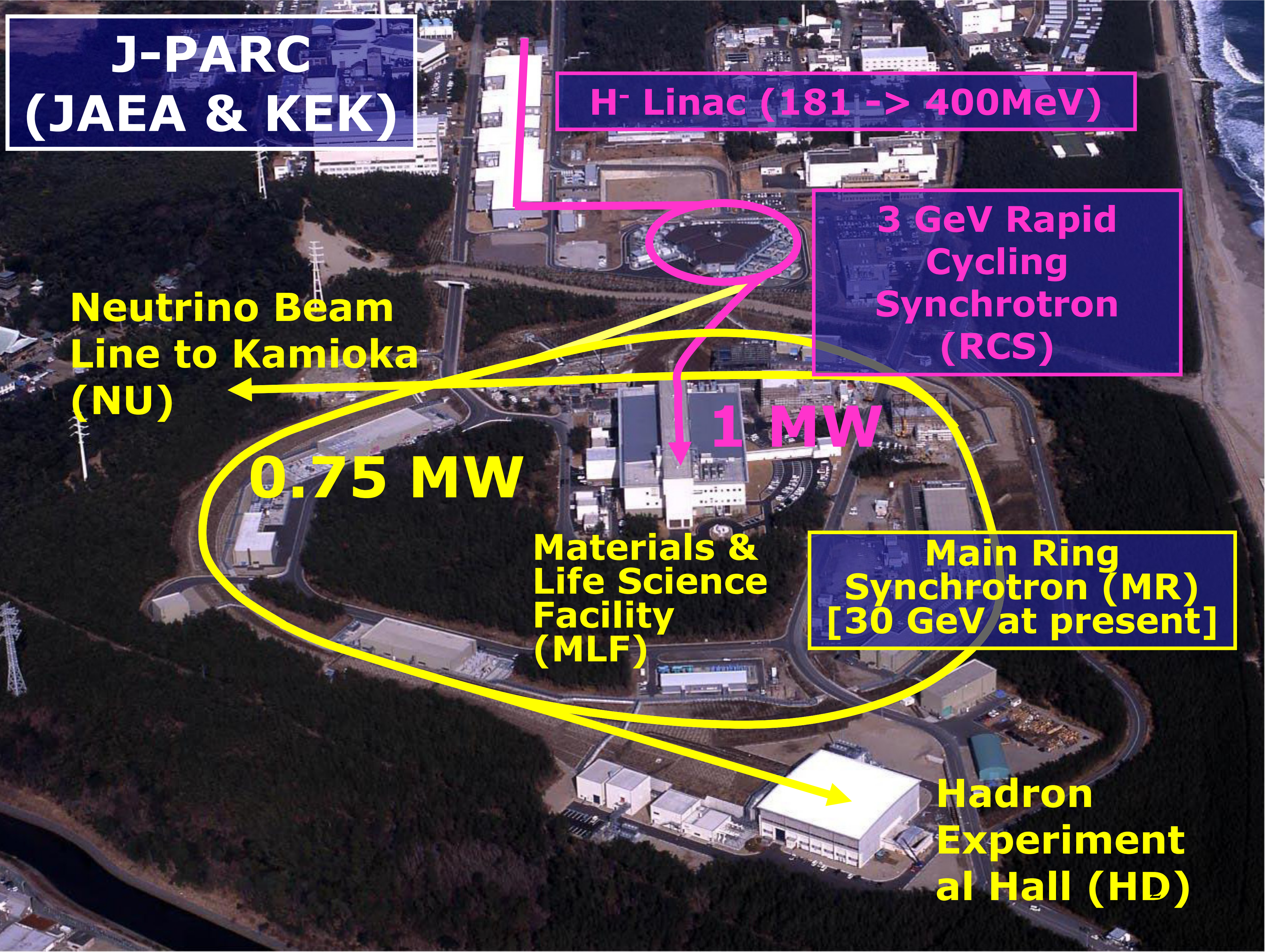
Commissioning of Energy Upgraded Linac of J-PARC

Kazuo Hasegawa for Linac Group
J-PARC Center/JAEA & KEK

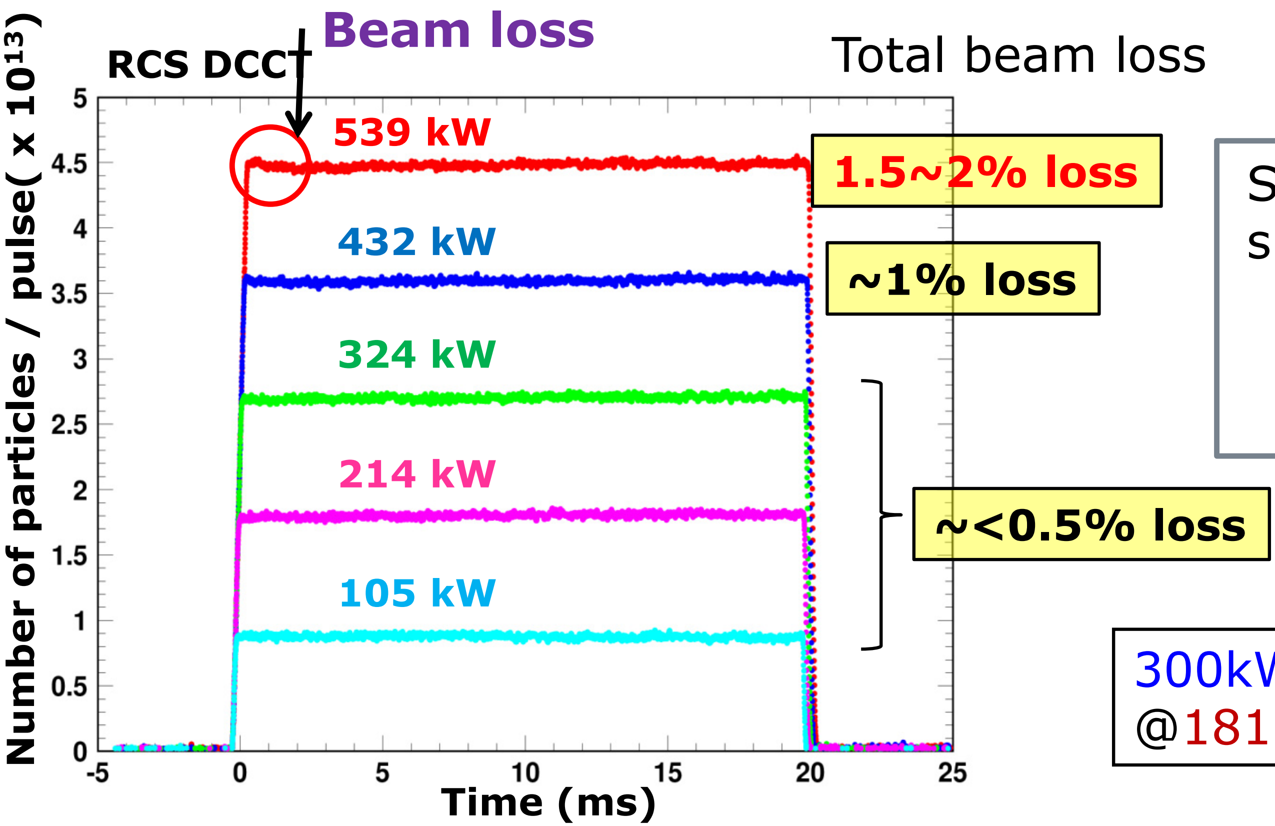
The 27th Linear Accelerator Conference (LINAC14)
Aug. 31- Sept. 5 2014, Geneva, Switzerland

Outline

- Purpose of Energy Upgrade
- Annular-ring Coupled Structure (ACS) as a high-β structure
  - Structure, Mass-production
  - Installation, High Power Conditioning
  - Beam Commissioning
- Next Scope: Beam Current Upgrade


J-PARC
(JAEA & KEK)
H- Linac (181 -> 400MeV)
3 GeV Rapid Cycling Synchrotron (RCS)
Neutrino Beam Line to Kamioka (NU)
1 MW
0.75 MW
Materials & Life Science Facility (MLF)
Main Ring Synchrotron (MR) [30 GeV at present]
Hadron Experimental Hall (HD)

Why energy upgrade?



Beam intensity in the RCS for high power demonstration at 181 MeV injection.

Scaling of Laslett tune shift at injection;

$$\Delta\nu = -\frac{n_t r_p}{2\pi\beta^2\gamma^3\varepsilon}\frac{1}{B_f}$$

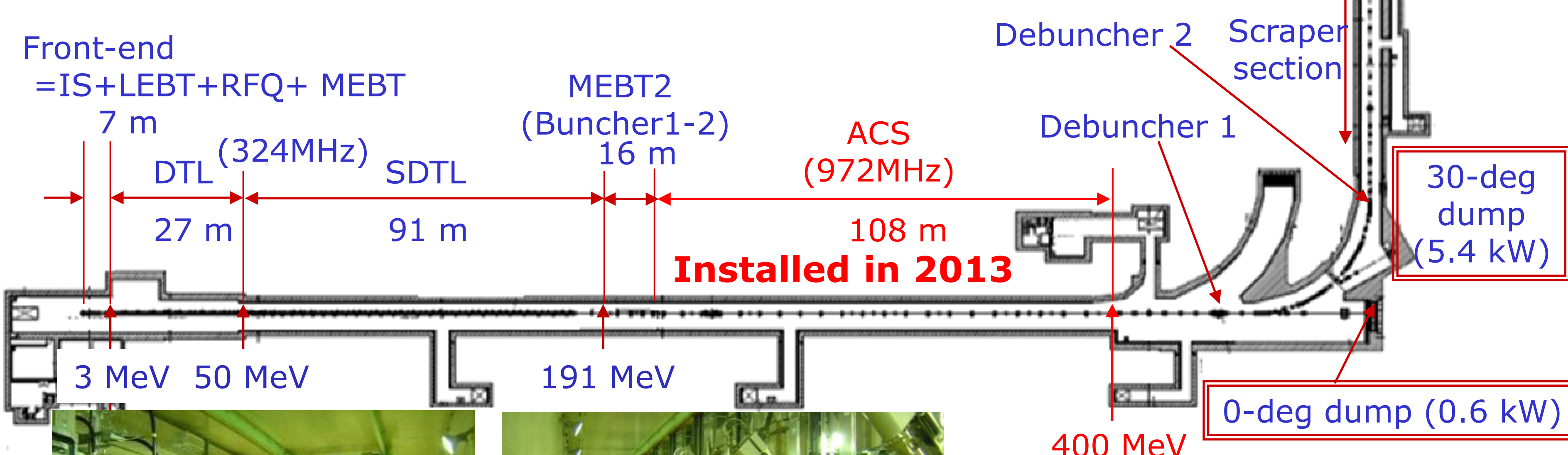
300kW @181MeV ⟷ 1MW @400MeV

Equivalent

The 400 MeV injection is crucial for 1 MW at RCS to mitigate beam loss due to the space charge effect at the injection.

