Status of Accelerating Cavities

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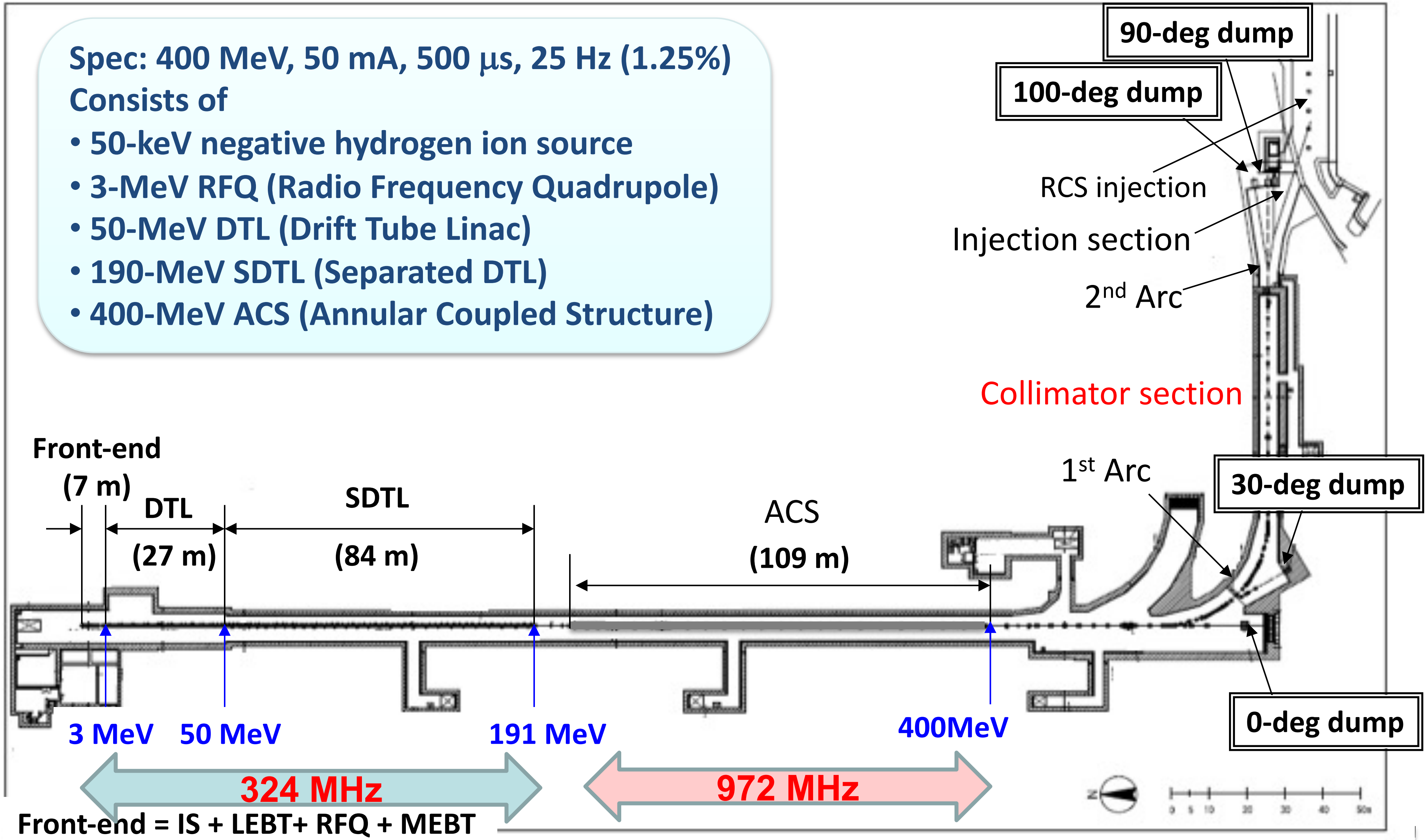
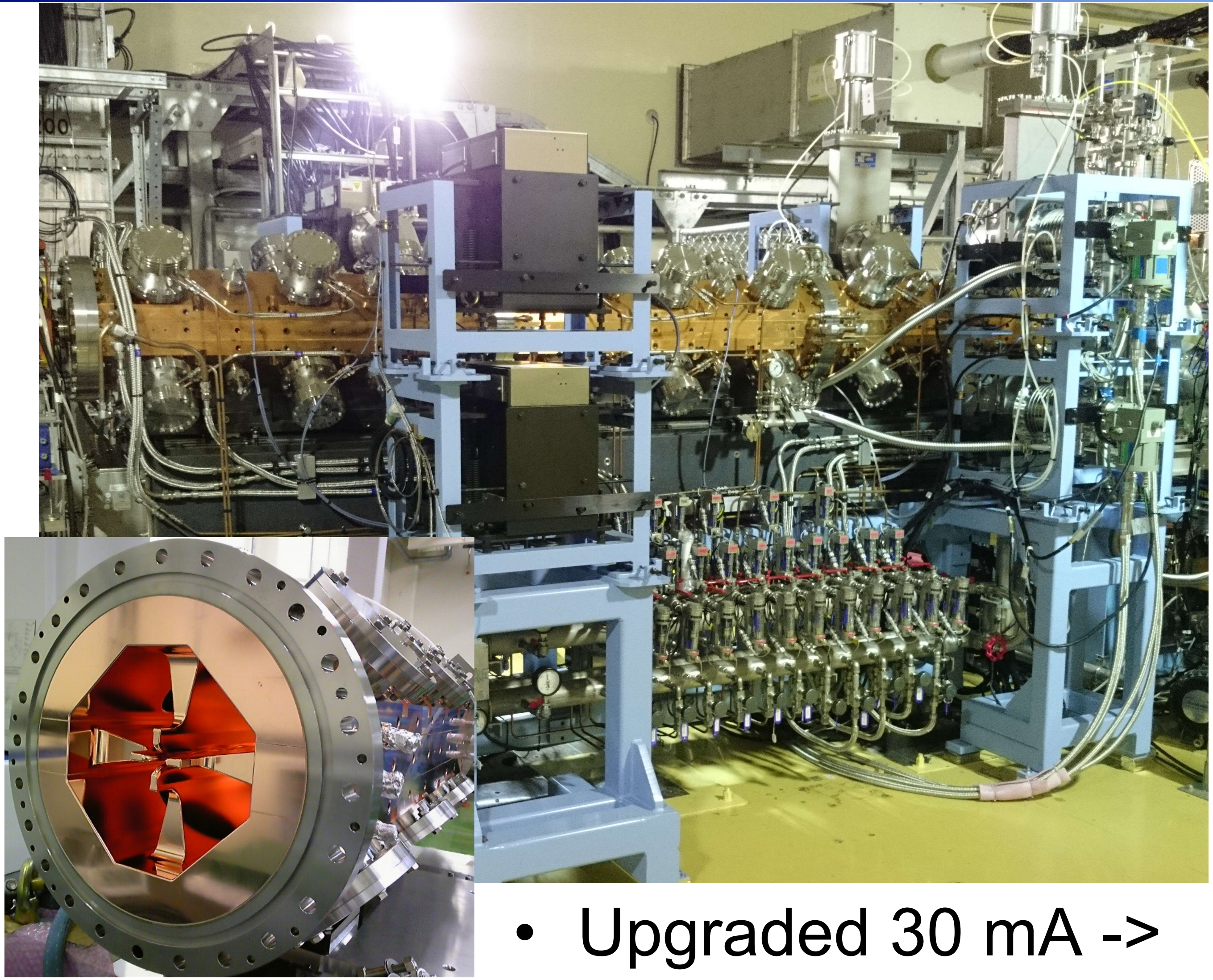
J-PARC H⁻ Linac layout

