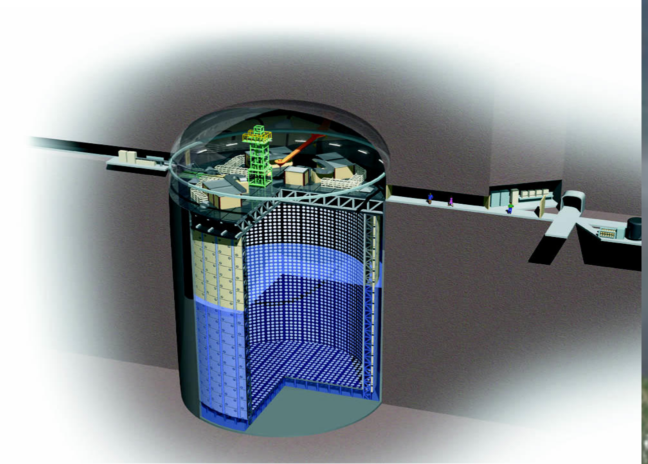
Study of Symmetry with an accelerator neutrino beam

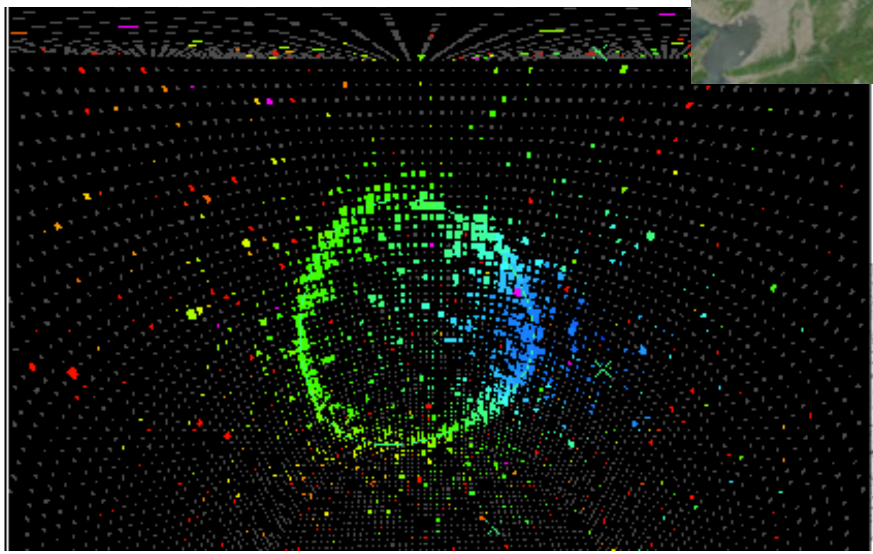
A02

Intense Neutrino Beam for $\overset{(-)}{\nu}_\mu \rightarrow \overset{(-)}{\nu}_e$ study

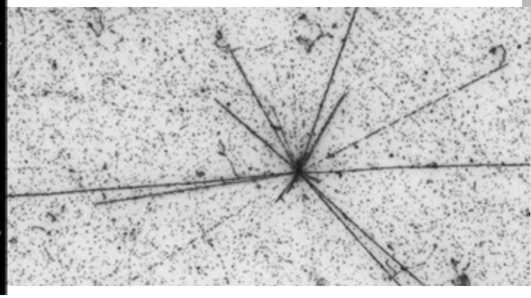
Super-K

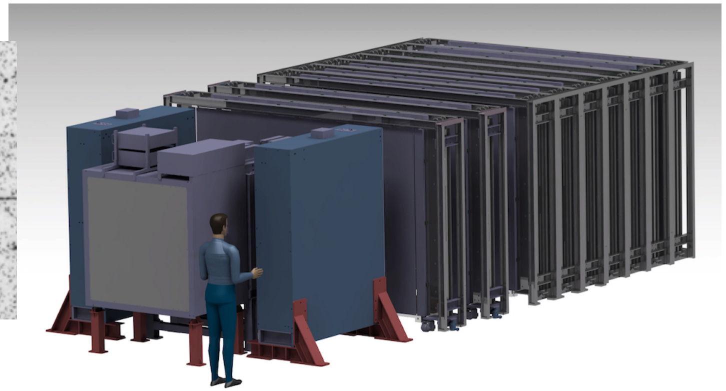


J-PARC



New detectors
at J-PARC for ν cross sections





Workshop on
“Exploration of Particle Physics and Cosmology with Neutrino”

J-PARC MR & Neutrino Beam

8 March 2022

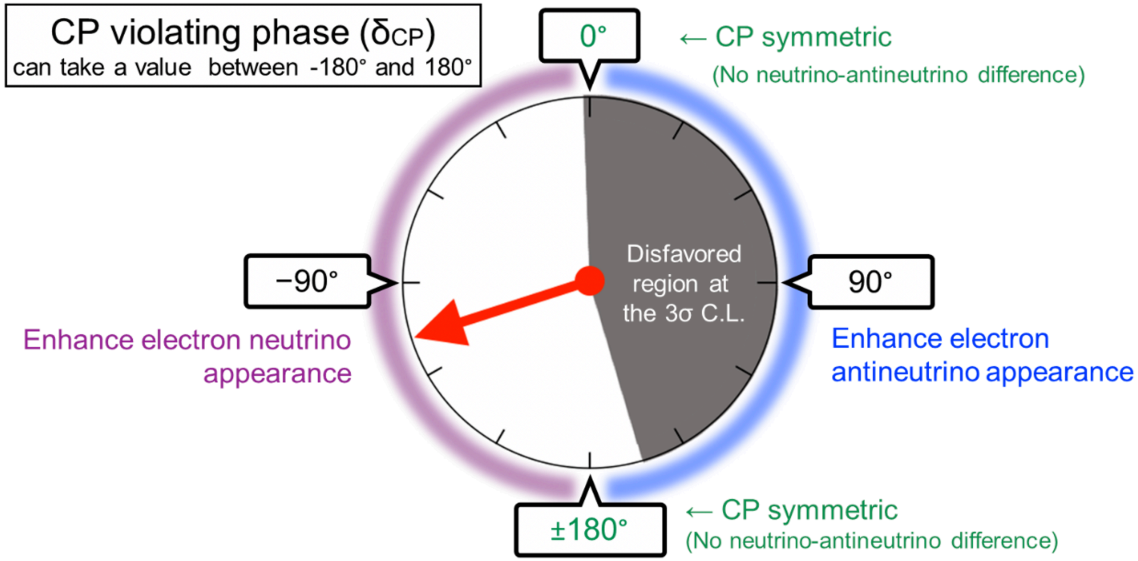
Tsunayuki Matsubara (KEK/J-PARC) for A02 group

Long-baseline neutrino experiment

T2K experiment

- Operating since JFY2009.
- Discovery of ν_e app. in 2013
- Anti-ν operation since 2014

to measure the CP violating phase (δ_{CP})



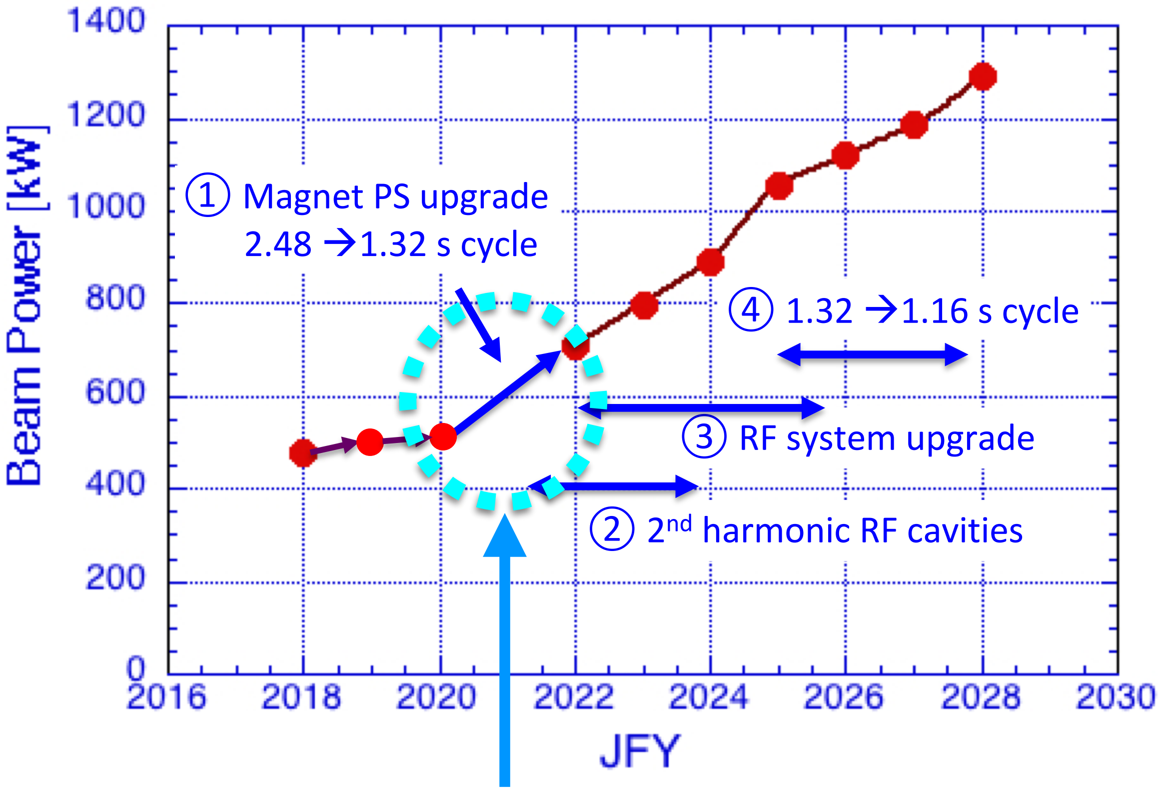
Recent results [Nature 580, 339-344 (2020)]

