Users' Requirements for Orbit Stabilization

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Golden Rules

Requests from SR Users are Unlimited.

Users doubt Light Source before doubting their Own Equipments.

Collaboration between machine people and users is essential to achieve ultimate performance.

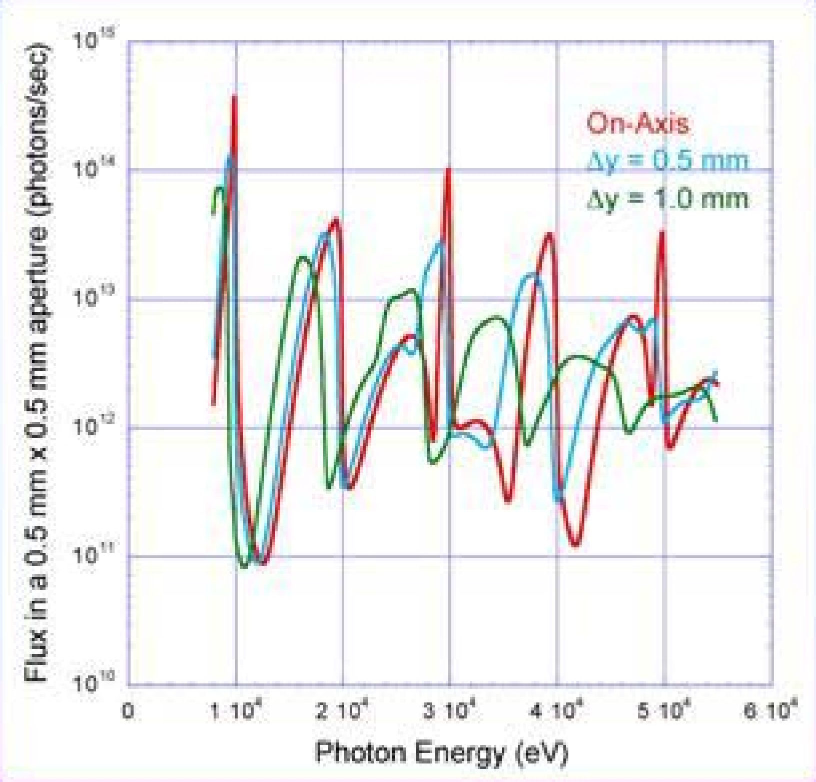
Introduction

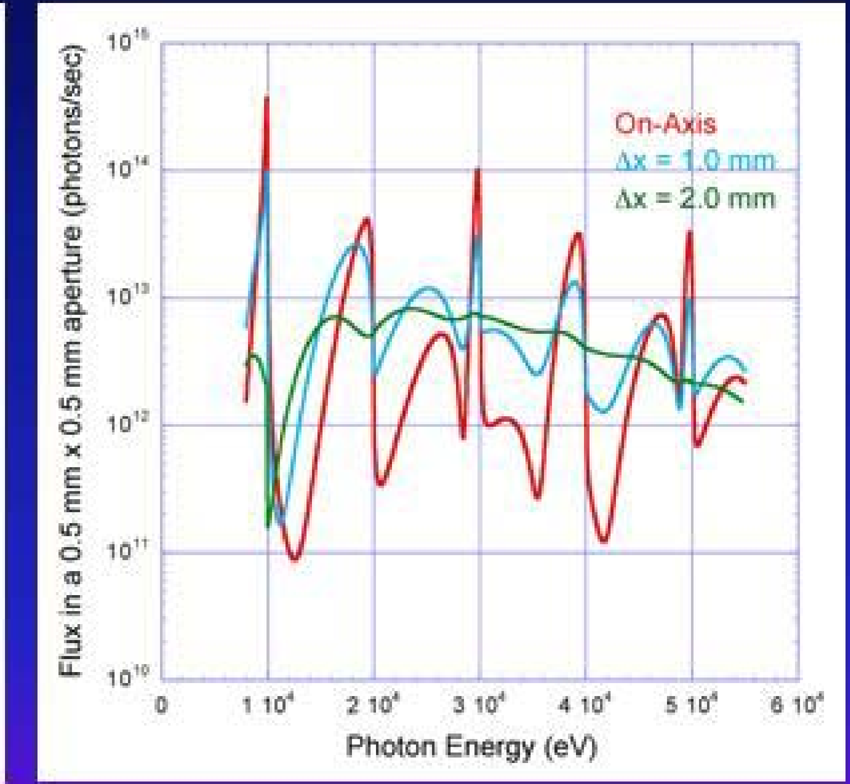
- Why the Beam Stability is Important for Users?
- How the Better Stability Improve the Quality of User Data?
- What New Sciences will Come Up with the Further Stability of the Beam?

Why the Beam Stability is Important for Users?

