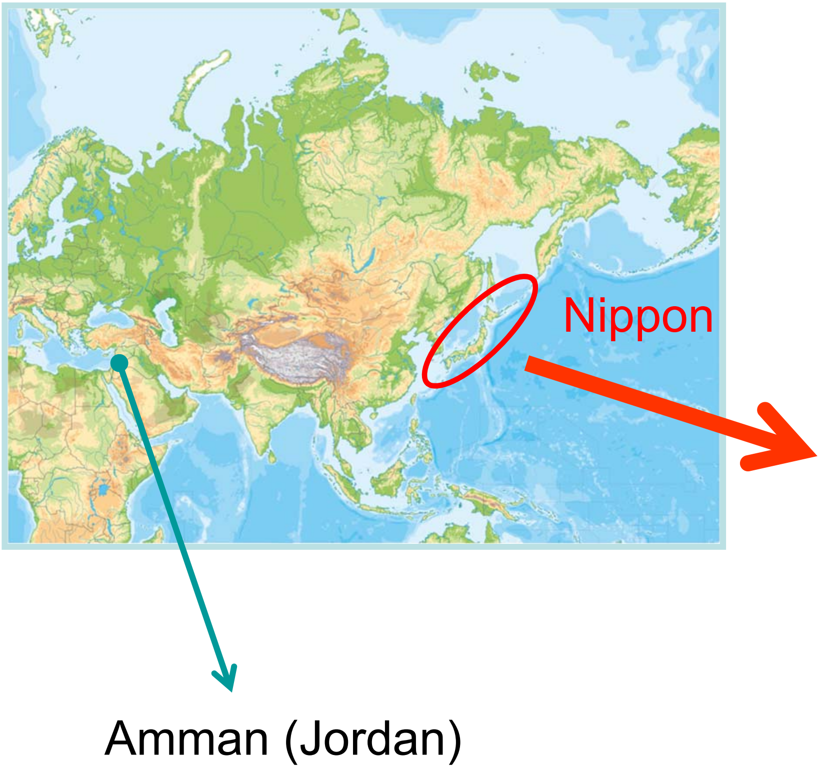
SESAME/JSPS School

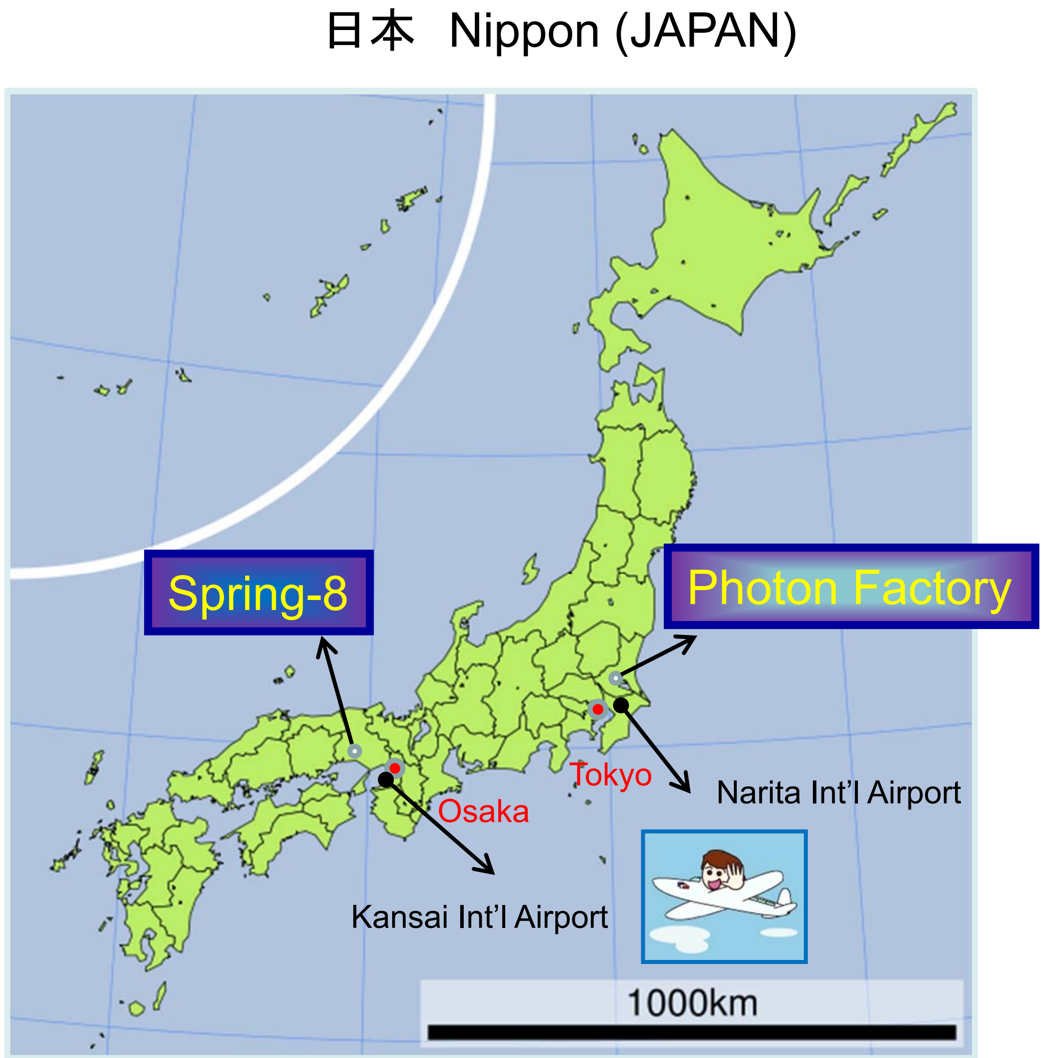
Beamline

Noriyuki Igarashi
(Photon Factory, IMSS, KEK, Japan)

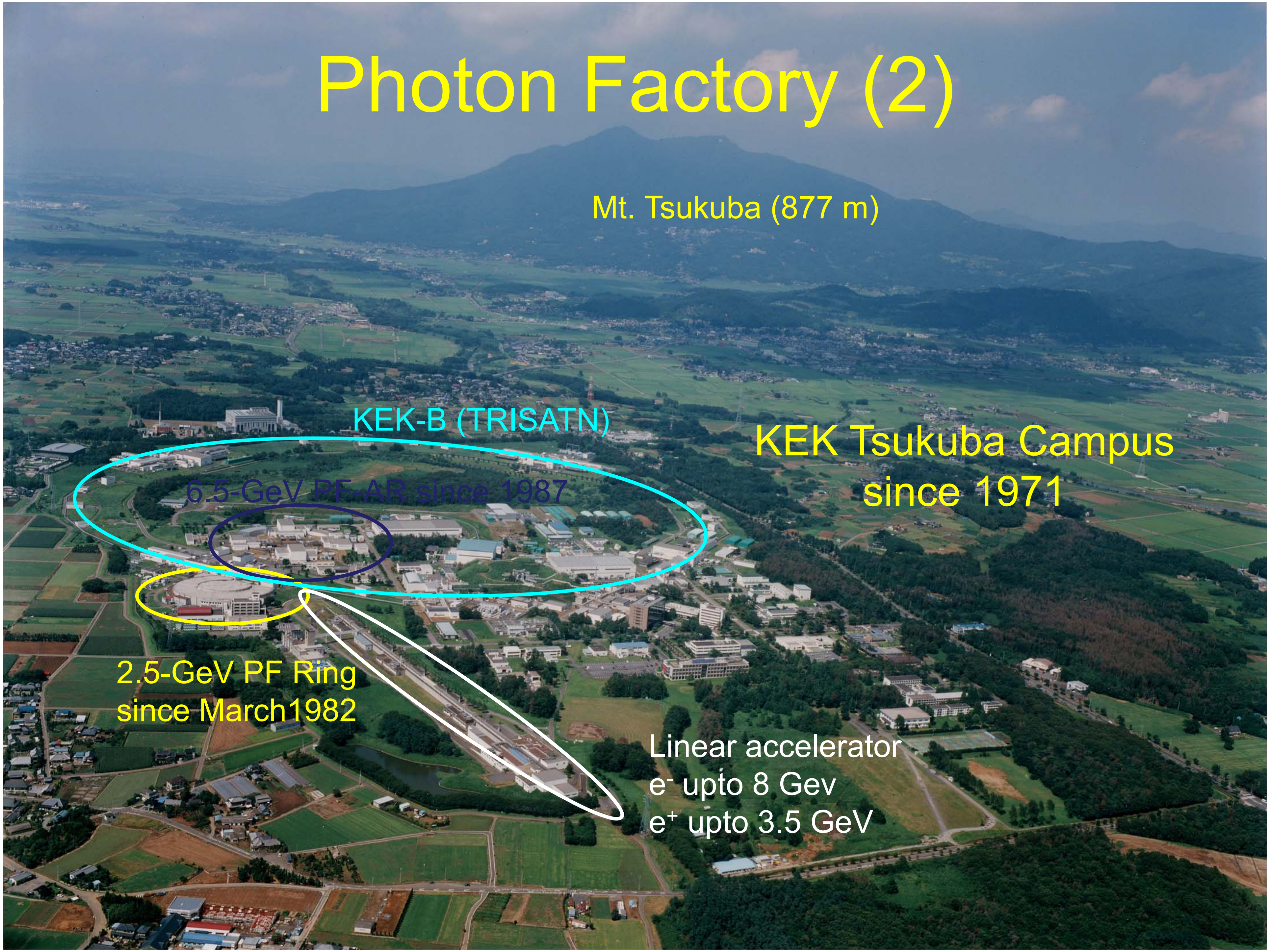
Anman(Jordan) on Nov 14, 2011

Photon Factory (1)

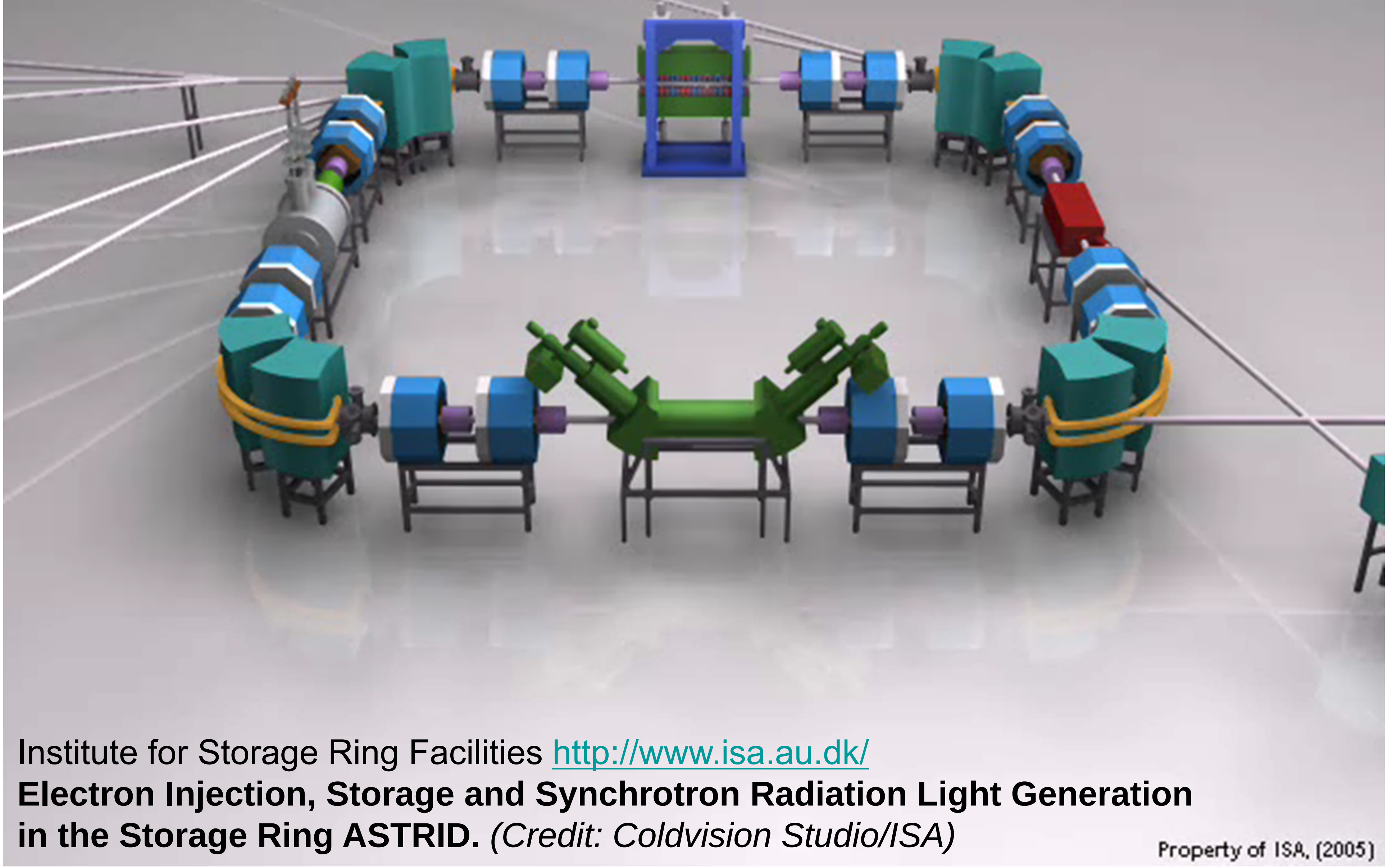




Photon Factory (2)



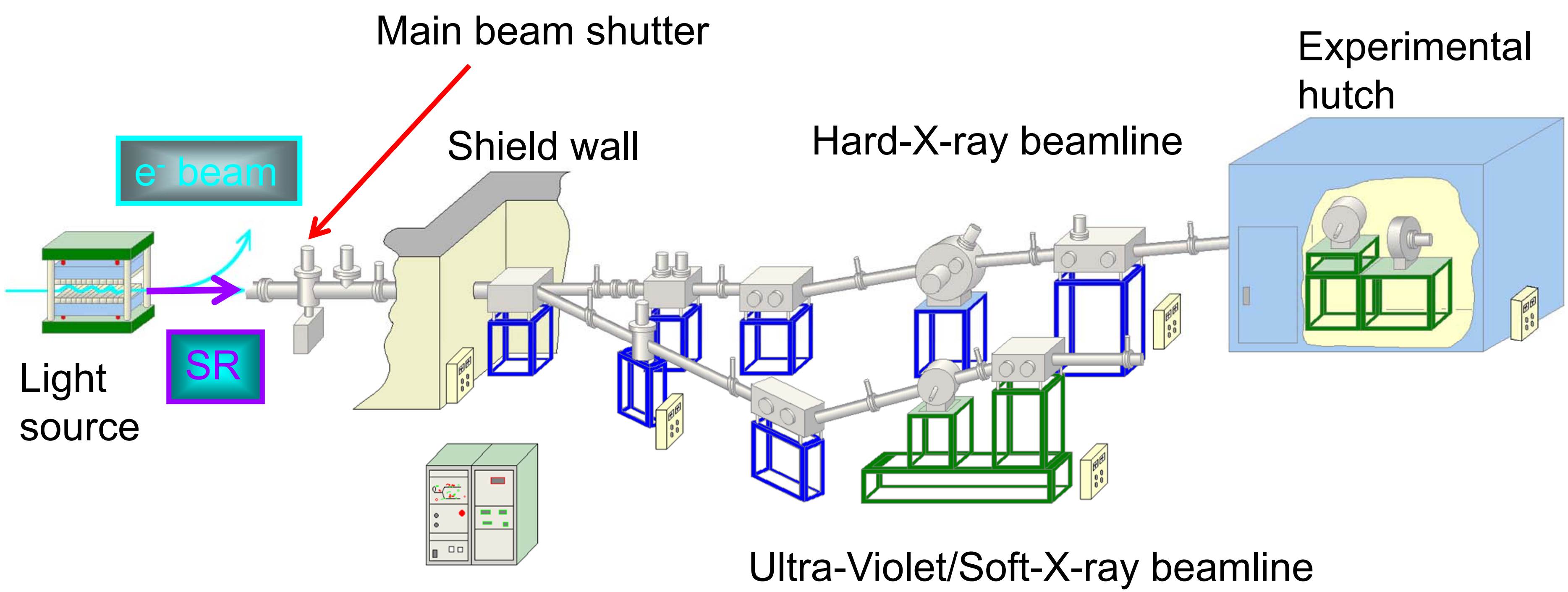
Animation of synchrotron ring and beamline



Institute for Storage Ring Facilities http://www.isa.au.dk/

Electron Injection, Storage and Synchrotron Radiation Light Generation in the Storage Ring ASTRID. *(Credit: Coldvision Studio/ISA)*

How the SR beamline looks



Roles of beamline

- Processing SR beam ⇒ beamline optics
- Conducting the beamline component ⇒ Interlock system
  (Keep in vacuum and radiation safety)

Properties of Synchrotron Radiation

Broad continuous spectrum (IR to hard X-ray):

wide energy selectivity

High brilliance:

beam can be focused down to extremely small size.

