Fabrication of Improved Quadrant-type X-band High-Gradient Accelerating Structure

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International Workshop on Future Linear Colliders (LCWS2019),

Sendai, Japan

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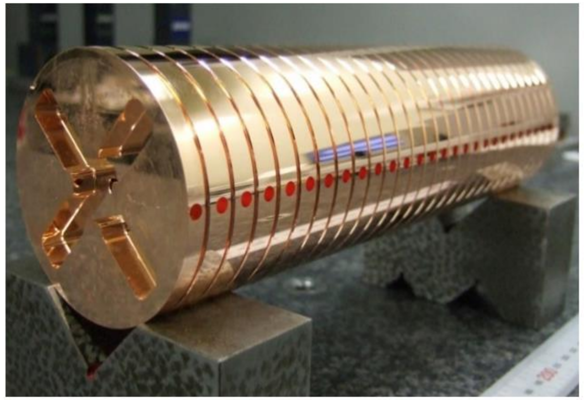
Disk-type v.s. Quadrant(or Half)-type

Disk-type

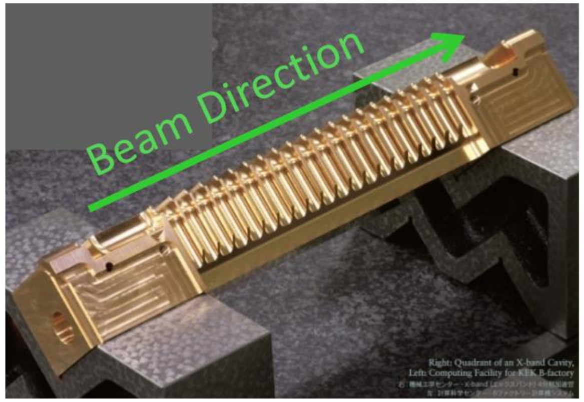
A damped disk



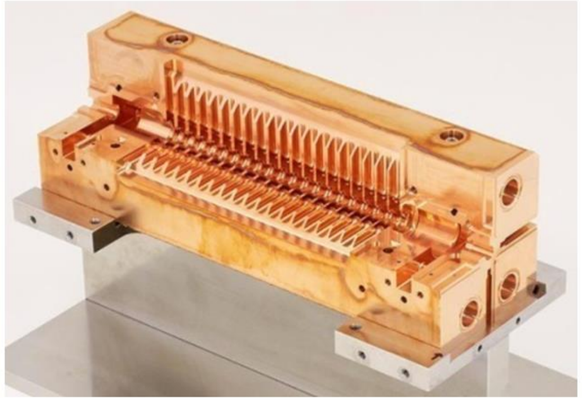
Disks stacked and bonded

- Advantages
  - ✓ Machining by turning for main parts
  - ✓ Very smooth surface (Ra = ~30 nm)
  - ✓ Shallow machining damage (depth < 1 μm)
- Disadvantages
  - ✓ Ultraprecision machining of dozen of disks
    - → Delicate stack and bonding
  - ✓ Great care needed to be taken
  - ✓ **Surface currents flow across disk-to-disk junctions.**

Quadrant-type



A Quadrant



Three Quadrants

- Advantages
  - ✓ **Surface currents do not flow across any bonding junction.**
  - ✓ Simple machining by five-axes milling machines
  - ✓ Simple assembly process with FOUR parts only
    - → Possibility of significant cost reduction
- Disadvantages
  - ✓ Not very smooth surface (Ra = ~ 0.3 μm)
  - ✓ Deep machining damage (~10 μm?)
  - ✓ **Possible virtual leak from quadrant-to-quadrant junctions**
  - ✓ **Field enhancements at the edges of quadrants**

DESIGN IMPROVEMENT

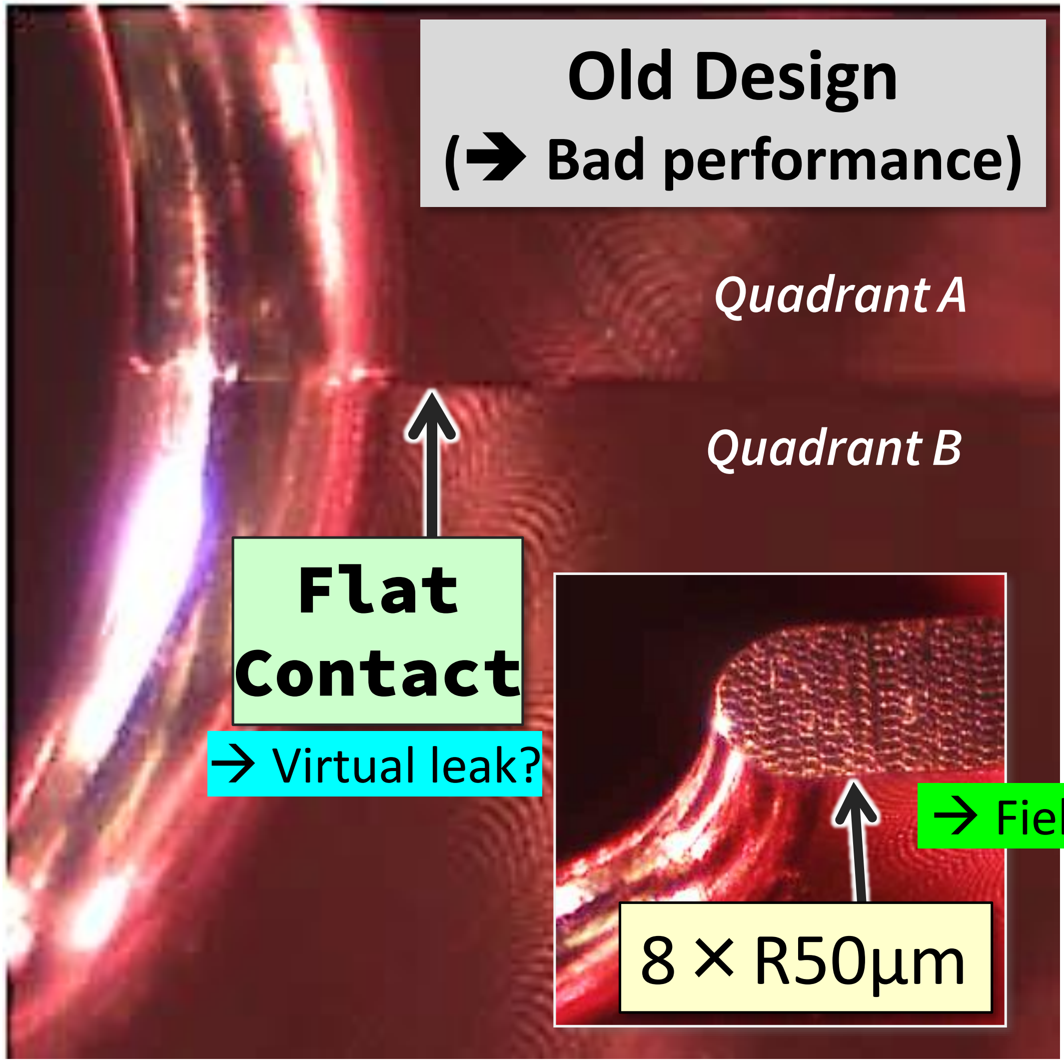
to
- ✓ Avoid virtual leak
- ✓ Suppress the field enhancement

The chamfer radius and small-gap size were optimized based on simulation to minimize

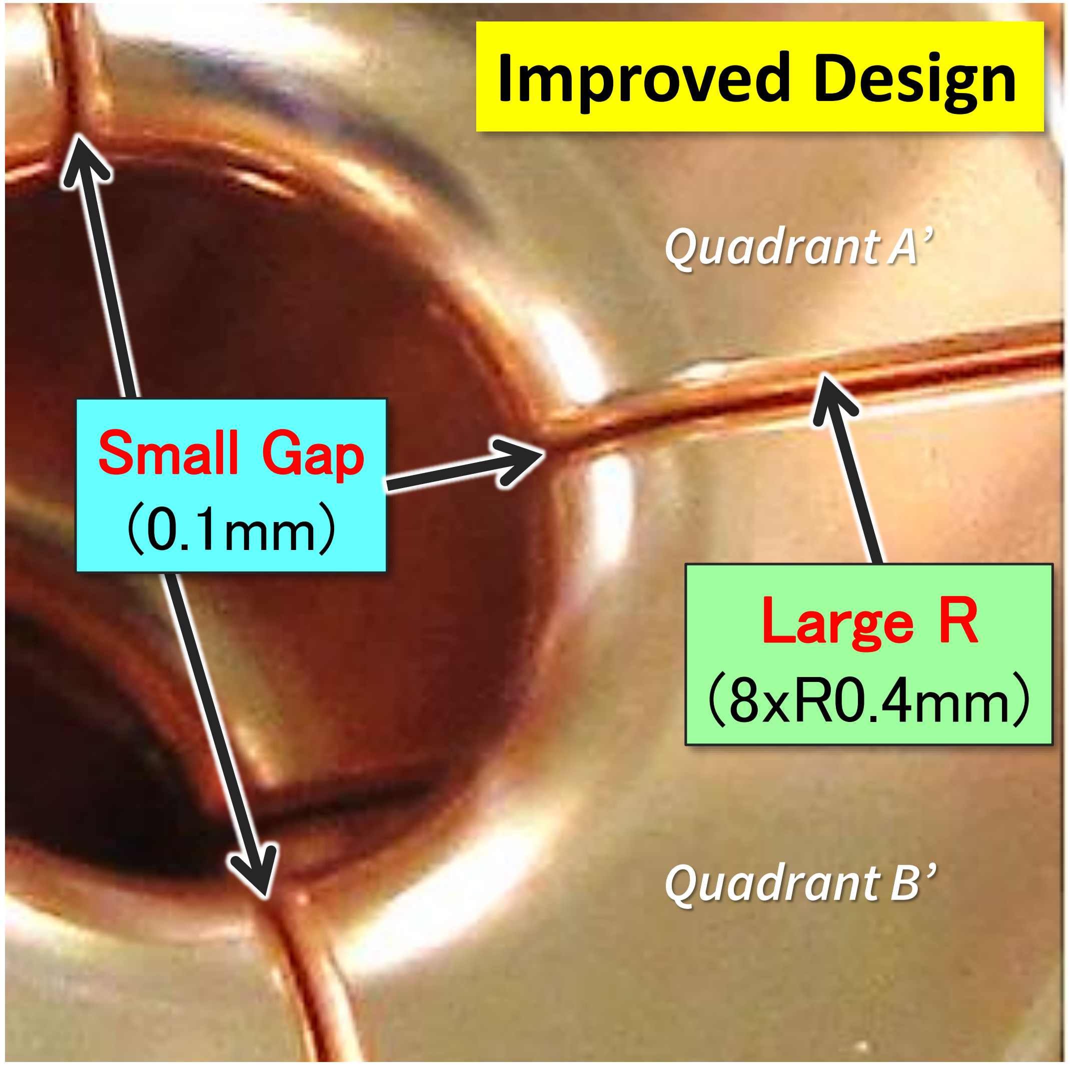
A) Field enhancement at the corner of the quadrants (→ +25%)

