ARES Upgrade for Super KEKB

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- Brief Review
- Fundamental Mode Issues
- HOM Load Issues
- Input Coupler R&D
- Summary

Accelerator Resonantly coupled with Energy Storage

ARES

3-cavity system stabilized with the π/2-mode operation

Fundamentals of the ARES cavity system

Operation of conventional copper cavities under the heavy beam loading (2.6A for KEKB LER) would bring on

The longitudinal CBI (Coupled-Bunch Instability, μ = -1, -2, • • •) driven by the accelerating mode, which is to be detuned downward from the f_{RF} by Δf_a where |dfa| would amount to ~2×f_{rev} .

cf. f_{rev} = 99kHz for KEKB

$$\Delta f_a = -\frac{I\sin\phi_s}{2V_c} \times \frac{R}{Q} \times f_{RF} = -\frac{P_b\tan\phi_s}{4\pi U} \quad \longrightarrow \quad |\Delta f_a| \propto \frac{P_{\text{beam}}}{U_{\text{acc. mode}}}$$

Fundamentals of the ARES cavity system cont'd

S-cav functions as a kind of EM flywheel.

A flywheel is a device for storing energy or momentum in a rotating mass, used to minimize variations in angular velocity and revolutions per minute, as in a machine subject to fluctuation in drive and load.

ARES scheme
3-cavity system stabilized with the π/2-mode operation

Engage C-cav in order to solve the following problems arising from coupling A-cav with S-cav:

- **How to stabilize the EM field distribution between A-cav and S-cav**
- **How to suppress CBI driven by the parasite(s) on the accelerating mode**

Fundamentals of the ARES cavity system cont'd

$Q_{C\text{-cav}} \approx 50$

$$\frac{U_s}{U_a} = \frac{k_a^2}{k_s^2}$$ for π/2 mode

Fundamentals of the ARES cavity system cont'd

- The stored-energy ratio of the π/2 mode: $\frac{U_s}{U_a} = \frac{k_a^2}{k_s^2}$

- The EM field distribution of the π/2 mode is stable against detuning of A-cav (= Δf_a) loaded with the beam.

- The amount of detuning of A-cav can be reduced as: $\Delta f_{\pi/2} = \frac{\Delta f_a}{1 + U_s/U_a}$

- The parasitic 0 and π modes can be selectively damped ($Q_L \approx 100$) with an antenna-type coupler attached to C-cav.

- Furthermore, the damped 0 and π modes are located almost symmetrically with respect to the π/2 mode. Therefore, their impedance contributions to CBI can be counterbalanced.

- C-cav functions as a filter to isolate S-cav from A-cav's HOMs.

ARES Operation Status in KEKB

RF Parameters of the π/2 mode:

U_s / U_a = 9
R / Q = 15 Ω
Q_0 = 1.1 x 10^5
P_c = 150 kW / cav
V_c = 0.5 MV /cav

LER (e^+): 20 ARES cavities

- ✓ Total Vc = 8~8.5 MV (0.4~0.425 MV/cav)
- ✓ Beam current (max.): ~1.8A
- ✓ Input RF power/cav: ~300kW
- ✓ HOM power/cav: ~5kW

HER (e^-): 12 ARESs and 8 SCCs

- ✓Total Vc = 15 MV = 3.84MV(ARES) + 11.16 (SCC)
- ✓Beam current (max.): ~1.1A

ARES cavities in the LER RF section Fuji D7

ARES Upgrade for Super-KEKB

KEKB

HER: 1.1 A by 12 ARESs + 8 SCCs
LER: 2.6 A by 20 ARESs

Super KEKB

HER: 4.1 A by 16 ARESs + 12 SCCs
LER: 9.4 A by 28 ARESs

We will be probably able to manage with the current version.

We are planning to remodel the A-cav part and to upgrade the HOM loads, whereas the S-cav will be reused. Furthermore, we will need to build about 10 sets of ARES cavities to increase the LER current up to 9.4 A.

Coupling Slot
between A-cav and C-cav

WG HOM Load

k_a

$$\frac{U_s}{U_a}=\frac{k_a^2}{k_s^2}$$

GBP HOM Load

ARES Upgrade for Super-KEKB

Fundamental mode issues

KEKB
Quest for CPV

2.6 A by 20 ARESs for LER
Δf_a = -200 kHz

↓

Super KEKB
Quest for BSM

9.4 A by 28 ARESs for LER
Δf_a = -710 kHz

- CBI driven by the π/2 accelerating mode:
  $\Delta f_{\pi/2}$ = -71 kHz if $U_s / U_a = 9$ unchanged. (cf. f_{rev}= 99 kHz)
  We need to increase the stored-energy ratio U_s / U_a
  by enlarging the coupling slot between A-cav and C-cav.

$$\frac{U_s}{U_a} = \frac{k_a^2}{k_s^2}$$

- CBI due to the parasitic 0 and π modes:
  The impedance imbalance will not be negligible.
  We have investigated the effect of the impedance imbalance when detuning A-cav by -710 kHz.

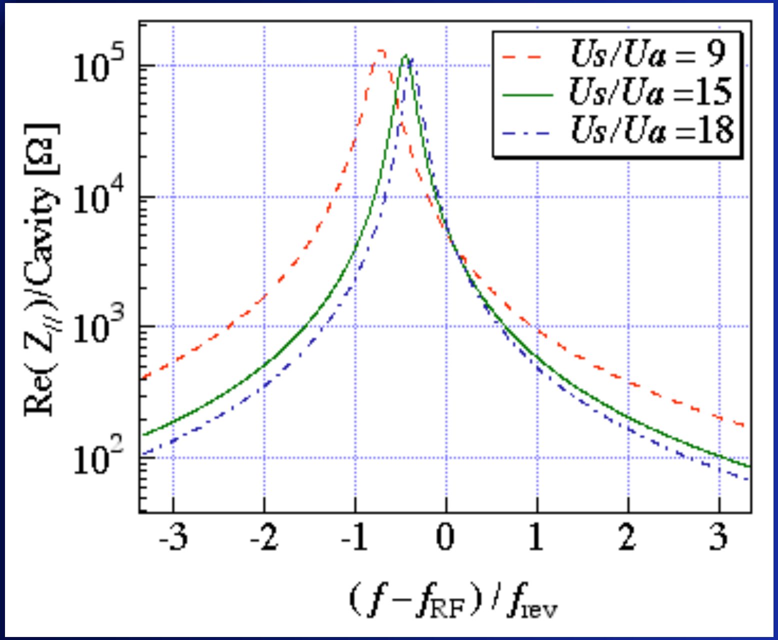
CBI due to the π/2 mode

Table 1: RF parameters of ARES cavity for Super KEKB LER.