Spec: 400 MeV, 50 mA, 500 μs, 25 Hz (1.25%)
Consists of
- 50-keV negative hydrogen ion source
- 3-MeV RFQ (Radio Frequency Quadrupole)
- 50-MeV DTL (Drift Tube Linac)
- 190-MeV SDTL (Separated DTL)
- 400-MeV ACS (Annular Coupled Structure)



Front-end = IS + LEBT+ RFQ + MEBT

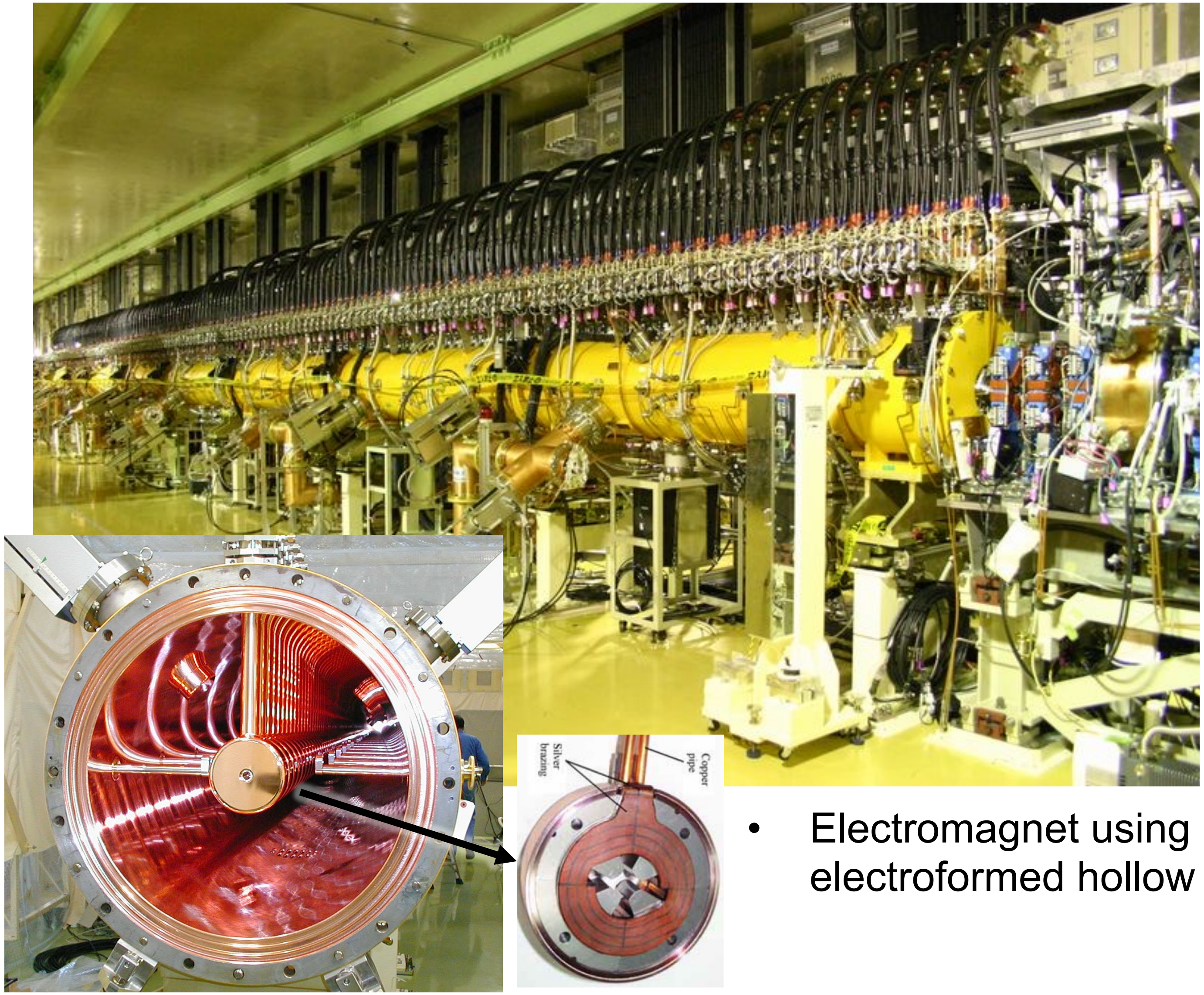
RFQ



Structure	4-vane RFQ
f_0	324 MHz
W_{in}	50 keV
W_{out}	3 MeV
Peak current	50 mA
Vane length	3.623 m
# of cells	317 + transition, fringe
r_0	3.49 mm
ρ_t/r_0 ratio	0.75 (ρ_t = 2.62 mm)
Longi. vane shape	sinusoidal
a_{min}	2.13 mm
m_{max}	2.13
$\phi_{s,max}$	-30.6 deg
V	81 kV
Max. surface field	30.7 MV/m (1.72 E_k)
Power dissipation	400 kW

