HIGH-GRADIENT TESTING OF X-BAND SINGLE CELL TEST STRUCTURES AT KEK/NEXTEF

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on behalf of Nextef team

LCWS2016 @ MORIOKA, IWATE, Japan

2016-12-08

Research Strategy

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

Multi-Cell Prototypes

Electrical Design

Mechanical Design

Fabrication

HG Test

Feedback

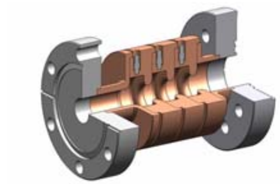
- ✓ Comprehensive study and development
- ✓ Cost and time consuming

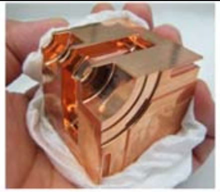
Problems / *Solutions*

Problems / *Solutions*

Problems / *Solutions*

Covered by this talk





Single-Cell Cavities

Design → Fabrication → HG Test

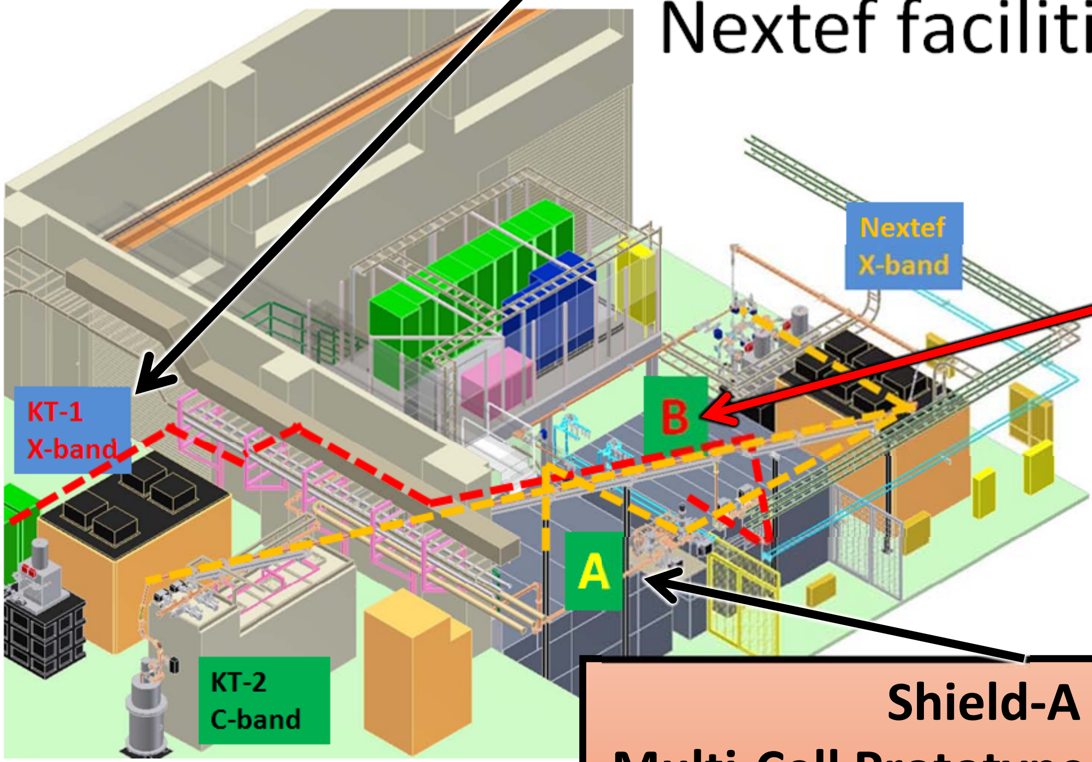
- ✓ Minimum structure keeping realistic RF fields for acceleration
- ✓ Palm-sized cavity
- ✓ Basic study, element test
- ✓ Easy to make and test

(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.)

KEK / Nextef for X-Band Accelerating Structure Developments

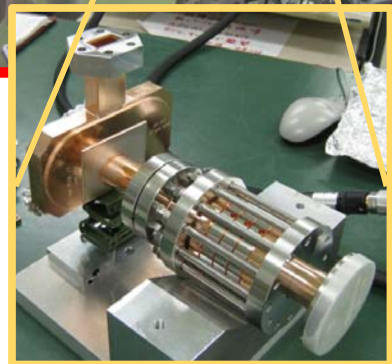
$P_{kly\text{-}out} \approx$ 30 MW at max. for stable operation

Nextef facilities



Shield-A for Multi-Cell Prototype Developments

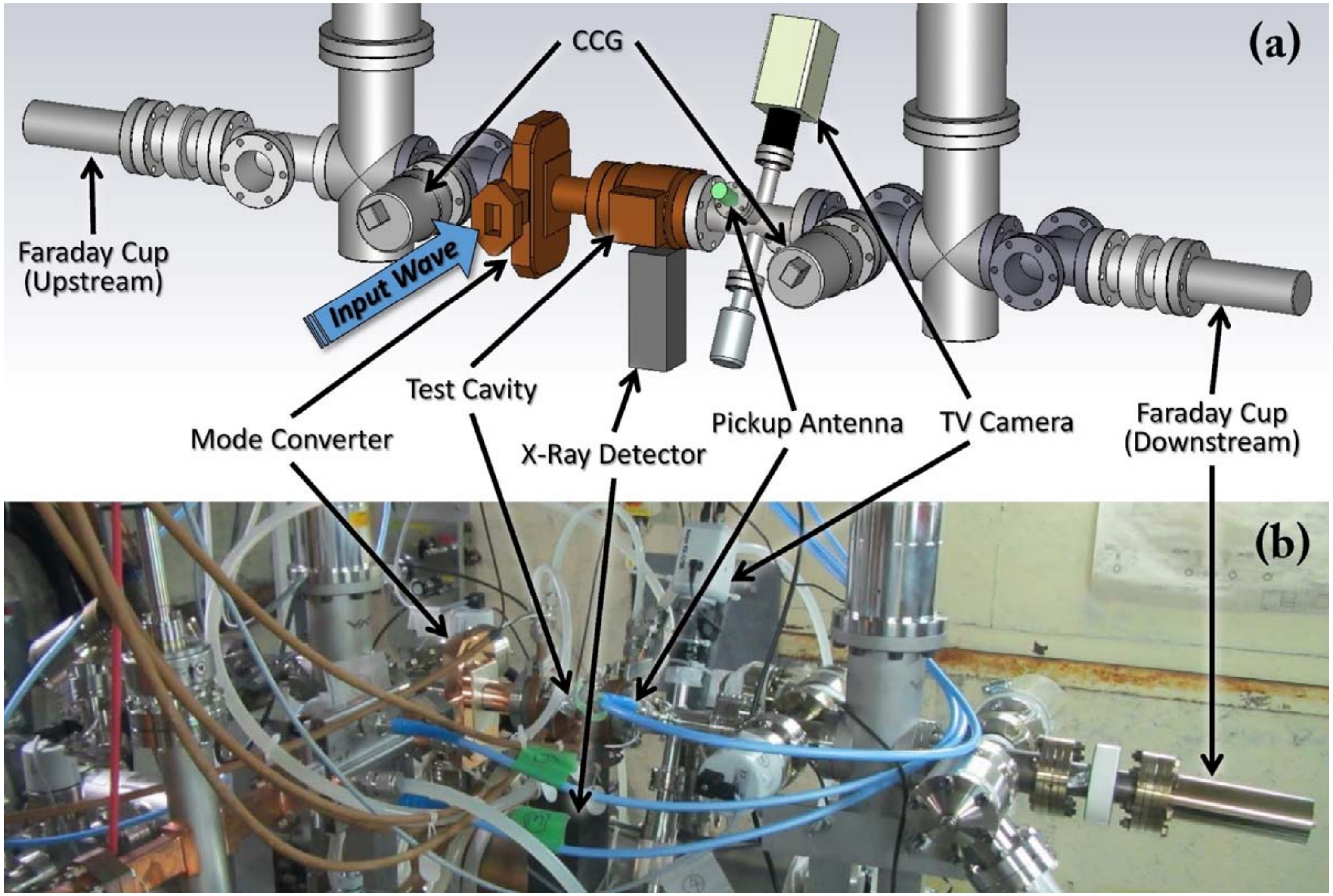
Shield-B for Single-Cell Tests



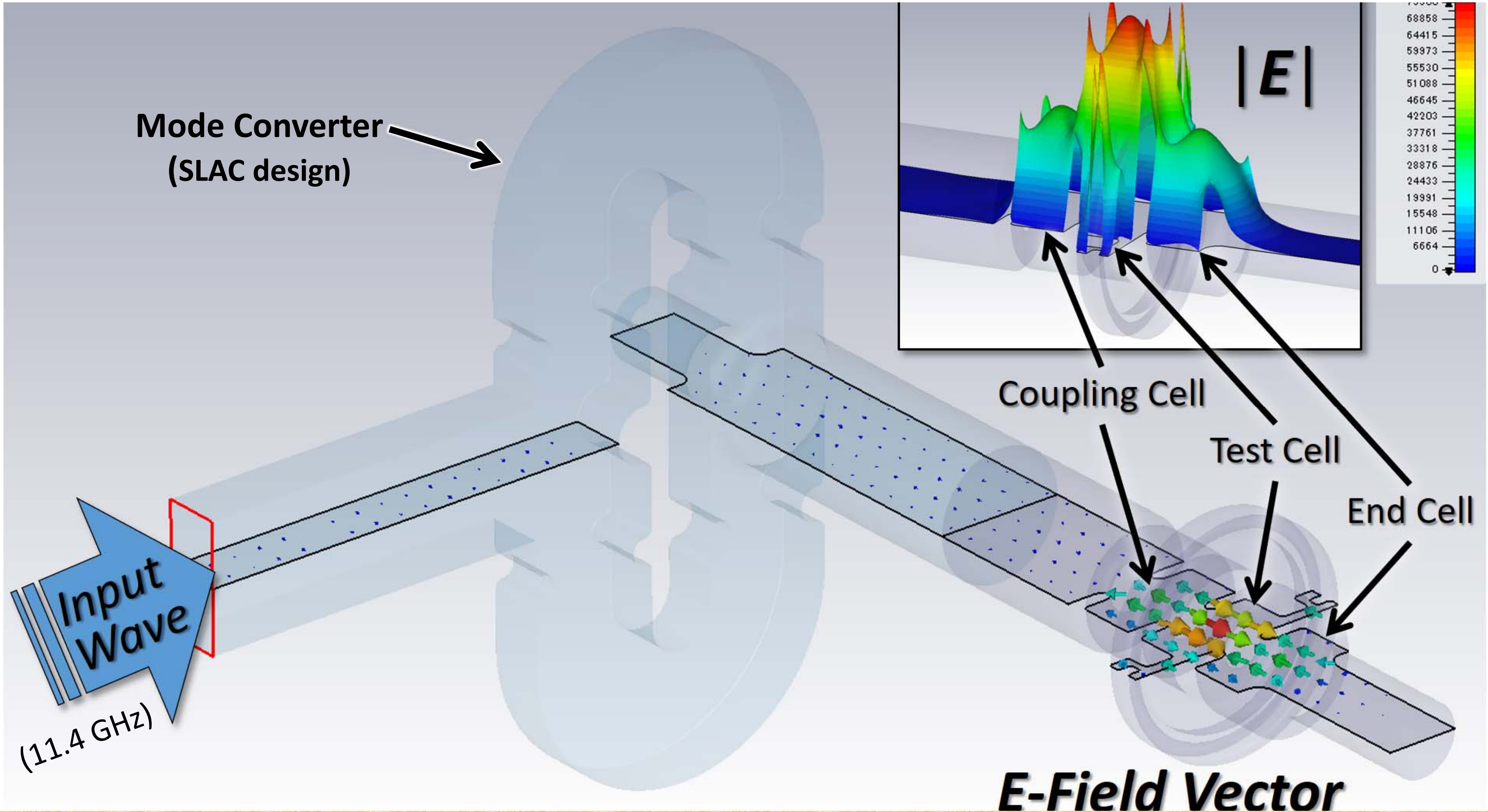
Example of test cavity setup

- - - Power Line from KT-1 to Shield-B (35 m long)

