

# Mechanical Stability for New Generation Light Sources



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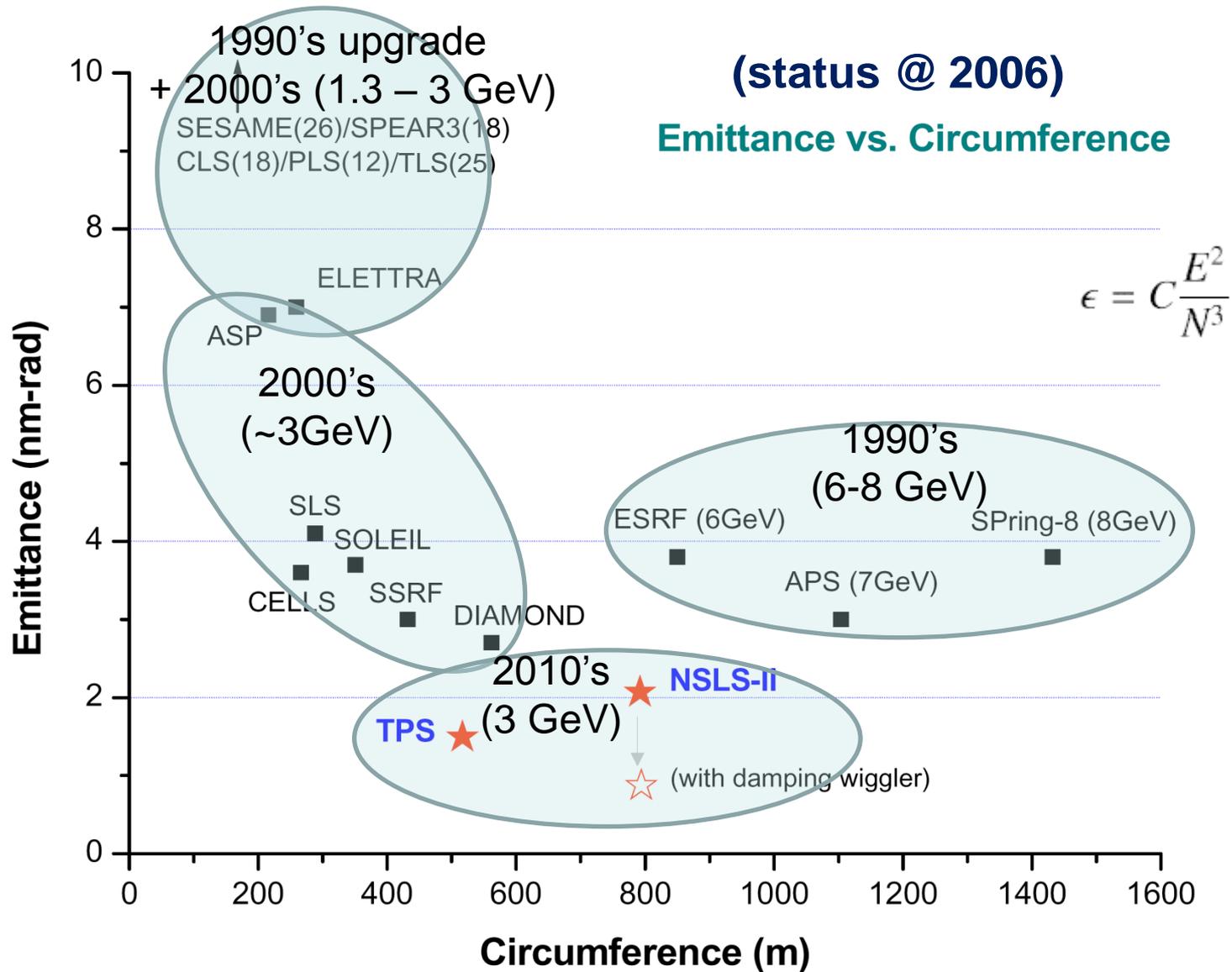
# Outline

- I. Introduction
- II. Mechanical Effects on Beam Orbit and Beam Size
- III. Thermo-Mechanical Effects
- IV. The Mag-Girder Assembly
- V. Summary

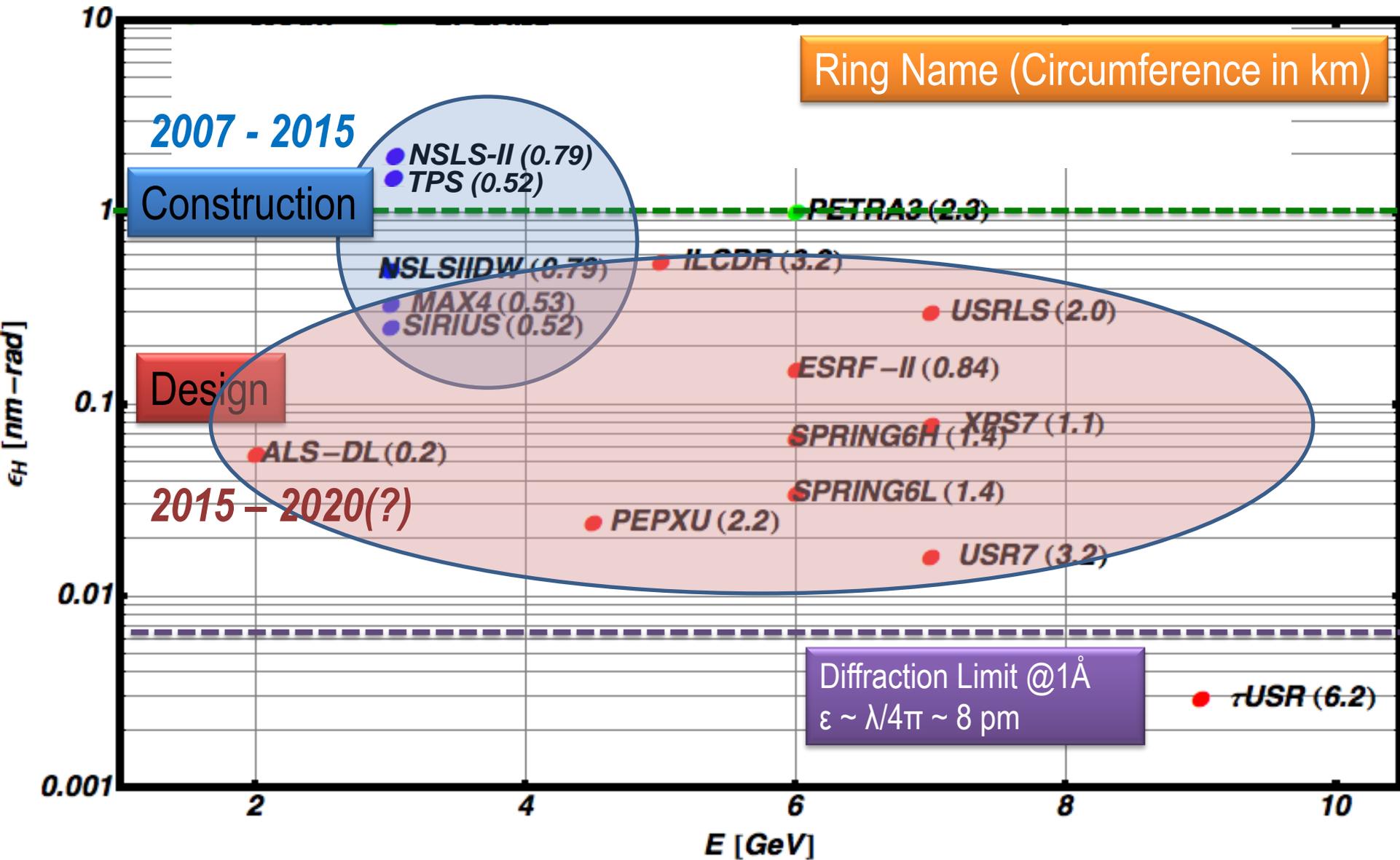
# I. Introduction

## New Generation Light Sources

# NSRRC *Emittance vs. Circumference*

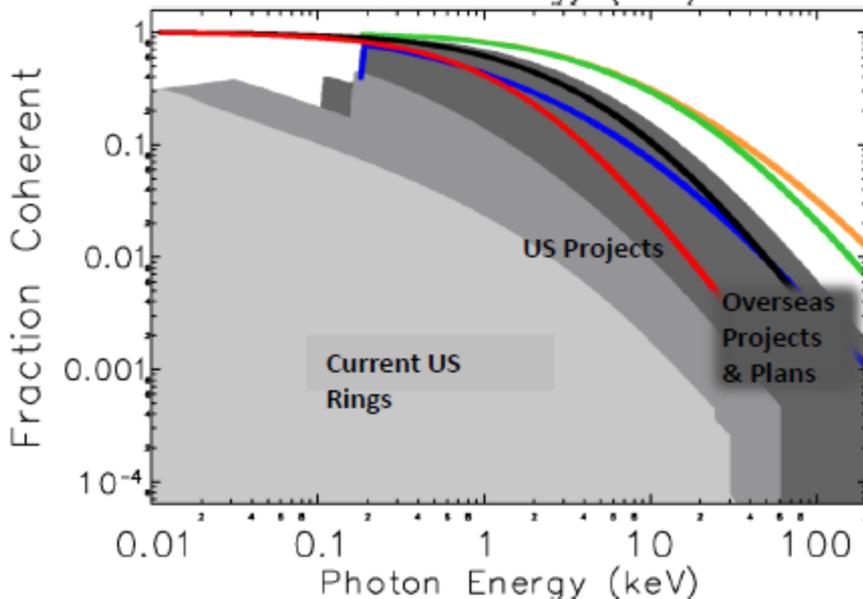
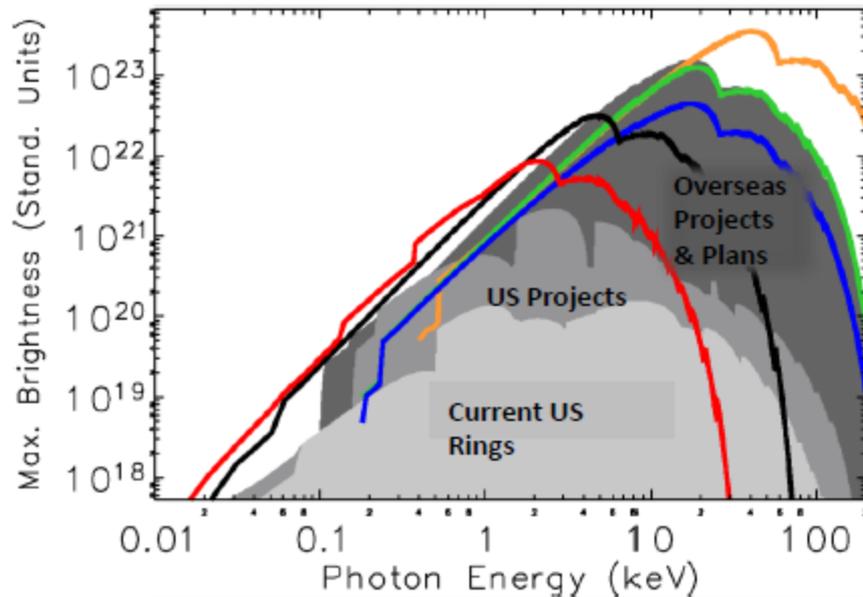


# Ring Horizontal Emittance vs Ring Energy



# Brightness and Coherence of Future Rings

M. Borland for BESAC Meeting, July 2013



## DLSR Designs

- Competitive pressure drives optimization
- Upgrades & greenfield facilities possible
- 2-3 orders of magnitude improved brightness over existing rings

## DLSR Science complements FELs, offering

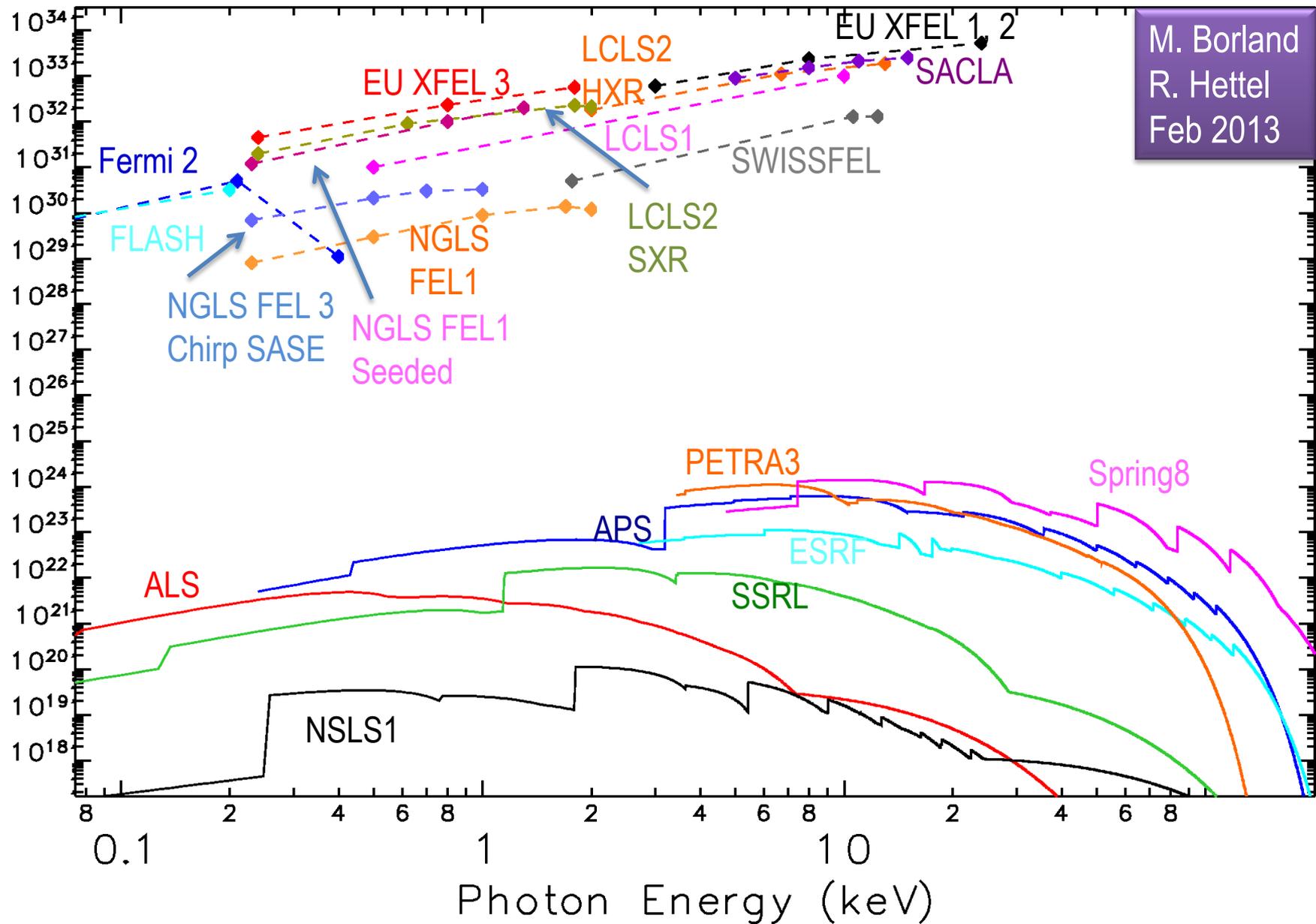
- Similar high transverse coherence
- Long pulses with high repetition rate
- High average / low peak power
- High stability
- High capacity

### Legend:

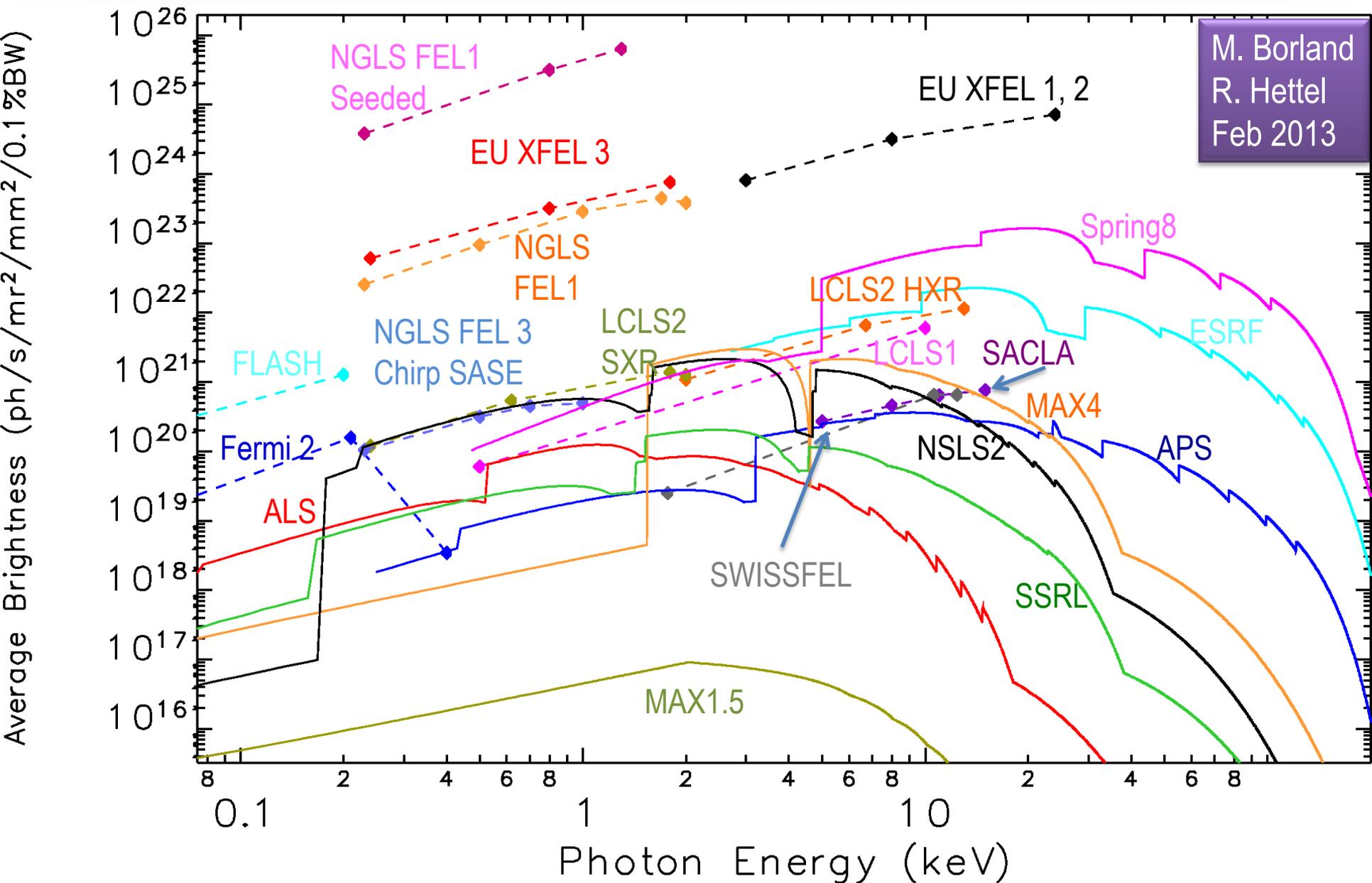
- 0.2km/2GeV: ALS-II, 52 pm
- 0.8km/3GeV: NSLS-III, 30 pm
- 1.1km/6GeV: APS-II, 80 pm
- 2.2km/6GeV: PEP-X, 5 pm
- 6.2km/9GeV: tauUSR, 3 pm

# Peak Brightness: SASE FELs & Existing Rings

Peak Brightness ( $\text{ph/s/mm}^2/\text{mm}^2/0.1\% \text{BW}$ )



# Ave Brightness: SASE FELs & Upgraded Rings



# Brief Summary

## (New Generation Light Sources)

### 1. Two major types

- x-ray FEL (long Linac + multi-Undulators)
- storage rings ( $1 \lesssim \varepsilon \lesssim 10$  nm-rad, DBA/TBA)  
( $\varepsilon \ll 1$  nm-rad, MBA)

### 2. Features

- small beam size
- small beam divergence
- (with small gap undulators/ coherent light)
- highly stable “pointing” beam (beam based alignment)

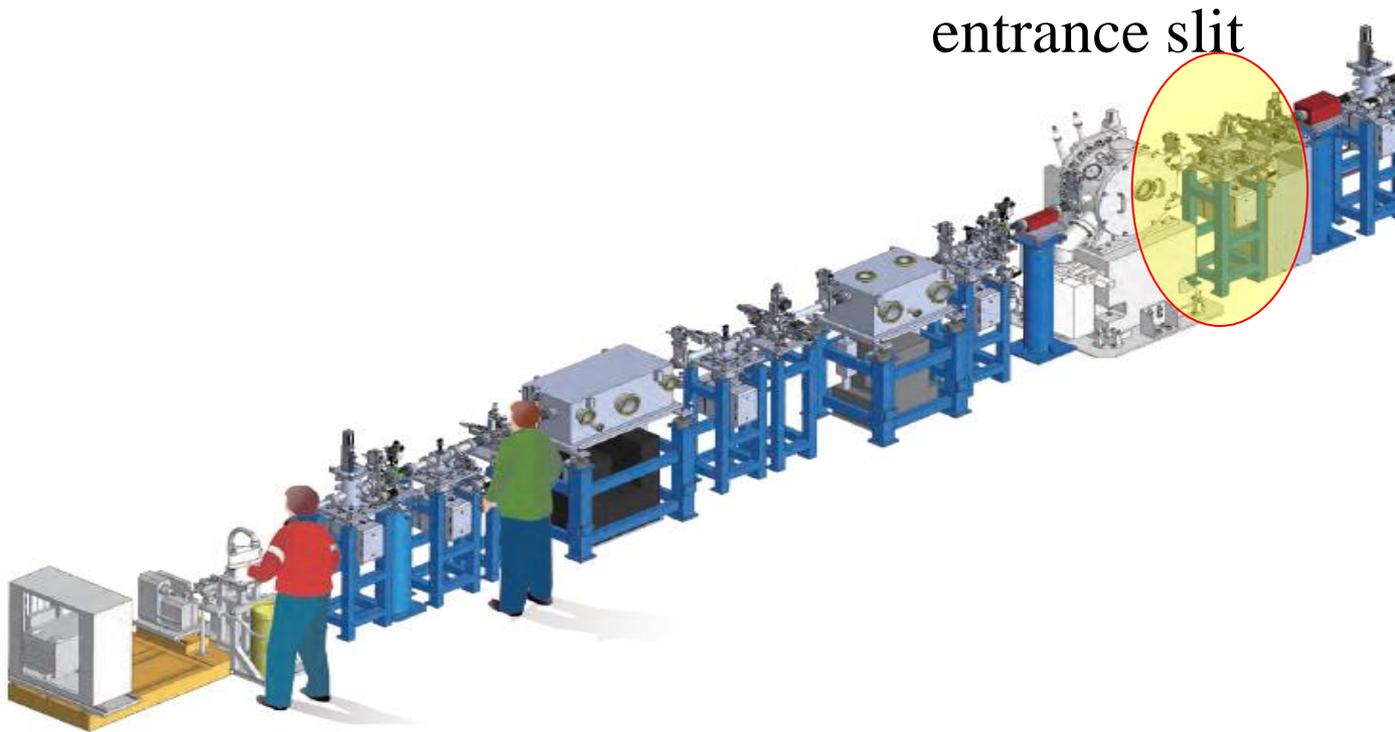
(APS Goal)

|            |         | AC rms Motion, 0.01-200 Hz |                     | Long-term drift (One Week) |                     |
|------------|---------|----------------------------|---------------------|----------------------------|---------------------|
|            |         | $\mu\text{m rms}$          | $\mu\text{rad rms}$ | $\mu\text{m rms}$          | $\mu\text{rad rms}$ |
| Horizontal | Present | 5.0                        | 0.85                | 7.0                        | 1.4                 |
|            | Upgrade | 3.0                        | 0.53                | 5.0                        | 1.0                 |
| Vertical   | Present | 1.6                        | 0.80                | 5.0                        | 2.5                 |
|            | Upgrade | 0.42                       | 0.22                | 1.0                        | 0.5                 |

