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Overview of Short Pulse X-ray Generation using Crab Cavities at SPring-8

T. Fujita, H. Hanaki, T. Nakazato,
JASRI/SPring-8

K. Hosoyama, K. Akai, K. Ebihara, T. Furuya, K. Hara, T. Honma,
A. Kabe, Y. Kojima, S. Mitsunobu, Y. Morita, H. Nakai, K. Nakanishi,
M. Ono, Y. Yamamoto
KEK

M. Matsuoka, M. Monde, K. Sennyu and T. Yanagisawa
Mitsubishi Heavy Industries, ltd.

Contents

- Short-Pulse Generation Schemes
- Design Concept
- Performance and Requirements
- How to satisfy the requirements
- Hardware R&D
- Summary

Short Pulse X-rays

Storage Ring

- Laser Slicing
  - ALS
  - SLS
  - BESSY-II
- RF Vertical Deflector
  - SPring-8 (plan)
  - APS (plan upgrade)
- Vertical Kicker Magnet
  - SPring-8 (under test)
  - APS (proposed)
- Isochronous-ring

XFEL

- LCLS
- XFEL(SPring-8)
- Euro-XFEL

ERL,

Laser-Plasma Acceleration

SPring-8 Campus

- 8GeV, 100mA, ε_x : 3.4nmrad
- 30m long straight sections
- > 60 beamlines
- > 5000 hours/year operation @ FY2009
- RF frequency : 508.58MHz
- natural bunch length : 26ps (2σ)
- 37ps (2σ)@ 1.5mA/bunch

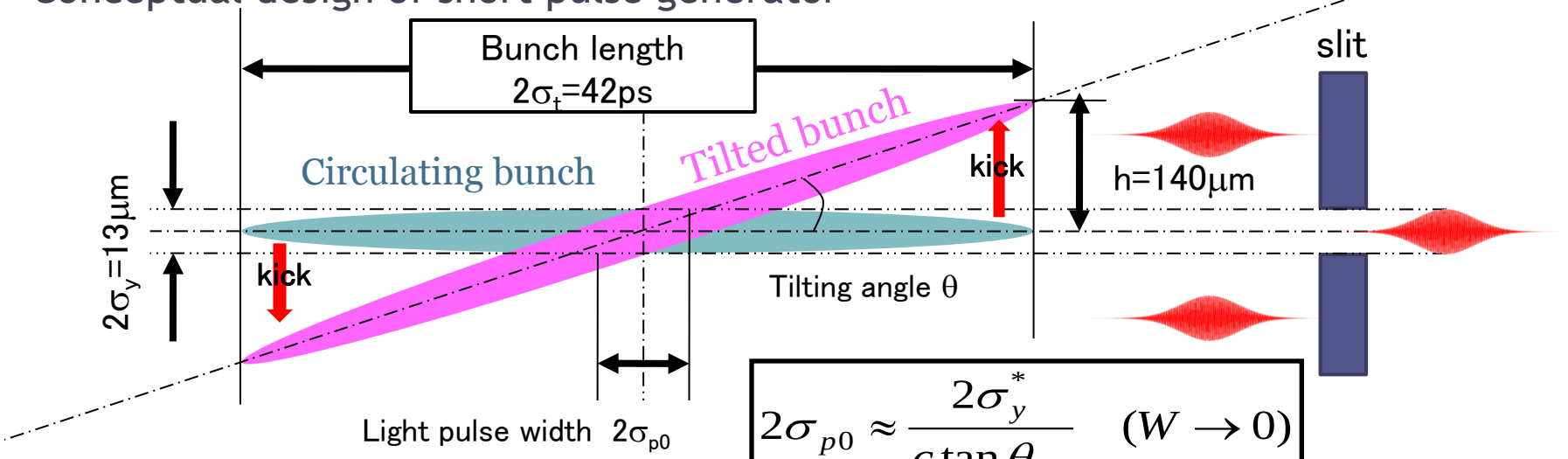
Design concept

- High repetition and stable X-ray
- No disturbance to other users
  - 30m Long Straight Sections of SPring-8
- Minimum R&D
  - KEKB crab cavity

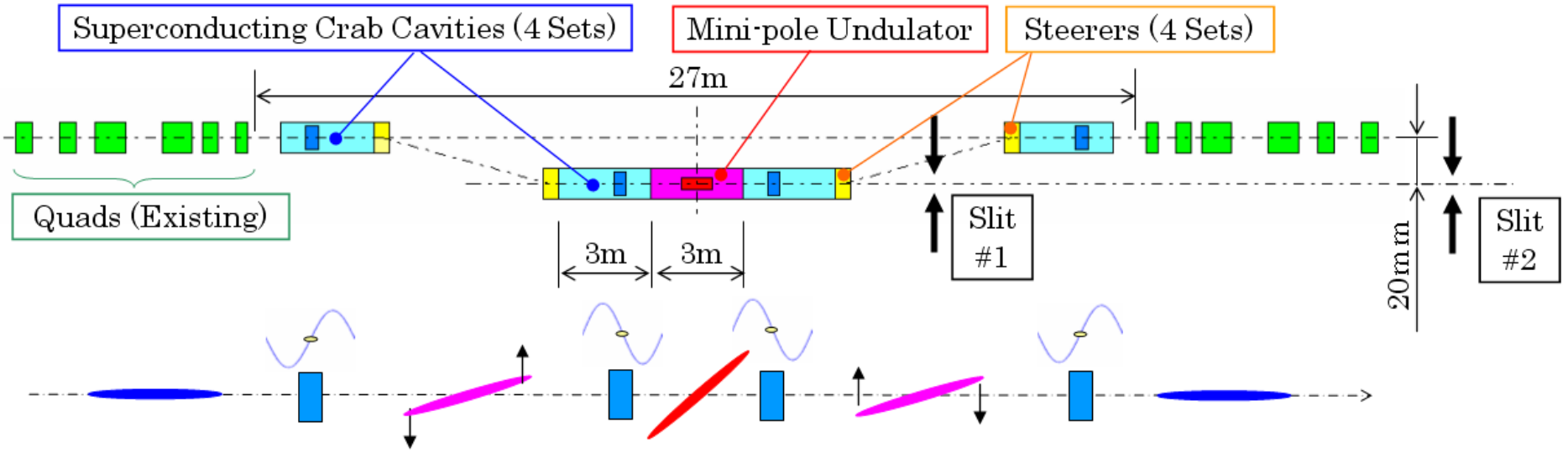
➡ Almost same frequency : SPring-8 ⇔ KEKB