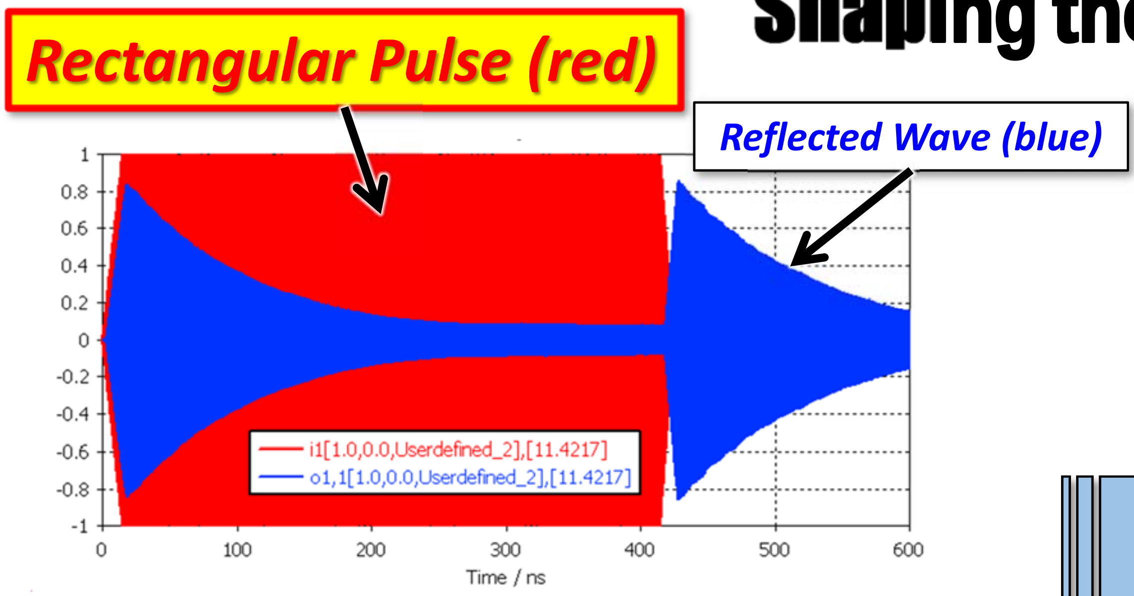
Experimental Setup of Nextef / Shield-B

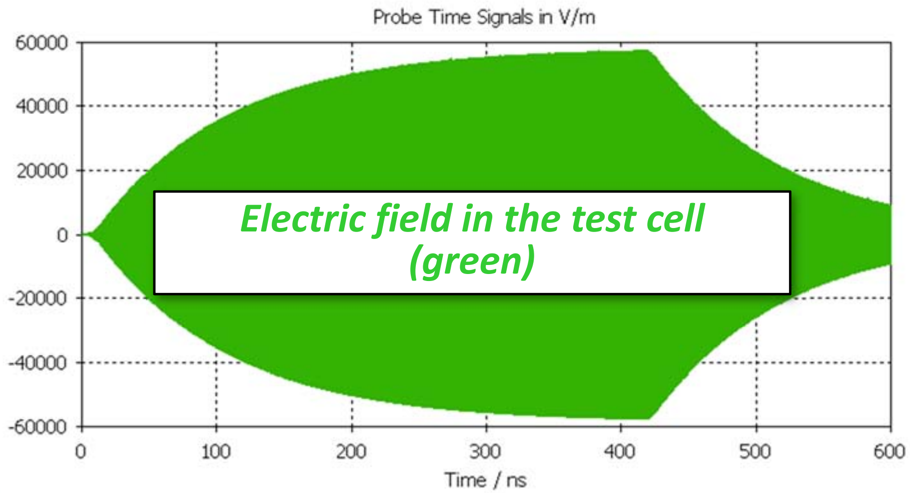


Standing Wave with the Maximum Field in the Central Test Cell

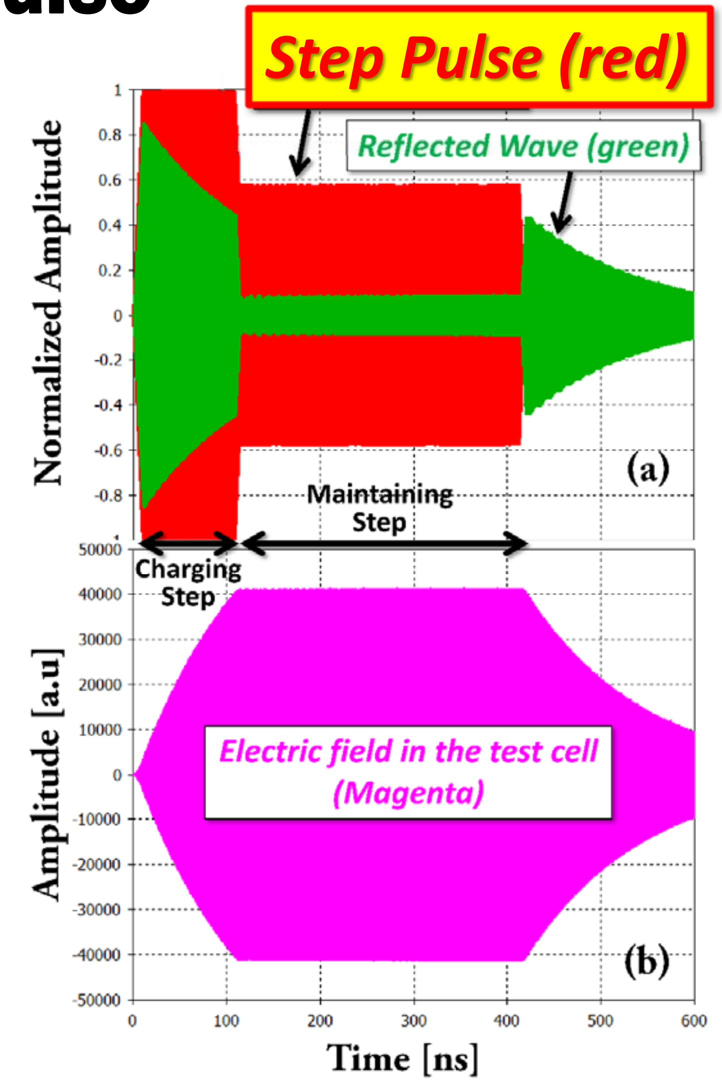


Shaping the Input Pulse



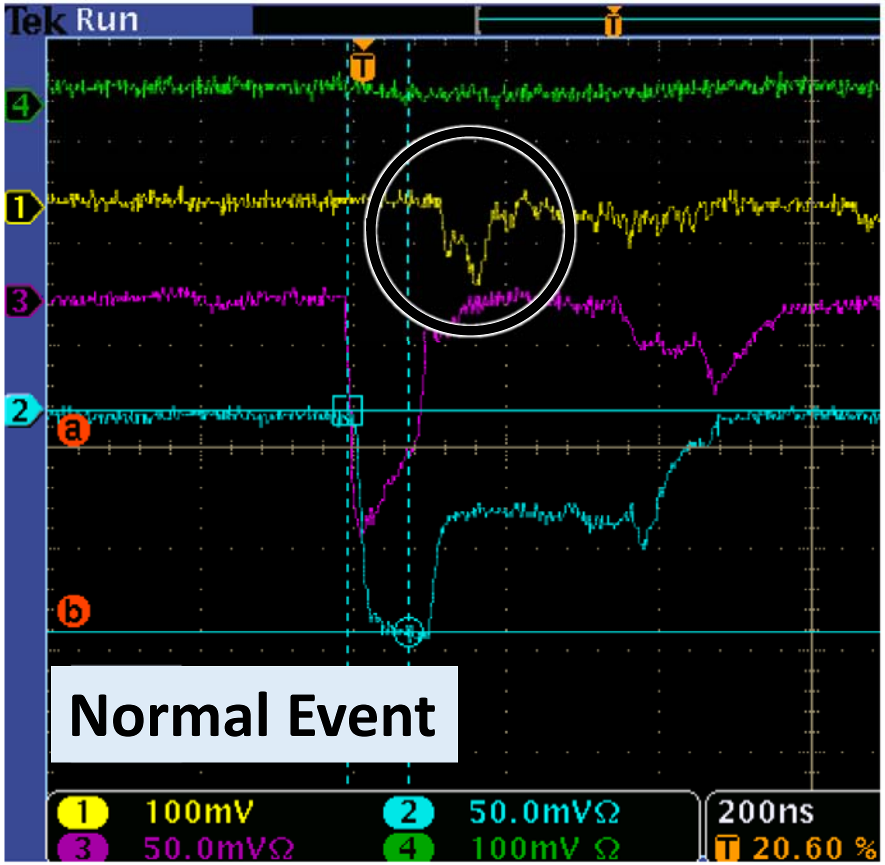