B) Deterioration of the shunt impedance (→ -2%)

For details, see T. Abe *et al.*, "Fabrication of Quadrant-Type X-Band Single-Cell Structure used for High Gradient Tests," presented at the 11th Annual Meeting of Particle Accelerator Society of Japan (2014), Paper ID: SUP042.

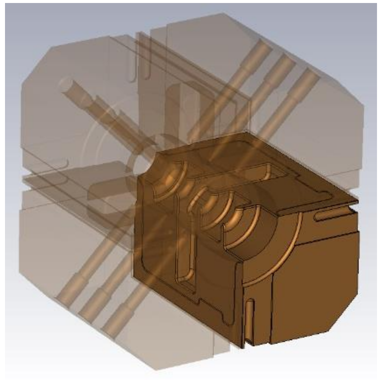


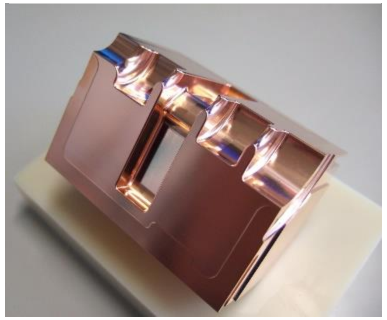
← Photo of the iris →

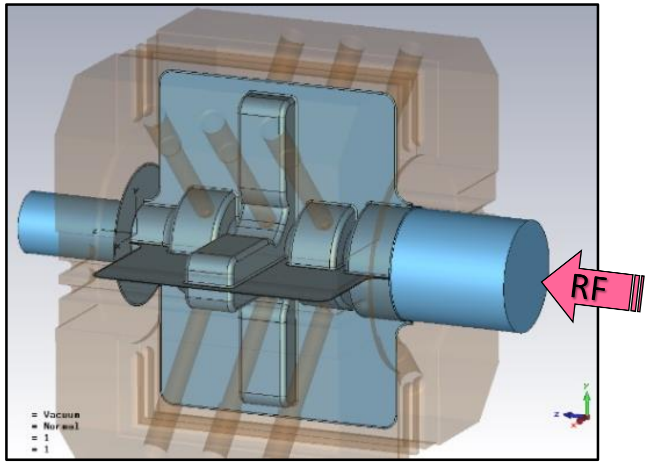


Demonstration of the High-Gradient Performance with a single-cell SW cavity

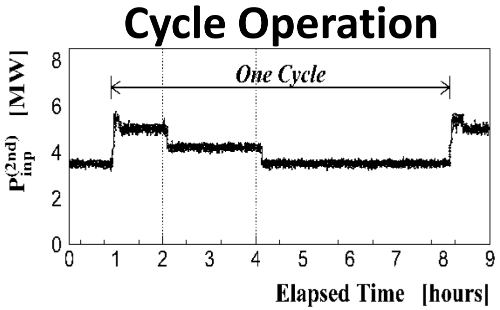
(SW: Standing Wave)







T. Abe *et al.*, "*High-Gradient Test Results on a Quadrant-Type X-Band Single-Cell Structure,*" presented at the 14th Annual Meeting of Particle Accelerator Society of Japan (2017), PaperID: WEP039.



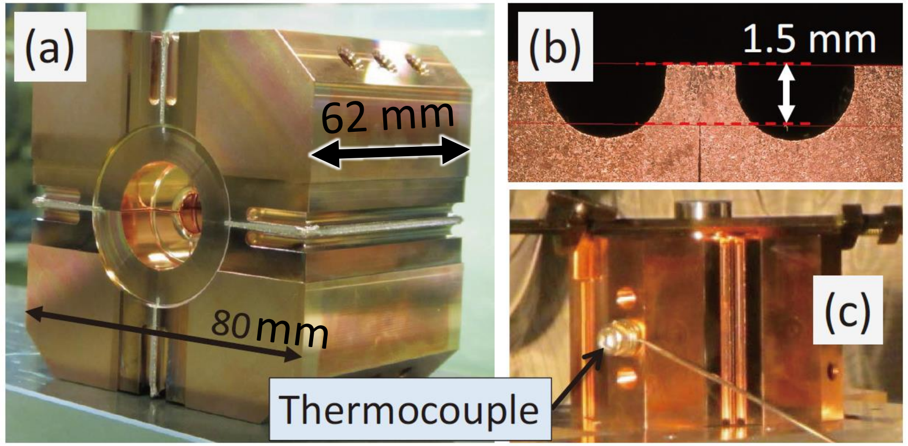
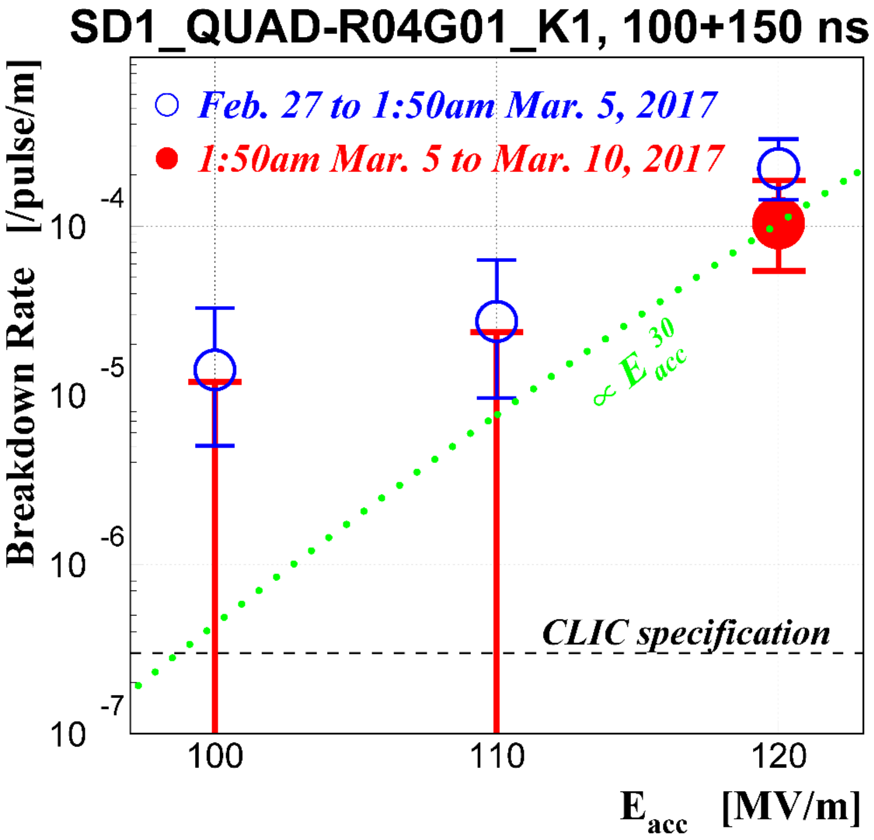


Figure 12: EBW of the quadrants. (a) After the EBW. (b) Welding penetration depth for the EBW conditions described in [13]. (c) A thermocouple is attached.

Breakdown-rate meas. after RF conditioning performed at KEK / Nextef / Shield-B



Good high-gradient performance demonstrated

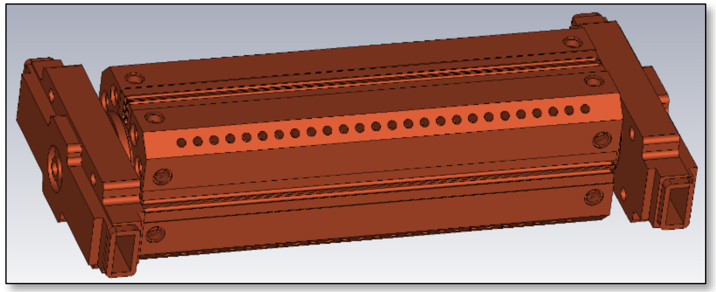
Nest step: Demonstration of the High-Gradient Performance for a 24-cell TW structure of the CLIC prototype structure:

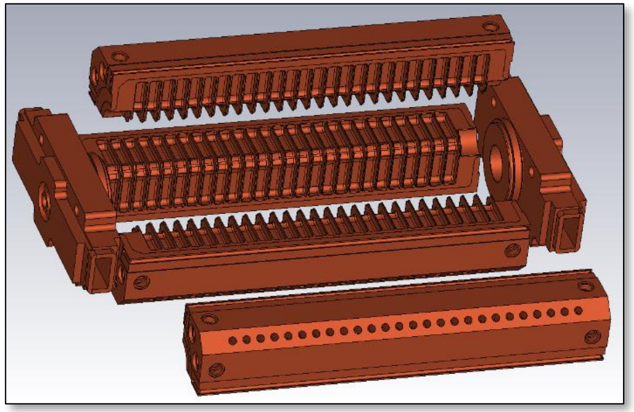
(TW: Traveling Wave)

