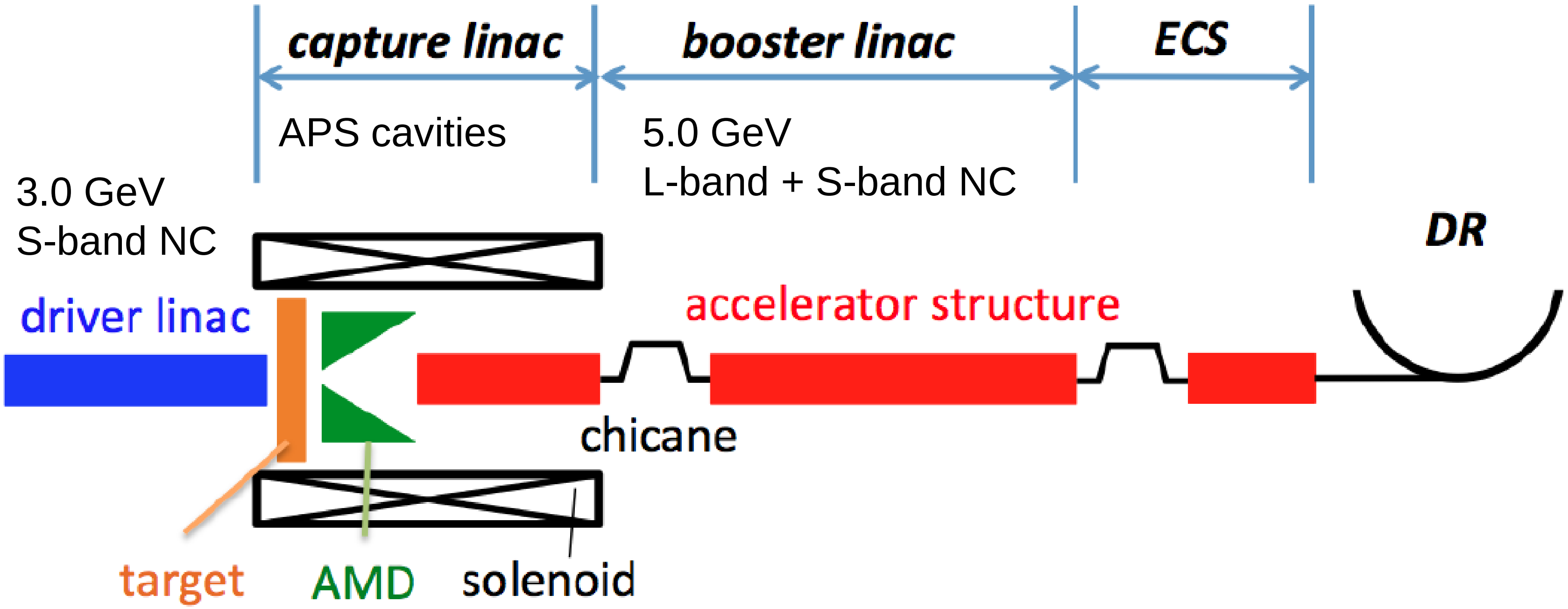
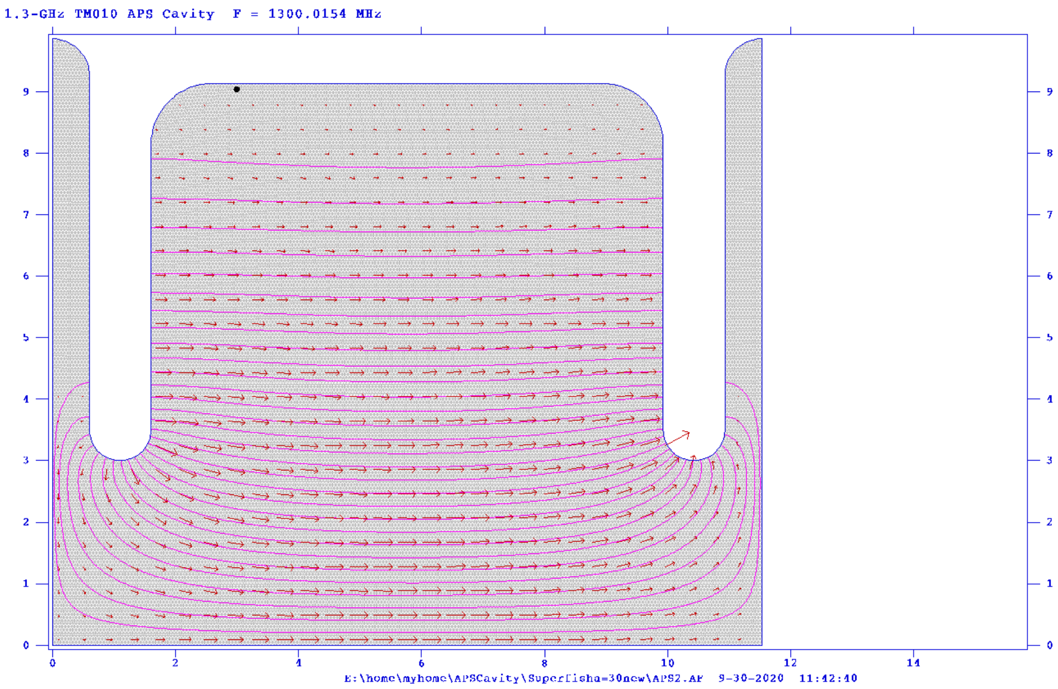
# Status of APS study



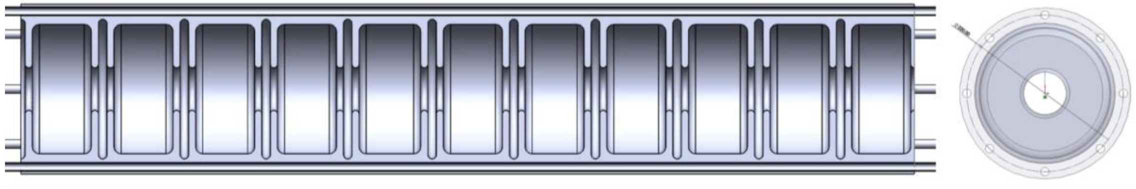

Masao KURIKI (Hiroshima U.)

# Positron Capture Linac

- L-band  APS (Alternate Periodic Structure).
- π/2 mode standing wave linac with a high stability.
- Large iris 2a=60mm is good for e+ capture.