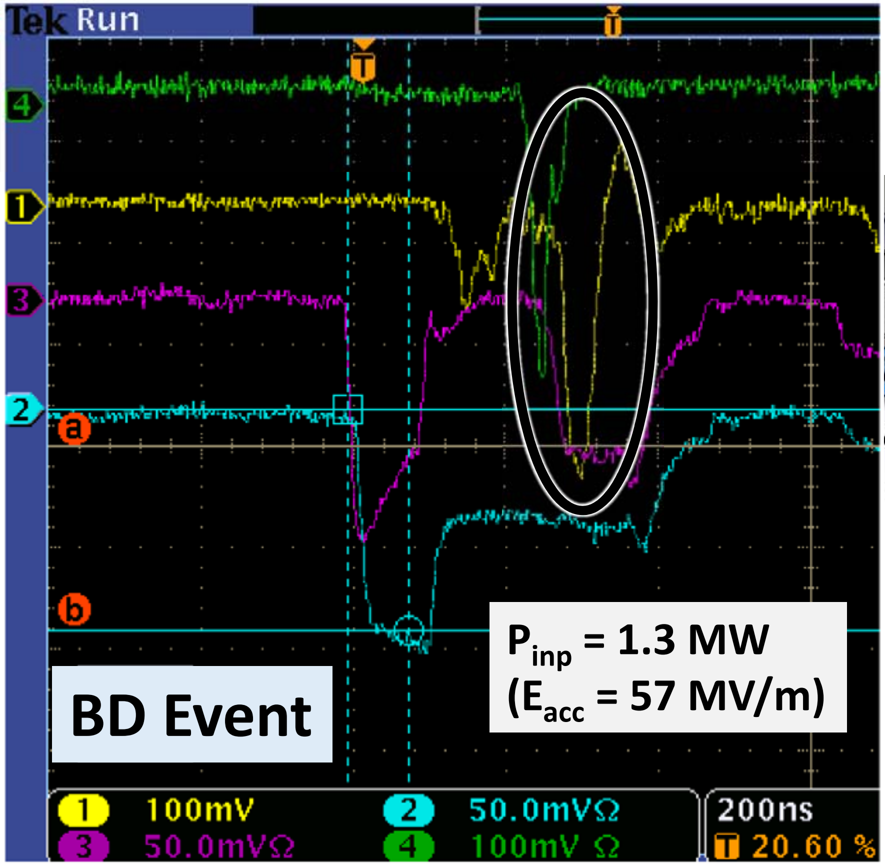
11.4 GHz, Q_L=4000
→ T_f = 110 ns

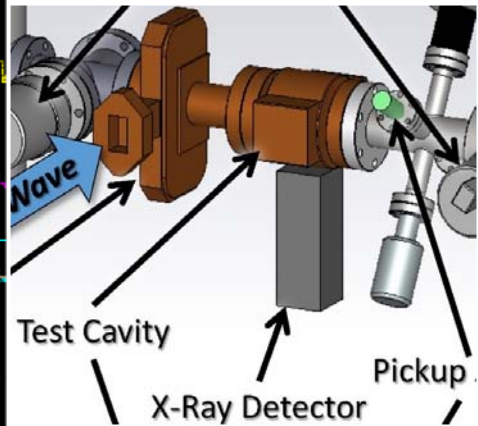


Examples of X-Ray Signals

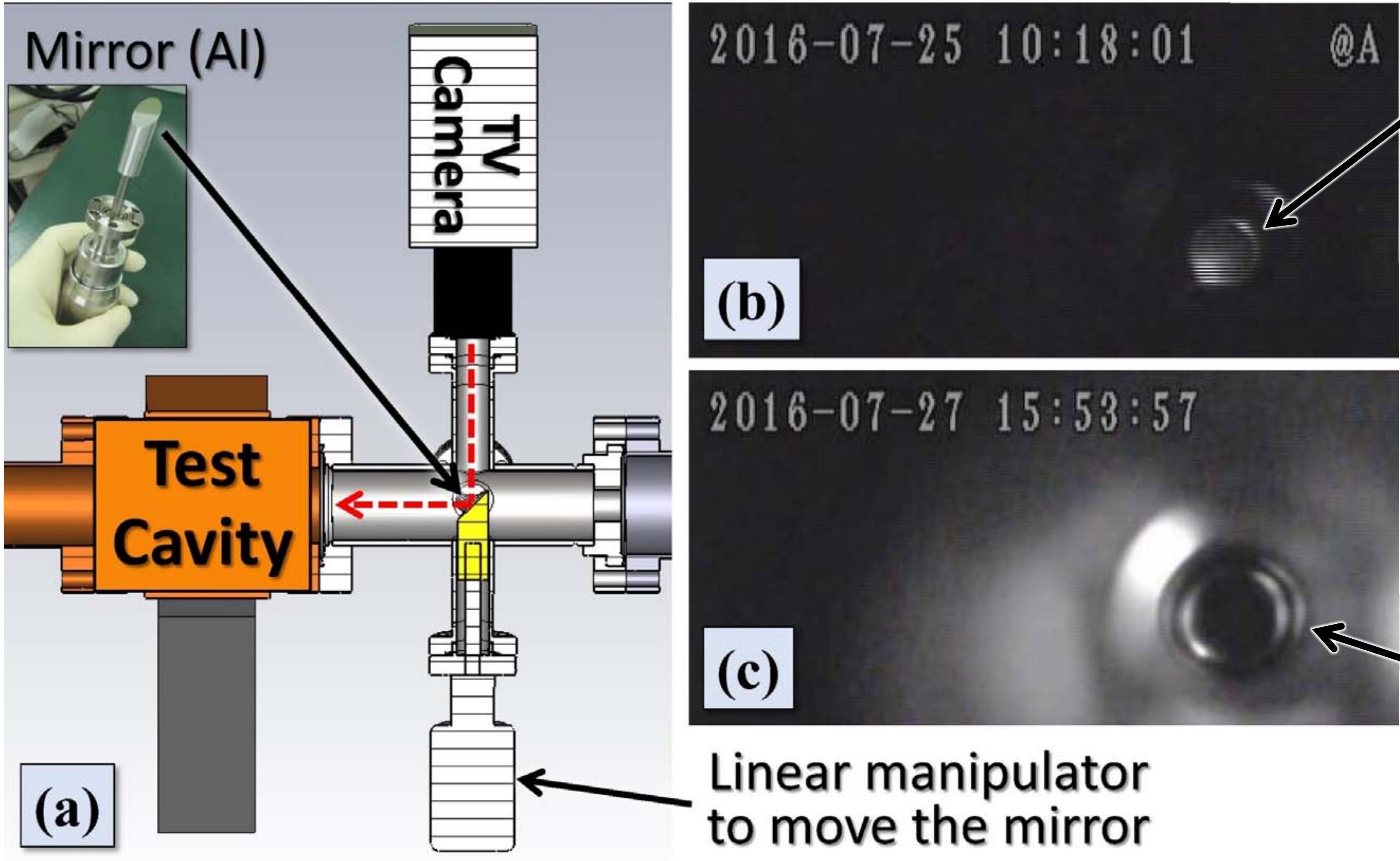
Ch.1: X Ray (yellow) Ch.2: Input Wave (blue)
Ch.3: Reflected Wave (magenta) Ch.4: Pickup Wave (green)





