Fabrication and Test of Cavity BPM for KEK-ATF2 and PAL-XFEL

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M. Ross, FNAL

Related Talks:
- **Y. Honda: WEZH102**
- **M. Ross: WEZH103**

APAC2007, Indore, Jan. 31, 2007

Introduction

✓ **Sub-micrometer BPM needed for KEK-ATF2 (ILC) / and PAL-XFEL**

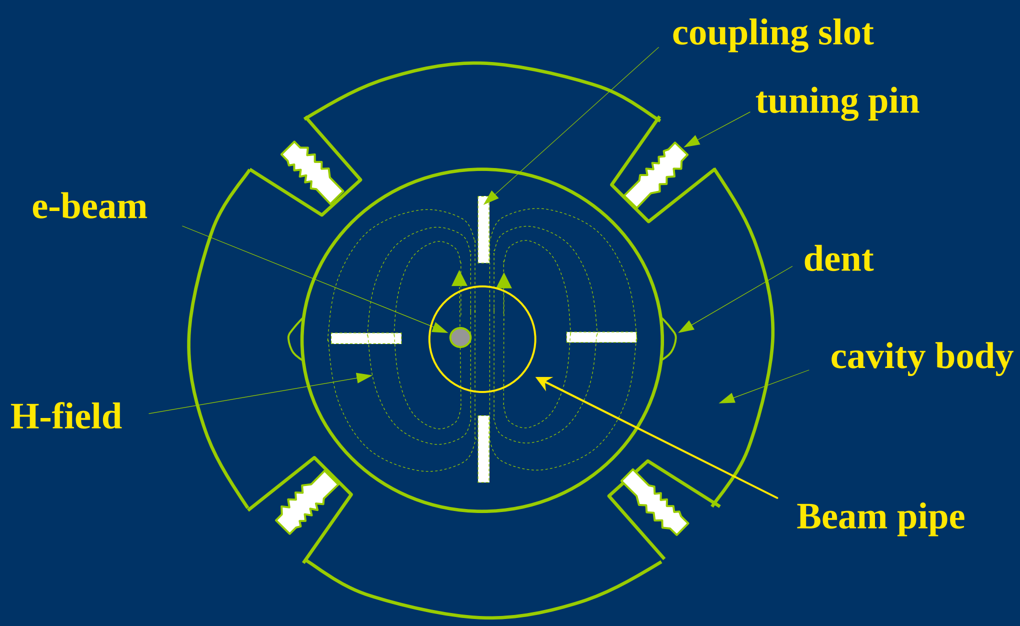
- **KEK-ATF2 : under construction in KEK-ATF for study of ILC**
- **PAL-XFEL : planned XFEL facility in PAL**

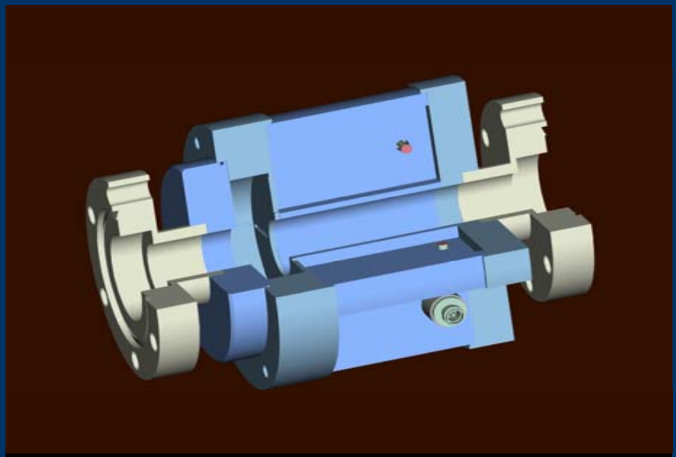
✓ **Use simple microwave BPM structure : Cavity BPM**

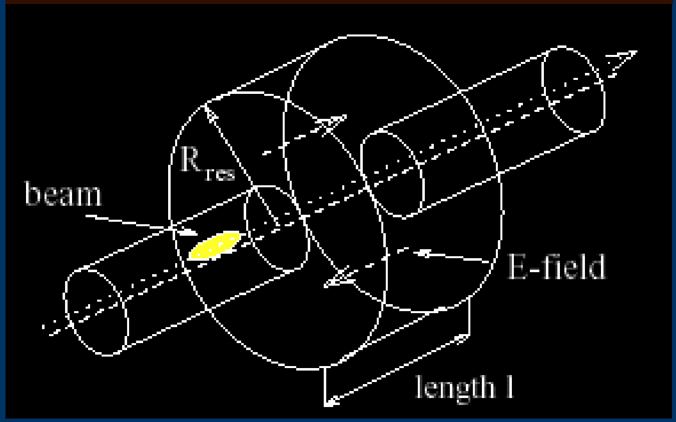
- **pill-box cavity tuned at TM110 transverse dipole mode**
- **signal proportional to the beam displacement and bunch charge**
- **stronger signal than the pickup BPMs**
- **mechanical stability**

Cavity BPM

- ✓ Basic design and tests have been done in KEK-ATF, by Y. Honda
- ✓ Further improvements in waveguide structure, tuning mechanism, brazing technology, and beam tests are performed by collaboration between KEK, SLAC, PAL







Requirements

cavity BPM

- **Precision BPM for KEK-ATF2 (ILC) / XFEL**

  - Resolution : 100 nm by single shot measurement

  - Measurable range > +/-50 um (+/-250um w/1um resolution)

  - x-y isolation : > 30 dB

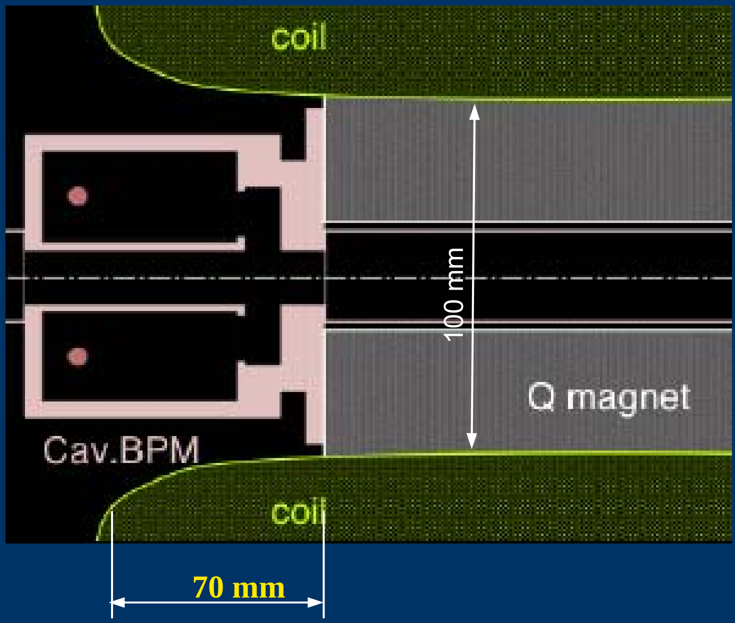
  - E-center offset: < 10 um

- **Compact but large aperture**

  to prevent noise from beam halo

- **Rigidly attached on each Q-magnet**

- **To work with 357 MHz multi-bunch**



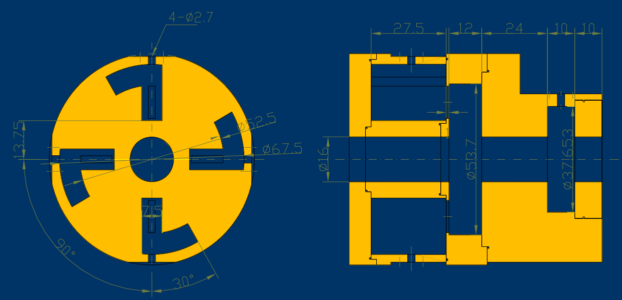
Cavity Parameter

- Frequency (cavity radius)
  - Keep the basic design of KEK (Honda)
    - Pill-box cavity, TM110 mode, C-band (for ATF's bunch length)
    - Magnetic coupling by slots through the end plate
    - 4-ports to keep symmetry
  - Digital wave form recording ; SLAC-type electronics
  - ❖ 6.426 GHz +/- 1 MHz
- Aperture: increase to the largest possible → 20 mm diameter
- Cavity gap (length)
  - Energy deposit, contamination from other modes
  - ❖ 12mm is optimal
- Slot size for signal coupling
  - Large size ; short decay time
  - Small size ; week signal
  - ❖ 1.5 x 13 x 1.5 mm (width, length, depth)