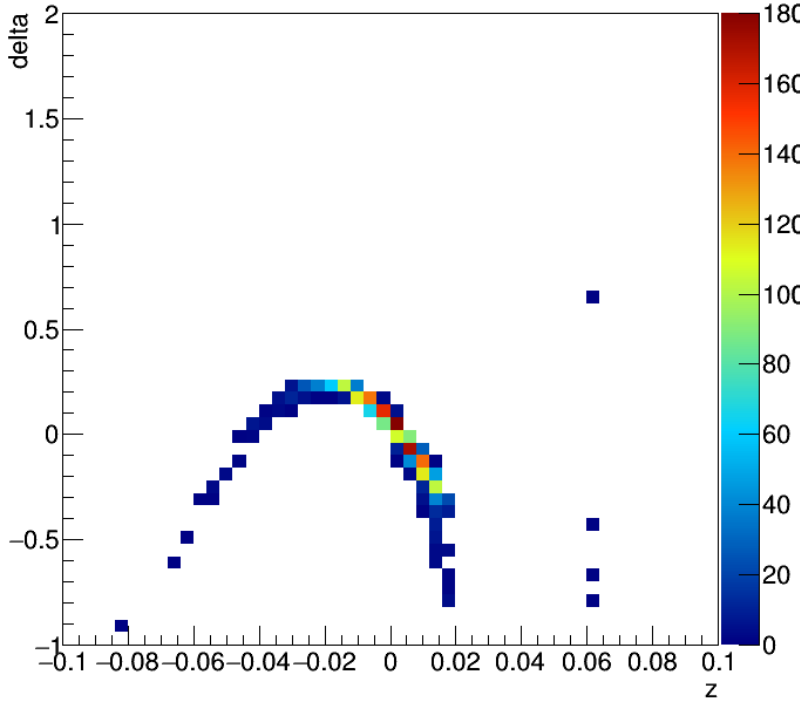


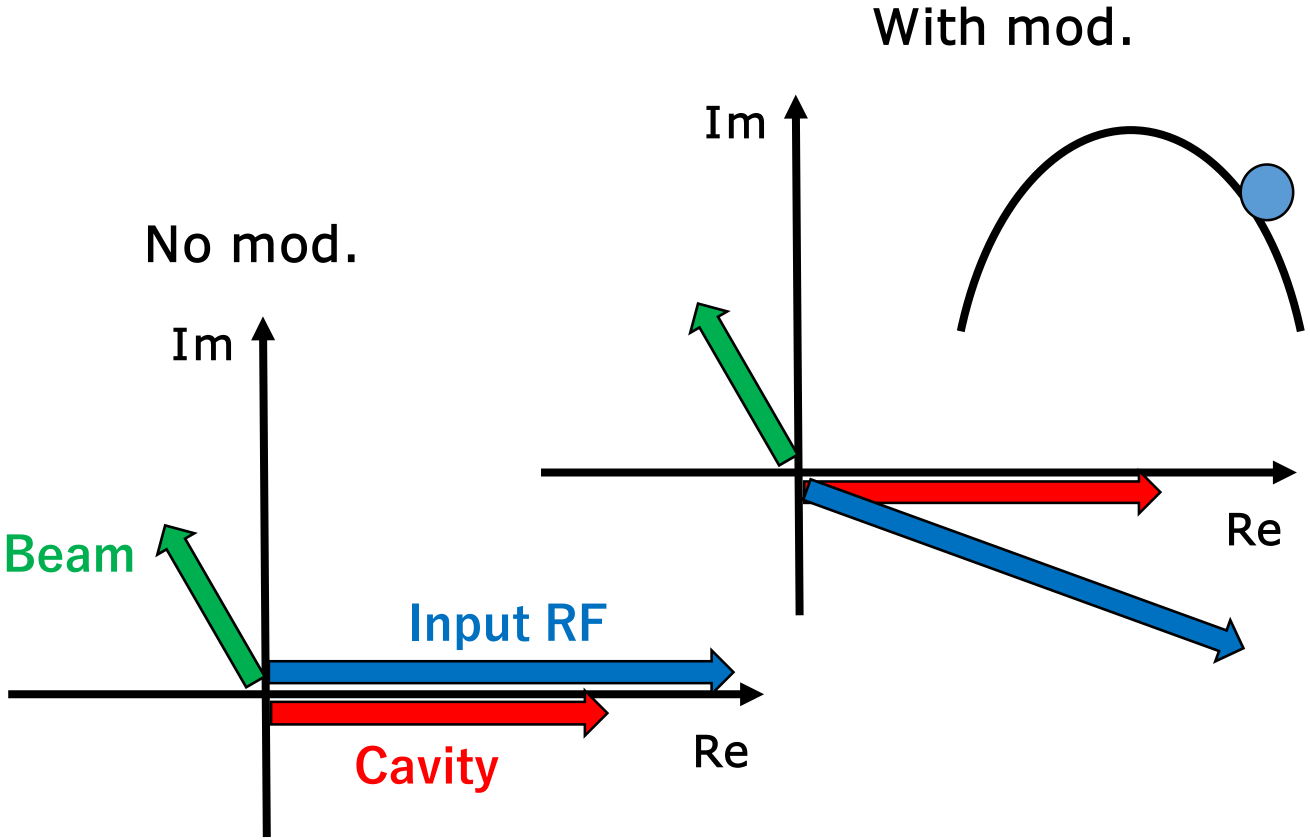

| Parameter | 値 | 単位 |
|---|---|---|
| Freq. | 1300 | MHz |
| Shunt Impedance | 31.5 | MΩ/m |
| Input Power | 22.5 | MW |
| Length | 1.3 | m |



# Beam-loading Compensation in the capture linac

- In the capture linac, the beam is off-crest phase of RF.
- Nominal beam loading compensation method cancelling the growth of RF and beam voltage does’t work.
- Phase modulation on the input RF is able to keep the uniform cavity voltage over the pulse.



# Phase and Amplitude modulation

- The beam loading is large because not only positron, but also electron contribute it.
- Not only the amplitude, but also phase should be controlled, because the acceleration is off-crest.
- By combining two RF sources with phase modulations, Amplitude and Phase modulation is made.

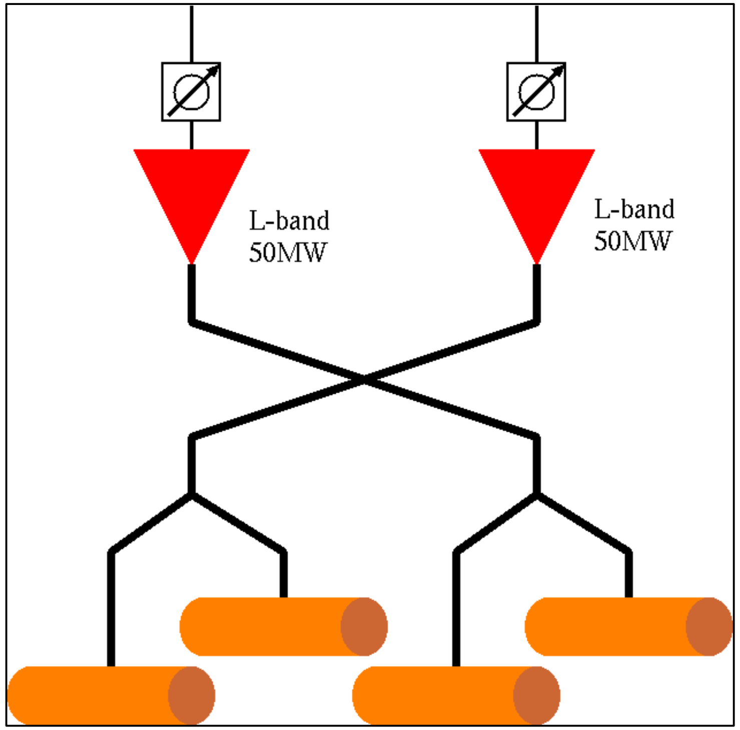
No modulation : $\cos\omega t + \cos\omega t = 2\cos\omega t$

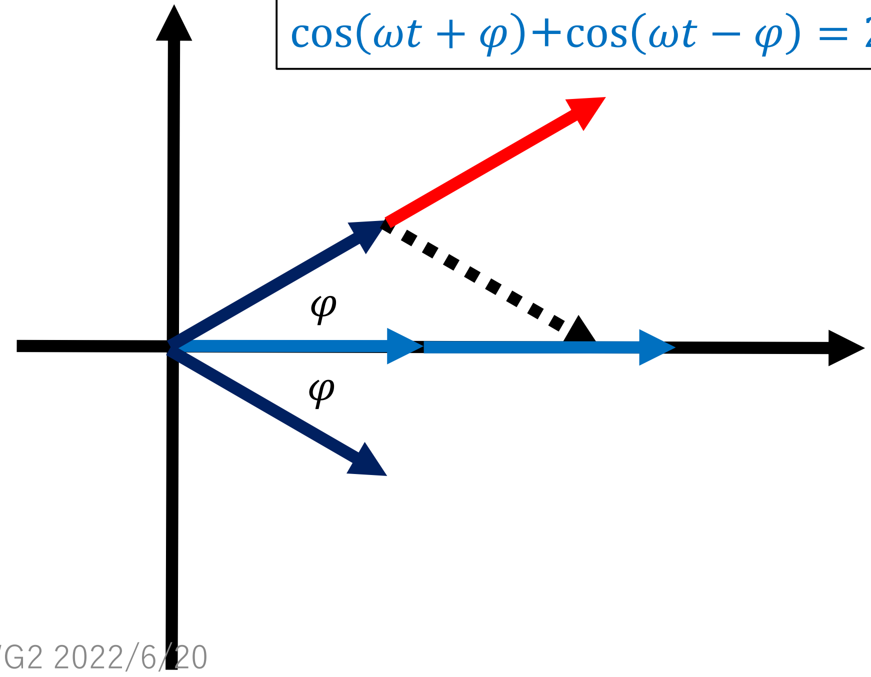
In phase mod. : Phase modulation

$\cos(\omega t+\varphi) + \cos(\omega t+\varphi) = 2\cos(\omega t+\varphi)$

Anti-phase mod. : Amplitude modulation

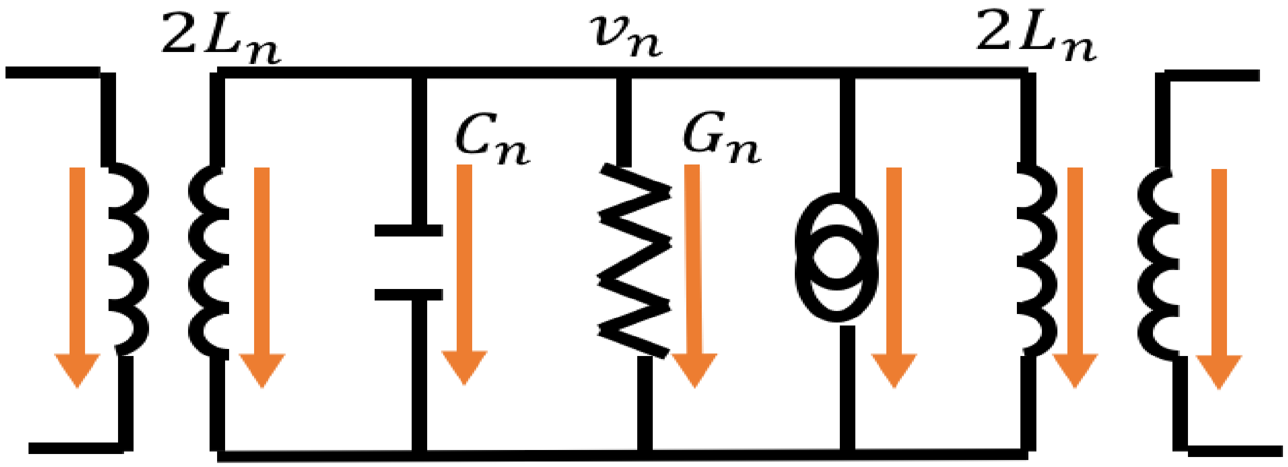
$\cos(\omega t+\varphi) + \cos(\omega t-\varphi) = 2\cos\varphi\cos(\omega t)$

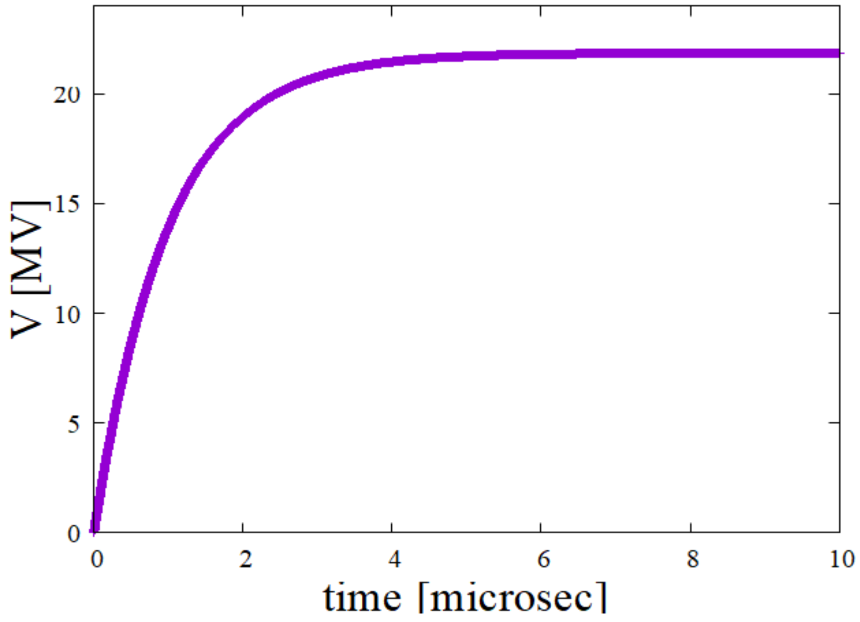


# Coupled pendulum equivalent circuit model

- 11 cell APS cavity is evaluated with the model.
- Temporal response of APS structure is simulated as time-discretized asymptotic formula.