- Upgraded 30 mA -> 50 mA in 2014

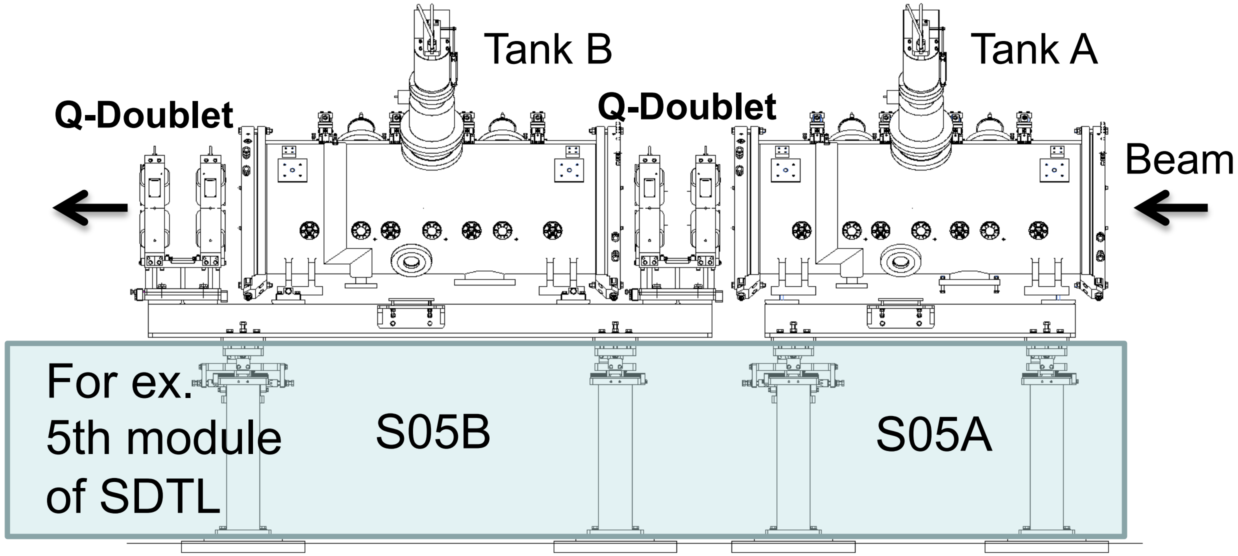
DTL



- Electromagnet using electroformed hollow coil.

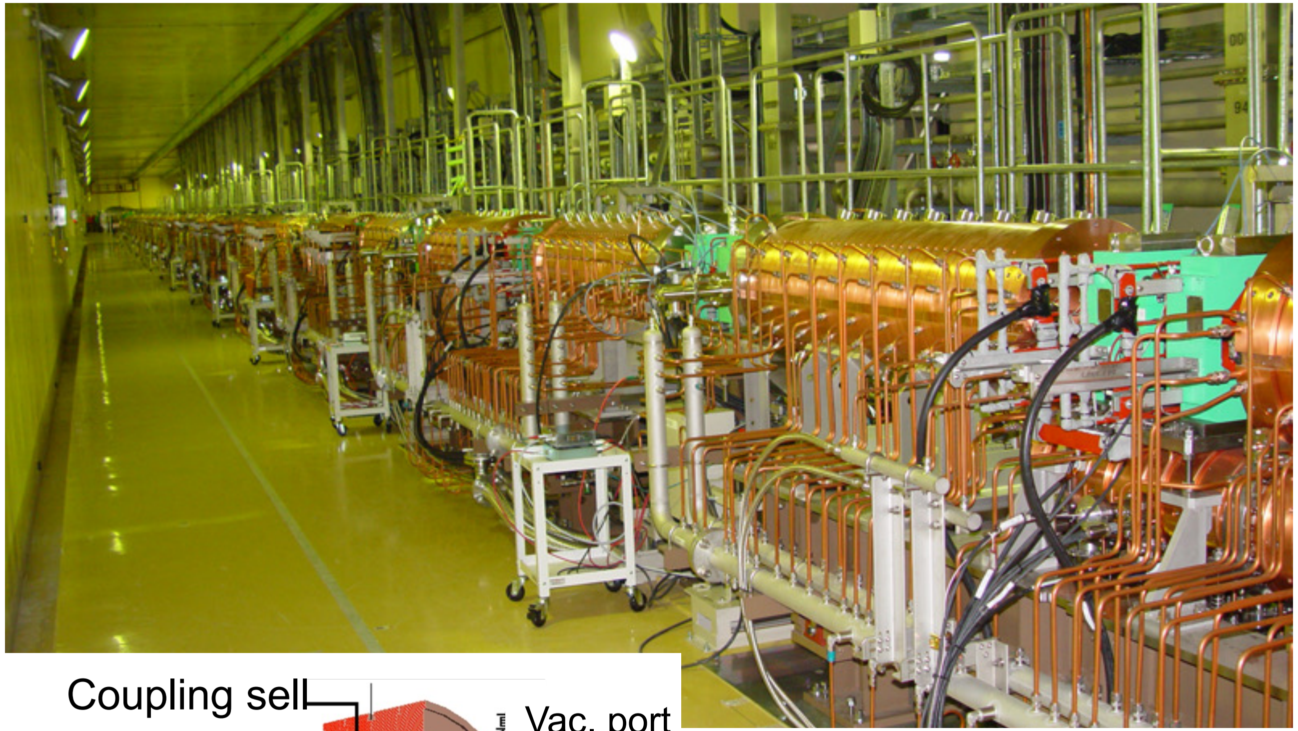
Structure	Alvarez DTL
f_0	324 MHz
Operation mode	2π
W_{in}	3 MeV
W_{out}	50 MeV
Section length	27.12 m
# of tanks	3
# of cells	146
Tank diameter	560 mm
Bore radius	6.5 - 13 mm
ϕ_s	-30 ~ -26 deg
E_0	2.5 ~ 2.9 MV/m
ZTT	47 ~ 36 MΩ/m
Max. surface field	11.2 MV/m (0.63 E_k)
Power dissipation	3.3 MW for 3 tanks

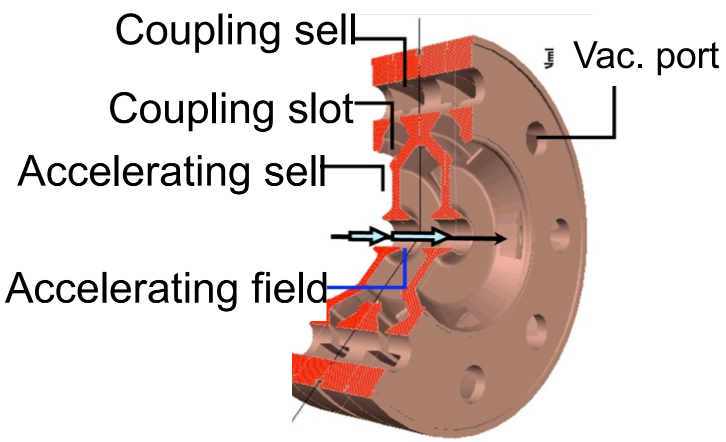
SDTL (Separated DTL)



Structure	Separated DTL
f_0	324 MHz
Operation mode	2π
W_{in}	50.1 MeV
W_{out}	190.8 MeV
Section length	91.2 m
# of modules	16
# of tanks / module	2
# of cells / tank	5
Tank diameter	520 mm
Bore radius	18 mm
ϕ_s	-27 deg
E_0	2.53 ~ 3.74 MV/m
ZTT	50 MΩ/m
Max. surface field	23.2 MV/m (1.3 E_k)
Power dissipation	16.6 MW for 32 tanks

ACS (Annular Coupled Structure)