- Obtained strong preference of the ν_e appearance enhancement.
- Constraining possible δ_{CP} value, excluding region at the 3σ C.L.
- But it is not yet clear if CP symmetry is violated or not.

To accumulate more data in a shorter time, J-PARC will increase the beam power by upgrading the accelerator and beamline.

Beam power upgrade

- The beam power will be increased up to 1.3 MW as shown in the plan below with the **"faster cycle time"** and **"increased protons per pulse"**.



J-PARC MR Power Upgrade Plan (shown at ATAC 2021)

- **Upgraded work in progress!!**

- This talk covers upgrades of **"J-PARC Main ring"** & **"Neutrino beamline"**

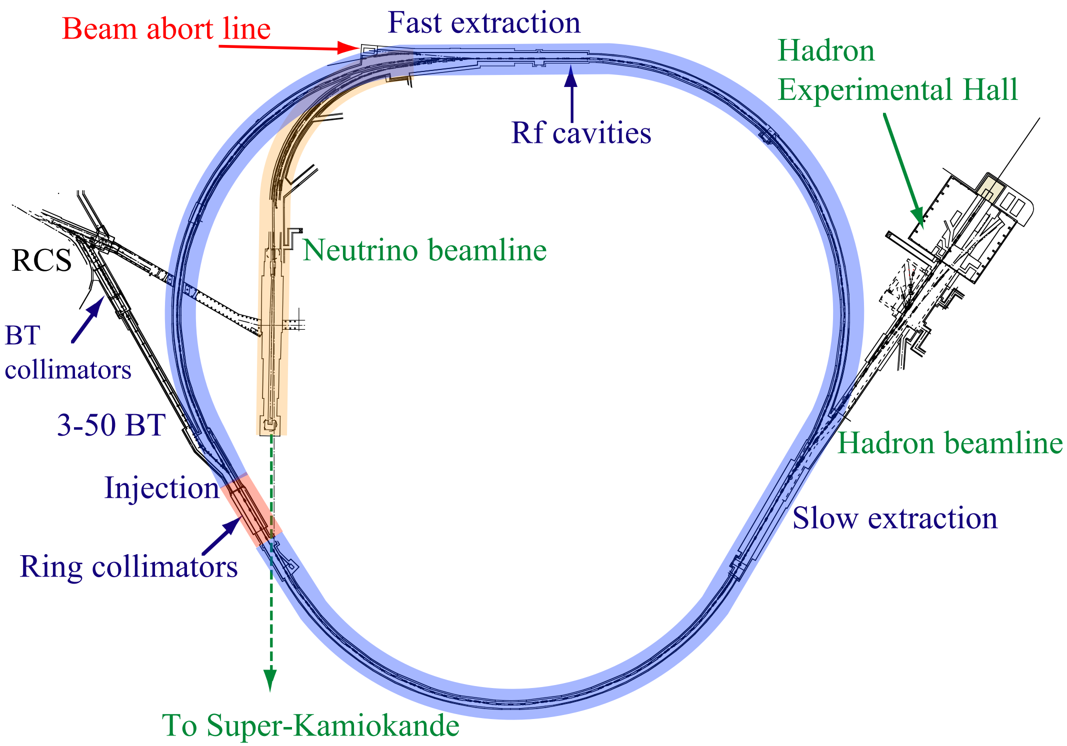
J-PARC Main ring

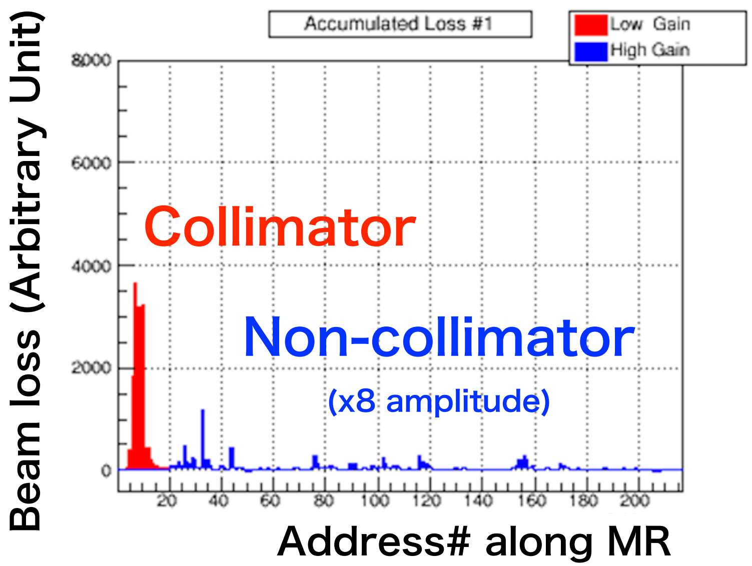
Overview of the J-PARC Main Ring

Main ring synchrotron
- ~1.6 km circumference
- Three-fold symmetry
- 3 (30) GeV injection (extraction)

Beam power : ~500 kW (FX)
- 2.48 sec cycle
- ~2.6x10^{14} proton per pulse (ppp)

(*) the world highest ppp in synchrotrons





Beam loss : 0.8 kW (estimated by DCCT)
- Mostly (~99%) localized at the MR collimator section, within the capacity of 2 kW
- Hands-on maintenance at non-collimator section is possible within minimum exposure of residual radiation

Slide from Takaaki Yasui

Beam loss after upgrades

Requirement

To enable **hands-on maintenance** in non-collimator area.

<300 μSv/h at 1 foot, 4h after user operation.

↓

Beam loss reduction and better loss localization are necessary.

	Cycle [s]	Intensity [ppp]	Power [kW]	Total beam loss [kW]	Coll. Capacity [kW]
Present	2.48	2.6×10^{14}	500	0.8	2.0
JFY2022	1.32	2.1×10^{14}	750	1.1	3.5
Future	1.16	3.3×10^{14}	1300	?	3.5
	×2 faster	×1.3	×2.6	Upper limit is determined by localization efficiency	

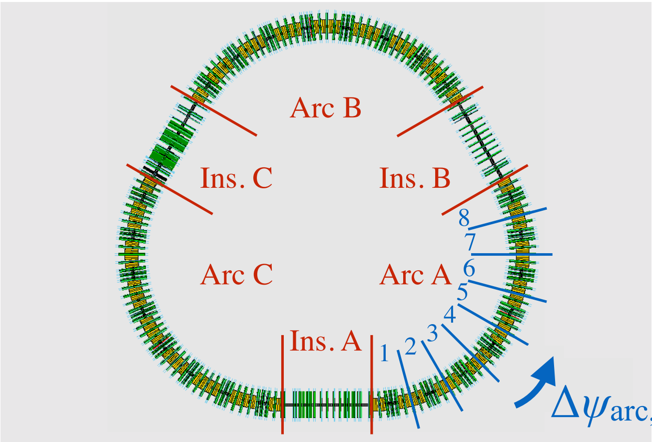
Reports in this talk:

(1) Beam optics for resonance compensation

(2) Evaluation/reduction of beam coupling impedance

Optics study for resonance compensation

Slide from Takaaki Yasui



$\Delta\psi_{\mathrm{arc},y}$ changed

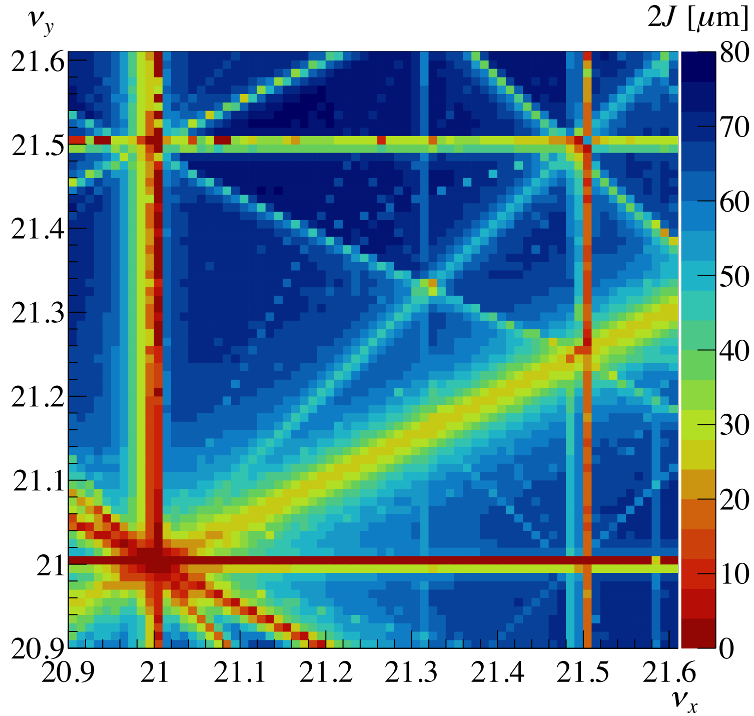
Structure resonances cause beam loss.

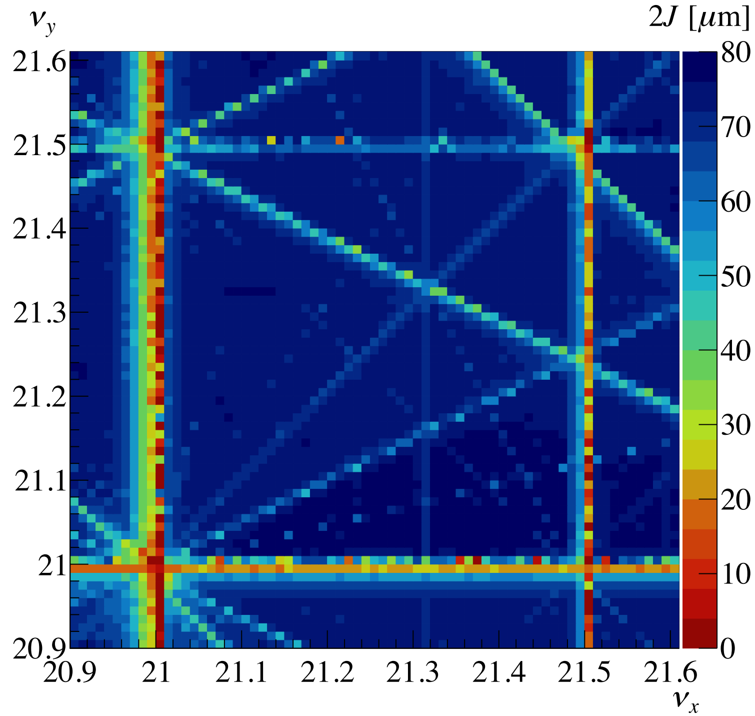
Vertical phase adv. in the arc section was optimized.

The 3rd-order sextupole-like structure resonance $\nu_x - 2\nu_y = -21$ was compensated.

<u>**T. Yasui et al., Prog. Theor. Exp. Phys. 2022, 013G01 (2022).**</u>

<u>Aperture survey simulations</u>





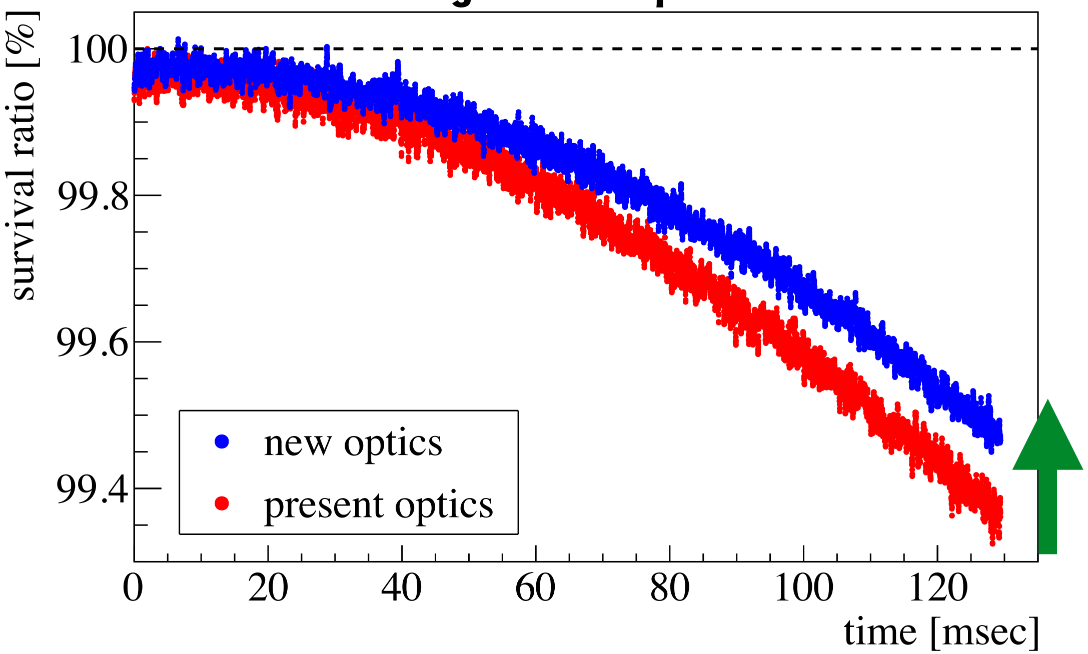
Optics study for resonance compensation

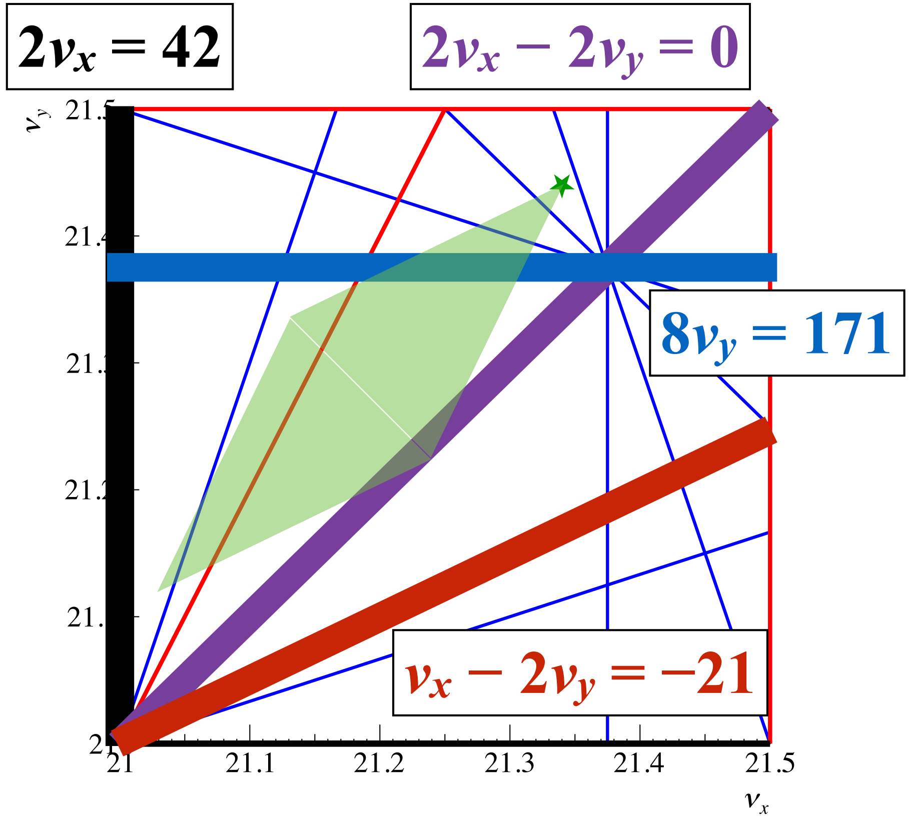
Slide from Takaaki Yasui

The new optics also suppress some space charge resonances.