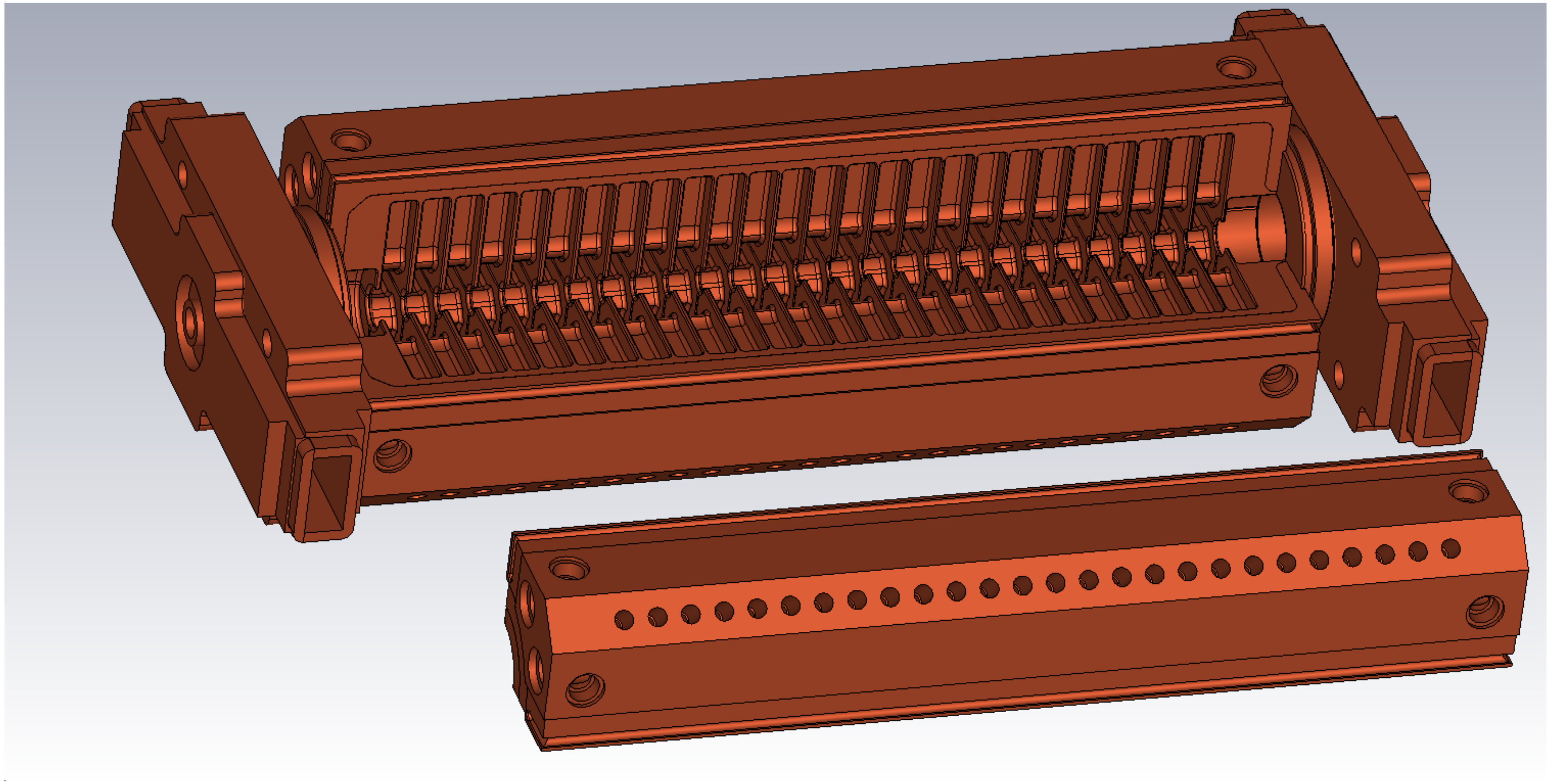
“TD24R10_QUAD-R04G01”