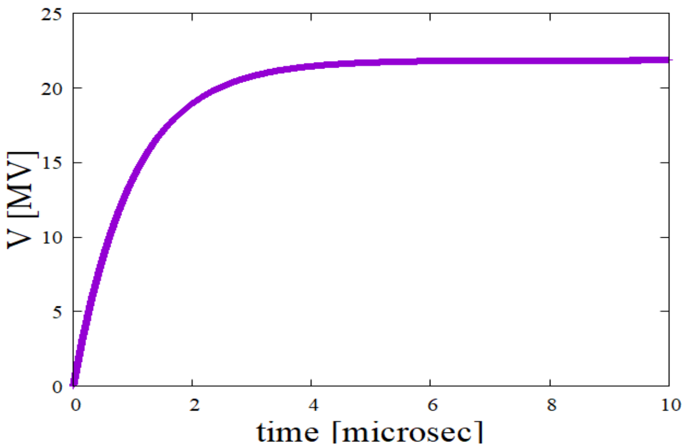
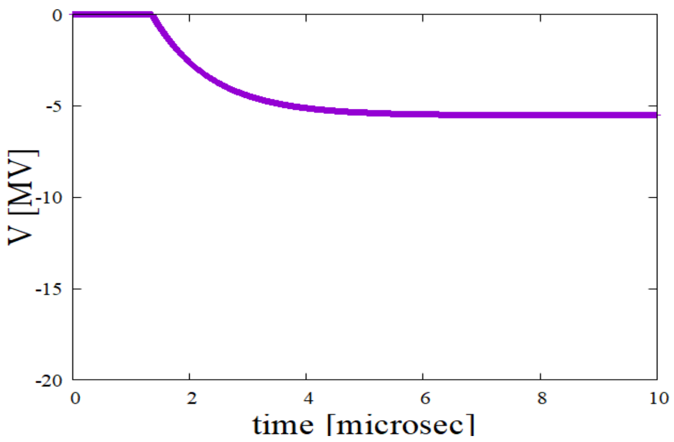
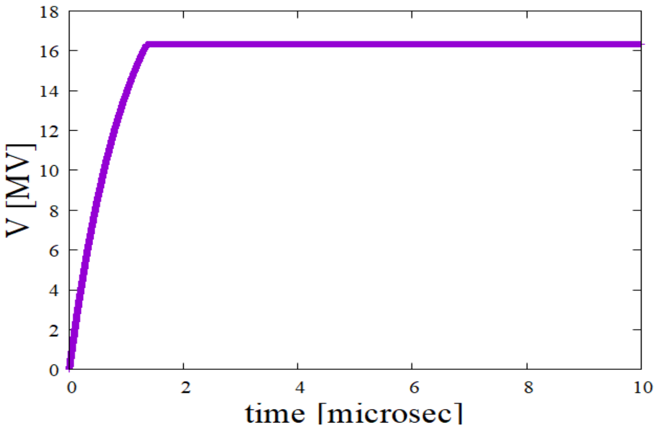
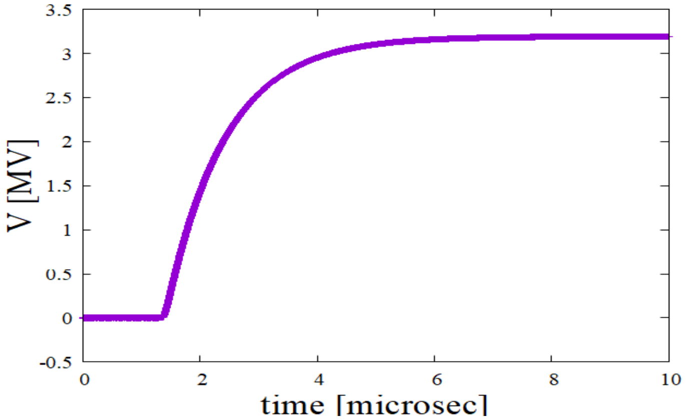
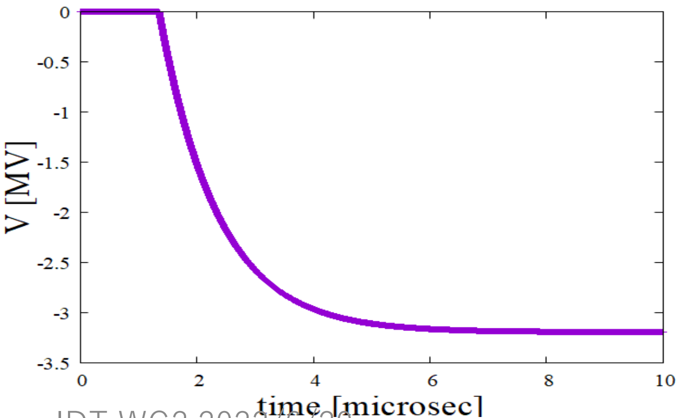
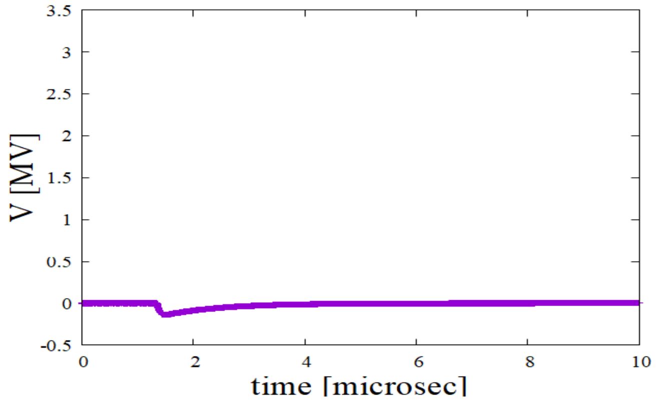



Modulation

$$I = \begin{cases} I_{RF} & (t < t_b) \\ I_{RF} e^{-\frac{t-t_b}{\tau}} + I_{RF} e^{\iota\theta}\left(1 - e^{-\frac{t-t_b}{\tau}}\right) & (t > t_b) \end{cases}$$

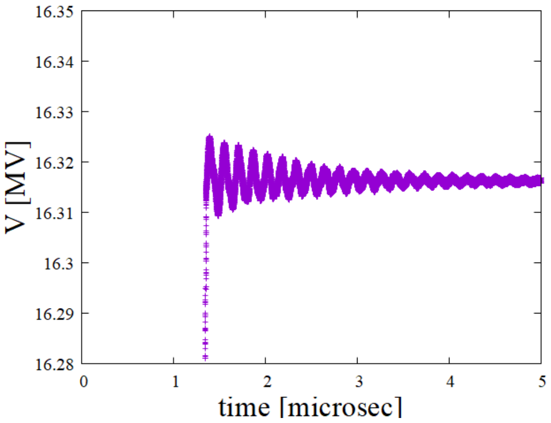
**θ = π/6**
**Q=2000**

Time constant
By klystron cavity

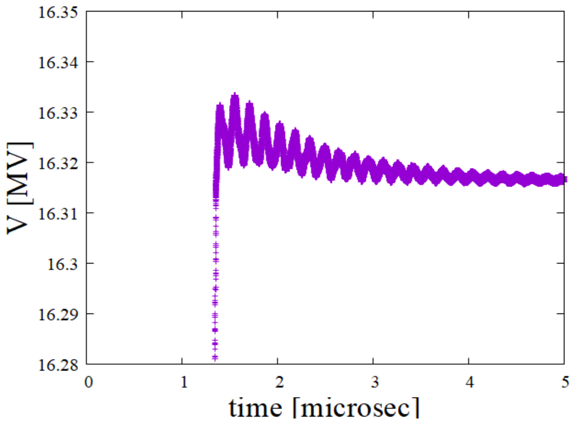
| | RF voltage | Beam voltage | Cavity voltage |
|---|---|---|---|
| Re. |  |  |  |
| Im. |  |  |  |

# Effect of klystron Q value

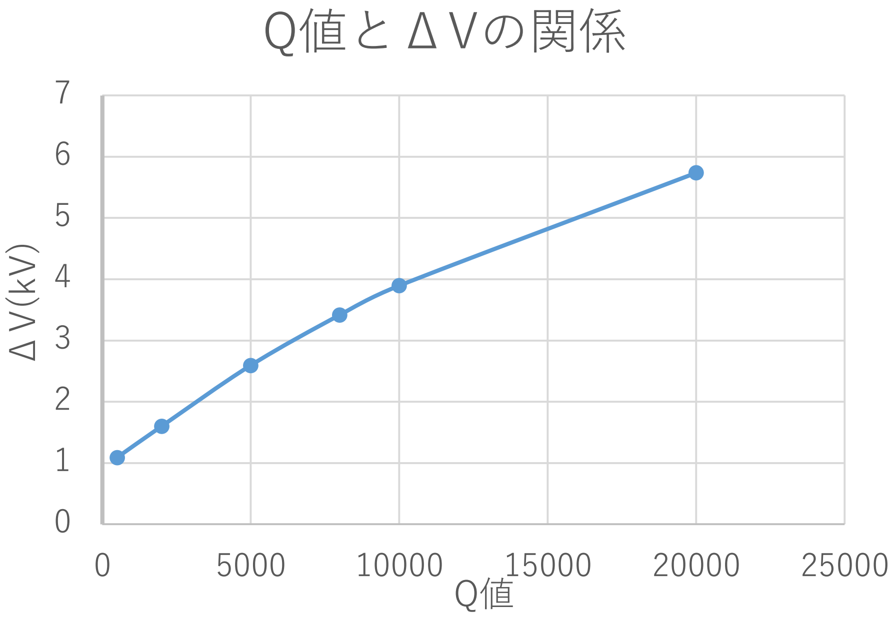
Re(V)




