APS cavity design for ILC E-driven positron capture linac

KEK M. Fukuda

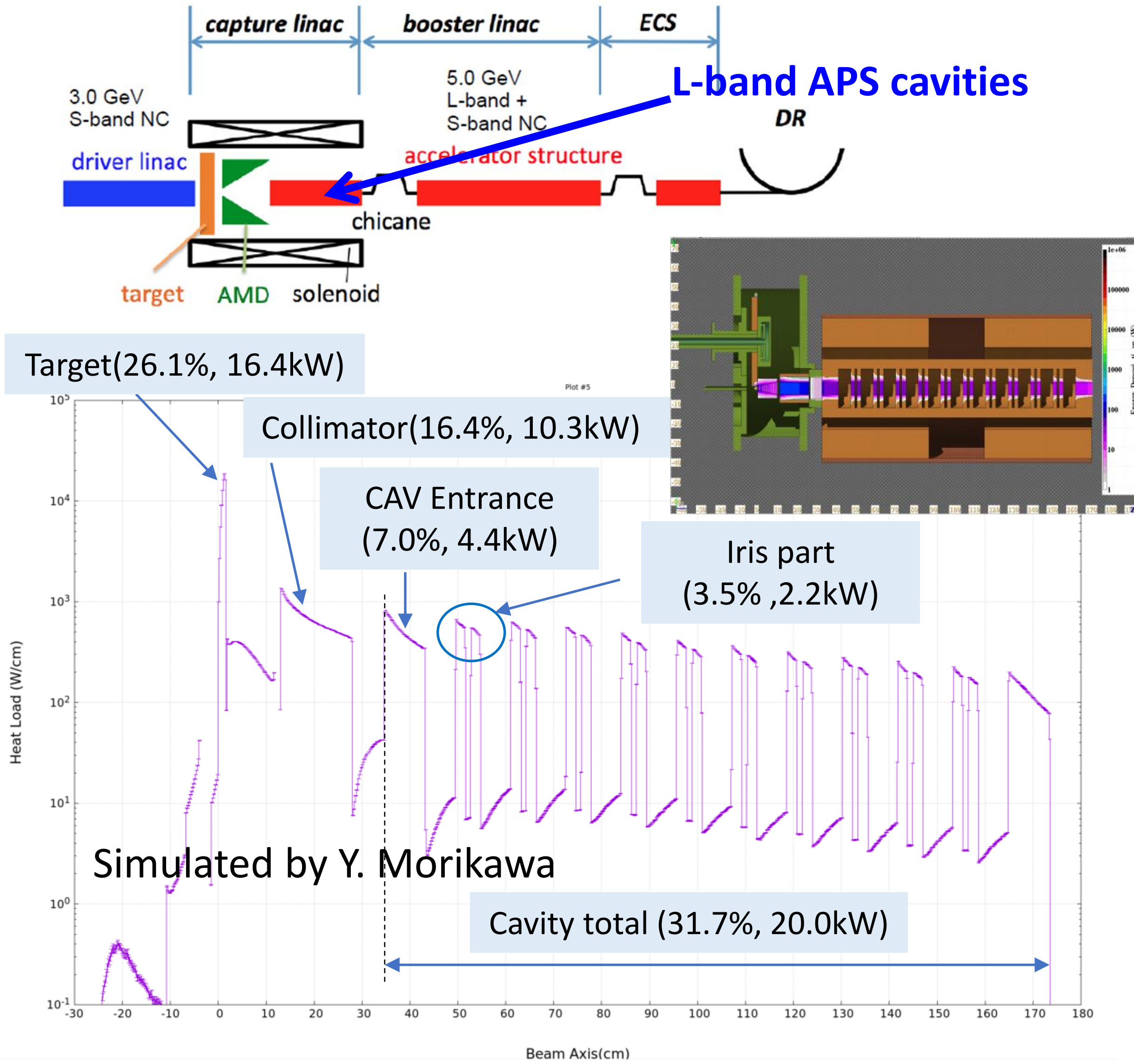
Design of a 21cell APS cavity for capture linac

Challenges

- **Beam loading compensation**
  - High beam current : > 0.6A in macro pulse.
- **Powerful cooling system is required.**
  - Very high heat load due to EM shower from the target
- **Remote beam flange connection**
  - High activation and the connection point is surrounded by solenoid coils

Design Policy

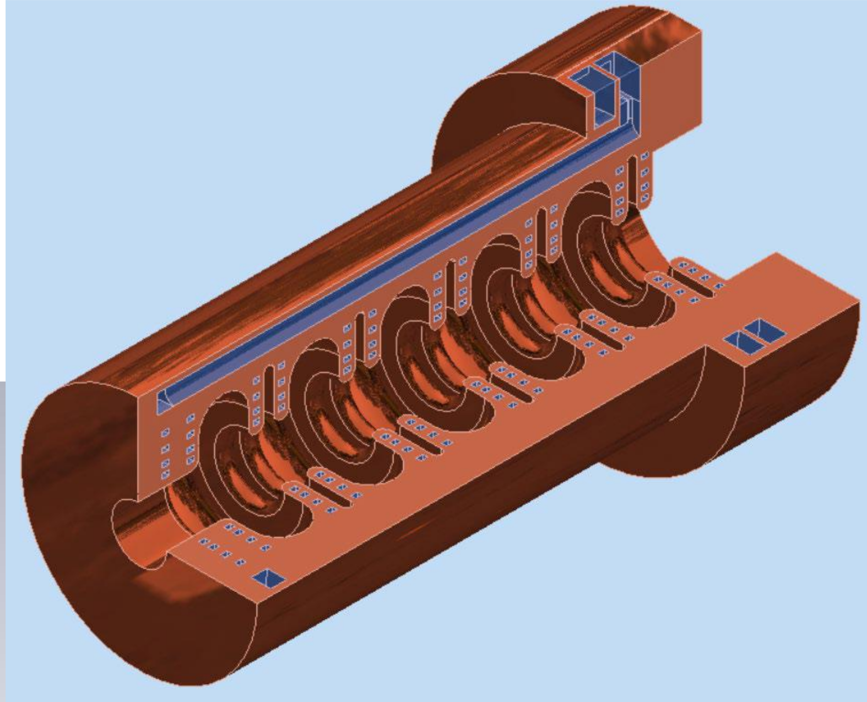
- **High group velocity(π/2 mode)**
  - It helps the compensation of beamloading and relax the effects of thermal deformation
- **Water channel in the disk is required.**
  - The shower from targets hits irises and heats the iris.
- **Large coupling β**
  - It is assumed the coupling is about 5 in the estimation of beamloading compensation by Kiriki-san.

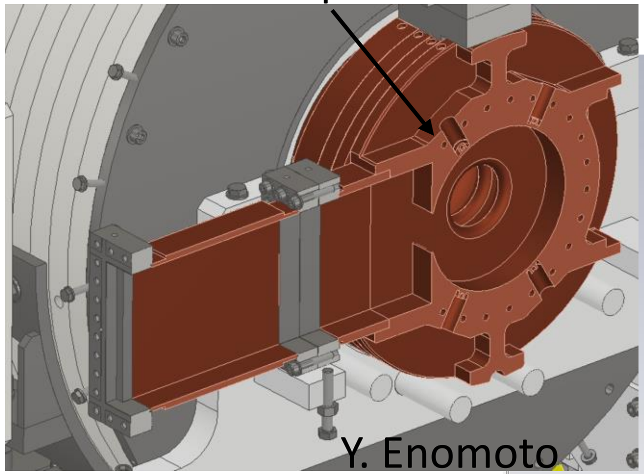


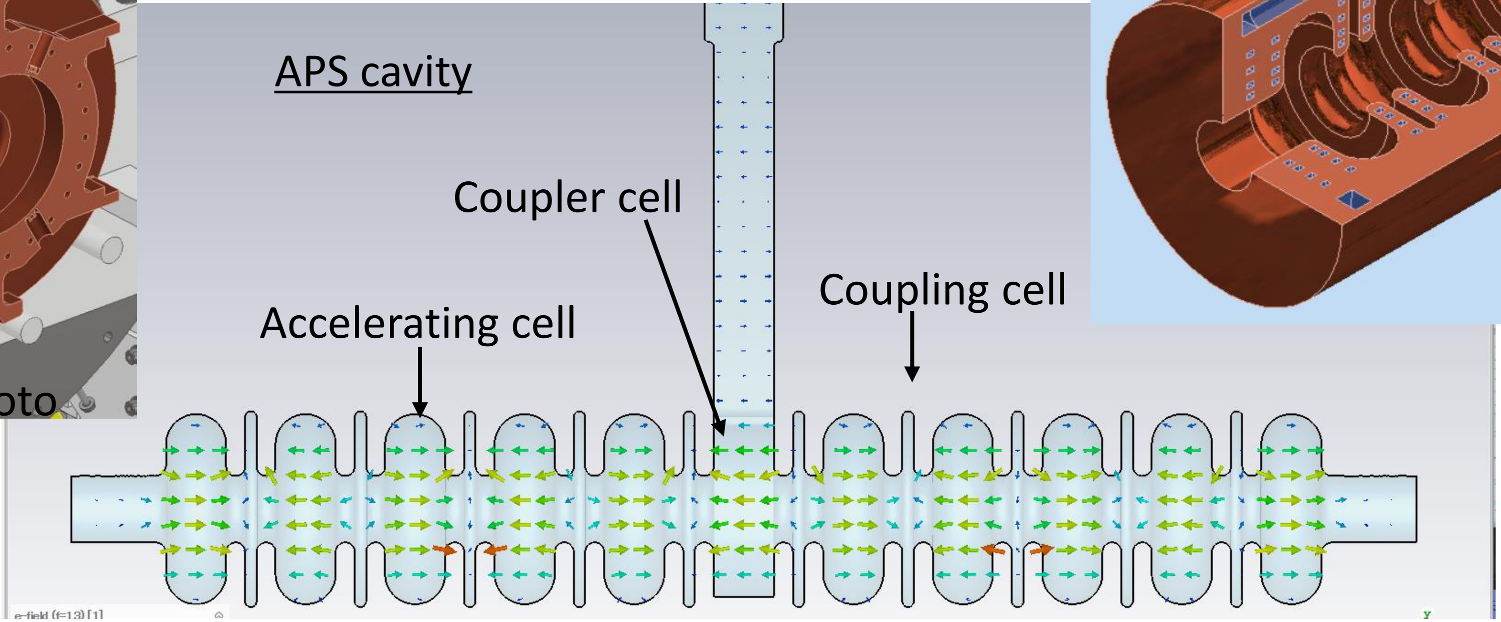
Design of a 21cell APS cavity for capture linac

- Design of accelerating and coupling cells
  - Thick disks to obtain the space of water load.
  - High group velocity (0.027c)
- Design of coupler cell
  - Coupling β : 5