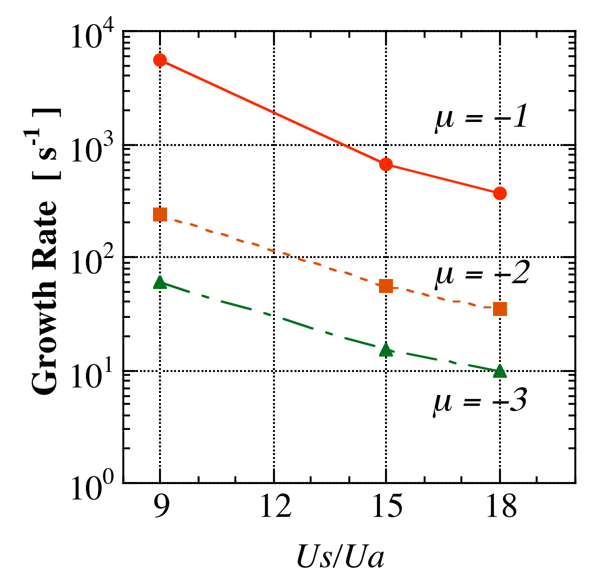
U_s/U_a Coupling Slot	9 120 × 160	15 120 × 175	18 120 × 182	 W×H mm^2
I		9.4 (2.6)		A
# of Cavities		28 (20)		
f_{RF}		508.887		MHz
h		5120		
V_c		0.5		MV
Q_0	1.11	1.27	1.32	×10^5
$(R/Q)_{\pi/2}$	15	9.4	7.9	Ω
input β	5.4 (2.7)	4.1	3.8	
P_c	150	210	240	kW
$\Delta f_{\pi/2}$	−72 (−20)	−45	−38	kHz

Numbers in ( ) for KEKB LER

CBI due to the π/2 mode (cont'd)



Coupling Impedance of the π/2 mode loaded with 9.4 A for U_s / U_a = 9, 15, 18.



Growth rates of the CBIs (μ = -1, -2, -3) due to the π/2 mode, plotted as a function of U_s / U_a .

By increasing U_s / U_a from 9 to 15, the growth rate of the severest CBI (μ = -1) can be reduced by one order of magnitude and down to τ = 1.5 ms, manageable with an RF feedback system .

S. Yoshimoto et al., "The -1 mode damping system for KEKB"

CBI due to the 0 and π modes

The damped 0 and π modes ($U_a:U_c$ = 1:1 when Δf_a = 0 kHz) are located almost symmetrically with respect to the π/2 mode ($\approx f_{RF}$).

For KEKB (Δf_a = -200 kHz), Re[$Z_{//}$] has a small asymmetry with respect to f_{RF}.

$|R^+ - R^-|_{max}$ ~500 Ω/ARES → τ ~46 ms

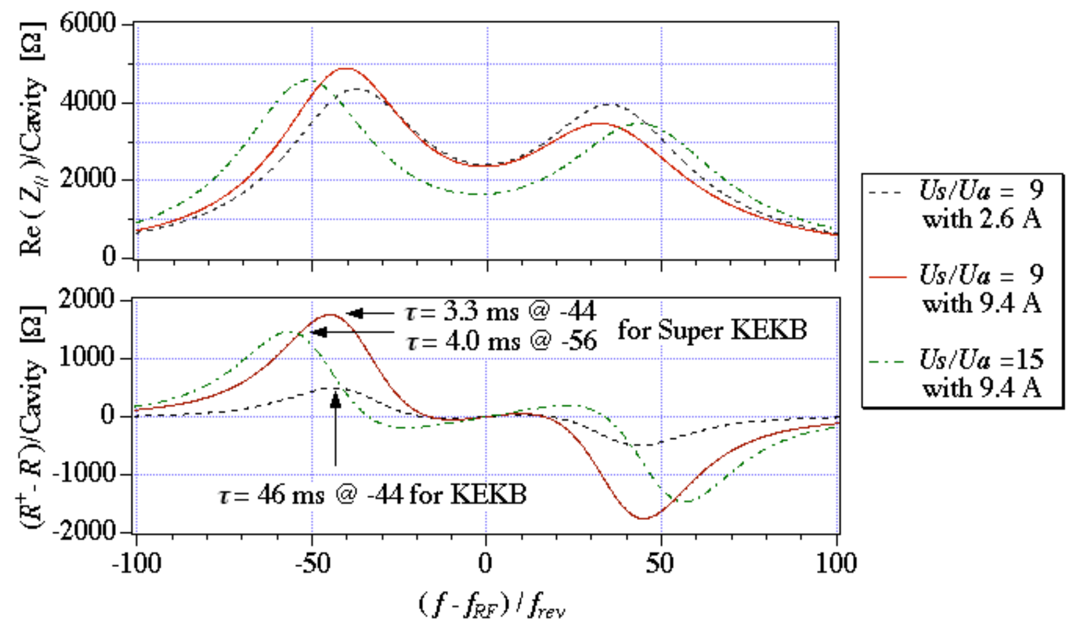
cf. τ_{rad} ~23 ms (KEKB)

The EM field distributions ($U_a:U_c$) of the 0 and π modes are subject to the perturbation of first order $\Delta f_a / (f_\pi - f_0)$.

Δf_a = -200 kHz (KEKB) → -710 kHz (Super-KEKB)

The delicate counterbalancing may be deteriorated in Super-KEKB.

CBI due to the 0 and π modes (cont'd)



Top:
Re[$Z_{//}$] of the 0 and π modes

Bottom:
Re[$Z_{//}$] imbalance R^+ - R^- with respect to f_{RF}.

Detuning A-cav downward,
$U_a > U_c$ for 0 mode,
$U_a < U_c$ for π mode.