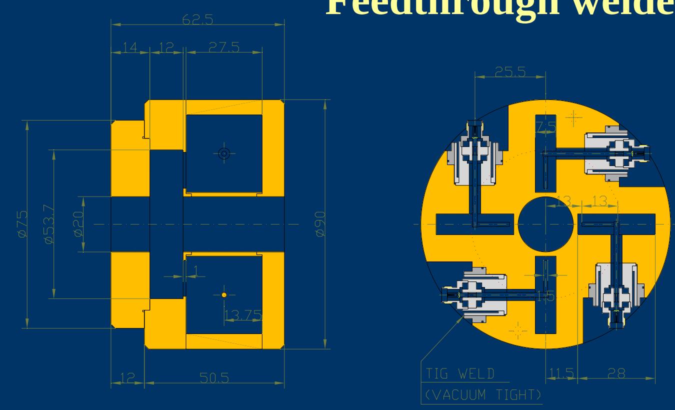
Design History

Y. Honda

L-shape waveguide

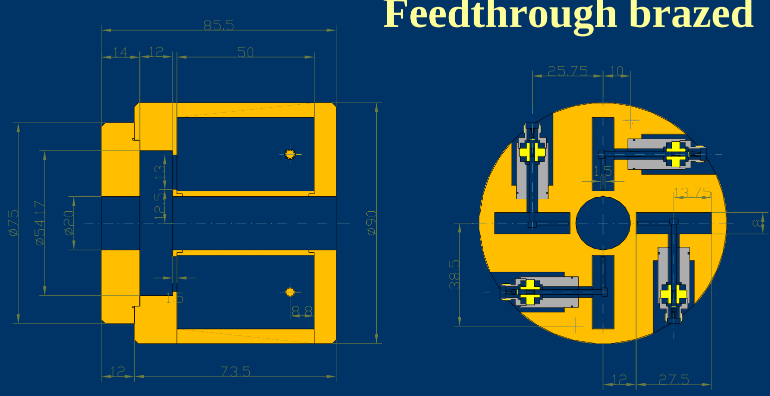


Straight waveguide
Feedthrough welded



Prototype

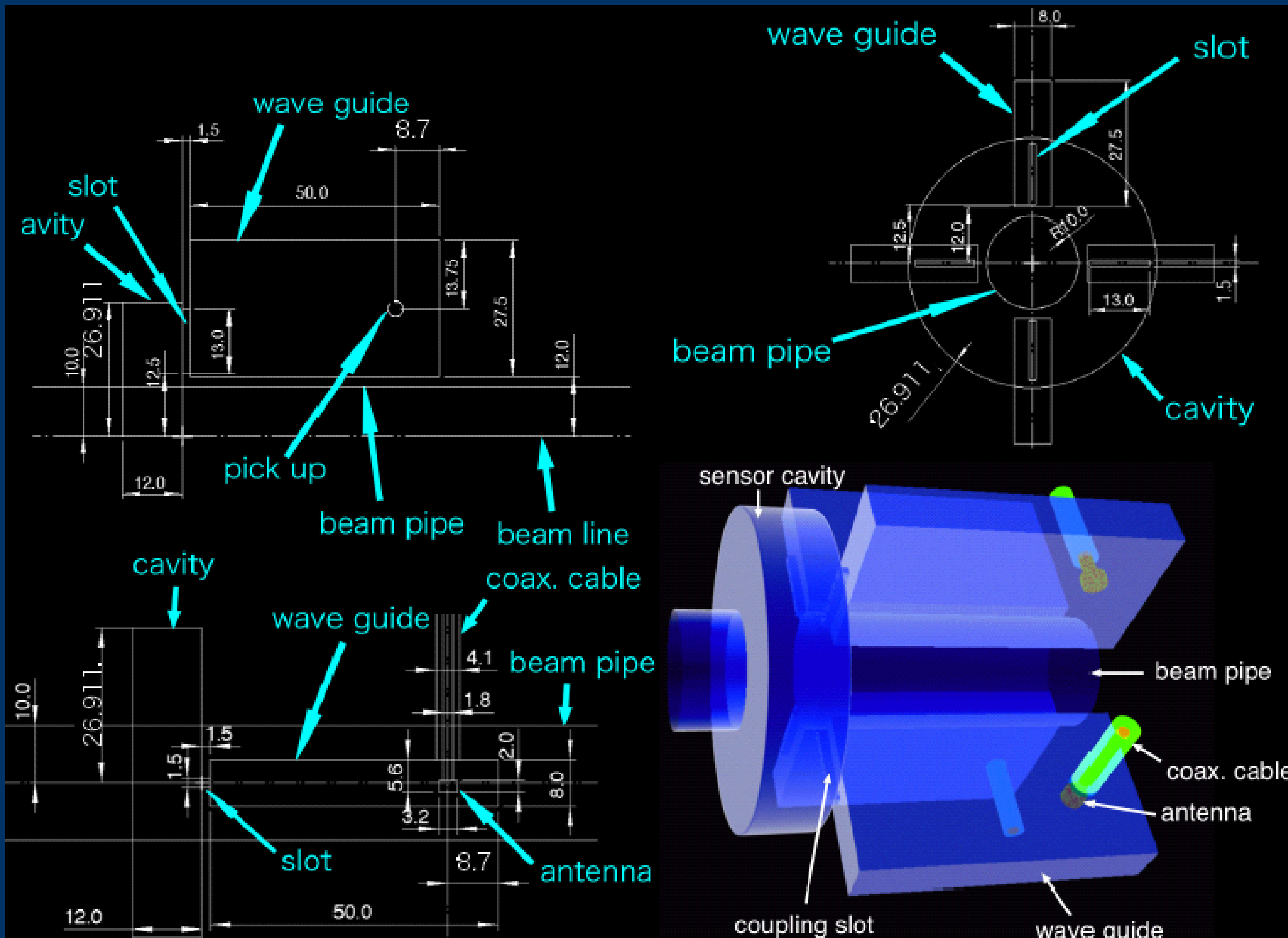
Larger waveguide
Feedthrough brazed



Production:

Longer (270mm) Beam Pipe

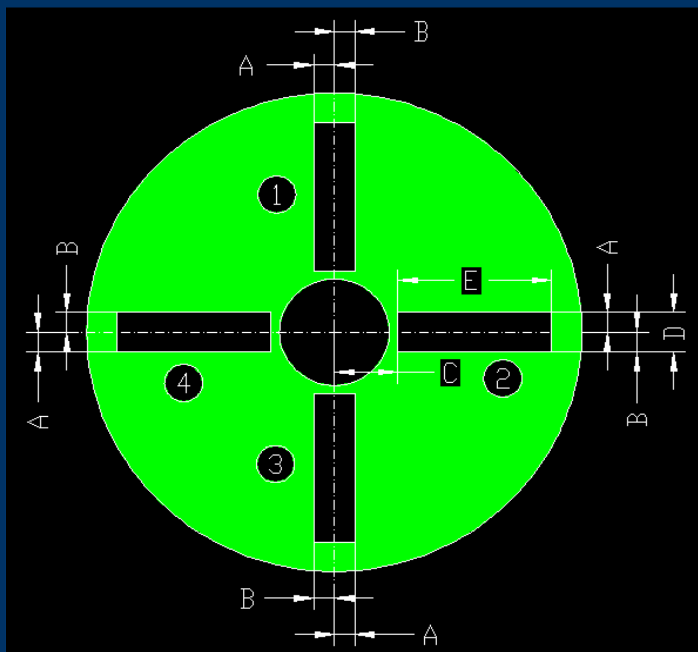
Design Summary

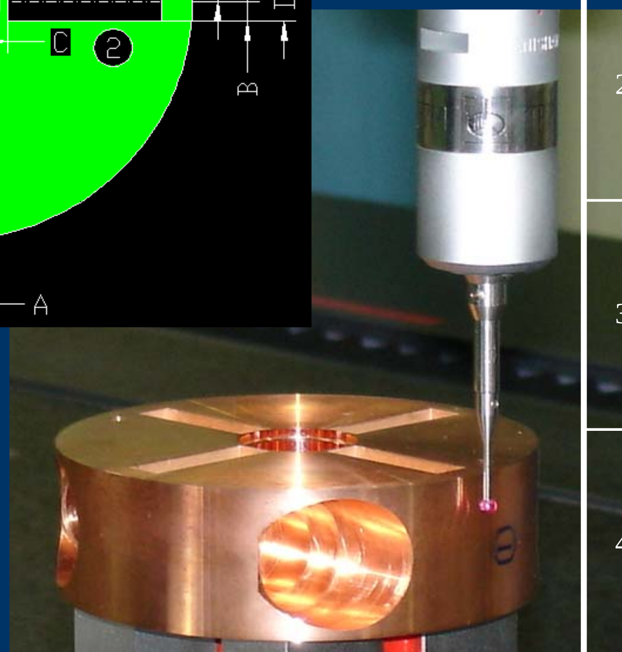


Fabrication

- ✓ **Mechanical Accuracies**
  - **- use jigs for machining accuracies (<10 um)**
  - **- diamond tool for cavity machining (Rmax <0.3)**
- ✓ **Brazing tests**
  - **- Filler metals: shape and quantity**
  - **- filler slots**

