# Introduction of cavity coupler tuning

The classical kyhl method

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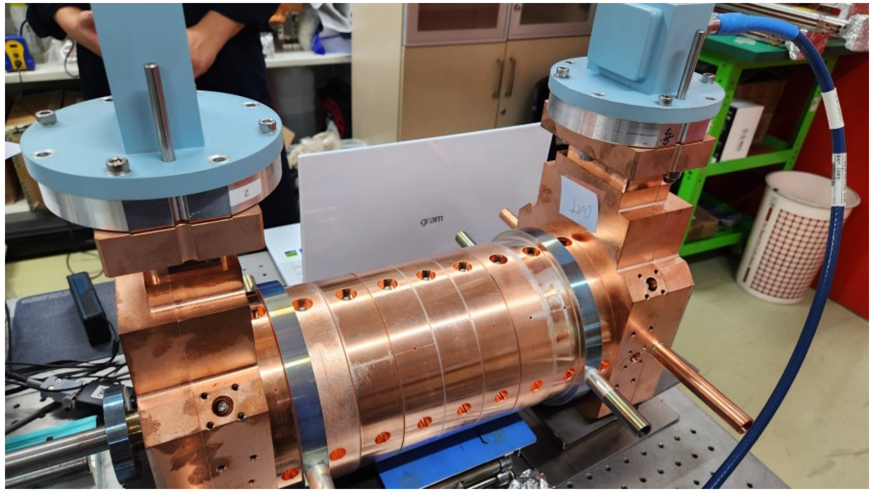
# Post-Brazing Verification

Brazing timeline, helium leak test, and pre-tuning S11 measurement.

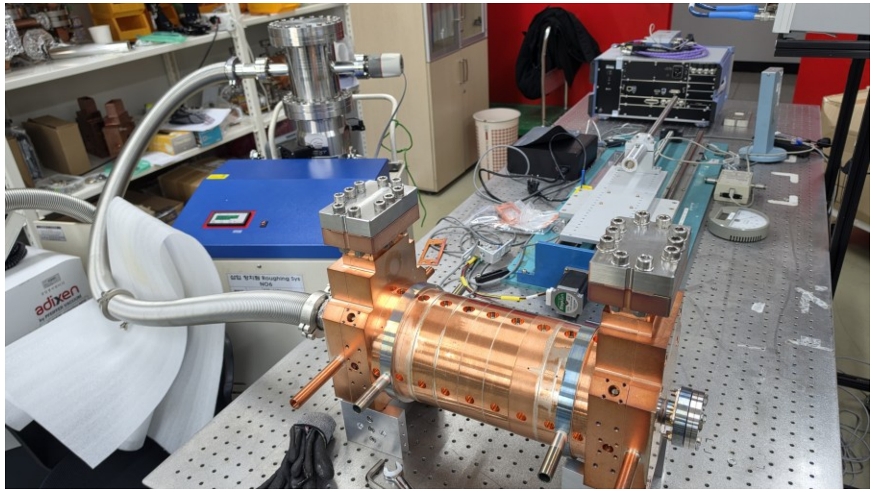
## Brazing timeline

- 2025. 08. In/output coupler presentation (half brazing)
- 2025. 11. Re-measurement and full brazing
- 2026. 03. Leak test
- 2026. 03~04. $S_{11}$ measurement (No tuning)



## Helium leak test

- No leak detected.

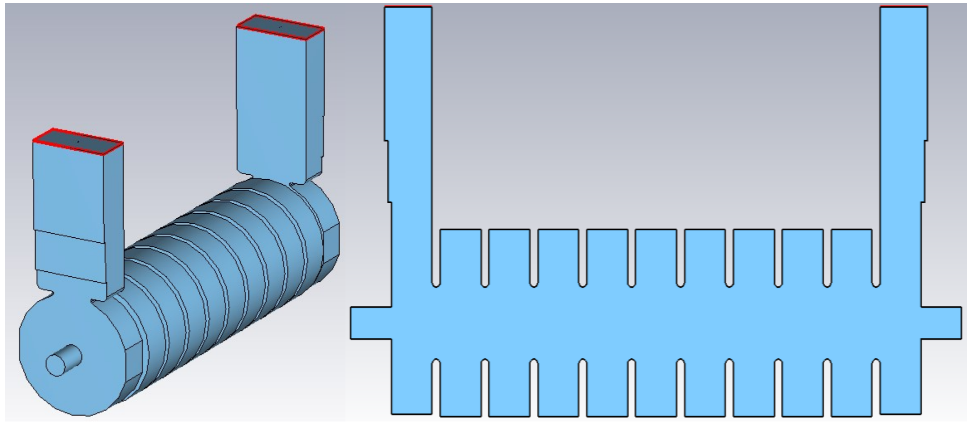



# Coupler Role

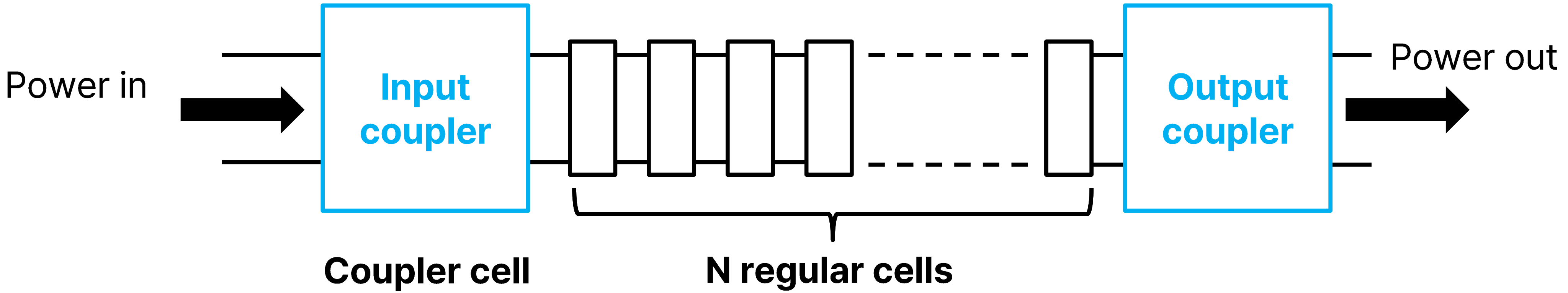
The coupler controls RF power transfer and strongly affects cavity performance.

## Why the coupler matters

- Impedance matching
  - Transfer RF power into and out of the cavity.
  - Coupling coefficient and external Q.
  - Mode purity (final resonant frequency).



coupling coefficient $\beta = \frac{P_{\mathrm{external}}}{P_{\mathrm{wall}}} = \frac{Q_0}{Q_{\mathrm{ext}}}$