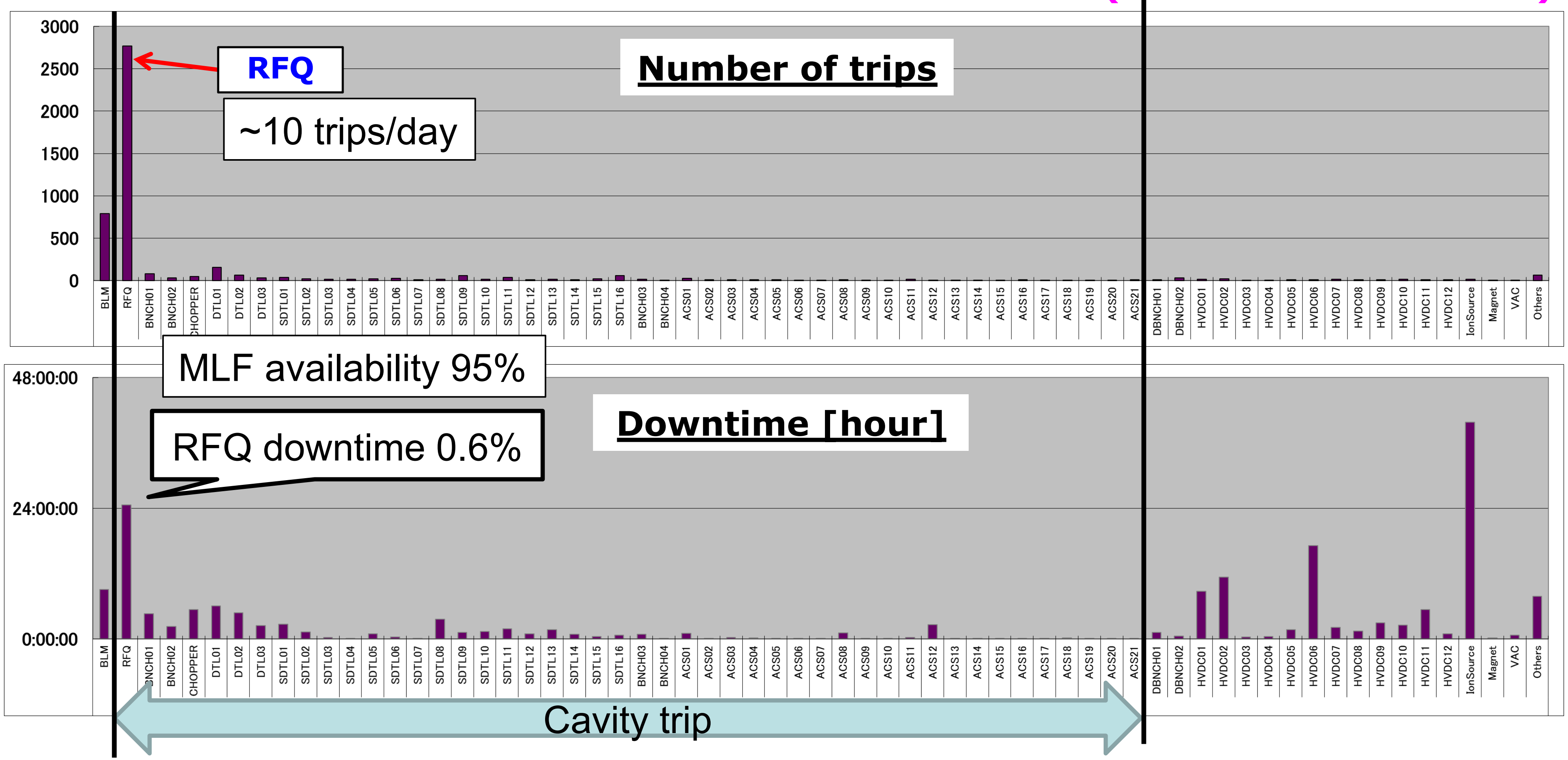


Structure	ACS CCL
f_0	972 MHz
Operation mode	$\pi/2$
W_{in}	190.8 MeV
W_{out}	400 MeV
Section length	108.3 m
# of tanks	46
# of modules	23
# of cells / tank	15
Bore radius	20 mm
ϕ_s	-30 deg
E_0	4.26 MV/m
ZTT	35.8 ~ 44.8 MΩ/m
Max. surface field	23.7 MV/m (0.85 E_k)
Power dissipation	33.4 MW for 46 tanks

Operation statistics FY2019

- In FY2019, cavities are already almost stable.
- Availability requirement > 90%. 1% downtime of RFQ was not negligible.

(Feb. 2019 - Feb. 2020)



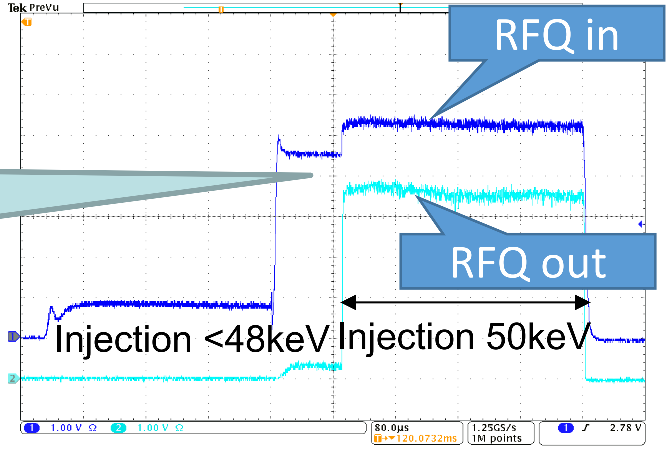
Why we so suffered from RFQ discharge?

- Simply because RFQ field is high.

Maximum surface field (E_k = Kilpatrick limit)			
RFQ	DTL	SDTL	ACS
1.7	0.63	1.3	0.85

- RFQ has many functions. One of the most important is filtering unnecessary beam, both in space and time.

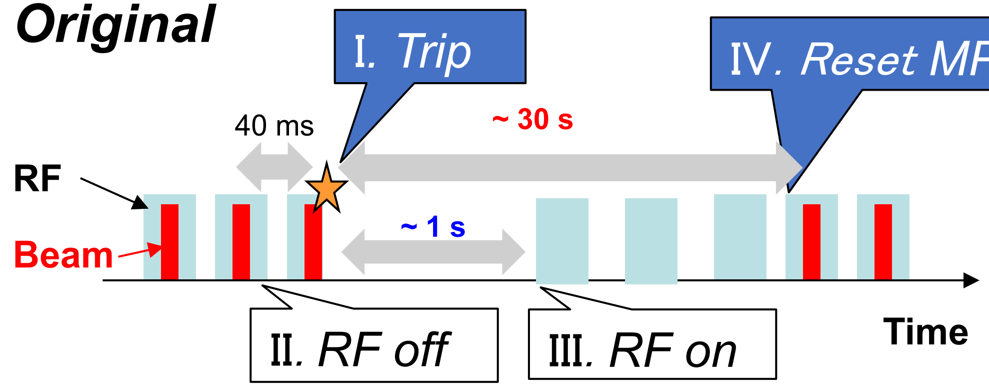
To make sharp edged beam, ramping of ion source beam is dumped in RFQ