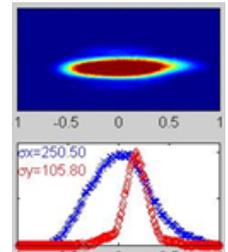
# I. Introduction

## Beam Stability Requirement

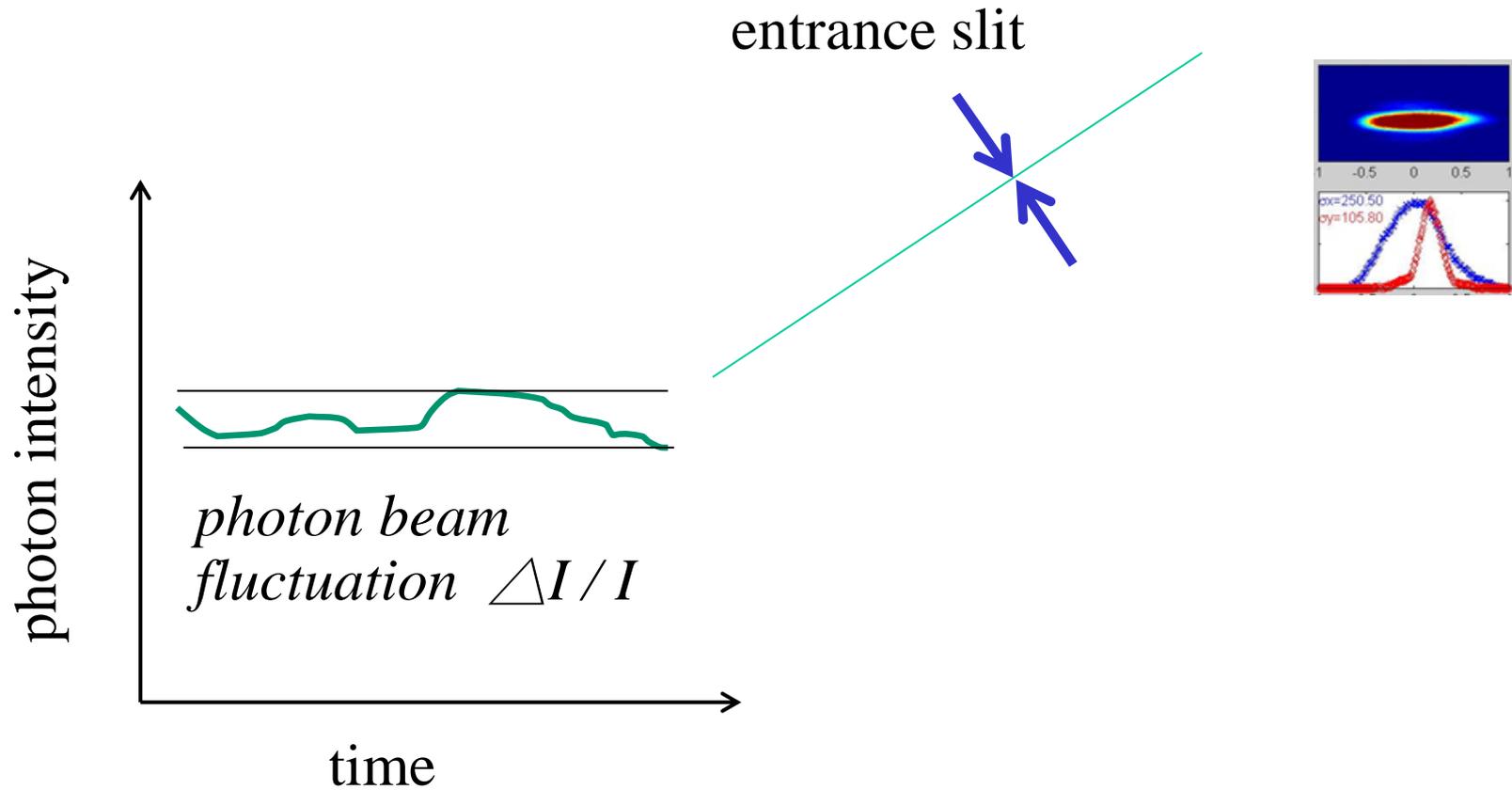
# Basic concept of photon beam stability.



entrance slit

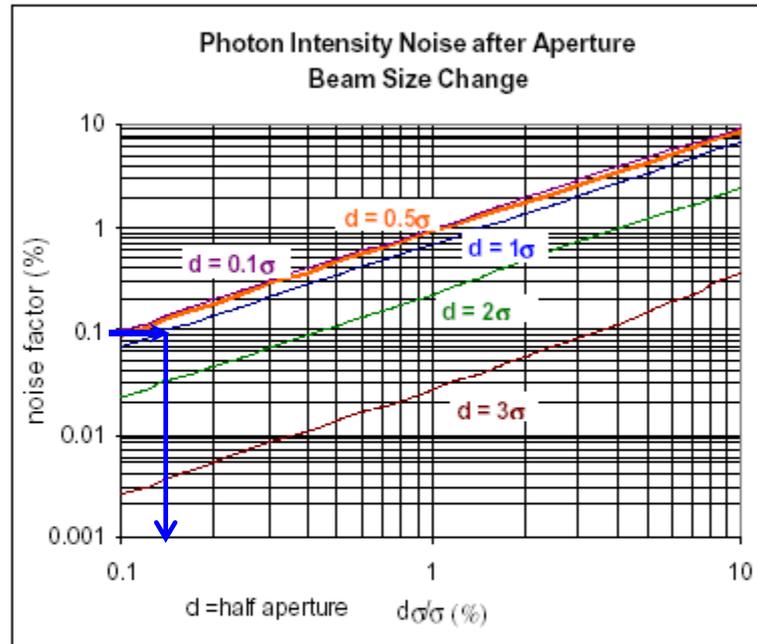
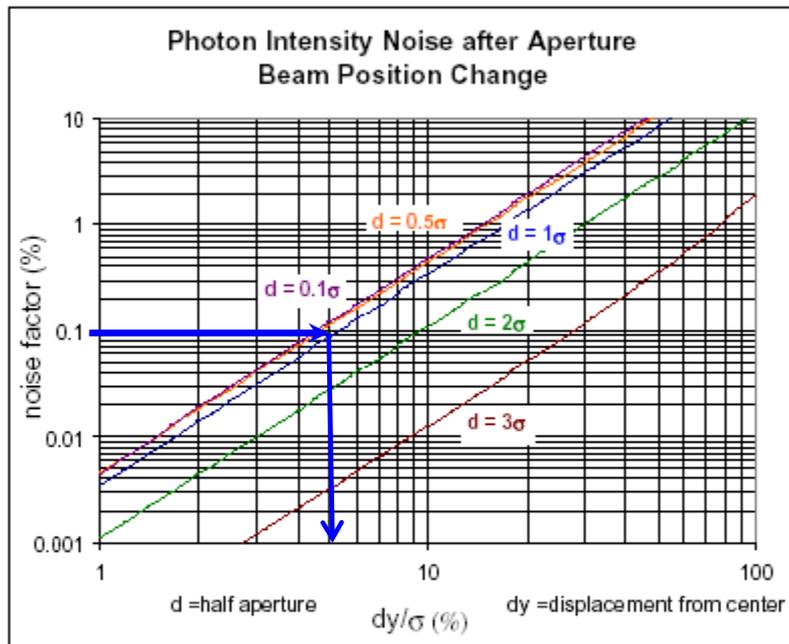


# Basic concept of photon beam stability.





## Beam Stability at Apertures



Intensity variations for beam with Gaussian size  $\sigma$  due to position motion  $dy$  from the center and beam size change  $d\sigma$  for various sized apertures.

# Stability Requirement on Beam Orbit and Size

Intensity fluctuation after aperture:  $< 0.1\%$   
(some experiments require  $< 0.01\%$ )

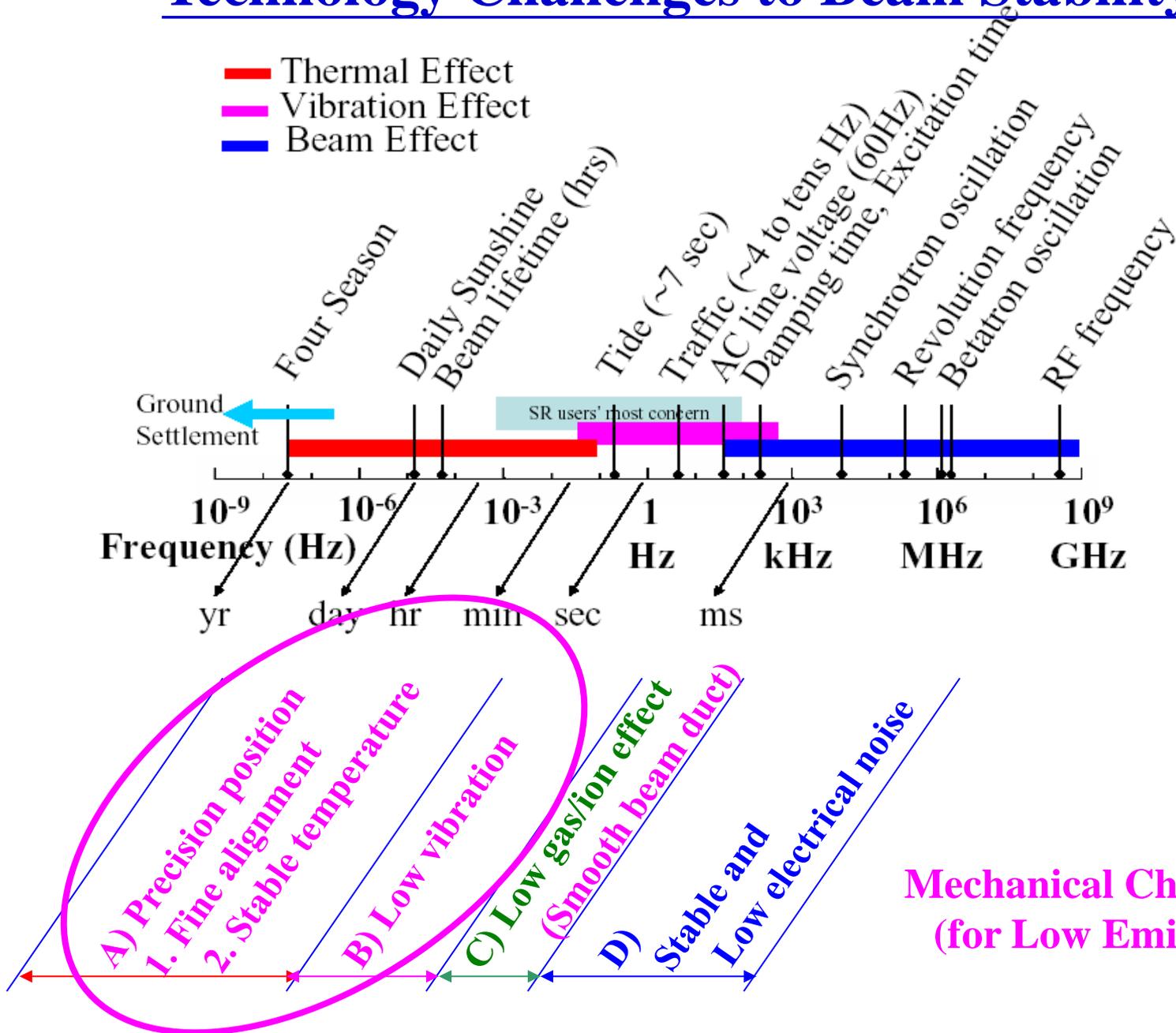
➔ Beam orbit fluctuation  $< 5\%$  beam size

➔ Beam size fluctuation  $\sim 0.15\%$  beam size

(Gaussian beam size)

(half aperture =  $1 \times$  beam size)

# Technology Challenges to Beam Stability



# *Brief Summary*

## (Beam Stability Requirement)

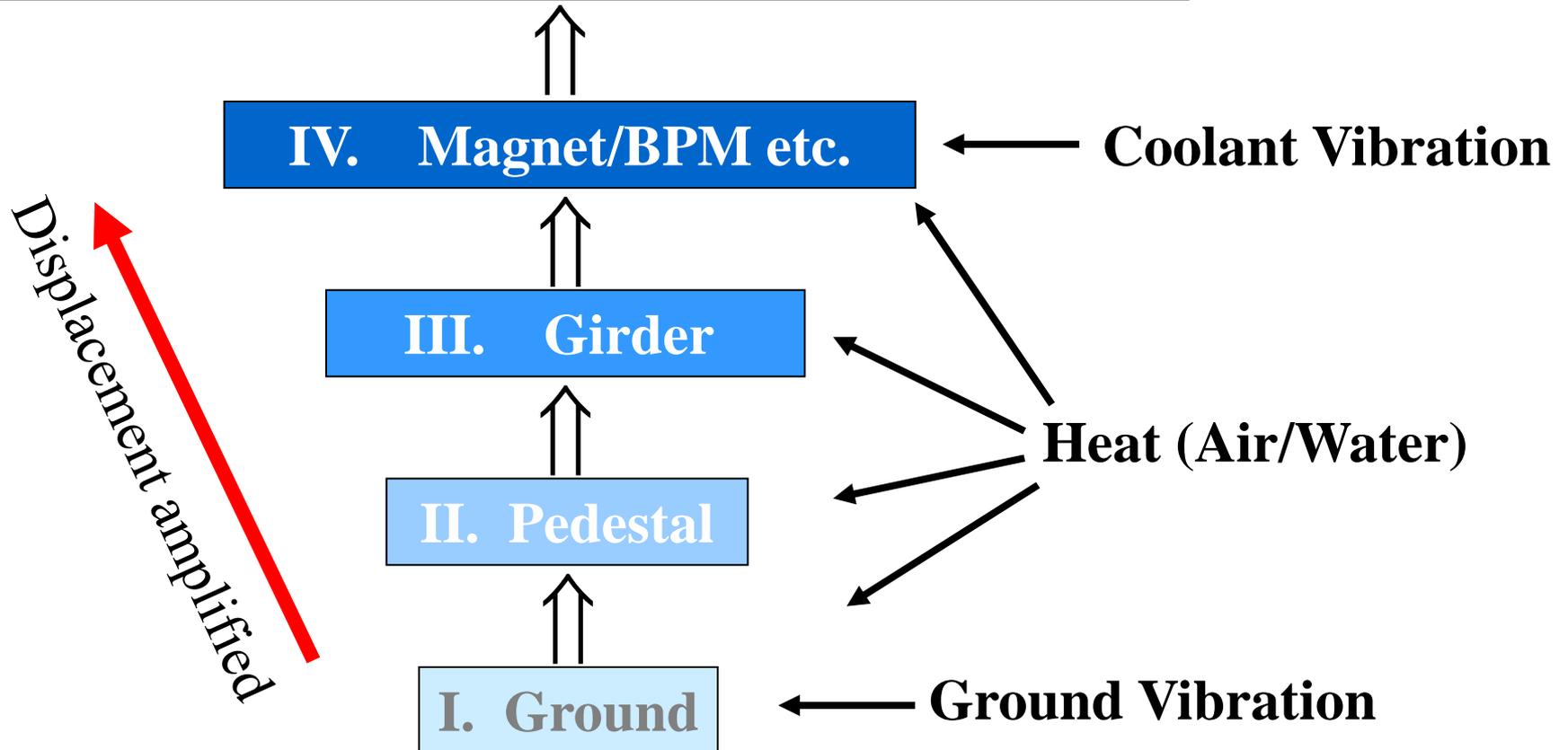
1. Mechanical issues, such as alignment, thermo-mechanical effects, vibration, smoothness of the beam duct, etc., are critical factors to the beam stability.
2. Stability requirements
  - A stability of a photon beam intensity fluctuation,  $\Delta I / I < 0.1\%$ , is usually requested by most of the users.
  - A beam size variation of 10% (or 5%) is normally set as the basic requirement to the beam stability of  $\Delta I / I < 0.1\%$ .

## II. Mechanical Effects on Beam Orbit and Beam Size

### The Mechanical Effects on Beam Stability

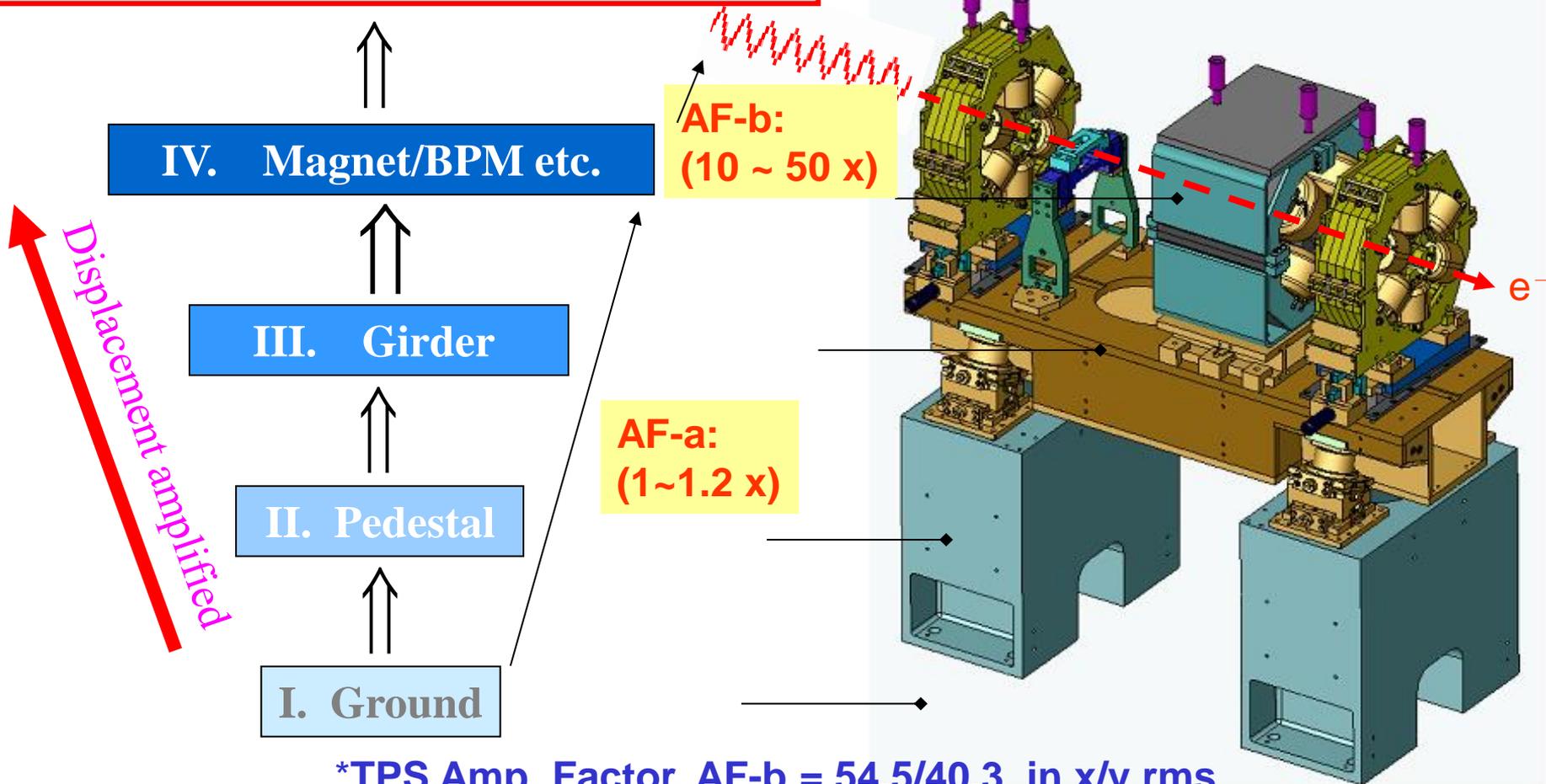
# Mechanical Effect on Beam Orbit and Size

## Beam Orbit Distortion, Emittance/Size Blowup



# Amplification Factors (AF)

Beam Orbit Fluctuation, Emittance Blowup



\*TPS Amp. Factor, AF-b = 54.5/40.3 in x/y rms  
with girder grouping → 30.6/8.0 in x/y rms

\*\* Better alignment → Lower amp. factor

# Orbit Distortion

## (storage ring)

The rms closed orbit distortion  $\sigma_{co}(s)$  at an azimuthal position  $s$  is

$$\sigma_{co}(s) = \frac{\sqrt{\beta(s)} \sqrt{\langle \beta \rangle}}{2 \sin \pi \nu} \frac{\sigma_q}{|F|} \sqrt{N}$$

with betatron tune  $\nu$ , focal length  $F$ , uncorrelated transverse rms quadrupole misalignment  $\sigma_q$ , and number  $N$  of identical FODO cells. The average  $\langle \beta \rangle$  is taken at the quadrupoles.

( $\sigma_q$  could be the displacement of the quadrupoles due to vibration or thermo-mechanical effects.)

(A. Chao and M Tigner, "Handbook of Accelerator Physics and Engineering", 1999.)

# Orbit Distortion (conti.)

(storage ring)

$$\sigma_{CO}(s) = \frac{\sqrt{\beta(s)} \sqrt{\langle \beta \rangle}}{2 \sin \pi \nu} \frac{\sigma_q}{|F|} \sqrt{N}$$

$\sigma_{CO}(s) \propto \sqrt{N}$  (The more the number of quadrupoles, the larger the beam orbit distortion.)

$\sigma_{CO}(s) = K \sigma_q$  (Ver. amp. factor,  $K \approx 40/8$ , w/wo girder grouping, for TPS)

(A. Chao and M Tigner, "Handbook of Accelerator Physics and Engineering", 1999.)

# Beam Displacement (Linac)

The rms beam displacement  $\sigma_z$  at the end of a linac due to random misalignment of all  $N_q$  quadrupoles (focal length  $f$ ) is

$$\sigma_z^2 = \sum_{N_q} \frac{\gamma_q}{\gamma_{end}} \overline{\beta \beta_{end}} \frac{1}{2} \frac{\sigma_q^2}{f^2}$$

with  $\overline{\beta}$  the  $\beta$ -function averaged over a FODO cell.  $\gamma$  is the energy factor.

(A. Chao and M Tigner, “Handbook of Accelerator Physics and Engineering”, 1999.)

# Beam Displacement (conti.)

## (Linac)

The rms beam jitter at the end of the linac is

$$\sigma_z = \frac{\sigma_q \sqrt{N_q}}{\cos \frac{\mu}{2}}$$

under the assumption of a constant phase advance  $\mu$  per FODO cell and  $\sigma_z \propto \sigma_q^n$ .  $n < 0.8$

\*\* This beam motion can lead to emittance growth due to wakefield excitation.

(A. Chao and M Tigner, "Handbook of Accelerator Physics and Engineering", 1999.)

# Emittance and Beam Size Blowup (storage ring)

$$\varepsilon = \gamma(s)x^2 + 2\alpha(s)xx' + \beta(s)x'^2 = \text{constant}$$

$$\varepsilon_y \cong k\varepsilon \quad (k = \text{coupling, } k \lesssim 0.1)$$

$$\alpha = -\beta'/2 \quad \gamma = \frac{1+\alpha^2}{\beta}$$

$$\sigma_x(s) = \sqrt{\varepsilon_x \beta_x(s) + (\eta(s)\delta E/E)^2} \quad \sigma_y(s) = \sqrt{\varepsilon_y \beta_y(s)}$$

$$\sigma_{x'}(s) = \sqrt{\varepsilon_x \gamma_x(s) + (\eta'(s)\delta E/E)^2} \quad \sigma_{y'}(s) = \sqrt{\varepsilon_y \gamma_y(s)}$$

Couplings:

H → V: by skew quads, orbit in sextupoles, resonances

longitudinal → transverse:  $\Delta x = \eta \Delta E/E$ , scattering etc.

# Emittance and Beam Size Blowup (conti.) (storage ring)

Transverse emittance growth due to fast (turn to turn) dipole angular kicks  $\delta\theta$  produced by bending field  $\Delta B/B$  fluctuations in dipole magnets or by fast motion of quadrupoles  $\sigma_q$  which has a rate of

$$\begin{aligned}d\varepsilon_N / dt &= (1/2)\gamma\langle\beta\rangle N_q f_0^2 S_{\delta\theta} (\Delta\nu f_0) \\ &\approx (1/2)\gamma\langle\beta\rangle f_0 N_q (\sigma_q / F)^2\end{aligned}$$

$$d\varepsilon_N / dt \sim \sigma_q^2$$

where  $f_0$  is the revolution frequency,  $\Delta\nu$  is fractal part of tune,  $S_{\delta\theta}$  is the PSD of  $\delta\theta = \sigma_q / F$ .

# Interaction of Ground Waves with Beam

**Vertical orbit distortion** (no amplification in GMA,  $AF_a=1$ )

$$y_c(t) = \text{Re} \left\{ \frac{\sqrt{\beta_0}}{2 \sin \pi \nu_y} \frac{\hat{y}}{F} e^{i(\omega t + \phi_0)} \times \left[ \sum_{n=2}^{2N} \sqrt{\hat{\beta}} e^{i(C/\lambda) \cos(\Phi_n / \nu_y - \theta_w)} \cos(\Phi_n - \pi \nu_y) \right. \right. \\ \left. \left. - \sum_{n=1}^{2N-1} \sqrt{\check{\beta}} e^{i(C/\lambda) \cos(\Phi_n / \nu_y - \theta_w)} \cos(\Phi_n - \pi \nu_y) \right] \right\}$$

where,  $\Phi_n$  is the vertical betatron phase advance between the observation point and the nth magnet.  $\beta_0$ ,  $\hat{\beta}$  and  $\check{\beta}$  are the values of the  $\beta$ -function at observation point, focusing and defocusing quads.

due to a single vertical ground wave with amplitude  $\hat{y}$ , phase  $\phi_0$ , angular frequency  $\omega=2\pi f$ , velocity  $v$ , wavelength  $\lambda=v/f$  and direction of incidence  $\theta_w$ :

$$\Delta y_n(t) = \hat{y} \text{Re} \left\{ e^{i \left[ \omega t + \phi_0 + \frac{C}{\lambda} \cos(\theta_n - \theta_w) \right]} \right\}$$

(A. Chao and M Tigner, “Handbook of Accelerator Physics and Engineering”, 1999.)