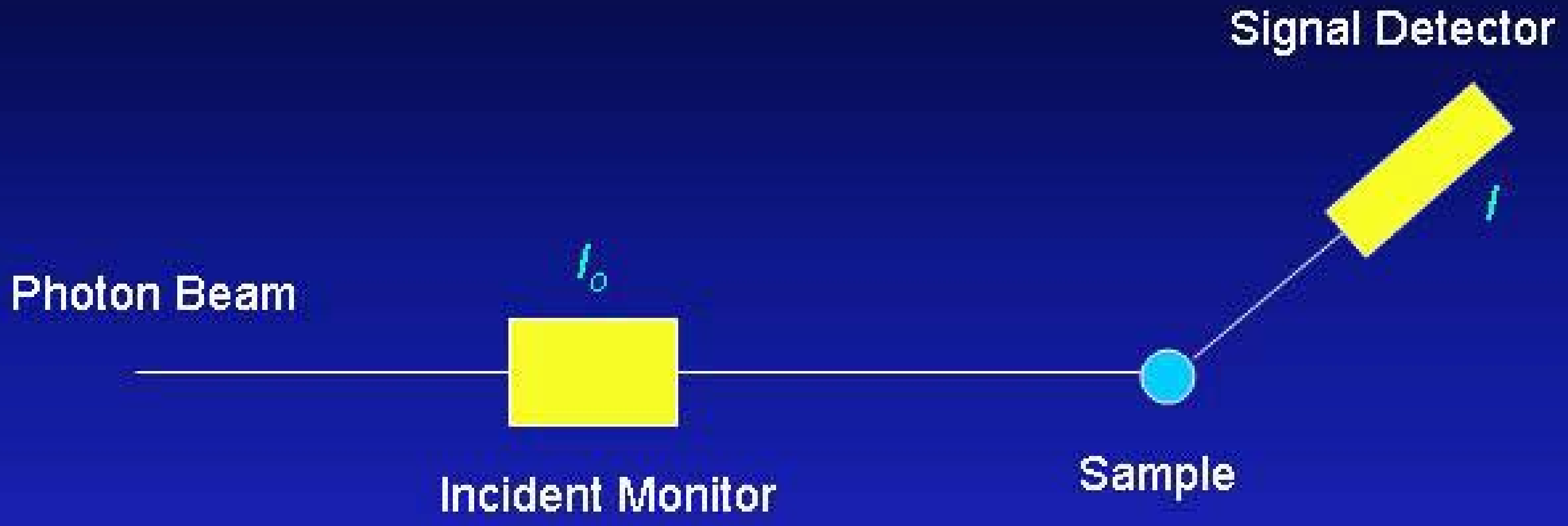
- SR Beam is Highly Directional.
- Changes in Source Position will Change the Photon Flux onto Samples.
- Changes in Beam Inclination will Change the Beam Parameters.

Undulator Spectrum





Usual Setup of User Experiments

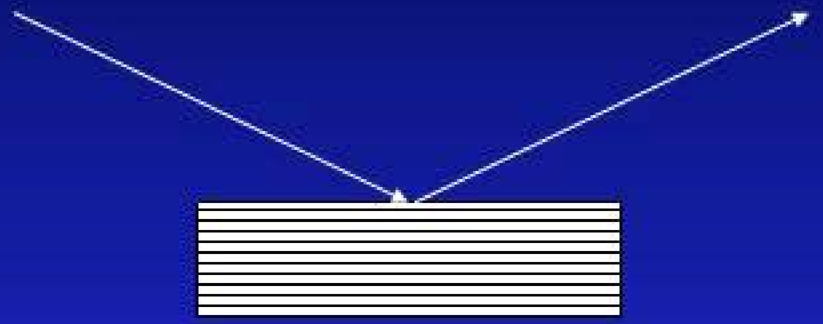


Since storage ring is a time-varying light source, users normalize the signal, I, by incident flux, I_0.

With fast fluctuation of incident flux, normalization process does not go well.

Spectroscopy: X-ray Monochromatization

Crystal Monochromator



Bragg Condition

$$\lambda = 2d \sin \theta_B$$

λ: wavelength

d: lattice constant

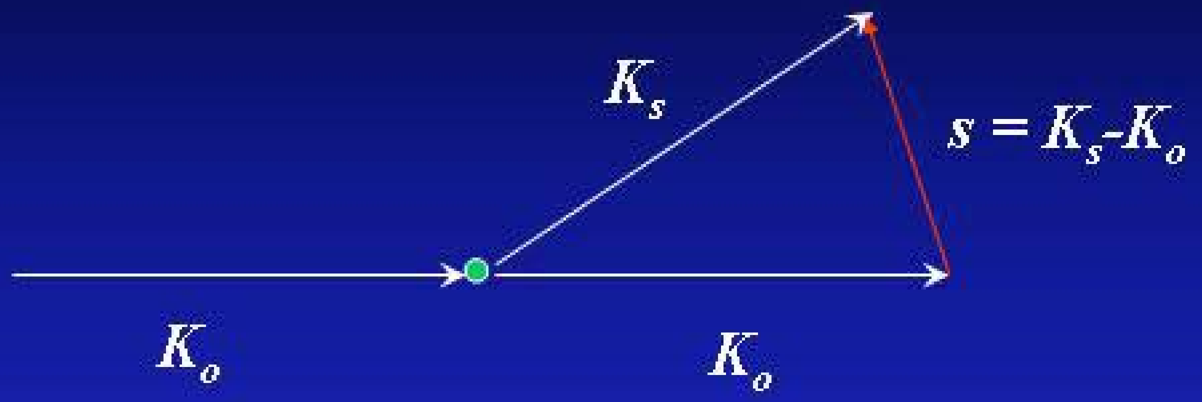
θ_B: glancing angle

Angular Deviation: $\Delta\theta$

$$\Delta\lambda = 2d \cos \theta_B \Delta\theta$$

Angular Fluctuation ➡ **Blurring Fine Structures in Energy Spectrum**

Scattering Measurements



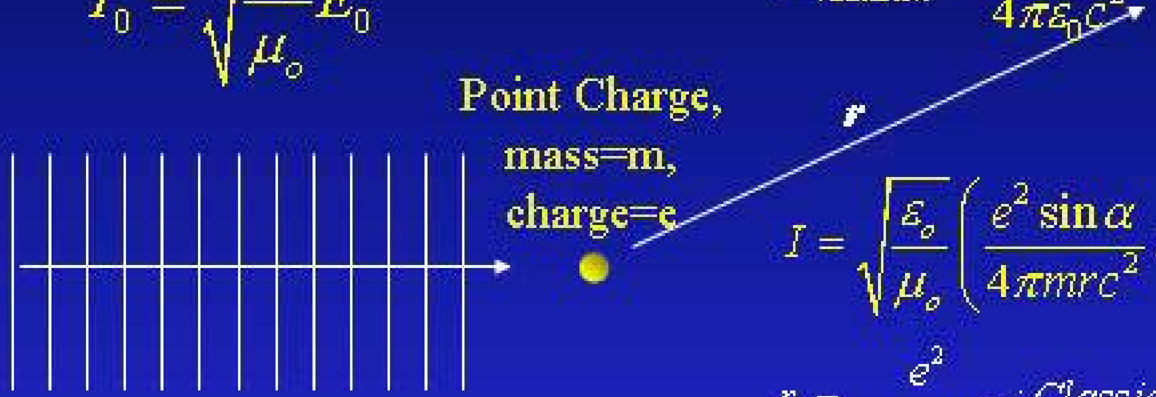
Important Parameter: Scattering Vector, s