Cooling water path designed by Y. Enomoto

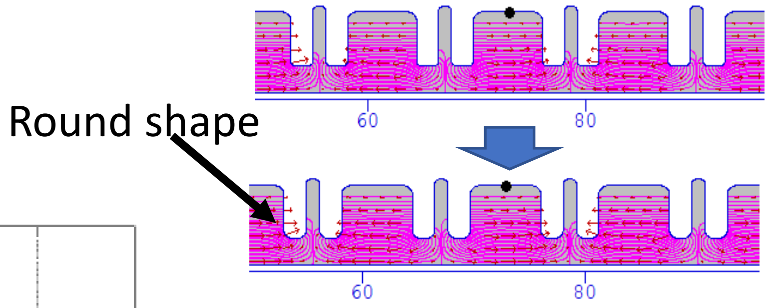






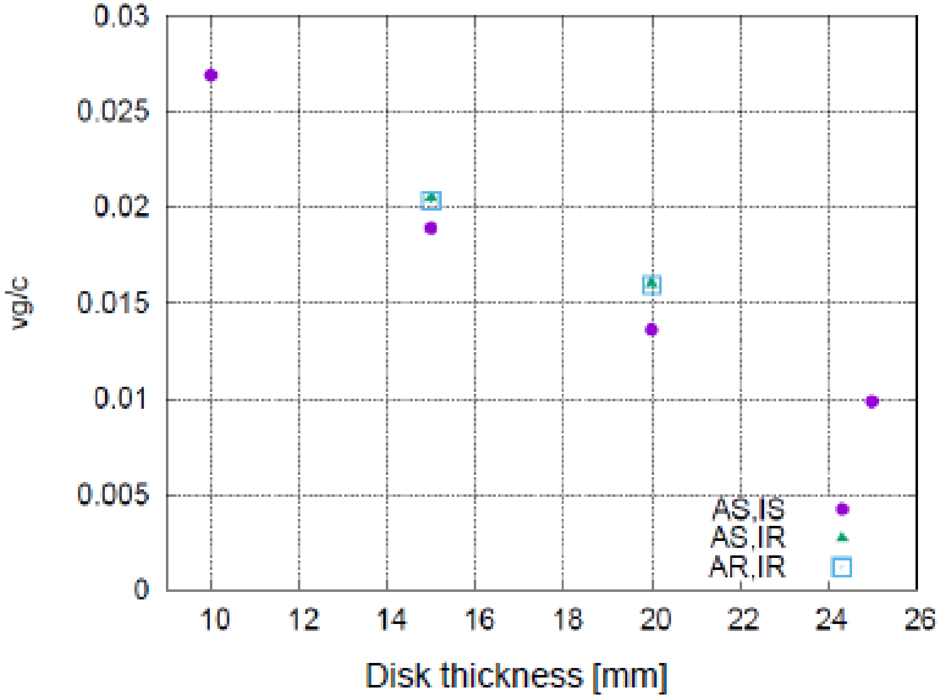
Design of accelerating and coupling cells

Both group velocity and shunt impedance decrease when increasing disk thickness.
To increase these parameters, the shape of iris and cavity is modified.

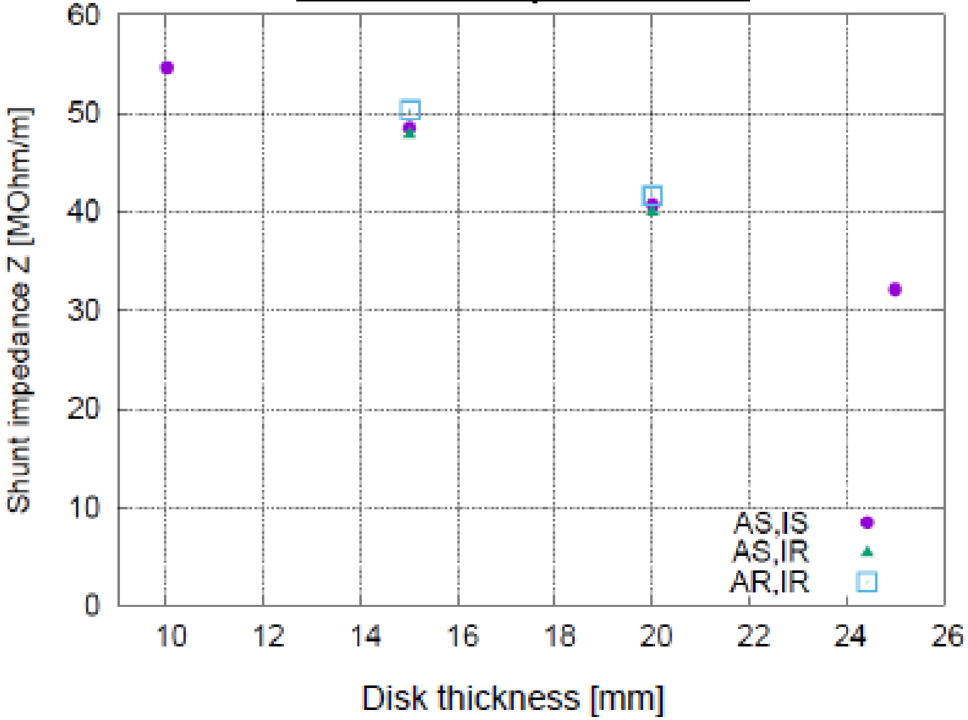


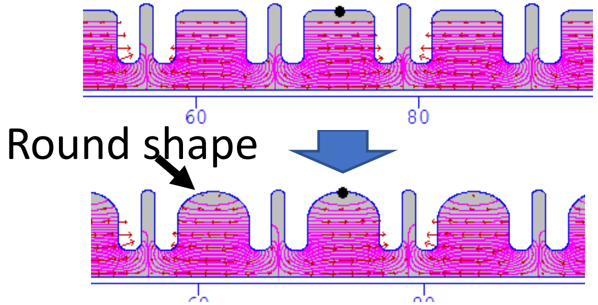
Group velocity slightly increases

Group velocity



Shunt impedance





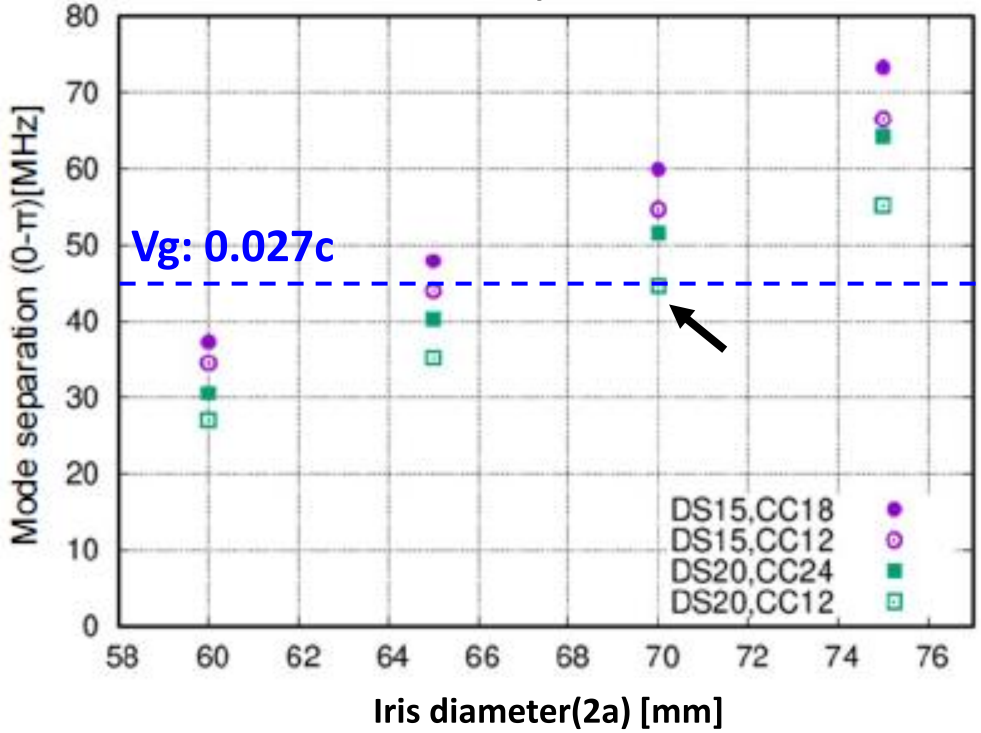
Shut impedance slightly increases

Design of accelerating and coupling cells

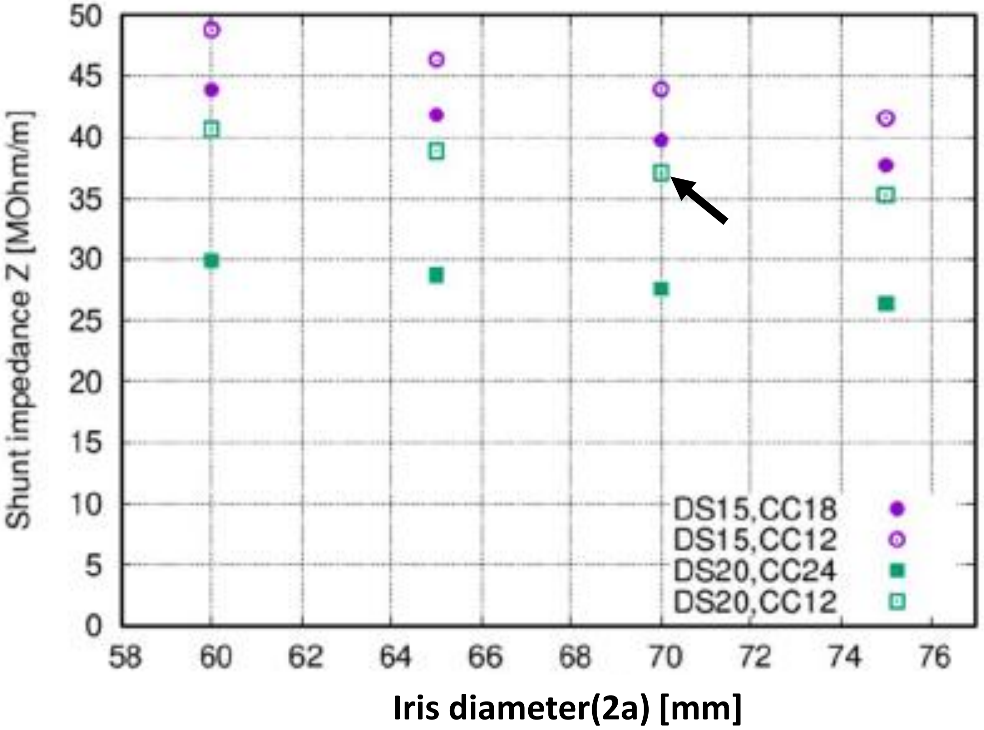
When the iris diameter is widened, mode separation increases significantly, i.e., group velocity increases. However, shunt impedance decreases.

