2nd ICFA Beam Dynamics
Mini-Workshop on
Deflecting/Crabbing Cavity
Applications in Accelerators

September 2, 2010

at Cockcroft Institute

The Short Pulse X-ray Generation Project at the SPring-8.

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SPring-8

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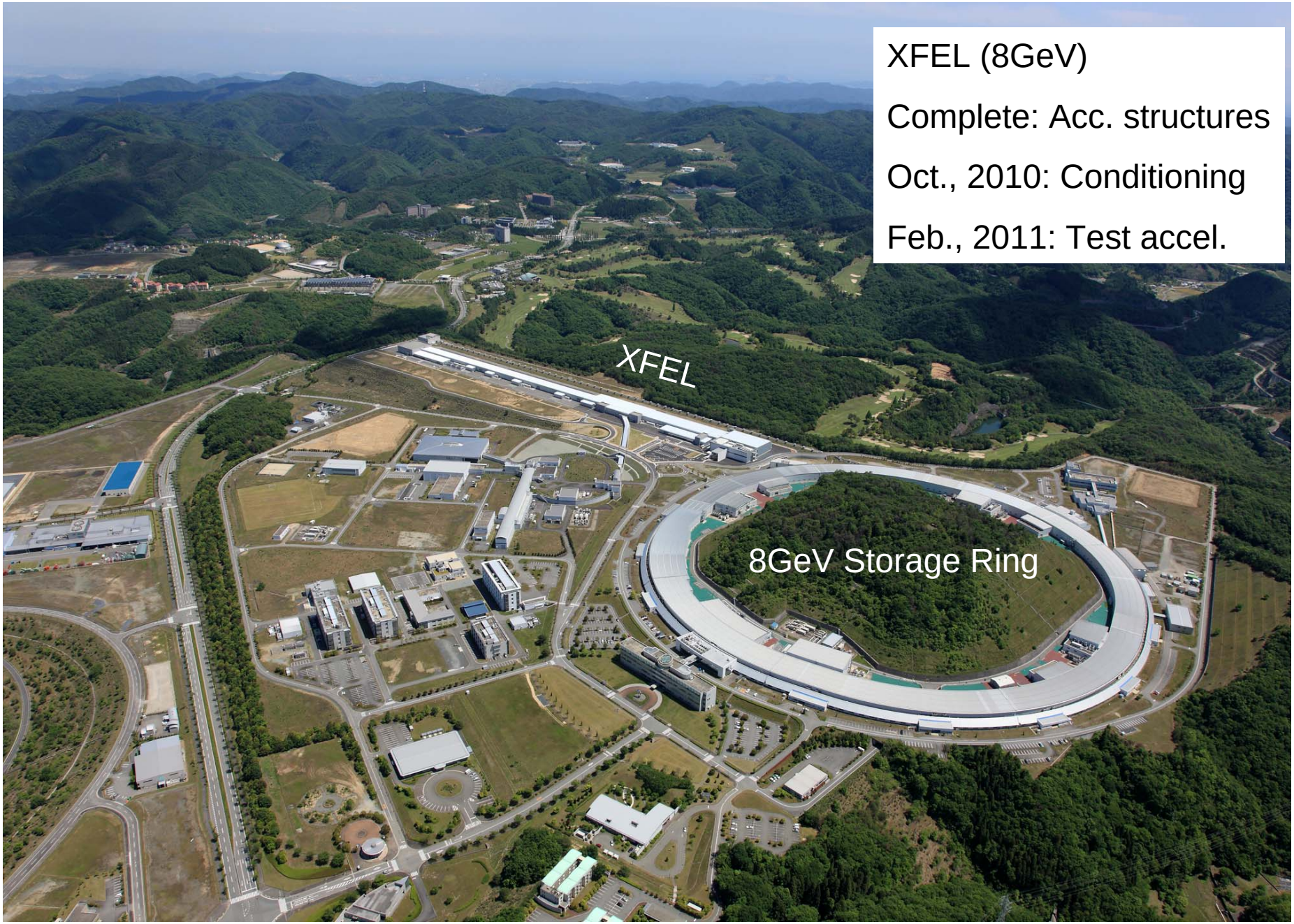
K. Nakanishi, K. Akai, K. Ebihara, T. Furuya, S. Mitsunobu, M. Ono
and Y. Yamamoto,
KEK

M. Matsuoka, M. Monde, K. Sennyu and T. Yanagisawa,
MHI

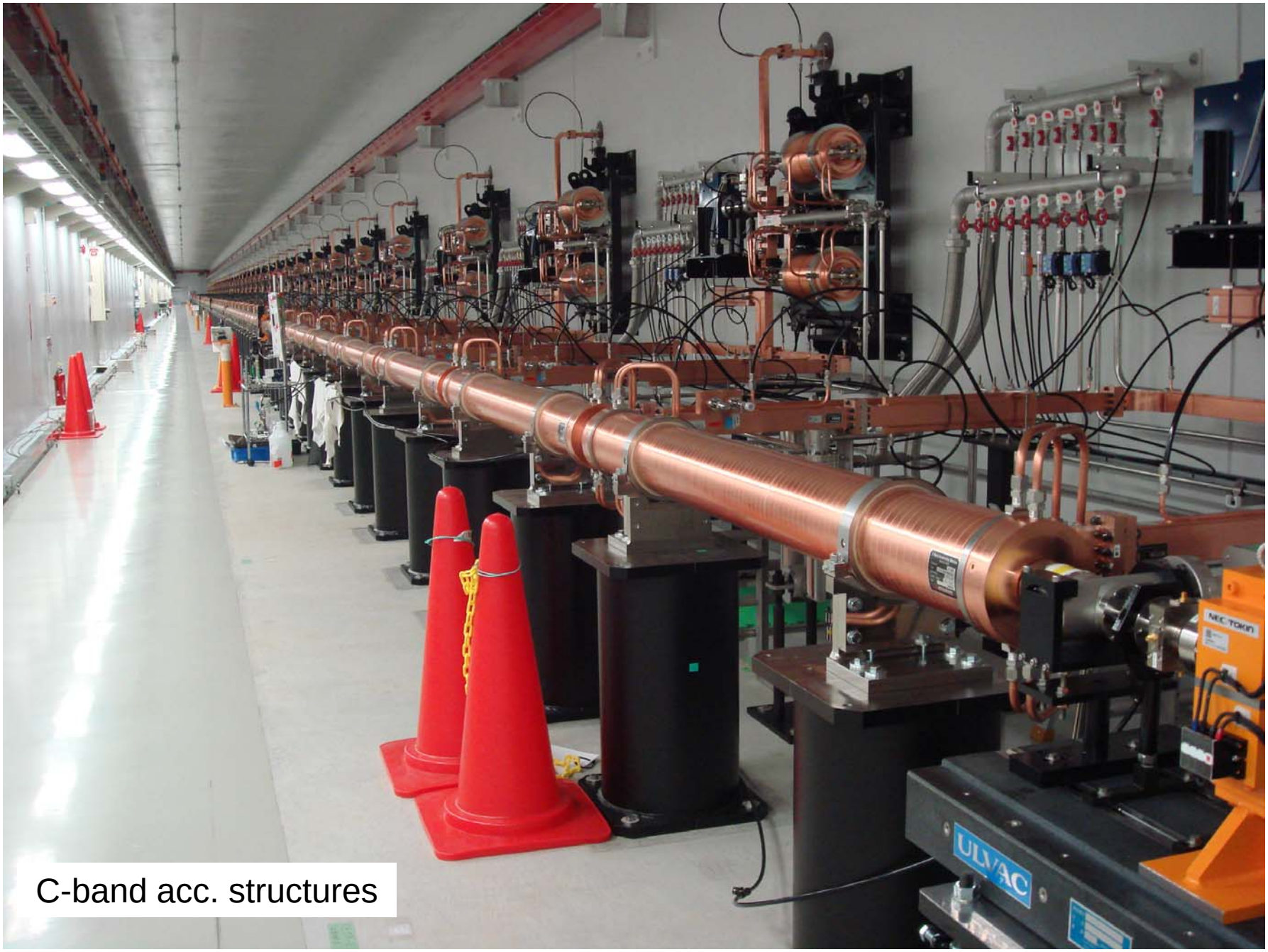


XFEL (8GeV)

Complete: Acc. structures

Oct., 2010: Conditioning

Feb., 2011: Test accel.



C-band acc. structures

Contents

- Outline of short X-ray generation at SP8.
- Conceptual design and problem (phase noise).
- X-ray pulse width and intensity.
- Phase noise source hunting at KEK.
- Simulation of phase noise suppression by PLL
- R&D of components
  - 300kW fast phase shifter.
  - Current supply for the phase shifter.
  - SP8-type tuner.

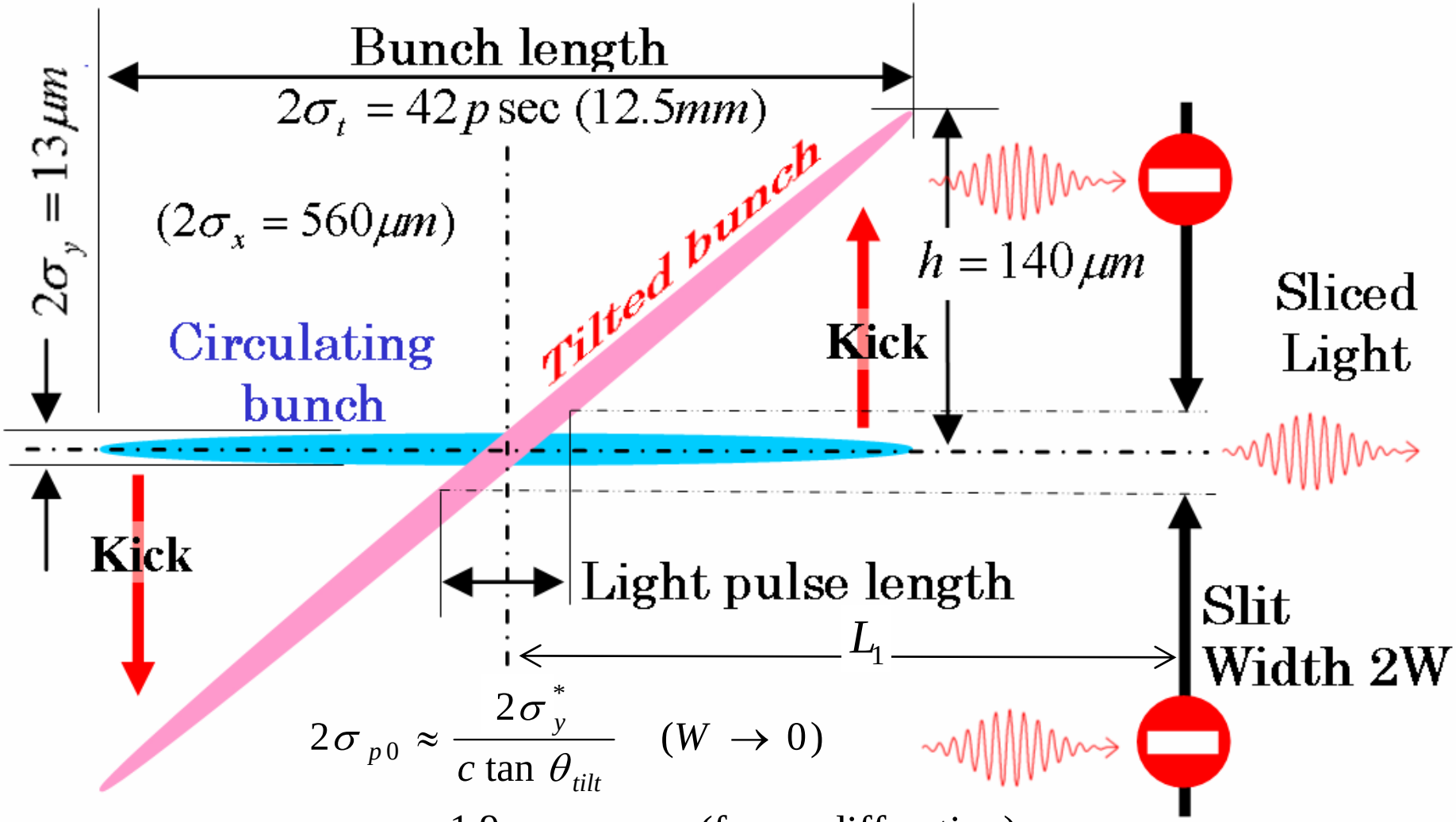
Design concept

- Upgrade of the Storage Ring with minor exchange.
- Experiments in the region from pico to sub-pico second. (see Yuelin Li' talk, on Wed.)
- A stable and reasonably intense short X-ray with high repetition rate. (complemental feature with XFEL)
- Install in one of four long straight sections.

  (inherent advantage of SP8)
- No disturbance to the other users.

  (coexistent w/o emittance degradation)
- Minimize R&D items. ←KEK crab cavity
- Settle down superconducting technology at SP8.

Generating a short light pulse from a bunch

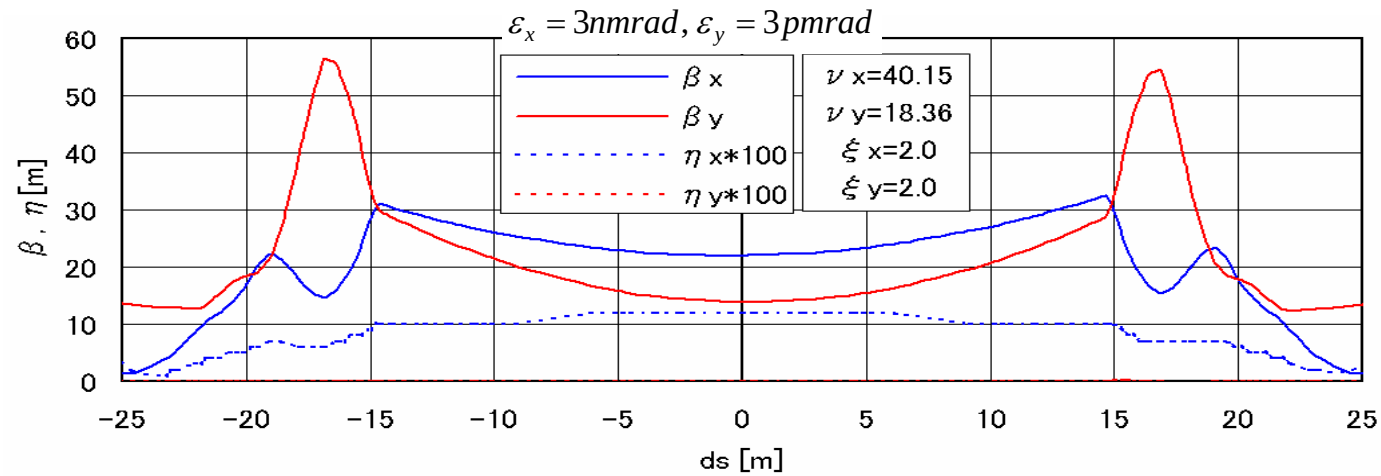


$$2\sigma_{p0} \approx \frac{2\sigma_y^*}{c\tan\theta_{tilt}} \quad (W \to 0)$$

$$= 1.9\text{psec} \qquad \text{(for no diffraction)}$$

$$\tan\theta_{tilt} = \frac{h}{c\sigma_t} = 0.022 \quad @V_\perp = 1.67MV, 8GeV$$

Concept design of a short pulse generator



$\lambda_u = 10mm$

$Gap = 5mm$

$N_u = 101$

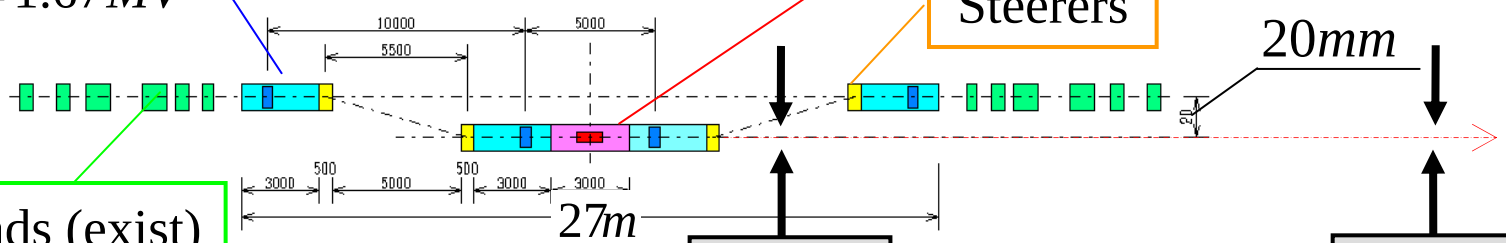
Superconducting Crab Cavities (4 Sets)

Mini-pole Undulator

$V_\perp = 1.67MV$

Steerers

20mm

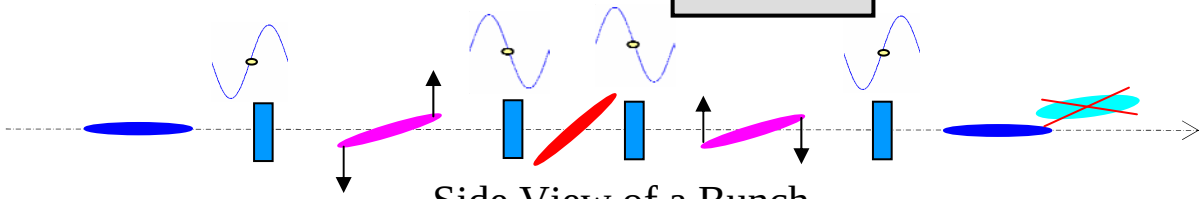


27m

Quads (exist)