Chamfer radius: 0.4 mm

Gap between quadrants: 0.1 mm

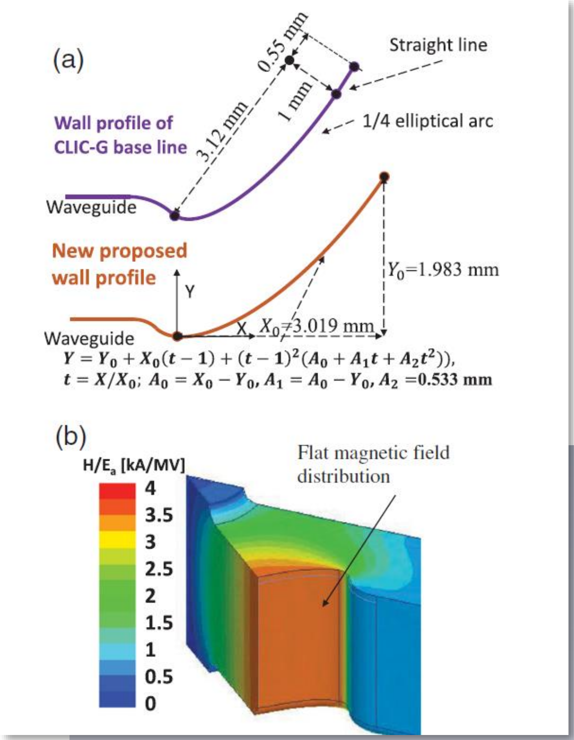


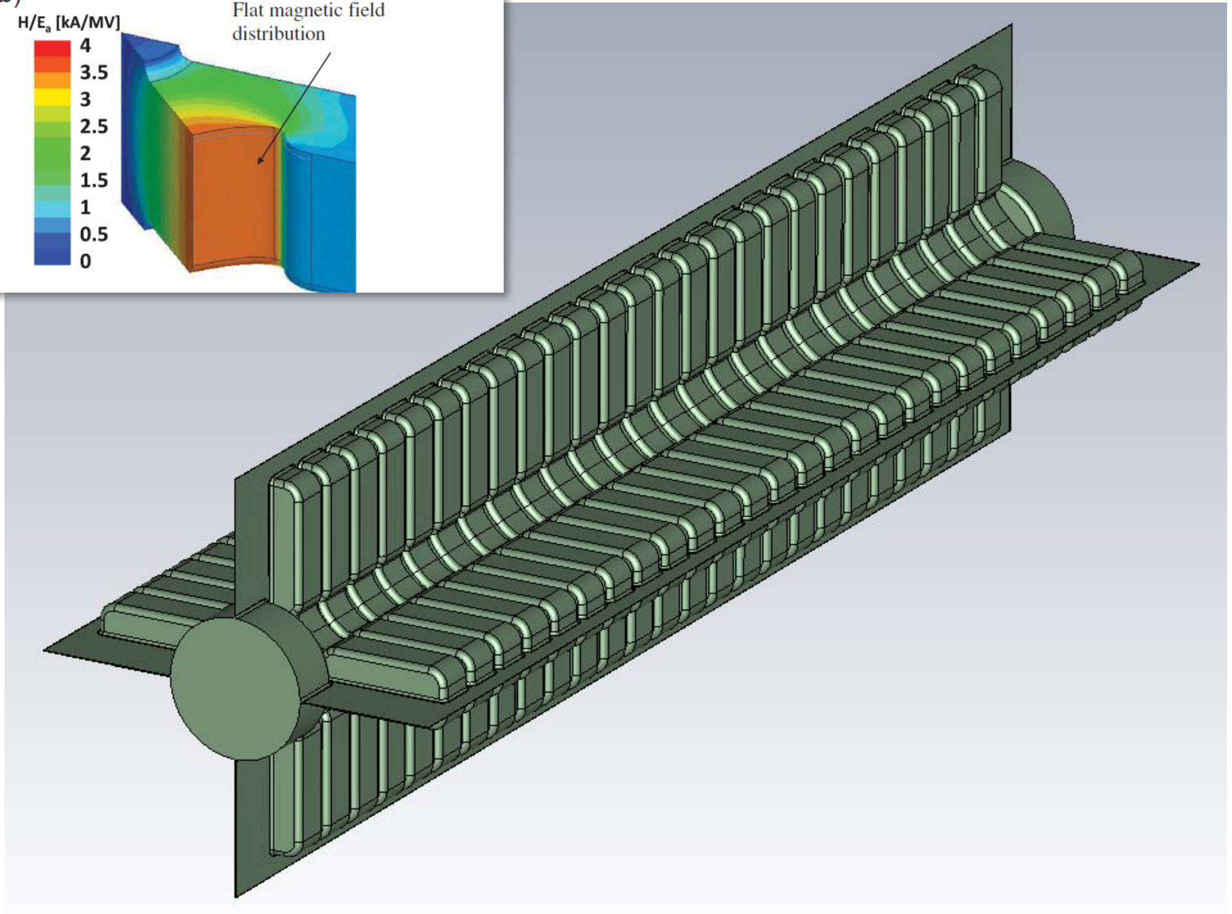


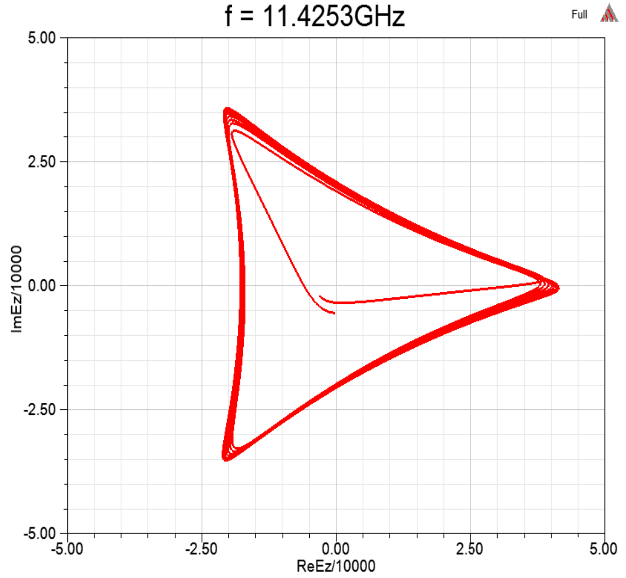


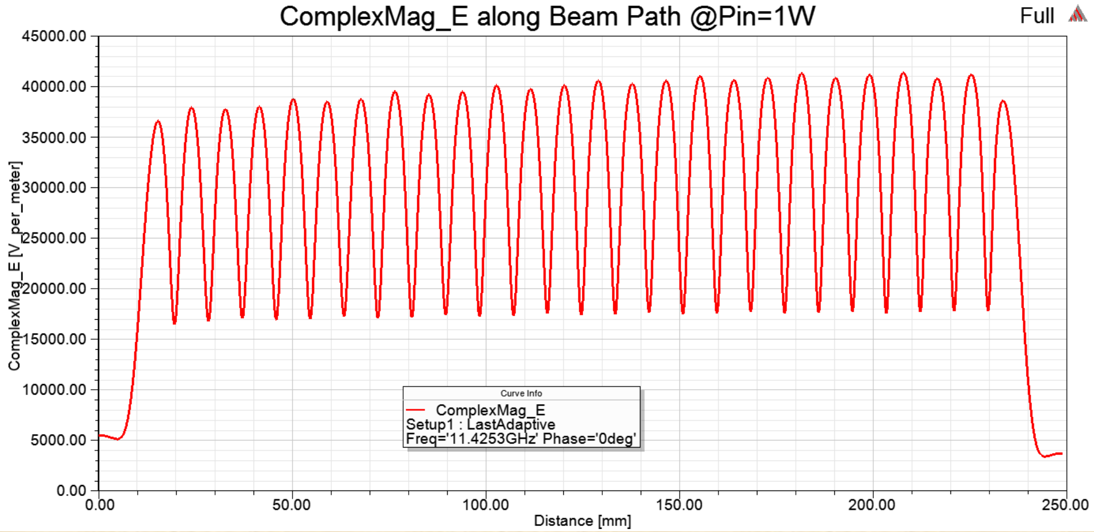
Cavity Design based on CLIC-G*

Made by Jiayang Liu (THU) and Alexej Grudiev (CERN)

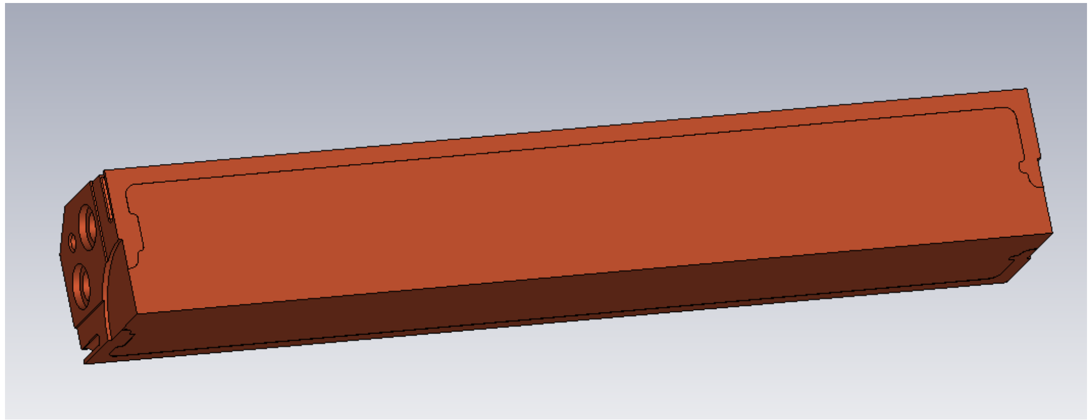




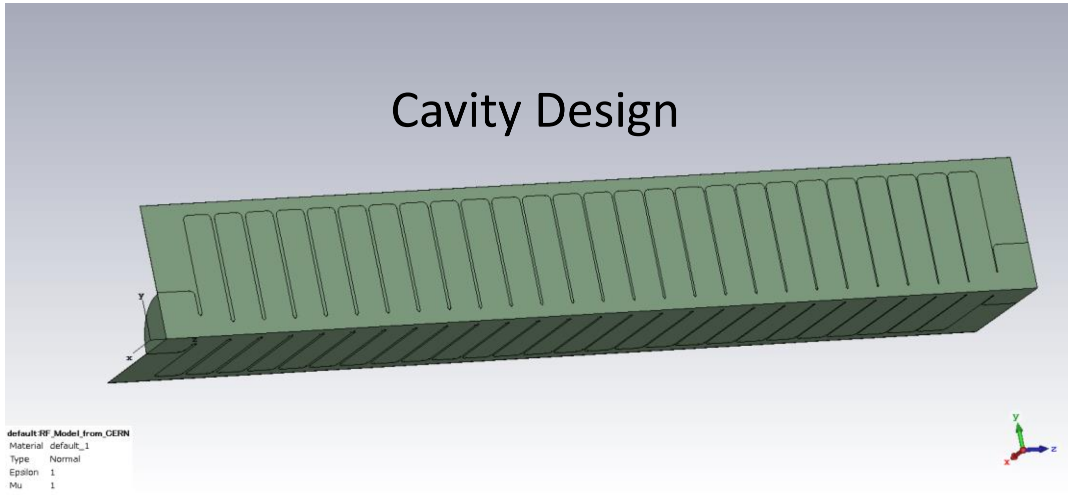




From the Cavity Design to the 3D Mechanical Drawing



minus



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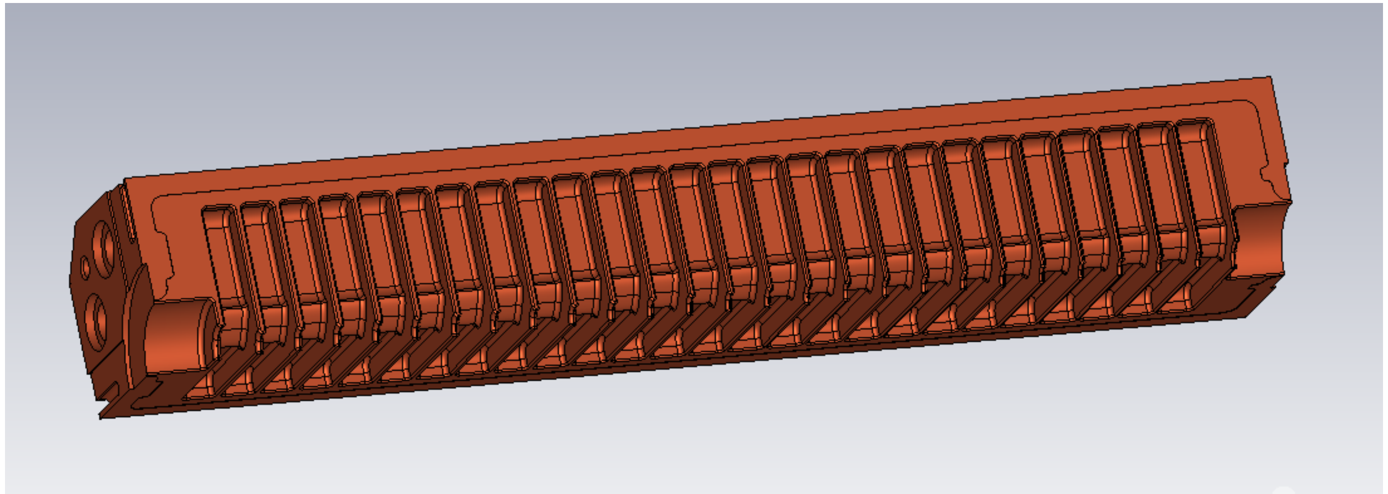
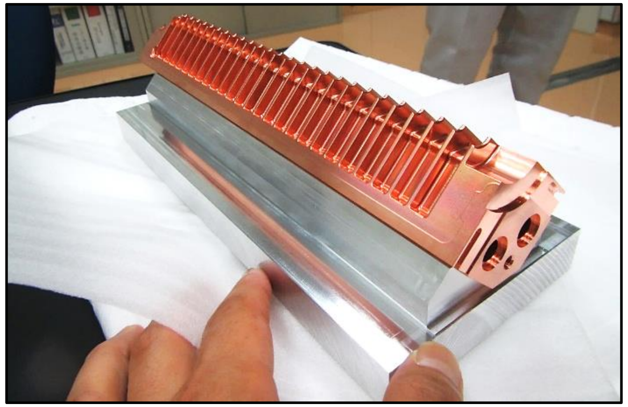
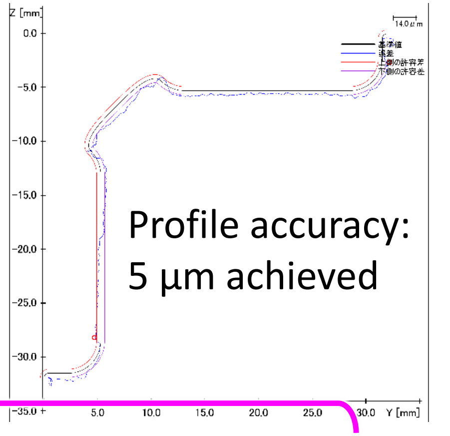