⇒small objects / small spatial resolution scannning

beam can be well-collimated.

⇒high definition imaging

Polarization:

anisotropic / magnetic structure analysis

Pulsed (time structure):

kinetics / dynamics study

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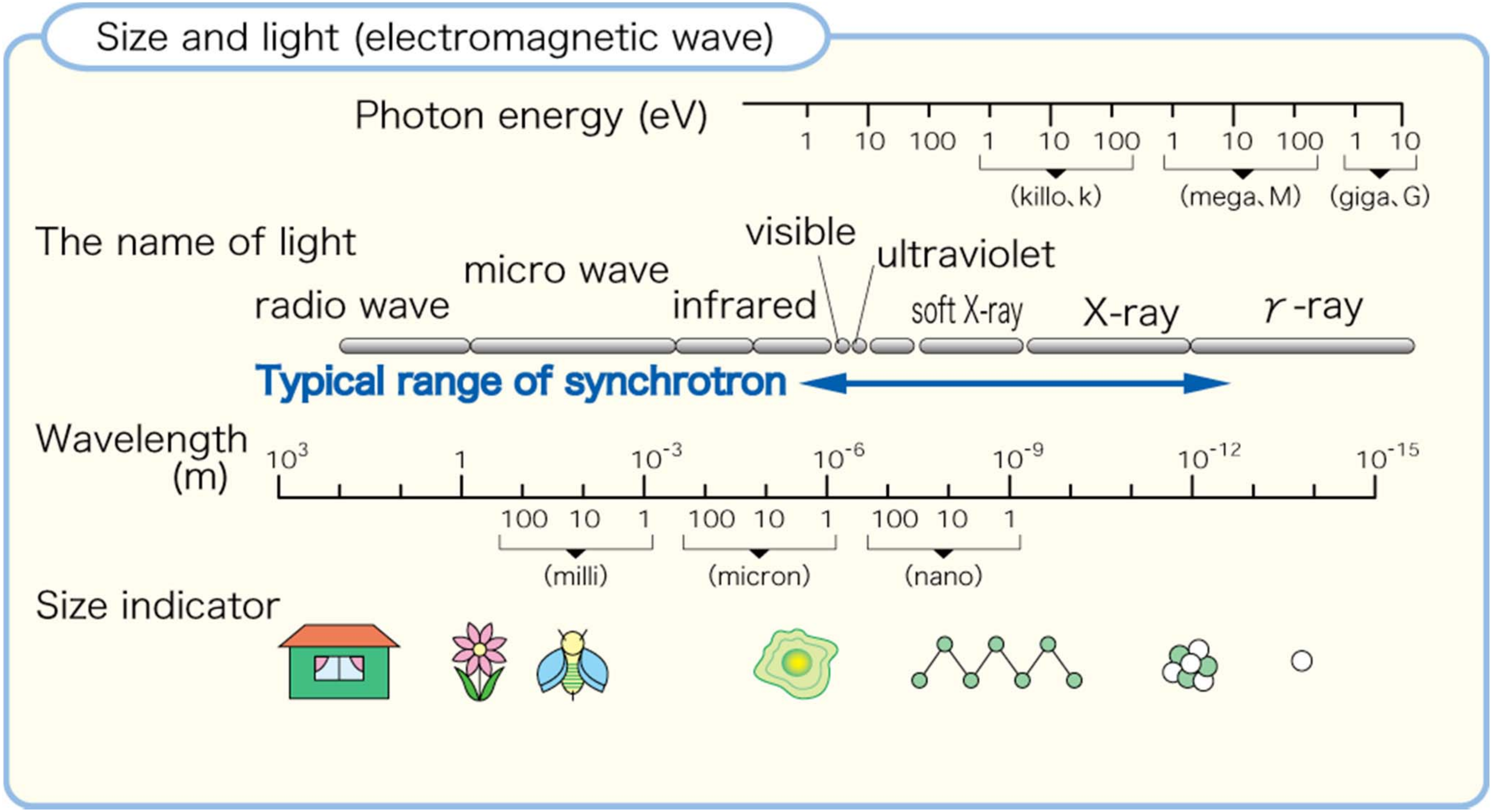
-Processing SR beam for experimental use-

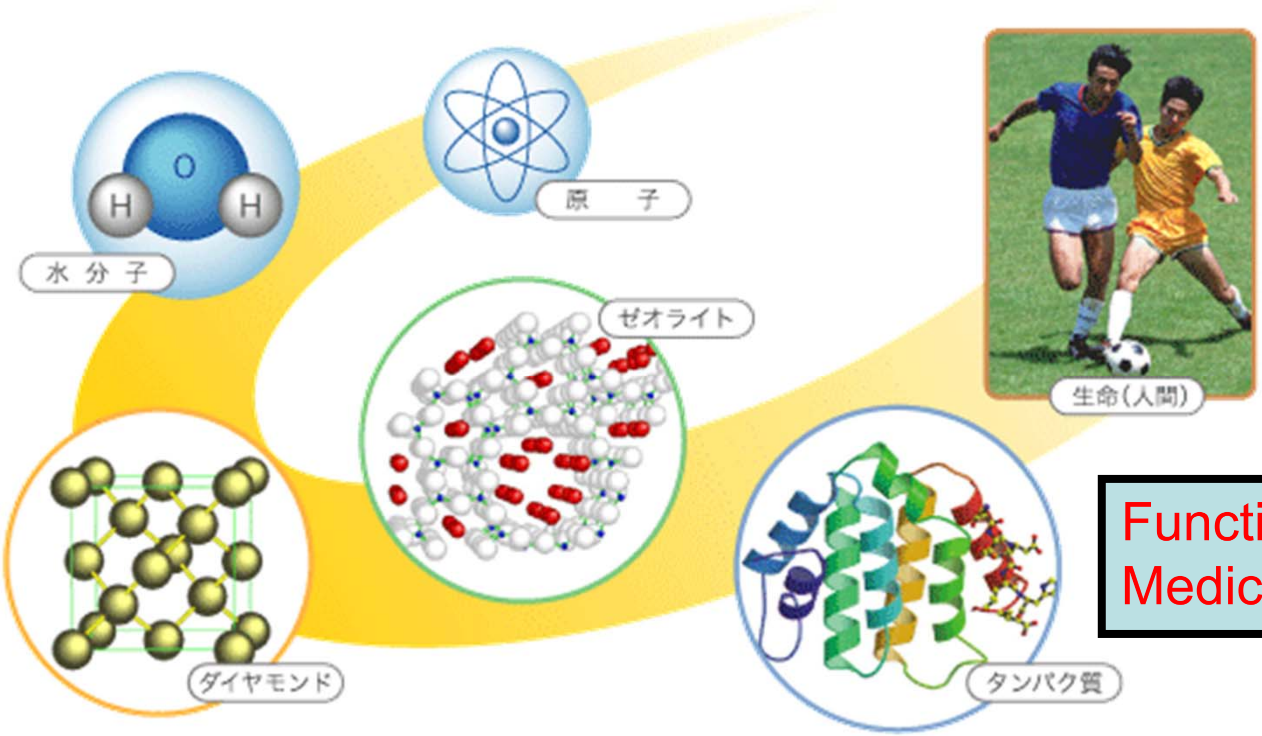
SR has a broad and continuous spectrum



Synchrotron Radiation can be used for a wide range of applications, from Infrared to hard X-ray applications on material sciences.

(mainly, UV to X-ray)

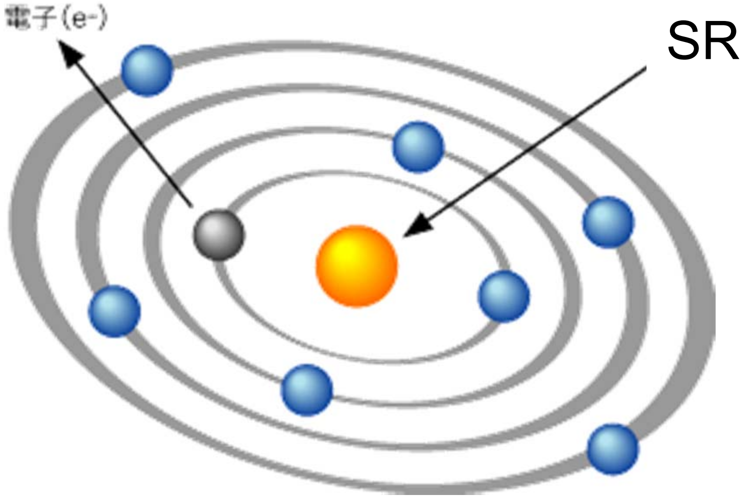
Investigation of material atomic structure with hard X-rays



Function of biomolecules
Medical manufacture

Wavelength of hard X-rays ≈ atomic distance in materials

Material science with vacuum ultraviolet and soft X-rays



Absorption spectra
Photoelectron spectra

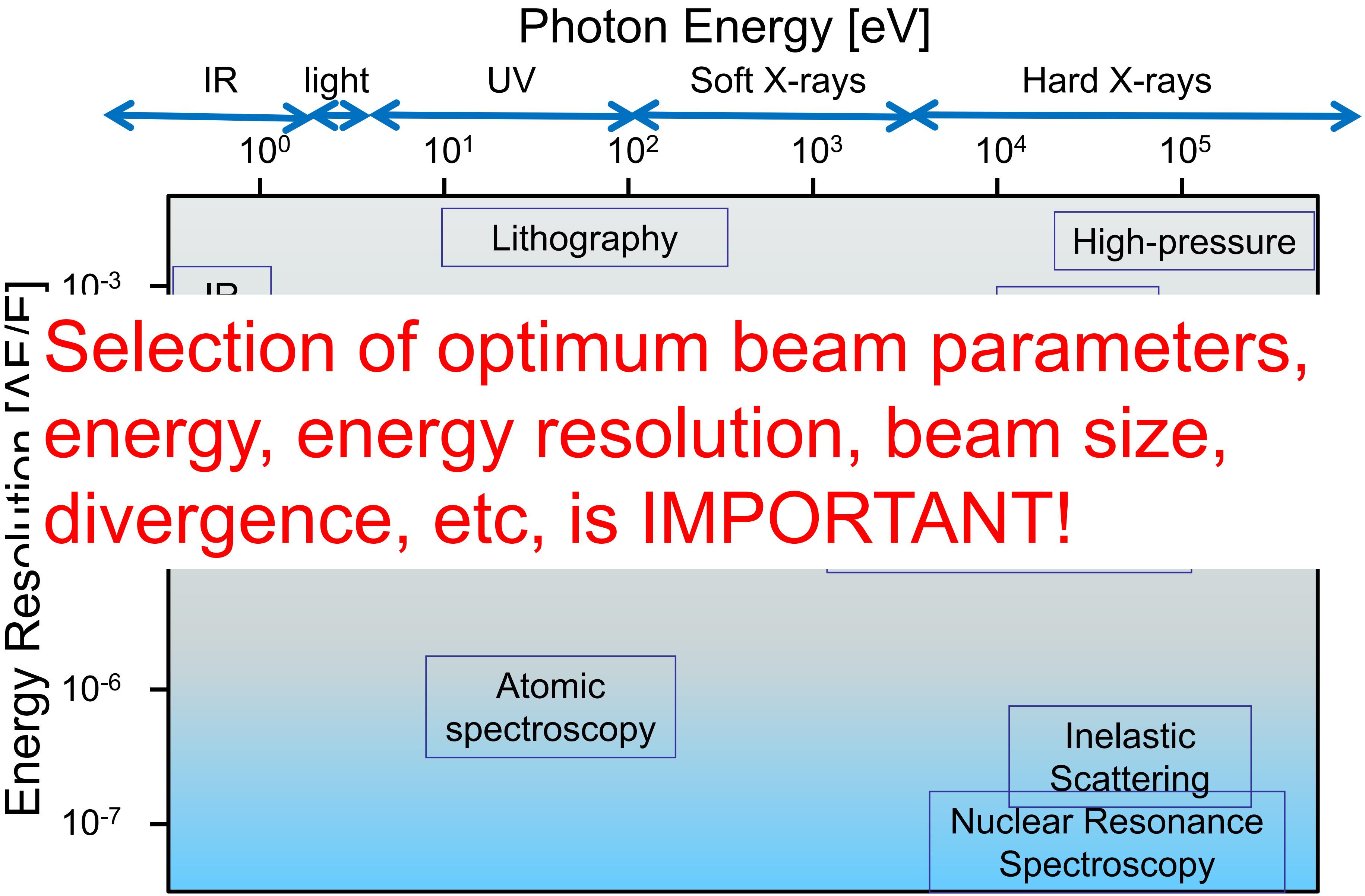
Information on electronic states

Materials with
- High-temperature superconductivity (HTC)
- Giant magnetic resistance (GMR)