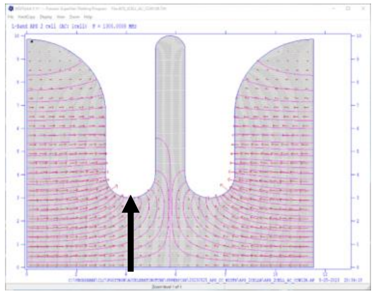
We decided to use a disk thickness of 20 mm and an iris diameter of 70 mm.
Here, the group velocity is 0.0263c and the shunt impedance decrease is relatively small.

Mode separation



Shunt impedance





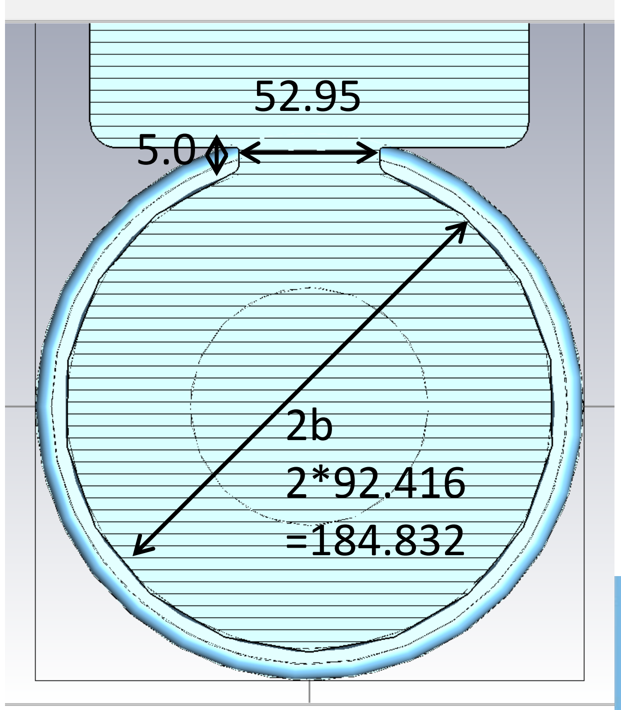
Iris diameter increased

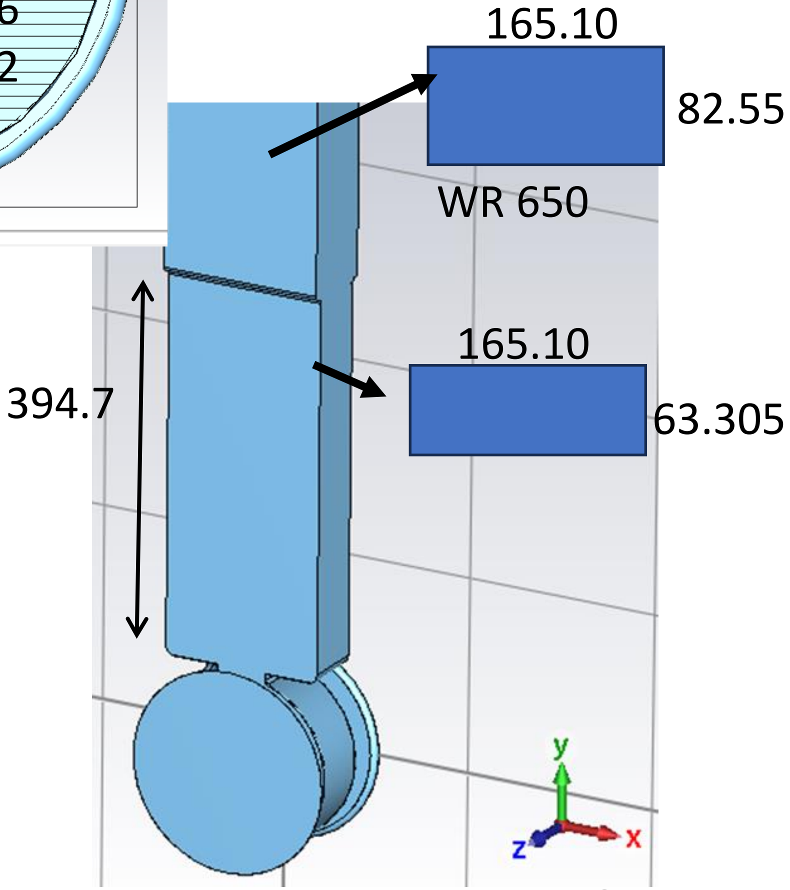
Design of Coupler cell

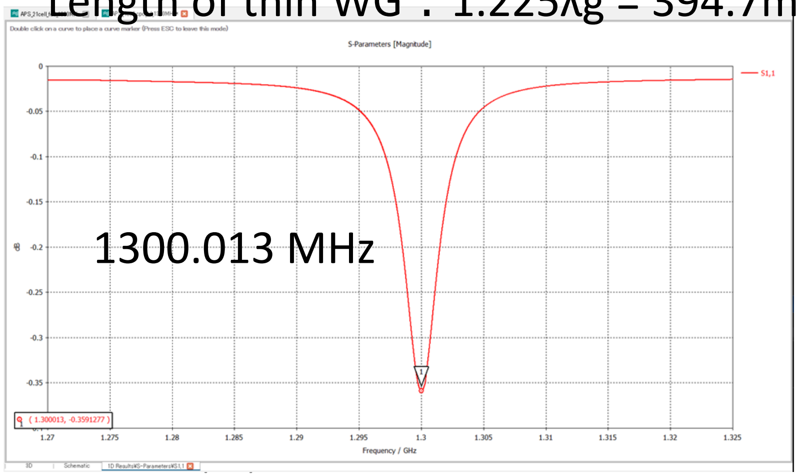
First, the design was performed in a single-cell coupler cell and this property was evaluated.

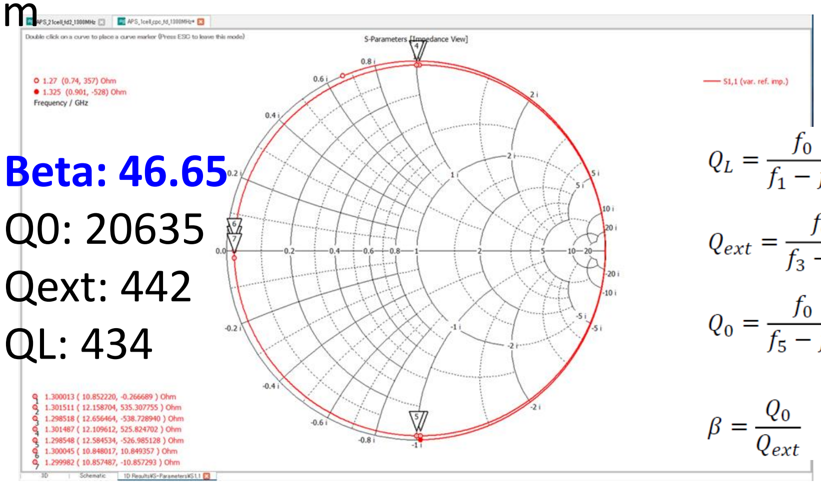
Designed parameters:
Resonant frequency：1300.013 MHz
Coupling β: 46.7

Diameter of coupler cell: 2b: 184.832 mm
Hole size(X,Z)：52.95mm, 63.305mm
Hole depth(Y)：5mm
Length of thin WG：1.225λg = 394.7mm









Beta: 46.65
Q0: 20635
Qext: 442
QL: 434

$$Q_L = \frac{f_0}{f_1 - f_2}$$

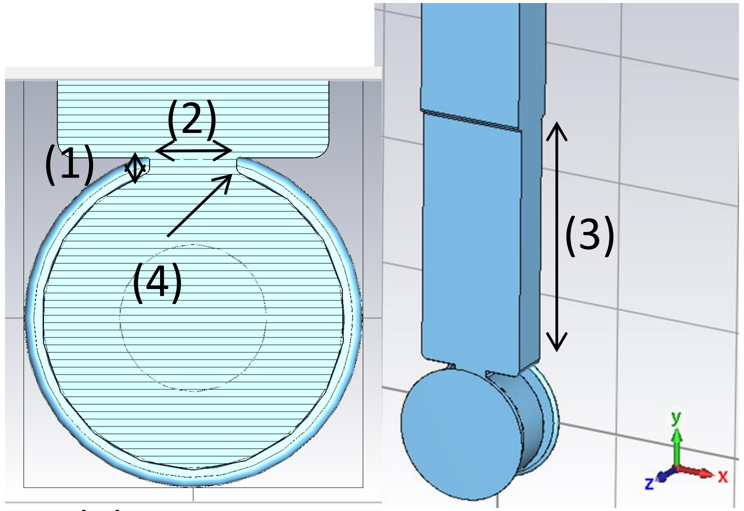
$$Q_{ext} = \frac{f_0}{f_3 - f_4}$$

$$Q_0 = \frac{f_0}{f_5 - f_6}$$

$$\beta = \frac{Q_0}{Q_{ext}}$$

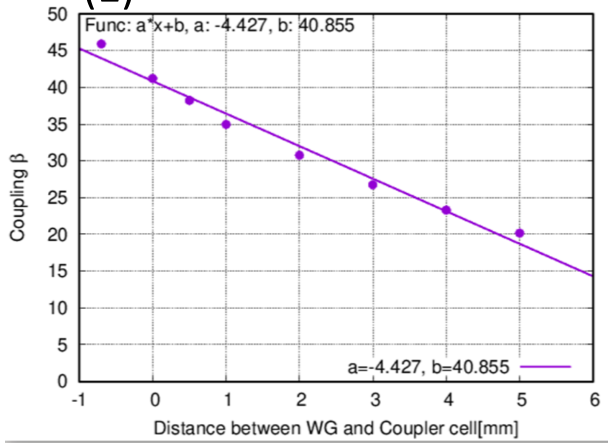
Parameter scan of coupler cell

We investigated how the coupling depends on the parameters.