Long-term beam loss was reduced by suppressing the resonance $8\nu_y = 171$ induced by the space charge effects.

Measurements of beam survivals at injection period





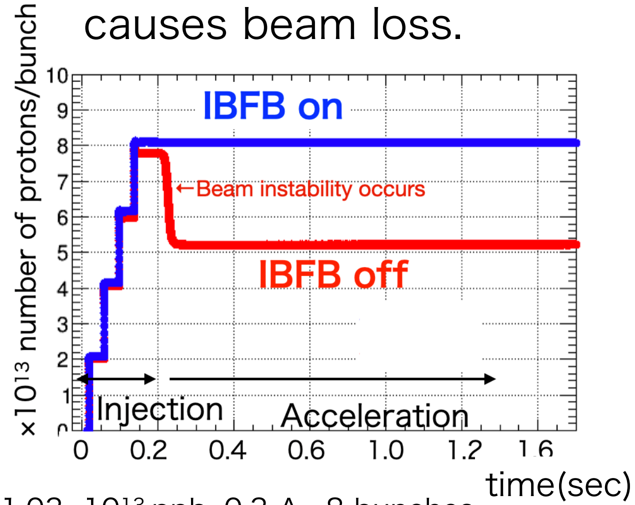
Beam survival recovered!
Beam loss reduced!

Further optics study is planned to realize 1.3 MW operation.

Beam loss and instability

Slide from Aine Kobayashi

For high-power beam realization, it is necessary to suppress the beam instability that causes beam loss.



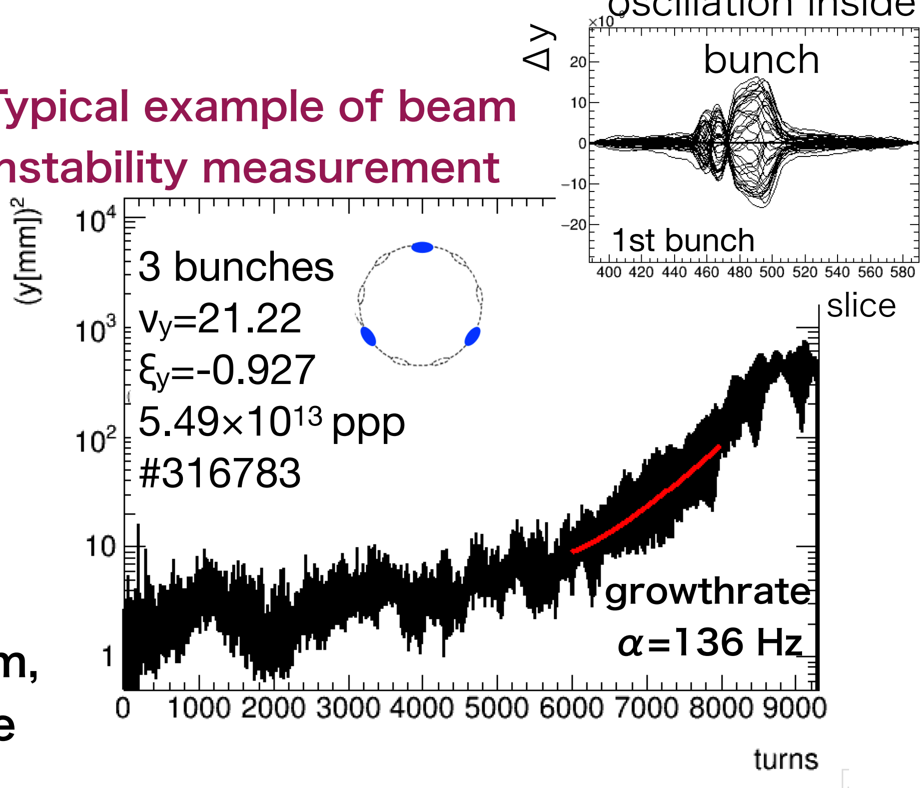
1.03×10^13 ppb, 0.3 A, 8 bunches

IBFB: Intra-bunch feedback system

It is necessary not only to strengthen the system to suppress the beam instability, but also to identify the cause and take countermeasures.

The resistive-wall effect, which is the main cause of the transverse beam coupling impedance, is being evaluated by calculations, simulations, and beam study measurements.→

Typical example of beam instability measurement



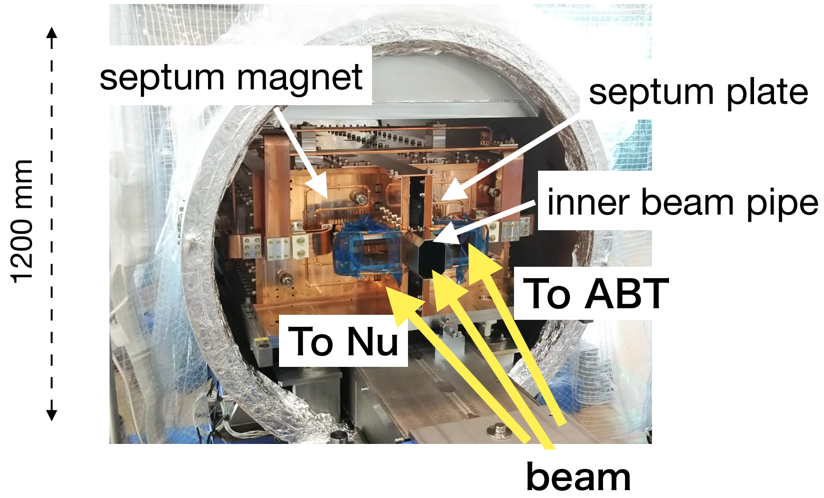
In order to predict the behavior of the beam, estimation of the beam coupling impedance is necessary.

Impedance measurements of the RF cavity and FX kicker, the next largest contributors, were completed during this fiscal year.

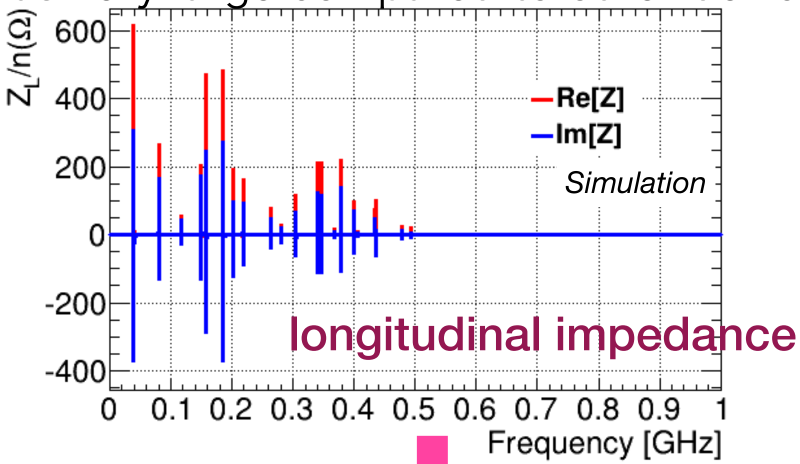
Impedance reduction of new FX septum

Slide from Aine Kobayashi

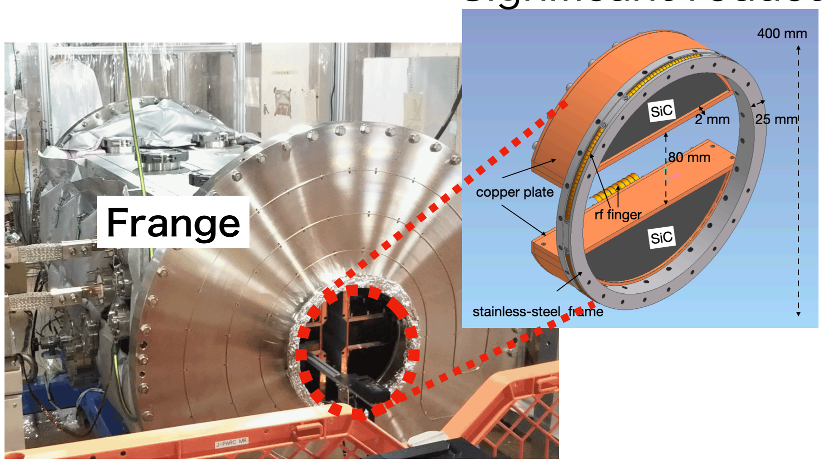
New FX septa (Eddy-current type septa) are being installed to accommodate the higher intensity and higher repetition rate of the beam.