Machining Accuracy





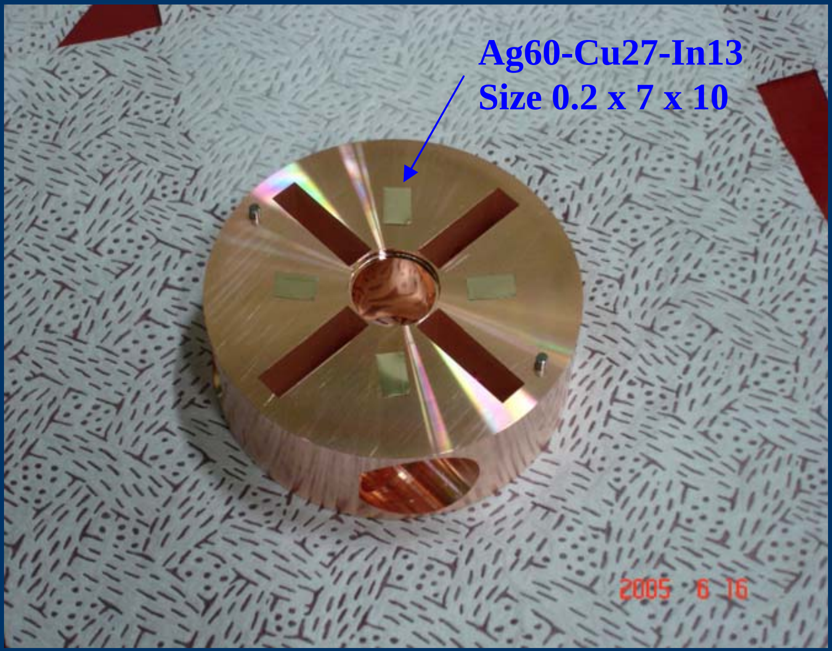
position		Dimension	Sample 1	Sample 2	Sample 3
1	A	8.75	-3	4	12
	B	8.75	2	-10	-10
	C	11.5	-10	-12	29
	D	7.5	-1	-6	2
	E	28	6	-28	5
2	A	8.75	-2	5	14
	B	8.75	1	-11	-8
	C	11.5	5	-5	-7
	D	7.5	-1	-6	6
	E	28	8	-8	4
3	A	8.75	7	-15	12
	B	8.75	-8	6	-3
	C	11.5	2	11	-27
	D	7.5	4	-9	9
	E	28	6	-15	6
4	A	8.75	5	-11	5
	B	8.75	8	8	-5
	C	11.5	9	-12	18
	D	7.5	8	-8	0
	E	28	7	-8	-2

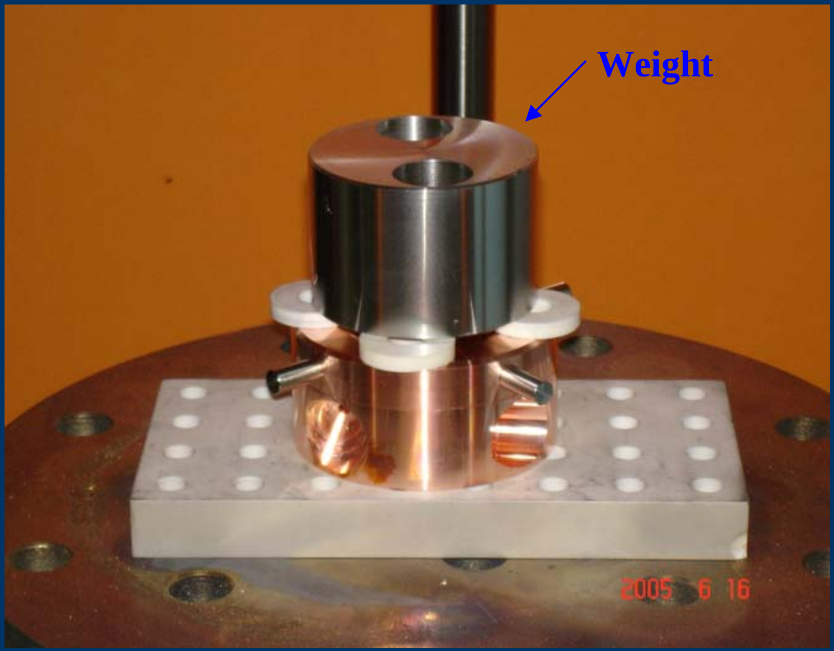
Dimension : mm
Tolerance & Sample : ㎛

Surface Roughness (waveguide) ; ≤ Rmax 5

Surface Roughness (cavity) ; ≤ Rmax 0.3

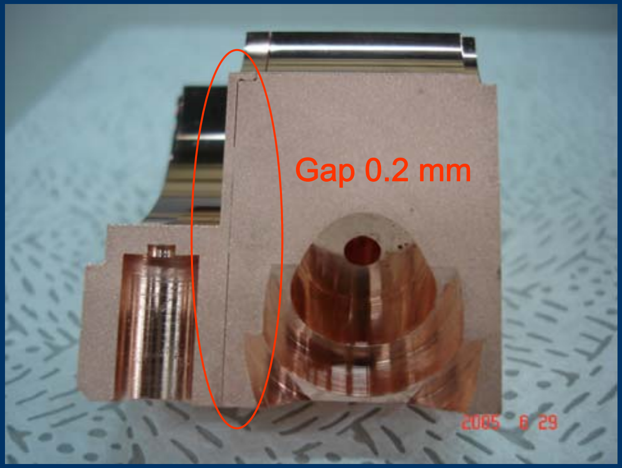
Brazing Test, "A"

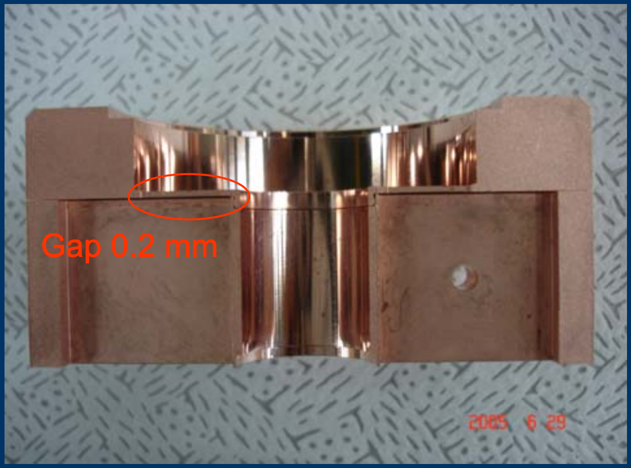


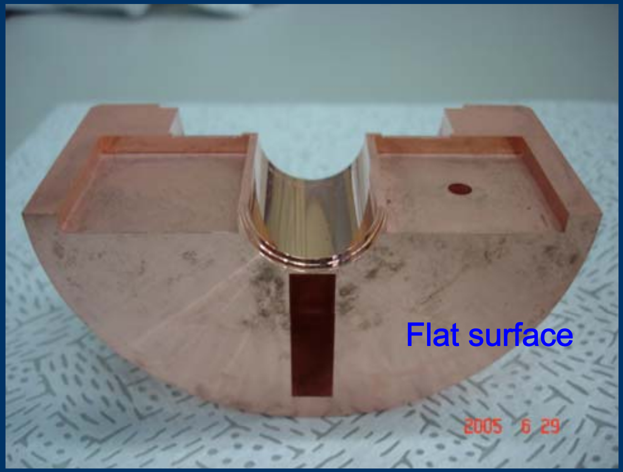


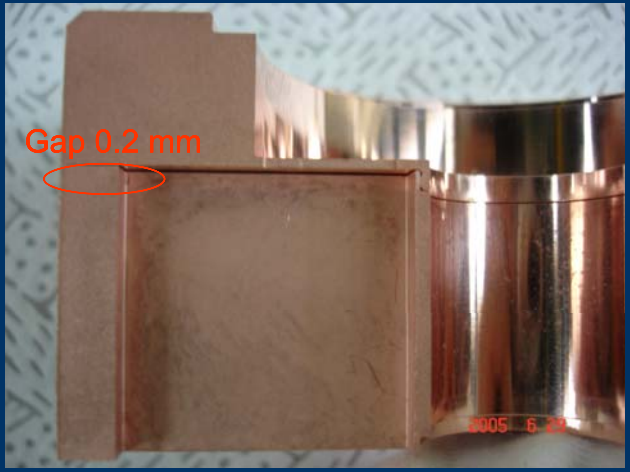
- ✓ Sheet type filler metal ; thickness 0.2 mm, Melting temp 720 deg.C
- ✓ Vacuum brazing
- ✓ 1.5 kg weight