➡ Quick construction

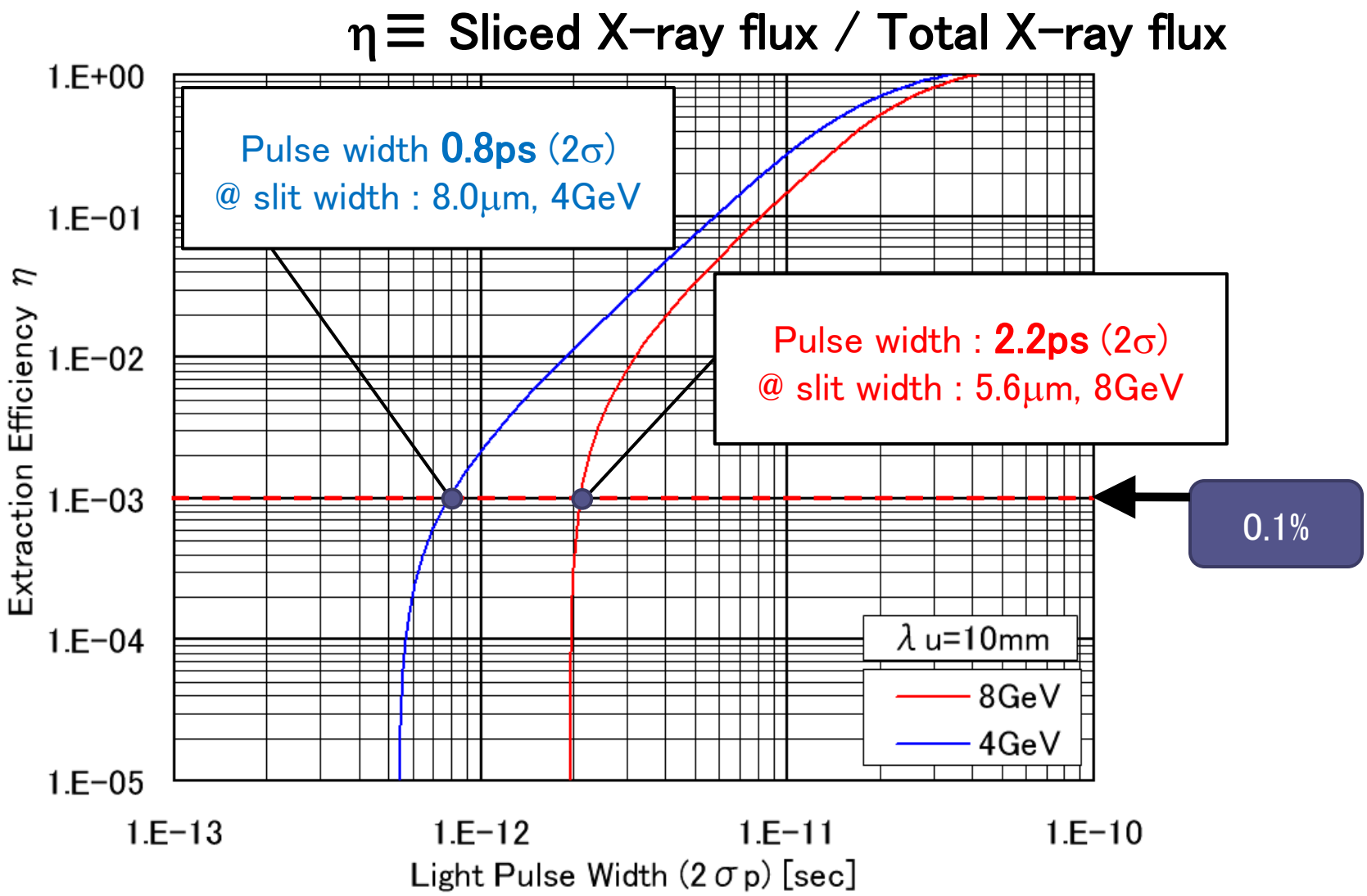
Conceptual design of short pulse generator



$$2\sigma_{p0} \approx \frac{2\sigma_y^*}{c\tan\theta_{tilt}} \quad (W \to 0)$$
$$= 1.9\text{psec}$$



Pulse width and extraction efficiency



RF parameters of the crab cavity

Cavity type	Superconducting crab cavity
Number of cavities	4
Deflecting frequency	508.58 MHz
Deflecting mode	TM110
R/Q	46.7Ω
Loaded Q	10^5
RF power	150kW / cavity
Length of drift space	10 m
Deflecting voltage	1.67 MV
Tilt angle	0.022 rad @ 8 GeV

508.887MHz @ KEKB

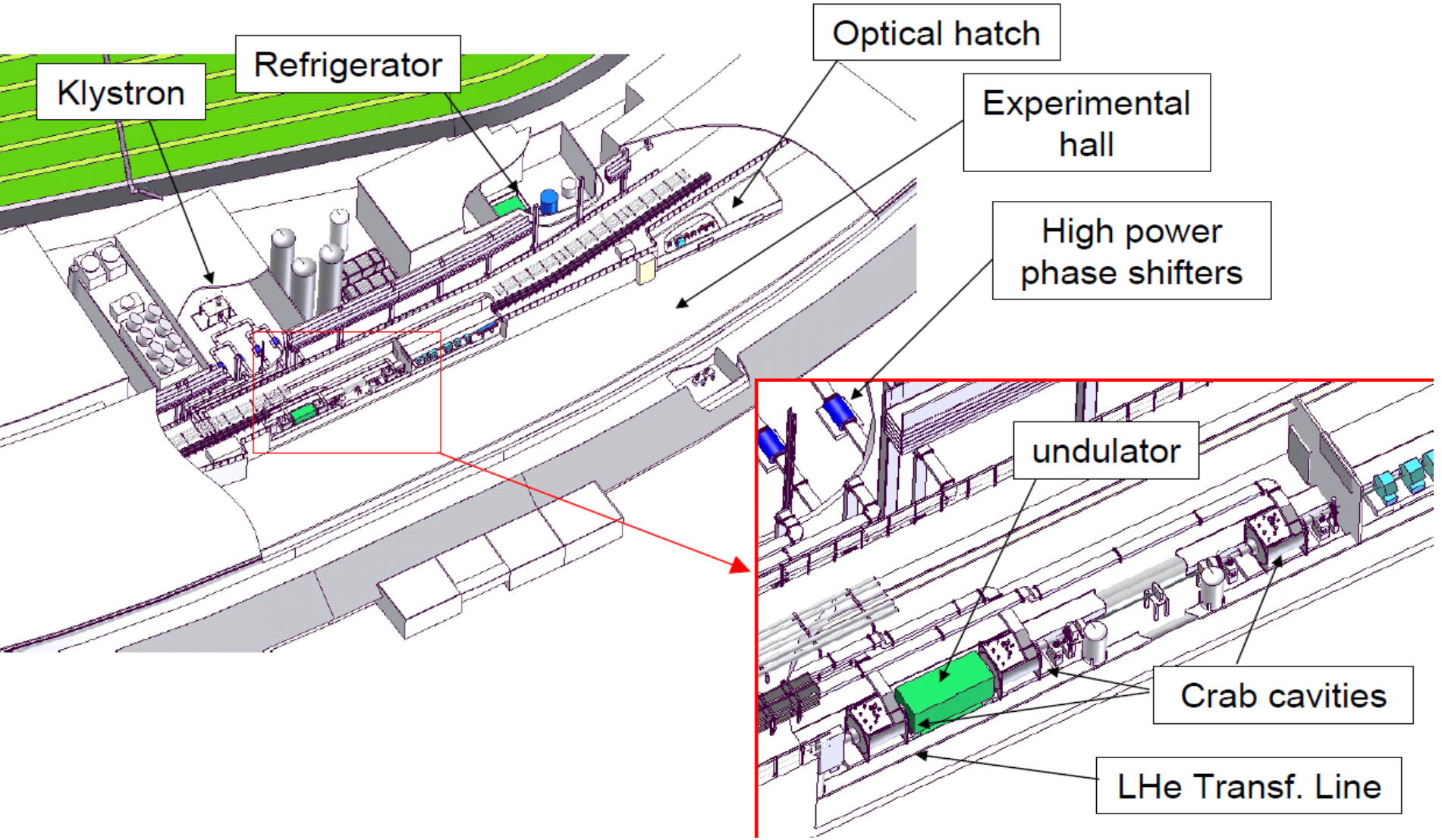
to suppress phase fluctuation

Cryogenics Parameters

Item	Loss / Unit	Number of Items	Power loss
Cavity loss	60 W / cavity	× 4 cavities	240 W
Cryostat loss	20 W / cavity	× 4 cryostats	80 W
Transfer line loss	1 W / m	50 m	50 W
Joint loss	2 W / joint	× 4 joints	8 W
Required refrigeration power (@$V_{\perp}$ = 1.67MV, $Q_0 = 10^9$, 4.2 K)			378 W

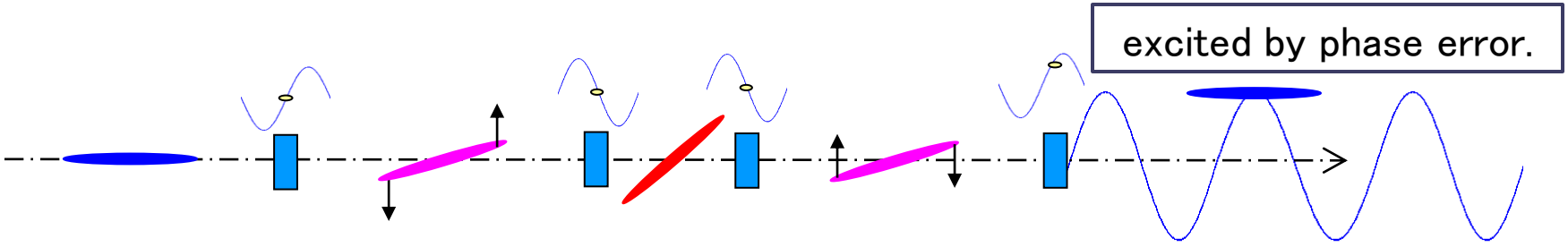
Operate crab cavities at 4.2K, at 1atm.

