# R&D Activities for ARES Upgrade

**Tetsuo Abe**

*for KEKB-RF/ARES-cavity group*

***High Energy Accelerator Research Organization (KEK)***

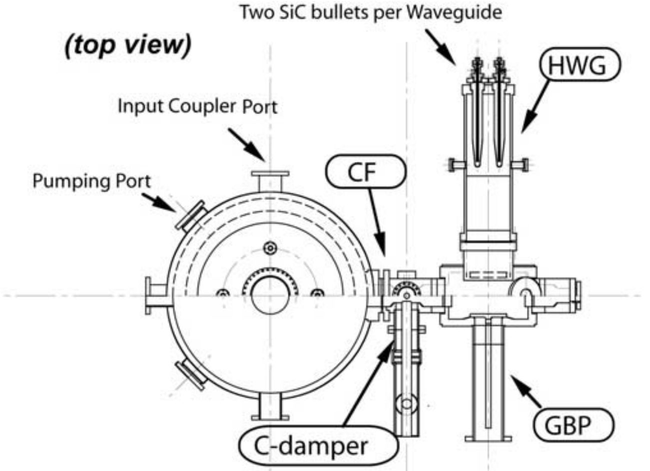
＜**Outline**＞

1. R&D programs for SuperKEKB
2. L-band HOM-load test stand
3. Input couplers with TiN coating
4. New copper electroplating for S-cav
5. Summary

*KEKB Review*
*@KEK*
*2005.02.22*

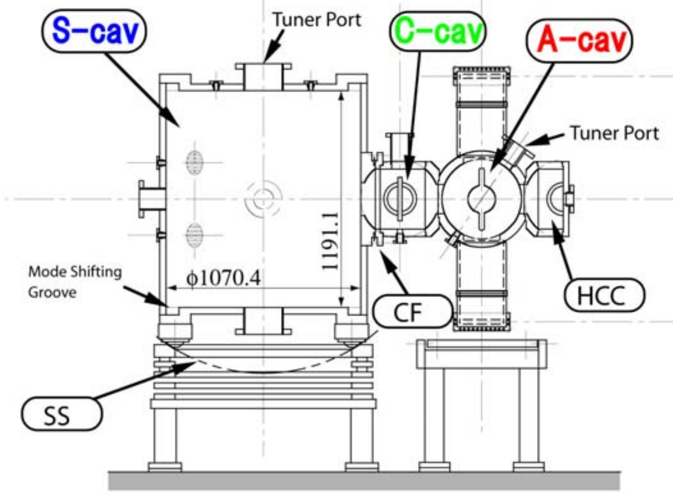
# Accelerator Resonantly-coupled with Energy Storage

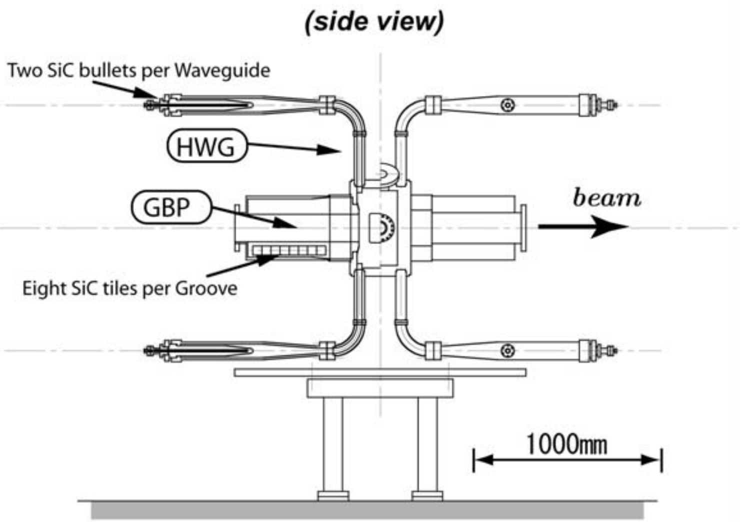
## *3-cavity system stabilized with the $\pi/2$-mode operation*




consists of

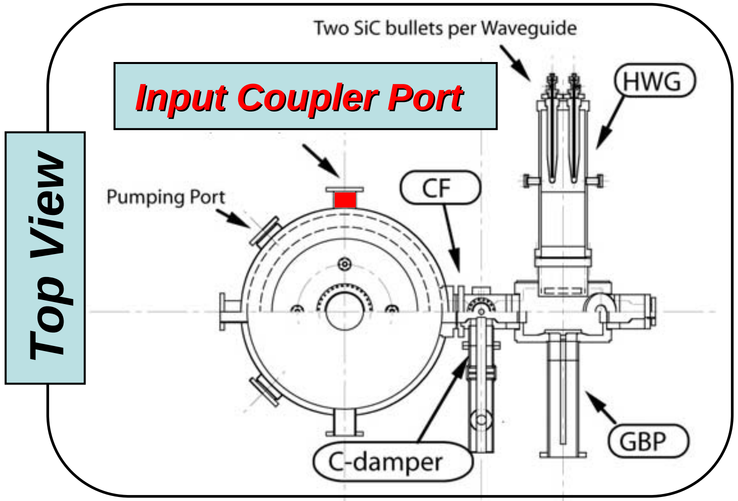
- HOM-damped accelerating cavity (A-cav)
- Energy-storage cavity with $TE_{013}$ (S-cav)
- Coupling cavity (C-cav)
  with a parasitic-mode damper



# **A**ccelerator **R**esonantly-coupled with **E**nergy **S**torage

## *3-cavity system stabilized with the $\pi/2$-mode operation*




consists of

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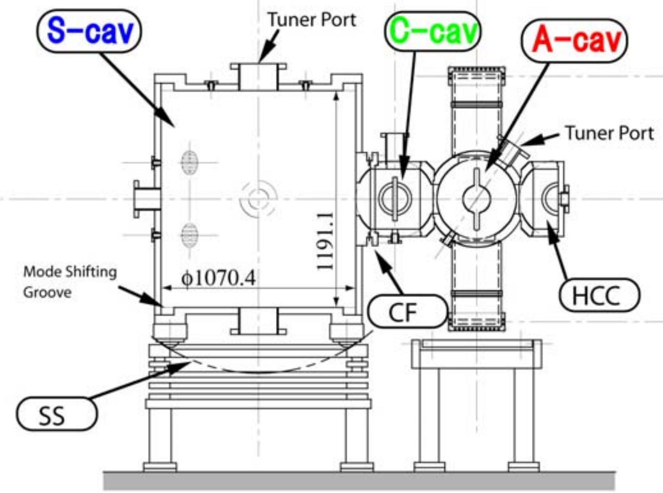
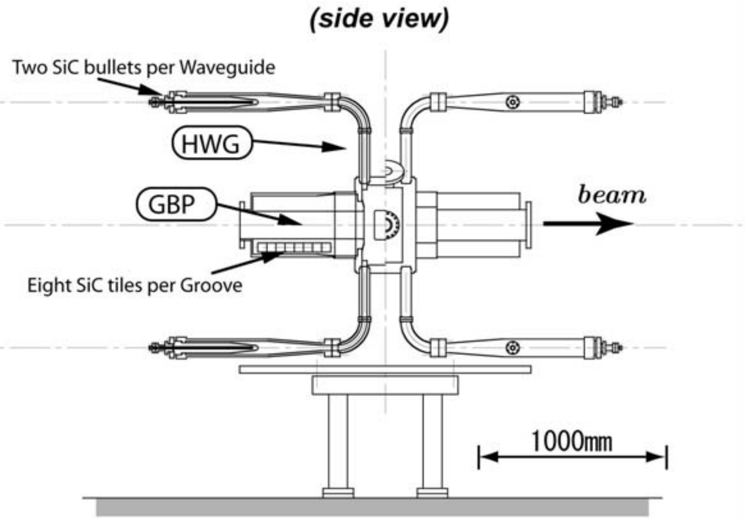


# Upgrade Items toward

*Measures against*

## Larger detuning

→ Increase the energy ratio: *Us/Ua = 9 → 15.*

$$\Delta f_{\pi/2} = \frac{\Delta f_a}{1 + Us/Ua}$$

→ Reported in the previous KEKB review

→ Skipped this time

## Higher HOM powers

→ HOM-load upgrade

## Higher input RF powers (400kW/cav → 800kW/cav)

→ TiN coating on the coaxial line

→ Coupler test stand upgraded for ~800kW(CW)

# R&D Programs 2004(JFY)

**[1] Construction of a new L-band HOM-load test stand**

→ Using 1.25GHz klystron (1.2MW, CW)

→ The 1$^{st}$ stage just finished

**[2] Input couplers with TiN coating**

→ Against multipactoring in the coaxial line

→ TiN(Titanium Nitride) has low secondary-electron yields and is good for vacuum.

→ Two couplers have been completed.

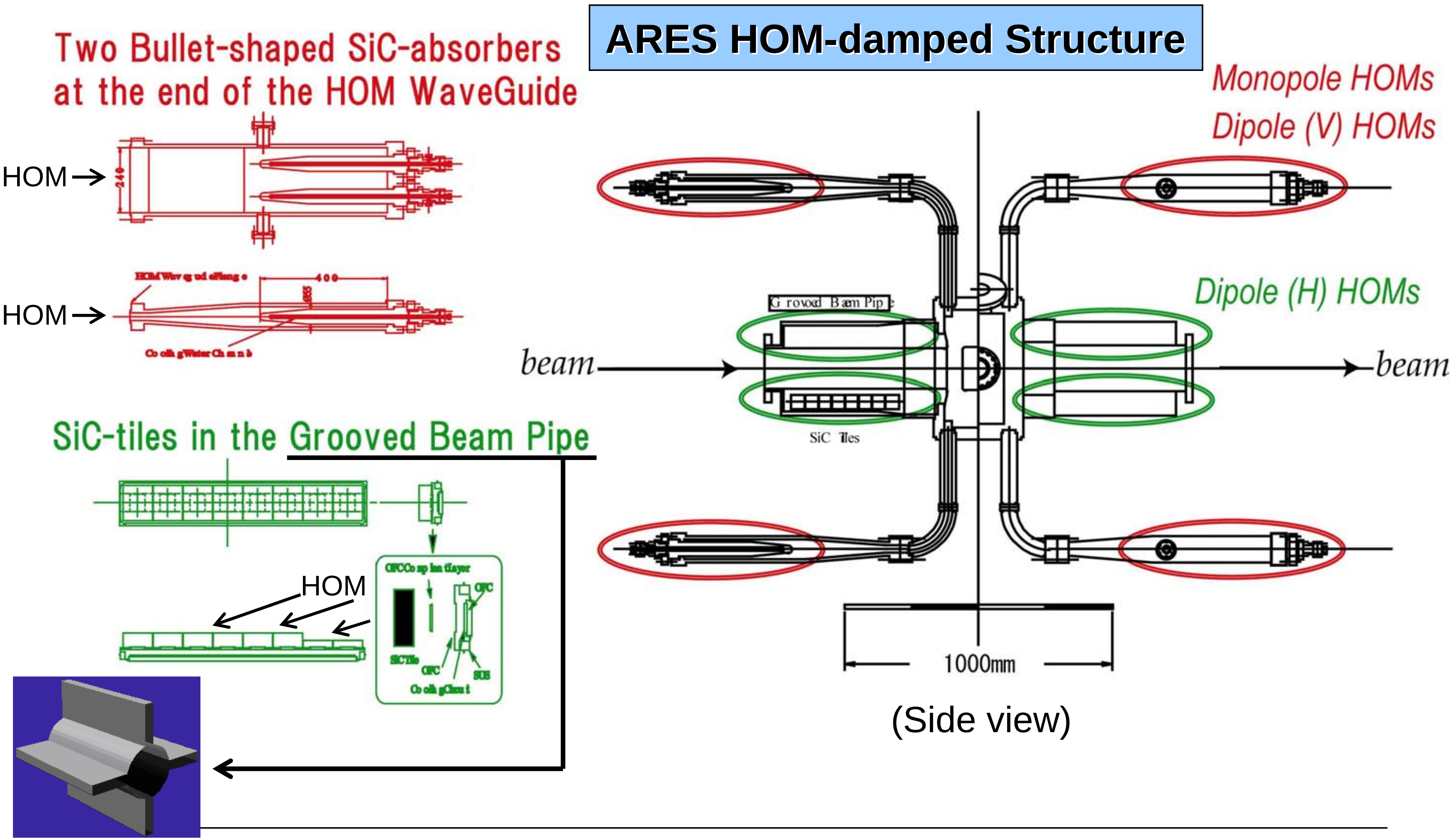
→ Being tested in the **upgraded coupler test stand up to 800kW**.

**[3] New highly-pure copper electroplating for S-cav**

→ The old facility has been retired.

→ Reusing a facility being used for J-PARC.

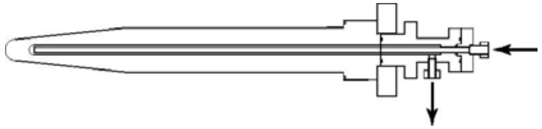
# [1] L-band HOM Test Stand



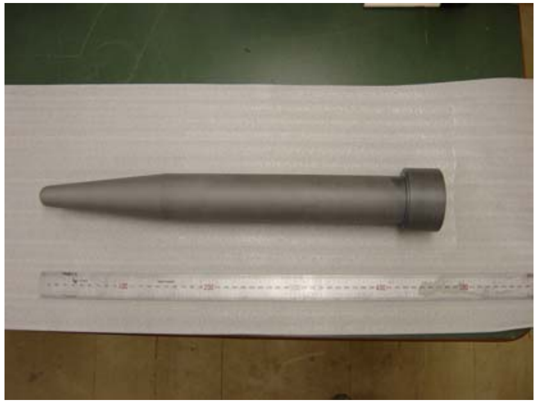
# SiC Absorbers

## ✎ In the HOM Wave Guide (WG)

- Direct water cooling

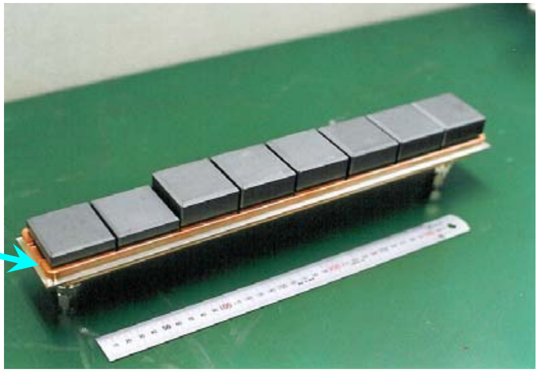


- Limit: >26kW/cav (HPT)



## ✎ In the Grooved Beam Pipe (GBP)

- Indirect water cooling
  → via the copper plate
- Limit: ~3.6kW/cav (HPT)



Max. power which can be supplied by the old L-band klystron.