Slit #1

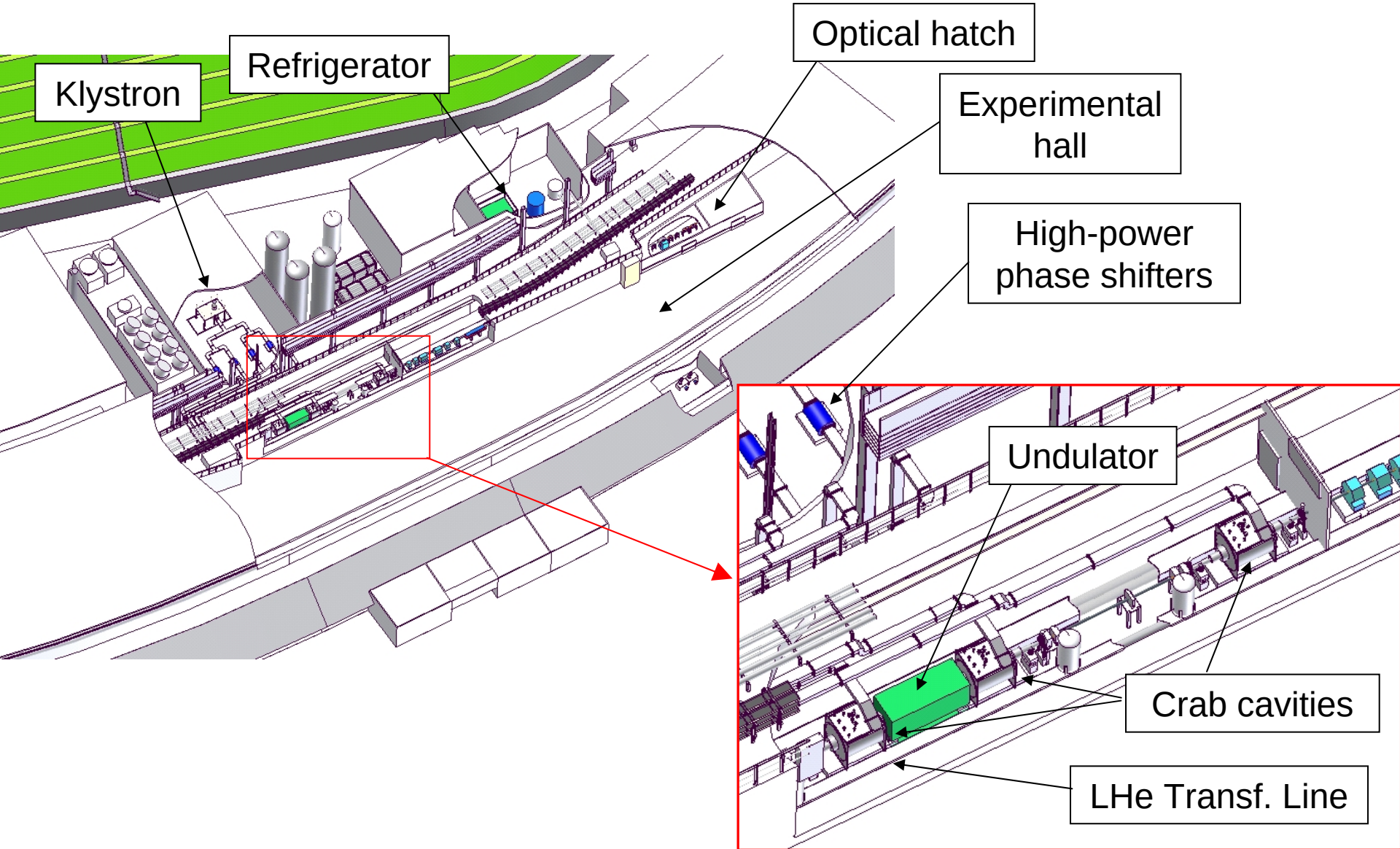
Slit #2



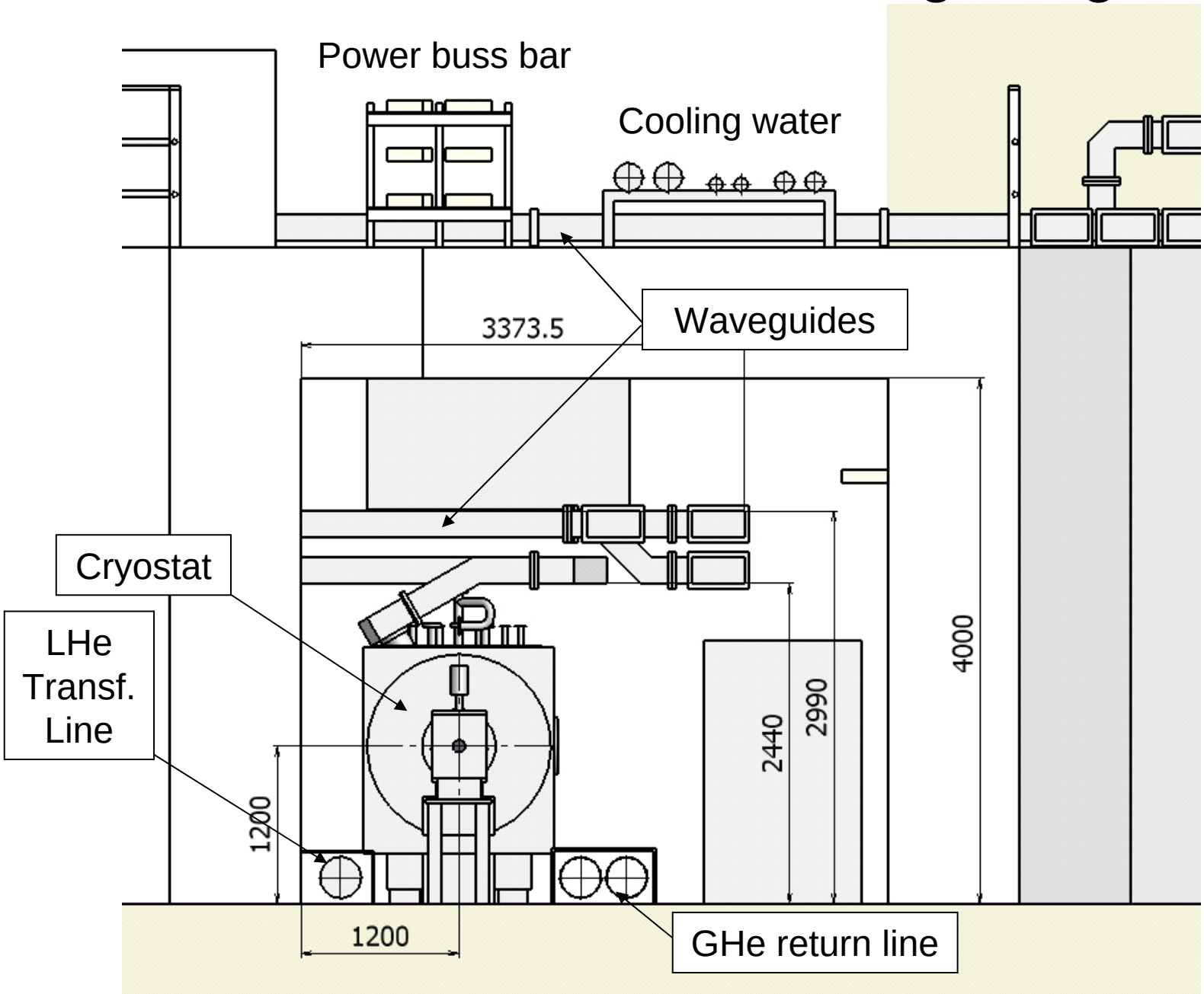
Side View of a Bunch

Required
RF phase stability
14 mdeg (0.24mrad) !

Layout of short X-ray generation system

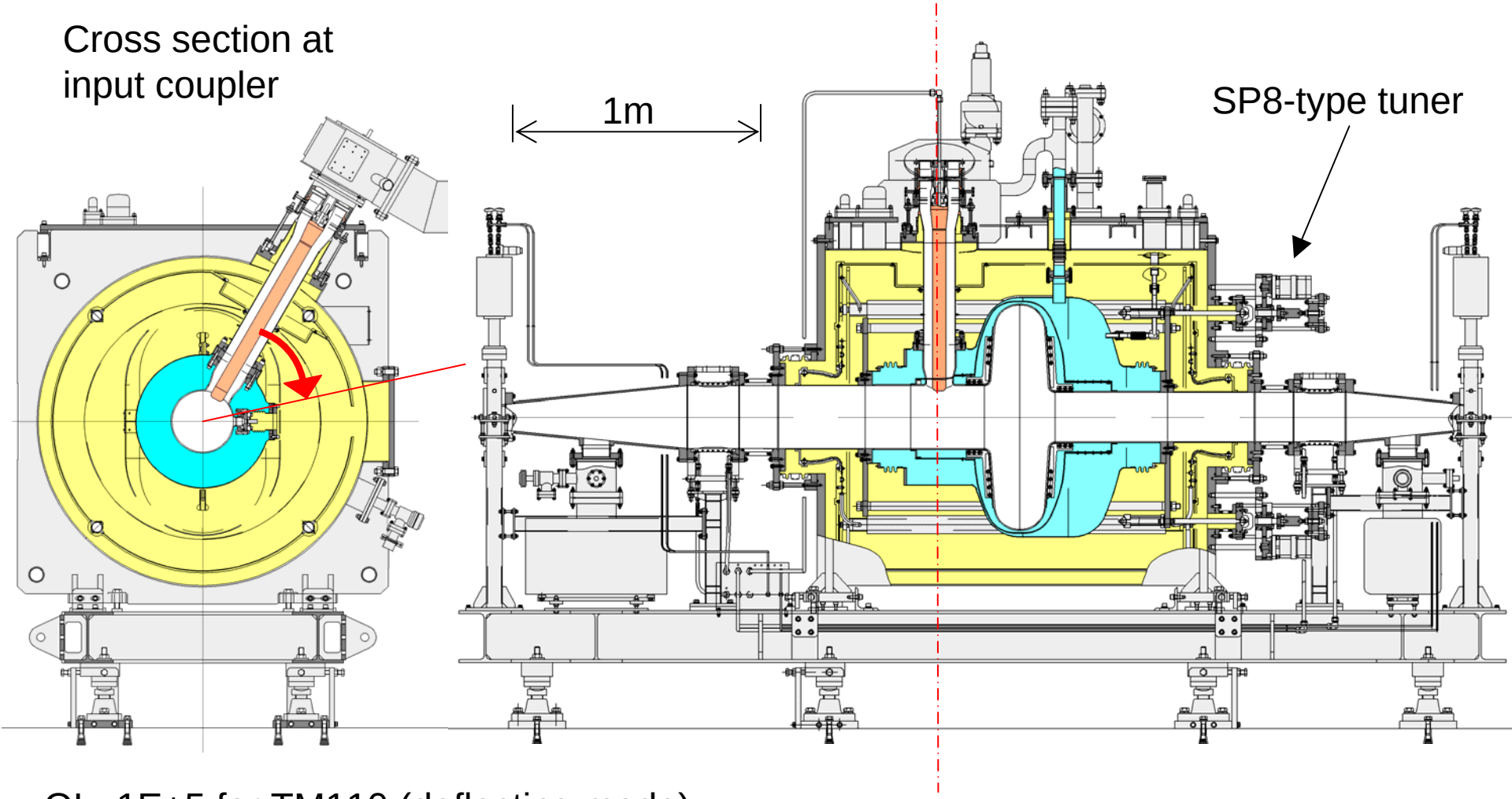


Cross section of the storage ring



Crab Cavity and Cryostat

Cross section at
input coupler



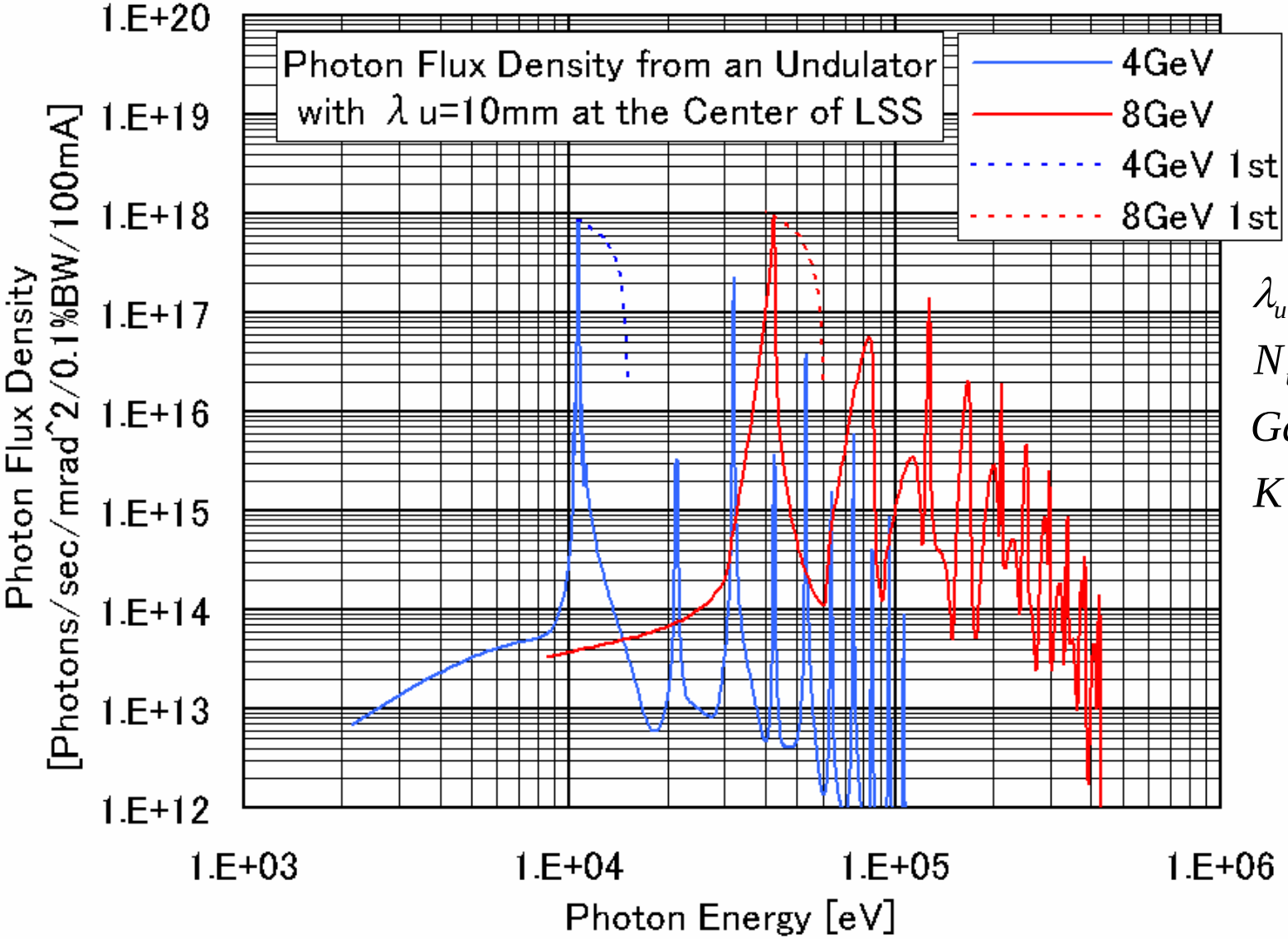
QL=1E+5 for TM110 (deflecting mode)

QL=1E+4 for TM010 (LOM)

RF parameters

•Cavity Type	Superconducting Crab Cav.
•Number of Cavities	4 or 2
•Deflecting Frequency	508.58 MHz
•Deflecting Mode	TM110
•R/Q	46.7 Ω
•Loaded Q (Q_L)	1×10^5
•RF power	150 kW/Cavity
•Length of Drift Space	10 m
•Deflecting Voltage	1.67 MV
•Bunch Tilting $\tan\theta_{tilt}$	0.044 at 4GeV
	0.022 at 8GeV
•Phase control stability	14 mdeg (0.24mrad)

Light spectrum for 100% efficiency



(as K→0)

(as K→0)

$\lambda_u = 10mm$

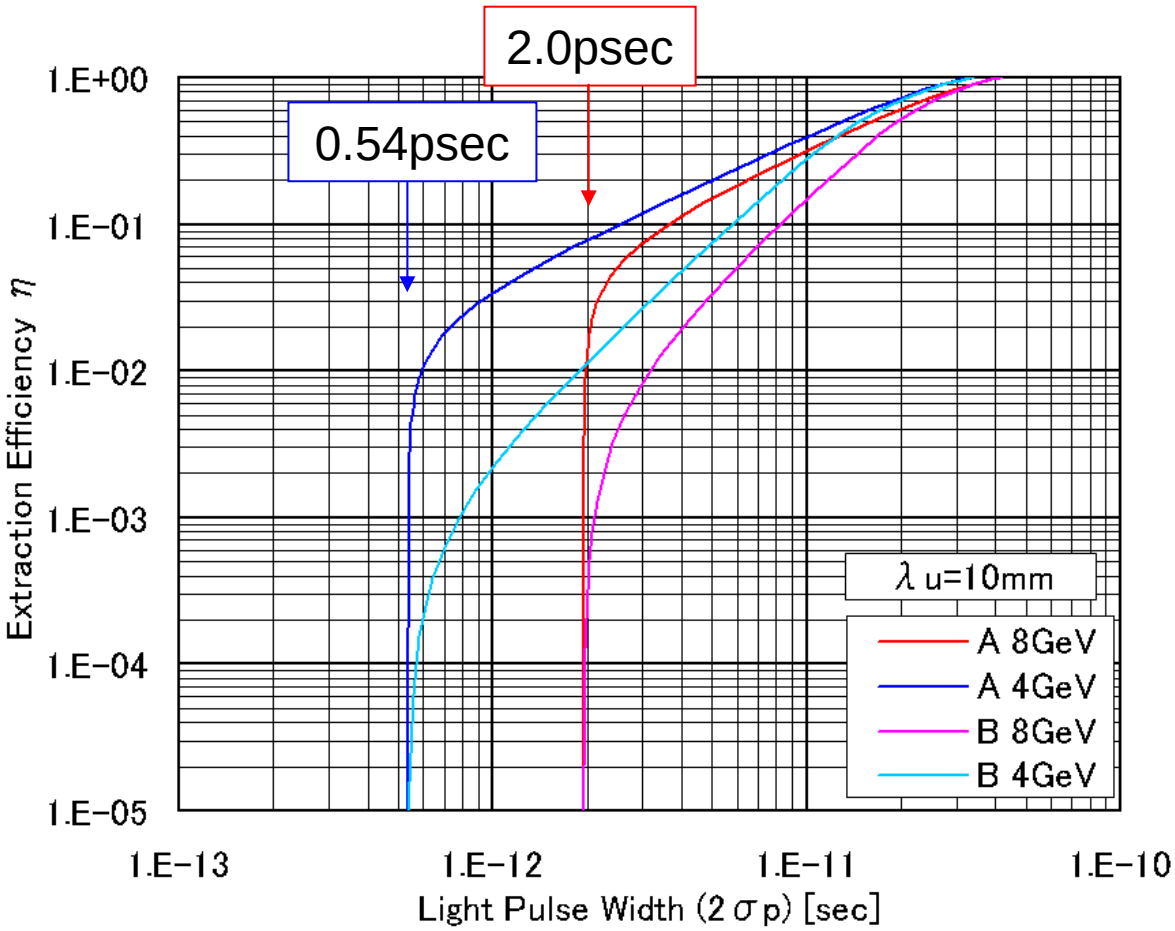
$N_u = 101$

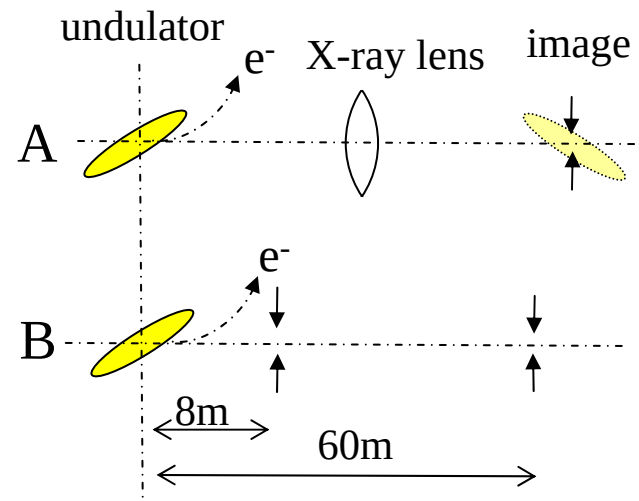
$Gap = 5mm$

$K = 0.92$

■To get brilliance in Photons/sec/mm^2/mrad^2/0.1%BW/100mA, multiply 6.3×10^2 (4GeV) or 1.7×10^2 (8GeV) for the 1st order peak.