# Interaction of Ground Waves with Beam (conti.)

**Horizontal orbit distortion** due to a single vertical ground wave

$$\Delta x_n(t) = \hat{x} \cos(\theta_n - \theta_w) \times \text{Re} \left\{ e^{i[\omega t + \phi_0 + \frac{C}{\lambda} \cos(\theta_n - \theta_w)]} \right\}$$

$$Rx = \frac{\hat{x}_c}{\hat{x}} = \frac{\sqrt{\beta_0}}{2F} \left\{ \left[ \sum_{p=-\infty}^{\infty} J'_{4p} \left( \frac{C}{\lambda} \right) C_{4p} - J'_{4p-2} \left( \frac{C}{\lambda} \right) C_{4p-2} \right]^2 + \sum_{p=-\infty}^{\infty} J'_{4p-1} \left( \frac{C}{\lambda} \right) C_{4p-1} - J'_{4p-3} \left( \frac{C}{\lambda} \right) C_{4p-3} \right]^2 \right\}^{\frac{1}{2}}$$

(A. Chao and M Tigner, “Handbook of Accelerator Physics and Engineering”, 1999.)

# Interaction of Ground Waves with Beam (conti.)

Factor 1: Damping factor of soil and concrete slab

Factor 2: Amplification factor (AF-a) of Girder Assembly  
(Ground vibration → Pedestal → Girder → Magnet)

Factor 3: COD Amplification factor (AF-b)  
(Magnet → Beam)

Factor 4: Attenuation factors of Fast Feedback System

# Interaction of Ground Waves with Beam (conti.)

The characteristic wavelengths of slow ground motions are far greater than betatron wavelength, the dynamic effects to the beam can be neglected.

-- Betatron wavelength

$$\lambda_{\beta y} = C/v_y = 518 \text{ m} / 12.2 = 42.4 \text{ m}$$

$$\lambda_{\beta x} = C/v_x = 518 \text{ m} / 26.2 = 19.8 \text{ m}$$

-- Assume  $v = 500 \text{ m/s}$  (soft ground)

$$\begin{aligned} \rightarrow f_{\beta} &= v/\lambda \approx 12 \text{ Hz} \text{ --- vertical} \\ &\approx 25 \text{ Hz} \text{ --- horizontal} \end{aligned}$$

$\rightarrow$  For frequencies  $\ll f_{\beta}$ , the effects to the beam can be neglected.

-- A threshold frequency was found at  $\sim 4\text{Hz}$  for TPS lattice. (by simulation)

# ESRF

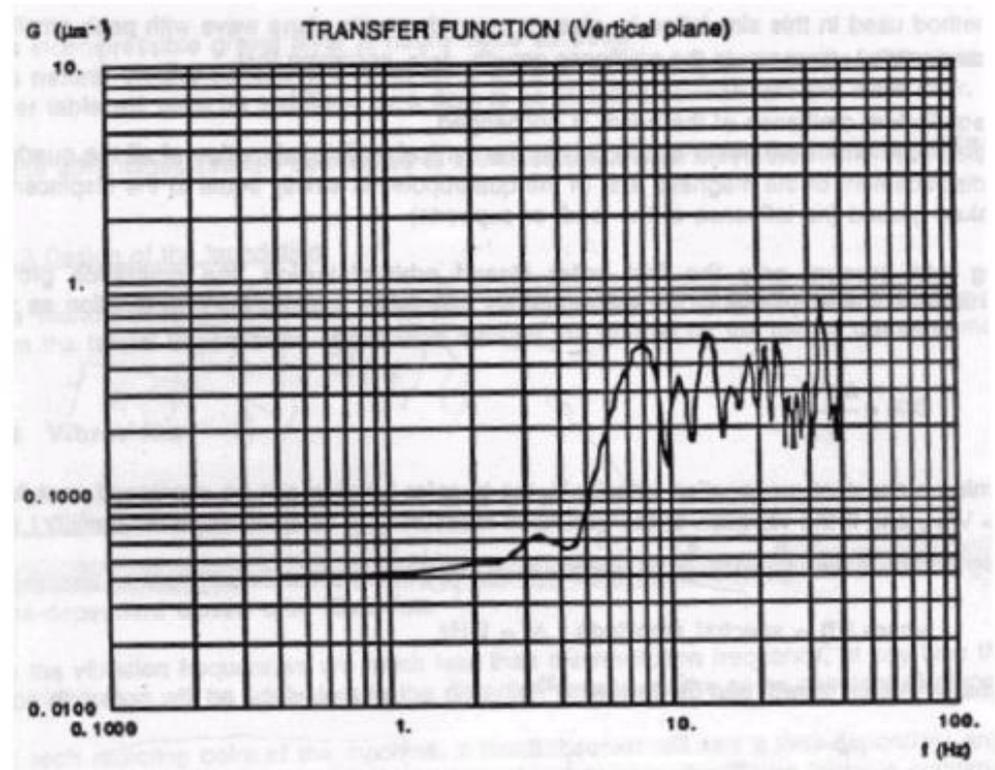
## Transfer function

(ground vibration  $d(f)$   $\rightarrow$  e-beam emittance growth  $\Delta\varepsilon/\varepsilon$ )

$$G(f) = \frac{\Delta\varepsilon/\varepsilon}{d(f)}$$

$\rightarrow$  e-beam sensitive to vibrations  $f > 4\text{Hz}$

*"ESRF foundation phase report", 1987*



# Criteria for Machine Stability

1. Temperature fluctuation criteria (for air and cooling water)
    - $\pm 0.1^\circ\text{C}$ , normally (depend on the sensitivity of the device)
    - $\pm 0.01^\circ\text{C}$ , for the most sensitive devices  
(e.g. rf system and photon monitors)
  2. Ground vibration criteria
    - beam size  $\times 0.1 / \text{AF-b} / \text{AF-a}$   
 $= 4.5 \text{ m} \times 0.1 / 10 / 1$  (AF-a  $\approx 1$ , girder design goal)
    - = 45 nm
- (TPS: 40 nm, equal to the measured value before construction, 4 -100 Hz)

# *Brief Summary*

## (The Mechanical Effects on Beam Stability)

1. The ground vibration and the temperature fluctuation, could induce the displacement of magnets, and cause the beam orbit fluctuation and the emittance blow up. Low vibration, stable temperature conditions, and low amplification factors (AF-a and AF-b), are necessary for beam stability.
2. Grouping the magnets to the girders is effective to reduce the amplification factor AF-b.
3. The wavelengths of slow ground motions are far greater than betatron wavelength, the dynamic effects to the beam can be neglected. ( $f < 4$  Hz for TPS)

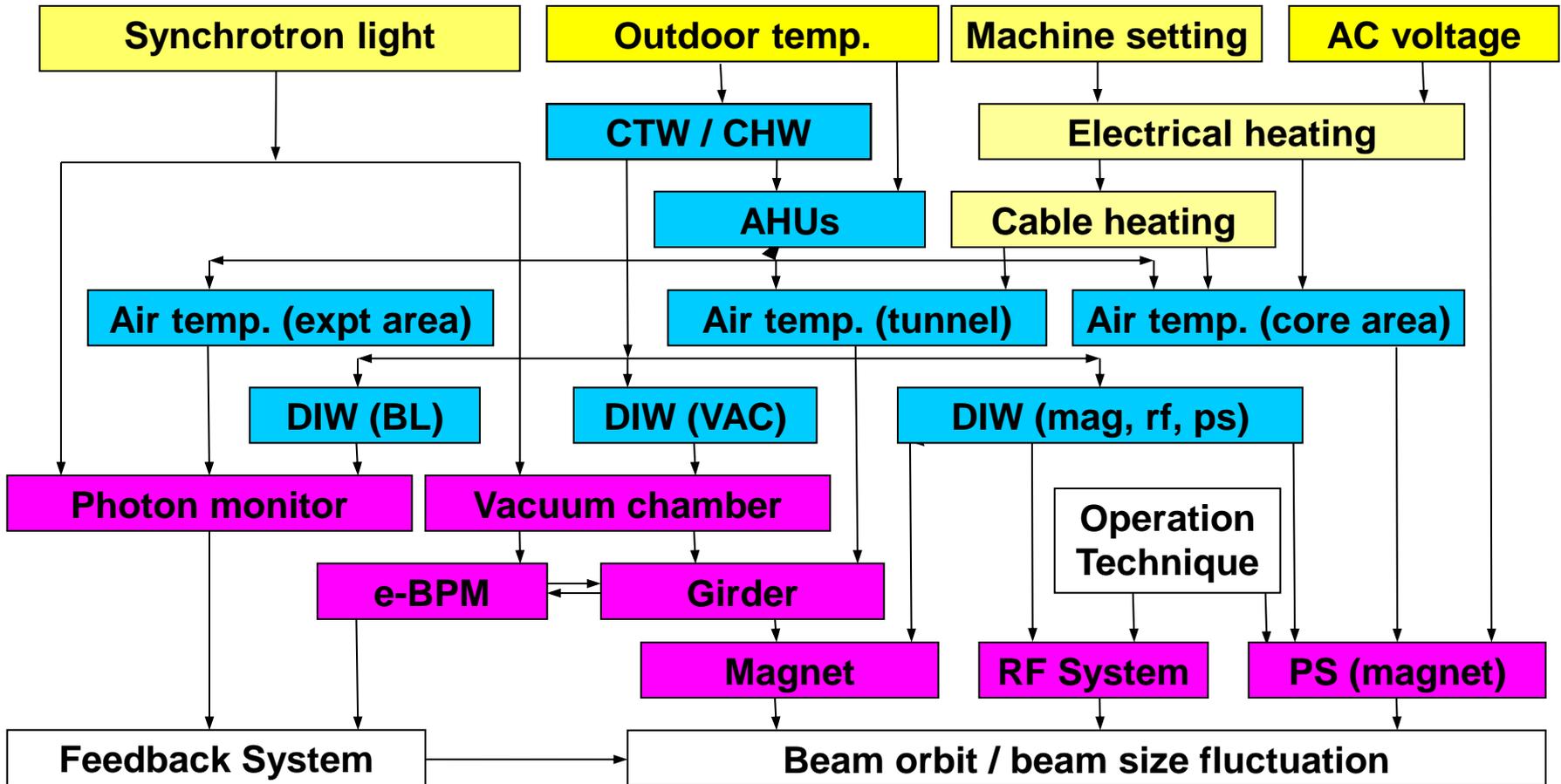
## II. Mechanical Effects on Beam Orbit and Beam Size

Heat Source and Vibration Source

# Heat Sources and Frequency Domain

1. Four Season: 1y
2. Tunnel warm up (first start up after long shutdown):  
~1w
3. Sunshine: 1d
4. Beam current decay (lifetime): ~ 10 hr  
(none for top-up injection mode)
5. Re-injection (energy ramp-up/down): ~ 1 hr  
(none for full energy injection mode)
6. Temperature (control) “jitter”: sec ~ min
7. Human body (stay or pass by)
8. Pulsed Equipment (high frequency)

# Typical propagation chart from heat sources to the fluctuations in beam orbit and beam size



**Sources of Noise**

**Utility System**

**Accelerator Components**

# Vibration Sources and Frequency Domain

## A. Natural

1. ATL:  $PSD(f) \sim 1/f^2$
2. Tide: 7 sec (Ocean wave)
3. Moon gravitation force (high/low tide): ~12 hour (long wavelength)
4. Earthquake
5. Wind: 0.03-0.1 Hz, Plane  $\rightarrow$  wind  $\rightarrow$  ground bending (HERA)
6. Long-term noise (BG):  $1/f^4$
7. Ground settlement (mo – y)

@ ATL law:  $\langle dX^2 \rangle = A * T * L$ , relative displacement of two points located at a distance  $L$  grows with time interval  $T$ ;  $A$ : site dependent coefficient,  $\sim 10^{-5 \pm 1} \mu\text{m}^2/\text{s}\cdot\text{m}$ .

# Vibration Sources and Frequency Domain (conti.)

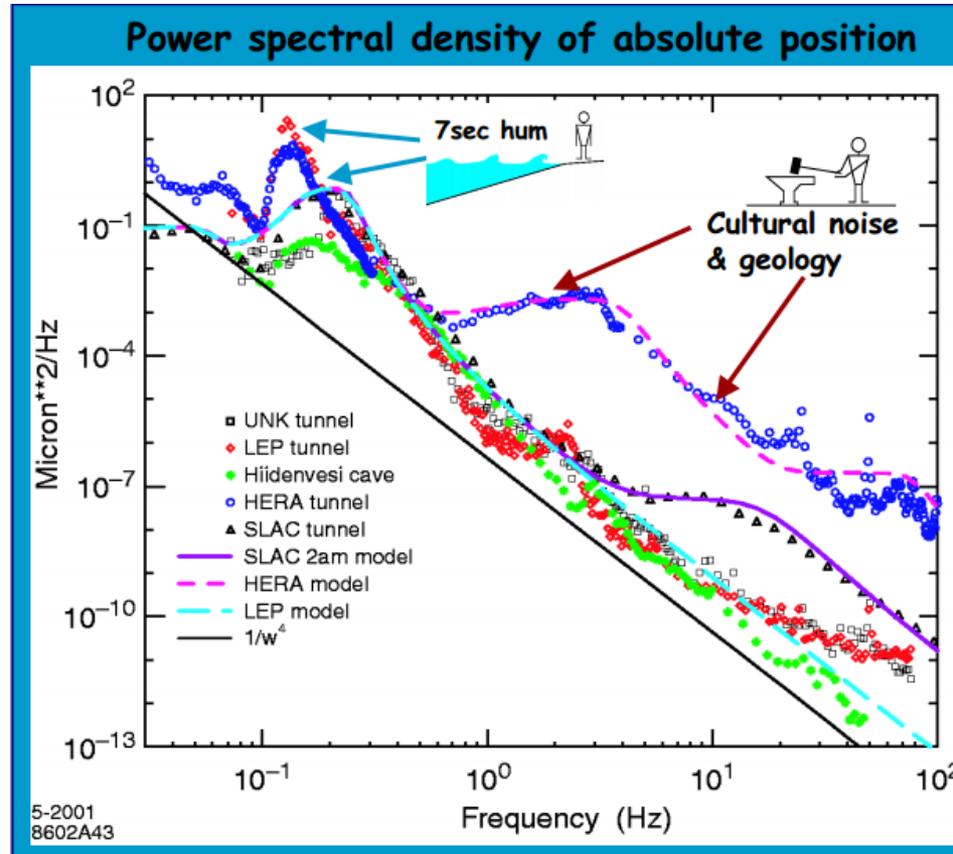
## B. Traffic

1. **Traffic**: ~ 4 Hz (hump on road), tens Hz (peak at 30Hz, SLS)

## C. Facility Equipment

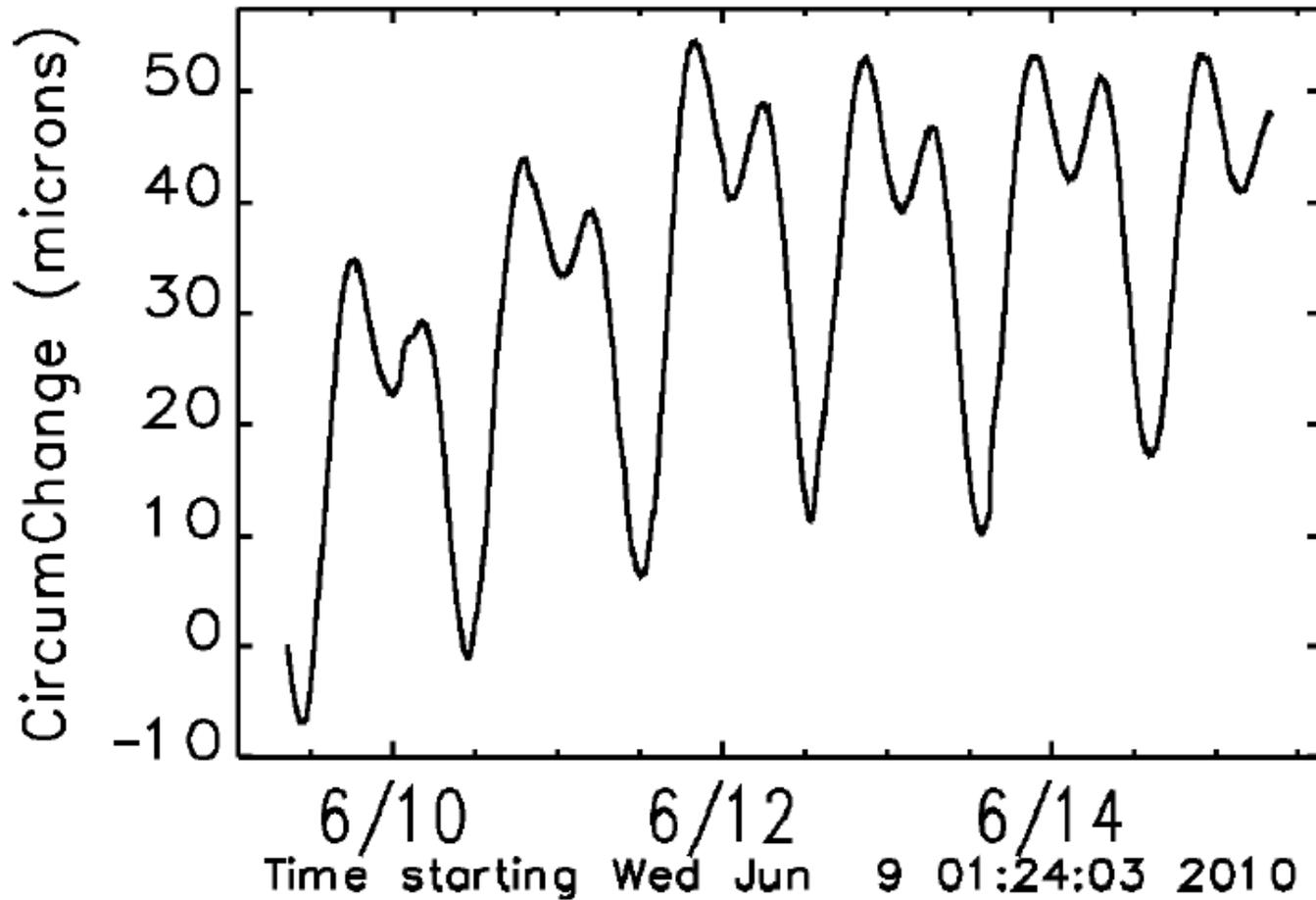
1. Pumps, motors, AHUs: tens Hz (15-70 Hz)
2. **Water vibration** : tens Hz (30-130 Hz)
3. LHe flow: 700-1500Hz (45g/s, SSC)

# Ground vibration (A. Seryi, APAC2001)



Andrei Seryi, SLAC, PAC 2001

Power spectrum of absolute ground motion measured at different sites. Smooth curves show modeling spectra. The high noise level at HERA is caused by cultural noise and, supposedly, by resonances of the clay/sandy site itself.



*APS circumference changes due to Earth tides over a one-week time period.*

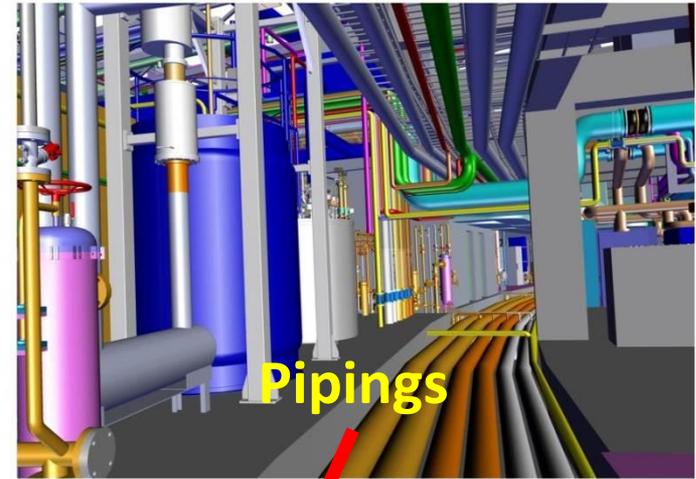
# The Vibration Sources Surrounding TPS

Main Traffic and Utility Machinery

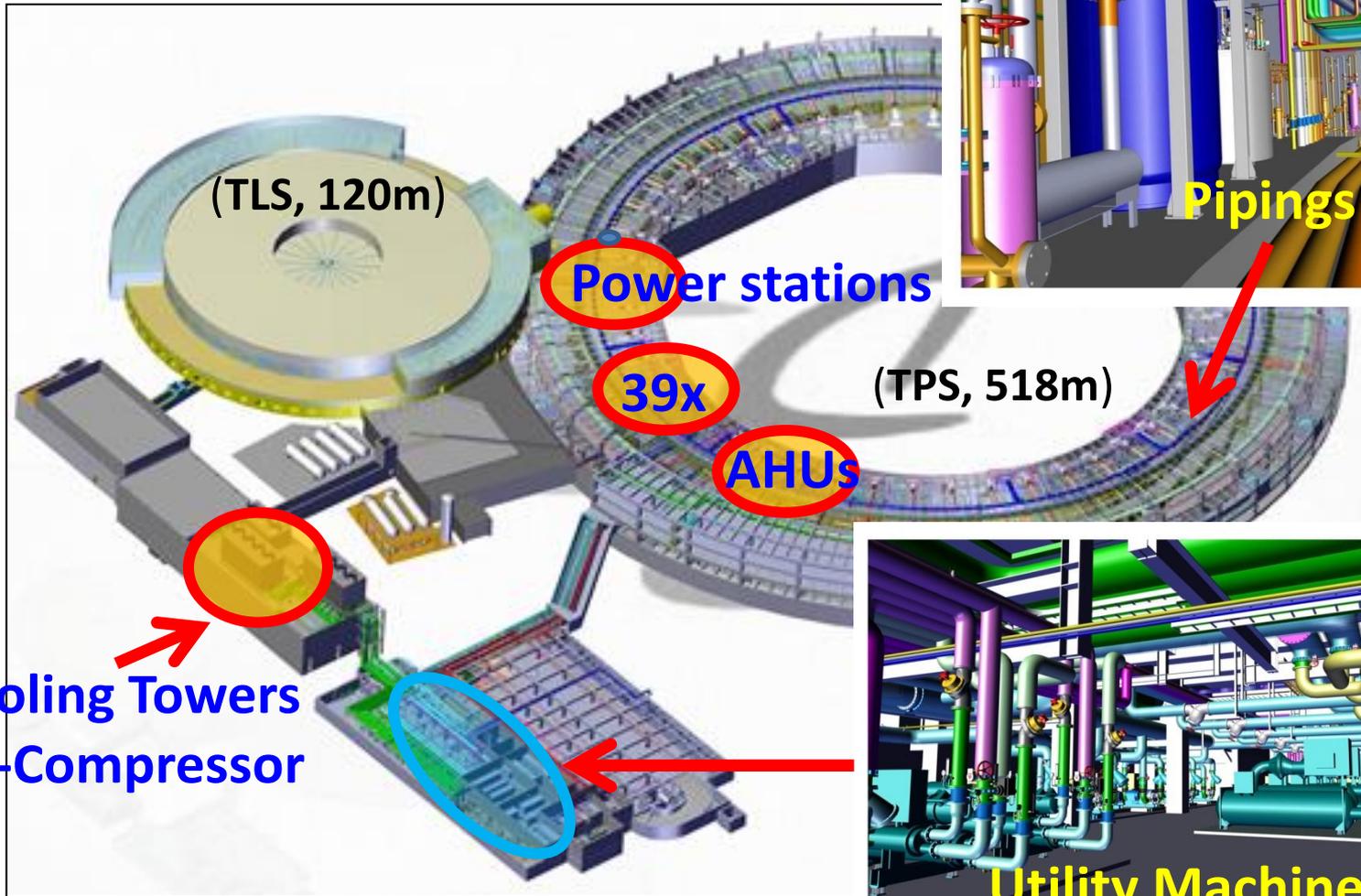


# The Vibration Sources Surrounding TPS

## Machinery Vibration Sources



Pipings



(TLS, 120m)

