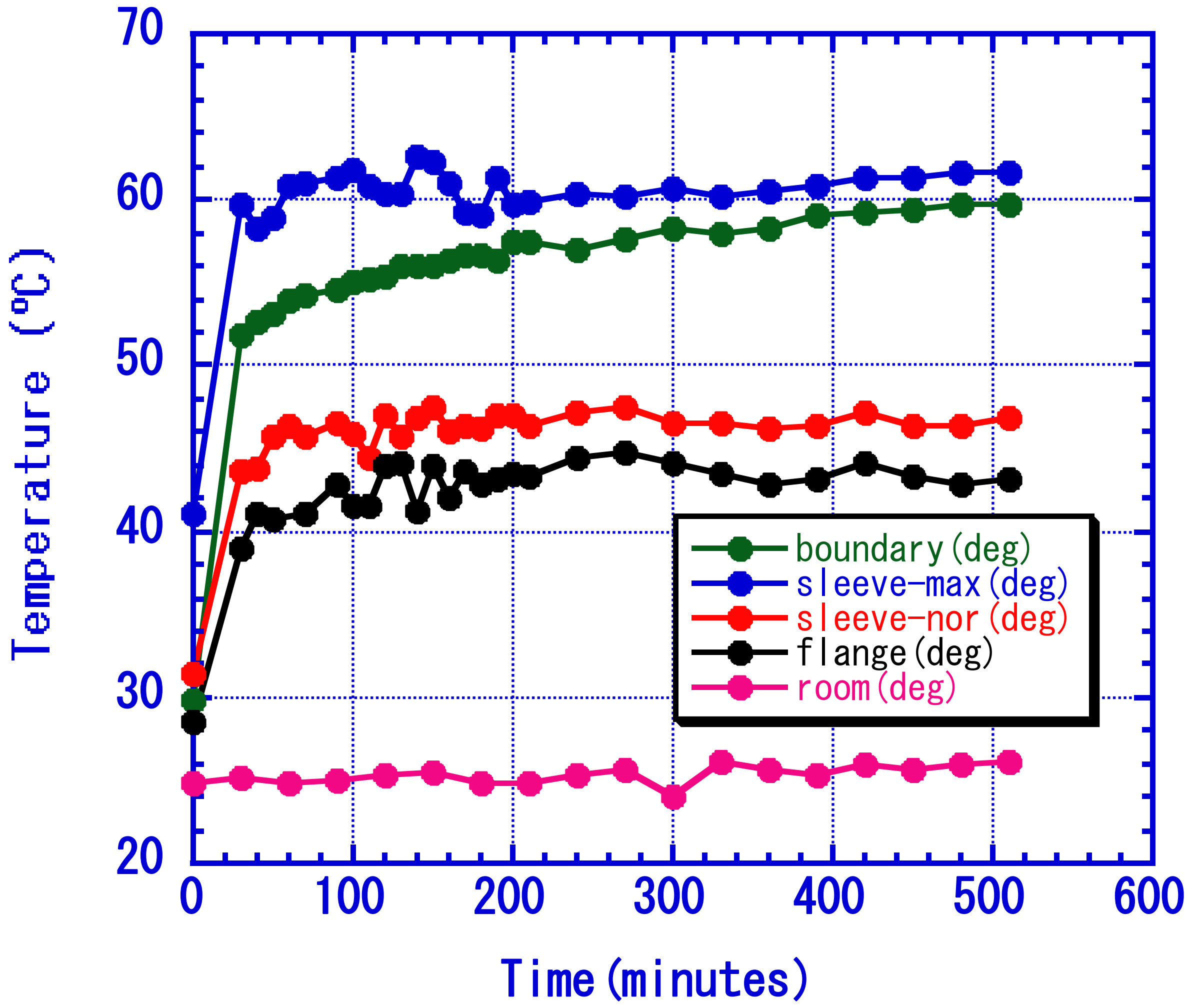
- Measurement points



- Dipole magnet were operated under normal operation conditions.
  - Repetition : 25 Hz
  - Magnetic field
    - Minimum : 0.17 T
    - Maximum : 1.1 T

- Temperature were measured by chromel-alumel thermocouple.
  1) boundary ceramics and Ti
  2) Ti-sleeve (thick area)
  3) Ti-sleeve (normal thickness area)
  4) Ti flange
  5) room

