J-PARC STATUS

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For J-PARC Accelerator Team

J-PARC, KEK & JAEA

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Fairmont Hotel Vancouver

Vancouver, Canada

2009 Particle Accelerator Conference
31 J-PARC publications

- MO2BCI03 Y. Yamazaki, Status of J-PARC
- TU3PBI01 A. Y. Molodozhentsev, Beam Dynamics and Low Loss Operation of the J-PARC Main Ring cancelled
- TU4RAC04 M. Yoshii et al., Proton Beam Acceleration with MA Loaded RF Systems in J-PARC RCS and MR Synchrotrons
- WE1GRI02 H. Kobayashi, Commissioning of Main Ring for J-PARC cancelled
- WE4GRC01 T. Toyama et al., MR Beam Diagnostics at the First Beam Commissioning of the J-PARC MR

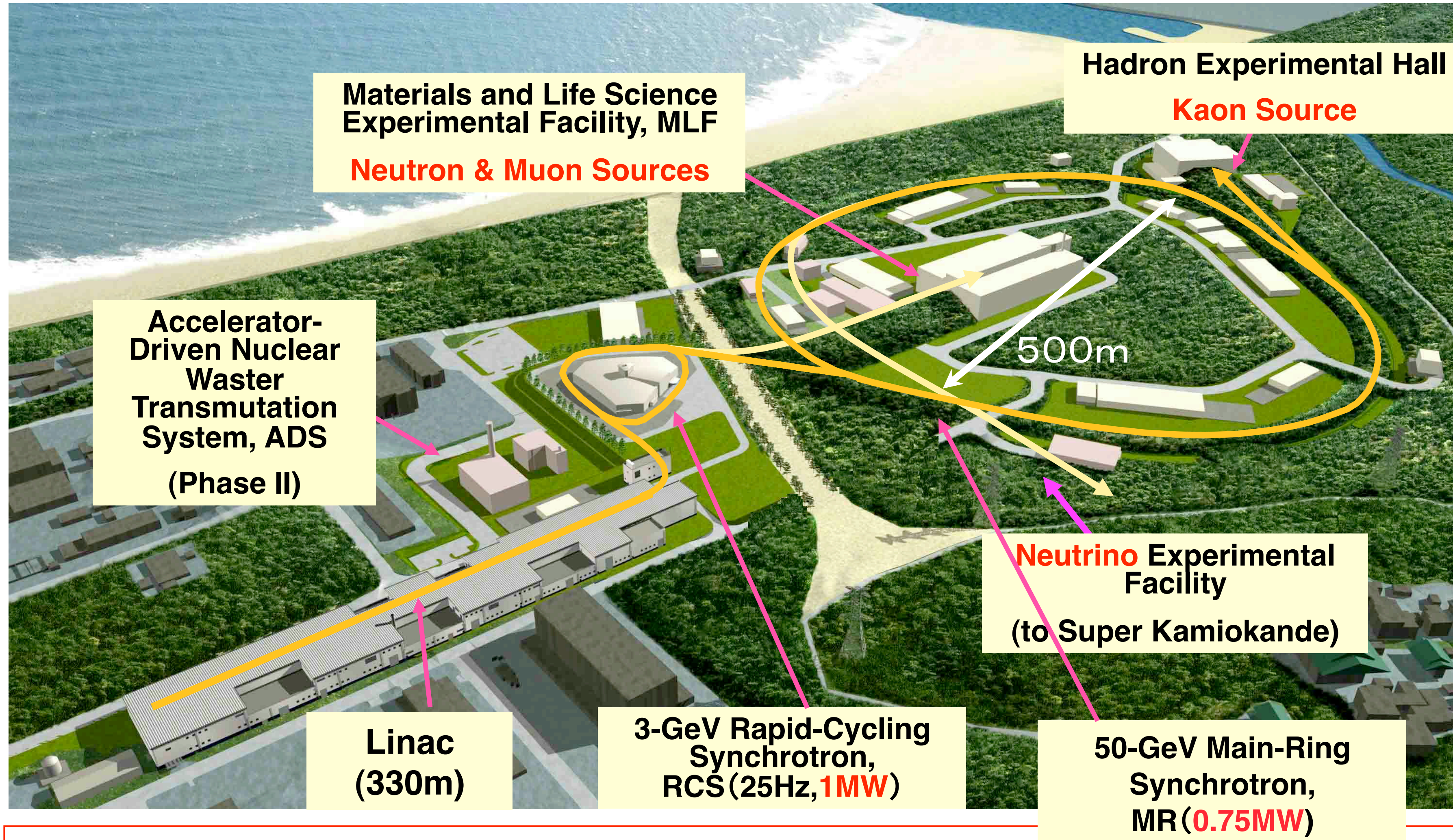
- MO6RFP016 J. Kamiya et al., Vacuum Status during the Beam Operation of RCS in J-PARC
- TU5PFP027 C. Ohmori et al., Design of a New J-PARC RF Cavity for Muon Short Bunch
- TU6PFP065 M. Kinsho, Status of the J-PARC 3-GeV RCS
- TU6PFP066 S. I. Meigo et al., Beam Commissioning of Spallation Neutron and Muon Source at J-PARC
- TU6PFP067 P. K. Saha et al, Beam Loss Issues Connected to the Foil Scattering: Estimation vs. Measurement at the RCS of J-PARC
- TU6PFP068 F. Tamura et al., Longitudinal Painting Studies in the J-PARC RCS
- TU6PFP070 T. Morishita, The Beam Dynamics Design for J-PARC Linac Energy Upgrade
- TU6PFP090 High intensity demonstrations in the J-PARC 3-GeV RCS
- TU6PFP091 T. Takayanagi et. al., Performance of the Bump System for the Painting Injcetion at J-PARC
- TU6RFP035 Development of Spill Control System for the J-PARC Slow Extraction
- TU6RFP083 Measurement Results of the Characteristic of the Pulse Power Supply for the Injection
- Bump System in J-PARC 3-GeV RCS
- WE5PFP002 Impedance Measurements of MA Loaded RF Cavities in J-PARC Synchrotrons
- WE5PFP003 Higher Harmonic Voltages in J-PARC RCS Operation
- WE5PFP082 Evaluation of Digital Feedback Control at 972 MHz rf System in J-PARC Linac
- WE5PFP087 Automatic Frequency Matching for Cavity Warming-up in J-PARC Linac Digital LLRF Control
- TH5PFP028 Longitudinal Particle Simulation for J-PARC RCS
- TH5PFP067 Longitudinal Phase Space Tomography at J-PARC RCS
- TH5RFP050 Measurements of Proton Beam Extinction of J-PARC MR Synchrotron
- TH5RFP059 IPM System for the Main Ring Synchrotron of the J-PARC
- TH5RFP060 Beam Based Alignment of the Beam Position Monitor at J-PARC RCS
- TH5RFP061 Study of J-PARC Linac Beam Position Monitor as Phase Monitor
- TH5RFP096 Study of Beam Loss Measurement in J-PARC Linac
- TH6PFP054 Beam Dynamics Design of Debuncher System for J-PARC Linac Energy Upgrade
- TH6PFP061 Design of Beam Monitor Configuration for Upgraded 400-MeV J-PARC Linac
- FR5RFP072 Stabilization of Beam Instability due to Space Charge Effect at J-PARC
- FR5REP012 Timing Delay Management Database for J-PARC Linac and RCS

Outline

- Introduction
- Linac
- Rings
- Ring RF
- RCS (Rapid-Cycling Synchrotron) versus AR (Accumulator Ring)
- Summary and Future

Introduction

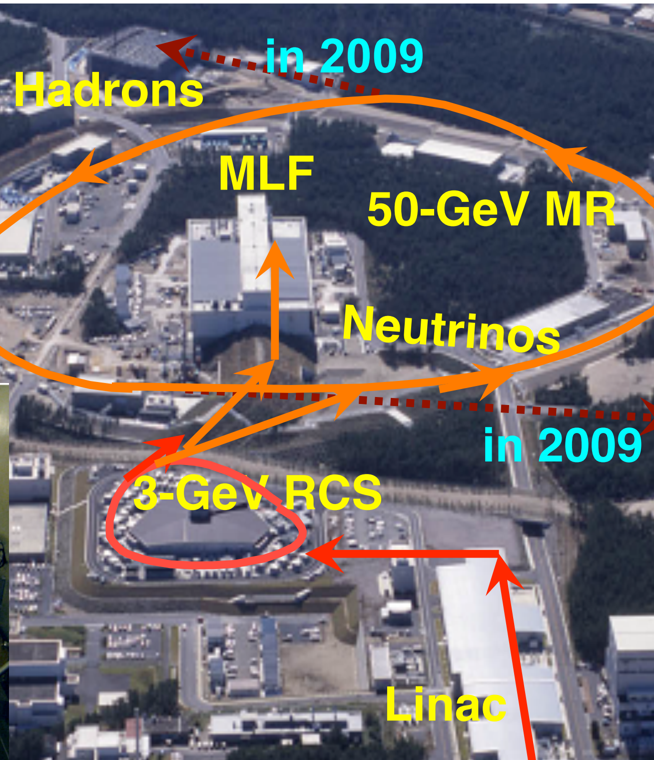
Japan Proton Accelerator Research Complex, J-PARC



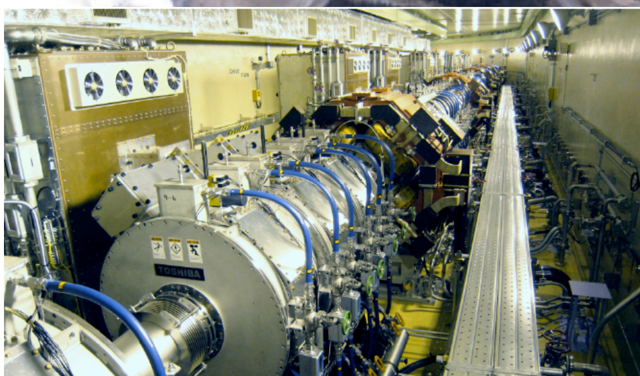
JoInt Project between High Energy Accelerator Research Organization, KEK and Japan Atomic Energy Agency, JAEA

Recent Progress in J-PARC Accelerator

First neutron from target
May 30, 2008

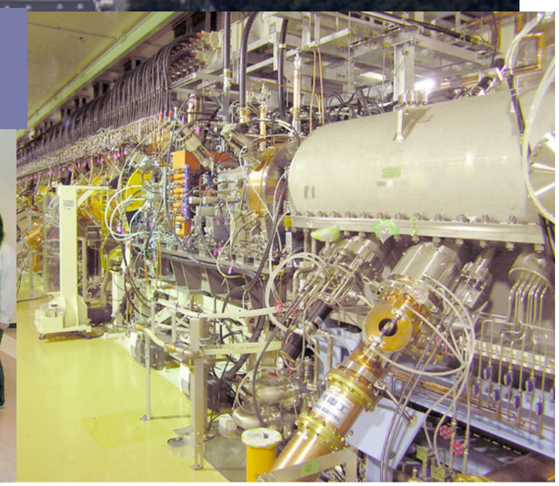


MR beam circulated and
rf–captured, May 22, 2008



RCS beam accelerated
As designed Oct, 31, 2007

LINAC beam accelerated as
designed Jan, 24, 2007



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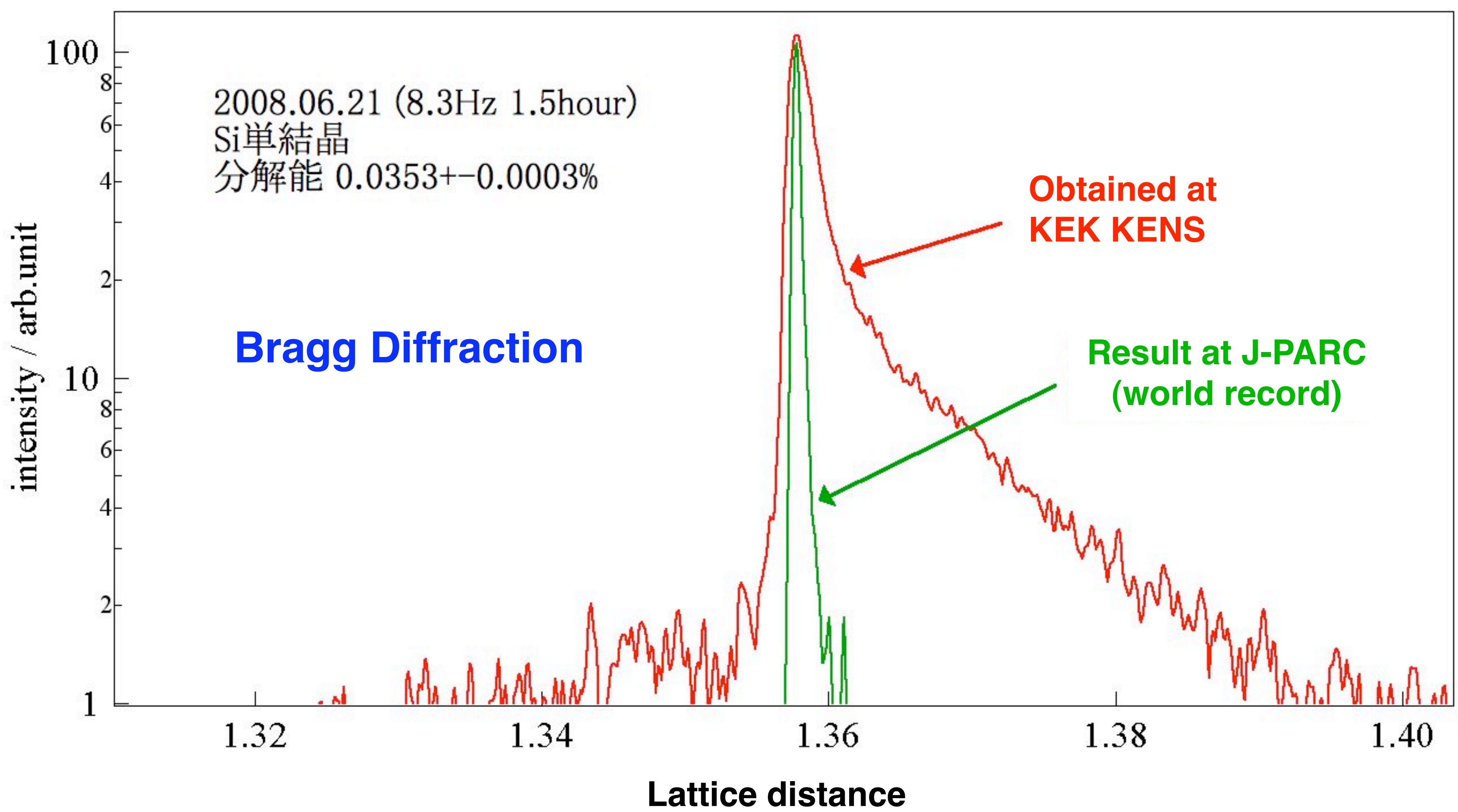
Example of Test Results in June, 2008