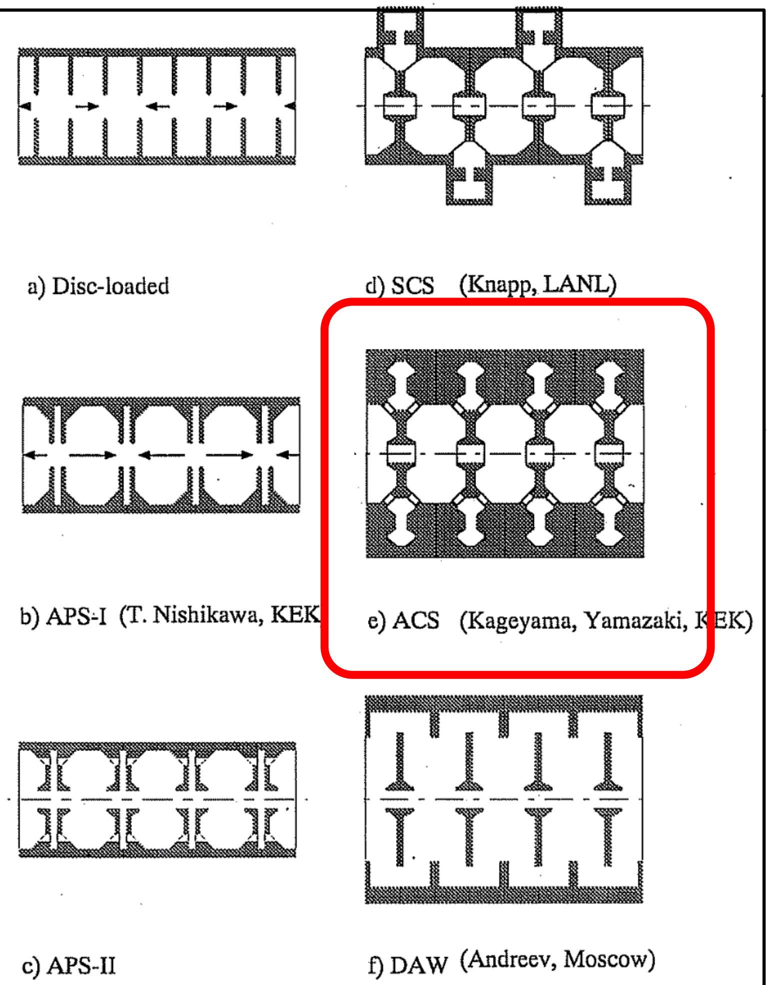
Linac: Parameters and Layout

- **Particle:** **H^-**
- **Energy:** **400 MeV**
  (181 MeV by 2Q/2013)
- **Peak current: 50 mA (30 mA by 1Q/2014)**
- **Repetition: 25 Hz**
- **Pulse width: 0.5 msec**



Annular-ring Coupled Structure (ACS)

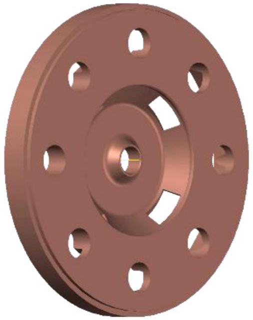
The ACS is a kind of coupled cavity linacs (CCLs).



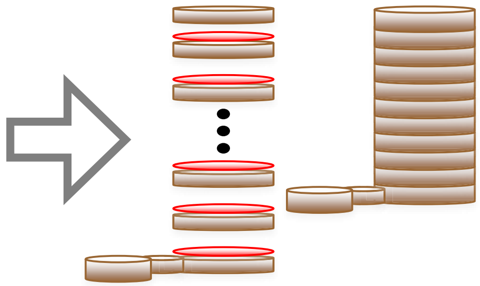
Typical CCL's

- Axial symmetry realizes following features:
  - ✓ Negligibly small transverse kick field,
  - ✓ Smooth surface with an ultra-precise lathe machining except for coupling slots, and
  - ✓ Mechanical stability.
- The shunt impedance and a coupling factor are comparable to the SCS.
- The ACS well satisfies the J-PARC operation with a duty factor of 3% and can meet 15% operation if requested in the future.

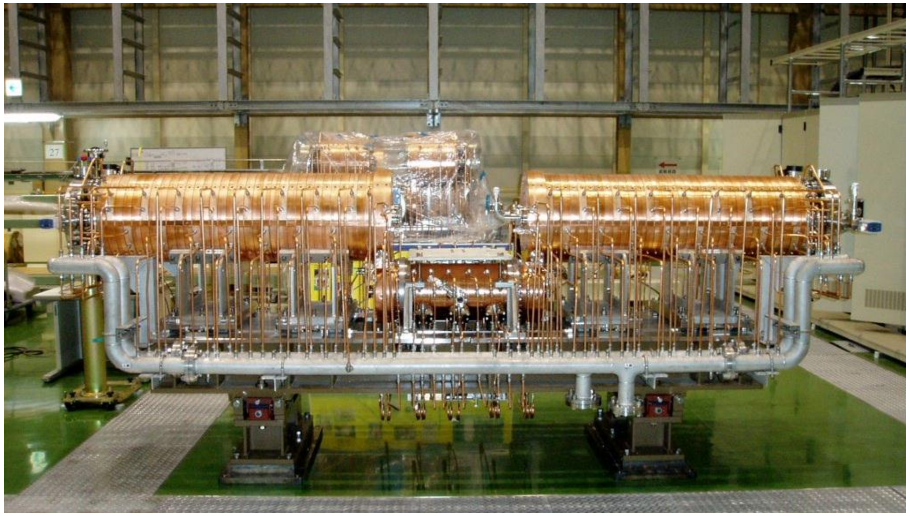
ACS Structure



ACS “Cell”



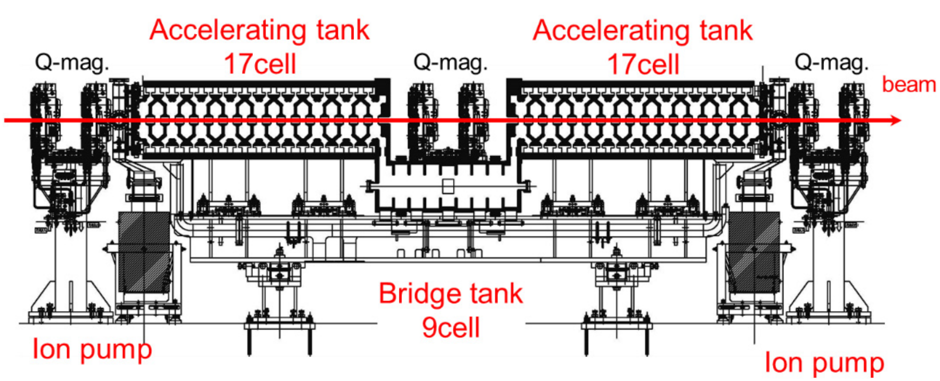
Brazed Joint



The lowest energy ACS module

Main parameters of J-PARC ACS

Energy	190.8-400	MeV
Frequency	972	MHz
Section Length	108.3	m
E0	4.1	MV/m
RF pulse length	0.6	ms
Duty factor	3	% max
Number of modules	21	Acceleration
	2	Bunchers
	2	Debunchers



ACS Accelerating module

Issues of Mass Production

21 ACS modules of mass production started in March 2009.

->It was supposed to be finished in 3 years.

- Cell machining : 1400 disks, and sizes are different by modules as β changes (proton accelerator) -> 21 kinds
- Brazing : 42 batches for accelerating tanks only
  -> Takes full 1 year.

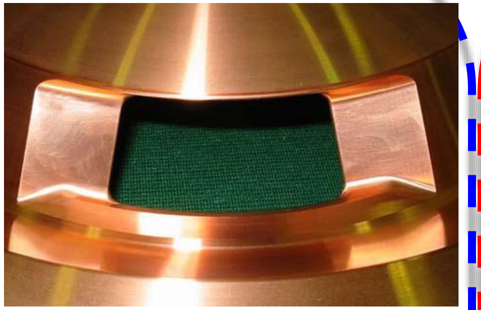
Strategies

✓Systematic measurements by Test cells ->Cell sizes are fixed for all modules as a function of β: in half year
-> Only one fine frequency tuning step (instead of 2 or 3)
✓Simplify the cell slot machining
✓Parallel fabrications: bridge couplers, RF windows, waveguides, etc.

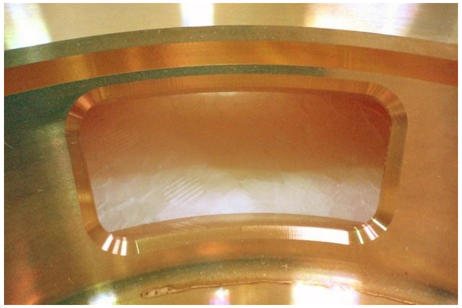
Simplification of Coupling Slot Machining

Prototype Slot

- 5-axis processing machine
- Smooth connection between surfaces
- Machining time:
  3h20m/slot
  Too long for mass production