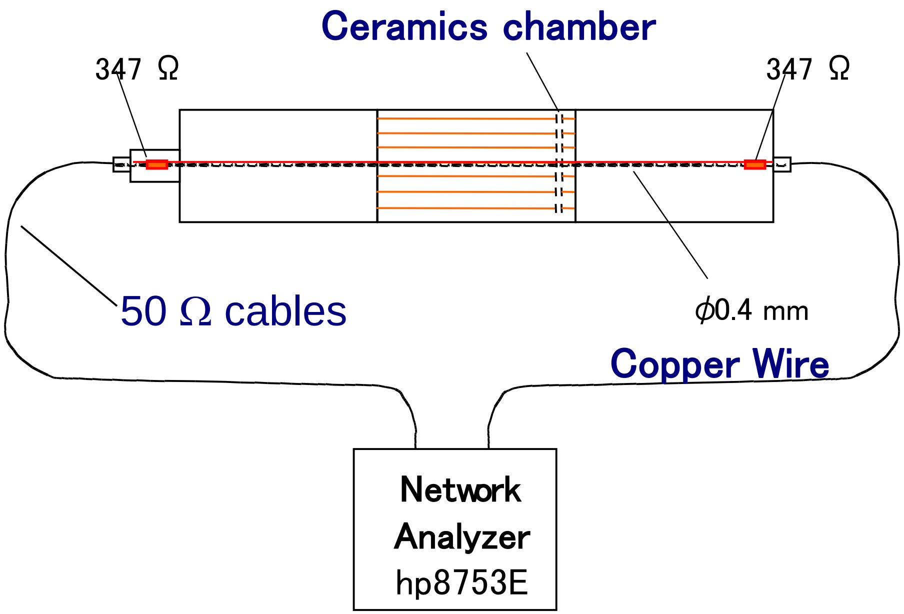
Temperature measurement - results -



Maximum temperature was about 65 °C and almost saturated.

➡ This chamber is usable for J-PARC accelerator !