Organic thin films
Bio-molecules

Development of new materials

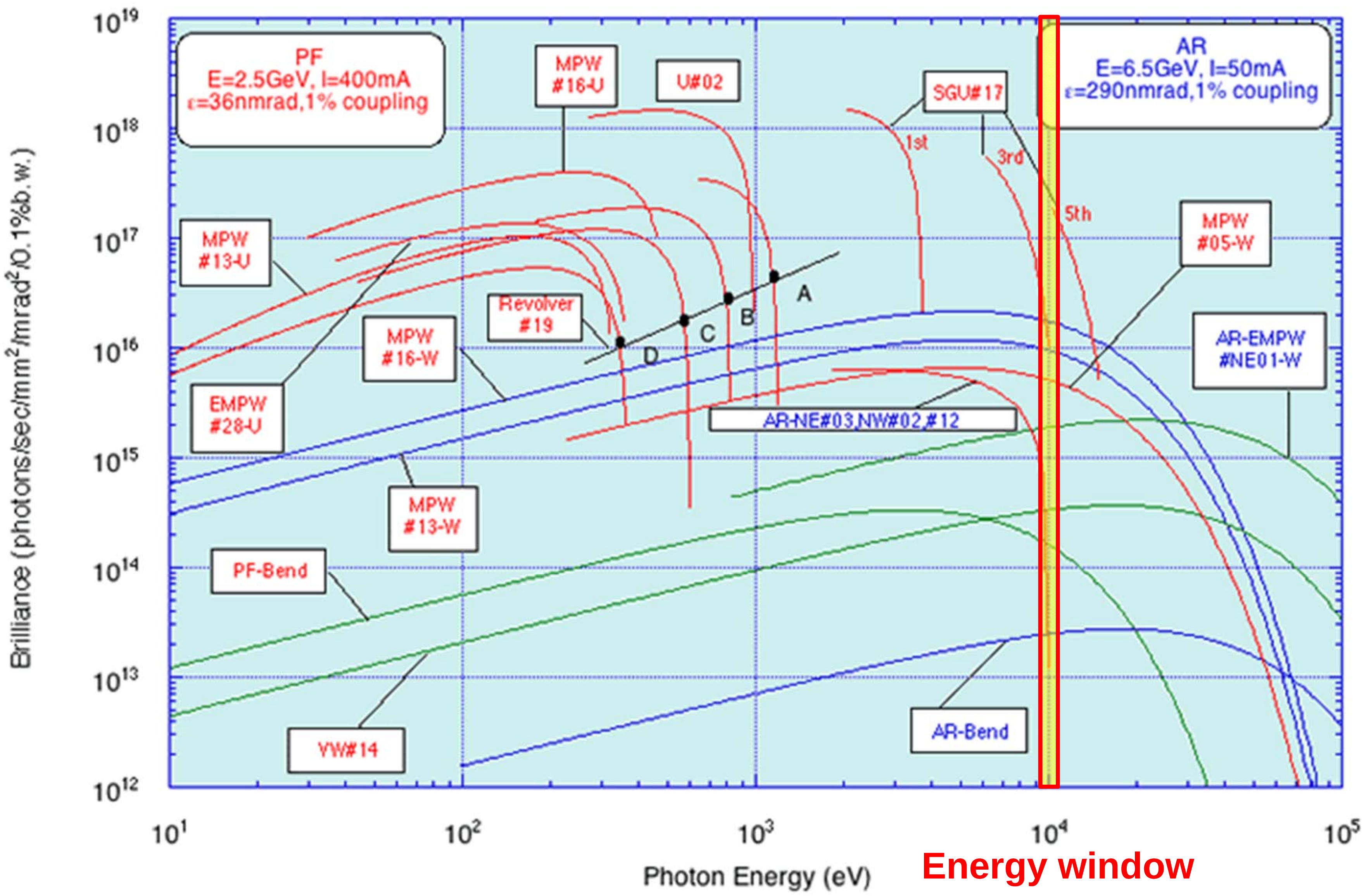
Various SR experimental methods



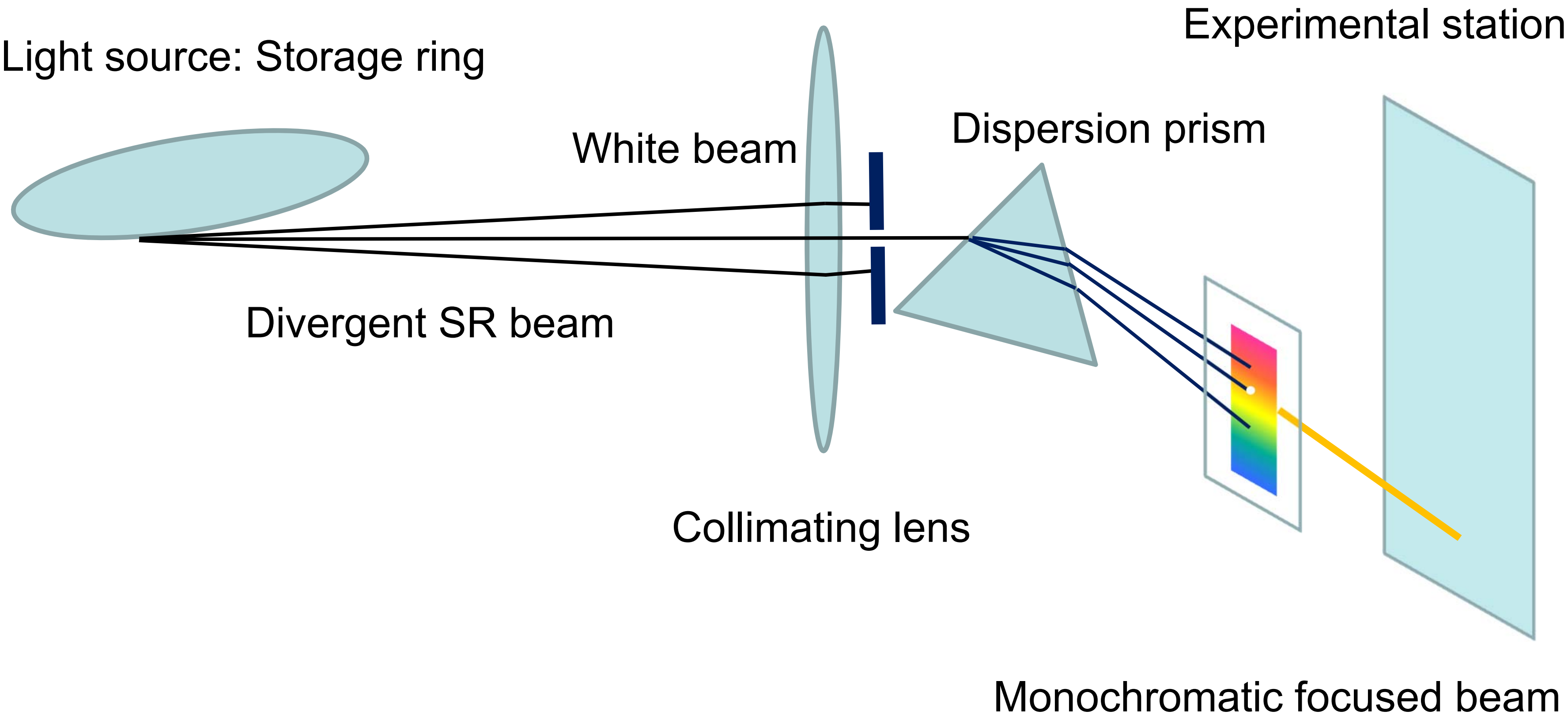
Selection of optimum beam parameters, energy, energy resolution, beam size, divergence, etc, is IMPORTANT!

Spectra of Photon Factory light sources

Bending magnet generates a white SR beam.



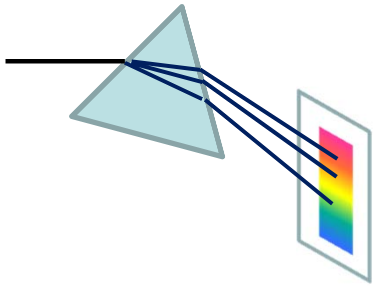
Processing SR beam



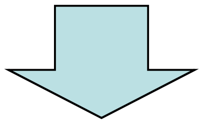
In case of visible light, we can use a prism to make choice of preferable energy.

Processing SR beam

Photon energy selection



Prism absorbs VUV photons extremely.
X-rays have nearly 1 of refractive index.

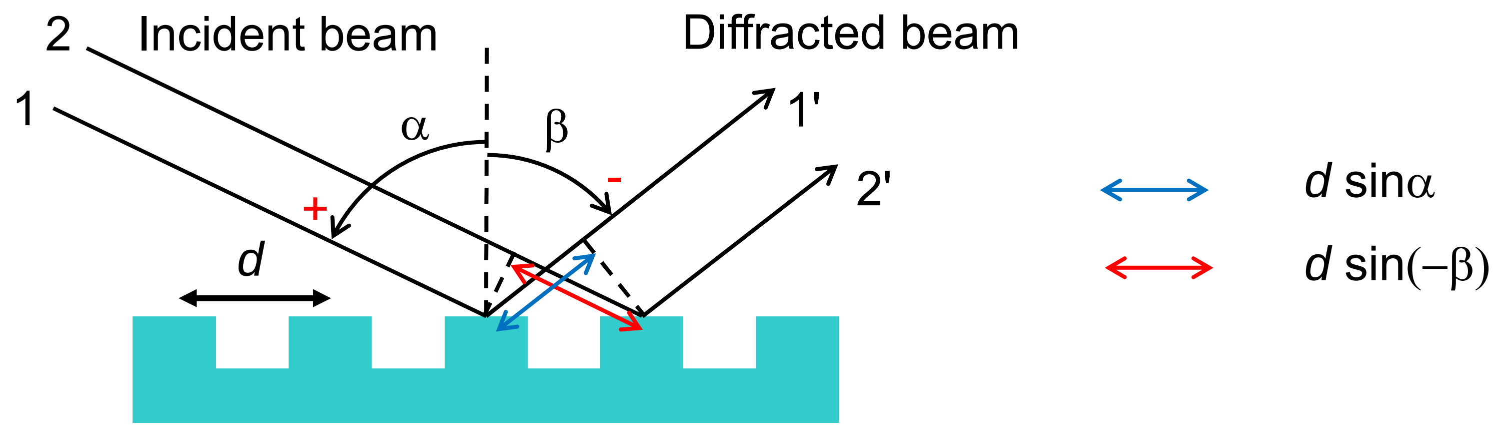


Diffraction
VUV-SX: gratings
HX: crystals

Suppression of higher order components

Photon energy selection in VSX

-Diffraction gratings-



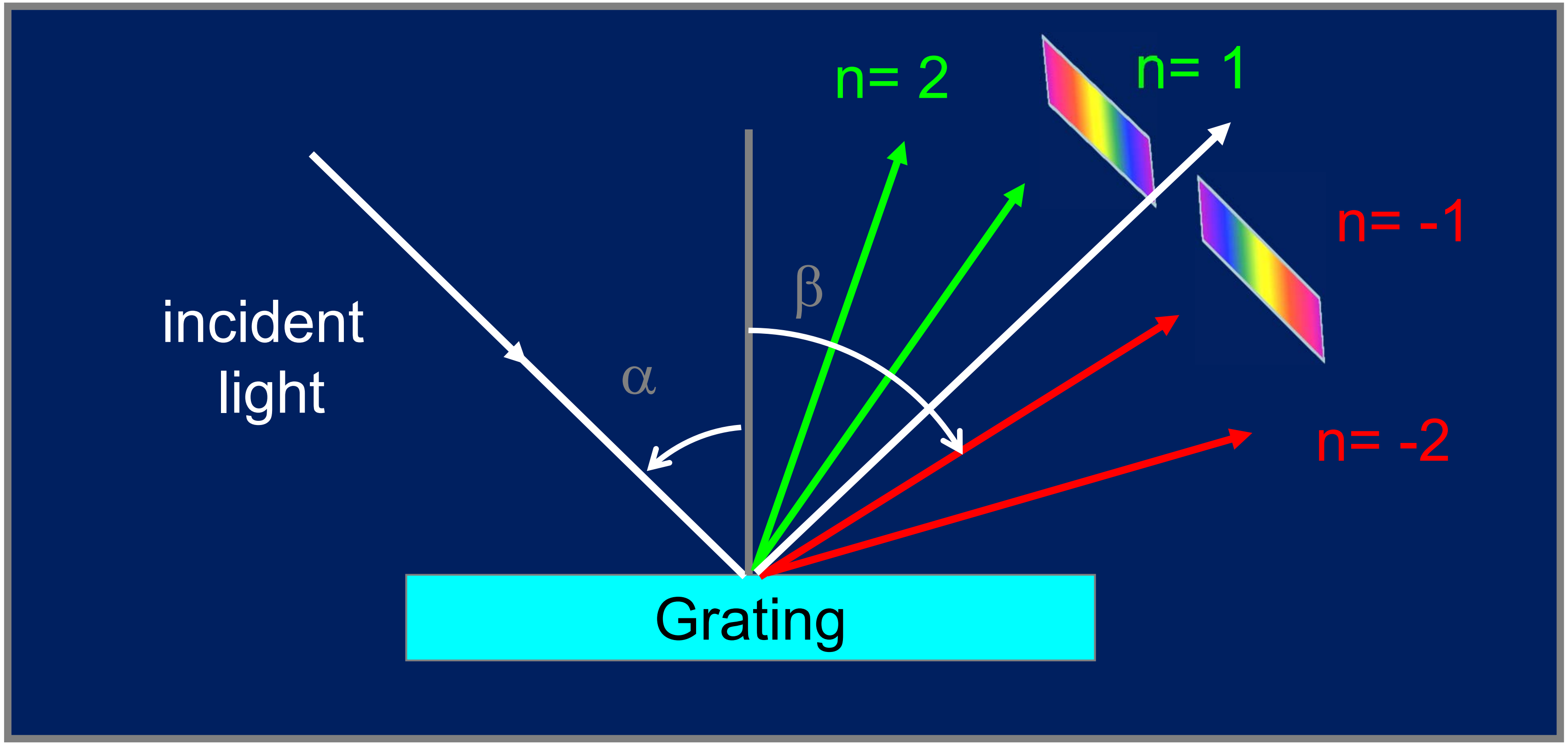
Enhancement occurs when the optical path difference between 1-1' and 2-2' is $n\lambda$, where n is an integer.

Grating equation : $\sin\alpha + \sin\beta = n\lambda/d$

d : several microns to several sub microns.