Pulse width and extraction efficiency





$$\eta = \frac{extracted\ \ flux}{total\ \ flux}$$

Pulse shaping by an asymmetric crystal

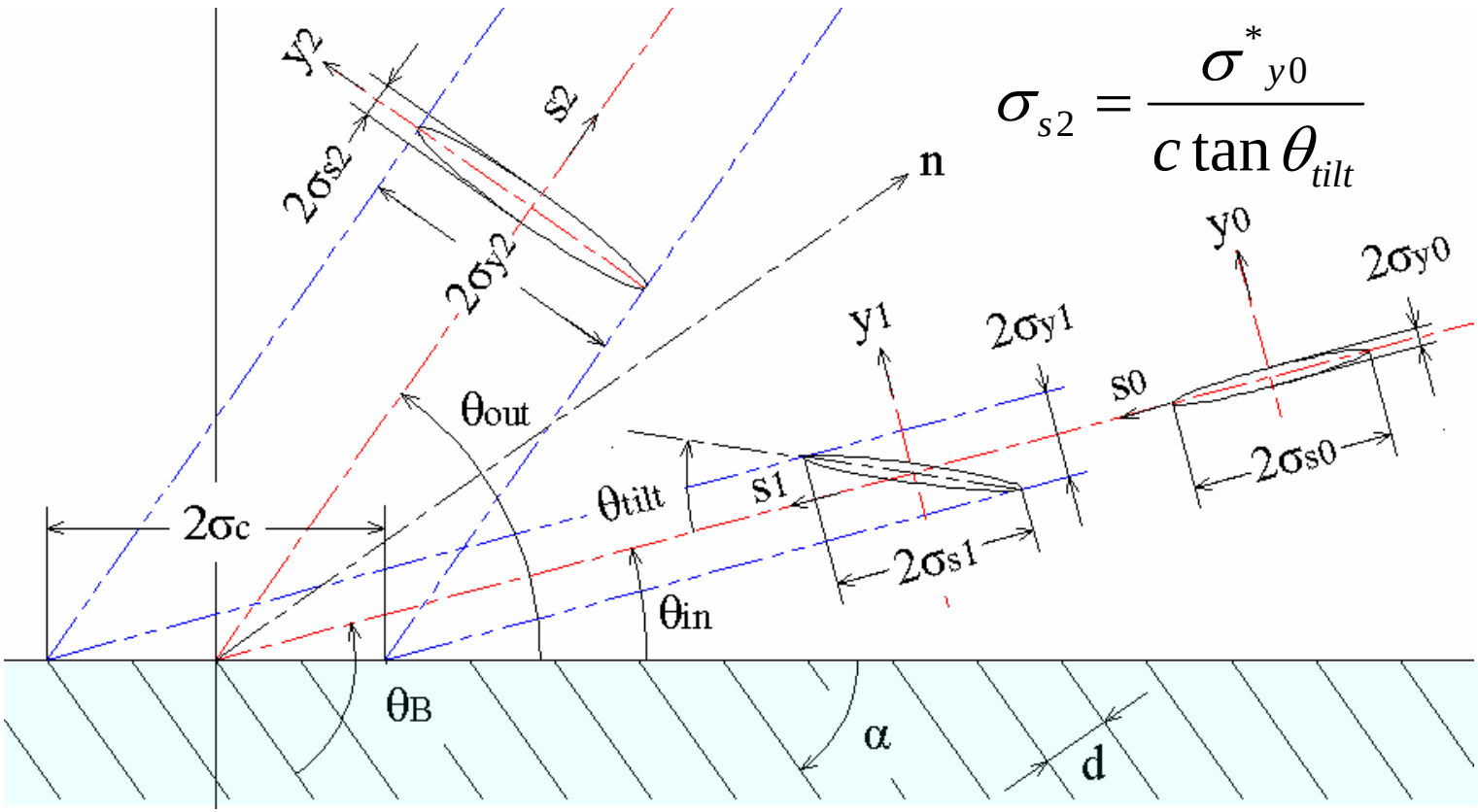
1)Bragg condition $\lambda = 2d \sin \theta_B$

Strong Constraint !

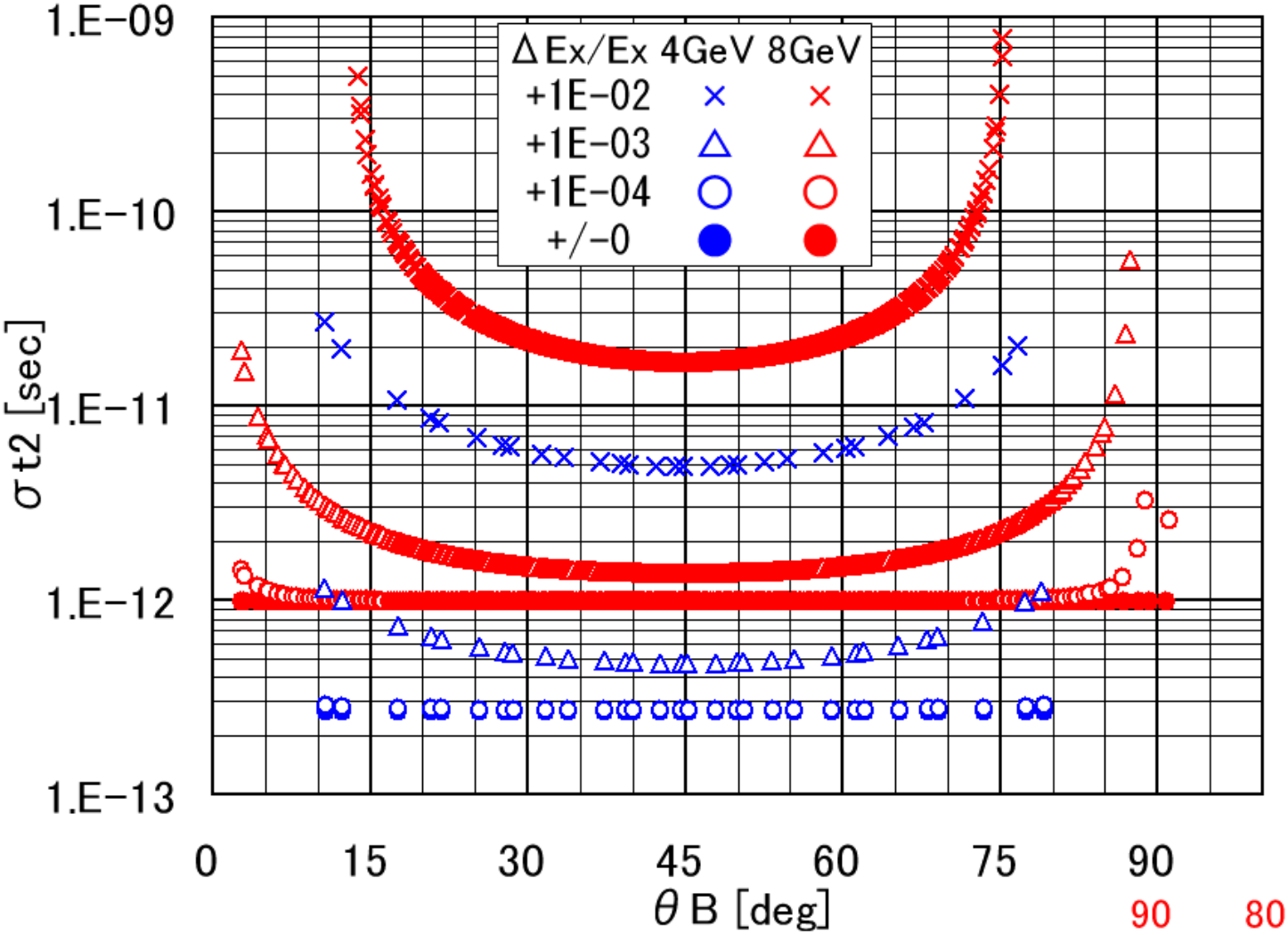
2)Short pulse condition

$$\cos\theta_{out} = -\sin\left(\theta_{in} - \frac{\theta_{in}^{\max}}{2}\right) \Big/ \sin\left(\frac{\theta_{in}^{\max}}{2}\right) \qquad \tan\frac{\theta_{in}^{\max}}{2} = \left(\frac{\sigma_{y0}^{*2}}{\sigma_{s0}^2 \tan^2\theta_{tilt}} + 1\right)\tan\theta_{tilt}$$

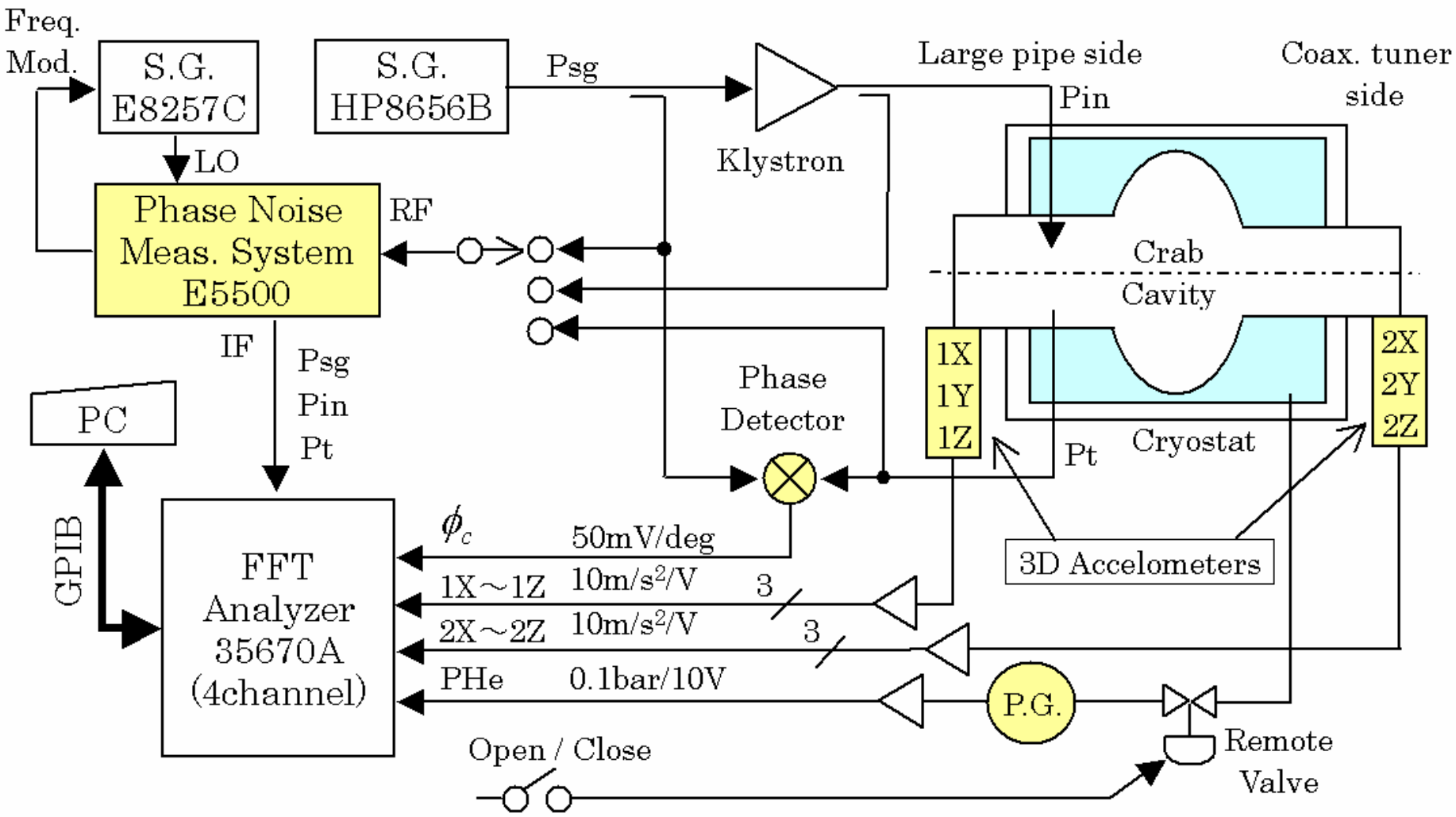
$$\sigma_{s2} = \frac{\sigma^*_{y0}}{c\tan\theta_{tilt}}$$