Power stations

39x

AHUs

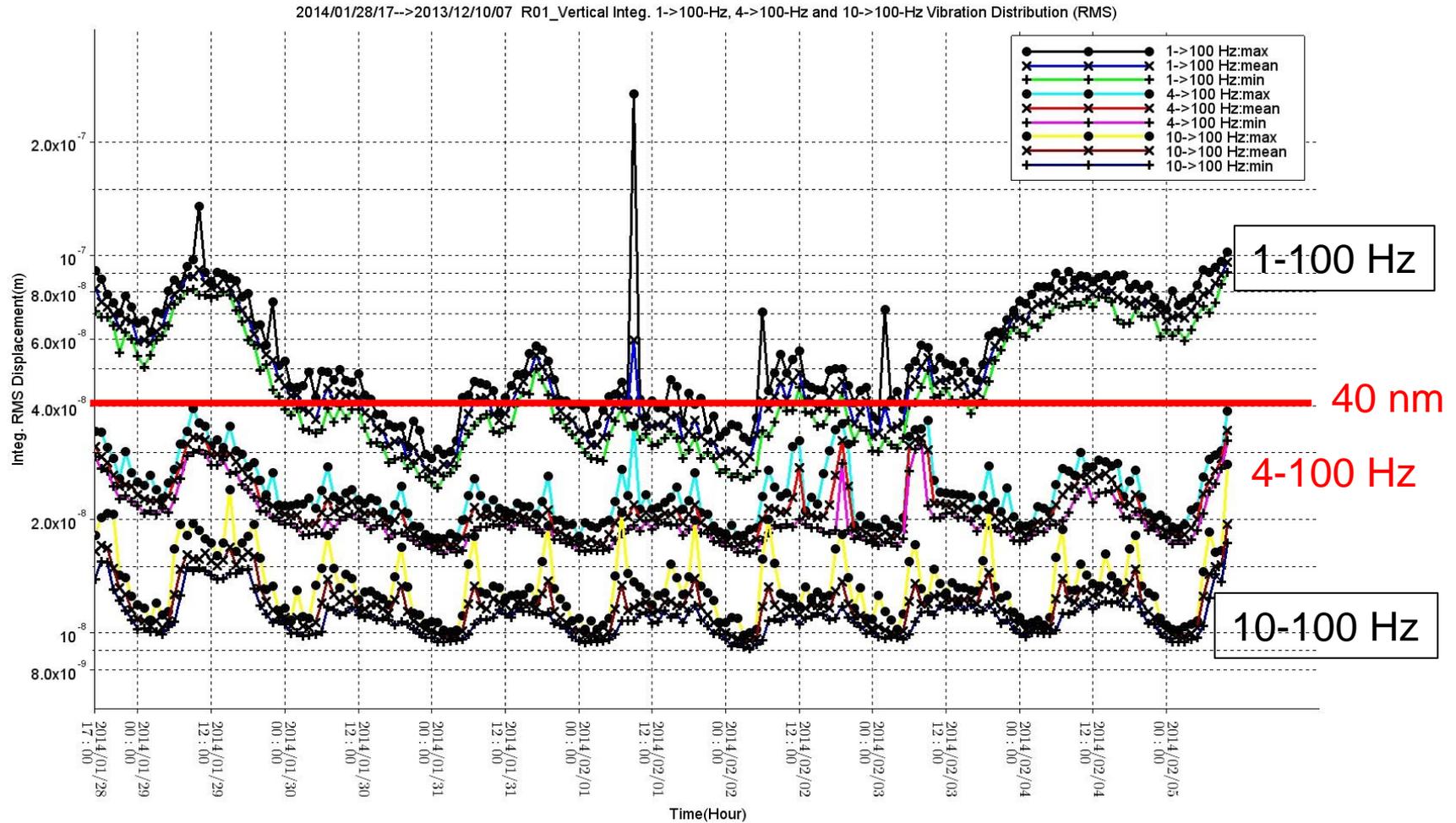
(TPS, 518m)

Cooling Towers  
He-Compressor



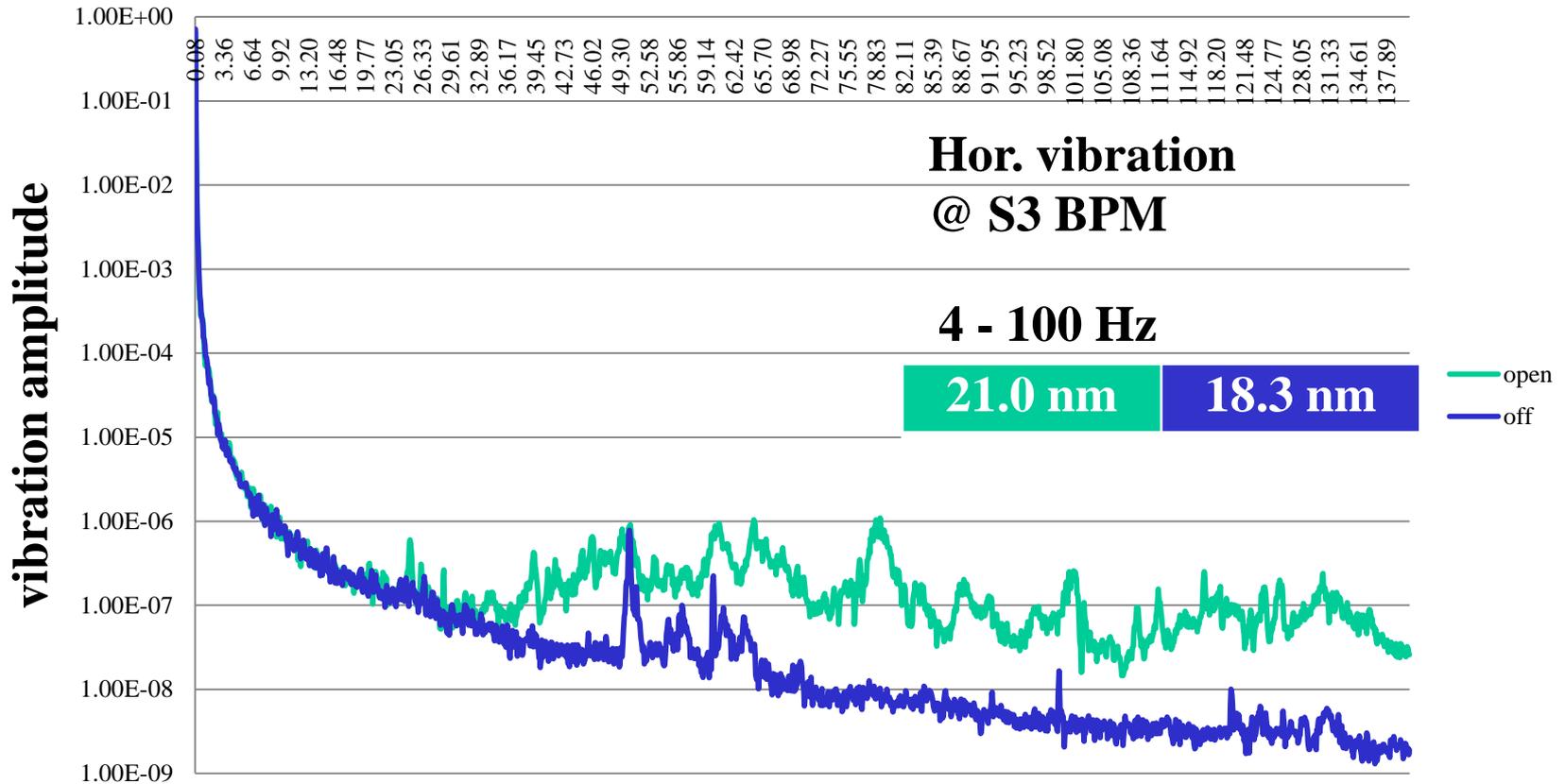
Utility Machinery

# Vertical Vibration, daily variations at TPS



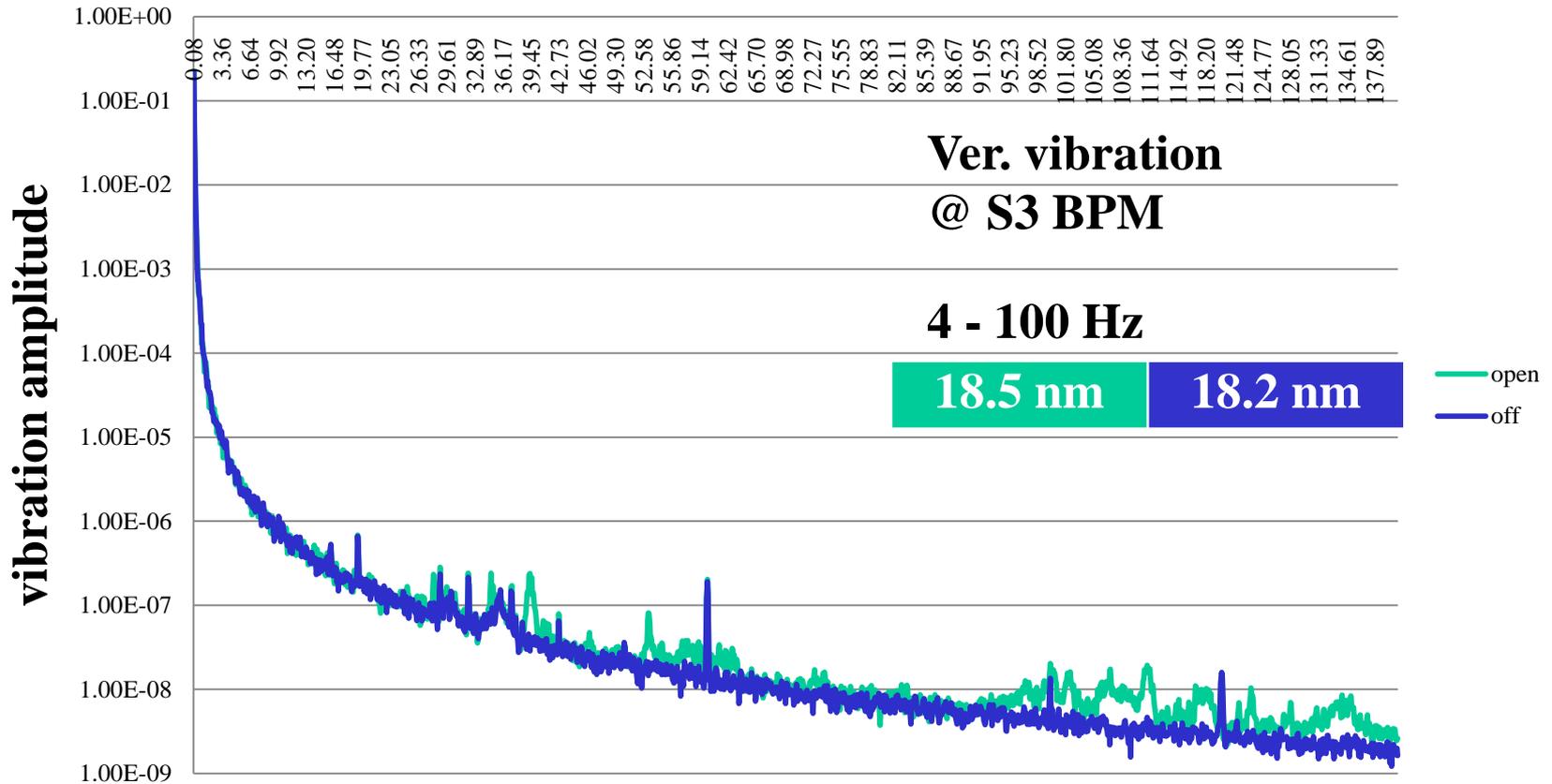
# Cooling Water Vibration at BPM (Horizontal)

Frequency (Hz)



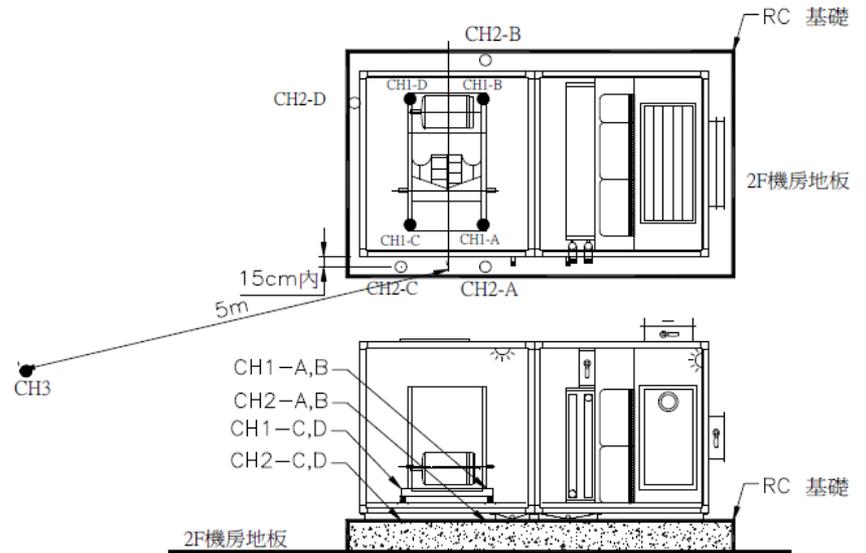
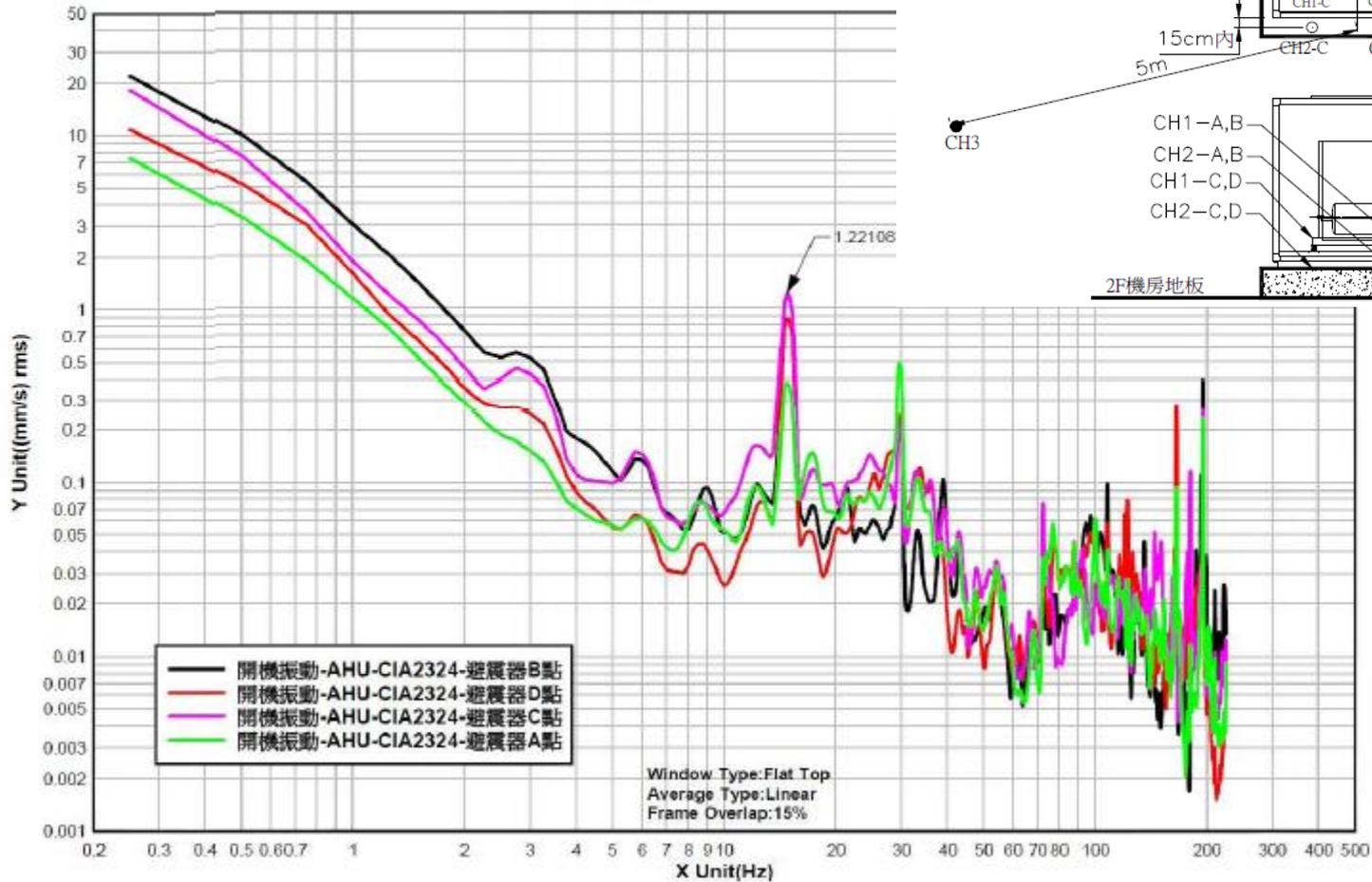
# Cooling Water Vibration at BPM (Vertical)

Frequency (Hz)



# AHU Vibration

光子源振動量測  
AHU-CIA2324 空調箱風機振動值



# *Brief Summary*

## (Heat Source and Vibration Source)

1. A machine is unavoidably surrounded by numerous disturbances of heat and vibration sources, distributed in a wide frequency range.
2. The disturbance sources transfer their energy via complex routes to the fluctuations of the beam orbit and beam size.
3. The thermo-mechanical effects and the vibrations (induced by traffic, the water cooling process, and the air conditioning system) could severely excite the beam instability and/or mislead the control system when the monitors are affected.

# Mag-Girder Vibration (TPS)

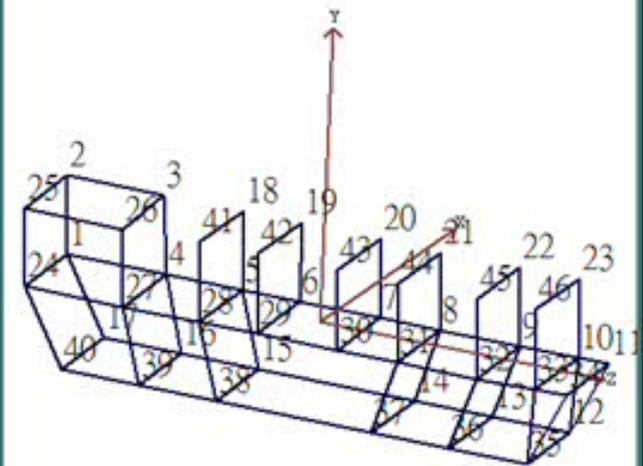


# Vibration Modal Measurements

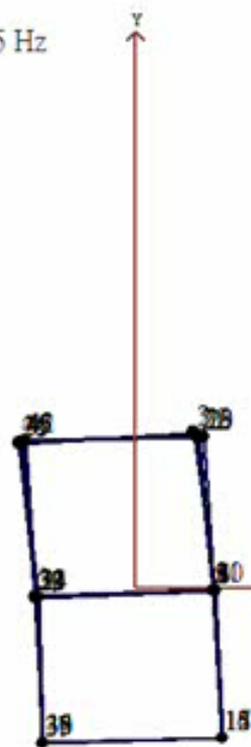
(TPS girder prototype)

| Mode | Frequency (Hz) /Vibration mode |                             |                      |
|------|--------------------------------|-----------------------------|----------------------|
|      | (after, locking @ 100kg-cm)    | (before, without locking)   |                      |
| 1    | 29.65 / G_Roll                 | 24.21 / G_Roll              | <i>f</i> - increased |
| 2    | 35.31 / G_Yaw                  | 28.70 / G_Z                 | Z- Disappear         |
| 3    | 39.32 / G_Pitch                | 30.98 / G_Yaw               | <i>f</i> - increased |
| 4    | 52.86 / Q6_Z                   | 32.87 / G_Pitch             | <i>f</i> - increased |
| 5    | 53.84 / G_Yaw, mag. swing      | 35.61 / G_Y                 | Y- Disappear         |
| 6    | 56.02 / G_Yaw, Q6_Z            | 41.11 / G_Roll , mag. swing |                      |
| 7    | 56.97 / Q6_Z                   | 44.12 / Q1_X&Z              | Fix. of M to G       |
| 8    | 60.06 / Q4_roll, Q6_Z          | 51.45 / Q4_X&Z              | Fix. of M to G       |
| 9    | 62.03 / Q3_Z, Q5_Z, Q6_Z       | 60.18 / Q5_X&Z, Q6_X&Z      | Fix. of M to G       |

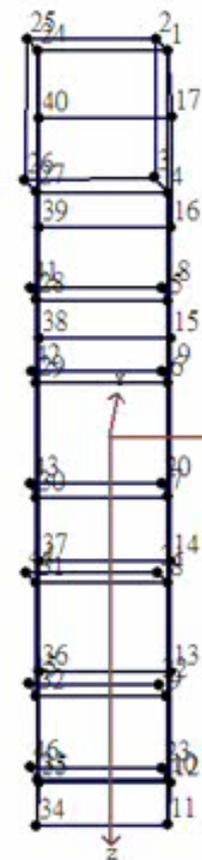
ModelView 1  
Mode 1 : 29.65 Hz



ModelView 2  
Mode 1 : 29.65 Hz



ModelView 3  
Mode 1 : 29.65 Hz



## Heavy machinery

- Need dynamically balanced.
  - Using dampers
- 'residual' vibrations still transfer through the ground and/or pipelines to perturb devices.



(Soleil)

pipe bellows



(DLS)

pipe hanger

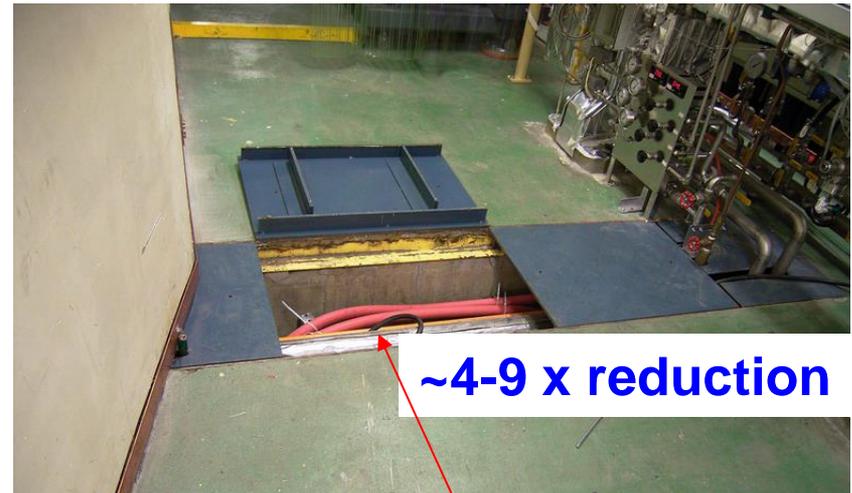
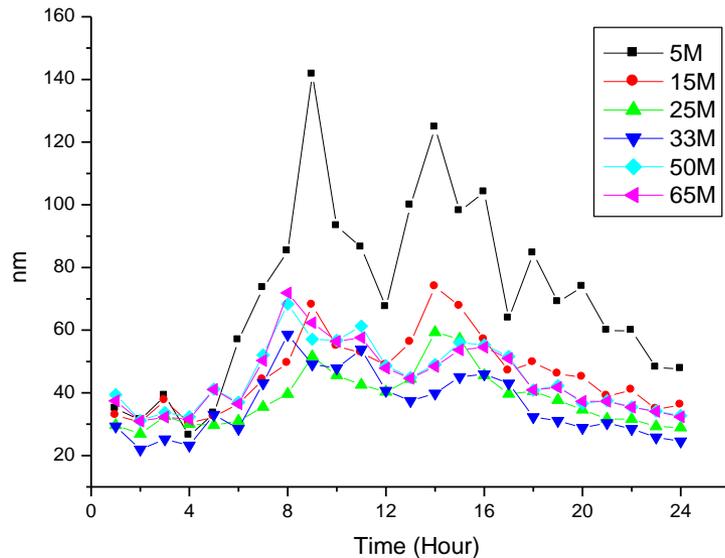


(DLS)

damper

## Further suppression along transfer routes

- As far away from sensitive components as practicable
- Using rubber tubes (to cut off the transfer route)
- Appropriate fixture for pipelines



|               | Ring floor | R3BPM5X | R3BPM5Y | R5Q5(Ver.) | R6Q5(Ver.) |
|---------------|------------|---------|---------|------------|------------|
| <b>Before</b> | 3.7-20nm   | 0.22um  | 0.34um  | 27nm       | 24nm       |
| <b>After</b>  | 3-12nm     | 0.1um   | 0.14um  | 3.3nm      | 4.5nm      |

- To decrease the rate of water flow,
- to smooth the piping curvature, and
- to fix the vacuum chamber as rigidly as practicable can diminish the vibration of the vacuum chamber.