Layout of the Short Pulse X-ray Generator



Requirement

- For coexistence with short pulse user and other users.
- Vertical deflection must be canceled downstream the generator.



- Required Specification

  Vertical oscillation < 1μm,

  ∵ $2\sigma_y$=13μm @ LSS

  = relative phase noise among 4 cavities < 14mdeg (1σ)

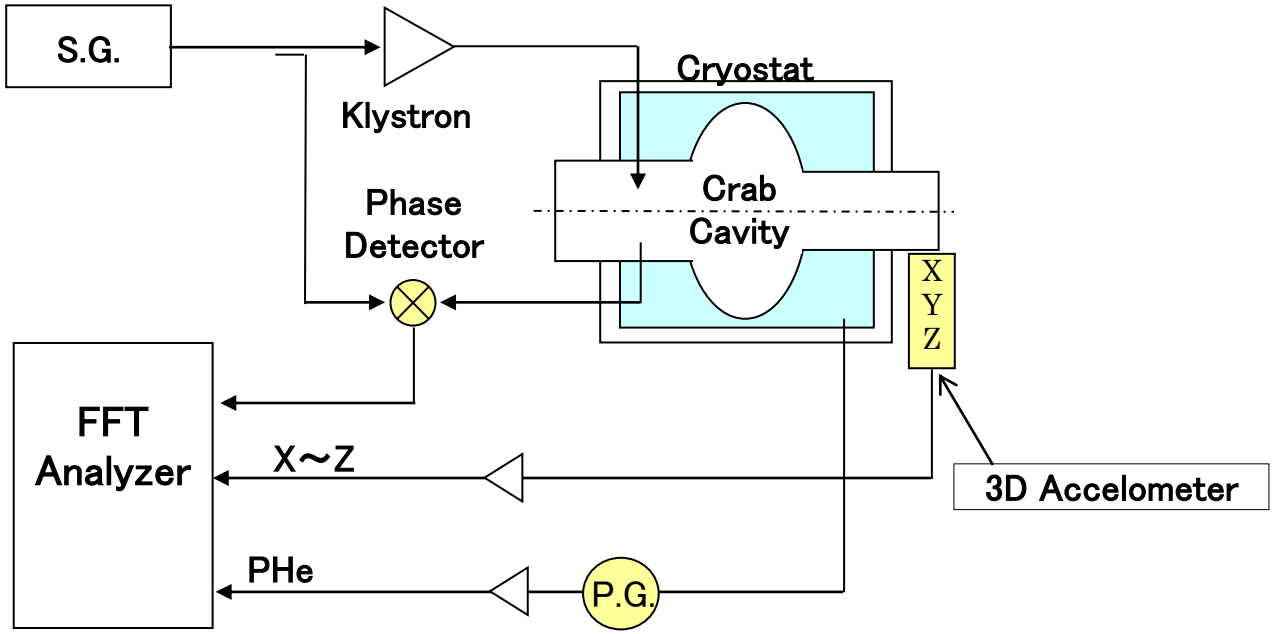
$$\theta = eV_{\perp}\sin(\omega\Delta t)/E$$

$$y = \frac{\sqrt{\beta_1\beta_2}}{2\sin\pi\nu}\theta\cos(\pi\nu - |\psi_1 - \psi_2|)$$

- Measure phase noise of the KEKB crab cavity and its source.

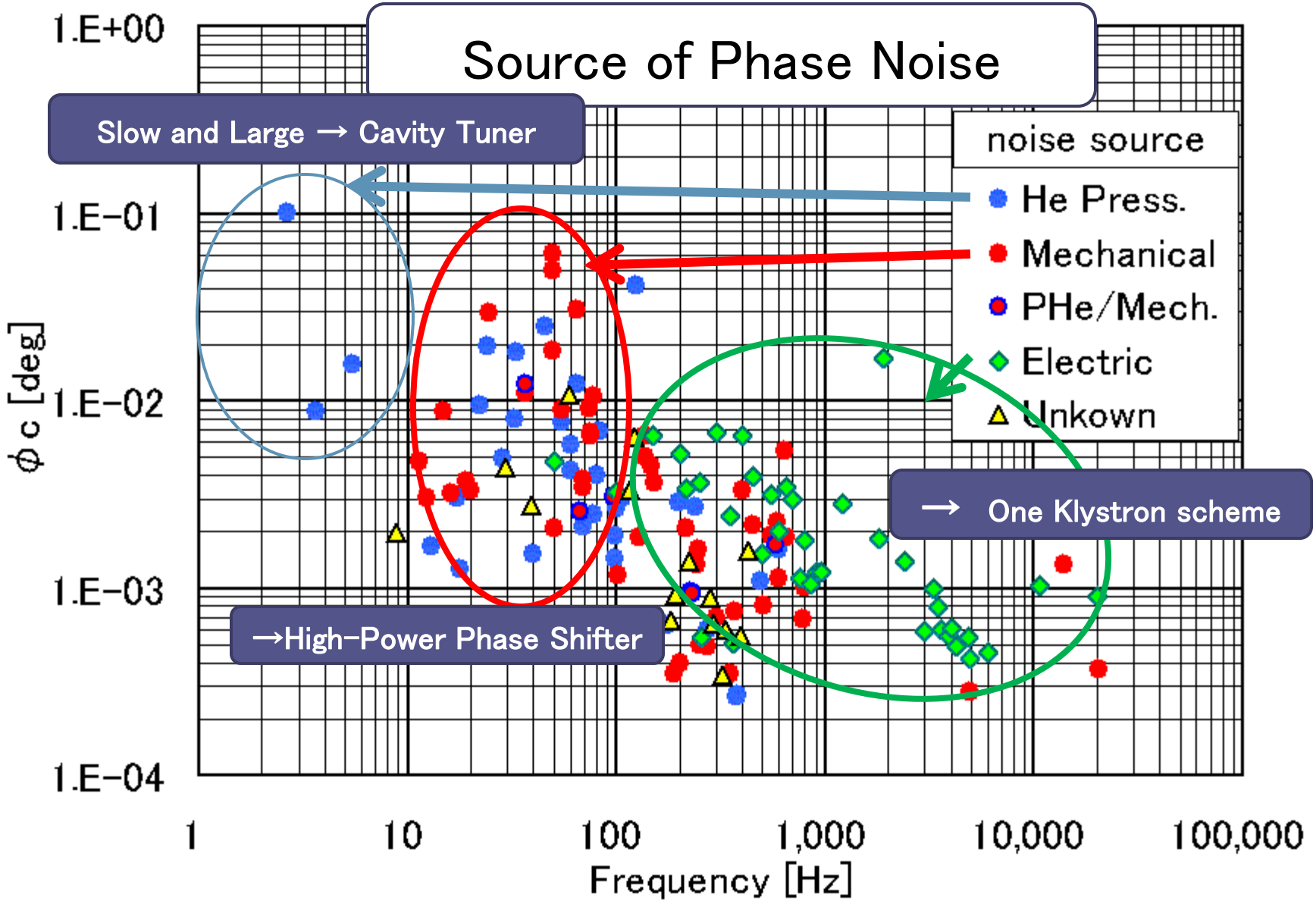
Source Hunting!

