The 4th International Particle Accelerator Conference, **IPAC'13** in Shanghai, China, May 12 - 17, 2013

Power Upgrade of J-PARC Linac

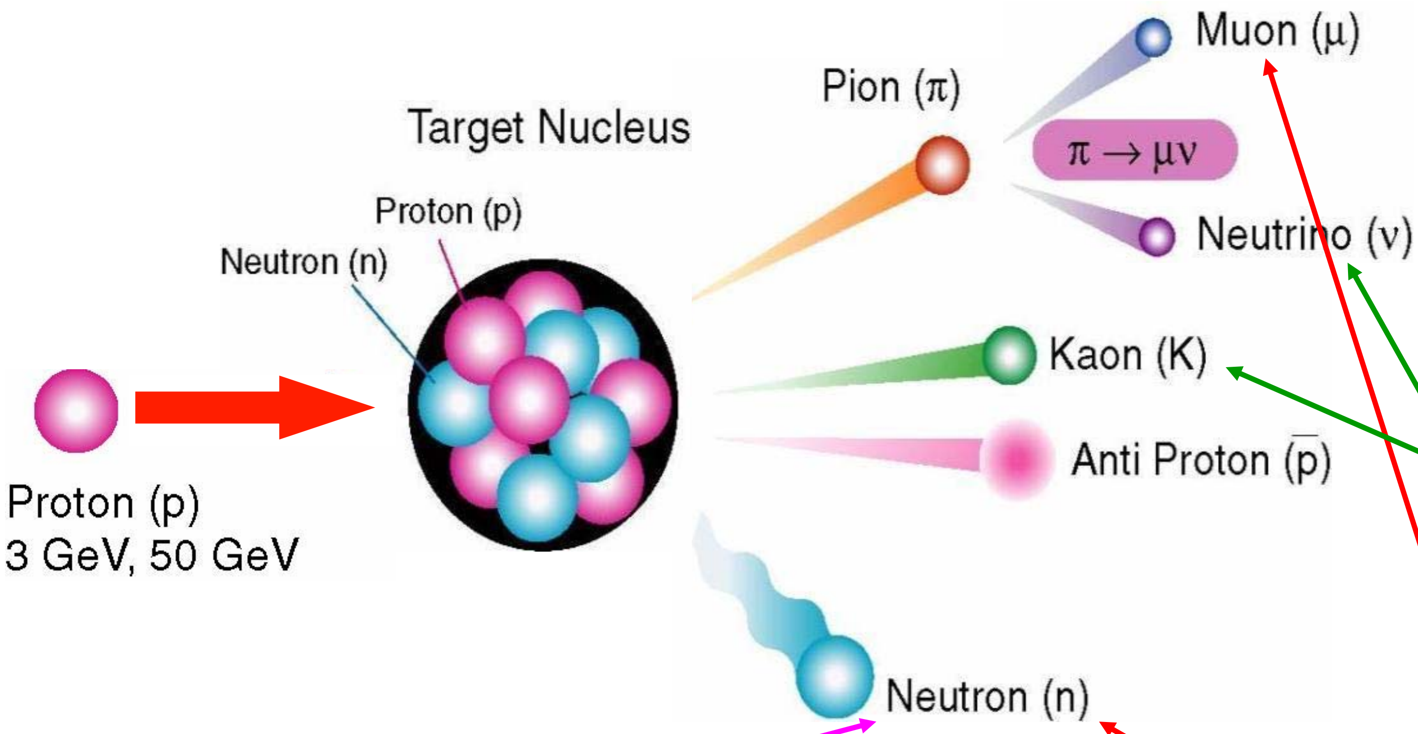
Hidetomo Oguri

J-PARC center

Contents of the presentation

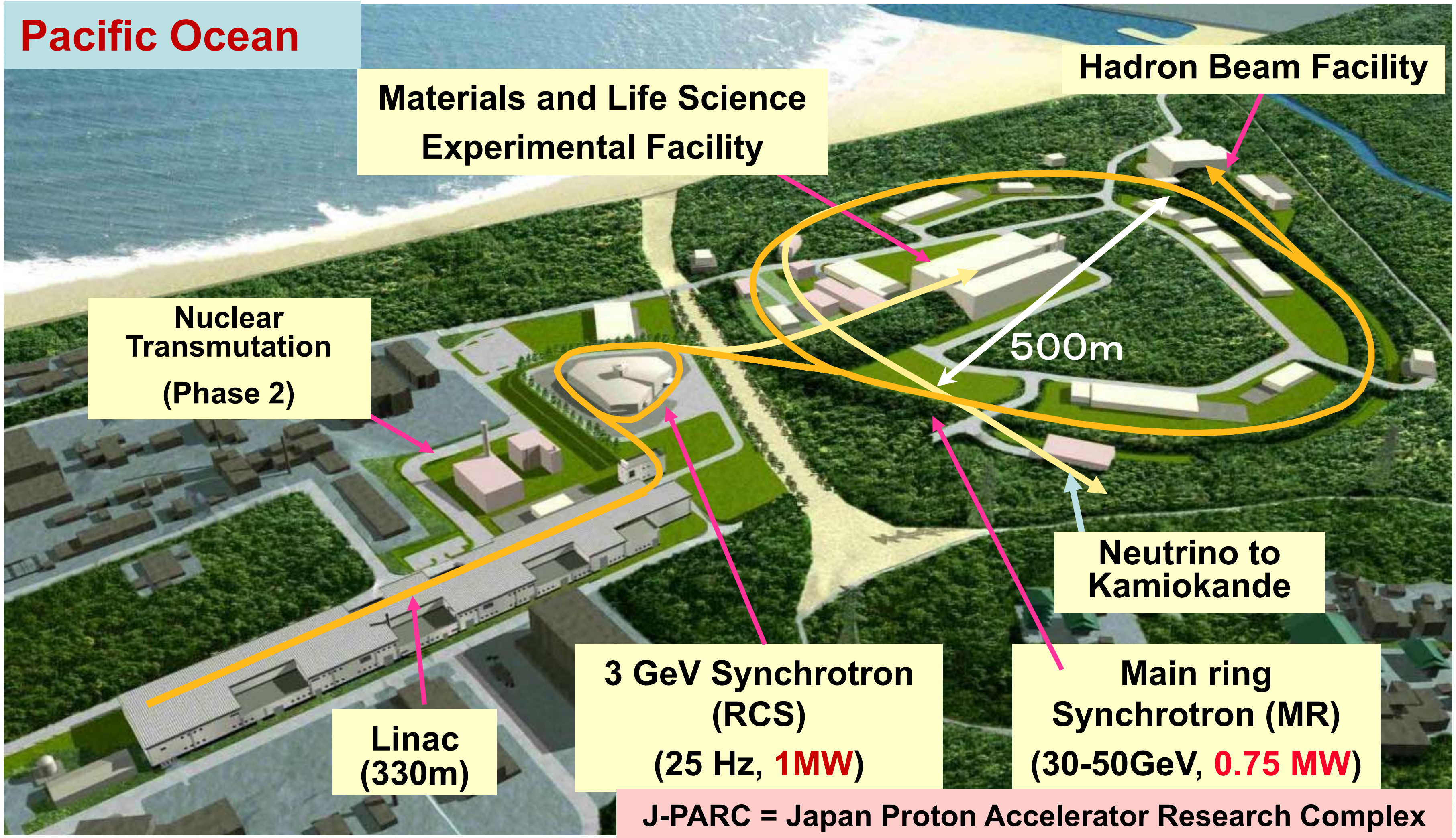
- Outline of power upgrade
- Status of some key components
  - Ion source
  - RFQ
  - ACS cavity
  - Bunch shape monitor
  - Beam chopper system
- Upgrade schedule
  - ACS installation schedule
  - Front-end installation schedule
- Summary

Goals at J-PARC



- Materials & Life Science at 3 GeV (1MW)
- Nuclear & Particle Physics at 30-50 GeV (0.75MW)
- R&D toward Transmutation at 0.6 GeV (200kW)

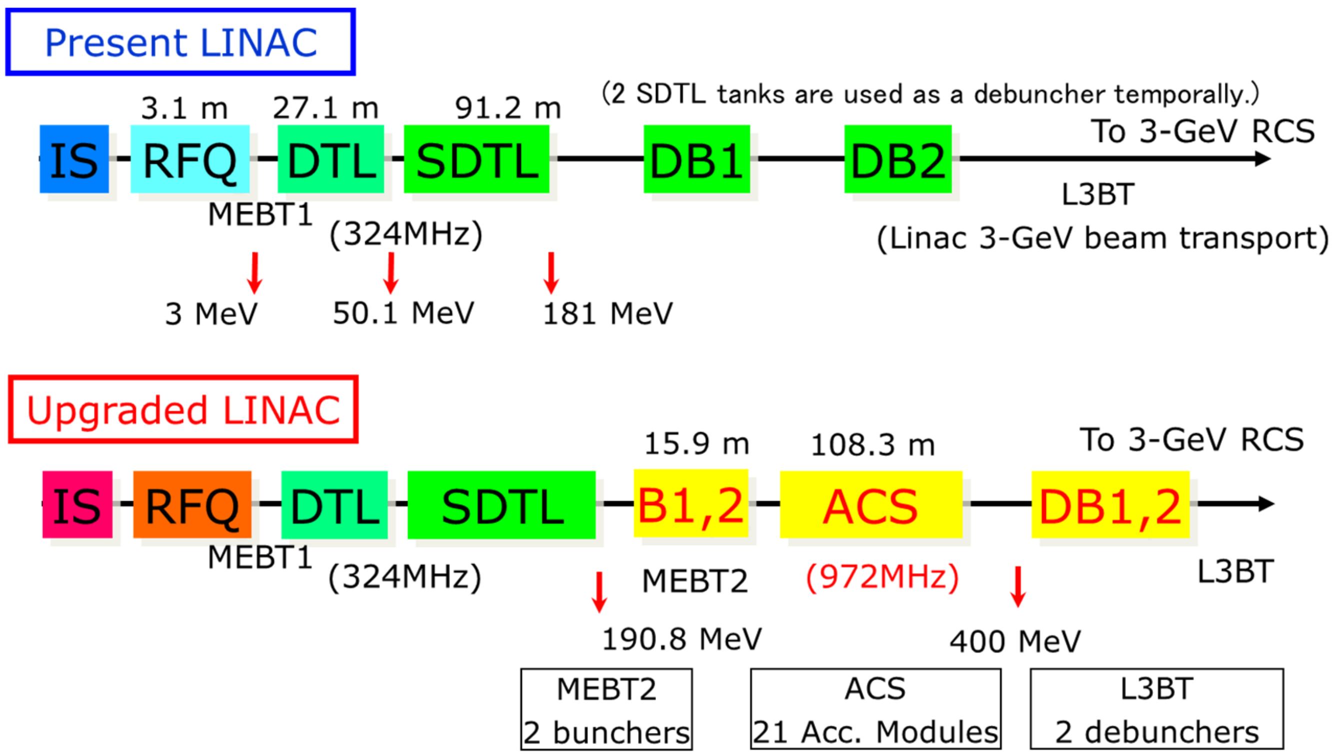
J-PARC Facility



Joint Project of KEK and JAEA

Upgrade plan of J-PARC linac

- Acceleration particle: Negative hydrogen ion (H^-)
- Energy: **181 MeV** at present -> **400 MeV**
- Peak current: **30 mA** (design) -> **50 mA**
- Pulse width/ repetition: 0.5 msec/ 25 Hz



- Energy will be upgraded with ACS linac.
- Current will be upgraded with new ion source and RFQ.

