Cheiron School 2012

X-ray Free Electron Laser Part-2: Beamline Part

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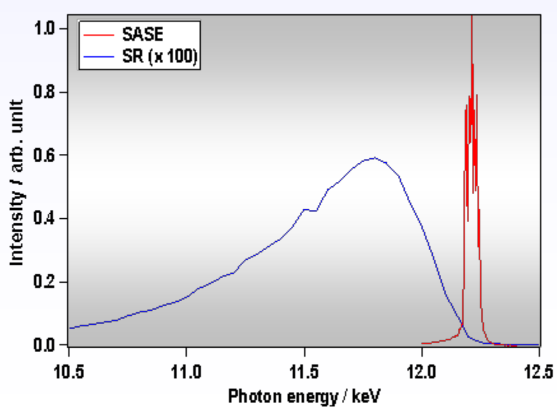
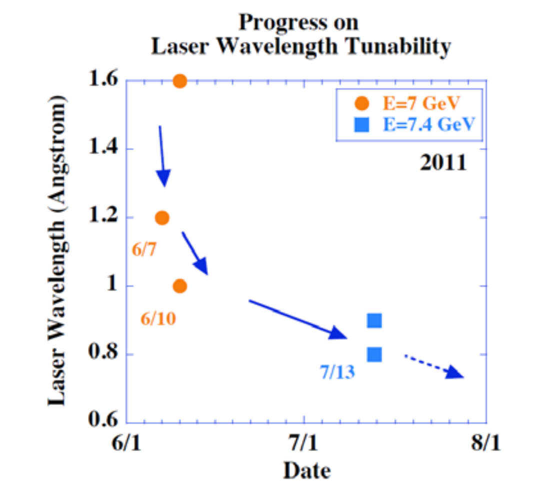
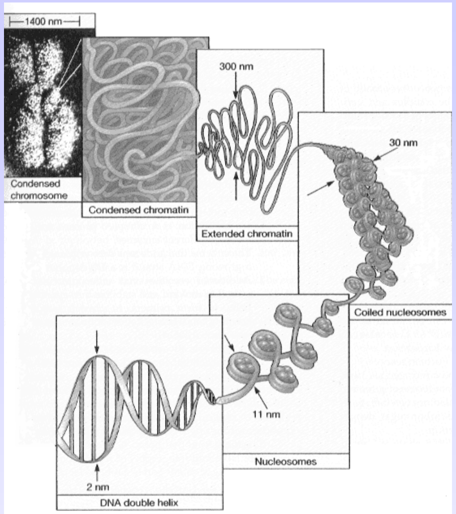
First Lasing of SACLA: June 7, 2011

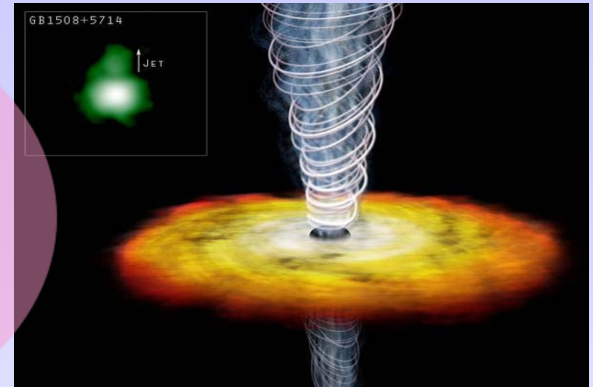




XFEL explores new worlds of science



Brilliance ($X10^9$)