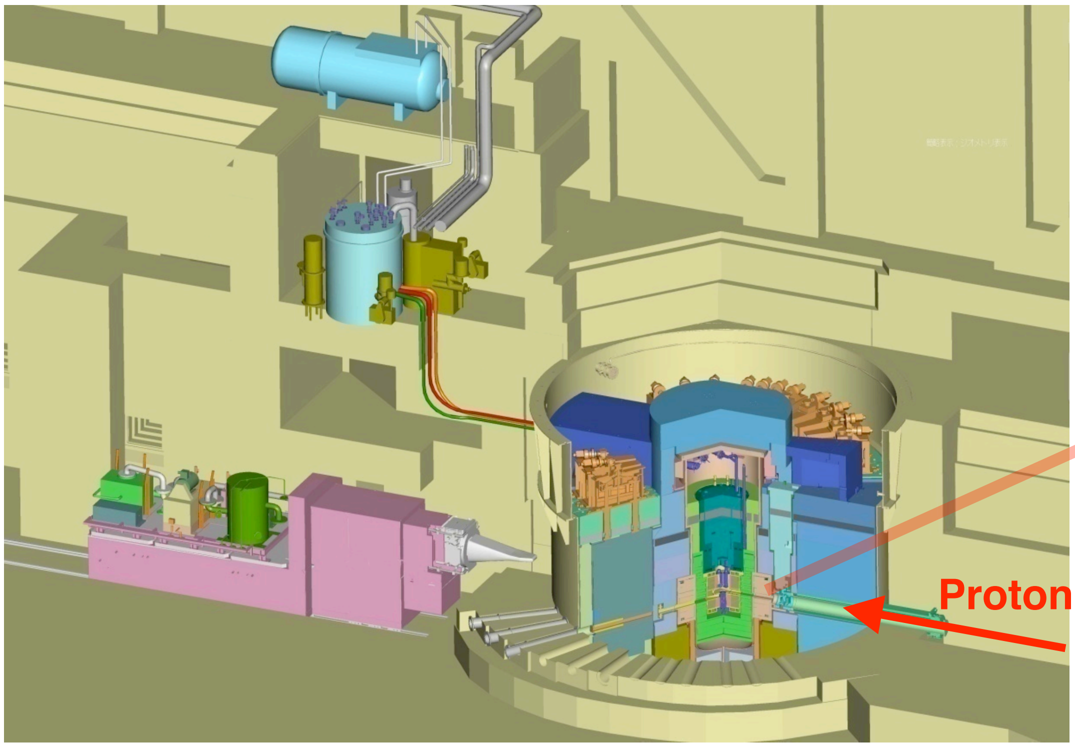


New Invention for J-PARC Moderator

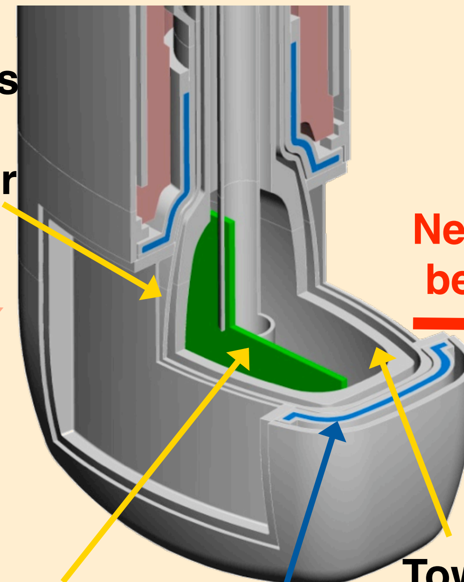
The result incorporating KEK technology and JAEA nuclear reactor one

J-PARC

Neutron Source



Moderator Type#1



Other two types of moderators have been prepared. All working exactly in the way as designed.

Ag,In,Cd

All the MR Mile Stones were accomplished on schedule.

On December 23rd, 2008, the MR beam was accelerated to 30 GeV, which is the present goal.

On January 27th, 2009, the 30-GeV MR beam was successfully extracted to the Hadron Experimental Facility.

(Drinks at hand were non-alcoholic.)

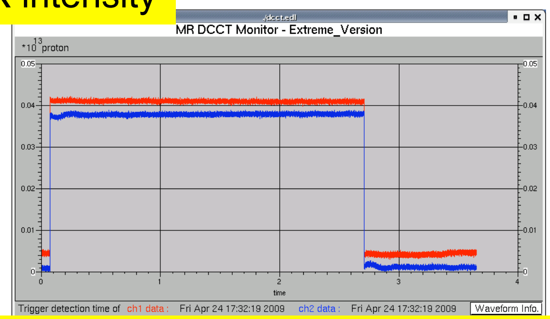
On April 23rd, 2009, the 30-GeV MR beam was fast extracted and guided to the neutrino production target, where the neutrino production was confirmed by observing the muons.

J-PARC

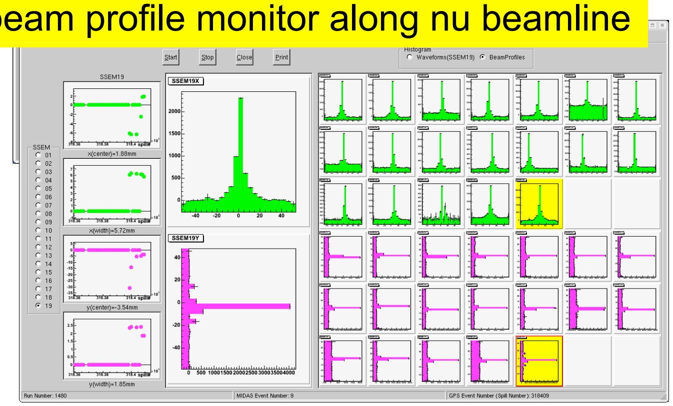
T2K(Tokai to Kamiokande) beamline started operation

After ~10 shots for tuning, proton beam hit around target center

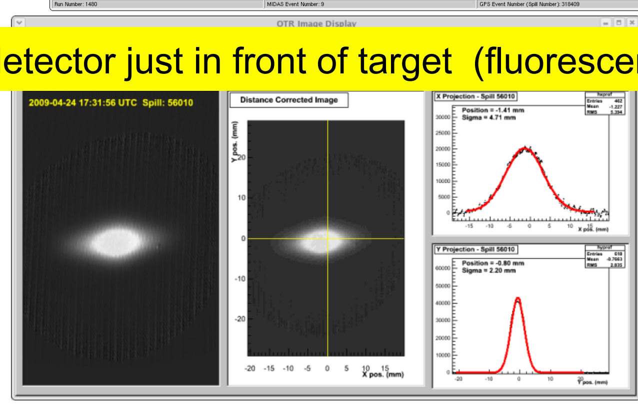
MR intensity



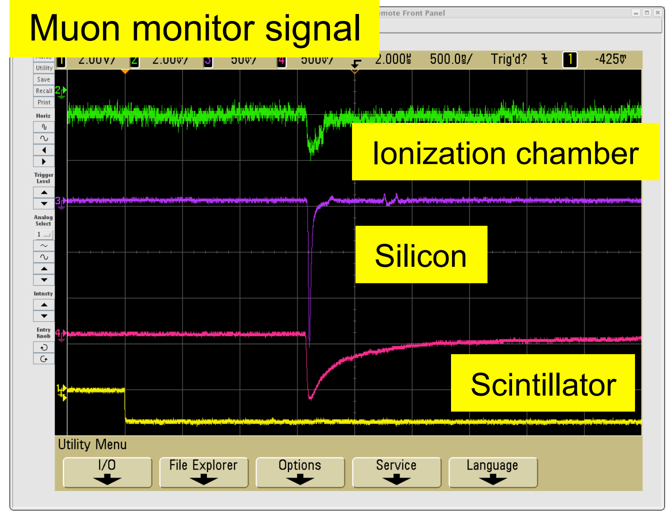
Proton beam profile monitor along nu beamline



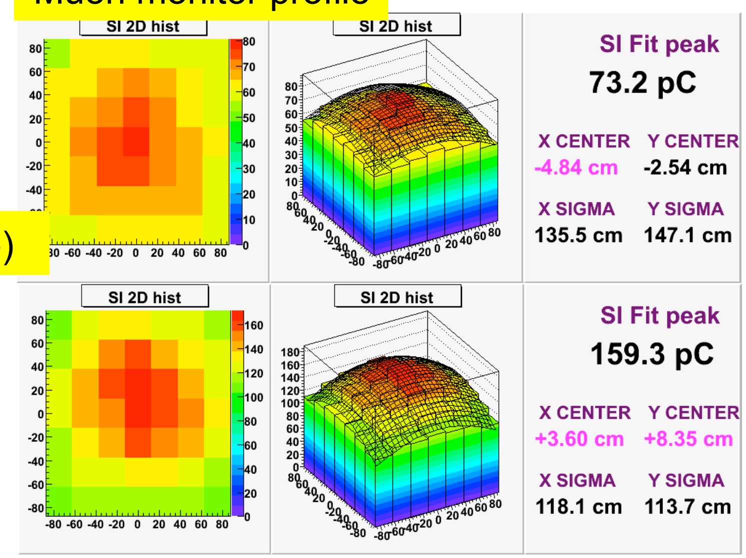
OTR detector just in front of target (fluorescence plate)



Muon monitor signal



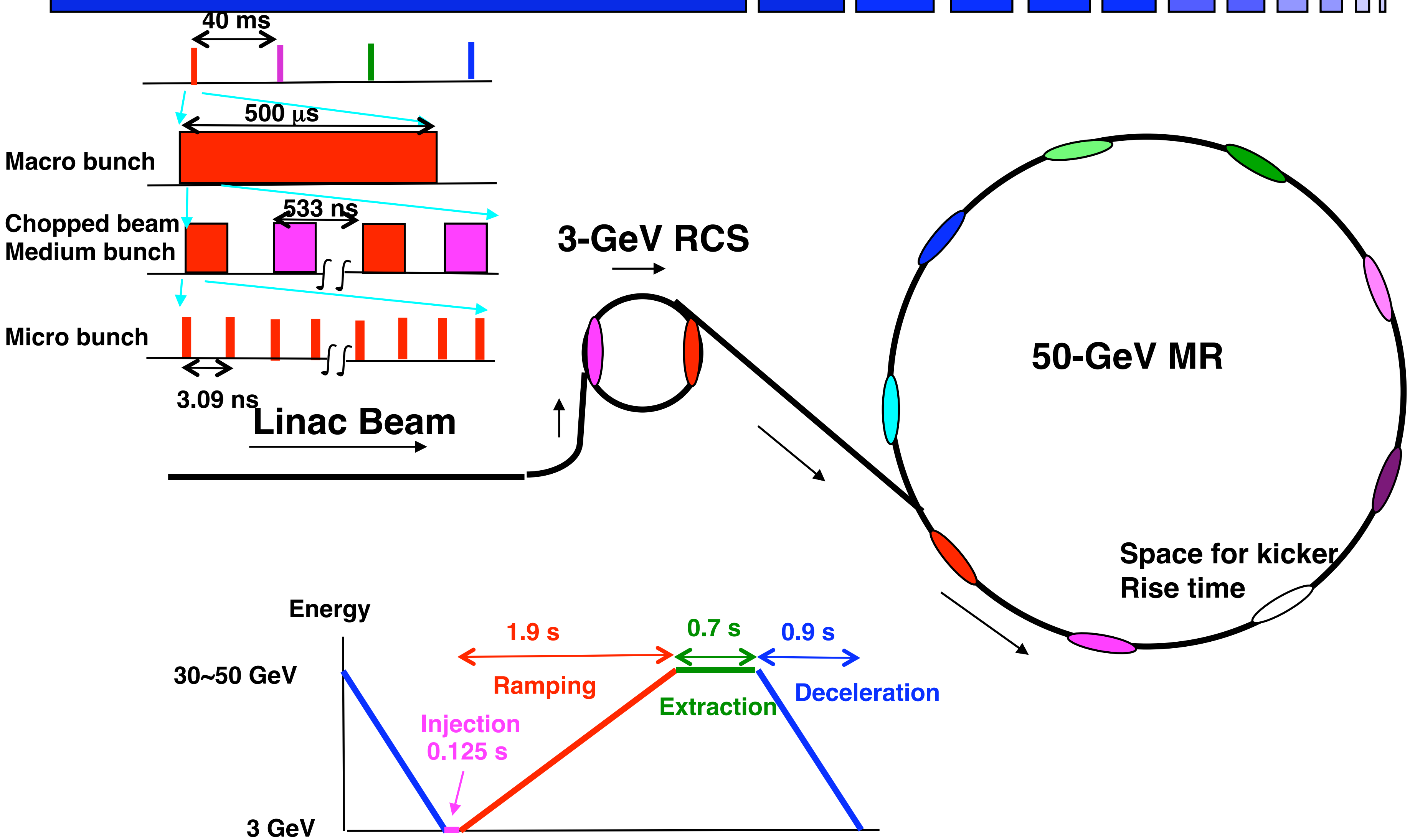
Muon monitor profile



Horn Off

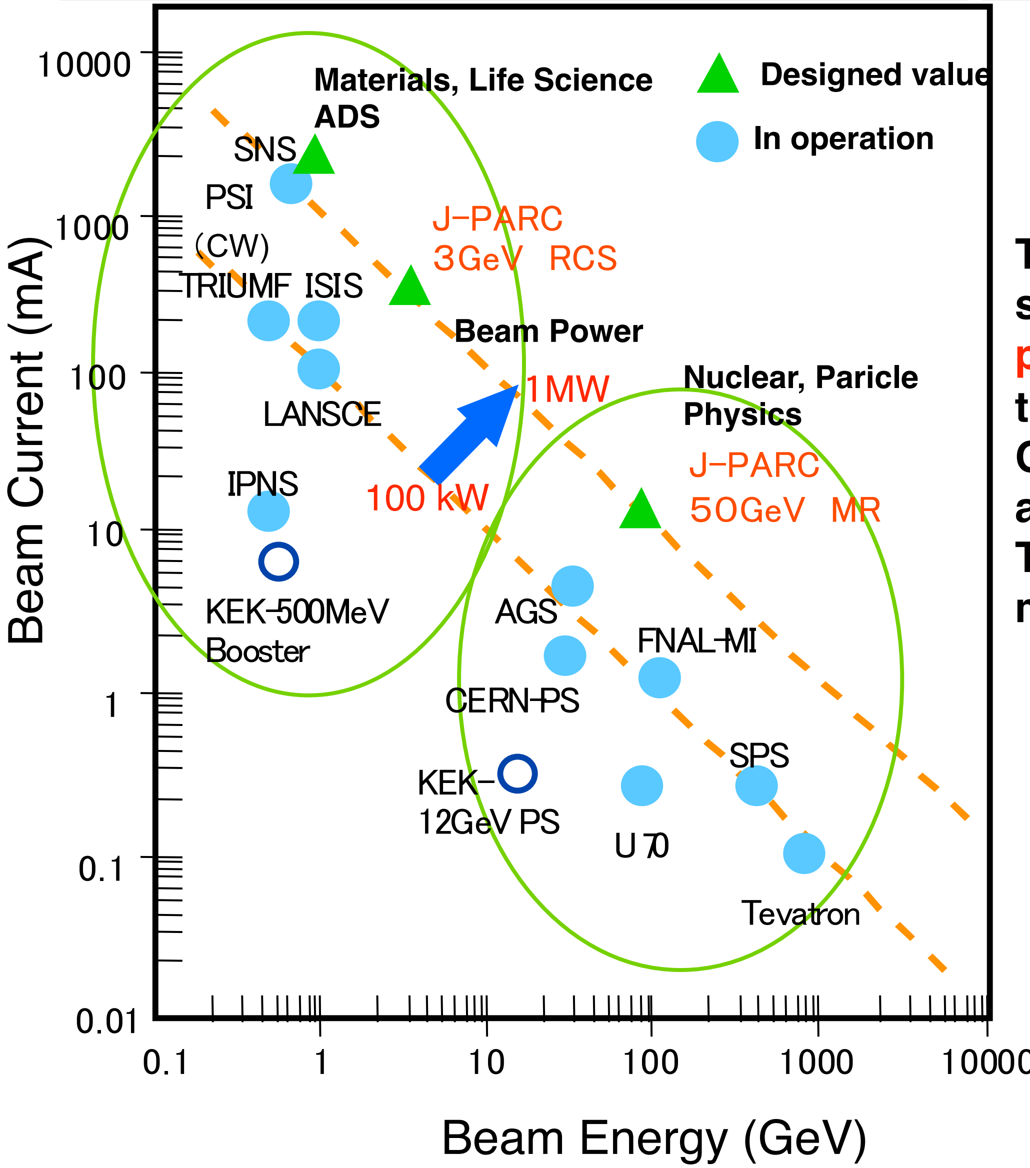
Horn 250kA

J-PARC Accelerator Scheme



MR Cycle 3.625 s for slow extraction

Beam Power Front



Beam Power (W)
= Beam Current (A)
X Beam Energy (V)