Result of Brazing Process "A"



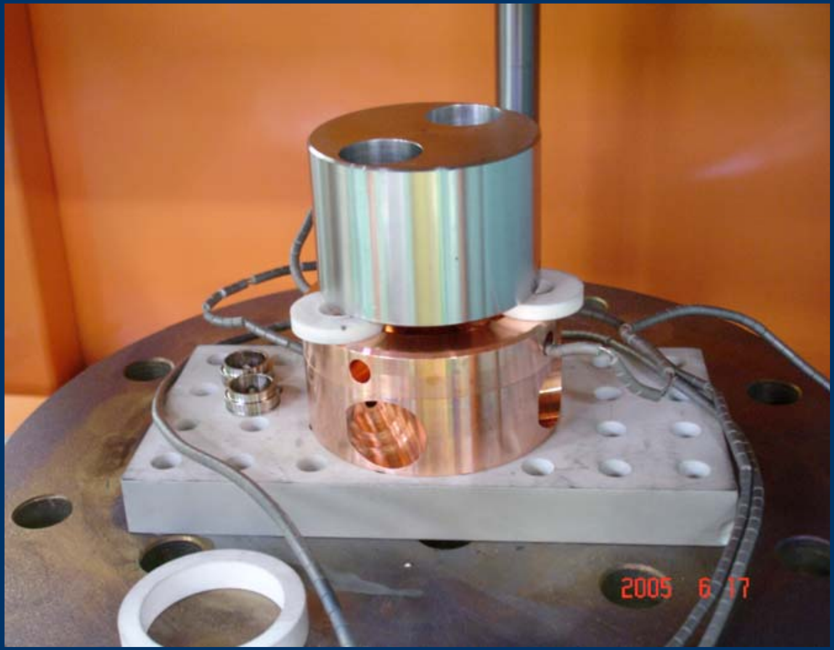






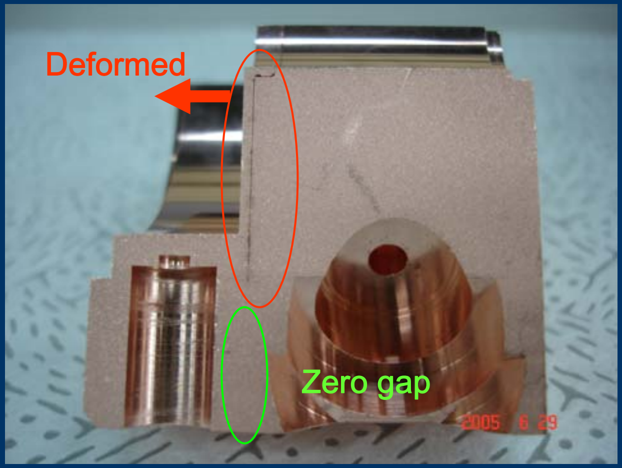
- ✓ **0.2 mm gap between W/G and Cavity after brazing**
- ✓ **Thin (1mm) coupling wall between cavity and W/G → deformed**

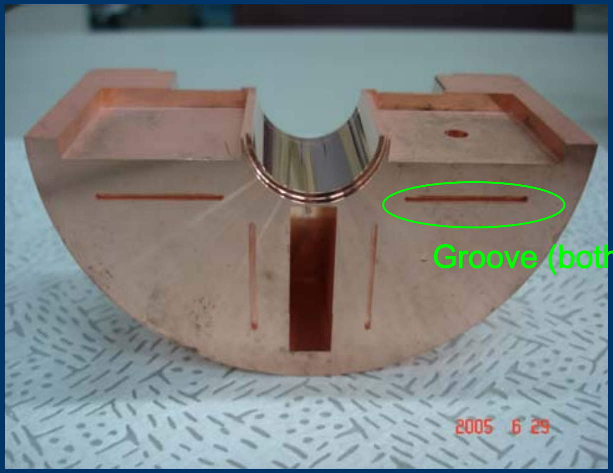
Brazing Test, “B”



- ✓ **Wire type filler metal ; Dia. 1.0 x <u>Length 10 mm</u>, Melting temp 720 deg.C**
- ✓ **Vacuum brazing**
- ✓ **1.5 kg weight**

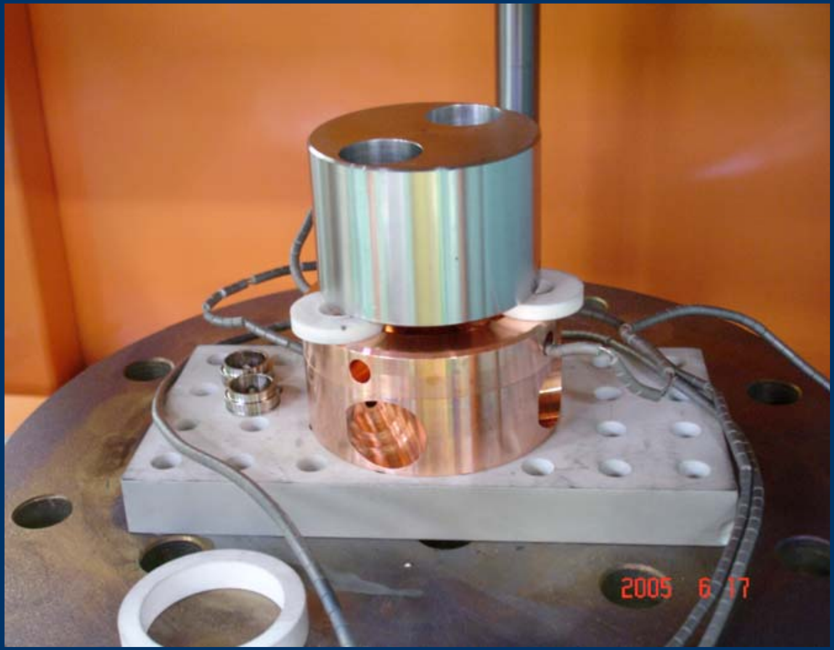
Result of Brazing Process “B”





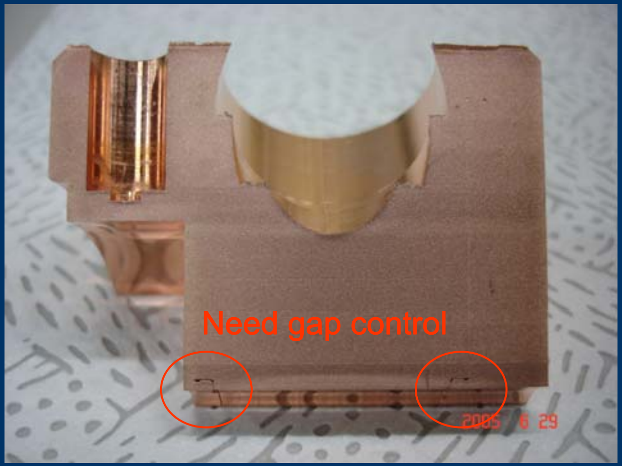
- ✓ **Zero gap between W/G and Cavity, but shortage of filler metal**
- ✓ **Thin coupling wall between cavity andW/G → deformed**

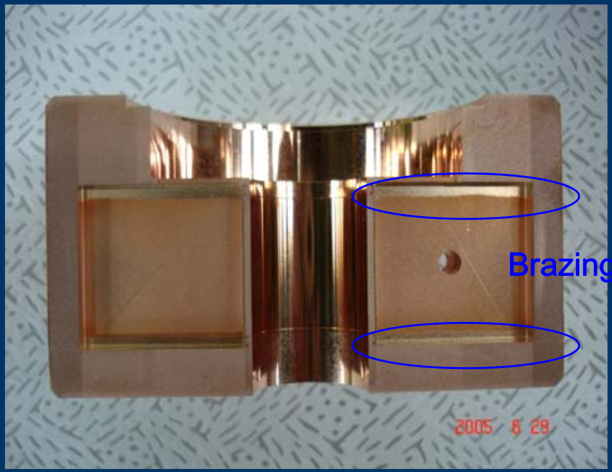
Brazing Test, "C"