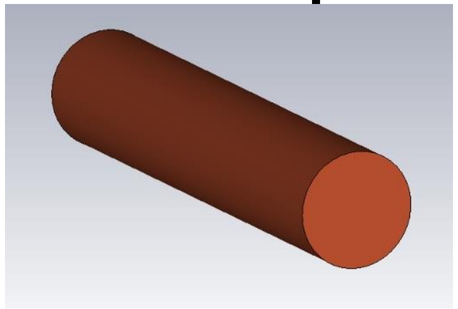


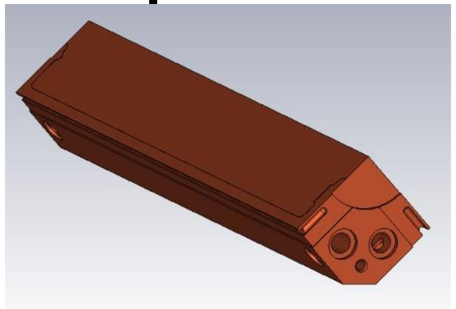
Ultraprecision Milling

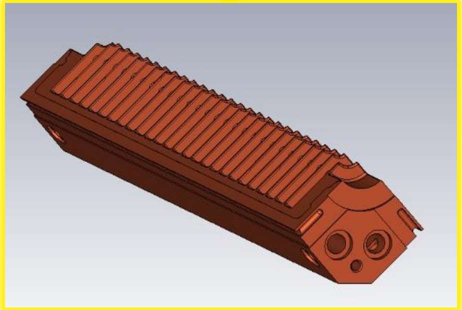
- ✓ *Machining by U-Corporation*
- ✓ *Milling machine used: YASDA H30i* (~1M USD)
- ✓ *Tool: carbide ball endmill*



	Step 0	Step 1	Meas.	Step 2	Meas.	Step 3	Meas.	Step 4
Unmachined thickness [mm]		0.1		0.1		0.03		0
Size of the endmill [mm]	Various	R2		R0.75				
Surface roughness achieved	n/a							Ra0.3μm
Machining time / quadrant	13 h	18 h		1 day		2 days		2 days



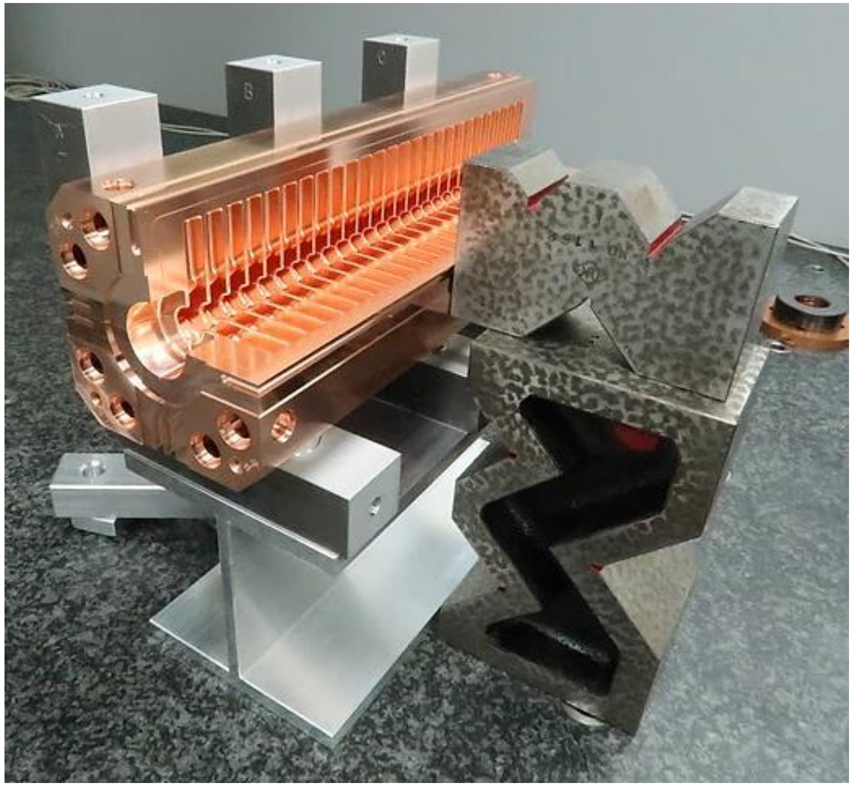


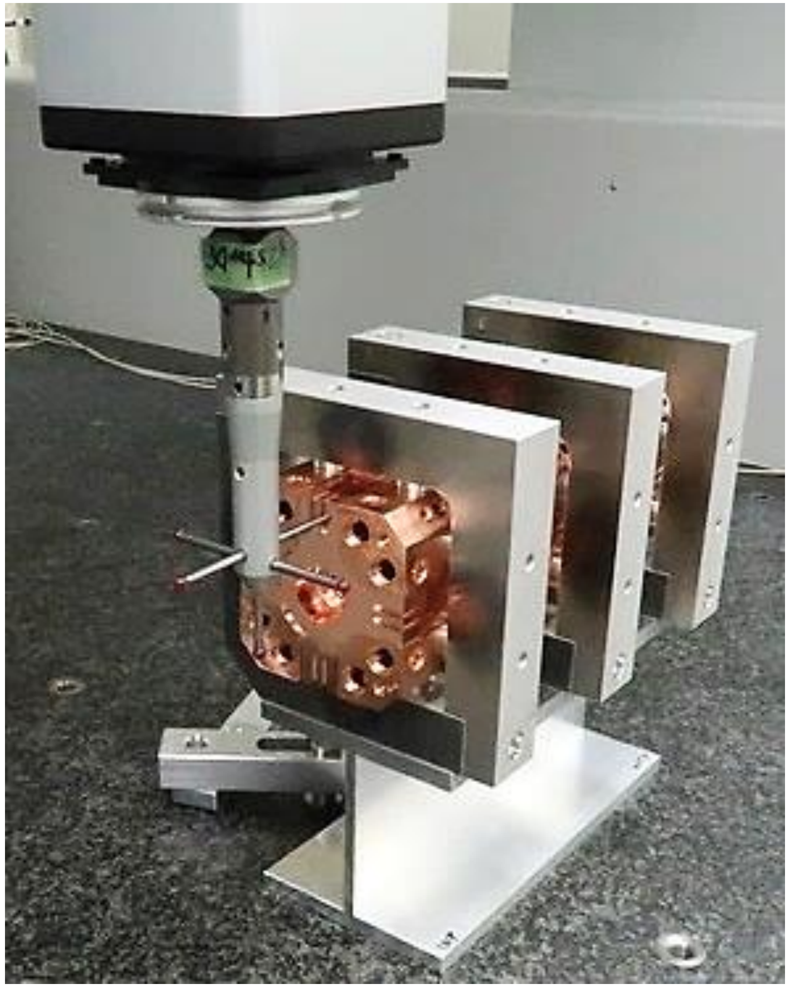


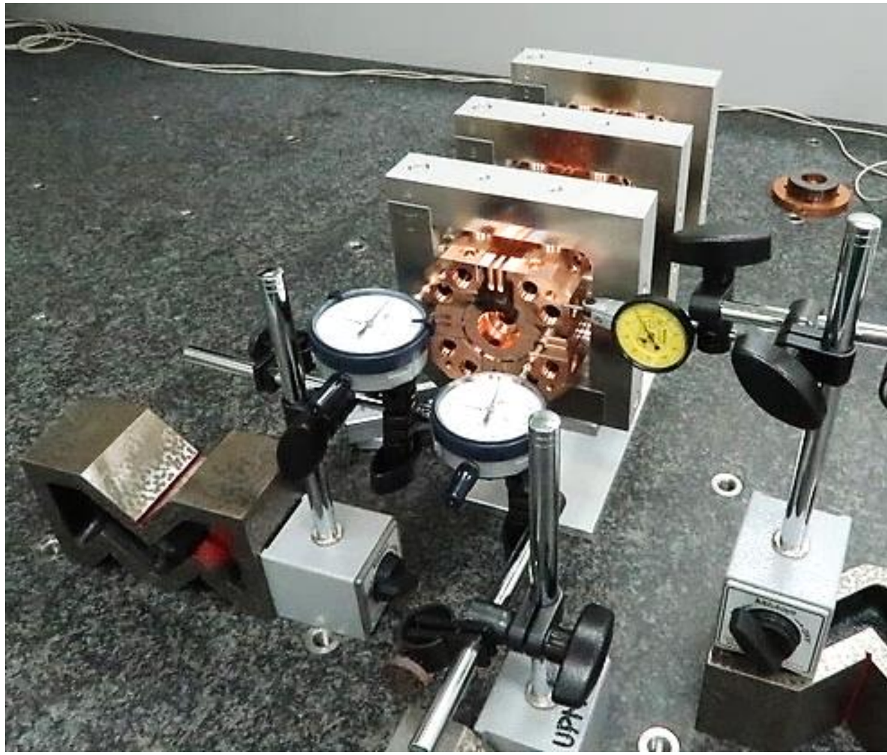
Machining-time reduction is needed for cost reduction.