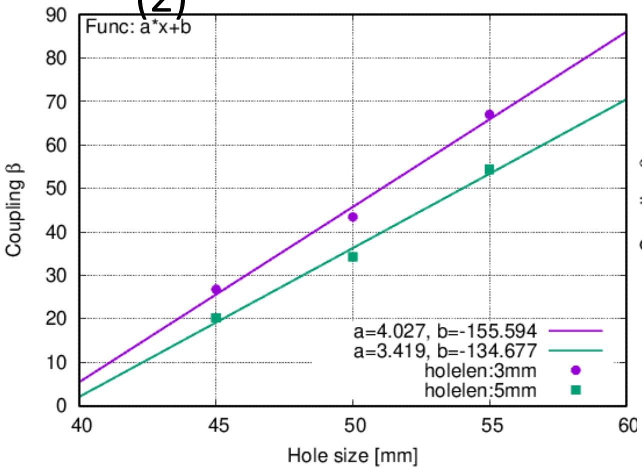


	Resonant frequency	Coupling
Hole depth (Y)	0.237 [MHz/mm]	-4.427 [1/mm]
Hole size(X) (Hole depth: 5mm)	-0.592 [MHz/mm]	3.419 [1/mm]
Length of thin WG	+/- 0.778 [MHz/0.25λg]	+/- 21.386 [MHz/0.25λg]
Round chamfering of hole	-0.171 [MHz/mm]	0.537 [1/mm]
Round chamfering of WG end	0.0 [MHz/mm]	0.0 [1/mm]

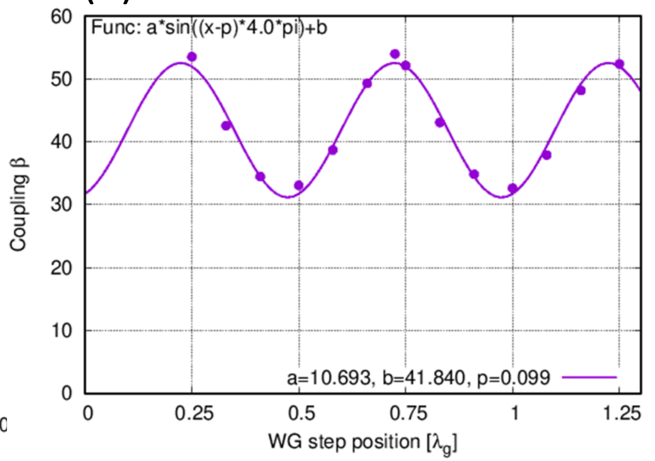
(1)



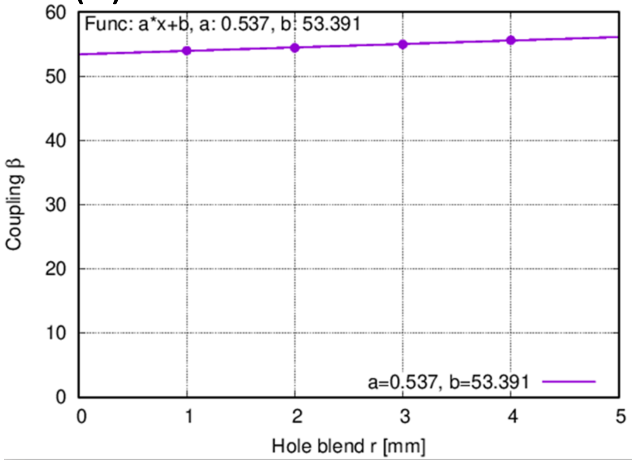
(2)



(3)



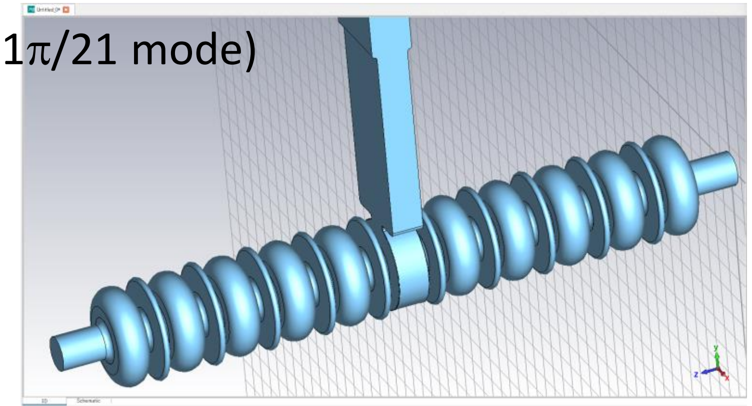
(4)



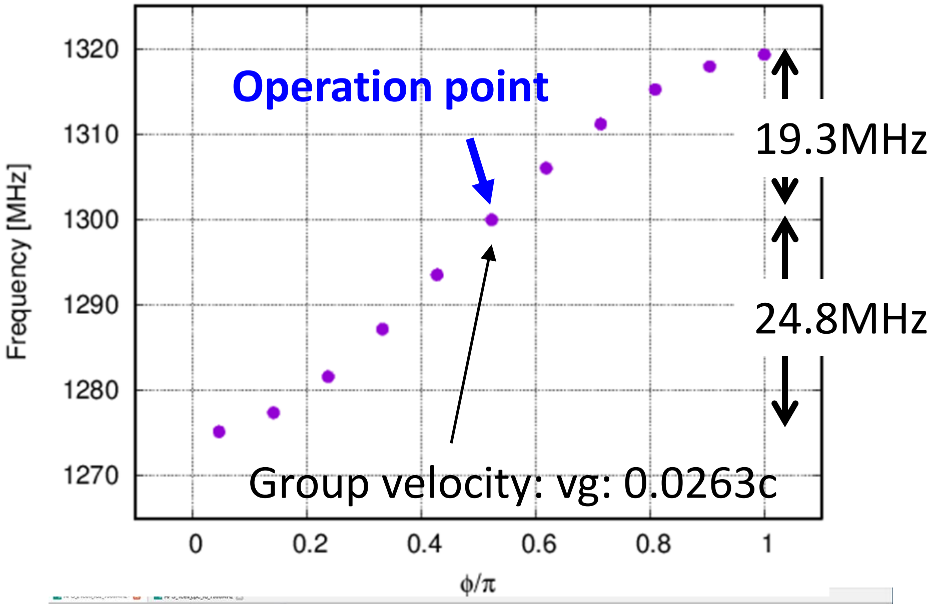
Coupling of 21cell APS cavity

The coupler cell was incorporated into a 21-cell APS cavity and couplings were calculated.

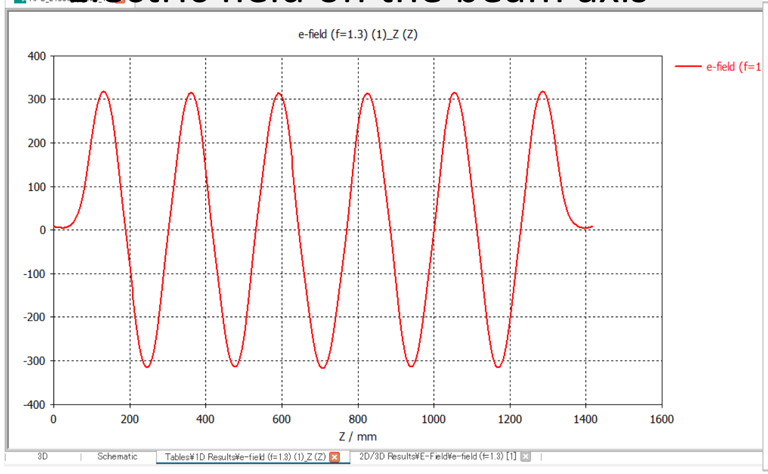
Resonant frequency: 1299.946MHz (11π/21 mode)
Group velocity: 0.0263c
Coupling β: 5.05.