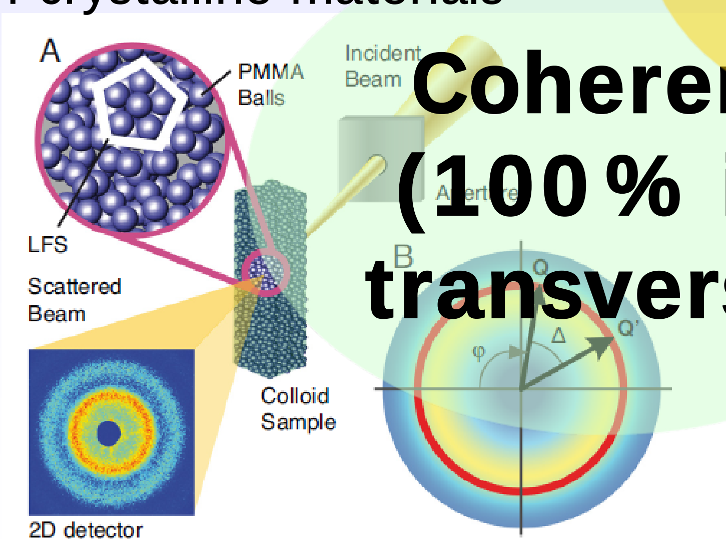


Fundamental Science: Create Extreme State

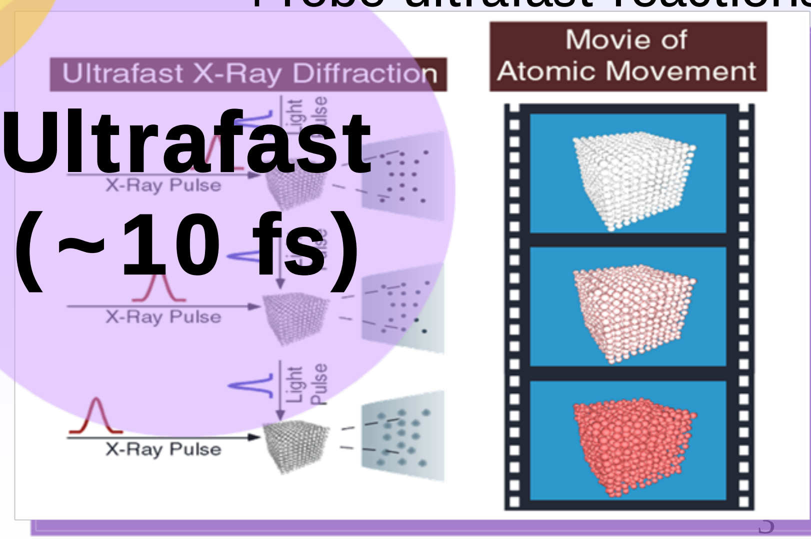
XFEL

Biology & Medicine: Investigate non-crystalline materials

Environmental & Energy Science: Probe ultrafast reactions



Coherent (100 % in transverse)