Source Hunting of Phase Vibration at KEK

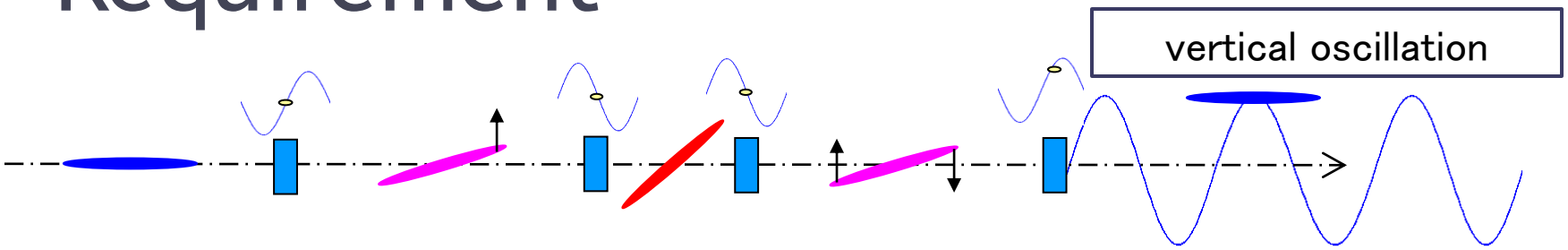


- Measure
  - phase noise
  - Mechanical vibration
  - LHe pressure variation
- Analyze coherence among data
- Identify vibration source of cavity phase oscillation

Source of Phase Noise



Requirement

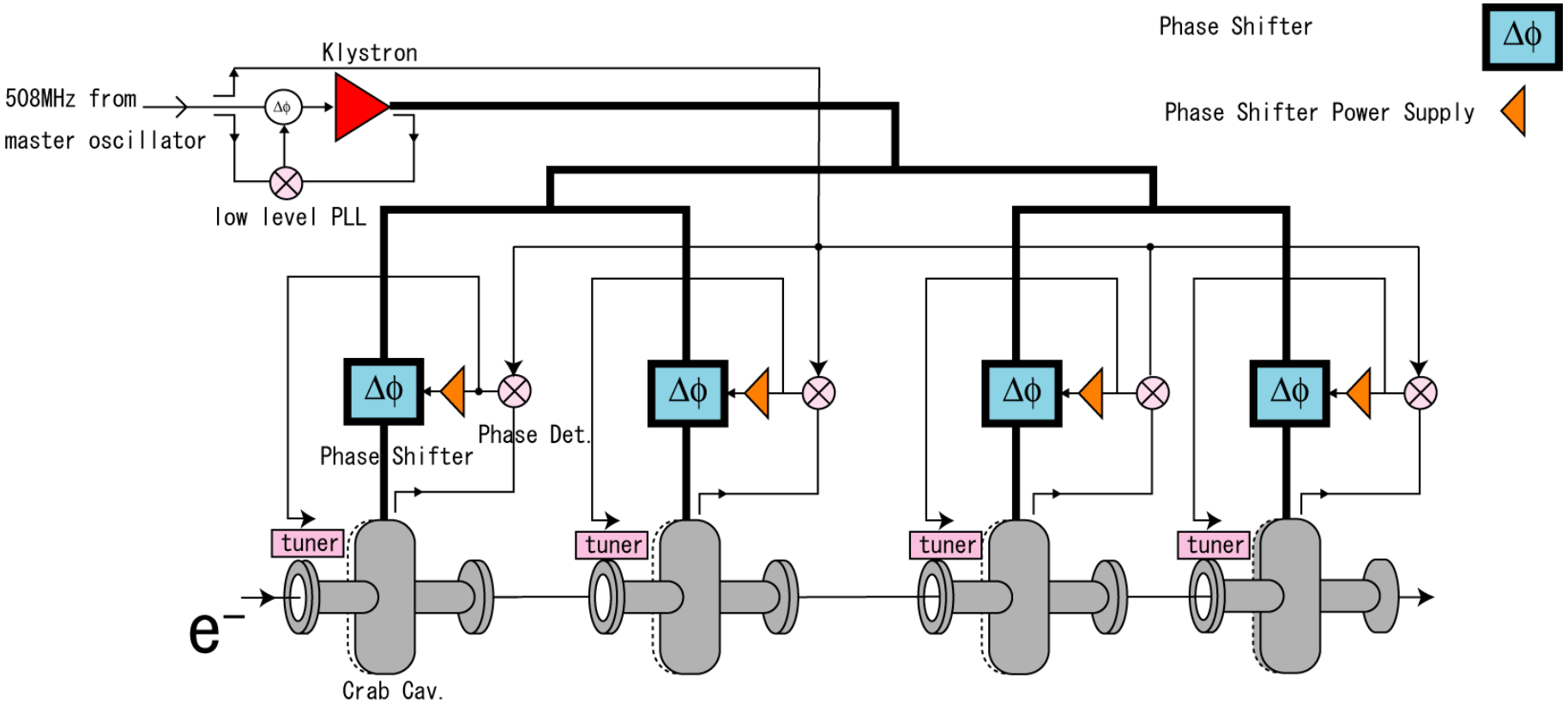


Vertical oscillation < 1μm,
= relative phase noise among 4 cavities < 14mdeg (1σ)

✔Measure phase noise of the KEKB crab cavity and its source

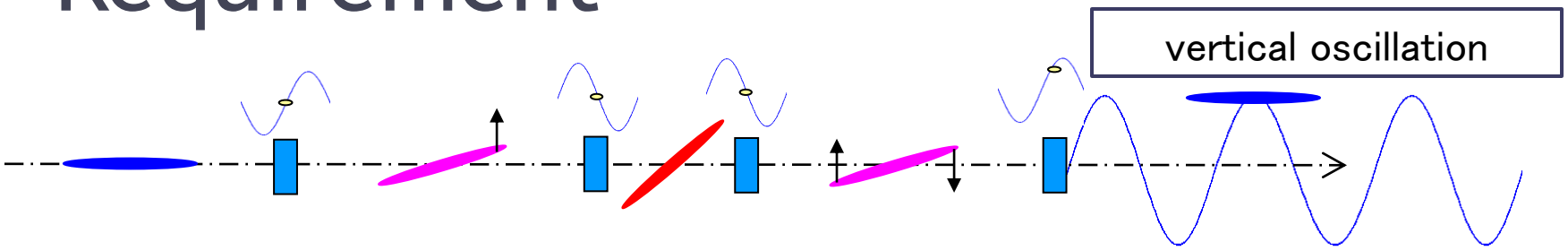
- Fast phase noise : Common phase noise is not problem
  → one klystron drives 4 cavities
- Individual phase noise : High-power phase shifter and frequency tuner were developed for phase noise of individual cavities.

One klystron scheme



With this scheme, phase fluctuation due to klystron become ignorable.

Requirement



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✔Measure phase noise of the KEKB crab cavity and its source

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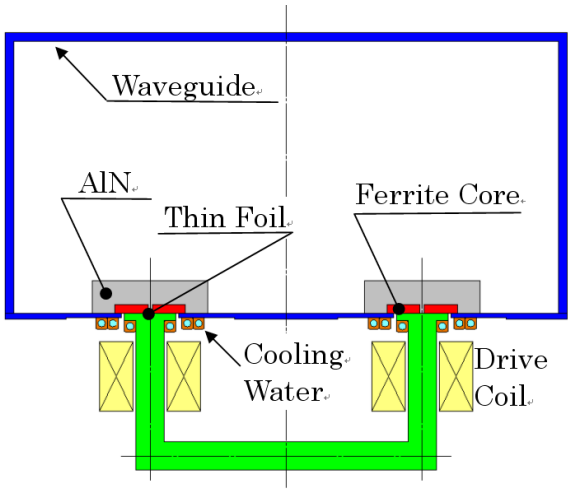
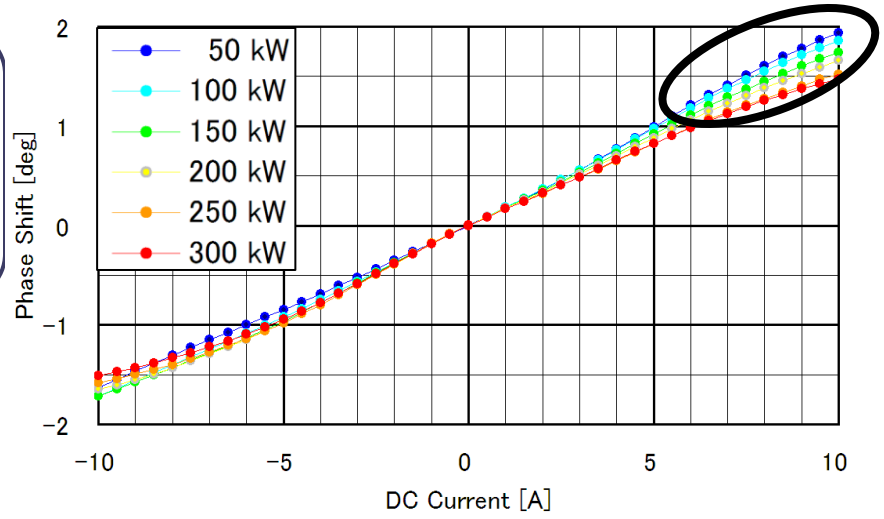
- Phase noise of individual cavity is independently suppressed by
  - High-Power Phase Shifter
  - Frequency Tuner