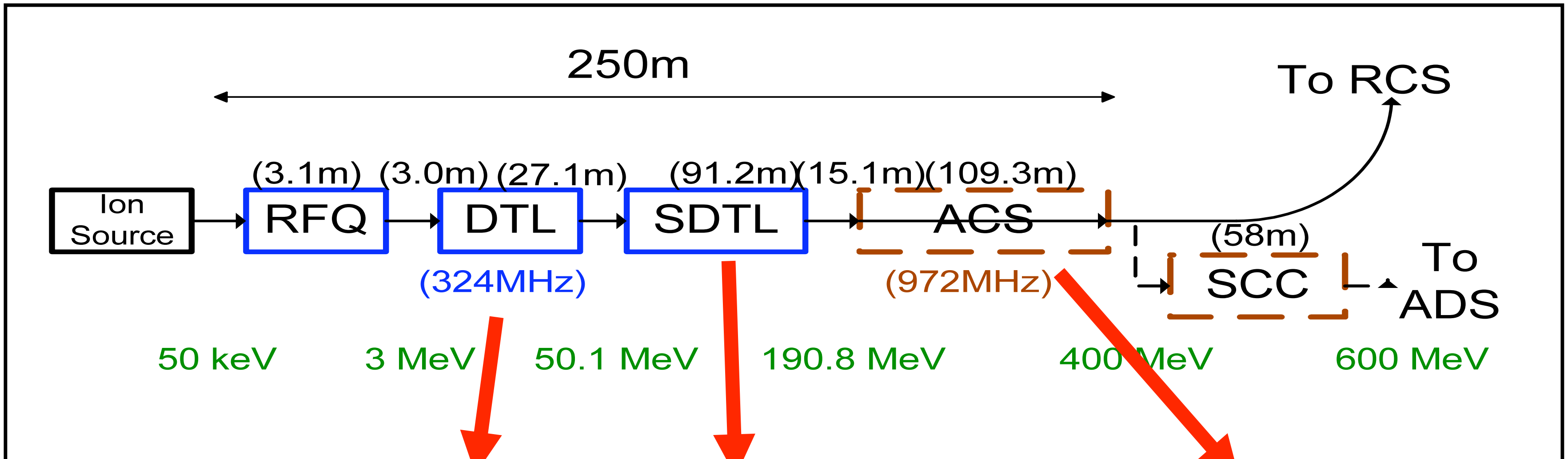
The yield of the secondary particles per second is proportional to the beam power, if the beam energy exceeds the threshold.
On the other hand, the radioactivity is also proportinal to the beam loss power. Therefore, the beam loss rate should be minimized in this case.

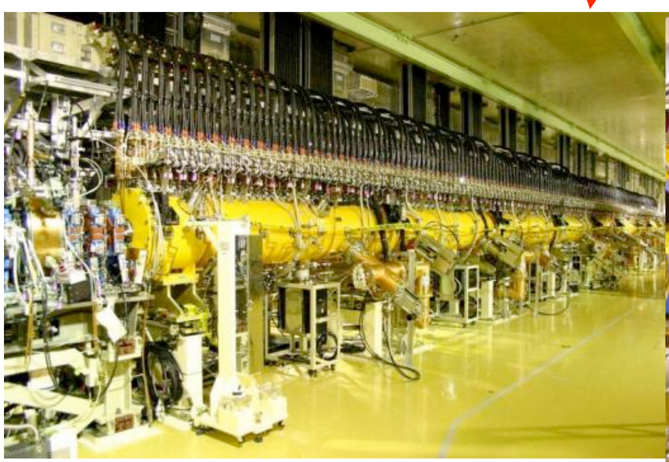
The number of the secondary particles per pulse is crucial for some important experments. The beams are accumulated in a ring, to be fast extracted.

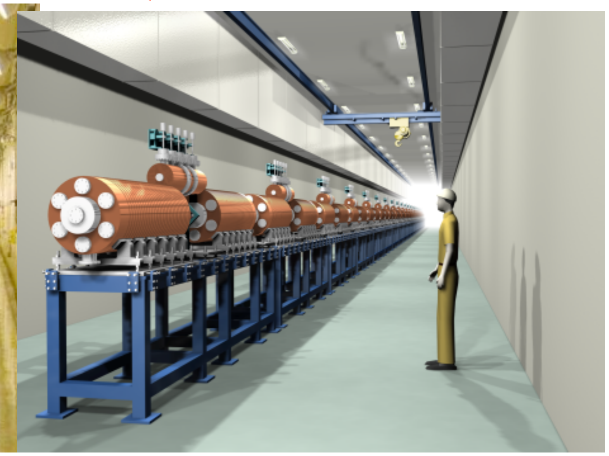
Accelerate in the ring?
Yes (RCS): J-PARC, ISIS
No (AR): SNS, LANSCE

Linac

J-PARC Linac Scheme and ACS
(Annular-Ring Coupled Structure)





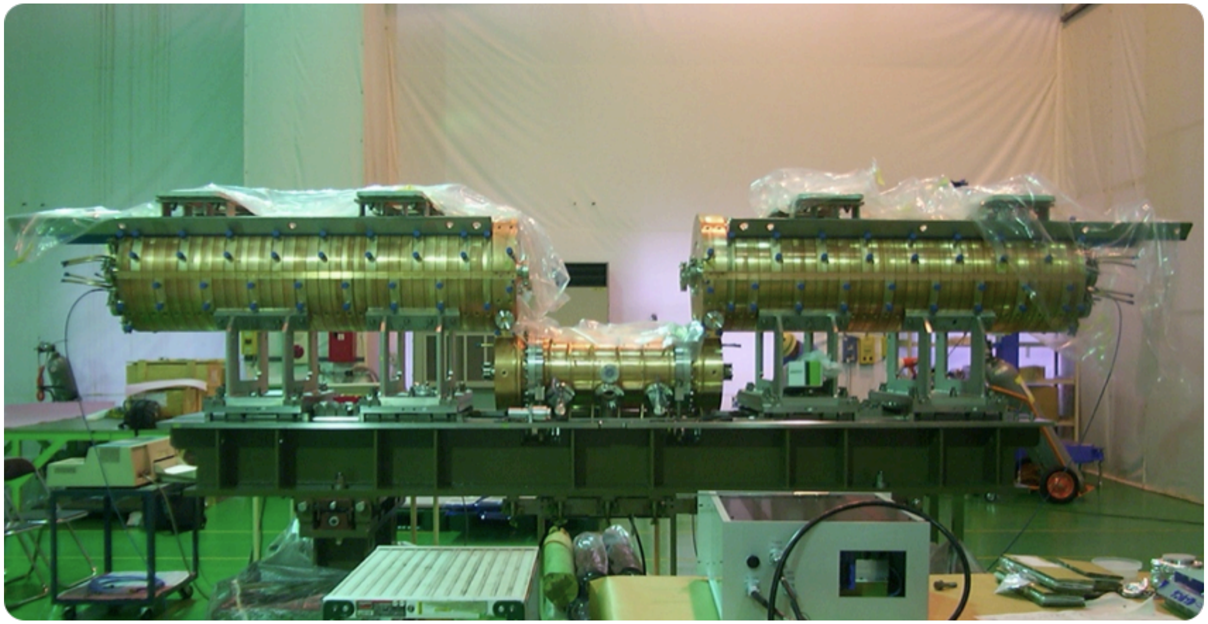


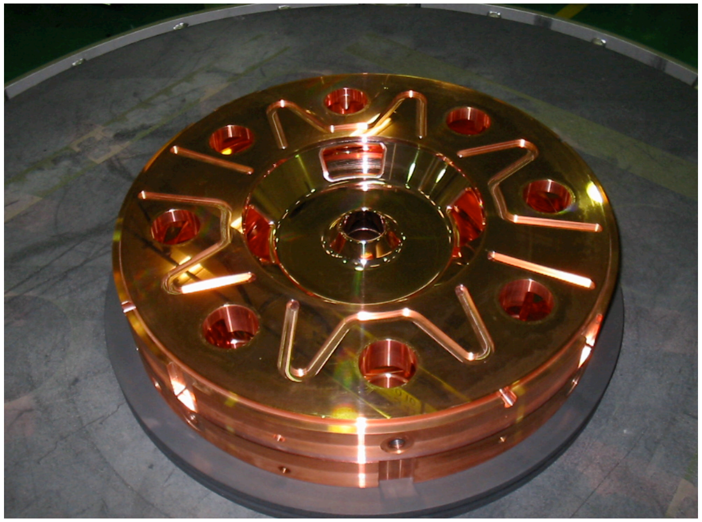
Drift-Tube Linac (DTL) **Separted DTL (SDTL)** **ACS**

The construction of the high-energy ACS linac was funded and just started at the end of March, 2009, thanks to Japanese Nobel Prize winners and recent economical recession.

J-PARC

Axially Symmetric ACS for High-Energy Structure

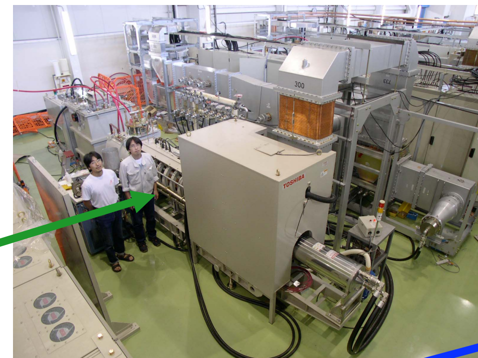
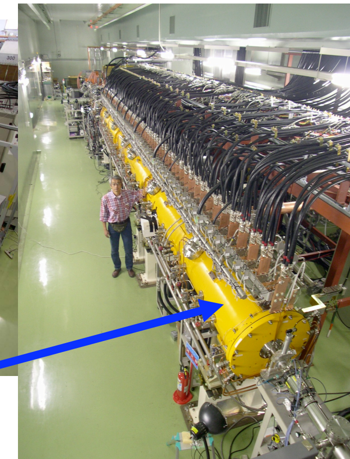




The two ACS buncher cavities and the lowest-energy ACS cavities shown above were powered up to the design value. The development of the ACS has been done in close collaboration with MMF (Moscow Meson Factory), INR, which has the 600-MeV Disk-And-Washer (DAW) linac.

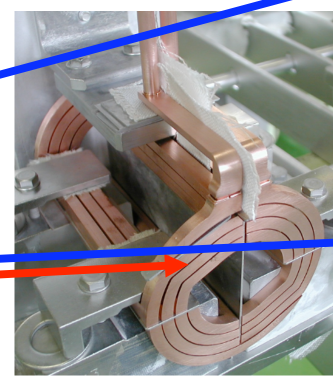
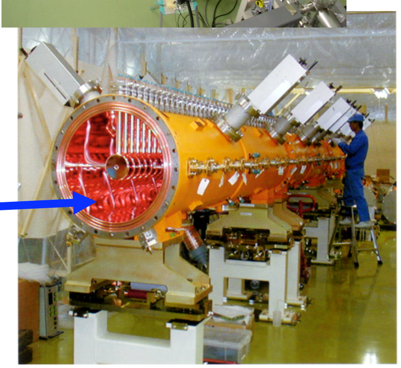
J-PARC

J-PARC Linac
(high-quality beams specified for injection to synchrotron)

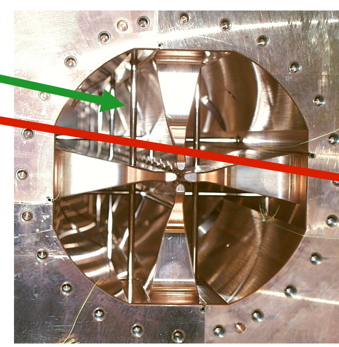
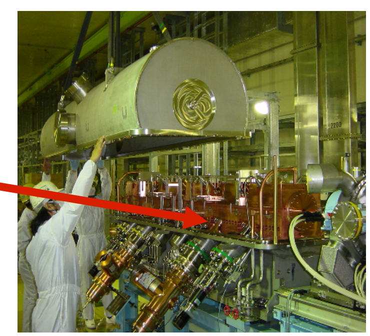
Conflicting Requirements

- **Higher accelerating frequency is preferable**
  - **lower bunch current**
  - **short focusing period**
  - **klystrons feasible for stable operation**
- **Electromagnet is preferable in order to keep the flexible knob (Large Drift Tubes, Lower frequency)**
  - **The parametric resonance can be avoided**