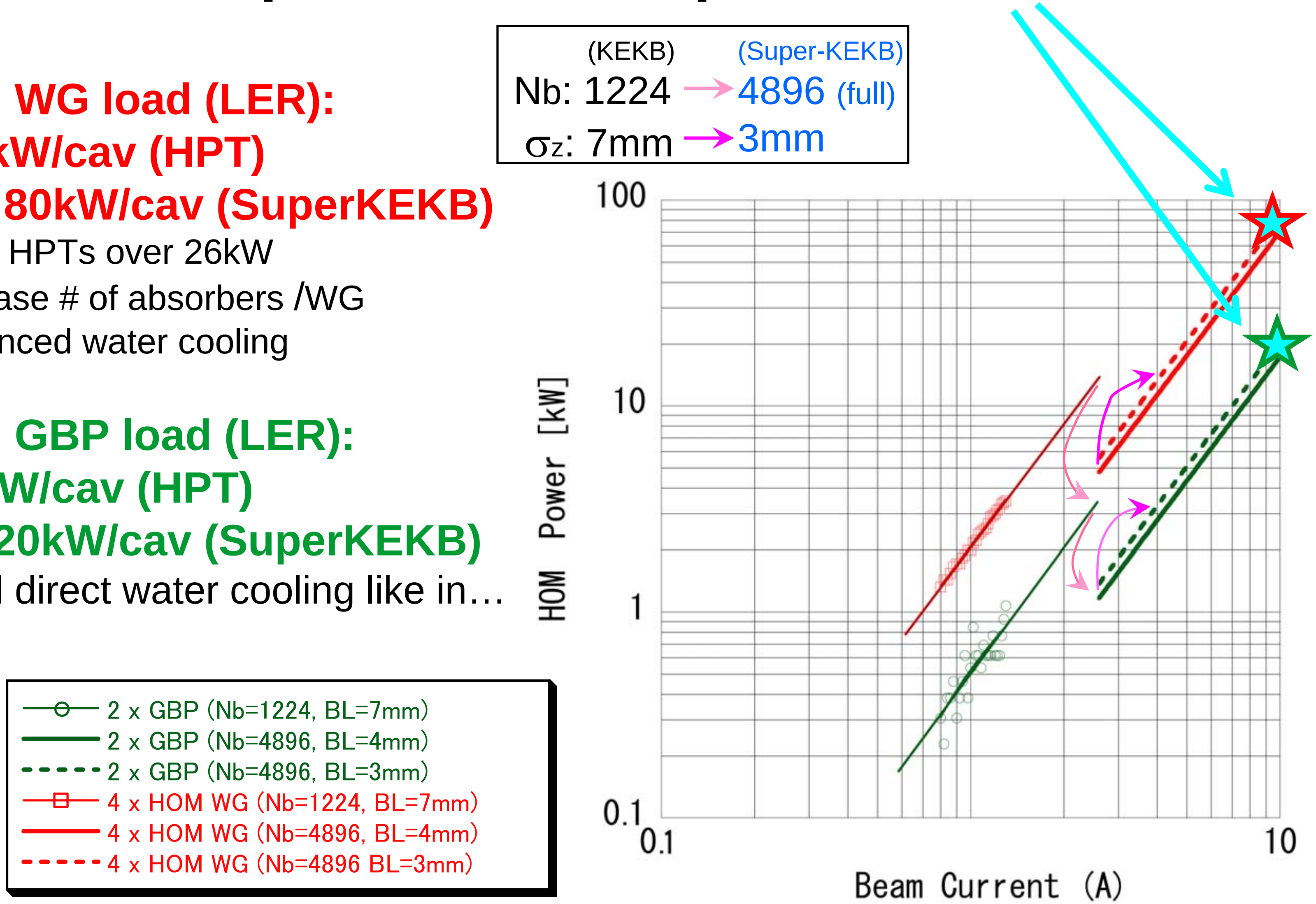
# HOM Extrapolation for Super-KEKB LER

**HOM in WG load (LER):**
**26kW/cav (HPT)**
**→ 80kW/cav (SuperKEKB)**

→ Need HPTs over 26kW
→ Increase # of absorbers /WG
→ Enhanced water cooling

**HOM in GBP load (LER):**
**3.6kW/cav (HPT)**
**→ 20kW/cav (SuperKEKB)**

→Need direct water cooling like in…

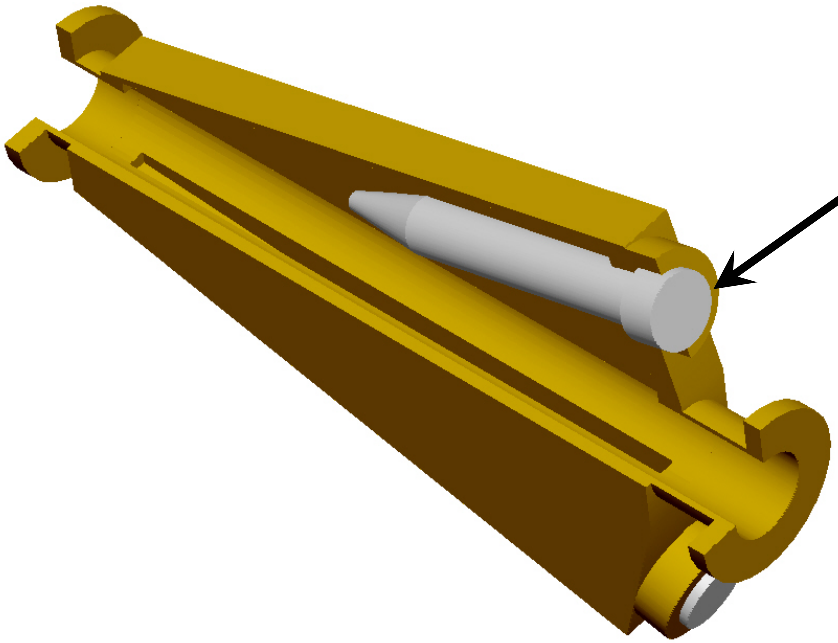


# Winged chamber loaded with SiC Absorbers

(used in the movable-mask sections)

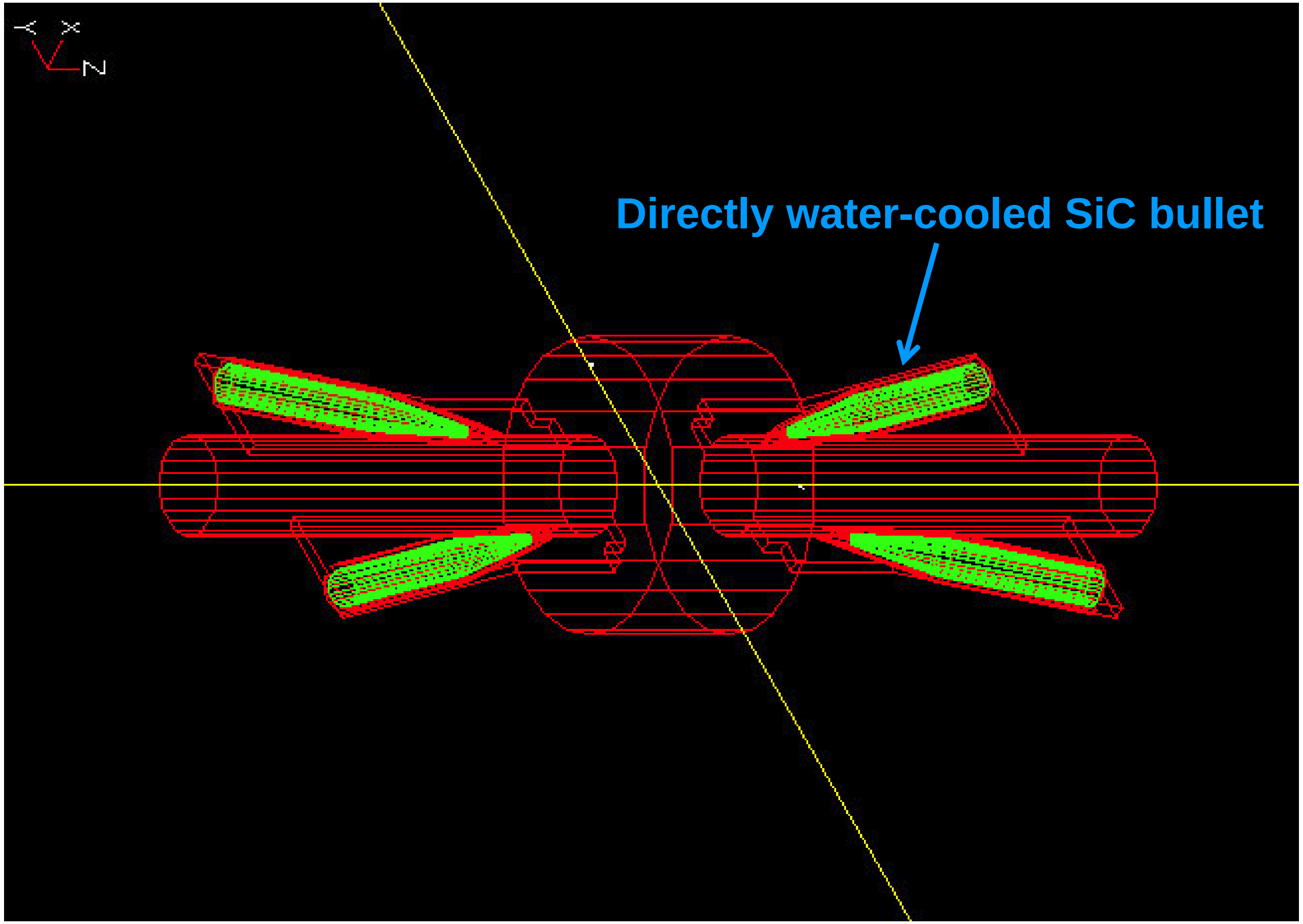
**Y. Suetsugu et al., "Development of Winged HOM Damper for Movable Mask in KEKB", Proc. PAC2003.**

→ Can be a prototype.



Directly water-cooled SiC bullet

# New A-cav Design with Winged Chambers



**We cannot test HOM loads with high powers for SuperKEKB.**

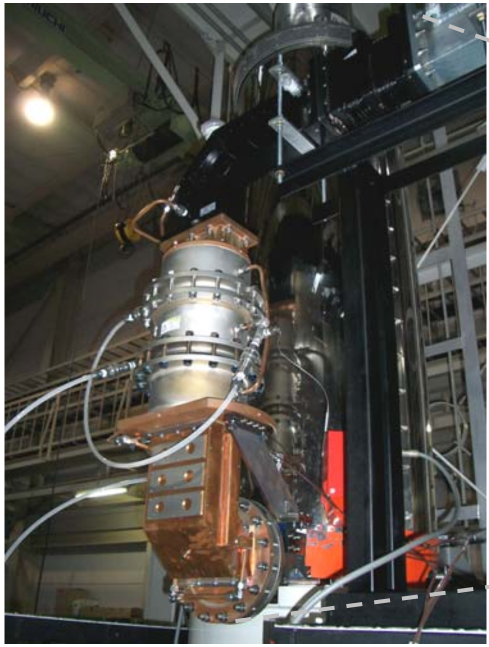
⇩

**More powerful klystron is needed to upgrade the HOM loads.**

# Construction of
# New Test Stand for the HOM-load Upgrade

- Reusing an L-band klystron, which is capable of 1.2 MW CW power ( freq. = 1.25 GHz).
- Operating conditions (HV & cooling system etc.) are going to be regulated for our purpose.
- The 1st stage of the construction has been just finished.