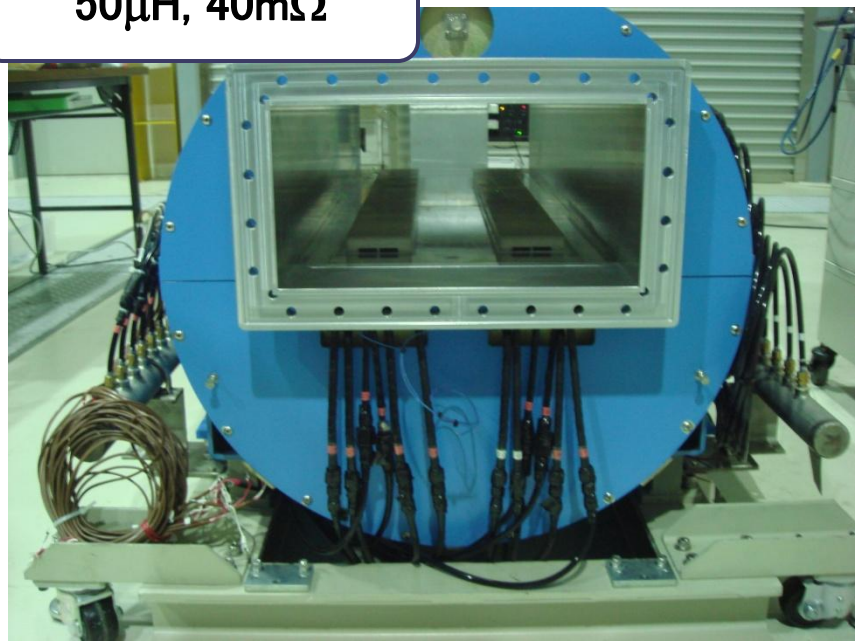
High-Power Phase Shifter

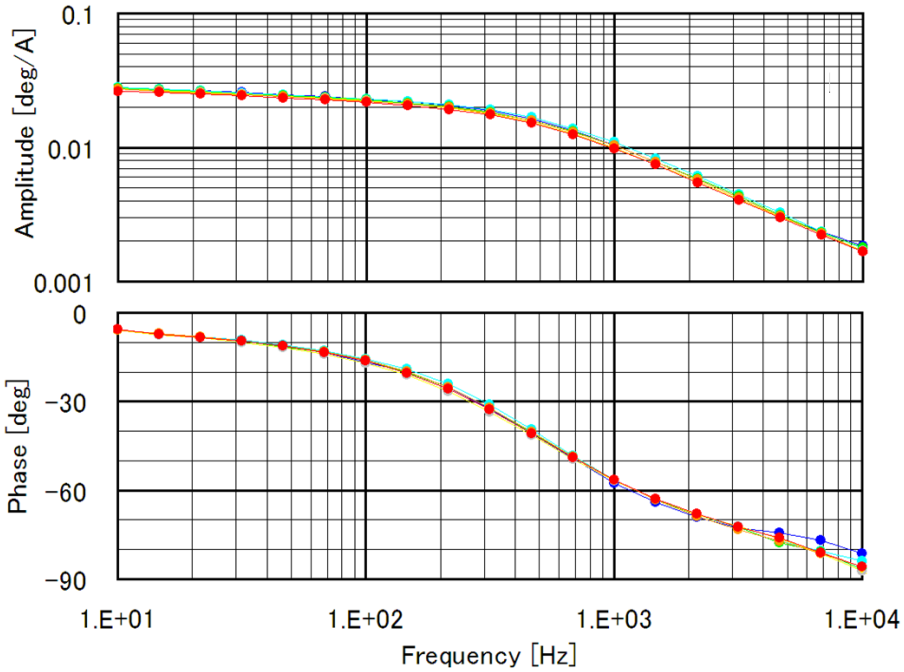


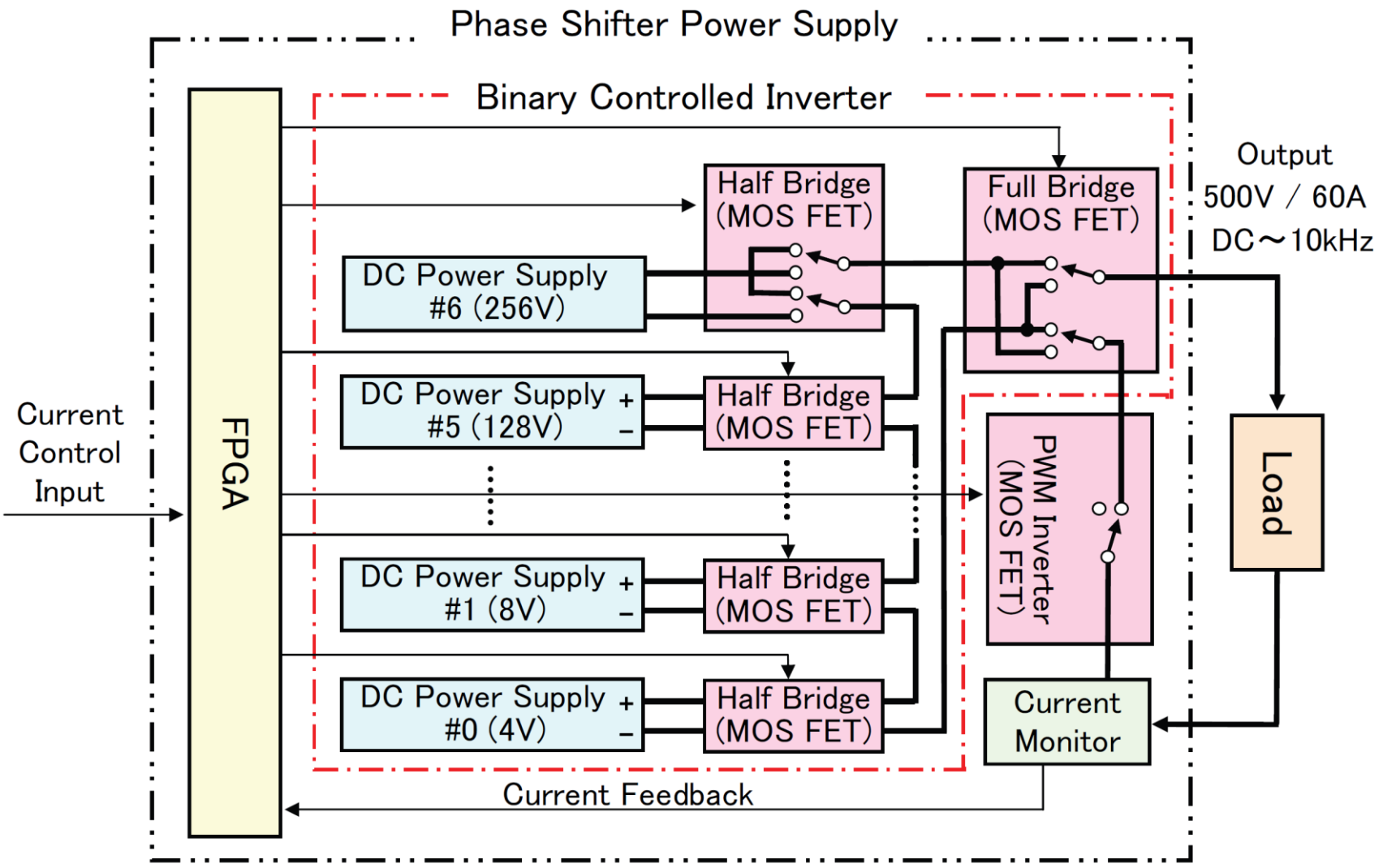
300kW fwd+bwd
±1.5deg
DC-1kHz



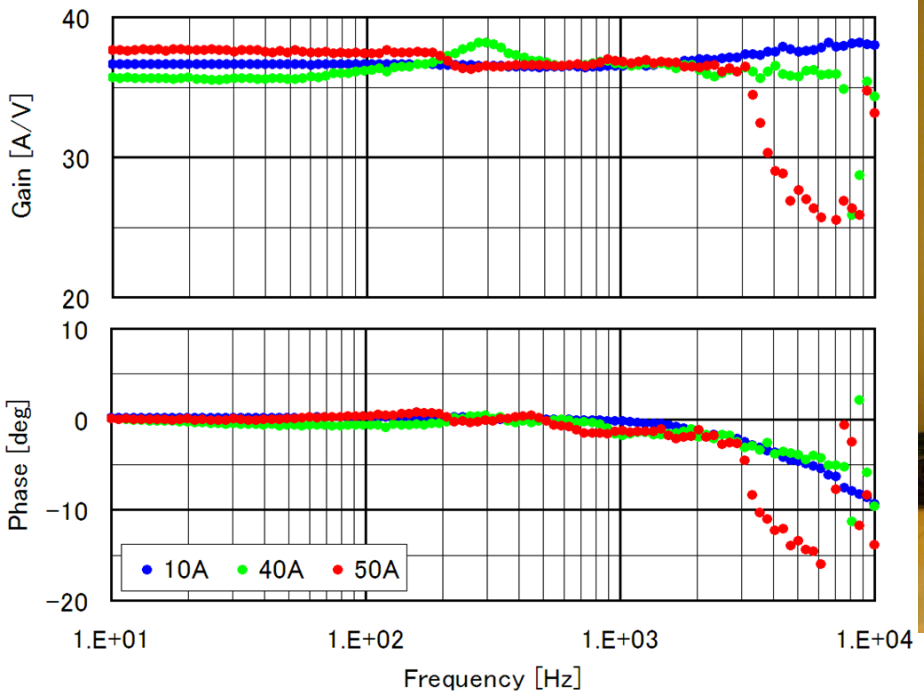
50μH, 40mΩ

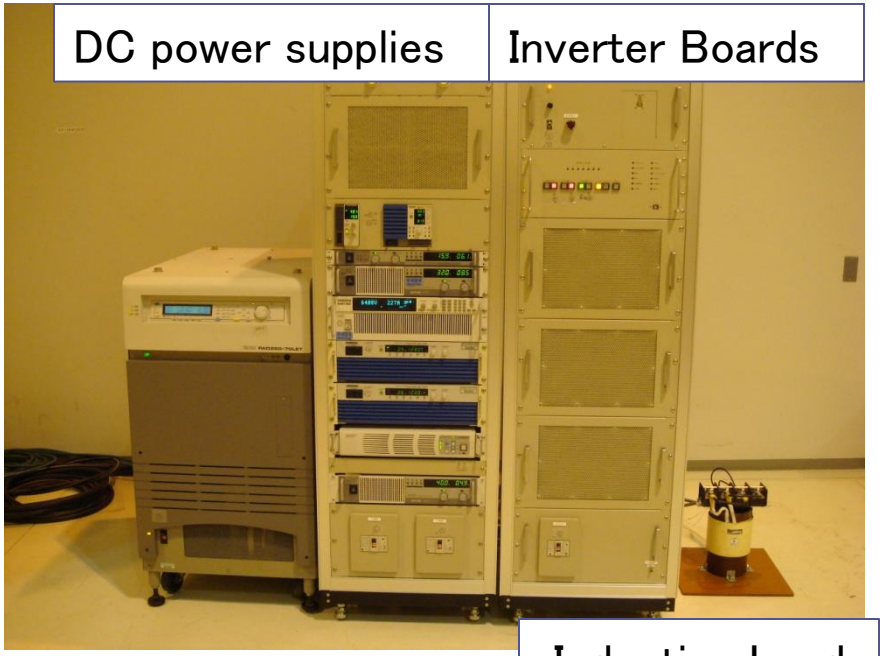





Phase Shifter Power Supply
Binary Controlled Inverter
FPGA
Current
Control
Input
DC Power Supply
#6 (256V)
DC Power Supply
#5 (128V)
DC Power Supply
#1 (8V)
DC Power Supply
#0 (4V)
Half Bridge
(MOS FET)
Half Bridge
(MOS FET)
Half Bridge
(MOS FET)
Half Bridge
(MOS FET)
Full Bridge
(MOS FET)