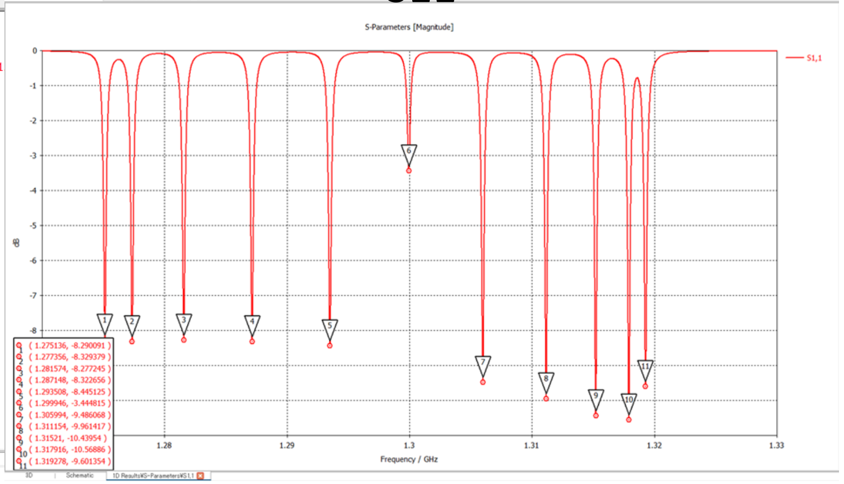
Dispersion curve

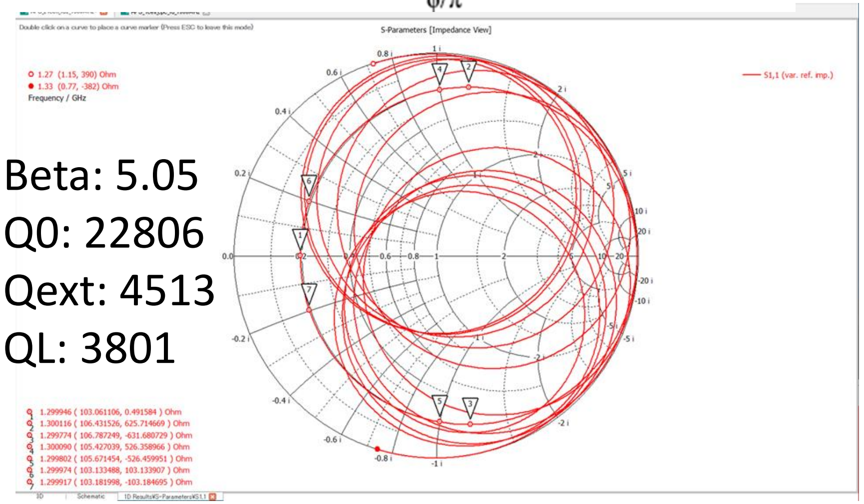


Electric field on the beam axis



S11

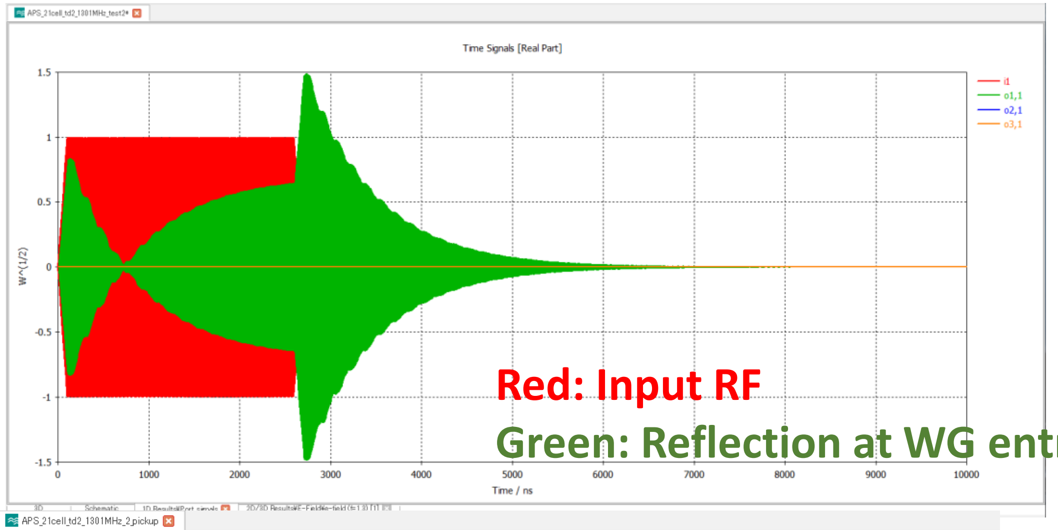


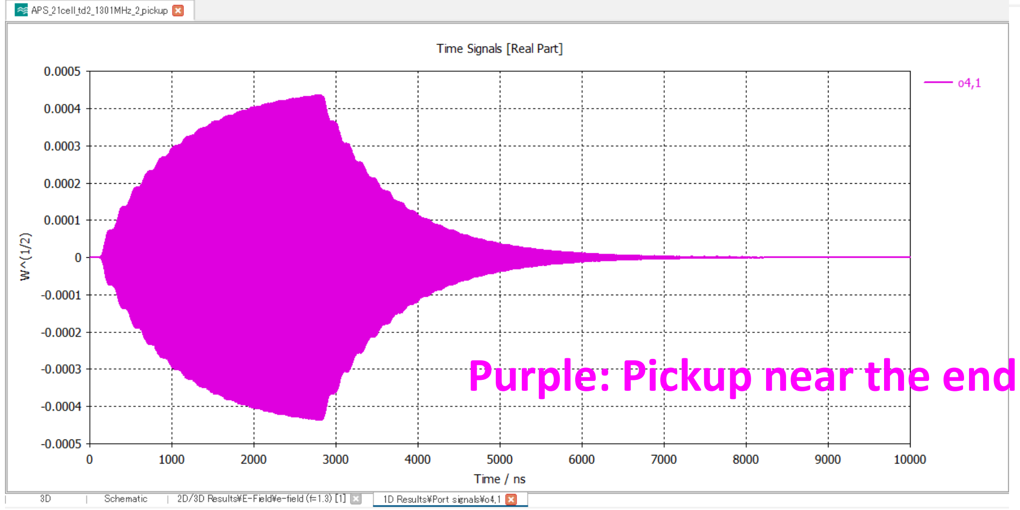


Beta: 5.05
Q0: 22806
Qext: 4513
QL: 3801

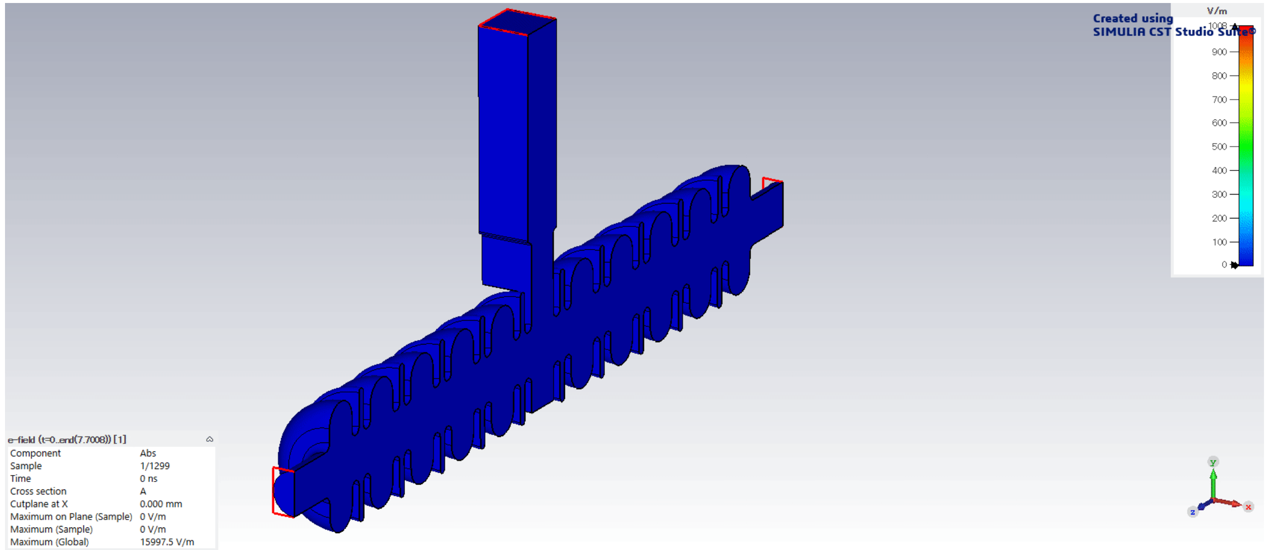
RF simulation in time domain

Filling time of 21cell APS cavity is 1us .

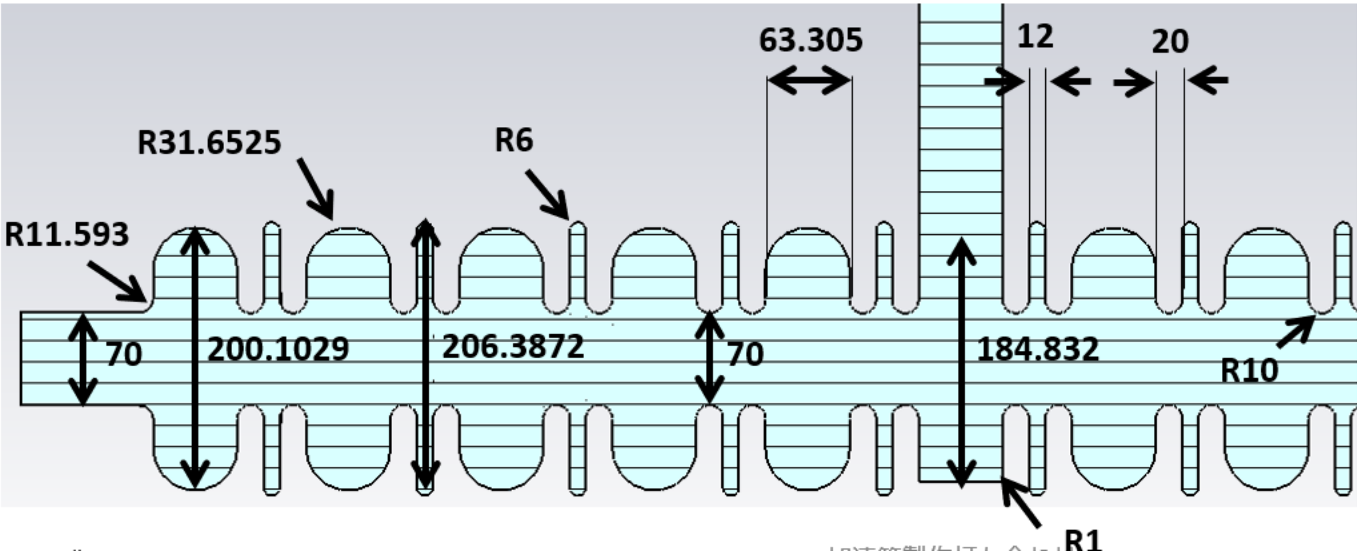


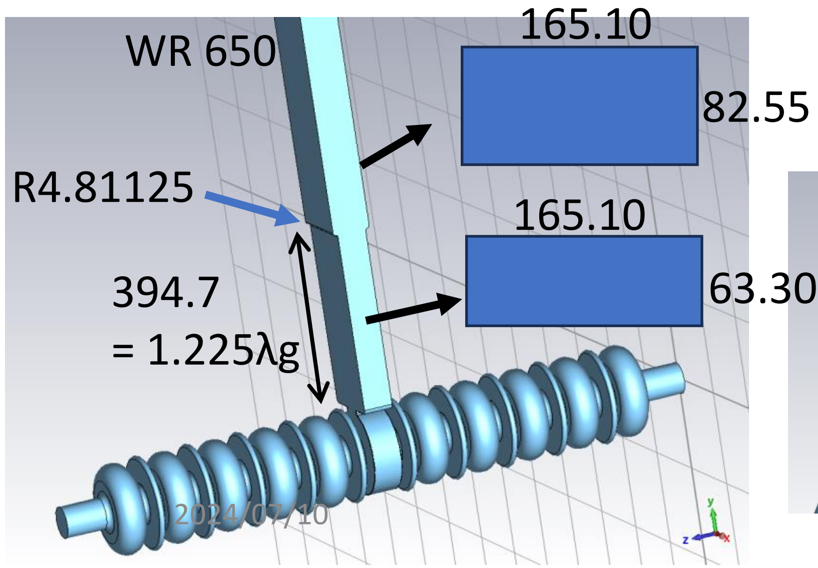


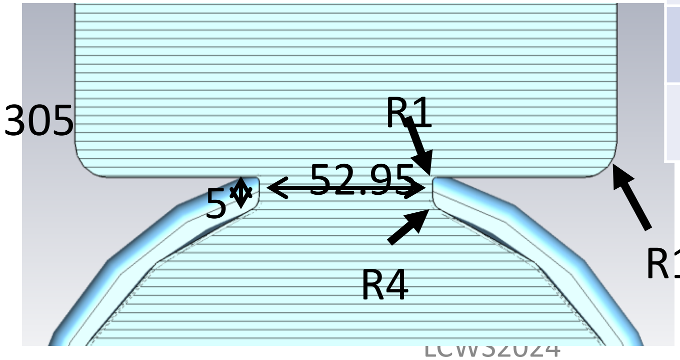
Time variation of electric field



Parameters and dimensions of 21cell APS cavity







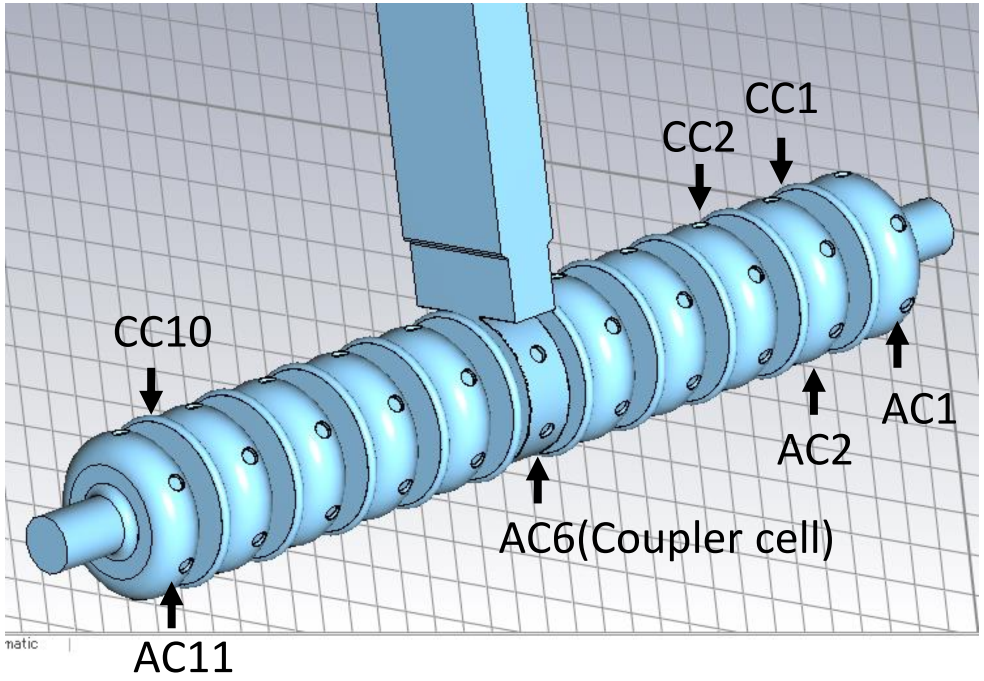
Parameters of 21cell APS cavity	
Resonant frequency (π/2) [MHz]	1300
Eacc [MV/m] (*1)	6.5
Vacc [MV] (*1)	8.2
Group velocity	0.0263c
Rsh [MΩ/m]	35.0
Q0	22806
Coupling β	5.05
Filling time [us]	1
Cavity length [m]	1.268
Number of cell	21 (AC: 11, CC: 10)

