Basic Study on High-Gradient Accelerating Structures at KEK / Nextef

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on behalf of Nextef group
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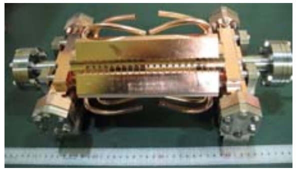
HG2015 Workshop at Tsinghua University, Beijing, China
2015-06-19

Research Strategy

*Based on NC **X-band technology***
developed by SLAC-CERN-KEK collaboration



Multi-Cell Prototypes

Electrical Design

Mechanical Design

Fabrication

HG Test

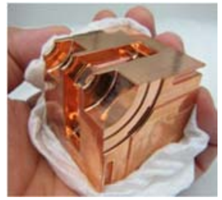
Feedback

Problems / *Solutions*

Problems / *Solutions*

Problems / *Solutions*

- ✓ Comprehensive study and development
- ✓ Cost and time consuming



Single-Cell Cavities

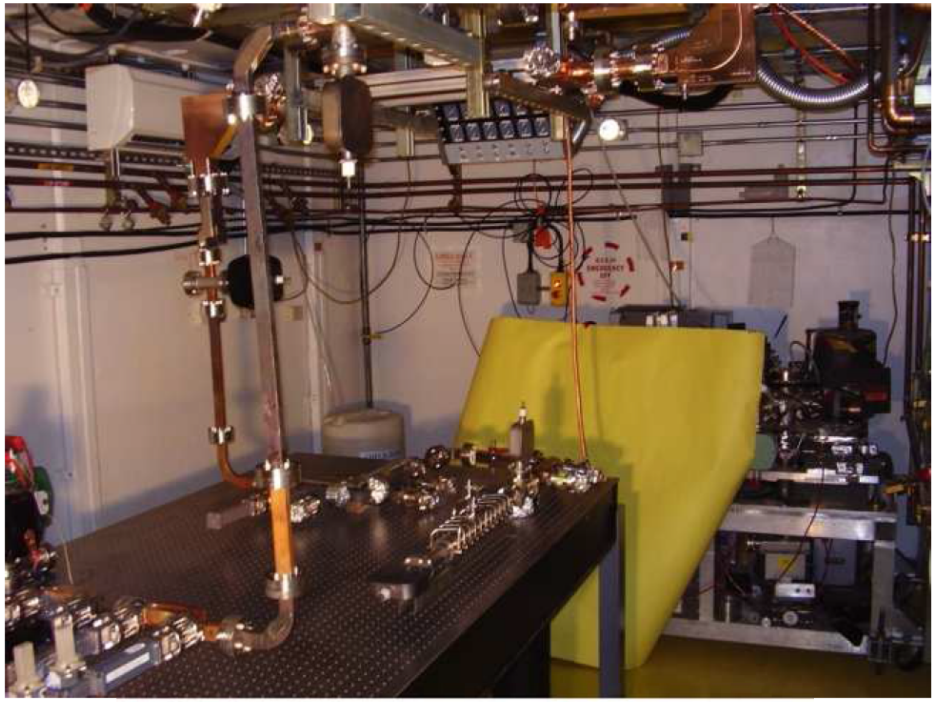
Design → Fabrication → HG Test

- ✓ Minimum structure keeping realistic RF fields for acceleration
- ✓ Basic study, element test
- ✓ Easy to make and test

V. A. Dolgashev, S. G. Tantawi, C. D. Nantista, Y. Higashi, and T. Higo, "Travelling wave and standing wave single cell high gradient tests," SLAC-PUB-10667, 2004.

Nextef / **Shield-B** has been booted with support of SLAC and CERN.

SLAC / ASTA



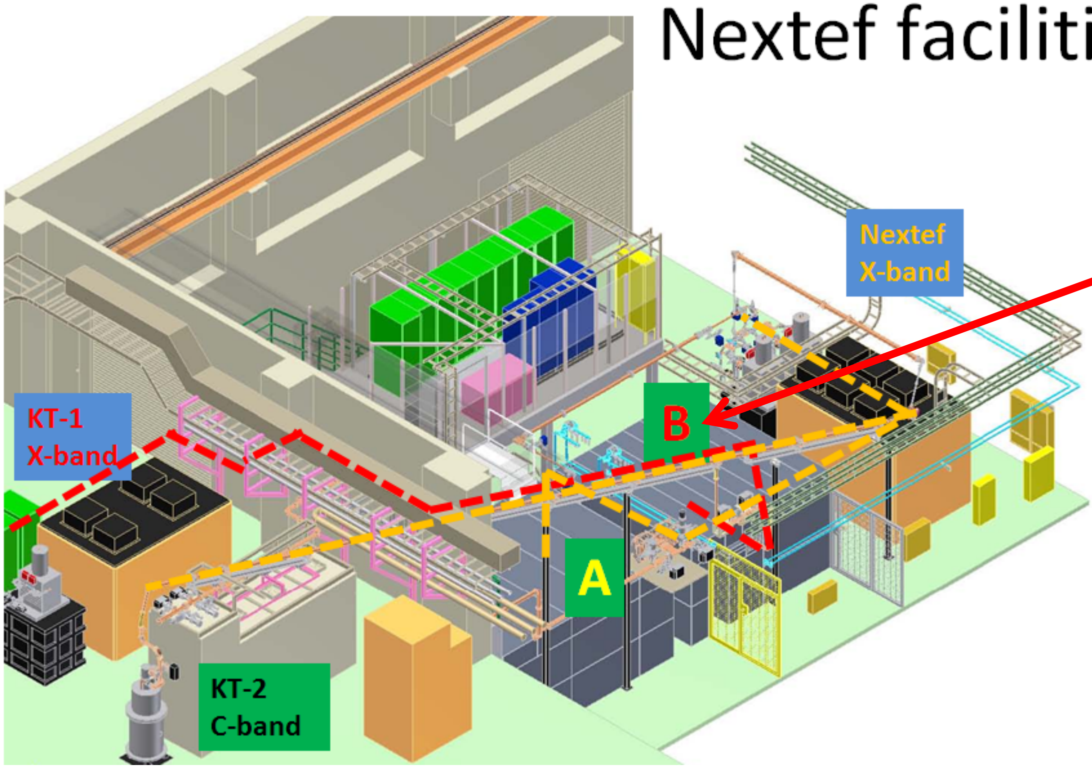
Tested many structures

KEK/ Nextef/ **Shield-B**

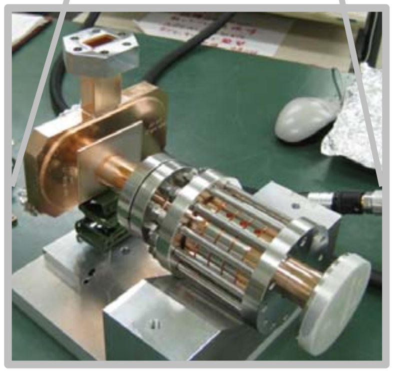
Now power-line conditioning

X-Band Single-Cell Test Stand for Basic Study : KEK/Nextef/Shield-B

Nextef facilities

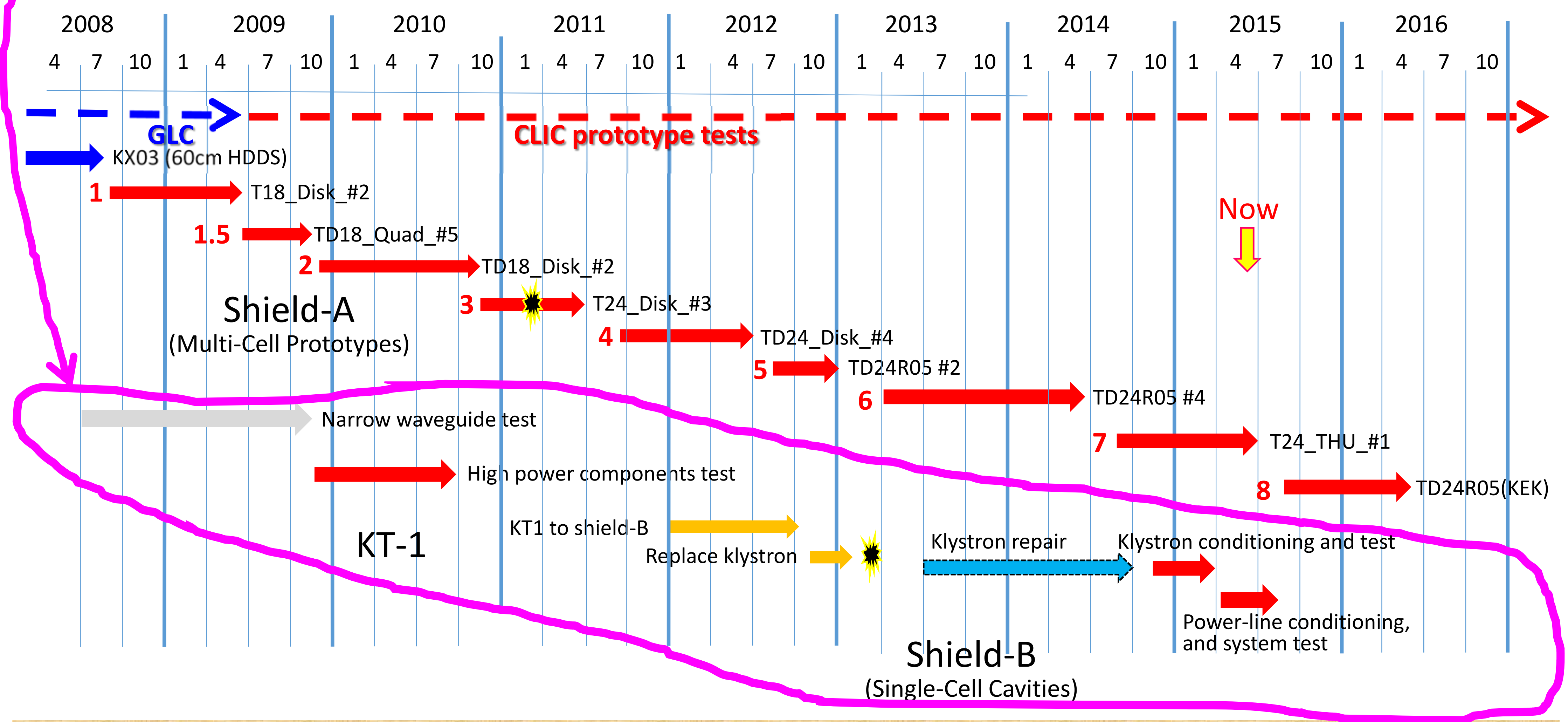


- - - **Power Line from KT-1 to Shield-B**

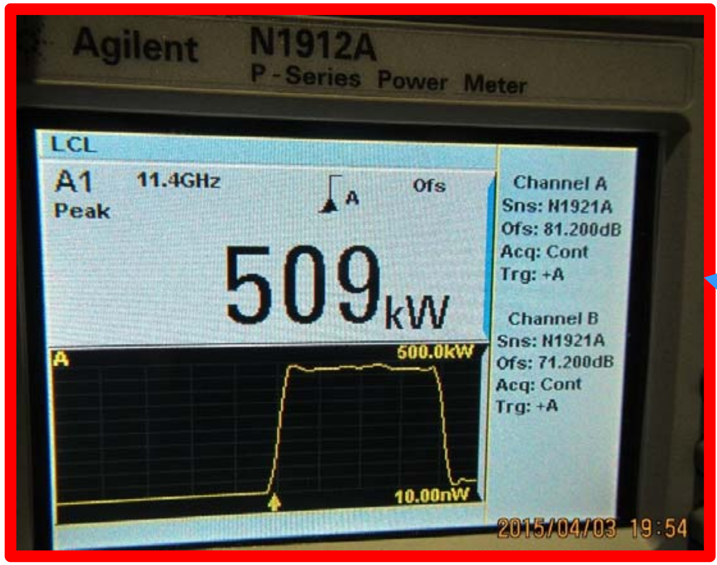


Example of
test cavity setup

History and Plan at KT-1 and Nextef / Shield-B

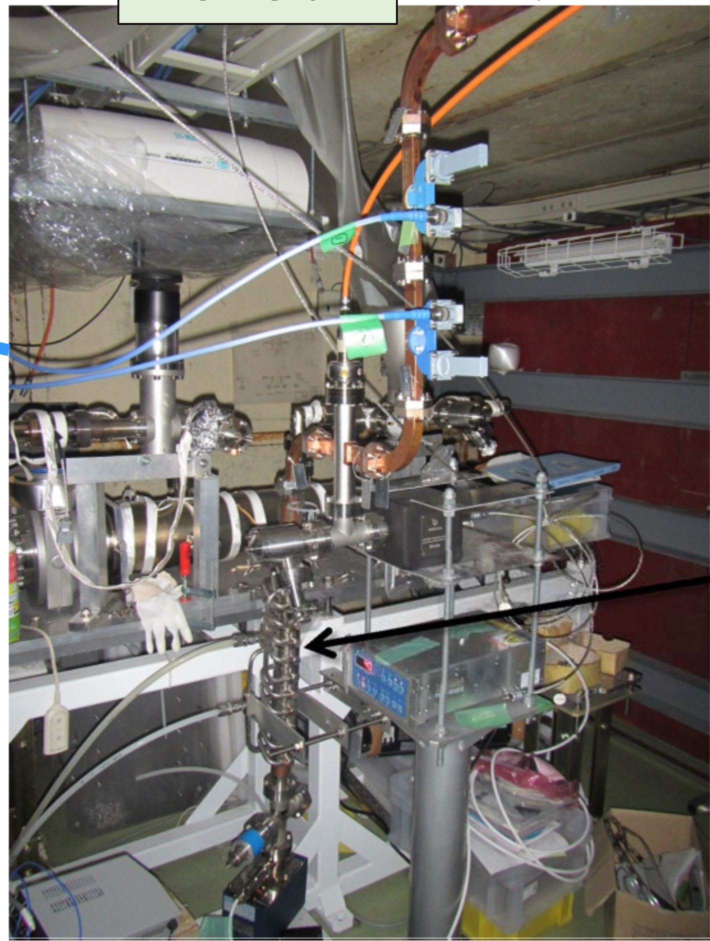


RF Power from KT-1 has reached Shield-B.