Angular Fluctuation, ΔK_o → $\Delta s = -\Delta K_o$

Scattering of x-rays by a point charge (Thomson Scattering)

$$I_0 = \sqrt{\frac{\varepsilon_o}{\mu_o}} E_0^2$$

$$\boldsymbol{E}_{radiation} = \frac{1}{4\pi\varepsilon_0 c^2} \frac{e\left(\ddot{\boldsymbol{x}} \times \boldsymbol{r}\right) \times \boldsymbol{r}}{r^3}$$



Point Charge,
mass=m,
charge=e

Electromagnetic Plane Wave

$$\boldsymbol{E} = \boldsymbol{E}_0 \exp\left[i\left(\boldsymbol{K}_o \cdot \boldsymbol{r} - \omega t\right)\right]$$

$$\boldsymbol{B} = \frac{\boldsymbol{k}}{\omega} \times \boldsymbol{E}_0 \exp\left[i\left(\boldsymbol{K}_o \cdot \boldsymbol{r} - \omega t\right)\right] = \frac{\hat{\boldsymbol{k}}}{c} \times \boldsymbol{E}$$

$$I = \sqrt{\frac{\varepsilon_o}{\mu_o}} \left(\frac{e^2 \sin\alpha}{4\pi m r c^2} E_0\right)^2 = r_0^2 \sin^2\alpha \left(\frac{I_0}{r^2}\right)$$

$$r_0 = \frac{e^2}{4\pi\varepsilon_o m c^2} \text{ : Classical Electron Radius}$$

$$= 2.81776 \times 10^{-15}\ m$$

Lorentz Force

$$m\ddot{\boldsymbol{x}} = e(\boldsymbol{E} + \dot{\boldsymbol{x}} \times \boldsymbol{B})$$

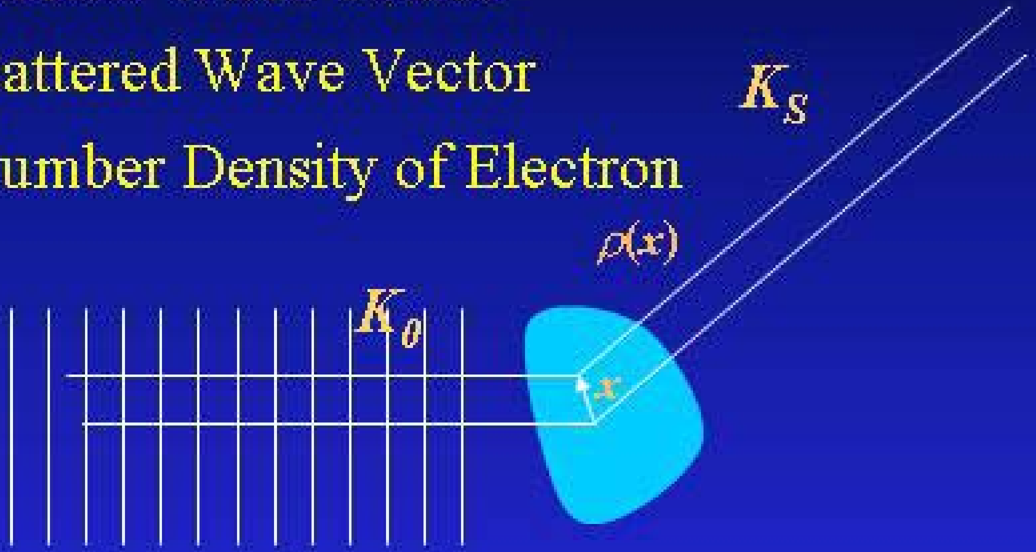
$$|\dot{\boldsymbol{x}}| << c \Rightarrow \ddot{\boldsymbol{x}} = \frac{e}{m} \boldsymbol{E}$$

Scattering of x-rays by distributed charge

K_0 : Incident Wave Vector

K_S : Scattered Wave Vector

$\rho(x)$: Number Density of Electron



Contribution from a volume element d^3x at x

$$dE_{radiation}^{distribution} = E_{radiation}^{point\ charge}\,\rho\left(x\right)\exp\left[-i\left(K_s - K_o\right)\cdot x\right]d^3x$$

Scattering of x-rays by distributed charge

$$E_{radiation}^{distribution} = E_{radiation}^{point\ charge} \iiint \rho(\boldsymbol{x}) \exp\left[-i(\boldsymbol{K}_s - \boldsymbol{K}_o)\cdot\boldsymbol{x}\right] d^3\boldsymbol{x}$$