The fastest growth rate of CBI due to the impedance imbalance of 0 and π modes when Δf_a = -710 kHz :

τ = 3.3 ms for $U_s / U_a = 9$ (9.4 A) cf. τ = 46 ms for $U_s / U_a = 9$ (2.6 A KEKB)

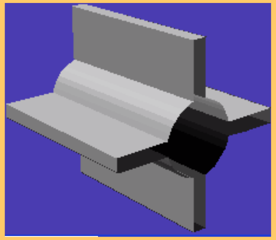
τ = 4.0 ms for $U_s / U_a = 15$ (9.4 A) to be damped by longitudinal FB kickers

first order term $\Delta f_a / (f_\pi - f_0)$, where $f_\pi - f_0 \propto k_a \propto (U_s / U_a)^{1/2}$

ARES upgrade for Super-KEKB
HOM load issues

HOM-damped structure for ARES

- Based on the conceptual demonstrator ARES96
- Carefully designed to be smoothly embedded into the whole ARES scheme
- Consists of 4 HOM WGs and 2 GBPs (Grooved Beam Pipe devised at KEK)



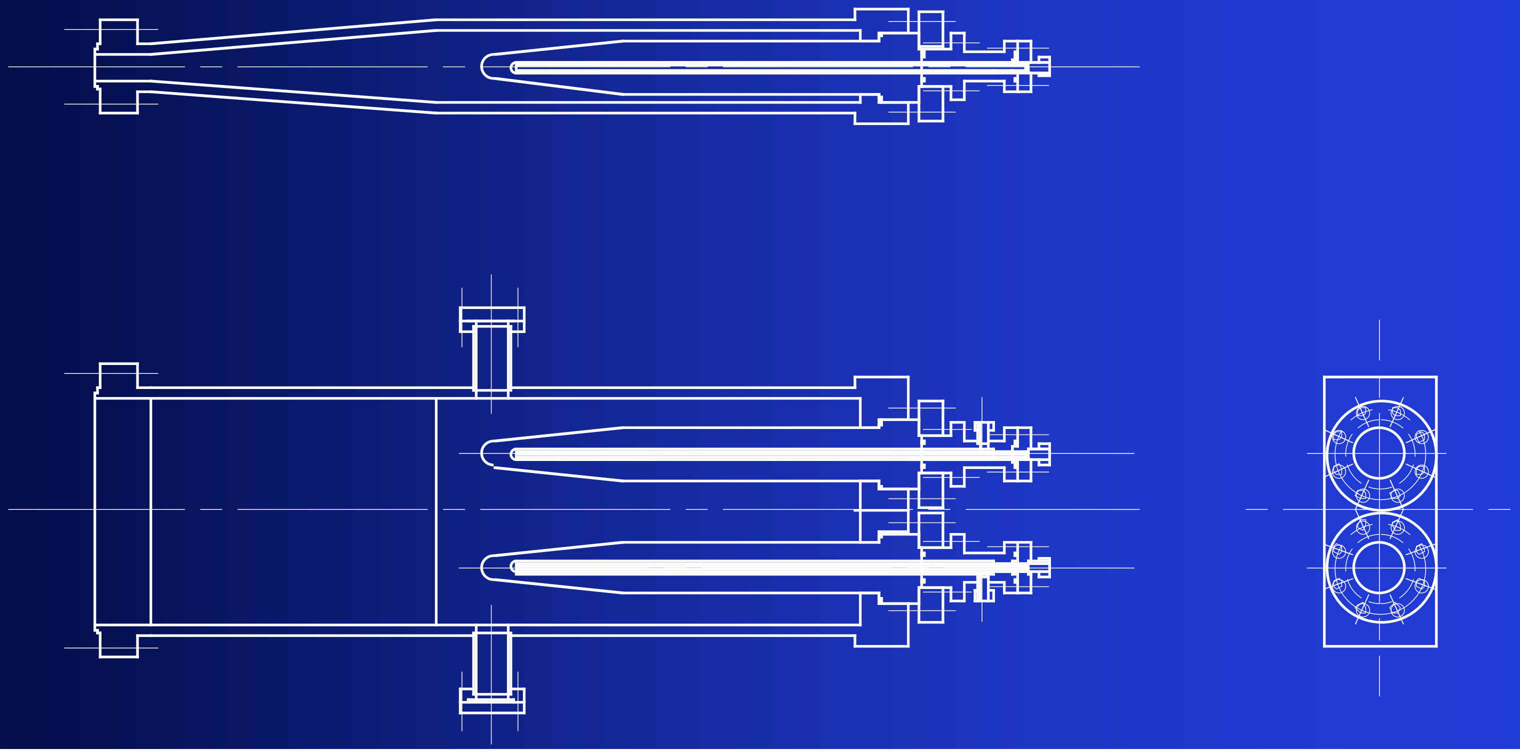
4 HOM WGs: Monopole & Dipole(V) HOMs

2 GBPs: Dipole(H) HOMs

WG HOM load (KEKB)

WG HOM load:

- Two bullet-shape SiC absorbers at the end of the HOM WG.
- Each absorber directly water-cooled.
- Power capability tested up to 3.3 kW / bullet (26 kW / cavity) with use of an L-band klystron.