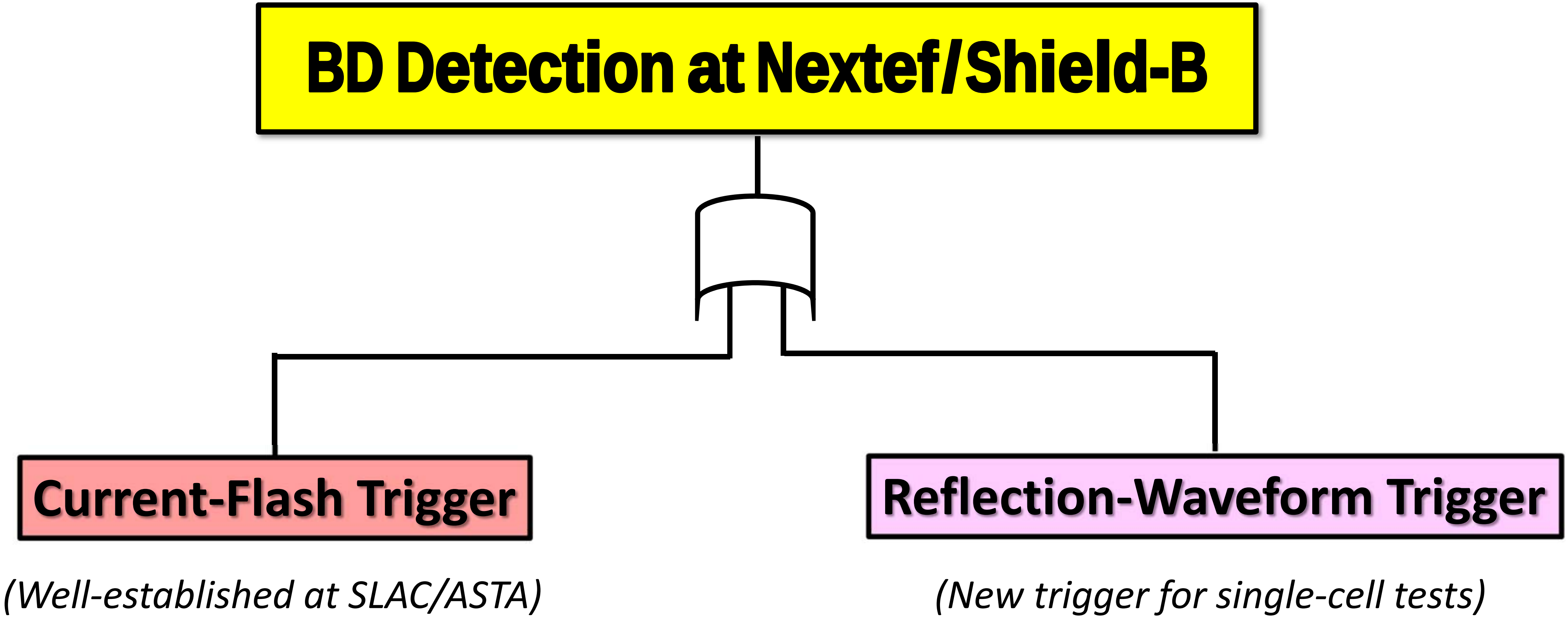


Example of Acquired TV Video Images with Discharge

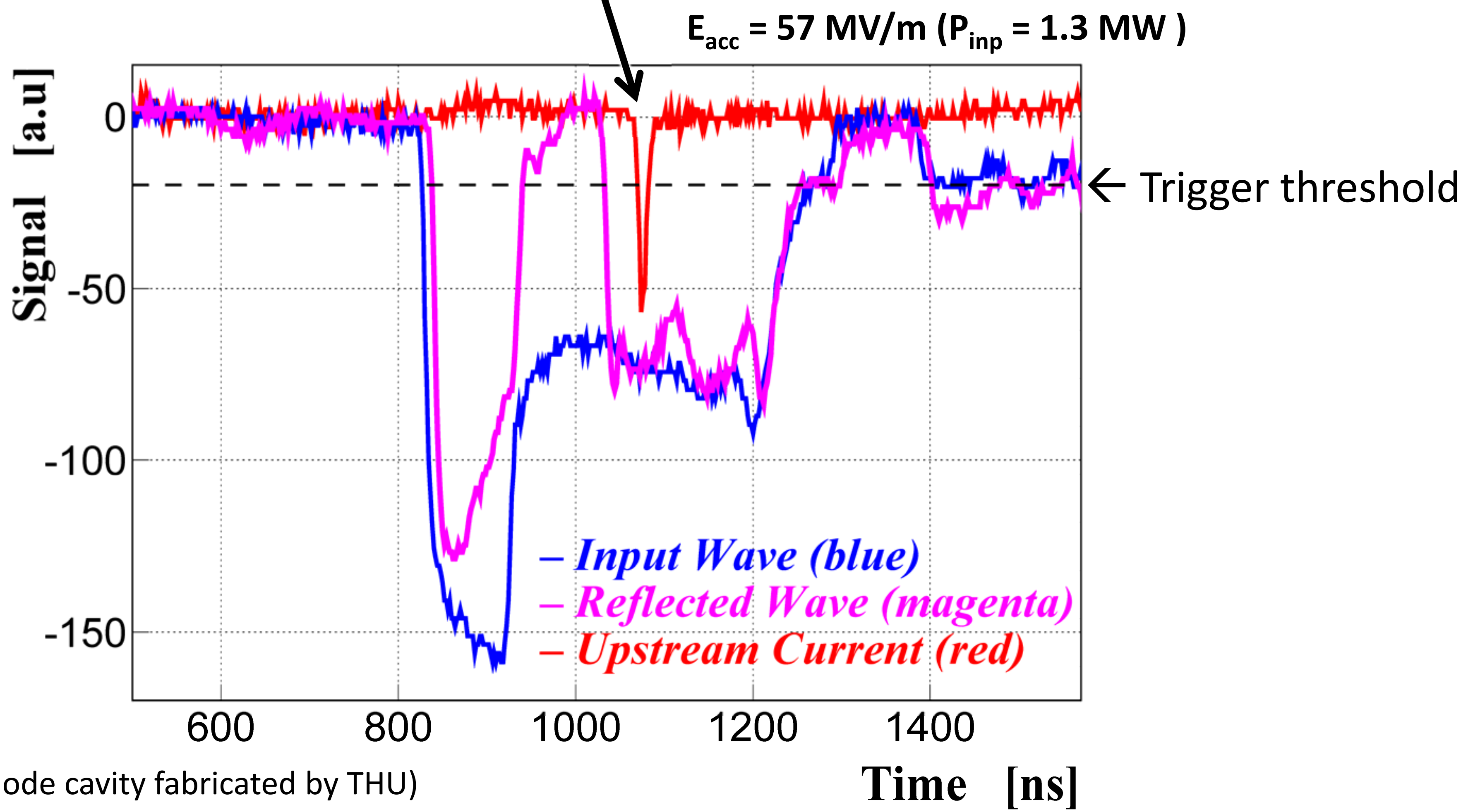


(for the choke-mode cavity fabricated by THU)

No RF.
Light injected into the cavity through one of the view ports (for comparison).


BD Detection at Nextef/Shield-B
Current-Flash Trigger
Reflection-Waveform Trigger
(Well-established at SLAC/ASTA)
(New trigger for single-cell tests)

Example of Current-Flash Triggered Events



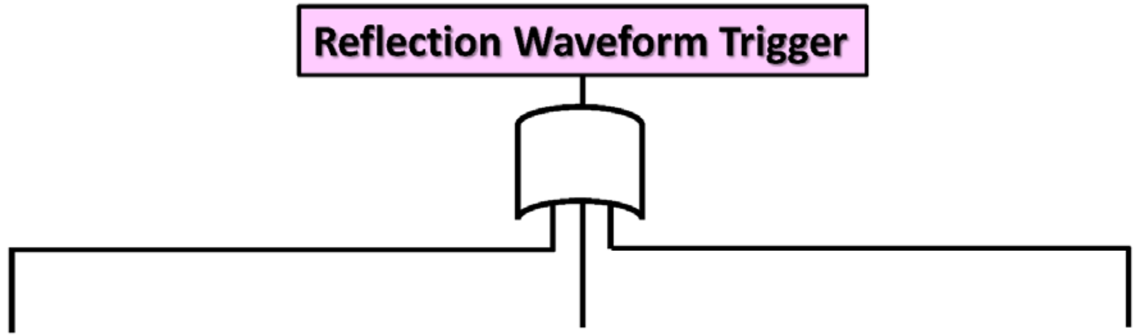
(For the choke-mode cavity fabricated by THU)

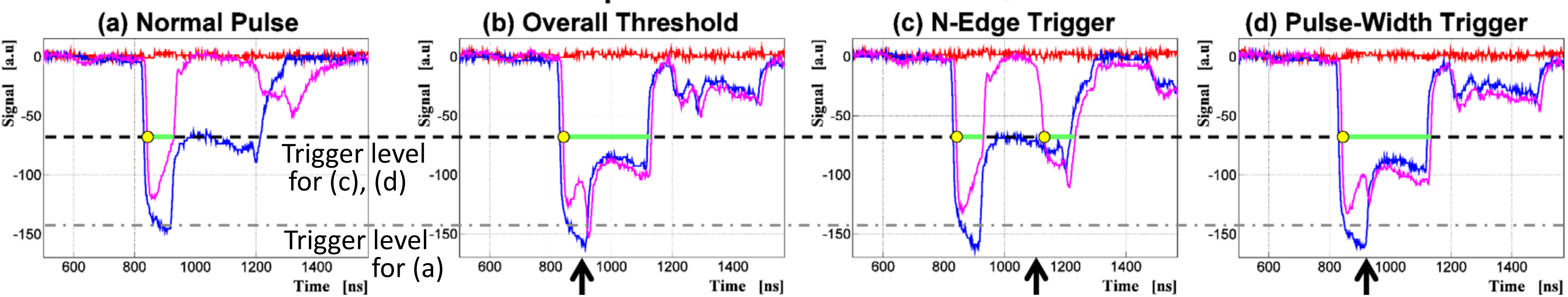
Reflection-Waveform Trigger System

- - - - Trigger level for (c) or (d)
○ Detected edge
▬ Detected width
↑ Trigger timing

For the details, see,
[T. Abe *et al.*, "High-Gradient Testing of Single-Cell Test Cavities at KEK/Nextef," presented at the 13th Annual Meeting of Particle Accelerator Society of Japan (2016), Paper ID: MOP015.]

– *Input wave (blue)*
– *Reflected wave (magenta)*
– *Upstream Current (red)*





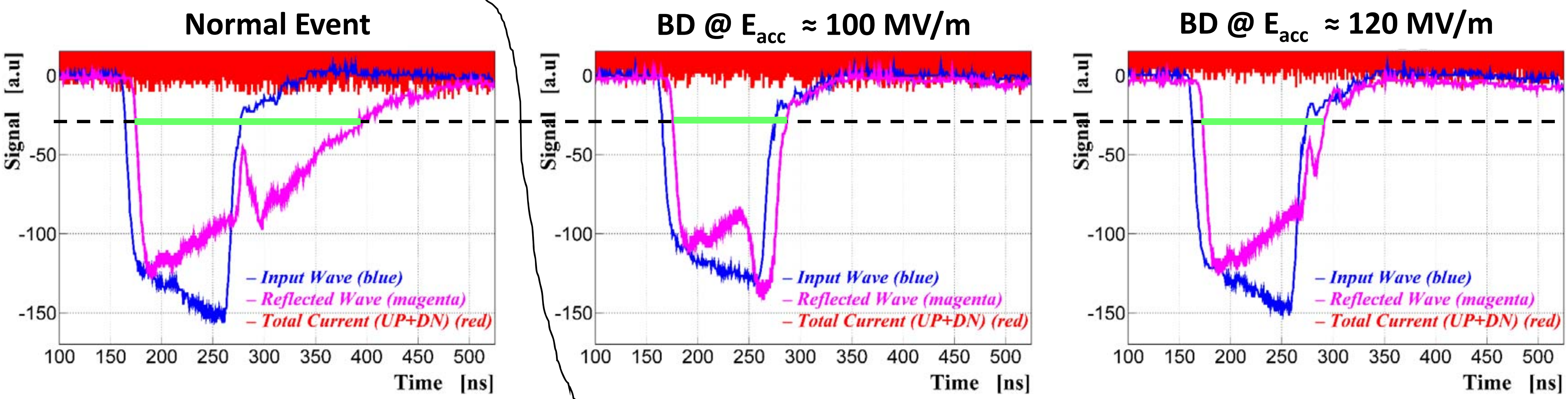
The trigger parameters have been continuously improved.

Examples of Waveform-Triggered Events with No Current Flash Detection

in the case of the undamped structure (fabricated by THU)

(Rectangular Pulse with 100 ns length)

If (the width at the trigger level) < 150 ns → Triggered



(Rectangular Pulse with 100 ns length)

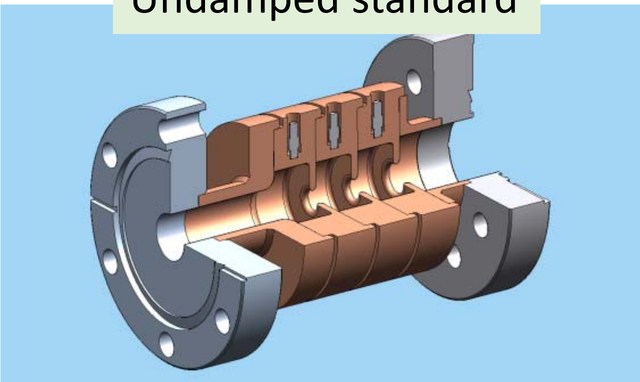
- ✓ **< 10% of the total BD events so far for the undamped structure**
- ✓ **Statistical analysis on-going**
- ✓ **For the choke-mode structures, we observed many BD events with no current flash (→ next talk).**

TEST STRUCTURES

Single Cell Structures to be tested at Shield-B

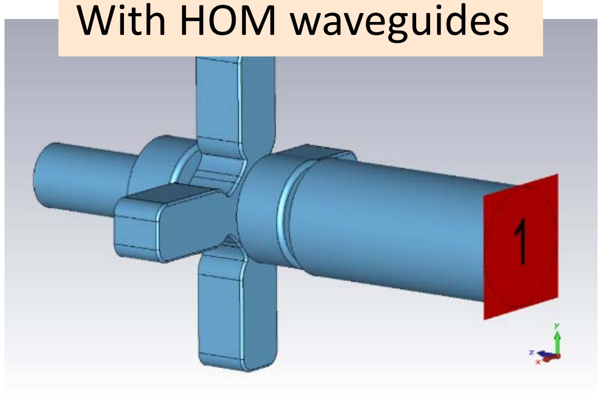
(Current list)

Undamped standard



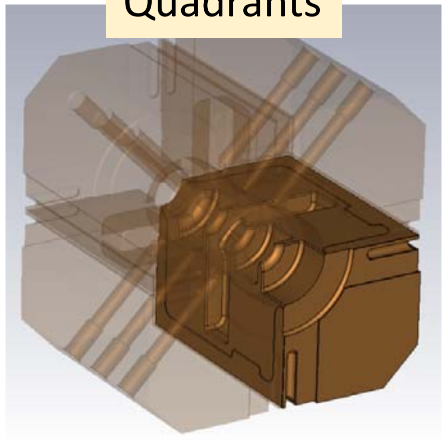
- With standard OFC (class1) and machined by turning
  → For reference BDR
- With large grain
  → To investigate grain-boundary effects