3D Fourier Transform of Charge Density

Scattered Intensity

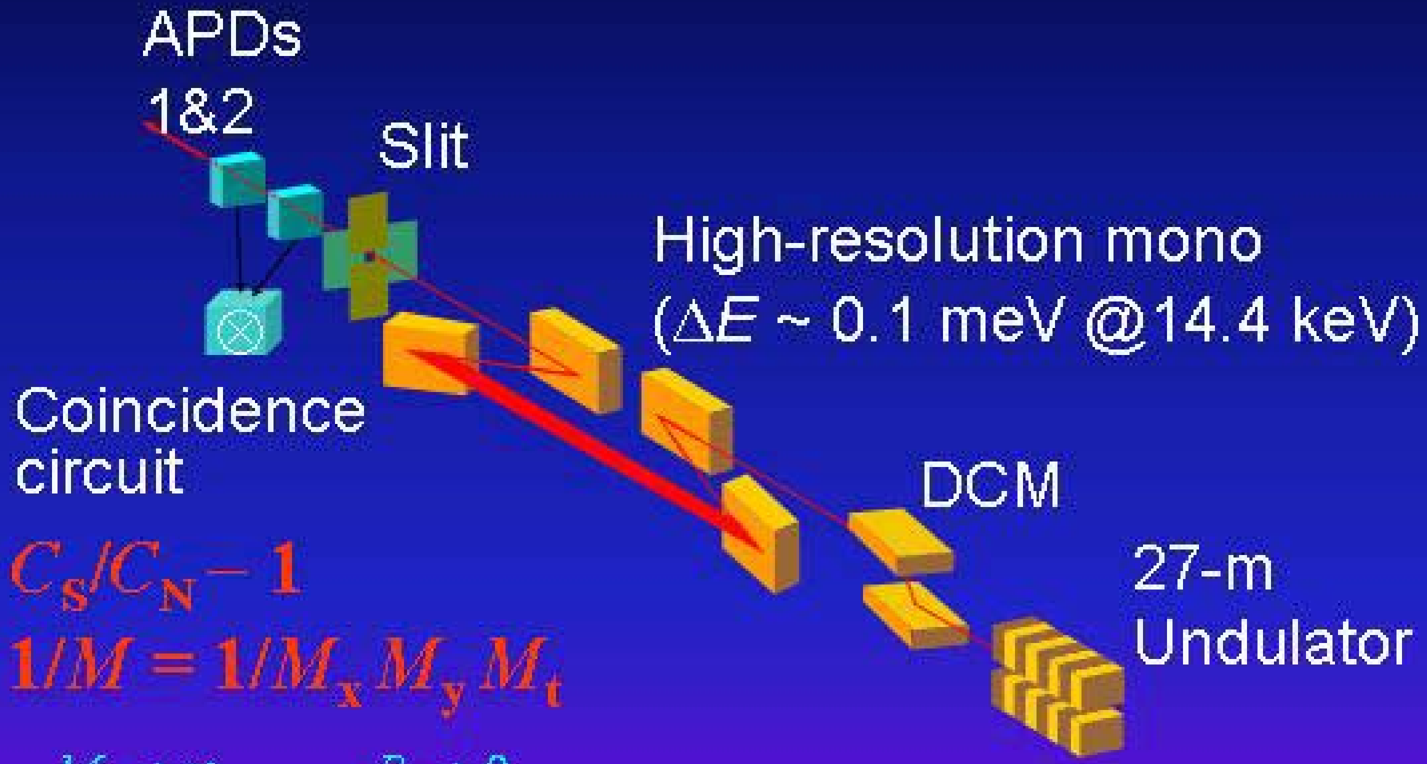
$$I = I^{single} \left| \iiint \rho(\boldsymbol{x}) \exp\left[-i(\boldsymbol{K}_s - \boldsymbol{K}_o)\cdot\boldsymbol{x}\right] d^3\boldsymbol{x} \right|^2$$

$$= \frac{r_o^2 \sin^2\alpha}{r^2} I_o \left| \iiint \rho(\boldsymbol{x}) \exp\left[-i(\boldsymbol{K}_s - \boldsymbol{K}_o)\cdot\boldsymbol{x}\right] d^3\boldsymbol{x} \right|^2$$

From User Side…..

- Beam Stability and Optics Stability are Equally Important.
- Better Beam Stability Elicits Finer Problems in Optics Instability.
- Reversely, Improved Optics Elicits Smaller Beam Instability.

X-ray Intensity Interferometry
(Hambury Brown-Twiss Interferometer)

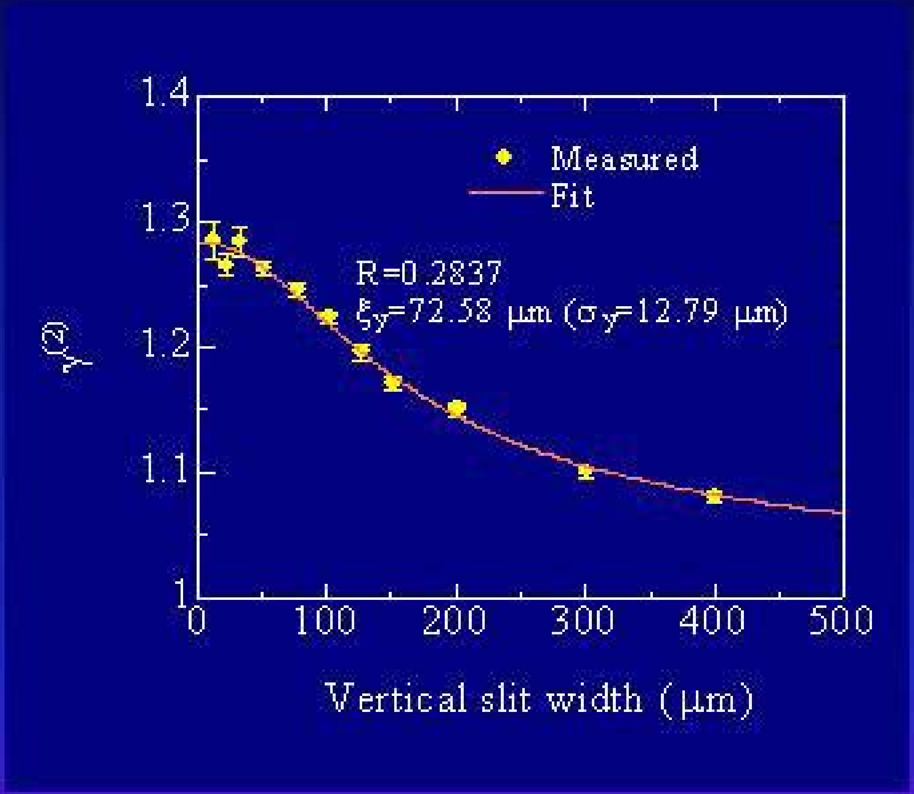


$$R = C_S/C_N - 1$$
$$= 1/M = 1/M_x M_y M_t$$

$M \to \infty$ $R \to 0$

$M \to 1$ $R \to 1$

Source Profile



$\gamma^{(2)}$ max = 1.28

(@ slit size 10 x 10 μm^2)