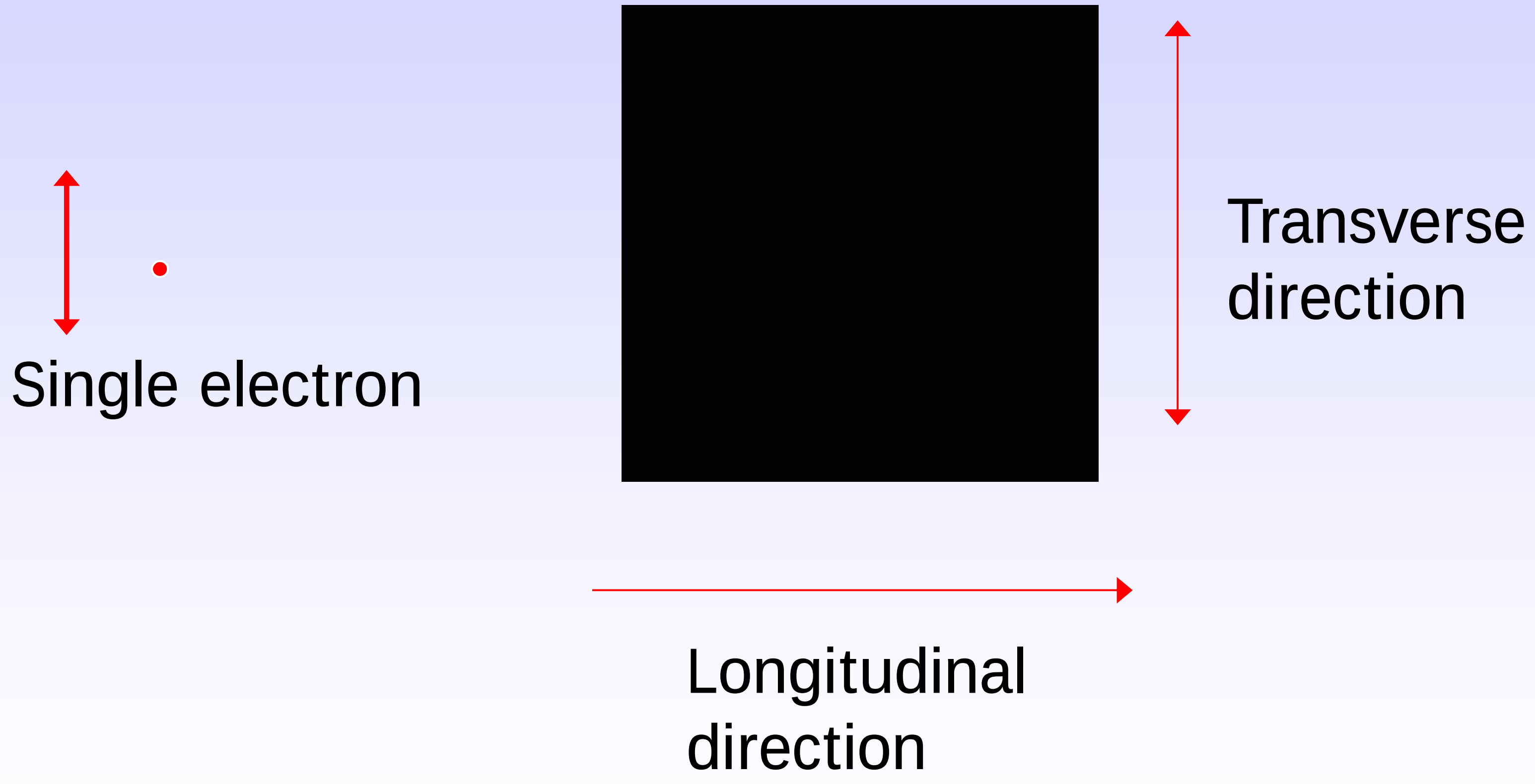
Ultrafast (~10 fs)

"Coherence"

Coherent Diffraction Imaging
Transverse coherence
Longitudinal coherence
Coherent radiation
Coherent light source
Incoherent scattering ...

Q. Do you have physical images of coherence ?

Radiation from single electron



Transversely coherence
Longitudinally incoherent

Radiation from "point" source with many electrons

Point source,
Many electrons
in random phase
(Chaotic source)

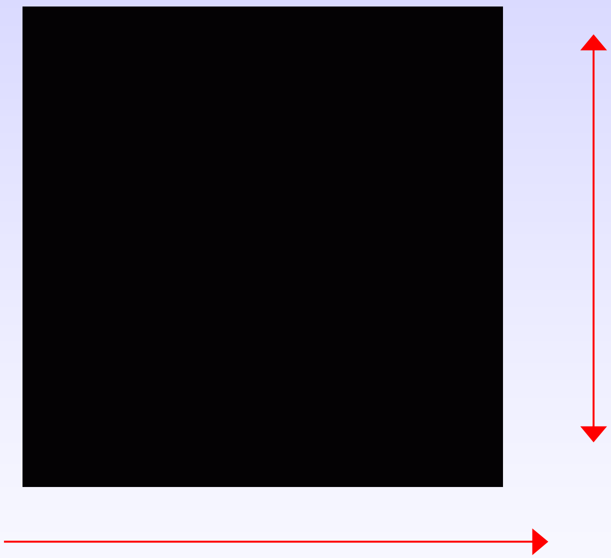
Transverse
direction

Longitudinal
direction

Transversely coherence
Longitudinally incoherent

Radiation from "extended" source with many electrons

Extended source,
Many electrons
in random phase
(Chaotic source)