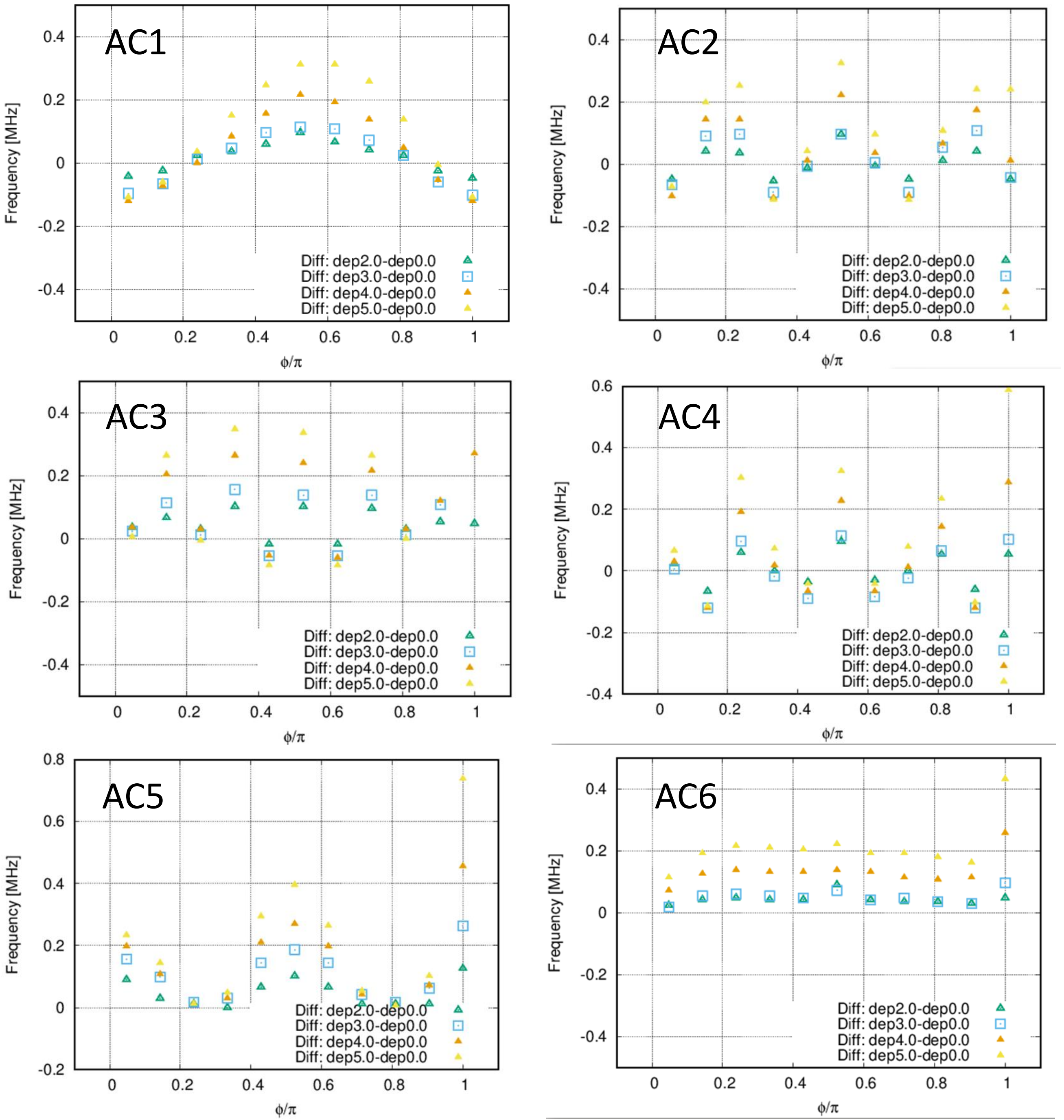
(*1) RF input power: 10MW (peak)

Tuner

There are 6tunters in each cell.
(1MHz/2mm in a single cell)

The shape of the difference in dispersion curves when the resonant frequency of each cell is shifted.

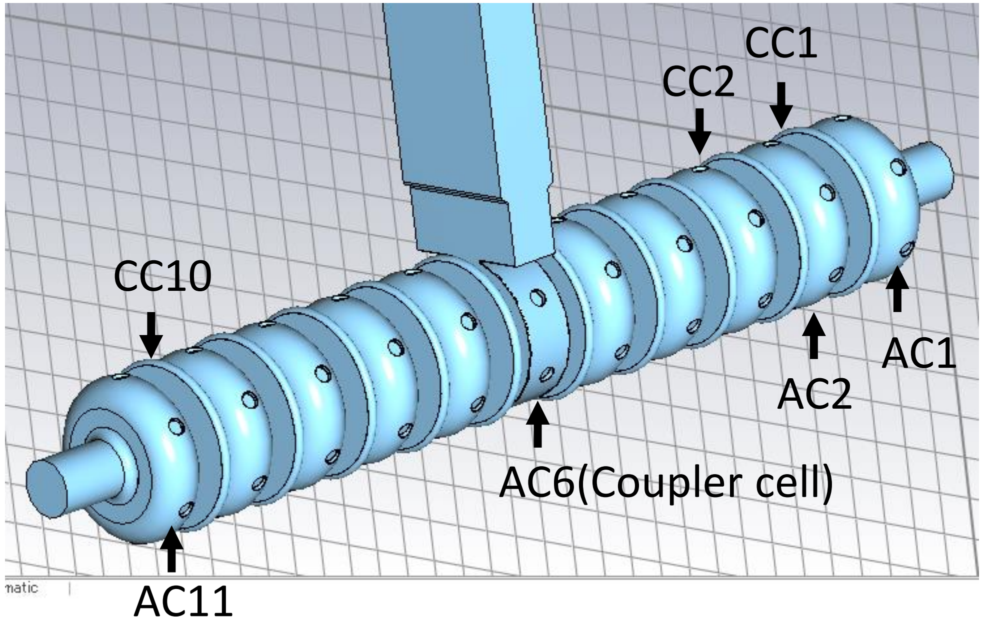


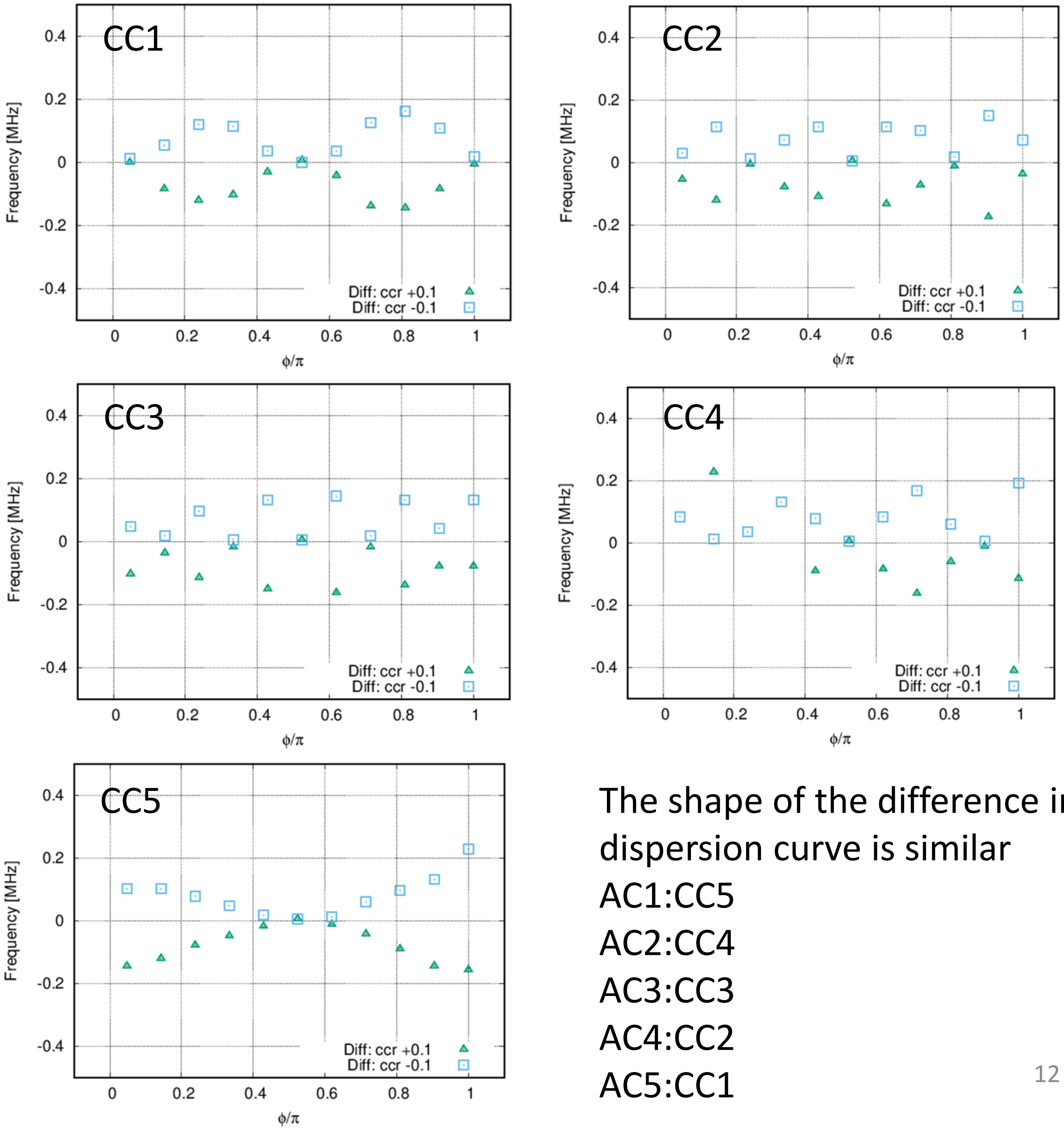


Tuner

The shape of the difference in dispersion curve is similar when resonant frequency of AC cells is changed.
→ Resonant frequency can be tuned by the tuner on AC.