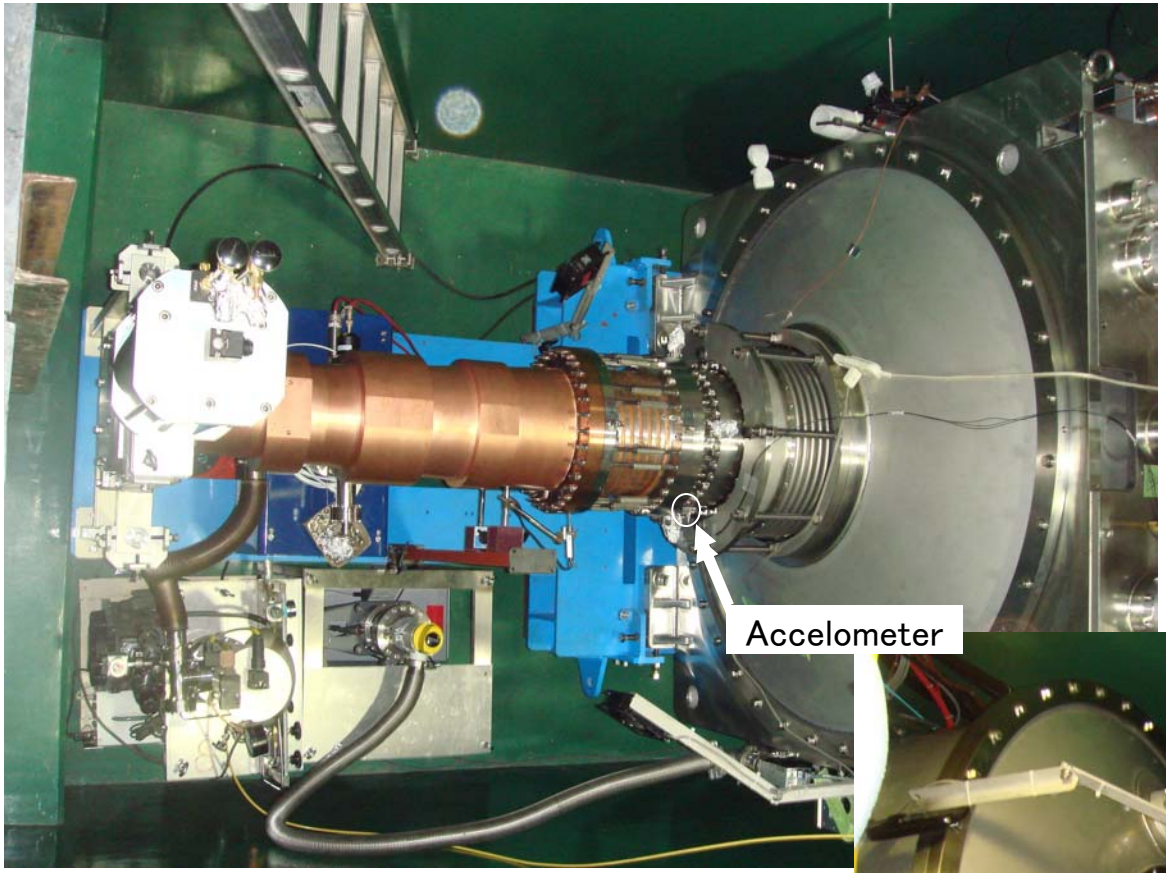
X-ray Energy vs. pulse width



Source Hunting of Phase Vibration at KEK

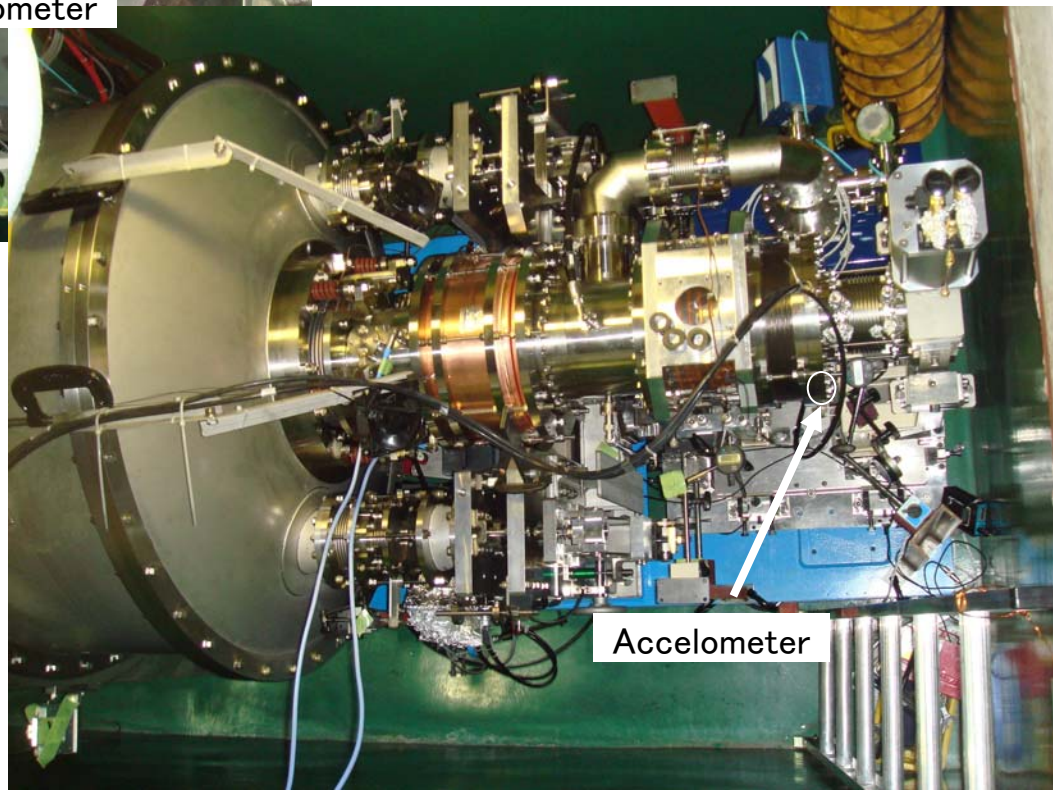


Vibration Measurement at KEK

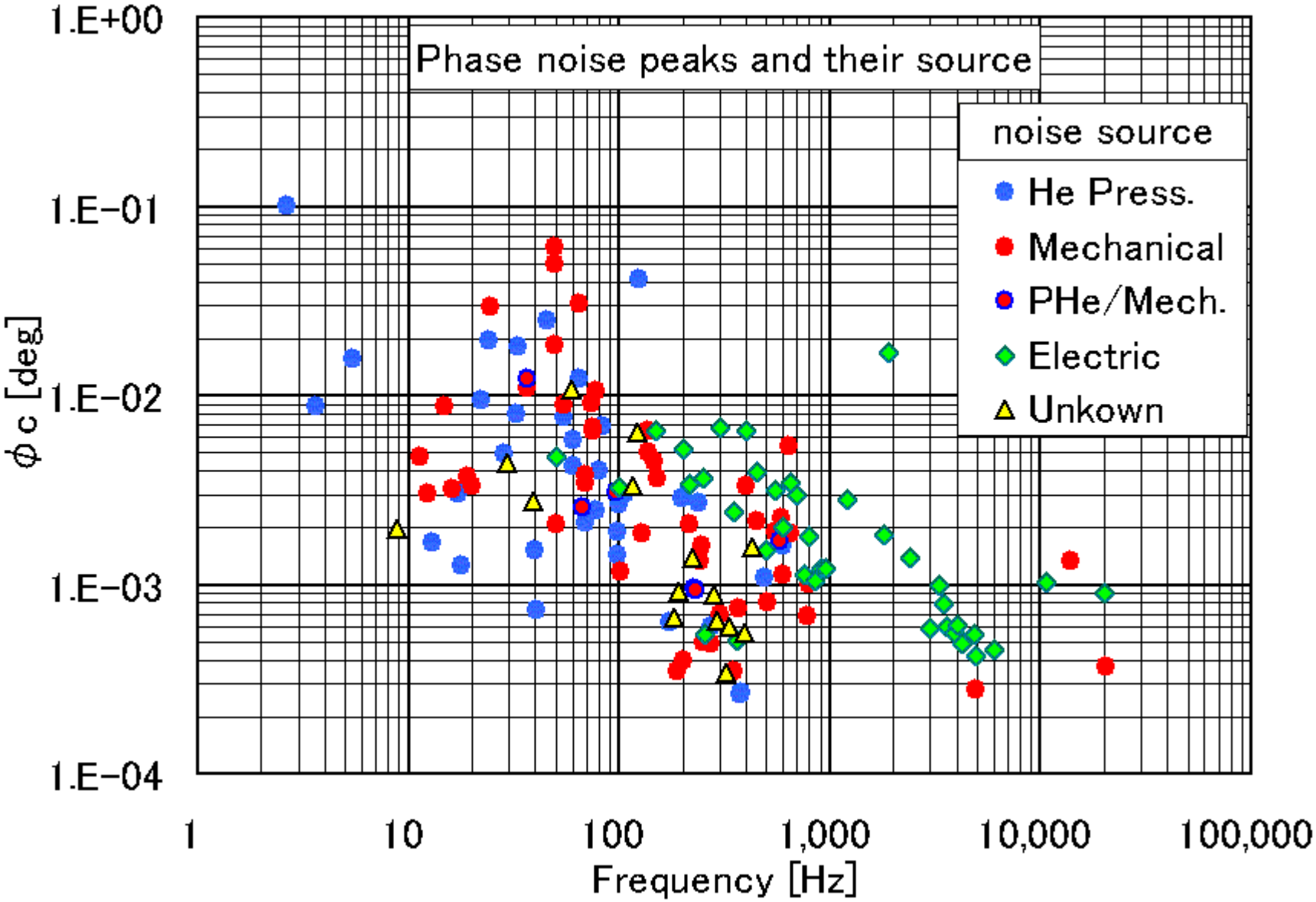


Large beam pipe side
1X, 1Y, 1Z

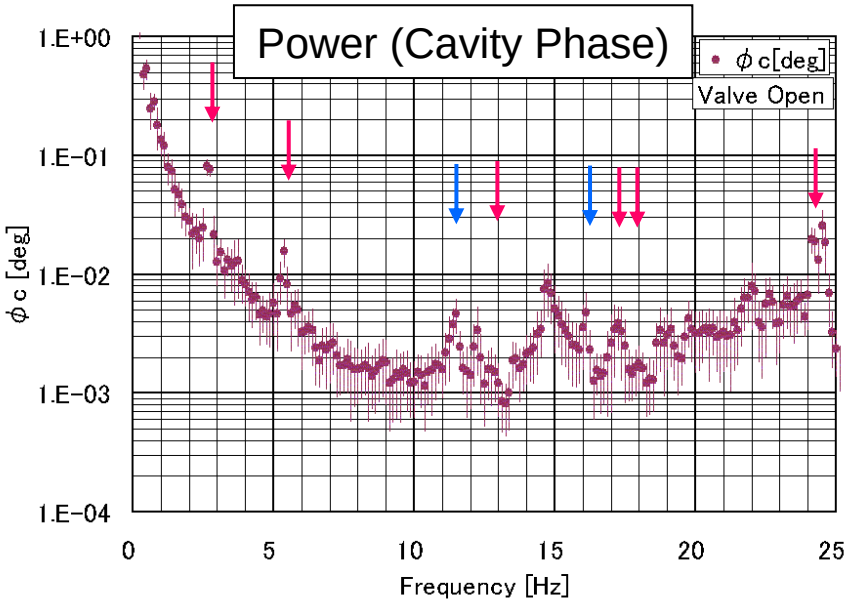
Tuner side
2X, 2Y, 2Z

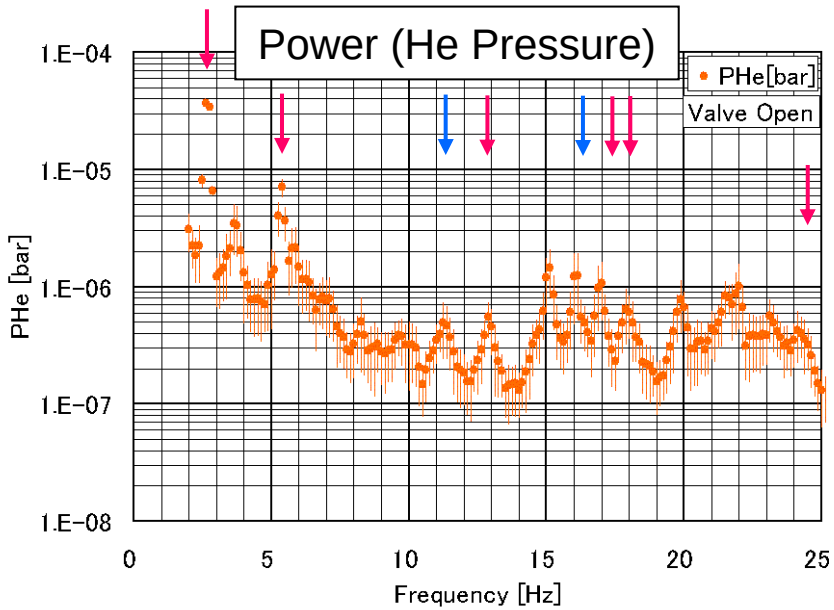


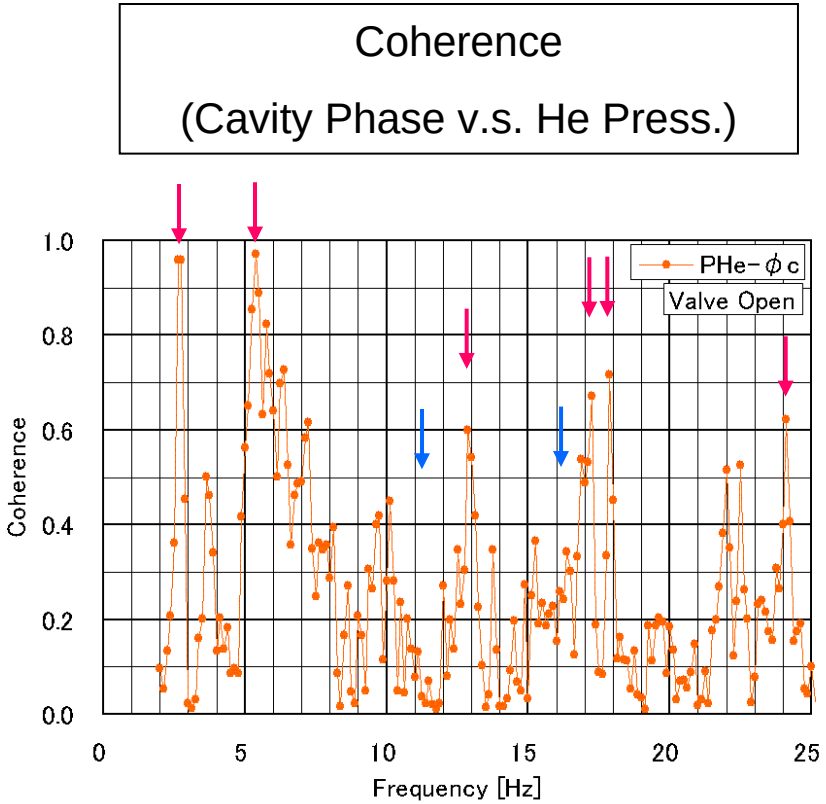
Who makes phase noise?



He Pressure v.s.



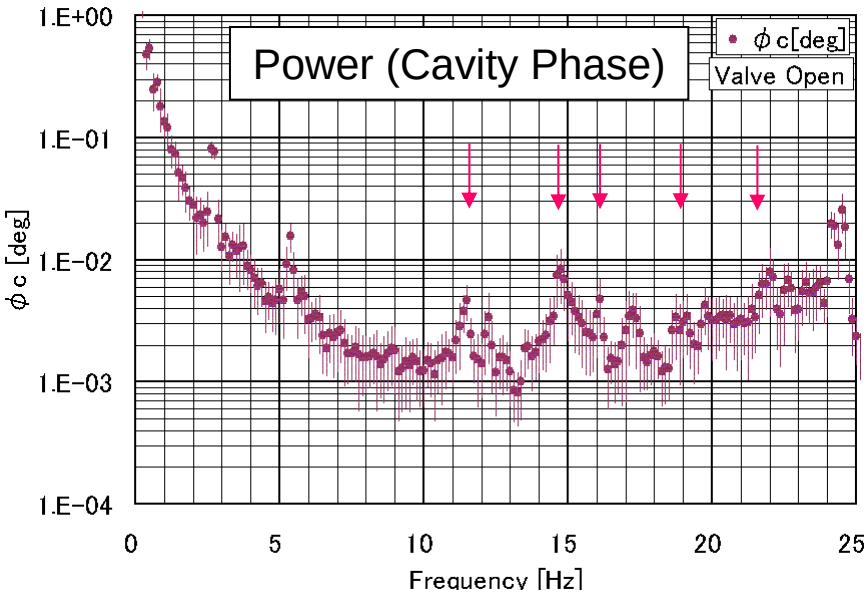


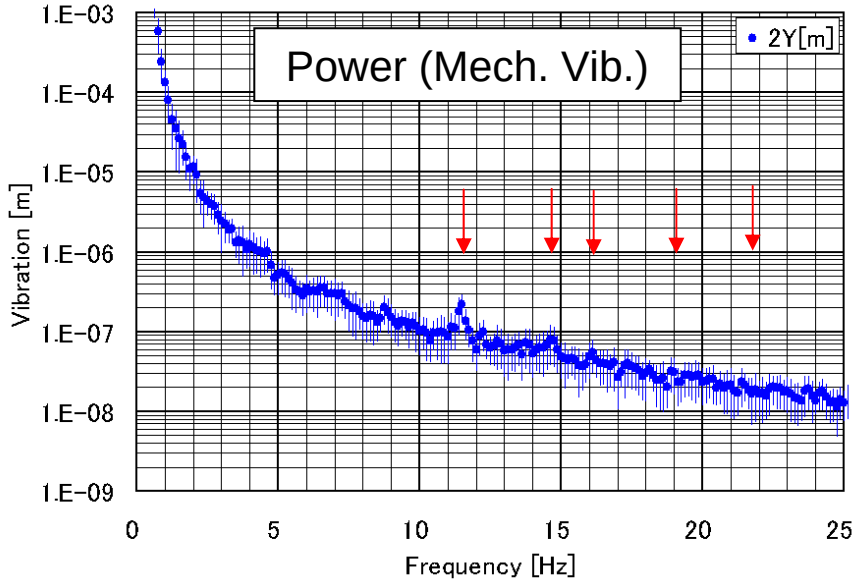


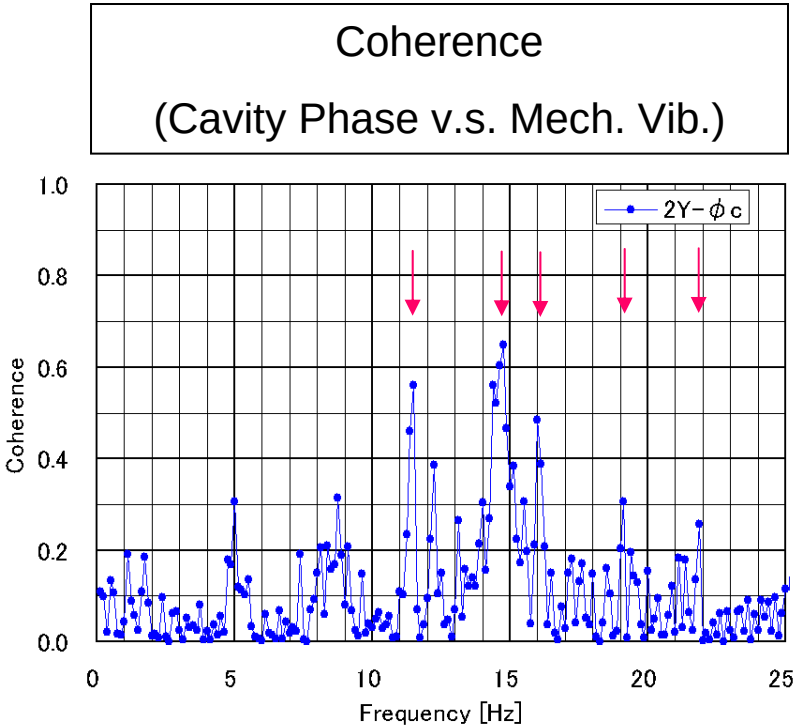
↓ synchronous

↓ asynchronous

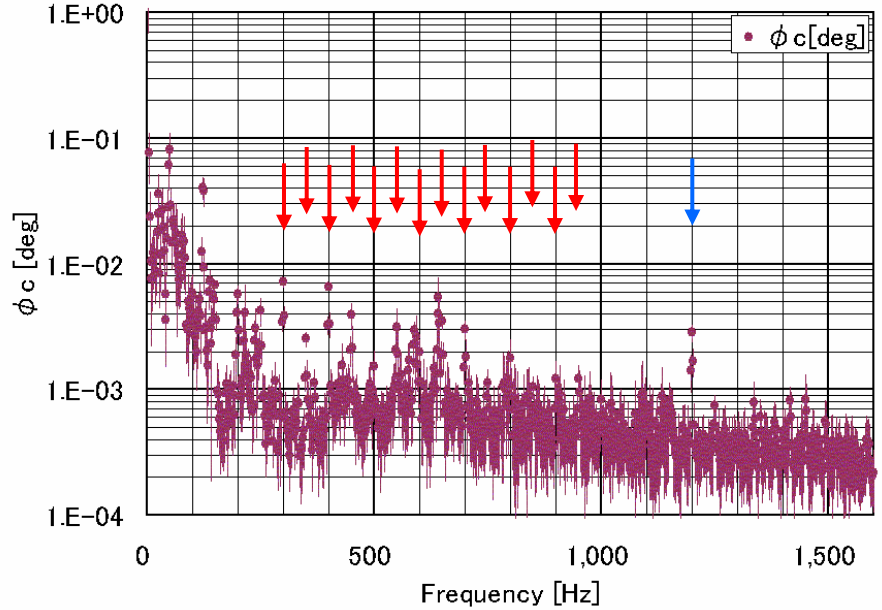
Mechanical Vibration

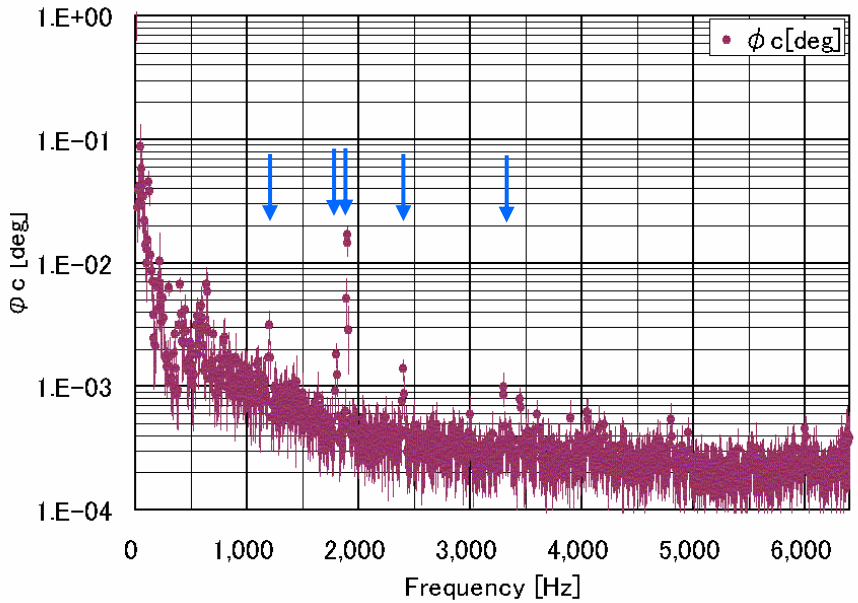


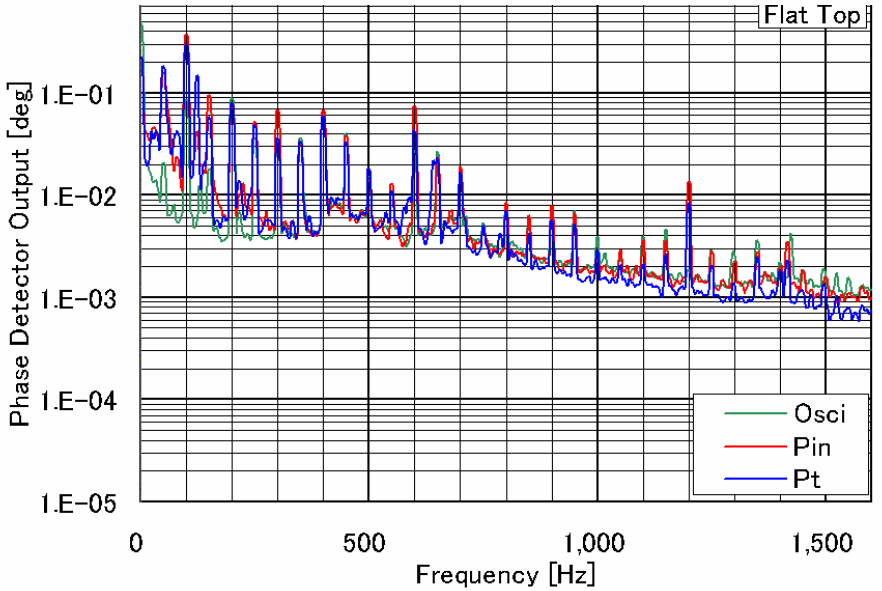


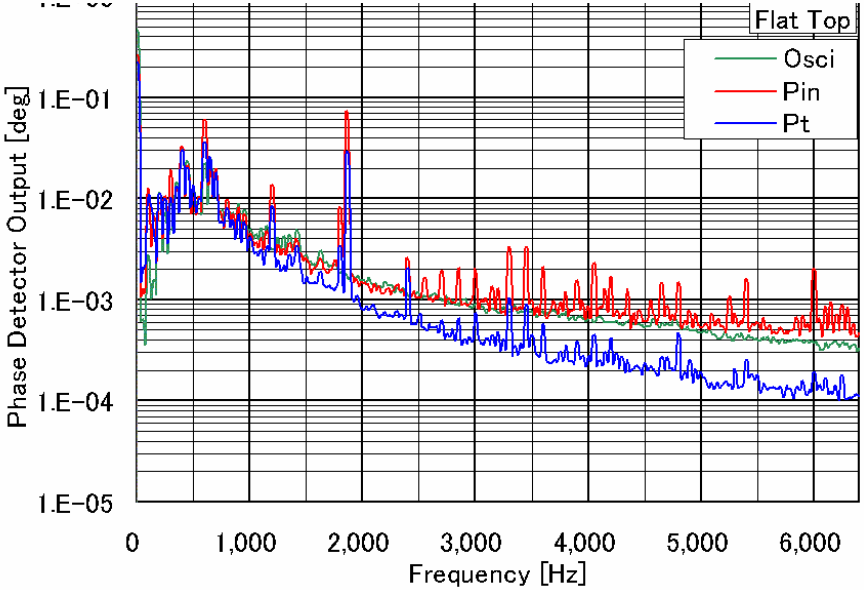


Electric noise (↓Master Oscillator & ↓Klystron)