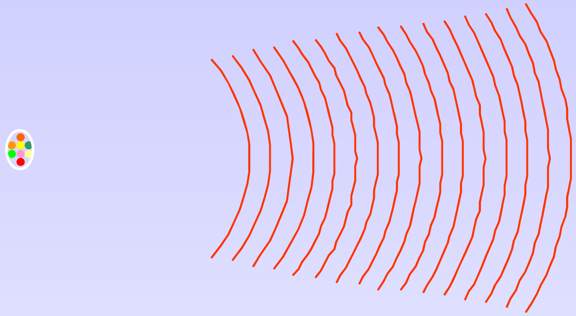
Transverse direction

Longitudinal direction

Transversely incoherence
Longitudinally incoherent

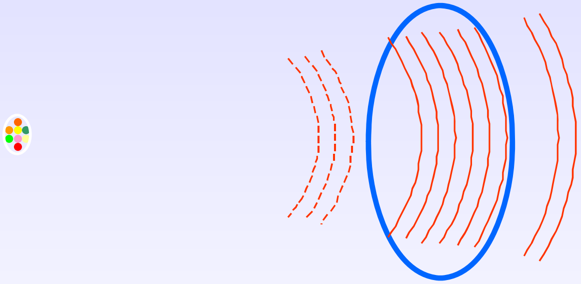
Summary

Coherent source



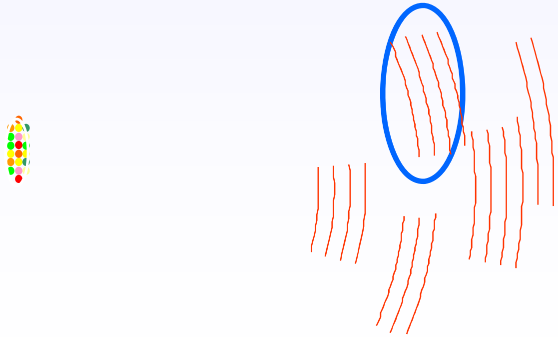
"seeded"-FEL
all electrons in phase

Point source
Multiple electrons



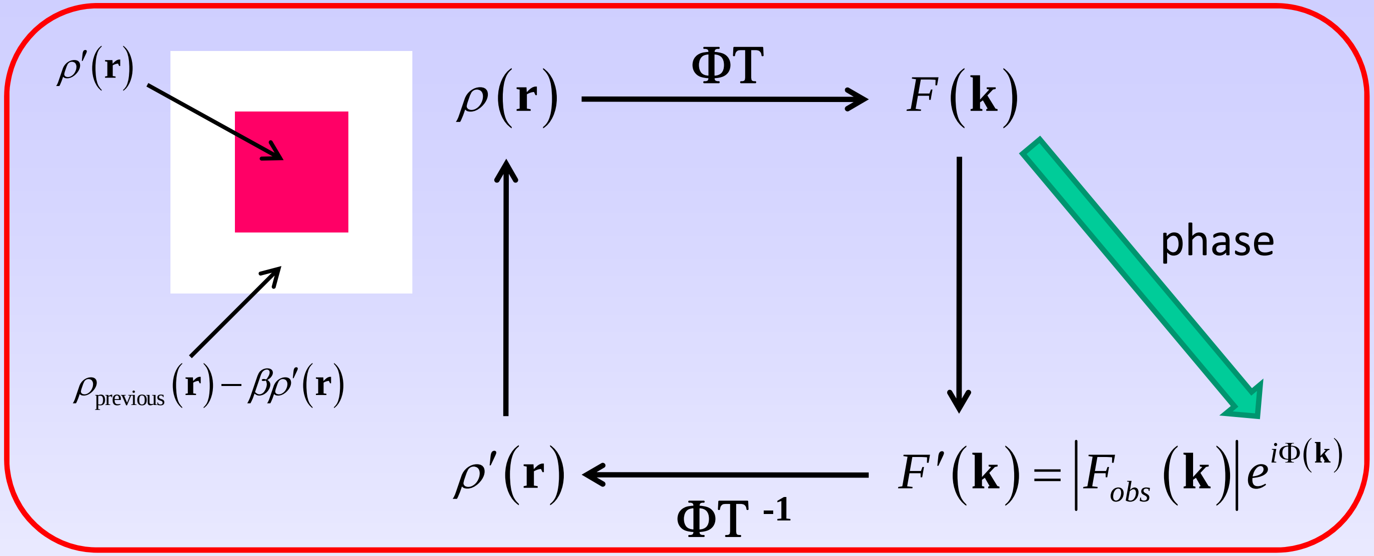
"SASE"-FEL
only neighboring
electrons in phase