Coherence length:

$\xi_y = 72.6\ \mu m$

↓

Source size

$\sigma_y = \lambda L/2\pi\xi_y = 12.8\ \mu m$

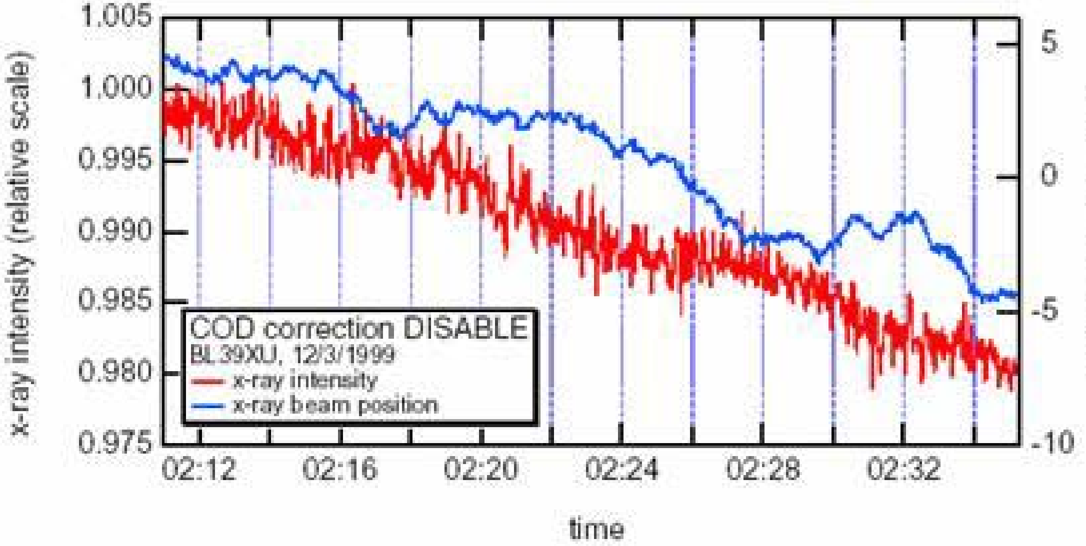
(Accelerator group measurement: 15.9 ± 1.5 μm)

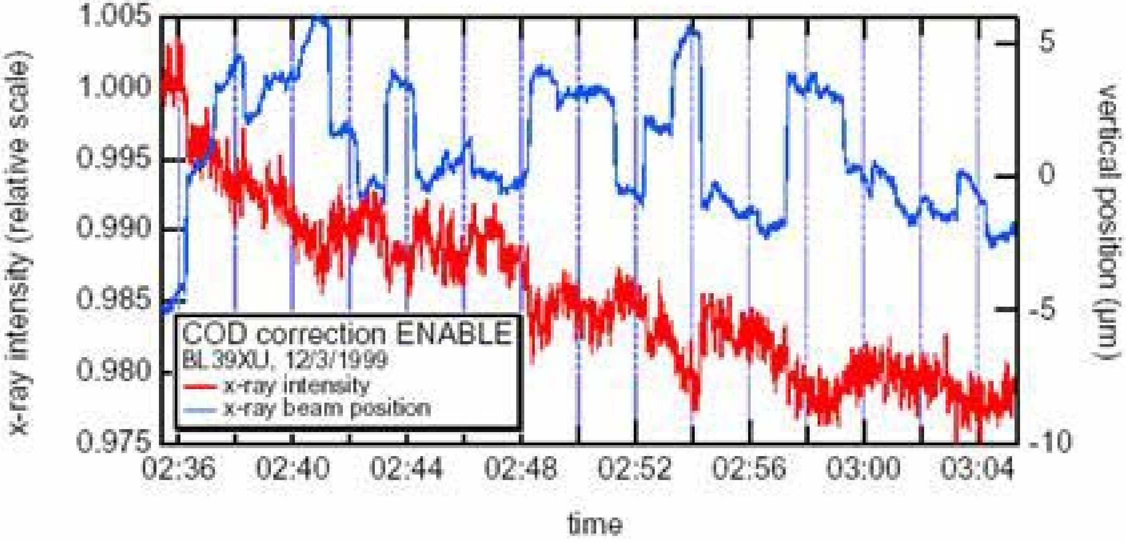
Yabashi, Tamasaku & Ishikawa, *PRL* (2001)

Users may be good monitors of orbit stability.