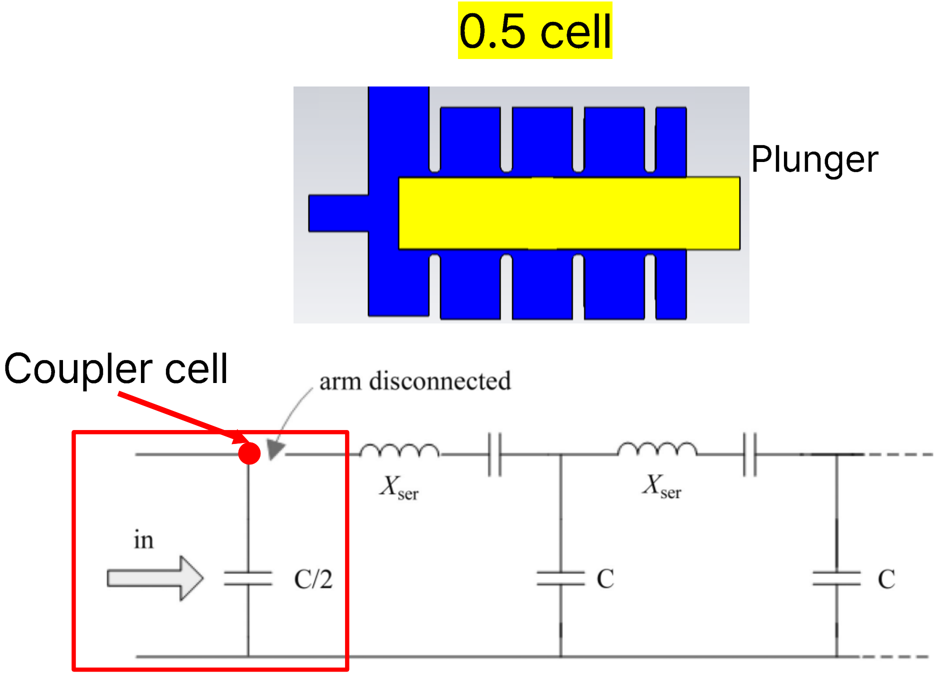


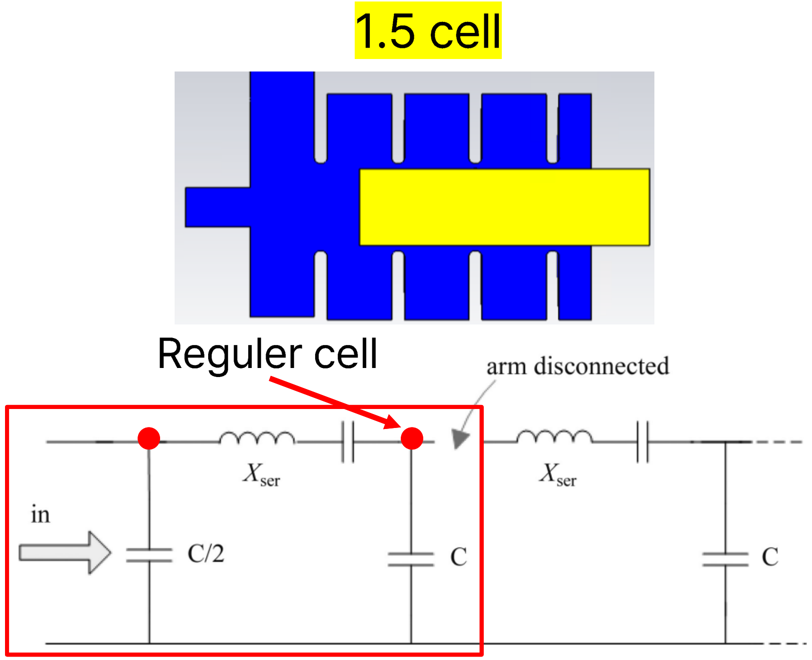
# Method: kyhl method (Impedance matching method)

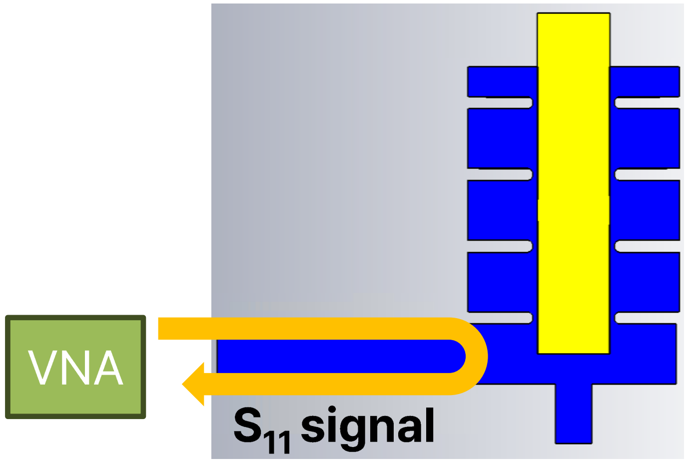
Frequency tuning based on the coupled-cell model.

## Method overview

- Coupled-cell equivalent model
- Plunger-based freq. tuning
- Imp. matching of the coupler



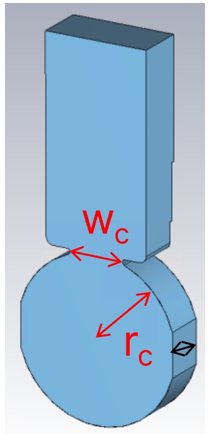
# Tuning procedure

## Tuning workflow

**Goals**

1. $\Delta f = f_{target} - f_{shifted}$ **= 0**
2. Coupling coefficient $\beta \sim 1$

- $\Gamma = \frac{\beta - 1}{\beta + 1}$
- $|\Gamma|$ = 0: No reflection
- $|\Gamma|$ = 1: 100% reflection



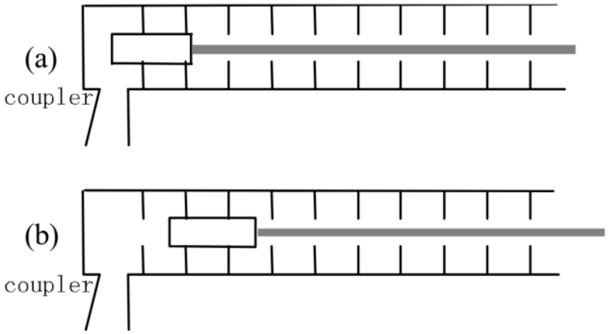

**Parameters**

1. Coupler radius $r_c$
2. Coupler width $w_c$

**Kyhl's method**

1. Detune three freq.
2. **Phase ΔΦ offsets**

Zheng et al., Proc. PAC 2001, Chicago, 2001.




Wang *et al.*, HEP&NP 30(6), 2006.

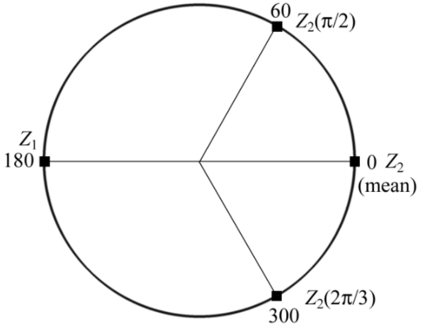


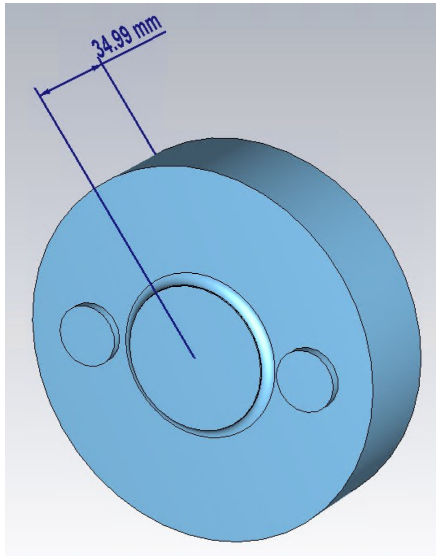

Fig. 1. Impedance points on a Smith Chart Plot.

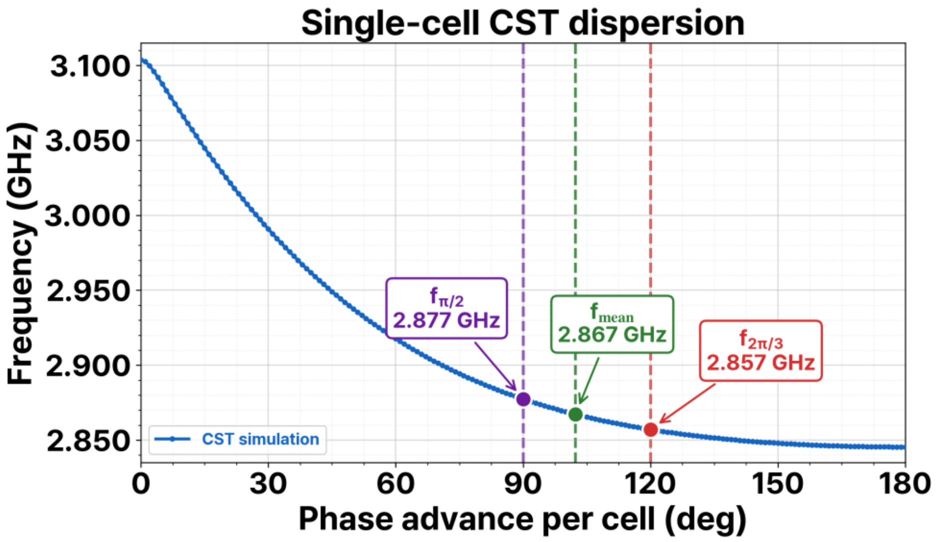
# Dispersion curve

$f_{\pi/2}$, $f_{2\pi/3}$, $f_{mean}$

## Freq. decision

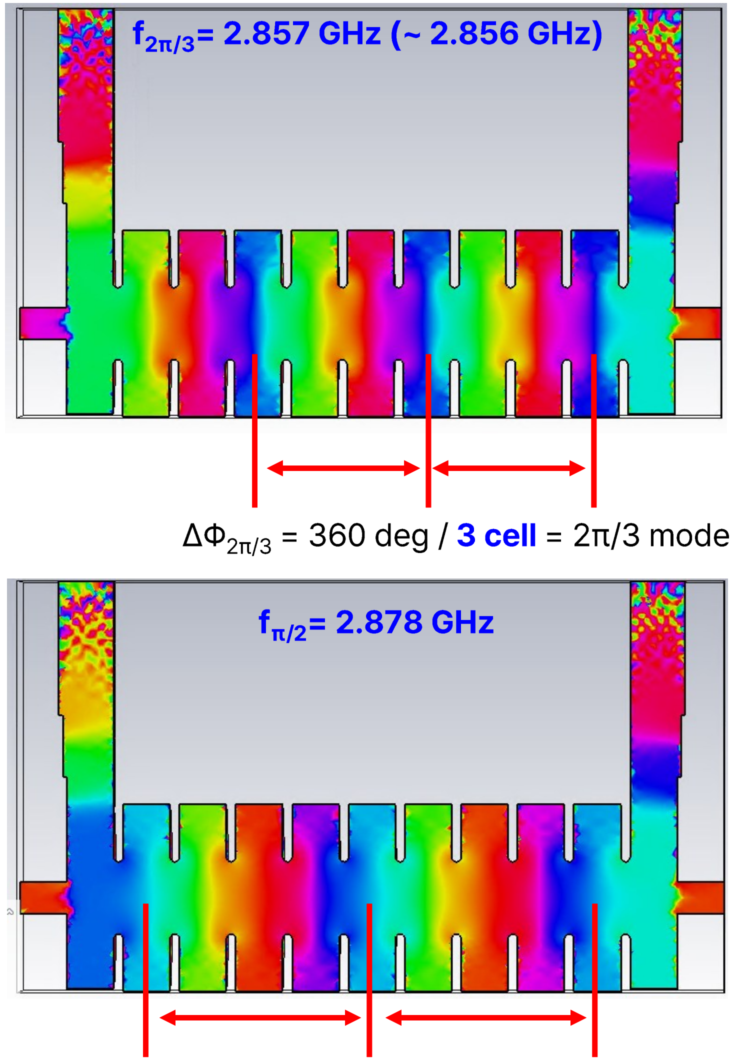
1. **Required freq.**: $f_{2\pi/3}$, $f_{\pi/2}$, $f_{mean}$
2. **CST simulation**: Dispersion curve
3. **Field distribution**: $f_{2\pi/3}$, $f_{\pi/2}$ mode verification.