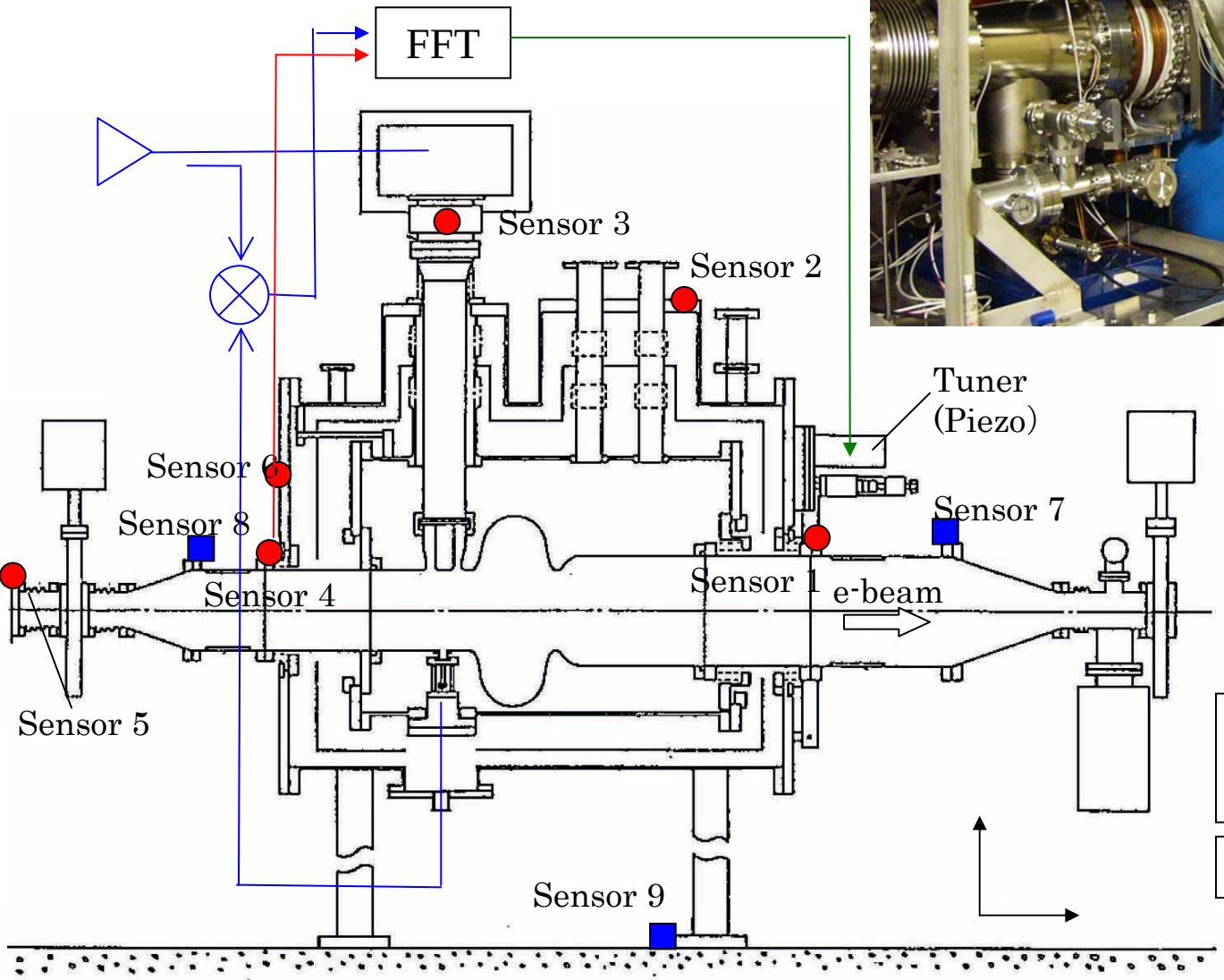


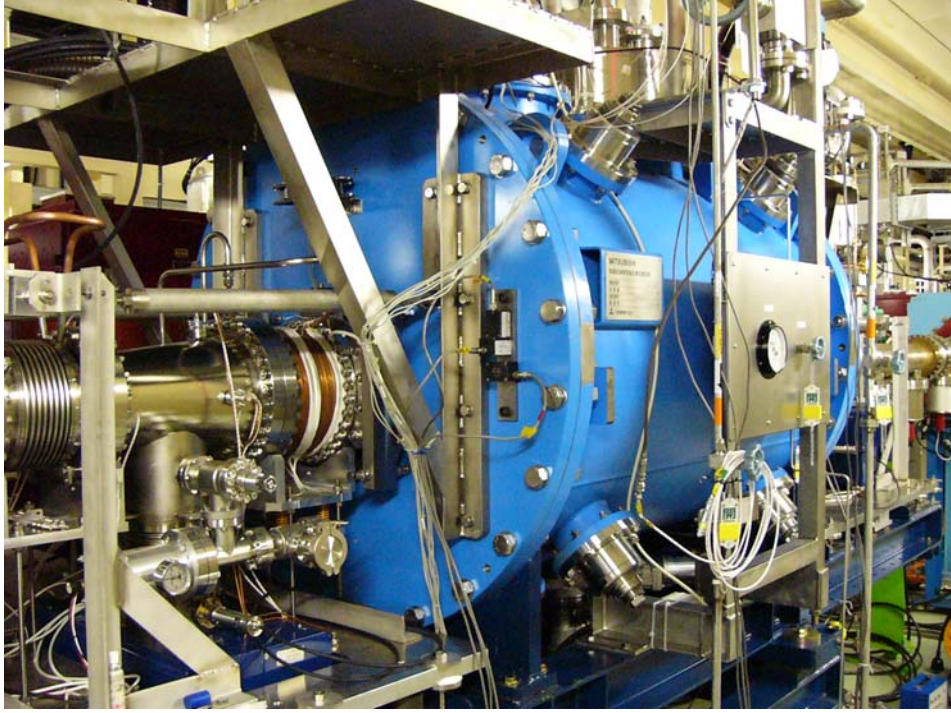


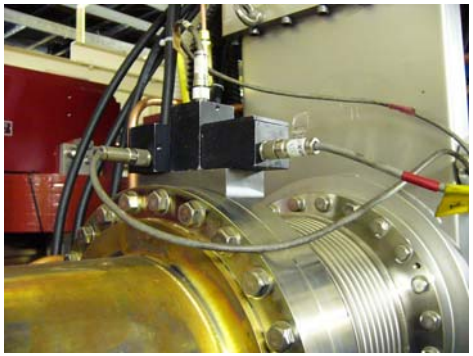




Vibration measurement of KEK-B Superconducting Cavity (1)





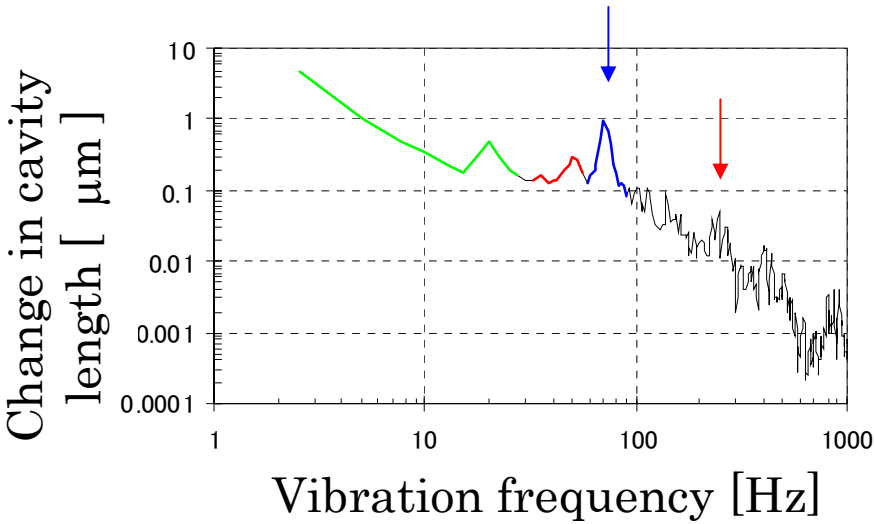


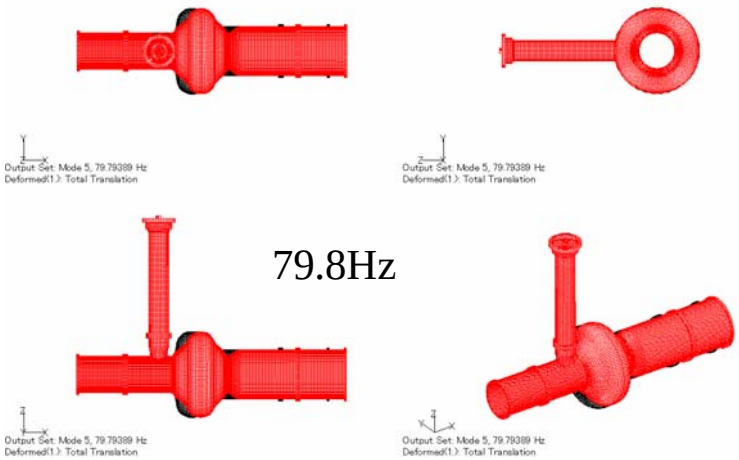
: 3D servo-accelometer

: 3D piezo-accelometer

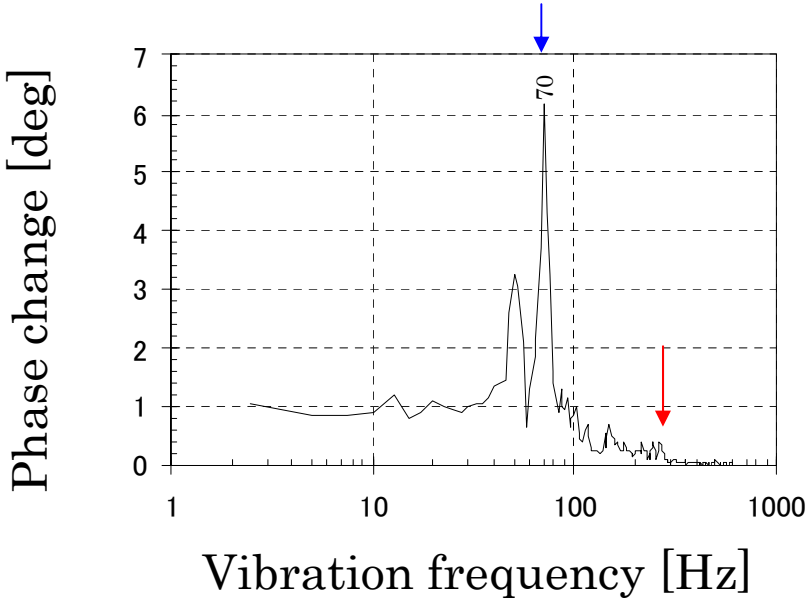
Pressure: Sensor 10

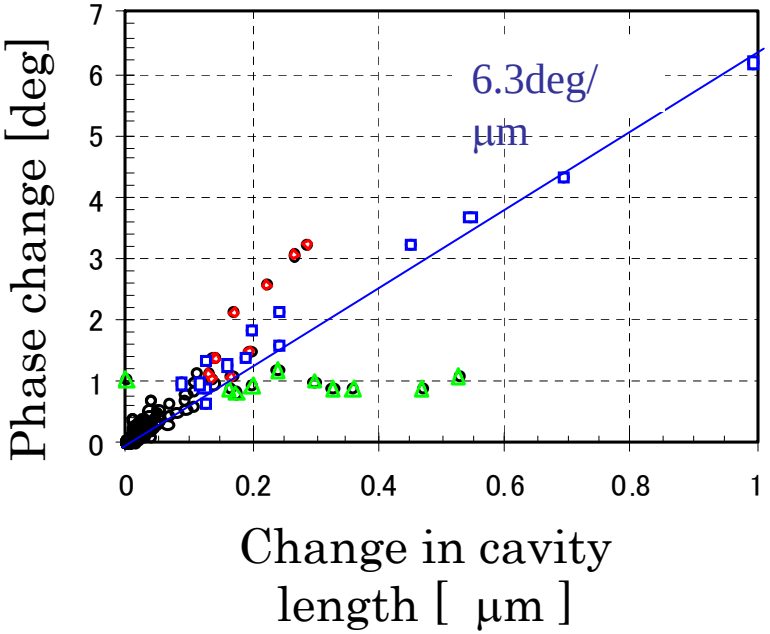
Forced vibration experiments of a KEKB SC Cavity



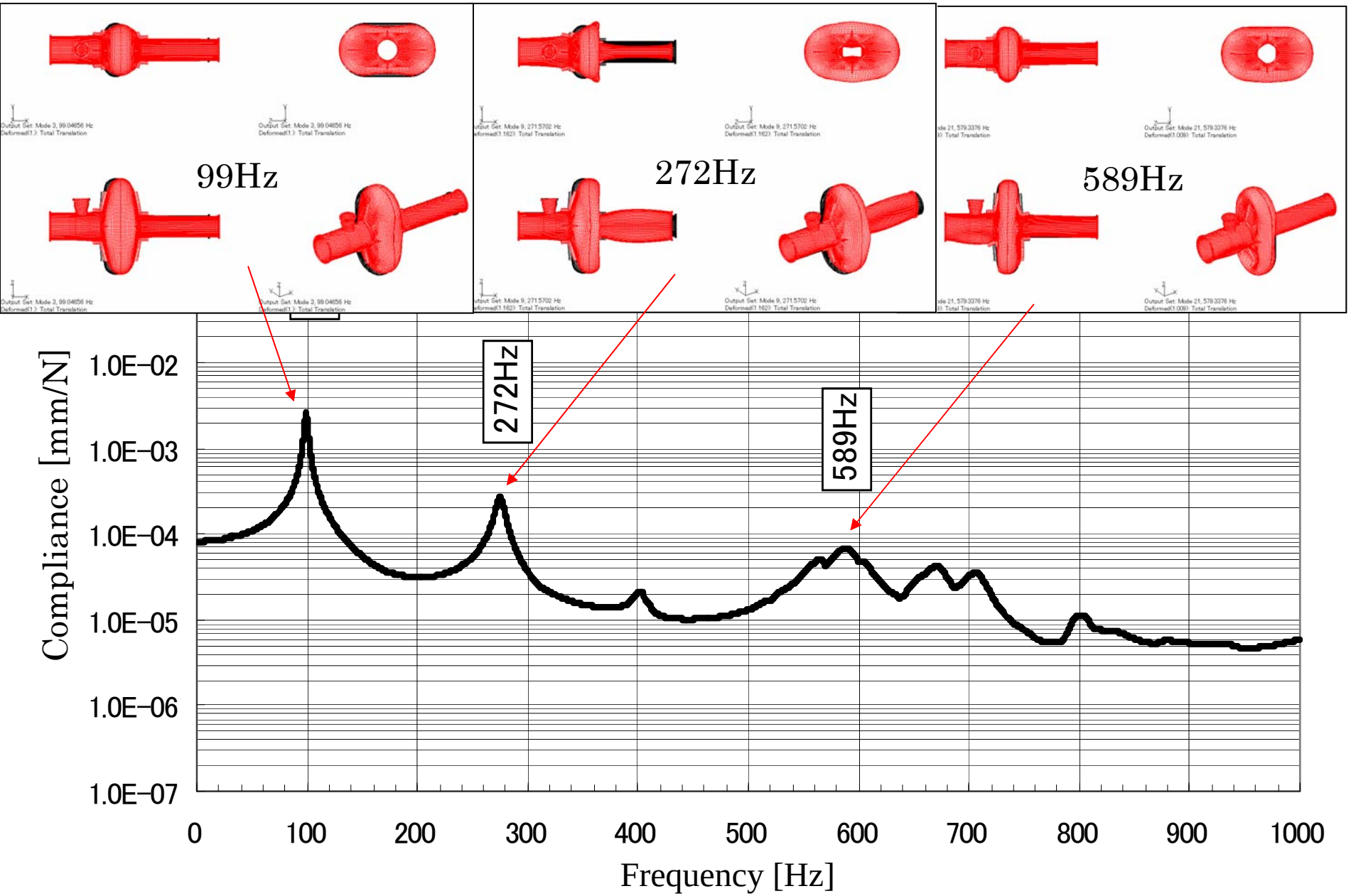


Mechanical Eigen Mode Calculation by NASTRAN

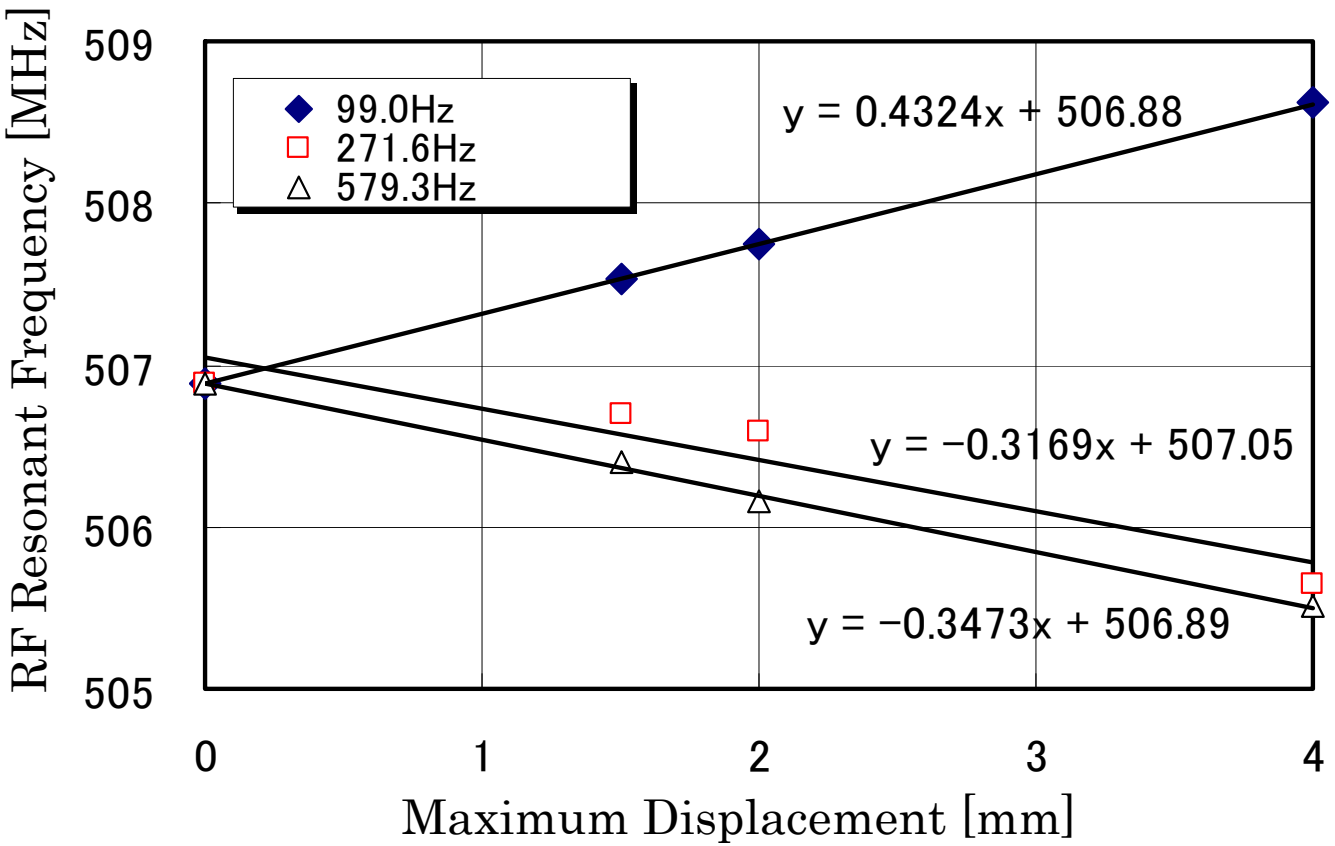




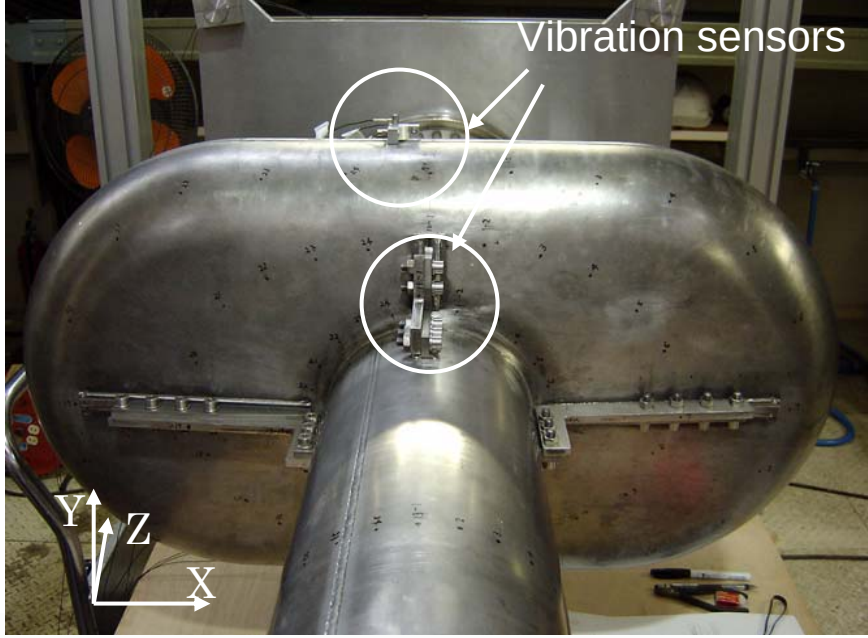
Vibration Modes of Crab Cavity

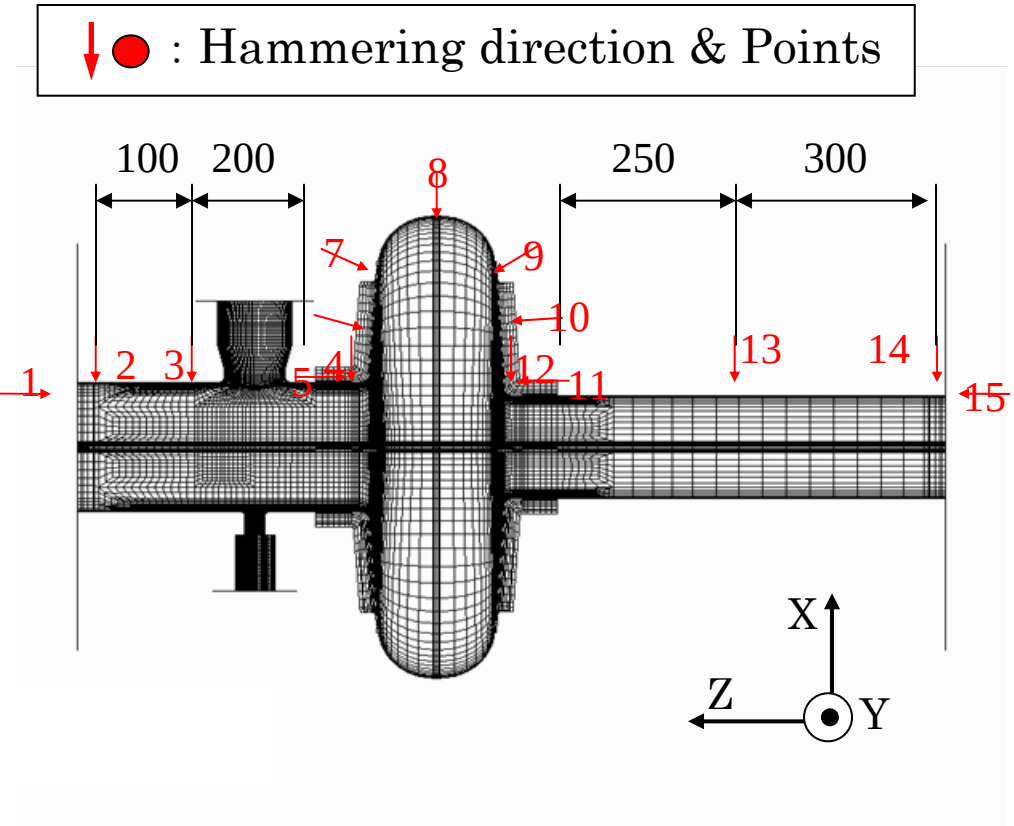


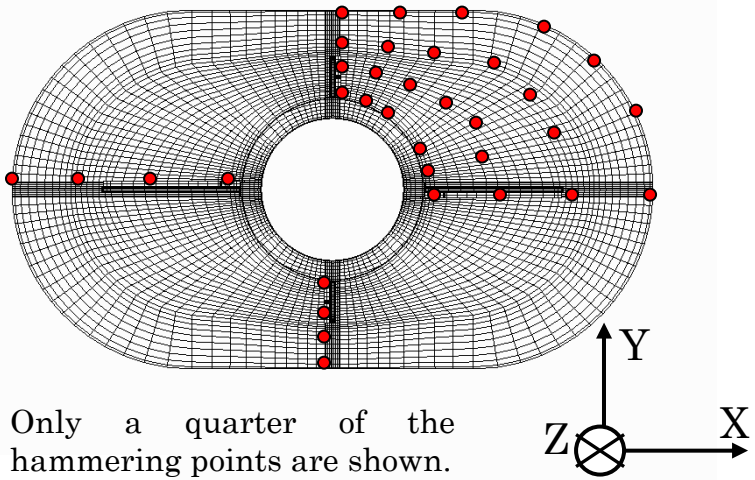
Sensitivity of vibration mode to RF resonant frequency.