In Shield-B

← RF Power from KT-1 klystron

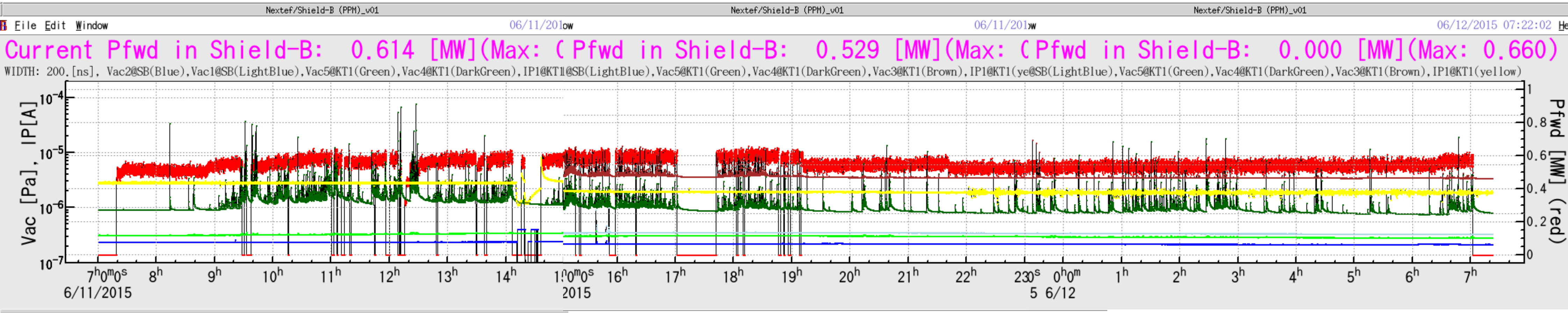


Dummy Load

Example of Conditioning Histories of the Power Line

From 2015-06-11 7:00 to 2015-06-12 7:00

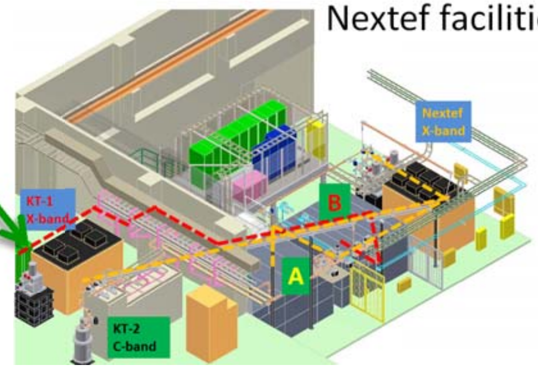
-- RF Power into the Dummy Load



-- Vacuum at the low-loss line entrance

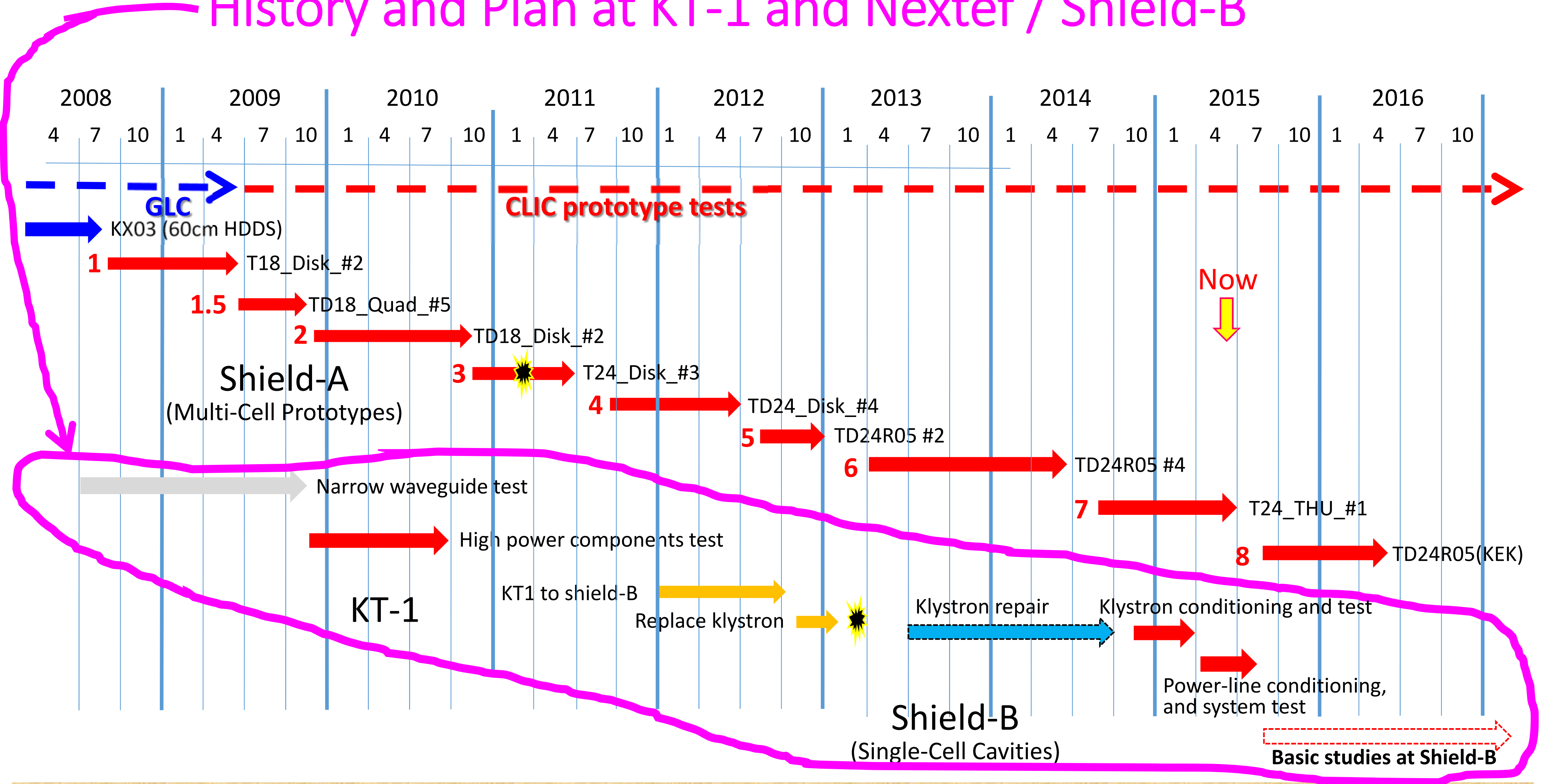
-- Vacuum near the dummy load in Shield-B

Nextef facilities



- Target at present: 10 MW
- Manual → Automatic conditioning for aggressive vacuum scrubbing

History and Plan at KT-1 and Nextef / Shield-B

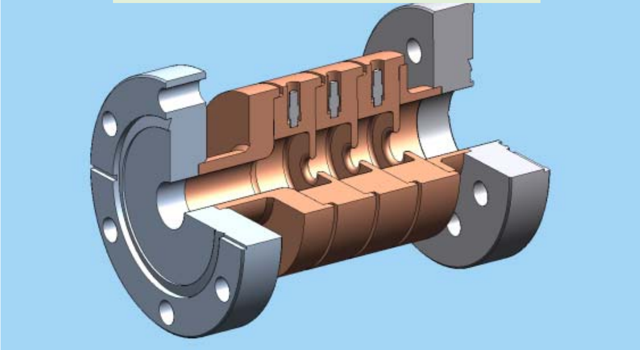


Test Structures

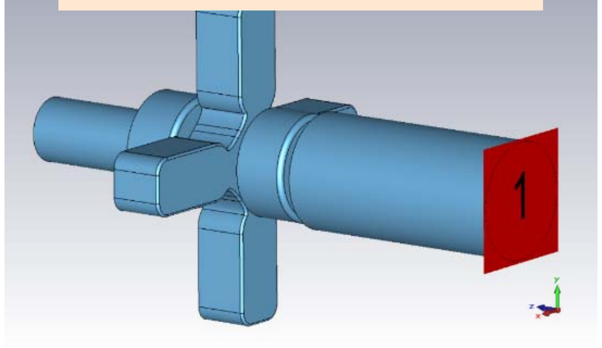
Single Cell Structures to be tested at Shield-B

(Current list)

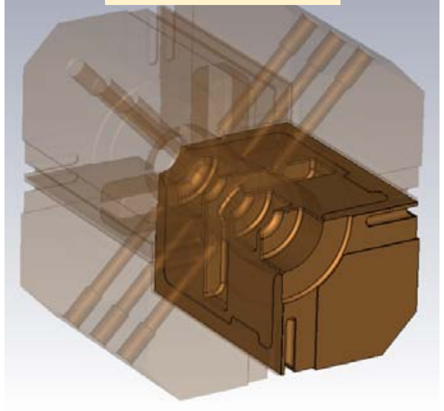
Undamped standard



With HOM waveguides



Quadrants



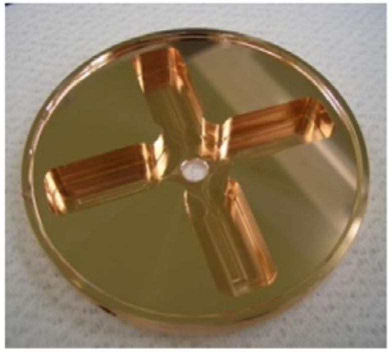
- With standard OFC (class1) and machined by turning
  → For reference BDR
- With large grain
  → To investigate grain-boundary effects

- Larger peak $\boldsymbol{H_{surf}}$
- To compare with undamped ones

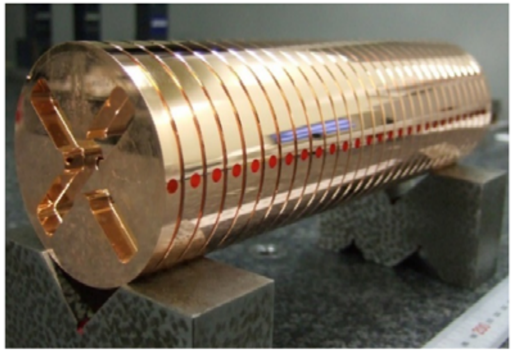
- To investigate the relation between surface current and bonding surface
- Etc…

Disk type v.s. Quadrant type

Disk type



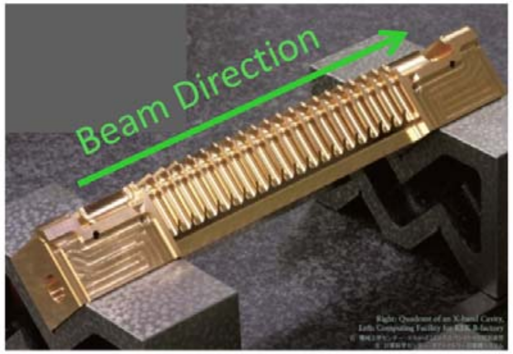
A damped disk



Disks stacked and bonded

- **Advantages**
  - ✓ Machining by turning
  - ✓ Very smooth surface (Ry: about 30nm)
  - ✓ Shallow machining damage (< 1μm?)
- **Disadvantages**
  - ✓ Ultra-high-precision machining of dozen of disks
    →Stack and bonding
  - ✓ Great care
  - ✓ **Surface currents flow across disk-to-disk junctions.**