Status of some key components

- Ion source
- RFQ
- ACS
- Bunch shape monitor
- Beam chopper system

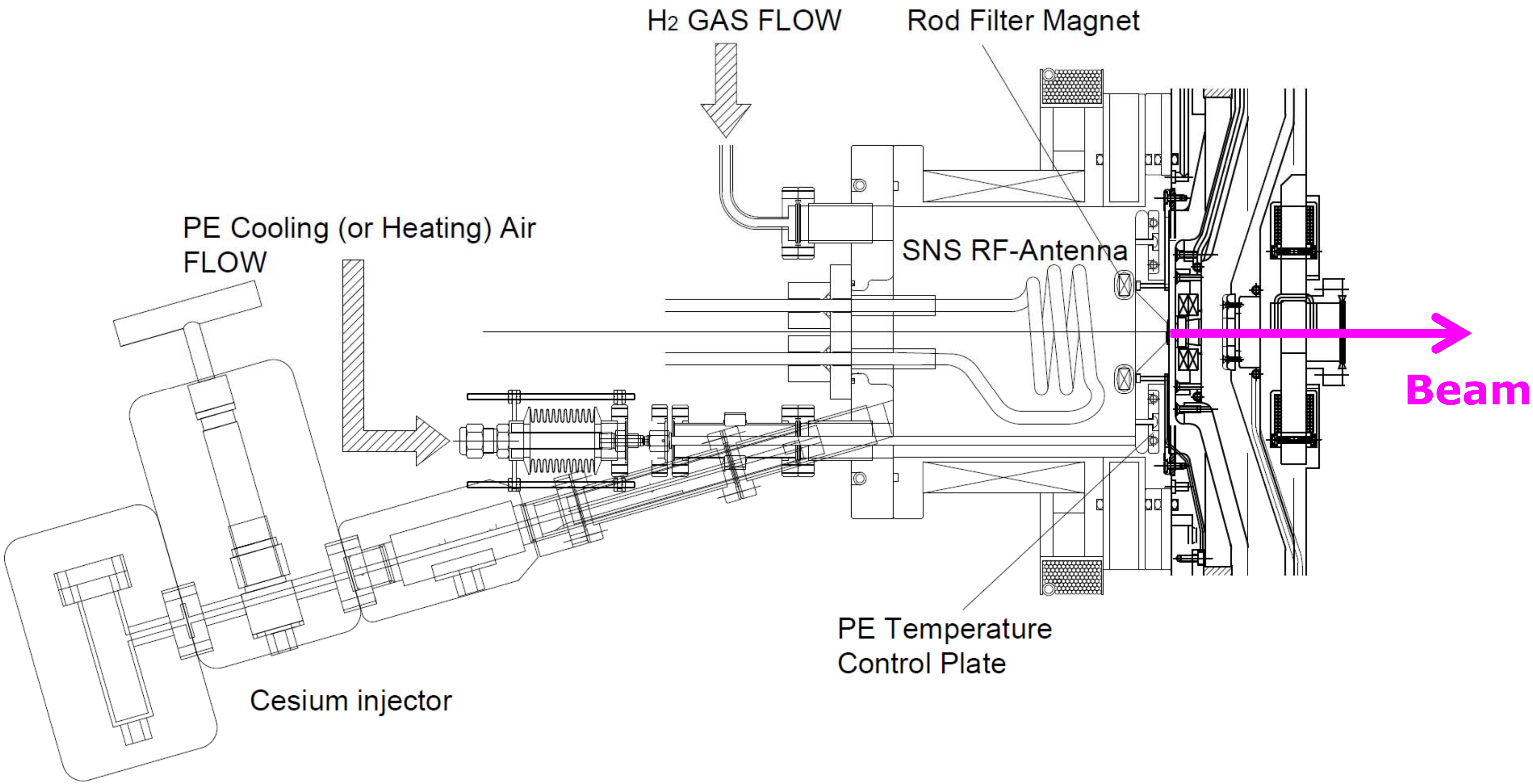
Overview of J-PARC Ion Sources

Ion source upgrade requirement: 60mA, 50days

Ion source	IH^- [mA] routine /(study)	Cs consumption	Spark rate	Lifetime [day]
Operating (LaB_6)	19/ (34)	Not	Less than once a day	50 @19mA
Prototype-1 (LaB_6+Cs)	(34)	[No Cs effect]		
Prototype-2 (W+Cs)	(76)	Several g /30day	A few times /hour	~4
Prototype-3 (RF+Cs) with SNS antenna	>60	0.74 g / 50day (Estimated)	Less than once a day	>50 (estimated from SNS results)

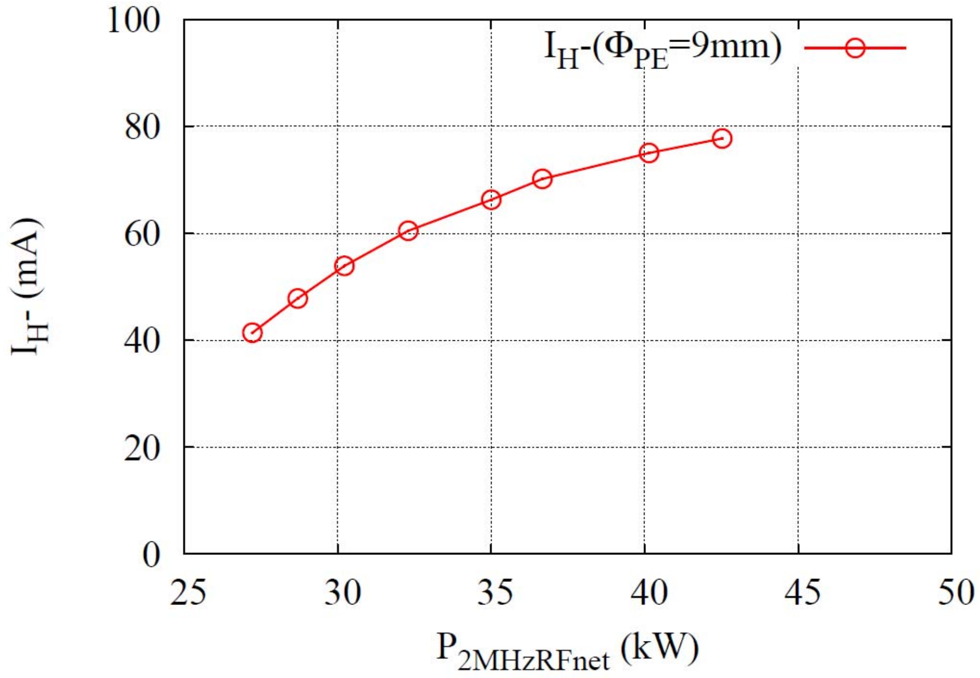
- **Cesiated RF-driven** ion source (prototype-3) are almost satisfied with the upgrade requirements.

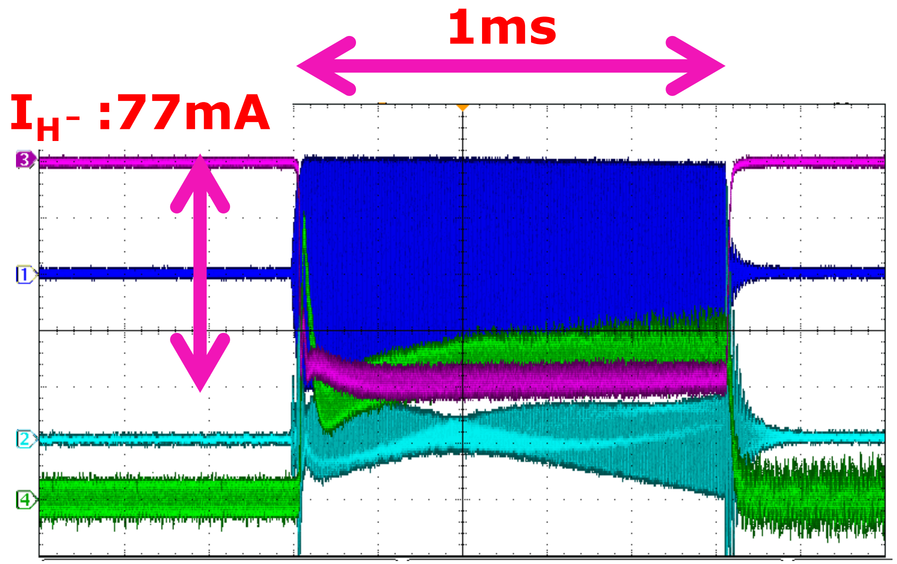
J-PARC RF-driven Ion Source



- 2MHz-RF with internal-antenna (developed at SNS)
- 120 mm in inner diameter of plasma chamber
- Cesium seeded using an oven
- Temp. of plasma electrode is controlled by air flow.
- Rod filter magnet