PWM Inverter
(MOS FET)
Output
500V / 60A
DC～10kHz
Load
Current
Monitor
Current Feedback

Power Supply of the Phase Shifter (Preliminary)



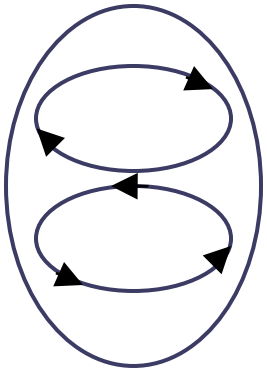


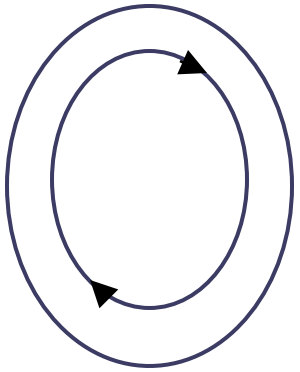
Inductive Load
(dummy)
(50μH, 40mΩ)

Frequency response is almost good.
Behavior at high current output is unstable.
→ need improvement of the circuit

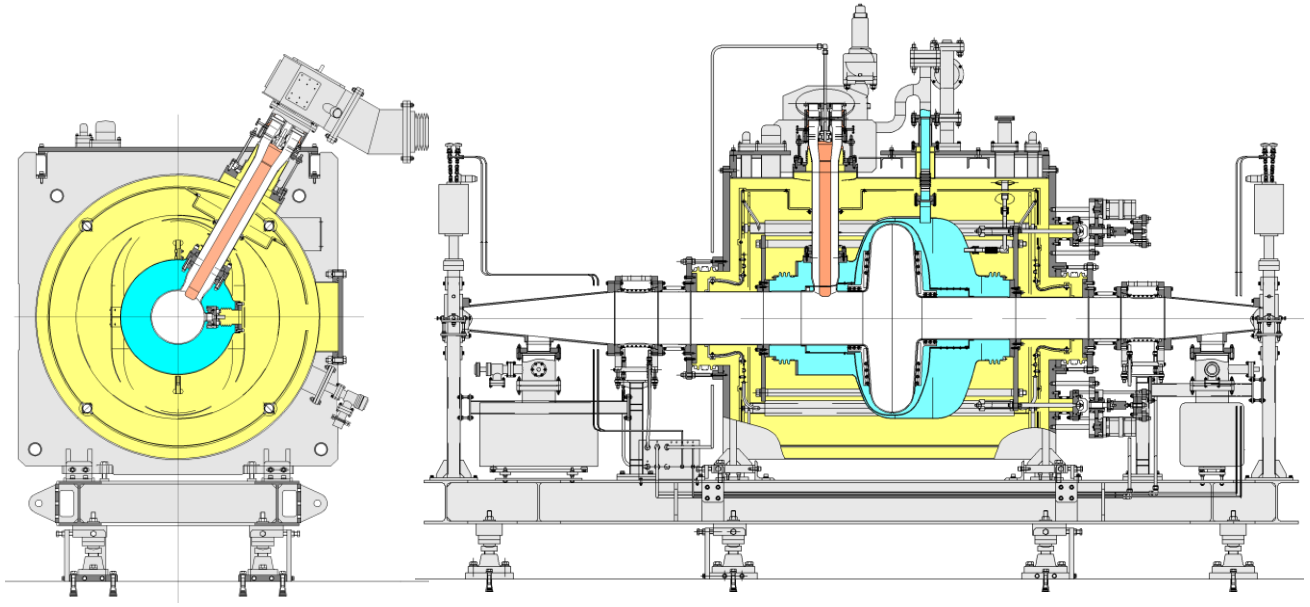
Extraction of Lower-order mode （ LOM ）

- LOM(TM010)
  - Q_L < 10,000-
- Input coupler (for TM110)
  - →extract LOM
- Can simplify tuner structure