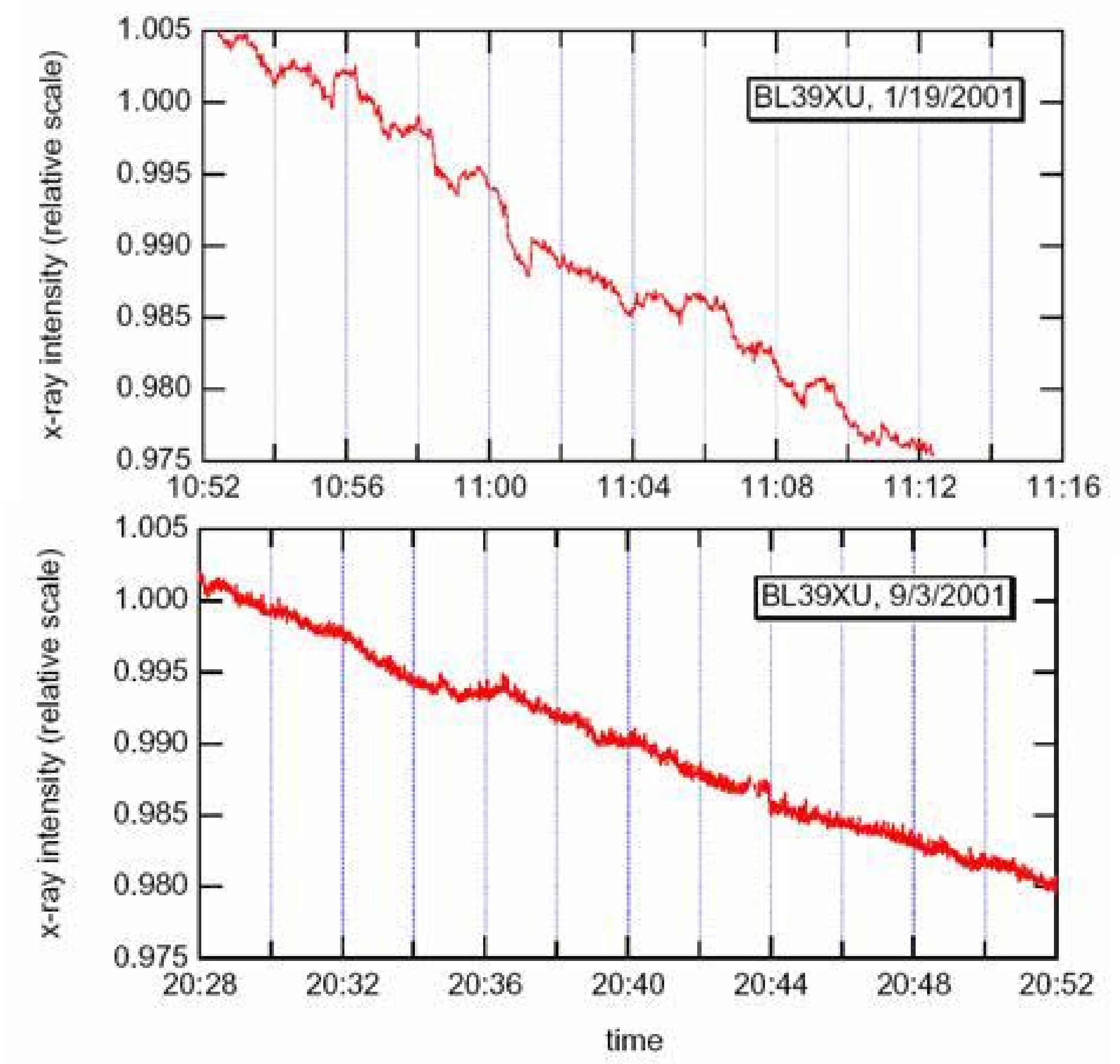
Collaboration between Machine People and Users is Important.