Ion source: Beam current





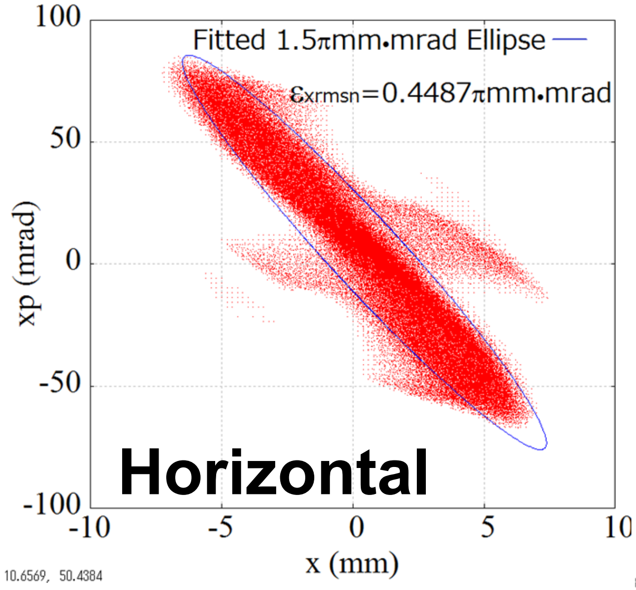
CH1: RF forward(100mV/div)
CH2: RF reflection(20mV/div)
CH3: H^- beam current (20mA/div)
CH4: Extraction current (50mA/div)

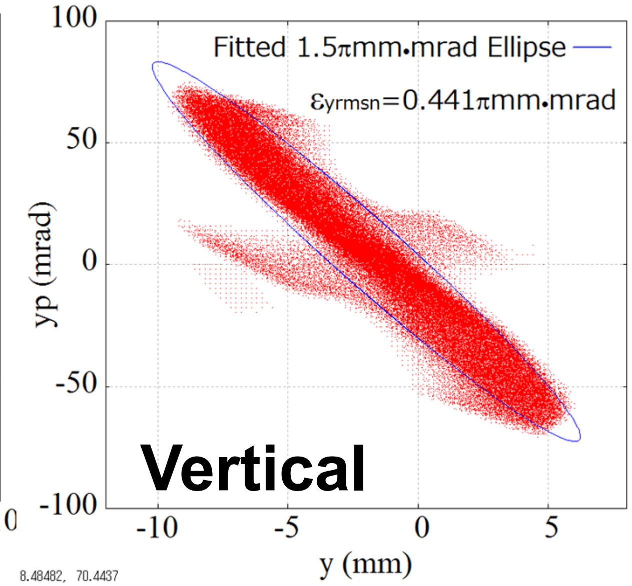
- H^- beam current increased with the 2MHz-RF power and reached **77mA** at 43kW.

*Pulse width: 500 μs
*Pulse repetition rate: 25 Hz
*H_2 gas flow rate: 20 SCCM

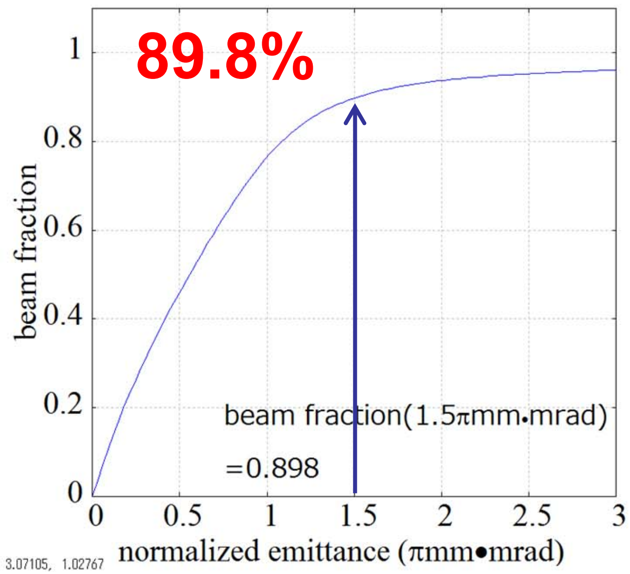
- Ratio of the reflected 2MHz-RF power to the forward one is estimated to be less than 1%.
- I_{H^-} is fluctuated about ±4.3% with the 2MHz frequency.

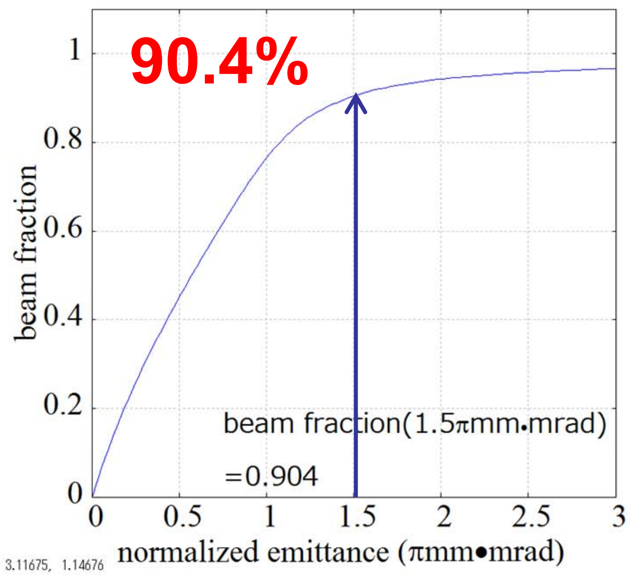
Ion source: Emittance





Beam current : 77mA
Nor. RMS emittance
Hori.:0.45πmm･mrad
Vert.:0.44πmm･mrad

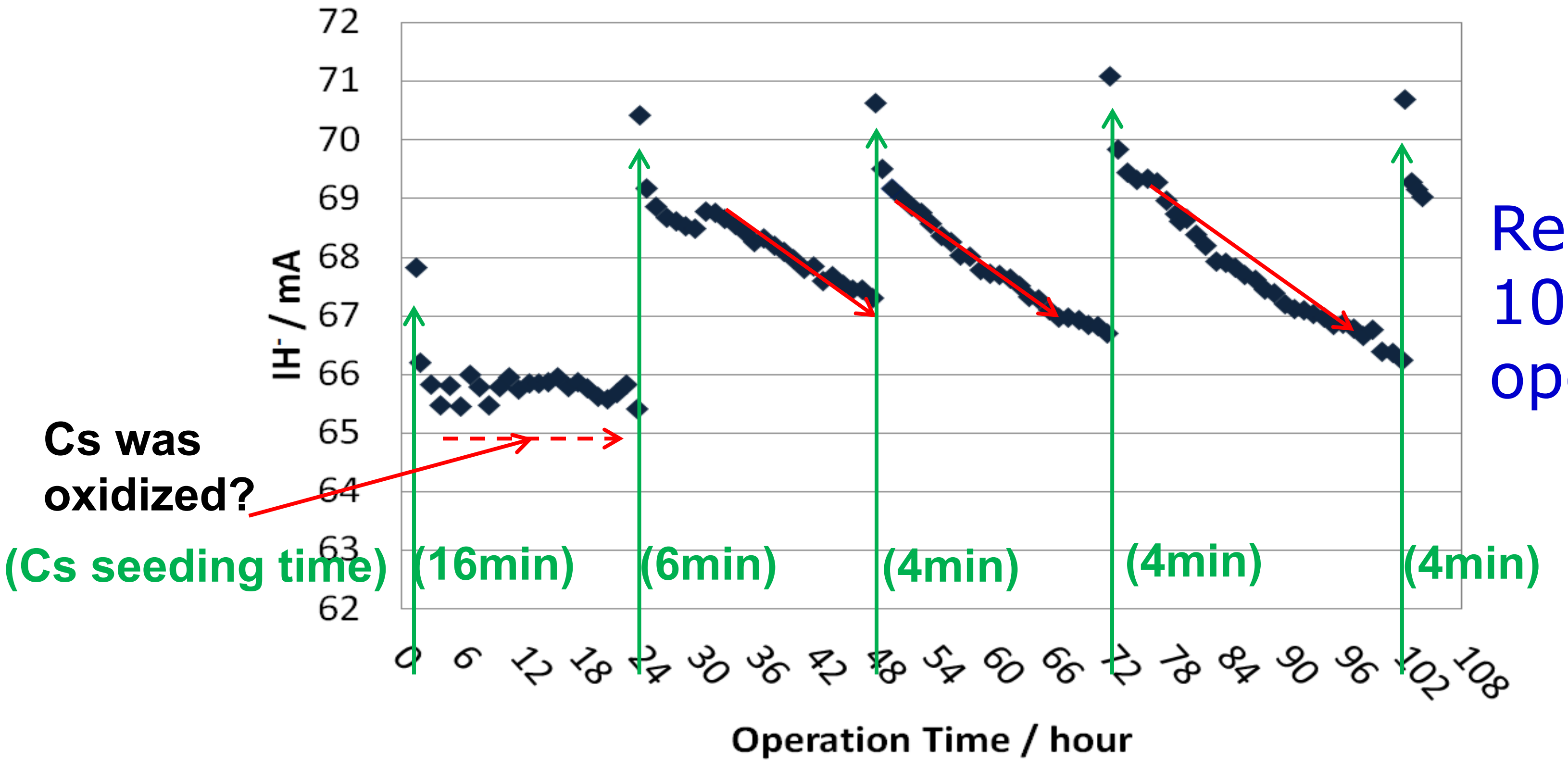




H^- within the ellipse of ε=1.5 πmm･mrad is calculated to be more than **60mA.**

Required beam(ε=1.5 πmm･mrad, 60mA) is obtained.