With HOM waveguides



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

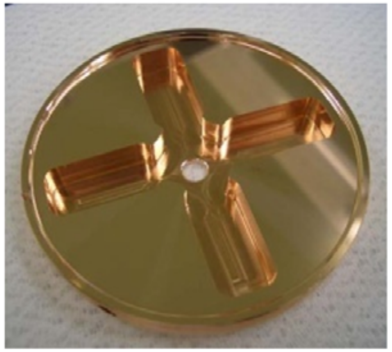
Quadrants



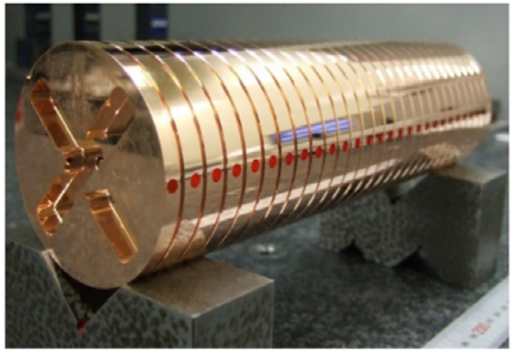
- To investigate the relation between surface current and bonding surface
- Etc…

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

Disk-type



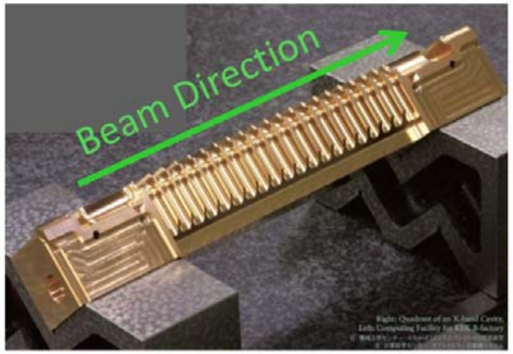
A damped disk



Disks stacked and bonded

- Advantages
  - ✓ Machining by turning
  - ✓ Very smooth surface (Ra = ~30 nm)
  - ✓ Shallow machining damage (< 1 μm)
- 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

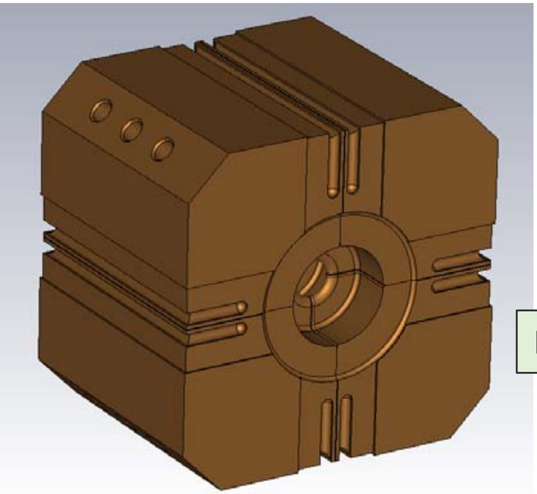
- Advantages
  - ✓ **Surface currents do not flow across any disk-to-disk junction.**
  - ✓ Simple machining by five-axes milling machines
  - ✓ Simple assembly process
    - → Significant cost reduction?
- Disadvantages
  - ✓ Not very smooth surface (Ra = ~ 0.5 μm)
  - ✓ Deep machining damage (10 - 20 μm)
  - ✓ **Virtual leak from quadrant-to-quadrant junctions**

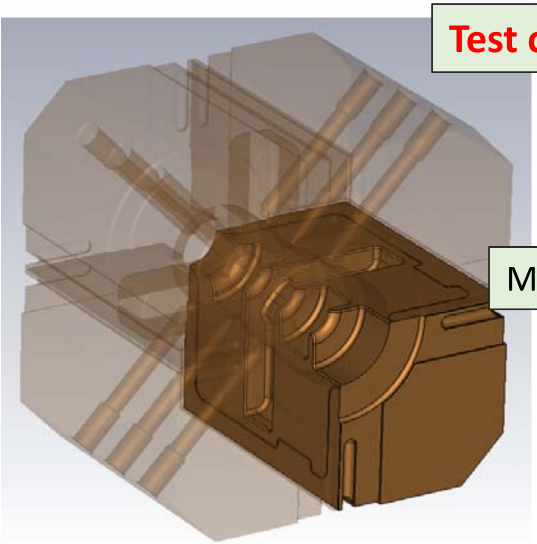
New Quadrant-type Structure as a Single-Cell Test Cavity

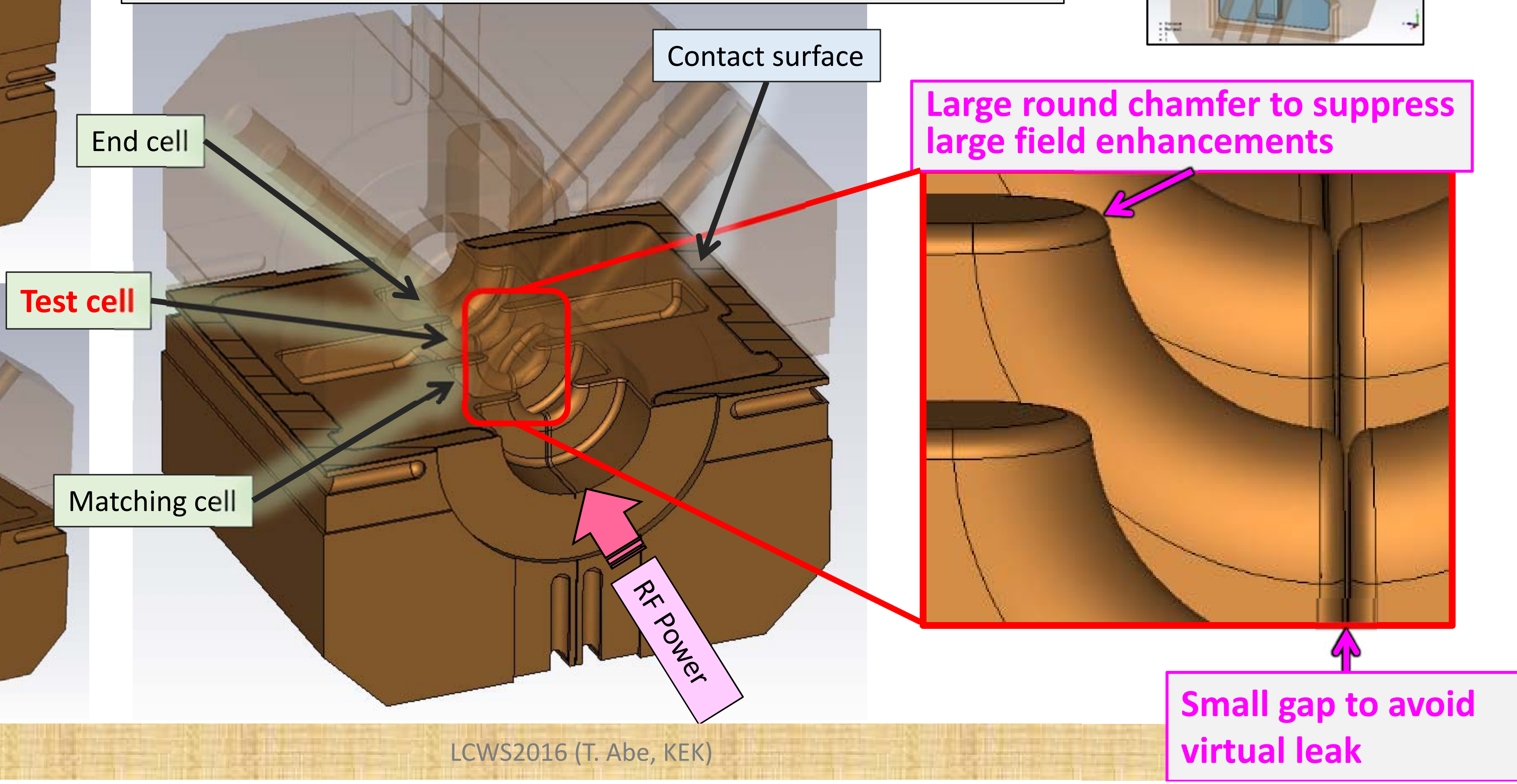
which overcomes all of the disadvantages

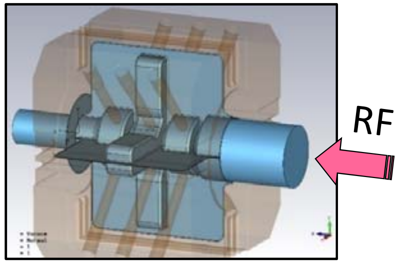
For the details, see,

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.

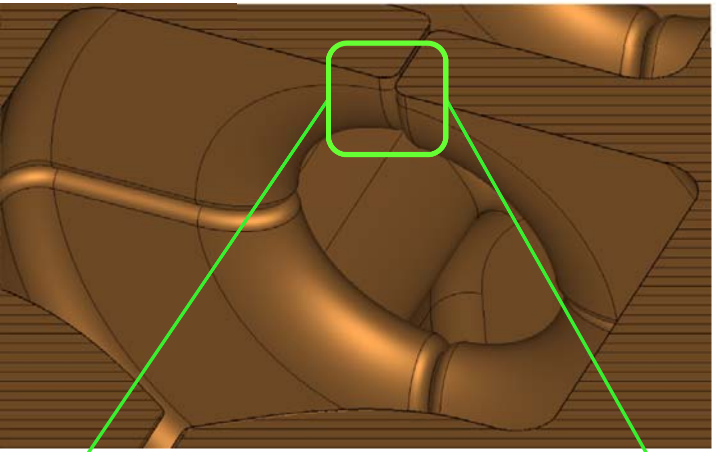


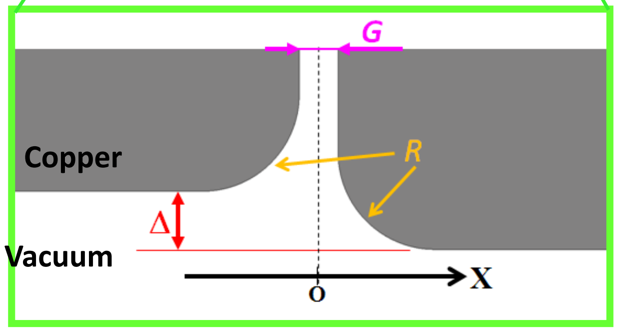


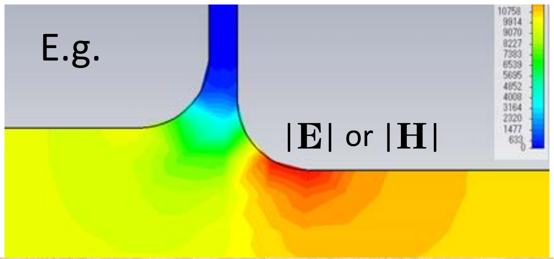




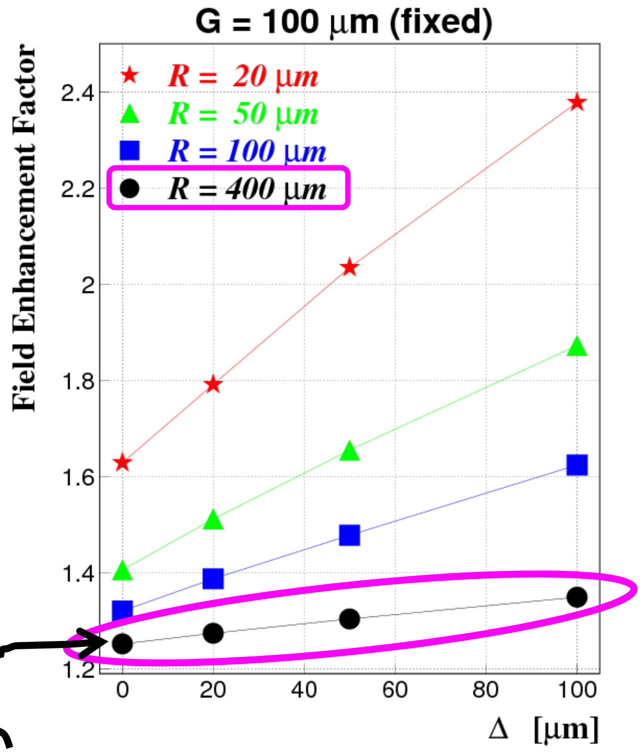
The large round chamber was optimized by a theoretical study on field enhancements due to misalignment of quadrants.