Fundamental measures to reduce discharges themselves are difficult

Change of MPS condition for RFQ

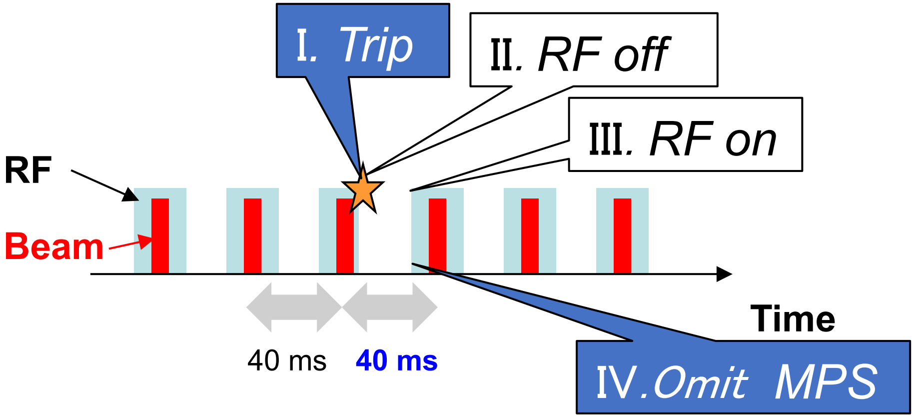
Original



~2019 : loss time ~30s

I. Trigger : Discharge in the RFQ
II. (~10 μs) Stop RF, then beam stopped by MPS.
III. (**~1 s**) Resume RF
IV. (**~30 s**) Reset MPS by operators.

2020~: Omit MPS activation

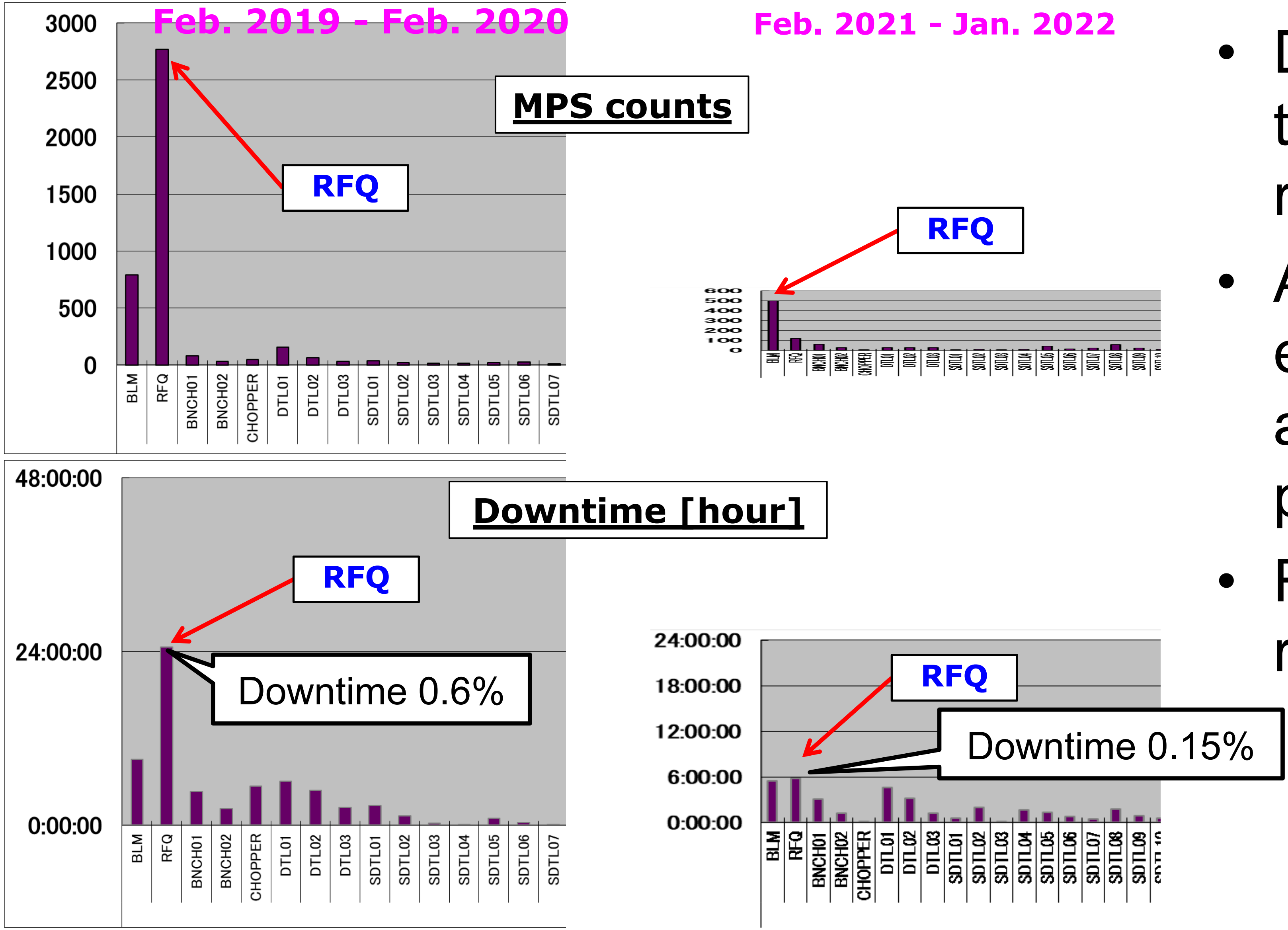


2020~ : No loss time

I. Trigger : Discharge in the RFQ
II. (~10 μs) Stop RF activates the MPS.
III. (**40 ms**) Resume RF
IV. If not trip again, **OMIT MPS**