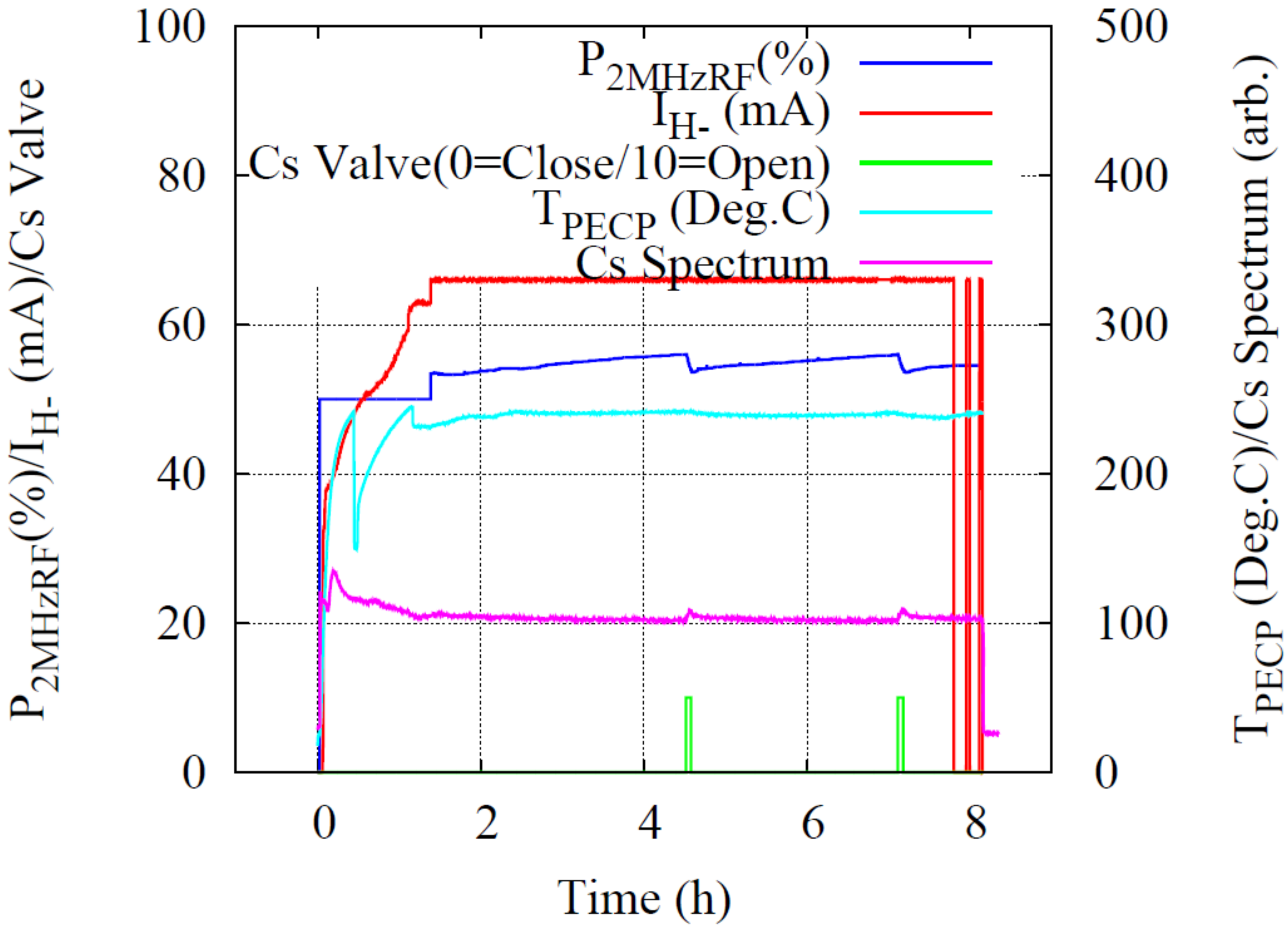
Ion source: Cont. test operation



Result of 100h test operation

- IH^- beam decreasing rate:0.1mA/h
- Four minutes Cs seeding par day is enough to maintain the I_{H-}.
- Extrapolated Cs consumption for 50days operation is **0.74g**.
- Spark rate of less than once a day was observed.
  - ➢ **Cesium consumption of 0.74g/50day seemed to be acceptable because the spark rate is the same level as that of the current cesium-free ion source.**

Ion source: H^- feedback control



- RF power is increased automatically to keep the I_{H-}.
- Cs valve is opened automatically when RF power becomes high.
  - I_{H-} is successfully stabilized for both slow (0.1mA/h) and fast (Cs valve open/close) fluctuations.

Ion source: Next step

□ Reduction of maintenance time

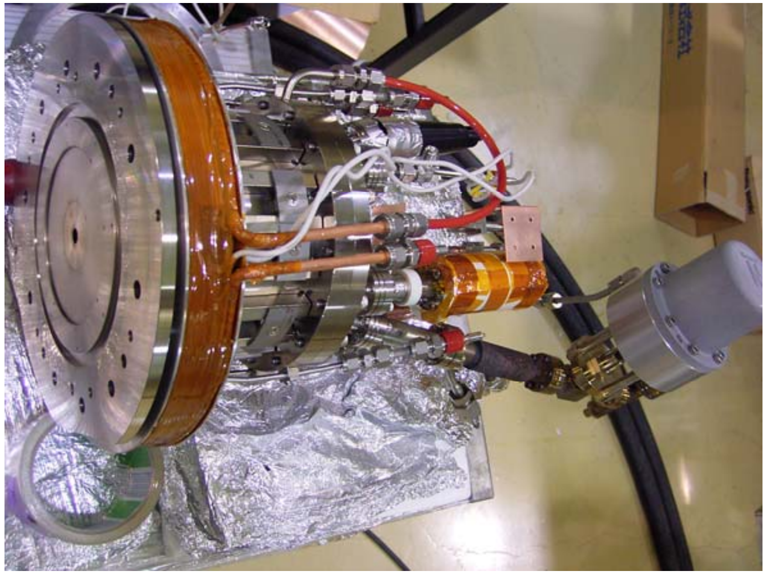
->Unitize the components (similar to the operating source)

- An plasma chamber, whose periodic replacement parts are unitized, was newly fabricated. The test of the ion source is in progress.

□ Long term operation test

-> Measure lifetime of the antenna
-> Check of stability and reliability

- We are now preparing for performing long term operation using a RFQ test stand.



New plasma chamber
(replacement parts are unitized)

Overview of J-PARC RFQs

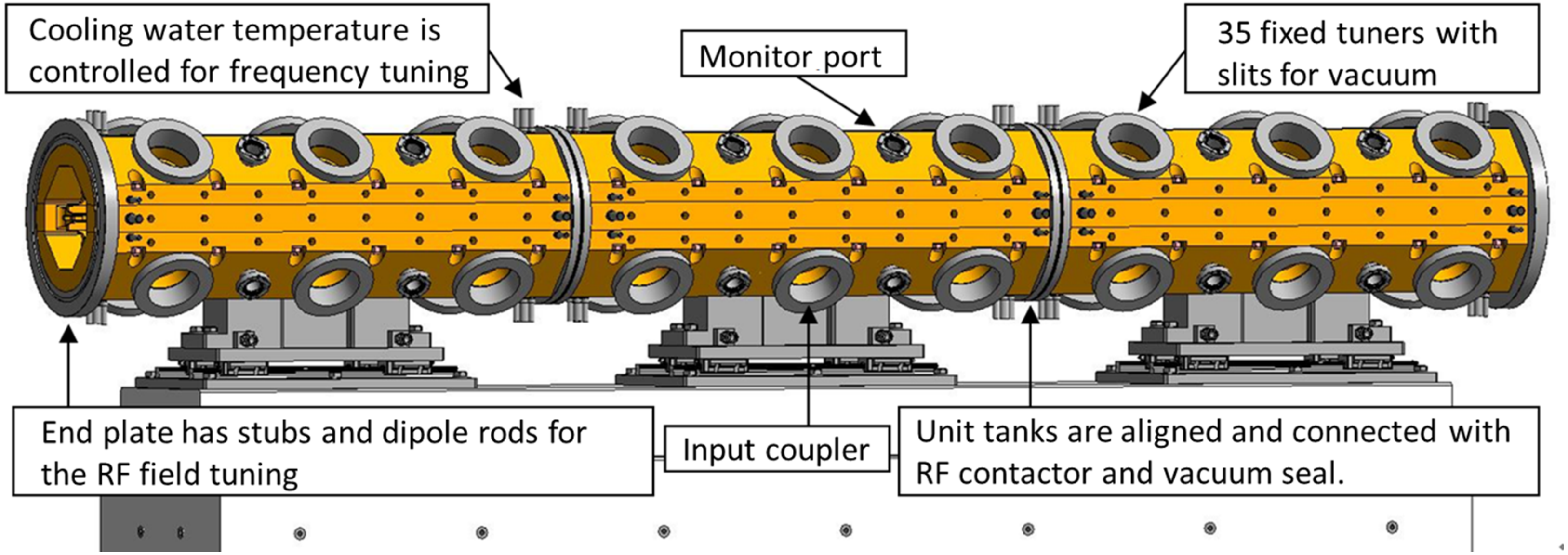
- The commissioning of the J-PARC linac started in 2006 using an RFQ with a design current of 30 mA (**RFQ-I**). Just after starting the user operation in 2009, serious sparking problem occurred at the RFQ-I. By some measures, the problem is almost solved.

- The **RFQ II** is originally planned to be a spare of the RFQ-I. Additional role of RFQ II is establishing and verifying the technical elements of J-PARC RFQ.

- To achieve the 1 MW, a RFQ with a design current of 50 mA is newly fabricated **(RFQ-III)** based on the same engineering design and the fabrication technologies as those of the RFQ-II.

	RFQ -I	RFQ- II	RFQ -III
Design current	30mA		50mA
Present status	Operating	High-power tested	Under testing

Structure of RFQ-II & III

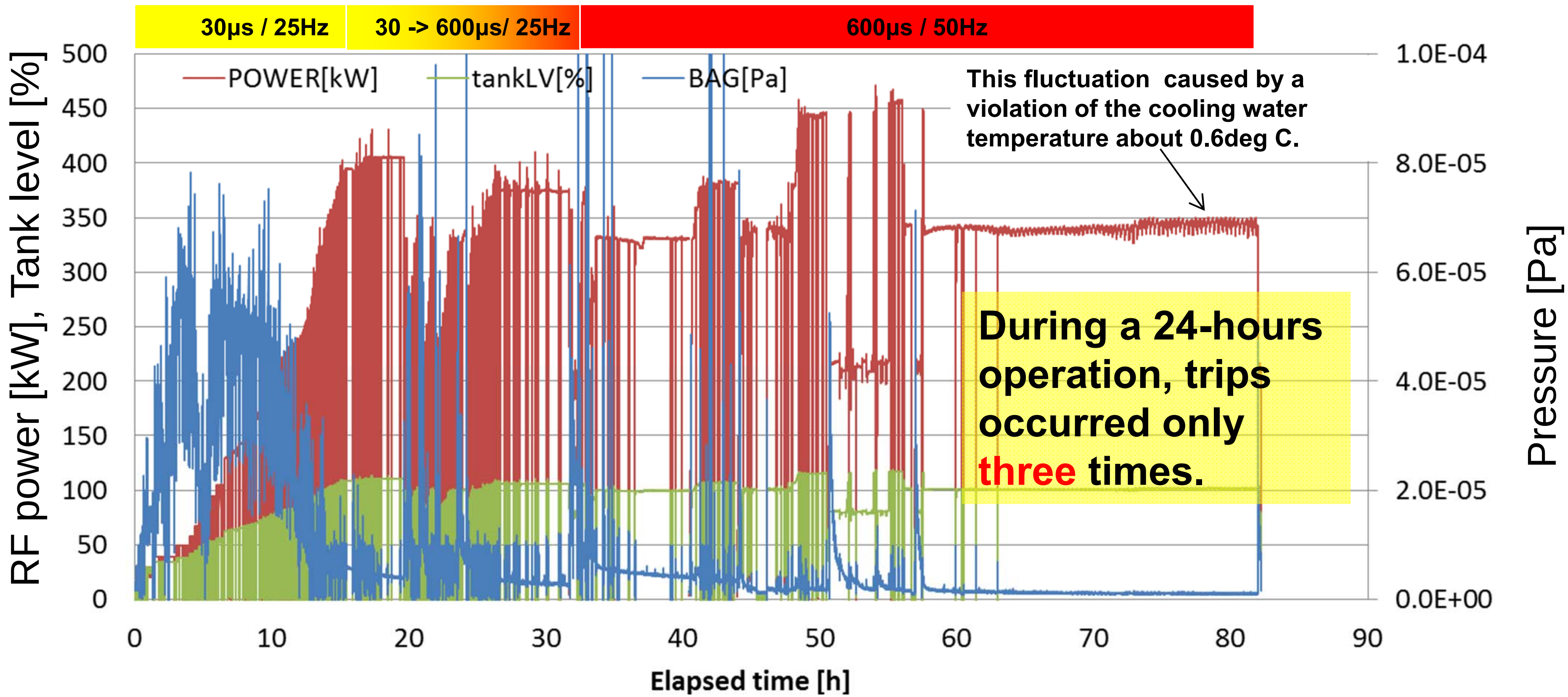


Basic structure of RFQ-II & III

- The major engineering change between RFQ-I and RFQ-II or III is the design of the **RF cavity structure**.