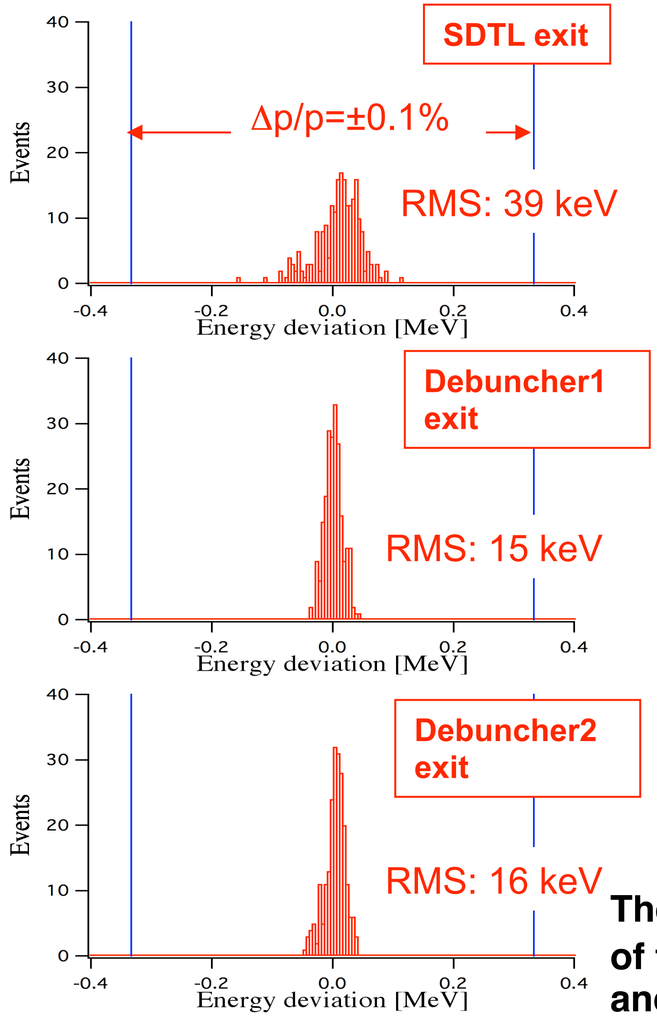
Invention

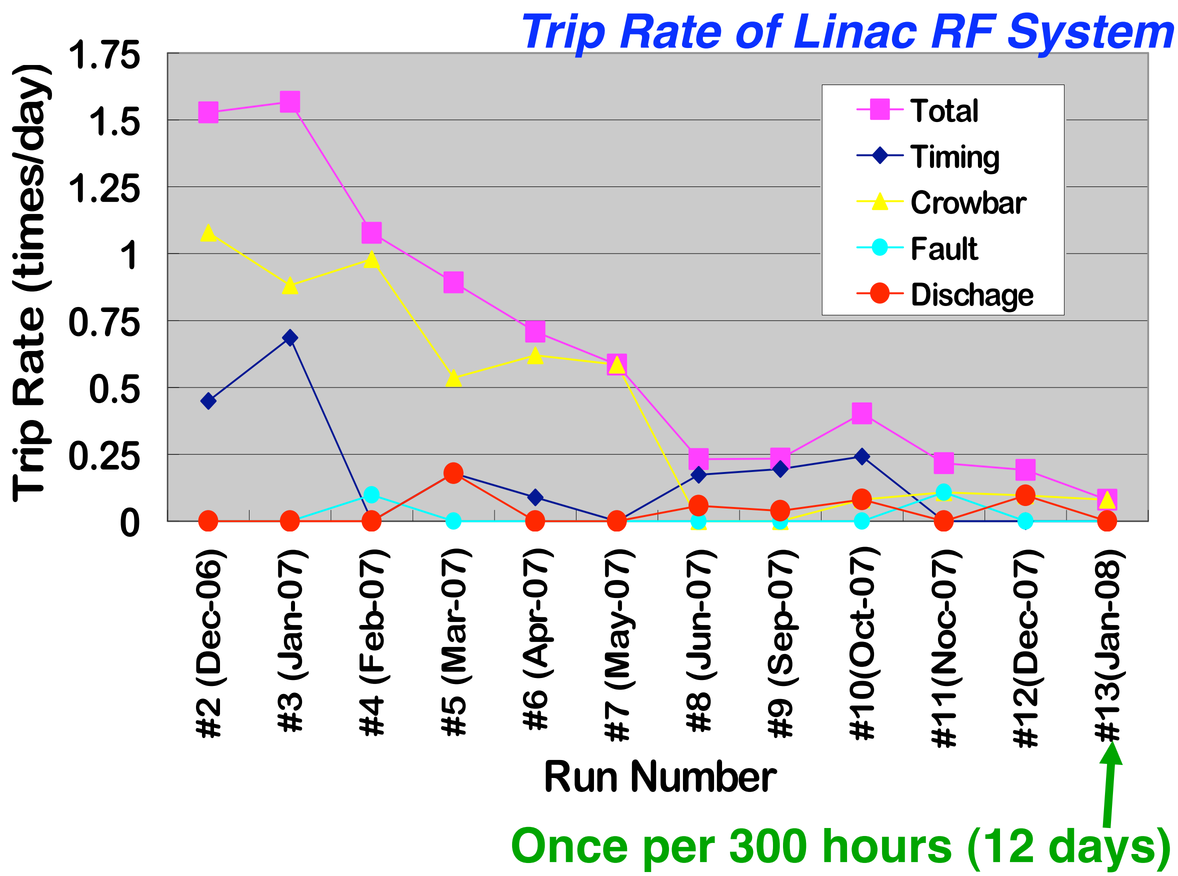
- **DTL coils produced by electroforming together with wire cutting**
- **Highest energy RFQ with PISL (π-mode Stabilizing Loop)**

Now, this RFQ has the most serious discharge problem, limiting the J-PARC performance

Linac system had been extremely stable and reliable until the recent RFQ issue happened





The unscheduled down time in **May and June**, 2008, was **5.4 %** of total linac operation of 508 hours, while that in **December**, 2008 and **January**, 2009, amounted to 27.0 % of operation of 863 hours, among which **24.8 %** was due to the discharge in the RFQ.

Energy Jitter (Required is Δp/p=±0.1% for RCS injection)

J-PARC

Measured transverse emittance

- 5 mA peak current

	H	V
DTL exit	0.27	0.25
SDTL exit	0.23	0.27
A0BT exit	0.25	0.27

- 30 mA peak current

	H	V
DTL exit	0.42	0.36
SDTL exit	0.35	0.40
A0BT exit	0.37	0.40

Design 0.3 0.3

The listed emittances are calculated from rms beam widths measured with an array of WS's.

The emittance is also measured at MEBT with a double-slit emittance monitor, and found to be 0.22 to 0.25 for both 5 mA and 30 mA cases.

We have significant emittane growth in DTL in the case of 30 mA peak current.

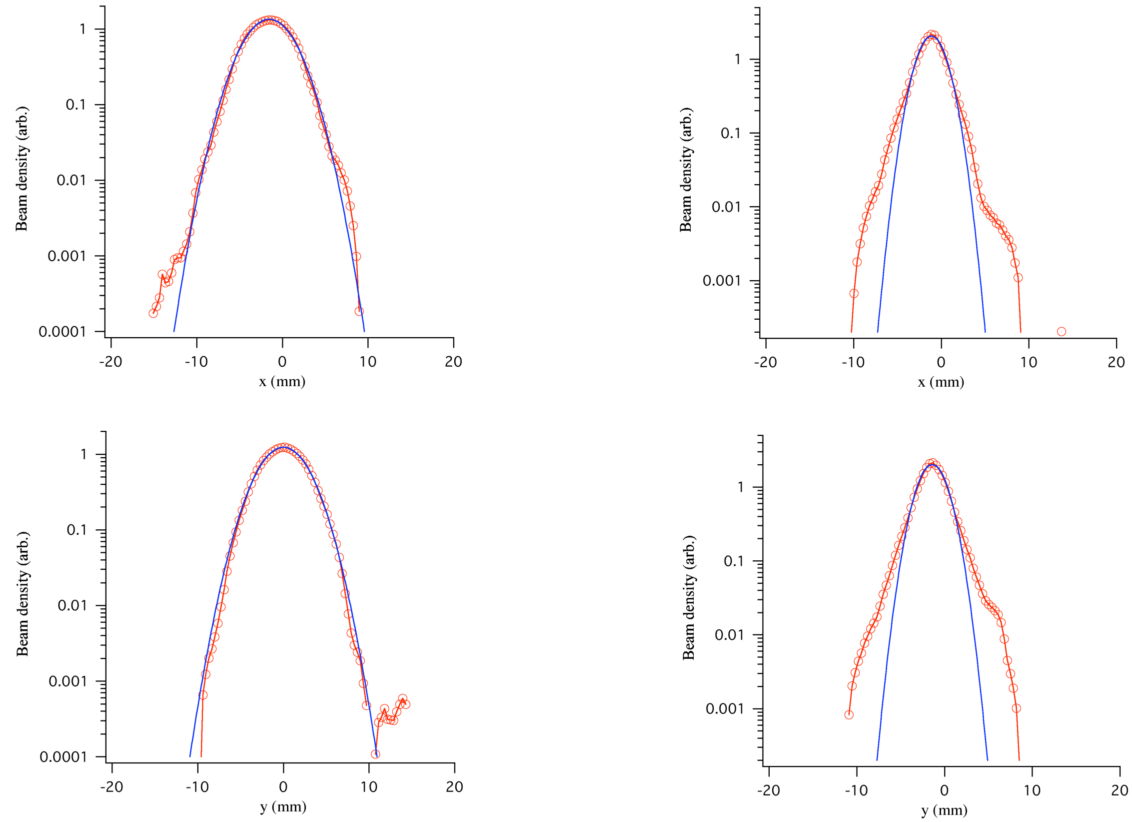
We don't have significant emittance growth after DTL exit.

* Normalized rms in πmm•mrad.

Measured profile at the DTL and SDTL exits (a peak current of 30 mA)

At the DTL Exit | At the SDTL Exit

Horizontal / Vertical



Beam profile is almost Gaussian at the DTL exit. On the other hand, clear halo is developed at the SDTL exit while there is no significant emittance growth. Perhaps, incomplete matching. We need more beam diagnostics.

Red circle: Measurement, Blue curve: Gaussian fit

Rings

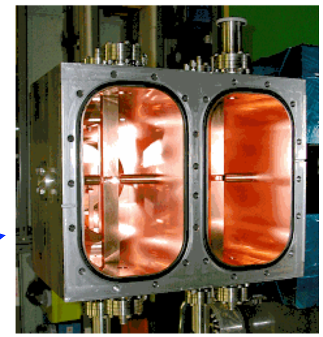
In order to eliminate the beam loss in the rings

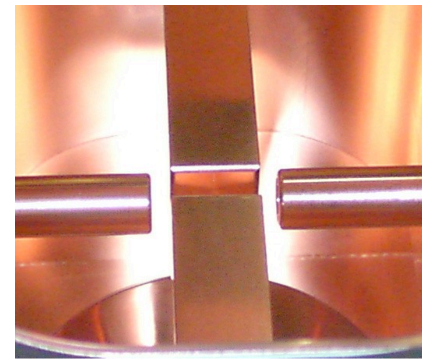
The linac beam which cannot be accepted by the ring RF is eliminated at the linac MEBT.

↓

The RF chopper was devised by T. Kato, and was developed together with Shinina Fu, who was working for JHF at that time.

RF Beam Choper installed at the linac MEBT





Separated-function scheme of bending magnets and focusing magnets were proposed by Kitagaki (published in Physical Review) for strong focusing lattice, and were used in KEK-PS MR.

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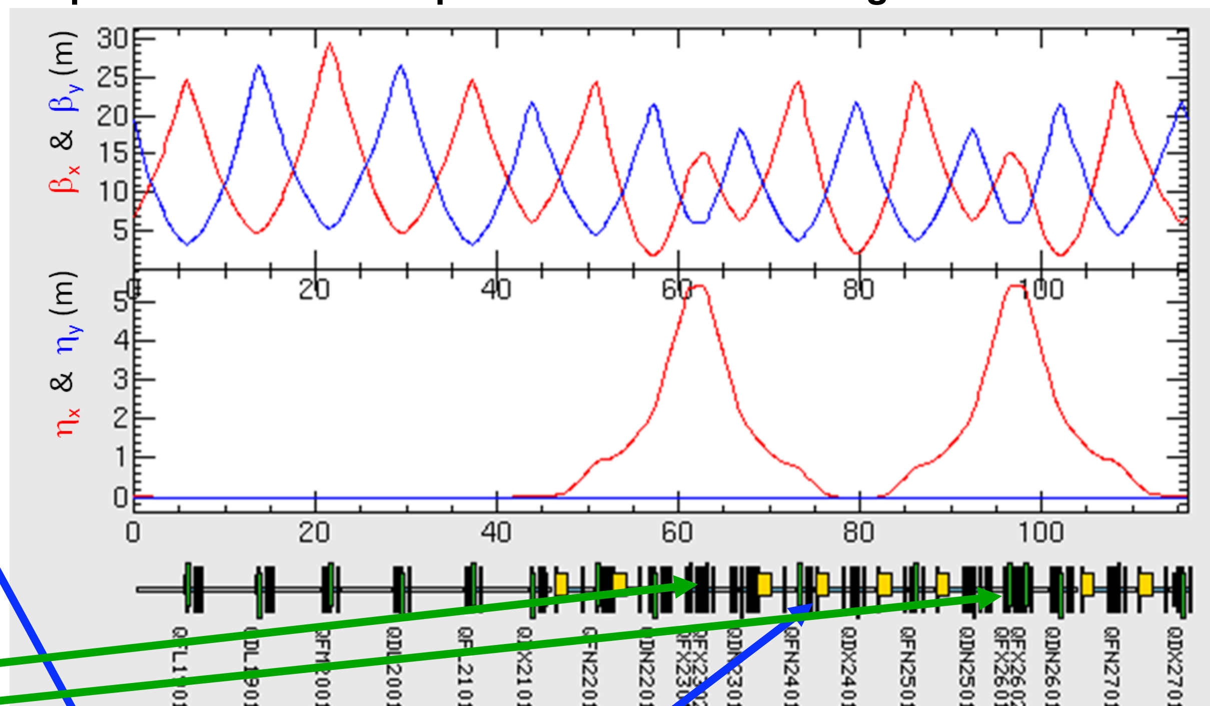
In J-PARC MR, the transition gamma is imaginary for eliminating the beam loss inherent at the transition.

MR lattice

High Gamma-T Lattice of J-PARC RCS

The low-energy non-relativistic particles arrive at the accelerating cavity later than the high-energy ones. The low-energy relativistic particles arrive earlier, since their orbit is inner. In both the cases, the particles have the phase stability. At a certain energy in between the non-relativistic and relativistic the beam becomes unstable, which is called "transition, or transition energy, or transition gamma, or gamma-T". The conventional normal FODO lattice implies that the beams pass the transition during the acceleration.