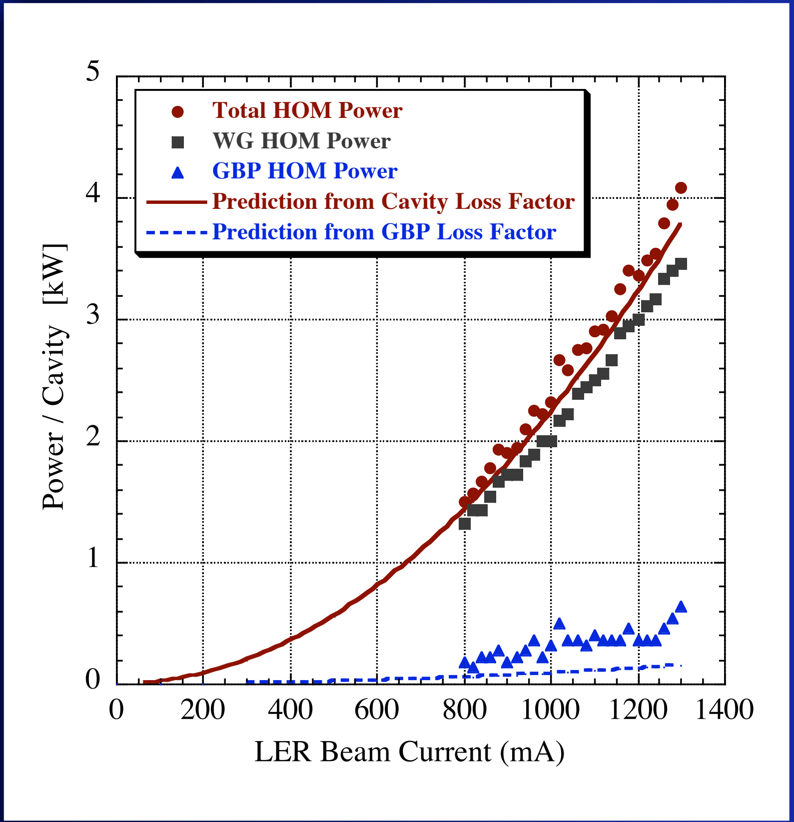


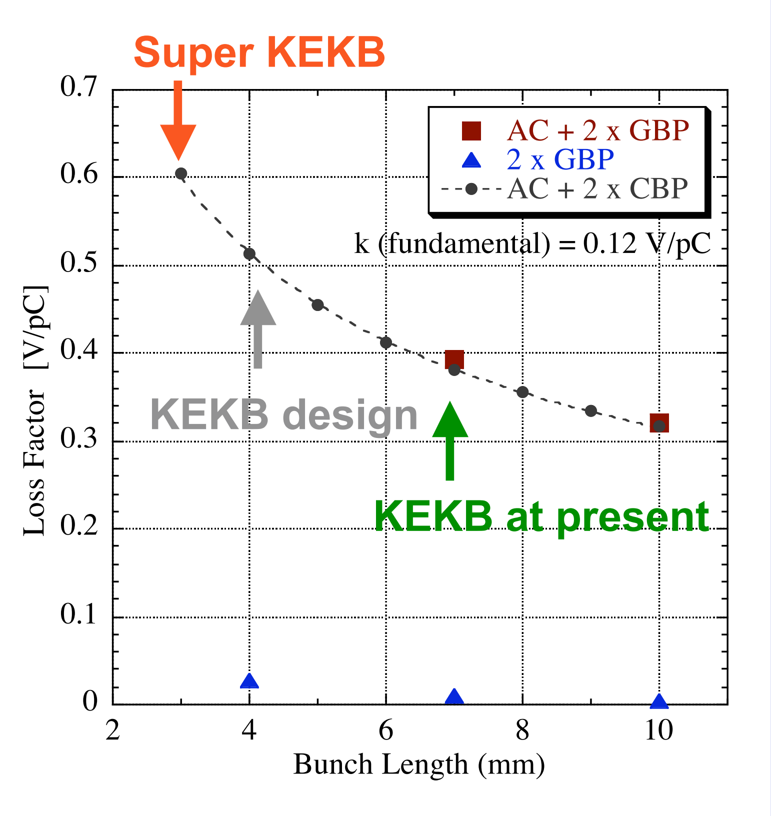
GBP HOM load (KEKB)

GBP HOM load:

- 8 SiC tiles per groove, brazed to a water-cooled OFC plate.
- Power capability tested up to 0.5 kW / groove (2 kW / cavity) with use of the same L-band klystron.

HOM load status in KEKB

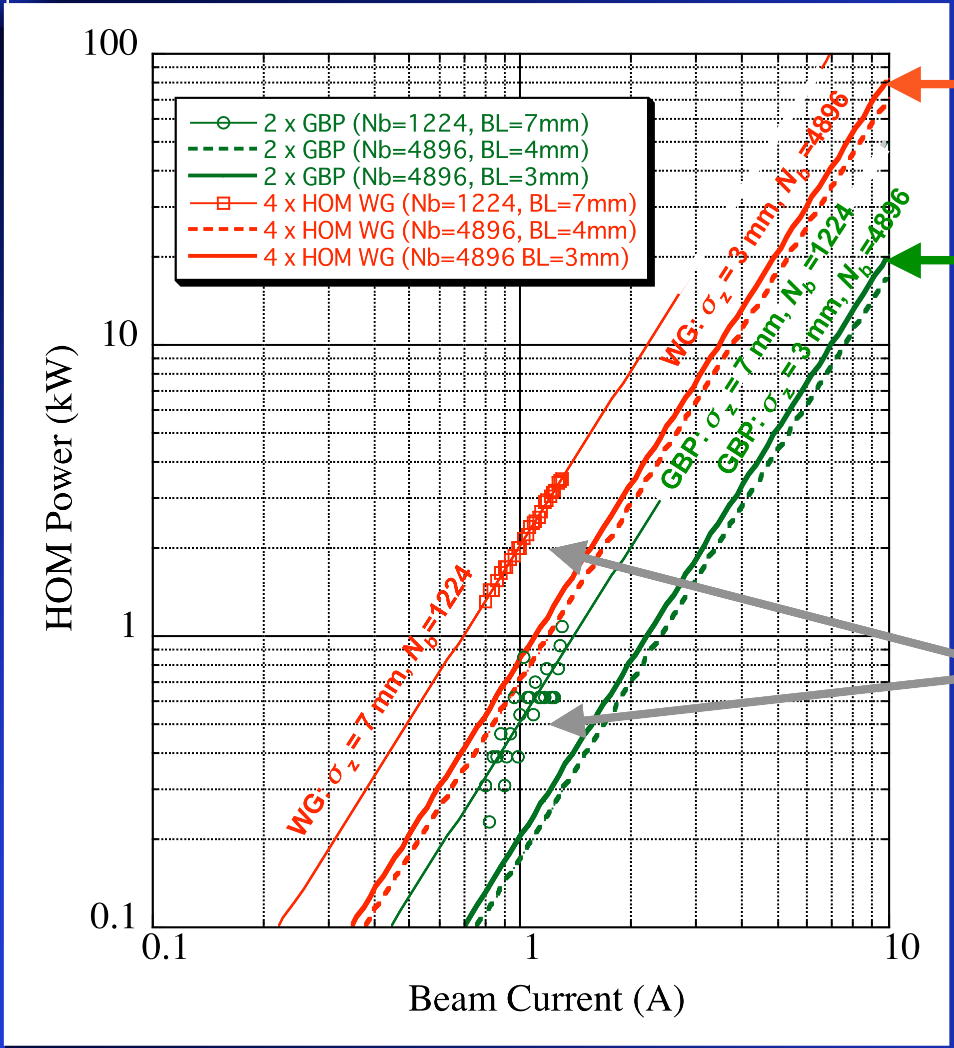




WG and GBP HOM powers per cavity measured in the KEKB LER, compared with theoretical predictions (σ_z = 7 mm).

Loss factors computed for the whole damped structure (3D) and the GBPs (3D), together with those for a simplified axially symmetric structure (2D) with circular beam pipes (CBPs).