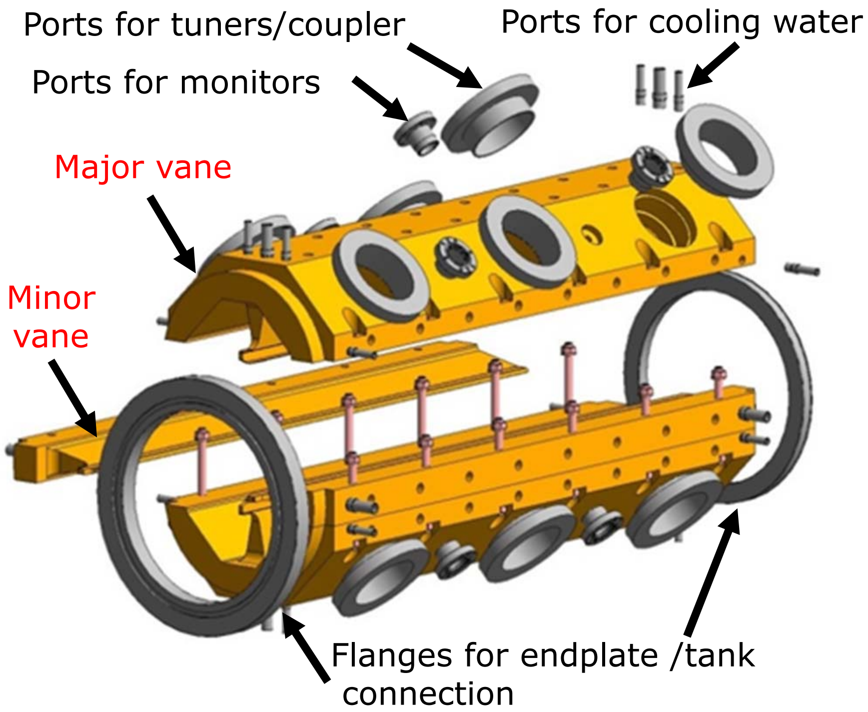
- **RFQ-I**: The RF cavity is installed in a large vacuum vessel. It is difficult to obtain good vacuum quality because the surface area of this type is very large.
- **RFQ-II and III**: Vacuum-tight cavity structure is adopted. To this end, we adopted brazing for the assembly method.

High Power test of RFQ-II

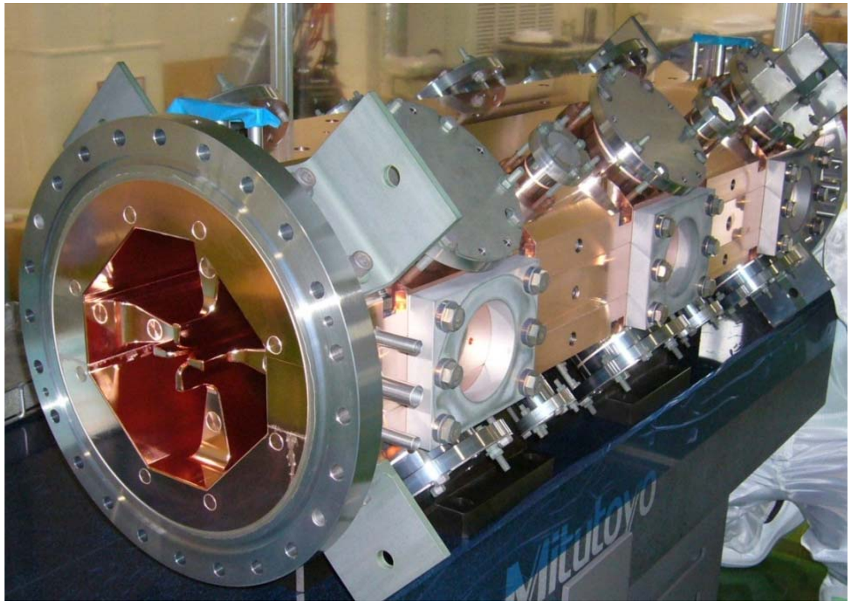


- About 50 hours of conditioning, the power reached up to 118 % of the nominal power.
- 24 hours operation test was conducted at the nominal power. Trips occurred **only 3 times**, and stable operation was confirmed.
- Such positive results encouraged us to develop the RFQ-III.

Fabrication of RFQ-III 1/2



Assembling of vanes and other components of the unit tank for brazing

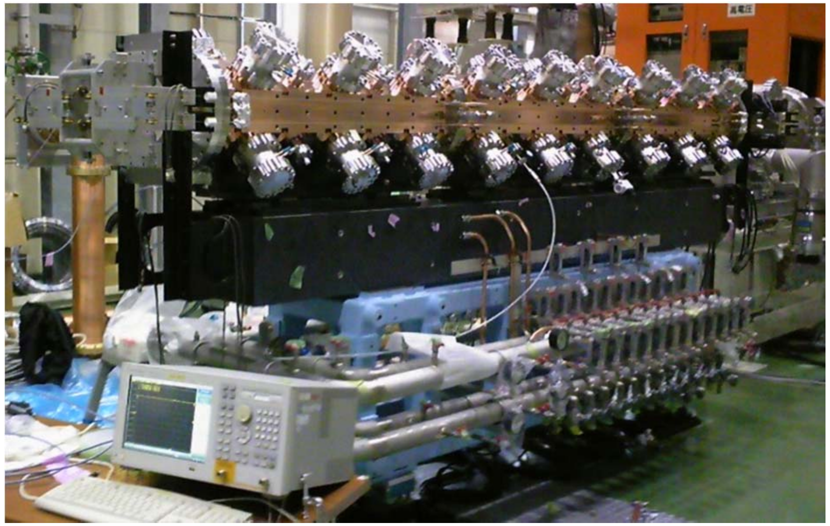


Unit tank after brazing

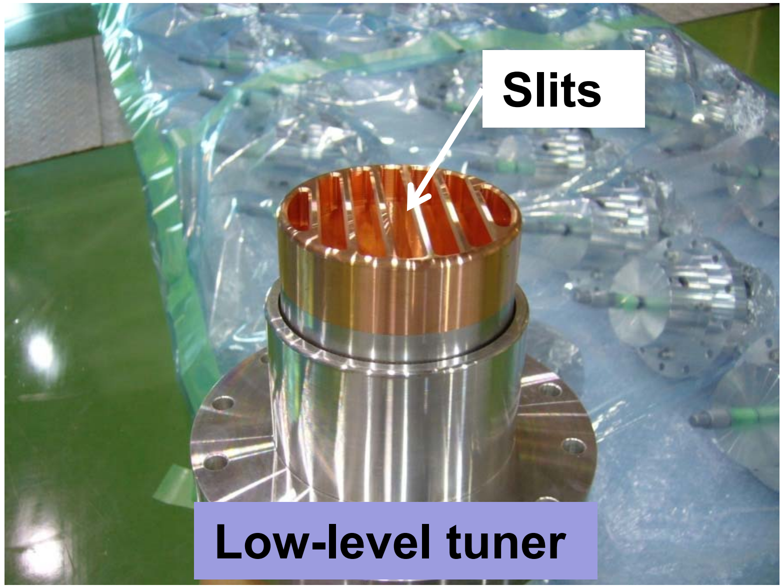
- Vanes are brazed at horizontal position.
- Vanes, ports, and flanges are brazed in one-step brazing to reduce the fabrication process and the cost.
- Relative position accuracy of vane tip are within +/- 0.03 mm in the unit cavity after brazing.

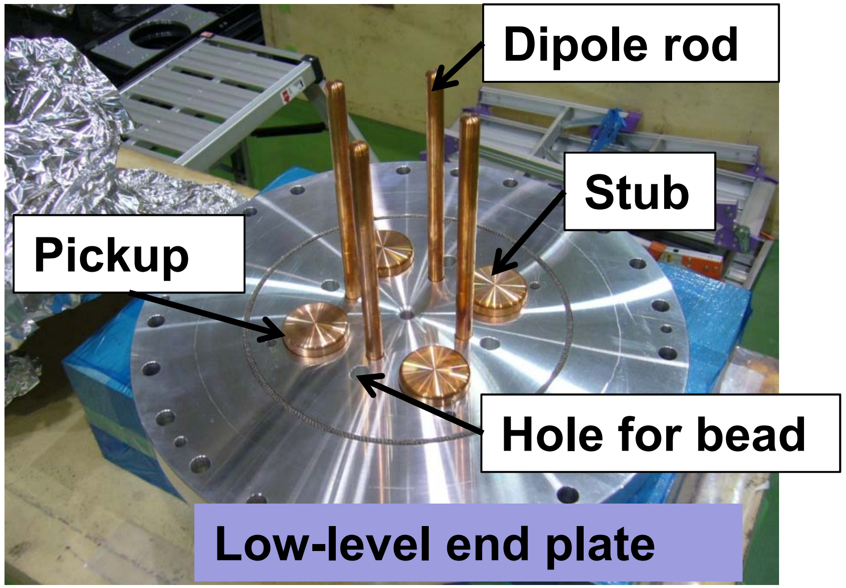
Fabrication of RFQ-III 2/2

- After the brazing, units are integrated together on the platform. The movable tuners, the endplates, and the loop coupler are equipped for a low-level tuning.