Missing Bend

Straight Section

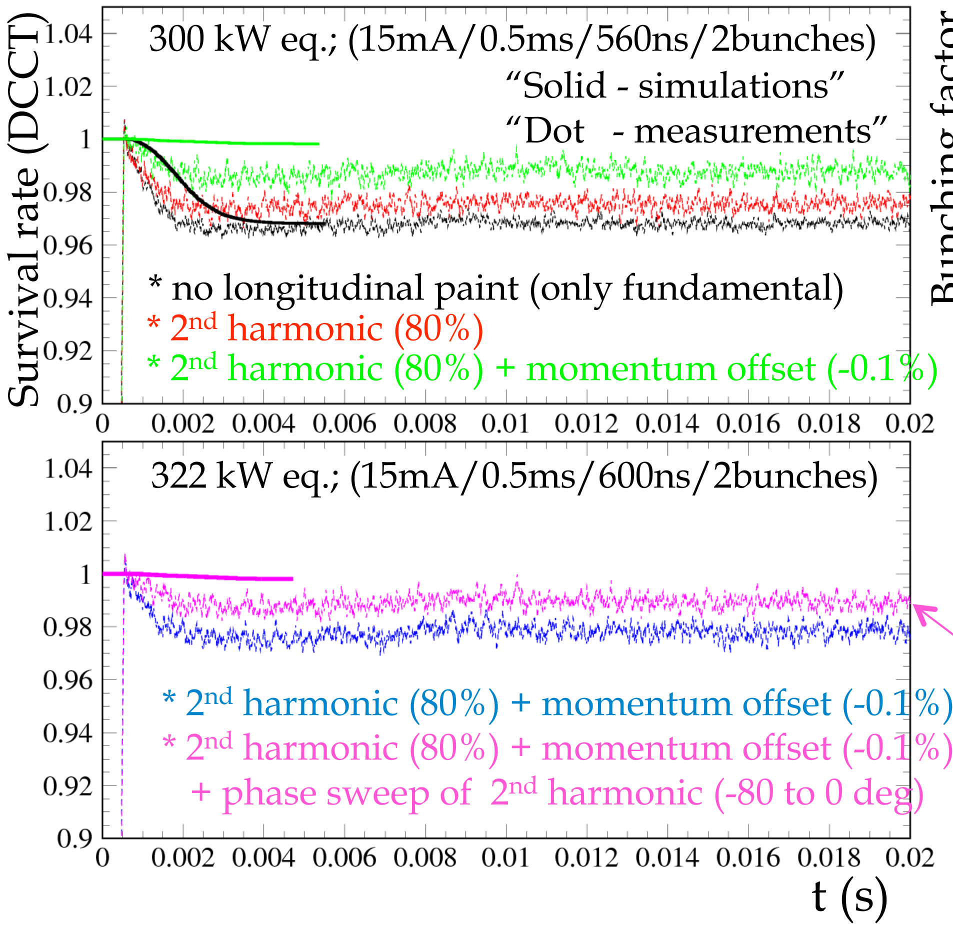
Arc Section

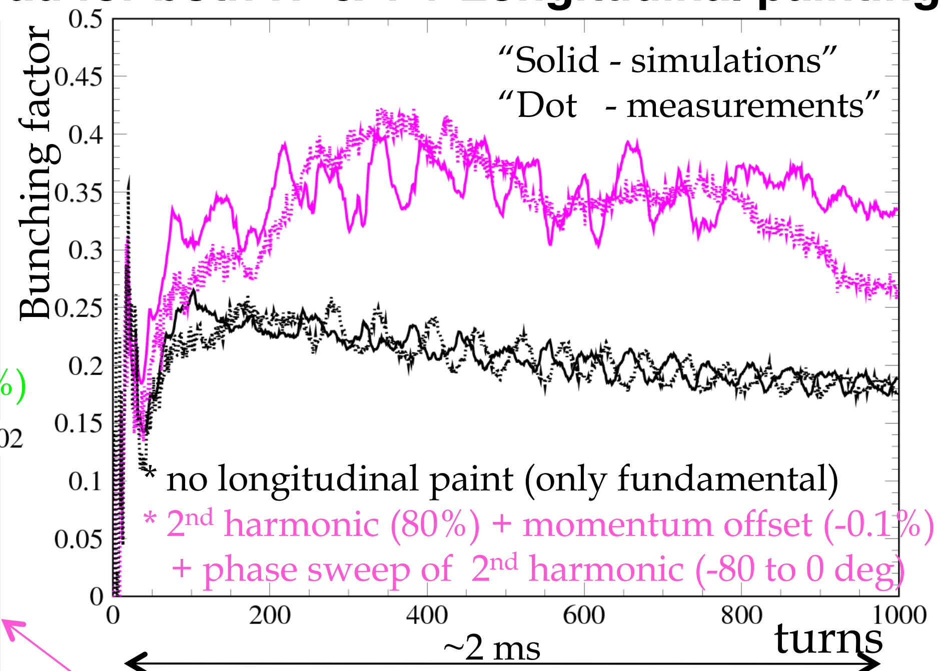
Bending Magnet

By this missing-bend lattice, the momentum dependence of the orbit is changed so as to increase the transition energy.

High-Intensity Demonstration
No beam loss during the acceleration

The beam loss is concentrated on the injection period.
Transverse painting ; set at 150 π mm mrad for both H. & V.+ Longitudinal painting



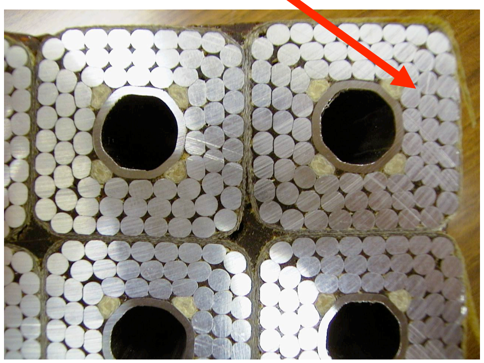


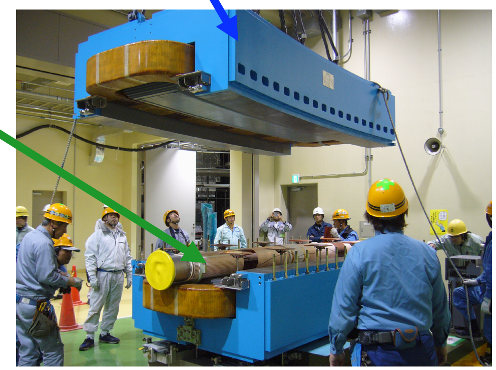
2.58×10^{13} ppp at 3NBT
(310 kW eq.)

This demonstrates that the J-PARC accelerator beam design is realistic.
If the injection energy is increased to 400 MeV, this corresponds to 1 MW.

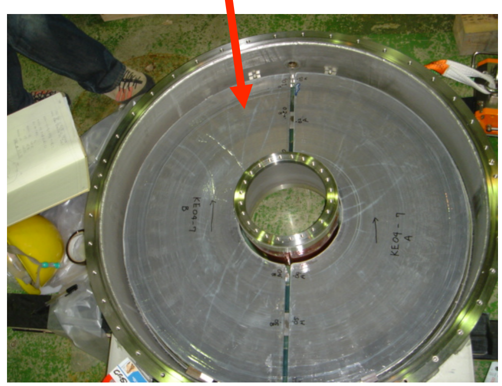
Rapid-Cycling Synchrotron (the world-rapidest)

- **Wide Aperture Magnets for storing a number of protons against the space charge force**
- **Stranded Coil, Ceramics Vacuum Chamber against the eddy current effect**





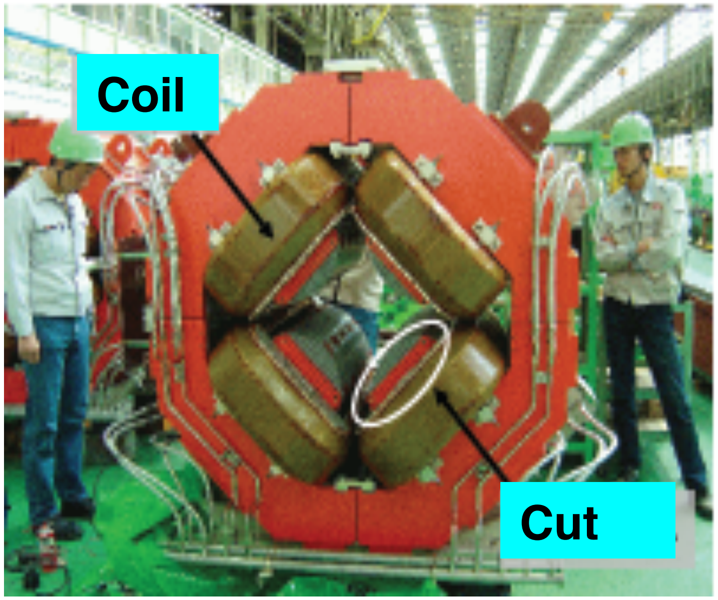
- **Magnetic Alloy (FINEMET)-Loaded Cavity**

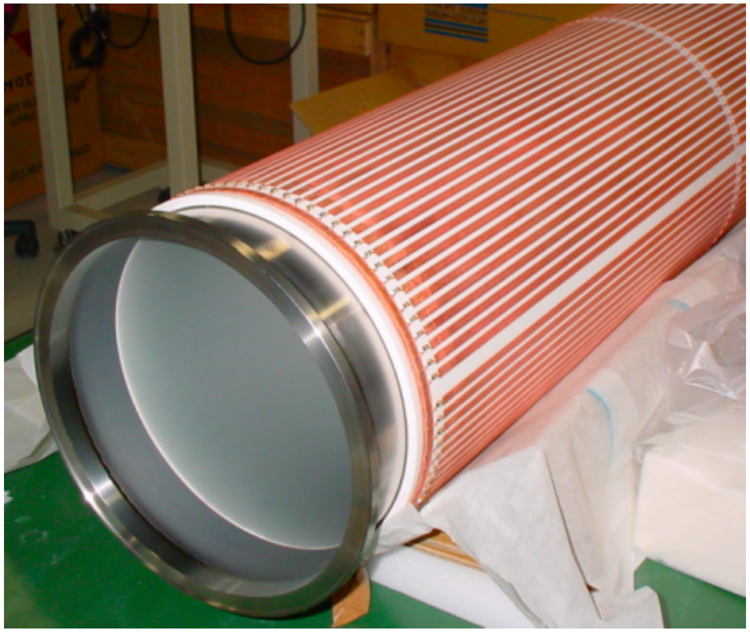


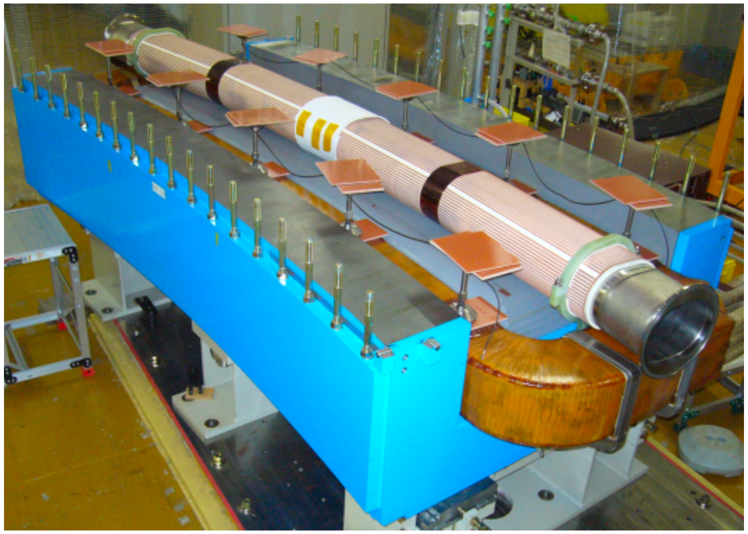
The Highest Field Gradient Cavity For the Rapidest Acceleration (25 kV/m in contrast to around 10 kV/m of conventional ferrite-loaded cavities)

Large Aperture Magnet and Ceramics Vacuum Chambers

Large Aperture Quadrupole Magnet and Cylincrical Ceramics Vacuum Chamber





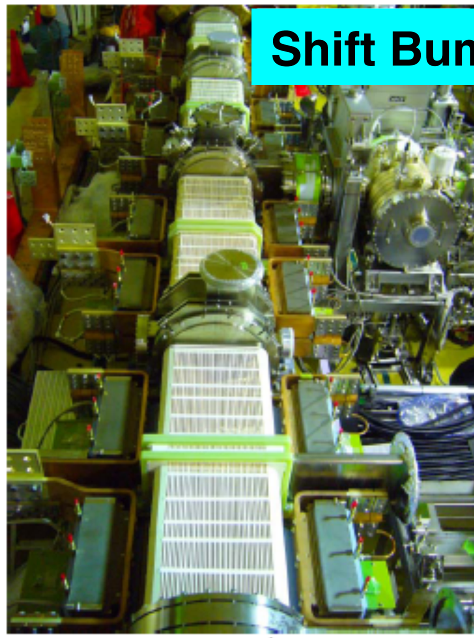


In order to keep the large aperture with the reasonable cost for the bending magnets, we chose the cross section of the race-track shape for the BM vacuum chambers.

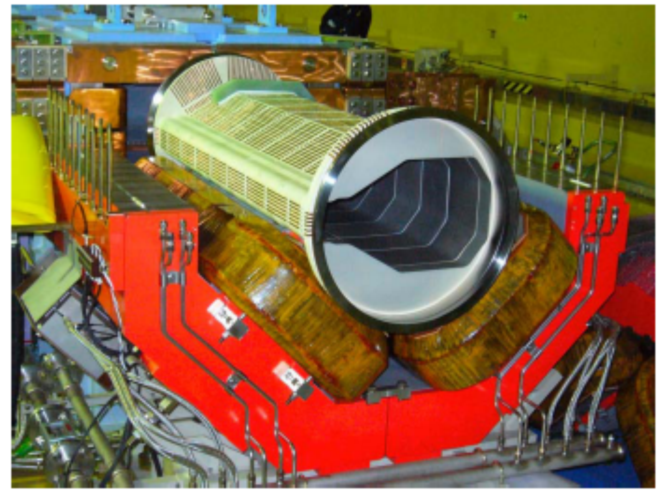
Injection Section and Ceramics Vacuum Chambers