No Q value

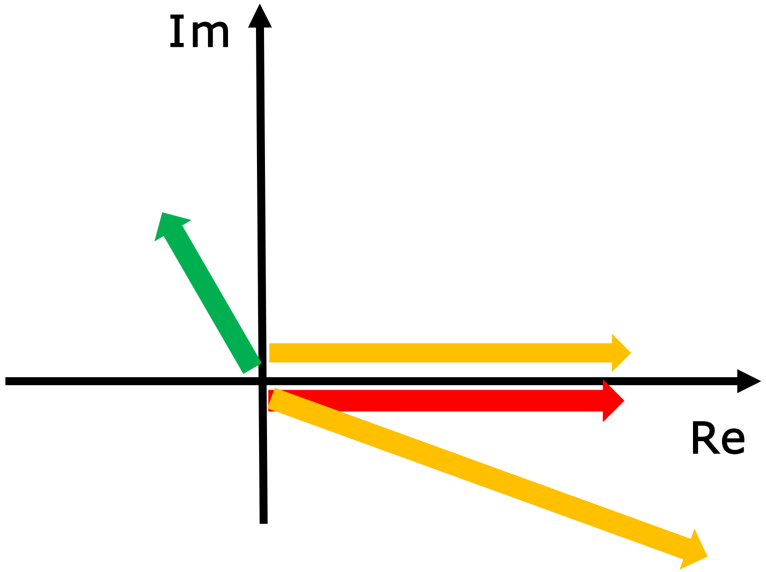


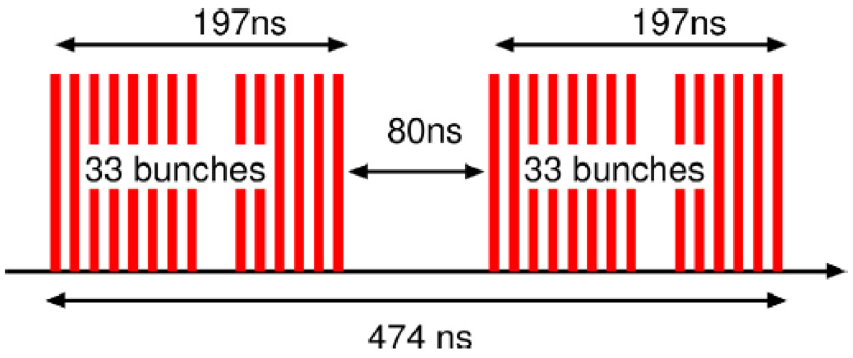

With Q Value

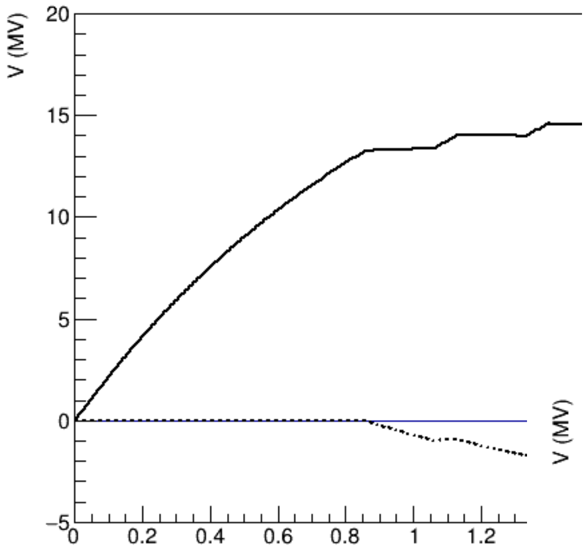


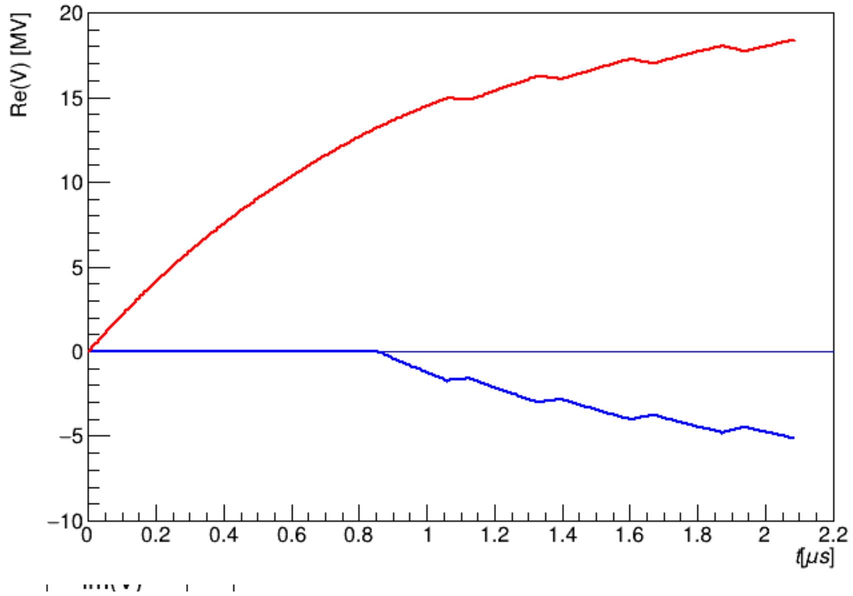

- Im(V)=0.15MV variation corresponds to 0.01 rad.
- Additional voltage variation on Re(V) ~$\Delta V$(p-p).
- $V_0 = 16.3\text{MV}$, Q=2000 gives $\Delta V$(p-p) 1.6kV, 0.01%. Negligibly small.

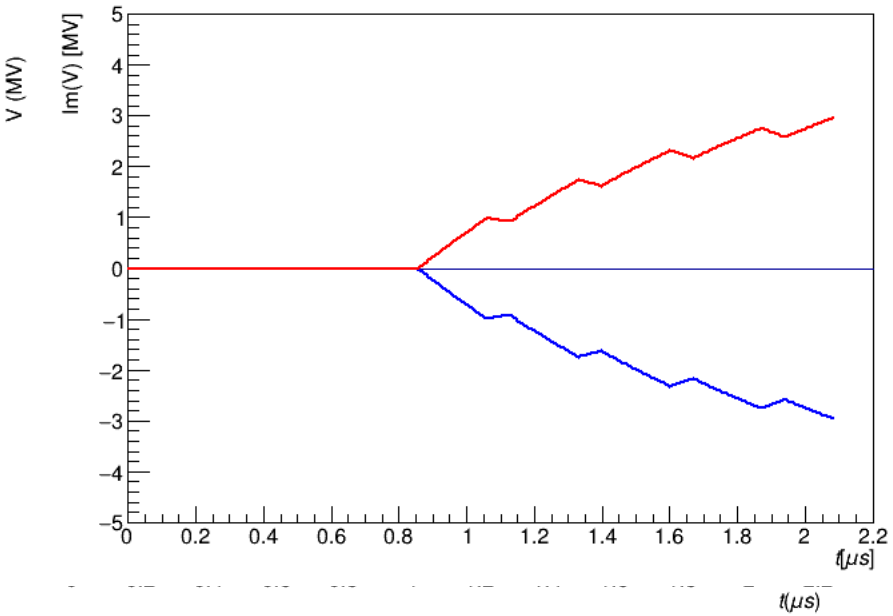
# Pulse Gap response



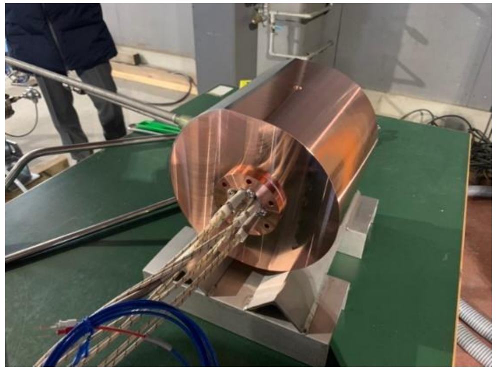



# Thermal Design

- Large heat load by beam is in the target, FC, and first accelerator tube.
- Thermal design: consider appropriate cooling structures and fabrication methods.
- Cooperation between researchers and companies with expertise is very effective.