Prospect of HOM power for Super-KEKB



WG HOM: ~80 kW / cavity

GBP HOM: ~20 kW / cavity

Super-KEKB LER
9.4 A, σ_z = 3mm, N_b = ~5000

Extrapolation

HOM data taken in KEKB LER when σ_z = 7mm and N_b = 1224.

cf. KEKB LER design:
2.6 A, σ_z = 4mm, N_b = ~5000

Upgrading WG HOM load for Super-KEKB

WG HOM load for Super-KEKB LER: ~80 kW / cavity

✓HPT'd up to 26 kW/cavity (3.3 kW/bullet) for KEKB:
This limit is only due to the maximum RF power supplied by the current L-band klystron.

➢Perform HPT over 3.3 kW/bullet:
We are planning to construct a new test stand for HOM loads with an L-band klystron capable of more than 10 kW (JFY 2004).

➢Increase # of absorbers per WG if necessary.

Upgrading GBP HOM load for Super-KEKB

GBP HOM load for Super-KEKB LER: ~20 kW / cavity

✓HPT'd up to 2 kW/cavity (0.5 kW/groove) for KEKB.

➢Need to upgrade the power capability by one order of magnitude.

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A new design with directly water-cooled SiC absorbers.

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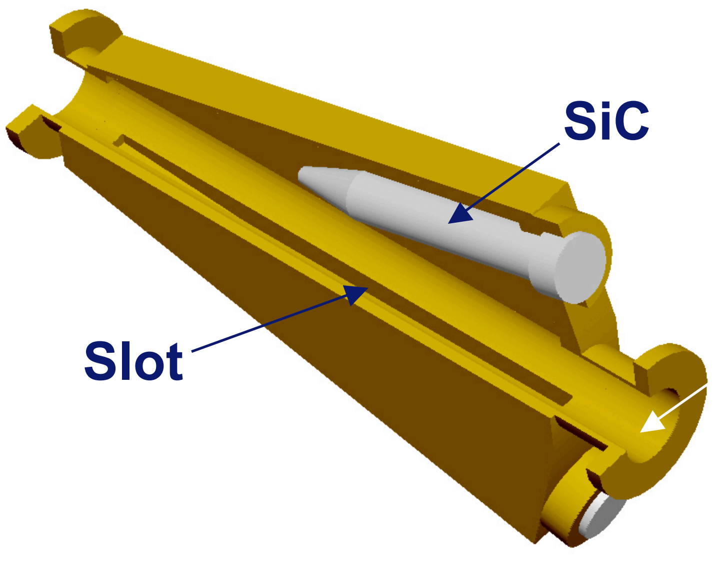
GBP may evolve into Winged Chamber



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

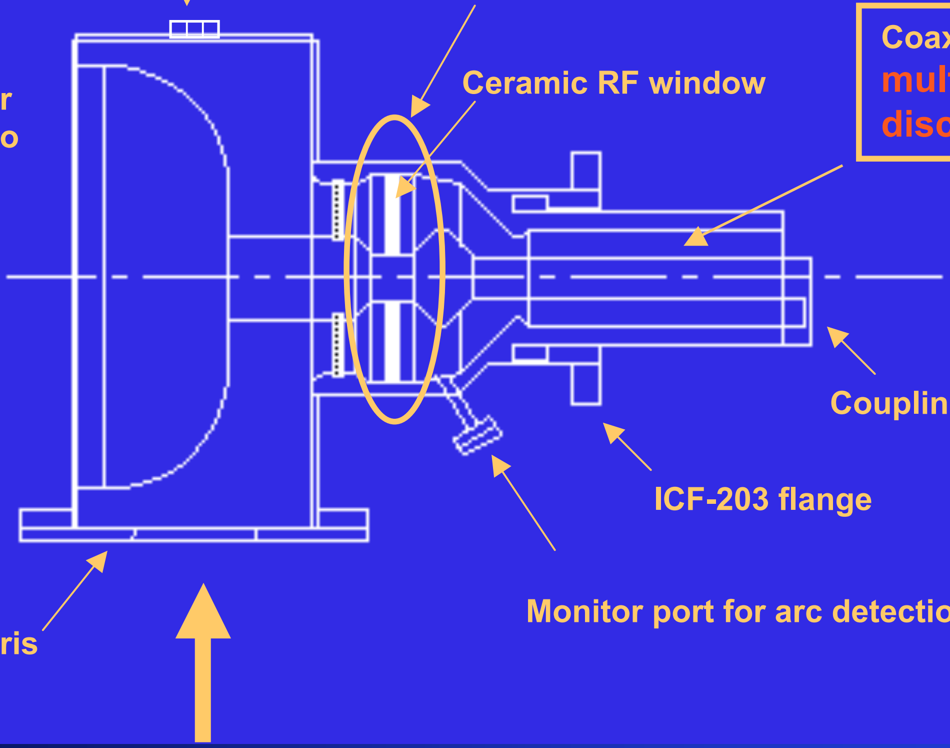
Beam Chamber

Winged chamber loaded with directly water-cooled SiC bullets:

- ✓Developed under collaboration between the KEKB vacuum and ARES cavity groups.
- ✓Used in the movable mask sections in KEKB since 2002.