However, the frequency offset is different.
Frequency tuning by temperature is finally required.

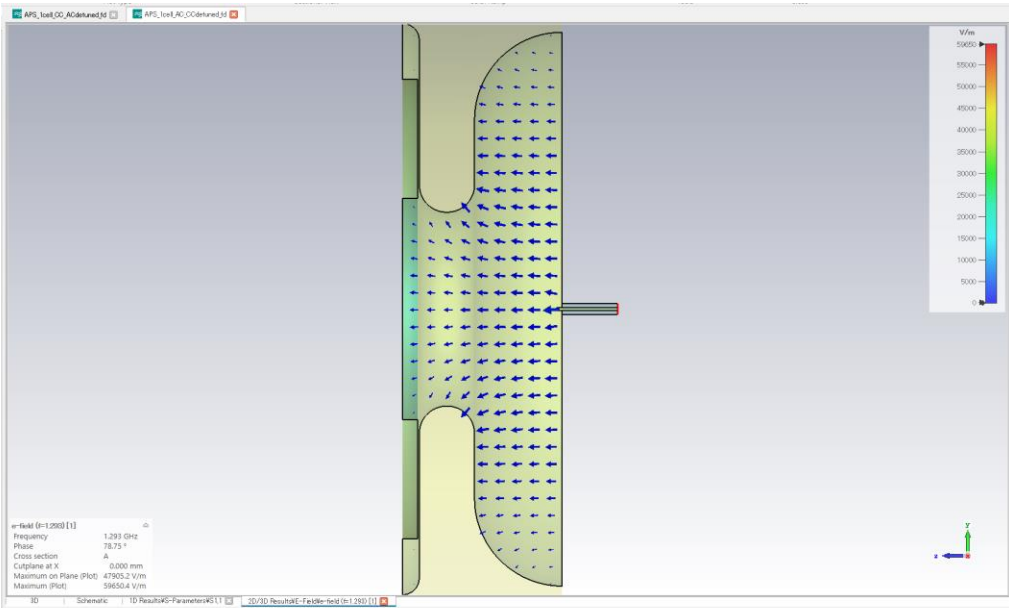


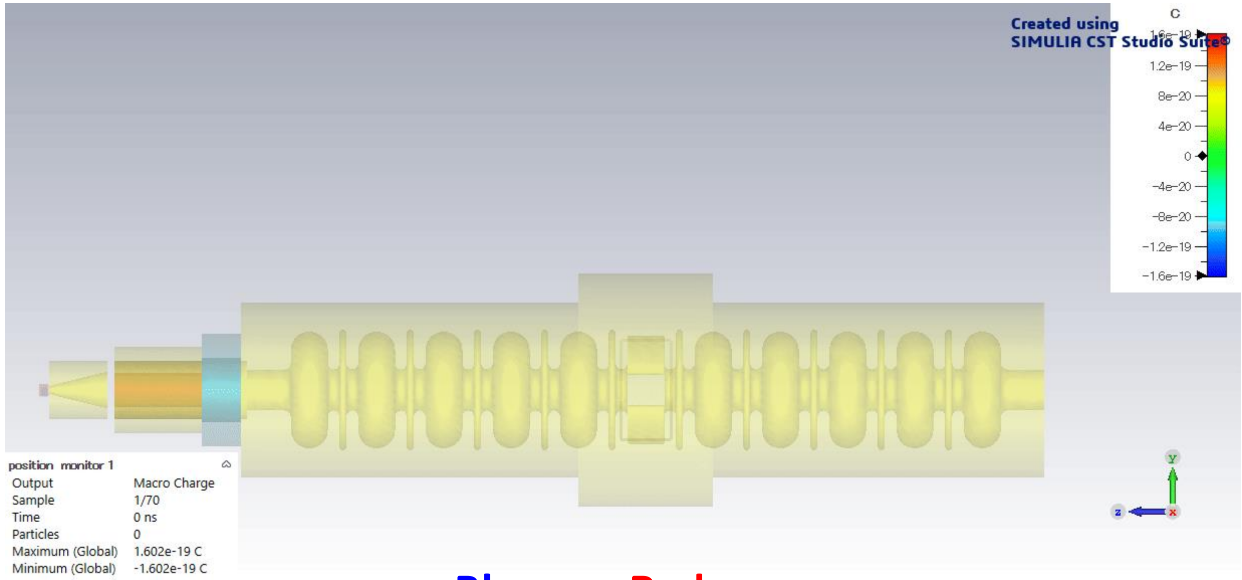


The shape of the difference in dispersion curve is similar
AC1:CC5
AC2:CC4
AC3:CC3
AC4:CC2
AC5:CC1

Summary and next step

- The design of the 21cell APS cavity was finished. The designed APS cavity will be manufactured this year and next.
- Frequency measurement and bead-pull measurement systems will be designed to manufacture this cavity.
- The simulation to estimate the beamloading effect will be started. We are testing this simulation with CST Studio.





Blue: e-, Red: e+

FY		2022	2023	2024	2025	2026	2027
Acc. structure	1st unit						

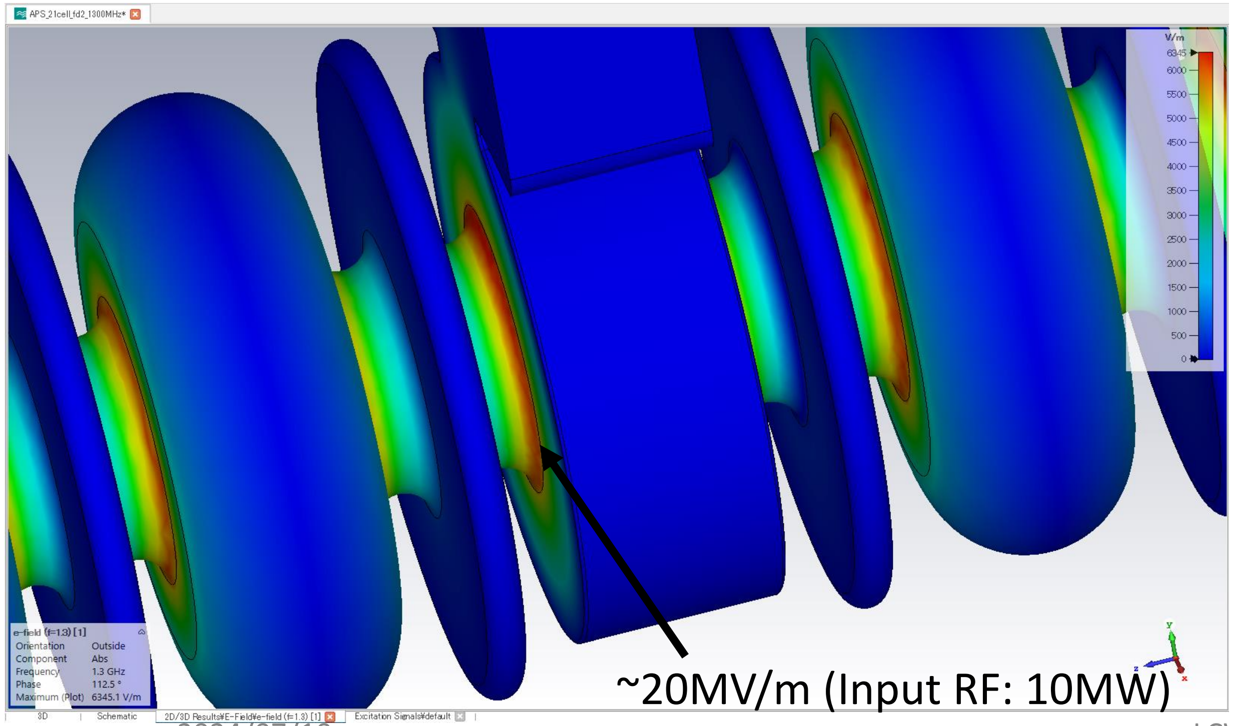
Design
Manufacuring
test

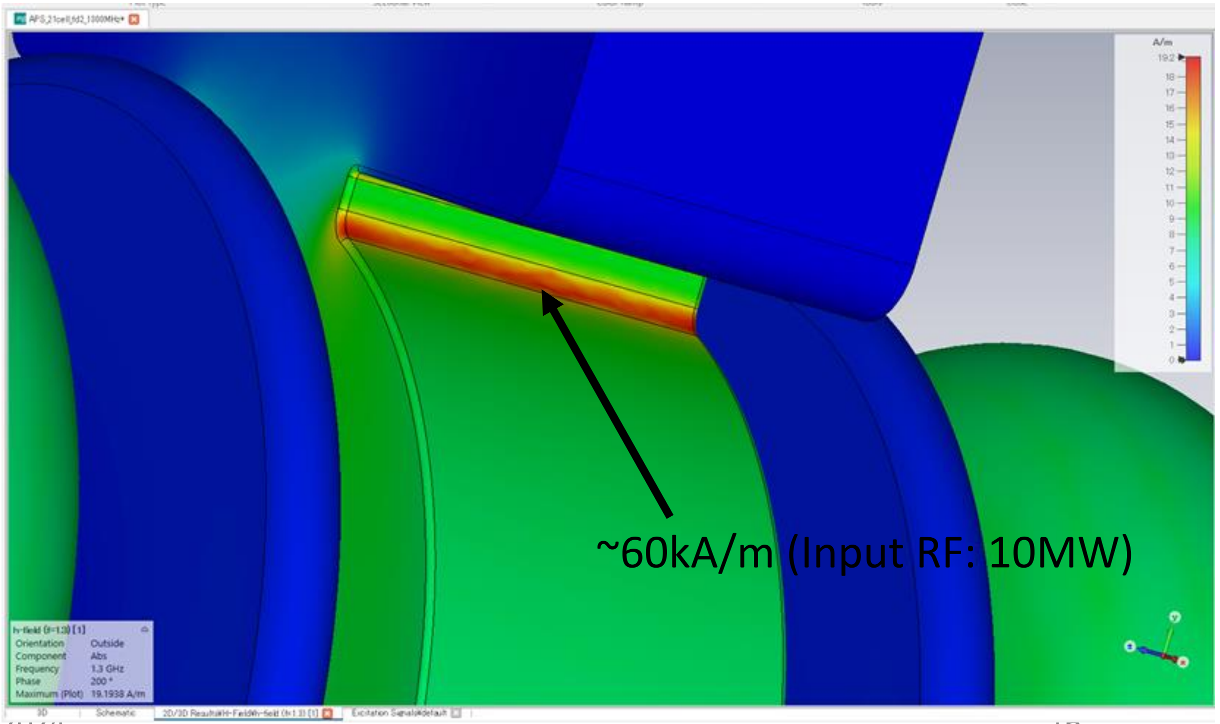
Acknowledgment

This work was supported by 【MEXT Development of key element technologies to improve the performance of future accelerators Program】 Japan Grant Number JPMXP1423812204.