注：入熱はシャワー＋オーミックロス

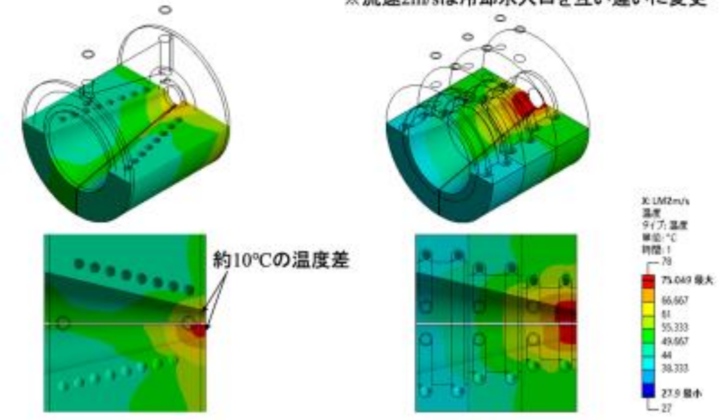
積層造形案

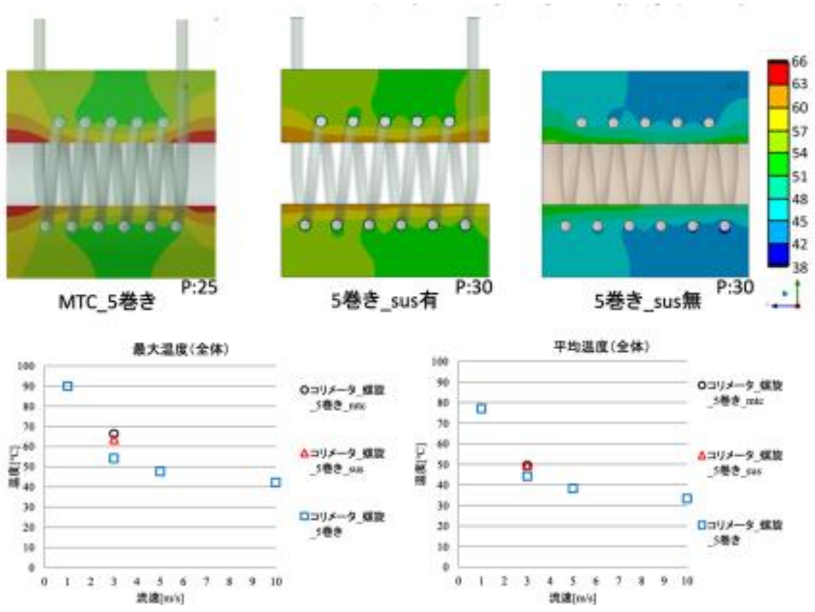
| | 2 | 5 | m/s |
|---|---|---|---|
| 最大温度 | 75 | 60 | ℃ |
| 平均温度 | 49 | 37 | ℃ |

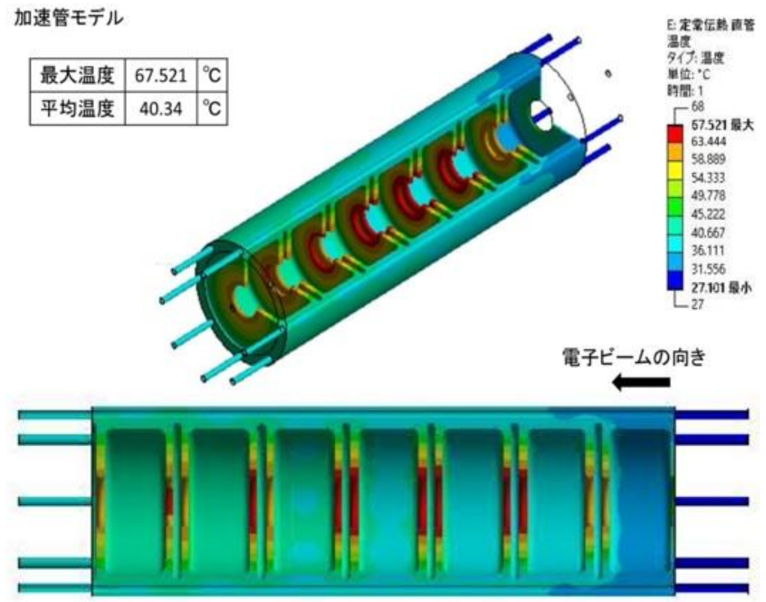
３分割案

| | 2 | 5 | m/s |
|---|---|---|---|
| 最大温度 | 77 | 65 | ℃ |
| 平均温度 | 46 | 38 | ℃ |

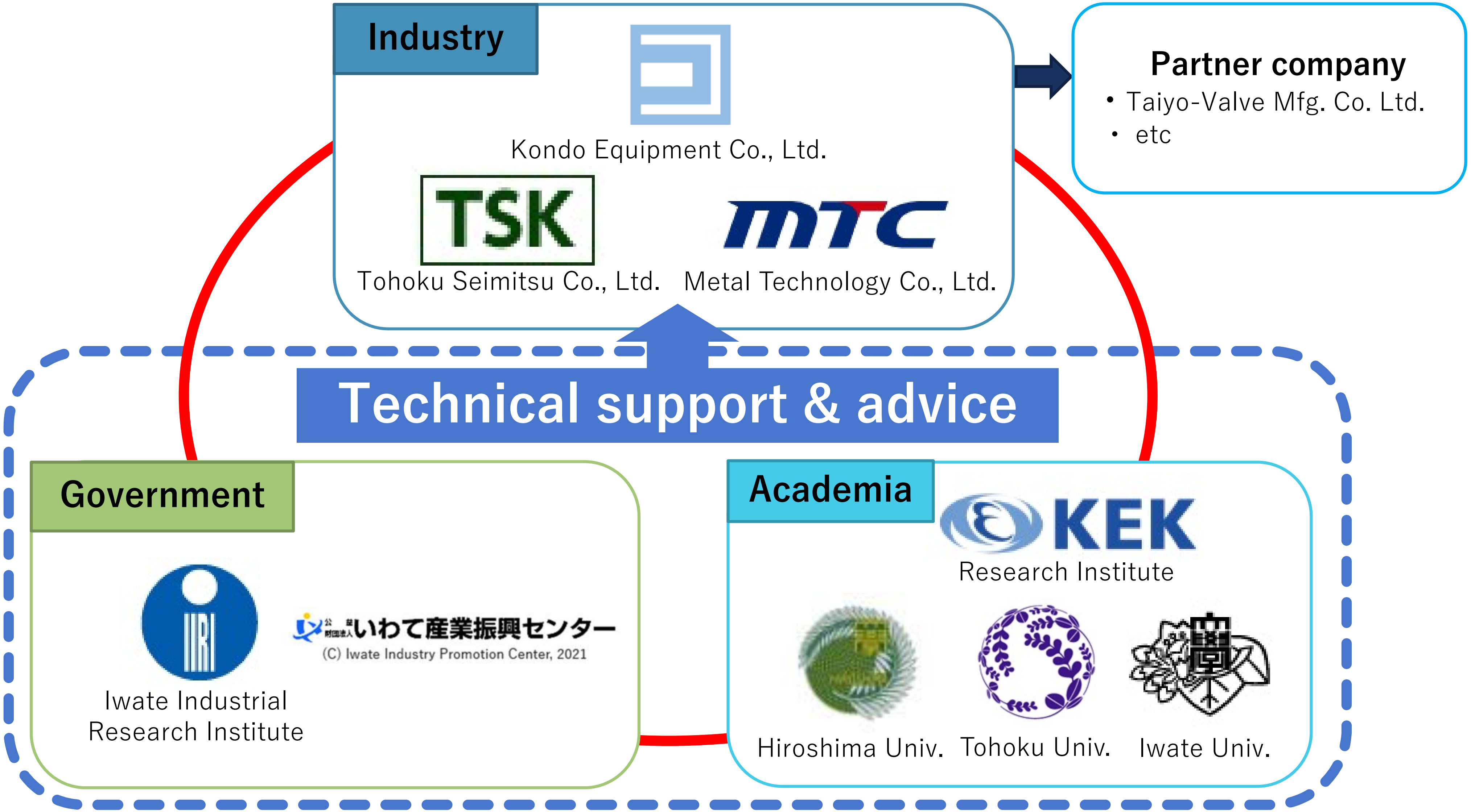
※流速2m/sは冷却水入口を互い違いに変更



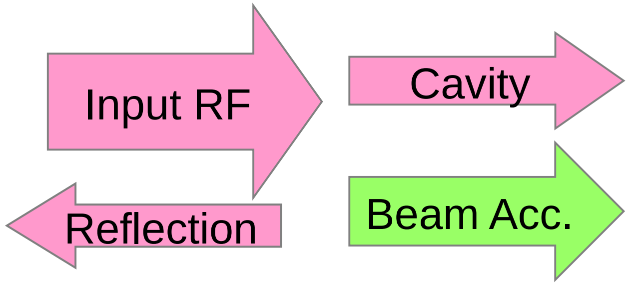



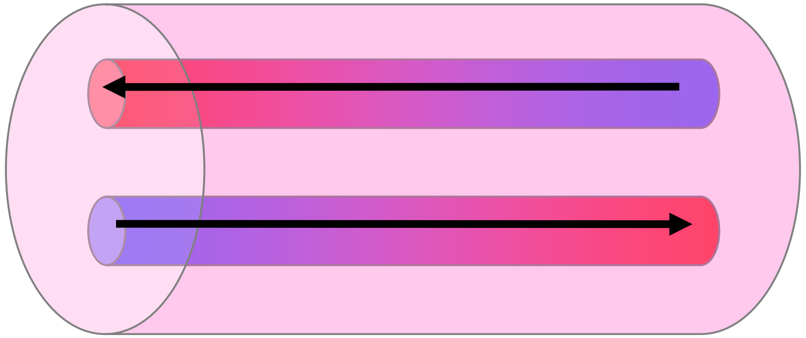
# Industry-Government-Academia Collaboration for ILC Positron source Study