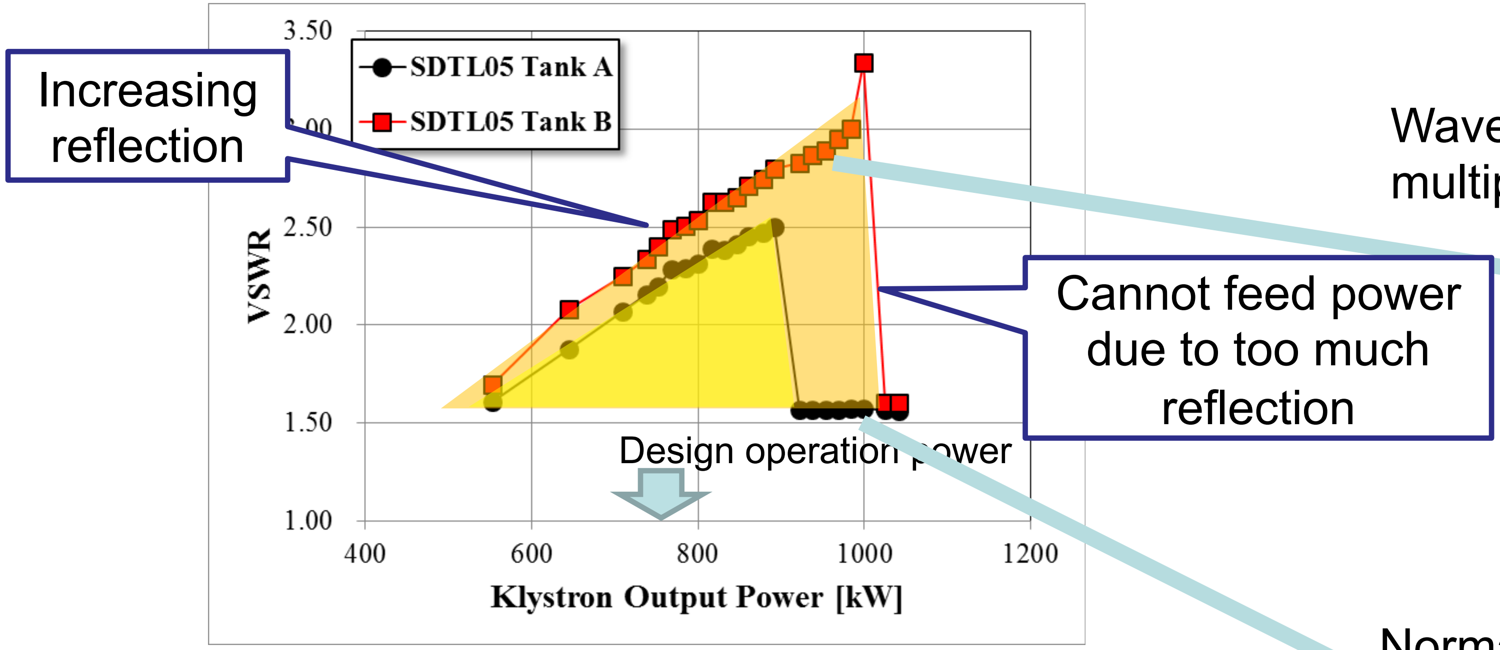
- Standard process for cavity trip
  - ~1s for recover of vacuum condition around electrodes.
  - MPS is manually reset after checking the machine status.
- According to operation experience,
  - Almost all RFQ discharge is slight and single.
  - Can recover easily form the very next pulse.
  - Negligible affect to beam loss
- Determined MPS is not necessary for RFQ trip due to single discharge.

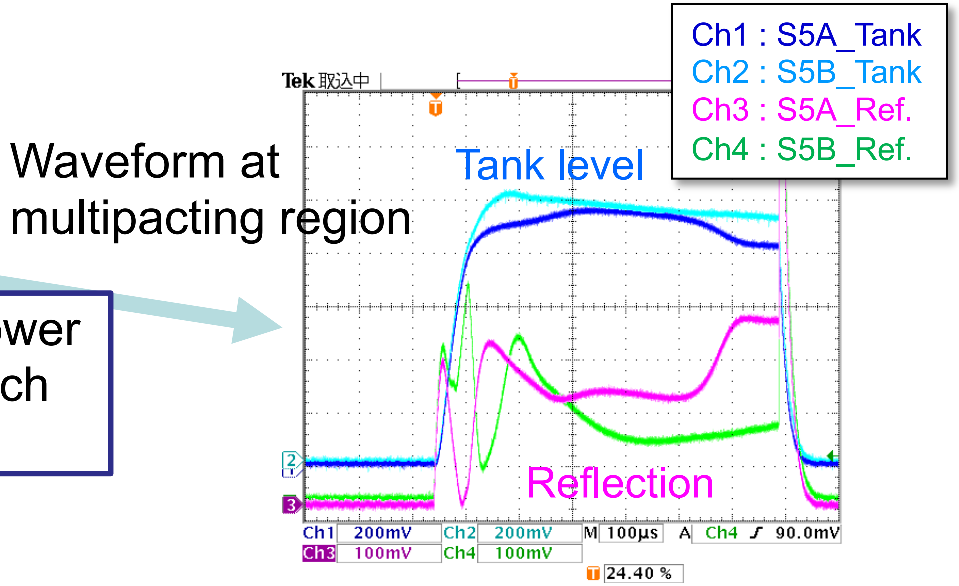
Improved RFQ operation

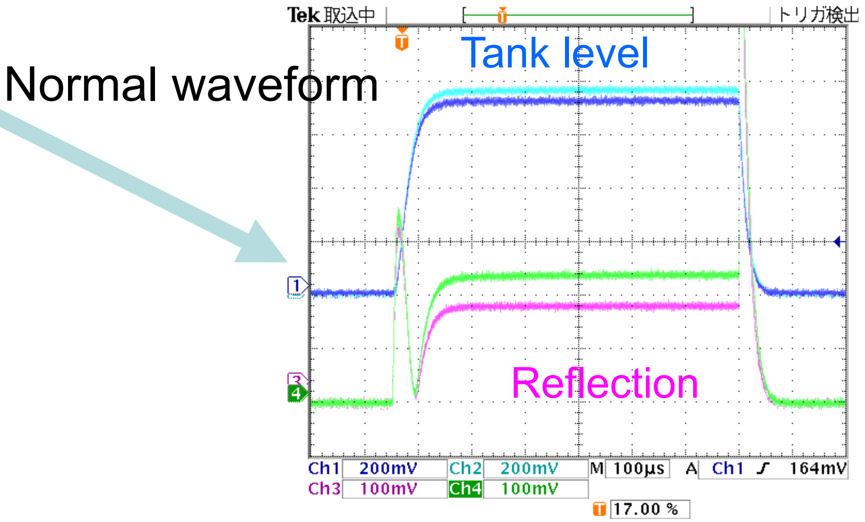


- Downtime due to RFQ trip is drastically reduced.
- Almost all RFQ MPS events occur in the accelerator study period.
- RFQ downtime in user run becomes negligible.