Assembly with 5 μm accuracy

by T. Takatomi

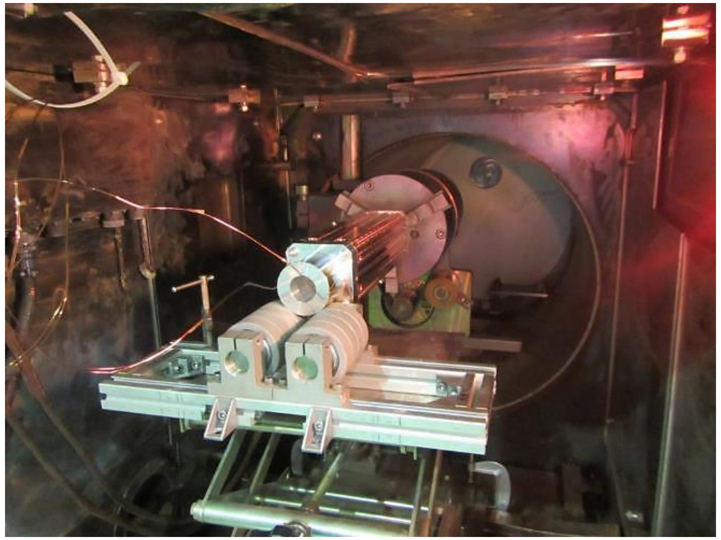


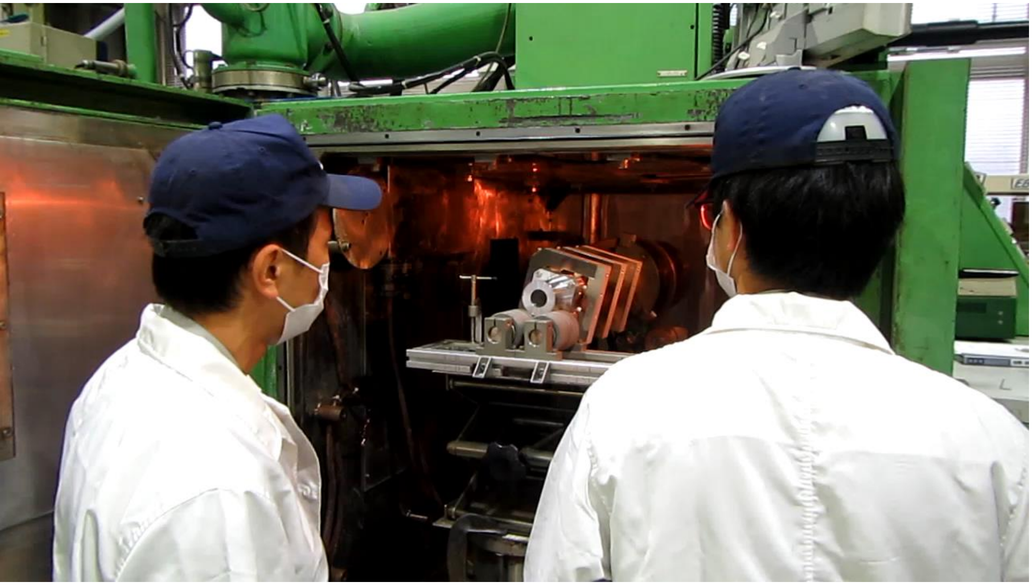




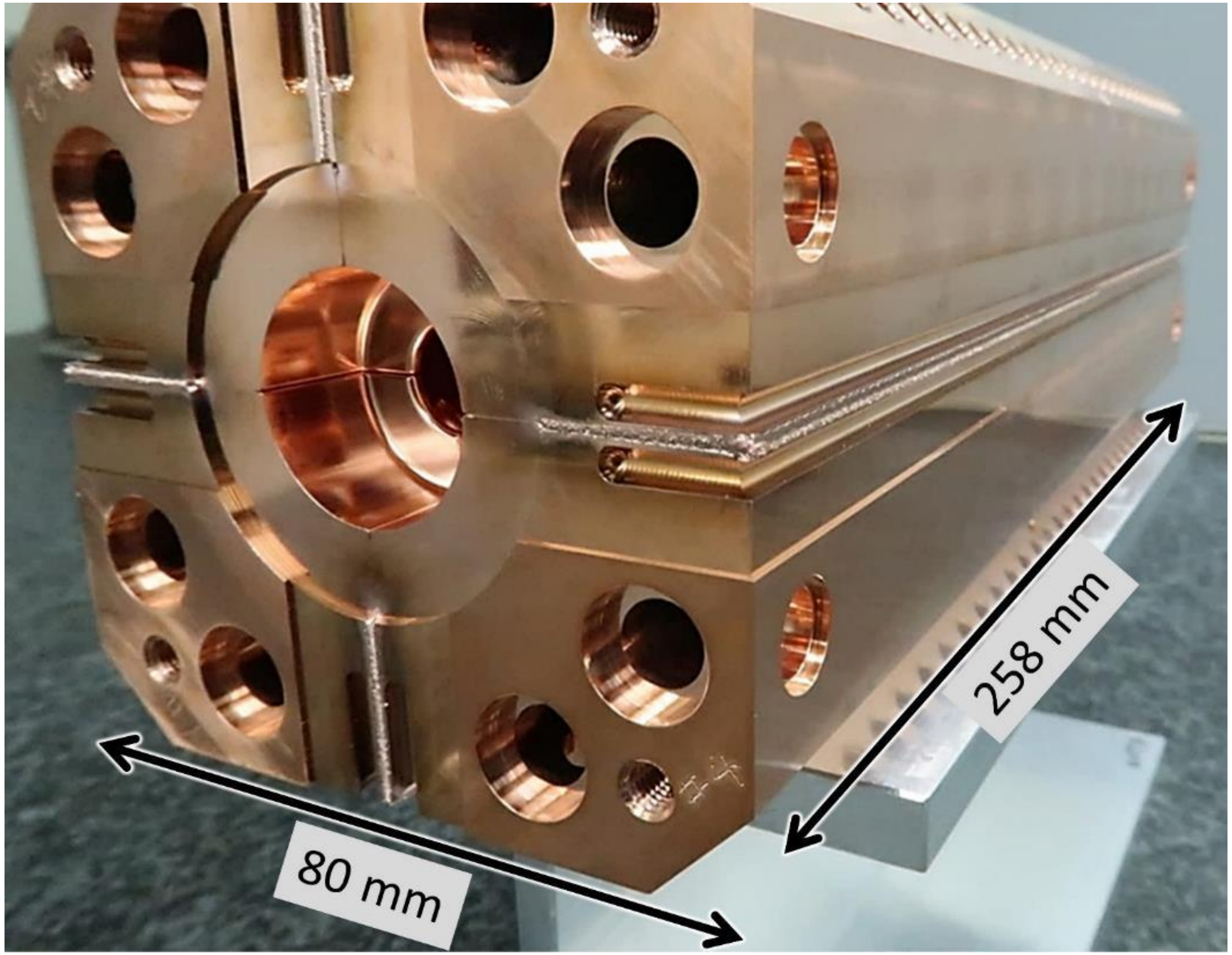
Bonding with Electron Beam Welding (EBW)