Quadrant type

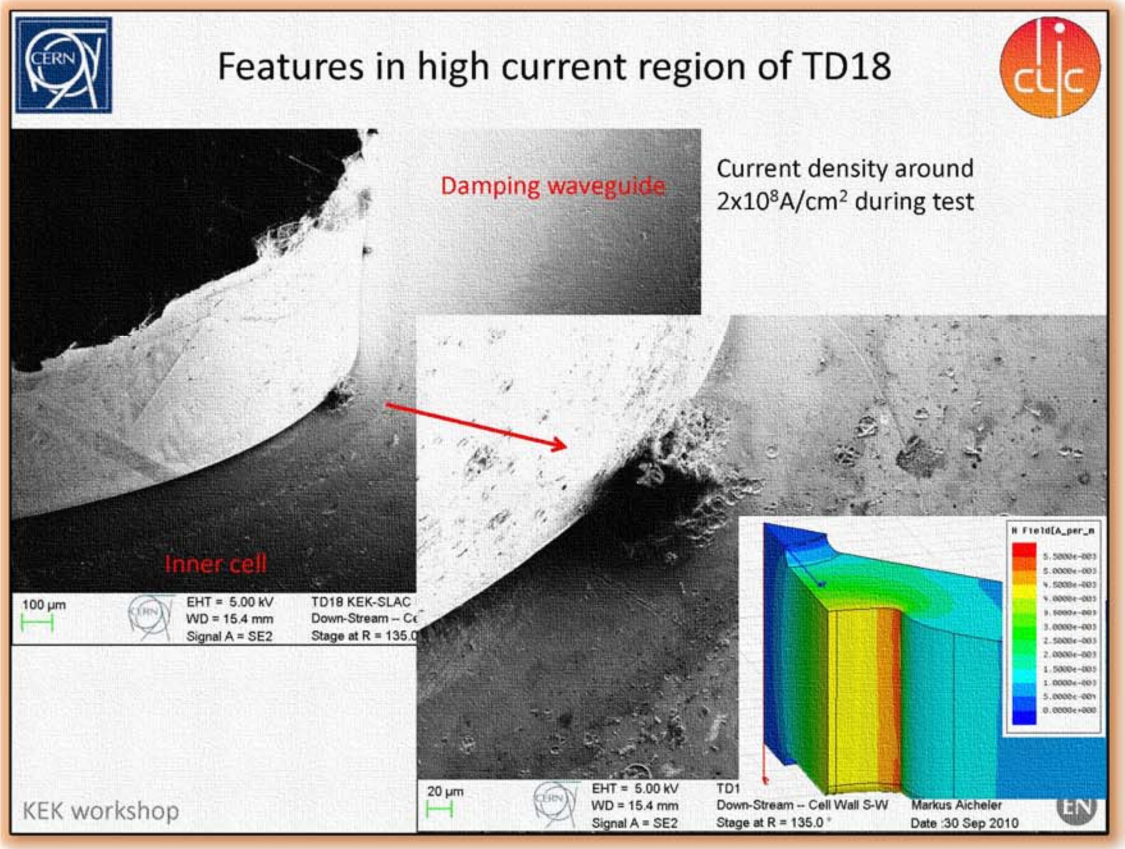


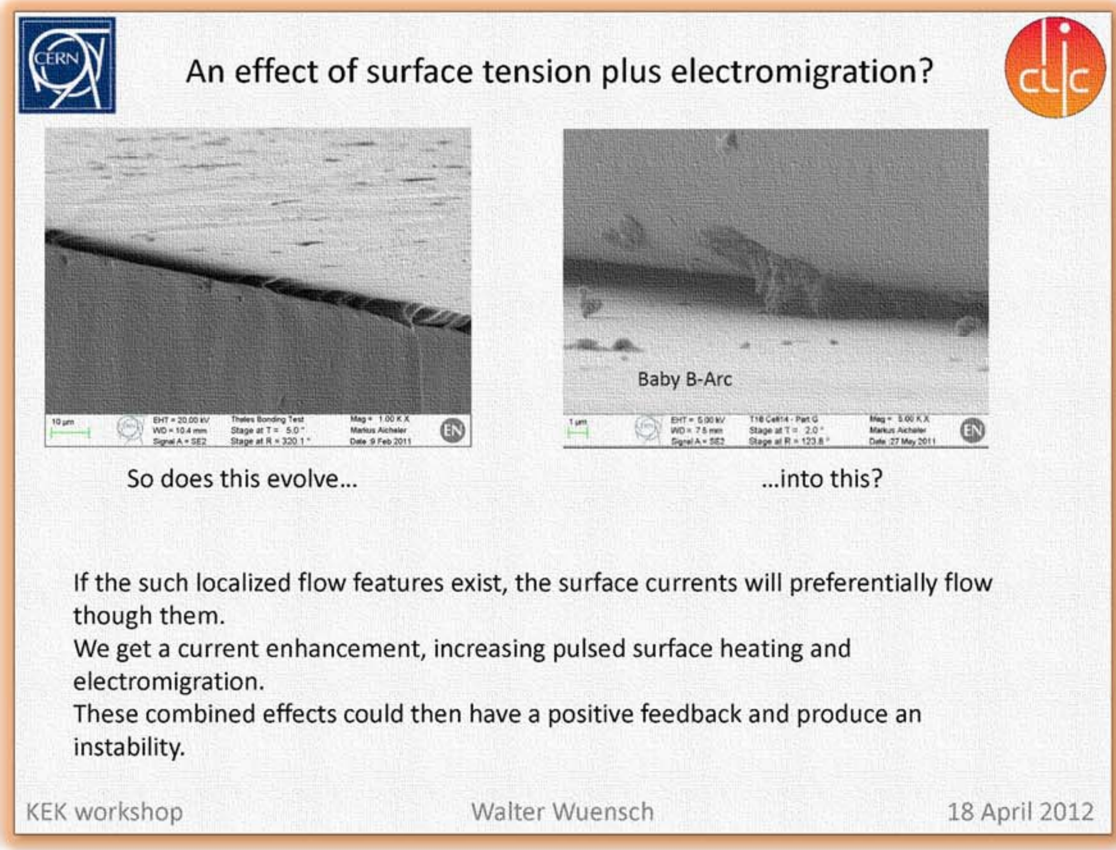
A Quadrant

Three Quadrants

- **Advantage**
  - ✓ **No surface current flows across any junction or bonding plane.**
  - ✓ Simple machining by five-axes milling machines
  - ✓ Simple assembly process
    → Significant cost reduction?
- **Disadvantages**
  - ✓ Not very smooth surface (Ry: about 1μm)
  - ✓ Deep machining damage (10-20μm)
  - ✓ **Virtual leak from quadrant-to-quadrant junctions**

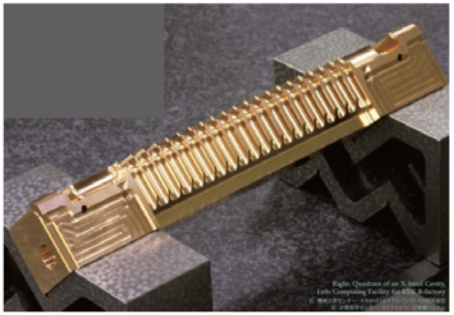
Suspicious-looking Objects
Observed by Microscopy for Disk-type Structures

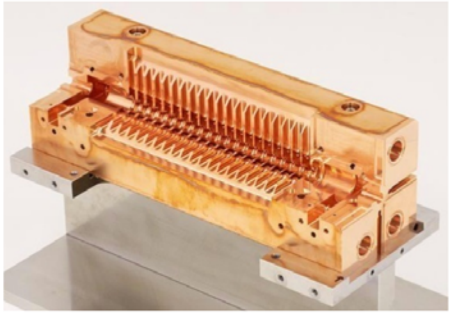


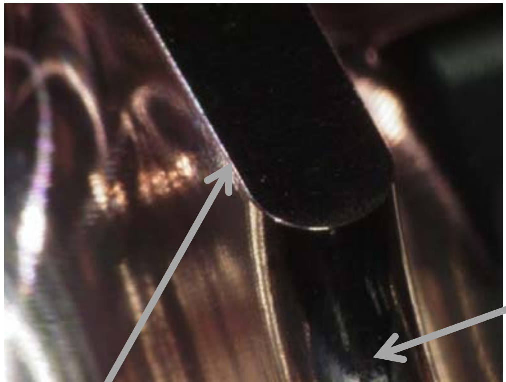


Fabrication and Test of TD18_Quad in 2009

Ultra-high precision milling (profile tolerance: 5μm)



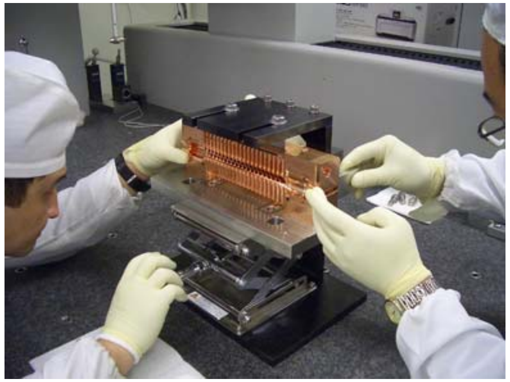


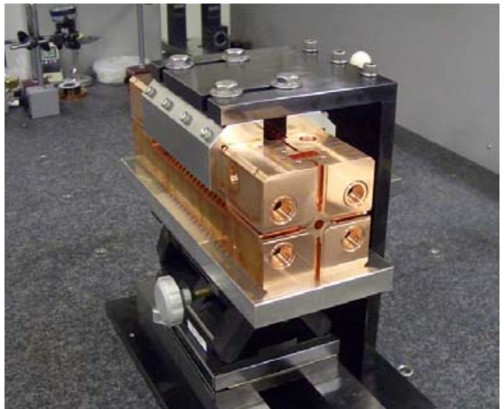


Iris

Round chamfer (R50μm)

High precision alignment (accuracy: 10μm)



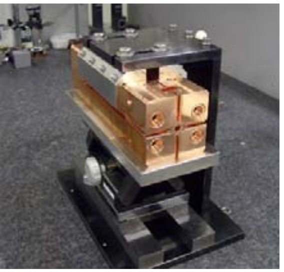


Put into a vacuum chamber

HG-Test Result of TD18_Quad in 2009

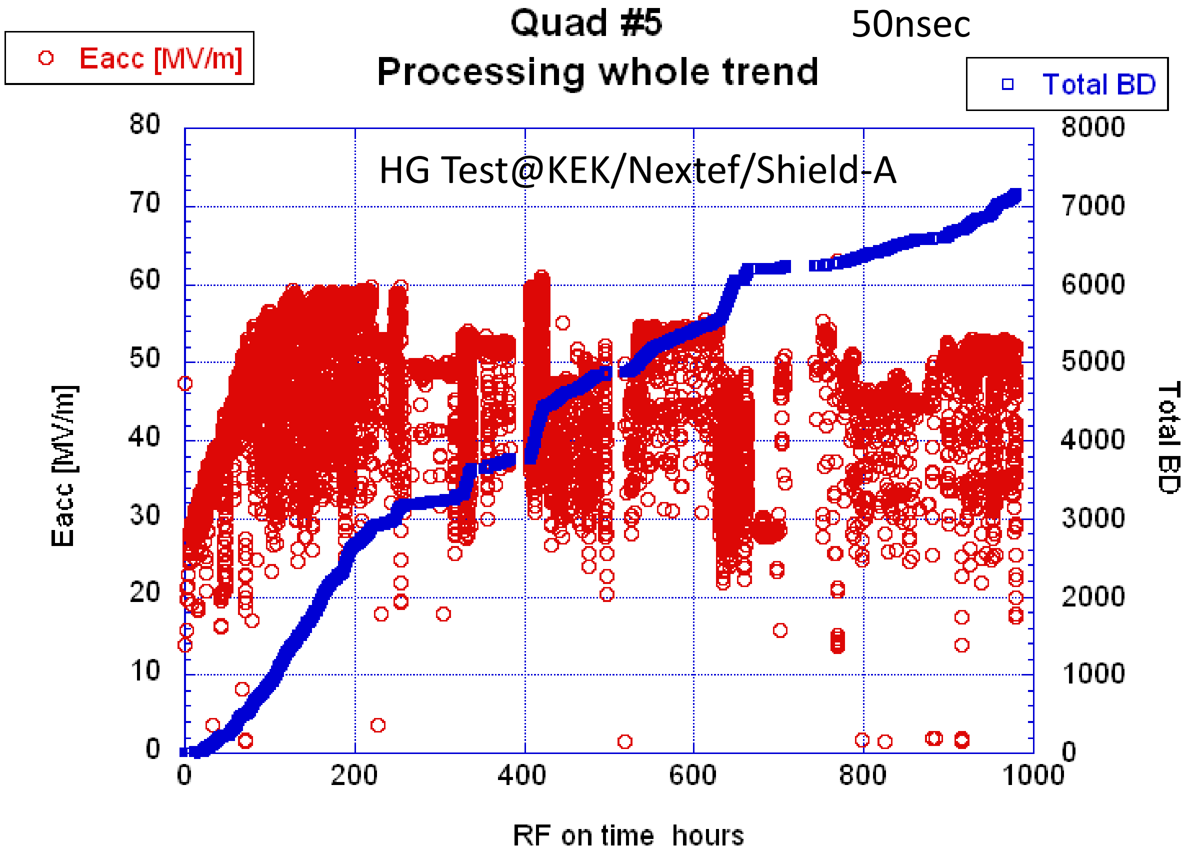
A quadrant

Three quadrants



4 quadrants
form a accl. str.

Into a vacuum chamber



✓ **Highest E_{acc}: 60MV/m (< 100 MV/m)**
✓ **No conditioning effect observed**

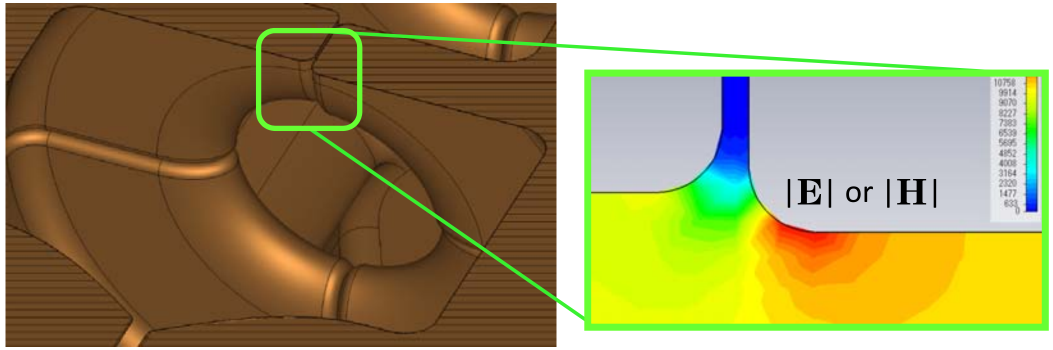
Bad Performance

Disadvantages of the naïve quadrant-type structure:

① Field enhancements

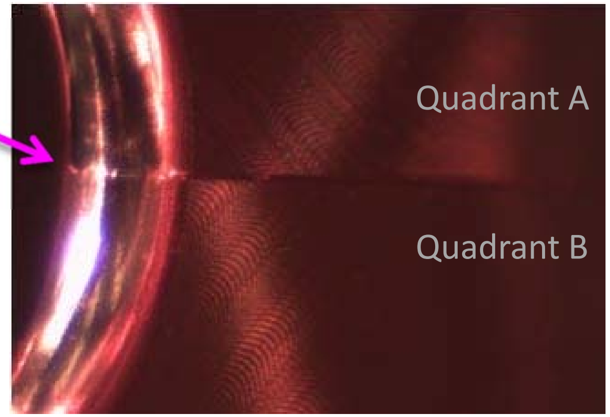
← Misalignment of quadrants

← Machining error



② Virtual leak **from between adjacent quadrants**

(TD18_Quad)



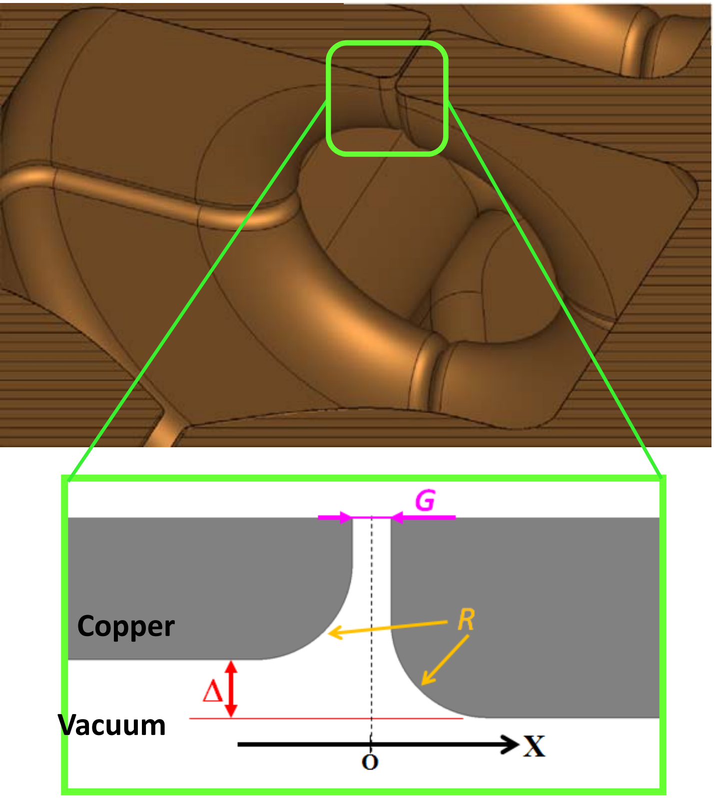
③ Worse surface conditions by five-axes milling

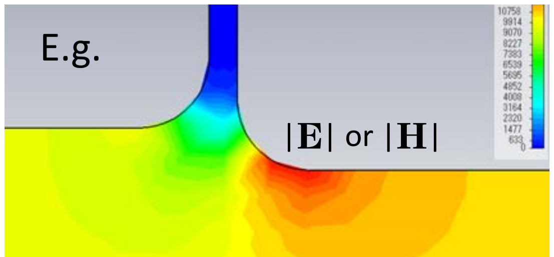
- Thicker affected layer
- R_y > ~1 μm (> skin depth of copper @ 11.4 GHz: ~0.5 μm)

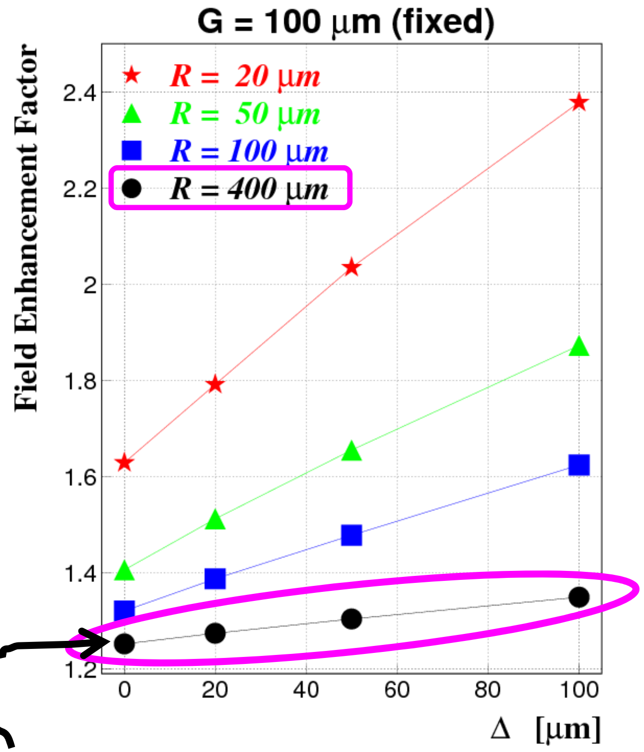
Field enhancements due to misalignment of quadrants

Numerically Calculated by the Floating Random Walk Method
with Accuracies Better than 0.5%

(For more details, see
T. Abe, "Study of Surface Field Enhancements due to Fine Structures,"
presented at the 8th Annual Meeting of Particle Accelerator Society of Japan, 2011 (Paper ID: TUPS086).)