@ Vibration of vacuum chamber (in the magnets)

→ Eddy current effect

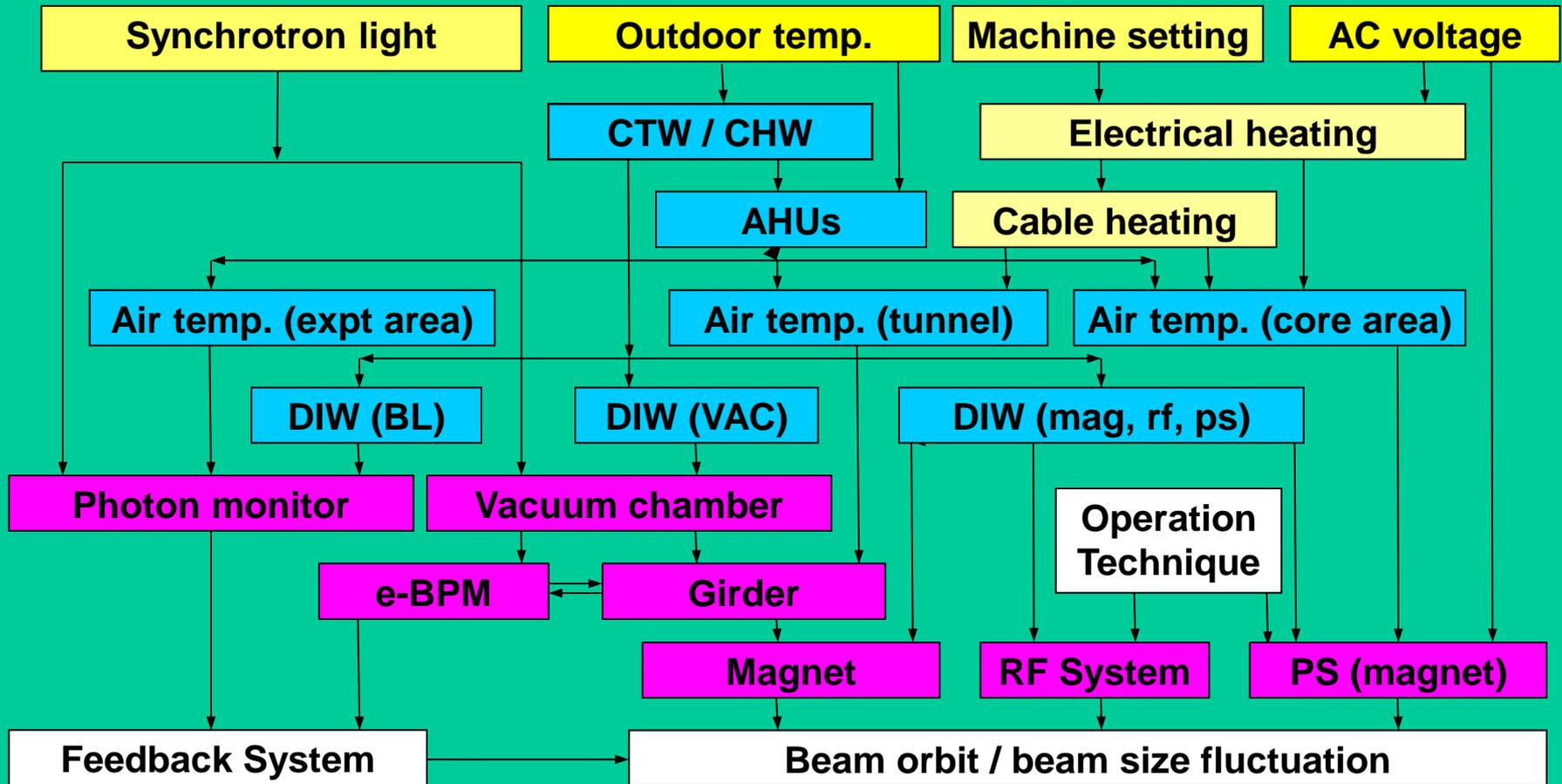
→ electron beam influenced

[SPring-8: 30 – 50 Hz vertically, 80 – 100 Hz horizontally]

### III. Thermo-mechanical Effects

## Sources, Routes and Sensitivities of the Thermo-mechanical Effects

# Propagation chart from heat sources to the fluctuations in beam orbit and beam size (TLS)

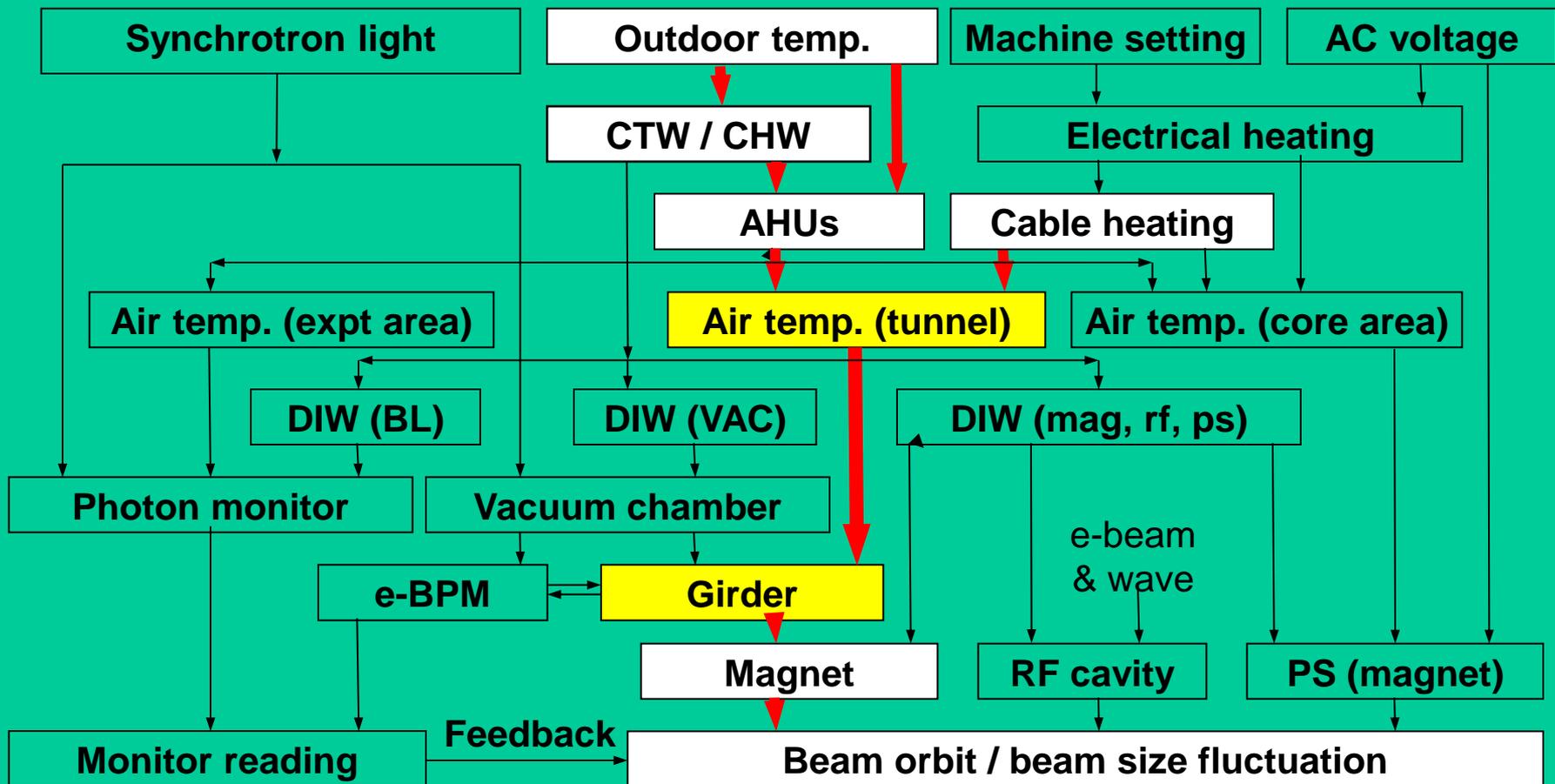


**Sources of Noise**

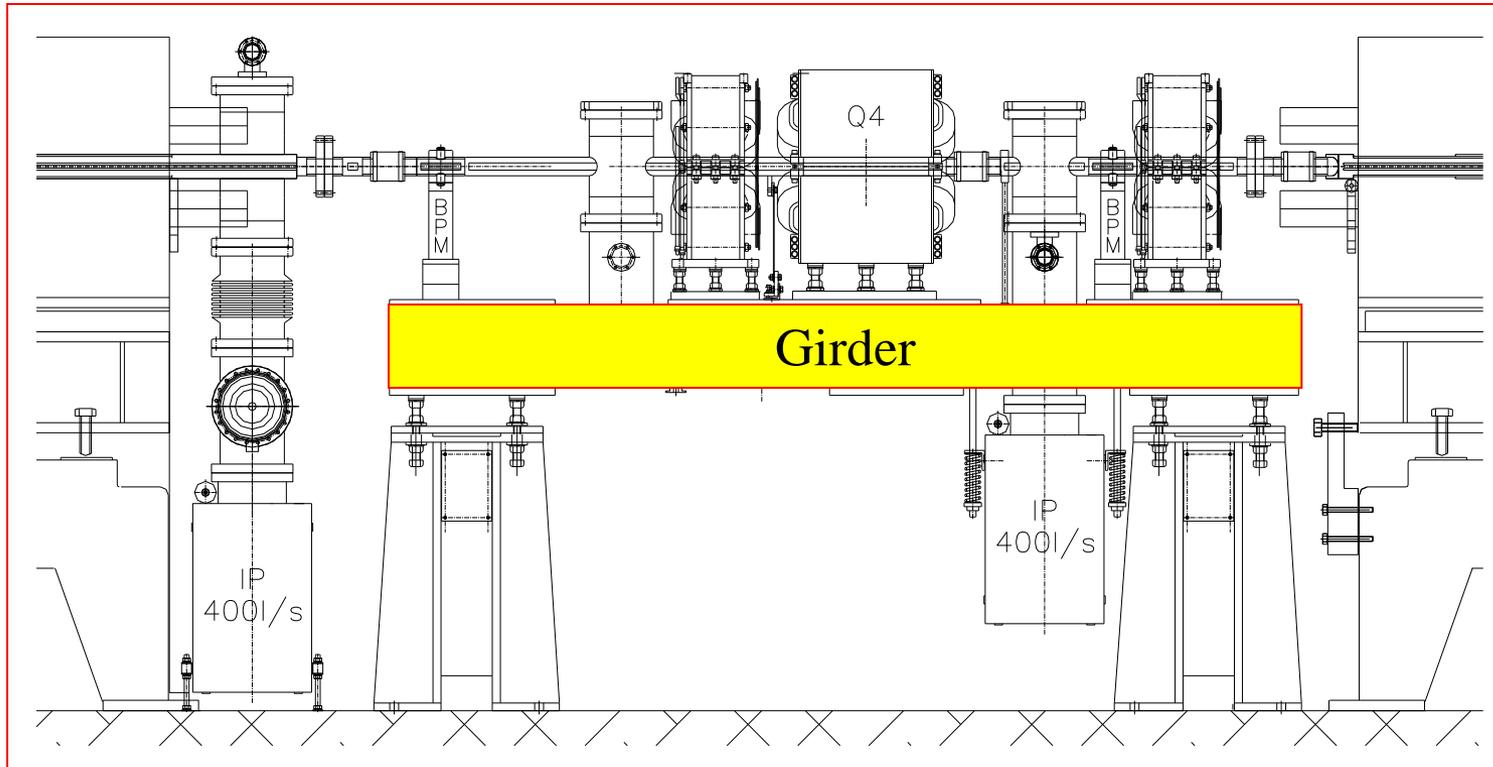
**Utility System**

**Accelerator Components**

# Air Temperature Fluctuation -- Girder Displacement --

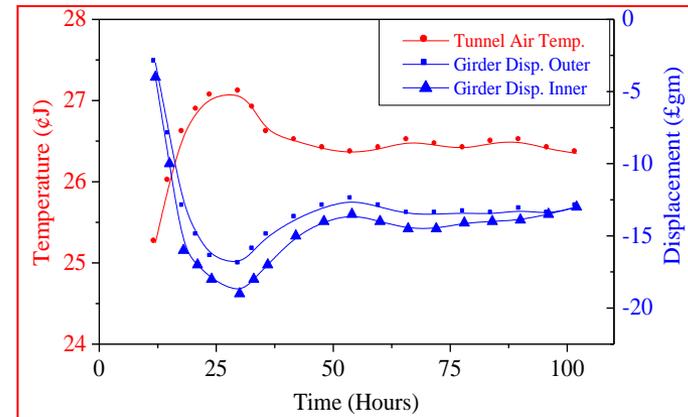
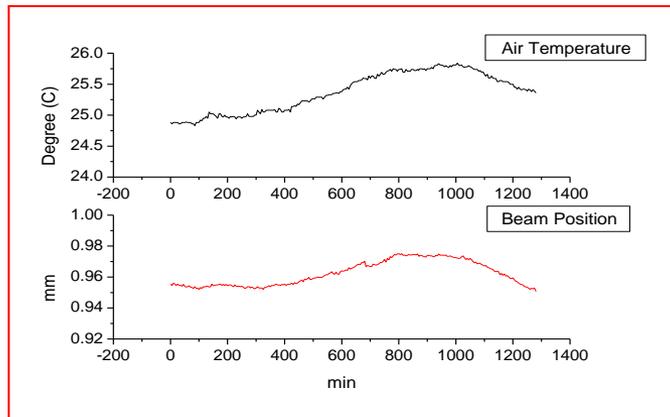


# Girder Displacement



An unstable girder will move all the components on it.

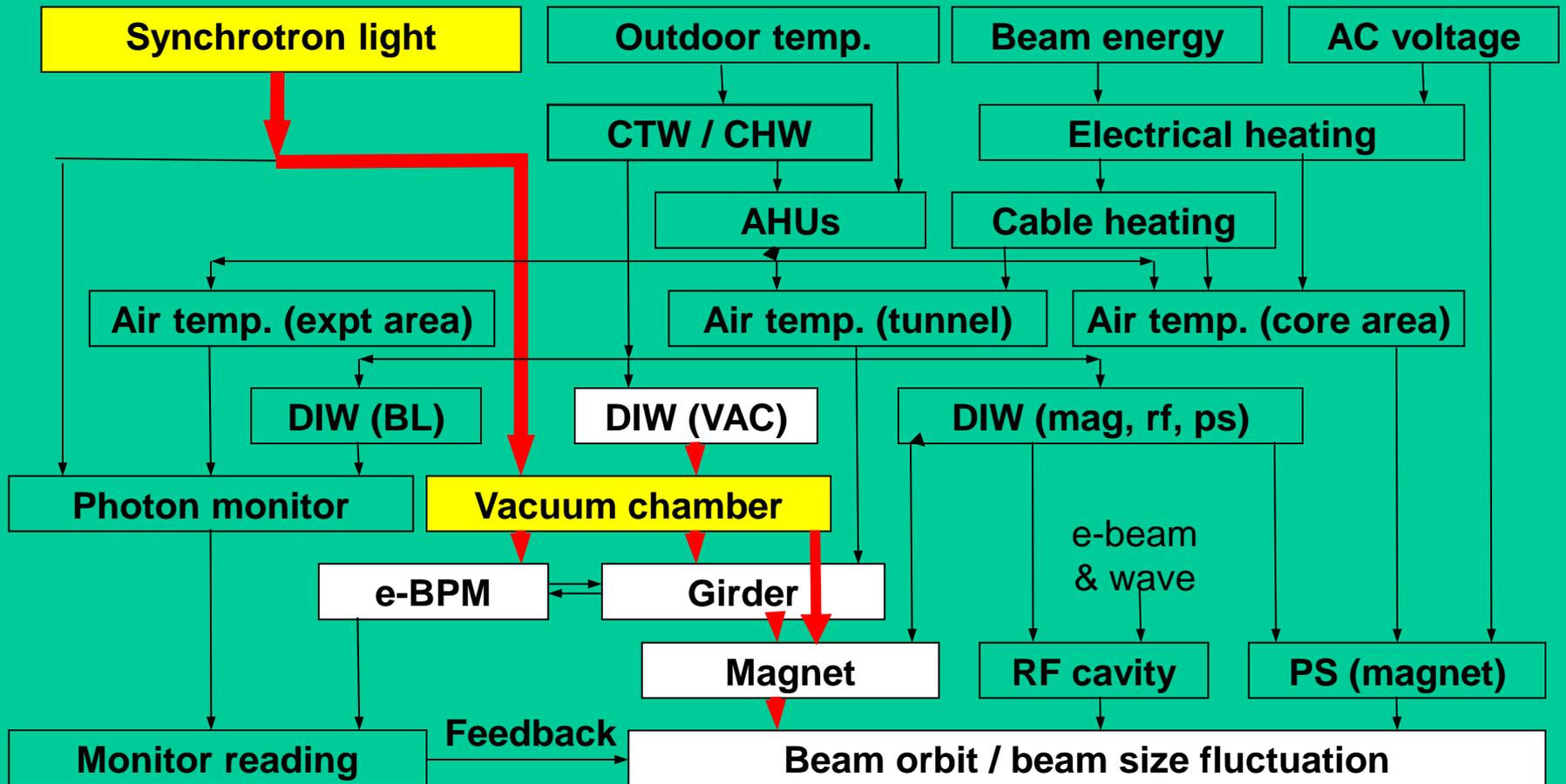
# Girder Displacement



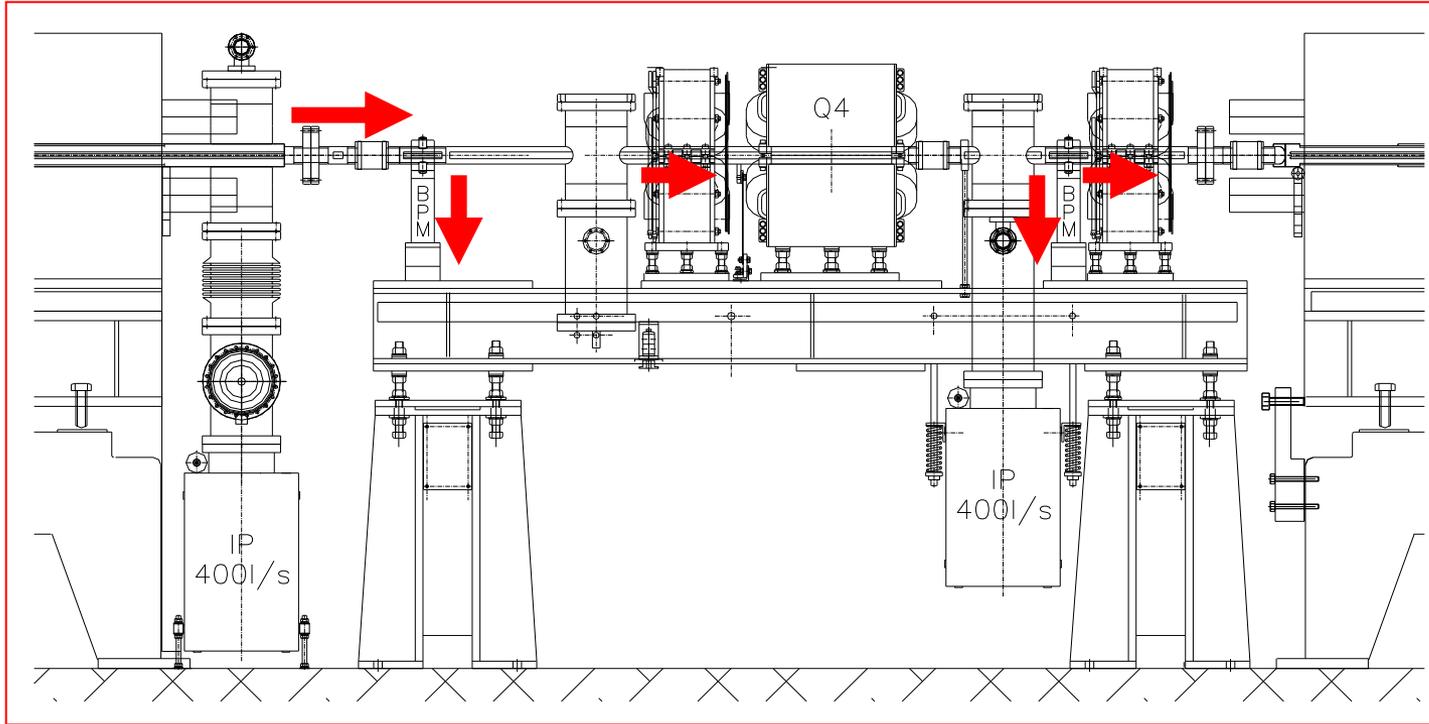
- Main cause: air temperature
  - Sensitivity to air temp.:  $\sim 10 \mu\text{m} / ^\circ\text{C}$
  - Induced beam orbit drift:  $20\text{-}100 \mu\text{m} / ^\circ\text{C}$
- Current status:  $< \pm 0.1 \mu\text{m}$  per 8 hr shift
  - Air temp. :  $< \pm 0.1^\circ\text{C}$  (utility control system improved)
  - Thermal insulator jacket

# Synchrotron Light Irradiation

## -- Expansion of Vacuum Chamber --

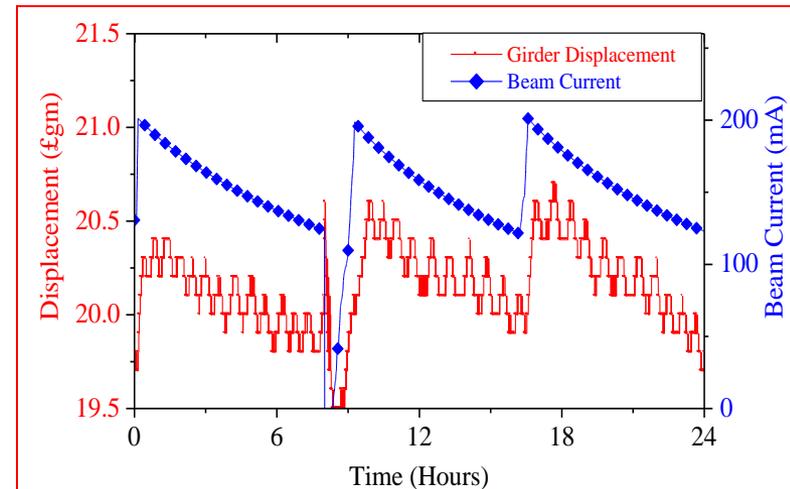
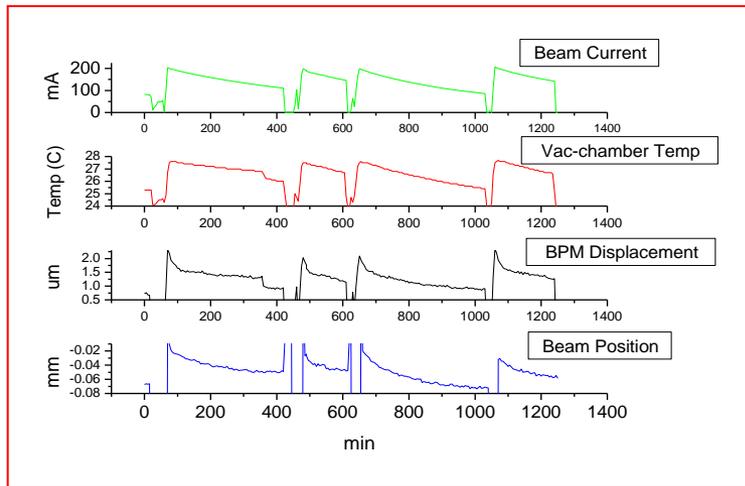


# Expansion of Vacuum Chamber



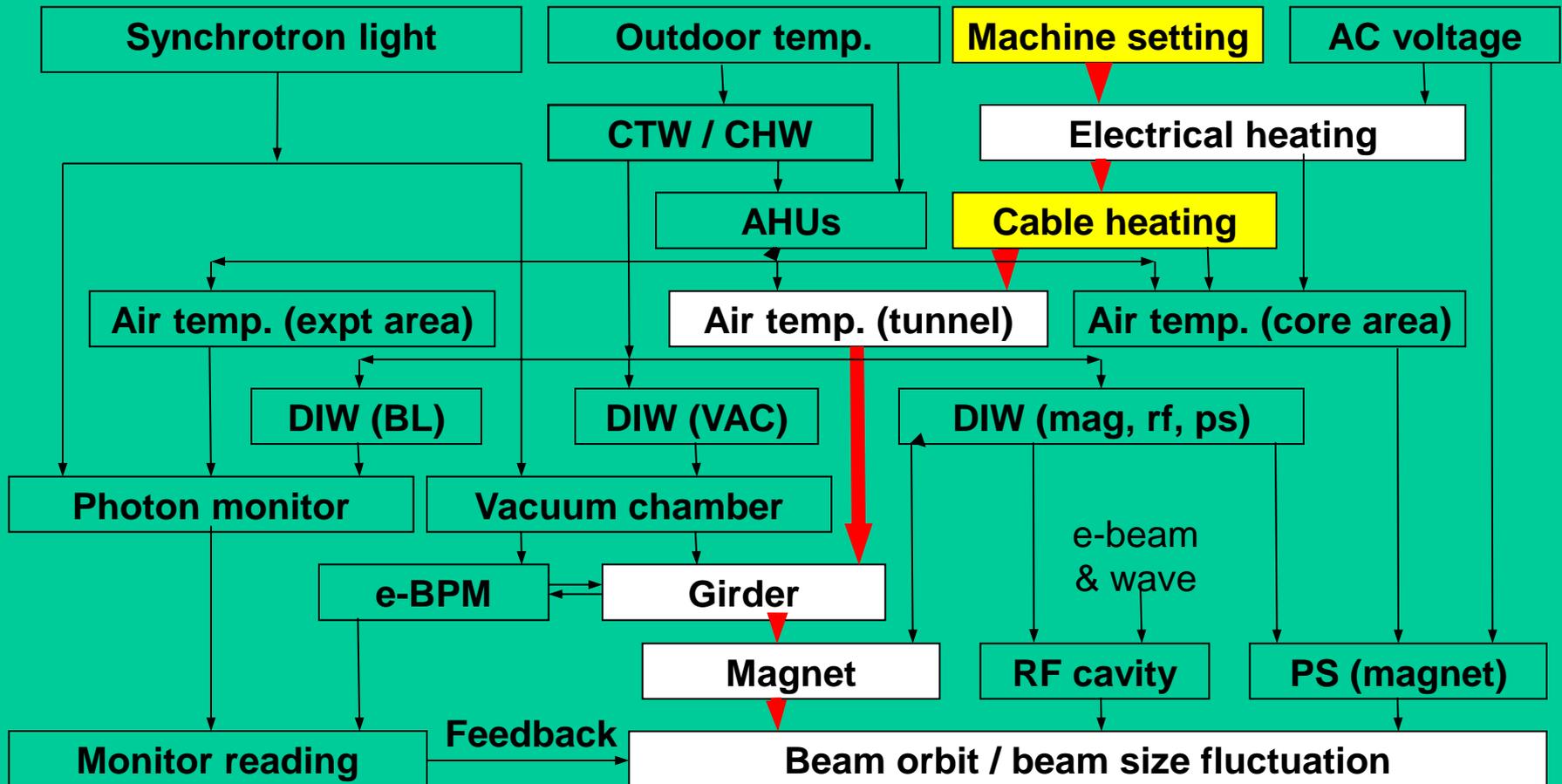
The expanded vacuum chamber moves the components touched or connected to it. The force transferred to the girder.