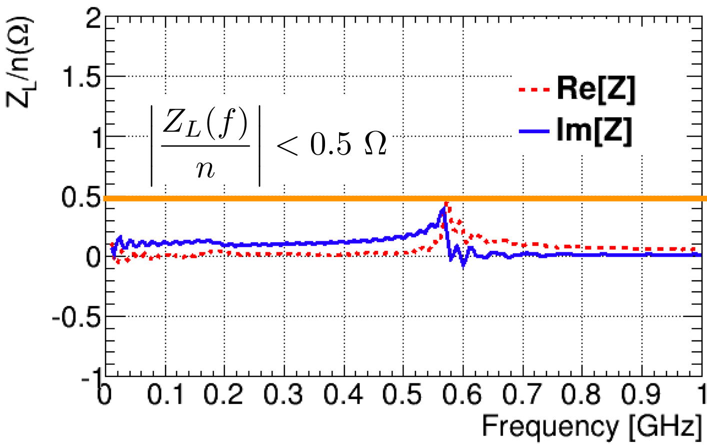


The simulation showed that the impedance was very large compared to other devices.



Significant reduction by adding copper plate and SiC to the flange!





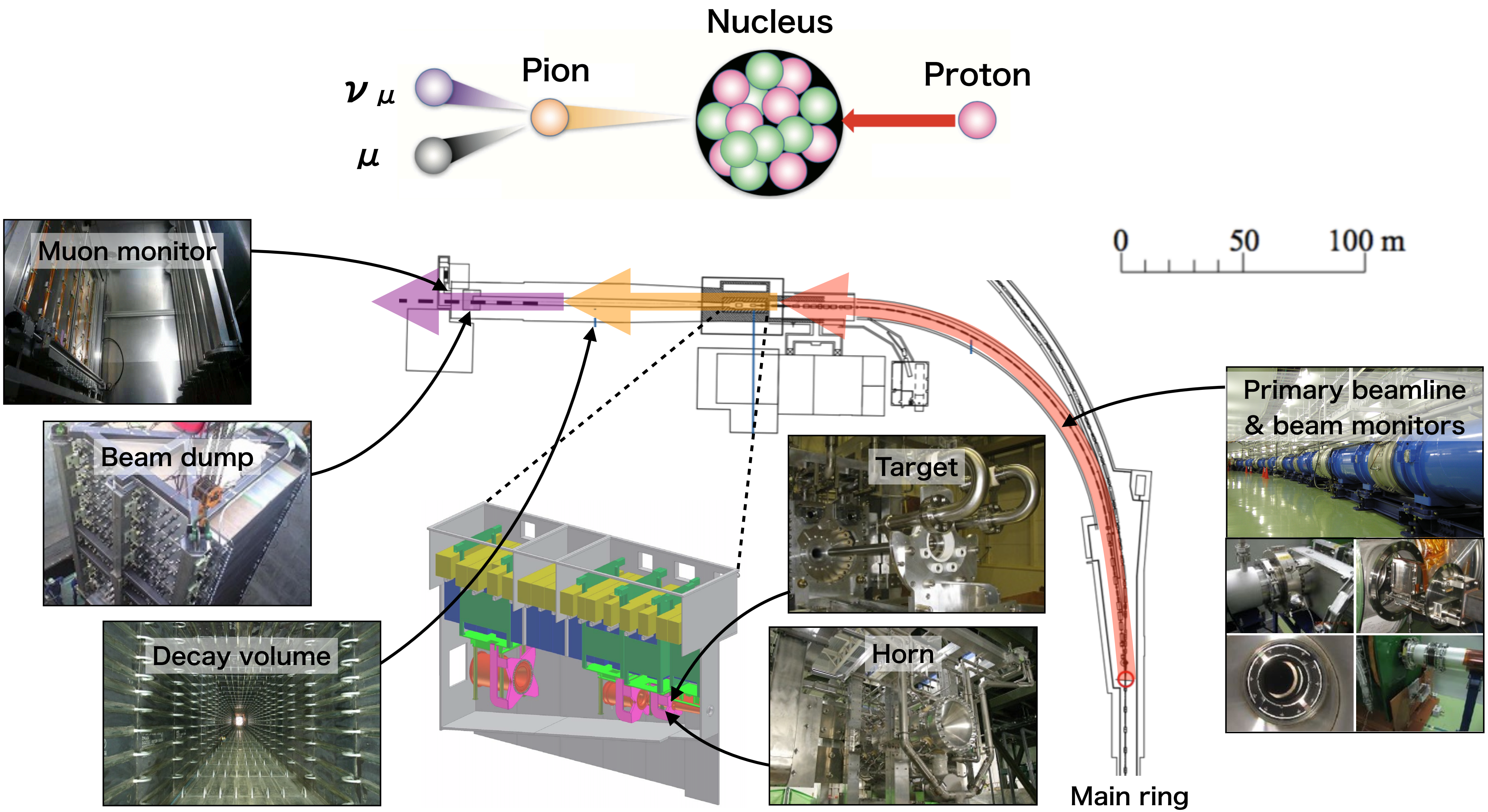
target value achieved!

n = frequency f/ revolution f_{rev}

Fabrication is in process, and measurement will be done next fiscal year.

Neutrino beamline

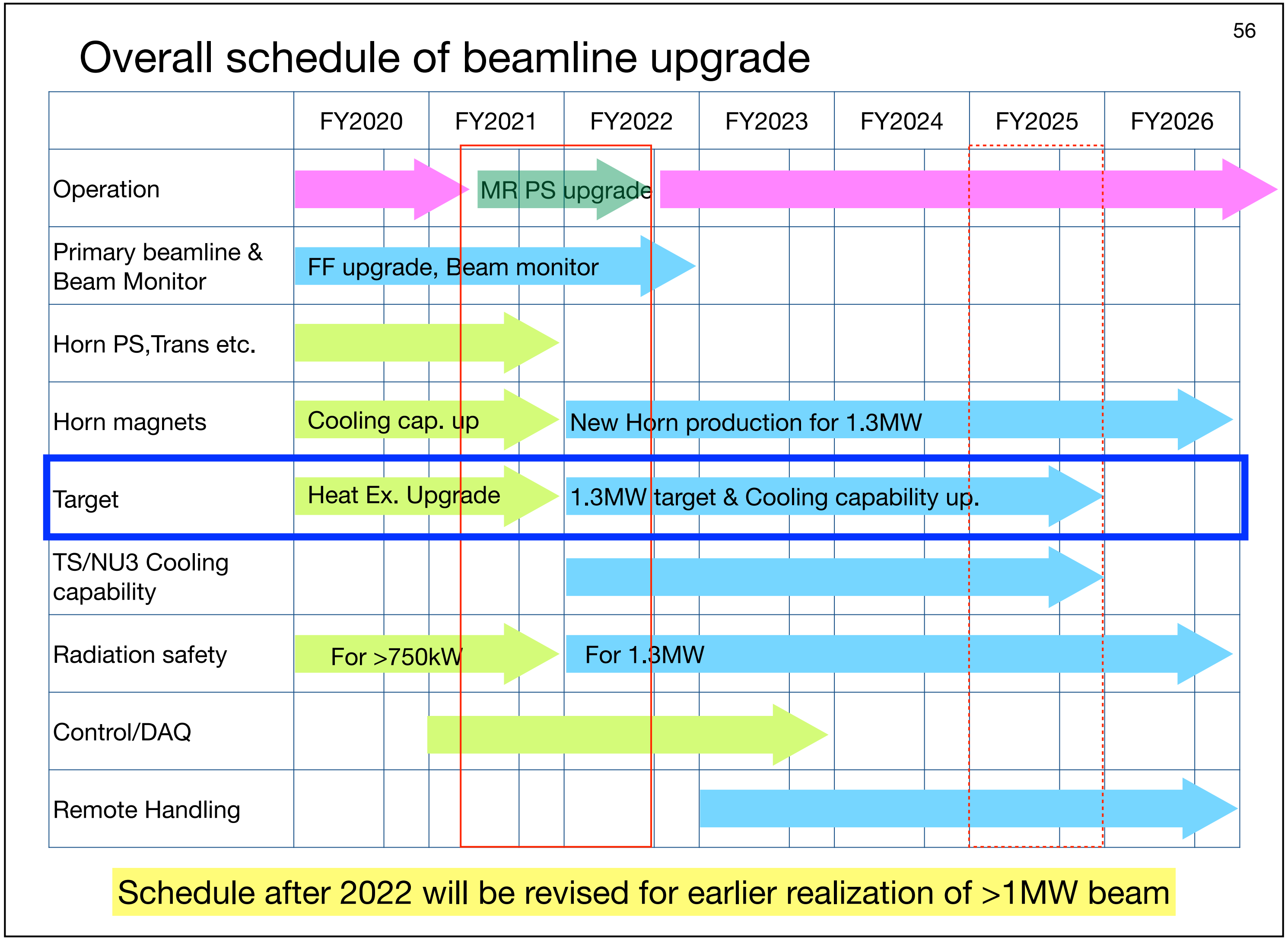
Overview of the J-PARC Neutrino beamline