| | $f_{2\pi/3}$ | $f_{\pi/2}$ | $f_{mean}$ |
|---|---|---|---|
| Freq. (GHz) | 2.857 | 2.877 | 2.867 |

<Phase propagation>




$\Delta\Phi_{2\pi/3}$ = 360 deg / **3 cell** = 2π/3 mode

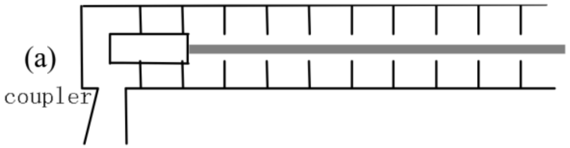
$\Delta\Phi_{\pi/2}$ = 360 deg / **4 cell** = π/2 mode

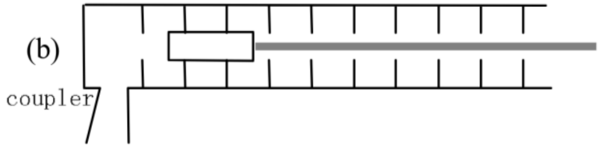
# Simulation Comparison: S11 Dip Shift

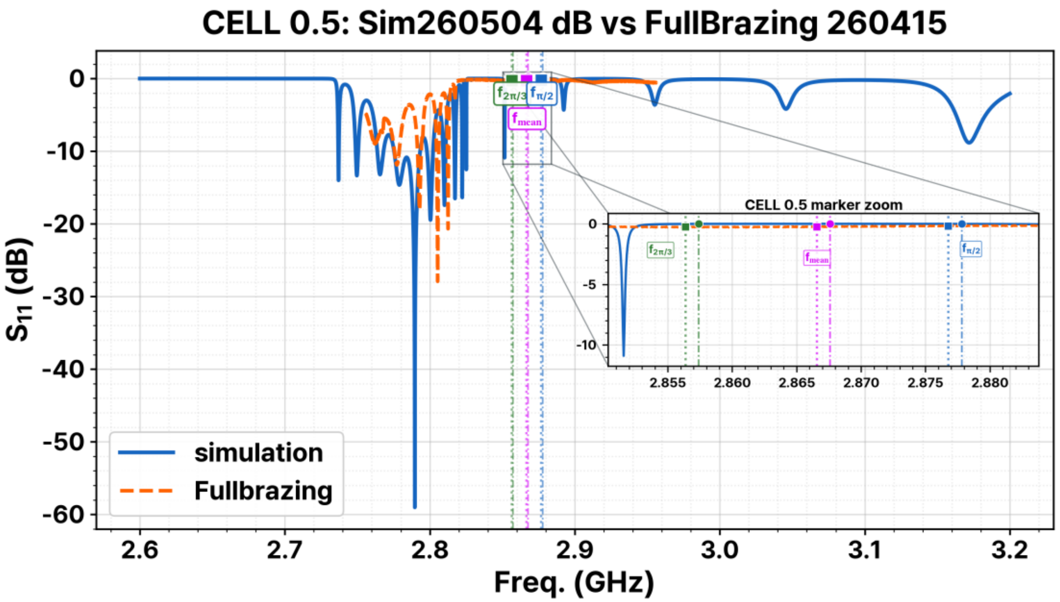
S11 were measured and analyzed to compare with the previous results.

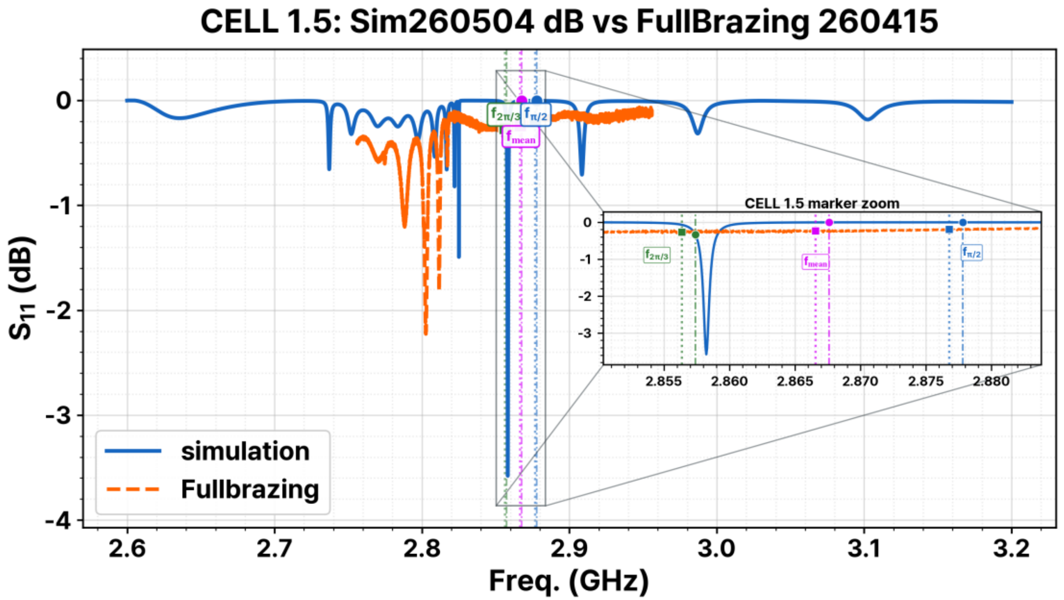
## Verification of three detuned short positions at the cell center (T=24.4 deg, H = 65%)

- $S_{11} = \Gamma$ @ one port network.
- $|\Gamma| \sim 1 \rightarrow$ 100% reflection
- 0 dB $\rightarrow |S_{11}| \sim 1$



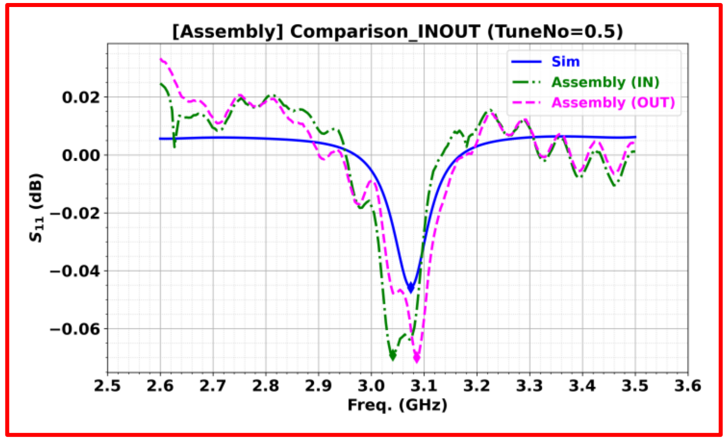



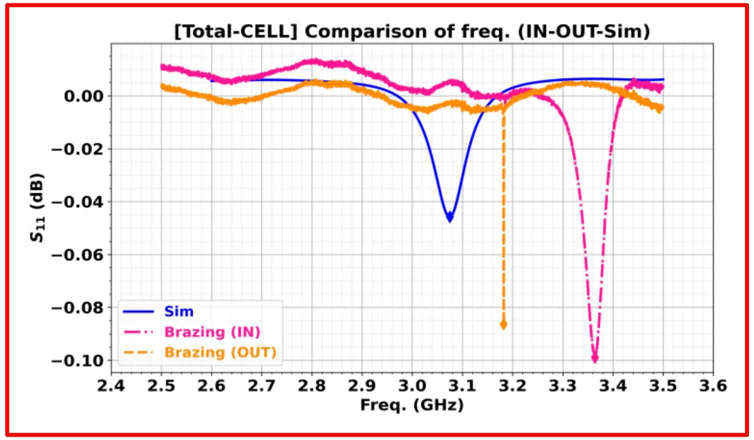
# [Recap] Previous results

Frequency shift after input/output coupler brazing.