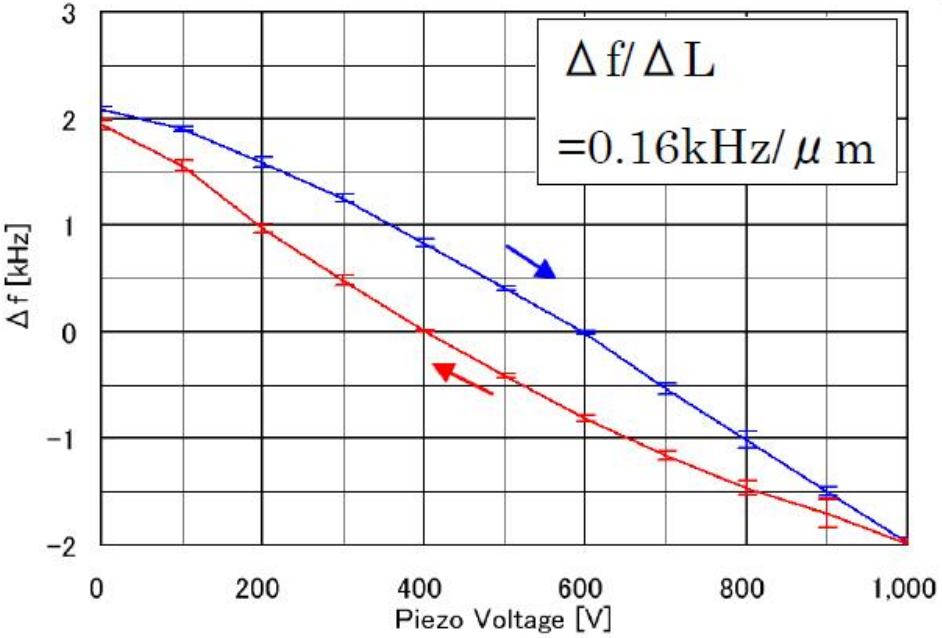




TM110 Deflecting mode	TM010 LOM (unwanted)



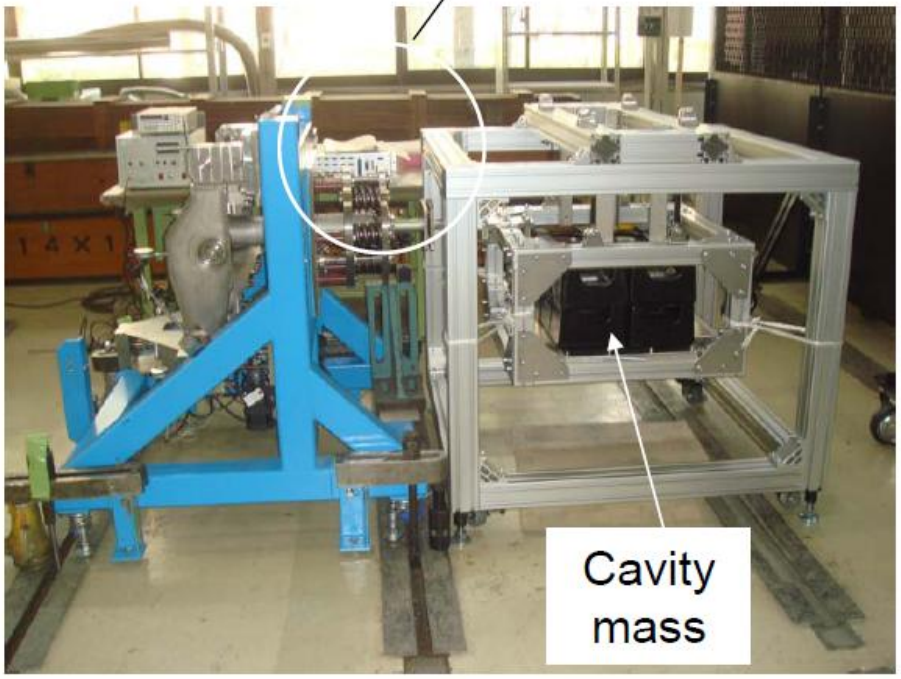
Test of SP8-type tuner

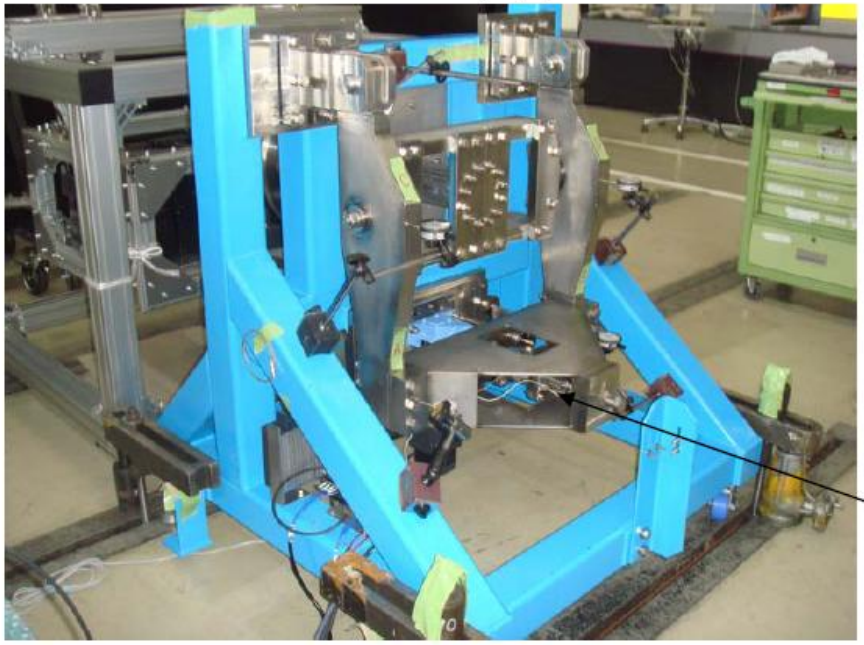


Spring loads

(cavity stiffness)

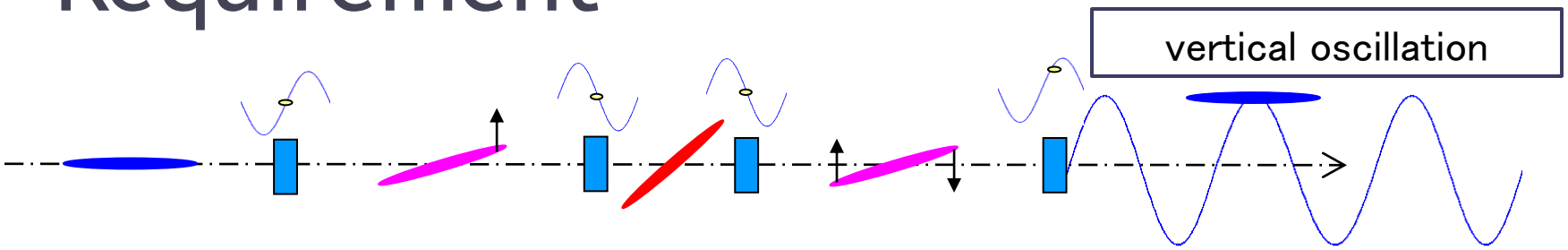
360kgF/mm





Motor + piezo

Requirement



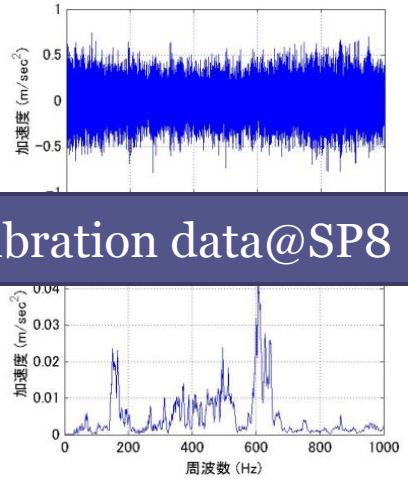
Vertical oscillation < 1μm,
= relative phase noise among 4 cavities < 14mdeg (1σ)

✔Measure phase noise of the KEKB crab cavity and its source

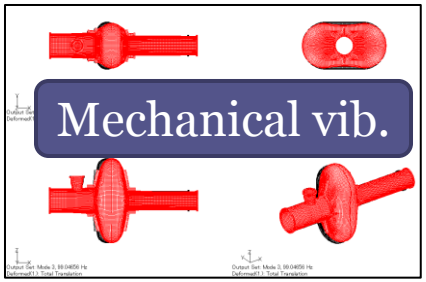
✔Fast phase noise : Common phase noise is not problem
→ one klystron drives 4 cavities

✔Phase noise of individual cavity is independently suppressed by
- ✔High-Power Phase Shifter
- ✔Frequency Tuner

Phase fluctuation of 14mdeg is possible?