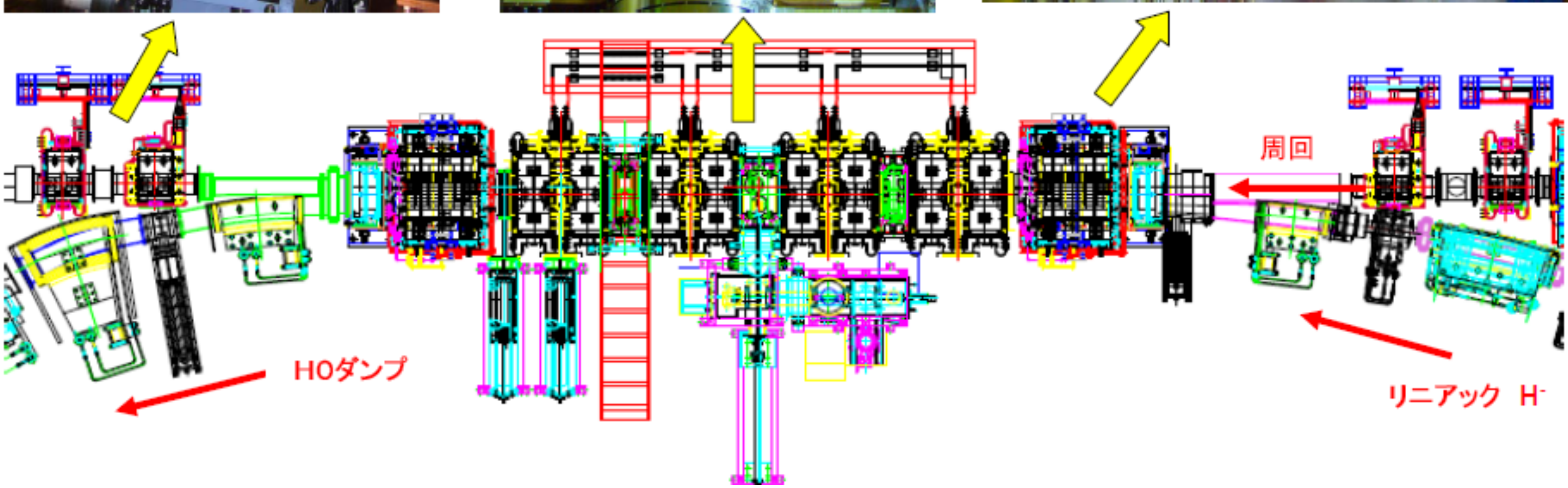
Paint Bump

Shift Bump

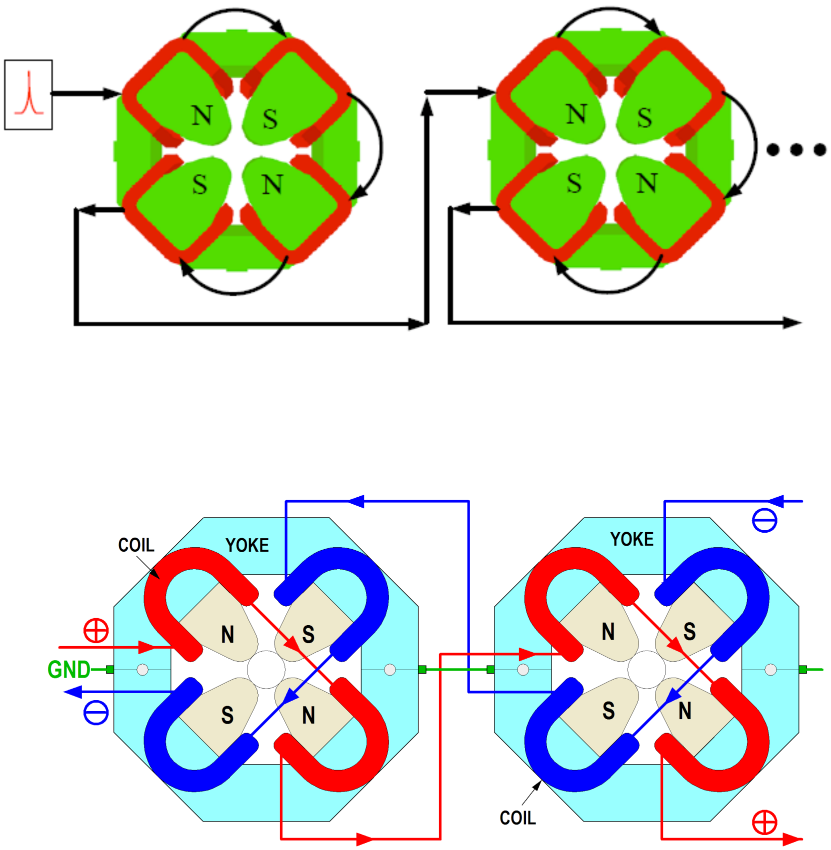


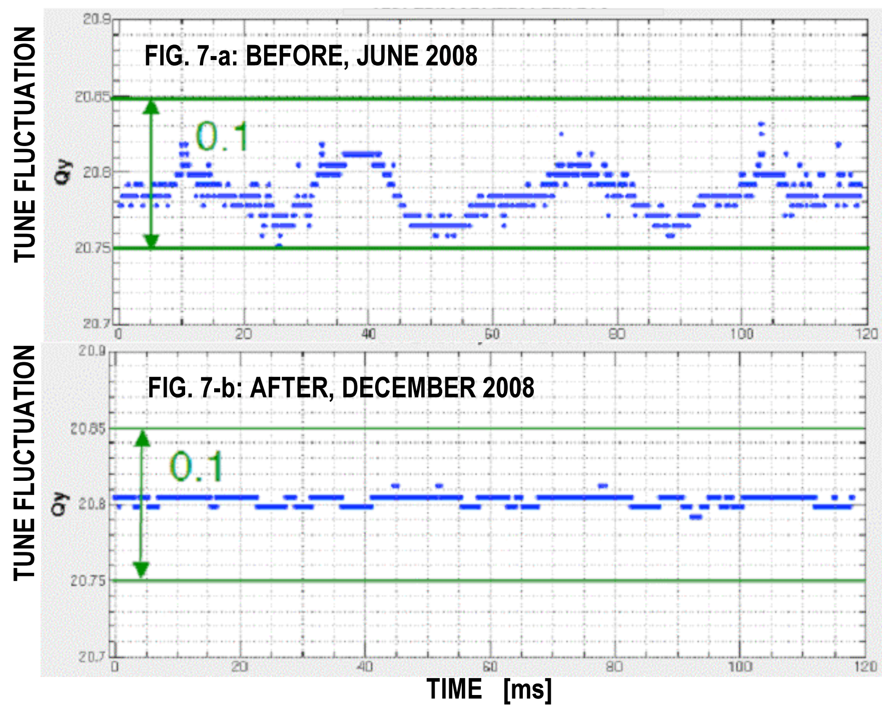
Injection and Q





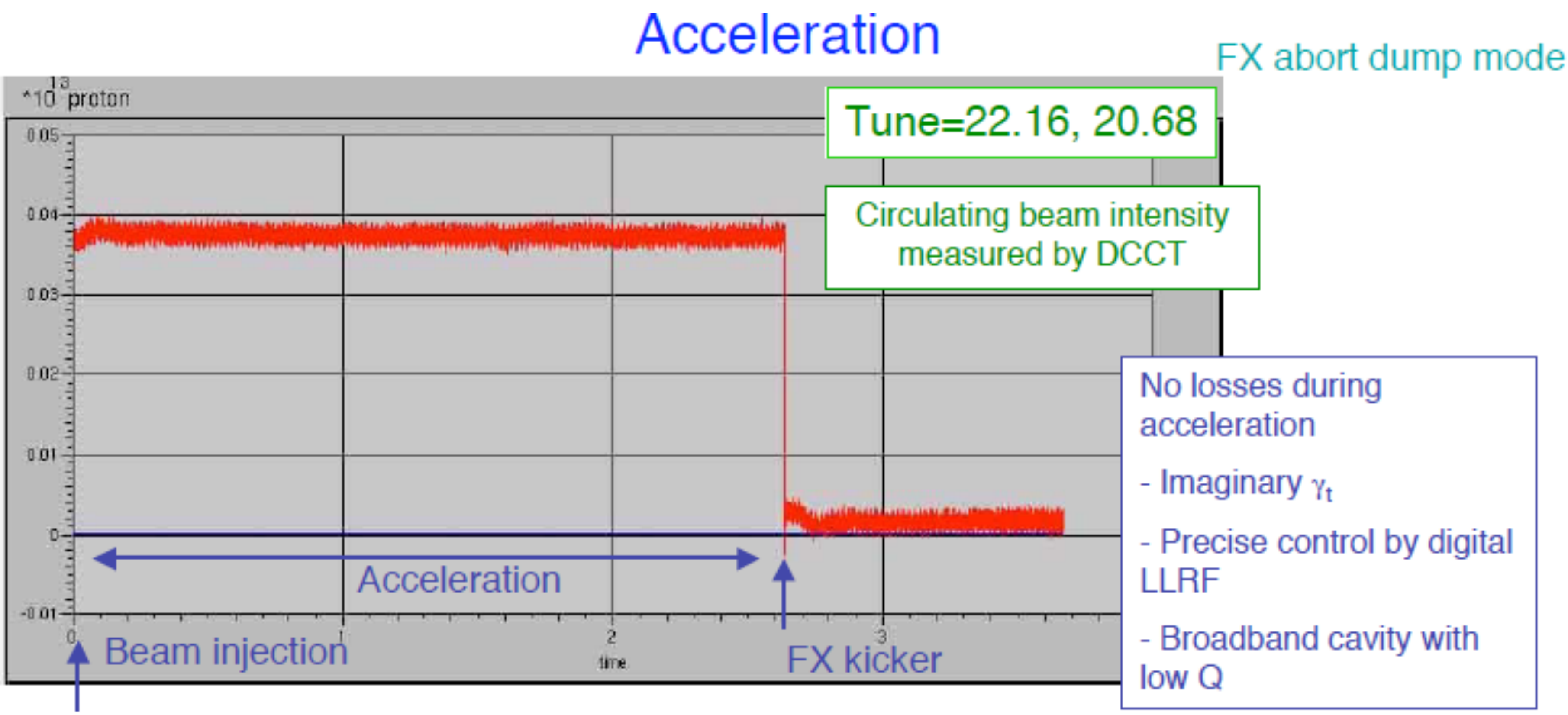
Cabling Network improvements in MR for mitigating the common-mode noise





Common-mode current has no influence on the quadrupole fieds in the lower cabling network.

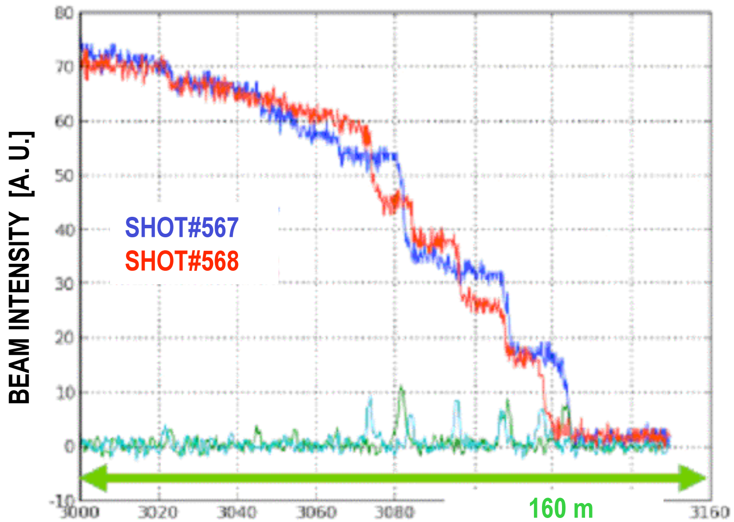
The first MR beam acceleration on Dec. 23rd, 2008



No losses during acceleration

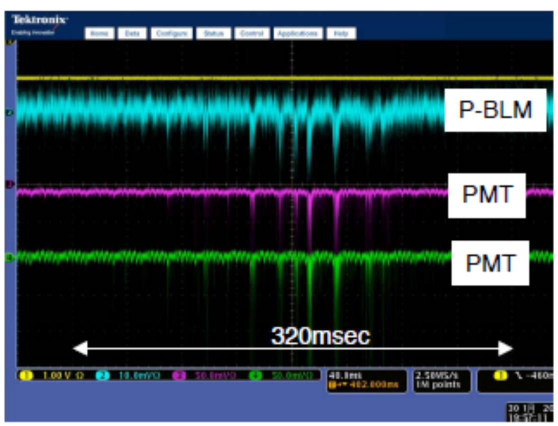
- Imaginary γ_t
- Precise control by digital LLRF
- Broadband cavity with low Q

The MR slow extraction on Jan. 27th, 2009

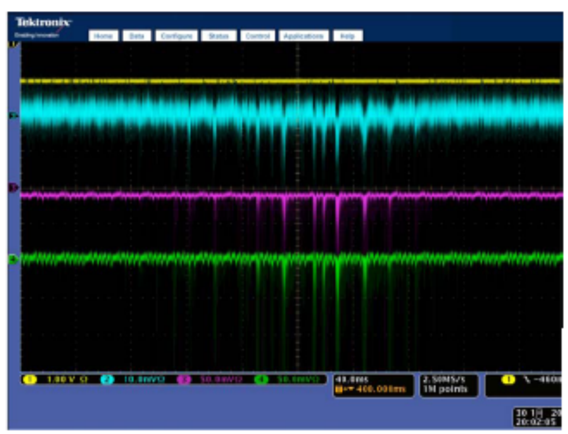


Spill measurement in HD beamline

RF off, ξ~0



RF off, ξ~-2



Measured by Hadron beamline group

By these data we cannot say that this is the slow extraction. Strictly speaking, this is the extraction using the third-order resonance. Further effort is necessary to mitigate the ripple problems.

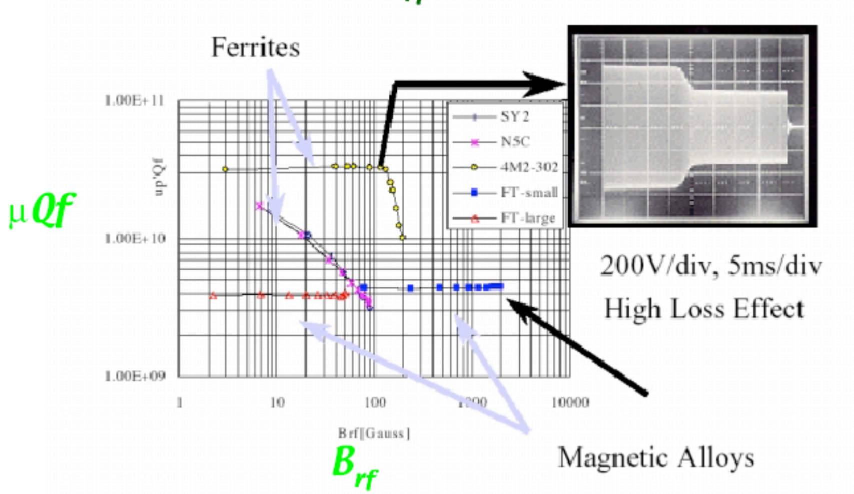
From now on, we will use the feed-back system, together with the improvements in the magnet power supplies.

Ring RF

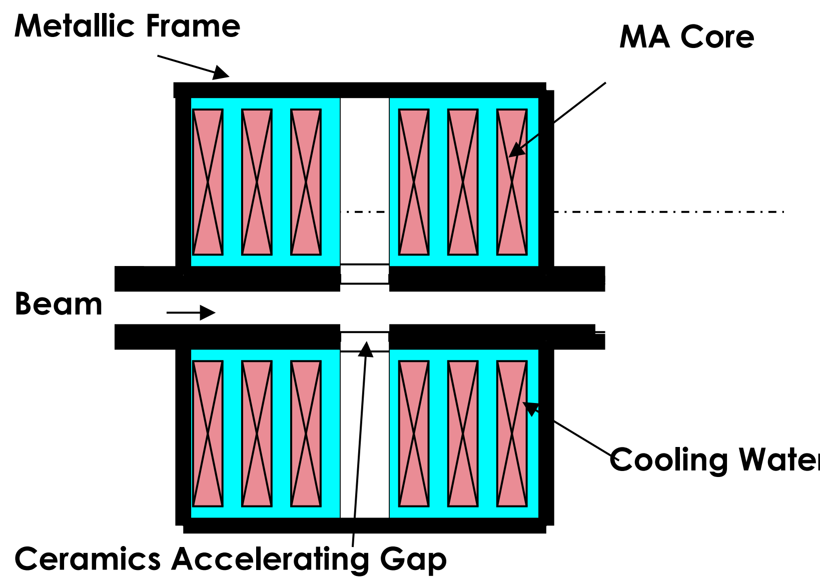
MA-Loaded Cavity is a must for high-power RCS
Magnet Alloy (MA)

* RF behaviour at high field

μQf (shunt.imp.) vs. B_{rf}



Reentrant Cavity

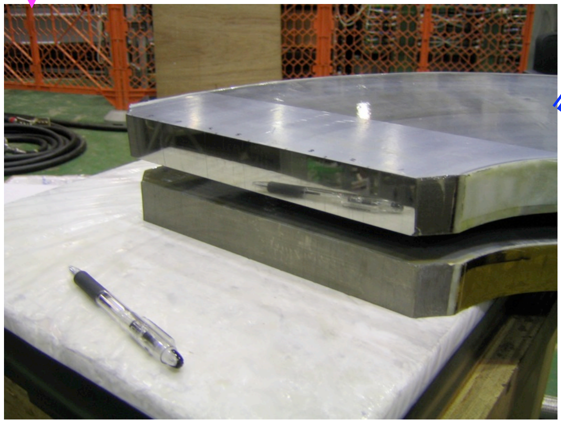


J-PARC RF team invented a method to adjust the quality factors of MA-loaded cavities: Cut-Core method. By this method, the Q value for MR Cavities is optimized. RCS is using uncut cores.