Extended source
Multiple electrons



Phase retrieval with HIO (Hybrid-Input-Output) method at oversampling condition

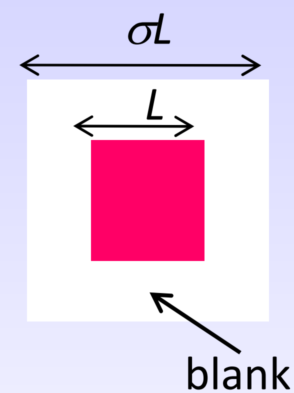
Courtesy of Joti-san



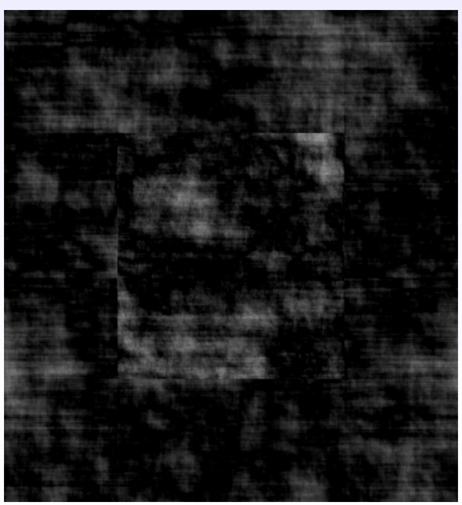
Input

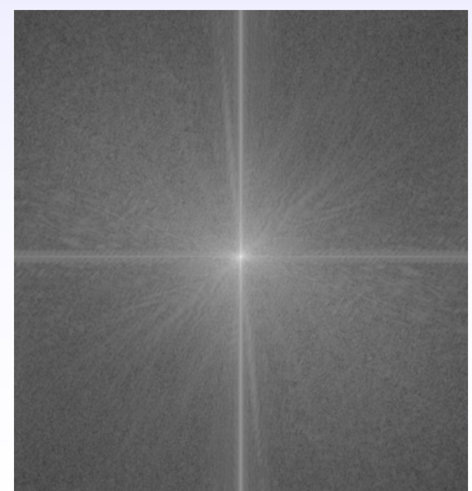
1. $|F_{obs}(\mathbf{k})|$

2.



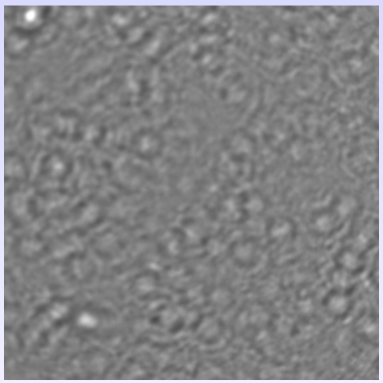
Hybrid Input Output (HIO) Algorism   J.R. Fienup, (1982) *Appl. Opt.* **21**, 2758-2769

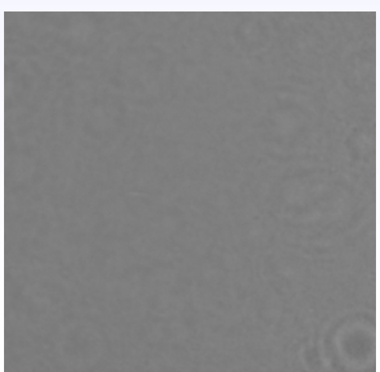




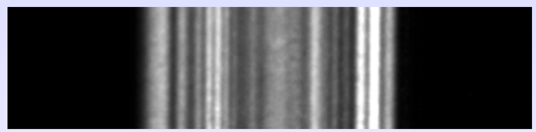
Coherent light: dangerous probe for imperfect optics

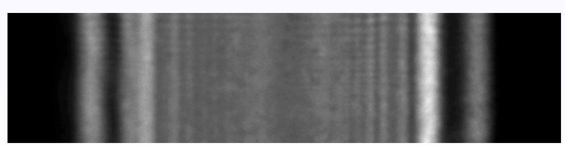
Transmission image from mid-quality beryllium foil with voids