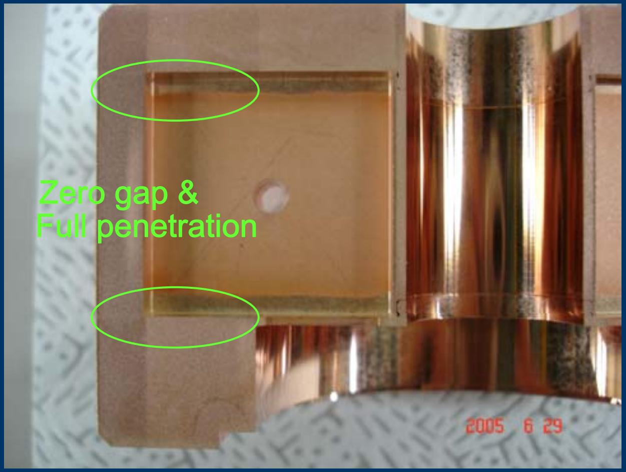


- ✓ **Wire type filler metal ; Dia. 1.0 x <u>Length 18 mm</u>, Melting temp 720 deg.C**
- ✓ **coupling wall between cavity and waveguide : 1.5 mm**
- ✓ **Vacuum brazing**
- ✓ **1.5 kg weight**

Result of Brazing Process “C”

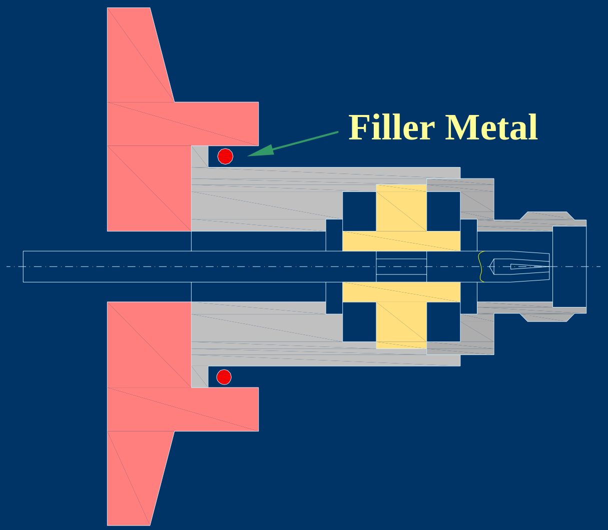






✓ **Accepted !!**

Brazing Test of Feedthrough

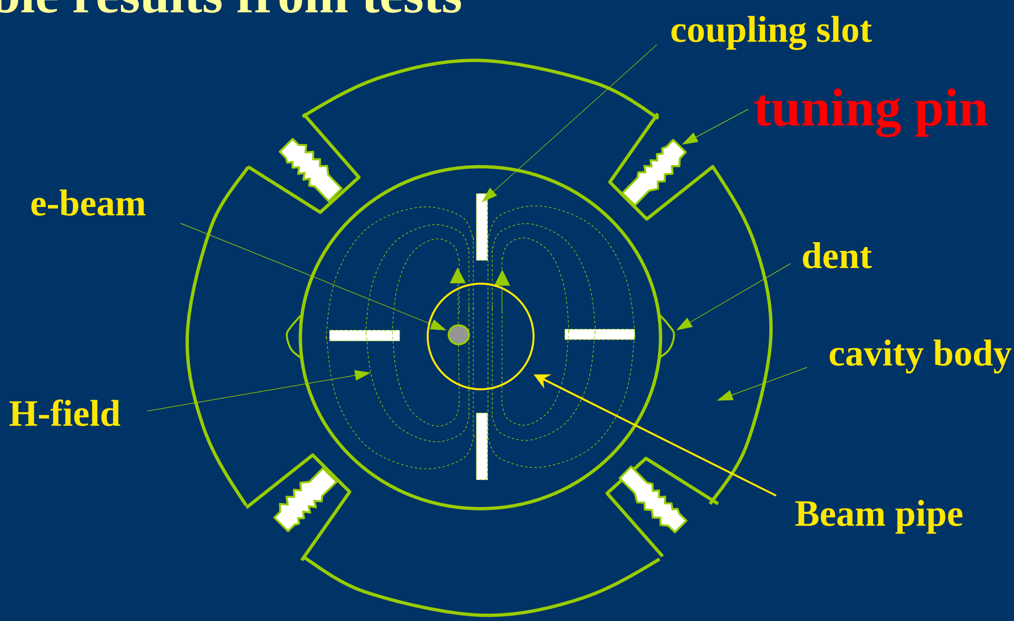


- ✓ Filler Metal
  Ag60-Cu27-In13, M.T 720 deg.C
- ✓ Sample
  Type A ; 0.5 wire type alloy
  Type B ; 1.0 wire type alloy
- ✓ Vacuum Leak Rate
  Type A - Not detected
  Type B – 2.0 E-9 Torr.l/s
- ✓ Type A: Adjust hold time @ melting point (5 sec → 10sec) & make groove

➢ **Process A. : accepted**

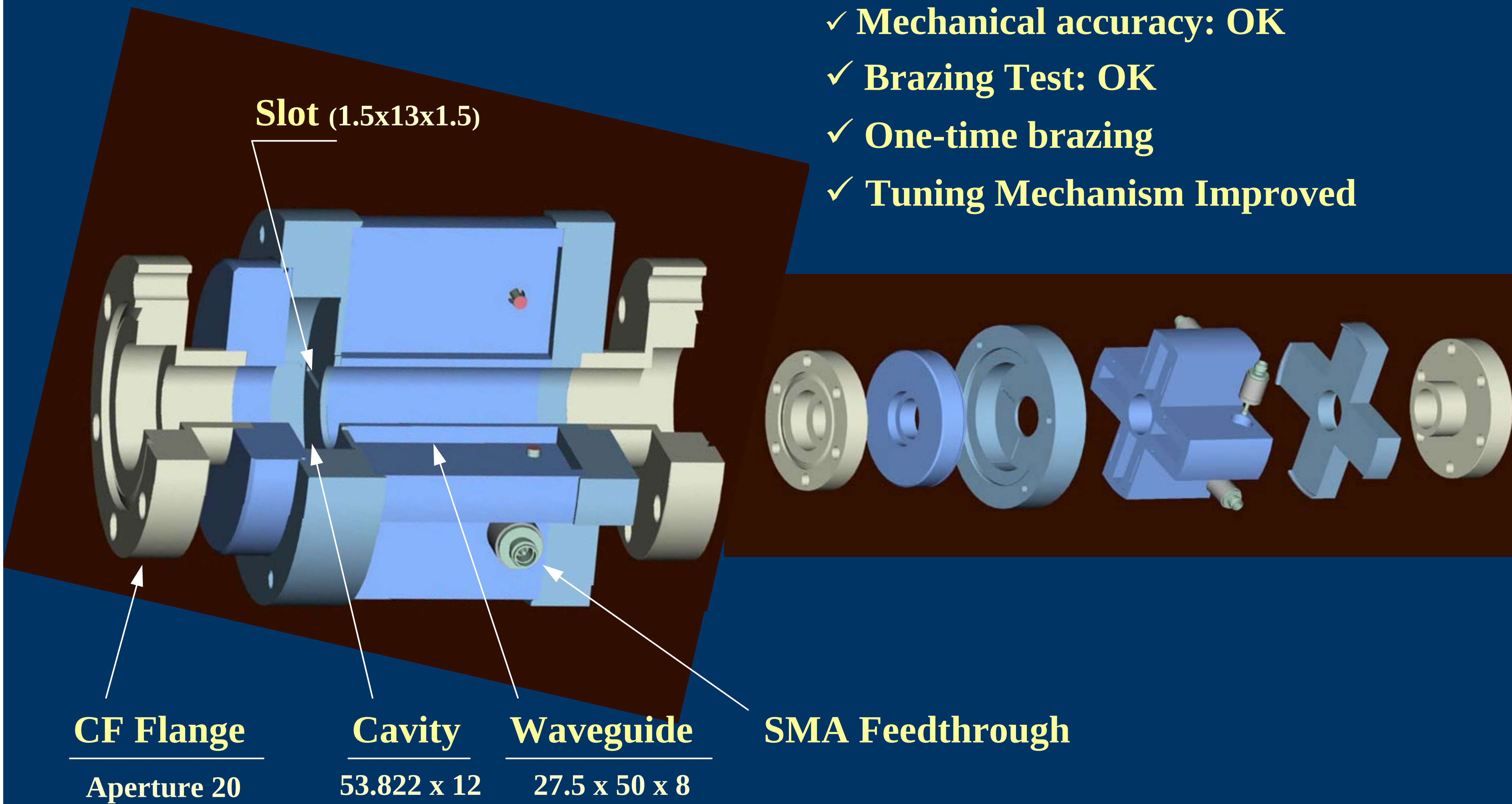
Tuning Mechanism

- ✓ Frequency: volume tuning (mechanical, thermal)
- ✓ Isolation: artificial asymmetry by making dents,
  or mechanical deforming for compensation of symmetry
- ✓ Invention of tuning pins with screw brazed in to cavity body
  cavity volume adjustable by push and pull
- ✓ Acceptable results from tests