Multipacting problem of SDTL cavities



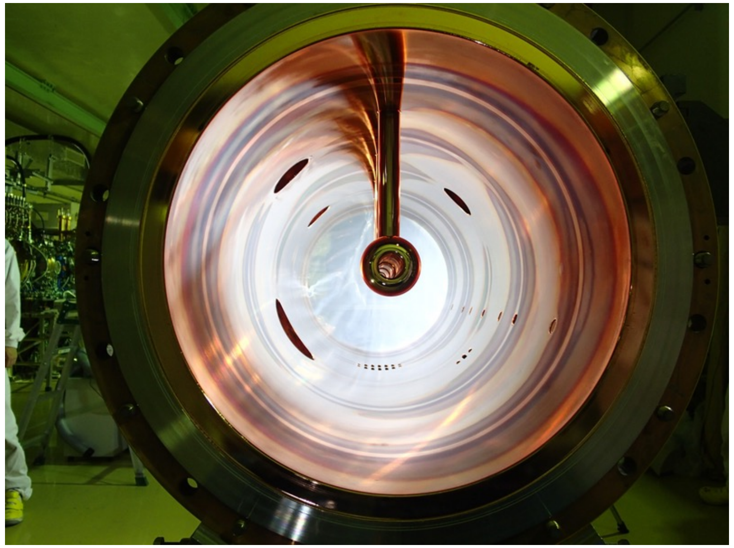




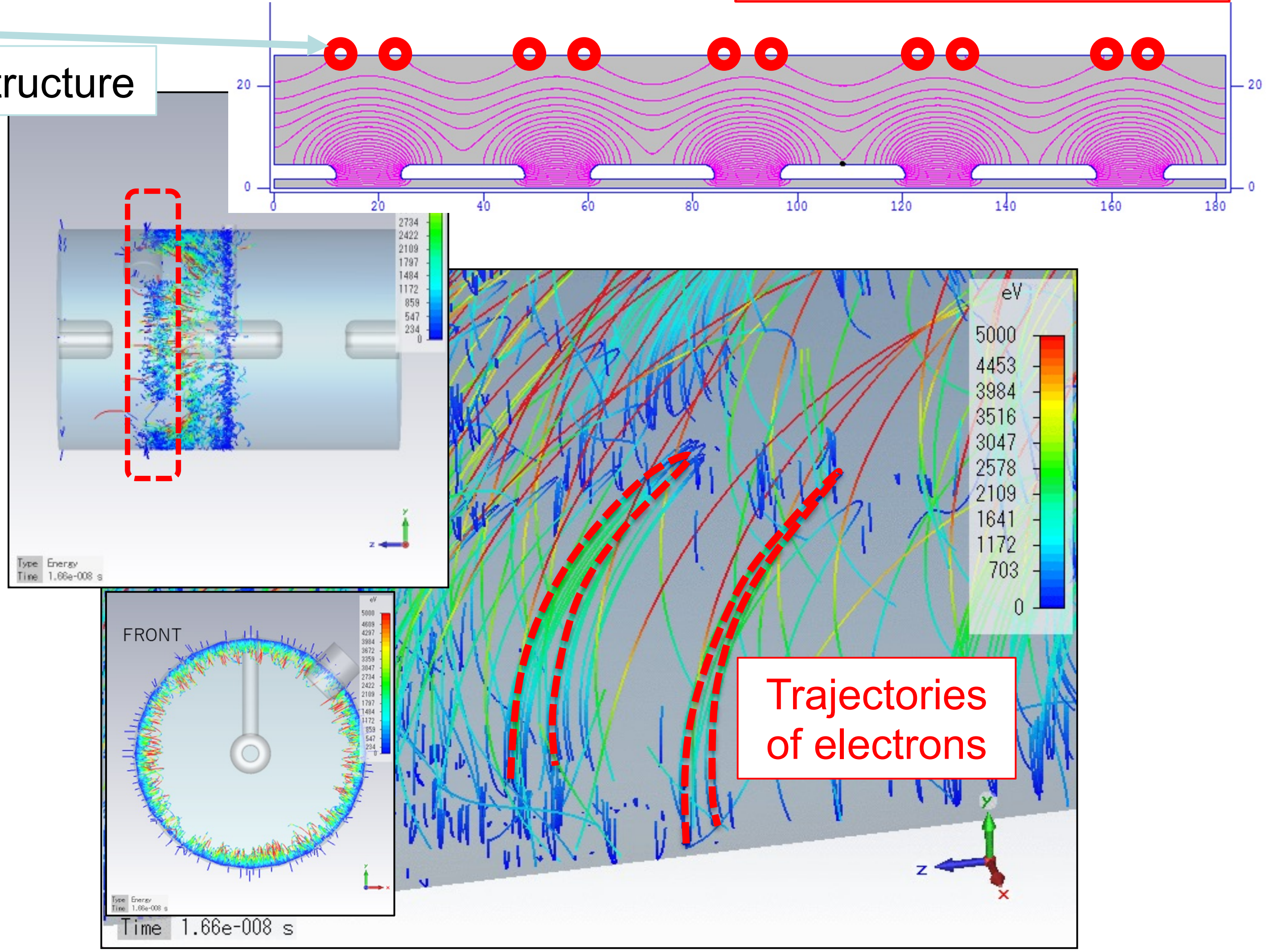
- Since the restart from the 2011 huge earthquake, suffering from significant Q-value degradation of some SDTL cavities.
- To avoid multipacting region, operate with higher power for S05.
- Due to exposure to humid air contaminated with concrete or soil components?