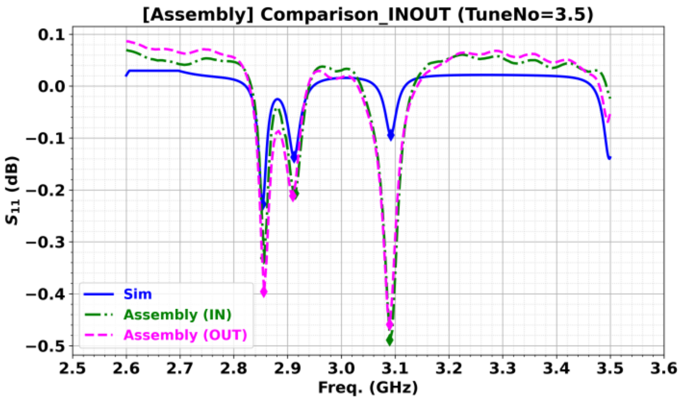
## Comparison $S_{11}$ results

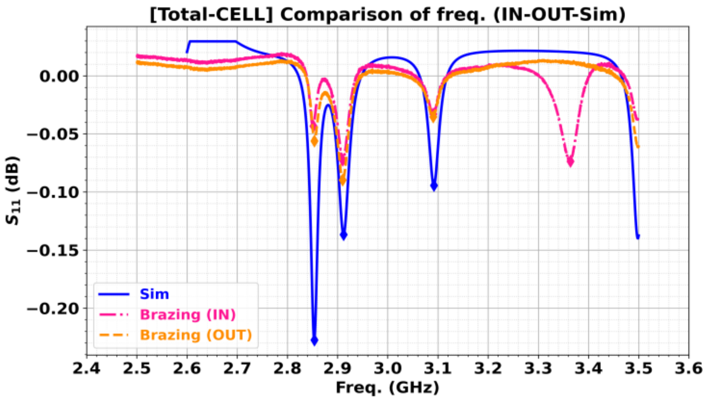
- ~300 MHz frequency shift in the coupler cell.
- Mode excitation in the regular-cell region.




| Assembly vs half | [IN] δf (MHz) | [OUT] δf (MHz) |
|---|---|---|
| $f_{peak,1}$ | 323 | 96 |



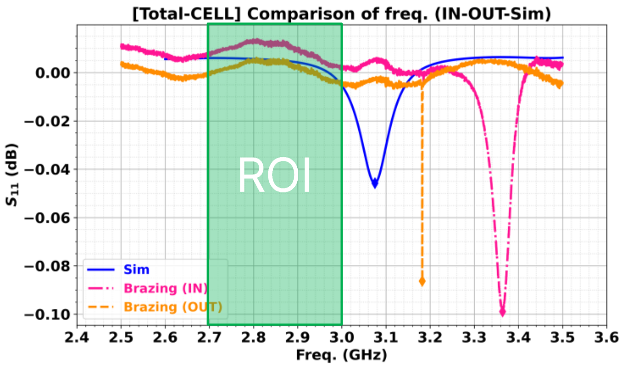

| Assembly vs half | [IN] δf (MHz) | [OUT] δf (MHz) |
|---|---|---|
| $f_{peak,1}$ | 4 | 2 |
| $f_{peak,2}$ | 5 | 0 |
| $f_{peak,3}$ | 1 | 1 |

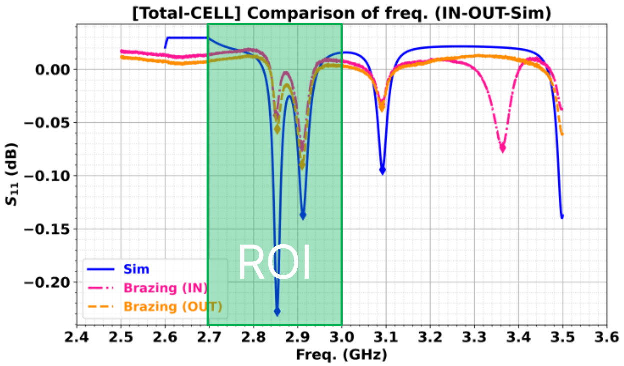
# [Comparison] Half brazing vs Full brazing

S11 measurement and analysis for comparison with the previous results

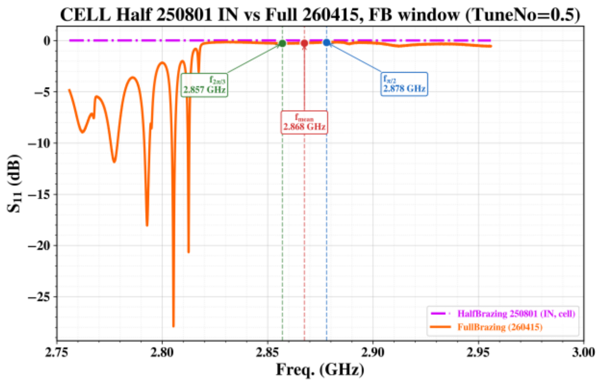
## Comparison of Half and Full Brazing

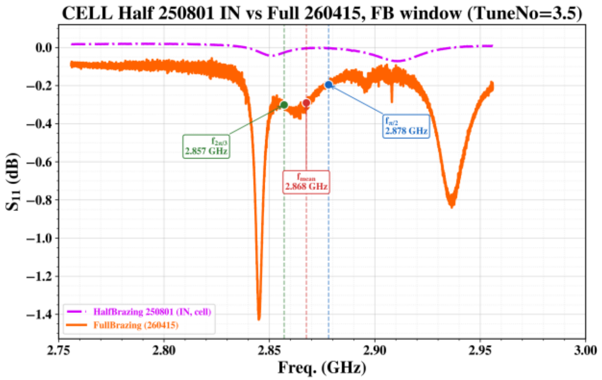
- **Passband region of interest:** $f_{\pi/2} \sim f_{2\pi/3}$
- **Unwanted mode generation after full brazing.**