Impedance measurements - method -



Schematic view of the impedance measurement with a coaxial wire method

$$Z_L = -2 Z_c \ln[S_{21}(DUT)/S_{21}(REF)]$$

ZL : Longitudinal impedance

Zc : Characteristic impedance

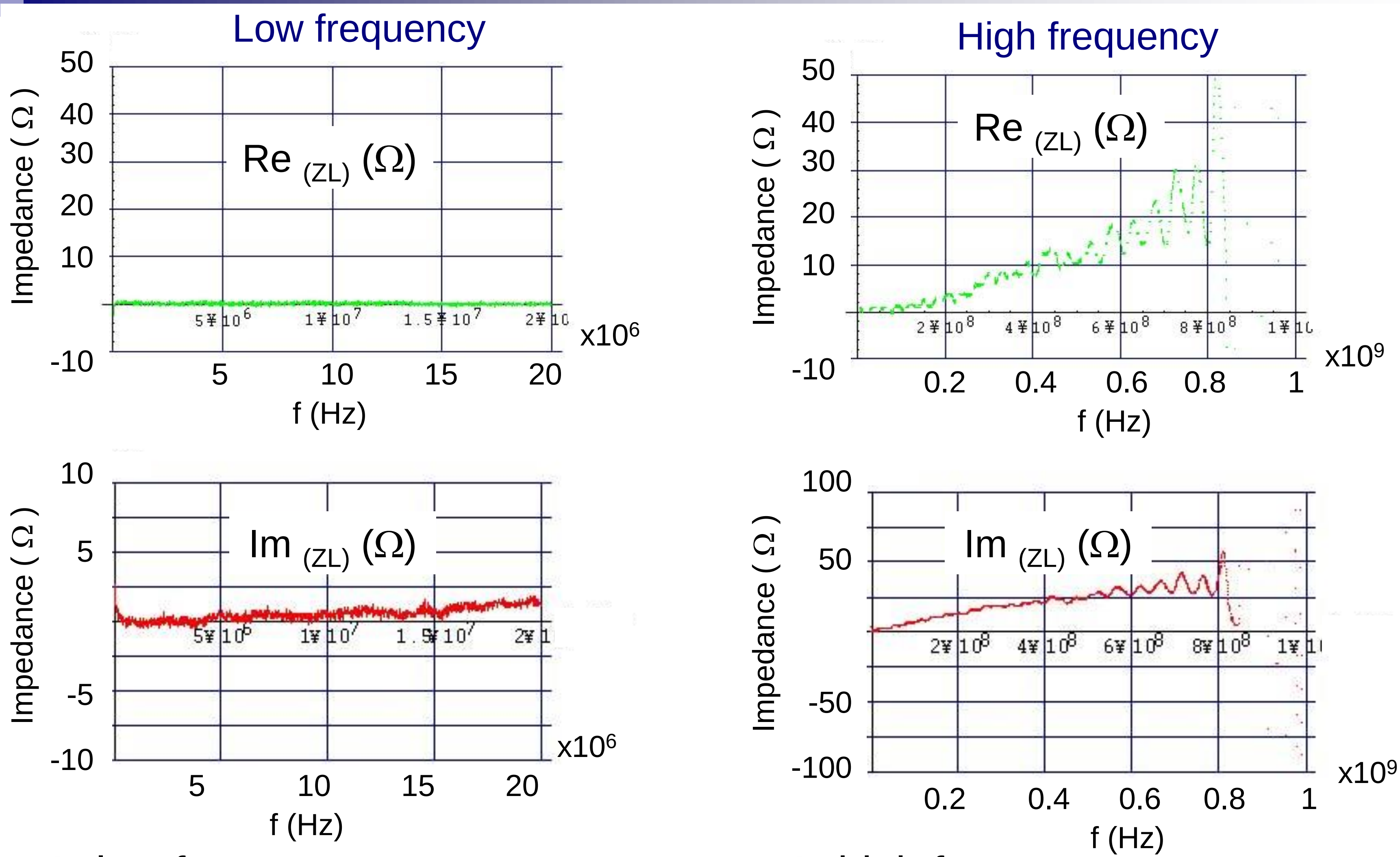
= 397 Ω as a coaxial circuit

- **A thin copper wire** of 0.4 mm diameter was stretched in the device under test with appropriate resisters for matching to 50 Ω cables at both ends.
- **Network analyzer** was connected to measure the S_{21}, transmission coefficient.

↓

- **The transmission coefficient** for dummy pipe, same in length and diameter as the ceramics chamber, was used as a reference, S_{21} (REF).
- **The transmission coefficient** was converted to the coupling impedance with the standard log formula.

Impedance measurements - results -



- At low frequency

  Impedance was very small.

- At high frequency

  Impedance was not so big.

➡ This chamber has good performance for the impedance !

Beam study at KEK-PS - set up–

Installed at KEK-PS

To determine the cahmber installation effect to beam, the ceramics chamber was installed in the 12 GeV main ring at KEK-PS.

⬇

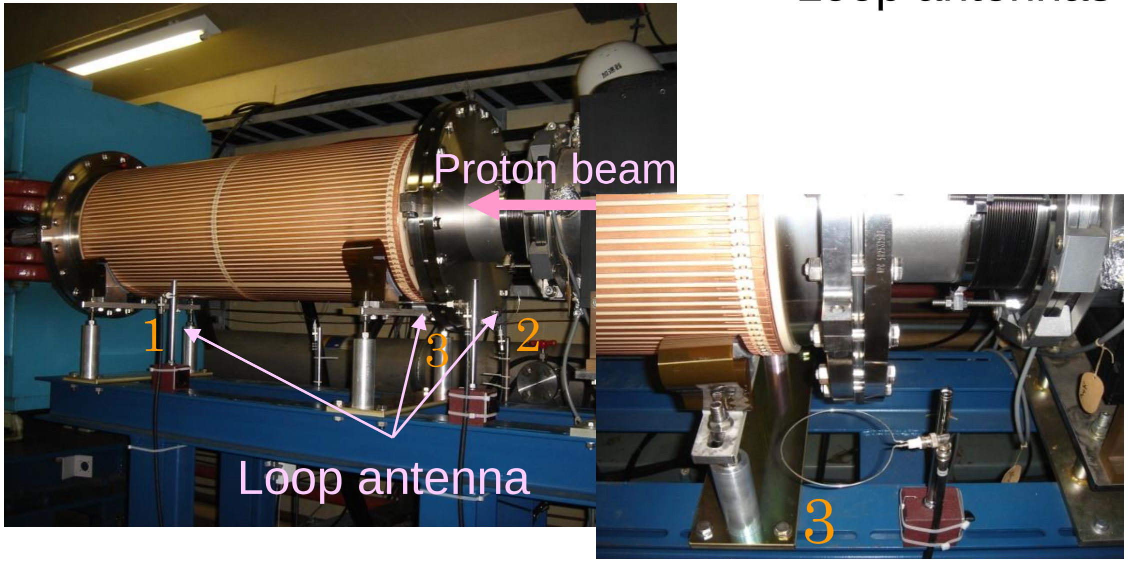
Proton beam has been kept to accelerate stably !!