➢**Perform HPT over 5 kW / bullet.**

Input Coupler Upgrade



Monitor port for arc detection

Over- and under-cut structure
for impedance matching

Coaxial line WX77D
multipactoring
discharge problem

Door-knob transformer from rectangular WG to coaxial line

Ceramic RF window

Coupling loop

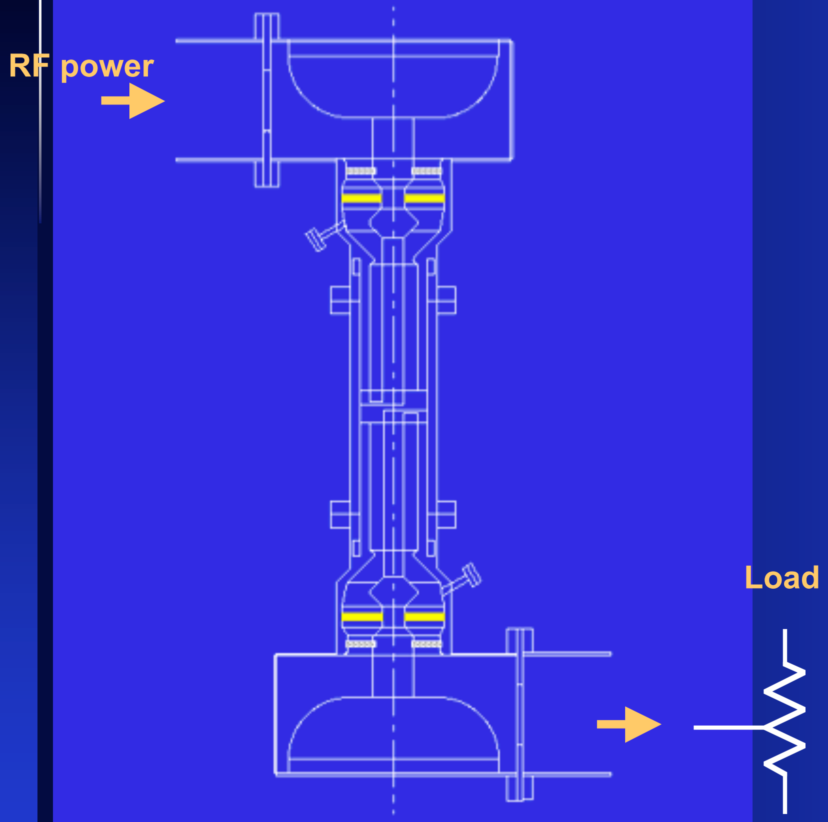
ICF-203 flange

Capacitive iris

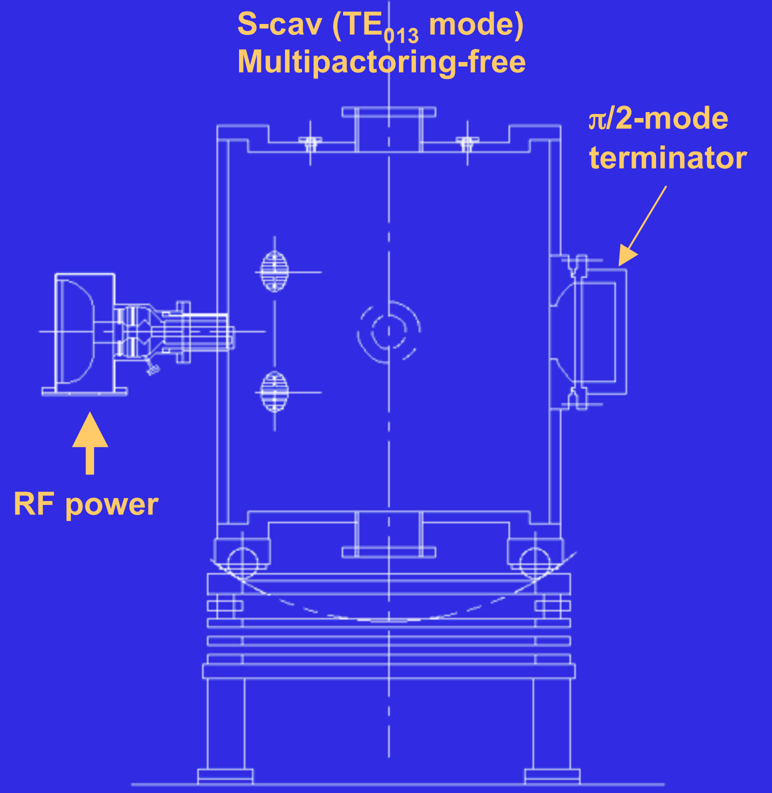
Monitor port for arc detection

RF power (= P_c + P_{beam})
~400kW for KEKB
~800kW for Super-KEKB

Input Coupler Upgrade (cont'd)

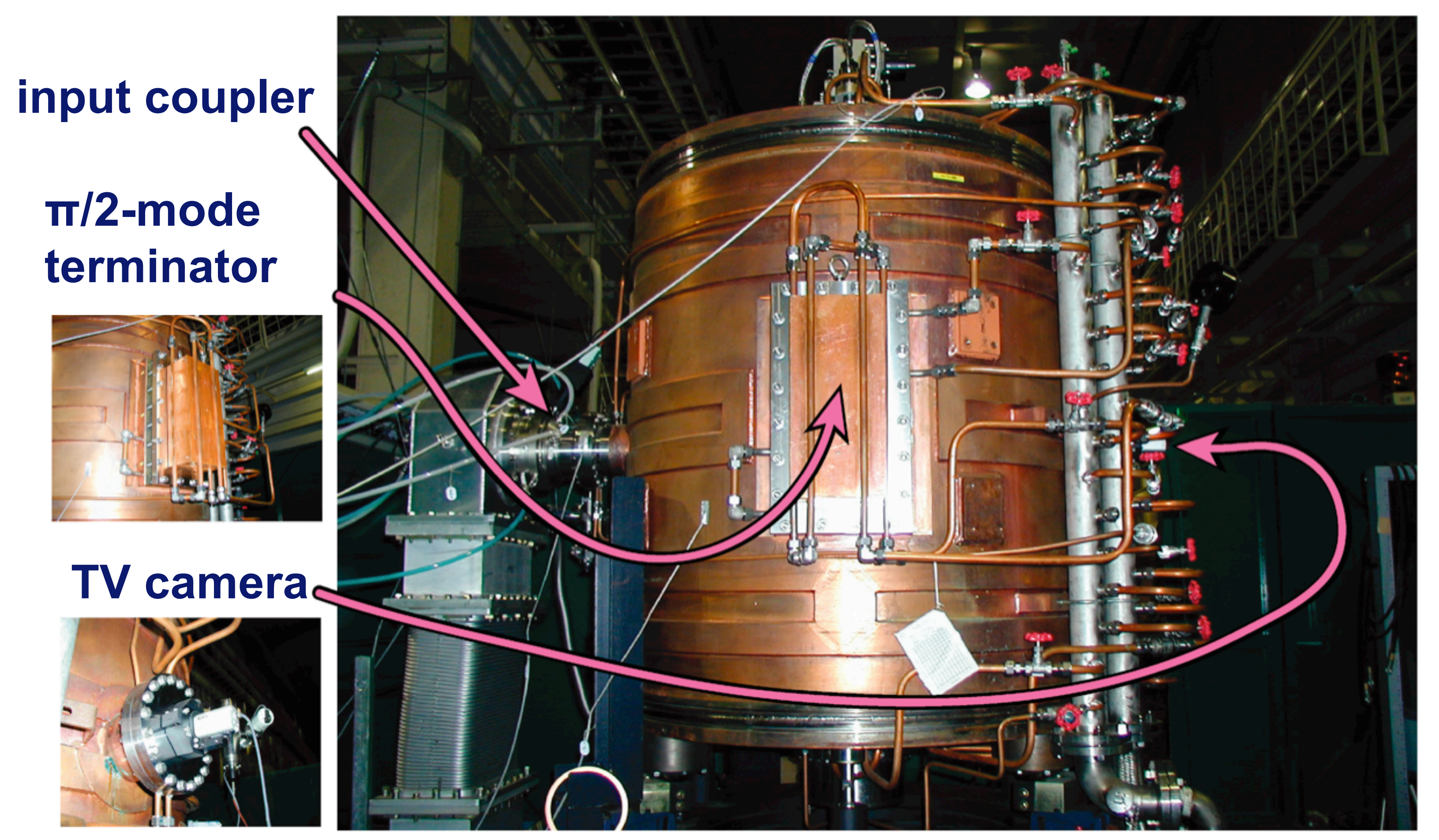


HPT setup (old)
RF power < 1 MW



HPT setup (new)
RF power < 500 kW

Input Coupler Upgrade (cont'd)