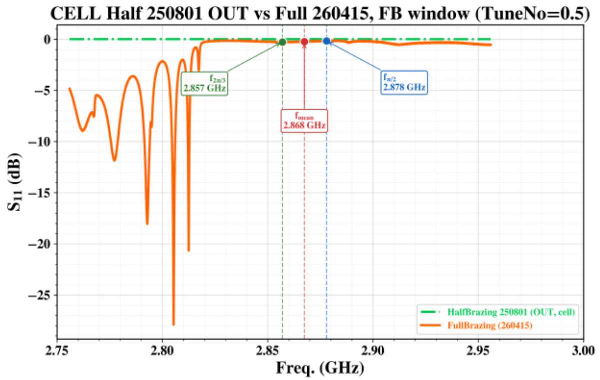



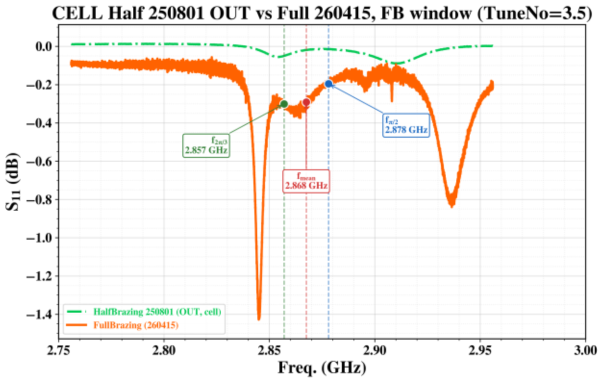

### Input half vs full




### Output half vs full

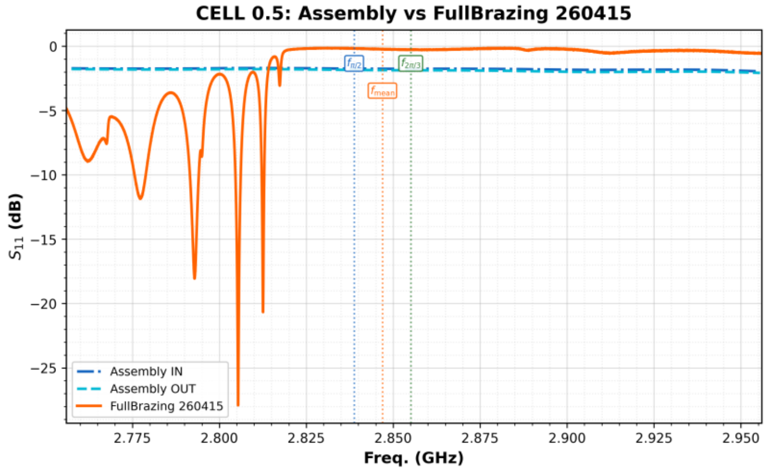


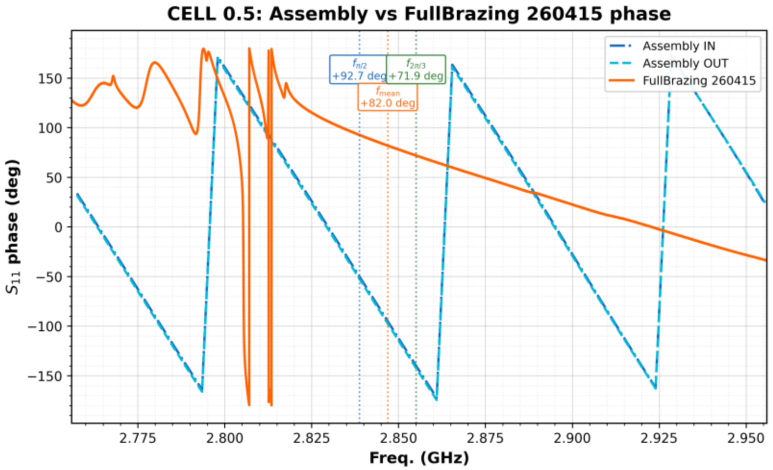



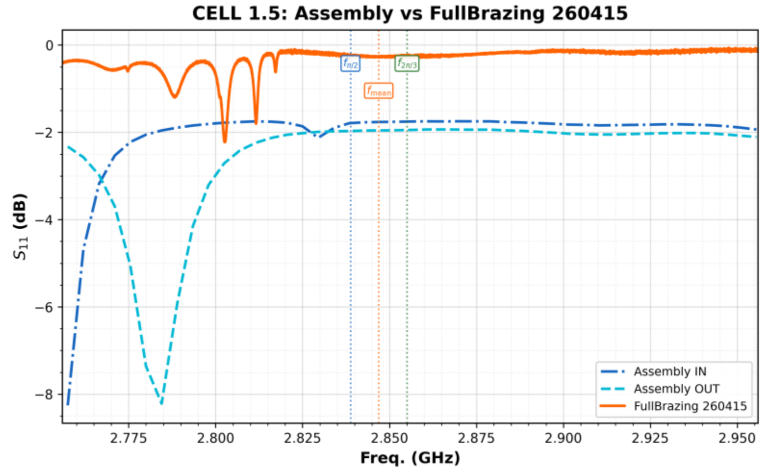
# [Comparison] Assembly vs Full brazing

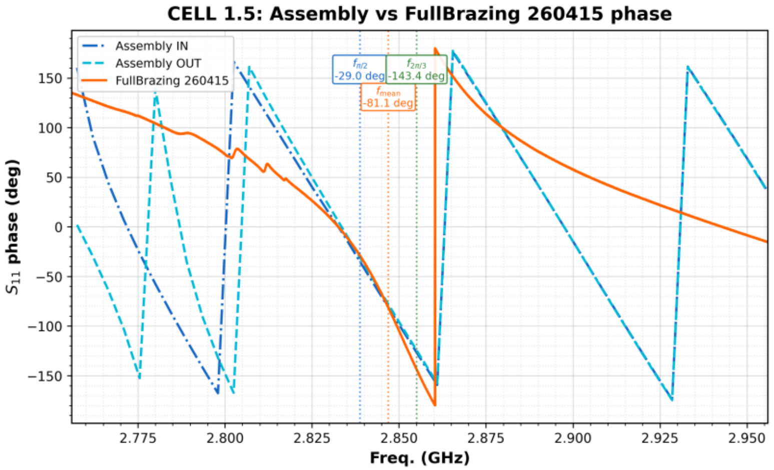
Phase comparison in ROI.

## Phase measurement results



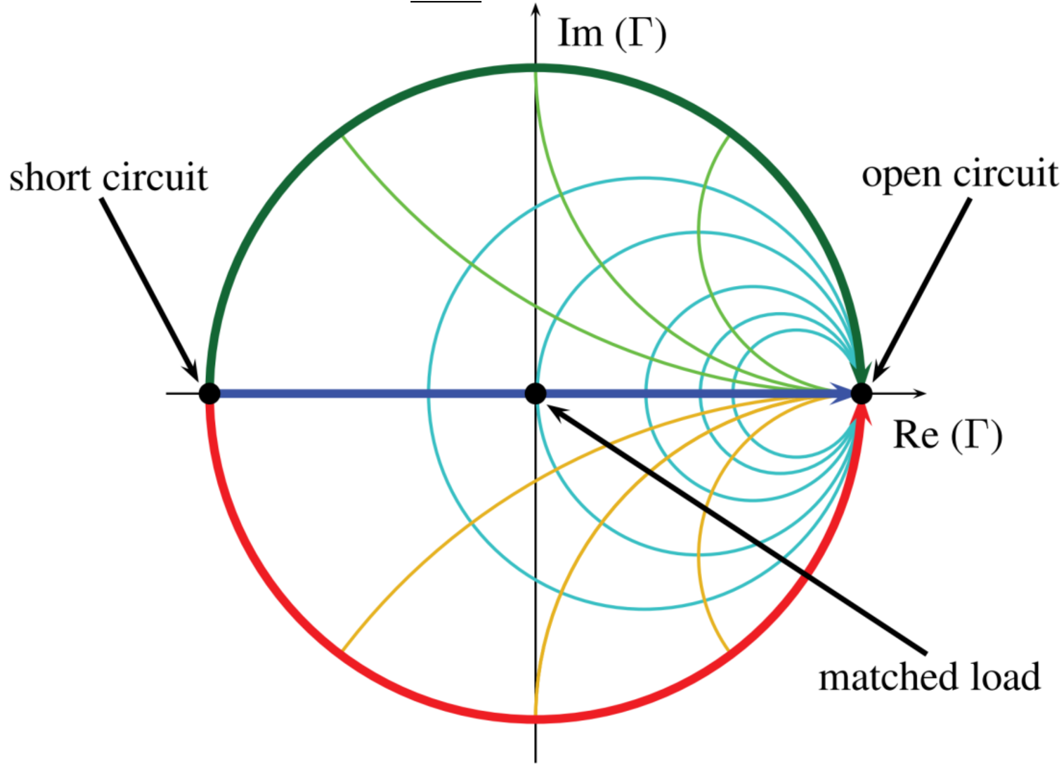



# Method: kyhl method (Impedance matching method)

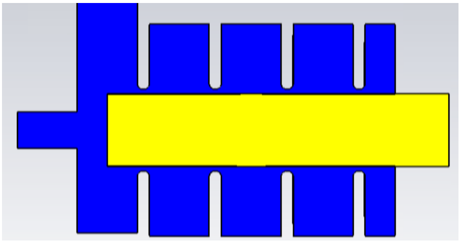
Frequency tuning based on the coupled-cell model.

## Detune position desicion

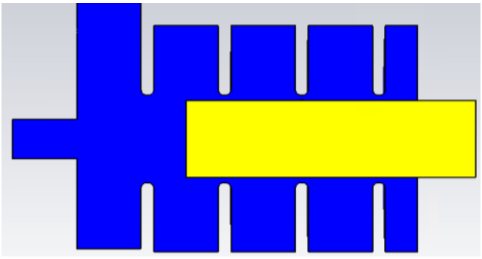
- Stage 1: check Re(Z) = 0 for three freq.
- Stage 2: confirm the phase spacing.
- $\Delta\Phi$ = 120 deg for $\underline{f_{\pi/2}}$, $f_{2\pi/3}$.
- $\Delta\Phi$ = 180 deg for $\underline{f_{mean}}$.




0.5 cell



1.5 cell



Wang *et al.*, HEP&NP 30(6), 2006.

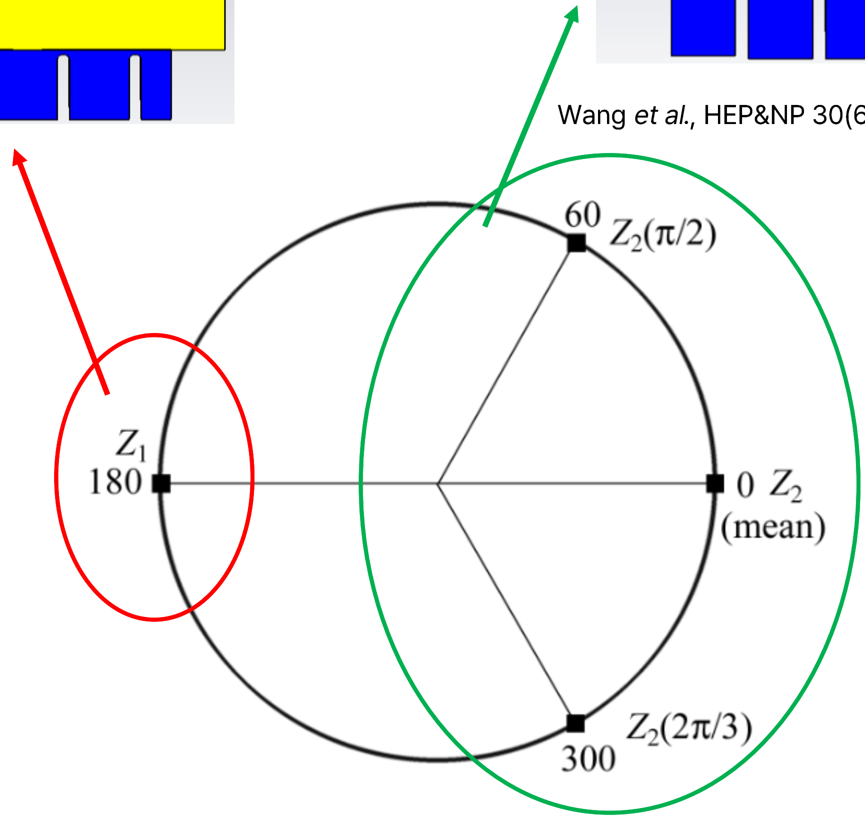



Fig. 1. Impedance points on a Smith Chart Plot.