- Neutrino beamline was originally designed for 750 kW (T2K goal)
  → Need to upgrade to accept higher beam power

Status and plan

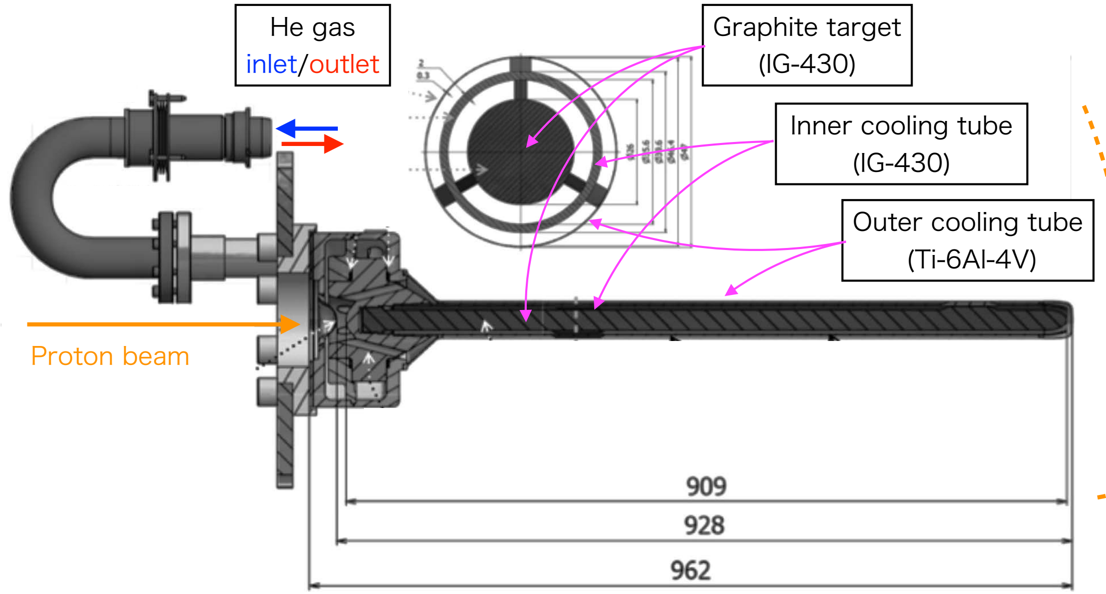
Slide from J-PARC PAC in July 2021

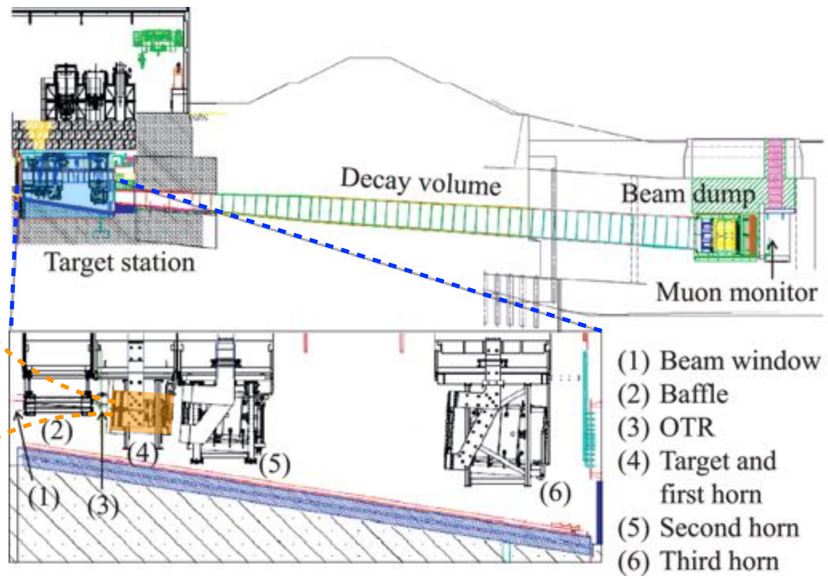


Report in this talk:

- Target cooling system upgrade in the current long shutdown

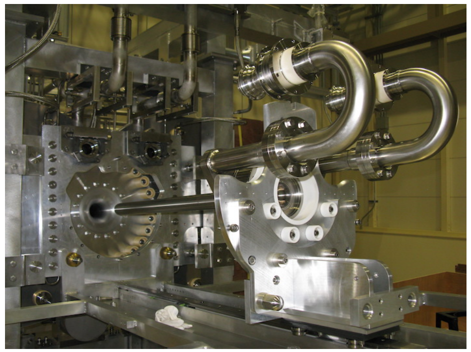
Neutrino production target





Mechanical features

- 90 cm long (for ~2 interaction length)
- 26 mmΦ (3σ range of beam size with $\sigma_x = \sigma_y = 4.2$ mm)
- Cantilever structure in the magnet (for remote exchange using a manipulator)