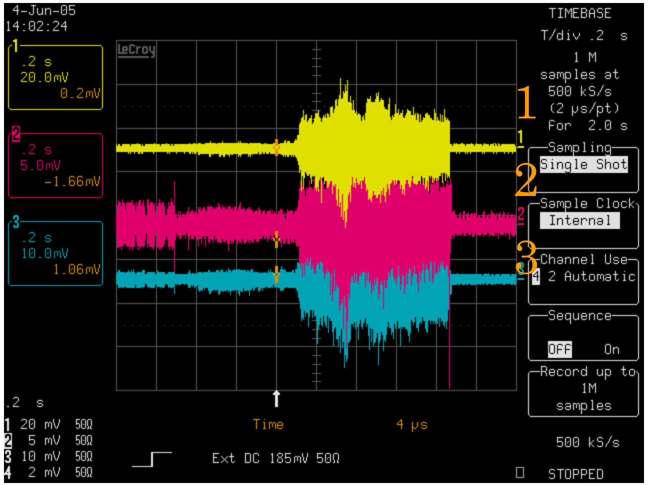
⬇

This chamber did not so much influence on the beam.

Set up of loop antennas

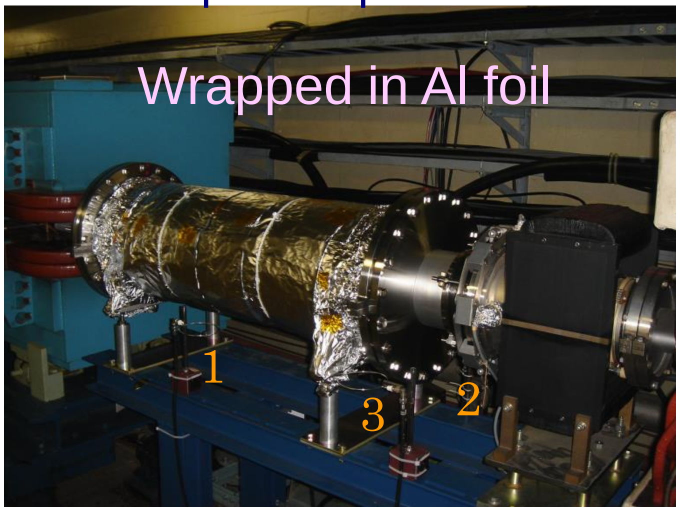
To measure for rf leakage generated by the beam, Loop antennas were set around the chamber.