# D01C/ARES HOM-load Test Stand NEW



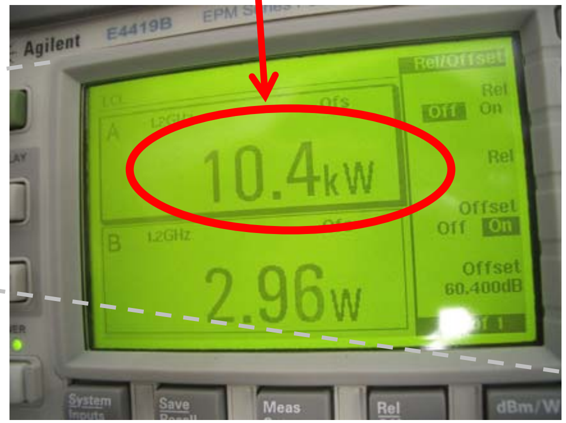
Output from the klystron

L-band klystron

Water dummy load

# The 1st RF Power Comes!

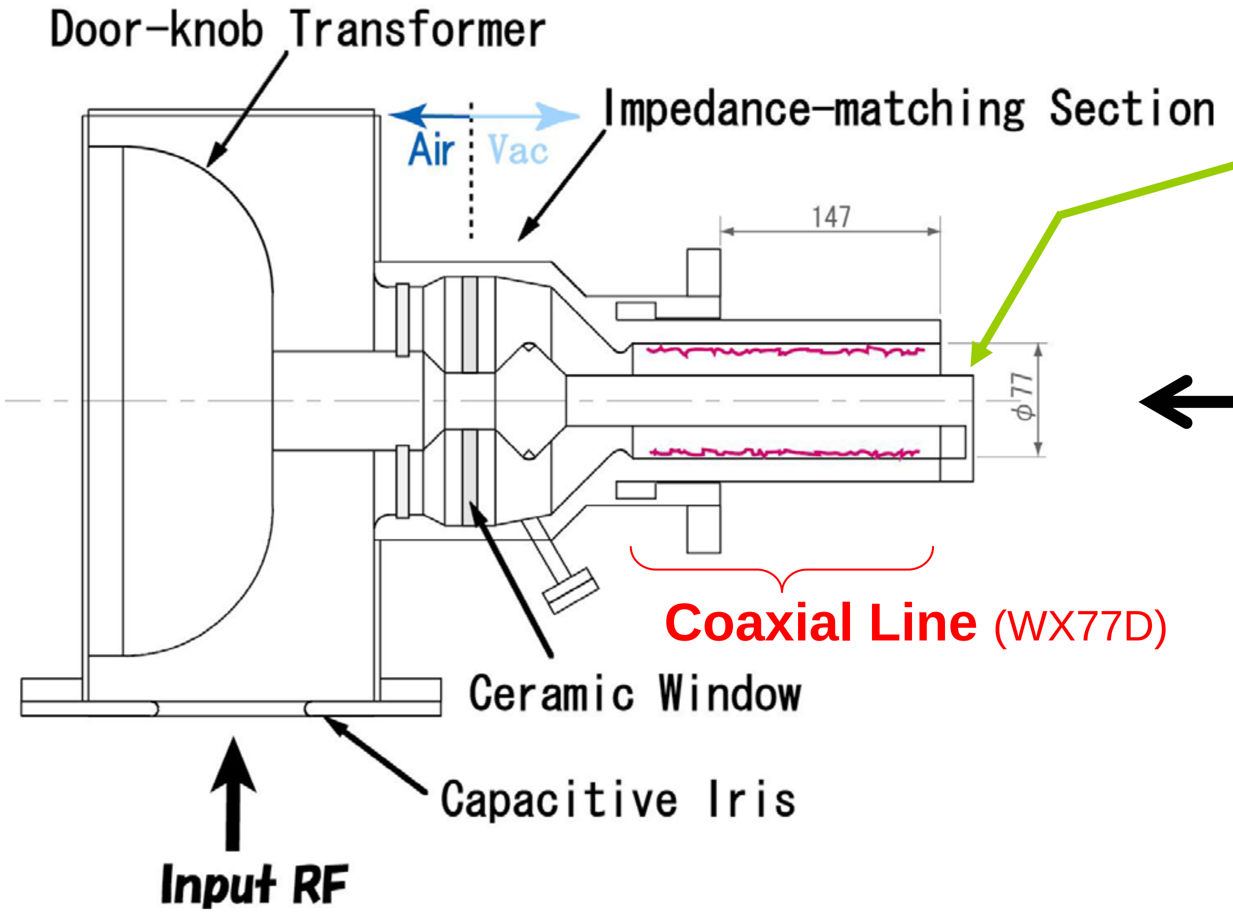

**Output power beyond the max. obtained in the old L-band test stand (3.3kW)**




→ ***Tuning to deliver more RF power up to 100 kW***

# [2] Input Couplers with TiN Coating

The problem is the *multipactoring* in the coaxial line.

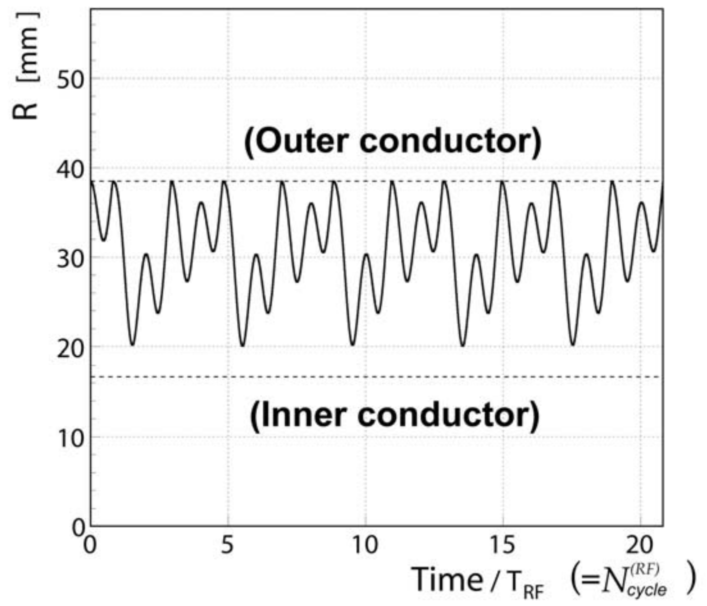



Coupling Loop

Example of
the TV-camera snapshots
of the multipactoring
in the coaxial line

# Simulation Study

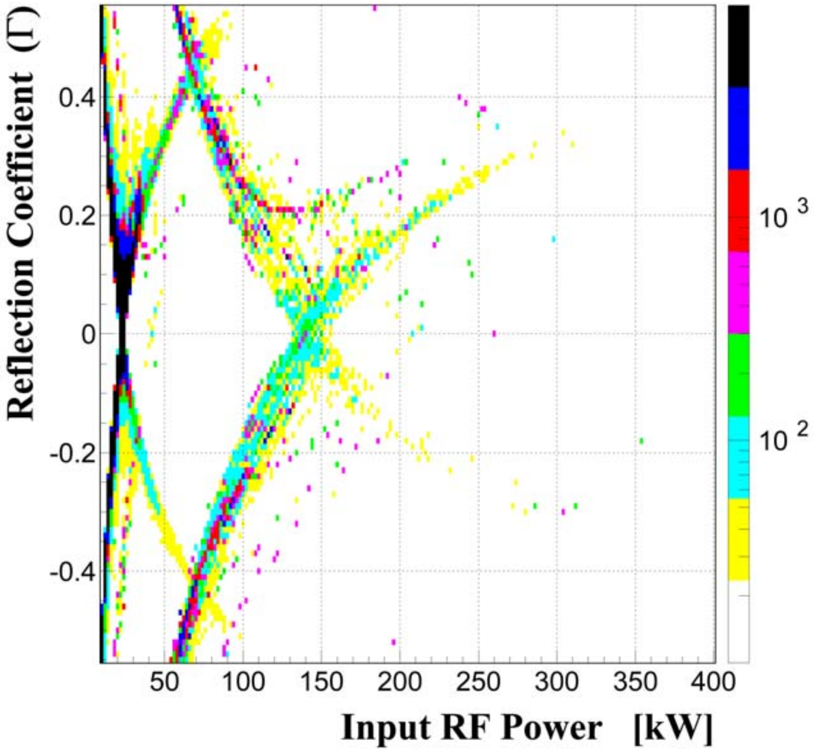
- Solving eq. of motion with the Runge-Kutta method
- Assuming the SEY of conditioned copper
- Count number of collisions.