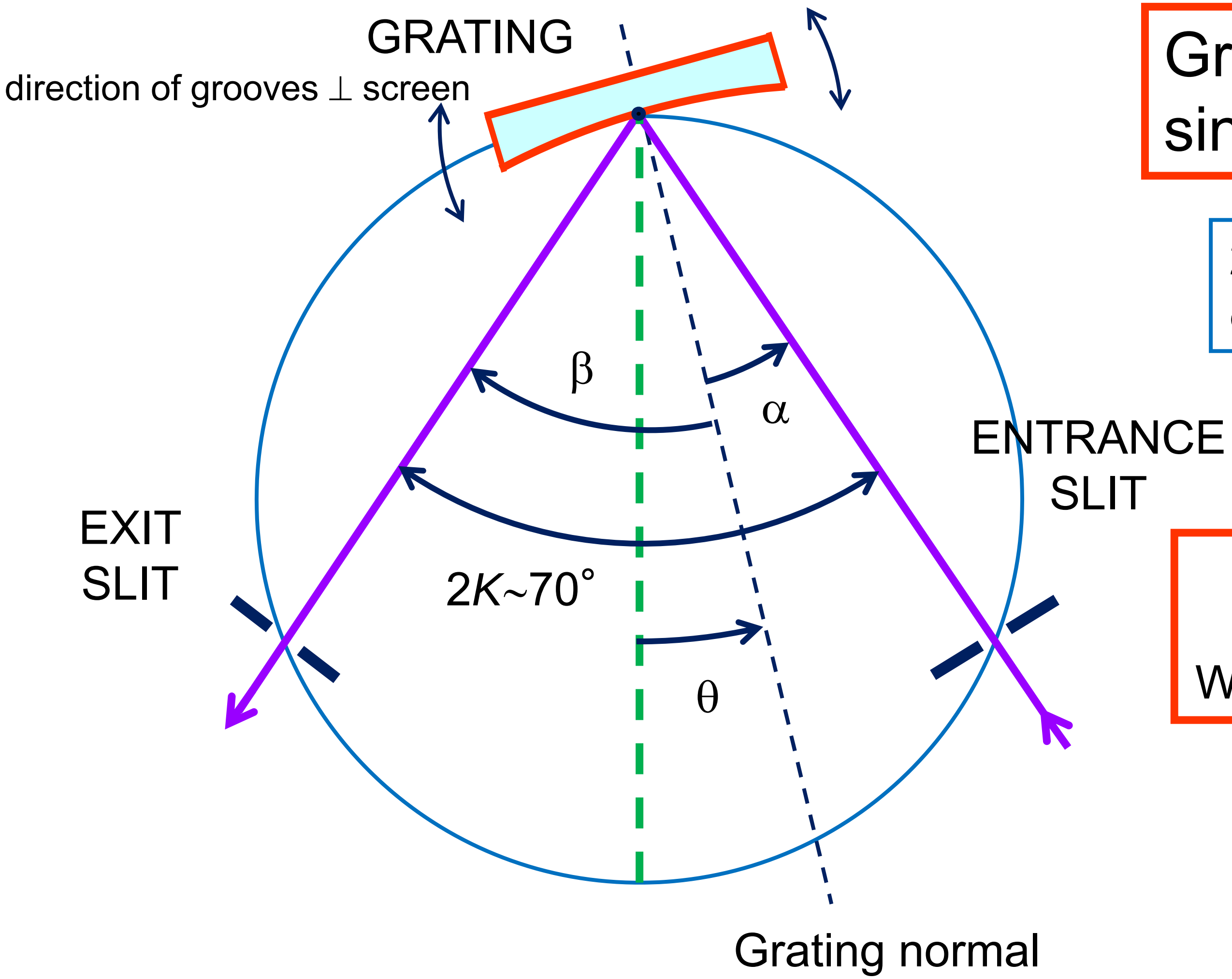
→ diffraction gratings are effective for the photons of $\lambda \geq 0.8$ nm ($h\nu \leq 1500$ eV).

Dispersion by a diffraction grating



Window size defines the energy resolution and intensity.

Schematics of grating monochromator



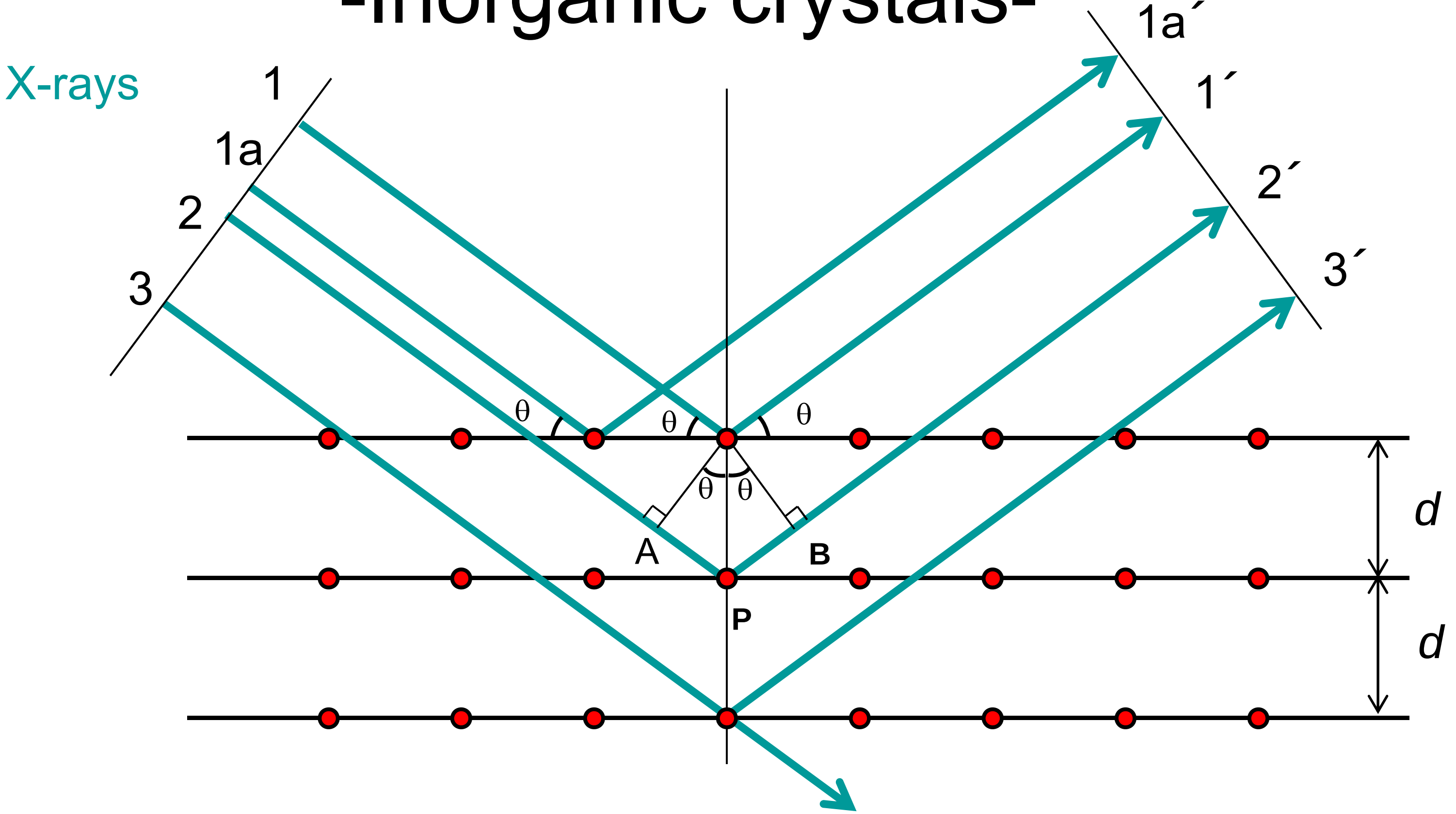
Grating equation
$\sin\alpha + \sin\beta = n\lambda/d$

$2K=\alpha-\beta$
$\alpha=K-\theta \quad \beta=-(K+\theta)$

Grating rotation
↓
Wavelength selection

Photon energy selection in HX

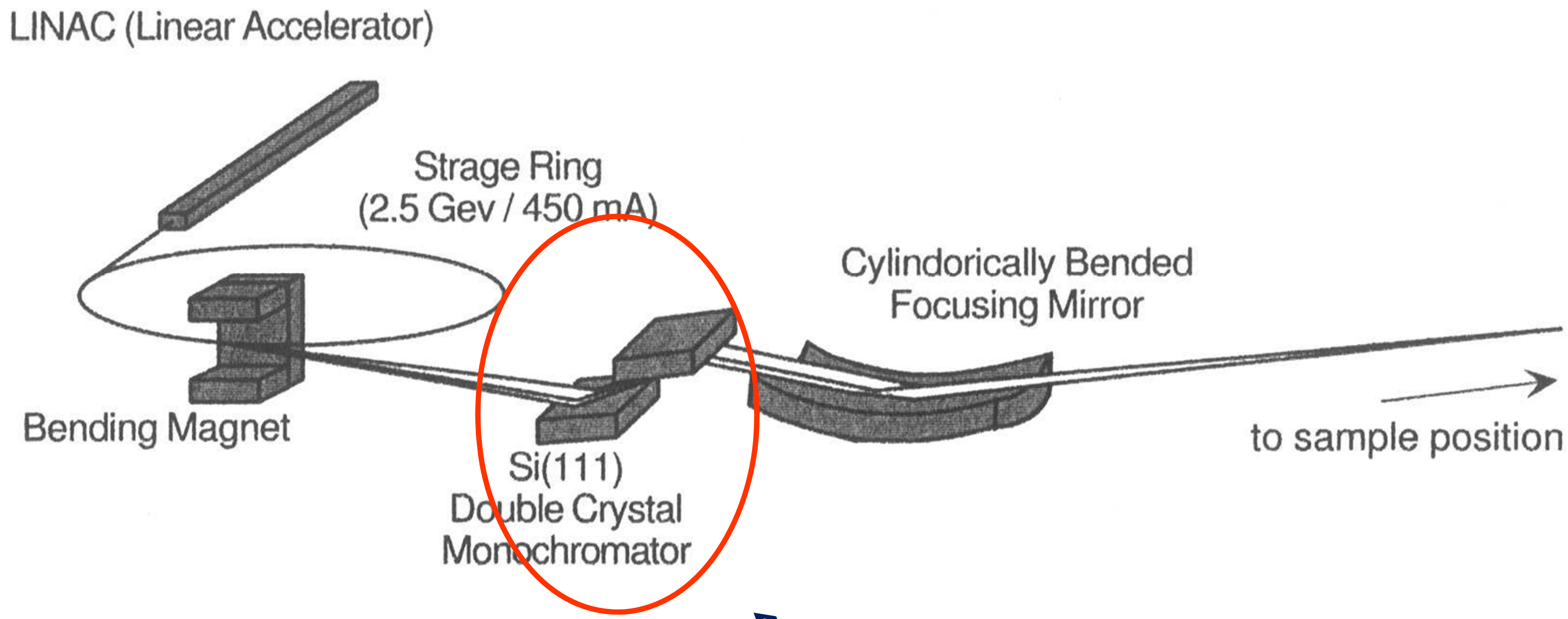
-Inorganic crystals-



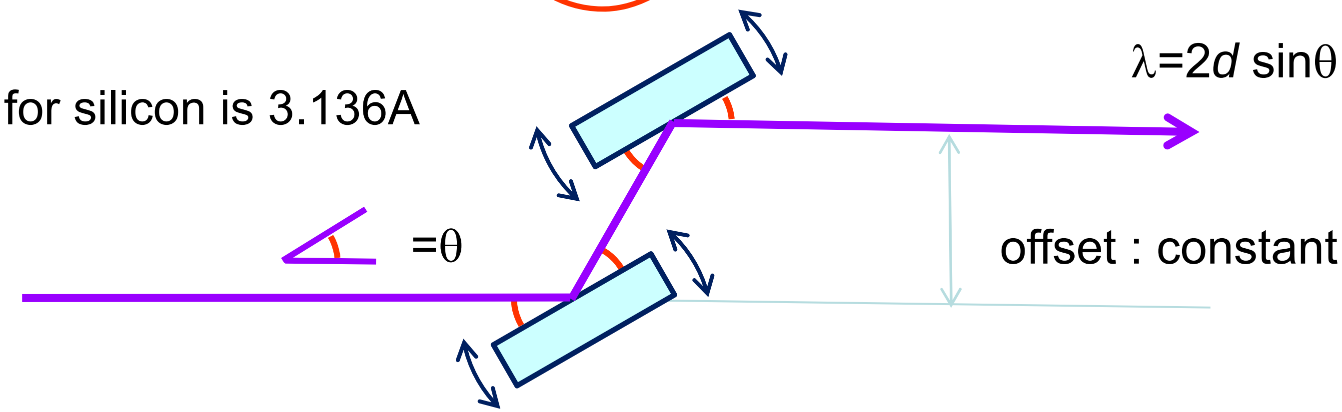
Optical path difference between 1-1´ and 2-2´ is AP+PB=2*d* sinθ.
Bragg´s law: diffraction occurs for **$2d \sin\theta = n\lambda$**, where n is an integer.
1-1´ and 1a-1a´ have the same optical path length.

Energy resolution is quite high (<10^{-3} ΔE/E)

Double crystal monochromator



d(111) for silicon is 3.136A



Rotation of θ → changing the wavelength (photon energy)

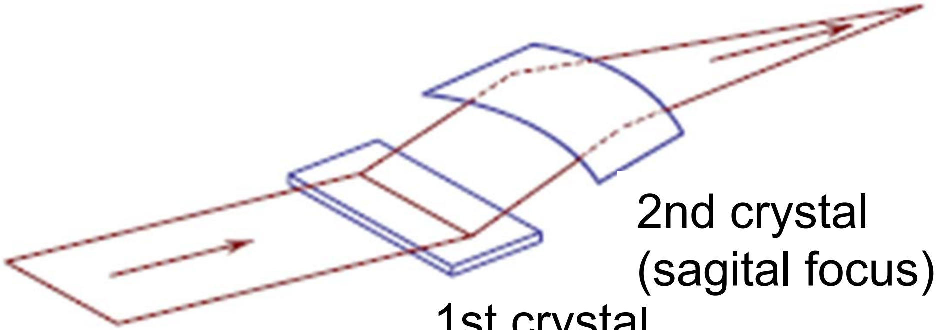
θ = 90 degrees,@2000 eV by smallest *d* spacing, Si(111).

→ Crystals are effective for the photons of λ < 0.6 nm (hν > 2000 eV).