Mass-produced Slot



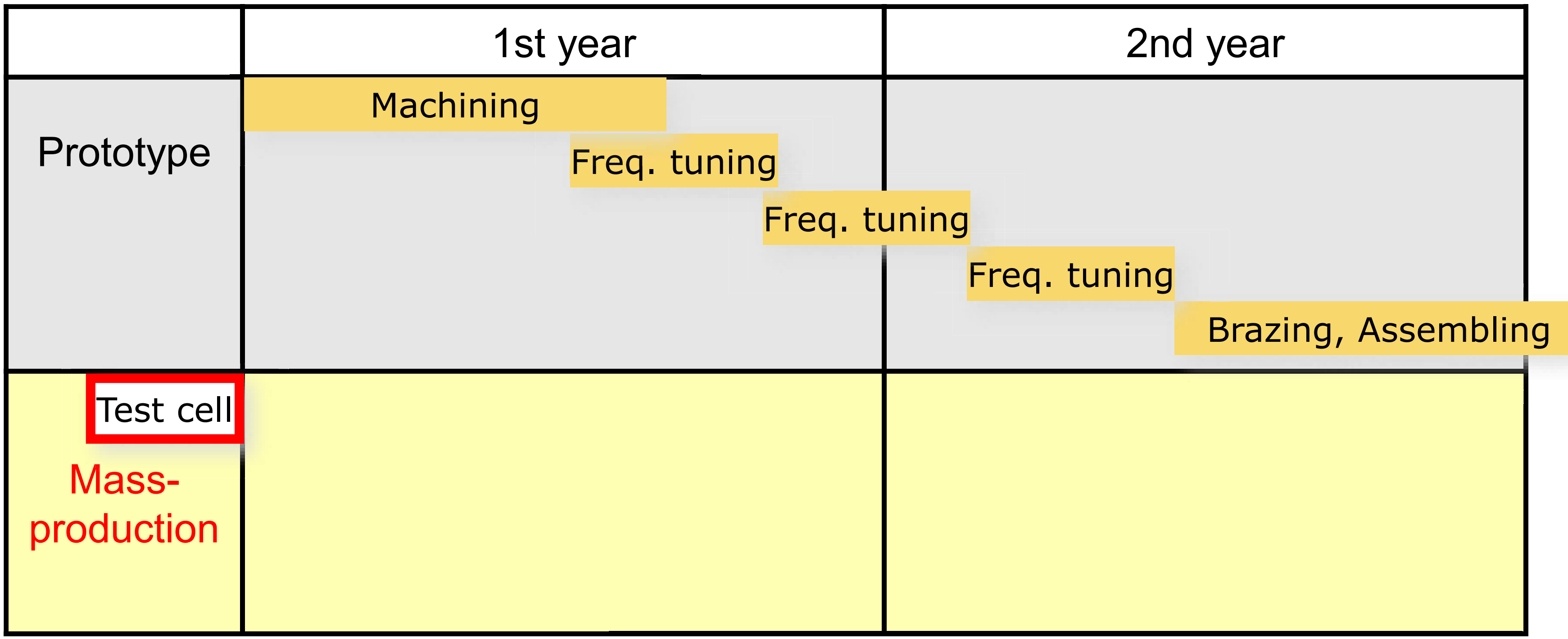
- Movement of a tool: XYZ and rotation
- Machining time
  46min/slot
  (1/5 of prototype)
- Shorter machining programing time
- Easy to take care of several venders

Confirmed the performance of the RF properties by a high power model, then, adopted in the mass production.

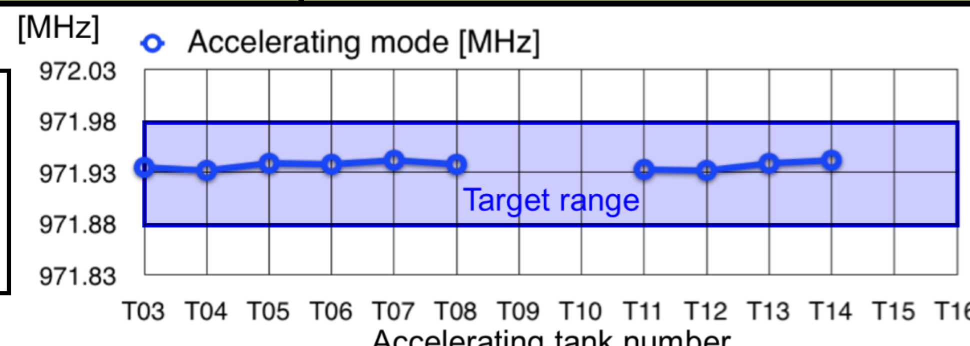
Time Reduction in the Mass Production

Requirement: 21 ACS modules in three years

Schematic schedule for one ACS module fabrication



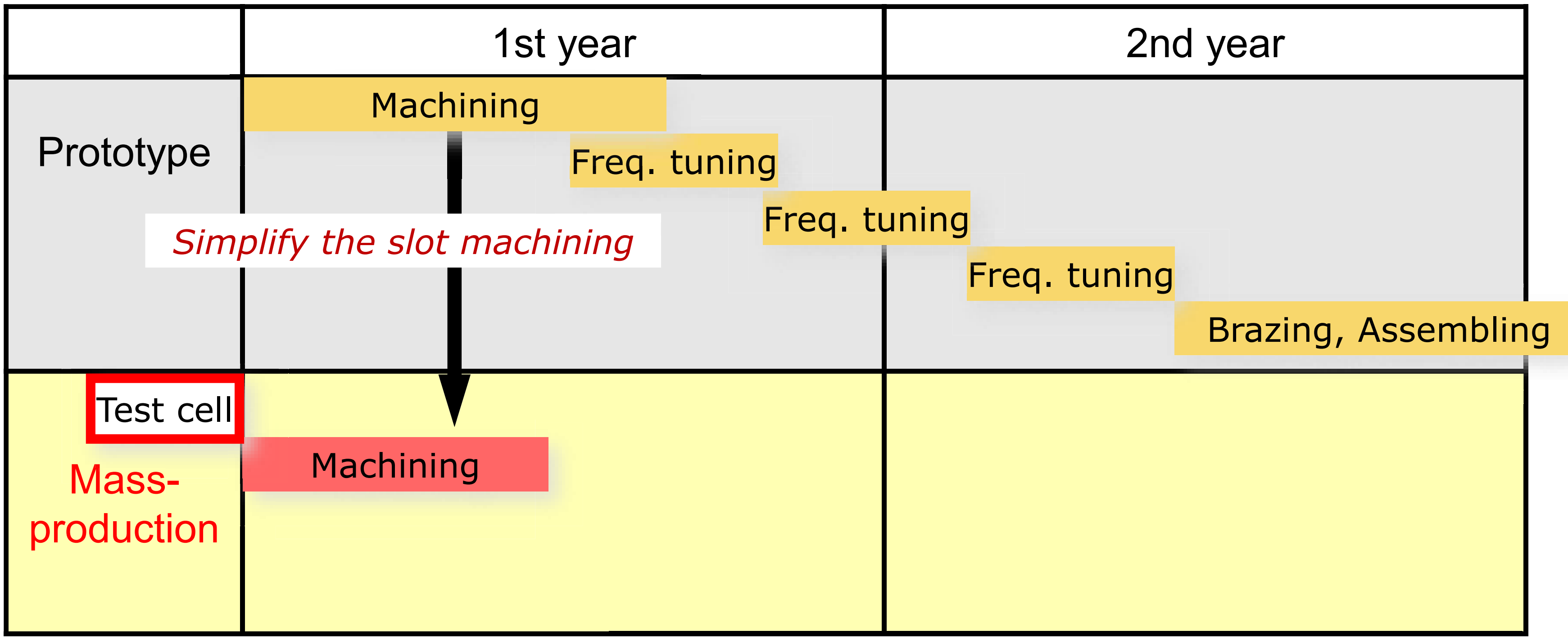
Test cell: Obtain coefficients (frequency sensitivity with machining depth) systematically throughout the β range.



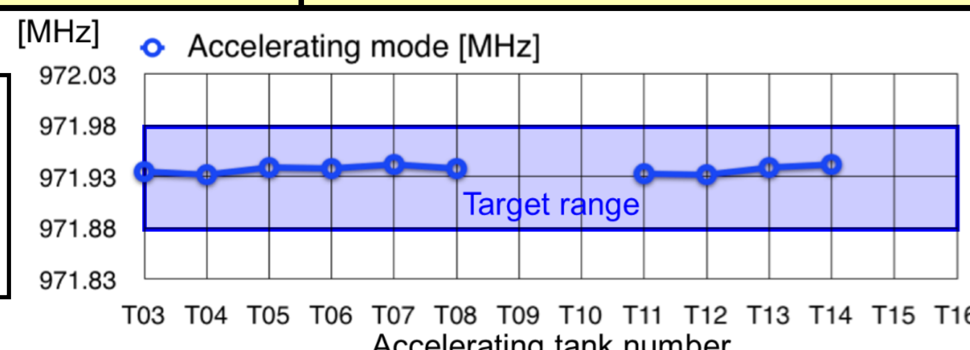
Time Reduction in the Mass Production

Requirement: 21 ACS modules in three years

Schematic schedule for one ACS module fabrication



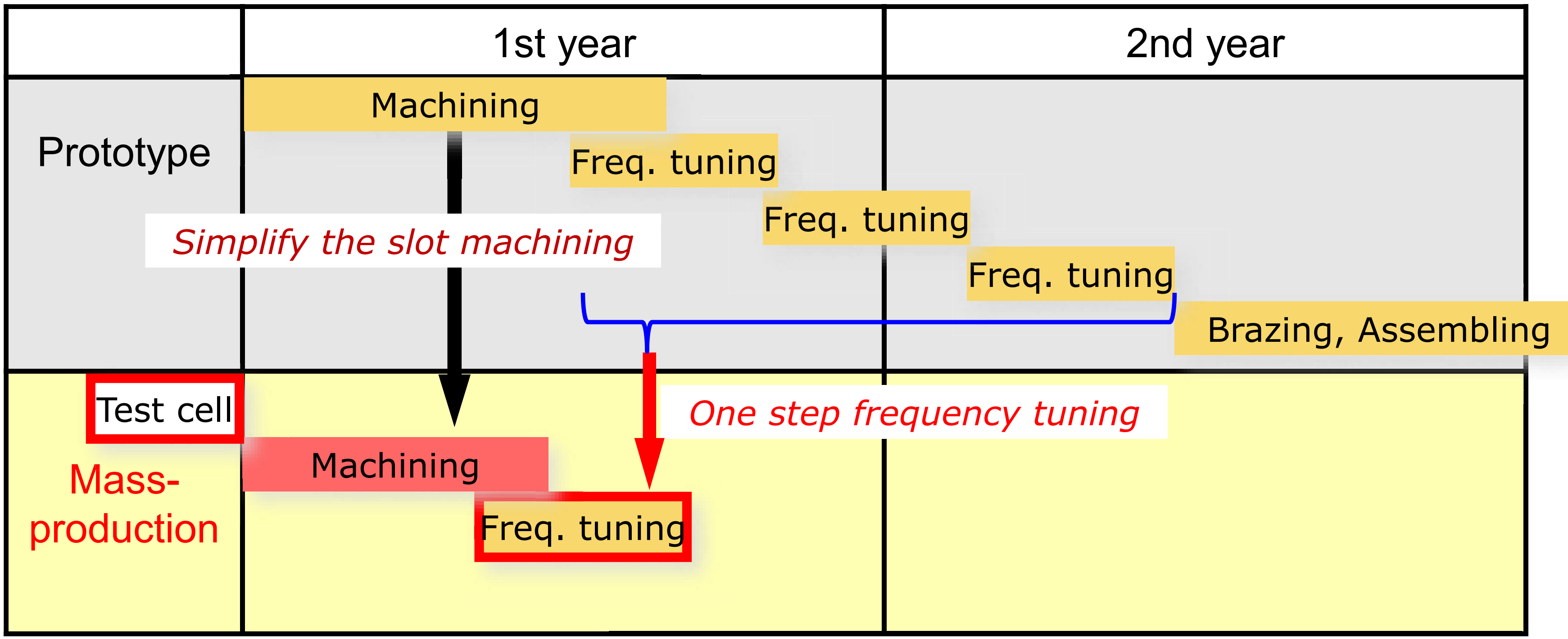
Test cell: Obtain coefficients (frequency sensitivity with machining depth) systematically throughout the β range.