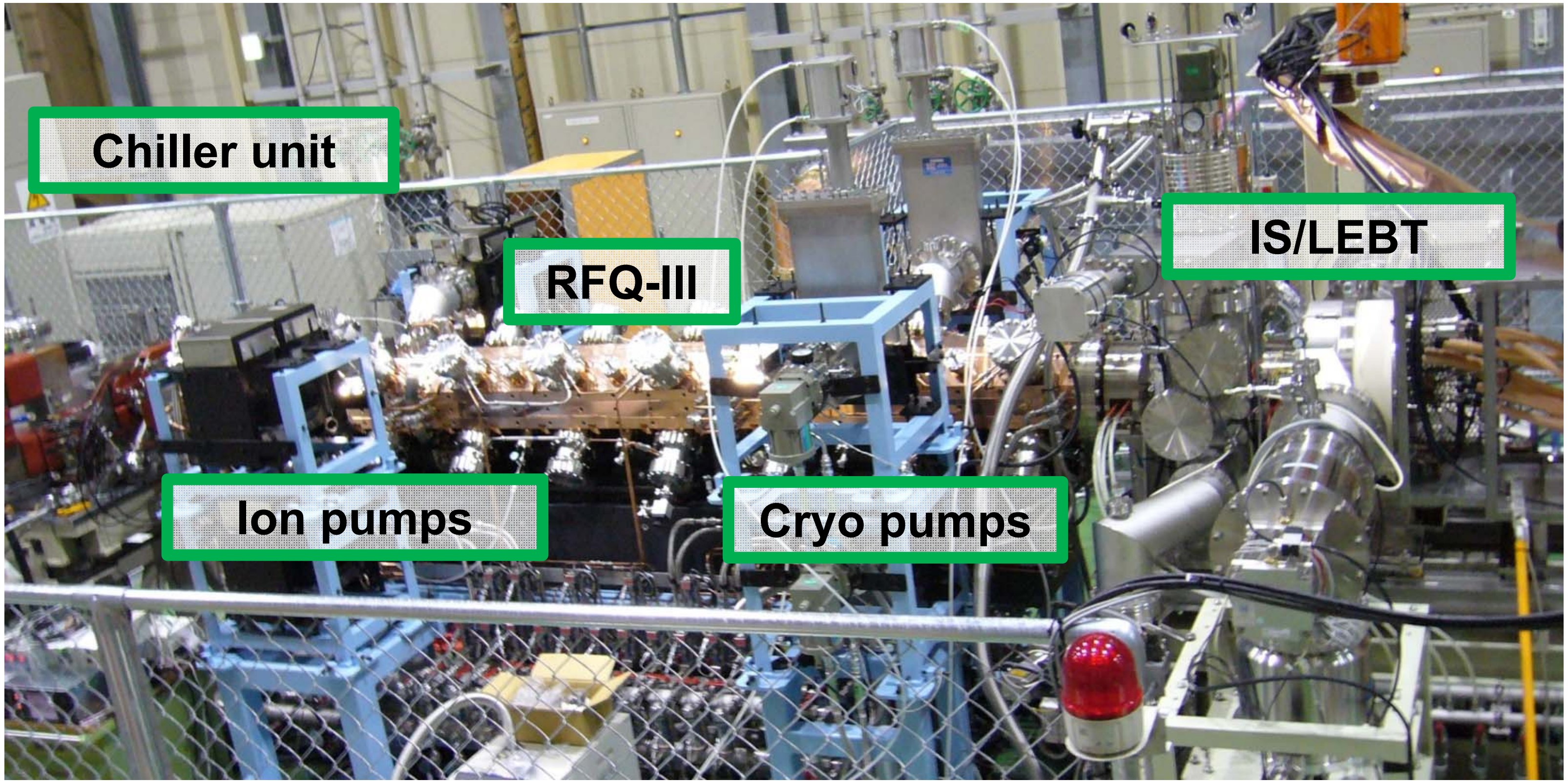
- Results:
- Uniformity of quadrupole field is 1%.
- The mixed two dipole modes are typically less than 1.5%





***Details: IPAC13 poster THPWO034 (T. Morishita et al.)**

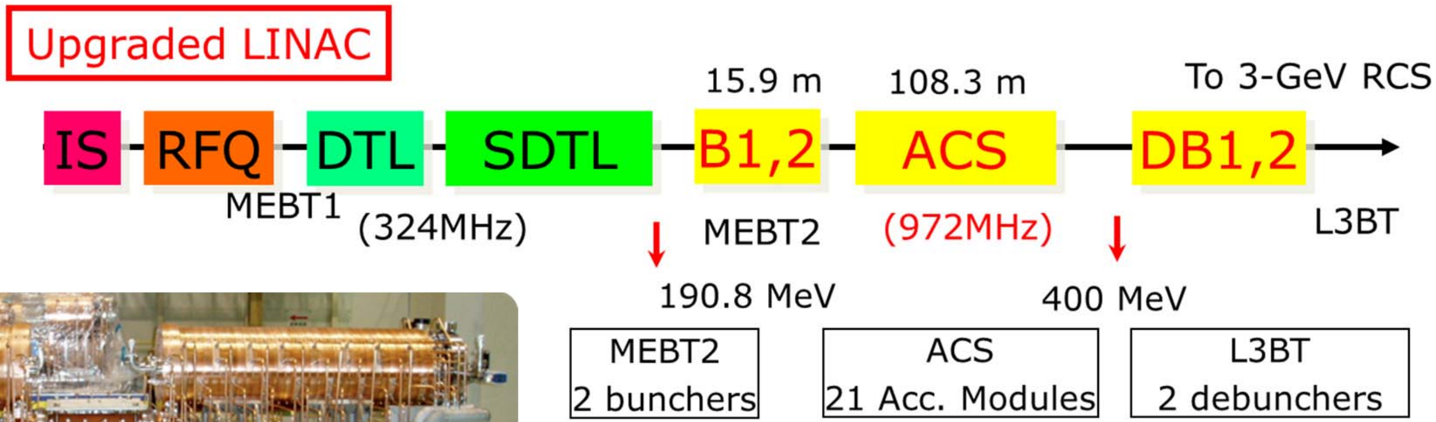
RFQ test stand for beam test

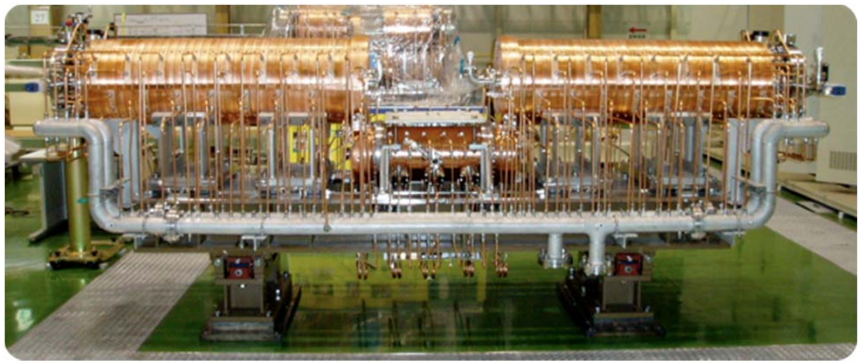


- RFQ test stand was newly constructed to perform the beam test of the **RFQ-III** before the installation to the linac.
- The **RF-driven H^- ion source** will be tested simultaneously to check the stability and reliability.
- The RFQ beam test will start in the middle of May, 2013.

Overview of J-PARC ACS

- 25 ACS modules are necessary:
  - 21 ACS modules (for the acceleration).
  - 2 ACS bunches (for longitudinal matching).
  - 2 ACS debunchers (for reduction of energy spread)

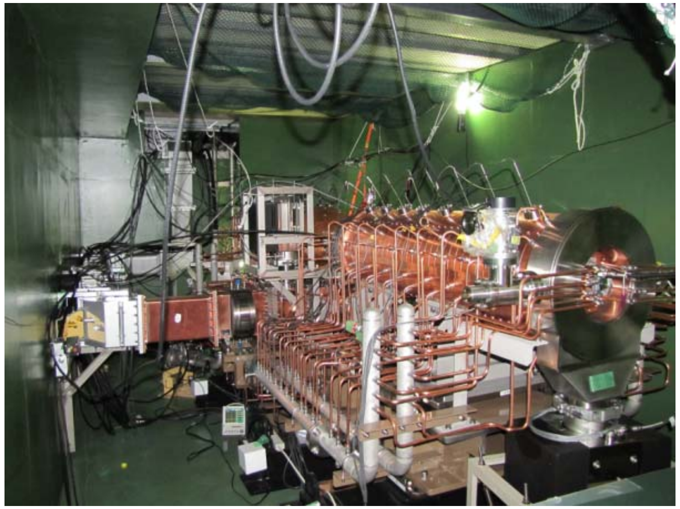


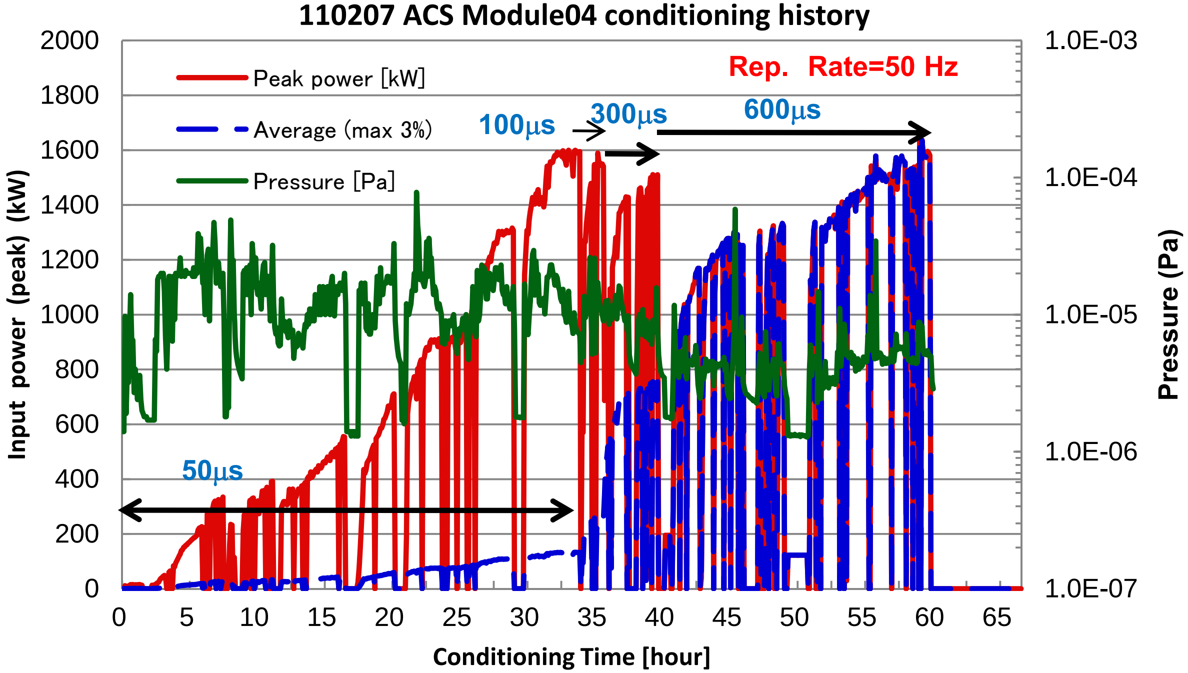


ACS accelerating module:
(two accelerating tanks and one bridge tank)