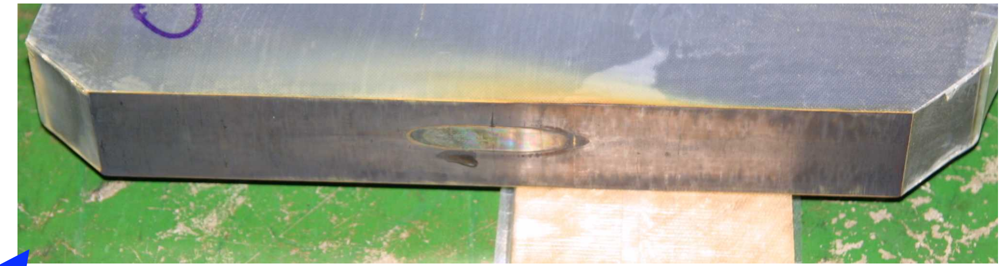
Development and Operation of MA Cores
(We need more effort for the robust MA cores)

Damaged cut surface

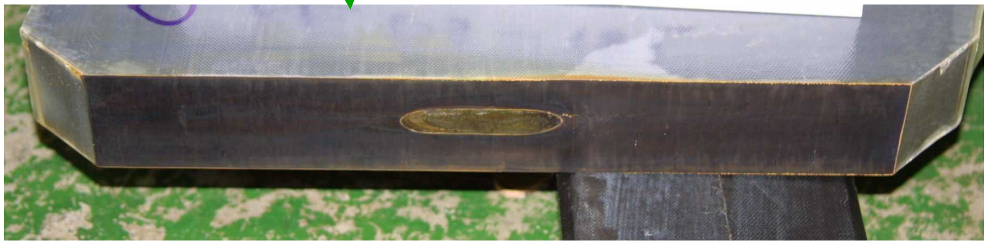
The polishing improvement



Upper: After diamond polishing
Lower: Before diamond polishing.

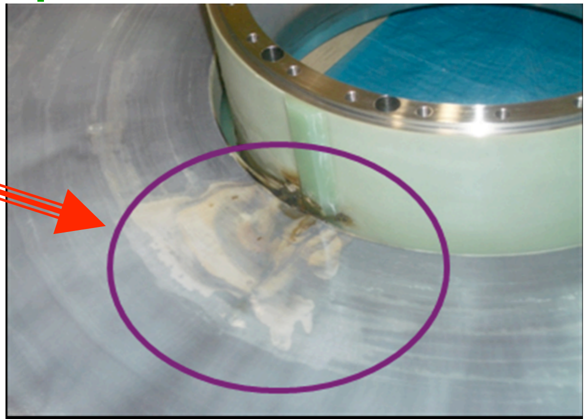


After 600-hour operation



After 1000-hour operation

More than 2,000-hour operation showed a new problem in uncut cores.
New technology is always like this . Further effort is also necessary here.



Core inside "tank 6"

RCS versus AR

J-PARC

RCS versus AR

- **RCS scheme has an advantage over the AR scheme, regarding the lower beam current for the same or more beam power. (the highest injection energy is practically limited to around 1.3 GeV for the reason of Lorentz stripping in the short injection section)**
- **The low energy injection to the RCS implies another advantage regarding the power of the beam loss (radioactivity issue during the injection process).**
- **The point at issue is entirely regarding the engineering technique, that is, whether it is possible or how difficult it is or how costly it is to accelerate the beam current of 0.333 mA to 3 GeV for example.**

J-PARC

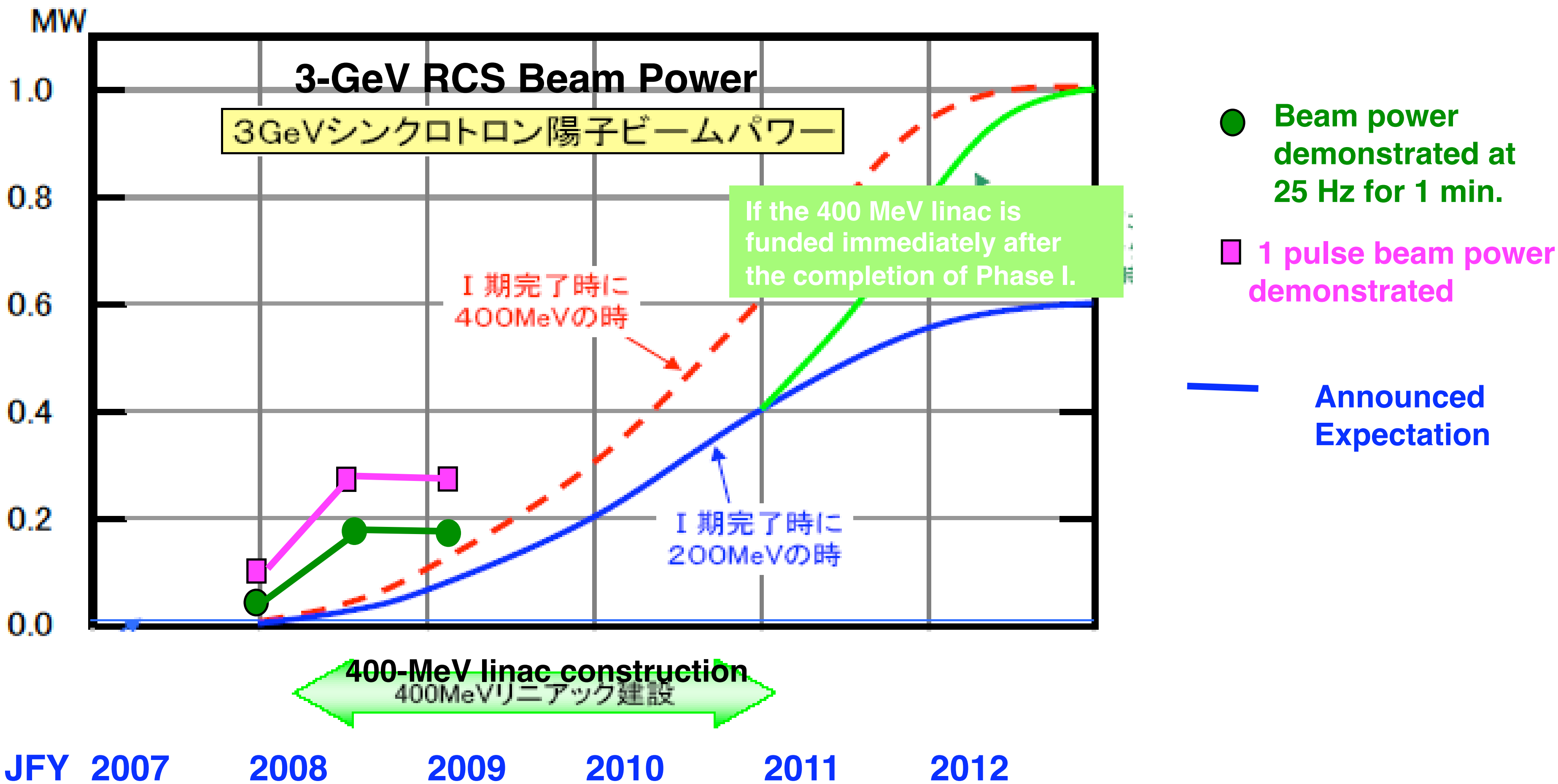
RCS versus AR

- Almost all the technical issues for the RCS as one option for MW-class pulsed spallation neutron source have been solved to some extent for J-PARC.
- However, the controversy has not yet come to conclusion, since the beam power of 1 MW has not been achieved in either AR or RCS.
- The successful start of the beam commissioning of the J-PARC RCS made the RCS option very promising as well as the AR option.
- We believe that both will accomplish the beam power of 1 MW.
- Then, we can combine both the technologies, SNS SC GeV linac and J-PARC RCS together, in order to realize the several and/or ten MW beam power, like Super B factory which will make use of both the KEKB ARES and PEPII comb filter together.

Summary and Future

J-PARC

Demonstrated and Announced

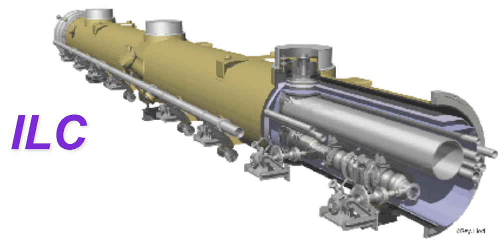


Good start, but for the stable, reliable operation of the J-PARC accelerator for user run, we need more conditioning, in particular, of the linac components like RFQ.

Summary

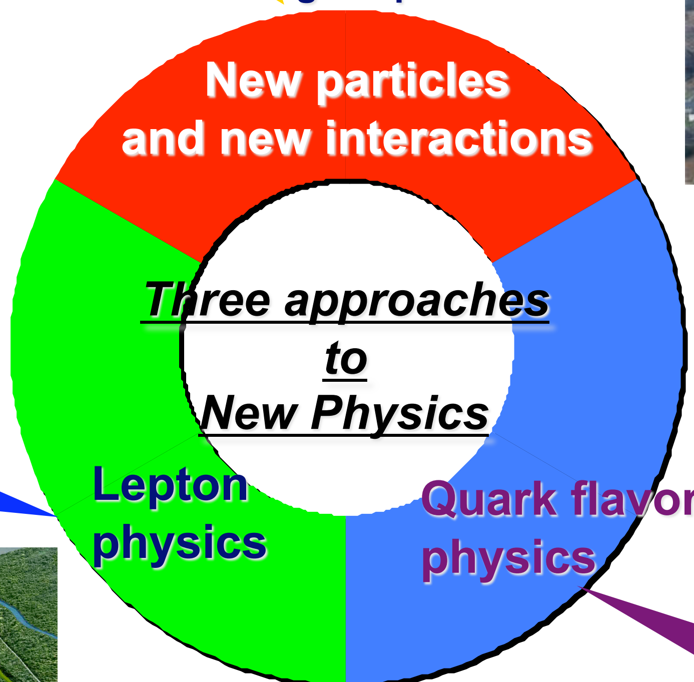
- The J-PARC accelerator technology is based upon the developments starting in 1986 for Japan Hadron Project (JHP) in KEK and a little bit later for Neutron Science Project (NSP) in JAERI. It took 22 years.
- The J-PARC accelerator includes a lot of challenges in order to meet the requirements from many kinds of user scientists.
- During the course of the development and construction, the technology has been in progress, while young scientists have grown up.
- This is the reason for the on-schedule, successful beam commissioning of the J-PARC accelerator.
- However, we still need the further effort to overcome the present technological issues at the RFQ linac and the ring RF systems.
- The developments and the operational experiences in J-PARC will contribute a lot to promote the world-wide technological advance in the accelerator field, for several-MW neutron sources, neutrino factories, and so forth.

High Energy Physics in the Next Decade
From KEK Road Map by its Director General



Energy frontier experiments
LHC, ILC, …

Higgs, SUSY, Dark matter,
New understanding of space-time…



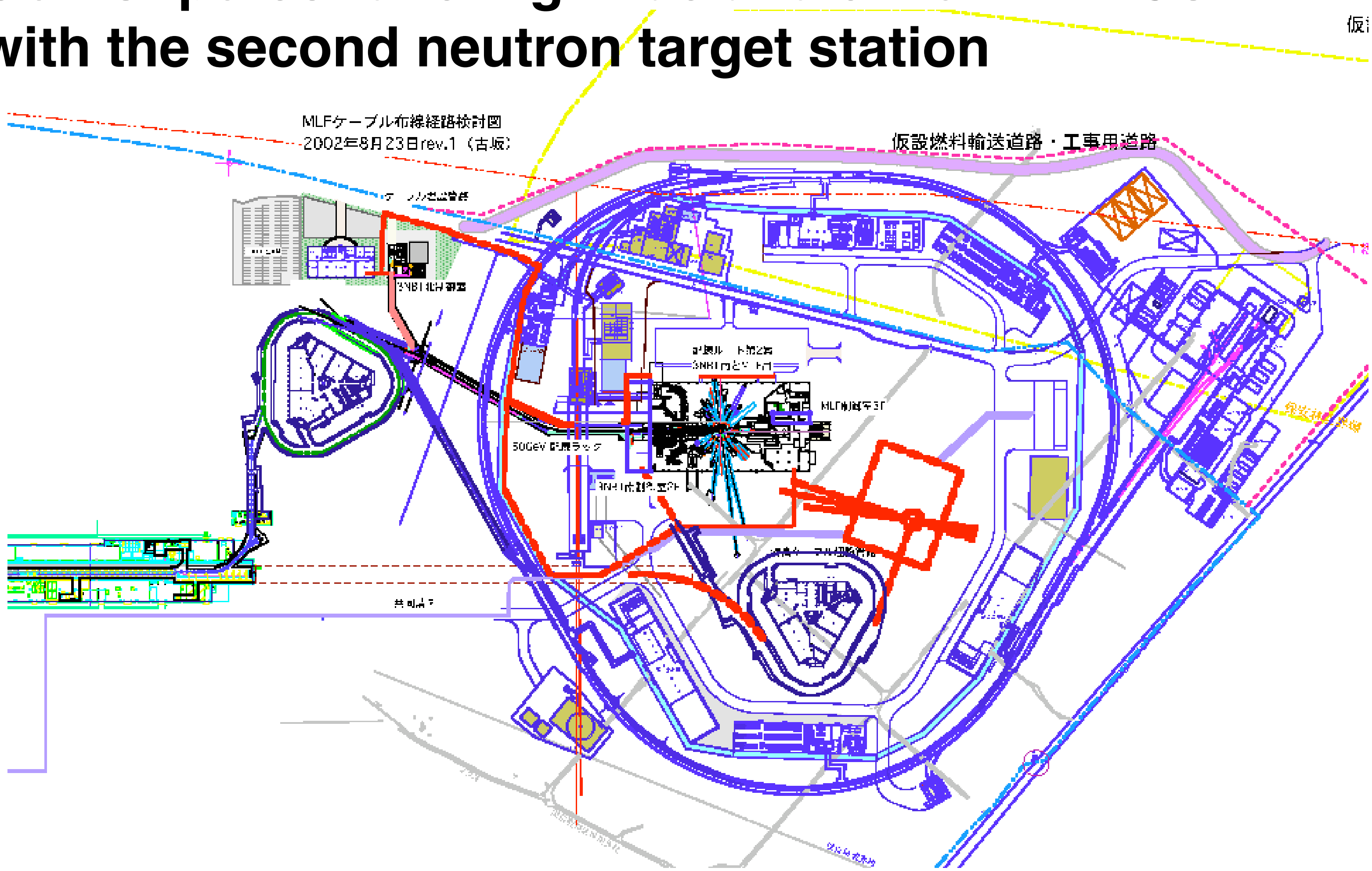
ν exp., μ LFV, τ LFV, g_μ-2, 0νββ …

B* Factories, LHCb, *K* exp., nEDM *etc.