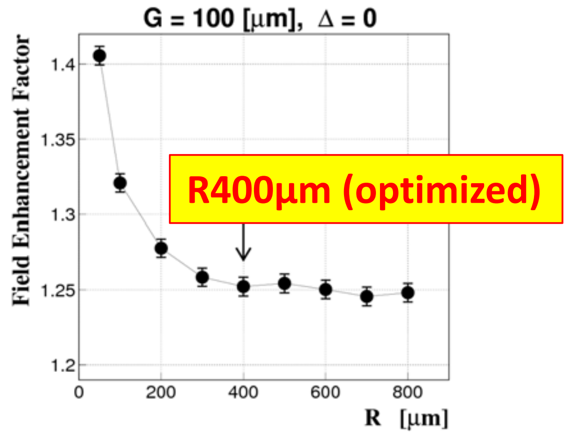


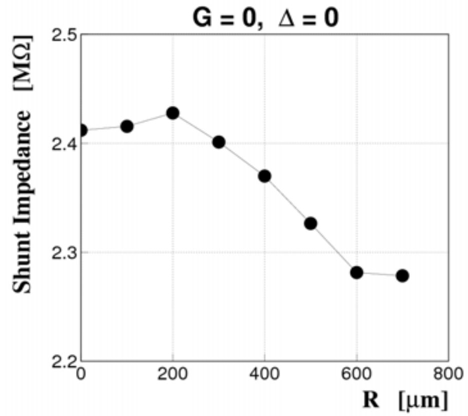


For more details, see
T. Abe, "Study of Surface Field Enhancements due to Fine Structures," presented at the 8th Annual Meeting of Particle Accelerator Society of Japan, 2011 (Paper ID: TUPS086).

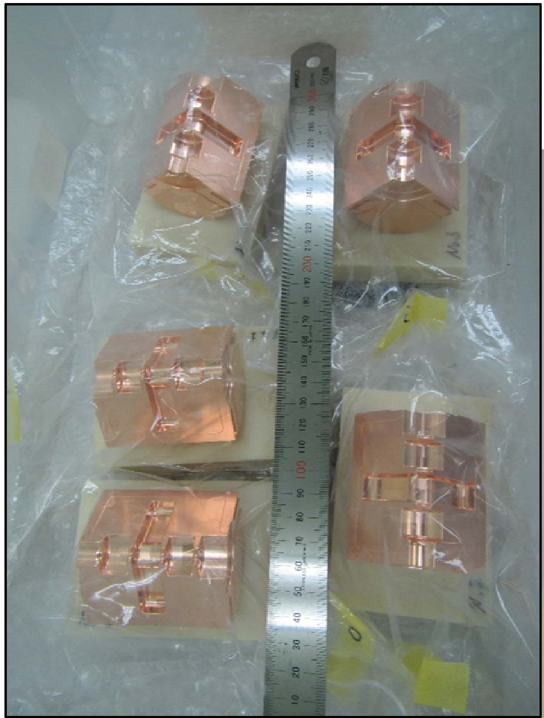


1.23 (G=0, Δ=0) (independent of R)
(**Minimum field enhancement!**)

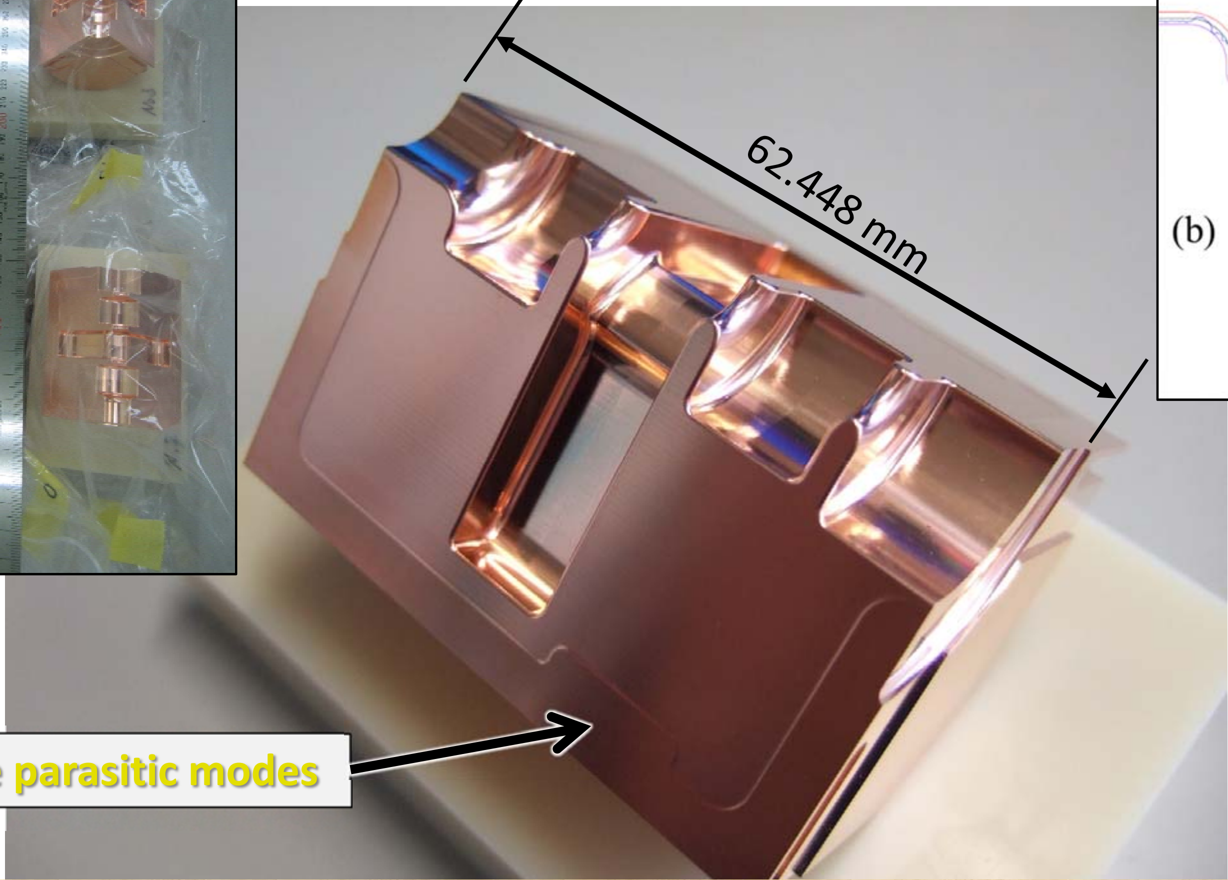




Delivered Quadrants for HG Test

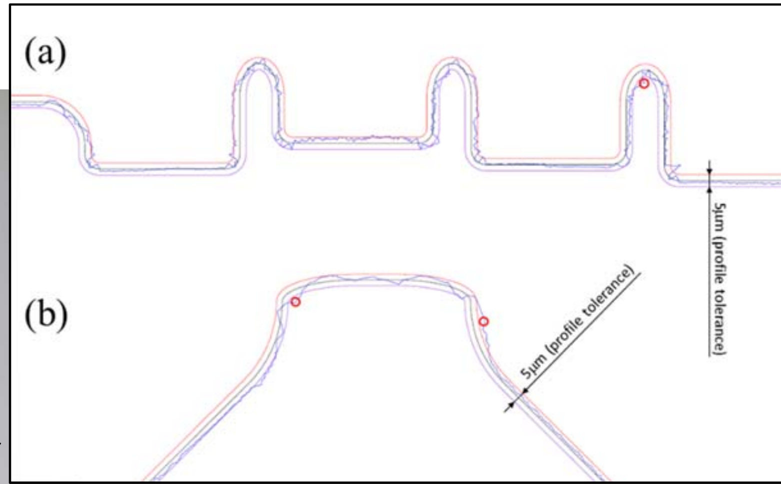


- ✓Material: OFC (class1)
- ✓Ultra-high precision milling with five axes
- ✓**Ry = 1 μm achieved**



Bump to purge parasitic modes

Profile accuracy 5 μm achieved



Precise Assembly and EBW (Electron Beam Welding)

T. Abe *et al.*, "Basic Study on High-Gradient Accelerating Structures at KEK/Nextef," in Proceedings of the 12th Annual Meeting of Particle Accelerator Society of Japan, August 2015 (Paper ID: WEP060).

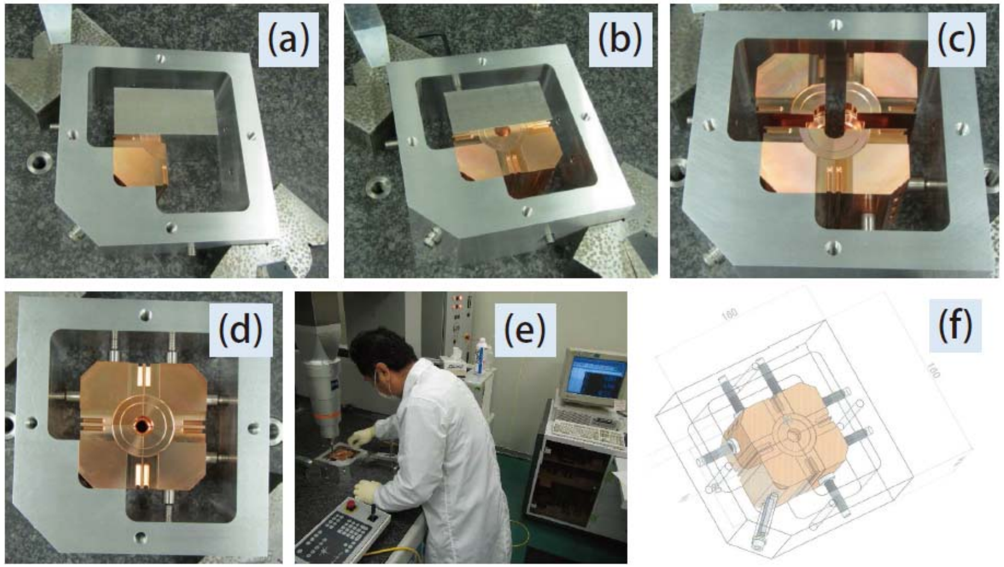


Figure 11: Precise assembly of the quadrants of the single-cell damped structure. (a) One quadrant fixed on an alignment frame. (b) Two quadrants aligned using an alignment block. (c) Replacing the alignment block by two quadrants. (d) After the last two quadrants aligned. (e) During the alignment of the last two quadrants using a CMM. (f) 3D drawing of the alignment frame including the quadrants.