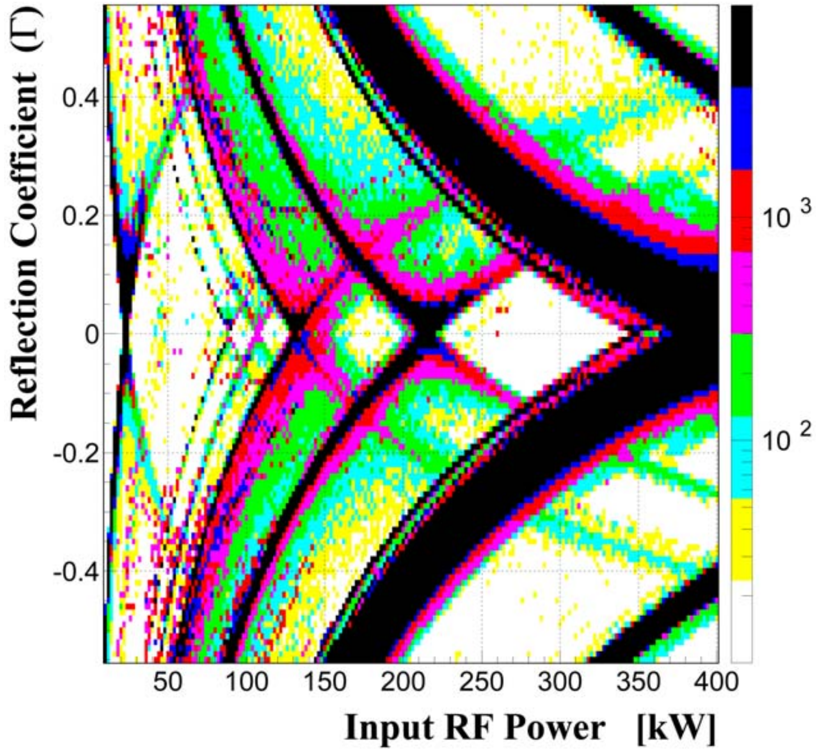

Example of the Orbits

# On Which Side?

On the **inner** conductor

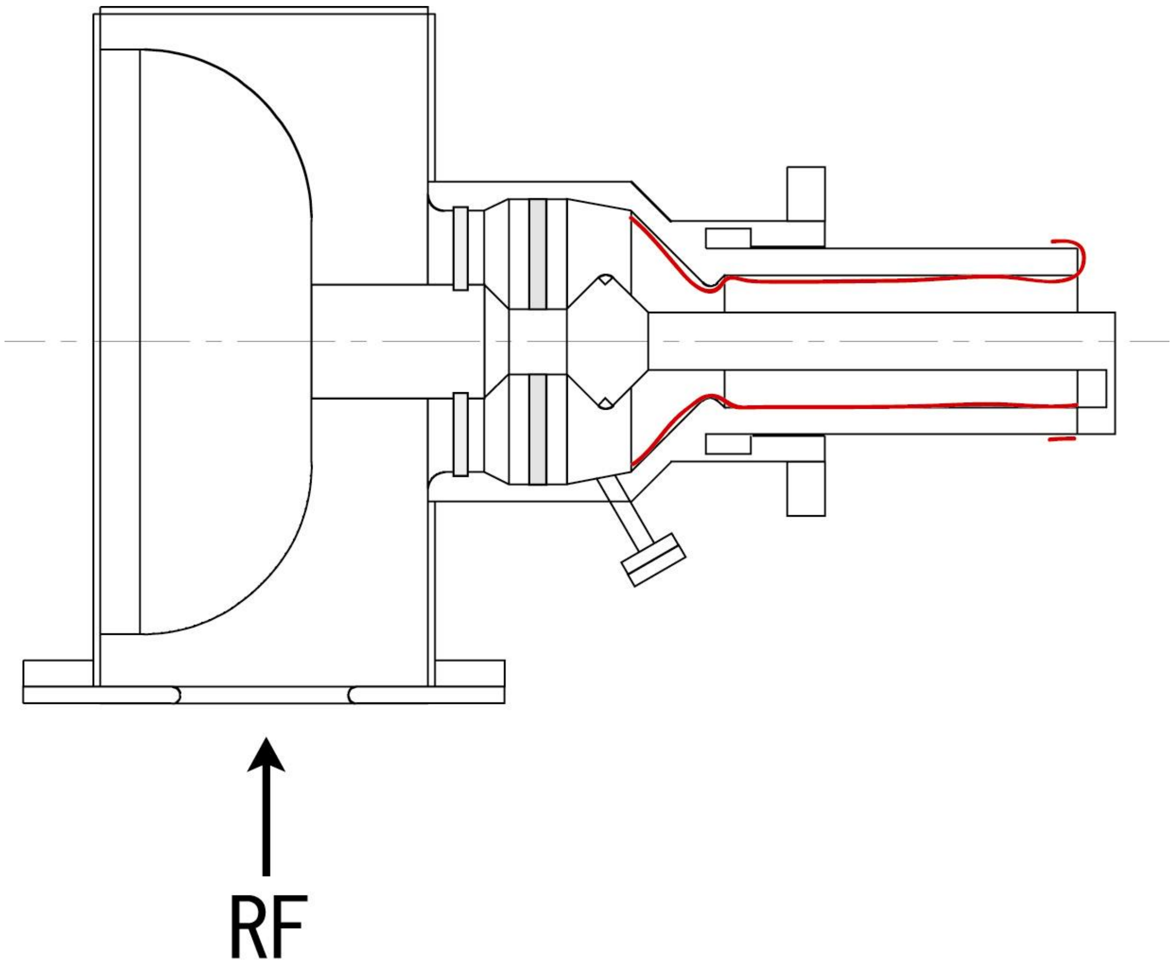



On the **outer** conductor



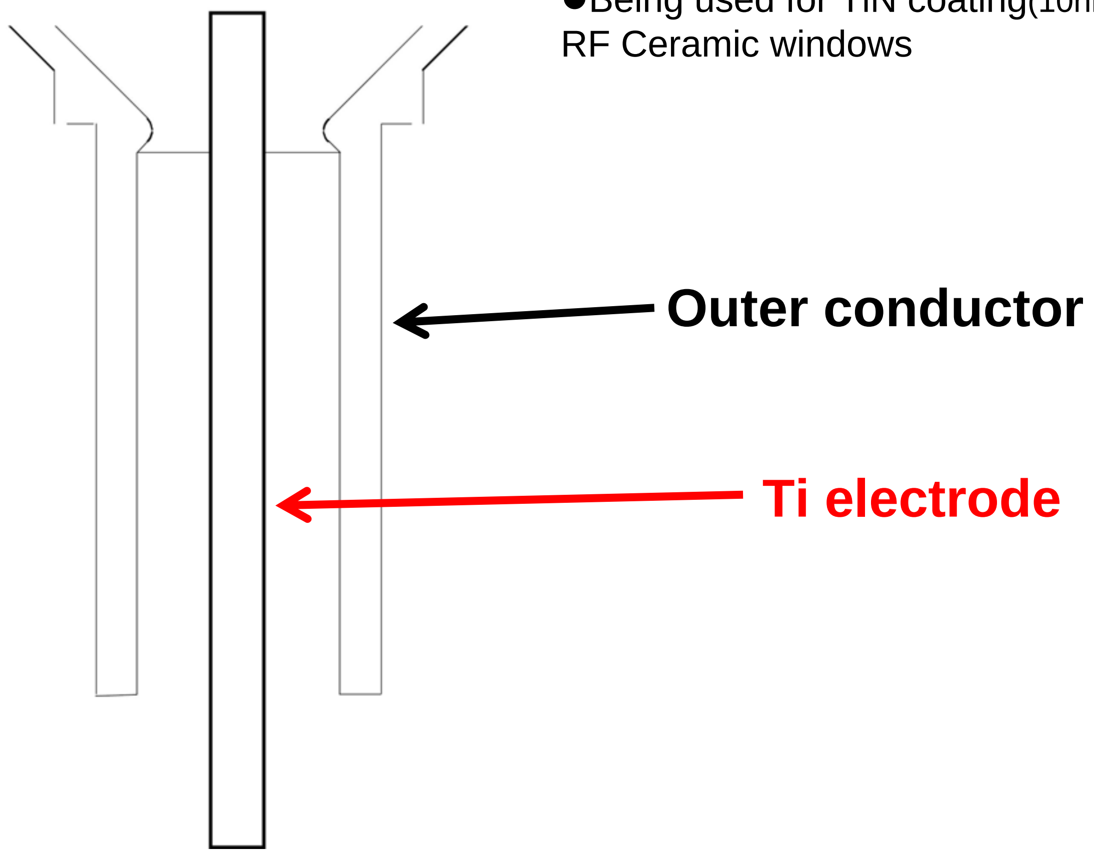

→ **Almost single-side multipactoring on the outer conductor**

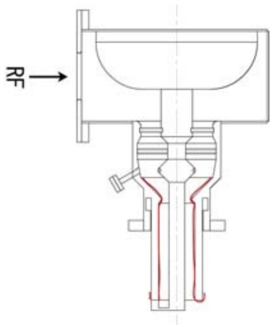
# Coating Area



# Setup of the TiN Coating
## (DC Sputtering)

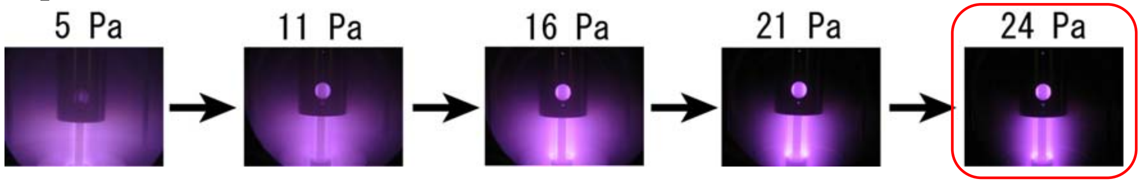
- 3E-4Pa before coating
- Injected gas: **Ar** and **$N_2$**
- Being used for TiN coating(10nm) of RF Ceramic windows



# Studies on

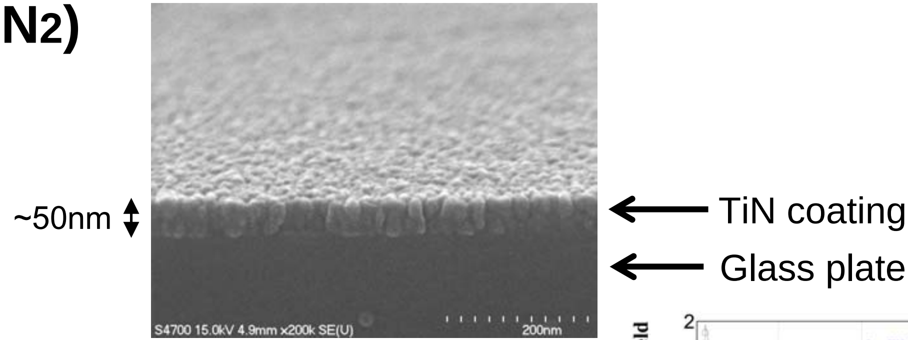
## Total gas pressure



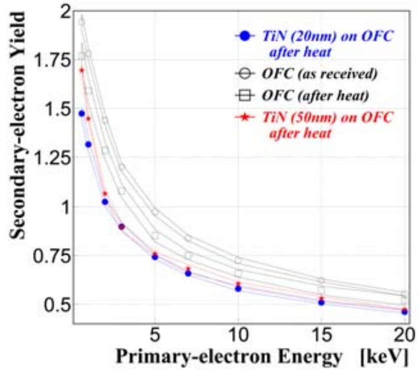

## Gas mixture ratio (Ar:$N_2$)

## Thickness meas.

done by direct observation using SEM

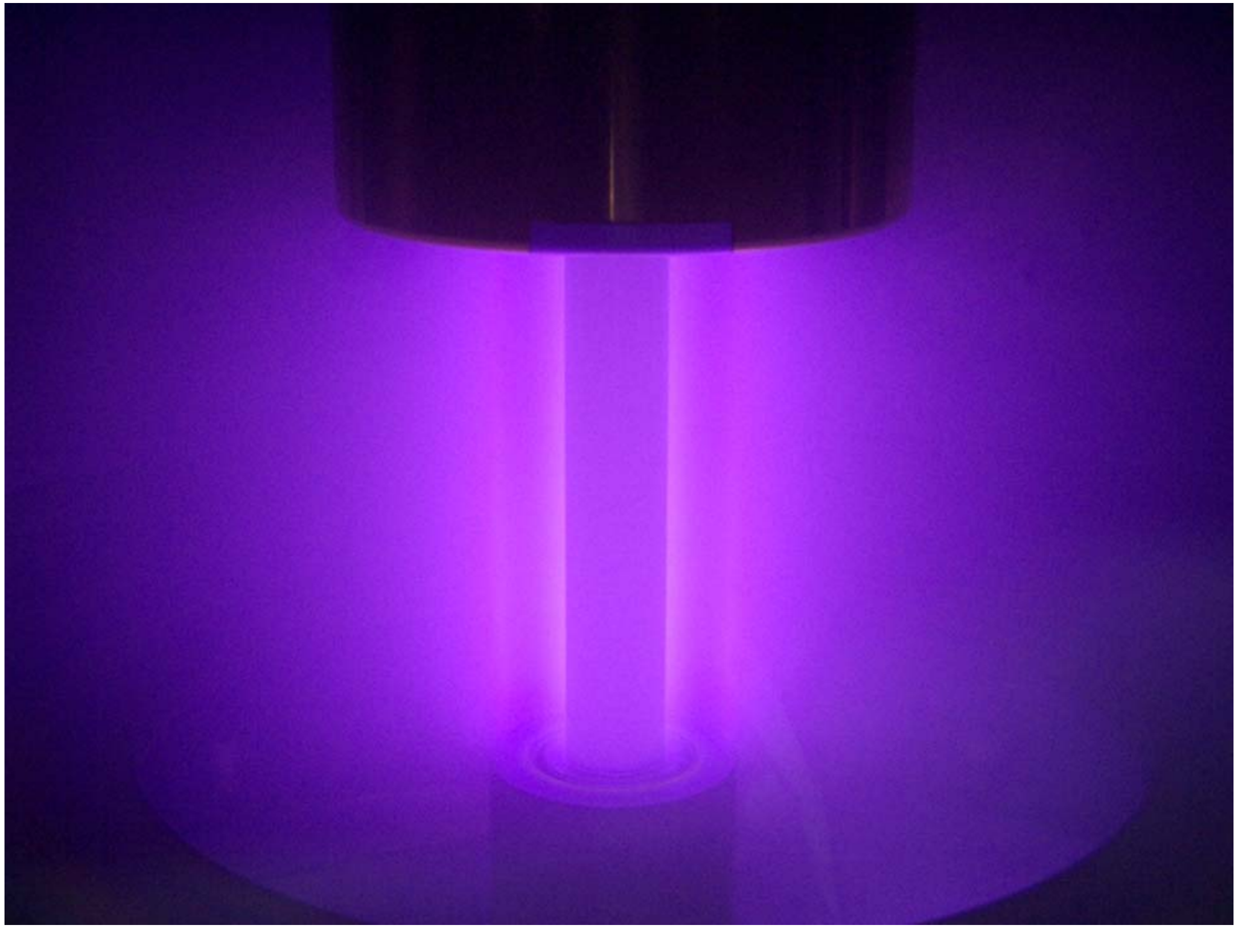



## Secondary electron yields



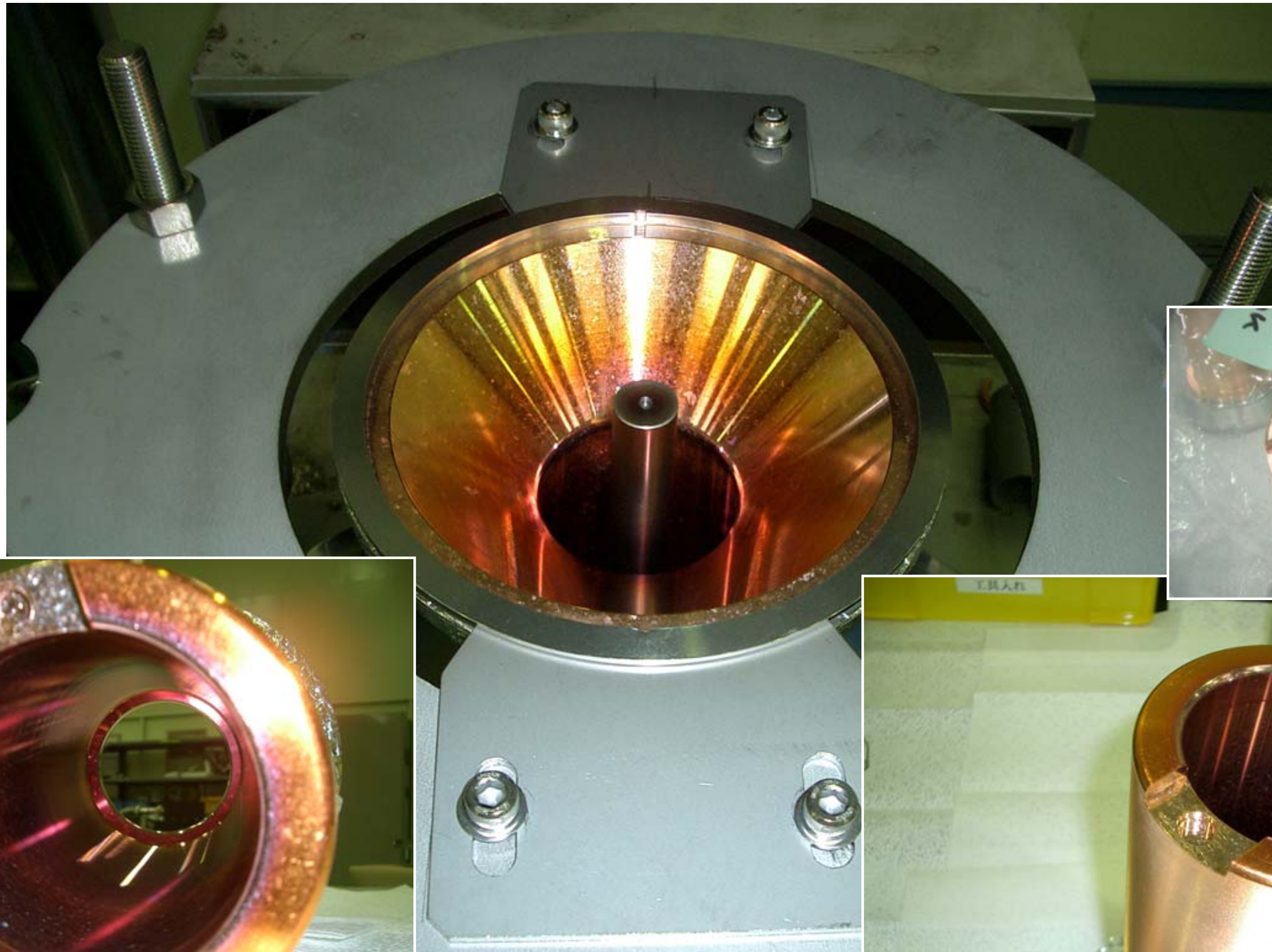

For the details, see the slides presented in the 6th Workshop on a Higher Luminosity B Factory: http://belle.kek.jp/superb/workshop/2004/HL6/program.html .