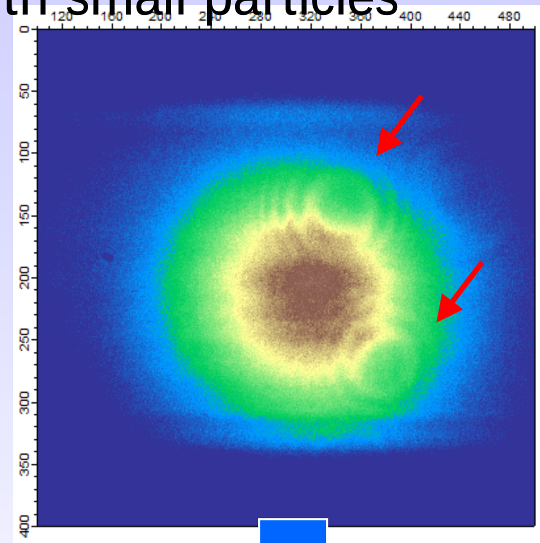


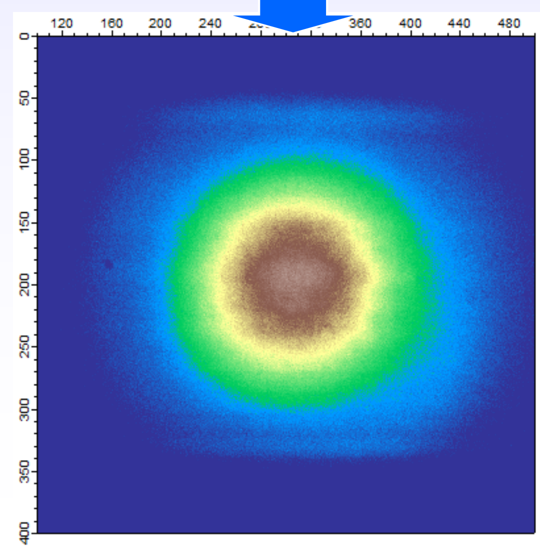
Reflection image from mid-quality mirror





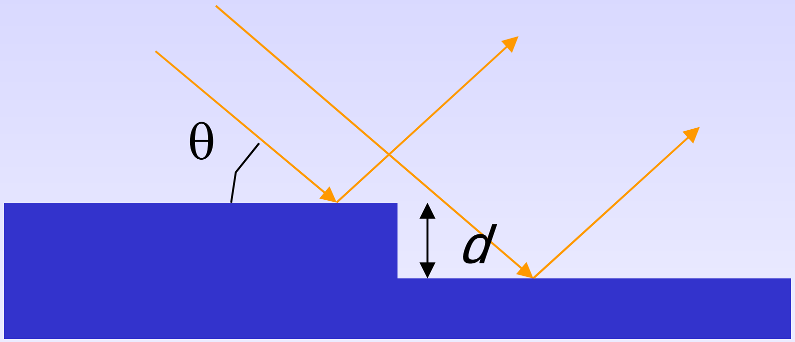
Reflection image of SACLA XFEL from double mirrors with small particles





Mirror requirement

Ultraprecise surface figure is required to prevent unwanted speckles under coherence illumination



Path difference: $\delta = 2d\sin\theta$

$\delta < \lambda/20$, $\lambda = 0.1$ nm, $\theta = 2.5$ mrad

$$d < \frac{\lambda}{40\sin\theta} = \frac{0.1\mathrm{nm}}{40\times 2.5\times 10^{-3}} = 1\mathrm{nm}$$

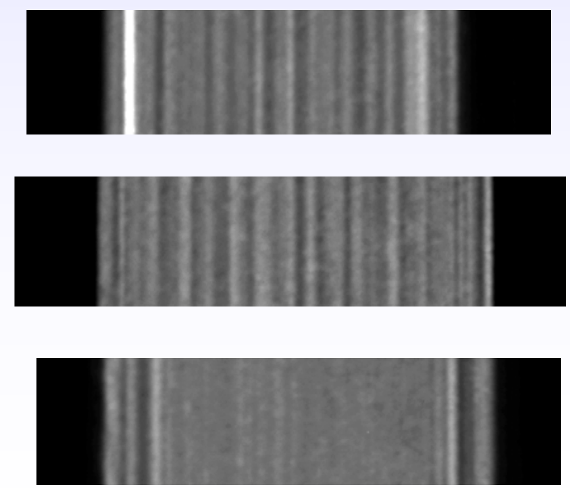
1st experiment of Osaka-SP8 collaboration (Mori et al, SPIE 2001)