Neutrino mixing/masses,
Lepton number non-conservation…

CP asymmetry, Baryogenesis,
Left-right symmetry, New sources of flavor mixing…

GeV Superconducting linac and 5~10-MW RCS with the second neutron target station

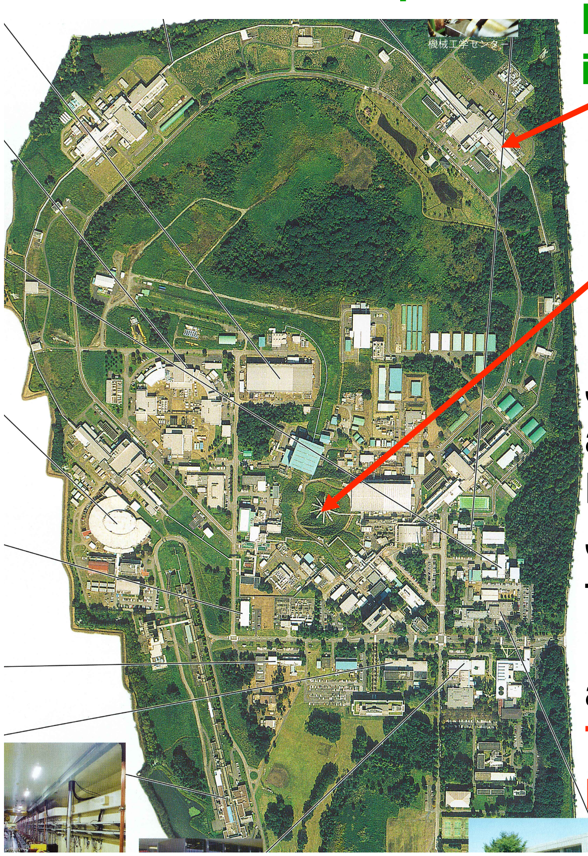


Thank you
And
Join us and help us to solve J-PARC issues, please

KEK Tsukuba Campus and KEK&JAEA Tokai Campus

J-PARC

KEK Tsukuba Campus



KEK B First beam in 1998

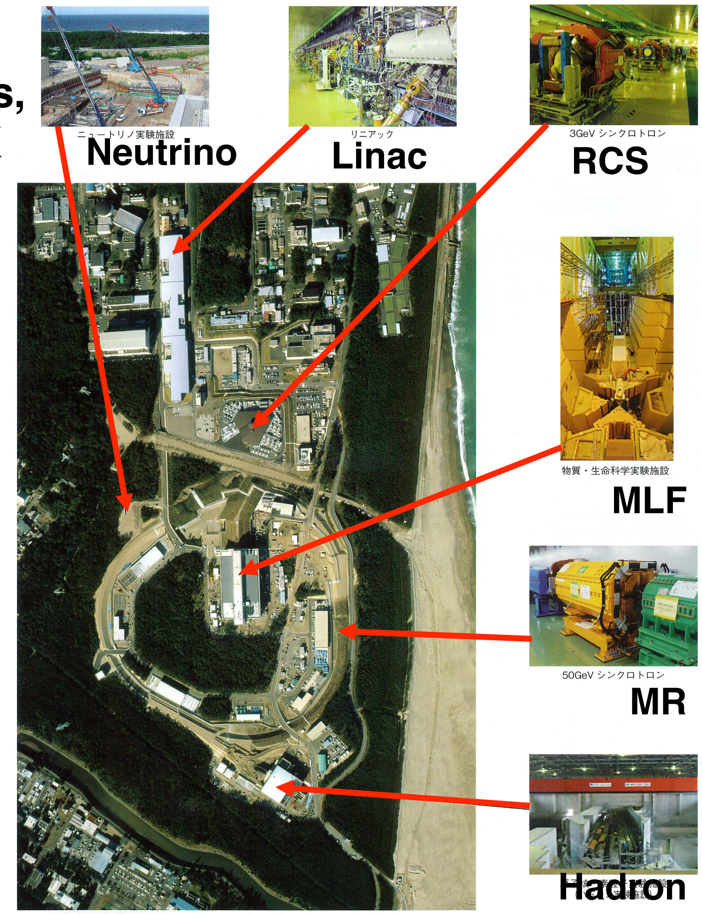
KEK-PS (40-MeV linac, 0.5 GeV RCS and 12-GeV MR) First beam in 1976.

J-PARC at Tokai Campus, JAEA and KEK

J-PARC MR is 5-times as big as KEK-PS MR, (while being a half of KEKB).

J-PARC may be said as a 5-times upgraded version of KEK-PS in both beam energy and beam current.

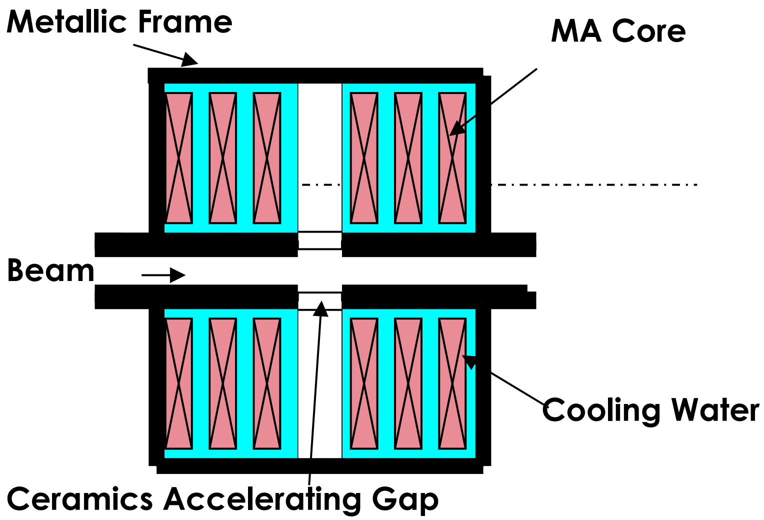
Two orders of magnitude in beam power.

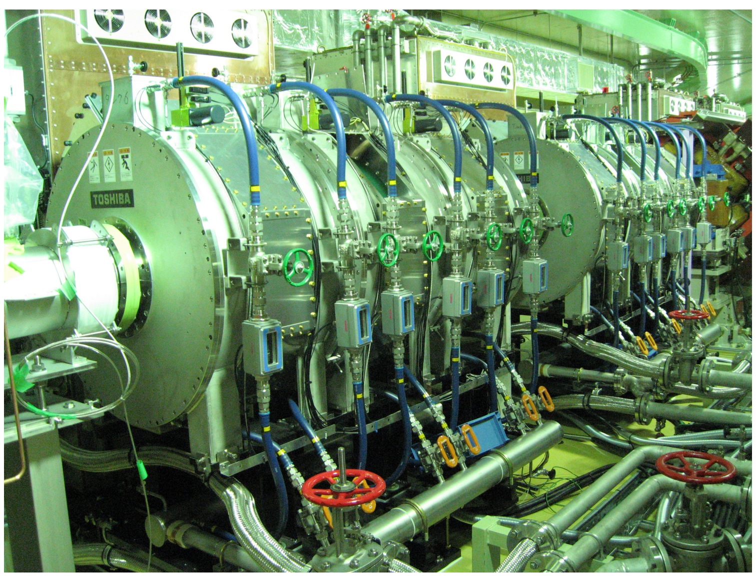


The KEK-PS inserted the RCS as a booster in between the injector linac and the MR as proposed by Kitagaki (FNAL first, KEK second). This scheme began used everywhere. In addition, the RCS was fully used in order to produce both neutrons and muons for materials science experiments. The ISIS followed this RCS scheme, but increasing its beam power.

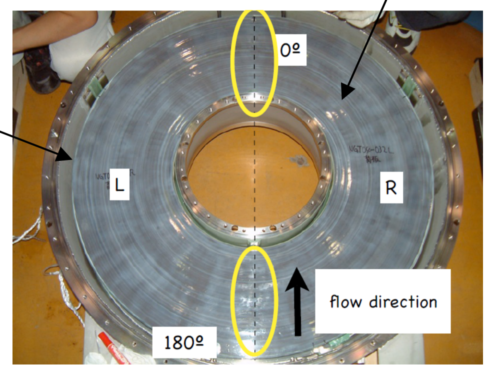
Even uncut-cores were damaged.

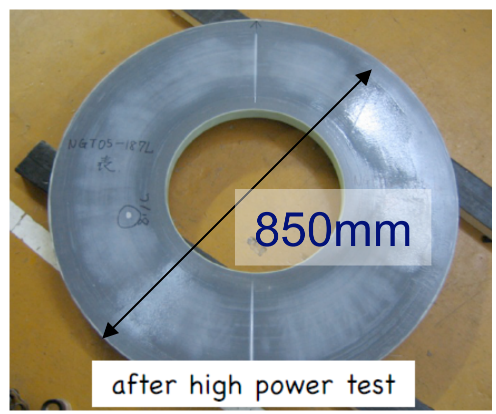
Reentrant Cavity





MA Core





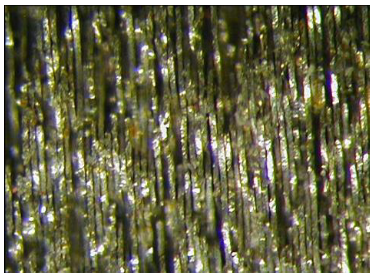
MA Core

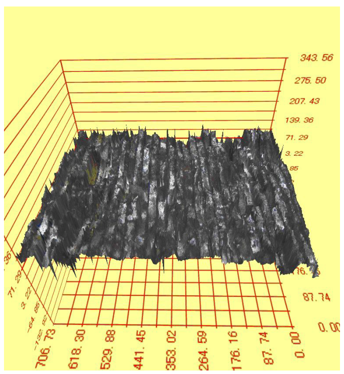
MA Layers are 18-μm thick, while silica instulation is 2- μm thick.

J-PARC

Cut Cores for MR RF

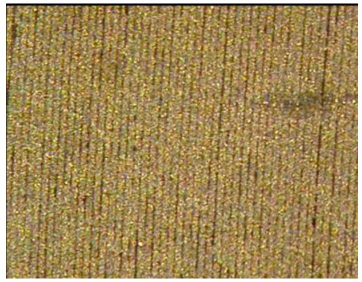
Water jet

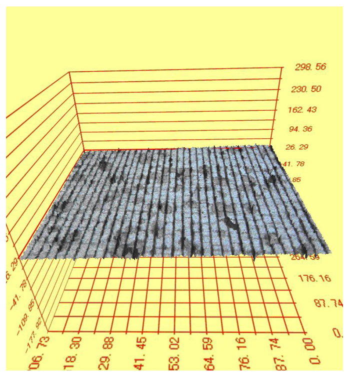




Roughness
: a few 100 μm
Damaged at the lower power than design

Grindstone

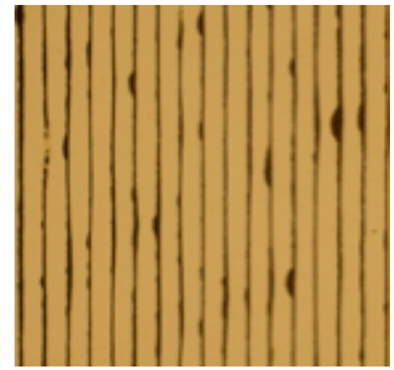




Roughness
: less than 10 μm
Damaged after 120-hour power test

But nitric acid is used to etch the cut surface for recovering the insulation between MA layers.
This nitric acid seems to give rise to the damages.
Thus, we developed the acid-free technology.

Diamond polishing



Roughness
: submicron

MA Layers are 18-μm thick, while silica instulation is 2- μm thick.

Causes for damaging the MA cores

- **It is reasonable to assume that the electric field, thus the current by this, damaged the rare shorts between the MA layers sandwiching the thin (2 micron, typically) silica insulator layer.**
- **The rare shorts between the MA layers arose from scratching the layers during the manufacturing process.**
- **After the manufacturing of the cores was very carefully controlled as to avoid any damage on the insulation during the manufacturing process, no serious damage was observed after the high-power test of the uncut cores.**
- **All the cavities have been power-tested beyond 300 hours; some ones beyond 1,000 hours.**
- **For this painstaking work, the following physicists from all over Japan helped J-PARC accelerator team by joining the power tests: Profs. Saito, Komatsubara, and Hasegawa from KEK IFN, and post-doctoral fellows and graduate students from Tamura group in Tohoku Univ., from Yamashita group in Tokyo Univ., from Nakaya group in Kyoto Univ., and from Muramatsu group, in Osaka Univ.**

J-PARC

J-PARC RCS versus SNS AR

	J-PARC RCS	SNS-like AR	SNS AR
Beam pulse length, μs	< 1	< 1	< 1
Ring Circumference, m	348	331	331
Repetition, Hz	25	25	60
Beam stored energy per pulse, kJ	40	40	24
Number of protons per pulse, 10^{13}	8.3	25	15
Beam energy, GeV	3	1	1
Beam power, MW	1	1	1.4
Beam current, mA	0.333	1	1.4
Injection energy, GeV	0.4	1	1
$\beta^2\gamma^3$	1.475	6.750	6.750
Beam emittance at painting, π mm mrad	216	142	91
Lasslette tune shift (Measure of space charge)	- 0.16	-0.16	- 0.15
Linac peak current, mA	50	150（75）	38
Linac beam pulse length, ms	0.5	0.5 (1)	1
Beam-on rate after chopping, %	56	56	68

J-PARC

Accomplished Parameters in J-PARC RCS

	J-PARC RCS Designed	J-PARC RCS Accomplished	J-PARC RCS Accomplished
Repetition, Hz	25	One pulse	25
Beam stored energy per pulse, kJ	40	12	8.0
Number of protons per pulse, 10^{13}	8.3	2.6	1.7
Beam energy, GeV	3	3	3
Beam power, MW	1	(0.31)[a)]	0.20
Beam current, mA	0.333		0.067
Injection energy, GeV	0.4	0.18	0.18
$\beta^2\gamma^3$	1.475		
Linac peak current, mA	50	15	9.2
Linac beam pulse length, ms	0.5	0.5	0.5
Beam-on rate after chopping, %	56	59	63

a) If operated at 25 Hz