Final Model (Prototype)

- ✓ Mechanical accuracy: OK
- ✓ Brazing Test: OK
- ✓ One-time brazing
- ✓ Tuning Mechanism Improved



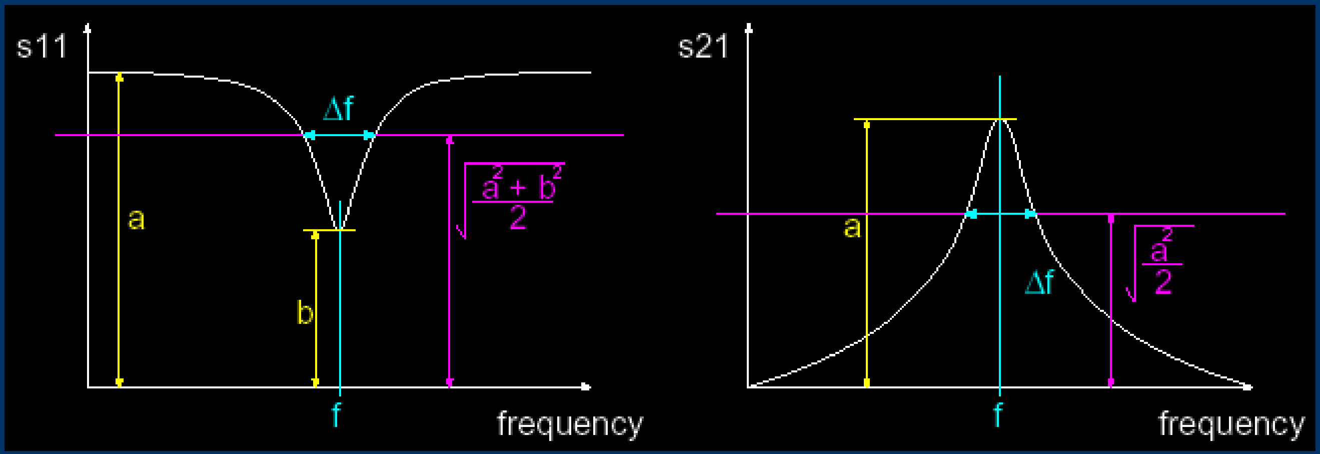
Tests

- ✓ uW characteristics
  - -Tuning method invented: improved tuning
  - -Tunable within requirements

- ✓ Beam Test at KEK-ATF

RF Parameter

- definition -



1-port measurement

2-port measurement

- $\beta = (1-S_{11})/S_{11}$: 1-port measurement
- $\beta = S_{21}/(1-S_{21})$: 2-port measurement
- $Q_L = f/\Delta f$
- $Q_0 = (1+\beta)\,Q_L$
- $Q_{ext} = Q_0/\beta$

RF Parameter

- before and after brazing test cavity BPM -

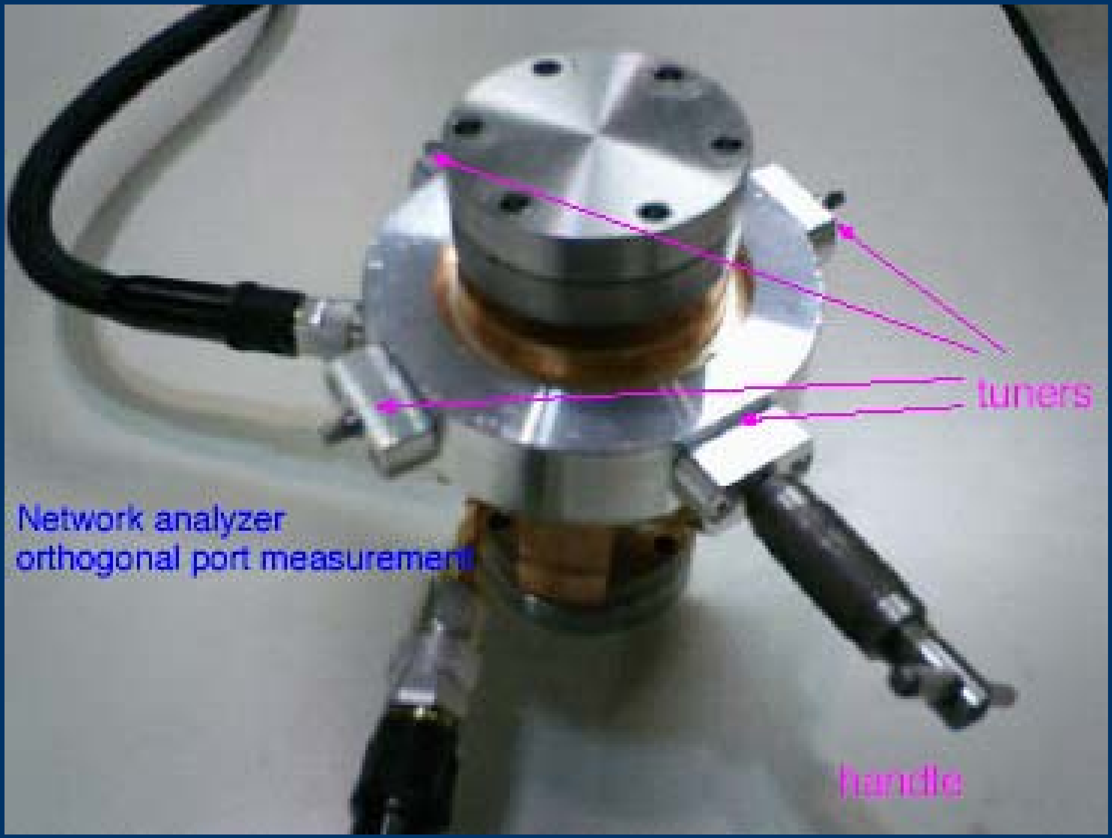
model	dents	compre-ssion	Before brazing			After brazing		
			Q_0	f(GHz)	isolation	Q_0	f(GHz)	isolation
#1	Yes	tight loose	8151 3775	6.41775, 6.41705 6.41843, 6.41795	-44.1 dB -19.8 dB	7229	6.42024, 6.41952	-21.7 dB
#2	No	tight	7641	6.41709	-29.6			
#2-m	Y-DD	tight	5012	6.41725, 6.41445	-47.7 dB	6928	6.41908, 6.41629	-30.7 dB
#3	Yes	tight		6.418, 6.417	-23 dB	7163	6.42051, 6.41979	-20.1 dB
#4	No	tight loose	7222 5198	6.41764 6.41880	-19.4 dB -18.7 dB	7556	6.42082	-28.7 dB

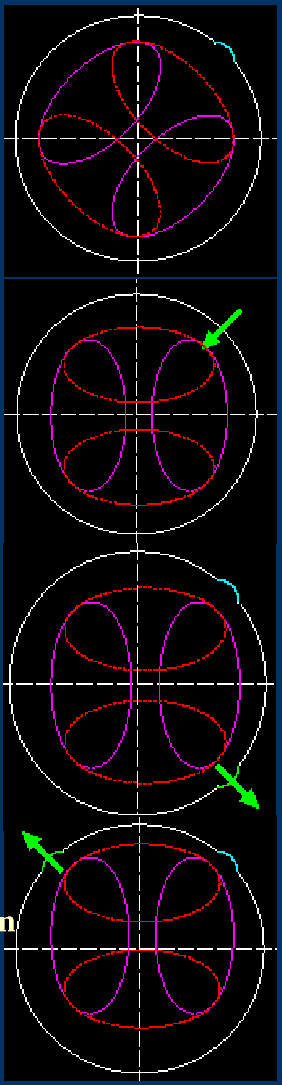
*** #2-m ; deep dents on the #2 model, dent depth is 0.35 mm.**