Vibration measurement
― Hammering ―



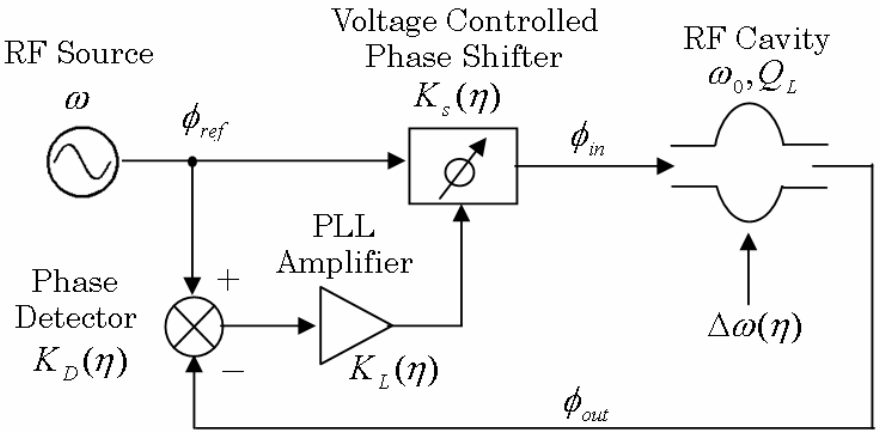




Only a quarter of the hammering points are shown.

PLL phase suppression function

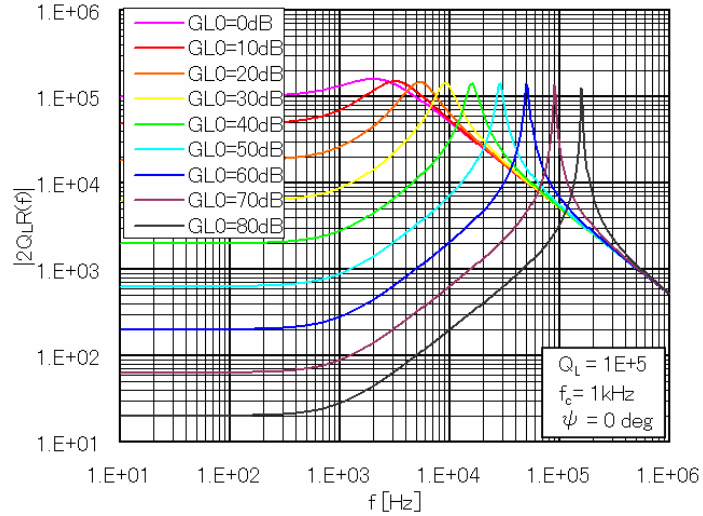
$$\phi_{out} - \phi_{ref} = -2Q_L \frac{\Delta\omega}{\omega_0} R(\xi,\eta) \qquad R(\xi,\eta) = \frac{G_\omega(\xi,\eta)}{1 + G_L(\eta) G_g(\xi,\eta)}$$

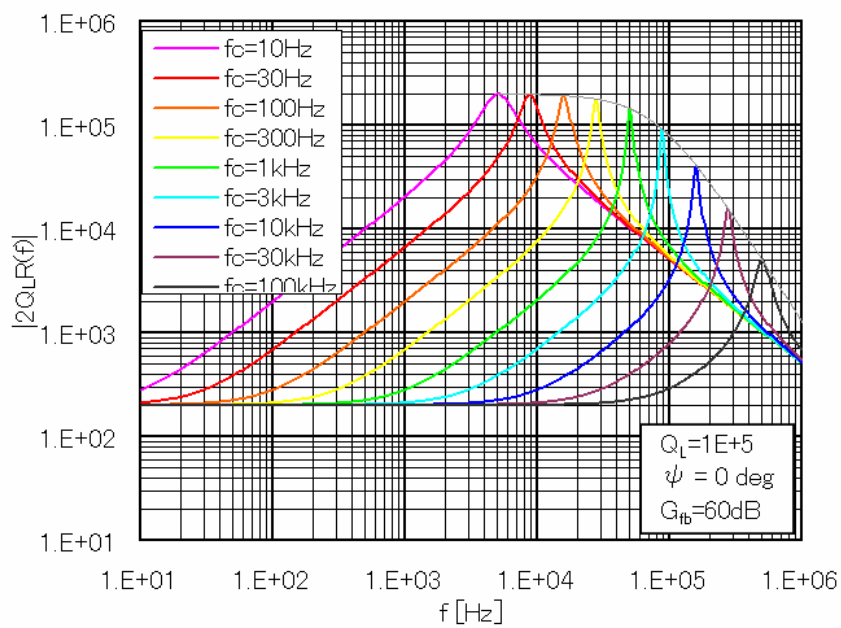


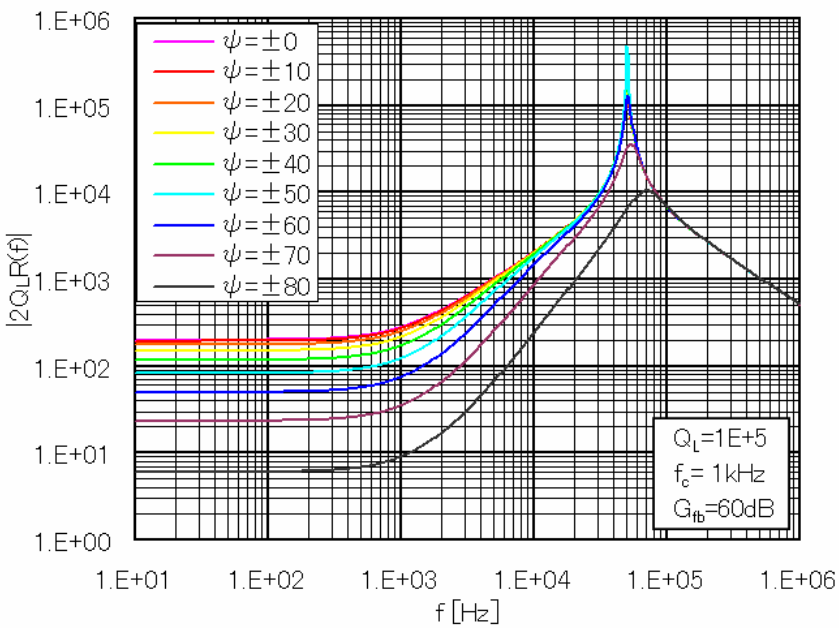
$$\xi = \frac{\omega - \omega_0}{\lambda}$$