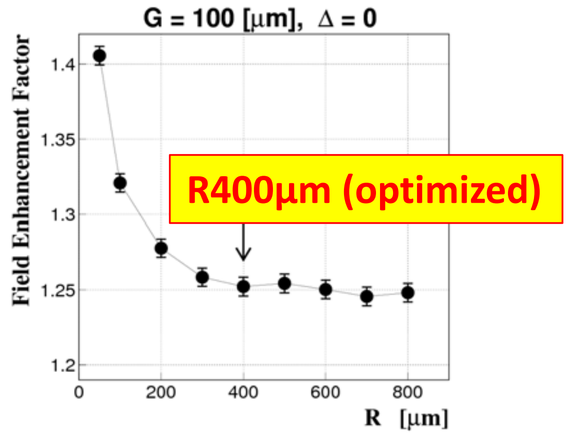


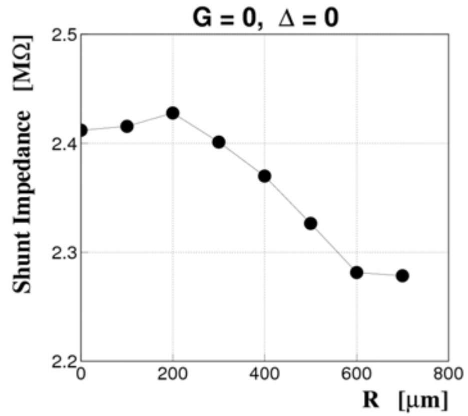




1.23 (G=0, Δ=0) (independent of R)

(**Minimum field enhancement!**)





Overcoming the disadvantages of the naive quadrant-type

For more 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).

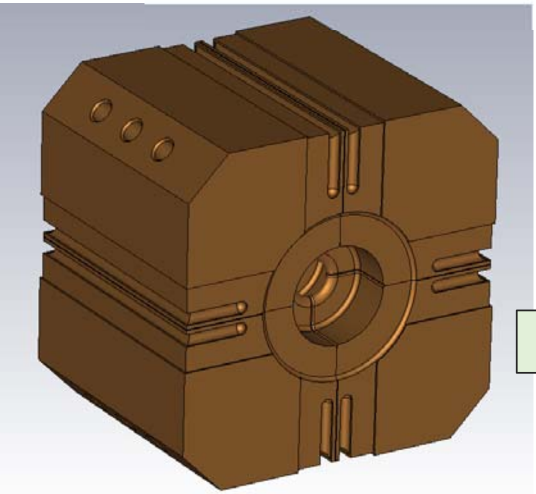
① Field enhancements due to misalignment of quadrants, etc.
→ Large round chamfer (R0.4mm)

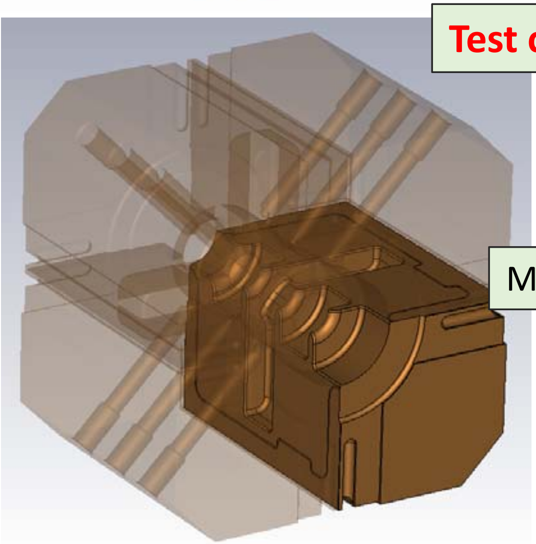
② Virtual leak from quadrant-to-quadrant junctions
→ Small gap (0.1mm) between quadrants

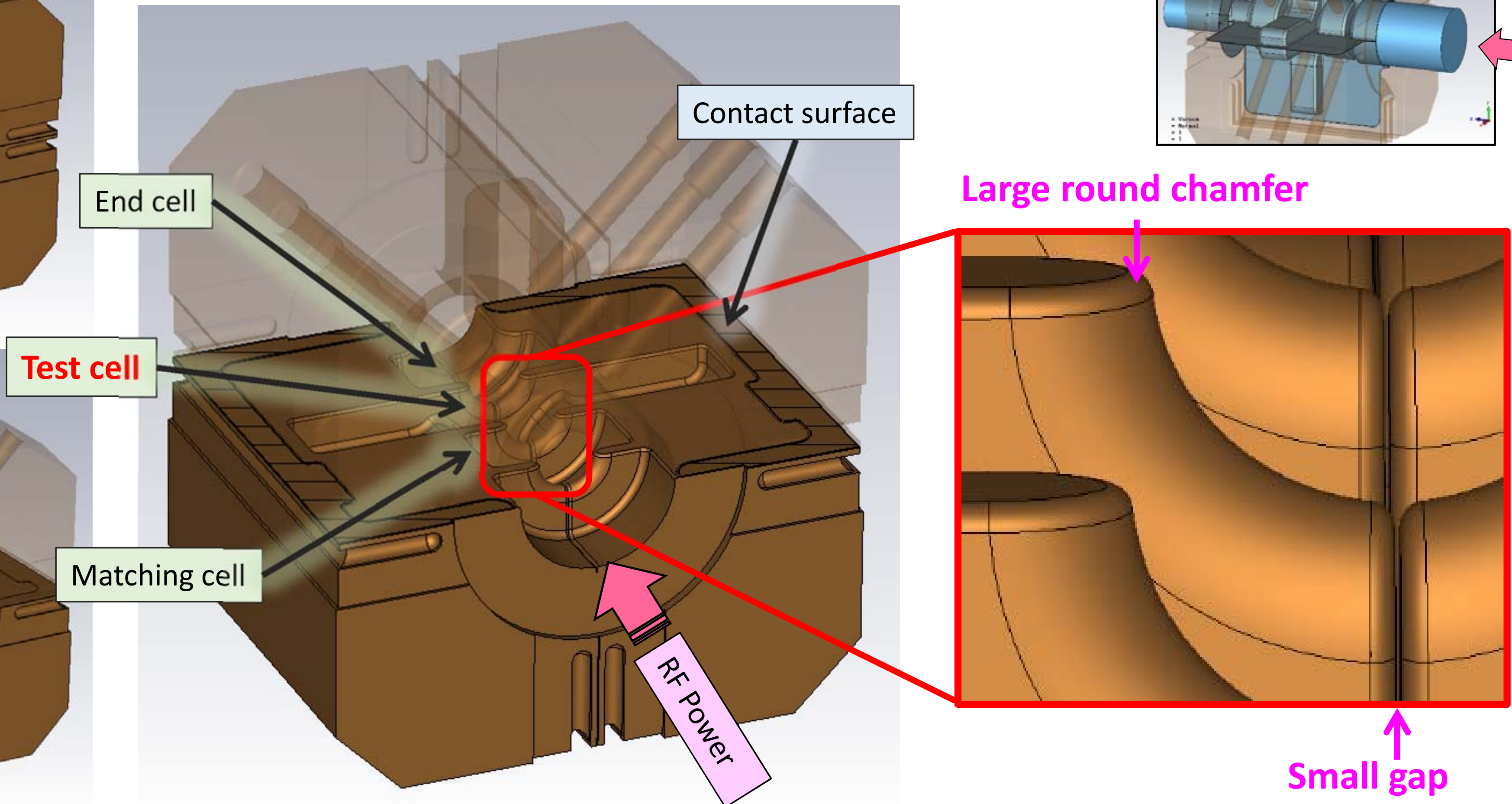
③ Worse surface conditions by five-axes milling
→ Advanced polishing

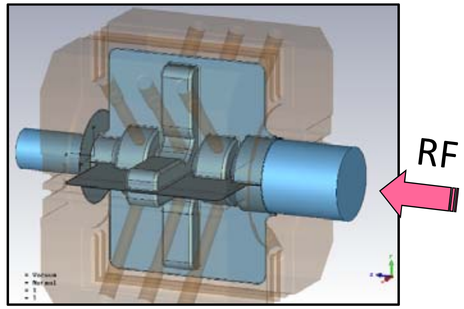
Quadrant-type structure as a single-cell test cavity