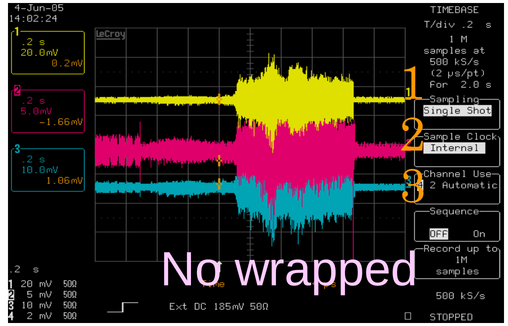


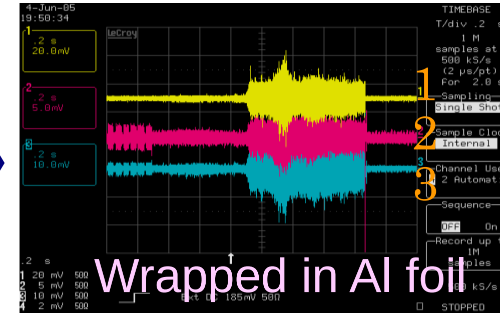


Beam study at KEK-PS

Set up of loop antennas



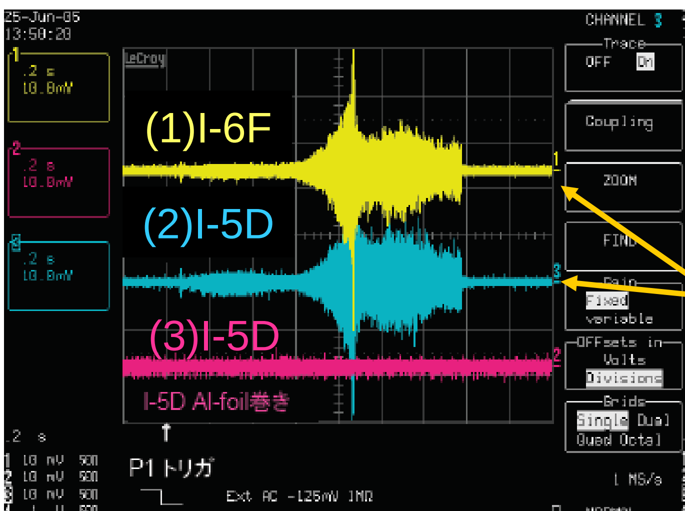




Almost same

Rf leaks not from ceramic chamber but another place !

Signal of loop antenna



- Signals

  (1)I-6F: Metal chamber was installed.

  (2)I-5D: Ceramics chamber was installed.

  (3)I-5D: Ceramics chamber was installed used by Al-foil wrapped antenna

Almost same

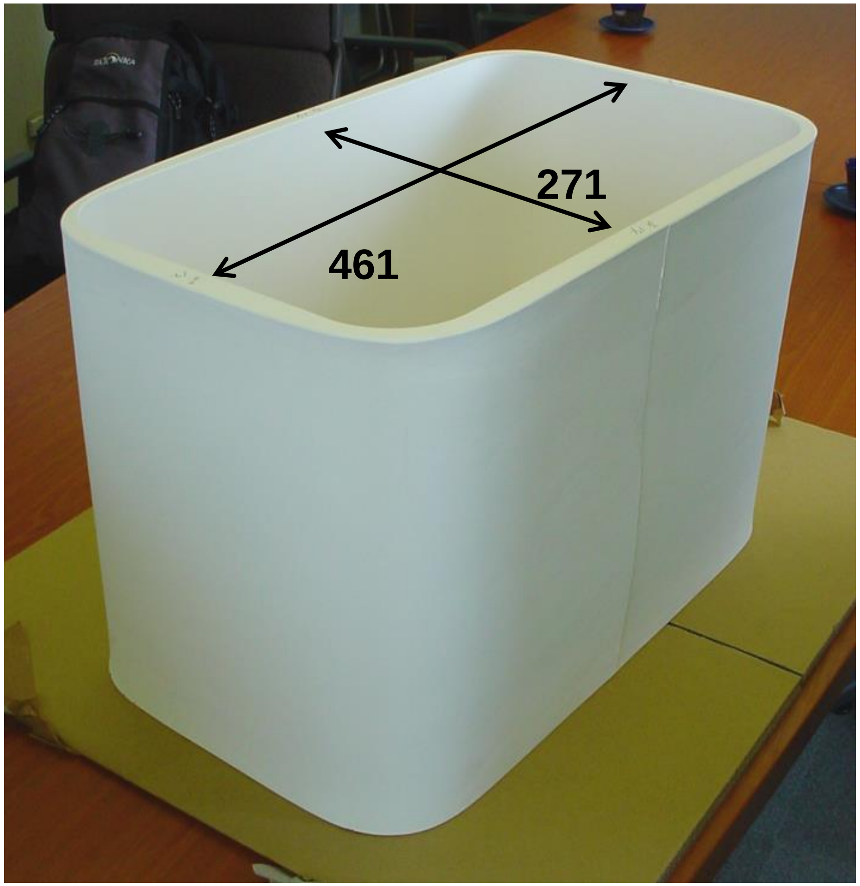
This ceramics chamber dose not have rf leakage !!