***Mass-production of ACS modules started from March, 2009.**

High power test of ACS





- In the end of 2010, we performed high-power test of the first mass-produced ACS module.
- The conditioning time to reach the target power of 1.6 MW was 60 hours, which is acceptable range for future conditioning of the mass-produced modules.
- The vacuum pressure was 2.0×10^{-6} Pa under the 1.6 MW operation after the 240 h conditioning.

Present status of ACS

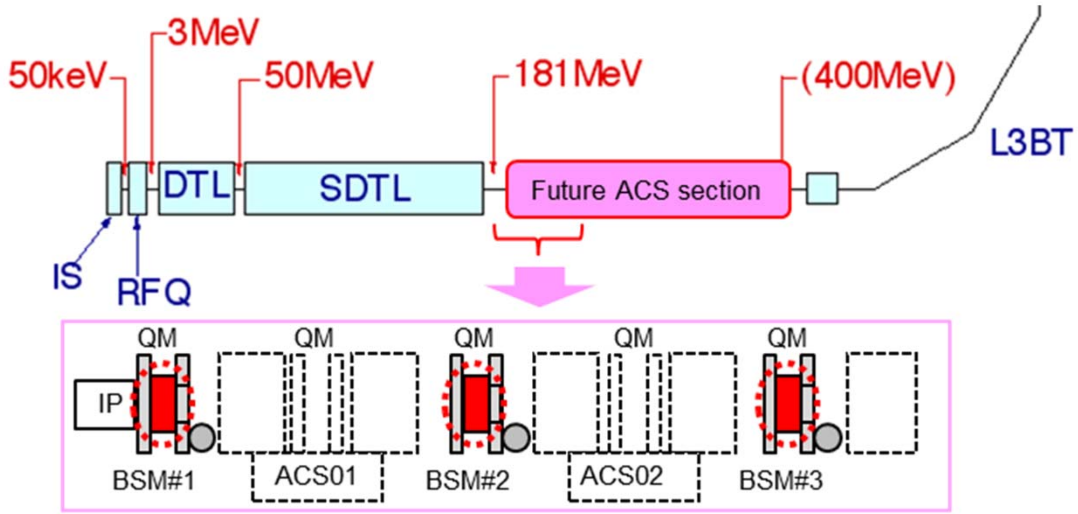
- All ACS modules have been fabricated and are stored in the J-PARC linac building.
- At present, we are measuring the vacuum pressure distribution in the ACS module precisely to increased in performance of vacuum condition using the stored module.

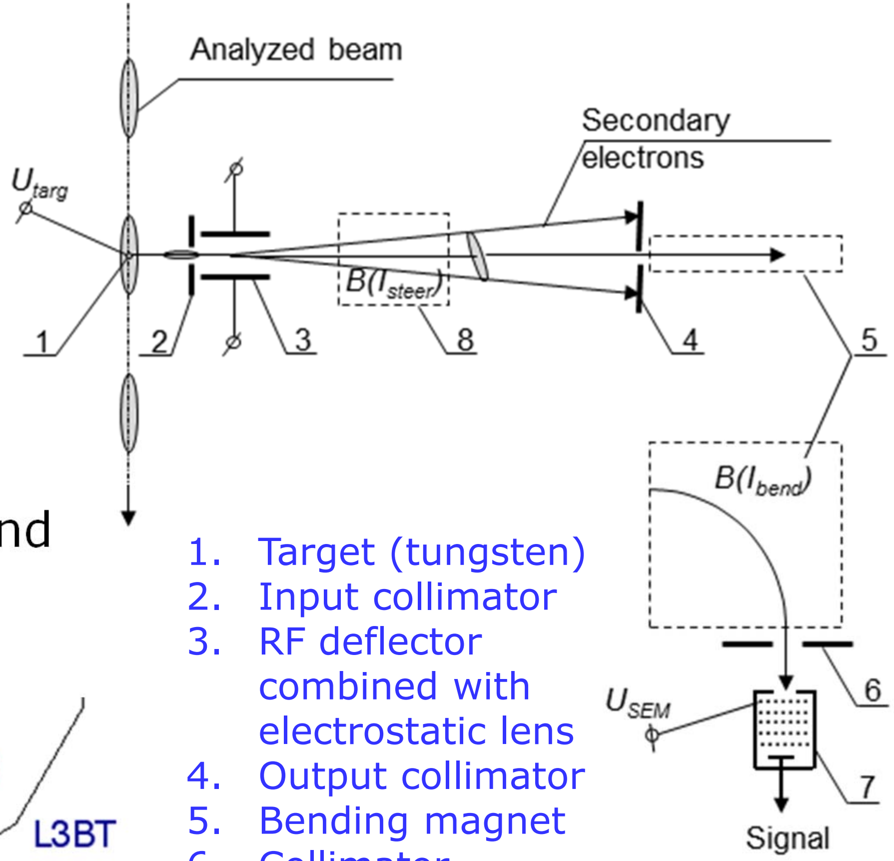
***Details: IPAC13 poster THPWO036 (H. Ao et al.)**

- In the original plan, high power test of all modules would have been performed before installation. However, the test was suspended due to the huge earthquake in 2011.
- High power test will be resumed in middle of May, 2013. 5 ACS cavities will be tested before installation.

Bunch Shape Monitor 1/2

- Bunch Shape Monitors (BSM) have been developed under collaboration with the INR (Russia) for the measurement of longitudinal distribution.
- Three BSMs are installed in the beginning of ACS section to tune the longitudinal matching, because the different acceleration frequency is employed between SDTL (324MHz) and ACS (972MHz).





1. Target (tungsten)
2. Input collimator
3. RF deflector combined with electrostatic lens
4. Output collimator
5. Bending magnet
6. Collimator
7. SEM- secondary electron multiplier
8. Steering magnet

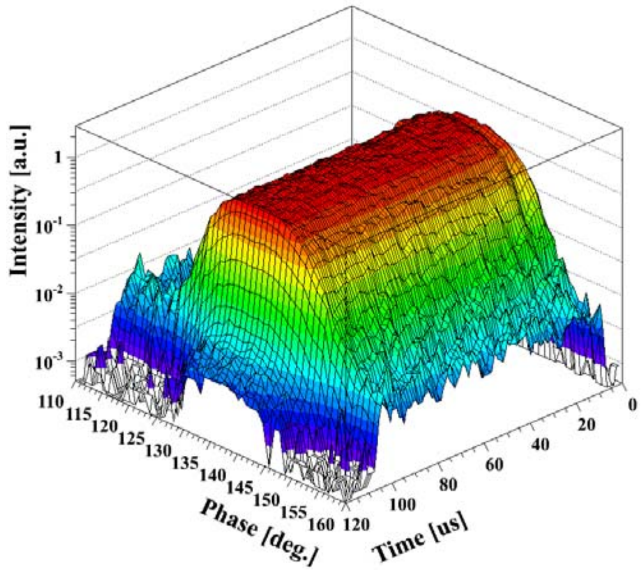
Principal of BSM

Bunch Shape Monitor 2/2

- The design of BSMs was started since 2009 and the fabrication of three BSMs was started since 2010.
- To perform the test measurement, all three BSMs were installed and the commissioning was started in 2012.
- In the first commissioning for the BSM tuning with the 181 MeV beam, we successfully obtained the bunch profile of the H^- beam at the end of the SDTL cavities.

***Details: IPAC13 poster MOPME027 (A. Miura et al.)**

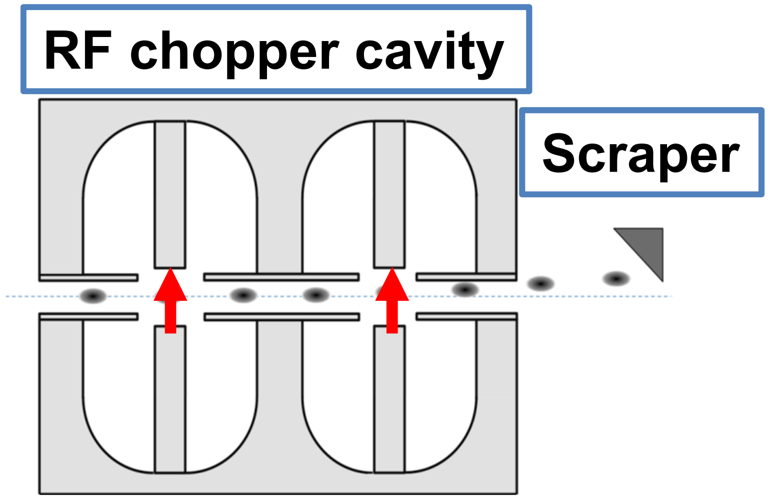
Installation at accelerator tunnel with INR staff



Example of Measurement

Current beam chopper system

In order to form the medium pulse structure, a beam chopper system has been used. The chopper system consists of an RF chopper cavity and a scraper, both of which are installed in the MEBT1 section.



RF chopper system

Present chopper system

- Designed beam current:
  -> 30 mA
- Measured extinction ratio @15mA:
  -> less than 10^{-6}
  (requirement: 10^{-5})
- Material of scraper
  -> carbon fiber composition

***Current chopper system works well.**

Issue of chopper with 50 mA

There are some issues with the 50 mA operation.