which overcomes all of the disadvantages

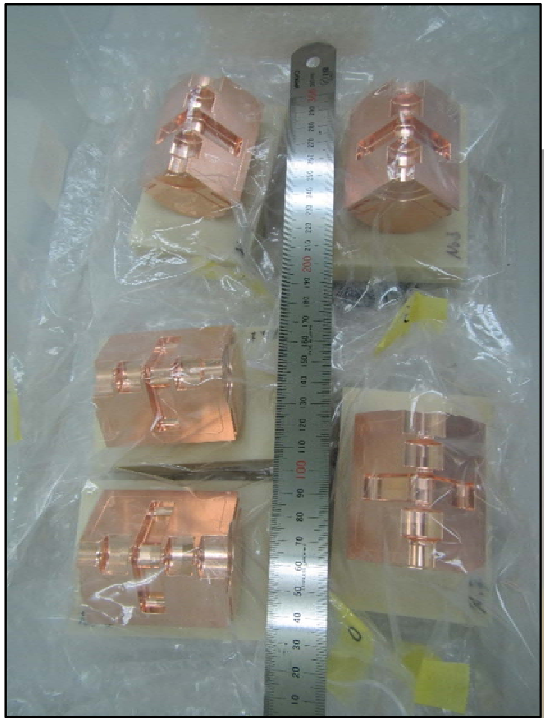




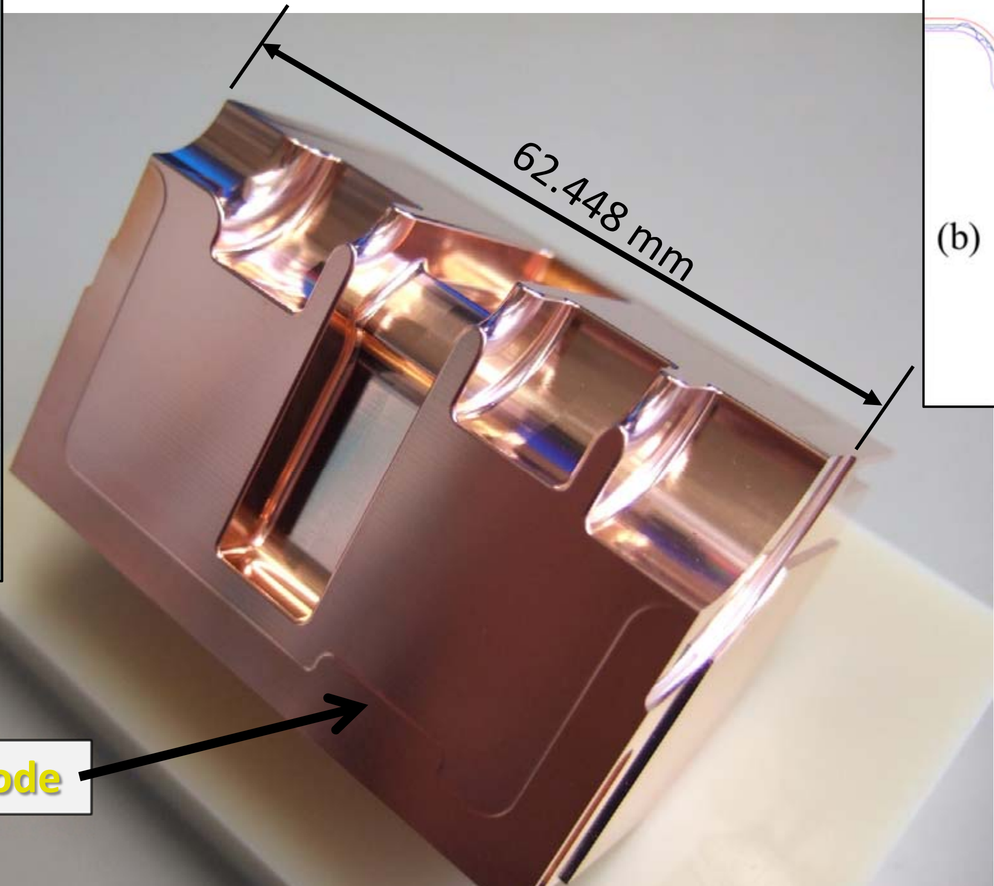




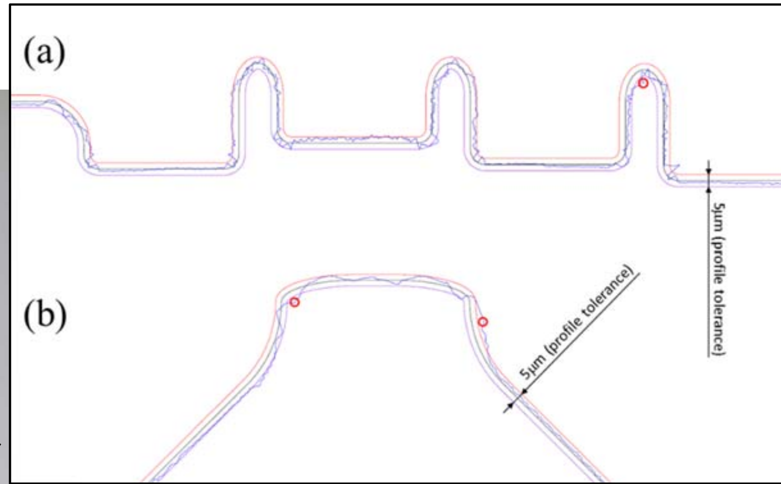
Delivered Quadrants for HG Test



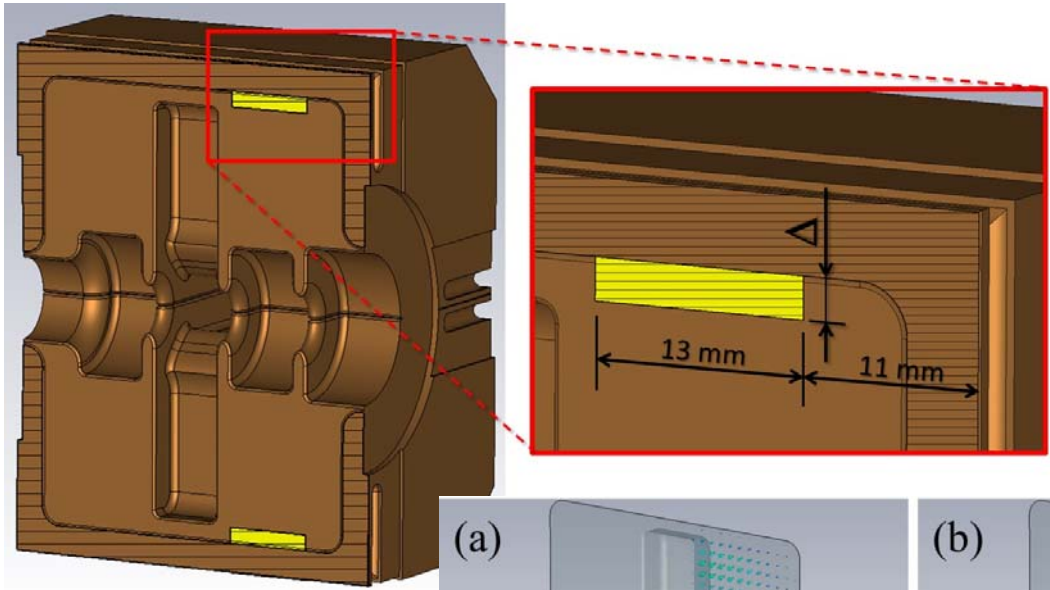
✓Material: OFC (class1)
✓Ultra-high precision milling with five axes
✓**Ry = 1 μm achieved**

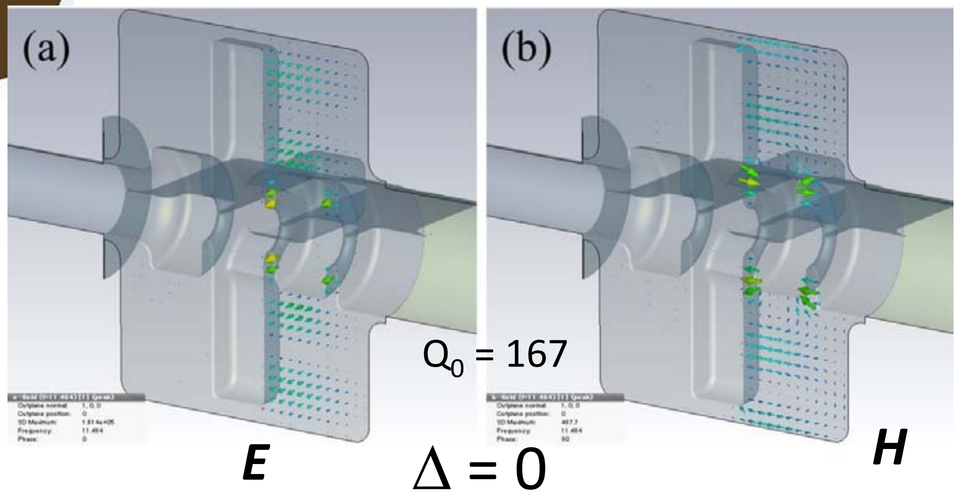


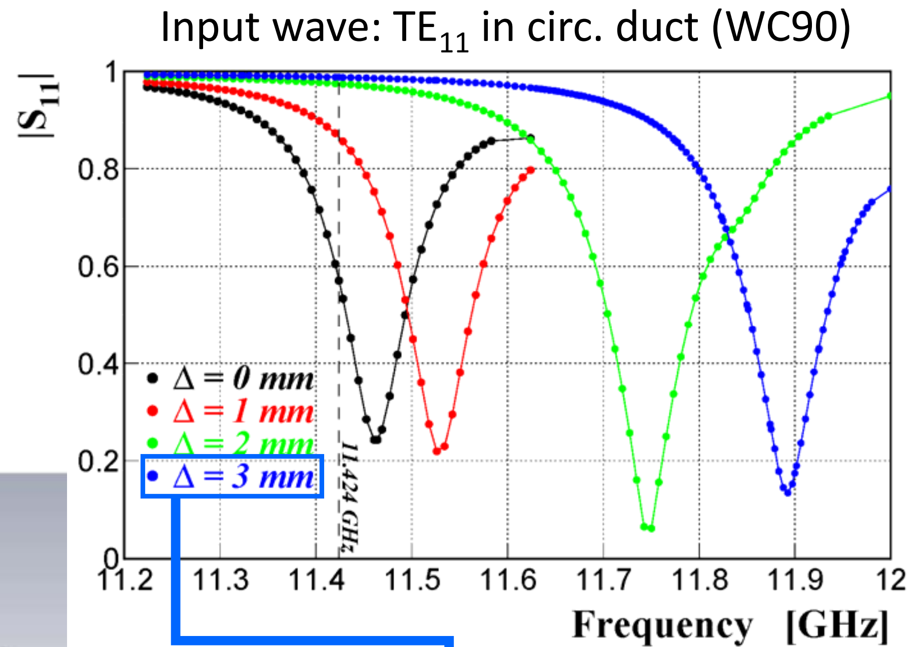
Profile accuracy 5 μm achieved



TE mode near 11.424GHz to be purged



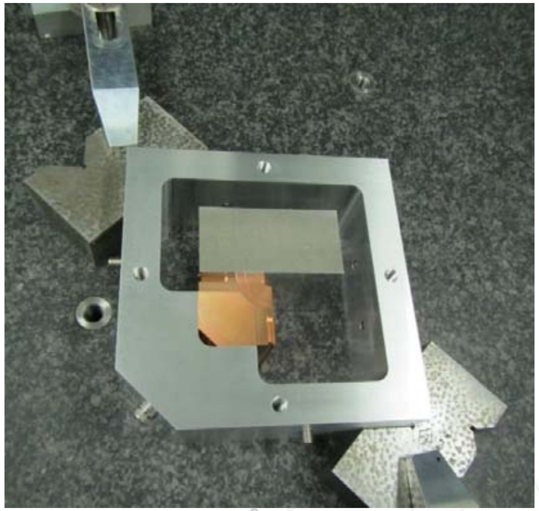


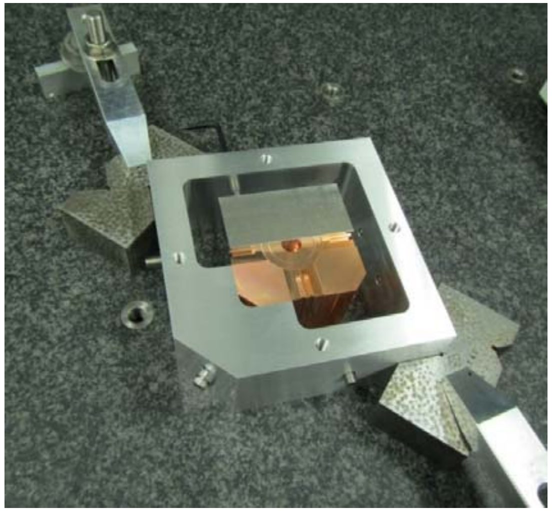


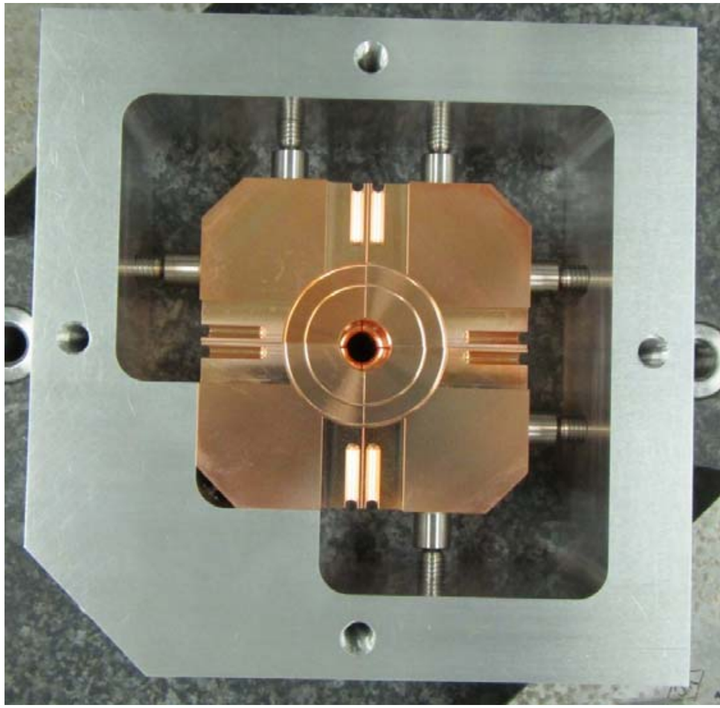
No TE mode
in 11.424 GHz +- 200 MHz

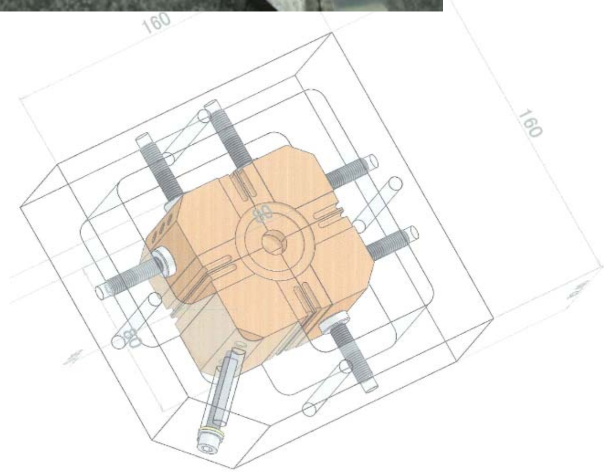
Precise Assembly of Quads for EBW

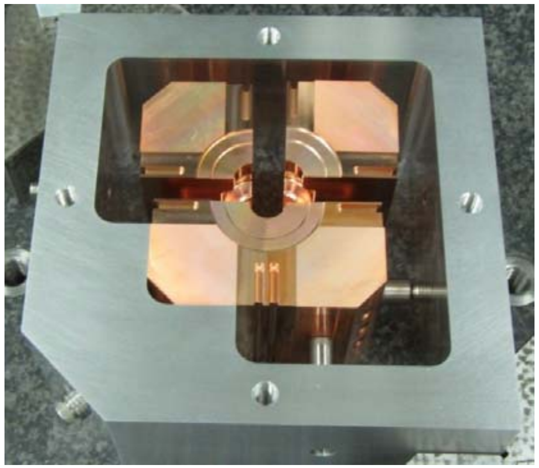
in 2015









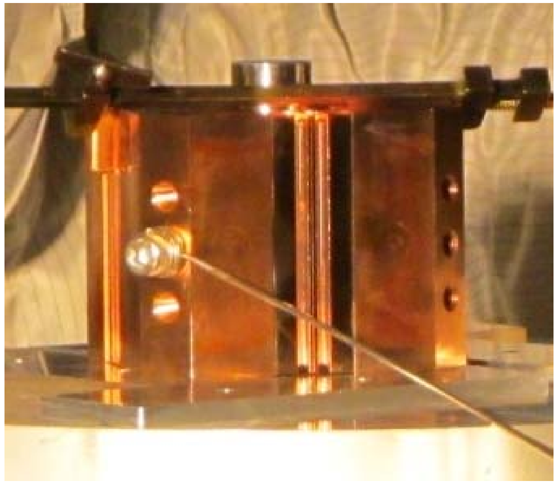


EBW →
- ✓ *Mechanical fixing*
- ✓ *Vacuum sealing*

1. ~10^{-2} Pa during the EBW
2. Max. Temp: 42degC, $\Delta T < 10$degC during the EBW
3. No vacuum leak verified