# Expansion of Vacuum Chamber

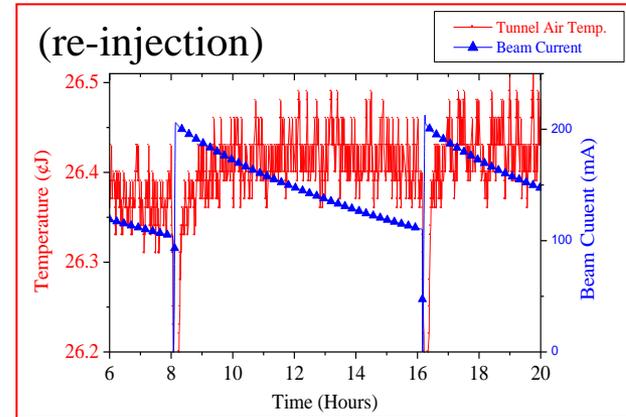
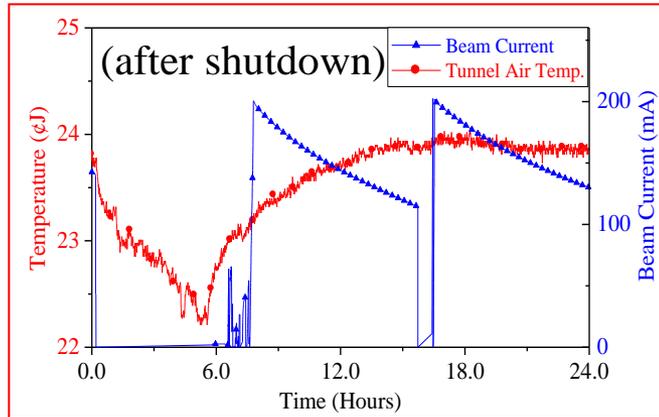


- Caused by synchrotron light irradiation.
  - Sensitivity to water temp.:  $\sim 10 \mu\text{m} / ^\circ\text{C}$
  - Move the girder ( $\sim 0.3 \mu\text{m}/^\circ\text{C}$ ) and BPM ( $\sim 1 \mu\text{m}/^\circ\text{C}$ )
  - Induced beam orbit drift:  $\sim 10\text{-}30 \mu\text{m} / ^\circ\text{C}$
- Current status
  - Vacuum cooling water temp.:  $< \pm 0.2^\circ\text{C}$
  - (Greatly improved after adopting the Top-up Injection)

# Power Supply and Electrical Effect (1)

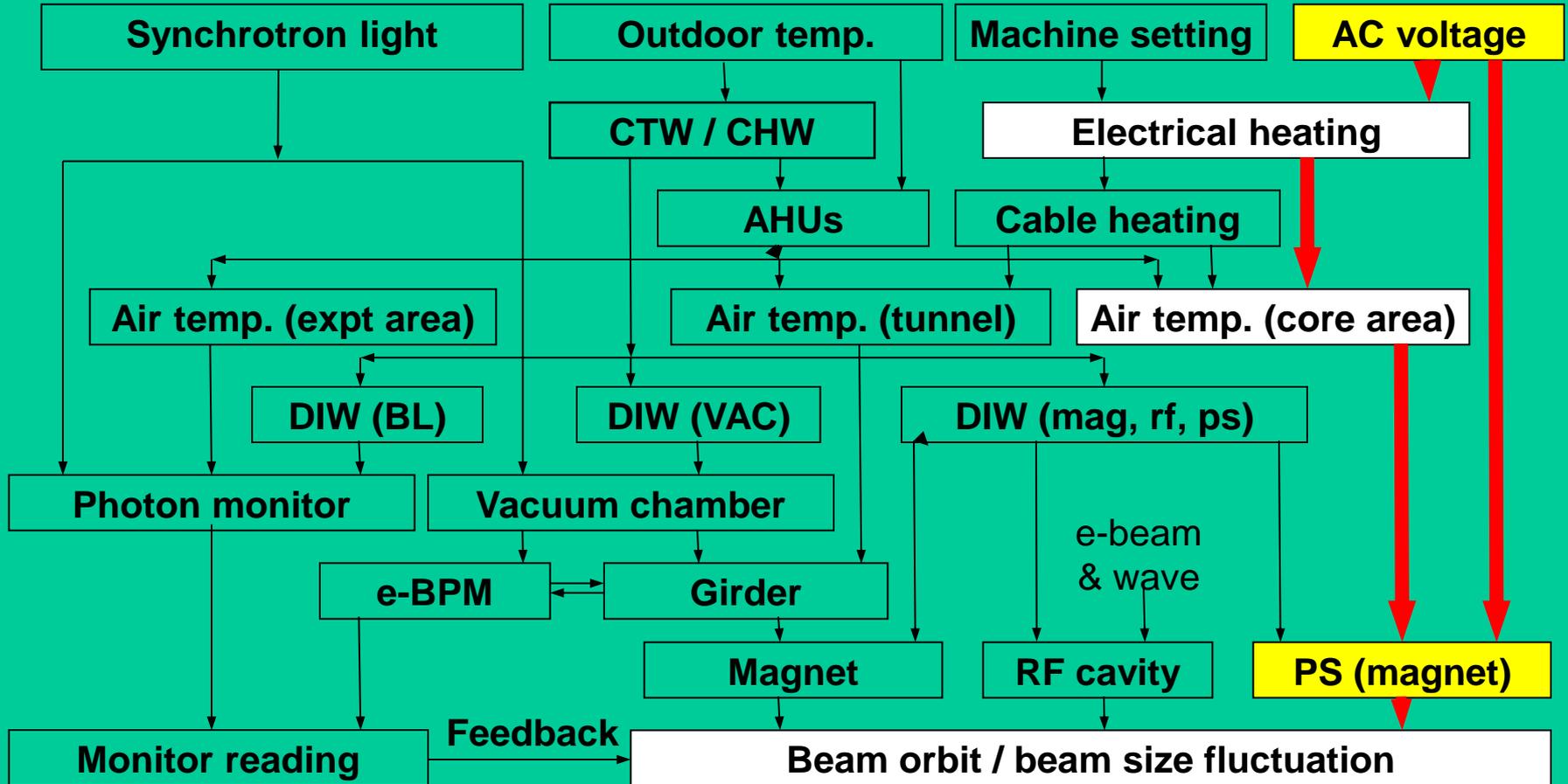


# Power Supply and Electrical Heating (1)

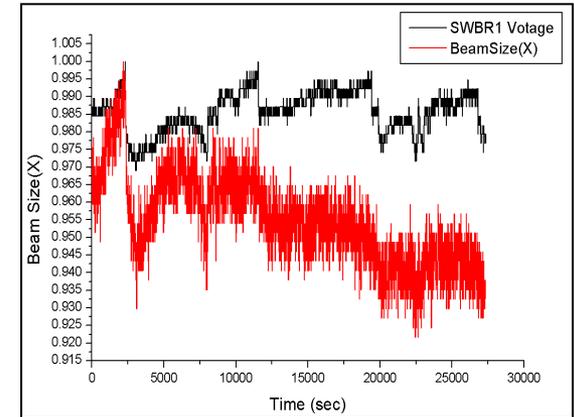
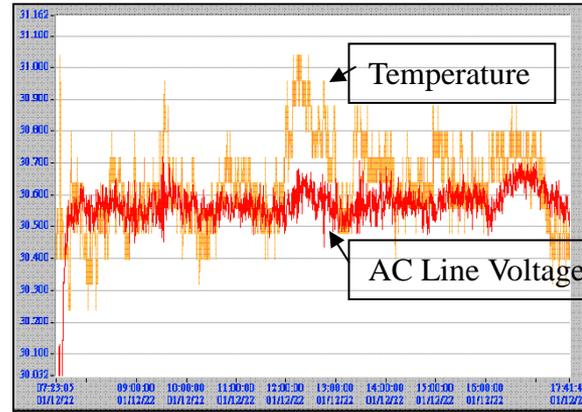
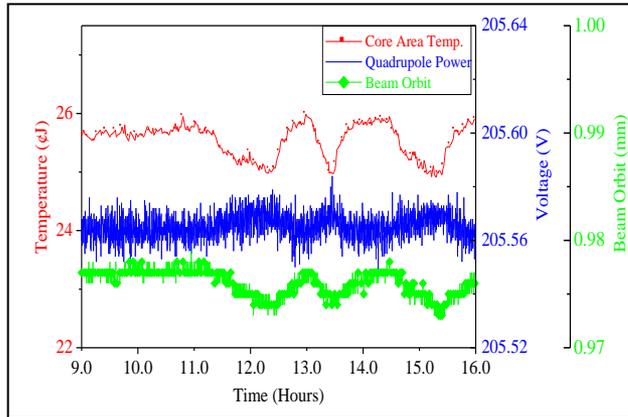


- **Transient after injection or shut down**  
**Heat source: mainly dipole-cables**
- **Transient time**
  - ~ 0.5 hr (after injection, insignificant after injector energy increased from 1.3 GeV to 1.5 GeV)  
 $\Delta T: > 0.5 \text{ }^\circ\text{C} \rightarrow \Delta T: < 0.2 \text{ }^\circ\text{C}$
  - ~ 12 hr (after shut down), it's better not to turn PS off  
 $\Delta T: > 1.5 \text{ }^\circ\text{C}$

# Power Supply and Electrical Effect (2)



# Power Supply and Electrical Heating (2)



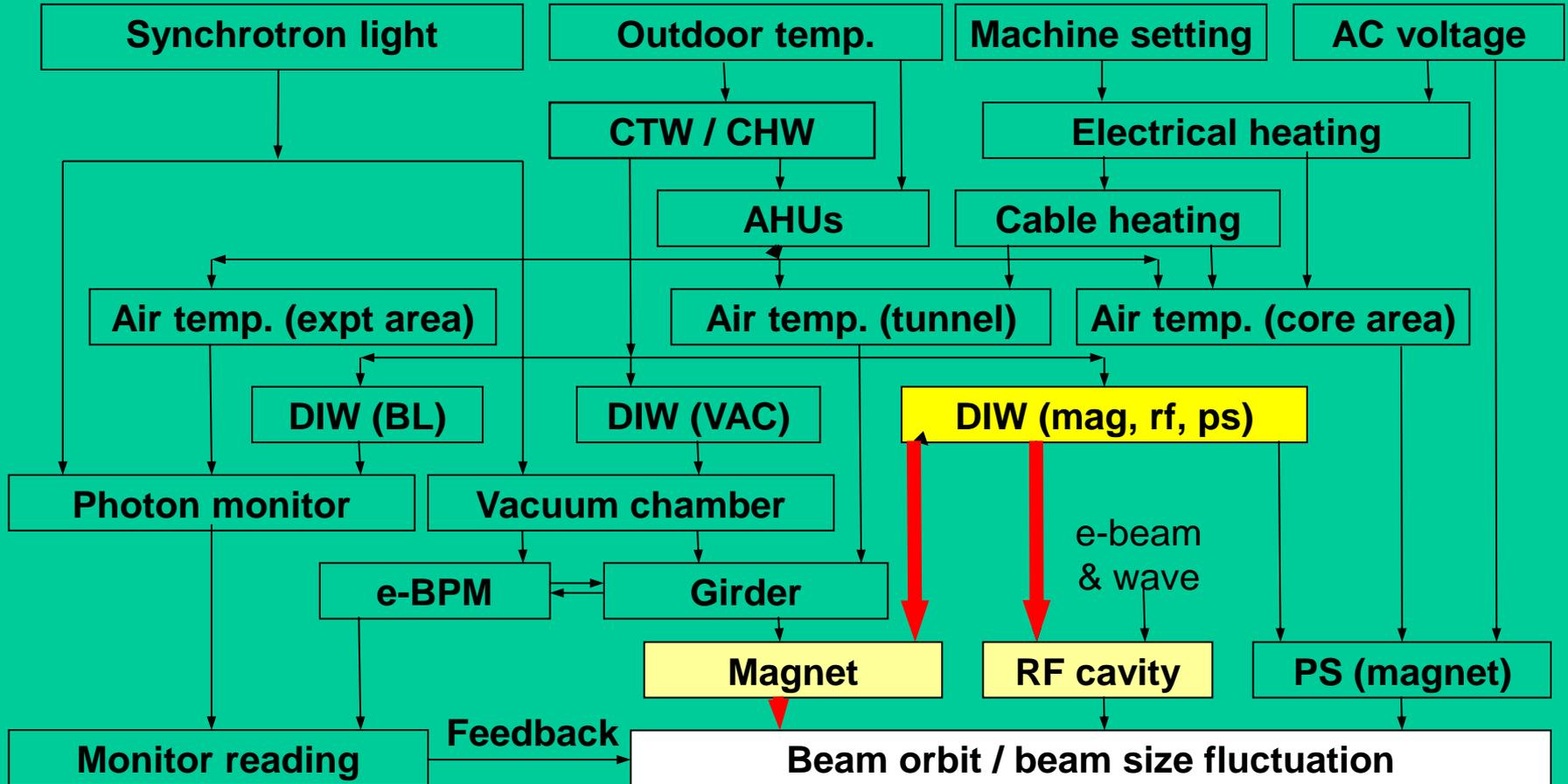
- **Phenomenon**  
 AC line voltage → air temperature  
 AC line voltage → output of DC-PS  
 Sensitivity:  $\sim 5 \mu\text{m} / ^\circ\text{C}$
- **Current Status**  
 Air temperature (core area):  $\sim \pm 0.3^\circ\text{C}$   
 A.C. line voltage fluctuation :  $\sim \pm 1.5\%$   
 ( $\sim \pm 0.05\%$  for PS-Q4)

**AC Line Voltage**  
 → Transmitter Water Temp.  
 → horizontal beam size

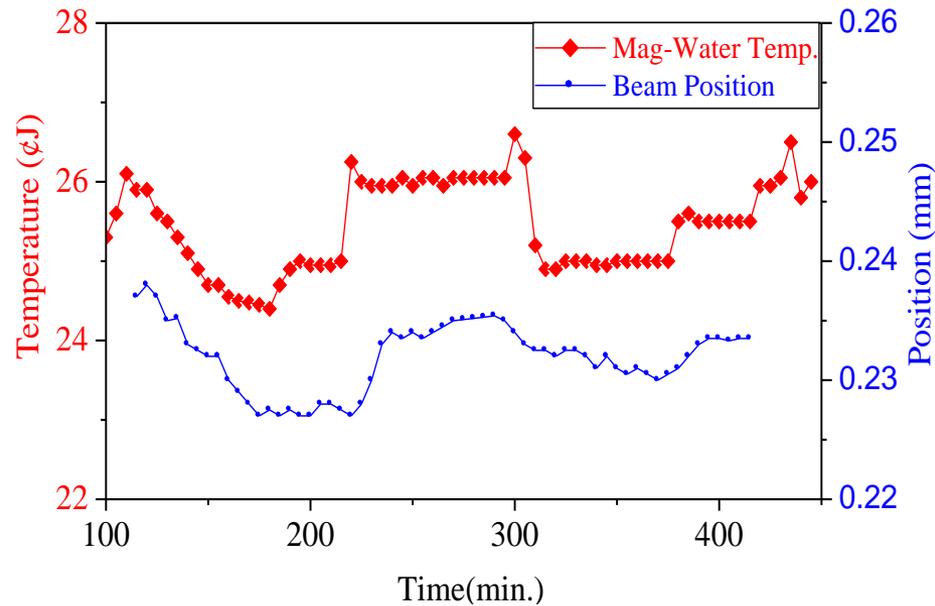
(Beam size):  $\sim 1 \mu\text{m}/\text{Volt}$

# Water Temperature Fluctuation

## -- Magnet & RF cavity --



# Magnet (Water Temp.)



**Caused by the temperature fluctuations of magnet cooling water**

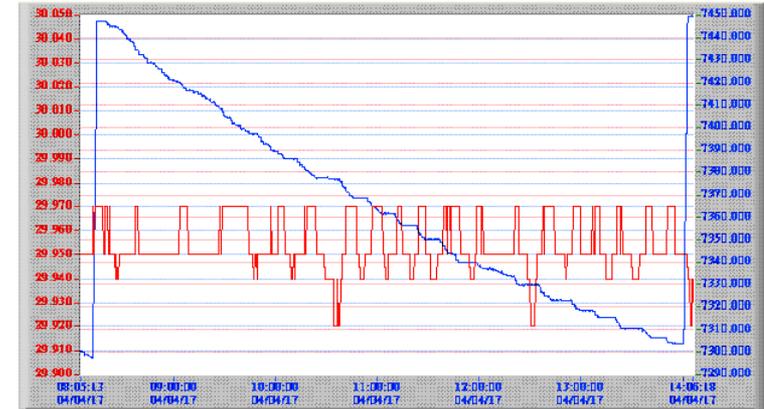
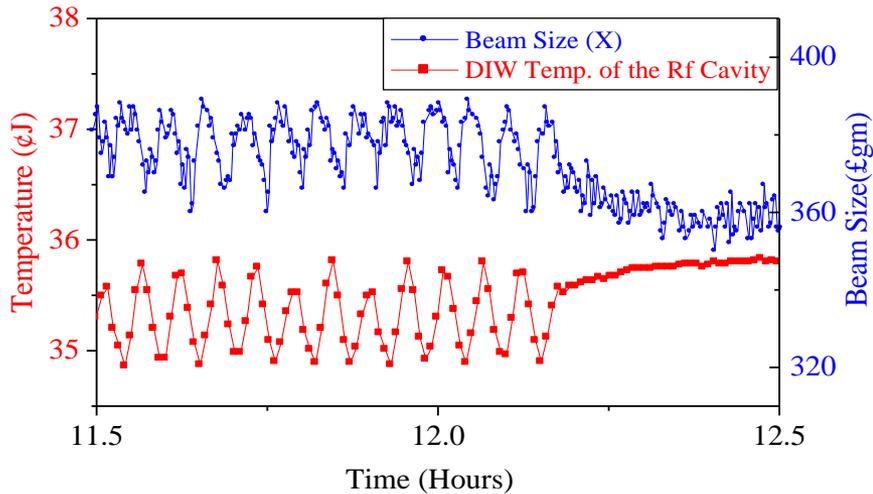
**Magnet deformed  $\sim 10\mu\text{m}/^\circ\text{C}$**

**Induced beam orbit drift:  $5\text{-}50\ \mu\text{m} / ^\circ\text{C}$**

**Current status**

**Cooling water temp.:  $\sim \pm 0.1^\circ\text{C}$**

# Beam Size Fluctuation Induced by RF-Water Temp.



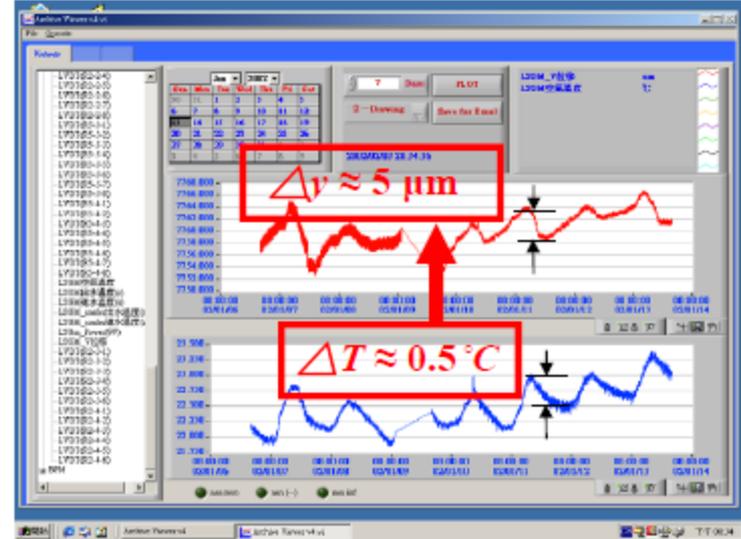
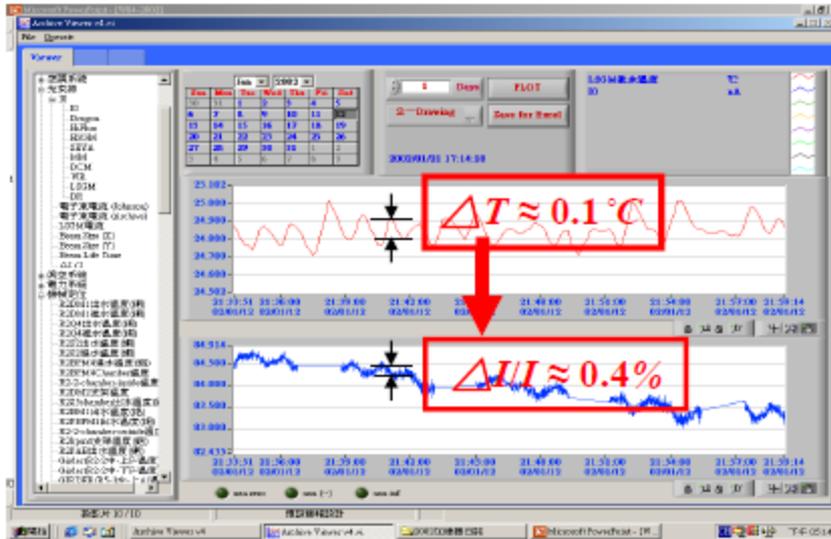
- **Phenomenon**  
Water temperature → beam size (x)  
Sensitivity: ~20 μm/°C (hor.)
- **Current Status**  
Water temperature (rf): < ± 0.02°C

Correlation between water temperature ( $\pm 0.015^\circ\text{C}$ ) and tuner position of rf system.