# Method: kyhl method (Impedance matching method)

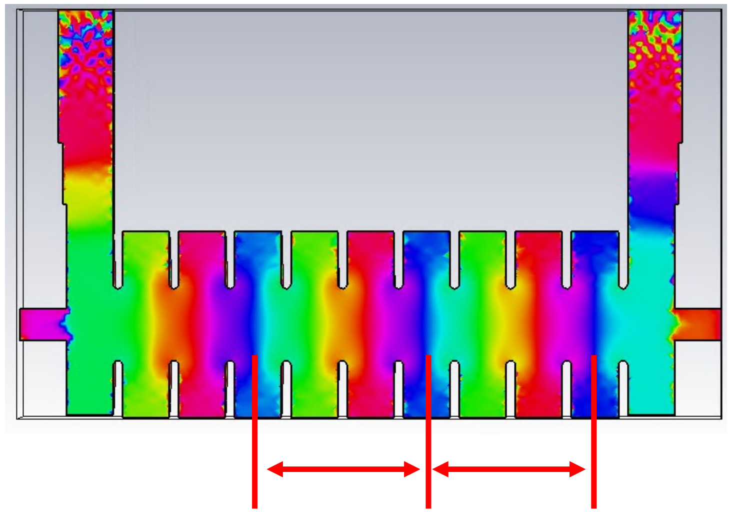
Frequency tuning based on the coupled-cell model.

## Detune position desicion

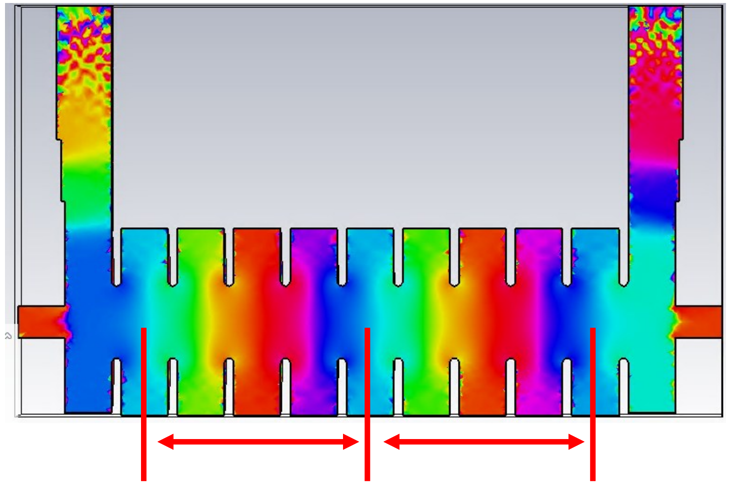
- Propagation coefficient [rad/m]: $\beta_i = \frac{2\pi}{\lambda_{g,i}}$
- Phase propagation: $Z_{in}(f_i) = jZ_0 \tan(\beta_i l)$
- $f_{mean} = \frac{f_{2\pi/3}+f_{\pi/2}}{2}$

| Freq. | cell phase advance $\beta_i l$ | transformed $Z_{in}$ |
|---|---|---|
| $f_{\pi/2}$ | 90 deg | $jZ_0 \tan(\beta_i l + 90)$ |
| $f_{mean}$ | 105 deg | $jZ_0 \tan(\beta_i l + 105)$ |
| $f_{2\pi/3}$ | 120 deg | $jZ_0 \tan(\beta_i l + 120)$ |

- ?
  - ➢ ΔΦ = 120 deg for $f_{\pi/2}$, $f_{2\pi/3}$.
  - ➢ ΔΦ = 180 deg for $f_{mean}$.



$\Delta\Phi_{2\pi/3}$ = 360 deg / **3 cell** = 2π/3 mode



$\Delta\Phi_{\pi/2}$ = 360 deg / **4 cell** = π/2 mode

# [Simulation Comparison] Detuning Analysis from S11 Markers

S11 marker positions and phase vectors from simulation and full-brazing cases

Wang *et al.*, HEP&NP 30(6), 2006.

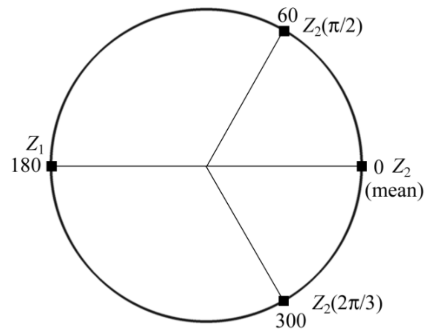
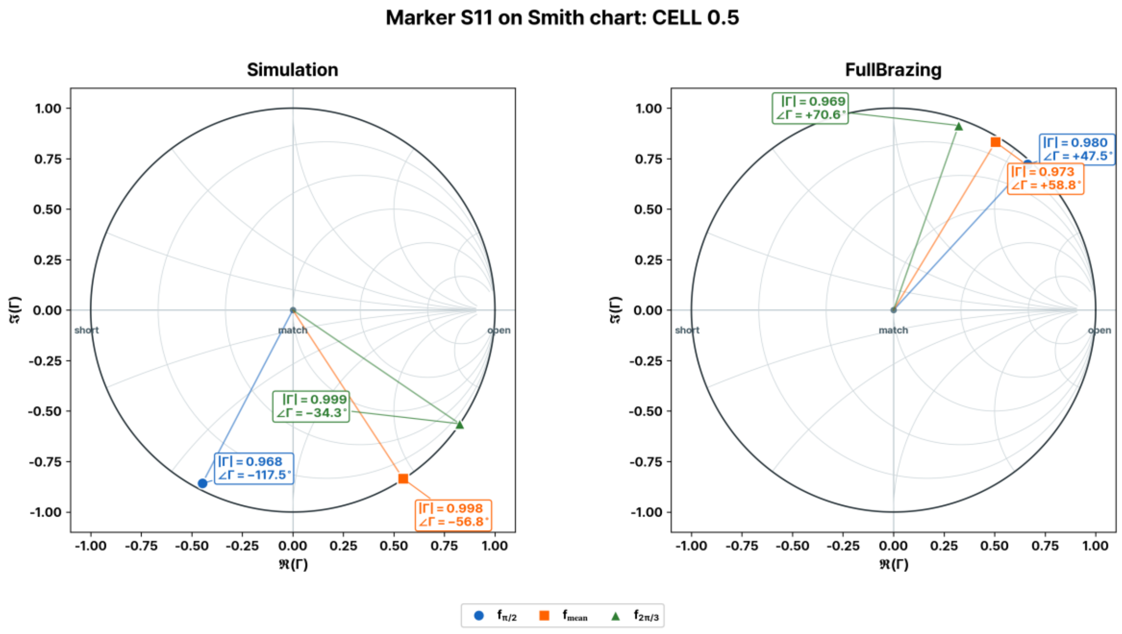
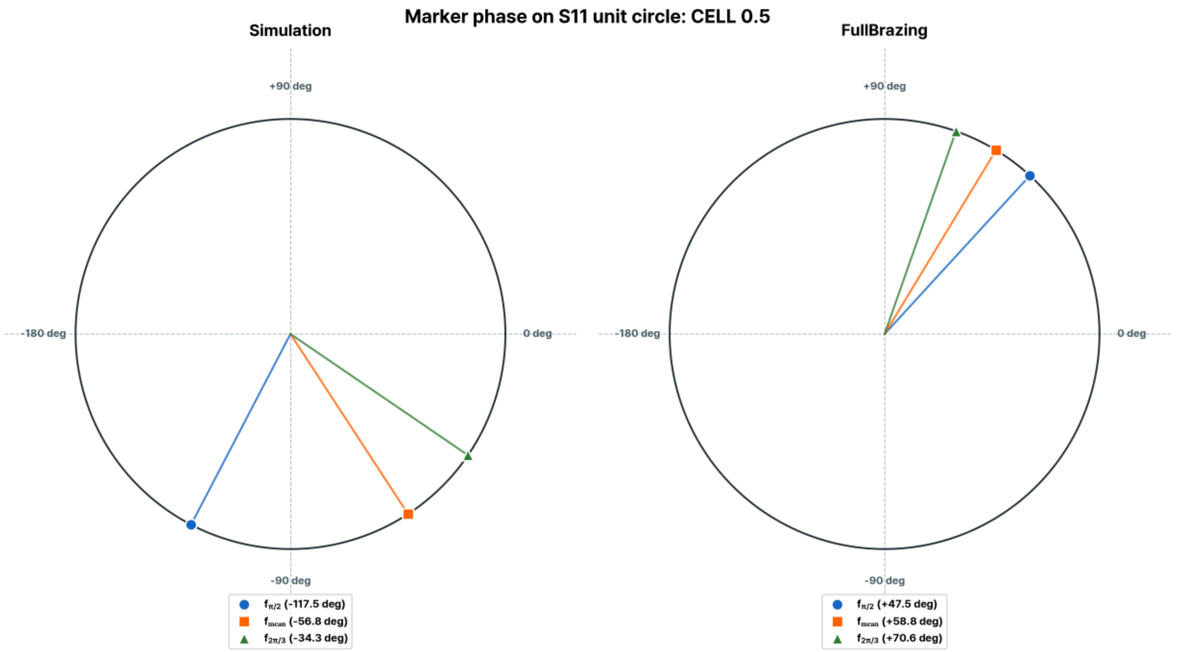