1. EBW in operation

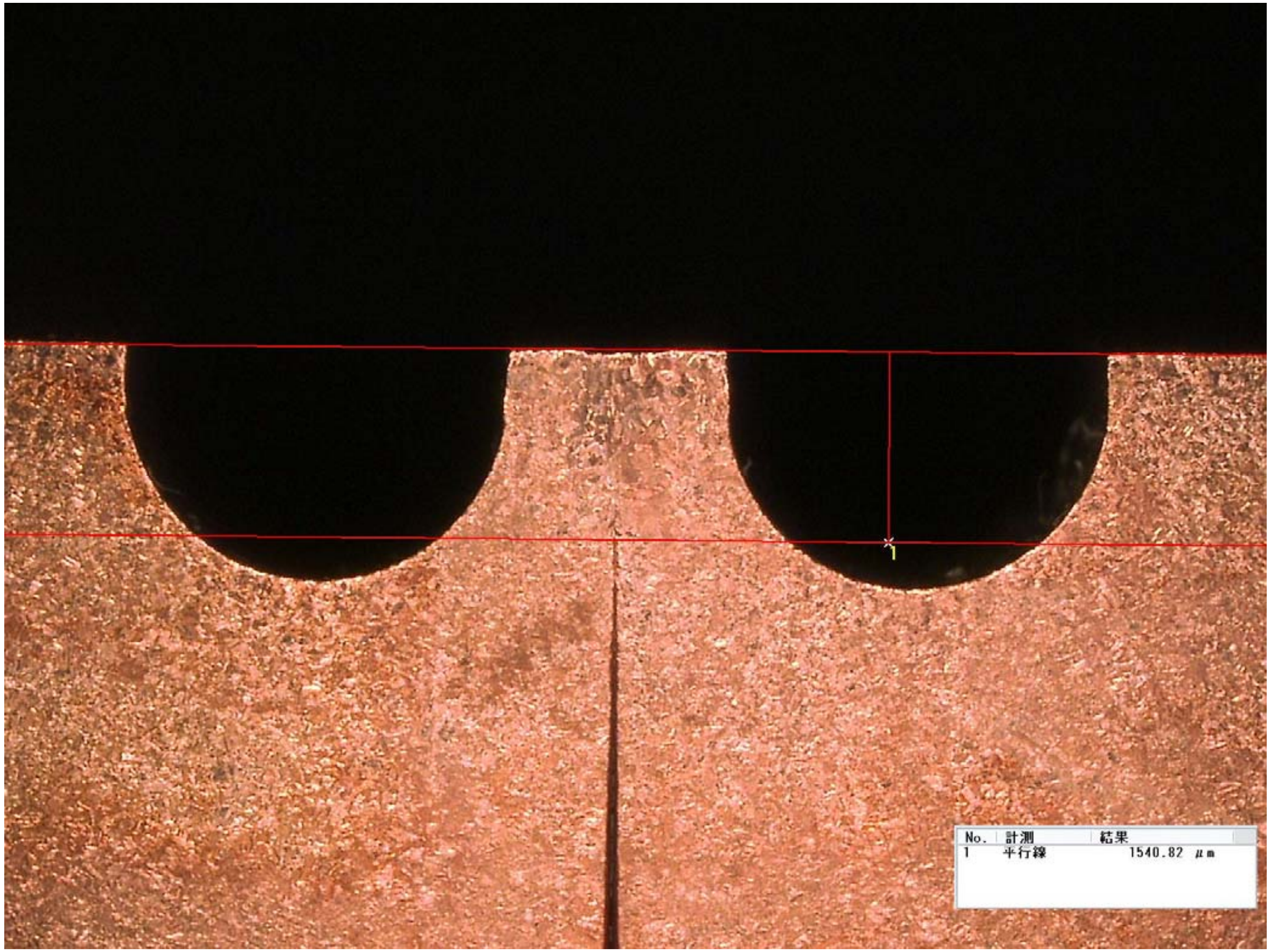
2. Thermocouple attached



3. Vacuum leak test just after the EBW

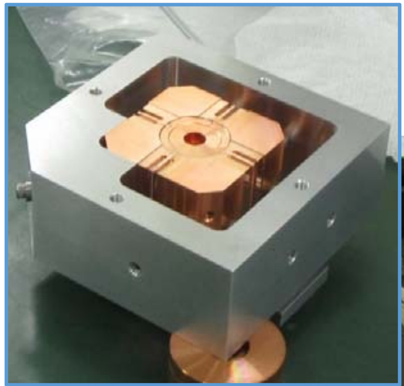
After the EBW

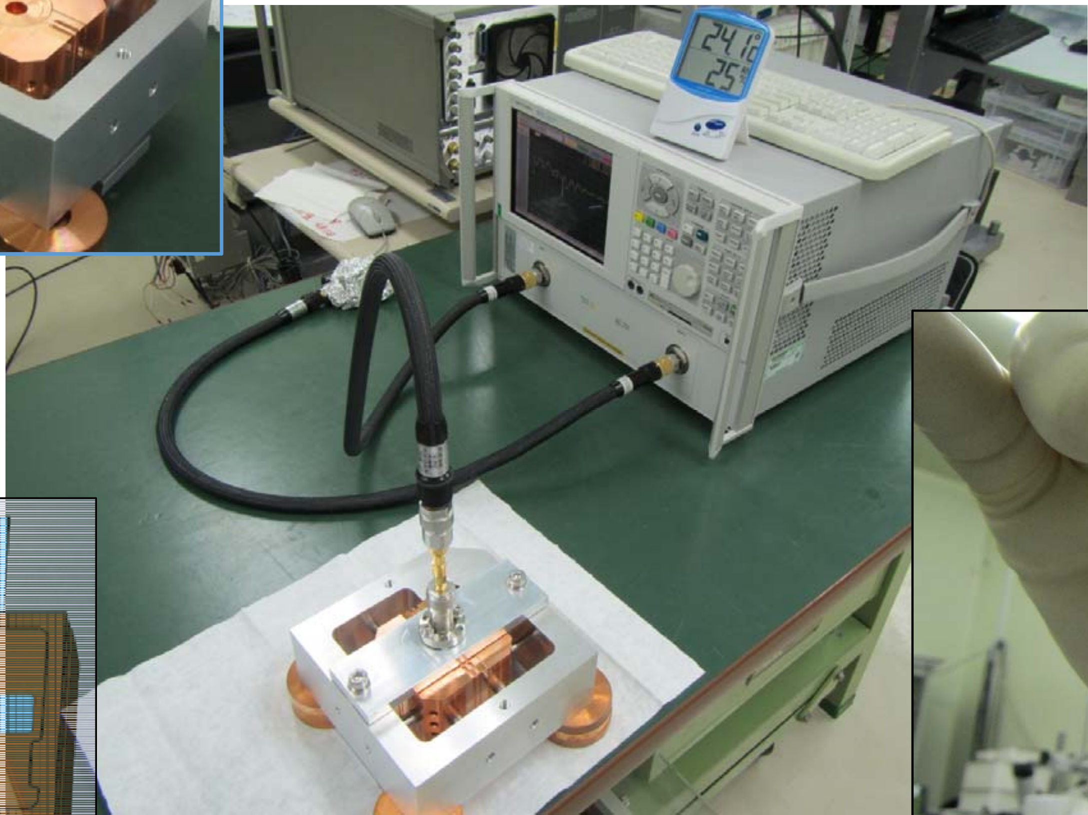
Weld Penetration Depth



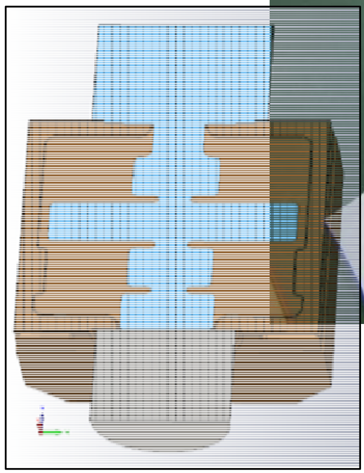
1.5 mm

Frequency Measurement



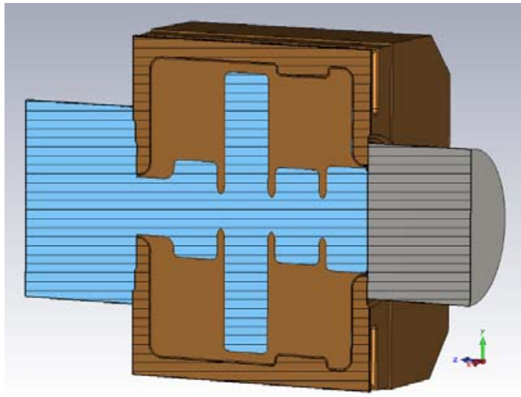


before and after the EBW

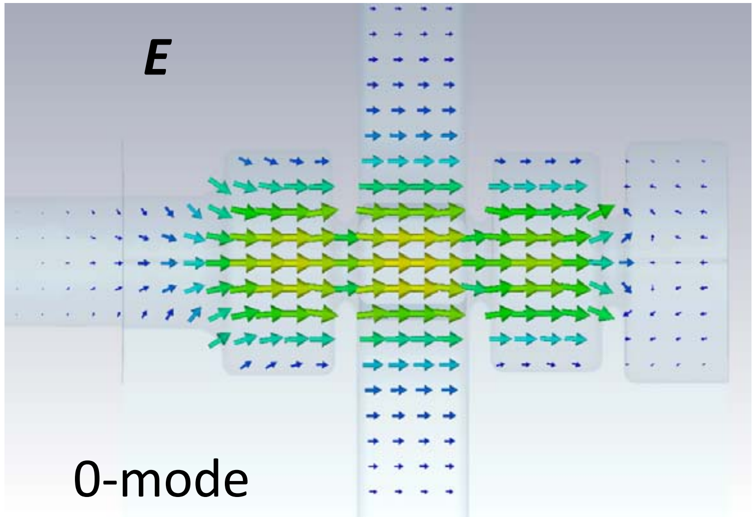


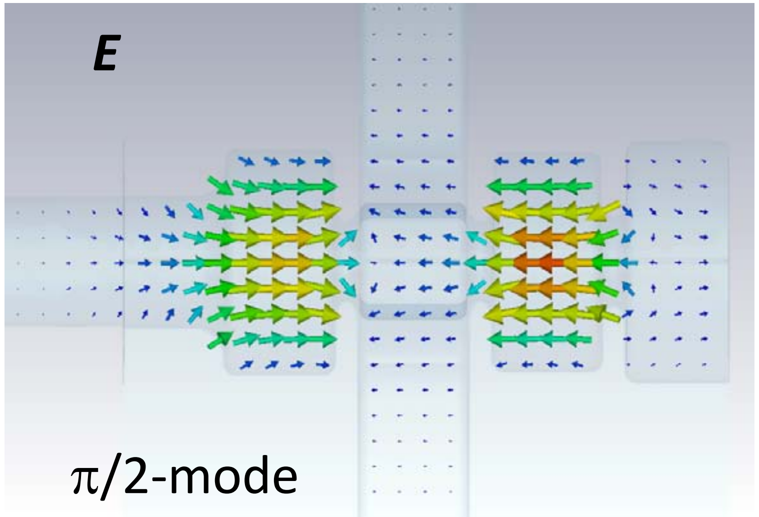
Pickup antenna

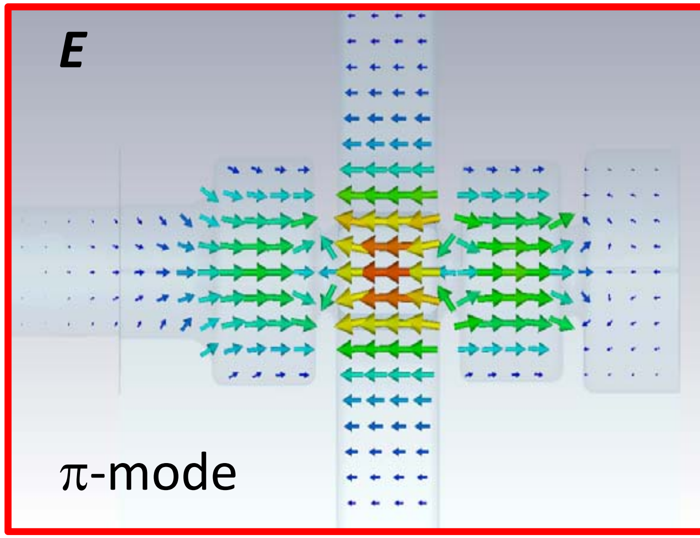
Measurements of the Mode Frequencies



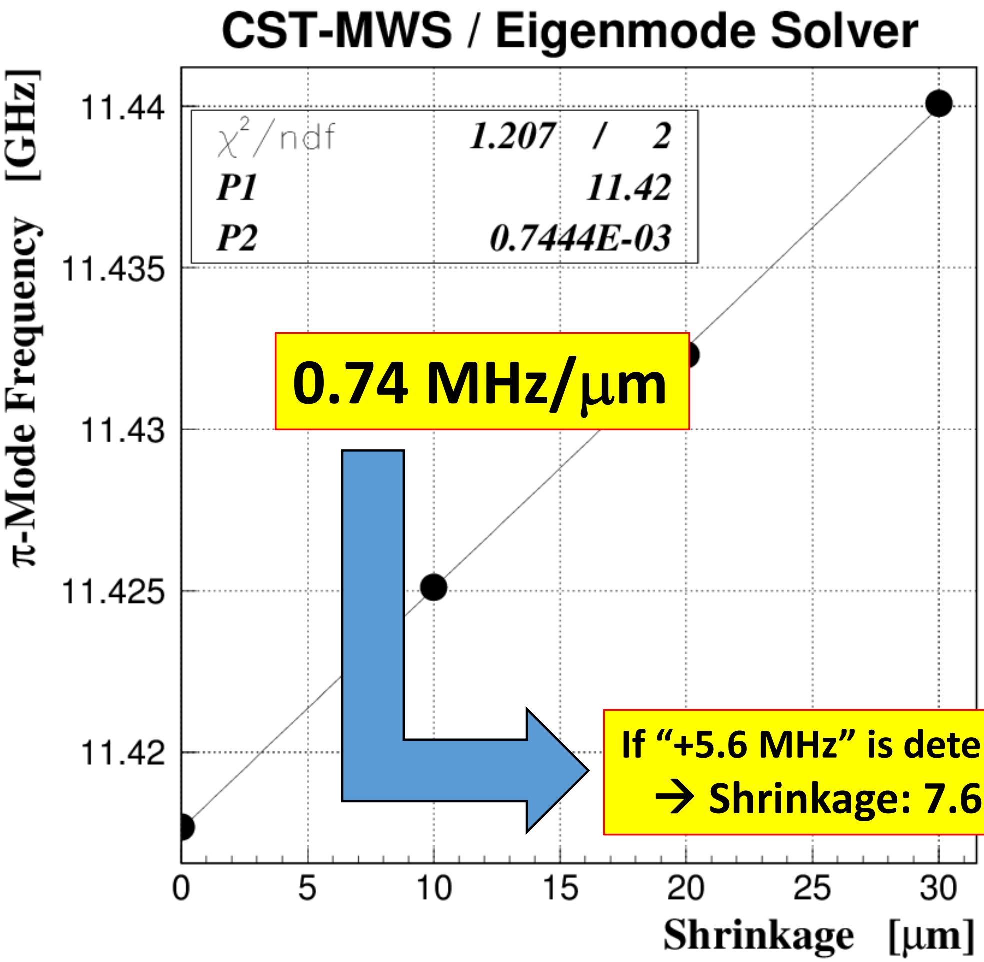
Mode	After the EBW	Before the EBW	After - Before
0	11.2872 GHz	11.2739 GHz	+13.3 MHz
π/2	11.3362 GHz	11.3259 GHz	+10.3 MHz
π	11.4160 GHz	11.4104 GHz	+5.6 MHz