Plane mirror is illuminated with coherent x-rays @ 1-km BL of SP8

Pre-machined

EEM

EEM+CVM



High peak intensity

"Pulse energy": J/pls

"Peak power": W

"Photon flux": photons/pls

Ex)

Photon flux: 10^{11} photons @ $h\nu$=10 keV, τ=10 fs

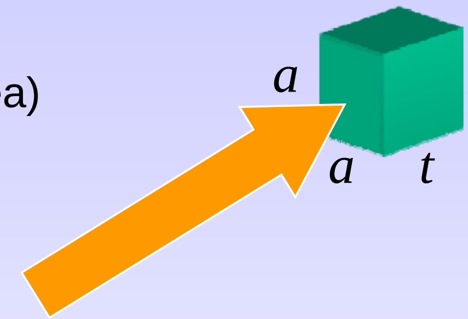
Pulse energy: I = 1.6e-19 (J/eV) x 10^{11} x 10000 (eV)

= 1.6×10^{-4} (J)= 160 uJ

Peak power: P=160 uJ/ 10 fs = 16 GW

XFEL pulse can melt or ablate materials

Absorbed energy > melting (ablation) threshold



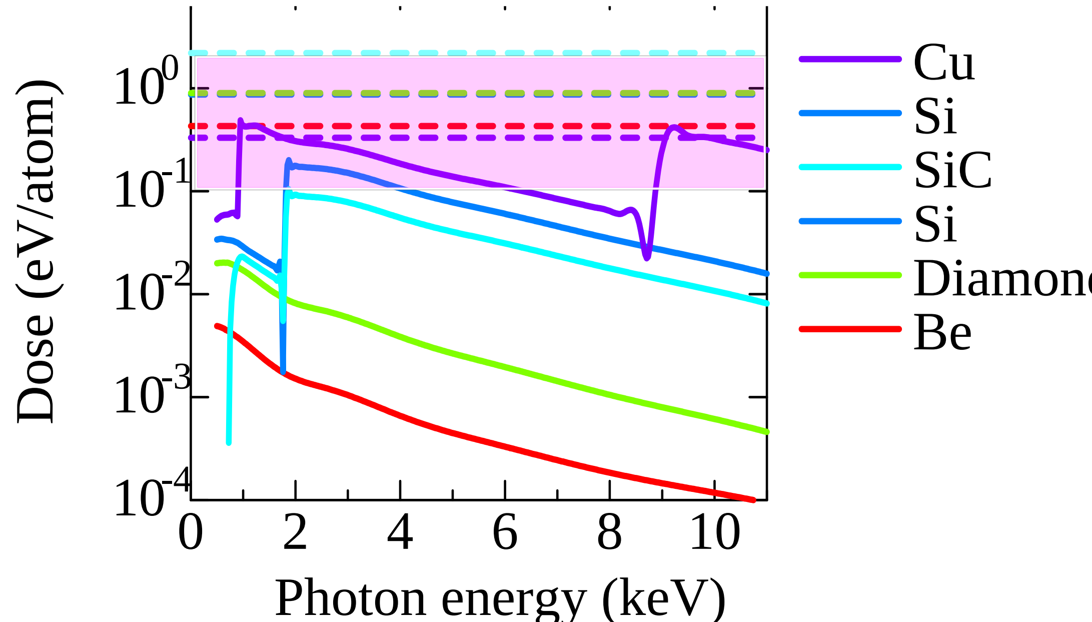
P-beam Intensity: I (# of photon per unit area)
Absorbed photon per cell: $\mu I a^2 t$
Number of atoms in cell: $\rho N_A a^2 t/M$
Absorbed photon number per atom

$$\frac{\mu I M}{\rho N_A}$$

μ: linear absorption coeff.
ρ: density
M : average atomic weight
N_A: Avogadro number

→ Dose (eV/atom)

Calculation for unfocused XFEL beam @SACLA



How to use XFEL ?