Electric and magnetic field on cavity surface

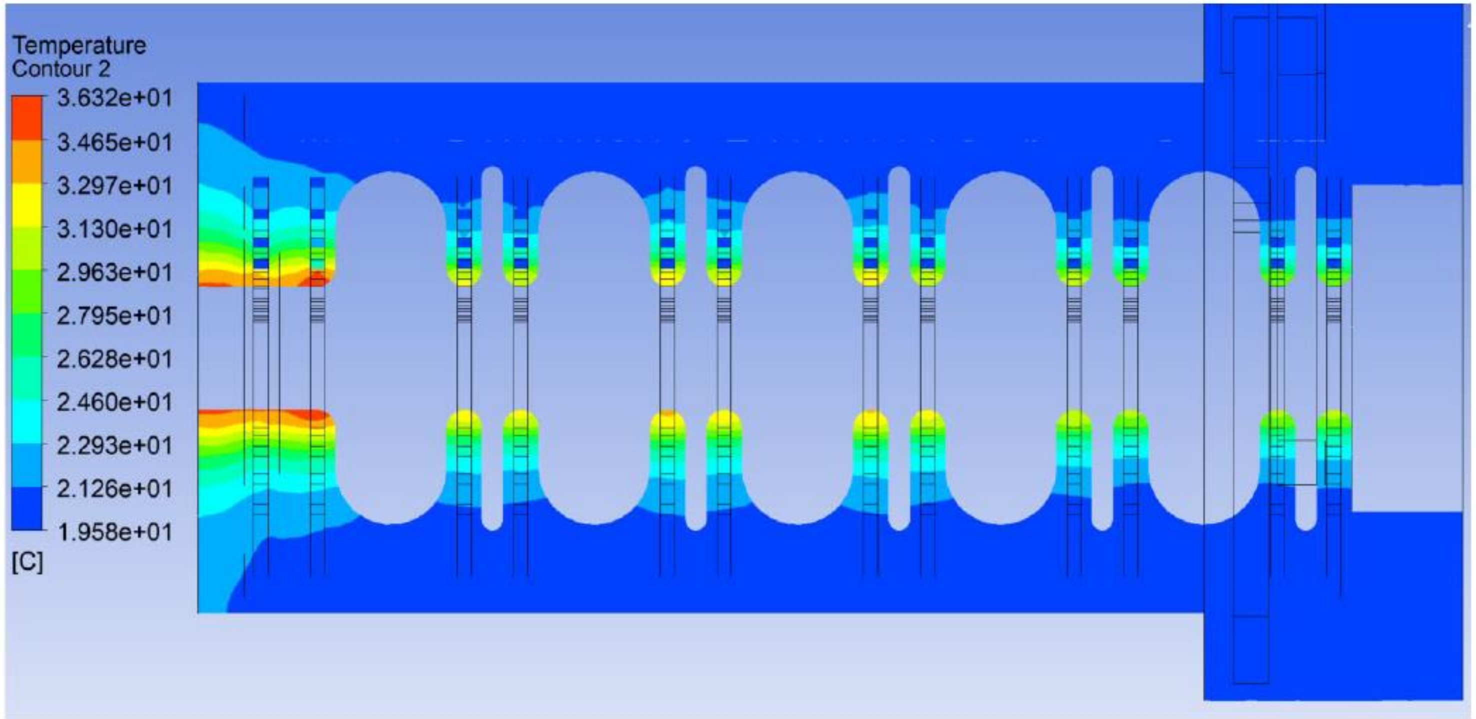
Maximum electric field is about 20MV/m near the iris when input RF power is 10MW.
The maximum magnetic field is about 60 kA/m at the coupler hole surface, which is about twice that at the cavity surface.





Acc. Structure - cooling design

・rough simulation with Φ90 uniform heat load (2.0e7 W/m3) = 1kW / 1 iris
・temperature rise ～10℃

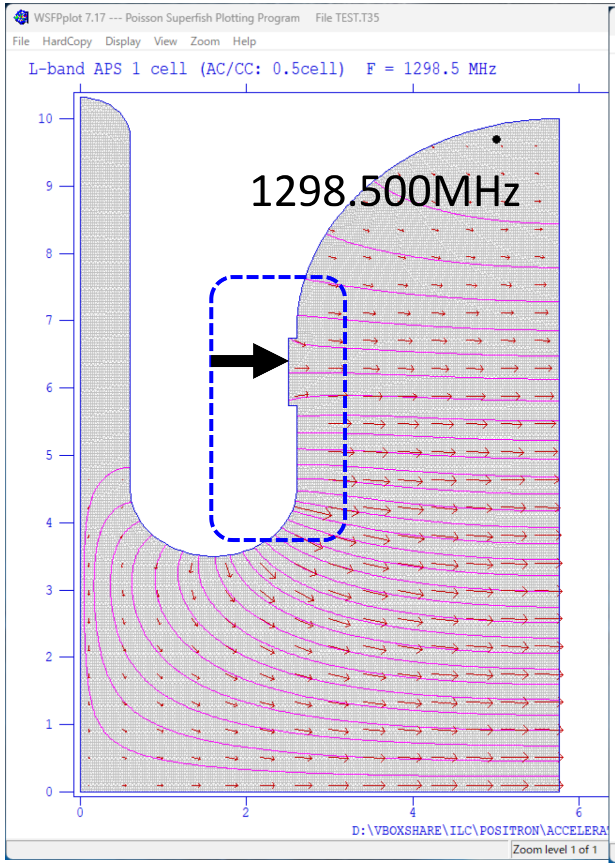


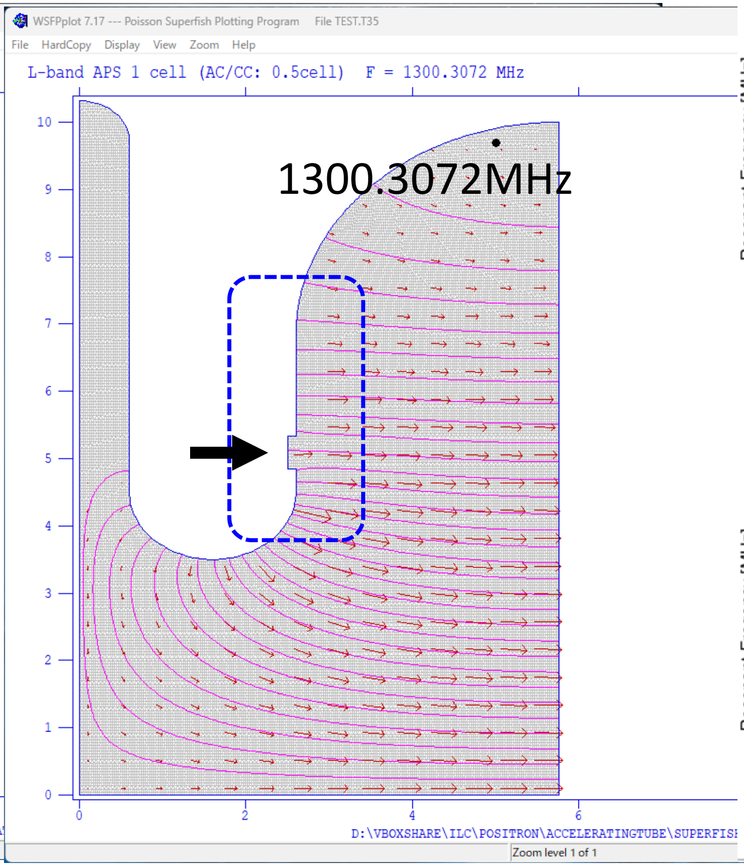
- Thermal simulation using ANSYS by Y. MorikawaS
- Export deformed shape and import it to RF simulation
  - Check shift of resonant frequency

LCWS2024
Y. Enomoto

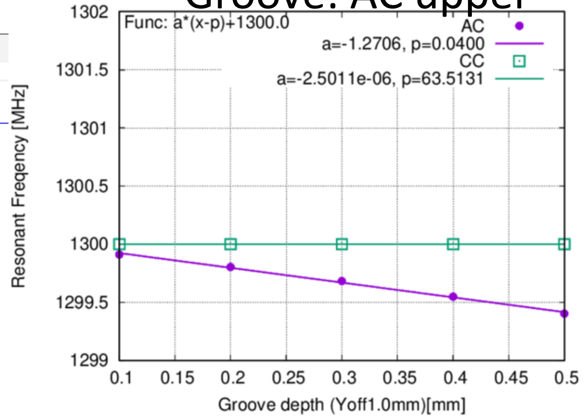
Tuning of resonant frequency

The frequency can be adjusted by digging a very thin groove.
The direction of frequency change depends on whether the trench is dug in a location with a strong electric field or a strong magnetic field.

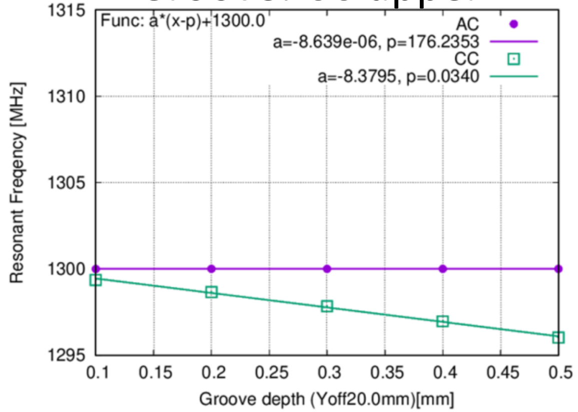




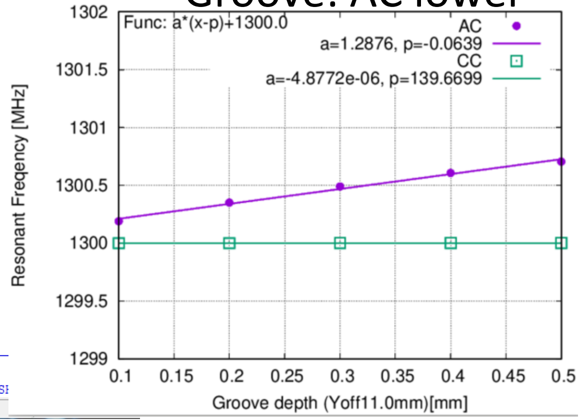
Groove: AC upper



Groove: CC upper



Groove: AC lower



Groove: CC lower