Summary

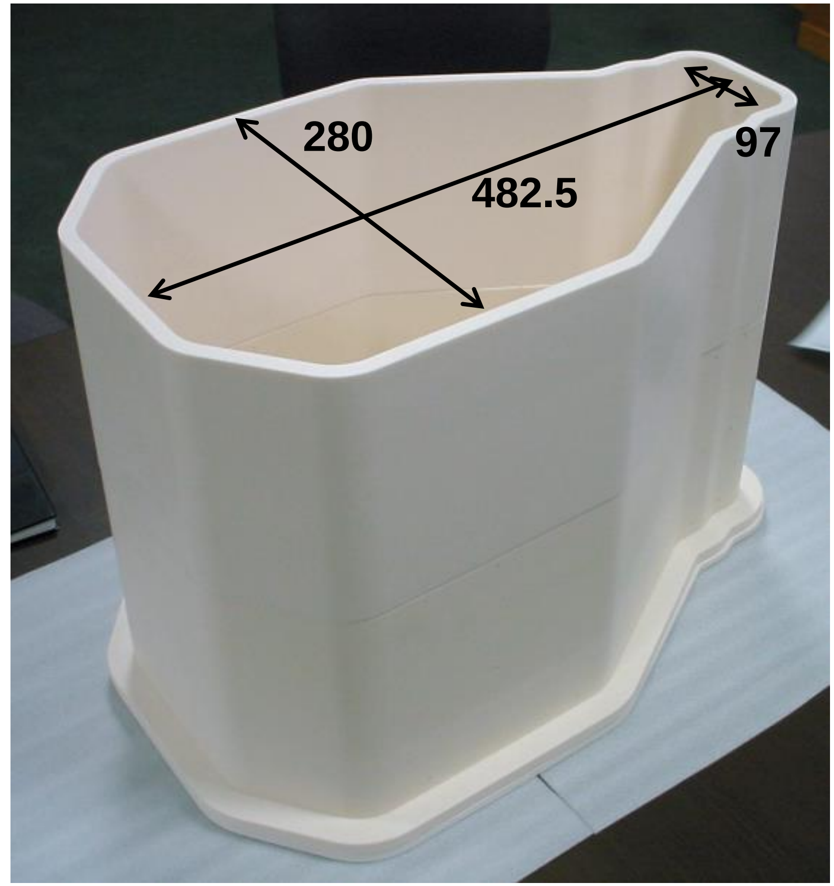
- It was success to produce a titanium flanged alumina ceramics vacuum chamber with low impedance.
- Outgassing rate of the chamber is 1.2×10^{-8} Pa $m^3 s^{-1} m^{-2}$ after 50 h pumping. This value is sufficient small for our vacuum system.
- Eddy current heating of the titanium sleeve and flange was not so big.
- This chamber has good performance for the impedance, because the duct impedance is sufficient small for inducing beam instability.
- This chamber did not influence on the beam.
- Mass production of the ceramics vacuum chamber is performing.

Status – ceramics unit duct for injection magnet –

for shift bump magnet



for injection quadrupole magnet



Production of unit duct for injection magnet almost has been done !

Present status of J-PARC as Sept, 05

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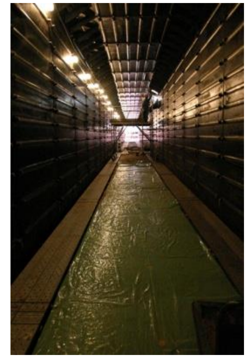
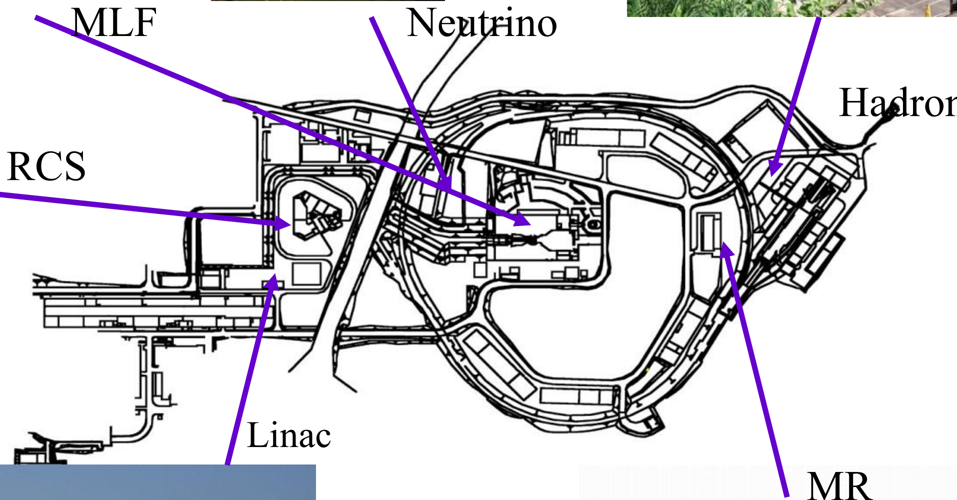
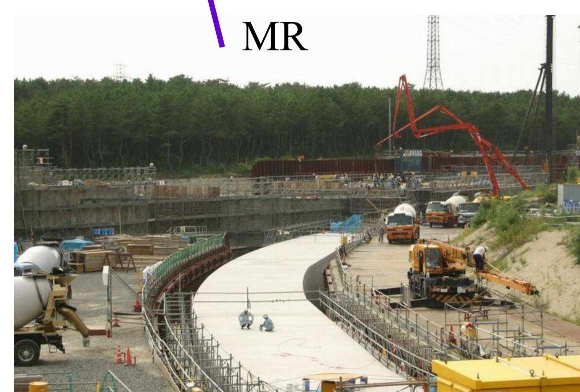