COD Correction: December 1999

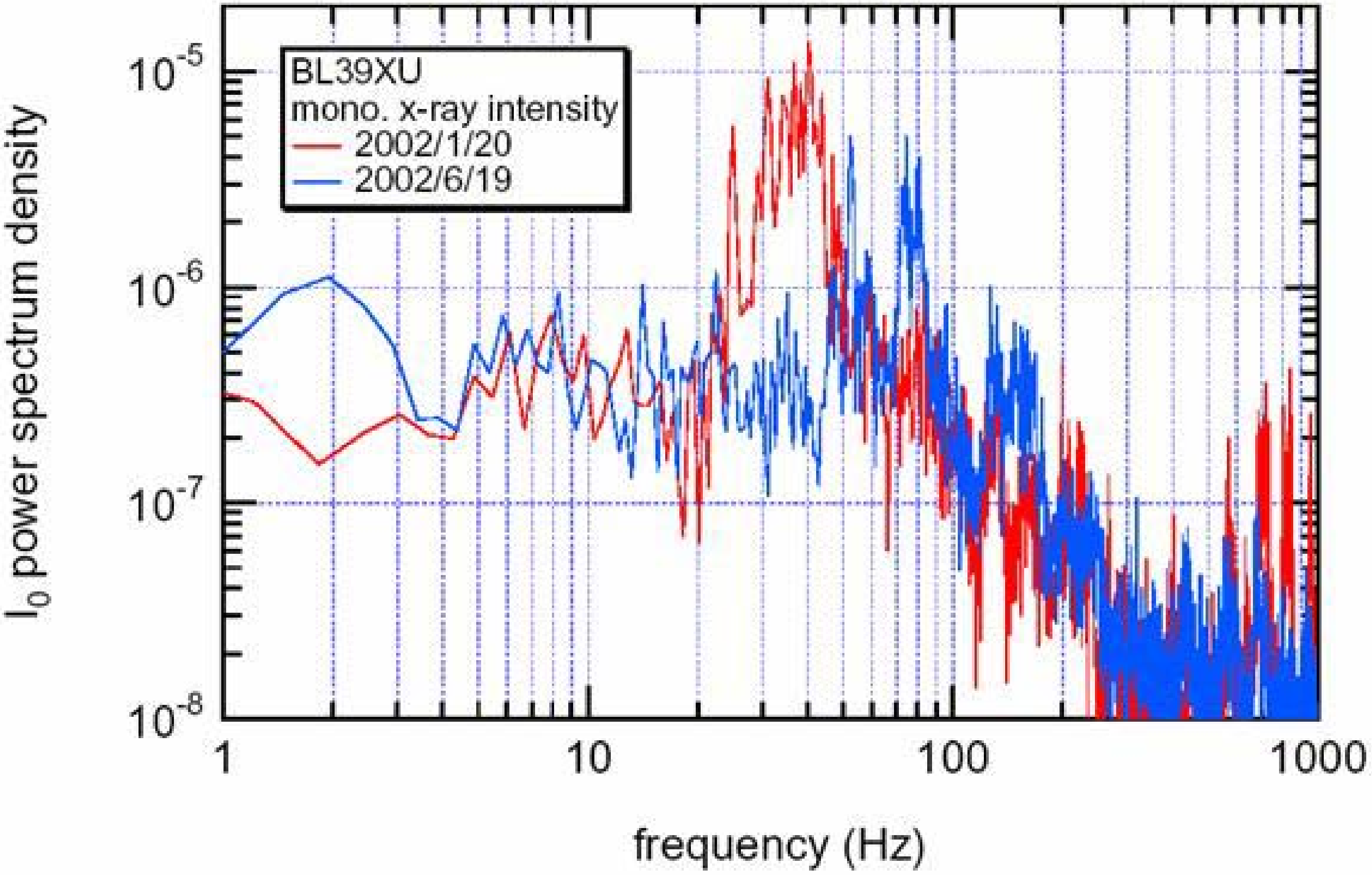




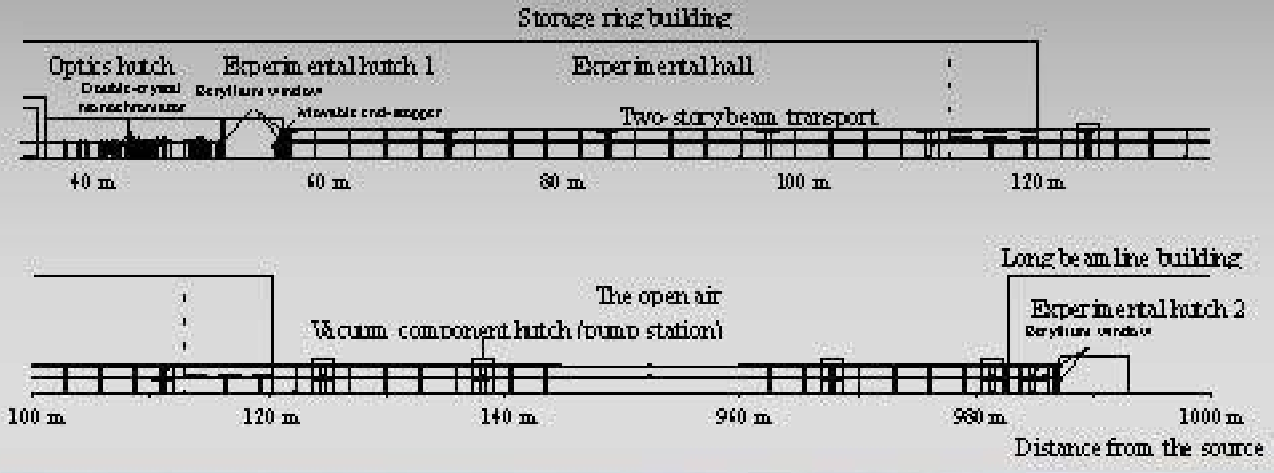
COD Correction: January 2001 vs September 2001



Frequency Power Spectrum: January 2002 vs June 2002



1000 m Beamline, BL29XU



Ishikawa *et al*, *Proc. SPIE* (2001)

What New Sciences will Come Up with the Further Stability of the Beam?

- Phase-Sensitive Imaging (such as holography) demands ultimate overall stability.
- Phase Retrieval of Coherent Scattering

Oversampling Phase Retrieval

What we can measure in diffraction/scattering experiment
= Intensity

All phase information is lost!

Non-Crystalline Charge Distribution:

$$I = \frac{r_o^2 \sin^2 \alpha}{r^2} I_o \left| \iiint \rho(\boldsymbol{x}) \exp\left[-i\boldsymbol{K}\cdot\boldsymbol{x}\right] d^3\boldsymbol{x} \right|^2 = \sqrt{\frac{\varepsilon_o}{\mu_o}} \boldsymbol{E}\cdot\boldsymbol{E}^*$$

$\boldsymbol{E}^*$: complex conjugate of $\boldsymbol{E}$

If $$E = \frac{r_o \sin \alpha}{r} \sqrt{I_o \sqrt{\frac{\mu_o}{\varepsilon_o}}} \iiint \rho(\boldsymbol{x}) \exp\left[-i\boldsymbol{K}\cdot\boldsymbol{x}\right] d^3\boldsymbol{x}$$

$$= \sqrt{I \sqrt{\frac{\mu_o}{\varepsilon_o}}} \exp(i\varphi)$$

is obtained, we can calculate $\rho(\boldsymbol{x})$ by Fourier inversion.

Iterative Phase Retrieval

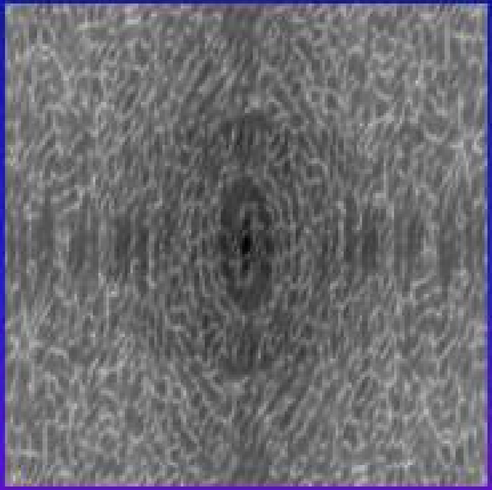
(Jianwei Miao & David Sayre)

X-ray intensity data: Phase Information is Lost!

Scattered pattern in Far Field with Coherent Illumination, Phase can be retrieved.

Phase Retrieval → Iterative Algorism developed by Gerchberg & Saxon, followed by the improvement by Fienup (Opt. Lett. 3 (1978) 27.)