# *Two input couplers have been TiN-coated with the final condition.*

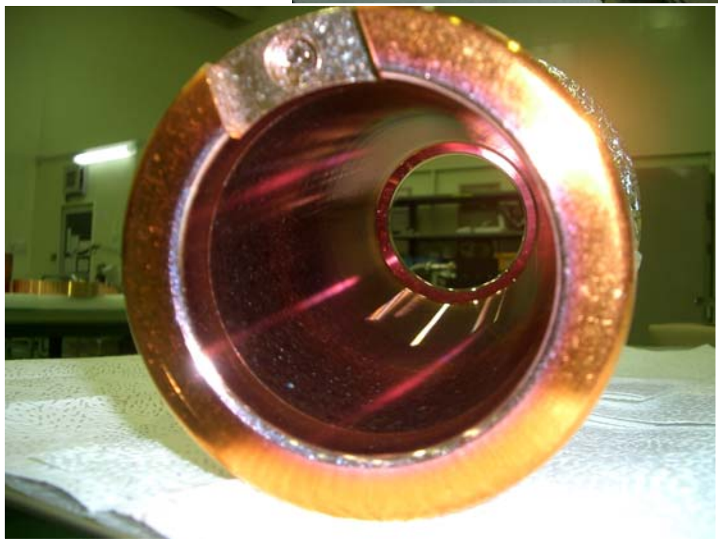


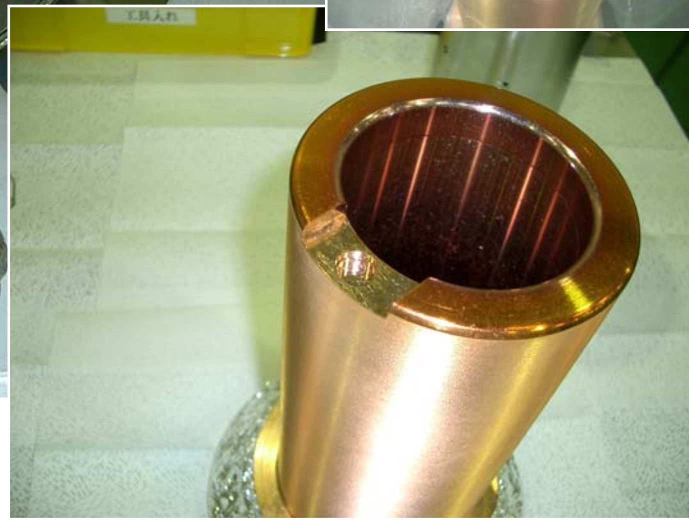
(taken on 2004.11.10)

# After Coating



Before coating





## Fabrication

## Leak test

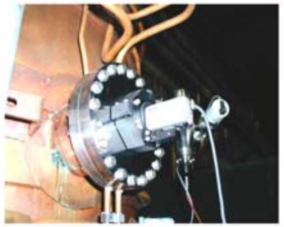
→ Tested in the upgrade coupler test stand

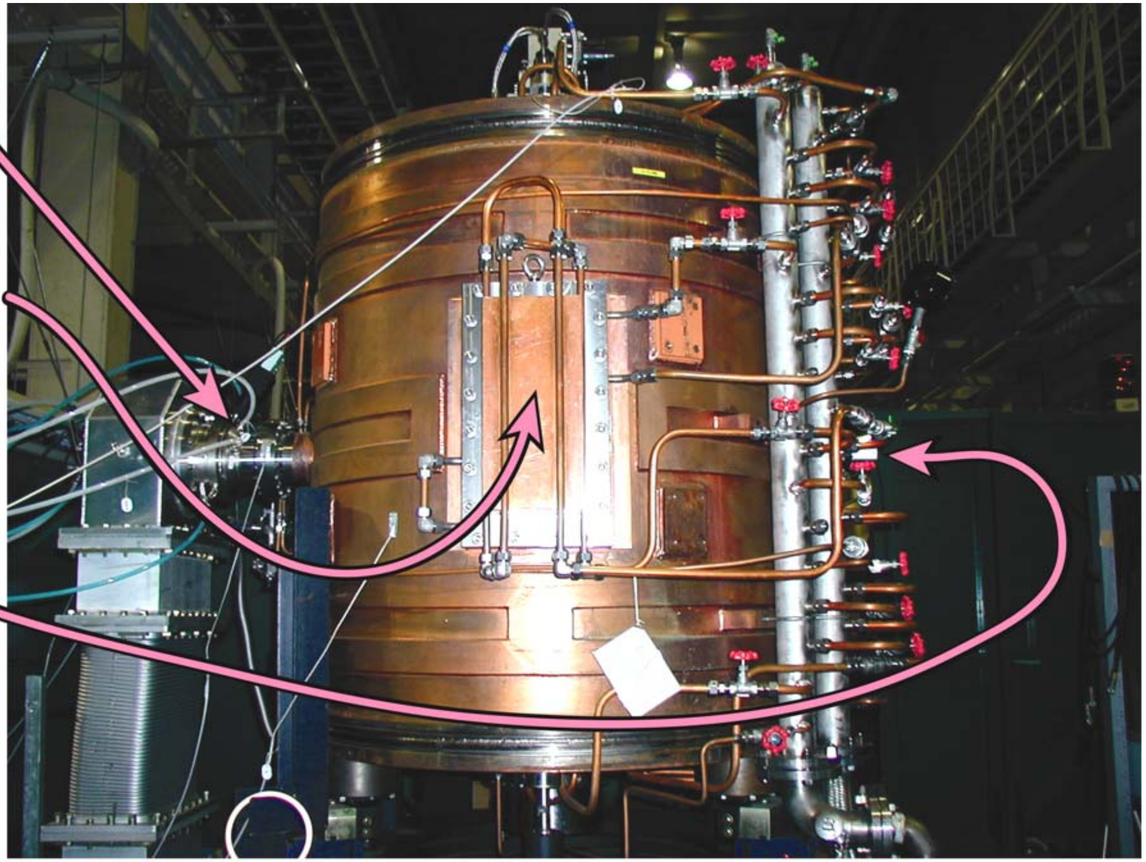
# Old Setup of the Coupler Test Stand

Input Coupler

$\pi$/2-mode
Terminator

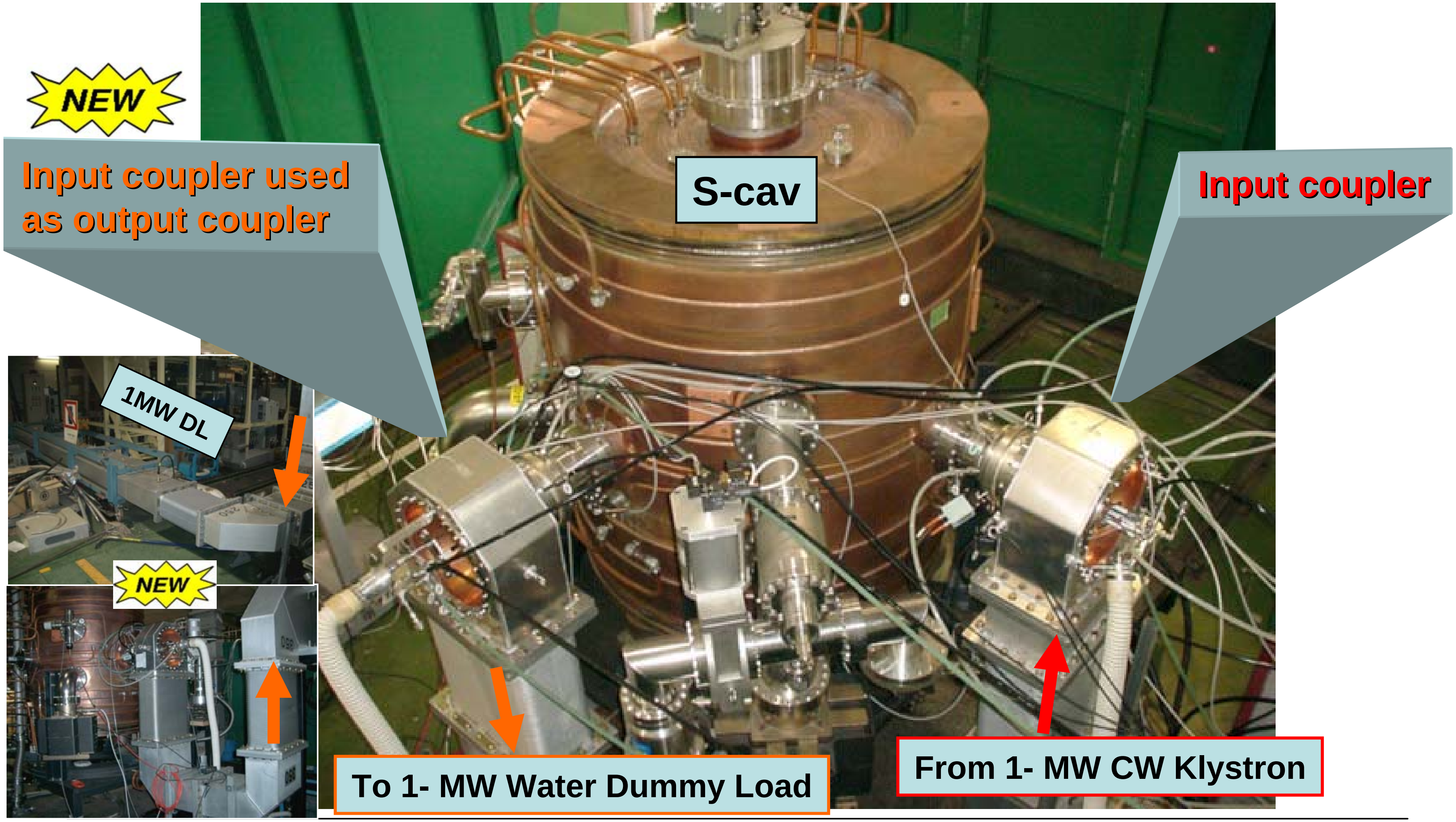
TV Camera





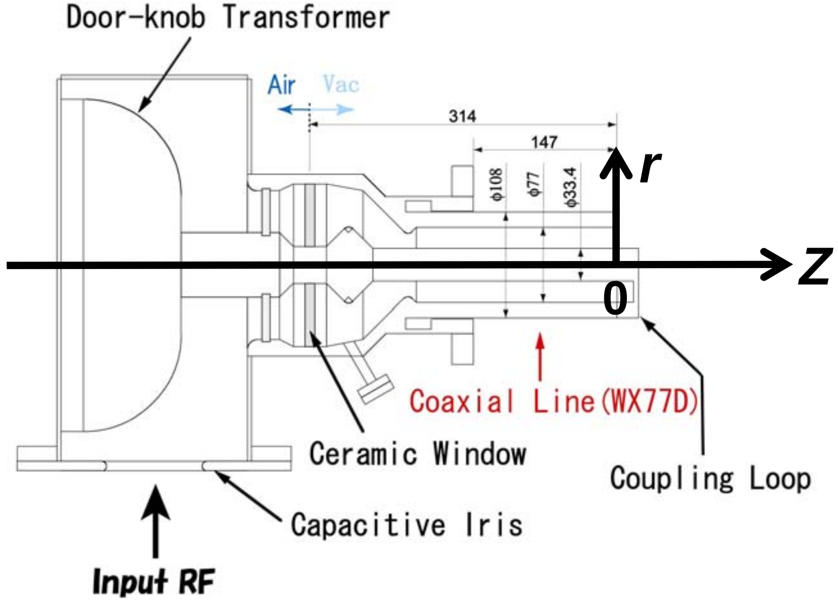
- **No RF output**
  - →**S-cav works as a dummy load.**
  - →**Input powers are limited: <400kW.**

# Coupler Test Stand
# Upgraded for Higher Power Capability: <u>400→800kW</u>



# Another characteristic:

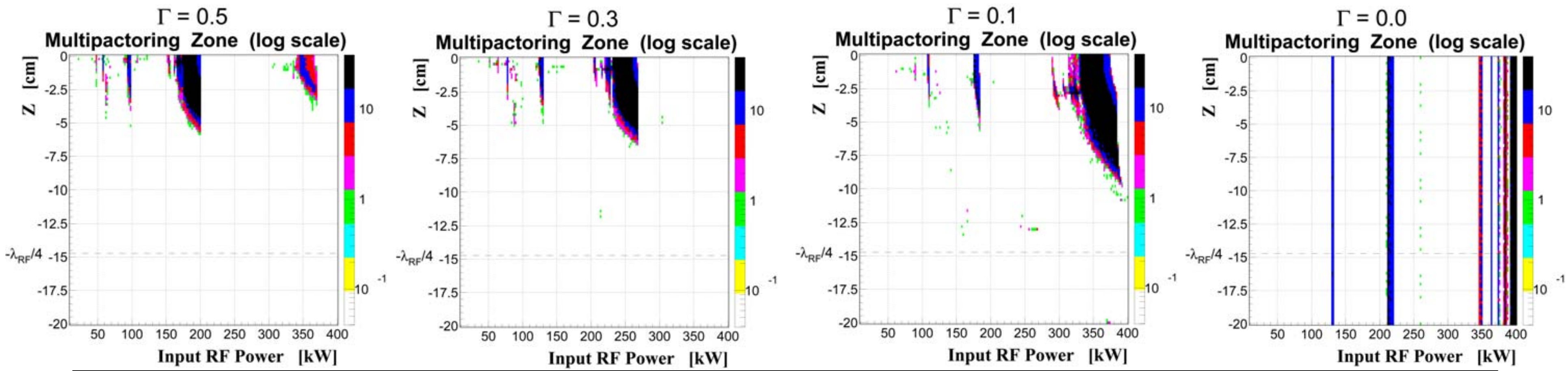
***The coupling-loop angles of the input and output couplers are set to be the same.***