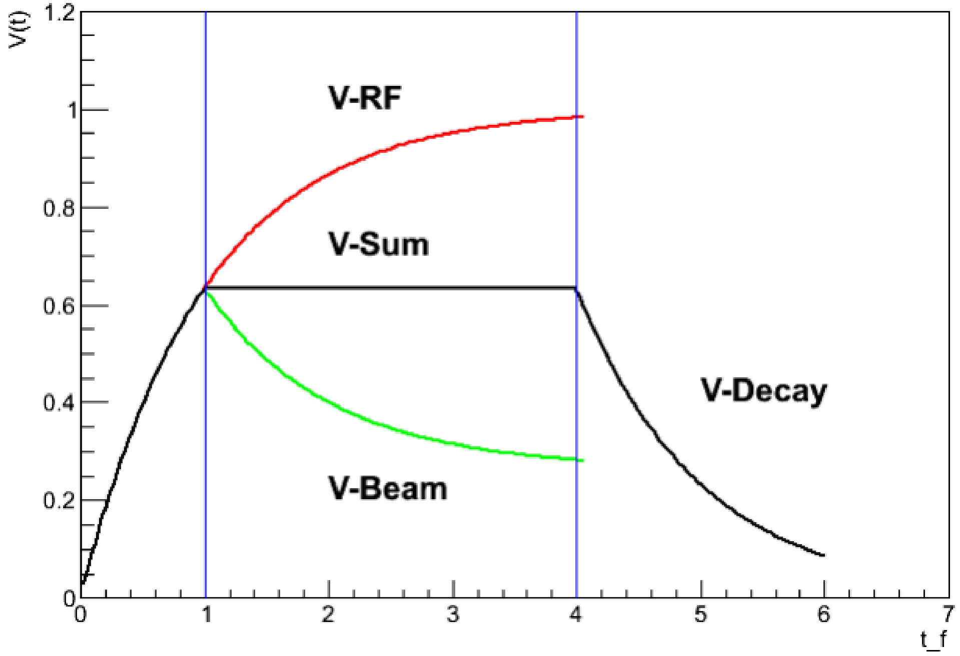
# Temperature control

- Temperature of structure should be controlled with $\Delta T$~0.05 K to keep the RF frequency.
- By one way flow, we need a ton of water for cooling because $T_{out}$-$T_{in}$ is similar to $\Delta T$.
- By two counter flows, $T_{out}$-$T_{in}$=10K is acceptable.



# Thermal load to cavity




$$
\begin{aligned}
E_{wall} &= \int_0^{\infty} P(t)dt = \frac{4\beta}{(1+\beta)^2} P_0 \left[ \frac{t_0}{3} \left[ 1 - \exp\left( -\frac{t}{t_0} \right) \right]^3 \right]_0^{t_b} \\
&+ \frac{4\beta}{(1+\beta)^2} P_0 \left[ 1 - \exp\left( -\frac{t_b}{t_0} \right) \right]^2 (t_1 - t_b) \\
&+ \frac{4\beta}{(1+\beta)^2} P_0 \left[ 1 - \exp\left( -\frac{t_b}{t_0} \right) \right]^2 \left[ -\frac{t_0}{2} \exp\left( -\frac{2(t-t_1)}{t_0} \right) \right]_{t_1}^{\infty} \\
&= \frac{4\beta}{(1+\beta)^2} P_0 \left[ 1 - exp\left( -\frac{t_b}{t_0} \right) \right]^2 \left[ \frac{t_0}{3} \left[ 1 - exp\left( -\frac{t_b}{t_0} \right) \right] + (t_1 - t_b) + \frac{t_0}{2} \right].
\end{aligned}
$$

- L-band SW(APS) (per tube)

| Beam current (A) | $P_{acc}(kW)$ | $V_{acc}$ (l/min) | $P_{load}(kW)$ | $V_{load}$ (l/min) |
|---|---|---|---|---|
| 0.1 | 3.32 | 4.75 | 5.49 | 7.13 |
| 0.5 | 1.79 | 2.55 | 3.46 | 4.49 |
| 1.0 | 1.08 | 1.54 | 2.45 | 3.18 |
| 1.5 | 0.656 | 0.937 | 1.78 | 2.31 |
| 2.0 | 0.376 | 0.537 | 1.27 | 1.65 |

- L-band TW (per tube)

| Beam current (A) | $P_{acc}(kW)$ | $V_{acc}$ (l/min) | $P_{load}$ | $V_{load}$ (l/min) |
|---|---|---|---|---|
| 0.00 | 2.16 | 3.08 | 3.15 | 4.09 |
| 0.50 | 1.66 | 2.38 | 2.42 | 3.14 |
| 0.80 | 1.40 | 2.00 | 2.04 | 2.65 |
| 1.00 | 1.23 | 1.76 | 1.80 | 2.34 |
| 1.50 | 0.867 | 1.24 | 1.27 | 1.65 |

- 2m S-band TW (per tube)

| Beam current (A) | $P_{acc}(kW)$ | $V_{acc}$ (l/min) | $P_{load}$ | $V_{load}$ (l/min) |
|---|---|---|---|---|
| 0.00 | 2.53 | 3.61 | 2.67 | 3.47 |
| 0.50 | 1.90 | 2.71 | 2.01 | 2.61 |
| 0.80 | 1.57 | 2.24 | 1.66 | 2.16 |
| 1.00 | 1.36 | 1.95 | 1.44 | 1.87 |
| 1.50 | 0.91 | 1.31 | 0.97 | 1.26 |

- 3m S-band TW (per tube)

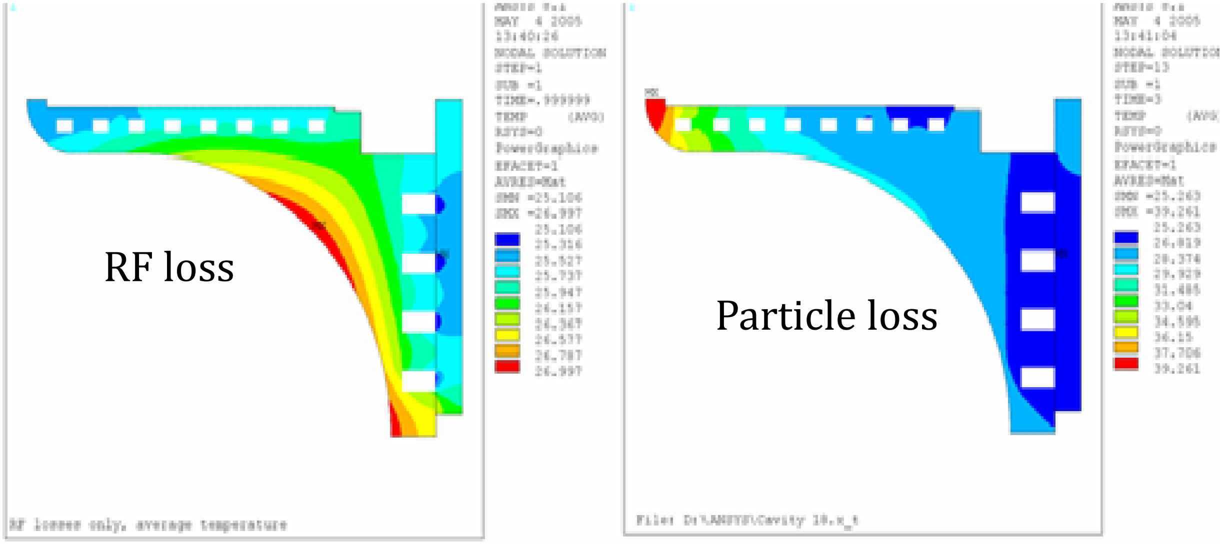
| Beam current (A) | $P_{acc}(kW)$ | $V_{acc}$ (l/min) | $P_{load}$ | $V_{load}$ (l/min) |
|---|---|---|---|---|
| 0.00 | 3.72 | 5.32 | 1.75 | 2.27 |
| 0.50 | 2.04 | 2.92 | 0.96 | 1.25 |
| 0.60 | 1.77 | 2.52 | 0.83 | 1.08 |
| 1.00 | 0.86 | 1.23 | 0.41 | 0.53 |
| 1.50 | 0.18 | 0.26 | 0.09 | 0.117 |

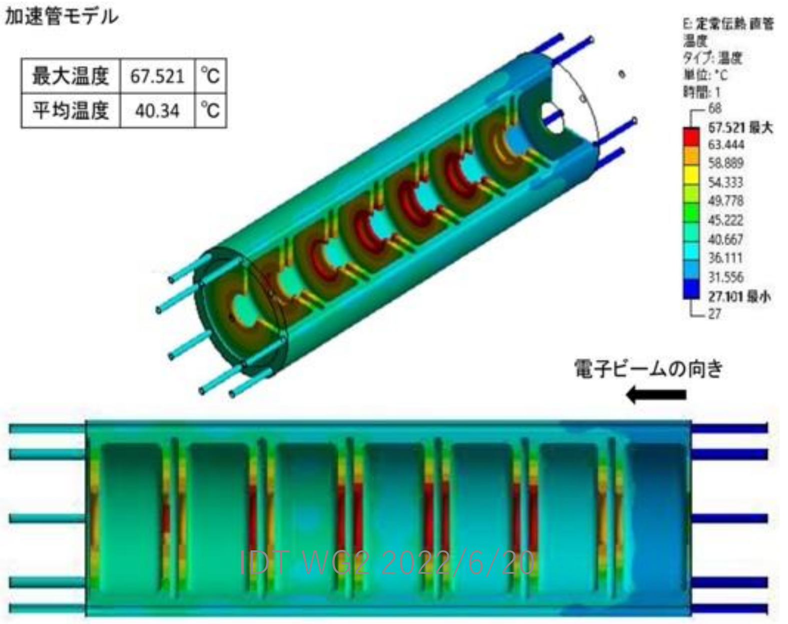
# Cooling Water Summary

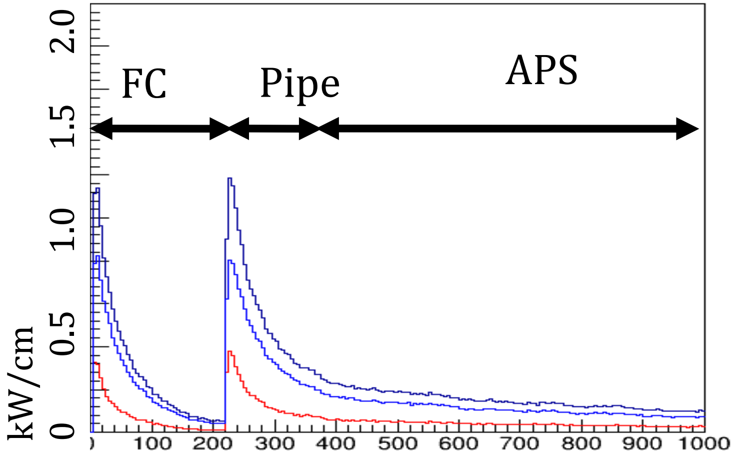
| Item | Cooling water (l/min) | Cooling water max (l/min) |
|---|---|---|
| L-band SW Acc. | 43 | 133 |
| L-band SW load | 89 | 200 |
| L-band TW Acc. | 242 | 373 |
| L-band TW load | 321 | 495 |
| S-band 2 m TW Acc. | 170 | 274 |
| S-band 2 m TW load | 164 | 264 |
| S-band 3 m TW Acc. | 307 | 650 |
| S-band 3 m TW load | 132 | 277 |
| Total | 1470 | 2670 |