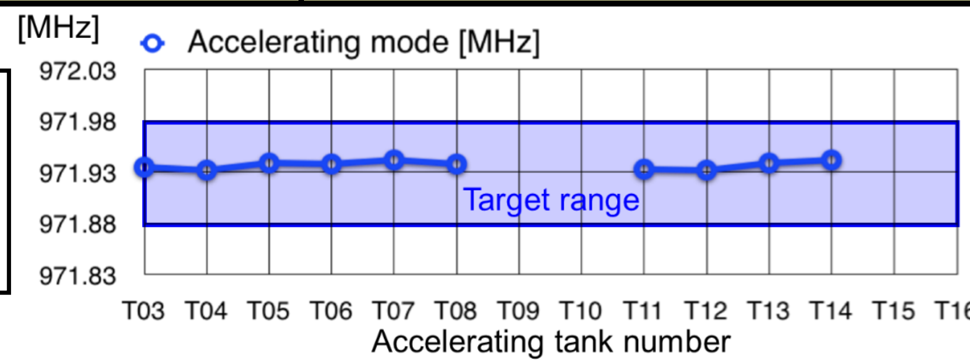
Time Reduction in the Mass Production

Requirement: 21 ACS modules in three years

Schematic schedule for one ACS module fabrication



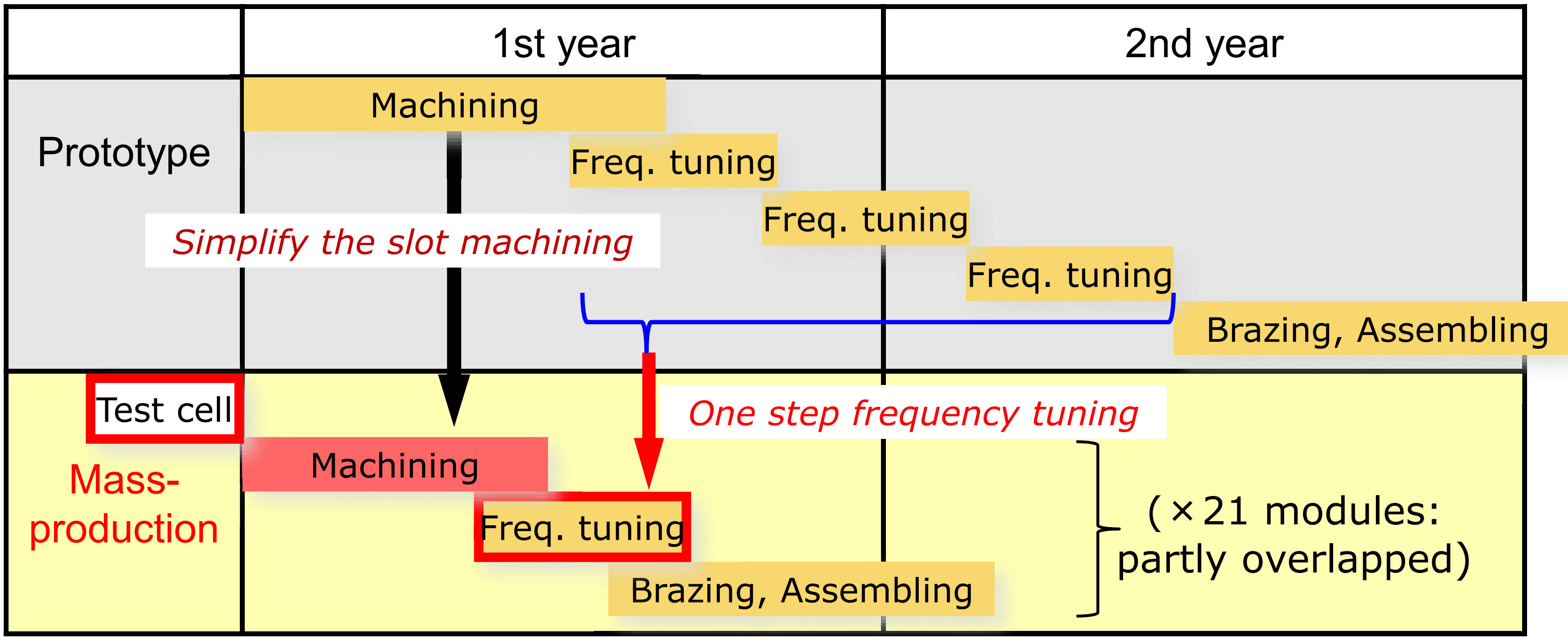
Test cell: Obtain coefficients (frequency sensitivity with machining depth) systematically throughout the β range.



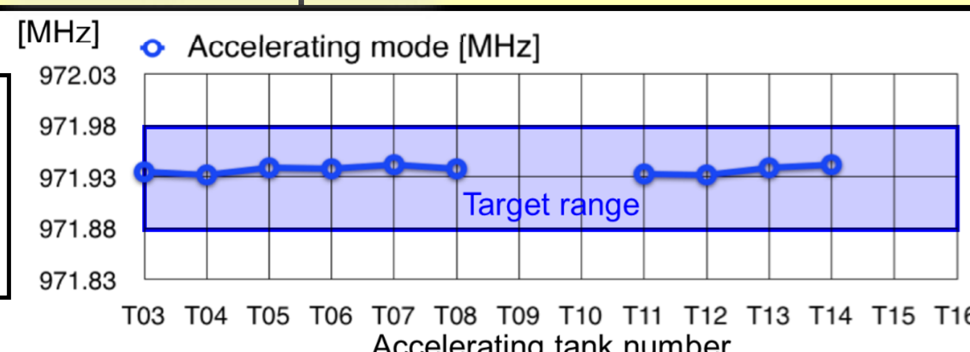
Time Reduction in the Mass Production

Requirement: 21 ACS modules in three years

Schematic schedule for one ACS module fabrication

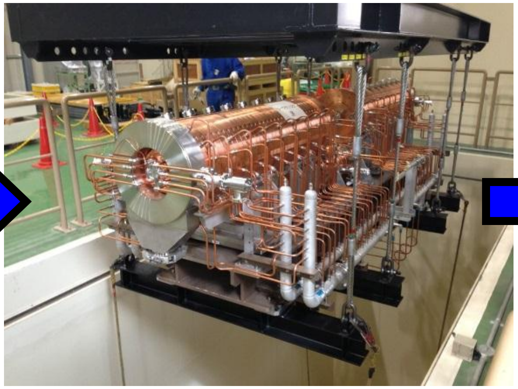


Test cell: Obtain coefficients (frequency sensitivity with machining depth) systematically throughout the β range.



Installation into the Tunnel

Storage area



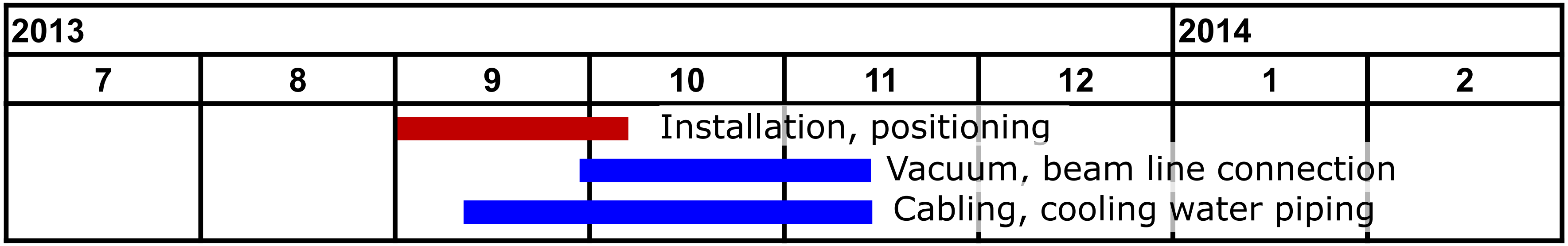
Lift down to tunnel (-13m)