Photon energy selection
-Others-

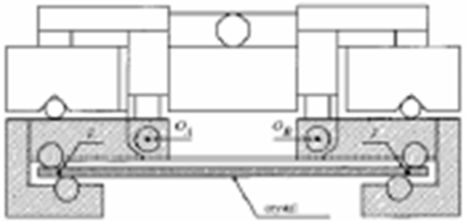
Sagital focusing monochromator

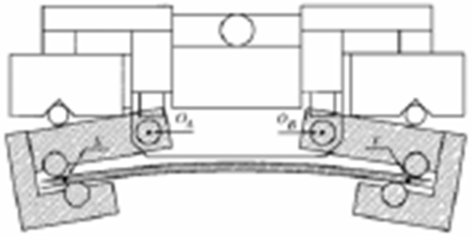
Focas

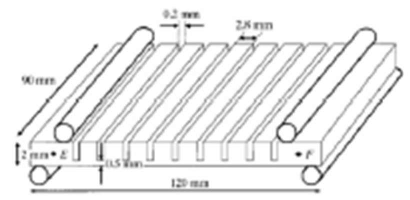


2nd crystal (sagital focus)

1st crystal (plane)

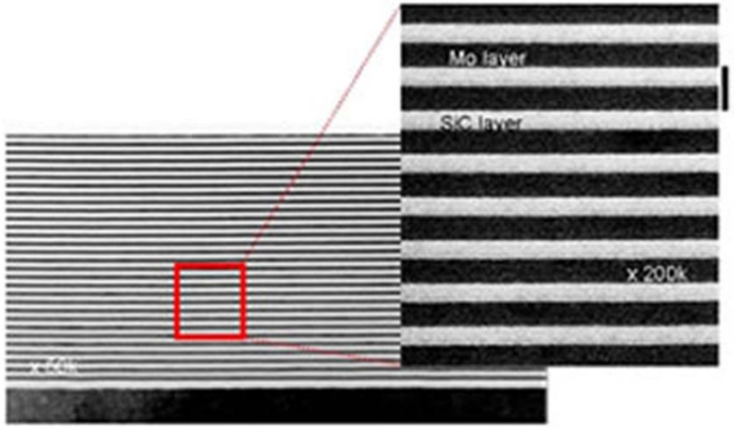






with courtesy of
Dr. S. Goto (Spring-8)

Multilayer mirror



Substrate

Easy control of energy resolution
⇒ pink beam

NTT advanced technology coap.
http://keytech.ntt-at.co.jp/nano/prd_3004.html

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Pulsed (time structure):

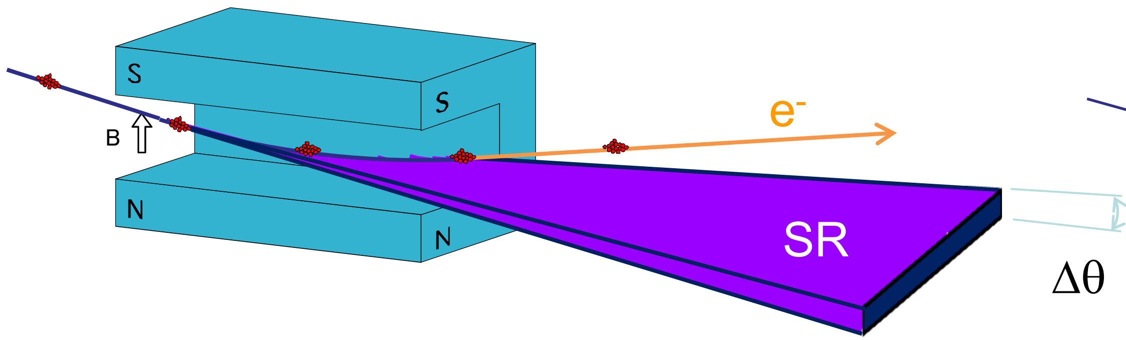
kinetics / dynamics study

Role of SR beamlines

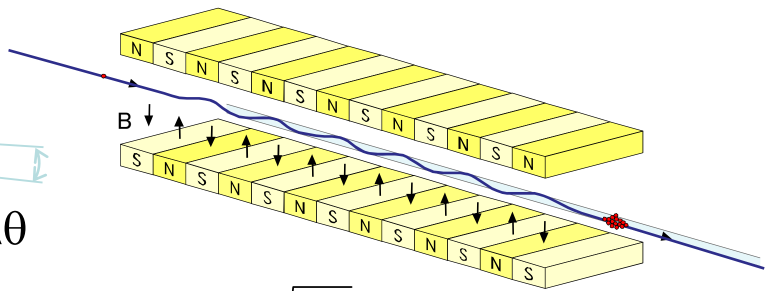
-Processing SR beam for experimental use-

SR is well collimated, however, still divergent (even undulator).

Bending magnet



Undulator



$$\sigma_{r'} = \sqrt{\frac{\lambda}{2L}} = 0.024 \quad mrad$$

$$\sigma_{r} = \frac{\sqrt{2\lambda L}}{4\pi} = 0.014 \quad mm$$

for L=2 m and λ=2 nm

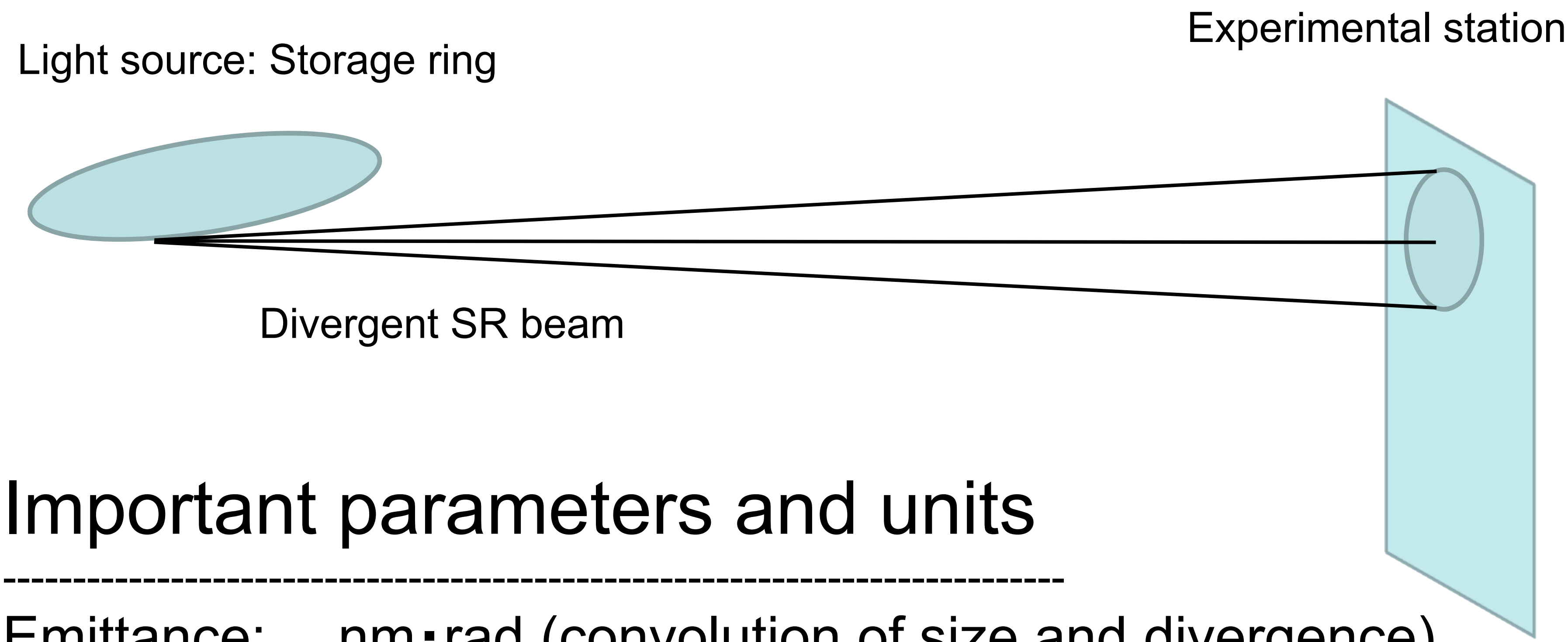
$\Delta\theta \sim 1/\gamma \sim 0.2$ mrad for 2.5 GeV

$\gamma = E_e/m_e c^2$

$\sigma_{y'}$=0.012 mrad $\sigma_{x'}$=0.178 mrad
σ_y=0.06 mm σ_x=0.41 mm

$\sigma_{y'}$=0.008 mrad $\sigma_{x'}$=0.055 mrad
σ_y=0.042 mm σ_x=0.654 mm

Processing SR beam

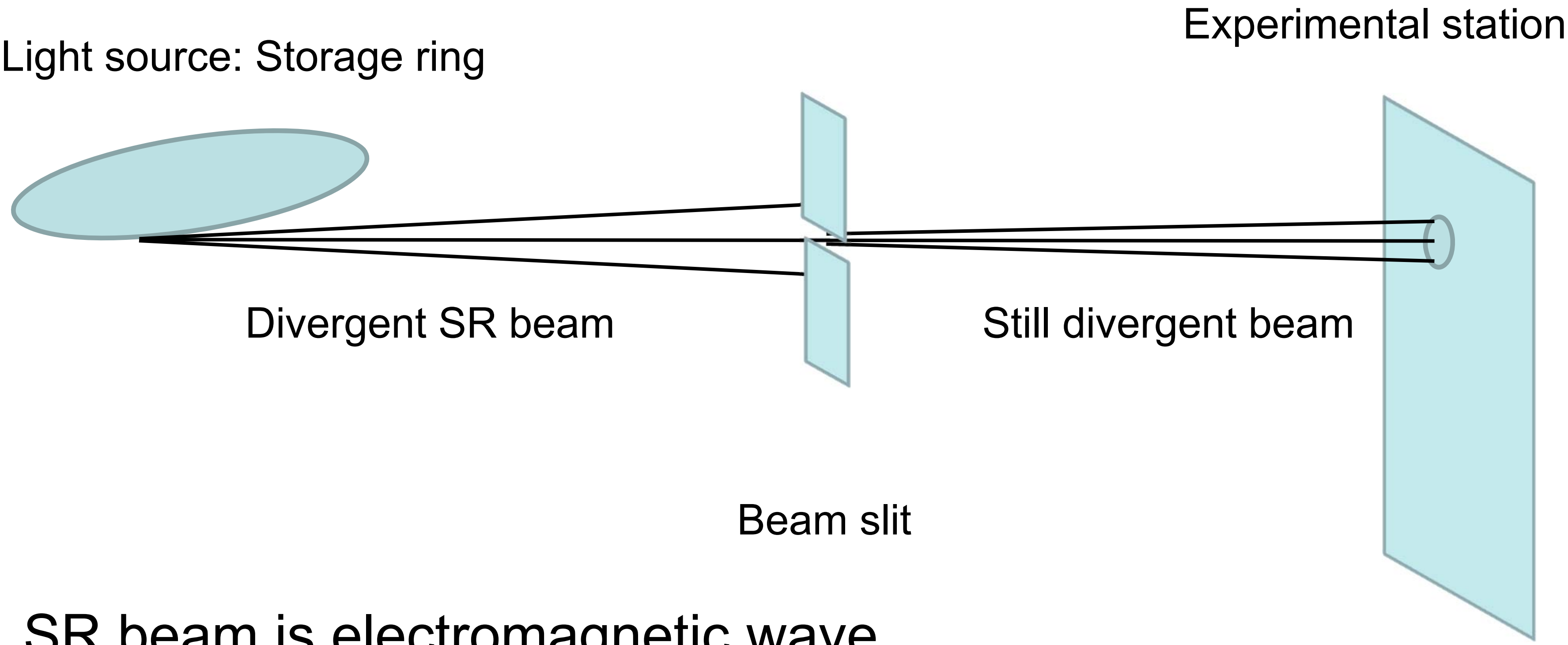


Important parameters and units

Emittance: nm・rad (convolution of size and divergence)

Brilliance: photons/s/mm^2/mrad^2/0.1%B.W.
Flux: photons/s/0.1%B.W.
Flux density: photons/s/mm^2/0.1%B.W.

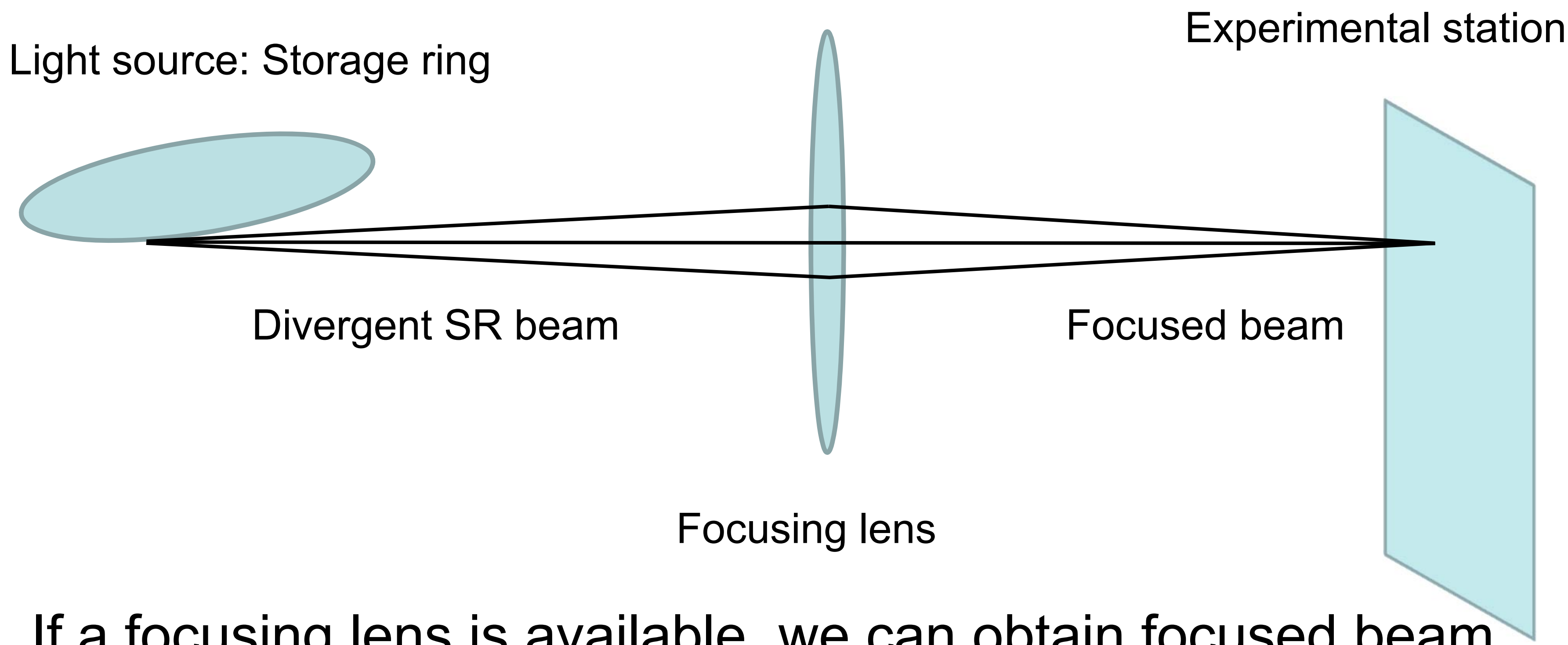
Processing SR beam



SR beam is electromagnetic wave.
We can imagine the beam processing same as visible light.

To make a small-size beam, slit system is available but
Still divergent.

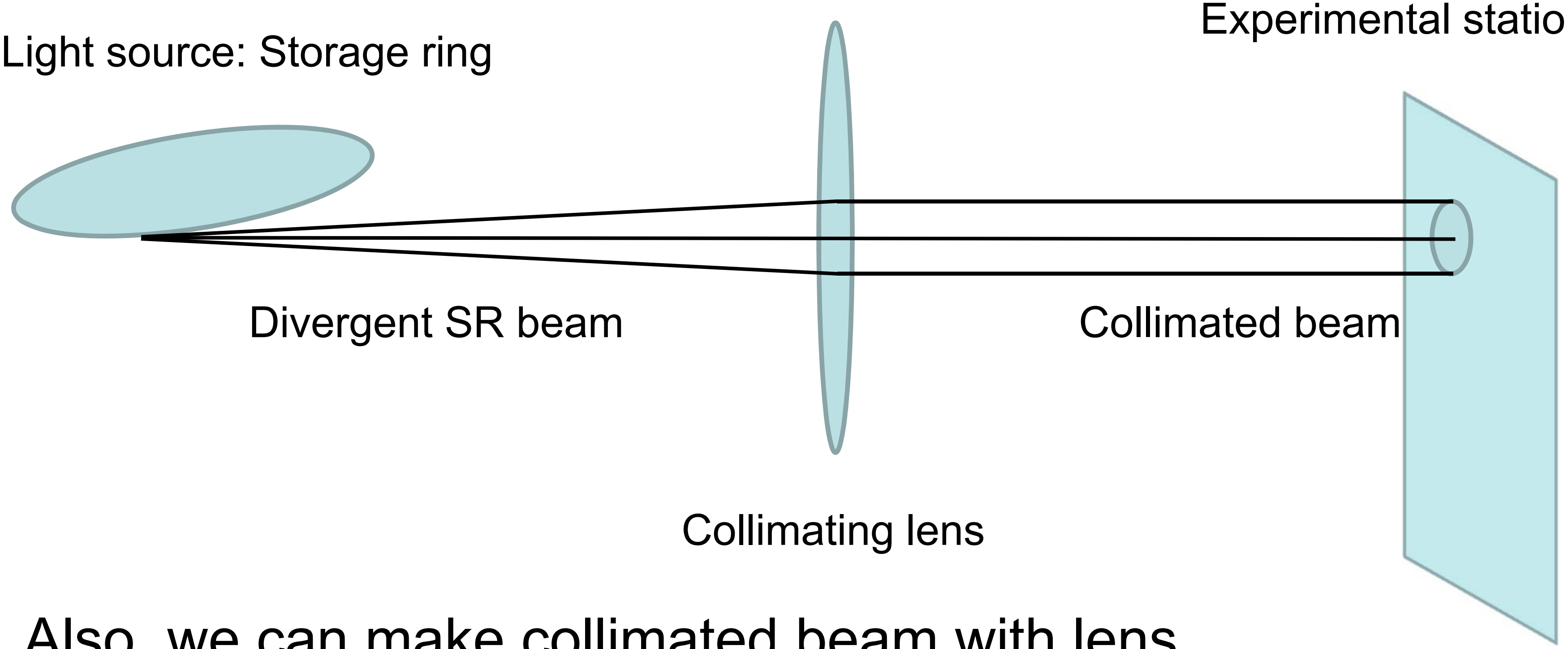
Processing SR beam



If a focusing lens is available, we can obtain focused beam.
(later I will show some focusing devices)

The smaller the source size is, the smaller the focus size is.
SR beam can light up a smaller object!