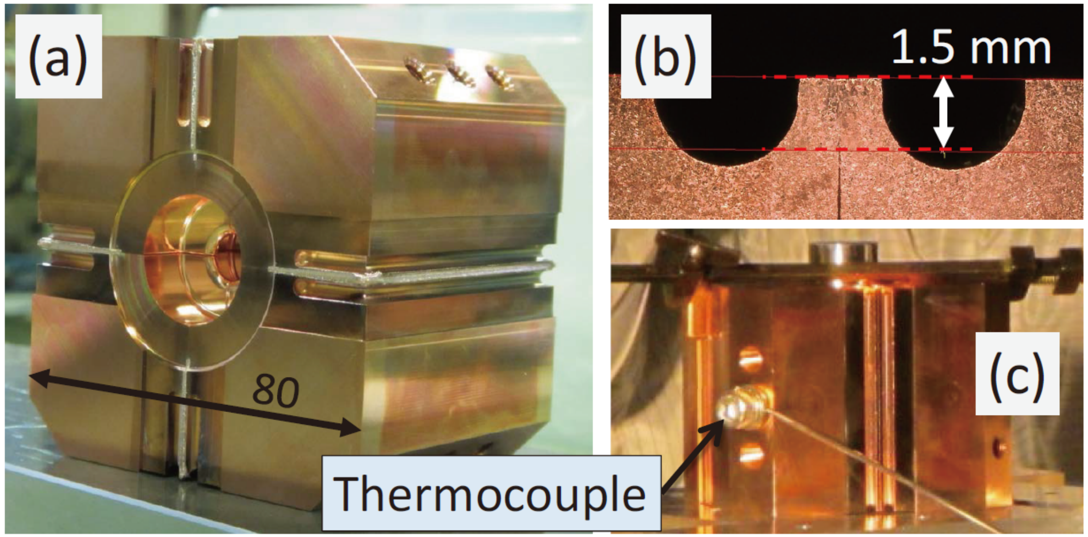
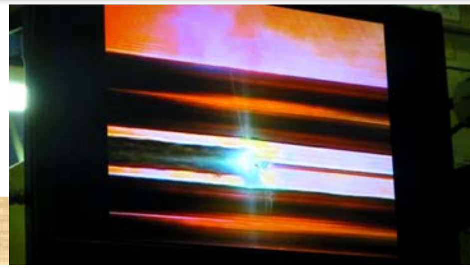
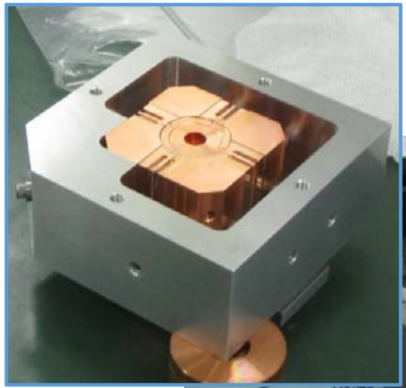


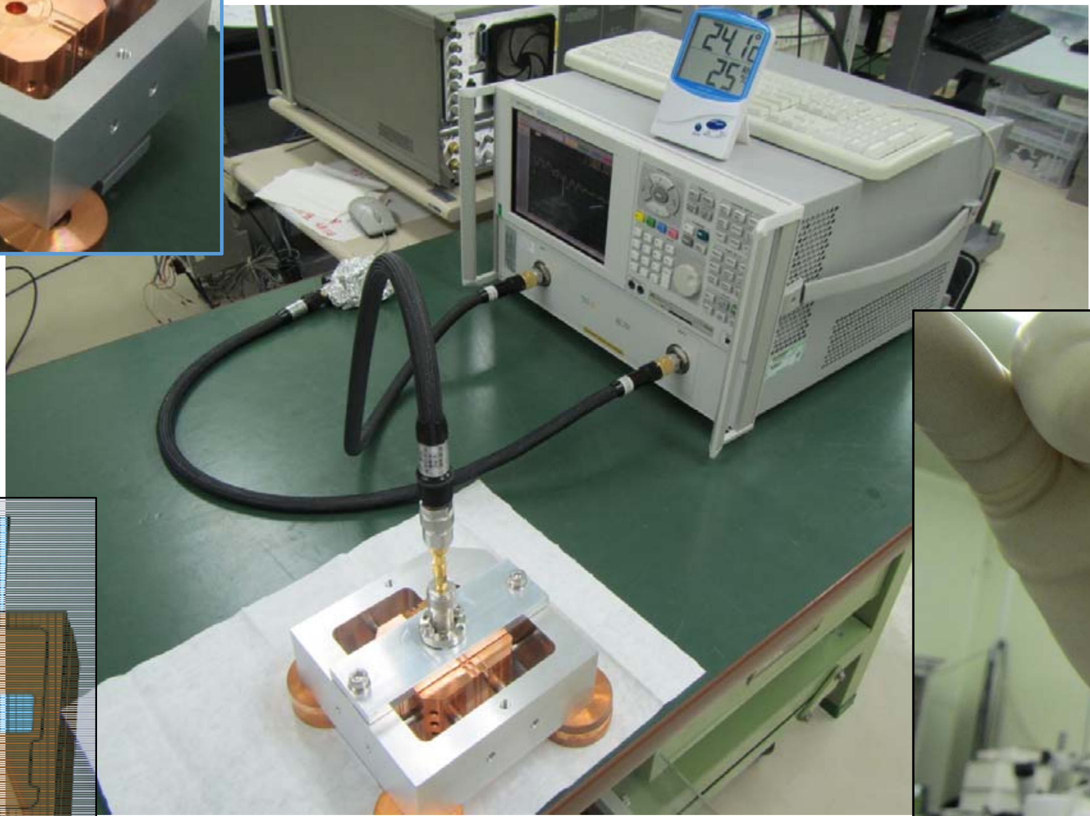
Figure 12: EBW of the quadrants. (a) After the EBW. (b) Welding penetration depth for the EBW conditions described in [13]. (c) A thermocouple is attached.

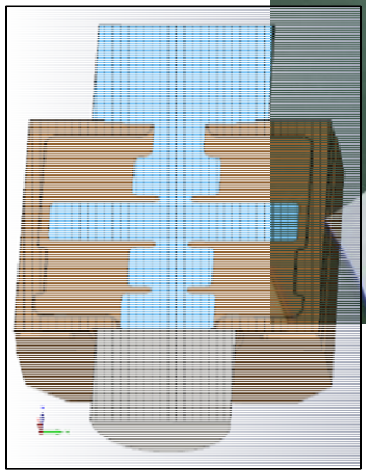


Frequency Measurement

before and after the EBW





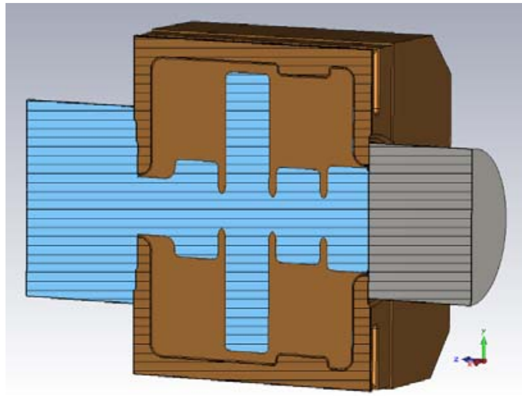


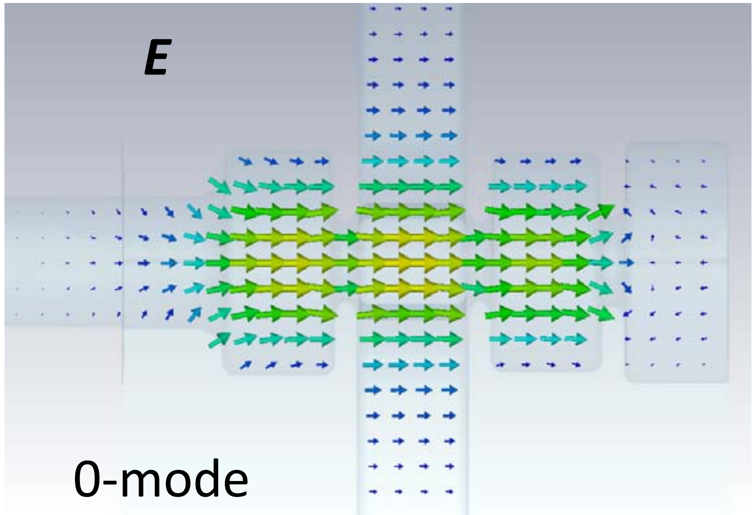
Pickup antenna

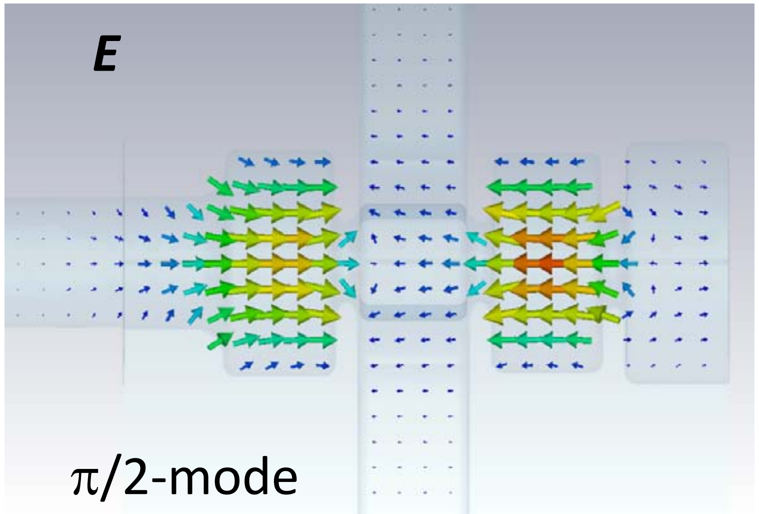
Measurements of the Mode Frequencies

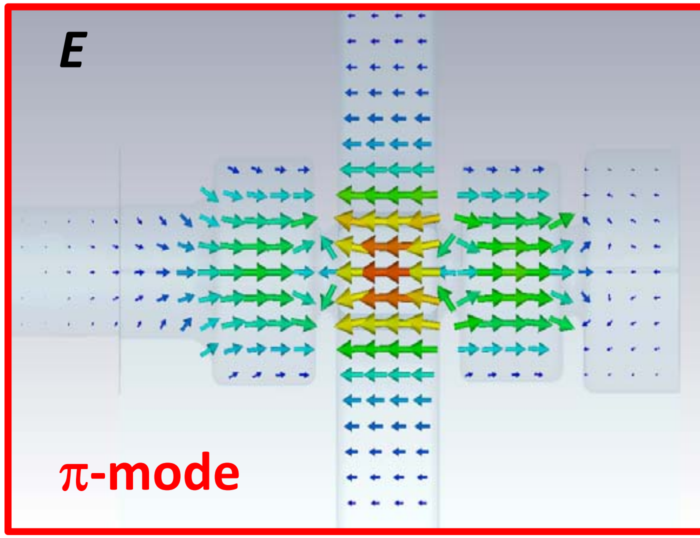
Mode	After the EBW	Before the EBW	After - Before
0	11.2872 GHz	11.2739 GHz	+13.3 MHz
$\pi/2$	11.3362 GHz	11.3259 GHz	+10.3 MHz
π (Accelerating mode)	11.4160 GHz	11.4104 GHz	**+5.6 MHz**