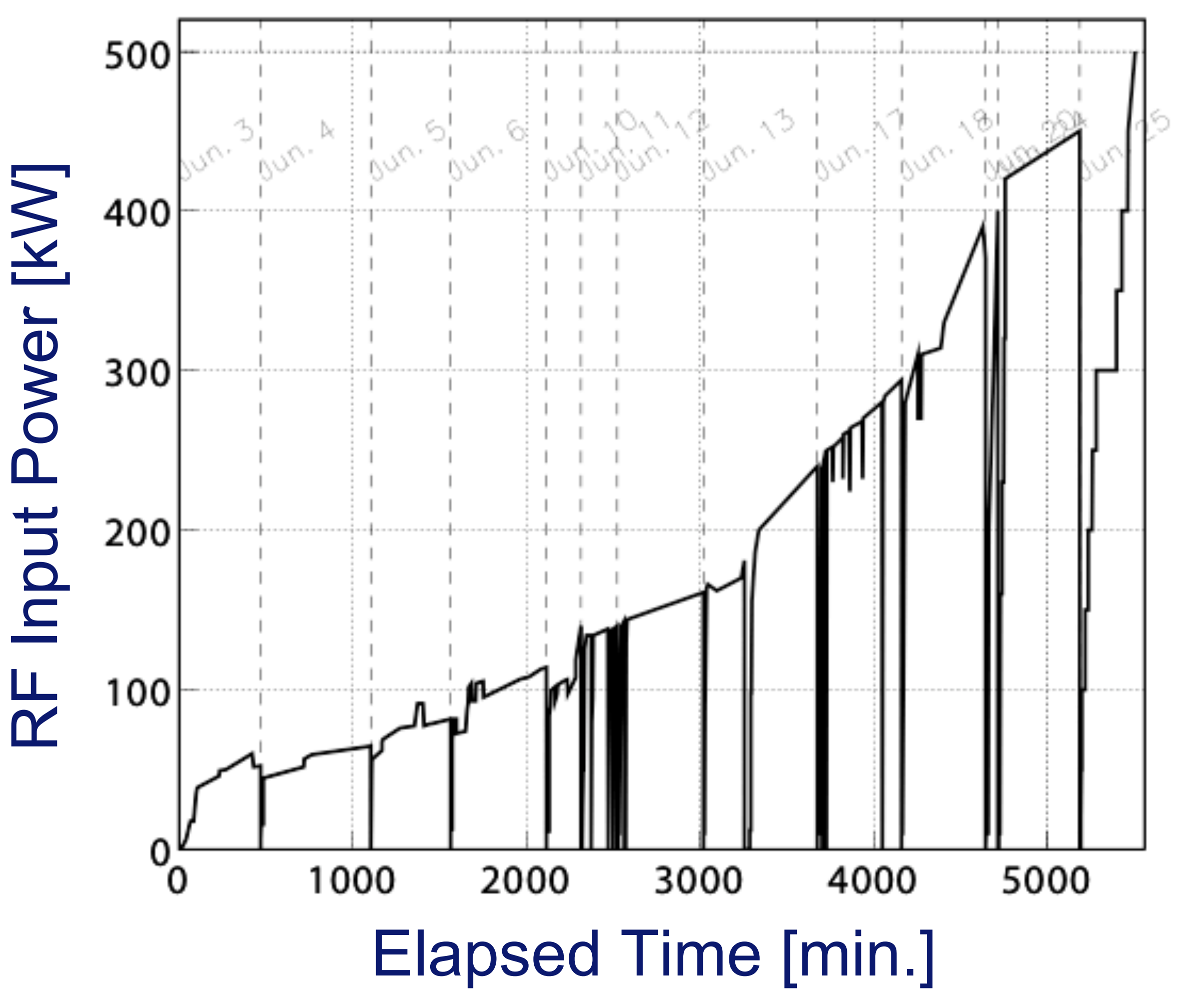
input coupler

π/2-mode terminator

TV camera

HPT setup

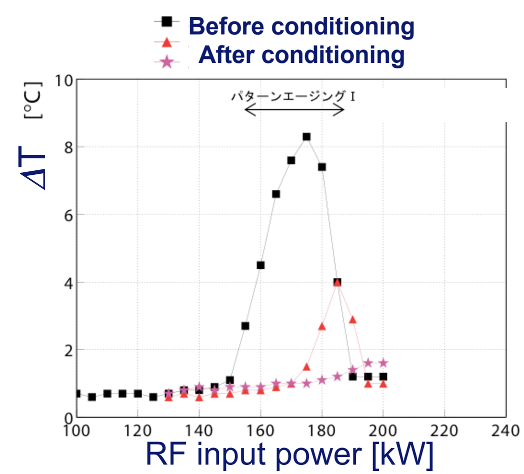
Input Coupler Upgrade (cont'd)

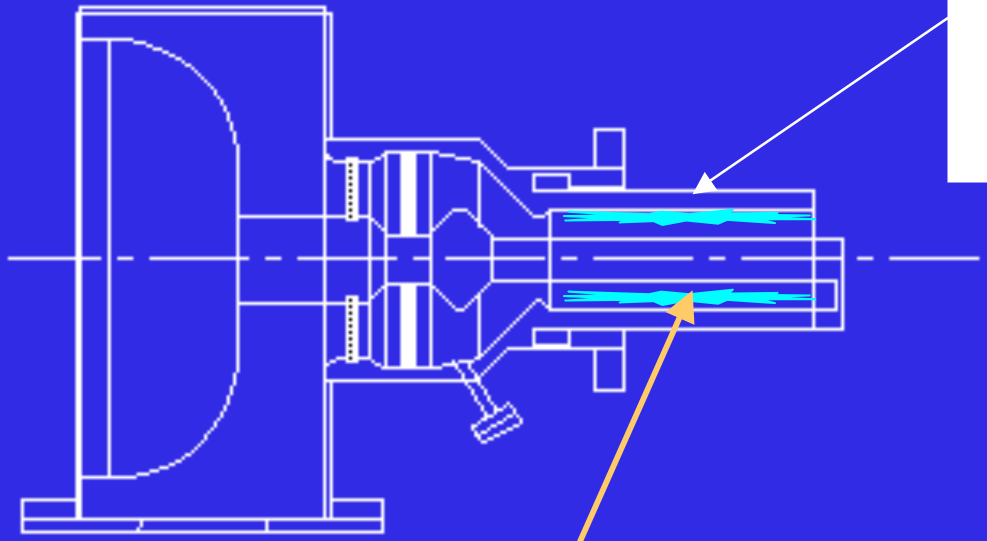


Limited by the S-cav wall power. ←

Input Coupler Upgrade (cont'd)