Real Space Image

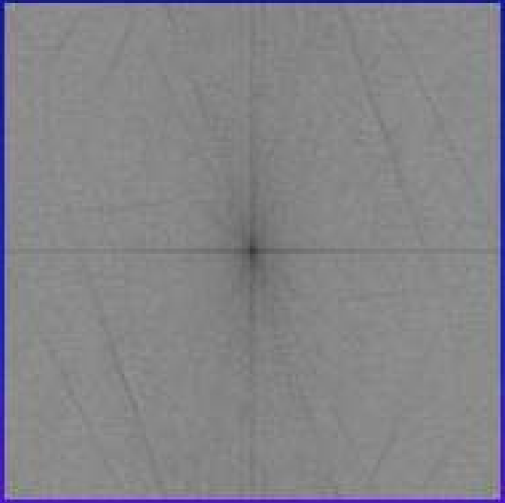


Scattered Intensity

Phase Retrieval

Reconstruction of Complex Real Space Images

Real Space



Scattered Intensity

Phase Retrieval

Original Image

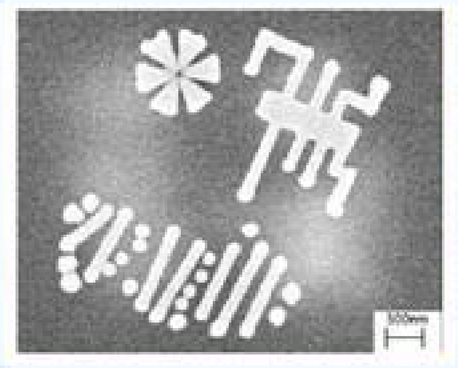
Reconstructed Image

After 5000 iteration

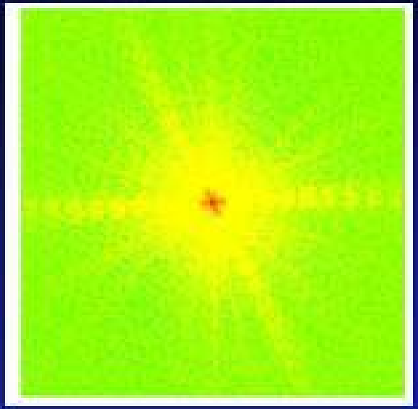
3D Diffraction Nanoscopy

Miao *et al.* *PRL* (2002)

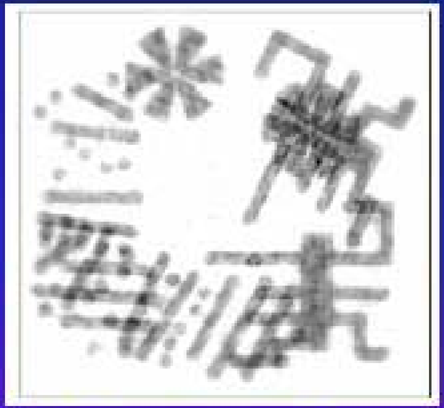
Two Layer Ni Pattern **8 nm resolution**



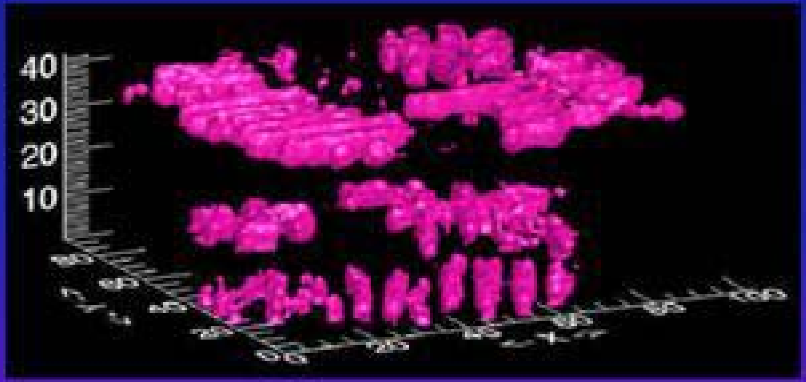
SEM image of Ni pattern on SiN



Coherent Scattering Pattern

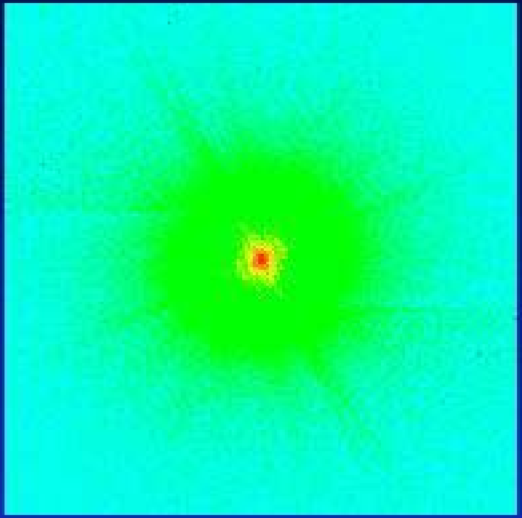


2D Reconstructed Image
(<10 nm resolution)



3D Reconstructed Image (~50 nm resolution)

E. Coli Bacteria

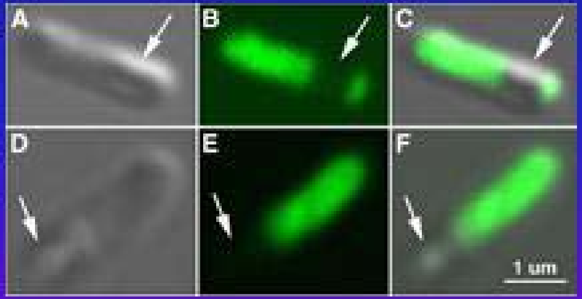


Coherent Scattering Pattern

25 nm resolution

J. Miao,et al.: PNAS, in press

Reconstructed Image



Visible, Confocal Microscopy

Summary

This talk gave addresses to:

- Why the Beam Stability is Important for Users?
- What New Sciences will Come Up with the Further Stability of the Beam?

Thank you for your Attention !

Acknowledgement

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Toru Hara (Calculation of Undulator Spectra)

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