- ✓ ***f*** **: 2.45 MHz increase w/ brazing.**
- ✓ ***f*** **: 2 MHz increase @ vacuum.**

RF Parameter

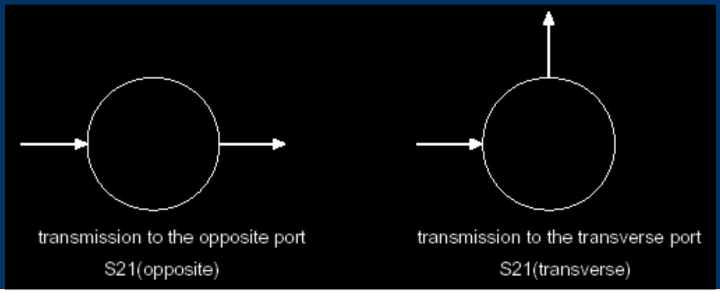
- isolation tuning and e-center measurement -





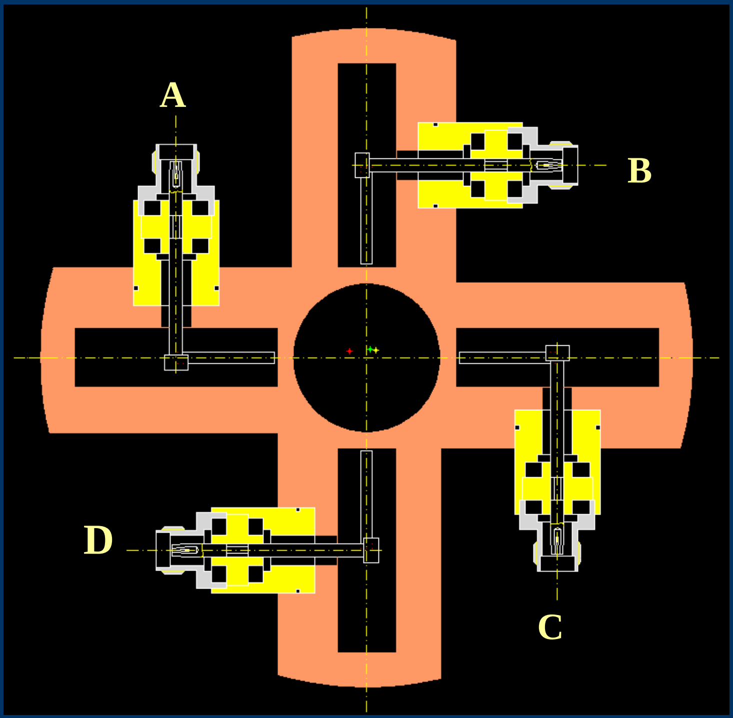
RF Parameter

- x-y isolation and e-center error -



Isolation $= 20 \log \dfrac{S_{21}(\text{vertical: A-B})}{S_{21}:(\text{A-C})}$

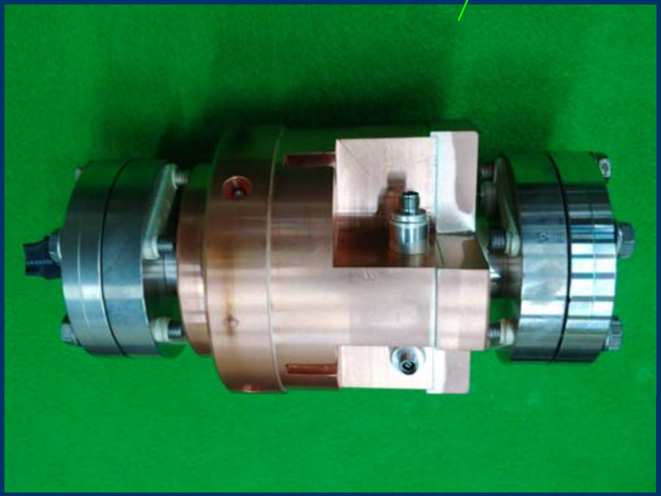
model		before brazing	after brazing	
			before tuning	after tuning
#1 dents	x-y isolation(dB) e-center A-C(µm) e-center B-D(µm)	-44.1	-21.7 -4.0±3.3 4.2±3.4	-50.8 -9.5±3.7 2.1±3.9
#2 deep dents	x-y isolation(dB) e-center A-C(µm) e-center B-D(µm)	-47.7	-30.7 6.9±2.6 4.2±3.5	-55.8 6.8±4.0 2.8±4.0
#3 dents	x-y isolation(dB) e-center A-C(µm) e-center B-D(µm)	-23	-20.1	
#4 no dents	x-y isolation(dB) e-center A-C(µm) e-center B-D(µm)	-19.4	-28.7 6.2±4.8 1.6±3.7	-53.2 6.9±6.3 1.1±2.4