→ ***No reflection ($\Gamma$~0.0)***

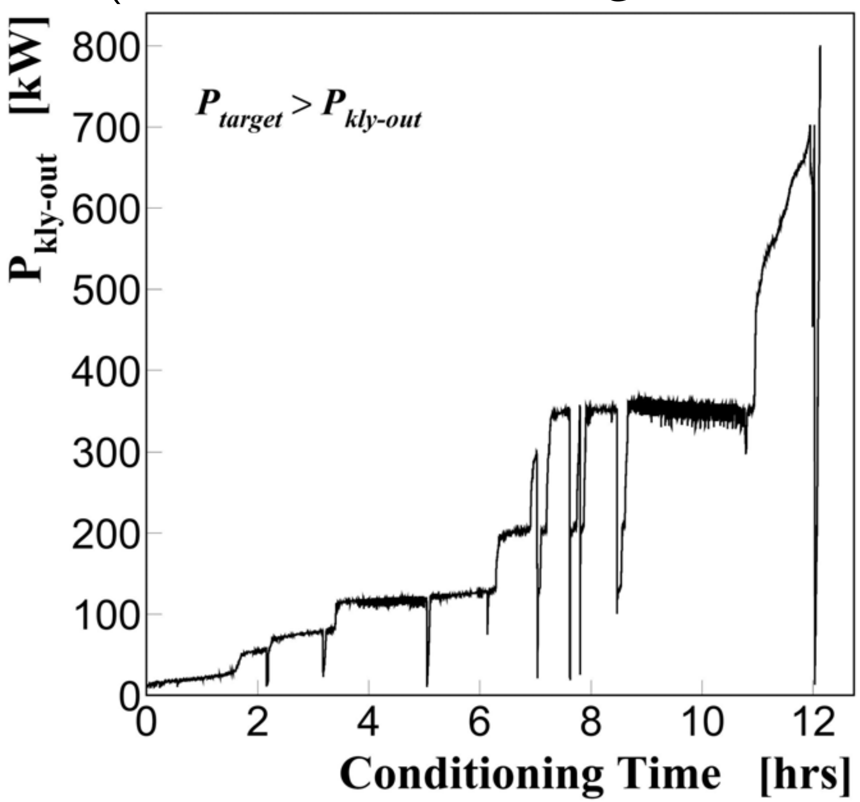
→ ***No Z-dependence***

**The hardest ordeal for couplers**



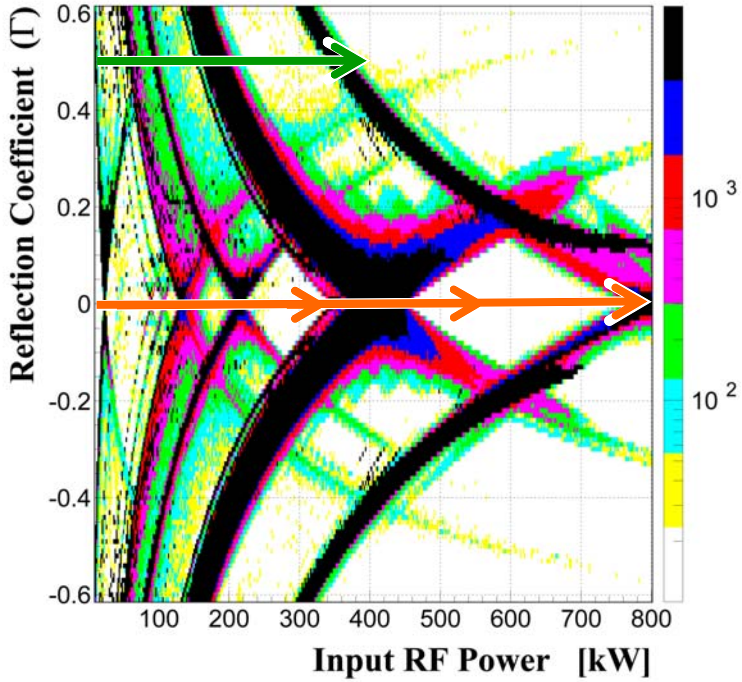
# Power History

(Data taken in 2005.02.01-10 @D01A/ARES TS)




(β=3) (β=1)

Routes of the **old** and **upgraded** test stands




→ Any operating condition can be simulated in the test stand by changing the coupling-loop angles of the input and output couplers!

→ **To be compared with results on a coupler w/o TiN coating**

→ **To be tested in the D04C station? (“*genuine*” test stand?)**

# [3] New Copper Electroplating for S-cav

**S-cav is made from Iron with copper electroplating.**

- Present S−cav −−− electroplating in a pyrophosphate bath
  - With brightener → little defect on the surface
  - The facility has been retired.

- S−cav for SuperKEKB −−− new electroplating in an acid sulfate bath performed in the ***periodic reverse (PR) process***

  (**H. Ino, et. al, "Advanced copper lining for accelerator components", Proc. of LAC2000, Monterey, CALIFORNIA, 1015 (2000)**)

  - Without brightener → high purity, high electric conductivity (102%IACS), but possible defects on the surface
  - Using the facility being used for J−PARC

Ex. DTL tank

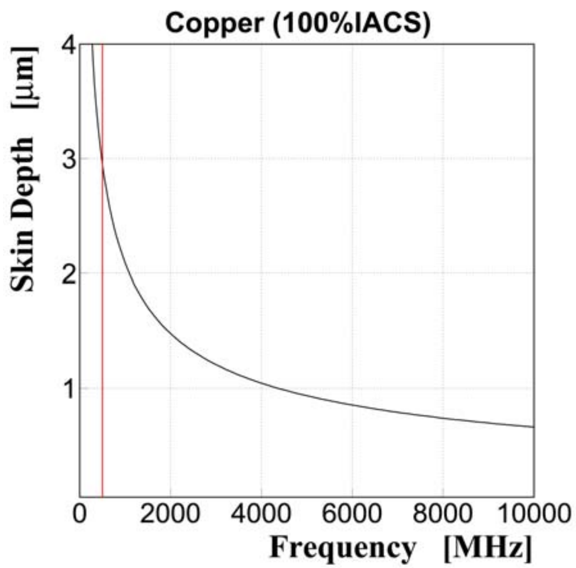
→

# Difference between J-PARC and SuperKEKB

- J-PARC case
  - Thickness:~1mm → Mechanical polishing(-0.5mm) → Electrolytic Polishing (EP)
- SuperKEKB case
  - Thickness:~0.2mm → Electrolytic Polishing (EP)

Studies on

- **Thickness** (targets)
  - Ground(alkalinity): ~50μm
  - Main(acidity): ~150μm
  - Electrolytic Polishing: about -40μm
- **Less defect**
- Electric performance
  - → Check $\mathbf{Q_0}$.

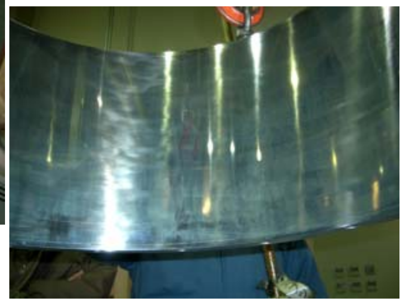


# Pillbox Test Cavity

Diameter: 451.2mm
Height: 260.0mm

(After copper electroplating)

Made from iron (SS400)



(Before copper electroplating)

# Theoretical Calculation of $Q_0$ ($=Q_0$(cal))

## Analytical solution of the electromagnetic field in the pillbox cavity

TE*mnp* mode

$$\begin{cases} E_r = A\dfrac{j\omega\mu_0}{k^2}\dfrac{m}{r}J_m(\dfrac{j'_{mn}}{b}r)\sin m\theta\sin\dfrac{p\pi z}{d} \\ E_\theta = A\dfrac{j\omega\mu_0}{k^2}\dfrac{j'_{mn}}{b}J'_m(\dfrac{j'_{mn}}{b}r)\cos m\theta\sin\dfrac{p\pi z}{d} \\ E_z = 0 \\ H_r = A\dfrac{1}{k^2}\dfrac{p\pi}{d}\dfrac{j'_{mn}}{b}J'_m(\dfrac{j'_{mn}}{b}r)\cos m\theta\cos\dfrac{p\pi z}{d} \\ H_\theta = -A\dfrac{1}{k^2}\dfrac{p\pi}{d}\dfrac{m}{r}J_m(\dfrac{j'_{mn}}{b}r)\sin m\theta\cos\dfrac{p\pi z}{d} \\ H_z = AJ_m(\dfrac{j'_{mn}}{b}r)\cos m\theta\sin\dfrac{p\pi z}{d} \end{cases}$$

TM*mnp* mode

$$\begin{cases} E_r = -A\dfrac{1}{k^2}\dfrac{p\pi}{d}\dfrac{j_{mn}}{b}J'_m(\dfrac{j_{mn}}{b}r)\cos m\theta\sin\dfrac{p\pi z}{d} \\ E_\theta = A\dfrac{1}{k^2}\dfrac{p\pi}{d}\dfrac{m}{r}J_m(\dfrac{j_{mn}}{b}r)\sin m\theta\sin\dfrac{p\pi z}{d} \\ E_z = AJ_m(\dfrac{j_{mn}}{b}r)\cos m\theta\cos\dfrac{p\pi z}{d} \\ H_r = -A\dfrac{j\omega\varepsilon_0}{k^2}\dfrac{m}{r}J_m(\dfrac{j_{mn}}{b}r)\sin m\theta\cos\dfrac{p\pi z}{d} \\ H_\theta = -A\dfrac{j\omega\varepsilon_0}{k^2}\dfrac{j_{mn}}{b}J'_m(\dfrac{j_{mn}}{b}r)\cos m\theta\cos\dfrac{p\pi z}{d} \\ H_z = 0 \end{cases}$$

## $Q_0$(m,n,p) $= \omega_{mnp}\dfrac{U}{P_{wall}}$

$$\begin{cases} U = \dfrac{\varepsilon_0}{2}\int_{cavity} dV\,|\vec{E}|^2 = \dfrac{\mu_0}{2}\int_{cavity} dV\,|\vec{H}|^2 \\ P_{wall} = \dfrac{1}{2}\sqrt{\dfrac{\omega\mu}{2\sigma}}\int_{cavity} dS\,|\vec{H}|^2 \end{cases}$$

## Assuming

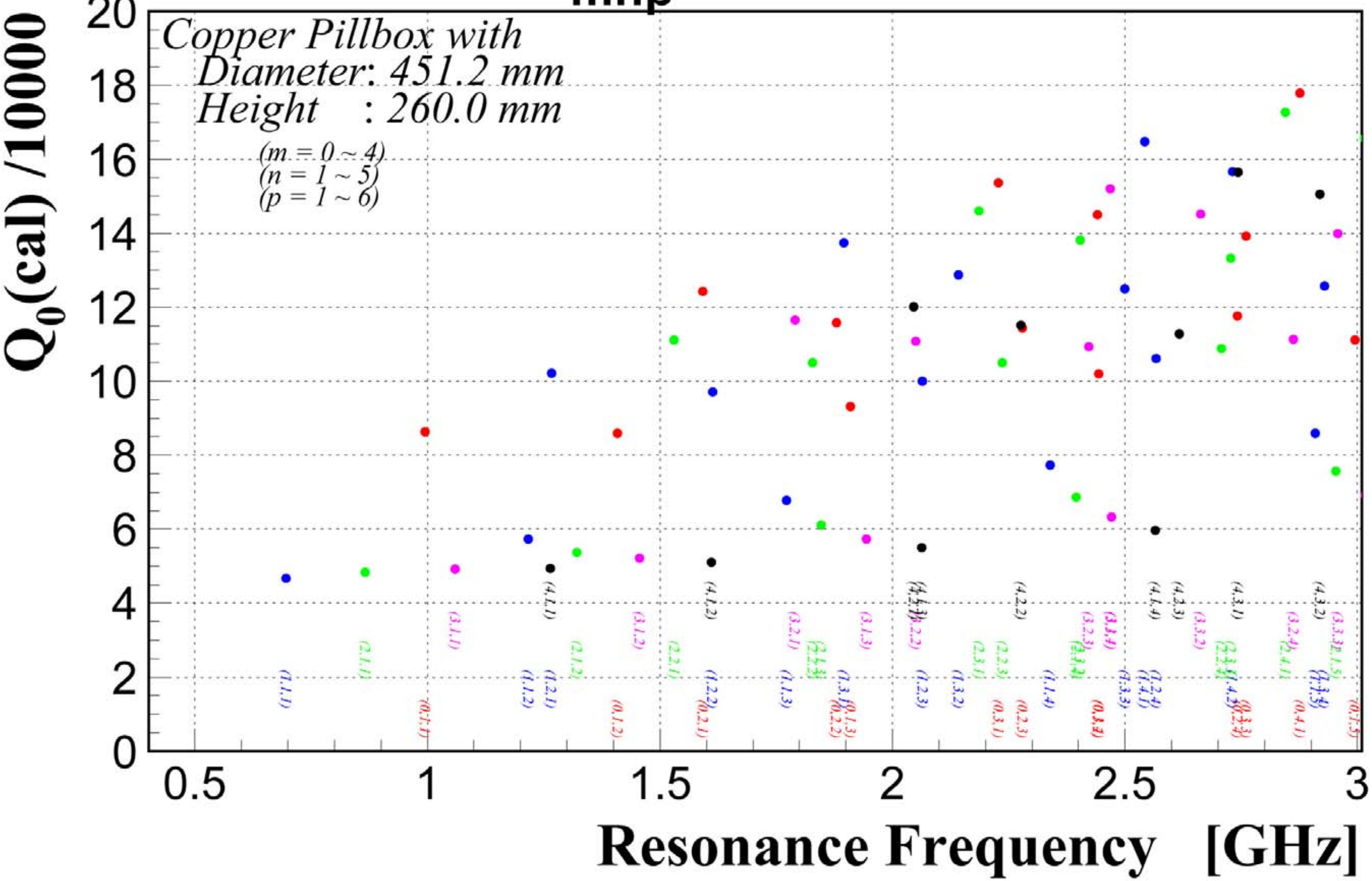
- **100%IACS** electric conductivity (=1/1.72E-8Ωm)
- **flat surface** (i.e. no defect)

# IACS

- **<u>I</u>**nternational **<u>A</u>**nnealed **<u>C</u>**opper **<u>S</u>**tandard
- 100%IACS electric conductivity: 1/1.72E-8Ωm
- The electric conductivity of the highest-class oxygen-free copper: <u>102%IACS</u>