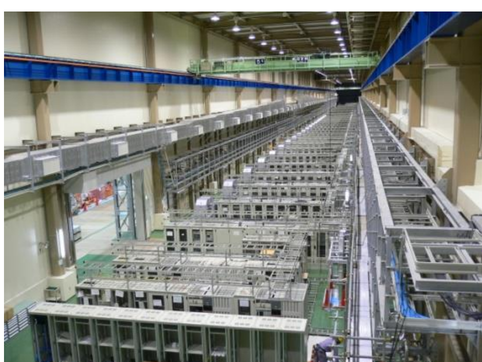
Present status of J-PARC as Sept, 05

Linac to RCS

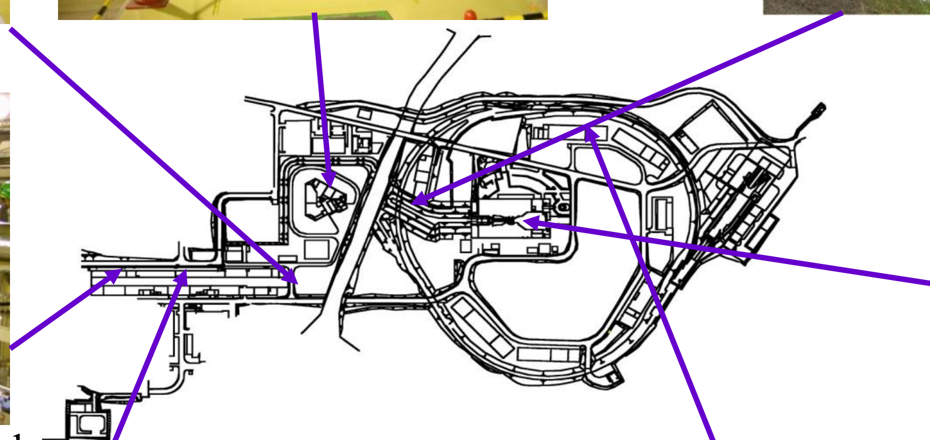
Branching to MR and MLF

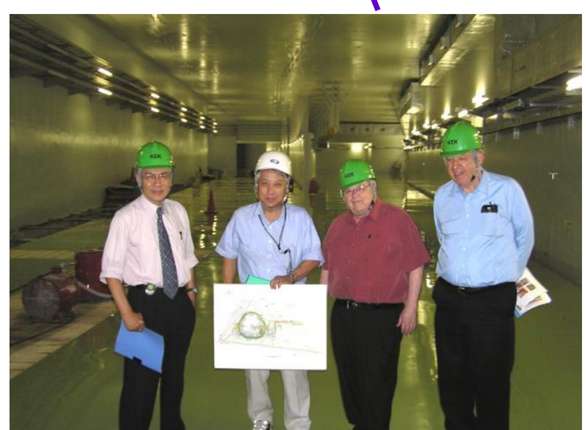
To MLF

RFQ and Linac front end



Klystron Gallery





Neutron Target

- MR tunnel with
- Profs. Richter and Friedman