by TAIYO EB tech

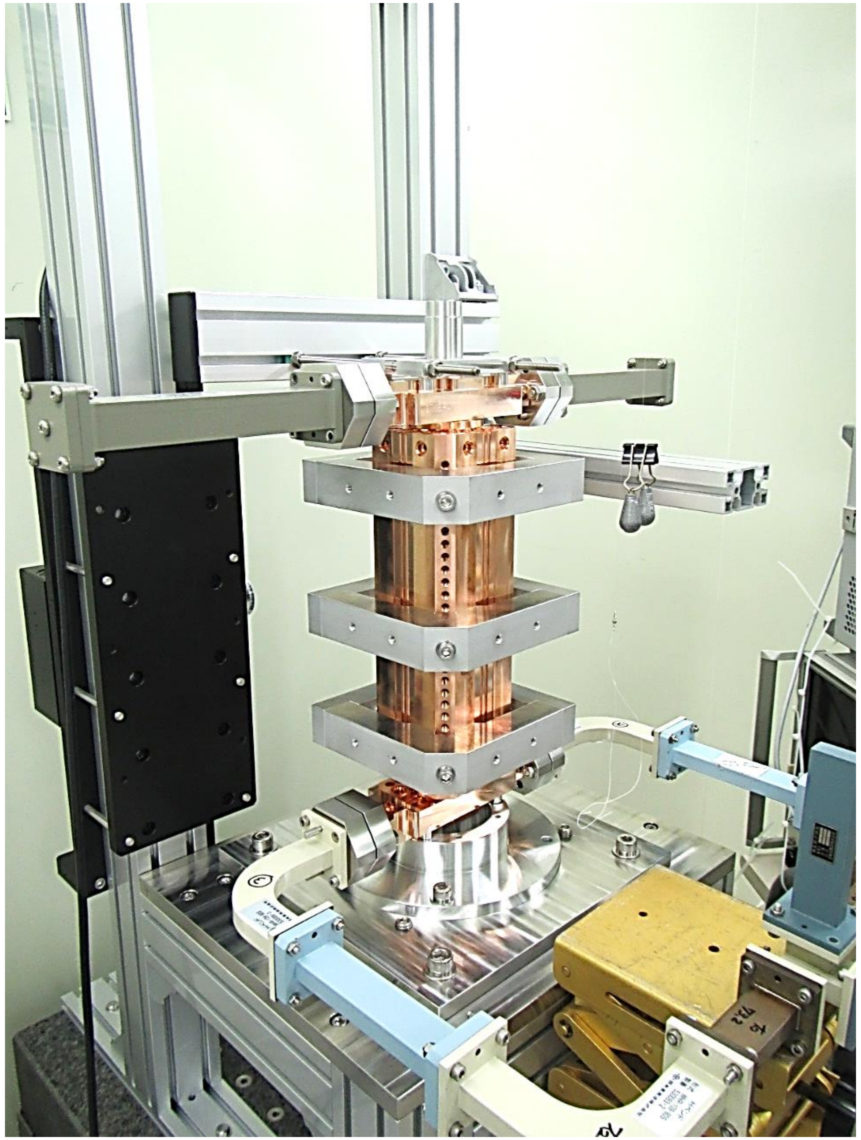




After the EBW



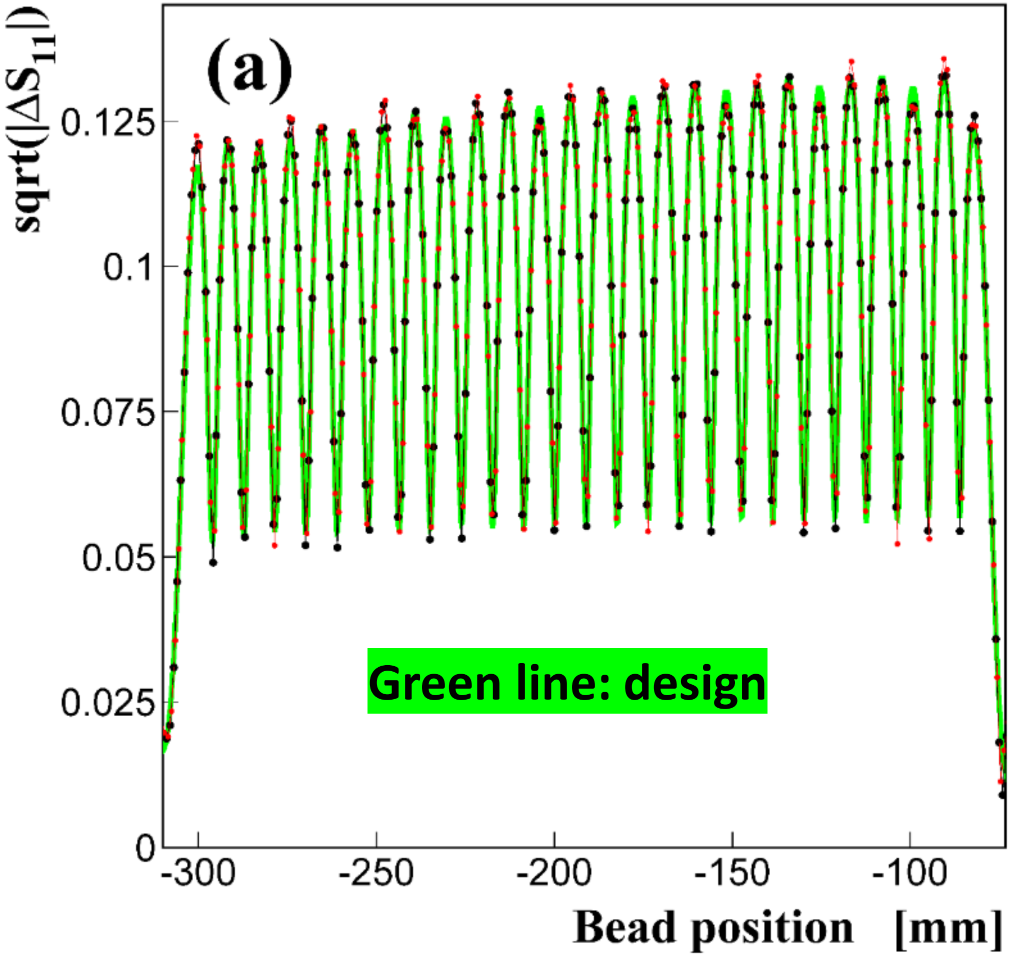
RF Measurement



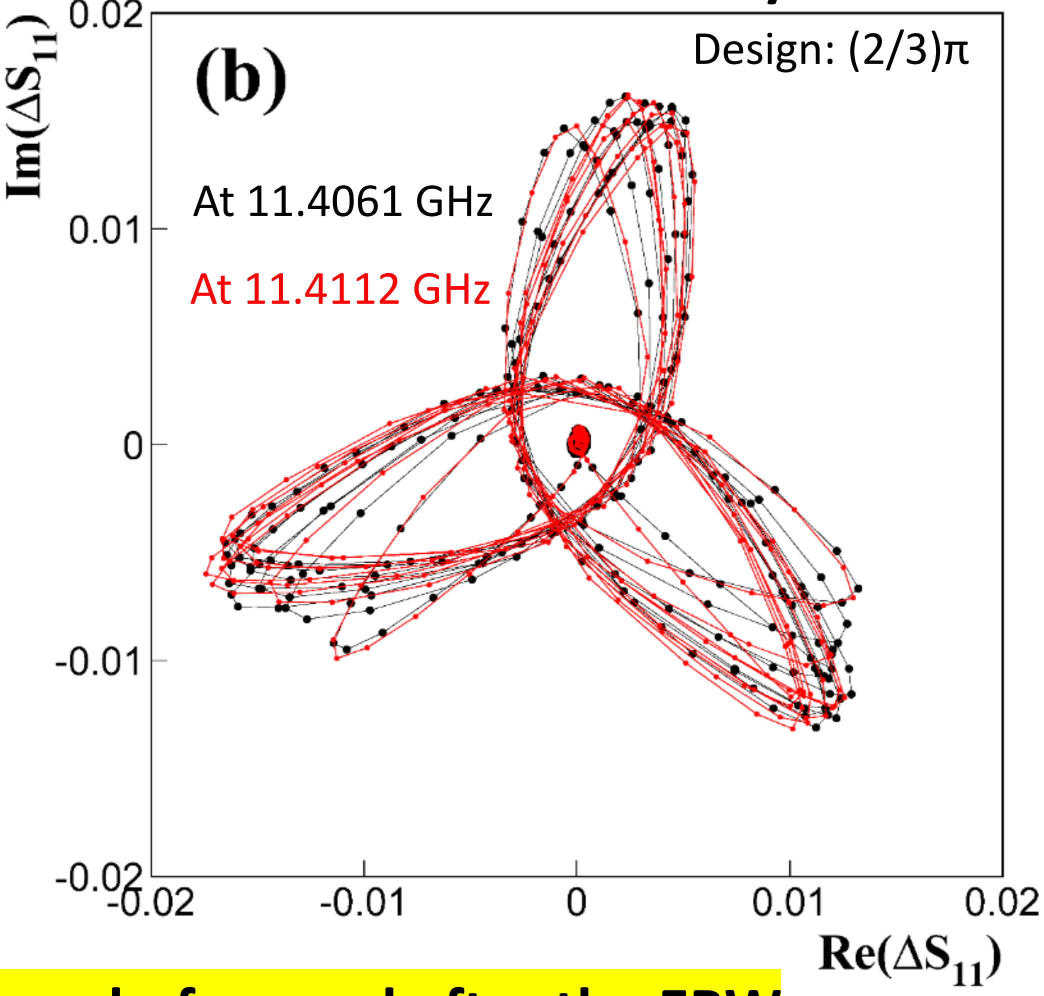
RF Meas. Results before (black) / after (red) the EBW (1/2)

No frequency tuning done yet

|Ez|



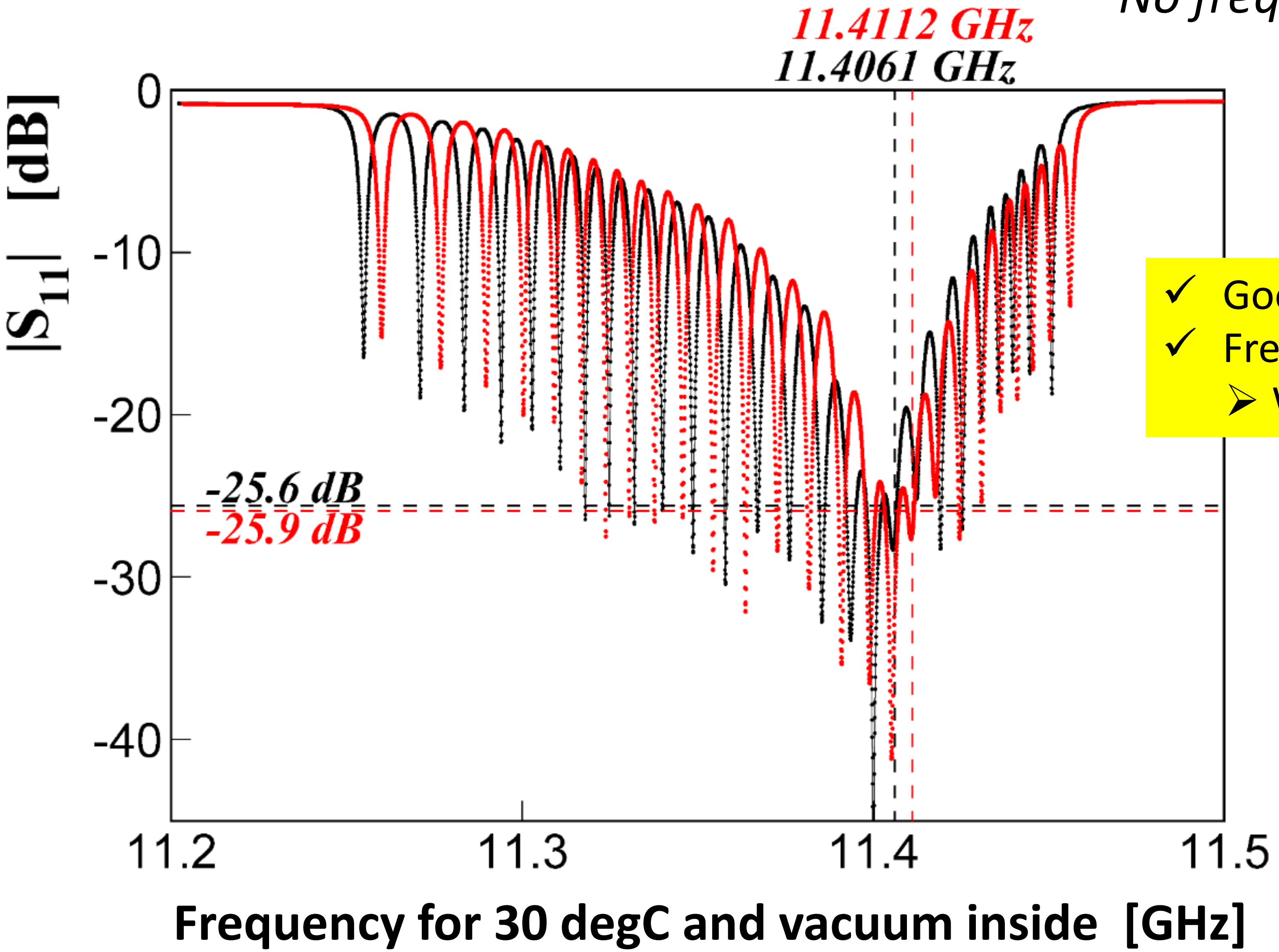
Phase advance /cell



- ✓ **No significant difference before and after the EBW**
- ✓ **These meas. close to the design**

RF Meas. Results before (black) / after (red) the EBW (1/2)