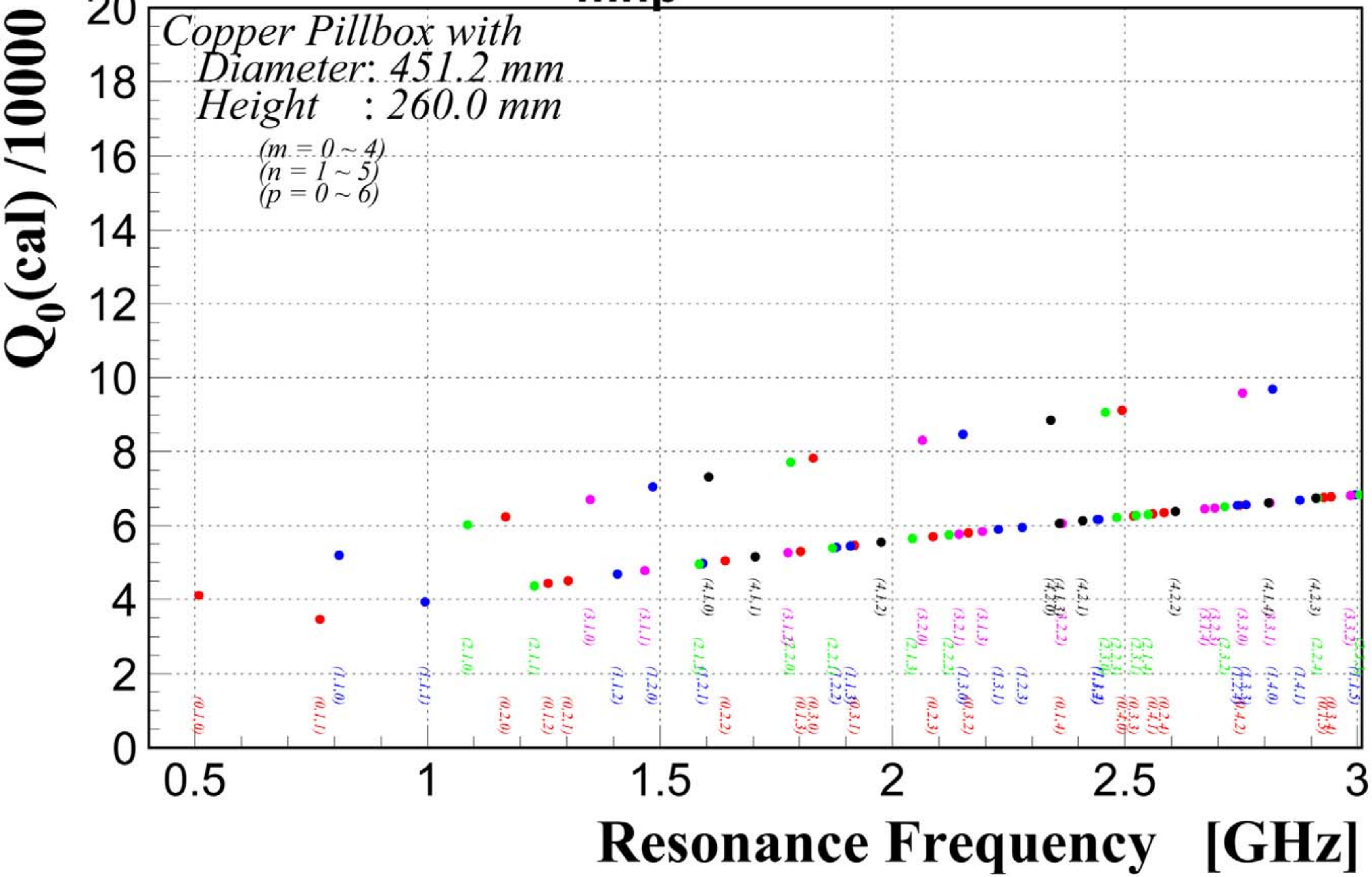
Cf. Electroplating in an acid sulfate bath w/o brightener: <u>102%IACS</u>

# $TE_{mnp}$ Waves



Copper Pillbox with
Diameter: 451.2 mm
Height : 260.0 mm
(m = 0 ~ 4)
(n = 1 ~ 5)
(p = 1 ~ 6)
$Q_0$(cal) /10000
Resonance Frequency [GHz]

# $TM_{mnp}$ Waves

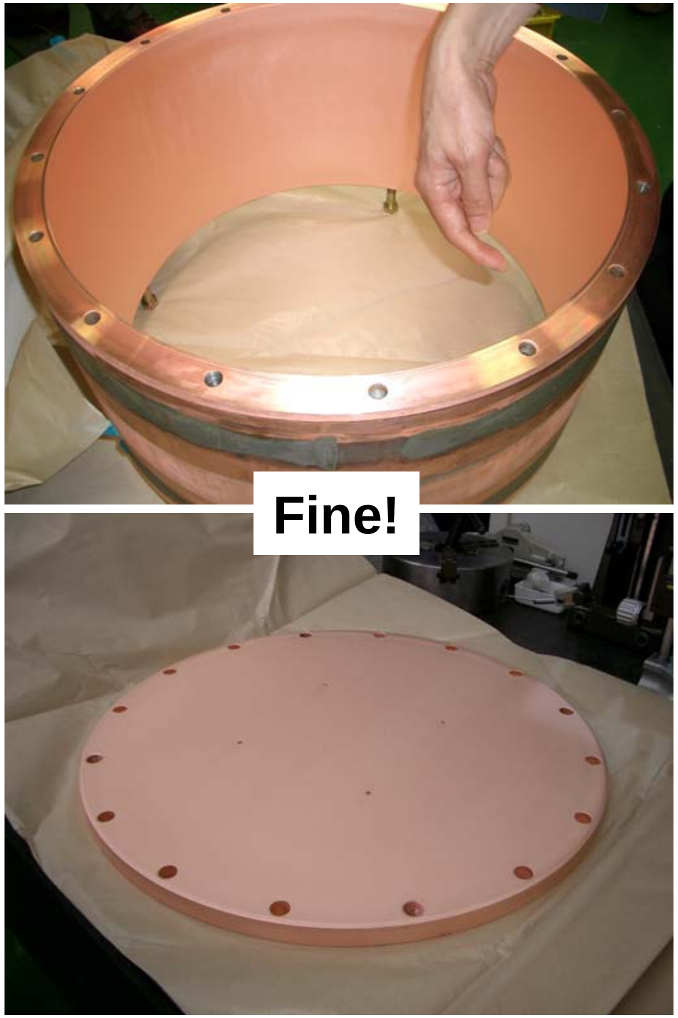

Copper Pillbox with
Diameter: 451.2 mm
Height : 260.0 mm
(m = 0 ~ 4)
(n = 1 ~ 5)
(p = 0 ~ 6)
Q0(cal) /10000
Resonance Frequency [GHz]

# After Trial and Error…

Copper Electroplating in an acid sulfate bath w/o brightener (PR process)

Barrel

Endcap



# After Trial and Error…

Copper Electroplating in an acid sulfate bath w/o brightener (PR process)

Barrel

**Fine!**

Endcap

**Electrolytic**

**polishing**

# After Trial and Error…

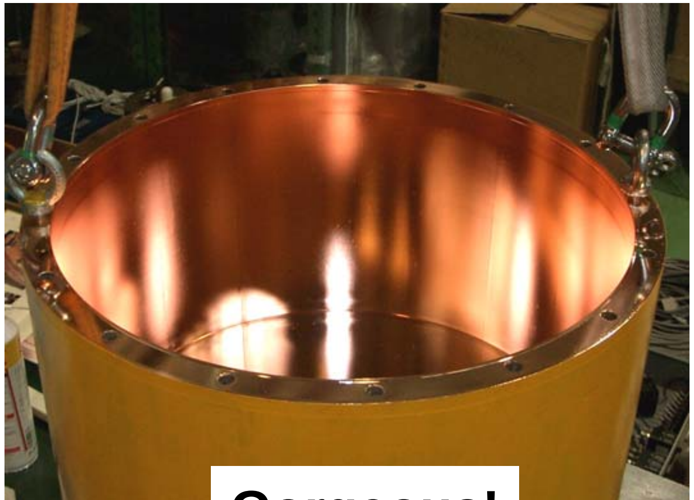
Copper Electroplating in an acid sulfate bath w/o brightener (PR process)

Barrel

Fine!

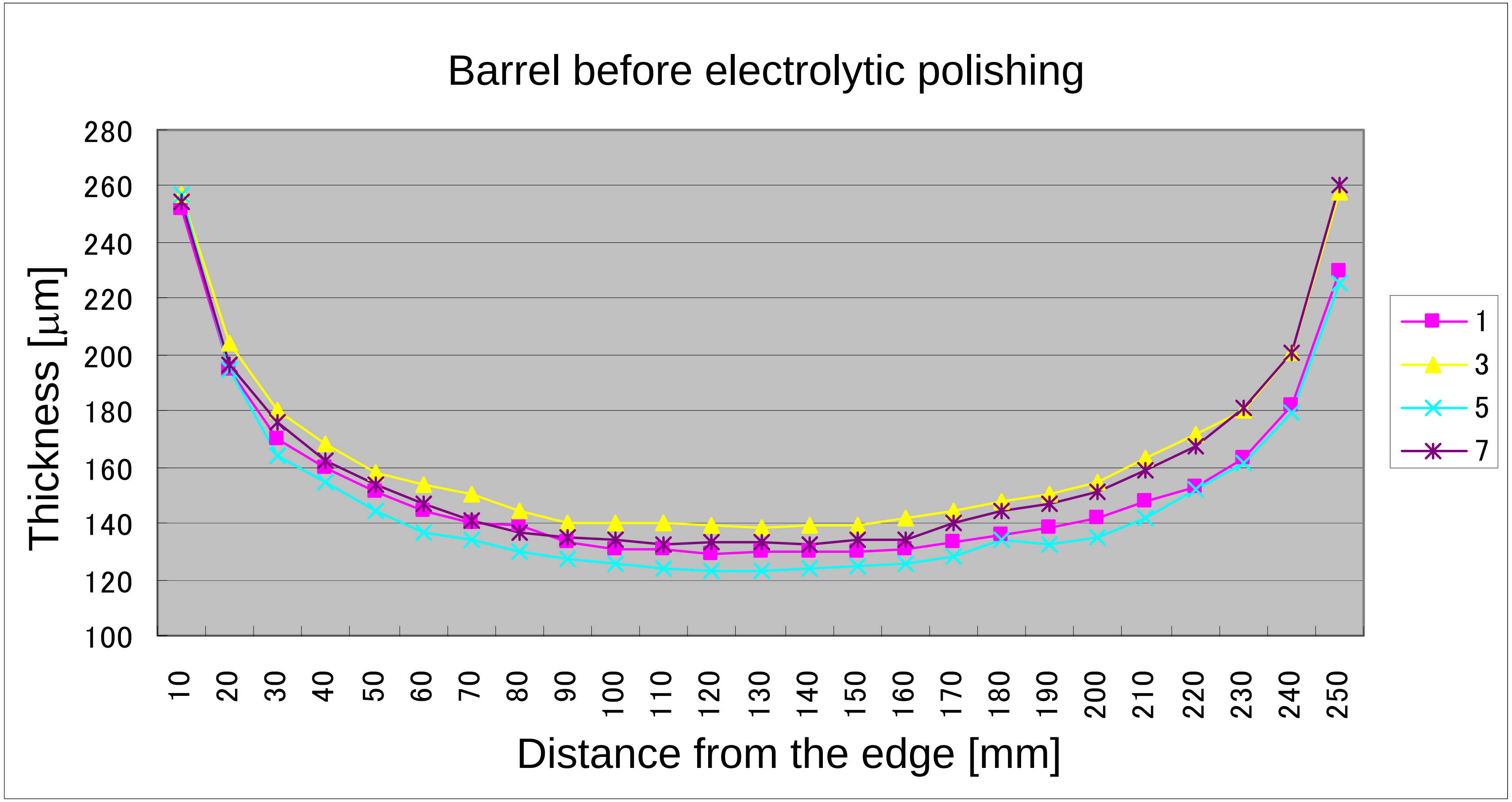
Endcap

Electrolytic polishing



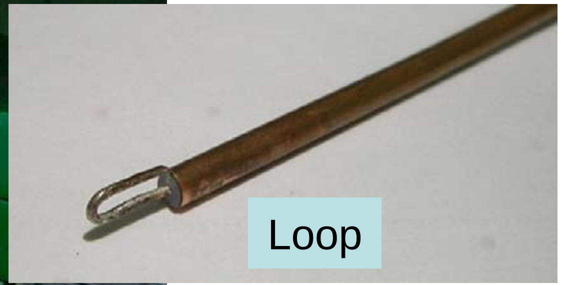
Gorgeous!