High peak power/flux in very short pulses

Can easily destroy samples after irradiation

Shot-to-shot change of pulse characters

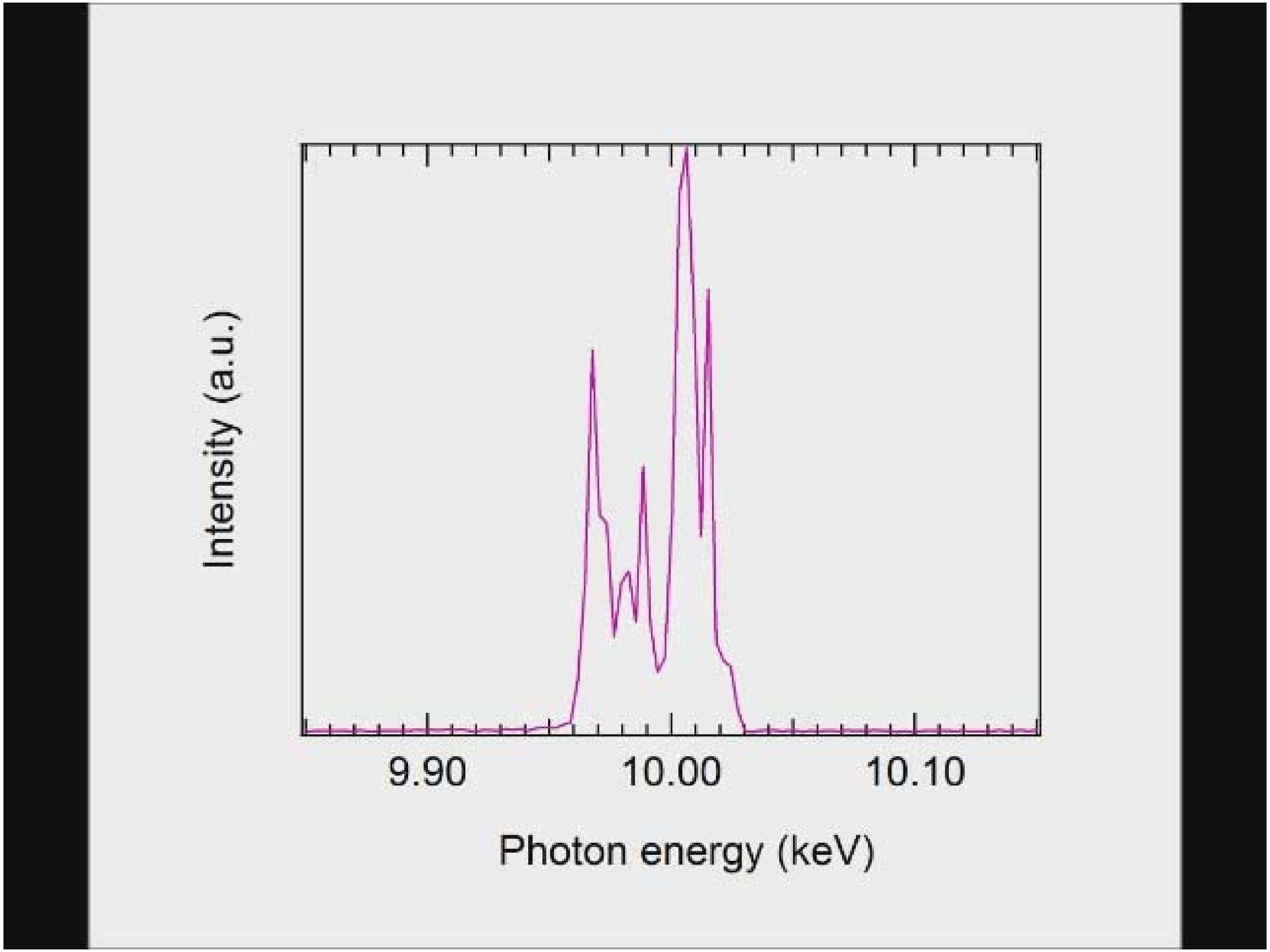
⬇

Single-shot measurement

SACLA Single-shot spectra

Central energy is stable

Spike profiles change in every shot



Example of XFEL Beamline: SACLA