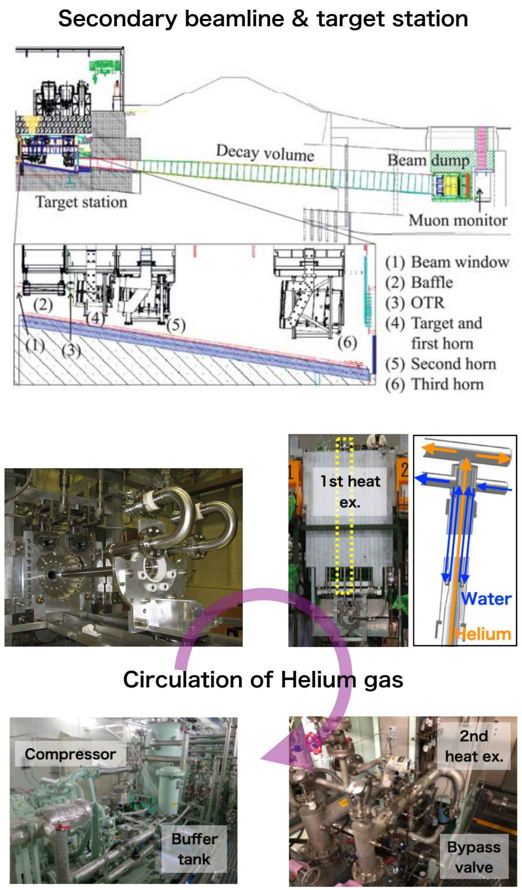


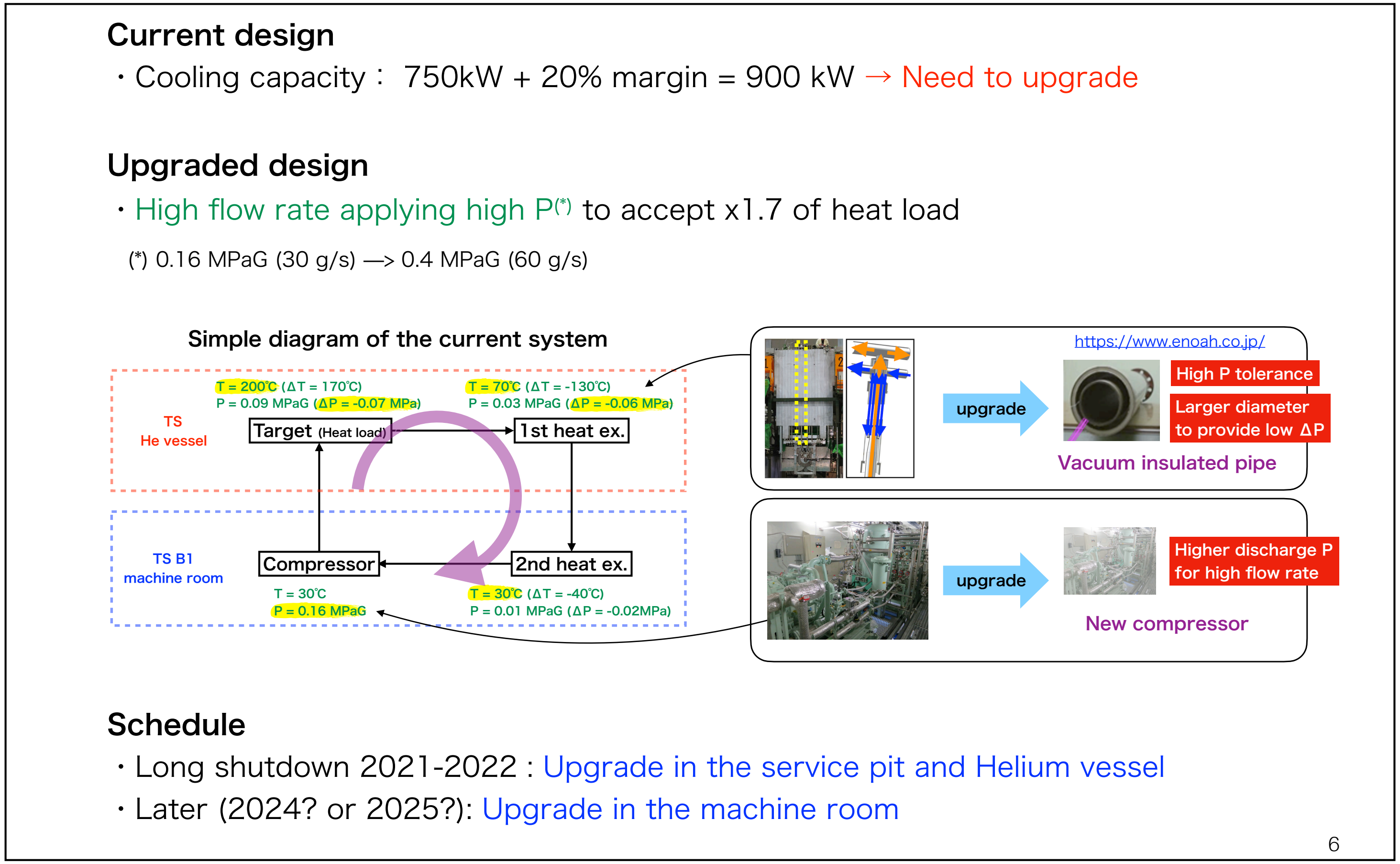
Functional features

- Thermal shock tolerance (< 3.3×10^{14} proton per pulse, equivalent to 7.4MPa stress)
- Radiation damage tolerance (Swelling mitigation by T control in [400, 700]˚C)
- Oxidation consumption tolerance (Oxidation mitigation by <100 ppm of O_2 & <700˚C of target surface T)
- Helium gas cooling (for cooling 24 kW of heat load to the target at 750 kW operation)

Concept of the target cooling system upgrade

- Current target and its cooling system in the target station are introduced.
- Then the concept of the upgrade is explained in a slide as shown here:





- “Vacuum insulated pipe” is one of key devices and newly developed.

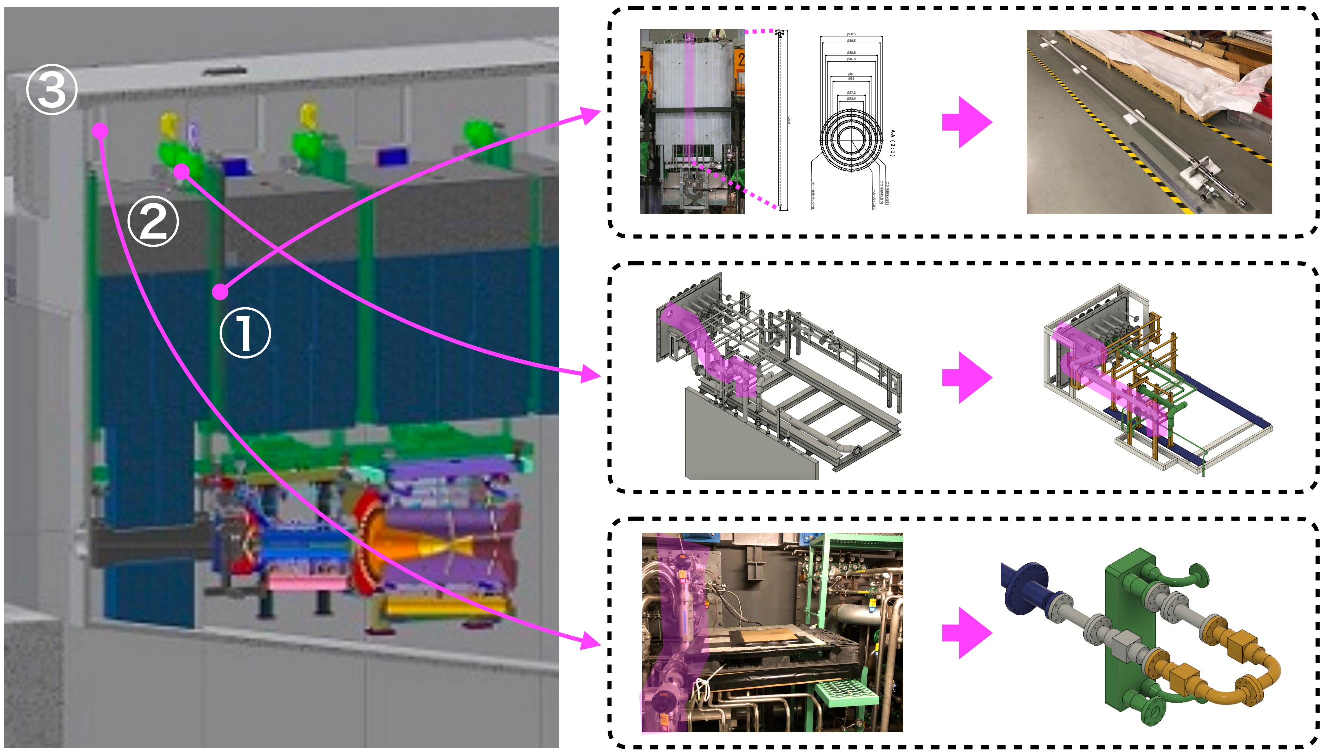
Current status & plan

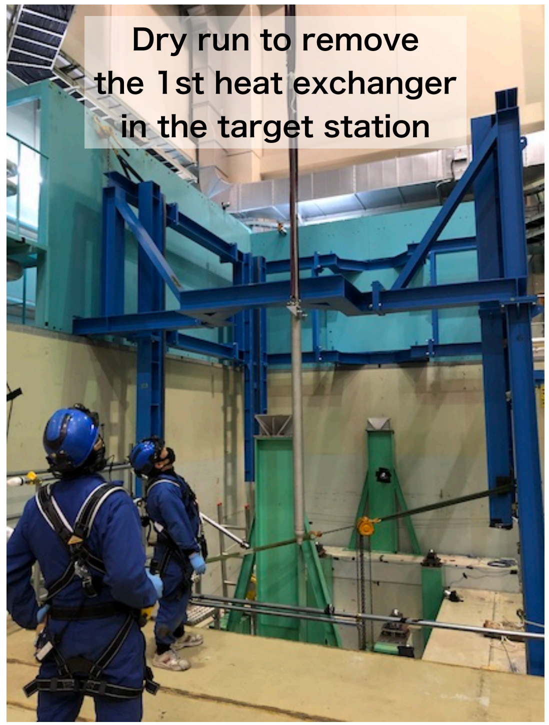
Status:

- R&D completed in ~2020 (heat insulation & low pressure drop)
- Detailed design completed in 2021. Most of components were already delivered.
- Removal and storage of the current 1st heat exchanger has been started.

Plan:

- Installation of new heat exchanger will be performed in several months.
- Schedule to be optimized together with other upgrade works in the target station





Summary

- Upgrades of the J-PARC Main ring and neutrino beamline are in progress for higher beam power up to 1.3 MW.
- Works for the MR upgrades related to the beam loss are reported.
- Works for the neutrino beamline upgrades, especially target cooling system is also reported.