Move by motor drive roller

Shift to beam line

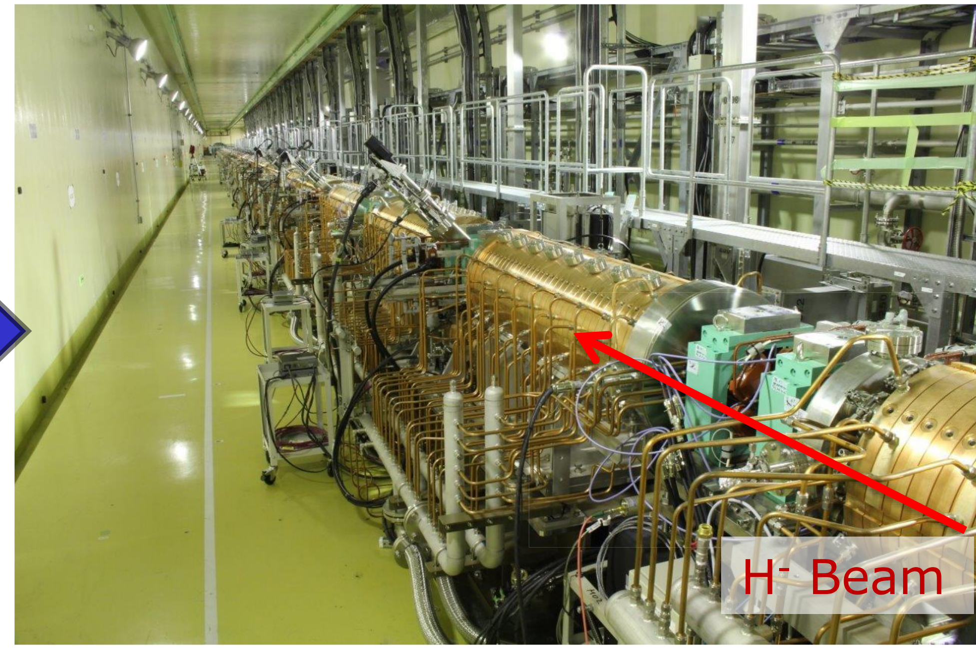
Set on the beam line

Installation and positioning
1 module / day
-> approx. 1 month

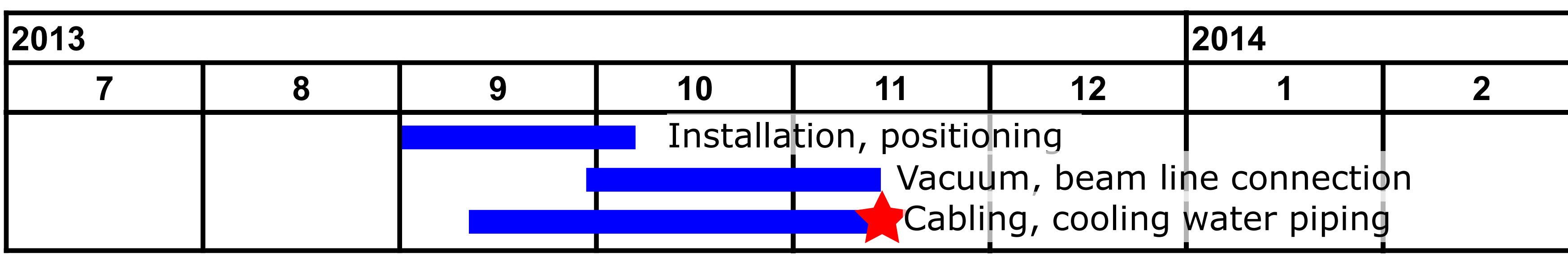


Installation into the Tunnel

Before installation:
Just beam transport line.

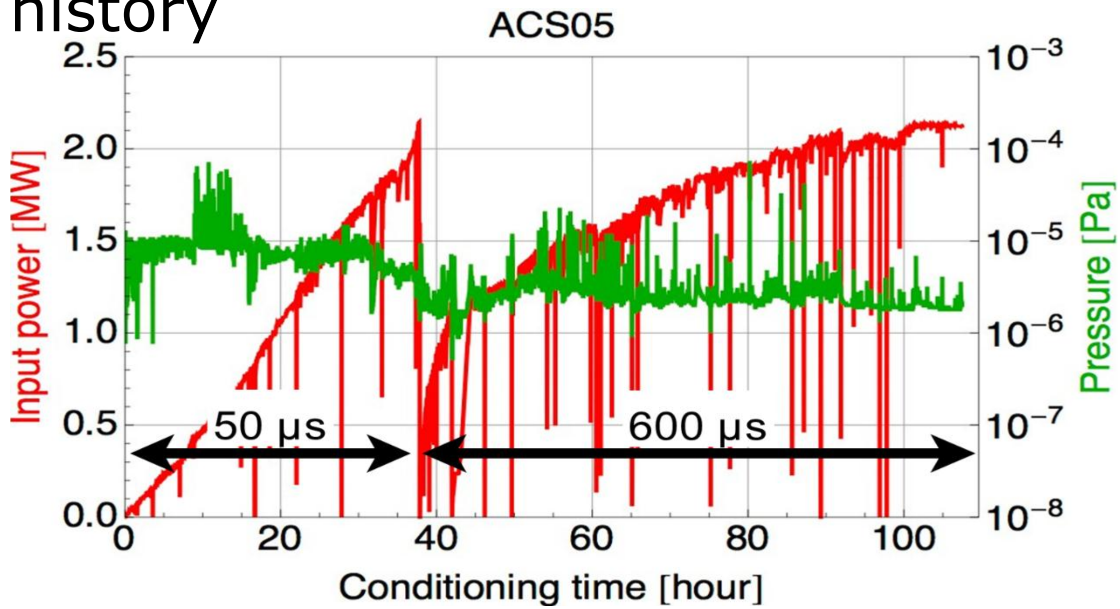


Finished installation after 3 months work: Stuffed with ACS.

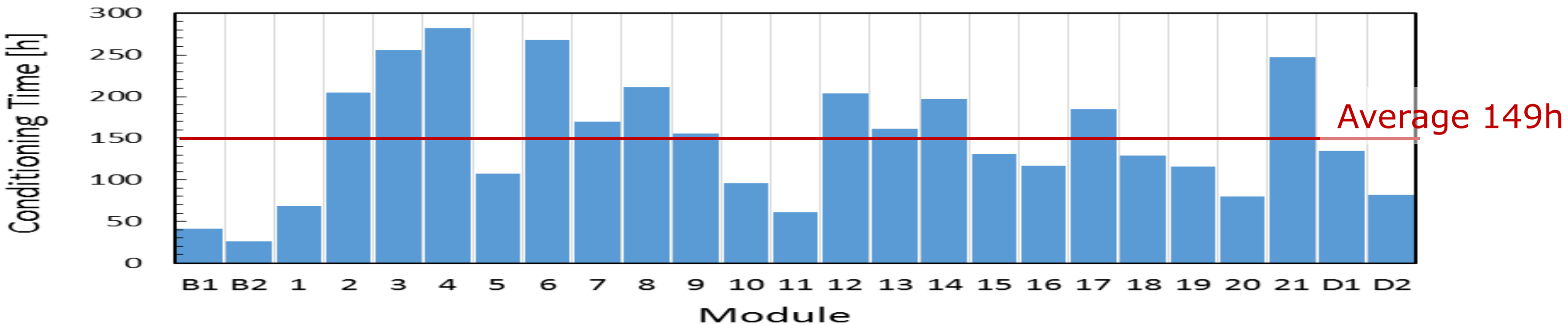


ACS High Power Conditioning

- Typical conditioning history



- In the first step, we put short pulse RF (50 μs) up to 2 MW.
- Then we put long pulse RF (600 μs) up to 2MW.



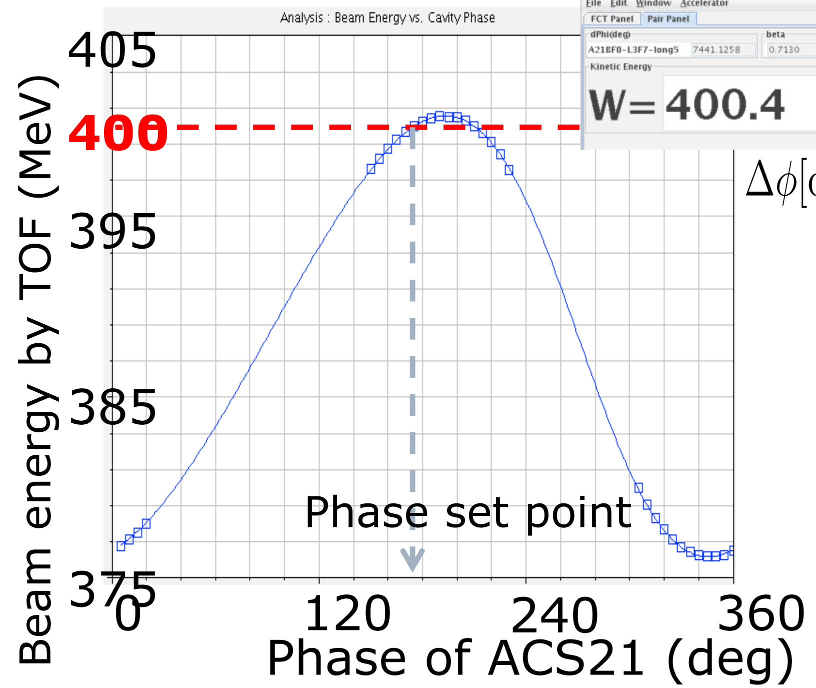
Conditioning time for ACS modules (Note: Required power levels for Bunchers (B1, B2) and Debunchers (D1, D2) are lower.)

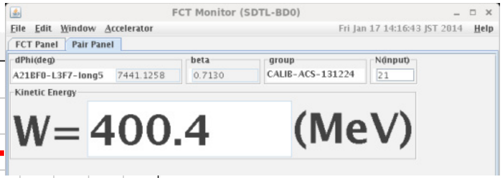
Beam Commissioning

Beam commissioning

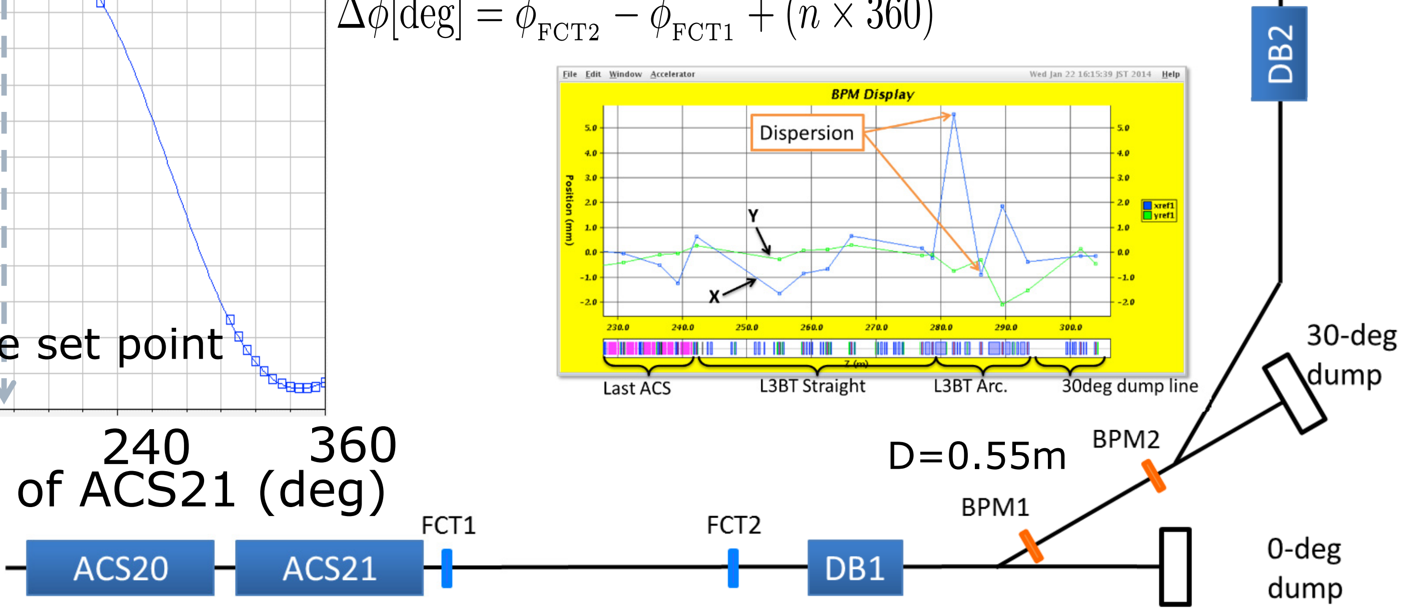
- Dec.16 – Dec. 29: Tuning FE to ACS14
- Jan.7 – Jan.9 SDTL matching
  (ACS conditioning for 6 days)
- Jan. 16: Restart ACS tuning
- Jan. 17: Achievement of 400 MeV