← Within the scope of frequency tuning

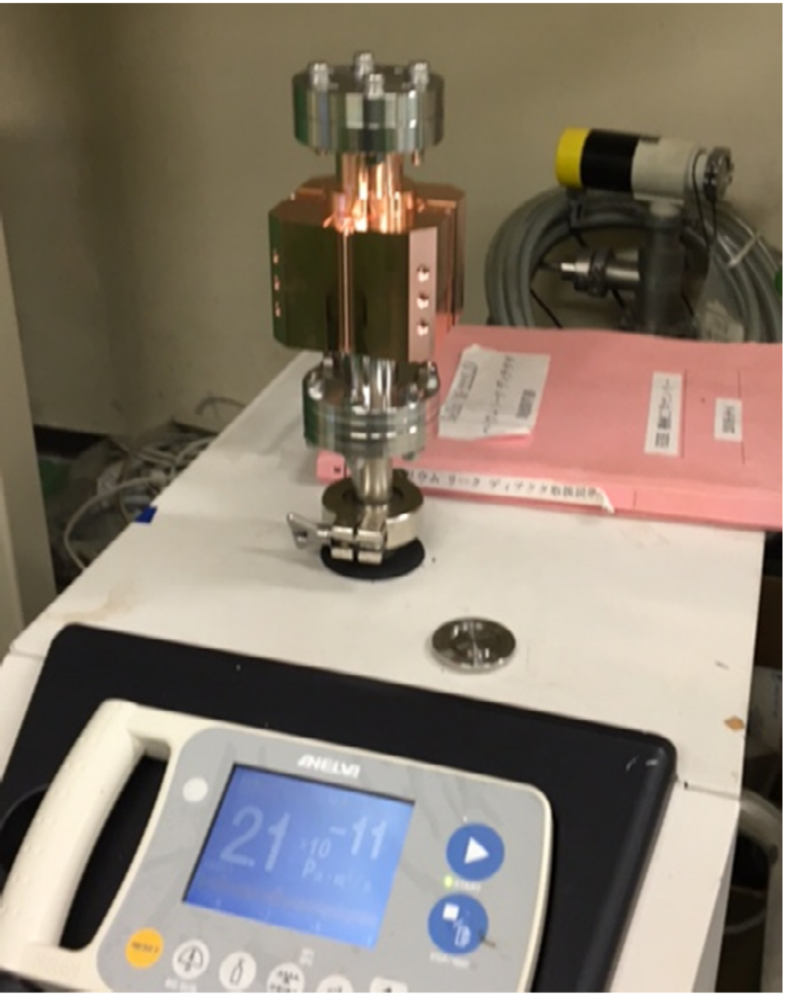






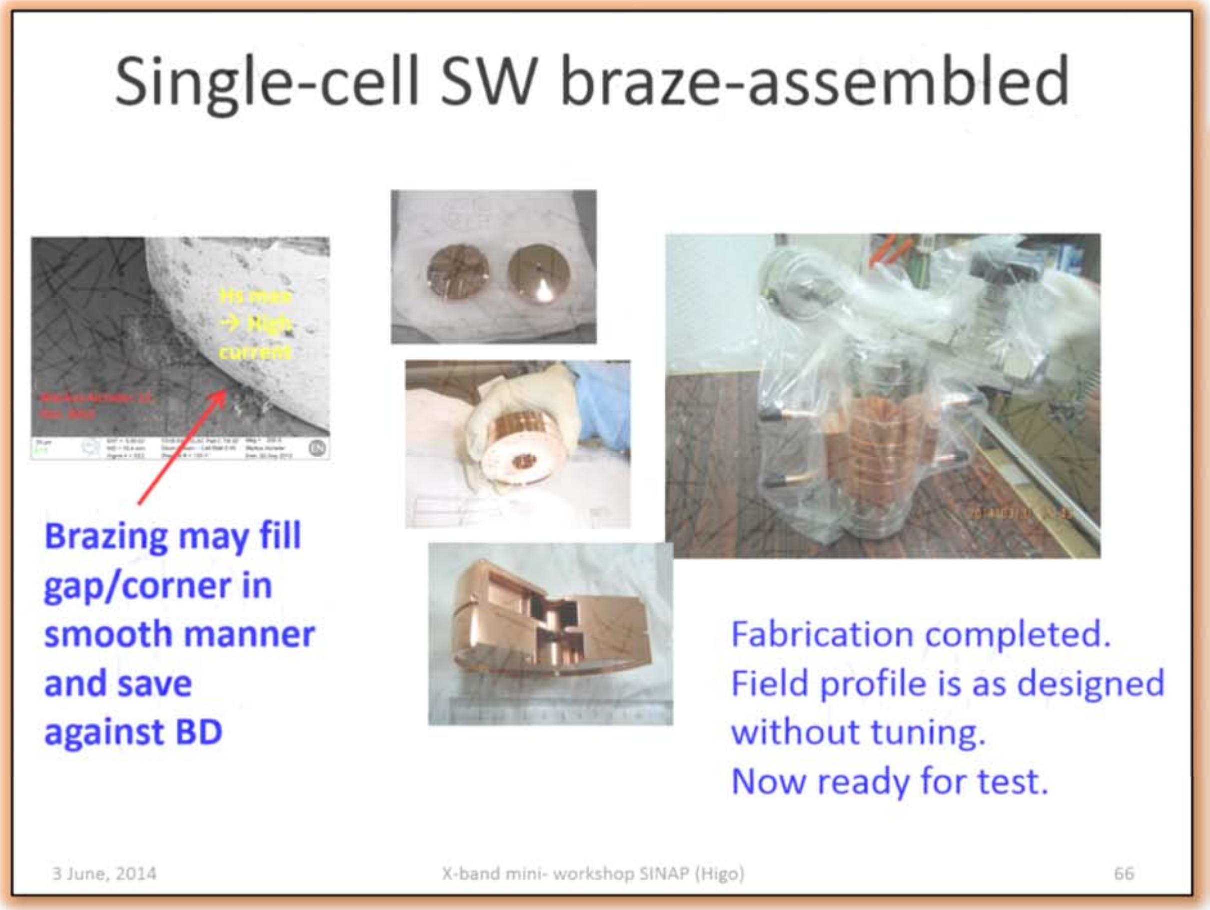


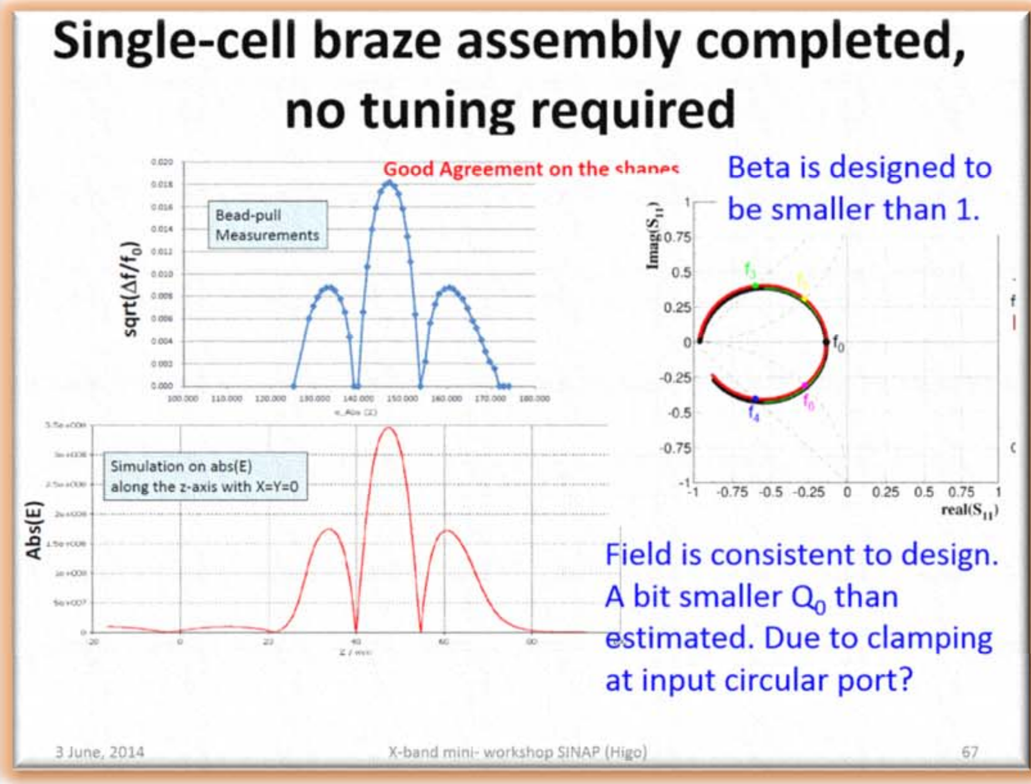
Beam Ports Brazed → No Vacuum Leak Confirmed → Cooling Pipes Brazed



→ RF measurements and tuning
→ High-Gradient Test (next month?)

Example of Other Test Cavities





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; First testing done:

- **Choke-mode**

- **Other candidates?**

Summary and Other Matters to be Considered

■ Basic study using X-band single-cell structures started at KEK/Nextef/Shield-B

- ✓ Max. E_{acc} ≈ 140 MV/m (P_{inp}≈ 20 MW, $P_{kly\text{-}out}$≈ 30 MW, Width: 400 ns at max.)
- ✓ 1 [BD/hour] ➔ BDR ≈ 4e-4 [BD/pulse/m] for L=13mm, 50 Hz rep. rate
  - → 100 Hz (or higher?) rep. rate to be tested at Shield-B
- ✓ Two choke-mode structures have been HG-tested.
  - ➢ Refection-waveform trigger system detected many BD events with no current flash.
- ✓ Now, the undamped reference cavity (fabricated by THU) is being HG-tested.
- ✓ The trigger, control, DAQ systems are working fine with continuous improvements.

■ Structures to be tested

- New quadrant-type waveguide-damped structure (next)
- Undamped reference, all turning or all endmilling
- Waveguide-damped structure fabricated by brazing
- Cavity made of OFC with large grain
- Others?

Thank you for your attention!