# Thermal load by Radiation

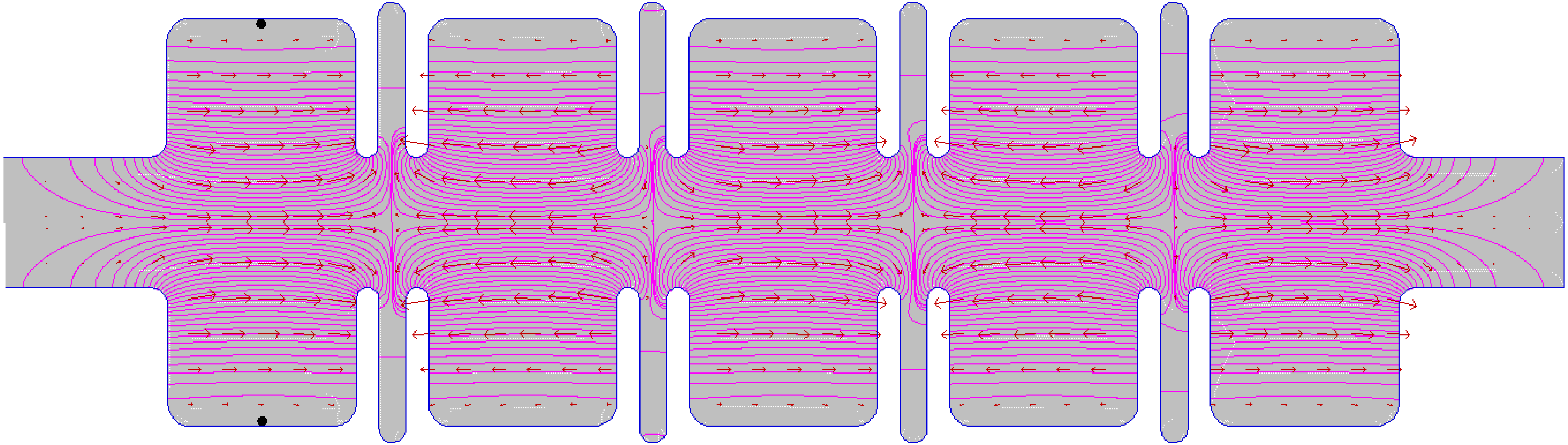
- In addition to Jule loss by input RF, heat load by particle loss is significant, especially in the upstream of the capture linac.
- It is 0.14 kW/cm at maximum.
- The heat load is concentrated on the iris, in contrast to the barrel part by RF (1kW per tube).



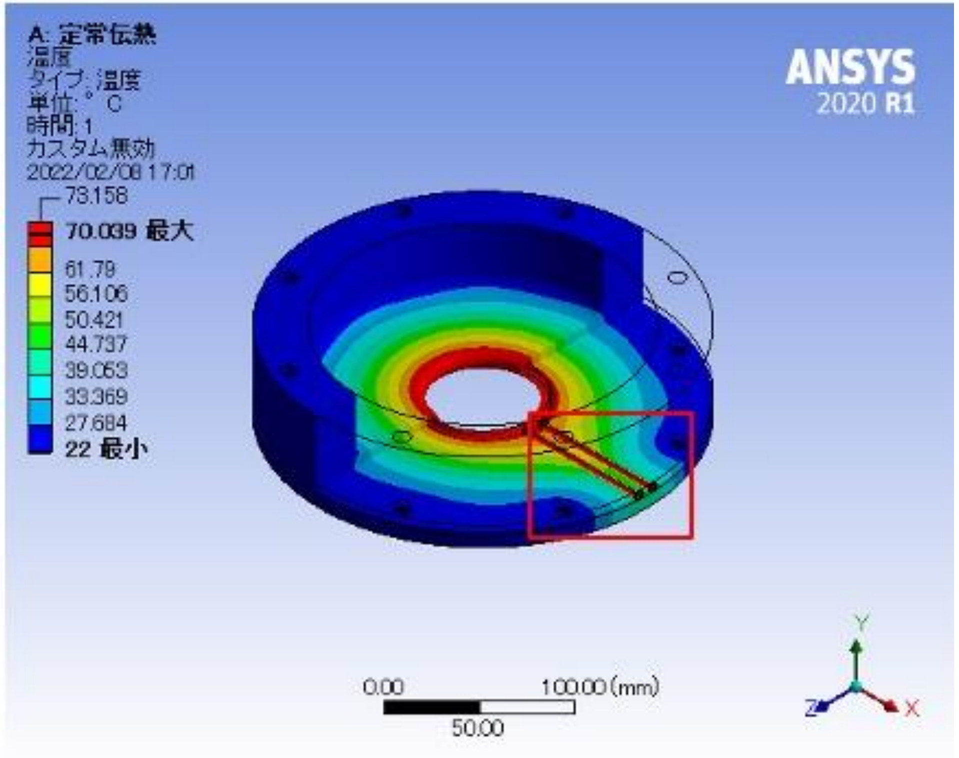
# APS test cavity

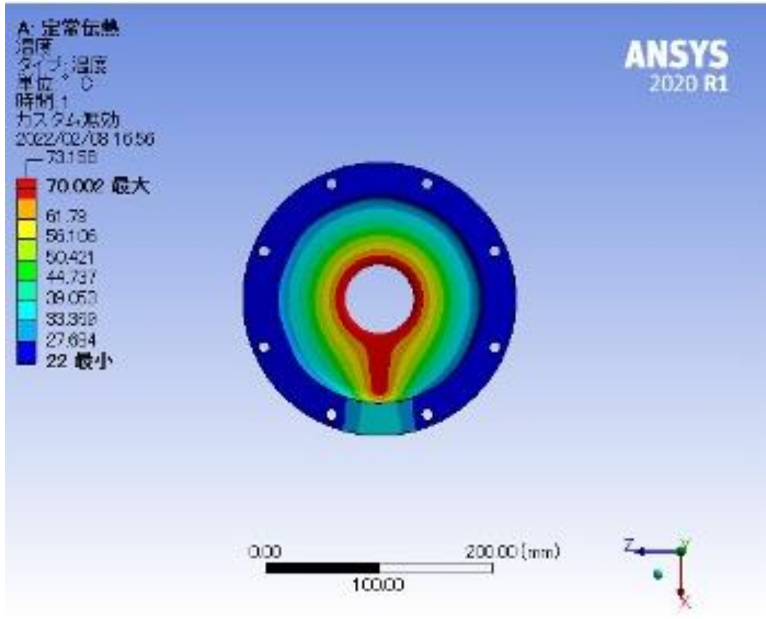


- To simulate RF detuning by radiation loss, we fabricate a test cavity module.
- 5 cells structure. RF frequency is monitored by antenna.
- Colling is provided by 4 counter flow cooling channels.
- RF thermal heat load is simulated by circulating hot water in a channel at the iris.

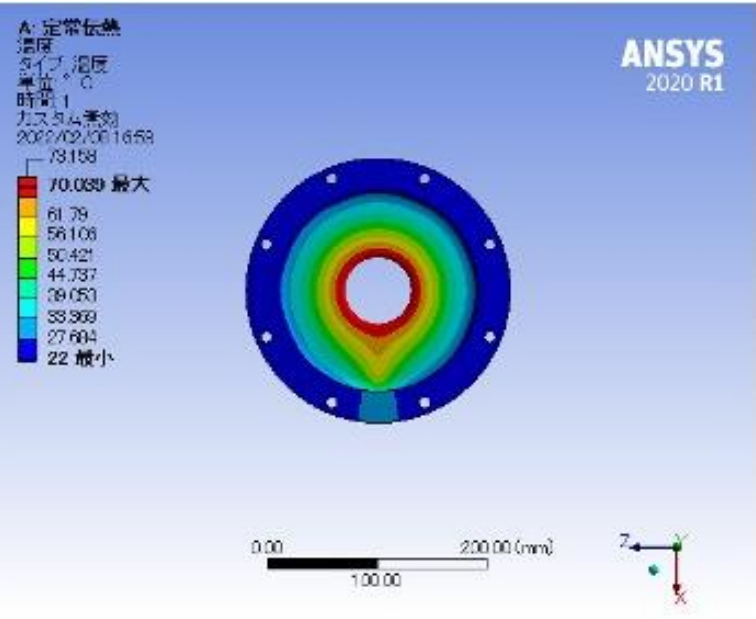
# Simulation of Radiation heat load

- Hot water is run through the iris section to simulate the heat load.
- To suppress heat conduction to the body, the pipe to the iris is made of SUS and the copper at the iris.