Confirmation: Phase scan and 30-deg bending line





$$\Delta\phi[\mathrm{deg}] = \phi_{\mathrm{FCT2}} - \phi_{\mathrm{FCT1}} + (n \times 360)$$

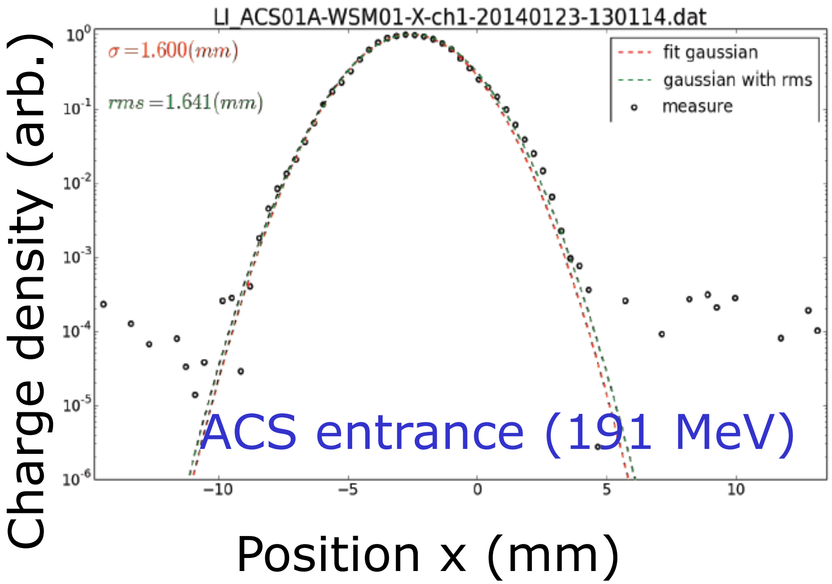


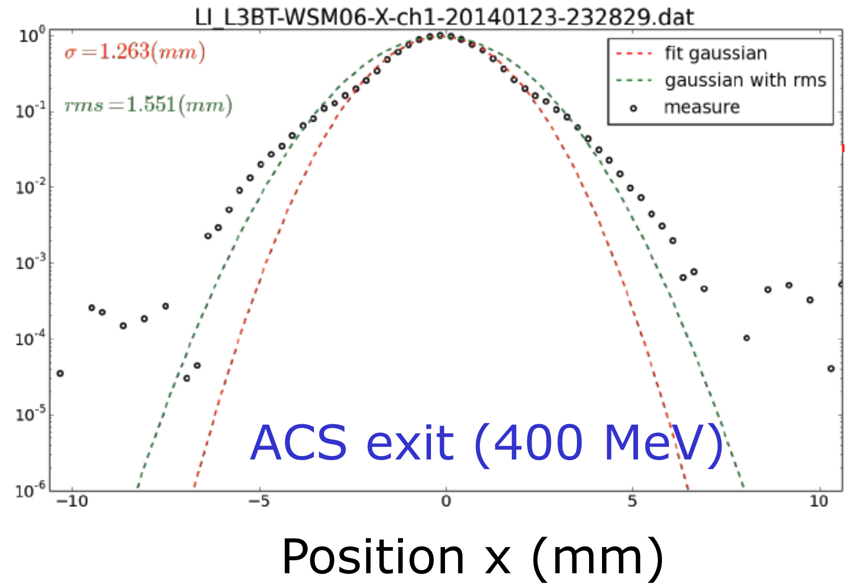
Beam Halo Formation at ACS

◆ Beam halo formation is observed at ACS

✓ The most probable cause is a longitudinal mismatch in the ACS section.
-> Transverse-longitudinal coupling through space charge
-> Emittance growth

✓ Longitudinal matching with "Bunch Shape Monitors (BSM)" is needed.
We have 3 BSMs: observed vacuum pressure deterioration
-> Off-line baking



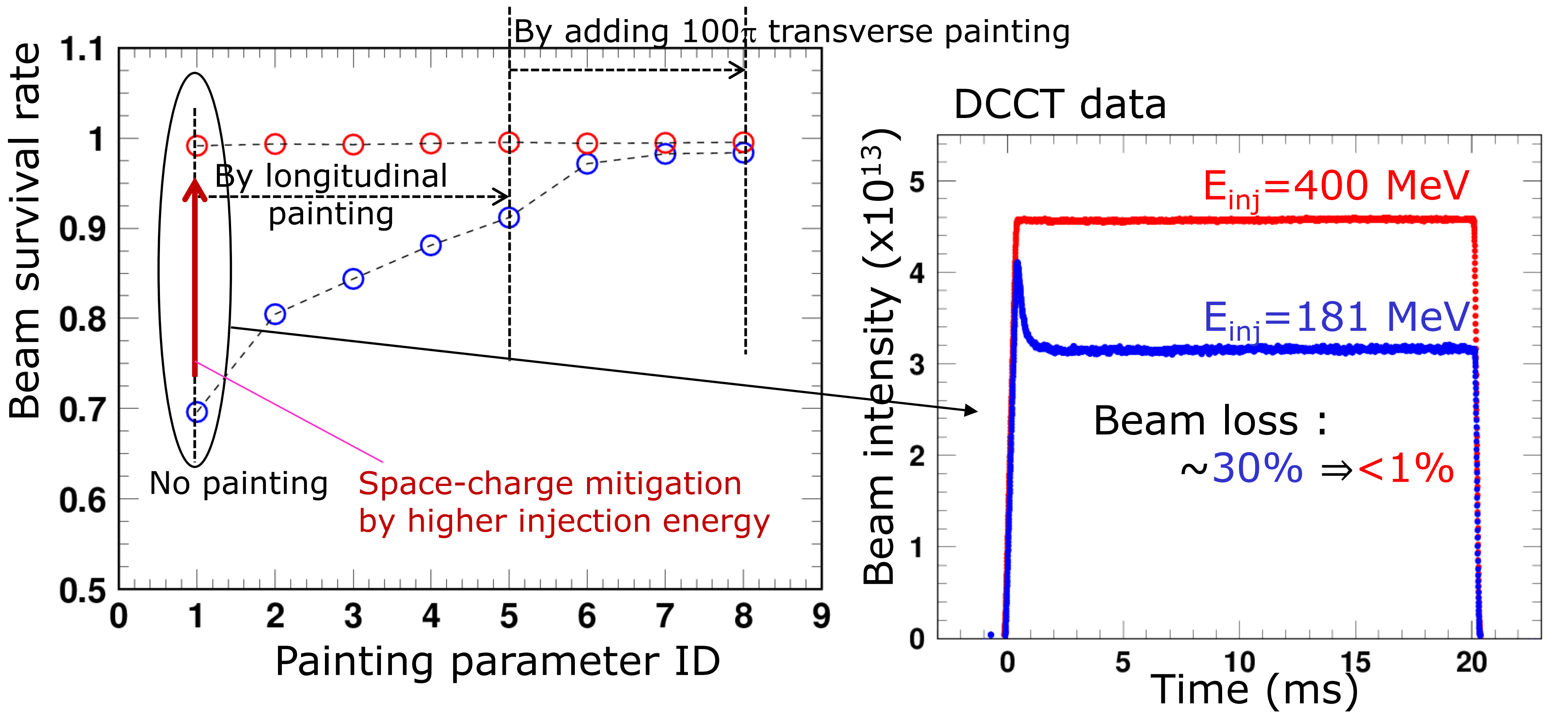


Beam profile before and after the ACS (I_{peak}=25 mA)

Advantages of Energy Upgrade

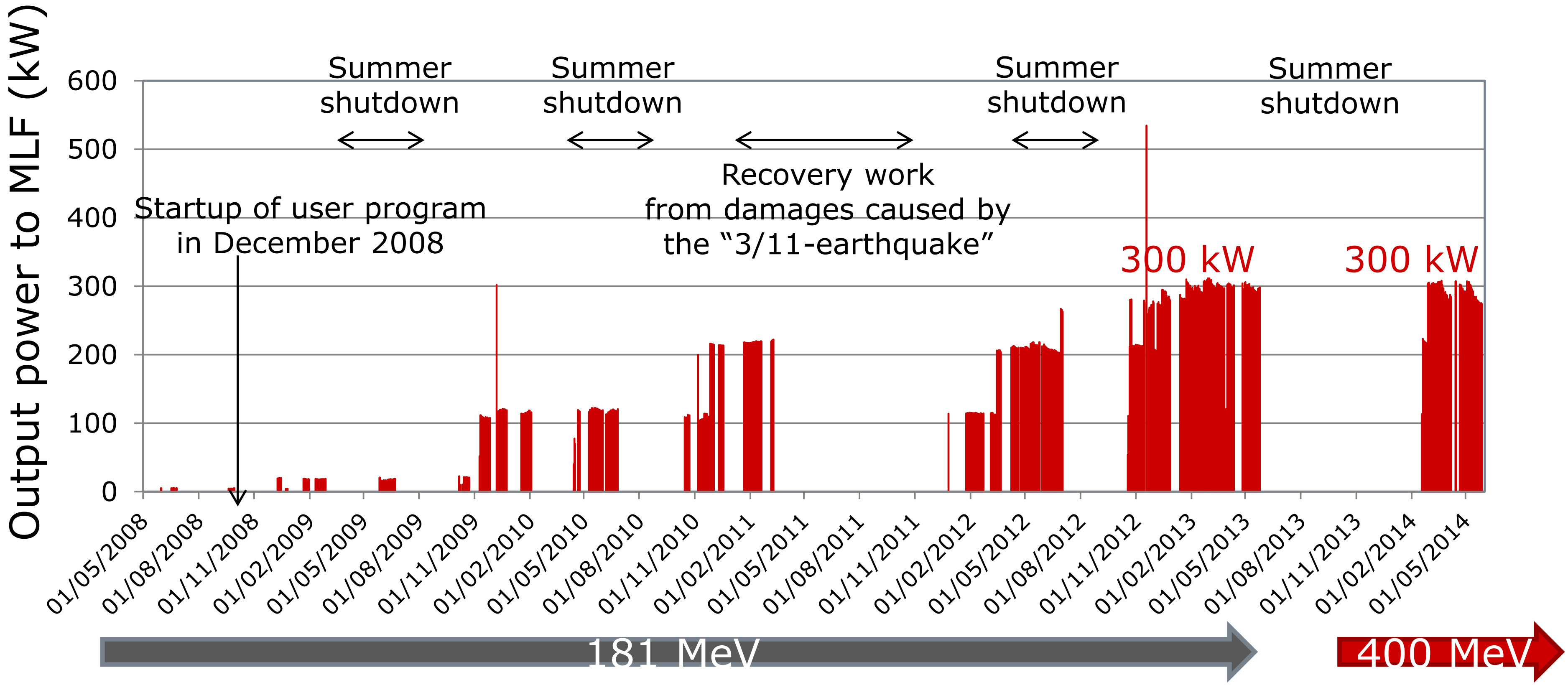
Beam survival rate at the RCS for two injection energies:

- E_{inj}=181 MeV, 539 kW-eq. intensity (Run#44, Nov. 2012)
- E_{inj}=400 MeV, 553 kW-eq. intensity (Run#54, Apr. 2014)



✓ These experimental data clearly show big advantages of the injection energy upgrade and the excellent ability of injection painting.

Beam Power to MLF (3GeV)

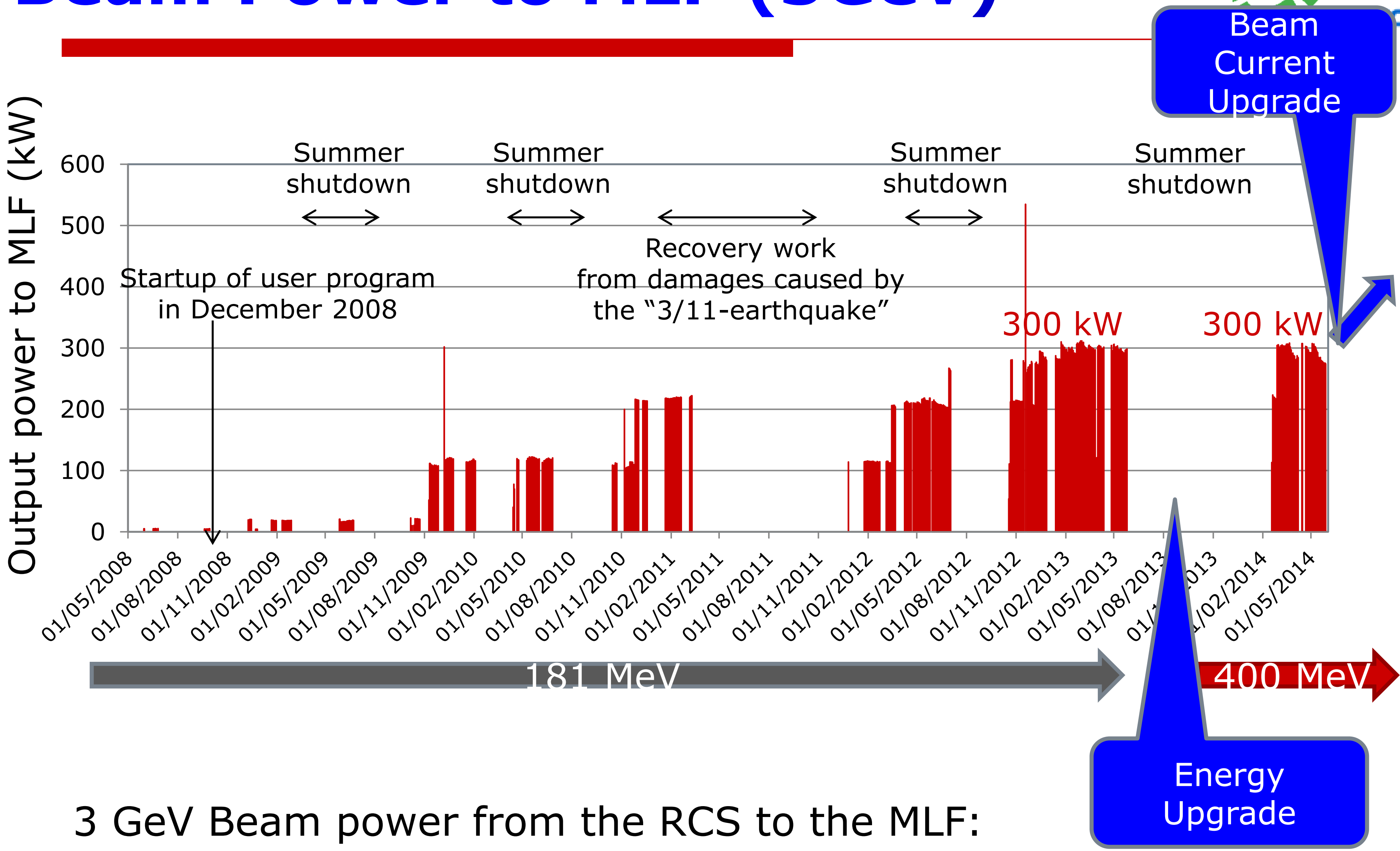


3 GeV Beam power from the RCS to the MLF:

Steadily increased up to 300kW

-> Linac power 18kW@181MeV, 40kW@400MeV

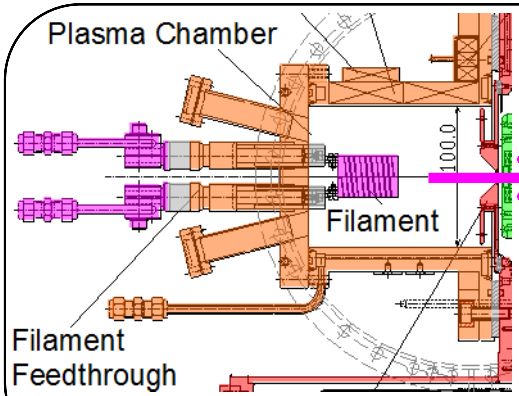
Beam Power to MLF (3GeV)

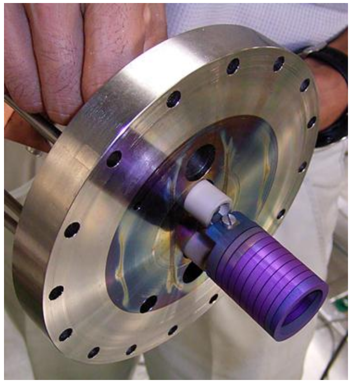


3 GeV Beam power from the RCS to the MLF:
Steadily increased up to 300kW
-> Linac power 18kW@181MeV, 40kW@400MeV

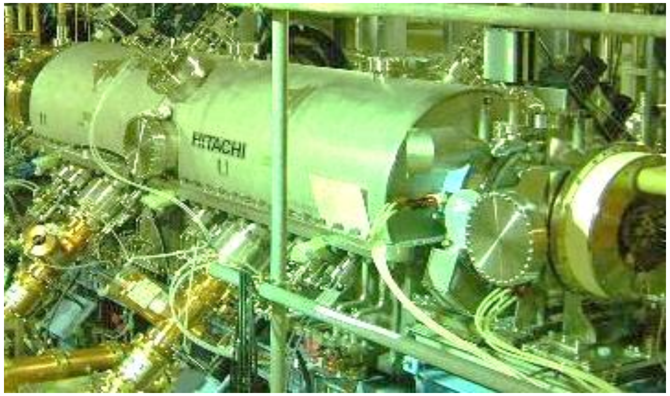
Front End: IS and RFQ (30 -> 50 mA)

Ion source



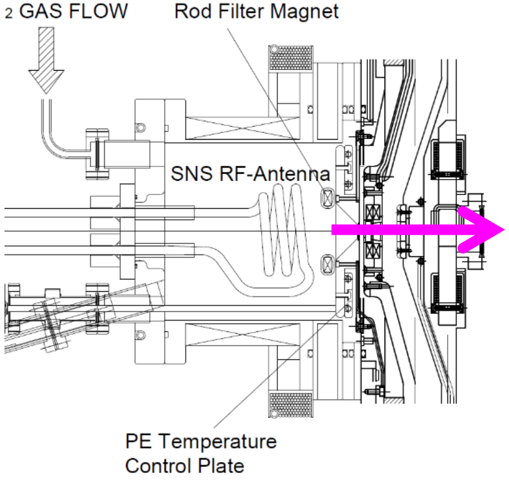


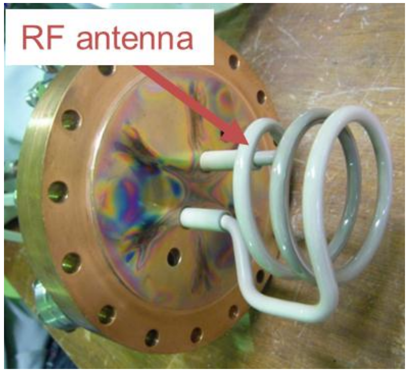
RFQ



New

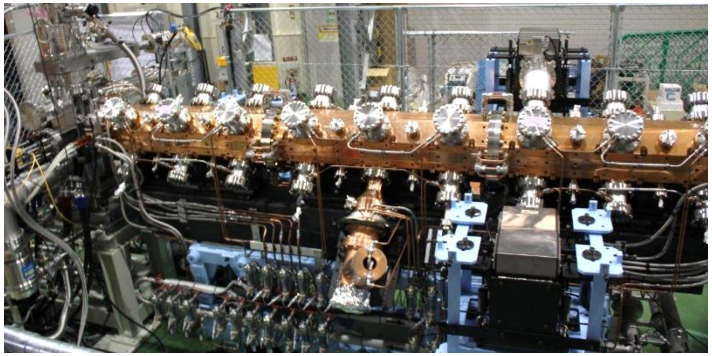
- Filament -> RF-driven
- Cs free -> Cs seeded