# Thermo-mechanical Effects on Photon Intensity (pin hole) Monitor (TLS)

(Water temperature fluctuation)

(Air temperature fluctuation)



For photon beam monitors,  $\Delta I/I < 0.1\%$  :  
 $\rightarrow \Delta T \sim 0.01^\circ\text{C}$

# Brief Summary

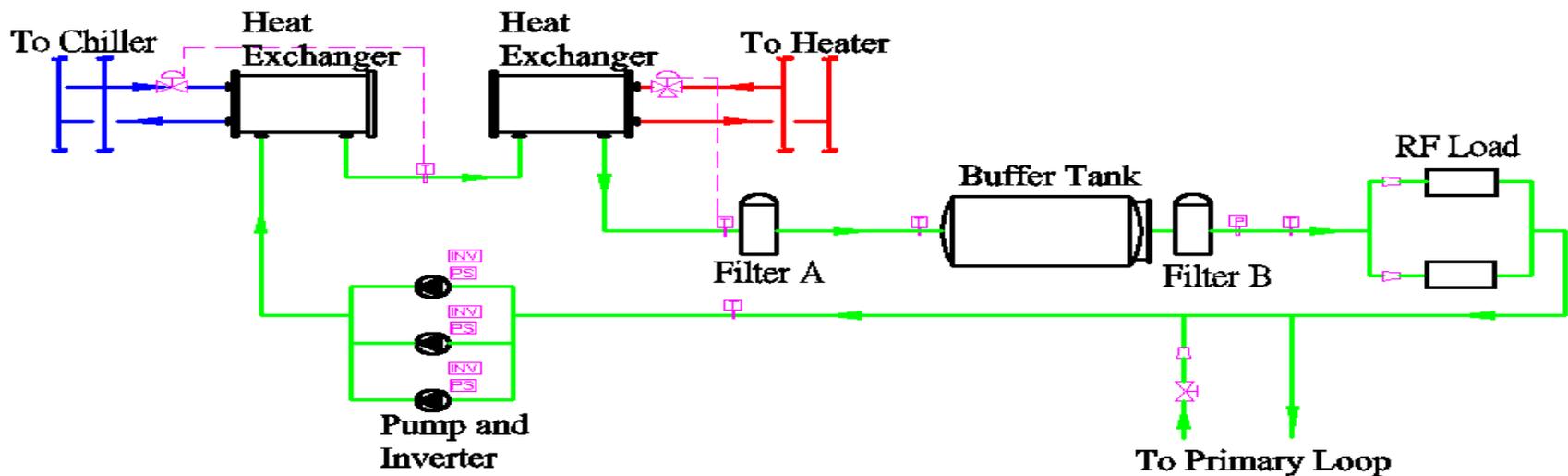
## (Thermo-mechanical Effects)

| Sources of disturbance   | Time constant  | Sensitivity to beam stability              | Structure influenced  | Solutions  |
|--|----------------|--|---|--|
| Seasonal temp. variation<br>- <i>Periodical</i>  | 1 y            | Circumference<br>~3mm/y                    | Floor   | RF frequency regulation  |
| Tunnel warming following a long shut down<br>- <i>Transient</i>                          | 1w             |  | Floor   | Wait (or to maintain tunnel temp. during shut down)            |
| Solar irradiation (tunnel air temperature variation)<br>- <i>Periodical</i>              | 1d             | 20~100 $\mu$ m/°C                          | Girder expansion<br>~10 $\mu$ m/°C (ver.)                   | Insulator jacket / air temperature control                     |
| Synchrotron light irradiation (current decay)<br>- <i>Transient</i>                      | hours          | 10-30 $\mu$ m/°C<br>(~1 $\mu$ m/°C to BPM) | Vacuum chamber & BPM displaced<br>~0.3 $\mu$ m/°C to girder | Top-up injection   |
| Re-injection with energy ramps (temp redistribution)<br>- <i>Transient</i>               | ~1 h           | 5-50 $\mu$ m/°C                            | Mag.- temp. changed (coil heating)<br>Mag-gap~10 $\mu$ m/°C | Full energy injection  |
| Limited capability of the system to control temp.<br>- <i>Periodical &amp; Transient</i> | Minute/seconds | 10-30 $\mu$ m/°C                           | Girder/ vacuum chamber/ magnets/ monitors/RF/PS             | Air/water temp. control $\pm$ 0.1C<br>rt-RF cavity $\pm$ 0.01C |
| Electrical heating (ac voltage fluctuation)<br>- <i>Random</i>                           | Minute/seconds |  | Power supply output<br>Air temp fluctuation                 | Ac regulator or better temp. control                           |

## III. Thermo-mechanical Effects

### Temperature Stabilization

- **Considerations on Temperature Stability Control**
  - \* Temperature of chilled (& hot) water should be stabilized  $< \pm 0.5^\circ\text{C}$ .
  - \* Eliminate the nonlinear effects in valves.
  - \* Use buffer tank to smooth the temperature variation  $< \pm 0.01^\circ\text{C}$ .
  - \* High resolution sensor and controller.
  - \* Variable frequency controller



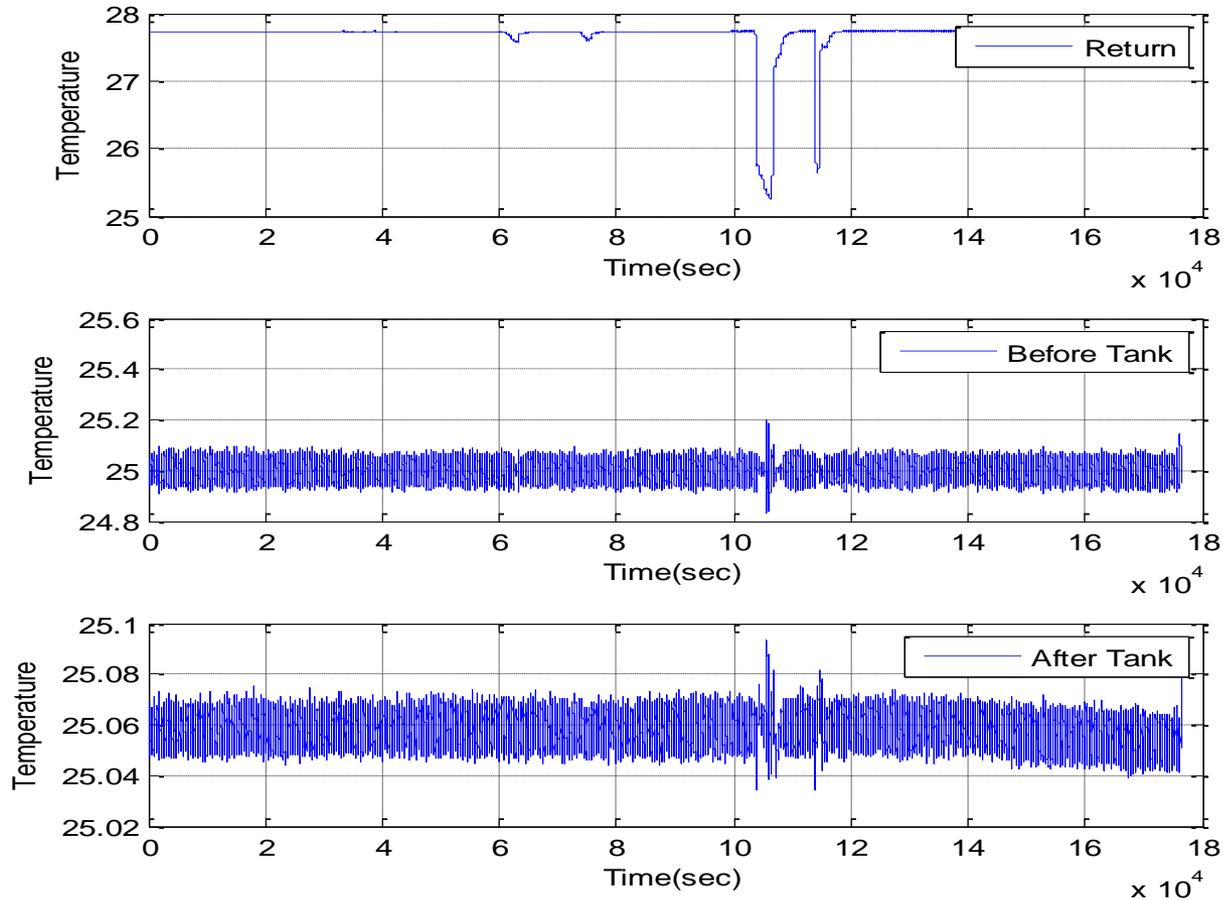
# Control Method (PID+PWM+Fuzzy)

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- Using cascade control for valve set
  - Easy to optimize operation point of load
  - Solve nonlinear matching between control valve and heat exchanger
  - Solve rangeability problem of control valve
- Small valve controlled by PID+PWM Control
  - Solve rangeability problem of control valve
  - Solve hysteresis problem of control valve
- Large valve controlled by Fuzzy Control
  - Solve control algorithm with multiple feedback
  - Overcome burst variation of load
  - Solve control sequence between small and large valve

# Water Temperature Variations after and before the Buffer Tank

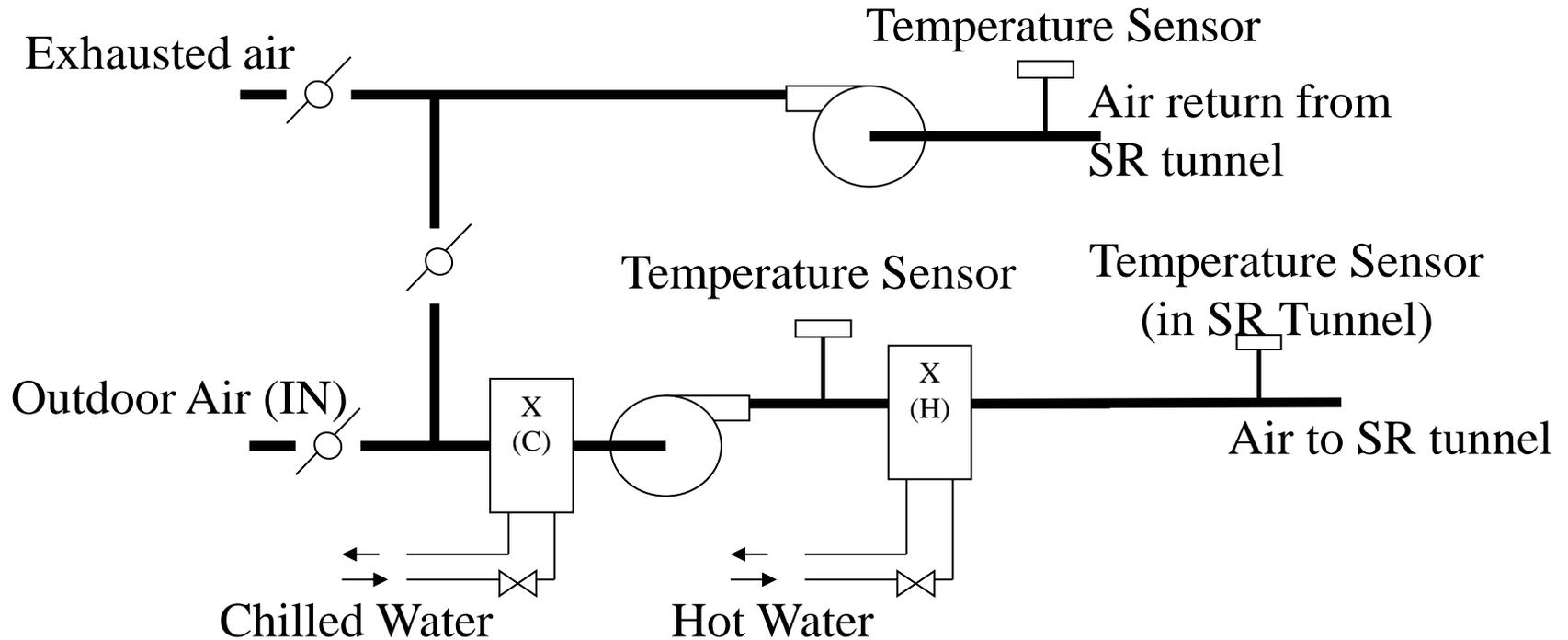
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(Z.D. Tsai, NSRRC)

# NSRRC *Temperature Control for Air*



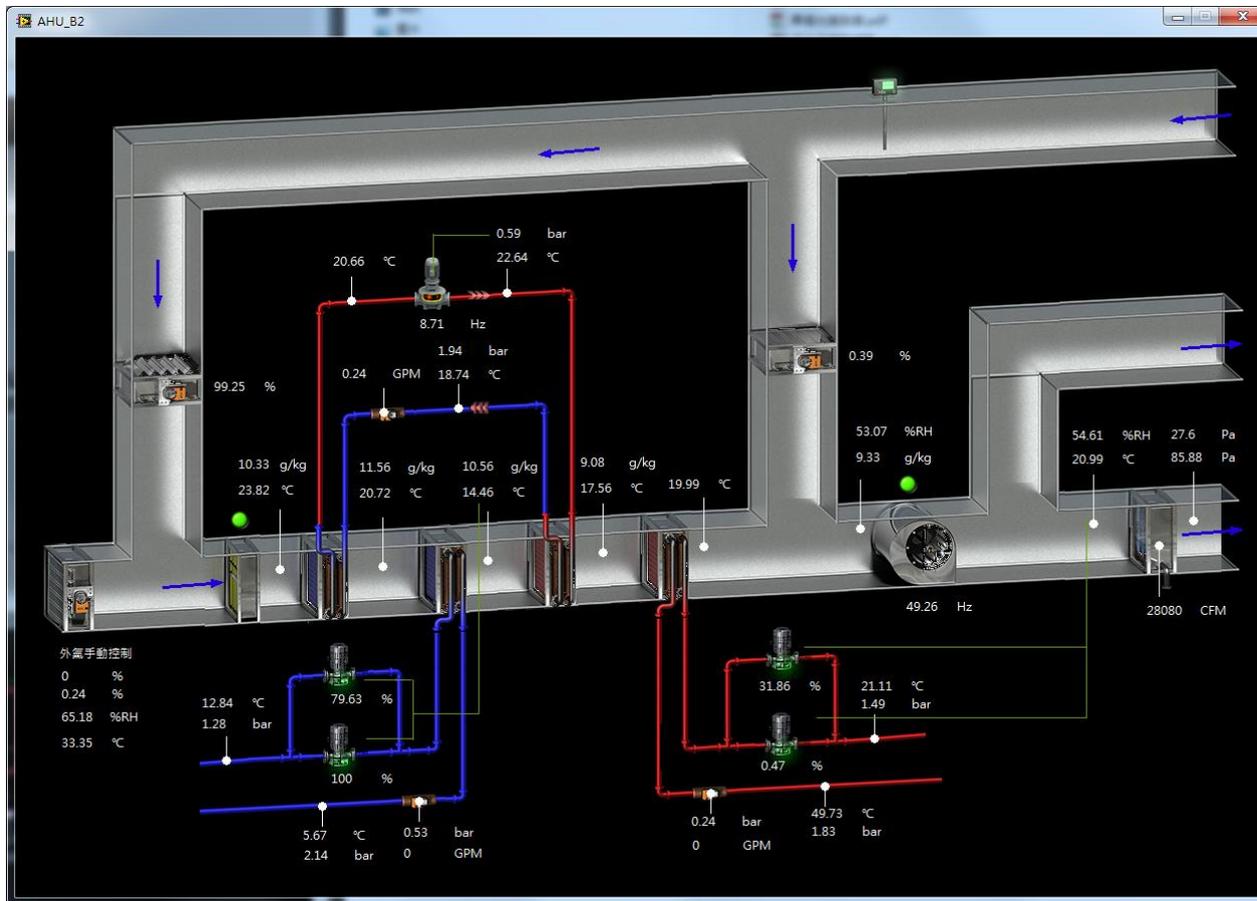
**CHW & HTW Temperature Control:**

**Fluctuation:  $< \pm 0.3^{\circ}\text{C}$**

**Air Temperature Control:**

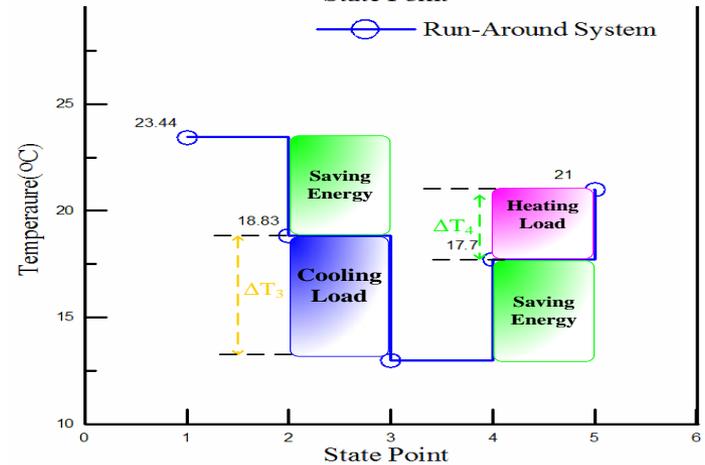
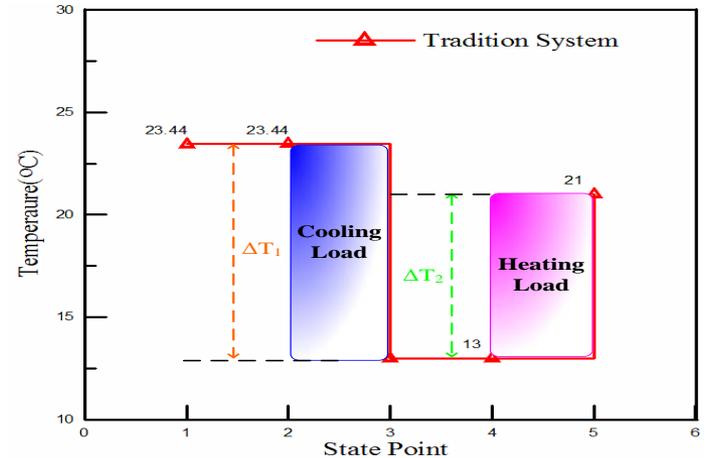
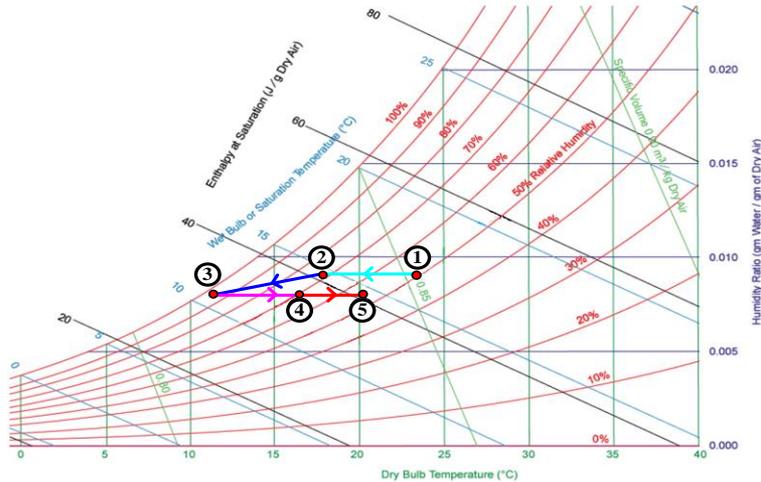
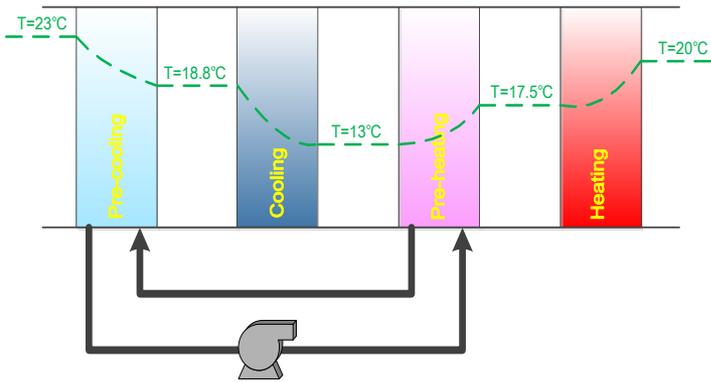
**Fluctuation:  $< \pm 0.1^{\circ}\text{C}$**

# Evolution of HVAC System



(Z.D. Tsai, NSRRC)

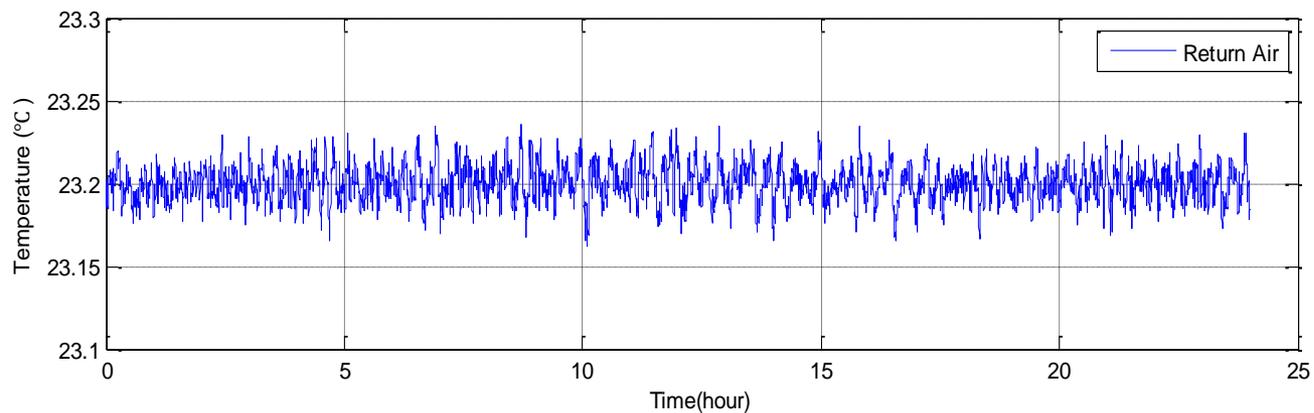
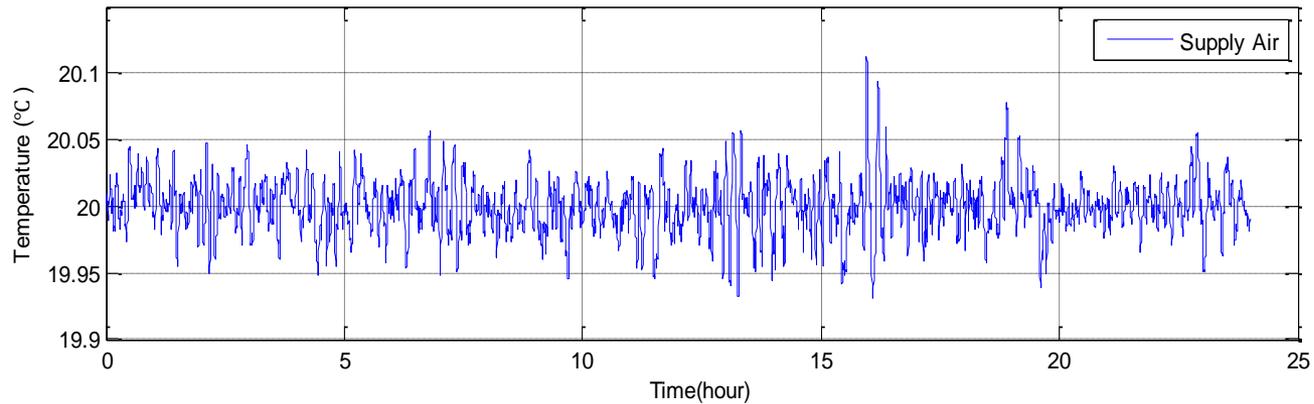
# Round-Around Design



(Z.D. Tsai, NSRRC)

# Highly Precise Control of Temperature with Run-around Coils

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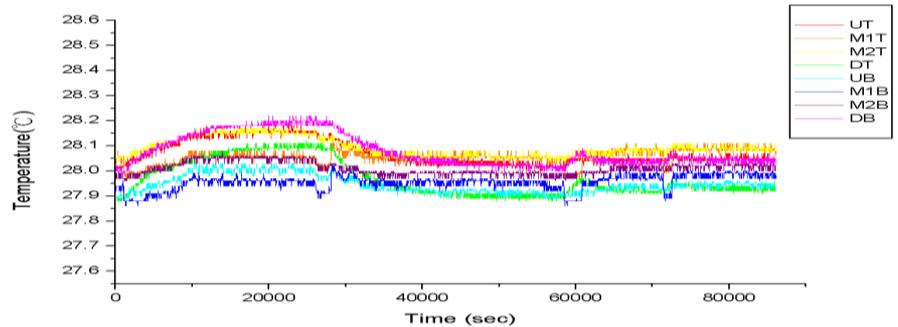
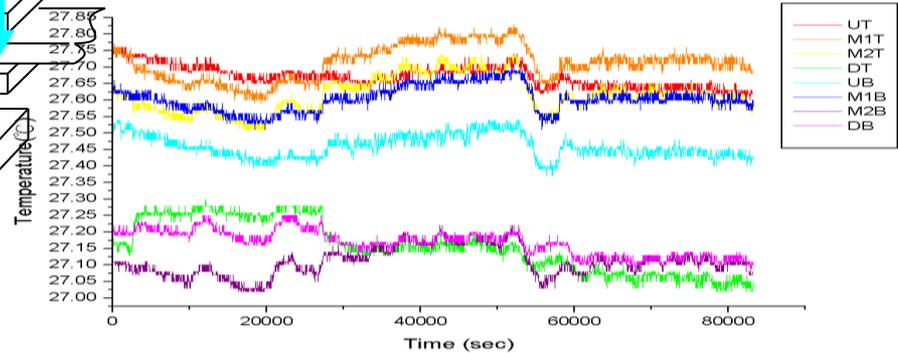
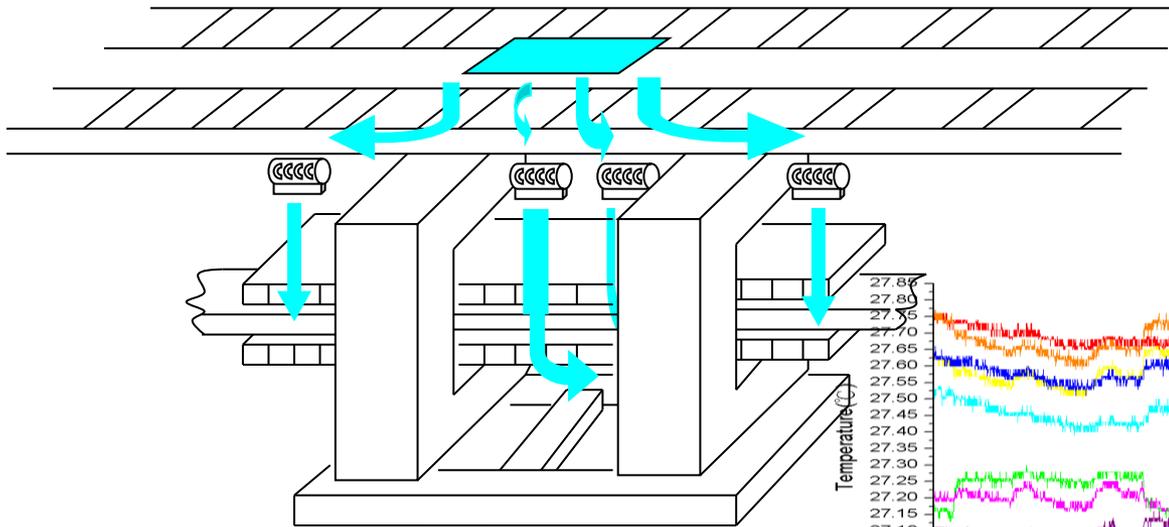
(Z.D. Tsai, NSRRC)



Girder with thermal insulation.