$$\eta = \frac{\Omega}{\lambda}$$

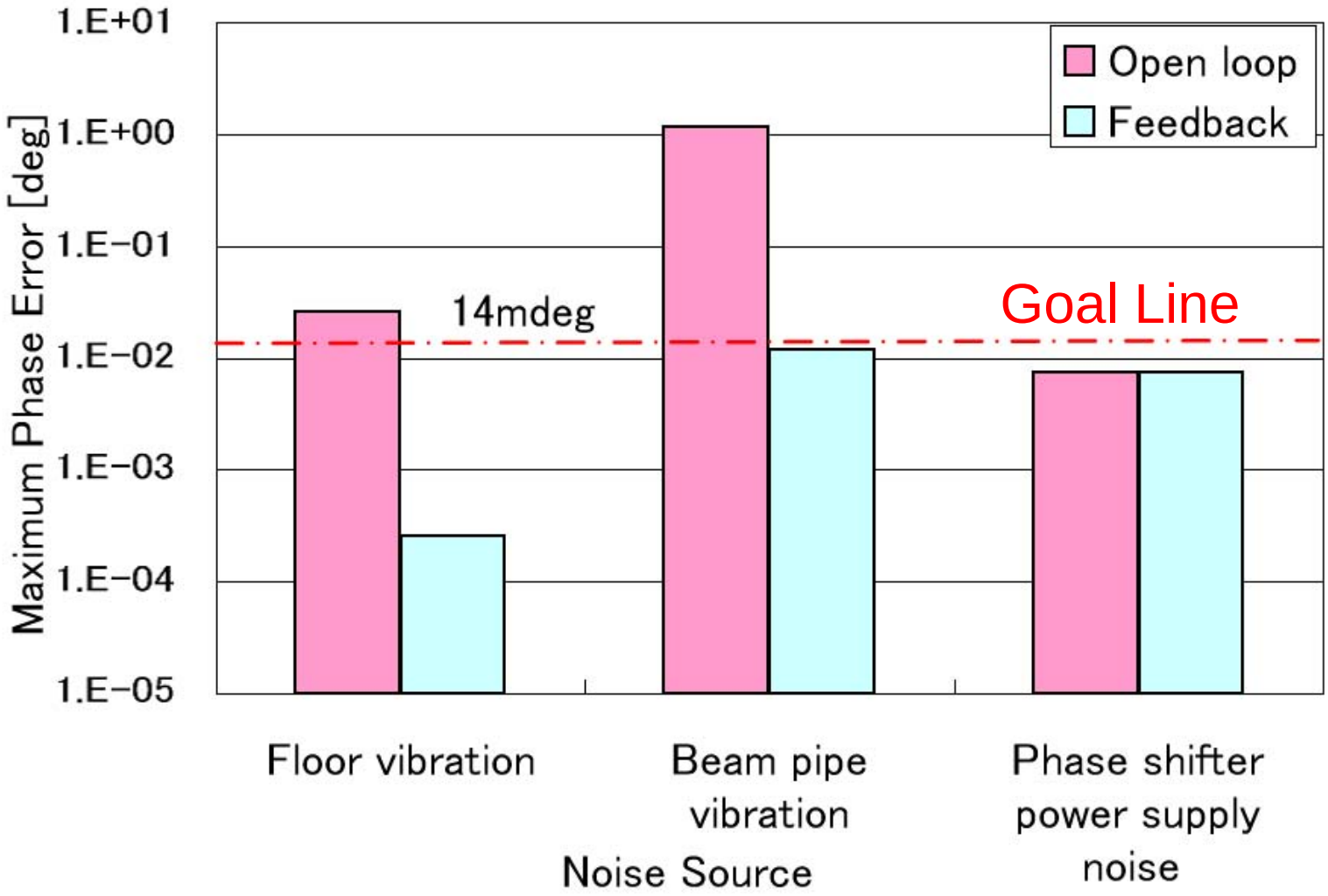
$$\lambda = \frac{\omega_0}{2Q_L}$$



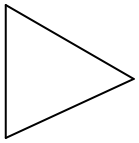




Simulation result of phase noise suppression by PLL



Development 300kW fast phase shifter



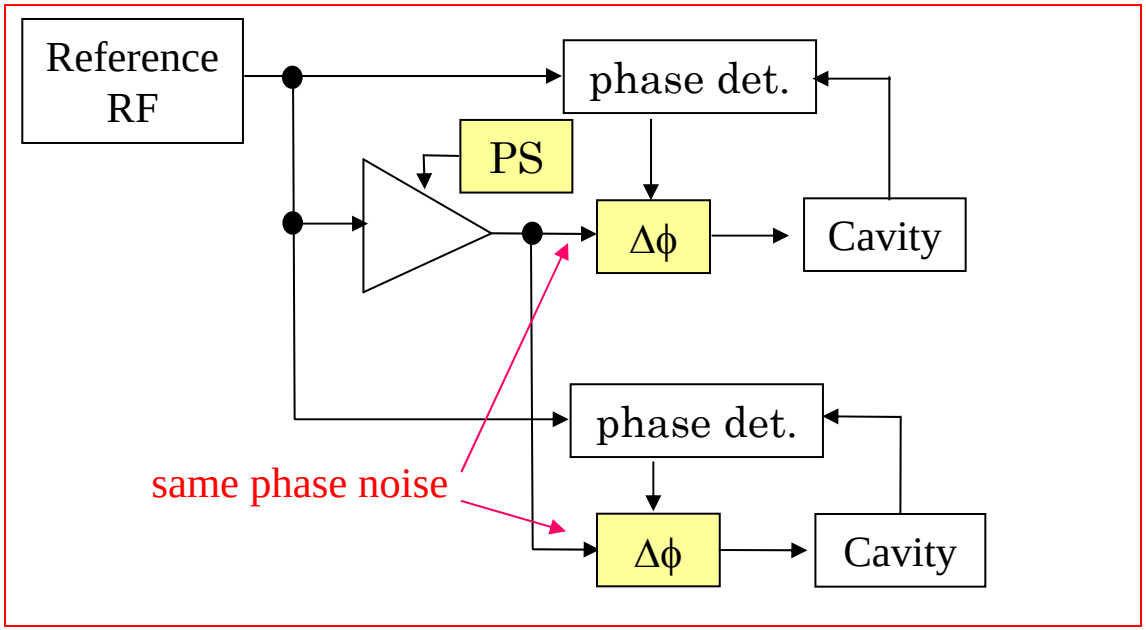
Klystron

PS

Klystron Power Supply

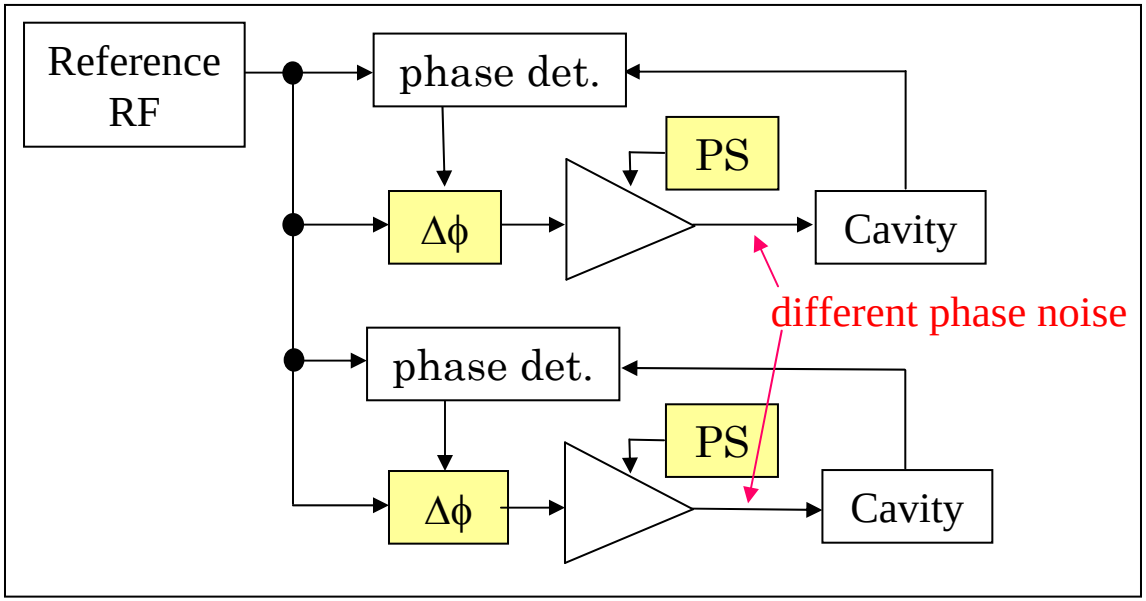
Δϕ

Phase shifter



One klystron scheme

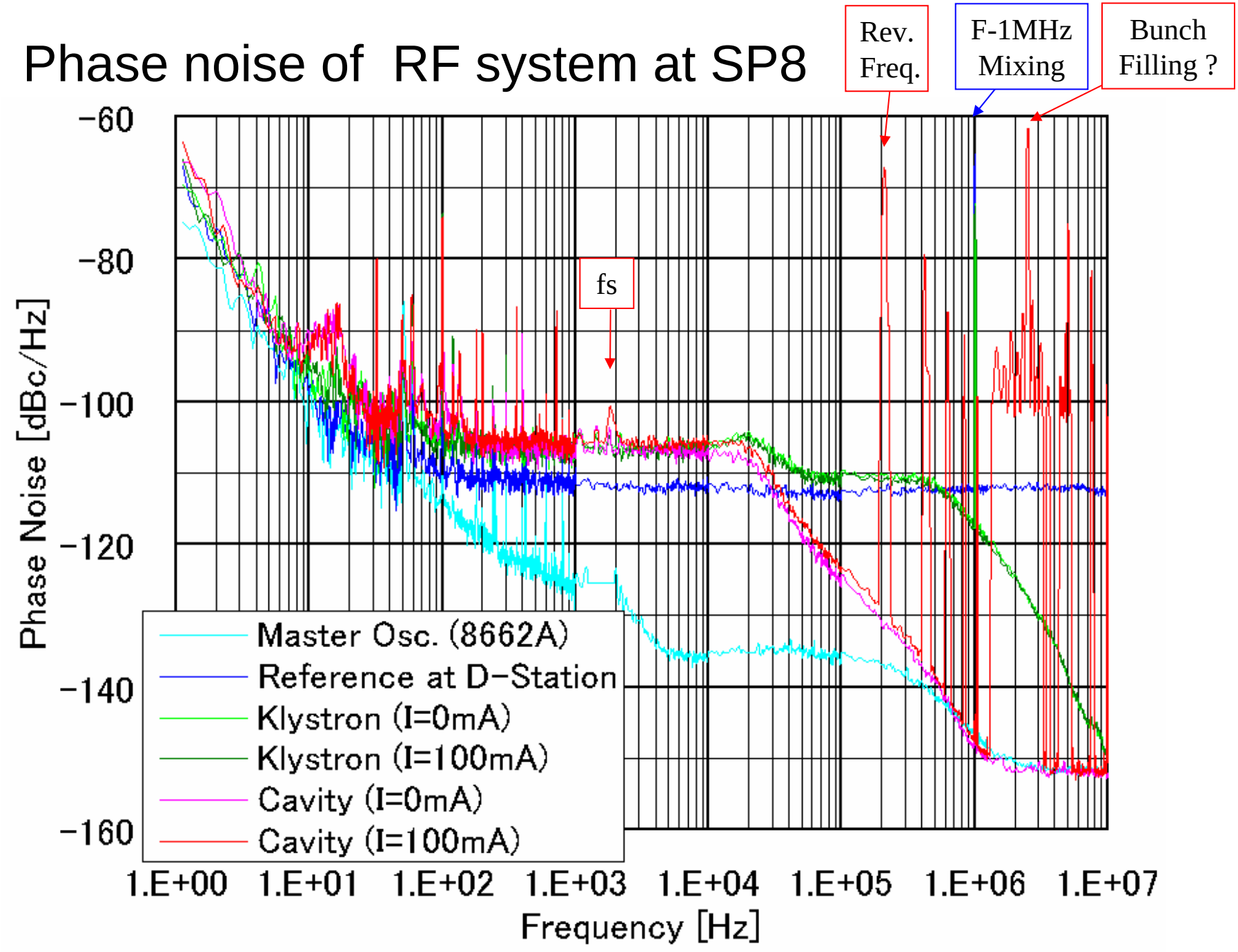
High power phase shifter



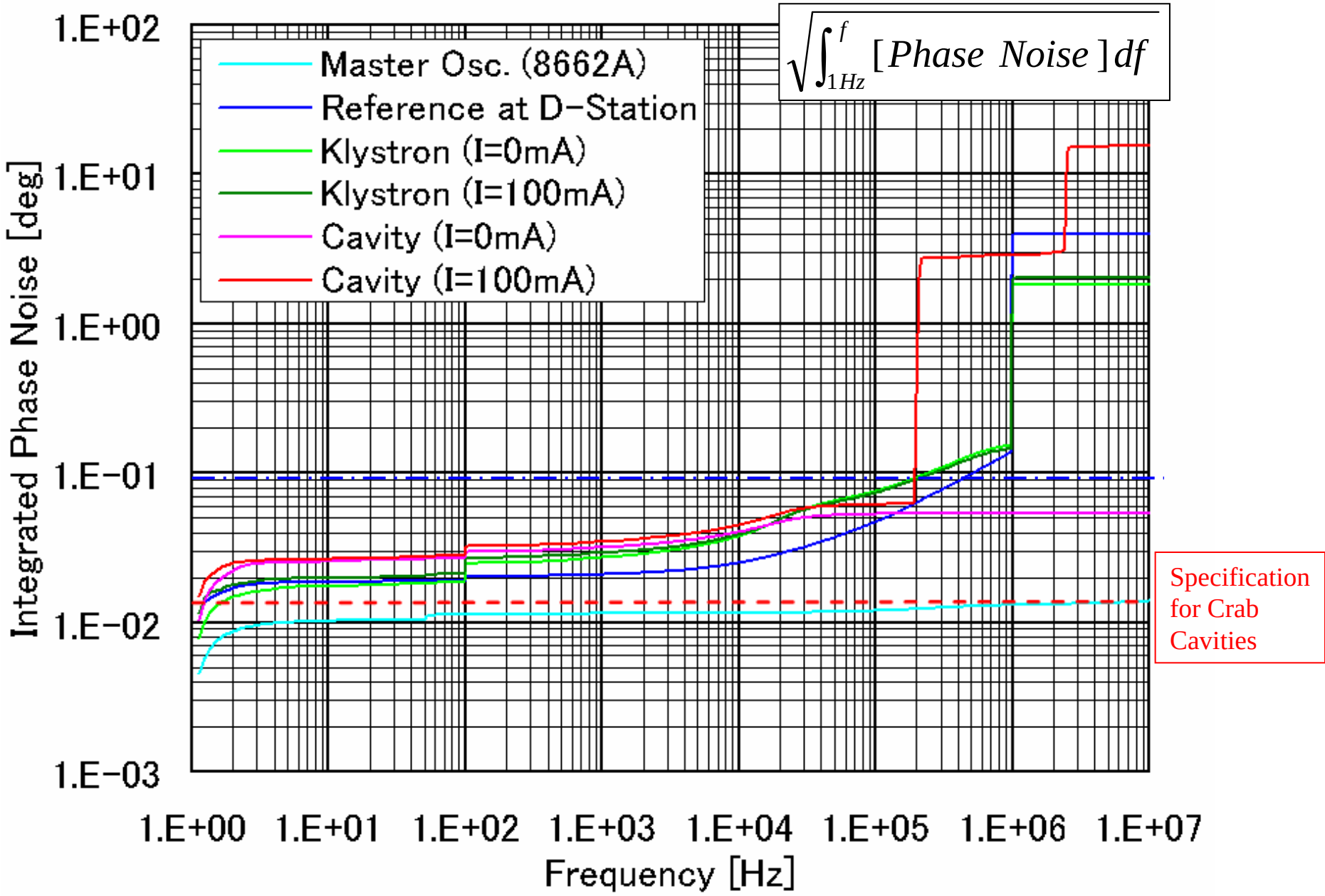
Many klystron scheme

Low power phase shifter

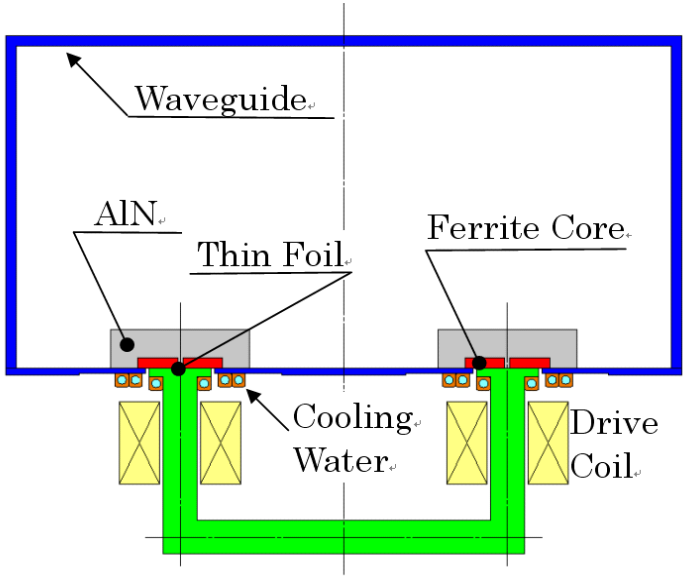
Phase noise of RF system at SP8

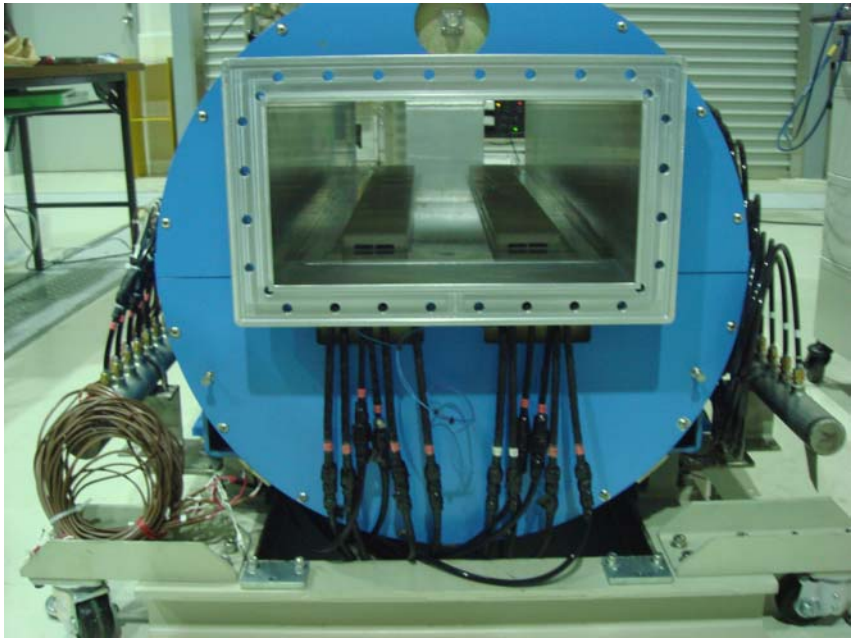


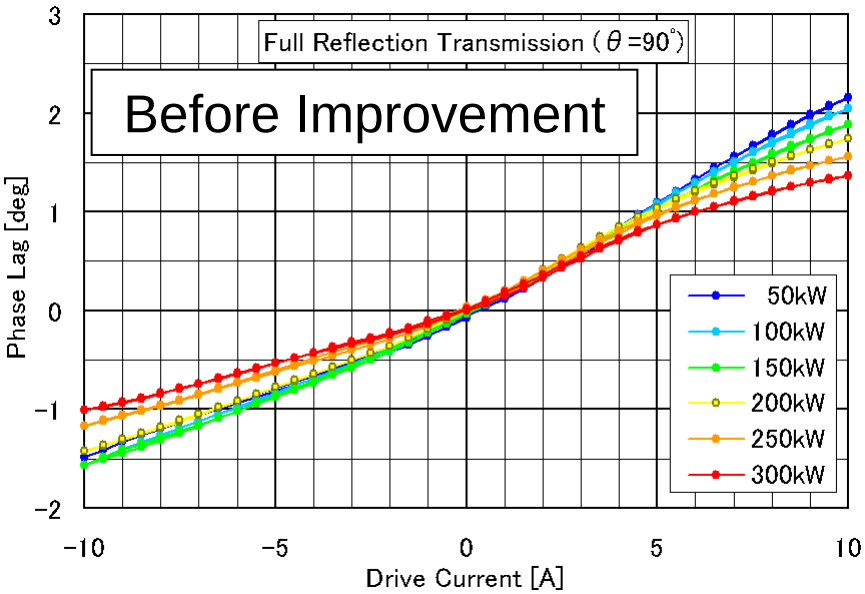
Integrated phase noise and specification