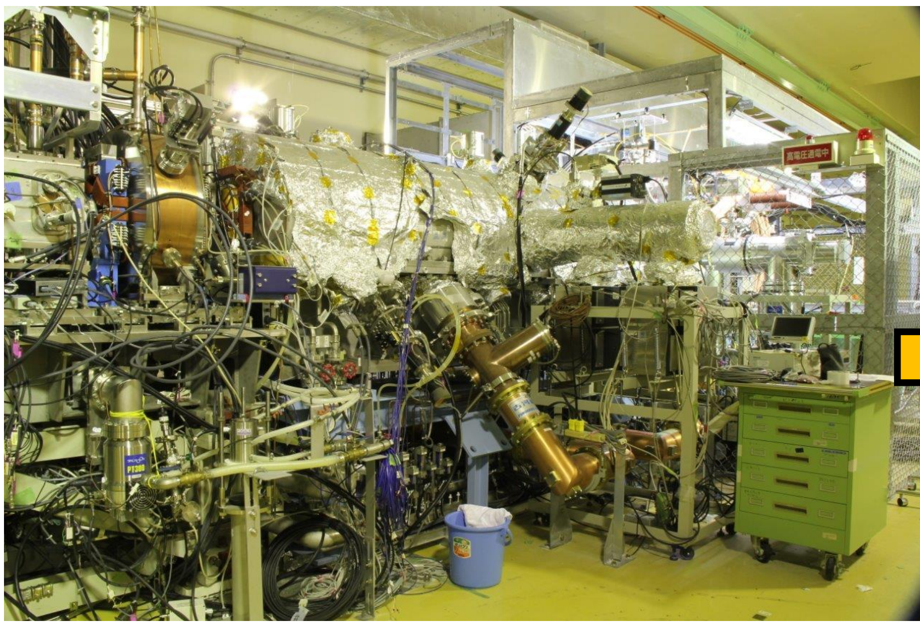


- Structure: Bolt -> Brazed
- Beam dynamics design for higher beam current

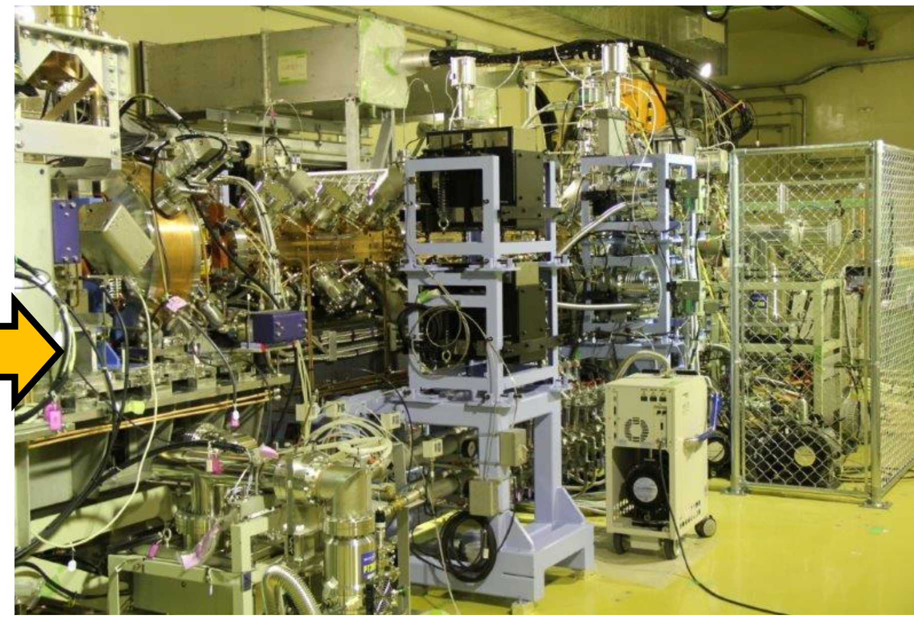
New



Installation of New Front-End



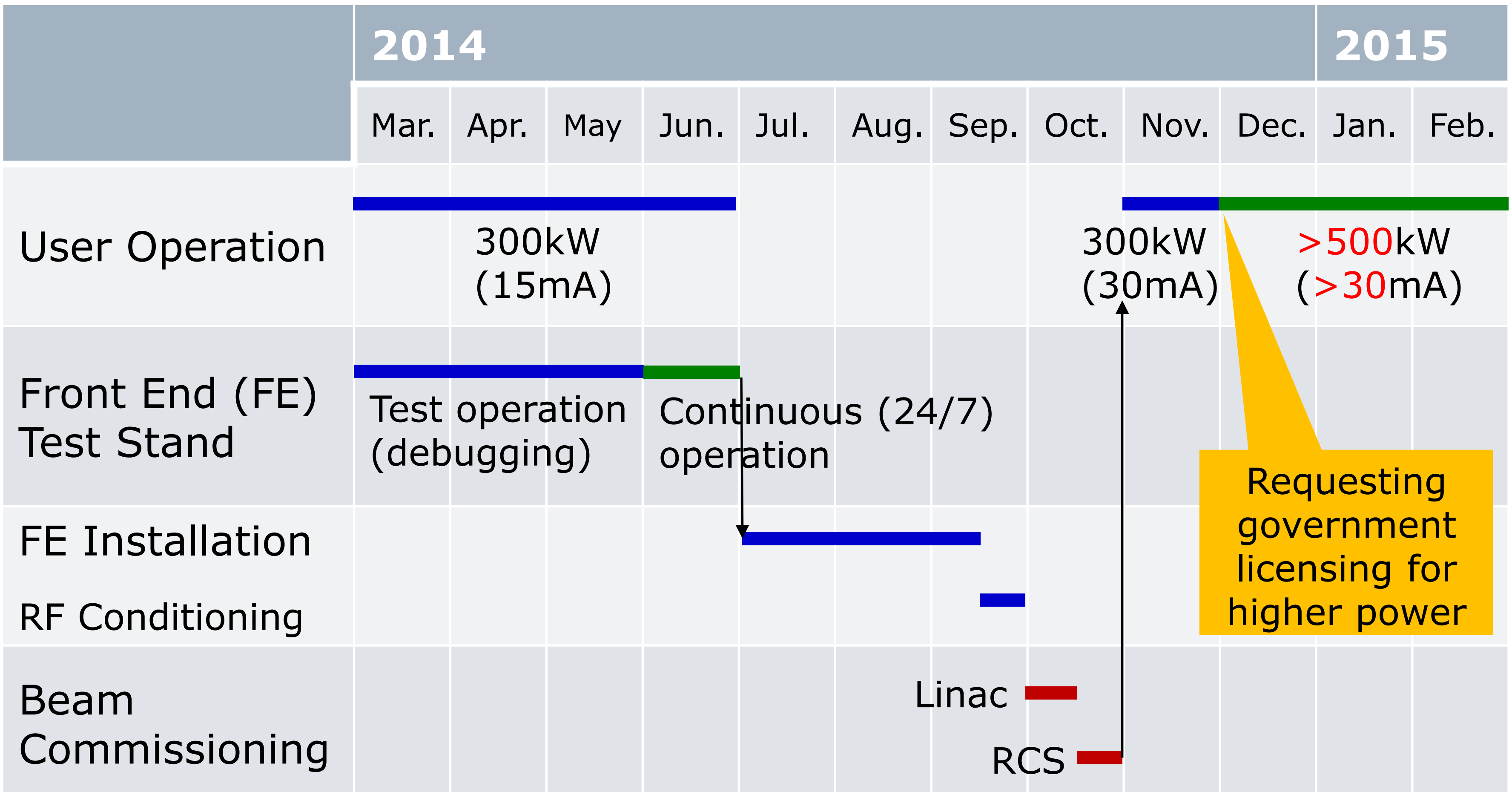
The old RFQ.
(Ion source in the cage).



The new RFQ.

(Aug. 27, 2014)

Master Schedule



High power demonstration
1 MW-eq.@3GeV
(50mA@Linac)

Summary

The energy upgraded 400 MeV linac has been successfully commissioned as scheduled from 2013.

- RCS demonstrates high intensity beam at 550 kW (equivalent). Confirmed the advantages of the energy upgrade.

- Linac and RCS provides 300 kW beam for MLF users. Corresponding Linac power: 40 kW.

- Remain several issues to improve stability and availability.
  - Some hardware issues treated in summer 2014.
  - Need more study (and instruments) for beam halo, loss and radioactivity.

- Beam current upgrade: installed new Ion Source and RFQ.
  - Beam commissioning in October 2014:
    Demonstration higher power towards 1 MW.

Related Presentations

- **MOPP072** Present Status of J-PARC LINAC LLRF Systems (Z.Fang)
- **MOPP090** Adjustment of the coupling factor of the input coupler of the ACS linac by a capacitive iris in J-PARC (J. Tamura)
- **MOPP091** Beam test of a new RFQ for the J-PARC linac (Y.Kondo)
- **TUPP067** Chopping Operation for the Tandem Scrapers at the J-PARC Linac (K. Futatsukawa)
- **TUPP070** STATUS AND RECENT MODIFICATIONS TO 324-MHZ RF SOURCE IN J-PARC LINAC (M. Kawamura)
- **TUPP072** Studies on wake field in Annular Coupled Structure (Y. Liu)
- **TUPP073, *TUPOL05*** Study of the ACS cavity without a bridge cavity (F. Naito)
- **TUPP094** Recent Progress of Beam Commissioning at J-PARC Linac (T. Maruta)
- **TUPP095** High-power test results of the RFQ III in J-PARC linac (T. Morishita)
- **THPP073** Cavity Excitation of the Chopping Beam at the J-PARC Linac (K. Futatsukawa)
- **THPP089, *THPOL07*** High Power Conditioning of Annular-ring Coupled Structures for the J-PARC Linac (H. Ao)
- **THPP090** Longitudinal Measurement of Annular-type Coupled Structure Linac in J-PARC (T. Maruta)
- **THPP091** Installation and Performance Check of Beam Monitors for Energy Upgraded J-PARC Linac (A. Miura)

Acknowledgements

- J-PARC Linac group members and accelerator group members

- Support staff and companies

- This work is achieved with many fields of linac components, and many contributors are involved, not limited to the ACS.
  But special thanks for ACS development to Y. Yamazaki, M. Ikegami, K. Takata, V. Paramonov, S.C. Joshi, N. Hayashizaki, N. Ouchi, etc.