# Thickness Measurement

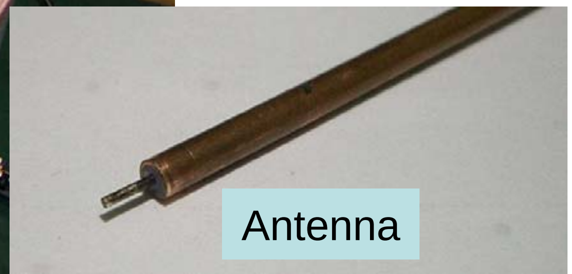


# Setup of the $Q_0$ Measurement

# Setup (close view)

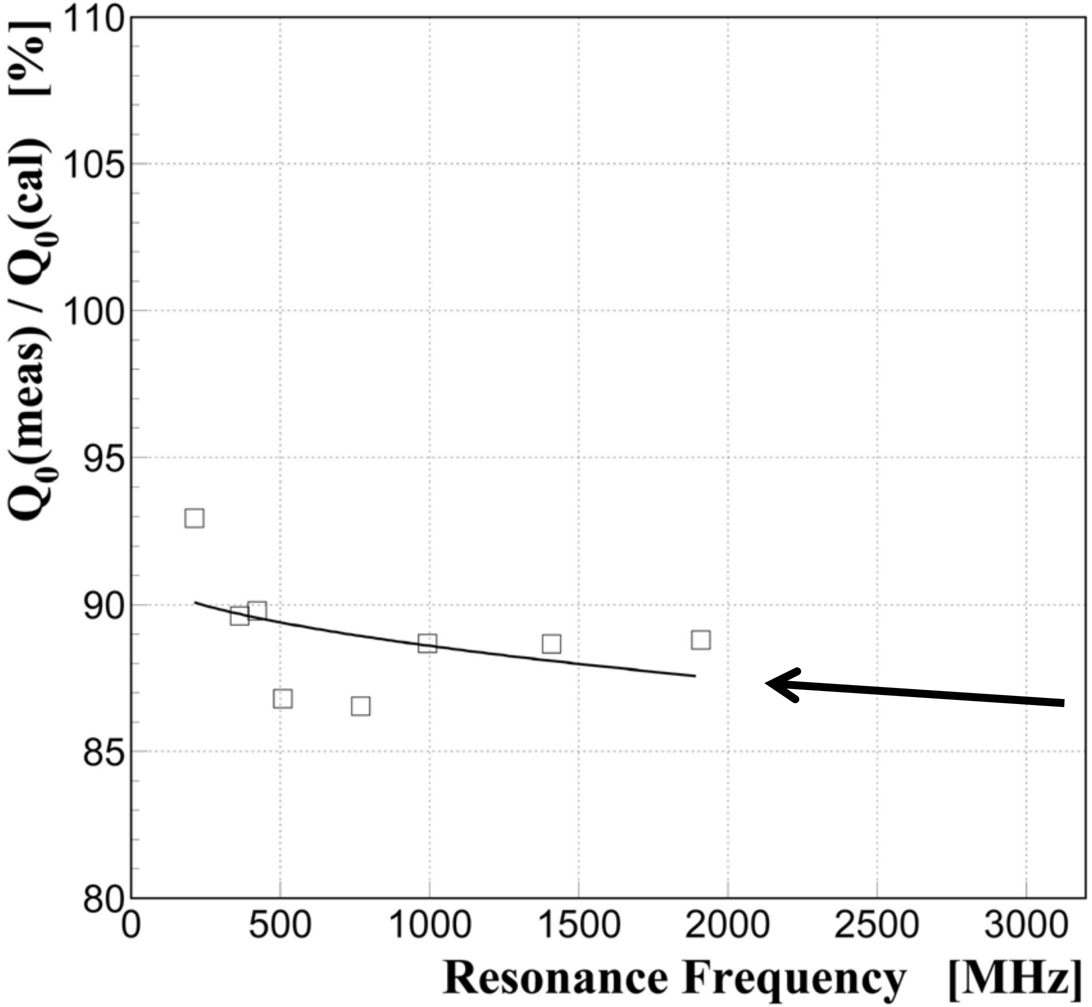



couples with magnetic field.



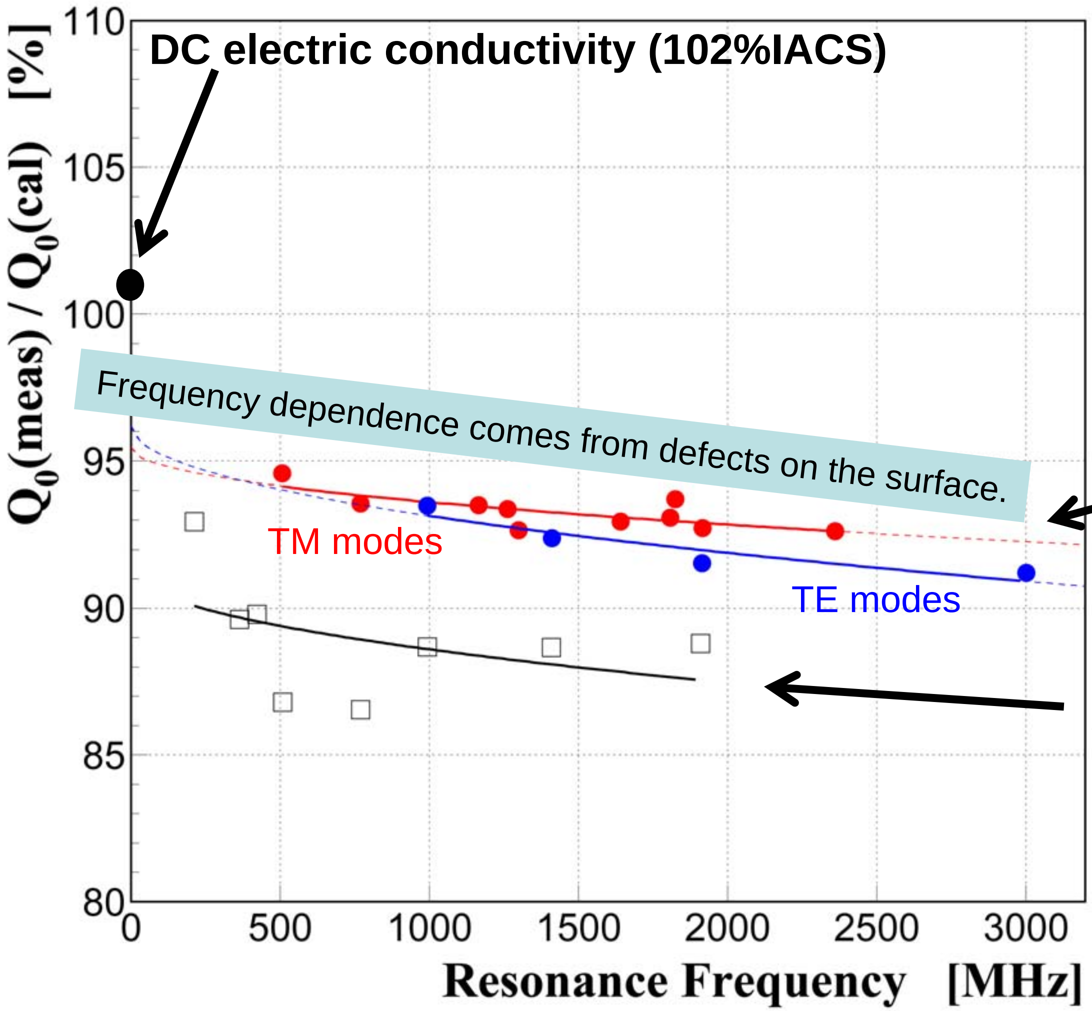

couples with electric field.

# Results of the $Q_0$ Measurements




Electroplating in a **pyrophosphate** bath **with brightener** (applied to the present S-cav's) (no temperature correction)

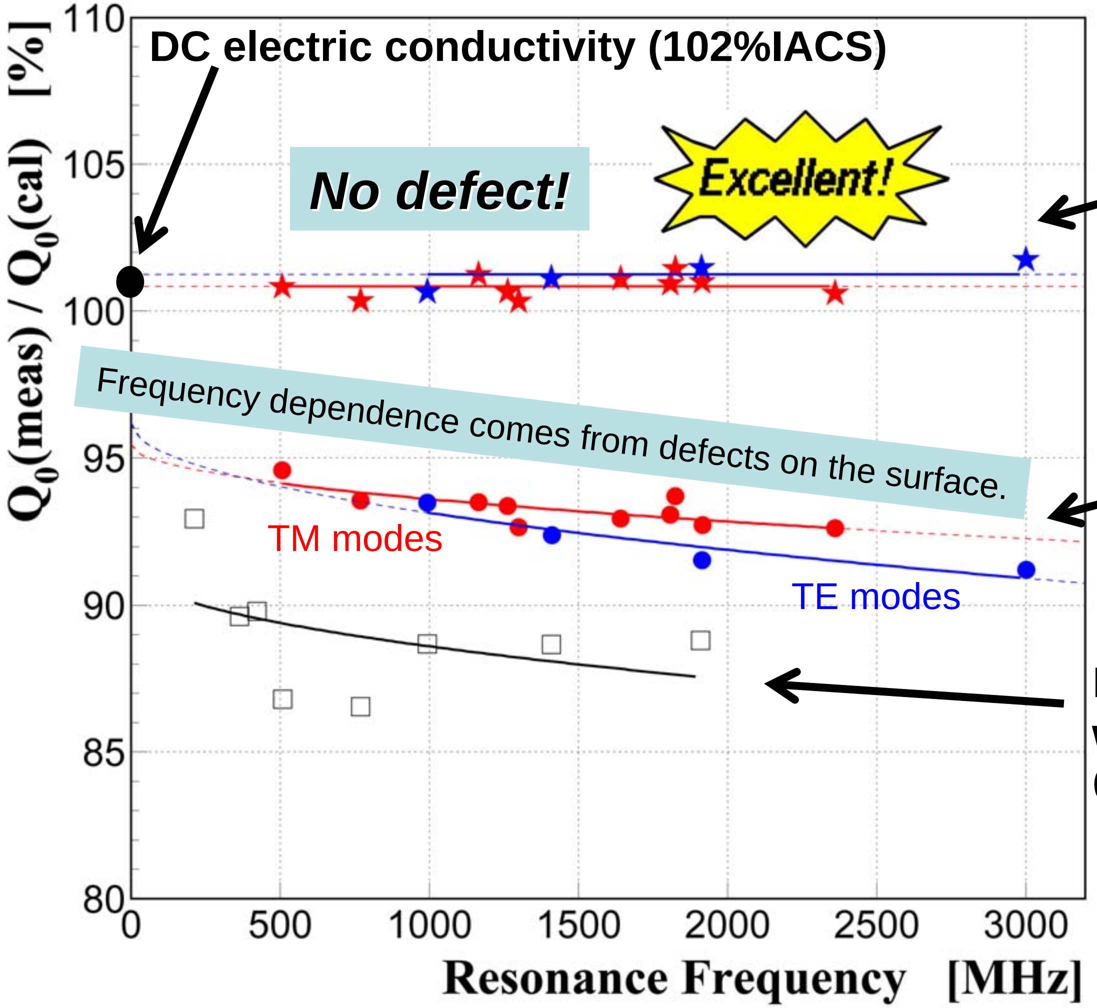
# Results of the $Q_0$ Measurements




Electroplating in an **acid sulfate** bath
**without brightener**
before electrolytic polishing
(@20degC)

Electroplating in a **pyrophosphate** bath
**with brightener** (applied to the present S-cav's)
(no temperature correction)

# Results of the $Q_0$ Measurements




Electroplating in an **acid sulfate** bath
**without brightener**
**after electrolytic polishing**
(@20degC)

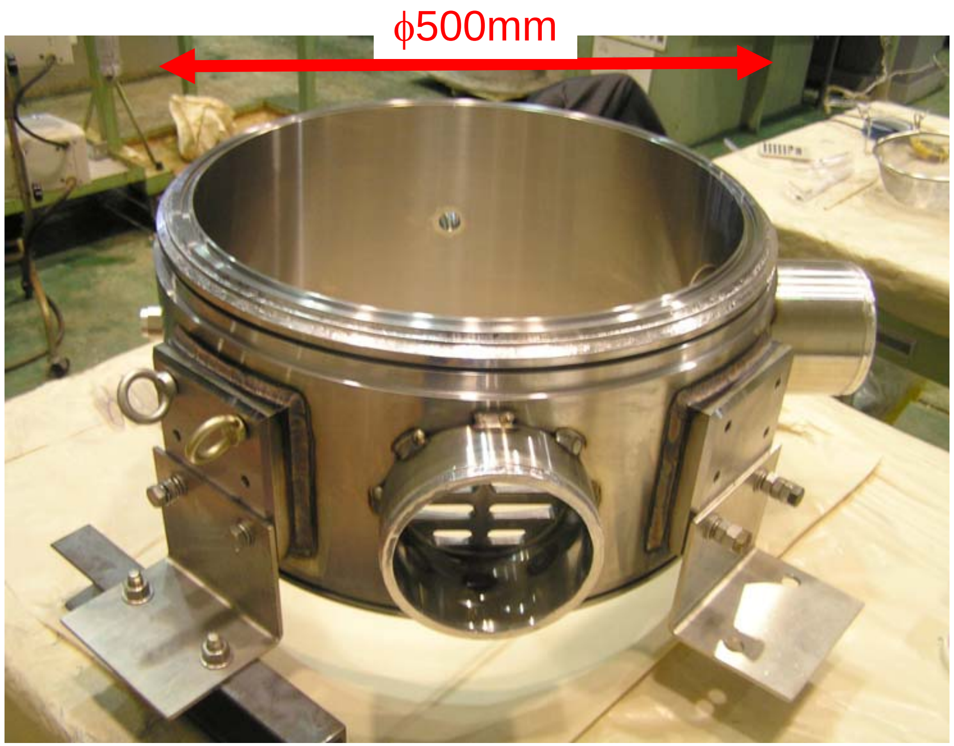
Electroplating in an **acid sulfate** bath
**without brightener**
before electrolytic polishing
(@20degC)

Electroplating in the **pyrophosphate** bath
**with brightener** (applied to the present S-cav's)
(no temperature correction)

# Next Step: Vacuum Test

- *The test cavity has been fabricated.*
- *The electroplating is ongoing.*
- *A vacuum test will be done next month.*

Endcap




Barrel

# Summary

- **ARES R&D programs are ongoing well.**

- **A new L-band test stand has been constructed**
  → For the HOM-load upgrade.
  → The 1st stage has been finished.
  → To be tuned for supplying high powers.

- **Input couplers with TiN coating**
  → Against multipactoring in the coaxial line.
  → Two TiN-coated couplers have been completed.
  → Being tested in the upgraded coupler test stand up to 800kW(CW).

- **New highly-pure copper electroplating for S-cav**
  → On the slightly different condition from J-PARC.
  → The electric performance is estimated to be excellent.
  → A vacuum test to be done next month.