Transient time constant  $\rightarrow$  Longer (smoothing effect)

# Air Flow Uniformity Control



# Brief Summary

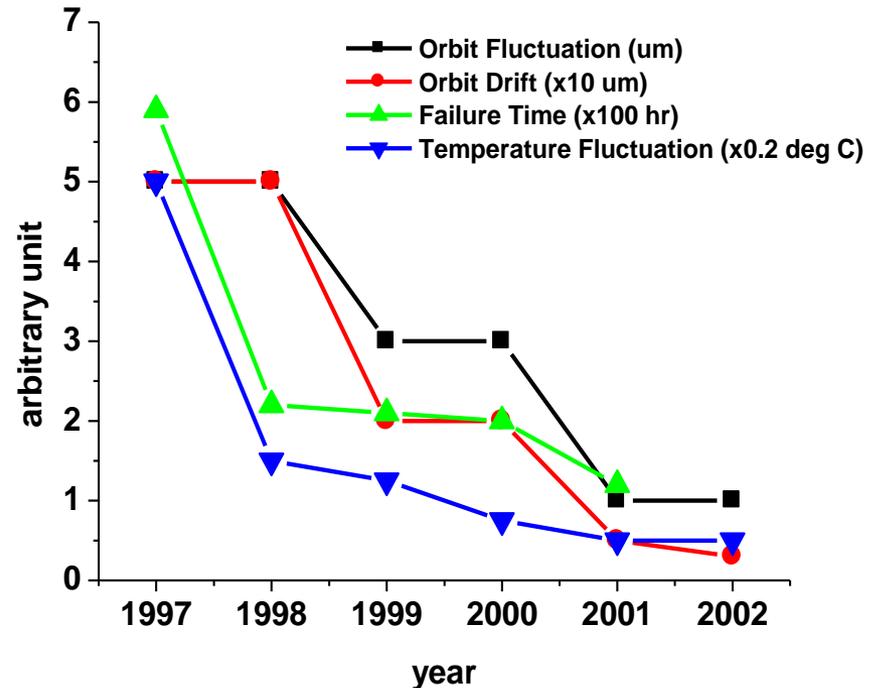
## (Temperature Stabilization)

**1. Delicate technologies have been developed to stabilize the air- and water- temperature fluctuation. A temperature fluctuation of  $< \pm 0.1^\circ\text{C}$  can be routinely achieved in several labs.**

**2. Thermal stability improves not only the beam stability but also the system reliability.**

**3. The technologies for a stability of  $\pm 0.01^\circ\text{C}$ , which will be beneficial to the new machines, are almost matured.**

**TLS Improvement (1997-2002)**



# IV. Mag-Girder Assembly

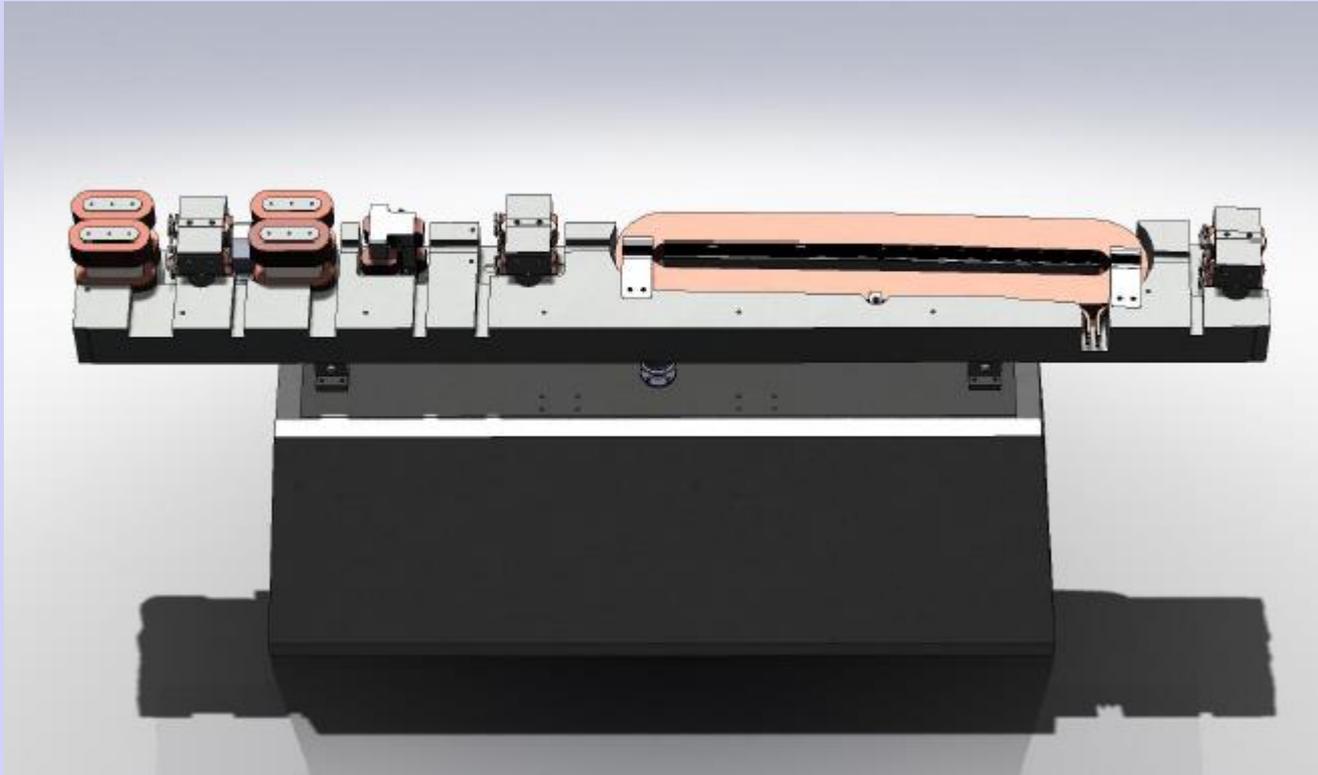


## IV. Mag-Girder Assembly

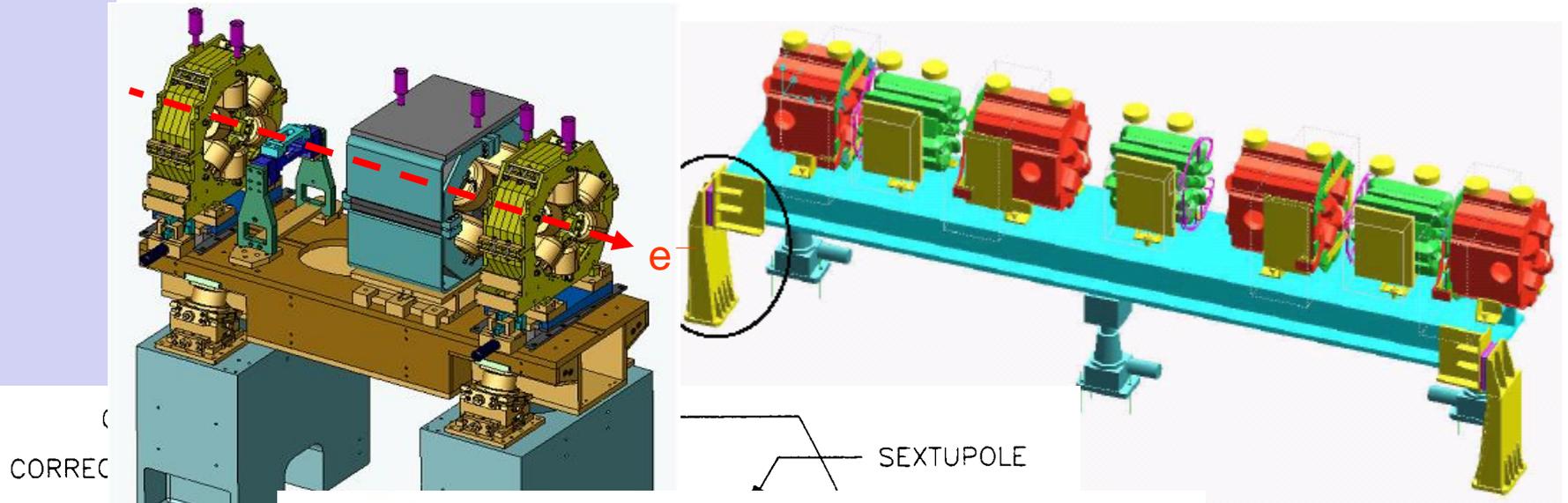


OR

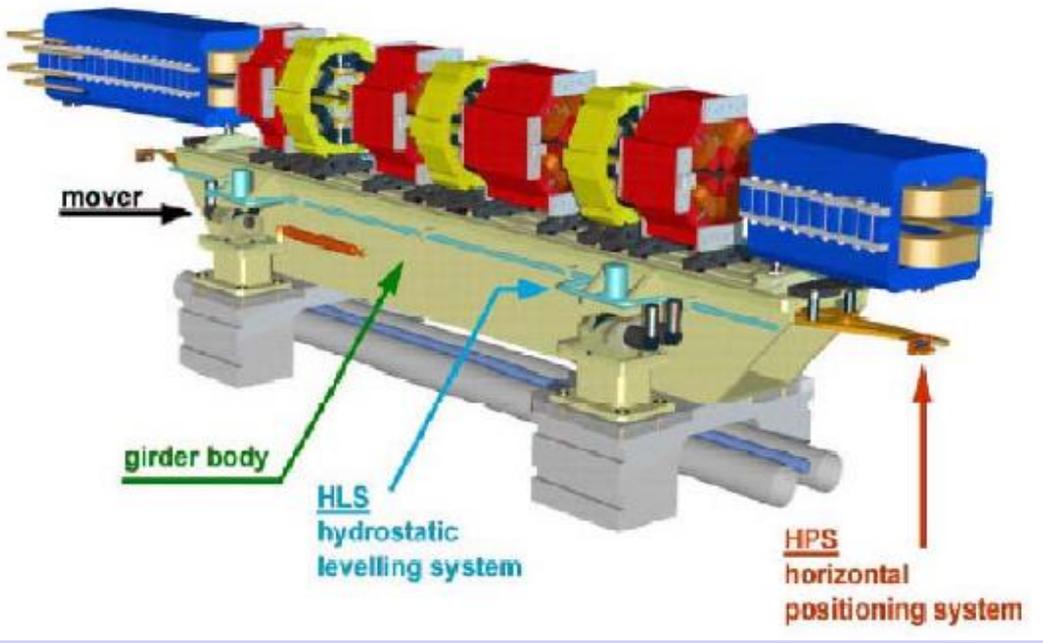
## IV. Mag-Girder Assembly



# Girder Developments



- WEDGE JACK
- DAMPING PAD
- PEDESTAL



n by a factor of 6  
 : 1<sup>st</sup> natural  
 to higher frequency



# Mag-Girder Assembly (basic concept)

1. Good mechanical behavior. (Stiff + damping property)  
Structure amplification factor  $AF-a = 1$ . Natural frequency  $>30$  Hz (or 50 Hz).  
(or adaptive vibration suppression  $AF-a < 1$ ).
2. Girder as an optical table.  
(with reference surfaces for component alignment)
3. Adjustable: 6 degree of freedom without over-constraint.  
(beam-based alignment)
4. Capable of girder-to-girder alignment.  
(vibrating wire for the magnets on the same girder)
5. Compensation to the ground settlement.

# Alignment and Stability Requirements

Alignment purpose → Small COD (within aperture)  
→ 100μm (30μm/ on girder)

Stability purpose → Stable photon beam intensity  
(fluctuation <0.1%)  
→ ~ 0.2 μm (0.05 ~ 0.1σ<sub>y</sub>) on magnet

~ 0.2 μm ground vibration  
→ Structure Amplification Factor  
**AF-a = 1**

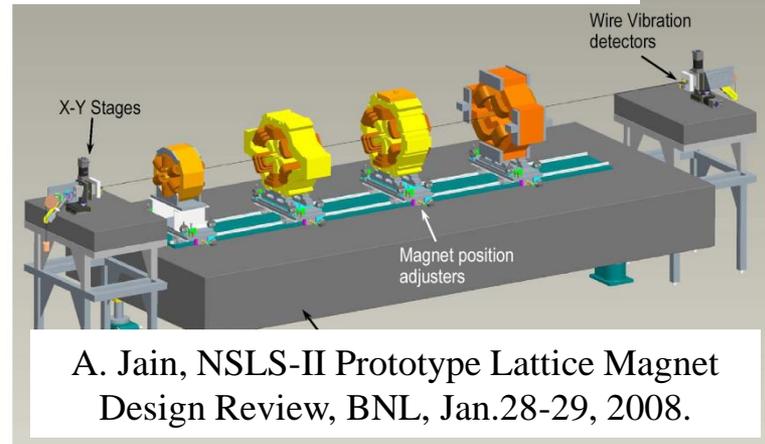
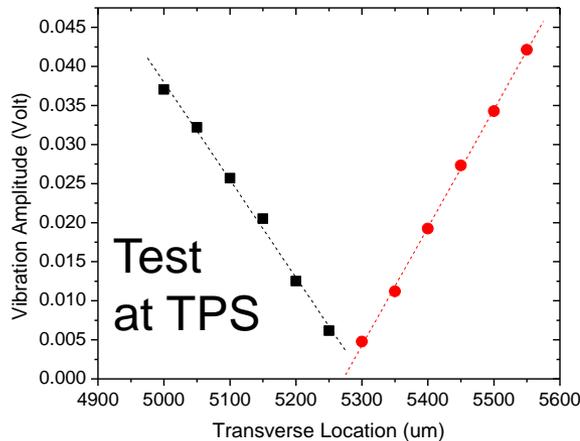
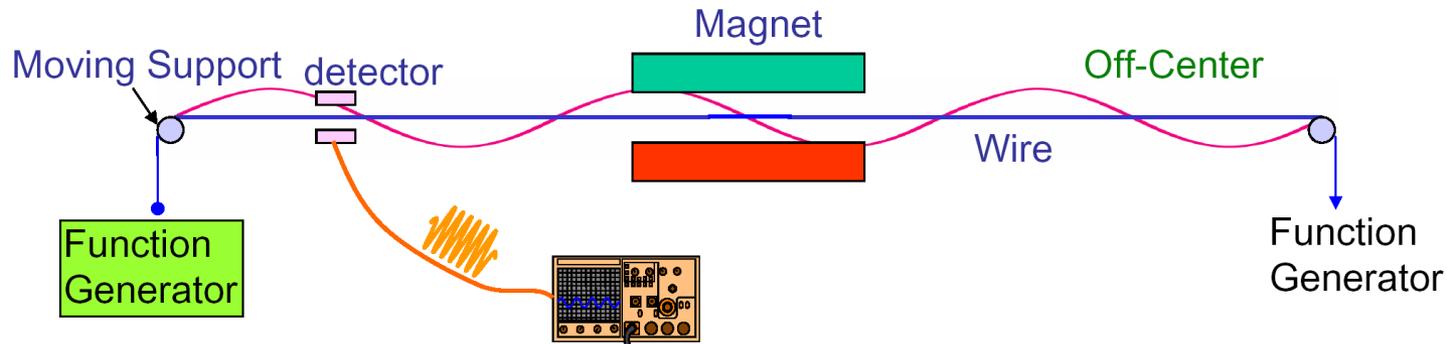
$$AF_b = \frac{\Delta x_{rms}}{\Delta q_{rms}}$$

$$AF_b = \frac{\sqrt{\beta_{obs}}}{2\sqrt{2} \sin \pi\nu} \sqrt{\sum_i \beta_i (Kl_i)^2}$$

$\Delta x_{rms}$  – beam displacement

$\Delta q_{rms}$  – quadrupole displacement

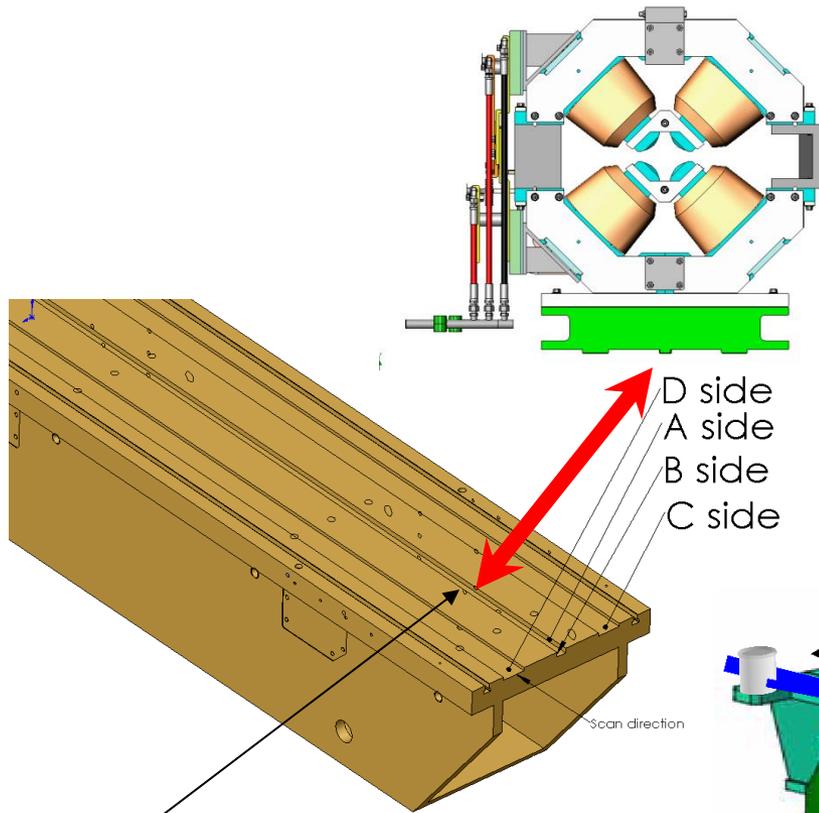
Whether the mechanical center of a magnet is the same as the magnetic field center is always in doubt. → **Vibrating Wire**



A. Jain, NSLS-II Prototype Lattice Magnet Design Review, BNL, Jan.28-29, 2008.

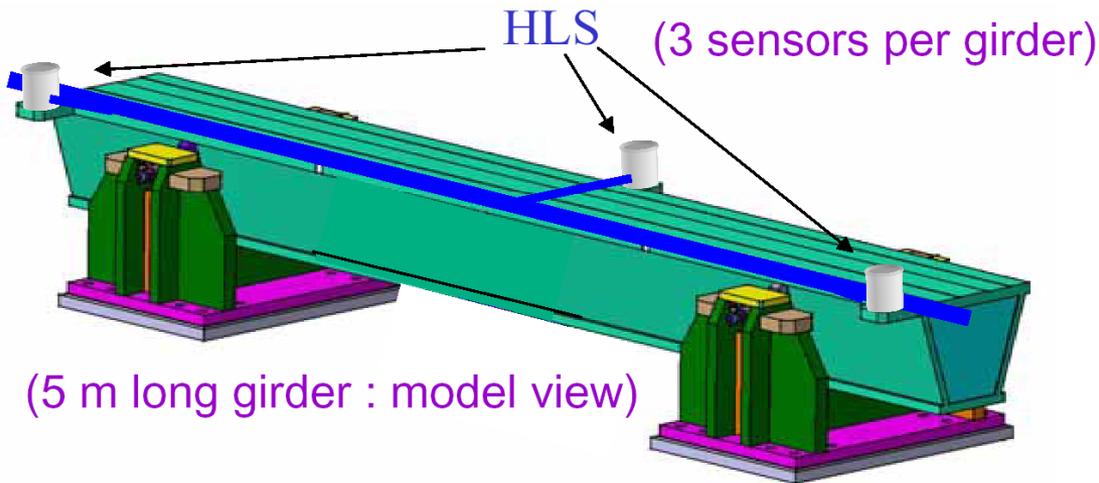
The positioning error for quadrupoles and sextupoles: ~ 5 μm.

# Aligning the magnets on the same girder



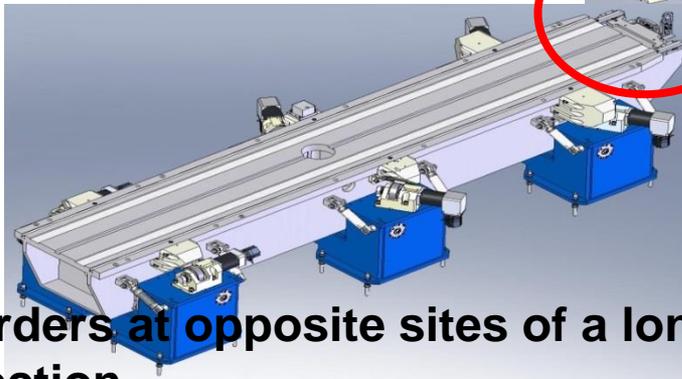
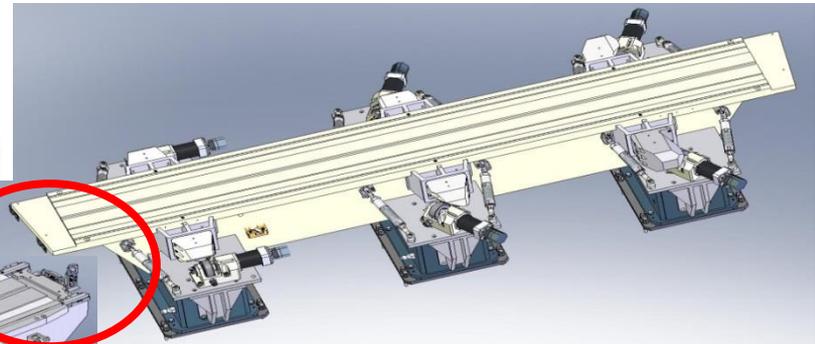
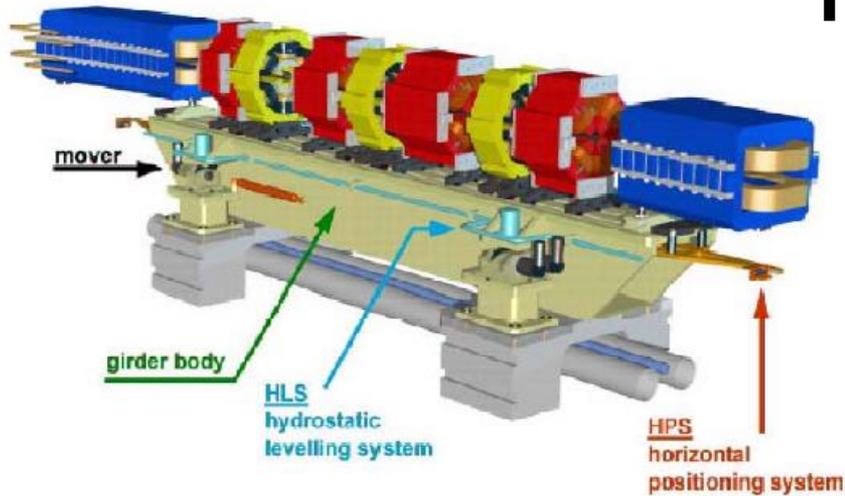
Magnets are fixed to the girder by matching the pre-machined reference surfaces at both the bottom of the magnets and the top of the girder.

References surfaces:  
SLS, DLS, Soleil, TPS, etc.



- \* Amp. factor without girder = 54.5/40.3 in x/y rms
- \* Amp. factor With girder = 30.6/8.0 in x/y rms

## Touch Sensors & Leveling Micron resolution



For two girders at opposite sites of a long straight section  
→ laser-based alignment system

**HLS: SLS, DLS, Soleil, etc.**  
**TPS: electronics leveling + touch sensors**

# V. Summary

- Essentials for the new generation light sources:

@ A precise-adjustable girder less sensitive to the perturbations.

@ Fine positioning

- a) precisely positioning the major components,
- b) protecting the position of major components from perturbation,

@ Temperature stabilization

- a) stabilizing the sources of heat,
- b) decreasing the sensitivity in each route of transfer from the heat source to the fluctuation of the electron beam,

@ Vibration suppression

- a) stabilizing the sources of vibration,
- b) suppressing vibrations along the transfer route from a source to a sensitive device of the light source,

***Thank you for your attention.***