No SUS pipe



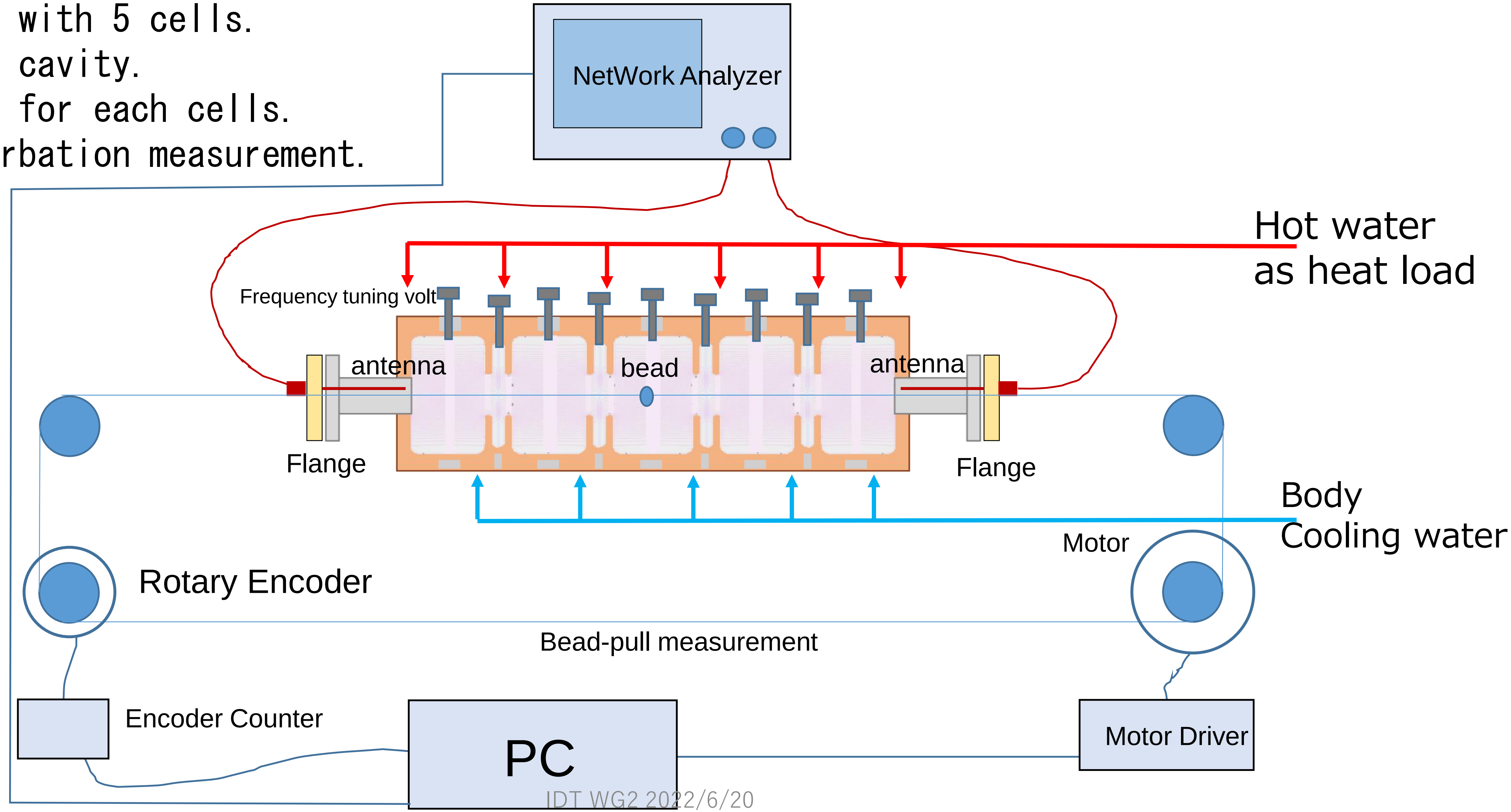

with SUS pipe

Metal Tech Company

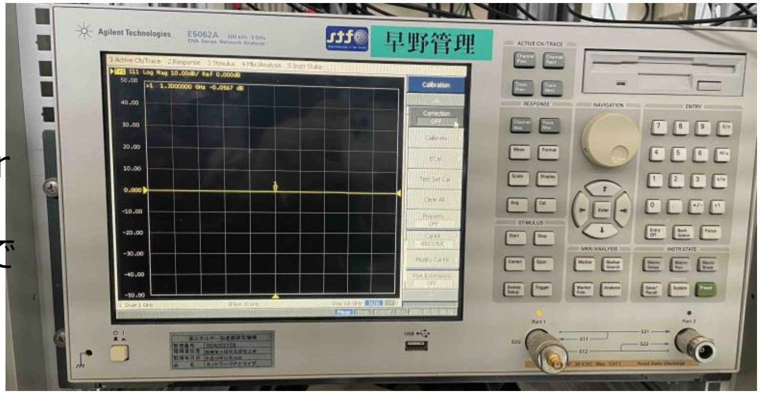
# RF measurement setup

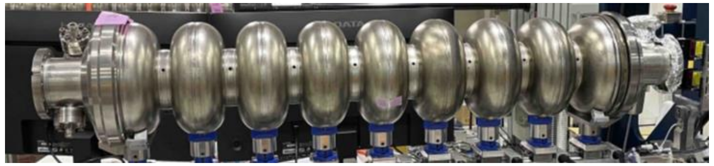
05202022 Hayano

Cold model with 5 cells.
Non vacuum cavity.
Tuning rod for each cells.
Bead perturbation measurement.

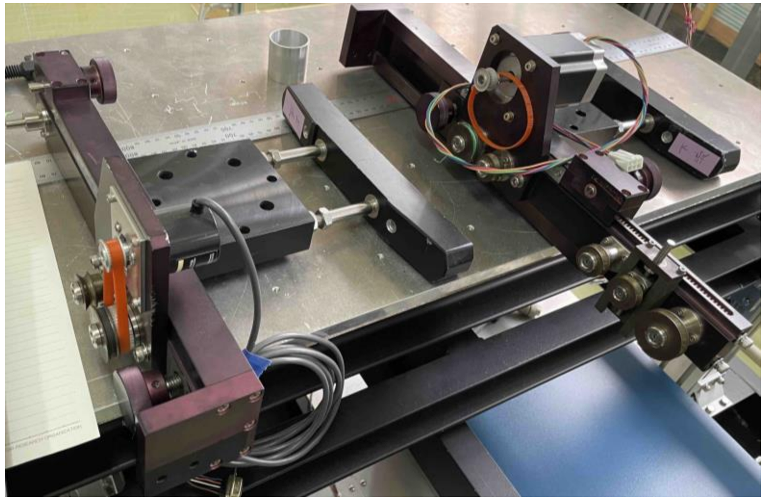


Network Analyzer
E5062A
300KHz-3GHzまで

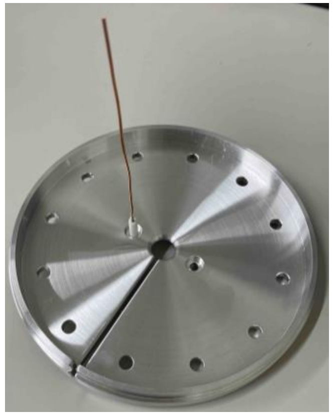


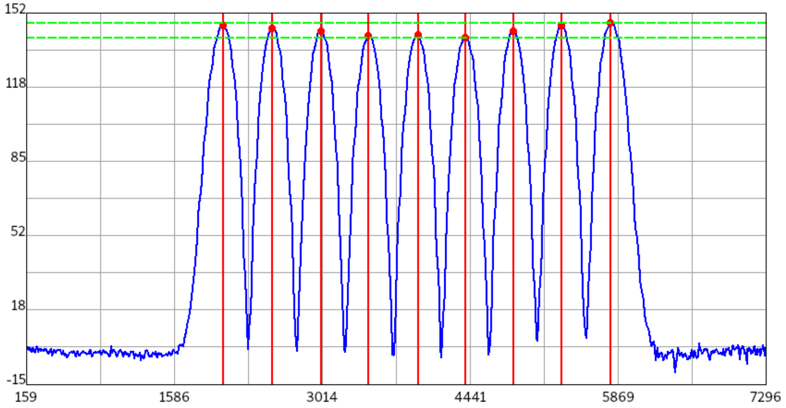
Rotary Encoder



Motor

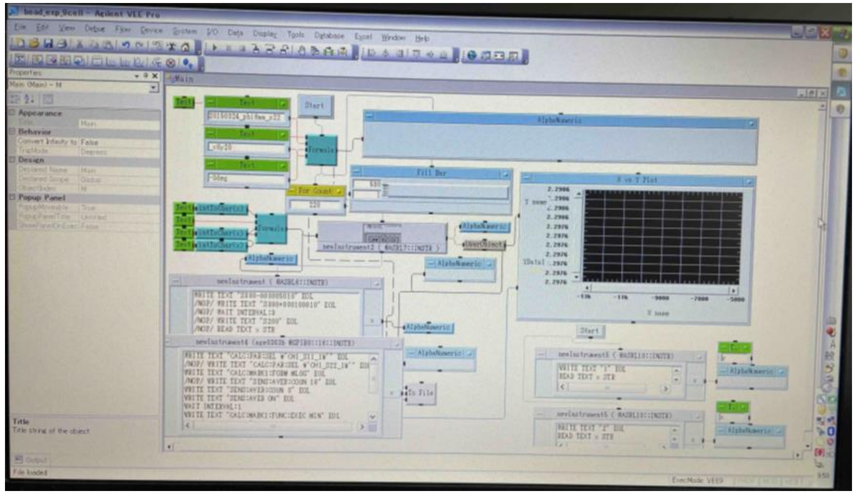


Flange with hole




Encoder Counter

(Motor Driver)



PC
+
VEE software

Motor controller

# Summary

- Study of the capture linac of E-Driven positron source shows a great progress.
- A solution of the beam loading compensation off-crest acceleration was derived as PM and AM in the input RF.
- The performance is confirmed with the equivalent circuit model based on Coupled pendulum including klystron Q-value effect.
- Thermal design of the injector part is started.
- Effect of beam heating on APS cavity is studied with the test cavity.