Processing SR beam



Also, we can make collimated beam with lens.

High brilliance beam (small size and divergence) gives better collimated beam. ⇒ better for imaging etc.
SR can analyze very fine structure!

Processing SR beam

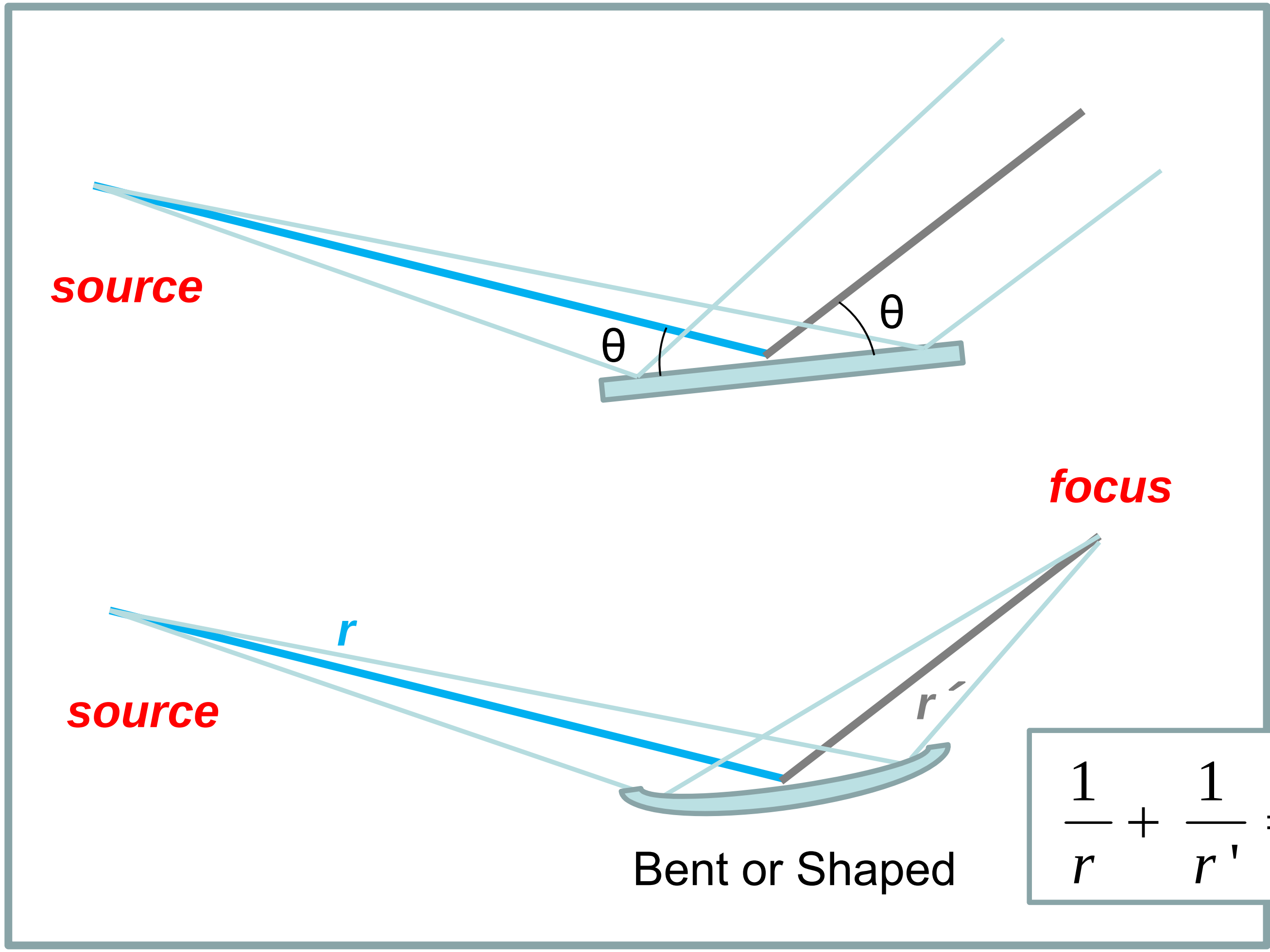
Shaping (→focus / collimate / magnify)

Lens absorb VUV photons extremely.
X-rays have nearly 1 of refractive index.

VUV-HX: Reflective mirrors
VUV: Fresnel zone plates
HX: Refractive lens
etc.

Shaping SR beam

-Reflective plain mirror-



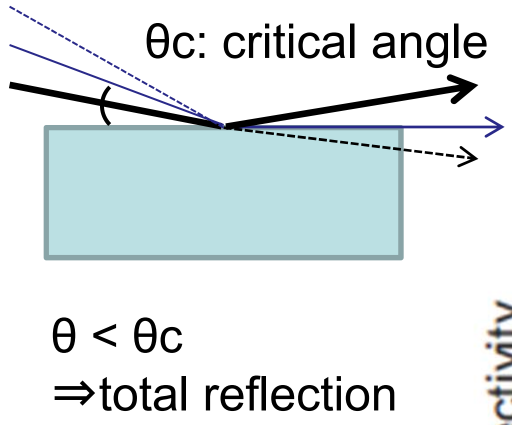
$$\frac{1}{r} + \frac{1}{r'} = \frac{2}{R \sin \theta}$$

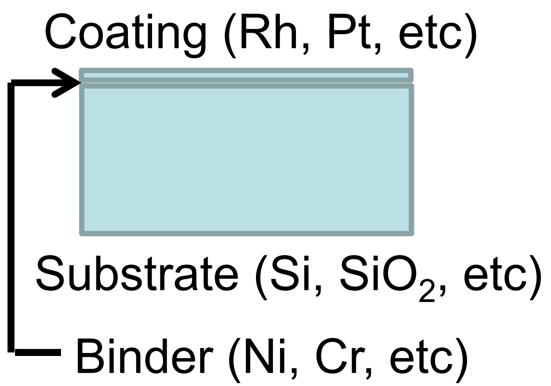
For fine focusing, perfect surface is necessary.

Slope error : ~0.25 arc sec or 1 μrad
surface roughness : ~2-3 Å in RMS

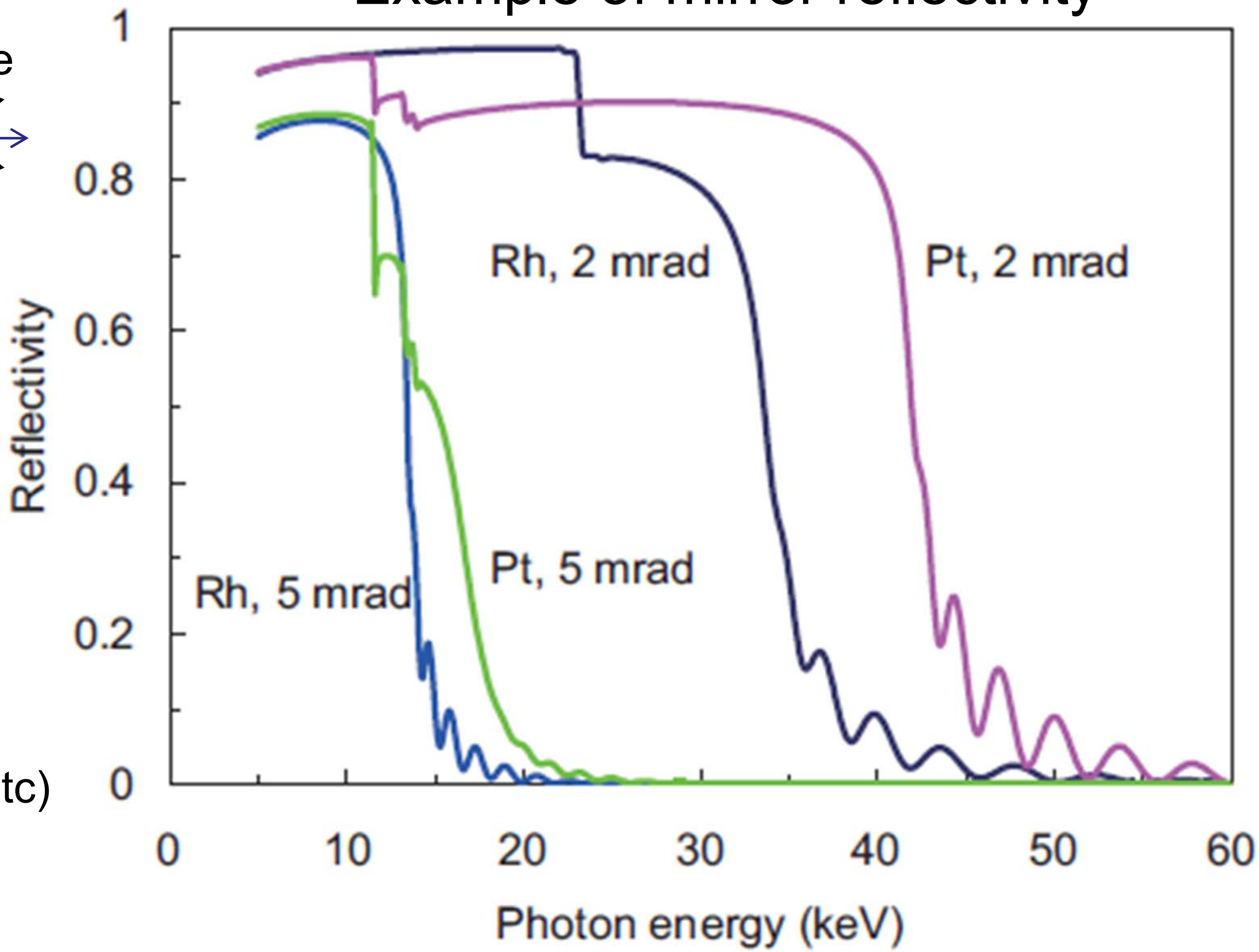
Heavy atom coated mirror is used for hard X-ray

In x-rays region, the critacal angle is quite small.
Even Pt, Rh case, a few mrad at 12 keV (about 0.1nm)





Example of mirror reflectivity

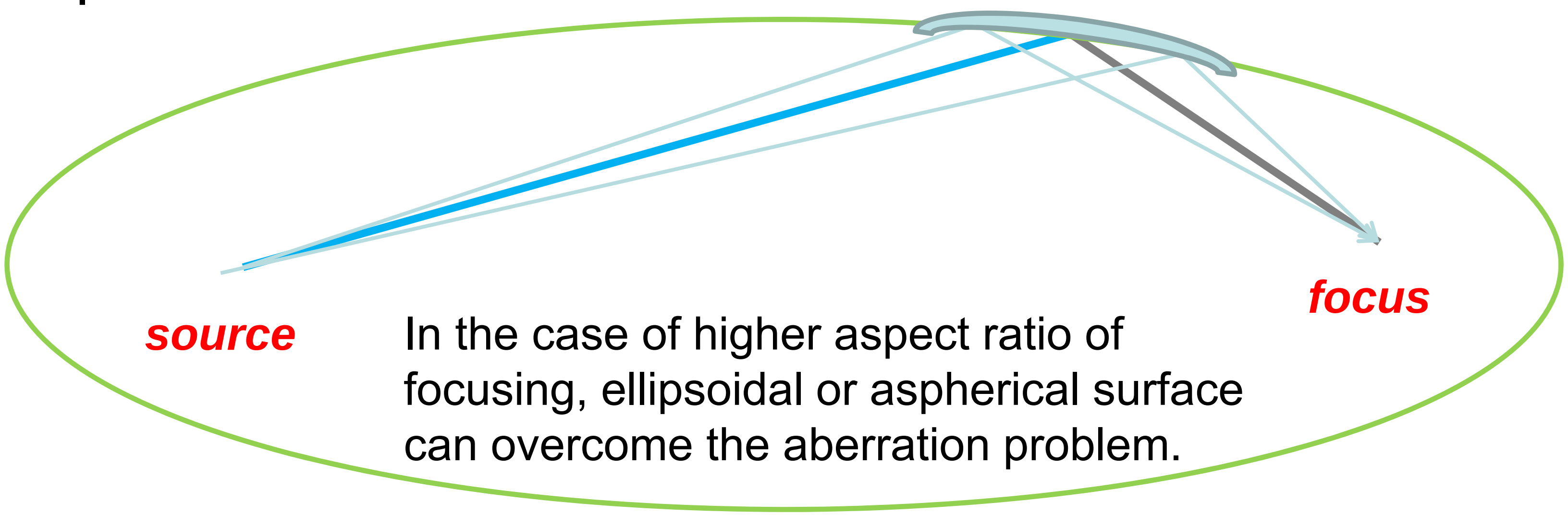


Shaping SR beam
-Reflective ellipsoidal mirror-

Spherical surface:

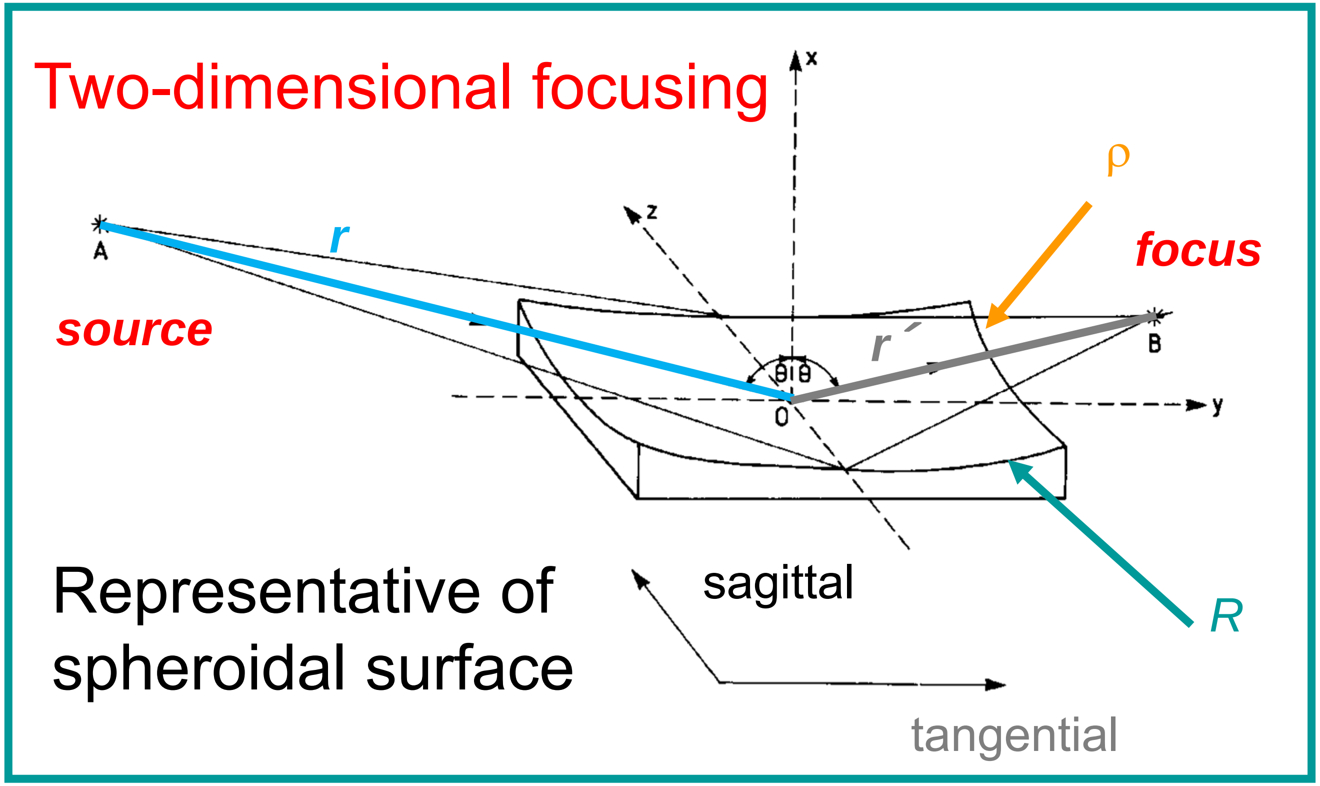
Aberration problem occurs.

Ellipsoidal surface:.



In the case of higher aspect ratio of focusing, ellipsoidal or aspherical surface can overcome the aberration problem.

Shaping SR beam
-Reflective Toroidal mirror-



$$\frac{1}{r} + \frac{1}{r'} = \frac{2}{R\cos\theta}$$

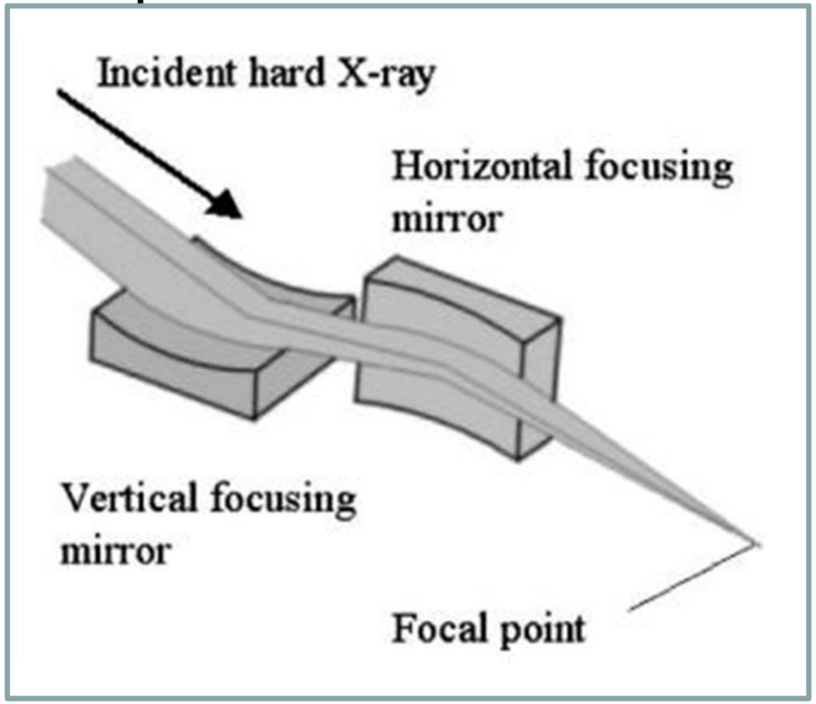
$$\frac{1}{r} + \frac{1}{r'} = \frac{2\cos\theta}{\rho}$$

- Pre-fabricated mirror ⇒expensive, size limitation, fixed focal point
- Bent cylinder mirror (approximated) ⇒ not perfect (small aberration)

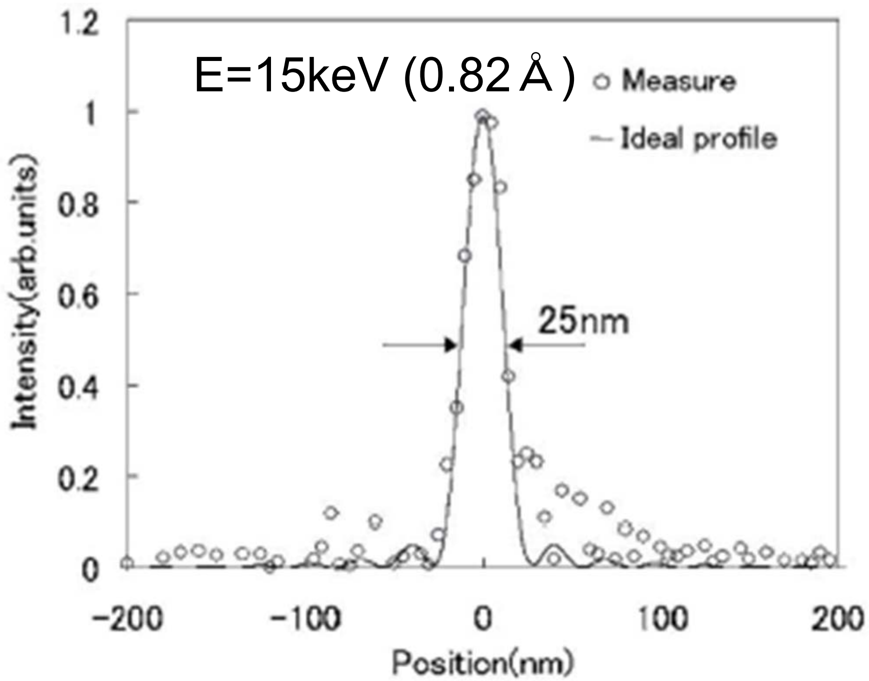
Shaping SR beam

-Microbeam by reflective mirror-

Kirkpatrick-Baez mirrors



Mirror fabricated by EEM method



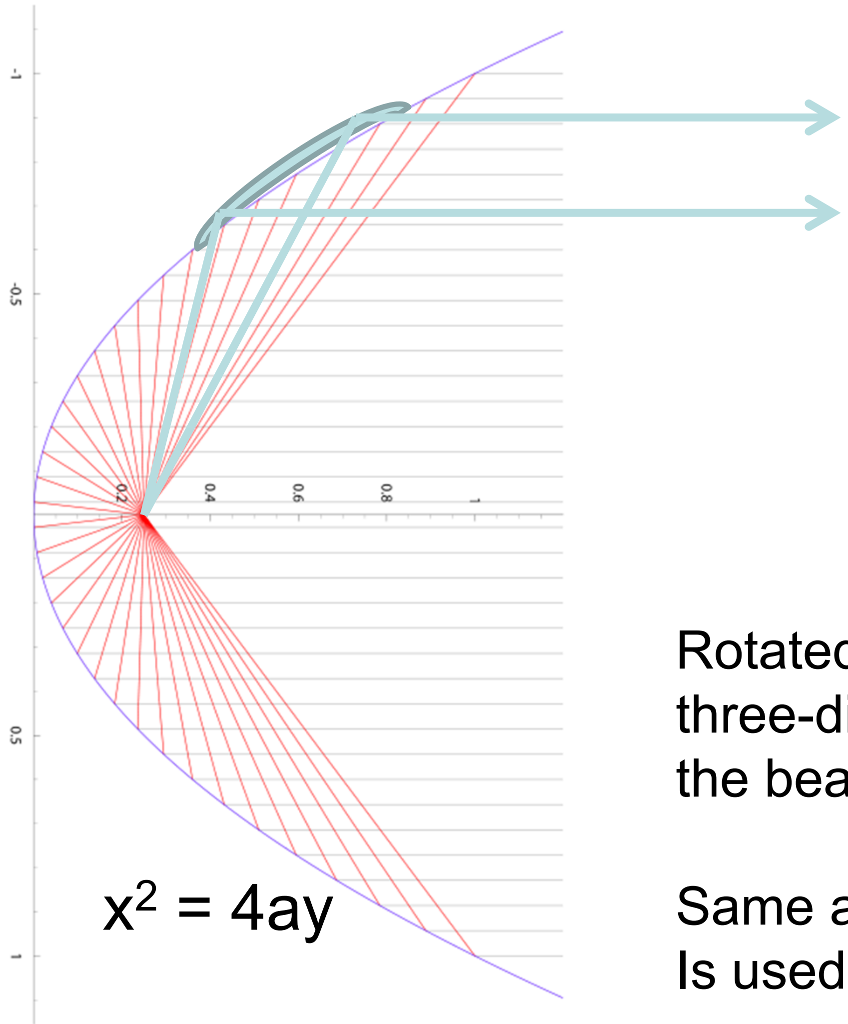
Independent focusing in H and V

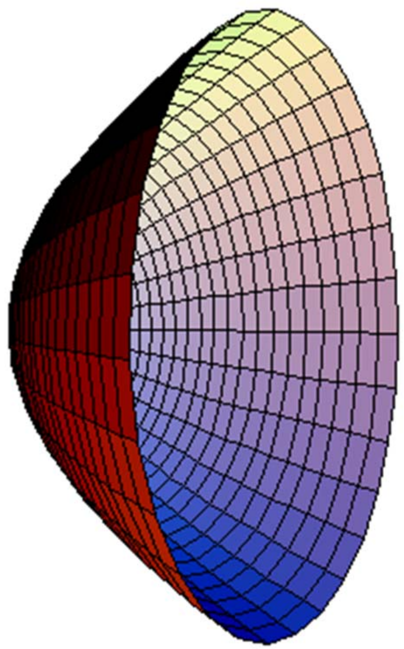
Depending on the quality, slope error and surface roughness, several 10 nm spot size is attained.

H. Mimura et al. Phys. Rev. Lett. (2007)

equal to diffraction limit!

Shaping SR beam
-Reflective paraboloidal mirror-



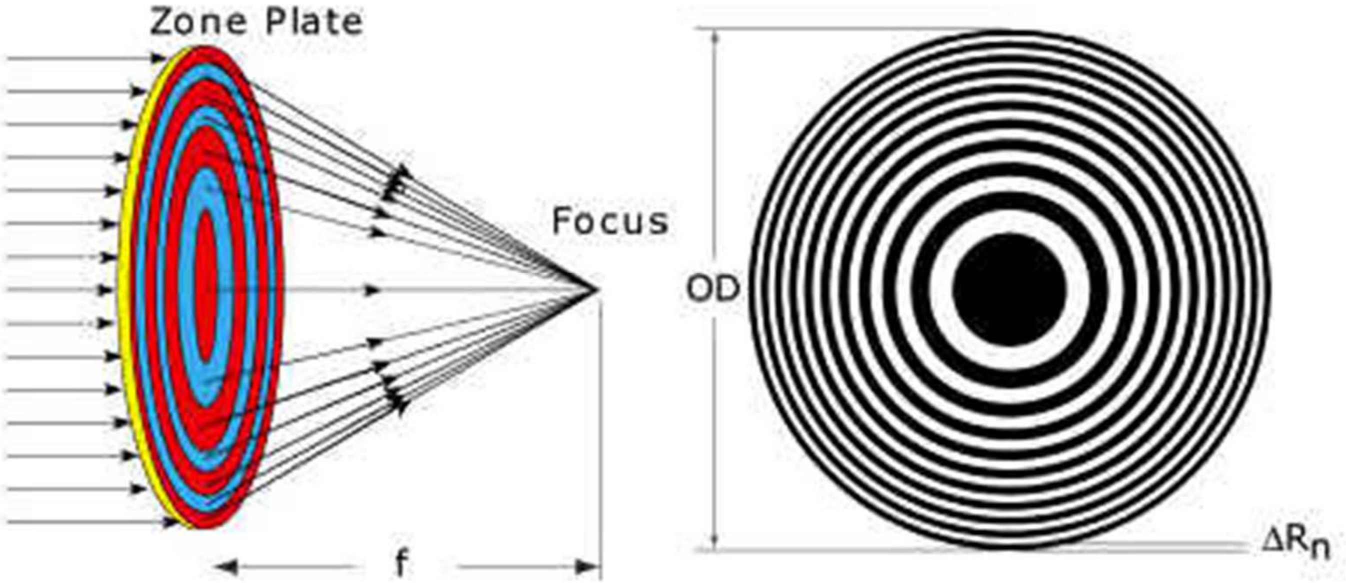


Rotated parabolic surface can
three-dimensionally collimate
the beam same as parabola antenna.

Same as toroidal mirror, bent conical mirror
Is used as an approximate paraboloidal surface.

Shaping SR beam

-Fresnel zone plates-



$$R_j^{out} = \sqrt{(f + j \times \lambda + \lambda / 4)^2 - f^2}$$

$$R_j^{in} = \sqrt{(f + (j - 1/2) \times \lambda + \lambda / 4)^2 - f^2}$$

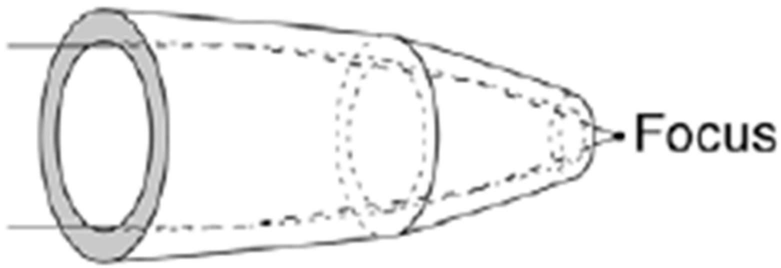
Focus size of several 10th nm is feasible now.
(depending on the fine structure of outer shell)

It's difficult to use this for hard X-rays, due to its strong penetration power.