Chopper cavity:

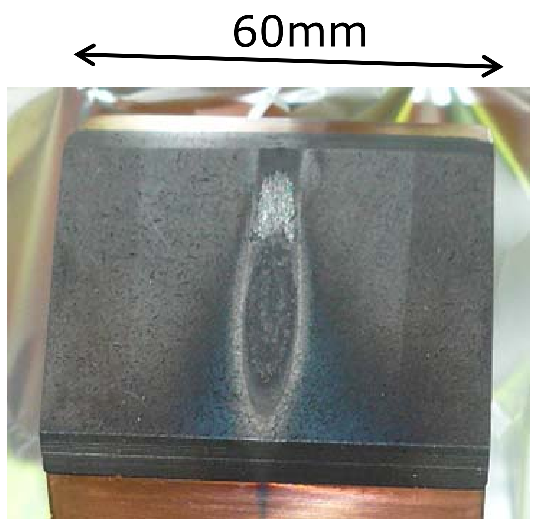
- RF field: 2.0 -> 2.6 MV/m (due to increase longitudinal size)
- Gap length: 10 -> 14 mm (due to increase transverse size)

  - Upgrade RF source for chopper: 30 -> ~100 kW
  - New chopper cavity: Similar geometry but wider aperture

Scraper:

- Scraper was removed in summer 2012, which had been used since 2007.
- Surface :Discolored and cratered (depth: ~1mm)

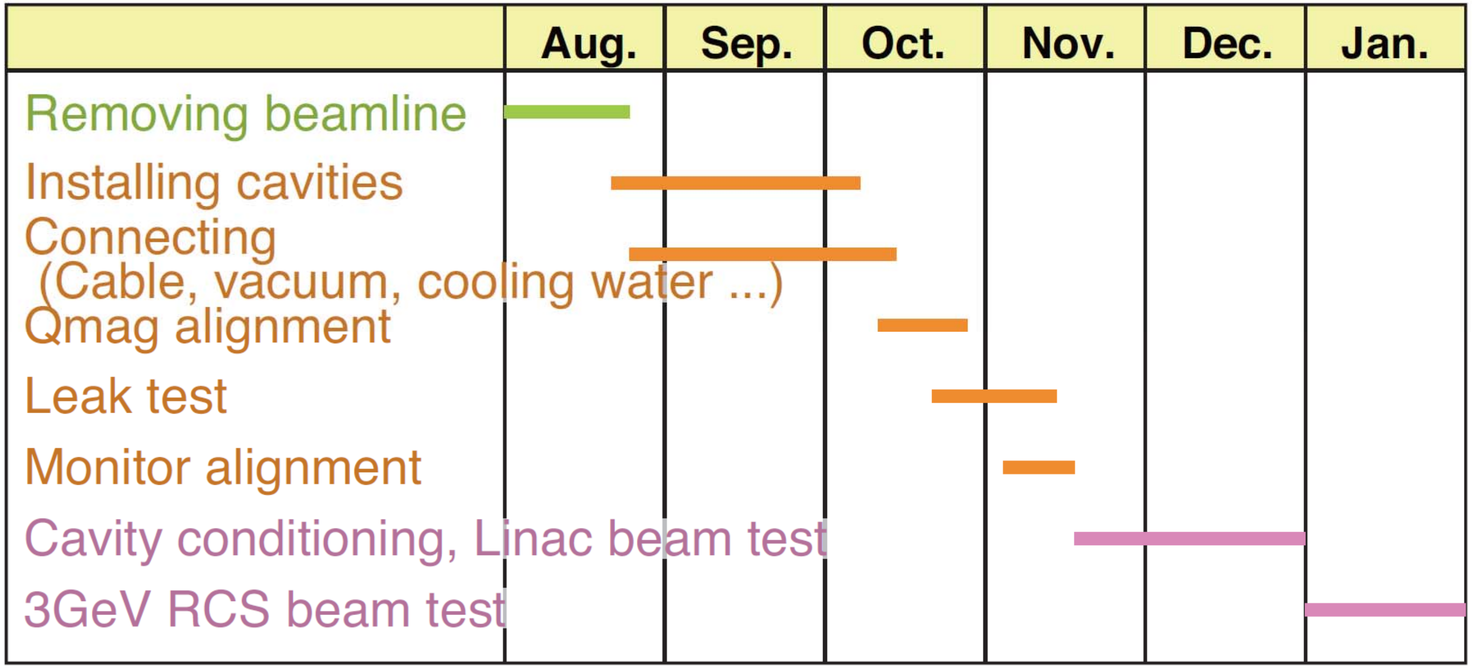
  - Strategy of the scraper is under discussion.
  - In order to find out if the CFC or another material can be used, we have a plan to perform irradiation experiment for the material development using the RFQ test stand in 2013.



Surface of used scraper

Upgrade Schedule

ACS installation schedule

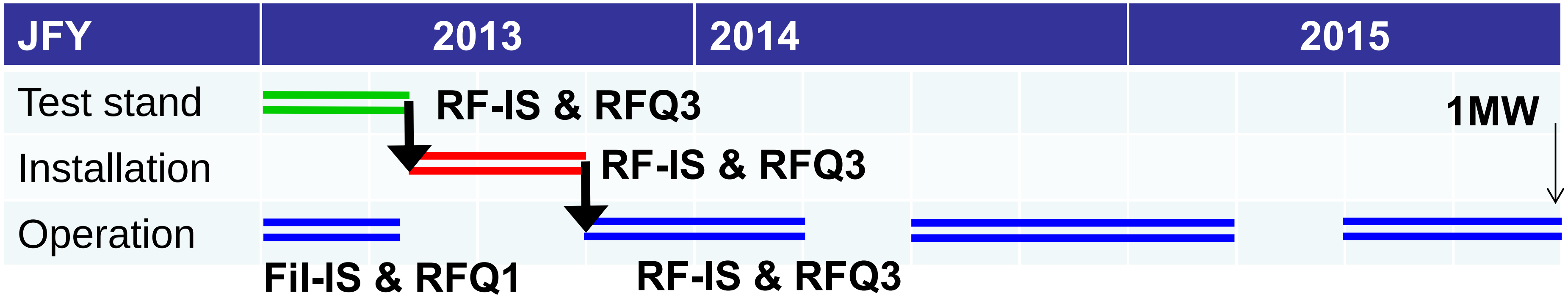


Preliminary ACS installation schedule in 2013

- Installation work will be started in August, 2013.
- Due to the strong demand by beam users, the user operation have to be restarted after 6 months.
- Consequently, all the installation works have to be completed until middle of November, 2013. The cavity conditioning and the linac beam commissioning will be performed by the end of December, 2013.

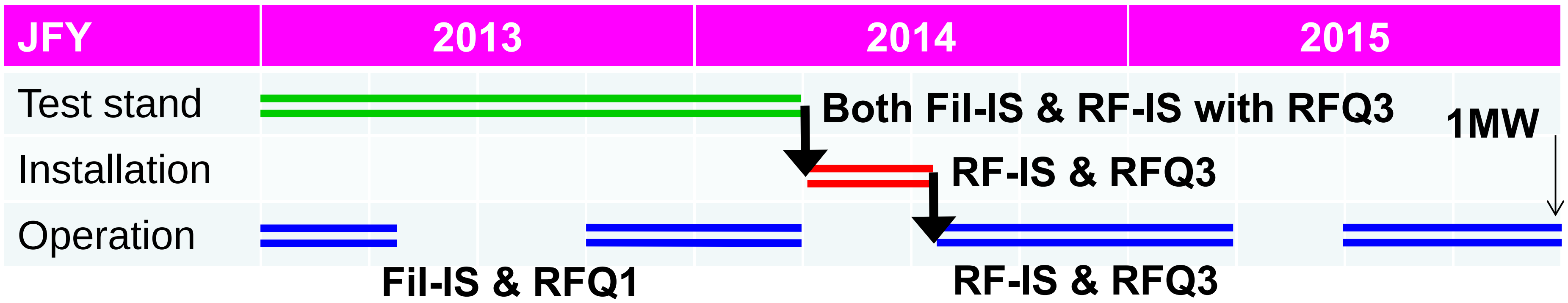
Front-end installation schedule

Original Schedule



◆ In the original schedule, the new front-end part will be installed at the same period as that of the ACS installation in 2013.

New Schedule (under consideration)



◆ In the new schedule, the installation is postponed till 2014 summer.
->User beam operation will be continued with the current front-end part.

Front-end installation schedule

New Schedule

□Advantage:

- Term of the off-line beam test can be extended from three months to one year. We will be able to perform precise examination of the beam property, check the operation stability and debug the system before the installation.
- Irradiation experiment for the material development of the chopper scraper can be conducted.

□Disadvantage:

- No high power demonstration run with more than 30 mA becomes possible until June 2014.
- Since the projected power requirement in early 2014 does not require 50 mA at end of linac, this disadvantage seems to be acceptable.

***We will decide on which option to choose soon.**

Summary

Summary 1/3

- **The linac power upgrade program is now in progress.**

- **Ion Source:**
  - The J-PARC RF-driven H^- ion source has satisfied the requirements, both in current and in emittance.
  - The spark rate of the ion source was observed to be less than once a day. This value is seemed to be acceptable level for practical use.

- **RFQ:**
  - The RFQ-II has been successfully tested up to 118 % of the nominal power.
  - The fabrication of the RFQ-III was completed in March, 2013, and the beam acceleration test will start in the middle of May, 2013 using the RFQ test stand.

Summary 2/3

☐ ACS:

- All ACS cavities have been fabricated.
- High-power test of the first mass-produced ACS module was performed. The conditioning time to reach the target power is acceptable range for future conditioning of other modules.
- 5 cavities will be tested at high power before installation.

☐ Bunch shape monitor:

- All three bunch shape monitors were installed at the beam line and the commissioning was started in 2012.
- In the first commissioning, we successfully obtained the bunch profile of the H^- beam at the end of the SDTL cavities.

☐ Beam chopper system:

- There are some issues for the present beam chopper system to be used for the 50 mA operation.
- An upgrade program of the RF chopper system is in progress.

Summary 3/3

☐ ACS installation schedule:

- ➢ Installation work will be started in August, 2013.
- ➢ All the installation works have to be completed until middle of November, 2013.
- ➢ The cavity conditioning and the linac beam commissioning will be performed by the end of December, 2013.

☐ Front-end installation schedule

- ➢ We have two option about the installation schedule (2013 or 2014).
- ➢ The installation of the new front-end part may be postponed to 2014 because there would be some advantages in doing so.
- ➢ We will decide on which option to choose soon.

Thank you for your attention !