No frequency tuning done yet

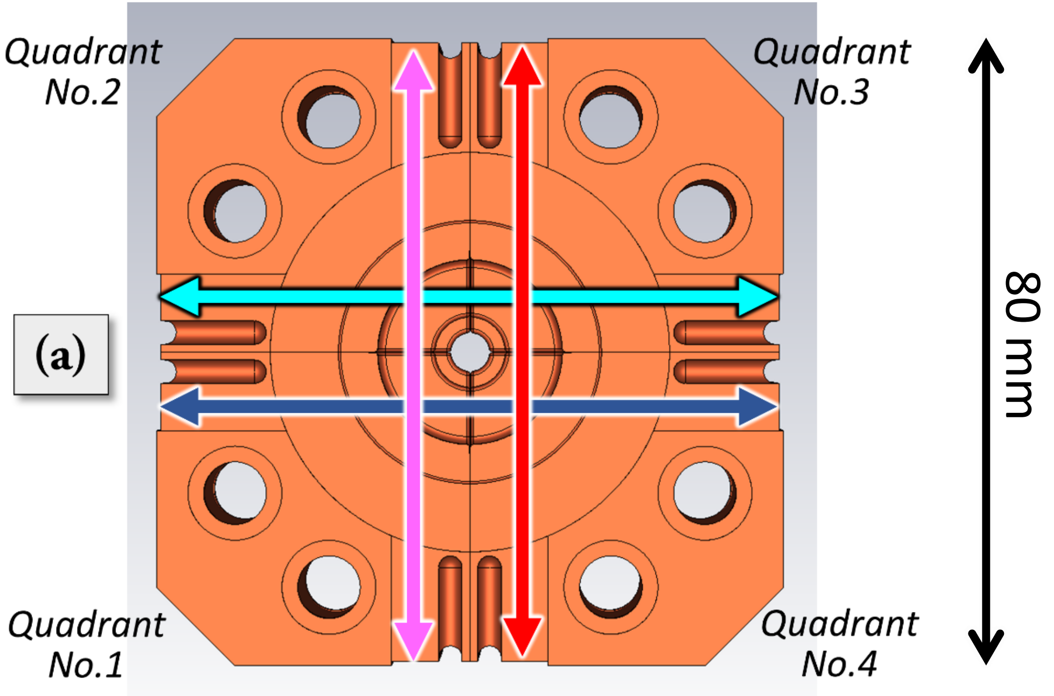


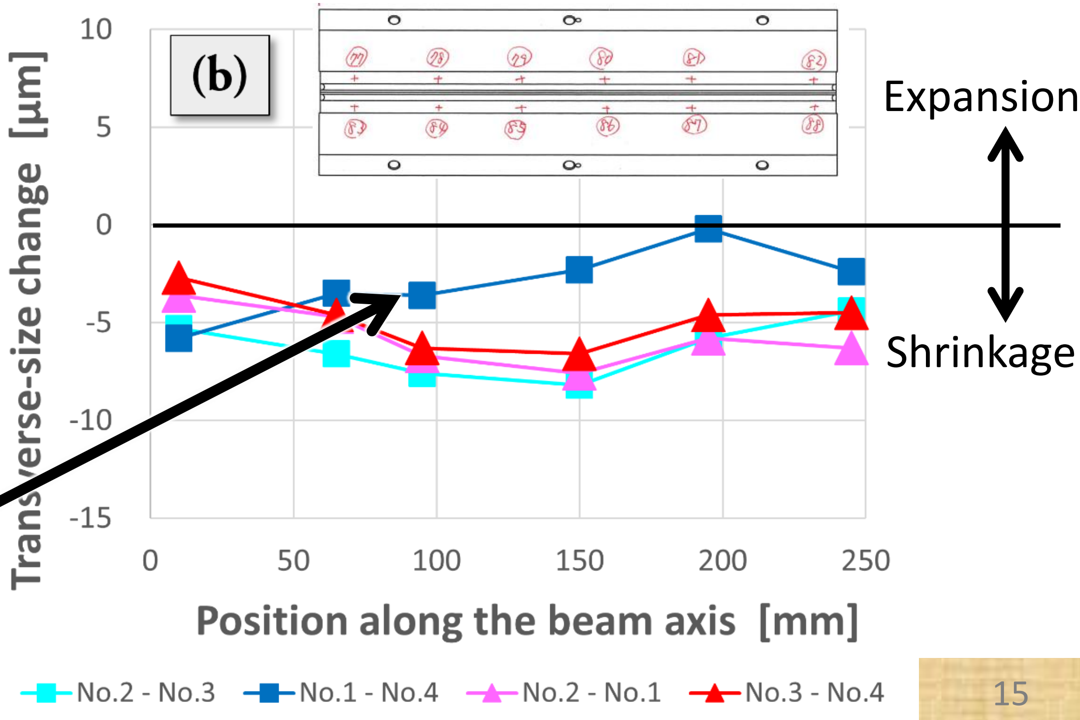
- ✓ Good matching without tuning（< -25dB）
- ✓ Frequency increased by +5.1 MHz
  - ➢ Within tuning rage: ± 40 MHz

Transverse-size change by the EBW measured using a CMM

by T. Takatomi

Using Carl Zeiss UPMC 850 CARAT
at KEK / Mechanical Engineering Center





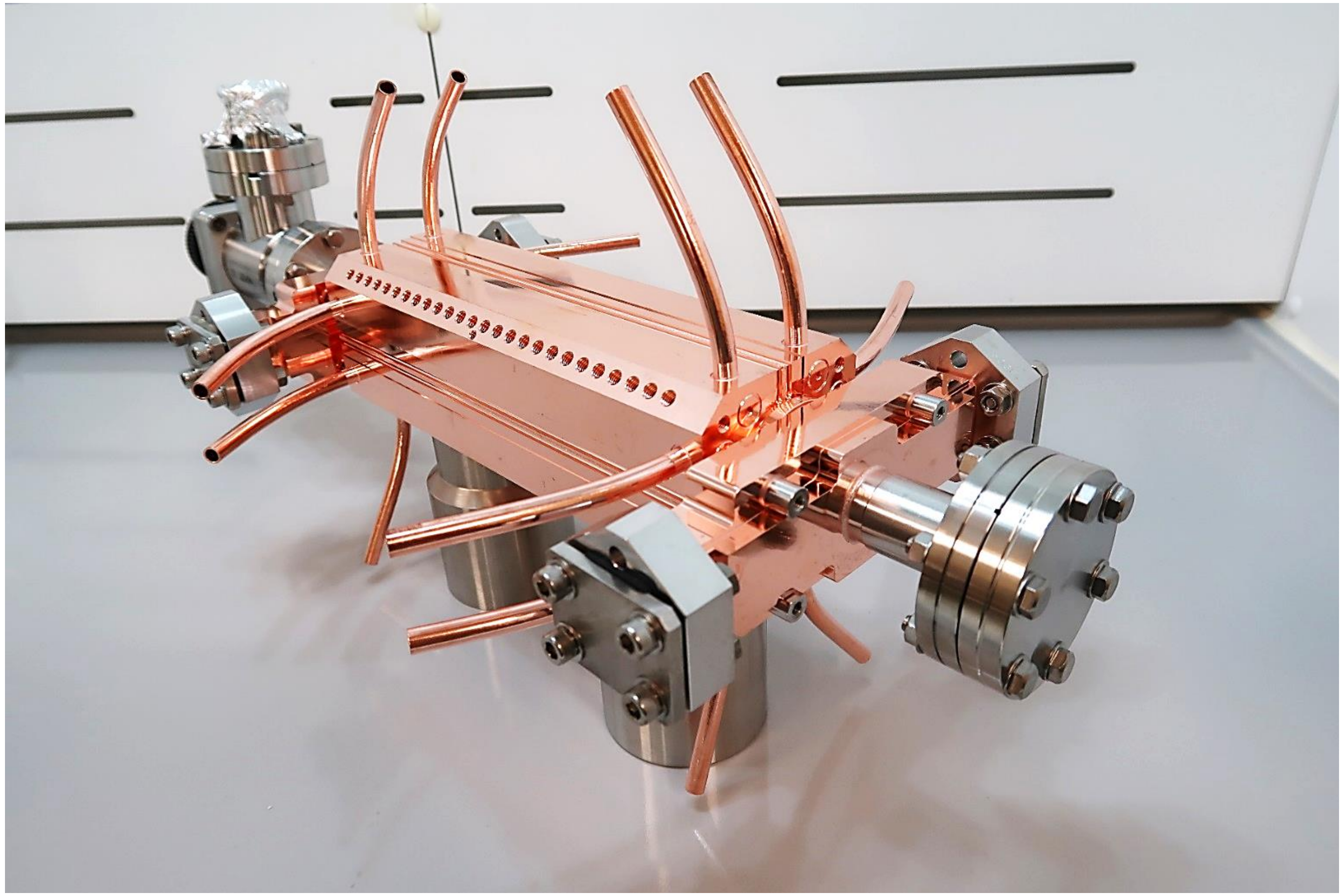
- ✓ 5 μm shrinkage in average
- ✓ Difference among the meas.: 2 to 3 μm

Check of the sequence in the EBW

Summary

- The quadrant(or half)-type fabrication method has advantages that:
  - Surface currents do not flow across any bonding junctions,
  - Possible significant cost reduction in fabrication, and
  - Bonding is easy with EBW without high temperature process.
    - Suitable for fabricating accelerating structures made of harder material with possibly higher high-gradient performance
- The naïve quadrant-type structure showed bad high-gradient performance.
- The design improved, characterized by:
  - Large round chamfer at the edges of quadrants
  - Finite gap between quadrants
- Good high-gradient performance for the improved quadrant-type single-cell SW cavity demonstrated
- The 24-cell TW structure (TD24R10_QUAD) has been fabricated for complete demonstration.
  - The quadrants were bonded with EBW.
  - No significant difference in the RF properties before and after the EBW
  - The frequency change: +5.1 MHz (<< frequency tuning rage: $\pm$ 40 MHz)
  - The measured RF properties found close to the design without frequency tuning

TD24R10_QUAD-R04G01_K1 fabrication completed



Waiting for high-gradient test…

Thank you for your attention!