Observation and analysis

Consistent structure

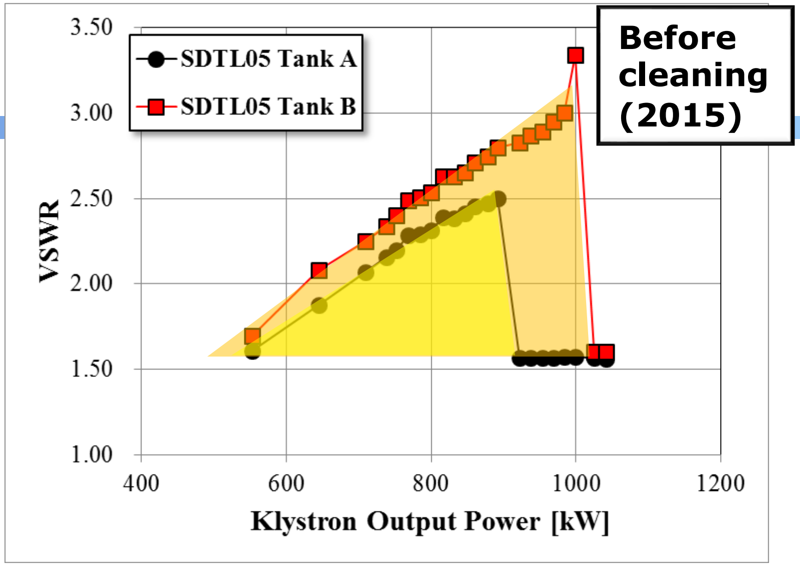


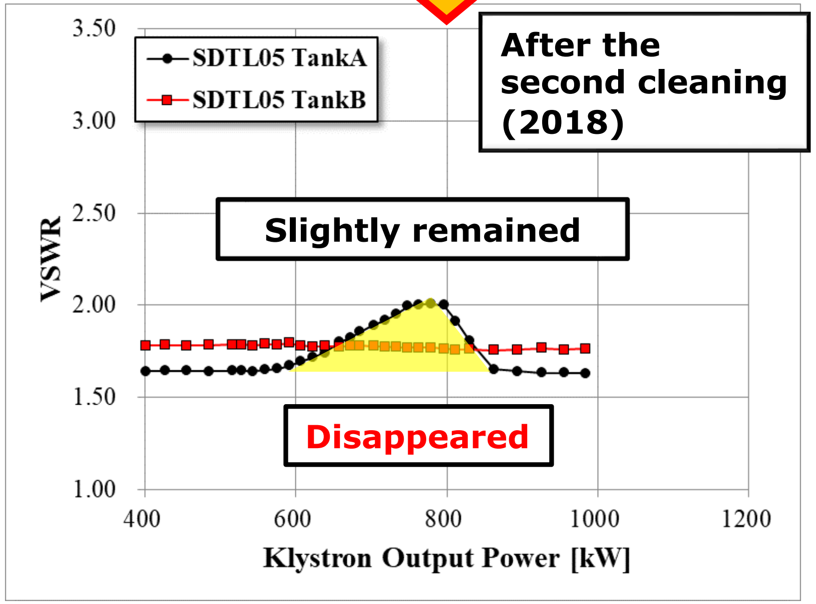
Multipactoring analysis



Trajectories of electrons

Acetone cleaning

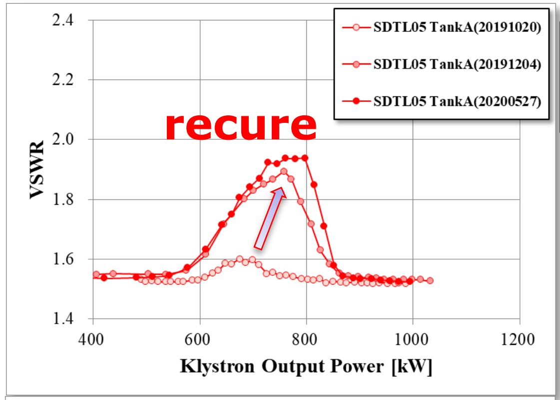




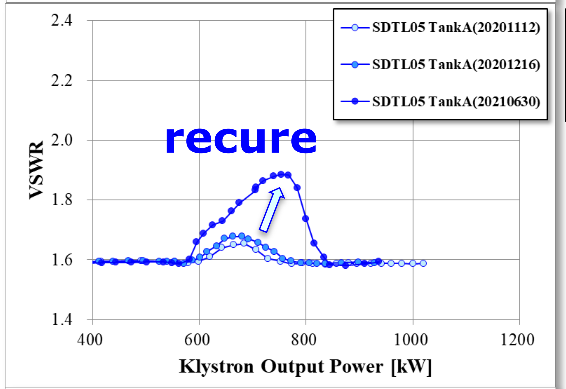
	S04A	S04B	S05A	S05B	S06A	S06B
2015				acetone disappear		
2016			acetone remain →recure		acetone disappear	acetone disappear
2017	acetone remain	acetone remain	acetone remain →recure			
2018						
2019			acetone remain →recure			
2020			H_2SO_4 remain →recure			
2021			HCl/H_2SO_4 disappear			

solution
result

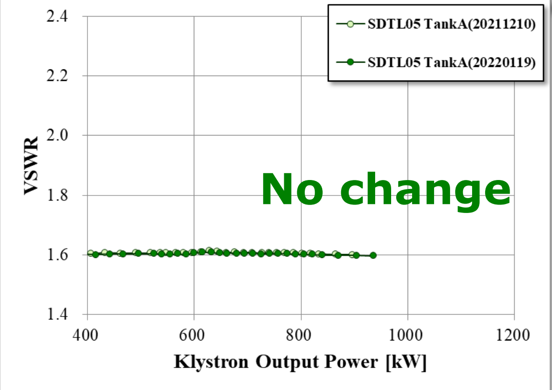
Current status



Acetone cleaning (2019)



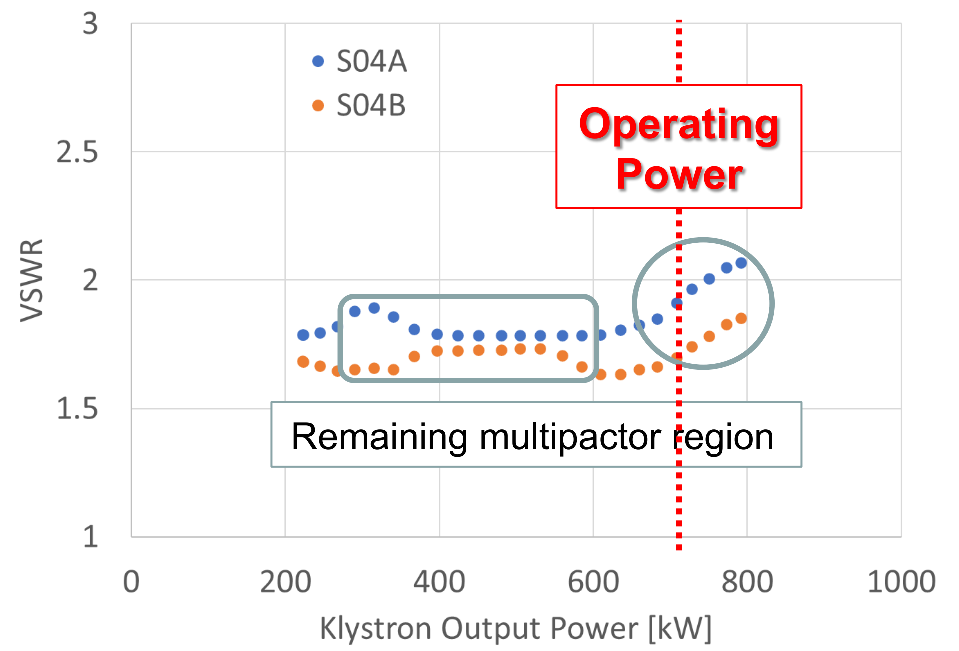
Dilute sulfuric acid cleaning (2020)



Dilute hydrochloric acid cleaning (2021)

☐ **Established standard recipe**

Cleaning agent (oil removal) → Water rinse → Acid wash (hydrochloric acid) → Water rinse → Alcohol substitution



- S05 multipucting resolved.
- HCl cleaning of S04 has been conducted in this summer (2022).

Summary

- We are employing four types of warm accelerating cavities with two different frequencies of 324 MHz and 972 MHz.
- All cavities are almost stable.
- Minor discharges of the RFQ are rather frequent, but the downtime was reduced by changing the MPS scheme.
- Some SDTL cavities are suffered from multipacting problem, but it is almost resolved.
- In conclusion, cavities of J-PARC linac are well operated. The operation will restart from November 1st after 4 month summer maintenance period.