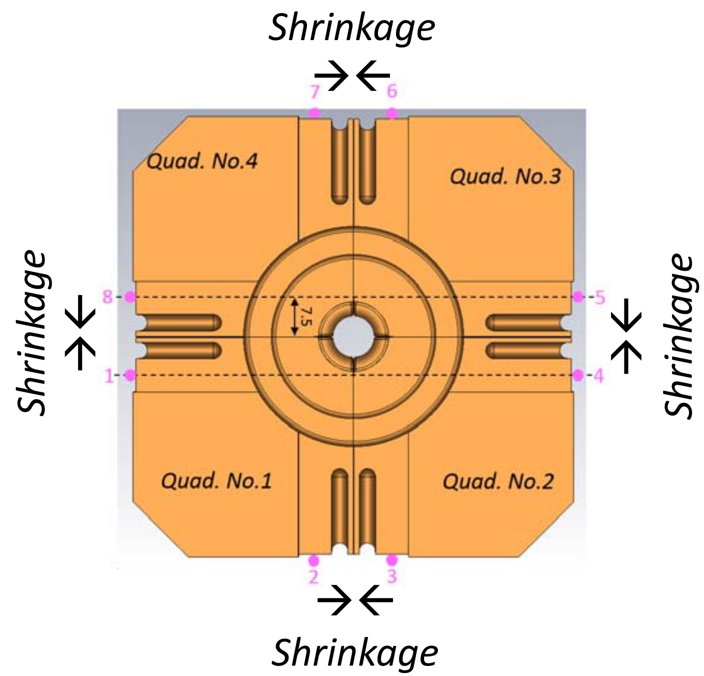




Shrinkage Dependence of the π-mode Frequency

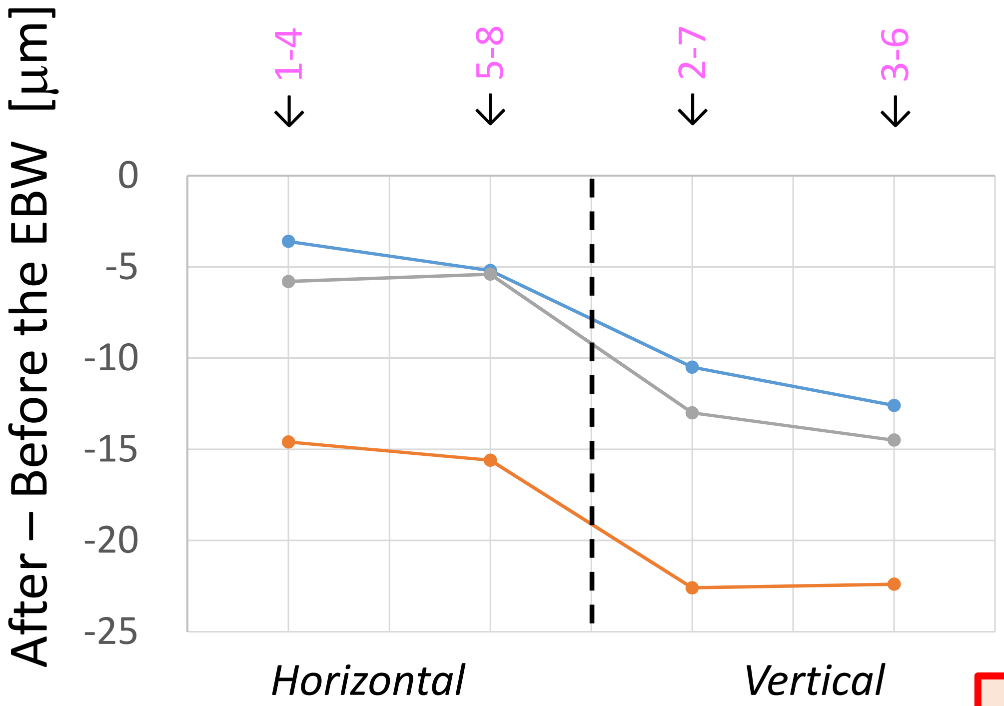


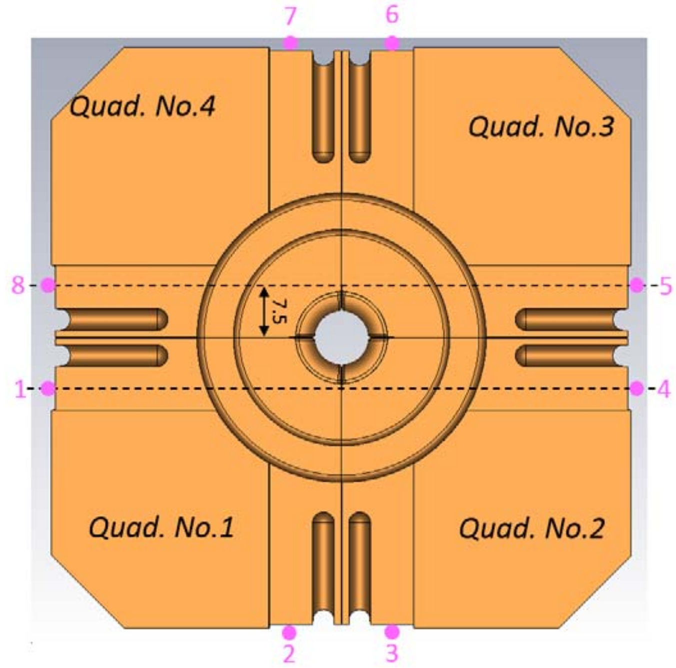
0.74 MHz/μm



If "+5.6 MHz" is determined only by this uniform shrinkage,
→ Shrinkage: 7.6 μm

Length change in the transverse plane



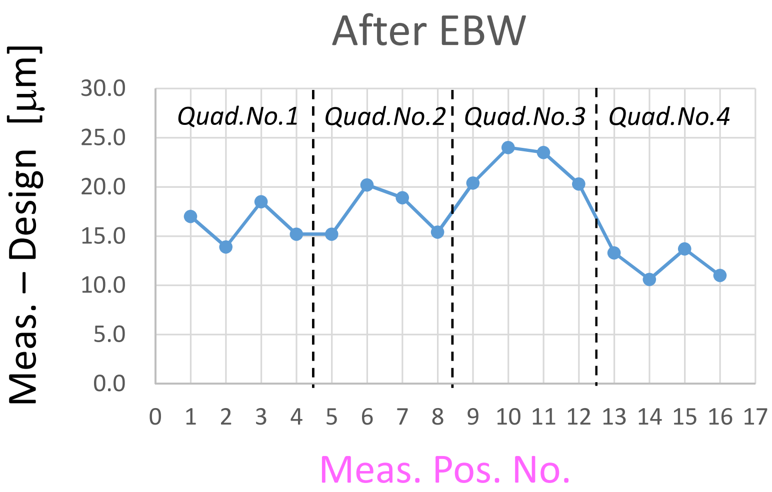


Shrinkage in average

- Cut-off side : 8.0 μm in average
- RF-input side: 18.8 μm in average
- Middle: 9.7 μm in average

π-mode frequency change can be attributed to transverse length change (shrinkage) at the contact surface of the adjacent quadrants.

Length change along the beam axis



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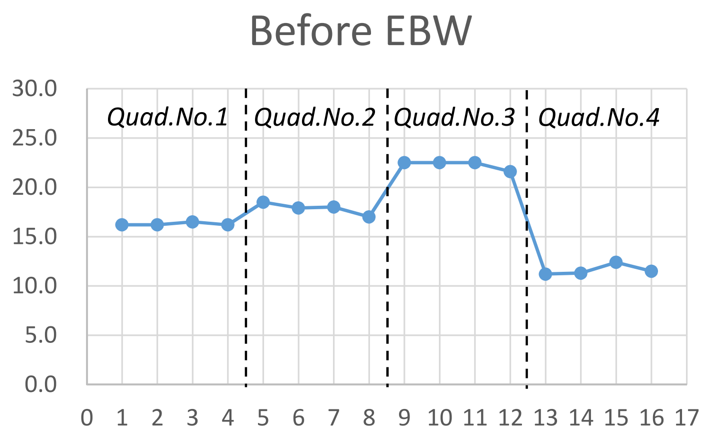
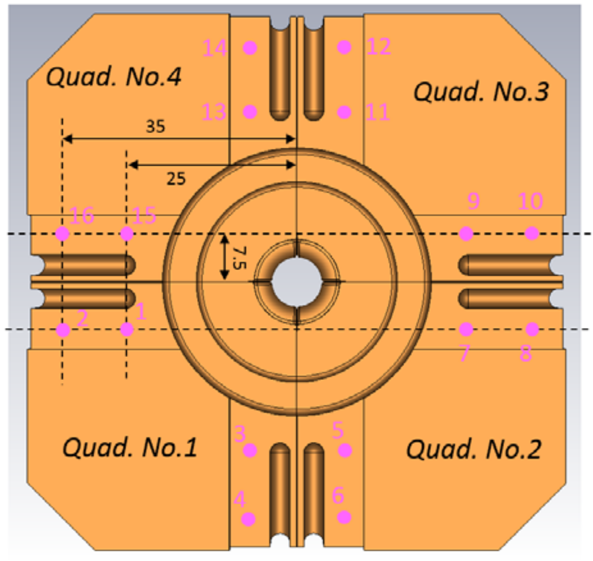
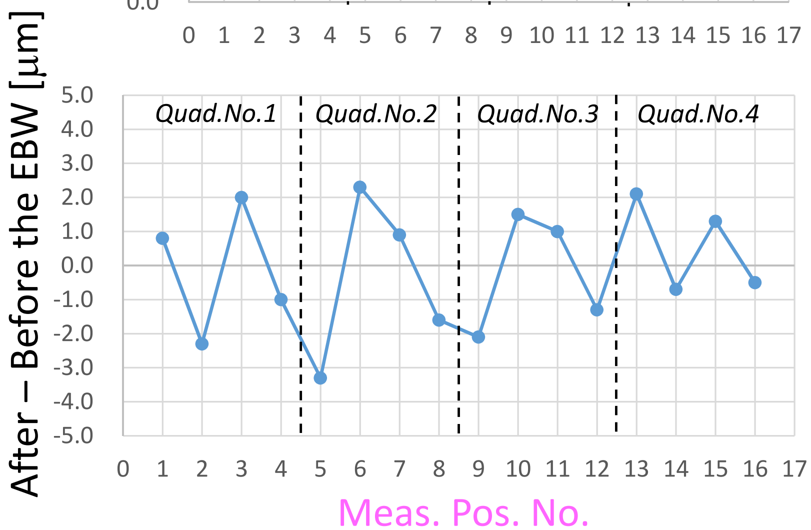




Meas. Pos.

=



A few μm or smaller

Structures to be tested at Nextef / Shield-B

Ready for HGT

- Undamped standard cavity : OFC (class1), turning, diffusion bonded
  - To be used for system check
- **Damped** cavity : OCF(class1), endmilling, **brazed**

Bonding finished

- **Damped quadrant** : OFC(class1), all endmilling, EBW
- Undamped standard cavities : OFC(class1), turning, diffusion bonded

Parts made; Waiting for bonding

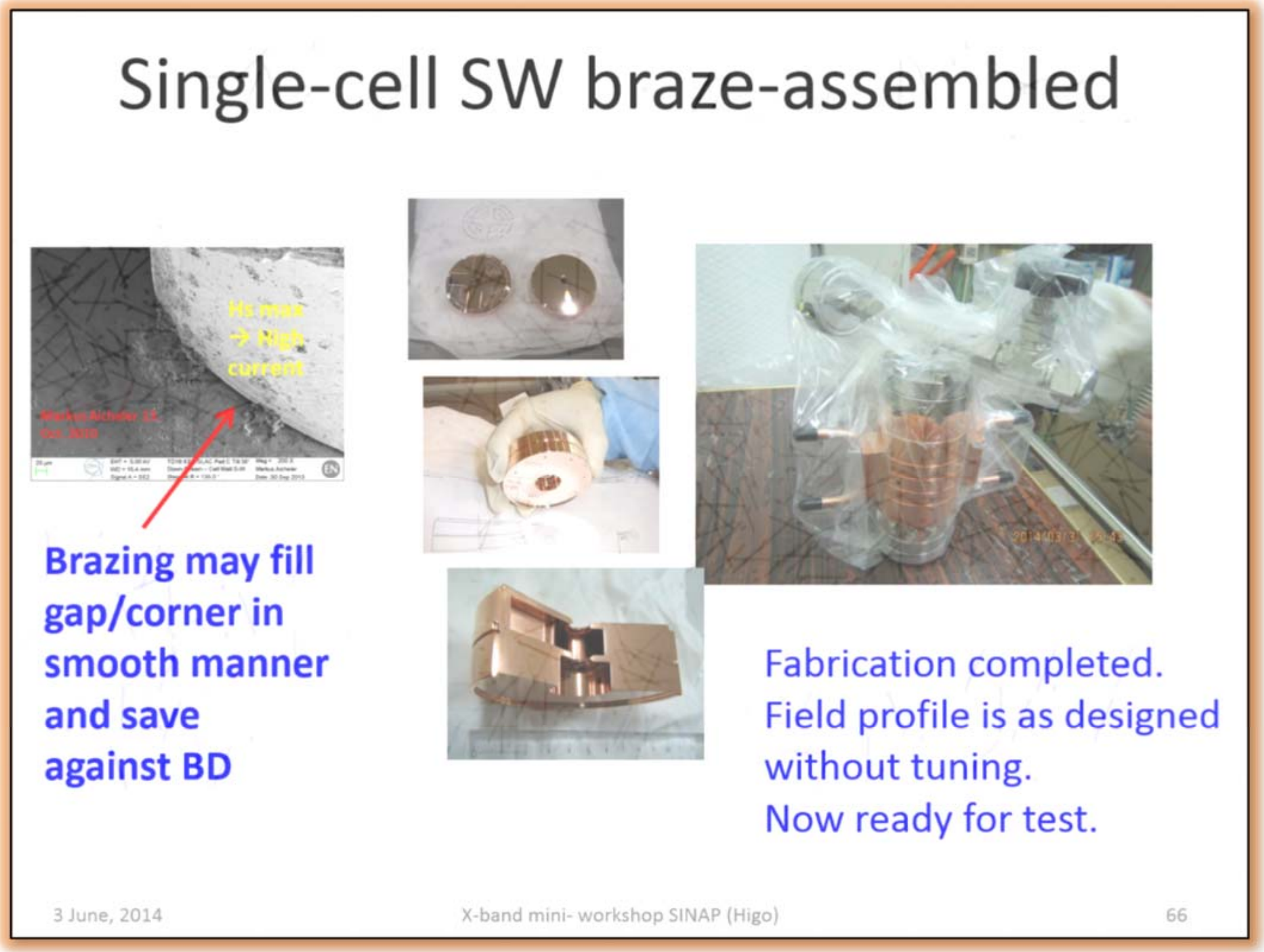
- Undamped cavities : OCF(class1), **endmill**, to be diffusion bonded
- Undamped cavities : OCF(class1) with **large grain**, turning, to be diffusion bonded
- **Damped** cavities : OCF(class1), endmill, to be diffusion bonded
- **Damped** cavities : OCF(class1) with **large grain**, endmill, to be diffusion bonded

Developed and fabricated by THU; Coming soon!