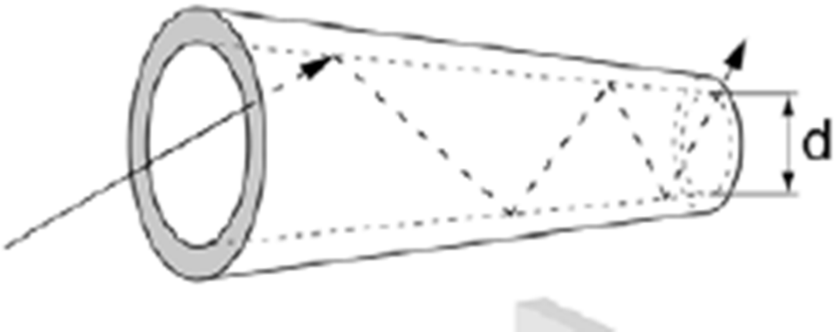
Shaping SR beam

-Other x-ray focusing tools-

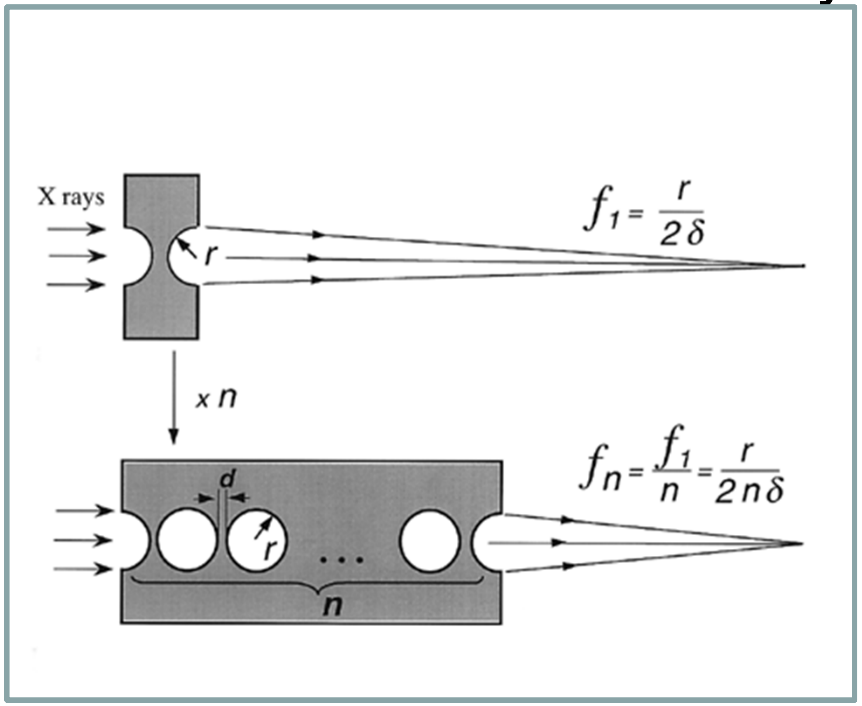
Wolter mirror



Capillary optics



Refractive lenses for hard X-rays



$\boldsymbol{n = 1 - \delta + i\beta}$ $\delta = 10^{-5}$ to 10^{-7}

Lenses are made of C, Be, etc.

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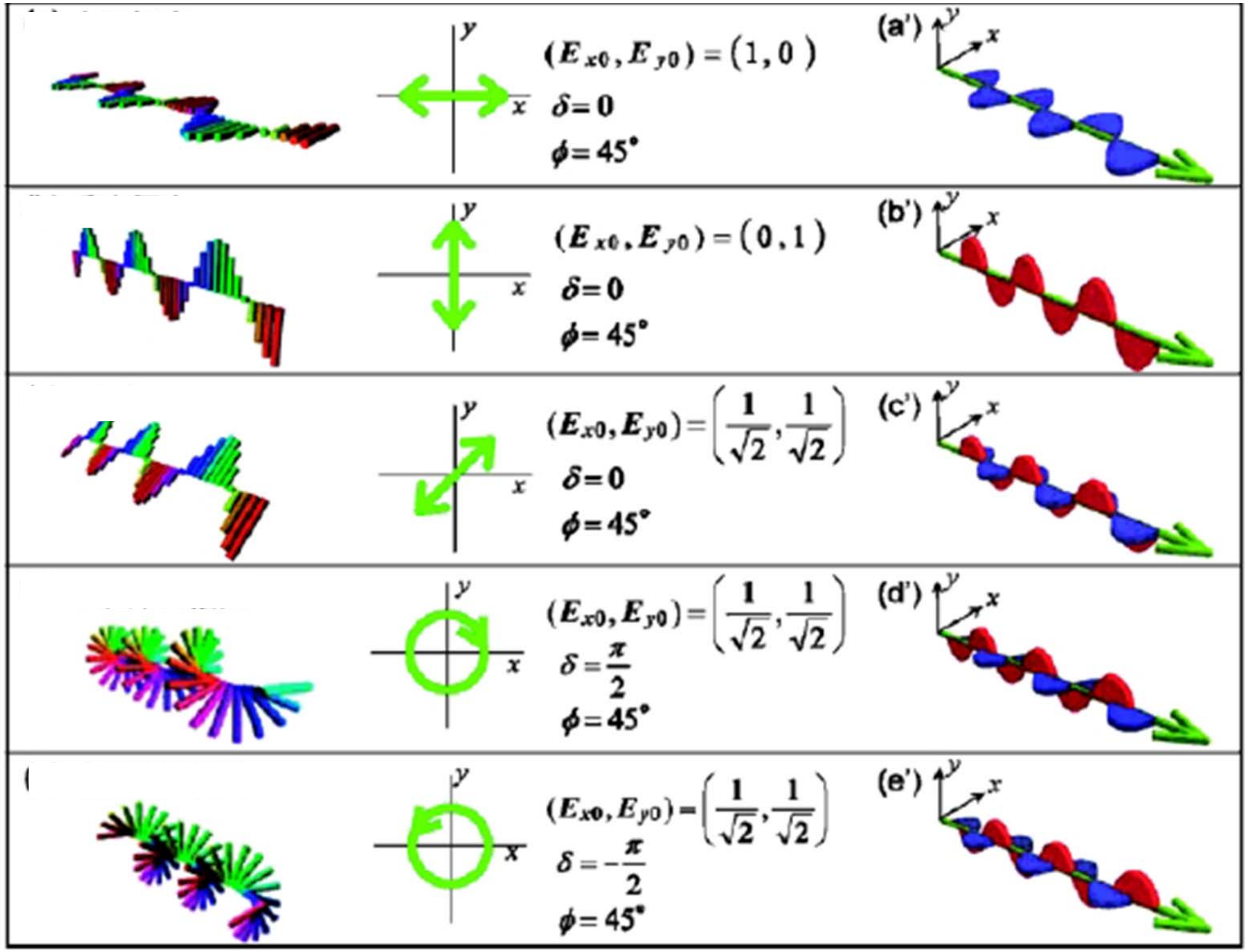
Various polarization states

Synchrotron provides different kinds of polarized beam and the polarization characteristics can be transformed by optics.



M. Suzuki and T. Hirono, JSSRR Vol. 19 No.6 (2006)

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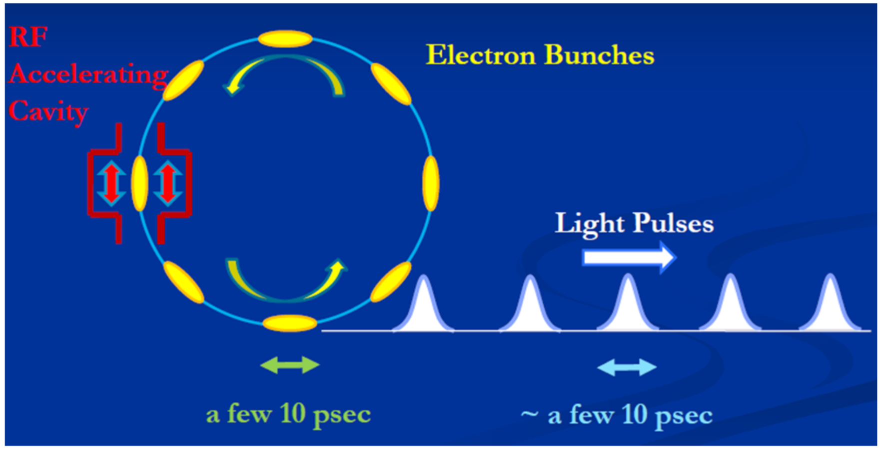
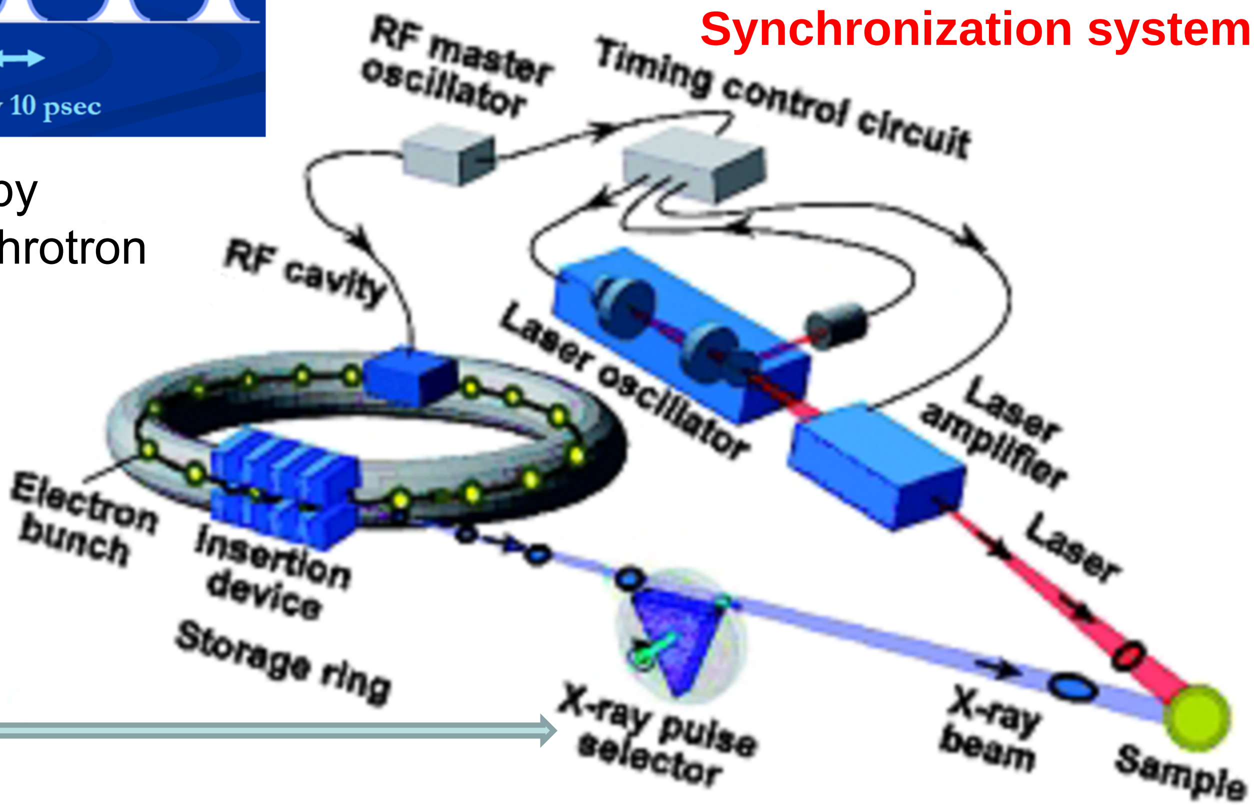
Pump-Probe time resolved measurement



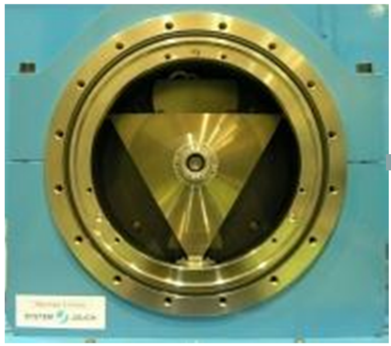
Photon pulse generated by electron bunches of synchrotron

Time-resolved structure analysis is now being pursued in pico-second scale at single-bunch operation of PF-AR ring

Synchronization system



X-ray pulse selector



S. Adachi and Y. Tanaka, JSSRR Vol. 20 No.2 (2007)

Other beamline components

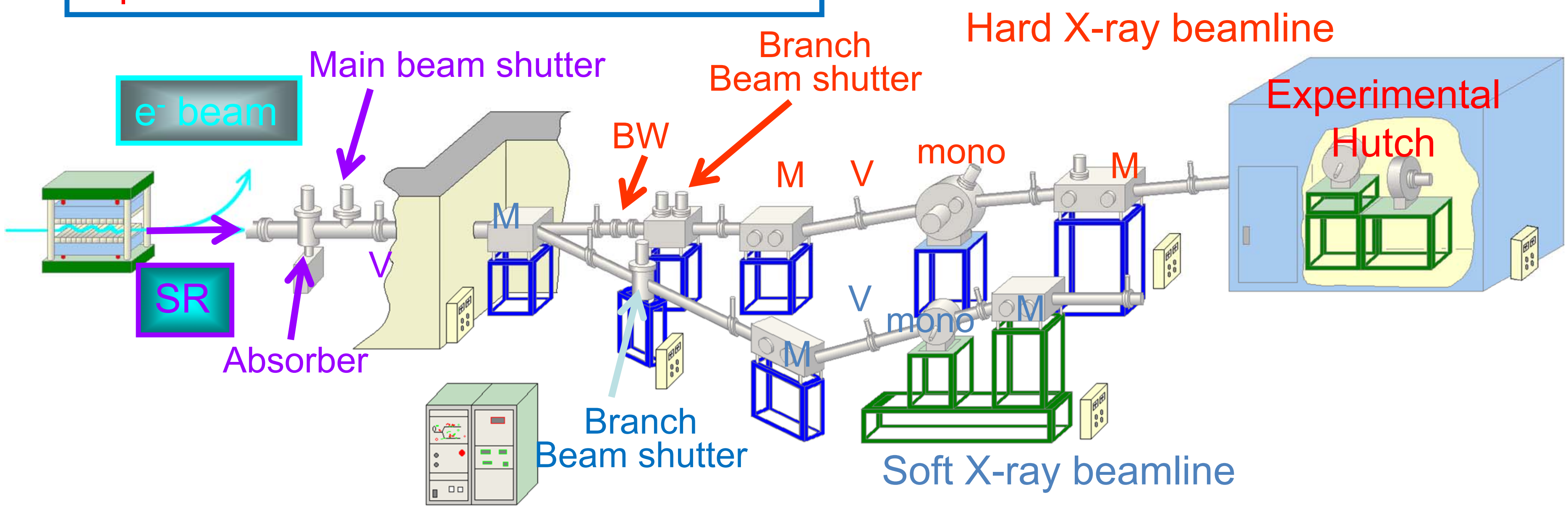
- Beam shutter
- Absorber
- Beam stopper
- Beam monitor (intensity/position)
- Slits
- View port
- Be window / Kapton window
- etc….

Conducting SR beam to experimental stations

1) VUV-SX region : absorption by air and any materials → ultrahigh vacuum
2) Hard X region : Beryllium windows (BW) to separate the ring and the BL
scattering by air → high radiation level → vacuum

Vessels to storage optical components
Pipes to connect the vessels

→ valves, vacuum gauges



Radiation hazard → Beam Shutters, Experimental Hutch
High heat load to BL elements → monitoring the cooling systems

SAFETY monitor and control system is critically important!