Backup

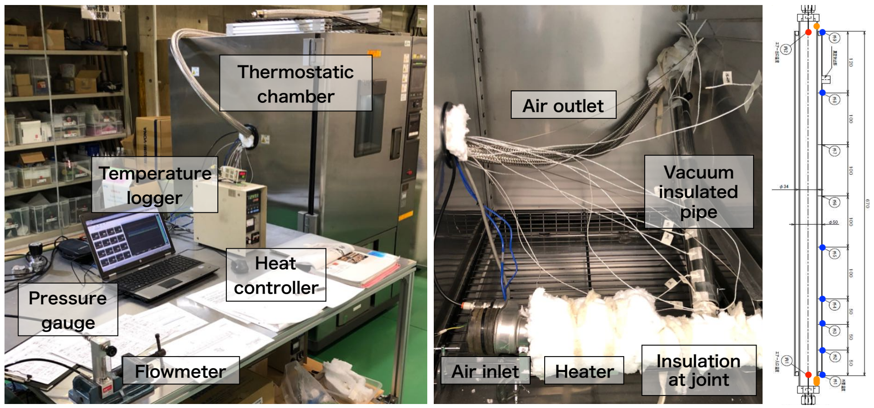
Vacuum insulated pipe R&D

- Confirmed low pressure drop by simulation

	Mass flow [g/s]	R_{pipe} [mmΦ]	ΔP [MPa] by Mike(RAL)	ΔP [MPa] by Matsubara	Comment
Current system	30	23.9	0.0445	0.044	Comparable w/ 0.06MPa.
Updated system (0.1→0.5 MPaG)	60	23.9	0.0509	0.051	
		30.7	0.0155	0.015	Increased diameter.

- Confirmed heat insulation performance by the prototype test and simulation

Test of heat insulation (16 Mar. 2020)

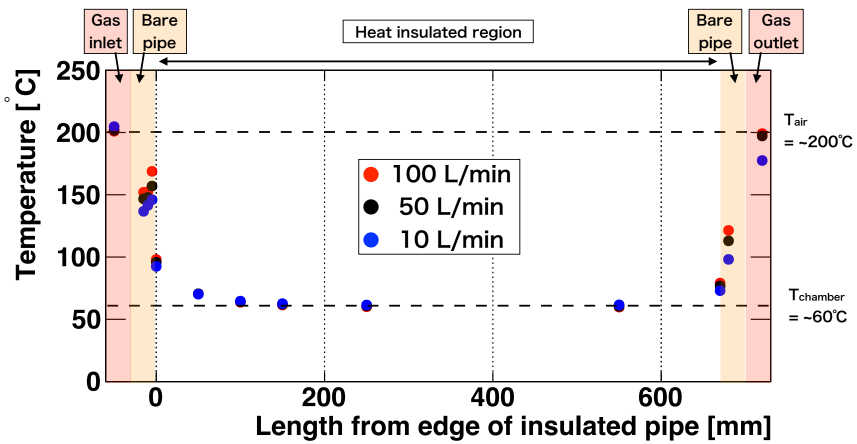


- Heat insulation test in a thermostatic chamber (Stable ~60˚C)
- Air flow (~200˚C) within a range of flow rate of 10~100 L/min
- Temperature measurement
  - 2 points at gas inlet/outlet, 4 points at surface of bare pipe, 7 points at surface of insulated pipe & one in the chamber

7

Results

- Equilibrium temperature was measured for 3 different flow rate



- Good capability of heat insulation at the region is confirmed
- No significant difference in this range of flow rate

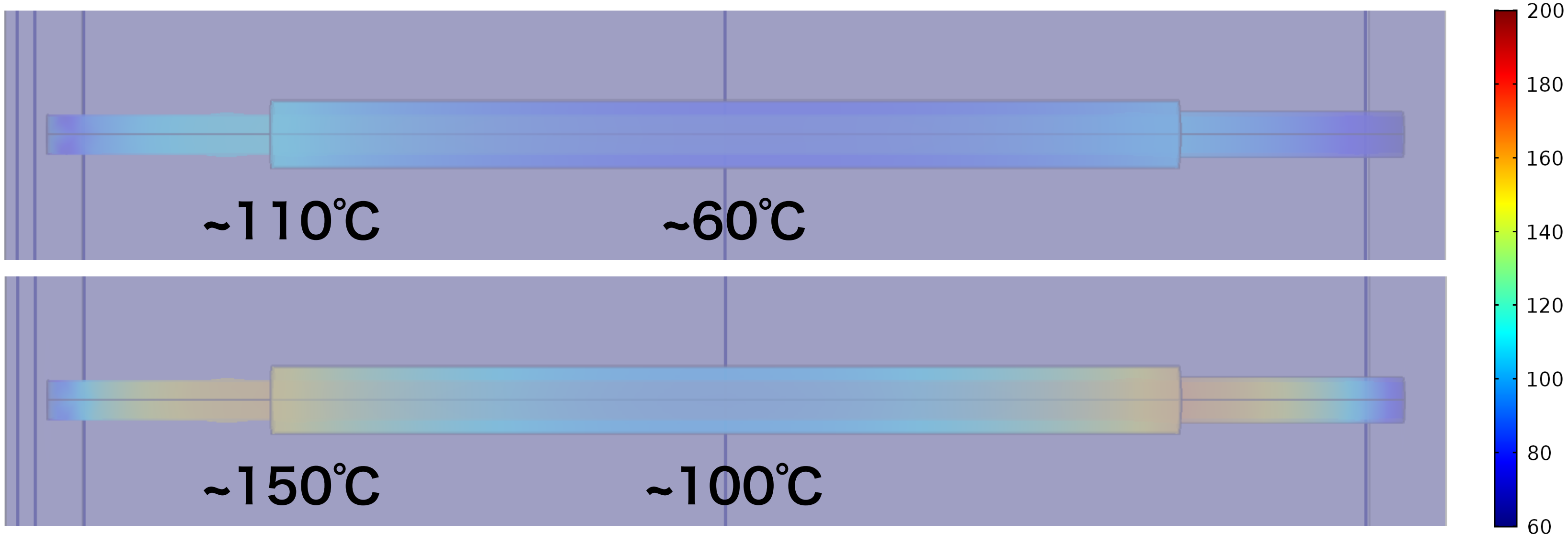
8

Comparison with simulation (COMSOL)

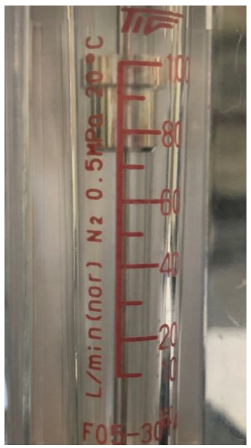
- Flow rate of 10~100 L/min → Mass flow rate of 0.12~1.2 g/s
  if calculating with density of air (1 atm・200℃) is 0.72 g/l
- Simulation was performed with conditions below

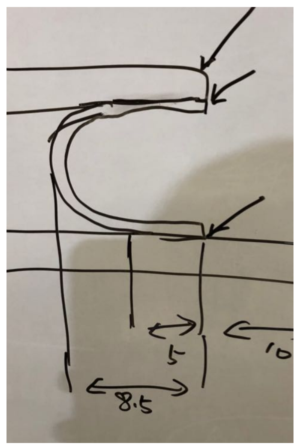
Air
0.1 g/s

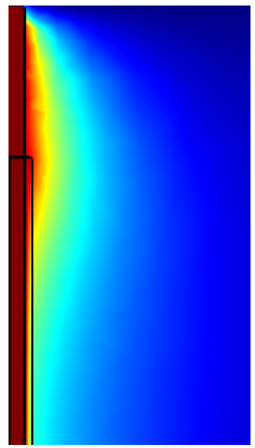
Air
1.0 g/s



- Comparable results in case of 0.1 g/s
  but higher than observation in 1.0 g/s
- Investigating the difference with observation
  - Flow rate correction?
  - Design of the edge of insulated region?
  - Boundary condition in a chamber?







Mid-term Plan of MR

FX: The higher repetition rate scheme : Period 2.48 s → 1.32 s for 750 kW.
(= shorter repetition period) → 1.16 s for 1.3 MW
SX: Mitigation of the residual activity for the beam power upgrade

JFY	2020	2021	2022	2023	2024	2025	2026	2027	2028
Event		Long Shutdown							
FX power [kW]	515	-	>700	800	900	>1000	>1100	>1200	1300
SX power [kW]	55	60–70	>80	>80	>80	>80	~100	~100	~100
Cycle time for Fast Extraction New Magnet PS	2.48s	Mass Production Installation/Test	1.32s	1.32s	1.32s	1.32s	<1.32s	<1.32s	1.16s
RF system upgrade									
2nd RF system upgrade									
Collimator system		Add.colli. (3.5kW)							
Injection system FX system	Kicker PS improvement Septa manufacture Test								
Beam Monitors (BPM circuits)									
SX: Diffuser/Bent crystal/VHF Local shield									

5