Temperature rise of the cooling water for the outer conductor

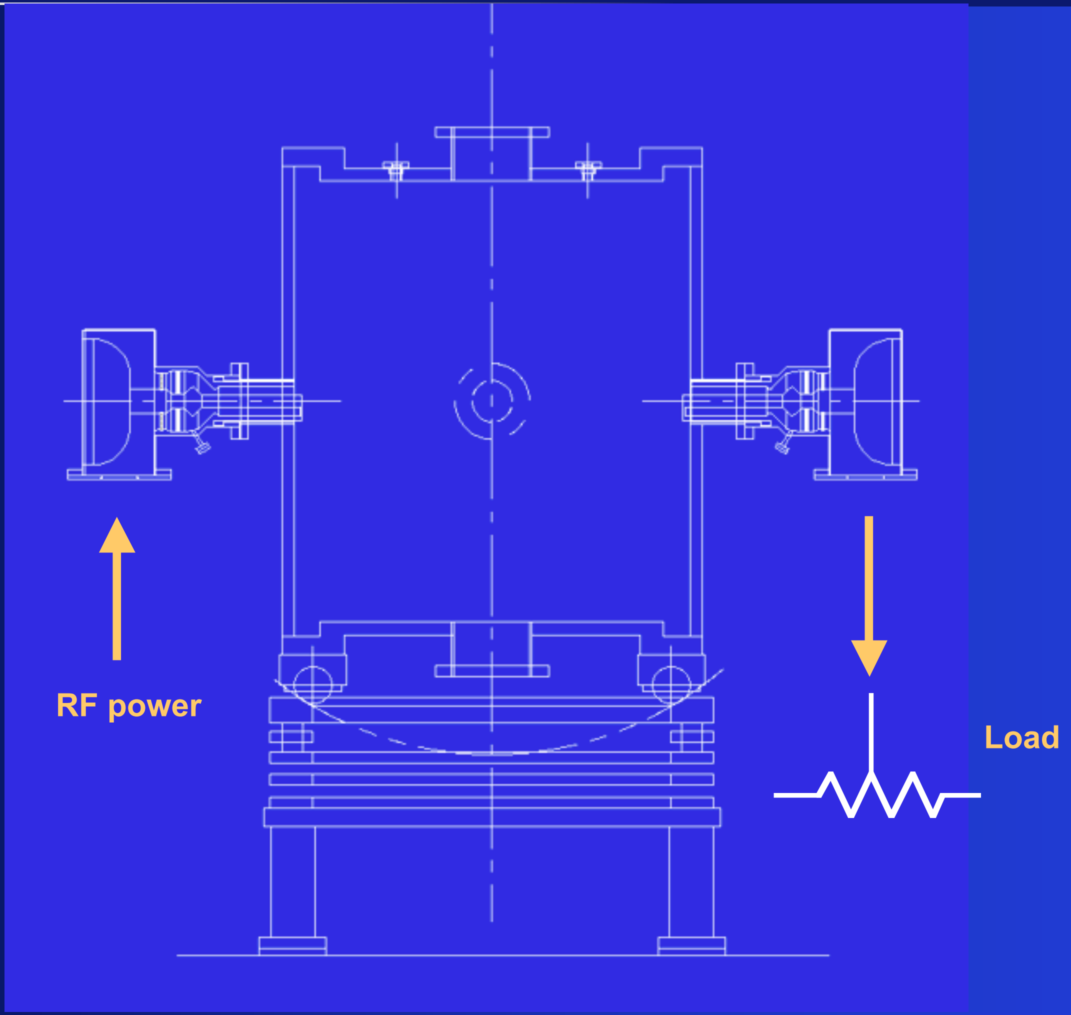




TV camera

Single-surface MP on the WX77D outer conductor when RF input power = 150~200kW.

Input Coupler Upgrade (cont'd)



HPT setup (future)
RF power up to ~1 MW

Summary

- By increasing U_s/U_a from 9 to 15, the severest CBI ($\mu = -1$) due to the $\pi/2$ accelerating mode can be eased by one order of magnitude and down to $\tau = 1.5$ ms (9.4 A for Super-KEKB LER), manageable with an RF feedback system.

- The fastest growth time of CBI due to the impedance imbalance between the parasitic 0 and π modes is estimated as $\tau = 4$ ms when A-cav is detuned by -710 kHz (9.4 A for Super-KEKB LER).

- We need to upgrade the power capabilities of the WG and GBP HOM loads up to ~80kW and ~20kW per cavity, respectively. The GBP with indirectly water-cooled SiC tiles may evolve into a winged chamber loaded with directly water-cooled SiC bullets.

- Aiming at improvements and upgrades for Super KEKB, HPT'ing of input couplers is being carried out with a new setup using an S-cav. Our immediate target is to suppress the single-surface MP discharge on the outer conductor of the coaxial line, which actually increases the trip rate of the HER RF station D4C.

Summary (cont'd)

R&D Status and Plans

A-cav part:

- Fabrication of ARES2K4, a high-power demonstrator (JFY2004).
- HPT and beam test of ARES2K4 (JFY2005).

S-cav:

- R&D on high-purity copper plating (ongoing).

HOM Loads:

- Resume the old test stand (Feb. 2003). That is for HPT'ing the current GBP load over 0.5 kW.
- A new test stand with an L-band klystron supplying RF power more than 10 kW (JFY2004).

Input Couplers:

- R&D on TiN coating to the outer conductor of the coaxial line section (ongoing).
- A new HPT setup with use of a S-cav loaded with a 1-MW water load (JFY2004).
- Prototype couplers for Super KEKB (JFY2004).