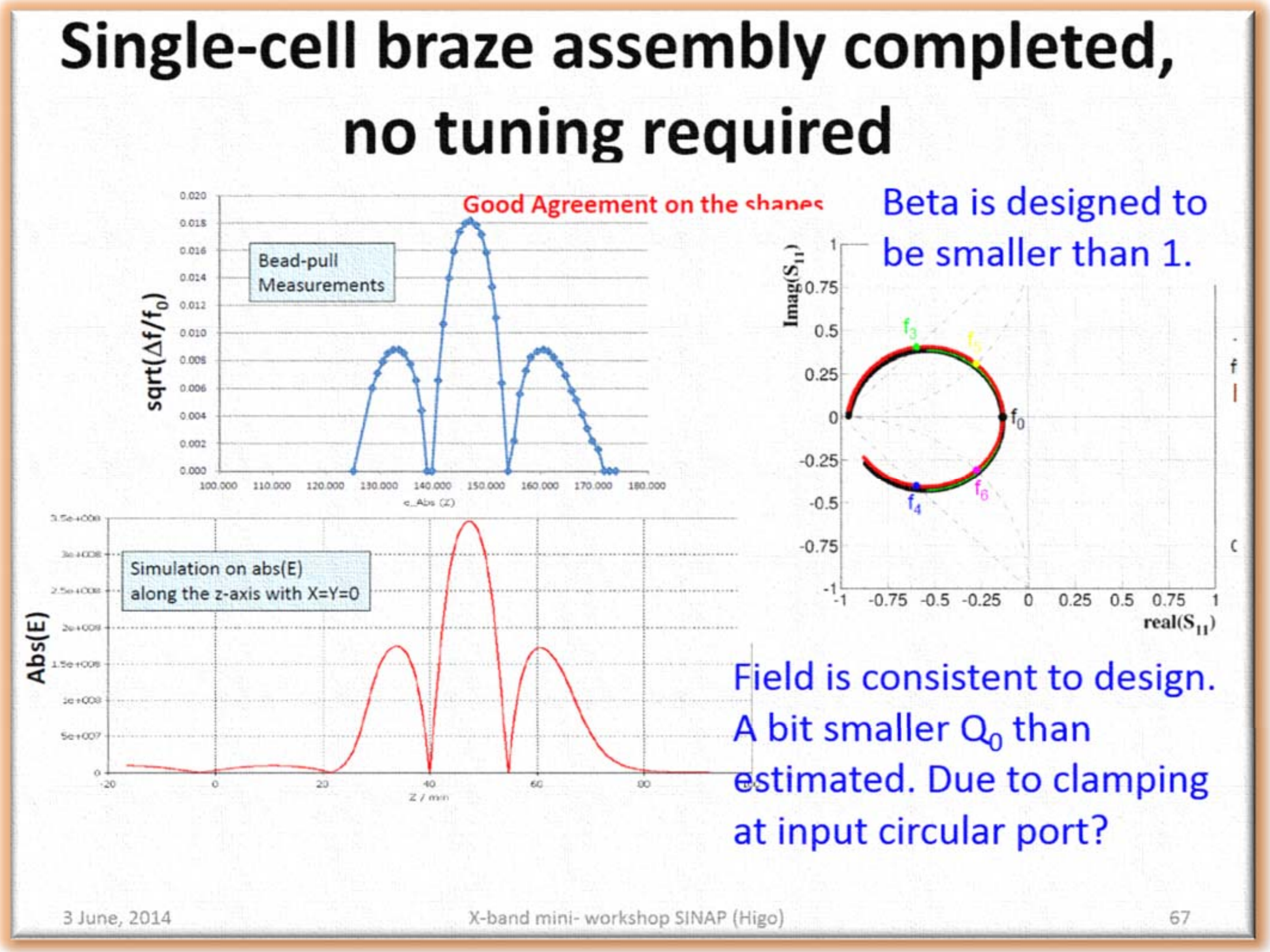
- **Choke-mode**

- **Other candidates?**

Damped cavity : OCF (class1), endmilling, **brazed**



Damped cavity : OCF (class1), endmilling, **brazed**



Structures to be tested at Nextef / Shield-B

Ready for HGT

- Undamped standard cavity : OFC (class1), turning, diffusion bonded
  - To be used for system check
- **Damped** cavity : OCF (class1), endmilling, **brazed**

Bonding finished

- **Damped quadrant** : OFC (class1), all endmilling, EBW
- Undamped standard cavities : OFC (class1), turning, diffusion bonded

Parts made;
Waiting for bonding

- Undamped cavities : OCF (class1), **all endmilling**, to be diffusion bonded
- Undamped cavities : OCF (class1) with **large grain**, turning, to be diffusion bonded
- **Damped** cavities : OCF (class1), endmilling, to be diffusion bonded
- **Damped** cavities : OCF (class1) with **large grain**, endmilling, to be diffusion bonded

Developed and
fabricated by THU;
Coming soon!

- **Choke-mode**

- **Other candidates?**

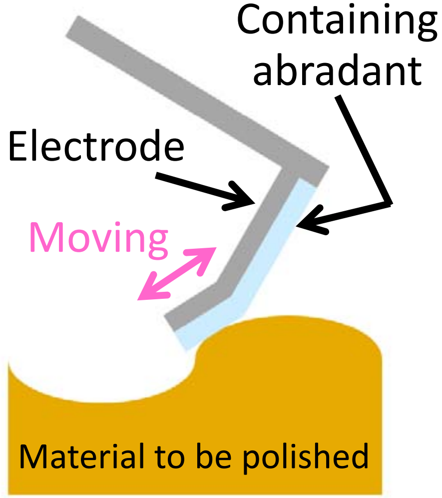
Research Policy and Plan

- The 1st HG test for the undamped standard cavity
  - Just after this summer shutdown
  - Measure reference BDR
  - Start with E_{acc} = 80 – 120 MV/m region for actual application
  - Step up for higher E_{acc} , depending on the results and our interests

- Next cavity
  - Undamped cavity with all-endmilling or large grain, or
  - Choke-mode cavity (from THU)

Surface Finishing for Quadrants

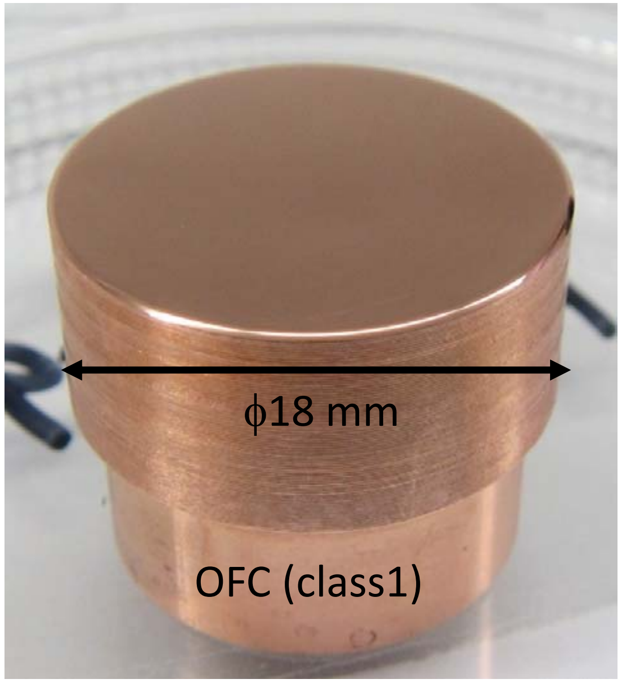
Polishing Test for Ultra-Smooth Surface

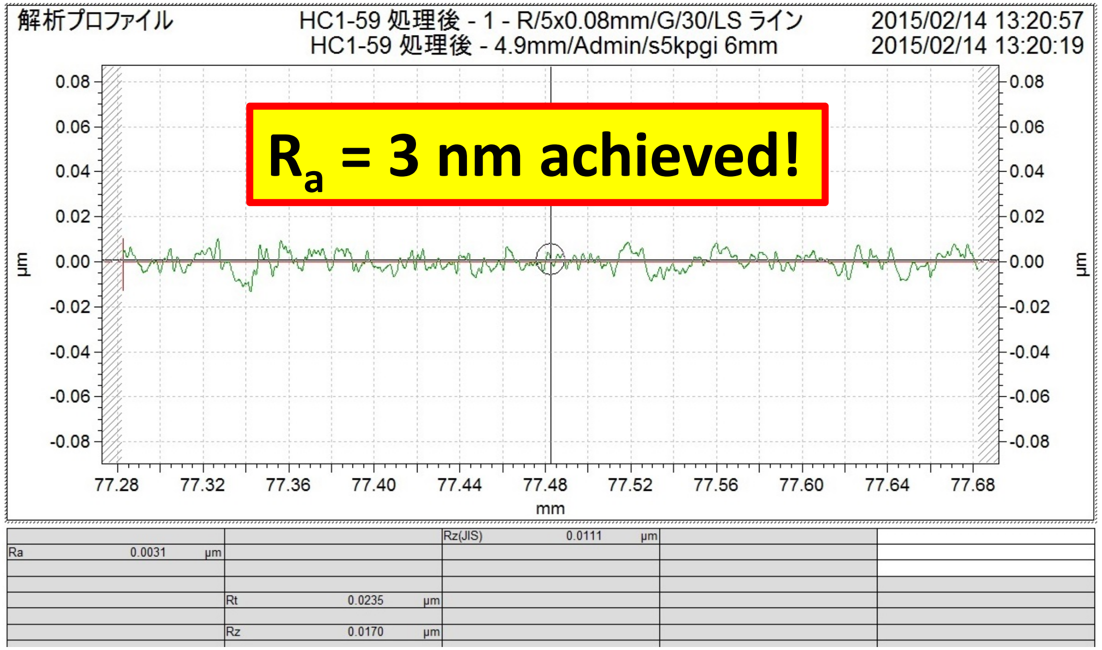


Usual electro-polishing cannot be applied to complicated surfaces.

→ **<u>Electrical + Mechanical</u>** polishing

can be applied to any curved surface in principle

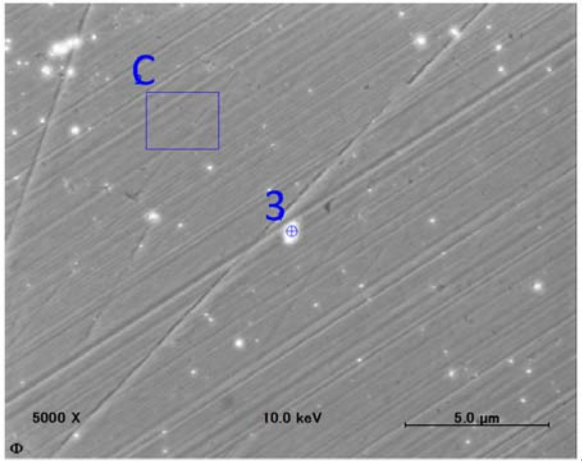




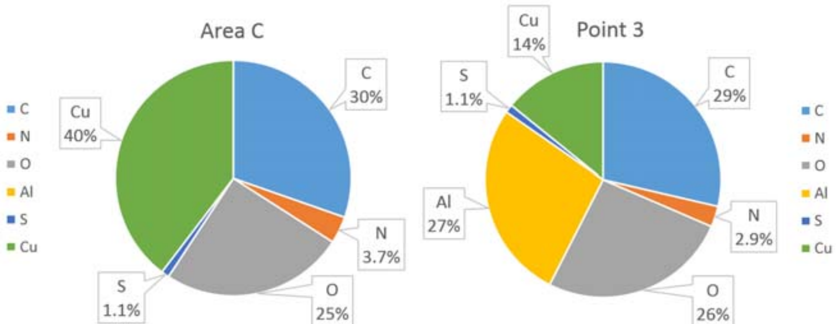
Surface Check by Microscopy

"Electrical + Mechanical" polishing
with Alumina abradant only

Ra = 3 nm

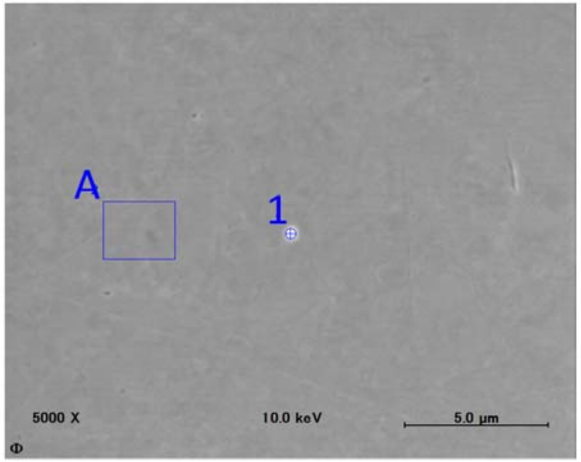


A lot of scratches and abradant



(By Auger electron spectroscopy)

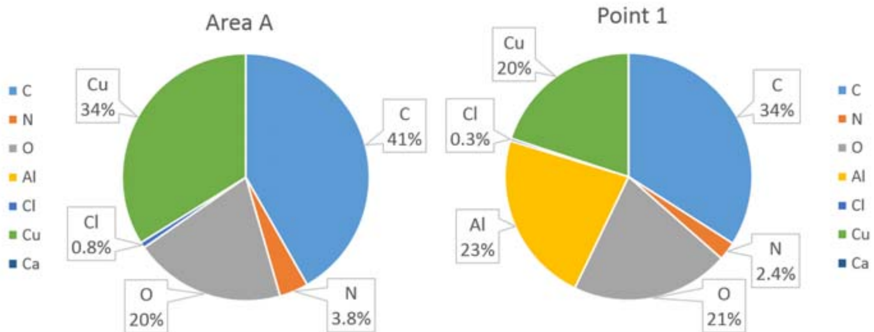
Advanced method based on
"Chemical + Mechanical" polishing



Ra = 1 nm!

Small scratches, few abradant

Promising Method!



(By Auger electron spectroscopy)

Summary

- Basic study, in the form of single cell, based on the X-band technology developed so far, is beginning at KEK / Nextef / Shield-B.
  - ✓ **The klystron (KT-1) is working well.**
  - ✓ **The power-line conditioning is on-going.**
  - ✓ **The 1st HG test will start just after this summer shutdown.**

- Structures to be tested
  - Undamped standard, all turning or all endmilling
  - Damped structures with HOM waveguides or choke-mode
  - New quadrants
  - With large grain
  - Others?

Thank you for your attention!