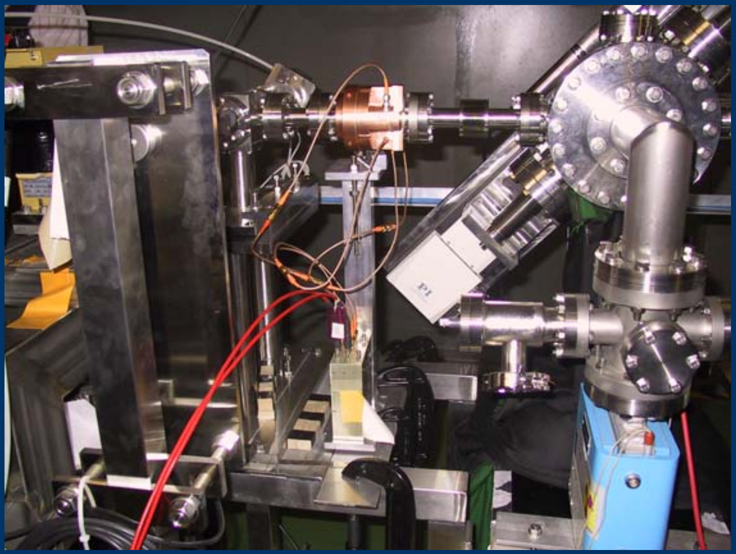


J. Y. Huang, PAL

Beam Test

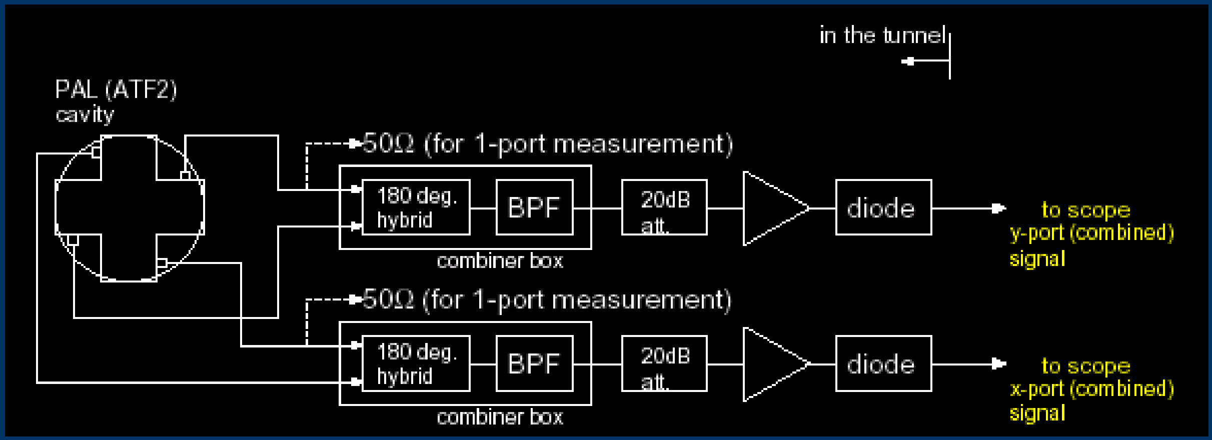
- KEK ATF-



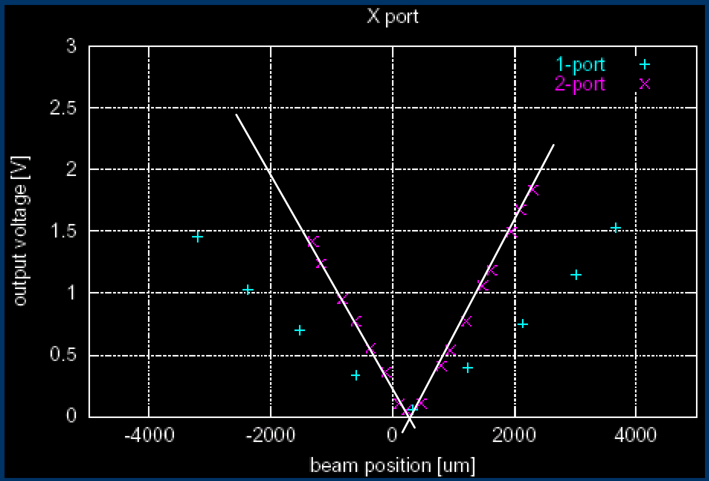


Sensitivity of BPM

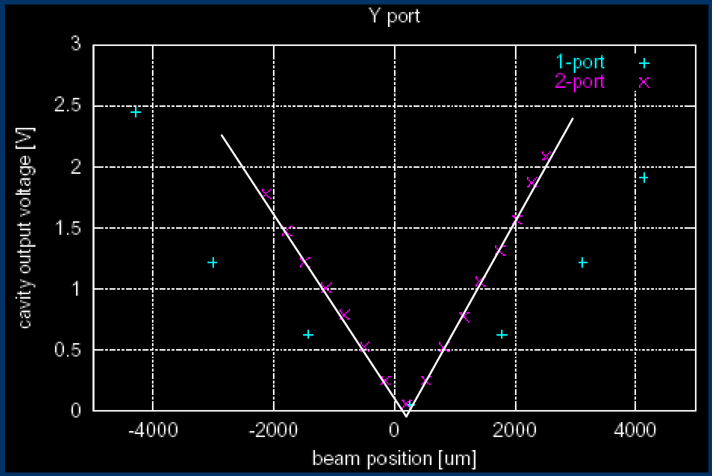
Detection electronics



X -port



Y -port



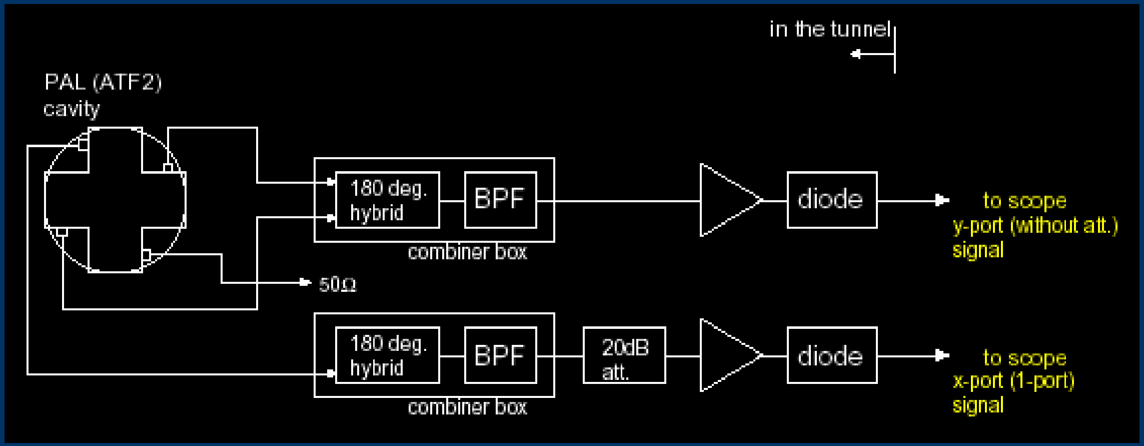
✓**Calculated sensitivity for 2-port is 0.8 V/mm @ 10^{10} e/bunch, 8mm bunch length**

✓**The experimental result seems consistent with prediction.**

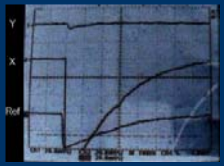
J. Y. Huang, PAL

X-Y Isolation

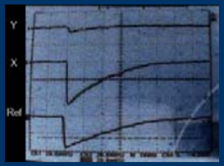
- cross talk measurement -



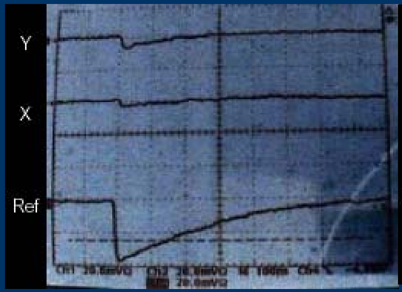
Setup for x-y isolation measurement



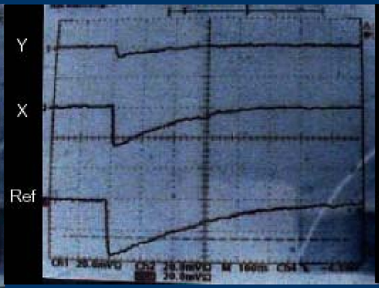
X = -5 mm



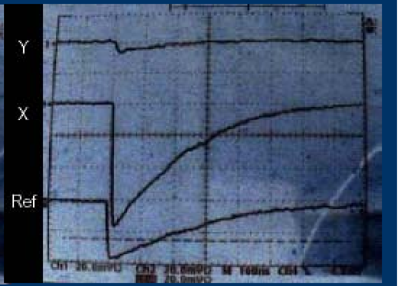
X = -2.5 mm



X = 0



X = 2.5 mm



X = 5 mm

✓**X-y isolation < 20 log(50 um / 5 mm) = -40 dB**

Prototype Summary

- Cavity-type BPM were developed in collaboration with KEK for future accelerator
- Tuning Mechanism Improved
- The resonant frequency is 6.422 GHz, 4 MHz lower than goal(6.426 GHz) → 34 um reduced for production
- Resolution is 100 nm, Measurable range is +/- 250 um
- X-Y isolation is better than -40 dB in the real beam test at KEK- ATF
- Production of 11 cavity BPMs done with a long beam tube and smaller cavity (53.788 mm: -34 um from old one)

Fabrication of 11 BPMs

- Assembly, Cold Test, Brazing -

Fabrication of 11 BPMs

- Assembly Drawing-

- Cavity diameter is 53.788 mm(← 53.822)
- A long beam tube for assemble on the Q-magnet

Prototype

Production BPM

Fabrication of 11 BPMs

- RF data -

BPM No.	Frequency (MHz)				X-Y Isolation(dB)				Beta : β @ vac	loaded Q @ vac
	Before brazing	After brazing & Vacuum			Before brazing	After brazing & Vacuum				
		Before tuning	After tuning	Δf(by tune)		Before tuning	After tuning	Δisolation		
	f				S21(13) / S21(12)				(1-S11) / S11	$Q_L = f / \Delta f$
Tol.			6426±1				< -40		> 0.3	> 5000
1	6422.234	6424.506	6425.844	-1.338	-33.2	-18.5	-33.2	14.7	0.36	6288
2		6424.797	6425.453	-0.656		-26.0	-43.7	17.7	0.34	5745
3		6424.128	6425.297	-1.169		-17.6	-54.2	36.6	0.38	6250
4	6422.107	6424.625	6425.669	-1.044	-16.0	-12.7	-45.5	32.8	0.37	6250
5		6423.650	6425.200	-1.550		-26.9	-48.3	21.4	0.38	5943
6	6421.125	6424.200	6425.434	-1.234	-46.1	-30.7	-44.5	13.8	0.38	6327
7		6423.897	6425.606	-1.709		-35.9	-55.5	19.6	0.40	6175
8	6420.897	6423.969	6425.581	-1.612	-12.1	-21.4	-46.5	25.1	0.37	6048
9	6421.538	6423.831	6425.231	-1.400	-23.5	-30.1	-42.9	12.8	0.31	5313
10	6421.367	6423.934	6425.416	-1.482	-16.9	-27.4	-37.1	9.7	0.36	6047
11	6421.591	6424.744	6425.619	-0.875	-11.3	-18.7	-53.6	34.9	0.35	5842
12	6421.778	6424.050	6425.513	-1.463	-30.3	-36.1	-48.1	12.0	0.39	6307
13	6421.584	6424.009	6425.334	-1.325	-23.7	-22.5	-53.1	30.6	0.32	5792
Average	6421.580	6424.180	6425.476	-1.297	-23.7	-25.0	-46.6	21.7	0.36	6025