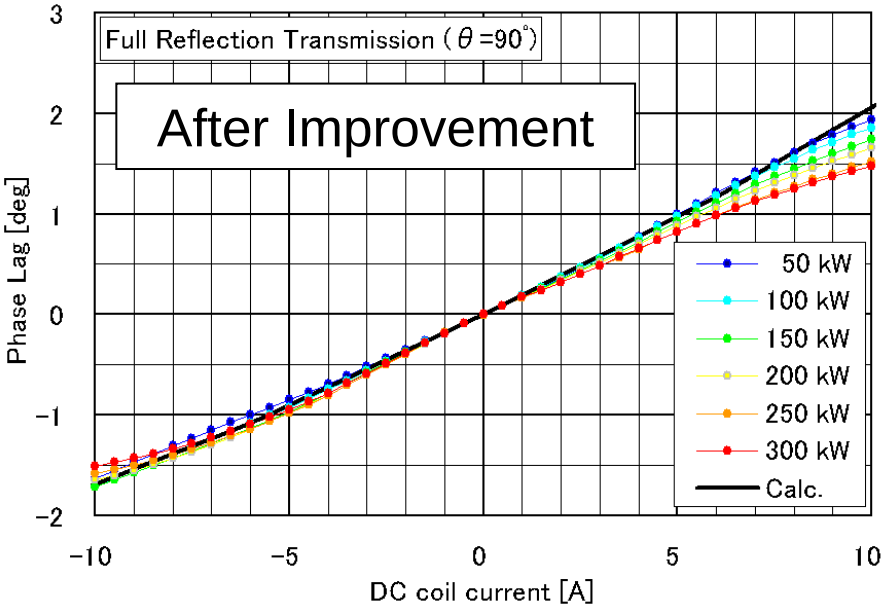


Improvement of phase shifter

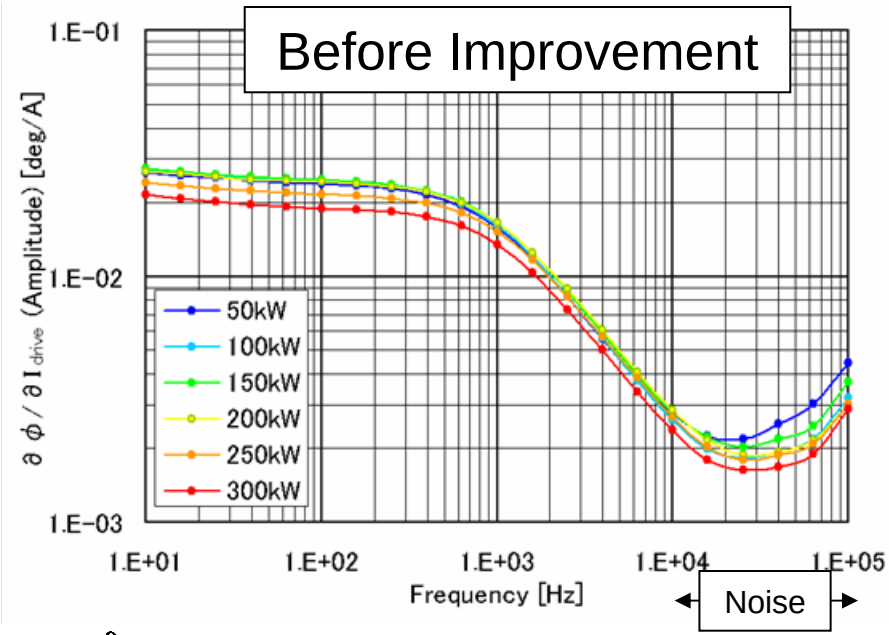


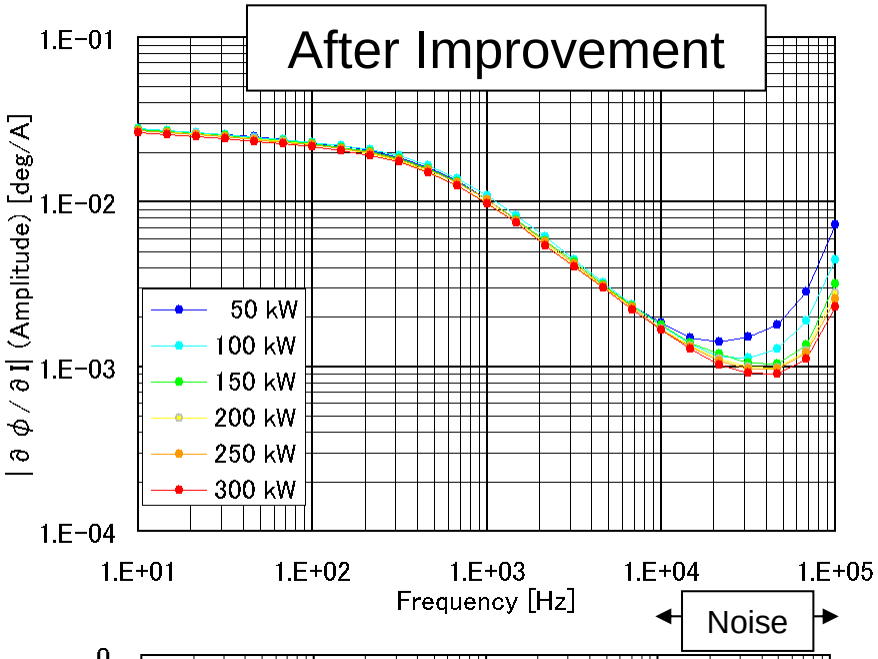




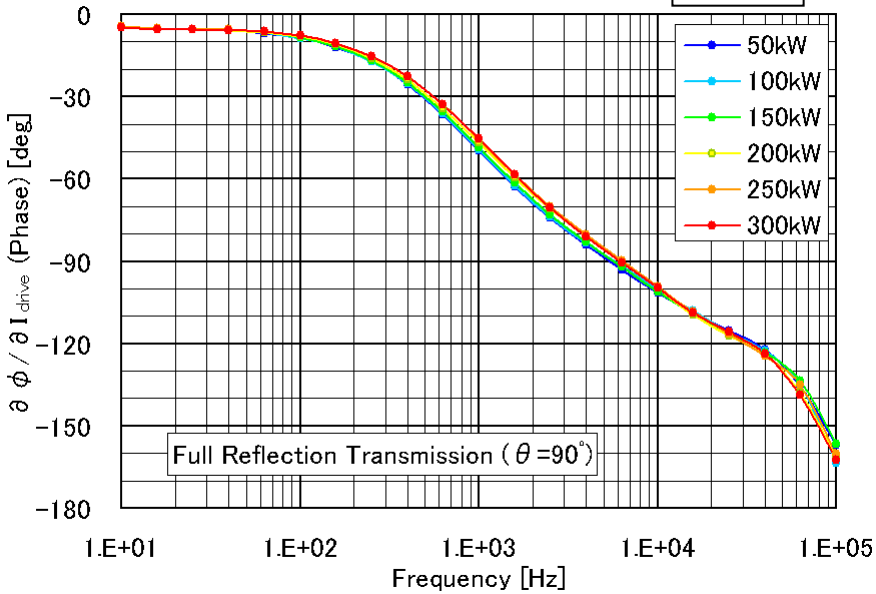


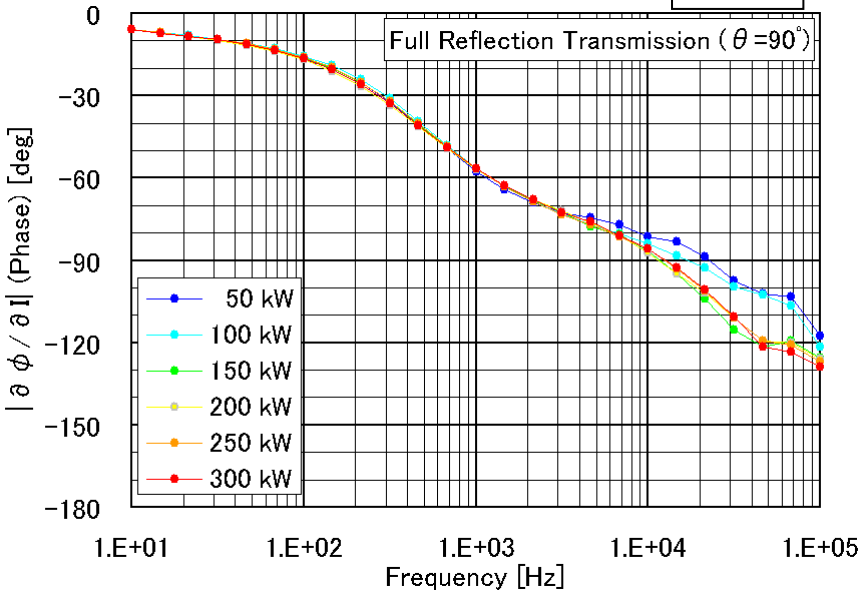
Frequency Response of Phase Shifter





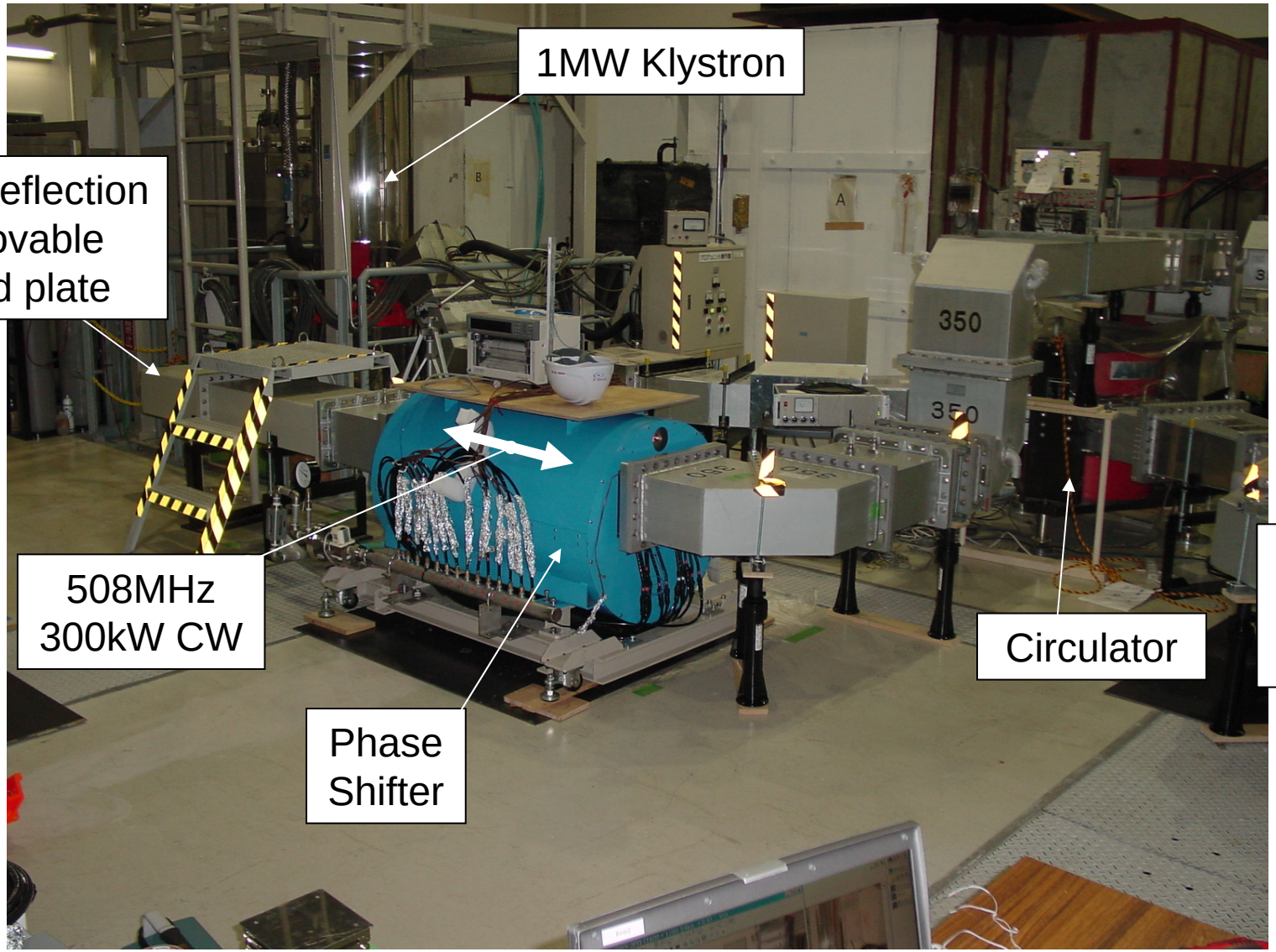
Noise



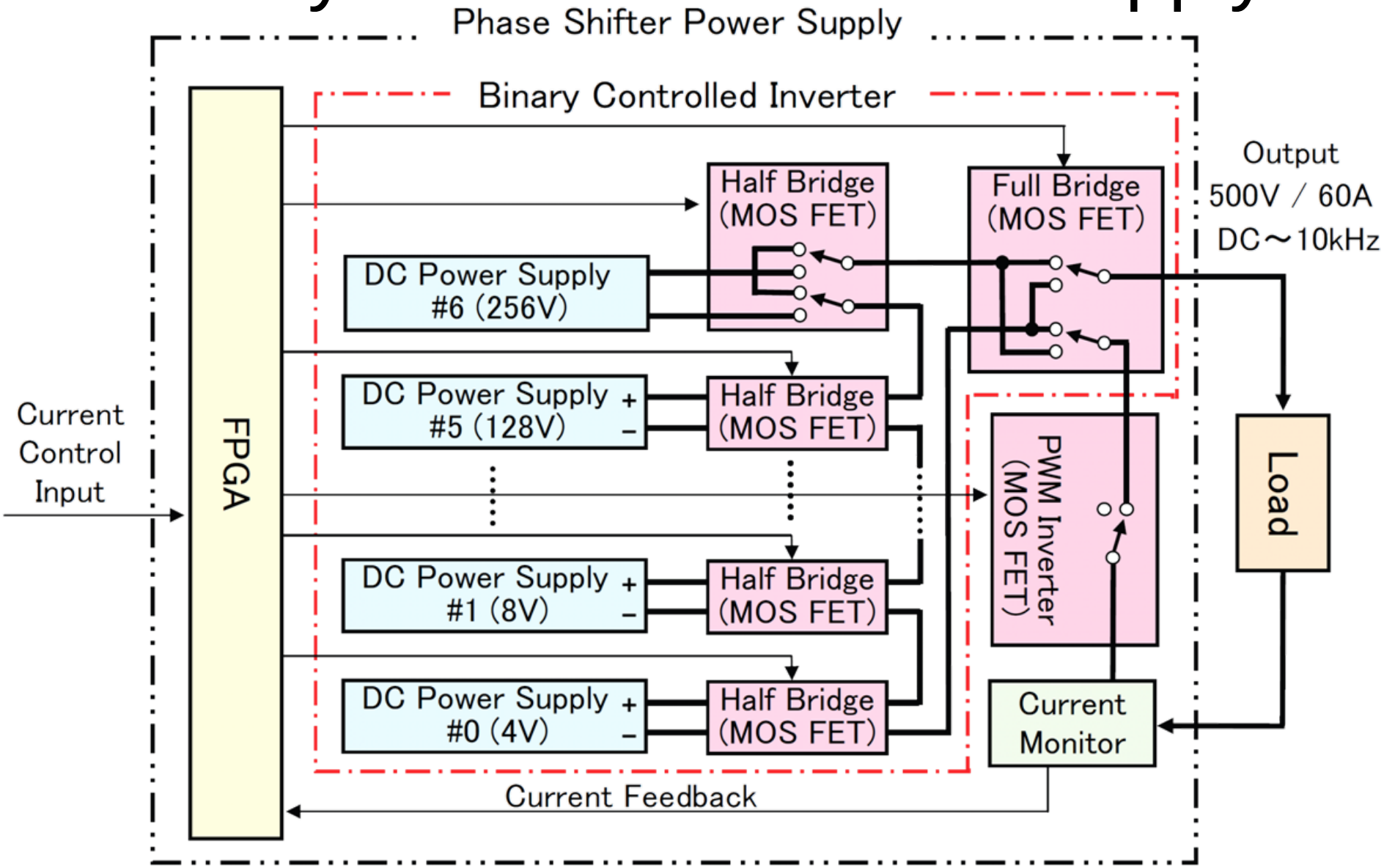


Noise

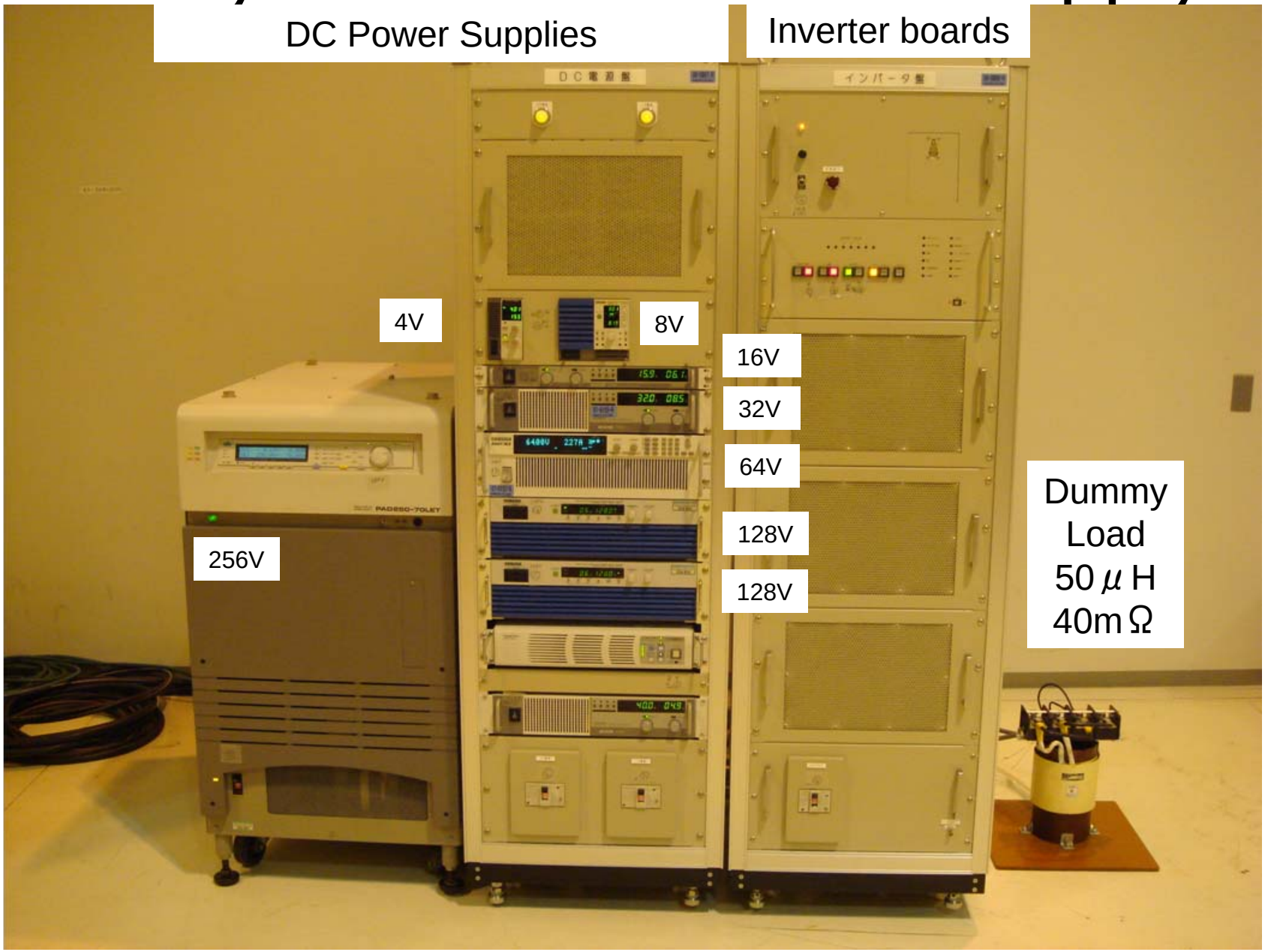
High power test of phase shifter



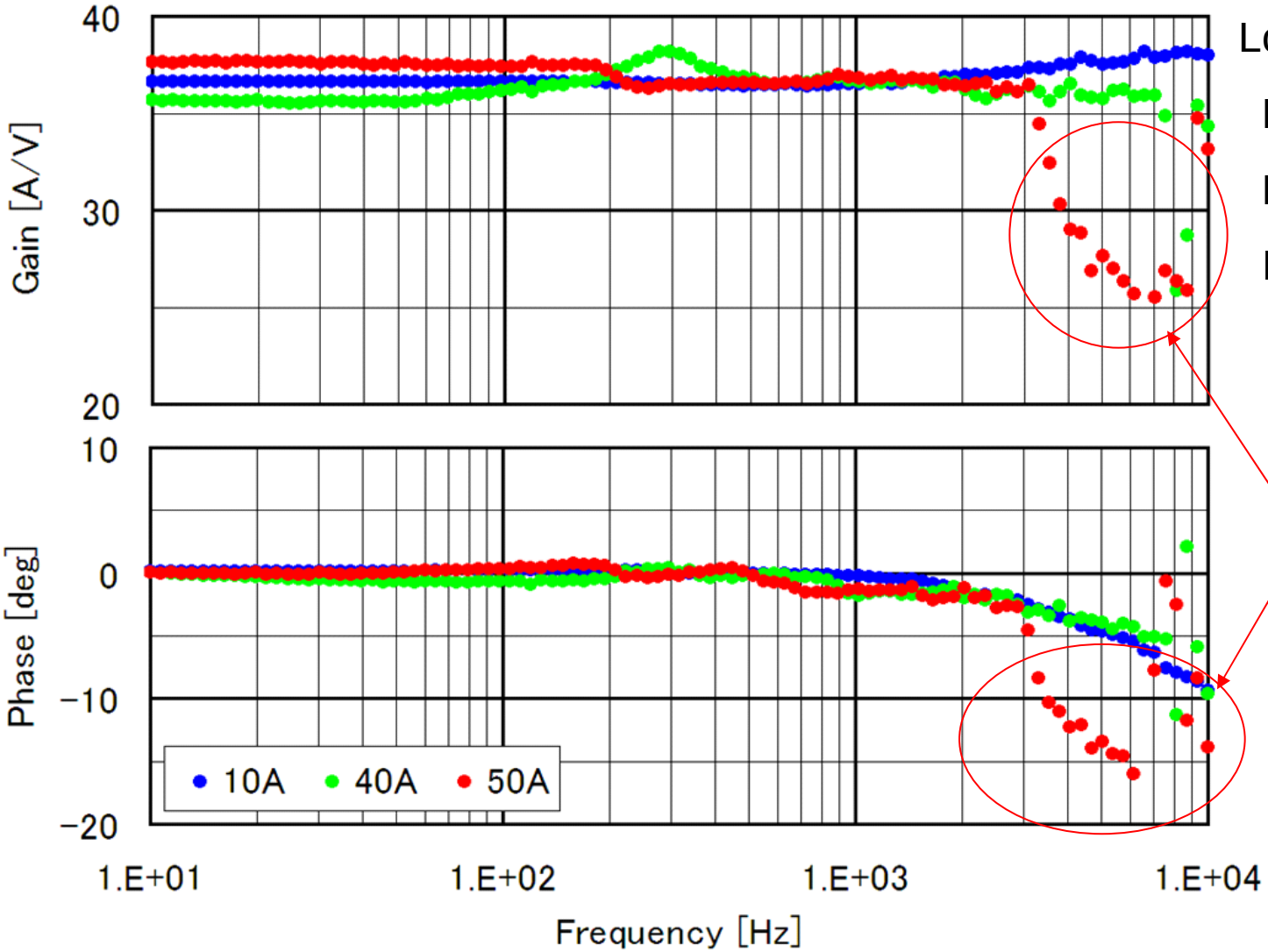
Binary Controlled Current Supply



Binary Controlled Current Supply



Frequency Response of Power Supply for Phase Shifter



Load (Phase Shifter)

R=40mΩ

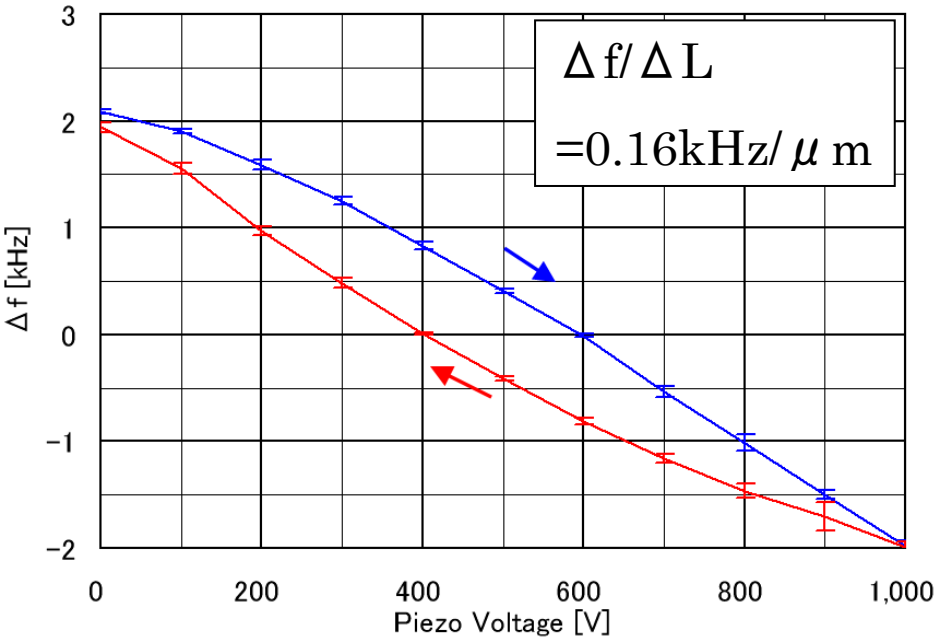
L=100μH

I・Lω=346V

@ 10kHz, I=55A

Need improvement of FPGA program

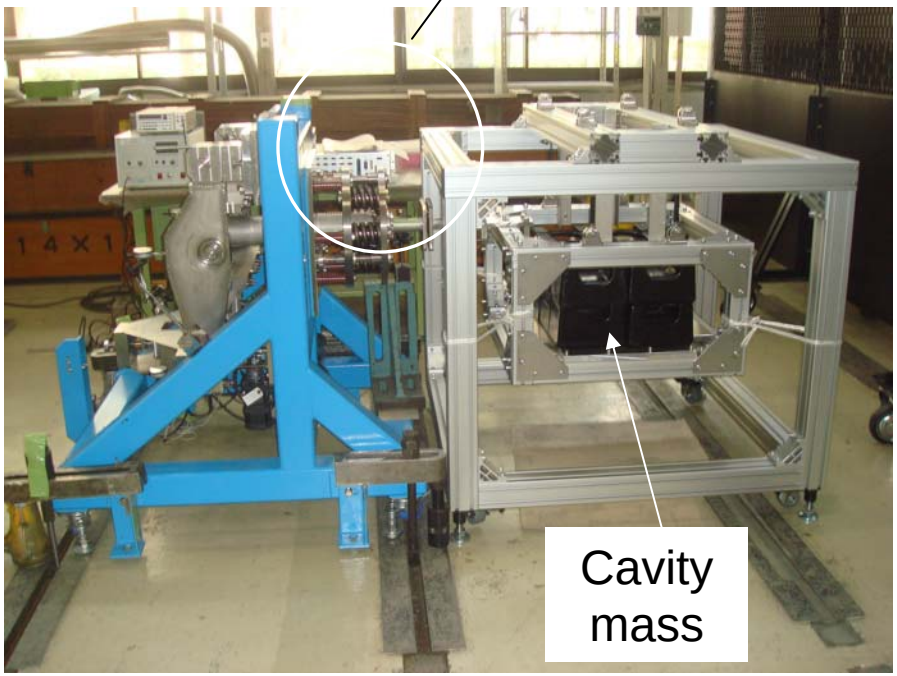
Test of SP8-type tuner

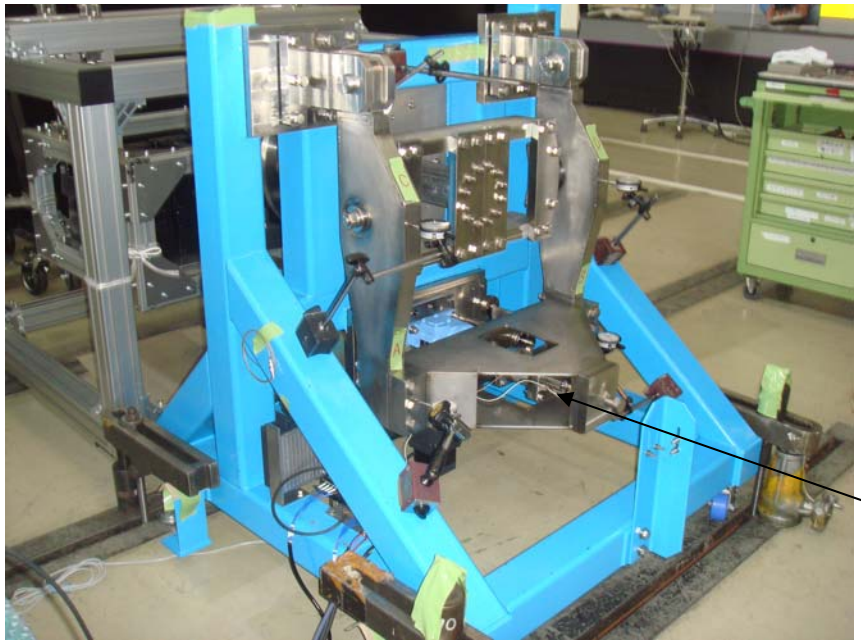


Spring loads

(cavity stiffness)

360kgF/mm





Motor + piezo

Summary

- Available X-ray: 2psec at 8GeV and 0.6psec at 4GeV using mini-pole undulator. (2σp)
- Double-slit method is more practical than asymmetric crystal.
- Key technology: phase stability within ±0.014deg.
- Phase noise source hunting:

  LHe pressure noise < 10 Hz. →can be suppressed with tuner

  Mechanical vibration from 10 to 1kHz.

  →can be suppressed with phase shifter

  Electric noise (Klystron & SG) >1kHz.

  →can ignore by employing one klystron scheme.
- FEM Analysis of mechanical vibration agrees with measured phase noise. →can estimate phase noise from mechanical vibration data.
- PLL simulation using phase suppression function.
- →can realize phase stability within ±0.014deg
- Complete: 300kW CW phase shifter.
- Under test: power supply of phase shifter & SP8 type tuner.