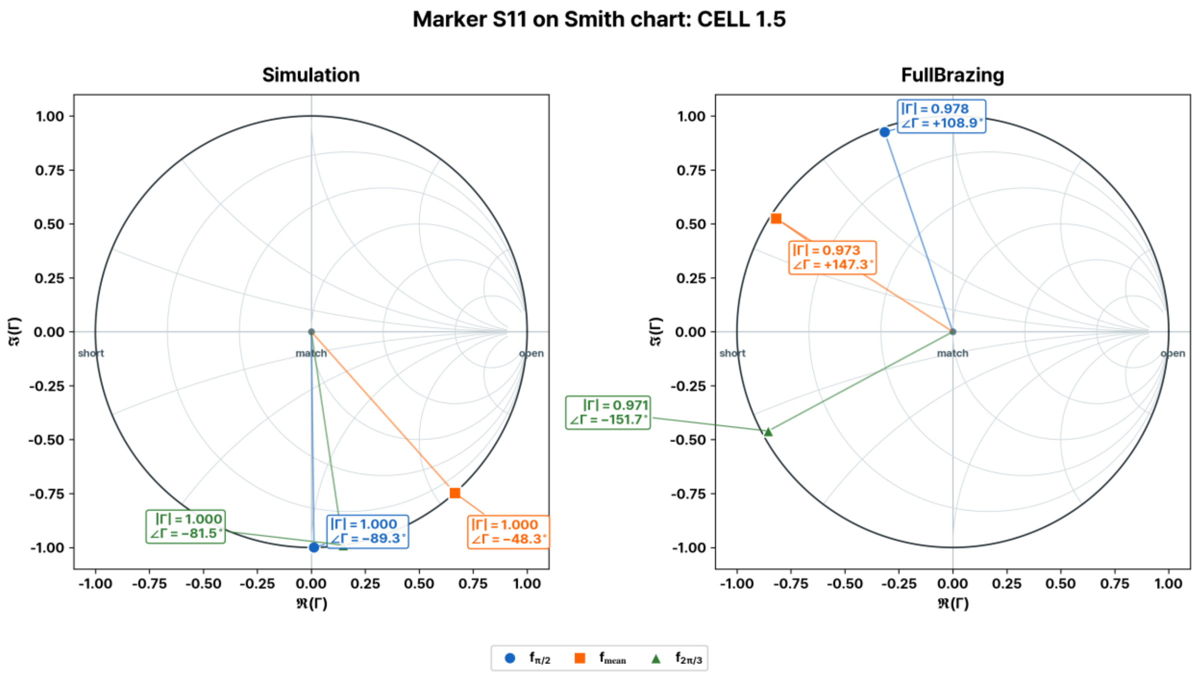

Fig. 1. Impedance points on a Smith Chart Plot.

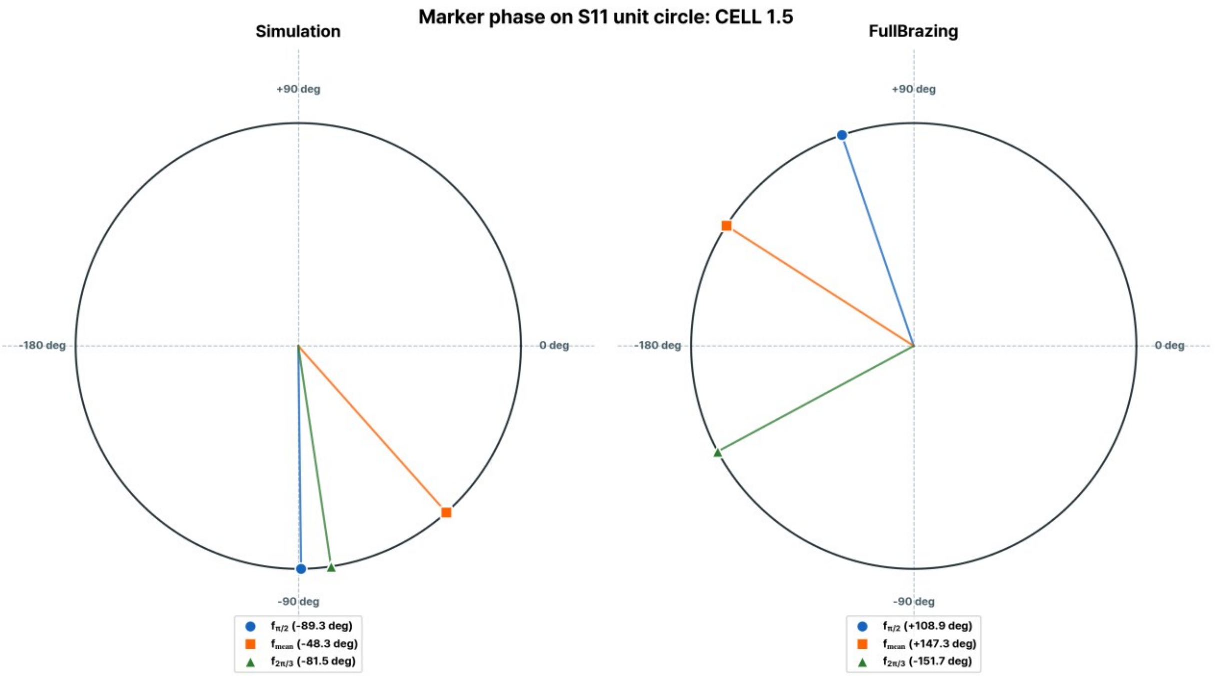


# [시뮬레이션 비교] Cell 1.5/2.5 에서의 detune 결과

이전 결과와의 비교를 위한 $S_{11}$ 값 측정&분석 수행.

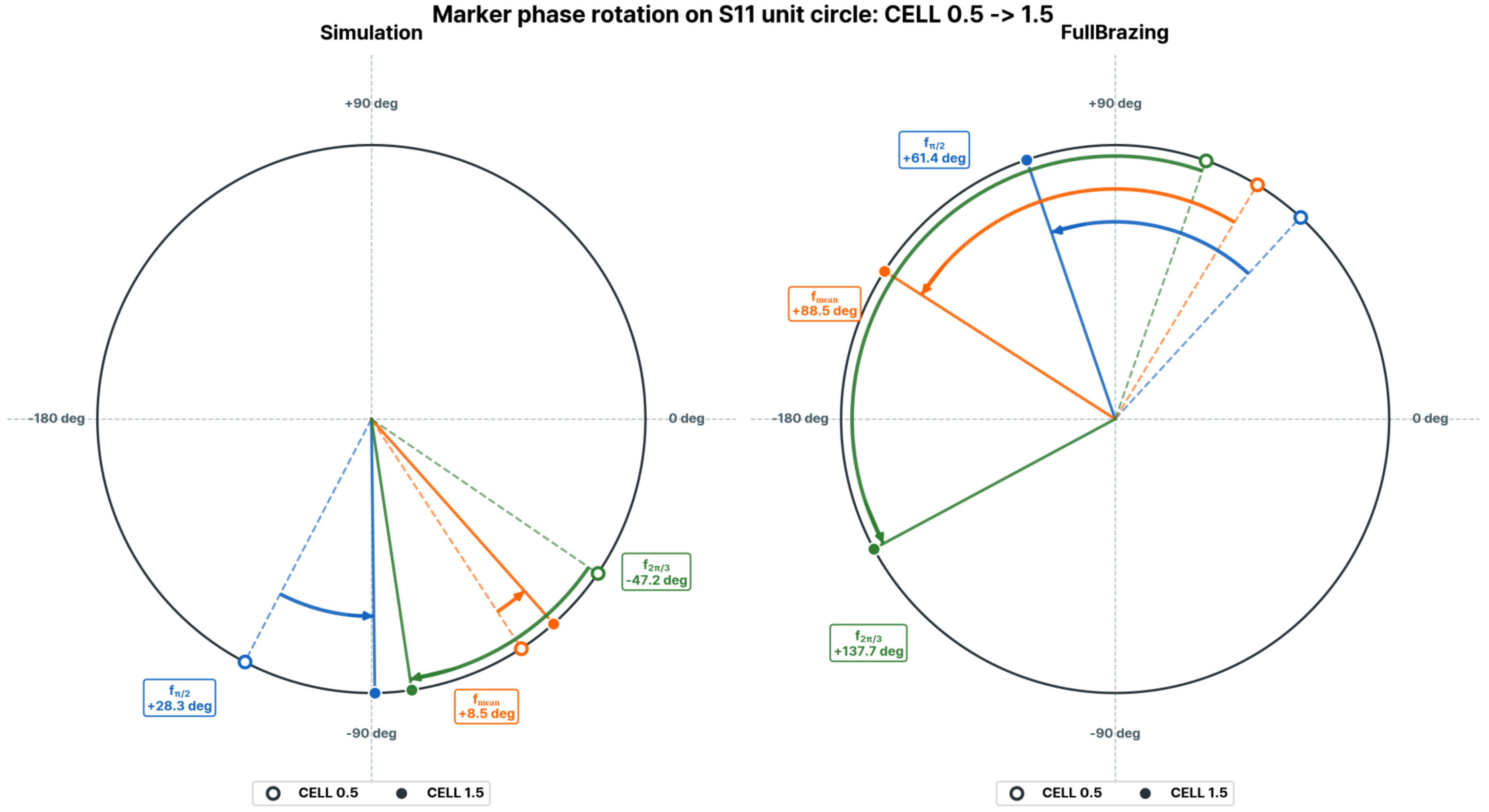


# Method: kyhl method (Impedance matching method)

Frequency tuning based on the coupled-cell model.