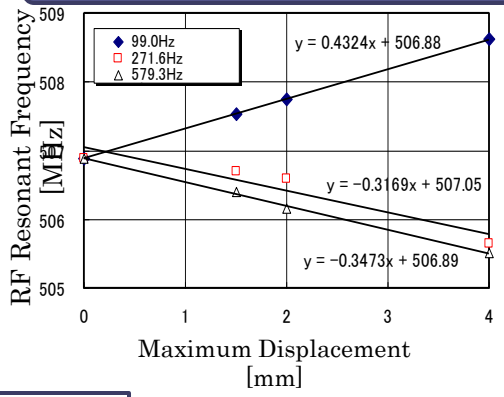


vibration data@SP8

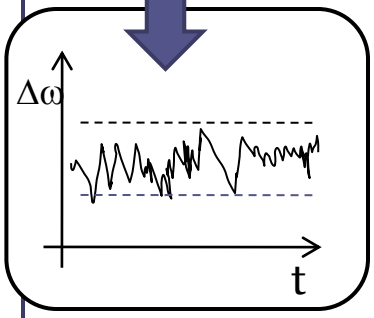


Mechanical vib.

Freq. sensitivity to the mode



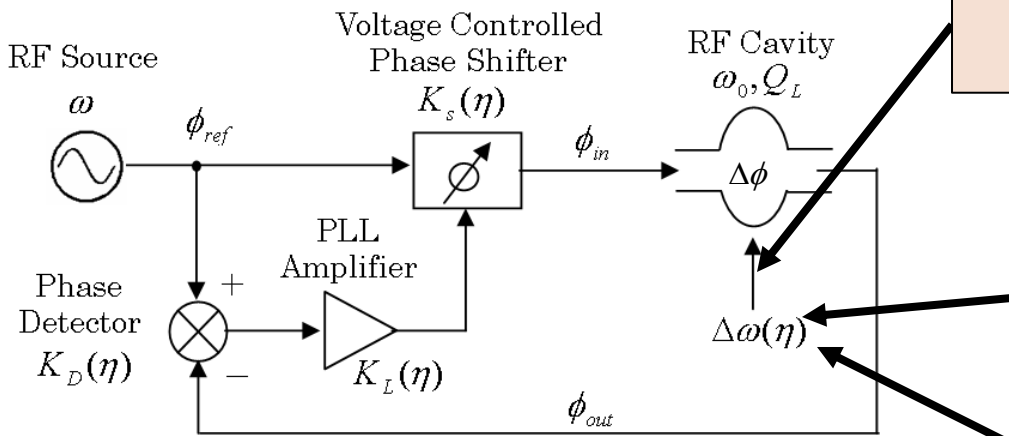
- Preparation for PLL simulation
  - Vibration data (floor, beam pipe)
  - Mechanical vibration mode of cavity (FEM analysis)
  - Sensitivity of RF $f_{Resonant}$ to cavity shape deformation



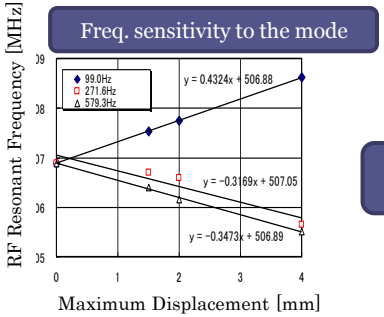
Freq. fluc. due to vib.@SP8

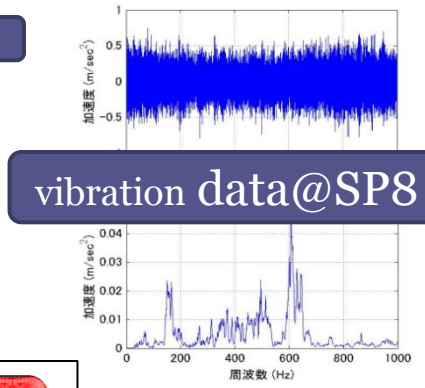
PLL simulation

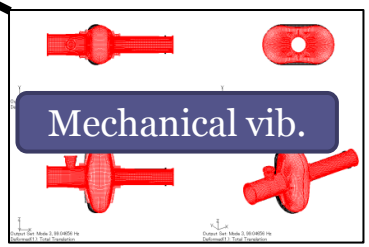
Simulation result of phase noise suppression by PLL

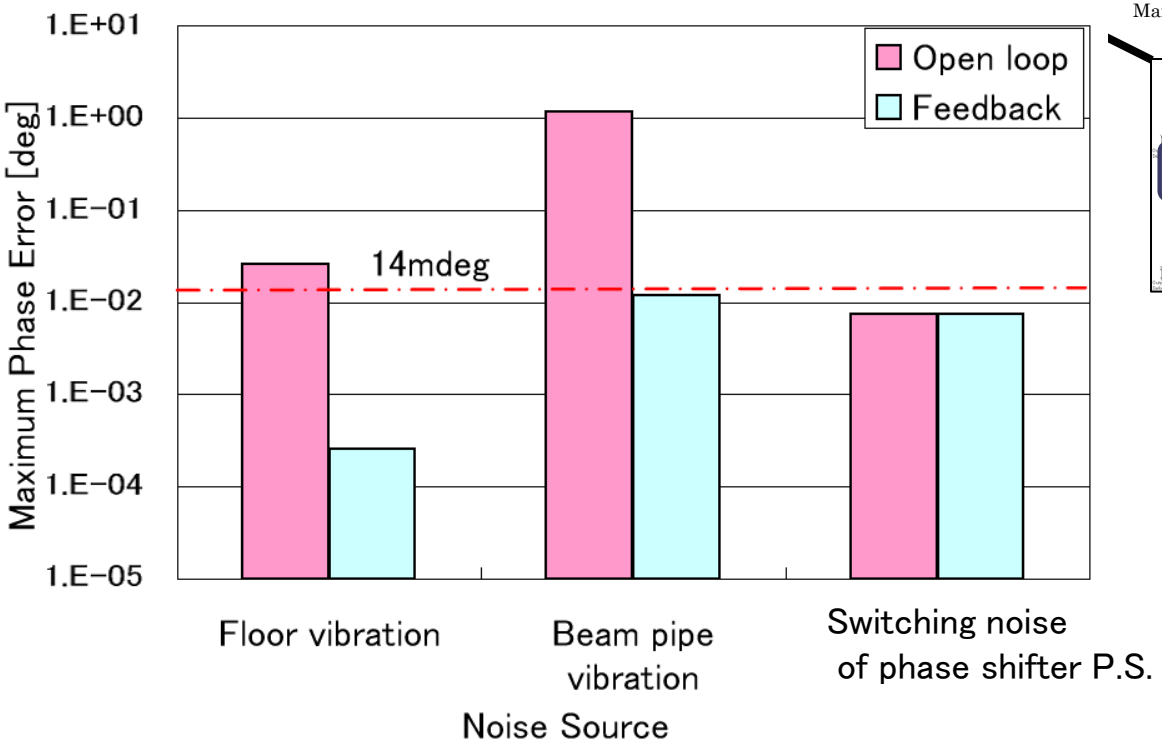


Phase response
of dynamic freq. change









Phase Noise < 14mdeg
is possible !

Summary

- 2.2ps(2σ) is available (0.8ps at 4GeV)
  using mini-pole undulator.
  - Four crab cavities, Slits, Bump orbit
- Key subject : suppress phase fluctuation < 14mdeg
- Phase noise and Countermeasures
  - LHe pressure vib. < 10Hz : SP8 type cavity tuner
  - Mechanical vib. 10Hz-100Hz : 300kW phase shifter, power supply
  - Electric noise > 100Hz : One klystron drives 4 crab cavities
- Feature
  - Coupling out LOM with input coupler
  - High reliability by simplified cavity tuner
- PLL simulation : 14mdeg phase stability is possible!
- R&D phase for the short pulse generation complete!