## Detune position desicion



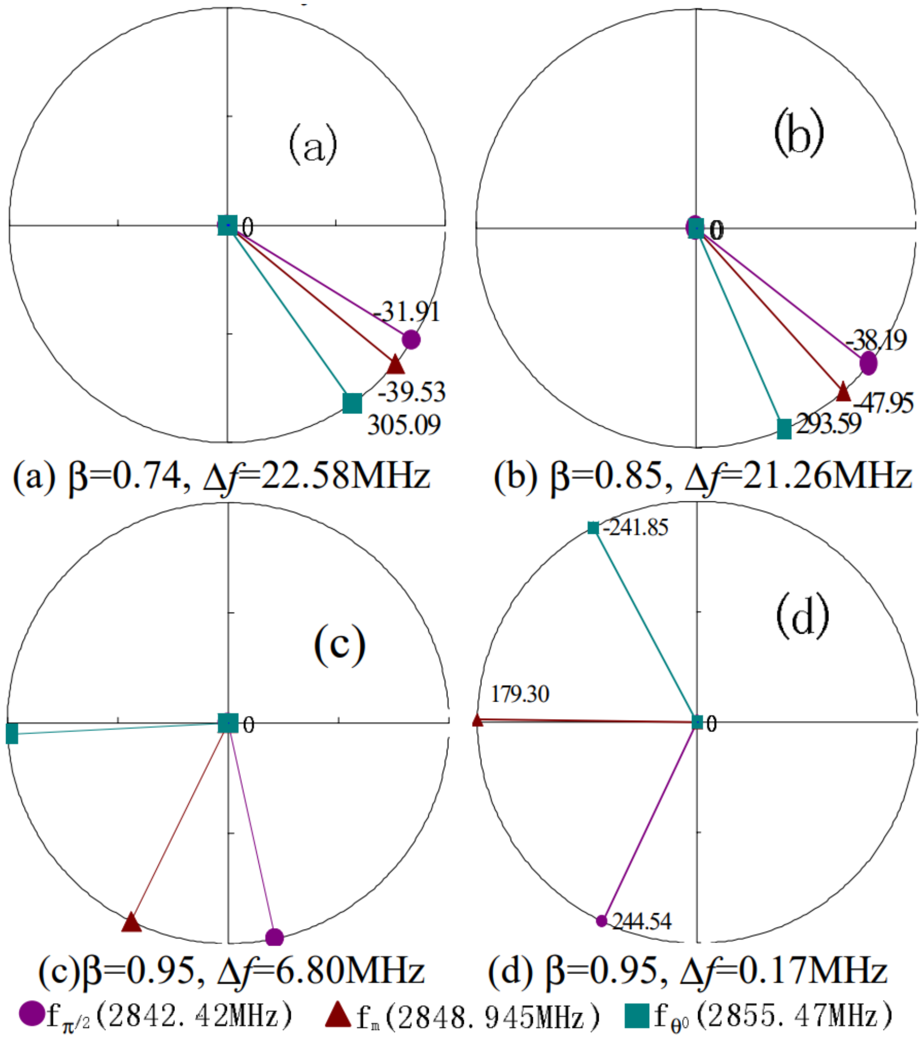



Figure 5. Example of one travelling wave accelerator coupler cavity tuning process

# Next plan

## Simulation: verify the simulation model

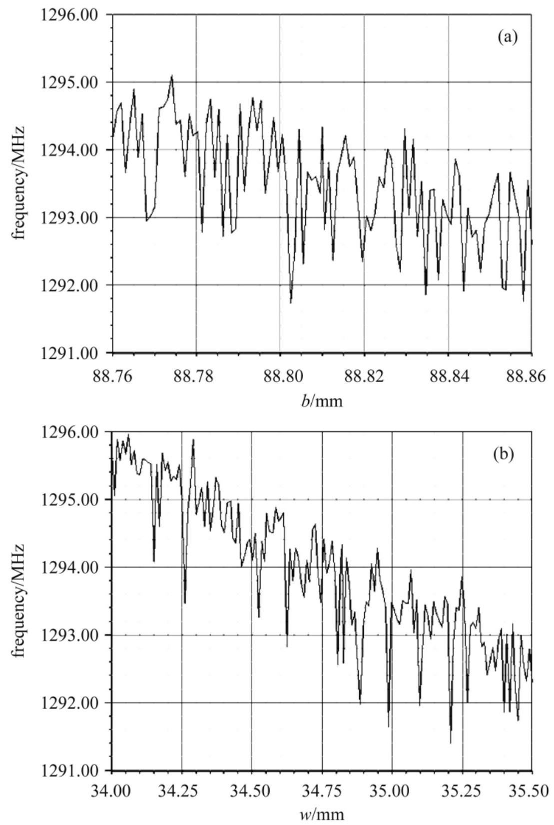



Fig. 5. The dependence of resonant frequency on coupler dimensions (a) $b$, (b) $w$ when the first accelerating cavity is detuned with the plunger.

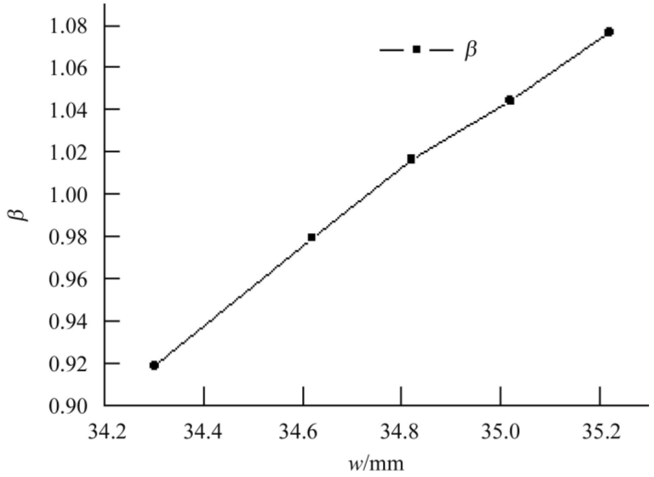



Fig. 6. The dependence of coupling coefficient on iris aperture.

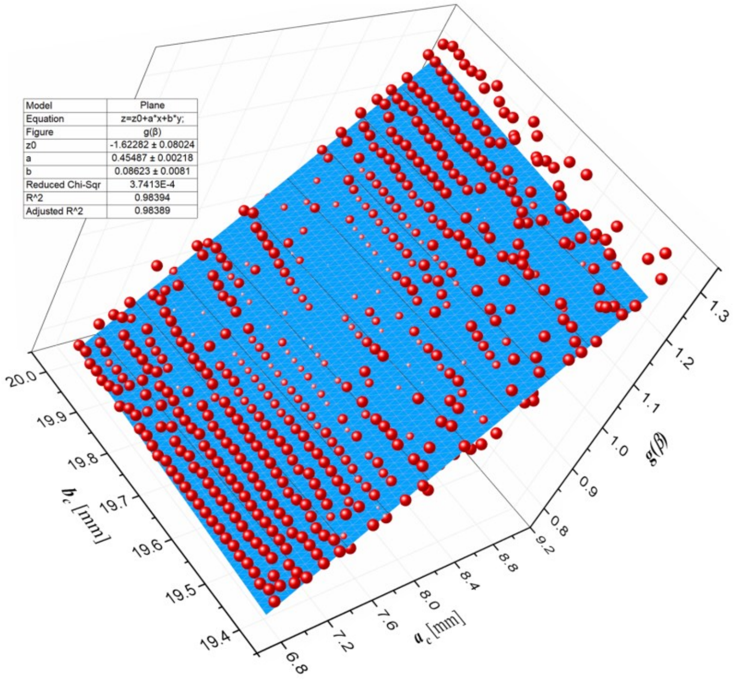



FIG. 6. $g(\beta)$ as a function of $a_c$ and $b_c$. It is inserted with a linear fitting plane, and $r^2$ denotes the fitting accuracy between a simulated plane and a fitting plane.